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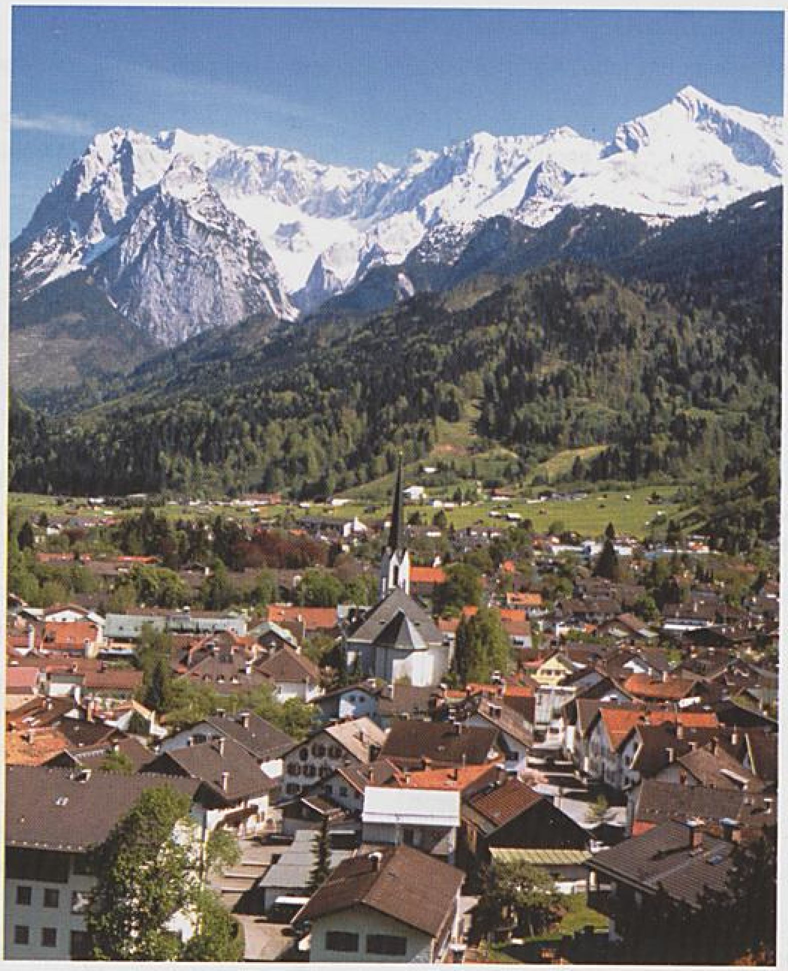

# 17th International Congress of Biometeorology ICB 2005

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**The publisher regrets greatly that the layout of some contributions does not meet the usual quality. This is due to the fact that, unfortunately, some of the manuscripts sent in were not in accordance with the given layout guidelines. The use of unprocessable fonts led to the appearance of unreasonable characters.**



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# Contents

Page

**AIR POLLUTION**



**ANIMALS**

**ARTIFICIAL/INDOOR/URBAN**

**CLIMATE CHANGE**



**HISTORY OF BIOMETERORQLGY**

**TOURISM**



**UV RADIATION**

**Welcome from the President.**

I am delighted to welcome ISB Members and other participants to this 17th International Congress of Biometeorology in Garmisch-Partenkirchen, 5-9 September 2005.

The theme of this congress is Adaptation to Weather, Climate, and Climate Change. A very impressive menu of papers and presentations awaits you on this and related topics. This promises to be a very exciting week of scientific learning, exchange of ideas and discussions about the present state of our interdisciplinary enterprise and our future directions. Never in the 50 years of the life of the International Society for Biometeorology has weather and climate and its impacts on the biosphere been so prominent in international affairs and so important to sustainable economic development and the welfare of peoples everywhere. It is not till 2006 that ISB technically reaches its half century. Nevertheless I think that we can confidently begin to celebrate this achievement here in Garmisch, and prepare the ground for another successful 50 years of research and professional activity in support of biometeorology.

Today's recognition of the importance of weather and climate, and how we can improve our understandings, and manage the new risks and opportunities, presents an unparalleled challenge and opportunity to our society and its members. My hope and expectation is that during this week we will once again demonstrate the vital contributions that biometeorology has to make, and that we will take steps to strengthen our contributions in the future and communicate them more widely to the policy, management, and scientific communities concerned.

It is with great pleasure that I express on your behalf our deep appreciation to our hosts here in Germany, and in Bavaria, and in Garmisch-Partenkirchen for their hospitality. I want to thank especially Dr. Peter Hoeppe, the members of the Scientific Committee, and all the organizers and helpers who have worked so hard to make this Congress possible, and to bring us together in such an attractive venue, and with such an impressive set of sessions, as well as a very active and interesting social programme.

I wish you and the Congress every success and am confident that the International Society of Biometeorology can look forward to three more productive years ahead under the leadership of the incoming President, Dr. Larry Kalkstein.

Ian Burton.
President 2002-2005.

# Phenology

# THE POTENTIAL OF DOCUMENTARY PHENOLOGICAL SPRING OBSERVATIONS FOR RECONSTRUCTING THE BEGINNING OF THE GROWING SEASON BACK TO THE 1700S

This Rutishauser[1], Jürg Luterbacher[1,2], Nicole Meier[1], François Jeanneret[1], Christian Pfister[2,3], Heinz Wanner
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## 1 INTRODUCTION

Phenological observations have been used to assess the impact of climate change in Europe for past decades (e.g. Schwartz 2003). For spring events such as leaf unfolding and flowering, significant changes in climatological parameters are reflected in changes in phenological dates (e.g. Menzel and Fabian 1999). Atmospheric circulation and related temperature were detected as the major drivers of plant development in midlatitude spring climates (Menzel et al. 2005). Statistical relationships within the second part of the 20th century indicate for many plant species in Europe that an increase of 1°C in the preceding weeks and months of the phenological event leads to its advancement of up to one week.

In order to assess the climate-phenology-relationship in a historical context, this study aims at reconstructing and analyzing a representative time series for the beginning of the growing season by combining single, not-continuous documentary sources from northern Switzerland and adjacent German areas back to the 1700s. Documentary sources include a wide range of archived, non-network phenological observations. The research area covers the climatologically homogeneous Swiss plateau region. German and Austrian parts of the Lake Constance region are included.

## 2 DATA AND METHODS

For this study, historical observations come from Euroclimhist databank (www.euroclimhist.com, Institute of History, University of Bern). They contain flowering and first leaf dates of fruit and deciduous trees (cherry (*Prunus avium*), apple (*Malus domesticus*), beech (*Fagus sylvatica*)) and vine (*Vitis vinifera*). Source specific meta-information is often available. For modern observations (i.e. 1951ff) we used data from the Swiss phenological network (www.meteoswiss.ch). Phenological phases for this study were selected on the basis of continuous historical availability.

For the first step to homogenize the individual observations, we correct the Julian day of the phenological event to a reference level of 500 amsl. Gradients are estimated by fitting a linear regression model on network observation data from the Swiss phenological network from 1951 to 2004. The locations vary between 410 and 850 amsl with a majority lying between 450 and 650 amsl (figure 1). The gradients were applied to all the data (figure 2). Annual mean dates of the phenological phases and an index for the beginning of the growing season were calculated with arithmetic means (figure 3, Chmielewski et al 2004).

## 3 RESULTS

Figure 1 shows the dependence of dates for cherry and apple tree flowering and leaf unfolding of beech with respect to the altitude for 1951 to 2004. Gradients for medians from the respective stations are 38 and 40 meters per day for cherry and apple, respectively. For beech trees the change is 108 meters per day. Slopes for the 10- and 90-percentiles are comparable with the slopes of the mean. Cherry and apple tree show 40 and 29 meters per day for the 10-percentile and 34 and 26 meters for the 90 percentile, respectively. Beech tree shows much greater variability for early and late years with gradients of 238 and 78 meters per day for the 10 and 90 percentile, respectively.

Figure 2a presents uncorrected phenological observation dates of the flowering date of cherry and apple tree, leaf unfolding of beech and full flowering of the vine 1721-2004. Figure 2b shows the same though correction for the altitude induced differences. Figure 3 presents the annual arithmetic mean dates of the respective phenological phases analyzed when more than one observation was available per year. In addition, the yellow line indicates the mean of the available observations as an indicator for the phenological onset of spring. For the whole series, the mean onset of spring is Julian day 114 (April 24) with high annual variability ($\sigma$ = 9 days). The earliest date of the beginning of the growing season is on Julian day 85 1722 (March 26), the latest date is on Julian day 148 1740 (May 28). In general, clusters of late onsets of spring appear around 1850 and in the 1960s. Clusters of early onsets are more frequent.

## 4 DISCUSSION

The estimation of regression slope allows the removal of altitude-induced differences in phenological spring observations. Calculations for mean, 10 and 90 percentile slopes show that the dependence of fruit trees is stable for early to late years. This suggests that phenological observations for these two phases can be corrected rather accurately within the study area. Leaf unfolding of beech tree, though, shows larger variability to an already much stronger altitude dependence. In this case, the application of altitude gradient-corrections must be interpreted more carefully. In general, the gradients of this study agree with the findings of Rötzer and Chmielewski (2001) for Europe. They estimated 32 meters per day for the beginning of the growing season from observations of the International Phenological Gardens for the period 1969-1998.

The removal of altitude-induced differences is a tool to correct the variability of phenological observations that are highly variable. The comparison of figures 2a and 2b suggests higher comparability after altitude corrections for the data of the Swiss phenological network (1951ff). Assuming stationarity of altitude dependence for the past 300 years, this method will be applied to earlier periods with a lower number of observations.

First comparisons with independent European spring temperature reconstructions (March-May, Xoplaki et al. 2005) show that the latest onset of spring in 1740 agrees with a cold spring season after one of the coldest winters of the millennium. However, the earliest year 1722 is not the warmest spring season in the temperature record. Warm spring temperatures found in the temperature record (1794, 1920, 1989, 1990) correspond with early onsets of spring (Julian days 93, 102, 109 and 105, respectively). Cold spring temperatures (1785, 1845, 1877, 1917, 1987) are generally related to late onsets of spring (Julian days 130, 134, 125, 121, respectively). However, the temperature influence has to be examined in more detail as the relations between large-scale climate and local to regional phenological data is supposed might unstable through the past.

## 5 CONCLUSION AND OUTLOOK

Altitude induced differences of phenological spring observations in Switzerland were removed and the observations corrected to a common reference altitude level. The corrected data allows for averaging single observations to annual mean values for a climatologically homogenous region North of the Alps. Mean observation dates are combined to estimate a unique "spring index" for the onset of spring back to the 1700s derived from observed phenological data.

This long-term documentary based time series will be more closely compared and verified with independent statistical climate reconstructions to estimate the beginning of the phenological growing season based on long European instrumental temperature series (Rutishauser 2003; Xoplaki et al. 2005). Further, large-scale atmospheric circulation patterns and other independent climate archives will be related and compared to the phenological data back to the early 1700s.

For methodological updates and additional maps and figures refer to:
http://sinus.unibe.ch/%7Erutis/publications.html

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## FIGURE CAPTIONS

**Figure 1:** Dates of full flowering cherry and apple tree and leaf unfolding of beech (Julian day) against the altitude of the observation's location (masl). Slopes of a fitted linear model indicate the influence of the altitude for the phenological date.

**Figure 2:** a) Uncorrected phenological observation dates (Julian days) of the flowering date of cherry (black) and apple tree (red), leaf unfolding of beech (green) and full flowering of the vine (light blue) for an ecologically homogenous region north of the Alps from 1721 to 2004. **b)** Corrected phenological observation dates (Julian days) of the flowering date of cherry (black) and apple tree (red), leaf unfolding of beech (green) and full flowering of the vine (light blue) after removal of altitude induce differences.

**Figure 3**: Mean flowering date of cherry (black) and apple tree (red), leaf unfolding of beech (green) and full flowering of vine (light blue) for a ecologically homogenous region north of the Alps from 1721 to 2004. The yellow line shows the mean of the available observations as an indicator for the phenological onset of spring.

Figure 1

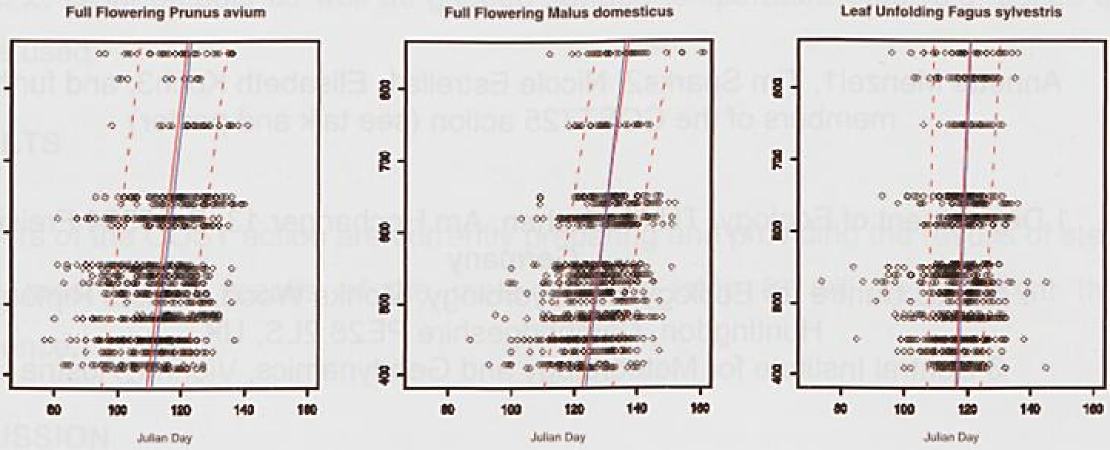



Figure 2

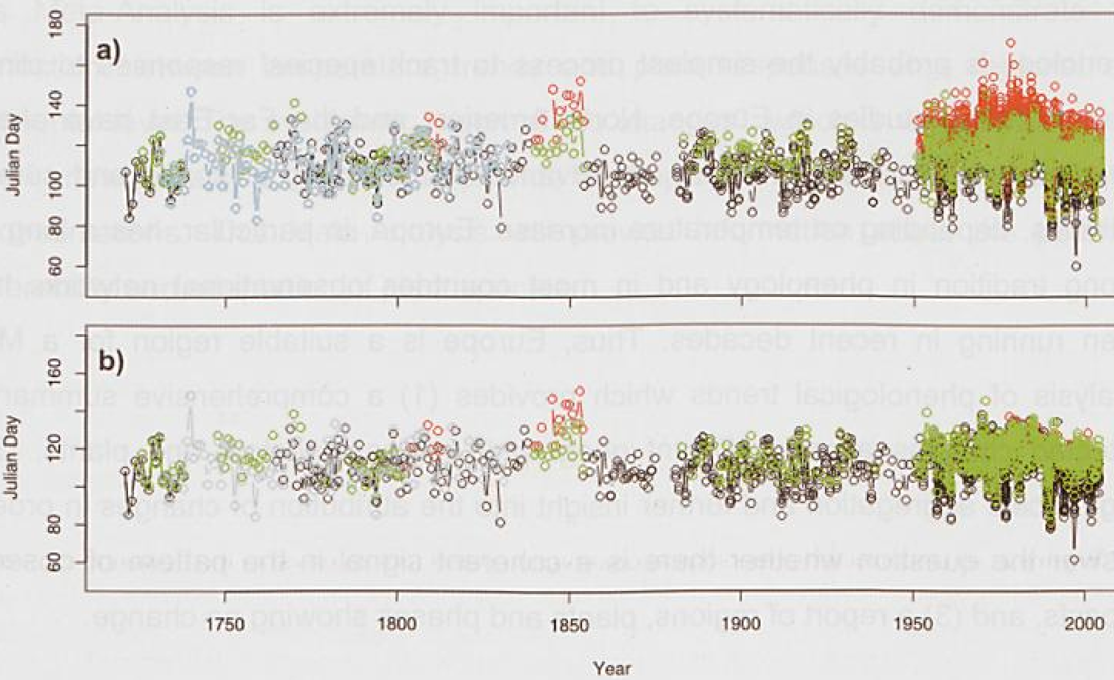
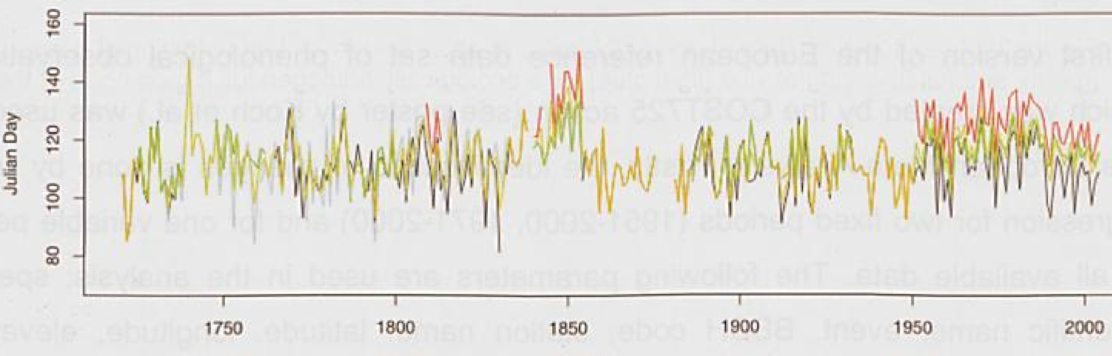



Figure 3



# META-ANALYSIS OF PHENOLOGICAL TRENDS IN EUROPE (COST725)

Annette Menzel1, Tim Sparks2, Nicole Estrella1, Elisabeth Koch3, and further members of the COST725 action (see talk and poster)

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## INTRODUCTION

Phenology is probably the simplest process to track species' responses to climate change. Many studies in Europe, North America, and the Far East have already revealed temporal trends, mostly an advance of the timing of spring and summer activities, depending on temperature increase. Europe, in particular, has a long and strong tradition in phenology and in most countries observational networks have been running in recent decades. Thus, Europe is a suitable region for a Meta-Analysis of phenological trends which provides (1) a comprehensive summary of detected changes across different geographic regions, sectors and plants, (2) a larger-scale aggregation and further insight into the attribution of changes in order to answer the question whether there is a coherent signal in the pattern of observed impacts, and (3) a report of regions, plants and phases showing no change.

## METHODS

A first version of the European reference data set of phenological observations, which was created by the COST725 action (see poster by Koch et al.) was used for this European Meta-Analysis. Firstly, the identification of changes is done by linear regression for two fixed periods (1951-2000, 1971-2000) and for one variable period of all available data. The following parameters are used in the analysis: species scientific name, event, BBCH code, station name, latitude, longitude, elevation, number of years, mean date, standard deviation of the mean, slope of the linear regression, standard error of the slope, significance (pr<F), temperature trend and correlation of event with temperature . Attribution of changes to local climate change is done in this first step. For the European wide analysis and larger scale attribution

of step 2, GCM outputs as well as gridded surface temperature data (e.g. Jones et al.) are used.

## RESULTS

Members of the COST action are currently preparing and providing the results of step 1, the most recent results of the meta-analysis (step 2) will be given at the conference.

## DISCUSSION

This Meta-Analysis is extremely important to systematically demonstrate the connection between temperature trends and plant responses at a regional and continental level. The systematic report of “no changes”, which is very unlikely to be done in new papers, is essential to provide a complete and unbiased assessment of all observations. This Meta-Analysis will provide information about the potential vulnerability and adaptation of plant species.

# CLIMATE CHANGES AND FROST HAZARD FOR FRUIT TREES

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[2]Saxony's State Department for Environment and Geology, Germany

## 1 INTRODUCTION

In the last years the blossoming time of fruit trees in Germany has advanced by several days, due to increasing temperatures in winter and in early spring. The recent changes in the timing of apple tree blossom are probably the strongest in the last 240 years. An increase of mean air temperature from February to April by 1 °C caused an advanced timing in the beginning of flowering by 5 days (Chmielewski et al. 2004a).
Earlier blossom of fruit trees could holds the danger of damages by late spring frosts. Frost damages on trees are not observed in winter, when dormancy and cold hardiness of trees is well developed, but in autumn if this stage is not reached yet or in spring if it is already broken. For this reason some authors use the time between the last frost in spring and the first frost in autumn to define the growing season.
This study will focus on possible impacts of climate change on fruit growing in Saxony (apple, red currant, sour cherry, sweet cherry, and gooseberry) - a state in southeast Germany - in the next decades up to 2050. For this reason phenological models (thermal time models) were constructed, which allow to estimate the shift of phenological phases due to climate change. On the basis of these results the risk of late frost damages in the stage of tree blossom were evaluated.

## 2 METHODS

### 2.1 DATA

To estimate the impact of climate change on the development fruit species in Saxony a regional climate change scenario (2021-2050) was used. It was developed within the project REKLISA and is based on a statistical weather-pattern downscaling method for individual climate stations in Saxony (Enke et al. 2005). The input for the downscaling procedure was derived from the SRES-B2 run of the coupled atmosphere and ocean model ECHAM4-OPYC3 of Max-Planck-Institute for Meteorology and Deutsches Klimarechenzentrum in Hamburg, Germany.
Phenological observations of different fruit species in Saxony were derived from the German Weather Service (DWD). The number of phenological stations in Saxony varies from species to species. For example, for beginning of flowering of gooseberry 63 stations and for the beginning of picking of sweet cherries only 9 stations were available. In the last case the number of stations is probably insufficient for this study, but for all other phases the investigation area is well covered by stations.

### 2.2 METHODS

Phenological models are important tools to predict the impact of global warming on plant development. For our investigation we used Thermal Time Models (Eq. 1), which differ in base temperature ($T_B$). In order to calculate this threshold, $T_B$ was varied between 0 and 10 °C in steps of 0.1 °C. $T_s$ is the heat sum, which has to be reached, before the phenophase is observed.

$$T_s = \sum_{t_1}^{t_2} \max(T_i - T_B, 0) \qquad (1)$$

To set up phenological models for Saxony the data base was spitted in two halves (fitting data: all uneven years, verification data: all even years, 1961-2000). For the development of the models the mean daily air temperature and the annual timing of phenophases at the phenological stations were used. Starting with a base temperature of 0.0 °C, the heat sum between 1 January ($t_1$) and the timing of the phenophase ($t_2$) was calculated for each year and then averaged over all years. Following, this mean heat sum was used to estimate the timing of the phenophases. To check the accuracy of the model, the root mean square error (RMSE) between estimated and observed dates was calculated. Now, the base temperature was increased by 0.1 °C and the procedure was repeated, and so on. The best model always was the model with the smallest RMSE. In order to model the beginning of picking maturity of fruits the heat sum between flowering and maturity was calculated. Any variations in base temperature did not improve the goodness of the models, because at the end of April or beginning of May (blossom dates) the daily mean temperature is always in a range which forces the ripening process. The mean absolute error of all models (verification period) is ranging between 2.8 and 6.1 days.

# 3 RESULTS

## 3.1 EXPECTED IPMACTS ON PLANT DEVELOPMENT

Table 1 shows the mean calculated changes in plant development in Saxony for the three decades up to 2050. The achieved results are in accordance with the recent changes in plant development. The earliest phenophase, the beginning of leaf unfolding of gooseberry, shows the strongest trend of -24 days up to 2025. In the future the first leaves of gooseberry in Saxony could be observed on average at the beginning of March. Also the beginning of flowering is clearly advanced by 17 days. The mean flowering dates of the other species are shifted between -5 (sour cherry) and -10 (apple) days. The changes in the dates of picking maturity are about in the quantity as the changes in blossom, so that the ripening time of fruits is not really extended or shortened, but shifted to the beginning of the year (Fig. 1).

Tab. 1: Average timing of different phenophases ($P_i$ in day of the year) in the control run (Ctrl.: 1981-2000) and in the scenario decades (Sc I: 2021-2030, Sc II: 2031-2040, Sc III: 2041-2050) and its changes (Δ in days) in relation to the control run.

| $P_i$ | Ctrl. | Sc I | Sc II | Sc III | ΔSc I | ΔSc II | ΔSc III |
|---|---|---|---|---|---|---|---|
| Leaf unfolding, Gooseberry | 91 | 68 | 80 | 67 | -23.0 | -11.0 | **-24.0** |
| Flowernig, Gooseberry | 103 | 87 | 97 | 86 | -16.0 | -6.0 | **-17.0** |
| Flowernig, Red currant | 110 | 102 | 109 | 104 | **-8.0** | -1.0 | -6.0 |
| Flowernig, Sweet cherry | 111 | 102 | 109 | 104 | **-9.0** | -2.0 | -7.0 |
| Flowernig, Sour cherry | 118 | 113 | 120 | 116 | **-5.0** | 2.0 | -2.0 |
| Flowernig, Apple (early) | 124 | 114 | 120 | 116 | **-10.0** | -4.0 | -8.0 |
| | | | | | | | |
| Picking maturity, Sweet cherry | 162 | 156 | 161 | 157 | **-6.0** | -1.0 | -5.0 |
| Picking maturity, Gooseberry | 185 | 178 | 183 | 178 | -7.0 | -2.0 | **-7.0** |
| Picking maturity, Red currant | 188 | 179 | 184 | 179 | -9.0 | -4.0 | **-9.0** |
| Picking maturity, Sour cherry | 201 | 196 | 200 | 195 | -5.0 | -1.0 | **-6.0** |
| Picking maturity, Apple (early) | 213 | 205 | 209 | 204 | -8.0 | -4.0 | **-9.0** |

## 3.2 EXPECTED IMPACTS ON LATE-FROST HAZARD

In order to examine potential changes in frost risk the number of days with frost, 10 days after the beginning of tree blossom were counted. The frost events were divided into three classes: weak frosts, average frosts, and strong frosts. For all investigated fruit species the weak and average frost events increase distinctly in scenario I (Fig. 2). The strongest change is observed for sweet cherry, where the number of average frost doubles and the number of strong frosts increases considerably. For all species the danger of frost during blossoming gradually decreases up to the decade 2041-2050, but for sweet cherry the risk of late frost in all classes is still higher than in the control run. The shift in the blossoming dates for sour cherry was not as strong as for sweet cherry, so that the risk of late frost damages is something lower. During the time of apple tree blossom, the frequency of light and average frost in the decade 2021-2030 is twice as much as present. Up to 2050, for all species the number of light frosts stays still higher than today. Generally, we can conclude that the frost risk for fruit growing in Saxony will increase in the case of climate change. The very early species have the highest frost risk.

# 4 DISCUSSION AND CONCLUSION

Thermal time models are able to predict the timing of flowering or leafing of trees in the same accuracy as chill-heating models. Since chilling requirement is not considered in thermal time models, it should be checked whether the chilling conditions in the climate scenario will change. This is very important in warm regions as Mediterranean areas were some species or varieties could not reach satisfaction of chilling requirement under a changed climate. For Saxony we found out that chilling conditions will not change in the future, since the expected changes in air temperature are relatively moderate in autumn. So, we assumed that up to 2050 the chilling requirement of the fruit species is nearly reached at the end of December.

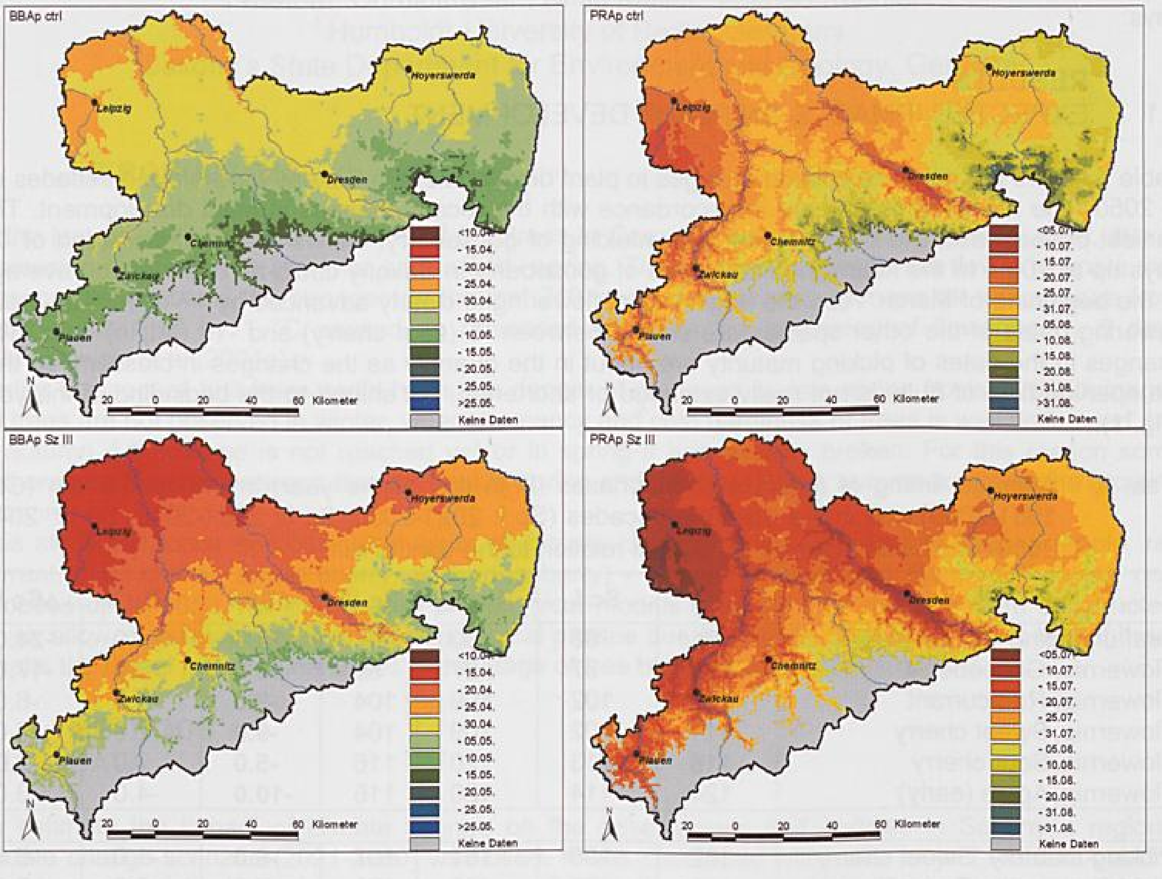


Fig. 1: Left: changes in the timing of apple tree blossom, above: 1981-2000, below 2041-2050, right: changes in fruit ripeness of apples in Saxony, above:1981-2000, below 2041-2050.

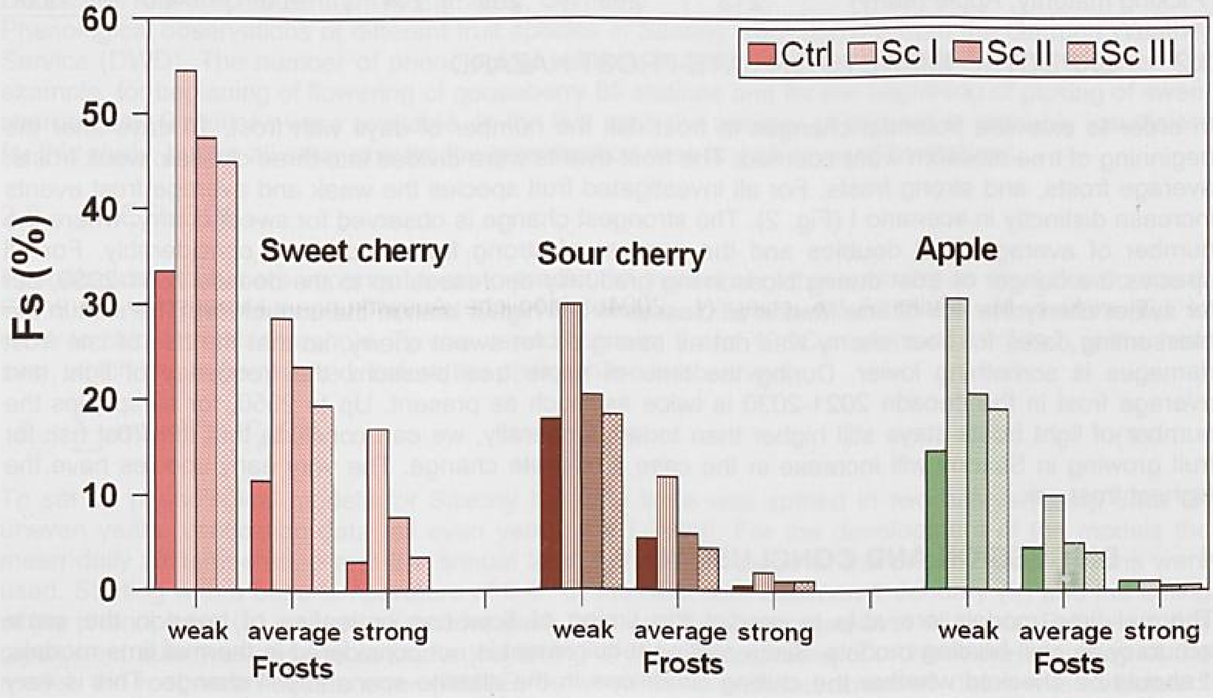


Fig. 2: Changes in relative frequency of weak ($0 > T_n \geq -2$ °C), average ($-2 > T_n \geq -4$ °C) and strong ($T_n < -4$ °C) frost ($F_S$) up to 10 days after the beginning of tree blossom.

According to the used climate scenario the rise in air temperature will continue with variations up to 2050. The strongest changes will happen in winter and in summer. As a result the blossoming time of fruit trees will further advances depending on the species by 5 - 10 days on average. Higher temperatures in summer (June, July) will also advance the maturity of fruits, so that the whole developmental period is more or less shifted to the beginning of the year. This behaviour of plants confirms the findings in the observations, were already the flowering time as well as ripeness is clearly advanced. If the ripening period is not clearly reduced, but only shifted to the beginning of the year, some positive effects on the soil water balance would be possible. Most climate scenarios for Germany point to an increase of precipitation in winter and a clear reduction in summer (Enke et al. 2005). In the main growing period (April to October) the air temperature in Saxony will rise by 1.3 °C, and up to 2050, the precipitation will decrease by more than 30 mm (Chmielewski et al. 2004b). If the ripening period of fruit species is shifted several days to the beginning of the year, the trees can profit much more from the winter precipitation. However, additional irrigation in the last stage of ripening could be inevitable.

On the other hand, one day of strong frost during the time of blossoming can harm the fruit yield much more than changes of the ripening period or even drought. The study showed that small changes in the beginning of flowering can increase the frost risk for some species significantly, even if the frost free season generally is extended. For Saxony the longer duration of frost free season was mainly the result of a later occurrence of early frosts. Scheifinger et al. 2003 investigated trends in the last occurrence date of frost events and phenological trends in Central Europe (1951-1997). They found that trends of frost events appear more negative than those of the phenological phases. Therefore, they concluded that the risk of late frost damage for plants should have been lower during the last decade as compared to the previous decades. In Italy (Emilia-Romagna region) an increase in frost risk damage has been already observed in the last decades (Anconelli et al. 2004). Investigations by Sušnik and Žust (2001) for Slovenia also point to an increase of spring frost frequency in 1990s and in 2001. In some parts of Germany, strong frost damages on fruit trees were observed in April 2005.

Even if the result in this study is site specific and cannot be generalized, we always have to distinguish between the gradual warming (climate trend) and the occurrence of cold spots (weather). Furthermore, the expected warming will not run homogeneous over all seasons. In Saxony no warming in spring was observed, because of an increased frequency of easterly circulation patterns. The study suggests that climate change can considerably increase the frost risk of fruit species in some regions. This can happen if the expected temperature rise in January and February forces the plant development, but the increase of temperature in spring fails. The result could be severe economic losses for fruit growers if no adequate frost protection is introduced.

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# TWILIGHT FAR-RED TRE ATMENT ADVANCES LEAF BUD BURS T OF SILVER BIRCH (BETULA PENDULA ROTH)

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## Abstract

Leaf bud development of boreal trees, once initiated, is driven by ambient air temperature, but the mechanism triggering bud devel opment remains unclear. Models of bud burst utilizing either the release of winter bud dormancy or change in day length in spring give comparable predictions for bud burst under current climatic conditions, but disagree when climatic warming is simulated. This uncertainty needs to be resolved if we are to accurately predict tree responses to climate change.

We conducted an experiment to find out if day length, night length or change in spectral conditions associated with twilight influence bud burst. We g rew 3-year old birch seed - lings cloned from a mature tree of boreal origin in light conditions simulating the lengthening days of spring. One group of seedlings was subjected to a morning and evening treatment emulating the reduced red to far -red (R/FR) spectral ratio of twilight, the other to the same light intensity without changing the spectral composition.

Shortening night length in spring appears to be the cue releasing bud dormancy, and the reduced R/FR ratio of twilight enhances this night effect sl ightly. Bud burst occurred 4 days earlier under the twilight treatment ($p=0.04$). To assess the interplay between release of dormancy and the subsequent response to warming, we fitted a thermal time model to the data using separate parameterizations for t he starting dates of heat sum accumulation in each treatment. Least -squares fitting suggested that bud development started under light regimes corresponding to late March in the Finnish region where these clonal seedlings originated. This is almost two mon ths after the chilling requirement for dormancy release is satisfied. The result gives experimental support to phenological models where the bud development initiates on a fixed date in spring, like thermal time (growing degree days) model. This fixed date should be interpreted to represent a signal from changes in the diurnal light regime of the plants, e.g. shortening of the night.

# QUANTIFYING THE ENVIRONMENTAL DRIVERS OF TREE PHENOLOGY

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## INTRODUCTION

An increasing concern over climate change and its impacts on the environment has developed over the last decade. A change in global climate could affect species range and distribution, cause extinction and have a destructive impact on human society (International Panel on Climate Change, 2001). These important issues have prompted research on global change and the development of primary and secondary indicators that could assess, quantify and monitor variations and trends in climate.

The analysis of long-term phenological records of plants has shown that the advance in spring phenophases corresponds to warmer than average temperatures in the months that precede them (Menzel and Fabian, 1999, Badeck *et al.*, 2004). This relationship has pointed out the importance of plant phenology as a biological indicator of climate change. However, while there is a clear relationship between the timing of spring phenophase and temperature, the effect of other environmental factors has not been taken into account in models of plant phenology. Most of the models simply establish a linear relationship between the timing of the observation and accumulated thermal time.

The understanding of the impacts of climate on plant phenology will improve when all environmental drivers are incorporated into mechanistic phenological models, which take into account the biological processes underlying plant development. For this reason, more experimental studies that explore the response of plant phenophases to their environmental triggers are necessary. The aim of this study is to experimentally test the effect of different environmental drivers on spring phenophases, so that more comprehensive models of plant phenology can be developed.

## METHODS

*Selection of the experimental material*

The International Phenological Gardens (IPGs) are a Europe-wide network of garden sites that were established in 1959 to collect phenological data from a series vegetatively propagated trees (Chimielewski, 1996). The fact that they are clones ensures genetic uniformity and any change in their phenology can be attributed to environmental variation at the site.

This historical data set provides an ideal way to study the influence of the different environmental factors on tree phenology

For the purpose of this study cuttings were taken from five tree species from the Irish IPGs and vegetatively propagated during the spring and summer of 2003. The selected species were *Betula pubescens, Fagus sylvatica, Salix aurita, Salix x smithiana* and *Tilia cordata*. The selection was made on the basis of the species phenological responsiveness to spring temperature (Sweeney *et al.,* 2002) and their ease of propagation.

*Experimental design*

The effect of chilling duration, chilling temperature, photoperiod and forcing temperature was tested during three experiments in controlled environmental conditions, performed between November 2003 and April 2005.

- *Experiment 1. Interaction between chilling duration and photoperiod*

The interaction between chilling duration and photoperiod on *Fagus sylvatica* and *Tilia cordata* was tested under controlled conditions. The clones were stored in a non-heated glasshouse during the summer of 2003 and transferred to a cold room (permanently dark, with a constant temperature of 3 °C) on the 11th of November. Four plants from each species were given 0, 11, 30, 55 and 105 days of chilling and subsequently transferred into growing cabinets, set at 22 °C during the light period and 14 °C during the dark period, with a photoperiod of either 16 hours (long day treatments) or 8 hours (short day treatments).

- *Experiment 2. Forcing temperature*

On the 28th of February 2004 dormant cuttings of *B.pubescens, F.sylvatica, T.cordata* and *S.smithiana* were taken from one of the Irish IPG gardens (JFK arboretum International Phenological Garden) and stored at 3°C until the start of the experiment. On the 16th March one-node cuttings were put in compost-filled trays and transferred into growing cabinets with a photoperiod of 16 hours and a temperature range of: 0, 6, 12, 18, 24 and 32 °C. Each treatment received 10 one-node cuttings per species. The number of days to budburst was recorded for each budstick, and averaged over the 10 replicates in order to express the mean time to budburst for each treatment. The forcing rate was obtained by dividing the overall minimum mean number of days to budburst by the mean number of days to budburst at each temperature (the optimum accumulation rate corresponds to the treatment that is most effective in anticipating budburst).

- *Experiment 3. Interaction between chilling temperature and chilling duration*

On the 21st November 2004, clones of *Fagus sylvatica*, *Betula pubescens*, *Tilia cordata* and *Salix x smithiana* were transferred into 4 incubators set at different temperatures: 2, 4, 6 and 10 °C. 4 clones of each species were present in each incubator. The plants were incubated at 4 different chilling durations: 30 days, 55 days, 95 days, 122 days. After which, cuttings were taken from the tree branches. Replicate groups of 8 one-node cuttings were put in compost-filled trays and transferred into growing cabinets, at 22 °C and with a photoperiod of 16 hours. The number of days to budburst was recorded for each budstick, and averaged over the 10 replicates in order to express the mean time to budburst for each treatment.

*Statistical analyses*

The effect of the tested environmental conditions was checked with the analysis of variance (ANOVA) and by fitting generalised linear models. All the analyses were performed using the freely available R statistical environment (http:// CRAN.R-project.org).

## RESULTS

*Interaction between chilling duration and photoperiod*

The phenological response of *Salix x smithiana* to the interaction between budburst and chilling duration is shown in Figure 1.a and 1.b. The response of budurst to chilling duration in *Salix x smithiana* is best described by an inverse exponential curve ($p<0.01$), while in the case of *Fagus sylvatica,* the best fit was obtained using a sigmoidal curve ($p<0.01$). For *Fagus sylvatica,* only long day treatments are displayed, as short day conditions were able to break dormancy only after the longest chilling duration (Figure 1.a).

For both species, there was a significant effect of photoperiod and chilling duration on the timing of budburst (ANOVA, $p<0.01$). With the increase in chilling duration, budburst occurred increasingly earlier. The interaction of the two factors was significant for both species (ANOVA, $p <0.01$).

*Forcing temperature*

Forcing temperature for all species was negatively correlated with number of days to budburst. This relationship was highly significant in all cases (generalised linear models and ANOVA, $p <0.001$). The greatest advance in budburst was observed between 12 and 18°C while for the two higher temperatures (24 and 32°C) the difference between budburst timing was comparatively small. This pattern suggested that the relationship between rate of budburst and temperature could best be described by a sigmoidal curve. (Figure.2).

*Interaction between chilling temperature and chilling duration*

Chilling temperature had the least significant effect on the timing of budburst for all species tested. In *Betula pubescens* and *Fagus sylvatica* chilling temperature significantly affected budburst (ANOVA, p=0.002 and 0.0028, respectively) but the significance was less than for chilling duration (ANOVA, p=0.0001 and 7.4e-08, respectively). In *Salix x smithiana* and *Tilia cordata* chilling temperature had no effect at all, while chilling duration appearead to be highly significant in both cases (ANOVA, $p<0.001$). There only appeared to be a significant interaction (ANOVA, $p<0.001$) between these two factors for *Fagus sylvatica*.

## DISCUSSION

The results from the 1$^{st}$ experiment suggested that photoperiod has a large effect on the timing of budburst in all species tested and therefore must be considered, in addition to chilling duration, when modelling the timing of spring phenophases. Traditional models (Sarvas 1974, Landsberg, 1974, Cannel and Smith, 1983) consider temperature as the only input into budburst models. While temperature is a very important driver of tree phenology, these experiments have shown that photoperiod also plays an important role. For example, all 4 replicates of *Fagus sylvatica* in the long day treatment were able to resume growth even when no chilling was received. On the other hand, *Fagus sylvatica* clones that did not receive chilling and were given short photoperiod during forcing never broke dormancy during the experiment. These results suggest that chilling temperatures traditionally considered active for dormancy breaking (usually given as between -5 and 12 (Richardson *et al.* 1974, Sarvas, 1974) are not necessary for *Fagus sylvatica*, when the a critical photoperiod is received (in this case, 16 hours). On the other hand, *Salix x smithiana* was only able to resume growth when at least 30 days of chilling were received. With this chilling duration, budburst occurred in all of the plants receiving long-day treatment, while only half of those receiving short-day treatment responded. Thus, even though long-day was not able to substitute fully for chilling (as in it did in *Fagus sylvatica* ), it had an important effect on dormancy breaking. In both cases, a relatively short photoperiod during the forcing treatment delayed budburst. The effect of photoperiod on phenology has already been documented in previous studies (Miking and Heide, 1995, Heide, 1993). For example, *Betula pendula* models of spring phenology were improved by the incorporation of photoperiod (Hakkinen *et al.,* 1998).

The results of the second experiment confirmed that forcing temperature plays a determinant role in affecting the timing of budburst. The sigmoidal pattern of the response of budburst rate to increasing temperature is inconsistent with classical models widely used in agriculture such as the Utah model (Richardson *et al.* 1974), or the Thermal Time model (Cannel and Smith, 1983). These experimental findings suggest that in order to accurately model the effect of spring temperatures on tree phenology, sigmoidal accumulation units should be considered instead of traditional linear units (degree days or thermal units accumulated above a base temperature).

Chilling temperature appears to be a factor of less importance than chilling duration. Among the chilling temperatures tested (2 to 10°C) 10°C and 6 °C proved to slightly delay budburst in *Betula pubescens* and *Fagus sylvatica* and had no effect at all on *Salix x smithiana* and *Tilia cordata.* The relatively small effect that chilling temperature had on budburst timing might imply that the response to this factor is abrupt and that the explored range of temperatures was not wide enough to find which are the extremes of the active chilling temperature range.

## CONCLUSION

These findings indicate that the influence of environmental factors on the timing of phenophases is too complex to be effectively modelled by empirical phenological models. On the basis of the present results, mechanistic models of tree phenology would benefit from the incorporation of photoperiod as this factor has proven to affect both dormancy breaking and timing. The response to forcing temperature was more accurately described by sigmoidal curves than by linear models, and this needs to be taken into account when considering the accumulation of heat units during forcing. Chilling temperature might not be as important as previously indicated. Finally, the varied response of the investigated tree species suggests that caution needs to be exerted when general remarks about tree phenology are to be made.

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Fig 1.a

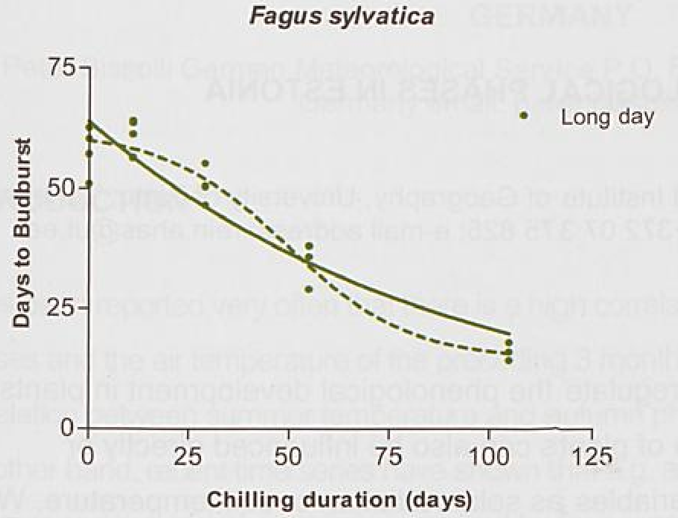


*Fig 1. Relationship between chilling duration and number of days to budburst after transfer into forcing conditions for Fagus sylvatica (1.a) and Salix smithiana (1.b). The green symbols indicate the treatments receiving a 16 hour photoperiod (long day treatment), the red symbols indicate the treatments receiving a 8 hour photoperiod (short day treatments).*

Fig 1.b

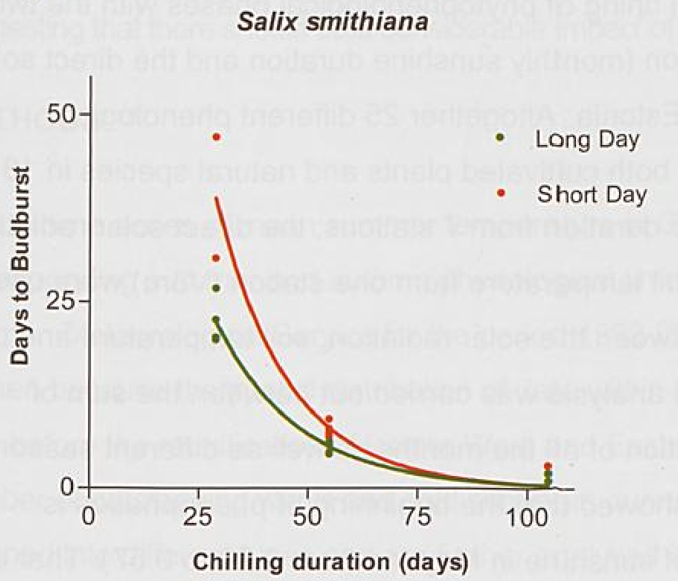


Fig 2

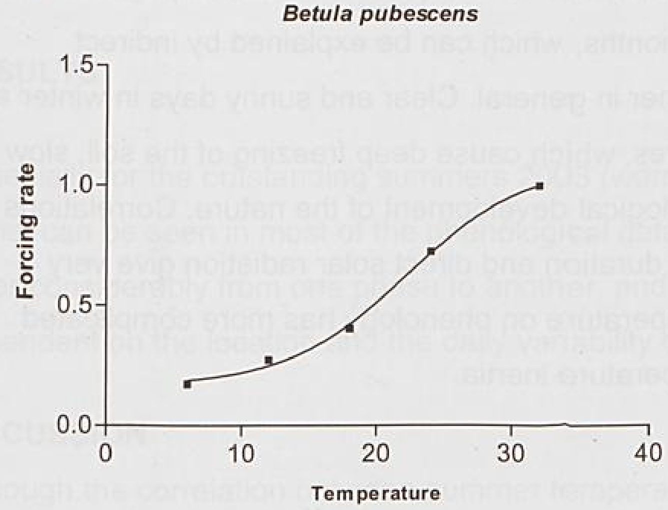


*Fig 2. Relationship between forcing temperature(°C) and forcing rate in Betula pubescens. This relationship can be modelled by a sigmoidal curve ($p < 0.01$).*

# INFLUENCE OF THE SOIL TEMPERATURE AND SOLAR RADIATION ON PHYTOPHENOLOGICAL PHASES IN ESTONIA

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Temperature is the main factor to regulate the phenological development in plants. In addition to temperature the growth of plants can also be influenced directly or indirectly by many other climate variables as solar radiation or soil temperature. We studied the correlations of the begi nning of phytophenological phases with the two different indicators of s olar radiation (monthly sunshine duration and the direct solar radiation) and soil temperature in Estonia. Altogether 25 different phenological phases were studied, which cover both cultivated plants and natural species in 13 stations. The data on the sunshine duration from 7 stations; the direct solar radiation from one station (Tõravere) and soil temperature from one station (Võru) were used. To reveal possible correlations between the solar radiation, soil temperature and the phenological phases, a correlation analysis was carried out between the sum of sunshine duration and direct radiation of all the months as well as different seasons and phenophases. The research showed that the beginning of phenophases is mainly influenced by the amount of sunshine in May ($r$ = from 0.29 to 0.57). That is especially true about the blossoming of woody plants. Sunshine in May can also greatly influence the further development of field crops. Correlation is positive with the duration of sunshine in winter months, which can be explained by indirect influence on the conditions of weather in general. Clear and sunny days in winter and in early spring bring low temperatures, which cause deep freezing of the soil, slow melting of the snow and late phenological development of the nature. Correlations of phenological phases with sunshine duration and direct solar radiation give very similar results. Influence of soil temperature on phenology has more complicated correlations as soil has strong temperature inertia.

# THE IMPACT OF SUMMER TEMPERATURE ON PHENOLOGICAL PHASES IN GERMANY

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## INTRODUCTION

It has been reported very often that there is a high correlation between phenological spring phases and the air temperature of the preceding 3 months in Central Europe. In contrast, the correlation between summer temperature and autumn phases is quite low in most cases. On the other hand, recent time series have shown that e.g. after the hot summer of 2003 many summer and autumn phases have occurred by far sooner compared to other years, suggesting that there should be a considerable impact of summer temperature on phenology.

## METHODS

Annual time series of mean summer temperature in Germany are compared with corresponding summer and autumn phenological time series of the network of the German Meteorological Service for the period 1992-2004/05. This period has been chosen because the spatial distribution of data within Germany is better for this period than before the reunification of former West and East Germany. There is also a sufficient number of outstanding warm and cold summers during that period. These summers are grouped into different types and are further analysed individually by regarding time series of daily temperature data. From this time series analysis special conditions of summer temperature behaviour having impact on phenological phases can be found.

## RESULTS

Especially for the outstanding summers 2003 (warm), 1993 and 1996 (cold) a clear signal can be seen in most of the phenological data. However, these signals can differ considerably from one phase to another, and the signals are also strongly dependent on the location and the daily variability of summer temperature.

## DISCUSSION

Although the correlation between summer temperature and phenological phase onset dates is in general quite low, it is possible to find some indications of the impact of extreme summers on phenology from time series analysis.

# PHENOLOGICAL MODELS FOR BLOOMING OF APPLE CV. 'GOLDEN DELICIOUS'

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## 1 INTRODUCTION

Various flowering models (Bidabè, 1967; Richardson et al. 1974 Anderson et al. 1986; Chuine et al. 1998, Valentini 2001) make use of «Chilling and Forcing» algorithms with different parameterisations of the CU and GDD summation. Chilling and forcing models usually split bud development into two stages. The first phase is where «Chilling Units» (CU) are accumulated to break dormancy when a certain value («requirement») is reached. The second stage, starting from the fulfilment of the CU requirement, is where "Growing Degree Days" – or Hours – (GDD or GDH) are accumulated, carrying on the ontogenetic process that leads to flower bud burst. Chuine et al. (1998) proposed different «chilling and forcing functions» for CU and GDH determination and suggested also that these functions should be used, depending on the temporal sequence between chilling and forcing stages.

Typically, the requirement for GDD is fixed by calibrating the model to yield a «universal» value, depending only on plant species. The challenging task, which we intend to pursue, is to investigate the association of the requirement with specific site-dependent variables, as already outlined by White et al. (1997). This approach should allow an extension of model validity, even to sites with climatic features slightly different from those of the region where the model has been calibrated.

## 2 METHODS

Phenological series were available from six locations in Trentino, in the Italian Alps, at different altitudes ranging from 210 to 727 m a.s.l. Series were homogenized to produce a database, which reported the yearly dates of initial flowering. With the aim of testing the model in a wider geographic and climatic context, more data were collected outside the province of Trento: at one site in Romagna (period: 1996 – 2001) and four sites in Piedmont (2003 only); all locations are in northern Italy, in plain or smooth hilly landscape. In most cases, phenological and meteorological observation sites coincided and so no adjustment was needed for meteorological data. Significant gaps in the meteorological dataset (full days) and missing periods were reconstructed by geostatistical methods on the basis of other stations in the network. Minor hourly gaps were filled by linear interpolation between existing records.

After calibrating and comparing some existing models, a new approach was developed by re-examining the «parallel model» proposed by Chuine (1998), where GDH efficiency at any time is a function of the summation attained at that time; the effect of this modification is that GDH is more effective when the summation attained is small. In this case, too, various functions of «actual GDH summation» were tested, obtaining GDH as in Eq. (1):

$$GDH(k)=\sum_{t=0}^{k} f\left(T_h(t)\right) f\left(GDH(t-1)\right) \qquad T_h \geq s \qquad (1)$$

where $T_h$ is the hourly temperature, $s$ is the threshold, $t$ is the time, $k$ is a generic time step and $f$ is a generic function.

To cope with the frequent unavailability of hourly data in meteorological archives, their estimate can be performed by empirical models, starting from daily maximum and minimum temperature. We employed the«TM model» (Cesaraccio et al., 2001), in reconstructing hourly data from daily values.

Besides temperature, also effects of photoperiod were tested.

## 3 RESULTS

The first, general, outcome of the application of the models is that a better estimation of flowering dates was obtained by the use of GDH instead of GDD. In our case, both values of forcing requirement (GDH) and flowering dates, obtained after reconstruction of hourly data, were similar to those obtained with measured values.

No evident effects of photoperiod were found in our series. The different functions of day length tested gave no real improvement in flowering prediction.

A comparison between models showed that the best estimate of initial flowering uses a CU accumulation approach, as in Richardson et al. (1974) and Eq. (1) for GDH requirement. The resulting model, which we called «progressive Utah», is a type of Utah model adapted in the forcing phase by the approach proposed by Chuine (1998):

$$GDH(k)=\sum_{t=0}^{k}[T_h(t)-s]+\left\{[T_h(t)-s]\cdot\left(\frac{GDH(t-1)}{\sum GDH_{\text{initial flowering}}}\right)^2\right\} \qquad T_h \geq s \qquad (2)$$

Threshold values for CU and GDH accumulation and total forcing requirements were varied in order to obtain the best estimates. The «Progressive Utah» model yielded a mean absolute error lower than 2 days in the two locations with the longest and superior phenological series, and lower than 4 days when applied to the locations with less observation years; it showed a very good fit, even for years with a pronounced advance or delay of flowering (Fig. 1).

Indeed, even if estimates are good, the model would still be poorly adaptable, since its forcing requirements in GDH are different for each of the six sites. This is due to other variables that, until now, had not been explicitly included in the model. So even the best model would need calibration for any new site to obtain the proper GDH requirement value. To improve model adaptability, the required value of GDH has been assumed to be a function of site-dependent variables, easily obtainable for any location (White et al. 1997), i.e. the topographic variables, added to mean yearly or spring temperature; all the information contributed one index ($I_{site}$), defined for each site:

$$\sum GDH_{\text{initial flowering}} = f(\text{slope, aspect, yearly mean temperature, water stress}\ldots) = f(I_{site}) \qquad (3)$$

where $\sum GDH_{\text{initial flowering}}$ is the requirement of GDH for initial flowering stage. $I_{site}$ was linearly composed by April–May mean temperature, slope and aspect:

$$_{site} = C\ T_{AM} + I_{slope} + I_{aspect} \qquad (4)$$

where $T_{AM}$ is climatic mean temperature from 1st April to 31st May, $I_{slope}$ is an index that varies from 0 to 2 depending on slope and aspect, $I_{aspect}$ is an index that varies from 0 to 2 depending on aspect and C is a coefficient equal to 4.5. Eq. (4) was calibrated as the best performing linear function; $R^2$ for the interpolating line $I_{site}$ – GDH requirement for all sites was close to 1.0 (Fig. 2). Worse relationships were detected using other existing indices (Regniere, 1996) or single variables.

An external validation, as suggested by Chuine (1998), was carried out. With a site-dependent GDH requirement, the model showed its ability in easily encompassing different climatic conditions, both for valley bottom and hillside locations, and it yielded good or acceptable results when applied to locations external to the model development area. In Romagna (one site), for the period 1996–2001, RMSE was, on average, 5.5 days over the period with a maximum error of 11 days); in the Piedmont region (four sites), better results were obtained, with a mean absolute error of 2.2 days for the only available year (2003), and a maximum of 4 days.

## 4 DISCUSSION AND CONCLUSIONS

Results from the identification and application of an optimum model («progressive Utah»), fully satisfy the aims of this study. Errors are smaller than in the application of existing models and, when the model is applied to sites having accurate and long phenological series, they are lower than 2 days, i.e. within the uncertainty implicit in the identification of the exact initial flowering date. The testing of the «progressive Utah» model with a site-dependent GDH requirement gave positive results, even on series collected outside the geographic and, to some extent, climatic context of their original calibration. This is particularly important for the general applicability of the model. The definition of the topo-climatic index "$I_{site}$" seems to fully meet the requirements of simplicity and completeness for the bioclimatic discriminants among sites.

As far as operational applications of the «progressive Utah» model are concerned, at least two are envisaged: blooming prediction and climatology. In the first case, we must acknowledge that blooming does not immediately follow the winter bud stage. On the contrary, four or five other phenophases occur between the two, and approximately in the two weeks before initial flowering, the two previous phenophases follow each another. Then, the flowering stage is not an unexpected event and can be probably better predicted by a direct field observation; the practical use of a phenological model for prediction of blooming is then questionable.

Of wider interest is the climatological use of the model. Its application to sites or, more frequently, for periods with no phenological observation, could generate flowering date series to be used for different purposes. For example, since frost sensitivity sharply increases when flowers open, the blooming model allows the identification, for any year or site, of a period (quite early in spring) at which trees go through a frost-prone stage. This information can be coupled to a climatic series. Constructive results can be inferred, in terms of climatology of frost events, by applying the model to climatic series encompassing past or future periods, when phenological surveys are unknown. The general effectiveness of the «progressive Utah» model makes it a valuable tool in cases of local climatic downscaling, i.e. in areas encompassing different elevation zones, where the phenological model must differentiate outcomes according to microclimatic features.

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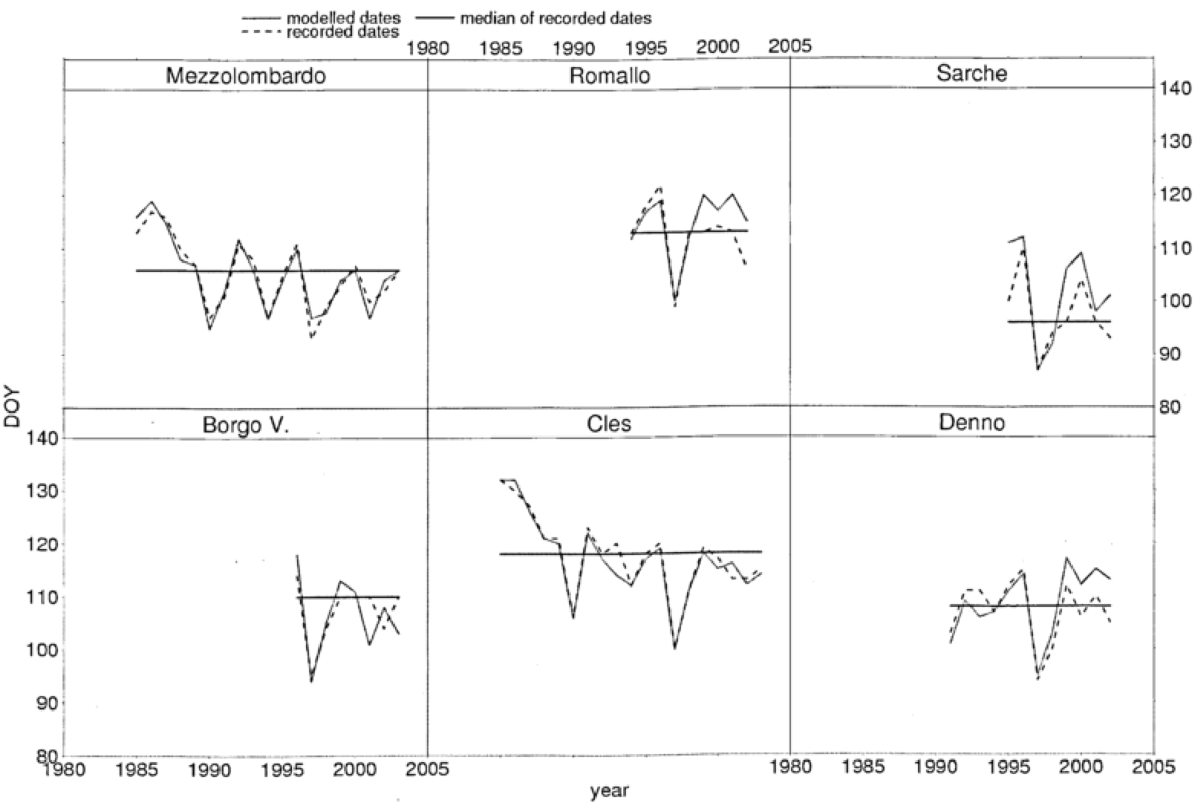


Fig. 1 – Recorded and modelled ("Progressive Utah") dates of flowering for the six stations in Trentino

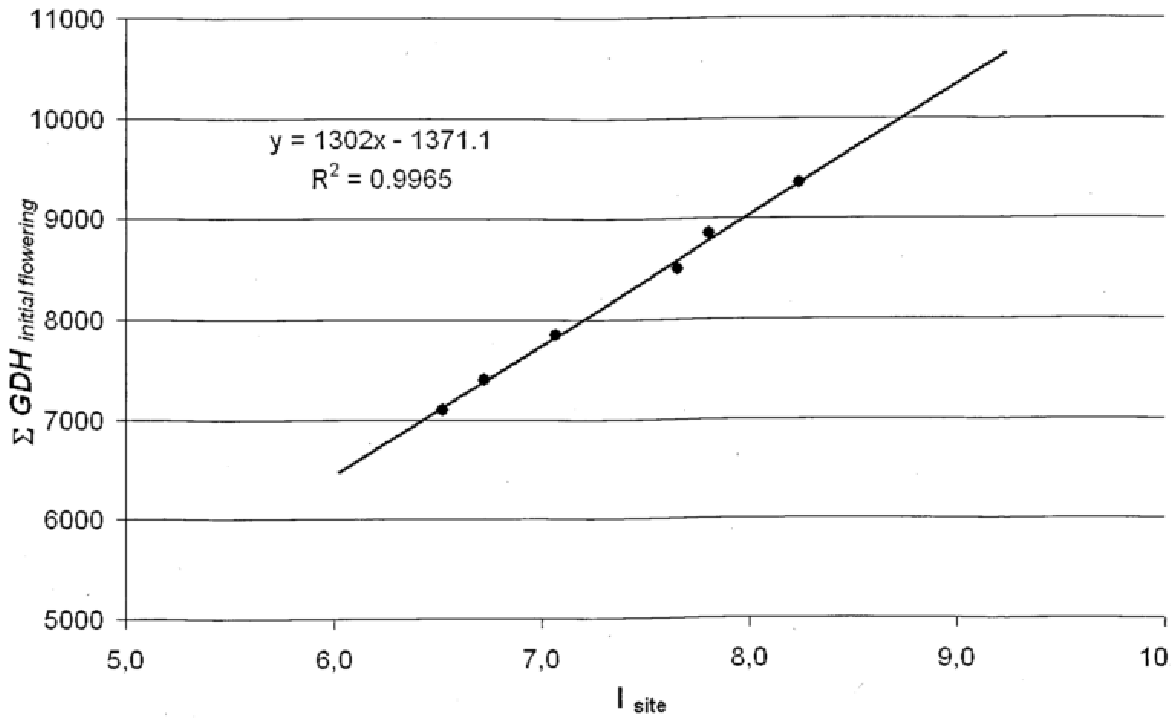


Fig. 2 – Forcing units requirements (GDH) for "Progressive Utah" model as a function of topo-climatic index "$I_{site}$"

# DEVELOPMENT OF INTERCOMPARISON STATEGIES FOR MULTIPLE MEASURES OF THE ONSET OF SPRING

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## 1 INTRODUCTION

Many methods are used to measure the onset and progress of vegetative growth during the spring season in temperate climates. These can be grouped into three major categories: 1) conventional phenological observations of numerous native and indicator plants (both cloned and normal types) recorded by human observers; 2) instrumental measurements of latent-sensible heat energy balance and carbon dioxide flux (related to plant photosynthesis and transpiration); and 3) satellite measurements of vegetative development (derived from visible and near-infrared band reflectance values). All of the measurements are valid (i.e., record a real characteristic related to plant development) but the three categories are looking at different features, and typically have incompatible levels of spatial representation. Even among conventional phenological observations, the differential influences of genetics and weather/climate (typically temperatures) may be difficult to account for between sites.

Given recent and likely future impacts of climate change on spring plant growth, the need to reconstruct past patterns, and the lack of standardized vegetation growth measurements around the world, more intercomparison work is needed to determine the relationship between the various measures, and the degree to which they may serve as substitutes for each other. This paper reports on initial efforts to standardize measurements at two phenology "super-sites" in eastern North America (where large numbers of plants species are monitored together with detailed recordings of atmospheric and remotely-sensed data), and explore strategies to evaluate the comparability of multiple spring vegetative growth measures.

## 2 METHODS

Extensive conventional phenological measurements are available at the University of Wisconsin-Milwaukee Field Station (UWMFS, 43.39°N, 88.02°W), and Harvard Forest, Massachusetts (HF, 42.43°N, 72.19°W) sites. These include bud-burst measurements of the native species (taken since 1990 at HF, and at both sites using the same protocol since 2000) *Acer saccharum, Amelanchier sp., Betula alleghaniensis, B. papyrifera, Cornus alternifolia, Crataegus spp., Fraxinus americana, Hamamelis virginiana, Populus tremuloides, Prunus serotina, Quercus rubra*, and the clone indicator lilac *Syringa chinensis* 'Red Rothomagensis' (since 1993 at UWMFS and both sites since 2000).

HF is an eddy covariance flux tower site, and thus has detailed latent-sensible heat energy balance and carbon flux data since 1990, while a Bowen ratioing system (which provides less-detailed but comparable energy balance data when averaged by day) was installed at UWMFS in 2002.

Both sites are test locations for the MODIS sensor carried aboard the NASA TERRA and AQUA satellites, and thus have 1 km resolution Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) data available for a 7 x 7 (49 pixel) area centered on their locations since 2000. These have been processed using the Delayed Moving Average (DMA) and Smoothed Midpoint NDVI (SMN) methods to produce Start-of-Season (SOS) dates for each spring (Schwartz et al. 2002).

These measures were all standardized at each site to either the Spring Indices (SI) First Leaf date (for early spring events) or SI First Bloom date (for late spring events), which were calculated using daily maximum-minimum air temperatures, available from co-located weather stations (Schwartz 1997; Schwartz and Reiter 2000). Correlations among all the measures were calculated, and graphical displays created using error bars in order to visualize their relative timing.

## 3 RESULTS

The standardization to SI dates allows the sequence of spring development as represented by conventional, instrumental, and satellite measurements of phenology to be effectively compared at each site and between the two sites. The relative timing of the events varies in a systematic way, with events at UWMFS proceeding earlier in phenological time than at HF.

## 4 DISCUSSION

Phenological responses differ between sites in a predictable fashion that is especially noteworthy between cool northern sites and warmer southern sites. This is because northern species are used to growing more efficiently with less energy than their southern counterparts. This effect has been demonstrated in numerous experiments were members of the same tree species have been brought from multiple sites to a single location. Schwartz (1992) showed that this effect could be detected on a continental scale using meteorological measurements.

## 5 CONCLUSION

In order to provide a context for understanding future changes, it will be important to develop a strategic approach for intercomparison of phenological events between sites. For those sites where daily maximum-minimum air temperatures are available, the Spring Indices (SI) are an effective method to standardize various measures to a common base, and may facilitate studies aiming to reconstruct past patterns and determine comparability of parallel measures.

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# A MULTIVARIATE ANALYSIS OF VARIABILITY AND TRENDS IN ALPINE SPRING PHENOLOGY

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## 1 INTRODUCTION

As a consequence of global climate change considerable impacts on ecosystems have to be expected In this context there is growing interest in the traditional, easy to observe plant phenological long-term observations as indicators of the influence of climate change on terrestrial ecosystems. An increasing number of studies show evidence of a shift in plant development towards an earlier onset of spring in Europe (Menzel, 2000; Roetzer et al., 2000; Defila and Clot, 2001; Menzel et al., 2001; Ahas et al., 2002) and in North America (Beaubien and Freeland, 2000; Schwartz and Reiter, 2000; Cayan et al., 2001). The trends found for several species and phases range from -1.4 to -3.8 days per decade over the last 50 years.

The aim of this study is to assess a representative spring pattern of plant phenological development over the past 40 years in the Alpine region and to quantify the impact of the variability of climate parameters such as temperature and precipitation thereon. We combined a wide range of spring phases from different species into a 'statistical plant' and applied robust multivariate methods to establish a spring phenology index and to assess the impact of temperature and precipitation on the phenological development (Studer et al., 2005).

## 2 METHODS

The data source was the Swiss phenological observation network consisting of a total of 69 observation stations with the longest series recorded since 1951. To provide a sufficient sample size, only time series from 1965 to 2002 were included in the analysis. 15 phenological spring phases (Table 1) were combined into one single multispecies data set. Altitudes of the observation stations range from 200 m asl (Locarno) to 1800 m asl (St. Moritz). Homogenised station data from 12 meteorological stations for temperature and precipitation were used as climate parameters (Begert et al., 2004). Temperature values for the phenological observation sites were calculated by applying a height correction factor to the daily mean temperature of the nearest of the 12 stations. Growing degree days (GDD) were calculated on the basis of the local daily mean temperatures by using the formula:

$$\sum_{i=1}^{k} \max[0, (T_m - T_0)]$$

where Tm = daily mean temperature, T0 = threshold value. The sum runs over all days with Tm > T0 between January 1st (i = 1) and the long term mean appearance date of the respective phenological phase (k). Considering the range of appearance dates from early spring to summer, an intermediate threshold value of 4 °C was chosen. In the following analyses the term temperature refers to growing degree days (GDD). The number of days with more than 3 mm precipitation between January 1st and the long term mean appearance date was included in the analyses as a measure of the water supply for the plants in the analysed years. To eliminate the altitude dependence and to provide comparability among the different parameters all time series were normalised.

The most important patterns of the phenological and climate year-to-year variability were identified by empirical orthogonal function analyses (EOF) (Bretherton et al., 1992). The time evolution of the dominant patterns (EOF one) was used to determine a robust trend estimate for the Swiss Alpine region. To statistically describe the link between the variability in phenological patterns and the variability in climate parameters multiple regression analysis was performed.

## 3 RESULTS

The dominant phenology pattern assessed by EOF analysis accounted for 39 % of the total variability in the phenological data (Table 1), while the three leading patterns together accounted for 54 % of the total variability. For temperature and precipitation the dominance of the first mode was even more pronounced with 74 % and 68 % explained variability respectively.

Table 1. Explained variance (%) by the first two EOF modes of phenology, growing degree days (Temp. GDD), precipitation (Precip) and mean trend over all stations in phenology in days per decade (Trend. pheno) with the corresponding P values (linear trend regression).

| EOF mode | Phenology | Temp. (GDD) | Precip. | Trend pheno | P value |
|---|---|---|---|---|---|
| 1 | 39 | 74 | 68 | -1.5 | 0.007 |
| 2 | 9 | 9 | 12 | 0.06 | 0.0002 |

The time evolution of the appearance dates in phenology is shown in Figure 1. From 1965 until 1988 no trend in the timing of the phenological events was evident. The same is true for the period 1989 to 2002, but in these 14 years the PC pattern clearly indicated the earlier appearance of phenological events. The overall linear trend found in the leading pattern revealed -1.5 days per decade earlier appearance of spring phenological events and is mainly due to the clear shift in level around 1988. Considerable correspondence was evident in the normalised first EOF time series between phenology and temperature ($r = -0.94$; $p < 0.01$) (Figure 1). Early appearance dates were registered in years with warmer winter and spring temperatures. The relationship between the leading phenology pattern and number of days with considerable rainfall was much weaker and not statistically significant ($r = 0.28$; $p = 0.09$).

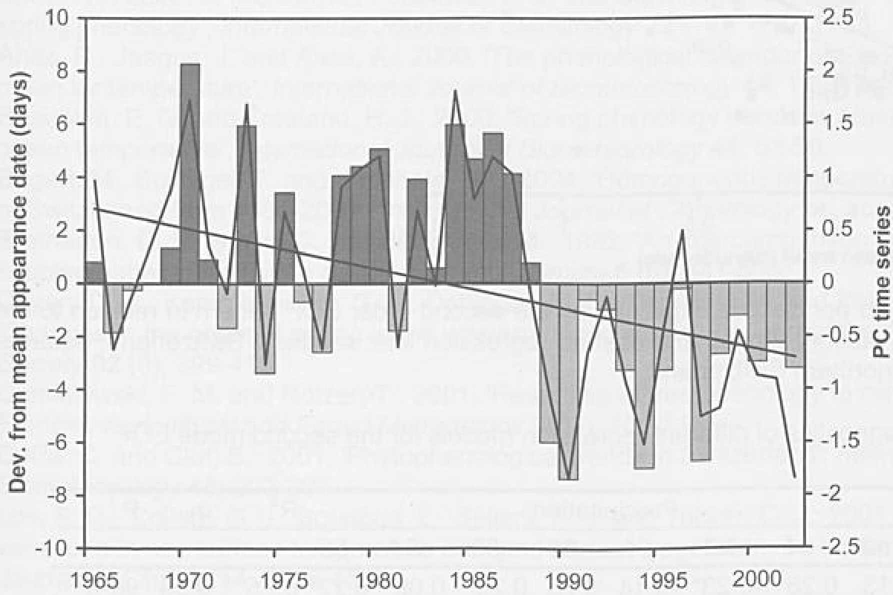


Figure 1 Mean phenology trend over all stations 1965 - 2002 (bars) and normalised leading PC time series temperature (GDD) (line). Left scale: deviances from the mean appearance date (phenology) in days. Right scale: standardised PC time series.

Table 2. Multiple regression for the first mode EOF phenology time series. The columns αi and βi give the regression coefficients of the PC time series of the EOF modes 1 to 5 from the temperature and precipitation analyses. Squared multiple correlation coefficient ($R^2$), residual standard error ($\sigma_E$ ) and P-value of the F-statistic (P) are given in the last three columns; * indicate 95 % significance of the respective coefficients.

| Model | Temperature | | | | | Precipitation | | | | | $R^2$ | $\sigma_E$ | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\alpha 1$ | $\alpha 2$ | $\alpha 3$ | $\alpha 4$ | $\alpha 5$ | $\beta 1$ | $\beta 2$ | $\beta 3$ | $\beta 4$ | $\beta 5$ | | | |
| Combined | -0.96* | -0.002 | 0.19* | -0.01 | -0.02 | 0.0003 | 0.03 | -0.01 | 0.04 | 0.09 | 0.93 | 0.31 | <0.001 |
| Optimal | **-0.94*** | | **0.2*** | | | | | | | | **0.92** | **0.3** | **<0.001** |

The first EOF mode was dominated by a spatially homogenously distributed trend in time evolution and without considerable regional effects. In contrast, the second EOF phenology pattern, which explained 9 % of the total variance in the phenological data, revealed no considerable trend (The dominant phenology pattern assessed by EOF analysis accounted for 39 % of the total variability in the phenological data (Table 1), while the three leading patterns together accounted for 54 % of the total variability. For temperature and precipitation the dominance of the first mode was even more pronounced with 74 % and 68 % explained variability respectively.

**Table 1**) but an interesting regional pattern (Figure 2). Stations in the lowlands tended to negative values whereas highland stations rather exhibited positive values. Additionally stations on the southern side of the Alps generally tended to later appearance dates but did not show a significant altitude dependence ($R^2 = 0.02$, $p = 0.6$) (Figure 2). In contrast, the pattern on the northern side of the Alps was found to be highly dependent on the altitude of the stations (R2 = 0.33, $p < 0.001$). To explain the pattern on the second phenology EOF, a combination of temperature and precipitation parameters was selected as optimal model (Table 3).

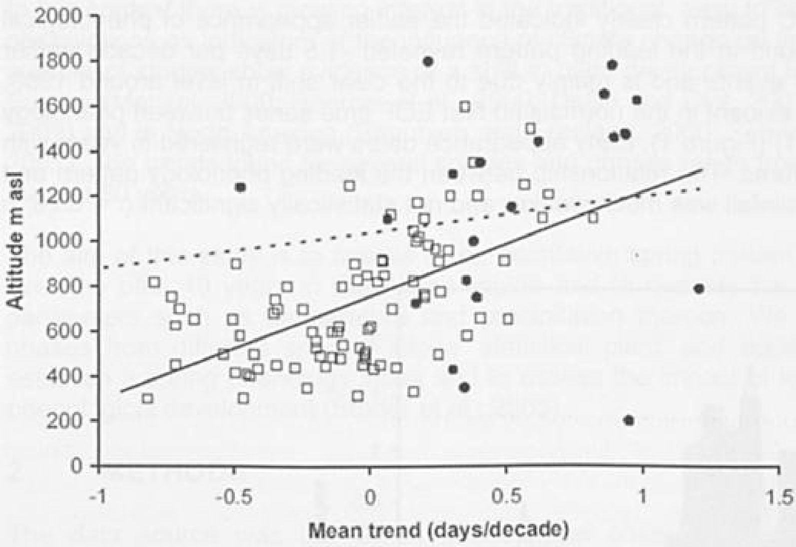


Figure 2. Mean trend in days per decade explained by the second order EOF pattern in relation to the altitude of the observation station. Circles and dashed regression line: southern Switzerland; squares and black regression line: northern Switzerland.

Table 3. As Table 2 but diagnostics of different regression models for the second mode EOF phenology time series.

| Model | Temperature | | | | | Precipitation | | | | | $R^2$ | $\sigma_E$ | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *α1* | *α2* | *α3* | *α4* | *α5* | *β1* | *β2* | *β3* | *β4* | *β5* | | | |
| Combined | -0.08 | -0.48* | 0.13 | 0.28* | -0.23* | -0.14 | 0.25 | 0.26 | 0.08 | 0.22* | 0.75 | 0.59 | 9e-6 |
| **Optimal** | | **-0.5*** | | **0.23** | **-0.26*** | | **0.26*** | **0.3*** | | **0.23*** | **0.72** | **0.58** | **2.1e-7** |

## 4 DISCUSSION AND CONCLUSION

We defined a 'statistical plant', using an EOF analysis on a composite of 15 different phenological phases. This statistical plant proved to be a good approach to assess the pattern of spring appearance during the last 40 years and showed that spring appearance was clearly happening earlier in recent years, mainly since 1988, when a clear shift in spring appearance dates occurred.
Similar shifts towards earlier appearance dates of various phenological spring phases, especially since the end of the 1980s, have also been observed by (Ahas et al., 2000), (Van Vliet et al., 2002), (Chmielewski and Rötzer, 2001) and (Scheifinger et al., 2002) for Europe.

Temperature was found to be the main driving factor for this behaviour. Our regional results are consistent with the two global meta analyses recently published by (Parmesan and Yohe, 2003) and (Root et al., 2003).
Although precipitation is not of critical importance to assess the large scale phenological development, it seems to be of some importance in explaining more regional effects. The clear north – south and altitudinal pattern on the second phenology EOF was influenced by both temperature and precipitation. The more regional influence of precipitation may be due to the fact that precipitation is mainly an important parameter in regions where moisture generally is a limiting factor (Los et al., 2001), which is the case in southern Switzerland where very dry periods in spring are common.

This second order pattern may be seen as regional correction factor to the strong overall trend represented in the first EOF mode. The trends found on the leading phenology mode therefore slightly underestimated the trend for lowland stations, and rather overestimated the trend for higher elevated sites. The trend in the southern part of the country was also overestimated. These geographical patterns indicate the high potential for phenological research in Switzerland due to its manifold topographies and climatic conditions.

The multivariate method that is often applied in climatological studies gives the opportunity to separate the relevant patterns from background variability or 'noise'. In the present study the regional patterns found on the second phenology EOF would probably not have become apparent by averaging over the 15 selected phases. The combination of different species and the application of a multivariate approach together successfully led to the desired extraction of the general patterns of spring phenology in time and space and the general development of the onset of spring in Switzerland could be described.

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# VARIABILITY OF THE START OF THE GROWING SEASON IN FENNOSCANDIA BETWEEN 1982 AND 2002


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## 1 INTRODUCTION

Fennoscandia and adjacent parts of northwest Russia are characterized by strong climate gradients running from north to south and from west to east. The regional variation in vegetation is associated with these contrasts in climate and can be expressed in terms of vegetation zones and sections. Vegetation zones are considered to mostly reflect temperature sums, whereas vegetation sections mostly indicate oceanity gradients (Fig. 1, Moen 1999). Hence, vegetation phenology might respond differently to climate change according to vegetation zones and sections. The boreal zones and the alpine belts within the continental sections are characterized by a short growing season (Karlsen et al. in press.), and even small changes in the start of the growing season (SGS) may have a large impact on these ecosystems. The start of plant phenological phases in spring depends strongly on the temperature regime in this period (e.g. Chmielewski & Rötzer 2002, Karlsson et al. 2003, Shutova et al. this vol., Wielgolaski 1999). In alpine areas greenness is also strongly linked to snow-free conditions (Inouye & Wielgolaski 2003, Moula et al. 2005).

When analysing phenology, satellite images provide a spatially complete coverage that can be used to interpolate traditional ground-based observations. Particularly, changes in the remote sensing based Normalized Difference Vegetation Index (NDVI) values are useful to map the SGS at a coarse spatial resolution (e.g. Schwartz et al. 2002). The NDVI is defined as: NDVI = (Ch2-Ch1)/(Ch2+Ch1), where Ch1 is red light reflectance and Ch2 represents near infrared reflectance. A number of studies confirm the relationship between climate variability and fluctuation in NDVI values (e.g. Yang et al. 1997, Gong & Shi 2003).

This study uses the GIMMS-NDVI satellite dataset to map the annual and spatial variability of the NDVI-based SGS across Fennoscandia for the period 1982-2002, and identifies corresponding climatic parameters according to vegetation zones and sections.

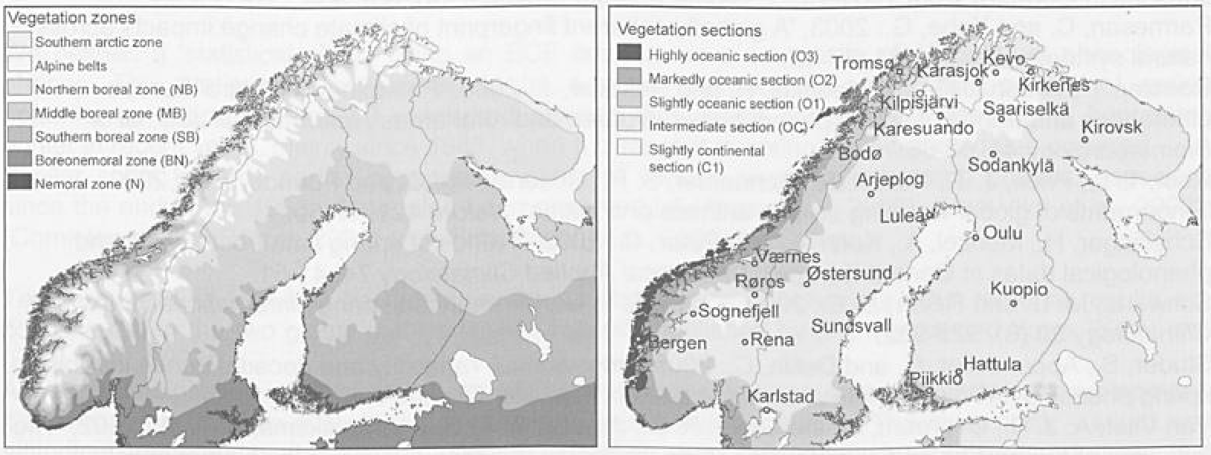


Figure 1. Vegetation zones and sections in the study area according to Moen (1999), redrawn with permission, and showing the position of the meteorological stations used in this study.

## 2 METHODS

We used the NDVI dataset produced by the Global Inventory Monitoring and Modelling Studies (GIMMS) group at NASA Goddard Space Flight Center. It is produced from data acquired by the AVHRR instrument onboard the afternoon-viewing NOAA satellite series. The GIMMS-NDVI dataset has 8 x 8 $km^2$ spatial resolution and is composed of the maximum NDVI value for half-month periods for the period July 1981 to December 2002. Specifications of the dataset are given by Tucker et al. (2001).

In a bioclimatic study, Karlsen et al. (in press) used the GIMMS-NDVI to find the mean SGS in Fennoscandia, based on correlations between NDVI and field observations of the onset of leafing of birch (*Betula* sp.). To link surface phenological data with NDVI data they used a method based on pixel-by-pixel threshold values. The current study uses the same dataset and method for estimating SGS.

We produced a map for each of the 21 years showing the deviations in SGS from the mean SGS in the 1982 to 2002 period. As climate data, we used air temperature and snow data from 21 meteorological stations across the study area (Fig. 1). For each of the stations, the dates of passing 5, 7, and 10° C thresholds were calculated, based on 21-days moving average values from daily mean temperature data. The last day of continuous snow cover was defined as the first snow free day, not succeeded in the same year by any period of 5 days or longer with snow cover. We analysed the correlation and time differences between the SGS and both the last day of snow cover and the dates of passing the different threshold temperatures. The results were then analysed according to vegetation zones and sections.

## 3-4 RESULTS - DISCUSSION

Figure 2 shows the maps for the first six years of the 21 year period, with each map depicting the deviation in the SGS from the average for 1982 to 2002. The year 1985 appears to be the most extreme in terms of generally late SGS, except in western Norway (Fig. 2). Other years had late SGS as well but more locally. The SGS in 1982 for example was late but not in southern Norway and southernmost Finland. The year 1983 shows a late SGS in southern Norway and southern Sweden, while the years 1987, 1995, and 1997 show a late SGS in most of central Fennoscandia, and the year 2000 a late SGS in the northern continental parts (the NB-C1 region, Fig. 1).

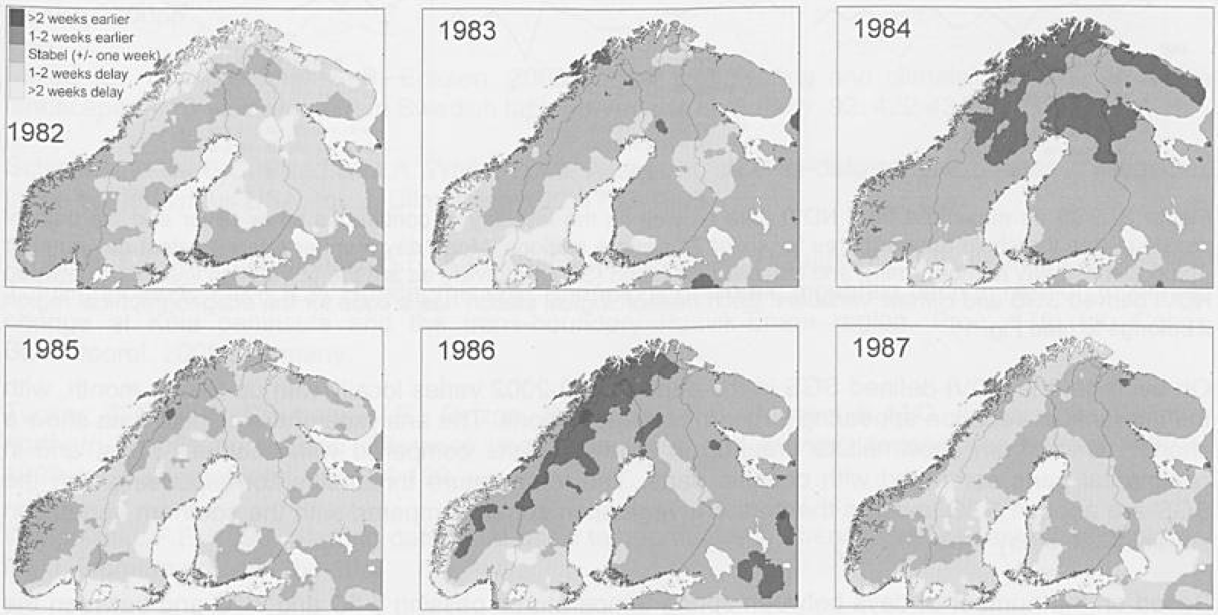


Figure 2. Regional deviation in the SGS from the 1982-2002 average. Only the first six years in the 21-years period are shown.

When it comes to early SGS, the year 1990 was by far the most extreme, showing early or very early SGS in the entire study area, except for the alpine parts. At 13 of the 21 climatic stations, the earliest SGS of all 21 years occurred in 1990. Most exceptional was the SGS at the climatic station Piikkio in southwesternmost Finland, where the NDVI data showed the SGS 25 days before the 21 year average (17 April vs. 12 May). The year 2002 was in general also early, particularly in the northern parts of the study area. The years 1984 and 1986 were early in the northern oceanic parts (Fig. 2).

Figure 3 shows the relationship between the SGS and climatic parameters at six of the 21 meteorological stations. All of the 21 stations show a positive correlation between the last day of continuous snow cover and the NDVI-defined SGS, with a mean correlation value (r) of 0.62, and ranging from 0.28 to 0.83. There is a trend of higher correlation between the disappearance of snow and SGS for northern stations, with the seven stations within the NB zone having a mean correlation value of 0.69.

The SGS correlated slightly less with the temperature data than with the last day of continuous snow cover, with mean r values of 0.47, 0.41, and 0.30 for the passing of 5, 7, and 10 °C thresholds, respectively. However, some negative outliers in the SGS estimates reduce these mean correlation coefficients. In some years the SGS maps show regions with exceptionally early SGS which are in disagreement with threshold temperatures. For example, at the station Karlstad in southernmost Sweden in 1997 the map shows the SGS 35 days earlier than the average while the temperature data indicate a normal year (Fig. 3). When we remove the year 1997, the correlation value between the SGS and the day of passing 7 °C increases from 0.44 to 0.66. These very early dates of SGS in a few regions and years are probably due to errors of the GIMMS-NDVI dataset or a weakness in the method used for estimating SGS, since phenological field data support the climatic data.

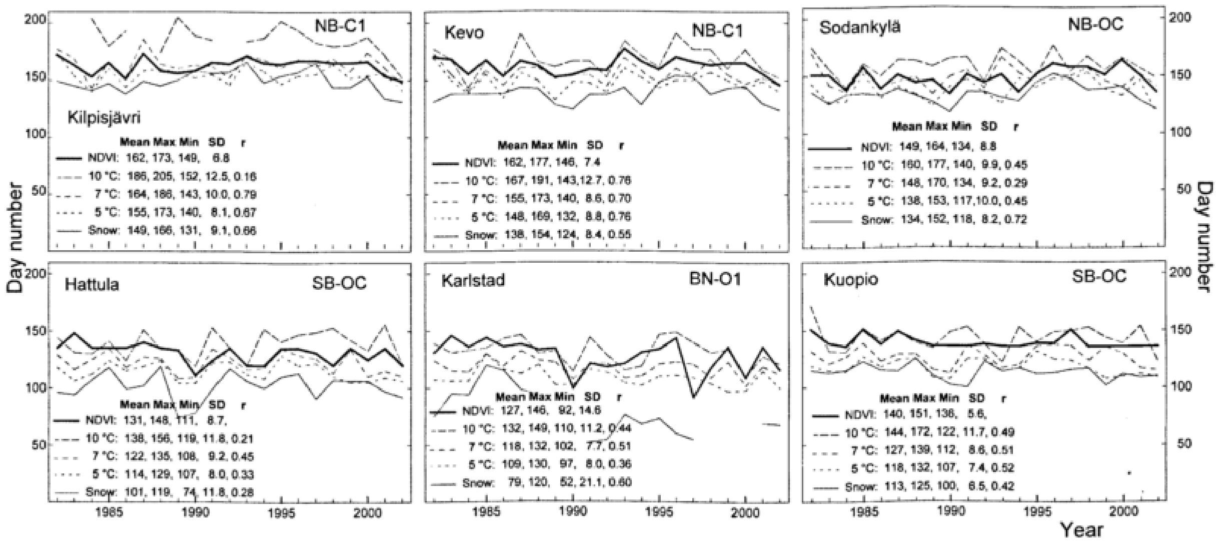


Figure 3. SGS as measured from NDVI data as well as the last day of continuous snow cover and the date of passing three threshold temperatures for six of 21 climate stations. Mean day number (mean), latest day number (max), earliest day number (min), and standard deviation (SD) are given, as are the correlation values (r) between NDVI derived SGS and climate variables. Each meteorological station has a code for the ecogeographical region it belongs to (see Fig. 1).

On average, the NDVI-defined SGS in the period 1982-2002 varies locally with up to one month, with the interannual variation appearing larger in oceanic regions. The analyses of the climate data show a shorter period from snowmelt to greenup in northern parts compared with southern parts, and in continental parts compared with oceanic parts. The temperature thresholds corresponding with the SGS are about 1.5 °C lower in the northern vegetation zones compared with the southern vegetation zones of the study area.

Based on the number of days between spring temperatures passing 5 °C and 7 °C and between the passing of 7 °C and 10 °C we estimated the effect of a 1 °C temperature difference on the SGS. The overall mean is 5.4 days change in SGS per 1 °C temperature change, however there is a clear trend according to the degree of oceanicity.

## 5 CONCLUSION

This study shows that the SGS corresponds with different temperature thresholds within Fennoscandia, and that the thresholds follow a pattern according to vegetation zones and sections. The preliminary results indicate that the NDVI-defined SGS varies locally between years by as much as one month, with a trend towards larger variation in oceanic regions. In the northern vegetation zones the SGS correspond with about 1.5 °C lower threshold temperatures compared with southern zones within the intermediate section of Fennoscandia.

The preliminary results also indicate that a 1 °C increase in April-May temperatures in general results in the SGS occurring five to six days earlier. However, there is a clear trend following the degree of oceanicity. At the most oceanic parts a 1 °C increase corresponds roughly with seven to nine days earlier greenup, compared to less than five days earlier greenup in continental parts.

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# ANALYSIS OF LONG-TERM PHENOLOGICAL RESPONSES TO CLIMATE CHANGE IN EUROPE BY BAYESIAN STATISTICS

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## INTRODUCTION

The detection and attribution of climate change related responses in observational data remains a topic of increasing interest and importance. For various pheno logical networks across Europe, a nearly coherent pattern of progressively earlier onset of spring and summer phases and, less homogeneously, a later end has been revealed. However, there are indications for regional variations, e.g. more pronounced changes in the maritime western and central part of Europe (Menzel & Fabian 1999, Ahas et al. 2002). Former studies were mostly based on linear trend analyses. Here, we use the new method for the analysis of phenological time series based on the Bayesian concepts, recently presented by Dose and Menzel (2004). Our results provide a quantitative representation of changes in observational data, and thus allow a rigorous larger scale attribution of these observed responses.

## DATA AND METHODS

Our challenging, comprehensive phenological data set consisted of long term observational records (> 30 yrs) within the 1951-2000 period across main parts of central Europe (A, CH, D, SLO, PL, EST, RUS), out of which we s elected 2600 quality checked records of 90 phases (mostly in spring and summer) . A smaller unified subset consisted of 8 phases in 4 countries with complete records (19681999) for a substantial number of stations. Following the Bayesian approach of non-parametric function estimation by Dose and Menzel (2004), we tested 3 models (constant, linear, one-change point model) and determined the rates of change (trends) as well as the corresponding change point distributions in these multiple phenological time series.

## RESULTS

The functional behaviour of all 2600 European time series is best represented by the one-change point model (on average 62 %), whereas the linear model ranks with 24% mean probability second. Thus, a constant functional behaviour is the least likely alternative. Even if there exists a great diversity between the countries and locations across Europe, an overall trend towards an earlier flowering can be determined at most places. The spatial analysis of spring events reveals larger changes, more synchronous trends and change point probability distributions in the western part of Europe.

## DISCUSSION

This study demonstrates that the Bayesian approach is an advanced method for the identification changes in phenological records and may allow an better larger scale attribution of these changes to the temperature rise in the second half of the $20^{th}$ century.

# SINGULAR SPECTRUM ANALYSIS: AN ADDITIONAL TOOL FOR EXAMINING PHENOLOGICAL TIME SERIES?

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## 1 INTRODUCTION

The recent phenological literature has highlighted the need for additional methods for examining time series (Dose & Menzel, 2004; Keatley et al., 2004; Sparks & Tryjanonwski, 2005). Singular spectrum analysis (SSA), introduced by Colebrook (1978 in Elsner & Tsonis 1996), is now routinely applied to geophysical and climatic data (e.g. Allen et al., 1994; Elsner & Tsonis, 1991; Ghil et al., 2002; Ghil & Vautard, 1991; Masson et al., 2000; Vautard & Ghil, 1989; Yiou et al., 2000). SSA is not, however, widely applied to phenological data (D'Odorico et al., 2002; Hudson et al., 2004; Studer et al., 2003). SSA is a linear approach which can decompose a time series into its underlying components (e.g. trends, oscillatory modes or seasonalities, changepoints & noise) and is useful for short, noisy time series (Allen & Smith, 1996; Elsner & Tsonis, 1996; Golyandina et al., 2001; Vautard et al., 1992), of which many phenological datasets are.

## 2 METHODS

A twenty year (1983-2002) record of the first flowering dates of 3 perennial plant species *Acacia myrtifolia*, *Glycine clandestina* and *Wahlenbergia stricta* were examined by SSA using Caterpillar™ software to identify trends. This method involves 2 stages each with 2 steps. The original time series is decomposed (stage 1) via embedding and singular value decomposition (SVD) and then reconstructed (stage 2) by grouping the SVD components and diagonal averaging (Golyandina et al., 2001).

The window length used was 10 which equates to 10 years. The window length used is dictated by "quantity of information extracted versus the degree of statistical confidence in that information" (Ghil et al., 2002).

A scree diagram (eigenvalues $\lambda_k$ plotted against $k$) was used to determine which of the principal components should be considered (Ghil et al., 2002; Vautard & Ghil, 1989). Eigenvalues which have the same amplitude and are harmonic (or almost) (Golyandina et al., 2001) are considered oscillatory pairs and may be grouped. The eigenvalues which are above the noise floor are those which are considered 'significant' (D'Odorico et al., 2002; Shun & Duffy, 1999; Vautard & Ghil, 1989).

These species' first flowering dates were also examined by simple linear regression (SLR) to enable comparison with one of the most popular methods for examining phenological time series.

## 3 RESULTS

SLA found *Acacia myrtifolia* and *Glycine clandestina* had significant changes ($P$ = 0.031 and $P$ < 0.001, respectively) in their date of first flowering (Fig 1). Using the derived equations these changes are an advance of 2.1 days/year (overall 42 days) in the flowering dates of *A. myrtifolia* and a delay of 2.3 days/year (46 days) in *G. clandestina*. Although the change in *Wahlenbergia stricta* was not significant ($P$ = 0.192) the negative trend equates to an advance in flowering of 0.75 days/year (15 days).

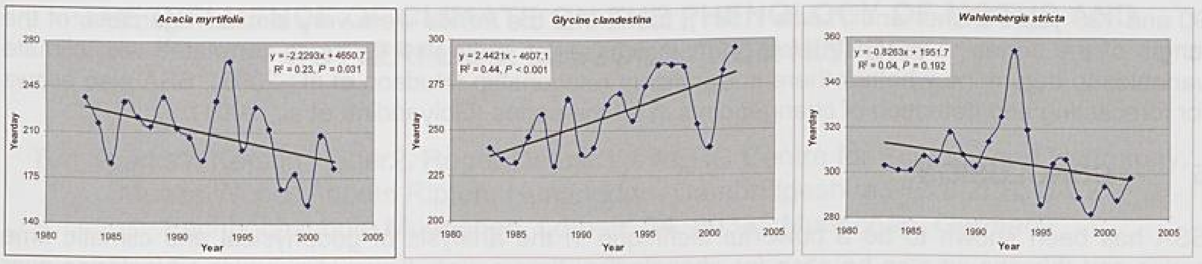


Fig 1. SLR trends in first flowering dates of the 3 plants

SSA identified the trend in the first flowering dates as significant in all 3 species – was above the 'noise floor' and accounts for >99.6% of the variation in the data (Fig 2). Of these only the trend of *G. clandestina* is close to linear.

The trend and advance in the number of days in first flowering dates of *W. stricta* indicated by the SSA agrees with the SLR results; 0.75 days/year, with the shift to earlier flowering commencing in early 1988. The trends indicated by SSA for *A. myrtifolia* and *G. clandestina* also agree with the SLR results but there is a difference in the number of days. The advance in the flowering dates of *A. myrtifolia*, which commenced in 1987, of 1.15 days/year (23 days) is less than with the SLR (2.1 days/year). There was closer agreement with the delay in flowering in *G. clandestina* between SSA and SLR, 2.6 days/year compared to 2.3 days/year.

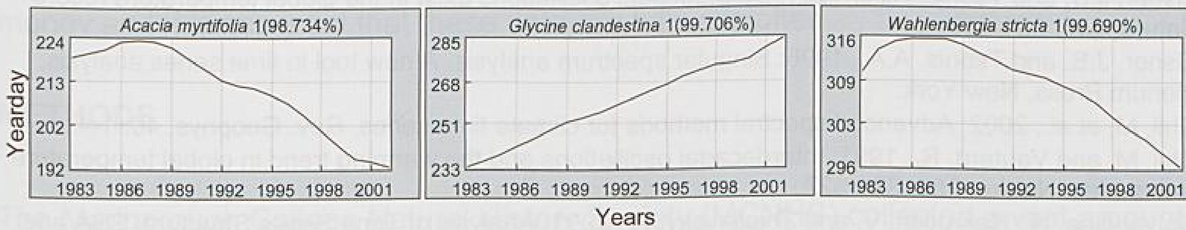


Fig 2. Trend determined by SSA in first flowering dates of the 3 plants

## 4 DISCUSSION

In this study, there was agreement between SSA & SLR in overall trend. There were, however, differences between methods in the size of shift in first flowering dates in *A. myrtifolia* and *G. clandestina*. It is not currently possible to determine which result is more accurate in relation to the rate of change.

SLR is one of the more popular method used in analysing phenological time series but has limitations (Sparks & Tryjanonwski, 2005) the slopes are influenced by the length of the phenological series, as well as when the series commences and finishes (Sparks & Menzel, 2002).

With SSA the leading eigenvectors or empirical orthogonal functions (EOFs) usually contain the trend (Golyandina et al., 2001; Vautard et al., 1992). These are usually above the noise floor and therefore considered 'significant'; however, more work is required on the statistical significance of these (Elsner & Tsonis, 1996). The resulting components of the analysis are also influenced by window length which is currently determined by the user. Understanding possible components within the series therefore assists in determining window length and interpreting the results (e.g. some patterns which appear to have a biological/physical basis can be noise) (Allen & Smith, 1996, Golyandina et al., 2001). Whether changes in window length also results in significant changes in the trend (if there is a trend in the series being analysed), and therefore rates of change, also needs further examination.

One significant disadvantage is the assumption that datasets are complete but methods to deal with this have been developed (Kondrashov et al., 2005; Schollhamer, 2001).

The advantages that SSA has over SLR are that it has no specific distributional assumptions and can cope with non-stationary data. SSA also overcomes the enforced linearity that SLR imposes. Additionally, in a study of 3 datasets of global surface air temperature which varied in length between

90 and 130 years Elsner and Tsonis (1991), found that the trends were very similar regardless of the length of the series. A reconstructed phenological series may also be cross-correlated with climate variables to determine whether there is significant relationship (Hudson et al., 2005). SSA also allows for forecasting and detection of changepoints in a time series (Golyandina et al., 2001).

## 5 CONCLUSION

SSA has been shown to be a powerful technique in the analysis of geophysical and climatic time series and this should also be case for phenological time series. It provides major advantages over SLR (e.g. deconstruction into underlying components) but more work is needed in determining the statistical significance of trends.

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# THE INFLUENCE OF CLIMATE ON THE PHENOLOGY OF MOTHS AND BUTTERFLIES: LESSONS FROM HISTORY

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## INTRODUCTION

Historical data can provide valuable evidence on the effects of temperature and other climate variables on the phenology of species, both plant and animal. For some species that have no current phenological monitoring, examination of past data is the only way we can understand the likely effects of climate change on the timing of its life cycle. Furthermore, historic data were co llected at an enormous cost in time and money and it is essential that these data are fully exploited.

## METHODS

The Marlborough College Natural History Society (MCNHS) collected a vast amount of phenological data in the mid-nineteenth century. The Society's founder, the Rev TA Preston, was later fundamental in the founding of a scheme to cover the whole of the British Isles organised by the Royal Meteorological Society. In 1885 The MCNHS published the first 19 years of its results. In this presentation we focus on the first observations in 1866-1884 of Lepidoptera (butterflies and moths) because the phenology of moths, in particular, is rarely studied.

## RESULTS

Over 500 species of Lepidoptera are included in the MCNHS report. We have focussed on the 155 species for which at least 10 years of data were present. We have examined these in relation to minimum, maximum and mean temperatures, rainfall and cloud cover recorded at Marlborough. Over 50% of the species display a significant response to one or more of t he climatic variables. Furthermore, an attempt has been made to ascertain whether the response to climate of these species falls into any natural or logical groupings.

## DISCUSSION

Since the phenology of moths has been rarely reported this use of historical data is valuable in increasing our understanding of the effects of climate on life cycle timings. The Lepidoptera include species of high conservation status and high pest status, and species of both low and high (migratory) mobility. As such they are an interesting group with which to further the study of climate impacts.

# PHENOPHOT: PHOTOMETRIC EVALUATIONS OF PHENOLOGICAL GROWTH STAGES IN FOREST STANDS: APPLICATION TO CLIMATE MONITORING USING DIGITAL IMAGE ANALYSIS.

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Phenological shifts have been observed in both regional phenological observations and global indices like NDVI, derived from remotely sensed data. Phenological variables to evaluate these shifts are start of growing season (SOS), end of growing season (EOS) and the growing season length (GSL). Different methods to determine these variables, however, yielded different absolute values. The European Phenological Network (EPN) has made big efforts to standardize phenological observations by allocating phenophases to the plant growth stages of the BBCH-Code. Whereas phenophases report fix dates (day of year, DOY) of the plant development, indices like NDVI and LAI could be calculated for each day, report the seasonal change of the vegetation. The COST 725 - project P HENOPHOT will close the temporal and spatial gap between these data-types, focussing on improving the accuracy of phenological observation by using the high temporal and spatial resolution of the digital information.

Since September 2004 a permanently installed digital photo camera has been collecting images at the "National Air Pollution Monitoring Network" (NABEL) station "Lägern" in Switzerland (mixed beech-forest). Standardized methods will be used in image recording and processing to minimize the influence of changing sun-surface-camera geometry trough the year and the visibility due to water vapour and aerosols in the troposphere. Some detailed studies investigate daily changes of the ratio caused by different illumination angle. According to species composition and distance to the camera position, test areas will be applied on the image-file. Preliminary results present the daily phenological development, emphasizing the detailed progression of leaf senescence. The G/R-ratio will be evaluated in all areas to quantify the changes in leaf unfolding and senescence. Other ratios will be evaluated and compared with ground observations.

Most of the selected widely spread plants in the common European reference data set of phenological observation are woody plants (Robinia, Betula, Fagus, Quercus, Sambucus, Corylus and others). Setting up observational procedures and quality assurance is an important topic of COST-Acton 725. The digital image data set of a mixed deciduous forest site and its evalutation will provide valuable benefit concerning these activites, especially for autumnal phenophases.

# INCREASING THE SOCIO-ECONOMIC VALUE OF PHENOLOGICAL MONITORING NETWORKS: EXPERIENCES FROM THE NETHERLANDS

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## INTRODUCTION

The primary objective of phenological monitoring networks is the monitoring of the timing of life cycle events. The strong focus on monitoring limits the financial support for the long-term continuation of these networks. Focusing on new socio-economic themes provides new opportunities for adding value to the data gathered. The increased added value will increase public interest in the networks, the number of funding sources, the success of acquisition and the number of observers that are willing to participate. However, it is still unclear in what way phenological networks increase their added value. Furthermore, there is no overview of the factors that facilitate the process of broadening the scope of phenological networks. The development of the Nature's Calendar programme in The Netherlands provides new insights in how to increase the added value.

## METHODS

The Nature's Calendar programme of the Netherlands is presented as a case study in this paper. The experiences of the last five years are used to analyse the processes and stakeholders involved in broadening the scope of phenological monitoring networks. We provide an overview of the factors that facilitate or limit the speed of the network development and the acquisition of funding.

## RESULTS

Phenological monitoring networks can add value to the following sectors: nature management, agriculture, gardening, tourism & recreation, human health, environmental communication, education and transportation. In order to realize the added value the phenological networks have to cooperate with a large number of stakeholders in various disciplines ranging from the private sectors, NGO's, scientists and media. The focus on other themes and activities provides a whole range of new funding opportunities. It also increases the popularity and visibility which results in an increase of the number of volunteers.

# PHENOLOGY OF NORDIC MOUNTAIN BIRCH IN RELATION TO CLIMATE CHANGE AT KOLA PENINSULA AND THE TRANS-BOUNDARY PASVIK-ENARE REGION

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## 1 INTRODUCTION

The interest on effects of climate change through the last decades of the previous century and presently also has increased the interest on phenology. The effects of a global warming are considered to be particularly important in the north due to the short growing season (Walker et al. 1995). Through the period 1982-1999 spring has seemed to be earlier and the growing season longer in lowland regions in Fennoscandia and along most of the coast of Norway (e.g. Høgda et al. 2001), probably due to the climate change by the positive North Atlantic Oscillation (Wielgolaski et al. 2004). However, in mountain areas and in cold, continental regions in the north of the region, an increased precipitation by this climate type often has come as snow, which may influence plant phenology and the growing season (Høgda et al. 2001).

In Fennoscandia there are few long-term phenological data sets, and most were terminated in the second half of the previous century before the phenological interest increased again. In Russia, however, phenological interest has been strong through several years (Podolski 1984). More than 70 years old continuous phenological time series are used in analyses from Kola Peninsula (Kozlov and Berlina 2002). Some Kola phenological observations are also presented for several plant species by Makarova et al. (2001).

Strongest variation in the development of phenophases with environmental factors, particularly temperature, is generally found for the spring phases. However, already Galakhoff (1938) found that autumn discolouring of tree foliage was delayed by wet, cloudy and cool weather, while bright weather with high day, but low night temperature accelerated the leaf yellowing in the autumn. Recently, Marchand et al. (2004) by continuous artificial warming of plots in Greenland by 2.5°C, has observed that the senescence process of plants is postponed and the yellowing delayed by 15 days.

In the present study long term phenological mountain birch field observations in northeastern Europe are analysed and compared with satellite images through 1982-2002.

## 2 MATERIAL AND METHODS

Phenological observations on Nordic mountain birch *(Betula pubescens* ssp. *tortuosa*, also called *B. p.* ssp. *czerepanovii)* are analysed and compared with climatic parameters through 40 years at three sites at the Kola Peninsula and through the last 10 years also at two more sites somewhat west of the Peninsula (Fig. 1). These data, however, are representative only for the place of observation, but may be used as control points in combination with Normalized Difference Vegetation Index (NDVI) from the 8 x 8 km resolution GIMMS satellite dataset (e.g. Tucker et al. 2001) to get values for regional areas. A new method for such comparison is developed based on individual pixel-by-pixel threshold values (cf. Karlsen et al. this vol.).

There are two geographical vegetation zones in the study area: taiga and tundra, with an ecotone between the two. In general, climate of the Kola Peninsula is moderate arctic-atlantic with highest precipitation through July-October and lowest through March-April (Atlas 1971). However, the territory of the northern part of the Peninsula, including the river Pasvik area, belongs to the atlantic-sub-arctic zone (Aleksov 1956). Most climatological stations are close to the phenological observation plots, except for the Lapland Reserve site, where the meteorological observations from Monchegorsk (about 50 Km NNE of the site) are used, and for the Pasvik Reserve, where the climate data from Janikoski (about 40Km WSW of the site) are used.

The phenophases observed on mountain birch were the same at all sites, and they were always observed along a fixed track at each site. The first phase observed in spring was called "First greening", determined as when the first leaves were unfolded and the first leaf stalk visible, phenophase 11 according to the BBCH code (Meier 1997). The yellowing of the birch leaves in autumn is somewhat more difficult to define objectively. However, at the sites Kandalaksha, Kirovsk and Svanhovd, the date was said to be observed for the first 10% autumn colour at 10% of the trees along the track (close to BBCH code 92). At the Lapland site, leaf yellowing was taken as the first "general" autumn colouring, which may be somewhat later, and at the Pasvik site by the first yellow leaves along the track, which may be even before the 10% colouring.

For the NDVI maps onset of growing season is very close to the definition of "First greening" of birch, while the end of the season is defined as the time when the NDVI value decreases below 0.7 of a 21-year long mean of the peak NDVI value (Karlsen et al. in press). This is normally somewhat later than the definition of first yellowing.

## 3-4 RESULTS - DISCUSSION

Average daily mean temperatures during May were lower during the period 1994-2003 than through 1964-2003 at the sites Kandalaksha, Lapland and Kirovsk, but only at the elevated site Kirovsk (c 300m a.s.l.) lower also later in the summer (Tab. 1). In winter low temperatures are generally observed at all sites, a mean of -13° to nearly -14°C in January, slightly lower at the two sites by the Pasvik river than at the other three sites. All the four lowland sites had a low annual precipitation, on an average between 400 and 500 mm in annual sum for the study years, while it was more than twice as high at the Kirovsk site.

According to trend analyses for the time of greening of birch (Fig. 2), only at Kandalaksha the lower May temperature through the most recent years, seemed to have caused a trend for later birch greening through the whole period 1964-2003. A stable time for bud break of birch at the Lapland site through the period 1930-1998 was also stated by Kozlov and Berlina (2002). The delayed greening at Kandalaksha fits well with satellite images for the region based on GIMMS-NDVI dataset for the period 1982-2002 (Fig. 3a), where onset of growing season seemed to be delayed just near the area of the Kandalaksha site, while no significant differences were found near the other sites of the present study. However, if only the period 1989-1999 is looked at (Fig. 2), there is a visual trend to delayed birch tree greening at all three sites through these years.

Generally, there is found a trend to earlier yellowing of birch leaves through the 40 year period 1964-2003 at all the sites Kandalaksha, Kirovsk and Lapland, all of the order 5-6 days earlier (Tab. 2), slightly smaller changes at the last site, which is also found by satellite images from the same areas for the period 1982-2002 (Fig 3b). At the Lapland site Kozlov and Berlina (2002) also found earlier leaf fall of mountain birch from 1930 to 1998. During the period 1994-2003, the Kirovsk and Pasvik sites seemed to have a considerably earlier birch yellowing trend (Tab.2), which is probably also visualized by the satellite images given in Fig. 3b for the period 1982-2002. However, the very early yellowing observed at the Pasvik site in some years, and particularly in 2002 (yellowing observed already 21. July), may also partly be due to rust attacks. The differences were small (Tab. 2) at the Svanhovd site, and at Kandalaksha the birch yellowing was even later in the 10 year period from 1994.

In the present study the subjectively determined "continued" (more than three subsequent days) decreasing autumn mean temperature at the sites Kandalaksha, Lapland and Kirovsk showed a trend to be earlier during the period 1964-2003 (Fig. 4). The difference was nearly 10 days at Kandalaksha, but less at the two other sites. This may explain the earlier yellowing of birch leaves through the same period (Tab. 2). Stenøien et al. (2002) and other authors have stressed that senescence of particularly northern populations of deciduous woody plants are strongly dependent on the light conditions, but Shults early stated (1957) that senescence in such plants clearly correlates with decreasing temperature both in northern and more southern latitudes. The temperature field experiments by Marchand et al. (2004) at plots in Greenland indicated that low mean temperatures might be as important in triggering the yellowing process in the autumn as low minimum temperatures (e.g. Galakhoff 1938). The present study also seems to give a similar result.

## 5 CONCLUSIONS

The timing of phenophases found in the present study of mountain birch in spring (partly delayed) and autumn (accelerated) suggests that by climate change, important changes take place in vegetation of particularly climatic sensitive regions, e.g. in all transition zones (ecotones) between more stable ecosystems as the sub-arctic and sub-alpine ecotone between forest and tundra studied here.

By the positive NAO through the last decades the increased temperature is also followed by higher precipitation. At higher elevation and in cold regions this increased precipitation has partly fallen as snow. This may be one reason why the growing season has been shorter in some mountain regions of Fennoscandia and in many continental, winter cold areas of Northeast Europe in contrast to the general observations elsewhere in Europe (IPCC 2001). In spring the increased snow cover may melt later, influencing the start of the growing season, while increased air humidity at the time of high light intensities in spring may cause advanced greening of birch (Wielgolaski 2001). With even more increased temperature, however, probably less of the increased precipitation will fall as snow even in the colder regions, and, then, spring also there may be earlier. In the autumn, reduced light in the north also in the future by heavy clouds, and therefore partly a lower average temperature even at a continued climate change, may cause a continued earlier end of the growing season.

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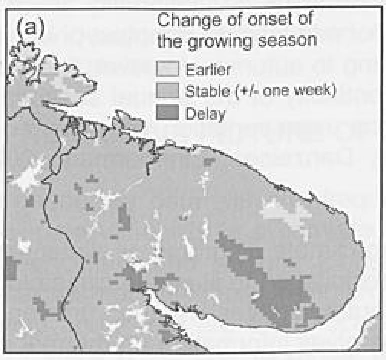
Table 1. Mean temperature and phenological data for mountain birch leaves at five Kola and Pasvik sites.

| Period | Sites | Mean temperature | | | | First greening | First yellowing |
|---|---|---|---|---|---|---|---|
| | | May | June | July | August | | |
| 1964-2003 | Kandalaksha | 4.3 | 11.1 | 14.4 | 12.0 | 1.06 | 17.08 |
| | Lapland | 3.5 | 10.3 | 13.9 | 11.5 | 4.06 | 29.08 |
| | Kirovsk | 2.1 | 9.2 | 12.7 | 10.0 | 10.06 | 18.08 |
| 1994-2003 | Kandalaksha | 3.6 | 11.7 | 14.6 | 12.1 | 4.06 | 16.08 |
| | Lapland | 3.1 | 10.5 | 14.5 | 12.1 | 4.06 | 28.08 |
| | Kirovsk | 1.6 | 9.3 | 12.5 | 9.7 | 9.06 | 16.08 |
| | Pasvik | 3.2 | 10.3 | 13.8 | 11.5 | 29.05 | 7.08 |
| | Svanhovd | 3.1 | 9.3 | 13.5 | 10.3 | 3.06 | 17.08 |

Table 2. Changes in the timing for "beginning of yellowing" of mountain birch leaves at five sites on Kola Peninsula and along the Pasvik river during two periods. Linear trend in days/year.

| Period | Lapland | Kandalaksha | Kirovsk | Pasvik | Svanhovd |
|---|---|---|---|---|---|
| 1964-2003 | -0.13 | -0.14 | -0.16 | | |
| 1994-2003 | -0.11 | 0.33 | -0.48 | -1.90 | -0.07 |

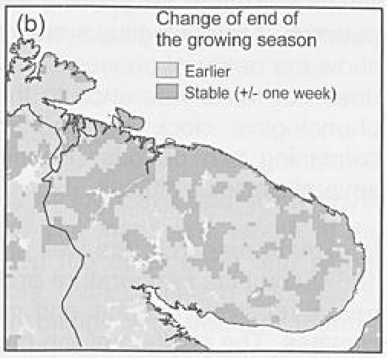
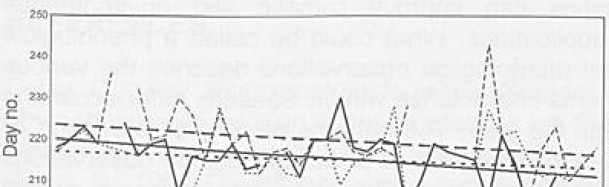




Fig. 1 (left): Study area in northeastern Europe. Position of phenological tracks (triangles) and meteorological sites (circles) used in the present study.
Fig. 3a-b (right): Changes of a) onset and b) end of growing season in the study area through the period 1982-2002, based on the satellite GIMMS-NDVI dataset .



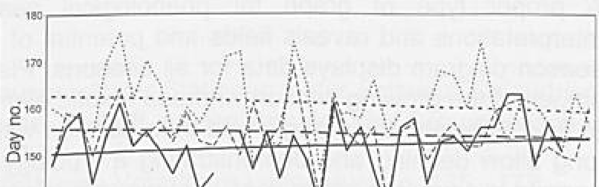




Fig. 2 (left): Beginning of birch leaf greening at three sites on Kola Peninsula through the period 1964-2003; actual observations and calculated linear trends for the period. Ordinate: Day no. of the year.
Fig. 4 (right): Beginning of autumn temperature decrease, else as in Fig. 2.

# PLANT PHENOLOGY, FOG AND SNOW COVER DURATION – A TOPOCLIMATIC SURVEY OF SEASONALITY

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## 1 INTRODUCTION: PATTERNS OF SEASONALITY

If phenology is "the study of the times of recurring natural phenomena especially in relation to climate and weather" (Van Vliet + De Groot 2003), it includes not only the timing of plant and animal life, but also other natural phenomena with seasonal character, such as the duration of ice and snow cover as well as the timing of thawing. Traditionally, phenology deals with observations rather than instrumental measurements as opposed to phenometry (figure 1) and climatology. In addition, aspects of seasonality put phenology into its particular position within time and spatial scales, which make the difference with chronobiology (figure 2). The timing can be detected in the terrain on single organisms or on populations, but also on terrestrial or remote sensed pictures and photos. Thus, phenology could also be defined as observed patterns and evolution of seasonality in the biotic and abiotic environment that are described by in situ observations, pictures and photographs.

## 2 METHODS: LOOKING FOR A PHENOLOGICAL SEASON DIAGRAM

There is a need for specific representations of seasonality which graphically reflect the rhythm and patterns of phenological seasons. For mid-latitude climates, phenological calendars (e. g. Defila 1992) show the range of phases from spring to autumn. However, the continuous upward trend of the curve does not make reference to the continuity of the annual seasonal cycles. In another approach, the phenological clock is a continuous representation of phases and seasons, which also allows combining two periods (Henniges, Danzeisen, Zimmermann 2005). However, the comparison of several clocks is difficult.

In climate research, the well known climate diagrams or climagrams (e.g. after Walter + Lieth 1960-1967) combine temperature and precipitation to illustrate climatological state. Flat temperature curves reveal relatively oceanic and moderate climates whereas uneven curves describe rather continental climates. The position of the curves gives information on thermal conditions, precipitation bars on the quantity and seasonal distribution of rainfall.

Plant phenology does not give any signal in the winter-rest (Gams 1961); abiotic elements can be used to structure this season. The climate typology and classification based on ecophysiology by Lauer and Rafiqpoor (2002) is based on vegetation months, humidity, aridity and nivality.

A proper type of graph for phenological seasons can improve climatic and environmental interpretations and reveals fields and potential of applications. What could be called a phenological season diagram displays data for all seasons. Plant phenological observations describe the various stages of the growing season whereas abiotic elements characterize winter. Seasons differ according to their intensity, their length and their position within the year. The patterns of early or late, short or long allow defining and demonstrating a typology. A combination of biotic and abiotic observations permits to cover the entire year. A curve reflecting plant phenology will depict spring phases in normal succession, whereas autumn phases are shown on a reversed scale. Duration of snow cover represents an integrating value for winter season. Fog characterizes thermal inversions and frost risks.

## 3 RESULTS: CURVES ON A SINGLE GLIMPSE

In the Canton of Berne (7000 km²) and adjacent areas in Switzerland, the topoclimatological network BERNCLIM founded in 1970 collects data of plant phenological phases during the growing season, fog frequency and snow cover duration in winter (Jeanneret 1997). The combination of a set of phenological phases from spring (blooming of the hazel *Corylus avellana*, dandelion *Taraxacum officinale* and apple trees *Pyrus malus*) to summer (wheat harvest *Triticum vulgare)*, autumn (coloring of the leaves of beeches *Fagus sylvatica*) and winter (snow cover and fog duration) characterizes the seasonal pattern of various topoclimates.

The observation area stretches from the Northern Jura Mountains across the central hill country to the Alps, offering a wide variety of climatic conditions over a cross-section of 120 km, from 400 m to 4000 m of elevation. Observation series of up to 35 years are precious for research on recent climatic variations as well as for different applications, such as forestry and bioclimatology. A planned GIS-based survey will update the existing mapping of the area (Messerli, Volz, Wanner and Witmer 1978) and allows its topoclimatic modelling on different scales.

With data from two selected stations, a first graphic solution of a phenological season diagram is presented in figures 3 and 4.

## 4 DISCUSSION: THE IDEA OF A STANDARD PHENOLOGICAL DIAGRAM

The climate on the lake shore of Lake of Bienne, in the village of Lüscherz (figure 3), is characterized by a relatively early beginning of spring and a long vegetation period. Winter is mild with little snow. Numerous fog days reflect the long lasting thermal inversions during high pressure periods in winter.

In the Emmental hills, represented by the station of Wyssachen (figure 4), the vegetation period starts later. As wheat harvest has not been recorded, the summer curve is not as round as in lower areas, symbolizing harsher conditions. In winter, a longer snow cover duration is typical for elevated areas, lying often well over the fog concentrations.

More examples linking plant with abiotic phenology offer the opportunity of a year-round, combined topoclimatic typology. Improved, well designed, standardized diagrams could be used in many publications and make phenology more popular.

## 5 CONCLUSION: A COMPREHENSIVE PICTURE OF SEASONS

It is challenging to combine plant phenology data with the frequency of fog days and snow cover duration. Each element reacts to climate variability in a complex way. The increasing length of the vegetation period is a chance for agriculture and summer tourism. On the other hand, the higher altitude and duration of winter fog causes not only more traffic problems, but also health risks due to smog situations in densely populated areas that are often located in basins with frequent thermal inversions. The reduced duration of snow cover due to winter warming has well-known economic consequences on winter tourism. All these changes are typically topoclimatic processes, depending very much on the relief situation that could be described throughout time by deriving seasonal pattern indexes by means of biotic and abiotic phenological observations. Clear graphical illustrations will contribute to a better understanding and application of phenological observation data.

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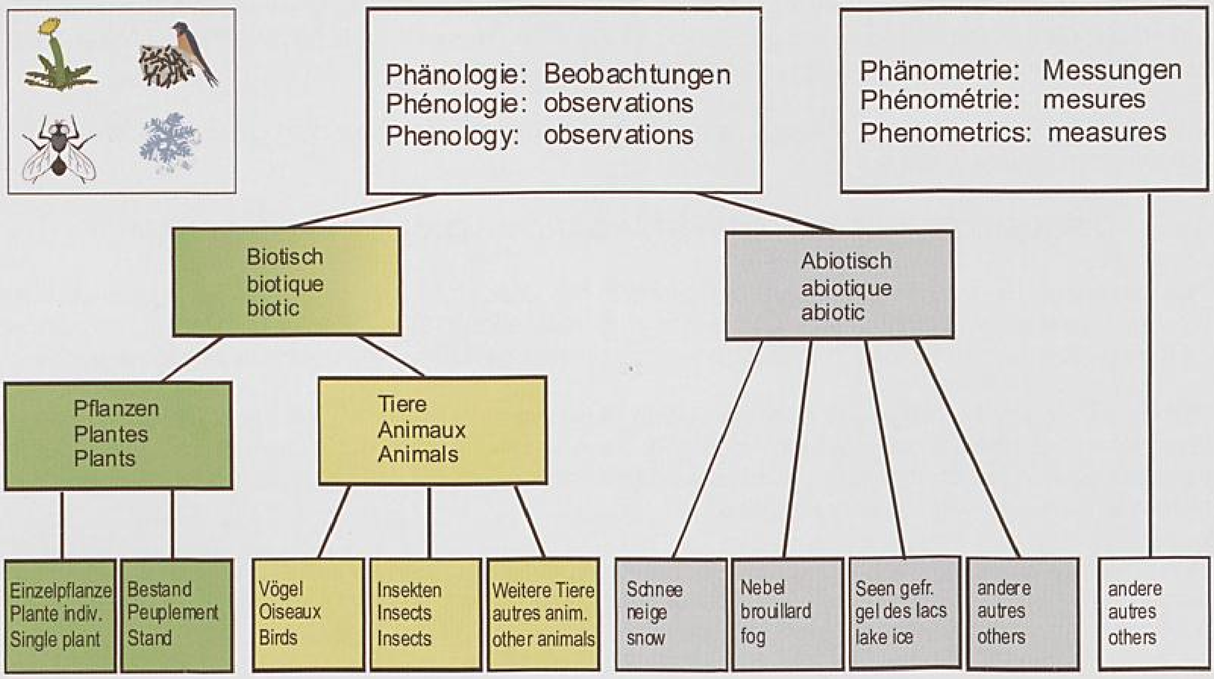



Figure 1: Phenology includes observations of biotic and abiotic phenomena in nature in order to assess seasonality.

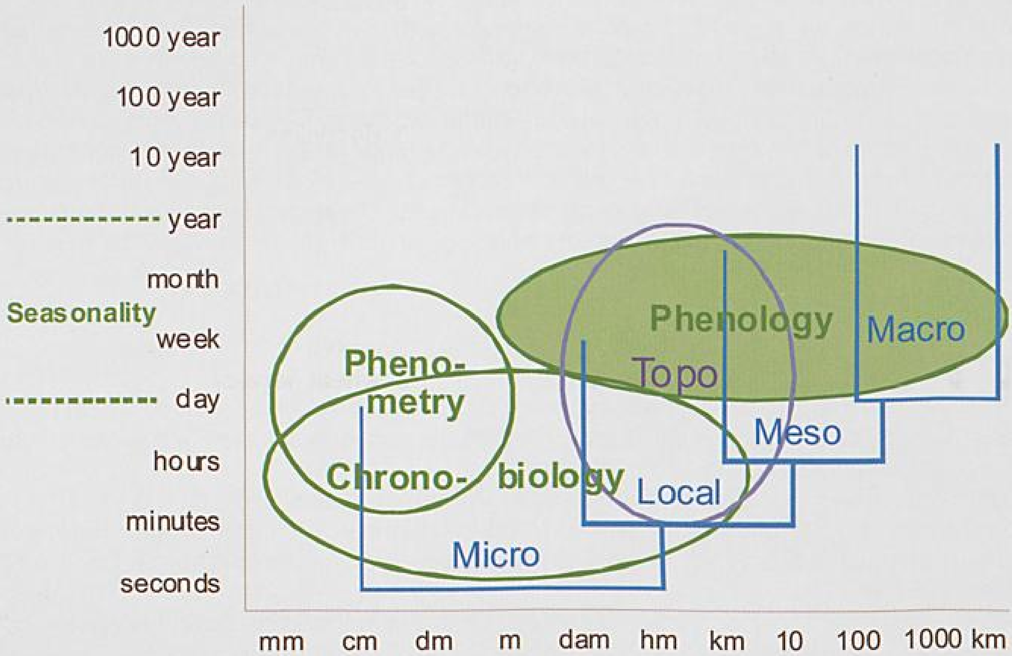
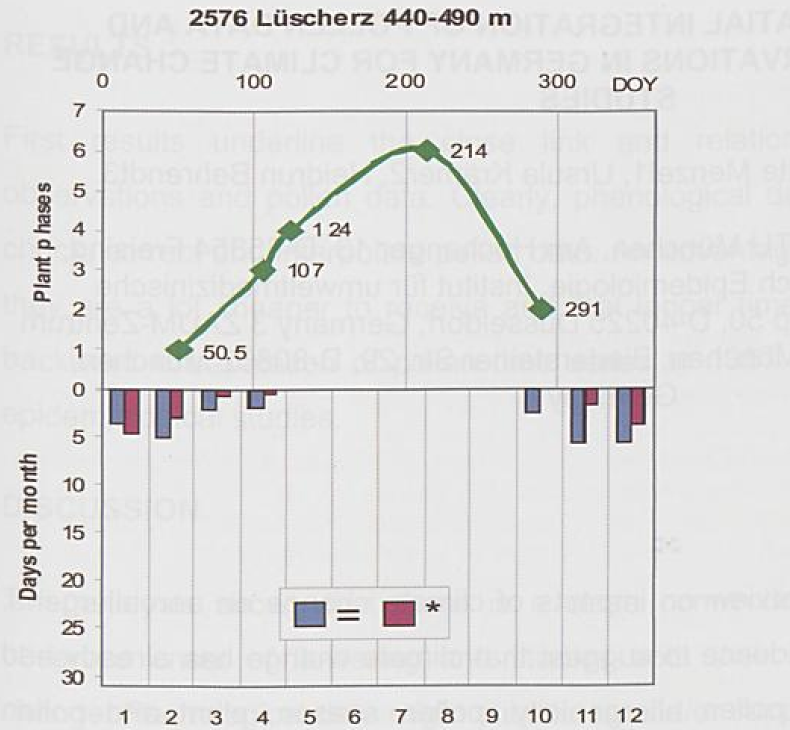



Figure 2: Phenology and seasonality studies are inserted within micro-, topo-, meso- and macroclimatological scale units (after Oke 1987).




**Seasonal phases**

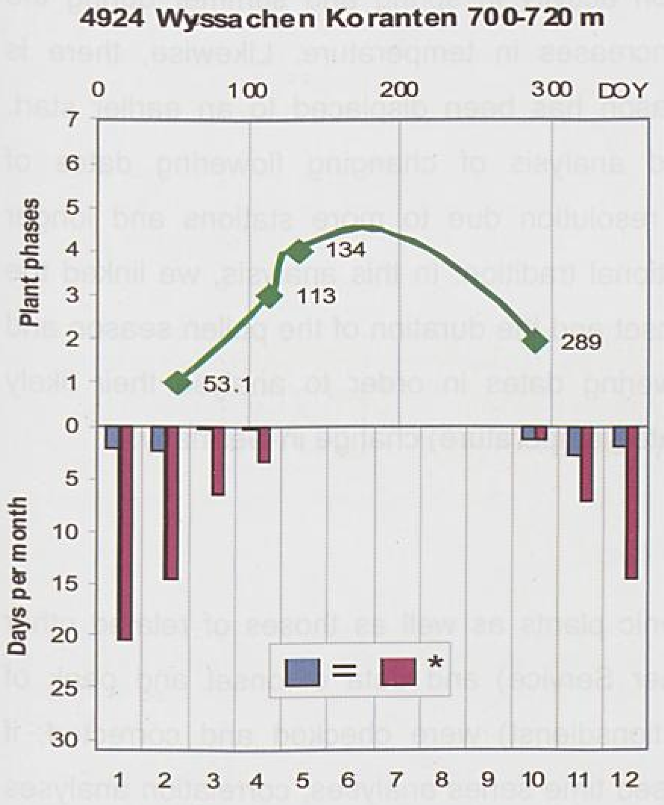
**Spring**
1 hazel
*Corylus avellana*, general blooming
3 dandelion
*Taraxacum officinale* general blooming
4 apple trees
*Pyrus malus* general blooming

**Summer**
6 wheat harvest
*Triticum vulgare*

**Autumn**
2 beech
*Fagus sylvatica* coloring of the leaves

**Winter**
= fog frequency
* snow cover duration

Figure 3: Lowland example of a combined phenological season diagram (south shore of the lake of Bienne): above the biotic phenological phases in summer (1971-2005) in days of the year, below the abiotic winter phases (1993-2003) in days per month.

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**Winter**
= fog frequency
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Figure 4: Phenological season diagram from the hill area of the Emmental, where there is no wheat culture – it is correct, that summer is therefore not represented equally. The curve between phase 4 and phase 2 is rounded (summer data from 1970-2004, winter data 1996-2003).

# TEMPORAL AND SPATIAL INTEGRATION OF POLLEN DATA AND PHENOLOGICAL OBSERVATIONS IN GERMANY FOR CLIMATE CHANGE STUDIES

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## INTRODUCTION

According to Beggs' (2004) review on impacts of climate change on aeroallergens, there is now considerable evidence to suggest that climate change has already had impacts on pollen amount, pollen allergenicity, pollen season, plant and pollen distribution. In this study, we focus on the linkage between changes in the pollen season and observed shifts of flowering dates of allergenic plants in Germany. In phenology, numerous studies in Europe, but also North America and Far Asia, have revealed an earlier onset of vegetation activity in spring and summer during the recent decades as a response to increases in temperature. Likewise, there is evidence that onset of the pollen season has been displaced to an earlier start. However, the direct observation and analysis of changing flowering dates of allergenic plants offer higher spatial resolution due to more stations and longer temporal records due to long observational tradition. In this analysis, we linked the temporal and spatial variation of the onset and the duration of the pollen season and the observations of phenological flowering dates in order to analyse their likely responses to responses to recent climate (temperature) change in Germany.

## METHODS

Phenological flowering data of allergenic plants as well as thoses of related other phenological phases (German Weather Service) and data of onset and peak of pollen shedding (PID Pollen Informationsdienst) were checked and corrected, if necessary. Statistical analyses comprised time series analyses, correlation analyses between records of both data sets and spatial interpolation for mapping. The latter displayed regional differences.

## RESULTS

First results underline the close link and relationship between phenological observations and pollen data. Clearly, phenological data can be used as a tool to check, correct and interpolate pollen data. An advantage of phenological data is, that they are a lot cheaper to receive and that longer time series are available, thus a backward extrapolation of pollen time series to 1951 may of fer further insight for epidemiological studies.

## DISCUSSION

This analysis shows that there is a close connection between pollen data and observed onset of flowering and studies both their responses to recent climate change. Phenological data might substitu te and/or supplement pollen data in regions or time frames, where phenological time series are available, but hardly any pollen data.

# PHENOLOGY AND CLIMATE CHANGE IN AUSTRALIA

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## 1 INTRODUCTION

Surface air temperatures have risen approximately 0.6°C globally since the mid-19th century (IPCC 2001a). Consistent with global trends, Australia's continental average temperature increased 0.7°C from 1910 to 1999, with most of the increase recorded since 1950 (Collins *et al.* 2000; Nicholls 2003).

Climate change is expected to have profound and complex impacts on virtually all natural systems, with evidence mounting that the anomalously high temperatures seen in the 20th century have already been associated with changes in many natural systems around the globe (Hughes 2000; Walther *et al.* 2002; Parmesan and Yohe 2003; Root *et al.* 2003, Chambers *et al.* 2005).

Recently there has been a resurgence of interest in the use of natural systems as indicators of climate change. This has occurred for a number of reasons. First, many natural systems have shown to be very sensitive to changes in climate. Changes in natural systems, such as alterations in the timing of bird migration or the flowering of plant species, are often easier for the public to understand than, say, a 0.6°C rise in global temperature. In addition, such changes are often seen in 'their backyard', making the climate change message more relevant and pressing, increasing motivation and the likelihood of involvement in climate change indicator monitoring programs.

Secondly, from an environmental management perspective, it is important to determine the impact of climate change on the environment, with the information obtained supporting policy development and further monitoring used to assess policy responses.

Thirdly, many plant and animal species respond to changes in not only temperature, but also in rainfall, humidity and other climate variables. This makes them valuable indicators of combined changes in the climate system through their integration of the various climate elements.

In the Third Assessment Report of the IPCC, despite many studies being listed for the Northern Hemisphere, there were very few studies linking natural processes or species with regional temperature change for the Southern Hemisphere, and none for the Australian region (Figure 1).

Australia contains a high proportion of endemic species, which have already adapted to a highly variable climate system (IPCC 2001b). Consequently, Northern Hemisphere climate impact results may not apply to these species. Recognising this has lead to heightened interest in climate change impact studies in Australia and the instigation of a national phenological meta-database.

## 2 STATUS OF KNOWLEDGE IN AUSTRALIA

Historically, very few studies have looked at the observed and likely impacts of climate change on Australia's natural systems and no national phenological networks exist. This lack of a national co-ordinated approach has seriously hampered current efforts to detect and attribute climate change signals in Australia's species.

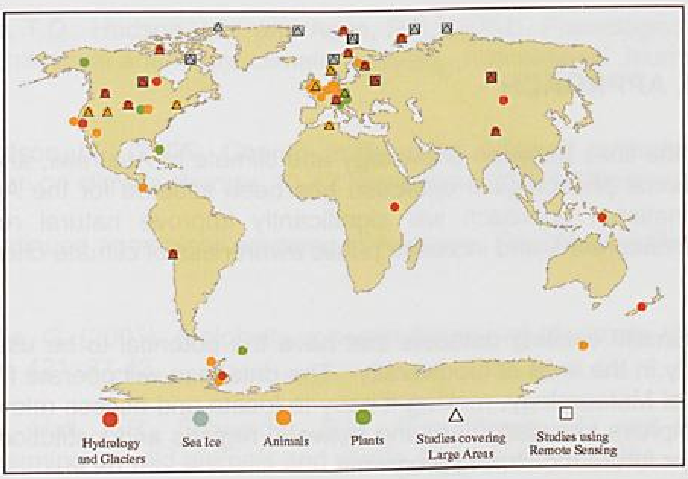


**Figure 1.** Locations at which systematic long-term studies meet stringent criteria documenting recent temperature-related regional climate change impacts on physical and biological systems. Note the absence of information for Australia (Figure TS-11 from IPCC 2001b).

In the four years since the third IPCC report was produced, a number of studies looking at relationships between species and climate have been documented. A recent review of the observed and projected impacts of climate change on Australia's avifauna (Chambers *et al.* 2005) lists a number of phenological changes, including earlier arrival dates of migratory species (Green 2003) and changes in breeding patterns (Dunlop and Wooller 1986). Further evidence of climate related changes in the timing of migration in birds can be found in Chambers (2005).

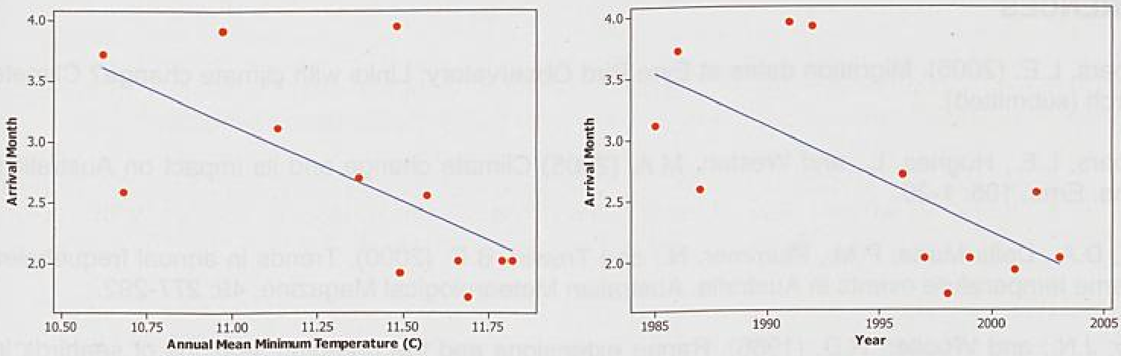


**Figure 2.** Arrival dates of Purple-crowned Lorikeet at Eyre Bird Observatory, Western Australia. Arrival dates correlated with regional minimum temperatures ($R^2$ = 35.1%), warmer temperatures corresponding to earlier arrivals. Over time, minimum temperatures have warmed ($R^2$ = 66.3%) and arrival dates have become earlier ($R^2$ = 42.3%) [Based on results in Chambers (2005)].

In south-eastern Australia changes have also been observed in the flowering dates of 56 species of Australian plants (Keatley and Hudson 2005). Over the 22-year period of the study, 24 species had a mean advancement in flowering of 13.6 days and the remaining species flowered on average 20.8 days later.

It is clear that further research is needed to obtain a clear picture of how a changing climate is impacting on the phenology of Australian flora and fauna.

## 3 A NATIONAL APPROACH

To further understand the links between phenology and climate in Australia, and to better coordinate research efforts, a national phenological database has been initiated for the Australian region. It is anticipated that this national approach will significantly improve natural resource management decisions, aid policy development, and increase public awareness of climate change and its impacts in Australia.

The database will document existing datasets that have the potential to be used for climate change impact work, particularly in the area of biodiversity. The database will operate from a central location, the Australian Bureau of Meteorology, making it easy to locate and access relevant data. In addition, the database should improve knowledge sharing between regions and institutions and can be used to identify baseline data for future monitoring programs.

Raising awareness of the usefulness of natural system data for climate change studies to governments and universities, as well as to the general public, is a high priority. For without their involvement and support many potentially useful datasets may go unrecorded.

## 4 CONCLUSION

Our current knowledge of what historical flora and fauna data has already been collected within Australia is largely unknown. With the development of a national phenological database a systematic and co-ordinated approach to the analysis of this data will be possible and will help to ensure that the results obtained are feedback into national and international programs, such as IPCC.

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## FLOWERING PATTERNS OF AMAZON LOWLAND FORESTS – A 30 YEAR STUDY

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### INTRODUCTION

Long term phenological studies are essential to the understanding of the tropical forest dynamic, the patterns of resource availability and to explore the effects of climatic changes on natural ecosystems.

The objective of this study was to investigate, the effects of natural climatic changes on tropical forest flower phenology over 30 years of observations and to compare the phenological patterns between two forest sites, aiming to answer the questions: (i) Are the flowering patterns seasonal and similar between the two forests? (ii) If seasonal, is the flowering phenology predictable? (iii) Is the forests' flower phenology affected by climate, especially El niño events?

### METHODS

The phenological observations of Amazon lowland forest trees started in 1965, at Reserva Florestal Ducke (RFD), and in 1974 at INPA Estação Experimental de Silvicultura Tropical (EEST) about 30 km from Reserva Ducke (Manaus, Amazonas State, Brazil). For each site 500 trees of 100 species (five per species) were selected and have been monitored monthly until today.

### RESULTS

Phenological patterns at both areas were seasonal, showing a fl owering peak in September-October, at EEST, during the less wet season, in most of the years. The flower peak was more variable at RFD, occurring from August to December. The predictability of flower events was higher at EEST than at RSF. Flowering was correlated to temperature and appears to be affected by strong El niño events.

### DISCUSSION

The long-term phenology observations revealed, for the first time, a very seasonal and predictable flower pattern for Amazon tropical wet forests. However, the flower production may be affect by climatic changes caused by El niño events, anticipating flowering and/or reducing the number of individuals producing flowers over the year following the event. The study highlights the importance of take into account phenology data when planning the management of tropical forest trees.

# SPATIO-TEMPORAL VARIATIONS OF GROWING SEASON IN THE TYPICAL STEPPE OF CHINA

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## 1 INTRODUCTION

Detecting growing season variability of terrestrial vegetation is crucial for identifying responses of ecosystems to recent climate change at seasonal and interannual time scales (Chen et al., 2001; Walther et al., 2002). Grasslands are one of the most widespread vegetation type worldwide, covering nearly one fifth of the Earth's land surface and play a major but poorly defined role in feedback to global climate change and biogeochemical cycle. Therefore, it is important to obtain more information about grassland ecosystems in their present form before they are modified, either by global climate change or by human activities. Comparing with studies on the growing season of trees, the growing season of herbs and its responses to climate change is less understand. This study focuses on the remote sensing growing season in the typical steppe of Inner Mongolia of China. Objectives of the study were (1) to determine the growing season of herbaceous vegetation on regional scales; (2) to reveal the spatio-temporal patterns of the growing season, and (3) to analyse the relationship between growing season parameters and climate factors.

## 2 METHODS

The study area is located in the east part of the Inner Mongolia Plateau, which can be divided into two parts. The north part is Hulunber highland with an area of 61440 $kim^2$, while the south part is Xilinguole highland with an area of 230144 $km^2$. The geographical coordinates are from 110°E to 120°E and from 40°N to 50°N (Fig. 1). Climatically, the study area covers the temperate zone and semi-arid region. The growing degree days above 10°C are from 2000 to 3000, whereas the annual total precipitation is between 250 and 350 mm. The natural vegetation is typical steppe and the dominant species include *Aneurolepidium chinense*, *Stipa krylovii*, *Stipa grandis*, *Artemisia frigida* and so on.


Figure 1 Location of the study area

Satellite data were derived from the AVHRR on the "afternoon" NOAA operational meteorological satellite. The Normalized Difference Vegetation Index (NDVI) was obtained from the NOAA/NASA Pathfinder AVHRR Land data set for 1982-2000 at 8-km spatial resolution. The NDVI composites were generated by selecting the highest NDVI value over each 10-day period in order to reduce the effect of cloud contamination. Because of lack of the original data in some years, the Marr function was used to fill the lack of NDVI data and obtain continuous NDVI profiles, which provides the reliable data basis for further studies.

The daily mean air temperature and daily precipitation at 9 meteorological stations from January 1982 to December 2000, were processed into monthly and annual mean air temperatures for each station, which then served as the driving parameter for carrying out a correlation analysis between the beginning and end dates of the growing season and climate factors.

In order to determine the beginning, end and length of the growing season in the whole region, the seasonal midpoint NDVI method (White, 1997) was used. First, for every pixel, the minimum and maximum NDVI are selected and then, the midpoint between them is calculated. This is repeated for every year from 1982 to 2000. The midpoint NDVI values are used as thresholds to identify the beginning and end of the growing season for each pixel and each year. Moreover, the relationships between growing season parameters and climate factors were analysed at the meteorological stations and the pixels overlaying them.

## 3 RESULTS

### 3.1 SPATIAL VARIATIONS

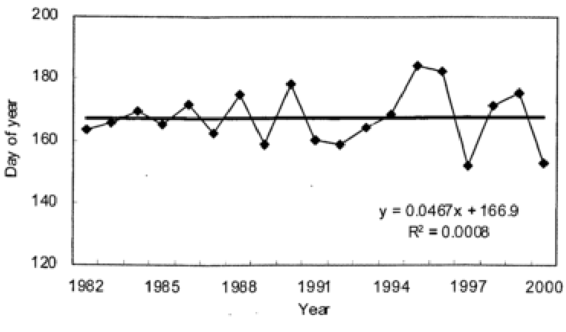
The spatial pattern of the growing season parameters shows quasi north-south and east-west differentiations in the study area. In the Hulunber highland, the average beginning date of grass green-up shows a gradual delay from east to west. At the east edge of the study area, namely, the piedmont of Daxinganling mountain, grass green-up starts in the last ten day period of May and the first ten day period of June, whereas at the west part of the Hulunber highland, it begins during the second and the last ten day periods of June. The delayed range is generally above 30 days and the maximum difference reaches 50-60 days. In the Xinlinguole highland, however, the average beginning date of grass green-up is earlier in the middle latitudinal zone with relatively abundant precipitation and high coverage density of vegetation than in the higher and lower latitudinal zone with poor moisture conditions and low coverage density of vegetation. In the mid latitudes, the grass green-up starts from the second ten day period of May to the first ten day period of June and shows a delay from west to east, whereas in the higher and lower latitudes, the grass green-up begins normally during the second and last ten day periods of June.

Generally speaking, the average beginning date of grass brown-off appears from the second to the last ten day periods of September in the south part of the Xinlinguole highland with a relatively high elevation. In the middle and north part of the Xinlinguole highland and the Hulunber highland, the average beginning date occurs earlier in east (from the last ten day period of September to the first ten day period of October) than in west (from the second to the last ten day period of October. The spatial difference reaches 20-30 days.

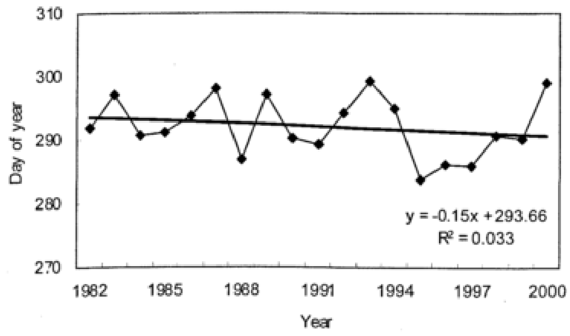
In the south part of Xinlinguole highland, the growing season duration is the shortest with 115 days, whereas in the middle and north part of the Xinlinguole highland, the growing season duration is longer in west with 185 days than in east with 125 days. In Hulunber highland, the growing season duration shows also a east-west differentiation but in a reversed direction comparing with in Xinlinguole highland, namely, longer in east with above 125 days than in west with 115 days.

### 3.2 GRWOING SEASON TREND

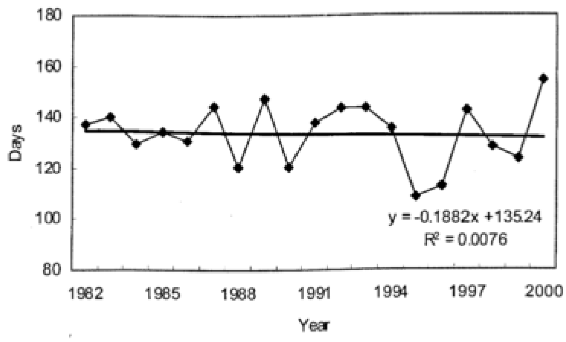
During the 1982-2000 period, regional average dates of the growing season beginning do not show any linear trends, whereas regional average dates of the growing season end indicates a slightly advanced trend (1.5 days/decade, $p$>0.1). The growing season duration is therefore slightly lengthened (1.9 days/decade, $p$>0.1). The spatial distribution of linear trends shows that (1) a significant advancement in the beginning date of the growing season appears in the east part of the Hulunber highland and the northeast part of the Xilinguole highland, whereas a significant delay occurs in northwest and south of the Xilinguole highland; (2) a significant advancement in the end of the growing season appears in the east part of the Xilinguole highland, whereas a significant delay occurs in south of the Xilinguole highland and in east of the Hulunber highland; (3) the area with significant lengthening of the growing season approximately overlaps with that with the significant advancement of the growing season. So, the beginning date of the growing season can indicate the length of the growing season in a certain extent, which is consistent with other studies (Chen, 2000; Chen & Pan, 2002).




a




b




c

Figure 2 Linear trends of growing season parameters in the typical steppe of Inner Mongolia
a. beginning; b. end; c. length

3.3 RELATIONSHIPS BETWEEN GRWOING SEASON PARAMETERS AND CLIMATE FACTORS

The relationships between growing season parameters and climate factors show significantly spatial heterogeneity characteristics. Generally speaking, the beginning date of the growing season correlates positively with air temperatures from February to April, whereas the end date correlates negatively with air temperatures from June to August. Therefore, higher temperature in spring can result in a delay of grass green-up of herbaceous plants and higher temperature in summer can cause an advancement of grass brown-up.

There is a dominantly negative correlation between the beginning date and the precipitation from February to April, but no dominantly positive or negative correlation between the end date and the precipitation from June to August on regional scales. Thus, more precipitation in spring triggers an advanced beginning date.

The growing season duration correlates negatively with the annual mean temperature, but positively with annual precipitation. So, regional warming has negative impacts on growth and development of herbaceous plants, whereas abundant precipitations are beneficial to growth and development of herbaceous plants.

## 4 CONCLUSION

(1) The Marr function can be used to fill the lack of NDVI data efficiently and obtain continuous NDVI profiles.
(2) The mid-point method can be efficiently used to determine the growing season of the typical steppe and reveal its temporal and spatial characteristics;
(3) The spatial pattern of the mean growing season parameters shows quasi north-south and east-west differentiations and the longest growing season appears in the west part of the Xilinguole highland;
(4) During the 1982-2000 period, the regional average date of growing season parameters did not show significant linear trends, however, this kind of linear trends was founded at the local scales with quasi north-south and east-west distribution and a significantly lengthening of the growing season appeared in the north part of Hulunber highland;
(5) The relationships between growing season parameters and climate factors show significantly spatial heterogeneity characteristics. Generally speaking, the growing season duration and temperature correlate negatively, whereas the growing season duration and precipitation correlate positively, which indicates that regional warming has negative impacts on growth and development of herbaceous plants, whereas abundant precipitations are beneficial to growth and development of herbaceous plants.

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# AN ANALYSIS ON THE RELATIONSHIP BETWEEN RECENT WARMING AND CHANGES OF SPRING PLANTS PHENOPHASES IN BEIJING

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## 1 INTRODUCTION

In recent years, the effects of climate on phenology and the response of plant phenophases to climatic change have been paid more attention among scientists, especially under the background of global warming (White, *et al.*, 2003). In particular, changes of spring phenological onset and autumn phenological offset are considered to be more important (Sparks and Menzel, 2002). But many studies tend to spend more energy to discuss changes of spring phenophases. Those in North America (Schwartz, *et al.*, 2000), in Oceania (Keatley, *et al.*, 2002) and Europe (Ahas, *et al.* 2002) have showed the importance of the applications of such studies in the field of global climatic change studies. In China, Zheng and Ge (2002) discussed the relationship between the warming trend and the phenophases change. Based on their hard work (Zheng and Ge, 2002), we now try to study features of spring and autumn phenological changes respectively, and the main purpose of this paper is to explore changes of the spring phenophases of some woody plants in Beijing (the species selected can be seen in Tab. 1), with special interests in spring phenology, such as the first bloom (1stB), full bloom (FB), and first leave (1stL ) of these woody plants.

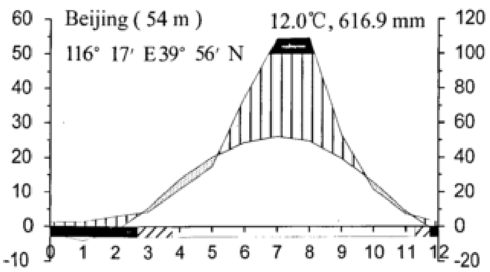


Fig. 1 Walter climate diagram for Beijing

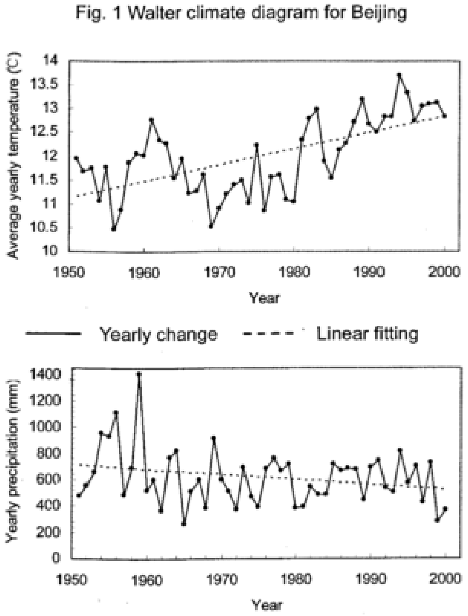


Fig. 2 Average yearly temperature (above) and yearly precipitation (below) changes in Beijing during the last 50 years

Tab. 1 Plant species selected in the study

| English name | Latin name |
|---|---|
| Canada Poplar | *Populusx Canadensis* |
| Chinese Pine | *Pinus tabulaeformis* |
| Chinese White Poplar | *Populus tomentosa* |
| Hankow Willow | *Salix matsudana* |
| Siberian Elm | *Ulmus pumila* |
| Flowering Almond | *Amygdalus triloba* |
| Common Apricot | *Armeniaca vulgaris* |
| Chinese Redbud | *Cercis chinensis* |
| False Acacia | *Robinia pseudoacacia* |
| Early Lilac | *Syringa oblate* |
| Yulan Magnolia | *Magnolia dendudata* |
| David Peach | *Amygdalus davidiana* |
| White Mulberry | *Morus alba* |
| Japanese Pagodatree | *Sophora japonica* |
| Phoenix Tree | *Firnuaba simplex* |
| Maidenhairtree | *Ginkgo biloba* |
| Common Crape Myrtle | *Lagerstroemia indica.* |
| Conlmon Smoketree | *Cotinus coggygria.* |
| Chinese Ash | *Fraxinus chinensis* |

Climatic background of Beijing: In order to analyze the relationship between climatic factors and plant phenophases, it is essential to know the background of climate in Beijing. Accordingly, the Walter Climate diagram (Fig. 1) is drawn to illustrate the primary climatic conditions in Beijing, including the seasonal variations, extremes as well as mean values. It can be seen that the climate in Beijing is a kind of typical warm temperate climate, with plenty of warmth and precipitation, but is very dry in spring (from middle March to May) and late autumn (during October). Changes of average yearly temperature and yearly precipitation in Beijing can be shown by Fig. 2, which implies the temperature in the past 40 year has increased obviously, while the precipitation has decreased slightly.

Phenological data are from Network of Phenological Observations in China, and we choose those observed in Beijing during the past 40 years, from 1951 to 2004. The systematic phenological observation in Beijing was advocated by Prof. Kezhen Zhu, and began in 1961, which still continues today, with a few short interruptions (Zhang and Jiang, 1996). And the observation site was situated in the Summer Palace, which is located in the northwest suburb of Beijing.

## 2 METHODS

Methods used in the study include both methods for field phenological observation and methods of the analysis itself. For the phenological observations, over 20 species of woody plants were selected, and their phenophases have been observed almost everyday in spring, but we select in this work include 19 species, with consideration of both the native species and widely distributed species, in order to compare with the same species distributed in different places in future studies. For the analyzing methods, various statistical methods, such as correlation analysis and regression analysis are used to explore the impacts of some climatic factors, for example, the sunshine duration, precipitation, as well as temperature, on plants phenophases, and they are also used to analyze the trend for phenophases changes.

## 3 RESULTS

The calculated results show that: Changes of spring phenophases for each woody plant are similar in Beijing during the last 6 years. (1) The spring phenophases for all the above woody plants have advanced very obviously. Tab. 2 shows some examples of such changes during the last 40 yeas. (2) Spring phenophases in Beijing during the last few years have advanced even more obviously, compared to the corresponding average phenophases during last 40 year. The most obvious advancement of phenophases is the first bloom of *Sringa oblata*, which advance 23 days compared to 40 years' average phenophases (See tab. 2). (3) The spring temperature is the most important climatic factor to affect plants phenological phases, but it proves that the sunshine duration and precipitation are not correlated so well with the plants phenology (see tab. 3). Among mean temperature, maximum and minimum temperature, the spring mean temperature for each phenophase is the most important climatic factor to affect spring plant phenophases. And this was put forward through a statistical regression model. The model also indicates that the relationship between changes of phenological phases and temperature is non-linear. (4) Changes of onsets for these phenophases in recent years are paid high attention to in this study, in order to find the links between the phenophases trend and recent warming. It is found that they correspond with each other very well. As a result, the average advancements for the onset of these species in the last 4 year are about 8.1 days compared to 40 years' average, and are consistent with the increasing warming trend in recent few years.

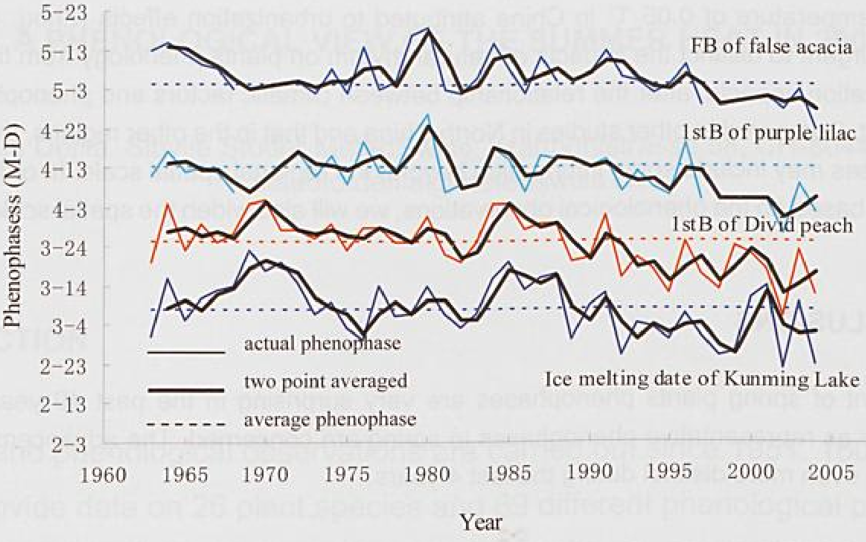


Fig. 2 Spring phenophases change in Beijing (1963-2004)

Tab. 2 Changes of spring phenophase in Beijing during the last 4 years compared to 40 years' average

| Phanophases | Date during 2000-2004 (m-d) | Deviation from average (days) | Earliest during 2000-2004 | Deviation from average (day) | Latest date during 2000-2004 | Deviation from average (day) |
|---|---|---|---|---|---|---|
| 1stB of *Populus Candensis* | 3-11 | -20 | 3-2 | -18 | 3-28 | -14 |
| 1stB of *Populus davidiana* | 3-7 | -17 | 2-27 | -10 | 3-15 | -15 |
| 1stB *Salix matsudana* | 3-24 | -11 | 3-14 | -10 | 4-4 | -16 |
| 1stL of *Ulmus pumila* | 4-1 | -11 | 3-28 | -4 | 4-6 | -16 |
| 1stB of *Ulmus pumila* | 3-9 | -9 | 2-26 | -7 | 3-19 | -10 |
| 1stL of *Prunus triloba* | 3-31 | -14 | 3-24 | -4 | 4-8 | -18 |
| 1stB of *Prunus triloba* | 3-31 | -7 | 3-24 | -8 | 4-6 | -16 |
| 1stB of *Prunus armeniaca* | 3-28 | -9 | 3-17 | -11 | 4-4 | -10 |
| 1stL of *Robina psudoacacia* | 4-6 | -14 | 3-31 | -11 | 4-10 | -18 |
| FB of *Robina psudoacacia* | 4-28 | -10 | 4-23 | -6 | 5-3 | -16 |
| 1stL of *Sringa oblata* | 3-22 | -16 | 3-14 | -14 | 3-30 | -23 |
| 1stB of *Sringa oblata* | 4-3 | -11 | 3-27 | -9 | 4-9 | -18 |
| 1stB of *Magnolia dendudada* | 3-23 | -11 | 3-14 | -6 | 3-30 | -16 |
| 1stL of *Prunus davidiana* | 3-23 | -15 | 3-16 | -10 | 3-31 | -14 |
| 1stB of Prunus davidiana | 3-13 | -13 | 3-6 | -6 | 3-23 | -12 |

**Tab. 3 Correlation of different phenophases with temperature, sunshine duration, and precipitation**

| Factors | 1stB of Prunus dividiana | 1stB of Syringa oblata | FB of Robina psudoacacia | 1stB of Ulmus pumila | 1stB of Salix matsudana | 1stB of Wisteria sinensis | 1stB of Magnolia dendudata |
|---|---|---|---|---|---|---|---|
| Mean temperature | -0.73** | -0.78** | -0.79** | -0.53** | -0.68** | -0.74** | -0.71** |
| Sunshine duration | -0.08 | -0.17 | -0.27 | -0.24 | -0.24 | -0.22 | -0.21 |
| Precipitation | 0.02 | 0.003 | 0.3 | 0.09 | 0.14 | 0.22 | 0.07 |

** p=0.01

## 4 DISCUSSION

Changes of phenophases for above plants could be regarded as the result of climatic change, especially the result of spring mean temperature change. But what lead to climate change is still unclear. The urban heat island is a very important factor for regional climate change in recent years, so the relationship between recent warming and changes of phenophases was discussed in the light of significant urbanization effects (Roetzer, *et al.* 2000). And it was also put forward that the warming of mean surface temperature of 0.05 ℃ in China attributed to urbanization effects (Zhou, *et al.*, 2004). Therefore, it is urgent to distinct the impacts of natural rhythm on plants phenology from that of human induced urbanization impacts, after the relationship between climatic factors and phenophases. And it will be done next. Compared to other studies in North China and that in the other regions, the changes of such phenophases may include some information beyond the regional spatial scale. In order to test this conclusion, and based on the phenological observations, we will also widen the spatial scale of the study afterwards.

## 5 CONCLUSIONS

(1) Advancement of spring plants phenophases are very surprising in the past 40 years in Beijing, especially as far as representative phenophases in spring are concerned. The advancement of spring phenophases is even more distinct during the last 4 years.

(2) Changes in phenophases are caused mostly by the spring mean temperature change during these years. And the relationship between phenophases and climatic factors can be used to reconstruct the past climate according to a variety of phenological records in history.

**ACKNOWLEGEMENTS:** The study was supported by the knowledge innovation fund of Chinese Academy of Sciences (Grant No. KZCX1-SW-01-09 ) and the National Natural Scientific Foundation of China (Grant No.40471047, 40371019).

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# A PHENOLOGICAL VIEW OF THE SUMMER HEAT IN 2003

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## INTRODUCTION

In Switzerland phenological observations are carried out since 1951. 160 observation stations provide data on 26 plant species and 69 different phenological phases. It is known that there is a strong correlation between air temperature and the phenological spring and summer phases. The summer heat of 2003 is therefore assumed to have strongly influenced the phenological development. The extremely warm temperatures were mainly measured in June and August. The climatological summer months (June to August) were 4 to 5.5°C warmer than on the average.

## METHODS

To investigate the direct impact of the summer heat in 2003 on the phenological occurrence dates two phases in late spring and five summer phases were accounted for. Six autumn phases were additionally selected to assess the influence of the summer heat and drought periods on the later occurring development stages. 225 time series covering the period 1951 -2003 based on 24 observation stations covering an altitudinal range from 200 to 1800 m asl were included in the analyses. The values for 2003 were assigned to one of the five following classes: very early, early, normal, late and very late.

## RESULTS

Very early occurrence dates were observed for the late spring and summer phases. 60% of all spring and summer values were classified as 'very early' 25% as 'early'. These phenological phases appeared between 10 days (full flowering of ox-eye daisy (Leucanthemum vulgare)) to 20 days (full flowering in summer littleleaf linden (Tilia cordata) days earlier than on the average. Within the 122 spring and summer time series 37 records (earliest occurrence dates ever observed) were recorded. No late occurrence dates were recorded in this year. The autumn phases seemed to be less strongly influenced by the special summer weather conditions. Nonetheless 37% of the autumn data were classified as early or very early. For the 103 autumn time series 21 records (earliest appearance dates ever observed) were registered. But there were also 20% of late appearance dates.

## DISCUSSION

These results s how that the climatologically extreme summer 2003 lead to an exceptional phenological year. The numerous earliest occurrence dates indicate that the plants did not yet reach their physiological limits and that earlier appearance dates are still possible.

# ANALYSIS OF LONG-TERM PHENOLOGICAL TIME-SERIES IN THE TERRITORY OF LATVIA

Gunta Grisule and Zane Malina

## INTRODUCTION

The study examines the mean leafing, flowering and colouring times of 4 plant species for the period 1927-1935 and 1959-2004 in the territory of Latvia. The recording of timing of plants has started in the 1927 and there were included more than 50 stations. For particular study observations of 34 stations has been used. Material and methods. Sites of phenological observations varied from year to year and the relative contribution of regions in Latvia have been changed through recording period, with all plant species were almost the same. The long term mean data of leafing, flowering and colouring has been calculated for *Padus racemosa, Betula pendula, Sorbus aucuparia and Tilia cordata*. Onefactor regression and Man-Kendall test was applied for time series.

## RESULTS

The results show variations of 3 – 6 days for the all species. During the last decade the beginning of leafing of *Betula pendula* is observed in average is 6 days earlier than in 60's of 20$^{th}$ century and beginning of colouring of *Tilia cordata* – 3 days earlier. Considering time series from 1959 to 2004 the growing season in total has prolonged for 9 days. The same changes are observed for whole territory of Latvia as well as on regional level. From 1959 to 1980 phenological phases started in average later for all the described species, while from1981 up to now phases started earlier comparing with long-term mean. Time series analysed by Man-Kendall test indicated statistically significant ($p < 0.0001$) decreasing trend for autumn phases for period 1959 -1979 and increasing trend for period 1980 to 2004. Regarding to spring phases the obtained trends for these time periods are opposite.

## DISCUSSION

Observed timings of phonological time series in Latvia were compared to available phenological data for Central Europe and in general there is no differences neither for growing season and phenological phases. The species examined have indicated a response to seasonal temperature at different points. Also trends for spring phases are showing similar character to Central Europe. It is found in some regions and proved also in particular study that spring phenological phenomena have greater amplitudes of deviation than summer and autumn phases. The conclusions drawn from this study are that phenological time series recorded in Latvia in general could be useful as climate change indicator on regional level, but there is necessity of detailed influencing factor analyses.

# RESPONSE OF GRAPEVINE (*VITIS VINIFERA* L.) PHENOLOGY TO AIR TEMPERATURE IN CENTRAL GREECE

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## 1. INTRODUCTION

Phenology investigates the interactions of individual phenophases or other events of the life of plants (Jones and Davis, 2000) or animals (Sparks and Menzel, 2002) that take place seasonally in response to climate. Many phenological studies describe and correlate the timing of a number of the above events and of their variability with the weather conditions and other events such as the date of harvest (Chmielewski and Rötzer, 2001; Sparks and Menzel 2002). The timing of various phenophases on many plant species in spring depends strongly on air temperature conditions in the same period (Aasa et al., 2004). Thus, the air temperature increase in spring promotes an earlier response of plant development (Chmielewski and Rötzer, 2001). Most recent phenological studies found linear response of the onset time of various phenophases of many plant species to air temperature (Chmielewski and Rötzer, 2001; Menzel, 2003).

Grapevine (*Vitis vinifera* L.) is a plant with great economic importance at Greece. The timing of grapevine phenophases varies greatly with variety, climate and geographic location (Jones and Davis, 2000). Literature provides no available information on the role of air temperature on the timing of grapevine phenophases in Greece. Therefore, this study aims to evaluate the response of several phenophases of grapevine cultivars Roditis and Muscat of Hamburg to air temperature at two regions of cultivation in Central Greece for the period 1997-2004.

## 2. METHODS

For this investigation, phenological data, from the Peripheral Center of Plant Protection and Quality Control of Volos, on grapevine (*Vitis vinifera* L.) at the regions of Nea Agxialos (39°13′N, 22°48′E, altitude 12 m) and Dafnospilia (39°22′N, 20°48′E, altitude 570 m), Periphery of Thessaly, Central Greece, were used for the period 1997-2004. Phenological observations took place every five days on grapevine cultivars Roditis (use mainly for wine production) at Nea Agxialos and Dafnospilia and Muscat of Hamburg (edible use) at Dafnospilia in order to evaluate the appearance of the following phenophases: 1. End of bud swelling- BBCH[1] 05 (ES) 2. beginning of bud burst-green tips- BBCH 07 (BB) 3. beginning of leaf unfolding- BBCH 11 (LU) 4. leaf unfolding of third leaf - BBCH 13 (LU3) 5. clear view of inflorescences - BBCH 53 (IV) 6. separating of inflorescences-BBCH 55 (IS) 7. full flowering- BBCH 65 (FF) and 8. end of flowering- BBCH 69 (EF).

Air temperature data were monitored by the meteorological stations of the previously referred Center which covered the study regions. From these data, average values of air temperature were calculated for different periods at Nea Agxialos and Dafnospilia.

For the comparison of the same phenophases between the two grapevine cultivars at the region of Dafnospilia as well as for the cultivar Roditis at the two study regions the t-test was used. Also, the above test was used to compare air temperature data between the regions of Nea Agxialos and Dafnospilia. For estimating relationships between air temperature and the average timing of phenophases a Pearson's correlation analysis was conducted.

Where appropriate, the response of the timing of grapevine phenophases to air temperature at the two study regions was assessed by using the regression technique. For the statistical analysis, SPSS 11.0 and MS Excel were used with a P level of significance $\leq 0.05$.

[1] BBCH: recommended scale for phenological observations according to Strauβ et al. (1994) which classifies plant growth phases of a lot of species according to a standardized system.

## 3. RESULTS

T-test analysis showed that the time of appearance of same phenophases for the cultivars Muscat of Hamburg and Roditis at the region of Dafnospilia was significantly different with an earlier appearance of all phenophases in the case of cv. Muscat of Hamburg (Tab. 1). The average timing of the majority of grapevine phenophases is negatively correlated with the average temperature of March and March-April (higher degree of correlation than those of March).

Table 1. Correlation between air temperature (March-June) and appearance of the average timing of various phenophases of grapevine cultivars Roditis and Muscat of Hamburg in Central Greece for the period 1997-2004.

| Phase | X (DOY) | s (days) | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_{34}$ | $T_{45}$ | $T_{56}$ |
|---|---|---|---|---|---|---|---|---|---|
| cultivar Roditis at Nea Agxialos | | | | | | | | | |
| ES | 79.8 | 3.8 | -0.530 | -0.327 | | | -0.562 | | |
| BB | 86.5 | 3.2 | -0.575 | -0.239 | | | -0.550 | | |
| LU | 93.8 | 3.7 | -0.780* | -0.392 | | | -0.780* | | |
| LU3 | 100.1 | 3.2 | -0.836** | -0.489 | | | -0.872** | | |
| IV | 105.0 | 3.1 | | -0.483 | 0.619 | | | -0.152 | |
| IS | 110.6 | 3.0 | | -0.544 | 0.584 | | | -0.232 | |
| FF | 136.4 | 1.8 | | | 0.600 | | | | |
| EF | 146.0 | 1.9 | | | 0.639 | 0.592 | | | 0.710* |
| cultivar Roditis at Dafnospilia | | | | | | | | | |
| ES | 87.6 | 3.3 | -0.825* | -0.290 | | | -0.861** | | |
| BB | 92.8 | 3.3 | -0.815* | -0.208 | | | -0.804* | | |
| LU | 97.5 | 3.3 | -0.838** | -0.233 | | | -0.838** | | |
| LU3 | 102.0 | 3.5 | -0.841** | -0.244 | | | -0.846** | | |
| IV | 107.5 | 3.8 | -0.870** | -0.205 | | | -0.847** | | |
| IS | 112.3 | 3.5 | | -0.194 | 0.450 | | | 0.184 | |
| FF | 141.4 | 2.0 | | | 0.297 | | | | |
| EF | 149.1 | 1.7 | | | 0.362 | 0.193 | | | 0.107 |
| cultivar Muscat of Hamburg at Dafnospilia | | | | | | | | | |
| ES | 84.0 | 3.2 | -0.819* | -0.320 | | | -0.874** | | |
| BB | 88.4 | 3.3 | -0.788* | -0.290 | | | -0.830* | | |
| LU | 94.1 | 3.6 | -0.840** | -0.251 | | | -0.849** | | |
| LU3 | 97.9 | 3.7 | -0.853* | -0.461 | | | -0.924** | | |
| IV | 102.9 | 3.6 | -0.908* | -0.209 | | | -0.881** | | |
| IS | 108.6 | 3.6 | -0.883** | -0.269 | | | -0.896** | | |
| FF | 136.4 | 1.8 | | | -0.015 | | | | |
| EF | 144.8 | 1.6 | | | 0.155 | | | | |

X: mean, s: standard error, DOY:day of the year,
$T_3$, $T_4$, $T_5$, $T_6$: average monthly air temperature for March, April, May and June, respectively,
$T_{34}$, $T_{45}$, $T_{56}$: average air temperature from March to April, April to May and, May to June, respectively. *, ** significant at $P \leq 0.05$ and 0.01, respectively. The empty cells of the table indicate the absence of the respective phenophases.
ES: End of bud swelling, BB: Beginning of bud burst-Green tips, LU: Beginning of leaf unfolding, LU3: 3rd leaf unfolding, IV: clear view of inflorescences, IS: separating of inflorescences, FF: Full flowering, EF: End of the flowering.

The time of appearance of phenophases ES, BB and LU of grapevine cv. Roditis significantly changed between the two study regions with an earlier onset at Nea Agxialos (Tab. 1).

Regression analysis indicated linear relationships between air temperature and timing of phenophases for the examined cultivars and regions. The rise of air temperature by 1.0 °C led to an earlier timing of various phenophases by about 5 days (Tab. 2).

Table 2. Response of average air temperature from March to April, to the timing of various phenophases on grapevine cultivars Roditis and Muscat of Hamburg in Central Greece for the period 1997-2004.

| Region | Cultivar | Phase | Temperature response $\Delta P/\Delta T_{34}$ (days/°C) |
|---|---|---|---|
| Nea Agxialos | Roditis | LU3 | -5.2** |
| Dafnospilia | Roditis | ES | -4.8** |
| | | LU3 | -5.0** |
| Dafnospilia | Muscat of Hamburg | ES | -4.7** |
| | | BB | -4.5** |
| | | LU | -5.1** |
| | | LU3 | -5.8** |
| | | IS | -5.3** |

ΔP: change of days, $\Delta T_{34}$: change of air temperature of March-April, *, **significant at P≤ 0.05 and 0.01, respectively. ES: End of bud swelling, BB: Beginning of bud burst-Green tips, LU: Beginning of leaf unfolding, LU3: 3rd leaf unfolding, IS: separating of inflorescences.

## 4. DISCUSSION

The results of our study concerning the significant changes of the average timing of various phenophases between the two different grapevine cultivars at the same region (Dafnospilia) could be explained by their possibly different genetic component, since phenology is a trait under the influence of a strong genetic control (Cuine, 2001).

The negative correlation of air temperature with the majority of phenophases of cvs Roditis and Muscat of Hamburg could be due to an earlier onset of their phases from the rise of temperature in spring at the two study regions, in agreement with Menzel (2003) for the LU of many woody plant species.

The established linear relationships between air temperature and timing of grapevine phenophases are confirmed by Chmielewski and Rötzer (2001) and Menzel (2003) for other plants of commercial importance. The earlier timing of various phenophases by about 5 days because of the rise of air temperature by 1.0 °C comes to agreement with the findings of Chmielewski et al. (2004) for the beginning of blossom of *Malus domestica* and *Prunus avium* trees.

## 5. CONCLUSIONS

The results of this study showed that the air temperature of spring played an important role on the appearance of grapevine phenophases cvs Roditis and Muscat of Haburg at Nea Agxialos and Dafnospilia, Central Greece. Therefore, it is necessary to develop phenological models for grapevine and other plants of economic importance in order to investigate the impact of air temperature and generally of future climate changes in Greece. The knowledge of the timing of phenophases of crops in Greece in relation to meteorological factors can improve the programming of cultivation operations such as planting, fertilizing, crop protection etc. and finally it will be a useful tool for a better yield and crop management.

**Acknowledgements**

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# COST ACTION 725 ESTABLISHING A EUROPEAN PHENOLOGICAL DATA PLATFORM FOR CLIMATOLOGICAL APPLICATIONS

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## SUMMARY

The main objective of the pan-European COST action 725 having started in 2004 and running for five years follows its name to establish a European reference data set of phenological observations including metadata, that can be used for climatological purposes, esp. climate monitoring, and the detection of climate change.
Secondary objectives lie in the harmonization of techniques for the definition of species and phases, in developing recommendations for monitoring and collection procedures, for observation rules, algorithms for the data quality control, and for the archiving and distribution of phenological data.
One working group is dedicated to the application of phenological data, especially in the topic of climate change (e.g. trend analyses, correlations between phenological phases and other climate elements) but also in developing mapping techniques of phenological information (see also http://www.cost725.org/).

## 1 INTRODUCTION

COST is an inter-governmental framework for European Co-operation in the field of Scientific and Technical Research. COST works on the basis of so-called Actions, i.e. networks of coordinated national research projects in fields, which are of interest to participants from at least 5 different member states. The actions are defined by a Memorandum of Understanding (MoU) signed by the Governments of the COST states wishing to participate. 26 out of now 34 COST member states have signed the Memorandum of COST Action 725 making it the biggest running action of the COST Domain Meteorology. Because of the close relationship between plant development, weather and climate the national phenological observation networks in many countries are operated by the meteorological services (WMO, 2000) or by NGOs (e.g. in the UK, The Woodland Trust) or were established by universities (e.g. in The Netherlands, Wageningen University) and also few international or European networks are existing e.g. since the 1960ies the IPG (International Phenological Gardens). The networks have different objectives and goals that have also been undergoing a paradigm shift in the course of time. At the beginning of modern phenology in the 18th century the data were used as compliment to met. data do show "..how areas differ" (Linnaeus, 1751). Phenological data are used for microclimatological purposes to show e.g. thermally favored zones, in agrometeorology phenological data are input for crop models; pollen forecasts are another example for the utilization. And since the late1990ies climate change impacts has been coming to the fore: Plants maybe viewed as 'Integrative Measurement Devices' for the environment as their development is influenced to a great extent by many environmental factors (weather and climate conditions in the micro and macro-scale, soil-conditions, water supply, diseases, competition, etc., Defila, 1992). The seasonal cycle of plants however is influenced to the greatest extent by temperature, photoperiod and precipitation (Sarvas 1972, 1974, Morellato and Haddad, 2000, Keatley, 2000).

## 2 OBJECTIVES OF COST725

As mentioned above many different services organize and collect phenological observations. Due to that fact the phenological observations don't follow the same guidelines the data are also widespread and storee at different institutions and in different data formats. The main objective of the Action is therefore to establish one European reference data set of phenological observations, that can be used for climatological purposes, especially climate monitoring, and detection of changes. This data set will be easy and free accessible for scientific purpose and will be made available via internet.

Secondary objectives lie in the harmonization of techniques for:

- the definition of species and phases, that shall be observed in a harmonised way
- the quality control of observations
- commonly used formats of archiving and distribution of data
- mapping of phenological information and other application methods

and the overall goal is increasing the knowledge of relations between weather/climate and phenological phases.

## 3 FIRST RESULTS

The action started with an inventory of all available phenological station-data, data including metadata including International Phenological Gardens (IPG). As can be seen the station density varies quite much with the most dense network in former West-Germany,

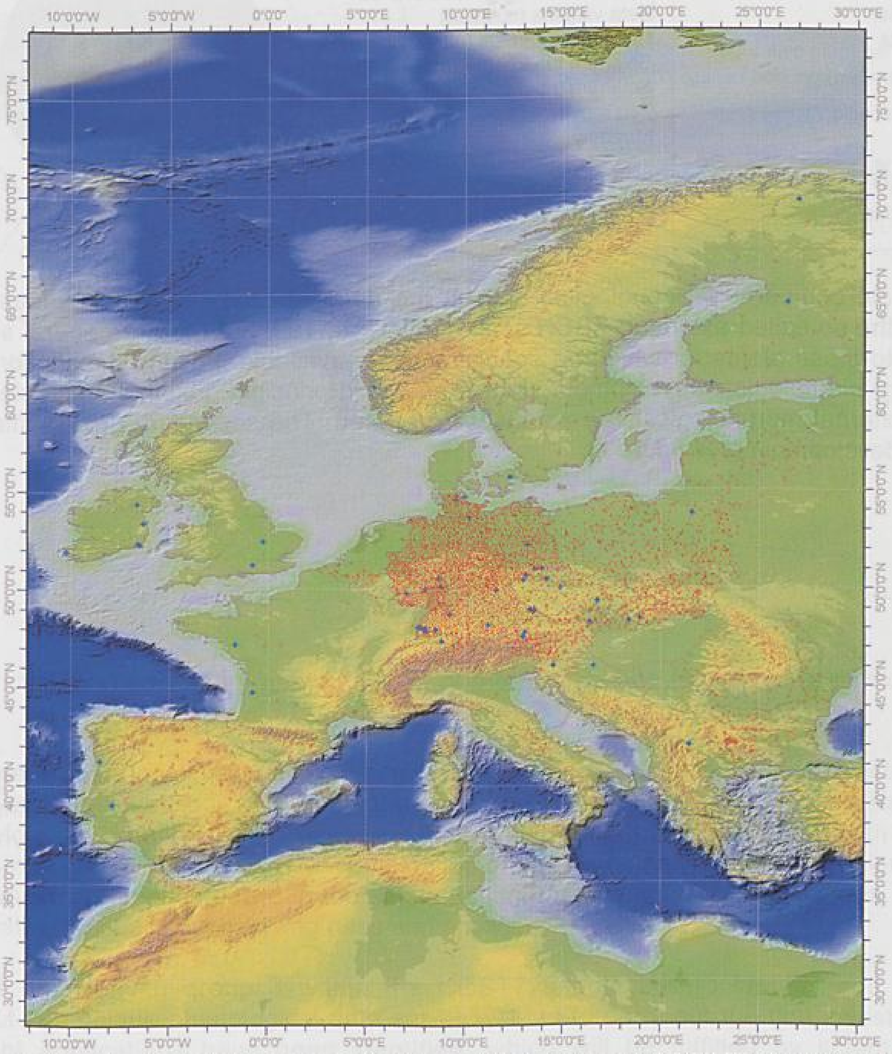



Figure 1: Map of phenological stations, recorded by working group 1 of COST725, state of April 2005

An even greater variability than in station density can be found in the plant species and phases under observation. Out of more than 300 observed species 64 were selected by working group 2 in cooperation with WG1 for the database following the criteria that the plant is observed in at least five networks and / or it is of importance for agriculture or is typical for a climate region. WG 2 has started already with the collection of the selected data from the participating countries (see table 1).

Table 1: List of plants selected for the common database

| native plants |
|---|
| Aesculus hippocastanum |
| Alnus glutinosa |
| Alopecurus pratensis |
| Ambrosia artemisiifolia |
| Artemisia vulgaris |
| Betula pendula (B. verrucosa, B. alba) |
| Corylus avellana |
| Fagus sylvatica |
| Forsythia suspensa |
| Picea abies (P.excelsa) |
| Quercus robur (Q.peduncula) |
| Sambucus nigra |
| Dactylis glomerata |
| Tussilago farfara |
| Acer platanoides |
| Acer pseudoplatanus |
| Alnus incana |
| Anemone nemorosa |
| Betula pubescens |
| Fraxinus excelsior |
| Galanthus nivalis |
| Larix decidua |
| Prunus spinosa |
| Robinia pseudoacacia |
| Salix caprea |
| Sorbus aucuparia |
| Syringa vulgaris |
| Taraxacum officinale |
| Tilia cordata |

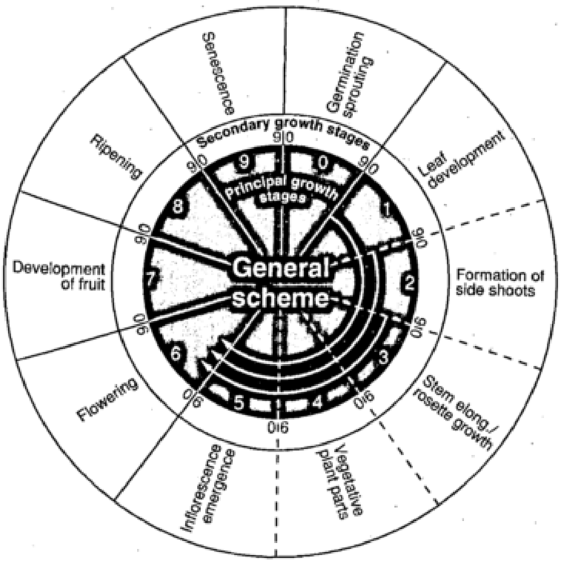
| fruit trees |
|---|
| Malus x domestica (early cultivar ) |
| Malus x domestica (late cultivar ) |
| Prunus avium (Cerasus avium) (early cultivar ) |
| Prunus avium (Cerasus avium) (late cultivar ) |
| Vitis vinifera (cultivar ) |
| Prunus domestica (early cultivar ) |
| Prunus domestica (late cultivar ) |
| Pyrus communis (early cultivar ) |
| Pyrus communis (late cultivar ) |
| Ribes rubrum |

| agricultural crops |
|---|
| Hordeum vulgare (spring, cultivar ) |
| Hordeum vulgare (winter, cultivar ) |
| Secale cereale (spring, cultivar |
| Secale cereale (winter, cultivar ) |
| Triticum aestivum (winter, cultivar ) |
| Avena sativa (spring, cultivar ) |
| Avena sativa (winter, cultivar ) |
| Beta vulgaris (cultivar ) |
| Helianthus annuus (cultivar ) |
| Solanum tuberosum (early, cultivar ) |
| Solanum tuberosum (late, cultivar ) |
| Zea mays |
| Meadow |

| northern plants |
|---|
| Calluna vulgaris |
| Cornus suecica |
| Epilobium angustifolium |
| Fragaria vesca |
| Geranium sylvaticum |
| Juniperis communis |
| Vaccinium myrtillus |
| Populus tremula |

| southern plants |
|---|
| Laurus nobilis |
| Olea europea |
| Prunus amygdalis/dulcis |
| Rosmarinus officinalis |

In order to gain comparable phenological data in the database the observed phases were coded according to the so called extended BBCH scale (Meier, U., 1997). As it is a general scale one can also apply it to those plants for which no special scale is available. For the description of the main (longer-lasting) phenological development stages, so called principal growth stages, clear and easily recognized external morphological characteristics are used. The secondary growth stages define a short step of development (see figure 2).




Principal Growth Stages

Description

0

Germination / sprouting / bud development

1

Leaf development (main shoot)

2

Formation of side shoots / tillering

3

Stem elongation or rosette growth / shoot development (maninshoot)

4

Development of harvestable vegetative plant parts or vegetatively propagated organs / booting (main shoot)

5

Inflorescence emergence (main shoot) / Heading

6

Flowering (main shoot)

7

Development of fruit

8

Ripening or maturity of fruit and seed

9

Senescence beginning of dormancy

Figure 2: Principal and secondary growth stages of the BBCH code (source Growth stags of plants, Meier, 1997)

One of the most evident application activity to phenological data is the mapping of selected phases as an actual (1 year) or climatological (at least the mean of 10 years) presentation. This has been done very often before on a national data base in different countries, but not so often with cross-border data, which is one goal of the action. The combination of data of national origin in a regional map often reveals systematic differences between the single national data sets at the borderlines. So, this may lead to an iterative feedback of observing rules and application methods.

The goals of the working group 3 within the COST725 action is to identify and demonstrate applications of this unique phenological data set as well as to carry out the first investigations. The following eight applications have been identified, which will be fulfilled by scientists with the appropriate expertise. A comparison of all data quality control, data correction, and gap filling methods (e.g. by meteorological indices, PCA, ..). The selection of appropriate procedures will allow the production of a quality tested data set. In addition, cross boarder differences might provide a further insight into the various methods of observations and further data processing. The second theme is the mapping of phenological data. Here, problems to be solved may arise from differences in station density, the different response of cloned and native plants, and various methods used in different countries. Maps will be produced for mean values for selected time intervals, trends, extreme years (e.g. the extreme dry and hot summer of 2003), variability, and climate response. The production of a higher level order product, a gridded data set of selected phases and phenological or seasonal indices, will allow a wide use of this data set in continental Europe wide studies. A forth theme will comprise analyses of temporal trends by different methods (e.g. linear regressions, Bayesian methods) and their Europe wide comparisons. The linkage of the onset of phenological events to weather and climate data in order to quantify the climate response of selected phases will be done by different type of analyses (e.g. correlation analyses). However, climate measures investigated should also include variability measures, extremes, various climate indices, such as agro-climatic models, weather type classes, circulation indices and different parameters, such as sunshine, rainfall, soil moisture, ... Here, there is a possibility of incorporating process based models. It is planned to study microclimate and local effects (e.g. heat islands, urban and rural areas), separately. An important last application is the link of various remote sensing / satellite data to phenological 'ground truth' and other measures, such as climatological metrics and agroclimatological indices.

## 4 DISCUSSION AND CONCLUSION

The COST action 725 meets the need to retrieve the treasure of phenological observations that have been hidden so far in many different databases, formats etc and make them easily accessible to different users. Numerous examples – from the duration of the growing season for gingko trees in Japan to the flowering of lilac in the US or the flowering of snowbells in Germany – show that climate change is significantly changing the seasonality of our eco-systems, especially in the middle and higher northern latitudes. The IPCC (Intergovernmental Panel on Climate Change) concluded in its Third Assessment Report in 2001 that many physical and biological systems, such as hydrology, glaciers and ice, vegetation, insects, birds and mammals, are already reacting to changing temperatures. COST725 will not only provide the database for further studies but will make applications of the data as e.g. shown in the presentation of A. Menzel et al. Meta-analysis of phenological trends in Europe (COST725) at the ICB 2005.

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# REPRODUCTIVE PHENOLOGY OF MYRTACEAE IN ATLANTIC FOREST: CLIMATIC FACTORS,PREDICTABILITY AND INTERESPECIFIC VARIATIONS

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The objective of this study was to analyze the reproductive phenology of 38 Myrtaceae species from Atlantic forest, aiming to answer the questions: 1) How is the Myrtaceae reproductive phenological pattern? Is the pattern similar among years? Does it reflect the local community phenological pattern? 2) Is the Myrtaceae phenology related to climate? 3) How is the relative contribution of each species to the family phenological pattern? and 4) Is the Myrtaceae phenology predictable? The study was carried out at Parque Estadual Intervales, Saibadela Sation, Sete Barras, São Paulo State, Brazil. Flower buds, open flowers, unripe and ripe fruits were observed monthly for six nonconsecutive years (April/1994 to March/1997 and April/1999 to March/2002) in 285 individuals. The largest percentages of individuals and species presenting buds and open flowers always occurred during the wetter and hotter season (October to March), mainly between November and February; unripe and ripe fruits were produced mainly over the less humid and colder season (April to September). The Spearman' correlations between the phenology and the climatic variables (temperature, rainfall and day length) were significant among bud and open flowers and the day length and the temperature of the same month of the phenological observation. Significant correlations were rare between fruiting and climate. The circular statistical analysis showed that the first date and peak date of the reproductive phenology in Myrtaceae were seasonal for most of the years. The species' contribution to the family phenological pattern differed in each month and in its duration. All the phenophases showed high predictability scores. The results confirmed the strong influence of Myrtaceae in the community phenological patterns. Myrtaceae presented a very seasonal flowering, related to temperature and day length, and a low seasonal fruiting, not correlated to climatic variables, as observed for Atlantic rain forest trees. The high predictability highlights the importance of Myrtaceae as a reliable food resource and suggests the existence of phylogenetic constraints on its reproductive phenology. (Financial support: FAPESP, CNPq)

# OLIVE FLOWERING AND CLIMATIC TRENDS IN THE MEDITERRANEAN BASIN (1999-2004): LOCAL EVIDENCES DIFFERING FROM THE GLOBAL WARMING CONCEPT

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## 1 INTRODUCTION

Global warming could induce chain reactions, that in contrast to its general warming effect could lead to local cooling in particular areas, one of which could be the mediterraneas.
The particularly rapid climate warming at the Earth's poles could cause the glaciers to melt and consequently the cold polar water would block the ocean's streams.
In the case of such a block in the Gulf stream there would be a marked decrease in the ocean temperatures. While the main streams on our continent have always been westerly the colder conditions in connection with the onset of these events is not easy to predict what sequel of related interactions could be induced.
Lower ocean temperatures could on the one hand result in a smaller steam, so the Atlantic atmospheric disturbances and western streams would be weaker on the other hand the European climate would become more continental with frequent incursions of icy winds from the north and north-east during the winter.
The aim of this study was to verify the relationship between climatic changes associated with this hypothetical scenario and the biological responses of olive (*Olea europaea* L.), a typical species found in the southern European forests (Mediterranean scrub) in its wild form (*Olea europaea* var. *oleaster*) and in several olive groves as cultivated (*Olea europaea* var. *communis*). Since the late 1990s, the study of flowering periods through phenological analyses has been one of the most frequently used methods to identify the developmental trends of various plant species and their relationship to their environment. Given the relative ease of identifying and registering the flowering periods, these data regarding the phenological phase have been studied the most and used for ecological analyses. Since the 1980s, techniques for monitoring the pollen count of anemophilous species that are of agricultural and environmental interest (grapes, olive, citrus, etc.) have been tested in an attempt to determine the periods of anthesis by directly registering the pollen emission through remote sensing techniques.
The results of pollen monitoring of olive carried out in five regions of south-central Italy (Sicily, Calabria, Puglia, Campania and Umbria) are reported.
Unfortunately, despite its insidious nature, few studies have been completed regarding the influence of climatic changes upon global ecosystems. The few attempts that have been made have focused attention on the energy and material fluxes in the ecosystems, rather than on the affect these changes have upon the species within the system.

## 2 METHODS

The pollen monitoring method (capture of pollen in the atmosphere) uses remote volumetric samples (Fig. 1) to obtain daily pollen concentrations, recently utilized in agronomic studies with the assumption that the number of pollen into the atmosphere during the flowering period is a good indicator of the crop yield potential (Fornaciari et al. 2002).
Pollen monitoring was conducted in olive groves located in the main Italian olive-producing areas (4 pollen-capturing units were set out in Sicily, 5 in Puglia, 3 in Calabria, 3 in Campania and 1 in Umbria). The overall study area represents more than 90% of the productive Italian olive groves which provide approximately 25% of the world olive oil production.
Pollen monitoring allows the daily concentrations (average n° of pollen grains for cubic metre) to be determined during the entire flowering period. Monitoring began in Perugia in 1982, while it was begun in the other areas in 1999.
To estimate the essential phenomena of pollen emission during flowering, the maximum pollen concentration days (MPC) in the different areas were used to interpret the anthesic phase of the higher percentage of olive plants in the different areas of study (Orlandi et al. 2005) to use as phenological parameters. The full flowering days (MPC) were calculated as the number of days after 1 January to evidence the 6-year trends in the different monitoring areas.

The meteorological data were obtained from the monitoring stations of the Italian meteorological network of the Central Office of Ecology (UCEA) nearest the study areas. The variables considered were: maximum, minimum, average temperatures (°C) and precipitation (mm).
To summarize the information related to the variables, the annual mean values of Tmax and min were calculated and then used to determine the mean thermal trend over a 11-year period (1994-2004).
Moreover, the quarterly mean values of the maximum and minimum temperatures, for all 16 study areas, were calculated and plotted to show the different trends of each annual season. The results were compared with those published by the NASA Goddard Institute for Space Studies (GISS), at Columbia University in New York City. The trend maps elaborated by this institute were considered in which the temperature change of a specified mean period (arbitrary) over a specified time interval (1951-2004) based on local linear trends are considered.
The statistical analysis considered the correlation among the annual full flowering dates and the calculated variables (annual mean values and the quarterly mean values of the min and max temperatures) since 1999 to 2004.

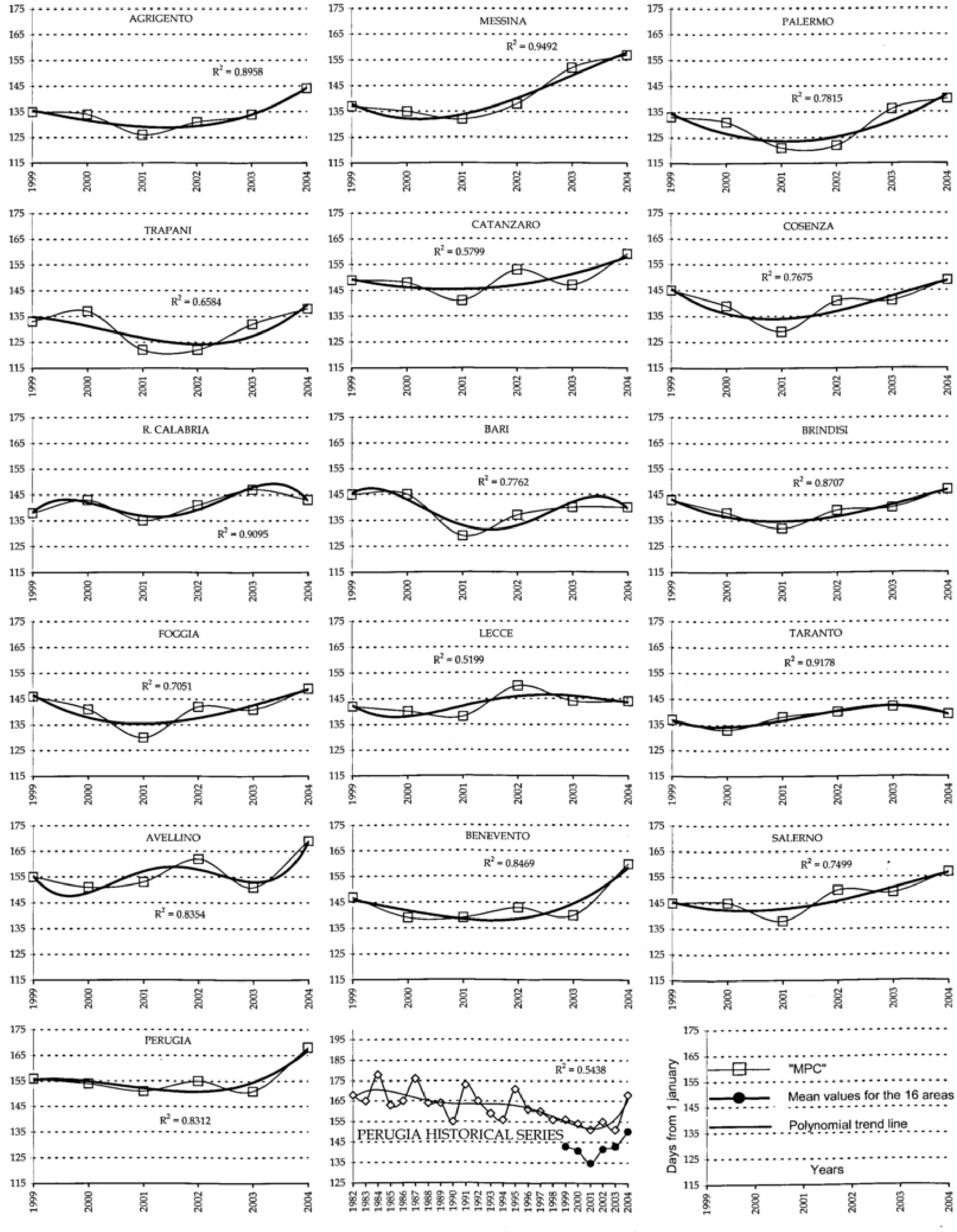
Figure 1. Pollen sampler (VPPS 2000)

## 3 RESULTS

The full flowering dates are shown in Figure 2 for each of the 16 monitoring stations from 1999 to 2004. A graph is also added in which the long-term pollen trend monitored from 1982 to 2004 in Perugia is presented. The mean values for the 16 areas since 1999 have been used to show possible relationships. In each graph the polynomial trend line was constructed to show the principal trends that characterize the 6-year series. The $R^2$ values of the regression analyses are shown which measure the fit of the trend line in comparison to the flowering data. The values obtained for all the monitoring stations were high (only in 3 cases were the values lower than 0.7); generally the polynomial trend lines show a minimum value during 2001 with an increasing trend in the successive years. The last graph compares the mean flowering trend of the 16 areas and that of the long-term series of Perugia for the last 6 years hypothesizing that there as been a similar behaviour in the past periods.
The annual mean min and max temperature values were calculated using data from all the monitoring areas. Both temperature trends show as significatives an increasing linear trend but even a sigmoidal trend due to different behaviours in the first years between 1994 and 2000 compared to the latter years (2001-2004). Moreover the quarterly mean min and max temperature values were calculated. The summer and autumn periods show increasing trends, while different behaviours were recorded for the winter (Dec.-Feb.) and the spring (March-May) clusters.
In particular, in the winter period both the min and max temperatures were characterized by a decreasing linear trend while, the spring period was characterized by a sigmoidal trend with the minimum value recorded in 1996 and the maximum in 2001.
Trend maps for the annual mean temperatures in Europe, elaborated from "GISS" data, were constructed considering two different clusters of years (1994-1999; 2000-2004). These reliable data suggest that a cooling phenomenon was occurring in this large area; the second period of the analysis

(2000-2004) was cooler than the base period. In fact, cool currents from the northern Russian regions invaded the Mediterranean area.

Figure 2. Full flowering dates in each pollen monitoring station with trend lines




The statistical correlations among the yearly flowering dates, the annual and quarterly mean min and max temperature values calculated as the mean values of all 16 monitoring stations are shown in

Table 1. The flowering dates indicate the closer relationship in the spring (March-May) thermal trend. The most influence was exerted by the max temperature (r= -0.93), however even the correlation coefficients for the annual mean values were significant.

Table I. Correlation analysis

| | Mean flowering dates | Annual means (T min) | Annual means (T Max) | Dec.-Feb. (T min) | March-May (T min) | Jun.-Aug. (T min) | Sep.-Nov. (T min) | Dec.-Feb. (T Max) | March-May (T Max) | Jun.-Aug. (T Max) | Sep.-Nov. (T Max) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean flowering dates | 1 | | | | | | | | | | |
| Annual means (T min) | -0.63 | 1 | | | | | | | | | |
| Annual means (T Max) | -0.75 | 0.79 | 1 | | | | | | | | |
| Dec.-Feb. (T min) | -0.41 | 0.40 | 0.32 | 1 | | | | | | | |
| March-May (T min) | **-0.82** | 0.13 | 0.45 | 0.28 | 1 | | | | | | |
| Jun.-Aug. (T min) | 0.26 | 0.50 | 0.08 | -0.15 | -0.75 | 1 | | | | | |
| Sep.-Nov. (T min) | 0.23 | -0.40 | 0.17 | -0.39 | 0.03 | -0.32 | 1 | | | | |
| Dec.-Feb. (T Max) | -0.42 | 0.06 | 0.11 | 0.90 | 0.51 | -0.53 | -0.32 | 1 | | | |
| March-May (T Max) | **-0.93** | 0.69 | 0.78 | 0.12 | 0.72 | -0.10 | -0.17 | 0.08 | 1 | | |
| Jun.-Aug. (T Max) | 0.06 | 0.69 | 0.43 | 0.07 | -0.58 | 0.91 | -0.12 | -0.37 | 0.06 | 1 | |
| Sep.-Nov. (T Max) | -0.25 | -0.28 | 0.34 | 0.16 | 0.50 | -0.68 | 0.73 | 0.34 | 0.08 | -0.39 | 1 |

## 4 DISCUSSION

Based on the meteorological data, the continental nature of the European climate seems to be extending southward and particularly towards the Mediterranean basin in the last four years.
This investigation has demonstrated that the flowering dates of olive, a species used as a bio-indicator of the Mediterranean scrub, have shown different behaviours until 2000 in comparison to those of the last years, showing a double trend inside the historical series.
Analysis of the quarterly mean min and max temperature values showed different trends. A consistent negative trend was recorded in the winter months (Dec.-Feb.) showing that a continuous cooling trend was in act from 1994 to 2004. The spring cluster months (March-May), on the other hand, showed a combined trend above all for the maximum temperatures (with the max value recorded during 2001 followed by a decreasing trend) that directly influenced the flowering dates.
The correlation analysis evidenced as the thermal trends of the annual mean values were close related to those of the spring quarter, in particular the spring quarter phenomena had the greatest influence on the annual trend. Moreover the spring quarter thermal trends were strictly related to those of the olive flowering phenomena. Really the thermal trends had a greater influence on the reproductive structure developments from March through May, the biological developments in olive (pollen mother cells, pollen tetrads, meiosis, binucleate pollen), and consequently the flowering dates, are compatted in a close pre-anthesis period of some weeks (6-7) from the end of April to the end of May in the study area.

## 5 CONCLUSION

This study shows how remote observation of biological events can facilitate a more attentive and in-depth study of climatic trends. The correlations between global climatic changes and world biodiversity have, to date, been largely ignored. However, it is possible to foresee some problems such as invasion of new habitat types and the corresponding loss of original habitat, changes in the type of habitat at the local level and a high rate of species migration.

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# Arrival Dates of Migrating Birds in Austria and Climate Variability

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## 1 INTRODUCTION

Plant and animal phenological observations constitute an easily available indicator, which allows to study the sensitivity of the biosphere to the variability of its atmospheric environment (Sparks and Menzel, 2002). In many countries time series of plant and animal phenological observations extending over several decades are readily available and are thus a valuable contribution to a quantitative description of the influence of climate variability on the biosphere. While most national phenological networks concentrate on plant phenology, some also collect animal phenological observations, like the first appearance of insects and the spring arrival and autumn departure of migrating birds. In western Europe migrating birds indicate a trend towards earlier arrival dates coincident with temperature variability along the migration route and the breeding areas (Huin and Sparks, 1998; Sparks, 1999; Cotton, 2003). Similarly earlier arrival dates of lark and wagtail have been reported from Estonia over the last decades (Ahas, 1999) and in Poland 14 out of 16 bird species show a trend towards earlier arrival dates over the time period from 1913 – 1996 (Tryjanowski et al., 2002). From the United States a trend towards earlier arrival dates has also been observed (Bradley et al., 1999). In contrast barn swallows tend arrive at later dates in Slovakia (1961 – 1985), which appears to be linked with a decreasing trend of mean April temperatures there (Sparks and Braslavska, 2001).

## 2 RESULTS AND DISCUSSION

Only a rather small fraction of the spatial variability of the long term mean entry dates (minimum time series length 30 years) can be explained by station coordinates and station elevation. In case of both swallow phases the explained spatial variability is about 10% and in case of the 'first cuckoo call' about 33%.

The mean long term entry dates of the 'first cuckoo call' move from east to west with about 100 to 200 km/day, however, the swallow arrival dates are not unequivocally related with the station longitude The swallows appear to leave first in the eastern part of Austria (70 to 140 km/day from east to west). The relation of the entry dates with station latitude is more clear-cut. The entry dates of the bird phases occur first in the south and move in case of the 'first barn swallow' with 40 to 200 km /day north and in case of 'first cuckoo call' with 20 to 56 km/day north. 'All swallows have left' occurs first in the north and moves with about 70 km/day south. As to be expected, birds arrive first at the low elevation stations. The phase 'first barn swallow' moves with 110 to 230 m/day from low to high elevation stations and the phase 'first cuckoo call' with 100 to 120 m/day. Swallows leave at about the same time at all altitudes in autumn.

Because most of the bird phenological time series are incomplete and because of the lack of information on the temporal development of the population density, which influences first sighting dates, the following conclusions about temporal trends have to be taken as tentative. A very first subjective spatial attribution of temporal trends of 'first barn swallow' from 1980 to 1999 shows 3 subregions in Austria, where the swallows in the Alpine area appear to arrive earlier and in the surrounding lowlands trends towards later arrival dates predominate (Fig. 1). The 'first cuckoo call' shows nearly everywhere trends towards later occurrence dates. With few exceptions the swallows seem to leave earlier in autumn.

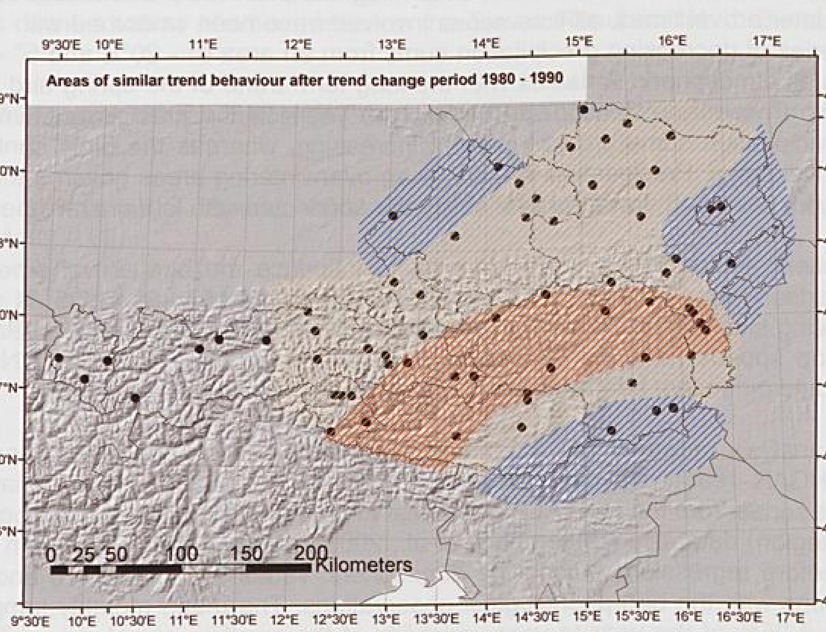


Fig. 1: Preliminary spatial distribution of the trends of swallow arrival times during 1980 – 1999. The red area indicates a trend towrads earlier, the blue towards later arrival dates and the brown area no clear trend.

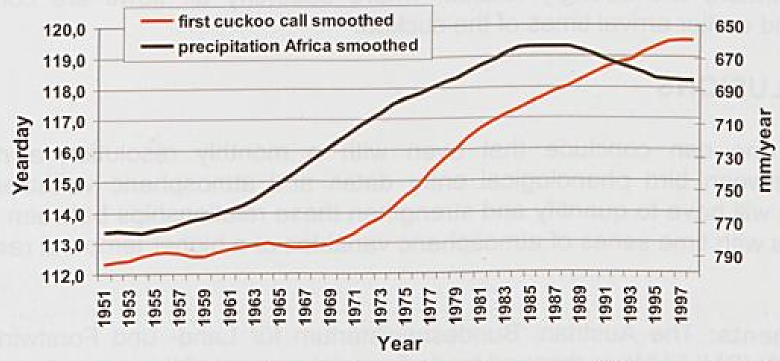


Fig. 2: Smoothed time series of ‚first cuckoo call' and yearly precipitation sums (from April of the previous year to March of the year of observation) over an area from 5°-30° N and 0°-20° E.

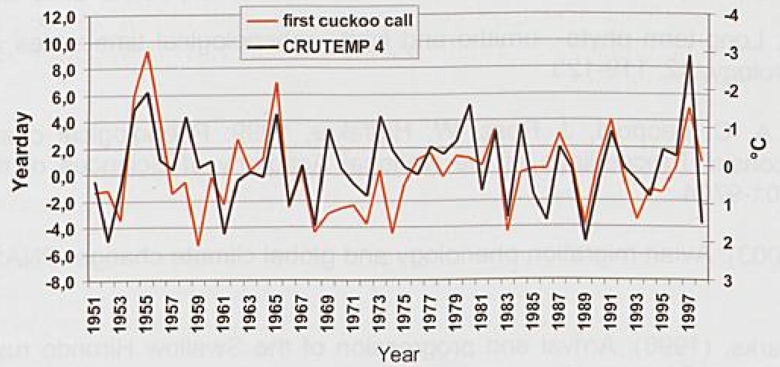


Fig. 3: Time series of the mean monthly temperature of April, averaged along 20°E from 23.5°-47° N (black) and the mean dates of the 'first cuckoo call' in Austria (red).

In order to make it easier to find candidates, which might explain the predominant trend of both bird phases towards later arrival times, all time series involved have been smoothed with a Gaussian filter (Fig. 2). Time series of decreasing precipitation sums from an area 0° - 20°E and 5° - 30°N show the best match from all atmospheric variables with the long term trend of the spring bird phases towards later arrival times. The only restriction are the last 15 years of the precipitation time series (1984-1999), where precipitation sums are still low but increasing, whereas the birds continue their trend towards later arrival times. Precipitation in the African overwintering areas governs the food supply of the birds, where dry years with low food availability are connected with late arrival times in Europe.

Another atmospheric factor with a good potential to influence the bird arrival time is the air flow situation. The northerly flow component for instance in March between 0° - 23.5° N over the Sahara has been increasing since the sixties of the last century at the surface and at 850 hPa. At the surface the northerly wind speeds have also increased during April between 23.5° - 47°N during the last decades. This could mean that headwind situations have become more frequent.

The correlation analysis between the bird phenological observations and atmospheric variables are based on the NCAR reanalysis data set with a monthly resolution and Austrian homogenised temperature time series from the HISTALP (**H**istorical **I**nstrumental **S**urface Climatological **T**ime Series of the **ALP**ine Region) database (Ungersböck et al., 2003). Linear trends have been subtracted from all time series before regression. Among the atmospheric variables temperature and wind show the highest correlations with the bird phenological observations. The mean monthly temperature of April can explain about 25% of the year to year variability of the swallow arrival dates. The year to year variability of the 'first cuckoo call' can be explained by about 35% with the April temperature (Fig. 3) and by 25% by the mean monthly distribution of the meridional geopotential component at 850 hPa along 20°E over a distance from 23.5° to 47°N during April. A multiple regression model combining both atmospheric variables can explain 39% of the year to year variability of the 'first cuckoo call'. Air flow and temperature are strongly related, where southerly air flows are connected with higher temperatures and earlier arrival times of the cuckoo.

## 3 CONCLUSIONS

Summarisingly one can conclude that even with a monthly resolution a number of potential relationships between bird phenological entry dates and atmospheric variables can be identified. Future research will have to quantify and strengthen these relationships between the atmosphere and bird arrival dates with time series of atmospheric variables at a higher temporal resolution.

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# SPRING PHENOLOGY 1982 – 2002 AS SEEN FROM EARTH AND SPACE – A COMPARISON

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## 1 INTRODUCTION

In the context of climate change knowledge of climatic impacts on plant phenology has become important: recent warming trends in the northern hemisphere clearly show up in phenological time-series with earlier springs and later autumn dates (Menzel, 2000; Roetzer et al., 2000; Defila and Clot, 2001). Vegetation on the other side can influence the atmospheric state - especially convection (Pielke, 2001) - and the surface climate (Bounoua et al., 2002). Therefore plant phenology (e.g. the seasonal course of leaf area index or vegetation greenness) is a strong biophysical driver variable for present and future climate model simulations. It is also known that interannual variability of the surface radiation and energy balance are related to changes in vegetation phenology (Guillevic et al., 2002). Ground observed phenology offers a high temporal resolution and detailed information about individual species, but it has a weak spatial coverage. Satellite derived phenology as a complementary observation method offers full spatial coverage and provides descriptive characteristics of phenological landscape events, rather than direct associations with the phenological performance of specific plants during the vegetation period (Reed et al. 1994). But the indirect nature of satellite remote sensing measurements make its interpretation cumbersome (Schwartz et al., 2002).
To assess the comparability to traditional ground observed phenological observations comparative studies are required (Ricotta and Avena, 2000; Chen et al., 2001).
In this study different algorithms to calculate the onset of spring based on satellite derived data are compared with traditional ground observations.

## 2 METHODS

### 2.1 GROUND DATASET

The source for the observed phenology data was the Swiss phenological network consisting of a total of 69 observation stations. For the comparison to the satellite derived phenology the multispecies index developed by (Studer et al., 2005) was applied. The phenological data set consists of a combination of 15 spring phases from different herb and tree species, covering the period from March to July. The same processed data set as for the above mentioned study was used but only the years 1982-2002 were included in the analyses. The same is true for the cumulated growing degree days (GDD) temperature data, consisting of interpolated homogenised station data from 12 meteorological stations in Switzerland (see Studer et al., this volume).

### 2.2 SATELLITE DATASET

In this study we use the 1982-2001 EFAI-NDVI dataset (Stöckli and Vidale, 2004), which offers continuous and consistent NDVI time-series at a 10day interval over Europe. In this dataset atmospheric effects and clouds were eliminated by applying second order discrete fourier series to the contaminated NDVI signal (Los et al., 2000; Stöckli and Vidale, 2004). The start of season (SOS) date was derived from NDVI time-series using simple methods (Reed et al., 1994; White et al., 1997; Jonsson and Eklundh, 2002; Schwartz et al., 2002). There are however a number of methods to derive e.g. start of the season (SOS) from NDVI time-series, and we have used a slope method (focuses on the rate of increase in vegetation greenness during the transition period between the dormant and the active growing season) and a threshold method. The analyses showed a better accordance of the observed and the threshold phenology and therefore only the results for the latter are presented here. The threshold is defined as the midpoint between the minimum and the maximum NDVI value of a time-series. In each year the first crossing of this threshold marks the SOS (White et al., 1997; Schwartz et al., 2002).
Ground observed phenological data is restricted to lower elevations. We therefore tested the effect of omitting NDVI values above 2000m (mean elevation within a particular pixel).

## 2.3 STATISTICAL ANALYSIS

To compare the main patterns in the different data sets empirical orthogonal function analyses (EOF) have been performed for all data sets. The time evolution of the dominant patterns (EOF one) was used to determine a robust trend estimate for the Swiss Alpine region.

# 3 RESULTS

The EOF analyses showed clear differences in the variance distribution among the different phenological parameters. The observed phenological data showed an intermediate proportion of variance on the first 4 principle components (PCs) (69%). For the threshold NDVI derived data the proportion of variance on the first PCs was clearly higher with more than 75% explained variance and a dominant proportion of variance was concentrated on the first PC (Table 1). The omission of the higher elevated data points in the satellite data led to a larger proportion of variance on the first PC.

**Table 1** Variance (%) explained by the first four EOF modes.

| Mode | Observed | Threshold NDVI | Threshold low | Temperature | Precipitation |
|---|---|---|---|---|---|
| 1 | 46 | 53 | 71 | 74 | 71 |
| 2 | 10 | 10 | 6 | 10 | 8 |
| 1 - 4 | 69 | 76 | 84 | 93 | 89 |

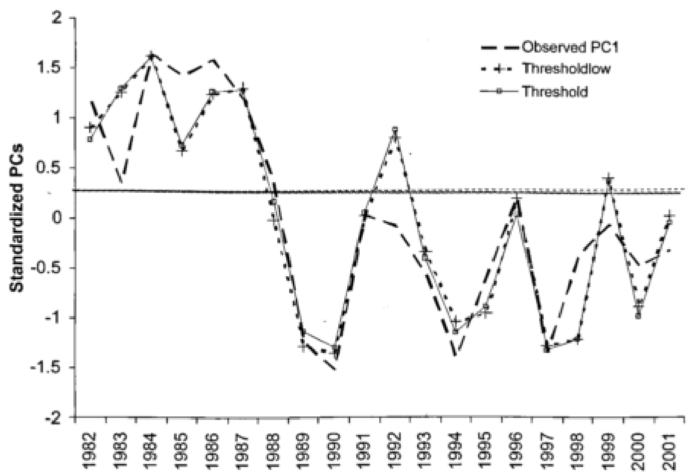


**Figure 1** Time evolution of the first principle components of the different phenology measurements.

The mean linear trend for the observed phenology is 3 days/decade. The trend values differ very much between ground observations and NDVI data. For the complete threshold and the lowland threshold data the trend is 8 and 8.6 days/decade respectively.

The omission of the high elevation data had no major effect on the first order EOF pattern (Figure 1Table 2). The observed phenology as well as the threshold NDVIs correlated very well with temperature (Table 2). While the two threshold NDVI measurements showed very similar results in the first EOF mode, they differed considerably in the second mode (figure not shown).

**Table 2** Correlation of the 1st principle components originating from the different methods

| | *Obs* | *Threshold* | *Thresholdlow* |
|---|---|---|---|
| Observed | | | |
| Threshold | 0.89 | | |
| Thresholdlow | 0.89 | 0.98 | |
| Temperature | 0.95 | 0.86 | 0.86 |
| Precipitation | 0.23 | 0.24 | 0.21 |

The second phenology pattern of the observed data explained 10% of total variability and showed an interesting regional pattern (Figure 2b). Stations in the northern part of the country tended to more pronounced trends towards earlier onset of spring than stations in the southern parts.In the satellite derived phenology data, the N-S pattern is present in the 1st and the 2nd EOF pattern (Figure 2). The spatial pattern not only represents a N–S effect but also a clear altitude dependence of the trend towards earlier appearance dates. As a result the mean trend value for the whole country is rather underestimated for northern and lowland sites and rather overestimated at southern and at higher elevated sites. For the observed phenology the altitude effect is found mainly on the second order EOF while in the satellite data the first order EOF represents the main altitude effect.

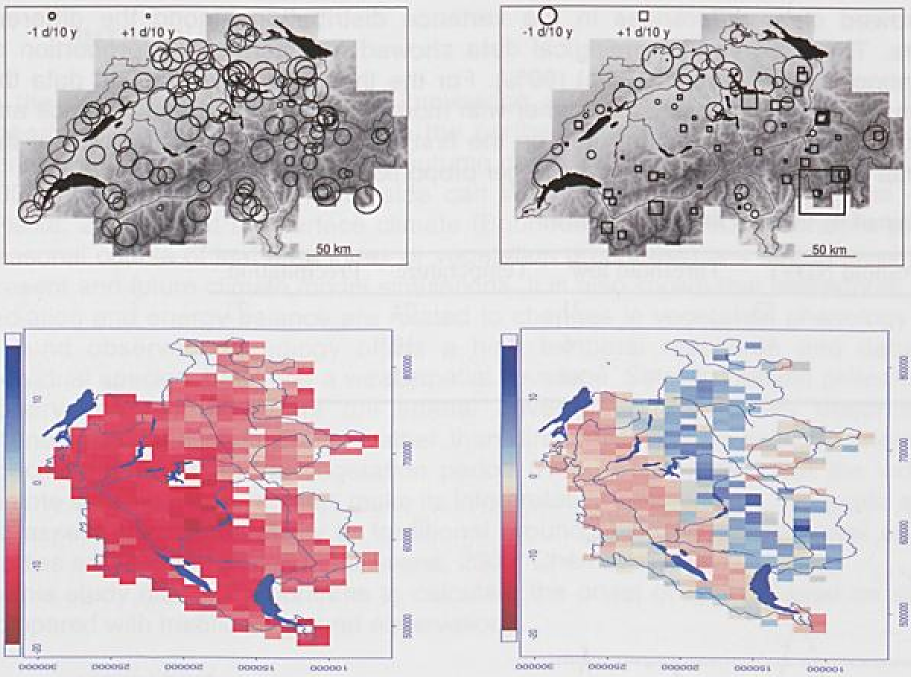


**Figure 2** Spatial pattern of the trends 1982 – 2001 (EOF pattern scaled to original units) of the different phenology parameters. a) first mode pattern (1st EOF) ground observed phenology, b) second mode pattern (2nd EOF) observed phenology, c) 1st EOF threshold NDVI, d) 2nd EOF threshold NDVI

## 4 DISCUSSION AND CONCLUSION

For the last decades numerous studies show evidence of a shift in plant development towards an earlier onset of spring in Europe (Menzel, 2000; Roetzer et al., 2000; Defila and Clot, 2001; Menzel et al., 2001; Ahas et al., 2002; Studer et al., 2005) and in North America (Beaubien and Freeland, 2000; Schwartz and Reiter, 2000). The trends found for several species and phases range from 1.4 to 3.8 days per decade over the last 50 years.

The threshold method to calculate a spring onset parameter on the basis of satellite derived data corresponds well to the temporal and spatial pattern of the multispecies spring index based on ground observations. In contrast to the observed phenology, the temporal and the spatial pattern are not as clearly separated on the first two modes of the EOF analysis of the satellite derived data. The omission of the data for higher altitude did not influence the main pattern of the NDVI phenology. Differences only appeared in the less important second order patterns.

The slope method, which is not presented here, is possibly more sensitive. It does not indicate the same state of vegetation for each year and it depends on the time of fastest progress in development. There might for instance be a high susceptibility to a rapid increase of NDVI due to snow melt.

(Myneni et al., 1997) detected an advance in the active growing season of 8±3 days for the years 1981 to 1991. Our results show similar values. The satellite derived phenology data seems generally to result in much higher trend values than the observed data. Further analyses with different thresholds could show, to what extent the intensity of the trend depends on the threshold.

Satellite derived phenological data are potentially very valuable data in applications that need a determination of the developmental stage of the vegetation, preferably online or near online (Braun and Hense, 2004), especially on a large spatial scale (Ricotta and Avena, 2000; Chen and Pan, 2002; Reed et al., 2003). But the temporal pattern of NDVI profiles is not only determined by seasonal variations in environmental conditions but also by human factors, such as agricultural and forestry activities. This is especially critical in fragmented landscapes. This small scale case study indicates that despite of these restrictions, satellite derived phenological data are well suited to represent the main temporal and spatial patterns as they are registered with traditional phenological ground observations.

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# Pollen

DWD

# CHANGES IN THE START OF BETULA SPP. POLLEN SEASONS IN SEVEN EUROPEAN COUNTRIES IN RELATION TO SPRING TEMPERATURES OVER 22 YEARS

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## 1. INTRODUCTION

Marked changes in climates over Europe during the last few decades have effected the phenology and distributions of some allergenic plants. These changes have also had impacts on the severity of pollen seasons and in some cases are implicated in observed changes in pollen allergenicity. These changes could have important impacts on allergy sufferers and requirements for health care. In Europe most central and southern areas have experienced more than 0.3°C rise per decade in daily maximum temperatures for the summer half of the year since 1976. In the extreme northern and eastern areas temperatures have remained relatively stable or have even decreased. The European Pollen Information service (EPI) collects data on average daily concentrations of airborne pollen for the main allergenic taxa from most European countries. Analysis of these data sets indicates notable changes to earlier start dates, longer duration and increased severity of the pollen season for many taxa over several decades. The WHO in Europe expressed concern over the impacts of climate change on allergic disease and held an interdisciplinary workshop on this in 2003 which included a consideration of the trends in pollen seasons. The theme was adopted for World Health Day in Europe that year and the WHO for Europe also published a report on the topic to highlight the importance of this topic.

Birch (Betula spp.) pollen is an important aeroallergen in NW Europe, and cross-reacts with many other related taxa including Alnus, Corylus and Carpinus. For example in Scandinavia it ranks as the most important allergenic pollen type over large regions and in the United Kingdom approximately 25 % of hay fever sufferers (about 6 million people) are allergic to pollen from this taxon. Birch pollen allergens also cross react with some foods such as apples and stoned fruits, producing symptoms of oral allergy.

On average, the growing season in Europe has increased by 10 – 11 days during the last 30 years. Considering the impact of this on pollen seasons, some of the clearest changes are evident in the start dates and within these the most noticeable trends appear for the spring trees, especially for Birch (Betula spp.). Changes in the start dates of Betula pollen seasons are significant as they effect the length of the "allergy" season and have consequences for health care.

The timing of Birch pollen seasons depends mostly on a non linear balance between winter chilling required to break dormancy, and spring temperatures. Previous work (Emberlin et al. 1997) has shown a recent trend for the seasons to begin progressively earlier in the UK by about 5 days per decade. A comparative analysis of long term records (1982 to 1999) from six sites across Europe (Emberlin et al . 2002) revealed marked regional differences in trends in relation to the features of temperature profiles. During this time evidence indicates that sensitisation to pollen allergens has also increased in many areas of Europe. For instance allergic sensitisation to Birch pollen has increased in Central and Northern areas, to Olive pollen in the Mediterranean and to Ragweed in Hungary.

This paper aims to investigate detailed temporal patterns in start dates of Betula spp. pollen seasons across a wide biogeographical range of sites in Europe over 22 years but with specially attention to changes since 2000. It also aims to explore relationships with changes in spring temperatures. The outcomes will facilitate prediction of future trends.

## 2. METHODS

Daily average Birch pollen counts taken with Hirst type Volumetric traps were used from Kevo, Turku, London, Brussels, Zurich, Vienna, Paris, Lyon and Poznan. At most sites continuous records of daily readings are available from the 1980s to present, and in the case of London since 1970 and Vienna since 1976. However the two Polish sites started in the early 1990s. Except for the Polish sites there are data sets spanning 22 years for the core period 1982 to 2004.

The sites cover a range of biogeographical areas from just within the Arctic Circle to North West Maritime and Continental Europe. Several species of birch grow in this range, together with various hybrids. Betula pubescens (verrucosa) predominates at Kevo with some B. nana; at Turku, London, Vienna and Brussels both B. pubescens and B. pendula are common together with hybrids. At Poznan, Krakow, Zurich and Paris B. pendula is common while B. pubescens occurs less frequently.

The pollen season start date was defined as the date on which an accumulation of 1% of the annual total was recorded . Monthly mean temperatures (daily mean, max and min temperature), and rainfall for January to May were obtained form the nearest weather station to the site. Cumulated temperatures over 5 degrees C were calculated for each month and from Jan 1$^{st}$. These figures and other weather variables were compiled as monthly data to five year running means (for example on Figs 1 and 2 " 1999" is the mean from 1999 to 2004). From these data the key variables were identified by correlations, multiple correlations and regressions .The start dates for the next ten years were calculated from regression equations for each site, and information from the latest climatic predictions.

## 3. RESULTS

The analyses show regional contrasts, e.g. the most northerly site, Kevo 69 $^{\circ}$ 28' N 27$^{\circ}$ 25' E (Fig 1) has a marked trend towards cooler springs and later starts. This concurs with reports of later and deeper snow lay in the spring over recent years. Turku 60 $^{\circ}$ 28 N 22 $^{\circ}$ 12 , exhibits cyclic patterns in start dates ranging over 10 days different through a decade but with a long term tendency towards earlier starts. A current trend towards earlier starts is expected to continue until 2007, followed by another fluctuation. London, Paris , Lyons, Brussels, Zurich, Vienna and Poznan show similar trends towards earlier start dates but with some regional differences. For example. London 51 $^{\circ}$ 30' N 0 $^{\circ}$ 10'W (Fig 2), there is a marked trend towards increasing warmth in mean April temperatures since 1970, especially in the 1990s. The trend towards earlier starts has slowed, possibly a result of decreased vernalisation leading to an enhanced demand for spring warmth. In Vienna (48 $^{\circ}$ 13' N 16$^{\circ}$ 22' E), April temperatures have also increased but the most marked changes in temperature have featured in January.

Predictions by regression indicate that if the trends continue the mean start dates at these sites will become earlier by about six days over the next decade.

Fig 1 **Finland Kevo Betula pollen season start dates ( 1% ) 1980 to 2004**
**Five year running means and predictions for next ten years**

**Trend line as third order polynomial. Predictions from regression.**

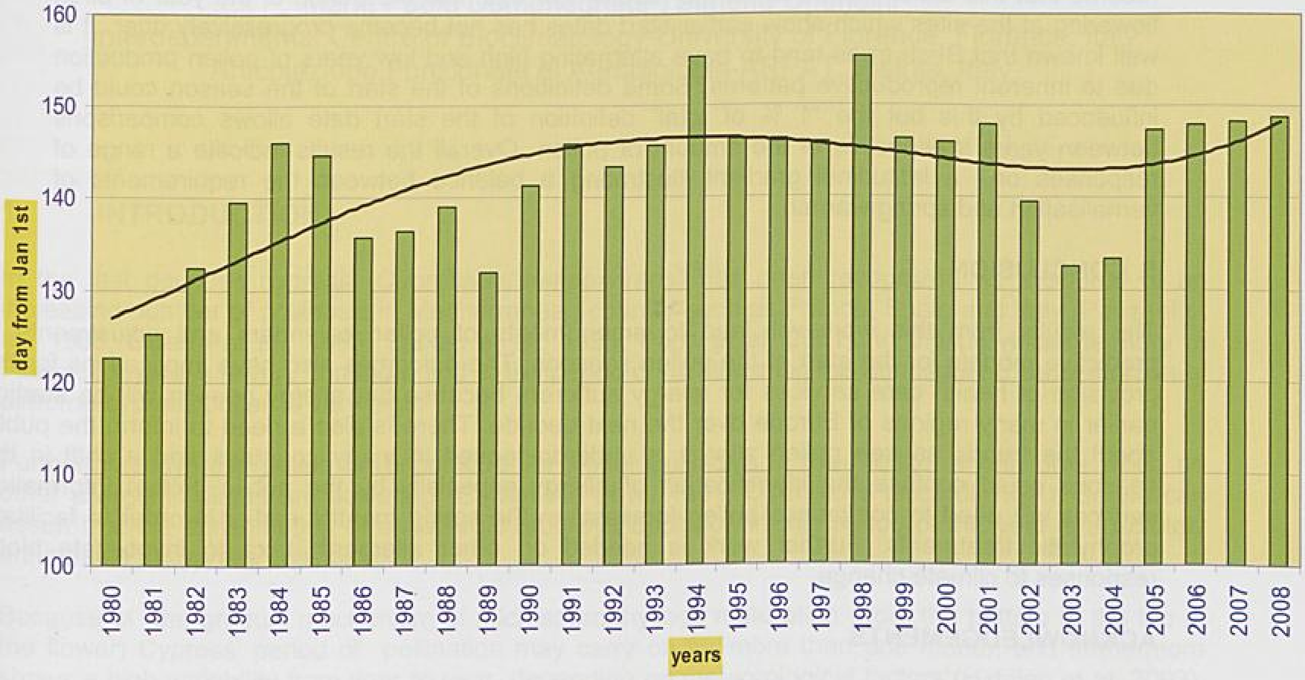
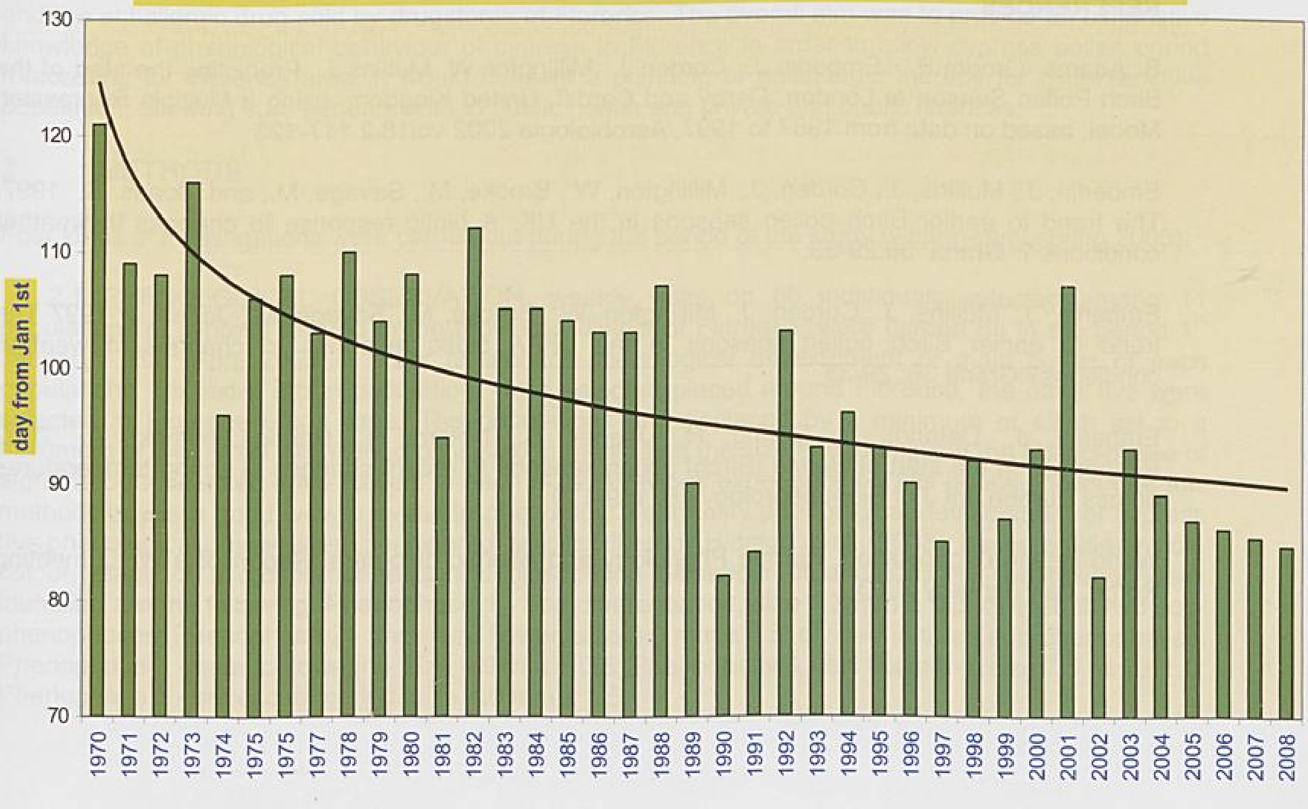



**Fig 2** **London Betula season Start dates (1%) as five year running means 1970-2004 with trend line prediction for next ten years.**
**Trend line as power function.**



## 4. DISCUSSION

This paper has taken a broad approach in order to identify the main trends. The pollen records indicate the times at which pollen is in the air rather than the actual flowering times or when the pollen matures on the plant. The dispersal of the pollen can be curtailed by adverse weather such as several days of rainfall. However there is no indication from the weather records that this factor has distorted the results. For example the period of the year of birch flowering at the sites which show earlier start dates has not become progressively drier. It is well known that Birch trees tend to have alternating high and low years of pollen production due to inherent reproductive patterns. Some definitions of the start of the season could be influenced by this but the "1 % of total" definition of the start date allows comparisons between years irrespective of the amount of pollen. Overall the results indicate a range of responses on a latitudinal gradient illustrating a balance between the requirements of vernalisation and spring warmth.

### 5. CONCLUSION

The results from this work will lead to amendments of pollen calendars and adjustments in predictive models for the start of the pollen seasons. The outcomes also have implications for the provision of health care services for allergy sufferers because the allergy season will be starting earlier in many regions of Europe over the next decade. There is also a need to inform the public about the trends as tree pollen allergy is underdiagnosed in many countries and a shift in the seasons could confuse the identification of allergy especially by the public. Pollen information services will need to commence pollen forecasts in the spring months earlier in order to facilitate prophylatic treatments. Further work is needed on other allergenic taxa to investigate biotic responses to climate change.

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# ANALYSIS OF METEOROLOGICAL CONDITIONS AND CYPRESS PHENOLOGY AND RELATIONSHIPS WITH POLLEN CONCENTRATIONS AND ANTIALLERGIC THERAPY

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## 1 INTRODUCTION

In the last decades cypress (*Cupressus sempervirens*) has been recognized as a source of an increasing number of pollinosis in Mediterranean country such as France, Spain and Italy (Panzani et al., 1986, Caiaffa et al., 1993; Subiza et al., 1995; Papa et al. 2001). In the provincial territory of Florence, cypress is very common, and in the period of his flowering the atmospheric concentration of airborne cypress pollen is very high.

Furthermore cypress pollen is responsible for winter pollinosis in the Mediterranean area when no other allergenic plants are flowering (Caramiello et al. 1991; D'Amato e Liccardi 1994). So we can assert that the consumption of antiallergic drug by population in this period of the year is absolutely attributable to cypress pollinosis.

Because of the gradual mechanism of microsporophyllous maturation (from the bottom to the top of the flower) Cypress' period of pollination may carry on for more than one month, and furthermore shows a high variability from year to year, depending on meteorological factors (Hidalgo et al, 2003). So hypersensitive population must be treated with antiallergic therapy for a period of two months or more.

The aim of this study was to investigate the relationships between meteorological factors and cypress male flower's development, between cypress male flowering and the atmospheric concentration of airborne cypress pollen, and finally between the atmospheric concentration of airborne cypress pollen and the antiallergic drug sold by drugstores of Florence. The overall aim was to provide an exhaustive knowledge of phenological behaviour of cypress in Florence in order to allow cypress pollen period forecasting for Florence area. It would consent a planning of antiallergic therapy for hypersensitive population, allowing sure benefits both to public health and private and public finances.

## 2 METHODS

Four kinds of investigations were carried out during the period of the study (winter-early spring 2005):

2.1 PHENOLOGICAL OBSERVATION: weekly visits on 66 individuals selected among 11 populations of cypress located in the provincial district of Florence, were carried on in the period 1$^{th}$ January - 30$^{th}$ April 2005 in order to monitor phenological development of male flower of each populations. Six extra urban population, were selected placed around Florence, the other five were selected in Florence urban area. The populations are displaced by a minimum of 49 m asl to a maximum of 545 m asl. Monitoring consisted in measuring the size and identifying the pheno-phase of eight random selected male flowers in each plant. Previous experience on this genus shows that this methodology is a good way to evaluate phenology. To identify phenological development of cypress five phenological phases were considered, as described by Hidalgo et al. (2003), based on dimension, colour, stage of microsporogenesis and blossoming behaviour of androecium. The phenophases identified are the following: Phenophase 1 - bud differentiation, size 1.2 mm ± 0.3, divided in two sub-phenophases; Phenophase 2 - immature flower, size 3.0 mm ± 0.5, divided in three sub-phenophases; Phenophase 3 - near to flowering, size 4.9 mm ± 0.5; Phenophase 4 - full flowering, size 7.0 mm ± 1.0; Phenophase 5 - senescent period, size 7.0 mm ± 1.5.

2.2 AEROBIOLOGICAL MONITORING: aerobiological data was collected in the period 1th January - 30th May 2005, using a 7-day spore trap (VPPS 2000 by Lanzoni srl) placed on the roof of Careggi hospital of Florence 20 m above ground level. Data were provided by 'Articolazione Funzionale di Aerobiologia-ARPAT, Pistoia'.

2.3 PHARMACO-ECONOMICAL SURVEY: daily data about the sale of antiallergic drugs were collected from a sample of ten Florentine drugstores. The most used over the counter drugs (freely available) and topical and systemic antihistamines and nasal corticosteroids (dispensed only with medical prescription) were selected. The brand name and the daily number of boxes of drugs sold were received from the selected drugstores in the period 1th January - 30th April 2005.

2.4 METEOROLOGICAL MEASURAMENTS: hourly temperature recorded by sensors placed close to each population subject matter of the study. From these, daily mean temperature have been obtained.

2.5 STATISTICAL ANALYSIS: bivariate regression analyses were carried out in order to correlate meteorological and phenological data, phenological and aerobiological data, and finally aerobiological and pharmacological data.

## 3 RESULTS

3.1 METEOROLOGICAL CONDITION-MALE CYPRESS PHENOLOGY RELATIONSHIPS: The statistical analysis pointed out the relationships between daily mean temperature and male cypress phenology. In particular it was emphasised in each cypress population studied, that the beginning and the duration of pollen dispersal period is correlated with daily mean temperature recorded in the population. Figures 1 and 2 show the relationships between daily mean temperature recorded in each populations during each phase and the beginning date of phenophase 4 (full flowering, beginning of main dispersal period) and phenophase 5 (senescent period, end of main dispersal period); in the first case the correlation is significant at 0.05 level, in the second at 0.01 level.

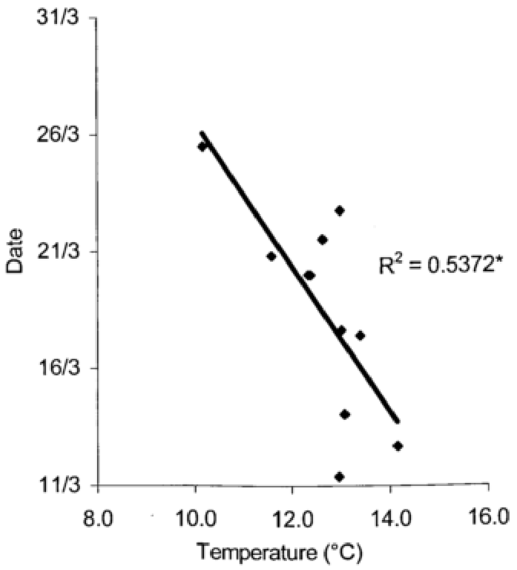


*Figure 1- starting date of phenological phase 4 vs daily mean temperature.*
**= Correlation is significant at the 0.05 level*

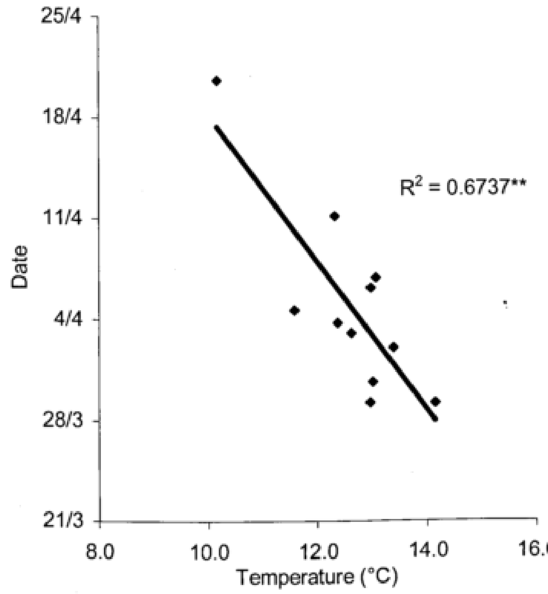


*Figure 2- starting date of phenological phase 5 vs daily mean temperature.*
***= Correlation is significant at the 0.01 level*

3.1 PHENOLOGY-AIRBORNE POLLEN CONCENTRATION-DRUG SOLD RELATIONSHIPS: Figure 3 shows the average temporal distributions of cypress pollen concentration in Florence atmosphere and of antiallergic drug sold in a sample of ten drugstores of Florence, for the period

January-March 2005; the two curves show the same trends, and their peaks correspond to the full flowering phase of cypress (pheno-phase 4). The correlation between daily pollen concentration and daily antiallergic drug sold (figure 4) is significant at the 0,01 level.

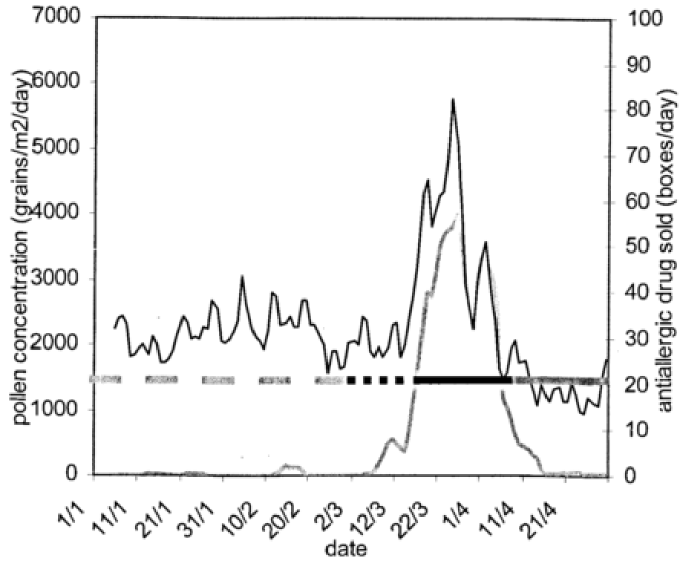


*Figure 3- trend of pollen concentration and boxes of antiallergic drug sold. Horizontal line represents phenological phases distribution LEGEND:*

Phenophase2 Phenophase4 pollen concentration

Phenophase3 Phenophase5 drug sold

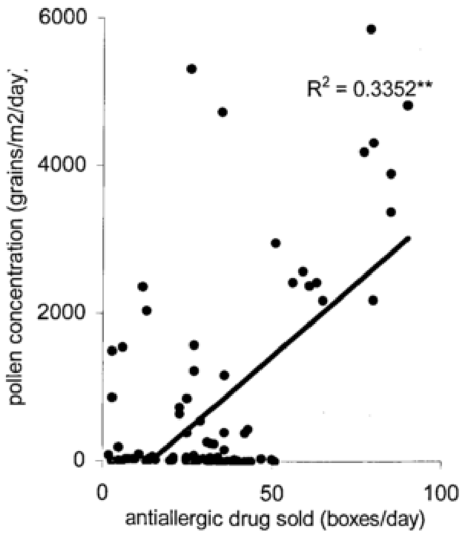


*Figure 4- pollen concentration vs boxes of antiallergic drug sold per day*
****= Correlation is significant at the 0.01 level*

## 4 DISCUSSION

The relationships found between daily mean temperature and the start and the duration of cypress main pollen dispersal period, and between this and the main cypress pollen concentration in the atmosphere, allow us to hypothesize the possibility to forecast the period of high cypress pollen concentration on the basis of temperature trends.

Furthermore the high cypress pollen concentration resulted correlated with a peak of antiallergic drug sold by Florentine drugstore.

For this reasons, in forecasting the period of high cypress pollen concentration, a sensible reduction of the therapy period for the hypersensitive population will be possible, ensuring sure benefits both for public, private finances and for the health of the population.

## 5 CONCLUSION

A correlation between meteorological conditions and the start and the duration of cypress main pollen dispersal period for provincial area of Florence, has been shown; a forecasting system to predict start and duration of main dispersal period of cypress is now available, and a reduction of antiallergic therapy period for hypersensitive Florentine population is possible.

Further investigations, to be carried on next years, are pleasing. They will allow a verification of the reliability of forecasting methodology, and will permit to carry out a phenological model for cypress in Florence.

Further verifications of the reliability of forecasting methodology and of phenological model for cypress could be done comparing findings with the ones obtained in analogue investigations carried on in other environments and growing season.

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# ONLINE MONITORING OF POLLEN – DEVELOPMENT OF A NOVEL TECHNIQUE AND FIRST RESULTS OF FIELD EXPERIMENTS

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## INTRODUCTION

Concentration data of pollen and fungal spores world-wide are still derived from tedious microscopic inspection of ambient air samples by eye. These data suffer from varying quality, limited reproducibility and late availability. Therefore in 2003 a project was started to develop a microscope-based automatic particle monitor providing reproducible, objective data of known quality.

## METHODS

A fully automated system has been developed for microscope-based single particle analysis employing a novel pattern recognition technique by extracting mathematical finger-prints basing of so-called grey scale invariants which are extracted from microscopic images. The system combines high-volume sampling, particle deposition by impaction, automatic preparation, imaging by various microscopic techniques, pattern recognition and particle classification by self-learning Support Vector Machines..

## RESULTS

First experiments showed a recognition rate of about 90% for the allergic pollen species. The recognition software was also successfully employed for an automated recognition of fungal spores without any change. It offers a wide range of applications for particle monitoring of the coarse particle fraction. Concentration data will be provided on an hourly basis.

## DISCUSSION

Validation of the monitor under field conditions will be carried out from April 2005 to June 2006. Sampling characteristics will be examined in comparison with Burkard and Rotorod sampler. On this basis recall and precision of the automatic particle recognition will be discussed. The production of a commercialised pollen monitor and the set-up of an automated monitoring network is planned for 2007. The available data will allow an further improvement of pollen forecast and dispersion modelling.

# NUMERICAL SIMULATIONS OF LONG-RANGE ATMOSPHERIC TRANSPORT OF BIRCH POLLEN

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## 1 INTRODUCTION

Birch pollen is a common cause of allergic rhinitis and asthma. High birch pollen concentrations are observed in Finland almost every spring a few weeks before the start of local flowering season. These early pollen peaks usually last for a few days and sometimes concentrations are even higher than later in spring, when the local birches flower. Concentration of pollen grains during such events seems to be increasing with a possible connection to climate change. Another possible consequence is an increasing total amount of long-range transported genetic material associated with pollen. Both phenomena – short but intensive spring-time episodes and bulk redistribution of genetic material - are almost impossible to evaluate and forecast using local observations alone.

This paper presents the first results of the Finnish Academy project "Evaluation and forecasting of the atmospheric concentrations of allergenic pollen in Europe" (see also Sofiev *et al.*, this issue). An overall goal of the study is to develop a numerical model for evaluation and forecasting of the early-spring pollen high-concentration episodes. This model can be also used for long-term evaluation of pollen transport.

The simulations presented are based on several pre-requisites: a European wide birch forest map, a unified European pollen emission model and a dispersion model adapted to pollen emission and transport specifics.

## 2 METHODS

Birch pollen grain is coarse (20 µm in diameter) but light (800 kg/m³), which makes it suitable for regional transport. Secondly, even a small fraction of emitted grains can cause allergenic effects. Thus, there can be thousands of grains per cubic meter at the source area but already 100 grains/m³ level is considered high for allergic people. These two reasons explain why the transport of such a coarse aerosol has to be considered at European level.

Some of the simulations of the birch pollen transport presented below required the emission flux or some other means for initiating the pollen concentrations in the modelled domain. All approaches require the European wide birch forest map as the main dataset. The most detailed dataset for Europe contains information on 115 different tree species in a 1 km x 1 km grid (Köbler and Seufert, 2001) and it also includes *Betula pendula* and *Betula pubescens*. A complementary dataset came from the European Forest Institute (EFI). These maps are a combination of the NOAA-AVHRR data and forest inventory statistics (Schuck et. al, 2002, Päivinen et. al, 2001). However, the latter datasets only recognize coniferous, broadleaf and mixed forests without any tree specification, which required a set of assumptions to be taken about the region-specific birch fraction in the broadleaf forest area. As a result, a lack of quantitative information concerning the geographical distribution of individual birch species did not allow their separate consideration. The birch species were mixed into "a general birch" with appropriate averaging of their characteristics.

The start of flowering was forecasted using statistical averages by Rötzer and Chmielewski (2001). The sink processes included dry deposition (with a primary role of gravitational settling) and scavenging with precipitations.

We started from examining the source areas of birch pollen for the cases when Finnish aerobiological stations (Turku, Kangasala, Kuopio, Oulu, Vaasa and Helsinki (see fig. 1a)) registered early-spring peaks of concentrations. Our tool was an emergency dispersion model SILAM (Sofiev & Siljamo, 2003), which was developed for accidental releases by the Finnish Meteorological Institute (FMI) and Technical Research Centre of Finland (VTT). It is an operational Lagrangian random-walk dispersion model, capable of solving both forward and inverse (adjoint) transport problems. Meteorological data were taken from the operational weather prediction models HIRLAM and ECMWF. The setup of SILAM adjoint runs used the data of the above Finnish aerobiological stations as a source term. Both the observations with non-zero pollen concentrations and those, which did not report a presence of grains in air, were taken into account. The sensitivity distributions computed for the first set of observations tells us where pollen source areas could be located while the distributions for the second set of measurements outlined the regions where no pollen emission could happen. The combination of these two cases provides a combined sensitivity distribution function and its integral over vertical – the "area of sensitivity" – that describes the area from where air parcels came to the stations by the times with non-zero observed pollen concentration. For such times, the sensitivity distribution function and area of sensitivity are positive. If pollen was not observed, the aerobiological stations only got clean air parcels and, consequently, the sensitivity distribution function becomes negative or zero.

## 3 RESULTS

In this section we present the results of the source-apportionment studies for the events of high birch pollen concentrations due to long-range transport, which were observed in Finland during last 4 years: 2002-2005.

In 2002, the aerobiological stations registered birch pollen grains at Turku, Kangasala, Kuopio, Oulu and Vaasa after Apr 22, while the flowering season of Finnish birch started at the beginning of May. During these days, a cold front moved over Finland to north-east and a high-pressure area migrated slowly to east. Therefore, the winds direction varied from south-west to south-east. The simulations showed the birch pollen source areas to be located in the Baltic Countries, Belarus and Russia.

The late spring in 2003 delayed flowering, so that the high concentrations were observed on May 5-6 at Turku, Kangasala, Joutseno, Vaasa and Oulu, which was again before the local pollen season. At that time, a low-pressure system was located east of Finland but later it gave place to a high-pressure system. The resulting front has crossed the European continent from north to south: Before the front the winds were from south while behind the front from east or south-east. A numerical analysis of the situation and inverse problem solution showed that, as in spring 2002, the Baltic Countries are an important source area again. However, pollen grains might be dispersed also from Poland and Southern Sweden.

In spring 2004, the four aerobiological stations measured two independent cases. Strong concentrations were observed in Turku, Vaasa, Oulu and Kangasala. The first peak of concentrations was noticed in the middle of April and the second followed a few days later. During these days, a large high-pressure system dominated over Eastern Europe slowly moving towards the north-east. Winds were weak near the centre of the high-pressure but stronger in the fringe area. At the stations, the wind during the first case was blowing from south-west and, during the second event, from south-east. The first case was so early that birches did not flower in the Baltic Countries (though the simulations highlighted that region as a possible source). The SILAM calculations also showed (fig. 1 a) that pollen could come from Poland and/or from Northern Germany where the flowering season had already started. A few days later, the flowering season started in the Baltic Countries and Belarus, thus creating the second peak in the Finnish observations. (fig. 1 b).

Spring 2005 was unusual. There were no long-range transported pollen in Finland at all (fig. 2 a and b). During most of spring, the northern winds dominated in Fennoscandia while birches were flowering in the Baltic countries and Central Europe. The model simulations confirmed this qualitative consideration.

## 4 DISCUSSION

Springs in 2002-2004 were characterized by high pollen concentrations recorded at Finnish aerobiological sites approximately one week before the local flowering started. According to the inverse modelling results, the most probable reason for such events was an atmospheric transport from Central Europe and the Baltic countries. In the spring 2002 the source areas were located in the Baltic Countries, Belarus and Russia. As in spring 2002, the Baltic Countries were an important source

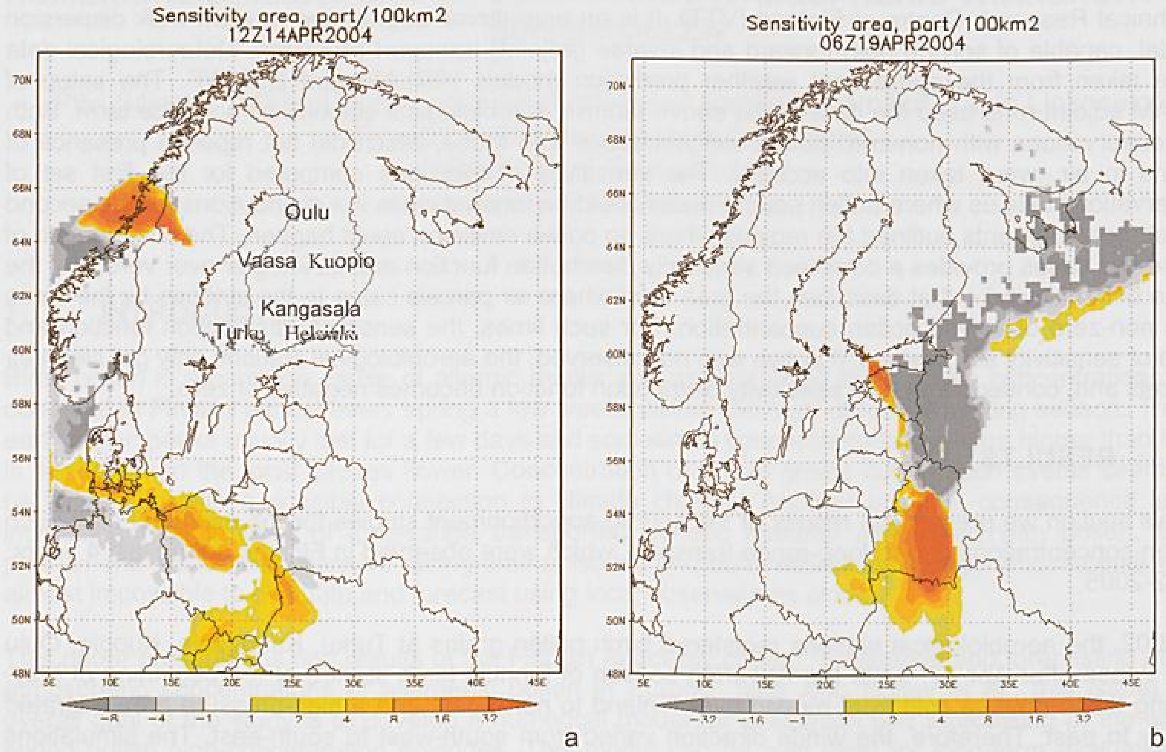


**Fig. 1** Possible source areas of the long-range transported birch pollen that was observed in Finland in spring 2004, 14$^{th}$-20$^{th}$ of April. Grey indicates area, which could not supply the grains; the yellow areas could serve as sources.

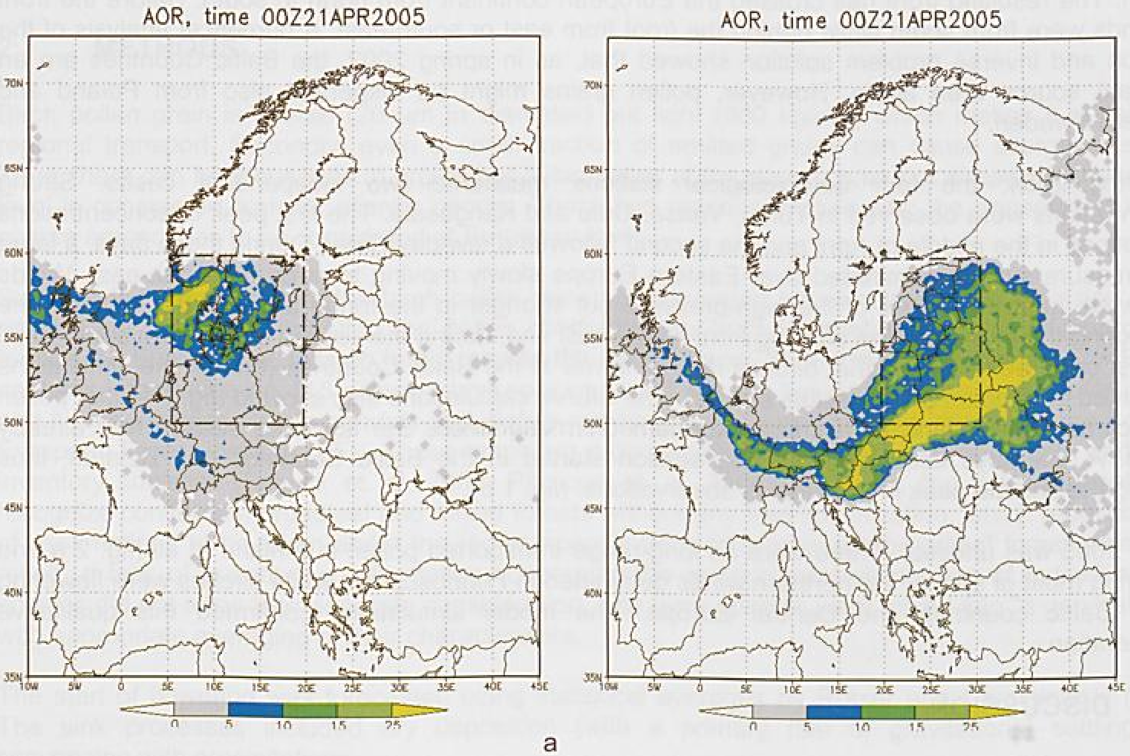


**Fig.2** Areas of influence in spring 2005. It is expected that birches inside boxes were flowering since 18$^{th}$ of April.

area in 2003, but then the pollen grains might be dispersed also from Poland and Southern Sweden. In the spring 2004, the aerobiological stations registered two independent cases. The SILAM calculations show that source areas in Poland or in Northern Germany caused the first episode, while the source areas in Baltic countries and Belarus were responsible for the second case.

Spring 2004 was the first one when we implemented the real-time semi-operational forecasts of the pollen concentrations. They were based on the SILAM model with a climatology-based emission source term – after Rotzer & Chmielewski (2001). This configuration, however, did not show impressive accuracy practically missing both above events. The reason was that climatologic-mean flowering dates were about 2 weeks later than the actual developments during spring 2004. Therefore, the source term has not shown any pollen emission leading to zero forecasted concentrations (however, the probabilistic forecast not connected to any flowering model has highlighted the favourable transport conditions). This pointed to limitations of climatologic approach to evaluation of pollen emission in conditions of a specific year.

In spring 2005, the Finnish aerobiological stations did not observed the long-range transported birch pollen. This is not a typical case in Finland but the weather situation was not favourable for the usual transport pattern. During the last spring, the SILAM model was run semi-operationally forecasting the birch pollen long-range transport over Europe and it also reported zero-level concentrations until the start of local season.

A specific problem with the pollen forecasting, as revealed by the last-years semi-operational simulations, is to forecast the pollen emission from the source areas. The statistical or climatologic models appeared to be too inaccurate for any forecasting purposes. Therefore, the key challenge remains in simulating the phenological processes that control the timing and intensity of the pollen emission for the specific meteorological conditions.

## 5 CONCLUSION

Four-years-long consideration showed that the Baltic Countries seem to the most important source for of long-range transported pollen in Finland. For some specific years, Russia, Belarus, Sweden, Poland or Northern Germany can serve as a source, too.

The forward simulation of the pollen forecasts appeared more complicated than the inverse ones, because they explicitly rely on the information about birch forest locations and flowering, which is currently very uncertain. Existing statistical models are not good enough and more complicated phenological models based on real-time meteorological data are needed.

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# EFFECTS OF SOME METEOROLOGICAL PARAMETERS ON THE RAGWEED POLLEN CONCENTRATIONS IN ZAGREB (CROATIA)

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## 1 INTRODUCTION

Regweed is extremely allergenic weed belonging to the family Asteraceae. It was brought to Europe from America with corn transports and spreaded to Hungary, the Czech Republic, Slovakia, Poland, Austria, Switzerland, France, north-west Italy, northern and eastern part of Croatia, Serbia and Bosnia. Because it's very allergenic character the monitoring of ragweed pollen has been performed since 1960 in Europe.

Pollen measurement in Croatia has been established in 2002 (Peternel et al. 2003). Recently study showed that ragweed pollen is the third most abundant pollen type to occur in the atmosphere of central Croatia (Peternel et al. 2004). Although the ragweed grows on uncultivated ground, along roads, railways and watercourses it was found in the air of the Croatian capital, Zagreb. The strong allergenicity and the increase of ragweed pollen in Europe encouraged us to study the impact of weather conditions on the variation in ragweed pollen concentration.

The aim of the study was to analyse the daily regweed concentration according to the meteorological data during three summer seasons (2002-2004) in order to determine the start and the duration of the pollen season. Results are expected to allow patients with allergic reactions to take preventive treatment and thus improving their quality of life.

## 2 METHODS

The air was sampled by seven-day Hirst volumetric pollen and spore trap (Hirst, 1952; Raynor, 1979). During 2002 and 2003 the trap was placed on the roof of the Zagreb Grič meteorological observatory in the city centre, 19.7 m above ground level (45°49'N and 15°59'E, 157 m above sea level). In 2004, the trap was moved on the flat roof of a building to the south of Zagreb, 10 m above the ground level. The sampler absorbs 10 l air/min, allowing for determination of pollen concentration at 2-h intervals. Pollen concentration was express as the number of pollen grains per cubic meter of air.

Meteorological data were recorded by Croatian meteorological service at the meteorological observatory Zagreb Grič in 2002 and 2003, and at the meteorological observatory Zagreb Maksimir in 2004. We used the climatological daily averaged temperatures and daily amounts of precipitation.

The start and the duration of regweed pollen season were determinate by days with the first pollen grain in the atmosphere at the beginning and end of summer. As more then 98% of the total regweed pollen was found during August and September the study was performed for the season constrained of that two months.

## 3 RESULTS

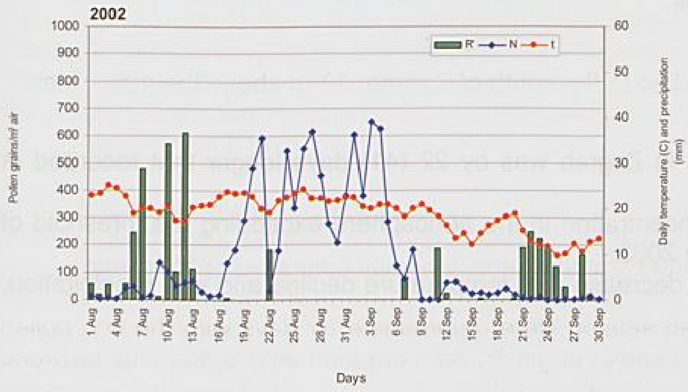
2002 and 2003 were in average very warm years. The concentration of ragweed pollen during two-month seasons in both years was over 9000 pollen grains. In 2004, the concentration was less than a half of the previous year's amount (about 4000 pollen grains). Although the analysed months in 2004 were also warmer than normal, the deviations from 1961-1990 period were not so pronounced. Measured precipitation during analysed period differs from month to month, but in general all three seasons were characterised by normal conditions.

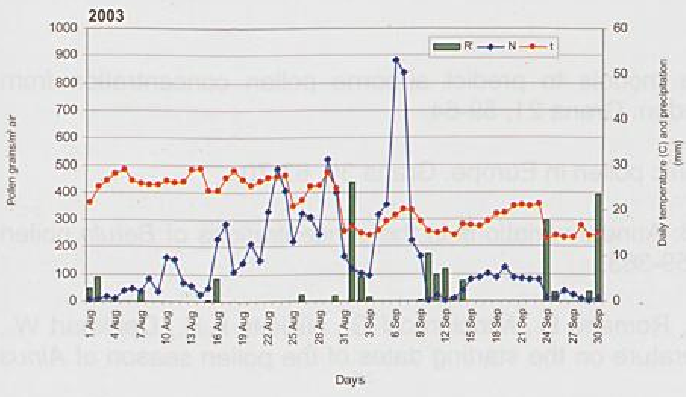
In 2002 the first pollen grains occurred at the beginning of August. In 2003 and 2004 regweed pollen was found in the air earlier, on the 28$^{th}$ of June and 14$^{th}$ July respectively. The longest season was during 2003 when the last pollen grains were recorded on 29$^{th}$ October (Table 1). The peak pollination with highest daily pollen concentration was recorded in the first week of September during 2002 and 2003, and during the last decade of August in 2004. In average, beginning of the ragweed season can be occurred from the end of June and it last approximately till the 20$^{th}$ October.

Table 1 *Presence of ragweed pollen in Zagreb in 2002-2004*

| Year | Period of occurrence | Peak day | Concentration on a peak day (pollen/m$^3$) | No. of days with > 30 pollen/m$^3$ | Ragweed pollen count during VIII-IX |
|---|---|---|---|---|---|
| 2002 | 1/8 – 22/10 | Sep-03 | 652 | 34 | 9215 |
| 2003 | 28/6 – 29/10 | Sep-06 | 883 | 46 | 9467 |
| 2004 | 14/7 – 21/10 | Aug-19 | 298 | 31 | 3983 |

From the Figure 1 it can be seen that the concentration of ragweed pollen during pollination is greatly influenced by temperature and precipitation. In 2003, the very early onset of pollen season (not shown here) was influenced by high temperature. June 2003 was extremely hot and July was very hot with the mean temperature higher for 5.2 °C and 2.3 °C from the 30-years mean. Both months had less than normal precipitation. Warm and dry conditions sped high concentrations during the whole season. On rainy days accompanied by temperature decline, the air pollen concentration decreased abruptly; as best demonstrated on August 22 and September 9, 2002; September 3 and 10, 2003; and August 22 and 26, 2004 (Fig 1). In August and September 2002 there were 30 rainy days, thus the concentrations of ragweed pollen were reduced to quite low and moderate levels. Although the 2004 was mostly normal in temperature and precipitation sense, decrease in total pollen concentration was probably influenced by human preventing actions (e.g. by plucking). The number of days with pollen grain concentrations exceeding the limit of 30 pollen grains per m$^3$ air was the highest in 2003 (46 days). During the peak ragweed pollination (4-9 September) daily temperatures were higher than normal and during that period there were no precipitation. In 2002 there were 34 days with more then 30 grains in the m$^3$ air, whereas in 2004 there were 31 days.



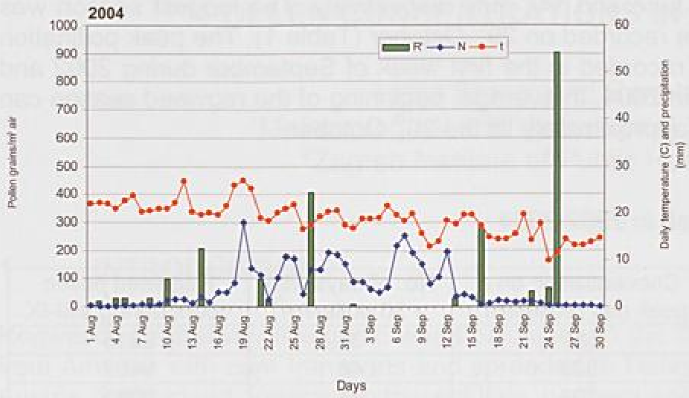



Figure 1 Daily variation in ragween pollen concentration, temperature and precipitation in Zagreb for August-September 2002-2004.

## 4 DISCUSSION

Accurate information on daily pollen concentrations of ragweed pollen, especially exceeding 30 pollen grains per $m^3$ air is of great importance to persons with ambrosia pollen allergy. The knowledge of its connection with weather conditions can allow the information on time and adjusting the daily activities in order to prevent from allergic problems.

More than 98% of total ragweed pollen occurred during August and September, which is consistent with the data reported for Austria, Switzerland and countries in the central part of east Europe (D'Amato and Spieksma, 1990; Jäger et al., 1991; Lejoly-Gabriel and Leuschner, 1983). Variation in ragweed airborne pollen concentrations depends on weather conditions (Peternel et al., 2004; Bringfelt, 1982; Emberlin et al., 1993; Frenguelli et al., 1991). Results of this study showed considerable variation in ragweed pollen concentration throughout the pollen season to decline with temperature decrease and days with precipitation. The highest pollen concentration over analysed period was in 2003 with almost 50 days over the allergologic threshold value. The peak concentration was on 6 September, with 883 grains in $m^3$ air.

## 5 CONCLUSION

1. In 2003, the pollination of ragweed in Zagreb was by 22 (41) days longer that recorded in 2004 (2002).
2. The number of days with pollen concentration in the atmosphere exceeding the threshold of 30 pollen grains per $m^3$ air was 46 in 2003.
3. Air concentration of ragweed pollen decrease with temperature decline and with precipitation, and vice versa.

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# PREDICTING *OLEA* FLOWERING SEASON IN REGUENGOS DE MONSARAZ (PORTUGAL) USING METEOROLOGICAL PARAMETERS

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## 1 INTRODUCTION

Olive trees are one of the most important crops in the Mediterranean countries, being of great interest for social and economic welfare.

The use of phenological forecast models, based on the meteorological parameters to predict some phenological stages, namely the flowering time, can be a powerful tool in agriculture, allowing management optimization in order to maximize and stabilize yield. The prediction of *Olea* main pollen season (MPS) features (mainly the knowledge of its onset flowering dates and pollen production) can be important in crop forecasting, for helping to determine the ripening date from the pollination peak and the cultivars most well adapted to the pre-floral meteorological conditions, for understanding the crop responses to environment.

The onset and duration of the flowering period is mainly determined by environmental factors such as meteorological conditions, soil and genetic factors (Hänninen, 1995). Having this in mind, the effect of temperature and precipitation parameters, observed in the prior months, on *Olea* onset flowering date and airborne pollen peak concentration in Reguengos the Monsaraz was studied.

The aim of our study was the estimation of predictive models for the annual *Olea* pollen concentration, the beginning of the MPS and the airborne pollen peak concentration dates for the Reguengos de Monsaraz region (Alentejo).

## 2 MATERIAL AND METHODS

Our work was carried out in the region of Reguengos de Monsaraz (40°0'N, 7°51'W) - Alentejo, during 7 years (1998 - 2004). The climate of this region is mesomediterranean without relief feature, with high temperatures in the spring-summer period and low rainfall levels.

*Olea* airborne pollen concentration (APC) was monitored using a Cour type sampler. The sampler was placed approximately 20 meters above ground level and pollen was collected on 400cm$^2$ vertical gauze filters, replaced two times a week (one filter exposed for 3 days and the other for 4 days long). After exposure pollen grains were removed from the filters using several chemical treatments (Ribeiro et al., 2003). The identification and counting of *Olea* pollen grains were carried out, independently of the pollen concentration, with 3 regular transverse rows of the microscope (X630).The MPS was defined as the period on which *Olea* pollen represented 5% to 95% of total pollen sampled during the flowering season.

Temperature (average and cumulative values of maximum, average and minimum) and precipitation (both amount and number of days) were provided by the meteorological station of the Mediterranean Agrarian Sciences Institute (ICAM), located approximately 5Km from the sampling point.

For the statistical processing of the data pollen counts were standardized (Moseholm et al., 1987). A regression model was used to investigate the relationship between the variability of the climatic parameters and the MPS features (starting flowering and airborne pollen peak concentration dates and total amount of pollen). The regression model was fitted by the stepwise multiple analysis technique for selecting explanatory variables significant at 5% level. The regression diagnostics of the most influential observations were tested according to the procedures provided previously and unless stated otherwise, the parameters tested were found not to be significant. A Durbin-Watson and a collinearity tests were performed in order to evaluate the possible existence of a correlation between the residuals of the regression model and of a relationship between the independent variables.

The regression models selected were validated using the absolute difference between the observed values of the starting flowering and airborne pollen peak concentration dates and total amount of pollen and the respectively calculated values using the models. The 2004 season, which was not included in the estimation of the models, was also utilized as external data for the validation of the forecast models computed.

## 3 RESULTS

The characteristics of the obtained regression models with the variables selected by the stepwise method are shown in Table 1. Appropriate statistical tests indicated that 76 to 99% of the annual variability in the *Olea* onset flowering and airborne pollen peak concentration dates and total amount of pollen could be explained by these models. The best model was the one predicting the onset *Olea* flowering date, presenting lower standard error and higher $R^2$, $R^2_{adj}$ values and validation.

The variables selected by the regression model for predicting the total amount of *Olea* airborne pollen concentration were: accumulated number of days with rain from February and March and accumulated maximum temperature registered during the autumn months. Ninety nine percent of onset *Olea* flowering date variability is explained by the accumulated minimum temperature from January through March, with a negative correlation, plus the accumulated rainfall in the previous autumn-winter months. Accumulated rainfall during January was the most important factor explaining 92% of the variability of *Olea* airborne pollen peak concentration date. The accumulated maximum temperature value from January and February was the second factor to enter the regression analysis by a negative correlation with the airborne pollen peak concentration date.

The analysis of the Durbin-Watson statistic test showed that no auto-correlation was found between the regression residues. Also, the multicollinearity test resulted in a variance inflaction factor (VIF) lower than ten.

The validation results show that the higher differences between the observed and calculated values of *Olea* starting flowering and airborne pollen peak concentration dates were registered in 1999 (of only one and three days respectively) while for the total amount of pollen the higher value (0.80) was observed in 2002 (Fig.1). When the models were used in 2004 (external data), the obtained forecast only deviated two days of the observed onset flowering and airborne pollen peak concentration dates and 0.76 of the annual pollen concentration.

## 4 DISCUSSION

The prediction models estimated used both temperature and precipitation values observed in the months prior to flowering as best independent variables, corroborating the influence of these climatic parameters in determining the features of the tree species pollen season (Fornaciari et al., 1997).

Cumulative values instead of average ones were selected by the regression analysis as best independent variables for the studied region. This was also observed in several other works where the onset *Olea* flowering was predicted using accumulated temperature values (Galán et al., 2001; Moriondo et al., 2001; Orlandi et al., 2005). The selection of cumulative values are in accordance with the suggestion that trees require an amount of heat summation to achieve the flowering developmental stage (Hänninen, 1995). Actually, the negative correlation observed with the temperature variables selected by the stepwise regression method implies that higher temperature summation is associated with earlier onset flowering and airborne pollen peak concentration dates.

The influence of pre-season high rainfall levels in determining the *Olea* annual pollen production and MPS starting and airborne pollen peak concentration dates was also observed in Italy and Spain (Fornaciari et al., 1997; González-Minero and Candau, 1997). This happens because the occurrence of rainfall in the previous autumn-winter months coincides with floral initiation. If a water stress situation is observed, then the floral bud production is lower and irregularly distributed in time (Pinney and Polito, 1990) causing a delay between onset and peak flowering dates.

The $R^2$ and $R^2_{adj}$ obtained for the regression models calculated in our study are higher than the ones obtained for Cartagena, using a three year data series (Moreno-Grau et al., 2000), but very similar to those obtained for Córdoba, using a 18-year data series (Galán et al., 2001).

The results of the Durbin-Watson and of the multicollinearity statistic tests indicate the absence of a relationship between the independent variables, showing that the models selected and its regression coefficients can be used with predicting purposes.

The absolute differences between the observed and predicted values for the 2004 season was small having in mind that the dates and total amount of pollen could be predicted one month earlier.

## ACKNOWLEDGEMENTS

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Table I – Results of the multiple regression analysis and statistical coefficients of the dependent variables for Reguengos de Monsaraz region (Alentejo - REM 1998 to 2004).

| Forecast models[a] | | Selected variables[b] | Model summaries | | | Model parameters | | | Durbin-Watson | Collinearity | | Validation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $R^2$ | $R^2_{adj}$ | SE | β | SE | Sig. | | T[c] | VIF[d] | Obs-Pred[e] |
| REM | V1 | Constant | - | - | - | 90.07 | 19.82 | 0.020 | | | | |
| | | ∑ NR F-M | 0.76 | 0.70 | 3.15 | 0.55 | 0.09 | 0.010 | | 0.963 | 1.038 | |
| | | ∑ Tmax 21/9-21/12 | 0.95 | 0.91 | 1.70 | 0.04 | 0.01 | 0.046 | 1.372 | 0.963 | 1.038 | 0.76 |
| | V2 | Constant | - | - | - | 159.02 | 1.45 | 0.000 | | | | |
| | | ∑ Tmin J-M | 0.97 | 0.96 | 1.16 | -0.08 | 0.004 | 0.000 | | 0.150 | 6.681 | |
| | | ∑ R 21/9-31/3 | 0.99 | 0.99 | 0.12 | 0.01 | 0.002 | 0.010 | 2.02 | 0.150 | 6.681 | -2 |
| | V3 | Constant | - | - | - | 156.12 | 2.42 | 0.000 | | | | |
| | | ∑ R J | 0.92 | 0.91 | 0.89 | -0.05 | 0.002 | 0.000 | | 0.927 | 1.079 | |
| | | ∑ Tmax J-F | 0.99 | 0.99 | 0.25 | -0.02 | 0.003 | 0.006 | 1.97 | 0.927 | 1.079 | -2 |

[a] The dependent variables are V1 – total APC; V2 – beginning date of the MPS; V3 – *Olea* pollen peak concentration date.
REM: Reguengos do Monsaraz.[b]Selected variables by stepwise regression method ($p<0.05$); [c]Tolerance; [d]Variance inflaction factor.
β – regression coefficients; $R^2$ – determination coefficient ; $R^2_{adj}$ - determination coefficient adjusted; SE – standard error; Sig. – significance level.
NR - number days with rain; Tmax - maximum temperature; Tmin - minimum temperature; R - rainfall;J -January; F - February; M - March.
∑ - sum; [e]Values in pollen (V1) and days (V2, V3) between the predicted and observed dates of total *Olea* APC and the MPS onset and peak dates.

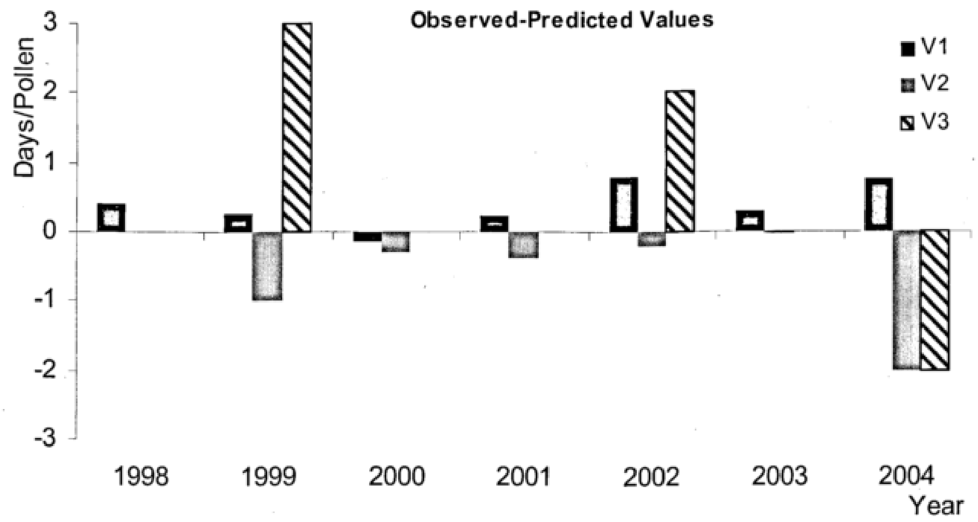


Figure 1 - Absolute differences between the observed values of the starting flowering (V2) and airborne pollen peak concentration dates (V3) and total amount of pollen (V1) and the respectively calculated values using the models computed for Reguengos de Monsaraz (Alentejo) during the study period (1998 to 2004).

# THE INFLUENCE OF RAIN ON HONEY BEES AND AIRBORNE POLLEN FLOWS.

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Airborne pollen flow is studied for long with three purposes: to advise people that can suffer of allergies; to study plant phenology and it's relation with ecological changes; to make forecasts of harvest in crops. In any situation, and independently of the airborne sampler used, the atmospheric pollen concentration changes are, sometimes, related to weather factors. Some parameters such as rain, wind and dry can, respectively, clean the airborne pollen, carry pollen from distant places, or allow the pollen remained in surfaces to re-suspend in air. The aim of our work was to compare the influence of rain on pollen flows sampled by honey bees and airborne samplers. For this, we studied, in 3 consecutive years (2001-2004), the chestnut tree (Castanea sativa) and olive oil tree (Olea europea) pollen flows in two villages of the northwest of Portugal, Cesar and Vairão, distanced about 70 km. We used two "Cour" airborne samplers and beehives equipped with pollen traps all the season long. Airborne pollen of chestnut was present in atmosphere about 17 weeks, but honeybees only collected this kind of pollen for 9 weeks. Pollen flow, and presumably the blossoming of olive tree, had the duration of 4 to 6 weeks, as honey bees results showed, in spite of it's presence in the air for more than 12 weeks. We consider that the larger duration of the airborne pollen flow was due to the re-suspension effect and long distance transport, obviously not present in the insect's case. It seams that there are not a significant effect of rain in the collection behaviour of honey bees, but only a soft negative tendency. The same was not observed with the results from the Cour sampler, where the rain had a significant negative effect on atmospheric pollen concentration. It is also interesting to report that we obtained a high correlation between pollen collected by honeybees and the pollen concentration in the air. There is also a high correlation between consecutive years, clearly shown by honeybees in the case of olive tree, which in all situations had its peak in the last week of May. Our work shows a new way to improve the precision of airborne pollen estimation models and ecological studies based in pollen flows, mainly to know with precision the beginning, peak and end of pollen flow of great number of species.

# EVALUATION AND FORECASTING OF THE ATMOSPHERIC CONCENTRATIONS OF ALLERGENIC POLLEN IN EUROPE

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## 1 INTRODUCTION

Diseases in the respiratory system due to aeroallergens, such as rhinitis and asthma, are major causes of a demand for increased healthcare, loss of productivity and an increased rate of morbidity. Pollenosis accounts for 12 - 45 % of overall allergy cases. The sensitisation to pollen allergens is increasing in most European regions. The adverse health effects of allergens can be reduced by pre-emptive medical measures. However, their planning requires reliable forecasts of high atmospheric pollen concentrations (Rantio-Lehtimäki, 1994), (Rantio-Lehtimäki & Matikainen 2002).

There is convincing evidence that the long-range transport of pollen from remote regions can significantly modify pollinating seasons in many European regions. This is particularly important for Northern Europe - and especially for Finland, where the flowering takes place later in spring. This transport causes unforeseen and sudden increases of concentrations of pollen that can occur up to a month before the start of the local pollen season (Siljamo *et al*, 2004). The long-range transport can substantially increase the concentrations of allergenic pollen also during the local pollen seasons.

However, the currently available pollen forecasts are based solely on local observations and do not consider the transport from other regions. At present, there is no modelling system in Europe that can simulate the pollen transport in the atmosphere. Further, there is no such model for evaluating the pollen emissions (including the pollinating season and the flowering characteristics of the relevant species) that would provide the input data for such atmospheric dispersion modelling.

The current paper presents an on-going project of the Academy of Finland aiming at:

- development of an integrated modelling system for simulating and forecasting the natural pollen emissions and transport at a European scale;
- evaluation of the spatial distributions of pollen emissions and concentrations in Europe.

## 2 MATERIALS AND METHODS

The birch pollen is the most important allergen with regard to atmospheric transport due to its ability to fly over large distances. There are two treelike birch species in Europe. Downy birch (*Betula pubescens*) is the most common in the northern part of Europe, while silver birch (*Betula pendula*) is dominating in more southern regions. Typical birch pollen grain has a size of 20-22 $\mu$m. It is fairly light (a full grain filled with protein material has a density of ~ 800 kg $m^{-3}$), and approximately spherical. It is therefore a comparatively typical coarse aerosol particle, which behaviour in the atmosphere is more or less known. However, already the birch pollen is bigger and heavier than a "typical" regionally-dispersed aerosol, which raises questions regarding the existence of the whole phenomenon.

The three key questions to answer are: (i) does the grain meet the assumptions behind all existing dispersion models, so that it can be treated as a "standard" (albeit coarse) atmospheric aerosol, (ii) what are the sources of pollen, their features and predictability by means of existing models; (iii) what are the features of such a pollutant, its physical and chemical transformations in the atmosphere and processes removing the grains from the air, which made it regionally- (or continentally- ) dispersing?

There are two types of the European-wide observations that can be used for answering the above questions, as well as for the development, initialization and verification of the pollen transport model: phenological observations of the seasonal development of canopies, and measurements of the atmospheric pollen concentrations. The networks cover most of Europe in space, several decades in time, and numerous pollinating species, including birch. Some observations, such as those performed in Russia, are not reported to European databases and have to be added to the dataset.

The modelling systems of Finnish Meteorological Institute (FMI) are connected to operational meteorological data produced by the numerical weather prediction model HIRLAM, as well as to the databases of the European Centre of Medium-Range Weather Forecast (ECMWF). The HIRLAM model has been used operationally at the FMI since 1990 for the numerical weather predicting. Currently, the model produces 54-hour long forecasts four times a day covering Europe, Northern Atlantic and Western Russia. FMI participates also in the international HIRLAM development project.

There are several regional-scale birch forest inventories (e.g. Alexeyev& Birdsey, 1998, Köbler & Seufert, 2001), which are going to be used in combination with the satellite maps, in order to obtain a unified inventory of the birch forests in Europe and Western Russia. Information from satellites such as ERS and ENVISAT (MERIS) will provide the near-real-time vegetation growing index.

There are several semi-empirical models for predicting the start and duration of the flowering seasons. Descriptions of the flowering start time are based on three main principles: (i) climatological averaging of long-term observations (e.g., Rötzer & Chmielewski, 2001), (ii) heat sums (such as the so-called degree-days, and period units (Hänninen, 1990, Linkosalo, 2000 a,b, Luomajoki, 1999 and Sarvas, 1972) and (iii) dynamic models (e.g., promoter-inhibitor model of Schaber & Badeck, 2003). The climate-based values are available over the whole of Europe, while the methods (ii) and (iii) are usually based on local or, at best, country-wide observations, and are therefore not representative at a European scale.

The description of other parameters of flowering such as its intensity and the total amount of released pollen also requires the use of semi-empirical models that predict the next-year flowering features, based on the conditions of the previous growing season (Masaka & Maguchi, 2001).

The development of the integrated model is based on the emergency modelling system SILAM (Sofiev, 2002), (Sofiev & Siljamo, 2003), which is currently used for the operational forecasting of the consequences of potential emergency situations in the vicinity of Finland. The system is based on a so-called Lagrangian Monte-Carlo random walk dispersion model. The treatment of aerosol is based on a modal representation of the aerosol size spectrum and state-of-the-art parameterizations of the dry and wet deposition processes. The transport modules have been tested in the EU-funded ENSEMBLE project (http://ensemble.ei.jrc.it/), the ETEX project (http://rem.jrc.cec.eu.int/etex/) and the Nordic NKS MetNet (http://hirlam.fmi.fi/MetNet) project.

The block diagram of data, models and model evaluation of this study is presented in (Figure **1**).

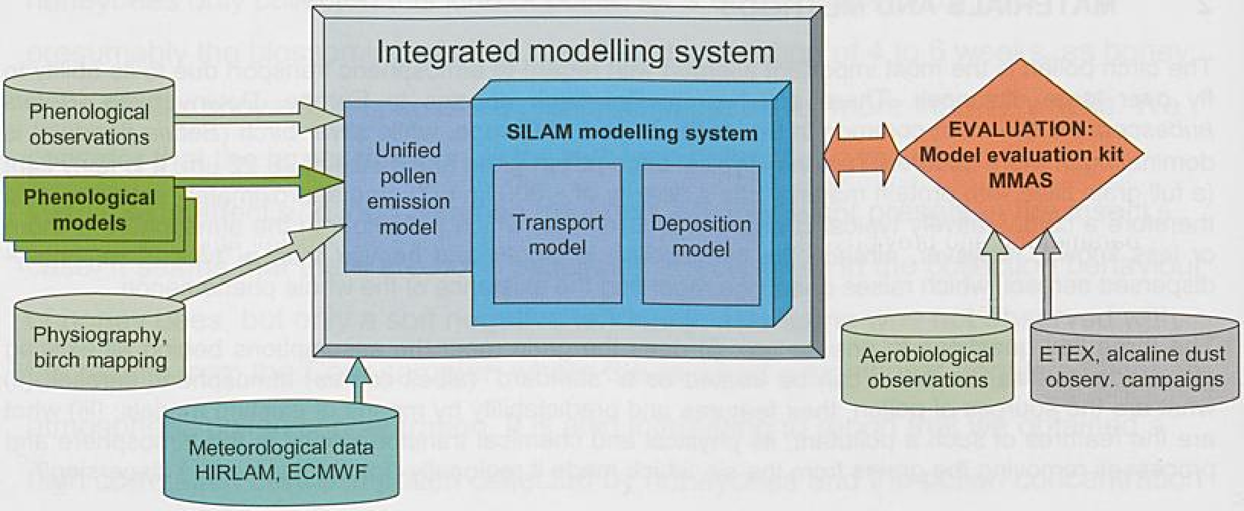


*Figure 1. A schematic presentation of the utilization of the various input datasets, the integrated modelling system, and the evaluation of the system against experimental data.*

## 3 RESULTS

The results presented in this section are largely based on a feasibility study conducted by the FMI and TU in 2003-2004. Examples of the model applications can be found in (Siljamo *et al.,* this issue). The primary goal of the feasibility study was to evaluate the problem and check the applicability of the existing technologies to simulating and forecasting the pollen long-range transport, in particular, by answering the three questions listed above.

The first answer (applicability of existing dispersion models to pollen transport simulations) follows from a simple theoretical consideration. Dispersion models assume that the pollutant follows both the macro- and micro- air flows (i.e., both the mean wind and turbulent eddies). It is therefore enough to consider the inertia of the pollen grain in comparison with forces pushing it along with the air streams. Using a spherical assumption on the grain shape, one can get that a typical relaxation time $\tau$ and distance $\lambda$ in such streams as a function of grain diameter *d*, material density $\rho_{part}$, and air viscosity $\eta$:

$$\tau = \frac{d^2 \rho_{part}}{18\eta} \sim 10^{-3}\ \text{sec},\ \lambda \sim 1\ mm$$

The above values are small enough to satisfy the main assumption of the dispersion models: the grains are capable of following even small turbulent eddies. This consideration also allows computing an equilibrium settling velocity (using the Stoke's equation) that determines the dry deposition:

$$u = \frac{g\rho_{part} d^2}{18\eta}$$

Here *g* is the acceleration of gravity. For birch pollen, this velocity is: $u \approx 1.2\ cm\ sec^{-1}$.

Wet deposition is less known. There is a classical work of Chamberlian (1953), who determined the sub-cloud scavenging due to impaction, while the in-cloud microphysics is uncertain. It is known that the grains tend to dry-up during the atmospheric transport in clear-sky conditions and refill with water inside clouds but quantitative studies of such processes are lacking. Therefore, at the current stage we accept the "standard" description of scavenging used in SILAM for broad-range particles, which was mainly parameterised using the Chernobyl data.

## 4 DISCUSSION

The most-difficult problem is a parameterisation of the pollen emission, i.e., the flowering description. As shown by trial forecasts for 2004, the long-term averages may not be representative for a specific year. Approaches relying on information on the real-time situation can be grouped into two classes:

- the "dynamical phenological emission" approach is based on empirical phenological models that predict the timing and intensity of flowering from historical and real-time meteorological parameters, and previous-year flowering characteristics. There are several empirical models for the evaluation of flowering start-time: various heat sums (Hänninen,1990; Linkosalo, 2000a,b; Luomajoki, 1999, Sarvas 1972) and more sophisticated models, such as the promoter-inhibitor approach of Schaber and Badeck (2003).

- the "emission data assimilation" approach relies on real-time observations (satellite-born or in-situ) of the phenological processes. An example of satellite products that might be used is shown by Høgda *et al.*, (2002). Another option is assimilating the real-time observed pollen concentrations directly into a dispersion model or using them to find out information about the grain sources – as in Sofiev & Atlaskin (2004)

So far, it is difficult to say in what form these methods will be the most effective. Each of them has both strong and weak points, and none is ready for an immediate Europe-wide application – mainly due to the strongly regional and empirical character of all the above models. Their generalization for the whole of Europe is not straightforward.

## 5 CONCLUSIONS

The long-range transport of allergenic pollen can significantly affect the local pollinating seasons well before or after the local flowering period. Such episodes are strong enough to cause harmful medical consequences and therefore require proper predictive methodologies, which have to be based on atmospheric dispersion models.

From general point of view, the pollen grain is quite close to a typical coarse aerosol but somewhat lighter and has lower threshold level of the significant concentrations, in relation to the near-source values. This makes it susceptible for regional scale of dispersion.

The key challenge in forecasting the pollen transport is the development of an adequate emission module. Available methodologies are of primarily local character or based on climatologic values and thus cannot be used for short-term Europe-wide simulations. A combination of such models and near-real-time satellite and in-situ observations might improve the accuracy of the forecasting.

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# Tourism

# SPECIFICATION AND VERIFICATION OF A NEW GENERATION CLIMATE INDEX FOR TOURISM

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## 1 INTRODUCTION

Climate is a dominant attribute of a tourist destination and has a major effect on tourism demand and satisfaction, but its relationship with tourism is complex. Because of this, considerable effort has gone into devising climate indices that summarise the significance of climate for tourism. An index approach is required because of the multifaceted nature of climate and the complex ways they come together in a social and cultural context to give meaning to a particular weather condition for tourism. An important limitation of most existing climate indices for tourism is that their rating schemes for individual climate variables and the weighting of climate variables in the index were largely based on the subjective opinion of the researcher(s) and not empirically tested on tourists or within the tourism marketplace. Other weaknesses of existing indices stem from their failure to address the essential requirements of an ideal index, which are discussed in detail later in this paper. In the present study we aim to address the deficiencies of past indices for tourism by devising a theoretically informed and practically useful climatic index called the Climate Index for Tourism (CIT). CIT facilitates interpretation of the integrated effects of climate and has a range of possible applications for both tourists and the tourism industry.

Six essential characteristics for a new generation climate index were identified. The index must be: 1) theoretically sound; 2) integrate the thermal, physical and aesthetic facets of climate; 3) simple to calculate and uses readily available data; 4) easy to use and understand; 5) recognise overriding effect of certain weather facets; and 6) empirically tested. Unlike most previous climate indices for the tourism-recreation sector, the performance of the index and its thresholds should be validated against measures of tourist satisfaction with weather conditions. The significance above has been discussed in some detail by de Freitas (2003).

## 2 METHODS

CIT is developed as an integrated index for tourism and recreation that rates climate and weather along a favourable-to-unfavourable spectrum. It is defined as:

$$CIT = f\,[(T, A) * P]$$

T, A and P are facets of climate that collectively determine CIT, except when certain threshold are exceeded in P, the effect is to override the other variables. T is a measure of the integrated body-atmosphere energy balance. This can be found using any of the established models that integrate the environmental and physiological thermal variables, such as solar heat load, heat loss by convection (wind) and heat loss by evaporation (sweating) and longwave radiation to and from the body, and metabolic heat (activity level). Rather than express the T as a net energy (calorific) value, CIT requires that it be expressed as thermal sensation using the standard nine-point ASHRAE scale (Table 1). In this way any of the several body-atmosphere energy balance assessment schemes may be used. For example, de Freitas (1990) showed that the contribution of the thermal component to the overall climate rating were correlated with the standardised ASHRAE scale thermal sensation responses (TSN) such that $CIT_{TSN}$ is given by: $CIT_{TSN} = 6.4 + 0.4\ TSN - 0.281\ TSN^2$. A is the aesthetic appeal of the sky condition ranging from clear to overcast. Thermal and aesthetic states are combined in a holiday weather typology matrix to produce a climate satisfaction rating class, CIT, ranging from 1 to 7: CIT ratings 1 = very poor, 2 = poor, 3 = fairly poor, 4 = marginal (but acceptable), 5 = fairly good, 6 = good, 7 = very good. P is the physical thresholds of high wind and rain. If either physical threshold is exceeded, then P over-rides T and A to affect the satisfaction rating.

The initial development of the climatic thresholds for A and P and satisfaction ratings for the CIT were based on the work of de Freitas (1985, 1990). In this work, beach users were interviewed on-site and their responses compared with detailed climate data monitored on-site. The results showed that ideal atmospheric conditions are those producing "slightly warm" conditions in the presence of scattered cloud (i.e. ≤ 0.4 cover). Conditions during which wind speeds were ≥ 6 m $s^{-1}$, and that rain of greater than 30 minutes duration or wind speeds of over 6 m $s^{-1}$ had an overriding effect on reducing tourist satisfaction too unacceptable (CIT = 1 or 2).

In the current work, a prototype questionnaire was developed and tested on 20 respondents for clarity, ease of use and timing. Based on this, questionnaire surveys in controlled settings of 168 respondents were used to measure satisfaction for a range of hypothetical atmospheric environmental conditions. First, the respondents were briefed on the nature survey. It was explained they were at the beach for the day to swim, to sit around or for picnic. The they were asked to give a rating (from 1-7) for each of the six thermal climate states (integrated thermal climate as expressed in the ASHRAE thermal sensation scale) for both cloudy conditions (cloud ≥ 0.5 cover), then, with same six thermal states, for clear sky or scattered cloud conditions (i.e. ≤ 0.4 cover). The respondents were also asked about their views on the perceived importance of temperature, sunshine/cloud and the presence/absence of rain and wind. Further questions asked whether or not rain or high wind would result in them leaving the beach. They were also asked how long it must rain before condition became unacceptable.

## 3 RESULTS

The thermal (T), aesthetic (A) and physical (P) states were combined in a holiday weather typology matrix of CIT ratings in classes 1 (worst) to 7 (best). Median (rather than mean or modal) responses from the questionnaire survey were used to identify central tendency and to complete the matrix, which covered every combination of T, A and P. The results show (Table 1) that conditions considered to be optimal (CIT = 6-7) were those that are "slightly warm" or "warm" with clear sky or scattered cloud. Acceptable conditions (CIT 4-5) extended to TSN between "indifferent" and "hot" even when the sky was overcast. The occurrence of wind greater than or equal to 0.6 m s$^{-1}$, or the occurrence of more than half an hour of rain (or 3 mm) had an overriding effect on CIT. Rain for greater than 30 minutes or wind in excess of 6 m s$^{-1}$ resulted in rating dropping to the lowest level (CIT = 1-2), that is, conditions considered to be unacceptable (Table 1).

Table 1. The results of the questionnaire survey (N = 168) giving CIT ratings based on thermal conditions (T) expressed as thermal sensation (TSN) on the ASHRAE scale, aesthetic quality (A), and physical factors (P). CIT ratings 1 to 7 are described in the text. The bracketed values are the thresholds derived from de Freitas (1990).

| ASHRAE Scale TSN [T] | Cloud ≤0.4 (n/N≤0.4) [A] | Cloud ≥0.5 (n/N≥0.5) [A] | Rain (>3mm or >1hr duration) [P] | Wind ≥ 6 m/s at ground [P] |
|---|---|---|---|---|
| Very hot (+4) | **4** (4) | **3** (3) | 2 | 2 |
| Hot (+3) | **6** (5) | **5** (3) | 2 | 2 |
| Warm (+2) | **7** (6) | **5** (4) | 2 | 2 |
| Sl. warm (+1) | **6** (7) | **4** (5) | 2 | 2 |
| Indifferent (0) | **5** (6) | **3** (4) | 2 | 2 |
| Sl. cool (-1) | **4** (4) | **3** (3) | 2 | 2 |
| Cool (-2) | 3 | 2 | 1 | 1 |
| Cold (-3) | 2 | 1 | 1 | 1 |
| Very cold (-4) | 1 | 1 | 1 | 1 |

Respondents were also asked to rate the importance the absence of strong wind, the absence of rain, the presence of sunshine and the importance of a comfortable temperature. The results show that temperature was considered to be the most important followed by sunshine, then the absence of rain and finally the absence of wind (Table 2). The absence of strong wind had the highest variance, which reflects the fact that not everyone considered high wind to be on overriding determinant of the acceptability of on-site weather conditions. Detailed distribution of these perceptions along the seven-point scale of importance is shown in Figure 1

Table 2. The perceived importance of key facets of on-site weather, where 1 is 'not important' and 7 is 'extremely important'.

| | Absence of high wind | Absence of rain | Sunshine | Comfortable temperature |
|---|---|---|---|---|
| Mean | 4.9 | 5.7 | 6.1 | 6.2 |
| Mode | 5 | 6 | 6 | 7 |
| Standard deviation | 1.50 | 1.34 | 0.97 | 0.93 |

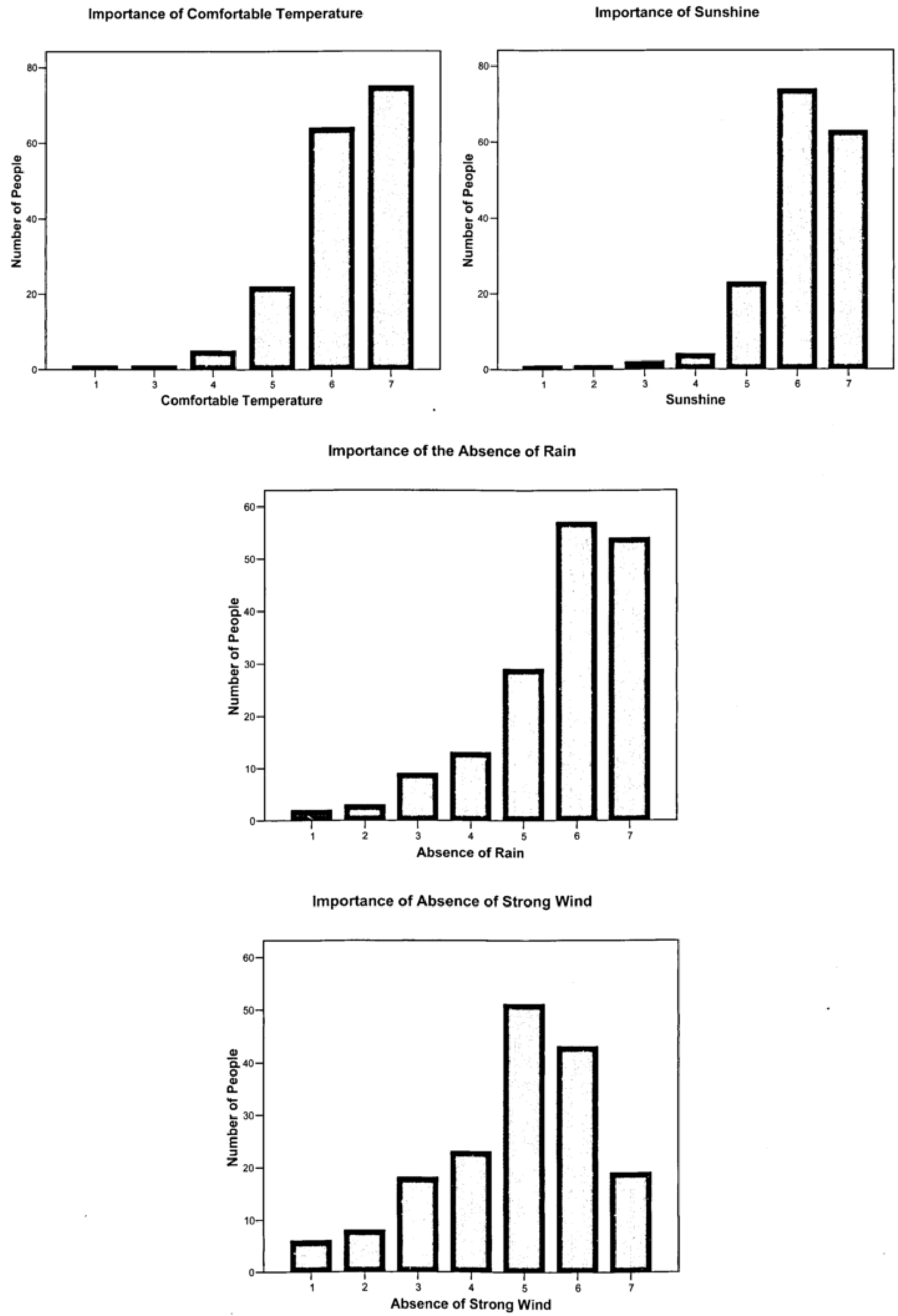


Figure 1. The importance of the four facets of climate used in the CIT, where 1 is 'not important' and 7 is 'extremely important'. The results of a statistical analysis of this data are given in Table2.

## 4 DISCUSSION

Rather than simply build on previous tourism climate indices, this study set out to develop a theoretically sound alternative that deals holistically with all the essential facets of tourism climate. Fcr ease of application, the index has been designed so that it can be used with either standard climate data or, for short-time forecasts, weather variables. In either case, the index relies on actual observations rather than on averaged data. The temporal resolution of climatic data must be daily in order that the index values can be expressed as probability estimates of likelihood of occurrence (e.g., there is a 90% chance of experiencing 'ideal' conditions during each day of a specified holiday period). Importance has been placed on the nature and form of the index output; namely, one that can be readily interpreted and understood by users in the tourism-recreation sector. Much research has been done on the international application and communication of the UV index and the lessons learned about the simplicity of the rating system and messaging are highly applicable to designing a climate index for the tourism-recreation sector. The end product of the index should be a rating system with five to seven classes, with clear descriptors of the quality of the climate conditions for the tourism activities the index was specifically designed for. In the case of CIT, the highly climate/weather sensitive activities of beach holidays are the focus.

An important feature of CIT is that it recognises that the combined effect of a given weather condition is not necessarily the sum total of its various facets. Under certain conditions and at certain thresholds, the physical facet has an overriding influence on the thermal and aesthetic facets. For example, heavy rain or high winds will cause people to leave the beach even if the thermal conditions are ideal. No previous climate index for tourism recognized this, thus they tend to overrate days when rain or wind dominated. Finally, unlike most previous climate indices for the tourism-recreation sector, the performance of CIT and its thresholds have been validated against measures of tourist satisfaction with weather conditions. Validation has avoided the usual 'demand' indicators such as attendance/visitation numbers, traffic flows, or campsite/motel occupancy rates. These are inappropriate because they are not necessarily a measure of tourist satisfaction with climate conditions. For example, peak demand is strongly influenced by state holidays (institutional seasonality), not just climate (natural seasonality). In fact, peak demand is observed to sometimes occur outside of the period when optimal climate conditions occur. This means statistical models of climate and tourism demand can be calibrated to non-optimal climate and thus may not predict 'optimal climate for generating tourism' as claimed. Self-reported tourist satisfaction with climate is a more reliable 'validator' for a tourism climate index. However, it is important that a climate index for tourism be cross-culturally validated, as climatic preferences might differ. In light of this, Further research is planned which examines whether climate preferences vary with different social and cultural groups internationally. Cross-cultural testing will be conducted with surveys conducted in Australia, Canada, Germany, Hungary, Italy, New Zealand, Portugal and the United Kingdom as part of a collaborative project by members of the International Society of Biometeorology's, Commission on Climate, Tourism and Recreation.

## 5 CONCLUSION

This work has shown that CIT can be reliably used as an integrated index for tourism and recreation where the thermal (T), aesthetic (A) and physical (P) facets of weather collectively determine CIT, except when certain thresholds are exceeded in P, namely continuous rain and high wind, where the effect is overriding. The T facet is a function of the net thermal effect of the body-environment thermal state that can be accounted for by any number of integrated body-atmosphere energy budget schemes reported in the literature. But instead of dealing with T as a net energy term, CIT expresses T as thermal stress using the well established and widely used nine-point ASHRAE thermal sensation scale, thus any of numerous well tested schemes can be used to asses T depending on data availability. The results show that each of the seven CIT classes correspond to clearly identifiable weather conditions along a favourable-to-unfavourable spectrum. The product is an index with clear descriptors for the quality of climate for tourism.

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# WEATHER RECREATION INDEX FOR EUROPE

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## 1. INTRODUCTION

Tourism and recreation are important to national economies and personal income of its citizens. There is also increase in the number of people interested in tourism/recreation services. When choosing the location and the period of recreation we should consider climate and weather features. They are key for outdoor recreation abilities and they affect our satisfaction/dissatisfaction as well as human's health (Blazejczyk 2000, Matzarakis, Mayer 1991, 1997). Favourable climate and weather conditions are essential advantages for recreational and tourism activity. However, in various European climates they are characterised by seasonality (Blazejczyk 2003).

Various concepts and methodologies are in the use when considering bioclimatic criteria for tourism and recreation (Kozlowska-Szczesna et al. 1997, Mieczkowski 1985, Lee 1980, Maarouf, Bitzos 2001). The methods based on the human heat balance brought the new dimension in the research of man-atmosphere relationships (Blazejczyk 2005, Freitas 1990). Another approach in climate-tourism research considers the complex weather that influences human organism (Blazejczyk 2001, Freitas 2003).

The aim of the present paper is to evaluate bioclimatic conditions of several sites in Europe for the needs of outdoor recreation. The seasonal fluctuations of weather that influence ability of outdoor recreation is examined. The new Weather Recreation Index is used in this purpose.

## 2. METHOD AND MATERIALS

The research dealing with climate-recreation relationships should consider three categories of information (Freitas 2003):

- aesthetic factors (cloudiness, visibility, sunshine duration, day length),

- physical state of the atmosphere (precipitation, snow cover, wind, solar radiation, UV radiation, air pollution),

- bio-thermal conditions (human heat balance considerations).

According to this concept, the actual weather is one of the basic demand indicators of recreational potential of any time, season and/or region. To assess recreational potential of climate the bio-thermal classification of weather was used (Blazejczyk 2003). An analysis of the frequency particular weather components is the base of Weather Recreation Index (*WRI*). The index bases on two models (Blazejczyk 1987). The first one is multiply function:

$$y = x^{z}$$

where x parameter represents quantity components of weather and z one the quality factors. The second is the model of system efficiency (Ef) based on the Ohm low. It assumes the functioning of any system depends on potential (P) and resistance (R) of the system components as follows:

$$Ef = P / R.$$

The final general model of evaluation considers both, potential and resistance features of quantity and quality components of weather:

$$y = (Px/Rx)^{(Rz/Pz)}$$

where Px is potential and Rx is resistance of quantity weather components. Pz is potential and Rz is resistance of quantity weather elements.

In the present studies the following model components are considered:

- as Px - frequency (%) of neutral physiological strain (T)

- as Rx - frequency (%) of extreme thermal sensations, i.e. cold, very cold, frosty, very hot and sweltering (STIex),

- as Pz - frequency (%) of moderate radiation stimuli ($Rad_2$),

- as Rz - frequency (%) of rainy days ($RR_1$).

Finally, the Weather Recreation Index (*WRI*) has the following form:

$$WRI = \left( 0.5 \frac{(100+T)}{(100+STI_{ex})} \right)^{\left(\frac{(100+RR)}{(100+Rad)}\right)}$$

Particular ranges of *WRI* indicate various usefulness of weather for recreation:

| *WRI* | Weather usefulness: |
|---|---|
| < 0.30 | - unfavourable, |
| 0.31 – 0.50 | - moderately favourable, |
| 0.51 – 0.70 | - favourable, |
| > 0.70 | - very favourable. |

The research is based on daily meteorological data for the period 1991-2000 for 10 stations over the Europe that represent various types of climate: Helsinki, Stockholm, London, Krakow, Paris, Zurich, Budapest, Valencia, Rome and Athens as well as 1 station represented high mountain climate (Tatra Mts.). The particular weather features were defined based on the human heat balance model MENEX_2002 for every day of the studied period with the use of BioKlima©2.3 software package.

## 3. RESULTS

The results show great seasonal and regional differentiation of *WRI*. In general, two patterns of annual course of Weather Recreation Index are observed. In northern and central Europe winter minimum and summer maximum of weather usefulness for recreation are typical. The same pattern occurs in the Tatra Mts. For the southern Europe the best conditions for outdoor recreation are observed in the spring and in the autumn; the winter and the summer weather are less favourable for outdoor recreation (Table 1).

In the eastern part of Mediterranean only in the summer the weather is unpleasant for active outdoor recreation. However, during the rest of the year *WRI* values indicate good condition for staying outdoors. In Scandinavia winter is the season with unfavourable weather for outdoor recreation. However, in spring and summer *WRI* are within the range of favourable or even very favourable for recreation. In central European mountains only in the summer WRI are higher then 0.5 (favourable weather) (Fig. 1).

In general, in majority sites in Europe mean annual values of Weather Recreation Index indicate favourable weather conditions (*WRI* of 0.51-0.7). However, they also show significant spatial differentiation. The highest one were calculated for Valencia (Spain) and Zurich (Switzerland). The moderately favourable weather for outdoor recreation were found for Helsinki (Finland) and Tatra Mts. (Poland) with *WRI* of 0.31-0.5 (Fig. 2).

Table 1. Monthly values of Weather Recreation Index for various stations in Europe, 1991-2000

| Station | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Helsinki | 0.178 | 0.323 | 0.437 | 0.558 | 0.596 | 0.639 | 0.656 | 0.698 | 0.604 | 0.489 | 0.270 | 0.176 |
| Stockholm | 0.318 | 0.366 | 0.513 | 0.593 | 0.719 | 0.791 | 0.773 | 0.788 | 0.629 | 0.502 | 0.383 | 0.249 |
| London | 0.440 | 0.507 | 0.509 | 0.526 | 0.610 | 0.657 | 0.679 | 0.756 | 0.715 | 0.545 | 0.494 | 0.434 |
| Krakow | 0.399 | 0.447 | 0.506 | 0.536 | 0.613 | 0.573 | 0.527 | 0.536 | 0.666 | 0.656 | 0.449 | 0.350 |
| Paris | 0.455 | 0.510 | 0.549 | 0.571 | 0.637 | 0.640 | 0.584 | 0.585 | 0.709 | 0.622 | 0.508 | 0.401 |
| Zurich | 0.392 | 0.484 | 0.581 | 0.630 | 0.754 | 0.708 | 0.685 | 0.731 | 0.712 | 0.590 | 0.388 | 0.324 |
| Budapest | 0.457 | 0.541 | 0.566 | 0.632 | 0.603 | 0.582 | 0.458 | 0.403 | 0.706 | 0.713 | 0.511 | 0.418 |
| Valencia | 0.670 | 0.836 | 0.801 | 0.790 | 0.670 | 0.451 | 0.318 | 0.296 | 0.520 | 0.816 | 0.841 | 0.675 |
| Rome | 0.613 | 0.565 | 0.634 | 0.642 | 0.611 | 0.430 | 0.311 | 0.315 | 0.527 | 0.840 | 0.646 | 0.566 |
| Athens | 0.663 | 0.660 | 0.633 | 0.759 | 0.622 | 0.368 | 0.397 | 0.383 | 0.375 | 0.721 | 0.783 | 0.692 |
| Tatra Mts. | 0.407 | 0.319 | 0.309 | 0.405 | 0.555 | 0.604 | 0.591 | 0.647 | 0.566 | 0.475 | 0.359 | 0.322 |

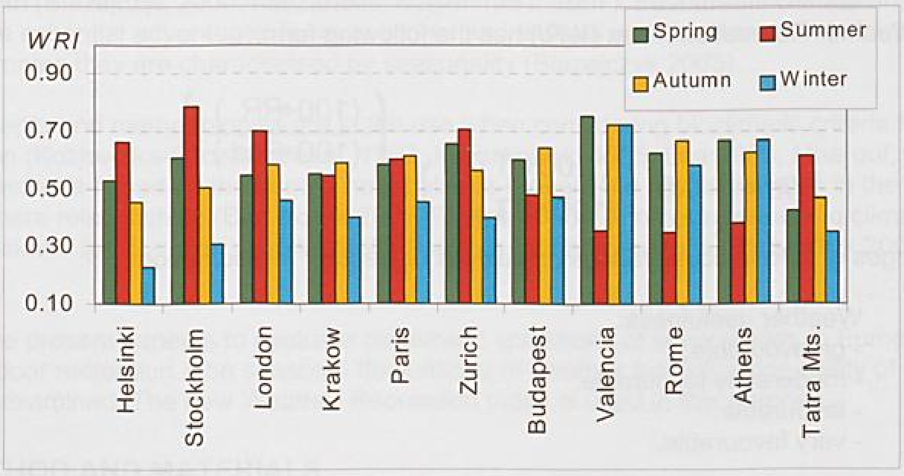


Fig. 1. Mean seasonal values of Weather Recreation Index (*WRI*) in various European stations, 1991-2000

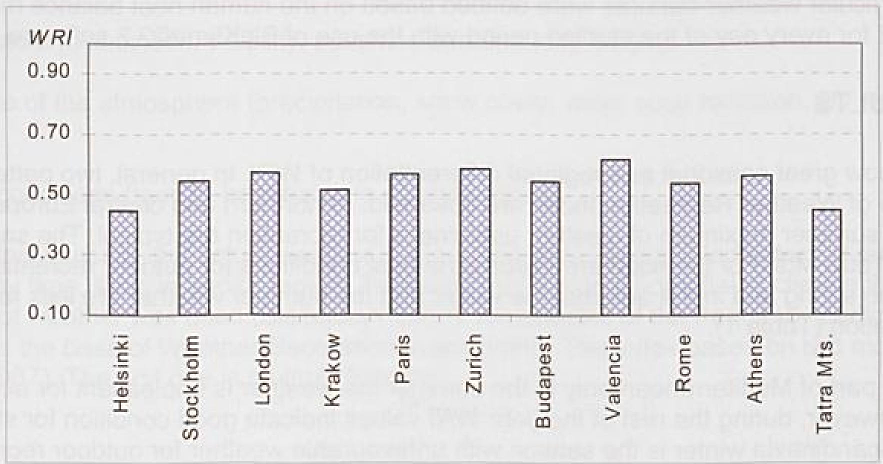


Fig. 2. Mean annual values of Weather Recreation Index (*WRI*) in various European stations, 1991-2000

## 4. CONCLUSIONS

The Weather Recreation Index (*WRI*) is a new approach to assess usefulness of weather for outdoor recreation. It bases on bio-thermal features of weather that derived from human heat balance considerations.

Both, seasonal and spatial differentiation of *WRI* is observed over the Europe. In the summer the most favourable conditions occurs in western Europe and Scandinavia. In the spring and autumn central Europe is the region with very favourable weather conditions. In Mediterranean only in the summer weather conditions are to loaded for active outdoor recreation. In the mountains the highest *WRI* is noted in the summer. In the winter they are to severe for some groups of recreants.

The results had shown also the necessity of flexible adaptation of tourism industry to actual weather. It seems that tourism organisers and proprietors of hotels and recreation centres should be more active to propose clients facilities to use various forms of activity both, passive and active.

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# THE ROLE OF CLIMATE INFORMATION IN TOURIST DESTINATION CHOICE DECISION-MAKING

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## 1 INTRODUCTION

A tourist's choice of destination will be based on what is expected from the chosen destination, and what is expected will be driven by the tourist's image of the destination. Of course, weather is not experienced as a set of separable and independent attributes but as a complex impression. In terms of climate, this leads us to ask: do tourists have an image of the climate and if so, how was this image formed? Moreover, it is unclear whether tourists form a complex picture of climate or if information on a few key attributes tells them enough about climate to construct an image. Therefore, we have focussed this study on climate image and climate information, which led to the following research questions:
A: How decisive is climate as a factor in decision-making?
B: At what point in the holiday decision-making process do tourists gather information about climate and weather?
C: What sources of climate information are most frequently used?
D: What are the most frequently used types of climate information?

## 2 METHODS

The emphasis on the time of information gathering lead us to survey the tourists shortly before departure. This allowed us to include the travel preparation phase. Our study population are those residents of Germany going on an outbound holiday and departing from Hamburg and its vicinity. Our sampling frame consists of those tourists departing from Hamburg and its vicinity at specific points of departure: the airport, the train station, the international bus terminal and the harbours of Travemünde and Kiel for ferries to Scandinavia. The convenience sample consists of those tourists travelling on the selected days and on the selected departures. All participants were aged 16 or over and resident in Germany. Additionally, only one person out of a travel party was questioned. We purposefully excluded business travellers in the sample used. We paid attention to the quotas of the German Travel Survey (F.U.R, 1998 and 2004) regarding the market shares of countries and transport modes.

The survey was carried out on 20 days spread over the months of July and August 2004, which covered the main parts of the local school holidays The days and times of the survey were chosen to correspond with departures to the countries with a high quota. The schedule and budget of this study did not allow for an inclusion of car travellers according to the market share of about one third of all travellers. Therefore, this group was left for future research. The quotas, therefore, corresponded to the relative market shares of the other transport modes.

### 2.1 THE HYPOTHESES

*Hypothesis A1: Destination climate is an important consideration for the choice of destination.*
This hypothesis will be tested by examining if climate is at least the third most important attribute for the choice of destination. In order to assess this we asked respondents to rank the three most important attributes out of ten attributes. The ten attributes were chosen according to an analysis of the attributes that were found to be the most important for tourists in studies on destination image. We assume that some tourists will search for warmer places to go, others may prefer a cooler climate than they experience in their home region at the same time of the year and some may be completely indifferent. Moreover, the individual's perception of the climate at the destination as being 'good' may be influenced by the home weather at the time of booking. In the region of Hamburg, where the survey has been undertaken, the summer of 2004 has been widely perceived as comparatively cold and wet. In order to hold this sort of seasonal deviation at a minimum, we focus on climate and do not value it.

*Hypothesis B1: Tourists gather climate information before they make their concrete holiday decision.*
*Hypothesis B2: Tourists gather weather information in preparation for their holiday.*

These hypotheses are tested using the results of two questions. The first question asks the tourists to state when they informed themselves about climate. There were seven options, which belonged to the following three groups: *before planning, during planning* and *after the decision*. We gave the tourists the opportunity to choose more than one option. *Before planning* is limited to the time before the tourist decides to go on holiday. It is not an active information gathering phase, since an image of the climate of the destination is there already either through previous experience in the country (or comparable climatic regions) or through knowledge gained from a general interest in the area. *During planning* covers the period after the tourist is motivated to go on holiday but has not made the concrete decision of where and when. In this phase, information will be actively gathered in order to make these decisions. *After the decision* includes information gathering in preparation for the holiday. This is carried out after the decision has been made but before the actual trip. The second question concerns the actual weather at the destination before the trip: we ask the tourists whether they have been following the weather during the week before their holiday.

*Hypothesis C1: Tourists rely on more than one information source.*
*Hypothesis C2: 'Friends and family' is the dominant information source category for first time visitors.*
*Hypothesis C3:'Own experience' is the dominant category for repeat visitors.*
We included 12 possible sources of information, including friends and family and own experience as well as weather information providers. We asked the tourists to rate on a five point Likert scale, the actual information sources used according to the importance for the decision. A filter question on previous visits is used to establish the two groups of first time and repeat visitors.

*Hypothesis D1: Tourists gather climate information on several different attribute types.*
*Hypothesis D2: Temperature is the dominant attribute for climate information.*
*Hypothesis D3: Tourists prefer a textual format for the presentation of climate information.*
In these hypotheses, we distinguish between the presentation of the information and the content of the information. An examination of the possible sources of destination information and destination climate information resulted in the inclusion of the following categories: text format, maps, diagrams and numerical data. The various information sources provide different types of climate information, these range from several temperature types to precipitation related information and less frequently mentioned attributes such as humidity or UV-radiation.

# 3 RESULTS

## 3.1 GENERAL RESULTS

In total 394 questionnaires were coded. The demographic profile of the tourists surveyed is comparable to that of the German Travel Survey data from 1998 (F.U.R, 1998). The average length of the holiday is 14.3 days, which corresponds to the average length of holiday (13.7 days) reported for the German Travel Survey 2004 (F.U.R; 2004). Surprisingly, a large share of the holidays were organised independently. The shares for package tours and booking through a travel agent are similar to that of international trips in the German Travel Survey 2004. Finally, the majority of respondents had visited their destination previously (58.6%). A detailed presentation of the results can be found in Hamilton and Lau (2004).

## 3.2 RESEARCH QUESTION A: CLIMATE AS A FACTOR IN DECISION-MAKING

From table 1, we can see that only two attributes are chosen more often than they are not chosen, namely climate and access to the sea/lakes. Not only was climate the most frequently chosen attribute, it also achieves the highest ranking of all attributes. The t-test for related samples shows that the mean rank value of climate is significantly different from that of sea/lakes, culture/history and nature/landscape, the three attributes closest in popularity to climate. For this reason, we can accept our hypothesis that climate is at least the third most popular attribute. Moreover, we can say that it is the most popular for the tourists in our survey.

## 3.3 RESEARCH QUESTION B: DECISION-MAKING PROCESS AND INFORMATION SEARCH

The most common phase for gathering information about climate is *during planning* (42%). Nevertheless, *shortly before the holiday* is the most frequently chosen single category (34%) and for those that only chose one category, the split between the three phases, *before planning, during planning* and *after the decision* is 25%, 35% and 39% respectively. The majority stated only one phase where they gathered climate information. Of the tourists that combined two or more options, 61% combined the phases during planning and after the decision. We can accept the hypothesis B1 that tourists gather climate information before they make their decision but with the caveat that the group of tourists informing themselves after the decision is also considerable.

The relationship between getting climate information and following the weather in the week previous to travel is significant. If tourists inform themselves about climate, they also inform themselves about the weather shortly before they travel. We can accept the hypothesis B2 that tourists gather weather information before they travel, as the majority of tourists do this. Nevertheless, we accept this hypothesis with the caveat that a large group of tourists (41%) showed no interest in weather.

### 3.4 RESEARCH QUESTION C: SOURCES OF CLIMATE INFORMATION

Tourists were asked to rate 12 different information sources and a thirteenth option of "other" on a scale of one to five for only those sources that they used. The question was answered in two different ways: first, that only the actual sources used were given a rank and second, that all sources were given a rank. Here we only discuss the results of the former group. We can accept the hypothesis C1 that more than one source is used, given that 21% of the respondents state only one source. For first time visitors, friends and family and travel guides are the most frequently chosen sources with 51% each (more than one response was possible). The second most important sources are travel agent and tour operator. For the group of repeat visitors, own experience was chosen by 69% of the respondents followed by friends and family (53%) and travel guides (40%). For climate information, there is no statistically significant effect of being a first time visitor on the tourists' likelihood to get information from family and friends. The relationship between previous visit and own experience is positive and significant. Therefore, we accept hypotheses C2 and C3.

### 3.5 RESEARCH QUESTION D: TYPES OF CLIMATE INFORMATION

An overwhelming majority of the respondents (91%) chose more than one climate attribute. The mean number of attributes chosen is 3.23. We can therefore accept the hypothesis D1 that tourists choose more than one attribute. In table 2, we can see that temperature is quite clearly the most frequently chosen attribute. Maximum temperature was chosen by two thirds of the respondents. 32% and 16% of the respondents chose average and minimum air temperature respectively. Other attributes that were chosen by more than half of the respondents were the number of rainy days, duration of sunshine and water temperature. As respondents were able to choose more than one attribute, we present the frequencies with which the air temperature attributes were chosen both singularly and in combination. As the lower half of table 2 shows, only 12% of the respondents did not chose one of the air temperature attributes. This gives very clear support for hypothesis D2, that temperature is the dominant attribute. From the five possibilities offered, textual format was the second least preferred option and if we discount the option "other" then it is the least preferred. In this case, we can reject the hypothesis D3 that tourists prefer a textual format. Numerical data is the most popular option.

## 4 DISCUSSION

Our results highlight the importance of information gathering before making a decision. Furthermore, this study shows that information gathering also occurs after the decision. Moreover, this study gives support for Fodness and Murray's theory (1999) that personal experience will be the main source of information for repeat visitors. The importance of friends and family as an information source for all of the tourists in our sample, reflects the results of Chaudhary (2000). The majority of tourists informed themselves about climate from a variety of sources. Therefore, the results of this study could also be useful for the providers of tourism information, in that they tailor the information they present to meet the preferences of tourists.

Studies of destination demand have been criticised of simplistically representing climate using single variables, such as temperature and precipitation and not a complex of variables. The results presented in this study support the use of temperature as the main determining variable in destination demand studies. Nevertheless, we cannot claim from these results that temperature alone is enough to represent the considerations of tourists about destination climate.

## 5 CONCLUSION

This study adds to the evidence that climate is an important factor in destination choice. In addition, it provides clarity over the role of climate and weather information gathering in the various phases of the decision-making process. Having carried out this survey, the first of its kind to focus on climate as a specific attribute of destination image and on its role in the decision-making process, we have produced a valuable database that can be used for further research. For instance, the issue of whether the tourists' images of climate are accurate when compared to the climate of their destination can be assessed. It would be an interesting extension of this study to examine, whether we find different information preferences for different demographic or holiday groups.

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| | 1st position value = 3 | 2nd position value = 2 | 3rd position value = 1 | Not chosen value = 0 | Total Chosen | Mean |
|---|---|---|---|---|---|---|
| Access to the sea/lakes | 53 | 79 | 56 | 182 | 188 | 1.01 |
| Accomodation | 14 | 33 | 22 | 301 | 69 | 0.35 |
| **Climate** | **91** | **65** | **40** | **174** | **196** | **1.20** |
| Cuisine | 2 | 12 | 10 | 346 | 24 | 0.11 |
| Cultural/historical attractions | 60 | 50 | 33 | 227 | 143 | 0.85 |
| Ease of access | 3 | 22 | 23 | 322 | 48 | 0.21 |
| Hospitality | 17 | 38 | 35 | 280 | 90 | 0.44 |
| Nature/Landscape | 62 | 58 | 36 | 214 | 156 | 0.91 |
| Price | 17 | 61 | 48 | 244 | 126 | 0.60 |
| Sport and leisure activities | 8 | 22 | 19 | 321 | 49 | 0.24 |

Table 1 Results of the ranking of destination attributes (n= 370)

| Climate attributes chosen | Frequency | Air temperature options chosen | Frequency |
|---|---|---|---|
| Maximum temperature | 67% | Maximum temperature | 27% |
| Water temperature | 52% | Average temperature | 19% |
| Duration of sunshine | 51% | Minimum temperature | 1% |
| Number of rainy days | 50% | Maximum and minimum | 8% |
| Average temperature | 32% | Maximum and average | 25% |
| Minimum temperature | 16% | Average and minimum | <1% |
| Amount of precipitation | 16% | Maximum, minimum and average | 6% |
| Humidity | 14% | Did not choose any temperature op | 12% |
| Cloudiness | 10% | | |
| Wind conditions | 7% | | |
| UV Radiation | 6% | | |
| None of these | 3% | | |

Table 2 Preferences for information about climate attributes (n=283)

# TRAVEL BEHAVIOUR INFLUENCED BY CLIMATIC FACTORS – THE CASE OF LAKE BALATON, HUNGARY

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## 1 INTRODUCTION

In Hungary, tourism is an important economic and social activity. Leisure tourism is typically seasonal and highly dependent on water and climatic resources, and the Lake Balaton Region, in the western part of the country, is the oldest and most established holiday destination in Hungary (Figure 1).

Figure 1

The tourist regions of Hungary


Source: Hungarian Tourist Board, http://www.hungary.com

Lake Balaton is the largest freshwater lake in Central Europe. It is a typical shallow lake of 588.5 $km^2$ surface, 3.25 m average depth and 236 km shoreline length with high sensitivity to the fluctuation of hydro-meteorological factors influencing water characteristics. In winter the lake is generally covered by ice up to 70 cm wide, in summer the average water temperature is 23C°. The southern shore of the lake consists of sandy beach, while on the northern shore there are mountains of volcanic origin with old ruins on their tops and vineyards on their slopes. The picturesque landscape and the water ideal for swimming and other water sports attract millions of tourists to the region.

Travel behaviour is a complex phenomenon which consists of destination choice and consumer decisions concerning products and services offered by the tourism industry. According to Liu (1999), the variety of goods and services consumed by the tourist is shaped by background tourism elements (BTEs) including natural resources, socio-cultural conditions and the man-made environment. Natural BTEs represent, among others, water resources, weather conditions, climate, flora and fauna, topography and scenic resources. Destination choice is affected by images and perceptions of the tourists who use culturally determined criteria to reduce the number of destinations in their awareness set. These criteria include the quality of the tourist product, cultural and man-made attractions, accessibility of the destination, needs and wants of the tourist, or the estimated price-value ratio of the tourist services. Actual choice however, particularly in domestic leisure tourism, is often influenced by last minute considerations such as the immediate weather conditions or the forecast for the next few days.

## 2 METHODS

Various research methods were used for the completion of the paper. Statistical data and qualitative information were gathered from secondary sources such as the tourist authorities of the Lake Balaton region and the Hungarian Tourist Board. Data collected from such sources were analysed in order to understand the current situation of tourism in the study area and to comprehend the potential impacts of climatic factors on tourist behaviour in the region. The authors' previous research findings on the development of tourism and its impacts on the destinations in the Lake Balaton region were also applied to gain further evidence (Puczkó – Rátz 2002).

In addition to secondary literature analysis, a questionnaire survey was carried out in the autumn of 2004 (with a sample size of 1100) in order to assess the extent to which weather and other climatic factors influence Hungarian tourists' destination choice. As the environmental conditions of Lake Balaton are significantly affected by the consequences of climatic fluctuation, and in turn, tourism is highly dependent on water quantity and quality of the lake, the survey also aimed to understand visitors' perceptions concerning Lake Balaton's environmental state. Due to financial limitations, quota sampling was used, based on respondents' age and gender, so the selected sample represents the Hungarian population by these two variables.

## 3 RESULTS

Descriptive characteristics of the sample's socio-demographic distribution are summarised in Table 1. Due to the quota sampling methods, the distribution of respondents represents the Hungarian population by age and gender. However, due to the shortcomings of the sampling method, Budapest and particularly the Central Western part of Hungary are overrepresented, while the rest of the country is underrepresented. Occupationally, respondents are drawn from diverse socio-economic circumstances.

Table 1

Respondents' characteristics (%)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Gender | Male 49.5 | | | Female 50.4 | | | Total* 99.9 |
| Age | 15-19 9.0 | 20-34 27.9 | 35-44 15.7 | 45-59 24.4 | | 60- 23.0 | Total 100.0 |
| Permanent residence | Budapest & environs 24.0 | Northwest 15.4 | Southwest 6.4 | Central West 32.0 | Northeast 10.2 | Southeast 9.5 | Total* 97.5 |
| Occupation | Retired 19.4 | Student 23.6 | Unemployed/ homemaker 1.4 | Manager/ Prof. 20.7 | Blue collar 13.2 | White collar 20.0 | Total* 98.3 |

* Less than 100% due to no response

Table 2 presents the role of different variables – including components of the tourism product as well as the destination's natural environment – in respondents' holiday destination choice. As the table shows, the attractions offered by the area proved to be most influential for travellers; however, material factors such as the price and the quality of the tourist services and the costs of travel to the destination also considerably affect respondents' decisions. Slightly surprisingly, the expected weather at home during the time of the planned holiday only influences 4.1% of the respondents: possible explanations may include the typically low level of spontaneity of Hungarian tourists' travel behaviour, particularly in outgoing tourism, as well as the country's relatively small size which usually results in rather uniform weather characteristics on a national level.

Table 2

Variables influencing destination choice (% of respondents)

| Variable | % | Variable | % |
|---|---|---|---|
| Natural attractions | 53.6 | Cultural attractions | 47.5 |
| Price of services | 44.8 | Service quality | 40.6 |
| Costs of travel to destination | 40.5 | Expected weather at destination | 39.8 |
| Quality of natural environment | 28.6 | Time of travel to destination | 26.5 |
| Distance to destination | 26.2 | Transport mode | 23.7 |
| Expected weather at home | 4.1 | | |

In order to analyse the level of association between age and the above variables influencing destination choice, crosstabs statistics were used. Based on the Pearson Chi-Square test, age proved to be a significant factor concerning distance between the respondent's home and the destination, travel time needed to reach the destination, and transport mode, indicating that older people are more likely to base their decisions on comfort and convenience (Table 3). The destination's supply of cultural attractions also play a more critical role in older respondents' decisions, while natural attractions proved to be significant for the 20-34 and 45+ age groups.

Table 3

Destination choice factors influenced by respondents' age

| Variable | Pearson Chi-Square |
|---|---|
| Geographical distance to destination | 49.206* |
| Travel time to destination | 23.604* |
| Transport mode | 18.774** |
| Cultural attractions of destination | 19.472** |
| Natural attractions of destination | 17.792** |

*df=4, sig.=0.000 **df=4, sig.=0.001

In addition to general destination choice variables, respondents were also asked to evaluate the influence of specific climatic and weather-related factors on their leisure travel decisions. As Table 4 shows, sunshine and the temperature of natural waters proved to be the most important, reflecting the results of previous market surveys on Hungarian tourists' customs and preferences according to which the major motivations of Hungarian travellers are relaxation and beach holidays (MT Rt. 2005). Additional natural factors mentioned by respondents as being influential in their travel decisions were wind, high fluctuation of temperature, mosquitoes, natural disasters, and the pollen content of the air.

Table 4

Climatic factors influencing destination choice

| Variable | Mean* | St.dev. |
|---|---|---|
| Number of sunshine hours | 3.88 | 1.10 |
| Temperature of natural waters | 3.85 | 1.15 |
| Average daytime air temperature | 3.74 | 1.09 |
| Average quantity of precipitation | 3.47 | 1.16 |
| Reliability of precipitation | 3.46 | 1.19 |
| Average nighttime air temperature | 2.82 | 1.12 |

* On a scale 1-5, with 1 being insignificant, 5 being highly significant

In order to analyse the possible relationships between socio-demographic characteristics and the impact of climatic factors on destination choice, an ANOVA variance analysis was performed. The analysis showed no significant relationship between gender and climatic factors. With respect to age however, the ANOVA indicated that the number of sunny hours (F=5.891, sig.=0.000) and temperature of natural waters (F=5.284, sig.=0.000) are more influential in the case of younger respondents who are more interested in beach holidays. Further crosstab analysis proved a correlation between the expected weather of the destination and all the selected climatic factors (Table 5), suggesting that "good weather" means sunshine and no rain for respondents.

Table 5

Relationship between climatic factors and expected weather at destination

| Variable | Pearson Chi-Square |
|---|---|
| Average daytime air temperature | 87.783* |
| Average quantity of precipitation | 50.067* |
| Number of sunshine hours | 49.824* |
| Reliability of precipitation | 44.360* |
| Temperature of natural waters | 44.114* |
| Average nighttime air temperature | 38.596* |

*df=5, sig.=0.000

## 4 DISCUSSION

Although the analysis of the survey data is not completed yet, research findings suggest that while weather at the destination is a major pull factor for visitors, it is relatively less important as a push factor in the travel decision making process: the expected weather at the visited destination affects almost 40% of the respondents, while only 4% are influenced by the expected weather at their permanent residence. Consequently, respondents are rather unlikely to make last-minute travel decisions based on the short-term weather forecast for their permanent residence. However, their destination choice is dependent on the visited area's expected weather conditions, which is also underlined by the fact that weather forecasts are considered as important information sources by the majority of respondents (Table 6).

Table 6

| Information source | Mean* | St.dev. | Often or always used** | Never or rarely used** |
|---|---|---|---|---|
| Own experiences of previous visits | 3.49 | 0.84 | 80.4 | 8.4 |
| Friends and relatives | 3.08 | 0.87 | 68.5 | 21.6 |
| Short-term weather forecast on TV | 3.04 | 0.96 | 67.4 | 22.7 |
| Brochures of the destination | 2.82 | 1.02 | 58.1 | 31.0 |
| Short-term weather forecast on radio | 2.71 | 1.07 | 51.9 | 37.6 |
| Travel guidebook | 2.61 | 1.09 | 47.2 | 41.5 |
| Long term weather prognosis | 2.31 | 1.08 | 37.4 | 51.4 |
| Websites presenting the destination | 2.13 | 1.22 | 33.6 | 54.6 |
| Short-term weather forecast on Internet | 1.96 | 1.16 | 27.3 | 61.6 |

* On a scale 1-4, with 1 meaning never used, 4 meaning always used ** % of respondents

Hungarian tourists' ideal weather is suitable for beach holidays, so it is characterised by high air and water temperatures and low level of precipitation. Holiday habits reflect this preference, as the majority of respondents who visited Lake Balaton in the last five years did so either in June (28.9%), July (52.7%) and August (53.8%). The shoulder season proved to be far less popular, with May accounting for 9.6% of the visits and September for 10.5%, while the rest of the year brings almost no visitors to the lake.

## 5 CONCLUSION

Weather and climatic factors are major components of the tourism environment, and the success of tourist destinations all around the world depends on these characteristics. In the case of Hungary, where leisure tourism mostly focuses on natural water resources such as Lake Balaton, it is particularly important to understand the extent to which these variables influence tourists' decision making.

The findings of the survey indicate that weather is a significant pull factor in Hungarian tourism and travel behaviour is considerably affected by weather-related information. However, when analysing factors influencing destination choice, it must be added that Hungarian tourists are relatively price-conscious in their choices, so the characteristics of the tourism product – particularly the price and the quality of the services offered by the industry – play an equally critical role in shaping their decisions.

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# TOURISM CLIMATOLOGY AND TOURISM POTENTIAL FOR CRETE, GREECE

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## 1 INTRODUCTION

Crete, the biggest island of Greece, located in the east Mediterranean, is the most frequently visited Greek island by foreign visitors (about 2 millions people) throughout the year. Tourism represents a major economic factor for Crete. Crete is the greatest tourism destination in Greece. The overnight stops in Crete reached the 26.7 % of all Greek Tourism market, in 1999. The number of arrivals in Crete in 2003 during the first six months reached the level of 642.757, while the corresponding overnight stops reached the level of 4.219.738. The most of the arrivals (91.2 %) were recorded during the period April – June, while the rest (8.8 %) the period January – March. So, in general, weather and climate/bioclimate information are required and demanded for the quantification of the existing climate conditions on the one hand, and for the approximate calculation of possible damages and implications to human health resulting from extreme weather events on the other.

Due to its location in the eastern Mediterranean, the island of Crete has a mild climate with only slight variations. Through its geographic location, Crete is protected from the cold air masses of central and western Europe in winter, and the high temperate air masses of North Africa in summer. Thus, the climate of Crete is temperate to maritime, except for most mountainous areas where [the climate] is mountainous. Crete has a very gentle and healthy climate. The winter is mild, particularly in plain and coastal areas. Also summer temperatures are rather pleasant due to the sea breeze and etesian winds (northerly winds from Aegean Sea). The plain and coastlines areas of Crete, and particularly its eastern parts, are one of the warmest areas of the country during winter, due to increased sunshine, scarce snowfalls and absence of frost.

First, an attempt is made in this paper to assess and analyse the thermal sensation and general climate factors of Crete and also their variations and trends for the time period 1960-2000. Secondly, it was attempted to define and quantify the tourism potential of the island.

## 2 METHODS

In order to quantify the tourism climate conditions, long term data from several stations of the existing climatic network of Crete were used, including daily mean, maximum and minimum temperatures, relative humidity, wind speed and cloud cover over the whole island From these parameters the daily Physiological Equivalent Temperature (PET) was derived (VDI, 1998, Höppe, 1999, Matzarakis et al., 1999). In addition, possible trends of thermal comfort in annual and seasonal basis and precipitation were taken into account.

Further, geo-statistical methods have been applied and available climate data from the 10 minutes climatology (New et al., 1999, 2000) have been used to construct high resolution maps of basic climatological parameters and the Physiological Equivalent Temperature for the period 1961 - 1990.

## 3 RESULTS AND DISCUSSION

The analysis of the tourism climate and tourism potential have been analysed through ombro-thermic diagrams for the investigated climate stations (7) and periods. Fig. 1 shows the ombrothermic diagram for Heraklion for the period 1961 – 1990. With regards to air temperature variations in Crete, the data shows that in the first (cold and rainy) period of October to March the coldest months are January and February. The mean minimum air temperature in these months varies between 7 - 9 °C in coastal areas, 4 - 6 °C in the mainland, and even lower in highlands. In general, in this period, the eastern plain parts of Crete along with Dodecanese (the most south-eastern islands of Greece), are the least cold areas of Greece (Fig. 1).

For each station the thermal human-bioclimate conditions in terms of mean conditions, extremes and frequencies of thermal perception classes were analysed. Fig. 2 shows the bioclimate diagram for Heraklion for the period 1955 – 2001. The thermal human-bioclimate conditions are in percentages of the occurrence of classes for ten day intervals (dekas). Results from fig. 2 show that 50 % of the days from the 11th dekas to the 30th dekas are lying in the PET-classes of 18 °C and above. It has to be mentioned that the results of Fig. 2 are based on daily mean values for the meteorological variables. From the 13th to 27th dekas also extreme thermal stress can be observed for the investigated region.

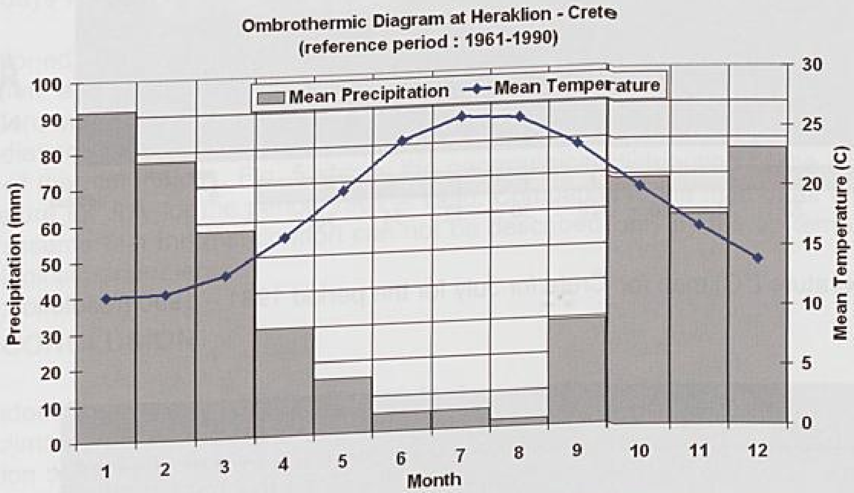


Fig. 1: Ombrothermic diagram at Heraklion for the climate period (1961-1990)

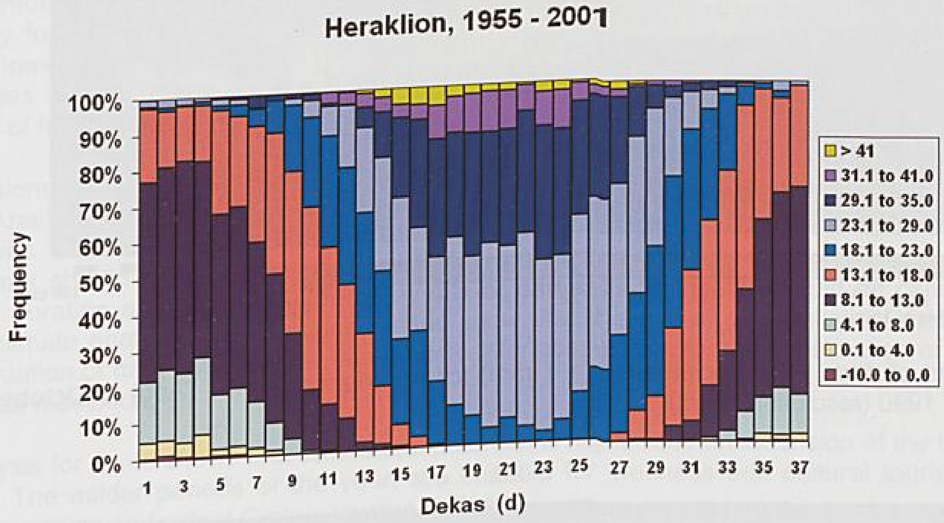


Fig. 2: Bioclimate diagram for Heraklion, Crete for the period 1955 – 2001.

The second (warm and dry) period of April to September is characterised by almost no precipitation and slightly hot temperatures. The warmest months of this period are July and August. The mean maximum air temperature in these two months varies between 28 and 32 °C, sometimes reaches 34 - 36 °C and scarcely, mainly in southern Crete, approaches 40 °C, particularly in plain mainland areas. These high temperatures in the southern part of Crete are associated with low air humidity and, thus, the thermal comfort conditions in these areas are still tolerable. June shows approximately the same temperature regime as September, with the later to be considered as summer month in Crete the precipitation increases from East to the West and from the northern coastal areas to the inland regions and the highlands, and then decreases to the southern parts. Maximum annual precipitation levels of 1100 – 1200 mm are observed in mountainous areas of Crete and with 1600 mm even higher levels in the Lefka Ori mountain range (west part). The lowest annual precipitation of about 500 mm or less are recorded in the southern parts of Heraklion Prefecture (central part), particularly in Mesara plain and Viannos area. Snow appears in high frequency in the mountains and particularly in Lefka Ori Mountain range (west part) and Psiloritis Mountain range (central part), while in the coastal areas snowfall is a sporadic phenomenon.

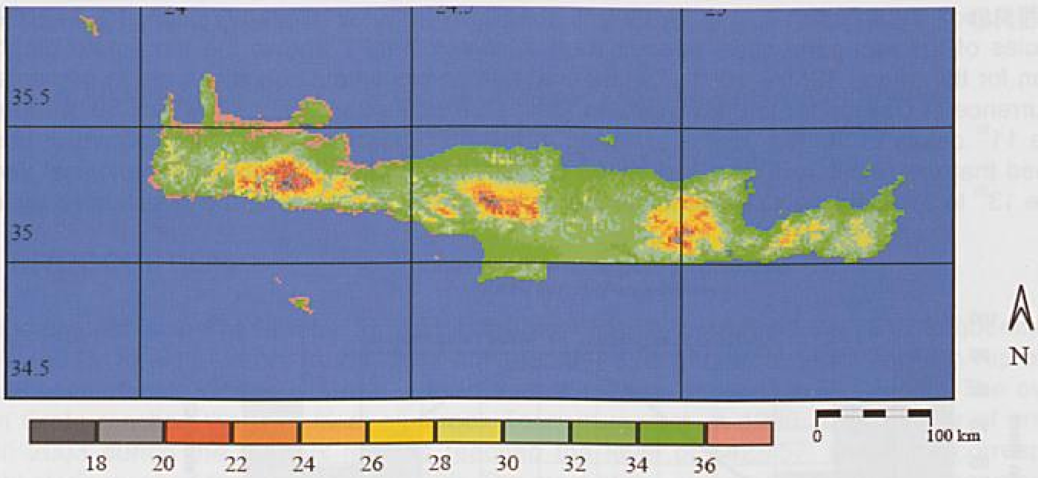


Fig. 3: Map of air temperature (°C) map for Crete for July for the period 1961 – 1990 (resolution: 1 km)

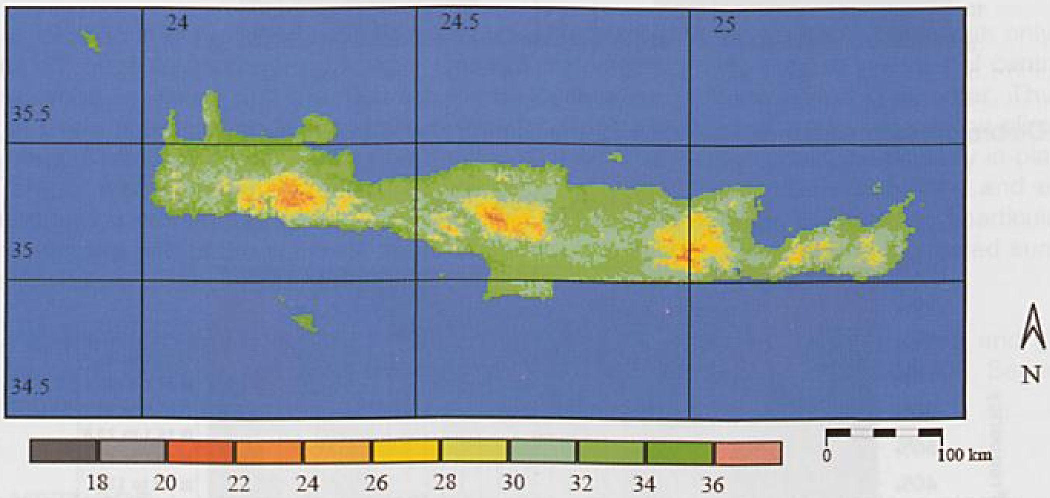


Fig. 4: Amount of days with precipitation (> 1 mm) for the tourism period (April to October) for the period 1961 – 1990 (resolution: 1 km)

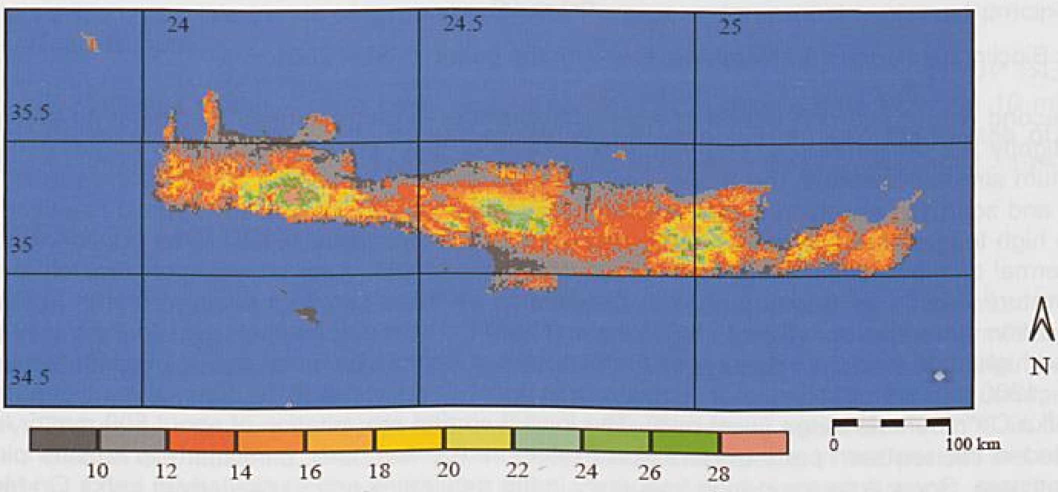


Fig. 5: Map of Physiological Equivalent Temperature (°C) for Crete for July for the period 1961 – 1990 (resolution: 1 km)

Fig. 3 shows the distribution of air temperature for July in a horizontal resolution of 1 km, which provides the possibility of quantification of the conditions for the whole island. Beside the air temperature as an ordinary climatic parameter, in terms of precipitation it is not only important to consider the precipitation sum for the whole year but the sum of precipitation or rain during the tourism period. More appropriate and complementary information for the tourism period can be provided by the amount of days with rain (> 1 mm). Fig. 4 shows the amount of days with precipitation for the tourism period in Crete (April to October) for the period 1961 –1990. From Fig. 4 it can be extracted that the days with precipitation are generally low, with less than 15 days for the areas of low altitude.

As mentioned above, results derived from thermal human-bioclimate data can provide more detailed information about the bioclimatic conditions of an area. They include no only air temperature information, but additional meteorological variables (air humidity, wind speed and also short- and long wave radiation fluxes) and thermo-physiological information. Thermal bioclimate can be quantified by the use of thermal indices. Fig. 5 shows the geographical distribution of the Physiological Equivalent Temperature for July for the period 1961 – 1990. Compared to the map of air temperature from Fig. 3, we can assume that thermal comfort can not be described only by the air temperature or other single meteorological parameters.

## 4 CONCLUSION

For the identification and quantification of the tourism climate and tourism potential, manifold climatic and bioclimatic information can be provided by applied climatology and biometeorology. The existing information and provided material have to be reliable and accessible. Information can be provided in traditional ways of presentations like ombro-thermal diagrams. The existing climatic networks, beside the synoptical networks from national weather services, offer appropriate data for the regionalisation of climate information by the use of geo-statistical methods. The existing data sets offer also the possibility for the calculation of thermal indices in order to access and to quantify the climate in human-biometeorological terms. The data of the climate networks allow also the calculation of frequencies and extremes i.e. the amount of days with precipitation for the tourism period or the detection of frequencies of heat waves.

Human-biometeorological methods can be adapted for tourism climatology and tourism potential issues. Analysis of single climatic variables and thermal indices in form of means, extremes and frequencies do not present an integral assessment of the tourism potential of an area. Integral assessment should cover diverse facets of the climate and physical environment. UV-Information, sunshine duration and possible extreme events or damages for health should be considered in the tourism climate analysis. The produced maps show that the use of geo-statistical methods and the implementation of data sets from climate models offer possibilities for the construction of results with a high spatial resolution.

The analysis for Crete shows that the natural potential is higher and an extension of the tourism period possible. The milder periods of the year, are suitable for wellness and cultural tourism of specific population groups and extent Crete's tourism period.

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# CLIMATE CHANGE AND THE LOCATION OF FUTURE WINTER OLYMPIC GAMES

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## 1 INTRODUCTION

The sustainability of winter recreation and tourism associated with skiing has been repeatedly identified as vulnerable to global climate change (McBoyle et al. 1986, Galloway 1988, Breiling et al. 1999, Elsasser and Bürki 2002, Scott et al. 2003, Fukuskima et al. 2003). In 2003 the United Nations Environment Program and the International Olympic Committee commissioned a report on the potential impacts of climate change on winter sports (primarily alpine skiing) as part of the 5th World Conference on Sport and the Environment in Turin, Italy. The report provided a review of the research literature available at that time and largely focused on European ski areas (Burki et al. 2003). Upon review of the report findings, the International Olympic Committee (IOC) indicated that it would begin to consider climate change in its evaluation of future sites for the winter Olympic Games.

If the IOC is to consider how climatic trends and projected climate change will affect a community's ability to host a successful Winter Olympic Games, an important challenge will be how to compare the relative vulnerability of different locations to climate change. As Scott (2005) indicated, the measurement of the potential impact of climate change on the reliability of snow conditions and the viability of ski areas has been accomplished in different ways, and the range of methodologies and different climate change impact indicators used currently precludes comparisons between international studies. The climate change impacts research community should begin to adopt similar terminology and develop standard climate change impact indicators to facilitate such comparisons. For example, host communities could be requested to provide the IOC with information on a standardized set of key indicators of climate trends (e.g., winter temperatures, snowfall and rain events; ski season lengths at the proposed venue; number of mid-season ski area closures) and climate change projections for the time period relevant to the Olympic Games bid (e.g., changes in snowfall and snow depth, snowmaking capacity, probability of having ski courses operational, condition of snow [using proxies like probability of melt event or rain]).

This paper applies two of the proposed standard indicators, ski season length and probability of ski areas being operational during the month of February (when Winter Olympics games have been traditionally held), to six North American locations that have held or bid for a Winter Olympic Games, in order to assess their relative vulnerability to projected climate change.

## 2 METHODS

Six past and future winter Olympic game host sites in different regions of North America were included in this analysis. Table 1 provides the climate station and the summit elevation of the ski area used to represent each location. While the base of a ski area is generally more vulnerable to climate change, the summits were selected for this analysis because Olympic calibre ski race courses are often set nearer to the summit of ski areas.

Table 1 – Study Areas

| Olympic Site | Year of Games | Summit Elevation (masl) | Climate Station | Station Elevation (masl)) |
|---|---|---|---|---|
| Calgary | 1988 | 2729 | Banff | 1384 |
| Vancouver | 2010 | 2182 | Williams Lake | 940 |
| Quebec City | Planned bid | 800 | Quebec City | 74 |
| Lake Placid | 1932, 1980 | 1417 | Chasm Falls | 314 |
| Salt Lake City | 2002 | 2819 | Salt Lake City | 1296 |
| Squaw Valley | 1960 | 2758 | Tahoe | 1900 |

The selection of the climate stations for this study was based on two considerations: the proximity of the climate station to the ski area of interest and the length and quality of the climate record (minimally daily temperature [maximum, minimum and mean] and precipitation [rain and snowfall] for 1961-90).

The climate change scenarios used in this analysis were constructed in accordance with the methodological recommendations of the United Nations Intergovernmental Panel on Climate Change (IPCC) Task Group on Scenarios for Climate Impact Assessment. A total of five climate change scenarios (CCSRNIES-A11, ECHAM4-A21, CGCM2-A2x, HADCM3-A1F1, NCARPCM-B21) representing a broad range of global climate models and future emission levels were considered for this analysis. Each scenario consists of estimates of possible temperature and precipitation change, relative to the 1961-90 baseline, for each month during three future periods: the 2020s (average changes over 2010-39), the 2050s (average changes over 2040-69) and the 2080s (average changes over 2070-99). For the purposes of concise presentation, only the results of the two climate change scenarios that represent the range of results (a low impact scenario and high impact scenario) are reported.

The methods for snow depth modelling and the integration of snowmaking with the locally calibrated snow model were based on the methods developed by Scott et al. (2003, 2006). Similarly, the climatic criteria for a skiable day were adopted from Scott et al. (2003). In order to compare the relative impact of projected climate change at the six locations selected for this study, the impact of climate change was modelled on a standardized hypothetical ski area, identical in size (skiable terrain) and snowmaking capacities, at each study area. This approach effectively isolates the importance of climate and projected climate change at each location, rather than the relative advantages of the specific snowmaking systems in place at each ski area and is again consistent with Scott et al. (2003, 2006). While not all locations will currently have the adaptive capacity offered by state of the art snowmaking systems, this technological adaptation would be considered cost effective by bid communities if such an investment was required for a successful Winter Olympic Games bid.

The results of this analysis are only considered valid for the location of the climate station selected to represent each location and surrounding areas that exhibit similar climatological characteristics. The ski areas of interest to this analysis are sometimes many kilometres away and may have microclimatic features that enhance or reduce their vulnerability to changes in climate.

## 3 RESULTS

When the summit areas of the six study areas were assess with snowmaking capacity, none were particularly vulnerable to projected climate change until the 2050s, and then only under the warmest scenario. Table 2 outlines the projected changes in the length of the average ski season under low and high impact climate change scenarios. The impact of projected climate change on the average length of ski seasons in the 2020s was negligible at all locations (no change to a -3% loss). The high impact climate change scenario for the 2050s had a meaningful impact (-17%) on the length of the ski season at the two lower elevation locations in eastern North America (Quebec City and Lake Placid).

Table 2 – Impact of Climate Change on Average Ski Season Length (% Change)

| Location | Modelled 1961-90 Ski Season (in days) | 2020s | | 2050s | | 2080s | |
|---|---|---|---|---|---|---|---|
| | | Low | High | Low | High | Low | High |
| Calgary | 181 | 0% | -1% | 0% | -6% | -1% | -18% |
| Vancouver | 181 | 0% | 0% | 0% | -1% | 0% | -6% |
| Quebec City | 179 | 0% | -3% | -2% | -17% | -2% | -29% |
| Lake Placid | 170 | 0% | -2% | -1% | -17% | -1% | -29% |
| Salt Lake City | 180 | -1% | -2% | -1% | -11% | -2% | -18% |
| Squaw Valley | 179 | -1% | -1% | -2% | -10% | -2% | -20% |

More important to the delivery of a successful Winter Olympic Games would be the snow conditions when the Games are held, which is typically in mid- to late-February. Table 3 indicates the number of days in the month of February that snow conditions were sufficient for the summit of the six ski areas to be operational for skiing. With snowmaking systems in place the probability of the ski runs at summit elevation being operational remained over 85% in all locations even under the warmest climate change scenarios. This is because ski area managers have sufficient time in the preceding months to build a deep snow base.

The availability of sufficient snow depth does not guarantee good snow conditions for downhill races as mid-winter melts and rain events (liquid or freezing) can adversely affect snow conditions. Further analysis would be required to assess the vulnerability of these locations to such climatic conditions.

Table 3 – Skiable Days in the Month of February

| Location | Modelled 1961-90 Ski Season | 2020s | | 2050s | | 2080s | |
|---|---|---|---|---|---|---|---|
| | | Low | High | Low | High | Low | High |
| Calgary | 28 | 28 | 28 | 28 | 28 | 27 | 26 |
| Vancouver | 28 | 28 | 28 | 28 | 28 | 27 | 27 |
| Quebec City | 28 | 28 | 28 | 28 | 28 | 27 | 27 |
| Lake Placid | 28 | 27 | 27 | 27 | 26 | 26 | 25 |
| Salt Lake City | 28 | 28 | 28 | 28 | 28 | 27 | 26 |
| Squaw Valley | 28 | 28 | 27 | 27 | 27 | 27 | 25 |

## 4 DISCUSSION

This study indicates that projected climate change will have little impact on the capacity of the six North American communities analyzed to host downhill skiing events for a future Winter Olympic Games, assuming that snowmaking capacity is in place at the downhill ski venue. Not until the 2050s, and under the warmest climate change scenario, did projected climate change have a substantive impact on the length of the average ski season (-17%) in Lake Placid and Quebec City (both lower elevation ski regions in Eastern North America). The potential impact on ski operations in the critical month of February was largely unimportant at all locations even into the 2050s. While the 2050s is well beyond the contemporary planning for future Olympic Games, this long-term impact may have planning implications for these communities, in that they may want to consider bidding for the Winter Olympic Games in the next two decades, in-case these climate change scenarios are realized.

It is important to reiterate that this analysis examined the summit regions of ski areas that might be used to host downhill ski races and assumed that advanced snowmaking systems were in place. With these modelling assumptions the impacts of climate change were very minor at all locations and would not preclude any of the locations from being considered for future Winter Olympic Games. The impact of climate change was greater at the base of the same ski areas and when no snowmaking capacity was included in the analysis. The IOC would therefore need to require that climate change impact assessments provided by each bid community be tailored to the specific circumstances of the proposed ski venue (e.g., specific elevation and micro-climate, snowmaking capacity). In this way, the IOC can better assess the comparative climatic and technological advantages offered by each location.

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# THE IMPACTS OF CLIMATE CHANGE ON ECOTOURISM IN TOBAGO

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## 1 INTRODUCTION

Tobago is an island region with a population of approximately 51,000 and lies within the national economy of Trinidad and Tobago. Tobago is widely recognised as one of the most unspoilt islands in the Caribbean; the island is home to the oldest protected Rainforest in the Western hemisphere and the island's dive sites are comparable to any in the Caribbean. According to the Policy Research and Development Institute of the House of Assembly in Tobago (PRDI) 54% of Tobago's GDP is attributable to tourism and tourism related activities. The importance of tourism and its continued sustainable development to local livelihoods and to the survival of the sub-regional economy cannot be overstated.

This extended abstract and conference presentation examines the crucial interdependence between the tourism industry, the environment, tourism stakeholders and communities within the ecotourism destination and evaluates the awareness and role of the island's tourism stakeholders concerning 'climate change readiness'. The project also evaluates tourism operators' knowledge of climate change impacts, their 'green' tourism practices, their existing and future adaptation and mitigation strategies and the relative importance placed by the stakeholders on the natural assets of the island. The presentation is based upon a research and development project funded by the British Academy currently being concluded by the authors on the island of Tobago. The aim of the project was to evaluate the existing and potential impacts of climate change on ecotourism in the island of Tobago through consultation with the stakeholders and analysis of existing data. The objectives are: (i) to enhance the sustainable development of ecotourism in Tobago; (ii) reduce the vulnerability of stakeholders and communities on the island through increased awareness and knowledge of the impacts of climate change; (iii) to enable the further conservation of biodiversity and the future design of appropriate and pragmatic adaptation and mitigation strategies for the industry stakeholders.

Identification of the impacts of climate variability and change on human and natural systems was recently recognized as one of eight "grand challenges" in the environmental sciences by the National Research Council (2000). While potential impacts of climate change in areas such as agriculture and hydrology have gained increasing attention over the past decade, likely effects on tourism activity remain "seriously understudied" (Morehouse, 2001, p. 221). The impacts of climate change on tourism are likely to be of the greatest consequence in areas that: (i) possess environments especially susceptible to climate-induced change; (ii) are heavily dependent on tourism for their economic viability. As a result, one geographic area that is likely to suffer disproportionately if global warming continues on its current trajectory is the Caribbean. According to the Intergovernmental Panel on Climate Change (IPCC), (2001), observational data show that temperatures and sea levels in and around the world's small island states (SIS), namely, those in the Pacific, Indian, and Atlantic Oceans, and the Caribbean Sea, have in the past been rising by as much as 0.1°C per decade and 2 mm per year, respectively. Projected annual mean warming for the Caribbean Sea according to five general circulation models equals 2.0°C for the 2050s and 3.1°C for the 2080s. Projections also suggest an increase in extreme weather events in the Caribbean, for example, more frequent droughts and floods.

Current literature displays some advances in the research of climate change and summer tourism for example Giles and Perry (1998) used the abnormally hot weather of 1995 as a temporal analogue to examine how projected climate change might impact the tourism industry in the UK. Braun et al. (1999) examined the potential impact of climate change on vacation destination choices in the North and Baltic Seas in Germany. Maddison (2001) used the pooled travel cost technique to model the impact of climate change on international flows of British tourists, while Lise and Tol (2002) replicated this work in the context of Dutch leisure travellers. Most recently, Giannakopoulos (2004) presented predictions regarding the occurrence and severity of extreme climatic events for the Mediterranean region, while Morabito et al. (2004) compared emergency room admissions among visitors to Florence in 2002 and 2003. Becken (2004) considered Fijian tourism in the context of vulnerability, adaptation and mitigation. Research on climate change and winter tourism has focused on Canada and Europe predicting changes in the length of the winter skiing season (Lipski & McBoyle 1991) and more recently on activities, technology and a wider range of ski-tourism impacts (Koenig & Abegg 1997; Harrison, Winterbottom & Sheppard, 1999; Elasser & Messerli, 2001; Scott, McBoyle & Mills 2003).

The Caribbean remains an under-researched region; this is of great concern considering its heavy economic dependence on tourism and relative lack of viable economic alternatives. Review of a recent bibliography of work with the terms 'climate *or* weather' *and* 'tourism *or* recreation' appearing in the publication's title or keywords (covering all aspects of weather and climate, not just climate change) revealed that, of 118 academic articles (refereed and non-refereed) published since 1936, just one; Gable 1997, focused on the Caribbean region (Scott, Jones, & McBoyle, 2004). This provided a review of facts and issues, and proposed a series of governmental strategies, regarding climate change impacts on coastal areas throughout the entire Caribbean region, rather than presenting any empirical evidence based on scientific research in the area. Gable's call for further study of the potential impacts of climate change on an island-by-island basis appears to have gone unheeded.

## 2 METHODS

This primary research seeks to establish and evaluate the impacts of climate change on ecotourism and its stakeholders and their adaptive responses in the project area through a series of analyses: Regional Scenario Analysis; Localised Observed Impact Analysis; Needs Analysis and Evaluation of Care. The understanding and knowledge of the impacts of climate change on ecotourism and its stakeholders on the island gained through this research will: (i) inform the wider research community and contribute to the currently limited body of research; (ii) be transferred to the local stakeholders through an awareness raising and participatory educational forum and (iii) be available to Small Island State tourism stakeholders around the world aiming to build capacity and resilience.

Members of the project team have completed two out of three scheduled visits to the study area and a regional scenario analysis is being concluded across the broader project area, extending earlier more general desktop assessment work into the impacts of climate change on small island states. This analysis will provide an integrated study and appreciation of the potential and current impacts on the environment and biodiversity and their interactions with ecotourism in the area. Evaluations and observations include: sea level rise, coastal erosion, coastal geomorphology, precipitation levels, humidity and temperature. A localised impact analysis was conducted through: transects of the island and specific ecotourism sites; engagement and consultation with stakeholders and; an in-depth survey of tourism operators collecting both quantitative and qualitative data. Current and potential climate change impacts on ecotourism in the project area were assessed as were adaptation strategies currently used by operators. Analysis was conducted to evaluate the interactions with climate change and socio-economic and environmental implications of climate change as it relates to the industry sector throughout the island. Based upon the above analyses and survey results a process of needs analysis and an evaluation of care required is being conducted and an overview of strategies for adaptation and planned responses is currently being developed for dissemination. Account is being taken of a range of issues including tourism infrastructure, community priorities, water resources, public health, utilities and services.

## 3 RESULTS AND DISCUSSION

The combination of warming and sea level rise projected by the IPCC suggest a number of potentially devastating physical consequences for SIS such as those in the Caribbean. These include: inundation of land; changes in the frequency and intensity of tropical cyclones, and in storm-surge heights; more frequent flooding; and, increased coastal erosion. As a result, the existence and health of numerous vital elements of many SIS, both ecologically and socio-economically, are directly threatened, including: coral reefs; mangroves; sea-grasses; terrestrial and marine biodiversity; and, water supply (IPCC, 2001). These negative impacts are likely to be exacerbated by the location of the majority of the population, socioeconomic activities (in most cases dominated by tourism, agriculture, and fishing) and infrastructure of SIS within close proximity of the coast (IPCC, 2001; United Nations Economic and Social Council, 2004). Thus, as noted by the IPCC, "owing to their high vulnerability and low adaptive capacity to climate change, communities in small island states have legitimate concerns about their future on the basis of the past observational record and present climate model projections" (2001, p. 855). Unfortunately there is a significant lack of hard and quantifiable climate or geological data for the island, with little or no Tobagonian meteorological information existing over any extended periods of time. Additionally there is currently only one meteorological station on the island, which is located at the airport. Despite this, anecdotal evidence from the stakeholder consultations and observed evidence from transecting the island plus information on the Caribbean region and on small island states is being utilised in the regional scenario and localised impact analyses. These analyses are providing an appreciation of the potential and current impacts on the environment and biodiversity and their interactions with ecotourism in the area.

The localised impact analysis, stakeholder consultation and survey process was paradoxically both aided and disrupted by the arrival of 'Hurricane Ivan' in September 2004, which struck Tobago at the very time that the project team were on the island and conducting the first level of the project's fieldwork. The hurricane, whilst hampering the physical progress of the project for a number of days due to the damage to infrastructure and communications also served to significantly raise the level of interest and commitment of the stakeholders to the project. This increase in stakeholder sensitivity to the subject enabled the project team to gather a greater quantity of more detailed information, particularly through the structured questionnaire based survey. The stakeholder survey was conducted on a face to face basis with tourism operators of all kinds throughout the island, including accommodation providers, dive operators, street curio vendors, café-bar and restaurant operators, tour guides, attractions and activity tour operators. The survey resulted in a total of 94 respondents, representing a robust and meaningful sample size. With the project not yet concluded the processing and analysis phase has not yet been fully completed, however some results are outlined below. In addition to the formal survey, semi-structured interviews and unstructured consultations were conducted with a number of key actors on the island including: Chief Secretary the Rt. Hon. Orville London, Head of the Tobago House of Assembly (THA); Hon. Minister Neil Wilson, responsible for the THA Division of Tourism; the director and staff of the THA Division of Tourism; the director and staff of the Tobago Department of Natural Resources and the Environment and; the three key Non Government Organisations (NGOs) active on the island, the Buccoo Reef Trust, Environment Tobago, and the Travel Foundation.

Results of the research to date, display a number of areas of both interest and concern for the industry and the communities reliant upon it and the information derived has advanced our knowledge and understanding of the impacts of climate change on the tourism industry, communities and biodiversity in Tobago. Identified climate change impacts on tourism include: 'seasonality blurring'; a blurring of the demarcation lines governing seasonality, that is to say the 'wet' and the 'dry' seasons can no longer be depended on to be generally carrying respectively more and less precipitation and as a result the season are less definable. The unpredictability of rainfall coupled with extreme weather conditions has also been noted, not only did Tobago experience Hurricane Ivan in September 2004 (Tobago has historically been known as lying in the "Hurricane Free Zone") but also in November 2004 a ferocious storm struck the island rendering some of the main transport arteries impassable for many days. Damage to road fabric was still to be observed in March 2005, this storm and 'Ivan' also severely affected communications around the island, again still observable in March 2005. It should be noted that the storm in November left more damage and fatalities than 'Ivan' in September 2004. Both gradual and rapid impacts on tourism, attributable to climate change, have been recorded; landslides, destruction and alteration of habitats and biodiversity, beach and shoreline erosion, seafront infrastructure destruction and erosion and the weakening of hillsides and road fabrics.

Interim results from the stakeholder survey also show that approx 50% of tourism operators who responded stated that they are aware of the term "Adaptation to Climate Change", however only 28% said they have an environmental policy and just 18% of respondents hold a risk management policy. The tourism operators surveyed stated that the most important factors for their business were "Beaches", "Marine Life", "Clear Ocean Water", "Reliable Climate" and the "Environmental Performance of their Business". Approximately 40% of the respondents stated that they make an effort to reduce their environmental impact and they recycle waste. 47% of tourism operators stated that unforeseen changes in seasonality affect their business, 51% that beach /shoreline erosion affects their business, 37% that increased storm intensity and 42% that storm frequency affects their business, 40% cite interruption to energy supply as affecting their business. Water salinity does not appear to be a big problem as only 8.5% cited this factor. Adaptation strategies currently adopted by respondents include the following: improved building structures (45%), 48% have their own water storage, 34% replant trees and 30% attempt to protect the beach. Barriers to initiating adaptation or mitigation measures were identified as: lack of incentives by government (58%), lack of legislation that requires compliance (43%) and lack of finance (36%). 90% of respondents believe they need more information on climate change and its interactions with tourism.

## 5 CONCLUSION

The data collected and assimilated on the impacts of climate change on the tourism industry in Tobago and the climate readiness of the tourism stakeholders has increased our knowledge and understanding of the awareness and requirements of the stakeholders. These areas of knowledge will be extremely useful to the Tobagonian tourism industry stakeholders in their short term and long term planning when they consider issues such as; infrastructure, operations, product development, sales and marketing. Additionally observed changes and communication of the project's results will serve to build capacity within the industry and the communities reliant on tourism as an integral part of their livelihoods. Dissemination of the project's full results to the local Tobago tourism stakeholders will be conducted at a forum, organised in cooperation with the Tobago House of Assembly, Division of Tourism, will take place in November 2005. Invitees will include representatives of host communities, terrestrial and aquatic biodiversity managers, the private sector, ecotourism operators (management and staff), national, regional and local governmental agencies, policy makers, NGOs, and the University of the West Indies.

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# THERAPEUTIC CLIMATE PARK 'HOCHTAUNUS'

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## 1. INTRODUCTION

In Germany there is a long tradition in health resort climatology. More than 50 climate health resorts are operational in prevention, rehabilitation, and recreation. From the various exposure procedures to favourable climate conditions a combination with physical body exercise, such as walking in slightly cool and clean atmosphere is considered as most beneficial with respect to cardiovascular training and generally to improve health conditions. To make use of this therapeutic approach on the individual level climate trails must be available fulfilling distinct characteristics with regard to climate stimulus as well as to length and slope.
So a generally valid (within a low mountain range in mid-latitude regions) system of rating a trail was to be created as well as a mode of presenting the scientific results to the public.

## 2. METHODS

According to existing health resort standards an area of 20 km² of the Taunus-Mts., north-west of Frankfurt/M., Germany, was evaluated considering the basic therapeutical appropriateness of the climate. Then the model KURKLIM (Kurort-Klima-Modell [= health-resort climate model]) was applied which consists of three modules: a bioclimatological map, the rating of the climate trails and an advice-terminal. KURKLIM applies GIS techniques using digital terrain and landuse data in 10 m² resolution. The bioclimatological assessment is based on Percieved Temperature PT considerations (see Fig. 1) while the instationary thermal conditions along the climate trails are calculated with the help of IMEM (Instationäres Münchner Energiebilanzmodell [= Instationary Munich Energy-balance Model]). Real time meteorological data from two climate stations within the area are used online to derive up-to-date results. For easier understanding we established three classes of demand concerning physiology and bioclimatology (low = green, middle = yellow, high = red).
According to cartographic principles a map as well as diagrams, and a logogram were developed.

## 3. RESULTS

For the Therapeutic Climate Park 'Hochtaunus' 34 climate trails were established that start at 12 different entry points (see blue circles in Fig. 2). According to the created system of classification all three classes of demand can be found.

For graphically representing the most important tool is the map showing the net of climatic trails. They are embedded in the picture of landuse and height a.s.l. – the major impacts on bioclimatology as well as the obvious characters for orientation. Each trail is shown in its colour of classification.
Furthermore, the provided diagrams (see Fig. 3) display each trail individually with its slope, its length, and its demand in respect to physiological and bioclimatological work.
Last but not least the logogram shows the three components of climate therapy: a person walking along the trail influenced by the atmospheric situation (see Fig. 4).

For the public the results are presented by words and graphical elements on panels as well as in flyers and booklets. At the advice terminal real time information on weather conditions and individual recommendations which climate trail to take are available. Along the trails the visitor is leaded by the logogram.
To complete the project from science to public the Therapeutic Climate Park 'Hochtaunus' was opened for visitors on May, 30th 2005.

## 4. DISCUSSION

The development of a standardised evaluation method for climate trails allows to transfer the system to areas and landscapes of similar structure. This will support the establishment of climate trails in other climatologically favourable regions and will contribute to their acceptance by the public.

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## 6. ACKNOWLEDGEMENTS


We thank very much the Administrative District Hochtaunus and the Federal State of Hessen (Germany) for financial and logistic support of the project.

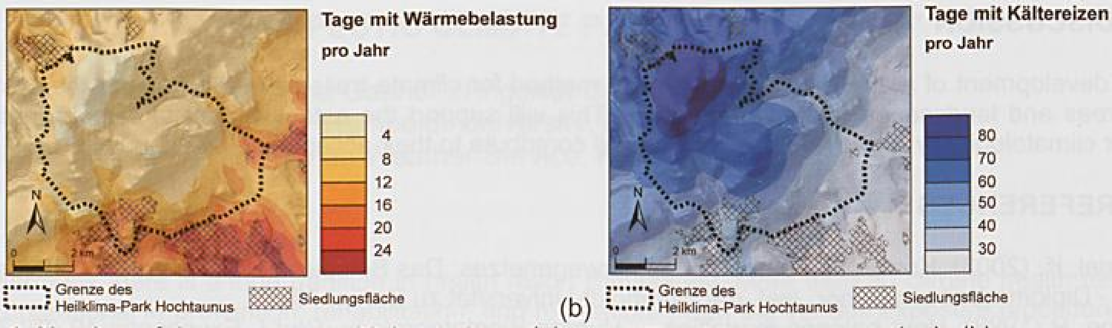


Fig. 1: Number of days per year with heat stress (a) and with cold stress respectively (b).

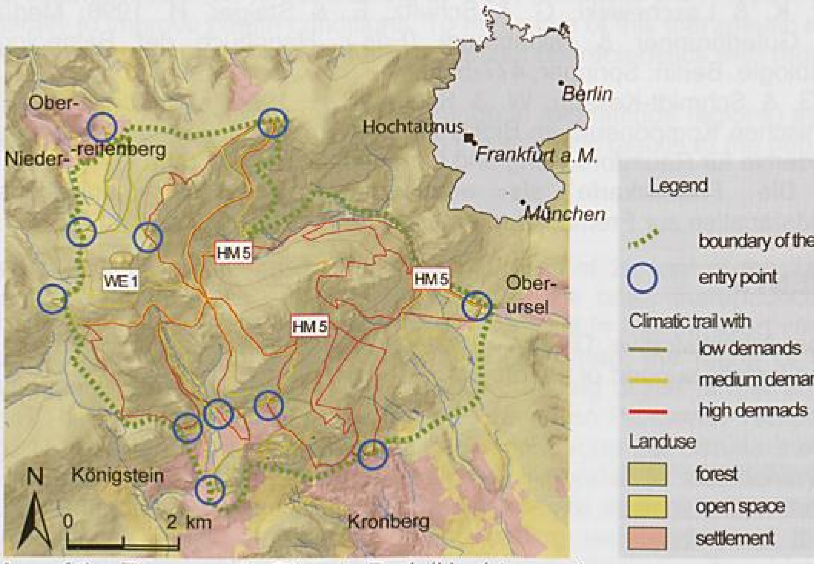


Fig. 2: Map of the Therapeutic Climate Park 'Hochtaunus'.

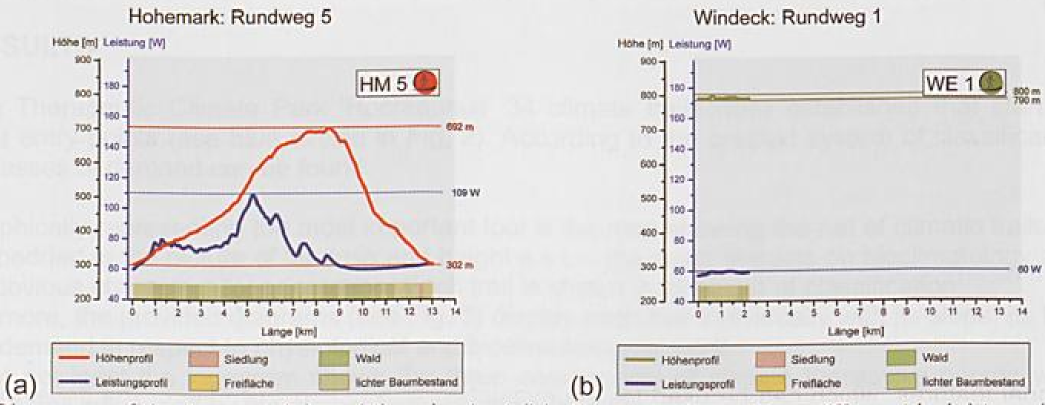


Fig. 3: Diagrams of the longest (a) and the shortest (b) climate trail reaching different height a.s.l.


Fig. 4: Logogram to lead the visitor along a climate trail of low (a), middle (b), and high (c) demand.

# APPLICATION OF RAYMAN FOR TOURISM AND CLIMATE INVESTIGATIONS

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## 1 INTRODUCTION

Because of the limited daily mobility of tourists, the most important effects of climate on tourism take place at the local level. These effects are significant for both the tourism industry and the owners of holiday homes themselves, but they are also of importance to the planning and design of tourism buildings, recreation facilities and a variety of other issues. With some modification, existing methods for assessing climate in human biometeorology and applied climatology can be applied for tourism climatology (Matzarakis et al., 2004).

For example, thermal indices that are derived from the energy balance of the human body can be of great use for tourism. Standard climate data, such as air temperature, air humidity and wind speed are required in order to calculate and quantify the thermal bioclimatic conditions. The most important environmental parameters for deriving modern thermal indices, however, are the short and long wave radiation (and the derived mean radiant temperature). These can be determined using special techniques. The RayMan model, which has been developed for urban climate studies, has a broader application spectrum, i.e. tourism climatology (Matzarakis et al., 2004). Further outputs as sunshine duration and shadow can be helpful in the design and structure of tourism facilities and recreation areas.

## 2 METHODS

The model „RayMan“ estimates the radiation fluxes and the effects of clouds and solid obstacles on short wave radiation fluxes (Fig. 1). The model, which takes complex structures into account, is suitable for usage and planning purposes in different local to regional levels (Fig. 2 left). The final output of this model is the calculated mean radiant temperature, which is required in the energy balance model for humans. Consequently, it is also required for the assessment of urban bioclimate and such thermal indices as Predicted Mean Vote (PMV), Physiologically Equivalent Temperature (PET) and Standard Effective Temperature (SET*). The model is developed based on the German VDI-Guidelines 3789, Part II: Environmental Meteorology, Interactions between Atmosphere and Surfaces; Calculation of the short- and long wave radiation and VDI-3787: Environmental Meteorology, Methods for the human-biometeorological evaluation of climate and air quality for the urban and regional planning at regional level. Part I: Climate. For the calculation of thermal indices based on the human energy balance, meteorological (air temperature, wind speed, air humidity and short and long wave radiation fluxes) and thermo physiological (activity and clothing) data are required. Data on air temperature, humidity and wind speed have to be available to run RayMan (Matzarakis et al., 1999).

Additional features, which can be used for the evaluation of a region's climate or the development of new tourism facilities are: a) calculation of sunshine duration with or without sky view factors; b) estimation of daily mean, max or total global radiation; and c) determination of shaded areas as outputs of RayMan.

When using the computer software "RayMan" (Fig. 2 left) an input window for urban structures (buildings, deciduous and coniferous trees) is provided. The possibility of free drawing and output of the horizon (natural or artificial) are included for the estimation of sky view factors (Fig. 2 right). The input of fish-eye-photographs for the calculation of sky view factors is also possible. The amount of clouds covering the sky can be included by free drawing while their impact on the radiation fluxes can be estimated (Matzarakis 2001).

In the field of applied climatology and humanbiometeorology the most important question about radiation properties on the micro scale is whether or not an object of interest is shaded. Hence, in the presented model shading by artificial and natural obstacles is included.

Horizon information (in particularly Sky View Factor) needs to be known to obtain sun paths (Fig. 3 left). Calculation of hourly, daily and monthly averages of sunshine duration, short wave and long wave radiation fluxes with and without topography and obstacles in urban structures can be carried out with *RayMan* (Fig. 3 left). Data can be entered through manual input of meteorological data or pre-existing files. The output is given in form of graphs and text data (Fig. 2 right, Fig. 3 left and right).

The model RayMan is developed based on the German VDI-Guidelines 3789, Part II (VDI 1994) and VDI-Guideline 3787 Part I (VDI 1998).

## 3 RESULTS AND DISCUSSION

The RayMan model can be applied for diverse applications. Results can even be produced without any meteorological or climatological data. Thus, it is of use for the quantification of sunshine duration at a given point with and without limited horizon (Fig. 3 and 3). Results on mean or total monthly sunshine duration can easily be presented for a variety of environments (Tab. 1 based on the building and vegetation data from Fig. 2 and 3). The calculations of a possible building and vegetation morphology presented in Table. 1 have been carried out for Freiburg, Germany, in a latitude of 49 °N.

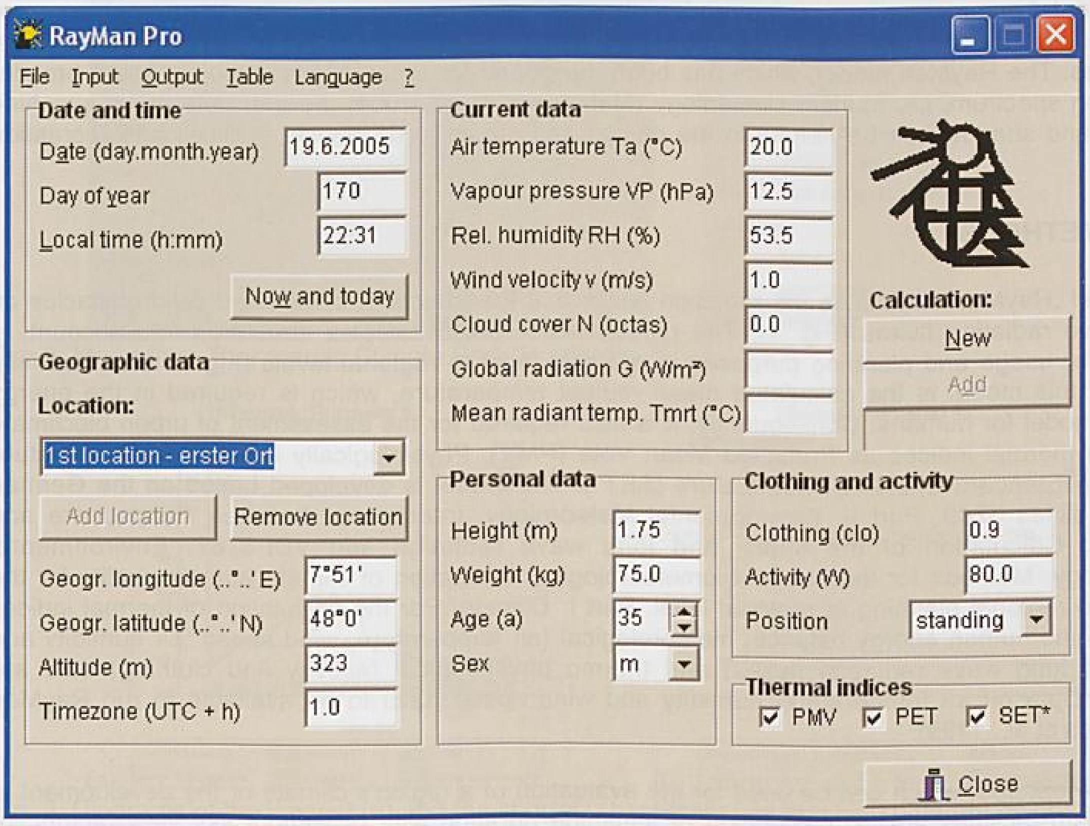
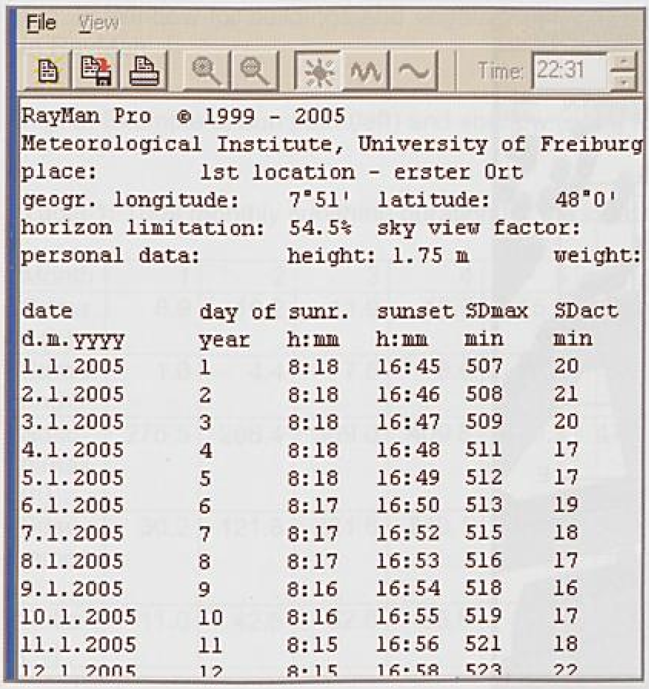



Fig: 1: Main window of RayMan

With existing meteorological or climatological data the RayMan model can be applied for the estimation of thermal indices such as PMV, PET or SET*, which are based on the human energy balance. Additionally, selected energy fluxes and thermo-physiological parameters, based on the MEMI (Munich Energy Balance Model for Individuals) can be derived. The thermal indices can be used for the quantification of the thermal conditions in several climate regions and environments. The derived output from MEMI can constitute the basis to understand and discover the energy fluxes for specific studies and analyses.



File View

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RayMan Pro © 1999 - 2005
Meteorological Institute, University of Freiburg
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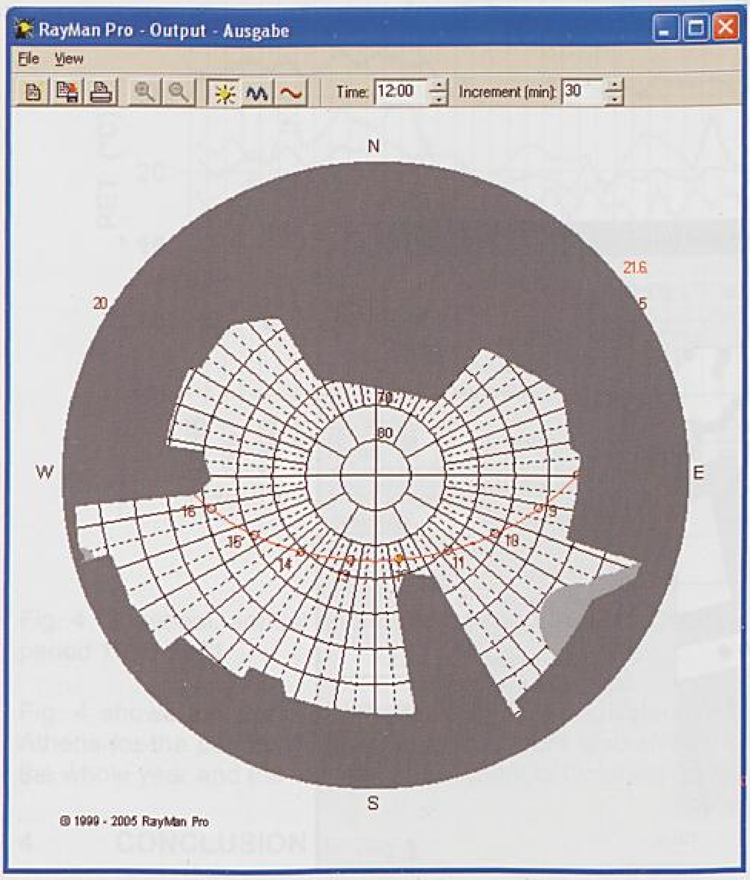
geogr. longitude: 7°51' latitude: 48°0'
horizon limitation: 54.5% sky view factor:
personal data: height: 1.75 m weight:

| date d.m.yyyy | day of year | sunr. h:mm | sunset h:mm | SDmax min | SDact min |
|---|---|---|---|---|---|
| 1.1.2005 | 1 | 8:18 | 16:45 | 507 | 20 |
| 2.1.2005 | 2 | 8:18 | 16:46 | 508 | 21 |
| 3.1.2005 | 3 | 8:18 | 16:47 | 509 | 20 |
| 4.1.2005 | 4 | 8:18 | 16:48 | 511 | 17 |
| 5.1.2005 | 5 | 8:18 | 16:49 | 512 | 17 |
| 6.1.2005 | 6 | 8:17 | 16:50 | 513 | 19 |
| 7.1.2005 | 7 | 8:17 | 16:52 | 515 | 18 |
| 8.1.2005 | 8 | 8:17 | 16:53 | 516 | 17 |
| 9.1.2005 | 9 | 8:16 | 16:54 | 518 | 16 |
| 10.1.2005 | 10 | 8:16 | 16:55 | 519 | 17 |
| 11.1.2005 | 11 | 8:15 | 16:56 | 521 | 18 |
| 12.1.2005 | 12 | 8:15 | 16:58 | 523 | 22 |




RayMan Pro - Output - Ausgabe
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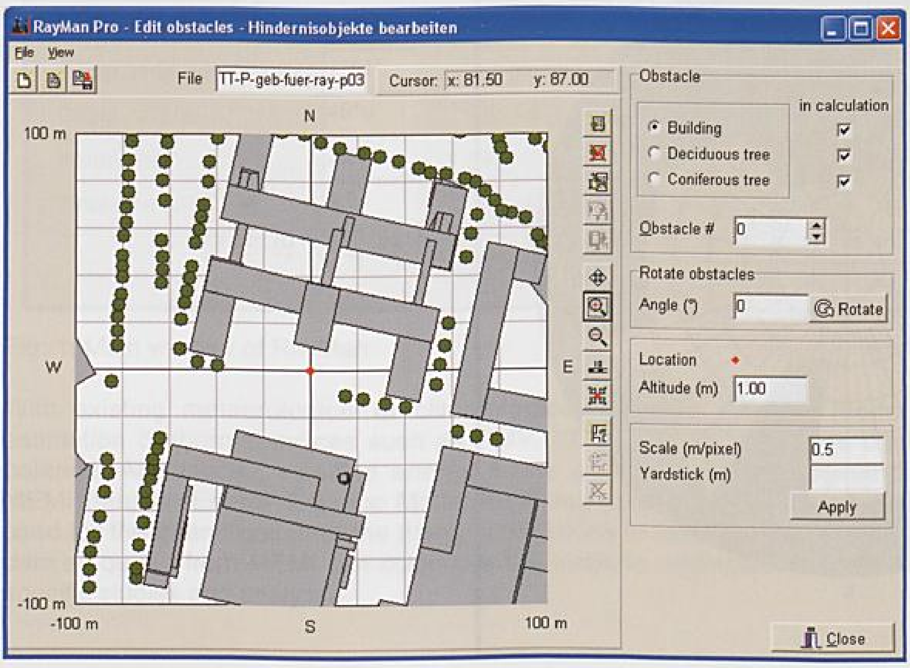
RayMan Pro - Edit obstacles - Hindernisobjekte bearbeiten
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Cursor: x: 81.50
y: 87.00
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-100 m
-100 m
S
100 m
Obstacle
in calculation
Building
Deciduous tree
Coniferous tree
Obstacle #
0
Rotate obstacles
Angle (°)
0
Rotate
Location
Altitude (m)
1.00
Scale (m/pixel)
0.5
Yardstick (m)
Apply
Close

Fig: 2: Window for buildings and vegetation input (left) and data output for SVF and sunshine duration in RayMan

Fig: 3: Example of sun path (left) and shadow (right) for June 21 for a complex environment

Table 1: Total monthly sunshine duration for the location from fig. 2

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sdmax (h) | 8.9 | 10.2 | 11.9 | 13.7 | 15.2 | 16.0 | 15.6 | 14.3 | 12.6 | 10.9 | 9.3 | 8.5 |
| Sdmean(h) | 1.0 | 4.4 | 7.5 | 8.0 | 8.3 | 8.6 | 8.5 | 7.8 | 8.2 | 5.7 | 1.9 | 0.3 |
| Sdsummax (h) | 275.5 | 286.4 | 369.0 | 409.8 | 470.5 | 479.3 | 483.6 | 442.6 | 377.9 | 336.5 | 278.9 | 262.1 |
| Sdsummean | 30.2 | 121.8 | 231.8 | 240.1 | 256.7 | 257.6 | 264.5 | 243.3 | 245.2 | 175.7 | 58.5 | 8.8 |
| Ratio (%) | 11.0 | 42.5 | 62.8 | 58.6 | 54.6 | 53.7 | 54.7 | 55.0 | 64.9 | 52.2 | 21.0 | 3.4 |

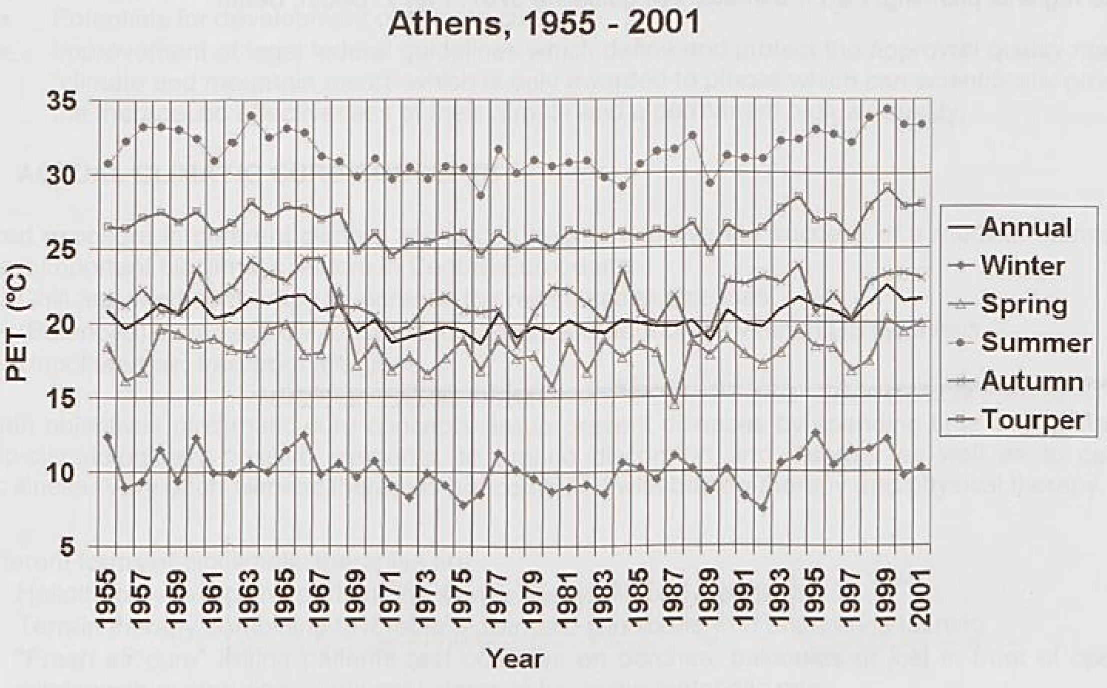


Fig. 4: Seasonal, annual and tourism period (April to October) trend of PET for Athens, Greece for the period 1955-2001.

Fig. 4 shows the trend of the Physiological Equivalent Temperature (PET) based on daily data for Athens for the period 1955 – 2001. The figure also shows calculations of PET for individual seasons, the whole year and the tourism period (April to October) based on monthly means.

## 4 CONCLUSION

The presented model provides diverse opportunities in applied climatology and also tourism climatology. Useful information can be derived in order to create climate oriented dwellings and facilities for tourism resorts. It can also be used for the calculation of shade to be provided by special devices in tourism areas and resorts in order to create more comfortable thermal conditions with protection from direct sunlight for recreational users and visitors.

Form the human-biometeorology point of view the offered thermal indices can describe and quantify not only mean conditions but also extremes like heat waves.

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# AUSTRIAN CLIMATE AND HEALTH TOURISM INITIATIVE (ACTIVE)

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## 1 INTRODUCTION

According to its geographical situation Austria owns a multitude of regions with favourable bioclimatic conditions. Unfortunately in many cases this is not used in an adequate way as in the neighbouring countries. Therefore the Federal Ministry of Economics and Labour of the Republic of Austria initiated the project ACTIVE (**A**ustrian **C**limate and Health **T**ourism **I**nitiati**ve**) with the goal

*To provide the scientific bases for the improved use of the natural resource "climate" in Austria* (Koch et al., 2005).

By interdisciplinary co-operation between physicians, climatologists and tourism authorities the following topics should be analysed:

- State of art of climatic cure concepts?
- Current offer of climate cure concepts in Austria and in the neighbouring countries
- Human-bioclimatic conditions in Austria
- Specific climate treatment at Austrian climate and mountain resorts
- Potentials for development of climate cures
- Improvement of legal federal guidelines which define and protect the approved quality mark "climate and mountain resort" which is only awarded to places which can scientifically prove the therapeutic effectiveness of their climate and a permanent high air quality.

## 2 ACTUAL CLIMATIC CURE CONCEPTS

Balanced exposure in different climate zones can help to improve the success of a medical therapy. The most important bioclimatic factors in Central Europe are

- Chill and wind as therapy to increase the resistance to diseases
- (Balanced) increased UV radiation for the amendment of the vitamin D3 synthesis
- Unpolluted air, free from allergens.

The main objectives of climatic cure concepts are to prevent diseases by spending time in a climate with bio-climatologically positive elements, to amend discomfort and disorder as well as to cure chronic illness. Very often climatic therapies are combined with balneo-therapy and physical therapy.

The different forms of bioclimatic therapies are

- Heliotherapy: exposing parts of the skin or the whole body to the sun
- Terrain therapy combining favorable bioclimatic conditions with endurance training
- "Fresh air cure" letting patients rest outdoors on porches, balconies or just in front of open windows thus enduring a light cold stress to lower the metabolic rate.

## 3 THE HUMAN- BIOCLIMATE IN AUSTRIA

Human organism has to deal permanently with its environment and thus with the atmosphere as a part of it. Human biometeorology and human climatology are the sciences that describe that relationship.

### 3.1 Thermal environment

One of the main part of the environment affecting humans is the thermal complex including all meteorological elements that have an effect on the human thermo-physiology, i.e. air-temperature, humidity, wind-speed as well as short - and long-wave radiation from the entire surrounding area. (Jendritzky et al., 1990).

### 3.2 Thermo-physiological assessment of Austria

Originally simple climatic indices were used for the assessment of thermal comfort, e.g. heat stress index, Discomfort Index (Thom, 1959) or Wind-chill index (Steadman, 1971). But these indices consider only a part of the relevant meteorological parameters and do not account at all for thermal physiology, e.g., they do not include the effects of short and long wave radiation fluxes as they are generally not available in climate records.

On the basis of this understanding since about 30 years heat balance models of the human body have gained acceptance in the field of assessment the thermal comfort. The heat balance equation of the human body takes into account the metabolic rate (internal energy production by oxidation of food), the physical work output, the net radiation of the body, the convective heat flow, the latent heat flow to evaporate water into water vapour diffusing through the skin, the sum of heat flows for heating and humidifying the inspired air, the heat flow due to evaporation of sweat and the storage heat flow for heating or cooling the body mass.

All the required components of the above equation can be calculated using synoptic/climatological and astronomical data (VDI, 1998, Matzarakis et al, 2000) plus physiological parameter. The full application of the energy balance equation of the human body gives detailed information on the effect of the thermal environment on humans (VDI, 1998, Höppe, 1999). The necessary meteorological inputs are air temperature, air humidity, wind speed, short and long wave radiation fluxes as well as physiological parameters as sex, weight-height-skin surface, activity level, and clothing factor. From the meteorological input data the radiant fluxes are most difficult to deal with, because measuring data are more often than not available. In this work we used the physiologically equivalent Temperature (PET) (VDI, 1998). The advantage of PET compared to other thermal indices also obtained from the human energy balance is the widely known unit °C. In addition PET can be used all year round and in different climates. Here the internal heat production was set to 80 W and the heat transfer resistance of the clothing to 0.9 clo (Matzarakis and Mayer, 1996).

The assessment in terms of PET (monthly means or frequency of extremes) is transferred into the area using GIS-techniques to construct bioclimatic maps. The resolution of the maps is 1 km for Austria (Fig. 1, example for amount of days with PET > 35 °C).

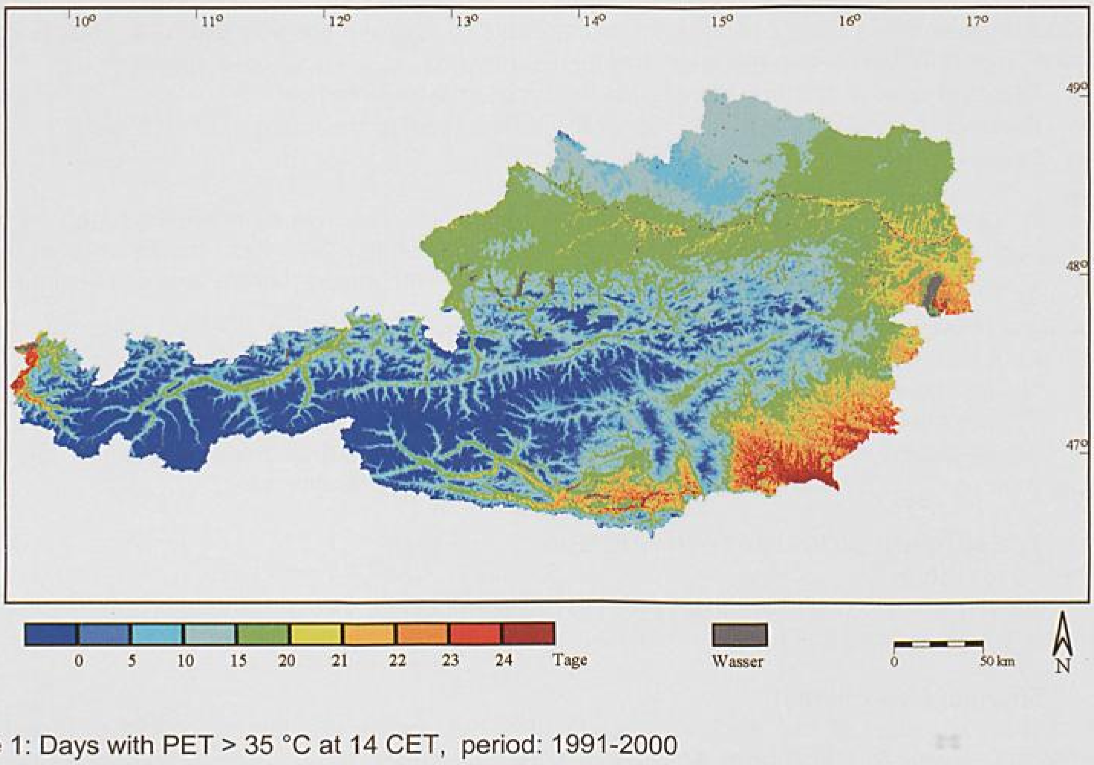



Figure 1: Days with PET > 35 °C at 14 CET, period: 1991-2000

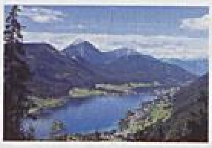
## 4 DESCRIPTION OF AUSTRIAN CLIMATIC HEALTH AND MOUNTAIN RESORTS

At present there are 40 climatic health and mountain resorts in Austria and many other sites are hoping be awarded this state-approved quality mark. Within ACTIVE a brochure was produced that describes each of the health and mountain resorts with its specific bioclimate with special emphasis on the thermal complex and gives an overview of the offered therapies and the recommended medical (see following example of the mountain resort Weissensee) (Koch et al., 2005).

## Weissensee

**Location**

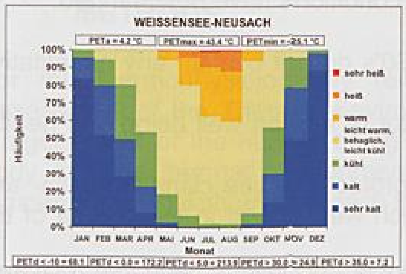
Height from 930 to 2221m, centre 945m a.s.l., imbedded in the Gailtaler Alps



**Climatic health resort**

Carinthia

Bioclimatic conditions




Thermal component
Weak strong or extreme grade of hot thermal perception (PET>35°) mean value 7 d/a, in the months May, June, July, August and September more than 50 % of all days are comfortable (see figure). Cold stress on more than 50 % of all days in January, February and December can be alleviated by increasing the personal stages of activity or by wearing thicker clothes.

<u>Thermal sensation:</u>
Monthly frequencies of certain thermal perceptions in% (100% correspond all days of the month). Basis of classification: Physiologically Equivalent Temperature (PET), 1991-2000

<u>Wind:</u>
Main wind direction: Northwest and east, in the summer months thermal wind system with forced ventilation during daytime, during the night and the winter months mostly calm, low frequency (<7 days) of strong winds( >Bf 6) low frequency of Foehnwind (<5 days)

Climate station:

13°19'00" eastern longitude,

46°43'00" northern latitude

<u>Precipitation:</u>
Mean yearly sum 1260 mm on 106 days, 24 days with snowfall and 108 days with snow cover

<u>Air pressure</u>
Mean annual value between 912 hPa in 900 m und 767 hPa in 2300 m asl

<u>Sunshine, cloudiness, fog:</u>
Yearly sum 1780 hours, 110 days with no sun, 25 days with fog

**Legal indications**

Prämorbiede Erholungsbedürftigkeit aller Altersstufen: Vorbeugung von Krankheiten durch Abhärtungskuren, Herstellung des körperlichen und seelischen Gleichgewichtes, Beseitigung von Zivilisationsschäden; Genesungsaufenthalte nach Krankheiten und Operationen; chronische Atemwegserkrankungen, insbesondere Folgezustände nach Exposition in luftverschmutzten Regionen, funktionelle Herz-Kreislauf-Störungen (Hypotonie, labile Hypertonie, funktionelle Durchblutungsstörungen), neurovegetative Regulationsstörungen (nervöse Erschöpfungszustände, Streßfolgen), Auswirkungen von Übergewicht, Bewegungsmangel und Fehlbelastung auf den Stütz- und Bewegungsapparat, Wiederherstellung der körperlichen Leistungsfähigkeit

**ACTIVE Proposal for indications**

Rekonvaleszenz
Vegetative Regulationsstörungen
Chronisches Erschöpfungssyndrom einschließlich Schlafstörungen
Chronische Erkrankungen der Atemwege
Herz- und Gefäßerkrankungen

**Additional therapies**

Massagen, Programme und Kurse (Autogenes Training, Yoga, Die fünf Tibeter, Gesunde Wirbelsäule, Figurgymnastik, Wagyment, Streching , ...) durchgeführt von staatlich geprüften Sportlehrern, Gesundheitstherapeuten und Wellnesstrainern. Bewegen im Heilklima – verschiedene Höhenlagen und verschiedene Klimareize. 140 km markierte Wanderwege, 80 km Mountainbike-Strecken, 12 markierte Laufparcours, 8 Nordic Walking Routen. Im Winter: Winterwandern, Eislaufen, Laufen und Nordic Walking

**Health care**

Health doctors with pharmacies

**Lodging**

Hotels/accomodations: 4000 beds

**Further Information**

Weissensee Information

A-9762 Weissensee
Techendorf 78
Tel.: +43 (0) 47 13 / 22 20
Fax: +43 (0) 47 13 / 22 20 44
e-mail: info@weissensee.com

**Homepage**

http://www.weissensee.com

Figure 2: Climate health resort description of Weissensee (Koch et al., 2005)

## 5 RESPECTS FOR NEW LEGAL REGULATIONS

Since 1958 there exists in Austria a legal basis to define and protect the title climatic health- and mountain resort. Because Austria is a federal republic with nine provinces there are federal legal guidelines which define the principles and provincial enforcement laws which describe the details of acquiring and maintaining the title of a special climatic region. In these legal specifications there are three major points concerning meteorology:

I. Existence of natural, scientifically approved climatic conditions to cure diseases or stimulate recuperation; e.g. the lack of severe weather conditions like long lasting fog, little sunshine, frequent sultriness, high cooling power.
II. Running a climate station with registration of several meteorological parameters like air-temperature, air humidity, sunshine duration, air pressure, wind speed, precipitation.
III. Every 10 years an expert opinion has to prove the climatic conditions have not changed.

That means the specifications which were issued in the early 1960's do not contain any quantitative threshold of meteorological or air quality parameter.
Because the air quality especially has become a determining factor of human well being and health, the lack of any threshold in the laws is a big disadvantage.
In the study a proposal of a new legal regulation to define and protect the title climatic health- and mountain resort is presented. Several quantitative thresholds which were found in the course of the study are proposed.

***Acknowledgement:*** *This study is part of the Austrian Climate and Tourism Initiative (ACTIVE) funded by the Austrian Federal Ministry of Economy and Labour.*

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# MACRO- AND MESOSCALE MAPS OF THE THERMAL ENVIRONMENT

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## 1 INTRODUCTION

For numerous applications in human biometeorology such as precautionary planning, tourism, and climate impact research the spatial presentation of the thermal environment in form of bioclimate maps is required. Scale, resolution and content of such maps depend on the specific problem.

## 2 METHODS

For the thermophysiologically relevant assessment of climate data **HeRATE** (**He**alth **R**elated **A**ssessment of the **T**hermal **E**nvironment) (Koppe, 2005) was available. **HeRATE** combines a heat budget model of the human being that takes all mechanism of heat exchange between the human body and the thermal environment into account (Klima-Michel-model with the outcome perceived temperature PT) with an approach that considers short-term adaptation.

**HeRATE** has been applied to the following tasks:

(1) Bioclimate maps of Europe: The analysis in terms of PT is based on the measured and observed meteorological data 1971 – 2000 of 921 first order weather stations across Europe and the adjacent countries around the Mediterranean sea. For the computation of the maps GIS-techniques have been used based on the topography data set of NOAA in a 5 minutes resolution.

(2) Global scale: The required meteorological input data are obtained from the results of climate simulation models with coupled AOGCMs. Here the time-slice experiment with ECHAM4 in T106-resolution (ca. 100 km in middle latitudes) has been used.

## 3 RESULTS

The European maps show clearly the effects of the different climate factors, such as latitude, altitude, distance to the sea (Fig.1 a,b). These maps present unfortunately still the result based on fixed thresholds. However. compared to this classical approach of fixed thresholds due to the consideration of adaptation to the local climate the differences in bioclimate in terms of the frequency of extreme thermal conditions will be smaller between the areas (will be presented in the poster).

The comparison of the global maps 1971 – 1980 (control run, assumed as status-quo) and future climate 2041 – 2050 for "business-as-usual" shows clear differences across the globe in the climate change effect in terms of PT.

## 4 DISCUSSION

The application of **HeRATE** obviously presents a progress compared to current procedures because the adaptation approch automatically adjusts threshold to the local climate. The complete approach provides therefore a useful tool that can be applied to various questions. In particular the climate change scenario makes clear in which areas extreme thermal conditions will increase with additional health impacts. This would require appropriate adaptation measures in order to reduce the vulnerability of the population. However, the confidence in climate change simulations is still small on a regional scale.

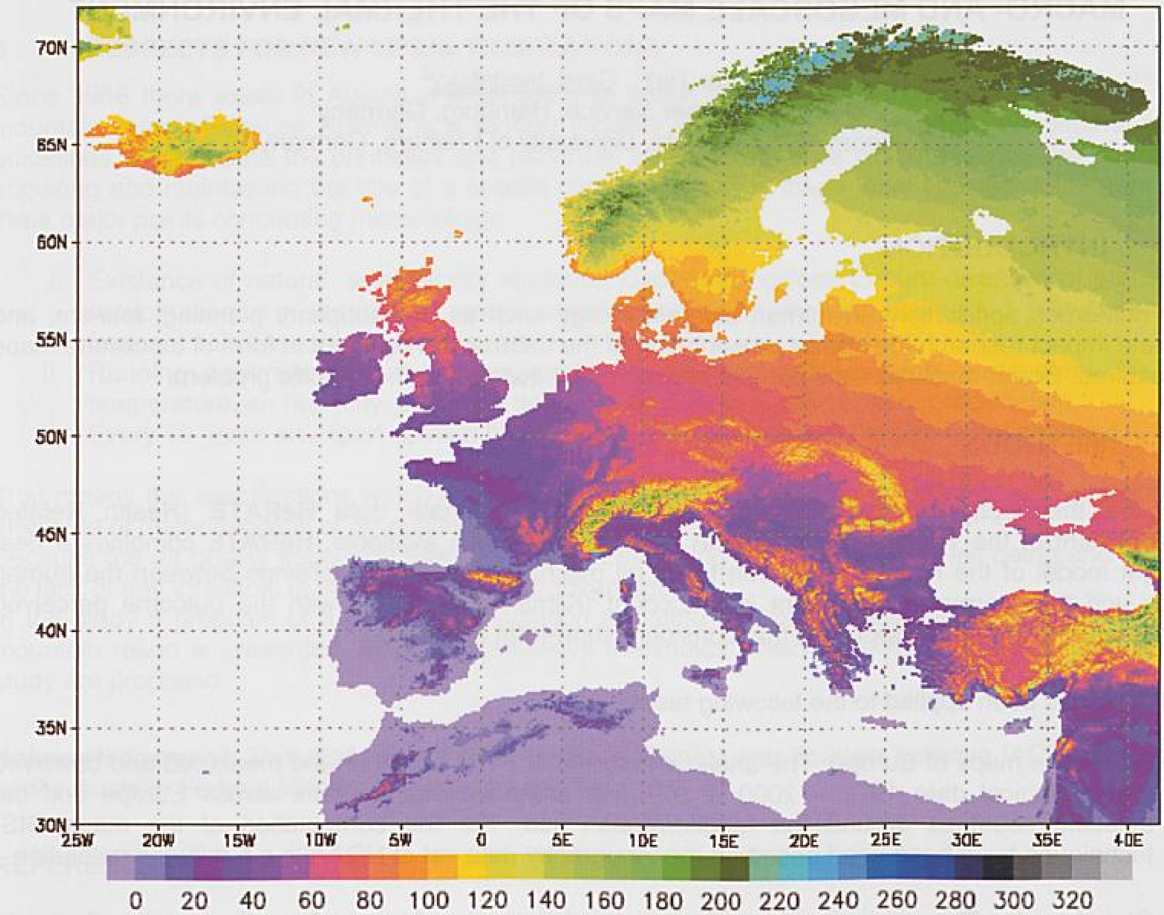
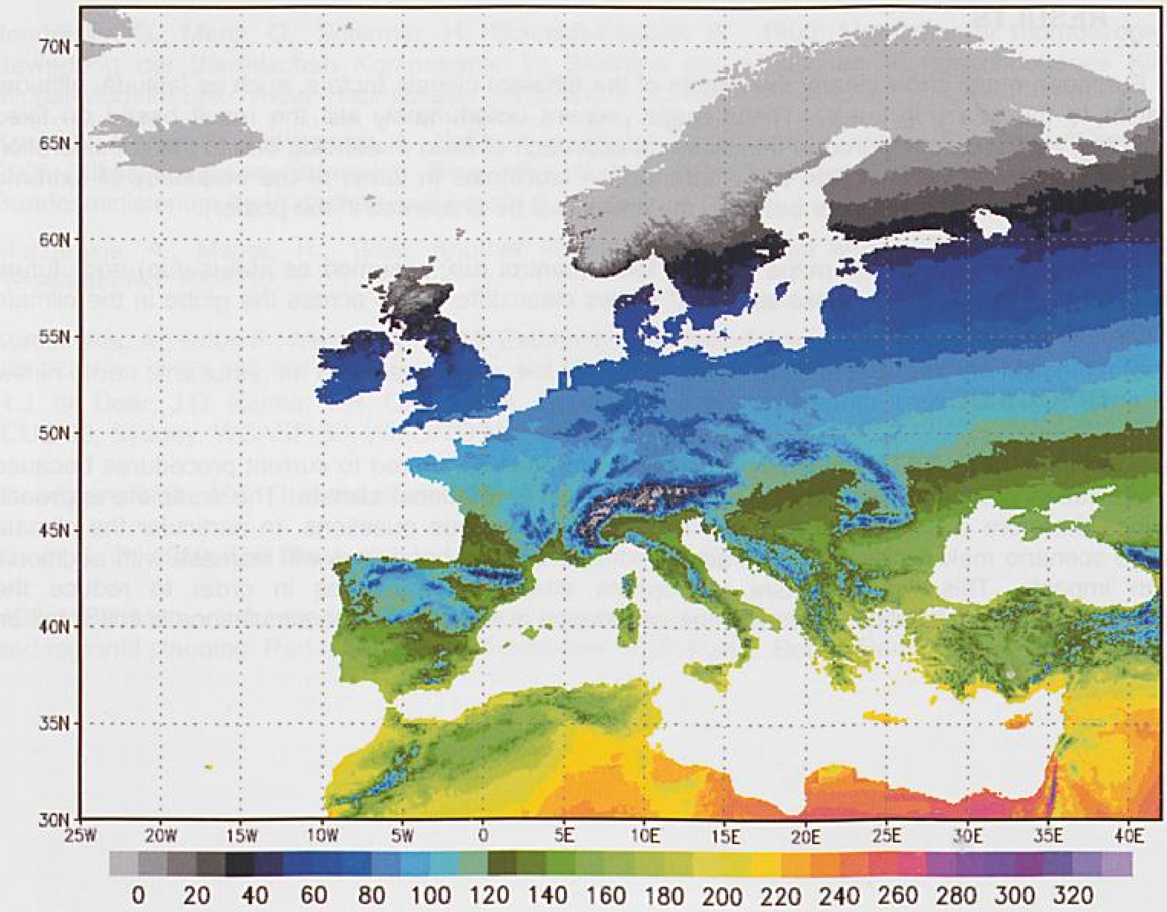



Figure 1 a,b Frequency of days with cold stress (above) and heat load (below), 1971-2000 (here still without the acclimatisation approach of HeRATE)



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# COMPARISON OF CLIMATE AND SYNOP MEASUREMENTS FOR THE BIOCLIMATE OF AUSTRIA

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## 1 INTRODUCTION

The project Austrian Climate and Health Tourism Initiative (ACTIVE) was aimed to improve the utilization of climate resources for tourism especially health tourism (Koch et al., 2005). The data used come from the climate-data archive (only Austrian stations) of the Central Institute of Meteorology and Geodynamics (ZAMG) as well as from the synoptic data archive including Austrian records and records from the neighbouring countries. The data cover the period from 1. January 1996 until 31. December 2000 with daily measurements of 201 climate stations and 278 synoptic stations. We emphasised the comparison of these two station and data types. The available meteorological parameters were: air temperature (°C), relative humidity (%), wind velocity (m/s) and cloud cover. Cloud cover is given in octas for synoptic and in 1/10 for climate stations. Climate data is measured at 7, 14 and 19 local mean time while synoptic observation hours are 6, 12, and 18 UTC. Aim of this analysis was to detect the differences in the input data, which are required for the calculation of Physiological Equivalent Temperature (PET) and their effects on PET.

## 2 METHODS

For the evaluation of the thermal component of humans, well-established methods of human-biometeorology have been applied. From the thermal indices PMV, PET and SET*, which are part of the calculation of the RayMan model (Matzarakis et al, 2000), we selected here PET, which is based on the Energy Balance of Humans as well all the other above mentioned thermal indices. For the calculation of PET air temperature ($T_a$), vapour pressure ($V_P$), wind velocity (v), as well as short and long-wave radiant fluxes from the thermal environment to the human body as the mean radiant temperature ($T_{mrt}$) are required (Höppe, 1984, 1993, 1999). PET is based on the calculation of Energy Balance of Humans for outdoor conditions (Höppe, 1993). According to the definition of PET the calculations have been run for a male, 35 years, height of 1,75 m and a weight of 75 kg. Mean radiant temperature and PET have been calculated by RayMan (Matzarakis et al., 2000).

201 stations from the Austrian climate network and 278 stations from the synoptic network in Austria and nearby countries for the calculation of PET have been used. The comparison was done for 19 locations, which have a climate and a synoptic station. Based on daily data at midday, monthly means were calculated. This time of the day is most important for tourists and for research, because it represents the most favourable thermal conditions during winter and the "worst" conditions during summer. Then the differences between the meteorological parameters in the different types of data sets have been analysed.

To visualize, the differences for the whole area of Austria, multiple linear regression analysis has been applied, which allows the construction of maps based on longitude, latitude, elevation, aspect, slope and land use. The grid resolution is 1 km x 1 km. For each monthly map of PET and the differences between climate and synop data have been constructed.

## 3 RESULTS

Figure 1, 2 and 3 show the monthly mean values of the air temperature, mean radiant temperature and PET for 19 locations with a climate (14 local mean time) and synoptic (12 UTC) observations. The air temperature of the synoptic stations is in every month lower than at the climate stations. On the other hand the mean radiant temperature of the climate stations is always smaller than at the synoptic stations. Climate stations show during the most time of the year higher PET values than synoptic stations. Only in December the 12 UTC PET value is higher than the 14 mean local time value, from January to March there are only slight differences.

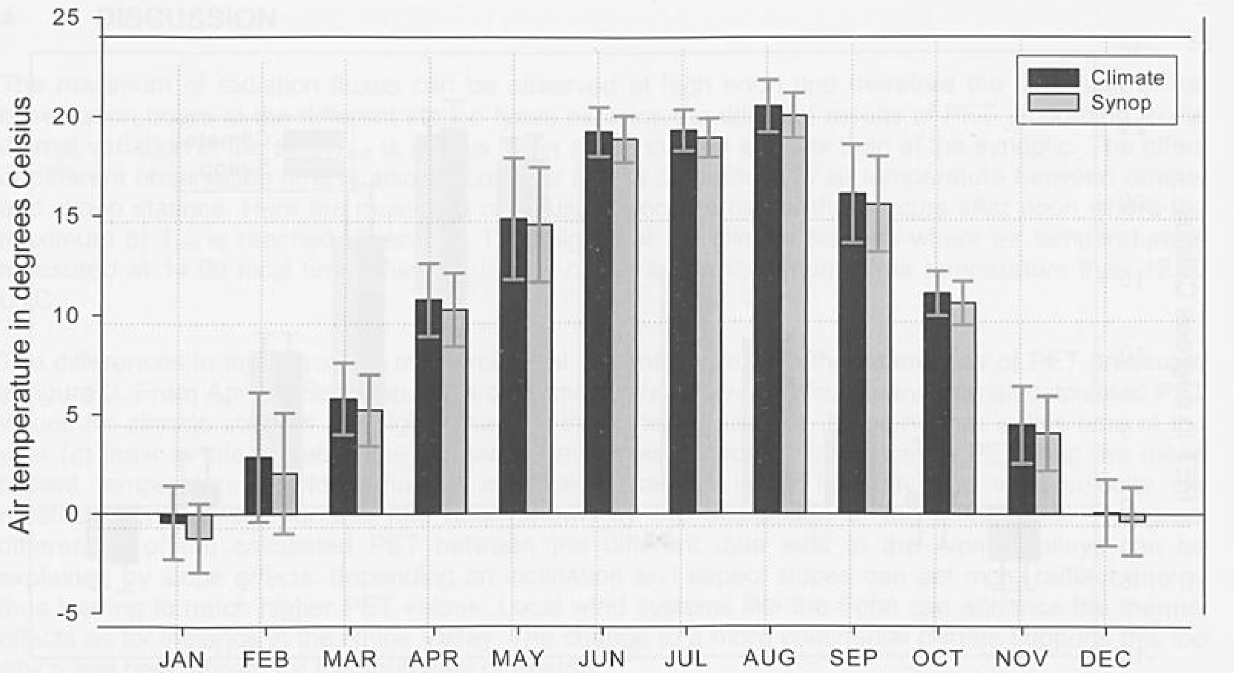


**Figure 1.** Monthly mean values of air temperature for 19 locations with climate (14 local mean time) and synoptic (12 UTC) stations

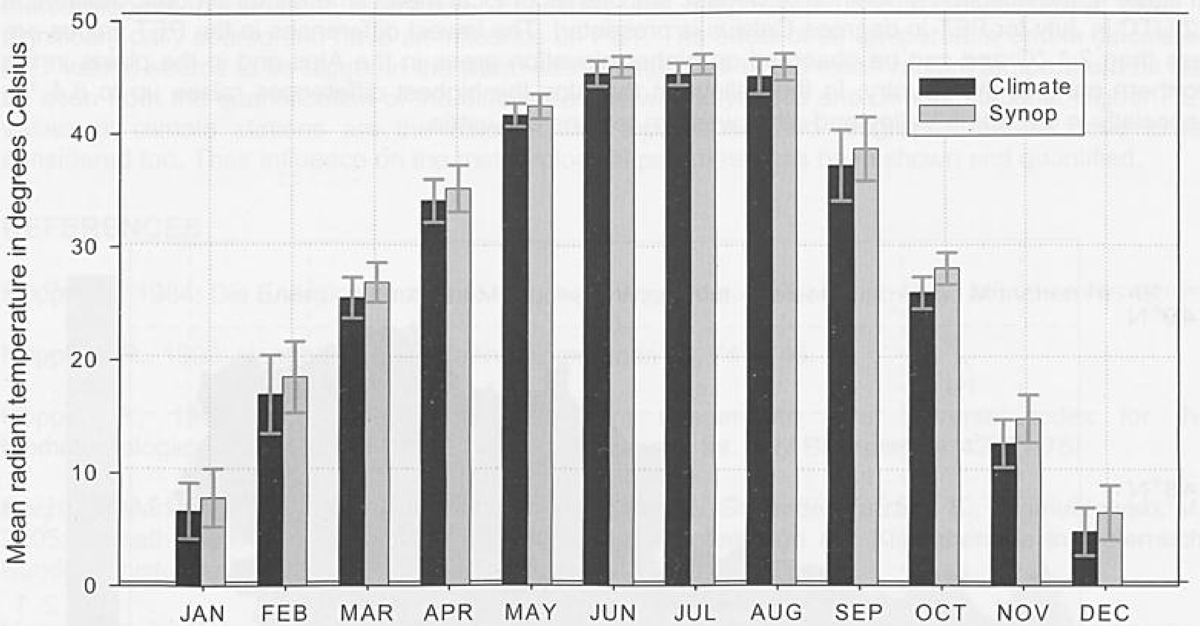


**Figure 2.** Monthly mean values of mean radiant temperature for 19 locations with climate (14 local mean time) and synoptic (12 UTC) stations

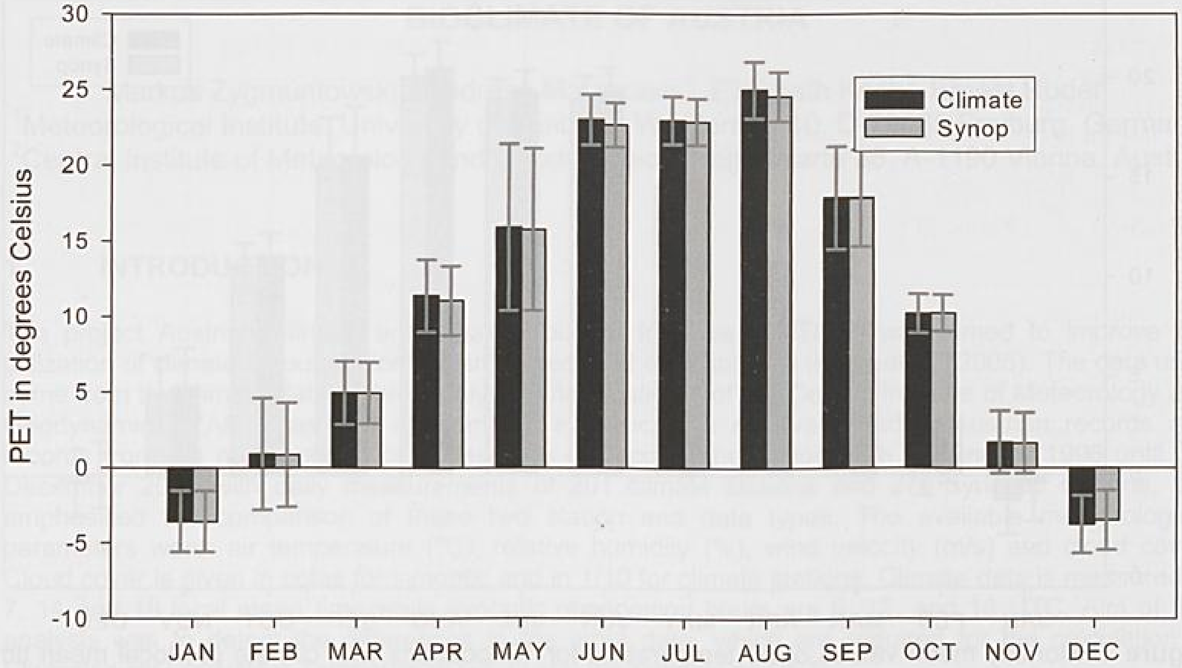


**Figure 3.** Monthly mean values of PET for 19 locations with climate (14 local mean time) and synoptic (12 UTC) stations

In figure 4, the absolute difference of climatic stations at 14 local mean time minus synoptic stations at 12 UTC in July for PET in degrees Celsius is presented. The lowest differences in the PET values are less than 2.1 °C and can be observed on higher elevation areas in the Alps and in the plains in the northern parts of the country. In the valleys in the Alps the highest differences raises up to 6.4 °C, especially in the Rhine Valley and other western regions of Austria.

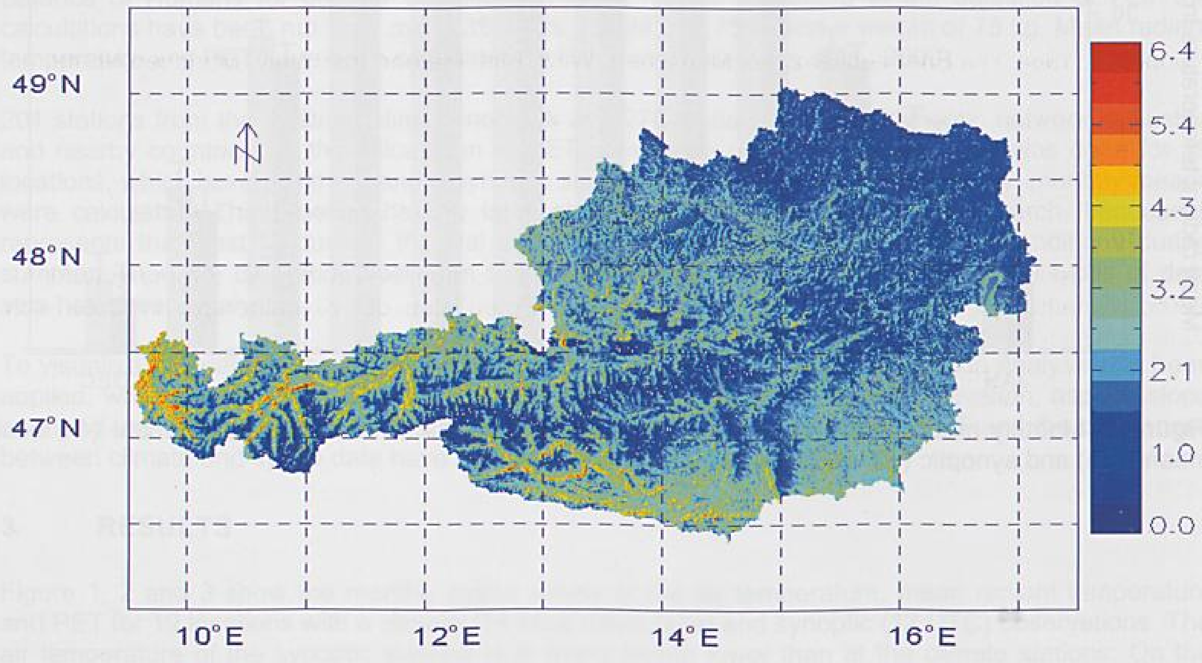


**Figure 4.** Absolute difference of PET in degrees Celsius between climatie (14 local mean time) and synoptic (12 UTC) station-data in July for PET (1996-2000)

## 4 DISCUSSION

The maximum of radiation fluxes can be observed at high noon and therefore the time shift of the observation hours at the different station types explains the different results of PET. According to the diurnal variation of the sun, $T_{mrt}$ is always lower at the climate stations than at the synoptic. The effect of different observation time is also responsible for the differences in air temperature between climate and synop stations. Here the maximum of $T_a$ usually occurs two or three hours after noon where the maximum of $T_{mrt}$ is reached. Therefore $T_a$ is higher at the climate stations where air temperature is measured at 14.00 local time which is usually closer to the maximum of air temperature than 12.00 UTC.

The differences in the described meteorological parameters lead to the differences of PET presented in figure 3. From April to September the differences are positive which means that all calculated PET values for climate stations are higher than for the synoptic stations. It seems that in this time of the year (at least in this climate zone) air temperature has a stronger influence on PET than the mean radiant temperature provided that no significant changes in air humidity and wind velocity are recorded. One reason for this has been shown by the distribution of the differences. The great differences of the calculated PET between the different data sets in the Alpine valleys can be explained by slope effects: depending on inclination and aspect slopes can get more radiant energy thus leading to much higher PET values. Local wind systems like the Föhn can enhance the thermal effects as for instance in the Rhine Valley. The change to a more continental climate supports this too which has been shown for the southeast of Austria.

## 5 CONCLUSION

The different observation times of climate and synoptic stations lead to differences in the meteorological parameters measured. Especially air temperature and radiative fluxes have a significant daily course and have an influence on PET. The effect of air temperature on the calculated PET values seems to be bigger in the warm season than that of the mean radiant temperature as can be seen from the quantification of the differences between synoptic and climate stations. Higher PET values at climate stations are the result. Other topographic and orographic effects have to be considered too. Their influence on the meteorological parameter has been shown and quantified.

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# UV Radiation

## GSE PROMOTE: SURFACE UV RADIATION

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### INTRODUCTION

In recognition of the mature state of the use of satellite data to better understand some aspects of the atmosphere, the European Space Agency has elected to fund the PROMOTE project as a part of its Global Monitoring for Environment and Security (GMES) Service Element (GSE) programme. The focus is on the operational delivery of services and products related to Air Quality, Stratospheric Ozone and Surface Ultraviolet Radiation. The Montreal Protocol and UNCED Agenda 21 are the primary policy drivers for the PROMOTE UV Services. The services support governmental agencies and scientists to assess various UV related effects on people and ecosystems. In this context PROMOTE aims at UV forecast services and UV monitoring services.

### METHODS

The Surface Ultraviolet Radiation service line will address past, present, and forecasts of various variables using information derived from satellite data and models. The general public is provided with health related UV information from a global to a local and individualised scale. The UV forecast s ervices provide daily forecasts of UV index, UV dose and sunburn time on global and regional scale. The UV monitoring services provide long-term time series of surface UV index and UV dose on global and regional scale for various applications.

## RESULTS

Examples will be presented of the UV index forecast by KNMI and DWD, the UV-check service via SMS by DLR, Public solar photoprotection service for the Mediterranean area by FlyBy, and the UV monitoring record of TOMS, GOME, SCIAMACHY by FMI and KNMI. The satellite derived products include dependences on regional and seasonal varying aerosol optical depth and single scattering albedo, altitude, the albedo of predicted snow and sea ice and cloud effects by applying empirical cloud modification factors derived from predicted cloudiness.

## DISCUSSION

Currently, the PROMOTE UV services are being presented to and evaluated by a set of Core Users who represent a variety of regional, national and international organisations. In addition to providing Core Users with products and services, a key aspect of PROMOTE is to plan follow-on activities, with a timeframe of up to 10 years, which are based on definitions of future services required by users. More information on the overall project can be found at the project website at http://www.gse-promote.org/.

# GLOBAL, WHO-CONFORM FORECAST OF UV INDEX FOR SITES BY GSE PROMOTE

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## 1 INTRODUCTION

Overexposure to ultraviolet (UV) radiation from the sun is of considerable concern to public health and plays a major role in the development of skin cancer and eye damage (WHO 2003). A marked increase in the incidence of skin cancer has been observed in fair-skinned populations world-wide since the early 1970s (WHO 2002). In Germany skin cancer incidence contributes to more than 25 % of cancer incidence in total (http://www.bfs.de/uv/uv2/ hautkrebs.html). It has been projected that in 2005 in the United States there will be more than 1 million new cases of basal cell carcinoma, more than 200,000 new cases of squamous cell carcinoma, more than 59,000 new cases of invasive melanoma, and 7,700 deaths related to melanoma. The cost of management of skin cancers is estimated to be more than $800 million per year in the United States alone (Lim et al. 2005). The skin cancer incidence is strongly associated with personal habits in relation to sun exposure and its ultraviolet component, and the societal view that a tan is desirable and healthy. Moreover the risk of UV overexposure has increased as a consequence of the depletion of the ozone layer. Therefore, in 1992 the United Nations Conference on Environment and Development agreed under Agenda 21 "to undertake as a matter of urgency, research on the effects on human health of increasing UV reaching the earth surface as a consequence of depletion of the stratospheric ozone layer; and on the basis of the outcome of this research to consider taking appropriate remedial efforts to mitigate the effects on human beings". In response to Agenda 21, WHO, in collaboration with WMO, IACR, and ICNIRP established INTERSUN, the Global UV Project (WHO 2003). An important objective is to facilitate the harmonisation of national activities and co-ordination of international activities through the use of the Global Solar UV Index and its associated health protection messages. The harmonised UV Index has been introduced collaboratively by WHO (2002), the ICNIRP (1995), the WMO (1995, 1998), and the UNEP to inform the public by means of an elementary quantity. Uniformity of UV Index presentation, and of sun protection messages associated with different UV Index values, will facilitate the delivery of a simple and relevant protection message (WHO 2002).

GMES Service Element (GSE) PROMOTE is the atmosphere service of a joint initiative of the European Space Agency and the European Commission on **G**lobal **M**onitoring for **E**nvironment and **S**ecurity. Inter alia PROMOTE will contribute to INTERSUN's objectives by providing regional highly resolved forecasts of the UV Index presented according to WHO recommendations. These forecasts are additionally intended to supplement relevant endeavours of national authorities by their global coverage combined with uniformity of presentation and associated sun protection messages.

## 2 METHODS

The UV Index is a dimensionless value defined as the integral over the spectral UV irradiance on a horizontal plane in W $m^{-2}$ weighted with the erythemal (sunburn effective) action spectrum (CIE 1987) of the human skin and multiplied by the constant 40 $W^{-1}$ $m^2$. It is independent of an individual skin type. The UV Index takes cloud cover and other relevant environmental variables into account (ICNIRP 1995). Thus it is a unit of measure and can be derived from physical measurements or radiative transfer calculations based on forecasts. The reported UV Index should at least present the daily maximum value, whenever it occurs, not a solar noon value (WMO 1998). DWD predicts the UV Index in post-processing to its global numerical weather prediction system (GME, 40 km grid) and its non-hydrostatic European model (LME, 7km) in a module structure. The forecasts have a resolution in time of one hour and comprise 78 hours allowing a reassembly of the hourly values to the daily maximum of UV Index and the accumulation to the daily erythemal effective UV dose.

### 2.1 RADIATION TRANSFER

In a first step a "large-scale UV Index" is calculated as proposed by COST-Action 713 "UV-B forecasting" (http://www.who.int/uv/resources/recommendations/COST713.pdf). It is calculated for the fixed conditions: clear sky, surface UV albedo of 3 % (summer grass), aerosol optical depth (AOD) at 550 nm of 0.20, and the aerosol type "continental average" (Hess et al. 1998). It depends on solar zenith angle (SZA) and forecasted ozone column. The effective ozone values are the PROMOTE ozone forecasts based on SCIAMACHY (Eskes et al. 2002), backed up by GME ozone forecasts. The root mean square error varies globally between 4.5 and 5.5 % compared to TOMS measurements. The forecast quality compared to persistence varies globally between 30 and 65 % with skills up to 90 % in the moderate and high latitudes and no skill in the tropics due to the almost unchanged ozone.

Lookup tables (LUT) are applied for calculation of the radiation transfer and are determined by the model STAR (Ruggaber et al. 1994) in the neural version STARneuro (Schwander et al. 2001). STAR is a high quality multiple scattering model, tested against models and measurements (Koepke et al. 1998; DeBacker et al. 2001, Mech and Koepke 2004). The LUT are calculated for the $15^{th}$ of each month, and in each hemisphere for 5 climatic belts using monthly mean profiles of ozone taken from the UGAMP climatology (Li and Shine 1995), temperature and pressure profiles taken from "COSPAR International Reference Atmosphere" (Labitzke et al. 1985, Rees et al. 1990), and humidity profiles taken from the AFCLR data (McClatchey et al. 1972). The uncertainties of LUT against modelled values for current profiles are < 3 %.

## 2.2 VARIABLE AEROSOL OPTICAL DEPTH AND SINGLE SCATTERING ALBEDO

Since forecasts of aerosol optical depth (AOD) and aerosol type, determined by its single scattering albedo (SSA), are not yet available, regional monthly mean values of AOD have been derived from the monthly NASA MODIS "MOD08_M3" data 2000 to 2003 (Kaufman et al. 2002). Because Antarctica and the Arctic have missing data in MODIS, background values are set from the "Global Aerosol Data Set (GADS)" (Koepke et al. 1997). In the Arctic the annual variation due to haze is parameterised from the measurements by Herber et al. (2002). Data gaps over the great deserts are closed using the 1979 to 2001 monthly means of aerosol optical depth at 550 nm derived from TOMS (Torres et al. 2002). The required SSA at 300 nm is taken from GADS for a relative humidity of 70 %. A factor is applied to adjust the "large-scale UV Index" to current values of AOD and SSA at sea level (Staiger and Koepke 2005). It depends on AOD, SSA and solar zenith angle (SZA). Uncertainties of the parameterisation against modelled values are < 0.27 UV Index for the whole range of SZA.

## 2.3 ALTITUDE EFFECTS

The UV Index adapted to current values of AOD and SSA at mean sea level is adjusted by a factor to any altitude between -500 m and +9000 m (Staiger and Koepke 2005). The mixing layer altitude is fixed at 3 km above ground; it begins to shrink when its upper boundary has reached the maximal approved altitude of 5000 m above sea level. The factor depends on altitude, AOD, SSA, and SZA. For the whole range of SZA and the whole range of altitudes the maximum absolute uncertainty for the adjustment to altitude against the modelled values is +0.23 UV Index.

## 2.4 ALBEDO OF SNOW AND ICE

In the UV the albedo of the ground is markedly high only for snow and ice. A factor is applied to account for the additional albedo of snow and (sea) ice cover. Differentiation is made between a terrain homogeneously covered with snow, that is assumed for Antarctica, the arctic region, the inland ice on Greenland, and sea ice, and a regional albedo. For this terrain the factor varies according to snow quality (Grenfell et al. 1994), SZA, and altitude a.m.s.l. The correlation coefficients of parameterised versus modelled values vary between 0.90 and 0.95. In the regions outside the aforementioned there are always in part snow free surfaces reducing the albedo to a "regional" value. The algorithm is derived from multiple regression of modelled versus observed albedo effects on the UV Index (Schwander et al. 1999, Lapeta et al. 2001). It requires as input snow height and snow height variations within the last 4 days. Deviations between measured and modelled UV global irradiances for conditions with snow are not significantly higher than for snow-free conditions (Schwander et al. 1999).

## 2.5 CLOUD MODIFICATION FACTOR

The UV Index clear sky is modified to a UV Index cloudy using cloud modification factors (CMF) (Schwander et al. 2002). The factor is empirical and recommended by the COST-Action 713 "UV-B forecasting" and depends on current cloud amount in the ceilings low, medium, and high. The high variability of cloud optical depth and the modification of the irradiance as effect of broken cloudiness account for the largest uncertainty within all effective atmospheric conditions (Koepke et al 2001). Comparisons of forecasted UV Index versus measured daily maxima from 11 European sites, May to September 2003, reveals that 80 % of the forecasts fall in the range of +/-1 UV Index of measured values (Staiger and Koepke 2005). UV Index cloudy compared to TOMS erythemal UV suggests that the root mean square error is comparable to that of forecasted versus observed cloudiness.

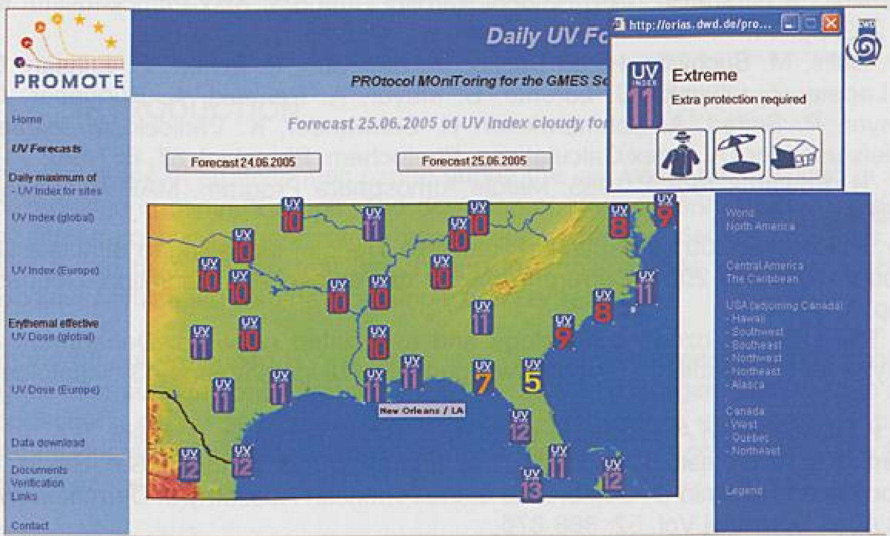


Fig. 1: Site specific forecast of daily maximum of UV Index cloudy, valid June 25th, 2005. Regional map for the south-eastern USA

## 3 RESULTS

The forecasts have a global coverage with a spatial resolution of 0.50° in latitude and 0.75° in longitude. For more than 1,100 sites the daily maximum of UV Index cloudy is derived from the fields. Differences between the GME topography and the true altitude of a location are additionally adjusted. The site specific forecasts are accessible via the internet (http://www.dwd.de/PROMOTE) and given in a WHO-conform (2002) presentation with 48 maps covering the whole globe (fig. 1) and the highest regional resolution over Europe. Click on the forecasted UV Index of a site displays the combined short protection message including the recommended protection symbols. A more comprehensive protection message is accessible via the button "Legend".

## 4 CONCLUSION

GSE PROMOTE presents WHO-conform site specific UV Index forecasts for all atmospheric conditions with a global coverage. They can supplement national campaigns on radiation protection for locations abroad. The largest uncertainty is due to actual cloudiness. With respect to this point, as well as for local aerosol properties, improvements in the future will be possible.

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# THE IMPACT OF CLIMATE CHANGE ON UV RADIATION AND NEAR SURFACE OZONE IN SOUTHERN GERMANY: SIMULATIONS WITH A COUPLED CLIMATE CHEMISTRY MODEL

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## 1 INTRODUCTION

The depleteion of stratospheric ozone during the last years has resulted in a pronounced increase of UV radiation in central Europe. The depletion of stratospheric ozone over central Europe is declining and the stratospheric ozone might recover during the next decades (Reuder et al. 2000). On the other hand it can be expected that the change in global climate will result in changed temperature and cloudiness which will also have an impact on UV radiation.

Among others enhanced UV radiation is ralated to an increased ozone photolysis and therefore to a higher near surface concentration of the OH radical. This again can result in an increased formation of tropospheric ozone and other photooxidants. Furthermore enhanced UV and visible solar radiation leads to increased isoprene emissions from plants, which contributes also to the formation of tropospheric ozone.

To investigate the potential effects of changed climate conditions on UV radiation and the consequences of changed climate conditions and UV radiation on the photo smog situation in Southern Germany, regional simulations with the coupled 3-dimensional meteorology-chemistry model MCCM were performed for present day and possible future conditions.

## 2 METHODS

Regional climate chemistry simulations were performed with the coupled regional meteorology-chemistry model MCCM (Grell et al., 2000). The simulations comprehend two ten year time slices, one representing present day (1991-2000) and one representing future conditions ('2031-2039).

In two consecutive one-way nesting steps, a global climate simulation with ECHAM4 (Roeckner et al., 1996) with resolution T42 (i.e. about 250 - 300 km) was downscaled with MCCM to a resolution of 60 km for Europe and 20 km for central Europe. For the model domain with 60 km resolution the lateral boundary conditions for the meteorological variables were extracted from the ECHAM4 output. For the chemical variables typical background values were assumed. For the model domain with 20 km horizontal resolution which covers central Europe with the Alpine region, all boundary conditions were derived from the output of the MCCM simulation with 60 km resolution.

The coupled regional meteorology-chemistry model MCCM (Grell et al., 2000), is based on the Penn State/NCAR meteorological community model MM5, which has been extended by gas phase chemistry and adapted to the requirements of long term climate-chemistry simulations. MCCM includes prognostic equations for temperature, humidity, pressure, wind speed, liquid and ice phase cloud and precipitation compounds, and the concentrations of gas phase pollutants. The soil model included in MCCM predicts soil temperature and moisture as well as the mass of a snow layer. The RADM2 chemistry mechanism (Stockwell et al., 1990) was used for the calculation of chemical transformations of gas phase pollutants. This mechanism predicts 39 chemical compounds and describes 152 chemical reactions including 21 photolysis reactions. UV radiation and photolysis frequencies are computed according to Madronich (1987) considering prescribed scenarios of the stratospheric ozone column and the values of temperature, cloud water and ice content, and tropospheric ozone which were currently predicted by the model. Emissions of biogenic organic compounds are simulated depending on the land use at each grid point and predicted temperature and short wave radiation.

The meteorological boundary conditions for the regional climate-chemistry simulations were extracted from a transient global climate simulation with ECHAM4 (Roeckner et al. 1996). This simulation is based on observed $CO_2$ concentrations during the first 130 simulation years (1860-1990) and after 1990 on the emission scenario IS92a (IPCC 2001). According to the scenario IS92a the $CO_2$ concentration increases by 100 ppm (28%) between the time slices selected for the regional simulations, i.e. 1991-2000 and 2031-2039.

For the computation of UV radiation stratospheric ozone depth is an important input parameter. For the present day time slice of the regional simulations monthly values of the average zonal mean ozone layer depths of the years 1985-1997 (Hein et al., 2001) were used. The change in the ozone layer depths between the nineties of the last century and the thirties of this century was estimated on the basis of the scenario 'PROB2050' given by Reuder et al. (2001) which was derived from a global scenario simulation for the development of stratospheric ozone.

The anthropogenic emissions of NO, $SO_2$, and hydrocarbons which are necessary for the simulation of tropospheric chemistry were derived from an emission inventory for 1998 (Friedrich et al. 2000). For the future time slice the same anthropogenic emissions as for the present day simulations were used in order to show the pure climate effect.

## 3 RESULTS

Generally, the downscaling of the ECHAM4 outputs already shows for the first domain with 60 km resolution more pronounced regional patterns of pressure, precipitation and temperature. This effect is still more distinct for second domain with 20 km resolution and affects also the simulated patterns of UV radiation chemical constituents. All results given below represent a subarea of the simulation with 20 km resolution.

The most obvious indication of global climate change is the increase of the near surface air temperature. Similar to the results of the ECHAM4 simulation, which is the basis of the regional simulations, a rise of the near surface temperature by almost 2 degrees is predicted between 1990 and 2030 for the summer months in Southern Germany. However, the meteorological parameter with the strongest impact on photochemistry is the cloud cover since it has a major impact on the UV radiation reaching the lower troposphere and on the photodissociation of tropospheric trace gases. For future climate conditions the simulations yield a pronounced decrease of the vertically integrated cloud liquid water content over Southern Germany during the summer months. (Figure 1). This decrease of the cloud water content corresponds to a relative change of -5 to -10 %. The cloud ice content in vertical column decreases for future climate conditions in the spring as well as in the summer months. As the cloud ice contributes only 5 to 10 % to the total cloud water in vertical column, the main impact on incoming radiation is due to the decrease of cloud water content. Until 2030 the simulated average UV-B radiation during the summer months increases in southern Germany for the selected scenario (Figure 2) by around 20 $mW/m^2$ or 9% in the western part of southern Germany while a significantly lower increase of only 2% was simulated for the southern part of Bavaria. Due to the strong impact of cloud cover on UV-B radiation the main features of the increase of UV-B radiation reflect the decrease of cloud water. The net decrease of the cloud water content during all summer is composed of a decrease during some weeks and an increase for the rest of the time in some regions. As the extinction of UV radiation reacts differently to changes in cloud water content for clouds of different depth, no complete agreement of the patterns for the seasonal averages of cloud water and UV radiation can be expected.

Outside the summer time, especially in the months of April and May and in October the model simulated over southern Germany an increase of the integrated cloud water content by 5 to 25% for future climate conditions (Figure 3) and a decrease of the UV radiation (Figure 4).

Under the model assumption of unchanged anthropogenic emissions the increased income of solar radiation and the higher temperatures under future climate conditions leads to an increase of near surface photooxidant concentrations in the summer months. In the case of ozone, the simulated increase of the mean daily maximum ranges between 4 $\mu g/m^3$ and 10 $\mu g/m^3$. As a consequence of the higher daily ozone maximum under future climate conditions, the number of days where the threshold value of 120 $\mu g/m^3$ for the 8 hourly mean is exceeded, increases by 3 day in northern Bavaria and by 13 days in the region near the Alps (Figure 5) and to a more frequent occurrence of very high ozone concentrations above 180 $\mu g/m^3$ (Figure 6).

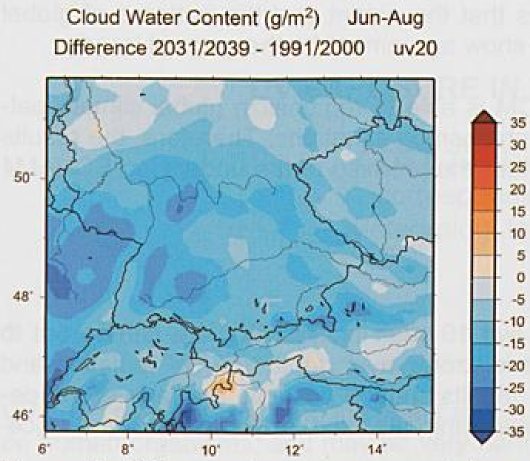


Figure 1: Difference between present day and future conditions for the spatial distribution of the vertically integrated cloud water.

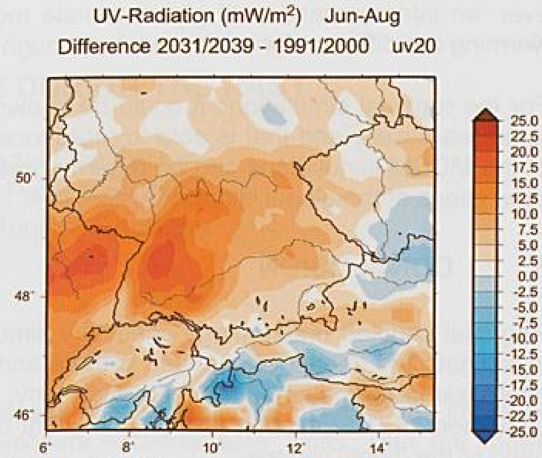


Figure 2: Difference between present day and future conditions for the spatial distribution of the UV-B radiation.

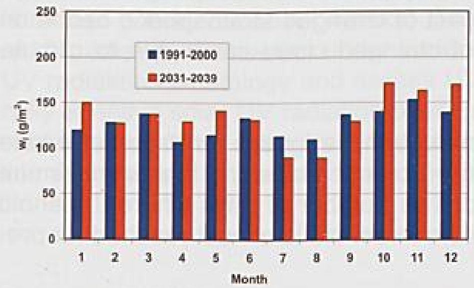


Figure 3: Simulated annual course of the mean cloud water content over southern Germany.

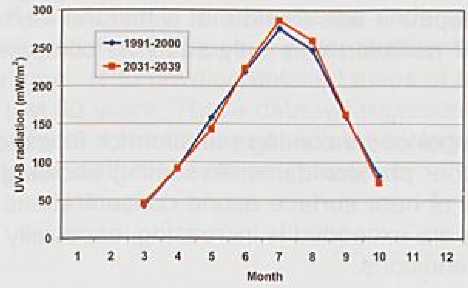


Figure 4: Simulated annual course of the mean UV-B radiation over southern Germany.

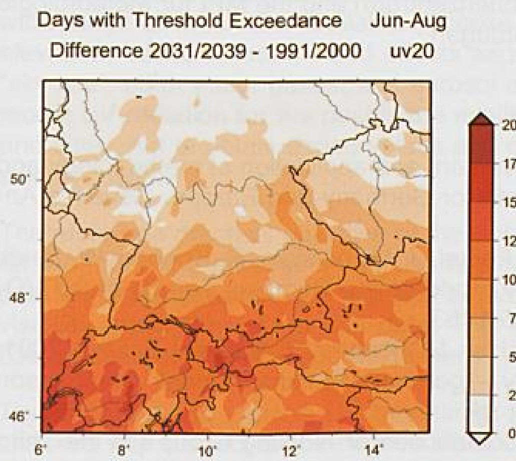


Figure 5: Spatial distribution of the difference between present day and future conditions of the number of days with exceedances of a target value of 120 μg/m³.

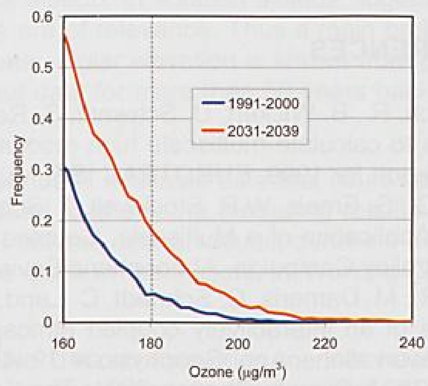


Figure 6: Frequency distribution of the simulated daily ozone maxima in southern Germany during June to August.

## 4 DISCUSSION

For the interpretation and a possible further processing of the above results it must always be considered that the results of the simulations presented here are not a forecast but a scenario simulation. The main assumptions of this scenario comprehend the future development of greenhouse gas concentrations specified by the green house gas emission scenario IS92a, the choice of the stratospheric ozone scenario, and the assumption of unchanged anthropogenic emissions of tropospheric ozone precursors. The global climate model ECHAM4 represents an internationally accepted standard. However, an intercomparison of global climate models shows that the extent and the patterns of global warming are different for each model, although all models show agreement for the general trend.

For the regional simulations it could be shown, that MCCM is able to regionalize global climate patterns realistically and that is able to reproduce observed photosmog situations. Therefore, the results of the MCCM simulations can be regarded meaningful under the premise of the underlying ECHAM4 simulations of the global climate.

## 5 CONCLUSION

Regional coupled meteorology chemistry simulations for two 10 year time slices were carried out to investigate the impact of changed climate and stratospheric ozone layer depths on UV radiation and photooxidant formation in southern Germany. The model results show a possible scenario of the development of UV radiation and photooxidant concentrations within the next 30 years for a given scenario of the global climate.

As main result the simulations show for the summer months a decrease of cloud water and cloud ice and a corresponding increase of UV-B radiation at the surface. Average UV-B radiation fluxes were found to increase by 5%. For the underlying scenario of the development the stratospheric ozone column depths it was found that within the next 30 years the impact of changed stratospheric ozone on the UV radiation was only small as compared to the effect of changed cloud cover due to climate change.

The enhanced incoming radiation for future conditions has consequences for the formation of ozone and other photooxidants. Assuming unchanged anthropogenic precursor emissions higher maximum values of near surface ozone concentrations can be expected. The number of days where threshold values are exceeded is increasing, especially in regions where the threshold is almost reached for present conditions.

**Acknowledgement:** This investigation was funded by the Bavarian Ministry for Environment, Health, and Consumer Protection within the joint project BayForUV. The global climate simulations with ECHAM4 were supplied by the DKRZ (Deutsches Klimarechenzentrum) and the MPI für Meteorologie in Hamburg and the anthropogenic emission data by IER Stuttgart.

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# UV EXPOSURE IN EUROPE DURING THE PAST

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## 1 INTRODUCTION

UV solar radiation plays an important role in many processes in the biosphere, including the influence on human organisms, and may be very harmful if UV exposure exceeds "safe" limits. Thus the knowledge of biologically effective UV radiation doses, their variation in the past, and their geographical distribution is important.

To derive these data for whole Europe, 2004 the COST action 726 "Long term changes and climatology of UV radiation over Europe" (http://i115srv.vu-wien.ac.at/uv/COST726/Cost726.htm) has been launched (Chair: Zenobia Litynska). The main objective of this Action is to advance the understanding of UV radiation distribution under various meteorological conditions in Europe in order to determine an UV radiation climatology and assess UV changes. A final goal is to develop detailed maps of biologically effective solar UV radiation over Europe during the last 50 years. These data will represent a basis for research on changes in UV dose regarding geographical distribution and variable biological action spectra, and for investigations of skin cancer inventories and other UV related questions.

## 2 METHODS

UV radiation in the past and at places without measurements can only be obtained by using models, a wide range of which are available (Koepke et al., 1998). The UV radiation is mainly affected by solar elevation, ozone amount, cloud effects and regional surface albedo. In addition altitude, together with "sky line", other minor gases, and aerosol amount and type are of relevance. Thus a main problem to model UV radiation for the past is the availability of input data. Solar elevation is known from position and time, but to obtain ozone values and other model input data for more than 50 years back needs scientific work.

Therefore one practical objective of the Action is to inventory both, available data that could be of use for the modelling purposes, and UV data which could be used to check the modelling results. These data are solar radiation, spectral and broadband, direct and diffuse, ozone, clouds, sunshine duration, visibility and relevant satellite data. This collection will be done in the Action in Working Group 1 (Data Collection, Chair: Hugo DeBacker )

The second main topic is UV modelling. Here the available UV reconstruction models have to be checked with respect to the needed input data, and how these requirements can be satisfied with the available information on atmospheric properties and to the quality of the resulting UV-radiation. This will be done in Working Group 2 ( UV-Modelling, Chair: Peter Koepke).

To advance the understanding of UV influence on ecosystems, effects of different biological weighting functions will be considered in Working Group 3 (Biological Effectiveness, Chair: Alois Schmalwieser). To use only UV data with high quality for comparison, Working Group 4 has been founded (Quality Control, Chair: Julian Gröbner).

To check the available models, procedures, and input data, the first step was to model daily exposure of erythemal weighted UV radiation for 2002 for the very different stations: Arosa/Davos, Belsk, Bergen, Lindenberg/Potsdam, Hradec Kralove and Thessaloniki. These stations have been chosen, since here both atmospheric input data and measured UV-radiation is available.

## 3 RESULTS

Erythemal weighted irradiance has been chosen as resulting quantity, since it is relevant for human UV damage and it is the quantity that has been measured most frequently. Daily dose has been chosen, because for higher temporal resolution at most places the information on atmospheric properties, especially cloudiness, is not available. Moreover, higher temporal resolution will result in very high modelling time. On the other hand, daily doses are an adequate time resolution for most UV effects.

The methods used to determine the UV exposure are different radiation transfer models, statistical models based on measured data, and combinations of both. Here, as an example, the daily UV-doses for 2002 with model results from STAR (Schwander et al., 2002) are shown for Thessaloniki and for Davos. The data have been modelled on the basis of hourly values. Solar elevation and Earth-sun-distance as well as altitude have been taken from date and geographical position. To use input data derived with the same method for the last 50 years, ozone amount has been taken from Krzyscin (2005), and sunshine duration and cloudiness to describe cloud effects.

Fig. 1 shows results for Thessaloniki. The surface albedo is set to 5 % for the whole year, and the aerosol type to maritime polluted (Hess et al.,1998), with aerosol optical depth given as a product of the boundary layer height and the extinction coefficient derived from visibility. Shown are the results from two different methods to evaluate the cloud effect. The blue crosses and regression line are the results from a neural network with the cloud effects taken into account via cloudiness, without additional information on cloud optical depth (CN 1 in Schwander et al., 2002). The cloudiness is derived linearly from sun shine duration. This method results in relatively high modelled UV-dose , about plus 15 %, since the cloud modification factors do not decrease linearly with cloudiness. The second way of modelling, shown in Fig.1 as "weight" with red crosses and line, weights the irradiance modelled under the assumption of no clouds with that modelled under the assumption of overcast conditions, with a weighting factor derived from sunshine duration. The assumption behind this is that the irradiance can be described as a mixture of two different states: one with the sun not covered by a cloud which is modelled with no clouds at all, and the other with a cloud in front of the sun, which is modelled by overcast conditions. The improvement due to the second method clearly can be seen in the figure, moreover the RMS improves from 500 for CN1 to 403 for weight. To improve the agreement furthermore the deviation of individual points has to be analysed and the results from other models have to be compared.

Fig. 2 shows similar results for Davos. Here the surface albedo is derived from snow height, and time after last snow fall (Schwander et al. 1999). Aerosol type is set to continental average (Hess et al.,1998) and aerosol optical depth is given from measurements. For consideration of cloud effects method CN1 (Schwander et al., 2002) has again been used (blue crosses and line) with cloudiness as the only information for cloud effects. Additionally a neural network has been chosen (green crosses and line), that uses measured values of solar global irradiance in addition to cloudiness (CN4). The second method results in modelled values which are 6 % to high in average. This deviation could be a consequence from systematic differences in the global radiation against that which has been used for training of the neural network. But a clear improvement is derived in the RMS, which reduces from 459 for CN1 to 411 for weight.

## 4 CONCLUSION

The Cost-Action 726 started very successful on its way to model UV-maps for Europe for the past. The contributions of scientists from 24 countries and organizations give the basis for the use of data from all over Europe and for the use of the numerical model which is best fitting to the available input data. The next steps will be the comparison of results from different models for the same stations and the detailed analysis of deviations.

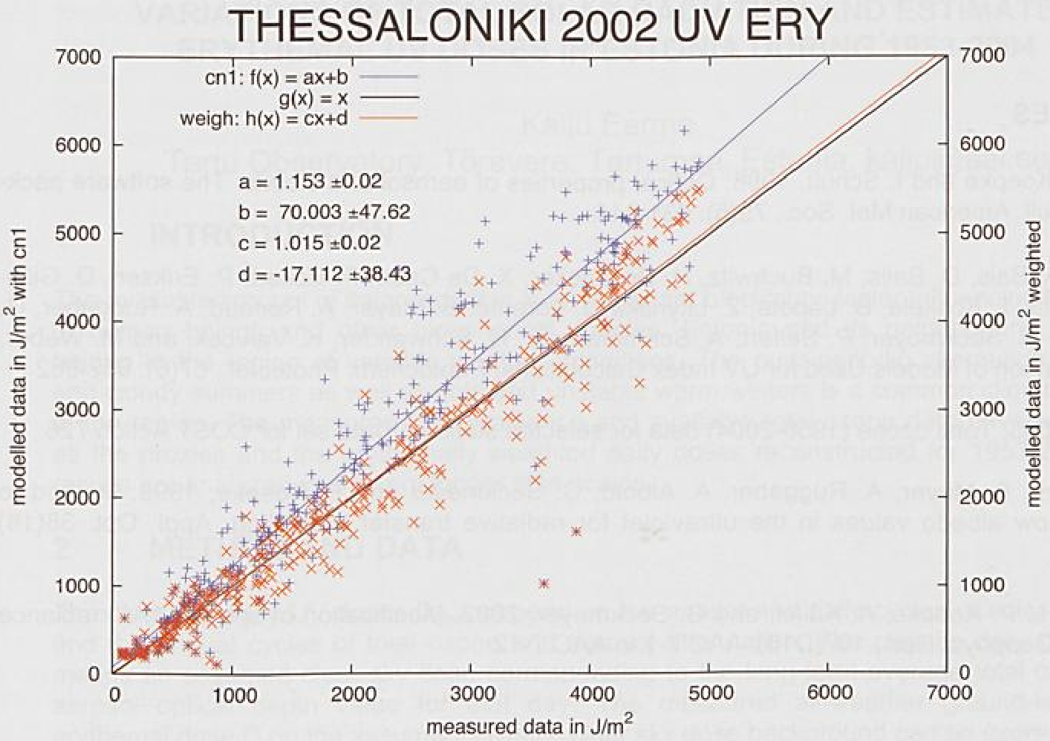


Fig. 1 Daily doses of erythemal weighted UV radiation in Thessaloniki 2002. Values modelled with STAR "CN1" and "weighted" (for details see text.)

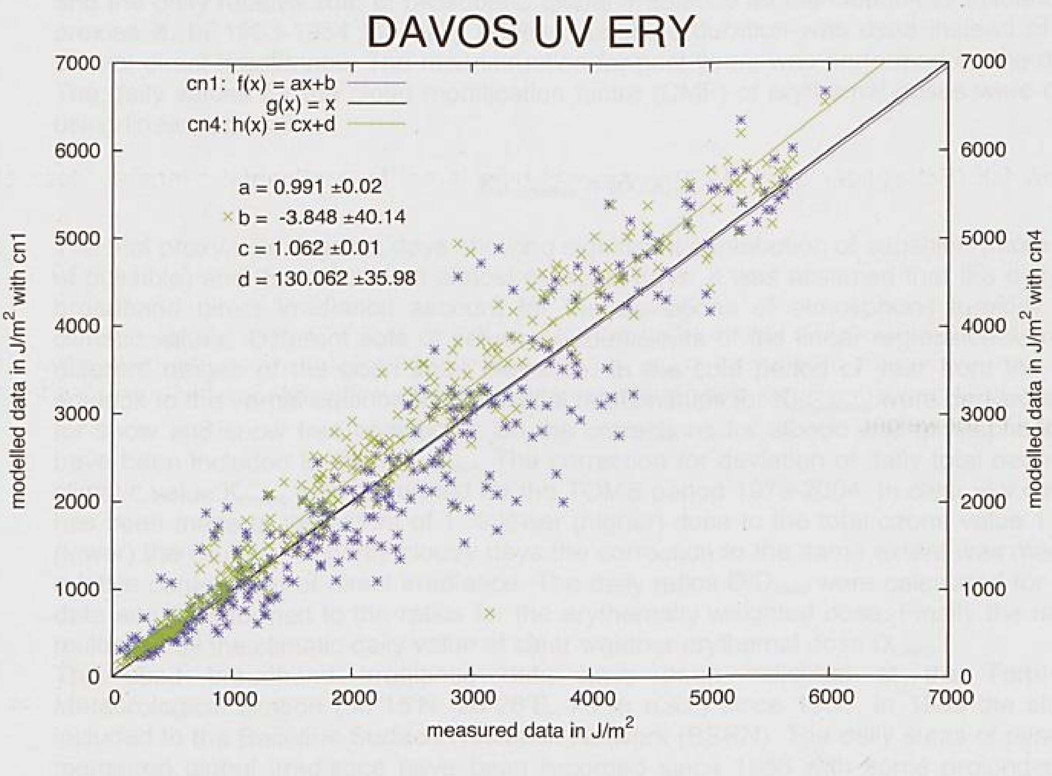


Fig. 2 Daily doses of erythemal weighted UV radiation in Davos 2002. Values modelled with STAR "CN1" and "CN4" (for details see text.)

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# VARIATIONS OF TOTAL SOLAR RADIATION AND ESTIMATED ERYTHEMAL UV DOSES IN ESTONIA DURING 1953-2004

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## 1 INTRODUCTION

The available amount of solar radiation is an important bioclimatic factor influencing the health of human beings and other biospherical species. Estonia and its neighbouring countries belong to the region of variable weather conditions. The quasiperiodic alternation of sunny and cloudy summers as well as cold and unstable warm winters is a common climatic feature of the region. The measured total irradiance and available total ozone data have been used as the proxies and the erythemally weighted daily doses reconstructed for 1953-2004. The results are analyzed in different longer time scales.

## 2 METHOD AND DATA

The clear sky daily UV doses $D_{clear}$ depend on the annual and daily cycles of solar elevation and the annual cycles of total ozone and aerosol attenuation. The climatic daily dose here means an assumed clear sky dose corresponding to the long-term average total ozone and aerosol optical depth value for that day. The measured all-weather ground-level daily erythemal dose D on the assumed climatic clear sky dose background can be expressed as

$$D = D_{clear} K_{cloudiness} K_{ozone} K_{albedo} K_{turbidity}.$$

The coefficients K account for the contribution of cloudiness, total ozone, albedo and atmospheric aerosols. A proxy-based reconstruction of the erythemally-weighted UV doses for 1955-2004 has been performed using the daily relative sum of broadband direct irradiance and the daily relative sum of broadband global irradiance as the cloudiness influence related proxies X. In 1953-1954 the daily relative sunshine duration was used instead of the daily sum of direct irradiannce. The reconstruction for past years was performed on the daily level. The daily values for the cloud modification factor (CMF) of erythemal doses were calculated using linear regressions

$$K_{cloudiness} = aX/X_{clear} + b.$$

The first proxy was used on days showing significant contribution of sunshine (more than 5 % of possible) and the second on almost overcast days. It was assumed that the daily sums of broadband direct irradiance account for the deviations of atmospheric turbidity from the climatic values. Different sets of values of coefficients of the linear regression were used in different ranges of the noon solar elevation. In the cold period of year from the autumnal equinox to the vernal equinox the statistical relationships for $K_{cloudiness}$ were derived separately for snow and snow free conditions. So the corrections for albedo and atmospheric turbidity have been included to the $K_{cloudiness.}$ The correction for deviation of daily total ozone from its climatic value $K_{ozone}$ was performed for the TOMS period 1979-2004. In clear sky conditions it has been made to the extent of 1 % lower (higher) dose to the total ozone value 1 % higher (lower) the climatic. In partly cloudy days the correction to the same extent was made for the relative contribution of direct irradiance. The daily ratios $D/D_{clear}$ were calculated for the proxy data and transformed to the ratios for the erythemally weighted dose. Finally the ratios were multiplied by the climatic daily value of clear weather erythemal dose $D_{clear}$.
The used broadband irradiance data have been collected at the Tartu-Tõravere Meteorological Station (58°16'N, 26°28'E, 70 m a.s.l.) since 1950. In 1999 the station was included to the Baseline Surface Radiation Network (BSRN). The daily sums of pyranometer-measured global irradiance have been recorded since 1950 with some prolonged gaps in 1952. The continuos record of the pyrheliometer-measured daily sums of direct irradiance are available since 1955. The daily sunshine duration data have been recorded in 1953-1958 and since 1967. Erythemally weighted UV doses have been regularly measured since January 1998 using a Scintec UV-SET sensor. Asymmetric relative to the summer solstice annual

cycle of clear-sky erythemal daily dose as well as the symmetric cycles of daily sums of direct irradiance and global irradiance were interpolated from the observed data as corresponding to average "normal" or climatic conditions and checked by radiative transfer calculations. The climatic yearly cycles for clear sky sums of direct and global irradiance were constructed using the data of 1955-2003 and the climatic yearly cycle of clear sky erthemal dose using the data 1998-2003.

## 3 RESULTS

The agreement between the measured and reconstructed daily erythemal doses in 2004 (data not used in constructing the regressions) did not differ from that in 1998-2003. The biases between the measured and reconstructed daily doses in 52-58 % of cases around the year were within ± 10 % and in 82-84 % of cases within ± 20 %. In summer half-year these amounts were 58-65 % and 85-92 %, respectively. In most of years the results of reconstruction of doses for longer intervals (month, season, half-year) did not differ significantly if the climatic value of total ozone was used with no correction for the daily deviations. On average the daily biases in 95 % of cases remained within ± 10 %. The biases exceeding 2 % for the summer half-year dose were met in years manifesting extended fine weather periods in summer and also in years after major volcanic eruptions.
The ranges of variation of the summer half-year and winter half-year reconstructed erythemal dose in 1953-2004 in per cent relative to the average value are presented in Table. During both half-years the range of variation of the erythemally weighted dose is narrower than the ranges of broadband irradiance related quantities. In yearly and summer half-yearly doses the interval from

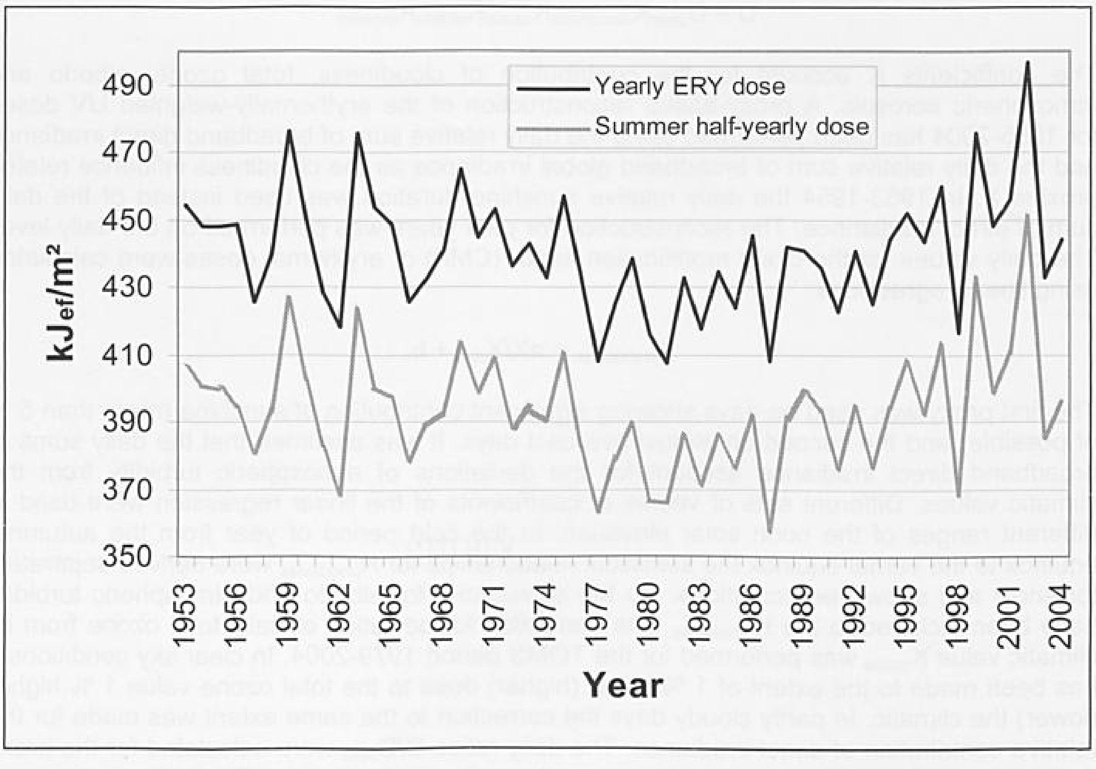


Figure 1 Variation of reconstructed yearly and summer half-yearly erytemal dose 1953-2004

1976 to 1993 manifests smaller values than were met before and after (Fig. 1). The major contribution comes from astronomical summer season. The darkest 100 days around the winter solstice when the noon solar elevation remains below 15° contribute on average only 2.7 % of the yearly erythemal dose. The range of variation of the erythemal dose of this interval is within ± 20 % of the average. It is close to the range of global irradiance variation.

The variations of both quantities in 1953-2004 are presented in Fig.2. The low values were found in winters manifesting extended snow-free episodes and high cyclonic activity. Since 2000 the midwinters have been darker of the average. To lesser extent darker winters were met also in 1959-1962, 1971-1975 and 1990-1992. On the monthly level the highest year-to-year stability (variations within ± 13 %) has been met in June.

Table 1. Ranges of variation of irradiance totals and their contribution to yearly sum in summer and winter half-years

| | Range, % | StDev, % | Of yearly, % |
|---|---|---|---|
| **Summer half-year** | | | |
| Global irradiance | 89.7 - 114.4 | 5.6 | 83.6 |
| Direct irradiance | 74.4 - 132.2 | 12.9 | 88.7 |
| Erythemal irradiance | 92 - 111 | 4.2 | 89 |
| Sunshine duration | 79.8 - 132.9 | 9.9 | 79.8 |
| | | | |
| **Winter half-year** | | | |
| Global irradiance | 75.1 -119.1 | 9.7 | 16.4 |
| Direct irradiance | 59.5 -139 | 19.6 | 11.3 |
| Erythemal irradiance | 87.0 -114 | 6.4 | 11 |

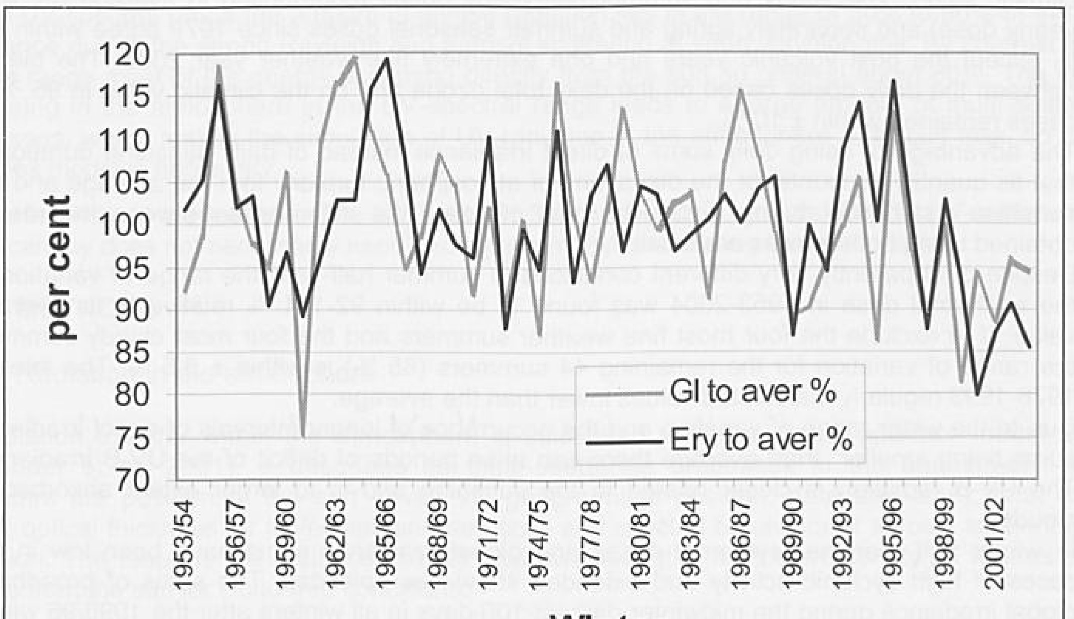


Figure 2 Variation of the midwinter darkest 100 days erythemal and broadband global relative dose

## 4. DISCUSSION

One of the tasks of the present work was to study how much can differ the UV doses for longer intervals if the climatic total ozone data are used instead of the real daily values. For the period when the daily values of total ozone were available the reconstructions based on climatic value were made in parallel and the results compared. The biases of the summer half-year as well as the whole year doses reconstructed on the daily ozone and on the climatic basis exceeded 2 % in the post-volcanic years 1983 and 1992. The largest deviation

3.5 % was met in the extremely fine weather year 2002. Due to the total ozone values systematically lower than climatic the erythemal dose based on climatic total ozone was underestimated. In also fine summer 1999 the underestimation was only 1 %. Similar fine weather summers when the underestimation could be suspected were in 1959 and 1963. In "normal" years the biases have been within ± 2 %.
The year-to-year variations of the erythemally weighted doses and also sums of broadband global irradiance are quite small. The clouds modify significantly the spectral composition of the erythemal irradiance and there can appear periods of deficit or surplus of the UV-B irradiance.

## 5. CONCLUSIONS

The daily sum of pyrheliometer-measured direct irradiance and the daily sum of pyranometer-measured global irradiance were chosen among all possible cloud-influence-related proxy quantities for the reconstruction of erythemal doses for past years. The first sum was used as a cloud attenuation and atmospheric turbidity related proxy on clear and partly cloudy days. The second was used as the cloud modification factor related proxy on overcast days. Using these two proxies the daily erythemal doses could be reconstructed with satisfactory agreement with the measured values around the year.
In most of years the reconstructed doses for longer intervals do not differ significantly if the climatic value of total ozone is used with no correction for the daily deviations from that day climatic value. The yearly and summer half-yearly doses (contributing in average 89 % of yearly dose) and separately spring and summer seasonal doses since 1979 agree within ± 2 % except the post volcanic years and one extremely fine weather year 2002. The biases between the daily doses based on the daily total ozone and on the climatic value in 95 % of cases remained within ± 10 %.
The advantage of using daily sums of direct irradiance instead of daily sunshine duration is that tis quantity accounts for the deviations of atmospheric turbidity fom the average and the sunshine distribution during a day. In most of years the differences between the results obtained using both proxies are small.
Despite of apparently very different conditions in summer half-year the range of variation of the erythemal dose in 1953-2004 was found to be within 92-111 % relative to its average value. If to exclude the four most fine weather summers and the four most cloudy summers the range of variation for the remaining 44 summers (85 %) is within ± 5.5 %. The interval 1976-1993 regularly manifested values lower than the average.
Due to the wider range of variation and the occurrence of longer intervals of direct irradiance sums being smaller than average there can arise periods of deficit of the UV-B irradiance. The UV-B radiation is closer related to the sunshine and is to larger extent absorbed in clouds.
In winter half-year the erythemal doses and global irradiance sums have been low in the cases of high cyclonic activity and extended snow-free episodes. The sums of broadband global irradiance during the midwinter darkest 100 days in all winters after the 1995/96 winter and the erythemal doses in six winters of eight have been lower than average. To lesser extent the winters darker than the average have been met in 1959-1962, 1971-1975 and 1990-1992.

# MODELLING THE UV-EXPOSURE WITHIN A PLANT STAND DURING A VEGETATION PERIOD

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## 1 INTRODUCTION

Plants are constantly exposed to solar UV-Radiation. In recent years, the so-called 'non-parasitic leaf spots' (NPLS) led in Bavarian barley fields to yield losses of up to 40%. It is assumed that this disease is caused by raised UV levels. Since much effort is necessary to measure radiation in plant stands, and even impossible without changing the shadow conditions in narrow canopies, a model has been developed to calculate the UV-radiation with high temporal resolution during a growing season. There exist a large number of models to describe the visible or PAR spectral range of radiation within plant canopies. Most of them focus on energy exchange with the atmosphere (e.g. Norman 1982) or have the aim of making predictions about the biomass production or agricultural yield of crops. For the UV-spectral range there exist only few attempts to model the irradiance on the plants (e.g. Grant 1999). When modelling UV-radiation within a plant stand three aspects have to be considered:

- Models that describe the energy exchange of a whole plant stand only need to describe the radiation available on average over the area. By contrast a model for the description of UV-exposure should consider the maximum UV-radiation exposure of single leaves.
- In the UV-spectral range the amount of diffuse radiation lies in the range of 50% to 90% of the total irradiance due to the strong Rayleigh and aerosol scattering at short wavelengths. By contrast in the visible range most of the energy is coming directly from the sun, in general about 80%. The strong scattering in the atmosphere in the UV-spectral range leads to a large amount of multi scattering processes, which makes the simulation of UV-radiation in the atmosphere a difficult task, so that a complex model is necessary.
- The reflectivity of the leaves in the UV is below 3%. Accordingly a model for the UV-radiation in a plant canopy does not necessarily need to describe multiple scattering between leaves.

## 2 METHODS

### 2.1 Radiation in the atmosphere

The radiation transfer within the atmosphere is calculated with the matrix operator model STAR (Schwander et al. 2001). It describes all multi-scattering processes in the atmosphere. Input parameters are position of the sun (given via geographical position, date and time), total ozone content, optical thickness for molecules and aerosols, and spectral behaviour of aerosol scattering and absorption. The result is the radiance field at given wavelengths for the whole sky as well as direct radiance from the sun for cloud-free conditions.

To model the radiation under a partly cloud covered sky the probabilities for cloud-free lines of sight from Lund and Shanklin (1973) are used. They are given for different zenith angles, cloud types and cloud coverages. For the three different cloud types low- , mid- and high level clouds typical optical thicknesses are assumed giving typical transmittances of the clouds for every zenith angle. From this an expectation value of the transmittance of the cloud covered sky can be calculated. This technique is valid if the source of radiation lies above the cloud level and if there is no multi scattering between clouds. This is true for direct solar radiation. It is roughly valid for diffuse radiation originating mainly from rayleigh scattering in the upper atmosphere. Diffuse radiation originating from aerosol scattering is not described precisely with this technique. But since Rayleigh scattering forms the major part of the diffuse radiation in the UV this can be regarded as a good approximation to reality.

The expectation values of the transmittances are calculated separately from observed cloud coverage of the three classes high-, mid- and low level clouds. The radiance fields modelled by STAR are then multiplied with these transmittances giving the probable radiance field.

## 2.2. Radiation within the plant stand

Inside the plant canopy the radiation is modelled according to the statistical approach of Norman (see Ross 1981). Input parameters are stem and leaf area distribution and the leaf angle distribution. From these parameters the probability to see the sky in a certain direction is calculated. Since the leaves absorb practically all radiation in the UV spectral range, this probability multiplied by the apparent radiance from that direction gives the expectation value for the UV-radiance in the canopy from that direction. For every level within the canopy the radiances from the upper hemisphere are integrated under consideration of a leaf orientation giving the irradiance. This integration is done separately for every wavelength. The resulting spectra are multiplied by an action spectrum describing the effect of the UV-radiation on the plants (Caldwell 1971).

As explained before, not only the average radiation exposure but also its maximum and the possible range are of interest. The described model is a statistical model and gives only average values, but the range of radiation inside the canopy is mainly produced by the occurrence of sunflecks. Since irradiance from diffuse sky radiation is the sum of radiances from many directions, the expectation value describes the real situation very well. The range of radiation in the canopy can be described by including or omitting the direct solar radiation. The average irradiance $E_{avg}$ at level $z$ thus lies between $E_{sun}$ for a leaf in the sun and $E_{sdw}$ for a leaf in the shadow.

Integrating the UV-irradiances $E$ in time gives the UV-exposure $H$ of the leaves. This exposure is a cumulative quantity and accordingly grows at all times. By contrast, it must be assumed that plants recover from the radiative stress of a certain day. This means that not the cumulative exposure of the whole vegetation period but the exposure of the most recent days triggers the appearance of NPLS. To describe this a fictive recovery is modelled by assuming that the impact of the UV-radiation decays exponentially with a time constant $T_x$.

## 2.3. Input parameters

The model was used to calculate the UV-exposure during the vegetation period of the year 2002 in one of the barley fields of the Bavarian State Research Center for Agriculture (LFL) at Frankendorf near Munich, Germany. Total ozone content was taken from the TOMS database, and information about cloud types and coverage from the German Meteorological Service (DWD), which maintains a station at Munich airport 14 km to the west.

There were no plant parameters, such as spatial leaf area distribution, available for the whole vegetation period in Frankendorf due to the high effort necessary. For this reason, data of leaf area density and stem area density published by Ross (1981) were used. These profiles were adapted to the situation in Frankendorf by taking into account real plant development stages and assigning the Ross-data to the respective day. The original Ross-data are available for 8 development stages. Between these dates a linear interpolation was performed to obtain the necessary information for every day of the vegetation period. For the leaf angles an elliptical leaf angle distribution was assumed. The parameter $x$ was assumed to be 1.7 following the estimate of Campbell and van Evert (1994).

# 3 RESULTS

With the described methods and parameters the irradiance for horizontal leaves were calculated for the period April 25 to June 10 of the year 2002 for every daytime hour. Figure 1 shows the course of the UV-irradiance under the assumption of cloud-free conditions on horizontal leaves as an example for the height of 33 cm in the canopy during the vegetation period. The thick lines show the course of irradiance during one day with zero values during night and a daily maximum at local noon. The thin lines interconnect these maximum values to accentuate the course due to varying meteorological conditions and the growing canopy. The variation of $E_{top}$ is mainly determined by the total ozone content of the atmosphere and the sun position in the sky. Beside this modulation the irradiances inside the canopy at 33 cm decay strongly till May 10 and weaken the following days until May 27. The reason is the strong increase of leaf area above 33 cm until May 10; the following merely weak increase until May 27 is a consequence of the decrease of leaf area due to ripening. With the increase of the leaf area the average UV-irradiance ($E_{avg}$) is shifted from the value for sunlit ($E_{sun}$) leaves towards the value for the shadow ($E_{sdw}$). As before, this shift reflects the decreasing probability for a sunlit place with increasing leaf area above. In the same manner $E_{avg}$ moves back towards $E_{sun}$ when the leaf area decreases again after May 27. Analogous patterns can be found for the other levels above and below 33 cm.

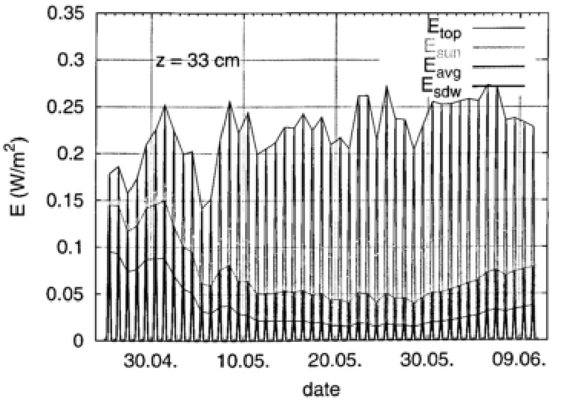


Fig. 1: Course of the 'plant'-weighted UV-irradiances on horizontal leaves at 33 cm inside the canopy without clouds. $E_{top}$ is irradiance at the top of the canopy. Thick lines show the daily course, and thin lines interconnect the daily maximum values at local noon.

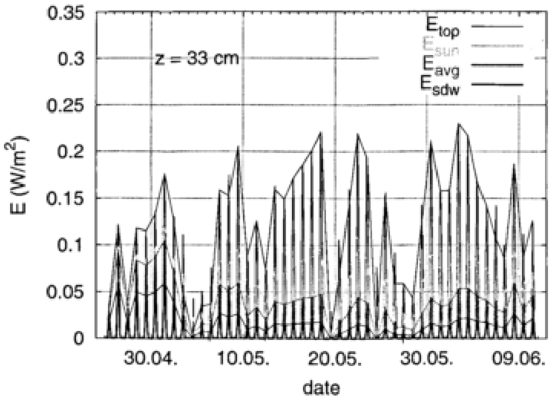


Fig. 2: Course of the Irradiance on horizontal leaves at 33 cm inside the canopy under consideration of observed clouds.

The picture changes considerably if clouds are included, as shown in figure 2 for the same conditions as in figure 1. Some of the maxima (e.g. May 1, May 8 or June 5) remain visible, because during these days the radiation was influenced only weakly by a few clouds. Very noticeable are the minima in the irradiance around April 26 and May 5, and on May 19 and May 28. These days are characterised by high cloud coverage of low-level clouds. The modulation of the UV-radiation at canopy top is so large that the influence of the growing plants on the irradiance at 33 cm becomes relative weak. As for the case without clouds the course at other levels within the canopy shows in principle the same behavior.

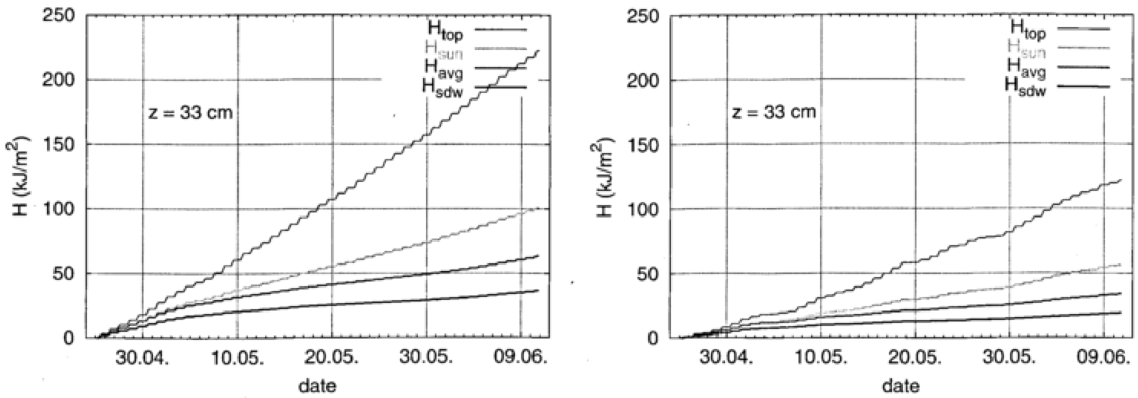


Fig. 3: Course of the UV-exposure of horizontal leaves at 33 cm inside the canopy without (left) and with consideration of observed clouds (right).

Figure 3 shows the course of the total time-integrated exposure, again as an example for 33 cm within the plant stand. The integration starts with April 25. The stair structure reflects the integral of the diurnal course of the radiation: every day leads to a rise of the exposure while during the night no change occurs. Without clouds (left panel of figure 3) the exposure at canopy top increases nearly linearly besides the stair structure and a slight concave tendency. The slight upward bend is due to the rising solar noon elevation and accordingly increasing irradiance. Inside the canopy this increase is in the beginning slightly reduced, and after May 5 strongly reduced by the increasing leaf area above the 33 cm level. The visible upward bend later on is due to the decreasing leaf area.

If clouds are included in the model (right panel of figure 3) the exposure is obviously smaller. Especially the periods with high cloudiness lead to a smaller or even negligible increase of the exposure with time. The result is 40-45% smaller exposure at the end of the growing season. During the period the difference from the case without clouds lies in the range 14-55% and depends strongly on time and position within the canopy.

To consider the possible effects of repair mechanisms, an UV-impact $H_x$ was modelled with a virtual recovery where the impact of irradiances further in the past are weighted smaller. The regeneration time constant $T_x$ for this model was assumed to be 24 hours because the plants react very sensitively to variations on the order of one day. The result is shown in figure 4. The peaks reflect the daily course with its maximum at noon. Due to the assumed regeneration time of one day the effect of the noon maximum of the irradiation decays rapidly, and only a small increase in $H_x$ remains from day to day as long as there are no clouds (e.g. May 14-19). During the strongly clouded periods $H_x$ falls to low values in a short time (e.g. May 4). But it increases again rapidly if clouds vanish and solar radiation increases (e.g. May 7). In total the UV-impact $H_x$ does not increase above a certain level and reaches large values only at times with intense solar radiation.

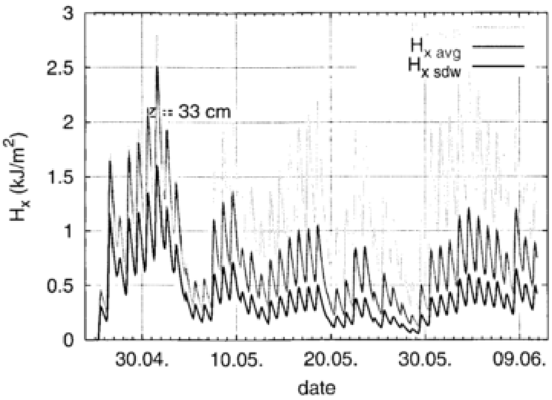

Fig. 4: Course of the exposure impact $H_x$ with a virtual recovery of the plants for horizontal leaves at 33 cm inside the canopy by use of a regeneration time constant $T_x$ of one day.

## 4 CONCLUSION

A model to describe the UV-radiation whithin a plant canopy during a vegetaion period has been developed. It is based on statisitcal considerations for the radiation transfer in plant canopies as formulated by Norman. The UV-radiation transfer during cloudy conditions is based on similar considerations using the cloud-free line of sight concept of Lund and Shanklin (1973). The model gives the range of variation between sunlit and shaded leaves.

The effect of clouds on the UV-irradiance inside the canopy varies from 14-55% and depends strongly on time and position in the canopy. This is due to the large amount of diffuse radiation in the UV, its distribution over the sky and the modulation by clouds. Inside the canopy the strongly direction dependend extinction modulates the radiation further resulting in this large variation.

The modelled UV-impact $H_x$ reaches large values only at times with intense solar radiation and thus provides an explanation of the findings of Baumer et al (2001) who observed that the NPLS appear in particular when the irradiance increases strongly after a period with high cloudiness and low radiation.

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# DEVELOPMENT OF A DOSIMETRIC TOOL TO MEASURE HUMAN UVA EXPOSURES

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## INTRODUCTION

Humans in their day-to-day lives are exposed to solar ultraviolet (UV) radiation. These solar UV exposures can be separated into UVB exposures (280nm to 320nm) and UVA exposures (320 to 400nm). Most acute responses of humans to UV exposure occur as a result of UVB exposures, as these wavelengths are highly sensitive in creating a human biological response. This however does not result in UVA radiation not having an impact on human UV exposures and health. UVA can cause erythema in human skin, yet, the exposures required to create such a response is much larger than UVB radiation. UVA radiation penetrates much deeper into human skin tissue than UVB, resulting in impacts that are not as acute, taking many years to manifest. UVA exposures are associated with wrinkling, loss of skin elasticity, ocular disorders and it has been implicated in the development of skin cancers.

## METHODS/RESULTS

Our research group has developed a personal UV dosimeter that can quantitatively assess UVA exposures. The chemical phenothiazine, cast in thin film form and which is responsive to both the UVA and UVB part of the spectrum was used and filtered with mylar. This combined system responded to the UVA wavelengths only and underwent a change in optical absorbance as a result of UVA exposure. Preliminary results indicate that this UVA dosimeter saturates reasonably quickly when exposed to sunlight. Results will be presented on the dosimeter's characteristics and preliminary results indicating how this tool may be used in environmental exposure risk assessment.

## DISCUSSION

Although the UVA dosimeter saturates reasonably quickly, it is not an insurmountable problem to extend the dynamic range of the dosimeter. This may be done using a similar technique to that used to extend the dynamic range of polysulphone as a UVB dosimeter by a factor of approximately 4 to 5 by using a carefully selected and characterized neutral density filter.

# A FIRST APPROACH OF FORECASTING THE VITAMIN D EFFECTIVE UV RADIATION

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## 1 INTRODUCTION

UV radiation (UVR) may cause a variety of damages in the human organism. However there are also positive effects like Vitamin D production or positive effects on mental health. A satisfying vitamin D level can nowadays being associated with reducing the risk for different diseases (e.g. rickets), for several kind of cancers (e.g. prostate, breast, colon) and for age caused dismantling (e.g. osteoporosis which affects 30% of all postmenopausal women). More than 90% of plasma vitamin D is produced endogenously on exposure to UVR. While oral intake could lead to oversupply and toxicity, solar UVR regulates the vitamin D level by degrading remaining vitamin D in the skin. A wise intercourse with the sun especially during autumn and winter could help to avoid vitamin D deficiency.

Information about the actual effectiveness of solar radiation in producing Vitamin D could therefore a very helpful tool for health care. For this we have introduced as a first step a world wide forecast of the vitamin D effective UVR for the next day which generates the global distribution of the vitamin D effective daily dose for the next day for a vertically and a horizontally oriented plane receiver. While the vertical orientation corresponds closer to the human face (Figure 1), the horizontal one is today's standard orientation for operationally measurements.

## 2 METHOD

The core procedure of the forecast model is a fast spectral model, also called physical model with simple parameterisation. The general idea traces back to a suggestion of Diffey (1977): spectral measurements are parameterised to solar height and TOC. The basing spectral measurements were made by Bener (1972) over many years at the alpine observatory (46°48´N, 9°49´E, 1590 m above sea level) of Davos, Switzerland. Splines are introduced for parameterisation. This procedure delivers the global spectral irradiance as the sum of the diffuse and direct component. From this the irradiance is calculated for 16 discrete wavelengths between 297.5nm and 400nm. To correspond to the altitude dependence of UV radiation a wavelength dependent factor gained by Blumthaler et al. (1997) is applied. The resulting spectral irradiance is weighted by the action spectrum of vitamin D (Figure 2) production (MacLaughlin et al. 1982). Integration over the whole spectral range delivers the vitamin D effective irradiance for a plane horizontal receiver.

The model contains a feature which allows to calculate the biologically effective irradiance on inclined planes. It was developed by one of us (Schauberger 1992) and takes into account the anisotropy of the diffuse irradiance. This feature has another advantage. It enables to calculate the biologically effective irradiance on inclined planes by inputting the measurements from a horizontally oriented device. For the vertically oriented plane receiver we assume that the receiver has no preferable orientation relative to the sun; that means a continuously rotation around its vertical axis whereas the rotational velocity is much faster than the azimuth change of the sun.

The temporal integration of effective irradiance from sun rise to sun set delivers than the effective radiant exposure over the whole day (daily dose).

Input parameters for the forecast are time and date, geographical co-ordinates, elevation above sea level and the total ozone content (TOC) of the atmosphere. Since showing both, spatial and temporal variability, appropriate TOC values have to be provided to ensure high accuracy of UV model calculations (e.g. Schwander et al.1997). As shown by Schmalwieser et al. (2003) TOC measurements from satellites can be prepared to deliver TOC values appropriate for a forecast of the erythemally effective UV radiation. For the presented forecast the TOC base are data from NASA's

Earth Probe TOMS (EPTOMS) (McPeters et al. 1998). Details on this simple global TOC forecast scheme can be found in Schmalwieser et al. (2003). By its use, daily mean TOC values for the day of forecast, for certain sites or on a global grid were gained. The later consists of 360x180 values, which correspond to a spatial resolution of 1.0° in latitude and longitude.
The model as well as the forecast procedure was already validated for the erythemally effective UV radiation on a horizontally oriented plane receiver by comparisons to other models (e.g. Köpke et al. 1998) and by measurements made at 4 continents (Schmalwieser et al. 2002, Schmalwieser et al. 2005).

**Figure 1:** Detail of a human mesh model which can be equipped also with different clothes.

## 3 RESULTS

The operational forecast of the Vitamin D effective daily dose has been done daily since October 2004 at the Institute of Medical Physics and Biostatistics, University of Veterinary Medicine Vienna, Austria. The forecast system generates the global distribution of the vitamin D effective daily dose for the next day for a vertically and a horizontally oriented plane receiver. While the vertical orientation corresponds closer to the human face (Figure 1), the horizontal one is today's standard orientation for operationally measurements. Forecast visualisation is done by maps (Figure 3). The levels are indicated by colours in the legend. To overcome the unavailability of a world wide cloud forecast the legend provides the numbers in dependence of cloud cover which are indicated by four classes of cloud cover symbols. The figures are updated daily at 0:00 GMT, for up to 48 hours in advance. They are available via the world-wide-web: http://i115srv.vu-wien.ac.at/uv/uv_online.htm. This web-page provides also some general information about Vitamin D.

The validation of model calculations and forecast can be done by comparisons to measurements from broadband meters. The spectral sensitivity of the chosen device (Model 501, SolarLight Inc.) is as similar to the action spectrum of the vitamin D initiation as the CIE action spectrum of the erythema (Figure 2). The application of conversion factors depending on solar height and total ozone delivers satisfactory agreement. In this manner we have converted the broadband meter readings from our measuring station in Vienna (48.26°N, 16.43°E, 153m a.s.l.). The validation was done for the daily dose for all sky conditions. The hit rate for the model are 38% and for the forecast 35%. As hit we count deviations less than 250 $J_{VitD}/m^2$ which we can simplified assume to be similar to 1 MED (minimal erythemal dose) for skin type II. Overestimation result mainly through cloudiness which is not an input parameter for the model and the forecast.

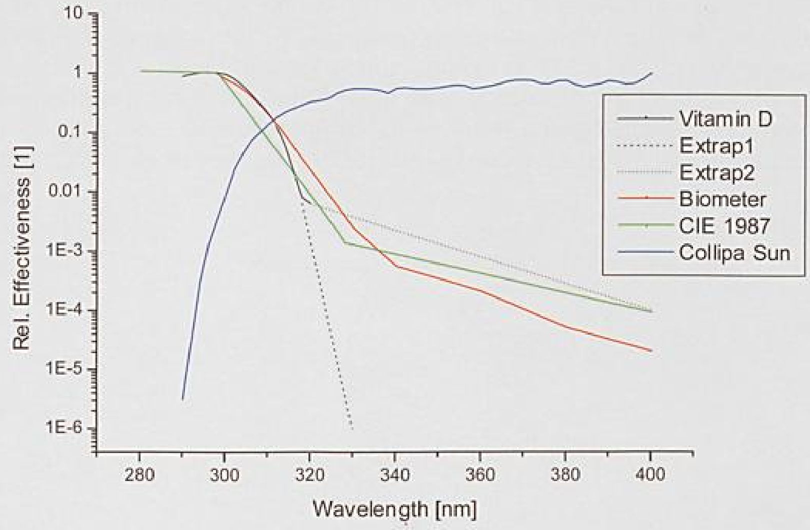


**Figure 2:** The black solid line shows the action spectra of Previtamin $D_3$ photosynthesis (MacLaughlin et al. 1982). The dotted lines give two examples for extrapolating into the UVA. Further shown are the action spectrum for the human erythema (CIE 1987), the spectral sensitivity of a UV-Biometer (Model 501, Solar Light Inc.) and a solar reference spectrum (Collipa 1994).

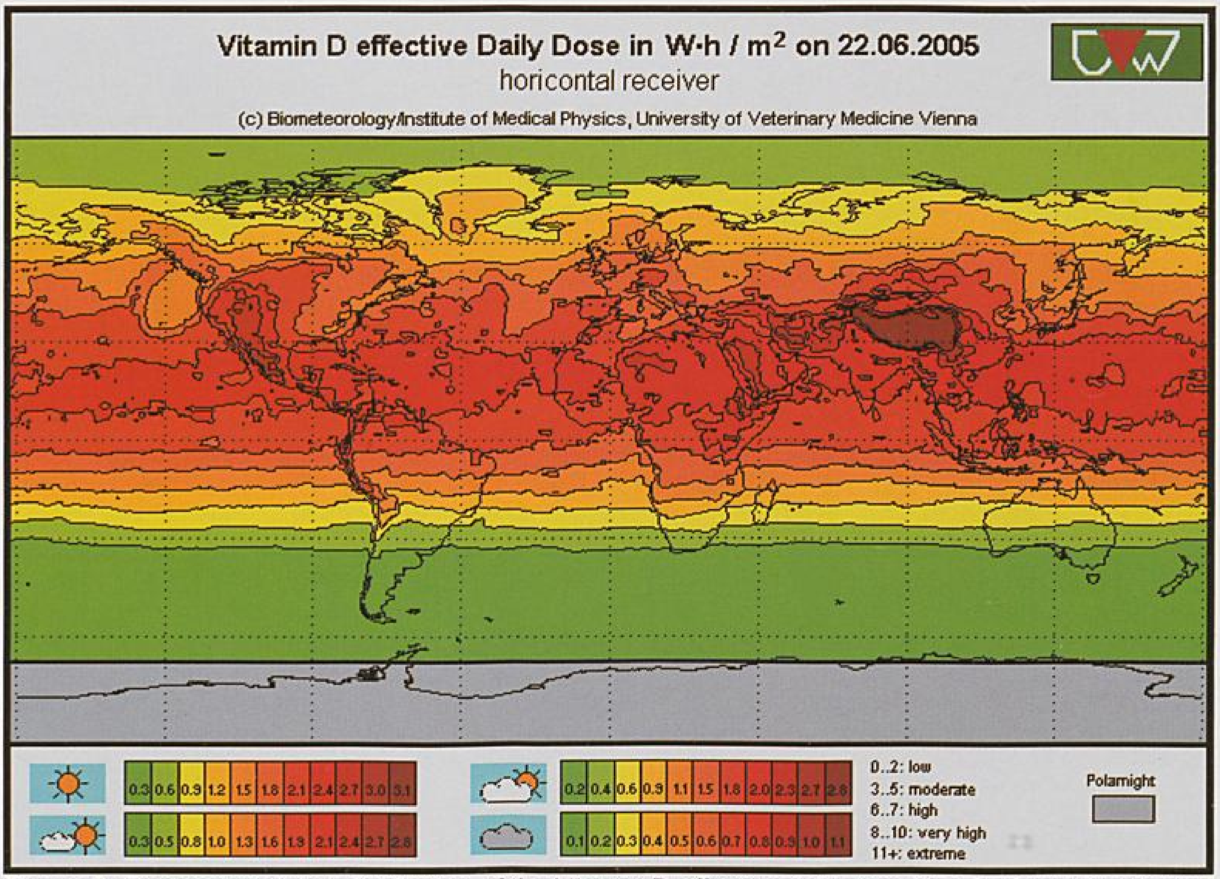


**Figure 3:** Forecasted global distribution of the Vitamin D effective daily dose for a horizontally oriented plane receiver.

## 4 DISCUSSION AND CONCLUSION

Modern live style may lead to an unproper intercourse with the sun. During holidays and spare time many people tend to overexpose themselves (by solar UV or sun beds). During the past years many efforts were undertaken to inform the public to avoid health damage due to overexposure on solar UVR (e.g. Vanicek et al. 2000). Since 1995 also a UV-Index forecast is done at our institute together with recommendations for a sun protection factor for different skin types. On the other hand low Vitamin D levels were reported e.g. by Brustad et al. (2003) for the European population. However a satisfactory vitamin D level should be ensured to reduce the risk for several diseases and types of cancer. Oral Vitamin D supplements or the use of sun beds may be critical and should be applied only under medical supervision.

We have made the first approach in forecasting the vitamin D effective daily dose. The forecast provides the global distribution of the vitamin D effective daily dose for a horizontally and a vertically oriented plane receiver visualised by maps. The forecast is free available via the internet and can be found at: http://i115srv.vu-wien.ac.at/uv/uv_online.htm. The validation for Vienna, Austria has shown that the forecast values are in good agreement with converted measurements from a broadband meter (Model 501, Solar Light, Inc.). The next challenge will be to give the forecasted or modelled effective UVR a deeper meaning so that people can adapt their behaviour.

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# SOLAR UVB RADIATION AND VITAMIN D SYNTHESIS: DIRECT MONITORING OF THE VITAMIN D SYNTHETIC CAPACITY OF SUNLIGHT IN KIEV AND IN ANTARCTIC

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## 1 INTRODUCTION

Small changes in solar UV-B radiation (280-315 nm) at the Earth's surface caused by ozone depletion may have a significant impact on biological systems. Excessive UV exposures are commonly associated with adverse health effects (erythema, skin cancer), but proper amounts of UV are beneficial for people and essential in the natural production of vitamin $D_3$ in skin that plays an essential role in calcium homeostasis [1].

Emerging new research indicates that vitamin D is a critical hormone that is more important to human health than previously thought. These investigations put a greater importance on vitamin D which the body develops from sunlight exposure. Recent epidemiologic studies [2] demonstrate that cancer mortality rates are correlated inversely with local solar UV-B doses for 13 types of cancer, and the most likely mechanism whereby solar UV-B radiation provides protection against cancer is natural production of Vitamin D.

The UV-B portion of sunlight converts provitamin $D_3$ (7-dehydrocholesterol, 7-DHC) in skin into previtamin $D_3$. Once formed, previtamin $D_3$ is thermally converted into vitamin $D_3$ (Figure 1). Just the photochemical stage vitamin D synthesis *in vitro* (ethanol solution of 7-DHC) was used for the first time [3] for direct measurement of the vitamin D synthetic capacity of sunlight. At that time HPLC-assisted analysis was applied to multicomponent photoisomer mixture formed during an exposure to sunlight due to the side photoconversions of previtamin D. Later on the original spectrophotometric analysis had been designed for an *in situ* 'antirachitic' UV dosimetry [4,5].

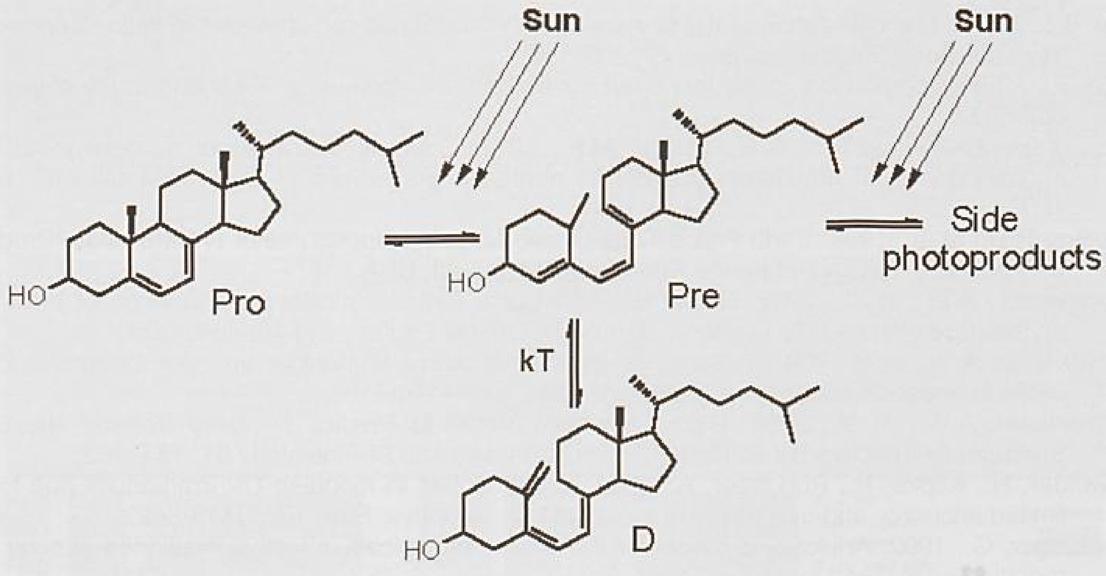


Figure 1. Schematic representation of vitamin D synthesis under solar irradiation

It is important to keep in mind that commonly used broadband radiometers that have an output in sunburn units, can not provide accurate data on the vitamin D synthetic capacity of sunlight because of significant difference between the CIE erythema and Vitamin D synthesis action spectra [4].

## 2 METHODS

Permanent monitoring of biologically active (antirachitic) solar UV radiation in Kiev (50°23'N, 30°32'E) and at the Vernadsky station in Antarctic (65°15'S, 64°16'W) was carried out during 2004. In Kiev two rectangular quartz cuvettes of 0.5cm thickness with 7-DHC ethanol solution (C = 20 mkg/ml) were exposed at the roof of the Institute of Physics building during 3 hours (from 11:30a.m. to 2:30p.m. local time). Normal incidence of sun rays to the cuvette plane was secured by specially developed servomechanism for auto tracking solar zenith angle. Additionally, in Antarctic the solution was exposed in spherical quartz cuvette to examine the albedo effect under global UV irradiance (Fig. 2).

Figure 2. Dr. Igor Gvozdovskyy installs quartz cuvettes with solution of 7-dehydrocholesterol for exposure to sunlight in Antarctic (left) and Ms. Tatiana Orlova provides UV monitoring in Kiev (right).

The solution absorption spectra were recorded before and after an exposure with UV-VIS spectrophotometer PerkinElmer Lambda 25 within spectral range 230-330 nm with a 1 nm step and further were processed with computer for concentration analysis [5].
In addition, accumulation of previtamin D accumulation during the exposures was calculated using the UV solar spectra calculated according to standard RT model [6] at the photoreaction model input [4].

## 3 RESULTS

The UV solar spectra were calculated for different ozone layer thickness. As an example, the calculated solar UV spectra for the minimum SZA = 41°48' (December 22, 12:00 local time, 16:00 GMT) at the Antarctic Vernadsky station and for the minimum SZA = 26°48' in Kiev (June 22, 13:00 local time, 10:00 GMT) are shown in Fig.3 together with provitamin D absorption spectrum.

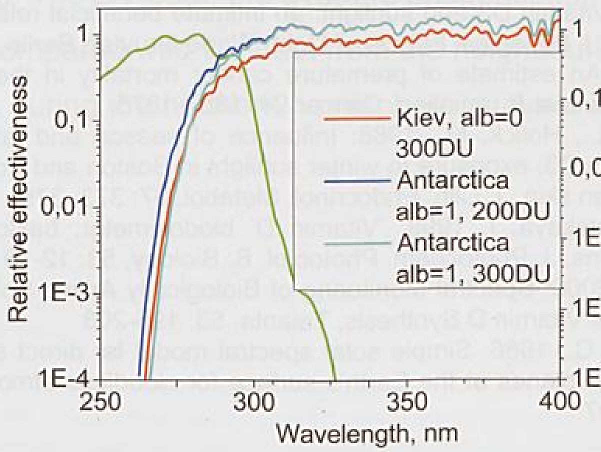


Figure 3. Calculated Solar spectra in Kiev and Antarctic using the Fastrt program (www.zardoz.nilu.no/~olaeng/fastrt/fastrt.html). Green line – the absorption spectrum of provitamin D.

Comparison of the experimentally measured and calculated (cloudless sky) concentrations of previtamin D in Kiev is shown in Figure 5 (left). The same data for the accumulation of previtamin D in Antarctic for global sunlight irradiation are shown in Fig. 5 (right) together with calculated concentrations of previtamin D.

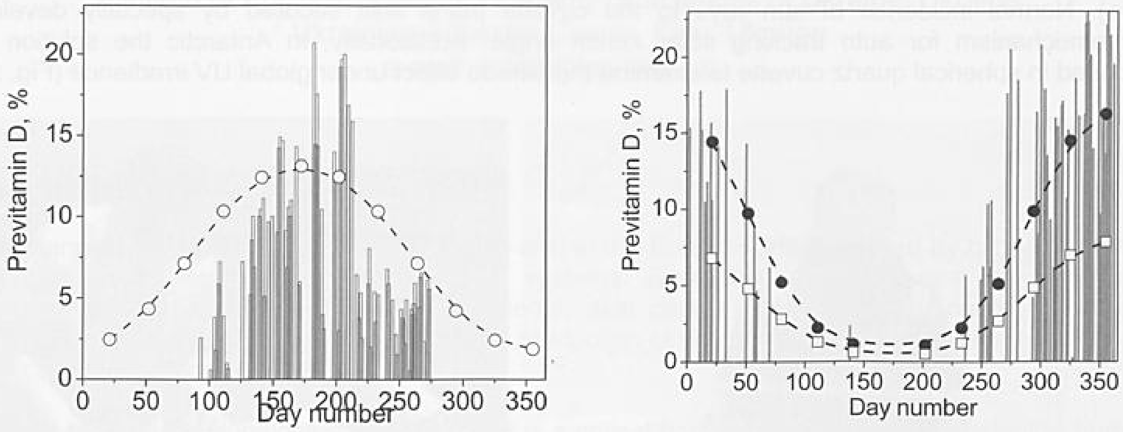


Figure 5. Experimentally measured photosynthesis of previtamin D (*in vitro*) in 2004 as a result of 3 hour exposure in Kiev (left) and in Antarctic (right) - *columns* and calculated concentrations for the ozone layer thickness 200 DU (*solid symbols*) and 300 DU (*open symbols*).

## 4 CONCLUSION

For the first time permanent monitoring of the vitamin D synthetic capacity of sunlight was carried out in Kiev and in Antarctic. The periods of the 'vitamin D winter' when vitamin D synthesis is inhibited due to the low levels of UV-B irradiance at the Earth's surface were determined both by calculations and experimentally. As one can see from Fig.5, during the observation period season and weather impact on solar UV radiation significantly affected the vitamin D synthetic capacity of sunlight. The role of stratospheric ozone layer thickness and of high albedo on the vitamin D synthesis in Antarctic is also clearly seen from Figure 5.

**Acknowledgments** The work was supported by the Science and Technology Center in Ukraine (Project Gr-50).

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# THE UV MEASUREMENTS ON THE HENRYK ARCTOWSKI POLISH ANTARCTIC STATION

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Large ozone deficiencies, “the ozone holes”, are observed over Antarctica from the beginning of the 1980’ with the potential implications of the UV increase, dangerous to the environment. It is therefore very important to perform UV radiation measurements in Antarctica. The Henryk Arctowski Polish Antarctic Station (62º10’ S, 58º28’ W), under Department of Antarctic Biology, Polish Academy of Science, is situated on the coast of the Admiralty Bay jutting out into the land, ie. King George Island one of the South Shetland Islands. During the southern hemisphere summers, 2003/2004 and 2004/2005, the UV measurements have been performed at the Polish Antarctic Station. The radiometers from the Centre of Aerology, IMWM, measured the erythemal UV radiation: during the summer 2003/2004 with the SL 501 UV-Biometer, during the summer 2004/2005 with three instruments: SL 501 UV-Biometer, NILU-UV and UV Radiometer UVEM 6C (Optix). One of the biggest total ozone holes was observed over Antarctica during the spring 2003. The minimum total ozone measured on the Brazilian Antarctic Station (on King George Island) was 121 DU on October 6 2003. The Henryk Arctowski Station was within the range of this ozone hole. The high UV-B radiation values recorded on the s tation during the Antarctic summer of 2003/2004 and 2004/2005 resulted from small ozone content in the declining ozone holes. The UV data, the average and maximum diurnal cycles, have been analysed and compared with UV data from the neighbouring Antarctic stations and with the UV data during the northern hemisphere summer at Polish station Leba (54.8º N, 17.5º E).

# RESPONSE OF POLYSULPHONE DOSIMETERS EXPOSED UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

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## INTRODUCTION

The importance of solar ultraviolet radiation UV and its impact on human heath is widely recognized in the scientific community. The only well-established beneficial effect of solar UV is the production of vitamin $D_3$ required for skeleton health, while the harmful effects (acute and chronic) of UV exposure mainly concern damage to the soft tissues of the eyes and skin.
Solar UV flux reaching the earth's surface is influenced by numerous atmospheric factors, such as the absorption and scattering by molecules (oxygen and ozone) and by aerosols and clouds. The Sun's activity, earth-sun distance, surface albedo, latitude and altitude above sea level affect the variability of UV radiation on the ground.
Currently there is still low spatial coverage of ground-based instruments measuring UV irradiance (spectral or on a wide wavelength range) and the length of time over which reliable UV observations have been made, is still only around 10 years. UV sensors can be classified as, spectroradiometers, broadband and narrowband multifilter radiometers. These instruments measure the irradiance on a horizontal surface (ambient UV radiation). Radiative transfer models and satellite instruments are further resources for studying ambient UV radiation typically over a broader (global) scale when compared to isolated instrument measurements.
The impact of UV radiation requires knowledge of the action spectra of biological systems, namely of functions expressing the effectiveness of electromagnetic radiation in causing a specific response in a biological system. The erythemal action spectra is a weighting function which simulates the damaging process occurring in the skin (Diffey and McKinley, 1987).
However, although the biological action spectra can help in understanding some biological effects, they do not contain information on the simultaneous effect of multiple wavelengths and feedback mechanisms.
An accurate methodology for recording level of exposure in different body postures is based on the use of polysulphone dosimeters, a polymer which changes its optical properties (absorbance) when exposed to UV radiation. Its response is close to the erythemal response of human skin (Kimlin, 2003).
This work aimed to define ambient UV radiation in terms of UV index at middle latitudes using well calibrated and maintained instruments and to quantify the exposure ratio (ER) of differently-oriented surfaces at sites having different environmental conditions.

## 1. CHARACTERIZATION OF AMBIENT UV RADIATION AT THE MID LATITUDE OF ROME

Solar spectral irradiance (from 290 to 325 nm at 0.5nm wavelength increments) and total irradiance has been measured at the Rome station by means of Brewer spectrophotometry (single monocromator) since 1992 and broad-band meter (model UVB-1, Yankee Environmental System, MA, USA) since 2000. Values of the erythemal dose rate using the C.I.E. action spectrum (McKinlay-Diffey, 1987), integrated up to 400 nm are obtained from Brewer UV measurements or alternatively from the YES radiometer which has a spectral response similar to that of skin erythema.
The solar radiometry station is located on the roof of the Physics Department building of the University of Rome "La Sapienza" (41.9°N, 12.5°E, 60m a.s.l.). This building is one of many on the extensive University campus, which itself is located very close to the center of the city and thus influenced by intense human activity. For this reason the site is classified as "urban" (Meloni et al., 2000). More details on the site and on data quality control can be found in Casale at al., 2000.
Rome is influenced by the European continental climate and the Mediterranean climate with precipitation in the cold and mid season and a dry, hot summer.

A characterization of this middle latitude site, in terms of UV index, UVI (COST -713, 2000) will now be provided. The UV Index is a measure of the intensity of harmful UV radiation at the Earth's surface and UVI is calculated by weighting the irradiance (280-400nm) using the erythemal action spectrum, and the dose rate obtained is divided by 25 $mW/m^2$ in order to produce a unit-less quantity.
Figure 1 shows daily means of the UV index values for Rome for the period 1992-2004 at approximately mid-day local time on clear-sky days. The seasonal variation is clearly evident, with higher values in summer (up to 8) and low ones ( <3) during winter.

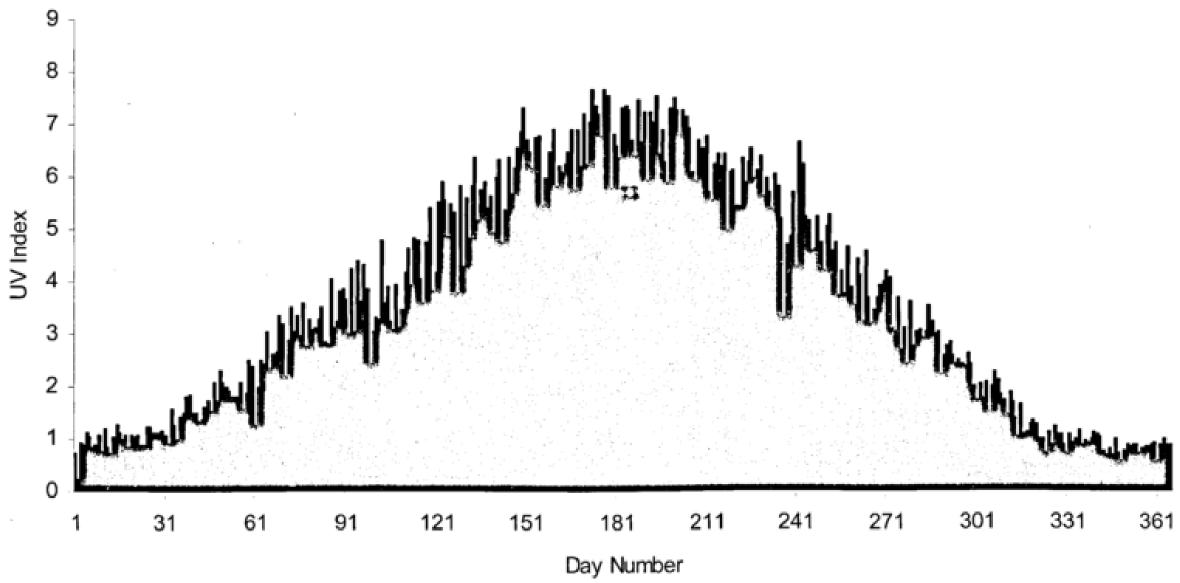


Figure 1: Daily means of UV index

Following the guidelines provided by COST-713, 2000) UVI values are grouped into exposure categories from low (0-2) to extreme ( >11).
Seasonal distribution of frequency of UVI values within each category at Rome is given in Table 1

*Table 1:* Seasonal UVI frequency distribution at Rome

| | Low UVI range: 0-2 | Moderate UVI range: 3-5 | High UVI range: 6-7 | Very high: UVI range:8-10 |
|---|---|---|---|---|
| Dec-Jan-Feb | 99.0% | 1.0% | | |
| Mar-Apr-May | 27.7% | 52.5% | 18.6% | 1.2% |
| June-July-Aug | 5.4% | 20.7% | 63.5% | 10.4% |
| Sept-Oct-Nov | 54.1% | 43.9% | 1.3% | 0.7% |

It can be seen in Figure 2 that in summer higher UV levels (UVI = 8-9) occur on only 10% of days, while the most frequent category is "High" (about 65%). The potentially harmful consequences of this situation for human skin cannot be ignored, especially when the time of exposure is prolonged. In the cold season levels of UV radiation are "Moderate

## 2. METHODOLOGY

Polysulphone dosimetry is a reliable and widely tested methodology to assess ultraviolet radiation exposure (Davis et al., 1976; Parisi et al., 1996, Kimlin 2003). Polysulphone is a polymer which changes its optical properties (absorbance) when exposed to UV radiation, and it has response matching closely the erythemal action spectrum. Following the procedure described in Kimlin (2003) polysulphone calibration curves were obtained by measuring doses and corresponding changes in absorbance (ΔA at 330nm), prior and post exposure. Doses were measured by the YES broad-band, detector calibrated at the European Reference Centre for Ultraviolet Radiation Measurements (Joint Research Centre, Ispra, Italy) in 2004 and they agree with those measured by Brewer at Rome "La Sapienza"(within 10% of uncertainty).

A pilot study using an exposure device capable to set the dosimeters at fixed different zenith angles (ZA) (Figure 3) under different environmental conditions is carried out to estimate the exposure ratio (ER). This is defined as ratio between the dose received by a differently-inclined surface to the ambient UV dose (i.e that received by horizontal surface). The device is a holder capable to expose dosimeters placed from ZA= 0° (horizontal dosimeter) to ZA= 90° (vertical dosimeter) at every angle of 15°. Such device can provide an useful estimate of ER when data from experiments *in vivo* or with manikins are not available. When ER is known for each angle and in different sites then it could be possible to model exposure of different parts of the body on the basis on their orientation, on measurements of the ambient UV levels, and on activity index (Kimlin,2003).

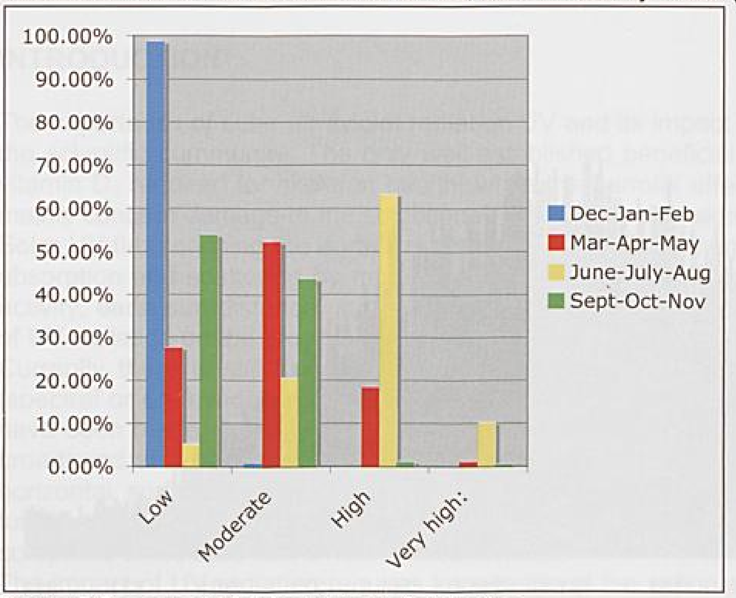


Figure 2 Seasonal UVI frequency distribution

Figure 3: The exposure device for estimating ER

In order to test the device and to assess the variability of exposure from local environment conditions, experiments took place at an urban site (Rome, city centre, Lat.41.9°, Long.12.5°), at a coastal site close to Rome (Fregene, Lat.42°, Long.12.2°), on the mountain site with snow cover (Roccaraso (AQ) on Apennine, Lat. 42°, Long.14°, 1680m a.s.l.), and at rural site (S. Felice (SI) in Tuscany, Lat.43.3°, Long.11.3°) during spring 2005 under clear sky conditions. All sites are located around the latitude of 42° and over the solar zenith angle (SZA) range of 21° to 61° during this season. During the field campaigns the device was faced at south, and the exposure time was chosen centred at local noon in order to have the same ambient dose in all sites (four hours at urban and mountain sites, five hours at rural site and three hours at the beach site.) In these field campaigns the YES radiometer was utilized as travelling instrument for measurements of the ambient exposure.

## 3. RESULTS

Measurements of ambient doses recorded by the radiometer located close to the exposure device were compared with doses incident on horizontal dosimeter (ZA=0° ER=1). Both values for each field campaign are reported in Table 2 and they show a reasonable agreement within the associated uncertainties.

*Table* 2: Ambient Exposure measured by the radiometer and derived from dosimeter at ZA=0°

| Site | Ambient Exposure($Jm^{-2}$) from the radiomter | Ambient Exposure ($Jm^{-2}$) Dosimeter at ZA=O° |
|---|---|---|
| S. Felice (on the 4th April,2005) | 1900±100 | 2000±200 |
| Roccaraso (on 20th March 2005) | 1800±100 | 2100±200 |
| Rome (on 2nd May 2005) | 1900±100 | 1700±200 |
| Fregene (on 27th May 2005) | 2000±100 | 1900±200 |

In Figure 4 values of ER versus ZA of exposed dosimeters are plotted for the considered sites.

All curves decrease gradually approximately at ZA= 30° except the mountain site where the ER curve remains close to 0.9. This can be due to the contribution of the additional upwelling radiation to enhance the exposure of inclined surfaces. In presence of snow the effect of ground albedo becomes significant while it is not visible in other conditions.

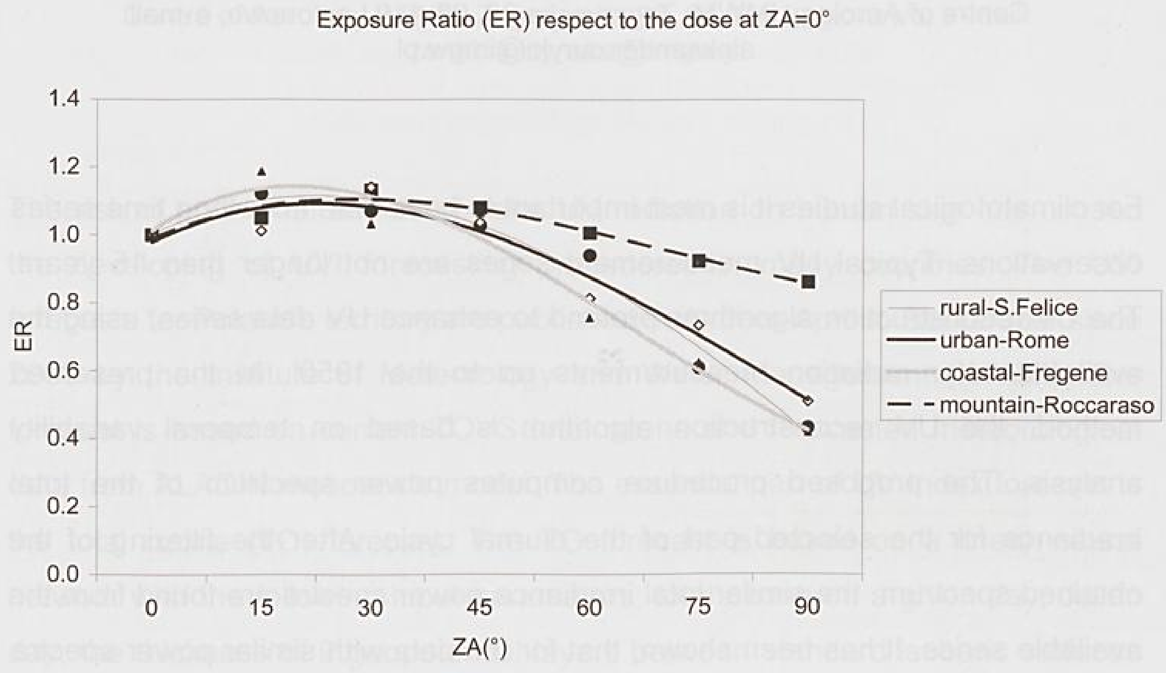


Figure 4 Exposure ratio respect to the dose at ZA=0°, the lines represent the best fit to the data.

## 4. CONCLUSIONS

In this preliminary study, results from pilot experiments, aiming at estimating the exposure ratio of inclined surface in different environment conditions were presented. An UV dosimeter exposure device capable to set the dosimeters at fixed different solar zenith angles (SZA) was used. It is interesting to note that when ground albedo is high ( specifically snow) produce an enhancement of the exposure of inclined dosimeters due to the increasing ratio of direct to diffuse radiation. In fact the exposure ratio is only slightly smaller than the horizontal value. Such results from this high albedo site indicate that human exposures in this region are altered when compared to a low albedo site.

This study will be followed by other field campaigns in order to collect more data about ER and hence to better assess environmental factors affecting human exposure.

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## A NEW APPROACH TO THE UV RECONSTRUCTION MODELING

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For climatological studies it is most important to have data from long time series observations. Typical UV measurement series are not longer then 15 years. The UV reconstruction algorithms pretend to enhance UV data series, using the available solar radiation measurements up to the 1950'. In the presented method, the UV reconstruction algorithm is based on temporal variability analysis. The proposed procedure computes power spectrum of the total irradiance for the selected part of the diurnal cycle. After the filtering of the obtained spectrum, the similar total irradiance power spectra are found from the available series. It has been shown, that for the data with similar power spectra in total irradiance, the power spectra in the UV transmittance are as well similar. So, it is possible to calculate the all-sky UV irradiance, using the UV transmittance and the radiation transfer model for clear-sky. This algorithm is particularly useful to estimate the effect of clouds on the downwelling shortwave irradiance (without direct cloud observations). The algorithm can be applied for UV reconstruction, using auxiliary information on total solar irradiance, total ozone and aerosols. The STREAMER and libRadtran radiation transfer models have been used for testing the proposed UV reconstruction algorithm. The testing has been performed on available long and good quality data from selected European sites within COST 726 Action, representing different climatological conditions.

# The UV Index forecasting and nowcasitng in Poland

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The risk of erythemal effects of solar UV radiation on human skin has caused the developing of UVI forecasting procedures in many countries. The UVI forecasts for Poland's territory are published daily from April to September since 2000 by the Institute of Meteorology and Water Management (IMWM). The forecast is based on current TOVS total ozone and forecasted meteorological data from ALADIN mesoscale model. The essential part of UV Index forecast is the total ozone (TO) forecast. The TO forecast is based on a linear neural network with the following input parameters: total ozone on a given day; Julian day, the thickness of 9 geopotential layers between standard isobaric surfaces on a given day and on the next day. UVSPEC radiation transfer model from libRadtran package has been applied for the UV Index forecast. To speed up the calculations, two look-up tables for different layers have been prepared. Linear interpolation between these layers allow to include the orography into the forecast.

UV Index forecast consists of two maps: one for clear sky conditions and the other one for all sky, using mesoscale cloud forecast and modification factor. The maps are presented with 0.25x0.25 deg spatial resolution.

As an extension of information for public about UV radiation in Poland, IMWM has introduced real time UV observations published since 2005. The observations are taken from UV network consisting of 6 erythemally weighted UV radiometers OPTIX UVEM 6C located across Poland's territory from Baltic coast up to Tatra Mountains. The results are presented in the form of UVI diurnal cycles actualised hourly during the day, and also as a map with the latest measured UVI.

The forecasting and nowcasting information are available on the IMWM web site www.imgw.pl.

# ULTRAVIOLET INDEX CLIMATOLOGY FOR ALL BRAZILIAN REGIONS

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## INTRODUCTION

The Ultraviolet Index has been used to avoid solar exposure problems in some parts of the world. In Brazil, the population's behavior get to a dangerous scenarios and the medical society is in alert. This was the motivation to study the Ultraviolet Index Climatology for all regions of Brazil.

## METHODS

Using data of the Nimbus7 (data serie from 1979 to 1992) and EarthProbe satellites (data serie from 1997 to nowadays), both using TOMS sensor (Total Ozone Mapping Spectometer) was developed a climatological study of the ultraviolet index (IUV) for all brazilian regions.

## RESULTS

Could be verified the highest values of UVI in the North and Northeast regions and there was not reduction at moderate levels (and safes) during the winter. Others brazilians regions presented contrasts between summer (high and dangerous values) and winter (low and safe values).

## DISCUSSION

The discussion involves the exposure levels and the Ultraviolet Index obtained for brazilian regions and mainly for the main beaches along the coast.

# GLOBAL ULTRAVIOLET RADIATION IN LODZ (CENTRAL POLAND)

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## 1 INTRODUCTION

Biologically active solar wavelengths 290-400nm (UVA+UVB) constitutes of 7.915% of Solar Constant on the upper limit of the atmosphere (Thekaekara 1971). The transmission of UV radiation through the atmosphere varies with solar elevation, content of ozone, water vapour, aerosol, dust particles, clouds parameters e.g. optical thickness, liquid water content, droplets size, location on the sky. UV radiation reaching the Earth's surface in Europe does not exceed 5% of global solar radiation under cloud-free sky (Feister and Grasnick 1992, Martinez-Lozano et al. 1999). The diverse geometry structure of urban surface and atmospheric turbidity there are additional factors determine amount of solar energy in the urban area. The urban street canyon, the basic urban surface unit is distinguished from the open environs by trapping and multiple reflection of solar beam, the diurnal courses of solar radiation flux, thermal conditions, concentration of pollutants etc. (Ludwig 1970, Nunez and Oke 1977, Oke 1987). The studies on UV radiation flux inflow in the urban area are rather uncommon in Poland and same results have been published for Lodz (Podstawczyńska and Pawlak 2003) and for Warsaw (Błażejczyk and Baranowski 2003). The aim of this research is to investigate the temporal variability of UVA+UVB radiation in relation to global solar radiation, the clouds effects and the urban street canyon impact on UV radiation in the centre of Lodz.

## 2 METHODS

The data base consisted of measurements of global UV radiation (UVA+UVB, 290-400nm, direct and diffuse) and global solar radiation (305-2800nm, direct and diffuse) by means of Kipp&Zonen CUV3 radiometer and CM11 pyranometer at Lodz-Lipowa meteorological station (51°45'N, 19°26'E, 220 m a. s. l.) in 1997-2002. The station was located on the roof of 18m height building in centre of Lodz (south-west part of the old compact residential area). The results of experimental research of UV and global solar radiation in the north-south oriented urban canyon (on Piotrkowska St. - "an axis" of centre of Lodz) 20m wide with 1.1 height to width ratio were also examined in the paper. The measurements in the canyon were carried out 1.8m above street level and 3m from the west – facing and east - facing canyon walls in May and June 2002 (radiometers CUV3 and CM11, maximum solar elevation 60°). The study focused on the 10-min averages of UV ($I_{UV}$) and global ($I_G$) solar irradiance on horizontal surface in $Wm^{-2}$, the daily values of solar energy ($D_{UV}$, $D_G$) in $MJm^{-1}$, the ratio of UV to global solar radiation ($R_{UV/G}$) in % and clearness index of UV and global solar radiation ($K_{UV}$, $K_G$) in %.

## 3 RESULTS

### 3.1 SOLAR RADIATION IN AN OPENED SITE (LODZ - LIPOWA STATION)

Over the year the maximum daily sun elevation at Lodz-Lipowa station varied from 14.7° (December) to 61.7° (June). Annual courses of the daily sums of UV and global solar energy were similar and the lowest values occurred in December (0.01$MJm^{-2}$ $D_{UV}$ and 0.3$MJm^{-2}$ $D_G$) and the highest occurred in June (1.2$MJm^{-2}$ $D_{UV}$ and 30.4$MJm^{-2}$ $D_G$) (Figure1). The solar energy sums were distinguished by the high day-to-day variation especially from April to August due to deep convective clouds. Total atmospheric transmission conditions for solar radiation can be described by clearness index defined as the ratio of incoming solar radiation ($D_G$, $D_{UV}$) on the Earth's horizontal surface to the extraterrestrial solar radiation ($D_{G0}$, $D_{UV0}$) on the horizontal surface (Liou and Jordan 1960, Iqbal 1983, Sadler 1992, Martinez-Lozano and Casanovas 1994). The daily clearness index of UV ($K_{UV}$) and global solar radiation ($K_G$) was obtained the following : $K_G=D_G/DG_0$ (in %), $K_{UV}= D_{UV}/D_{UV0}$ (in %). UV clearness index ($K_{UV}$) was approximately half less than the global solar radiation clearness index ($K_G$). The mean daily $K_{UV}$ varied from 14% in December to 26% in May (Figure 2).

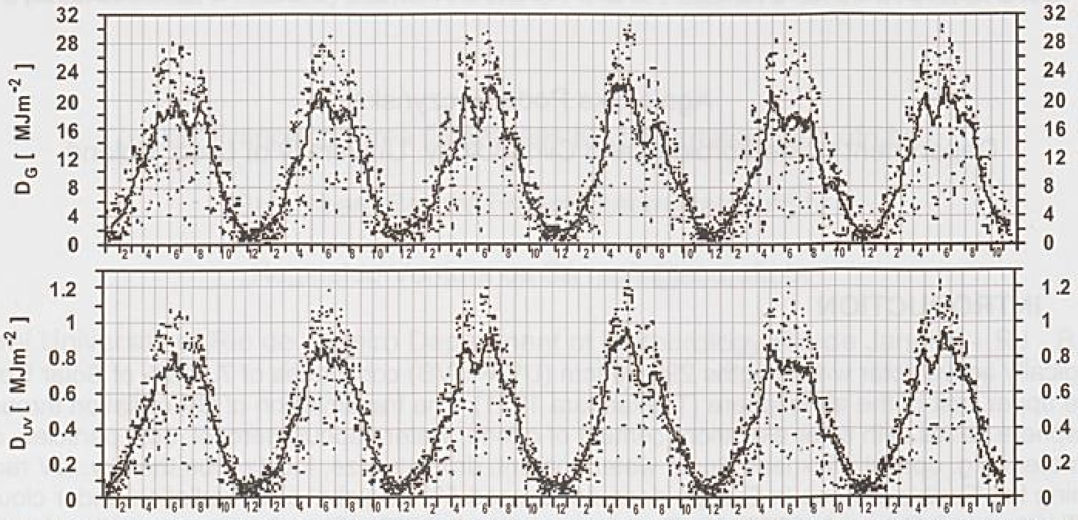


Figure 1. Annual course of the daily sums of global solar radiation ($D_G$) and ultraviolet radiation ($D_{UV}$) at Lodz-Lipowa station in the period 1997-2002. Solid line – 31-day running average.

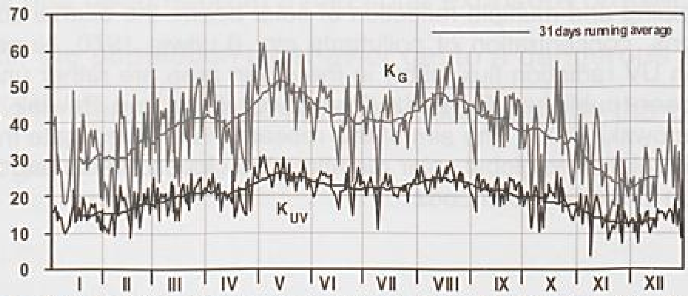


Figure 2. Annual course of the daily clearness index of global ($K_G$) and UV ($K_{UV}$) solar radiation at Lodz-Lipowa station in the period 1997-2002. Solid line - 31-day running average.

The absolute maximum values of $K_{UV}$ amounted 37% occurred in May, the minimum were obtained in November and December and amounted less than 10%. In the summer the maximum irradiance did not exceeded 40Wm$^{-2}$ ($I_{UV}$) and 920Wm$^{-2}$ ($I_G$) during cloudless condition. The absolute maximum irradiance recorded at Lodz-Lipowa st. in 1997-2002 were higher about 10-20% than the values in clear days (Figure 3). The irradiance increases were caused by reflection from the lateral sides of *Cumulus* - type clouds (Mims and Frederick 1994, Estupinan and Raman 1996). The duration of the phenomenon usually was less than an hour and typically it was 10-20 minutes.

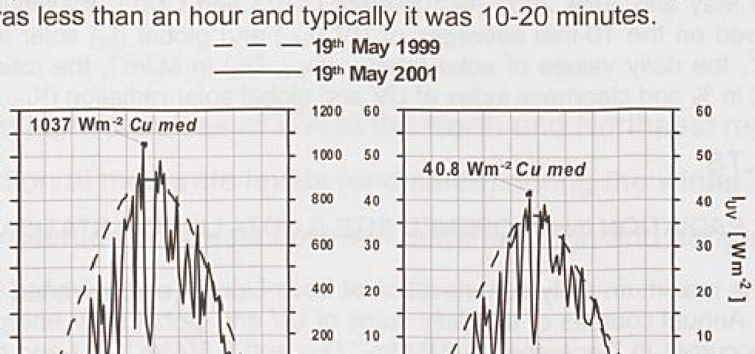


Figure 3. Daily course of global ($I_G$) and UV ($I_{UV}$) solar irradiance in the clear day (19$^{th}$ May 1999) and in the day with convective clouds (19$^{th}$ May 2001) at Lodz-Lipowa station.

In clear days the ratio of UV to global solar radiation ($R_{UV/G}$, %) varied from 2.1% (in winter) to 4.5% (in summer). Clouds thickness variation influenced on transmission of UV to a lesser degree than the global solar radiation and at Lodz-Lipowa st. the increase of $R_{UV/G}$ reached 8% when the global solar irradiance decreased during cloudy condition (Figure 4).

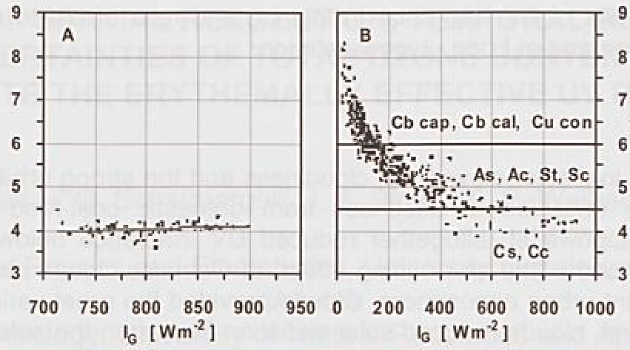


Figure 4. The ratio of UV to global solar irradiance($R_{UV/G}$, %) as a function of global solar irradiance ($I_G$, %) in various atmospheric condition at Lodz-Lipowa station: A – cloudless sky, sun elevation ≥50°, B – overcast sky, sun elevation ≥50°.

## 3.2 ULTRAVIOLET RADIATION IN THE URBAN STREET CANYON

The horizon obstruction in the urban canyon described by sky view factor (SVF) was half less than at Lodz - Lipowa st. (Figure 5). In the canyon UV irradiance ($I_{UV}$) was in the range of 20-25Wm$^{-2}$ during sunlit period and it was lower about 25% than $I_{UV}$ registered at opened site (Figure 6). $R_{UV/G}$ value at Lipowa station amounted 3.9% on average while in the urban canyons the ratio depended on the inflowing solar radiation components. When the measurement instruments in the canyon were sunlit, $R_{UV/G}$ was lower than the ratio at Lipowa station and amounted 2.9 % on average. The ratio in the urban canyon amounted 6.5% on average when the instruments in the canyon were shadowed (Figure 6).

Canyon N-S (the east-facing wall) SVF=0.424; H/W= 1.1

Canyon N-S (the west-facing wall) SVF=0.432; H/W= 1.1

Lodz-Lipowa meteo station, SVF=0.993

Figure 5. Fish eye photographs from experiments' sites in the urban canyon and at Lodz-Lipowa meteorological station.

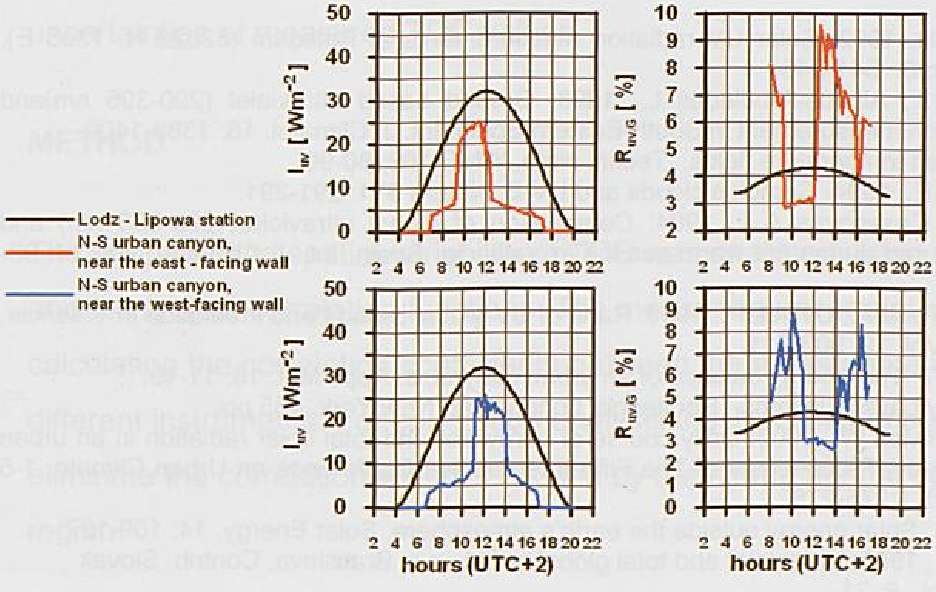

Figure 6. The daily courses of UV ($I_{UV}$) solar irradiance and ratio of UV to a global solar irradiance ($R_{UV/G}$) in the urban canyon and at Lodz - Lipowa station.

## 4 DISCUSSION

In the winter months the low solar elevations, cloudiness and the strong urban impact i.e. increase of air turbidity due to the emission of dustiness from domestic coal-fired heating system in the neighbourhood of Lodz-Lipowa st. altogether reduced UV irradiance below 10% of extraterrestrial values. In the summer months "the silver lining effect" of *Cumulus* clouds partly compensated losses of UV radiation in pollutant urban atmosphere. Clouds provided the great variability of surface UV and global radiation. In general, clouds reduced solar radiation flux when the solar disk was obscured but caused enhancement the relative contribution of UV in global radiation. The higher albedo, the stronger scattering process on clouds elements in UV wavelength and the stronger absorption by water vapor in near infra-red wavelength were the reasons for the increase of the ratio of UV to global radiation. The increase of the ratio $R_{UV/G}$ under cloudy sky was stated at European stations e.g. Potsdam (Germany, Feister and Grasnik 1992), Valencia (Spain, Martinez-Lozano et al. 1994,1999), Bratislava (Slovakia, Zavodska and Reichrt 1985), Jungfraujoch (Switzerland, Blumthaler et al. 1994), Granada (Spain, Foyo-Moreno et al. 1998).

The main role in forming the amount of attenuation of the UV radiation in the urban street canyon played the canyon geometry, the horizon obstruction, spectral albedo on surfaces (UV radiation was more absorbed on the canyon surfaces) and spectral characteristics of the scattering process.

## 5 CONCLUSION

In clear days UVA+UVB irradiance consisted 2-4.5% of global solar irradiance while in cloudy weather reached 8%. "The silver lining effect" of convective clouds caused increase of UV irradiance at Lodz-Lipowa station even to 120% of the clear sky value usually for a period of 10-20 minutes. The maximum UV irradiance at 1.8m above street surface in the main urban canyon in center of Lodz did not exceed 75% the UV values recorded at an open site. Cloud influence on surface UV solar energy (scattering and reflection processes) modified the urban impact. This problem needs to be investigated.

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# COMPARISON OF SPATIAL RESOLUTION, TEMPORAL RESOLUTION AND MEASURING UNCERTAINTIES OF TOTAL OZONE CONTENT AS AN INPUT TO CALCULATE THE ERYTHEMALLY EFFECTIVE UV RADIATION

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## INTRODUCTION

Beside the sun elevation angle, the total ozone content of the atmosphere (TOC) is one of the main model input parameters to calculate the erythemally effective UV radiation under clear skies. Therefore the TOC was analysed for the domain of Central Europe. The data contains the area from 9°E to 17°E in longitude and from 46°N to 52°N in latitude. Ground based measurements performed at the Solar and Ozone Observatory in Hradec Kralove (Czech Republic) and at Sonnblick High Mountain Observatory (Austria) were used. Measurements were made by Dobson and Brewer Spectroradiometers. To gain the spatial variability satellite measurements (EPTOMS) were analysed. Comparing measurements from Dobson, Brewer, EPTOMS, GOME and TOVS has allowed to estimate the uncertainties of measured TOC values.

## METHOD

The temporal and spatial variability of TOC was analysed using auto-correlation and fitting auto-correlation functions. The measuring uncertainty was estimated by calculating the correlation coefficients between the measurements from the five different instruments. For correlation analysis the TOC has to be de-trended to eliminate the correlation which is caused by the strong annual cycle of TOC in this region.

**RESULTS**

The highest correlation was found for TOC measurements of Brewer and Dobson (0.97). Close to this level are those calculated for Dobson and EPTOMS (0.96) as well as for Brewer and EPTOMS (0.95). Correlation coefficients between all other instruments are significantly lower at levels of

1. 0.88 to 0.84. The lowest correlation becomes visible for GOME and TOVS (0.79).

The temporal correlation decreases rapidly within the first days. A coefficient of

2. 0.97 is reached after 0.2 days, 0.86 after 0.4 days and the lowest level of 0.79 after 0.6 days. Spatial correlation is somewhat different in latitude and longitude. Measurements at a spatial distance less than 10 km posess a correlation coefficient of 0.97, a distance of 30 km is comparable to 0.86 and a distance of 45 km to 0.79.

For calculations of the erythemally effective UV radiation this study shows that one has to account to a monthly mean bias in irradiance up to 0.3 UV-Index (UVI) respectively 2.0 UVI-hours for the daily dose. On the daily base however differences respectively uncertainties in measured TOC may cause errors reaching 1.0 UVI or 10 UVI-hours.

# MODELLING THE SPATIAL DISTRIBUTION OF THE BIOLOGICALLY EFFECTIVE RADIATION FROM MEASUREMENTS AT CERTAIN SITES

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Introduction Operational measurements of the total ozone content (TOC) are made since many years. The period where measurements of the UV radiation are done is much shorter. Information on UV levels and changes in the past as well as their biologically effectiveness can therefore only gained by model calculations. In this work we present a model which enables the recalculation of the UV radiation for the past. The whole model consists of three parts. The core is a radiation model which allows calculations of the biologically effective radiation using at least total ozone values as input parameter. Another important part is a topographic model of the earth's surface enabling the inclusion of altitude effects. To gain a spatial distribution from punctually measured input parameters the interpolation method "Krigging" is applied.

The Model Irradiance as well as some input parameters varies with altitude. For the calculation of the spatial distribution it is therefore essential to include topography. We apply the digital topographic model GTOPO30 which provides altitude values with a spatial resolution of 30arcsec. Altitude depending parameters have to be recalculated to a joint l evel. Otherwise interpolation would already bring in a smoothed topography. Krigging is a so called "blue" method (Best Linear Unbiased Estimator). With this method a matrix can be calculated from spatially irregularly distributed data and even extrapolation is possible to a certain extend. Krigging is applied to the input parameters so that we get their spatial distribution. These distributions together with topography are used finally to calculate the biologically effective radiation over the region of interest.

Calculations are done with a fast spectral model. The minimum requirement to run the model is the availability of total ozone, geographical position (latitude, longitude and altitude) and date and time. Other atmospheric parameters like cloudiness, sunshine duration, aerosols, global radiation etc. can be used optionally. The increase with altitude is handled by a spectral altitude factor. This model calculates the global spectral irradiance for 16 discrete wavelengths between 297.5nm and 400nm. The spectral irradiance can be weighted by any biologically weighting function (action spectrum). The model delivers than the biologically effective irradiance for a certain time or the biologically effective radiant exposure (dose) over a certain period.

# INFLUENCE OF GROUND ALBEDO AND CLOUDINESS ON GROUND UV AT THE SONNBLICK OBSERVATORY (3106 M, AUSTRIA): MODEL - MEASUREMENT COMPARISON

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## 1 INTRODUCTION

Changes in the Earth's atmosphere (e.g., stratospheric ozone and climate) will change UV radiation at the earth's surface. UV radiation at the ground increases with decreasing stratospheric ozone. However, there are other important factors that determine UV radiation levels. The most important are cloud cover, aerosol content, and surface albedo. These parameters are changing as a consequence of the climate change. Knowledge of UV variability and the mechanisms that control this variability are essential information for the development of UV scenarios related to climate change.
Spectral UV measurements at wavelengths from 280 to 400 nm performed during the period from 1994 to 2004 and radiative transfer calculations are used to estimate the influences of ground albedo and cloudiness at the Sonnblick Observatory (3106 m, Austria). UV irradiance is strongly enhanced when the ground is covered by snow due to multiple reflections between ground and atmosphere. The enhancement is larger under overcast than under clear-sky conditions because of the increased atmospheric backscattering due to clouds. McKenzie et al. (1998) showed that - due to snow - UV-B increased by about 30% under clear sky and about 70 % under cloudy sky conditions at Lauder, New Zealand. Kylling and Mayer (2001) investigated the influence of the snowline on the irradiance at 340 nm studying snow-free conditions and moving the snowline from 0 to 1000m. With increasing snowline, enhancement in UV of 23-27% for cloudless sky was obtained, while for overcast conditions the enhancement was around 40-60%.
UV irradiance reflected by the surface is of great importance, especially in snow-covered Alpine regions. 16% of the surrounding area of Sonnblick is covered with glaciers and in winter 88% of the surface is covered with snow, if one assumes that no snow covers the rock faces. An algorithm is introduced using routine observations of snow conditions and snow lines of the Austrian Weather Service to estimate the effective surface albedo in the UV range on a daily basis. Variability of UV-radiation with varying snowline will be shown for clear sky and cloudy sky conditions. Enhancements of irradiance with decreasing snowline are determined using measurements and the radiation transfer model DISORT.

## 2 METHODS

Spectral UV measurements at Sonnblick observatory have been performed with a Brewer single spectroradiometer since 1993 and with a Bentham DM 150 spectroradiometer (double monochromator) since 1997. The Brewer spectroradiometer is used to measure global UV irradiance, the total ozone and the sulphur dioxide column. It is a single grating monochromator with spectral range 290-325 nm and step width of 0.5 nm. Bentham spectroradiometer (double monochromator) is used to measure global UV irradiance with a spectral range of 280-500 nm and step width of 0.5 nm. The radiative transfer model (DISORT) is a tool to estimate the effects of the contributing factors on the observed irradiance variability. Daily time series of total column ozone are available from Brewer spectroradiometer.
The 'effective' albedo that affects the surface UV irradiance is an averaged albedo of the surrounding area. The reflected irradiance from the surrounding is reflected back to the earth by the atmosphere and may therefore cause an enhancement of surface UV irradiance.
Regression analysis (Eqn. 1) delivered parameterisation of the regional albedo, which uses routine information of snow line (G), fresh fallen snow (N) and days since the snowfall (T). The regression equation for the albedo A is:

$$A = 0.659 - 2.04 \cdot 10^{-4} \cdot G + 4.97 \cdot 10^{-3} \cdot N - 3.23 \cdot 10^{-3} \cdot T \qquad (1)$$

Fresh fallen snow increases the 'effective' albedo whereas it decreases with increasing snowline and days after the snowfall. 500 cases are included to generate this regression equation. The explained variance of this parameterisation is 70%, and effective albedo varies from 0.02 to 0.89.

Figure 1 shows calculated values of the effective albedo. Mean values of the albedo determined over a 10 years period are 0.3-0.6 during winter and spring and 0.09-0.25 during summer.

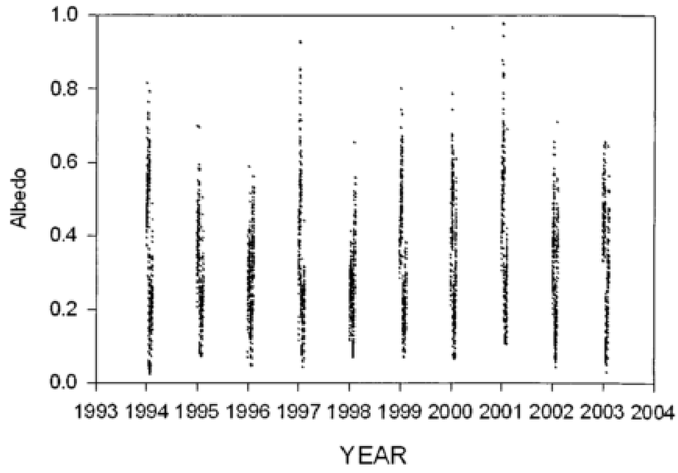


Figure 1: Daily climatology of the effective surface albedo at Sonnblick Observatory

## 3 RESULTS

Figure 2 shows the average enhancement of irradiance at 305 nm incl. standard deviation with decreasing snowline for clear sky and overcast conditions. The ordinate in Fig. 2 shows quotient of irradiance at different snowlines and mean irradiance at a snowline of 3000 m. At a snowline of 800 m this quotient is 1.24 (± 0.04) and at snowline 1500 m 1.14 (± 0.03). Cloudiness enhances the influence of the albedo since multiple reflection between surface and lower bond of the clouds become more probable. 600 measurements with 8/8 cloud cover are included in Fig. 2 to represent overcast conditions. Under 8/8 cloud cover, UV irradiance at 305 nm is enhanced by factor 1.7 when the snowline is 800 m instead of 3000 m.

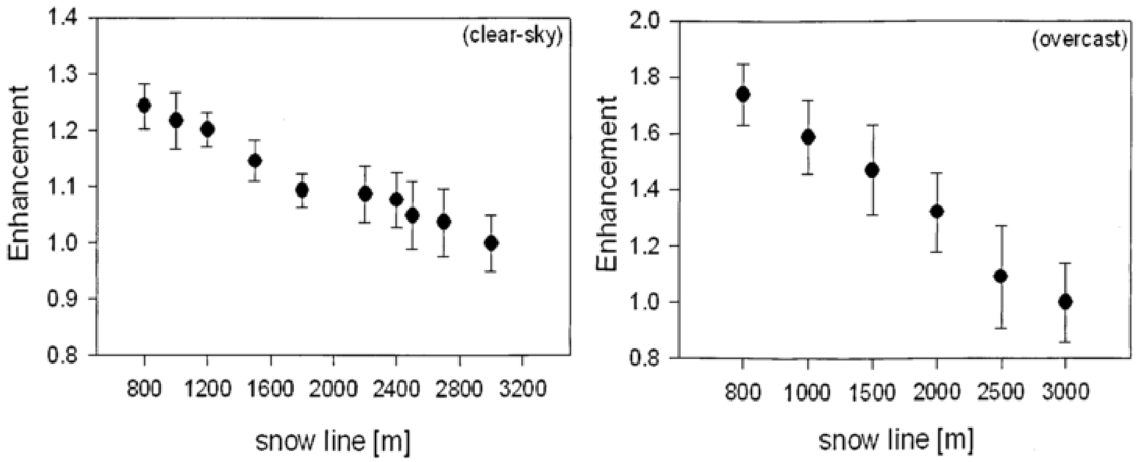


Figure 2: Measured snow line enhancement at 305 nm for clear sky and overcast condition

Multiple reflections between ground surface and lower bond of the clouds could be demonstrated solely for 6/8 cloud cover or more. At 8/8 cloud cover with middle clouds mean UV irradiance is 21% higher if the albedo is 0.4 instead of 0.18 (Fig. 3). In contrast, the cloud modification factor in presence of high clouds is not affected by the albedo (Fig. 3).

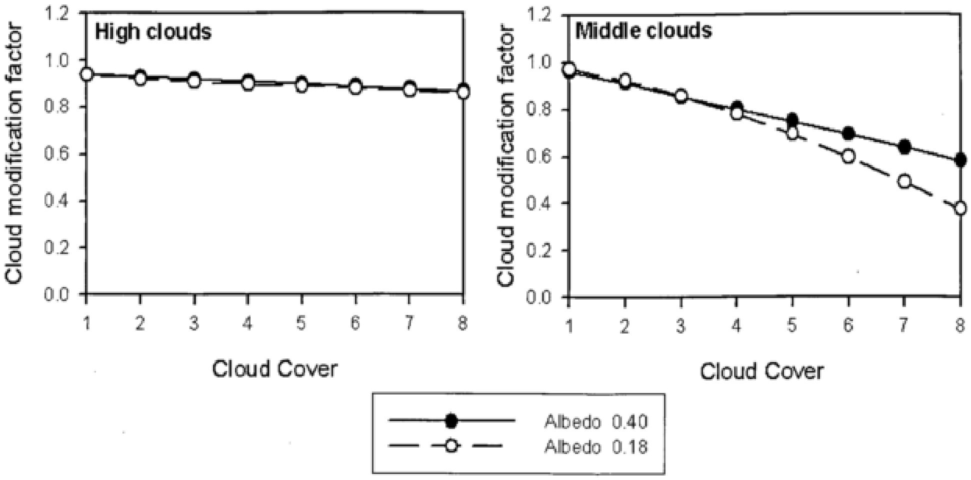


Figure 3: Cloud modification factor versus cloud cover for high clouds (left) and middle clouds (right) and albedo 0.40 and 0.18, respectively

In addition to the snowline, clouds situated below the Sonnblick are responsible for increased albedo and consequently increased radiation. Clouds below the Observatory (upper bond at 3000 m) can increase the UV-radiation by 25 %. The average albedo may be enhanced by some cloud types. The ratio of measurement and model was compared to the fraction of clouds below the top of the mountain for 370 nm and is shown in Fig. 4 as a function of cloud fraction. At cloud fraction greater or equal 4/8 the mean quotient of measurement and model is 1.07. 75% of the investigated cases shown in Fig. 4 are within a quotient of 1.02 and 1.14. Model calculations show that average albedo is increased by 0.28 ± 0.15 due to 4/8 cloud cover or more below the top of the mountain.

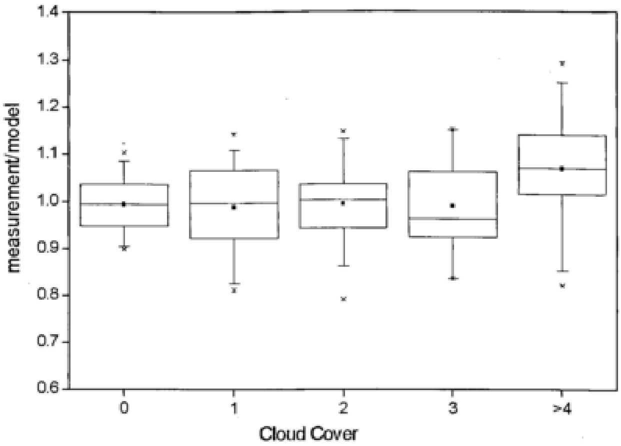


Figure 4: Box plot presentation of measurement model ratios at 370 nm as a function of cloud cover below the Sonnblick summit.

## 4 DISCUSSION AND CONCLUSION

The influence of ground albedo and cloudiness on ground UV at the Sonnblick Observatory is estimated from spectral UV measurements and radiative transfer calculation. UV irradiance is strongly enhanced when the ground is covered by snow due to multiple reflections between ground and atmosphere. Table 1 summarises the average enhancement of UV irradiance moving the snowline under clear sky and overcast conditions. Mean effective albedo is included for different snow lines. Effective albedo of 0.63-0.78 determined for snowline 800 m is comparable to the model calculations presented by Weihs et al., (2000). Rengarajan et al., (2000) measured the albedo at the Sonnblick observatory in winter. Their experimentally determined values in the range from 0.73 to 0.78 are well comparable to the albedo values determined in this study at low snow line.

| *Snow Line [m]* | *305 nm (clear-sky)* | *305 nm (overcast)* | *3-D RT calculations clear sky* | *Effective Albedo* |
|---|---|---|---|---|
| *800* | *1.24 (±0.04)* | *1.73 (±0.11)* | *1.21* | *0.63-0.78* |
| *1000* | *1.21 (±0.05)* | *1.58 (±0.13)* | *1.21* | *0.55-0.75* |
| *1500* | *1.14 (±0.04)* | *1.47 (±0.16)* | *1.17* | *0.38-0.58* |
| *2000* | *1.09 (±0.05)* | *1.32 (±014)* | *1.12* | *0.28-0.43* |
| *2500* | *1.05 (±0.06)* | *1.08 (±0.18)* | *1.10* | *0.08-0.3* |

Table 1: Enhancement of UV irradiance with decreasing snow line and effective albedo determined with the 1D radiative transfer model and comparison with 3- D radiative transfer calculations.

Effects of multiple reflections between ground and cloud bases are detected for cloud cover greater than 6/8. In addition to the snowline, clouds situated below the Hoher Sonnblick are responsible for increased albedo and consequently increased radiation. Model calculations show that average albedo is increased by 0.28 ± 0.15 due to 4/8 cloud cover or more below the top of the mountain. The complexity of radiation phenomena in such a mountainous environment was however demonstrated when using a 3-D Monte Carlo radiative transfer (RT) model. The RT model showed to respond in a very sensitive way to changes in ground albedo characteristics. The best fit with the measurements was obtained for an albedo of 0.1 over the snow line and of 0.5 below the snow line -assuming the whole area below the snow line was covered with snow, which is not realistic. No account was taken of all the rock faces at lower altitudes which are usually not snow covered. These first 3-D RT simulations showed that it is only possible to gain a better accuracy with very complex models compared with empirical algorithms if the quality and accuracy of the model input parameters is also strongly improved. Complexity in calculations requires complexity in model input determination, simple algorithm are therefore in many cases better suited.

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# EVALUATION OF DIFFERENT HARMFUL EFFECTS OF THE UV RADIATION FROM ARTIFICIAL SOURCES

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## INTRODUCTION

Since a few years ago a part of the population undergoes UVA rays sessions in cabs for esthetic reasons. As a consequence of this fact, an important industry has developed to correspond to this increasing demand. There is a great variety of tanning lamps and so a wide range of spectra, some of them very different from the solar spectrum both in distribution and in intensity.

## METHODS

Concerning the harmful effects of UV radiation, nowadays a large number of action spectra are defined which describe the relative effectiveness of radiation in producing a certain biological response depending on the wavelength. For the present work we have chosen some of them with the aim of calculating the corresponding biologically effective irradiance, both from artificial sources and from the sun. The spectral measurements were carried out with a double monochromator spectroradiometer Bentham DM150 which has a 0.5 nm-resolution. The measured sources were different kind of artificial tanning lamps, solar simulators used with clinical purposes, just as measurements of solar radiation at different latitudes and altitudes.

## RESULTS

Some emphasized results are that in general, the tanning equipment emits more erythematic radiation than the sun in mid-latitudes summer above sea level (considered this to be the reference) although they emit less UVB radiation. This is because of the fact that emissions can be 15 times higher for some wavelengths in

UVA region. The DNA damage, with an action spectrum centered on UVB region too, shows opposite behaviors depending on the considered artificial source. The biologically effective irradiances calculated for photo-aging and for generation of singlet oxygen are several times higher than the corresponding to the solar radiation. In general, all the biologically effective irradiances sensitive to UVA radiation increase strongly, with relative differences higher than 300% in some cases, but there is an important dependence on the characteristics of each radiating device.

## DISCUSSION

It is important to consider the negative effects derived from the exposure to UV radiation sources: short term effects as erythema and photokeratitis and long term ones due to a continual exposure to solar radiation through the years as the photoaging and elastosis. Especially because the high UV emissions of certain lamps imply a reduction in the required time to be up to a dose in relation to the sun.

# SPACE-BASED SURFACE UV MONITORING FOR EUROPE USING SCIAMACHY AND MSG

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## 1 INTRODUCTION

For several applications, most importantly related to human health and ecosystems, it is highly desirable to establish a climatology (containing averages, variabilities in space and time, trends and extremes) of the incoming UV radiation levels at the Earth's surface. However, to build such a climatology global monitoring is required on a time scale of decades. For this purpose surface UV monitoring by ground networks is and will be limited in the foreseeable future by the size, representativity and homogeneity of the networks. On the other hand, long-term surface UV monitoring with global or continental coverage can also be obtained by calculations based on combinations of satellite measurements, albeit that the calculations and each underlying satellite product needs adequate and continuous ground validation for quality assurance and quality control.

This paper focuses on two important satellite products that are needed for space-based surface UV radiation monitoring: the daily total ozone column and the diurnally varying cloud cover. Calculations of two surface UV products are presented, the UV index and the erythemal UV daily dose. However, extensions to other UV products are rather straightforward because space-based surface UV monitoring is based on spectral radiative transfer calculations using constrained input parameters. Using the same algorithms as for monitoring, UV forecasts can be made if forecasts of the underlying satellite products are available, e.g., based on total ozone column forecasts (Allaart et al., 2004).

## 2 METHODS

The combination of satellite data sources that is needed for space-based monitoring of surface UV radiation includes predominantly total ozone column data, detailed cloud information, the aerosol load and optical properties, UV surface reflection data and the incoming solar irradiance (Madronich et al., 1998). The QA/QC procedures require in addition a validation program for the calculated surface UV radiation levels with the aid of a surface UV network and ground-based and in-situ observations of, at least, ozone, clouds and aerosols to validate the various applied satellite products.

Instruments on polar-orbiting platforms monitor the total ozone column. The TOMS-OMI record dates back to the late 1970s and the GOME-SCIAMACHY-GOME-2 series dates back to 1995. The column observations are typically accurate within a few percent. Present-day instruments obtain (near-) global coverage in one day. In addition, data assimilation based on ozone tracer transport in numerical weather prediction models has been shown a powerful method to fill in minor data gaps.

The usefulness of cloud information from polar-orbiting platforms is much more limited. Cloud cover and cloud optical parameters typically vary on time scales of minutes to hours. The satellite data products necessarily depend on the (representativity of the) local overpass time of a polar-orbiting platform. Therefore, representative high frequency observations can only be obtained from a geostationary platform such as Meteosat in the case of Europe and Africa. The required quantitative cloud information is now becoming available from Meteosat Second Generation (MSG). Most important is the cloud mask, but the cloud optical thickness product is also needed to determine UV cloud transmission.

## 3 RESULTS

At KNMI total ozone columns are operationally retrieved in near-real time from the SCIAMACHY nadir observations using the TOSOMI scientific algorithm. In combination with ECMWF meteorological forecasts, data assimilation by a chemical transport model provides an accurate forecast of the global ozone fields, giving the possibility to provide accurate forecasts of the clear sky UV index several days ahead using the Allaart et al (2004) algorithm. Figure 1a shows an example for Europe. For the latest ozone and UV forecasts, see http://www.temis.nl.

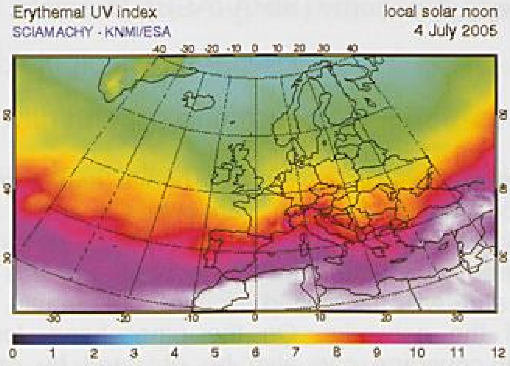


***Figure 1.*** *a) Clear sky UV Index over Europe predicted for 4 July 2005 and b) Erythemal UV dose over Europe calculated for 3 July 2005 (coverage limited by the Meteosat cloud mask product). Note that surface elevation effects are taken into account in the algorithms.*

In combination with a cloud mask the daily-integrated erythemal (McKinley and Diffey, 1987) UV dose is calculated every day for the day before. Figure 1b shows an example for 3 July 2005. Figure 2 shows the assumed reduction in surface UV for a given amount of cloudiness as derived from concurrent ground-based observations of spectral surface UV radiation and standard cloud observations at KNMI in De Bilt, The Netherlands.

***Figure 2.*** *The assumed reduction in surface UV for a given amount of cloudiness (in blue) as derived from concurrent ground-based observations of spectral surface UV radiation and standard cloud observations at KNMI in De Bilt, The Netherlands (in red).*

## 4 DISCUSSION

Ultimately the usefulness of the space-based surface UV monitoring depends on the quality of the calculated UV products. This quality is determined in the first place by the quality of the underlying satellite products, and, secondly, by the applied parameterisations to calculate UV products from a given set of input parameters. The quality of the underlying products can be verified by validation studies using independent data sources. Often a lot of information is already available in the scientific literature.

The quality of the parameterisations can be verified by accurate radiative transfer modelling calculations for given input parameters. Although the use of parameterisations such as presented in Figure 2 can be avoided on theoretical grounds, e.g. by application of full 3-D radiative transfer modelling for a given 3-D cloud field, it should be realised that this would be a very time consuming set of calculations. Further, the uncertainty in the 3-D input cloud field would be too large to justify the approach. On the other hand, parameterisations such as the one presented in Figure 2, have their limitations as well. For example, different relations may exist between cloud cover and incident surface UV radiation at different locations. Clearly, high spatial and temporal resolution information on cloud cover and more complete cloud information including cloud optical thickness such as now available from MSG and other satellite instruments is most useful to improve on the calculations of the UV dose on cloudy days.

First validation studies have been performed with the surface spectral UV data contained in the European UV database EDUCE hosted by the Finnish Meteorological Institute (FMI) at http://ozone2.fmi.fi/uvdb. The comparisons that are shown are for products based on GOME and Meteosat. The main difference between these products and the products based on SCIAMACHY and MSG is the improved spatial and temporal resolution of the latter two instruments. Figure 3 shows two examples of validation of the erythemal UV dose for cloud free days with different aerosol load at the island of Lampedusa (35 N; 13 E).

***Figure 3.*** *Validation of the erythemal UV dose at Lampedusa (35 N; 13 E) for two cloud-free days with different aerosol load. Space-based UV calculations are denoted with 'TEMIS', the surface UV measurements by 'BASINT'. The lowest curve represents the space-based UV calculation if overcast conditions would have prevailed. (UV observations Lampedusa courtesy Alcide di Sarra)*

## 5 CONCLUSION

The optimal method for space-based surface UV monitoring combines satellite products from different satellite platforms. The approach has been proposed first by Verdebout (2000). More and more of the required input parameters are becoming available from (operational) satellite instruments. A major next step will be to include space-based aerosol products in the calculations. A suitable parameterisation has already been developed based on radiative transfer modelling (Badosa and van Weele, 2002). Product improvements should further derive from extensive validation studies. More information on recent developments in space-based UV monitoring can be found at the ESA monitoring project 'PROMOTE' with project website at http://www.gse-promote.org/.

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# A SATELLITE-DERIVED UV CLIMATOLOGY OVER EUROPE: DATASET AND APPLICATION TO HUMAN EXPOSURE AND MARINE BIOLOGY

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## 1 INTRODUCTION

Exposure to high levels of UV radiation is harmful to human health (skin cancer, cataract, immuno-suppression), and influences many natural biological processes (marine life, plant physiology). Our awareness of these effects has been raised by ozone depletion, which leads to an increase in the intensity of the UV radiation reaching the Earth surface in some regions of the world. It is now felt important to monitor the changes that occur in this environmental parameter. Although the ground radiometers will remain the reference in terms of accuracy, they are too few to offer a comprehensive geographical coverage. Hence the development of methods that aim at mapping the surface UV radiation intensity by combining modelling and satellite data. The work presented here is using the full resolution images from METEOSAT, the operational European geostationary weather satellite. Over Europe, the spatial resolution is typically 5 km (degrading at high latitudes because of the increasing viewing angle). METEOSAT acquires the Earth disk image several times per hour and thereby allows taking into account the high temporal dynamics of clouds when estimating daily doses; this is a specific advantage of the method.

## 2 METHODS

The mapping methodology is described in detail elsewhere (Verdebout, 2000). To summarize, UV radiation maps over Europe (34N-74N, 12W-32E) are generated with a spatial resolution of 0.05 deg., and potentially every 30 minutes or 15 minutes with METEOSAT Second Generation (MSG). The surface UV dose rate is obtained by interpolation in a Look Up Table (LUT) of modelled irradiance, the entries of which are solar zenith angle, total column ozone amount, cloud optical thickness (COT), near surface horizontal visibility, surface elevation and UV albedo. The LUT was computed with the UVspec code (Mayer and Kylling, 2005) of the libRadtran package (version 1.00). Both satellite and non-satellite (synoptic observations, meteorological model results, digital elevation model) data are exploited to assign values to the influencing factors. The total column ozone is extracted from the gridded TOMS data or other satellite ozone sensors data (e.g. TOVS, GOME). The aerosol optical thickness is tentatively taken into account by gridding daily measurements of near surface horizontal visibility performed at about 1,000 ground stations. The digital elevation model is the GTOPO30 data set from United States Geological Survey (USGS).

With the help of another LUT simulating the "at sensor radiance" (proportional to the image digital count), METEOSAT data are processed to retrieve the cloud optical thickness. The entries of the METEOSAT signal LUT are solar zenith angle, METEOSAT viewing zenith angle, relative azimuth between illumination and viewing vectors, effective surface albedo, and cloud optical thickness. A preliminary step consists in generating an effective surface albedo map (in the visible band) by finding cloud-free pixels in a series of ten consecutive days. Once the composite cloudless digital count image has been constructed, it is transformed in an effective albedo map by inversion, using the LUT reduced to the cloudless case. The effective albedo map is then used to estimate the cloud optical thickness for the day and time of interest, by inversion using the full LUT. Most of the Earth surfaces are very dark in the UV spectral range, with the important exception of snow. Fresh snow can reflect almost 100% of the UV radiation and the induced increase in the surface radiation intensity in snow-covered areas is substantial. The UV surface albedo is therefore assigned uniform values for land (0.03) and sea/ocean (0.06), except where snow is detected. In this case it is given a value proportional to the METEOSAT effective albedo. The rationale for proportionality between the albedos in the two spectral ranges is that partial snow cover should affect them in a similar way. The outputs of the METEOSAT processing are fed into the UV map processor to generate surface UV irradiance maps or dose rate maps when a spectral weight is applied.

The daily dose is constructed by numerical integration of the dose rate estimated at regular intervals from and including the local solar noon (for each pixel). At each of these times, the solar zenith angle is computed and the cloud optical thickness is assigned a value. The other influencing factors (column ozone, surface albedo, aerosol optical thickness and surface UV albedo) are considered constant. The COT time dependence is described with a stepwise function with as many time intervals as the number of METEOSAT images used per day. Using only one image means that the COT is constant. At the other extreme, if all METEOSAT images are used the COT value is sampled at half-hourly intervals (15 minutes with MSG).

## 3 RESULTS

With the method outlined above, it has been undertaken to build a European climatology of UV radiation. As of today it consists in daily dose maps from January 1st 1984 to August 31st 2003. For practical reasons (processing time and amount of data) one METEOSAT image per day only has initially been used. The data set is progressively upgraded to using 3 images per day; this is already the case for March and July from 1990.

The maps have been generated for UVB, UVA, and PAR (Photosynthetically Active Radiation, 400-700 nm) spectral ranges and using the CIE87 erythemal action spectrum. However, the model output is spectral and the dose corresponding to any desired action spectrum can be generated on request. These data are available from JRC for scientific purpose (e.g. impact studies). The examples shown in this paper are all relative to erythemal doses, which are the most commonly used UV data.

Systematic geographical features in the distribution of surface UV radiation are best identified in multi-year averages. As an example, figure 1 shows monthly averaged erythemal daily doses, themselves averaged from 1984 to 2003, over the alpine arc in March and August. The geographical distribution of the UV radiation is essentially related to latitude, altitude, presence of snow and patterns in the cloudiness. In the area of figure 1, the cloudiness is higher over the mountains but this is over-compensated by altitude and snow in spring. The effect of clouds is dominant in the Pô valley. The contrast between land and sea is caused by higher overall cloudiness over land. More examples can be found in (Verdebout, 2004).

The data set also documents the year-to-year variability in UV radiation. Figure 2 shows the deviation with respect to the 1984-2003 average of the monthly averaged erythemal daily dose over Europe in April. One can first notice that the variability is quite large, reaching -40% to +50%. Although some other factors (snow, aerosols) also contribute, the year-to-year differences are mostly related to the variability in total column ozone and cloudiness. Any combination is encountered. The particularly high UV in 1997 corresponds to low ozone (~ 310 DU) and low cloudiness. Inversely the low UV 1991 corresponds to the conjunction of high ozone (~400 DU) and high cloudiness. The lows in 1986 are entirely caused by particularly high values of ozone (up to 450 DU) while the cloudiness is one of the lowest in the series. The high UV over the Nordic area in 1996 corresponds to low ozone (~310 DU) with an about average cloudiness. Springtime is the period in the year that shows the largest year-to-year variability in surface UV radiation, due to the strongest variability in stratospheric ozone. This variability in ozone is also stronger at high latitudes. Deviations of up to ±30% are still found in summer, mostly due to the variability in cloudiness.

## 4 DISCUSSION

Validation is a necessary step before using the modelled UV data in application projects. Comparison between satellite estimates and ground measurements is best conducted on daily doses. The satellite estimate is by nature an average over a certain area (the map pixel) while the measurement is at a single point. The instantaneous measurement of surface irradiance is sensitive to the detailed cloud structure (it is for instance influenced by a small cloud obscuring the sun). The satellite-modelled value on the other hand corresponds to a uniform cloud reproducing the average cloud optical thickness over the area. Because the clouds move, the time integration performed to estimate the daily dose from the measurements smoothes the cloud structure and has an effect similar to the spatial integration in the satellite image. Even so, part of the observed difference between the two data reflects their different nature. Comparisons with measured erythemal daily doses have been performed at various stations (Thessaloniki, Ispra, Garmisch, Brussels, Bilthoven, Jokioinen, Bergen, Tromsoe, Moscow). The bias is usually within ±7% and the rms scatter of the order of 30% (including the intrinsic difference mentioned above) (Arola et al., 2002).

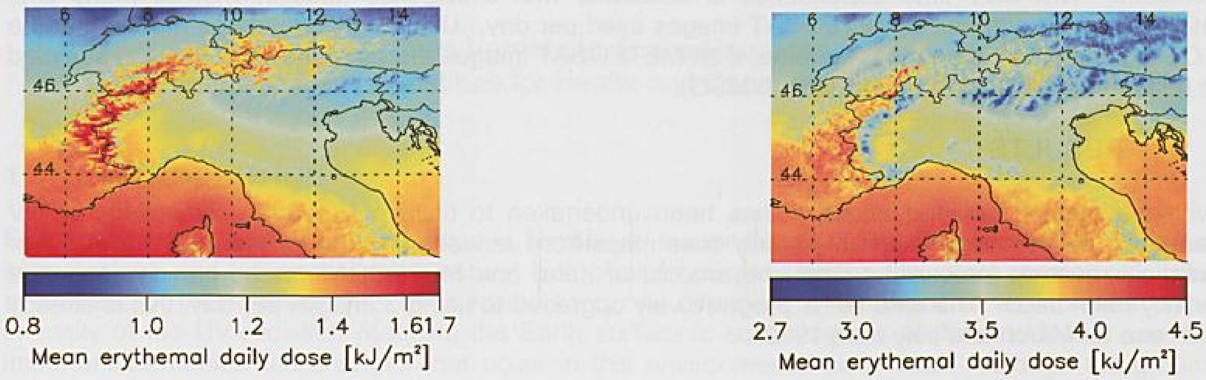
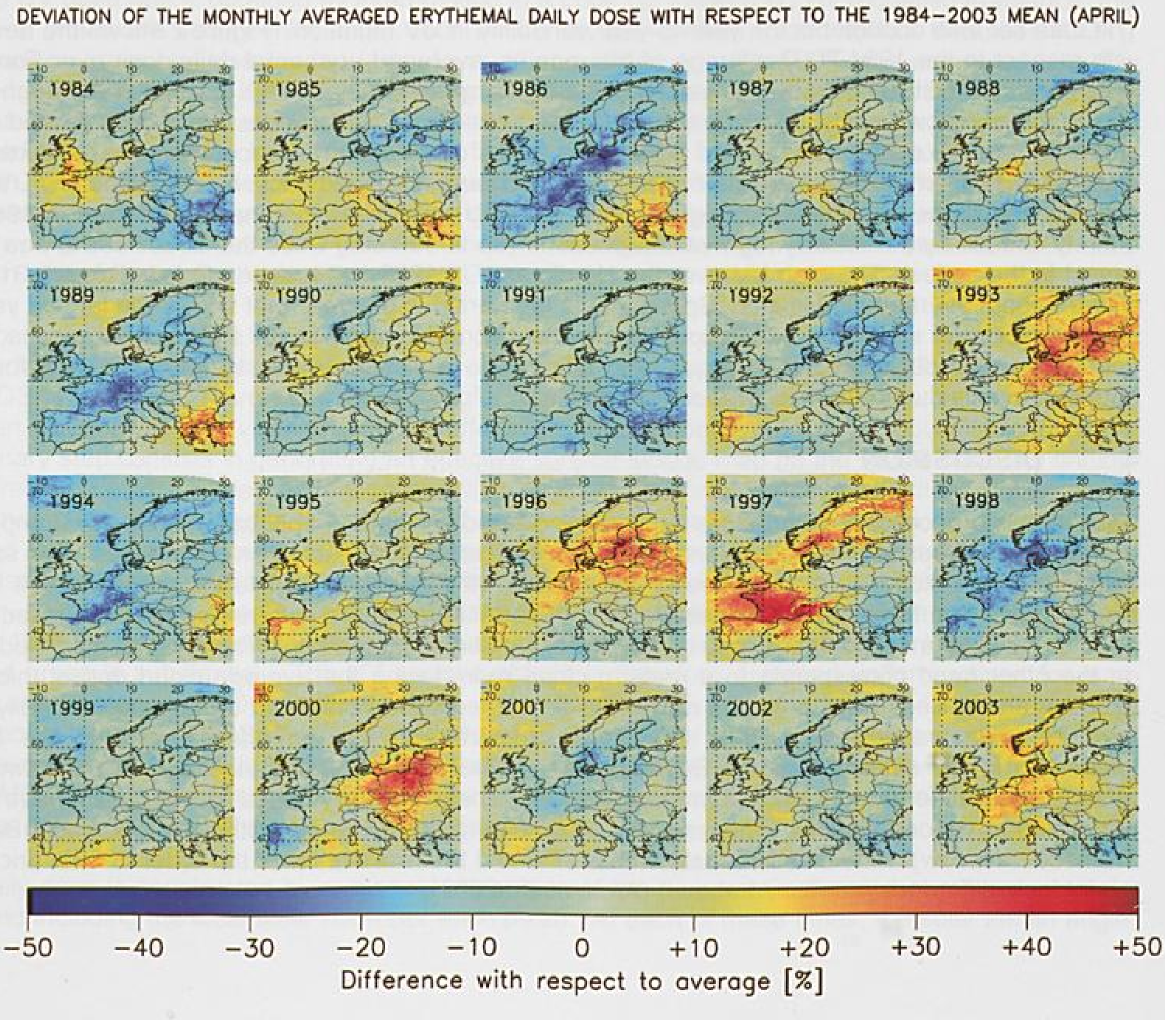



Figure 1: Multi-year (1984-2003) average of the daily erythemal dose over the alpine arc; left: in March, right: in August.

Figure 2: Sequence of maps showing the year-to-year variability of the monthly averaged daily erythemal dose in April.



These METEOSAT-derived UV data have been used in the European UVAC project, which studied the influence of natural UV radiation on the population strength of the arctic cod. It is known that exposure to UV radiation causes mortality in zooplankton, cod eggs and larvae. The object of the project was to assess whether this is a factor influencing the population strength of the economically important arctic cod. 20-year time series of the UV radiation daily doses over the spawning areas in the Lofoten islands were provided to the biologists in the project. In this case specific action spectra related to the mortality of cod eggs and Calanus Finmarchicus (zooplankton) were applied. Correlations were searched between these UV data and historical records of the cod population strength. Only very weak correlation was found. The likely explanation is that the organisms are moving up and down in the almost always-turbulent surface layer of the sea. As the UV radiation is rapidly attenuated in water, they are protected from excessive exposure. Large amounts of dead eggs have sometimes been observed in the absence of turbulence but these events are too rare and local to have an impact at the population level.

At JRC, the satellite data are used in a human UV exposure model to support studies on UV health effects. In this case, the surface UV radiance field is modelled rather than just the downwelling irradiance. In this way, the exposure of an arbitrarily oriented surface can be calculated. This enables estimating the exposure of the various body parts of a person, also taking into account his/her posture. The model has for instance been used to estimate the daily exposure of an office worker in Dusseldorf on the basis of a scenario of occupational schedule, including two periods of holidays (1 week in a sky resort and 2 weeks on a Greek island). The output indicates that the risk of an erythema practically only exist during the holidays, which also account for about half of the yearly exposure. A preliminary validation of this exposure model has been performed by comparison with dosimetry measurements on mannequins.

The UV data have also been provided to external users in the fields of agronomy and radiation protection.

## 5 CONCLUSION

A satellite-derived climatology of the surface UV radiation over Europe is available for impact studies. It allows documenting this environmental parameter where no measurements are or were available. It spans the period from 1984 to 2003 with daily maps and a spatial resolution of the order of 5km. The quality of the satellite-derived estimates has been assessed at several sites in Europe. With its relatively high spatial resolution and time coverage, this climatological data set permits to document the spatial and temporal variability of the surface UV radiation with a level of details that enable impact studies. In particular, it reflects the effects of altitude, snow cover and regional/local weather. The plans are to maintain, update and upgrade this data set.

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