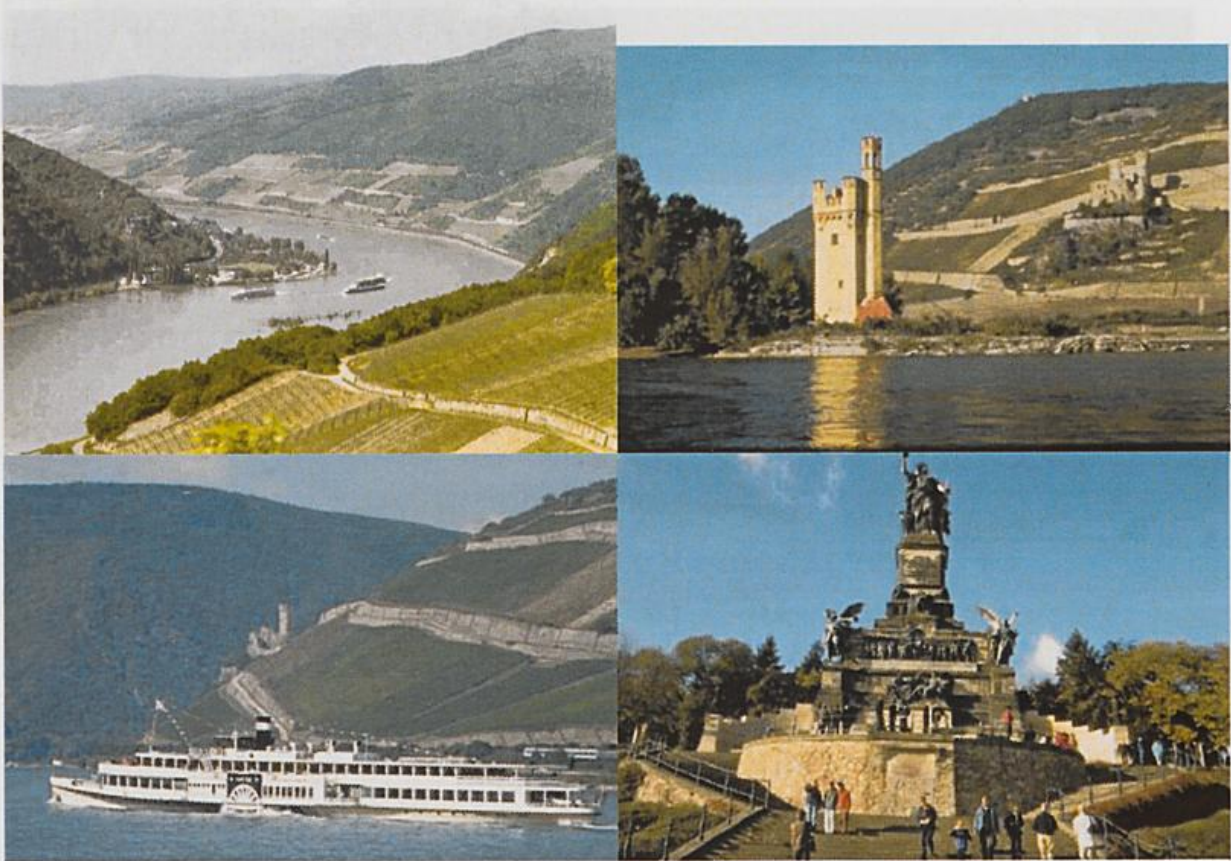


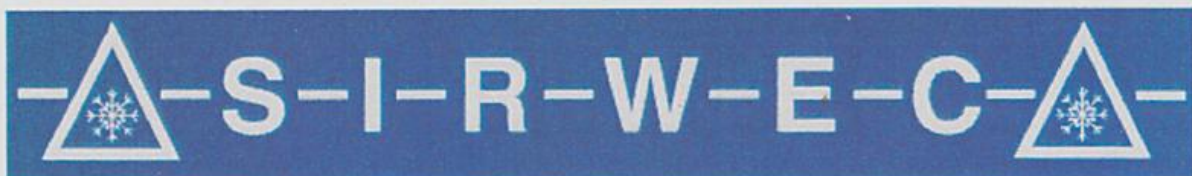
08. Dec. 2004



SIRWEC 2004

12th International Road Weather Conference
16th - 18th June 2004
Bingen (on Rhine), Germany

Conference Volume



725



04.720

SIRWEC 2004

12th International Road Weather Conference
16th - 18th June 2004
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Conference Volume

The „Standing International Road Weather Commission“ (SIRWEC) is a forum for the exchange of information on the state-of-the-art technology between road engineers, climatology researchers and meteorologists. The objective of the biennial meetings is to promote improvements in snow and ice control operations with focus on specialised road weather forecasting and climatological measuring techniques as well as improvements in the organization of winter maintenance.

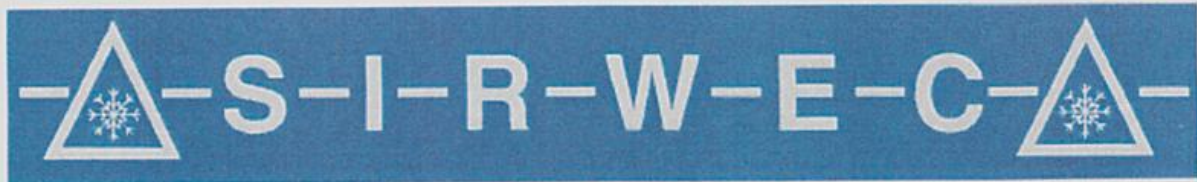
The Topics of the Conference are:

- I Climatology, Weather Conditions
- II Forecast Methods and Accuracy
- III Sensors and Equipment
- IV Presentation and Interpretation of Road Weather Information Data
- V Winter Maintenance Management Systems, Methods and Policy

Content

1. Preliminary Programme of the Conference
2. History of SIRWEC Conferences
3. Sponsors of SIRWEC 2004
4. Papers of the SIRWEC 2004 Conference
 - 4.1. Session I: Climatology, Weather Conditions
 - 4.2. Session II: Forecast Methods and Accuracy
 - 4.3. Session III: Sensors and Equipment
 - 4.4. Session IV: Presentation and Interpretation of Road Weather Information Data
 - 4.5. Session V: Winter Maintenance: Management Systems, Methods and Policy

In the chapters I to V you can find all accepted papers for each topic, not only the papers which are presented orally. At the beginning of the chapters you find a list of all papers. The numbers of the papers are the same as in the preliminary programme.



12 th International Road Weather Conference 2004 Bingen Germany

PRELIMINARY PROGRAMME

Wednesday, June 16th 2004

- 10:00 h Registration (up to 13:00 h), Opening of the Exhibition
- 13:00 h Opening of the 12th International Road Weather Conference
- (0-1) Keskinen (FIN): Road Weather 30 Years – Hindsight, Insight, Foresight
- Session I: Climatology, Weather Conditions**
- (I-1) Liechti (CH): Industrial Snow
- (I-2) Miyoshi et al (JP): Meteorological Factors associated with Avalanches in the Lake Shikotsu Area and their application to Road Management
- (I-3) Sulan (CZ): Experiences with Hoar Frost and its Monitoring in Western Bohemia
- (I-4) Takahashi et al (JP): Using Taxi GPS to gather High-Quality Traffic Data for Winter Road Management Evaluation in Sapporo
- 15:00 h Coffee Break
- 15:30 h **Session II: Forecast Methods and Accuracy**
- (II-1) Grimbacher/Schmid (CH): Nowcasting nocturnal cloudiness with an ultra-dense Road Weather Measurement Network
- (II-2) Gjertsen et al (N): Monitoring Precipitation Intensity and type-combined Use of Radar and Temperature Measurement
- (II-3) Skuthan (CZ): The Significance of the Severe Events Warning Service in Relation to the classic Methods of Road Meteorology
- (II-4) Pasero et al (I): NEMEFO – Neural Meteorological Forecast
- (II-5) Hopwood (GB): Improvements in Road Forecasting Techniques and their Applications
- (II-6) Rohn/Raatz (D): Providing an optimized Dataset for Road Weather Forecasts
- (II-7) Sass/Petersen (DK): A coupled automatic Road Weather Forecasting System
- 17:15 h End of Session
- 17:30 h SIRWEC Executive Committee Meeting (only for Members)
- 19:00 h Apéro, Welcome Buffet

Thursday, June 17th 2004

- 8:30 h **Continuation Session II: Forecast Methods and Accuracy**
- (II-8) Chapman/Thornes (GB): Road Ice Prediction using Geomatics
- (II-9) Thornes/Cavan/Chapman (GB): The Use of GIS and Icemiser to predict Winter Road Surface Temperatures in Poland
- (II-10) Badelt/Moritz (D): Use of Data on Road Condition and Weather for Winter Maintenance
- 9:10 h **Session III: Sensors and Equipment**
- (III-1) Deckert/Hauf (D): An experimental Study of Drying-Up Paved Surfaces
- (III-2) Lahtinen/Kantonen (FIN): Finish Road Weather Camera System
- (III-3) Paulsen/Schmokel (N): Laser Road Surface Sensor LRSS
- (III-4) Badelt/Seligler (D): Testing Sensors for Road Weather Systems
- 10:10 h Coffee Break

- 10:40 h **Session IV: Presentation and Interpretation of Road Weather Information Data**
 (IV-1) Kagaya/Kajiya/Yamagiwa (JP): Smart Sapporo Snow Information Experiment
 (IV-2) Sigurdsson (DK): Flow and Presentation of Road Weather Data and Winter Maintenance Activities on the Internet
 (IV-3) Schmid/Mathis (CH): Validation of Methods to detect Winter Precipitation and retrieve Precipitation Type
 (IV-4) Eriksson/Johansson (S): Winter Weather and Municipal Winter Road Maintenance
 (IV-5) Iivanainen/Pettersson (FIN): Quality for Road Weather Information System – Applying ISO 9001
 (IV-6) Toivonen/Kantonen (FIN): Supporting IT System for Road Weather Quality Measurement
- 12:15 h Lunch
- 13:45 h **Parallel Workshops** (every participant can choose one workshop)
 Workshop 1: What kind of forecast products are needed by the road winter maintenance organizations?
 Workshop 2: What kind of developments are needed to improve road weather forecasting?
 Workshop 3: What kind of road weather data do maintenance people and meteorologists need?
 Workshop 4: How can road weather forecasts be used in practical winter maintenance decisions?
- Including Coffee Break at about 15 h
- 17:00 h End of Workshops
- 17:30 h Departure of Rhine River Tour to Loreley with Conference Dinner

Friday, June 18th 2004

- 8:30 h **Session V: Winter Maintenance: Management Systems, Methods and Policy**
 (V-1) Cypra (D): Optimization of Winter Maintenance on heavily travelled Freeways
 (V-2) Yamada/Sugimura/Maruyama (JP): Research on the Level of Winter Road Management
 (V-3) Hanke (D): Construction of a Winter Maintenance Management System for optimized Controlling of Winter Maintenance Operations
 (V-4) Devaud (CH): Surface Condition Management
 (V-5) Jonasson/Palsson (ICE): Icelandic Winter Maintenance Management System
 (V-6) Nixon/Stowe (USA): Operational Use of Weather Forecasts in Winter Maintenance – A Matrix based Approach
 (V-7) Pisano/Stern/Mahoney (USA): The U.S. Federal Highway Administration Winter Maintenance Decision Support System MDSS Project
- 10:00 h Coffee Break
- 10:30 h **Reports from the Workshops**
 Discussion of the Results of the Workshops
- 12:00 h **Closing of the Conference and Exhibition**
 Venue to the 13th SIRWEC Conference
- 14:00 h **Excursion**
 Rudesheim on Rhine: Sightseeing Tour and Wine Tasting

History of SIRWEC Conferences

1984	1st Conference	The Hague	Netherlands
1985	2nd Conference	Copenhagen	Denmark
1986	3rd Conference	Tampere	Finland
1988	4th Conference	Florence	Italy
1990	5th Conference	Tromsö	Norway
1992	6th Conference	Minneapolis	USA
1994	7th Conference	Seefeld	Austria
1996	8th Conference	Birmingham	UK
1998	9th Conference	Luleá	Sweden
2000	10th Conference	Davos	Switzerland
2002	11th Conference	Sapporo	Japan
2004	12th Conference	Bingen	Germany
2006	13th Conference	Sestriere	Italy

Sponsors of SIRWEC 2004

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Here we must give a great thank to all sponsors supporting the 12th SIRWEC Conference 2004.

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Submitted Papers Topic I:

Climatology, Weather Conditions

- (0-1) Keskinen (FIN): Road Weather 30 Years – Hindsight, Insight, Foresight

- (I-1) Liechti (CH): Industrial Snow
- (I-2) Miyoshi et al (JP): Meteorological Factors associated with Avalanches in the Lake Shikotsu Area and their application to Road Management
- (I-3) Sulan (CZ): Experiences with Hoar Frost and its Monitoring in Western Bohemia
- (I-4) Takahashi et al (JP): Using Taxi GPS to gather High-Quality Traffic Data for Winter Road Management Evaluation in Sapporo
- (I-5) Matsuzawa/Kajiya (JP): Height-Dependent Difference in Visibility in Roads
- (I-6) Sato et al (JP): Wind and Air Temperature Distribution in the Wake of a Running Vehicle
- (I-7) Sato et al (JP/UK): Variation in Meteorological Variables in Mountainous Regions and their Effects on Road Surface Temperature Prediction

Introduction

There is a story on how Finland was engaged in this project. In the 70's Finland was not a member of the European Union, however, many COST projects had Finnish participants since COST activity was open to other countries than the Member States at their own expense. At the beginning of COST 30 preparatory meetings organized by the COST Transport Committee were held in 1973-1974. Prior to the meeting, which COST 30 plans were in the agenda the Finnish representative of MoTC had an ad hoc discussion with the Director of Vareski Ltd. During the discussion the idea emerged that Finland would benefit from participating in an electronic development project on weather-related issues. In the meeting the Finnish representative explained about weather hazards for traffic and suggested that this problematics should be included, because weather surely is an important factor affecting driving conditions. The meeting finished smoothly but did not make any decision. It then happened that the chair of the Transport Committee crashed in a flood while driving a car in Yugoslavia the following summer, and was afterwards convinced of the importance of weather phenomena for traffic. In the next Transport Committee meeting when the Finnish representative raised the issue again, the meeting readily agreed after having heard the chair's story. Then the chair asked if Finland would take the responsibility for the weather and traffic project. This was agreed by the Finnish MoTC, and financing was cleared finally by the MoP. The theme's Automatic Detection of Bad Weather had later a co-sponsoring theme 9) was added in the COST 30 project to be implemented by Finland. The development and results of the Road Weather Research and System in Finland is thoroughly presented by Auli Keskinen, the co-leader of SEWEC (Keskinen, 1999).

Road Weather 30 Years - Hindsight, Insight, Foresight

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Abstract

The COST30 project, which formed part of the COST programme of European Co-operation in the Field of Scientific and Technical Research, was set up in 1970 (EUCO-COST30 BIS 1985). The overall objective of the project was to improve traffic safety and flow on major, high-speed roads throughout the promotion of electronic traffic aids for detection of road conditions and for communication with the drivers. The project specifically aimed at the development of functional specifications and standards for the interface between the driver and the system that would ensure compatibility across the national borders. One of the project's themes dealt with road and weather and was chaired by Finland.

Introduction

There is a story on how Finland was engaged in this project. In the 70's Finland was not a member of the European Union, however, many COST projects had Finnish participants since COST activity was open to other countries than the Member States at their own expense. At the beginning of COST 30 preparatory meetings conducted by the COST Transport Committee were held in 1973-1974. Prior to the meeting, where COST 30 plans were on the agenda the Finnish representative of MoTC had an *ad hoc* discussion with the Director of Vaisala Ltd. During the discussion the idea emerged that Finland would benefit from participating in an electronic development project on weather-related issues. In the meeting the Finnish representative explained about weather hazard for traffic and suggested that this problematique should be included, because weather surely is an important factor affecting driving conditions. The meeting listened carefully but did not make any decisions. It then happened that the chair of the Transport Committee stranded in a flood while driving a car in Yugoslavia the following summer, and was henceforth assured of the importance of weather phenomena for traffic. In the next Transport Committee meeting when the Finnish representative raised the issue again, the meeting readily agreed after having heard the chair's story. Then the chair asked if Finland would take the responsibility for the weather and traffic project. This was agreed by the Finnish MoTC, too, and financing was cleared finally by the MoF. The theme 8 'Automatic Detection of Bad Weather' (and later a co-ordinating theme 9) was added to the COST 30 project to be co-ordinated by Finland. The development and results of the Road Weather Research and Systems in Finland is thoroughly presented by Auli Keskinen, the co-founder of SERWEC (Keskinen, 1999).

Hindsight: Road Weather Research and Development

From the Finnish point of view, the *road weather has now been researched and developed* for 30 years, since Finland joined COST activities in 1971 and the COST30 project in 1974. The next phase, COST30, in 1977-1980 was executed on the basis of a concerted action covering co-ordinated national research programmes. The third phase COST30 Bis consisted of two parts, an interim phase from April 1980 to April 1982 and final phase from April 1982 to April 1984, subsequently extended to the end of March 1985. (EUCO-COST30 Bis 1985). The COST30/8 activities were also continued as a new COST309 project during the years 1987-1990 (COST309 1992). The overall time schedule for the EUCO-COST projects and the parallel Finnish application projects for Road Weather System and Service are presented in the following table 1 (Keskinen 1999):

Table 1. Time periods and Activities of COST 30 and Road Weather Service Projects

Time Periods	Activities	Actions / Comments
1970	COST30 project started by EU/DGXII.	7 European Union MSs.
1970 - 1977 1971 1974 - 1976	Preparatory phase for R&D in road traffic. Finland joined in COST activities. Basic R&D done for both COST30 and the Finnish application started by the MoTC Steering Committee.	4 more countries joined.
1977 - 1980 1977 1978 - 1979 1979	COST30 started (MoU signed), with 9 themes. Theme 8 chaired by Finland. Automatic road weather station (AWS) prototype. First experiments of Road Weather Service. Final report of Theme 8.	Each theme chaired by different countries (MSs mostly). New microprocessor technology employed. System running 1979-1981
1980 - 1984 1980 - 1982 1980 - 1982 1979 - 1982 1982 - 1984	COST30 Bis, continuation phase, Finnish Application. Interim Phase of COST30 Bis. Preparation of the Finnish systems development plan and the Finnish application project period. Experiments of Road Weather Service. Final Phase of COST30 Bis.	Special working group of MoTC. Experiments in Turku and Helsinki areas, coming of videotex.
1983 - 1985 1983 - 1984 1985	Routine use of the Finnish Road Weather System. COST30 Demonstration in the Netherlands. Final report of COST30 and COST30 Bis.	Enhancement of the system. Final conference in Paris. SERWEC starts.
1986 - 1987	Development plan of the Finnish system by NBR who takes responsibility of the total system.	FMI & NBR activities re-organised, Networking.
1987 - 1990	COST309 Project.	Finland co-ordinated two subprojects New name 1990: SIRWEC.
1987 - 1992	New Development of Extensive Road Weather Service System.	Upgraded technology.

In the table, FMI is Finnish Meteorological Institute, NBR is National Board of Roads, SERWEC is the Standing European Road Weather Committee, MoTC is the Ministry of Transport and Communications, and MoU is the Memorandum of Understanding.

The COST30 project included 9 themes:

Theme 1: In-car oral communication with the driver,

Theme 2: In-car visual communication with the driver,

Theme 3: Communication with the driver by variable traffic signs or signals,

Theme 4: Radio broadcasting of traffic information,

Theme 5: Information needs from the part of drivers and road authorities, benefits and advantages of communication with drivers,

Theme 6: Automatic or manual detection of incidents affecting traffic,

Theme 7: Clear, correct and unambiguous terms for use in messages in different languages,

Theme 8: Automatic detection of bad weather,

Theme 9: Equipment required for control centres and data transmission, strategies for traffic regulation on motorway networks and proposals for an international demonstration.

The themes were chaired by different countries, Theme 8 by Finland. The project ended with a sizeable demonstration system, which was built on the Dutch motorway network between the Hague and Rotterdam from April 1983 to April 1984. (EUCCO-COST30 Bis 1982 and 1984, Keskinen 1982a). The Finnish results of R&D were also at display, including the automatic road weather station with new sensors and a road weather service system. (EUCCO-COST30 Bis 1982 and 1984.)

COST30 Theme 8: Road Weather (Automatic Detection of Bad Weather). The Theme 8 was about research and development on automatic detection of bad weather conditions. The aim of the research was to study the interconnection between road traffic and weather and to develop up to a prototype stage an electronic system for detecting and warning for weather and driving conditions and their predictable changes. The system should detect, predict and give warning of hazardous changes in each of the following conditions: visibility, wind speed and gustiness, skid risk due to changes in weather, and flood risk. Furthermore, the aim was to examine the problem of short-term weather forecasting and its repercussions on road maintenance, traffic strategy and the identification of bad weather 'blackspots'. (EUCCO-COST30 Theme 8 Working Group 1979.)

The work of theme 8 was largely concerned with the development of a road weather detection system comprising a number of localised road weather monitoring stations. Each station would enable road weather conditions to be automatically detected on a particular section of road. The system could monitor particular blackspots or be extended to cover selected points along a road or even the entire road network. More detailed information than that provided by the existing meteorological services would then become available, and drivers, road maintenance crews, and traffic control authorities might all expect to benefit. By using the information from the weather service and the data automatically observed on the road weather stations it has become possible to predict the surface temperature of the road some hours ahead. All in all, the main aims were to: a) improve traffic safety, b) reduce traffic costs, and c) optimise road maintenance operation and reduce maintenance costs. (EUCCO-COST 30 Theme 8 1979.)

Finland joined the COST30 project in 1974 and started to co-ordinate Theme 8 in 1975. Participants in the working group of COST30/Theme 8 were from the National Board of Public Roads and Waterways (NBW) in Finland, Transport & Road Research Laboratory in the UK (TRRL), Bundesanstalt für Strassenwesen in the Federal Republic of Germany, Rijkswaterstaat in the Netherlands, National Swedish Road Administration in Sweden, Ministerialrat im Bundesministerium für Inneres in Austria, Finnish Meteorological Institute in Finland (FMI), Swiss Meteorological Institute in Switzerland, Elin Ltd in Austria, Vaisala Ltd in Finland, State Technical Research Centre in Finland (VTT), Statens väg- och trafikinstitut in Sweden and the EC Commission in Switzerland. (EUCCO-COST30 Theme 8 1979.). From the beginning of 1975 the MoTC Steering Committee and the FMI Working Group were set up to conduct R&D on road weather.

Outcome of COST30. The final conference of the EUCCO-COST 30 and 30 Bis projects was held at OECD headquarters in Paris in June 1985 (EUCCO-COST 1985) (Keskinen 1985b). In this conference the theme 8 was actively participated and supported, and there was the consensus that European co-operation should continue within this theme. At the closing session the chairman made the following statement:

There is need for R&D work in the field of road weather conditions, in order to improve traffic safety, and to help winter road maintenance. Taking into account the resources needed and the need for harmonisation and standardisation, co-operative research work is highly appreciated. The following are examples of the important research topics: detection and short term forecasting of road and weather conditions. It would be very much appreciated if SERWEC could prepare a proposal for this new research project. (EU Commission 1992, 4.)

Hence the Standing European Road Weather Commission (SERWEC), which was set up by the second international road weather conference held in Copenhagen in February 1985 (Vejdirektoratet 1985), was given the task to draft future R&D co-operation. Already before that, the first international Road Weather Expert Meeting was held in the Hague in conjunction with the demonstration in February 1984 where the R&D co-operation continuation of road weather was first discussed (Thornes 1986).

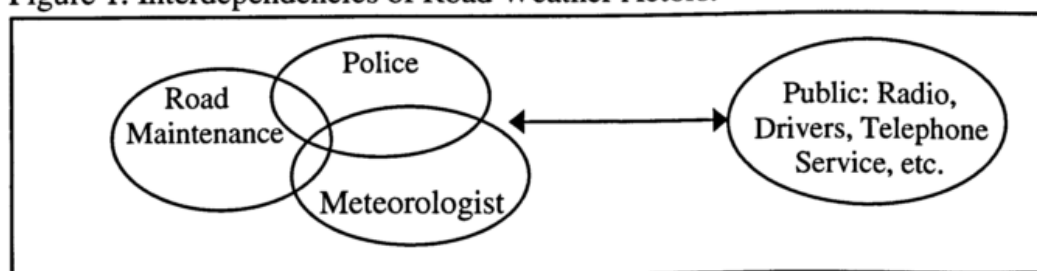
Allen Perry from Swansea University and myself chaired the first Road Weather Expert Meeting in the Hague in 1984 (FMI 1986, Thornes 1986). We were then elected by the participating 50 experts from 13 European countries as the first chairs for the ad hoc co-operation group, given the name ERWEC (Keskinen 1985a). We were elected as chairs of the Executive Committee as well. The Executive Committee had the first meeting in Birmingham in 1984 and prepared the Constitution and future actions for the newly acquired road weather community (Thornes 1985). The next SERWEC (Standing ERWEC) conference, participated by 90 experts from 14 countries, in Copenhagen in 1985 was chaired by me (Vejdirektoratet 1985).

The COST30 project ended in 1985 but needs for further R&D were apparent. The SERWEC co-operation, which started in 1984 is but one manifestation of this. A new COST project was evidently also needed. COST309 on 'Road Weather Condition', was established for the years 1987-1990. The aim of this project was "to improve traffic safety and traffic flow and to reduce road winter maintenance costs and environmental pollution", and it consisted of 12 themes (subprojects) of which Finland co-ordinated two: Weather Radar and Cost-Benefit Analyses of Road Weather Service. (EU Commission 1992, 5-6.). The first book on road weather was published in 1991 bearing the name: 'Highway Meteorology' (Perry & Symons 1991). Later, the SERWEC was enhanced to cover international co-operation, thus becoming SIRWEC.

Insight: Summary of results of COST30

In summary, COST30 was pioneering in a new interdisciplinary field. To succeed, such activity needs: a) basic and applied R&D, b) new relevant knowledge base creation, c) testing and experiments, d) co-operative decision making routine method development, e) joining resources and bringing various actors to the same negotiation table - virtually or physically, and e) studying and developing joint operations on the joint interest area. The interdependence of the actors concerned can be summarised as in the following figure 1 (Keskinen, 1999).

Figure 1. Interdependencies of Road Weather Actors.

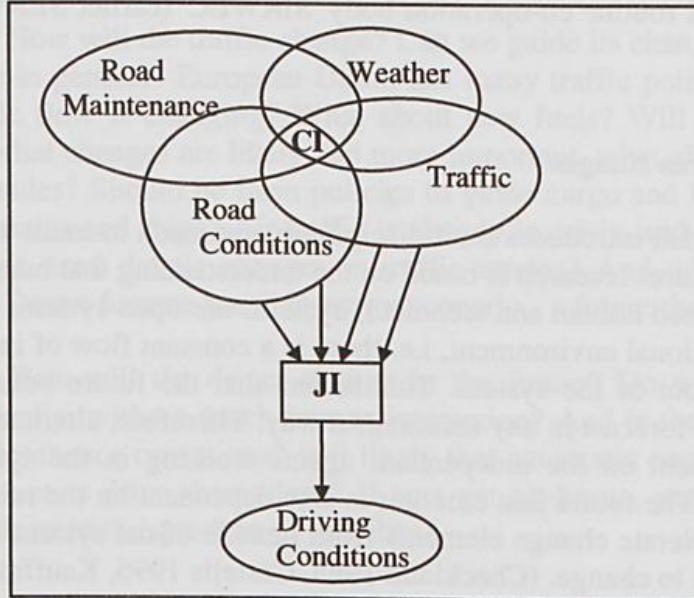


The Finnish application of the results of the COST30/8 work were developed and implemented in the early 80's, and the system still runs today, with various systems changes and enhancements introduced along the way. A general winwin approach was used in research and development as well as in routine operations and in implementing the systems change.

Some research highlights in Finland. The road weather research concentrated on road condition measurements and forecasting conducted by the Research Co-operation Group (Keskinen et al. 1981, Keskinen 1980b). It was found out early that there was a strong cross-impact between road conditions and traffic and that the joint impact of road maintenance and weather was crucial for the

kind of driving conditions that emerged (MoTC 1982). The cross-impact between road conditions and traffic and the joint impact of road maintenance and weather on driving conditions can be illustrated by applying the framework of cross-impact (CI) & joint impact (JI), as is presented in the following figure 2 (Keskinen, 1999).

Figure 2. Cross-impacts and Joint Impact of Road Weather.



The automatic road weather station was developed to form a consistent set of hardware and software, see the following figure 3. It now consists of one pole to be erected by the roadside. The attached sensors include those of air and road surface and road layers temperatures, wind, rain amount and intensity. The on-site processor attached to the pole collects the sensor measurements every minute, analyses the road conditions from the data, and sends the data to the local server computer (Pilli-Sihvola 1993).

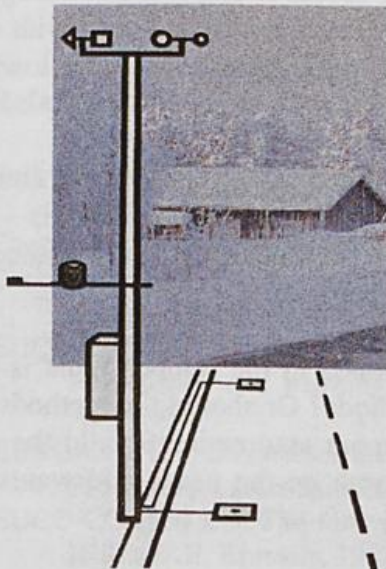


Figure 3. Automatic Road Weather Station 1992.

In the figure, there are several sensors attached, which measure temperature in the air, on the surface of asphalt and inside the road structure. Especially the surface measurement sensor has needed a long development process, since the traffic with studded tyres and the freezing-thawing process of surface wetness often combined with salt, sand, and dirt, causes several types of stress, wear and tear. Wind speed and direction, humidity and amount of rain are also measured. (The figure is from Pilli-Sihvola 1993)

The road weather system has been further advanced after 1992 by a joint research effort with the European Union. The Road Administration is developing new telematics solutions to improve traffic flow, traffic safety and driving comfort. Transport telematics increase the effectiveness of traffic control, traffic information and winter maintenance. This activity is included in the Viking project within the Trans-European Network for Transport (TEN-T) and PROMISE, having here one of the demonstrated test areas, i.e. the highway between Turku-Helsinki-Vaalimaa in 1996-1998.

Summary and Conclusions. The Road Weather Service development in Finland was based on European R&D Co-operation in the field of Transport. The EU-COST30 project made basic and applied research and development on electronic aids for major roads. Finland steered the R&D on the impact of weather on road traffic. The major outcomes of the work are: a) new data, information and knowledge was generated concerning the previously *terra incognita* of 'road weather', b) intersectoral decision making practices were developed, c) new ICT was successfully developed and exploited, and d) an international routine co-operation body 'SIRWEC' (earlier SERWEC) was created. (Keskinen 1999).

Foresight: Futures Thinking, Futures Images

Futures research is a new discipline that introduces multidisciplinary approach to multi-stakeholder phenomena such as road weather. Futures research is based on the understanding that human (and in our knowledge society ever more mixed human and technical) systems are open systems that are in continuous interaction with its operational environment, i.e. there is a constant flow of information, energy, material and actors in and out of the system. This means that the future behaviour and "destiny" of such a system cannot be forecast in any meaningful way. Therefore, alternative futures of such systems are heavily dependent on the independent agents working in the system, their actions, decisions and collaboration. The future that emerges is also dependent on the robustness of the system itself - how well it can tolerate change elements from outside of the system and within the system, and how well it can adapt to change. (Checkland 1985, Castells 1996, Kauffman 2000)

Futures research is research on present from a specific futures knowledge point of view. It studies the futures alternatives using what-if analyses, expert Delfoi-surveys, futures workshops, trend and wild card analyses etc. This type of research relies heavily on human interaction and collaboration of diverse expertise and establishing common interest areas. (Bell 1997, Malaska 1991). The basic questions are: when thinking about future, what kind of future is desirable, what is possible, what is probable and what is avoidable. The future that is fulfilled is thus dependent on the joint outcome of future images based on these research results. But no desirable future can be pursued in real life without human will, motivation, competence and access to relevant knowledge.

What possible future changes will affect the future of road weather. We can start with the elements in figure 2 and discuss their alternative possible and desirable futures in the following manner:

Weather and Climate: How will the weather and climate change in the future? These are of course natural systems that are only partly affected by human actions. But how probable it is - as suggested by climatologists and other experts - that climate changes so that winter maintenance is not so very important anymore, as it is dependent on the winter weather?

Road Maintenance: How will road maintenance actions be developed in the future? What is the desirable future like? Is it important to find new more efficient methods? Or should the methods be more environment-friendly? More steerable on the site and even more automatic? Should the de-icing substances be more advanced? This type of interactive research on the needs and wants of society are needed when planning future actions.

Road Surface: What changes do we expect for the road surface itself? Do we want different materials to be used on the road surface that are not slippery and do not react to weather so readily? Then again, is it possible to develop new materials of this kind but that these would be cheaper and more readily available? Or, can we imagine some other innovation to be created for constructing road surface in a quite different manner? What would then be the desirable future?

Vehicle: What are the vehicles like in the future? Do they have rubber tyres or wheels at all, for that matter? What if the cars will be air-borne? Then the slipperiness is quite another matter? What impacts would this have for the road maintenance? What if the tyres are not made of rubber? Do we need or want to innovate new type of interface between the car and the road surface that would not be slippery at all? In this question, so many stakeholders come into play. The most important question here is: What do we actually want?

Traffic: How will the traffic change? Can we guide its changes? Who will have impact on the flow of traffic in general? European Union has many traffic policies so can we see from there whereto the traffic flow is changing? What about new fuels? Will that have an effect on traffic? Traffic modes, what changes are likely and more important, what changes are wanted in the break down of traffic modes? Should be form policies to guide cargo and human traffic to change over more and more to trains and ships? Air traffic is already in crisis, and so is road traffic in many urban areas - maybe we need drastic changes in traffic modes? And who are the prime actors in this policy change? Do we foresee possible horror scenario - a future that we want to avoid at all costs?

Driver: How will the driver change in the future? Do we see the car driving more and more automatically, without much human interaction? And is that desirable? How does this then affect road maintenance operations? Is it likely that automatic cars will result to fewer accidents? Do the people want to drive themselves? If cars get air-borne, perhaps automatic driving is a necessity? This leads us to the question of mobility.

Mobility: Is it not so, that the fact the people and goods travelling constantly around the globe is very unecological and very uneconomical? Is it really necessary to e.g. milk the cows in northern Finland, transfer the milk to Denmark, make yoghurt there and transfer the canned yoghurt back to the neighbouring supermarket nearby the dairy where the milk started its journey? This is a factual situation, but why is it done? In the knowledge society, would it not be much more economic and sustainable development to transfer the recipe of the yoghurt to the yoghurt factory built in the same town as the original dairy? And what effect would this type of development have on road weather services?

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INDUSTRIAL SNOW

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ABSTRACT

This paper describes the phenomenon of industrial snow. In freezing conditions with stagnant low stratus/fog industrial snow is observed locally. Nocturnal radiative cooling at the top of the stratus initiates and drives convective mixing. Near localized sources of water vapour the supercooled droplets in the supersaturated stratus crystallize and fall out as industrial snow. Predictions of industrial snow are possible if the air temperature and the cloud base and top, respectively, of low stratus can be predicted.

1 INTRODUCTION

At several locations in Switzerland local snowfall is observed regularly in freezing conditions with a stagnant low stratus. The phenomenon is named «industrial snow» in Switzerland and «beer snow» in Munich as it occurs in the vicinity of waste disposal plants and of production plants for beer, steel and paper. Snow depth is usually small and can be countered by salting roads and sidewalks. The very local occurrence of a snow cover on otherwise dry roads can be surprising for drivers. Road maintenance services would appreciate to anticipate the conditions that lead to industrial snow. Based on reported cases of industrial snow the corresponding meteorological conditions and processes have been analyzed.

2 PHENOMENOLOGY

Industrial snow has been reported for a number of locations on the Swiss plateau between the Jura mountains and the Alps (Figure 1). Most frequently industrial snow is reported for Bern, Zurich airport, Winterthur, and St. Gallen. Complete documentations of cases with industrial snow could be collected for the city of Winterthur and for Zurich airport. During the four winter seasons from 1999/2000 to 2002/2003 industrial snow occurred on 4.5 days per winter as an average value at both sites. In most cases industrial snow occurs at both locations simultaneously.

Industrial snow is basically a nocturnal phenomenon. Fall out occurs most frequently in the hours before and around sunrise (Figure 2) after low stratus/fog has formed during the night. If low winter stratus does not dissipate during the day industrial snow may already fall a few hours after sunset (Figure 3).

Snow depth is typically 1 to 2 mm and not evenly distributed in the affected area. In Winterthur a local snow depth of 20 mm has been observed. As extreme values local snow depths of 50, 100, and 150 mm have been reported for the motorway near Kriegstetten on a distance of about 1000 m requiring mechanical removal of the snow.

The area affected is on the order of 4 km² in Winterthur (Figure 4). Starting out from the source chimney at the waste disposal plant the affected area extends into one of three directions: NE, W, or SE.

Industrial snow is also reported for locations near the runways of Zurich airport where aircraft climb and sink through the low stratus.

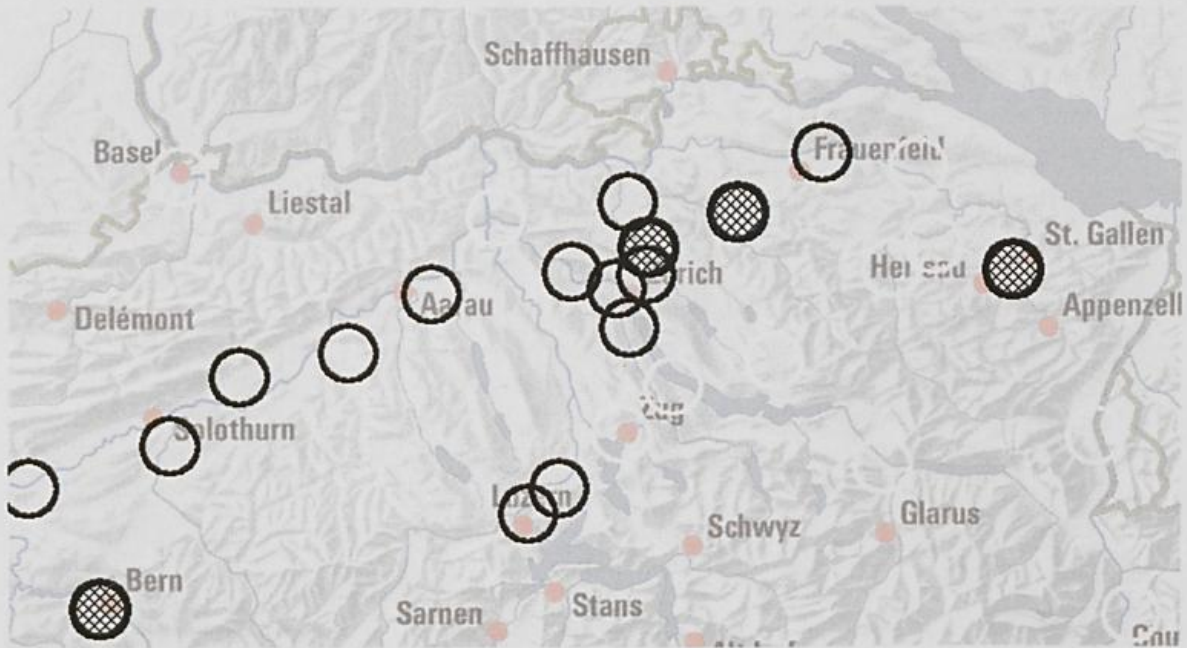


Fig. 1 Locations with industrial snow in Switzerland (hatched: most frequent)

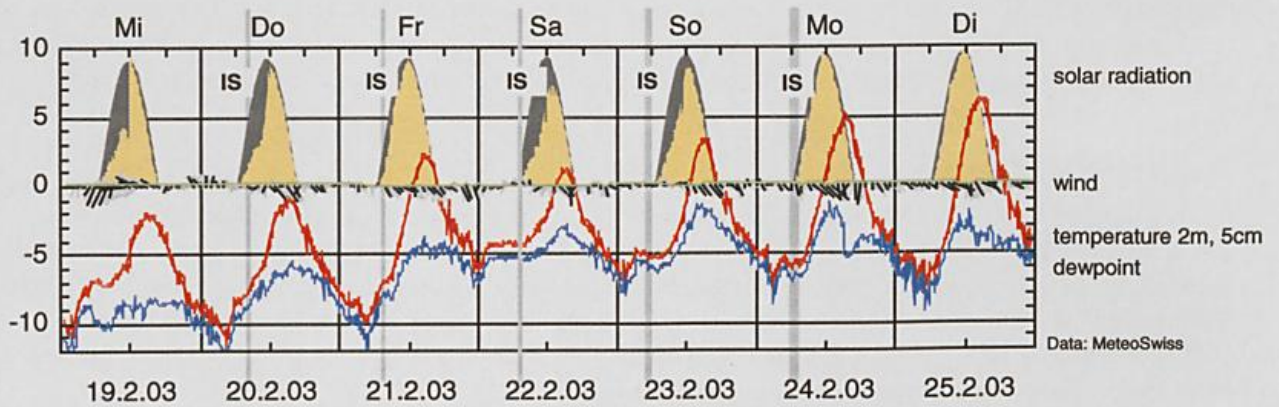


Fig. 2 Industrial snow (IS) at Zurich airport with dissipating stratus

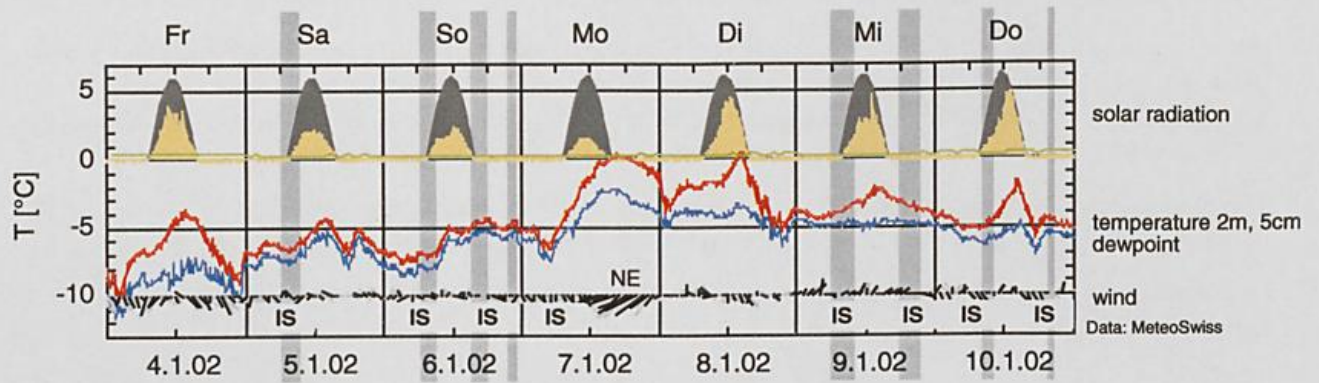


Fig.3 Industrial snow (IS) at Zurich airport with persisting stratus

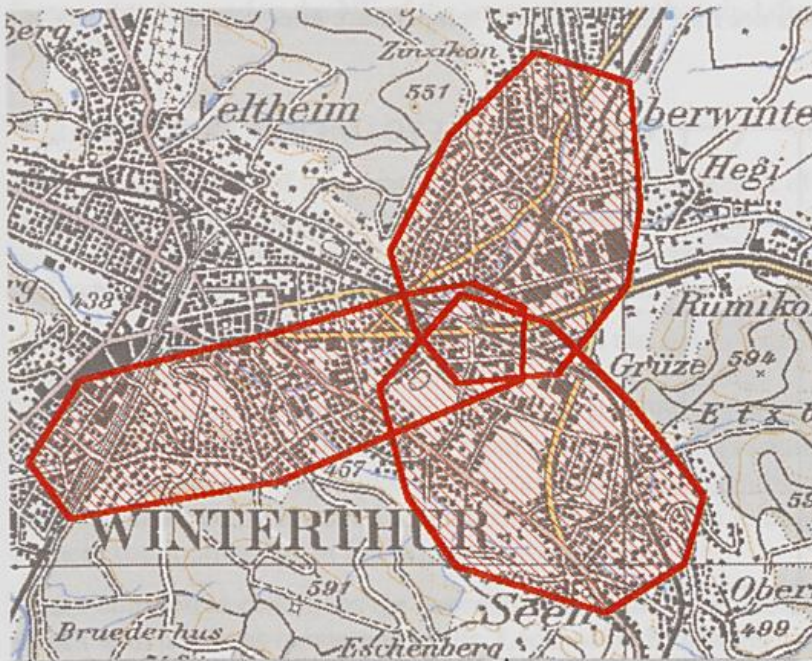


Fig. 4 Areas with industrial snow in Winterthur

Industrial snow on the Swiss plateau requires a stagnant cold air pool topped by a stratus cloud with temperatures in the freezing range. Such conditions are found in winter (Dec, Jan, and Feb) during periods of high pressure. The cloud base of the stratus must be low (0-150m above ground), the depth of the stratus is on the order of 200 m (Figure 5). Above the stratus the sky must be clear .

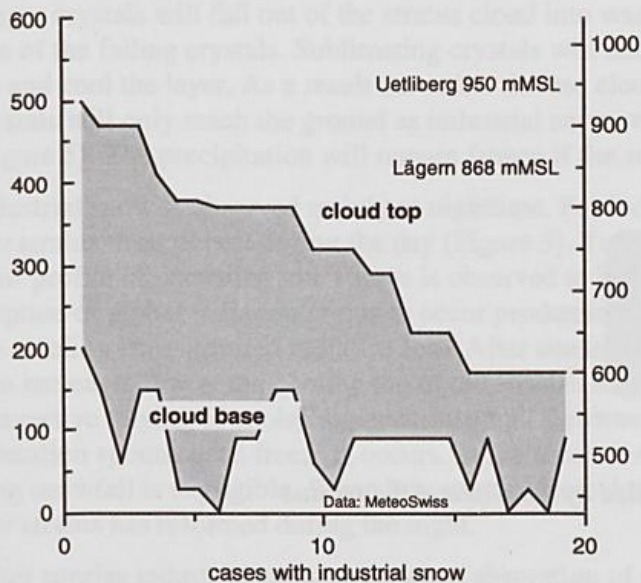


Fig. 5 Cloud base and top of stratus during industrial snow

In conditions with fog or low stratus nocturnal cooling is either very slow or air temperature is constant. During fallout of industrial snow temperature tends to fall slightly and the stratus becomes inhomogeneous. The snow falls for about half an hour, snow depth is usually 1 to 2 mm only. The fallout can occur

again after some time, if temperature does not rise. An increase of temperature after sunrise will usually stop the phenomenon.

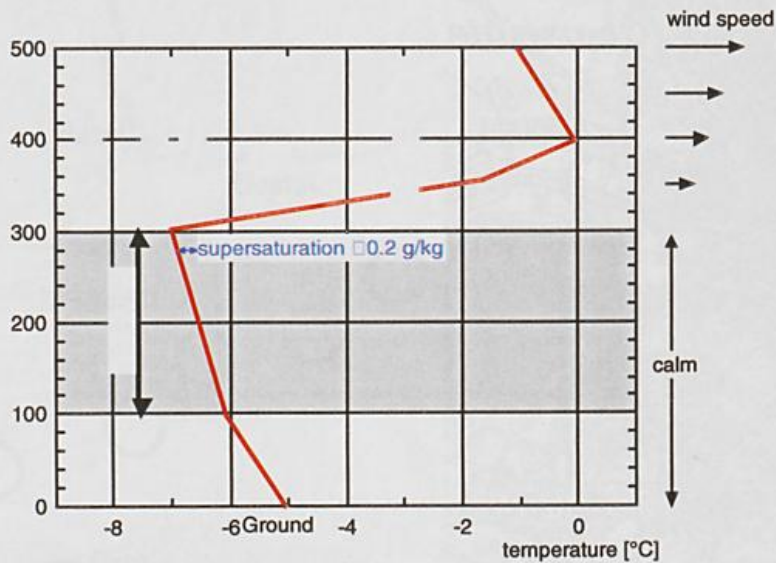


Fig. 6 Temperature, humidity and wind profile for industrial snow

When industrial snow falls the atmospheric lapse rate is wet-adiabatic within the stratus cloud and dry-adiabatic below. The stratus is confined by a marked temperature inversion of dry air (Figure 6). Relative humidity near ground is very high (the dewpoint depression is less than 1°C) and the cloud base of the stratus is very close to the ground.

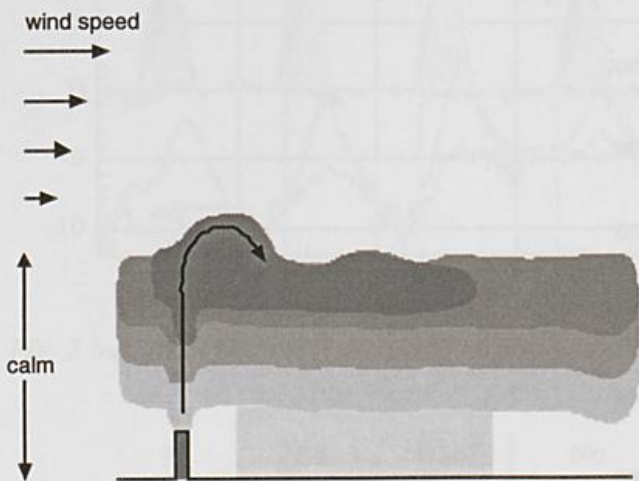


Fig. 7 Displacement of industrial snow is controlled by wind above the stratus

Warm and moist air from industrial sources climbs easily through convective low stratus and penetrates into the inversion. The vertical motion is not strong enough to break through the inversion. The warm and moist air returns into the stratus layer without significant entrainment of warm and dry air. Wind in the inversion layer, however, will displace the reflected plume. Industrial snow will then fall out on the downwindside of the source. The distribution of industrial snow around the source is basically controlled by the wind above the stagnant pool of cold air (Figure 7). In Winterthur (Figure 4) industrial snow is

frequently observed to the NE of the source because the wind direction above the low stratus is often from SW.

3 RADIATIVE COOLING OF LOW STRATUS

The vertical profiles of temperature and moisture are the result of vertical mixing in the cold air pool. In stagnant air the mixing is due to convection driven by radiative cooling at the surface of the stratus during long winter nights under clear sky. The mixing depth grows downward from the cooling top of the stratus and eventually reaches the ground of the cold air pool.

As the cooled body of air is much deeper than in the absence of cloud, the cooling is slow ($-0.05^{\circ}\text{C}/\text{h}$) when compared to clear conditions ($-0.65^{\circ}\text{C}/\text{h}$ with deposition of hoar frost). In Figures 2 and 3, clear and cloudy conditions can also be distinguished by the temperature difference between 2 m and 5 cm above the surface. In clear conditions with rapid cooling the temperature at 5 cm is below the temperature at 2 m. In cloudy conditions with minor cooling temperature at 5 cm is equal or higher than at 2 m. In addition to the mass of air being involved in the nocturnal cooling the release of latent heat in cooling cloud also reduces the cooling rate in low stratus to some extent.

Under convective conditions the concentration of the supercooled water droplets within the stratus increases with height as temperature falls. Local sources of water vapour will increase the supersaturation, as long as the added water vapour can not escape vertically into and through the stable layer above the stratus.

Locally supersaturation in the upper part of the cooling stratus must reach values that allow spontaneous freezing of supercooled droplets at temperatures around -7°C . Ice crystals colliding with supercooled droplets will grow at the expense of the supercooled droplets that will freeze. Crystal growth is supported by the vertical mixing of the cooling stratus. Concentrated industrial moisture sources are also heat sources and create good local growth conditions by feeding moisture and enhancing the convective mixing.

Larger crystals will fall out of the stratus cloud into warmer, unsaturated air. Sublimation will reduce the size of the falling crystals. Sublimating crystals will add moisture to the unsaturated layer below the stratus and cool the layer. As a result the rather diffuse cloud base of the stratus will be lowered. Falling ice crystals will only reach the ground as industrial snow, when the cloud base is close enough to the surface (Figure 5). The precipitation will remain frozen if the surface temperature is in the freezing range.

Industrial snow is observed mainly at nighttime. For industrial snow to occur already soon after sunset low stratus must persist during the day (Figure 3). Towards the end of daytime on a winter day the temperature profile of persisting low stratus is observed to be isothermal. With small solar elevations the absorption of global radiation seems to occur predominantly in the upper layers of the stratus and to exceed the cooling from infrared radiative loss. After sunset radiative cooling becomes dominant. Supersaturation increases first at the cooling top of the stratus. Radiative cooling at the top of the stratus leads to convective mixing of cooled supersaturated air downward into the stratus. At a certain degree of supersaturation spontaneous freezing occurs. In the absence of powerful local moisture sources the corresponding snowfall is negligible. When low stratus clears during the day industrial snow can only occur after low stratus has reformed during the night.

After sunrise industrial snow stops when absorption of solar radiation near the top of the stratus leads to stabilization and heating reduces the supersaturation.

4 CONCLUSION

Industrial snow is a convective phenomenon that occurs in the vicinity of localized heat and moisture sources in freezing conditions with a stagnant low stratus cloud. Radiative cooling of the stratus under

clear sky is necessary and the base of the stratus must be close to the ground. Predictions of industrial snow depend on the predictability of fog and low stratus in pools of stagnant cold air.

Meteorological Factors Associated with Avalanches in the Lake Shikotsu Area and Their Application to Road Management

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1. Introduction

Countermeasures against avalanches have been improved and effectively implemented on roads in cold, snowy regions. However, when avalanches are greater in scale than the design capacity of the countermeasures, they sometimes cause road closure. As road administrators are required to make quick, proper decisions regarding such events, their accurate understanding of avalanche likelihood is crucial.

This study aims to assist road management by clarifying localized formation mechanisms of avalanches in Hokkaido and establishing a simplified method of determining the avalanche likelihood. This paper investigates the relationship between avalanche formation and meteorological conditions on National Highway 453 in the Lake Shikotsu area, toward establishing a method of determining the avalanche likelihood in a specific area. We report the results of an experiment using the method in road management.

2. Outline of the investigated section

The section investigated in this study measures the nearly 5 km between Kilometer Post (KP)42 and KP47 on National Highway 453 along Lake Shikotsu in Chitose, Hokkaido (Figure 1). This section was hit by avalanches almost simultaneously at 16 locations on February 1, 2001, holding up buses and cars. As a consequence of this disaster, a study on avalanches in this area was launched. The road section runs along Lake Shikotsu at the foot of Mt. Mombetsu. The slopes adjoining the section have a gradient of 35° and face southwest. The vegetation is rather sparse: The uppermost part of the slope is bare ground and shrubs; halfway down is mostly broadleaf tree; and the slope immediately above the road is grassy.

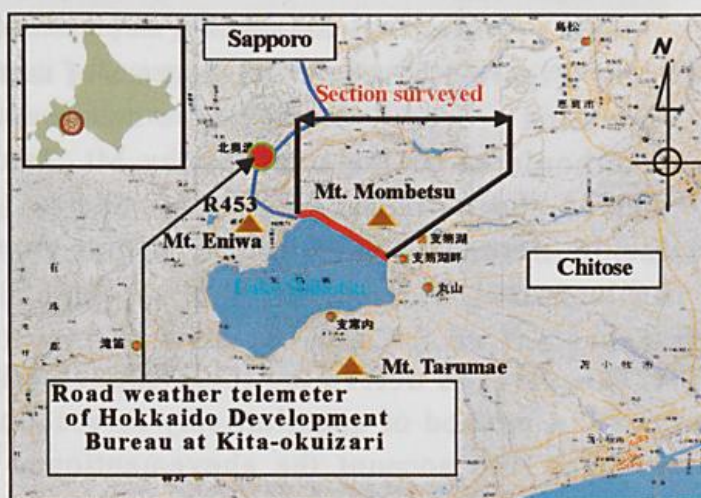


Figure 1 Section surveyed

3. Hypothesized avalanche formation process

Figure 2 shows changes in temperature and snow depth before and after the avalanche on February 1, 2001. Previous examinations on meteorological conditions at the time of avalanches on roads near Lake Shikotsu¹⁾ identified a relationship between avalanche and a weather pattern in which a low-pressure system approaching from the southwest brings a rise in temperature accompanied by heavy snowfall. Such snowfall is assumed to abruptly increase the snow depth, thereby increasing the load that new snow exerts on previously fallen snow and causing the driving force to exceed the resistance force. This eventually results in a surface avalanche.

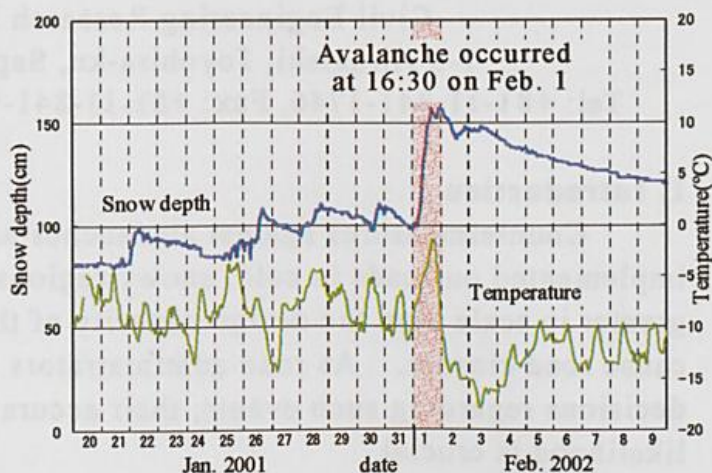


Figure 2 Meteorological conditions around the time of avalanche

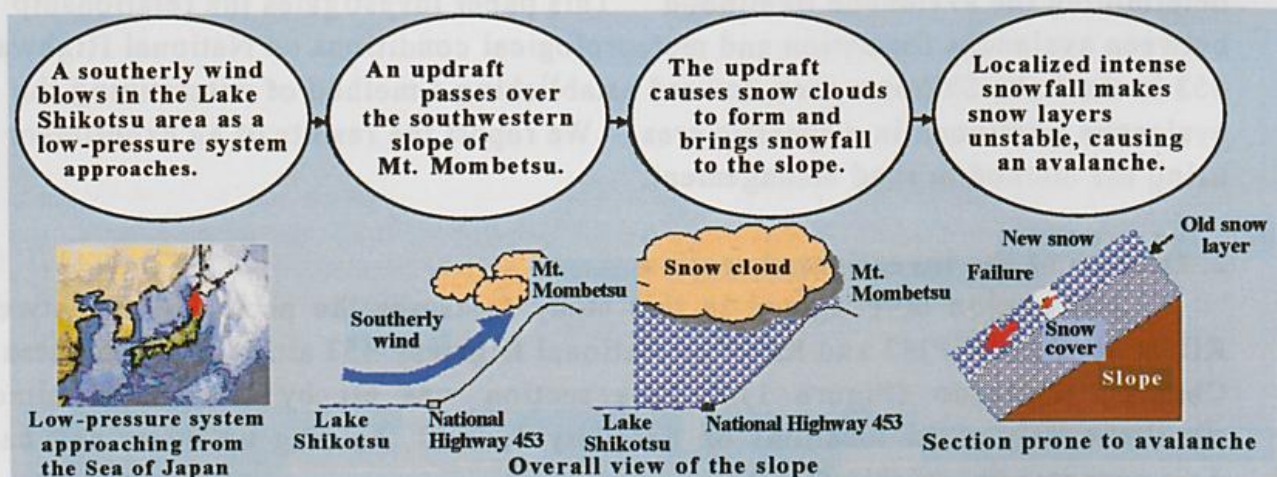


Figure 3 Schematic diagrams depicting the process of avalanche formation in the Lake Shikotsu area

Figure 3 is schematic diagram of meteorological changes and the avalanche formation process. It should be mentioned here that Lake Shikotsu is a caldera lake bordered on the southeast by Mt. Tarumae, on the northwest by Mt. Eniwa, and on the northeast by Mt. Mombetsu (the study area). Such topographical factors were considered to induce snow clouds and bring heavy snowfall, as Figure 3 illustrates.

4. Measures to determine the avalanche likelihood

A method of quantitatively forecasting avalanche likelihood was developed. It takes into account the abovementioned conditions of avalanche formation at Lake Shikotsu.

For meteorological factors, this study focuses on low-pressure system and snowfall amount as triggers for avalanche formation. Low-pressure system is an

indirect factor in snow cloud formation and heavy snowfall, depending on its movement and location. Amount of snowfall is a direct factor, as snow cover deepened by heavy snowfall induces avalanches.

4.1 Pressure gradient (*I*)

To determine a pressure gradient (*I*) around the Lake Shikotsu, hypothesized coordinates were structured, with four locations surrounding the lake (Figure 4) positioned on *x* and *y* coordinate axes and their atmospheric pressures positioned on the *z* coordinate axis. Kutchan, Tomakomai, Sapporo and Muroran were placed at (*x*₁, *y*₁, *z*₁), (*x*₂, *y*₂, *z*₂), (*x*₃, *y*₃, *z*₃) and (*x*₄, *y*₄, *z*₄) respectively.

The Tomakomai-to-Kutchan vector was expressed as $a(a_x, a_y, a_z) = (x_2 - x_1, y_2 - y_1, z_2 - z_1)$ and the Sapporo-to-Muroran vector as $b(b_x, b_y, b_z) = (x_4 - x_3, y_4 - y_3, z_4 - z_3)$.

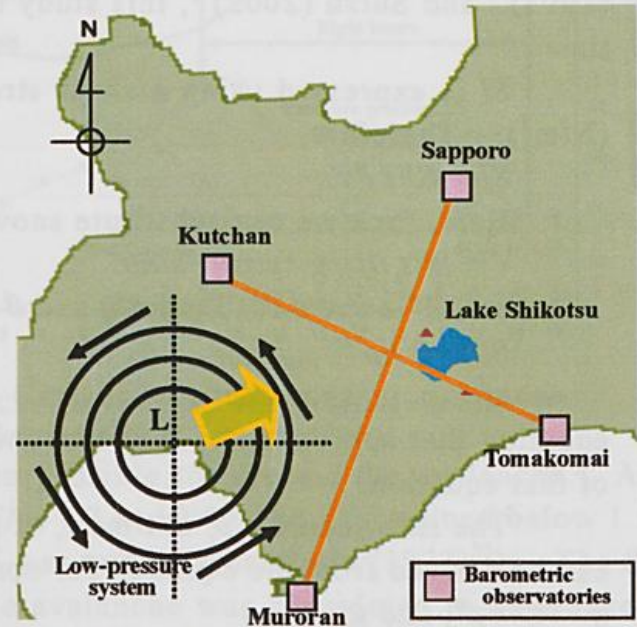


Figure 4 Relative positions of Lake Shikotsu and barometric observatories

These two intersecting vectors determined the atmospheric pressure plane. A normal vector crossing the atmospheric pressure plane at right angles was derived from a vector product $a \times b$, and therefore,

$$a \times b = (a_y \cdot b_z - a_z \cdot b_y, a_z \cdot b_x - a_x \cdot b_z, a_x \cdot b_y - a_y \cdot b_x) \dots (1)$$

Derived from *x* and *y* components of this normal vector, the direction of atmospheric depression, θ (clockwise, with north as 0°), can be expressed as follows:

$$\theta = 180^\circ - \tan^{-1}(Y/X) - 90^\circ(X/|X|) \dots (2)$$

where *X* and *Y* respectively represent *x* and *y* elements of the normal vector.

Then, the slope of the atmospheric pressure plane, or pressure gradient, was calculated from *x*, *y* and *z* components of the normal vector.

$$V = \sqrt{(X^2 + Y^2)} / Z \dots (3)$$

where *Z* represents *z* components of the normal vector.

As several case studies have indicated that southerly winds in the Lake Shikotsu area induce avalanche, this study defined the pressure gradient (*I*) of a low-pressure system approaching from the west ($\theta = 270^\circ$) as the index for avalanche prediction. *I* is defined in this paper as

$$I = V \cos(\theta - 270^\circ) \dots (4)$$

4.2 Stability index (*SI*)

To examine a method of determining the avalanche likelihood from heavy snowfall, the avalanche records collected from the Lake Shikotsu area were

referred to. It was hypothesized that in a surface avalanche a new snow layer accumulates on the surface of the previously accumulated snow, beginning at time t_i , until it slides as an avalanche.

Base on previous studies on SI (Endo, Ozeki and Niwano (1990)²⁾, Endo (1993)³⁾ and Suizu (2002)⁴⁾, this study attempted to obtain the SI of the t_i layer at time t .

SI is expressed using a shear stress τ (N/m²), and a shear frame index SFI (N/m²). Therefore,

$$SI = SFI / \tau \quad \dots (5)$$

Here, for τ we can substitute snow load $W(t, t_i)$ above the t_i layer at time t .

$$\tau = W(t, t_i) \cdot g \cdot \cos\theta \cdot \sin\theta \quad \dots (6)$$

where, W is snow load (N/m²) and θ is slope angle. SFI is given by

$$SFI = B \cdot \rho^m \quad \dots (7)$$

where, ρ is snow density (kg/m³), B is the intercept of the power series equation that approximates the relationship between SFI and ρ , and m is the slope of that equation.

The snow density ρ , at time t , of a layer accumulated from time t_i through t , can be derived from the equation for compressive viscosity coefficient of dry snow $\eta = C \cdot \rho^n$, and given as

$$\rho(t, t_i) = \{ ng/C \cdot \cos^2\theta \cdot Q(t, t_i) + \rho_0^n \}^{1/n} \quad \dots (8)$$

where, ρ_0 is initial snow density (kg/m³), $Q(t, t_i)$ is cumulative snow load (N/m²) obtained by integrating snow load above the t_i layer from time t_i to t , C is the intercept of the power series equation that approximates the relationship between η and ρ , and n is the slope of that equation.

To combine these equations, the SI of the t_i layer at time t is expressed as

$$SI(t, t_i) = \frac{B \{ ng/C \cdot \cos^2\theta \cdot Q(t, t_i) + \rho_0^n \}^{m/n}}{W(t, t_i) \cdot g \cdot \cos\theta \cdot \sin\theta} \quad \dots (9)$$

where the following values were substituted for the SFI -related coefficients B and m , and for the compressive viscosity coefficient (η) related coefficients C and n .

$$B = 3.10 \times 10^{-4} N \cdot m^{-2} (kg/m^3)^{-m}, m = 3.08$$

$$C = 1.09 \times 10^{-4} N \cdot m^{-2} \cdot hr \cdot (kg/m^3)^{-n}, n = 4$$

The slope angle θ of the section with avalanche was 45° and the initial snow density ρ_0 were defined by the following equation given by Suizu (2002)⁴⁾:

$$\rho_0 = 54 \quad (Ta(\text{temperature}) \leq 2^\circ\text{C})$$

$$= 79 + 12.5 \cdot Ta \quad (Ta(\text{temperature}) \geq 2^\circ\text{C})$$

5. Determination and evaluation of the avalanche likelihood

The equations for pressure gradient (I) and stability index (SI) were applied to the ex-post forecast of an avalanche that occurred on February 1, 2001, and another on January 27, 2003. Atmospheric pressure data used in this study were based on hourly data issued by the Japan Meteorological Agency. The rate of snowfall (hourly increase in snow depth) and temperature were taken from hourly data of a road weather telemeter of the Hokkaido Development Bureau (at Kita-okuzari).

Figure 5 illustrates the analysis results for the avalanche on February 1, 2001, showing the relationship between avalanche occurrence time and pressure gradient (I). The pressure gradient (I) increased and exceeded the threshold value of $I = 2.86$ (minimum value of past avalanches) at 7:00, and the avalanche took place eight hours after I reached its maximum.

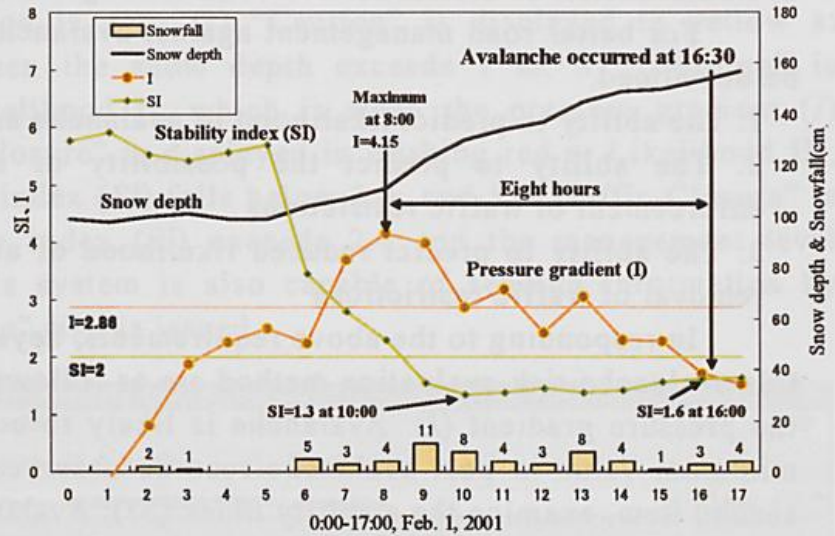


Figure 5 Changes in the risk factors before and after the avalanche of February 1, 2001

This suggests that that it may have been possible to forecast the avalanche. As for the stability index SI , starting from $SI = 1.3$ at 10:00, the SI remained below 1.5 until 14:00 (the reference value $SI < 1.5$ was quoted from Perla (1977)⁵). The SI was 1.6 around 16:30, at which time the avalanche was considered to have taken place; therefore, the forecast was not accurate perfectly. However, as it was possible to predict the likelihood of avalanche early enough for road management, the method's validity was verified by and large.

Figure 6 shows occurrence conditions of the avalanche on January 27, 2003. Similarly, the pressure gradient (I) increased and passed the 2.86 border at 13:00, and reached its maximum at 21:00. The avalanche took place two hours after the maximum was reached. The stability index (SI) fell below 1.5 after 19:00 and marked its minimum (1.1) at 23:00, which is the time avalanche occurred.

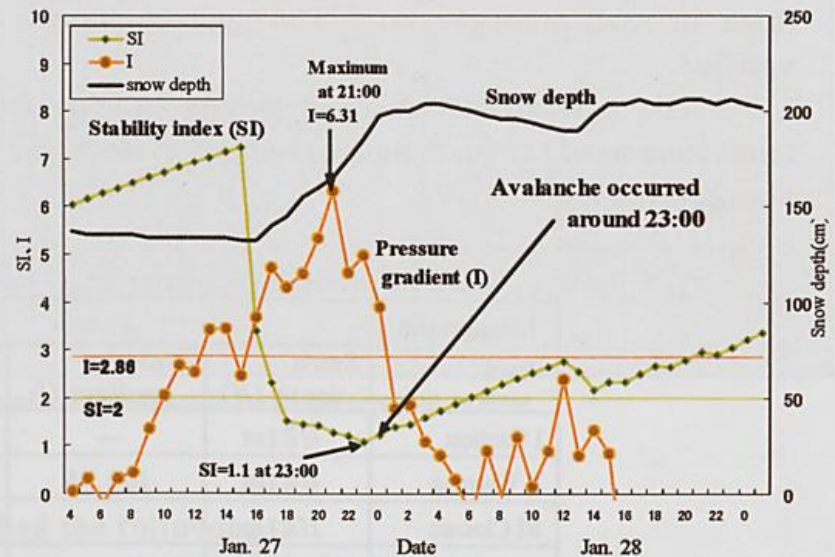


Figure 6 Changes in risk factors before and after the avalanche of January 27, 2003

The avalanche occurrence was forecast at each hour. Thus, the method developed in this study using pressure gradient and stability index is considered to be highly effective in evaluating the likelihood of surface avalanche induced by heavy snowfall at Lake Shikotsu.

6. Examination of assistance for road management

For better road management against avalanche, the following abilities must be developed.

1. The ability to predict likelihood of avalanche and conduct effective patrol.
2. The ability to predict the possibility of avalanche and determine the enforcement of traffic restrictions
3. The ability to predict reduced likelihood of avalanche and to determine the removal of traffic restrictions

In responding to the above requirements, keys to the effective application of this avalanche risk evaluation method are as follows. For the first item, examine the pressure gradient (I): Avalanche is likely to occur when I exceeds 2.86 (the minimum value in past avalanche records observed at Lake Shikotsu). For the second item, examine the stability index (SI): Avalanche is likely to occur when SI falls below 1.5. For the third item, consider the inverse result of the second item: Avalanche risk decreases when SI increases.

To establish a more effective management system, a criterion for each indicator should be set by taking these conditions into account. At this point, however, the draft of avalanche management criteria for the Lake Shikotsu area (Table 1) has set the pressure gradient at $I \geq 2.86$ (based on the records of avalanche observed at Lake Shikotsu) and stability index has been set at $SI \leq 2.0$ to allow for a margin of safety. Moreover, the snow depth $H \geq 1$ m was included as a third factor, and an attempt was made to integrate these three factors and apply them to road management. The appropriateness of these criteria needs to be verified.

The system will take advantage of data from the existing road weather telemeters used for road management; therefore, the installation of new facilities is not required.

Table 1 Avalanche management criteria for the Lake Shikotsu area (draft)

Management level	Factor		
	Snow depth (H)	Pressure gradient (I)	Stability index (SI)
I Caution	$H \geq 1$ m	—	—
II Warning	$H \geq 1$ m	$I \geq 2.86$	
III Closure	$H \geq 1$ m		$SI \leq 2.0$
Removal			$SI > 2.0$

7. Avalanche likelihood factor monitoring system

An avalanche monitoring system was designed in light of the abovementioned pressure gradient (I), stability index (SI) and management criteria (draft).

Figure 7 shows a website image of current avalanche likelihood and corresponding management level, changes in avalanche likelihood for the past 24 hours and diagrams of snow depth and other indicators. To briefly explain the

management levels, 1) “Normal” is displayed when the snow depth is less than 1 m and the avalanche likelihood is zero; 2) “Caution” is displayed in yellow at Likelihood I, which is when the snow depth exceeds 1 m; 3) “Warning” is displayed in orange at Likelihood II, which is when the pressure gradient (I) exceeds 2.86; 4) “Traffic Closure” is displayed in flashing red at Likelihood III, which is when the stability index (SI) falls below 2.0; and 5) “Traffic Closure” is removed when the stability index (SI) exceeds 2.0 and the management level returns to “Warning.” This system is also capable of sending information by e-mail when “Traffic Closure” sign is issued.

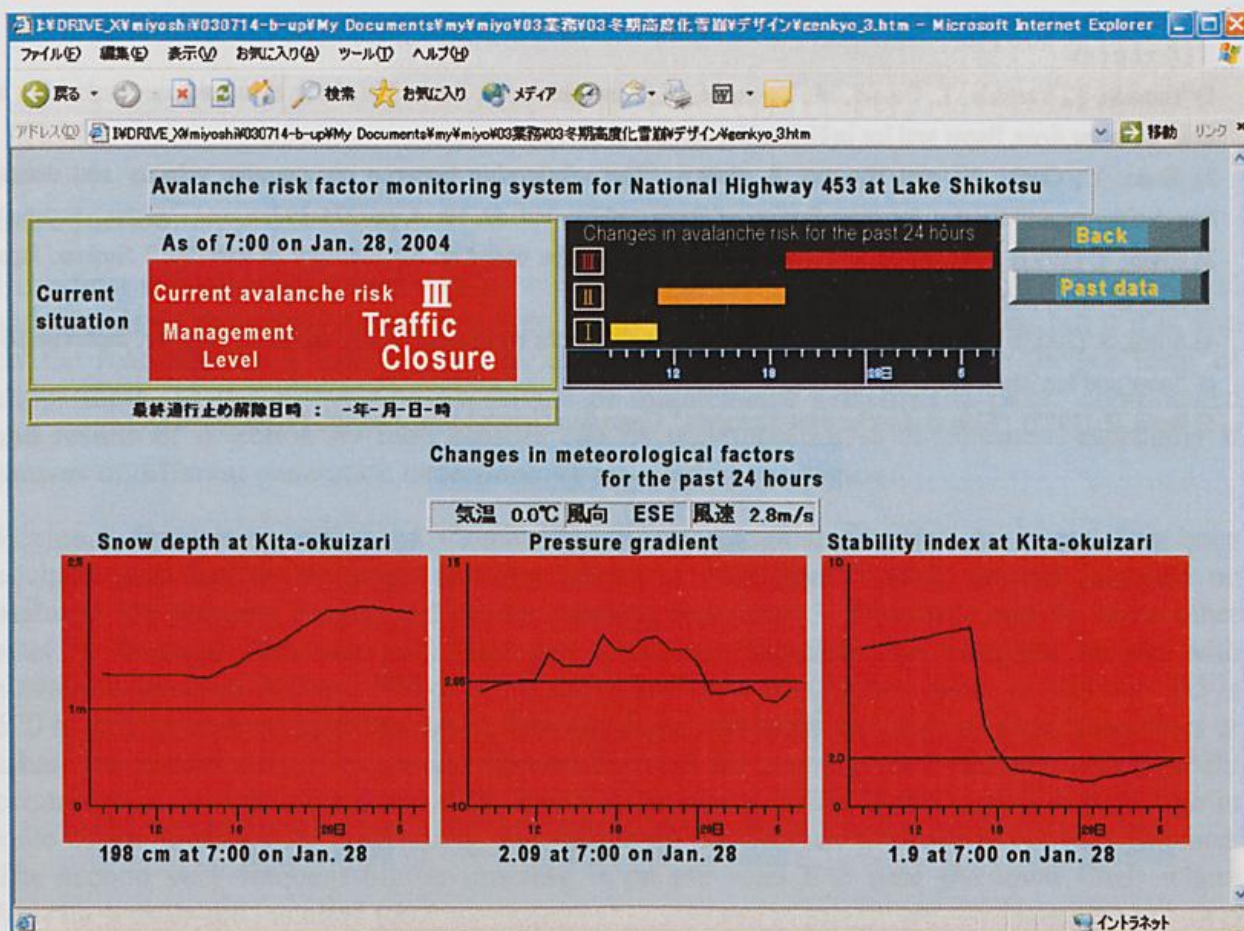


Figure 7 Display of Avalanche risk factor monitoring system

8. Conclusion

This study accomplished the following.

- (1) The process of avalanche formation in the Lake Shikotsu area was understood.
- (2) A method of hourly forecast for likelihood of surface avalanche induced by heavy snowfall in the Lake Shikotsu area was established, although with some limitations.

The following are issues to be addressed.

- (1) As the examination was conducted using few avalanche records, more data need to be stored to enhance the analytical accuracy.
- (2) The study should be further developed so that it can be applied to avalanches of different types and to other areas.

9. Postscript

It should be verified that the avalanche likelihood monitoring system that begun experimental operation is effective in improving road management and patrol systems, and in determining traffic restrictions.

Acknowledgements

I would like thank the staff at Kokusai Kogyo Co., Ltd. for their help in developing this method.

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Experiences with hoar-frost and its monitoring in Western Bohemia, Czech Republic

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Introduction

Hoar-frost still plays important role in winter maintenance of roads. Its formation is gradual and it is sensitive to local conditions. Sometimes it forms only on car windows but if it is also on the road surface it can be hard to say when this thin sheet turns to danger form of slipperiness. Visual observation by drivers or maintenance personnel is rather complicated and results of detection by road sensors can be unambiguous in some cases, especially if sensors of different generation or technology are used in one region.

Regional forecasting office of Czech Hydrometeorological Institute in Pilsen has been equipped with IceCast software and has access to data from Vaisala sensors installed on highway D5 between Prague and border crossing Rozvadov – Waidhaus and on some other sites in Western Bohemia too. This part of Czech Republic has complex terrain with elevations between 300 and 900-1000 m above sea level (the highest point of highway D5 is 620 m asl), some road stretches are in forested areas and some are close to water reservoirs or lakes. Our border mountains are also natural frontiers for temperature inversions with frequent occurrence of low cloudiness and fogs. Intensity of transit traffic in this region is very high in spite of the highway A6 to Amberg and Nürnberg on German territory is not still finished. The second very frequent border crossing is on the road E48 near the town Cheb where Vaisala sensors are installed too.

Accident statistics shows that besides of black ice and snow cover the hoar-frost is often the cause of crashes. The danger comes to different dimension on highways, due to higher speed. So we utilize the opportunity to study data from relatively dense measuring network along the highway D5 and we prepared some basic statistics of conditions of hoar-frost formation.

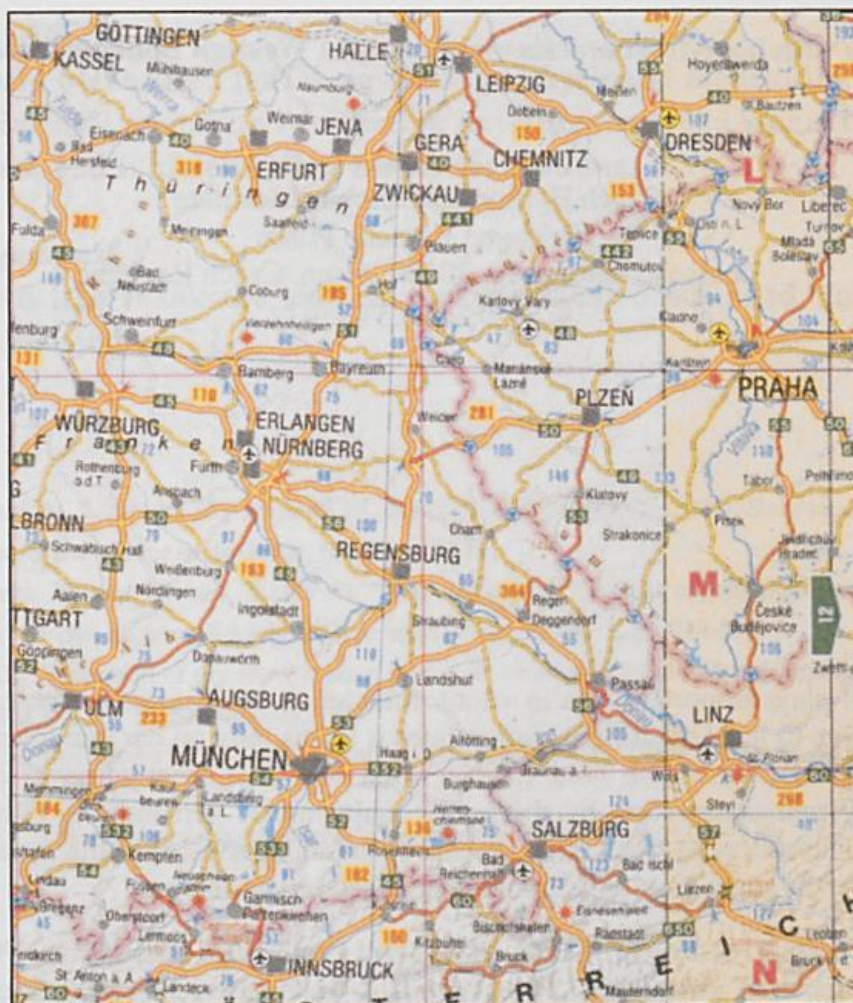


Figure. 1 Situation of connection Prague-Nürnberg, highway D5 on Czech territory

Measurements

Winter season 2002/2003 was chosen because of its numerous situations with influence of high pressure areas and cold spells followed by warm advection. The second reason is that new Vaisala station "As" in elevation 650 m asl has started its operation since 19th December 2002 (so this dataset is shorter than in other sites).

The highway D5 between Prague and Rozvadov border crossing is 150 km long and at this distance 12 measuring stations has been installed since 1997 all with following basic equipment: temperature and humidity sensors and precipitation detectors at high of 2 m. Older type of road sensors are situated especially in part Prague – Pilsen, new sensors DRS511 are in some stations between Pilsen and Rozvadov and in western part of region. Positions and description of all stations are in Fig. 2 and its legend:

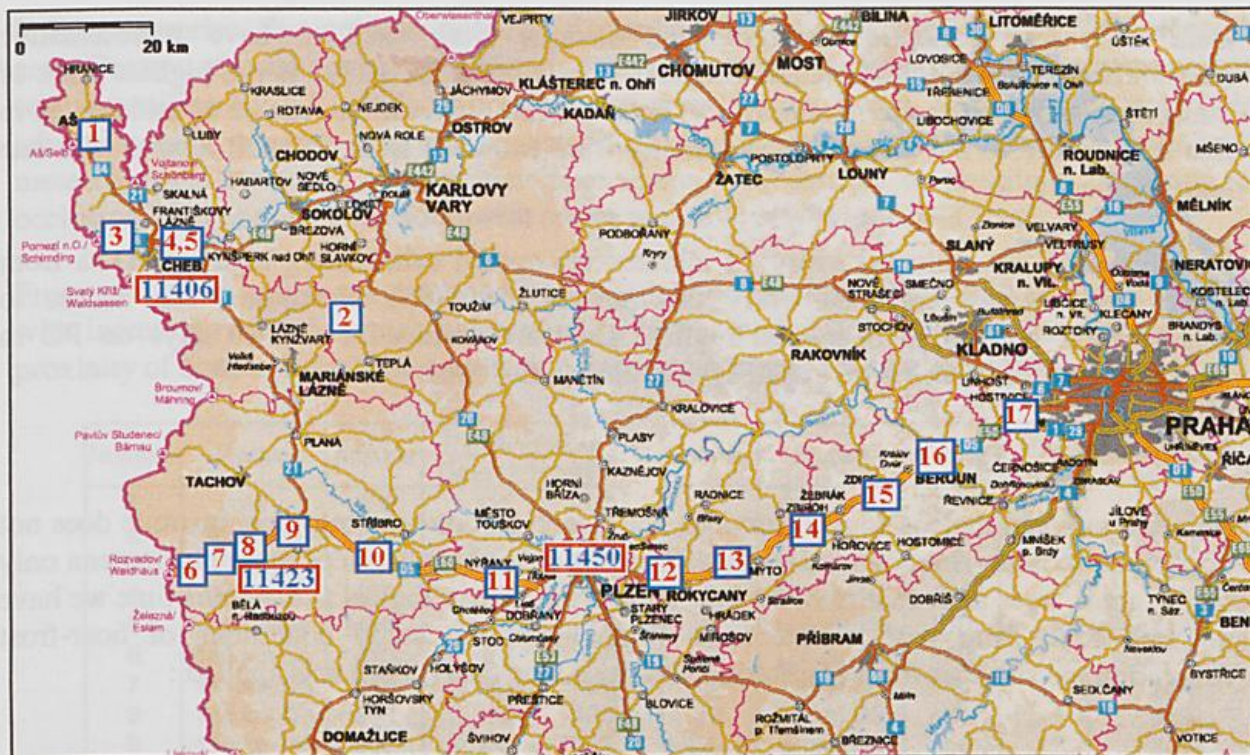


Figure.2 Vaisala stations on highway D5 and 1-st class road near the town Cheb, two instalations (1,2) are in elevation 650 resp. 730 m above sea level. Reference synoptic meteorological stations with indikatives 11406, 11423, 11450.

- 1 **As (650 m)** – western suburb of the town, screened by trees during late afternoon, exposed to W-SW winds
- 2 **Mnichov (730 m)** – open upland area
- 3 **Skalka (460 m)** – in shallow valley close to bridge and water reservoir
- 4 **Estakada (450 m)** – bridge over shallow valley with river, open area
- 5 **Jindrichov (450 m)** – in front of bridge Estakada
- 6 **145.km D5 (510 m)** – on the northern edge of forest in humid area close to small peat-bogs, not screened
- 7 **141.km D5 (550 m)** – in forest and cut of hill, in direction from northeast to southwest, screened, sheltered, western side of ridge of the hill
- 8 **136.km D5 (550 m)** – open station, exposed to E winds, eastern side of hill ridge
- 9 **128.km D5 (480 m)** – open station close to small forest, area of ponds (in circle 1-2 km)
- 10 **112.km D5 (410 m)** – open station, forest towards the south, not screened
- 11 **96.km D5 (340 m)** – open area, close to streams, small forest towards the southwest
- 12 **62. km D5 (360 m)** – shallow valley close to water and bridge, not screened
- 13 **53.km D5 (460 m)** – eastern edge of forest, station screened during late morning and afternoon
- 14 **41.km D5 (410 m)** – shallow valley between forested hills, next to bridge over local road
- 15 **35.km D5 (360 m)** – open and flat area
- 16 **23.km D5 (250 m)** – deep valley with river and next ponds, not screened
- 17 **12.km D5 (340 m)** – valley under forested hill, slope exposed to E winds, not screened

11406 (470 m) – synoptic meteorological station Cheb

11423 (750 m) - synoptic meteorological station Primda

11450 (330 m)- synoptic meteorological station Plzeň

10791 (1450 m) - synoptic meteorological station Grosser Arber, not in the picture

Data from four synoptic meteorological stations were used to have representative measurements of wind. The station Grosser Arber with index 10791 is the highest point of Sumava mountains (on German territory) and its wind observations can be considered as in free atmosphere. Wind direction and velocity were extracted from SYNOP reports with one hour frequency.

Data from D5 are collected every 12 minutes via optical cable along highway. Data from other localities are collected every 20 minutes via GSM. Forecaster has access to measurement outputs in operational regime. Data are archived every 10 days on PC in forecasting office. There is no expert system used at this time.

Methodology

As other national meteorological services, the Czech Hydrometeorological Institute does not observe or monitor rime on road surface. There is only observation of these phenomena only on the grass, trees and other terrain forms around the climatological site. At this time we have no feedback from road maintenance dispatchings. To study conditions of hoar-frost deposition the simpler form of criterion used by J.Norrman (2000) was applied :

$$T_r < T_d \quad T_r < 0^{\circ}\text{C}$$

For the purpose of this study the light hoar-frost formation was also accepted. All situations from archived data that fulfilled the criterion were registered with respect to the term of occurrence, duration, wind conditions and type of meteorological situation. Cases of warm air advection and pooling of cold air were distinguished. Information about surface state from sensors was used only marginally because in many cases residual salt was present or maintenance operations were applied.

Results

During winter season November 2002 – March 2003 conditions for deposition of hoar-frost were positive at least at one location in 75 days from 148 ones recorded. Warm air advection was present in 39 cases and cold air pooling in 36 cases. Other conditions are in following table:

station	warm air advection			cold air pooling		
	predominant winds			predominant winds		
	SW-NW	SE-NE, calm	velocity m/s	SW-NW	SE-NE, calm	velocity m/s
11406	21	18	2-6	8	28	0-3
11423	30	9	2-10	10	26	2-8
11450	20	19	1-5	6	30	0-3
10791	34	5	5-17	16	16	2-15
conditions	warm or occlusion fronts pressure troughs or lows 15 days with pressure high			out of frontal zone or after front passage 30 days with pressure high		

It is not surprise, that cold air pooling is common for synoptic situations of high pressure area. Centres of them were over different parts of Europe but most often in northwest sector with prevailing SE-NE winds, in lowlands of speed below 3 m/s. In cases with warm air advection high pressure area was present in 15 days mostly as a consequence of previous meteorological situation. Predominant phenomena was passage or proximity of warm or occlusion front coming from southwest sector with SW-NW winds over 2 m/s.

From next table we can see that conditions needed for hoar-frost forming were more suitable with increasing altitude which correspond to higher probability of lower temperatures and proximity of bottom base of inversion cloudiness with higher relative humidity:

Number	Station	Altitude	Tr<Td, Tr<0°C		Number	Station	Altitude	Tr<Td, Tr<0°C	
			Days	Hours				Days	Hours
1	As	650	41*	384*	2	Mnichov	730	58	580
2	Mnichov	730	58	580	1	As	650	41*	384*
3	Skalka	460	25	163	7	141.km D5	550	58	758
4	Estakada	450	29	236	8	136.km D5	550	13	106
5	Jindrichov	450	11	71	6	145.km D5	510	27	277
6	145.km D5	510	27	277	9	128.km D5	480	24	237
7	141.km D5	550	58	758	3	Skalka	460	25	163
8	136.km D5	550	13	106	13	53.km D5	460	44	339
9	128.km D5	480	24	237	4	Estakada	450	29	236
10	112.km D5	410	10	62	5	Jindrichov	450	11	71
11	96.km D5	340	8	49	10	112.km D5	410	10	62
12	62.km D5	360	4	17	14	41.km D5	410	9	30
13	53.km D5	460	44	339	12	62.km D5	360	4	17
14	41.km D5	410	9	30	15	35.km D5	360	8	37
15	35.km D5	360	8	37	11	96.km D5	340	8	49
16	23.km D5	250	5	19	17	12.km D5	340	0	0
17	12.km D5	340	0	0	16	23.km D5	250	5	19

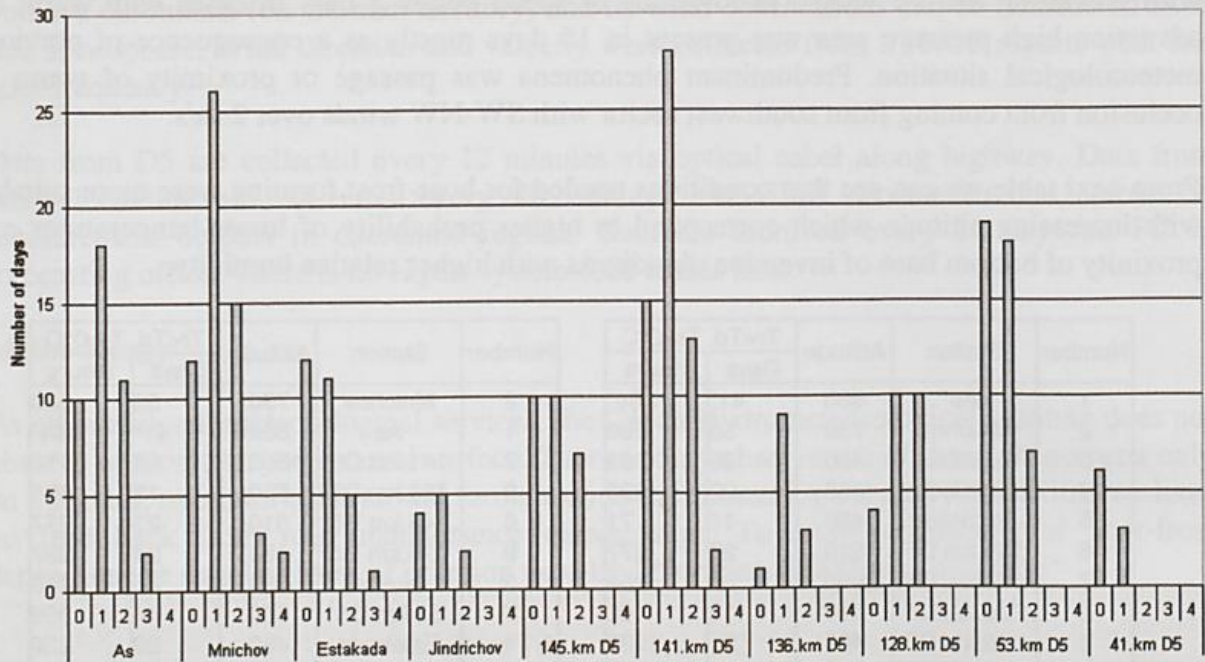
Station As started to measure in 19th December 2002, so the dataset is shorter.

But there are some exceptions apparent after ordering the table according to altitude:

1. maximum time of positive criterion values was found in location 141.km D5 at altitude 550 m asl, which is screened, sheltered and exposed to SW-W winds during warm air advection situations
2. at the same altitude but on the opposite side of crest a hill is location 136.km D5 with extremely reduced „positive time“ – it is open site exposed to east winds with lower humidity
3. only 8 km away in location 128.km D5 we can find more than twice longer „positive time“ – this is lower situated site in area of ponds
4. screened and sheltered site 53.km D5 surrounded by forest has several times longer „positive time“ than any other station between Prague and Pilsen
5. site 23.km D5 in deep valley in elevation 250 m has some „positive time“, but open station in 340 m only 11 km away has none
6. there is also interesting difference between Estakada site on the bridge and Jindrichov site only 500 m away in front of bridge

Besides of „positive time“ (criterion Tr<Td, Tr<0°C fulfilled), where also light hoar-frost is acceptable, we can compare occurrence of different values of (Td-Tr)max:

Frequency of temperature difference (Td-Tr)max



This graph confirms results assigned before. Sheltering and screening effect plays more comperable or maybe more important role than altitude.

Conclusion

At this study data from winter season 2002/2003 were used to find basic statistics about conditions suitable for hoar-frost deposition. Simple criterion according to Norrman (2002) was applied and important role of screening and sheltering effect was confirmed. The most critical place with the longest time of suitable conditions was found on sheltered and screened site in elevation 550 m above sea level on highway D5 near the border crossing Rozvadov – Waidhouse. This result confirms the judgment from thermal mapping according to which this stretch is one of the most critical places of Czech highway network at all.



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Using Taxi GPS to Gather High-Quality Traffic Data for Winter Road Management Evaluation in Sapporo, Japan

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How can we increase the quality of traffic data to provide effective and efficient winter road management in the City of Sapporo? In Sapporo, not only residents' daily activities but also business and industrial activities depend heavily on automobile mobility. The not-enough winter road management is, however, the critical problem: it leads to worsen traffic movement through the City. The problem is not simply that travel speed is remarkably reduced as a result of icy roads and street width narrowed by snow pile. The problem is that slowing traffic speed down leads ever-worsened traffic congestion as shown in Figure 1; consequently, it results in economic losses and air pollution.



Figure 1. Narrowed Street Caused by Snow Pile

A primary goal of our study is to identify the effective and efficient traffic data gathering technique in order to develop winter road management measurement that might be implemented in the context of Sapporo. Throughout the course of this study, we have attempted to demonstrate how the cutting-edge technology has the potential to help solve the problems with existing traffic analysis methods and increase the quality of data to determine the unique traffic feature in winter.

The cutting-edge technology we are interested in is "floating-car data" collected through putting Global Positioning System (GPS) on "taxis" running through the City. Because of its advantage covering the great Sapporo area and running throughout the day, this would enable up-to-date traffic data to be supplied over a wide area. Besides, "partnership" with taxi-companies provides cost-effective data collection solutions.

BACKGROUND

The City of Sapporo is the prefectural capital of Hokkaido, the northernmost island of Japan, and is Japan's fifth largest city with a population of approximately 1.8 million in 2003. The City is located on latitude 43 north and longitude 141 east, and cities at roughly the same latitude include Vladivostok (Russia), Chang Chun (China), Rome (Italy), Marseille (France), Boston and Chicago (U.S.). The City is one of the few metropolitan cities with severe, snow-covered winter in the world; indeed, the City has the annual cumulative snowfall reaching five meters and the maximum depth of snowfall reaching one meter (see figure 2).

This is the City's most distinguishing feature.

In Sapporo, residents' daily activities depend heavily on automobile mobility. The auto-usage also provides important means of transportation in business and industrial activities. Road traffic conditions in winter, nevertheless, have get worse because of heavy snow cover and snowfall, and declining temperatures. Although studded tires had been widely used in Japan, its use was regulated in early 1990's to eliminate deterioration of the living environment caused by dust from studded tires. As a result of this regulation, air quality has been significantly improved, though, on the other hand, it causes several traffic issues specified in winter ⁽¹⁾.

Especially, as shown in Figure 3, an increasing number of car accidents typically in winter such as one slipped on icy path, the worsening traffic movement and safety caused by "extraordinary slippery-roads (see Figure 4)", and an increasing amount of anti-freezing agents and abrasives are the critical problems.

Road administrations have taken some measures, including snow removal operation, to ensure urban traffic functions in winter. On the other hand, the total amount of winter road management cost has significantly increased for the last 15 years, as shown in Figure 5. This is mainly due to the ban on the use of studded tires from the late 1980's and the road users' growing demand for maintenance quality over the years. Indeed, The City Government's FY2002 budget provided for carrying out the snow and ice control measures of more than 16.5 billion yen while delivering almost 70 % of the budget for snow plowing and removal from streets and sidewalks.

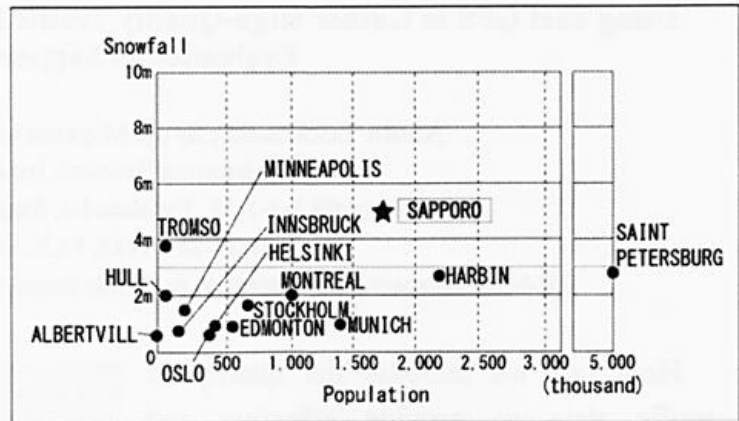


Figure 2. Snowfall and Population

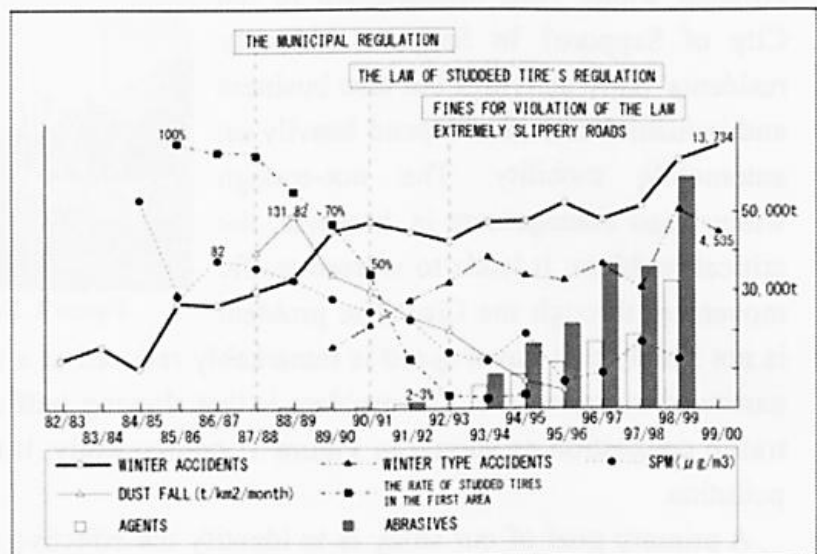


Figure 3. The Several Indices Related to the Rate of Studded Tires



Figure 4. "Extraordinary Slippery-Road"

It is also interesting to note huge economic losses caused by heavy snowfall and snow cover for Sapporo. Asano et al. (2001) calculated the direct and indirect economic losses before and after the ban on studded tires ⁽²⁾. The estimated annual economic losses were more than 18.5 billion yen in the great Sapporo area

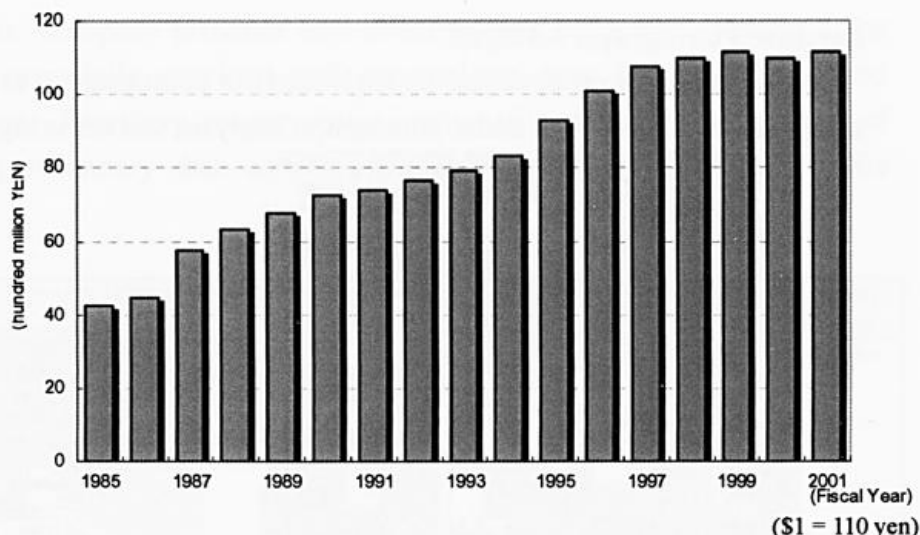


Figure 5. Expense Growth of Road Snow Removal
Source: City of Sapporo

caused by the increasing of driving time and costs, road accidents, and costs for maintenance and management. Considering that the lessening traffic function was observed in summer even while the use of studded tires was permitted, it might be larger losses than before.

STUDY METHODS:

In order to study the traffic issue in winter, it is significantly important to understand the winter traffic feature in quantitative manner. The traffic feature in weekdays notably differs from that in weekends and holidays. Especially, the traffic feature in winter seems to vary greatly from specific weather condition to the other such as snow cover and snowfall, and declining temperatures; consequently, it is almost impossible to understand the varied traffic features by using the conventional study methods in which days and number of times for surveys are fixed. We therefore attempt to apply taxi floating-car data (Taxi GPS Data) to analyze traffic situations on urban roadways as an advanced survey method. Before moving on to the description of our findings, we would like to briefly discuss characteristics of the survey with taxi GPS and the existing approaches, and Table 1 shows a comparison of these traffic data gathering techniques.

Winter Road Traffic Census

In Japan the road traffic information survey, known as "Road Traffic Census," has been conducted all over the county in once a few years in order to recognize the existing traffic conditions in summer. In Hokkaido "Road Traffic Census" has been conducted not only in summer but also in winter to collect baseline traffic data in winter.

Aerial Photograph Analysis

Conducted by our research institution experimentally, this data-gathering method takes aerial photographs the certain areas with lapping at intervals of few seconds (see Figure 6). The collected information of two-dimensional image helps to analyze traffic condition in and around the City of Sapporo in quantitative manner and regional level.

Satellite Photograph Analysis

Traffic information obtained through satellite photographs, as shown in Figure 7, fills the same analytical role with aerial photograph analysis, but covering wider area.



Figure 6. Aerial Photograph for Traffic Analysis

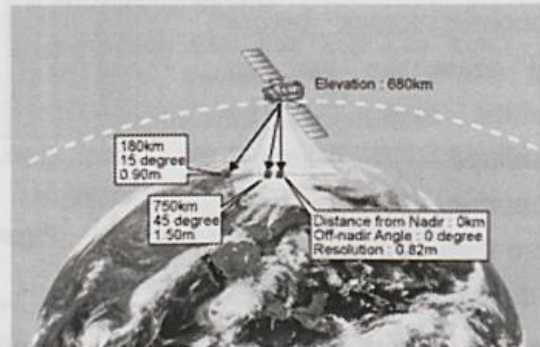


Figure 7. Satellite Photograph Analysis (image)

Taxi GPS Data

Building partnership with the taxi-company which has accumulated detailed information on taxi traveling throughout Sapporo by means of putting GPS on taxis, we attempt to apply data of their time instants and locations as “floating-car data.” Figure 8 shows the system configuration of taxi GPS data. Locational data are recorded to memory cards after those data are confirmed with maps of car navigation systems operated by GPS installed inside the taxi. The GPS-based data are then compiled and analyzed after reconfirming processes of location and elimination of unusual values.

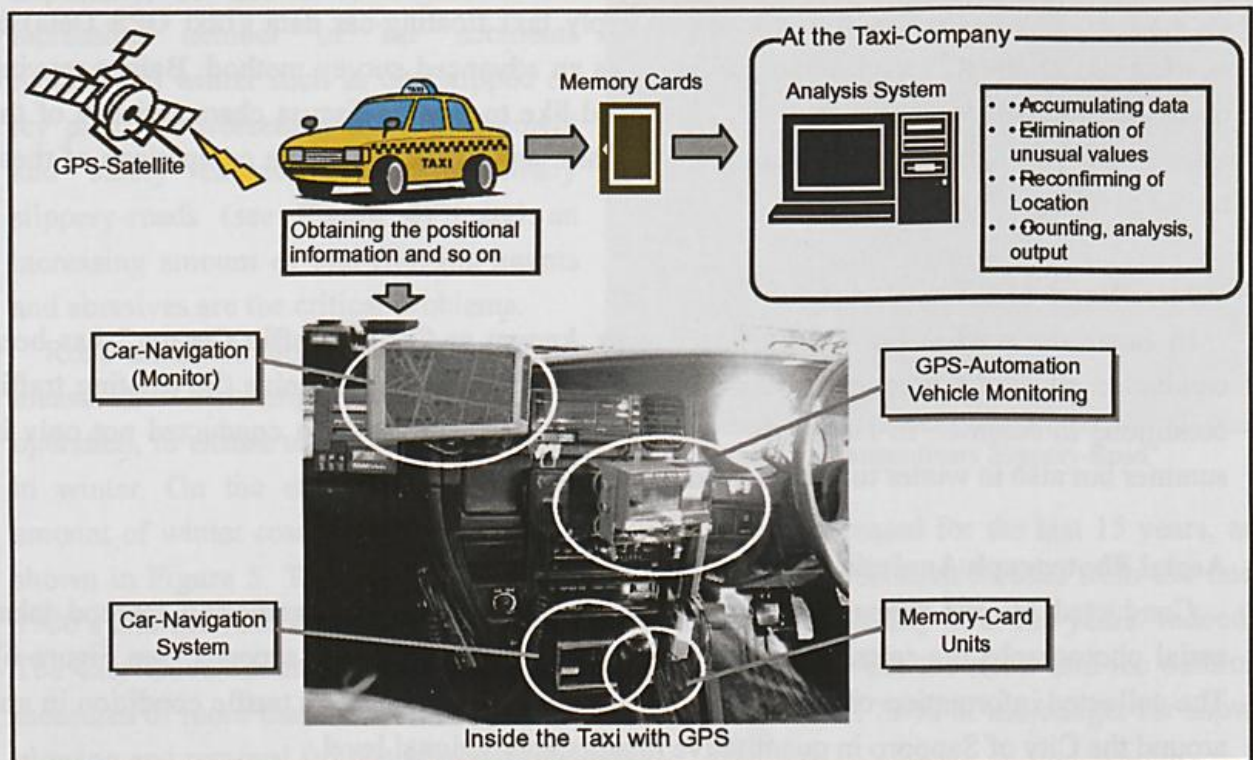


Figure 8. System Configurations of Taxi GPS Data

“Partnership” with the taxi-company provides cost-effective data collection solutions. The partnership company has essentially obtained and accumulated data for supervising and effective running management. Therefore, we can obtain high quality and enormous amount of data at low cost by using secondary data collected through the taxi-company for traffic analysis.

TYPES	SUMMARY	SURVEY ITEMS	METHODS AND ANALYSIS	ADVANTAGES	DISADVANTAGES	COST (yen)*
Winter Road Traffic Census	<ul style="list-style-type: none"> Apply nationwide survey done in summer only to winter 	<ul style="list-style-type: none"> Traffic volume (12- and 24-hours) Average travel speeds during rush hours (on weekdays) 	<ul style="list-style-type: none"> Travel volume (manually observed from road side) Travel speeds (observed by a probe car) 	<ul style="list-style-type: none"> Commonly used across the county 	<ul style="list-style-type: none"> Conducted in once a few year Few survey points Surveyed at arterials only Not exact data because of only one probe car observing 	5 million
Aerial Photograph Analysis	<ul style="list-style-type: none"> Recognize the traffic features quantitatively with 2-D image 	<ul style="list-style-type: none"> The number of vehicles (Travel volume and travel density can be calculated) Travel speeds 	<ul style="list-style-type: none"> Counting the number of vehicles on the photographs manually 	<ul style="list-style-type: none"> Possible to recognize traffic condition in quantitative manner and regional level at the same time period 	<ul style="list-style-type: none"> Can know only the instantaneous traffic condition Can't be conducted in bad weather (especially in winter it is impossible to conduct surveys when it is snowing) 	4 million
Satellite Photograph Analysis	<ul style="list-style-type: none"> Recognize the traffic features quantitatively with 2-D image 	<ul style="list-style-type: none"> The number of vehicles.(Travel volume and travel density can be calculated) Travel speeds 	<ul style="list-style-type: none"> Processing of data of photographs semi-automatically 	<ul style="list-style-type: none"> Possible to know traffic conditions in much wider area than aerial photographs 	<ul style="list-style-type: none"> Conducted only when satellite passing through the areas Survey time and days are fixed Can know only the instantaneous traffic condition Can't be conducted in bad weather.(Not work when the amount of cloud is more than 20 percent) 	4 million
Taxi GPS Data	<ul style="list-style-type: none"> Using Traveling data of taxis (GPS) secondary 	<ul style="list-style-type: none"> Travel speeds 	<ul style="list-style-type: none"> Recording Data on memory cards then being processed by analysis systems 	<ul style="list-style-type: none"> Enormous amount of data (60,000 km per day) Possible to obtain data by day and night Possible to obtain data of any road As new equipments and workforce don't be needed, cost will be low 	<ul style="list-style-type: none"> Not sure the traffic volume Traveling routes and frequency are not even Do not know where traveling on multi-stories roads Different traveling characteristic between empty taxis and carrying passengers 	7,000

(\$1 = 110 yen)

*It is the estimated costs in the case a survey is conducted in and around the city of Sapporo per day (the costs of data analysis don't be included.)

Table 1. Comparison between Taxi-GPS Data and Existing Approaches

EMPIRICAL FINDINGS

This section describes winter road traffic conditions in the entire Sapporo area based on travel speed data in all of the road sections where traveling

# of Taxi with GPS	115 cars
•Data items	Date, Time (second unit)
	Locations (latitude, longitude)
	Speed, Traveling •irections (16 directions)

Table 2. Summary of Taxi GPS Data in this Study

information of taxis were obtained (see Table 2). The time range we calculated average travel speeds is between 7 a.m. and 7 p.m. which is the same as the range used for the Road Traffic Census. In the City of Sapporo, the snow removal and plowing has been operated in the nighttime when traffic densities are low to avoid influences on road traffic. Therefore, we select the best possible time range in which the study result might not be influenced by external factors such as traffic regulation for snow removal and plowing.

Weather Conditions in the Winter of 2001

Table 3 shows a variety of winter climatic conditions between October in 2001 and April in 2002. Even though 200-cm snowfall was observed in December, which was nearly double average year (the average of the 30 years between 1971 and 2000), it had light snowfall after January. The total amount of snowfall in the winter of 2001 was 415 cm: it was about 80 cm less than average year (496 cm on the average). The date of first snow was in November 4th, 2001, and this was about a week later than average year (in October 27th on the average). The average and the highest temperature of each month was higher than average year, even if the lowest temperature of each month in the winter of 2001 was lower than average year. Besides, snow cover and snowfall are usually observed on April, but not in 2002. Therefore, it could be said that the winter of 2001 was light snowfall and a mild winter.

	Ave. Temp. (°C)		Highest Temp. (°C)		Lowest Temp. (°C)		Snowfall (cm)		Max. Snow Depth (cm)	
Oct.	12.1	11.3	19.8	15.8	2.5	6.9	0	1	0	1
Nov.	5	4.6	16.4	8.1	-5.1	0.9	34	25	21	12
Dec.	-3.4	-1	5.3	2.1	-10.8	-4.4	200	109	81	44
Jan.	-2.5	-4.1	6.9	-0.9	-11.7	-7.7	71	158	76	73
Feb.	-0.6	-3.5	9.8	-0.3	-10	-7.2	73	132	83	98
Mar.	2.5	0.1	12.8	3.5	-8.7	-3.5	37	67	66	81
Apr.	9.6	6.7	20.3	11.1	1	2.7	0	8	0	22

Average Year

Table 3. Winter Climatic Condition from Oct. in 2001 to Apr. in 2002

Average Travel Speeds on a Daily and Monthly Basis ⁽³⁾

Figure 9 shows the monthly- and daily-based average travel speeds based on traveling information from taxis with GPS. The average travel speed in April was just under the speed of 30 km/h and it slightly rose and fell at the speed of 30 km/h between in May and October. It started dropping in late November, and December had the lowest with the speed of 22.1 km/h. It rose slowly in January through February, and it almost recovered its April level in mid-March. It is interesting to note that the average travel speeds have risen periodically; those are in Sunday and in national holidays.

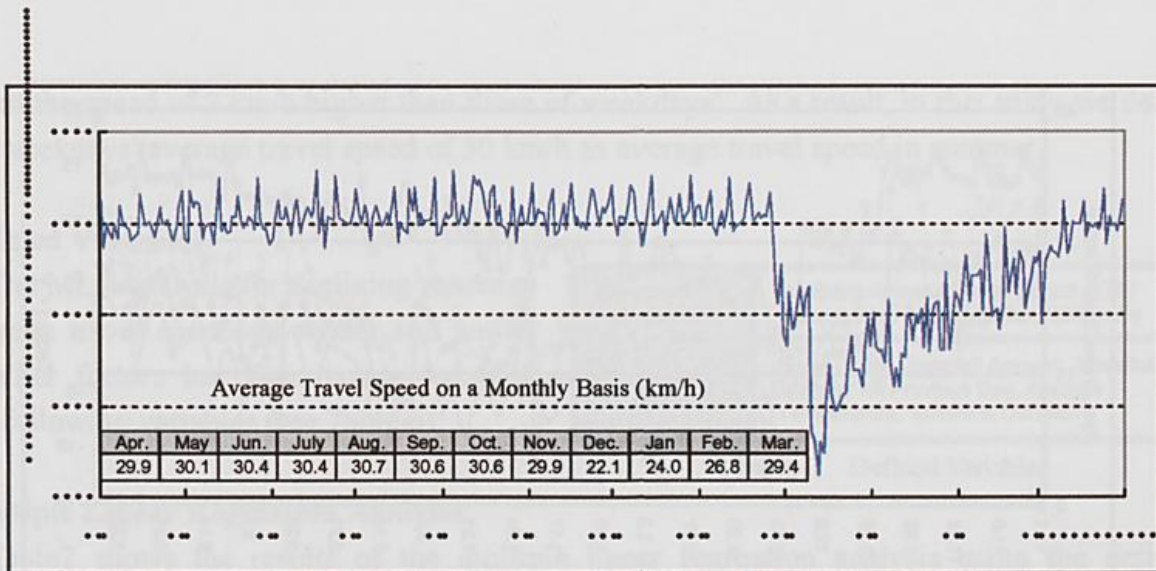


Figure 9. Average Travel Speed on a Daily Basis (2001)

Relations between Average Travel Speeds and Snow Cover & Temperatures

Figure 10 shows the relationship between average travel speed and snow depth (the maximum snow depth) on a daily basis, and figure 11 shows the relationship between daily average travel speed and temperature on a daily basis.

The average travel speed dropped after November 27th in which the temperatures also dropped and snowfall was observed. November 27th was the first day on which the temperature dropped below 0 degrees Celsius in the winter of 2001 and heavy snowfall was observed. (Table 4 shows the meteorological data and the average travel speeds between November 24th and 30th.)

Around December 10th, the travel speed dropped again. This might be due to heavy snow for four straight days from December 9th. It snowed 56 cm in December 10th only, and it was the second-heaviest snowfall on record⁽⁴⁾. Because of this heavy snow, the average travel speeds dropped to the level of the speed of 10 km/h between December 10th and 14th, and the average travel speed in December 12th was the lowest of the speed of 16.2 km/h, though the average travel speeds slightly rose and fell at the speed of around 25 km/h in early December. (Table 5 shows the meteorological data and the average travel speed between December 8th and 14th.)

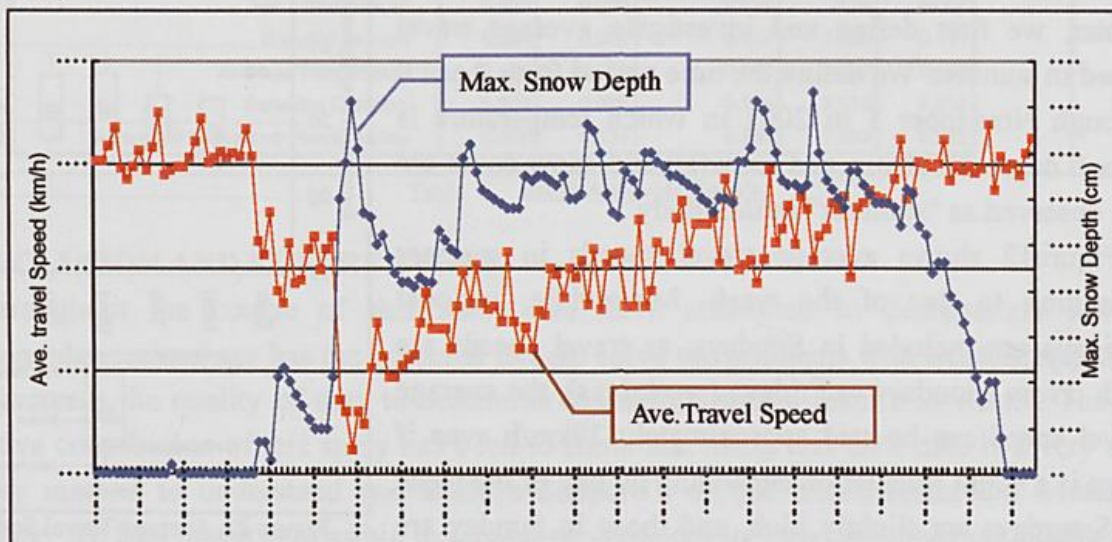


Figure 10. Average Travel Speed & Max. Snow Depth

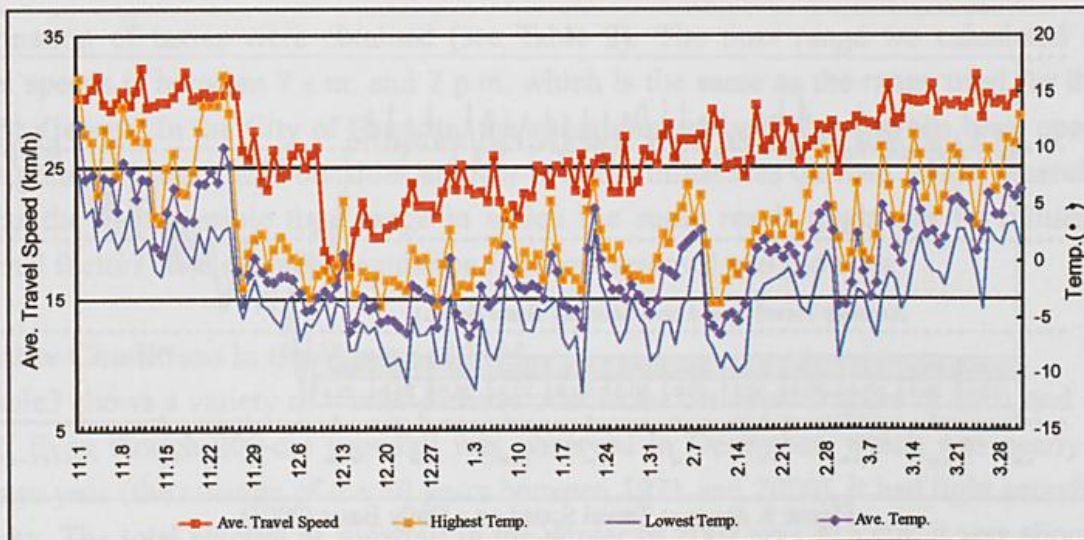


Figure 11. Average Travel Speed & Temperature

	Ave. Trave Speed (km/h)	Ave. Temp. (°C)	Highest Temp. (°C)	Lowest Temp. (°C)	Snowfall (cm)	Max. Snow Depth (cm)
11.14	30.4	10.1	16.4	2.8	0	0
11.25	31.7	8.5	13.1	3	0	0
11.26	30.4	-0.8	3.3	-3.3	0	0
11.27	26.3	-3.7	-2.4	-5.1	5	7
11.28	25.6	-1.2	0.7	-3.2	8	7
11.29	27.7	0.3	2	-1.6	0	3
11.30	23.9	-0.9	2.4	-3.8	18	21

Table 4. Ave. Travel Speed & Winter Climatic Condition (Nov. 14-30)

	Ave. Trave Speed (km/h)	Ave. Temp. (°C)	Highest Temp. (°C)	Lowest Temp. (°C)	Snowfall (cm)	Max. Snow Depth (cm)
12.8	25.9	-4.3	-3.2	-5.8	0	10
12.9	26.5	-3.2	-1.2	-4.9	15	21
12.10	18.6	-2.7	-0.8	-3.6	56	60
12.11	18	-3.2	-1.6	-5.8	22	68
12.12	16.2	-2.2	-0.4	-3.7	23	81
12.13	18	0.6	5.3	-4.1	0	71
12.14	17.4	-6.2	-1.4	-8	12	57

Table 5. Ave. Travel Speed & Winter Climatic Condition (Dec. 8-14)

FACTOR ANALYSIS

The previous section provides that winter weather conditions have a profound effect on declining average travel speeds in winter. In order to explore the effect of each weather factor in declining travel speeds in winter, a multiple linear regression (MLR) analysis ⁽⁵⁾⁽⁶⁾⁽⁷⁾ has been conducted.

Average Travel Speed in Summer

In order to analyze the declining travel speeds in winter, we first define and investigate average travel speed in summer. We define the time period from April 8 through November 3 in 2001 in which temperature is over 0 degrees Celsius, and snowfall and snow cover are not observed as "summer" in this study.

Figure 12 shows average travel speeds in summer according to day of the week. Meanwhile, national holidays are included in Sundays, as travel speeds are high. From Mondays to Fridays (weekdays), the average travel speed can be said approximately 30km/h even if there is a slight fluctuation depending on day of the week. In Saturdays are slightly high, and those in Sunday are

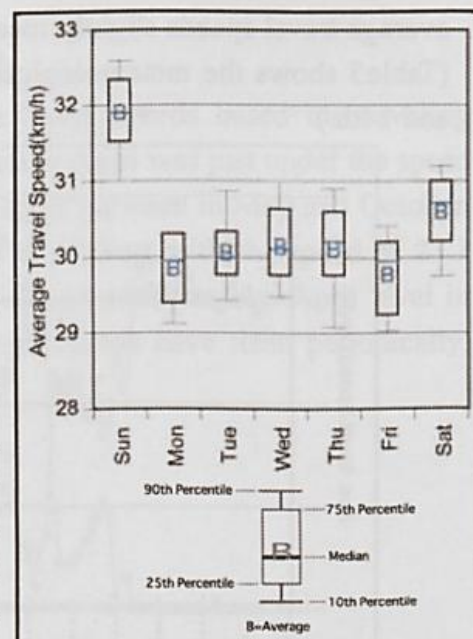


Figure 12. Average Travel Speed in Summer (Day of the Week)

about the speed of 2 km/h higher than those of weekdays'. As a result, in this study we define the weekdays' average travel speed of 30 km/h as average travel speed in summer.

Defined Variables

The MLR analysis for declining weekday average travel speeds in winter and winter weather factors has been conducted with the following variables (see Table 6).

Dependent Variable	Declining Average Travel Speed (ATS) Compared to ATS in summer (30 km/h)
Explanatory Variable	Snow Depth, Snowfall Amount, Snowfall Amount on Previous Day, Average Temperature, Sunshine Duration

Table 6. Defined Variables

Multiple Linear Regression Analysis

Table 7 shows the results of the multiple linear regression analysis using the defined variables in Table 6. Multiple correlation coefficient was the high value of 0.831. As the result of conducting variance analysis, we got the level of significance $\alpha=0.05$ and null hypothesis was dismissed, which means multiple regression equation is useful for predictions.

The MLR analysis shows that the dropping average temperature has the most profound effect on declining average travel speed in winter. It is interesting to note that the amount of snowfall and that on the previous day has little effect on declining travel speed even though a popular idea exists nowadays that snowfall amount has marked effects on travel speed.

MODEL			
Model	R	R-Square	Adjusted R-Square
1	0.831	0.69	0.674

ANOVA					
Model		Sum of Squares	df	Mean Square	F
1	Regression	908.883	5	181.777	43.619
	Residual	408.404	98	4.167	
	Total	1317.286	103		

COEFFICIENT						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.416	0.484		7.059	0.000
	Snow Depth	0.025	0.009	0.019	2.74	0.007
	Snowfall Amount	0.084	0.032	0.167	2.598	0.110
	Average Temperature	-0.454	0.064	-0.501	-7.093	0.000
	Sunshine Duration	-0.234	0.075	-0.184	-3.113	0.002
	Snowfall Amount on Previous Day	0.078	0.031	0.161	2.563	0.012

Table 7. MLR Analysis Results

CONCLUSION AND FUTURE STUDY

Throughout the course of this study, we have attempted to demonstrate how the cutting-edge technology has the potential to help solve the problems with existing approaches and increase the quality of data to determine the unique traffic feature in winter. The main positive contribution of this study has been to show that using taxi GPS data is a very useful survey method to understand and analyze Sapporo's unique traffic feature in winter. For instance, we find that it is possible to recognize variances in traveling speed on a daily basis,

which is unrecognizable by the existing approaches, throughout year by using floating-car data. Besides, the study finds that snow cover, snowfall and declining temperature give not a little influence to declining travel speed, and unexpected events such as heavy snowfall have a profound effect on its traveling speed.

Furthermore, a multiple linear regression analysis has been conducted to evaluate the effect of weather factors in declining travel speed in winter. The result of analysis shows that the declining temperature has a strongest effect in declining travel speed in winter while the amount of snowfall and that on previous day has less influence in. This might be due to the consequence of little snow in the winter of 2001.

Most importantly, we find that traffic speed declines even after road administrations are conducted various winter road management measures such as snow removal and plowing and anti-freezing agents spread over roadways. This suggests that winter road management activities might not be conducted as effectively as possible. Indeed, measures for winter road surface condition, which is significantly affected by temperature, might be inadequate in comparison with measures for snow removal and plowing.

Even though we do not extend into evaluating effect on measures for winter road management in quantitative manner at this time, in the future we move on to recognizing the traffic characteristics in winter of Sapporo and considering proper balance to conduct measures for winter road management and the standard for the measures while doing accumulations and analyses of data including coefficient of friction on road surface. Furthermore, by applying the method to calculate economic losses against winter road traffic, we hope that it might help evaluating winter road management.

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Height-Dependent Difference in Visibility on Roads

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1. Introduction

Vehicles running in the harsh winters of cold, snowy regions encounter severe road conditions, including icy road surfaces and blowing-snow-induced poor visibility. When visibility is reduced, particularly by drifting and blowing snow, the recognition of a traffic accident or stopped vehicle ahead tends to be delayed, and this sometimes results in multi-vehicular collision. Kajiya et al. (1998) noted that multi-vehicular collisions of dozens of vehicles typically involve a heavy vehicle, and that many such collisions occur when a large trailing vehicle collides with a small leading vehicle that has stopped in blowing snow.

Several studies have been conducted in recent years on height-dependent variation in visibility. Sato et al. (2002) obtained visibilities at different heights by mathematical calculation, and demonstrated that when the wind velocity at a height of 10 m is 12 to 14 m/s, the visibility at a height of 2.4 m is greater than 300 m but at a height of 1.2 it is less than 300 m. This, however, was visibility at a snowfield, not on a road. Tozuka et al. (2001) measured visibility on the road while driving a vehicle equipped with the Snow Particle Counters at different heights. They confirmed that visibility depended on height, with visibility improving with increase in height. However, no quantitative examination was made as to how the height-dependent difference in visibility varied with weather and road conditions, or which factor made the greatest contribution to such variation.

This paper uses observation of mass flux of snow to investigate the effects of weather conditions and snowbank height on the height-dependent variation in visibility above the road.

2. Observation method

2.1 Observation equipment

The mass flux of snow was observed using a blowing-snow trap of net type with mouth diameter of approximately 10 cm. Plankton net of 105- μ m mesh pore was used. The snow trap was mounted on a specially designed bracket. A bearing between the upper and lower parts allows the neck of the top part (where the trap is mounted) to swivel freely. When a snow trap is placed on the upper part of the anchor, the opening automatically faces windward because of the streamer principle (Figure 1).

Each snow trap was weighed before the observation. The lower part of the bracket was fixed on an appropriate pole, so that when the trap was mounted, its center came to the target height. First, the snow trap was mounted on the upper part of the bracket. Then the lid of the trap was opened and clocking started. The lid was closed before the net became clogged. Closing of the lid marked the end of clocking. Next, after snow accreted on the outside was brushed off, the trap was weighed immediately to avoid sublimation of the snow particles in the net. This weight minus the weight of the counter measured in advance is the weight of the captured snow particles. Dividing the weight of the captured blowing snow by the length of time the lid was open and the cross-sectional area of the trap meter opening yields mass flux of snow in g/m^2s .

The obtained mass flux of snow can be used "as is," but it is easier to understand when converted into visibility in blowing snow. To do this, we used the following equation of Matsuzawa and Takeuchi (2002).

$$\log(Vis) = -0.77 \cdot \log(Mf) + 2.85 \quad \dots(1)$$

Where Vis: visibility (m), Mf: Mass flux of

snow ($\text{g}/\text{m}^2\text{s}$)

Furthermore, when a blowing-snow trap of net type is used, it is necessary to take the capture rate into consideration. Based on the study by Takeuchi and Fukuzawa (1976), only the aerodynamic capture rate was taken into account herein, and it was corrected to 85% at a wind velocity of 5.0 m/s or greater and 75% at velocities from 3.0 to 5.0 m/s.

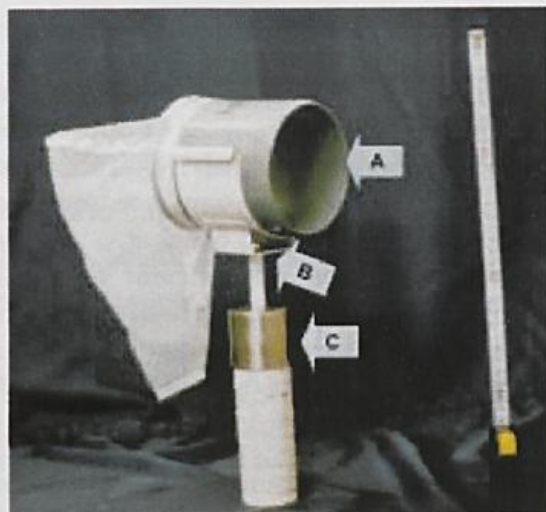


Figure 1. Blowing-snow trap of net type (A), and mount (B). Part (C) contains the bearing. The trap mouth faces windward.

2.2 Observation conditions

The observation site is a road at the Ishikari Blowing Snow Test Field of the Civil Engineering Research Institute of Hokkaido. The test field is on the dry riverbed of the Ishikari River, on the right bank at the lower reaches, about 17 km north of central Sapporo. The prevailing winter winds in this area come from between west-northwest and northwest. The observation was made on the straight section running north-south. Windward of the observation spot is grassland with a fetch of at least 300 m.

Mass flux of snow was measured windward of the snowfield (at a height of 1.2 m above the snow surface) and on the roadway (at heights of 1.2 m and 2.4 m) (Figure 2). The heights of 1.2 m and 2.4 m correspond to the respective eye levels of a small-vehicle driver and a large-vehicle driver. Wind velocity was measured using three-cup type anemometers. The air temperature was measured at the Ishikari Blowing Snow Test Field every ten minutes

with a platinum resistance thermometer installed at a height of 2.5 m. Likewise, a velocity meter of windmill type (aerovane) was installed at a height of 10 m and a value was obtained every ten minutes. Snowfall intensity was not measured at the site. Instead, we used mean values of snowfall intensity obtained every ten minutes at Oyafune Observation Station (4 km northwest of the site) and Futomi Observation Station (4 km southwest of the site) of Sapporo City's weather telemeter system. Snow cover distribution on the cross section of the road at the observation site was also measured (Figure 3).



Figure 2 Observation of mass flux of snow

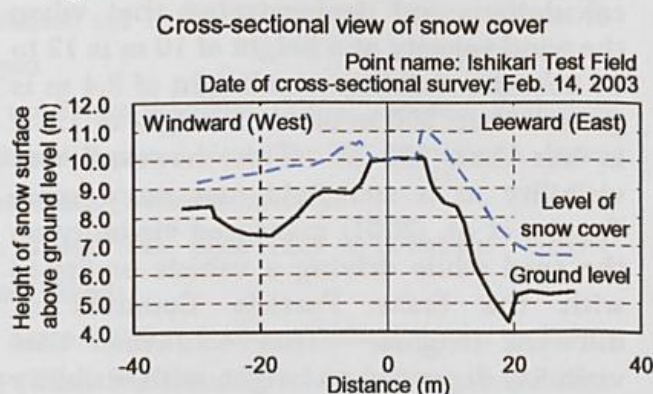


Figure 3 Snow cover distribution on the cross section of the road

3. Factors that affect visibility on the road

Before examining height-dependent differences in visibility, we present the findings on two relationships: visibility vs. weather conditions, and visibility vs. snowbank height.

3.1 Relationship between visibility and weather factors

Figure 4 shows the relationship between visibility at a height of 1.2 m above the road in blowing snow and weather factors. From the top to the bottom, the figure shows visibility's relationship with wind velocity, air temperature and snowfall intensity. The figures demonstrate that visibility correlates negatively with wind velocity and snowfall intensity, and positively with air temperature.

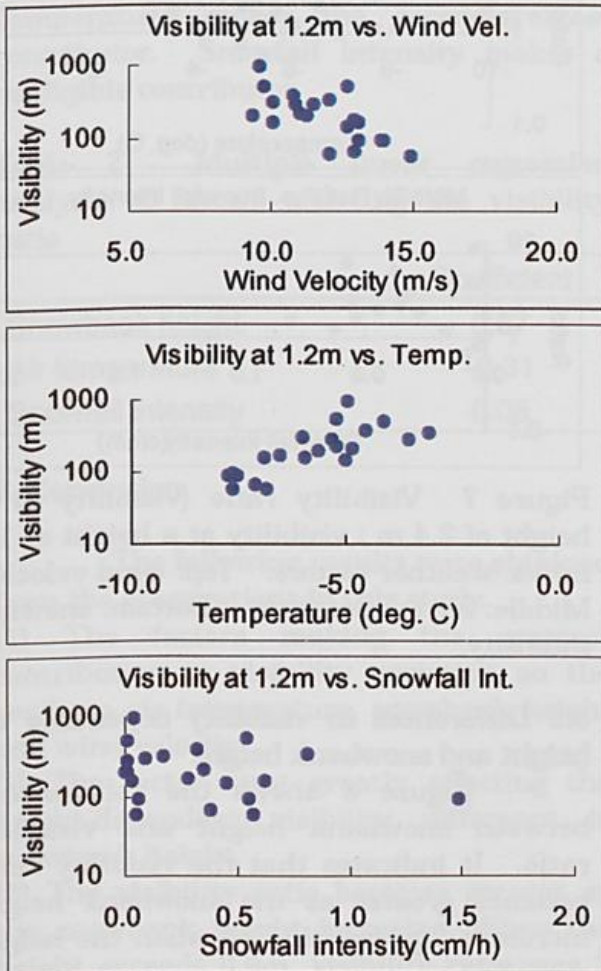


Figure 4 Relationship between visibility at a height of 1.2 m above the road and weather conditions. Top: visibility vs. wind velocity. Middle: visibility vs. temperature. Bottom: visibility vs. snowfall intensity

3.2 Visibility above the road and snowbanks

Factors other than weather conditions also affect visibility above the road. The effect can be particularly adverse if there is a high snowbank at the roadside, in which case snow blowing from the top of the snowbank passes at the driver's eye level.

Figure 5 shows the relationship

between snowbank height and visibility. It indicates that visibility tends to decrease as the snowbank height increases.

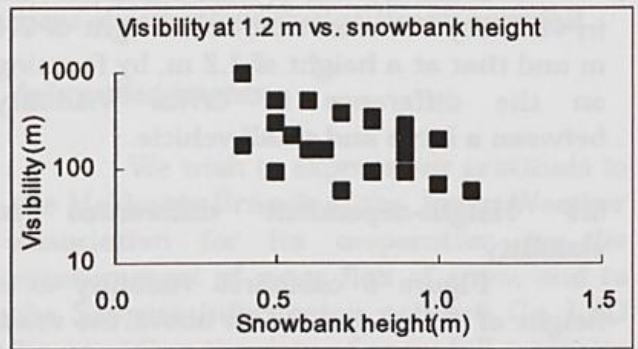


Figure 5 Visibility at a height of 1.2 m vs. snowbank height

4. Factor analysis

A relationship has been confirmed between visibility and each weather factor, and visibility and snowbank height. Next, to examine the contribution of these factors to visibility, we performed multiple linear regression analysis. Air temperature, wind velocity at a height of 10 m, snowfall intensity and snowbank height were chosen as explanatory variables. Values were standardized to examine their contribution to visibility.

The findings are shown in Table 1. Visibility at a height of 1.2 m above the road depends most strongly on air temperature, correlating positively. It depends the next most strongly on snowbank height and then wind velocity, correlating negatively with both. It also correlates negatively, but weakly, with snowfall intensity.

The values measured in this study, however, include only one datum of snowfall intensity exceeding 1 cm/h. To properly evaluate the impact of snowfall intensity on visibility, it is presumed necessary to add data measured under heavy snowfall.

Table 1 Multiple linear regression analysis of factors affecting visibility

	Coefficient
Air temperature	0.53
Snowbank height	-0.47
Wind velocity at 10 m	-0.34
Snowfall intensity	-0.10

5. Height-dependent differences in visibility

Next, we will discuss the difference in visibility between that at a height of 2.4 m and that at a height of 1.2 m, by focusing on the difference in driver visibility between a large and small vehicle.

5.1 Height-dependent differences in visibility

Figure 6 compares visibility at a height of 1.2 m and 2.4 m above the road. It shows that the values of visibility at 2.4 m exceed those at 1.2 m. This is consistent with the findings of Tozuka et al. (2001).

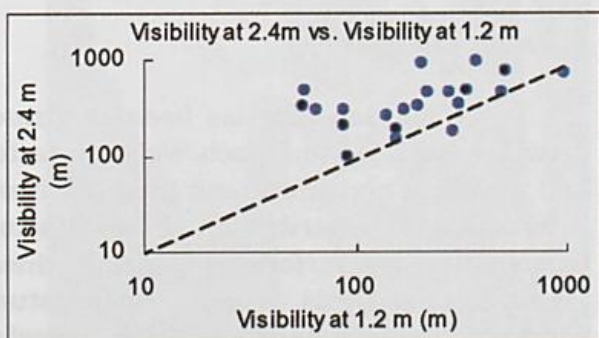


Figure 6 Comparison of visibility at 2.4 m and 1.2 m above the road. The dotted line indicates a visibility ratio of 1, i.e., where visibility at 2.4 m and 1.2 m are equal.

5.2 Difference in visibility depending on height and weather conditions

Figure 7 plots the relationship between visibility ratio and weather conditions. ("Visibility ratio" is defined hereinafter as "ratio of visibility at a height of 2.4 m to visibility at a height of 1.2 m.") From the top to the bottom, the plot shows the relationship of the visibility ratio with wind velocity, air temperature and snowfall intensity, respectively. Figure 7 indicates that the visibility ratio is independent of wind velocity. A relatively weak correlation is found between the visibility ratio and temperature and between visibility ratio and snowfall intensity.

However, the visibility ratio varies widely from 1 to 10, even when snowfall intensity remains around zero. To determine the cause of this variation, we examine the relationship between snowbank height and visibility ratio.

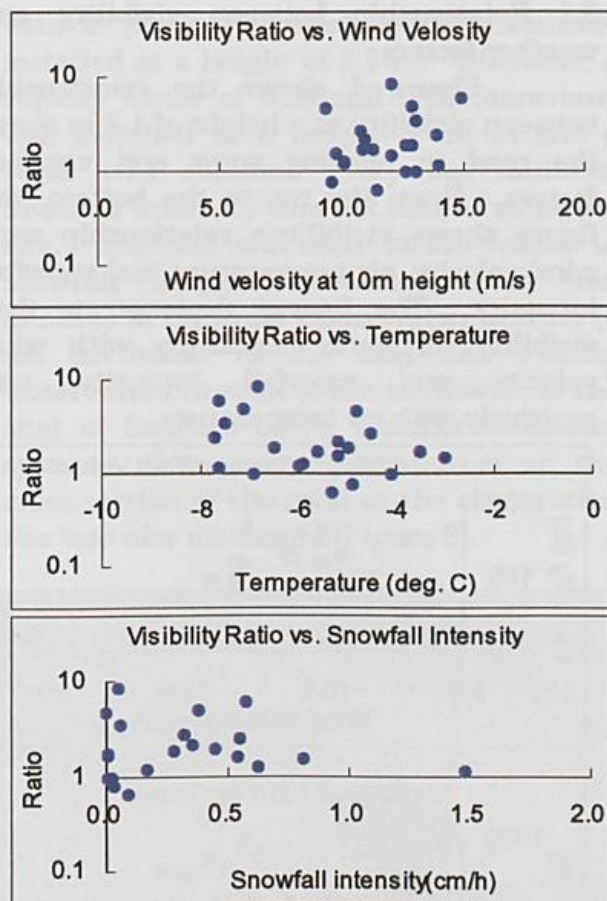


Figure 7 Visibility ratio (visibility at a height of 2.4 m : visibility at a height of 1.2 m) vs. weather factors. Top: wind velocity. Middle: air temperature. Bottom: snowfall intensity.

5.3 Differences in visibility depending on height and snowbank height

Figure 8 shows the relationship between snowbank height and visibility ratio. It indicates that the visibility ratio becomes greater as the snowbank height increases, approaching 10 when the height exceeds 1 m.

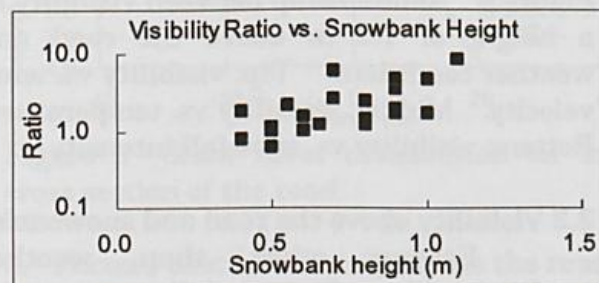


Figure 8 Visibility ratio (visibility at a height of 2.4 m : visibility at a height of 1.2 m) vs. snowbank height.

6. Analysis of factors that affect the visibility ratio

We then performed multiple linear regression analysis to examine the contributions of factors that affect the visibility ratio. Air temperature, snowfall intensity and snowbank height were chosen as explanatory variables. Table 2 shows the result of analysis. It indicates that the snowbank height gives the greatest contribution to the visibility ratio. Temperature makes the second-greatest contributor. Snowfall intensity makes a negligible contributor.

Table 2 Multiple linear regression analysis of factors affecting the visibility ratio

	Coefficient
Snowbank height	0.67
Air temperature	-0.31
Snowfall intensity	0.08

7. Conclusion

The following results were obtained from the observations in this study.

- (1) The factors making the greatest contribution to visibility variation on the road are air temperature, snowbank height and wind velocity.
- (2) The factor most greatly affecting the height-dependent visibility difference is snowbank height.
- (3) The visibility ratio becomes greater as the snowbank height increases. When the height exceeds 0.9m, visibility ratio was 3 to 10.

This study had few cases of measurement under the condition of snowfall intensity exceeding 1 cm/h. There were no cases where measurement was conducted under snowfall intensity exceeding 2 cm/h. These results show that snowfall intensity contributes slightly to visibility variation on the road and to difference in visibility depending on the height. However, experience shows that when snowfall is heavy, visibility on the road deteriorates. The results of this study, therefore, are considered to hold true only for low-intensity snowfall (< 1 cm/h).

In our future study it is necessary to clarify relationship between visibility and weather conditions by doing more observations during heavy snowfall.

Acknowledgments

We wish to express our gratitude to the Hokkaido Branch of the Japan Weather Association for its cooperation in the measurement of mass flux of snow, and to the Sapporo information network Co. LTD for providing the data of snow fall intensity of Sapporo City's weather telemeter.

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Variation in Meteorological Variables in Mountainous Regions and Their Effects on Road Surface Temperature Prediction

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INTRODUCTION

Predicting the road surface temperature in a rugged, mountainous environment is challenging due to the sub-regional climate that is contained within a relatively small area. A research project is being conducted in a mountainous region in Japan, in which a road surface temperature prediction model is evaluated. The model utilizes both topographical parameters along the highway and a meteorological forecast at a point location.

The study area is located in the mountainous region of central Japan (approximately 200 kilometers from Tokyo). Figure 1 illustrates the study area and highlights a short stretch of the national highway 17 which is the study segment for the prediction model. It has an elevation difference of 675 meters over a 25-kilometer stretch of the highway. There are several tunnels, snow sheds and snow shelters that protect the highway from natural hazards. Highly rugged, mountainous terrain is assumed to affect the input meteorological variables used for the prediction model.

This study looks into different meteorological input variables in terms of how mountainous terrain affects them, and then it investigates the varying effects that the mountainous terrain exerts on the road surface predicted model.



FIGURE 1 Overview of the study area.

TOPOGRAPHIC BOUNDARIES AND THEIR EFFECTS

The placement of road weather information systems (RWIS) in the study area seems to have been decided strategically based on their respective relationships with topographic features of the study area. Location-specific sensors are placed between any topographic boundaries which are demarked by tunnels, snow sheds or snow shelters. These RWIS are actually monitoring the sub-regional climates of the entire study area. This study investigates whether any particular sub-region in the study area has unique characteristics in its measured meteorological variables when they are compared with other sub-regions.

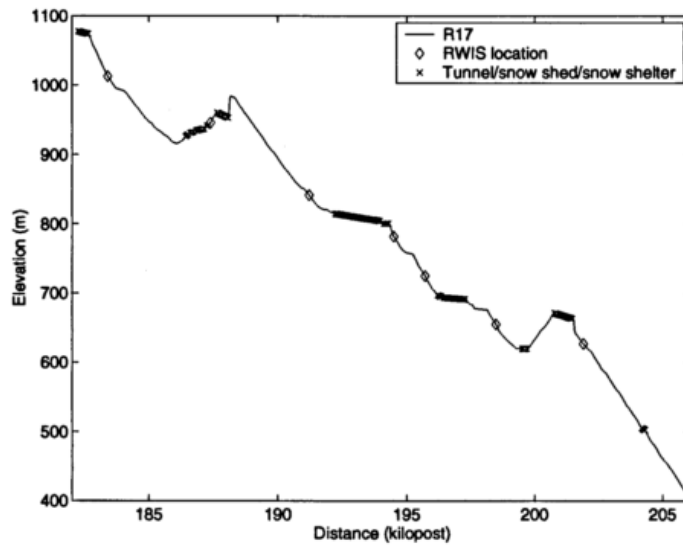


FIGURE 2 RWIS locations with their topographic relationships.

LAPSE RATE

Figure 3 illustrates lapse rates under different meteorological conditions. Data illustrated in the figure is from the RWIS locations represented in Figure 2. The meteorological forecast that is used for the prediction model is from the RWIS location at an even lower elevation, which is located a few kilometers away from the study area. As represented in Figure 2, RWIS are placed in the areas between various topographic boundaries. This study analyzes whether a rugged mountainous area has unique elevation-related characteristics. In other words, it examines what type of relationship exists between meteorological variables and elevation.

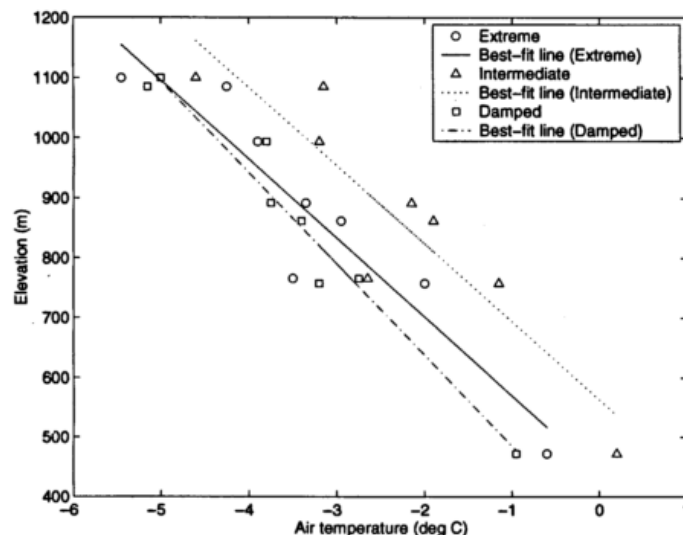


FIGURE 3 Different lapse rates of air temperature.

METEOROLOGICAL FORECAST VARIABLES

Figure 4 shows the differences in any two given consecutive air temperature forecasts. Every 12 hours, hourly values of meteorological variables are forecasted for the next 48 hours. The first 12 hours of a forecast are compared with the corresponding hours of the previous forecast. In

this way, it is possible to determine the efficiency of the forecast in general over a certain period of time.

For the period of time plotted in Figure 4, an input meteorological variable appears to be relatively unbiased, whereas its variance increases dramatically at certain time periods. The meteorological forecast is an important set of input variables for the prediction model; thus, it is clear that the meteorological forecast affects the resulting road surface temperature predictions. This issue becomes even more complicated when it is concerned with the nature of mountainous topography. A meteorological forecast is for a fixed point or an area. Therefore, this study analyzes the effects of variability in the input meteorological forecast variables. Specifically, it questions how a meteorological forecast for one point location could represent other areas that are separated by topographic boundaries even if they are located in a relatively small area.

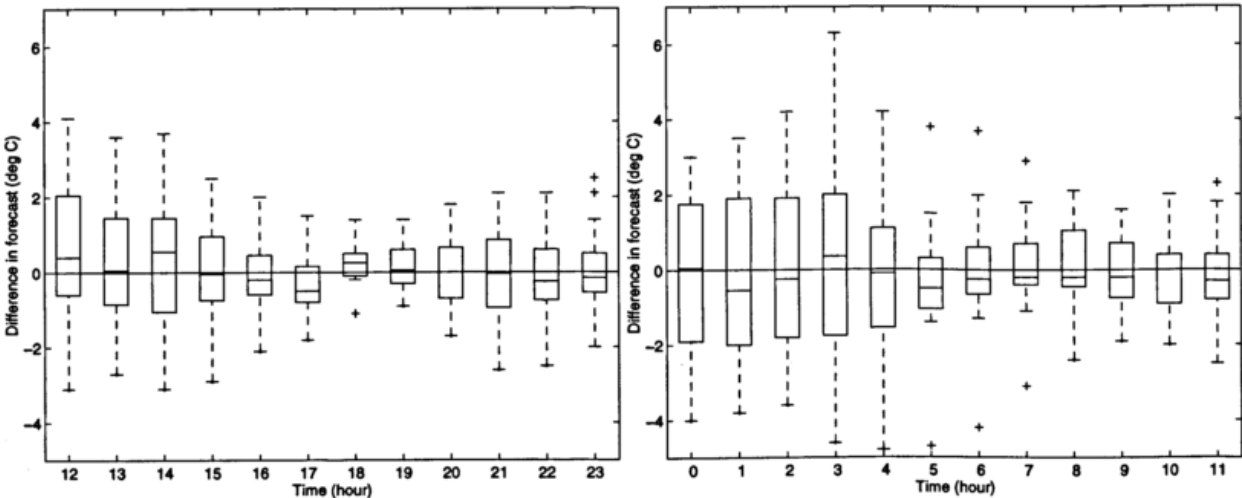


FIGURE 4 Data dispersion in input variable.

FREEZE-AND-MELT CYCLE AND TIME OF THE YEAR

Another important issue is how often road surface repeats a freeze-and-melt cycle. Figure 5 illustrates the median diurnal trends in air and road surface temperatures at a point location in the study area. During the winter season, it is not rare that road surface temperature goes through a diurnal (or even more frequent) freeze-and-melt cycle, while air temperature may not reach the melting point.

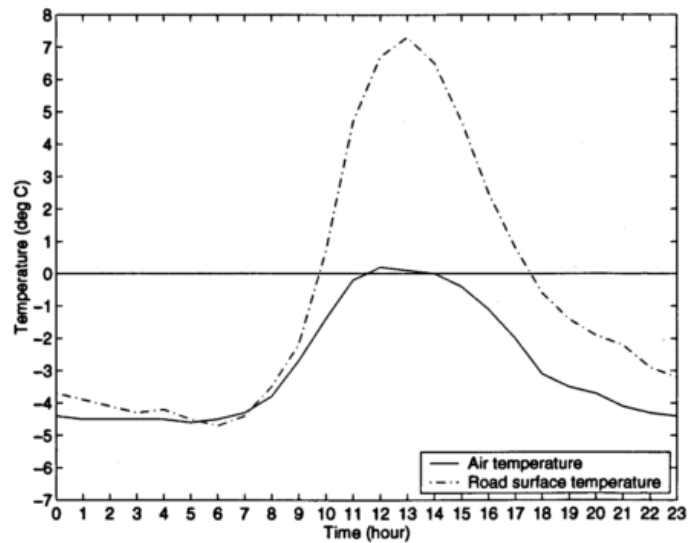


FIGURE 5 Mean monthly diurnal patterns for air and road surface temperatures.

This study examines how often a freeze-and-melt cycle takes place at particular RWIS locations that have road surface temperature sensors, and it compares the result with actual road freezing (with moisture) detected at the same site with road surface condition sensors.

PROPOSED STUDY

The road surface temperature prediction model will be run based on a set of meteorological forecast variables. Moreover, as part of the study, the actual road surface temperature will be measured with a vehicle equipped with an infrared thermometer multiple times during the winter season, and this is going to be a supplemental dataset to evaluate the prediction model itself. Topography and elevation-induced effects are identified and investigated, and results of the predictions will be compared with an analysis of the meteorological forecast and RWIS-providing actual meteorological data. The results of this study will be presented at the SIRWEC meeting.

Wind and Air Temperature Distributions in the Wake of a Running Vehicle

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Abstract

The snow and ice melt or refreeze through natural heat exchange and they are also subject to the mechanical and thermal effects of running vehicles. This study focuses on the turbulent heat transfer in the wake of a running vehicle. For the first step of its estimation, we observed the wind and air temperature distributions in the wake, air temperatures around the running vehicle, and exhaust pipe temperature.

The wind speed in the wake decreased with distance from the rear end of the vehicle and increased with vehicle speed. The turbulence characteristics had a similar tendency. Applying the surface layer theory to the wind field in the wake, we found the turbulent momentum transfer in the wake to be enhanced. The heating of air in the wake due to the running vehicle extended up to about 20 m from the rear end. The temperature of the exhaust pipe depended not only on the vehicle speed but also on the inclination of the road, since the engine revolution changes accordingly. The heating of air, defined by the air temperature difference between 'front' and 'end', depended on the vehicle speed, inclination of the road, and atmospheric stability on the road.

1. Introduction

The state of snow and ice on roads influences the safety of traffic in winter. Snow and ice melt or refreeze through heat exchange whose components are short- and long-wave radiations, sensible and latent heats under windy conditions, and heat conduction to/from the roadbed. This situation is identical to that in the case of natural snow cover. In addition, on roads, snow and ice are subject to the mechanical effects of running vehicles, and vehicles generate heat. The heat is transferred to the snow and ice by heat conduction from tires (e.g., Kinoshita *et al.*, 1970; Takeshi *et al.*, 2002), thermal radiation (e.g., Ishikawa *et al.*, 2000), and turbulence generated by the vehicle itself.

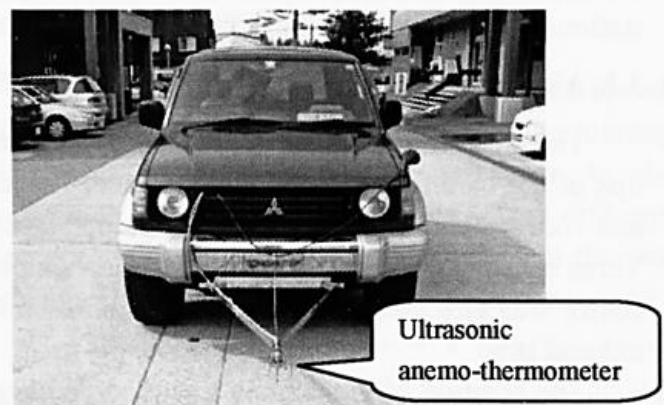


Fig. 1 The wind and air temperature sensor attached to the observing vehicle in OBS-A.

The present study focuses on this turbulent heat transfer. Turbulence behind a vehicle has been studied from the viewpoint of air pollutant diffusion (e.g., Eskridge and Hunt, 1979), but it is not known whether the turbulent heat transfer to the road surface is effective, and no method for estimating it has been established.

As the first step to answering these questions, we observed the wind and air temperature distributions in the wake formed behind a running vehicle (OBS-A), and observed the air temperatures around a running vehicle and the exhaust pipe temperature (OBS-B).

2. Method

2.1. Wind and air temperature distributions in the wake (OBS-A)

A vehicle drove at a constant speed, 40 or 60 km/h, and an observing vehicle followed it at the same speed, keeping a constant distance. An ultrasonic anemo-thermometer attached to the observing vehicle measured the three components of wind speed and air temperature at a frequency of up to 10 Hz (Fig. 1). The sensor height was 50 cm above the ground surface. The distance to the vehicle in front was measured with a laser range finder.

The wind speed observed from a coordinate system fixed to space is given by

$$\vec{V} = \vec{V}_m + \vec{V}_c \quad (1)$$

where \vec{V}_m is the measured wind speed and \vec{V}_c is the vehicle speed. This observation was carried out on a straight flat road under calm conditions. If the observed wind and air temperature are stationary, their spatial distributions are considered to move at the same speed as the vehicle speed.

2.2. Air temperatures around the vehicle (OBS-B)

The temperature sensors to measure the air temperature around the vehicle were attached to the tips of the bars fixed to the front and rear fenders, and attached above the roof (Fig. 2). The front and roof sensors measured the air temperatures that were not thermally affected by the vehicle. Three sensors at the rear measured the air temperatures heated by the vehicle. Another temperature sensor was attached to the hottest part exposed to the underfloor airflow, namely the surface of the exhaust pipe.

The position of the vehicle was recorded every two seconds using GPS, from which the vehicle speed was calculated. This observation was carried out on two routes; one was a flat route, where the road was dry, and another was an uphill and downhill route, where there were some tunnels and the road was wet or covered with slush or compacted snow.



Fig. 2 The air temperature sensors attached to the vehicle in OBS-B.

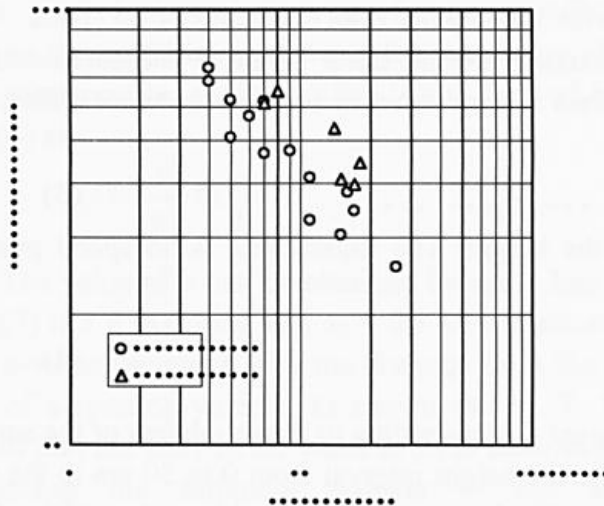


Fig. 3 The relationship between the wind speed and the distance from the rear end of the running vehicle.

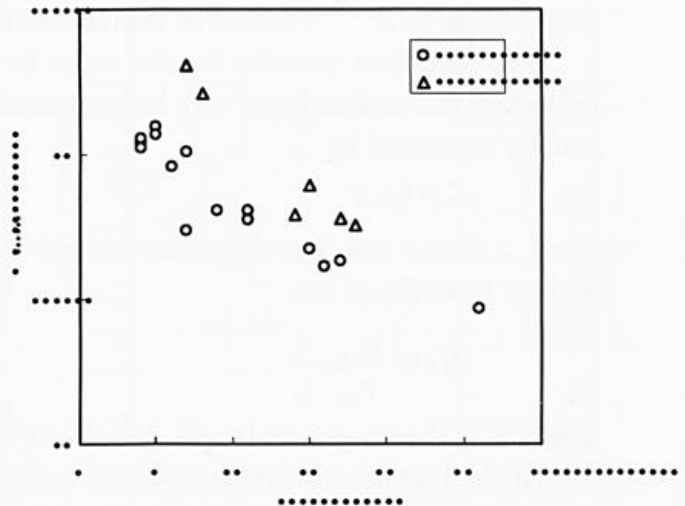


Fig.4 •• The relationship between the standard deviation of the vertical component of fluctuating wind and the distance from the rear end of the running vehicle.

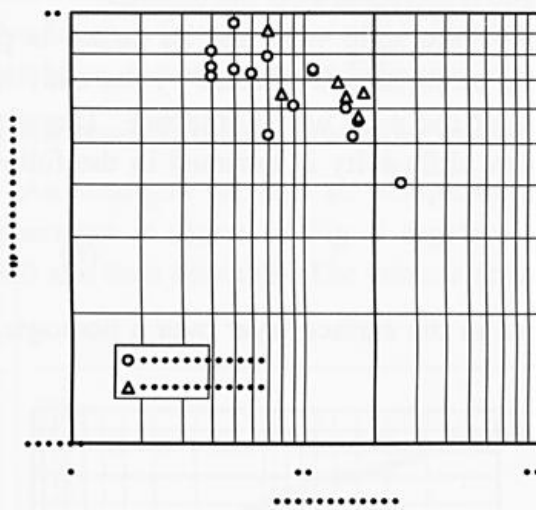


Fig.5 •• The relationship between the friction velocity and the distance from the rear end of the running vehicle.

2.3. Selection of data

In OBS-A, the data satisfying constant vehicle speed were selected. In OBS-B, the data were selected, which satisfied a vehicle speed of more than 40 km/h and the gentle change of road steepness in order to avoid rapid changes of running conditions. The data in the tunnel were not analyzed for OBS-B.

3. Results and discussion

3.1. Wind and air temperature distributions in the wake (OBS-A)

Figure 3 shows the distribution of wind speed, U , in the wake, which is a component in the running direction and is defined with reference to the coordinate system fixed to space. The different

symbols correspond to the vehicle speed. The wind speed decreases with the distance from the rear end of the vehicle, X , and increases with the vehicle speed. The relationship is expressed by

$$U \propto U_c^{2/3} X^{-1/2} \quad (2)$$

where U_c is the vehicle speed. Since U_c has only two values, the dependence on U_c is tentative. If the wake is characterized by the wind speed distribution, it extends more as the vehicle speed becomes high.

Figures 4 and 5 show the distributions of the characteristics of turbulence in the wake. The standard deviation of the vertical component of fluctuating wind (Fig. 4) decreases with distance and increases with vehicle speed. The friction velocity, u_* , showed a similar tendency (Fig. 5); u_* is

proportional to $X^{-1/3}$. The rate of decrease of u_* with X is smaller than that of the wind speed.

The turbulent transfer in the wake is discussed on the basis of these measurements. For reference, the surface layer on a homogeneous plain is considered, where the turbulent diffusivity is usually expressed by

$$K = ku_*z \quad (3)$$

Here, k is the von Karman constant and z is the height. The logarithmic wind speed profile is derived from Eq. (3) as

$$U(z) = \frac{u_*}{k} \ln \frac{z}{z_0} \quad (4)$$

where z_0 is the roughness length, which is a constant corresponding to the roughness of the surface.

If the logarithmic law is assumed to hold for the height interval from 0 to 50 cm in the wake, the apparent roughness length, $z_{0,e}$ (hereafter, the effective roughness length) can be obtained from the following equation:

$$U(z) = \frac{u_*}{k} \ln \frac{z}{z_{0,e}} \quad (5)$$

The effective roughness length is plotted in Fig. 6 against the distance from the rear end of the vehicle. The effective roughness length is not constant and it increases with the distance.

In the wake, generated turbulence is constrained by the solid wall and its nature is partly affected by the ground surface. In other words, the wall turbulence is affected by the eddy in the wake, and the turbulent transfer is modified from that of the pure wall turbulence. Therefore, a factor, α , is introduced to account for this. The turbulent diffusivity is assumed in the following way:

$$K = \alpha ku_*z \quad (6)$$

If $\alpha = 1$, the turbulent transfer has the same efficiency as in the surface layer over a homogeneous

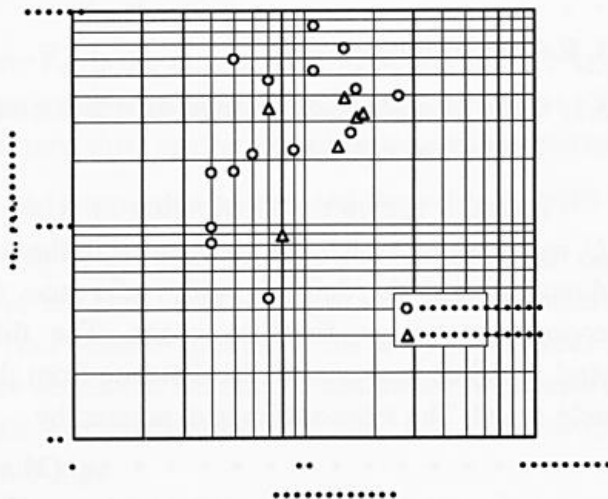


Fig.6 The relationship between the effective roughness length and the distance from the rear end of the running vehicle.

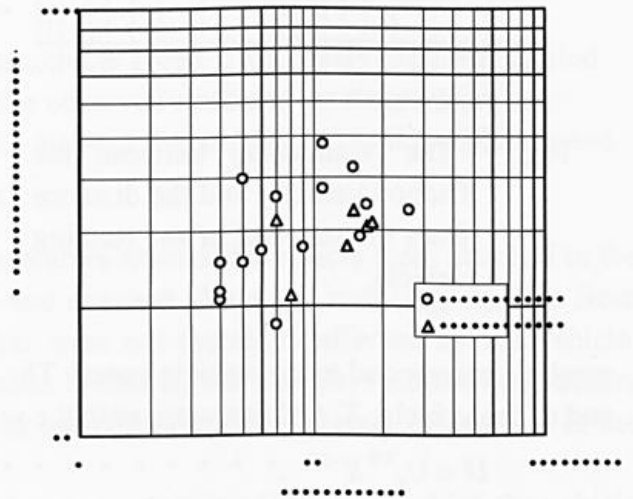


Fig. 7 The relationship between α and the distance from the rear end of the running vehicle.

plain. If $\alpha > 1$, the turbulent transfer is more efficient than in the surface layer over a homogeneous plain. The wind profile, similar to Eq. (4), is derived from Eq. (6) as

$$U(z) = \frac{u_*}{\alpha k} \ln \frac{z}{z_0} \quad (7)$$

The value of α can be obtained by using Eqs. (5) and (7) if $z = 500$ mm, and $z_0 = 0.1$ mm is assumed. The α -value increases with the distance from the rear end of a running vehicle, as shown in Fig. 7. This means that the eddy in the wake evolves downstream, enhancing the turbulent transfer in the wake compared to that in the surface layer over a homogeneous plain.

Next, the air temperature distribution in the wake is shown in Fig. 8, where the ordinate is the air temperature difference between inside the wake and outside the wake. The temperature difference is large if the distance from the rear end is short, and it decreases with distance. At a distance of more than about 20 m, the temperature difference is close to zero, showing that the hot air is almost diffused.

3.2. Air temperatures around the vehicle (OBS-B)

An example of the air temperatures around the running vehicle and the exhaust pipe temperature is shown in Fig. 9 together with the altitude and vehicle speed. The route was first uphill and then downhill. The vehicle drove at almost constant speed. The exhaust pipe temperature

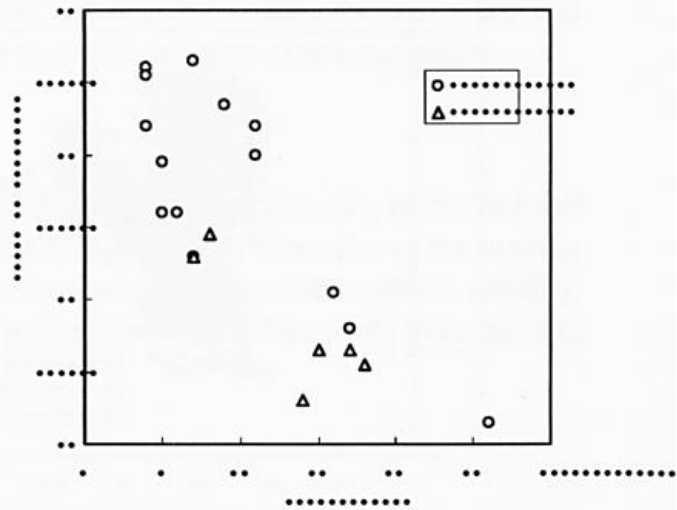


Fig. 8 The relationship between the air temperature difference between inside the wake and outside the wake and the distance from the rear end of the running vehicle.

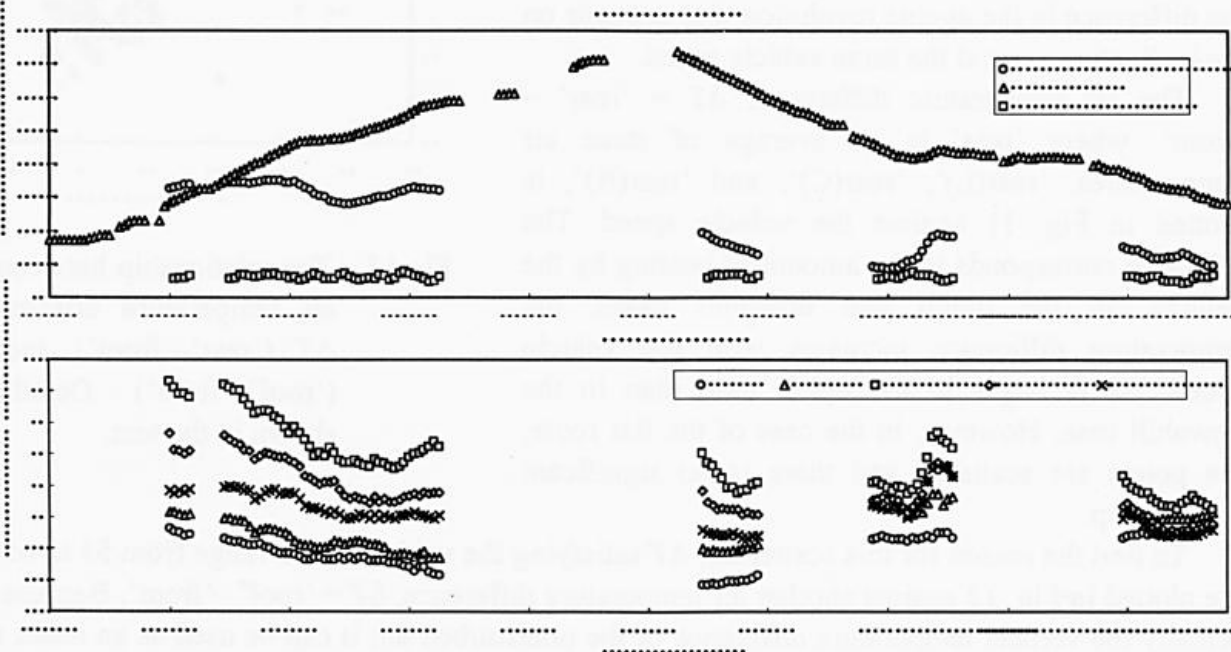


Fig. 9 Time series of the exhaust pipe temperature, altitude, and vehicle speed (upper), and air temperatures around the running vehicle (lower).

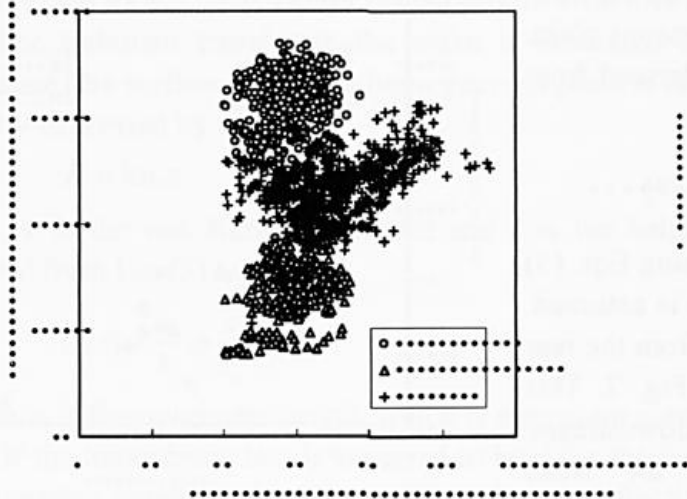


Fig.10 The relationship between the exhaust pipe temperature and the vehicle speed.

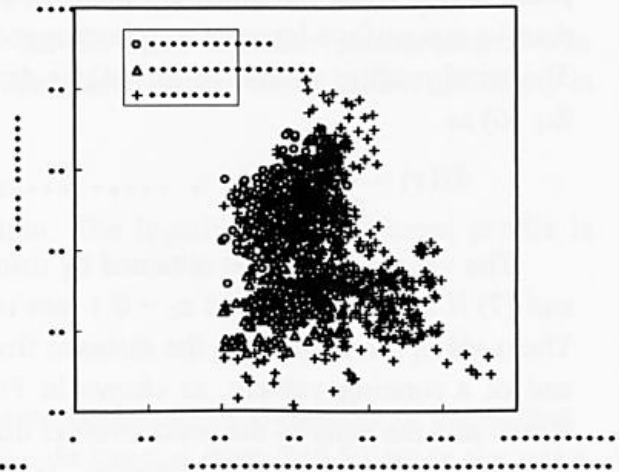


Fig.11 The relationship between the air temperature difference, ΔT ('rear'-'front'), and the vehicle speed.

was higher on the uphill route and lower on the downhill route. The lower figure shows the air temperatures around the running vehicle.

The exhaust pipe temperature is plotted in Fig. 10 against the vehicle speed. The temperature increases with the vehicle speed, which can be seen in the flat case. The temperatures are clearly classified according to the inclination of the road. This can be ascribed to the difference in the engine revolution that depends on the inclination even at the same vehicle speed.

The air temperature difference, $\Delta T = \text{'rear'} - \text{'front'}$, where 'rear' is an average of three air temperatures, 'rear(L)', 'rear(C)', and 'rear(R)', is plotted in Fig. 11 against the vehicle speed. The ΔT -value corresponds to the amount of heating by the vehicle. In the uphill and downhill cases, the temperature difference increases with the vehicle speed. ΔT is larger in the uphill case than in the downhill case. However, in the case of the flat route, the points are scattered and there is no significant relationship.

To find the reason for this scattering, ΔT satisfying the vehicle speed range from 55 to 65 km/h are plotted in Fig. 12 against another air temperature difference, $\delta T = \text{'roof'} - \text{'front'}$. Because δT is actually the vertical temperature difference of the undisturbed air, it can be used as an index of the atmospheric stability on the road. If it is negative (positive), the atmosphere is unstable (stable). The measurements on the flat route are distributed over a wide range of stabilities. The stability dependence is approximated by the solid line. The ΔT -value for the stability range of uphill and

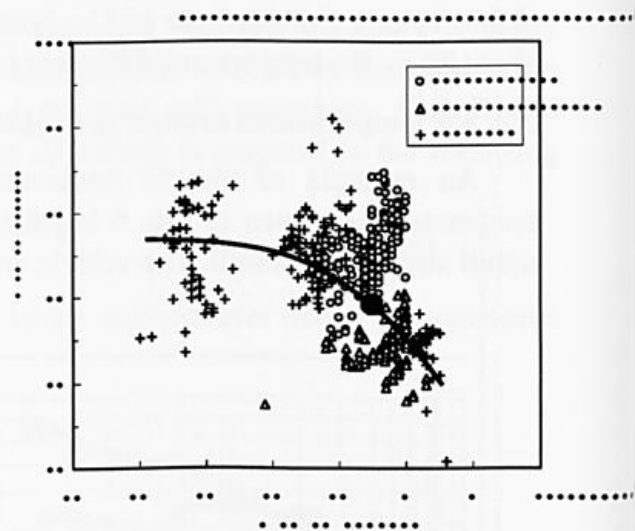


Fig.12 The relationship between the air temperature differences, ΔT ('rear'-'front') and δT ('roof'-'front'). Details are shown in the text.

downhill cases, which is shown by the solid circle, lies between the values for the uphill and downhill cases. The order of the ΔT -value coincides with that of the exhaust pipe temperature.

4. Concluding remarks

Our results show that the turbulent momentum transfer is enhanced by the eddy in the wake of a running vehicle. We clarified the amount and the distribution of heating of air due to the running vehicle, and its dependence on the vehicle speed, the inclination of road, and atmospheric stability. It remains for us to evaluate the turbulent heat transfer to the snow and ice on roads from running vehicles.

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Submitted Papers Topic II:

Forecast Methods and Accuracy

- (II-1) Grimbacher/Schmid (CH): Nowcasting nocturnal cloudiness with an ultra-dense Road Weather Measurement Network
- (II-2) Gjertsen et al (N): Monitoring Precipitation Intensity and type-combined Use of Radar and Temperature Measurement
- (II-3) Skuthan (CZ): The Significance of the Severe Events Warning Service in Relation to the classic Methods of Road Meteorology
- (II-4) Pasero et al (I): NEMEFO – Neural Meteorological Forecast
- (II-5) Hopwood (GB): Improvements in Road Forecasting Techniques and their Applications
- (II-6) Rohn/Raatz (D): Providing an optimized Dataset for Road Weather Forecasts
- (II-7) Sass/Petersen (DK): A coupled automatic Road Weather Forecasting System
- (II-8) Chapman/Thornes (GB): Road Ice Prediction using Geomatics
- (II-9) Thornes/Cavan/Chapman (GB): The Use of GIS and Icemiser to predict Winter Road Surface Temperatures in Poland
- (II-10) Badelt/Moritz (D): Use of Data on Road Condition and Weather for Winter Maintenance
- (II-11) Z'graggen (CH): Average Diurnal Temperature Devolution for Different Weather Situations – A prognostic Aid for Regions with Complex Topography
- (II-12) Liechti (CH): Topographical Boundary Layer Model for Road Weather Prediction

Nowcasting nocturnal cloudiness with an ultra-dense road weather measurement network

by
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Abstract

Ice and snow are important risks in winter precipitation. In this study we show several events of slipperiness in Switzerland, mainly caused by rain or snow falling on a frozen surface. Other reasons for slippery conditions are frost or freezing dew in clear nights and nocturnal clearing after precipitation, which goes along with radiative cooling. All these risks are connected with the existence or absence of clouds. Forecasting the cloud amount on a scale of 1-3 hours therefore is of special interest for road weather.

Cloud amount and the difference between air and surface temperature are important parameters of the radiation balance. In this contribution, we show the relationship between them, proved at several stations all over Switzerland. We found a quadratic correlation coefficient of 80% and improved it considering other meteorological parameters like wind speed. We conclude that temperature difference is a signature for nocturnal cloudiness.

We investigated nocturnal cloudiness for a case from winter 2001/02 in northern Switzerland. There, an ultra-dense combination of two networks with 70 stations in total is operated, measuring air and surface temperature, wind and other parameters. With the aid of our equations, these measurements were converted into cloud maps, including also precipitation seen by radar. We identified a frontal precipitation area, postfrontal clearing, freezing, and the first clouds of a following frontal passage.

These findings will improve the observation of clouds and cloud movement as well as the prediction of road surface state and the risk of slippery conditions.

1. Introduction

Road weather forecasting is one of the key topics in today's meteorology. Worst cases in road weather are those who lead to unexpected slipperiness, caused by snowfall, rain falling on supercooled ground or freezing rain water after (postfrontal) clearing. Especially in clear nights, hoarfrost or freezing dew are other important risks. The aim of this work is to find a better way to forecast these risks, depending most of all on near-surface temperatures.

A key parameter is the cloud amount. A change from overcast to cloudy or clear sky and back – due to radiation reasons or advection – can cause big variations in surface temperature. We intend to investigate the relationship between cloud amount and near-surface temperatures, and to quantify the influence of clouds on ground measurements. Because most critical cases occur at night, and due to the cease of solar radiation as a complicating factor, we decided to concentrate on nocturnal events.

Slipperiness occurs preferably in certain meteorological circumstances. A main factor is that surface temperatures should be around freezing point. At lower temperatures, there would be no rain, and the probably falling dry snow can be handled much better. With warmer temperatures, there is no reason why surface temperature should reach the freezing point, even if there is a strong radiative cooling in clear nights. Because meteorological situations often are not changing too fast, there are just a few dangerous time periods every winter.

For the time period from November 2001 to April 2002, ice and snow detected on the roads of the canton of Lucerne in central Switzerland are shown in Fig 1. There are only three critical time periods in the whole winter, two around December 15 and 25, and another one in the second half of February. All three periods lasted for several days, and the road weather maintenance had to pay great attention. Some case studies of this winter are already published by Grimbacher and Schmid (2002).

In the rest of the winter, the risk of icing or other reasons for slipperiness is fairly small. Nevertheless temperature, cloudiness and precipitation should be regarded very well to handle even these small risks.

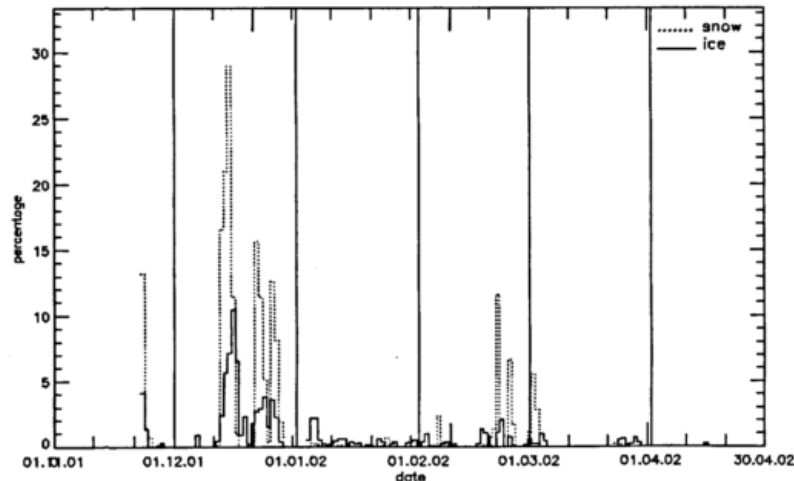


Fig 1: Occurrence of snow (dotted) and ice (solid) in the canton of Lucerne. Percentage of all measurements at 52 road weather stations in winter 2001/02.

In the next section, we will introduce the data networks included in our study. We will summarise our methods to analyse these data and show an equation for cloud amount calculations. After applying our method at single stations of different types, we will concentrate to a case in November 2001 with postfrontal clearing and slipperiness due to freezing rain water in the canton of Lucerne and the surrounding areas in northern Switzerland. Finally, we summarise the main results of the study and give an outlook on further and ongoing work.

2. Procedure

2.1 Data

2.1.1 Road weather station network in the Lucerne area

To study small-scale phenomena like clouds, one needs a measurement network as dense as possible. In central Switzerland a road weather network with 52 stations within an area of about $40 \times 40 \text{ km}^2$ has been installed by the road inspection office of the canton of Lucerne. Placed on the side of cantonal routes, every station measures every quarter of an hour the most important road weather parameters like air and surface temperature (temperature in 2m above ground and in 0.05m above ground), humidity, visibility, rain rate, wind speed and direction, ground temperature (temperature in 7cm below the surface) and road surface conditions (Mathis, 2000).

2.1.2 Automatic Network (ANETZ)

Another measuring system called ANETZ is operated by MeteoSwiss. This network covers 72 meteorological stations all over Switzerland. At each station almost all parameters of interest, such as air and surface temperature, pressure, rain rate, humidity, wind direction and speed, and ground temperature are measured in a temporal resolution of 10 minutes. Additionally, every three hours six of these stations do have direct observations by eye, including the total amount, type and height of the clouds. The observers estimate cloudiness in Octa, assigning clear sky with zero Octa, overcast sky with eight Octa and fog with nine Octa of clouds (SMA, 1982).

2.1.3 Precipitation seen by radar

All over Switzerland, there are three C-band weather radars owned by MeteoSwiss. Every five minutes a full volume scan is taken, and a composite image of whole Switzerland is created. The measured values are classified in 16 levels of reflectivity, connected to 16 levels of precipitation intensity. The spatial range of this composite data set is $2 \times 2 \text{ km}^2$ (Mecklenburg et al., 2000). Although there are several well-known measurement problems like clutter, attenuation or the underestimation of snow amount (Schmid and Mathis, 2004), the radar image gives a good overview on precipitation.

2.2 Methods

2.2.1 Clouds and radiation

The search for a relation between cloudiness and near-surface temperatures leads to a flashlight onto radiation equation theory. Several authors (e.g. Bogren et al., 2001 or Best, 1998) claim that the short-wave and long-wave radiation balance has the greatest influence on air and surface temperature (T_{air} and $T_{surface}$) and especially on the temperature difference

$$(1) \quad T_{diff} = T_{air} - T_{surface}$$

Since short-wave radiation is zero in nocturnal cases, radiation balance depends on long-wave radiation. At overcast conditions and with low clouds, the long-wave emission of the ground and the irradiation of clouds are of the same range. Therefore, $T_{surface}$ or T_{diff} remain relatively unaffected by radiation. The fewer clouds we observe and the higher (colder) they are, the more long-wave emission of the ground cannot be compensated by irradiation (Czeplak and Kasten, 1987). Energy is taken from ground or from the air near ground, and T_{diff} increases.

Empirically we found an equation to correct the height-dependency of the cloud influence. We define a New Cloud Parameter (Ncp) with

$$(2) \quad Ncp = \exp(-h/h_{max}) \cdot N,$$

where N is the observed cloud amount, h is the mean height of the cloud base and $h_{max} = 10000\text{m}$ is the maximum cloud height near the tropopause. We want to point out, that according to equation (2) there are two reasons for a change in Ncp . The Ncp increases due to a larger amount of clouds or due to a reduction in cloud height, and vice versa.

The other parts of the energy balance, such as the turbulent fluxes of latent and sensible heat, heat of fusion and the heat flux to soil, are normally considered to be small. Especially the turbulent fluxes depend on wind speed. Heat of fusion is connected to humidity and to precipitation events. However, these contributions should be kept in mind.

2.2.2 Connection between cloud amount and temperatures

We assume that near-surface temperatures are influenced by clouds. Because we focus on critical winter road weather, we concentrate on the nights from November to April. As already mentioned, there are nocturnal observations of cloud amount and corresponding measurements of temperatures at six ANETZ stations and for several winters. One of these stations is located in Payerne. There, we tested the relationship between cloud amount Ncp and temperature difference T_{diff} for well defined conditions: wind speed between 0 and 2m/s, air temperature between -5°C and $+5^{\circ}\text{C}$. Out of several function types, the exponential function type

$$(3) \quad Ncp = c + \exp(b \cdot T_{diff} + a)$$

leads to the highest correlation coefficient of 0.90 (Grimbacher and Schmid, 2003).

There are several other measurements related to cloudiness. E.g., the difference between surface and ground temperature is connected to Ncp in an exponential equation with a correlation coefficient of 0.79, or the difference between the mean air temperature of the last hour and the mean air temperature of the hour before is coupled to Ncp through a third order polynomial with a correlation coefficient of 0.63. Further we will concentrate on the exponential relation between Ncp and T_{diff} .

2.2.3 Equation parameters under certain circumstances (wind, temperature ranges)

With increasing wind speed the influence of turbulence increases. Best (1998) suggested a wind speed up to 3m/s not to influence radiative cooling too much. For the measurements in Payerne, we found this value quite realistic. There, for wind speeds between 0m/s and 1m/s the correlation coefficient is 0.9, for wind speeds from 3m/s to 4m/s it's 0.82 and for stronger winds it's getting insignificant very soon (Grimbacher and Schmid, 2003).

Concerning the temperature range, we found a similar tendency. The warmer it is, the lower the correlation coefficients are. With air temperatures below freezing point we gained a correlation coefficient of 0.9, for the temperatures above 10°C it's only 0.83.

We decided to use a specific equation parameter set for five wind speed and four temperature classes.

<i>Ncp</i> / Octa	0 to 5	5 to 6	6 to 7	7 to 8	fog	Total
wind speed up to 2m/s	0	0	14	58	20	92
wind speed over 2m/s	0	3	38	83	1	125
Total	0	3	52	141	21	217
Percentage	0	1.4	24.0	65.0	9.7	

Table 1: Precipitation measurements and cloud observations in Payerne.

2.2.4 Cloudiness and precipitation

The intensity of precipitation is measured at all ANETZ and road weather stations used in this study. We want to consider it as an additional indicator of cloudiness. Another source of precipitation information is weather radar, detecting precipitation not only at a single point but over a spatial area.

Precipitation mostly indicates overcast conditions. A few weather situations are imaginable, where convective precipitation comes along with less than eight Octa up to nearly clear sky. For Payerne, the statistic is shown in Table 1. In 75% of all precipitating cases the *Ncp* is larger than seven Octa, and in only 1.4% it is lower than six Octa. While considering wind speeds lower than 2m/s the connection is very good. With stronger winds it's still acceptable. Note, that only 5.9% of all measured data sets are connected with precipitation.

According to these results we define the *Ncp* to be 7.5 Octa for all times with precipitation observation.

2.2.5 Sources of error

There are several sources of error related to our calculations and their verifications. The two most important ones should be mentioned here:

Cloud observation by eye isn't easy. Especially in dark nights without moonlight it is often difficult to decide whether there are clouds or there are none, and in which height the clouds occur (Feijt and de Valk, 2001). These uncertainties in both, height and amount of clouds, have effects on the calculation of the observed *Ncp* with equation (2) and to the quality of the following comparisons.

Road weather stations are located on roads normally consisting of black tarmac. Especially on sunny days in spring or late in winter the tarmac heats up and therefore surface temperature rises. After twilight the energy has to be emitted through radiation or through turbulence (Bogren et al., 2001). Ground and surface temperatures, starting at a high level, are dying out in the first part of the night. Because the air temperature is not affected and normally smaller than the surface temperature, our method calculates eight Octa for these periods. So, we decided not to calculate an *Ncp* at the beginning of the night as long as the surface temperature is monotonically decreasing. About 15% of all data from road weather stations are affected by this problem. Because the ANETZ stations are normally situated on grassland where the heating effect is small, they are not affected.

3. Results

3.1 Comparison of observed and calculated cloud amount at one station

3.1.1 Result in Payerne

We investigated our method with the measurements in Payerne in winters 1996 to 2002. All temperature ranges and all wind speeds are taken, and the *Ncp* is calculated with the particular relation parameters. 80% of the nights are used to retrieve the relation parameters, the other independent 20% are used to check the quality.

As a result the comparison between calculated and observed *Ncp* is shown in Fig 2. Most points are concentrated near the diagonal. The correlation coefficient is 0.91, and the root mean square error (RMS) is 1.34 Octa.

3.1.2 Results at other ANETZ-Stations

We implemented the equations retrieved in Payerne at three other ANETZ stations with cloud observations, located in Wynau, Vaduz and Kloten. The results are listed in Table 2. For Wynau and Kloten, they are nearly as good as for Payerne. The results for Vaduz are bit worse. Vaduz is located in the Rhine valley and the surrounding mountains may influence the radiation balance and the near-surface temperatures.

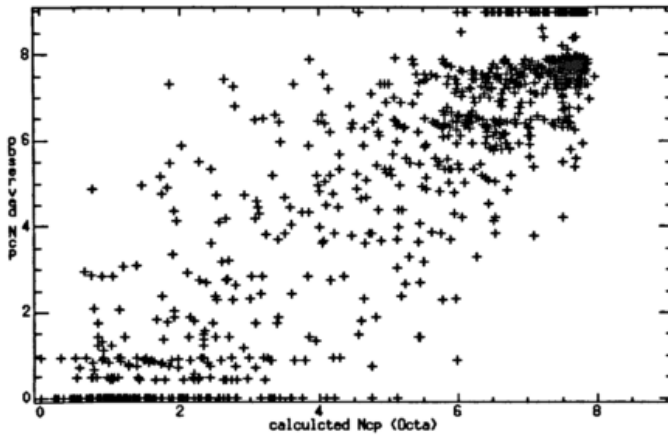


Fig 2: Observed and calculated New Cloud Parameter (Ncp) in Payerne. 1152 points of independent data are used.

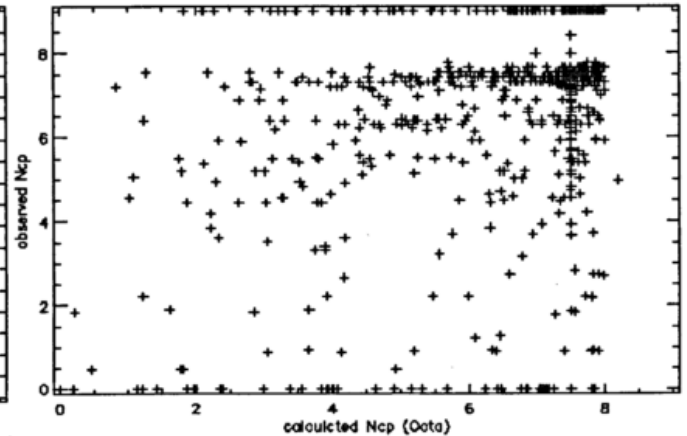


Fig 3: Comparison of cloud observations in Wynau (ANETZ) and calculated Ncp in Roggliswil (road weather station), 8 km away.

Station	Number of measurements [#]	RMS [Octa]	Correlation coefficient [1]
Payerne	1152	1.34	0.91
Wynau	1154	1.56	0.84
Vaduz	1087	2.36	0.71
Kloten	1155	1.33	0.88

Table 2: Proofing our method at several ANETZ stations by calculating an Ncp with the relation parameters of Payerne and comparing the results to the observed cloudiness. Results for independent data.

Wind speed	Number of measurements [#]	RMS [Octa]
All	995	2.00
> 1 m/s	589	1.68
> 4 m/s	130	1.53

Table 3: Proofing our method at the road weather station in Roggliswil by calculating an Ncp out of their data with the relation parameters of Payerne and comparing the results to the observations of Wynau.

3.1.3 Comparing ANETZ-Station Wynau with road weather station Roggliswil

Located in the canton of Berne, Wynau is the ANETZ station next to the road weather network in the canton of Lucerne. The nearest station to Wynau is Roggliswil in a distance of 7.98km. This is not too far away to make a comparison impossible, but it's not close enough to compare without any problems. The cloudiness observed in winters 2000 to 2002 in Wynau and the related calculations for Roggliswil are shown in Fig 3. As in Payerne, most points are concentrated near the diagonal, but some errors are visible especially with clear sky observation and overcast calculation or with overcast conditions at one station and broken sky at the other. In both cases fog and high fog at only one of the stations may influence the observed scatter in Fig 3.

Table 3 shows the RMS of a comparison between Wynau and Roggliswil. It is of the same order as at a single ANETZ station (Table 2). In disadvantage to our results in Payerne, the RMS of this comparison decreases with increasing wind speed. Without wind, the two stations can behave decoupled and due to their own environment. This is especially true for the foundation of fog. The stronger the wind blows the more homogenously clouds are distributed over a wider area. Now, the measurements in Wynau and Roggliswil are influenced by almost the same type and amount of clouds.

Considering the spatial differences we conclude that our method works very well, even at stations of other type.

3.2 Case study: November 27 to 28, 2001

3.2.1 Synoptic situation

On November 27, the synoptic situation of Europe is dominated by two lows near Iceland and a high slide east of the Azores. Several fronts pass through central Europe driven by the west wind regime. In the afternoon a cold front streaks Switzerland from north-west. In Lucerne precipitation starts at 14UTC, and it is raining all the afternoon. The precipitation area crosses through northern Switzerland until the early evening. The frontal passage is followed by a short period of high pressure influence, but an occlusion reaches Switzerland in the course of November 28.

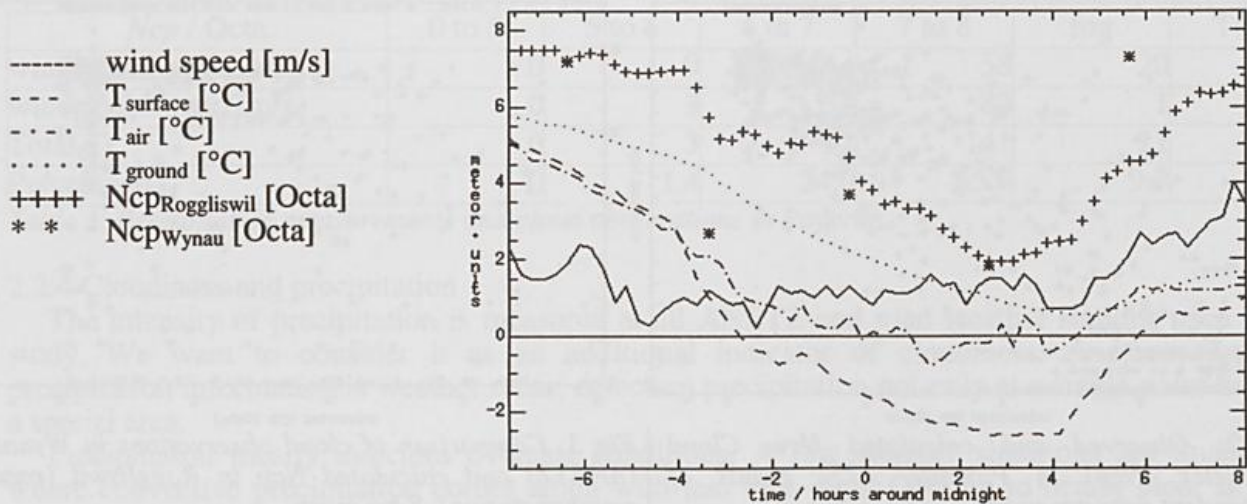


Fig 4: Some meteorological parameters in the night from November 27 to 28, 2001 in Roggliswil. Solid: wind speed, dashed: surface temperature, dash-dotted: air temperature, dotted: ground temperature, crosses: calculated Ncp, asterisks: observed Ncp (Wynau).

3.2.2 Meteorological parameters

Fig 4 shows the most important meteorological parameters, measured at the road weather station of Roggliswil. Additionally, the observed cloud amount of Wynau is marked.

All temperatures are falling, starting at about 5°C. The near-surface air cools down the fastest and drops below freezing level 2½ hours before midnight. Air temperature reaches the 0°-level after midnight but remains warmer than surface temperature all through the night. Some of the changes in air temperature are clearly related to increases and decreases in wind speed. The ground temperature reacts more slowly but also significantly.

Both the cloud amount calculated out of these data and the observed Ncp in Wynau, 8km away from the calculation, show a related behaviour. Starting with overcast conditions (and a few rain measurements) there's a rapid postfrontal clearing leading to the lowered surface temperature. The cloud conditions change between broken and nearly clear throughout the night, and in the early morning just before sunrise cloud amount increases back to six to eight Octa as a first sign of the approaching occlusion.

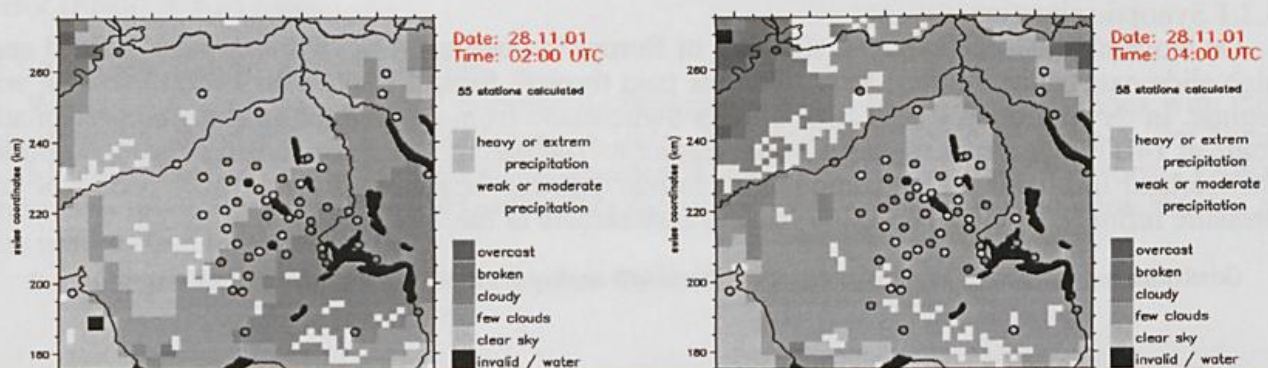
3.2.3 Cloud and precipitation map

For the night from November 27 to 28, 2001, all data of both networks are calculated every 15 minutes. The resulting Ncp at approximately 70 stations are interpolated, and precipitation seen by radar is overlaid. In Fig 5 some cloud and precipitation maps of our study area in northern Switzerland are displayed. Each station and its calculated cloud value is marked with a circle. By considering the cloud conditions at consecutive time steps one can clearly identify the movement of precipitation, clouds and clearing tendency.

The first half of the night is dominated by the cold front already mentioned. At 18UTC it is still raining or snowing in large parts of the study area. Other parts are overcast, and only in the very north-western regions of Switzerland clouds are broken. Later on, cloudiness decreases in the northern part of the map, but in the south-easterly part it's still overcast or precipitating.

In the second half of the night it gets clear almost everywhere. At 02UTC, most of the stations of both networks detect no or only few clouds. Exceptions are some stations at the lake of Lucerne and in the very south-east. Two hours later, it is clear there, too. But in the north-westerly part there are new clouds and some precipitation is visible. This is the first sign of an occlusion, reaching and crossing Switzerland in the following hours.

There's a radar echo marked as precipitation in all four maps at about Swiss coordinates 610 /



The 52 stations of the road weather measurement network are located in the centre of the maps. Even in this dense network, neighbored stations often show a different calculated cloud amount. E.g. at 2UTC, most of the stations identify clear sky, but also few and more clouds are detected. Clouds can be small scale phenomena, but at the same time calculations can fail or stations can react differently to our method, because they are influenced from different surroundings. Another possibility for a small temperature difference may be an evaporative effect after rain or snow. On the other hand it is still possible that there is a local variation in cloudiness, or locally limited fog or high fog. This shows to us the uncertainty in single point measurements and therefore the importance of having a network as dense as possible.

3.2.4 Influences on surface state

The area of postfrontal clearing reaches the road weather measurement network in the canton of Lucerne around and after midnight. In consequence, surface temperature decreased and reached the freezing level at nearly all stations. Surface states changed from wet to frozen or iced. Freezing rain water was detected at several stations in the canton of Lucerne, and road maintenance had to use de-icing chemicals. In Fig 1, this event is connected to a clear peak in the second half of November, indicating ice or snow in up to 15% of all surface state measurements. Some more information of this event, including maps of surface state, are already published by Grimbacher and Schmid (2003). In the early morning new clouds were advected and another precipitation area arrives.

4. Conclusions

The way to describe the radiative and advective interaction between cloudiness and near-surface temperatures seems to be a good direction to learn more about the predictability of surface state. On the other hand, cloudiness and surface state are highly critical parameters in the domains of road weather, and their forecast is not easy. Surface state is closely linked to precipitation, remaining rainwater and the near-surface temperatures, and its change often is related to advection. Either cold air is advected, or the postfrontal clearing, caused by advective motion of possibly precipitating clouds, leads to radiative cooling.

We found that there are general connections between cloudiness, temperature difference and precipitation. First of all we developed an equation to correct the height dependency of observed cloud amounts. The resulting cloudiness is named Ncp. With precipitation, the sky is almost always overcast, otherwise the relation between Ncp and temperature difference is of exponential type and has to be adapted to different conditions of wind speed and temperature. Once we got the parameters of the relationship in Payerne, we could use them at all other stations. We achieved RMS between 1.3 and 2.4 Octa, depending on the particular location of the stations.

In a case study, we showed the cloud conditions in northern Switzerland during a critical winter night. We detected the advective motion of a nearly cloud free area after a cold frontal passage and the arrival of a following occlusion. The clearing was coupled with radiative cooling and followed by a decrease in surface temperature and a change in surface state from wet to frozen. Some stations of the ultra-dense network in the canton of Lucerne rested at a rather higher value of calculated cloud amount, probably due to their special surrounding, to evaporation effects or fog. We conclude that one should use a measurement network as dense as possible to calculate two-dimensional cloud maps, because only several neighbored stations give a good impression of the real cloud situation of a region.

In the created maps we can identify both the motion of precipitating areas and the advection, foundation and dissipation of cloud fields. We calculated spatial cloudiness with a time resolution of 15 minutes. Precipitation measured by radar already can be nowcasted with tracking algorithms like COTREC (Mecklenburg et al., 2000). As ongoing work, we will try to track radar precipitation together with cloud information gathered in this study. Using this information, we intend to create high resolution forecasts of near-surface temperature and road surface state.

Acknowledgments

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MONITORING PRECIPITATION INTENSITY AND TYPE – COMBINED USE OF RADAR AND TEMPERATURE MEASUREMENTS

by

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Abstract

Two new products developed for road authorities and other customers of the Norwegian Meteorological Institutes Market Division are presented and verified in this paper: A precipitation type forecast and a radar precipitation type product. The HIRLAM model is used to forecast the precipitation types rain, sleet and snow. The operational HIRLAM-forecasts are biased towards predicting too many cases with snow. The paper shows that additional calculations of snow melting based on temperature and humidity in the lowest model layer reduce this error. For the radar product, the precipitation type is estimated from synoptic observations of 2m-temperature and dew point temperature. The observations are interpolated in space using a Digital Elevation Model (DEM) after deriving local vertical temperature gradients. A precipitation type dataset is derived and combined with the actual radar precipitation intensity image. The radar product is verified against observed precipitation types at the synoptic stations for the winter season 2002/2003 (October to March). The percentage correct is 85%. The Probability of Detection is 0.9 for rain and 0.91 for snow. A comparison of estimated and forecasted precipitation types is carried out for January 2002 against an independent set of precipitation stations in Southern Norway. The results confirm the good quality of the radar product and show that the adjustment of HIRLAM precipitation type to real topography improves the forecast.

Introduction

Road managers have been using radar reflectivity images and precipitation forecasts from the HIRLAM atmospheric model for several years. The radar provides detailed information about the spatial distribution of precipitation in real time. For the management of winter snow clearance and salting, information about the type of precipitation is of great value. In the region Helsinki in Finland, where radar products have been available for several years, the cost savings are in the range of 200 000 EUR each winter (Koistinen and Saltikoff, 1998). Two new products developed at the Norwegian Meteorological Institute are evaluated in this paper: The forecast of precipitation type from the HIRLAM model, and radar precipitation intensity images with precipitation type information.

In the HIRLAM model, precipitation distributed on snow and rain has been available from the condensation schemes for many years, but has not been available to customers. In a number of cases the model is forecasting snow when rain is observed at ground level. This is related to the mainly positive difference between model orography and the real topography, particularly in the valleys and the fjords. The approach presented here uses the temperature and humidity in the lowest model layer to predict melting of snow on the way from the model's lowest layer to the real topography. The precipitation type estimation for the radar product uses a different approach. Where the humidity and temperature information is taken from the HIRLAM model for the precipitation type forecast, observations from synoptic stations are used for the radar product.

Data and methods

Precipitation type from HIRLAM

The operational atmospheric model at the Norwegian Meteorological Institute is HIRLAM 5.2 with a resolution of 20*20 km and 40 levels. The method for extrapolating precipitation type to real topography is based on Golding (1989), and applied at the Norwegian Meteorological Institute by Ødegaard (1997). Melting of snow below the model surface is applied using the following equation:

$$\frac{\partial P}{\partial z} = -0.0028T_w P \quad (1)$$

T_w is the wetbulb temperature, P is the precipitation rate. The wetbulb temperature is used, because the melting of snowflakes is assumed to be delayed by evaporation from the snowflakes in subsaturated conditions. To compensate for the cooling of air caused by melting of snow, the vertical gradient varies in the range 0.1-0.6K/100m depending on precipitation rate. For high precipitation rates, the gradient of the wetbulb temperature is small. The wetbulb temperature used in the model is the mean of the wetbulb temperature in the lowest model layer and the wetbulb temperature extrapolated to station height.

A 30h forecast is run at 00 UTC for each day. The 6h accumulated precipitation at +12, and +18, and the 12h accumulated precipitation at +30h are used in this comparison. The precipitation type (pt) is calculated from accumulated rain (r) and snow (s) in mm. The result is a number between -1 and 1 on a continuous scale where precipitation type $pt > 0.33$ is interpreted as snow, $0.33 \geq pt \geq -0.33$ is interpreted as sleet and $pt < -0.33$ is interpreted as rain.

$$pt = \frac{(s - r)}{(s + r)} \quad (2)$$

The radar precipitation type product

The radar precipitation type product is based on the operational precipitation intensity data set derived from PseudoCAPPI data. Here, data from two of the four Norwegian C-band weather radars is used, the radars Oslo and Hægebostad in Southern Norway. The Marshall-Palmer relationship is used for converting from radar reflectivity to precipitation intensity, and a gauge adjustment is performed to improve the quantitative accuracy. The gauge adjustment method is under development, the most recent documentation of the method can be found in (Gjertsen and Dahl, 2001) and (Gjertsen, 2002). To derive precipitation type, observations of 2m-temperature (T) and dew point temperature (T_d) from synoptic stations are used in real time. T_d is converted to relative humidity (RH). A test for observation errors is not yet implemented.

A digital elevation model (DEM) from US Geological Survey is used to interpolate T and RH between the synoptic stations. The DEM is transformed to the radar data resolution and geometry (1*1 km, polar stereographic). Local vertical profiles for T and RH are derived for each raster element in the radar data set using a local linear regression with the DEM height as the independent variable. Input data to the regression are the ten closest synoptic stations within a predefined search radius (200 km in the actual implementation of the model).

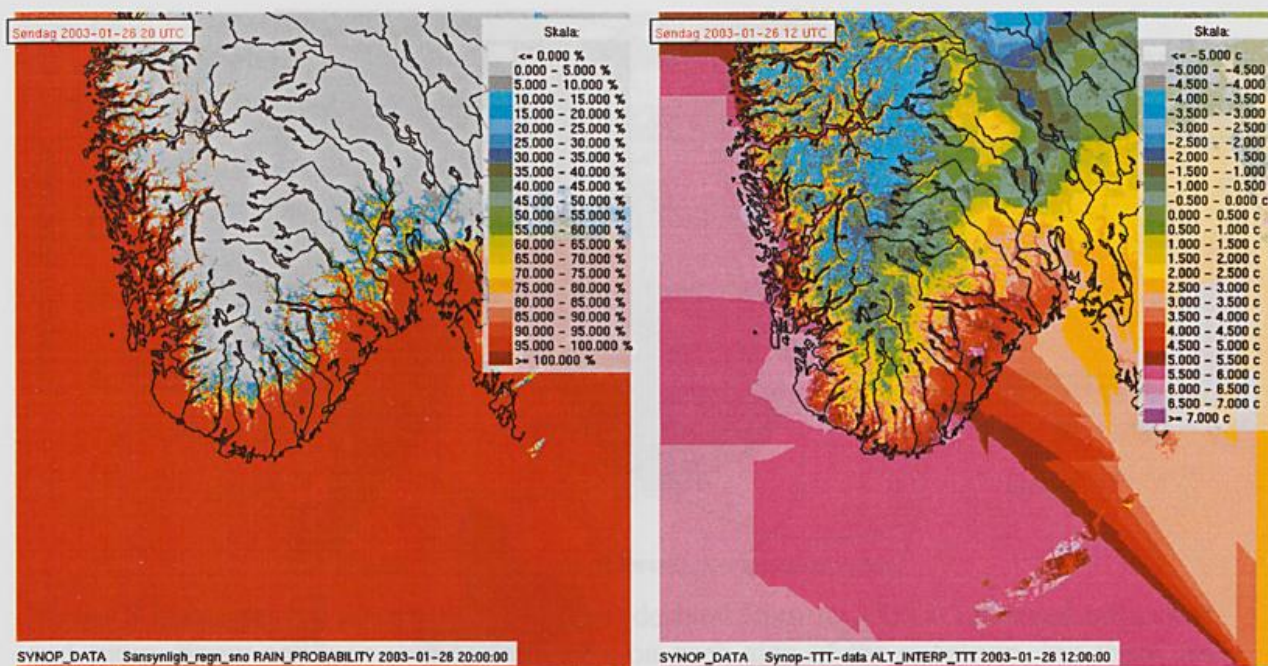


Figure 1 – Probability of rain and temperature interpolation for 26.1.2003.

Each raster element is then assigned a value for T and RH according to the DEM-height. When T and RH are available as raster datasets, the probability of rain is derived using the equation by Koistinen and Saltikoff (1998):

$$p(\text{rain}) = \frac{1}{1 + e^{(22 - 2.7T - 0.2RH)}} \quad (3)$$

Examples of the T and p(rain) datasets are shown in *Figure 1*. The probability of rain is converted to precipitation type and overlaid with the actual radar precipitation intensity image every 15 minutes. The precipitation types are displayed in different color scales as shown in *Figure 2*. The images are generated both as composites and single site products.

The ground reference

For verification, the results from HIRLAM and the precipitation type estimation are compared to precipitation types observed at stations from the synoptic and the precipitation station network. Observations of actual weather from the synoptic network (00, 06, 12, 18h UTC) are used for the verification of the radar product for the winter season 2002/2003. The data is used after a conversion to the classes rain, sleet, snow. These are the same stations used for the generation of the T and RH data sets, therefore, no information about the accuracy of the temperature interpolation is obtained. A separate verification is therefore performed on data from the network of precipitation stations. These stations report with a delay and are therefore not used in the processing of the radar product.. All stations covered by the two radars are used (around 280). The precipitation stations report daily at 06, 12 and 18 UTC.

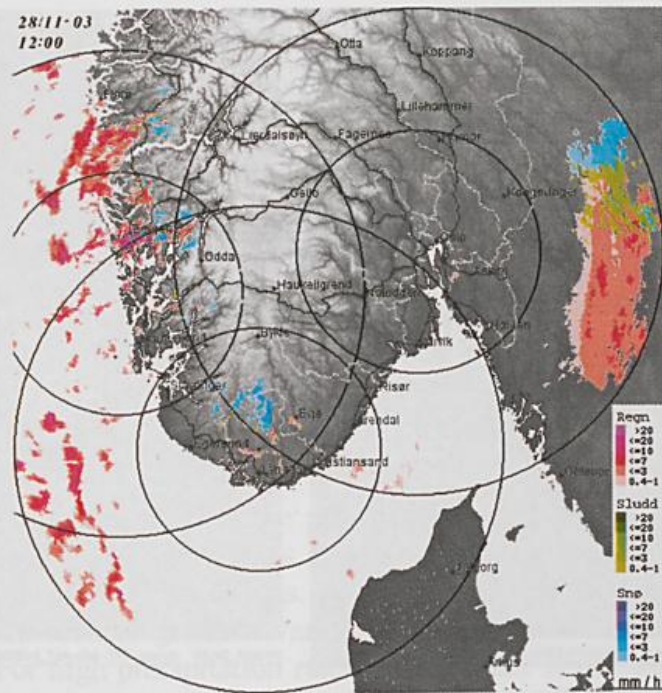


Figure 2 – Precipitation type composite for 28.11.2003, 12:00 local time

The weather including precipitation type is described with three symbols covering the period since the last observation. The symbols are given numerical values 1, 0 and -1 according to the coding of the HIRLAM product. When determining the value for a single observation period, the observation codes for the period are averaged. The radar product is coded accordingly, i.e. precipitation is accumulated for the periods 6-12, 12-18 and 18-06 UTC. For periods where precipitation is observed, the type is calculated as the mean of the precipitation types estimated during the period.

Ground observations of precipitation type are subjective. It is not clearly defined how much of the snowflake is melted in sleet, or when sleet goes over to rain. Averaging the observation codes for 6 or 12 hours is therefore not the same as using the mean precipitation type from a 6h or 12h period from HIRLAM, or averaging the precipitation type estimation from the radar product. The results presented in the following sections have to be interpreted being aware of these limitations.

Verification of the radar product against synoptic stations

In this section, the accuracy of the precipitation type estimation is verified against observations of actual weather at the synoptic stations for the months October 2002 – March 2003. Only cases where both radar and station observe precipitation are used. The quantitative accuracy of the radar precipitation product is not subject of this verification. The actual weather type is read from a climate data base and classified into the precipitation types rain, snow and sleet.

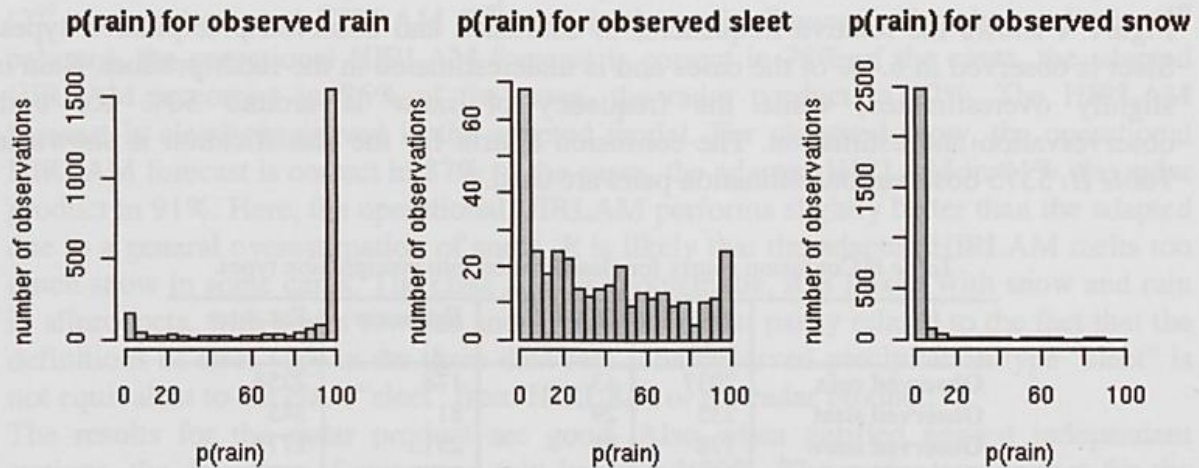


Figure 3 – $p(\text{rain})$ for observed precipitation types.

Figure 3 illustrates the distribution of $p(\text{rain})$ derived from eq. (3) for observed rain, sleet and snow. Snow and rain show clear peaks on each side of the spectrum, but there are cases where rain is observed despite very low probability. This is most likely due to temperature inversions not modeled correctly by the vertical temperature profile regression. Sleet is observed for all $p(\text{rain})$ and shows no clear maximum. There are however many cases where sleet is observed for low probability of rain. Also in this case, temperature inversions are a possible cause.

Table I FAR and POD for precipitation types.

Observed precipitation type	False Alarm Rate	Probability of Detection
Rain	0.15	0.9
Sleet	0.84	0.08
Snow	0.09	0.91

The probability of rain is a continuous variable on a scale from 0 to 1. The class boundaries for rain, sleet, snow were found by balancing the False Alarm Rate (FAR) and Probability of Detection (POD) for snow and rain. The class boundaries used by Koistinen and Saltikoff (1998) lead to an overestimation of snow, equivalent to a high False Alarm Rate for snow. By adjusting the class boundaries, the FAR for snow and rain are reduced and the POD are increased. The total number of hits is 77% for the original class boundaries and 85% for the adjusted class boundaries. The POD for sleet is very low (0.08). Only 8% of the cases with observed sleet are classified correctly by the model. For observed rain, the model classifies correctly in 90% of the cases, for snow in 91%.

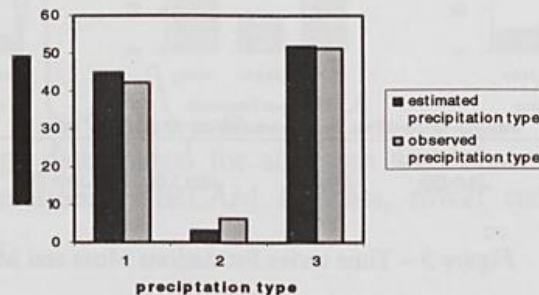


Figure 4 – Frequency histogram for estimated and observed precipitation types (1=rain, 2=sleet, 3=snow) October 2002 – March 2003.

Figure 4 shows the relative frequencies of estimated and observed precipitation types. Sleet is observed in 6.4% of the cases and is underestimated in the radar product. Rain is slightly overestimated, while the frequency of snow is around 50% for both observation and estimation. The confusion matrix for the classification is shown in Table II. 5375 observation/estimation pairs are used.

Table II Confusion matrix for classification into precipitation types.

	Est. rain	Est. sleet	Est. snow	Est. sum
Observed rain	2037	43	178	2258
Observed sleet	235	29	81	345
Observed snow	178	81	2513	2772
Observed Sum	2450	153	2772	5375

Verification of forecast and radar product against independent precipitation stations

In this section, the adapted HIRLAM forecast (with melting of snow between model layer and real topography), and the estimated precipitation type are compared to observations from the network of precipitation stations for January 2002. In Figure 5, two time series for the stations Moss (131 m asl.) south of Oslo, and Madland (297 m asl.) on the Western Coast of Norway are shown as examples.

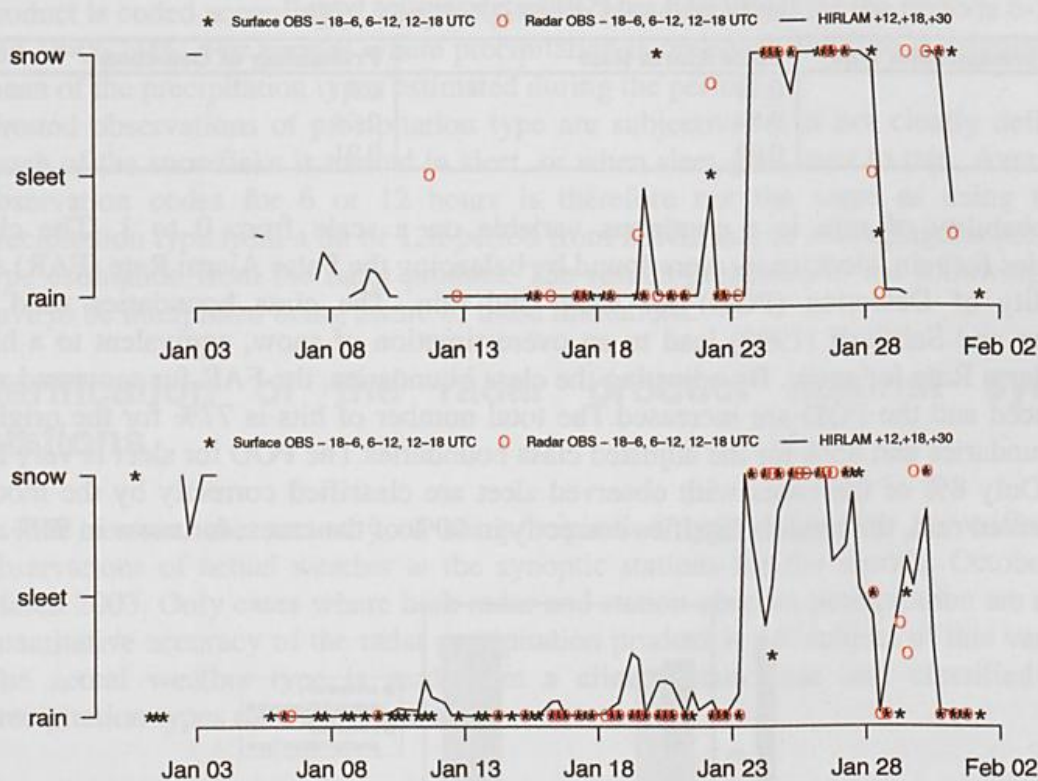


Figure 5 – Time series for stations Moss and Madland.

The result of the summary verification for operational HIRLAM (1st row), radar product (2nd row) and adapted HIRLAM (3rd row) is shown in *Figure 6*. For observed rain (1st column), the operational HIRLAM forecast is correct in 73% of the cases, the adapted HIRLAM is correct in 86% of the cases, the radar product in 87%. The HIRLAM forecast is clearly improved in the adapted model. For observed snow, the operational HIRLAM forecast is correct in 87% of the cases, the adapted HIRLAM in 84%, the radar product in 91%. Here, the operational HIRLAM performs slightly better than the adapted model due to a general overestimation of snow. It is likely that the adapted HIRLAM melts too much snow in some cases. The class sleet is problematic, it is mixed with snow and rain in all products, with a bias towards snow. This is at least partly related to the fact that the definitions of sleet vary in the three data sets. The observed precipitation type “sleet” is not equivalent to the class “sleet” from HIRLAM or the radar product. The results for the radar product are good. Also when verified against independent stations, the detection of snow and rain is around 90%. The percentage correct for the precipitation stations is 84.6% as compared to 85% for the synoptic stations. These results show that the temperature interpolation technique performs well.

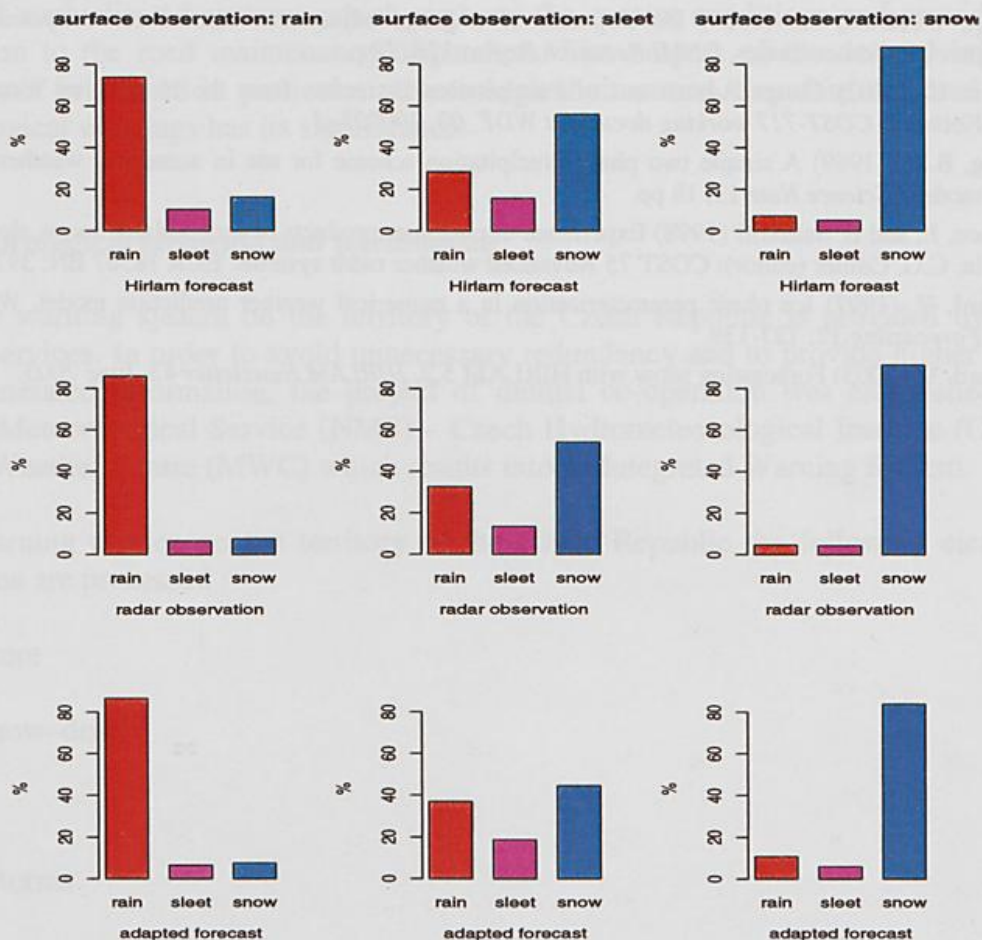


Figure 6 – Precipitation type distribution for all cases with observed rain/sleet/snow in January 2002. Row1: operational HIRLAM forecast, row2: radar estimation, row3: adapted HIRLAM forecast.

Conclusions

The verification of the adapted HIRLAM precipitation type forecast and the precipitation type product from synop- and radar data shows that the HIRLAM forecast improves with adjustment to real topography. The bias towards predicting too many cases with snow is removed. The detection of snow is slightly reduced, this might indicate that the model melts too effectively in some cases, possibly also cases with temperature inversions. An adjustment of the T-gradients is possible. The adapted HIRLAM model improves the forecast for locations in complex terrain where the operational HIRLAM forecasts too many cases with snow. The estimated precipitation type in the radar product is correct in 85% of occurrences when verified against synop- and precipitation stations. The classification of sleet is difficult. This is partly a matter of definition of class boundaries. In a next step, we plan to compare the quantitative accuracies of HIRLAM precipitation forecast and radar precipitation accumulations.

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The significance of the severe events warning service in relation to the classic methods of road meteorology

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1. Preface

It is a well known fact, that the national meteorological services are providing besides the classic forecast products also a number of warnings, concerning the probability of occurrence or possibility of extravagating of certain meteorological elements or phenomena. Routinely there are several levels of hazardousness of respective phenomena.

The warning service has its inevitable role also in the field of applied road meteorology, where a good working early warning system can prevent the influence of severe weather impacts on road traffic by means of „in time“ employment of proper winter maintenance technologies. A significant role is a good working network of road weather stations and the outputs of sophisticated systems which evaluate the current conditions and provide relevant information to the road maintenance dispatchers. The outputs of the derived informations however can be limited in particular meteorological situations, therefore the need of „pure“ meteorological warnings has its significance.

2. Meteorological elements and phenomena

The early warning system on the territory of the Czech Republic is provided by civil and military services. In order to avoid unnecessary redundancy and to provide higher efficiency in the generated information, the project of mutual co-operation was established between National Meteorological Service (NMS) – Czech Hydrometeorological Institute (CHMI) and Military Weather Centre (MWC) which results into an Integrated Warning System.

In the warning service on the territory of the Czech Republic the following elements and phenomena are processed :

- Temperature
- Wind
- Snow (snow–drift)
- Glaze
- Rime
- Rain
- Thunderstorms
- Floods

A whole complex of criteria for each of the elements and phenomena, which was created to meet the needs of the end users from state and private enterprises comprises a part of the „Integrated Rescue System“ in the country.

A great majority of the above mentioned elements and phenomena have an influence on the roads and not exclusively in the winter period (in summer the informations are frequently used in order to optimise the construction and reconstruction technologies of the roads)

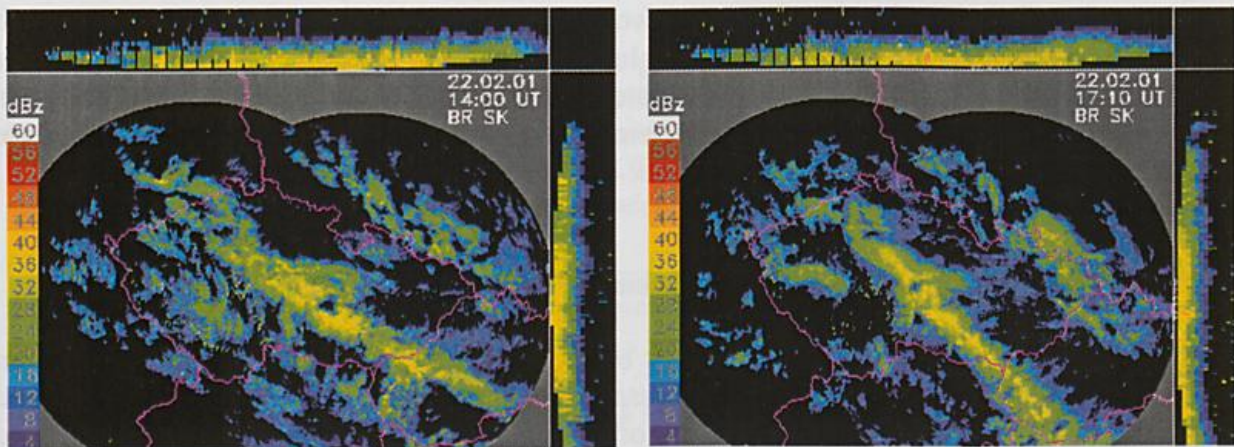
3. Necessity of meteorological inputs

The process of the road maintenance needs a quick response to the state of the weather in the particular location, road line or region. In most of the cases the future development of weather is available from the forecast outputs. An essential status have the specialized road weather forecasts for the road maintenance which are provided with the respect to the specific end user as regional, line, and forecasts for urban agglomerations.

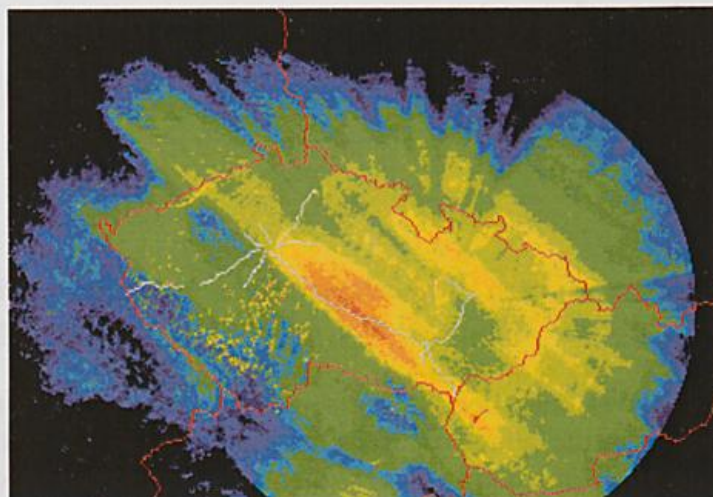
Increased attention is paid to the short term road weather forecast for the next 9 hours (in some cases this forecast has the characteristics of nowcasting) and the outlook for the next 24 and 48 hours.

The above mentioned specialized weather forecast usually contains the warnings on severe elements and phenomena and in some cases involve warnings on glaze and black ice.

Primary however is the warning of the Integrated Warning System of CHMI and MWC which shall involve all severe situations. As a typical example let me mention the situation with heavy snowing accompanied with strong gusty wind reduced on a small territory of the Czech Republic on 22th February, 2001.



The presented images from the precipitation radar network of CHMI illustrate the situation of strong north-west flow reaching from the North Sea over Central Europe towards south-east, a secondary cold front has developed and proceeded over the territory of the Czech Republic. The good visible, relatively narrow zone of precipitation related to the strong north-west flow and strong convergence of the wind in the unstable air masses within the passage of the mentioned cold front.



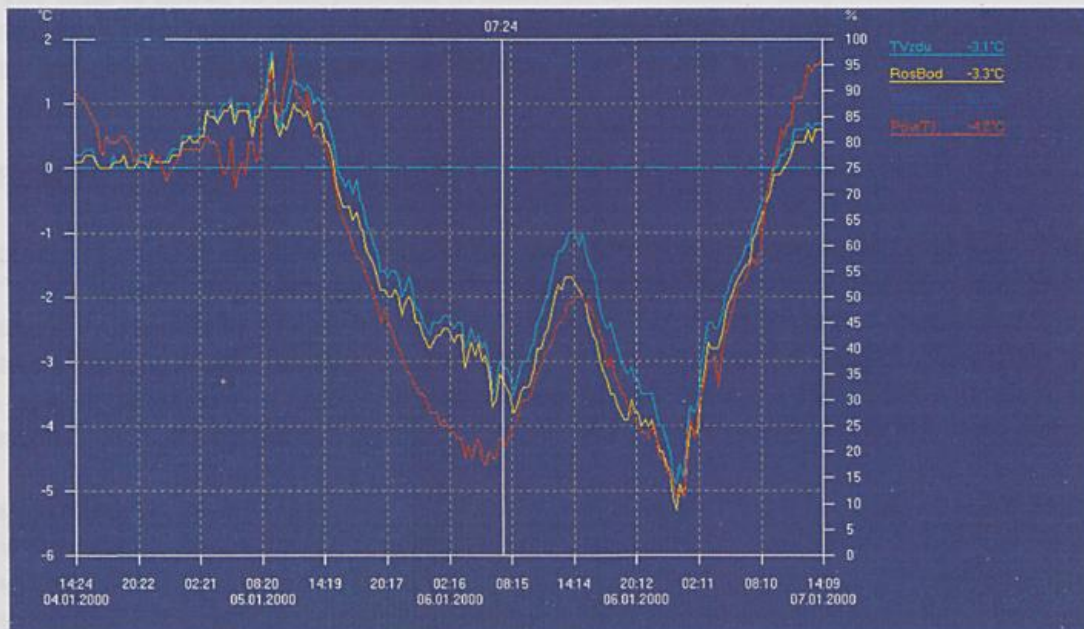
The above presented image shows the 24 hours sum of precipitation where a significant cumulation of precipitation is located in the region of the Czech-Moravian highlands. The height of snow cover there is 30 to 40 cm. Due to the influence of the wind gusts in the higher locations in particular (over 800 m a.s.l.) massive snow drift was observed. The total duration of the heaviest snowfall was from 5 to 6 hours.

The severe weather resulted in a complete closing of one of the main traffic routes in the country, the highway D1 connecting the two largest cities Prague and Brno, for the first time in history. The mentioned situation clearly illustrates the essential role of severe weather warnings for the road maintenance. In such case the outputs from the road weather stations and its sensors have only secondary role. However the classic weather forecast information is inevitable.

4. Significance of sensors and sophisticated systems

In contrary to the last mentioned situation the role of the road weather stations and its sensors is essential for forecast of the road state for the next 24 hours in typical anticyclonal winter weather. The weather is characteristic by little cloud cover, no precipitation and light breeze. In these situations it is possible that by prevailing the low air temperatures due to the advection of humid air masses from the near water surfaces to the body of the road the black ice build up occurs. (the state of the road prior to this phenomenon has of course its basic role).

The role of the data coming from the remote sites of the road weather stations and the surface sensors in particular is inevitable. The special forecasts can only seldom precisely describe this often very local development. Here the major role is the application of sophisticated system and the skills of the road maintenance dispatcher.



The presented image shows a situation with build up of icing on 63rd km of the highway D5 followed by a series of car accidents due to the road conditions.

5. Presentation of warnings

For effective dissemination of the warnings in the Czech Republic a multimedial information platform is applied.

Direct connection to the central dispatching centres

Internet

Teletext

SMS

RDS

Fax and telephone

A project of implementation of these information into the car navigations system is in progress. For a wide public the informations on severe weather conditions is presented on statutory TV and radio broadcasting stations and some others.

6. Conclusion

This paper was not aimed to describe the different severe weather elements and phenomena having effect on the roads. The main task was to emphasize on the role of the NMS integrated severe weather early warning systems as an essential complement to the sophisticated systems used on the roads.

On this place let me mention that the exchange of early warnings among the NMS of neighbouring countries is a great contribution to the quality of road weather forecasts as we experienced in several mutual projects in the past.

NEMEFO: NEural MEteorological FOrecast

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Abstract – Artificial Neural Systems are a well-known technique used to classify and recognize objects. Introducing the time dimension they can be used to forecast numerical series. NEMEFO is a “nowcasting” tool, which uses both statistical and neural systems to forecast meteorological data in a restricted area close to a meteorological weather station in a short time range (3 hours). Ice, fog, rain are typical events which can be anticipated by NEMEFO.

I. INTRODUCTION

Typical meteorological forecast systems base their methods on complex mathematical studies rather than large databases coming from satellites and ground weather stations. The approach of NEMEFO is different: it's a “nowcasting” system. A weather station collects meteorological data every fifteen minutes and stores them in a database. The system analyses these data and foresees their evolution up to three hours in advance. NEMEFO can be configured to forecast several parameters such as temperature, humidity, pressure, solar radiation, wind speed and direction and rain. It uses a weather station which samples these data at a given sampling rate. A statistical program, based on the Parzen method [3], evaluates the cross correlation among these parameters and selects the best groups, in the historical database, suitable to forecast the next three hours. This method is shown in section III. These data are used to train an artificial neural network [2], shown in section IV, able to forecast numerical series. The time is added to this network to allow us to evaluate a temporal evolution. The system has been tested on a five years database of actual data coming from an agricultural weather station. A set of data was not used to train the network but was used to test its performance. Results are shown in section V.

II. A SHORT HISTORY

The project begun with the goal to predict the ice formation on a mountain highway. The idea was to use a “data driven” approach to allow security systems to prevent the ice formation in advance. Unfortunately data driven systems need the “ice event” to estimate its occurrence and nowadays this information isn't available because no ice sensor is available on the market. Therefore we decided to use an analytical model to verify the condition of ice on the road. This model is based on six parameters:

Air temperature
Relative humidity
Wind velocity
Solar radiation
Road temperature
Precipitation

We decided to evaluate the evolution of these data to forecast the ice formation three hours in advance.

III. STATISTICAL ESTIMATOR

As we said in the introduction, the statistical tool's [7] goal is to choose the better predictors to predict the meteorological data. The concept used is that of entropy; the formula is the following:

$$e(x) = - \int_{-\infty}^{+\infty} \log(p(x)) \cdot p(x) dx \quad (1)$$

In this formula $p(x)$ is the Probability Density Function (PDF) of a random variable x . $e(x)$ is an index of dispersion that lies in the range $]-\infty, +\infty[$. Let Z be the vector of all the possible predictors that can be used to foresee the variable y (predictand). Now let X_1 and X_2 be two particular subsets of predictors taken from Z . The number of elements in X_1 and X_2 has to be the same. In order to establish the best set of predictors between X_1 and X_2 we calculated the following entropy difference:

$$\begin{aligned} d(X, y) &= e(X, y) - e(X) = \\ &= - \int \log P(X, y) \cdot P(X, y) dX dy + \quad (2) \\ &+ \int \log P(X) \cdot P(X) dX \end{aligned}$$

where $p(X, y)$ is the joint PDF of X and y and $p(X)$ is the PDF of X (the predictors). But the problem is that both PDFs are unknown, so that it's impossible to evaluate the integrals in (2). We circumvented this problem by estimating the unknown PDFs through the Parzen [3] method. This method estimates the unknown probability density functions making a sum of Gauss kernels, each one centred on a record of the historical database. The formula is the following:

$$P_x^*(X; D, \Lambda) = \frac{1}{n} \sum_{i=1}^n \prod_{j=1}^m \frac{1}{\sqrt{2\pi\lambda_j^2}} \cdot \exp\left[-\frac{(x_j - x_{ij})^2}{2\lambda_j^2}\right] \quad (3)$$

where,

- $D = \{X_1, \dots, X_n\}$: it's the observations' vector
- n : database dimension (number of records)
- x_i, x_{ij} : these are the j -th component of X and X_i
- Λ : standard deviation vector, $\Lambda = (\lambda_1, \dots, \lambda_m)$

Each standard deviation in Λ regulates the resolution of the estimator along the corresponding dimension.

In its turn this allows us to estimate – say – $d(X_1, y)$ and $d(X_2, y)$. The best between X_1 and X_2 is the one that gives rise to the smallest entropy difference.

For example for the prediction of the relative humidity one hour ahead, we found that the best predictors for the network were:

- Humidity value one hour before the forecast instant*
- Humidity value two hour before the forecast instant*
- Humidity gradient of the last four hours*
- Air temperature gradient of the last four hours*
- Air temperature value two hour before the forecast instant*

IV. ARTIFICIAL NEURAL NETWORK

A neural network [1], considering the timing evolution of these parameters, seems to be the best approach to foresee time series data and the probability of ice formation.

The system profile can be modelled as the output of some dynamic system, influenced by weather variables, time and other environmental variables. A neural network with feedback can simulate a discrete time dynamically system. The general feed-forward topologies with weights sharing can represent feedback connections by unfolding in time the basic network. Of course using this technique, feedback can be followed for a finite time (also arbitrary large). In this way general feed-forward networks can simulate the dynamic systems, but only for their transient behaviour. It's necessary to define a network topology (*equations and connections*). The relation between the network input and output depends on several weights that can be modified. Then we must fix a *training rule* in order to adjust the weights and, consequently, to reduce the difference between the network output and the real value (*target*). We have used a feed-forward network with three layers:

Input layer

Hidden layer (5 neurons)

Output layer (1 neuron)

Each neuron has, as transfer function, the hyperbolic tangent function

$$\tanh(x) = \frac{\exp(x) - \exp(-x)}{\exp(x) + \exp(-x)} \quad (4)$$

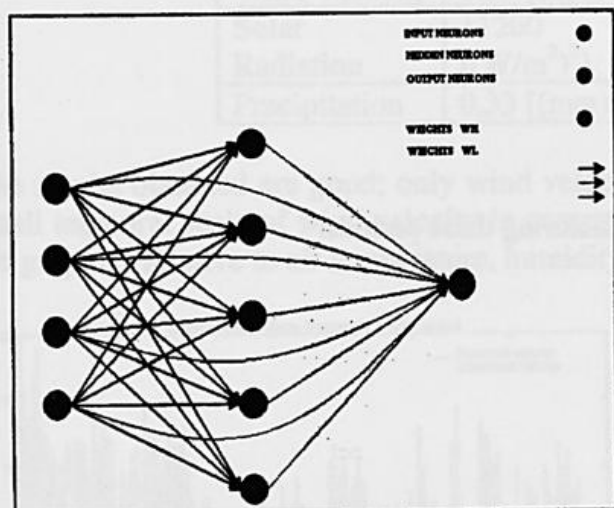


Figure 1: Neural network scheme

We decided to use backpropagation rule to train the network. In this method we choose the weights in order to minimize the square error on training set

$$E = \sum_{t=1}^T E(t) = \sum_{t=1}^T \sum_{i=1}^n 0.5 \cdot [\hat{y}_i(t) - y_i(t)]^2 \quad (5)$$

The singularity of backpropagation [2] is how this expression is minimized. First of all we fix the weights of the network. It's usual to choose random numbers between -0.1 and 0.1. Then we calculate the network output $\hat{y}(t)$ and the errors $E(t)$ with the previous weights. After we consider the derivative of E as to the weights:

$$F_{-}W_y = \sum_{i=1}^I F_{-}net_i(t) \cdot x_j(t) \quad (6)$$

In this way we adjust the network weights, moving towards the opposite direction to the gradient. The formula used is the following:

$$W_y = W_y - learning_rate \cdot F_{-}W_y \quad (7)$$

The first step has been to simulate a real meteorological station using real data both for training and test phase. We used the database from the meteorological station of Spilimbergo (PN), Italy. The parameters observed are the following:

Time

Air temperature (2 meters of altitude)

Relative Humidity

Wind velocity

Terrain temperature (10 centimetres of depth)

Solar radiation

Precipitation

The sampling is hourly. We have collected the data during these periods:

January – February (1998)

November – December (1998)

January – February (1999)

November – December (1999)

January – February (2000)

November – December (2000)

January – February (2001)

November – December (2001)

January – February (2002)

We used 10056 training patterns, hourly sampled from January (1998) to February (2001) whereas other 2880 patterns sampled from November (2001) to February (2002) were used for test.

V. RESULTS

In order to judge the forecast quality, we calculated the VRC (Variance Reduction Coefficient) in this way:

$$VRC = \frac{\frac{1}{N} \sum_{i=1}^N (\hat{y}_i - y_i)^2}{\frac{1}{N} \sum_{i=1}^N (y_i - \bar{y})^2} \quad (8)$$

Numerator represents the mean square error whereas denominator stands for the variance of the training set. VRC is very meaningful as it puts in evidence how much meteorological parameter variability is explained by network inputs used. The more VRC is small the more the prevision is careful. In the following table we reported VRC values for each prevision and each meteorological parameter.

Table 1: VRC values for each prediction

	VARIANCE	VRC 1 hour	VRC 2 hours	VRC 3 hours
Air Temperature	27,99 [(°C) ²]	3,6%	8,7%	13,9%
Relative Humidity	479,88	4,7%	13,2%	20,9%
Terrain Temperature	11,37 [(°C) ²]	0,026%	0,063%	0,082%
Wind Velocity	1,39 [(m/s) ²]	34%	48,7%	60%
Solar Radiation	11200 [(W/m ²) ²]	5,6%	13,2%	19,8%
Precipitation	0,33 [(mm) ²]	7,2%	14,2%	19%

The results obtained are good; only wind velocity case isn't satisfactory. This bad result is due to the small temporal scale of wind velocity in comparison with the forecast interval. As example, we report the graphics relative to air temperature, humidity and rain forecasts.

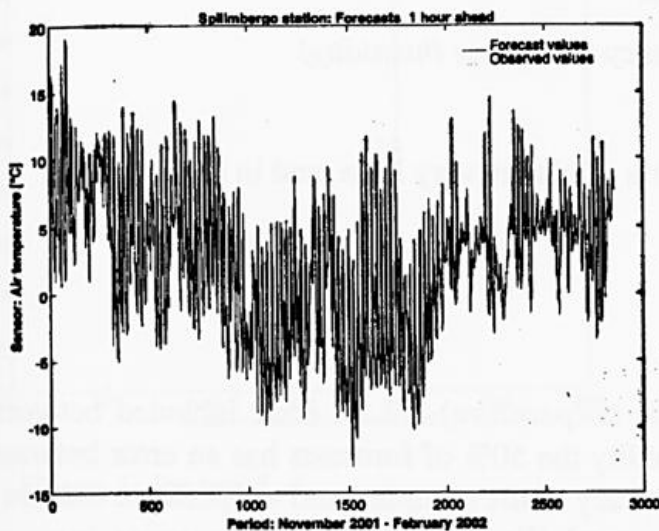


Figure1: Air temperature forecasts 1 hour ahead

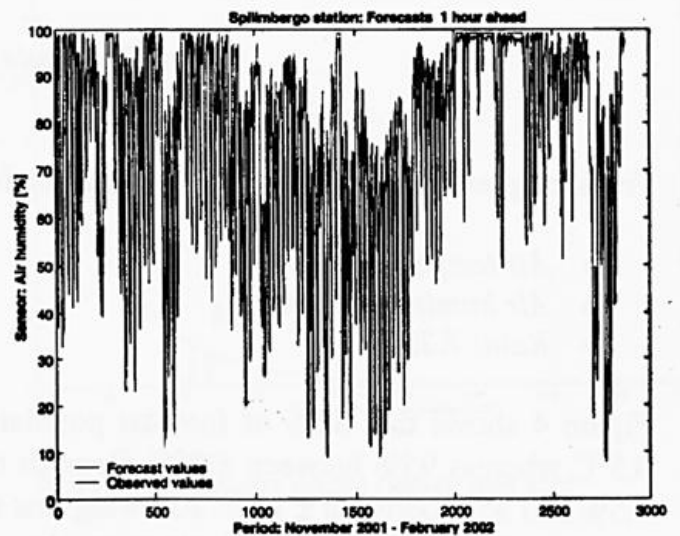


Figure2: Air humidity forecasts 1 hour ahead

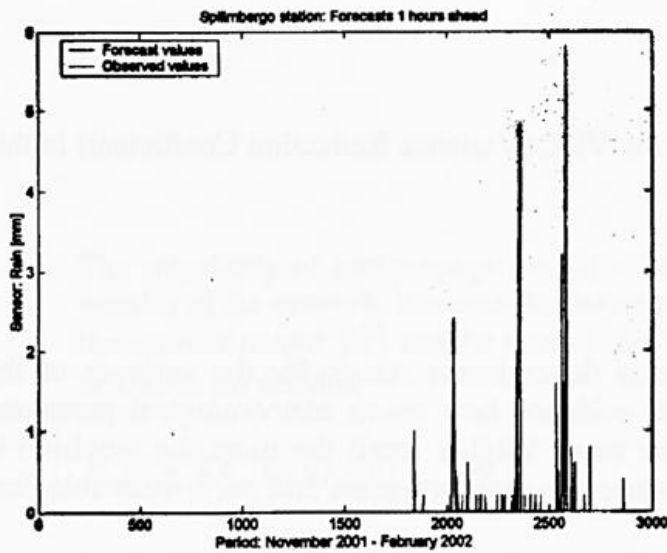


Figure3: Rain forecasts 1 hour ahead

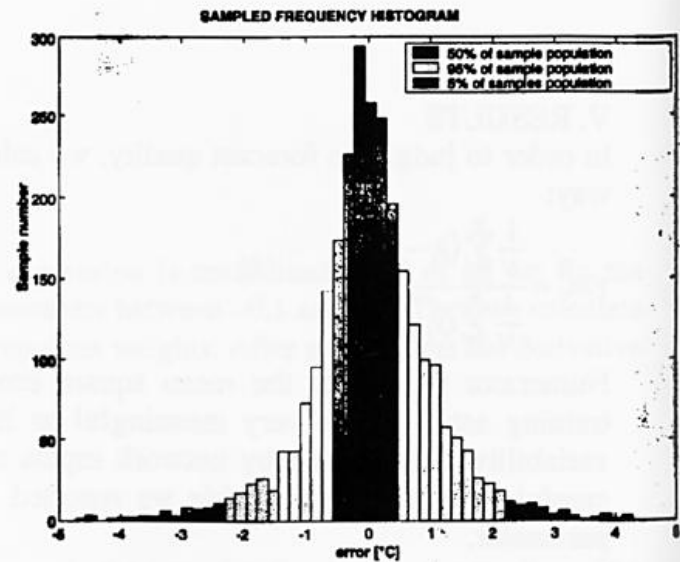


Figure4: sample frequency histogram (temperature)

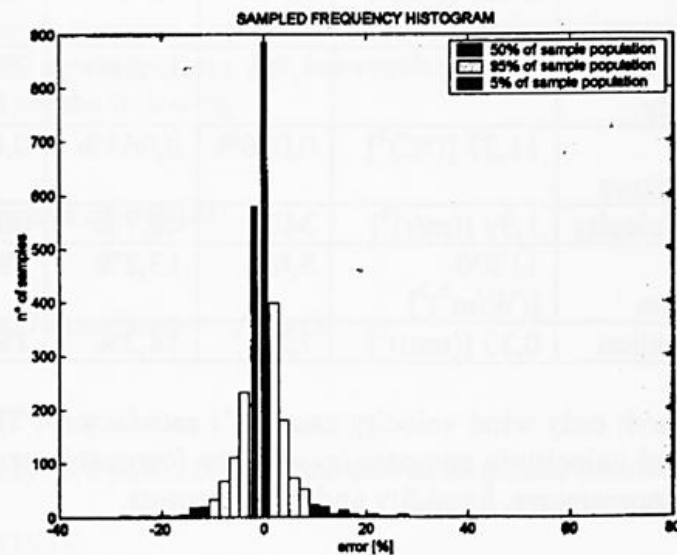


Figure5: sample frequency histogram (humidity)

From the previous graphs we can see that the forecast's errors are very little, and in particular:

- Air temperature: 3.6%
- Air humidity: 4.7%
- Rain: 7.2%

Figure 4 shows that 50% of forecast population (*air temperature*) has an error included between $\pm 0,5^{\circ}\text{C}$ whereas 95% between $\pm 2^{\circ}\text{C}$. Regards to humidity the 50% of forecasts has an error between $\pm 4.5\%$ and 95% between $\pm 10\%$. Knowing that the accuracy of the humidity and temperature sensors are respectively $\pm 3.5\%$ and $\pm 0.5\%$, these results are very good. We can improve performances, increasing the training patterns number. As regard as the evaluation of ice formation probability we used an

analytical model [7]. This model calculates the amount of ice that is present on the road at the end of the forecast period. It needs receiving the forecast values of the meteorological parameters by the forecast neural system described in the previous paragraph. Four modules make it up:

1st module: it [4,5,6] calculates water plus ice mass balance on the road.

2nd module: it [4,5,6] reckons water minus ice mass balance on the road. This modulus is used only when the road temperature is 0°C. In fact only in this case it's possible the water change phase. As far as this process is concerned it's very important the energy balance on the road.

3rd module: it calculates the snow heap and the snow melting on the road.

4th module: this module, according to the air – asphalt interface temperature, integrates opportunely the previous modules. On the starting integration instant we used the observed meteorological parameters whereas on the last instant we used that one forecast.

As we hadn't the interface temperature in the database, we calculated it with the following formula,

$$T(z) = T_0 + \left[\frac{T_{210} - T_0}{210 \cdot Rapp} \right] \cdot z \quad (9)$$

where,

T_0 : road temperature (10 centimetres of depth)

T_{210} : air temperature (2 meter of altitude)

Putting $z=10$ in the formula, we get the interface temperature. The coefficient *Rapp* represents the ratio between asphalt and air thermal volumetric capacity. *Rapp* is necessary because we aren't in a homogeneous system. We tested the model on the period November (2001) – February (2002).

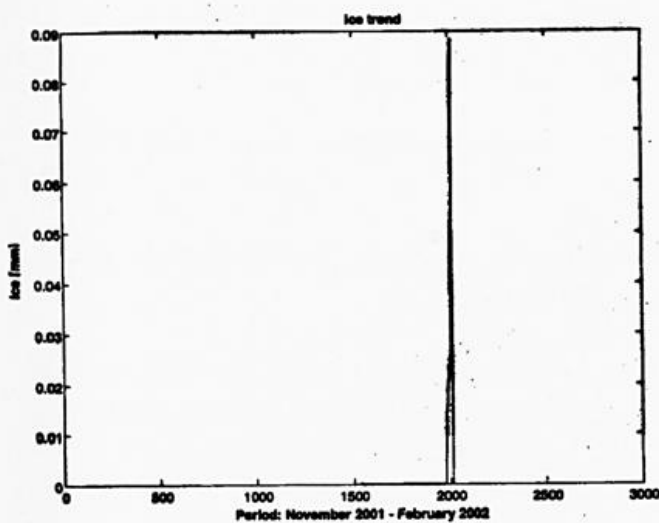


Figure 6: Ice trend

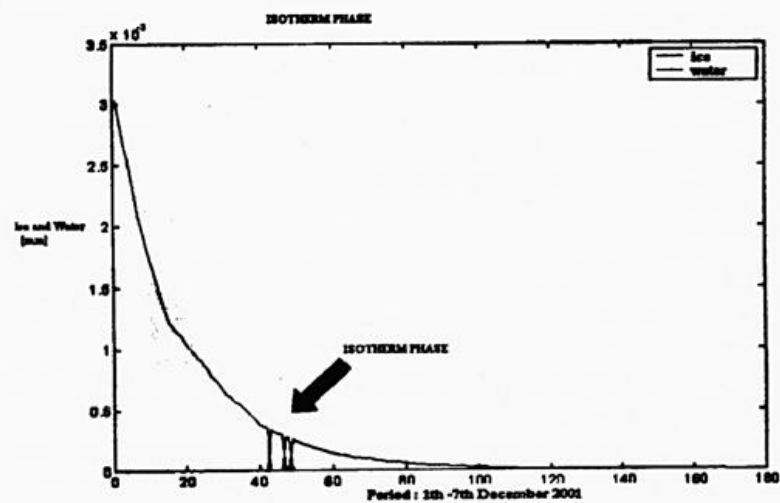


Figure 7: Isotherm phase (water and ice)

VI. CONCLUSION

Nowcasting seems to be a new interesting topic in meteorological forecast. The possibility to have an accurate estimate of the weather conditions in next three hours can be a useful tool for several situations, such as ice on the road, fog, rain and so on. A powerful software, NEMEFO, was shown in this paper. It's now used in some prototype weather situations in Italy and gives a good performance. A reduced version is visible 24 hours a day at www.neuronica.polito.it. Next version of NEMEFO will integrate the forecast of a network of stations to evaluate weather forecast for a large area.

ACKNOWLEDGEMENTS

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IMPROVEMENTS IN ROAD FORECASTING TECHNIQUES & THEIR APPLICATIONS.

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Background

The Met Office has been providing guidance to local administrative bodies within the UK on winter road conditions through its OpenRoad service for about 15 years. Ice and snow on roads is considered a particular concern as a risk to driver safety and general traffic flow. The Met Office currently provides forecasts via its distributed local forecast offices. These are normally delivered to customers at around midday for the night ahead based upon the latest Numerical Weather Prediction (NWP) guidance available to meet this delivery time (06Z). After delivery of this initial forecast the performance of the forecast is monitored against the observed evolution combined with later NWP guidance and, where divergent, a warning and an amended forecast are delivered to customers. This is done for the nationwide network of about 600 road sites many of which have automated observations available that allow real time monitoring and post-event verification.

The forecasts of road ice are generated by coupling the NWP guidance to a local road ice prediction model that outputs a forecast of road surface temperature and road state. The quality of the product generated by this arrangement has two sources of degradation or error: the error in the NWP guidance for synoptic scale evolution; e.g. the passage of a front is mistimed; and the error in the prediction of local road conditions by the local road ice model due to, for example, inadequate description of the surface physics. Forecasters therefore occupy a role of quality control and error mitigation to add value to a raw product.

Until the winter of 2000-01, forecasters at the distributed forecast offices ran the road ice model by-hand using the NWP guidance as input together with their own local knowledge. Hence the quality control was implied as inherent within the model process. From the winter of 2001-02, following development of an enhanced road ice model, the running of the road ice model was centralised with the NWP, to Met Office HQ to generate a forecast 1st guess product. Consequently, the role of the forecaster in the distributed forecast offices changed from one of forecast creation to one of quality control, amendment and subsequent monitoring.

Although the NWP capability of Met services has improved steadily over the past decade, the rationale behind this fundamental change in forecaster involvement was the much more rapid progress made in the performance of road ice prediction models. This is because road ice prediction models are relatively simple surface exchange models and the identification & correction of errors and deficiencies is more tractable. In 2000 this development coincided with a need to streamline the production of Met Office road ice forecasts to make the service

to customers more cost effective. A by-product of this change in the road ice forecast process was that the value added by forecasters to the raw "automated" product could be measured and therefore the impact of improvements in the NWP or road ice modelling better quantified.

Forecaster Added Value

The main variable used to assess the quality of the OpenRoad service is the minimum road surface temperature, as this is indicative of the worst road state during the night. Figure 1 shows mean and RMS errors for the minimum road surface temperatures over the whole OpenRoad network since 1996-7, comparing initial model forecasts with forecaster intervened forecasts.

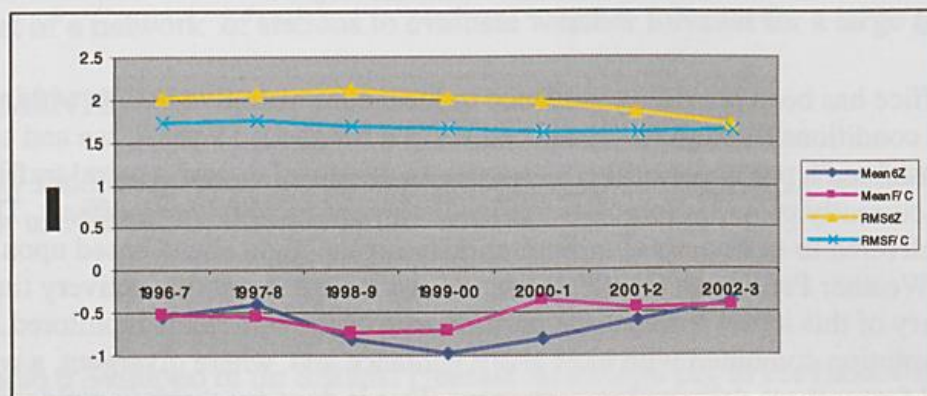
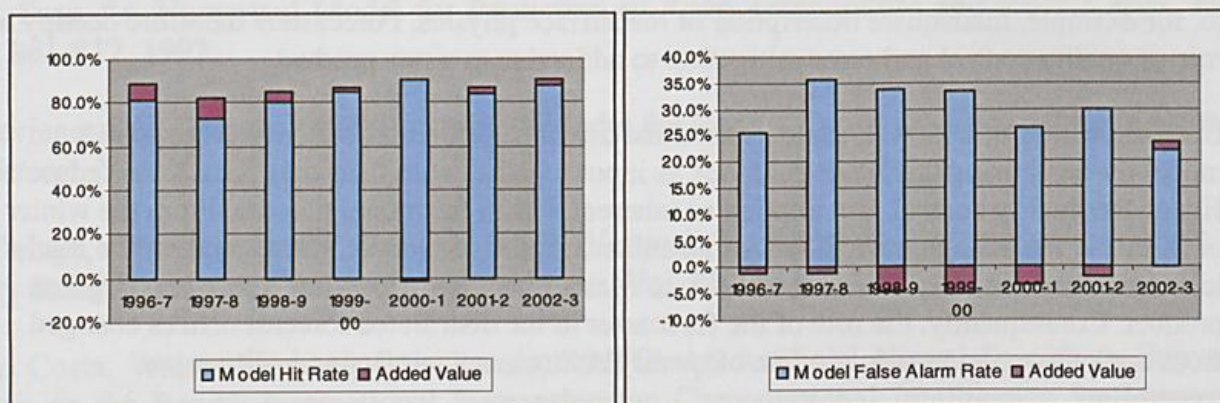


Figure 1 - Mean and RMS error for minimum road surface temperatures since 1996-97.

Over the whole period, the RMS error for forecaster issued forecasts has improved slightly from ~1.75°C to 1.6°C. Since 1998-9, the RMS error in the automated 1st guess has fallen from 2.1°C to 1.7°C. Similar improvements can be seen in the ability to forecast ground frosts (i.e. RST ≤ 0°C), as measured by Hit rate and False Alarm rate skill scores as seen in Figures 2 & 3.



Figures 2, 3 - First guess hit rate and false alarm rate, and improvements made by forecasters (target HR is >87%, target FAR is <30%). Note that forecasters generally able to improve hit rate and reduce false alarms, though could only increase hit rate last year at expense of FAR.

A number of developments have lead to these improvements, the more important of which are:

- In 1999-2000, the Site Specific Forecast Model (SSFM), rather than UK Mesoscale model was used to drive the road ice prediction model. This local NWP model provides descriptions of non-linear local physics particularly that of sub-gridscale heterogeneous landuse and orography enabling the site-specific impacts on the lower boundary evolution to be better estimated. The capturing of the effects of complex terrain has particular benefit to road ice forecasting as forecast sites tend to be at locations significantly affected by small scale orographic processes, e.g. frost hollows.
- In 2000-01, the centralisation of the 1st guess production system was brought in. This included the introduction of a new road ice prediction model, MORST, that addressed many of the known deficiencies in the road ice prediction model, e.g. an improved surface exchange scheme that significantly reduced general cold bias; better representation of surface water/snow budget. A basic Kalman Filter correction was also introduced to downscale to local processes further.
- In 2001-02, the utilisation of the sophisticated two-stream, multi-band Edwards-Slingo radiation scheme within the road ice modelling package. The main benefit of this scheme is the inclusion of cloud radiative interactions in both the long and short wave regions.
- In 2001-02, an upgrade to MORST was introduced, that included parametrizations of the turbulent, heating and water-removing effects of traffic and 'urban warming'. This addressed a cold bias seen at many city-centre locations. Also adaptive site-specific sub-surface diffusion coefficients, derived from the automated roadside observations, were introduced to take account of differing road constructions.
- In 2002-03, a revised and more sophisticated "adaptive" Kalman Filter correction was introduced to correct for systematic biases in forecast temperature.

Areas Where Forecasters Add Value.

Road-side forecast sites are not as well sited as standard synoptic observing sites in that, as mentioned previously, the terrain is often not flat, can be surrounded by buildings or trees, and the roads they are adjacent to have cars running up and down them for example. Unless these are accounted for, there will be systematic errors in any forecast. Accommodation for this can be done intuitively by forecasters, modelled explicitly or some combination of the two. The use of the SSFM data to drive the ice prediction model takes some account of the local terrain and land-use. The introduction of traffic and urban parametrizations has addressed missing physical processes in the ice prediction model, i.e. the extra turbulence generated by moving traffic, the heat emitted from car engines, the removal of road water and snow by tyres and the downward LW heat flux emitted by buildings. The Kalman Filter has been used as a further downscaling tool so that other systematic biases caused by very local effects (e.g. local shading, sites on bridges, traffic jams, proximity to lakes) which are either poorly represented, not represented at all or we don't know how to represent in the ice prediction model can be mitigated.

Due to improvements in the quality of the road ice prediction modelling described above, forecasters are only realistically still able to enhance the site-specific products when there is a systematic bias, or an error (temporal or magnitude) in the large-scale forecast, i.e. the data that used to drive the road ice prediction model. This is because surface temperatures are sensitive to cloud cover, so timings of synoptic scale systems and in particular frontal zones are important. Consequently they are an area where forecasters can significantly improve the automated forecasts. However ongoing long term improvements in NWP capability (e.g. 3D-

VAR, New non-hydrostatic dynamics scheme) mean that this is becoming less frequent and further improvement is expected to filter into the NWP modelling system with future enhancements such as the introduction of 4D-VAR data assimilation.

Forecaster benefit can also be made by ensuring that the product is physically consistent and appears realistic such as adding value at sites that are particularly poorly sited. For example there is one UK prediction site that is shaded from direct sunlight by a number of large trees, so daytime temperatures are often much lower than forecast centrally, especially on cloud-free days. The Kalman Filter "learns" about this bias and reduces the daytime temperatures accordingly. Unfortunately it even corrects this bias on cloudy days when the shading of the trees has little effect (there being little direct sunshine). Through experience forecasters have learned that on cloud-free days, the bias-corrected forecasts are better at that site, but that the uncorrected forecast is better when it is cloudy or overcast.

Forecasters can sometimes add value in marginal cases, where the forecast minimum temperature is close to 0°C. It generally costs more not to salt an icy road (as there are more accidents, disruption etc) than to salt unnecessarily, so forecasters will tend to have a pessimistic bias at the expense of a few extra false alarms. In past years, forecasters have been able to off-set these extra false alarms against others where the 1st guess was overly pessimistic, and delivered a lower overall FAR than the raw forecast. Last year, there were sufficiently few of these 1st guess false alarms that forecasters were not able to do this.

Can We Predict When Forecasters Won't Add Any More Value?

The above results suggest that the limit of capability with the road ice prediction model is very close to being reached because the errors, as demonstrated by perfect prognosis statistics, are dominated not by processes that are not captured or understood but by ancillary information that is either not available or highly complex to interpret and validate. Furthermore it is very costly to collect and maintain. For example, the vector positioning of obstacles that impact on the radiation budget through shadowing and/or the turbulence budget through wake dynamics that also requires detailed knowledge of obstacle shape. Hence development focus in more cost effectively spent on reducing the error in the large scale forecast data used to drive any road ice prediction model. Three ways of achieving this present themselves:

- Improve the large scale NWP system through better data assimilation techniques, such as 4D-VAR assimilation, as well as increased horizontal and vertical resolution in order to resolve the local physical processes that are currently sub-gridscale. This assumes that processes that remain sub-gridscale continue to be adequately parametrized.
- Use the known errors in the large scale NWP system to infer extra useful information. This can be done by running ensembles of the NWP forecast model to test how sensitive an individual forecast is to errors in variables that are important to road ice prediction, such as cloud impacts on the surface radiation budget.
- Central forecaster modification of the large scale NWP fields in a meteorologically consistent way prior to input into the road ice prediction model.

1) Improvement of the large scale NWP system – continual and long term research & development.

The Met Office intends for the UK domain to have an operational 4km NWP Mesoscale model that should outperform the local schemes within the current SSFM by 2005 and an operational 1km Mesoscale model by 2007-08. For the European domain an operational 12km Mesoscale model is intended by summer 2004.

2) Ensembles and Confidence Estimation.

The use of ensembles is attractive because it enables confidence limits in the forecast to be estimated in order to target forecaster intervention. In the example below, for an eight member ensemble of SSFM simulations there is a reasonable spread in minimum temperatures between the ensemble members, but since the worst case ensemble member stays well above freezing, it is unlikely that a forecaster will add much to the decision on whether to salt or not. If this case had happened slightly later in the winter and temperatures were ~4C cooler, then a forecaster may well be able to have some impact.

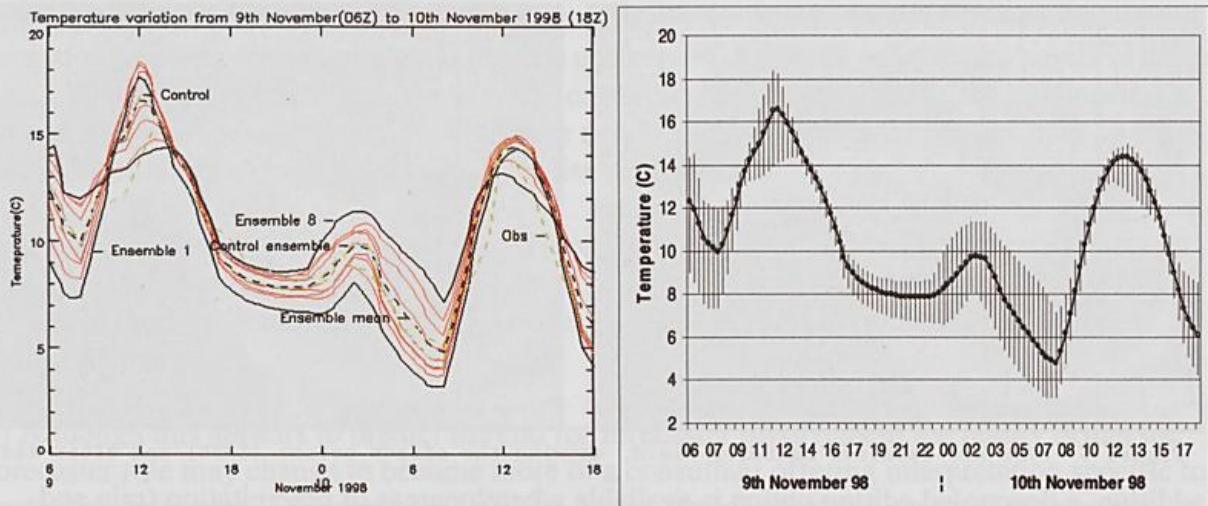


Figure 4 - MORST forecasts from an ensemble of SSFM runs, and an indication of forecast 'confidence'.

Despite these attractions the technique is computationally expensive and to provide and improve disseminated forecasts it needs a reliable mechanism to choose the likely evolution to drive any road ice prediction model.

3) Central Forecaster Modification.

The use of central forecaster modification of the large scale NWP fields in a meteorologically consistent way provides the most tractable short-term way of reducing the error in the large scale forecast prior to input into the road ice prediction model. It also provides a mechanism for reducing or eliminating downstream forecaster intervention on the road ice prediction forecasts. The Met Office has developed an application that allows forecasters, centrally within the Met Office National Meteorological Centre, to reposition and change the intensity of synoptic features such as fronts and depressions as well as clouds and precipitation. Called "on-screen field modification" (OSFM) it allows NWP model fields to be altered, via potential vorticity inversion, in a meteorologically consistent way. A number of modification

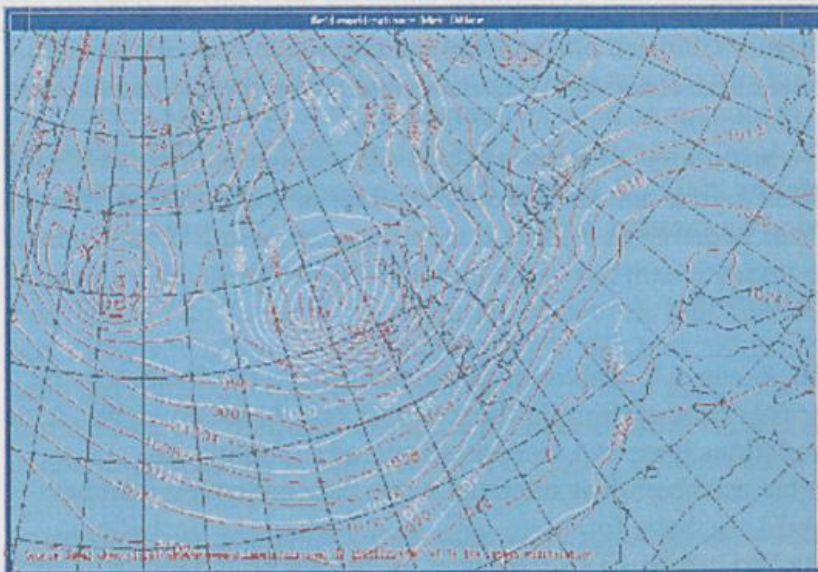


Figure 5 - Surface pressure field, showing original (white) and modified (red) surface pressure pattern

methods allow the forecaster to ensure the changes proposed are meteorologically consistent throughout the atmosphere. A “time-link” feature enables modified fields to be propagated in time, allowing an optimised method of modifying a number of forecast periods at once. Modification to the precipitation and humidity (surrogate cloud) fields are moved along with the dynamic fields, so a coherent structure is retained. In

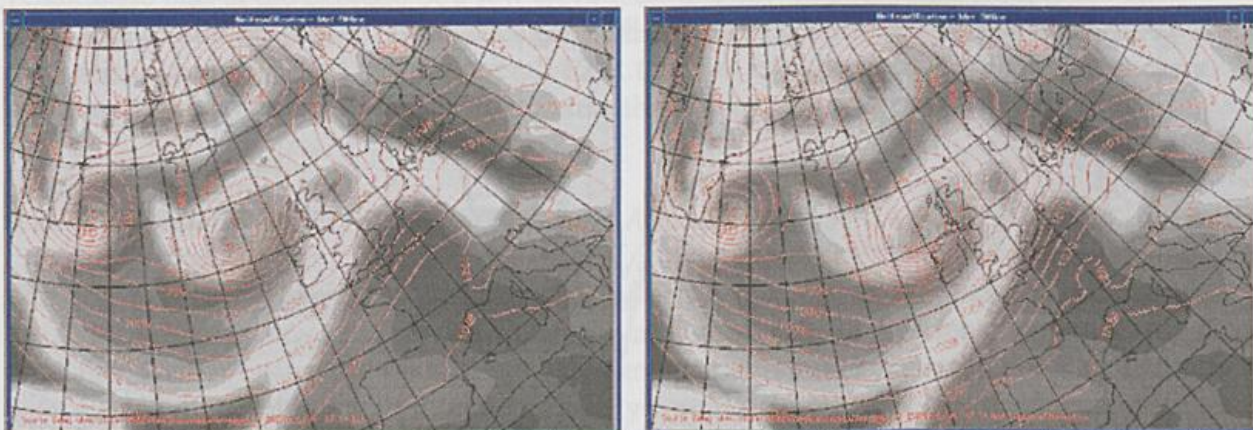


Figure 6 - 700 hPa relative humidity field, showing the effect before (left) and after field

addition, a decoupled editing option is available whereby areas of precipitation (rain and snow) can be moved, pasted in or cut out, or the rain/snow divide in existing areas of precipitation can be moved. This allows the forecaster to override the NWP output, increasing orographically enhanced rain or reducing precipitation in the light of experience with the model. Also when the dynamical fields are modified via potential vorticity, a new consistent wind field is generated automatically. Examples are shown in Figures 5 & 6.

The OSFM methodology, as it is inverting the potential vorticity field, is limited to changes to synoptic scale features. Applying it to Mesoscale and local scale phenomenon such as cloud introduces an imbalance into the boundary layer. This can be brought back into equilibrium and continue to propagate the changes made by the OSFM system by coupling the output to the SSFM. As an added benefit this coupling takes advantage of the local physical schemes encompassed within the SSFM. To take full advantage of this methodology requires the subsequent downstream coupling of the field modified SSFM output to the centralised ice prediction model. This is currently under development and is expected to become operational in 2004 in preparation for the 2004-05 northern hemisphere winter.

Conclusions

The conclusions are summarised below:

- a) Accuracy of ice predictions is dominated by two errors: the error in the large scale synoptic evolution (NWP) and the error in the local diagnosis of road ice (ice prediction model) from the large scale synoptic evolution.
- b) The performance of ice prediction models, though easier to improve, have reached the limit of cost-effective technology.
- c) Further, due to the recent improvement in ice prediction models, forecasters mainly add value to road ice forecasts by correcting errors in the large scale synoptic evolution.
- d) Hence to make further improvements and fully open the possibility of semi or full automation the focus of work needs to turn to methods of either correcting or mitigating the occasional errors in the large scale evolution (NWP).
- e) Improvement in NWP to reduce the occurrence of errors in the large scale synoptic evolution is a long term incremental process unlikely to deliver benefits in the next five to ten years. This is because although we have the capability to use high resolution 3D models we do not yet know enough about modelling the newly resolved processes and the data assimilation methodology required to optimise performance.
- f) The use of ensemble techniques to gain forecast confidence information in order to target forecaster intervention, though scientifically tractable, is too computationally expensive. Central forecaster field modification provides an alternative short to medium term way forward.
- g) Although this appears to predict the end for forecaster involvement the reality is that the forecaster role may change to become more of a consultant offering interpretation specific to particular customers. For example focussing on the outcomes of the ice prediction service and helping customers decide how to deploy their salting vehicles and where and at what time is the most optimum to salt.

Providing an Optimized Dataset for Road Weather Forecasts

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Abstract

The concept for „Objective Optimization“ describes a system to integrate different sources of weather information into one single local forecast product. Two main objectives are the automatic and continuous relaxation of the forecast guidance given by numerical weather prediction (NWP) models towards the actual observation and the automatic integration of nowcasting products. The system is currently under development at the Deutscher Wetterdienst (DWD).

1. Introduction

Generally, the process of local weather forecast is based upon the assessment of a large variety of different point forecasts from numerical model output, observational data, and nowcasting products, mainly from remote sensing techniques such as radar and satellite. In order to issue a single forecast all these data sources have to be evaluated, the most valuable information has to be identified, and different data has to be combined by the forecaster into one final forecast product. By doing so, the forecaster includes his/her meteorological experience, his knowledge of the synoptic situation and of the specific site characteristics. Some of the necessary steps in achieving the local forecast can be grouped into the following activities:

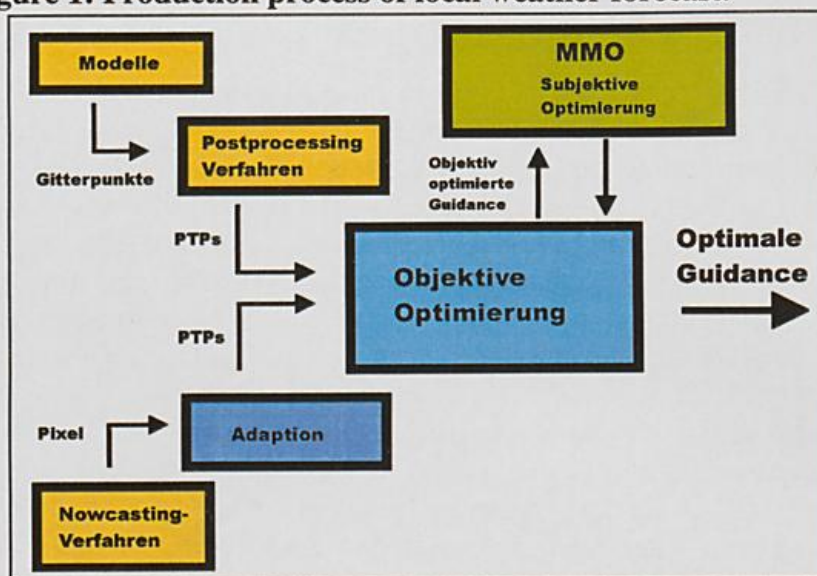
- Selection of a guidance from numerical weather prediction (NWP):
At DWD several approaches are currently being used to derive point forecast guidance from NWP results. Two statistical postprocessing schemes, namely Model Output Statistics (MOS) and a Kalman filter, are applied to the forecast data of the global atmospheric model (GME) of DWD. The Kalman scheme is also applied to the results of the high resolution local model (LM). Additionally, the unprocessed grid point information of both models is provided as Direct Model Output (DMO).
- Correction of NWP guidance on the basis of recent observations:
NWP guidance is provided on the base of two model runs for initialization times at 00UTC and 12UTC. The postprocessing results are generally available around six hours after the initialization time. In the meantime, observational data was received which has not been yet assimilated into the weather guidance.
Part of the forecaster's work is the comparison of NWP guidance to the observed development and a possible correction towards the observations. In a recent paper describing the forecast work at the Canadian Meteorological Center it has been estimated that a considerable part of the forecasting work consists in the manual merging of the latest observations (Landry *et al.*, 2003).
Additional nowcasting products on the basis of remote sensing data (e.g. radar and satellite) are routinely being included in the assessment of local weather. Generally, these data sources provide pixel information with a spatial coverage where no conventional observations are available. Loops of subsequent images allow an immediate spatial extrapolation and a good estimate of corrections necessary due to advection.

The assessment of all available data types, the required work in decision taking and merging of information is a challenging task. It requires usually considerable personal resources. The

manual correction by an experienced forecaster can not be omitted, in particular in the context of a high quality forecast input needed for the initialization of the energy balance model. However, the time restrictions in issuing a forecast for developments within the next 1 to 3 hours for a large number of sites to be processed (e.g. 450 road weather monitoring stations in Germany) do set a clear limit to the potential of even the most experienced meteorologist. Hence, any support in minimizing the manual workload appears helpful. Less manual work allows the forecaster to concentrate on phenomena which are wrongly forecast and cannot be corrected automatically.

The Deutscher Wetterdienst (DWD) is planning to support the forecast process by the automatic production of one single guidance, so-called optimal guidance. These corrections are applied by using a set of plausible algorithms (objective optimization). Finally, the guidance data resulting from these correction process undergoes a final manual quality check and optional further corrections (subjective optimization). The overall process is illustrated below (Figure 1).

Figure 1: Production process of local weather forecast.



The features of the system „objective optimization“ currently under development are:

- Selection of guidance information:
This can be considered as a suggestion for the selection of the various guidance types described above. The selection represents the past observed skill of the different data sources. The skill of the different data sources is subject to the continuous operational verification of local weather forecasts at DWD.
- Continuous relaxation of numerical weather guidance towards observations:
This is intended to ensure a consistent transition between the latest observed weather element and the corresponding element within the guidance data.
- Temporal extrapolation of observational corrections to future time:
The corrections applied at the time of the observation are extrapolated to correct the next time steps. This approach represents a trend forecast for these corrections. It affects the next few hours.
- Spatial spreading and extrapolation of synoptic information:
Pixel information from remote sensing data will be included to spread horizontally synoptic information. In addition, the displacement of these analysed patterns with time will include advective processes.

2. Relaxation of a guidance towards observation

The observed corrections of guidance data due to observed values are extrapolated to future time steps. The extrapolation is based on a structure function which attempts to describe the temporal autocorrelation in a simple way. The effect is illustrated in Figure 2.

$$W(t) = W_{\text{absolut}} * \text{EXP} (-(1/T_{\text{trend}}) * (t_{\text{guide}} - t_{\text{obs}})^S)$$

The exact shape of the structure functions can be customized by a few parameter to accomodate for the statistical characteristics (Weingärtner, 1987) of different elements (Figure 2):

- W_absolut: Absolutes Gewicht der Beobachtung
- S: Exponent (exponentieller Abfall bzw. Normalverteilung)
- T_trend: charakteristischer Zeitscale (Halbwertszeit bzw. Standardabweichung)

Figure 2: Temporal autocorrelation for different elements (2m temperature and mean sea level pressure at 18:00 UTC at one location).

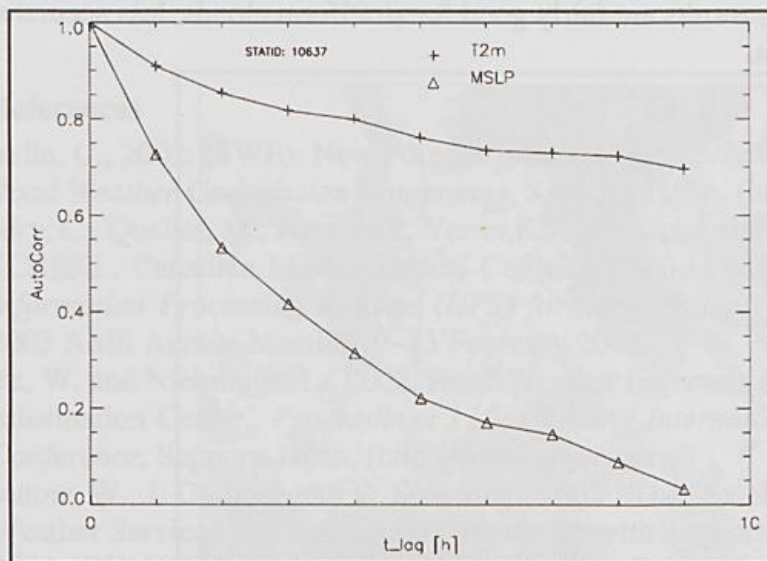
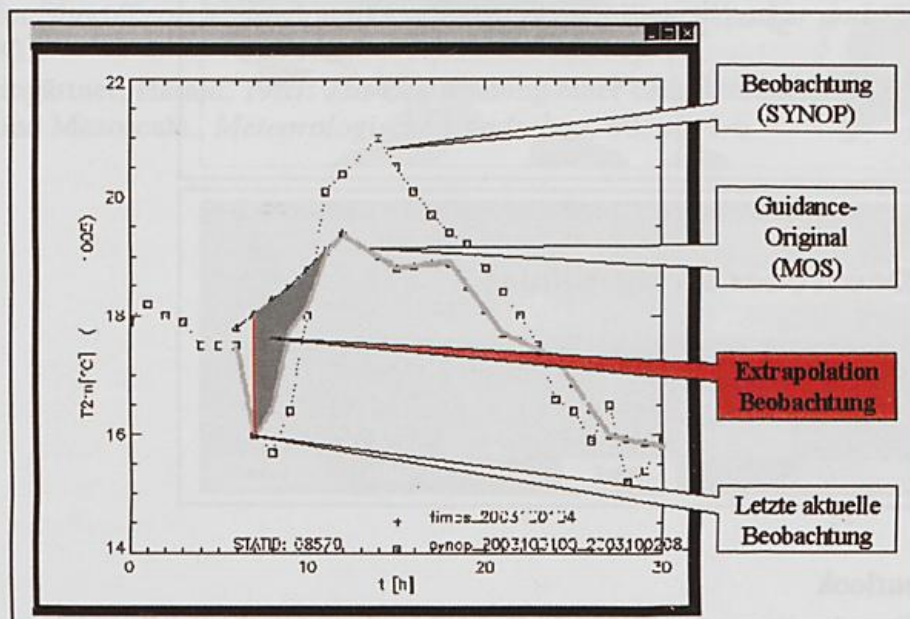


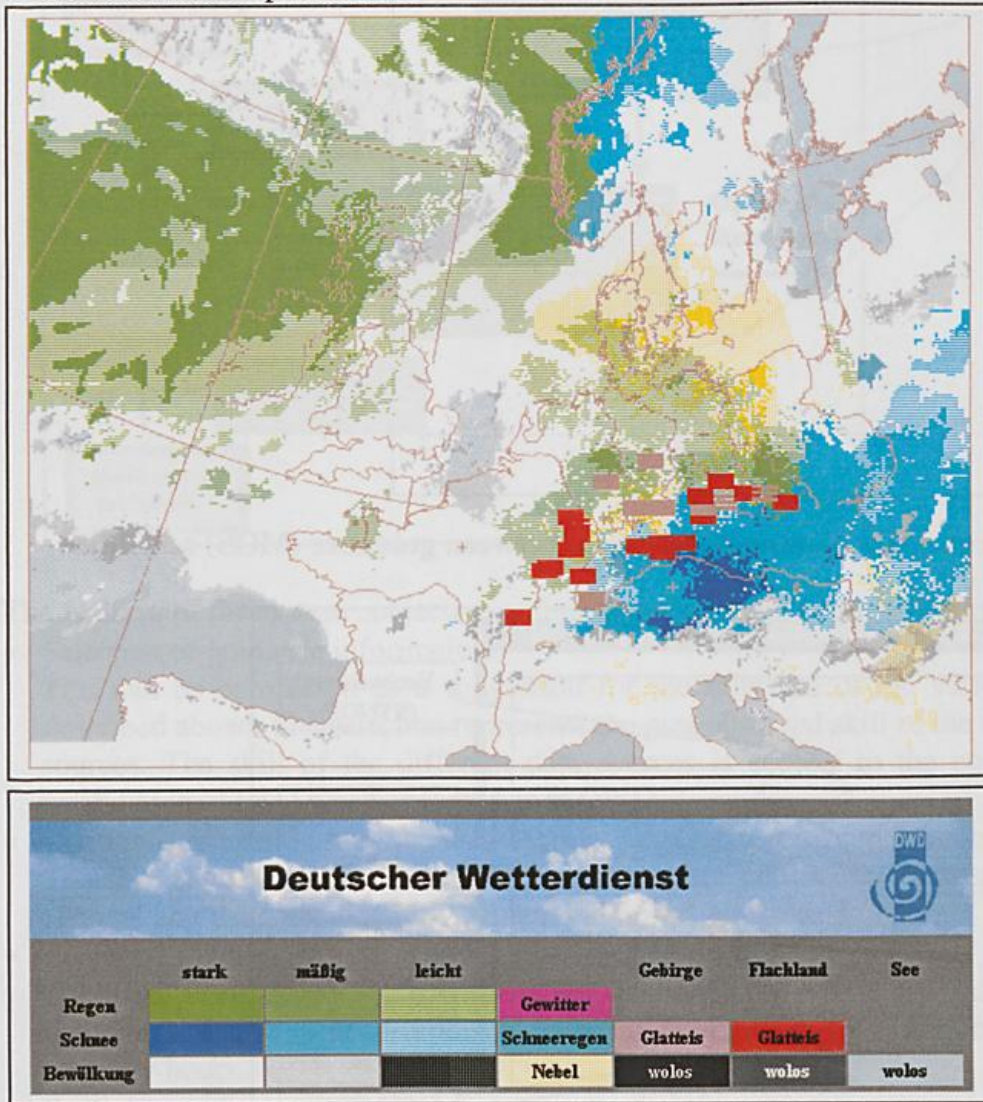
Figure 3: Temporal extrapolation of difference between guidance (MOS) and latest observed value.



3. Adaptation of nowcasting data

The extrapolation of local information into time is appropriate during synoptic situations, when there is little change. However, when there are e.g. air mass changes, nowcasting methods become important. A simple nowcasting method is the extrapolation of a current radar or satellite image. Thus, it is possible to advect weather information observed upstream. The nowcasting product to be included first in the „objective optimization“ is the so-called „satellite weather“. It combines satellite information and surface observations. This product has been presented in the context of road weather forecast before (Raatz and Niebrügge, 2002). An example of this product is shown in Figure 4. The synoptic situation between 13-14 January 2003 was determined by considerable precipitation with the phase changing from snow to rain causing the corresponding road icing conditions. The red symbols mark this situation in the vicinity of changing precipitation phase from snow to ice.

Example of a nowcasting product called „satellite weather“. The analysed product can be extrapolated up to 3 hours. The results are fairly good for stratiform clouds, less accurate for convective weather phenomena.



4. Summary and outlook

This paper describes the setup of a system, called „objective optimization“, which supports the production of surface weather forecasts at specific locations. The main potential of this system is expected in the following areas:

1. Support in selection the information from various sources ,
2. continuous automatic corrections of the NWP guidance due to recent observations,
3. providing the best possible guidance as input for further automatic production and further forecast methods
4. minimizing manual work: a) especially important for nowcasting, when there is little time and b) providing the opportunity to concentrate on the interpretation of the synoptic situation.

The Deutscher Wetterdienst plans to use the optimal guidance as input for the energy balance model to predict road weather in different ways:

1. as input to predict road weather for the next 24 hrs for an area (minor road network),
2. as input to predict site specific road weather for the next 24 hrs (highways, major road network),
3. as input to predict site specific road weather for the next 1 to 3 hrs.

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A coupled automatic road-weather forecasting system.

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1. Introduction

Automatic road-weather forecasting in Denmark started in the early 1990s with the development of a road weather model (RWM) as a joint project between the Danish Meteorological Institute (DMI) and the road authorities in Denmark. This development has been justified from the rapidly growing work related to the manual road weather forecasting by duty meteorologists at DMI. The present report describes the latest developments of the automatic prediction system for the great number of road weather locations in Denmark.

Automatic forecasts of road weather conditions has become possible due to the rapid development of computers in recent years. The RWM forecast tool is a numerical computer model which determines the local energy and moisture fluxes at the road surface. The final forecast parameters are water and ice/snow on the road surface. In practice the evolution of road surface temperature, temperature and dew point at 2 m height, cloud cover and precipitation are also vital parameters in order to forecast whether ice can be formed or persist on the road surface. This is because these weather parameters control the energy conditions and moisture evolution on the road. The developed model has been documented (Sass 1992; Sass 1997).

The weather parameters including precipitation, cloud cover, wind, temperature and humidity in the atmosphere are not forecasted by the RWM which computes the local road conditions. An atmospheric model at DMI, namely the operational numerical weather prediction model (DMI-HIRLAM) is used to predict the time evolution of atmospheric weather parameters which are transferred as input to the RWM. In this way the quality of the road weather forecasts depends on both the DMI-HIRLAM forecast and the RWM prediction.

Over the years it has become clear from operational experience (Kmit and Sass 1999; Sass and Petersen 2000) that the quality of the atmospheric weather input to the RWM is critically important. This feature is specifically addressed in the present report.

In the first years of operational road weather prediction the DMI-HIRLAM and the RWM were separate models. The RWM received new predicted values hourly from DMI-HIRLAM. In order to improve the exchange of data between the two models the RWM has recently been integrated into the framework of the atmospheric model. This allows in principle for a 2-way interaction between the two systems including use of observational data from the RWM system (e.g. temperature, dew point at 2m and precipitation from road weather stations). The new integrated forecasting system is quite

unique in the sense that it is perhaps the first operational system of its kind worldwide.

A brief overview of the new coupled forecasting system is given in section 2. Also methods to assimilate new data for cloud cover and precipitation are mentioned in order to highlight the developments related to the use of new data of importance for predicting the road weather. The new forecasting system has become operational at DMI in October 2003. The potential of the system is illustrated in section 3 by a forecast example where the atmospheric transport processes are of vital importance for the prediction. Finally some concluding remarks are presented in section 4.

2. A coupled forecasting system

DMI-HIRLAM (Sass et al., 2002) is the operational atmospheric model for short range weather prediction at DMI. HIRLAM stands for High Resolution Limited Area Model. This means that forecasts are made for a limited part of the globe. The new system combining DMI-HIRLAM and the RWM is called DMI-HIRLAM-R. Figure 1 shows the model area of the operational DMI-HIRLAM-R covering Denmark and surrounding areas. It turns out that an area of this size is needed if it is taken into account that the information from meteorological data may spread over a large distance during 6 hours or more relevant for road-weather forecasts. Currently the atmospheric prediction is carried out in a model grid with 40 vertical levels and 82×92 grid points in the horizontal directions, with a resolution of 0.15° . At the geographical boundaries DMI-HIRLAM-R receives the necessary time dependent atmospheric information from a host model which is another operational model (DMI-HIRLAM-E) using the same horizontal resolution, but operates on a larger model domain.

Technically, the coupling of DMI-HIRLAM and the RWM means that the RWM operates as a model component of DMI-HIRLAM. The coupling is active every time step of DMI-HIRLAM. The virtues of the atmospheric model is that it can transport (advect) heat and humidity from one location to another. This process is directly linked to 'changing weather' at a given place.

The challenge is to assimilate observational data into the atmospheric model in order to provide the best possible weather input to the RWM. The DMI-HIRLAM system is already having an advanced system for assimilating atmospheric observations (Sass et al. 2002), but efforts are being devoted to assimilate additional new information on cloud, precipitation and surface data prior to the time of the RWM prediction. The new observed data are not inserted directly into the atmospheric model at a given time because the data and the model state are most often not in a complete 'balance'. The observations sometimes represent local features which one cannot expect the atmospheric model to fully represent. Instead there is a risk that a direct insertion of information into the model leads to undesired unsteady behaviour ('noise') in the model. It turns out to be better to gradually force the model in the assimilation process towards an analysed state which is a combination of a previous model prediction at analysis time and available observations. This method of data-assimilation is known as 'analysis nudging'. It is adopted in DMI-HIRLAM-R to assimilate a cloud cover analysis, a precipitation intensity analysis and analyses of near surface temperature and humidity, using information from the many road stations (≈ 370) in Denmark.

The procedure for assimilation of new information is briefly outlined below. For a more detailed description the reader is referred to Sass and Petersen (2004).

2.1. The data assimilation

The assimilation and forecast is illustrated schematically in figures 2 and 3. Figure 2 illustrates the processes involved, each having a number between 1 and 5. The initial time of the road weather forecast is at 0h. The assimilation run ('3') starts 3 hours prior to the initial time of the RWM.

The DMI-HIRLAM-R is run every hour. The model starts from a combination of information from the larger scale operational model (DMI-HIRLAM-E) and the previous 1 hour old run with DMI-HIRLAM-R (step '1'). The temperature and humidity variables at the surface are taken from the DMI-HIRLAM-R model while other variables are taken from DMI-HIRLAM-E.

The assimilation process is illustrated by '3' in figure 2. At every model hour of the assimilation it is possible to analyse cloud cover, precipitation and surface variables 'an hour ahead', because observed data are known during the assimilation period from -3 h to 0 h. Analyses of all variables are determined from a combination of the preliminary value ('first guess') of a previous DMI-HIRLAM-R run and observed parameter values near to the analysis point (process '2'). The first guess is not modified if there are no observations nearby (see Sass and Petersen 2004). Currently, the observed information (cloud type, cloud height, cloud cover, precipitation information, temperature and dew point at 2 metres) are obtained from meteorological synoptic observations including also the road-weather stations. It is planned to utilize also high resolution satellite information in the future. Analyses at all times of the assimilation period is obtained by time interpolation of the hourly analyses.

The analysis nudging operates by modifying the time tendencies of the humidity variables in the model ('cloud condensate' and 'specific water vapor') by terms which increase with growing differences between analysed cloud cover and precipitation intensity compared to the corresponding values in the model. Close to the surface, humidity and temperature tendencies are adjusted as a result of assimilating surface information. In this way the model gradually approaches the analysed state during the data assimilation period.

Figure 3 illustrates conceptually how the cloud cover assimilation operates. The coarse dashed line is an imagined cloud cover of DMI-HIRLAM-E. The finer dashed line is the corresponding time evolution of cloud cover in DMI-HIRLAM-R. The finest dashed line is the cloud cover evolution during the forecast of the RWM from 0h and later on. The solid line displays the analysed cloud cover extended beyond 0h to illustrate how forecasts deviate from the observed (analysed) values. Figure 3 shows that the cloud cover of DMI-HIRLAM-R comes closer than DMI-HIRLAM-E to analysed cloud cover during the assimilation run. During the forecast the additional extra information is gradually lost and the cloud cover of DMI-HIRLAM-R usually approaches that of DMI-HIRLAM-E after some time. The figure shows that cloud cover of the RWM has a small advantage initially compared to DMI-HIRLAM-R, because it starts from the analysed cloud cover valid at the position of the road station site. Details of the cloud analysis and nudging

procedure are given in Sass and Petersen (2002a, 2002b).

2.2. The forecast

At the start time (0h) of the forecast the RWM is initialized (process '4'). The purpose of the RWM is to produce site specific forecasts which should start from the the best possible local information. For 2 m temperature and dew point local observations are available and used. For cloud cover the same cloud cover analysis as mentioned above is used, but using the specific geographical location of the road weather station. This means that small differences exist between the DMI-HIRLAM-R simulated cloud cover from the assimilation and the cloud cover analysed at the road station site. The actual cloud cover (a vertical profile) used in the RWM during the forecast is a combination of the values transferred every time step from DMI-HIRLAM-R and the initial values analysed at the stations. In other words, the cloud cover of the RWM is described as the initial cloud cover plus a statistically based transition towards the values from the atmospheric model. The transition function is described by Sass and Petersen (2002b) A similar method is used for 2 m temperature and humidity. The input every time step from DMI-HIRLAM-R and the forecast procedure of the RWM (process '5') makes it possible to produce site specific forecasts for all road station sites in Denmark.

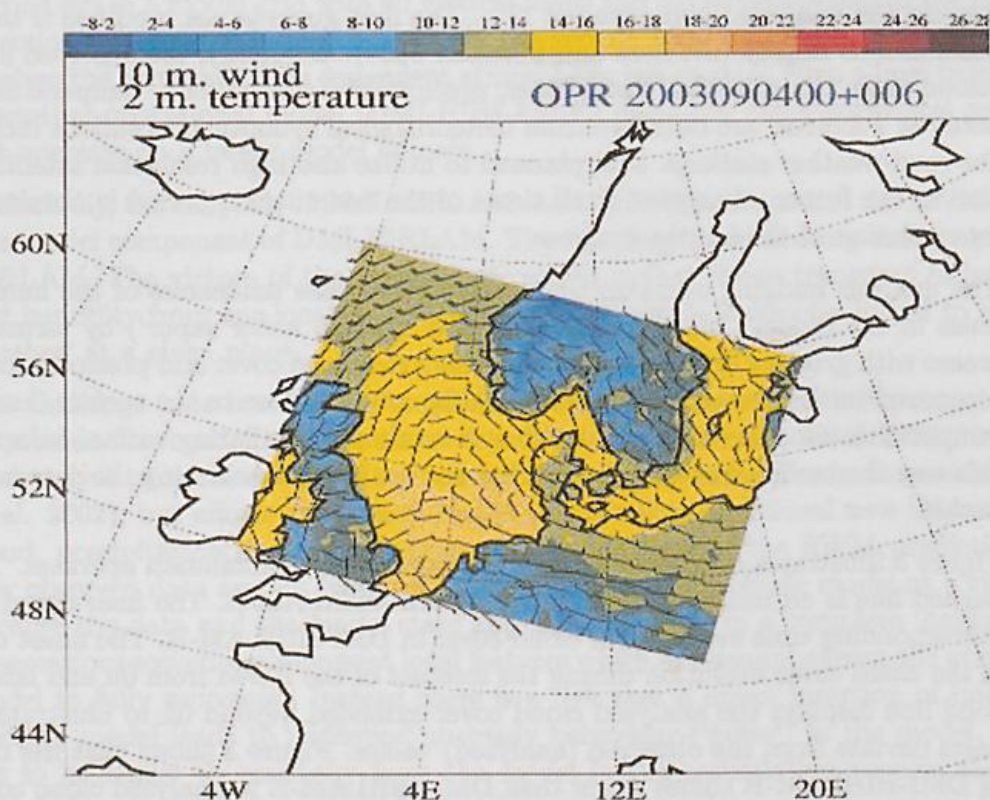


Figure 1: 6 hour forecast on 4 September 2003 using DMI-HIRLAM-R area with a presentation of 2 m temperature and 10m wind arrows

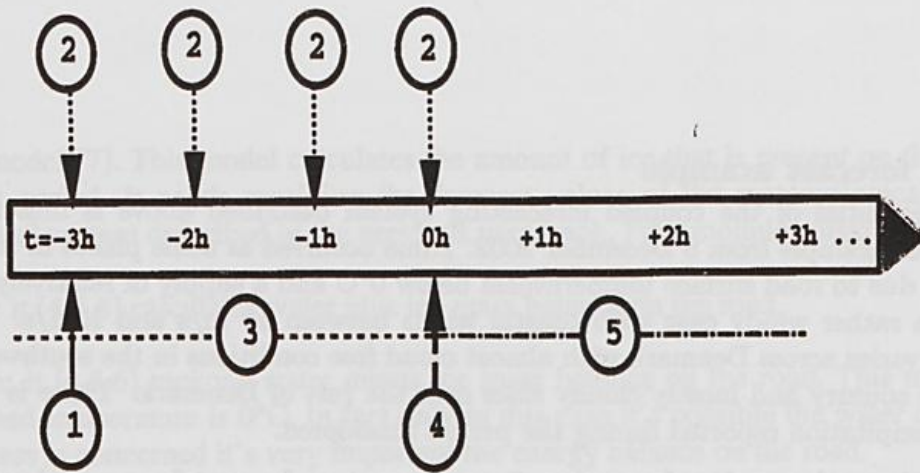


Figure 2: Processes (1-5) in the combined system DMI-HIRLAM-R (see text).

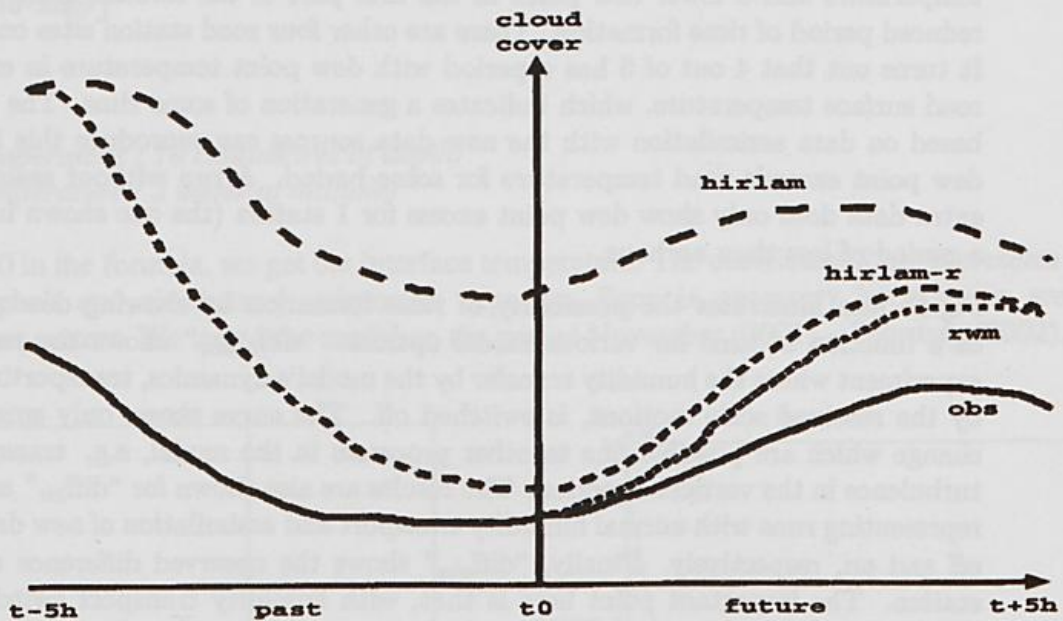


Figure 3: Illustration of the assimilation of cloud cover in the new model DMI-HIRLAM-R (fine dashed) compared to analysed values (obs) and the default forecast DMI-HIRLAM (dashed). The forecast of the RWM is given by the dotted line. For details see text.

3. A forecast example

The potential of the coupled forecasting system described above is illustrated by a forecast example from 8 December 2002. Rime occurred at some places in the morning hours due to road surface temperatures below 0°C and a supply of relatively moist air. It is a rather windy case with coastal winds between 10 m/s and 15m/s. The cloud cover varies across Denmark with almost cloud free conditions in the southwestern part of the country and mostly cloudy skies over the rest of Denmark. There is practically no precipitation reported during the period considered.

Fig.4 shows the results of a road surface temperature forecast for a model run based on assimilation of both cloud and surface information on temperature and dew point. The results apply to a station site on a bridge (55.5°N, 9.7°E) between the Island of Fyn and Jutland where almost cloud free conditions occurred. It is seen that the forecast manages to produce a higher dew point temperature ("td_{nud}") than road temperature ("ts_{nud}") for the last two hours of the prediction period. The observations of dew point temperature ("td_{obs}") also become larger than the observed road surface temperature ("ts_{obs}"). This means that conditions of rime formation are reproduced in the prediction. The duration of the period favorable for rime formation is almost one hour less in the forecast compared to observations. It is seen that a somewhat too high surface temperature and a lower dew point in the first part of the forecast contribute to the reduced period of rime formation. There are other four road station sites on the bridge. It turns out that 4 out of 5 has a period with dew point temperature in excess of the road surface temperature, which indicates a generation of some rime. The present run based on data assimilation with the new data sources can reproduce this feature that dew point exceeds road temperature for some period. A run without assimilating the extra data does only show dew point excess for 1 station (the one shown in Fig.4), for a period of less than an hour.

Fig.4b also illustrates the possibility of rime formation by showing dew point excess as a function of time for various model options. "diff_{noadv}" shows the results for an experiment where the humidity transfer by the model's dynamics, transporting humidity by the resolved scale motions, is switched off. The curve shows only small humidity change which are possible due to other processes in the model, e.g. transport due to turbulence in the vertical direction. The results are also shown for "diff_{hir}" and "diff_{nud}" representing runs with normal humidity transport and assimilation of new data switched off and on, respectively. Finally, "diff_{obs}" shows the observed difference at the same station. The important point here is that, with humidity transport switched off, the model completely fails to predict the developing rime formation. The best prediction is obtained with the assimilation of the new observational data.

Fig.5a and 5b show the total fractional cloud cover (%) at the initial time of the runs with and without assimilating extra data, respectively. The figures exhibit significant differences between the two options showing that 'nudging' of additional information leads to important differences in the initial state of cloud cover. Synoptic observations of total cloud cover during the night on 8 December 2003 (not shown) reveal that the run with cloud assimilation is quite realistic. This is consistent with the finding that the model during assimilation gets closer to the analysed cloud cover. The wide area of

analytical model [7]. This model calculates the amount of ice that is present on the road at the end of the forecast period. It needs receiving the forecast values of the meteorological parameters by the forecast neural system described in the previous paragraph. Four modules make it up:

1st module: it [4,5,6] calculates water plus ice mass balance on the road.

2nd module: it [4,5,6] reckons water minus ice mass balance on the road. This modulus is used only when the road temperature is 0°C. In fact only in this case it's possible the water change phase. As far as this process is concerned it's very important the energy balance on the road.

3rd module: it calculates the snow heap and the snow melting on the road.

4th module: this module, according to the air – asphalt interface temperature, integrates opportunely the previous modules. On the starting integration instant we used the observed meteorological parameters whereas on the last instant we used that one forecast.

As we hadn't the interface temperature in the database, we calculated it with the following formula,

$$T(z) = T_0 + \left[\frac{T_{210} - T_0}{210 \cdot Rapp} \right] \cdot z \quad (9)$$

where,

T_0 : road temperature (10 centimetres of depth)
 T_{210} : air temperature (2 meter of altitude)

Putting $z=10$ in the formula, we get the interface temperature. The coefficient *Rapp* represents the ratio between asphalt and air thermal volumetric capacity. *Rapp* is necessary because we aren't in a homogeneous system. We tested the model on the period November (2001) – February (2002).

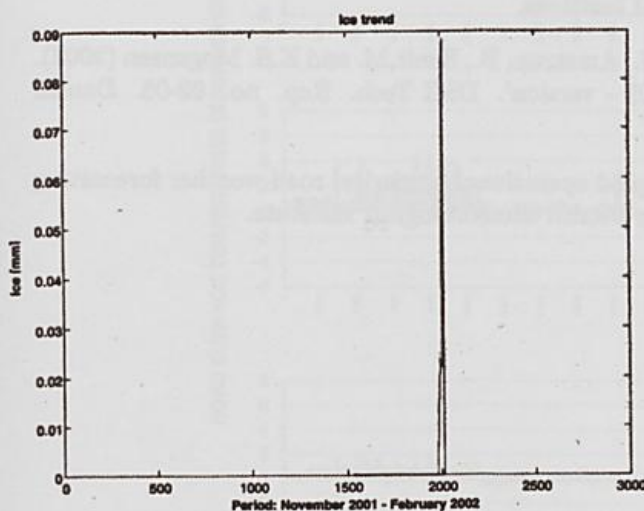


Figure 6: Ice trend

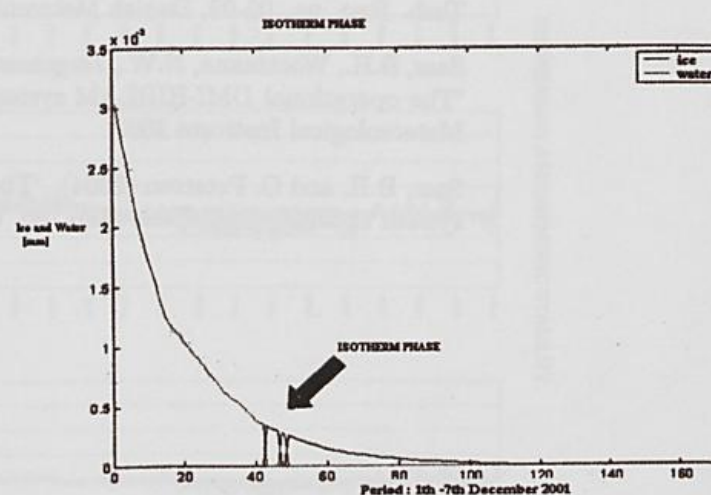


Figure 7: Isotherm phase (water and ice)

cloud cover, precipitation and near surface information of temperature and humidity. The data assimilation is still at a state of development where further improvements can be made, in particular with respect to the accuracy of the cloud analysis which is significantly limited by lack of high resolution data in space and time. The case study mentioned above is also affected by this limitation since only traditional synoptic observations have been used. A project has started to make use of high resolution satellite data through the EUMETSAT Satellite Application Facility (SAF) projects. This effort is likely to significantly enhance the quality of the cloud analyses used in the data assimilation. It is also very important to have a high quality surface analysis of temperature and humidity in the atmospheric model. The number of observations over land has now increased with the addition of data from road station sites. However, observations over sea areas are still sparse. Experience with the model system shows that it is also important for the Danish area to have a good knowledge of temperatures over sea. In the future the new satellites will also be able to supply good quality sea surface temperatures.

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ROAD ICE PREDICTION USING GEOMATICS

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ABSTRACT

A GIS based model for the prediction of road surface temperature is presented which has the ability to explain up to 74% of the spatial variation in road surface temperature in the West Midlands, UK. The approach combines basic spatial datasets with GPS based surveying techniques to produce a geographical parameter database which drives the spatial component of a road weather prediction model.

1. INTRODUCTION

Over the last couple of decades, thermal interpolations between road weather outstations have been made using thermal mapping surveys. By using a vehicle mounted infrared thermometer, nocturnal road surface temperatures (RST) are measured at a set spatial resolution across the road network. The magnitude (amplitude) of temperature variations across an area is dependent on atmospheric stability, but the actual pattern of RST variation (thermal fingerprint) generally remains similar on a nightly basis (Figure 1). Such variations are controlled by the surrounding geography of the site under study. For example, sections of road through urban or forested areas are always the warmest sections of the network, regardless of weather conditions. The impact of various geographical parameters and how they are measured is summarised in Table 1.

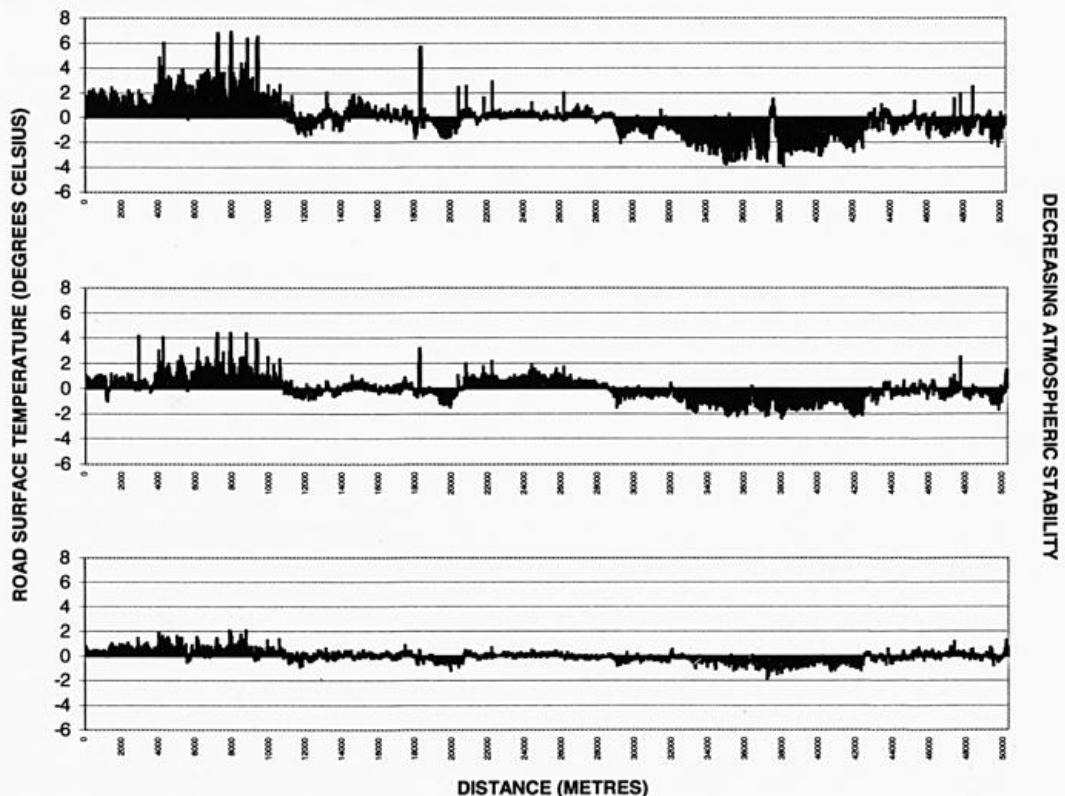


Figure 1: Thermal fingerprints showing the variation in residual road surface temperature for various levels of atmospheric stability.

Table 1 Geographical parameters affecting road surface temperature

Parameter	Impact upon road surface temperature	Measurement technique
Latitude ¹	Major control upon theoretical maximum incoming short-wave radiation and thus daytime RST.	GPS.
Altitude	Non-linear control on RST (Shao <i>et al</i> , 1997). RST decreases with altitude in line with lapse rates and is a dominant parameter during times of low atmospheric stability (Chapman <i>et al</i> , 2001)	GPS or Digital Elevation Models.
Topography	During stable conditions, katabatic flow can generate pools of cold air in hollows and valley bottoms. Any decrease in air temperature is linearly related to RST (Gustavsson, 1990)	Commonly estimated empirically (e.g. Bogren & Gustavsson, 1991; Laughlin & Kalma, 1990).
Slope & Aspect ¹	Unfavourable slope and aspect reduce the theoretical maximum of incoming short-wave radiation and thus daytime RST.	Easily derived from digital elevation models.
Sky-View Factor	A dimensionless parameterisation of the amount of visible sky at a location (Chapman <i>et al</i> , 2001b). Surface geometry is the dominant parameter controlling surface radiation loss and the sky-view factor enables this geometry to be quantified.	Calculated from fish-eye photographs or proxy techniques (e.g. Chapman <i>et al</i> , 2001b, Grimmond <i>et al</i> 2001, Chapman & Thornes, 2004)
Screening ¹	Closely related to the sky-view factor, this is a measurement of how canyon geometry prevents short-wave radiation from reaching a surface.	Can be estimated by plotting sun-tracks on fish eye photographs (Chapman <i>et al</i> , 2001b).
Landuse	The thermal properties of surfaces will vary with landuse. For example, a city centre will have increased canyon geometry, surface roughness, traffic and anthropogenic heat. The impact of landuse can be quantified by measuring the urban heat island.	Impacts can be estimated empirically. An alternative is to use classified satellite imagery. (e.g. Bradley <i>et al</i> , 2001)
Road Construction	Variations exist in the construction materials used and depth of construction across the road network. The 'thermal memory' of a surface is related to such properties (Thornes, 1991).	Site specific quantifications can be obtained by coring. Alternatively, estimates can be provided remotely by the use of ground penetrating radar.
Traffic	Traffic increases RST by additional heat sources, blocking radiative loss and promoting mixing of layers (Thornes, 1991).	Traffic counters can be used and empirical formulae derived on multi-laned roads (Parmenter & Thornes, 1986).

¹ These parameters influence daytime RST and impact upon night-time temperatures by providing an increased lag effect.

To achieve an adequate sample of different weather types, a series of thermal surveys are conducted for three pre-defined levels of atmospheric stability; *extreme*, *intermediate* and *damped*. These can be roughly classified into the Pasquill Gifford stability classes G, F/E and D respectively (Pasquill & Smith, 1983). To provide a forecast for a particular night, the thermal fingerprint (map) most closely representing the current atmospheric stability is made 'live' by adjusting the values in line with RST forecasted at the outstation.

Thermal surveying techniques have remained largely unchanged over the past 20 years, but they are now starting to date:

- Several surveys are required to adequately cover the different weather types, making thermal maps expensive and time consuming to create.
- It is assumed that the use of three thermal maps adequately covers the range of atmospheric stability and weather conditions experienced over the course of a winter.
- Thermal maps contain no information regarding the temporal thermal behaviour of the road. Such information is advantageous as it enables the time of the onset of freezing conditions to be predicted allowing for optimisation strategies.

These problems can be overcome by modelling rather than just measuring RST spatially.

The recent proliferation of 'commercial off-the-shelf' geomatics technology, in particular Geographical Information Systems (GIS) and Global Positioning Systems (GPS) has enabled massive innovation in winter road maintenance. GIS provides a means of visualising RST variation across the road network as temperature data can now be plotted accurately to within $\pm 5\text{m}$ when using GPS. However, GIS applications are not limited to visualisation. Li & Eglese (1996) used GIS to devise a heuristic algorithm to optimise treatment routes, while Gustavsson *et al* (1998) present a technique to predict likely winter maintenance costs for planned new road stretches. Such studies provide good examples of how the use of new geomatics technologies can greatly facilitate improvements in winter maintenance. This paper outlines how geomatics can be used to unite pre-existing components of road weather prediction systems to provide a high-resolution GIS-based road ice prediction system.

2 GEOGRAPHICAL DATA

Road-weather outstations are strategically located to measure climatic variability in a particular 'climate zone'. Climate zones are simply a classification of a geographical area into a series of regions which experience a similar climate e.g. coastal plains, urban areas, etc. At least one outstation is located per climate zone and the weather recorded is considered representative of the zone as a whole. It can be hypothesised that as the regional climate is constant, any variation in climate and RST across the zone is controlled by the variation in geographical parameters. Therefore, by measuring local variations in geography and modelling the impact on RST, it should be possible to provide an accurate 'virtual' forecast away from the outstation. However, in order to achieve this, it is necessary to have efficient techniques to measure or estimate the geographical variations across the climate zone.

Chapman *et al* (2001a) use a mobile platform to measure the spatial variation in geographical parameters. 3D positional data are obtained from a GPS, ψ_s is calculated from fisheye imagery (Chapman *et al*, 2001b), where as ordinal landuse and road classifications were manually recorded by the driver whilst surveying. Disadvantages of this approach include:

- No scope for identifying the advective impact of geographical features
- Subjective interpretations of landuse and road classifications.
- Calculation of ψ_s by fish-eye imaging is restricted to homogenous overcast conditions (Chapman *et al*, 2001b). The limited surveying window available compromises the potential of using the surveying technique operationally.
- Unreliability of GPS to provide accurate altitude data. In order to achieve a good 3D positional fix, the trilateration of four or more satellites is required; the visibility of four satellites cannot be guaranteed in heavily urbanised or forested areas.

Overall, the survey method employed provided fast results but was unreliable and subjective. By translating many of the survey tasks into a GIS environment, more objective surveying and hence, modelling can be achieved.

2.1 Spatial Data Sets

The simplest variable to be obtained using a GIS is altitude data. High resolution Digital Elevation Models (DEM) accurate to within $\pm 5\text{m}$ are now freely available to the academic community. In this study *Panorama* data are used, which is a 50m resolution gridded altitude dataset developed by the UK Ordnance Survey. This provides an excellent base layer for the GIS from which other useful spatial datasets can be derived. For example, slope gradient and aspect are important parameters when calculating incoming radiation and these can be easily calculated using standard surface analysis functions. There is also the potential for algorithms to be developed to model the temporal and spatial development of katabatic drainage and cold-air pools (e.g. Laughlan & Kalma, 1991).

Vector road data is also freely available to the academic community at a variety of scales from the UK Ordnance Survey. The spatial data product used in this study was the *Meridian 2* dataset, which contains attribute data on all the public roads in the UK. An algorithm is also run on this product to provide a simple, but effective proxy classification of landuse density. This is achieved by clipping the road network with a delineated urban area polygon (part of the *Meridian 2* product) and running a density analysis to locate dense areas of the road network. As urban areas have a much denser road network than rural areas, this algorithm approximates population density by proxy. A kernel with search radius of 1000m is used and the results classified into five classes with respect to standard deviation.

2.2 Survey Data

In addition to the GIS data described, RST and ψ_s data still need to be collected in the field. Nocturnal RST data is collected using an infrared camera (emissivity set to a constant 0.95) and is used to identify systematic thermal anomalies or singularities which cannot be explained by simple modelling. A typical example would be a bridge, whose shallower construction would reduce the 'thermal memory' of the road (Thornes, 1991). Modelling just using just geographical parameters would not be able to pick up such a feature and hence an undetected cold spot, or thermal singularity, would occur on the network.

The second parameter measured via surveying is ψ_s . Both empirical and numerical modelling of RST has shown this to be the dominant parameter for controlling variations in RST (Chapman *et al.*, 2001a). Traditionally, measurements of ψ_s are calculated from fisheye imagery taken during homogenous overcast conditions (Figure 2a: e.g. Grimmond *et al* 2001). The delineation of buildings and trees from sky pixels on fisheye imagery requires the use of a threshold algorithm. If light levels are either too low or too bright, then a single threshold cannot be set for the entire image and ψ_s cannot be calculated. In the past, this has severely restricted ψ_s research, but recently a new all weather proxy technique has been developed which enables large ψ_s datasets to be rapidly assembled. Chapman & Thornes (2004) use an artificial neural network to calculate ψ_s by proxy using raw GPS data (Figure 2b). By measuring the number and quality of incoming signal to noise ratios from satellites in the global GPS network, a real-time approximation of ψ_s can be obtained (typical $R^2 = 0.69$).

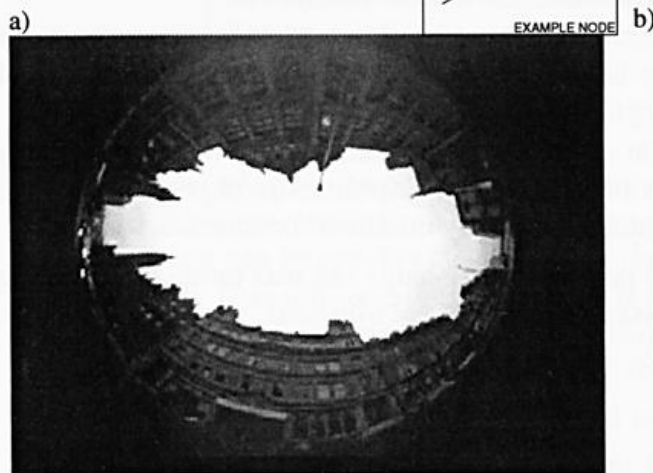


Figure 2 a) Sample fisheye imagery and b) Artificial Neural Network used to calculate the sky-view factor by GPS proxy. SOL is the number of visible satellites used in the position solution where as SNR is the sum of signal to noise ratios of available satellites.

There are two main advantages of using the ψ_s by GPS proxy technique. Firstly, as there are no environmental constraints, real-time ψ_s data can be collected simultaneously with RST data during a thermal mapping survey, thus reducing the total number of surveys required. Secondly, unlike traditional techniques no additional, specialist fisheye imagery apparatus is required. In this study, RST and ψ_s by GPS proxy data is collected and processed in real-time at a one second temporal resolution. Each survey point is stored in a database format file and contains RST data from the infrared thermometer along with 2D positional and ψ_s data from the GPS. Surveys are undertaken prior to sunrise on *extreme* (Class G) nights of high atmospheric stability. This is to ensure that all possible thermal singularities (e.g. katabatic drainage) are identified.

2.3 Spatial processing

The GIS used is ESRI's ArcGIS 8. Macros can be freely written in Microsoft Visual Basic for Applications™ (VBA) to customise the GIS and to perform bespoke tasks. The GPS survey database is converted into a shapefile and loaded into the GIS with the other spatial datasets. The GIS now contains examples of the three common GIS data models ranging from the point data contained in the GPS survey datafile, to vector road data, to the raster DEM. It is now necessary to compress the datasets into one useful geodatabase file which can be read on a site by site loop. This is achieved by using a series of spatial joins which relate the vector data and identifies the raster data for appending to the point survey file. A schematic diagram of the GIS is shown in Figure 3.

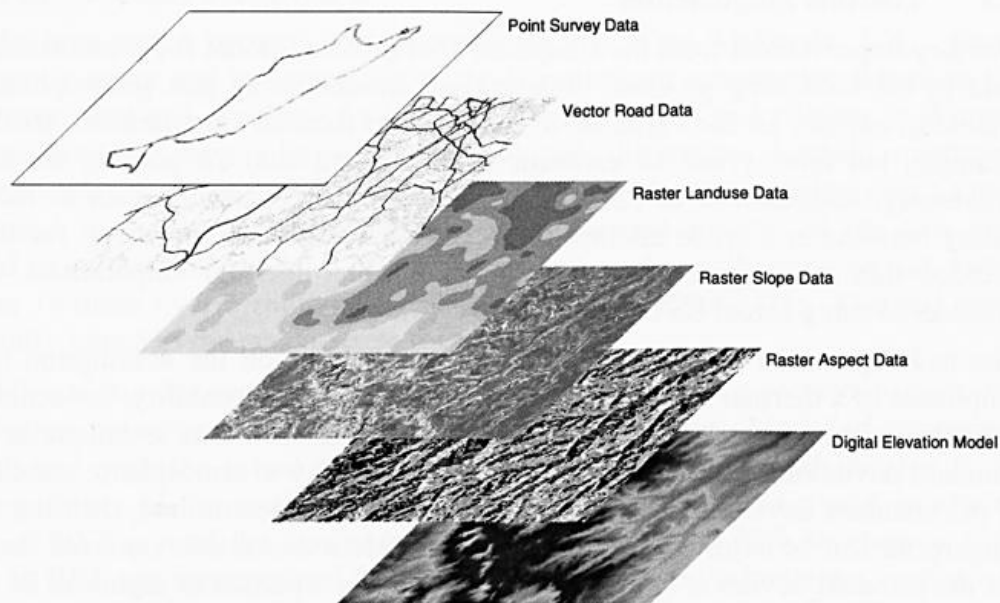


Figure 3 Schematic diagram of layers of geographical data used by the GIS based model.

3 THE GIS MODEL

After the spatial processing is completed, the geodatabase is ready to be used for the forecasting of RST. The model can generally be broken into two distinct parts. Firstly, there is the temporal component which consists of a standard road weather prediction model. This uses forecast meteorological data to produce an RST forecast curve. Secondly, there is a spatial component which uses geographical attribute data to modify the forecast curve on a site-specific basis. In effect, the road weather prediction model is run on a loop to provide a forecast curve for each site in the GIS.

3.1 Temporal Component

The temporal component of the model is based around the Thornes (1984) model and uses a zero-dimensional energy balance approach. RST is forecasted by finding the equilibrium temperature which balances energy flow across a surface. The model uses 3-hourly forecast meteorological data to produce the 24-hour site specific RST forecast curve. A sensitivity test of the model is described in Thornes & Shao (1991) and the temporal forecasting ability of the model is covered in Parmenter & Thornes (1986). Both studies indicated that the model has significant forecasting ability and compares favourably with other road weather models.

3.2 Spatial Component

Chapman *et al* (2001a) added a spatial component to the Thornes (1984) model by replacing the geographical constants with variables. In the original model, latitude, roughness length (landuse), road construction and the ψ_s were all constant. In the revised model, these variables along with altitude and traffic are parameterised. A full explanation and sensitivity analysis of the parameterisations is given in Chapman *et al* (2001a) and will not be discussed here. In this study the model was incorporated directly into the GIS environment by rewriting the original FORTRAN commands as a VBA macro. When the macro is run, it reads in both the meteorological and spatial attribute data and produces a forecast curve for each survey point in the GIS. For example, a point located in the central business district of a major city with low ψ_s will have a substantially warmer forecast curve than that of a high altitude rural site. A major advantage of running the model directly in a GIS environment is that the output data can be displayed as a new 'results' layer. Any point can then be selected in the view and a 24 hour forecast graph displayed (Figure 4).

3.3 Thermal Singularities

One key improvement from the Chapman *et al* (2001a) model is the inclusion of RST training data in the modelling process. The current model, using just geographical parameters, is unable to explain all the variation in RST due to thermal singularities. Bridges provide one example, but areas prone to katabatic drainage and cold air pooling are also problematic. Previously, Chapman *et al* (2001a) differentiated GPS altitude data to locate and classify valley bottoms in a crude attempt to model such features. However, for this model it was decided that the impact of topography and other thermal singularities would be easily considered using actual RST values.

The technique used to incorporate thermal data relies on the assumption that although the amplitude of a thermal fingerprint varies with atmospheric stability, the actual pattern of RST actually varies very little (Figure 1). A useful classification technique is to calculate the standard deviation of the fingerprint for use as a proxy to atmospheric stability (Shao, 2000). If the standard deviation for a particular night can be determined, then the amplitude of the fingerprint can be adjusted accordingly to provide a reasonable *expected* thermal fingerprint. As the standard deviation (atmospheric stability) for a particular night can be determined from model predictions, by adjusting the amplitude of the training fingerprint to match the standard deviation of the model predictions, a useful comparison can be made between expected and modelled RST. Any sites where modelled RST is $\pm 1^\circ\text{C}$ different from expected is considered a thermal singularity and the modelled value is substituted by the expected value. Although this step ensures greater forecasting ability, it does compromise the dynamic nature of the approach. Expected temperatures are only estimates of the minimum temperature and therefore cannot be used to provide time-slice information on cooling rates. However, due to the low frequency of thermal singularities, this is not considered to be a major problem.

3.4 Data Dissemination

Although a COTS GIS is a self contained means of displaying model results, it does require the end-user to have the software installed locally. A simpler way of disseminating the data rapidly to the engineer is via the internet. This requires the engineer to have no specialist software (other than a web browser) or indeed, GIS skills. An internet version of the model was realised by recoding the macro in PHP4. The results are displayed using an interactive Java GIS applet (Figure 4a) which displays a map of RST across hourly time-slices throughout the night. Each time slice consists of a series of points which when clicked display the forecast curve for the particular site under investigation (Figure 4b).

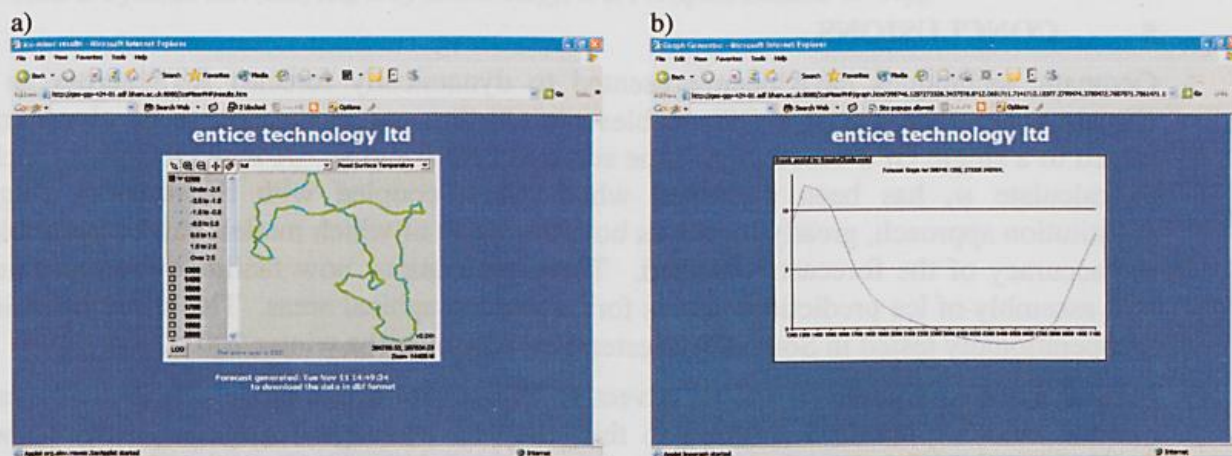


Figure 4 Internet disseminated model output showing a) GIS applet and b) forecast graph.

4 MODEL PERFORMANCE

The model was tested on two survey routes in the West Midlands, UK. One route is predominantly urban and traverses across the Birmingham conurbation where as the second route is more rural and consists of a transect of small towns and villages in Worcestershire. Both routes however, have a large variety of altitude differences, landuse, roadtypes and ψ_s . Firstly, the routes were surveyed to provide the ψ_s and thermal training data to produce the geodatabase. Secondly, a number of additional thermal surveys of the two routes were conducted to validate the model. The urban route was thermally surveyed 24 times and the rural route 14 times over 2 winter seasons (1999-2000 & 2002-2003). Thermal surveys were then spatially joined to the geodatabase for analysis.

The model was run for each of the validation thermal mapping surveys using retrospective meteorological data from the nearby Coleshill weather station. Modelled temperatures were then compared with the actual temperatures measured from thermal surveys to assess the forecasting ability of the model. The overall performance of the model in explaining the variation of RST around the study routes is variable. Up to 73% (average = 62%) of the variation in RST can be explained from model predictions in urban areas compared to up to 58% (average = 46%) in rural areas. The model was on average residually correct to within 1°C for up to 95.1% (average = 86.5%) of the urban route and up to 94.7% (average = 84.3%) of the rural route. These figures indicate significant forecasting ability and are backed up by average RMS errors of 1.07 and 1.06 for urban and rural areas respectively. The decreased model performance in rural areas can be partially attributed to the limitations of mapping ψ_s by GPS proxy in rural areas. Variations in the transmissivity and crown closure of trees ensure that ψ_s is highly spatially variable, thus reducing the performance of the ψ_s by GPS proxy neural network algorithm (Chapman & Thornes, 2004). Thermal variations on the rural route are also more subtle than in urban areas.

The spatial performance of the model (correlation coefficients) generally improves as atmospheric stability increases, although forecasting accuracy (RMS error) is reduced.

Increased spatial performance is to be expected as the model is trained using thermal data collected under stable conditions. However, RMS errors are greater due to the increased amplitude of thermal fingerprints in stable conditions. The percentage of residual RSTs correct to within $\pm 1^\circ\text{C}$ increases with atmospheric stability as expected in rural areas. However, the opposite is true for urban areas and is hypothesised to be a consequence of the accuracy of the spatial joining technique used. As it is virtually impossible for the same site to be surveyed twice on subsequent surveys, a point may be modelled to be under a bridge when in actuality it is several metres away. The result is a thermal singularity which will become increasingly apparent in stable conditions.

5 CONCLUSIONS

Geomatic techniques have been presented to dynamically forecast RST across an entire climate zone. The use of a GIS enables pre existing spatial datasets to be algorithmically joined to a single GPS based night-time survey of RST and ψ_s . A new GPS proxy technique to calculate ψ_s has been presented which when coupled with the thermal singularity substitution approach, greatly improves both the speed of which models can be assembled and the accuracy of the forecasts obtained. These innovations now facilitate the rapid and low cost assembly of ice prediction models for large geographical areas. The utility of which will be operationally tested in South Gloucestershire, UK over the winter 2003/2004.

Further work is required to add an advective component to the model. Although mesoscale climate models provide a solution to this, they do add significant complexity to what is essentially a simple working environment. Model performance could also be improved at lower atmospheric stability by incorporating other thermal maps into the training process. However, any future improvements to the model need to be undertaken on the understanding that the overall accuracy of the model (as with other road weather models) is still hugely dependent on the accuracy of the meteorological forecast data.

Overall, the use of a 'commercial off the shelf' GIS enables these new technologies to be easily disseminated to the end user. Other winter maintenance tasks could then be translated into the same GIS environment such as GPS fleet monitoring and salting route optimisation. Indeed the proliferation of internet GIS products will make this task even simpler. Easy access to such detailed information will enable the engineer to reduce the high costs of winter road maintenance both financially and environmentally.

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THE USE OF GIS AND ICEMISER TO PREDICT WINTER ROAD SURFACE TEMPERATURES IN POLAND

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Introduction

Poland has a transitional climate with both maritime and continental elements. The dominance of maritime or continental air masses causes annual variations in the seasons. Winters are variable - sometimes mild or sometimes severe, and similarly, summers can be cool and rainy or hot and dry. Sub-zero temperatures are recorded between November and March. Annual precipitation varies between the lowlands and mountains, with totals ranging between 500-600mm. New technology has recently been invested into Poland's road network, including the installation of a network of about 70 RWIS. The study road links the City of Krakow to the mountainous border with Slovakia, as shown in Figure 1. This is a very busy road approximately 200km in length, and includes a variety of land uses, road constructions and changes in topography. There are 10 RWIS along the road, provided by Vaisala and a local company. Krakow has an average winter temperature of -3°C and an average temperature in March of -1°C . This marginal winter weather in Poland creates a problem for road maintenance, and there is little emphasis on ice prediction to optimise salt use. This means that roads can be treated up to three or four times a day (Bartlett and Logiewa, 2002), at a great cost to the road maintenance budget and to the environment.

RELIEF MAP AND TESTING ROAD
(MALOPOLSKA PROVINCE)

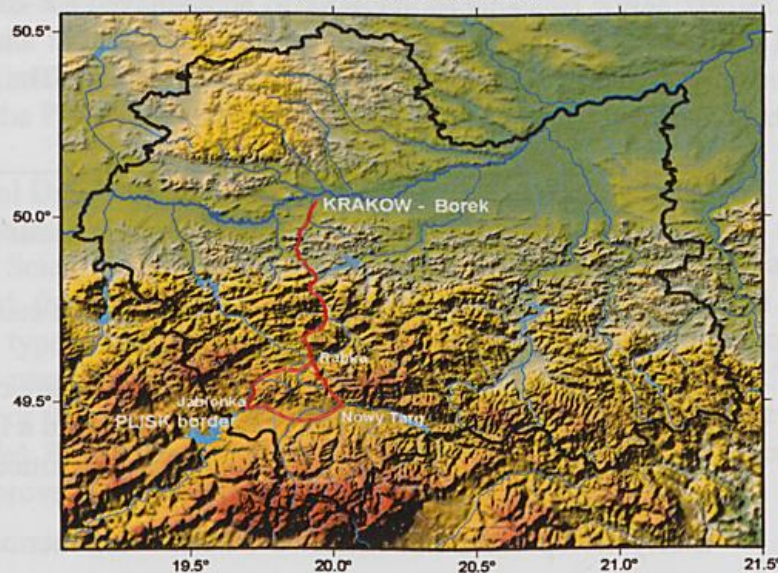


Figure 1: Study area in Krakow, Poland
(Source: Dyras, 2003).

The rapid growth of commercial ‘off the shelf’ geomatics technology including GIS and GPS, has enabled the development of a new ice prediction technique called IceMiser (Chapman and Thornes, 2003). The ESRI GIS program ArcView is used in this study to run the IceMiser model.

IceMiser Numerical Model

Numerical models provide a tool to investigate inaccessible phenomenon, such as environments in the future, which create concern for possible impacts of decisions made for future generations (Lane, 2003). There are two approaches to mathematical modelling: empirical and physically based. Lane (2003) notes that it is possible to conceive of a continuum from models that are largely built around a set of observations (empirical models) to models that are built around a set of laws (physically based models). The IceMiser model was developed by Chapman *et al.* (2001), and comprises an empirical geographical database within a physically based numerical model. IceMiser accounts for the influence of site-specific geographical parameters on the climatology of the road. The model simulates the energy transfer regime at a location by calculating the unique equilibrium temperature which balances energy flow across a surface:

$$(1-\alpha)(Q + q) + \sigma T_{sky}^4 - \sigma T_0^4 = LE + H + S$$

where: α is surface albedo, Q is direct beam solar radiation, q is diffuse radiation, σ is the Boltzman constant, T_{sky} is the radiation temperature of the sky hemisphere, T_0 is the surface temperature, R_N is net radiation, LE is latent heat flux, H is sensible heat flux and S is heat flux to soil. Thus, it uses a zero-dimensional energy balance approach (Chapman and Thornes, 2001). Meteorological data is combined with a high resolution geographical parameter database (incorporating SVF, landuse and elevation data) in the forecast model, to predict the road surface condition at thousands of sites around the road network (at spatial and temporal resolutions of approximately 20 meters and 20 minutes respectively). This enables the RST to be displayed for any site along the road network, at any particular time (Chapman *et al.*, 2001b). This model is a vast improvement on existing techniques using thermal mapping. The benefits of this new approach are outlined in Figure 2.

Benefits of IceMiser:

- Allows users to identify exactly where the road needs treating at a continuous range of atmospheric stability
- Enables salting route optimisation, as times when each section of roads needs treating are indicated
- Cheap to survey and install, as no specialist software or training is required and an operational system can be set up in a few days
- Easily integrated with winter maintenance fleet fitted GPS units for GPS monitoring
- Easily incorporated and validated with existing thermal maps and sensors

Figure 2: Benefits of IceMiser (Source: Chapman and Thornes 2003b).

Chapman and Thornes (2002) note that due to climate data being typically point source in nature, the biggest challenges facing meteorology is the extrapolation of point climate data across a wide spatial domain. This can be overcome by the extraction of climate

data using digital terrain models (DTMs), which enable a good estimate of an area's climatology without the need of extensive climate records and networks of weather stations. Unfortunately, a DTM was not available for this study, and instead, meteorological data from two climate stations were chosen to be representative of two geographical regions.

Meteorological Database

The meteorological database is comprised of retrospective data from two climate stations in Poland; Krakow and Zakopane. The meteorological data input into the model are listed in Table 1. These parameters were recorded hourly and were obtained for the month of March 2003. Retrospective data was chosen because this would identify the validity of the IceMiser model, rather than highlight errors in the forecasting of meteorological variables.

Table 1

Meteorological Data	Geographical Data	Survey Technique to get Geographical Data
RST at noon	Latitude	GPS
Air temperature*	Longitude	GPS
Dew point*	Altitude	GPS
Wind speed*	Sky-view factor	GPS
Rainfall*		
Cloud cover**		
Cloud type**		

* Nine values at 12:00, 15:00, 18:00, 21:00, 00:00, 03:00, 06:00, 09:00, 12:00.

** Eight values averaged over the time periods 12:00-15:00, 15:00-18:00, 18:00-21:00, 21:00-00:00, 00:00-03:00, 03:00-06:00, 06:00-09:00, and 09:00-12:00.

Road surface temperature data was obtained from 10 RWIS along the route, and was recorded at 10-minute intervals. The locations of these RWIS are shown in Figure 3. Validation data for road surface temperature was also used from the RWIS. A simple cloud classification procedure was used to allocate cloud type to three classes as supplied by the Polish Met Office.

Geographical Database

The geographical database is comprised of variables collected using a GPS, during a Short Term Scientific Mission (STSM) for COST 719. The geographical variables collected and the method of data collection are listed in Table 1. Landuse, road construction type, aspect, slope, drainage and topography were not collected for this study. These parameters have been set to default values in the model. This does affect the accuracy of the results, as results will be the most accurate with the maximum input into the model. These parameters could be collected at a later stage and input into the model to improve these preliminary results.

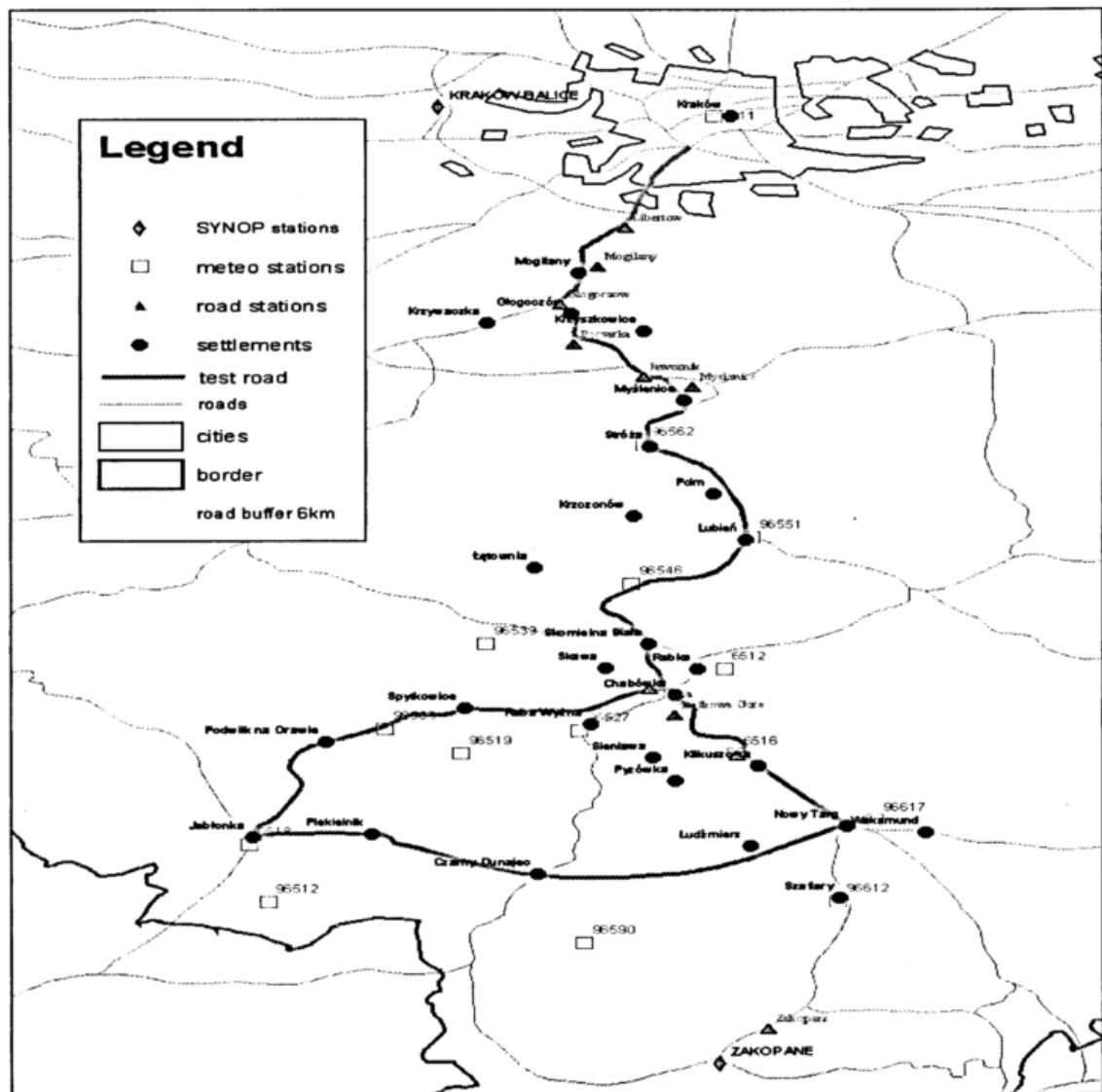


Figure 3: Location of the study area and RWIS

The geographical variables provided included: eastings, northings, altitude, latitude and sky-view factor, and enabled the creation of a shapefile. The geographical database was firstly created in Excel, and converted into a .dbf file before being converted into a shapefile. This enabled the road to be displayed spatially in ArcView as a series of points. Each point has a field representing the geographical data which was input into the database created in Excel. This allowed the creation of two separate shapefiles for each of the geographical regions; Krakow and Zakopane, based on altitude. Experiments with the number of classes (using the natural breaks technique) indicated a clear divide in the road at 400m. Krakow was chosen to be representative of lower topography (0m-400m). Zakopane is situated on the mountainous Polish border, and was chosen to represent mountainous topography and climate (400+ m).

The accuracy of the IceMiser model forecasts

The model has been run for two RWIS from each section of the road (four RWIS in total). IceMiser model results are compared to actual RST data from the RWIS. A 24hr forecast has been made for each day in March for each of the meteorological stations (Krakow and Zakopane). This has been displayed in ArcView as a series of colour-

coded maps. The nearest coordinate to each of the 4 selected RWIS along the road has been obtained, and actual and forecast data has been compared for each day.

Results from the IceMiser model

IceMiser forecasts were displayed in ArcView as hourly thermal projections for each night. Figure 4 illustrates that the RST falls below zero first at the higher altitude sites around 22:00h (at the settlement of Klikuszo \acute{w} a) and remains below freezing for about 12 hours. These are the coldest areas of the route throughout the night. Krakow city centre remains above freezing throughout the night, and the RST along the route does not fall below freezing until it reaches the settlement of Lubien (see Figure 3 for location). It is clear that the route in the higher altitude area of Zakopane is colder than Krakow throughout the night. At 09:00h in the morning, the road is above freezing at all sites. This information is of significance for winter maintenance engineers. It indicates that the Zakopane region needs priority salting, and only selective salting needs to take place in the Krakow region around 06:00h.

The IceMiser model was run for each of the 4 stations for the number of nights available: Libertow (18), Myslenice (22), Skawa (21), Piatkowa Gora (25). Model outputs were then plotted against actual RST data from the RWIS. These were plotted in graphs of forecast versus actual RST, and samples are displayed in Figure 5. Figure 6 shows the mean hourly root mean square (RMS) error for a sample of stations.

Table 2 illustrates sample IceMiser results for Libertow. It can be seen that on most days, the model predicts RST extremely accurately, and the hourly RMS error decreases to below 2.5°C. The minimum RST occurs at Libertow at about 06:00am every night, and the model predicts the temperature at this time very accurately, with an average RMS error of 1.4°C. Analysis of the frequency of snow at Libertow revealed that snow occurred on 10 of the 18 nights – far more frequently than at the other road monitoring stations. Despite suggestions that the model is insensitive to snow, these results indicate that a high accuracy is achieved at Libertow.

Table 2

Libertow		Actual	Forecast	Category	Error
1/2 March	1	-2.20	-4.00	F/F	-1.80
2/3 March	2	-2.20	-4.20	F/F	-2.00
3/4 March	3	-2.10	-3.20	F/F	-1.10
4/5 March	4	-6.10	-7.20	F/F	-1.10
5/6 March	5	-3.60	-4.40	F/F	-0.80
7/8 March	6	-5.50	-4.90	F/F	0.60
8/9 March	7	0.50	2.10		1.60
11/12 March	8	3.50	6.80		3.30
12/13 March	9	-1.30	-2.60	F/F	-1.30
13/14 March	10	-1.20	-1.70	F/F	-0.50
14/15 March	11	-0.30	-0.90	F/F	-0.60
15/16 March	12	0.10	1.00		0.90
16/17 March	13	-2.60	-1.80	F/F	0.80
26/27 March	14	2.10	3.20		1.10
27/28 March	15	5.90	4.60		-1.30
28/29 March	16	4.70	7.70		3.00
29/30 March	17	2.70	4.80		2.10
30/31 March	18	8.20	8.00		-0.20
Mean		0.03	0.18		0.15

F/F = frost forecast/frost occurred

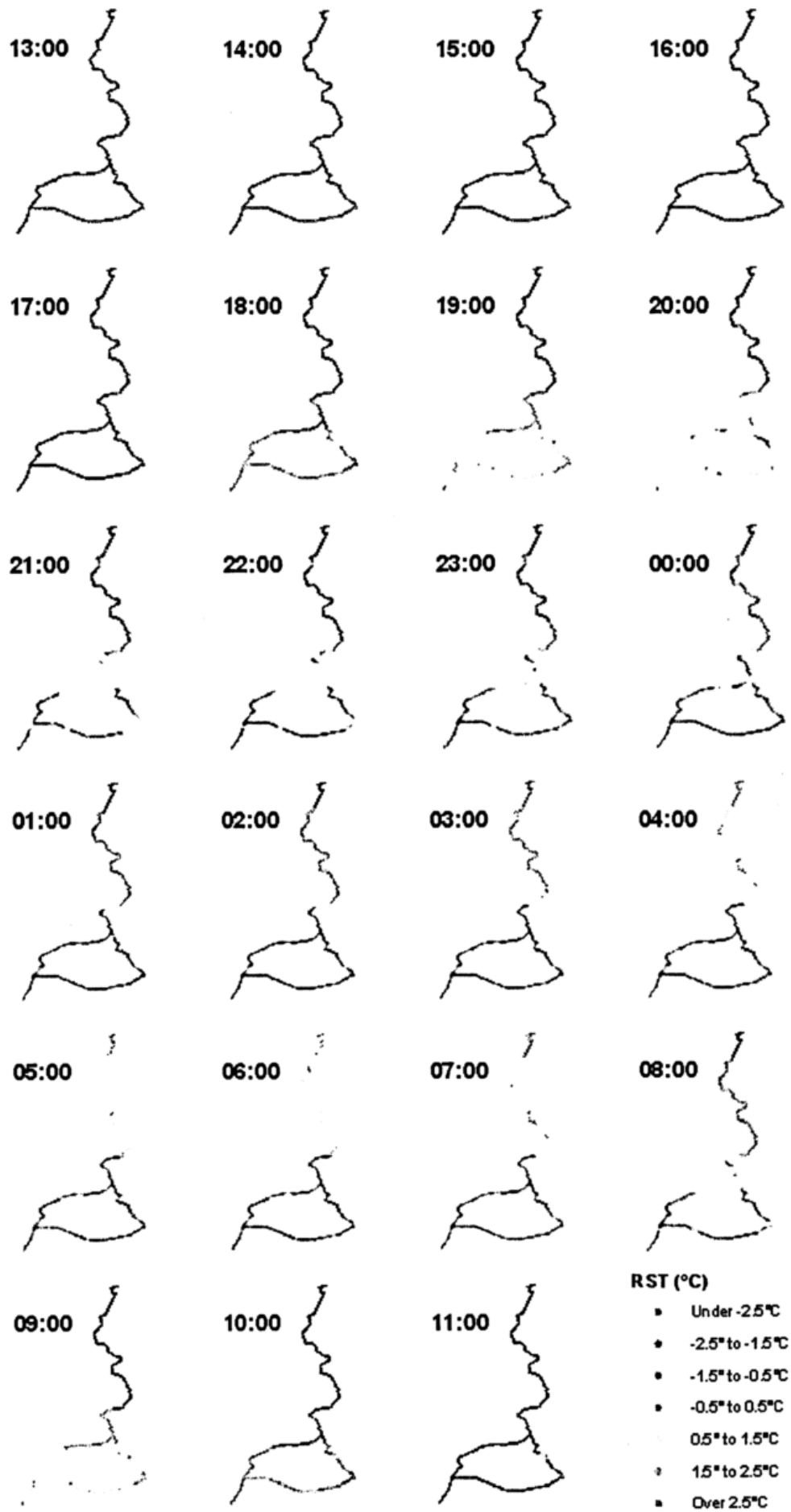


Figure 4: Hourly time-slices of the numerically predicted RST along the study route

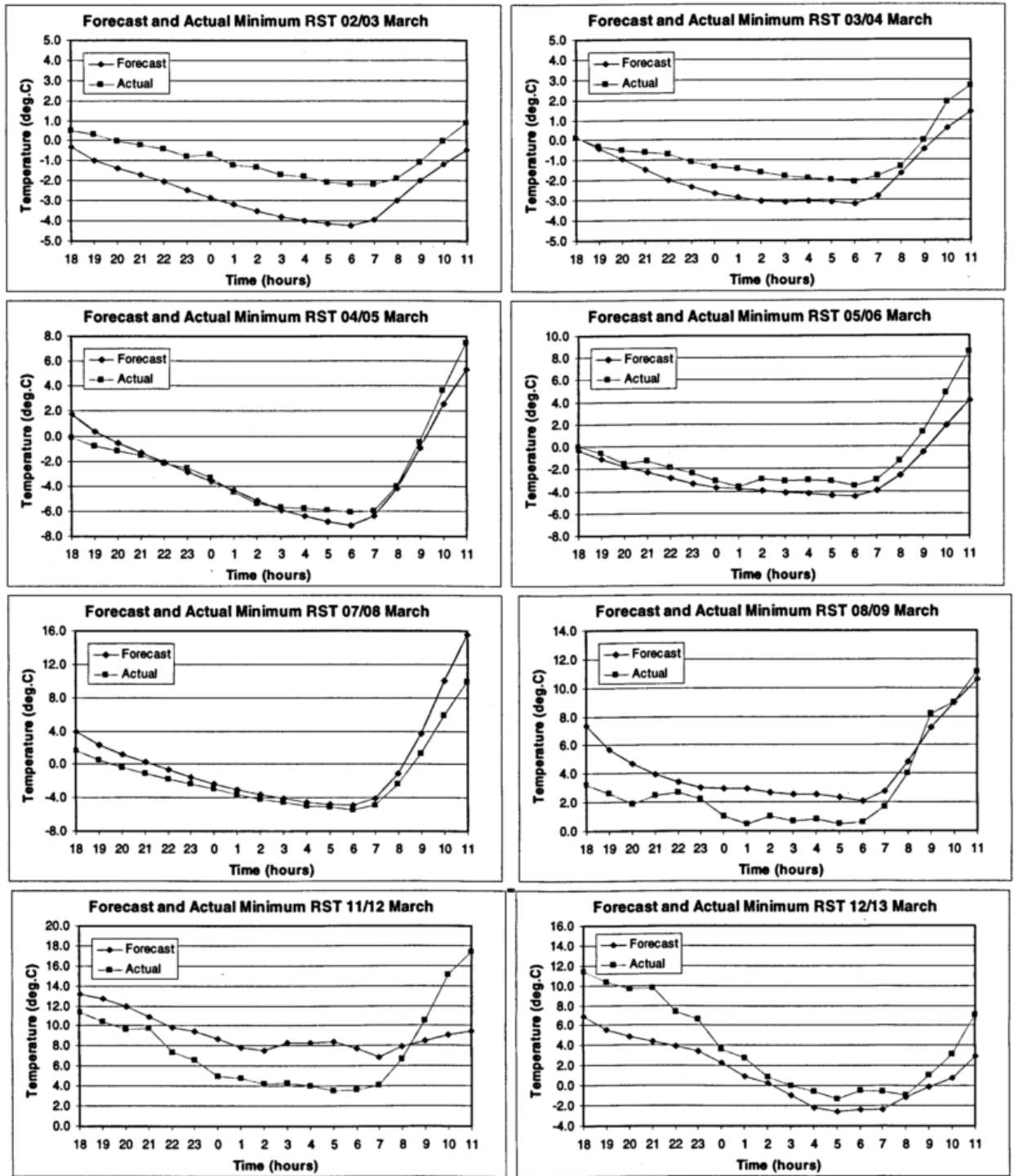


Figure 5: Sample Forecast versus actual minimum RST at Libertow (264.2m)

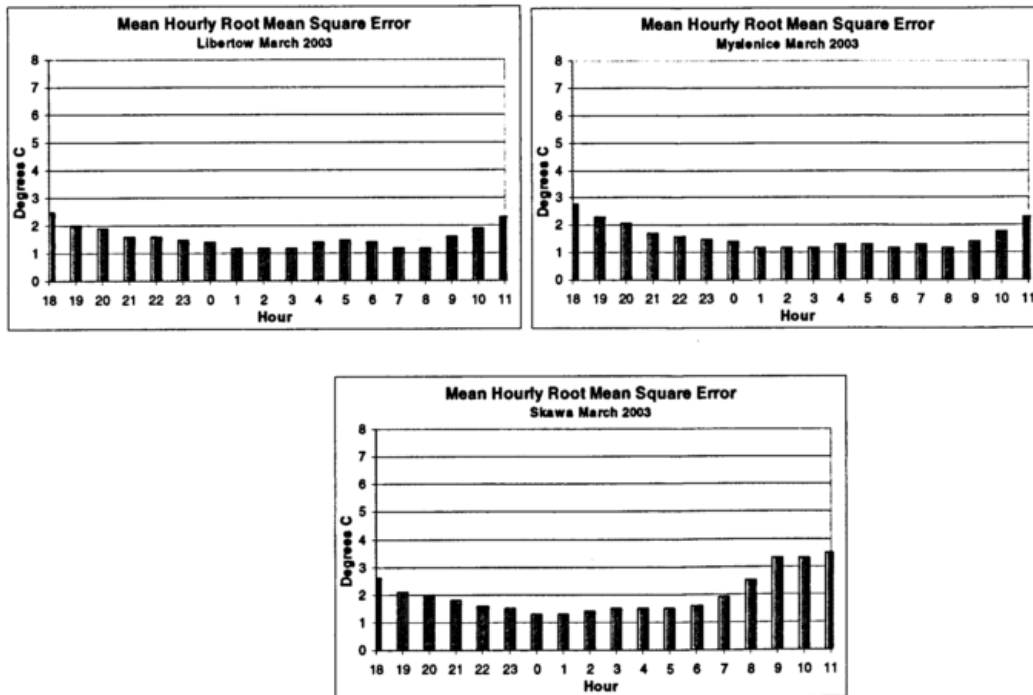


Figure 6 Sample Root Mean Square Errors in the Forecast

Conclusions

The results indicate that the model was able to forecast RST for the study route in Poland with a high level of accuracy. At best, the model forecast RST with 100% accuracy, and a bias of just 0.15°C. Additionally, the model was able to forecast the time of freezing and daily minimum RST (which occurred at about 0600h every morning) very accurately. Forecasts of RST using meteorological data from Krakow were found to be the most accurate, possibly due to the closer proximity of the RWIS, or the higher SVF explanation in an urban area.

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Short Bibliography:

Dr John E. Thornes is a Reader in Applied Meteorology at the University of Birmingham, UK. He is currently Editor of the journal *Meteorological Applications* and Chairman of Working Group 3 of the COST 719 GIS in Meteorology and Climatology programme. He was President of SIRWEC twice 1992-1994 & 1996 - 1998 and was Vice President in 1994 – 96. He has been to every SIRWEC conference and helped to draw up the constitution in Birmingham in 1984.

Use of Data on Road Condition and Weather for Winter Maintenance

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1 Introduction

A precise knowledge of roadway conditions and the ambient air facilitates the decision on commencing winter maintenance call-outs. Highway authorities in Germany thus use extensive sensor systems whose measured results are used for various purposes. They are incorporated in the medium and long-term forecasts (SWIS: Road Condition and Weather Information System) made by the German Meteorological Service (Deutscher Wetterdienst) which are primarily of interest for human resources planning on the one hand. This application is not discussed further in this paper. The measurement data is used for directly triggering call-outs (road weather systems) on the other. A third application consists in control of de-icing agent spraying systems.

2 Use of data on roadway condition and weather for triggering call-outs

2.1 Initial situation

Despite all the development progress made, meteorological services are, today, still unable to make weather and roadway condition forecasts for very small-area stretches of road (e.g. for bridges and valley sections etc.) incorporating precise times. The highway administrations use sensors to measure the relevant parameters in order to allow them to better monitor roadway and weather conditions at stretches of road which are particularly at risk. The measurement data recorded provides those responsible for providing meteorological services with information on the actual condition at the relevant measuring point. A further trend can be derived from the progression of the measurement data as a function of time. This trend may change very quickly only to factors including changing cloud cover and the position of the sun or shading which change during the day. It is not possible to derive a more precise estimate as to whether the existing trend will continue as previously from the data of one measuring point alone. This requires synoptic considerations including a knowledge of microclimatic parameters which still do not provide satisfactory results with state-of-the art technology.

Comprehensive assessment of the measurement data takes a great deal of time. The time required increases substantially if an area to be monitored includes many measuring points. Consequently, so-called skid-hazard warning models assist in assessment of the measured values faster. On the basis of the actual values and the progression of the data as a function of time, they derive skid-hazard warnings from which persons responsible for winter maintenance can draw conclusions on the possible skid hazard more quickly.

Those responsible for winter maintenance must distinguish between three possible forms of skid hazard with reference to the origin and of which a model should also provide a warning:

– **Skid hazard resulting from falling precipitation**

This skid hazard is produced by the impact of ice crystals on an undercooled roadway surface. The ice crystals are unable to thaw. Depending on the shape of the crystals, a distinction is made between a **slippery snow** or **freezing rain**. Rain which freezes immediately on contact with an undercooled roadway surface is also referred to as freezing rain.

– **Roadway frost**

The air is oversaturated with water. The excess water vapour is precipitated in the form of ice crystals (frost) at temperatures below 0 °C.

– **Black ice**

Water which freezes as the result of undercooling covers the roadway.

Some of the skid-hazard warning models offered in Germany do not warn against all forms of skid hazard. Various providers refuse to openly disclose the logic of the model offered. Skid-hazard warnings from these models cannot be reconstructed by and are thus not comprehensible to the user owing to the fact that the algorithms are unknown. For these two reasons, the Federal Highway Research Institute has developed its own model which can be made available to the highway administrations.

2.2 Model description

The parameters of roadway surface temperature, air temperature, dew point temperature and the roadway condition (dry, moist to wet, slippery) are included in the algorithms of this model. The aim of the calculation is to warn those responsible for winter maintenance at least 90 minutes prior to occurrence of a skid-hazard event. It is not the aim to provide them with a time span until possible occurrence of skid hazards. Such a specification is considered to be too imprecise for the reasons specified in Section 2.1.

The alarms issued by the system can be subdivided into four essential categories. They can split into “no risk of skid hazard”, “warning: skid hazard may occur soon only if the trend changes”, “warning: skid hazard may occur soon owing to the trends” and “warning of the risk of skid hazard which may occur immediately”. The reports are shown in different colours for faster assimilation. The differentiation results from the relevant roadway surface temperatures and their trend.

The first indication of the risk of skid hazard occurs even at a roadway surface temperature of +5 °C. This temperature has been selected since, on the basis of experience available, a temperature drop by more than 5 Kelvin, i.e. to the freezing temperature of water at 0 °C in this case, occurs only extremely rarely. No temperature drop exceeding 5 Kelvin within a period

of 90 minutes was recorded in a series of measurements conducted over two winter periods on a stretch of motorway.

The temperature trend is considered in the range of a roadway surface temperature between $+2\text{ }^{\circ}\text{C}$ and $+5\text{ }^{\circ}\text{C}$. If linear extrapolation of the measured values leads one to anticipate a drop in roadway temperature below the $0\text{ }^{\circ}\text{C}$ mark during the next 90 minutes, the risk of possible occurrence of skid hazard is indicated. If the roadway surface temperature remains above $0\text{ }^{\circ}\text{C}$ during the next 90 minutes on the basis of this consideration, only the following warning is issued: skid hazard may occur soon only if the trend changes.

The trend calculation uses the measurement data of the last 10 minutes. The onset of greater changes can be converted more quickly to a warning message using the data of this time span. However, even small trend changes lead to changing statements of the warning messages. If the measurement data of the last 60 minutes is included, it is possible to achieve a higher constancy of the indication. Figures 1 and 2 compare measured roadway surface temperature with the trends calculated from the measured values of the last 10 and 60 minutes in each case. The illustrations also show the radiation balance as an essential influencing parameter on roadway surface temperature.

Figure 1 shows a uniform progression of the roadway surface temperature which does not fluctuate in the short term on a largely cloudless day in January. The trend calculations correspond well to the actual values in the case of constant changes over a larger time span but, if major changes do occur, necessarily lead to differing results, primarily at sunrise or when the sun starts to go down.

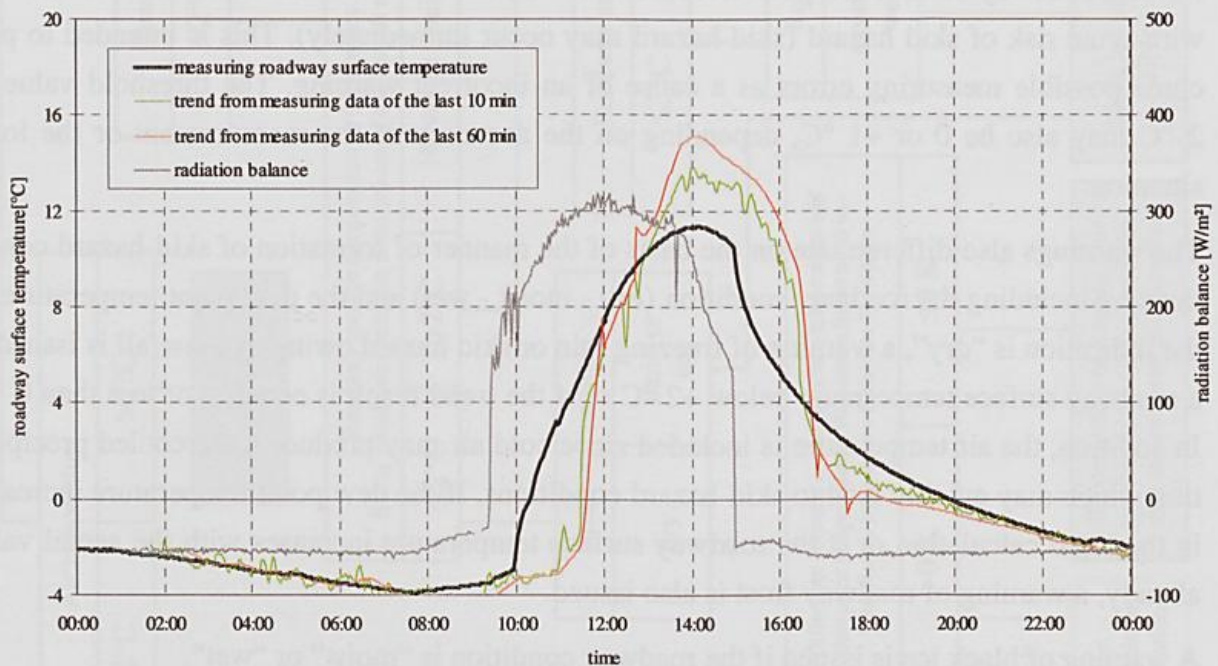


Figure 1: Actual and calculated roadway surface temperature progression over 24 hours on a largely cloudless day (mid-January)

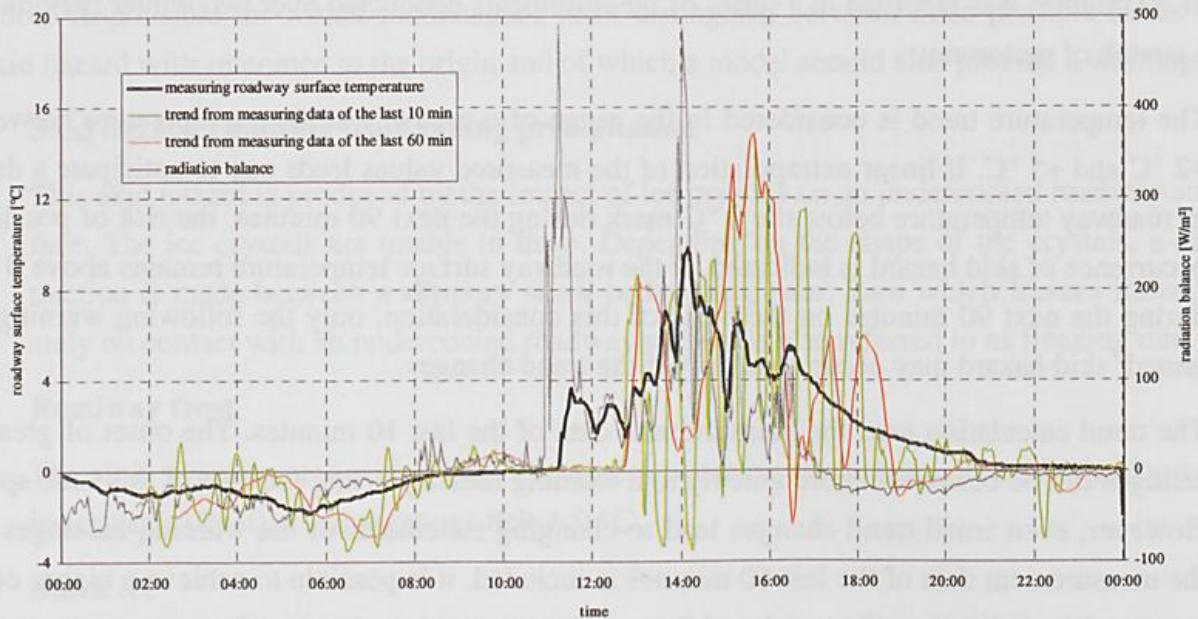


Figure 2: Actual and calculated roadway surface temperature progression over 24 hours on a day subject to changing cloud cover (early March)

Figure 2 shows a constantly changing progression of the roadway surface temperature during the daytime owing to changing cloud cover. Both the trend calculations with measured values of the last 10 minutes and the trend calculations with measured values of the last 60 minutes lead to differing results by comparison with the actual roadway surface temperatures which occurred.

As of a roadway surface temperature below $+2\text{ }^{\circ}\text{C}$, the model issues a skid-hazard warning with acute risk of skid hazard (skid hazard may occur immediately). This is intended to preclude possible measuring errors as a cause of an incorrect warning. The threshold value of $2\text{ }^{\circ}\text{C}$ may also be 0 or $+1\text{ }^{\circ}\text{C}$, depending on the accuracy of the measurement or the local situation.

The warnings also differentiate on the basis of the manner of formation of skid-hazard conditions by including the roadway condition (dry - moist - wet) and the dew point temperature. If the indication is “dry”, a warning of freezing rain or skid hazard owing to snowfall is issued at a roadway surface temperature below $+2\text{ }^{\circ}\text{C}$ or if the trend result is equal to or less than $0\text{ }^{\circ}\text{C}$. In addition, the air temperature is included since cold air may produce undercooled precipitation which may quickly lead to skid-hazard conditions. If the dew point temperature increases in the trend calculation or if the roadway surface temperature increases with the actual value already, a warning of roadway frost is also issued.

A warning of black ice is issued if the roadway condition is “moist” or “wet”.

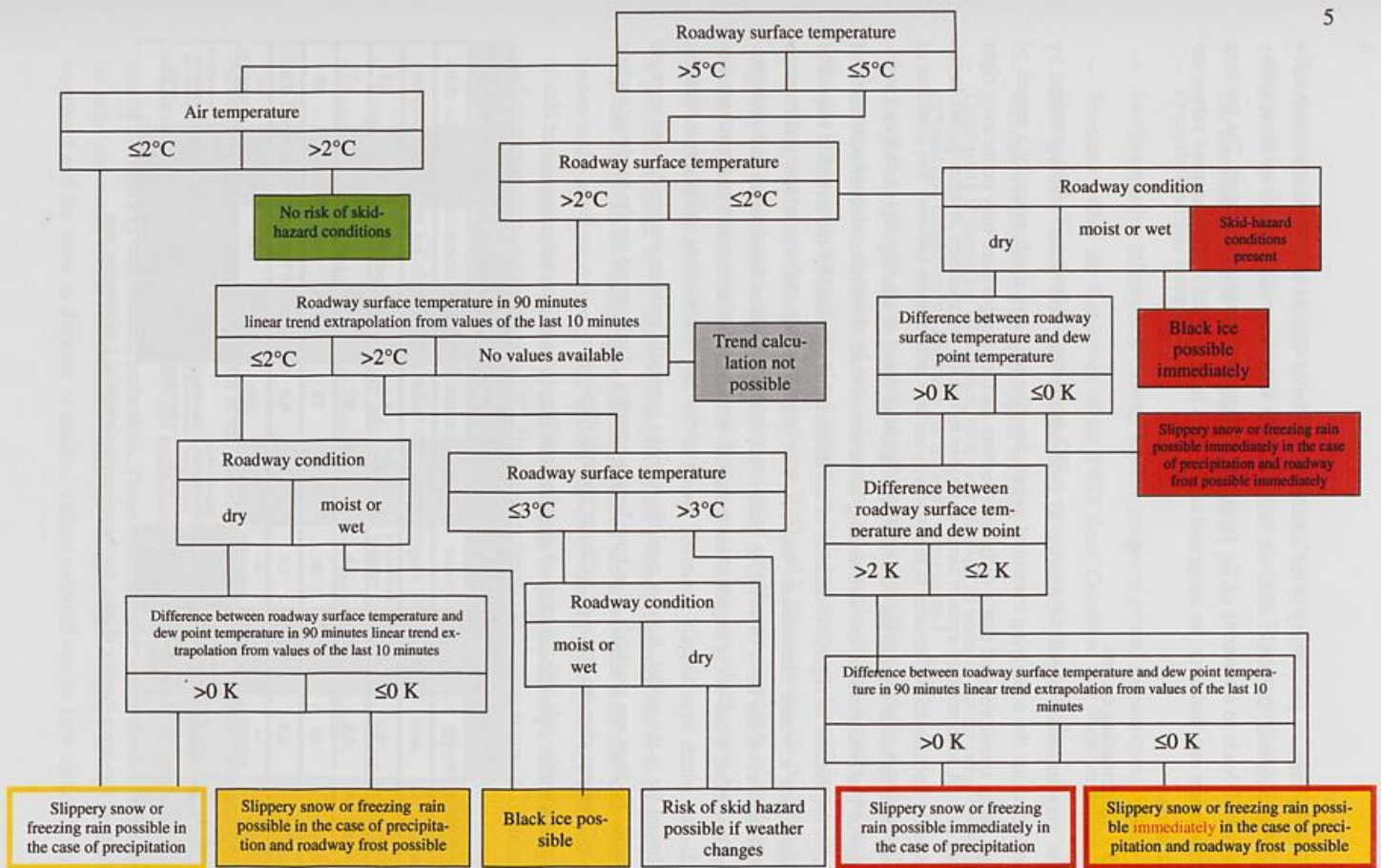


Figure 3: Skid-hazard warning model on the basis of road weather systems

Owing to the low plausibility of the results of sensors of various manufacturers which have been investigated, the model does not allow for salt which has been spread on the roadway and which leads to a lowering of the freezing temperature of existing moisture. The freezing temperature can, however, be integrated at any time in the model if the measured values are plausible.

2.3 Information on use

One very important aspect in relation to evaluation of the skid-hazard warning issued by models is that the underlying measured values describe only one single point for a stretch of road being monitored and that a different roadway surface temperature may occur even right next to it. A road weather system alone is unable to record the situation at other points in the network. Substantial differences in the roadway surface temperature between two stretches of road close by occur even in the case of differing cloud cover or shading. This is why a knowledge of the behaviour of the surrounding stretches of road in various weather stations is of major importance as regards evaluation of the information provided by the model in respect of dispatching a winter maintenance call-out. The person responsible for winter maintenance must decide, on the basis of situation (measured roadway surface temperature and precipitation), whether a call-out is required. He must also include in his decisions winter maintenance call-outs which have already occurred, owing to the fact that freezing temperatures are not allowed for in the model. It is not possible to make generally valid recommendations since no precise findings are available as to how long a quantity of salt spread on the roadway surface is still present after the action of traffic or precipitation.

Figure 4 shows a possible display of measurement data in an area to be monitored.

	Oberaudorf	Kiefernfelden	Dettendorf direction Salzburg	Dettendorf direction Munich	Autobahn- dreieck Rosenheim	Innbrücke Rosenheim	Prienbrücke direction Salzburg	Prienbrücke direction Munich	Bernauer Berg
roadway surface condition	2,6	2,2	1,0	2,6	3,5	-1,6	6,0	-2,5	1,5
roadway condition	moist	dry	dry	dry	moist	wet	wet	slippery	dry
freezing point	-3,3	no measuring possible	no measuring possible	no measuring possible	-5,5	-15,0	-3,0	-1,5	0,0
air temperature	2,0	1,0	2,5	3,0	5,0	-1,0	5,0	-1,0	2,0
relative humidity	86	99	95	87	75	98	97	99	58
dew point temperatur	-0,1	1,1	1,8	-0,2	4,0	-1,2	-2,8	-1,5	-3,0
precipitation	no precipitation	no precipitation	no precipitation	no precipitation	rain	snowfall	rain	snowfall	no precipitation
Skid-hazard warning on the dates of last 10 minutes	Black ice possible	Slippery snow or freezing rain possible in the case of precipi- tation and road- way frost possible	Slippery snow or freezing rain possible immediately in the case of precipitation and road-way frost possible immediately	Slippery snow or freezing rain possible in the case of precipitation	Risk of skid hazard possible if weather changes	Black ice possible	no risk of skid hazard	Black ice possible	Slippery snow or freezing rain possible in the case of precipitation

Figure 4: Specimen monitor display for the measuring points in a monitoring area

It is necessary to use other sources of information on the current weather situation and its development for an estimation of the risk of skid hazard resulting from weather changes, e.g.:

- The measured values of the surrounding measuring points
- Precipitation radar images
- Satellite weather information (linking satellite images to ground measurement results)
- Forecasts within the framework of the SWIS Road Condition and Weather Information System of the German Meteorological Office or systems of other providers
- Weather warnings from meteorological services
- Third-party information (the police, motorists phoning to warn of traffic jams, breakdown services and neighbouring highway surveillance centres etc.)

It is possible to estimate more reliably how the roadway conditions and the weather will develop only by using as much of this information as possible. If, for instance, the satellite weather information indicates no cloud formations, it is not necessary for call-outs to be dispatched at roadway surface temperatures below 0 °C and if the air is dry. On the other hand, precipitation radar images or the measuring points of neighbouring stretches of road may indicate an approaching weather front even though no precipitation which could lead to a skid hazard is yet falling in the area being monitored.

A plausibility check of the model developed by the Federal Highway Research Institute with real data from various measuring points has indicated that it provides correct reports with reference to the anticipated type of skid hazard. The early warning times prior to a reported case of skid hazard were, in some cases, very long owing to the primary decision with the roadway surface temperature above/below +5 °C. However, extremely short time spans (< 10 minutes) until a reported, immediately possible case of skid hazard also occurred in very few cases. In such cases, undercooled precipitation had fallen on a roadway surface whose temperature dropped by almost 5 Kelvin within a few minutes owing to this event.

Consequently, users of the model are advised, at all times, to watch out for up-to-date information on weather changes which road weather systems are unable to indicate.

3 De-icing agent spray systems

Ambient and roadway condition data is still used by meteorological services for control of de-icing agent spray systems. De-icing agent spray systems are systems used by stationary winter maintenance intended to complement the snow clearance and de-icing agent application call-outs of the highway maintenance authorities. These systems make winter accident black-spots far safer and avoid traffic obstructions. Black ice which occurs suddenly can be effectively countered and the snow in the case of sudden, violent snowfall can be kept clearable by the

use of a de-icing agent spray system until the clearance vehicles arrive, thus allowing slippery snow to be avoided.

De-icing agent spray systems make a contribution towards speeding up winter maintenance overall in extreme weather conditions, which keeps traffic flowing more easily by avoidance of queues and traffic jams and helps to reduce overall economic loss. Operational savings can be achieved by dispensing with preventive winter maintenance call-outs, additional monitoring trips and also by staff not having to remain on standby at stretches of road subject to the risk of skid hazard.

Operation of a de-icing agent spray system is largely tripped automatically but can also be tripped manually. Incipient skid hazards are detected by a computer-aided road weather system, which by measuring the roadway condition and ambient data, trips a spraying operation if the risk of skid hazard is acute. Both data from conventional ground sensors for determining roadway surface temperature and freezing temperature and roadway humidity and meteorological sensors for air temperature, precipitation and relative humidity are included in this.

4 Summary

Road weather systems represent an indispensable element for winter maintenance control on federal highways in Germany, despite certain imponderables described. The measured data which they are used to obtain provides a far better knowledge of the roadway condition and weather parameters in the road network. In turn, this allows preventive measures to protect against the occurrence of skid hazards to be taken in targeted manner, thus making an essential contribution towards maintaining traffic and road safety and traffic flow on the most densely used roads.

The measured results of the sensors directly trip the operation of de-icing agent spray systems at stretches of road which are particularly subject to the risk of skid hazard.

One other advantage of the improved state of knowledge is the fact that it allows more accurate deployment of human resources in relation to scope and time of winter maintenance. In general, the resultant, targeted call-out saves substantial human resources costs.

Average Diurnal Temperature Devolution for Different Weather Situations - a Prognostic Aid for Regions with Complex Topography

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Introduction

The air temperature and the amount of clouds are the most important meteorological parameters determining the condition of a road. In most cases the amount of clouds can be well estimated by the regional weather forecast models. The temperature shows larger differences between different locations, because it is a product of several elements, for example the altitude. Temperature also varies between day and night considerably.

The diurnal devolution of temperature in mountainous regions is dependent from the location of the measuring station. Especially in the winter season, when the position of the sun is low, the exposition has a great influence to the temperature. On sunny days in the afternoon a south faced slope is about 3 or 4 degrees warmer than a north faced slope. The steepness of a valley is even more important. In narrow steep valleys the night is very less cold than a flat opened valley. Another important factor is the tendency to fog conditions. When a station is situated near a river or a lake, there are more days with fog than in other locations, especially with anticyclonic weather situations. Also, if the weather is determined by strong winds, temperature and other climatic elements would have large variations between different stations, because the mountains induce Foehn- and barrage effects.

The study region

The region of this study is the canton Lucerne in the centre of Switzerland. Its size is about 1400 qkm. The altitude of the stations differs between 400 and 800 m.a.s.l.. 3 different stations were choosen:

1. Wigger
2. Rickenbach
3. Weggis

Wigger has an altitude of 800 m. a. s. l. in a flat, open valley. During the night on clear sky conditions there is a strong inversion or in other words a regional lake of cold air. On the other hand, fog occurs very rarely. Rickenbach is situated on 700 m. a. s. l. or 250 or 300 meters above the deepest locations of the canton Lucerne. The terrain of this station is rather sloped. Therefore, inversions are in the most cases inexistent. The altitude of the station Weggis is 450 m. a. s. l. The lake of Lucerne is situated only several 100 meters from this station. Due to the higher humidity in the air, fog is very common, but temperature inversions are weakened by the influence of the lake.

The climatic differences

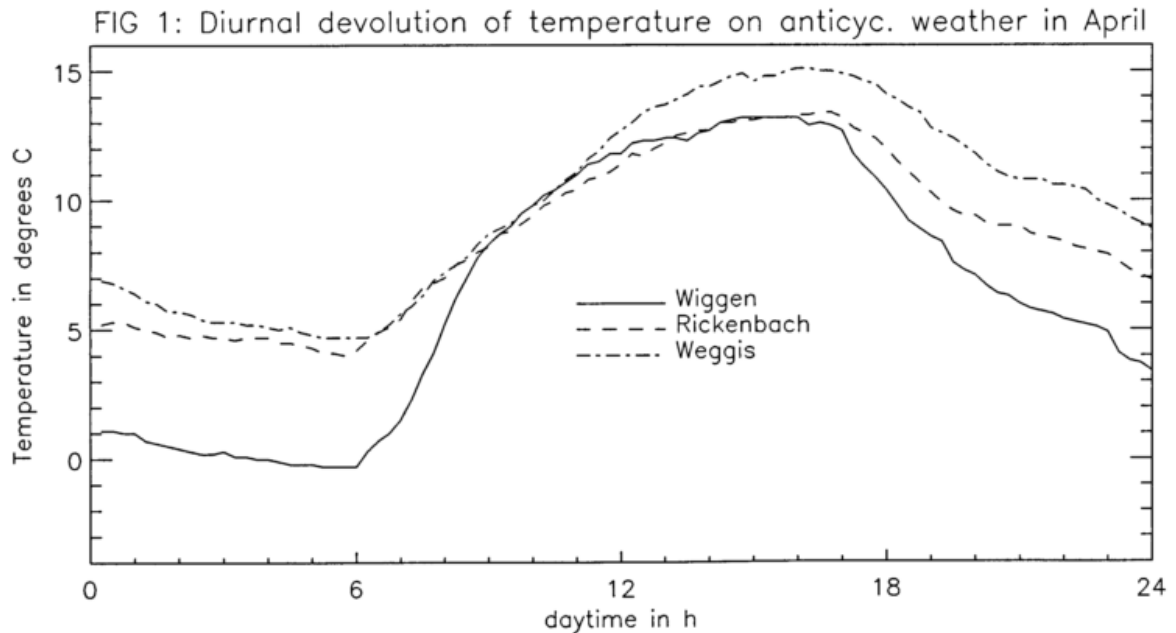
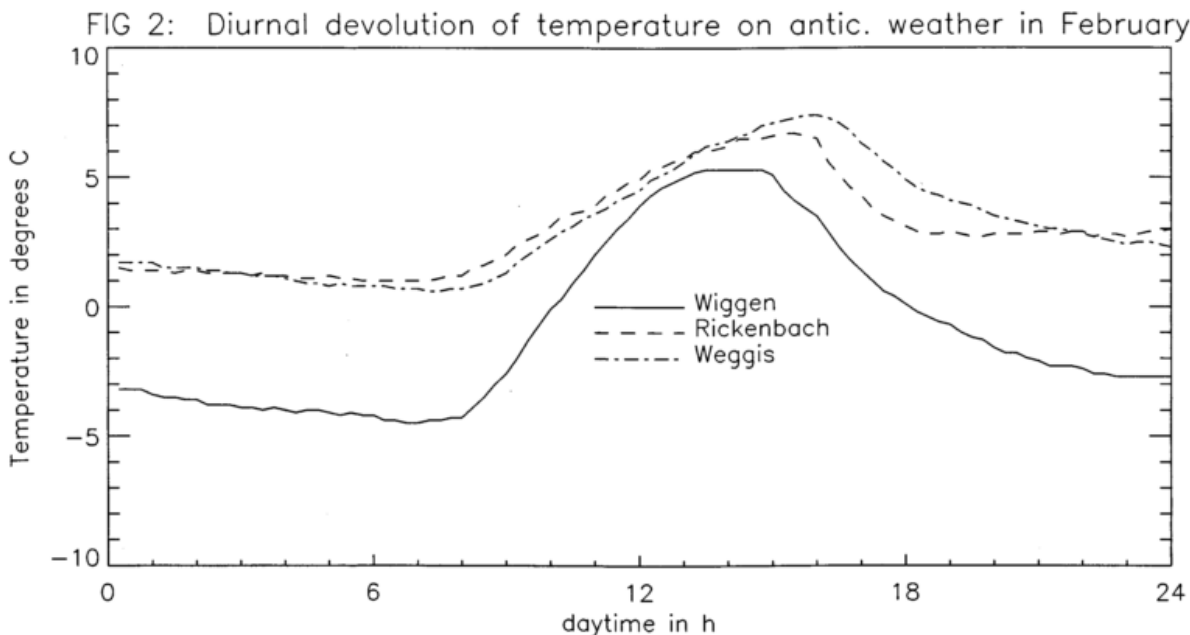


FIG 1 shows the temperature devolution on high pressure conditions in April. Due to the high positive net radiation during the day, the temperature arises strongly until the afternoon. The temperature amplitude decreases with altitude, because stations at higher altitudes are better ventilated. So Weggis shows the higher diurnal temperature variation than Rickenbach. Especially in the afternoon, when the atmosphere is well mixed, Rickenbach is cooler than Weggis. At night the difference is rather small, because at night the atmosphere is more stable due to the large outgoing long wave radiation of the earth surface. Wigen shows at night different temperatures than Weggis or Rickenbach. In Wigen the lake of cold air induces about 5 degrees deeper temperatures than Rickenbach, whereas during day, Weggis and Rickenbach have almost the same values.



On FIG 2, the diurnal devolution of temperature on high pressure conditions in February are plotted. Due to the deeper position of the sun the warming during the day is reduced compared to April and the amplitudes are 2 degrees smaller. The stable atmospheric condition during the night does not completely disappear until the afternoon. Hence, Weggis and Rickenbach have almost the same temperatures. Wiggen, on the other side, is 5 degrees colder during the night than the other two stations due to the lake of cold air.

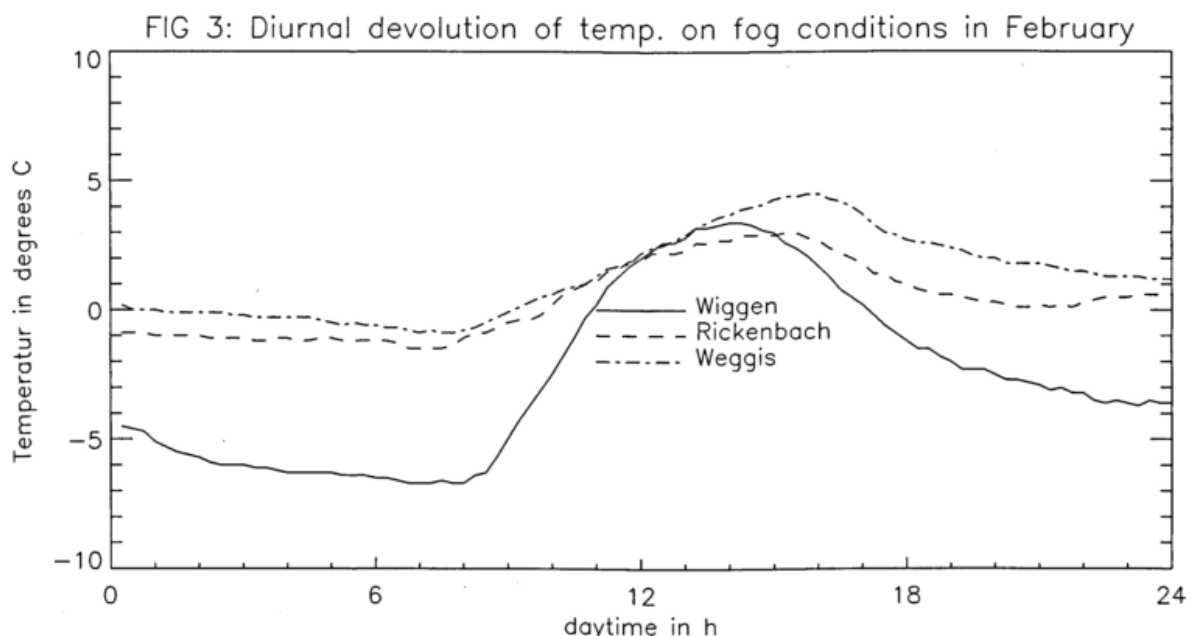
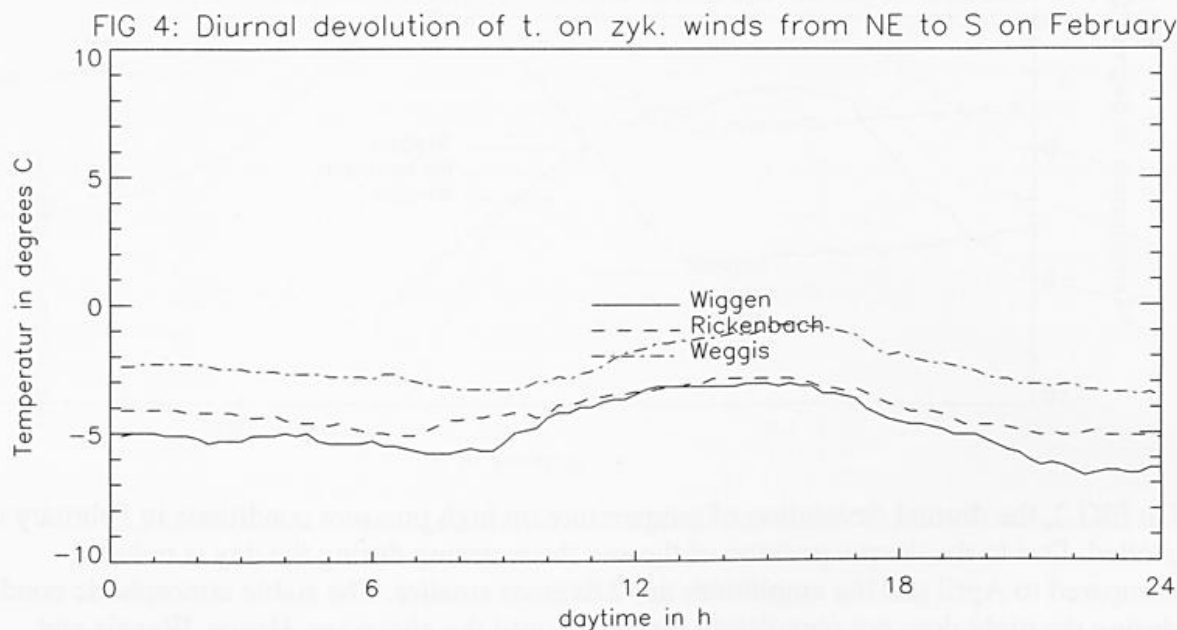


FIG 3: During high pressure weather fog occurs in the deeper regions most of the time in winter. This fog has a top of 600 to 700 m. a. s. l. In that case the temperature amplitudes are a little bit smaller than at clear sky weather. But the difference is not very great, because the small fog layer cools down almost so strong like the earth surface on clear sky conditions. On the other hand, in many cases the fog resolves during the morning in February and the shortwave incoming radiation can heat up the air. Wiggen, which is situated on 800 m. a. s. l.,

has no fog in such weather conditions. Under this condition a lake of cold air that establishes during the night, too.



As Fig 4 shows, there are totally other temperature devolutions by cloudy and wet weather. If region has this weather type, cyclonal winds come from the sectors Northeast and South. Then, the amplitude of the temperature during the whole day is with 2 degrees only very small. In Wigen, there is no lake of cold air, and the temperature in Wigen and in Rickenbach are almost the same. Weggis has the same amplitude like the other two stations, but the temperature is 2 degrees higher. Therefore, the vertical temperature gradient is about 0.7 degrees of 100 m, which is normally the case for cloudy and wet weather conditions.

Conclusions

The advantage of climatology for different weather conditions consists of the knowledge of the diurnal temperature devolution due to the radiation type. They are always in the same ranges at specific weather types and months. Especially at cyclonal weather conditions the the advection of colder or warmer air masses has to be considered. But this changes of air masses can be estimated from the weather forecast models. If the time interval and the amount of advection are known, they can be added to the diurnal temperature devolution due to the radiation. In most cases, with this procedure a fairly good temperature forecast for the next 12 or 24 hours can be obtained.

If the weather conditions are known, the forecaster has not to worry about local climatological phenomena, because they are almost the same in a specific weather type.

The same procedure as the determination of the temperature can be made with the dewpoint. For other parameters, such as wind, at least a qualitative information could be obtained.

The implementation to an automatic forecasting procedure is planned at MeteoSwiss forecasting centre in Zürich.

TOPOGRAPHICAL BOUNDARY LAYER MODEL FOR ROAD WEATHER PREDICTION

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ABSTRACT

This paper describes a boundary layer model for the localization of synoptic model predictions. The local area-elevation distribution of topography and its soil characteristics are considered, convection is calculated explicitly, and the cloud effect on diurnal and nocturnal radiation transfer is treated in detail. Model forcing with local measurements is useful and the prediction range covers day and night with any atmospheric stability. Predictions of road surface temperatures and local fog formation and dissipation can be expected from such a model.

1 INTRODUCTION

The localization of meteorological predictions from the synoptic scale down to particular sites like roads, bridges, and airports remains a challenging task for the weather community (Chapman and Thornes, 2002; Bogren and Gustavsson, 2002; Sass, 2002). Atmospheric processes of sub-synoptic scale must be considered and local topography is of crucial importance. Heating and cooling is controlled by radiation and thus affected by clouds, soil characteristics, and local topography. A successful technique developed for the prediction of regional convection in aviation meteorology has the potential to improve predictions for local road and airport weather.

2 LOCAL WEATHER PREDICTION WITH A BOUNDARY LAYER MODEL

Nested synoptic models (SM) take care of predicting atmospheric processes on a global and national scale. Locally a SM can provide the advection of weather. Boundary layer processes like convection, turbulence and pooling of cooled air can not be calculated explicitly in synoptic models if they are to be used for predictions.

For local weather phenomena the boundary layer processes must be considered and the local topography taken into account. Localized boundary layer models (BM) can focus on the vertical dimension. This allows the detailed calculation of convective mixing as a cloud formation and dissipation process. The horizontal dimension of a localized BM can be very close to zero, as long as areas with horizontally homogeneous atmospheric conditions are to be looked at.

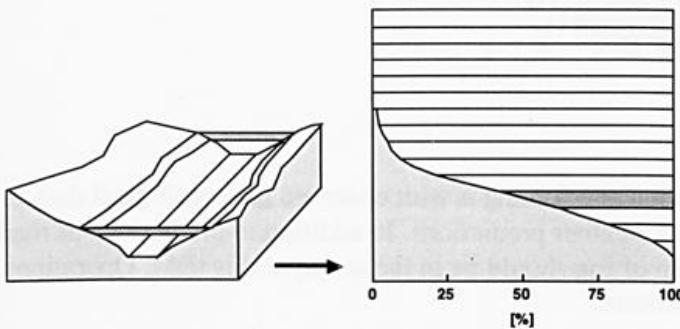


Fig. 1 Area-elevation distribution in complex topography

The local area-elevation distribution (Steinacker, 1984) of complex topography, however, is a key element to localization and should therefore be considered for local weather prediction with a BM. A BM with such a representation of topography shall be denoted as a **tBM**. Surface heating and cooling in a tBM will occur at the correct altitudes and the atmospheric mass will depend correctly on altitude (Figure 1). The volume effect will be present in such a model (Liechti *et al*, 1994). By retaining the topographical area-elevation distribution the nocturnal formation of cold air pools in basins can be treated with a tBM.

The horizontal extension of the model area depends on the requested horizontal homogeneity. An area of e.g. 7x7 km² – corresponding to a single grid-point of a routinely used synoptic model – may have an area-elevation distribution that differs significantly from a flat surface. Soil characteristics like albedo, evaporation, and ground heat flux may then vary with altitude.

A tBM coupled to a SM for advection has been in operational use at several national weather services since 1995 and produces diurnal convection predictions for soaring (Liechti, 2002). The obtained quality is sufficient to offer meteorological flight planning (Liechti *et al*, 2003) to glider pilots based on these regional forecasts. Region size in this application is on the order of 5000 km² with smaller regions in alpine topography.

A further tBM has been developed in order to simulate the nocturnal cooling over complex topography. The infrared radiation processes in a cloudy boundary layer were implemented and the vertical resolution refined to 10 m in order to apply it to areas on the order of 100 km² (Figure 2). Nocturnal cooling with and without fog can be simulated for complex terrain on a local scale.



Fig. 2 Scale for local predictions with a tBM

Coupling this tBM to a synoptic model for advection and forcing it with observed meteorological data will allow its application for local road and airport weather predictions. In addition to predictions of road surface temperatures the formation and dissipation of fog should be in the scope of this tBM. Operational application will show its potential for local predictions.

3 CONCLUSION

Nocturnal cooling and diurnal heating in complex terrain can be calculated with a topographical boundary layer model. Air temperature and humidity predictions can be localized to scales useful for road and airport operations. Significant improvements can be expected from such a meteorological model for predictions of local fog, visibility, and road surface temperature.

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Submitted Papers Topic III:

Sensors and Equipment

- (III-1) Deckert/Hauf (D): An experimental Study of Drying-Up Paved Surfaces
- (III-2) Lahtinen/Kantonen (FIN): Finish Road Weather Camera System
- (III-3) Paulsen/Schmokel (N): Laser Road Surface Sensor LRSS
- (III-4) Badelt/Seliger (D): Testing Sensors for Road Weather Systems
- (III-5) Almkvist (SWE): Detailed climatic Measurements above and beside the Road

An experimental study on drying-up paved surfaces

Rudolf Deckert*and Thomas Hauf†

30th November 2003

1 On the representativeness of road condition measurements

The quality of automatical road condition measurements depends i. a. on the road condition's spatial inhomogeneity. The state of dampness on a road, for instance, is usually quantified from routine observations involving water film thickness measured at a point of the road surface (Norrman, 2000). However, due to the spatially varying water film thickness on a road the representativeness of such measurements for a larger road section may be questionable.

When measuring evaporation rates at a moist road surface the eddy correlation technique might provide an advantage. It implicitly integrates over a large surface area (Schmid, 2002) and thus over spatially inhomogeneous road conditions, i. e. dry patches. On the other hand the representativeness of such measurements is problematic if used in connection with areas of limited extent (Foken and Wichura, 1996). Wojcik and Fitzjarrald (2001), for example, used an eddy correlation technique in order to obtain evaporation rates from a concrete bridge. The measurements turned out to be strongly influenced by the bridge's surrounding area.

This study addresses the use of a water film sensor and an eddy correlation system for a better quantification of the drying-up process on paved surfaces. A field campaign is undertaken. The resulting data are assessed concerning the water film sensor's performance, and the representativeness of both, water film thickness and evaporation rate measurements.

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2 Methods

2.1 The water film sensor FP2000

Texture and colour of the MicKS FP2000 water film sensor are designed to imitate a true road surface. The device is reported to measure calculational water film thickness in a range from 0 mm to 3 mm at a resolution of 0.01 mm and a relative accuracy of 20%. A sensor calibration was undertaken at the Bundesanstalt für das Verkehrswesen, Bergisch-Gladbach / Germany. The applied calibration procedure is standardised and described in Badelt et al. (2002). With the tested sensor, however, reproducibility was weak for reasons which remain unclear (see Figure 1). Therefore, a composite calibration curve was taken and used during all further calculations. The temporal change of calculational water film thickness can be determined more accurately since among the individual calibration curves the slope differs not as greatly as the value.

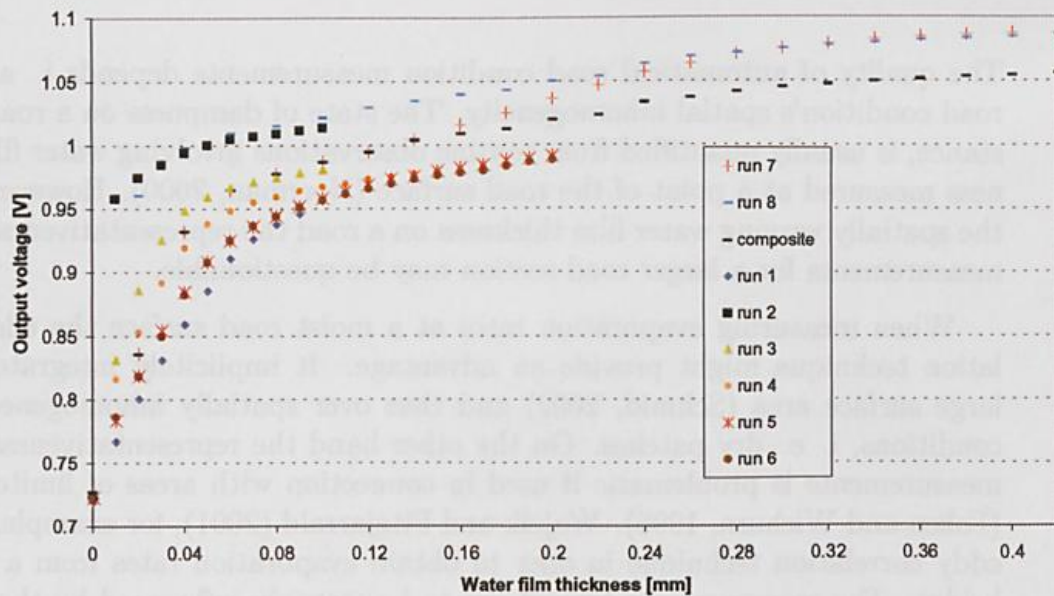


Figure 1: Calibration curves for the water film sensor.

2.2 Eddy correlation technique

The eddy correlation technique can be used for obtaining evaporation rates from a simultaneous high-frequency measurement of vertical wind velocity w , and water vapour density ρ_v . Evaporation rates are calculated from $\overline{w'\rho'_v}$, where $w' = w - \bar{w}$



Figure 2: Measuring mast and box. The mast is equipped with a sonic anemometer/thermometer, a Krypton hygrometer, and a sensor for mean temperature/relative humidity (from right to left).

represents fluctuations in vertical wind velocity, $\rho'_v = \rho_v - \bar{\rho}_v$ fluctuations in water vapour density. The overbars represent a temporal mean of 1/2 h. Thus, one single evaporation rate value is based on a half-hour measuring "history".

The measured evaporation rates are associated with a certain area on the ground. That source area can be interpreted in analogy to the "field of view" of a measuring instrument (Schmid, 1997). Only if the source area is located roughly within the surface of interest the measurements will be representative of the latter. The source area's size and location depend on mean wind direction, measuring height, atmospheric stability and roughness of the surface.

The eddy correlation system used in this study (see Figure 2) consists of a METEK USA-1 ultrasonic anemometer/thermometer and a Campbell KH20 Krypton hygrometer. The sampling frequency is 20 Hz. For the given set of measuring devices the measuring height should not be lower than about 2.5 m in order to prevent for large measuring errors. The latter result from line averaging due to the anemometer's path length and from de-correlation due to the anemometer-

hygrometer sensor separation. A continuous operation of the eddy correlation system remains limited due to window scaling of the Krypton hygrometer and a large amount of measuring data per hour.

3 Field campaign

3.1 Measuring site

The measurements took place on the air field of a military airport at Bückeberg, Niedersachsen/Germany. The air field is situated on flat terrain, about 70 m above sea level. The measuring devices (red plus signs) are located at the eastern end of a large paved area (see Figure 3). The concrete surface consist of 5m x 5m plates showing a bright-grey colour. The joints between the concrete plates are sealed with black tar. The tarmac surface shows a dark-grey colour and reveals a greater roughness than the concrete plates. The wind field can be expected to be fairly undisturbed by obstacles if the wind comes from WSW.

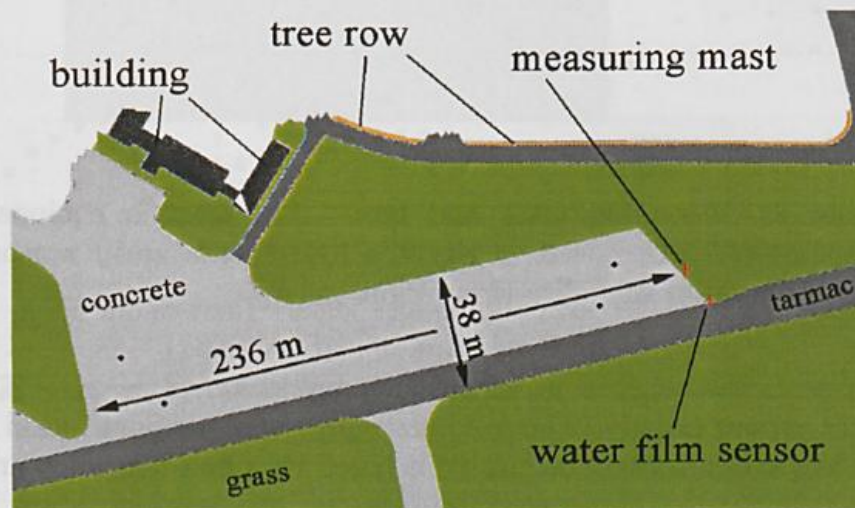


Figure 3: Plan of the measuring site [adapted from Vermessungs- und Katasterbehörde Schaumburg (2003)]. North is up.

3.2 Location of the measuring devices

The water film sensor was placed on bare soil next to the paved surface and the area around the sensor was poured with concrete (see Figure 4). Characteristics of the poured concrete such as heat capacity and heat conductance may be quite different from those of the large paved surface.



Figure 4: Water film sensor (dark round circular area). The sensor is located next to the paved surface. Sections of the grass-grown, concrete (grey) and tarmac (dark-grey) surfaces can be seen as well.

The eddy correlation mast was placed over grass 3 m away from the concrete surface. It was expected that this distance from the paved surface would not influence the flux measurements greatly.

3.3 Measurements

Measurements took place on 13 days between the 6th of March and the 5th of June 2003. Favourable weather conditions were associated with an alternation of sunshine and precipitation events, and a steady WSW wind direction.

4 Results and discussion

4.1 Water film sensor

Figure 5 shows time series of calculational water film thickness as determined by the FP2000 water film sensor. The linear decline is followed by a rapid reduction of water film thickness, resulting in a dried-up sensor surface within five minutes. In general, the water film sensor signal can be divided into a roughly linear part and a non-linear part. The linear part continues as long as the sensor surface is covered by a homogeneous water film. This linear decline is expected since the potential evaporation rate is usually not subject to great changes within an interval of a few minutes (Brutsaert, 1984). The non-linear part starts as soon as dry patches appear on the sensor surface, and ends with a completely dried-up sensor surface. During this phase the sensor signal depends mostly on the area of the water film on the sensor surface. In most cases, the phase of rapid reduction replaces the linear decline entirely

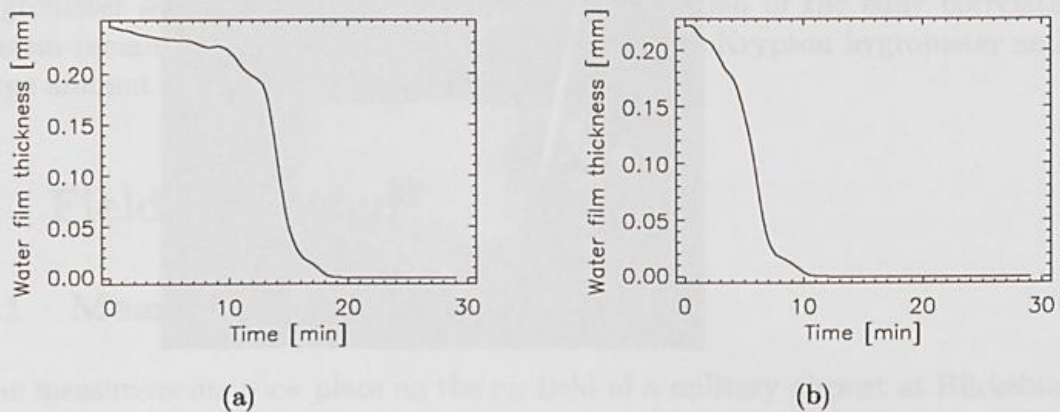


Figure 5: Calculational water film thickness as a function of time.

4.1.1 Temporal and spatial representativeness with regard to the paved surface



Figure 6: Water film sensor and the surrounding paved area. The sensor has dried-up even though the paved area is still moist.

Figure 6 shows both, the water film sensor and the surrounding paved surface. The sensor has already dried-up even though the paved surface is still covered by a non-disrupted water film. The possibility of additional heating due to voltage supply is unimportant since the sensor surface's drying behaviour was checked while being switched off. Reasons for the short drying-up time of the water film sensor surface might be identified in a small water storage capacity due to small roughness and zero porosity, a greater heat storage capacity, or an enhanced evaporation rate due to a disturbance of the wind field close to the sensor surface.

In addition, any spatial representativeness of the sensor is confined to the time prior to the first appearance of dry patches on the paved surface. The area of an individual dry patch quickly becomes greater than the area of the water film

sensor. Furthermore, temporal development and initial location of the patches vary depending on the atmospheric conditions.

4.2 Eddy correlation system

Evaporation rates were obtained from eddy correlation measurements. They turned out to be greater for the paved surface being moist (0.128 mm/h to 0.268 mm/h) than for the surface being dry (0.025 mm/h to 0.111 mm/h). Due to a missing possibility of comparison the rates could not be checked thoroughly. However, it is the spatial representativeness of the measurements which is of main interest here. Non-zero evaporation rates despite of a completely dry surface point towards an upstream source area which is not confined to the paved surface, but extends into the surrounding evapotranspiring grassland.

Here, the term fetch is referred to as the distance along the horizontal mean wind direction, from the edge of the paved surface (see Figure 3) to the measuring mast. Accordingly, the fetch varies with mean wind direction, and can obtain a maximum value of about 236 m (see Figure 3). A conditional sampling technique provides evidence that for a large fetch the paved surface dominates the evaporation rates (source area inside the paved surface), for a small fetch the grassland (source area outside the paved surface).

5 Conclusion

Difficulties occurred during both calibration and operation of the FP2000 water film sensor. Reproducibility during the calibration was weak. During the measuring campaign the sensor surface dried-up much quicker than the paved surface. In general, any spatial representativeness of the sensor is confined to the time prior to the first appearance of dry patches on the paved surface.

Concerning the eddy correlation technique there is evidence that the measured evaporation rates reflect a composite of paved parking area and surrounding grassland, but not the parking area alone. Non-zero evaporation rates despite of a completely dry surface point towards an upstream source area, which extends into the evapotranspiring grassland. Furthermore, a conditional sampling technique provides evidence that for a large fetch the paved surface dominates the evaporation rates, for a small fetch the grassland.

5.1 Recommendations for future work

All measurements were undertaken next to a large paved surface without any influence of traffic. However, according routine measurements at a real road

impose additional difficulties:

- The water film thickness measurements should be based on a non-contact principle. This allows a greater sensitive area. The influence of traffic (i.e. shadowing by vehicles) on the non-contact water film measurements has to be taken into account.
- The eddy correlation measurements should be undertaken at a measuring height lower than 10 cm in order to locate the source area within the road surface (Bogren et al., 2001). Thus, a different set of measuring devices is necessary with a smaller path length and smaller sensor separation. The measurements might be affected by the influence of traffic and two or more independent measuring systems are necessary in order to account for all wind directions.

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Finnish Road Weather Camera System

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Introduction

In Finland, road weather information system has been gradually developed since the beginning of the 1980s. The first road weather cameras were taken into use in 1992 to complement the road weather station network. Since then the number of cameras has increased yearly – at first just a couple of units per year, recently at a pace of about 25–30 units per year. There are already 250 road weather cameras (figure 1) along the Finnish roadsides and there is need for about a hundred cameras more to cover the road network properly.

The first road weather cameras were acquired solely for road condition monitoring purposes and were directed down at the road surface. Later they have been used also for traffic monitoring, especially in the capital area, and hence are directed further, still avoiding showing skyline. The images can be utilized in professional use (traffic information centres and winter maintenance contractors) and also in public communications, for example road weather images are the most popular pages at Finnra's Internet site along with the road weather conditions pages and traffic situation information pages (<http://www.tiehallinto.fi/alk/english/>)

A short history of techniques used

The first road weather cameras were either colour cameras in places with road lighting, or black and white cameras with infrared light in places with no road lighting. They had fixed focal length optics and their angles of view were also fixed. The cameras had specially designed housing with heated front pane. At sites, there were ordinary PCs with modems and special video capturing cards with their own special software. They were placed in device cabinets made of stainless steel. At the office end, a PC with DOS command scripts retrieved the images with a modem. The same computers also had an application for viewing the



Figure 1. Finnish Road weather cameras (12/2003)

images. An Image Product application was introduced in the beginning of 1995 thus making it possible to view the road weather camera images also with other computers.

A need for traffic monitoring as a secondary use for the road weather cameras, arose in the middle of the 1990s. On line connections had to be arranged to certain cameras. Thus, 'SafeNet'-concept was introduced in Finnra. The new colour cameras had varifocal lenses, pan & tilt devices and a preset positioning feature. Preset positions were made for still images – the camera was directed to a certain preset before retrieving the image. On live connection the camera could also be controlled (pan, tilt, zoom, focus) manually. A couple of starlight cameras were also tested with this system, but the quality of the images was poor both day and night. At sites, there were PCs with Integrated Services Digital Network (ISDN) -cards and special software. At the office, ISDN-cards and special applications were needed for live connections to view the dpeg stream from the cameras. The live video stream quality was quite good. The cameras accepted calls only from pre-defined phone numbers.

The data collection application that is a part of the Finnish RWIS and is used for collecting data from the road weather stations was modified to be able to collect the SafeNet road weather images.

The new video server concept for road weather cameras

The SafeNet system was not as reliable as it was expected to be, and also the development and support of the system ended at the end of 1990s, so this concept was also becoming obsolete. At the same time the demand for road weather camera images boomed, and a sustainable development had to be guaranteed.

A survey was given to find a suitable solution. The requirements for the new equipment/concept were: still images of good quality, reasonably good live stream, easy maintenance and remote configuration. Axis 2401 video server (www.axis.com) was picked for further testing and then accepted to be the new video server concept in Finnra.

Axis 2401 video servers (picture 1) support common pan & tilt devices and also preset positioning. Thus, almost any available camera and pan & tilt device can be used with them, if only all the other requirements for the equipment are fulfilled. Axis servers enable single snapshots and motion JPEG images with user controlled compression level. They can be easily configured with a web browser. Axis video server has also a relay output, and in road weather cameras it is used for invoking the infrared light.

Axis servers needed to be connected to a local area network (LAN), so there had to be a PSTN (Public switched telephone network) or ISDN router, depending on the connection type at the roadside. Also Asymmetric Digital Subscriber Line (ADSL) and LAN connections could be used, and they proved to be cost effective, especially in viewing the live stream (25 - 30 frames per second if enough bandwidth available) in traffic information centres. For live viewing the only requirement apart from the actual connection is an ActiveX component added to web browser.

Axis, besides the many good qualities, has a disadvantage compared to prior concepts: the operating temperature has to be over +5°C. Finnish winters are a great challenge to road weather cameras' equipment in general, and to Axis video servers in particular, so heating

elements and isolation had to be added to the stainless steel device cabinets at roadsides (picture 2). Most of the old road weather camera PC's were updated to Axis in quite a short time.



Picture 1. Axis video server



Picture 2. Device cabinet at roadside

The data collection application was modified to be able to collect the Axis based road weather images. Images are retrieved from Axis video server with http-commands. Also the pan & tilt devices, as well as the infrared lights, can be controlled with http-commands, so it is possible to direct the camera to the desired direction and to invoke the infrared light before retrieving the image.

New road weather cameras

In the beginning of year 2000 there was a competitive bidding on cameras. A general agreement for acquiring cameras and optional pan & tilt devices, as well as routers and other equipment needed, was made for two years. Also a general agreement on service and maintenance was negotiated with the same vendor.



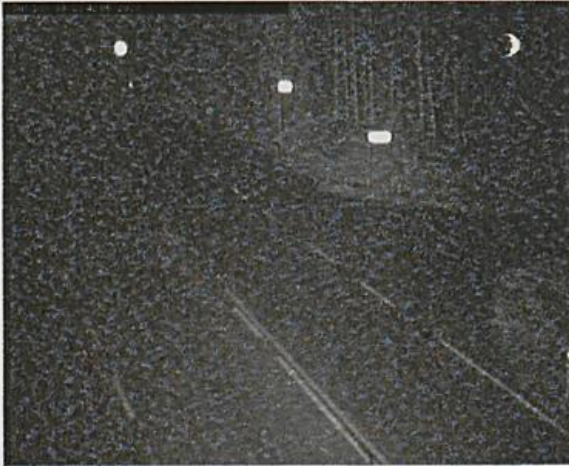
Picture 3. Testing cameras at site, 2003



Picture 4. Camera at site (device cabinet opened)

The first two year general agreement expired in 2002 and again a competitive bidding was arranged. This time the basic technique was already fixed, so the attention could be fully focused on quality and properties of the cameras, optics and pan & tilt devices. It was especially important to ensure good image quality in poor lighting conditions. Also the matter of the housing being waterproof and sufficiently heated was of consequence.

The tenders and their products were compared first on paper, and after that the best four cameras were chosen to be taken into a field test. The cameras and the pan & tilt devices were tested for a fortnight in winter in different weather and lighting conditions (picture 3). The camera that was finally chosen was superior at night. On daylight all the cameras tested produced images of almost equal quality.



Picture 5. Old camera with infrared light



Picture 6. New camera with infrared light

Placing the road weather cameras

The road weather camera images are primarily for road maintenance use, observing road conditions and weather by road maintenance contractors and in traffic information centres (TIC). Also the traffic monitoring use of the cameras in TICs is becoming more and more important. Keeping in mind those main purposes, the road weather cameras are placed on the road network

- to complement the road weather station (RWS) network with cameras,
- to help maintenance in special places (e.g. slippery hills, special micro climates),
- for traffic surveillance (bypasses of cities) and
- equal treatment of contractors (there should be some road condition monitoring devices in every contractor's area)

Electricity is obligatory and also some form of telecommunication, be it fixed or dial-up. The cameras can be installed on lamp posts or portals, also specially built steel masts are commonly used. The camera is normally installed about eight metres above the road level. The height can, however, vary quite a lot depending on the site, the height of the neighbouring light poles etc. It is good to place the camera as high as possible, so the car headlights will not blind the camera so easily. A slight uphill angle of view is beneficial for the image. The cameras should preferably be installed at places with road lighting, but also infrared lights have been and will be used. Fortunately, the new cameras work well with infrared light.

The first fixed cameras were directed down to observe the road surface (picture 7). Nowadays the cameras are directed higher, in the lower part of the image one can see clearly the road surface, and the upper part of the image shows the road a bit further and also the traffic (picture 8). If the camera has pan& tilt device and suitable preset positions are made, it is also possible to get images from more than one preset position, for example east, west and road surface.



Picture 7. Observing road surface



Picture 8. Observing road surface and traffic situation

Collecting images

The data collection has been decentralised to road regions in order to keep the telecommunications costs lower. There are nine servers around the country to collect the road weather station data and the road weather images using PSTN and ISDN lines, so no trunk calls are necessary. ADSL connections have also become reasonably priced and widely available and used.

The frequency of collecting images can be varied automatically according to weather, thus adding the cost-effectiveness. The computing application, that is used to calculate the recommendations to the variable speed limit signs, can also calculate the suitable collecting frequency for the road weather stations and road weather cameras. The equation is based on data from road weather stations, and the worse the weather is, the more often the images are collected. The collecting times vary from 15 to 120 minutes, 15 minutes being used at extremely bad weather and 120 in summer time. The ADSL and LAN cameras are collected at 10 or 15 minutes intervals at all times.

The collecting servers transfer the images to a central file server, from where the images can be retrieved for different purposes. Images are saved on the server for two days and then deleted. There are no image archives, because of the great volume of the images - roughly 1 GB daily. Developing an archiving system is in the near future plans.

The road weather images are available to road maintenance contractors and TICs - as well as all Finnra employees - via Web Road Weather application that taken into use in autumn 2001. The images are also available to the public at Finnra's Internet and are very popular - almost ten million page loads every month. Finnish broadcasting companies show road weather

images on their weather forecasts on television to illustrate the road weather conditions in different parts of Finland.

There can be only one connection to a road weather camera at a time when using dial-up networking, while ADSL connection allows several concurrent connections. The possibility to view live stream from the road weather cameras has been limited to TICs, thus ensuring that the still images can be collected reliably. The problem can be solved also by using dial-on-demand routers. They can handle several concurrent connections to the same camera through one dial-up connection. These routers are already in use in three road regions and will be taken into use in all the road regions. The routers make it possible also to swap the collecting server with no extra telecommunications costs in case of server break down, or even to centralise the road weather image collecting.

Future plans

For half of the year the most northern roads in Finland are covered with thick ice and snow. Therefore the road weather stations may not be fully made use of. There is already testing of a light RWS going on. The light RWS could then be attached to road weather camera's Axis server and the data could be collected with the image. For example, air temperature, wind speed and direction and rain measurements added to the road weather image could be the next step.

Finland is a large and sparsely populated country with long distances. Sometimes it is too expensive, even impossible, to build telephone lines to places where road weather cameras would be needed. GSM data has been tested for such places, but it is too expensive and too unreliable. There would be need for reliable and cost-effective wireless data connections for cameras. One possible solution could be General Packet Radio Service (GPRS) network that is already being tested on collecting road weather station data and automatic traffic counter data.

The quality of the road cameras and the road weather images will continue to have a high priority in developing the road weather camera part of the Finnish RWIS. Also the acquisition processes of equipment and maintenance will be further developed, and possibilities and techniques for image archives explored.

Laser Road Surface Sensor - LRSS

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Background:

Scanmatic have been producing Road Weather Stations for more than 15 years and have now our 3rd generation of stations in the market. We are producing our own electronics but have an open interface-policy to be able to connect the best sensors to be able to fulfill our customers need.

We have been working together with Goodrich in Minneapolis in the USA for several years, buying Ice-detectors and Pitot-tube anemometers from them.

Goodrich had developed a sensor called IceHack® several years ago for detecting ice on airplane wings before and after deicing the airplanes. The unit could take an image of the hole wing area showing ice as red on a small screen on the unit. The unit was expensive and heavy, but we saw the potential in using the techniques on the road.

Two years ago Goodrich and Scanmatic started a project together to develop a new sensor for the road marked, based on the same principle, but using newer and more modern technology.

Scanmatic have been testing lots of Road Surface Sensors during the last 10 years, all based on a sensor placed in the road surface beside the tire paths. Some of the sensors have rather good performance, but the negative point is that they only measure a very small area in the road, and the surface at the sensor can be different in the tire path.

The big difference with the new sensor is that it is placed away from the road surface and covers a much larger area than other sensors.

The cost of the sensor may seem high, but the user has no cost by changing sensors in the road surface after wearing and when new asphalt is put to the road.

The big advantage is however that the new sensor can see a whole area and not only a very small part of the road (a few cm²)

The system illuminates the areas of interest using an eye-safe laser with unique properties. Using the unique properties of the laser, the system analyzes the reflected energy and is capable of imaging a 20 x 30 degree field of view with ranges up to 23 meters.

Laser Road Surface Sensor - LRSS



Figure 1: Picture of the new Laser Road Surface Sensor (LRSS)

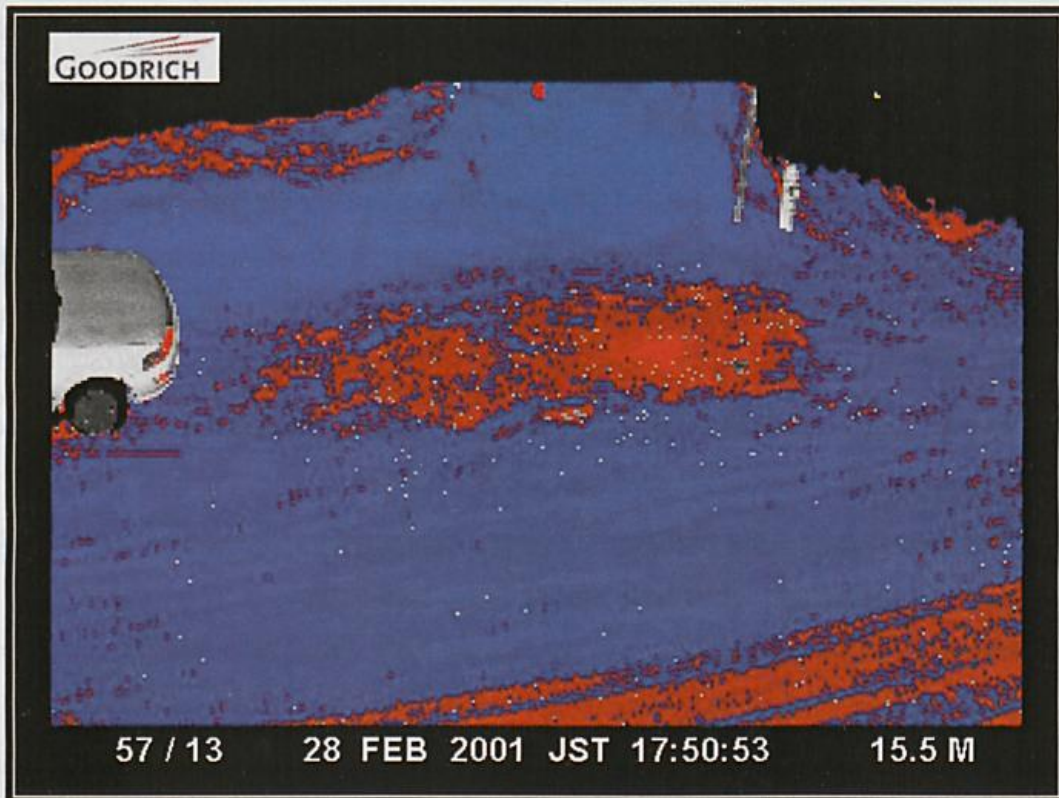


Figure 2: A typical "picture" of a road surface taken by the new type of sensor

Advantages

- **Non-intrusive:** doesn't need to be installed into the roadway surface
- **Much larger area of detection:** above and beyond single spot detectors
- **Little to no on-going maintenance costs**
- **Can be replaced or upgraded without affecting traffic** (pole-mounted, not embedded into road)

Applications

- **Road condition monitoring and management**
- **Tracking the quality of ice/snow removal services**
- **Ice alert warnings / speed limit control on roads**
- **Bridge deck monitoring / Automatic spray operation**
- **Airport runways**
- **Portable road condition monitoring in construction areas**

Technical operation

- **System builds a 200 x 300 pixel image (20 x 30 degree field of view) using an eye-safe infrared beam of light**
- **200x300=60,000 points of detection**
- **Analyzes the reflected energy, classifying each pixel as dry, snow, ice or wet areas.**
- **Displays image in gray scale with red, blue, and cyan colors to highlight dry, ice, snow and wet areas.**
- **Able to calculate percentage of ice, snow or water coverage for alarm based operations**

System installation / operation

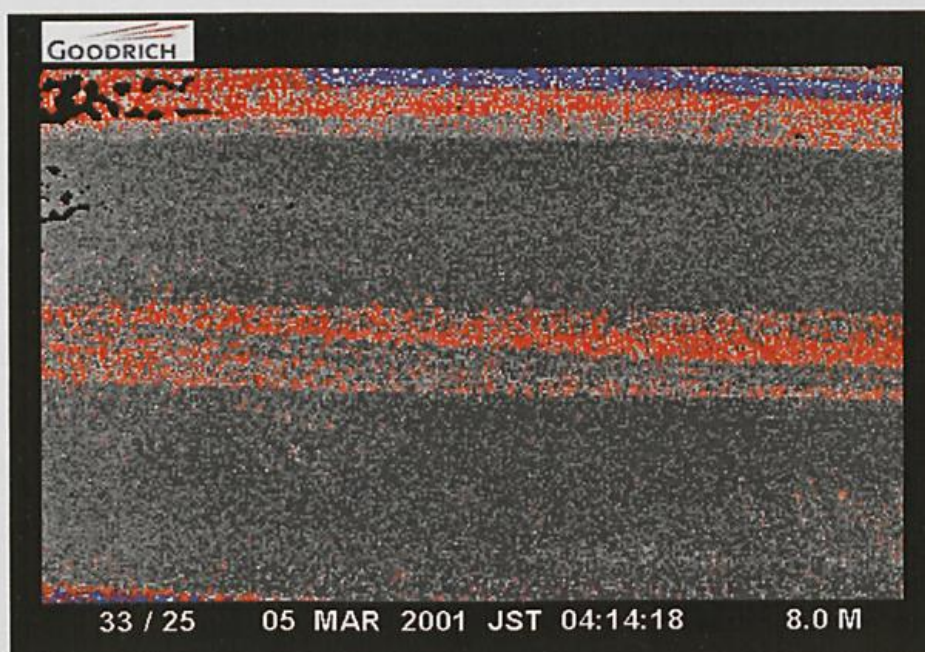
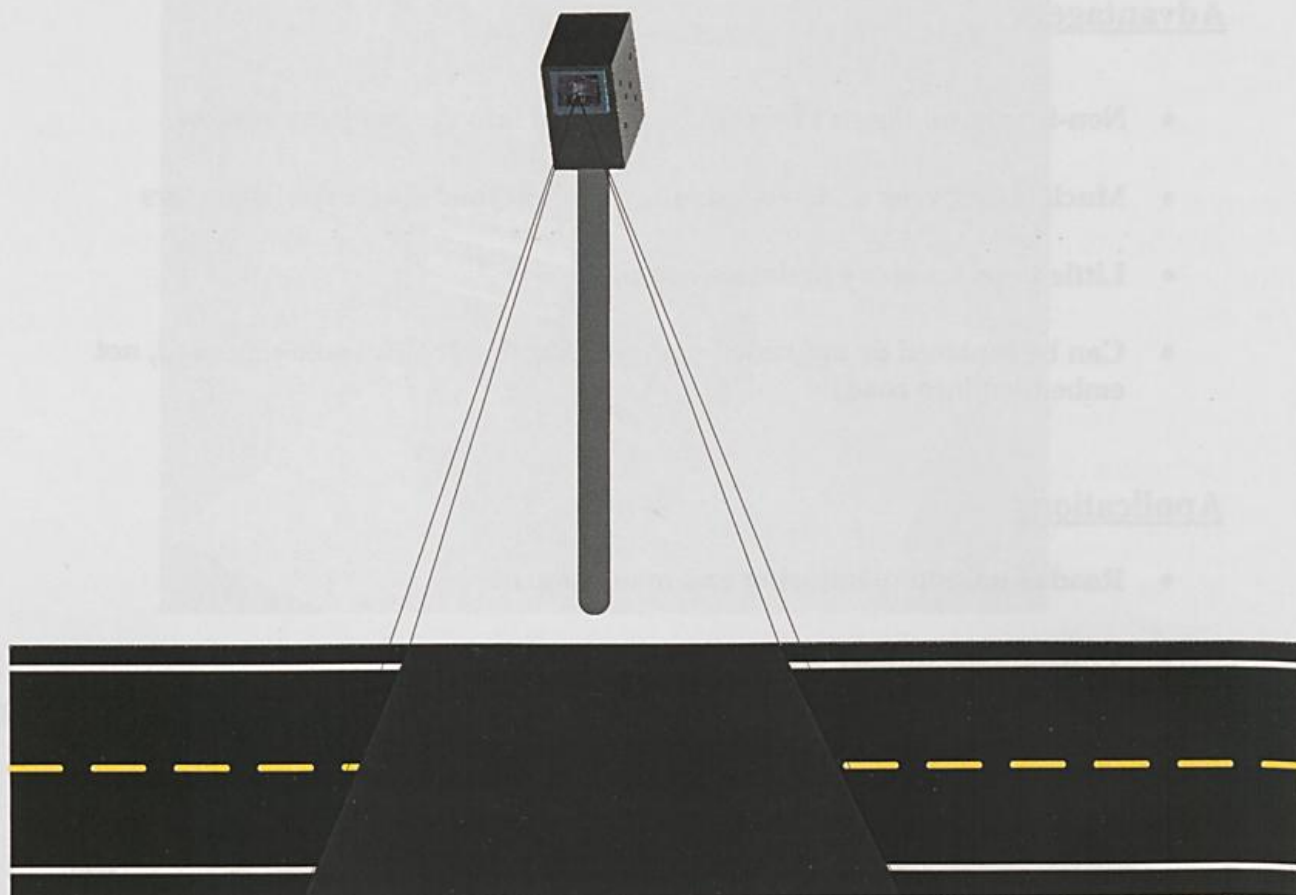






Figure 3: Typical installation and result

Image classification

- Red represents areas of ice → 
Ice
- Blue represents areas of snow → 
Snow
- Cyan represents wet areas → 
Wet
- Black represents out of range or not enough information → 

Gray represents areas of no precipitation

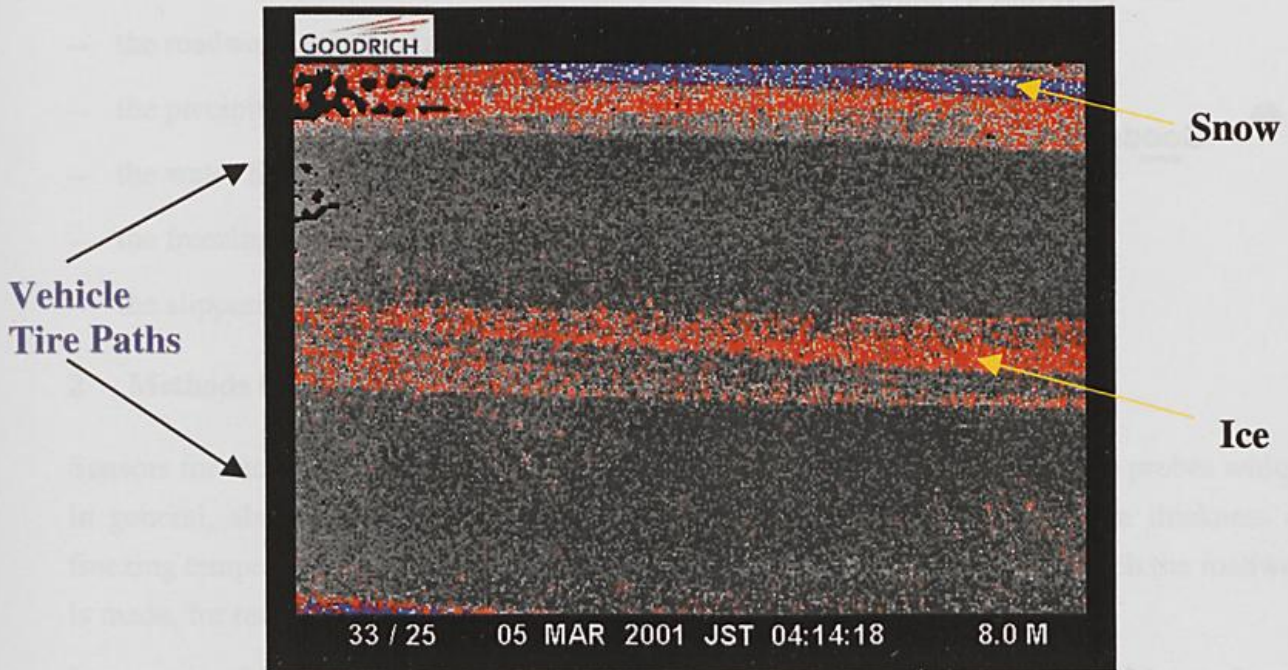


Figure 4: A typical LRSS image and the meaning of the different colors

System Specifications

- **Field of view: 20° x 30°** **Range: up to 23 meters**
-
- **Dimensions: 23cm x 38cm x 33cm** **Weight: 9kg**
- **Operating voltage: 10-14 VDC**
- **Temperature range: -30 to +50 °C**
- **Connectivity: Ethernet (TCP/IP) or RS232**
- **Image storage capacity: up to 2,000 images**
- **Windows® software compatible**
- **Additional I/O (for future expandability)**
- **Alarm (automatic) or manual operation capable**
- **User-friendly configuration software allows for a multitude of applications**

Informational Contacts

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Testing Sensors for road weather systems

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1 Introduction

Skid hazards on wintry roads should be avoided by taking effective measures in good time or, if it is not possible to effectively prevent such skid hazards for various reasons, the risks should be eliminated quickly. A knowledge and forecast of the conditions on the roadway and the atmosphere above the roadway are of essential importance for control of winter maintenance and for providing a warning to motorists of restricted driving conditions which may be practical in certain cases.

Such conditions can be detected by road weather systems with corresponding sensors. The indicating accuracy of these sensors is very important since the data of the sensors impacts on decisions made in the winter either directly or in interaction with other data. The Federal Highway Research Institute considers it to be its task to further-develop the sensors offered on the market and to assess their suitability on the basis of objective test methods.

These examinations cover sensors for

- the roadway surface temperature,
- the precipitation intensity,
- the water film thickness,
- the freezing temperature and
- the slipperiness of the roadway.

2 Methods for testing sensors for the roadway surface temperature

Sensors for the roadway surface temperature have, to date, been incorporated in probes which, in general, also integrate other sensors, including sensors for the water film thickness or freezing temperature. These probes consist of materials other than those of which the roadway is made, for reasons which are generally related to the measurement technique.

In a series of tests, the roadway surface temperatures were measured with probes used conventionally in road weather systems under the same conditions and compared with each other (see Figure 1).

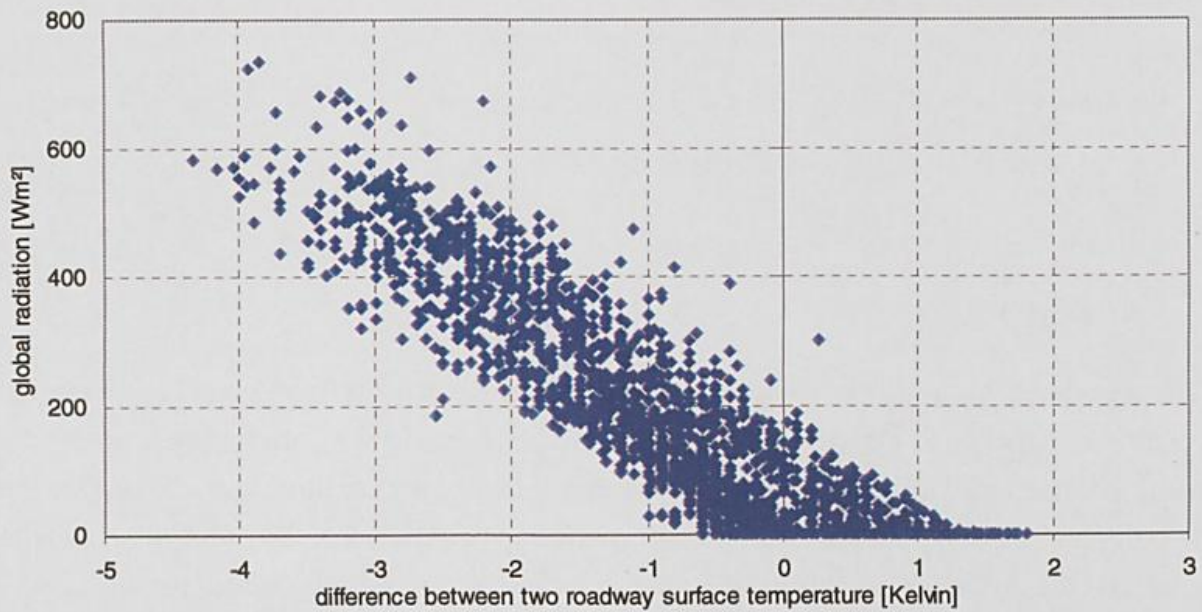


Figure 1: Dependence of the difference between two measured roadway surface temperatures on the global radiation under the same conditions (3,998 pairs of measured values)

In a second series of tests at a different time, three identically designed temperature sensors were incorporated directly in a roadway not subject to vehicle traffic. Using a drilled hole, they were incorporated flush with the roadway surface (see Figure 2) together with a mixture of fine sand and bitumen. This mixture very largely corresponds to the materials of which the roadway is made.



Figure 2: Installation of a sensor for roadway surface temperature on the roadway surface

Results of this series of tests are shown in Figure 3.

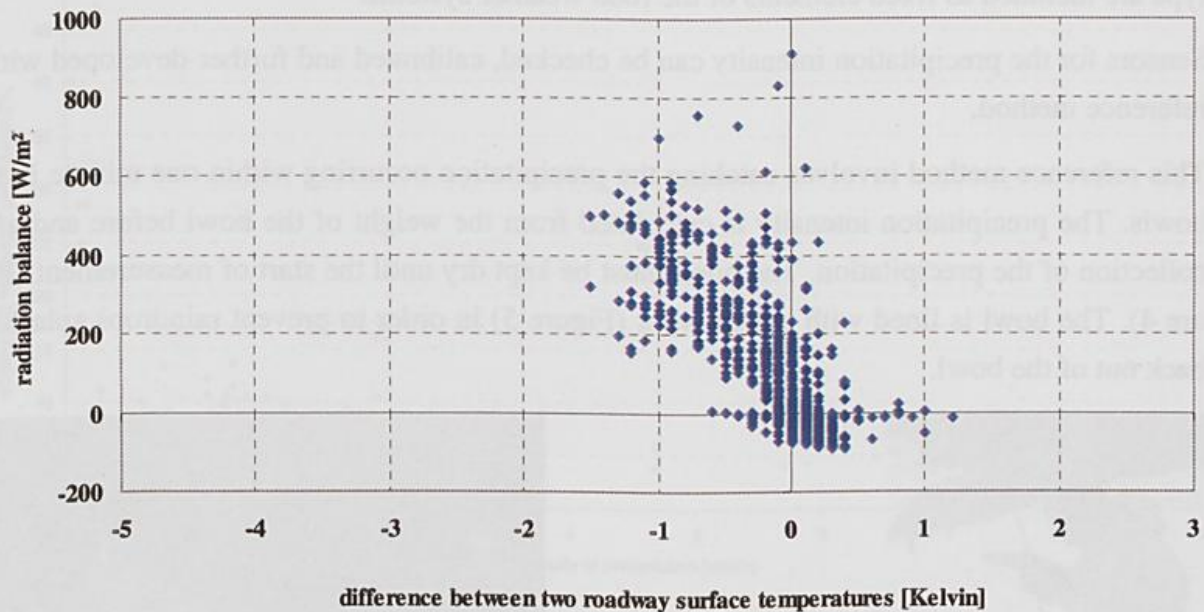


Figure 3: Dependence of the difference between two measured roadway surface temperatures under the same conditions on the radiation balance (1,728 pairs of measured values)

A comparison between Figures 1 and 3 indicates that the differences in Figure 3 are far lower over the entire spectrum of global radiation or radiation balance occurring than they are in Figure 1. With the same radiation, the sensors obviously detect different surface temperatures as a function of the materials surrounding them.

From this, we can conclude that these sensors either need to be fitted directly in roadway pavements or that the previous probes should be adjusted in a long-duration development process on the basis of a reference specimen in order to increase the measuring accuracy.

On the basis of experience to date, thermocouples (diameter 0.5 mm) can be used to advantage as reference specimens to enhance measuring accuracy and protection against moisture. However, the reference specimen, still require investigation to establish how they can be durably integrated in the roadway surface with what joint cement.

3 Methods for testing sensors for precipitation intensity

The precipitation intensity parameter is essentially used for warning motorists against the danger of aquaplaning. For the purposes of algorithms for switching a variable traffic sign system, it is necessary for the sensors to already reliably indicate the precipitation quantity within one minute.

In addition, for the purposes of warning against skid hazard, it is important that the information on precipitation even in very small quantities and in different types (rain or snowfall) also

be included. This is why sensors for detecting low precipitation intensities and precipitation type are included as fixed elements of the road weather systems.

Sensors for the precipitation intensity can be checked, calibrated and further-developed with a reference method.

This reference method involves catching the precipitation occurring within one minute in flat bowls. The precipitation intensity is calculated from the weight of the bowl before and after collection of the precipitation. The bowl must be kept dry until the start of measurement (Figure 4). The bowl is lined with cotton wool (Figure 5) in order to prevent raindrops splashing back out of the bowl.



Figure 4: Wiping the stand dry

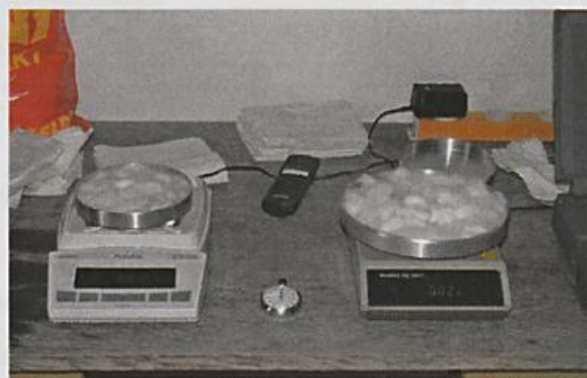


Figure 5: Cotton wool-lined measuring bowl

In order to check the indicating accuracy, a detailed investigation was conducted into the particular catchment area of the bowl which provides a greater degree of correspondence in the results under the same conditions. For this purpose, two bowls of the same size were exposed to the precipitation simultaneously and positioned adjacently.

The results are shown in Figures 6 and 7. The following result was obtained by a comparison of the catchment areas of 200 cm² and 400 cm²:

- larger catchment areas achieve a higher degree of coincidence and
- the degree of coincidence for the larger bowls is lower as the result of a greater weighing error owing to the higher intrinsic mass only in the case of very low precipitation intensity.

The results specified indicate that the reference method should be based on catchment bowls with a catchment area of 400 cm².

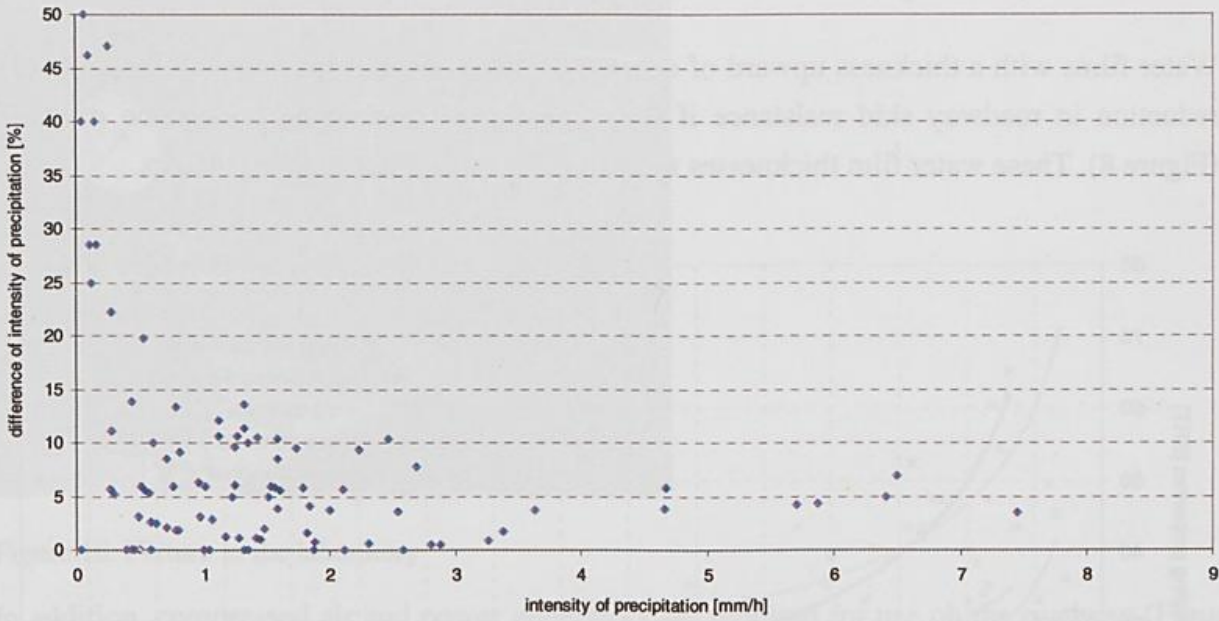


Figure 6: Correlation between the differences of two measured precipitation intensity values determined simultaneously and the precipitation intensity achieved as a mean value of the two measured values (bowls with 400 cm² catchment area, values from 97 measurements)

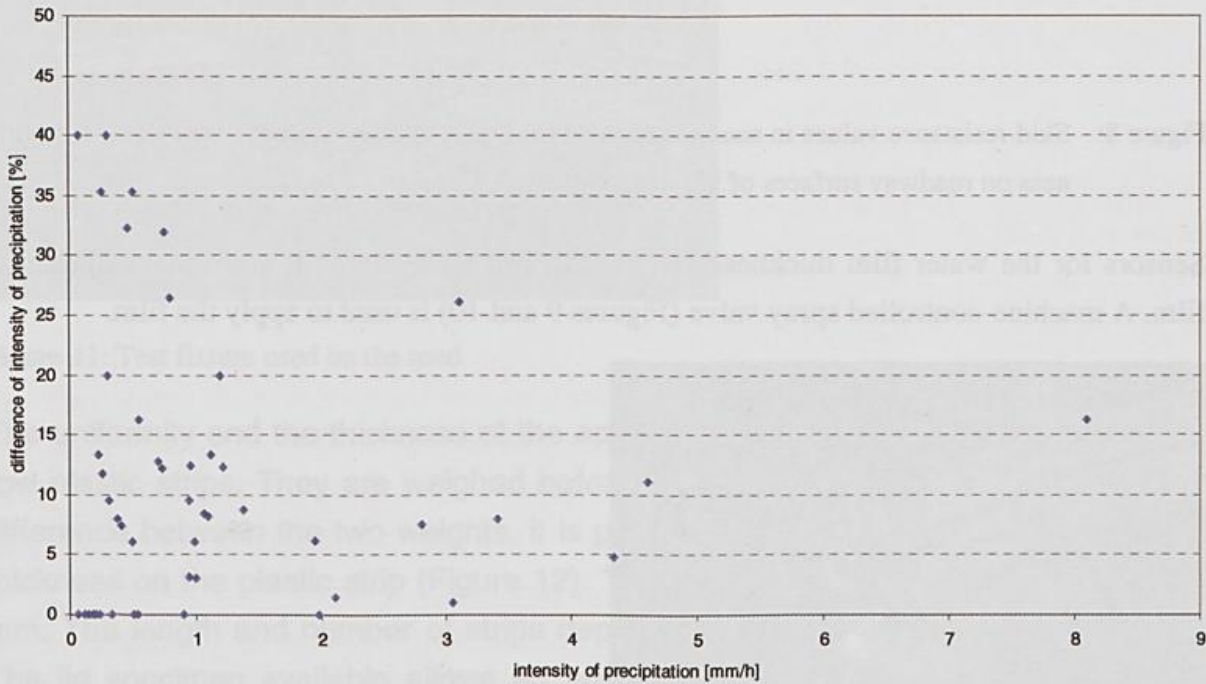


Figure 7: Correlation between the differences of two precipitation intensity measured values determined simultaneously and the precipitation intensity achieved as a mean value of the two measured values (bowls with 200 cm² catchment area, values from 51 measurements)

4 Method for testing sensors for water film thickness

Water films with a thickness upward of approx. 0.01 to 0.03 mm may already lead to a clear reduction in roadway skid resistance if they freeze over, depending on surface roughness (Figure 8). These water film thicknesses must thus be reliably detected by sensors.

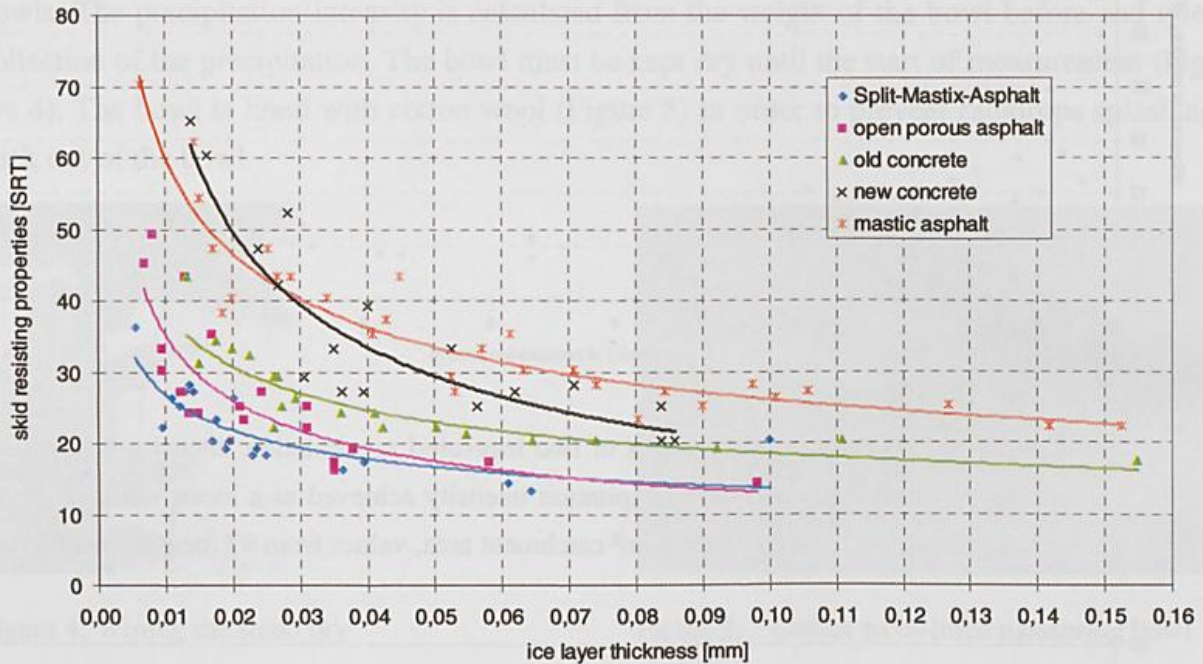


Figure 8: Skid resistance values in accordance with SRT as a function of the frozen water film thickness on roadway surfaces of various roadway structures

Sensors for the water film thickness can be checked by applying a uniform, defined water film. A machine-controlled spray valve (Figures 9 and 10) is used to apply the film.

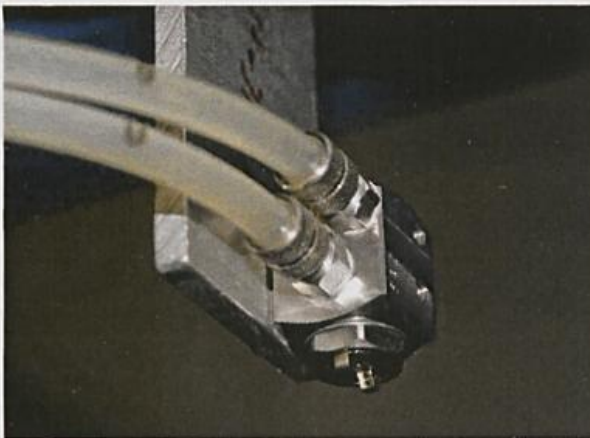


Figure 9: Spray valve

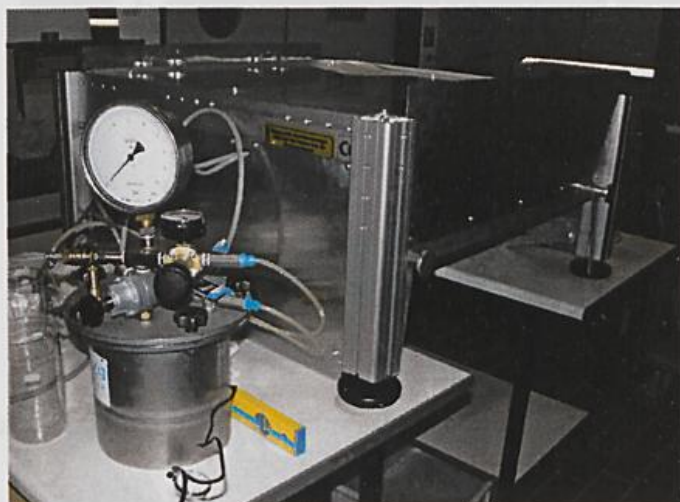


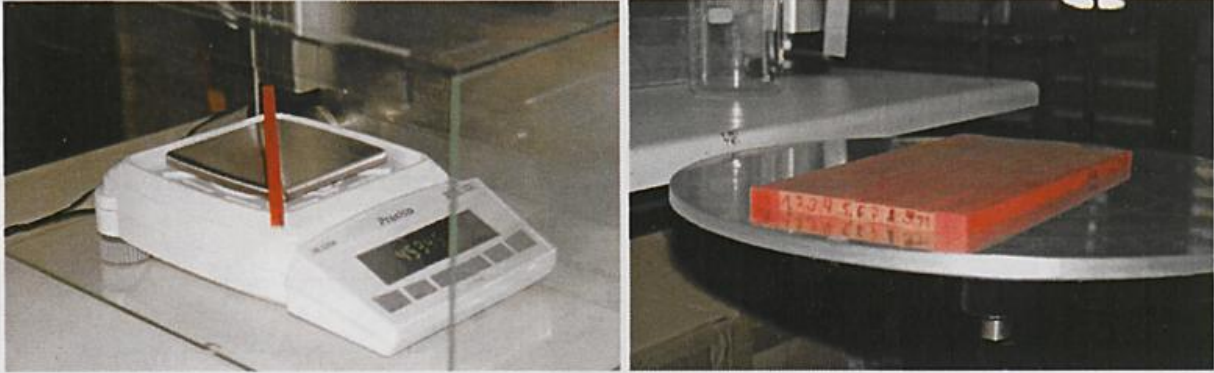
Figure 10: Fixture in the laboratory

In addition, compressed air and power generators are required for use on the roadway (Figure 11).



Figure 11: Test fixture used on the road

The uniformity and the thickness of the applied water film can be verified using narrow plastic strips. They are weighed before and after spraying. On the basis of the difference between the two weights, it is possible to calculate the applied water film thickness on the plastic strip (Figure 12). The strips have a cross-section of 10 x 10 mm. The length and number of strips depend on the size of the sensor under test. The jig specimen available allows an area of approx. 20 x 30 mm to be sprayed evenly.



Figures 12 and 13: Plastic strips on the scales and under the jig for determining the water film thickness and the uniformity of application

With this method, it must be noted that a sensor fitted in the roadway cannot be fully tested. Owing to the required roadway camber, applied water already flows away at a water film thickness greater than 0.1 mm. Comprehensively checking the water film thickness is possible only on a relatively level surface (laboratory).

5 Method for testing sensors for the freezing temperature and roadway skid hazard

Sensors for the freezing temperature are tested with the same method as the sensors for the water film thickness. De-icing salt solutions are sprayed onto the sensors instead of water. The solutions can be varied depending on the required application.

Likewise, the same test jig as for the water film thickness is to be used for testing sensors for the roadway skid hazard. In this case, water is to be sprayed onto the sensors of temperatures below 0 °C.

6 Summary

Checking the indicating accuracy of sensors for road weather systems is of major importance since the data from sensors impacts on decisions made in respect of winter maintenance either directly or in interaction with other data. The paper outlines in detail what methods can be used to test the indicating accuracy of sensors. In addition, it is proposed that sensor manufacturers adapt their road weather systems to the constantly changing requirements in consultation with the Federal Highway Research Institute and by using corresponding series of tests.

How to measure the energy balance of a road surface

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Summary

In Road Climatology great emphasis is put on predicting the surface temperature of a road. Good predictions will give information of the road conditions and warn for risk of slipperiness. Thereby accidents can be avoided by maintaining the road. In this study the emphasis is put on validating the models, not only with surface temperature, but also by studying the various heat fluxes to and from the road surface. Radiation and ground heat flux can be measured with well known techniques, but the turbulent latent and sensible heat flux is very difficult to measure for a road surface. In order to measure the turbulent fluxes it is necessary to get very close to the road surface, so that influence from the surroundings is minimized. Various techniques from micrometeorology have been tested at a test site outside Göteborg in south western Sweden. The Eddy covariance technique seems to underestimate the flows, but the Bowen-ratio technique seemed to work under good conditions.

1 Introduction

Many road ice prediction models are energy balance models. The results are normally verified by comparing the observed and the modelled surface temperature. In this study the energy fluxes are measured and compared to the output of an energy balance model. Measuring the energy balance of a road surface is a very demanding task. Normal micrometeorological techniques cannot be applied. It is necessary to understand the properties of the internal boundary layer (IBL) of the road. The internal boundary layer has been thoroughly investigated by many researchers (Garratt, 1990), (Antonia et al., 1977). The road surface can be seen as an anomaly in a larger landscape, where the larger scale climate is determined by the surroundings. The climate of the road itself is then defined by the IBL forming after a step change in surface roughness or surface heat flux. The IBL of the road will develop from the edge of the road and grow with increasing fetch length. Within the IBL there is an equilibrium boundary layer (EBL), sometimes called fully flux adjusted layer. This is defined as the height where 90 % of the energy fluxes are adjusted to the new surface. In order to do energy balance measurements one needs to get within the EBL. These features have been investigated in Almkvist et al. (2003) and it was found that the road has an EBL lower than 10 cm. Most micrometeorological measurements are done above 2 meters, so the instruments are constructed to measure

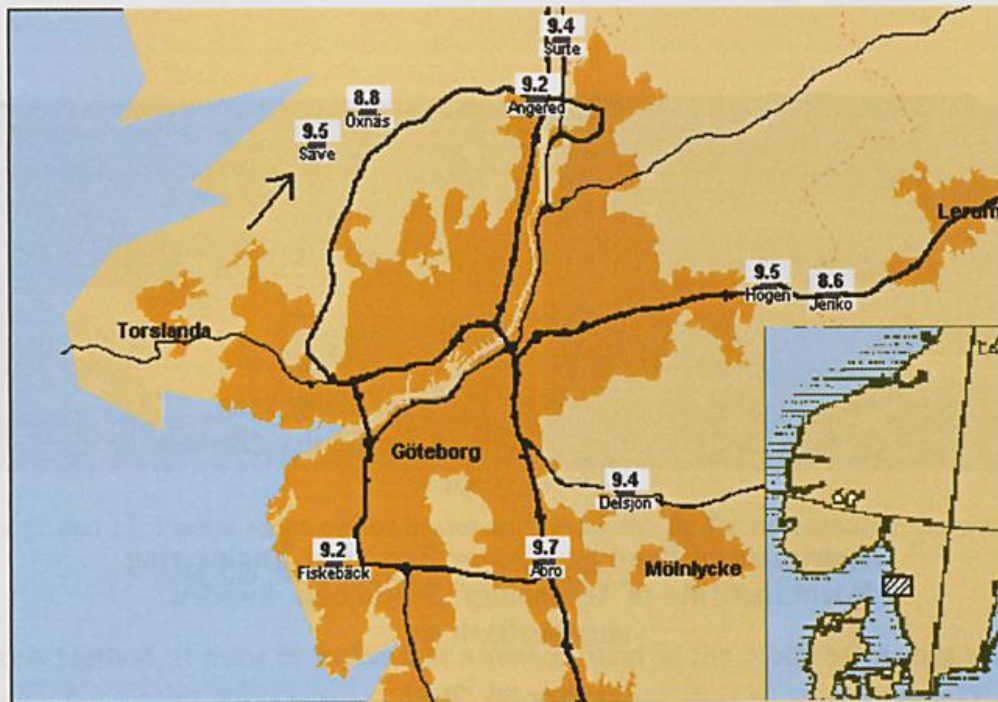


Figure 1: A map of the RWIS-stations in Gothenburg and its surroundings. The test site at Säve airport is indicated by an arrow. Scale 1:300 000.

at this level. If the measurements are done at the 10 cm level new techniques have to be used. In this article two methods are tested to measure the energy balance and surface fluxes: a traditional eddy covariance method using a sonic anemometer and an improved version of a Bowen ratio method where the temperature and humidity gradient below 12 cm is measured. The measurements are validated with an energy balance model.

2 Site and instrumentation

The test site is situated at Säve Airport 10 km north of Göteborg as seen in figure 1. The measurement area consists of a 24x24 m asphalt surface in an open area along a two lane road. There is a 2 m wide ditch that separates the road from the asphalt area. Two masts with instrumentation are situated at the west side of the asphalt area (figure 2). There is a workmen's cabin at the east side of the surface while the south and western sides are fenced. The main wind direction is western, so the influence from the cabin is normally small, but the fence will cause extra turbulence. The asphalt surface was built up to be representative of a normal Swedish road. It was therefore constructed with a top layer of 7 cm asphalt followed by 70 cm of crushed rock. A geotextile was placed to separate the crushed rock from the clay soil below.

The permanent instrumentation consists of a net radiometer, a heat flux plate, road temperature profile and an RWIS-station (Road Weather Information System)(table 1), which was developed for monitoring road conditions. The RWIS-stations measure air temperature, road surface temperature, relative humidity, wind speed and precipitation. At this site the road surface temperature was measured at the test area and not at the road. The net radiometer measured upward and downward short- and longwave radiation. The heat flux plate was self calibrating to account for differences in conductivity of the asphalt and the plate. The validation variables are used to test the model. For the Bowen ratio method, thermocouples were used to measure the temperature and an infrared gas analyzer was used to measure the humidity (table 2). The heights were reversed every 5 minutes to account for differences due to instrumental errors.



Figure 2: The asphalt surface at Säve as seen from the north-west. The RWIS-station is mounted on the left tower, while the instrument measuring the radiation components is on the right tower. The road is seen as a grey line in the foreground.

Table 1: The instrumentation at the test site.

Variable	Location	Instrument	Comments
Climate variables			
Air temperature [$^{\circ}\text{C}$]	2 m	Pt-100	RWIS
Relative humidity [%]	2 m	Capacitive	RWIS
Global radiation [$\text{W} \cdot \text{m}^{-2}$]	2.5 m	Pyranometer	Kipp & Zonen
Wind speed [$\text{m} \cdot \text{s}^{-1}$]	10 m	3-cup anemometer	RWIS
Precipitation [mm]	10 m	IR-sensor	RWIS
Validation variables			
Net radiation [$\text{W} \cdot \text{m}^{-2}$]	2.5 m	Pyrano/Pyrgeometer	Kipp & Zonen
Road temperature [$^{\circ}\text{C}$]	0 cm	Pt-100	RWIS
Asphalt temperature [$^{\circ}\text{C}$]	6 levels, 0-100 cm	Pt-100	
Asphalt heat flux [$\text{W} \cdot \text{m}^{-2}$]	4 cm depth	Heat flux plate	Hukseflux
Sensible heat flux [$\text{W} \cdot \text{m}^{-2}$]	15 cm	Sonic anemometer	USAT-1
Latent heat flux [$\text{W} \cdot \text{m}^{-2}$]	12-15 cm	Infrared	Licor 7000

Table 2: The instrumentation for the Bowen ratio measurements.

Variable	Location	Instrument	Comments
Air temperature [$^{\circ}\text{C}$]	4 and 12 cm	Thermocouples	Copper-Constantan
Absolute humidity [$\text{kg} \cdot \text{m}^{-3}$]	4 and 12 cm	Infrared	Licor 7000

3 Measurements

The measurements at the test site have been running since March 2003, but for this study measurements from the period 2-April to 11-April. Temporary measurements of sensible and latent heat flux with the sonic anemometer were made from 2-April to 10-April. The Bowen ratio measurements were made 3 April.

In order to get sufficient fetch on a road surface one needs to measure very close to the surface. This can be a problem since the eddies close to the surface are smaller, dissipate faster and therefore require a faster sampling rate than when measuring at a higher level. The measurements were made at both 10 Hz and 48 Hz. The sonic was placed 15 cm above the surface at the center of the test site. Thereby a fetch of at least 10 m was achieved. A simple estimate of the height for the fully flux adjusted layer or Equilibrium Boundary Layer (EBL), is 1/100 of the fetch length (Blackadar, 1997). This gives a height of the EBL of 10-14 cm, which suggests that the sonic was slightly influenced from the surroundings. The sensible heat flux was calculated from the covariance between the vertical wind-speed and the temperature. The temperature measured by the sonic anemometer is nearly equal to the virtual temperature, which can introduce an error of about 10-20% when calculating the sensible heat flux (Schotanus et al., 1983). This error was neglected in this study since these measurements mainly aim at testing the eddy covariance method for a road surface. Other errors can be more significant.

4 Analysis

The model used in this work, the COUP-model, was originally constructed as a heat and mass transfer model for the soil-vegetation-atmosphere systems. The model allows for a great deal of flexibility and was here parameterized to resemble the soil-road-atmosphere system. The first version of the model was presented by Jansson and Halldin (1979) and a detailed model description is available by Jansson and Karlberg (2001). The model was run on hourly values of global radiation, air temperature, vapour pressure and wind speed. More information of the model runs can be found in Jansson et al. (2003). Important parts of the model as it was used in this study can also be found in Alvenäs and Jansson (1997).

5 Results and Discussion

The net radiation and ground heat flux can be measured by traditional methods. These variables agree well with model results as seen in figure 3 and 4. The model was run on tabular values for asphalt properties. The accuracy of the results could be improved further by fine tuning the model. The turbulent fluxes are both more difficult to model and to measure. The results are shown in figure 5 and 6. The sensible and latent heat fluxes are underestimated by the measurements compared to the model. In order to close the energy balance, the sensible heat flux needs to be about the same order of magnitude as the modelled flux. Therefore the modelled sensible heat flux is more likely to be correct than the measured flux. The eddy covariance technique is designed for measurements above 2 m, so the problems arrive since the small eddies are not resolved by the sonic at 15 cm. The path length of the sonic is probably too large to measure at this low level. The latent heat flux was difficult to model. During the first day the surface was wet and evaporation should be present. The other days were dry, so the modelled latent heat flux is probably unphysical. In figure 7 the results from the Bowen ratio method are shown. The results seem to be reasonable. There was a clear temperature and humidity gradient that gives the fluxes of sensible and latent heat. The measurements were made immediately after a rainfall, so there should be fluxes of water vapor present. There occurred problems with dew formation in the tubing leading to the gas analyzer during the days following the 3 April. To avoid this problem, the tubes should be heated.

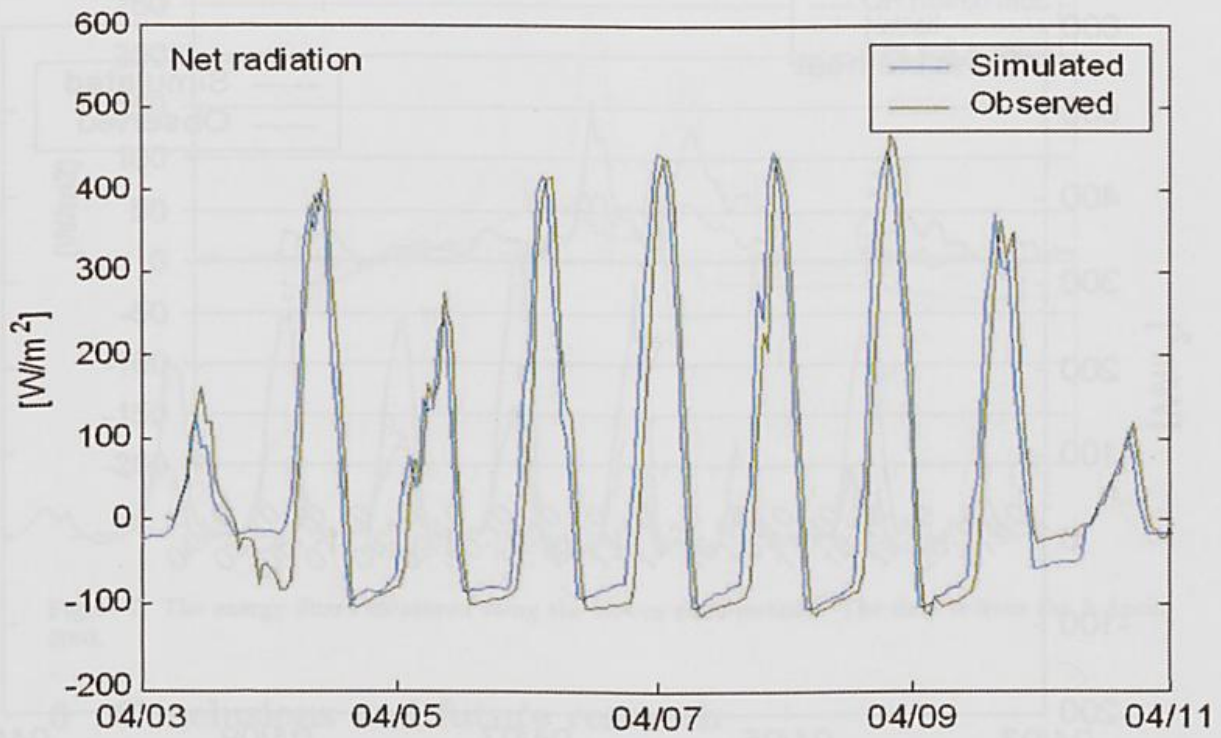


Figure 3: The measured energy flux compared to the modelled energy flux. The data is from the 3-11 April, 2003.

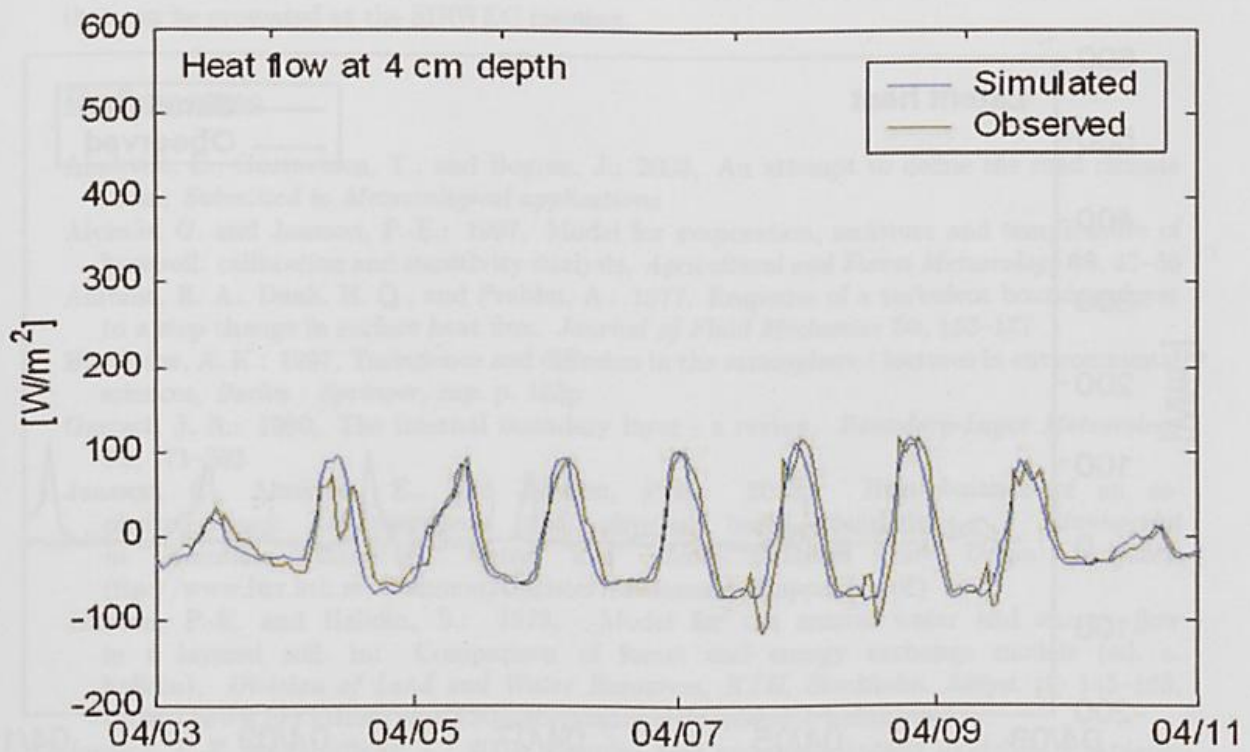


Figure 4: The measured energy flux compared to the modelled energy flux. The data is from the 3-11 April, 2003.

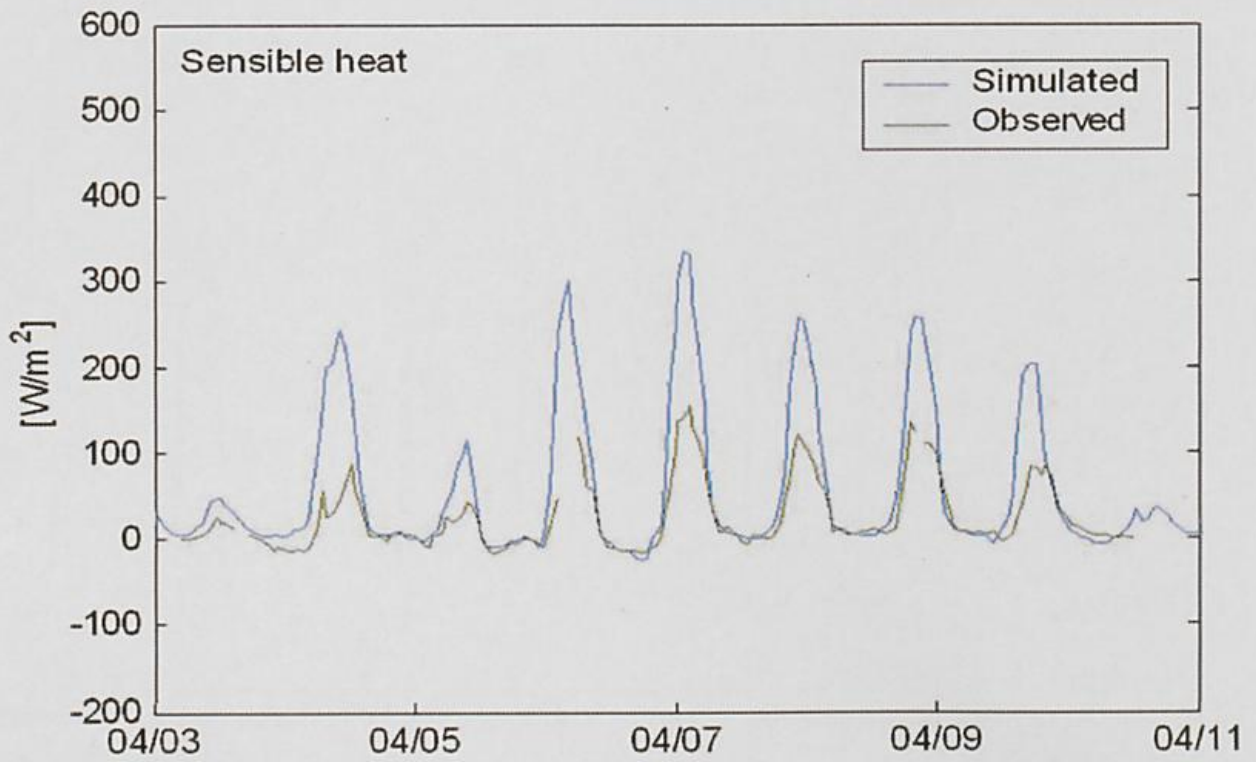


Figure 5: The measured energy flux compared to the modelled energy flux. The data is from the 3-11 April, 2003.

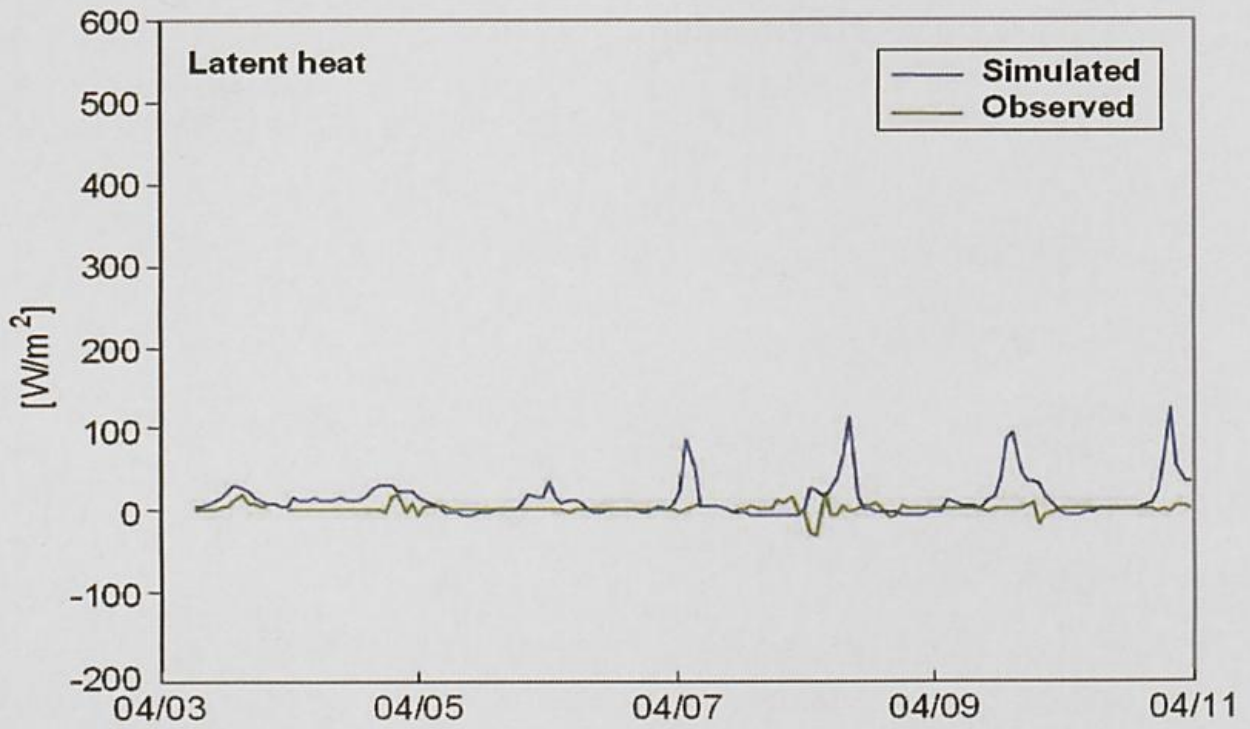


Figure 6: The measured energy flux compared to the modelled energy flux. The data is from the 3-11 April, 2003.

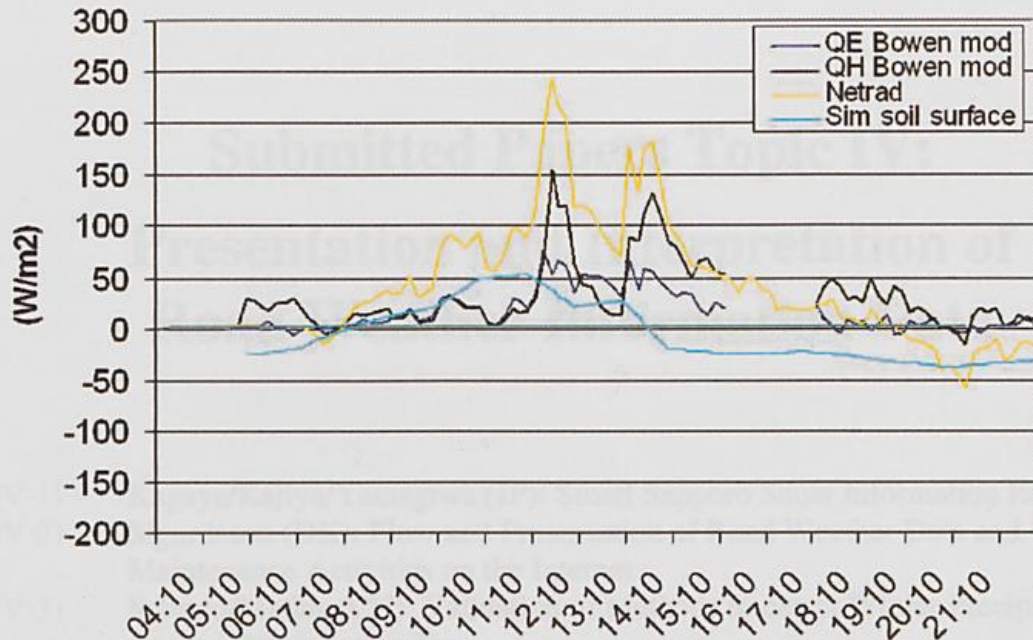


Figure 7: The energy fluxes measured using the Bowen ratio method. The data is from the 3 April, 2003.

6 Conclusions and future research

The results show that measurements of net radiation and ground heat flux are useful to validate the energy balance model. The eddy covariance method is difficult to apply, but the Bowen ratio method can be useful if care is taken to avoid instrumental errors. For frost events the latent heat flux is very important. By studying the humidity gradient and latent heat flow with the Bowen ratio method, valuable information about frost processes can be found. More measurements will be made during the winter 2004 which hopefully will give some good results that can be presented at the SIRWEC meeting.

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Validation of methods to detect winter precipitation and retrieve precipitation type

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1. Introduction

Weak or moderate precipitation in winter, e.g. snowfall or freezing rain, may have dramatic consequences on traffic. Therefore, there is a need to see and foresee weak and moderate winter precipitation with adequate techniques. A key instrument for this is the weather radar (e.g., Atlas, 1990), in spite of several deficiencies:

1. The inability to identify precipitation type (e.g., rain or snow)
2. The difficulty to detect winter precipitation, especially in mountainous areas, due to shadowing and clutter effects and due to the small height above ground of precipitating clouds.

The first point can be overcome with polarisation radars (Atlas, 1990). However, these next-generation radar systems are not yet available for operational use. We proposed a much simpler method to identify precipitation type as rain, melting snow or snow (Schmid et al., 2002). Profiles of air temperature and dew point temperature are generated from ground data at various altitudes. These data are converted into fractions of snow within total precipitation mass (Koistinen and Saltikoff, 1998). Specific thresholds of this fraction define the height and thickness of the melting layer. This method to identify precipitation type is referred to as the KSS-method (Koistinen/Saltikoff/Schmid) hereafter.

For operational applications, it is important to know the performance of methods measuring and nowcasting precipitation in winter. In Switzerland, radar image data and short-term radar image forecasts are widely used for road maintenance (Schmid, 2000). Products resulting from the KSS-method (e.g., a radar image showing the height of the melting layer, see Schmid and Mecklenburg, 2001) have become popular, and the customer responses are very positive. However, an objective and quantitative validation of the KSS-method is missing up to now, mainly due to missing direct measurements of the type of precipitation.

This situation can be overcome with the Vaisala road weather measuring network, operated by the canton of Lucerne (Mathis, 2000). The type of precipitation is registered by an optical sensor. Hence, the data from this sensor are suitable for validation of the radar information and the KSS-method. This is the main purpose of this study. For „predicting“ precipitation and its type, we use the radar images from MeteoSwiss (covering Switzerland and the neighboring regions) and ground network data of temperature and humidity (the so-called ANETZ, also operated by MeteoSwiss). The Lucerne data are used for validation. In the next section, we describe the data and procedures. After that, the main results of the study are shown. We end up by summarizing our findings and by discussing their consequence for future studies and operations.

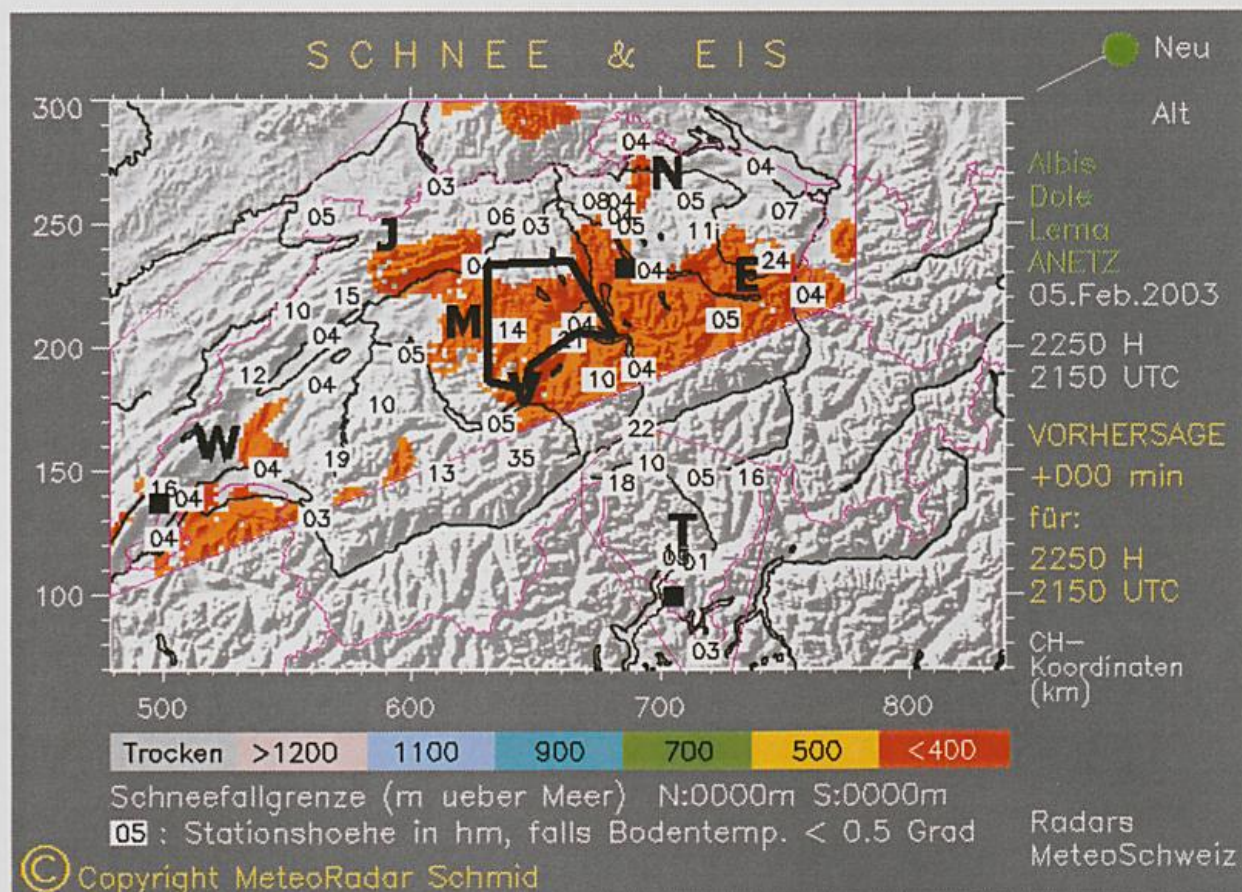


Fig. 1: Example of the product "snow and ice", showing a map of radar echoes and coloured with the height of the melting layer between 400 and 1200 m MSL. In addition, the map shows white boxes of all ANETZ stations whose temperature near ground (typically 5 cm above ground) is below 0.5°C. The numbers within the boxes indicate the height of the station in Hectometers (e.g., "05" = 500 -600 m MSL). The height of the melting layer and the associated ANETZ stations are only shown in two regions, one in the north, and one in the south of the alps. These regions are divided into 7 sectors, whose centers are indicated with letters W (western Switzerland), J (Jura mountains), M (Swiss midland), V ("Voralpen" = prealps), N (Northern Switzerland), E (Eastern Switzerland) and T (Ticino area). A group of ANETZ stations is defined for each region and used for retrieving the melting layer, following the procedure outlined in the text. The Vaisala ground network of 52 stations, used for verification in this study, is located within the canton of Lucerne in Central Switzerland, bounded schematically with a black line in the figure. The black squares mark the locations of three weather radars operated by MeteoSwiss.

2. Data and procedures

a. Radar data

Three C-band weather radars are operated by MeteoSwiss in Switzerland. Black squares indicate their locations in Fig. 1. The radar data are merged to a composite image covering Switzerland and the neighboring regions. The atmospheric volume from 0 to 12 km MSL is scanned every 5 min by 20 revolutions of the radar antenna. The maximum of registered intensity within each vertical column is projected to the plane of the radar image. In order to handle evaporating precipitation, we use the radar data near ground to correct the projected maximum under specific circumstances. The radar measurements are converted into logarithmic rainfall intensities and digitized to 16 intensity levels. A sophisticated procedure is used to handle clutter and shielding effects within the radar image (Germann and Joss, 2002). In general, the ability of the radar to see precipitation depends on the orographic

pattern. In the interior of the Alps, the viewing range of the radars is inhibited by mountains reaching 4800m MSL. In the Swiss midlands north of the Alps and the Ticino area south of the Alps, the visibility is quite good. For this reason, we reduce our study area to the regions north and south of the Alps.

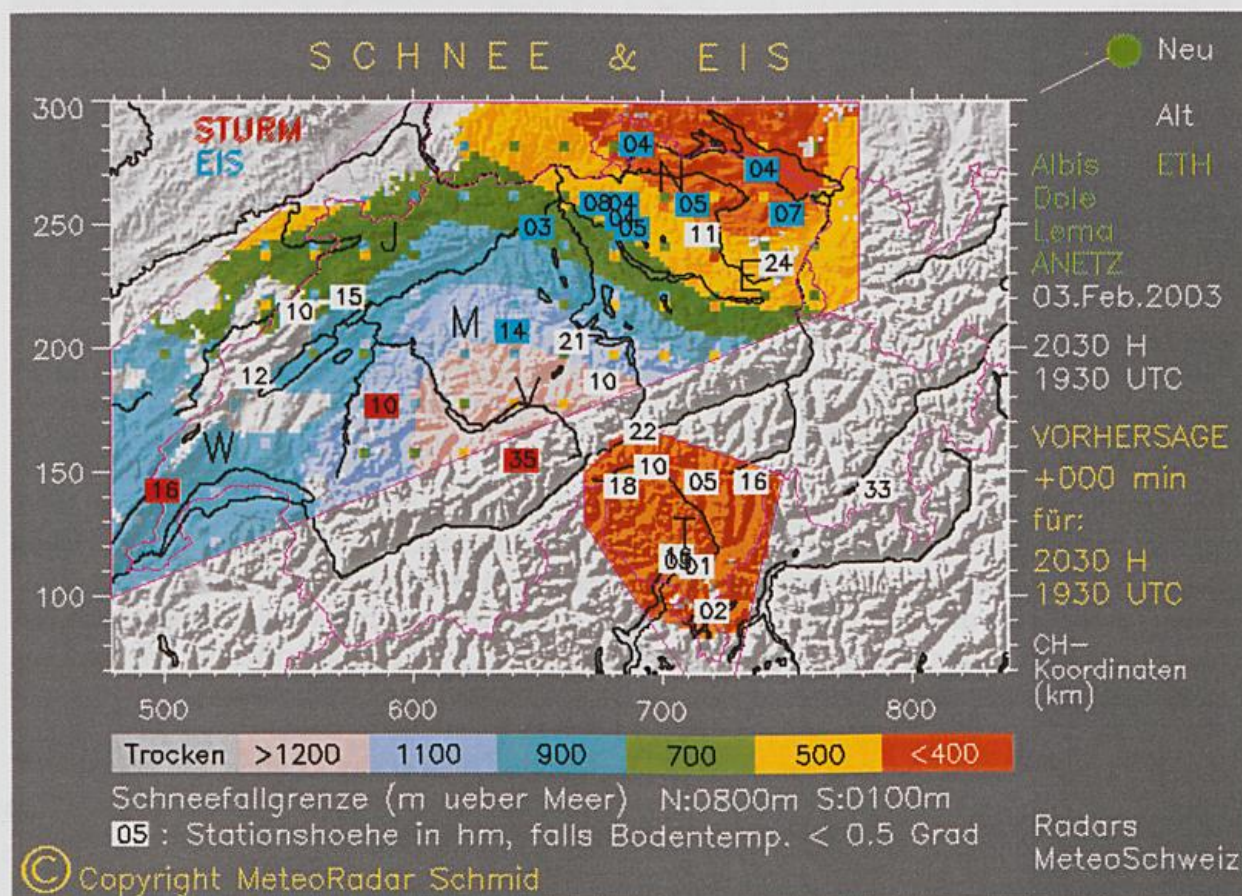


Fig. 2: Same as Fig. 1 but for a situation with varying height of the melting layer over a short horizontal distance. Blue stations ("grey" in grey-scale) indicate liquid water on the ground, together with surface temperatures below 0.5°C. Red stations ("dark grey" in grey-scale) have wind gusts larger than 100 km/h.

b. ANETZ data and the KSS method

MeteoSwiss operates a network of 72 ground stations, measuring various meteorological parameters with a time resolution of 10 min. We use air temperature and dew point temperature. The two experimental regions north and south of the Alps are divided into seven sectors. In each sector, a sufficient number of stations can be found covering a height range from 200 up to 2000 m MSL. Hence, individual profiles of air and dew point temperature can be constructed for each sector. Above 2000 m, few stations can be used to expand the profiles to higher altitudes. Fig. 1 gives an overview of the two experimental regions and the centers of the seven defined sectors (labelled by letters W, J, M, V, N, E and T). The air and dew point temperature data are converted into fractions of snow within total precipitation mass, following the method by Koistinen and Saltikoff (1998). The melting layer and its thickness is obtained by using these thresholds of snow fraction: 20%, 50% and 80%. The resulting heights are assumed to be valid for the centers of the seven sectors, and standard procedures are used to interpolate the height values in between.

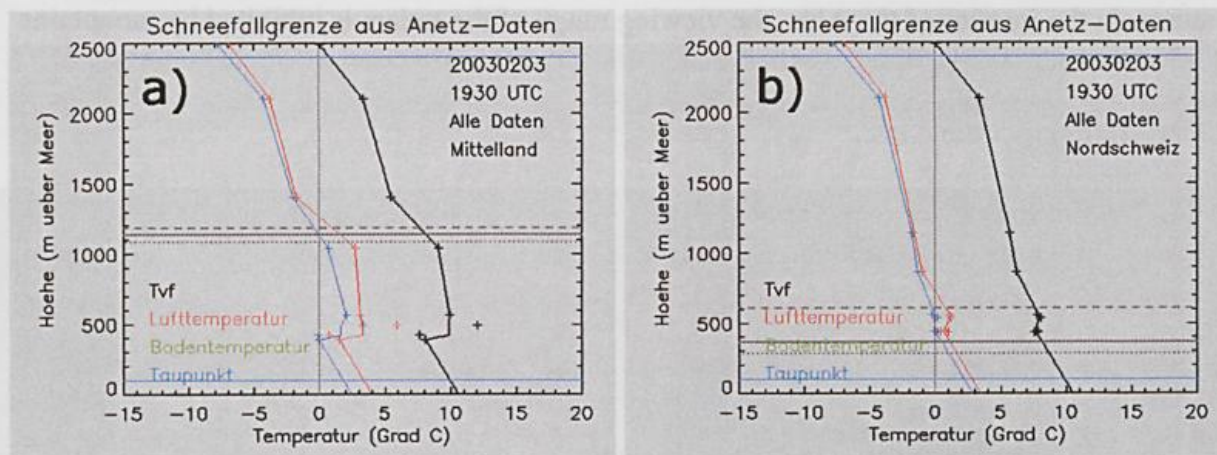


Fig. 3: Profiles of air temperature (red, in the middle) and dew point temperature (blue, to the left), for the "Mittelland" (a) and "Northern Switzerland" (b). The black profile (to the right) is an internal quantity, used for calculation of the melting layer height (solid horizontal line). The dashed and dotted horizontal lines mark the upper and lower boundaries of the melting layer.

The example in Fig. 1 shows a winter situation with snowfall down to the ground in some regions north of the alps. To illustrate the procedure furthermore, we show in Fig. 2 a second example with a varying height of the melting layer over a short horizontal distance. Fig. 3 shows, at the same date and time, two profiles of temperature and dew point temperature for sectors M and N. The melting layers in Fig. 3 are marked with a solid horizontal line, and the melting layer boundaries are marked with dashed and dotted lines, respectively.

Based on that information, one can retrieve precipitation type at any location and height as "snow" or "rain", simply by comparing the height of the given location with the height of the melting layer. Since the ground network data are available in time steps of 10 min, one can update this information every 10 min. This is done operationally since January 2001.

c. Vaisala data and validation

A dense network of 52 RWIS stations, manufactured by Vaisala, is operated by the canton of Lucerne since 1996. The stations measure in time steps of 15 min a number of parameters that are relevant for road weather (air temperature, surface temperature, below-surface temperature, wetness of ground, and others). Here, we use the data of the optical sensor PWD11, registering 16 types of precipitation (Table 1). An unequivocal identification of precipitation type is not possible in all cases. Just "precipitation" (codes 1-3) is identified when detection of rain, snow or graupel is not possible. Just "rainfall" or "snowfall" (codes 10 or 20) is identified when discrimination among the three intensity classes is not possible. Note that the three intensity classes are not clearly linked to precipitation intensity, normally measured in units of mm/h.

For validation, we identify all registrations of precipitation type within a two-month period (Jan./Feb. 2003) from the Vaisala data for each station and time. All unknown precipitation types (code -99) are thrown away. In a second step, we search the closest temperature/humidity profile, and we use these profile data for "prediction" of precipitation type. In a third step, we select the radar value above the station for the time of interest. With this procedure, we obtained a sample of 99745 cases. Precipitation of any type was registered in 11339 cases (11%) by the Vaisala network, the rest was "dry".

Table 1: Precipitation types registered by the optical sensor PWD11, manufactured by Vaisala.

Precipitation type	Numeric code
Dry	0
Weak precipitation	1
Moderate precipitation	2
Heavy precipitation	3
Rainfall	10
Weak rainfall	11
Moderate rainfall	12
Heavy rainfall	13
Drizzle	14
Snowfall	20
Weak snowfall	21
Moderate snowfall	22
Heavy snowfall	23
Weak graupel	31
Moderate graupel	32
Ice pellets	34
Unknown	-99

3. Results

a. Validation of the KSS-method

A contingency table for judging the performance of the KSS-method to discriminate between rain and snow is shown in Table 2. The table shows an excellent result. The KSS-method is able to find the correct precipitation type in 92 % of all cases. This result is hard to improve furthermore. Inspection of the two groups with a wrong identification leads to the following result: predicting snowfall in case of rain occurs more frequently than the opposite. This has a favorable effect in practice. A short-term snow forecast is provided in cases of a continuously sinking melting layer. This is preferable to the opposite, at least for road maintenance. For this reason, we see no need to perform a fine-tuning of our method, at least not at the moment.

In summary: the threshold between snow and rain, as found in Finland (Koistinen and Saltikoff, 1998), is valid in Switzerland as well. This is not the case in Norway, as recently discussed by Gjertsen et al. (2003). There, the thresholds of snow fraction have to be shifted in order to obtain the best possible performance. The reasons for this discrepancy between the three regions are unknown at the moment. Climatic differences in precipitation physics or differences in the observations and procedures are possible explanations.

Table 2: Contingency table for validation of the KSS-method to discriminate between rain and snow. Two months of data (Jan./Feb. 2003) are evaluated.

	KSS - rain	KSS - snow	Total
Vaisala - rain	3311	790	4101
Vaisala - snow	59	6939	6998
Total	3370	7729	11099

b. Validation of precipitation seen by radar

In a second test, we judge the ability of the radar to discriminate between “precipitation” and “no precipitation”. Table 3 shows that decisions about the occurrence of precipitation based on radar are erroneous in many cases. Radar-seen precipitation may be wrong in 35% of all cases. Evaporation of precipitation between radar and ground is probably one important error source. On the other hand, 65% of all precipitation events seen on the ground remain undetected by the radar. In order to understand these two findings, we perform further stratifications of the data shown in the third line of Table 3 (“Vaisala – precipitation”). The results are given in Table 4.

Table 3: Contingency table for judgement of precipitation detection by radar.

	Radar - dry	Radar - precipitation	Total
Vaisala - dry	86245	2161	88406
Vaisala - precipitation	7331	4008	11339
Total	93576	6169	99745

Table 4 : Number of precipitation events seen with the Vaisala network, stratified according to precipitation type.

	Radar - dry	Radar - precipitation	Total
Weak precipitation	111	127	238
Moderate precipitation	0	1	1
Heavy precipitation	0	1	1
Rainfall	50	5	55
Weak rainfall	1399	2330	3729
Moderate rainfall	1	154	155
Heavy rainfall	1	7	8
Drizzle	127	27	154
Snowfall	132	13	145
Weak snowfall	5474	760	6234
Moderate snowfall	21	582	603
Heavy snowfall	0	0	0
Weak graupel	0	0	0
Moderate graupel	0	0	0
Ice pellets	15	1	16
Total	7331	4008	11339

Table 4 shows that “weak snowfall”, “snowfall” and “drizzle” are hardly detectable by radar. Only 12% of all events with weak snowfall can be seen by radar. Two unfavourable effects come together and inhibit the detection of weak snowfall with radar. First of all, the sensitivity of a radar to see “dry” particles (such as snowflakes or snow crystals) is lower than for “wet” particles, such as melting snowflakes or raindrops (Atlas, 1990). Second, snowclouds are often shallow and only visible near the ground, but the radar beam near the ground is either shadowed by hills or mountains, or contaminated by clutter echoes. In Jan/Feb 2002 an unusually high number of days with fog, low stratus and easterly flow

occurred. Weak snowfall may develop within fog and low stratus clouds. Sometimes, human sources for ice nuclei can be identified, leading to so-called "industry snow".

For "weak rainfall", the detection rate is much better and reaches 62%. Even better results are found for "moderate snowfall" (detection rate with radar 97%), and almost every event of "moderate and heavy" rainfall can be seen by radar (detection rate 99 %).

4. Conclusions and Outlook

In this study, we tested a simple method based on temperature and humidity measurements to discriminate between rain and snow (the so-called KSS-method), and we validated the ability of radar measurements to detect winter precipitation over hilly terrain. The following main results are found:

- a) The KSS-method works fine and provides the correct precipitation type in 92% of all cases.
- b) The detection rate of a radar for weak snowfall is low (12%), but the radar is able to detect the majority of all cases with weak rainfall. Moderate snowfall, and moderate and heavy rainfall are detected in almost all cases by radar.

The first finding allows a real-time monitoring of the melting layer which has several applications, for instance: interpretation of precipitation observations with radar, improving precipitation estimates on ground, and nowcasting snowfall or freezing rain.

The second finding calls for further efforts assessing the detection of weak snowfall. Either, radar systems with a better sensitivity are installed, or, a dense network of proper sensors on the ground is operated. A possible solution could be the use of X-band radars, having better properties for clutter suppression and detection of weak precipitation than C-band radars. Considering ground stations, it is also possible to operate a dense network of precipitation sensors, being able to register precipitation with a good resolution in time (typically 5-10 min). The information about the type of precipitation (rain or snow) can be obtained with the KSS-method, based on a less dense network of stations measuring air temperature and humidity. However, the KSS-method, as discussed in this study, is only usable in hilly or mountainous terrain.

For future, we plan to expand our data sample for validation. Sensor data about the type of precipitation are available since 1999. Hence, the data from several winters can be used for validation. We also plan to validate short-term forecasts of winter snowfall, based on our extrapolation technique COTREC/RainCast (Schmid, 2000). We believe that short-term forecasts of moderate snowfall are reliable since the detection rate of moderate snowfall with radar is close to 100%. Finally, there is also a need to develop and validate methods identifying and nowcasting freezing rain. Similar concepts as outlined in this contribution can be used for this purpose.

Acknowledgements

We are grateful to MeteoSwiss for having access to the ANETZ and radar data for this study. Valuable comments and suggestions of Tobias Grimbacher are gratefully acknowledged.

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Flow and presentation of road weather data and winter maintenance activities on the Internet

by
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Abstract

The decision on whether a call-out is needed on the road network in Denmark is made at individual winter surveillance centres. To support these tasks at the surveillance centres, two computer systems have been developed. The systems are a Road Weather Information System (RWIS), and a management system for winter maintenance (VINTERMAN). The RWIS system has been operational in Denmark since 1983 and VINTERMAN has been operational since 1998.

The aim of developing these two systems was to optimize the winter maintenance activities. But all the stored data in the systems make it at the same time possible to send out very precise information to the road users about activities and road conditions. The information is given via telephone, radio, television, Text-TV and via the Internet. The development of IT technology and an increased data flow speed has made it possible to show more information on the Internet than earlier, and it's still improving.

In this paper a description is given of the data flow, - that is, from the two systems sources mentioned before, out on to the Internet.

Introduction

The Danish road network has a total length of about 72.000 paved kilometres. The administrative and economic responsibility for the road network is shared by three levels of road authorities. National roads have a length of 1.618 km and are administrated by the Road Directorate. Regional roads are covering 9.964 km for which the 13 counties in Denmark are responsible. Local roads cover 60.328 km and are administrated and maintained by the 271 municipalities. The Road Directorate administers the national roads, but daily maintenance and operation including winter maintenance are performed by the counties.

The RWIS system and the VINTERMAN system are installed in the winter surveillance centres in each county. The information from the RWIS system, together with weather forecasts and radar images, are used to determine the right time for starting the salt spreading and snow clearing operations. Once the decision is made, VINTERMAN is used as a decision support system to assist the operators in carrying out the activities. Information from the two systems is sent out on to the road users.

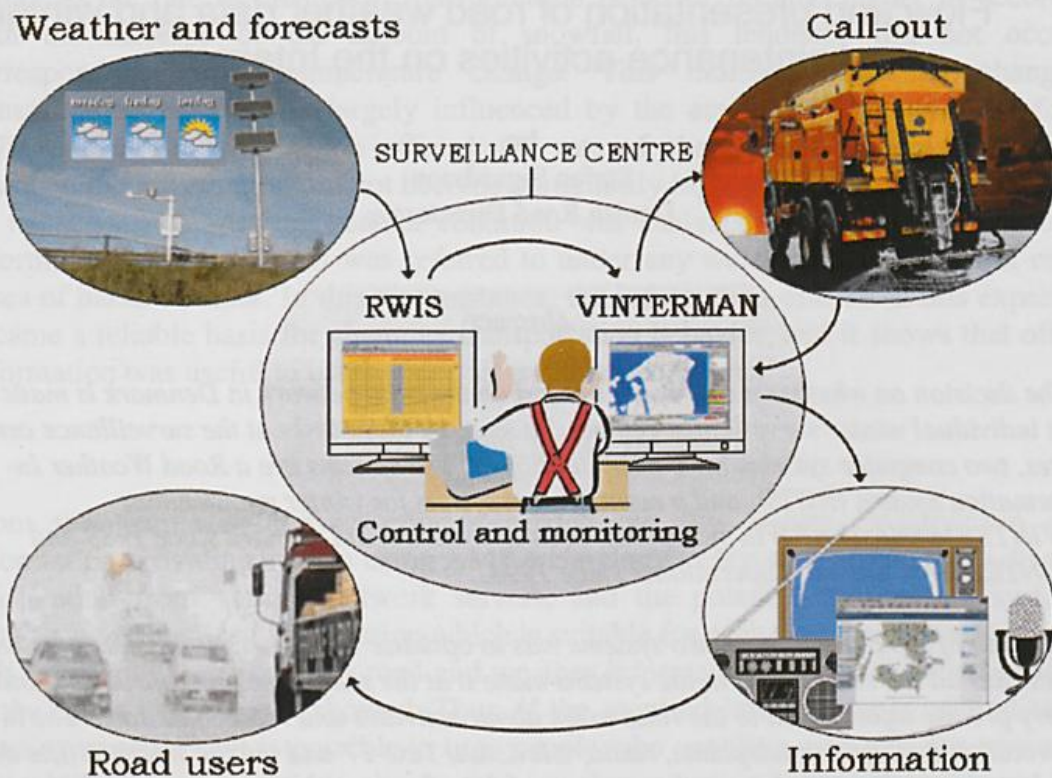


Figure: Information flow for the Road Weather Information System and VINTERMAN

To monitor the road conditions the centres have on-duty personnel from the 15th of October to the 15th of April. In a typical winter in Denmark, there are about 95 call-outs for salting due to risk of icy conditions. Salting as a result of snowfall, on the other hand, occurs only 5-10 times a year. In Denmark, we experience the particular problem of temperature fluctuations around zero, which means that during the winter the roads are slippery and dry, alternately. Therefore it is very important for the road administrations to have access to an operational RWIS system and to very short range weather forecasts. Furthermore it is very important to have as short response time as possible in the call-out situation. Due to how seldom snowfall occurs in Denmark, very few cars are equipped with studded tires. Sudden occurrence of black ice can therefore lead to major accidents, and snowfalls will always have a big negative impact on the traffic flow.

As a result of these circumstances, preventive actions are always taken to salt the roads before they get slippery. The circumstances also make it very important to give as much and accurate information as possible to the road users, to avoid eventual traffic jam and accidents. With reliable real-time information on the road conditions and activities, makes it possible for the road users to determent if they are needed to take precautions due to different road conditions, or simply to stay at home. Knowing this, before starting the journey, will make the drivers more relaxed. Now let's take a look at the data sources.

RWIS

Development of a warning-system for slippery roads in Denmark began in 1983, when the first measuring-stations were installed. Since then, the system has been continuously developed concomitantly with research on slippery-road warning. The number of stations today has now grown to 310 stations along the road network. The stations are situated all over the country and collect data every 10 minutes. The stations are measuring the following: Road temperature, conductivity of the road surface (dry, wet or salt), air temperature, humidity, wind direction, wind speed and precipitation. For each region, the Danish Meteorological Institute (DMI) computes forecasts every hour, based on observations from the measuring stations located in the region.

At appropriate times the system can send out visual and acoustic alarms. These alarms are activated e.g. when certain weather parameters exceed specified limits or are such that slippery road conditions are likely to arise.

All the data can be seen in each winter surveillance centre, but a part of the information is sent further on to the Internet. On the site www.vintertrafik.dk, road and air temperatures can be seen for all of the measuring stations. Similarly, there is a map showing the alarm status of the weather stations on DMI's website. (<http://www.dmi.dk/vejr/glatfore/glatfore.html>). The information is given for both observations and a 3-hour forecast and is shown as coloured areas on a map of Denmark. Green colour indicates that the situation is normal, yellow colour indicates that the road temperature is below zero and red indicates that slippery road conditions are likely to arise.



Figure: A 3-hour forecast showing risk of icy roads

VINTERMAN

Once the decision of making a call-out is made, VINTERMAN is assisting the operators in carrying out the activities. VINTERMAN controls the communication with the contractors and stores all appropriate information in a logbook. This provides the opportunity to monitor and control the work quality.

Based on the list of activities, VINTERMAN is also able to display all ongoing activities on a map. The activities are coloured distinctly to indicate their status on the routes. Equipment provided with on-line data collection (GPS) will be displayed on a map as a dot that indicates its position and direction. Information regarding the current position is typically used when transfer is needed and resources are moved from one route to another. Together with the list of activities the map gives the on-duty officer a good view of the situation.

Data Collection

VINTERMAN contains special features for the presentation of data obtained from data-collecting equipment. During and after the activity (with the use of on-line data collection), the facility shown on the figure will be able to display the received data from an equipment. The picture is divided into three presentation windows that are linked together. In this way, a click on either the map, graphics or list will automatically place focus correctly on the other two windows.

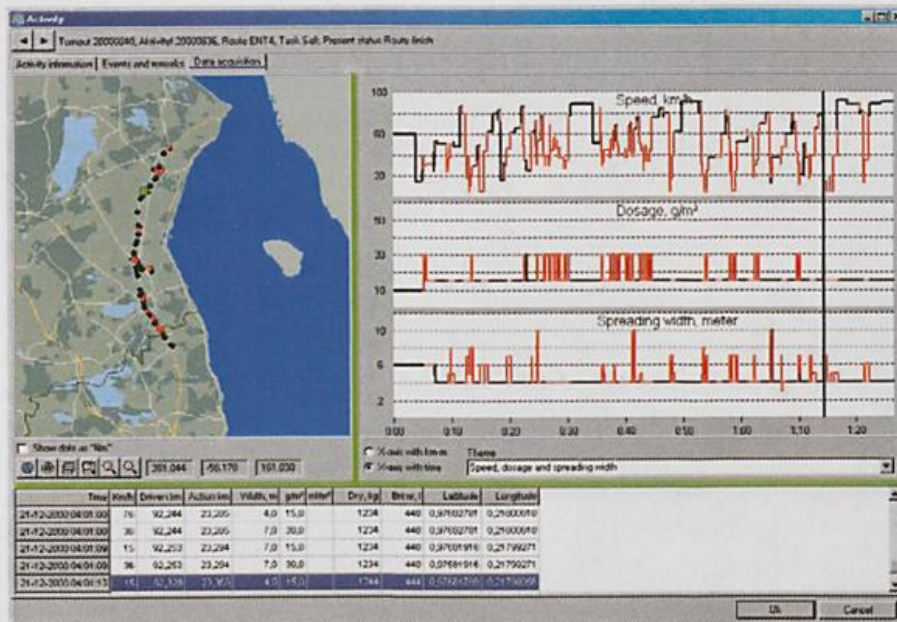


Figure: Presentation of detailed data from the salt spreaders

Data collection was initially only used on salt spreaders, but it is now available for trucks and tractors that are equipped with ploughs, and special patrol vehicles that are capable of measuring air and road surface temperature, air humidity, residual salt etc. Data from these vehicles are also presented in VINTERMAN, where the graphic is cor-

rected so the curves for items (e.g. road surface temperature) are replaced by data from a patrol vehicle.

Road Reports

VINTERMAN includes a report module in which each road officer regularly reports on the road condition. The reports describe the officer's perception of the road condition based on the Road Weather Information System, his/ her knowledge of the distance to patrols, and ongoing activities. The reports can be sent by e-mail, SMS or fax to specified groups. Reports are also published on the internet site www.vintertrafik.dk. Here, the reports are combined with observations and forecasts on air and road surface temperatures from all measuring stations in Denmark. If an observation or a forecast indicates a risk of icy roads there will be a special warning issued. A road report includes the following:

- A scheme where information on road condition and start time for activities is entered.
- A text box where messages can be written if the road condition is abnormal or in cases of extreme weather. This could be e.g., closed road, blizzard, stormy weather, tree blocking road and so on. This information will appear instantly on the site vintertrafik.dk.
- In the text box at the bottom of the scheme, the actual situation can be described from a more technical point of view. Only relevant on-duty personnel will receive this message.

The colours in the scheme are used to group the different types of information. The green line is used to report on normal road condition. The pink lines are used to give information on the winter maintenance activities on the roads. The blue lines are used to report a changed road condition and the white lines are used to give information on the weather.

Rapport	Overalt	M40	Nordtjyn	Østtjyn	Vesttjyn	Midtjyn	Sydtjyn og søer
Normal condition at this season							
Preventive salting started at							
Salting against slippery condition s							
Snow removal started at							
Snowfall		X					
Heavy snowfall			X	X			
Snow drifting					X		X
Problematic road condition							
Only one track open							
Closed roads						X	
Spots with snow/ice							
Snow/ice on the road							
Slippery on special places							
Black ice							
Wind							

Figure: A road report in VINTERMAN

All the information in the scheme is automatically extracted to vintertrafik.dk. On the site a map of the whole country is shown. If there is any ongoing activity or risk of slippery roads, a sign will be displayed. As a supplement to the information on activities and road condition, pictures from several web cams are available. This makes it possible for the road users to get a visual view of the situation on the roads.

To get more detailed information it's possible to get a map of each county. On the county maps the air and road surface temperatures are shown. Signs presenting the road conditions, activities and the weather situation will automatically be displayed when a report is sent via VINTERMAN. The signs have a mouse over function. If the mouse is held over a sign more detailed information will pop up. On the figure this can be seen as a yellow text box where start time of salting is given for the respective area. When a salting activity is over, the time for the last activity is shown. This information is frequently used by road users who don't want to get their vehicles exposed to salt, e.g. motorcyclists.



Figure: A detailed map on www.vintertrafik.dk showing road condition, activities and the weather situation

Users

Many different groups of people use the information on vintertrafik.dk. The professional users are e.g.; the personnel at the winter surveillance centres, the Traffic Information Central (TIC), municipalities, media people and local contractors.

The personnel at the different surveillance centres use the site to get a quick overview of the road and weather situation in other parts of the country. At TIC and at different radio stations, the site is used to distribute information to the road users.

Many municipalities use the site to monitor the activities on the county- and national roads, especially those municipalities that don't have access to a road weather information system. If they learn that there has been a call-out on the main road network in the area due to e.g. black ice, the on-duty personnel will inspect the municipality roads to decide whether a call-out is needed or not. Local contractors who work for private companies or private organizations use the site for the same purpose.

The professional users are almost constantly monitoring the site, and on a normal day, where nothing special is happening, the number of visitors is about 1000 – 2000 a day. On the other hand, when there is a winter situation with black ice, freezing wet road surface, freezing rain or snowfall, the number of visitors will rise up to 80.000 a day, and in these cases a main part of the visitors are the ordinary road users. The peaks are especially in relation to heavy snowfall. In these situations people want to know if there are big delays and in worst case closed roads due to snow or accidents.

Statistics

The on-line data collection from the salt spreaders and the trucks as described before make it possible to view many different types of statistics in VINTERMAN. VINTERMAN is able to provide statistics on the number of activities, consumption of salt, duration and time of call-out along with the cost of salt and payments to contractors. The statistics can also be graphically displayed. Furthermore the authorities use the information to administrate and optimize the winter maintenance.

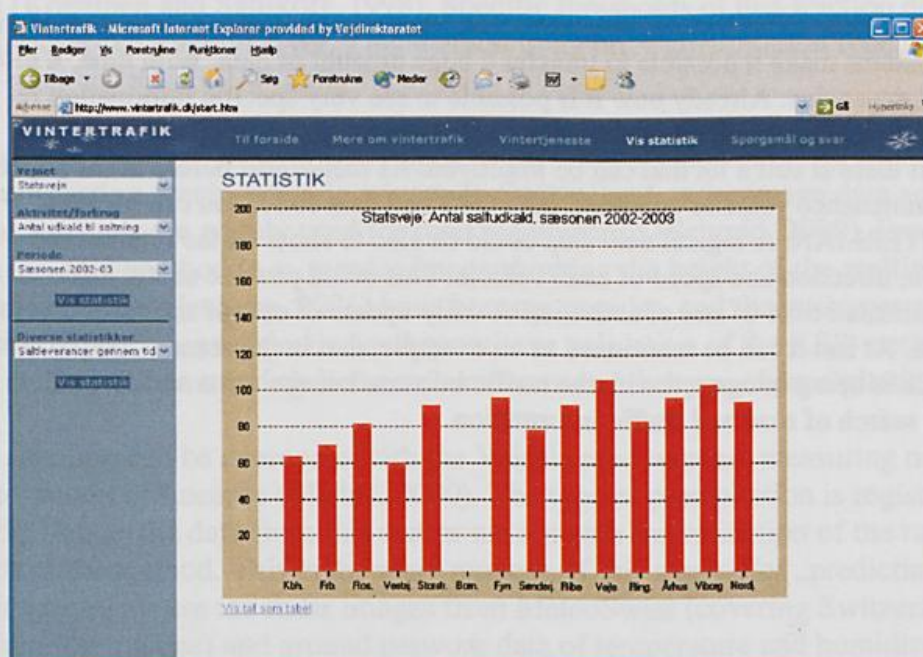


Figure: Statistics showing number of turnouts for each county on vintertrafik.dk

Information regarding activities and salt consumptions are updated in real time in VINTERMAN. Many different partners are interested in this kind of information, and having this information in the system, gave the idea of bringing it further on to the Internet. The result is that information on number of turn-outs, number of hours used to clear snow and salt consumption in tons and in kg/m² is updated daily on vintertrafik.dk. This can be seen by choosing "Vis statistik". Data is available since the winter season 2001-2002, but more historical data will be implemented in the near future.

And one might ask, - why bother to put all this statistics on the Internet? The information is already available in VINTERMAN, so the effort to transmit them further on to the Internet is not that big. It facilitates the information from the road authorities on winter related activities to different partners. For example, when a snow storm occurs it often makes big headlines in the media. How much salt was used, how much did it cost the community and so on. Having this very precise and updated information on the Internet makes it easy to give the information and at the same time easy to get hold of. Among others that ask for that type of information are other road authorities, politicians and students to mention a few.

Other information

Information such as winter service standards on each type of road and answer to many frequently asked questions is also available on the site. Questions such as; when do slippery roads occur, how often can I expect slippery roads, who maintain the roads, how much does a typical winter cost, when are the roads cleared for snow, why not to use sand instead of salt, how does salt affect the environment and so on.

Conclusion

The winter maintenance technology improves very fast, and high speed communication cables and systems make it possible to transfer a huge amount of data. With time, it also becomes less expensive. Already now it is possible to see very specific information regarding e.g. temperatures, winter maintenance activities, road conditions and salt consumption, but there is still a lot that can be improved. As mentioned before in the paper, all winter maintenance vehicles equipped with GPS and data collection can be monitored in VINTERMAN. A logical next step could be also to show on the Internet the exact position, direction and speed of each vehicle. This could provide useful information on an estimated time of end of activities. A daily update of cost of activities is also an alternative. At last it can be mentioned as an example, that in the season 2003-2004 vintertrafik.dk is being integrated with the traffic information site www.trafikken.dk to facilitate the search of road and traffic information.

Submitted Papers Topic IV:

Presentation and Interpretation of Road Weather Information Data

- (IV-1) Kagaya/Kajiya/Yamagiwa (JP): Smart Sapporo Snow Information Experiment
- (IV-2) Sigurdsson (DK): Flow and Presentation of Road Weather Data and Winter Maintenance Activities on the Internet
- (IV-3) Schmid/Mathis (CH): Validation of Methods to detect Winter Precipitation and retrieve Precipitation Type
- (IV-4) Eriksson/Johansson (S): Winter Weather and Municipal Winter Road Maintenance
- (IV-5) Iivanainen/Pettersson (FIN): Quality for Road Weather Information System – Applying ISO 9001
- (IV-6) Toivonen/Kantonen (FIN): Supporting IT System for Road Weather Quality Measurement

INTRODUCTION

The Greater Sapporo Area has a large population (two million) and extremely heavy annual snowfall (about 5 m). In winter, snowfall and road surface freezing potentially obstructs traffic movement. It is important to assure reliable and accurate winter road traffic so that the region may enjoy socioeconomic stability.

To meet these problems, a joint research group made up of members of the Civil Engineering Research Institute of Hokkaido and other private organizations including the author (Kagaya) has performed information-providing experiments beginning in winter 2001 with the help of road administrators, relative organizations and citizens. These information-providing experiments largely utilize web description language called RWDL (Road Web Markup Language) or web based on XML (Extensible Markup Language).

These experiments demonstrated that the provision of specific road and weather information was effective in mitigating urban traffic problems in winter. Also, they have shown that the use of an XML data format enables the information provider to efficiently construct systems for the collection of data from information sources distributed across the Internet, to compile the collected data according to user needs, and to provide users with the requested data. This affords flexibility in adapting to specification upgrades.

In this report, we shall retrace the experiments in the winters of 2002 and 2003, and discuss the issue of providing personalized information by mobile and provider with the use of XML technology.

Smart Sapporo Snow Information Experiment

- Personalized Road Weather information Services using XML Technology -

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ABSTRACT

In the winter of 2003, we carried out an ITS trial project called "Smart Sapporo Snow Information Providing Experiment". This experiment was carried out to deal with city roads traffic problems in winter in the Greater Sapporo area with the use of advanced information and communications technologies such as the Internet and mobile information terminals. We found that XML technique enabled us to offer personalized weather information for roads suitable for each user. The information provided is very detailed so that it enables us to make sure the information is very useful in smoothening the traffic in wintertime.

INTRODUCTION

The Greater Sapporo Area has a large population (two million) and extremely heavy annual snowfall (about 5 m). In winter, snowfall and road surface freezing perennially exacerbate traffic congestion. It is important to assure reliable and punctual winter road traffic so that the region may enjoy socioeconomic stability.

To meet these problems, a joint research group made up of members of the Civil Engineering Research Institute of Hokkaido and other private organizations including the author(Kagaya) has performed information-providing experiments beginning in winter 2001 with the help of road administrators, relative organizations and citizens. These information-providing experiments largely utilize web description language called RWML (Road Web Markup Language) for roads based on XML (Extensible Markup Language)¹⁾.

These experiments demonstrated that the provision of specific road and weather information was effective in mitigating urban traffic problems in winter. Also, they have shown that the use of an XML data format enables the information provider to efficiently construct systems for the collection of data from information sources distributed across the Internet, to compile the collected data according to user needs, and to provide users with the compiled data. This affords flexibility in adapting to specification upgrades.

In this report, we shall summarize the experiments in the winters in 2002 and 2003, and discuss the issue of providing personalized information for roads and weather with the use of XML technology.

OUTLINE OF THE EXPERIMENT

(1) Objectives

This experiment is to test providing personalized road and weather information by means of the latest communication technology and to study the degree of effectiveness of the provided information to smoothen the traffic in winter.

(2) Method

The duration of the experiment carried out was 3 months, from December 4, 2002 till February 28, 2003. With the use of the Web description language RWML (based on XML technology) information was selected, gathered, and organized from various resources available on the Internet, for the needs of each monitoring participant.

Information on road conditions of their commuting routes for the next day and the amount of snowfall around their houses from the night before was provided through the web and also sent through the e-mail to computers and mobile phones. Types of information offered are for commuters to workplaces and schools, for people who move within Sapporo city, and for businesses persons and workers who move around the inner city and suburbs as part of their job (see Table 1.).

Table 1. Outline of the experiment

Experiment period	December 4, 2002, to February 28, 2003 (about three months)
Experiment area	The ten wards of Sapporo, and the cities of Otaru, Ebetsu, Kitahiroshima, and Ishikari
Experiment	
Provision of Snow-Related Information to Commuters by E-mail	Information on snowfall, temperature, and road surface conditions was provided to commuters twice a day (early in the morning and early in the evening) via Web. E-mails were sent to monitors who wished to receive snowfall and temperature information (615 monitors registered for this).
Provision of Sapporo Snow Information on the Web	Weather information at transportation hubs, ski areas, and other places in the city was provided on the Web.
Snow-related information exchange among residents on the Web	Residents posted snowfall and road surface conditions in their neighborhoods and whether they would use public transportation. These reports were compiled for release over the Web.
Information on snowstorm in suburban areas	Information on snowfall or snowstorm in suburban areas was provided to drivers (pre-departure and while traveling).
Provision of Information to Businesses on the Web	For professional drivers traveling in Sapporo and its environs, road and weather information on their travel routes was offered on the Web.

The system of e-mail distribution for the commuters to workplaces and schools is set to enable the receivers to choose from various content options: the target area for the information, the delivery date, and morning delivery time for receiving, temperature or the amount of snowfall, etc. to suit their individual needs.

CONSTRUCTING THE INFORMATION PROVIDING SYSTEM

XML is an extended and extensible version of HTML, and was designed to define the method of extension so that any machine can recognize and dealt with information as machine readable data. This enables information to be efficiently circulated on the Internet. In this experiment, an information providing system was constructed, starting from the web description language RWML^{2,3)} which was designed by the joint research group to utilize the XML technology in the field of road and weather information.

The construction of the system network from this experiment is shown in Figure 1.

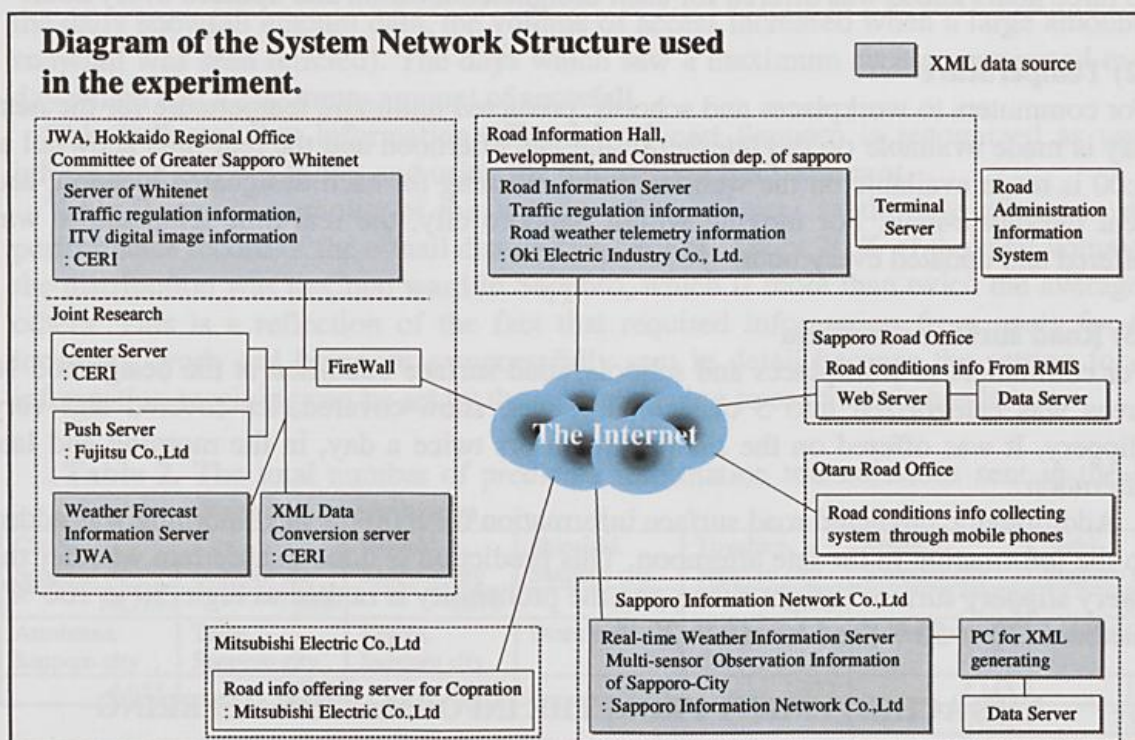


Figure 1. Diagram of the system network structure used in the experiment

Information, which each organization owns, is made available on the Internet from their own servers. If a server needs information which becomes available, it can obtain the information, translate and modify it as needed.

Information on the Internet for users is made available on the Center Server, shown on the left of the Figure 1. The information offered to the users is the modified data which was originally described in RWML, obtained from other servers through the Internet.

On the Center Server, e-mail, another key service of the information providing, is distributed, and other processes such as recording e-mail addresses, setting the contents to be distributed and storing the information are performed.

OFFERING WEATHER INFORMATION

The following is a detailed account of the weather information provided in the experiment carried out this winter.

(1) The amount of snowfall

The information regarding the amount of snowfall was offered with the following ranking system: 0-1 cm, 1-5 cm, 5-10 cm, 10-15 cm, 15-20 cm and over 20 cm.

Regarding the information for commuters to workplaces and schools, it was sent twice a day in the morning and late afternoon: the predicted amount of snowfall from 18:00 to 6:00 the next day was sent in the late afternoon and the actual amount of snowfall from 18:00 the day before to 6:00 the day were placed in the morning on the website and sent

through e-mail. For commuters within Sapporo city, predicted snowfall information up to three hours ahead was offered for each designated location and updated every hour.

(2) Temperature

For commuters to workplaces and schools, predicted minimum temperature for the next day is made available on the Internet in the late afternoon and the real-time snowfall at 6:00 is made available on the website in the morning for each designated location, and sent through e-mail. For moving within Sapporo city, the real-time temperature was offered and updated every hour.

(3) Road surface condition

For commuters to workplaces and schools, road surface condition at the designated 16 areas was categorized into 5 classes: dry, wet, snow-covered, ice-covered and very slippery. It was offered on the Internet for users twice a day, in the morning and late afternoon.

Additionally, predicted road surface information for 8:00 the next morning was added to the information in the late afternoon. This prediction is done to ascertain whether the "very slippery surface" might occur, and the probability is ranked as high (50 to 100 %), medium (20 to 50 %) and low (0 to 20 %).

THE ACHIEVEMENT FROM THE INFORMATION OFFERING

(1) Usage based result during the course of the experiment.

The following shows the utilization of weather information during the experiment.

Total number of access to the website: 82,313 (average access: 946 per day)

Of the total, the number of access from PCs: 45,297

Of the total, the number of access from mobile phones: 37,016

Daily pattern of access is shown in Figure 2.

Figure 2. Time series for the access on the website against the snowfall in Sapporo.

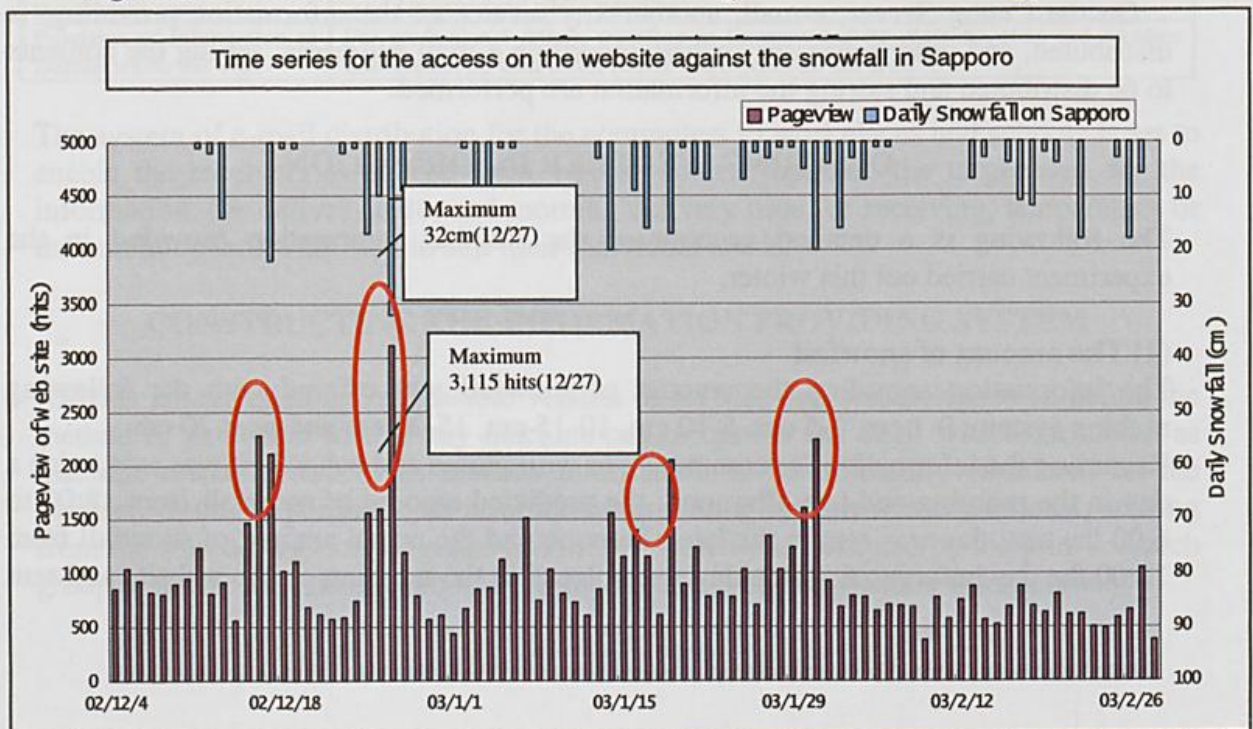


Figure 2. shows the daily access pattern on the website. When it is shown together with the daily snowfall amount data, the volume of access increased when a large amount of snowfall was seen (circled). The days which saw a maximum access correspond to the day which had a maximum amount of snowfall.

This indicates that information offered by Smart Sapporo is recognized as useful information when it snows and using the information has taken root.

Table 2. shows samples of the volume of e-mail sent in the late afternoon as a performance record of the e-mail distribution service. About 20 % of the total volume of the distribution was to Chuo ward in Sapporo, which is more than twice the average of others. This is a reflection of the fact that required information from users for two locations, work and home, was successfully sent in detail because the setting for the information receiving can be set by the user according to each user's needs.

Table 2. The total number of predicted information transmissions sent in the late afternoon to each area

Chuo, Sapporo city	Kita, Sapporo city	Higashi, Sapporo city	Shiroishi, Sapporo city	Toyohira, Sapporo city	Minami, Sapporo city	Nishi-, Sapporo city	
14,374	7,058	6,276	6,841	6,658	3,394	5,983	
Atsubetsu, Sapporo city	Teine, Sapporo city	Kiyota, Sapporo city	Otaru city	Ebetsu city	Kitahiroshima city	Ishikari City	
4,655	3,917	5,174	3,873	3,327	2,145	1,613	
						Total	75,288

(2) Achievement of information accuracy during the course of the experiment.

Prediction for the amount of snowfall

The most important information in this experiment proved to be the prediction for the amount of snowfall, and the results are organized bellow. The accuracy for the actual information for the snowfall sent in the morning and the predicted information for the snowfall sent in the late afternoon the previous day is compared and evaluated. If the predicted information is in the same rank as the actual information, the information is evaluated as accurate, and the accuracy (where 1 is 100%) is shown below.

Table 3. Accuracy level for the amount of snowfall prediction in each area.

Chuo, Sapporo city	Kita, Sapporo city	Higashi, Sapporo city	Shiroishi, Sapporo city	Toyohira, Sapporo city	Minami, Sapporo city	Nishi-, Sapporo city
0.70	0.59	0.63	0.68	0.60	0.70	0.72
Atsubetsu, Sapporo city	Teine, Sapporo city	Kiyota, Sapporo city	Otaru city	Ebetsu city	Kitahiroshima city	Ishikari City
0.72	0.62	0.61	0.58	0.62	0.70	0.59

The degree of accuracy is distributed in the range between about 0.6 and 0.7, which produces the average of 0.65 as a whole. This shows that the information offered had enough accuracy for practical use. Thus, to have been able to offer accurate information for practical use is thought to be one of the reasons for that the information was utilized as much as it was, which can be seen from the number of access on the website which increases when it snows.

Prediction for ice-covered road surface

In all 16 designated locations, daily updates of predicted information for frozen road surface shows the result that 69 % was low probability, 15 % was medium probability and 16 % was high probability.

In practice terms, this winter did not see a large amount of snow and the temperature was quite high. Subsequently there was a low incidence of Slippery Road Surface, and as a result, the slippery road surface tended to be over-estimated.

It was the first attempt to predict the incidence of Slippery Road Surface and to offer the information to citizens. Consequently, the system is assumed to need improvements for the future use, and the aim is to offer more accurate information which can be applied to the actual situations.

SURVEY FROM QUESTIONNAIRE

(1) Outline of the questionnaire survey

Monitors who registered to receive e-mails were surveyed by questionnaire during and after the experiment. The questionnaire during the experiment sought to survey changes in travel behavior, i.e., how and why the behavior changed, the post-experiment questionnaire investigated how travel behavior was changed by the information, and the level of satisfaction with weather and other information (e.g., how such information helped winter commuting). (see Table 4.).

Table 2 shows the result based on the questionnaire to those who use their own cars. It is thought that this group shows a particularly high correspondence between the weather information provided and change in transportation behavior.

Table 4. Outline of the questionnaire survey

	Questionnaire during the experiment	Post-experiment questionnaire
Outline	At the start of the experiment a questionnaire was sent by post. The monitors were asked to fill out the questionnaire regarding their commuting behavior. The questions differed for drivers and non-drivers.	At the end of the experiment, a questionnaire was sent by post. The monitors were asked to send it back enclosed with questionnaire during the experiment. The questions differed for drivers and non-drivers.
Questions	Transportation mode for commuting Alternative transportation mode in case of change Reasons for changing Duration of commute	Change in travel behavior Level of satisfaction with the currently provided information Evaluation on the information provided Willingness to change travel behavior Value of information
Respondents	Drivers: 74 (Total instances of travel behavior: 2,989) Non-drivers: 128 (Total instances of travel behavior: 5,436)	Drivers: 96 Non-drivers: 156
Response rate	41% (252 of 615 monitors responded.)	

(3) Changing behavior in view of weather condition

During the experiment (total of 87 days), a total of 2,989 instances of commuting behavior, or an average of 34 per day were collected.

(a) Overall tendency for changing transportation behavior

) For the reason that this winter was quite warm and did not see much snow, the number of people who changed the type of transportation itself considering the weather and road surface condition were 100 (3 % of total). Of the 100, the majority, 58, are those who changed the time to leave their homes, etc.

) Based on the information offered in this experiment (information on weather and road surface condition for commuters to workplaces and schools, information sent from citizens), the days that they changed their commuting behavior were 55 days (55 % of changed behavior). This revealed that the information offered in this experiment was referred to and used at a high rate.

(b) Changing commuting behavior with regards to snowfall conditions (shown in Figure 3.)

) When the rate of changing the commuting behavior with respect to the snowfall condition is examined, the more the amount of snowfall from the previous day become large, the more people change their transportation behavior. When more than 15 cm snowfall was seen, approximately 15 % changed their behavior.

) Among these cases, many participants (40 to 80 %) changed their transportation behavior based on the information transmitted. The rate of participants referring to the provided information was particularly high when a more than 15cm snowfall was seen.

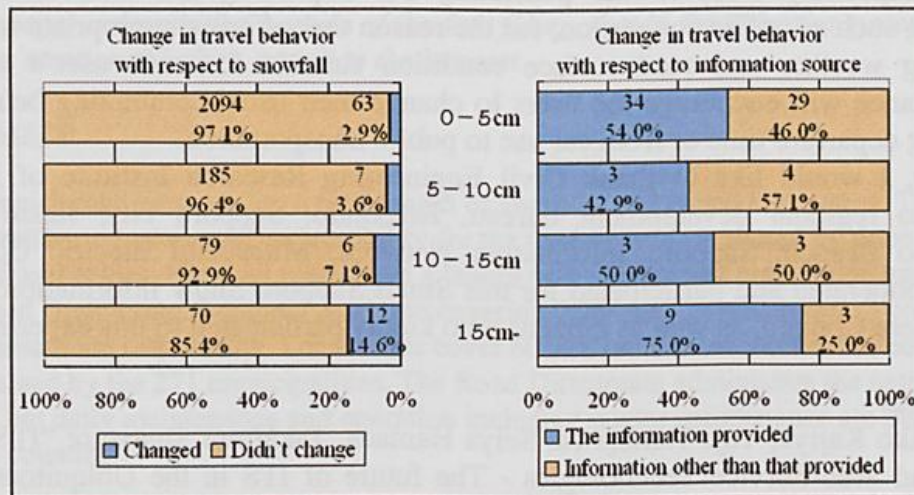


Figure 3. Instances of change in travel behavior with respect to snowfall and information source

(c) Changing the commuting behavior with respect to temperature.

) When the rate of changing transportation behavior was compared against temperature, the rate of change was between 2 % and 6 % and there is no particular tendency to change transportation behavior remarkably in accordance with the cases when low temperature.

Although the rate of change in transportation behavior became higher in accordance with the increase of the amount of snowfall, this tendency did not occur in correspondence with temperature change. This indicates that the change in transportation behavior is largely influenced by the amount of snowfall. As for the utilization of the information offered, the rate of change in transportation behavior based on the information did not become particularly high when the information offered on the days with specific weather condition was analyzed. This seems to be because information sent via e-mail was referred to under any weather conditions, not only in cases of harsh weather. In this circumstance, the information offered in this experiment became a reliable basis for changing transportation behavior, and it shows that offering information was useful to users under all weather conditions.

CONCLUSION

From the results of the experiment carried out this winter, construction of an information providing system using XML technology to organize and manage dispersed information from various network servers, and the potential to use this system to provide individualized information which is suitable for each user were clearly attested.

It is obvious that needs for road and weather information are much higher in winter, as the usage based result showed. Thus, if the required information is offered to road users appropriately, it is possible to urge people who use their own cars for commuting to workplaces and schools to change their usual commuting behaviors, as shown in the results of questionnaires.

This especially leads to the possibility for improving and smoothening traffic situation, such as traffic congestion, for the reason that offering appropriate information regarding weather and road surface condition suitable for each user's commuting circumstance will encourage the users to change their usual commuting behavior, e.g. changing departure time or from car use to public transportation.

Lastly, I would like to thank Civil Engineering Research Institute of Hokkaido, Hokkaido regional development bureau, Hokkaido, Sapporo city, Japan Highway Hokkaido Branch, Sapporo Information Network, Mitsubishi Electric Corporation, which cooperated and participated for this Smart Sapporo Snow Information Providing Experiment Council, as well as citizens who kindly participated to this experiment.

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3)Road Web Markup Language Web Site (<http://rwml.its-win.gr.jp/eng/>): Civil Engineering Research Institute of Hokkaido.

Winter weather and municipal winter road maintenance

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Background

Municipalities as local governments are usually responsible for winter road maintenance in built-up areas contrary to state road authorities that are mainly responsible for winter road maintenance in rural areas. For many reasons, municipal winter road maintenance is a complex task to accomplish and no two municipalities are alike regarding that type of service. In Sweden, the number of built-up areas in a municipality range from very few to more than 20, but not every municipality is responsible for the winter road maintenance in all of its built-up areas. Furthermore, every built-up area has different types of traffic areas for different types of road users. Traffic areas are often used by more than one type of road user. Other factors contributing to make every municipality unique are geographical location, political majority, number of inhabitants, land area, organisation, traditions, priorities, methods of working, equipment, etc.

Weather conditions is one of the factors that governs the actions taken for snow and ice control of streets and roads, foot and cycles paths, and other traffic areas in a municipality. In its report on the need of weather services for municipal winter road maintenance, the Swedish Association of Local Authorities (SALA) (1993) established that good weather information increases the chances to optimise actions of snow and ice control. In this respect, good weather information should involve that weather forecasts are reliable and give early warnings of difficult road conditions.

In an inquiry dealing with the organisation and handling of municipal winter road maintenance during the winter season 1997/98 in Sweden, Johansson (2000) found that the municipalities used various types of winter weather information. The most common types of information used by the 288 municipalities were forecasts bought from the Swedish Meteorological and Hydrological Institute (SMHI), forecasts presented on TV or radio, and visual observations made by their personnel. However, the use of forecasts from the SMHI varied greatly. Most small municipalities did not afford to buy the forecasts, while all the 11 largest municipalities bought the forecasts. In 1997/98, the Swedish National Road Administration (SNRA) had since long established its road weather information system (RWIS) with nearly 700 stations all over the country. Most of these stations are located along rural roads and not within built-up areas. Only 49 municipalities had a station within or just outside the largest built-up area. This information system was therefore used by less than 20 percent of the municipalities that mostly had to pay for that service.

The maintenance action taken depends on the level of service decided on. For example, it can be described by a snow depth that determines when to start ploughing or whether to use preventive ice control methods or not. Sometimes the payment for executed actions is regulated by the amount of precipitation (snow in water equivalent) and by the number of temperature fluctuations around zero degrees that has resulted in slippery road conditions. These circumstances call for detailed weather information and measuring of weather conditions.

Berntman (1999) conclude that a few days with very slippery road conditions generate many injuries, especially among pedestrians but also to some degree among cyclists. Her advice to municipal road authorities and their contractors is to learn more about the special weather conditions that occur at such occasions to be able to provide preventive and early actions. In his "good advise for municipal winter road maintenance", Johansson (2000) states that it is important for all personnel involved in winter road maintenance to have a good knowledge of how different types of winter weather develop and of the specific road conditions that may occur from severe winter weather. It is also important to understand how to interpret weather forecasts and other weather information correctly to be able to take the right actions at the right time, thereby exposing road users as short time as possible to accident hazards because of snowy and icy traffic areas. The understanding is most important for supervisors that have the responsibility to decide when to call out personnel and units to start actions.

Because of the need for providing municipalities with road weather information, the Section for Infrastructure and Property Management at SALA made a deal with the SNRA in 2000 that the municipalities can use information from the RWIS for free. The municipalities only have to ask for usernames and passwords for those who need the information in their work with winter road maintenance.

In the light of this background, it seemed to be a good idea to present a course in winter weather and winter road maintenance to the Swedish municipalities. Therefore, such a course was discussed with the City of Göteborg, the second largest municipality in Sweden. The reaction from the city was clear enough: "Give us that course as soon as possible!" The first course was given in the autumn of 2002.

Course contents

Winter weather

Winter road maintenance personnel constantly need to estimate the risk for slippery road conditions. The next step is to make a suitable decision about when and where to perform winter road maintenance. The decisions require an understanding for why and how different road conditions develop. The course participants have seldom been given the opportunity to any education in weather-related subjects before. However, the maintenance personnel develop a large experience and "feeling" for road conditions through the years. The main purpose with this course has been to give a general background and increased understanding for winter weather. The consequences could be an increase in the number of "correct" maintenance actions.

The course gives knowledge in basic meteorology and climatology, with focus on situations and processes that may lead to difficult winter road conditions. An understanding for surface

warming and cooling is important as well as typical weather associated with warm and cold fronts. The general background can then be used to explain local climate variations, especially in urban areas. Urban climate is a wide research subject and the urban heat island is well known as well as the importance of sky view factors for temperature distributions in urban areas (e.g. Oke, 1990). Road climate studies have traditionally focused on variations in rural areas. Gustavsson et al. (2001) points out the important factors for air- and road surface temperatures within an urban area. Especially the urban heat island was shown to be important for temperature variations.

As discussed earlier, one of the most important subjects to discuss with the municipal maintenance personnel is weather information and the tools available today. General weather maps and forecasts are widely available on TV, radio, daily papers and on the internet. The larger municipalities also buy local forecasts from SMHI. Even if this information is clear and easy to interpret, a person with some meteorological background can also understand the implications for road conditions. Satellite images are information that can be useful when following fronts etc. One exercise during the course is to compare satellite images and weather maps (figure 1). The exercise increases the understanding for how weather conditions are associated with different weather elements.



Figure 1. The photo shows how weather maps can be compared with satellite images.

Road weather information systems provide another important piece of information. There is a great need for education in how to use and interpret this information. Since few stations are placed in built-up areas, even more knowledge is needed to use and interpret the RWIS information correctly. Awareness of local climate variation is necessary, since the stations are placed in different local environments. It is also possible to use the RWIS presentation to follow regional climate variation (e.g. Eriksson, 2001). For example, weather changes can be monitored through studying how road surface temperature is affected. Figure 2a and 2b shows how the road surface temperatures react when a front passes southern Sweden.

Municipal winter road maintenance

Usually, in a course there are participants from several municipalities. Therefore the participants as a part of the course are encouraged to discuss municipal winter road

maintenance from a more comprehensive view and compare their experiences etc. Such a discussion usually covers different topics on municipal winter road maintenance, such as:

- Juridical aspects including delimitation towards property owners.
- Different forms of client-contractor relationships including questions on contracts, "push-the-button", inspection and monitoring.
- The use of internal and/or external units including equipment
- Priorities regarding different types of traffic areas and snow and ice control including starting criteria and completion times.
- Different types of ice control methods and material.
- Environmental impacts.
- Information to and from the public.

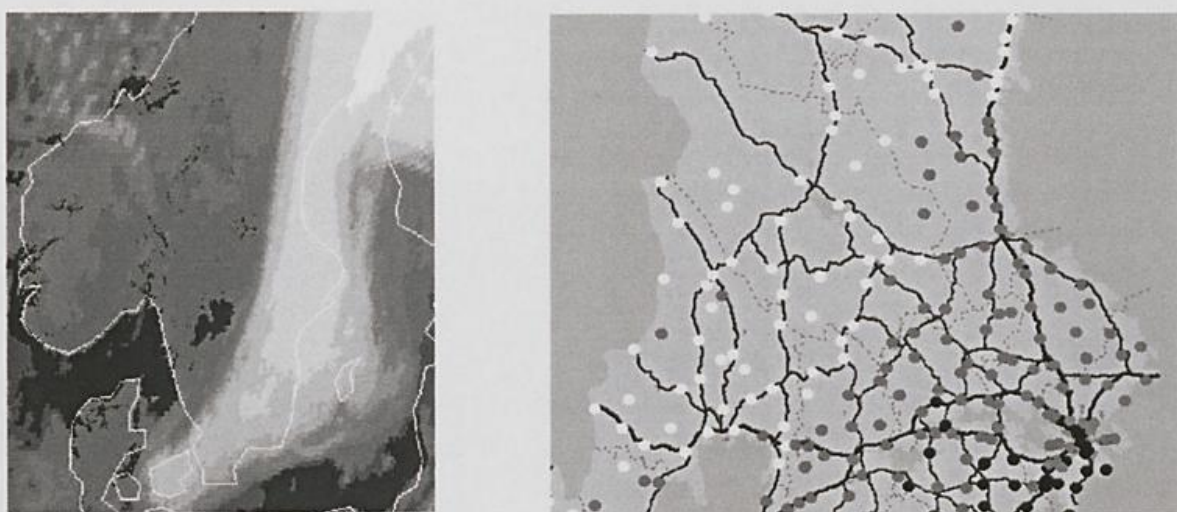


Figure 2. 2a shows a satellite image of southern Sweden and 2b shows the responding road surface temperatures where different shades of grey represent different temperature intervals (black = warm and white = cold).

Concluding remarks

In Sweden, the need for a course like this has turned out extremely high. Until the end of 2003, about 500 supervisors and contractors from about 100 Swedish municipalities (figure 3) have participated in almost 20 courses. However, so far very few of the small municipalities (with less than 10 000 inhabitants) have participated. There are mainly two reasons given not to participate in the course. Either, a municipality recently participated or will participate in a course on winter weather given by the SMHI, or the municipality does not have the money for letting people take the course.

Even if information from the SNRA's RWIS has been free to use for municipalities since 2000, not many of the municipalities did use the information before they participated in the course. The main reason was that they did not consider the information to be valuable and/or they found it difficult to get and understand the information. According to SALA, after participating in the course most of the municipalities have asked for usernames and passwords to be able to use the RWIS. Actually, SALA has continuously been able to notice in what area of Sweden a course has been given.

So far, no course has been given in the northern part of Sweden. The reason for this can be illustrated by the message from the municipality of Umeå: "The winter here in the north is predictable. It will snow and we will plough". It seems to be a more complex task to handle winter road maintenance in the southern part of Sweden than in the northern part of the country. The municipalities in the south often have to deal with weather conditions around 0°C, thus facing more occasions with slippery conditions during a winter season.



Figure 3. The map shows which municipalities in southern Sweden that has participated in the course as of December 2003 (dark grey).

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Quality for Road Weather Information System - Applying ISO 9001

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INTRODUCTION

Road weather data quality has several characteristics. These include

- How exactly the data describes the road conditions (validity)?
- How well the data can be generalized?
- How comprehensively the data covers the road network?
- Is the data available all the time?

Validity of data is further affected by several factors, including:

- Properties of the road weather measuring device in use.
- Assembly of the device.
- Maintenance of the device.

The purpose of the project described in this paper is to ensure the quality of road weather information by developing a quality management system for the road weather information system in Finland. Road weather data is collected from about 320 road weather stations and about the same number of CCTV cameras. Weather forecasts and radar and satellite images as well are passed through the system from weather service providers to supplement data collected by FINNRA. The system was initially built up to provide data for the planning of winter maintenance operations, but nowadays data is also used to inform road users and to control variable message signs (for a more detailed description of the system see Toivonen and Kantonen, 2000).

The project was initiated by FINNRA and it started in autumn 2002. A project group was formed, members of which come from FINNRA, winter maintenance provider organizations, measuring equipment assembly and service providers, Finnish Meteorological Institute and the authors as quality experts. The group worked from autumn 2002 through spring 2003 to build a quality manual for the road weather information system.

MOTIVATION FOR THE PROJECT

The main purpose of road weather information is to facilitate optimization of performance and determining an acceptable level for risk. Drivers use information to find an optimal course or

timing for their trip. Variable message signs are used to control speed in challenging road weather conditions in such a way that risk is acceptable. Winter maintenance operators optimize their use of resources and for example their use of salt to prevent freezing.

To be useful for the intended purposes the quality of road weather data must be high enough. Otherwise optimization and risk management fails. Data quality has always been an important topic while developing the road weather system, but there are some factors why quality should be considered in a more systematic way than before.

Outsourcing winter maintenance and data use

Some years ago road administration in Finland was reorganized and as a result winter maintenance operations are now carried out by independent service providers. This outsourcing has changed the role of the road weather information system, which remained within FINNRA. Information is now used by independent organizations, whereas earlier it was mainly used within FINNRA itself. Moreover, one of the future goals in Finland and elsewhere is that commercial information services be built based on road weather data. So most of the users of data are outside FINNRA.

This outsourcing of data use means more formal relations between producers and users of data. As part of the formality, a need to define a quality level for the information becomes more explicit. At the moment, the winter maintenance contracts include a general statement of the availability of information. But particularly those looking for new business opportunities would also like to get more detailed information about accuracy of measurement and about possible breaks in the flow of data. Besides they would like to see some evidence, facts about quality of data.

Use in automated systems

There are several areas in Finland where speed limits and info signs are controlled by road weather data and the number of such areas is increasing. Data used in these systems must be highly accurate, so that speed limits and info signs reflect real driving conditions. Drivers seem to be sensitive to the justification for a speed limit; if they have the feeling that limits are often too low, they tend to disregard the limits.

Another example of automated systems is Internet pages: data from some road weather stations is shown on FINNRA's web pages. Here the requirement of accuracy is not exactly that high, but there is another common feature: data is used immediately. There is no possibility to human control until afterwards. This means that actions to ensure data quality must be mainly preventive in nature.

The VIKING guidelines

One of the long term goals in VIKING project is to achieve a harmonized and consistent level for road weather monitoring within Nordic countries. For that purpose, a set of guidelines has been prepared for monitoring (Kulmala R. and Luoma S., 2001). The guidelines include a set of common minimum quality requirements for monitoring road weather. The guidelines are an important step in assuring the quality of information. Still, it is only the first step: having defined a set of standards, we must also make sure that the whole system all the time (or most of the time) complies to the standard.

Quantity and quality

The overall coverage of road weather stations in Finland is quite good - at least on main roads - and the data collection applications are quite reliable. However, while the size of the system is increasing and at the same time the number of personnel responsible for monitoring and maintaining the system decreases, there is a risk of lowering quality. This stresses the need for preventive actions and also the need for straightforward routines for detecting and handling of problem situations, supported by automatic tools.

THE APPROACH

As a conclusion, there was a need to

- a define a quality level for road weather data;
- b ensure that the level is achieved;
- c continuously monitor the level;
- d collect evidence of quality.

From the very beginning, quality standard EN ISO 9001:2000 was taken as a frame of reference for the work, as it serves a generally accepted framework for quality and covers all the aspects (a-d) above. Moreover it has an explicit customer focus, which is one of the leading principles of FINNRA. Figure 1 shows the general outline of the project.

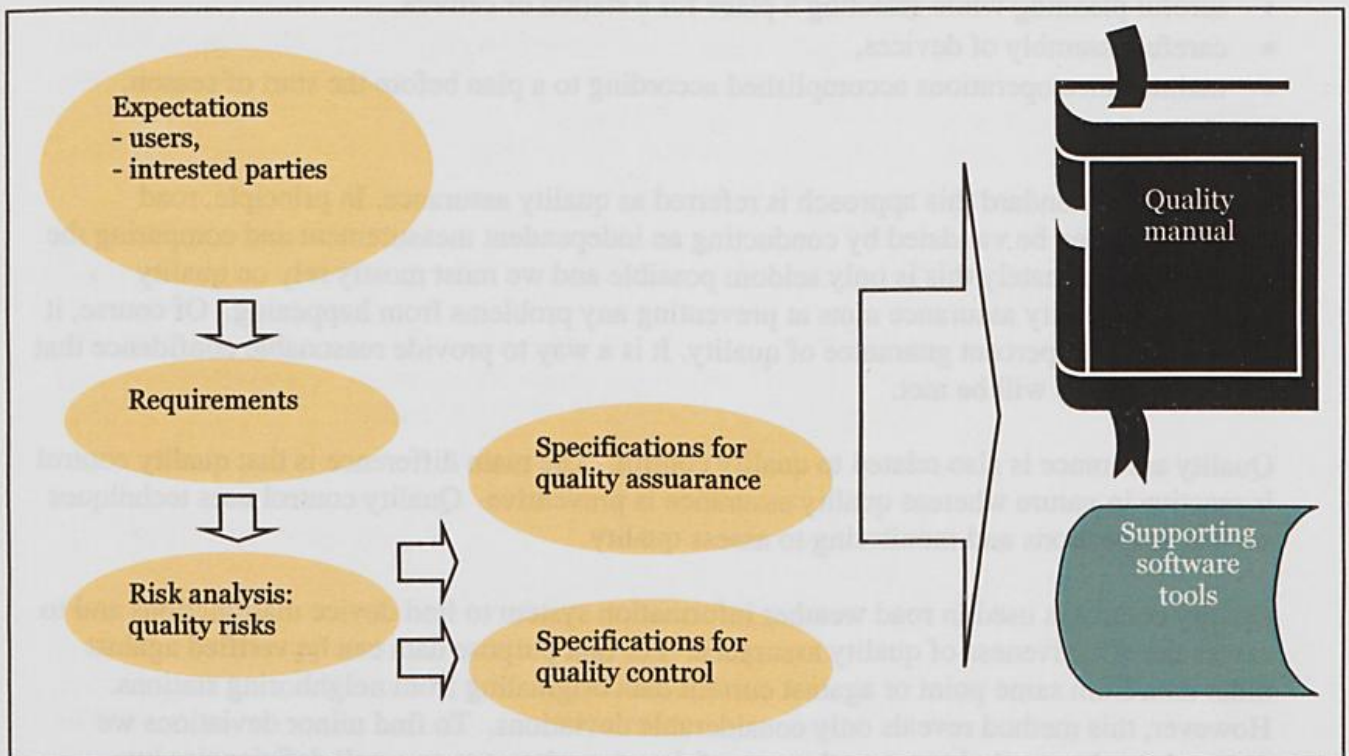


Figure 1. Project tasks

In the quality standard, quality is not considered in absolute terms. Quality is defined as "degree to which a set of inherent characteristics fulfils requirements". Thus the first task in the project was to define the requirements. Interviews were used to determine needs and expectations of data users and other interested parties. Invaluable information was also received from a concurrent project on future visions of road weather system (Lähesmaa and Levo, 2003). The needs and expectations were then analyzed to establish a set of

requirements for road weather data quality. The resources available for road weather information system were taken into account, so that unrealistic expectations were not accepted in the set of requirements.

The requirements include

- density and placement of stations and camera installations
- accuracy of measurements,
- availability of data and video images.

The VIKING monitoring guidelines where accepted were applicable.

Next task was to consider how to fulfil quality requirements. It is evident, that data quality is determined, when the measurement is done. Afterwards one can search and filter out clearly incorrect data, but the accuracy of an individual measurement cannot be increased. Thus actions to ensure data quality must be mostly taken before the measurement.

The method used to find the actions needed to ensure data quality was risk analysis. The whole process of producing road weather data was analysed step by step. At each step it was consider, what factors might risk the ability to produce and deliver high quality data. Actions were then planned to eliminate the risks. The actions include:

- careful planning while selecting a place for a station or camera,
- careful assembly of devices,
- maintenance operations accomplished according to a plan before the start of season,
- etc.

In the quality standard this approach is referred as quality assurance. In principle, road weather data can be validated by conducting an independent measurement and comparing the results. Unfortunately this is only seldom possible and we must mostly rely on quality assurance. Quality assurance aims at preventing any problems from happening. Of course, it is not a hundred percent guarantee of quality. It is a way to provide reasonable confidence that the requirements will be met.

Quality assurance is also related to quality control. The main difference is that quality control is reactive in nature whereas quality assurance is preventive. Quality control uses techniques such as inspections and monitoring to assess quality.

Quality control is used in road weather information system to find device malfunctions and to assess the effectiveness of quality assurance. For that purpose data can be verified against older data from same point or against current data originating from neighboring stations. However, this method reveals only considerable deviations. To find minor deviations we must rely on human judgement: the user of data may detect even small deficiencies by comparing road weather data to information from other sources and by monitoring data for a longer period of time. Results from calibrations are used to assess the effectiveness of preventive maintenance.

Collecting data describing quality achieved or activities performed is an important part of quality management. To be able to improve quality, one must have facts about current state. Collected data is also used as evidence while showing the quality.

PROJECT RESULTS

Evidently, the most important result of the project is better quality. However, it is still too early to make an assessment whether this was achieved. In a project like this, the general competence building is another, yet hard to measure result. The competence of the personnel was increased by arranging several courses on quality issues; some members of the project group even passed a quality auditor exam during the project.

The first visible outcome from the project was the Quality manual, first version of which was accepted in May 2003. In autumn 2003, several software tools were implemented both to road weather data users and to the personnel.

The most important goal while designing new tools for road weather data users was that of adding the overall transparency of the system. New features were integrated into the existing viewing tools to show the users as much background knowledge of each station and camera installation as possible. The motivation for this was that the background knowledge helps the user in interpreting the measurement results correctly; clearly a quality goal in itself.

With the aid of new tools supporting personnel detects problem situations more quickly. The system itself records data about problem situations in the data base. Moreover, the system collects feedback from the users. All this data can be viewed by the supporting personnel as well as by the user. The system makes it easier for the supporting personnel to send maintenance requests for device maintenance service providers, helping to shorten the time while data is not available.

Frequently done maintenance operations on stations and camera installations are a key in maintaining the accuracy of data. By new tools the personnel can track that the maintenance operations are carried out as intended making their management easier. Data recorded can also be used for auditing purposes.

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Supporting IT system for Road Weather Quality Management

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1 Introduction

Finland's Road Weather Information System (RWIS) has been developed as a winter maintenance tool already since the mid-1980s. Utilization of road weather data has increased considerably in recent years not only in traditional applications, but also in traffic informing and control of variable traffic signs. During the past few years winter maintenance of roads has been transferred from the Finnish Road Administration (Finnra) to external contractors, and road weather data is increasingly being used in services directed toward road users. The significance, availability and validity of road weather data is becoming more and more important. To address these needs, creation of a quality management system (QMS) for road weather data and the RWIS was started in the autumn of 2002. Already in the beginning it was clear that the introduction of a QMS and its integration as a part of daily routines would require the support of a quality information system. Construction of the Road Weather Quality Information System (RWQIS) began in the spring of 2003.

2 RWIS in Finland

The RWIS developed by the Finnish Road Administration comprises road weather stations and cameras that observe weather and road conditions, computers that gather and analyze data, centralized data banks and users' graphical workstations. The Finnish RWIS also includes road weather predictions and rain radar and satellite images purchased from external sources.

The purpose of the RWIS is to provide winter road maintenance with information about weather and road conditions on the road network in winter. The system facilitates more correct timing of maintenance procedures and optimal use of anti-slipping agents. Another task of the system is to also provide weather and road condition information to road users. Nevertheless, the system offers the greatest calculated benefit as a winter maintenance tool. The system also produces automatic speed limit and information recommendations for controlling variable traffic signs. The intent is to make traffic safer and smoother.

3 Changes in contracting

The RWIS was originally developed for the needs of winter road maintenance. At the end of the 1980s, when larger-scale development of the Finnish RWIS began, road maintenance comprised around 150 regional districts. In winter nearly all the districts employed weather observers. By patrolling on the road, the weather observers acquired information about the weather in their own districts, but only in their own districts. It was possible that the weather observer was ignorant of completely different weather conditions only a few kilometers away.

As the network of road weather stations expanded and became denser, the RWIS began to provide a more accurate picture of the weather and road conditions throughout Finland, so it was no longer necessary to have 150 weather observers monitoring changes in the weather during evenings and weekends. In the beginning of the 1990s a road weather center was set up in each of the nine regions to monitor weather and road conditions in the region. With the development of the road weather system the weather observers had an overall picture of changes in the weather, movement of areas of rain and snow, and the development of weather predictions.

In 1997-98, road planning, construction and maintenance were separated into their own Production unit within the Finnish National Road Administration of that time. At the same time the number of road weather centers decreased to six. Currently the Production unit, which became today's Finnish Road Enterprise, has only four road weather centers left. Thus, the size of the area monitored by each center has naturally grown considerably.

Around the turn of the millennium some of the maintenance areas were opened to competitive bidding, whereupon completely new enterprises have begun taking care of maintenance (in the winter of 2003-04 there are seven enterprises in addition to the Finnish Road Enterprise). These new maintenance contractors did not previously have their own road weather centers. At the same time, however, 'Suomen Kelitieto', a private company that provides road weather center services, was established. The new contractors began using the services of the new company.

In 2004 the remaining contract areas will get contractors on the basis of open competition. During the transition period the Finnish Road Enterprise got part of the contracts as negotiated contracts without competitive bidding.

4 Development of informing

With the establishment of the road weather centers, informing road users about weather and road conditions gradually began to become common. At first informing was limited to periods of congestion during holidays or problematic road conditions caused by major weather disturbances. Gradually informing began to increase.

When road maintenance was finally separated from Finnra to the Finnish Road Enterprise, the road weather centers began to focus on maintenance tasks. Finnra was left with the responsibility of informing, for which reason nine traffic centers were established under Finnra. As the traffic centers developed, their range of tasks expanded continuously. In addition to informing about weather and road conditions, their tasks include informing about road work, accidents, other permanent or temporary traffic incidents, weight limits on frost-damaged roads, etc., in their regions.

In the summer of 2003 the Traffic Center was separated into its own profit unit within Finnra and four points of operation was established.

In the early 2000s external players also began to participate in informing. By utilizing road weather data and road condition camera images they have developed various data services for the Internet and mobile communicators capable of displaying graphical information.

5 The need to specify and itemize the quality of road weather data

A contractor is able to lower the price of a maintenance area contract if the contractor always has access to reliable information about developments and changes in the weather and road conditions prior to a moment of observation and reliable predictions regarding the weather in the near future. The contractor must also be able to somehow indicate the reliability and quality of the information before it can have an impact on the price. Likewise, the need to indicate the correctness of road weather data and the functionality of the system has increased considerably with the entry of new contractors and the increased size of the observation areas.

The use of road weather data to control automatically variable traffic and information signs on weather-controlled roads as well as continuously expanding use of road weather data in various types of informing have also contributed to the need to obtain information about the reliability of road weather data.

In the beginning of the 2000s it was decided to create a QMS for the road weather data and the RWIS. The work started with a preliminary study to examine the QMS in general, to determine and document the current state of the Finnish RWIS and road weather data. On this basis implementation of the actual QMS and its quality manual and appendices was started in 2002.

6 QMS for road weather data

The purpose of the road weather QMS is to assure the quality of road weather data by assuring the quality of the production process.

In principle, road weather data can be verified by making reference measurements. However, this is not possible in practice due to the large number of stations and the continuous collection of data. Another way to verify the information is to compare it with information from surrounding stations. This method only catches major errors in a station's information.

The only reasonable way to assure the quality of road weather data is to control the production of the information and the chain of production, beginning with careful installation of the stations, regular maintenance of the stations and sensors, etc. Nevertheless, user input is always needed in order to detect faulty station data. The user has a sense of the correctness of the station's data. The user is able to compare the station's data with information from other sources and is aware of the station's history.

The core of the road weather QMS consists of collecting information about the quality of road weather data and the functionality of the system's different components.

The first version of the QMS was completed in May 2003. Naturally, completion of the QMS's documentation is not enough, but the entire QMS will be taken into use in 2003-04. When it is taken into use, the issues included in the QMS will become a part of daily routines.

7 Road Weather Quality Information System (RWQIS)

The RWQIS makes it possible to begin using the QMS in the production process of the road weather data. The RWQIS supports quality control and quality reporting related to the QMS. With the RWQIS, users are better able to assess the reliability of road weather data. The RWQIS promotes more efficient use of resources in the RWIS. The degree of use of road weather stations and other components can be raised and personnel resources can be allocated more sensibly.

The interest groups involved with the RWQIS are:

- Internal and external customers of the road weather data
- The persons appointed to the quality organization related to the road weather QMS
- Responsible persons of the RWIS
- The staff of traffic centers
- Maintenance and repair service providers of the RWIS (incl. observation stations and cameras)
- Transport Services process managers at Finnra

7.1 RWQIS project

The project for creating a quality information system that supports the road weather QMS was started in late spring of 2003. The project RWQIS has gone ahead and it consists of the following phases:

1. Functional specification of the system
2. Technical planning
3. Implementation of processing of faulty data
4. Implementation of processing of metadata and monitoring of functionality
5. Implementation of maintenance reporting and automatic testing of data
6. Commissioning of the system

The RWQIS will be taken into use in phases during the winter of 2003-2004. The entire RWQIS will be in use by the autumn of 2004. The system will be taken into use everywhere at Finnra at the same time. Six days of training will be arranged for users. The most important user groups are the staff of Finnra's traffic centers, the staff of the road weather centers of winter maintenance contractors, and the persons who maintain the road weather stations and road condition cameras. The total cost of the RWQIS project, not including Finnra's own work, is around 75,000 €.

7.2 Description of the RWQIS

Thus, the RWQIS is an information system that supports Finnra's road weather QMS. The RWQIS

- performs quality-related verifications of the road weather data and the RWIS
- supports execution of quality assurance procedures, such as repairing, thereby increasing the quality of information and the degree of use of the RWIS
- makes it possible to constantly monitor and indicate the quality of road weather data and the functioning of the RWIS
- makes it possible to further develop the quality of road weather data over the long term, based on documented quality information.

The RWQIS includes all the information that describes the quality of road weather data, which users of road weather data and other interest groups need in order to assess the reliability and usability of individual pieces of information for a given purpose, as well as the functionality of the RWIS. This data includes:

- Metadata that describes a station's relatively permanent characteristics, such as location, sensor equipment, and sensor placement. Metadata is needed especially to assess the generalizability of data received from a station over a wider area.
- Results of verifications of measurement data as well as fault and repair data that indicate the functionality and maintenance situation of the stations and the RWIS. The reliability of the measurement data can be assessed on the basis of this information. Fault data is also used to control maintenance operation and to assess the functionality of the RWIS.
- Other records that the management, quality manager and quality team of Finnra's Transport Services need to monitor and indicate quality.

Monitoring the quality of road weather data is important not only for the persons responsible for the RWIS, but also and above all for the users of road weather data. Due to its nature, road weather data can never be proved to be entirely correct, nor can verifications done automatically or by responsible persons catch all error situations. For this reason the RWQIS is as transparent as possible from the user's viewpoint, so that the user of the data has access to all the available data on which basis the user can also assess the quality of the measurement data himself. The RWQIS also offers the user of the data tools with which to report detected problems to the RWIS's responsible persons and to observe how necessary repairs are progressing.

The RWQIS functions integrally with the RWIS. Part of the quality information is automatically produced in conjunction with normal operation of the RWIS, and part of the collected information is also visible to the user alongside road weather data. Part of the RWQIS is realized with minor modifications of existing software, while part of the system requires separate information input and viewing application.

7.2.1 Processing of metadata

Metadata refers to data that describes the relatively permanent characteristics of a road weather station or road condition camera, such as location, equipment, etc. Part of the metadata is created already when the station is being designed. At that time the reasons for the necessity and location of the station are recorded. Likewise, the equipment of the station is

recorded. The metadata is supplemented in conjunction with the installation of the station and during the installation inspection when the installation is finished. All special factors that affect measurement are recorded during the inspection. The metadata is updated on the basis of changes noticed in conjunction with repairs and annual inspections. The history of changes in the metadata is archived.

Updating metadata. Metadata is updated using a separate updating application.

Viewing metadata. The user of road weather data can view the data using expansions of existing visualization applications.

Archiving metadata. Metadata is archived along with road weather data in a metadata database. The history of changes is also archived.

7.2.2 Processing fault and repair data

Fault data indicate different types of problem situations or suspected faults in the components of the RWIS. A component can be a hardware or software component. Repair data show the repair history of a component.

Measurement data can be observed to be faulty by comparing it with information acquired from another source. If the measurement data disagrees often with other information, there is reason to suspect that the measurement data is faulty. Information from another source may be measurement data from other sensors of the same station or other stations or individual observations on the road. Some of the comparisons can be described as accurate deduction rules, but others are so heuristic by nature that they are difficult or impossible to automate.

Automatic verifications of the RWIS. Fault data or a suspected fault may be created automatically as a result of automatic verifications added to the RWIS. Deduction rules used in verifications are not a part of the application logic. Decisions are made using a recommendation and alarm calculation application, which will be developed further as needed.

Entry of suspected faults. Fault data entered by the users of the data as well as part of the problems detected by automatic verifications are classified as suspected faults until the responsible persons have determined that they are faults that require repairs. Suspected faults are also made known to the providers of repair services.

The users of or the responsible persons for road weather data enter the fault data using expansions of existing visualization applications.

Verification of faults. Faults are verified by the persons responsible for the road weather stations and RWIS.

Sending a request for repair. When a fault is verified, the persons responsible for the road weather stations or system send a request for repair by means of the system. A record of the request is left in the database.

Receiving a request for repair. The providers of repair services acknowledge the receipt of a request for repair.

Repair reports. Completed repairs are reported into the system.

Acknowledgement of repairs. The persons responsible for the road weather stations or RWIS change the status of the component to normal only after its functioning has been monitored sufficiently after the repair.

Viewing repair and fault data. In existing user interface applications the station-specific fault situation is visible to the users together with the measurement data and camera images. The fault data has five different statuses:

- problem or suspected fault
- confirmed fault
- request for repair sent
- repair completed
- in operating condition.

The users can also view more detailed information about the type of fault.

Updating basic repair data. There are two kinds of basic repair data: basic data related to station-specific repairs (repair metadata) and basic data of repair service providers.

The basic data of repair service providers are their name, address, phone and email address.

Summary reports. The persons responsible for the road weather stations and the RWIS can run summary reports of repair and fault data.

Archiving repair and fault data. Repair and fault data are stored in a database, where they are saved until the beginning of the next winter season. After that the data are archived.

7.2.3 Processing of other records

Other records and documents are included in the document file as links. The files are centrally saved in a separately agreed location.

7.2.4 User interface

The user interface of the RWQIS is a form-based Windows application. The users use the road weather application to select the desired road weather station or road condition camera and enters a suspected fault, request for repair, repair report or approval of a repair for that station (Fig. 1). The status of the possible fault data of the road weather stations is visible to the users in the familiar road weather application (Fig. 2).

8 Experiences

Already during the early phase in the autumn of 2003 it is apparent that taking the RWQIS into use at Finnra and the contractors involved with the system is a major, demanding operation. A large group of users needs to be trained. The users must become familiar with the technical operation of the system, but above all, the system must become a part of daily work routines.

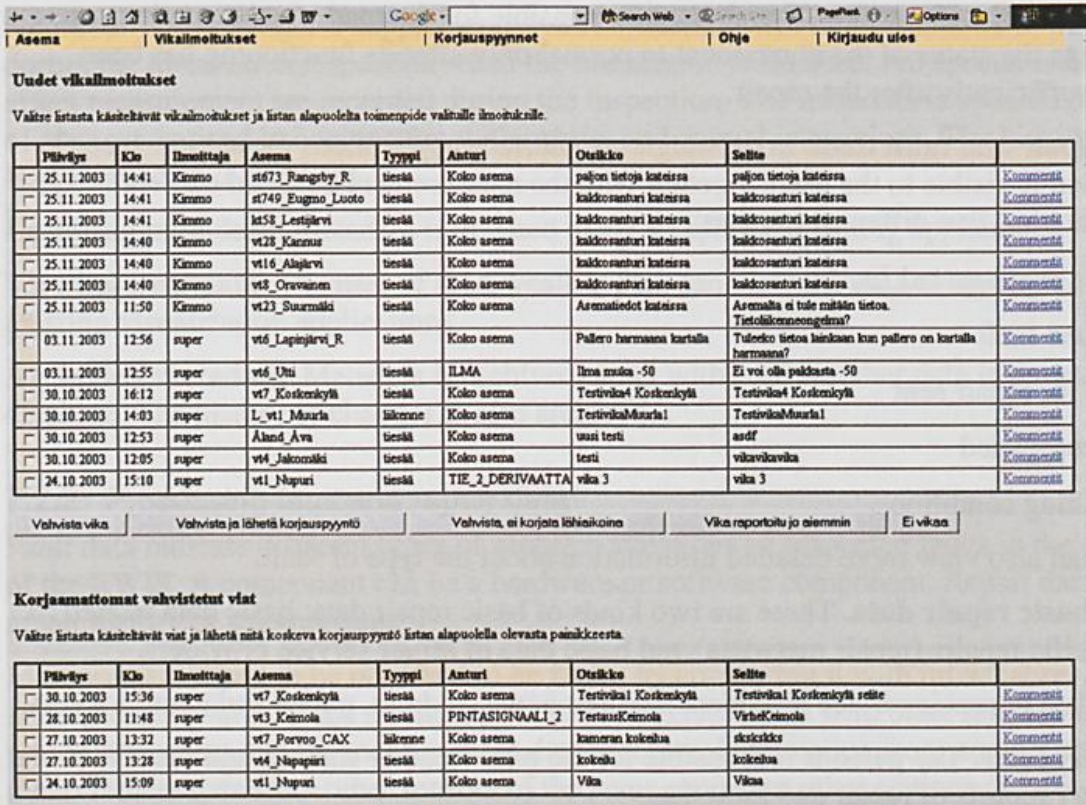


Figure 1. Verifying the status of all stations

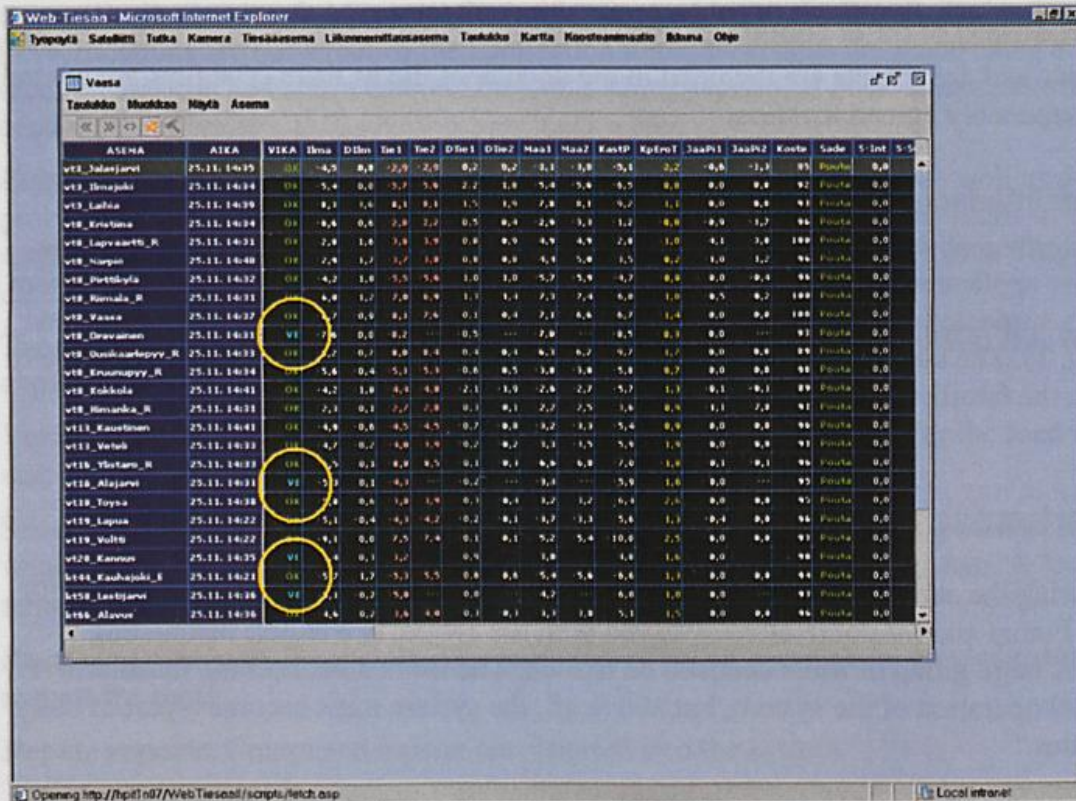


Figure 2. Presenting the status of a station as sensor data

Submitted Papers Topic V: Winter Maintenance Management Systems, Methods and Policy

- (V-1) Cypra (D): Optimization of Winter Maintenance on heavily travelled Freeways
- (V-2) Yamada/Sugimura/Maruyama (JP): Research on the Level of Winter Road Management
- (V-3) Hanke (D): Construction of a Winter Maintenance Management System for optimized Controlling of Winter Maintenance Operations
- (V-4) Devaud (CH): Surface Condition Management
- (V-5) Jonasson/Palsson (ICE): Icelandic Winter Maintenance Management System
- (V-6) Nixon/Stowe (USA): Operational Use of Weather Forecasts in Winter Maintenance – A Matrix based Approach
- (V-7) Pisano/Stern/Mahoney (USA): The U.S. Federal Highway Administration Winter Maintenance Decision Support System MDSS Project
- (V-8) Tsuji et al (JP): Cost Performance of Pipe Heating System by Thermal Energy in Mountain Tunnel
- (V-9) Liu/Spitler (USA): A Simulation Tool for the Hydronic Bridge Snow Melting System
- (V-10) Mimura et al (JP): Influence of Heating Pipe on Snow Melting and Mechanical Properties
- (V-11) Brodard (CH): TMS 3000 High Pressure Spray System – A new Concept for stationary Prevention of winter-induced Dangers on Roads and Highways

Optimization of winter maintenance on heavily travelled freeways

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1 Introduction

Efficient freeways form the backbone of traffic and thus of our economy, as the latter is becoming more and more dependent on a - at all times - functioning infrastructure element: the road. Restraints imposed on driving in the wintertime are therefore becoming less and less acceptable. As a consequence, the standards of winter maintenance for heavily travelled or problematic road sections of federal freeways have become very high. Successful winter maintenance in these areas considerably contributes to avoiding or at least reducing winter-related restrictions and thus, the costs these entail for the road-user. In connection with an early and quick winter maintenance, road safety is also improved and micro-economic and economic costs of freight and public transport are reduced through less accidents, loss of time, etc.

Therefore, the Institute of Highway and Railroad Engineering (Head: Prof. Dr. Ralf Roos) of the University of Karlsruhe was commissioned in the summer of 2001 to carry out the research project „Optimization of Winter Maintenance on Heavily Travelled Freeways”. The project primarily pursues two aims: Firstly, checking the capacity of highway cross-sections under wintry road conditions through a traffic investigation of winter-related congestions. Secondly, several pilot projects with individual highway surveillance centres shall be investigated with regard to optimizing the winter maintenance. These centres shall further receive scientific support throughout practical tests. In spite of the high standards of winter maintenance observed in Germany, individual measures for dealing with problematic road sections are gaining in importance, especially when considering the loss of capacity under wintry road conditions. It are these measures that shall be further developed within the stated research project.

2 Investigating the capacity under wintry road conditions

In the HANDBUCH FÜR DIE BEMESSUNG VON STRASSENVERKEHRSANLAGEN (2001), (Engl. Handbook for Design of Road Traffic Facilities), „capacity“ is defined as „the highest traffic density that a traffic stream can reach at its cross-section under the given road and traffic conditions.“

The capacity of freeway cross sections depends on several ancillary conditions and is thus subject to wild, time-related fluctuations. The factors of influence can be divided into four different groups:

- road conditions,
- traffic conditions,
- traffic control conditions and
- environment.

Road conditions mainly involve the geometrical and structural design of the roads. Examples are road bendiness, longitudinal gradient and cross section, i.e. the number and width of lanes. Due to its straight run of the road, bendiness hardly plays a role when looking at highways and can thus be neglected. The same is true of the lane width.

Unlike the road conditions, traffic conditions include time-variable factors. Traffic conditions mainly mean the composition of the traffic flow (traffic column) and lane distribution. The decisive parameter for traffic composition is the heavy vehicle traffic proportion, fluctuating throughout the day, week and year.

Traffic control and check conditions are ancillary conditions imposed in order to influence the traffic flow. For freeways, especially the speed limits and restrictions on passing and driving for heavy goods vehicles are important.

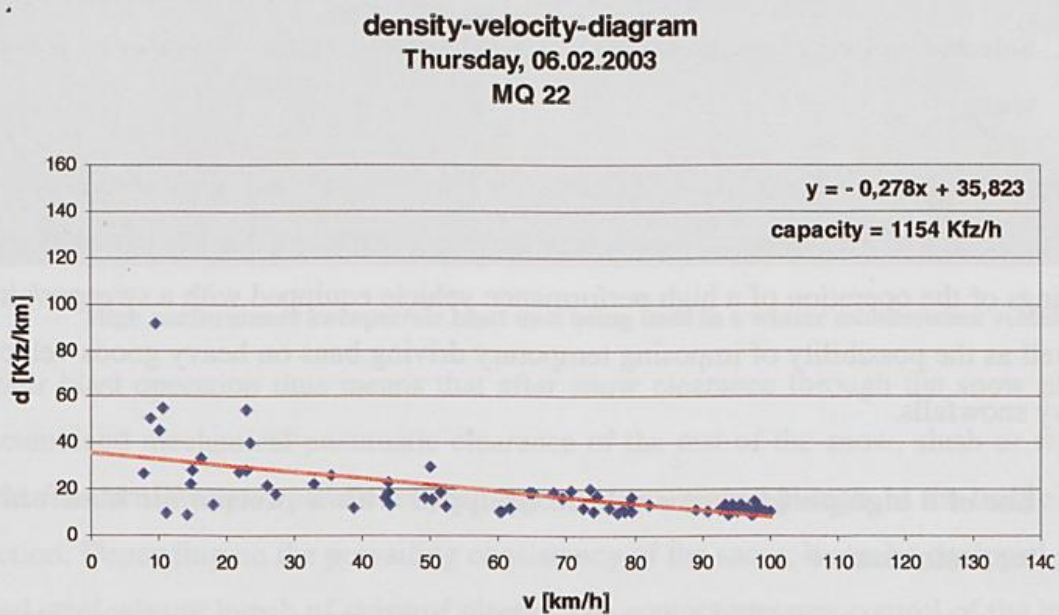
Environment factors are light, weather and road conditions. Wintry road conditions play a major role in influencing the traffic flow.

For determining the capacity under wintry road conditions, basically the following data was used:

- winter maintenance reports by the investigated highway surveillance centres,
- additional reports evolved by the Institute of Highway and Railroad Engineering for congestion registration carried out by the highway surveillance centres' personnel

- details about the investigated road sections (longitudinal gradients, number of lanes, etc.),
- data with differentiated density- and velocity-values obtained from long-term stationed census points and
- accident reports.

The road sections investigated were the A 8 under the jurisdiction of the highway surveillance centre Ulm-Dornstadt (Baden-Württemberg) and the A 5 belonging to the area of responsibility of Alsfeld (Hesse). For traffic investigation, the highway surveillance centres carried out congestion registration half-yearly, in the winter periods of 2001/02 and 2002/03.



For evaluating larger amounts of data and obtaining the capacity, the winter-related congestions due to wintry road conditions were filtered. As only when congestions are due to high traffic volume does the traffic state indicate the capacity. In case of an accident for instance, as a rule, at least one lane is blocked for a certain time, creating a congestion long before the actual capacity of the cross section is reached.

After creating of a velocity/time variation curve that represents the exact time window of congestions, the data of the decisive time was analyzed. Then using the density-velocity-diagrams (d-v-diagrams) the maximum traffic volume that corresponds to the capacity is determined for winter-related congestion (see Fig. 1).

Figure 1 Example of a d-v-diagram of a winter-related congestion – q_{\max} capacity determined

With this data, 14 winter-related traffic congestions could be analyzed and the capacity determined. The evaluation of the traffic congestions produced under wintry road conditions showed a decrease in capacity between 10 and 65 % at the measurement cross sections in Baden-Württemberg. At the census points in Hesse, capacity decreases of between 35 and 40 % were found. Due to the still very limited amount of collected data at present, these results can only serve as an initial clue. In further investigations in the winter period 2003/04, the method developed for evaluating the various influences on the capacity of wintry roads shall be extendedly applied and to back up the results

3 Selected optimization measures for winter maintenance on heavily travelled freeways

Parallel to looking at the capacity behavior, a group of selected optimization measures was examined. Examples of these measures will be presented in this contribution, namely the findings of the operation of a high performance vehicle equipped with a sweeper/airblast unit, as well as the possibility of imposing temporary driving bans on heavy goods vehicles during heavy snowfalls.

3.1 Use of a high performance vehicle equipped with a sweeper/air blast unit for winter maintenance

The special vehicle tested within the scope of this pilot measure is a winter maintenance vehicle, originally meant for airport operations and equipped with an additional sweeper/air blast unit. Two high performance vehicles were operated on a freeway for the first time in the winter period 2002/03 in jurisdiction of the Hessian highway surveillance centre Alsfeld. The results presented here basically refer to the introductory phase of the new winter maintenance vehicle. So what may be expected is that the potential for snow clearing speed and quality is actually greater. We are thus on the safe side using this data.

For winter maintenance purposes, the vehicle is equipped with a snow plough (see Figure 2) of which the clearance width is adapted to the entire system. It normally has a swivel share element and the clearance width is > 4 m. It further has a sweeper/air blast unit placed between both axles and blow jets for right or left-side clearance at the rear. The sweeper/air blast unit is a combination of rotating brushes and blow jets. A high performance turbine provides the blow jets of the sweeper and those at the rear of the vehicle with a controllable air stream.

For spreading pre-wetted salt, a 4 m³ superstructure, consisting of a standard-grit spreader and the pre-wetting salt machine is mounted on top of the high performance vehicle.



Figure 2: High performance sweeper/air blast unit being used in a winter maintenance vehicle

Sweeper/air blast operation thus means that after snow clearance through the snow plough, another combined mechanical-pneumatic clearance of the rest of the snow, slush or water is performed. The brush rotates parallel to the diagonally positioned plough, in the traffic opposite direction. Depending on the prevailing consistency of the snow, it can be equipped with a corrugated steel wire or bunch of strips of plastic. The contact pressure control of the brushes is continuously variable. The brush is automatically adapted to the pavement structure and is meant to work at high clearance speeds. The rest of the snow is swept in front of the vehicle by the brush and blown to the road side by the swivel blow jets on the sweeper. This allows a high clearance quality with only slightly tilted brushes. The last bits of snow are then moved to the rear of the vehicle where they are removed from the clearance cross section with the aid of the blow jets.

For analysis and evaluation of the high performance sweeper/air blast units, the Institute of Highway and Railroad Engineering had photos taken and the freeways filmed before and after the winter maintenance operations. Further, the provided winter maintenance reports and tachographs were evaluated and interviews carried out with the concerned highway surveillance centres' personnel. The aim was to examine the clearance quality at high clearance speed, the actual clearance speeds, as well as the high performance sweeper/air blast units - focussing on exceptional cases that might arise during operation.

When determining the average clearance speed, most courses of speed provided by the tachographs could be clearly reassigned to the corresponding road sections with the aid of the winter maintenance reports. In order to determine the average clearance speeds, only the average speeds were counted that were easily reached on continuously travelled roads. The average clearance speed in the introductory phase was already found to be 45 km/h. Unlike standard winter maintenance vehicles, the high performance sweeper/air blast unit was only little influenced by longitudinal gradients.

Clearance quality was judged visually. For this purpose, the clearance procedure was videotaped and photos were taken while driving behind the special vehicle equipped with the high performance sweeper/air blast unit. Further, photographing and filming were also carried from higher spots, as for instance from bridges. This allowed a direct visual comparison of the road conditions before and after clearance at the computer screen.

When comparing the photographs showing the results obtained with standard winter maintenance vehicles (that only use a single snow plough for clearance) and high performance vehicles (with a snow plough and sweeper/air blast unit), the results of the additional mechanical-pneumatic clearance are clearly visible. After having evaluated the first clearance operations, an improved clearance can be seen and even snow removals are possible at high clearance speeds, as depicted in Figure 3. In order to back up these results, further investigations shall be carried out in the winter period 2003/04. They will then include the sweeper/air blast units the highway surveillance centre Freudenberg in North Rhine-Westphalia have been using since spring 2003.



Figure 3: Clearance comparison of standard winter maintenance vehicle (left) and vehicle with high performance sweeper/air blast unit (right)

3.2 Further measures

In order to avoid long traffic breakdowns, partly producing catastrophic conditions, further winter maintenance measures have to be systematically analyzed for heavily travelled road sections and periods of longer snowfall. In extreme situations, for instance imposing a temporary driving ban on heavy goods vehicles has to be considered. This allows the clearance vehicles to move forward easily and not possibly get stuck in a traffic jam themselves. After clearance, the freeway can be opened for heavy goods vehicles again. The Institute of Highway and Railroad Engineering will investigate these kind of measures as well in the winter period 2003/04 and work out recommendations when to best use them.

4 Prospects

The first results of loss of capacity due to wintry road conditions have clearly proved the great importance of winter maintenance, especially for heavily travelled freeways. For this reason, traffic investigation should be continued following the method developed in order to cover the various influences of wintry road conditions on the capacity. With the aid of a differentiated knowledge of capacity under wintry road conditions, winter maintenance could be made more efficient, especially on problematic road sections.

Evaluation of the research results has shown that special measures in winter maintenance, as for instance the use of a high performance vehicle equipped with a sweeper/air blast unit, present the possibility of specific support for winter maintenance, especially with regard to problematic road sections. Here, too, further investigations of individual measures are recommended. In extreme situations, measures such as imposing a temporary driving ban on heavy goods vehicles should also be considered.

It has therefore been planned to carry on with capacity investigations and examine selected measures in the winter period 2003/04 in order to back up the results that have so far been obtained.

Sources:

Handbuch für die Bemessung von Straßenverkehrsanlagen (HBS) (engl. Handbook for Design of Road Traffic Facilities)

Forschungsgesellschaft für Straßen- und Verkehrswesen (engl. German Road and Traffic Research Association)

Cologne, 2001

Research on the Level of Winter Road Management

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1. Introduction

Snow removal is road service that is essential in heavy snow zones in Japan, not only to guarantee safe smooth road traffic, but also to stabilize social life and contribute to the growth of regional economies. And in today's mature society, the needs of these regions have grown and diversified and their people demand the improvement of this service. But road managers must meet these demands under severe budget restrictions.

The Nagaoka National Highway Office that is responsible for the Yuzawa District that is one of these heavy snow zones has, as one measure to achieve this goal, studied Road Performance Management intended to provide management that satisfies the needs of regions through a partnership between the public and private sectors. This approach is implemented by, based on the characteristics of the region and the views of road users, setting management goals for winter road surface management that is the most important challenge facing the region, performing management based on these goals, and evaluating its effectiveness. And, according to circumstances, working cooperatively with road users to improve this service.

This research that has been undertaken in response to the above circumstances is a study of the winter road management level suitable for a heavy snow region by focusing on the management goals and analyzing characteristics of the region, snow removal costs, and the degree of satisfaction of road users. The conclusions presented in this report do not directly reflect the views of the Nagaoka National Highway Office

2. Outline of the research

A variety of analyses were performed using meteorological and traffic data obtained from reference documents and from the findings of a fixed observation system installed beside National Highway No. 17 that passes through the Town of Yuzawa in Niigata Prefecture and is managed by the Nagaoka National Highway Office. Figure 1 shows the district studied and the snow removal sections on National Highway No. 17.

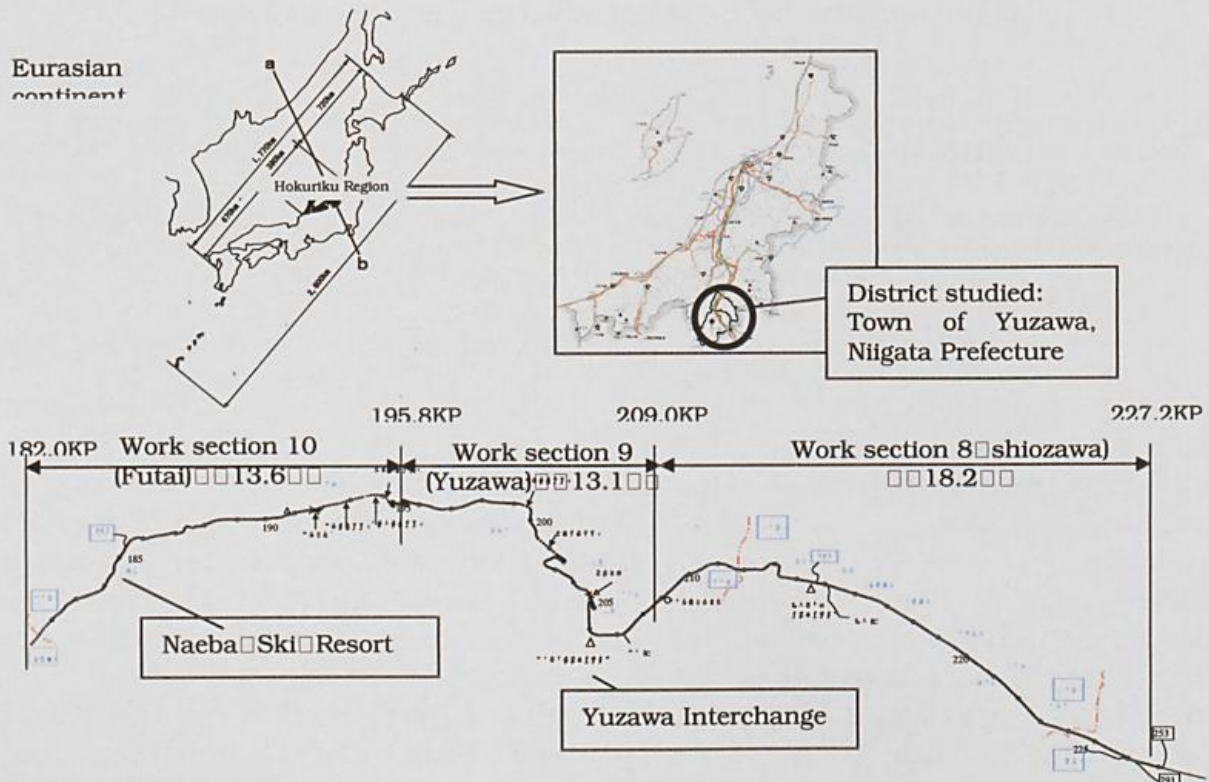


Figure 1. District Studied and the Snow Removal Sections on National Highway No. 17 in the Yuzawa District

3. Winter Road Management Level Index

It is necessary to establish an index suitable for regional characteristics in order to set the level of winter road management. The authors studied an index for the level of winter road management by analyzing meteorological characteristics, traffic characteristics and the state of snow removal.

3.1 Meteorological characteristics

Figure 2 shows changes of the cumulative snowfall in the Yuzawa District, and Figure 3 shows winter meteorological conditions in Yuzawa District. The cumulative snowfall exceeded 10m every year except 1996 and 1997, showing how heavy snowfall is in this district. The temperature begins to fall in early November, reaches its minimum from January to mid February and begins to rise in late February. Another characteristic of the district are climatic conditions that cause extreme variability of road surface conditions. Specifically, a daily temperature differential reaching as high as about 10°C with the daily maximum and minimum above and below 0°C that is the road surface freeze-thaw boundary from late December to mid February: a period snowfall is extremely heavy.

Another feature of this heavy snowfall district is its high population concentration: 20,000 in Shiozawa and 9,000 in Yuzawa.

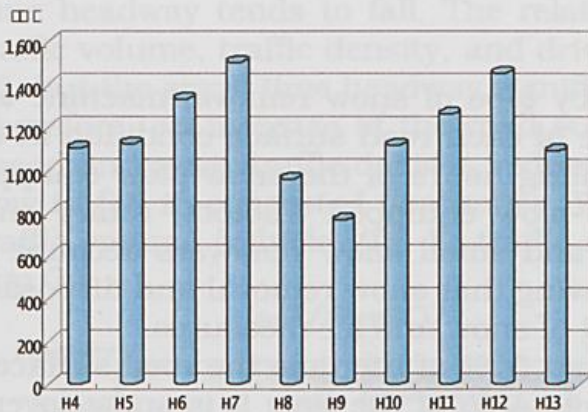


Figure 2. Changing Cumulative Snowfall in the Yuzawa

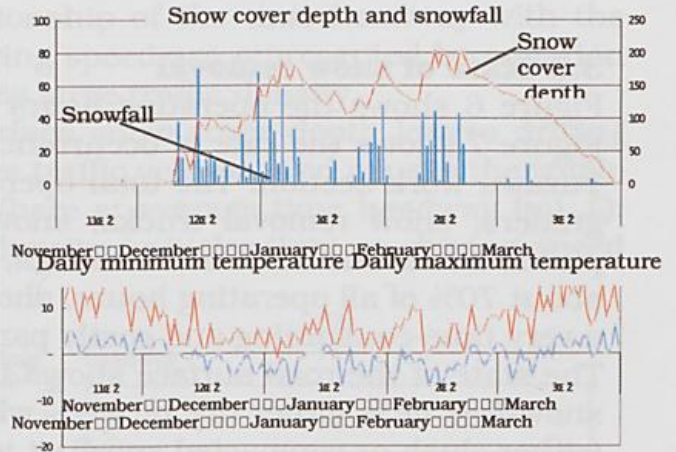


Figure 3. Winter Meteorological District in Yuzawa District Conditions

3.2 Traffic characteristics

Figure 4 shows the monthly average traffic volume by snow removal work section and Figure 5 shows the average monthly driving speed by snow removal work section in the winter. In the Shiozawa work section, the traffic volume exceeds 10,000 vehicles in both the autumn and winter, that is far heavier than in the Yuzawa and Futai work sections. By day of the week, the autumn traffic is heavier on weekdays than on holidays, but in the Futai and Yuzawa work sections, winter traffic is heavier on holidays than on weekdays. (Fig. 4) In the Shiozawa section, the driving speed on weekdays is slowest at 30km/h, and the degree of congestion is highest at approximately 2, but the degree of congestion on holidays is highest in the Futai work section. (Fig. 5)

It can be hypothesized that because there are ski resorts, hot springs, and numerous other tourist facilities that attract many winter visitors to this district, the traffic volumes rises and falls complexly according to the number of visitors. It is, therefore, necessary to carry out prompter and more reliable winter road management in this district.

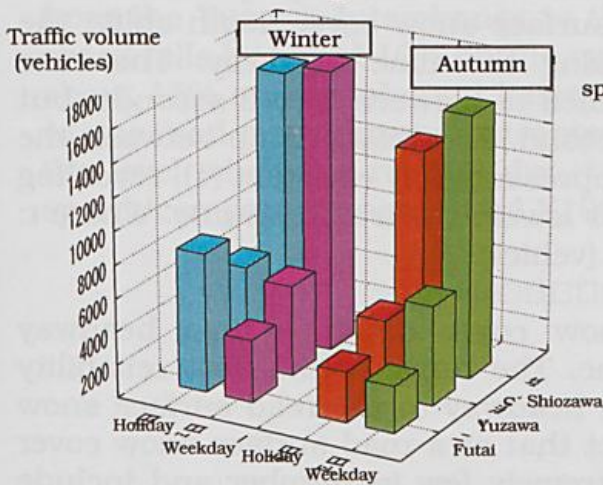


Figure 4. Average Monthly Traffic Volume by Snow Removal Work Section (2003)

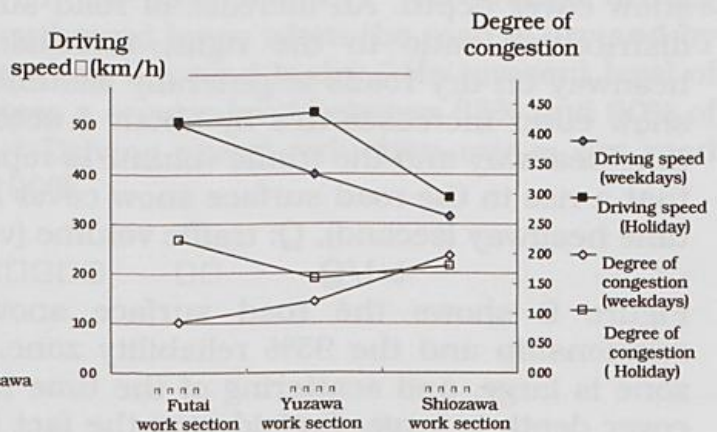


Figure 5. Monthly Average Driving Speed by Snow Removal Work Section (Winter 2003)

3.3 State of snow removal

Figure 6 shows the operating hours by type of snow removal machine and Figure 7 shows the rate of occurrence of each road surface condition in the Yuzawa work section. The total operating hours of the snow-plow equipped graders, snow removal trucks, snow-plow equipped tractors, rotary snow plows, small snow removal vehicles, and small snow removers account for about 70% of all operating hours, showing that snow removal and disposal is a very time-consuming and costly part of snow and ice measures.

The state of the road surface shows that 51% of the time the road surface is snow-free (it is either dry or wet), while 43% of the time it is snow covered (either slush or compacted snow). It is frozen 6% of the time.

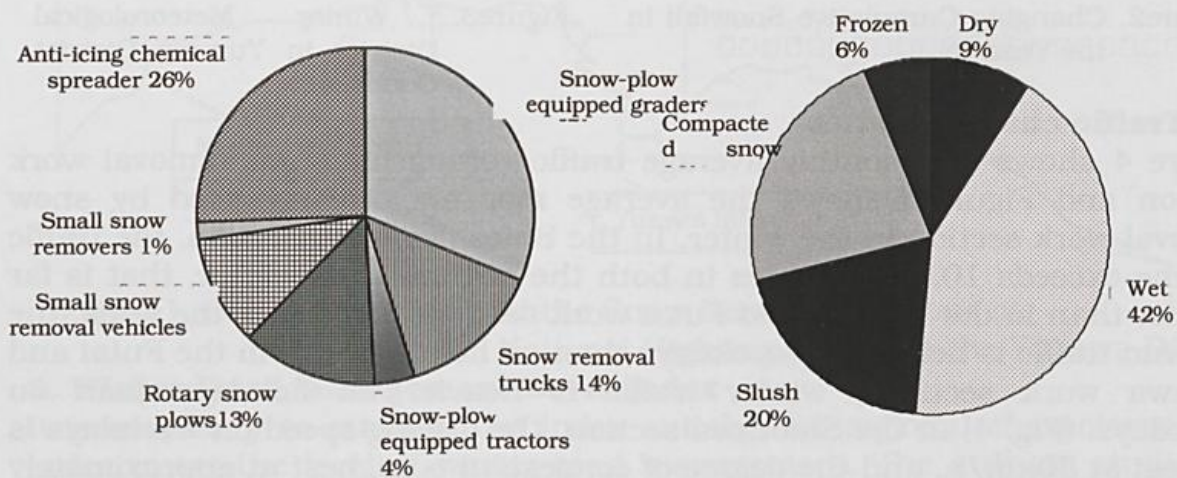


Figure 6. Operating Hours by Type of Snow Removal Machine

Figure 7. Road Surface Condition Occurrence Rate

3.4 Impact of road surface snow cover on road traffic

Because the removal and disposal of snow accounts for most of the time and cost of road management in the Yuzawa District, the impact of road surface snow cover on road traffic was analyzed.

Figure 8 presents the distribution ratio of the time headway by road surface snow cover depth. An increase of road surface snow cover depth shifts the distribution ratio to the right, increasing the time headway. The time headway on dry roads is generally assumed to be between 2 to 3 seconds, but snow cover increases this by about 1 second. The relationship between the time headway and the traffic volume is represented by equation (1), revealing that a rise in the road surface snow cover lowers the traffic volume. Where t : time headway (second), Q : traffic volume (vehicles/h)

$$t = 1/Q \quad \square \square \quad \square \square \square \square \square \square (1)$$

Figure 9 shows the road surface snow cover depth - time headway relationship and the 95% reliability zone. The range of the 95% reliability zone is large, and scattering of the time headway to the road surface snow cover depth is large. Considering the fact that at a road surface snow cover depth of 6cm or more, the data are extremely few in number and include many abnormal values, and if the road surface snow cover depth rises, the

time headway tends to fall. The relationship of the time headway with the traffic volume, traffic density, and driving speed are represented by equation (2), but the small time headway signifies large traffic density.

Therefore, an increase of the road surface snow cover depth lowers driving speed, increases traffic density, reduces traffic volume, and causes the traffic flow to fall in congested flow zones. Where s : average time headway (m), Q : traffic volume (vehicles/h), K : traffic density (vehicles/km), v : driving speed (km/h)

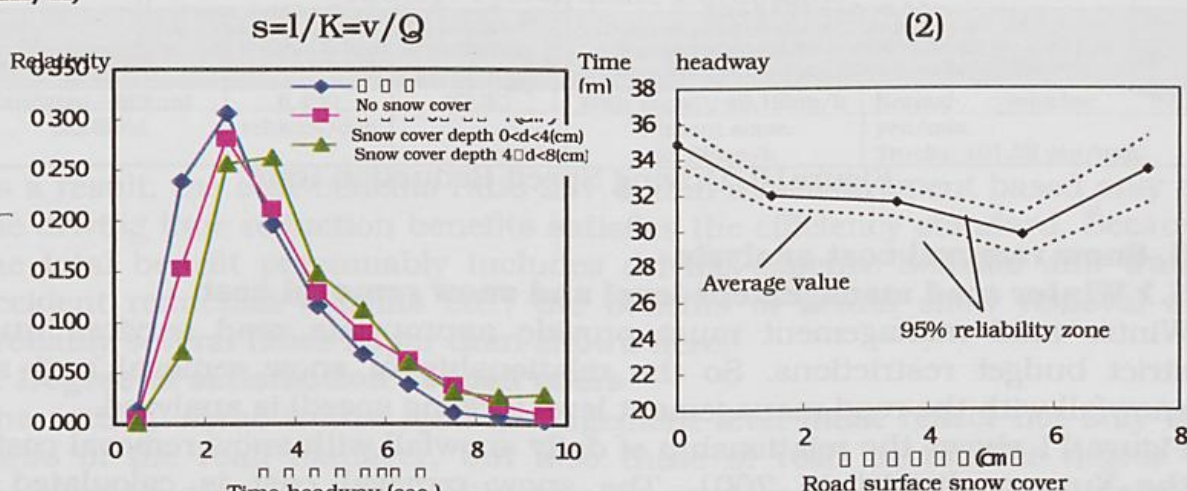


Figure 9. Distribution Ratio of Time Headway. Figure 10. Road Surface Snow Depth - Time Headway Relationship

For the above reasons, roads are managed in the winter by setting management goals with driving speed as one of the indices for the level of the service in a district where snowfall is heavy, snow removal and disposal account for more than half of road management, and road surface snow cover remarkably reduces the driving speed. And because the characteristics of traffic in different snow removal work sections differ, it is necessary to set the driving speed separately for each snow removal work section.

4. Level of present winter road management

In a case where driving speed has been hypothesized to be an index of service level, road management is performed considering the level of service to be guaranteed. Figure 10 shows the rate of decline of the driving speed from the Yuzawa Interchange to the Naeba Ski Resort. The average driving speed falls by about 10% on the outbound lanes when the road is dry and by about 15% on the inbound lanes when the road is dry. The present level of winter road management guarantees a service level between 85% and 90% of the level when the road is dry. * Driving speed reduction rate = dry road speed/compacted snow speed X100%

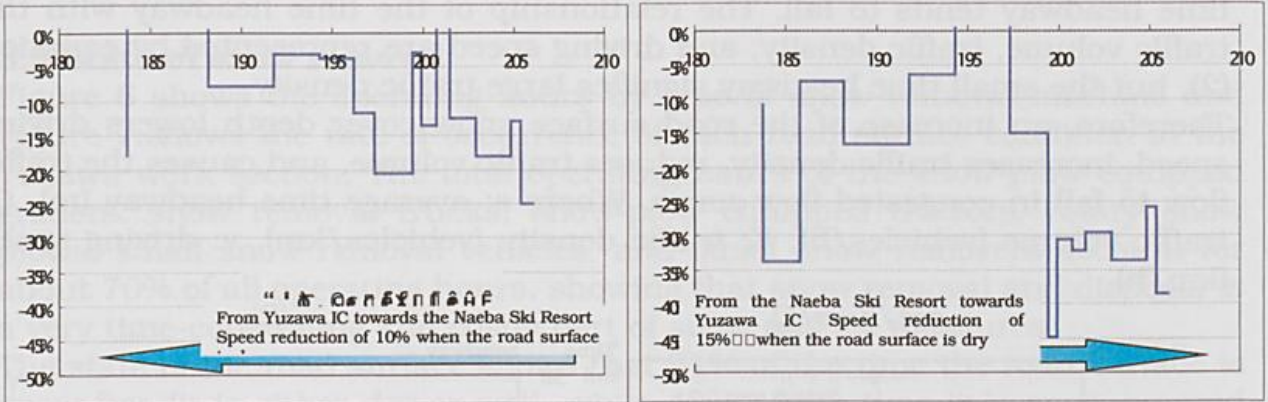


Figure 10. Driving Speed Reduction Rate

5. Snow removal cost analysis

5.1 Winter road management level and snow removal cost

Winter road management must provide appropriate road services under strict budget restrictions. So the relationship of snow removal cost and snowfall with the road management level (driving speed) is analyzed.

Figure 11 shows the relationship of daily snowfall with snow removal cost in the Yuzawa district in 2001. The snow removal cost is calculated by multiplying the operating time of snow removal machines by the snow removal cost per unit of time based on past performance. As the snowfall rises, the snow removal costs rises, with a high coefficient of determination of 0.94. This shows that by predicting the snowfall, it is possible to use it to set the snow removal cost and use this cost to plan the target budget.

Figure 12 shows the relationships of driving speed and daily snowfall with snow removal cost. As the snowfall rises, the snow removal cost also rises, but the driving speed inevitably falls. The driving speed when snowfall is heavy (35cm/day) is about 20% less than it is during a light snowfall (0cm/day), and is about the same level as the road management stated above. Considering that present snow removal is performed by full operation of snow removal machines for road management, it is difficult to seek significant improvement of the service level using only snow removal machinery.

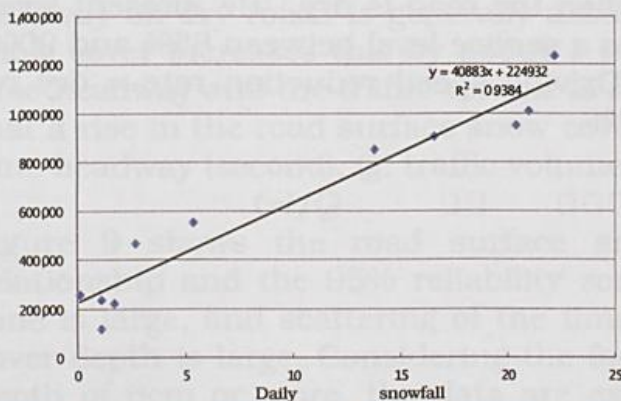


Figure 11. Daily Snowfall - Snow Removal Cost Relationship

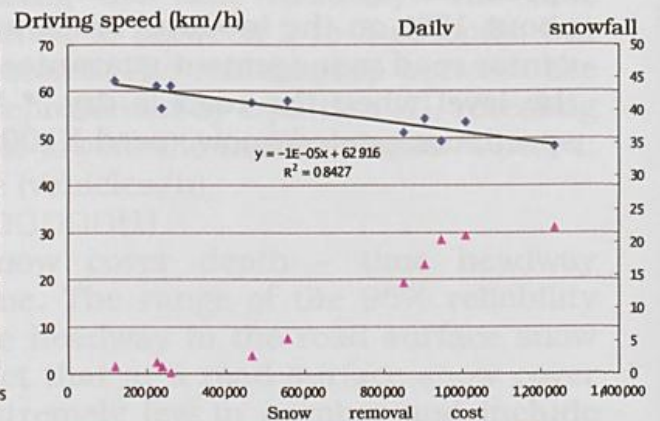


Figure 12. Snow Removal Cost - Driving Speed - Daily Snowfall Relationship

5.2 Cost - benefits

A cost benefits analysis of present snow removal was performed based on the prerequisite conditions in Table 1. It obtained the driving time reduction benefits to measure this as the snow removal effects based on the difference between the driving speed with and without snow cover on the road surface.

Table1. Prerequisite Conditions

Work section	Traffic volume	Large vehicle percentage	Travelling speed	Time value
Kandatsu - Mikuni (23.8km)	6,400 vehicles/day	27.3%	With snow: 49.19km/h Without snow: 53.88km/h	Normal vehicles: 67.27 yen/min. Trucks: 101.39 yen/min.

As a result, the cost-benefits ratio is 1.4, and a measurement based only on the driving time reduction benefits satisfies the efficiency standard. Because the total benefit presumably includes driving expense benefits and traffic accident reduction benefits etc., the benefits of actual snow removal are probably several times larger than shown here.

6. Degree of satisfaction of road users

The setting of the winter road management level must reflect not only the views of the road manager, but also those of road users. The degree of satisfaction of road users with present road management was analyzed based on the content of requests and comments received by the Road Consultation Office. The complaints concerning snow and cold include many complaints of problems closely related to daily life, requests for snow blowing, post-processing of snow banks, but few complaints about winter road surfaces.

7. Summary

It is also appropriate to set the winter road management level premised on the fact that the present service level will be maintained in order to guarantee economic suitability and the degree of satisfaction of road users. It is assumed that it is possible to achieve effective and efficient winter road management by setting this driving speed as the target for management of winter roads and by removing snow in order to provide specified benefits to road users. Driving speed can be used beneficially by both road managers and road users, by for example, allowing a road manager to provide an index or pass through time in order to help road users more easily understand the benefits of snow removal.

8. Future challenges

Managing roads with the driving speed as a road service index guarantees road users speed and on-time arrival at their destinations, but there have not been adequate surveys of the psychological state of road users, their concern with safety and comfort. It is also necessary to set detailed management goals such as the range of permissible driving speeds.

In the future, many-sided analyses such as detailed traffic analysis including traffic accident analyses and interview surveys of road users must be

performed to complete the data.

References

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Implantation of a Winter-Maintenance-Management-System for an optimised intervention control

Introduction

Road winter maintenance is one of the most important tasks of road maintenance service. It shows as a permanent tightrope walk between the requirements of economy, traffic safety and environmental protection. Success in winter maintenance is dependent on rapid, target orientated and effective intervention thus generating its economic efficiency (politically as well as applied). Relevant research projects concerning winter traffic safety and economy have proven that fact.



For rapid and target orientated interventions actual information on present and forecasted weather situation, on present weather and road conditions in the network as well as on actual winter maintenance activities are of major importance.

Situation

During recent years within the Federal Republic of Germany a Road Weather Information System (named SWIS) was implanted in connection with a network of ice warning stations (GMA) thus offering an important assistance to winter maintenance and its organisation. A related problem is that this weather information is only spot orientated, related to their direct

environment, and mostly are restricted to the motorway network. Wide area covering information, especially concerning the subordinate network, is at present not available in Germany.



Ice warning systems at salient positions in the network may automatically collect and process data about road and weather conditions. These data are automatically transmitted to the central office.

But winter accident analysis have shown that exactly that spot orientated icing in the subordinate network is most dangerous and generating highest accident rates, especially because often the situation is not recognized neither by maintenance service nor by drivers. On the other hand a wide area covering permanent winter maintenance under such weather conditions or a permanent control service is unaffordable, neither financially nor from the side of personnel.

Instead of this it is much more economic and target orientated to improve the information about weather and road conditions in the subordinate network, thus enabling an improved winter maintenance coordination.

Another problem of winter maintenance organisation is poor information about winter maintenance activities. Handwritten, mostly few expressive, intervention reports are more and more replaced by board computer generated data collection, but even with this new technology the information are not available before intervention end. The actual intervention coordination is effected, if ever, by acclamation or radio. Thus an in-time and flexible operation coordination is only conditionally possible.

Such type of winter maintenance organisation is no more up-to date, respectively as technical possibilities allowing important optimisation are available.

WMS – Winter-Maintenance-Management-System Hessen

To compensate the mentioned deficiencies, the federal state of Hessen in 2002 started the project Winter-Maintenance-Management-System (WMS). It bases on the idea to use and combine all available and ingenious possibilities for winter maintenance to achieve an optimum support operation organisation.

A pilot project is performed in the district of the office for roads and traffic Bad Arolsen , which shows a pretentious network on climate and topography with a length of 1200 kilometres in Northern Hessen with four road maintenance centres. As the district is touched only by one motorway (A 44 in the north), up to now no information from GMA and SWIS were available.



Übersichtskarte
ASV Arolsen
mit SM-Bezirken

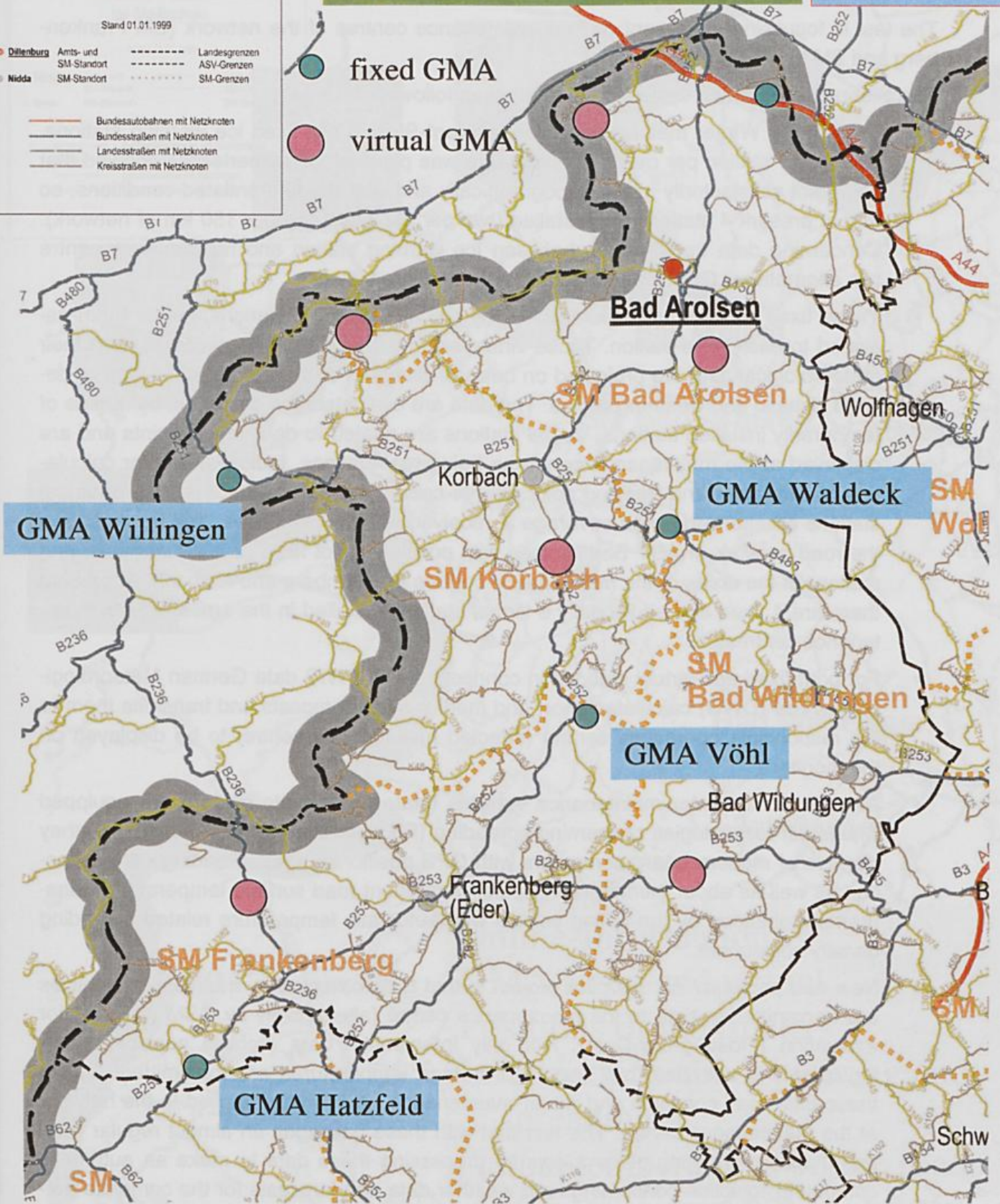
Stand 01.01.1999

- **Dillenburg** Amts- und SM-Standort
- **Nidda** SM-Standort
- Landesgrenzen
- ASV-Grenzen
- SM-Grenzen
- Bundesautobahnen mit Netzknoten
- Bundesstraßen mit Netzknoten
- Landesstraßen mit Netzknoten
- Kreisstraßen mit Netzknoten

ASV Bad Arolsen: 1.200 km Netz, 4 SM'n

GMA BAB

- fixed GMA
- virtual GMA



The district of ASV Bad Arolsen that way was perfectly suitable for the pilot project because this district with extremely pretentious and problematic winter maintenance showed almost no local weather, road condition or intervention data.

The test is focussing at present on two maintenance centres of the network (SM Frankenberg and SM Korbach).

The pilot project shows a system configuration as follows:

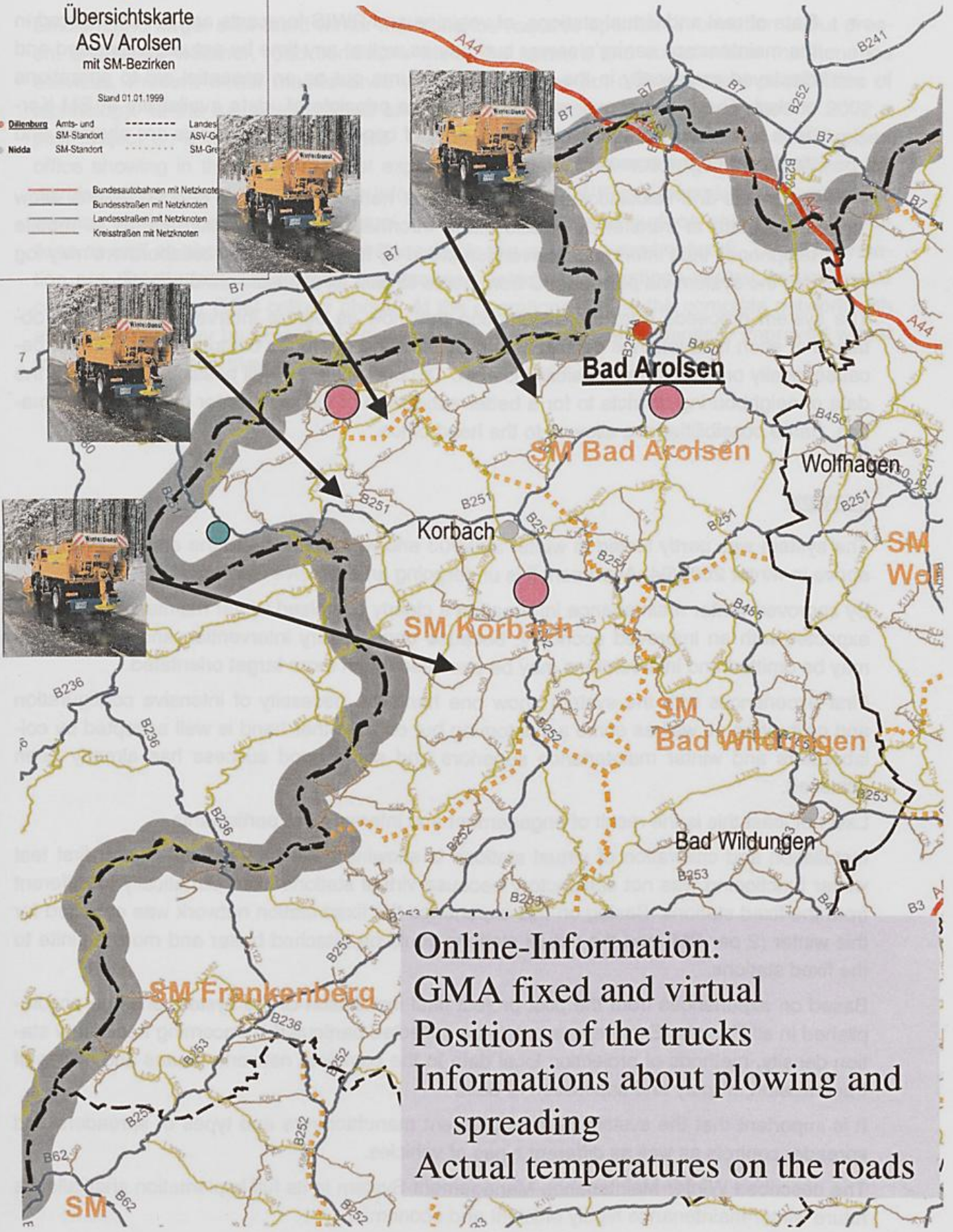
- Core of the Winter maintenance-Management-System are fixed ice warning stations. Basically 1 station per maintenance centre was planned, but experiences showed that being not satisfactorily under topographically and climatic differentiated conditions, so that at present 4 stations are installed (two per SM resp. one per 150 km of network). Concerning data transmission between Ice warning station and maintenance centre two alternatives, GSM phone and internal radio, are tested.
- These fixed stations are accomplished by so called „virtual“ stations, two of them assigned to each fixed station. Those virtual stations are not existing in reality, but their meteorological data are projected on basis of real data of the fixed stations and of defined climatic and weather profiles. The data are evaluated and calibrated by means of temporarily installed stations. Virtual stations are related to definite waypoints and are displayed at the maintenance centre as being real stations. Indication and/or calculation of salt factor and freezing point may of course not be provided. By use of virtual stations a better wide area coverage is received with low expenses. The figure shows the road network of ASV Bad Arolsen with positioning of fixed and virtual measuring stations in the areas of the maintenance centres Frankenberg and Korbach. At present there are 4 fixed and additionally 6 virtual stations installed in the areas of both maintenance centres.
- For both fixed and virtual stations in connection with SWIS data German Meteorological Service (DWD) calculates short and medium term forecasts and transmits them to the responsible operations central (affected maintenance centre) to be displayed on the monitor.
- All operational winter maintenance vehicles (state and private owned) are equipped with latest technologies concerning spreading (FS30) and machinery technology; they dispose of modern board computers with GPS positioning and spreading data collection as well as about thermographics, i.e. permanent road surface temperature measurement obtained by the rolling vehicle with automatic temperature related spreading density adjustment.
- New and particular on this pilot project is that data collected by intervention vehicles are transmitted in time to the maintenance centre (alternatively by GSM or radio) for evaluation (Floating-Car-Data). Not only intervention data (vehicle position, clearing/spreading activities) but also road surface temperatures are transmitted. Out of these data road condition and winter maintenance situation are applied to the network at the maintenance centre. The fact that with these passages an almost regular thermal mapping is taking place allows by processing these data to make an automatic computer projection concerning road weather data and forecasts for the complete network. Furthermore the passage of the vehicles at real and virtual stations allows mutual balancing of data to self test and recalibrate the complete system.



Übersichtskarte ASV Arolsen mit SM-Bezirken

Stand 01.01.1999

- **Dillenburg** Amts- und SM-Standort
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- Landesstraßen mit Netzknoten
- Kreisstraßen mit Netzknoten



Online-Information:
 GMA fixed and virtual
 Positions of the trucks
 Informations about plowing and
 spreading
 Actual temperatures on the roads

- Data of real and virtual stations, of vehicles and RWIS forecasts are not only stored in the maintenance centre's server but may as well at any time be actually visualised and displayed graphically in the network. This turns out as an essential aid to operations control. The figure shows an example of the principle of data availability at SM Korbach. It is essential that all available data of condition and prognosis are chained and displayed on the screen.
- Prognosis and calculations for the complete network as well as defined alarms allow the system to transfer automatic alarm information or intervention alarms to mobile telephones thus informing intervention stand-by forces. Alarmed collaborators may log into the system via portable PC from home to gain all available condition data.

The system proceeds from the assumption that now as before intervention control is obtained at each maintenance centre, i.e. no overlapping operation centres are implanted, because locally orientated responsibility is best. Of course it is as well possible to claim for the data of neighbouring districts to for a better estimation of the own winter maintenance situation. Same possibilities are allowed to the head office.

Preview

The system was partly tested in winter 2002/03 and was operative to the amount described above in winter 2003/04. At present it is undergoing an extensive feasibility test.

By improved winter maintenance information a clearly optimised winter maintenance may be expected with an improved economy, because unnecessary intervention and control rides may be omitted and interventions may be executed much more target orientated.

First experiences with the system show one hand the necessity of intensive configuration and calibration as well as some accustoming but on the other hand is well accepted by collaborators and winter maintenance superiors and some good success has already been achieved.

Last not least this is the result of engagement and interest of all participants.

Installation and calibration of virtual stations is showing quite problematic. During first test winter functioning was not satisfactory because virtual stations were climatically too different from the fixed stations. Basing on this experience the fixed station network was enlarged for this winter (2 per SM) and the virtual stations could be attached better and more definite to the fixed stations.

Based on experiences from the pilot project final installation of the system shall be accomplished in all Hessen. Experiences are to be collected particularly concerning necessary station density, methods of projection local data to the complete network, means and cycles of transmission, display and application of data.

It is important that the system permits different manufacturers and types of spreaders and spreader controls as well as different types of vehicles.

The described Winter-Maintenance-Management-System in its full implantation shall allow a future winter maintenance highly efficient and economic.

Abstract

Efficient and target orientated winter maintenance requires optimum information about present and future weather, road conditions within the network and actual winter maintenance activities. Present winter maintenance organisation does not utilise present possibilities of technology to the full extend. Road and traffic administration of Hessen started in 2002 a pilot project on a winter maintenance management system in the district of Bad Arolsen office showing in the meantime first experiences. Herein information gained from fixed ice warning stations and road weather information system SWIS are completed by virtual ice warning stations combined with actual information about road surface and weather conditions as well as about actual interventions within the complete road network. These information are directly transmitted from maintenance vehicle to operations central (maintenance centre) by radio or GSM cellular phone. At the operations central the complete network with all actual data may be graphically displayed. On such basis an essentially improved winter maintenance control may be obtained.

12th International Road Weather Conference

Bingen (on Rhine), Germany

Boschung Mecatronic SA - Switzerland

Surface Condition Management

A global concept for winter maintenance operations

By Pierre-Alain Brodard, COO

1 Introduction

Road maintenance operations in winter aim at providing the road users with clean and safe pavement conditions. Although the objective is clear, the variety in available methods and equipments sometimes prevent the professionals from making the best use of all resources : the lack of communication or real time data sharing between the various key players prevent them from adapting their activities to a fast evolving situation.

The Boschung group of companies has analysed this problem and come up with a global concept : the **Surface Condition Management**.

2 Characterization

The first step of this analysis was to characterize the various activities and equipments being part of winter maintenance operations. With this respect, a two-dimensional chart has been defined : the various types of activities are represented in the vertical dimension, while the types of equipment are grouped horizontally.

		Equipment	
		Mobile	Fixed
Activities	Surface Condition Assessment		
	Surface Treatment		
	Surface Data Management		

Fig. 1

2.1 Activities

The various activities have been grouped based on their objective and the type of information they provide. Basically, the activities linked to typical winter operations can be grouped in three levels :

2.1.1 Level 1 : Surface Condition Assessment activities

The purpose of these activities is to provide accurate and reliable information about pavement/runway and weather conditions. Getting a good understanding of the real time situation on the complete road network or airport, together with history and forecast data,

allows the maintenance crew to carefully monitor the situation. Early warnings and alarms are used to draw personnel's attention when the conditions get too close to critical levels and require decision-making. This advanced information will allow the maintenance crew to defuse potentially dangerous conditions by planning preventive treatments.

Another important role of the Surface Condition Assessment activities is to provide a feedback of on-going operations : the measured pavement/runway conditions will automatically reflect the effectiveness of treatments applied.

The very crucial role played by the Surface Condition Assessment activities must not be underestimated. Nearly all the saving and optimization potential in winter maintenance operations lies in the reliability and accuracy of the information obtained at this level.

2.1.2 Level 2 : Surface Treatment activities

Usually triggered by the aforementioned assessment activities, the treatment activities group all snow removal and de/anti-icing operations. The purpose of these activities is to maintain the pavement/runway in safe and practicable conditions, thus keeping the traffic in motion.

In order to be efficient, the Surface Treatment activities have to meet the following 3-dimensional requirements :

- Space : occur at the right place
- Time : occur before the driving conditions get critical
- Intensity : be proportional to the conditions they intend to cure

Development of critical conditions on a road network or on an airport rarely takes care of driving directions, distance from the maintenance center or flight priorities. Early warnings can provide enough reaction time to reach the critical spots, although the drive of a fully equipped and loaded vehicle to treat only a distant location may not turn out to be cost-effective. Therefore, a smart combination of fixed, locally installed anti-icing equipment and mobile "wide range" vehicles is the best way to meet the "Space" and "Time" requirements with a minimum amount of resources. Once again, the availability and sharing of timely and accurate information is of paramount importance. Besides, a detailed knowledge of the current local conditions allows to optimize the "Intensity" requirement.

2.1.3 Level 3 : Surface Data Management activities

The two previous levels clearly show the importance of information gathering and sharing in the Surface Condition Management concept. The purpose of the Surface Data Management activities is therefore to ensure proper use, storage and display of the data.

With this respect – and due to the evolution of the hardware and software technologies - customers' expectations have increased, which could not be easily fulfilled by available software solutions. These new requirements on data management software can be described as follows :

- Easy access to data : classical client-server type software application are perceived as being limitative, as they need dedicated access computers. Customers want to have the ability to check the situation from their office or home computer.
 - ⇒ Software application should be based on web technologies, allowing access to the data via a standard browser.
- Easy distribution of data : data is no more confined to the road maintenance centers : higher levels in the organization want to have an overview of the situation. Besides, a

lot of data measured in the Surface Condition Management concept can be very valuable for Traffic Management systems (fog warning for example). Many customers propose also their own web site with on-line traffic and road condition information.

- ⇒ Software application should provide a standard interface for data exchange with other applications. Security of the data must however be guaranteed.
- Intuitive displays : although detailed information is still necessary for analysis and statistical purposes, the decision making process has to be quick, and personnel without much technical knowledge must have the ability to clearly identify a critical situation.
 - ⇒ Data display should be map-based, with visual indication of critical situations.

2.2 Equipment

The activities described in the three aforementioned layers make use of specific equipment. Although each equipment can be used individually, the analysis above has demonstrated that the ability to acquire and share data is the only way to increase the overall system efficiency. As shown in the first part of this chapter (see fig. 1), the equipment used in winter road maintenance can be grouped in two categories : **mobile** (automotive) and **fixed** equipment. Both categories have a similar architecture (see fig. 2 below), based on the activity layers described in the previous section.

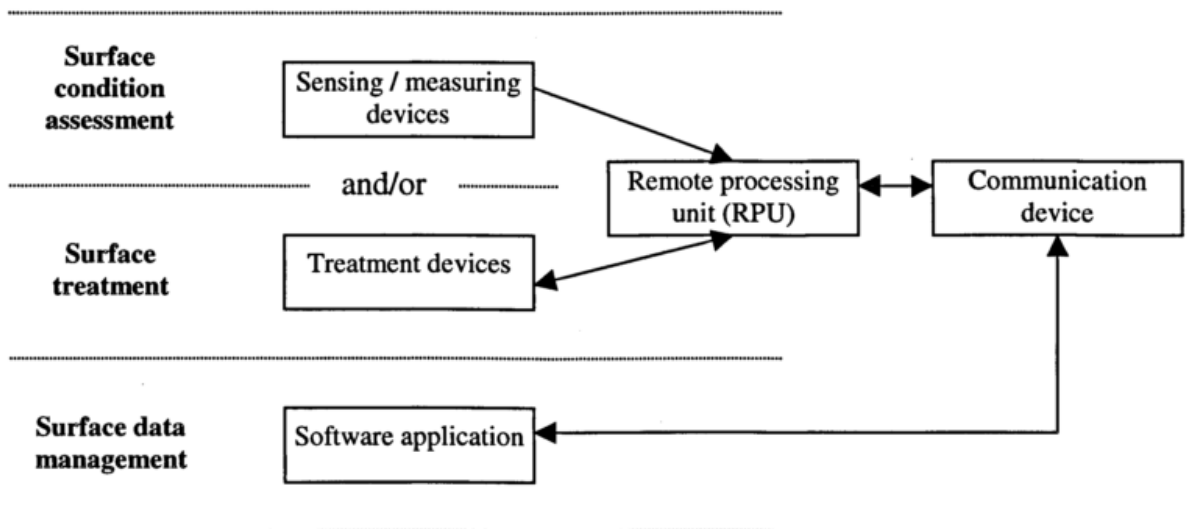


Fig. 2

Fig. 2 clearly shows the information flows : local automation of treatment activities can be achieved by coupling the sensing device to the treatment device through the RPU. Remote actuation of local treatment activities can also be performed from the software application.

2.2.1 Category 1 : mobile equipment

This category groups all sensing and treatment devices installed on vehicles, as well as the RPU and communication hardware to ensure proper acquisition, temporary storage and transmission of data.

Mobile equipments have the advantage of covering large road networks, and can be sent to specific locations. The drawbacks are however that they are depending on traffic fluidity (cannot go through if the traffic is already stopped), and need time to reach the assigned locations. As a consequence, the decision making process has to be realised far in advance if a timely action is desired.

Fig 3 below shows examples of mobile equipment.

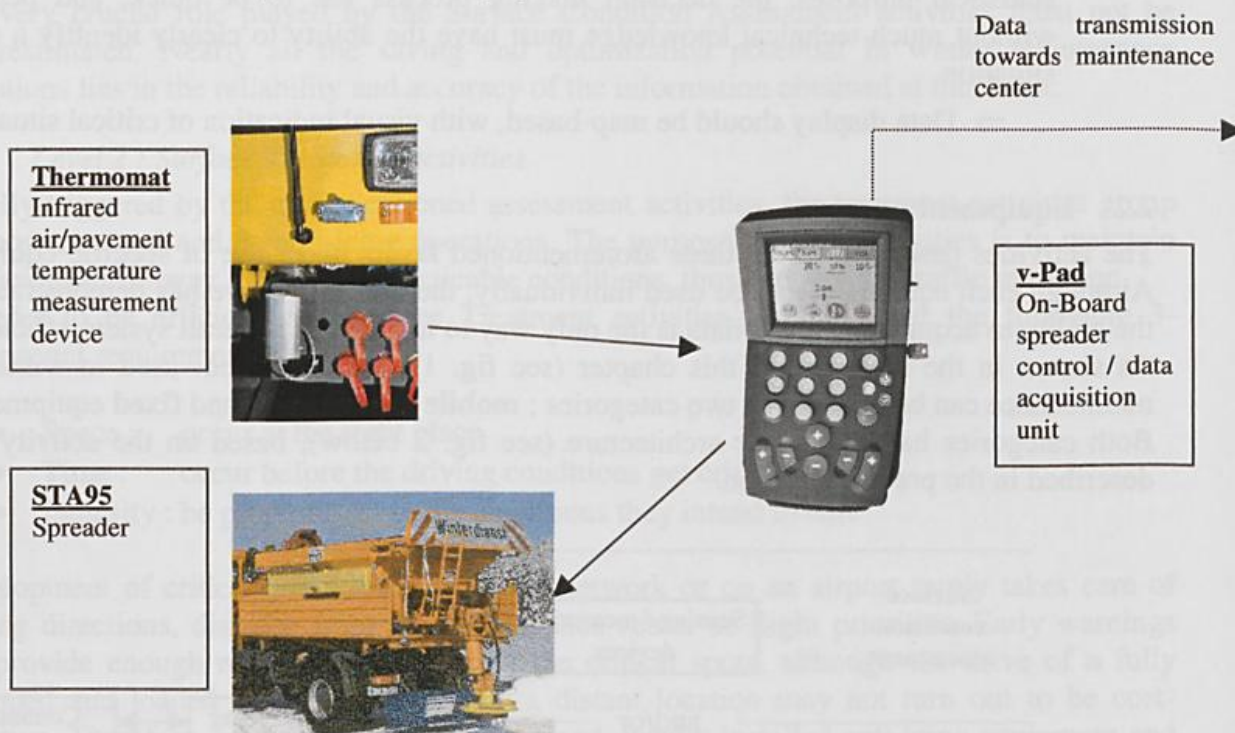


Fig 3

Note : the pavement temperature readings are directly used by the spreader control unit to automatically adjust salt quantity.

2.2.2 Category 2 : fixed equipment

This category groups all sensing and treatment devices installed permanently at fixed locations, as well as the RPU and communication hardware to ensure proper acquisition, temporary storage and transmission of data.

Fixed equipments are complementary to mobile equipments : they are independent of traffic congestion, and can be activated immediately upon critical conditions. The drawback is that they are confined to a specific location.

A smart combination of both mobile and fixed equipment is the best way to achieve optimal winter maintenance.

Fig. 4 below shows examples of fixed equipment.

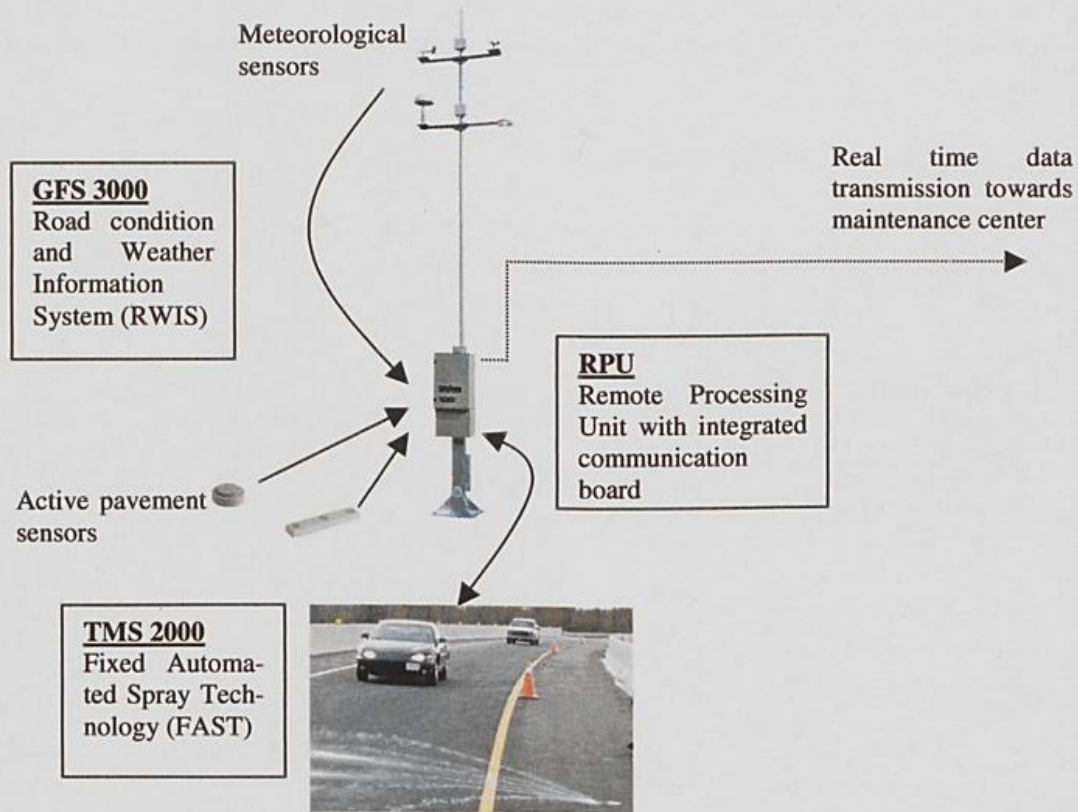


Fig 4

Note : Pavement and weather conditions measurements are directly used in the RPU to automatically activate thawing agent spray system.

3 BORRMA-WEB, the backbone of Surface Condition Management

Until now, the “equipment” (software) used for Surface Data Management activities always reflected a distinction between mobile and fixed equipment, each group having its own software suites for data display, storage and analysis.

However, the characterization described in the previous sections has demonstrated significant similarities at process level between mobile and fixed equipment. Furthermore, our analysis has shown the necessity to share data from both sources in order to optimise the overall performances of winter maintenance.

Taking all the above into consideration, the Boschung Mecatronic company has developed a unified software application meeting the various requirements of the Surface Condition Management concept : the **Borrma-Web**.

3.1 Easy access to data

The Borrma-Web application software is based on a 3-tiers type application server. This unique platform makes use of the latest web technologies and runs on a Java virtual machine. It is therefore independent from the operating system of the hosting server. An integrated load

balancing function allows to use several machines in parallel, thus offering an unequalled flexibility to cope with any system dimension.

Access to data is performed via a standard browser. Upon customer's wish, the application server (or a second machine) can be installed outside the intranet, and thus allow access to the data from the Internet.

Fig. 5 below shows a typical IT network.

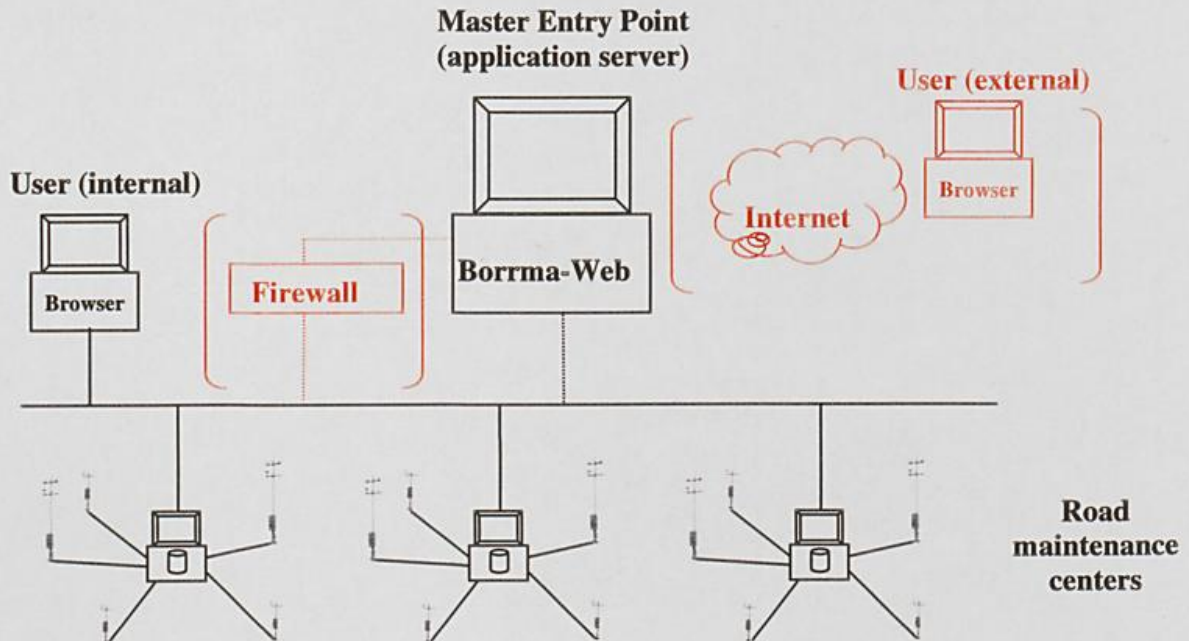


Fig 5

3.2 Easy distribution of data

The Internet Server platform described above provides special web services for data exchange. Standard XML requests via SOAP protocol will allow any authorized user (software application) to instantly get the desired data. As for human users, software applications will be granted a username and password, and get a specific profile detailing what sets of data can be viewed, or what actions can be performed (acknowledgement of alarms for example).

3.3 Intuitive display

Alpha-numerical and graphical displays allow for detailed analysis of special weather events. Reports and statistics can be generated for performance analysis or other administrative purposes (invoicing, benchmarking, etc.).

However, the main tool is the so called **dynamic map**. This display is based on a geographical map of the area. Standard zooming and scrolling functions are provided. All components of the Surface Condition Management concept which are delivering information (weather stations, spray systems and vehicles) are displayed at their geographical location,

together with a configurable flag for real time data. This display summarizes the global situation, with current weather stations readings, spray systems and/or vehicle status. In order to enhance the ergonomics of the display, the road network is **colored** based on user-configurable parameters. For example, alarms generated from the RWIS will color adjacent road segments, which will be turned back to "green" once they have been treated (fixed spray system, or mobile salt spreader). A user configurable trail can be assigned to all mobile equipments, showing the past activities : its color code will reflect the tools used by the vehicle. The objective of this new display is to provide a quick and geographical notification of the critical zones, together with the position and status of available resources.

Fig. 6 below shows a typical dynamic map display.

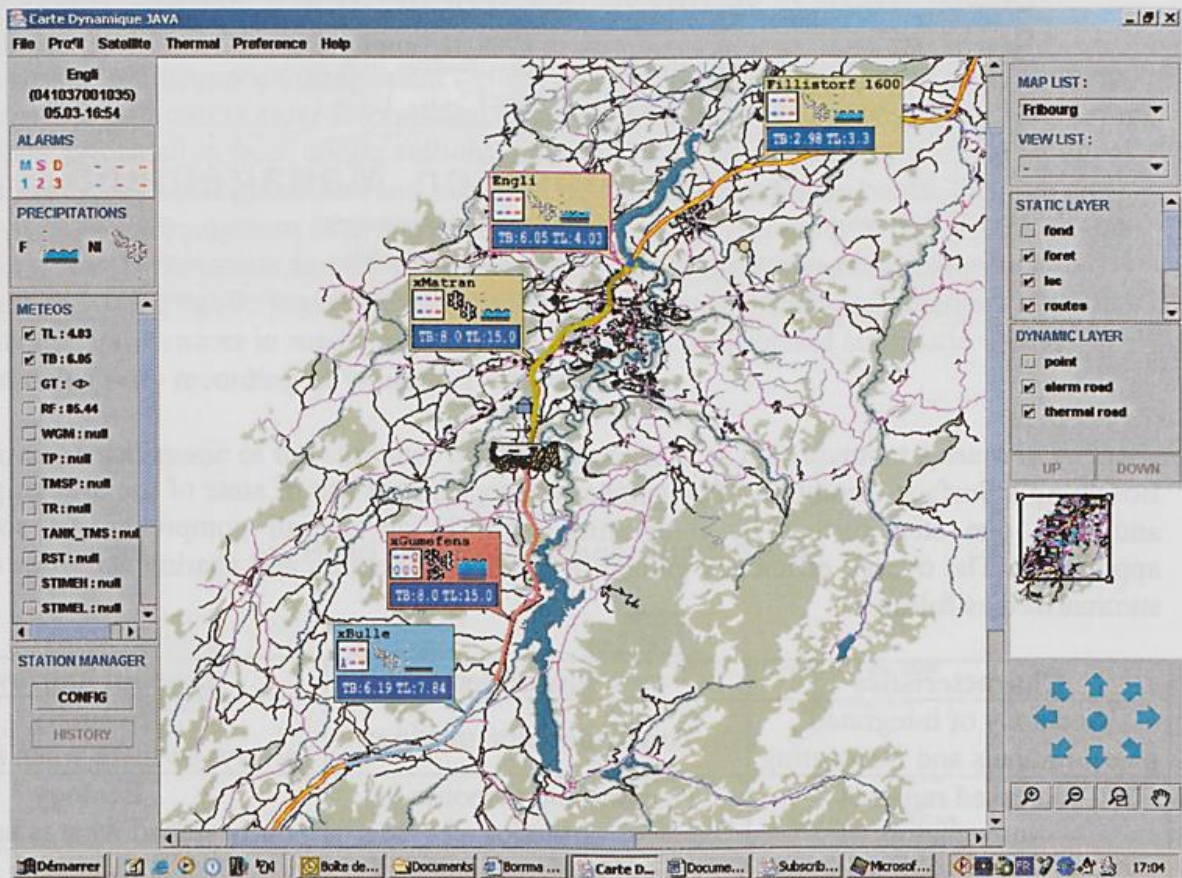


Fig 6

A time cursor allows the user to go back in the past : all values, colors and vehicle positions will change to the value they had at the time specified by the cursor. This allows for a quick analysis of the evolving situation. The same cursor allows also to go in the future : powerful forecasting algorithms provide detailed RWIS-level forecast, which will be displayed using the same color coding.

4 Summary

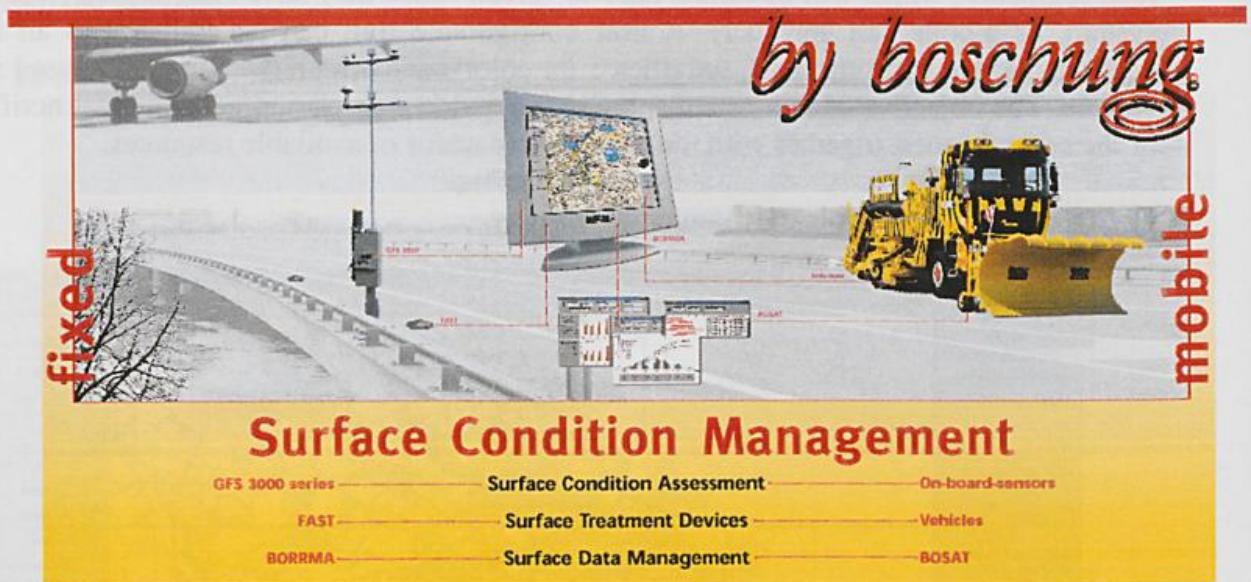


Fig 7

Boschung's Surface Condition Management concept makes use of state of the art equipment, and goes one step further by integrating them in an overall comprehensive software application. The overall efficiency gained in the data collection and sharing activities can be summarized as follows :

Characteristics	Value added	Domain improved
Accuracy of integrated measurements and forecasting	Timely decision making	Security (always be there when necessary)
Increased range of information	Proportional response to situation	Ecology (only spread what is necessary)
On-line information about available resources	Dynamic management of resources	Economics (only do what is necessary)

11/2003/PAB

SIRWEC 2004

Call for papers, November 30th 2003

Topic: Winter maintenance management system

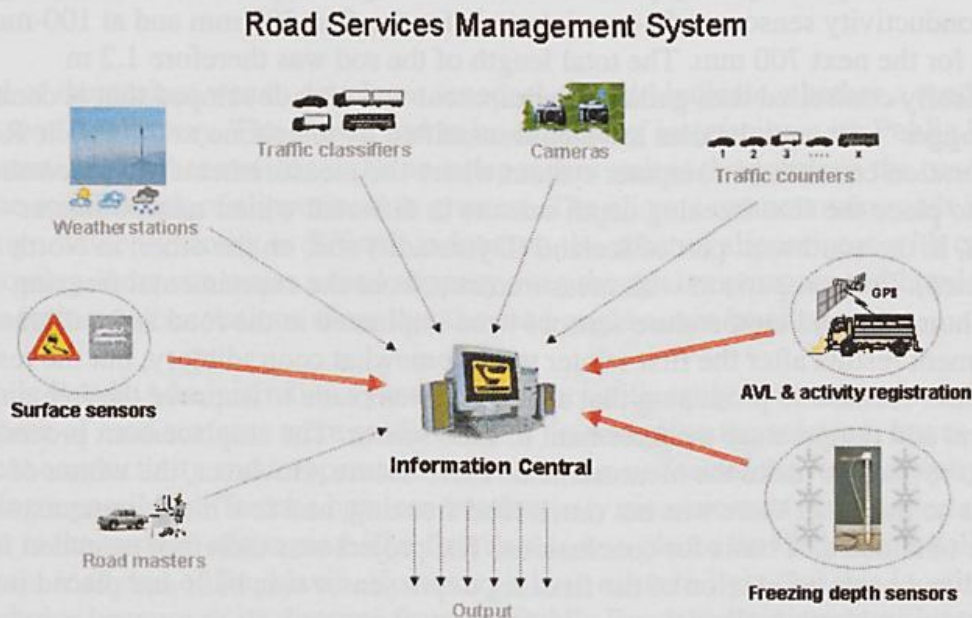
Public Roads Administration, Iceland

Nicolai Jonasson, Chief of Traffic Service, and Einar Palsson, Project Leader

Icelandic winter maintenance management system

The winter maintenance management system in Iceland is a centralised computer system, where 18 road masters enter information about road passability and weather in the relevant regions. Information from winter stations, cameras, road slipperiness sensors, freezing depth sensors, traffic classifiers and counters, as well as information on the location and activities of the equipment used for winter services is also entered into the system. In this lecture, Nicolai Jonasson and Einar Palsson will discuss three important things being developed at the Public Roads Administration that are a part of the management system: freezing depth sensors in roads, road surface condition sensors and automatic vehicle location/activity recording of winter service vehicles.

Below is a schematic of the structure of the winter services management system in Iceland.



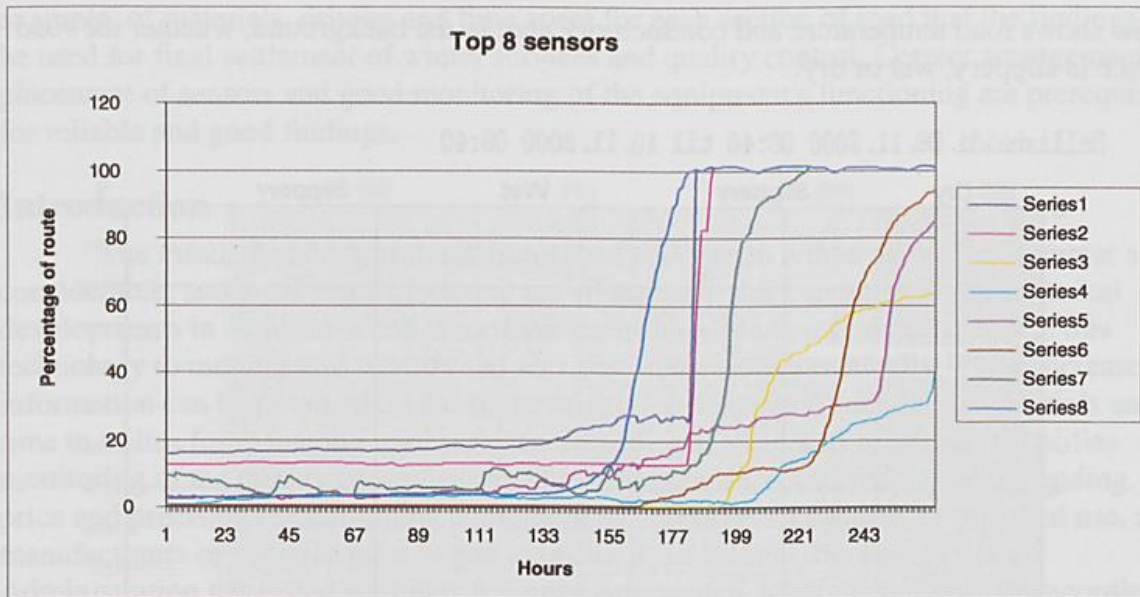
Measurement technology to control axle weight limits

Every spring it is necessary to control the axle weight of vehicles on a number of roads as a precaution against their being ruined when their subgrade support layers are thawing. It is very difficult to determine with sufficient advance notice when to impose the weight limits, and it therefore often happens that the carrying capacity has already deteriorated before the weight limits are set, which can lead to permanent deterioration of the road's carrying capacity and durability and/or cause damage to the pavement.

The goal of this project is to develop methodology and/or a mathematical model to determine when and what weight limits shall be set, based on automatic measurements of temperature and conductivity in a road cross-section along with information from Public Roads Administration weather stations and weather forecasts of the Icelandic Meteorological Office. Being able to see when it is timely to impose weight limits clearly reduces the chances of roads being damaged because weight limits were not timely set. It is also clearly advantageous for truckers to have timely knowledge of whether weight limits are to be set for a road in the next few days.

At the conclusion of this research and development work, it is the ultimate goal to be able to control weight limits automatically from a control centre in the Public Roads Administration Services Department. Temperature and conductivity sensors in roads all over Iceland will transmit information that a mathematical model will process and indicate when weight limitations shall be set.

Initial efforts at the beginning of the project focused on designing a freezing depth sensor that could be easily and quickly placed in a road. The prototype of the freezing depth sensor had 16 conductivity sensors at 50-mm intervals for the first 500 mm and at 100-mm intervals for the next 700 mm. The total length of the rod was therefore 1.2 m. Electronically controlled data gathering equipment was also developed that is connected to a "data logger" unit, and the data are then transmitted by telephone to the Public Roads Administration centralised computer system where the measurements are processed. It was decided to place the first freezing depth sensors in different winter microclimates - on the one hand, in the southwest part of Iceland (Dýrastadir) and, on the other, in North Iceland (Vatnsskard). For comparison with measurements from the experimental freezing depth sensors, humidity and temperature sensors were implanted in the road and calibrated. The measurement results after the first winter were somewhat contradictory, but the results nevertheless seemed so promising that a decision was made to improve the freezing depth sensor and add temperature measurement to each sensor. The emplacement procedures were also revised to make the measurements more secure. However, the winter of 2002-2003 was so mild that there was not much road freezing, and few measurements were therefore obtained as a basis for conclusions. The project was therefore extended for one year, and an improved version of the freezing depth sensor was built and placed in Skagafjörður in North Iceland.



Graph showing change of state from ice to water for the 8 top sensors

After the experience of previous years, the researchers believe that development of the freezing depth sensor and electronic reader make secure measurements likely. Also, revised methods for emplacement and securing of the equipment have led to more fail-safe measurements.

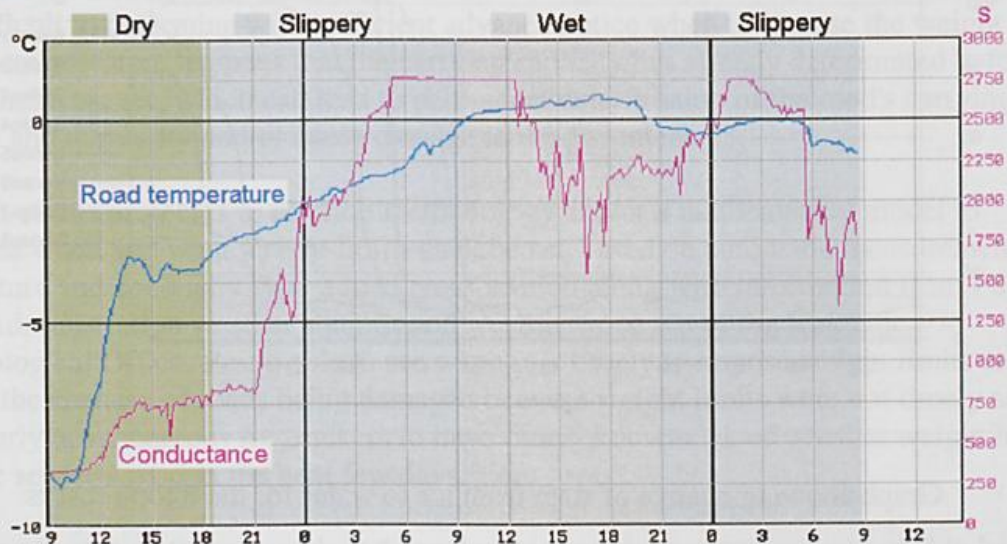
Measurement of road surface conditions

The goal of the project was to develop a sensor that could indicate whether a road surface was dry, wet or slippery. The sensor had to be capable of interfacing with Public Roads Administration weather stations or be an independent unit at the points in the road system where the relative risk of slipperiness is greatest. The climate on mountain roads in Iceland can change suddenly, and it is difficult to forecast the onset of slipperiness with certainty. Also, blowing snow can make a road slippery even though temperature and humidity readings from weather stations show that the road ought not to be slippery.

The Public Roads Administration's first experiments with equipment to measure slipperiness of road surfaces were made in 1997. In designing the solution, it was decided to implant conductivity and temperature sensors in the surface of the road, thereby precluding a possible difference between conductivity measurements of a material other than that in the surface of the road. The first device was placed on Hellisheidi Fell, which is a mountain road east of Reykjavik. However, it later came to light that this location was not a good choice because of its distance from the Public Roads Administration Centre. It took some time to calibrate the device and verify the reliability of the readings. The first findings held promise, and it was decided to continue research with this measurement method. The data coming from the device are sent to a centralised computer system for processing. No final interpretation and presentation of the data have been developed, but the graph

below shows road temperature and conductivity and, in the background, whether the road surface is slippery, wet or dry.

Hellisheiði 08.11.2000 08:40 til 10.11.2000 08:40



Experiments in measuring road surface conditions were not done for some time, but now a revised version of the method is ready, and five measuring devices will be put in place near Reykjavik in November 2003. The main changes in the new version are a new, electronically controlled reader for the measuring devices in the road surface and a revised technique for placement of the devices in the surface of the road. Plans call for presenting the findings of the new test in the spring of 2004.

AVL & activity registration

Summary

Can automatic vehicle location and activity registration be utilised for settlement of winter services? Automatic vehicle location equipment, consisting of a telecommunications device (GSM) and sensors, was installed in snow removal equipment with a salt and brine spreader as well as front and under teeth to automatically collect information about location, activities, speed, distance and time. The control equipment was purchased from the manufacturers of the spreader since it was available (in this instance, this was the manufacturer of the salt and brine spreader - EPOKE). Emphasis was placed on developing data reception and processing and testing the reliability of the equipment. Upon receipt of data from a device, the grid position is slotted into the road system, i.e., information about activities is collected for certain roads and stretches of road for further processing. In this way, additional information can be collected about the scope of service programs, activities, driving, use of materials, lengths of road cleared, etc., for each road, region, etc., for any period.

The first findings indicate that, after processing, the information obtained with the above-specified equipment provides so good and reliable an overview of quantities, for

example, of materials, driving and time spent for each section of road that the findings may be used for final settlement of winter services and quality control. Correct arrangement and placement of sensors and good monitoring of the equipment's functioning are prerequisites for reliable and good findings.

Introduction

The Public Roads Administration's road services in winter as well as summer are considerable, and great sums of money are allocated to this category. Rapid technical developments in equipment and communications have made it feasible to utilise this technology to monitor and record road services, not least automatically. Thus, increased information can be obtained on the scope of service programs, quantity of materials and time to utilise for managing road services. In addition, increased recording simplifies monitoring of the quality of services and can promote improved utilisation of funding. The price and precision of positioning equipment has become acceptable for practical use, and manufacturers of vehicles have begun to utilise it. In Iceland, the Public Roads Administration has tested solutions for automatic vehicle location and activity recording with data transport through the TETRA system and, now, via the GSM mobile telephone system. The TETRA system is an interesting alternative; it is well suited to data transport since the data are received in almost real time. If there is always a need to know where equipment is located in the road system in real time, then TETRA is a good solution. However, its limited coverage still restricts its actual use except in SW-Iceland.

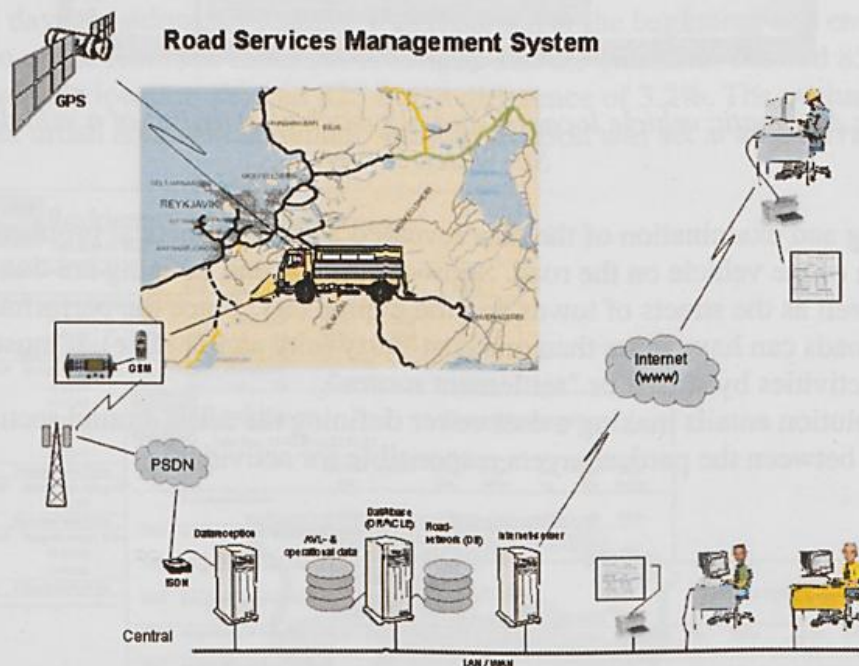


Figure 1: A schematic representation of automatic vehicle location and activity recording

The manufacturers of de-icing equipment, for example, EPOKE and STRATOS-NIDO, have developed solutions for automatic vehicle location and activity recording for their equipment with data transport over the GSM mobile telephone system. The manufacturers have designed control equipment for productivity and spreading in accordance with a vehicle's capabilities and speed. Data consequently indicate variable use of materials that would otherwise have had to be set at a fixed rate, such as the quantity of

salt in grams/m², relative to the total quantity of material used. These standard solutions are optimised to produce a planned result for each piece of control equipment and are purchased with service contracts.

Vehicle location and activity data

A fundamental aspect of utilising vehicle location and activity data is to pinpoint the vehicle's location in the road system. As soon as data from vehicles is input, it is identified with a road in the Public Roads Administration's road database.

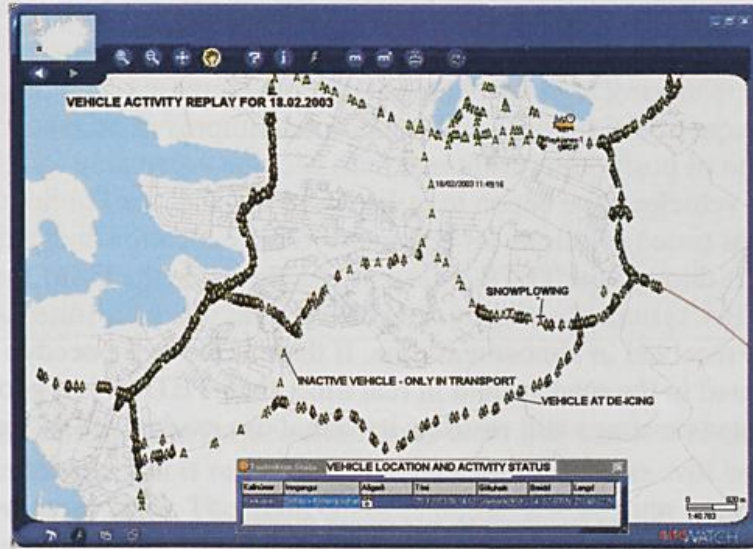


Figure 2: Automatic vehicle location and playback of activities of a vehicle on the SiteWatch server

Testing and examination of the data revealed a certain practical problem in slotting in the location of the vehicle on the road. Snow ploughing and de-icing are done on highways as well as the streets of towns and the capital city. Since the performance of activities on roads can have more than one cost-party (city and/or state), it must be possible to segregate activities by streets or "settlement routes".

The solution entails making a data cover defining the areas around sections of road to distinguish between the parties/payers responsible for activities.



Figure 3: Areas around sections of road (settlement routes)

In processing, it is interesting to get a summary of a vehicle's driving broken down by driving route (road, snow route or settlement route). On the other hand, it is of less interest to break down driving of a vehicle by intersections or approach and exit lanes. This is important if activity data are utilised for settlement, for example, regarding contractors. A contractor makes a bid for winter services for certain roads/streets. For settlement, it must be possible to distinguish between the contractor's driving and activities on roads/streets not on the settlement routes since the contractor's activities on such routes do not fall within the tender. On the other hand, a reasonable settlement route must include driving on ramps, access roads and exits, turnarounds, etc. An access route is therefore defined as the areas through stretches of road/streets that the operations manager deems to be within the normal limits of the driving route for the vehicles servicing it.

Processing - reports

Standardised reports on data have been designed to provide an overview based on snow routes: quantity figures for materials and time, service hours and activities as well as daily settlement. Finally, provision is made for transferring the results of automatic vehicle location and activity recording within the internal Public Roads Administration system for further processing and settlements with contractors.

Reports are published on an intranet, so that operations managers as well as contractors can, at the end of the day, get an overview of the day's activities by defined settlement routes.

A reliability evaluation of automatic vehicle location was done for stretches of road. For several days the odometer reading was recorded at the beginning and end of trips. Comparison of the recorded distances indicated that the odometer showed 852 km, while automatic vehicle location showed 825 km, a difference of 3.2%. The evaluation was of driving in an urban area, and automatic vehicle location was set at an interval of 500 m.

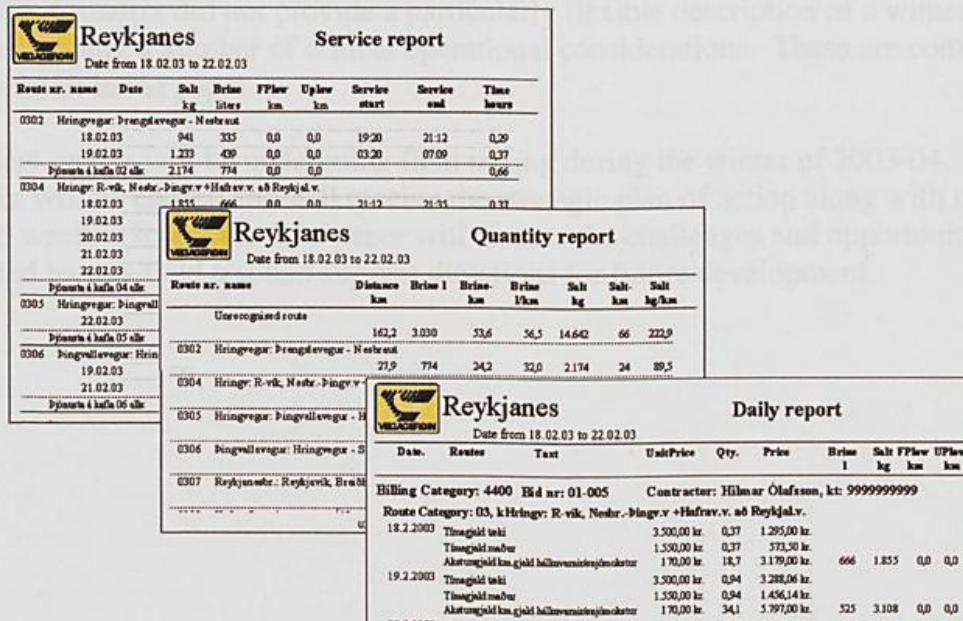


Figure 4: Quantity report, daily report and service report

Operational Use of Weather Forecasts in Winter Maintenance: A Matrix Based Approach

Wilfrid A. Nixon¹ and Robert Stowe²

ABSTRACT

In winter maintenance operations, weather forecasts have the greatest value when they can drive the operational activities of an agency or a work unit within an agency. Thus if an agency does not begin to plow snow until two inches (five centimeters) of snow have accumulated on the pavement, the weather forecast is of much less value than if that agency anti-ices and thus applies chemicals prior to the storm.

A major effort is underway in the US through the MDSS (Maintenance Decision Support System) to enhance the value of weather forecasts to winter maintenance agencies. While part of MDSS is focused on improving the accuracy of forecasts, an important part is also focused on providing real time operational advice to agencies deployed fighting the storm. Thus, for example, one aspect of the MDSS is to recommend to agencies when to apply chemicals on a given plow route.

Such advice clearly has enormous potential benefits, but it is also stretching the limits of the technology at present and it suggests that an intermediate step may have significant value. The intermediate step considered in this paper provides a strategic plan of action (as opposed to what might be termed a tactical plan focused on individual plow routes) based on the forecast. The plan of action is derived using a matrix similar to that presented in Appendix C the FHWA Manual of Practice for Anti-Icing. However, the Appendix C matrix did not provide a particularly flexible description of a winter storm and was missing a number of critical operational considerations. These are considered in greater detail in the paper.

This new matrix will be undergoing field testing during the winter of 2003-04. Three agencies will be chosen and will receive the strategic plan of action along with their tailored weather forecasts. The paper will discuss the challenges and opportunities presented by this field test and suggest directions for future development.

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THE U.S. FEDERAL HIGHWAY ADMINISTRATION WINTER MAINTENANCE DECISION SUPPORT SYSTEM (MDSS) PROJECT

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1. Introduction

Managing a winter maintenance program today is an increasingly complex endeavor. Just making sure that a plow blade is at the ready when the first flake falls is only a small part of the task. With tight budgets and the high expectation of the public for keeping roads clear of snow and ice, today's maintenance manager has to be able to handle multiple tasks or risk getting behind the onslaught of winter weather. Good information leads to effective practices, however all of the regulations concerning chemical applications, environmental impacts and multiple, often contradictory weather forecasts can lead to information overload.

The United States Department of Transportation (DOT), Federal Highway Administration (FHWA) recognized this potential problem in the late 1990's as part of its Road Weather Management (RWM) program. Generally speaking, there were plenty of weather forecasts, along with a few companies that issued road-specific forecasts, but there was a lack of linkage between the information available and the decisions made by winter maintenance managers. It was this weak link that became the genesis for the winter Maintenance Decision Support System

(MDSS).

The MDSS has since matured into a functional prototype. During the winter of 2002-2003, the prototype was deployed at several maintenance garages in central Iowa for a field demonstration. This paper will document the implementation of the demonstration, a summary of lessons learned, and technology transfer activities. It will also describe plans for a longer, more comprehensive demonstration during the winter of 2003-2004.

2. Organizational Overview

The MDSS is a research project that is funded and administered by the FHWA RWM program. Five U.S. national laboratories in coordination with state DOTs, academia and the private sector have also been participating in the development and implementation of the project, including:

- U.S. Army Cold Regions Research and Engineering Laboratory (CRREL)
- National Center for Atmospheric Research (NCAR)
- Massachusetts Institute of Technology – Lincoln Laboratory (MIT/LL)
- National Oceanic and Atmospheric Administration (NOAA) Forecast Systems Laboratory (FSL)
- NOAA National Severe Storms Laboratory (NSSL)

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The MDSS project integrates state-of-the-art weather forecasting and data fusion techniques with computerized winter road maintenance rules-of-practice. The result is a set of guidance aimed at maintenance managers that provides a specific forecast of surface conditions and treatment recommendations customized for plow routes.

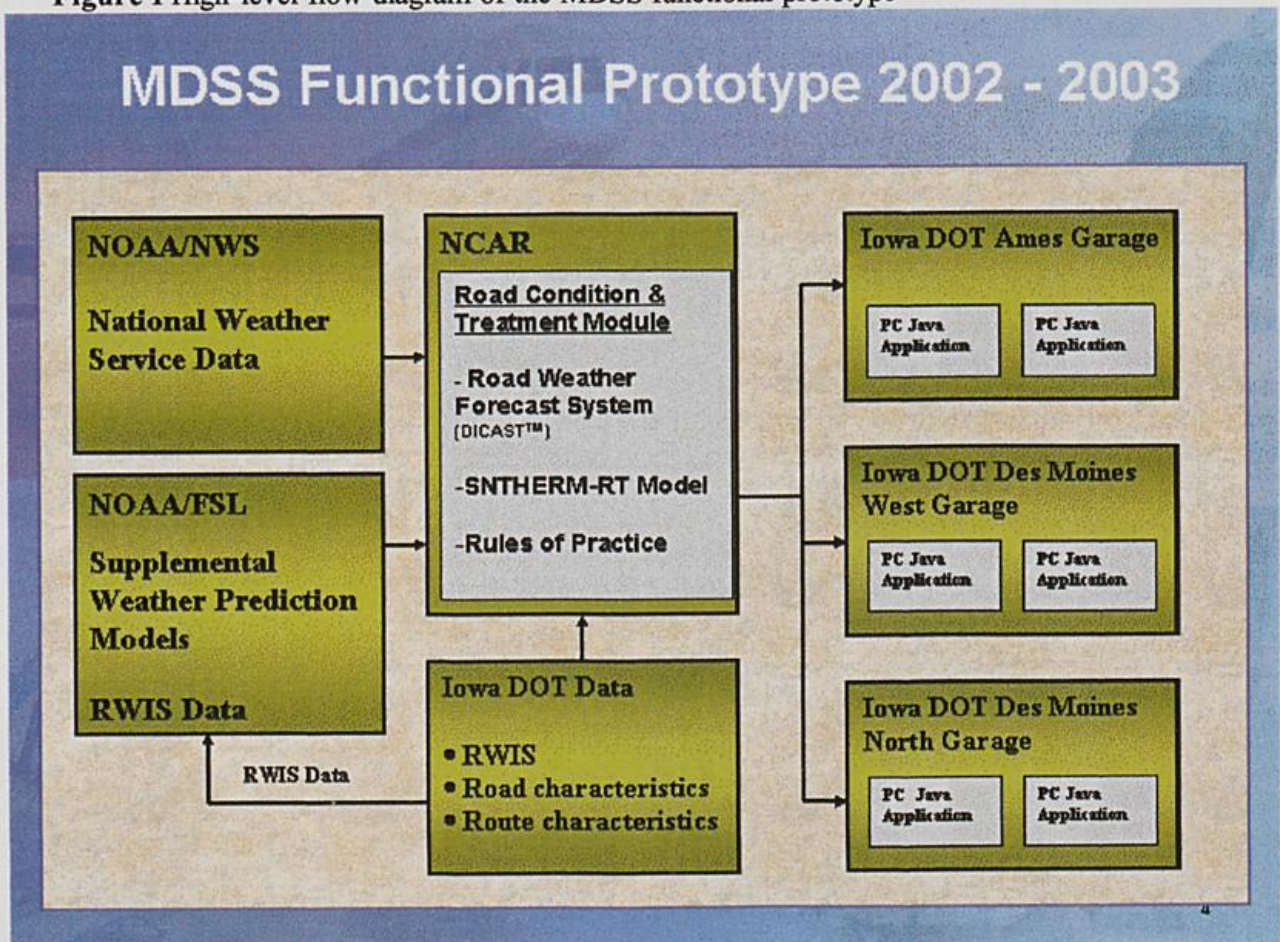
The project has several goals:

1. Demonstrate to the state DOTs that new technologies are available to assist maintenance managers with maintaining safety and mobility on roadways and provide for more efficient use of chemicals, equipment and staff.

2. Show the private sector road weather providers that there is a market for these new technologies within the states. To aid this process, the FHWA will provide the core MDSS modules to any company in hopes that they will be integrated into their product lines.

Success, as defined by the FHWA, will be reached when private sector companies integrate MDSS components or similar functions into their products. It is anticipated that state DOTs will purchase these new services. In the end, the project will serve to raise the bar on standards for services provided by the private road weather forecasting industry.

Figure 1 High-level flow diagram of the MDSS functional prototype



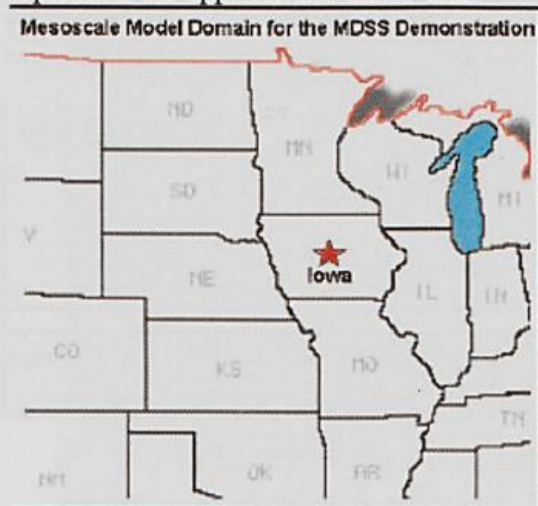
3. System Overview

Each national laboratory brings unique capabilities and expertise to the project. Much of the software used in the core MDSS modules has been reused from other projects and tied together via inter-process communications.

Figure 1 shows a high-level flow diagram for the MDSS functional prototype that was used in the winter 2002-2003 demonstration (Mahoney, 2003). The top box in the left column represents data received from the U.S. National Weather Service (NWS), National Centers for Environmental Prediction (NCEP). These data include surface observations, statistical guidance products, daily weather summaries and numerical weather prediction model output from both the Eta and GFS (Global Forecast System – formerly known as AVN) models.

Figure 2 shows the coverage area of the supplemental mesoscale numerical weather prediction models that were provided and run by FSL. These models were the MM5 (Mesoscale Model 5), the RAMS (Regional Atmospheric Modeling System) and the WRF (Weather and Research Forecasting model). The models had a grid spacing of 10 km and were run four times per day out to 24 hours.

Figure 2 Model domain for the MDSS demonstration. Area under the red star represents the approximate demo area.



In order to provide diversity into the data fusion module, FSL used the NWS models to provide lateral boundary conditions to initialize each mesoscale model. Hence, four times per day, FSL would generate six model solutions for the forecast domain.

Differing from the NWS models, the mesoscale models used a new initialization routine to add realistic distributions of moisture and clouds to the model atmosphere. This method, called “hot-start” (McGinley, 2000), allows the mesoscale models to begin with a much better representation of clouds and precipitation. The benefit of the hot start process is a more accurate prediction, particularly in the first 6 hours of the forecast cycle.

Forecast output from the models, plus surface observations from state DOT road weather information systems (RWIS) were forwarded to NCAR’s data fusion engine called the road weather forecast system (RWFS). The RWFS module uses a fuzzy logic ensembling scheme that has the ability to generate more accurate forecasts than any one individual model input (Mahoney, 2003).

Specialized algorithms such as the road temperature forecast module and the road condition and treatment (RCTM) module use the model outputs to generate temperature forecasts for the state and condition of the road surface as well as guidance for chemical concentration and dilution rates.

The final module in the system contains the rules-of-practice algorithms. The rules-of-practice are customized rules and techniques that are used at DOT maintenance garages for maintaining mobility during winter conditions. These rules tend to be different for each state and in many cases are different for each garage. Hence, this module has the ability to customize many of its inputs so that it can be portable between garages.

Output from the rules-of-practice module includes treatment recommend-

datations for the DOT garage supervisor. Some of the guidance information contains:

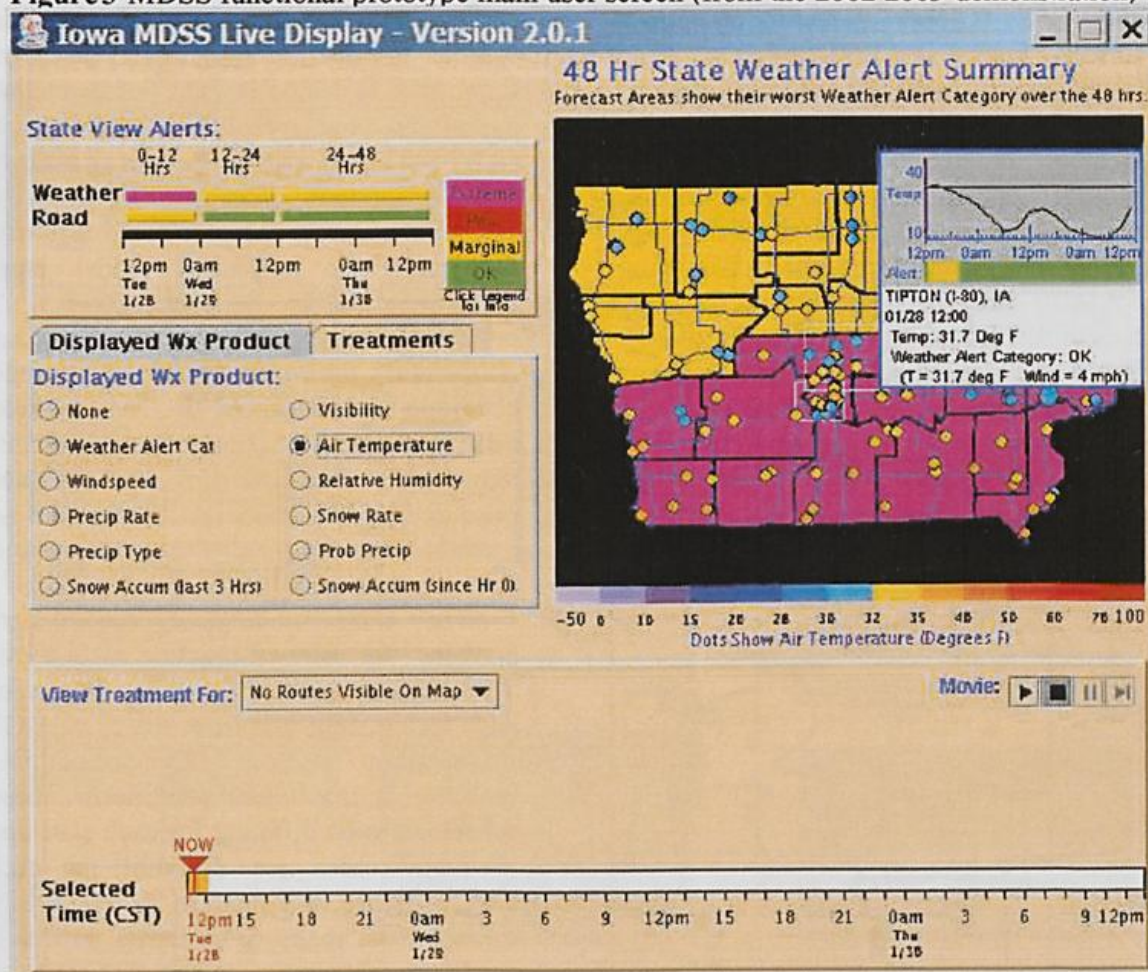
- Recommended treatment plan (plow only, chemical use, abrasives, etc).
- Recommended chemical amount
- Timing of initial and subsequent treatments

Figure 3 is an example from the MDSS prototype main display. The top left panel shows a summary table with color-coded bars showing forecast weather and road conditions for the next 48 hours. The panel

at the left center provides access for displaying weather parameters or treatment routes. The bottom section controls the forecast time selection and animation. The main map (top right) can show either an entire state view or a zoomed-in route view (Figure 4).

Each dot on the main map represents an observation point. Forecasts are generated for these points and also for locations along each plow route using interpolation techniques. Moving a cursor over any point brings up a time series graph of the selected forecast parameter plus additional site specific details.

Figure 3 MDSS functional prototype main user screen (from the 2002-2003 demonstration)



The MDSS contains a "what-if" scenario treatment selector. This means that the operator is able to modify the recommended treatment times, chemical types or application rates, and see how the road condition predictions might change.

In Figure 5, a chemical concentration display shows the results of two scenarios following an initial application prior to this time period. The green trace shows the dilution rate of sodium chloride on the road surface if no additional treatments of chemicals are applied. In this case, given the forecast weather conditions, the chemical concentration on the road surface would fall to 10 percent or less within 24 hours. With a second application of sodium chloride (at a rate of 300 pounds per lane mile), the red trace indicates that the chemical concentration would stay

about constant through the 48 hour forecast period.

Figure 4 Des Moines area MDSS routes and forecast points

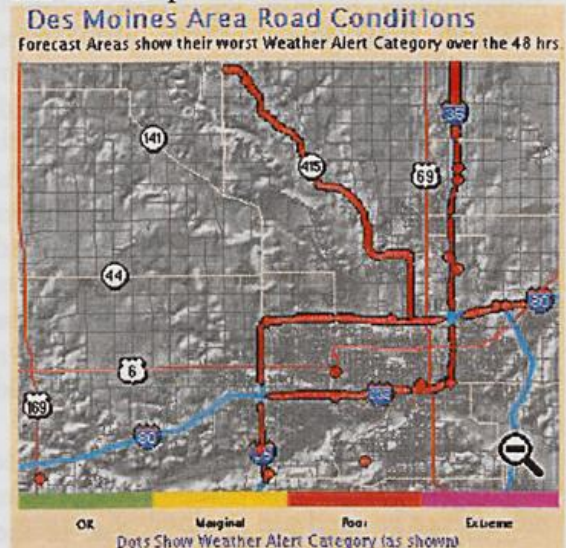


Figure 5 MDSS treatment selector screen. The red trace (top window) shows the predicted chemical concentration if the treatment application is followed. The green trace shows the chemical dilution rate if no chemicals were applied. Note that a prior application has left a 28% chemical concentration on the road surface at the beginning of this time period.



4. Field Demonstration 2003

During the summer of 2002, a half dozen states competed to win the opportunity to host the MDSS project. While there were several very good candidates, the Iowa Department of Transportation (IADOT) was selected. Determining factors included their progressive maintenance programs, the availability of high speed communications and computers at maintenance garages and a willingness of the DOT personnel to participate in training and verification activities. Iowa also was surrounded by a dense network of surface observations and did not have complex terrain.

In all, 15 routes and three maintenance garages around Des Moines and Ames Iowa were selected to participate in the demonstration (Figure 6) (MDSS Evaluation Plan, 2003).

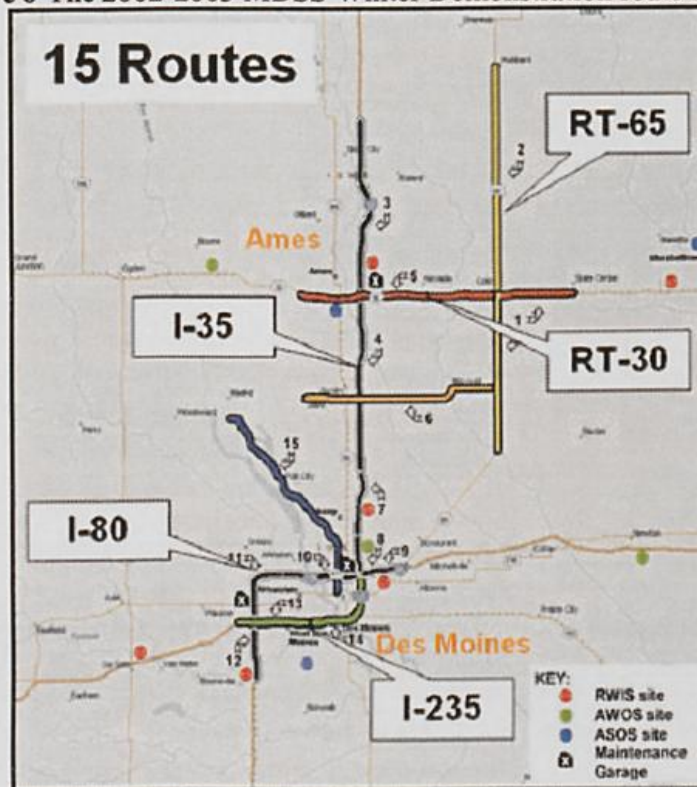
The Des Moines West garage is located just to the west of I-80 and is responsible for portions of I-80 and I-235.

The Des Moines North garage is located near the intersection of I-80, I-35 and I-235. This garage is responsible for the expressways through and north of downtown including secondary roads to the north of the city. The Ames garage is located about 40 miles north of Des Moines near the intersection of I-35 and U.S. 30. The Ames garage is responsible for longer, but less traveled routes through the rural areas of central Iowa.

The colored dots along the roadways represent automated surface observing stations that were either operated by the NWS, the state or the FAA. These stations served as ground truth for forecast initialization and verification.

The demonstration period began on Monday, 3 February 2003 and concluded on Monday, 7 April 2003. During that time, five light snow events (3 inches or less accumulation), three heavy snow events (accumulations of greater than 3 inches) and one mixed rain/snow/ice event occurred.

Figure 6 The 2002-2003 MDSS Winter Demonstration route map



4.1 Summary of Lessons Learned

The following list contains lessons learned or confirmed from the 2002-2003 MDSS field demonstration:

- The MDSS requires highly specific forecasts of precipitation, which is pushing the limits of predictability.
- The rules-of-practice module needs additional development to handle a wider variety of weather and road condition scenarios and treatment responses.
- The availability and quality of observed real-time precipitation rate data are very poor for snow and ice.
- Light snow and intermittent events are critical to DOT operations and are particularly hard to predict.
- The road temperature prediction model needs more development to account for the impact of travel, chemicals, snow compaction, and blowing snow.
- Because weather will not soon be predicted perfectly at road scales, probabilistic products should be developed.
- Just varying the lateral bounds models (Eta, GFS) has little effect on adding dispersion to the ensemble.

5.0 Plans for Demo II – Winter 2004

The FHWA has funded a second field demonstration of the MDSS. It will take place in central Iowa from 29 December 2003 until 19 March 2004 (MDSS Evaluation Plan, 2003).

This second field demonstration will attempt to close gaps found from the first demonstration and to allow for one more full development cycle for the overall software package. The exercise will also generate an entire season's worth of verification data that can be presented to both public and private sector stakeholders for evaluation.

6.0 Technology Transfer

During the course of the MDSS project, the system technologies (software and documentation) have been made available publicly through software releases. Two software releases have been made thus far. Once the second field demonstration is complete, the laboratories will begin to compile new verification statistics and evaluation reports. The FHWA will also continue the process of outreach and technology transfer. In 2004, the focus will be on identifying organizations and public/private partnerships that can assist in the technology transfer process. It is hoped that components of the MDSS will be integrated into the product lines of private companies so that the technology can be used to raise the level of service for all state DOTs.

The sixth meeting of the MDSS stakeholder group will be held in July 2004 in Boulder, Colorado. At this meeting, the laboratories will be holding a workshop to provide a detailed engineering overview of the MDSS and exchange technical information with any company that is interested in exploring the MDSS technology.

In addition, CDs with all of the software and documentation associated with the winter 2004 demonstration (MDSS Release-3) will be distributed to interested parties during the fall of 2004 via the NCAR MDSS web site:

http://www.rap.ucar.edu/projects/rdwx_mdss/index.html

7.0 Summary

The FHWA has been funding and directing a team of national laboratories to create and refine a decision support system for the winter road maintenance community. A demonstration of the MDSS prototype was conducted in central Iowa during the winter of 2003. Reviews from this first demonstration were mixed. The

system showed consistent improvement as the season progressed and a list of lessons learned has been presented. A second demonstration will be conducted during the winter of 2003-2004.

Evaluation of the second demonstration will be presented at a stakeholder meeting in July 2004. Technology transfer activities will include presentations at conferences, an engineering workshop and the establishment of public/private partnerships to assist in bringing core MDSS modules into the marketplace.

Current documentation, progress reports and contact information for prospective stakeholders can be found on the NCAR web site:

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Cost Performance of Pipe Heating System by Thermal Energy in Mountain Tunnel

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1 INTRODUCTION

In order to maintain the safety road condition, traffic in the snowy season needs the facility for snow thawing. Such facility has been serviced in the heavy snowy region of Japan. Traffic accidents due to covering snow on road happen even in warmer regions where it is rarely snow. Drivers in warmer regions don't get used to drive on snowy road, and the facility is not provided as sufficient as the heavy snowy region. Road administrator bureau in such regions has small budget for removing snow on the road. They must manage to maintain the better road condition within the limited budget. Thus, more economical facilities for thawing snow are required in such regions.

Most of traffic accidents in the snowy season happen on the road condition changed from non-snowy road^{1), 2)}. For example, such locations are curves, bridges, tunnel exits and so on. In other words, removing the snow on such location can be appropriate management for winter road. Warmer regions have generally higher thermal energy in natural. When the natural energy is used appropriately, the higher effect for preventing the traffic accident may be obtained with lower cost. Mountain tunnels are generally planned to enable to cross short over pass. Therefore some tunnel exits are located on the high attitude and steep slope, and bridges and sunshades are possibly located at tunnel exits. The traffic accidents often occur at such locations during snowy season in mountain road. On such locations, e.g. bridges near mountain tunnel exit, snow-removing facilities are needed in order to keep the safety traffic condition.

The present study mainly focused on the pipe heating system for applying to tunnel exit. This system has considerably economical advantage when warmer tunnel spring water is used and where sufficient spring water is available. This paper discusses on the cost performance of pipe heating system by natural energy in a tunnel, i.e. initial cost and running cost. Cost-benefit ratios of each facility are also evaluated with assumption of service interval 15 years.

2 TUNNEL FOR COST EVALUATION

Tunnel for cost evaluation in this study is Ushinogou tunnel that reported in the previous research¹⁾. Ushinogou tunnel shown in Fig.1 locates at a central mountain area in the Chugoku region of Japan. The maximum amount of snowfall reaches to 30cm/day, the slip traffic accidents often occur in this area. However, continuous snowfalls over 20cm/day rarely occur in this area, and this is a typical area in west Japan.

The road for snow melting at the tunnel exit is normal road with 2850 m² and a concrete bridge with 650 m². An image of the tunnel and the snow melting area are shown in Fig.2. The normal road has a down slope with 3%. The bridge is a sharply curved bridge with R = 60 m, and has a down slope approximately 6%.



Fig.1 Ushinogou tunnel

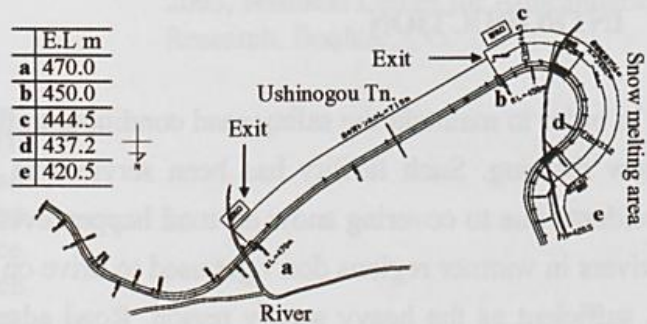


Fig.2 Tunnel exit at Ushinogou tunnel

3 SNOW MELTING SYSTEMS

This paper presents the cost performance of various snow-thawing facilities. The objective facilities in this study are sprinkled water system, electric heating system, borehole heat exchange system and pipe heating system. Each snow thawing system is explained in follows:

3.1. Sprinkled Water System -System 1-

Sprinkled water system is usually employed in the snowy region, where is relatively warm. The equipment cost of this system doesn't require much money than the other system. The employment of this system is limited in the region that has rich groundwater or river water etc.

The river water, which is a little warm in the snowy season, can be employed to this system so that a river locates near Ushinogou tunnel. The aim of present study is to evaluate the cost of this system employing the river water. This system has a possibility of re-freezing of sprinkled water,

and a problem of drainage of thawing water.

3.2. Electric Heating System –System 2-

Electric heating system utilizes electric resisting wire to thaw snow. This system has wide application for various roads so that it can melt snow on the road conditions, e.g. steep slope. The running cost of this system, however, generally tends to be higher than the running cost of the other systems. In addition, the maintenance work is costly for inspection and repair.

3.3. Borehole Heat Exchange System –System 3-

Borehole heat exchange system (BHES) is illustrated in Fig.3. This system works by the thermal energy of ground under approximately 100 meters. The thermal energy of deep-ground is exchanged to the heat energy for snow melting. The borehole consists of twofold pipe; heating liquid in the pipe is usually employed non-freezing agent. This system requires relatively large number of boreholes for snow melting area and the initial cost tends to become higher.



Fig.3 Borehole heat exchange system³⁾

3.4. Pipe Heating System A –System 4-

This system consists of heating pipe by using groundwater such as tunnel spring water. The temperature of the groundwater, however, may not sufficiently melt snow on such wide road. The groundwater is possibly heated with a boiler in order to obtain the sufficient temperature. The water for snow melting circulates to the upper stream in the heating pipe. Concept of the

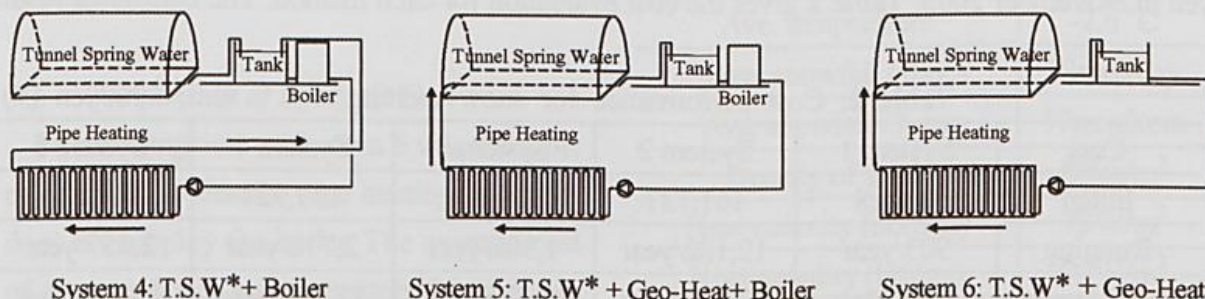


Fig.4 Concept of pipe heating system (*Tunnel Spring Water)

pipe-heating system is summarized in Fig.4.

3.5. Pipe Heating System B –System 5-

The pipe heating system B is a system that geothermal energy around the tunnel is used for heating method of circulation water. This method can decrease the running cost for boiler heating. The circulation water is flowed to the opposite exit of tunnel for snow melting and the water temperature rises through the center-drainage along the tunnel¹⁾.

3.6. Pipe Heating System C –System 6-

This system does not use boiler for heating water, and dependent on only the natural energy of the tunnel, that is groundwater and geothermal energy. Such natural energy, however, insufficiently heats the water up to the temperature of snow melting on the road. This system probably becomes an effective system for control of anti-freezing. The present study employed this system only for cost evaluation of designing anti-freezing.

4 EVALUATION OF COST FOR SNOW MELTING

4.1. Conditions for Evaluation

The cost performance for snow melting was evaluated for Systems 1 to 5 in this section. The design conditions for snow melting in Ushinogou tunnel are given in Table 1. The average atmospheric temperature and quantity of snowfall is based on the statistics during 10 years at this location.

Table 1. Design conditions for snow melting

Ave. temperature	-2.6 °C
Ave. snowfall / day	73mm/day
Ave. snowfall / hour	17mm/hour
Density of snow	80kg/m ³
Heat quantity (normal)	161W/m ²
Heat quantity (bridge)	210W/m ²

4.2. Comparison of Initial Cost

The cost evaluation in this study is based on Japanese yen, and 1 US dollar is equivalent to 110 yen in November 2003. Table 2 gives the cost evaluation for each method. The calculated results

Table 2. Cost performance for snow melting unit; 1000yen (¥)

Cost	System 1	System 2	System 3	System 4	System 5
Initial	40,128	161,737	627,164	189,324	201,214
Running	903/year	12,182/year	1,307/year	2,778/year	2,057/year
Ave.15years	3,578/year	22,964/year	43,118/year	15,400/year	15,471/year
Ratio	0.231	1.484	2.787	0.995	1.000

1 US\$ = 110 yen in Nov./2003

indicate that sprinkled water system is the most economical. The initial cost of BHES is over 15 times higher than that of sprinkled water system, and it is the most expensive method. Pipe heating systems with tunnel spring water had almost equal cost for equipments; they were slightly higher than the initial cost of the electric heating system.

4.3. Comparison of Lifecycle Cost

Life of concrete pavement is dependent on cracking or abrasion, it is generally 10 ~ 20 years in Japan. The lives of each snow melting system are assumed as 15 years in the present study. The calculation for average cost of initial cost and running cost in 15 years is given in **Table 2**. **Table 2** gives the ratios of lifecycle cost when System 5 is designated as 1.0.

Table 2 represents that the sprinkled water system is the most economical method. This method is considered as the most rational method when the water on road surface is not re-iced. The running cost of electric heating system is calculated as ¥12,182*10³/year, which is the most expensive method. BHES, which is the most expensive in the initial costs, has the lowest running cost except for sprinkled water system. Pipe heating system with natural energy needs the running cost of ¥2000~2800*10³/year, which are slightly higher than the cost of BHES.

5 EVALUATION OF COST FOR ANTI-FREEZING

5.1. Conditions for Evaluation

The cost for anti-freezing was evaluated for pipe heating systems with natural energy, i.e. Systems 4 to 6. The design conditions for anti-freezing are given in **Table 3**. Fundamental conditions are common in all the systems for snow melting except for heat quantity.

5.2. Comparison of Initial Cost

Table 4 gives the results of cost evaluation for each method. Systems 4 and 5, which requires boiler, has almost equal cost for equipment. System 6, which does not require the artificial heating facility, has the lowest initial cost in 3 methods.

5.3. Comparison of Lifecycle Cost

The running cost of System 6 was the most economical so that the pipe heating system C does not employ the boiler. The average cost of System 6 was approximately 20 % lower than the other methods when the life span is assumed as 15 years. This system can be an effective method for anti-freezing when sprinkled

Table 3. Design conditions for snow melting

Ave. temperature	-2.6 °C
Ave. snowfall / day	73mm/day
Ave. snowfall / hour	17mm/hour
Density of snow	80kg/m ³
Heat quantity (normal)	72W/m ²
Heat quantity (bridge)	94W/m ²

water system cannot be employed from some reasons.

6 CONCLUSIONS

This paper presents an example of cost

performance of various snow-melting systems for a tunnel exit on mountain roads. Especially, the present study assumes that some of systems need natural energy for reduction in cost. The conclusions of this paper are listed as follows.

- 1) Sprinkled water system is the most economical in initial cost and running cost.
- 2) Electric heating system has relatively the lower cost at initial stage, and the running cost tends to be extremely higher than the other method.
- 3) BHES with natural energy in the deep ground is effective in running cost, however it requires higher initial cost.
- 4) Pipe heating system with natural energy from tunnel spring water or geothermal heat has higher economically than the other road heating system.

ACKNOWLEDGEMENT

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- 3) <http://www.ecomisawa.com>

Table 4. Cost performance for anti-freezing unit; 1000yen (¥)

Cost	System 4	System 5	System 6
Initial	174,534	175,114	152,064
Running	1,794/year	1,349/year	722/year
Ave.15years	13,430/year	13,023/year	10,860/year
Ratio	1.031	1.000	0.834

1 US\$ = 110 yen in Nov./2003

A Simulation Tool for the Hydronic Bridge Snow Melting System

Xiaobing Liu Jeffrey D. Spitler¹

ABSTRACT

The design of hydronic heating systems for bridge snow melting requires assessment of long-term performance under expected future weather conditions, especially when geothermal energy is used as the heat source. This is important to be able to predict the snow melting performance, analyze the economics, and investigate the effects of controls and design parameters on the system performance. A simulation tool for modeling hydronic bridge snow melting systems using ground source heat pumps (GSHP) or other heat sources has been developed to facilitate the design. In this paper, a numerical model of the hydronically-heated bridge deck and the experimental validation results of the model predictions are described. In addition, the structure and features of the simulation tool are presented. As an application of the simulation tool, the ASHRAE guidance for required surface heat fluxes for snow melting is evaluated with a simulation-based parametric study.

INTRODUCTION

Melting snow with a hydronic heating system can eliminate the need for snow removal by chemical or mechanical means and provide greater safety for pedestrians and vehicles. As a result, a large number of snow melting systems have been installed, including sidewalks, roadways, ramps, bridges, runways and parking spaces for the handicapped. Hydronic heating systems circulate a heated fluid through a pipe network embedded in the slab to melt snow and ice on the surface of the slab. The pipe network consists of number of circuits, which are usually laid in a serpentine configuration. The pipe material is usually either cross-linked or high-density polyethylene. Typical pipe spacing ranges from 150 to 300mm at a depth of 50 to 75mm. Nominal pipe diameters are commonly 18 to 25 mm. A variety of fluids, including brine, oils, and glycol-water, are suitable as heat carrier fluids in hydronic heating systems. Freeze protection is essential since most systems will be operated intermittently in subfreezing weather. A number of heat sources can be used for such systems, including boilers, electrical heater, ground water, and ground source heat pump.

Design of hydronic snow melting systems is a topic of current and recent research. Current guidance in the ASHRAE handbook (ASHRAE 2003) for required surface heat fluxes is based on a one-dimensional steady-state heat balance (Ramsey, et al. 1999) of the snow-melting surface. This approach is limited by the fact that real systems are almost never operated continuously through the winter, nor do weather conditions remain constant. Accordingly, the large thermal mass of the bridge deck requires that transient performance be considered. In addition, two-dimensional effects, such as pipe spacing and depth, are clearly important, but neglected by the procedure. Furthermore, the required heat fluxes were all computed assuming that there would be no contribution from solar radiation. This is a conservative approximation but its effect is not well understood. Given the transient, two-dimensional and solar effects, it is unclear how an actual snow melting system performance might compare to the ASHRAE guidance.

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The design will be more complicated if a GSHP system is used as the heat source. This is due to the need to consider the long-term changes in performance of the ground heat exchangers. It is usually necessary to model the performance of the ground heat exchangers over a period of as long as 25 years in order to ensure an adequate design. It is accordingly necessary to consider, not static design conditions, but the time varying nature of heating loads over these periods. Proper consideration of these complexities requires some reliance on system simulation in the design process.

This paper describes a numerical model of the hydronically-heated bridge deck and the experimental validation results of the model predictions. In addition, the structure and features of a simulation tool of the hydronic bridge snow melting system using ground source heat pump (GSHP) or other heat sources are presented. As an application of the simulation tool, the ASHRAE guidance for required surface heat fluxes for snow melting is evaluated with a simulation-based parametric study.

MODELING SNOW MELTING ON A HYDRONICALLY-HEATED SLAB

The process of melting snow on a hydronically-heated bridge deck is complex. Heat transfer mechanisms involved in the snow melting process include the phase change of water (melting and evaporation), solar radiation, thermal radiation, convective heat transfer on the surface, and the conductive heat transfer from the pavement slab. Furthermore, snow is a porous material composed of ice crystals and air, and its melting is characterized by the permeation of melted water due to capillary action. Depending on the water permeation through the porous structure of snow and the refreezing of permeating water, the snow can be fully saturated with water, which is usually called slush; or retain its air-filled porous structure, which is recognized as dry snow. While dry snow can significantly reduce the heat loss from the surface, the slush has little "insulating effect". Due to the variation of weather conditions and the discrete layout of the embedded pipes, the surface conditions can vary both temporally and spatially. Different surface conditions are associated with different heat transfer mechanisms. Figure 1 shows a cross-section view of the pavement slab while snow is melting on it.

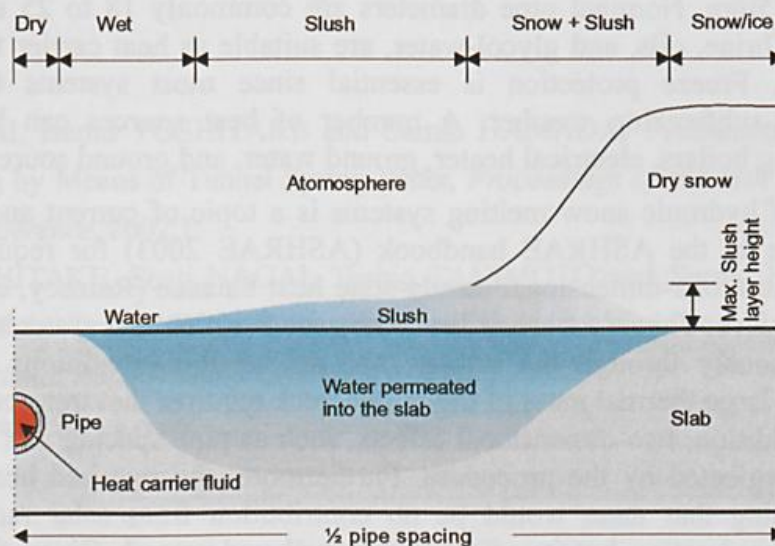


FIGURE 1 Variation of surface conditions in snow melting – a cross-section view of the slab while snow is melting on it.

A number of models for snow melting on hydronically-heated slabs have been previously presented. However, previously developed models are unsuitable for facilitating the design in that they are: steady-state, and therefore incapable of modeling transient effects

(Schnurr and Rogers 1970; Kilkis 1994); or incapable of accounting for snow accumulation (Leal and Miller 197; Schnurr and Falk 1973), or did not account for the insulating effects of the snow (Chiasson, et al. 2000), or too detailed and requiring an infeasible amount of computational effort for multi-year hourly or sub-hourly simulations (Rees et al. 2002).

The model adopted in the simulation tool is developed from an existing model (Chiasson, et al. 2000). While the transient conduction heat transfer in the slab is still modeled using the two-dimensional finite difference method, the modeling of the snow melting process occurring on the surface has been significantly revised. The mass of snow is tracked along with the surface temperature at each surface node. Thus, the condition at each surface node can be identified and the distribution of snow/ice and slush over the surface can be predicted. The coupling between the surface heat balance and the conduction heat transfer in the slab is processed with a modified "time marching" method to deal with the phase change of water involved in the snow melting process. In addition, an improved model for calculating the equivalent sky temperature (Brown 1997) is employed in the model to calculate the radiative heat loss from the slab surface to the sky. This model may also be useful for modeling electric resistance heating systems and predicting the road surface temperature. Detailed description of this model is given in the paper of Liu and Spittler (2004).

EXPERIMENTAL VALIDATION

Individual component models and system simulation of a GSHP based hydronic bridge snow melting system have been validated with experimental data. The experimental facility consists of an 18.2 m x 6.1 m bridge deck with a 9.1 m x 6.1 m area hydronically heated by a GSHP system. The facility and data collection procedures were reported in a previously published paper (Liu, et al. 2003). In the previous work, surface condition measurements were not available to validate model predictions of the ratio of the snow-free surface area to the total surface area. In this paper, the comparison between the predicted and actual variation of the snow free area ratio (SFAR) will be presented. The actual SFAR is estimated from images of the bridge surface, which was taken and recorded with a digital camera at 30-minute intervals. A completely snow-free surface leads to a snow free area ratio of 1; a completely snow covered surface leads a ratio of zero; and "striping" leads to intermediate values.

The event selected for validation occurred in Stillwater, Oklahoma on December 23, 2002. It started with rainfall at about 6:00 in the morning; the rainfall changed to snow around 9:00 am and the snowfall ceased at about 4:30 pm. The total amount of precipitation in equivalent water was 29 mm during the whole event. In this event, the heating system was activated 1 hour after the snowfall began because of a problem with the automatic control system. Although unintentional, it provided a good scenario for validating the simulation performance.

As can be seen in Figure 2, SFAR falls to zero at the beginning of snowfall, and then rises to one as the system heats the bridge; the predicted snow free area ratios satisfactorily match the actual surface conditions. Measured and predicted bridge average surface temperatures during the heating operation are also compared in the same figure. As illustrated in Figure 2, the surface temperature dropped immediately after snowfall began at 9:00 am and stayed at about 0.7 °C until the heating system was started at 10:00 am. From then on, the bridge surface temperature began to increase continuously. At about 1:00 pm, snow on some areas of the bridge surface was completely melted and "stripes" began to appear (SFAR > 0). Since heat flux required for snow melting is reduced, the speed of the temperature rise increased significantly. Good agreement between measured and predicted values of the

average bridge surface temperatures is observed before the snow free area ratio reaches 1; after that, the predicted surface temperatures deviate further from the measured values. This may be partially due to the variation of the thermal properties of the concrete, as it is saturated with water and gradually dries out following the snow melting process, and partially due to snow drifting from the unheated portion to the heated portion of the bridge. These phenomena can either reduce the heat conducted to the surface or introduce additional heat fluxes for snow melting and water evaporation on the surface and thus decrease the average surface temperature.

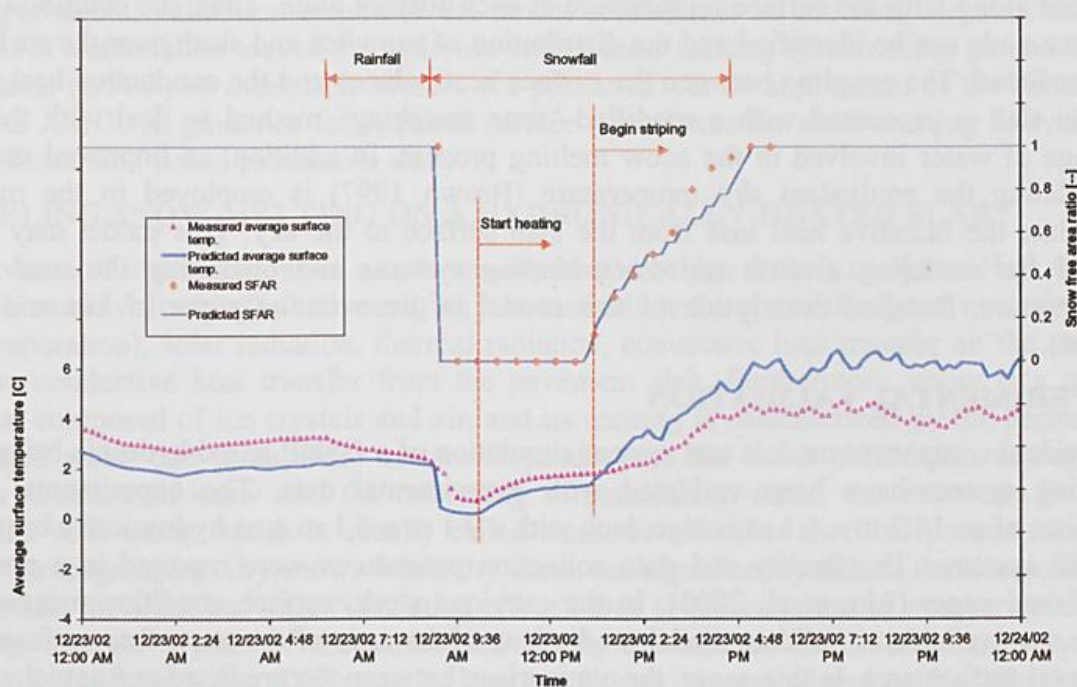


FIGURE 2 Comparison between measured and predicted bridge average surface temperature and snow free area ratio.

STRUCTURE OF SIMULATION TOOL

The simulation tool consists of a collection of component models of the hydronic bridge snow melting system, a system simulation tool, HVACSIM+ (Clark 1985), and utility programs to generate required input files of the simulation and to analyze the simulation results. Table 1 categorizes the currently available component models. A parameter-estimation-based model developed by Jin and Spitler (2002, 2003) is used for the water-to-water heat pump. The various parameters of the model are estimated from the manufacturers' catalog data by applying a multi-variable optimization algorithm. The model for the vertical ground loop heat exchanger (VGLHE) was developed by Yavuzturk and Spitler (1999), which extends the g-function method proposed by Eskilson (1987) and thus is able to predict both the short and long term performances of a field of VGLHE.

TABLE 1 List of Component Models

Heating Element	Heat Source	Controller	Accessories
Hydronically-heated bridge pavement	Water-to-water heat pump	Linear proportional control	Circulating pump
	Vertical ground loop heat exchanger	On-off control with dead band	Conduit
	Electric heater		Valve

Boiler

The simulation is implemented with a graphical interface (Varanasi 2002) for HVACSIM+(Clark 1985), which is a public domain dynamic simulation program developed at the National Institute of Standards and Technology (NIST). This simulation program employs a hierarchical, modular approach that allows the component models to be connected together in a flexible way (and also facilitates investigation of novel system configurations). In the system simulation, the mass flow rates of the heat carrier fluid can either be treated as constants or solved explicitly. To explicitly solve the mass flow rates, the flow-pressure problem of the fluid network and the thermal problem of the system may be solved subsequently at each simulation time step. Thus, the variation of mass flow rates resulting from the changes of the fluid viscosity can be accounted. However, it increases the complexity and computational time requirements of the simulation.

Weather data required in the system simulation include: ambient temperature, effective sky temperature, humidity ratio of air, wind speed, wind direction, solar radiation, solar angle, snowfall rate, and rainfall rate. A utility program has been developed to convert weather data from various sources, including SAMSON (NCDC 1993), Oklahoma Mesonet (Elliot et al. 1994), and NVDS (2002), to the boundary condition file required by the simulation. The g-function data used in the VGLHE model and the parameters of the water-to-water heat pump model are generated separately with special utility programs prior to the simulation.

APPLICATION OF THE SIMULATION TOOL

As an application of the simulation tool, a preliminary evaluation of the ASHRAE guidance for required surface heat fluxes for snow melting is conducted by a simulation-based parametric study. Current guidance in the ASHRAE handbook (HOA 2003) for required surface heat fluxes is based on a one-dimensional steady-state heat balance (Ramsey et al. 1999) of the snow-melting surface. For 46 North American locations, the required heat flux to maintain a specified snow free area ratio for a statistically-determined percentage of hours with snow fall has been tabulated. Required heat fluxes are given for snow free area ratios of 0, 0.5, and 1, and for percentage-of-snowfall-hours-not-exceeded of 75%, 90%, 95%, 98%, 99% and 100%. For intermittently operated systems, these heat fluxes would be correct only for systems that could instantaneously transmit their heating capacity to the road surface. However, it is desirable to estimate the percentages for transient operation with the tabulated heat flux capacities, and the use of the simulation tool to do so is described in this section.

A simple hydronic snow melting system is simulated. This system consists of a hydronically-heated slab, a circulating pump, a heater and a controller. The parameters of the hydronically-heated slab are intended to be typical for a heated bridge deck application and are summarized in Table 2. The heater, when operating, provides a constant heat input to the slab. The heat provided by the heater is specified to be the multiple of the heated area and the tabulated ASHRAE surface heat fluxes. To provide the specified heat input, the fluid temperature will rise to the necessary level although this may sometimes result in unfeasibly high fluid temperatures. Since the purpose of this simulation is to evaluate the surface heat flux, neither thermal mass nor transport delay is considered in the heater model. The controller is assumed to be perfect – it will turn on the heating system a certain number of hours in advance of the snowfall, and will turn it off at the end of the snowfall. This number of hours is referred to as the idling time. This perfect control is accomplished by looking ahead in the weather file.

Since the weather conditions associated with snow events vary widely, it is desired to investigate the snow melting performance with a number of years of weather data in order to draw more reliable conclusions on the effect of transient weather/operation conditions on the snow melting performance. We have chosen ten different North American locations to represent a range of climates: Spokane, Reno, SLC, Colorado Springs, Chicago, OKC, Minneapolis, Buffalo, Boston and Philadelphia. SAMSON data from 1981-1990 for each of the locations were used in the simulations. The computational time for each 10-year hourly simulation is around 40 minutes on a Pentium 4, 2.8G HZ personal computer.

TABLE 2 Parameters of the Hydronically-Heated Slab

Parameter Name	Parameter Value
Slab Thickness	203 mm
Slab Thermal Conductivity	1.4 W/m.K
Slab Volumetric Heat Capacity	2200 kJ/m ³ .C
Slab Surface Solar Absorptance	0.6
Pipe Spacing	152 mm
Pipe Depth Below Surface	76 mm
Pipe Diameter	25mm
Pipe Wall Thickness	2 mm
Pipe Wall Thermal Conductivity	0.39 W/m.K
Bottom Insulation	Adiabatic
Heat Carrier Fluid	Propylene Glycol (42% concentration by mass)

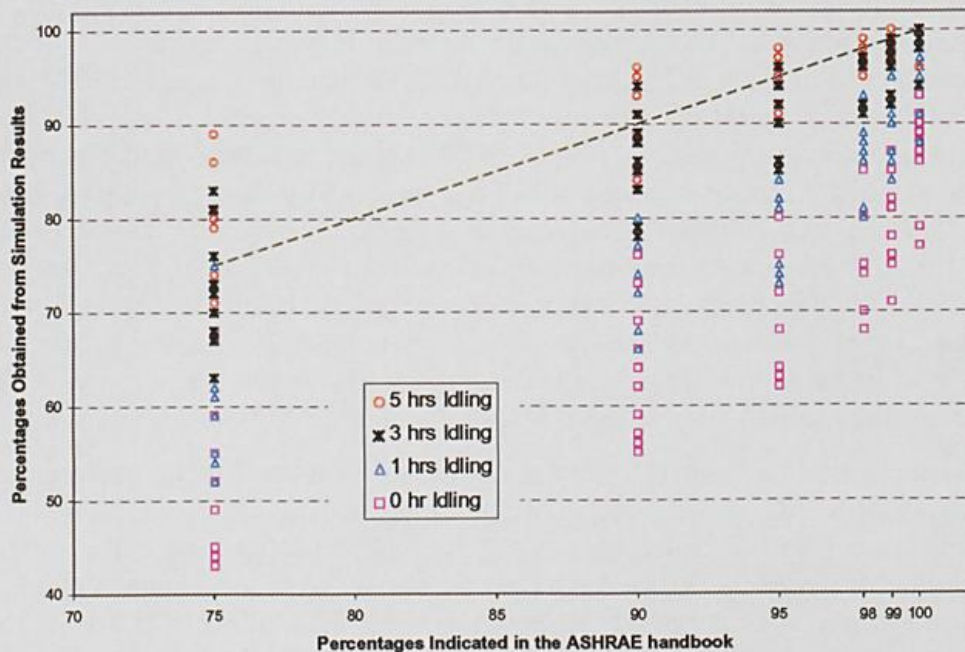


FIGURE 3 Comparison of snow melting performance between predictions of the 2-D transient simulation and those indicated in ASHRAE handbook

The predicted snow melting performance is shown in Figure 3. The horizontal axis represents the percentage of snowfall hours where the surface would be snow free, based on the tabulated ASHRAE surface heat flux values, which vary with location. The vertical axis represents the percentage of snowfall hours where the surface would be snow free, based on transient simulation results of the systems with heating capacity corresponding to the ASHRAE surface heat flux. The diagonal line represents a one-to-one match between the

performance of the system calculated with the transient simulation and the performance calculated based on a steady state heat balance. A point on this line would represent a case where the actual performance is as good as that predicted with the ASHRAE steady state heat balance analysis. In the plot, different symbols refers to cases with different idling times; individual data points with same symbol show the system performance at different locations.

As expected, the performance increases increasing idling times. For zero hours idling, i.e. the system is turned on when snowfall starts, the performance for all locations falls substantially below that predicted with a steady state heat balance. For most locations, approximately 5 hours of idling will give system performance similar to that expected from the steady state heat balance. However, it may be noted that a few data points show good performance for even one hour of idling, and performance exceeding that expected from the steady state heat balance with three hours of idling. These data points correspond to Reno and Salt Lake City where the average dry bulb temperature coincident with snowfall is comparatively high.

The simulations results illustrate that, for the system investigated in this parametric study, preheating the slab 3-5 hours before snowfall with the full heating capacity obtained from the ASHRAE surface heat flux requirement is necessary to achieve the desired snow melting performance. Such operation is considerably more energy efficient than the continuous idling operation described in the ASHRAE Handbook, which is to maintain the slab surface temperature at 0.6 °C by supplying heat to the slab anytime the ambient temperature is below 0°C and it is not snowing. Therefore, forecasting-based control systems should be utilized in the hydronic snow melting systems.

CONCLUSIONS AND RECOMMENDATIONS

The dynamic nature of the hydronic bridge snow melting systems requires that the long-term seasonal performance be assessed in their design. This design exercise can most conveniently be undertaken by the application of simulation methods.

A numerical model for the snow-melting process occurring on a hydronically-heated surface has been developed. Various surface conditions encountered during the snow melting process have been identified and modeled with a simplified approach to achieve a balance between model accuracy and computational time requirement. Experimental validation results have shown that the model is able to predict bridge deck surface temperature and SFAR sufficiently accurate for the purposes of system design and performance analysis.

A simulation tool for the hydronic bridge snow melting systems has been developed. It consists of component models, the modular simulation environment HVACSIM+, a graphical user interface, and associated utility programs. The simulation tool allows the convenient analysis of hydronic bridge snow melting systems with various configurations.

The simulation tool has been used to evaluate the performance, under realistic transient operating conditions, of snow melting systems designed with the heat fluxes given in the ASHRAE handbook. Simulation results demonstrate that the heating capacity calculated directly from the tabulated ASHRAE surface heat fluxes is not enough to achieve the expected snow-melting performance without idling, even if the heat loss from back and edges of the slab are eliminated. However, idling the system in advance of the snow event can significantly improve the snow melting performance. It is more energy efficient compared with the continuous idling operation described in the ASHRAE Handbook. Therefore, forecasting-based control systems should be utilized in the hydronic snow melting systems.

To achieve an economically feasible and technically reliable hydronic bridge snow melting system, a systematic design procedure and proper optimization algorithm are recommended for future development of the simulation tool.

ACKNOWLEDGEMENTS

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Influence of Heating Pipe on Snow Melting and Mechanical Properties

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1. INTRODUCTION

The region of west Japan has relatively warmer climate in winter and it rarely has continuous snowfalls over 20cm/day. Even in such warmer region, slip traffic accidents often occur due to a sudden change of road condition, especially on the bridge and tunnel-exit.

Pipe heating system is an example of the snow-removing facility. This system has an economical advantage when natural energy is used. It is relatively easy to obtain the natural energy from warmer spring water and geothermal heat. When such energy is used appropriately for the pipe heating system, the traffic accident can be reduced at lower cost.

The authors had reported the fundamental data for designing of pipe heating system by natural energy¹⁾⁻³⁾. The purpose of this study is to provide the fundamental data for the rational design of the pipe heating system. This paper presents the experimental results on snow melting and mechanical properties. The snow-melting test was carried out to investigate the pipe arrangements, and loading tests were conducted in order to study the strength of the concrete with pipes.

2. ROLE OF PIPE FOR SNOW-MELTING

2.1. Objective of Snow-Melting Test

There are several parameters in rational design of the pipe heating system. The most important parameters are embedded pipe arrangement and running water temperature. However, little is known about the relation between snow melting and these parameters. This section provides the effect of the pipe spacing for the snow melting.

2.2. Specimen for Snow Melting Test

The specimens for pipe heating are detailed in **Fig.1**. The size of specimen is 600*500*200mm of width, length and thickness, respectively. Copper pipes were embedded with spaces of 100mm, 200mm and 300mm, and thermocouples for temperature measurement were arranged as shown in

Fig.2. The embedded pipes had an internal diameter of 15mm and an external diameter of 18mm. The cover of pipes was provided as 80mm. This cover was determined from the thickness of the concrete pavement thickness (50mm) and the protective cover (30mm) not to damage the pipe at pavement repair.

Table 1 gives the mix proportion of concrete. Concrete materials were mixed with the ordinary Portland cement with a density of 3.15 g/cm³, sea-sand with a density of 2.60 g/cm³ and crushed andesite rocks with a density of 2.72 g/cm³ respectively.

2.3. Experimental Program

The snow melting tests were carried out in the testing freezer that can control the room temperature with an error of 0.5°C in error. In order to maintain the specimen and room at a constant temperature, the specimen was put in the freezer in the day before the experiment. The specimens were located on the stage to simulate the weather in the room to the actual bridge. In this experiment, the snow of 50mm thickness was directly mounted on the surface of specimen.

Fig.3 shows the flow in testing system of snow melting. Hot water, temperature of which was controlled by heater in the outside water tank, was flow in the embedded pipe by pressure.

The amount of water is determined as 327cm³/sec, which results in the velocity of 138cm/sec. The snow height was measured every hour, and the temperature data from the embedded thermocouples was recorded every ten minutes.

2.4. Experimental Results and Discussion

Some temperature distributions in specimens are shown in **Fig.4**. Narrower space such as specimen1 supplies uniform heat to the specimen surface. On the contrary, a temperature contour line of 5°C in specimen3 with a pipe spacing of 300mm was narrower, and the internal temperature was significantly influenced by the outside temperature.

Fig.5 shows that the height of snow on the specimen under a condition of the outside

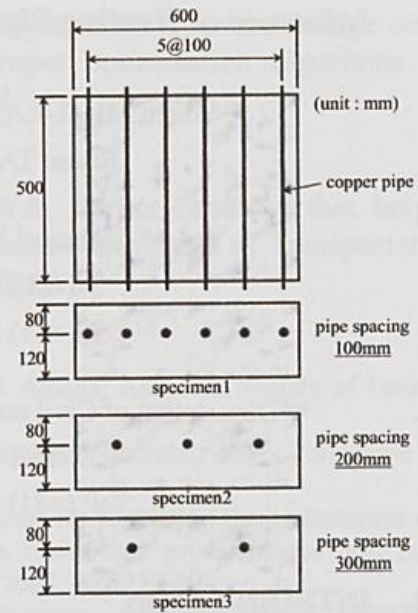


Fig.1 Specimen for pipe heating

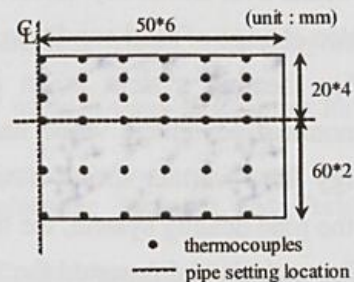


Fig.2 Embedded thermocouples

Table 1 Mix Proportion

Water-Cement Ratio	54 %
Sand percentage	45 %
Water	162 kg/m ³
Cement	300 kg/m ³
Fine Aggregate	811 kg/m ³
Coarse Aggregate	1048 kg/m ³
Admixture	0.6 l/m ³

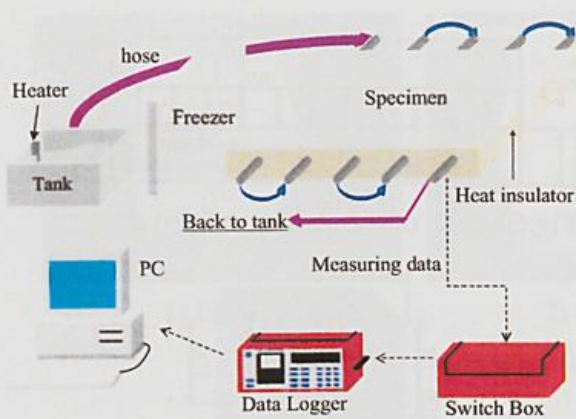


Fig.3 Flow of snow melting test in laboratory

temperature of 0°C and the water temperature of 30°C. The narrower pipe spacing could melt the snow uniformly. On the other hand, the snow melted well only above the embedded pipe for the specimen with wider pipe spacing. In actual traffic on the bridge, the traffic activity prevents the snow on road from bumping. To exposure 50% of the road surface can be regarded as sufficient for prevention of the traffic accidents⁴). The snow on specimen3 was melted approximately 50% after 6 hours.

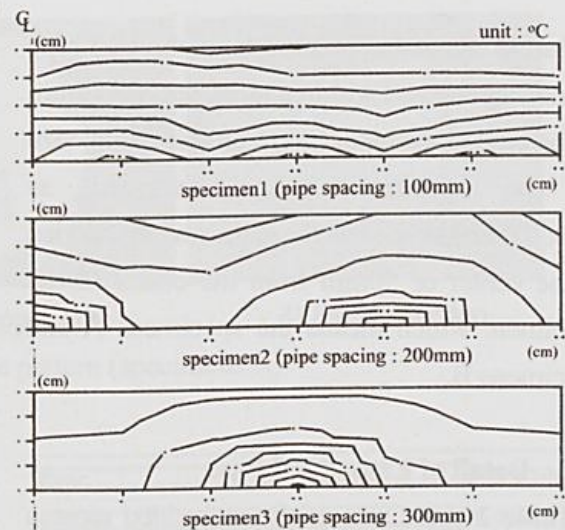
3. INFLUENCE OF THE EMBEDDED PIPE IN CONCRETE

3.1. Objective of Loading Test

Previous studies on the pipe heating mainly focused on the effective utilization of heat energy. Few studies had dealt with the mechanical durability of pipe heating slab. Embedded pipes in concrete possibly become a structural defect of concrete slab. This section presents the failure pattern and compressive strength of rectangular specimens with pipes.

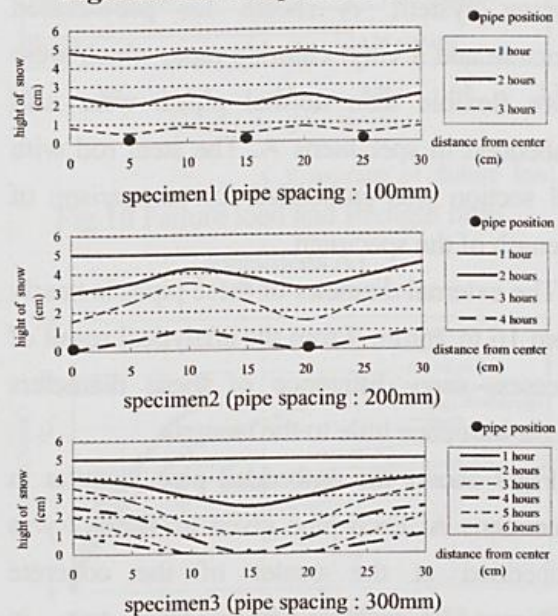
3.2. Specimen for Loading Test

In order to determine to the specimen size, stresses were obtained around the embedded pipe, which was calculated by 2 dimensional FEM. Analytical conditions are illustrated in Fig.6.



Outside temperature: 0°C
Temperature of water: 20°C

Fig.4 Internal temperature condition



Outside temperature: 0°C
Temperature of running water: 30°C

Fig.5 Height of remaining snow

As the calculated results, the embedded pipe influences stresses within a range around 15mm of the embedded pipe. Based on this result, size of the specimen was determined as 200x200x200mm, and the pipe was embedded at the center or 50mm from the center of the specimen, which means the specimens A and specimens B.

3.3. Detail of Embedded Pipe

Table 2 gives size of the embedded pipe in the experiment of strength test. A steel pipe and a copper pipe are generally used for pipe heating system. A sheath for pre-stressed concrete and a vinyl chloride pipe, which were more flexible than normal pipes, were also embedded in specimens A. The steel rod with full section was embedded for comparison of strength of the specimen.

The external diameter of these pipes is nearly from 16 to 26mm. From the analytical result of stresses, such difference of these diameters might influence little to the strength.

Fig.7 shows the embedded pipe location in specimens A. Each pipe given in Table 2 was embedded at the center of the concrete specimen. Compressive loading test in specimens A was conducted in order to investigate the failure pattern. Compressive loading test were conducted to specimens B with various pipe locations shown in Fig.8. The pipe was a steel pipe in specimens B. For the comparison, the loading test was carried out with the plain concrete specimen without the embedded pipe.

3.4. Loading Method

Fig.9 illustrates the compressive loading test. In order to decrease the friction of edge side, a rubber plate was set between the specimen and the loading plate. Strains of

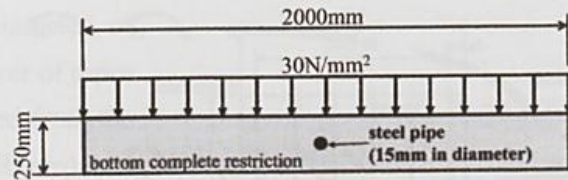


Fig.6 Model of the stress condition analysis

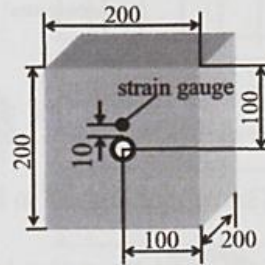


Fig.7 Embedded pipe location (specimens A)

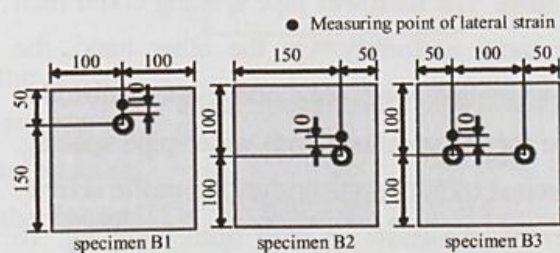


Fig.8 Pipe embedded location (specimens B)

Table 2 Size of embedded pipe (unit : mm)

Sort	External diameter	Internal diameter	Thickness
Steel pipe	21.8	16.0	2.9
Copper pipe	16.0	14.0	1.0
PC Sheath	24.5	23.0	0.8
Vinyl chloride pipe	26.0	19.8	3.1
Steel rod	17.0	---	---

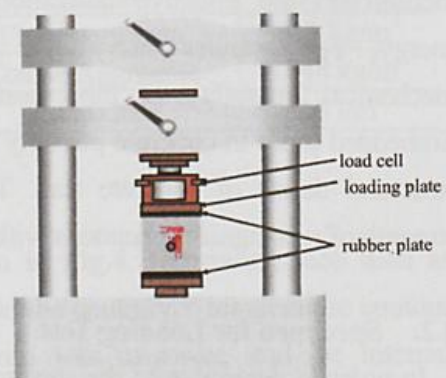


Fig.9 Compressive loading test



1) Plain

2) Copper pipe

3) Failure section

Picture 1 Failure pattern (specimens A)

concrete near the embedded pipe were measured by every load of 20kN.

3.5. Experimental Results and Discussions

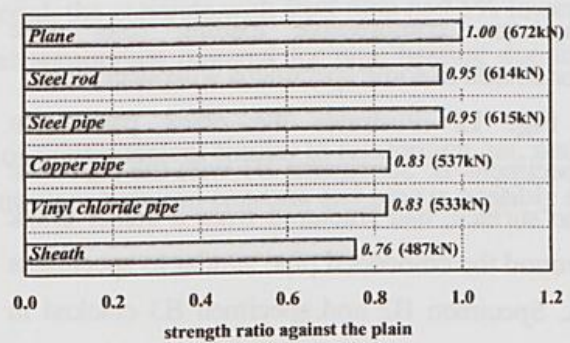
3.5.1. Specimens A

Failure pattern of the plain concrete specimen and the specimen with copper pipe in specimens A is shown in **Picture 1**. All specimens in specimens A were cracked at the center due to splitting brittle failure. The embedded pipes were hardly damaged as shown in **3)** of **Picture 1**.

Fig. 10 shows the strength ratios against the plain concrete specimen without embedment in specimens A. This figure represents the average failure load of three specimens. The failure load was range from 468 to 698kN, and the strength of plain concrete was the highest in specimens A. On the contrary, the failure load of specimens with a sheath was the lowest. The strength ratio of specimen with a steel rod was also 5% lower than the strength of plain concrete. The strength ratio of the specimen with any pipe was within 95 to 75% to the strength of plain.

The lateral strain above the embedded pipe is presented in **Fig.11**. The lateral strains of the plain specimen or the specimen with steel rod had no sudden change. On the other hand, the specimens with some pipe had the sudden change, which obviously increasing the lateral strain. Such sudden change was occurred due to the local cracks.

The failure load of specimen with a steel pipe is higher than the specimen with the other



(): average of failure load

Fig.10 Failure load and strength ratio (specimens A)

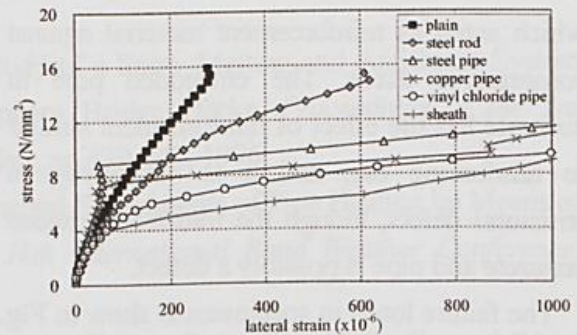


Fig.11 lateral strain above the pipe (specimens A)

embedded pipe, and it has lower strength by only 5% than the strength of plain concrete. Based on these results and previous results on snow melting test^(2),5), steel pipe can be regarded as an appropriate material for pipe heating.

3.5.2. Specimens B

In order to investigate the failure pattern and loads at failure of specimens with various pipe locations, compressive loading tests were conducted to some specimens with steel pipe.

Fig. 12 illustrates the crack pattern in specimens B. Specimens B1 with the pipe near the surface, had fractured from a center crack around the embedded pipe similar to specimens A. Specimen B2 and specimen B3 cracked in various ways, that is, cracked around the pipe or other location.

One of reasons was resulted from higher stiffness of steel pipe than other specimen, which acted as reinforcement material against compressive stress. The embedded pipe in concrete has the effect of reinforcement similar to reinforcing bar, and it is not always a structural defect, though the interface between concrete and pipe is possibly a defect.

The failure loads in specimens B show in Fig. 13. Some specimens had the strength more than the maximum load of the plain concrete, while the strength of the plain concrete was the highest in specimens A. Especially, the maximum load of specimens with two embedded pipes, whose location was rather less stress concentration, was approximately 10-25% higher than the strength of plain concrete.

The lateral strains above the embedded pipe in specimens B were presented in Fig. 14. Though the sudden change of the lateral strain in specimen B1 and specimens A occurred at almost the same load, the stress at sudden change of specimen B2 was higher. Little lateral strains due to cracking was measured in specimen B3 and lateral strains became in compression before the cracking. The embedded pipe has two characteristics as roles of reinforcement and structural defects for the stress concentration.

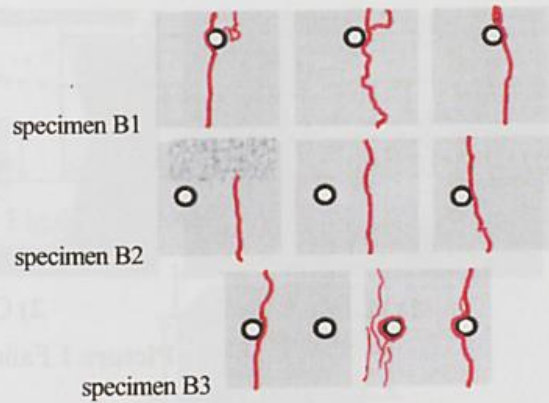


Fig.12 Crack pattern (specimens B)

Table3 Load at failure (specimens B)

specimen B1	600 kN	603 kN	605 kN
specimen B2	623 kN	624 kN	703 kN
	720 kN	723 kN	740 kN
specimen B3	805 kN	733 kN	---

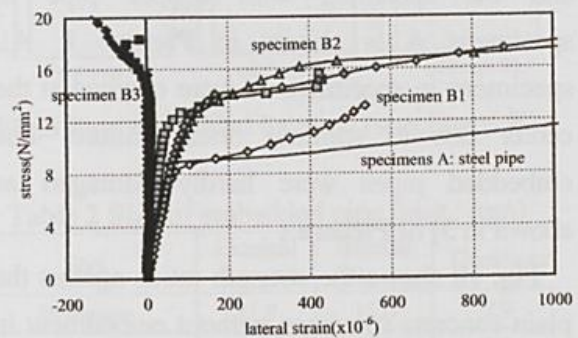


Fig.14 Lateral strain above the pipe (specimens B)

4. CONCLUSIONS

This paper presented the fundamental data for rational design of pipe heating system in the pavement. Especially, the present study focused the snow melting ability in the various pipe spacing and the failure conditions in various pipe arrangements. The conclusions of this study are summarized as follows.

- (1) The narrower pipe spacing provides uniform temperature distribution to the surface, consequently it can melt the snow uniformly.
- (2) All specimen having pipe in center were failed from a center crack near the pipe. The strength were influenced by stiffness of embedded material, the concrete with steel pipe had 5% lower than strength of plain concrete. Steel pipe was appropriate material for pipe heating due to higher durability and snow melting ability.
- (3) The embedded pipe in concrete has the effect of reinforcement similar to reinforcing bar, and it is not always a structural defect, though the interface between concrete and pipe is possibly a defect.

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12th International Road Weather Conference

Bingen (on Rhine), Germany

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Boschung Mecatronic SA - Switzerland

TMS 3000 high pressure spray system
A new concept for stationary prevention of
winter-induced dangers on roads and highways

1 Foreword

The BOSCHUNG products for winter service are in use world-wide with great success. Fixed and mobile equipments for both surface condition assessment (on-board sensors or Ice early warning systems) and surface treatment (snow plows, salt spreaders or fixed automated spray technology), as well as state-of-the-art data display and management software are all part of the unique product range of the Boschung group of companies. With nearly 50 years of experience in the machinery and over 30 years of experience in the electronics, Boschung clearly paves the way of winter maintenance equipment.

2 Fixed automated spray technology (FAST)

Boschung pioneered the Fixed Automated Spray Technology with a first system installed back in 1979 on the bridge of Flamatt, Switzerland. The TMS 1000 and TMS 2000 generations have lead this unequalled technology to world-wide recognition.

In its constant effort to improve and refine its products, Boschung has now set a new milestone in the Fixed Automated Spray Technology : the patented TMS 3000 high pressure spray system.

3 Special features of the TMS 3000

Compared to the previous generations, this new system has the following features :

- The spraying process is almost invisible, thanks to the high degree of pulverisation
- The spreading pattern is improved, thanks to closer distance between nozzles (typically 5 meters)
- Bigger surfaces are treated faster (typically 100 meters in one shot)
- Less components in overall system concept, hence lower installation and maintenance costs
- Almost maintenance-free
- Installation depth in the pavement is not greater than 40 mm

The other standard characteristics of the previous generations remain :

- Works independently of the type of thawing agent
- One spray operation provides the equivalent of 2 grams of salt per square meter

4 Technology

The key element of the high pressure fine-spray installation is a longitudinal profile (pressure tube) with built-in jet-sticks every 5 meters (see fig. 1)



Fig. 1

The jet-sticks are equipped with two micro-nozzles, which dispense the thawing agent onto the road surface almost invisibly, thanks to the high degree of pulverisation. The thawing agent is then equally distributed on the carriageway surface by the traffic, achieving a coverage close to 100% on the surface. The longitudinal profile is installed in sections of 100 meters. Different sections of a system can be supplied in parallel with thawing agent, in order to achieve a faster treatment of the surface.

The jet-sticks are fixed by means of a sealing compound in the upper layer of the carriageway or runway, and are designed to sustain the load generated by traffic or airplanes.

A working pressure of 16 bars and a spray duration of 30 seconds ensure the proper coverage of the surface with the equivalent of 2 grams of salt per square meter. As stated in paragraph 3 above, this new technology provides an improved spray pattern. Fig. 2 shows the typical image of a spray profile installed in the center of a two lane road.



Fig. 2

The system can execute various spray programs, which differ by the spray time and/or the number of sprayings, adjusting the quantity of dispensed thawing agent to the road and meteorological conditions, thus optimising the thawing agent consumption while ensuring the traffic safety.

With pump-stations and tanks for thawing agent, connected in series, any surface can be covered, regardless of the size. The capacity of a single pump-station is enough to feed two spray profiles in parallel, that is, to treat 200 meters of two-lane carriageway simultaneously. The nozzles are equipped with cone-check valves to prevent the penetration of dirt, keeping the system maintenance-free. Filters ensure the cleanliness of the thawing agent.

Fig. 3 below shows a schematic representation of the jet-stick.

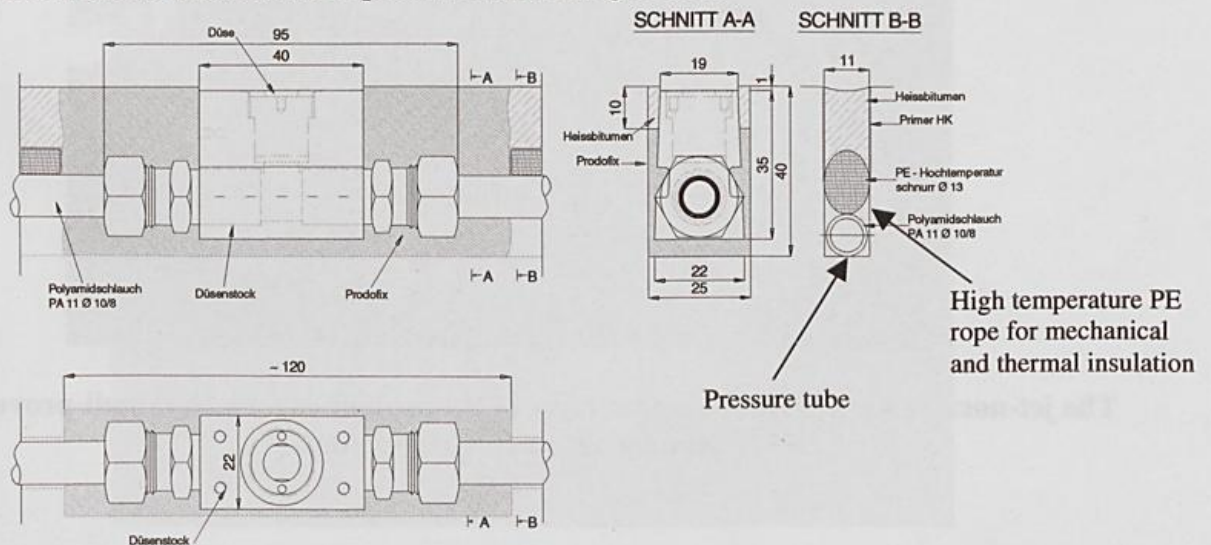


Fig. 3

5 Installation of the system



One single, narrow slot is executed in the middle of the carriageway, between the lanes.



The jet-nozzles are held in the upper layer of the asphalt cover with a well-proven, two-component sealing compound.



The slot is then filled with hot bitume, on the special PE rope (see fig. 3 above).

The system is installed in the middle of the carriageway, between two traffic lanes and is resistant to vehicle loads and to the wearing induced by snow ploughs and tires.

Thanks to the small installation depth of 40mm, the spray-profile can also be installed on bridge plates or concrete decks with reinforcement.

Fig. 4 below shows a typical installation in a 4 lanes highway.



Fig. 4

6 Summary

This new and revolutionary spray system marks another Boschung milestone in the field of winter maintenance : bigger surfaces can now be protected, effectively and economically, against wintry dangers. Furthermore, the addition of an ice early-warning- station with active pavement sensors to automatically control the system allows to take care immediately of dangerous situations without human intervention.



Weather-induced dangers, for example freezing rain, are immediately defused thanks to the active probes and the micro high-pressure spray system

This new system, which has been patented worldwide, has been tested for more than 3 winter seasons on airports and highways with high traffic volumes, meeting and even exceeding all design objectives. It is the result of the combination of modern technology and over 30 years of experience collected by Boschung worldwide.

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