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CEOP REFERENCE SITE – SODANKYLÄ, FINLAND

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CEOP REFERENC SITE – SODANKYLÄ, FINLAND

Abstract

This report presents the contributions of the Finnish Meteorological Institute to the international Coordinated Enhanced Observation period (CEOP) with its related studies on the water and energy cycles, which were performed between 2001 and 2004 in northern Finland. This report includes the relevant measurements, examples, calculations, tests sites and model simulations in Northern Finland concerning the water and energy cycles studies of CEOP phase I. A set of parameters and relationships from the dataset are documented and available from the reference site for the benefit of other scientists.

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Tiivistelmä

Tämä raportti esittelee Ilmatieteen laitoksen tekemiä veden ja energian kiertokulun tutkimuksia, joita on tehty Suomen pohjoisosassa osana kansainvälistä CEOP- (’’Coordinated Enhanced Observing Period’’) ohjelmaa. Tämä raportti sisältää oleelliset mittaukset, esimerkit, laskelmat, testit ja mallisimuloinnit Pohjois-Suomessa, jotka koskevat veden ja energian kiertokulun CEOP-tutkimusohjelman ensimmäistä jaksoa. Tietyt parametrit ja yhtälöt, jotka on saatu datasta, ovat saatavissa dokumentoituina referenssisivuilla muita tutkijoita varten.

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APPENDIX

1 INTRODUCTION

The water and energy cycles are of fundamental importance to the climate systems, but they are not handled well enough within climate and numerical prediction models. Such deficiencies are the motivation for the international efforts performed within the World Climate Research Programme (WCRP) Global Energy and Water Cycle Experiment (GEWEX, Fig. 1), which focuses on the measurement, understanding and modelling of water and energy cycles within the climate system. One of the most critical issues associated with water in the climate system is its availability over land areas. The timing of the new generation of Earth observing satellites coupled with the progress being made through individual GEWEX Continental Scale Experiments (CSEs) provides an outstanding opportunity to derive a large potential benefit from a more coordinated observation period – that can also take advantage of additional activities, such as those in CLIVAR and other WCRP projects. This is the focus of a major activity initially organised by the GEWEX Hydrometeorology Panel, the international Coordinated Enhanced Observing Period (CEOP), from 2001 through 2004, with a primary focus to develop a 2-year dataset for 2003-2004 to support research objectives in climate prediction and monsoon system studies. CEOP has been endorsed as the first element of the new Integrated Global Water Cycle Observation Theme approved by the Integrated Global System Partners (IGOS-P). [12].

Figure 1. GEWEX[1] continental-scale experiments overlapping in time (2001–2004) with the new series of earth observing satellites.

BALTEX[1] (Fig. 2) is one of the GEWEX continental scale experiments and was started 1992 and finished 2003. BALTEX Phase II covered years 2003 – 2012. BALTEX

[1] http://www.gewex.org/

contributes to CEOP with four Reference Sites located in the Netherlands (Cabauw), Germany (Lindenberg, [1]), Sweden (Norunda) and Finland (Sodankylä).

For CEOP, the Finnish Meteorological Institute (FMI)[2] provides 2D data from the Arctic Research Centre (FMI-ARC) at Sodankylä. In principle, this reference station could also provide 3D data, if the measurements at the nearby arctic fells were included.

This report presents the studies performed within the CEOP phase I in northern Finland, and includes the relevant measurements, examples, calculations, tests and model simulations, with special attention to the Sodankylä site.

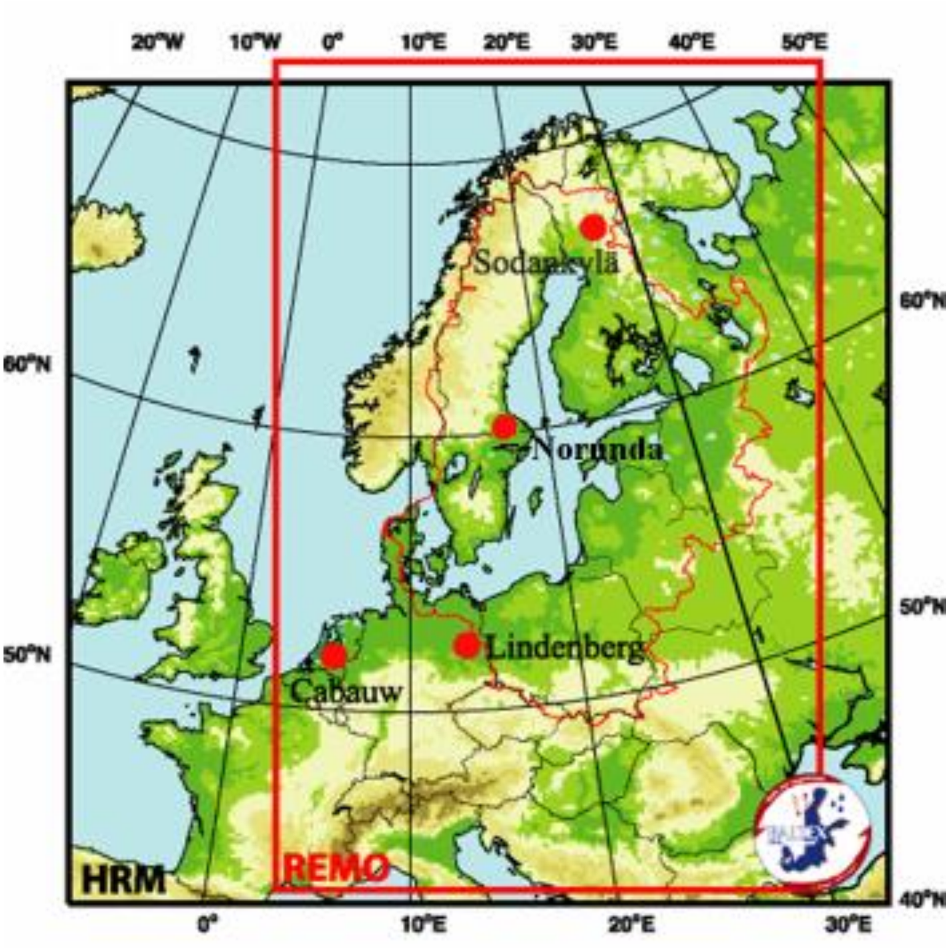

Figure 2. Locations of the BALTEX Reference Sites for CEOP. The BALTEX research area is depicted by the red line.

2 THE SODANKYLÄ – FMI-ARC SITE

The Finnish Meteorological Institute (FMI) Arctic Research Centre (FMI-ARC)[3] is located on the eastern bank of the river Kitinen, some 7 kilometres SE from the

[2] www.fmi.fi
[3] http://fmiarc.fmi.fi/

Sodankylä town centre, and about 100 kilometres north from the Polar Circle and Rovaniemi. The coordinates for the site are 67° 22’ N, 26° 38’ E and 180 m a.s.l.

Due to the warming effect of the Gulf Stream the area can be classified as continental subarctic or boreal taiga, by Köppen classification climate region, Dfc (Continental subarctic or boreal (taiga) climates). However, with regard to stratospheric meteorology, Sodankylä can be classified as an Arctic site, often lying beneath the middle or the edge of the stratospheric polar vortex and in a zone displaying intermittent polar stratospheric ozone depletion. Its strategic location, coupled with ready accessibility from all parts of the world, makes the FMI-ARC an excellent base for studying various themes of global change in a northern context.

The beginning of meteorological activity at Sodankylä dates back to the mid-nineteenth century: Societas Scientarum Fennica founded the first weather station at Sodankylä in 1858. The next milestone was its involvement in the first Geophysical Year in 1882-83, when a group of visiting scientists at Sodankylä operated a modern magnetic-meteorological observatory. It was not until 1908, however, that the continuous time series of the Sodankylä temperatures began, first at the village about 7 km north from the present location and from 1914 on at the present observatory site. As one of the first stations in the Arctic, the Sodankylä meteorological observatory started radio soundings in October 1, 1949. Solar radiation measurements started during the third Geophysical year (1957/58) and the first air quality measurements were performed in the early 70's.

Today, in addition, FMI-ARC (LPNN: 7501, WMO: 02836) provides synoptic observations and serves as a platform for different types of atmospheric research. FMI-ARC infrastructure also acts as the international UV research centre FUVIRC, which provides field test sites and research facilities supporting research in atmospheric chemistry, ecosystems and human health. FMI-ARC participates in many international networks, for example the WMO coordinated GAW (Global Atmospheric Watch), GRUAN (GCOS Reference Upper Air Network), NDACC (Network for Detection of Atmospheric Composition Change), and TCCON (Total Carbon Column Observing Network).

Synoptic observations

Ground-station observations every three hours record information on weather conditions prevailing at ground level. In addition to standard weather observations, the basic observational duties at the Observatory includes regular recordings of solar radiation, sunshine and hydrological quantities.

Figure 3. The FMI-ARC observatory seen from the top of the 25 m tower.

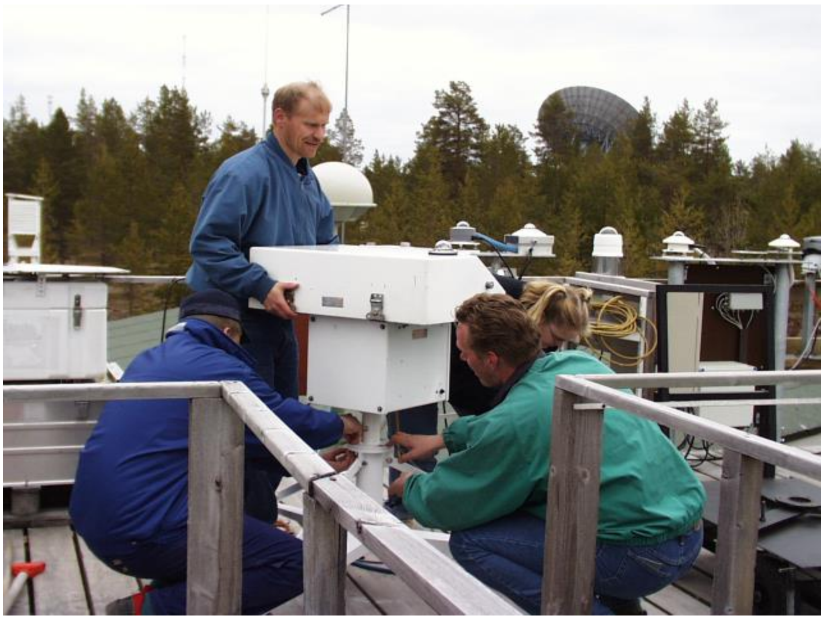

Figure 4. Atmospheric total ozone is measured with a Brewer spectrophotometer
(Photo from the roof of the observatory.)

Figure 5. Precipitation gauges at the observatory.

Balloon soundings

The most noticeable part of the traditional weather observational work carried out at the FMI-ARC is the radiosonde ascents. Ever since 1949, a sensor package equipped with a small radio transmitter has been dispatched twice a day into the atmosphere [7]. Lifted by a hydrogen or helium-filled balloon it collects information on atmospheric conditions from the ground upwards to heights of 30 km.

In the framework of upper atmosphere research activities, the Centre participates in the global Network of Detection of Atmospheric Composition Change. The facility includes various balloon-borne sounding operations, Brewer and SAOZ spectrometers, a MW-radiometer laboratory, a UV calibration laboratory, and a FTS laboratory. On the average, about 80 ozone sondes have been launched yearly since 1989 to measure the ozone profile over Sodankylä [10]. The assessment of ozone sensors performance by performing dual sonde flights is another example of research activity [9]. Since 1994, aerosol backscatter sondes have been flown from Sodankylä during each winter. The purpose of this activity is to study polar stratospheric cloud properties [8] as well as stratospheric background aerosols [21]. More recently considerable effort has been devoted to investigating the performance of light-weight hygrometers capable of accurate water vapour measurements in the dry upper troposphere and lower stratosphere. The performance of hygrometers was assessed with a series of 35 multiple soundings performed in January-February 2004 in Sodankylä in the framework of the international LAUTLOS/WAVVAP project. The second major international intercomparison campaign of water vapour instruments took place in January-March 2010 (LAPBIAT Atmospheric Sounding Campaign) [11].

Boundary layer studies

Micrometeorological studies close to the observatory are conducted on a 48 m mast standing in a Scots pine forest on sandy Podsol. The forest is mostly 55-80 years old with some much older trees. The average tree height is 15 m, the tree density 2100 trunks per ha and the projected leaf area 1.2 m^2.

The mast measurements include eddy-covariance fluxes of CO_2, latent and sensible heat and momentum, most radiation components as well as vertical gradients of CO_2 concentration, temperature and wind. Ambient air ozone concentrations and gradients along the mast are measured continuously, while the number concentration of condensation nuclei is measured on a campaign basis. Soil measurements include temperature and volumetric moisture gradients, heat flux and soil CO_2 efflux by an automated chamber. Mast measurements are completed with ceilometer profiles ranging up to 13 km.

Figure 6. Picture of the 48 meters-high mast.

Satellite Data Centre

The Satellite Data Centre of FMI-ARC started officially on 22nd of May 2002. The first stage of the satellite data centre consisted of the processing facility for the GOMOS ozone instrument on board the Envisat environmental satellite, which received operational acceptance from the European Space Agency (ESA) in January 2001. Since early 2000 the satellite data processing activities have gained an increasing role at Sodankylä. A new receiving antenna and data archiving/processing centre was established in 2011, which has considerably increased the capacity to process satellite data at Sodankylä. Today, the Satellite Data Centre processes, archives and delivers to the users data received from a number of spaceborne instruments. The various satellite operation tasks are performed in cooperation with major space agencies, including the European Space Agency (ESA), the European Meteorological Satellite organisation (EUMETSAT) and the National Aeronautics and Space Administration (NASA). The receiving antenna at Sodankylä has an excellent location for receiving signals from polar orbiting satellites. In addition, the in-situ and remote sensing instrumentation at Sodankylä has been used for satellite calibration and validation.

The Luosto weather radar and testing platform

FMI's weather radar network is currently renewed with dual polarisation radars. The northernmost Finnish weather radar is situated on top of the Luosto fell, some 45 km south from Sodankylä (67°08´N, 26°54´E; LPNN7509/WMO: 05841). Luosto is at the northern end of a chain of arctic fells. The height of the gently-sloping fell is 515 m a.s.l. and the rounded top lies 250 m above the surrounding flat land. The older Doppler radar was replaced by the dual polarisation radar in July 2014.

FMI provides weather radar pictures for both internal and external use. Images from the weather radar are a valuable aid to duty meteorologists in producing weather forecasts and warnings. Radar data are also useful in meteorological research. The general public has become familiar with weather radar images through TV forecasts.

The FMI testing site for ice-free sensors and for atmospheric icing is also located on the top of the Luosto fell. The measurements are monitored via several video cameras, and real time data are collected at FMI-ARC and FMI Technical Services in Helsinki. This test site has been used, e.g., for the EUMETNET SWS project on ice-free sensors and the EU research project New Icetools.

Figure 7. The FMI Luosto weather radar with the testing site for studying the impact of icing upon meteorological sensors visited by Santa Claus (standing on the test platform).

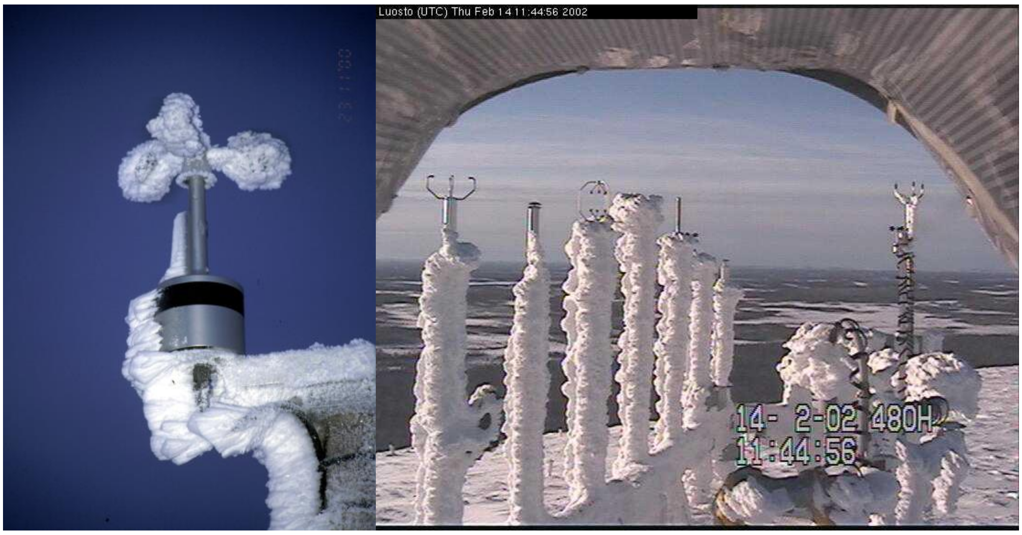

Figure 8. Testing ice-free wind sensors at Luosto during the EUMETNET SWSII project.

Pyhätunturi

The FMI meteorological measurements at Pyhätunturi fell were started in connection to the first arctic test station for wind turbines in 1993. The Pyhätunturi fell (500 m a.s.l.) is located very close to Luosto, within the Pyhätunturi National Park. FMI is operating one weather station at the top of the fell (LPNN: 7708, WMO: 02705). All wind sensors are fully heated.

With the additional measurements at Luosto and Pyhätunturi the CEOP Sodankylä station could be considered as a 3D station.

Figure 9. The automatic weather station at the top (left) and on the slope (right) of the Pyhätunturi fell.

The correlation between the wind speed observed at FMI-ARC and at Pyhätunturi is very poor, especially during the winter months. Due to the high frequency of so called ground inversions, with a typical height of 450-500 m a.s.l., the wind speed at

Pyhätunturi correlates much better with the geostrophic wind than with the surface wind.

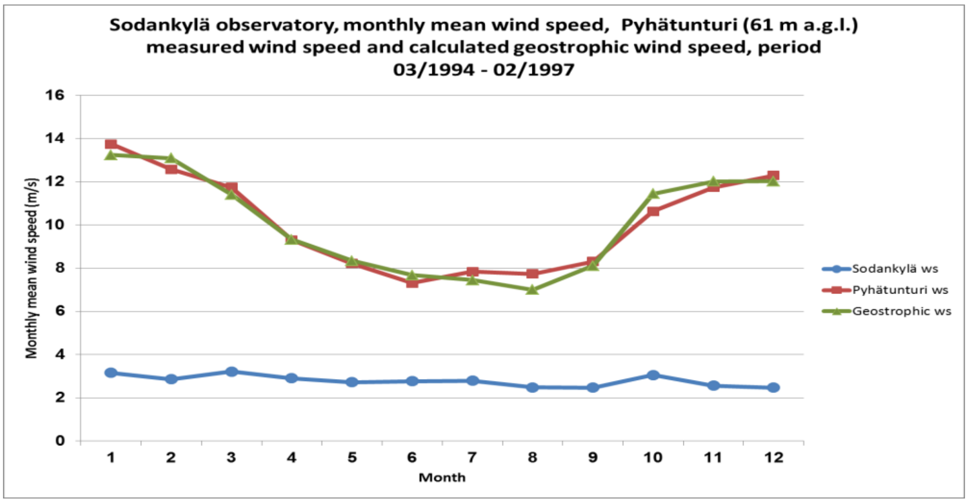

Figure 10. Measured monthly average wind speed at FMI-ARC (Sodankylä ws) and at Pyhätunturi (1994-1997). The geostrophic wind calculated from the pressure field for the Pyhätunturi region is also shown (Geostrophic ws).

3 CLIMATOLOGICAL CONDITIONS AT SODANKYLÄ

The basic climatological averages for the reference period 1971-2000 at the Sodankylä site are compiled in Table 1 and Fig 11 (temperature parameters), Fig. 12 (wind speed), Fig. 13 (snow depth), Fig 14 (radiation). Fig. 15 (day duration) and Fig. 16 (atmospheric stability).

Table 1. Monthly mean 2 m-temperature, mean daily minimum temperature and mean daily maximum temperature in Sodankylä for the period 1971 - 2000.

Month	Monthly Mean	Average min	Average max	Absolute min	Year	Absolut max	Year
1	-14.1	-19.6	-9.5	-49.5	1999	6.9	1971
2	-12.7	-18.2	-8.3	-44.4	1971	6.5	1972
3	-7.5	-13.0	-2.6	-42.7	1971	7.7	1973
4	-2	-7.4	2.6	-31.6	1977	15.2	1983
5	4.9	0	9.6	-17.8	1981	27.1	1971
6	11.6	6.4	16.6	-3.7	1998	30.1	1974
7	14.3	9.1	19.4	-0.6	1975	30.4	1972
8	11.2	6.6	16.1	-5.5	1986	27.9	1989
9	5.8	2.1	9.8	-11.4	1986	22.6	1999
10	-0.6	-3.7	2.3	-28.0	1988	13.1	1994
11	-7.7	-11.8	-4.3	-34.5	1983	7.7	1983
12	-12.4	-17.4	-7.9	-41.0	1981	4.7	1997
Year	-0.8	-5.6	3.6	-49.5		30.4	

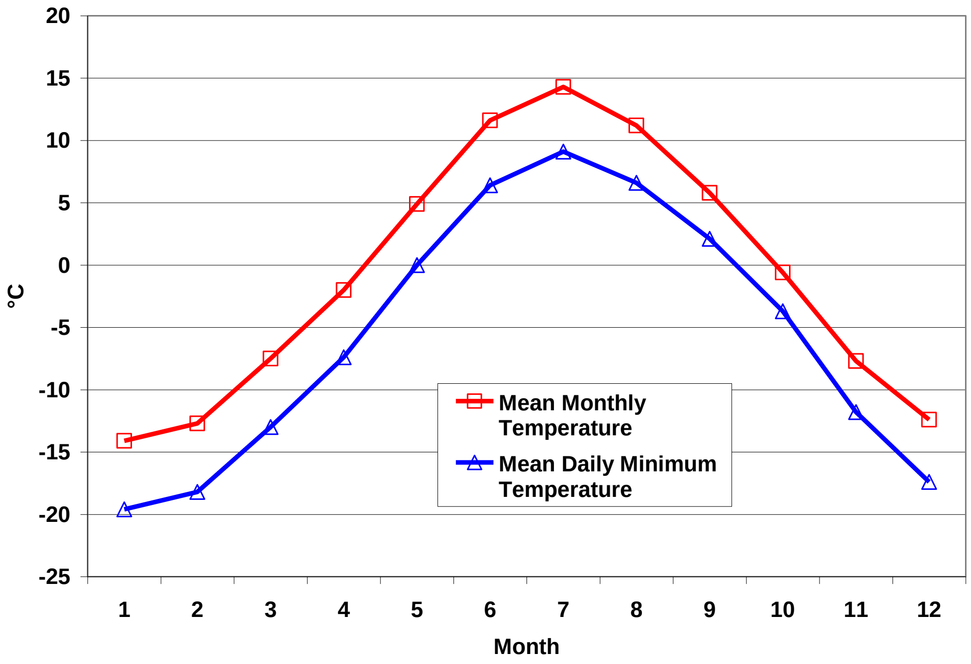

Figure 11. Average mean monthly air temperature °C (at 2 m) and average minimum temperature (2 m) at FMI-ARC during the period 1971-2000.

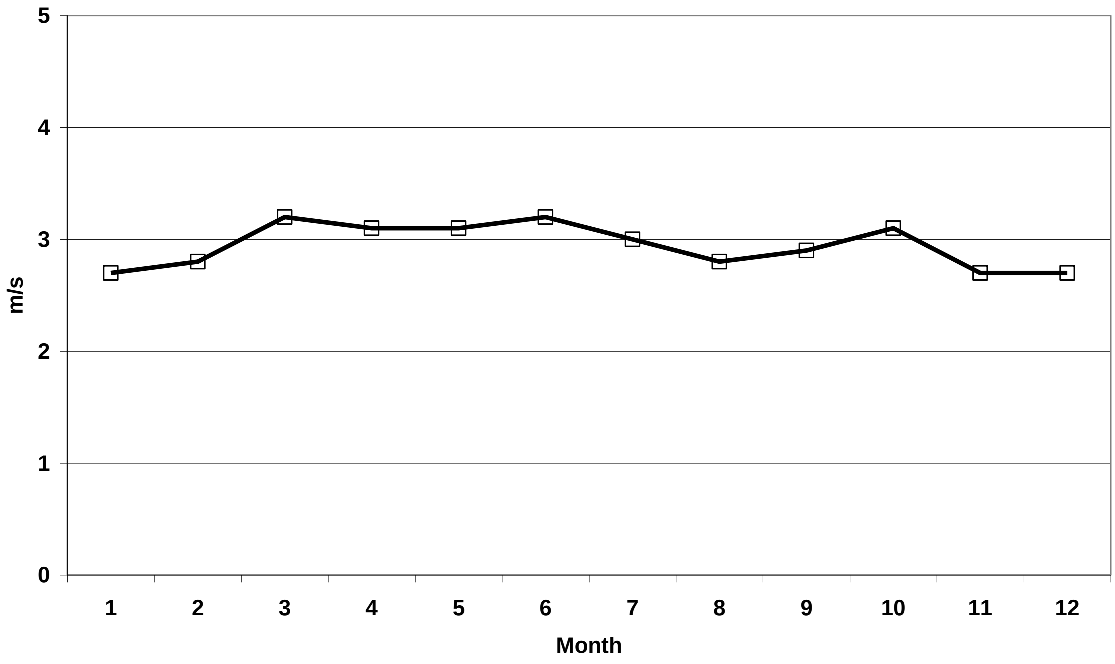

Figure 12. Average wind speed measured at a 21 m height during the period 1971-2000.

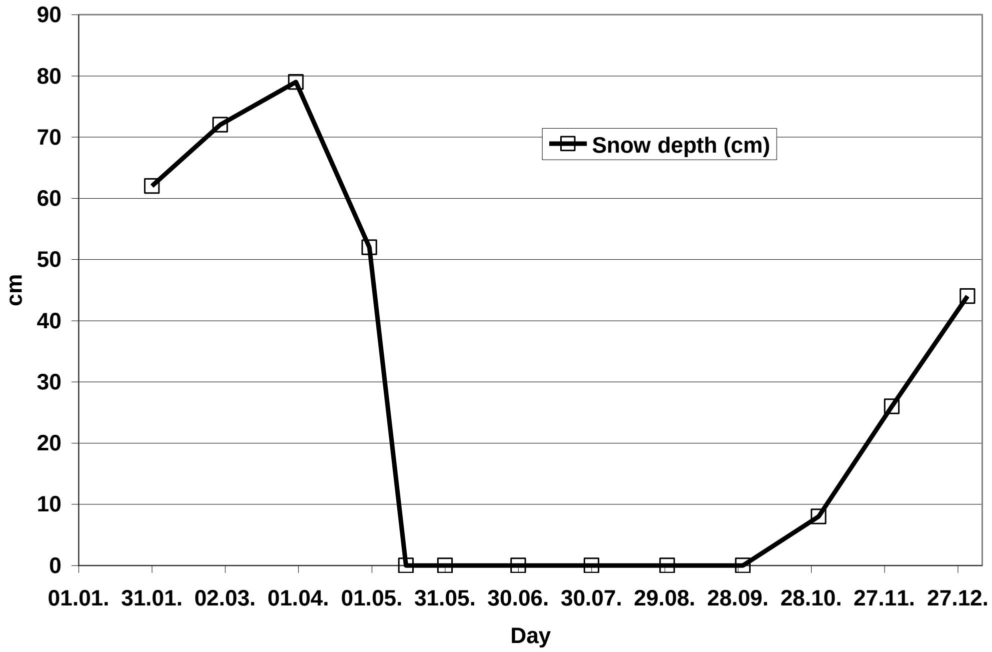

Figure 13. Monthly average depth of snow at FMI-ARC (1971-1991).

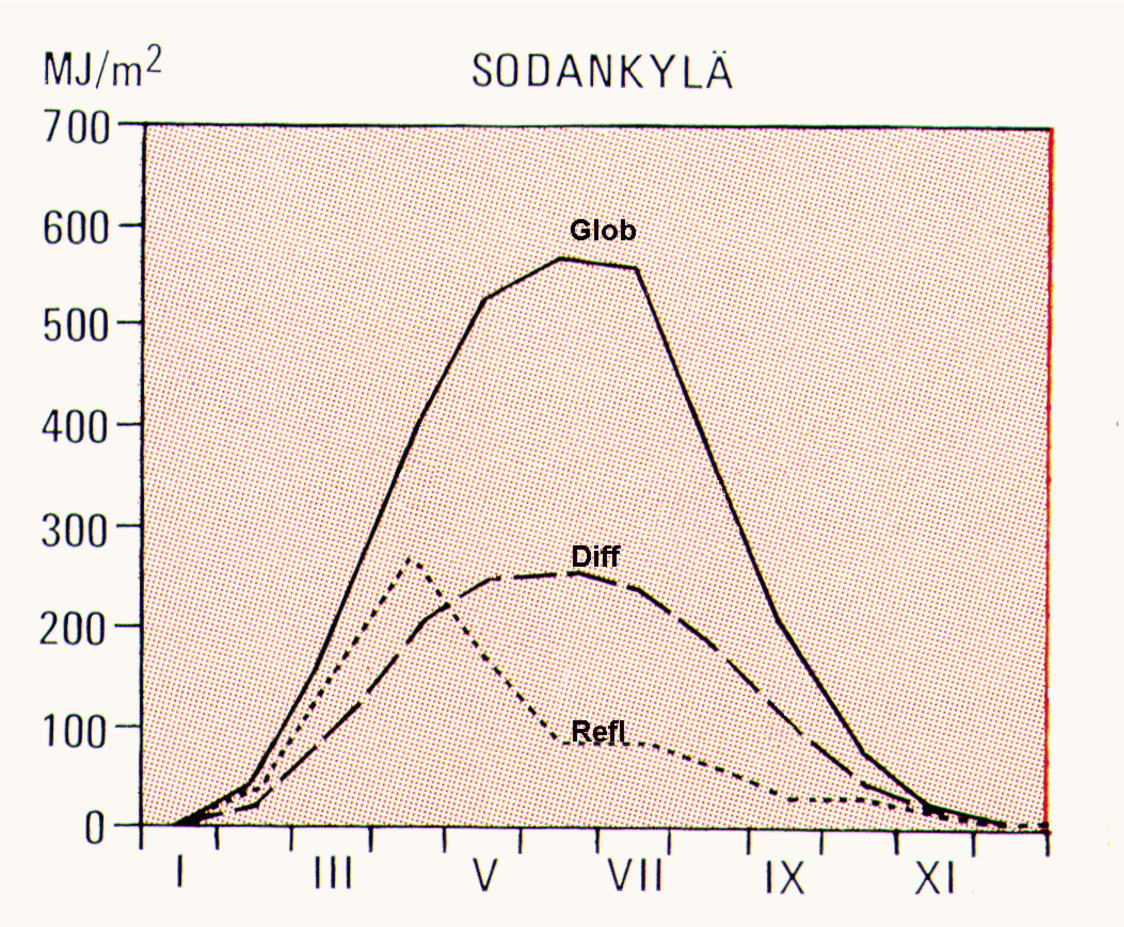

Figure 14. Average daily global (Glob), Diffuse (Diff) and Reflected (Refl) radiation (MJ/m2) for the period 1971-80.

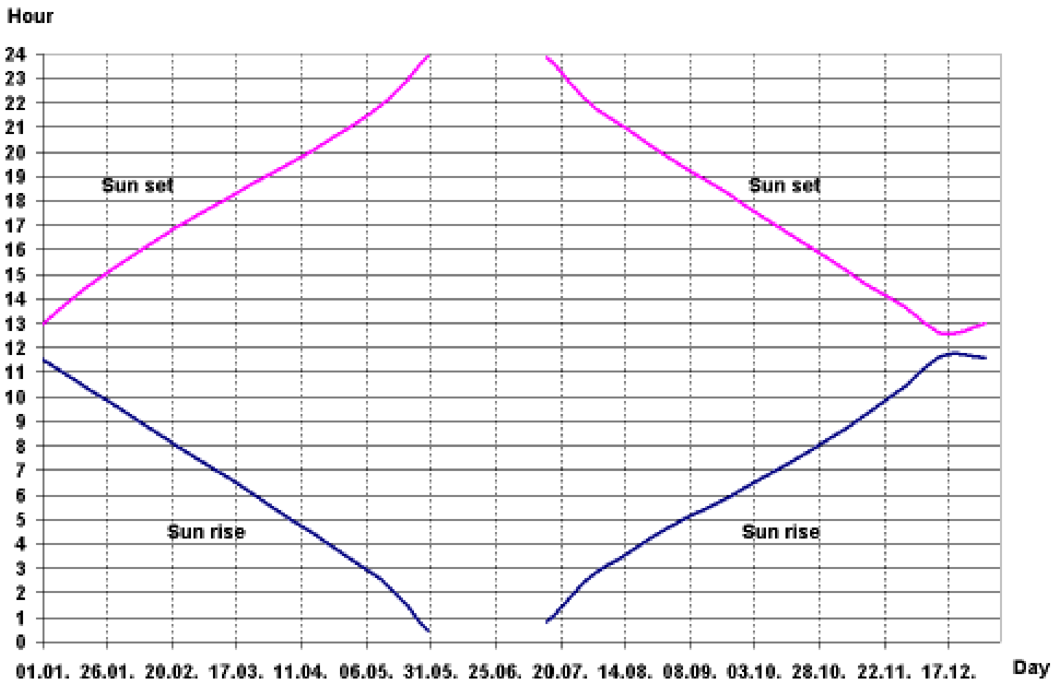

Figure 15. Annual variation of the daily time of sunrise and sunset.

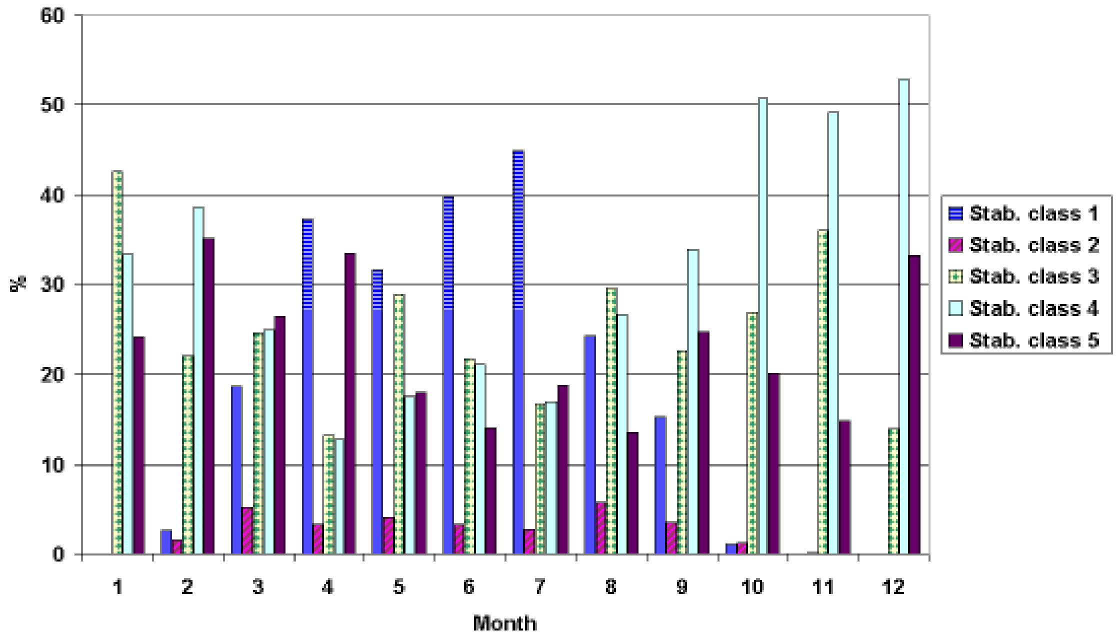

Figure 16. Frequency of occurrence of Pasquill Stability Classes during one year (class 1 = very unstable to class 5= very stable).

Atmospheric icing

The potential for atmospheric icing of instruments imposes special requirements on sensors used for meteorological measurements. The impact of icing on measurements may be very significant especially for wind speed measurements as shown by several theoretical and experimental studies: [15], [17], and [19].

In-cloud icing is formed, when super-cooled cloud droplets moving with the wind hit on the upwind side of an object and freeze. The types of ice are mainly defined in accordance with their density, hardness and appearance. Most severe in-cloud icing situations occur at freely exposed hills or mountains top, or in suitable mountain valleys.

Unfortunately, the rate, number or events of in-cloud icing are not available so far for the Sodankylä site. Table 2 shows the average number of icing days calculated from temperature and cloud observations made at the Sodankylä observatory.

The criteria for in-cloud icing is (WECO method [17]):

$T_a < 0$ °C,
$H_b \leq H_s$ and
$v > 0$ m/s

where T_a is the air temperature, H_b the height of cloud/fog base, H_s the height of the site and v the wind speed. In-cloud icing can only occur when the height of the cloud base is lower that the height of the site of interest.

Table 2. Calculated average number of monthly icing days (N) in Sodankylä caused by in-cloud icing (during 1986-96).

Value	Oct	Nov	Dec	Jan	Feb	Mar	Apr
N	14	21	20	20	18	20	10

At the Luosto testing site, the icing measurement system has been in operation since October 2001, where several instruments and methods of measurement of atmospheric icing have been used and tested. The Rosemount ice detector has been used for measurements of icing events. The FD12P weather sensor has been used for visibility observations (fog and clouds). Three to four video cameras have been used to verify the performance of sensors and the video monitoring is also considered as a direct way of making icing indications.

The data from the Rosemount ice detector, the FD12P visibility sensor (temperature < 0 °C and visibility 300 m or less meaning fog) and camera observations were used to calculate the respective number of icing days during the winter 2003/2004 (Figure 17). For comparison, these results from Luosto were compared with icing events estimated using standard meteorological data (air temperature, cloud height and amount) from the Sodankylä observatory for the same winter.

The number of icing days observed with the different methods varies from one month to another. Anyway, the observed number of icing days was fairly close to the estimated yearly averages shown in Table 2. Both ice detector measurements and synoptic data analyses indicate that heavy icing occurs at the Luosto site.

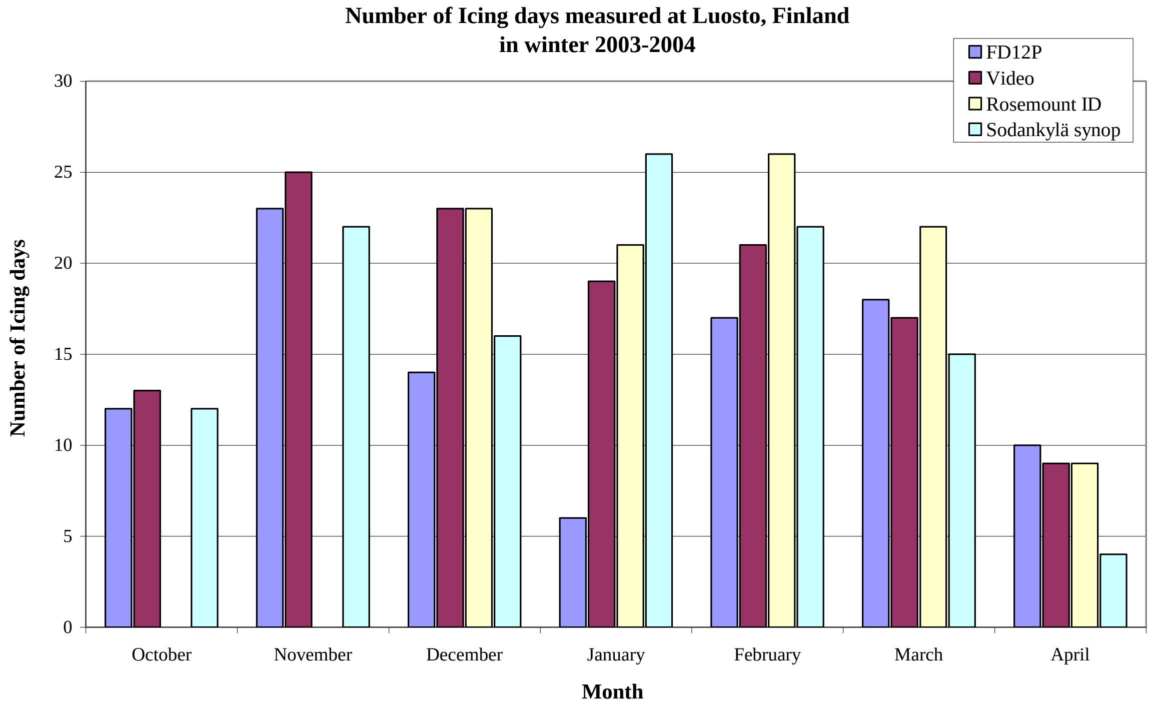

Figure 17. Monthly mean number of icing days during winter 2003-2004 at Luosto (515 m a.s.l.), observed with the Rosemount ice detector, the FD12P weather sensor and video camera pictures. Synoptic meteorological observations from the Sodankylä (179 m a.s.l.) weather station from the same time period have been used for the estimations of icing days. Icing is defined as for in-cloud icing (see criteria above).

4 THE CEOP REFERENCE SITE MEASUREMENTS

The data provided for the CEOP data sets consist of FMI-ARC synoptic data, upper air sounding data and some of the measurements taken on the 48 m mast.

4.1 Synoptic measurements

The CEOP surface meteorological and radiation dataset is built from the data measured at the Observatory. This consists of hourly data from automated weather station (station pressure, air temperature, dew point, relative humidity, wind speed and direction), hourly radiation data (global and reflected radiation) as well as manual observations of precipitation and snow depth. Manual rain observations are performed twice a day and corresponding values represent 12 hour accumulated rain amount. Manual snow depth observations are given as daily values. In addition, the data set includes calculated values for specific humidity and horizontal wind components. The equations used in the calculations are given in the CEOP documentation
(http://www.eol.ucar.edu/projects/ceop/dm/insitu/sites/baltex/).

4.2 Soundings

PTU soundings during CEOP were performed with Vaisala RS-90 radiosondes on a regular basis twice a day, at noon and at midnight. The vertical resolution of the data is 2 seconds which corresponds to 10 m assuming a mean rise rate of 5 m/s. The wind-finding system used in Sodankylä during CEOP was Loran-C, data processing was performed with the DigiCora II ground equipment manufactured by Vaisala Oy. The tropospheric data of pressure, temperature, relative humidity, wind speed and wind direction have been submitted to the CEOP database with a 2 second vertical resolution.

Figure 30. Balloon launch at FMI-ARC. In addition to conventional sensors this payload is also equipped with ozone measurement sensors.

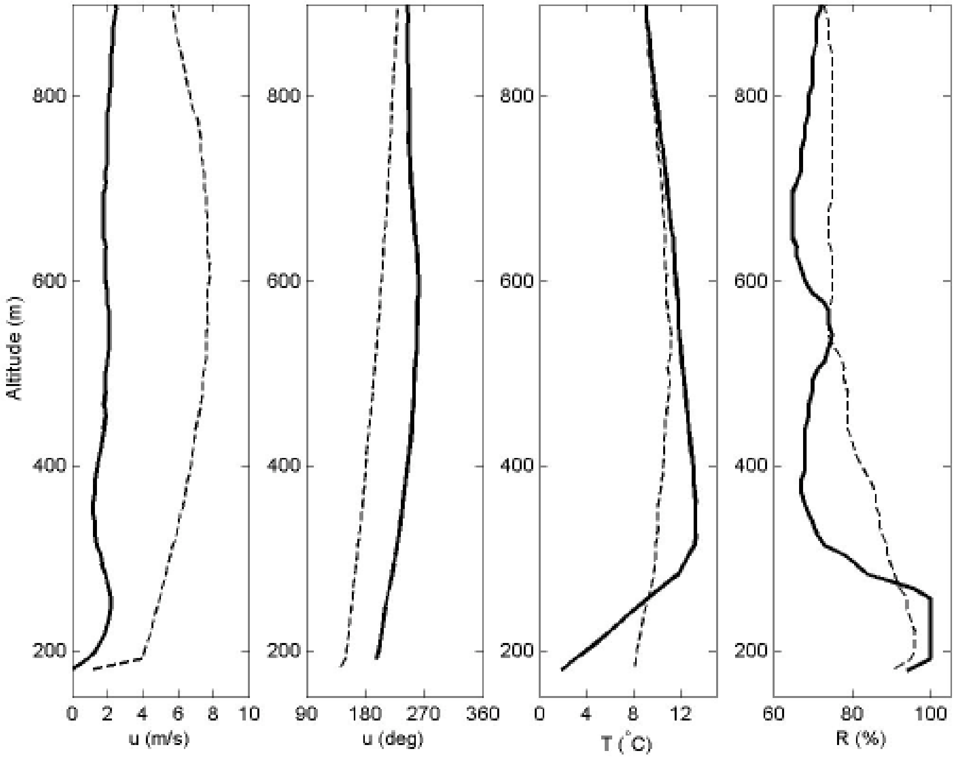

Figure 31. An example of high-resolution radiosonde profiles measured at Sodankylä on August 28. 2001 at 11:30 UT (dashed line) and at 23:30 UT (solid line). From left to right: wind speed, wind direction, temperature and relative humidity measured by radiosonde.

4.3 Mast measurements

4.3.1 The mast instrumentation

The 48 m high research mast was erected in 2000. The mast carries equipment for meteorological research and air chemistry research. Additional near ground measurements are performed at platforms near the mast. The sensors and the acquisition system have been changed during the CEOP period. The Champbell-logger was changed to a Milos-500-logger, to allow the Observations Unit to better calibrate and maintain observations with their own routines. The collection system was also changed to a program made by LABVIEW to better control the collection and depository of observations.

Figure 18. The 48m-meteorological mast (shown here in winter time) is an example of an inter-discipline research tool. The mast is used e.g., for measuring the exchange of carbon dioxide between vegetation and the atmosphere.

Figure 19. Top picture: in the foreground is the sonic anemometer (USA-1, METEK) that measures the exchange of carbon dioxide between the atmosphere and vegetation (the CO_2 analyser is in a nearby shelter), while in the background is the old meteorological-station that measured among other things soil and snow temperature and soil humidity. Bottom picture: display for UV-exposure experiments.

Even though the Sodankylä mast is not prone to the most severe atmospheric icing, the impact of icing upon sensors and measurements has to be taken into account [9], and fully heated cup anemometers have been in use from the beginning. However, the acoustic 3D wind sensors used to be unheated, but these sensors have now (unfortunately quite late) been changed into heated ice-free sensors. Measurements of solar radiation are also affected by rime accreted upon the glass dome. Ice and snow can also be accreted upon the temperature and humidity sensors, but these measurements are not strongly affected by this situation. Additionally, the evaporation sensor operated for the meteorological research is affected by low temperatures. These remarks emphasize that special attention on data quality has to be accounted especially for winter time measurements.

Figure 20. Iced Gill sonic in March 2003.

Figure 21. The Gill sonic anemometers have been replaced by ice-free Metek 3D sensors. The one in the figure is placed at 2 m height close to the mast to measure fluxes close to the ground.

The instrumentation of the mast has been improved during the CEOP programme. The instrumentation used at the start of the Programme in 2001 is shown in Figure 22 and the instrumentation valid at the end in December 2004 in Figure 23.

The turbulent fluxes are calculated using the eddy correlation method using data from the sonic anemometers and separate humidity sensors. The method is based on high-frequency measurement of the three orthogonal wind components, humidity and temperature in a small volume of air above the surface. The vertical fluxes are obtained by calculating covariances between these rapidly varying components and averaging over a suitable time period, which is this case was 30 minutes.

The processing of the turbulence data was done using a set of programs developed at the Meteorological Research branch of the Finnish Meteorological Institute. In the pre-processing phase, the data files were first checked and corrected, if necessary, and finally combined to a more suitable form for further analysis.

The actual calculation of the fluxes was done with tools developed by Tapio Tourula and used earlier, e.g., in the NOPEX project [20]. The high frequency temperature, wind and humidity files were first combined and spikes in data checked and removed with the program routine TURBU. The actual calculation of the fluxes was performed with the program routine ANALYSE.

In the post-processing phase, the results were combined in an Excel worksheet to yield the measured fluxes in desired units. During this phase, a special correction to account for the influence of sensible heat flux on latent heat flux [22] was also applied.

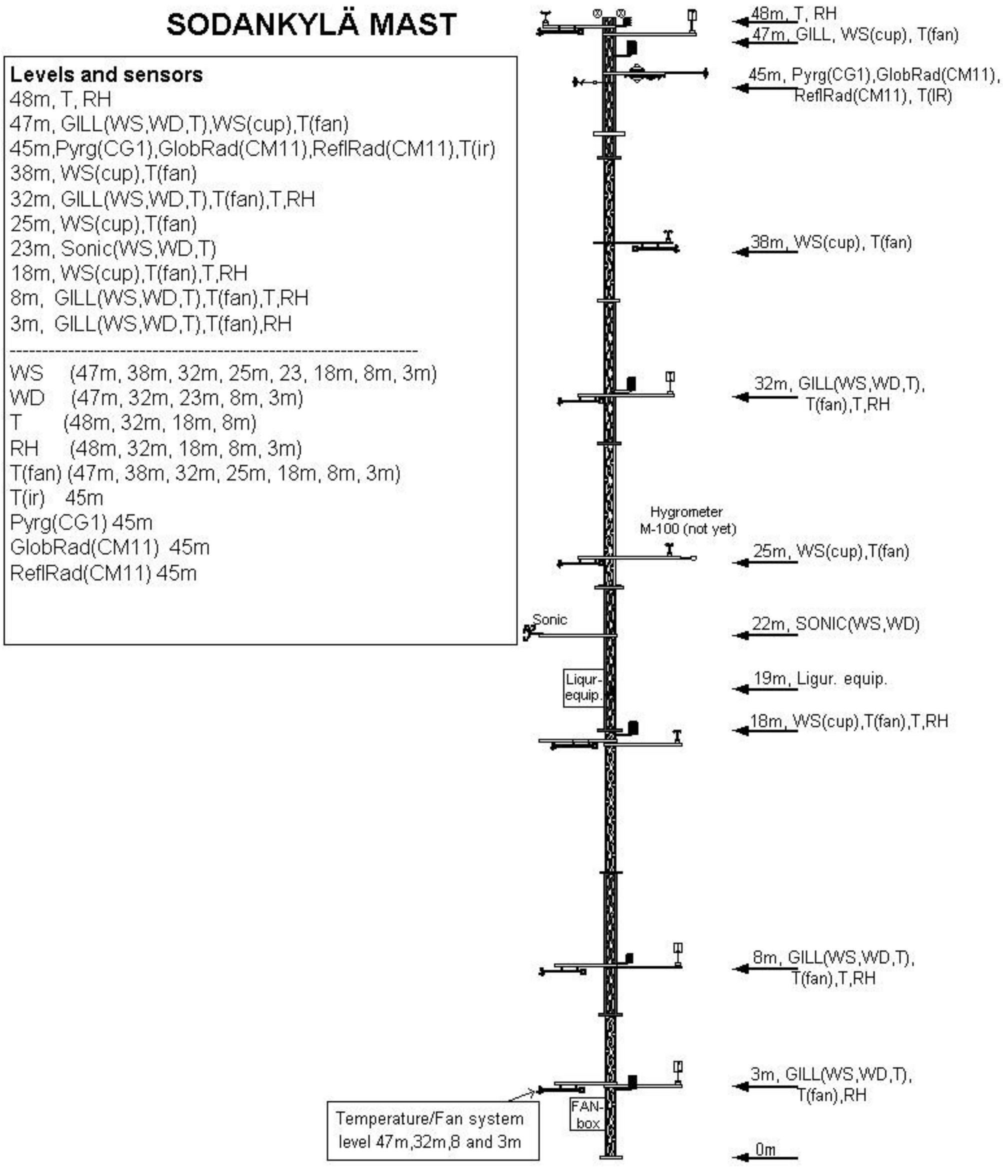

Figure 22. The instrumentation of the mast in 2001.

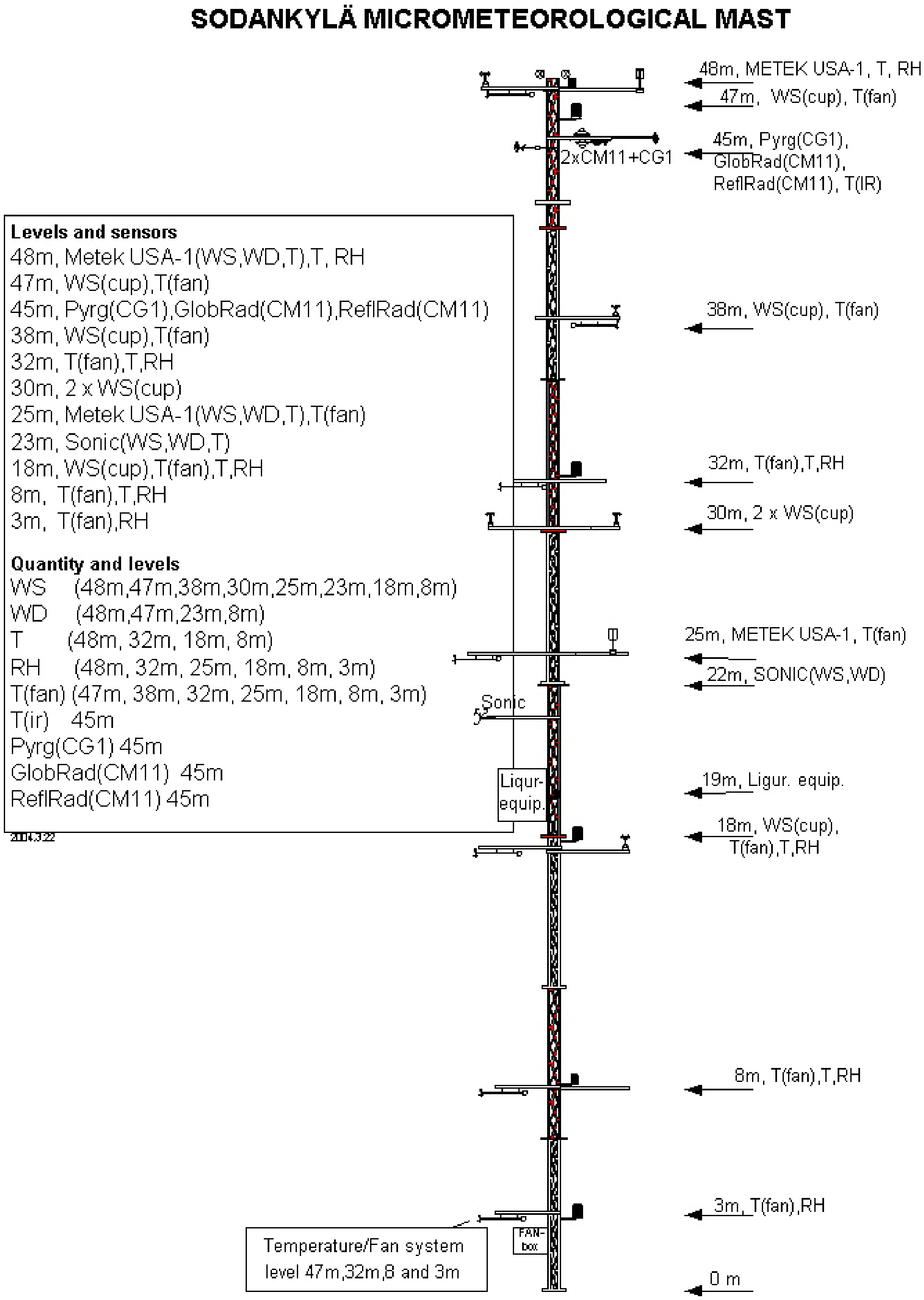

Figure 23. The instrumentation of the Sodankylä mast in March 2004.

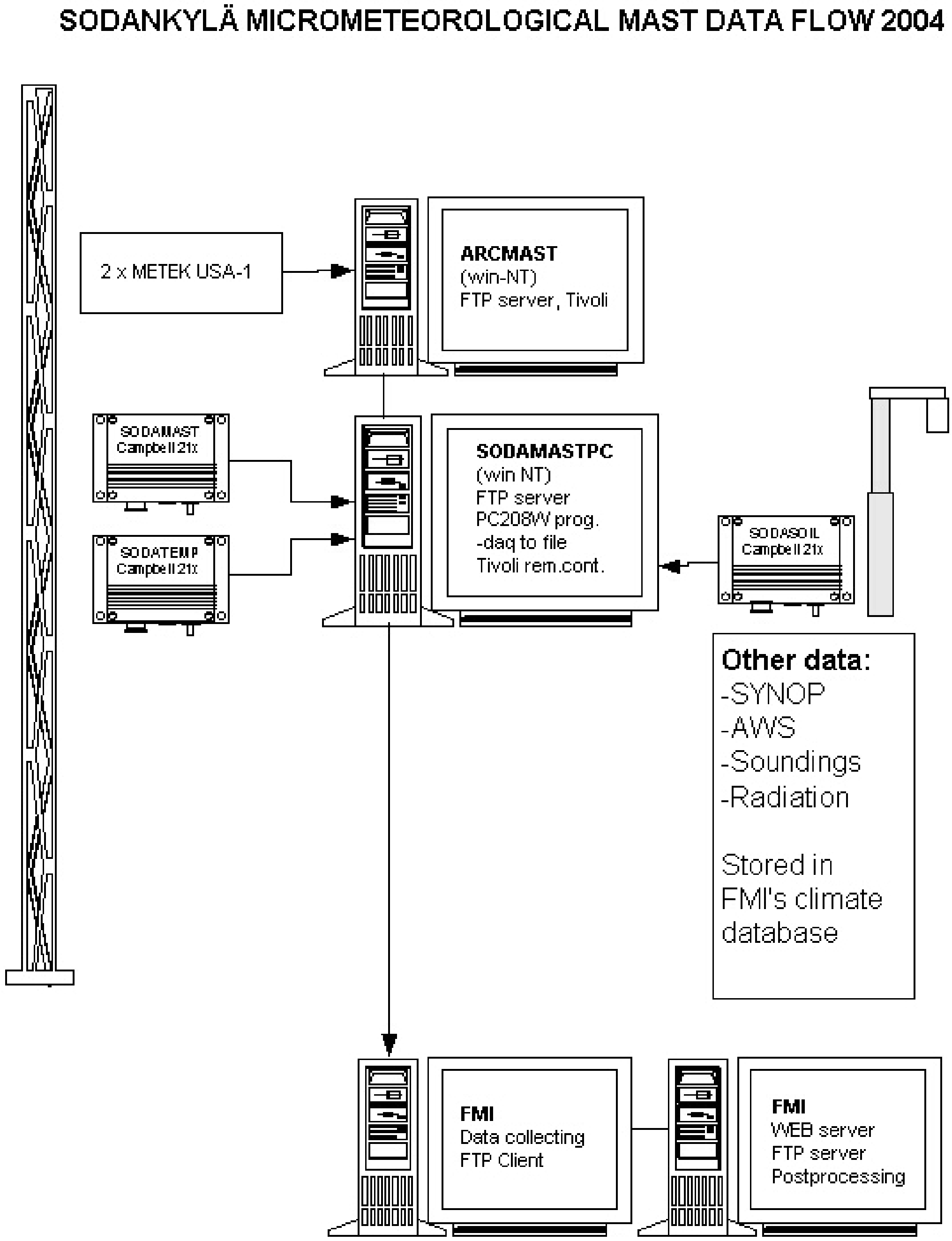

Figure 24. Mast data flows in 2004.

4.3.2 Physiographic properties around the mast

The Sodankylä site is a typical area for the subarctic Northern Finland with sparse Scots pine forests. The terrain around the 48 m mast is rather flat both at small and large scale, so that in first approximation the effect of topography on flow statistics can be neglected. Therefore the landscape is heterogeneous, the canopy density changing directionally for different ranges, with some small open areas and the presence of the river Kitinen, as shown in Fig. 25.

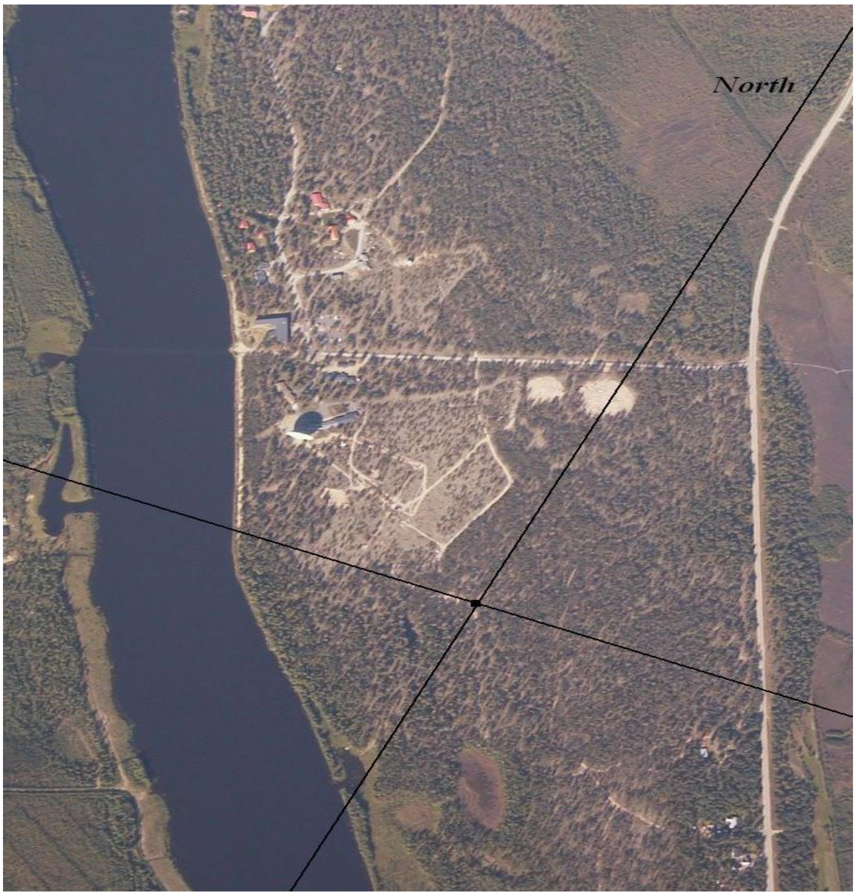

Figure 25. Aerial picture of Sodankylä site. The tower position is indicated by a dot in the intersection of the lines.

The influence of landscape heterogeneity on the aerodynamical properties of the flow is evident above the forest within the roughness sublayer, i.e. the region at the bottom of the boundary layer, where the presence of the canopy impinges directly on the characteristics of turbulence. This influence extends between the height of the vegetation h_c and some height $z^* \approx 3\ h_c$ [4], representing the lower limit of the atmospheric surface layer (ASL), above which the Monin-Obukhov surface scaling with a logarithmic velocity profile under hydrostatic neutral conditions may be expected. At the site of Sodankylä with hc≈15 m, the lowest level z* for applying surface scaling would then be approximately 45 m. Since the highest measurement level is 47 m, only this single level can be expected to correspond to blended flow conditions where the direct effect of roughness elements is not strongly felt. However, the value of the ratio z*/hc is not well settled and values between 2 and 5 [14], can be found in the literature (meaning between 30 and 75 m in Sodankylä).

Above the forest, the turbulent features of the boundary layer flow depend on the efficiency of the canopy to absorb momentum in terms of the bulk transfer coefficient Cf=u*/U. Assuming a logarithmic surface layer, it is possible to derive the roughness length in near-neutral condition as z0= (z-d) exp (-k/Cf), where k is the von Karman constant and the displacement height d is estimated as ≈2/3hc=10 m [2]. The range of roughness length values includes the all directional average estimates made for the same area by Joffre et al. [4] (≈1.4 m) and Zilitinkevich et al. [23] (≈0.8 m).

In particular the maximum and minimum values occur for the south and north-west directions, respectively, corresponding to two different kinds of non-homogeneity (see Fig. 25).

4.4 *Maintenance*

The maintenance of meteorological instruments at the micrometeorological mast obviously constitutes an essential part of preventive routines by FMI's Observational Services, as these instruments are commonly used within FMI observation network. This is particularly true for resistance temperature detectors, humidity sensors and mechanical anemometers. To take care of any faulty functioning, the observation site is included in Observational Services' error reporting system. Anyone having access to FMI intranet is able to request a repair or to inform on suspicious behaviour in the measurements. Also, equipment at the mast base is daily inspected by the local staff in Sodankylä.

For more specialized research measurements, their performance is monitored by data users and actions on instrumentation maintenance are performed by them or at their request. For example, sonic 3D-anemometers are regularly recalibrated in zero wind speed. Recalibration is needed due to system delays, which consist of signal propagation within sensor electronics, and it also includes checking of path lengths.

5 SOME APPLICATIONS OF USING SODANKYLÄ MEASUREMENTS

In the following, some examples of the use of the measured data taken at Sodankylä are shown

5.1 Turbulence profiles

Vertical profiles of mean wind velocity and turbulent statistics up to second order were calculated. The vertical profiles are wind direction dependent, showing different characteristics determined by the combined effect of the density and of the fetch over a certain type of canopy. For several directions, the wind velocity shows a discrete deceleration just above the canopy top, departing from a classical logarithmic profile (see Fig. 26). However, according to our estimates for the lowest level z* of the applicability of the surface layer scaling, we should not expect similarity profile below the highest or second highest measuring levels.

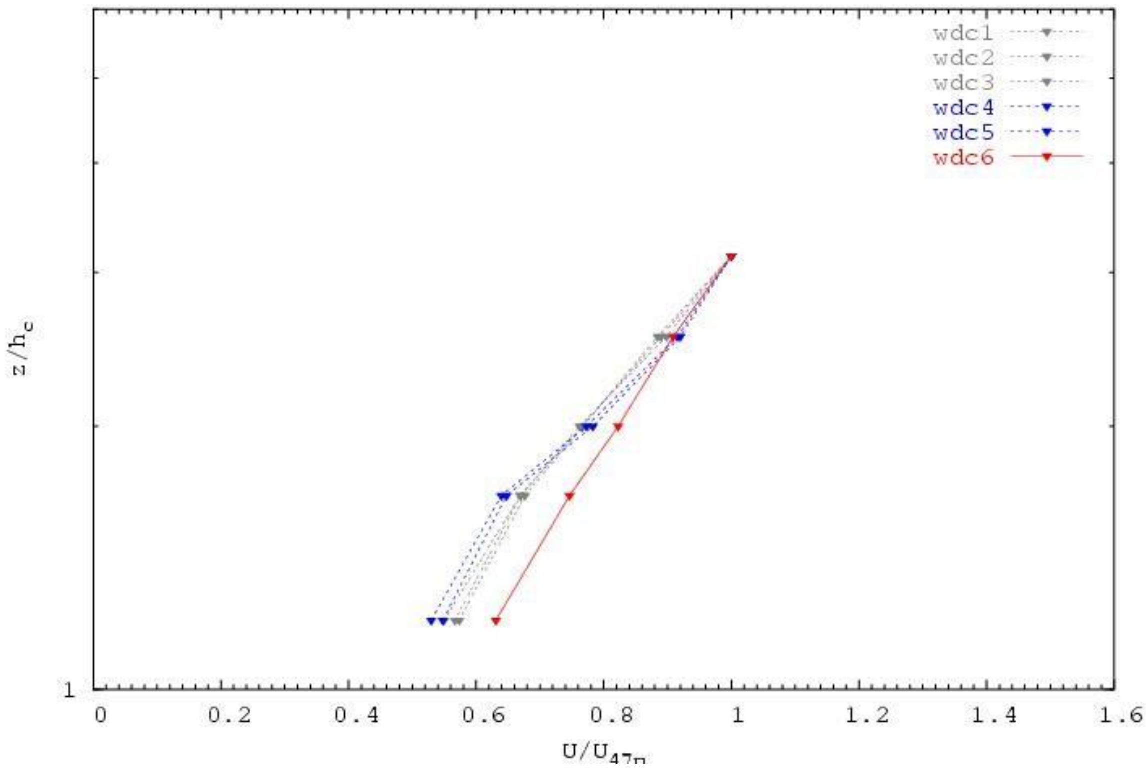

Figure 26. Near-neutral wind velocity profiles normalized by wind velocity at 47 m, for different wind directions.

We can to group the directional classes in three sectors: north-east/east (green lines), characterised by dense canopy and a longer fetch, south (blue line), characterised by a shorter fetch and north-west (red line), the open area sector. Within the same sectors, the different directional classes have the same behaviour [13].

Turbulent statistics profiles can be analysed in the context of the Monin-Obukhov similarity theory, as determined by stability at the top level (47 m), to assess the extent to which surface scaling is valid as the canopy top is approached. For instance, Figure 27 shows how the profiles of velocity standard deviations σ_i,, normalized by the friction velocity measured at z=47 m, are influenced by the non-homogeneity of canopy density and do not follow a similarity scaling for several wind directions, showing an increase of turbulent energy at z=22 m and z=25 m.

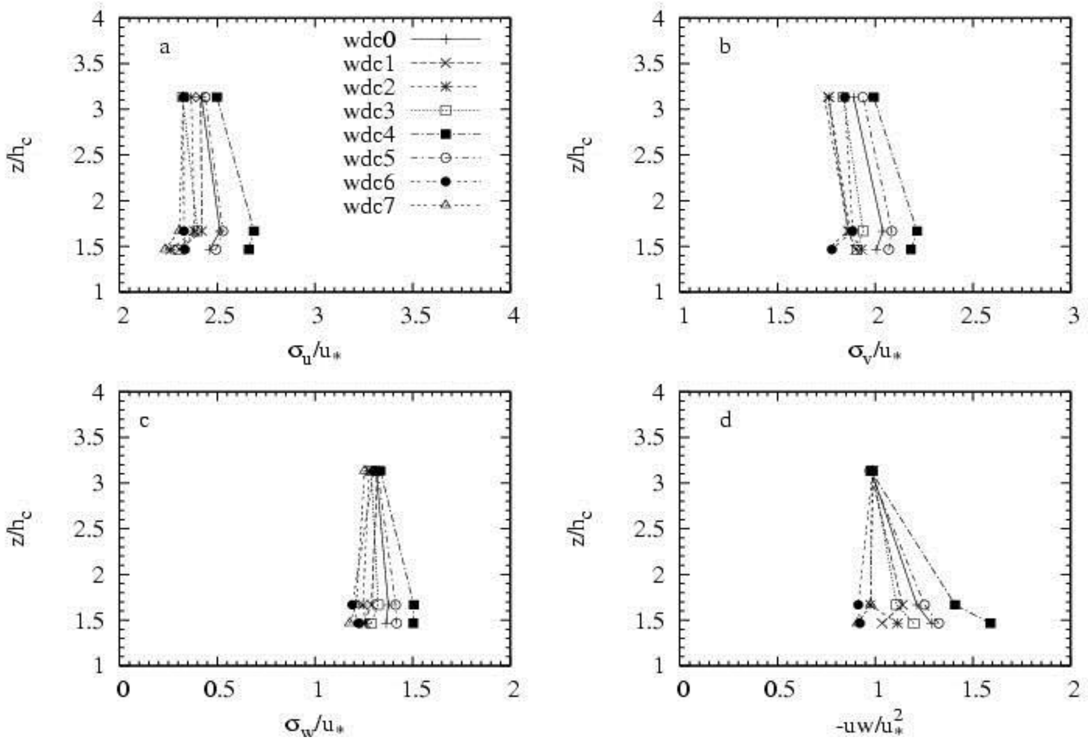

Figure 27. Profiles of turbulent statistics in near-neutral conditions for different directional classes.

Stratification strongly affects the evolution and the structure of the ABL. In wintertime, stable conditions dominate in Sodankylä, under which the turbulent exchange between the atmosphere and the surface can vanish and the atmosphere decouple from the surface, and therefore surface layer similarity cannot be applied on many days. The very strong diurnal variations are particularly characteristic in spring and autumn, while unstable thermal stratifications are more frequent in summertime. Figure 28 shows how the profiles of normalised wind velocity change according to different stability conditions. The curves generally agree with the expected trend in the surface layer, with an increase in the vertical velocity gradient in stable conditions (sc5) and a decrease in unstable conditions (sc1). For the cases (b) and (c), the vertical variations of U/U_{47m} is influenced also by the geometry of the canopy, following however the expected trend as a function of different thermal stratifications.

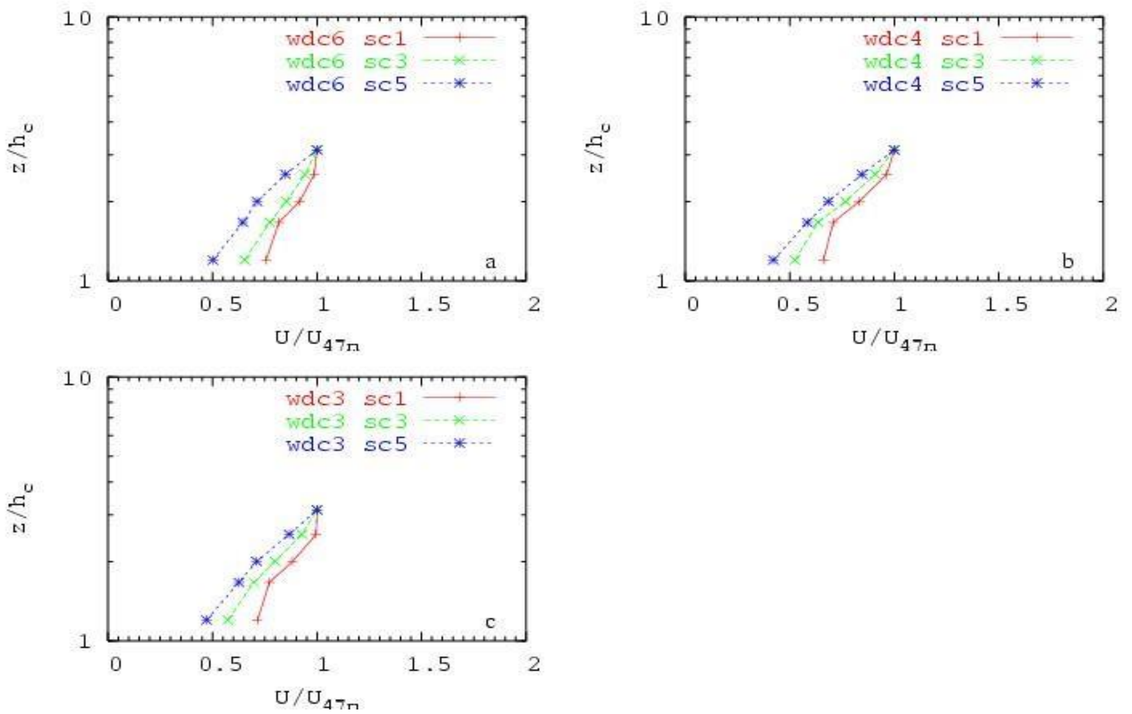

Figure 28. The profiles of normalized wind speed in different stability conditions (sc1=unstable, sc5=stable) and wind direction classes (a: open area sector, b: short fetch over canopy, c: dense canopy and longer fetch).

5.2 Model intercomparison

The fifth-generation Pennsylvania State University-National Center for Atmospheric Research (Penn State-NCAR) Mesoscale Model (MM5) has been used for a test case study under very cold temperature, between 30.01.2003 and 01.02.2003. Wind speed- and temperature-results have been validated against mast observations at 30 and 3 meters height. The results have also been compared to output from the HIRLAM (High Resolution Limited Area Model) [26] at 32 meters (see also the next section 5.3).

The MM5-model [3] is a three-dimensional, prognostic and non-hydrostatic model. It is suitable for simulations down to 1 km resolution and it is an open-source model also providing pre- and postprocessors. The MM5-model solves a fully compressible, non-hydrostatic set of prognostic equations for velocity, perturbation pressure and temperature on a terrain following coordinate system. Additionally, prognostic equations for water vapour, clouds and precipitation are solved if a moist atmosphere is simulated. Staggered grids in the horizontal and vertical are used, with an Arakawa B-grid in the horizontal. There are different schemes for the planetary boundary layer, ground temperature, radiation and cumulus parameterization available.

For the initial and lateral boundary conditions, horizontal winds, temperature, moisture conditions, surface pressure and optionally microphysical files are specified. These are normally taken from either ECMWF- or NCEP-reanalysis data and prepared using standard MM5 pre-processors. Here we have also used HIRLAM as boundary fields. A five cell thick layer around the rectangular model domain is directly affected by the lateral boundary conditions. The outermost two layers are specified by the time-dependent boundary condition value. The next four inner layers are relaxed toward the model values from boundary values, with a relaxation constant that decreases linearly away from the boundary.

The available pre-processors programs in MM5 set up the model grid including surface topography and other land-surface features using standard geographical datasets like GTOPO-30 elevation data, which is a global dataset with resolution 0.9 km, and 24-category land-use data of United States Geographical Survey.

In the vertical, the model was set up with 34 levels, 9 levels within the lowest 200 meters. ECMWF, TOGA- and HIRLAM-meteorological fields have been used as input data to MM5-model, here shown in the figures as “MM5-ECMWF” and as “MM5-HIRLAM”. The model results from HIRLAM are called just “HIRLAM”. Two-way nesting was used to downscale the meteorological fields, with steps of 27-, 9-, 3- and 1-km resolution. The mast observations data are 1 hour averaged values from 1 minute measurements.

The HIRLAM model is a hydrostatic grid-point model, in which the dynamical core is based on a semi-implicit semi-Lagrangian discretisation of the multi-level primitive equations, using a hybrid coordinate in the vertical. Optionally, an Eulerian dynamics scheme can be used.

The prognostic variables, horizontal wind components u, v, temperature T, specific humidity q and linearised geopotential height G are defined at full model levels. Pressure p, geopotential height Φ and vertical wind velocity are calculated at “half” levels. For the horizontal discretization, an Arakawa C-grid is used. The equations are written for a general map projection, but in practice normally a rotated lat-lon grid projection is adopted. A fourth-order implicit horizontal diffusion is applied. More details on the dynamical and numerical aspects of HIRLAM can be found in the HIRLAM Scientific Documentation [26].

A variety of sub-gridscale physical processes are taken into account by parametrization schemes. These include:

- The Savijärvi radiation scheme
- An adapted Rasch-Kristjansson condensation scheme
- The Kain-Fritsch mass-flux convection scheme (optional)
- The STRACO condensation-convection scheme (optional)
- A prognostic TKE scheme (moist CBR)
- The two-layer force-restore ISBA scheme with surface tiling
- A MSO/SSO parametrization of vertically propagating buoyancy waves, resonance effects and blocked-flow drag

As to data assimilation, a 3D-VAR [26], 3D-VAR with FGAT or optimum interpolation scheme was used in this study (the present Hirlam employs 4D-VAR). The observation data types that are assimilated by default are conventional observations (TEMP, SYNOP, AIREP, PILOT, SATOB, SHIP, DRIBU) and AMSU-A / ATOVS radiances over sea. Additionally, it is possible to assimilate AMSU-A over land and sea ice, AMSU-B, geostationary and MODIS atmospheric motion vectors, SEVIRI cloudcleared radiances, GPS zenith total delay, wind profilers, radar radial winds and profiles and Seawinds scatterometer data.

Initial and boundary conditions are normally taken from the ECMWF IFS model. Normally a relaxation zone of 10 grid points is adopted. Boundary relaxation is performed after the horizontal diffusion. At the upper boundary a condition of zero vertical velocity is imposed. To reduce noise and spin-up, analyses are initialized out by digital filter initialization. An incremental DFI scheme is applied by default with a Dolph-Chebyshev filter.

In this study, the Hirlam version 5.1.4 with 40 vertical levels (10 within the lowest kilometre) and with horizontal resolution of 33 km was used.

The test case period lasted during 55 hours between 31.1 – 2.2 January 2003. The bias for the 2m-temperature between MM5-ECMWF and the observations was 5.2°C. For the HIRLAM-model, the corresponding bias was 8.3°C. The bias for temperature at 30 meters, gave for MM5-ECMWF a bias of 2.9 degrees, for MM5-HIRLAM a bias of 3.4°C and for the HIRLAM-model 5.7°C. At 30 meters height, the wind speed bias was for MM5-ECMWF 0.8 m/s and 0.9 m/s for the HIRLAM-model. The temporal variation can be seen in figures 32.-34.

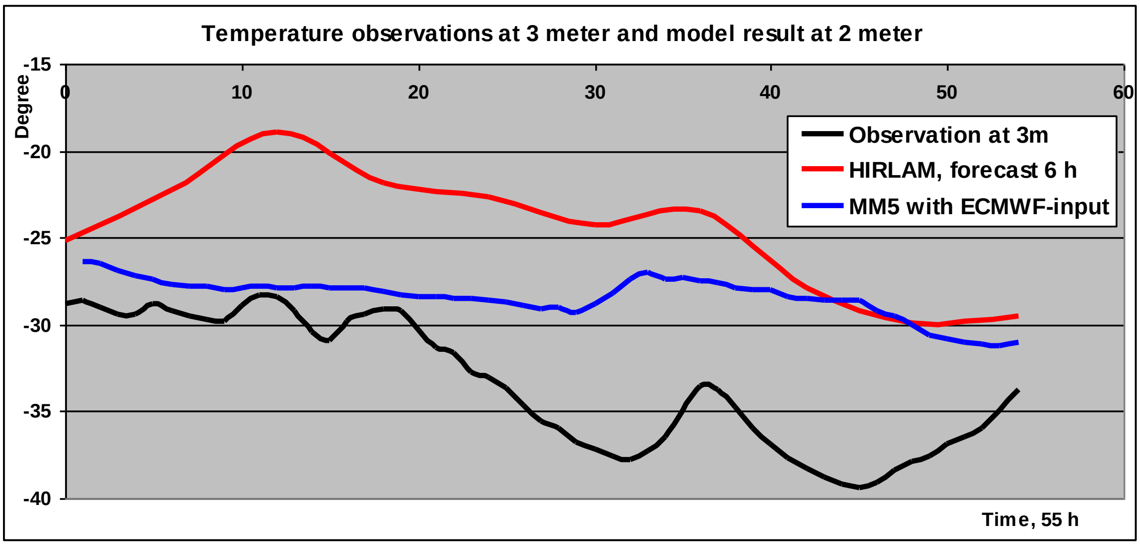

Figure 32. Temperature observations (at 3m) compared to MM5 results (at 2m) and HIRLAM (at 2m) for the period 31/01 – 02/02, 2003.

Comparing model outputs for higher levels in the surface layer roughness (30-32 m) shows less discrepancy with observations in the absolute values of the temperature, but still a bad correlation with diurnal variability (Fig. 33).

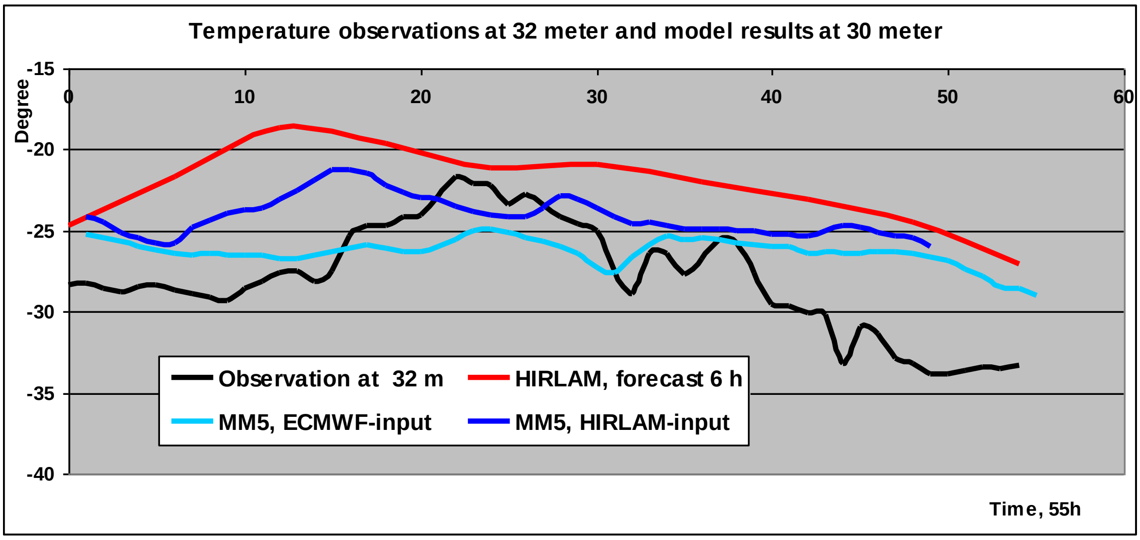

Figure 33. Temperature observations (at 32 m) compared to MM5 (at 30 m) and HIRLAM (at 30 m) for the period 31/1 – 2/2 2003.

Simulations for wind speed with observations (Fig. 34) shows, as for temperature, more or less comparable absolute levels but rather disparate temporal variability.

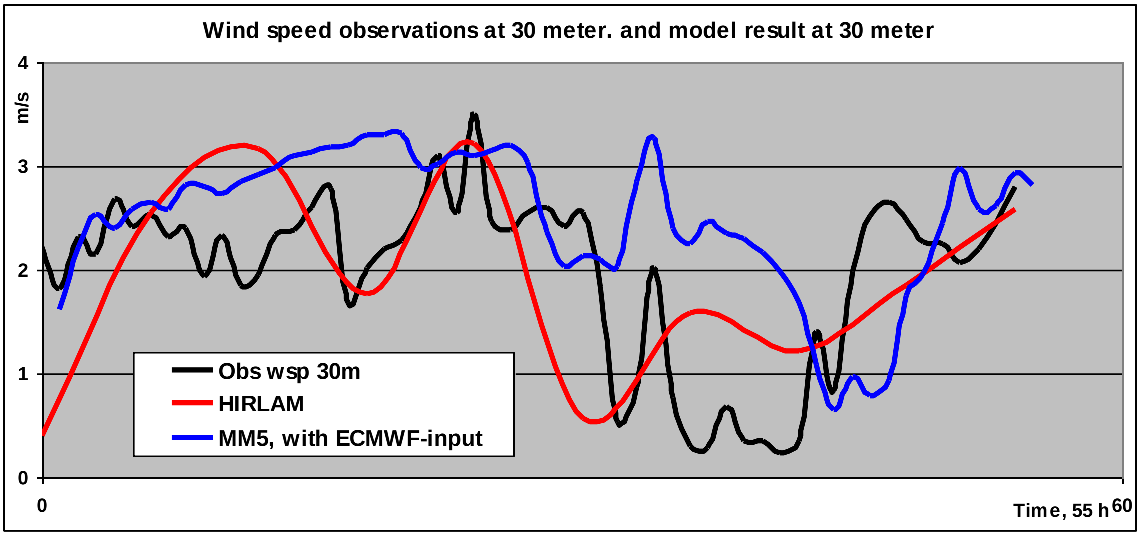

Figure 34. Wind speed measurements (at 30 m) compared against MM5 results (at 30 m) and HIRLAM results (at 30 m).

5.3 Weather model verification monitoring

The observations taken at Sodankylä are also used for the continuous verification of the outputs from both FMI’s own weather prediction model HIRLAM [26] and the MM5 mesoscale model [3]. Such verification studies can be used to check how well the model simulates not only the boundary layer mean conditions but also the turbulent schemes in the models. A visualisation application has been developed, which operationally plots a large number of parameters from both HIRLAM forecasts and mast measurements, thus enabling not only monitoring forecasts, but also on-line comparison of forecasts and measurements.

In the following examples the configuration of the HIRLAM-model (version 5.1.4) is with a spatial resolution of 33 km and 10 levels in the lowest kilometre.The MM5-model configuration is described in the previous section 5.2.

Figure 32 in particular showed the common difficulties for models to properly simulate stable conditions (typical in wintertime in Sodankylä), especially characterised by very low temperatures.

An example of the HIRLAM monitoring plots can be seen in Figure 35, which shows the modelled turbulent heat flux compared to mast observations. Red solid line denotes the observations, while dotted lines show a number of consecutive 00 and 12 UTC HIRLAM forecasts. For each forecast, the first 24 hours are plotted. As can be seen from the plot, the model had in this case a tendency to generate a daily cycle for the heat flux though observations displayed near-zero values.

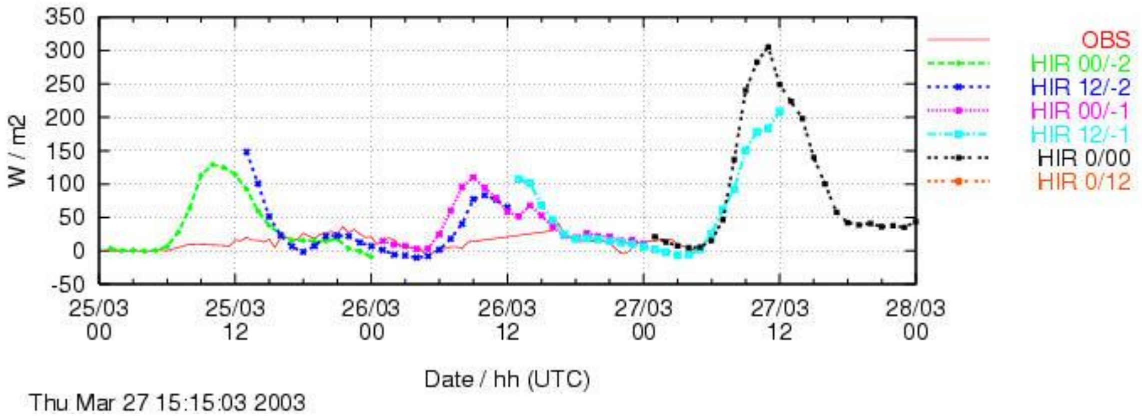

Figure 35. An example of surface heat flux predicted by the FMI HIRLAM weather forecast model and measured at 25 m on the Sodankylä mast on 25-28 March 2003.

In addition to the Sodankylä mast, at the time of the study three other masts were included for verification of HIRLAM outputs in the suite. The additional masts were the TV broadcast masts of the National Television Corporation (YLE). They are less instrumented than the Sodankylä mast, but they do provide better vertical coverage (up to the height of 300 metres), and also improve the spatial coverage of the monitoring (see Fig. 36). The monitoring suite is run every two hours. The parameters included in the plots are shown in Table 3.

Fig. 36. Location of the Finnish masts used for the verification of HIRLAM forecasts at FMI.

Table 3: Parameters included in the mast-model comparison plots.

Mean parameters	Turbulent quantities
Temperature (T2m , T1ModLevel)	Momentum flux (u'v')*
Temperature difference (T2m-T1ModLevel)	Sensible heat flux (w'T')*
Relative humidity (Rh2m)	Latent heat flux (w'q')*
Wind speed (v10m)	Evaporation (Evap)*
Global radiation (SWrad)*	
Surface LW radiation (LWrad)*	

*) available for Sodankylä only

As one can see in Table 3, three temperature values are plotted. First, we have two temperature values, the surface temperature and first model level temperature. The third plot shows the difference of these two, giving thus an indication of the strength of the temperature inversion and of the stratification. As an example, a plot for the 2 metre temperature during January 2003 is shown in Figure 37. As with Figure 35, solid red line shows the measurements and dotted lines denote forecasted temperatures.

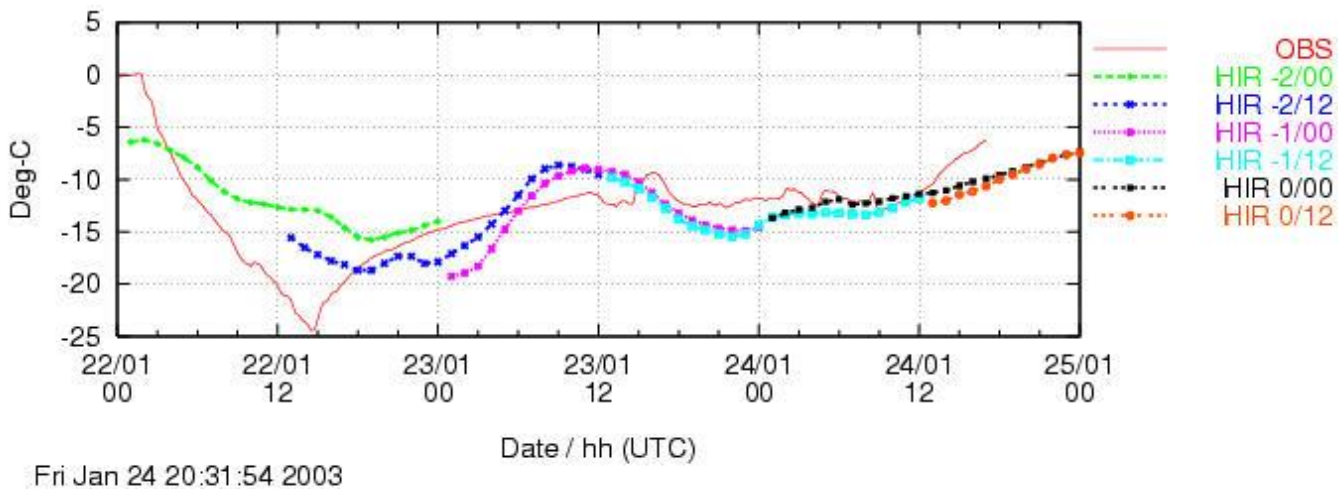

Figure 37. An example of temperature predicted by the FMI HIRLAM weather forecast model and measured at the Sodankylä mast at 2 m on 22-25 January 2003.

The Sodankylä mast data has also been used in another way for the HIRLAM-model development. In order to enable a more efficient use of the measurements in model development, datasets covering specific periods are being collected. The idea is to choose some interesting periods for further research and collect all available relevant data. The dataset consists of five subsets:

- mast measurements: "basic" data (temperature, radiation, wind)
- mast measurements: turbulent fluxes
- mast measurements: soil and snow properties
- balloon soundings
- SYNOP measurements

In the future, more masts and datasets will be made available for model developers.

6 CONCLUSIONS

The international Coordinated Enhanced Observing Period (CEOP), from 2001 through 2004, with a primary focus on developing a 2-year dataset for 2003-2004 to support research objectives in climate prediction and monsoon system studies, is part of international efforts focusing on measurement, understanding and modelling of the water and energy cycles within the climate system. CEOP studies are performed at four Reference Sites located in The Netherlands (Cabauw), Germany (Lindenberg), Sweden (Norunda) and Finland (Sodankylä).

This report describes the measurements and studies carried out by the Finnish Meteorological Institute in northern Finland, especially at the FMI Arctice Research Center in Sodankylä. The measurements include synoptic meteorological measurements as well as soundings and boundary layer measurements using specially instrumented masts (APPENDIX). A Satellite Data Centre for receiving, processing and delivering satellite measurement data in co-operation with ESA, EUMETMETSAT and NASA is also in operation at Sodankylä.

Some applications of the measurements in Sodankylä and near-by sites at Luosto and Pyhätunturi are also described. These include the use weather radar and icing measurements as well as the use of mast measurements in weather forecast model verification. Some comparisons of measurements with the HIRLAM and MM5 weather forecast models are also presented.

The observational periods for CEOP phase I ended officially on 31 December 2004. The plan was to continue the CEOP measurements and observations with a somewhat different strategy, for example a strengthening of the hydrological component and with revised set of reference sites. The CEOP phase II lasted between 2006 and 2010. The CEOP data policy is described at http://www.eol.ucar.edu/field_projects/ceop/.

The Sodankylä CEOP data sets have been delivered for the use of CEOP researchers and can be obtained from http://data.eol.ucar.edu/master_list/?project=CEOP/EOP-3/4. Additional data not included in the datasets can be obtained from FMI.

FMI-ARC at Sodankylä has become a significant scientific centre. It provides an interesting platform for national and international multidisciplinary research, especially for those dealing with arctic climate.

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APPENDIX

Description for Sodankylä soil and mast measurements

07.05.2004

Order of the parameters on the list may differ from raw data files.

Mast coordinates (WGS-84): 67° 21'42,7", 26° 38'16,2", 179,3 m a.s.l.

Mast height: 48 m

Email additions and corrections to: jani.poutiainen@fmi.fi

Parameter	**Parameter ID**	**Meas. unit**	**Sensor**	**Sensor holder**	**Data acquisition and other remarks**
Soil temperature at -2cm	TC_2cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Soil temperature at -5cm	TC_5cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Soil temperature at -10cm	TC_10cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Soil temperature at -20cm	TC_20cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Soil temperature at -50cm	TC_50cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Soil temperature at -100cm	TC_100cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Soil volume moisture at -5 cm	volm_5cm,	mV	Delta-T Devices	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w TDR or ThetaProbe ML1, or ML2. Raw engineering unit.
Soil volume moisture at -10 cm	volm_10cm	mV	Delta-T Devices	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w TDR or ThetaProbe ML1, or ML2. Raw engineering unit.
Soil volume moisture at -20 cm	volm_20cm	mV	Delta-T Devices	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w TDR or ThetaProbe ML1, or ML2. Raw engineering unit.
Soil volume moisture at -30 cm	volm_30cm	mV	Delta-T Devices	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w TDR or ThetaProbe ML1, or ML2. Raw engineering unit.
Soil volume moisture at -50 cm	volm_50cm	mV	Delta-T Devices	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w TDR or ThetaProbe ML1, or ML2. Raw engineering unit.

Soil volume moisture at -100 cm	volm_100cm	mV	Delta-T Devices	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w TDR or ThetaProbe ML1, or ML2. Raw engineering unit.
Soil heat flux at -7cm	SHF__7cm	W/m^2	Campbell heat flux plate	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w Most likely model HFP01, HFT1, or HFT3.
Soil heat flux at -7cm	SHF_7cm	W/m^2	Campbell heat flux plate	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w Most likely model HFP01, HFT1, or HFT3.
Skin temperature	Tsurf_IR	Deg-C	Infrared sensor Everest Model 110	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w
Air relative humidity at 1,7 m above soil or snow	RH_10cm	%	Rotronic MP100	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w. Height changed 25.11.2002. Unit questionable.
Air temperature at 1,7 m above soil or snow	Tair_10cm	Deg-C	Rotronic MP100	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w. Height changed 25.11.2002.
Net radiation at 2 m	NetRad_2m	W/m^2	REBS net radiometer	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w
Wetness	wetness	0=dry 100=wet	Campbell leaf wetness sensor model 237	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w Unit questionable.
Snow temperature at 10cm	T_Sn_10cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Snow temperature at 20cm	T_Sn_20cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Snow temperature at 30cm	T_Sn_30cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Snow temperature at 40cm	T_Sn_40cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Snow temperature at 50cm	T_Sn_50cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Snow temperature at 60cm	T_Sn_60cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Snow temperature at 70cm	T_Sn_70cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Snow temperature at 80cm	T_Sn_80cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Snow temperature at 90cm	T_Sn_90cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w

Snow temperature at 100cm	T_Sn_100cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Snow temperature at 110cm	T_Sn_110cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w
Air temperature 1,7 m above soil or snow	TCair10cm	Deg-C	Campbell copper-constantan thermocouple 105T	FMI/Meteorological research	Campbell 21X "sodasoil" , Campbell AM416, NT4/Pc208w. Height changed 25.11.2002.
Snow temperature reference	Sn_107ref	Deg-C	Campbell 107 thermistor probe	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w
Reference temperature for soil temperature measurement	107_ref	Deg-C	Campbell 107 thermistor probe	15.11.2002 FMI/Air quality research	Campbell 21X "sodasoil", NT4/Pc208w
Reference temperature for soil temperature measurement	107_2	Deg-C	Campbell 107 thermistor probe	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w
Snow depth	SnowDepth	cm	Campbell SR50	FMI/Meteorological research	Campbell 21X "sodasoil" , NT4/Pc208w Use with caution.
Wind speed at 47m	WCUP_47m	m/s	Vaisala WAA251	FMI/Meteorological research	Campbell 21X "sodamast , NT4/Pc208w Heated.
Wind speed at 38m	WCUP_38m	m/s	Vaisala WAA252	FMI/Meteorological research	Campbell 21X "sodamast , NT4/Pc208w Heated.
Wind speed at 30m	WCUP_25m	m/s	Vaisala WAA252	FMI/Meteorological research	Campbell 21X "sodamast , NT4/Pc208w North-east: not measuring Heated. Connection corrected in summer 2002 (WCup_18m <> Wcup_25m).Sensor height changed from 25m to 30m 4.9.2002 and measurement doubled 17.9.2002 at 30m.
Wind speed at 18m	WCUP_18m	m/s	Vaisala WAA252	FMI/Meteorological research	Campbell 21X "sodamast , NT4/Pc208w Heated. Connection corrected in summer 2002 (WCup_18m <> Wcup_25m).
Air temperature at 48m	Temp_48m	Deg-C	Pentronic PT100	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.
Air temperature at 32m	Temp_32m	Deg-C	Pentronic PT100	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.
Air temperature at 18m	Temp_18m	Deg-C	Pentronic PT100	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.

Air temperature at 8m	Temp_8m	Deg-C	Pentronic PT100	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.
Air temperature at 3m	Temp_3m	Deg-C	Pentronic PT100	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.
Air relative humidity at 48m	RH_48m	%	Vaisala HMP 45	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.
Air relative humidity at 32m	RH_32m	%	Vaisala HMP 35C	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.
Air relative humidity at 18m	RH_18m	%	Vaisala HMP 45	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.
Air relative humidity at 8m	RH_8m	%	Vaisala HMP 35C	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.
Air relative humidity at 3m	RH_3m	%	Vaisala HMP45D	FMI/Meteorological research	Campbell 21X "sodamast , Campbell AM416, NT4/Pc208w Vaisala radiation shield.
Global radiation at 45 m	GlobalRad	W/m^2	Kipp & Zonen CM11	FMI/Meteorological research	Campbell 21X "sodamast , NT4/Pc208w Not ventilated.
Reflected radiation at 45 m	ReflRad	W/m^2	Kipp & Zonen CM11	FMI/Meteorological research	Campbell 21X "sodamast , NT4/Pc208w Not ventilated.
Outgoing long-wave radiation at 45 m	LW_Up	W/m^2	Kipp & Zonen CG1	FMI/Meteorological research	Campbell 21X "sodamast , NT4/Pc208w Not ventilated.
Air temperature at 3m	Temp3m	Deg-C	Ventilated copper-constantan-thermocouple	NDRE / melker.nordstarnd @ume.foa.se	Campbell 21X "sodatemp", NT4/Pc208w Swedish National Defence Research Establishment, Department of NBC Defence (NDRE)
Air temperature at 8m	Temp8M	Deg-C	Ventilated copper-constantan-thermocouple	NDRE / melker.nordstarnd @ume.foa.se	Campbell 21X "sodatemp", NT4/Pc208w
Air temperature at 18m	Tem18m	Deg-C	Ventilated copper-constantan-thermocouple	NDRE / melker.nordstarnd @ume.foa.se	Campbell 21X "sodatemp", NT4/Pc208w
Air temperature at 25m	Tem25m	Deg-C	Ventilated copper-constantan-thermocouple	NDRE / melker.nordstarnd @ume.foa.se	Campbell 21X "sodatemp", NT4/Pc208w
Air temperature at 32m	Tem32m	Deg-C	Ventilated copper-constantan-thermocouple	NDRE / melker.nordstarnd @ume.foa.se	Campbell 21X "sodatemp", NT4/Pc208w
Air temperature at 38m	Tem38m	Deg-C	Ventilated copper-constantan-thermocouple	NDRE / melker.nordstarnd @ume.foa.se	Campbell 21X "sodatemp", NT4/Pc208w

Air temperature at 47m	Tem47m	Deg-C	Ventilated copper-constantan-thermocouple	NDRE / melker.nordstarnd @ume.foa.se	Campbell 21X "sodatemp", NT4/Pc208w
Logger input panel temperature	TempPa	Deg-C	Campbell 21X	NDRE / melker.nordstarnd @ume.foa.se	Campbell 21X "sodatemp", NT4/Pc208w
Wind speed, wind direction, turbulence, temperature at 25m	2METEK (10Hz data), 4MET-TURBU (10min turbu-message)		Acoustic anemometer/thermometer Metek USA-1	FMI/Meteorological research	PC/LabView
Wind speed, wind direction, turbulence, temperature at 47m	5METTOP (10Hz data), 6METTOPT (10min turbu-message)		Acoustic anemometer/thermometer Metek USA-1	FMI/Meteorological research	PC/LabView
Net radiation at 47m			REBS Q-7 net radiometer	FMI/Air quality research	
Ground temperature at -5cm		Deg-C	Optic StowAway Temp	FMI/Air quality research	
Ground temperature at -5cm		Deg-C	5/2002 Pt100	FMI/Air quality research	
Temperature at 30cm		Deg-C	5/2002 Humicap/Pt100	FMI/Air quality research	
Humidity at 30cm		%	5/2002 Humicap/Pt100	FMI/Air quality research	
Wood increment	ohm			FMI/Air quality research	
Photosynthetically active radiation at 45m			LI-COR 190SZ	FMI/Air quality research	Up-looking
Photosynthetically active radiation at 45m			LI-COR 190SZ	FMI/Air quality research	Down-looking
Long-wave radiation at 45m			Eppley PIR	FMI/Air quality research	Down-looking
Radiation temperature of the canopy			Everest InterScience IR-thermometer at 47m, model 4000.4GL	FMI/Air quality research	
CO_2, H_2O, heat and momentum fluxes at 23,5 m			LICOR 7000 analyzer + Metek USA-1	FMI/Air quality research	

Wind speed, wind direction, turbulence, temperature at 2 m			Acoustic anemometer/thermometer Metek USA-1 Standard version	FMI/ Air quality research	PC; temporary measurement, fall 2003. To be replaced with 15.9.2003 removed 8m Metek.
CO_2 concentration gradient at 4 m			LICOR 6262 $C0_2/H_2O$ analyzer	FMI/Air quality research	
CO_2 concentration gradient at 10 m			LICOR 6262 $C0_2/H_2O$ analyzer	FMI/Air quality research	
CO_2 concentration gradient at 23 m			LICOR 6262 $C0_2/H_2O$ analyser	FMI/Air quality research	
CO_2 concentration gradient at 48 m			LICOR 6262 $C0_2/H_2O$ analyser	FMI/Air quality research	
NO_2 photolysis at 45 m (?)			Metconsult GmbH JNO2 500 photolysis sensor	FMI/Air quality research	Up-looking
NO_2 photolysis at 45 m (?)			Metconsult GmbH JNO2 502 photolysis sensor	FMI/Air quality research	Down-looking
Canopy and Scots pine shoot reflectance			Analytic Spectral Devices (320-1050 nm, 512 channels)	FMI/Air quality research	
Dark-adapted chlorophyll fluorescence of Scots pine needles			Hansatech fluorometer	FMI/Air quality research	
Cloud height			Vaisala LD40 Week 20/2003	FMI/Observation Services	Location: observatory. Serial line data collection to PC at mast.
Wind			Sodar 17.3.2004	VTT	Continuous, but campaign based measurements in the area.
Parameter	**Parameter ID**	**Measurement unit**	**Sensor**	**Sensor holder**	**Data acquisition and other remarks**