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Site and Data Report for the Lindenberg Reference Site in CEOP – Phase I

by
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Summary

The Coordinated Enhanced Observing Period (CEOP) has been developed and implemented within the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP) in order to establish the prototype of an integrated global observing system for the energy and water cycle. The CEOP implementation strategy includes the collection, central archiving and management of satellite, in-situ and model data. During the first phase of CEOP data have been collected over a time period of two consecutive full-year cycles (October 2002 to December 2004).

Major contributions to CEOP come from the so-called Continental Scale Experiments (CSEs) within GEWEX, where Europe is represented by the Baltic Sea Experiment (BALTEX). The Meteorological Observatory Lindenberg (Richard-Aßmann Observatory) has been nominated through its participation in BALTEX as one of the 36 world-wide in-situ reference sites for CEOP – Phase I. Data submitted to the CEOP Central Data Archive (CDA) include half-hourly values of surface meteorological variables, soil temperature and soil moisture profiles, profiles of wind, temperature and humidity from tower measurements in the lower atmospheric boundary layer, energy flux densities (radiation and ground heat flux, turbulent fluxes of sensible and latent heat) and six-hourly high-resolution radiosonde profiles. Micrometeorology data were provided from the Falkenberg boundary layer field site and from the Kehrigk forest station representing the two major land use classes (grassland / farmland and pine forest, respectively) in the heterogeneous landscape around Lindenberg.

This report consists of three parts. In Part I, a brief introduction to CEOP is given. Part II contains the "Lindenberg Reference Site Data Set Metadata Information" document for CEOP Phase I that has been prepared according to the guidelines agreed on within the CEOP working group on data management. It includes a description of the measurement sites, the instrumentation, the data collection and quality control procedures and some remarks pointing at peculiarities of specific data. This part is considered as a general reference to the micrometeorological data collected at the Meteorological Observatory Lindenberg during the 2003 / 2004 period. Finally, some basic climatological data from the two Lindenberg reference site stations during CEOP Phase I are presented and discussed in Part III.

Zusammenfassung

Das Projekt CEOP (*Coordinated Enhanced Observing Period*) wurde konzipiert und realisiert im Rahmen des *Global Energy and Water Cycle Experiment* (GEWEX) des Weltklimaforschungsprogramms (*World Climate Research Programme*, WCRP) der WMO mit dem Ziel der Schaffung eines Prototyps für ein integriertes Beobachtungssystem des globalen Energie- und Wasserkreislaufes. Die CEOP-Strategie umfasst die Sammlung, zentrale Archivierung, Verwaltung und Bereitstellung von Satelliten-, *in-situ-* und Modelldaten. In der Phase I von CEOP wurden Daten für zwei volle, aufeinanderfolgende Jahreszyklen (Oktober 2002 bis Dezember 2004) gesammelt.

Wesentliche Beiträge zu CEOP werden durch die sogenannten *Continental Scale Experiments* (CSEs) in GEWEX erbracht, wobei Europa durch das internationale Ostseeprojekt BALTEX vertreten ist. Das Meteorologische Observatorium Lindenberg (Richard-Aßmann Observatorium) ist über seine Mitwirkung in BALTEX als eine von 36 weltweit verteilten *in-situ* Referenzstationen für die Phase I von CEOP nominiert worden. Die an das *CEOP Central Data Archive* (CDA) übermittelten Daten umfassen halbstündige Werte bodennaher meteorologischer Parameter, Profile von Bodentemperatur und Bodenfeuchte, Wind-, Temperatur- und Feuchteprofile aus Mastmessungen in der unteren Grenzschicht, Energieflussdichten (Strahlungsflüsse, Bodenwärmestrom, turbulente Flüsse von sensibler und latenter Wärme) sowie die hochaufgelösten Profile der operationellen in 6-stündigen Intervallen durchgeführten Radiosondierungen. Mikrometeorologische Messdaten wurden der Heterogenität der Landoberfläche im Gebiet um Lindenberg mit ihren Hauptlandnutzungstypen Agrarland (Grasland) bzw. Kiefernwald Rechnung tragend sowohl vom Grenzschichtmessfeld (GM) Falkenberg als auch von der Waldstation Forst Kehrigk zur Verfügung gestellt.

Der vorliegende Bericht umfasst drei Teile. In Teil I wird eine kurze Einführung in das Projekt CEOP gegeben. Teil II enthält das entsprechend den Richtlinien der CEOP-Arbeitsgruppe Datenmanagement erstellte Dokument "Lindenberg Reference Site Data Set Metadata Information". Dieser Teil umfasst eine allgemeine Beschreibung der Standorte und ihrer Instrumentierung, der Prozeduren zur Erfassung und Qualitätskontrolle der Messdaten sowie Hinweise auf Besonderheiten einzelner Datensätze. Er liefert somit generelle Referenzinformationen zu den 2003 / 2004 am Meteorologischen Observatorium Lindenberg durchgeführten mikrometeorologischen Messungen. Abschließend werden in Teil III einige klimatologische Auswertungen der Messungen an den beiden Standorten GM Falkenberg bzw. Forst Kehrigk während der Phase I von CEOP präsentiert und diskutiert.

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Part I – A Short Introduction to CEOP

1. CEOP Goals and Strategy

The Coordinated Enhanced Observing Period (CEOP) has been initiated, developed and implemented within the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP). The fundamental issue of GEWEX is to improve both our understanding of water and energy fluxes and reservoirs over land areas and our ability to properly describe and predict the overall cycles and budgets of water and energy over these regions at time scales from diurnal to annual (see also http://monsoon.t.u-tokyo.ac.jp/ceop/). Within GEWEX, CEOP was proposed as an initial step for establishing an integrated observation system for the global water cycle. Based on these goals, the CEOP implementation strategy includes the collection, central archiving and management of

- data from the full spectrum of available experimental and operational satellites,
- comprehensive land surface / atmosphere data sets collected at a number of worldwide distributed reference sites, and
- model output products from leading numerical weather prediction (NWP) and climate modelling centres around the world.

In this way, CEOP seeks to establish the prototype of an integrated global observing system for the energy and water cycle which responds to both scientific and social needs of the human society. This overall idea is illustrated in Figure 1.

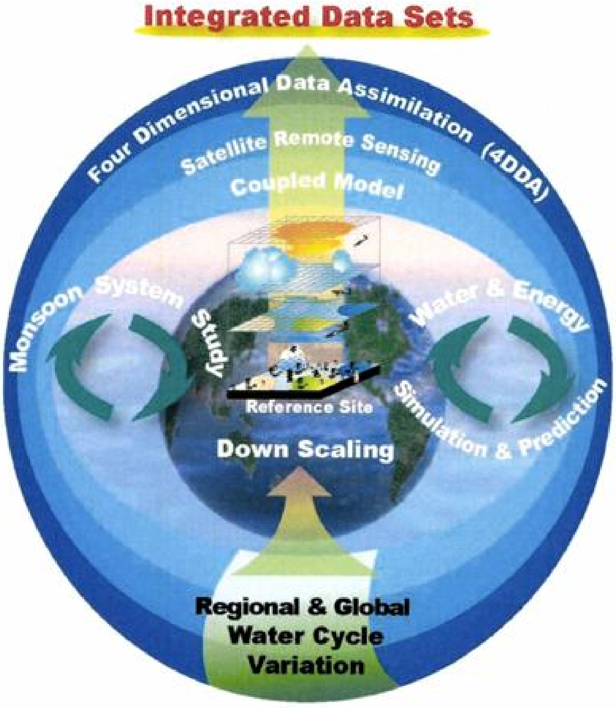

Figure 1
The CEOP strategy of integrated data sets for water and energy budget studies
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Main contributions to CEOP come from the various Continental Scale Experiments (CSEs) within GEWEX (e.g., GAPP, MAGS, LBA, CAMP, and BALTEX). Some of these CSEs have been performed regional-to-continental scale studies of the water and energy cycle since the middle of the 1990ies including the collection of comprehensive data sets from operational and experimental measurement programmes (both ground-based and space-borne) and from numerical model simulations. Within CEOP it has been attempted to integrate all these water-cycle related studies to develop a unique, consistent data set that can be used to address global as well as regional issues. CEOP has been built in co-operation with the World Meteorological Organization (WMO) and the Committee on Earth Observation Satellites (CEOS) under the framework of the Integrated Global Observing Strategy Partnership (IGOS-P). It thus became an important component of the WCRP's scientific strategy as expressed in the COPES (Coordinated Observation and Prediction of the Earth System) strategic framework for the 2005-2015 time period and has been selected as a demonstration project within the Group on Earth Observation System of Systems (GEOSS) representing the atmospheric component of the global climate system.

The CEOP built-up phase (phase I) covered the time period from 2001 to 2005. During this first phase data have been collected over two consecutive annual cycles (October 2002 to December 2004). Data have been archived in three data archives, namely

- satellite data at the Data Integrating and Archiving Centre of the University of Tokyo and JAXA at Tokyo, Japan
- in-situ reference site data at the National Center for Atmospheric Research / Earth Observing Laboratory (NCAR/EOL) in Boulder / Colorado, USA
- model output data from NWP and climate modelling centres at the World Data Centre for Climate (WDC-Climate) at the Max-Planck-Institute for Meteorology in Hamburg, Germany.

The satellite data centre has been designed to archive, process, and manage a broad spectrum of data from operational and experimental satellites (see Figure 2 for illustration).

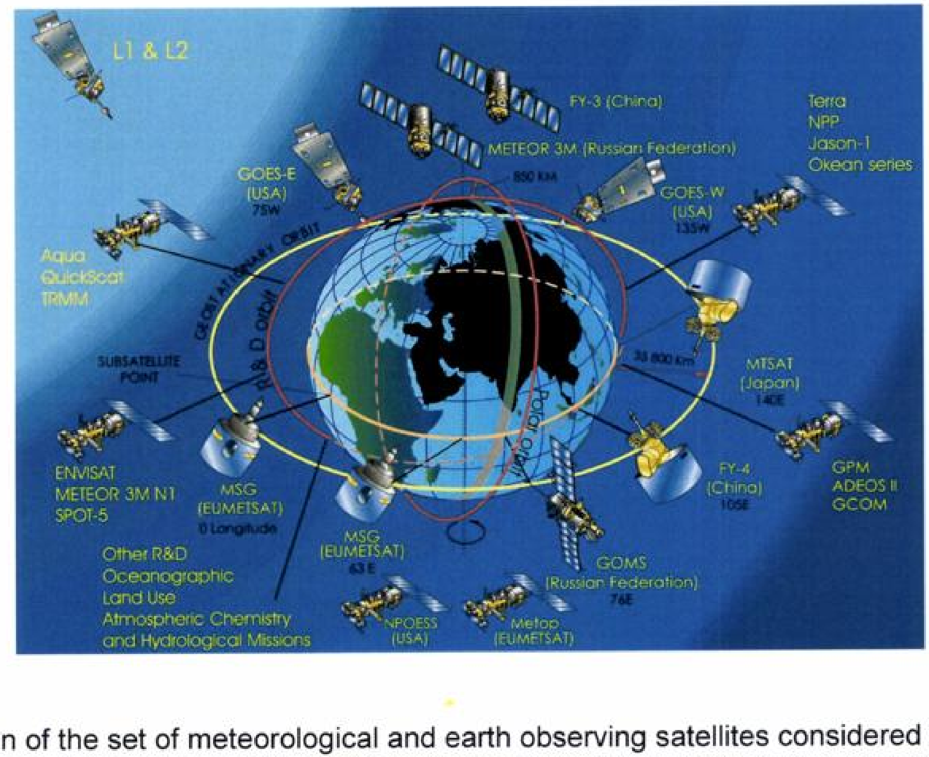

Figure 2
Illustration of the set of meteorological and earth observing satellites considered for CEOP (© this figure is reproduced with kind permission of the CEOP secretariat, Tokyo)

Data sets available so far include products from ADEOS-II, NOAA-AVHRR, TRMM, Aqua, and DSP13-15 (SSM/I), data from Terra and MSG are being prepared.

The model data archived include both grid data and MOLTS data (Model Output Location Time Series) from the model grid points closest to the in-situ reference sites. An overview on the model data available at the WDC-Climate in Hamburg for CEOP Phase I is given in Table 1 (Status: February 2006).

Table 1 – Model Output Data from CEOP Phase I available at the WDC-Climate in Hamburg

Centre	**MOLTS data**	**GRID data**
NCEP	01-DEC-2002 – 31-MAY-2005	01-OCT-2002 – 31-JUL-2005
UKMO	01-OCT-2002 – 31-DEC-2004	01-OCT-2002 – 31-DEC-2004
NASA-GMAO	01-JUL-2001 – 31-OCT-2002	01-JUL-2001 – 30-SEP-2001
NASA-GLDAS	01-JUL-2001 – 31_DEC-2004	-
JMA	01-OCT-2002 – 30-DEC-2004	01-OCT-2002 – 30-DEC-2004
BMRC	01-OCT-2002 – 30-SEP-2003	-
ECMWF	-	01-JUL-2001 – 31-AUG-2002
NCMRWF	-	01-OCT_2003 – 30-APR-2004
ECPC	SFM : 01-JUL-2001 – 31-DEC-2004 RII : 01-JUL-2001 – 31-DEC-2004	SFM : 01-JUL-2001 – 31-DEC-2004 RII : 01-JUL-2001 – 31-DEC-2004
CPTEC/INPE	-	01-JUL-2001 – 30-SEP-2001

The overall data management and archiving strategy of CEOP is illustrated in Figure 3

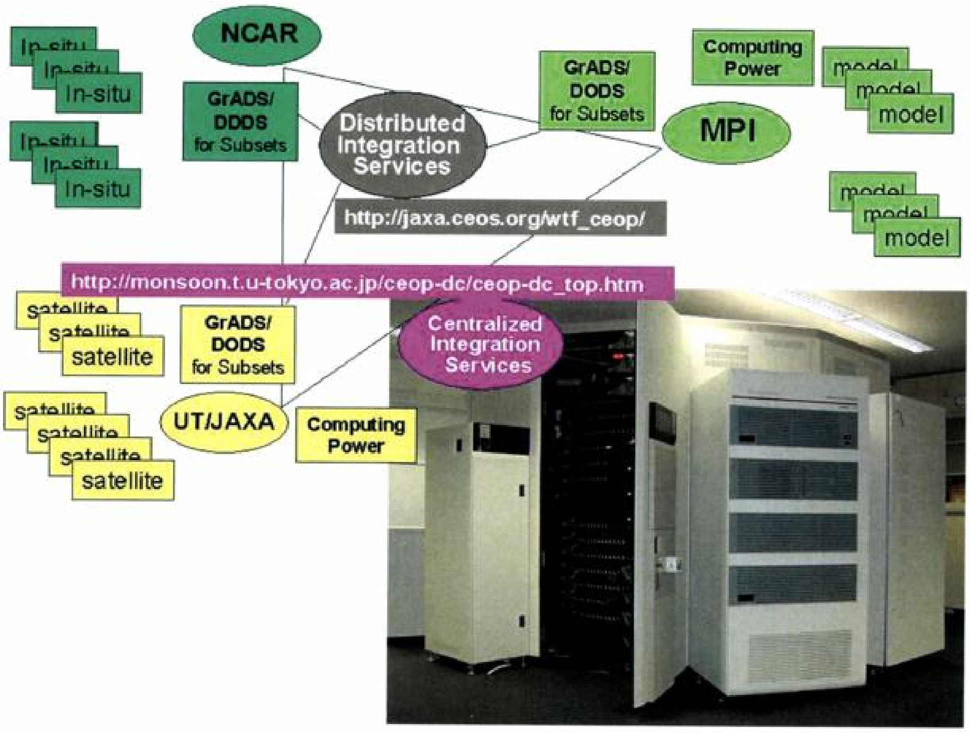

Figure 3
CEOP data management strategy
(© this figure is reproduced with kind permission of the CEOP secretariat, Tokyo)

2. In-Situ Reference Site Data in CEOP

For CEOP phase I, 36 land sites had been nominated as ground reference sites. They represent the different geographical and climate conditions around the globe (Figure 4).

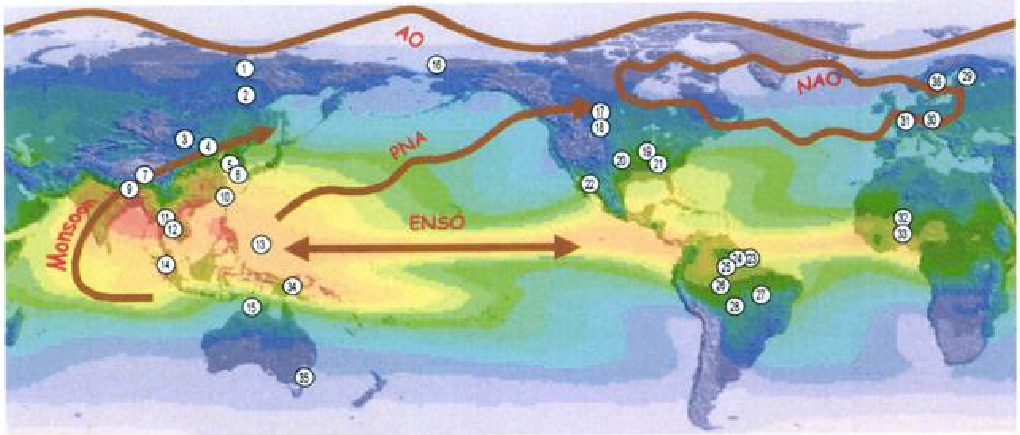

Figure 4
Globally distributed ground-based reference sites during CEOP phase 1
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Four European sites had initially agreed to provide data for CEOP all of which are also reference sites in BALTEX: Sodankylä (Finland), Norunda (Sweden), Cabauw (The Netherlands), and Lindenberg (Germany). Due to funding limitations a reduced data set (surface and flux data for 2003 only) could be finally made available from Norunda. Further discussion therefore refers to Sodankylä, Cabauw, and Lindenberg only. These sites represent major climate and vegetation regions in the BALTEX study domain (see Table 2, and Figure 5).

Table 2 – BALTEX in-situ reference sites for CEOP Phase 1

	Sodankylä	Cabauw	Lindenberg
Site co-ordinates	67.4°N, 26.7°E	52.0°N, 4.9°E	52.2°N, 14.2°E
Elevation	179 m	-1 m	73 m
Climate	sub-arctic	temperate, dominating marine influence	temperate, transition from marine to continental influence
Vegetation	boreal forest	mainly grassland	mixed farmland / forest

While the surface characteristics are relatively uniform around the Sodankylä and Cabauw sites, land use in the Lindenberg area is characterised by a mixture of forest and farmland (see Figure 5). Data sets from Lindenberg therefore cover two field stations, namely the Falkenberg boundary layer field site and a forest tower site about 10 km to the West of Falkenberg (see also Beyrich and Adam, 2004, Stiller et al., 2005). These two sites represent the farmland and forest part of the region, respectively.

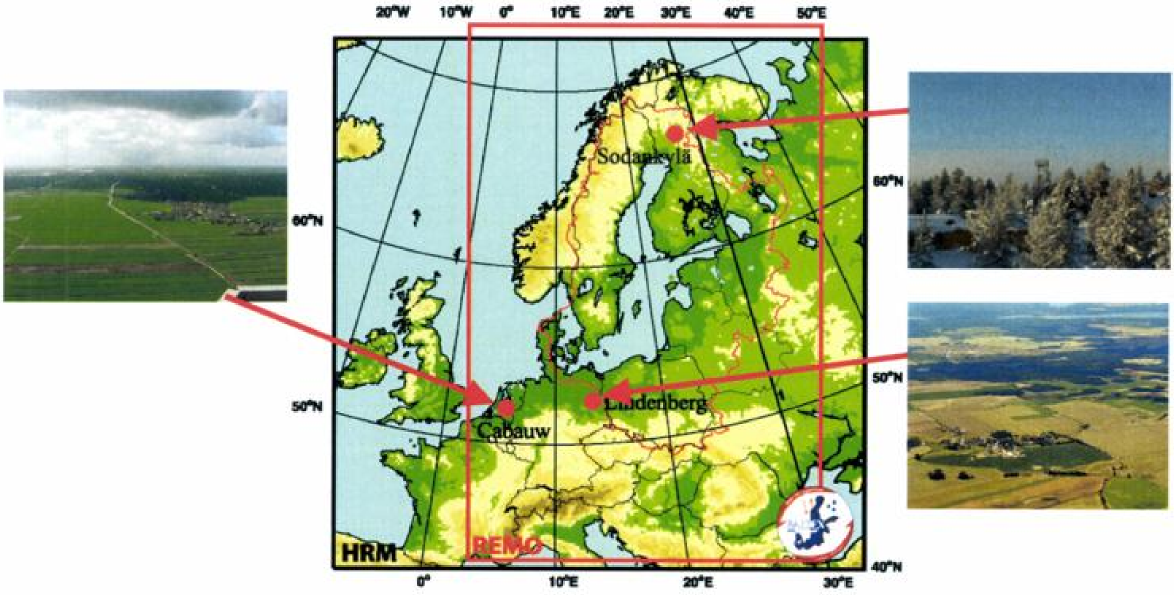

Figure 5
Map of the BALTEX area with the position of the BALTEX CEOP reference sites and the modelling domain of the HRM and REMO models indicated, the photos show the typical land use around the reference sites (© The map has been created by the BALTEX secretariat)

A standard set of measured parameters organised in five types of data tables has been defined within the CEOP Working Group on Data Management to be made available from all the reference sites. These data sets are organised as follows:

→ standard surface meteorology and radiation data (data set code **SFC**): air temperature (T), humidity (RH), wind speed (V) / wind direction (dir), air pressure (p), up-/downward short-/longwave radiation (R_{sw}, R_{lw}), net radiation (R_{net}), photosynthetic active radiation (PAR), radiative surface temperature (T_s), precipitation (RR), snow depth (Snow),
→ soil parameters (data set code **STM**): soil temperature (T_{soil}) and soil moisture (q_{soil}) profiles,
→ energy fluxes (data set code **FLX**): sensible heat flux (H), latent heat flux (LE), ground heat flux (G), CO_2 flux (CO2),
→ tower profile data (data set code **TWR**): profiles of temperature, humidity, wind speed and wind direction from tall towers,
→ radiosonde data (data set code **SONDE**): high-resolution vertical profiles of pressure, air temperature, humidity, wind speed and wind direction from operational radiosoundings.

All reference site data were collected and made available to the scientific community at the CEOP Central Data Archive (CDA) managed by NCAR-EOL (the former Joint Office for Science Support, JOSS, at the University Center for Atmospheric Research, UCAR). They are available through the internet, see at http://www.eol.ucar.edu/projects/ceop/dm/.

The data listed above had to be provided from each of the CEOP reference sites

- within a certain time frame,
- in a well-defined harmonised data format,
- with quality flags assigned to each measured value, and
- with a time resolution of 30 minutes or 1 hour (except for the radiosoundings).

In addition to these standard data, each site could offer to provide additional data upon users request.

A detailed overview on the parameters available from the three BALTEX reference sites for the CEOP phase 1 period is given in Table 3.

Table 3 – Parameter list from the BALTEX - CEOP reference sites

	SFC							STM		FLX				TWR [1]			additional data [2]					
	p, T, RH	V, dir	Rsw	Rlw	Rnet	RR	Snow	Tsoil	qsoil	H	LE	G	CO2	T, RH	V, dir	radiosonde	ceilometer	WPR / RASS	cloud radar	AOD	ozone	moment. flux
Sodankylä	X	X	X			X	X	X		X	X			X		X	X				X	X
Cabauw	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X		X
Lindenberg	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X

[1] the upper tower heights are 48 m (Sodankylä), 200 m (Cabauw), and 98 m (Lindenberg), respectively

[2] additional data are available upon request from the data providers

All data are quality-controlled according to procedures implemented at the institutions of the data providers, and an overall formatting and range control is again performed at the CDA. Each data value reported is accompanied by a letter-coded quality flag distinguishing six levels of data quality: Good (G) – Dubious (D) – Bad (B) – Interpolated (I) – Unchecked (U) and Missing (M).

The BALTEX reference sites have completed data delivery to the CEOP-CDA according to the proposed schedule by June 30, 2006 (Beyrich et al., 2006). Actually (October 2006), complete reference site data sets for the 2003-2004 period are available from the CEOP CDA for about half of the 36 sites nominated.

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Part II – The Lindenberg Reference Site Data Set Metadata Information

Reference Site: **BALTEX Lindenberg**
Station Identifiers: **Falkenberg / Forest**
Time Period: **EOP3 / EOP4**
October 01, 2002 to December 31, 2004
(for Forest January 01, 2003 to December 31, 2004)

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Abstract

This document includes the metadata and information the user should be aware of when using any of the BALTEX Lindenberg reference site data from the CEOP Central Data Archive (CDA) submitted for the measurement period October 01, 2002 to December 31, 2004. It includes a description of the measurement sites, the instrumentation, the data collection and quality control procedures and some remarks pointing at peculiarities of specific data.

1. Data Set Overview

1.1 Site and Time Period

This description refers to the data from the BALTEX Lindenberg reference site for the period October 01, 2002 - 0030 UTC to December 31, 2004 - 2400 UTC. The BALTEX Lindenberg reference site comprises two independent stations named Falkenberg and Forest. These represent the two major land use types in the Lindenberg area (grassland / farmland, forest). Data from the Forest Station are available for the period January 01, 2003, 0030 UTC to December 31, 2004, 2400 UTC, only.

1.2 Site Co-ordinates

All surface ~, soil ~, tower ~ and flux measurements of the Falkenberg station have been performed at the Falkenberg Boundary Layer Field Site (in German: Grenzschichtmessfeld <GM> Falkenberg) of the Meteorological Observatory Lindenberg - Richard-Aßmann Observatory (MOL-RAO).
The co-ordinates of the GM Falkenberg are given by:

52° 10' 01" N	14° 07' 27" E	73 m NN
52.17° N	14.12° E	

The radiosondes are released at the site of the Meteorological Observatory Lindenberg – Richard-Aßmann Observatory (MOL-RAO) which is about 5 km to the North of the Falkenberg site.
The co-ordinates of the radiosonde release point at MOL-RAO are given by:

52° 12' 36" N	14° 07' 12" E	112 m NN
52.21° N	14.12° E	

The Forest Station is situated in a pine forest about 10 km to the West of the Falkenberg site. The co-ordinates of the Forest Station are given by:

52° 10' 56" N	13° 57' 14" E	49 m NN
52.18° N	13.95° E	

1.3 Site Operator

The Meteorological Observatory Lindenberg – Richard-Aßmann Observatory (MOL-RAO) is part of the business area Research and Development of the Deutscher Wetterdienst (DWD), the national meteorological service of Germany.

1.4 General Site Description

Landscape

Lindenberg is a small village situated in a rural landscape in the East of Germany about 65 km to the South-East of the centre of Berlin, the capital of Germany. A map of the area around Lindenberg is presented in Figure 1, and a view from a birds perspective across the area with the GM Falkenberg in the centre is shown in Figure 2.

Figure 1 Map of the area around Lindenberg with the GM Falkenberg, Forest Station and MOL-RAO sites

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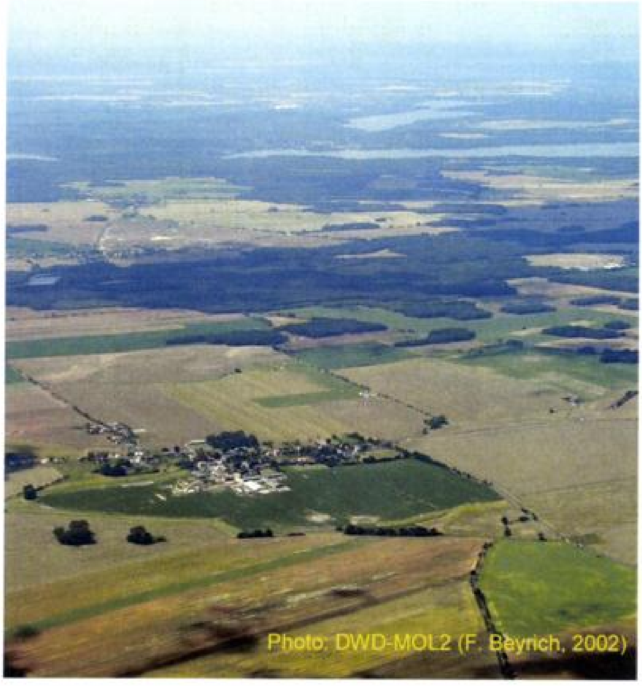
Photo: DWD-MOL2 (F. Beyrich, 2002)

Figure 2 Aerial view towards NW at the landscape around the boundary layer field site GM Falkenberg (the L-shaped area in the centre of the photo)

The landscape in the region around Lindenberg was formed by the inland glaciers during the last ice age exhibiting a slightly undulating surface with height differences of less than 100 m over distances of about 10 km. The lowest areas in the Spree river valley (which forms a wide bend around Lindenberg in the South, East and North at distances of between 10 and 20 km) are at about 40 m above sea level and a few hills north-east of Lindenberg reach 130 m above sea level. A number of small and medium-sized lakes are embedded in this landscape. Both, the orography and the mixture of surface types are rather typical for large parts of northern Central Europe south of the Baltic Sea.

Land Use

The land use in the area is dominated by forest and agricultural fields (40 - 45 % each), lakes cover 5-7 %, villages and traffic about 5 %. For the agricultural fields, triticale (a hybrid between wheat = *triticum* and rye = *secale*) is the dominating vegetation, significant parts of the farmland are also covered by other cereals, grass, rape, and maize. The land use classification in the vicinity of the two stations depends on the scale considered, a characterisation at different scales is given in Table 1.

Table 1 – Land use around the Lindenberg reference stations depending on scale

Land cover within	Falkenberg	Forest Station
100 m	Grassland	pine forest
500 m	grassland / cropland	pine forest
10 km	grassland / cropland – 60 % pine forest – 30 % open water – 5 % settlements – 5 %	grassland / cropland – 28 % pine forest – 60 % open water – 7 % settlements – 5 %

Soil

The soil type distribution in the area around Lindenberg is dominated by sandy soils. In the forested parts west of Lindenberg (see Figure 1), the sand reaches a depth of several meters. Dominating soil reference groups are brown soil - *Cambic Arenosol*, and *Ferric Podzol*. At the GM Falkenberg, sandy soils (pale soil - *Eutric Podzoluvisol*, brown soil - *Cambic Arenosol*) cover a layer of loam, which can be typically found at a depth of between 50 cm and 80 cm, locally even below.

Typical physical parameters of the soil are listed in Table 2

Table 2 - Physical parameters of the soil at the Lindenberg reference stations

layer no.	horizon	upper boundary [cm]	lower boundary [cm]	clay / poor clay [M%]	sand [M%]	dry density [g/cm^3]	pore volume [%]	field capacity *) [V%]	wilting point [V%]	hydraulic conductivity [cm/d]	soil heat capacity [*10^6 J/(K*m^3)]
					Lindenberg – Falkenberg station						
1	Ap	0	30	26	74	1.6	37	16	4	110	1.32
2	Al	30	60	26	74	1.7	36	18	3	80	
3	Bt	60	120	40	60	1.7	34	24	11	20	
					Lindenberg – Forest Station						
1	Ap	0	30	12	88	1.5	37	16	4	550	
2	Bs	30	60	8	92	1.6	37	16	4	550	
3	IIC	60	>150	8	92	1.6	37	16	4	550	

*) Soil physical parameters given in Table 2 are partly based on standard soil data tables, winter measurements at GM Falkenberg indicate a field capacity of about 23 ± 2 % for the upper two soil layers and of about 30 ± 3 % below.

Climate

Lindenberg represents moderate mid-latitude climate conditions at the transition between marine and continental influences. Monthly mean temperatures (1961-1990) vary between –1.2 deg C (January) and 17.9 deg C (July), and the mean annual precipitation sum is 563 mm. The annual precipitation pattern shows a main maximum during summertime and a secondary maximum in December with minima in February and October. The climate diagram is shown in Figure 3, and selected climate data are given in Table 3. The minimum / maximum temperatures recorded since 1906 in Lindenberg are – 28.0 °C (11 Feb 1929), and + 38.5 °C (11 Jul 1959, 9 Aug 1992), respectively.

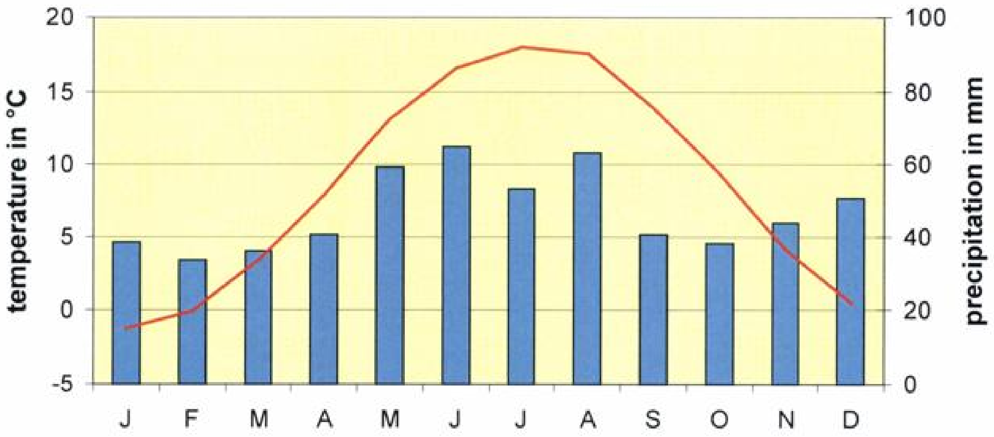

Figure 3 Climate Diagram for Lindenberg (1961-1990)

Table 3 – Selected climate data for Lindenberg (1961-1990)													
	J	F	M	A	M	J	J	A	S	O	N	D	Year
T mean (deg C)	-1.2	-0.1	3.4	7.9	13.1	16.5	17.9	17.6	13.9	9.3	4.1	0.4	8.6
RR sum (mm)	38.6	34.0	35.9	40.7	59.1	64.8	53.2	63.0	40.8	38.5	44.1	50.4	562.8
Sunshine (hrs)	46.2	70.1	123.2	165.1	225.3	228.2	228.9	217.1	157.2	115.3	50.9	37.4	1664.9
No. of days with													
Tmin < 0 °C	23	19	16	5	-	-	-	-	-	1	8	17	89
Tmax < 0 °C	10	6	2	-	-	-	-	-	-	-	2	7	27
Tmax > 25 °C	-	-	-	0	3	9	11	10	3	0	-	-	36
Tmax > 30 °C	-	-	-	-	0	1	3	2	0	-	-	-	6
precip. ≥ 0.1 mm	17	15	14	13	14	13	13	12	13	13	16	19	172
snow cover	17	12	6	0	0	-	-	-	-	0	2	10	47
thunderstorm	0	0	1	1	5	7	7	6	3	0	0	0	30
fog	9	7	5	3	3	2	2	3	5	9	9	9	66

1.5 Site Details

Falkenberg

The terrain around the GM Falkenberg is slightly slanted from NNE towards SSW with height differences of less than 5 m over a distance of about 1 km. The central part of the field site is a flat meadow of 150 * 250 m^2 covered by short grass, this area is surrounded by grassland and agricultural fields in the immediate vicinity, a small village is situated about 600 m to the SE, and a small, but heterogeneous forest area lies to the W and NW at about 1 to 1.5 km distance (see Figure 2).

The Falkenberg site was used for agricultural farming activities until around 1990 when it was transformed to a grassland area. Main vegetation species are perennial ryegrass (*Lolium perenne*), red fescue (*Festuca rubra*), dandelion (*Leontodon autumnalis*, *Taraxacum officinale*), bromegrass (*Bromus hordeaceus*), and clover (*Trifolium pratense*, *Trifolium repens*). Management of the site includes fertilisation with about 35 kg / ha of urea pellets (46% of nitrogen) once per year. The meadow is mowed regularly (up to six times per year) in order to keep the mean vegetation height below 20 cm. This leads to a typical roughness length for momentum (z_0) below 0.01 m. A time series of vegetation height and roughness length (determined from the momentum flux measurements during near-neutral stratification) over the 2003 / 2004 annual cycles is shown in Figure 4. The leaf-area index (LAI) at the Falkenberg field site may vary in dependence on the vegetation growth stage between values of < 1 m^2 m^{-2} up to values around 3 .. 4 m^2 m^{-2} (e.g., Falge et al., 2005).

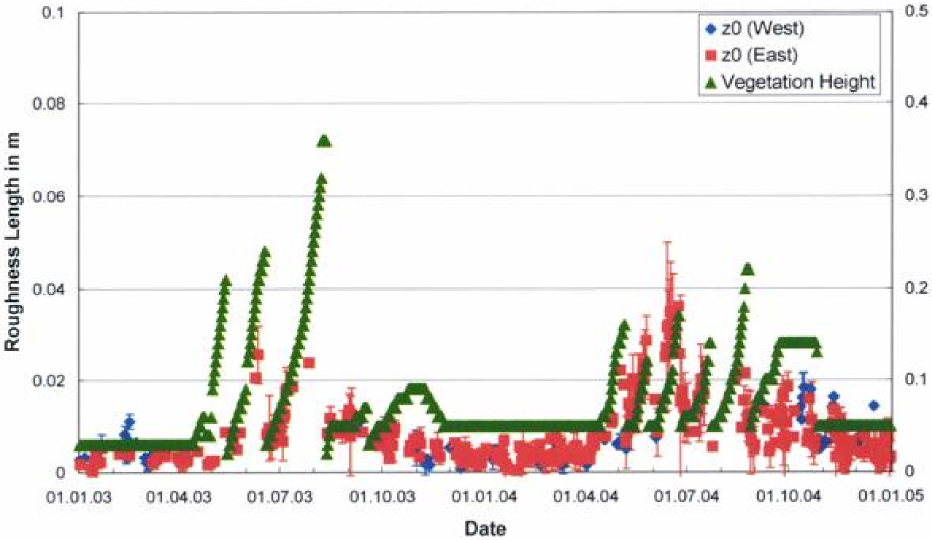

Figure 4 Time evolution of the estimated values of mean vegetation height (right y-axis) and roughness length for momentum (left y-axis) at the Falkenberg boundary layer field site for the 2003 / 2004 annual cycles (red and blue symbols indicate estimates based on measurements at the two flux stations in the eastern and western part of the field site – see section 2)

A soil profile from the GM Falkenberg is shown in Figure 5. The depth of the upper layer of sand (pale soil - *Eutric Podzoluvisol*) is around 60 cm at the place where the operational soil temperature and moisture measurements are performed. Within this layer, the plough horizon (resulting from the former farming activities) at a depth of about 30 cm can be clearly seen. The content of organic matter in this upper soil horizon is about 1-2 % of mass. Below the sand there is a layer of loamy sand or loam, the transition depth varies between about 50 cm and 1m.

Figure 5 Soil profile at the Falkenberg boundary layer field site

Forest Station

The Forest Station is situated about 10 km to the West of the GM Falkenberg (see Figure 1). A photograph across the forest with the forest tower and a birds view from directly above the tower site are presented in Figure 6 and Figure 7, respectively.

Photo: DWD-MOL2 (J.-P. Leps, 2003)

Figure 6 View towards NW across the pine forest with the Forest Station tower in the upper left quadrant

Figure 7 Birds view at the forest plantations around the Forest Station tower

The terrain at the Forest Station site is slightly slanted from East and South towards West with a height difference of about 10 m over a distance of 1 km. A small lake and a clearing of a few hectars in size are situated about half a kilometer to the West of the forest tower. The forest consists of regular sectors (see Figure 7) of pine plantations (*pinus sylvestris*). The mean tree height around the tower is 14 m, but it reaches up to 18 m in other (older) parts of the plantations in the vicinity of the forest tower. The mean stem diameter is about 14 cm, and the number of stems is roughly 1800 per hectar. The roughness length for momentum (z_0) and the displacement height (d) at the forest site have been estimated based on wind profile and turbulence measurements, the mean values are z_0 = 1.8 .. 2.0 m, and d ≈ 9 m.

1.6 Site References

WWW: http://www.dwd.de/en/FundE/Observator/MOL/
Literature: Neisser et al. (2002), Beyrich et al. (2002), Stiller et al. (2005), Beyrich and Mengelkamp (2006)

2. Instrumentation Description

2.1 The Falkenberg Field Site

A photograph of the Falkenberg boundary layer field site and its infrastructure and measurement installations is shown in Figure 8. The basic installation of the GM Falkenberg was performed in 1998, and the number of sensors and measurement systems has gradually been complemented over the following years.

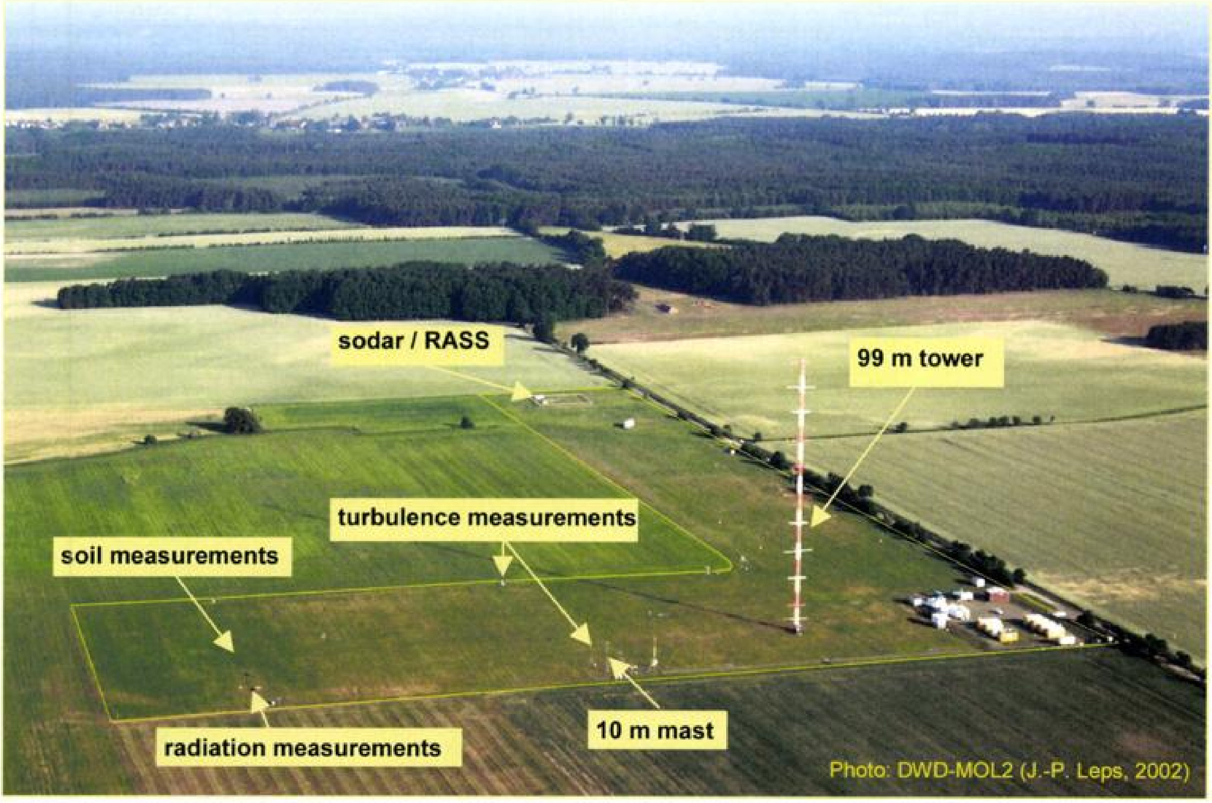

Photo: DWD-MOL2 (J.-P. Leps, 2002)

Figure 8 The DWD-MOL boundary layer field site (GM) Falkenberg towards WNW

The central measurement facility at GM Falkenberg is a 99m tower, a lattice construction of rectangular cross section with a side length of 1.2 m. It is equipped with booms to carry sensors at every 10 m, three booms are mounted at each level pointing approximately towards S, W, and N (with a shift of 11 deg). Standard meteorological profile measurements (wind speed, temperature, humidity) are performed at levels 10 m, 20 m, 40 m, 60 m, 80 m, and 98 m. Wind sensors are mounted on each of the three booms at these height levels in order to ensure that there is always at least one sensor not influenced from the structure of the tower. The measurement levels at 30 m, 50 m, 70 m, and 90 m are planned to be instrumented with turbulence sensors in the future, up to now turbulence measurements were realised during field experiments of several weeks duration in 1998, 2000, 2002, and 2003, respectively.

The basic meteorological data are measured at a 10 m lattice mast (Figure 9). This mast is of triangular shape with a side length of 40 cm, the wind sensors are mounted at booms of 1.5 m length oriented towards SW. The rain gauge and the pressure sensor are operated in the vicinity of this mast. The radiation measurements are performed at a bar construction erected about 120 m to the South of the 10 m mast (see Figure 8). Soil measurements are performed west of the radiation measurements.

Foto: DWD-MOL3 (D. Dauß, 2002)

Figure 9 The 10 m mast for standard meteorological measurements from SSW

Flux measurements are performed using omni-directional sonic anemometer-thermometers. Two of these instruments are operated at the western wiring of the 10 m mast (S1) and at the western edge of the field site (S2, see Figure 8), respectively, providing flux data representative for the grassland area both for westerly and easterly wind directions. The sonics are mounted on top of tall tube masts (see Figure 10). Fast-response infrared hygrometers have been added to the sonics in spring 2003 for the direct measurement of the latent heat flux using the eddy-covariance method.

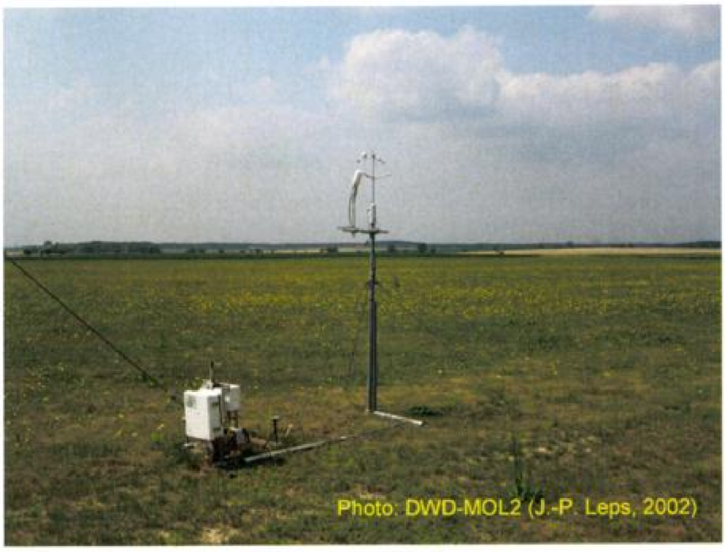

Photo: DWD-MOL2 (J.-P. Leps, 2002)

Figure 10 Turbulence measurement system S1 (USA-1 + LI7500 hygrometer)

2.2 The Forest Station

The Forest Station in its present configuration has been set up in autumn, 2002. After a test phase the operational measurements started on December 01, 2002, data were delivered to the CEOP archive starting on January 01, 2003. The central measurement facility is a lattice tower construction of triangular shape with a side length of 40 cm (see Figure 11). Standard measurements of mean meteorological parameters (wind speed, temperature, humidity) are performed at nine levels: 2.25 m, 4.05 m, 9.50 m, 12.05 m, 14.55 m, 17.45 m, 21.00 m, 24.15 m, and 28.30 m, respectively. The first two levels represent the stem region, the next three levels are immediately below, inside and slightly above the crown region, and the upper four levels represent the above-canopy part of the atmospheric surface layer. Wind sensors are mounted on booms pointing towards SSE at 1.15 m distance to the tower. Radiation measurements are performed above the canopy, sensors are mounted at the tower. The turbulence measurements using eddy covariance instrumentation are carried out at the top of the tower. Soil measurements are performed along two different profiles close to the tower down to a depth of 1.5 m, the distance between the two profiles is about 1.5 m. The rain gauge for precipitation measurements is situated at the forest clearing about 500 m to the West of the tower.

Figure 11 The 30m tower at the Lindenberg Forest Station

2.3 Sensor List

A list of sensors used at the GM Falkenberg and at the Forest Station is given in Table 4.

Note that a replacement of the combined temperature-humidity sensor HMP-35D by the more recent model type HMP-45D was realised both at the 10m mast and at the 99m tower on March 23, 2004, and on April 14-15, 2004, respectively. At the forest tower, HMP-45D has been operated during complete CEOP – phase I.

A few other sensor replacements (e.g., of the turbulence sensors and of the cup anemometers in connection with configuration updates or regular maintenance and calibration activities, respectively) were performed without changing the sensor type.

Operational radiosonde measurements at MOL are performed four times daily. Before July 01, 2004, release time was around 0445 UTC, 1045 UTC, 1645 UTC, and 2245 UTC, respectively, and the soundings were performed using Vaisala RS-80-30 (RS-80-30E) radiosondes (Vaisala Oy, Finland - http://www.vaisala.com) and Vaisala PC-Cora ground equipment. Wind finding was done by radar tracking of the balloon using Gematronik 300WF radar. Since July 01, 2004, Vaisala RS-92-AGP radiosondes have been used in connection with Vaisala Digi-Cora III ground equipment and GPS wind finding. Release times have been slightly shifted to around 0515 UTC, 1115 UTC, 1715 UTC, and 2315 UTC, respectively.

For details on sensor specifications, see the web sites of the different manufacturers.

Table 4

Parameter	Measurement Height	Sensor	Measurement principle	Manufacturer	Reference	Remarks
basic meteorology						
- Temperature / Humidity	2 m (Forest: 2.55 m)	Frankenberger Psychrometer /	Pt-100 / psychrometer	Th. Friedrichs	http://www.th-friedrichs.com	ventilated, radiation shielded
		HMP-35D/45D	Pt-100 / capacitive	Vaisala	http://www.vaisala.com	
- wind speed	10 m (Forest none)	F460	cup	Climatronics	http://www.climatronics.com	
- wind direction	10 m (Forest none)	wind dir. transm.	vane	Thies	http://www.thiesclima.com	
- pressure	1 m	PTB220A	piezo-resistance	Vaisala	http://www.vaisala.com	
	(Forest: 28.00 m)	RPT410V	piezo-resistance	Lambrecht	http://www.lambrecht.net	
- precipitation	1 m	Pluvio	weighing	Ott Hydrometrie	http://www.ott-hydrometrie.de	
- snow depth	- (Forest none)	snow stick	manual reading			
Radiation						
- shortwave	2 m (Forest 28.95 m)	CM24	thermopile	Kipp & Zonen	http://www.kippzonen.com	ventilated
- longwave	2 m (Forest 28.95 m)	DDPIR	thermopile	Eppley	http://www.eppleylab.com	ventilated
- surface temp.	2 m (Forest 26.10 m)	KT15.82D	pyro-electric	Heitronics	http://www.heitronics.com	
- Phar	2 m (Forest none)	LI190SZ	photo diode	LiCor	http://www.licor.com	
Soil						
- soil temperature	-5, **-10**, -15, **-20**, **-30**, -45, -50, **-60**, **-90**, -100, -120, **-150** cm	Pt-100	Pt-100	TMG		bold: measurement levels Forest
- soil moisture	-8, -15, **-30**, -45, **-60**, **-90** cm	TRIME EZ	TDR	IMKO	http://www.imko.de	bold: measurement levels Forest, also -10, -20, -150 cm
- soil heat flux	- 5, -10 cm	HP3	flux plate	RIMCO		
tower						
- temperature / humidity	40 m, 98 m (Forest: 14.55 m, 28.3 m)	Frankenberger Psychrometer /	Pt-100 / psychrometer	Th. Friedrichs	http://www.th-friedrichs.com	ventilated, radiation shielded
		HMP-35D/45D	Pt-100 / capacitive	Vaisala	http://www.vaisala.com	
- wind speed	40 m, 98 m	wind transmitter	cup	Thies	http://www.thiesclima.com	
	(Forest: 14.55 m, 28.3 m)	F460	cup	Climatronics	http://www.climatronics.com	
- wind direction	40 m, 98 m	wind dir. transm.	vane	Thies		
	(Forest: 30.55 m)	USA-1	sonic	METEK	http://www.metek.de	
turbulent fluxes						
- momentum	2.4 m (Forest: 30.55 m)	USA-1	sonic	METEK	http://www.metek.de	
- sensible heat	2.4 m (Forest: 30.55 m)	USA-1	sonic	METEK		
- latent heat	2.4 m (Forest: 30.55 m)	LI-7500	infrared hygrometer	LiCor	http://www.licor.com	after April 01, 2003

3. Data Collection and Processing

3.1 Data Collection

Sampling and averaging times for the data are given in Table 5.

Table 5 - Sampling and averaging times of data for Lindenberg CEOP site

Parameter	Sampling Interval	Basic averaging Interval	30-minute data creation
basic meteorology			
• temperature	1 sec.	10 min.	arithm. average
• humidity	1 sec.	10 min.	arithm. average
• wind speed	1 sec.	10 min.	arithm. average
• wind direction	1 sec.	10 min.	vector average
• pressure	1 sec.	10 min.	arithm. average
• precipitation	1 min.	10 min.	sum
• snow depth	1 reading / day	none	none
radiation			
• shortwave	1 sec.	10 min.	arithm. average
• longwave	1 sec.	10 min.	arithm. average
• surface temp.	1 sec.	10 min.	arithm. average
• phar	1 sec.	10 min.	arithm. average
soil			
• soil temperature	1 sec.	10 min.	arithm. average
• soil moisture	1 sec. 10 min. (Forest)	10 min.	arithm. average
• soil heat flux	1 sec.	10 min.	arithm. average
tower			
• temperature	1 sec.	10 min.	arithm. average
• humidity	1 sec.	10 min.	arithm. average
• wind speed	1 sec.	10 min.	arithm. average
• wind direction	1 sec.	10 min.	vector average
turbulent fluxes			
• momentum	0.05 sec. 1)	10 min.	average acc. to eq. (6)
• sensible heat	0.05 sec. 1)	10 min.	
• latent heat	0.05 sec	10 min.	
Radiosonde			
• pressure	10 sec. 2)	none	does not apply
• temperature	10 sec. 2)	none	does not apply
• humidity	10 sec. 2)	none	does not apply
• wind speed	30 sec. 2)	none	does not apply
• wind direction	30 sec. 2)	none	does not apply

1) Sampling interval of the turbulence measurements was 0.1 sec until January 22, 2003 at S1 and until April 15, 2003 at S2

2) Radiosonde data have been reported with a resolution of 5 sec. since the introduction of the RS-92 sonde on July 01, 2004.

3.2 Data Processing

In this section, a few remarks are given on specific steps in the data processing. Parameters for which no comments are given, were directly derived from the sensor output.

Temperature (in the meteo ~, soil ~ and tower data sets) was derived directly from Pt-100 resistance measurements (4-wire connection) using standard linearised Pt-100 characteristics.

Relative humidity (both in the surface and tower data sets) was measured simultaneously by HMP-35D / HMP-45D capacitive humidity sensor and by aspirated psychrometer

during the warm season. A correction equation for the HMP was derived based on these parallel measurements by minimising the rmsd when compared to the psychrometer data. This correction equation has then been regularly applied to the HMP measurements over the winter period. Relative humidity values > 100 % were set equal to 100 %.
According to the "CEOP Reference Site Data Set Procedures report" (see at http://www.joss.ucar.edu/ghp/ceopdm/), the following equations have been used to determine relative humidity from the psychrometer measurements:

$$(1) \qquad E_{Sat}[hPa] = 6.1078 * \exp\left\{\frac{17.08085 * t[°C]}{234.175 + t[°C]}\right\}$$

$$(2) \qquad e[hPa] = E_{Sat}[hPa] - 0.00066 * (1 + 0.00115 * t_{wet}[°C] * p[hPa] * (t[°C] - t_{wet}[°C]))$$

$$(3) \qquad RH[\%] = \frac{e[hPa]}{E_{Sat}[hPa]} * 100\%$$

Note that the coefficients in (1) are valid over water only, the use of (1) therefore implies small inaccuracies when calculating specific humidity and dew point temperature for winter measurements at temperatures below 0 deg C from the HMP measurements.

The ***surface wind*** data (10 m) at ***GM Falkenberg*** were taken from the measurements at the 10m mast (see Figure 9). Due to the mast construction there are flow distortion effects on the wind speed measurements for winds from the sector between 045 and 075 deg, these data are flagged correspondingly (see section 4). The ***tower wind*** data (measurements are available from three anemometers at the three booms of each level) at ***GM Falkenberg*** were processed as follows:

1. Determination of wind direction from the measurements at three booms by vector averaging of those measurements which differ by less than 10 deg - if all three measurements differ by > 10 deg → comparison with the near-surface wind direction and selection of the closest tower wind direction value - if no data available from near surface → vector averaging of all three wind direction values.
2. Selection of representative wind speed measurement in dependence on wind direction.

For both, the surface and tower wind data, wind speed values less than 0.3 ms^{-1} were interpreted as calm and set to zero in the original 10-minutes data set, in this case wind direction is set equal to zero as well. Note that wind direction equal to zero marks calm conditions, while wind from North is indicated by a wind direction of 360 deg.
No ***surface wind*** data are reported for the ***Forest Station*** since the lower measurement levels are within the canopy. The ***tower wind*** data for the ***Forest Station*** include the measurements from the 14.55 m and 28.3 m levels, respectively. Wind direction data are available for the top of the tower only, u- and v- wind components have therefore been calculated for the upper level only. Due to the mast construction there are flow distortion effects on the wind speed measurements for winds from the sector between 290 and 350 deg, these data are flagged correspondingly (see section 4).

Shortwave radiation measurements were corrected for a mean zero-offset of the night-time measurements (usually 1-3 Wm^{-2}, this correction is applied for the Falkenberg data only), radiation values < 2 Wm^{-2} were set equal to zero.

Longwave radiation (Rlw) was computed from the voltage measured at the thermopile (U_{emf}) using both measured body (T_B) and averaged dome temperatures (T_D) for correction (see Philipona et al., 1995):

$$(4) \qquad Rlw = \frac{U_{emf}}{c}(1 + k_1 \sigma T_B^{\ 3}) + k_2 \sigma T_B^{\ 4} - k_3 \sigma \left(T_D^{\ 4} - T_B^{\ 4}\right)$$

Net radiation was calculated considering the downward / upward components of the measured shortwave and longwave radiative fluxes.

Soil moisture (qsoil) at the ***GM Falkenberg*** was measured at the upper two levels by 4 (at – 8 cm) and 3 (at – 15 cm) sensors, respectively. Reported soil moisture values are an average of all measurements at a given depth which differ by not more than Max (5 Vol-%, 0.5 qsoil). ***Soil moisture*** data at the ***Forest Station*** are from profile 1 at –10 cm, –30 cm, and – 60 cm, data at –20 cm, –90 cm, and – 150 cm is from profile 2. ***Soil temperature*** data at the ***Forest Station*** down to 90 cm come from profile 1, the 150 cm data are from profile 2.

Soil heat flux at all levels was measured by 6 flux plates (GM Falkenberg) and 3 flux plates (Forest Station). Reported values are averages over all available sensors. During summer 2003, the number of flux plates available for the averaging decreased from six to four at the –10cm level at GM Falkenberg.

Turbulent momentum and sensible heat fluxes were determined from the high resolution measurements of the three wind components and of the sonic temperature by computing mean eddy covariances. Double rotation (see, e.g., Kaimal and Finnigan, 1994) has been applied to the <u'w'> and <v'w'> covariances, both covariances were used to compute friction velocity:

$$u_* = \left(\langle u'w' \rangle^2 + \langle v'w' \rangle^2 \right)^{1/4} \tag{5}$$

The sensible heat flux has been corrected for buoyancy and cross-wind effects according to Schotanus et al. (1983) using the modified equations from Liu et al. (2001).

Turbulent latent heat flux for the period October 01, 2002 till March 31, 2003 was estimated with the modified Bowen ratio method after Liu and Foken (2001) for the GM Falkenberg. This method uses the measured sensible heat flux (see above) and a Bowen ratio estimated from temperature and humidity measurements at two levels:

$$l_v E = \frac{l_v \Delta T}{c_p \Delta q} H \tag{7}$$

Temperature and humidity measurements from the 0.5 m and 2 m levels at the 10m meteorological mast were used to determine the finite differences in (7). After April 01, 2003, fast-response humidity measurements were available from the operation of infrared hygrometers coupled to the sonic anemometer-thermometers at S1, S2, and at the Forest Station tower, respectively. The turbulent latent heat flux was then determined by computing the mean eddy-covariances between the vertical velocity and humidity fluctuations. The fluxes were corrected for density effects after Webb et al. (1980), and a mean correction for flux losses due to sensor separation and path averaging based on Moore (1986) was applied with different values for stable / unstable stratification.

Averaging of the ***turbulent fluxes*** from original 10-minute sampling intervals to half-hourly values was performed before applying rotations and corrections according to:

$$\langle w'x' \rangle_{30} = \frac{1}{3} \sum_{i=1}^{3} \langle w'x' \rangle_{10,i} + \frac{1}{3} \sum_{i=1}^{3} \overline{w}_{10,i} \overline{x}_{10,i} - \frac{1}{9} \sum_{i=1}^{3} \overline{w}_{10,i} \sum_{i=1}^{3} \overline{x}_{10,i} \tag{6}$$

A composite flux data set has been created from the measurements with the two sonics (see section 2.2) at the ***GM Falkenberg*** taking into account the corresponding fetch conditions. The following rules have been applied:

wind direction from sector > 000...010 deg: data were taken from S1
wind direction from sector > 010...030 deg: fluxes from S1 and S2 were averaged
wind direction from sector > 030...150 deg: data were taken from S2
wind direction from sector > 150...190 deg: fluxes from S1 and S2 were averaged
wind direction from sector > 190...360 deg: data were taken from S1.

Bad data were replaced by the measurements from the other site if a lower quality flag was assigned to these data.

Radiosonde humidity measurements at MOL undergo an elaborated data processing procedure. This covers the following steps.

- ground preparation (100% RH test), ground check and correction
- temperature correction
- sensor response time correction
- detection of sensor icing and deletion of humidity values under icing conditions.

For details see Leiterer et al. (2004).

Other derived parameters were computed according to the equations given in the CEOP Reference Site Data Set Procedures Report.

4. Quality Control Procedures

The quality control algorithm of the field data covers several steps. For most of the data quick-look plots are created regularly. Obvious outliers identified in these plots are flagged manually.

As a second step, an automatic range test is performed for all measured parameters with the acceptance threshold values given in Table 6.

Table 6 - Acceptance range limits for automatic data quality control

Parameter	lower limit	upper limit
basic meteorology		
• temperature	– 30 deg C	+ 50 deg C
• humidity	10 %	100 %
• wind speed	0.3 ms^{-1}	30 ms^{-1}
• wind direction	0 deg	360 deg
• pressure	950 hPa	1040 hPa
• precipitation	0 mm	40 mm
radiation		
• shortwave down	0 Wm^{-2}	1230 Wm^{-2}
• shortwave up	0 Wm^{-2}	800 Wm^{-2}
• longwave down	150 Wm^{-2}	500 Wm^{-2}
• longwave up	150 Wm^{-2}	700 Wm^{-2}
• surface temp.	– 40 deg C	+ 60 deg C
• phar down	0 μmol*m^{-2}*s^{-1}	2500 μmol*m^{-2}*s^{-1}
• phar up	0 μmol*m^{-2}*s^{-1}	1600 μmol*m^{-2}*s^{-1}
soil		
• soil temperature	– 30 deg C	+ 50 deg C
• soil moisture	3 Vol-%	50 Vol-%
• soil heat flux	– 100 Wm^{-2}	+ 200 Wm^{-2}
tower		
• temperature	– 30 deg C	+ 50 deg C
• humidity	10 %	100 %
• wind speed	0.3 ms^{-1}	30 ms^{-1}
• wind direction	0 deg	360 deg
turbulent fluxes		
• friction velocity	0.01 ms^{-1}	3 ms^{-1}
• sensible heat	– 250 Wm^{-2}	+ 750 Wm^{-2}
• latent heat	– 250 Wm^{-2}	+ 750 Wm^{-2}

Measured data exceeding the limits given in Table 6 are set to -9999.99 and get Flag = M.

The third step of the QC algorithm consists of a number of automatic tests, including sensor inter-comparison or physically based parameter check. An overview on these tests is given in Table 7.

Measured data that do not meet the physically based tests get Flag = D.

Finally, a manual control of those data which were automatically given Flag = D is performed. If auxiliary measurements and / or physical arguments give reason for acceptance of the data, Flag = D is transformed to Flag = G, otherwise Flag = D is kept or set to Flag = B.

Table 7 - Physically based tests of measured parameters

parameter	test description
basic meteorology	
• temperature	comparison psychrometer vs. HMP, Flag = G if $\Delta T < 1$ K
• humidity	comparison psychrometer vs. HMP, Flag = G if $\Delta RH < 5$ %
• wind speed	Flag = G if V (10 m) > V (8 m)
• wind direction	-
• pressure	-
• precipitation	-
radiation	
• shortwave down / shortwave up	Falkenberg: Flag = G if albedo: 0.15 ... 0.30 (0.15 ... 1.00 in case of snow) Forest: Flag = G if albedo: 0.07 ... 0.13 (0.00 ... 1.00 in case of snow) These limits apply if Rsw_down ≥ 50 Wm^{-2}
• longwave down	Flag = G if $0.6 * \sigma T_{2m}^4$ < downward longwave radiation < $1.0 * \sigma T_{2m}^4$
• longwave up	Flag = G if $\sigma (T_{2m} - 5\text{ K})^4$ < upward longwave radiation < $\sigma (T_{2m} + 5\text{ K})^4$
• surface temp.	Flag = G if $\sigma (T_{surf} - 3\text{ K})^4$ < upward longwave radiation < $\sigma (T_{surf} + 3\text{ K})^4$
• phar down / phar up	Flag = G if phar albedo: 0.12 ... 0.30 (0.12 ... 1.00 in case of snow) (GM Falkenberg only)
soil	
• soil temperature	Flag = G if difference between neighbouring levels doesn't exceed height-dependent threshold (GM Falkenberg) or if difference between profile 1 and profile 2 is smaller than 2 K (at –5 cm) respectively 0.5 K (below –5 cm) at Forest Station
• soil moisture	Flag = G if difference between sensors < 5 Vol-% or 50 % of the measured value (upper levels at GM Falkenberg only) and if difference in time between two subsequent values < 5 Vol-%
• soil heat flux	Flag = G if difference between sensors < 30 % (tested only if $\|G\| > 30$ Wm^{-2})
tower	
• temperature	Comparison psychrometer vs. HMP, Flag = G if $\Delta T < 0.5$ K
• humidity	Comparison psychrometer vs. HMP, Flag = G if $\Delta RH < 5$ %
• wind speed	GM Falkenberg: Flag = G if -1 ms^{-1} < ΔV < $+2$ ms^{-1} per 20 m height difference Forest / 14.55 m: Flag = G if V (14.55 m) = 0.6 .. 0.85 V (17.45m) Forest / 28.3 m: Flag = G if V (24.15 m) = 0.85 .. 1.00 V (28.3 m)
• wind direction	GM Falkenberg: Flag = G if wind direction difference of at least 2 booms < 10 deg
turbulent fluxes	
• friction velocity	Flag = G if $u_* < 0.15 * V$ (if V > 3 ms^{-1}) and if σ_w / u_* is within certain limits
• sensible heat	Flag = G if sign (H) matches sign ($\Delta T/\Delta z$) and if (H + LE) < (net radiation - soil heat flux)
• latent heat	Flag = G if sign (LE) matches sign ($\Delta q/\Delta z$) and if (H + LE) < (net radiation - soil heat flux), for LE > 50 Wm^{-2}

It should be remarked that all tests are generally performed on the 10min averaged original data.

In addition to the tests described above, the wind speed measurements in the surface data set and the turbulent flux values are generally given Flag = D if distortion of the measurement from tower constructions or nearby obstacles has to be assumed. For the wind measurement at 10 m (GM Falkenberg) this holds for the wind direction sector 045 deg to 075 deg, tower wind data from the Forest Station suffer from flow distortion effects for the wind direction sector 290 deg to 350 deg. For the turbulent fluxes from GM Falkenberg flow distortion and poorly defined fetch conditions were considered for the wind direction sector 330 deg to 060 deg (over N) over the year 2003. In January 2004, the sensor mounting at S2 has been modified such that the flux composite does not contain any flow distortion sectors (see section 6). Turbulence measurements at the Forest Station tower experience flow distortion of the sonic measurements from the infrared hygrometer mounted nearby for a wind direction sector 330 deg to 030 deg.

The flagging rules applied when producing the 30min averages for the CEOP data set from the original 10min averages are summarised in Table 8.

Table 8 - Flagging rules for 30minute averaged data

Flag i	Flag j	Flag k	Flag (ijk)	average covers
G	G	G	G	30 minutes
G	G	D, U	G	30 minutes
G	D, U	D, U	D, U	30 minutes
D, U	D, U	D, U	D, U	30 minutes
G	G	M	G	20 minutes
G	M	M	G	10 minutes
D, U	D, U	M	D, U	20 minutes
D, U	M	M	D, U	10 minutes
M	M	M	M	no data

5. Gap Filling Procedures

No gap filling procedures using model assumptions have been applied for the data period October 01, 2002 to December 31, 2004.

6. Data Remarks

This section gives specific additional information on different parameters the user should be aware of when using the data.

General
Due to a power failure at the Forest Station no data (except of the precipitation sensor) are available for the period Mar 28, 2003, 2300 UTC to March 31, 2003, 0830 UTC. Data logger problems caused general data losses at the Forest Station on December 08-09, 2003.

Humidity
Relative Humidity (both in the surface and tower data sets) was measured simultaneously by HMP-35/45 capacitive humidity sensor and by aspirated psychrometer during the warm season. If available, the psychrometer data were selected for the CEOP data set. The time intervals for which the humidity data are based on the psychrometer measurements are given in Table 9.

Table 9 - Availability of psychrometer humidity data

Year	GM Falkenberg		Forest Station	
	Surface data set	Tower data set	Surface data set	Tower data set
2002	Oct 01 till Oct 31	Oct 01 till Oct 31	-	-
2003	Mar 27 till Nov 04	Apr 01 till Nov 03	Apr 16 till Sep 02 Sep 19 till Nov 19	Apr 16 till Sep 02 Sep 24 till Nov 19
2004	Mar 29 till Oct 31	Jun 24 till Sep 05 Sep 24 till Oct 31	Apr 01 till Nov 14	Apr 01 till Nov 14

For the rest of the time, corrected HMP measurements (see section 3.2) were used.
HMP measurements had to be included in the data set as well during periods with (mainly nighttime) temperatures below freezing point when the psychrometer wet bulb temperature measurement becomes unreliable. This concerns periods in the second half of October and first half of November both in 2003 and 2004, during the first half of April, 2004, and also on May 14, 2004.
Periods of missing psychrometer measurements indicated in Table 8 during April to June 2004, and during September 2004 (at the GM Falkenberg tower) and also during September 2003 (at the Forest Station) were due to problems with the proper wetting of new charges of wicks applied for the wet-bulb temperature measurements with the Frankenberger psychrometers.

Wind Speed
No correction for overspeeding was performed on the cup anemometer measurements.
The wind speed measurement at 10 m (reported in the surface data set of the GM Falkenberg station) is influenced by the mast construction for wind directions from the sector 45° ... 75°, measurements are given Flag = D. Wind speed measurements at the Forest Station tower are influenced by the mast construction for wind directions from the sector 290° .. 350°, measurements are given Flag = D.
Icing during winter conditions caused a series of missing data values in the GM Falkenberg surface data set and in the Forest Station tower data set, especially during the periods 20021217-20021221, 20021230-20030106, 20030111-2030113, 20030129-20030206, 20031221-20031223, 20040102-20040105, 20040110-20040111, 20040118-20040122, 20041213-20041215, 20041219-20041222, and 20041228-20041229.
At the Forest Station tower, the cup anemometer at 14.55 m was damaged during a severe storm on April 05, 2003 causing missing data until April 16, 2003 when the broken cup was replaced.

Precipitation

The sensitivity threshold of the Pluvio sensor corresponds to a rain amount of 0.03 mm, smaller amounts can not be recorded. Continuous precipitation of weak intensity can therefore artificially appear as a series of single events. Each increase in mass of the gauge is detected by the sensor as precipitation (e.g., heavy insects). Isolated single values at the detection limit have therefore usually to be interpreted as questionable / corrupted data.

Strong frost caused a failure of the Pluvio sensor during the period Jan 01 to Jan 16, 2003, and again from Feb 01 to Feb 03, 2003. For these periods, measurements from a tipping bucket (manufactured by Friedrichs) operated side by side to the Pluvio were included in the GM Falkenberg data set. No replacement was possible for the Forest Station. Precipitation data for the Forest Station are also missing for the periods Aug 07 to Aug 18, 2003, (due to sensor malfunction), Feb 01 to Mar 10, 2004, (due to a sensor theft), and Nov 08 to Dec 06, 2004 (due to sensor failure).

Snow depth

Snow depth at the GM Falkenberg is measured manually with a snow stick during working days only (not during weekends and public holidays). The measured data were assigned to the measurement time 0600 UTC. No snow measurements are performed at the Forest Station.

Radiation

Due to data logger failure, original radiation data at GM Falkenberg were missing over the period August 28 to September 01, 2003. Data have been replaced by back-up measurements with an independent second radiation complex (same sensor types as the standard system) operated West of the 99m tower (see Figure 4).

At the Forest Station there is a data gap for the longwave radiation components from June 24, 2004, till July 07, 2004, due to a sensor failure.

Surface Temperature

During summer days with high insolation, measured surface temperature values at GM Falkenberg frequently exceeded the threshold of + 3 K when compared to a (fictive) surface temperature calculated from the upward longwave radiation measurements. Flag = D has been assigned automatically to all these measurements (see section 4). These flags were not corrected manually although we believe that the high surface temperature measurements are generally correct which was confirmed by independent surface temperature measurements at the back-up radiation complex. Instead, we would like to give a warning to the data user that there may be a problem of representativeness when comparing the spot-like surface temperature measurement with the half-space field of view of the longwave radiation sensor. At the Forest Station, measured surface temperatures occasionally exceed the + 3 K threshold during the period with high solar elevation angles depending on the time of the day, radiation and wind conditions. This is attributed to the fact that the surface temperature sensor may see sun spots at the forest floor rather than the forest canopy under these conditions.

Soil Moisture

Soil moisture determination using the gravimetric method and the Lumbricus sonde (http://www.meteolabor.ch) is performed regularly during frost-free periods for comparison with the continuous TDR measurements (see Beyrich, 2006). If upper soil layers were frozen for longer time periods during the winter, this lead to unphysical soil moisture values which were given Flag = B.

Soil Heat Flux

Soil heat flux data reported in the data set were measured at - 5cm and - 10 cm depth, respectively. No correction for heat storage effects in the uppermost soil layers has been performed. Liebethal (personal communication, 2004) has found that a consideration of the heat storage may increase the measured soil heat flux below the short grass at GM Falkenberg by up to 100 % if interpreted as soil heat flux at the surface.

Turbulent Fluxes

Flux measurements of both eddy-covariance systems are affected from poorly defined fetch conditions and flow distortion effects for a certain wind direction sector. Flow distortion is unavoidable due to the mounting of the infrared hygrometer close to the sonic. Additional flow distortion arises from the vicinity of the 10m-mast in case of S1. The mounting of the infrared hygrometer relative to the sonic was changed twice during the data collection period in case of the S2 system. The following disturbed sectors are valid

S1 system	060-120 deg	during 20021001-20030331
	030-120 deg	during 20030401-20041231
S2 system	330-030 deg	during 20021001-20040415
	330-090 deg	during 20030416-20040121
	300-030 deg	during 20040122-20040329
	300-010 deg	during 20040330-20041231

The disturbed sector at the Forest Station is 330-030 deg.

Original flux data for the two systems at GM Falkenberg generally got Flag = D, if the wind direction was within these ranges. The final setup of the S1 and S2 systems (after 20040330) ensures, that no flow distortion and limited fetch effects occur for the flux composite (see section 3.2) at GM Falkenberg.

During summer 2004, a sensor failure occurred with the sonic at S2 following a thunderstorm event on June 09. This failure was not obvious in the pre-processed data and thus remained undetected for several weeks. The sensor was finally replaced on September 03, 2004. For the time period between June 09 and September 03, the momentum flux measured at S2 is not usable at all. For the scalar fluxes (of sensible and latent heat) several specific tests were performed and no obvious deviations from the typical behaviour were found. However, data were flagged with Flag = D for this time period as a warning to the user.

In order to assess the uncertainty of turbulent flux measurements using fast response sonic anemometer-thermometers, numerous inter-comparison experiments have been performed in the past. Three such experiments took place in Lindenberg in 1997, 1998 and 2002. The typical uncertainty of the turbulent flux measurements due to sensor specifications and sensor set-up has been found to be about 3-8 % for the sensible heat flux and about 10-15 % for friction velocity and latent heat flux. These uncertainties may increase by 5-10 % due to differences in the data processing algorithm applied by different research groups or being implemented in different types of sonic anemometers by the manufacturer (e.g., Mauder et al., 2006).

Icing during winter conditions caused a number of sensor faults of the sonic anemometer.

Latent heat fluxes for the period Oct 01, 2002 to March 31, 2003, at GM Falkenberg were estimated in an indirect way using vertical gradients of temperature and humidity (see section 3). Since the Bowen ratio is not well defined, if the gradients are very small, such situations were excluded from the computations. This caused a rather high number of missing values in the latent heat flux data set during the first half of EOP3.

The footprint conditions for the flux measurements have been analysed in detail based on data from the LITFASS-2003 experiment (Beyrich et al., 2006). An estimate of the footprint area that is covered by the surface of interest (the grassland surface of the boundary layer field site, the pine crowns at the forest station) in dependence on wind direction and stability is given in Table 10. For the Falkenberg flux composite, the minimum values are given for the wind direction sectors where both S1 and S2 data were used to determine the surface flux.

Table 10 – Estimated percentage of flux footprints originating from the study surface for the Lindenberg – Falkenberg and Lindenberg Forest sites

wind direction in °	030	060	090	120	150	180	210	240	270	300	330	360
stratification	Falkenberg											
stable	90	95	85	95	95	90	95	90	85	90	95	90
neutral	95	95	90	95	95	95	95	95	90	90	95	95
unstable	> 95	> 95	95	> 95	> 95	>95	> 95	> 95	95	95	>95	95
	Forest											
stable	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95
neutral	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95
unstable	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95	> 95

These footprint estimates are base on calculations with a stochastic footprint model that were performed by M. Göckede (Department of Micrometeorology, University of Bayreuth), see, e.g., Göckede et al. (2005)

Energy Budget Closure

A non-closure of the energy budget is typically found when determining all relevant flux parameters from independent measurements. The reason for this non-closure is not clear yet and is discussed controversially in the scientific literature (e.g., Wilson et al., 2002, Culf et al., 2004). Achieving closure of the local energy budget in micrometeorological field data therefore is still an issue of international research activities. In the present data set, the majority of residual values is in the range of between 0 and 60 Wm^{-2}, but it amounts up to 100-150 Wm^{-2} (corresponding to about 20-25 % of the available energy) during summer days with high insolation.

Disclaimer

The data from the Lindenberg reference site have undergone the QA/QC procedure described in section 4 before being transferred to the CEOP Central Data Archive (CDA). The data supplier, however, can not guarantee the absence of any errors and can not take over any responsibility for results coming out of the use of the data. Data users who should discover problems, inconsistencies or any questionable effects when using the Lindenberg data are kindly invited to contact the Lindenberg site and / or data managers.

7. Reference Requirements

Use of the Lindenberg reference site data should be made according to the CEOP data policy rules outlined in the CEOP Reference Sites Data Release Guidelines. In particular every data user who should discover internal inconsistencies, questionable effects, missing data, or any other problems is encouraged to contact the responsible site and / or data managers.

The data source should be referred to as:
Deutscher Wetterdienst (DWD) - Meteorologisches Observatorium Lindenberg / Richard-Aßmann Observatorium.

Data users are requested to send a copy of any publication making use of Lindenberg data to MOL-RAO (see address above).

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Part III – Some Aspects of the Lindenberg Reference Site Climatology for CEOP Phase I

1. Air Temperature and Precipitation

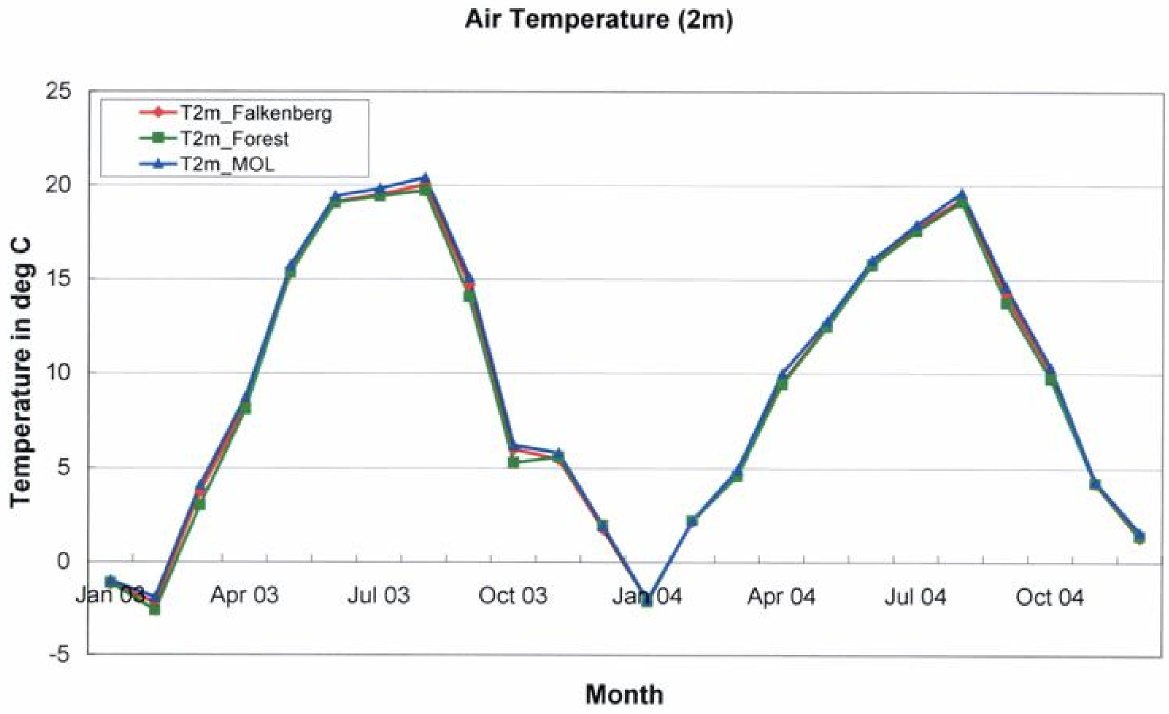

Figure 1
Annual cycle of the mean 2m air temperature during 2003 and 2004 at the Meteorological Observatory Lindenberg and at the GM Falkenberg and Kehrigk Forest CEOP reference sites

The annual mean air temperature at the Meteorological Observatory Lindenberg (MOL) was 9.5 deg C (in 2003) and 9.4 deg C (in 2004, respectively). This was 0.9 (0.8) K above the long-term climatological mean value (1961-1990). The mean temperatures at GM Falkenberg were 0.3 K less than at the MOL site. A positive temperature bias between the MOL and GM Falkenberg sites could be found during all the months which is probably explained both by the more exposed location of the GM Falkenberg field site and by differences in the measurement set-up. The differences are smallest during the winter months and exhibit maxima in spring and autumn. Temperature differences between the GM Falkenberg and Kehrigk forest sites vary in sign and magnitude. The most dominant influence on these differences appears to be the frequency of high-pressure situations with weak winds from preferably easterly directions. Under such conditions, the nocturnal pooling of cold air around the forest station (situated in a shallow depression area) causes significant differences in the nighttime temperatures. This is particularly obvious for February, March, and October 2003, when the nocturnal minimum temperatures between GM Falkenberg and the forest site differed by up to 5-7 K during single nights.

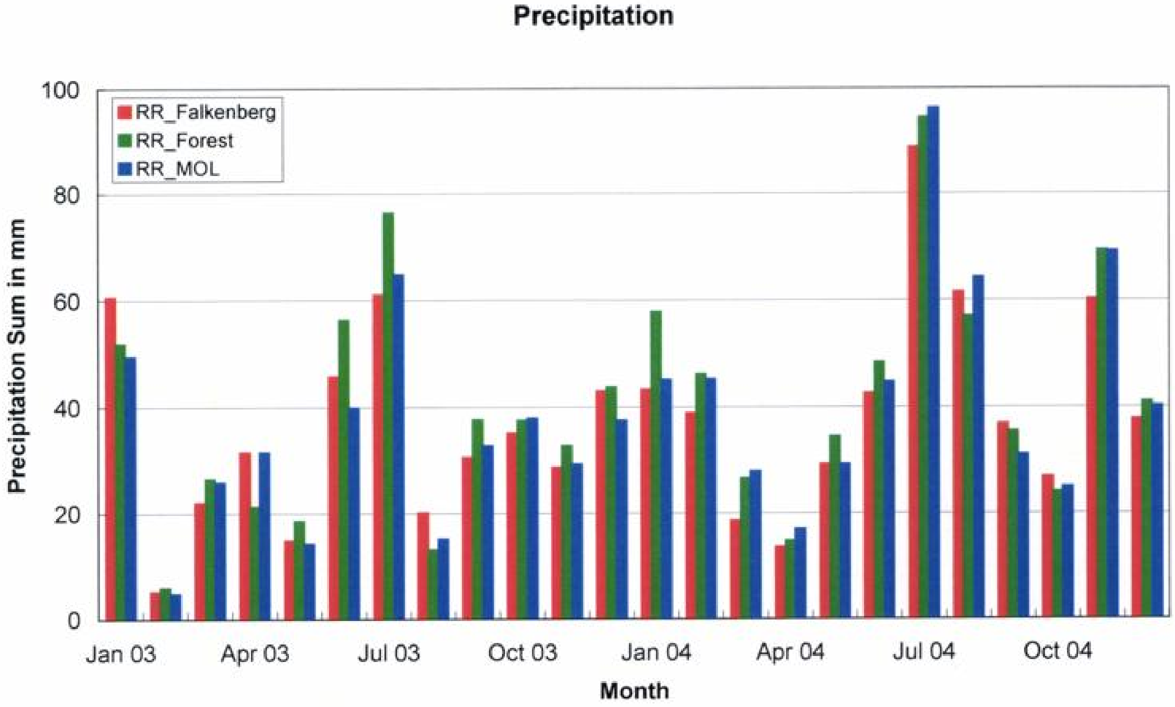

Figure 2
Time series of the monthly precipitation sums during 2003 and 2004 at the Meteorological Observatory Lindenberg and at the GM Falkenberg and Kehrigk Forest CEOP reference sites

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The annual precipitation sum at the Meteorological Observatory Lindenberg (MOL) was 382.6 mm (in 2003) and 534.6 mm (in 2004, respectively). This corresponds to 68 % (95 %) of the long-term climatological mean value (1961-1990). At the forest site, slightly higher amounts of precipitation were measured during both years (by 10 % and 3 %, respectively), while the precipitation sum at Falkenberg was slightly higher in 2003 (+ 4%) and lower in 2004 (- 7%) compared to the MOL site. Monthly precipitation sums at GM Falkenberg were smaller than at the forest site in most cases (for 18 out of the 24 months) which may partly be interpreted as an uncertainty of the measurements since the GM Falkenberg is much more exposed to the wind than the forest site. Site differences for the single months reflect the typical regional variability of precipitation over distances of 5 to 10 km, they are less than 25 % in the majority of cases (20 out of the 24 months).

2. Wind Direction and Wind Speed

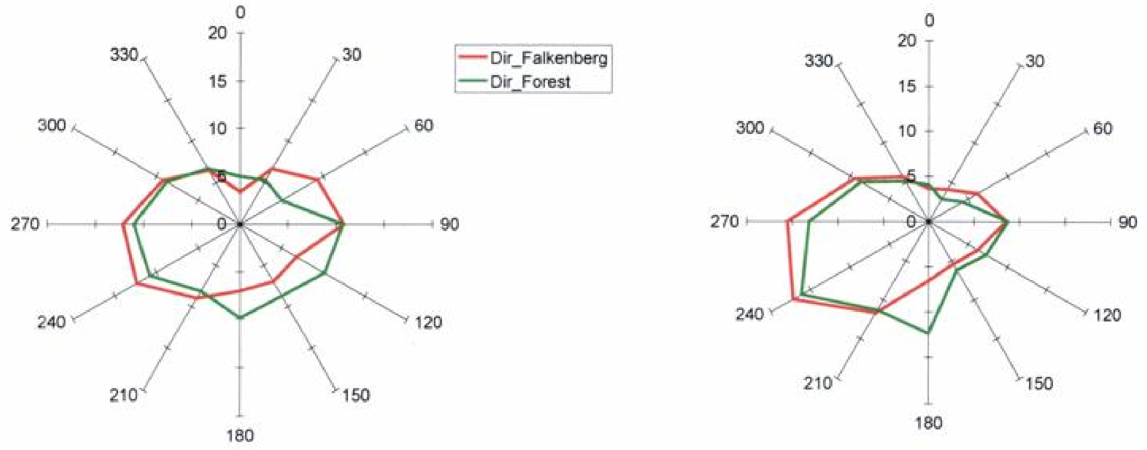

Figure 3
Wind direction frequency distribution at the GM Falkenberg and Kehrigk Forest CEOP reference sites for the years 2003 (left) and 2004 (right)

The frequency distribution of wind direction at the two sites reveals the dominance of winds from South-West to West attributed to the geographic location within the west-wind zone of the midlatitudes. A secondary maximum exists for winds around East which regularly occur under anticyclonic weather conditions. The frequency of such situations was significantly higher in 2003 when compared to 2004. Winds from ENE often occur during clear nights with strongly stable conditions at the GM Falkenberg due to larger deviation angles of the near-surface wind from the geostrophic wind with increasing stability and additionally favoured by local terrain influences. Local terrain effects also explain the secondary peak for southerly winds at the forest site.

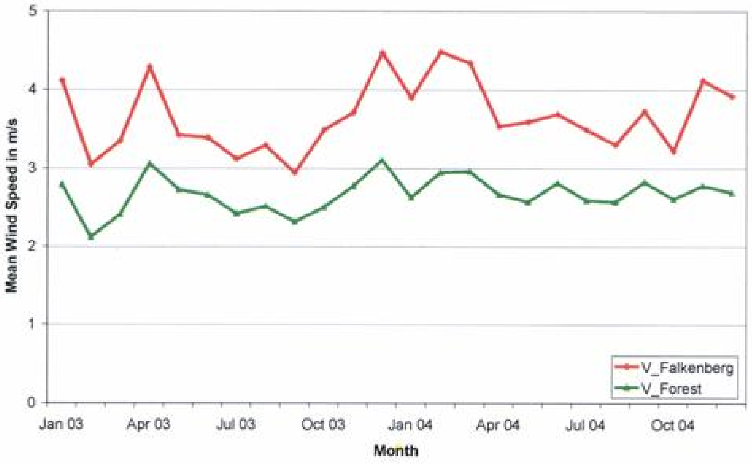

Figure 4
Mean monthly wind speed at the GM Falkenberg and Kehrigk Forest CEOP reference sites during 2003 and 2004

Mean wind speeds close to the ground are fairly well correlated between the two sites and show the same type of variability in time. They were lower in 2003 on the average when compared to 2004 due to the higher occurrence frequency of anticyclonic weather situations typically associated with low wind speeds. The mean wind speed measured at 10 m above ground at GM Falkenberg is always higher than the wind speed measured at the forest tower about 15 m above the forest canopy. This has to be attributed to terrain and surface type effects. While the forest station is situated in a shallow terrain depression, the GM Falkenberg lies on a quite open plain. Moreover, the high roughness of the forest extends the influence of the surface on the wind profile up to higher levels. Note that a measurement height of 10 m at GM Falkenberg corresponds to a $((z-d)/z_0)$ ratio of about 10^3, for the forest site this value amounts to an order of magnitude of 10^1.

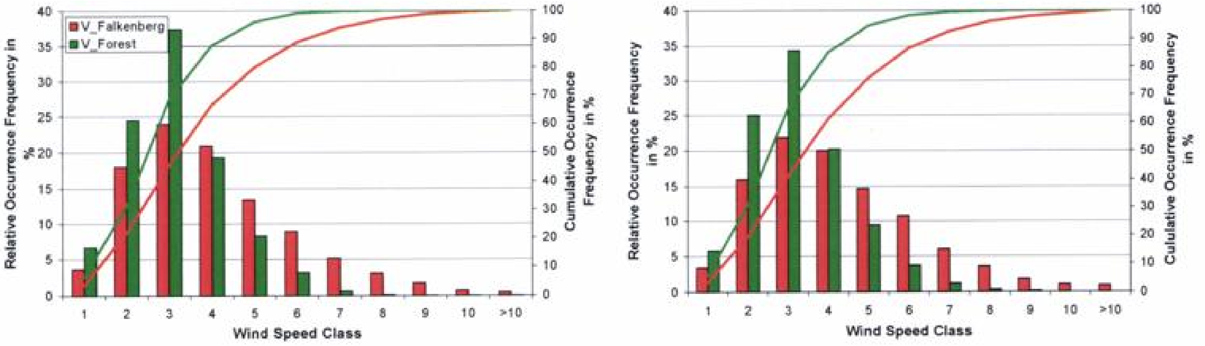

Figure 5
Frequency distribution of wind speed values at the GM Falkenberg and Kehrigk Forest CEOP reference sites during 2003 (left) and 2004 (right)

The frequency distributions of wind speed clearly illustrate the higher occurrence of weak winds at the forest site. For up to about 2/3 of the time the mean wind speed is less than 3 ms^{-1}, and wind speeds higher than 6 ms^{-1} occur for less than 2 % of the measurements. The latter value for Falkenberg is higher than 12 %.

3. Soil Temperature and Soil Moisture

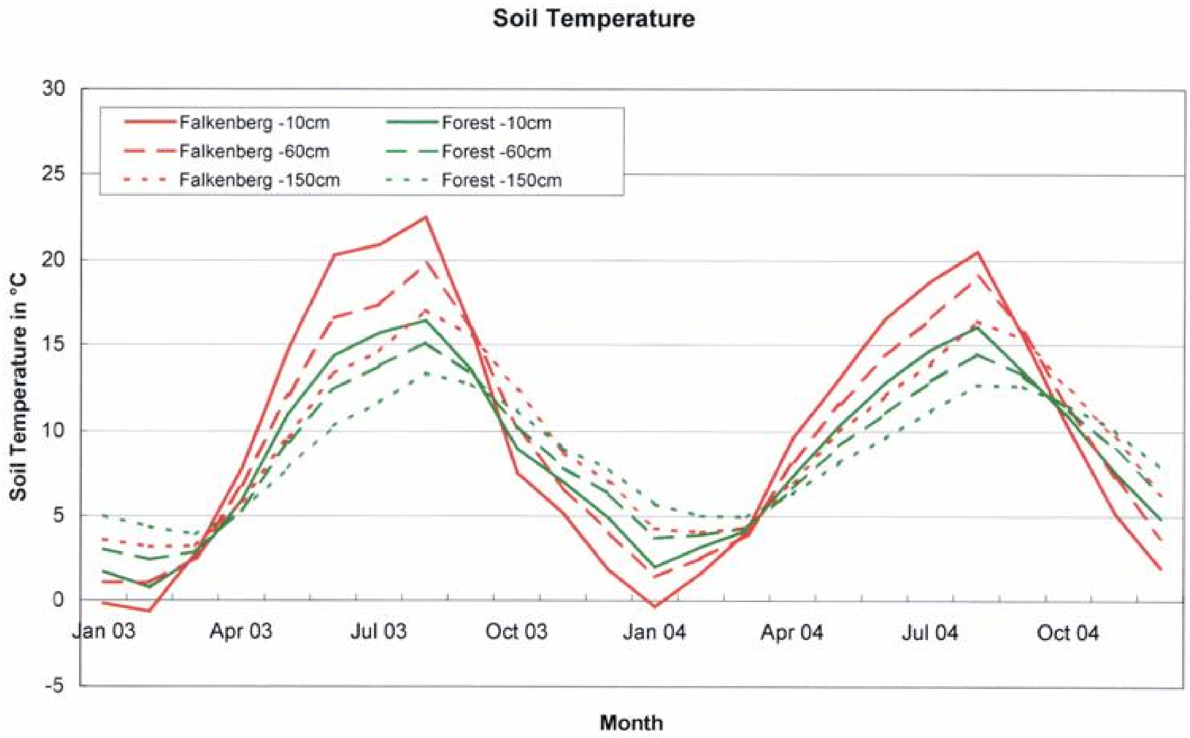

Figure 6
Time series of the monthly mean values of soil temperature at various depths during 2003 and 2004 for the GM Falkenberg and Kehrigk Forest CEOP reference sites

The time series of soil temperature show the expected behaviour: The amplitude of the annual cycle decreases with increasing measurement depth and a slight phase shift can be noticed between the upper and lower levels (although this is not well displayed on the basis of monthly mean values). Amplitudes at the forest site are smaller than for the grassland surface due to the reduced coupling between the soil and the atmosphere in the presence of a vegetation canopy. Soil temperatures during summer differed up to 6 K at –10 cm in August 2003 and still up to about 3.5 K at –1.5 m. Heating of the soil was more pronounced during the hot summer 2003 when compared to 2004, but the autumn cooling proceeded much faster in 2003. During the cold winter months early in 2003 the soil was temporarily frozen at GM Falkenberg down to the –30cm level while it remained frost-free at the –10 cm level at the forest site although soil temperatures of just 0 °C were reached for some short time periods.

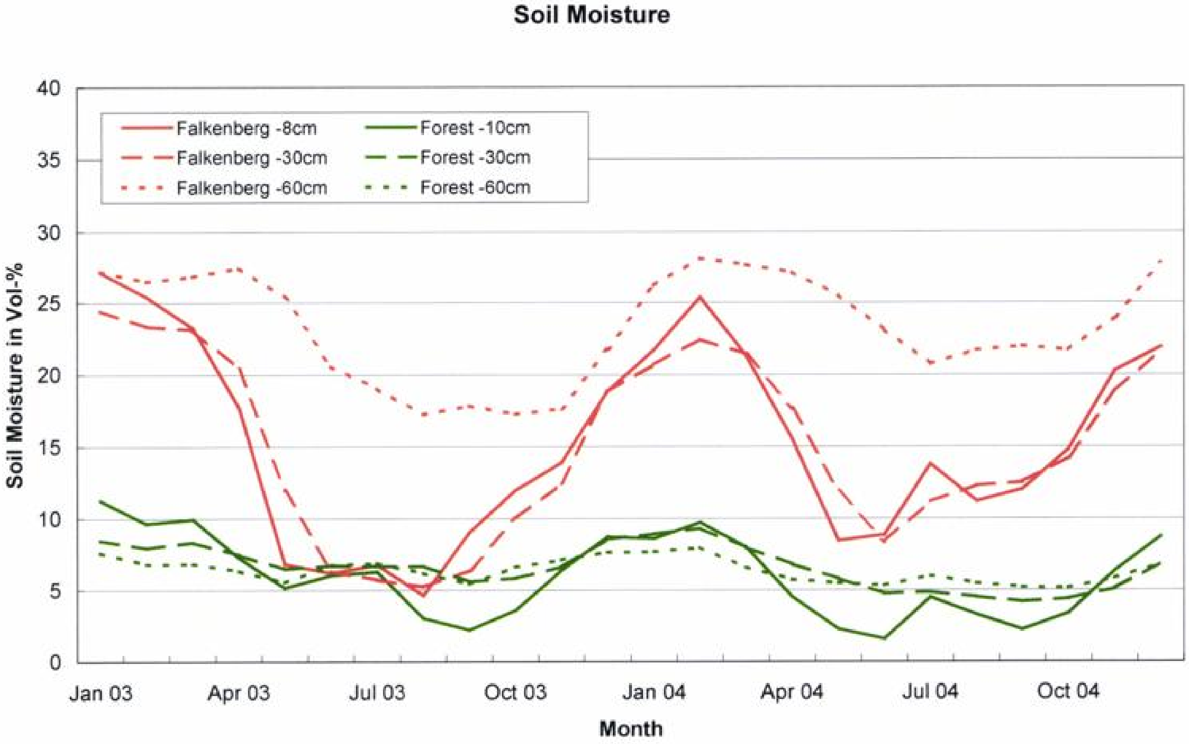

Figure 7
Time series of the monthly mean values of soil moisture at various depths during 2003 and 2004 for the GM Falkenberg and Kehrigk Forest CEOP reference sites

The time series of soil moisture exhibit pronounced differences between the GM Falkenberg and forest sites. These have to be explained by the different soil characteristics which are described in Part II of this report. At the sandy forest site, soil moisture is below 10 Vol-% almost all of the time, and the vertical soil moisture gradient is only small. At the GM Falkenberg, the layer of loam present below the plough horizon causes enhanced soil moisture values at levels deeper than about –50 cm. Upper soil layers at the grassland site are regularly filled up to field capacity during winter which is obviously reached at about 22-25 Vol-% of soil moisture. Temporally higher values have to be attributed to retained water above frozen soil in winter. It should be noticed in this connection that monthly means during winter are based on a limited number of single measurements occasionally, if the soil was frozen over longer time periods which makes the TDR measurements unreliable. This especially holds true for the upper measurement level at GM Falkenberg. The differences in precipitation described in section 1 above resulted in corresponding differences in soil moisture between the two years 2003 and 2004. While the soil rapidly dried out during the spring in 2003 reaching a moisture content around 6 Vol-% by the end of May, soil moisture never decreased below 8 Vol-% in 2004, and the soil water was refilled again during the wet month of July. In autumn / winter 2003, it took until January 2004 before soil moisture values above 20 Vol-% were reached again in the upper soil layers.

4. Radiation

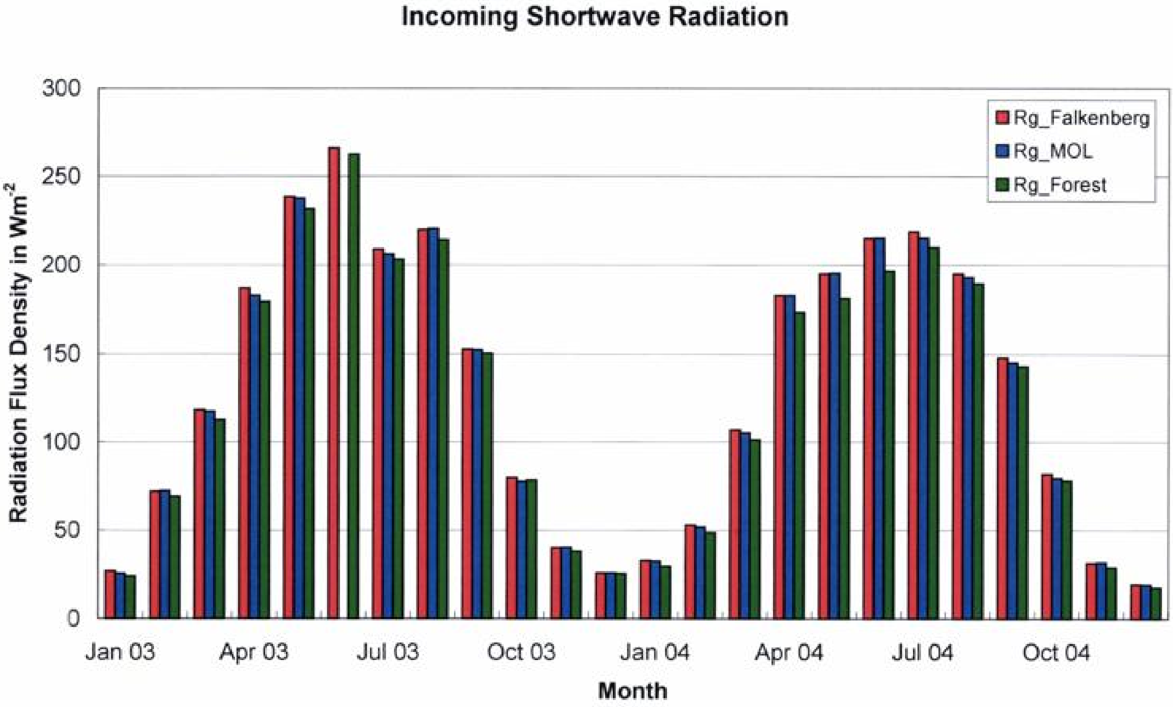

Figure 8
Time series of the mean monthly global radiation during 2003 and 2004 at the Meteorological Observatory Lindenberg and at the GM Falkenberg and Kehrigk Forest CEOP reference sites (due to a movement of the instruments platform of the BSRN station, the radiation data set for June 2003 at the MOL site has some gaps and no monthly mean values was calculated)

The monthly mean values of Incoming shortwave radiation show considerable differences between the two years, 2003 and 2004. More insolation was recorded in 2003 especially during spring and summer (except for July) due to the higher frequency of weather situations with easterly winds (see also section 2) and clear-sky conditions. Differences in the mean values between the GM Falkenberg and the Lindenberg observatory sites were within ± 1 % for about half of the months and exceeded 5 % for just one month (January 2003 with low mean values, absolute difference is just 1.3 Wm^{-2}). On the other side, systematic differences can be noticed between the monthly mean global radiation at the GM Falkenberg and at the Forest station – incoming shortwave radiation was systematically higher at the Falkenberg site during all 24 months. The relative differences amount up to about 10 % during single months (January 2003 and 2004, November and December 2004, but also June 2004). In order to exclude instrumental effects, both the maximum and daily averaged global radiation values for days with clear-sky conditions have been compared separately, values between the Falkenberg and forest sites differed by less than 2 % under these conditions, and even cases with higher values measured at the forest station regularly occurred in the clear-sky data subset. It is therefore suggested that the systematically lower global radiation values at the forest site should be attributed to the local site conditions (shallow depression area surrounded by a number of lakes).

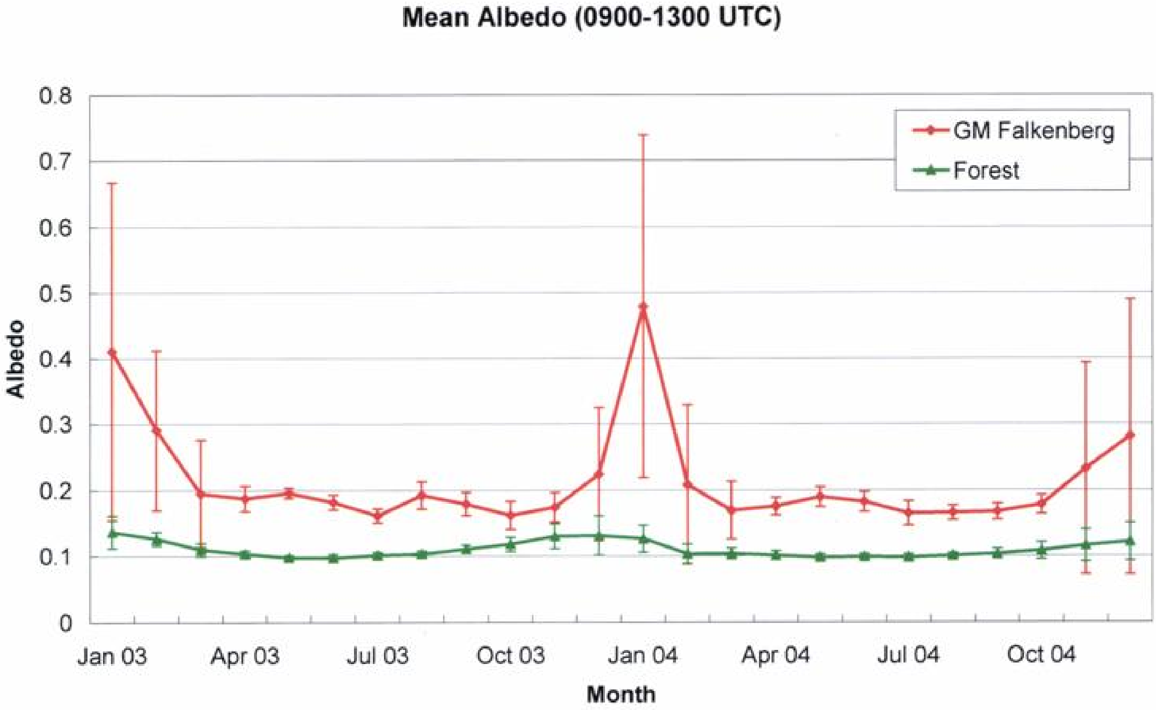

Figure 9
Monthly mean albedo values and standard deviations during 2003 and 2004 at the GM Falkenberg (grassland) and Kehrigk Forest (pine) sites.

Time series of the monthly mean albedo values and the corresponding standard deviations are shown in Figure 9. Statistics have been calculated considering all measurements around local noon (0900 to 1300 UTC) with incoming shortwave radiation higher than 100 Wm^{-2}. Mean albedo values of the forest are about 0.10 during large parts of the year. Slightly enhanced values during the winter months are attributed partly to the lower sun angle and also to episodes with snow on the crown of the trees. These normally last for a short time only since the snow is rapidly removed from the trees by the wind. On contrary, for the grassland site, episodes with snow cover cause significantly enhanced monthly mean values of the albedo and a high standard deviation. Albedo values at the Falkenberg site in the absence of snow vary between 0.16 and 0.20 depending on the soil moisture (precipitation) and on the actual vegetation height of the grassland surface.

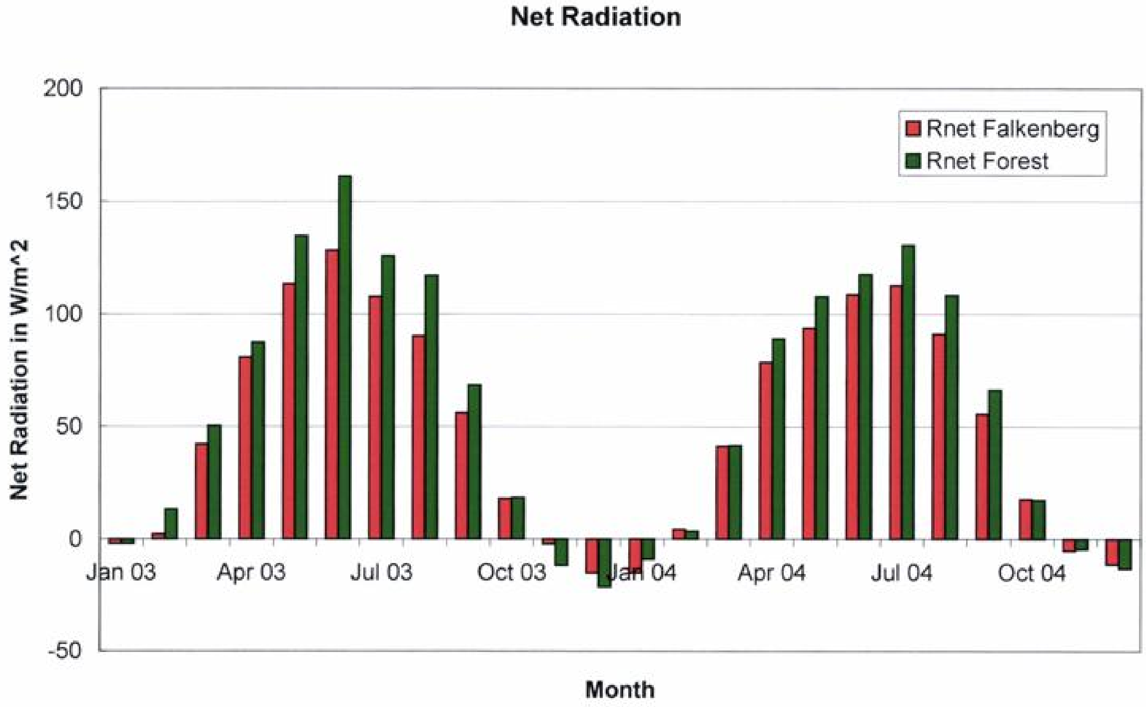

Figure 10
Time series of the mean monthly net radiation during 2003 and 2004 at the GM Falkenberg and Kehrigk Forest CEOP reference sites

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For the net radiation, again systematic differences can be found between the two CEOP reference stations where now the higher values were measured at the forest site in most cases. This is basically attributed to the lower albedo of the pine forest when compared to the short grass at the GM Falkenberg. Moreover, the surface of the trees is not heated as much as the soil at the Falkenberg site during summer days with strong insolation resulting in reduced longwave outgoing radiation. This effect of surface temperature was more pronounced during the dry and sunny summer in 2003 explaining the higher surplus of net radiation at the forest site when compared to the following summer, 2004. In contrary to this – during winter – the forest canopy is often warmer than the grassland surface at GM Falkenberg resulting in higher values of outgoing longwave radiation and thus in a more negative value of net radiation over certain periods. Surface temperature differences in winter are most pronounced if there is snow on the grass at Falkenberg, but the snow has already been removed by the wind from the forest canopy. However, the albedo effect and the surface temperature effect partly compensate each other in winter while they sum during the warm season.

5. Turbulent Fluxes of Sensible and Latent Heat

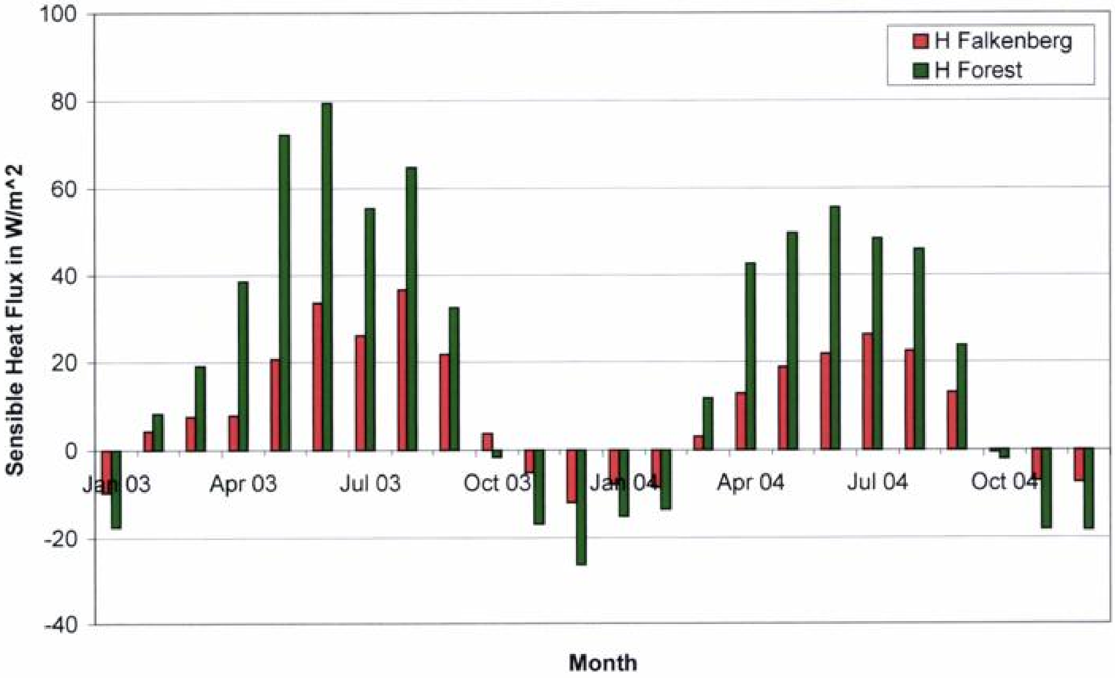

Figure 11
Time series of the mean monthly sensible heat flux during 2003 and 2004 at the GM Falkenberg and Kehrigk Forest CEOP reference sites

The measurements of the turbulent sensible heat flux exhibit substantial differences between the GM Falkenberg and forest sites. The mean heat flux over the forest is typically twice as high as over the grassland surface. Two main reasons are seen to cause this effect. At first, the forest surface receives a higher amount of net radiation when compared to the grassland surface (see section 4 above). At second, the soil moisture at the forest site is lower than at the GM Falkenberg – as a consequence the surplus of available energy from the higher net radiation is basically transformed into enhanced values of the sensible heat flux. As a result of the dry, warm and sunny conditions (see sections 1 and 4 above) the sensible heat fluxes at both sites were significantly higher during the warm season in 2003 when compared to 2004. In the latter year, the diminishing effect of the reduced radiation input on the sensible heat flux was additionally enhanced by the fact that due to higher precipitation and soil moisture values a larger fraction of the available energy was spent for forcing evaporation instead of sensible heat transfer.

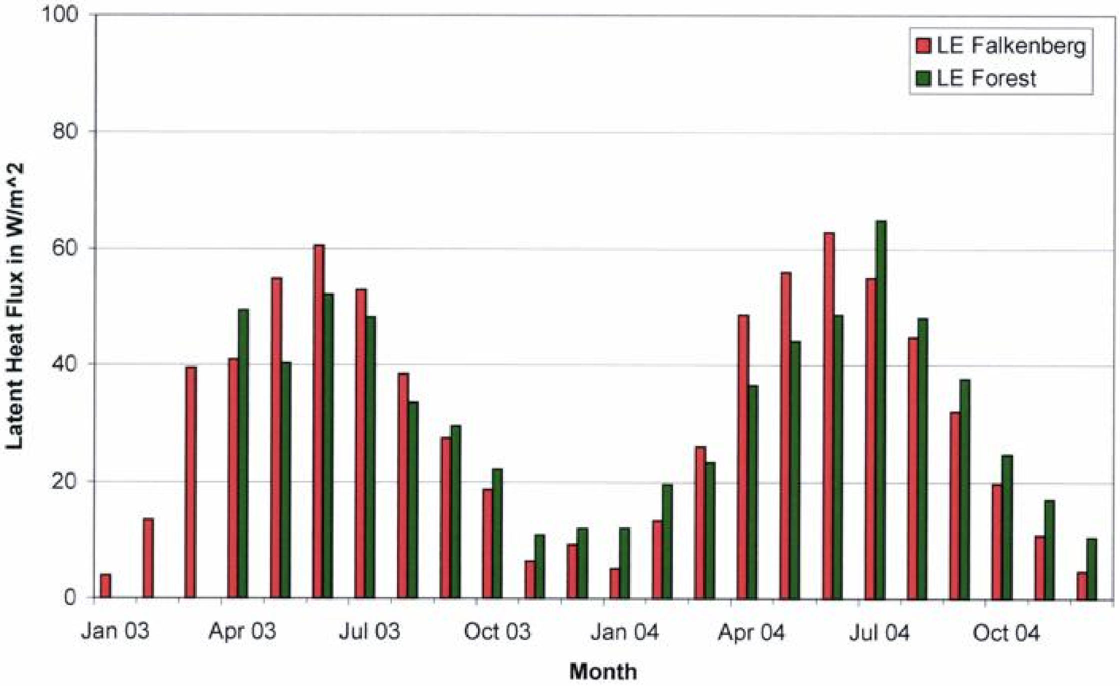

Figure 12
Time series of the mean monthly latent heat flux during 2003 and 2004 at the GM Falkenberg and Kehrigk Forest CEOP reference sites

The behaviour of the latent heat flux appears to be different when compared to the sensible heat flux as described above. Higher values were found over the grassland regularly during the growing season while later in summer and autumn evaporation of the pine forest was higher than for the grassland site. This is attributed to the annual cycle of vegetation activity. Differences between the two sites are less pronounced than for the sensible heat flux supporting the argumentation that the surplus of available energy at the forest site is basically consumed for the turbulent transfer of sensible heat. Higher values of the latent heat flux during the summer season in 2004 are mainly seen as a response to the enhanced precipitation forcing.