ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

RAPORTTEJA
RAPPORTER
REPORTS
2014:7

SNORTEX, SNOW REFLECTANCE TRANSITION EXPERIMENT

TERHIKKI MANNINEN
JEAN-LOUIS ROUJEAN

Raportteja
Rapporter
Reports
2014:7

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978-951-697-835-5 (paperback)
978-951-697-836-2 (pdf)

Helsinki 2014

Unigrafia

FINNISH METEOROLOGICAL INSTITUTE

Published by	Finnish Meteorological Institute (Erik Palménin aukio 1) , P.O. Box 503 FIN-00101 Helsinki, Finland	Raportteja - Rapporter - Reports 2014:7 Date
Author(s)	Terhikki Manninen and Jean-Louis Roujean	Name of project SNORTEX Commissioned by FMI and Météo-France

Title SNORTEX, SNOW REFLECTANCE TRANSITION EXPERIMENT

Abstract

Finnish Meteorological Institute and Météo-France organized a measurement campaign related to the reflectance characteristics of snow in Sodankylä during 2008 – 2010. Finnish Geodetic Institute, the Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE) and University of Eastern Finland also participated in the campaign. The central OSIRIS instrument provided by Météo-France was attached to a helicopter for measurements of the directional characteristics of the reflectance of snow. The helicopter was used simultaneously as the measurement platform also for pyranometers and UV sensors to estimate the albedo both in broad band and in the UV wavelength range. In addition, a wide optics camera was attached to the helicopter to assess the leaf area index of the forests.

To support the airborne measurements an extensive data set of ground based measurements was also gathered concerning the basic properties of snow. Some parameters characterized the whole snow pack (thickness, density and water equivalent). Some other parameters were determined for vertical profiles (temperature, density, grain size etc.). Also in situ measurements were carried out about the reflectance characteristics of snow using an albedometer and the FIGIFIGO instrument. In addition, the surface roughness estimated using laser scanning and photos. Daily ground measurements were carried out in Sodankylä at the intensive test site at the Arctic Research Centre of FMI and in varying test sites in its surroundings.

Publishing unit: Meteorological Research

Classification (UDC) Keywords: snow, albedo, airborne measurements

ISSN and series title
0782-6079 Raportteja – Rapporter -Reports

ISBN	978-951-697-836-2 (pdf) 978-951-697-835-5 (paperback)	Language: Engllish	Pages: 69

ILMATIETEEN LAITOS

Raportteja - Rapporter - Reports 2014:7

Julkaisija	Ilmatieteen laitos, (Erik Palménin aukio 1) PL 503, 00101 Helsinki
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Nimeke	SNORTEX, SNOW REFLECTANCE TRANSITION EXPERIMENT

Tiivistelmä

Ilmatieteen laitos ja Météo-France järjestivät lumen heijastusominaisuuksiin liittyvän mittauskampanjan Sodankylässä vuosina 2008-2010. Geodeettinen laitos, Le Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE) ja Itä-Suomen yliopisto osallistuivat myös kampanjaan. Mittausten keskeinen instrumentti oli Météo-Francen tuoma OSIRIS-laite, jolla mitattiin helikopterista käsin lumen heijastuksen suuntautuneisuutta. Helikopteriin oli myös kiinnitetty pyranometrejä ja UV-sensoreita, joilla samaan mitattiin lumen heijastuksen kokonaismäärää sekä laajakaistaisesti että vain UV-aallonpituuksilla. Lisäksi helikopterissa oli laajakuvakulmainen kamera, jolla määritettiin metsien lehtialaindeksien suuruutta.

Lentomittausten tueksi kerättiin mittava määrä aineistoa lumen perusominaisuuksista maastomittauksin. Osa suureista luonnehti lumikerrosta kokonaisuudessaan (paksuus, tiheys ja vesiarvo). Joitakin suureita määritettiin profiileina (lämpötila, tiheys, raekoko ym.). Lumen heijastusominaisuuksia mitattiin myös maastossa sekä albedometrillä että FIGIFIGO-laitteella. Lisäksi mitattiin lumen pinnankarkeutta mm. laserkeilauksella ja valokuvin. Maastomittauksia tehtiin Sodankylässä päivittäin sekä Ilmatieteen Arktisen tutkimuskeskuksen intensiivialueella että vaihtuvalla koealueella sen ympäristössä.

Julkaisijayksikkö: Meteorologinen tutkimus

Luokitus (UDK) — Asiasanat: lumi, albedo, lentomittaukset

ISSN ja avainnimike
0782-6079 Raportteja – Rapporter -Reports

ISBN	978-951-697-832-2 (pdf) 978-951-697-835-5 (paperback)	Kieli: englanti	Sivumäärä: 69

SNORTEX

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SNORTEX

SNOW REFLECTANCE TRANSITION EXPERIMENT

SNORTEX

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1. Introduction

In European boreal regions, sampling of snow BRDF from space is jeopardized by a high cloud occurrence. This places a severe limit to obtain an appropriate characterization of snow metamorphism from space based. In this regard, SNORTEX was implemented to provide a solid background reference for depicting changes in snow properties during the snow-melting period. The time component is investigated at 3 levels: ground, airborne, and satellite. A peculiarity is an acquisition of airborne BRDF using shortwave multi-directional instrument OSIRIS (airPOLDER) at various footprint sizes as a function of aging of snow and illuminations – from partially cloudy to clear sky situations. Airborne compound is completed by concomitant aboard pyranometers measurements and a collection of photos. As a result, SNORTEX will contribute to build a solid database of snow-forest BRDF and albedo, completed by snow fraction and water equivalence essentially. A set of auxiliary snow measurements completes the database. Moreover, the acquisition of scenes with different footprints (from 2 to 30 meters) will serve exploration of BRDF spatial variability and be of great support for validation of a snow-vegetation coupled radiative transfer model. Expected result is a clear BRDF signal at landscape scale for further validation of pixels from coarse resolution sensor like Metop and POLDER. A dynamic prescription of snow-forested albedo from airborne BRDF will yield a priori information for tuning Land SAF snow albedo product. In a future stage, an off-line assimilation of the Land SAF snow albedo will be performed (SURFEX, HIRLAM). SNORTEX will last 3 years for investigating variations in snow cycling in a region, the Finnish Lapland, where the precursor effects of the global warming may be observed, as it is expected for high latitudes.

SNORTEX is a 3-years investigation in 2008 - 2010, which is piloted by Météo-France and FMI with the two following key objectives:

1) to better characterize the snow-melting patterns at a landscape scale using a multi-scale strategy supported by multi-angular and multi-spectral remote sensing information;
2) to provide solid database information for the validation of the SAF (Satellite Application Facilities) snow-related products (albedo, fraction, water equivalence);

The overall goal is to lead to improvements of the snow properties (albedo, fraction, water equivalence) in Numerical Weather Prediction (NWP) models in taking advantage of satellite observations. A special characteristic of SNORTEX is the investigation of high vegetation (forest) in open areas, as snow albedo in climate models is under-estimated due to disregard of the quantity of light travelling through canopy gaps. Amongst meaningful parameters, Bidirectional Reflectance Distribution Function (BRDF) of snow-forest system is at the core of the study since it characterizes well the anisotropy of the medium. Time component is investigated during snow-melting period.

In 2008 the emphasis was carrying out snow measurements in a larger area (~250 km^2) within a few weeks' time in midwinter April 1-18. In 2009 special interest was put on studying the seasonal change of the snow cover. Therefore three separate sections were carried out. The first one was aimed at midwinter (March 9-20), the second one at the onset of melting (April 19-29) and the third one at the time of fractional snow cover (May 4 – May 8). The snow measurements were concentrated in an area with a diameter of roughly 10 km, but additional remote measurements of the macroscopic snow properties were carried out in some characteristic test sites of 2008 by the technical staff of FMI-arc in order to enable the generalization of the snow pack properties. In 2010 the measurement scheme was very much the same as in 2009 (March and April), but a few new instruments were used.

2. Airborne measurements

2.1. Flight protocols

The company HeliFlite Oy based on the Sodankylä airport operated the flights in all three years (Table 1, Table 2, Table 3). The airborne vehicle was all the time the same Eurocopter Ecureuil AS 350 helicopter. The configuration of the helicopter had been modified to host OSIRIS sensor, four pyranometers, four UV sensors, a wide optics camera, a humidity sensor (Humicap) and thermometer (Pt100). Two aeronautic GPS antennae (Omnistar OXTS 3040 LI/L2, power supply 5VDC, gain 26 dB) were placed at the front and rear on the helicopter for the OSIRIS. A real-time correction system was effective. They are connected to an inertial system fixed on the same platform than OSIRIS placed below the helicopter. Operating systems for instruments (rugged laptops) are placed in the helicopter cockpit. The power unit is distributed as shown in Figure 1. For the widefield camera and the pyranometers additional GPS sensors were placed at the front ceiling of the helicopter. In 2009 also a laser scanner was integrated in the OSIRIS platform. The pyranometer and UV sensor system and the wide optics camera system were the same in all three years, except that the GPS height coordinate was integrated to the pyranometer system in 2009 and a pressure gauge for altitude registration in 2010. The distribution of the power unit in 2008 appears in Figure 2 and the version used in 2009 and 2010 appears in Figure 2.

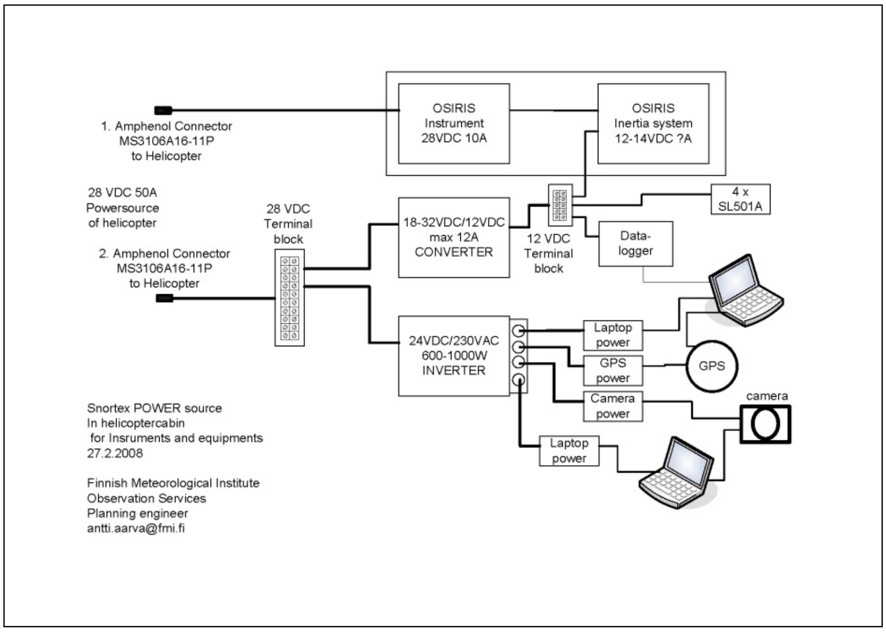

Figure 1. Distribution of power supply inside the helicopter in 2008.

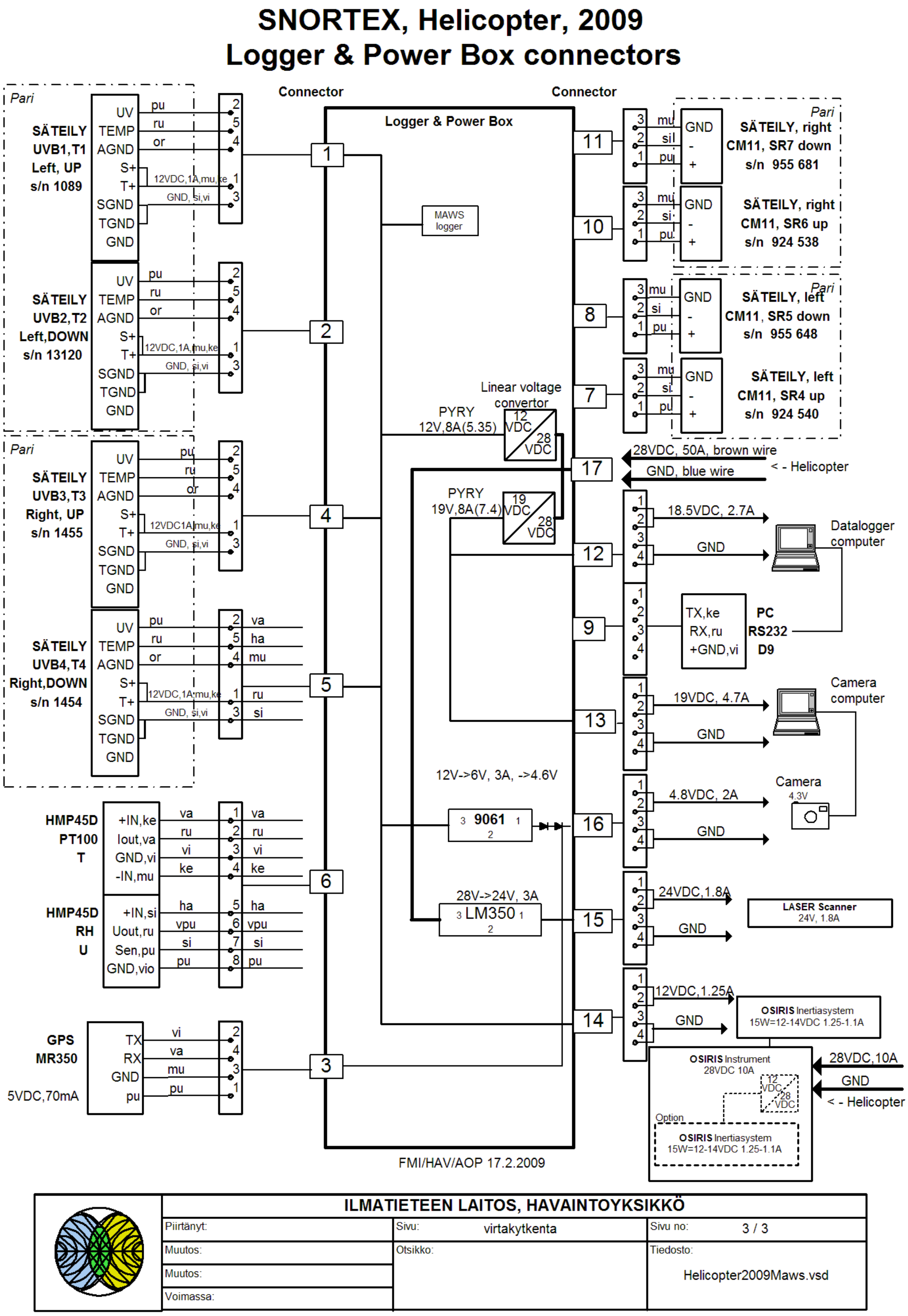

Figure 2. Distribution of power supply inside the helicopter.

In 2008 a typical flight was directed to northern side of Tähtelä (FMI-ARC location). It generally started with a pyranometer calibration check at the Tähtelä weather mast, followed by a long continuous line from Tähtelä to lakes Porttipahta and Lokka and/or shorter line to Luosto field via lake Orajärvi. Optionally, in overcast situations a low altitude flight over Tähtelä was operated for LAI analysis with emphasis on the vertical profiles to obtain various footprints. Nominal altitude in cruise configuration was about 2 km. Flight dates are given in Table 1 and flight routes for the scientific flights are shown in Figure 3 on a CORINE land cover map.

Table 1. Summary of the 2008 flight operations. Brackets indicate technical testing.

Date	Flight type	Altitude above sea level (m)	OSIRIS	Pyranometers and UV sensors	Wide optics camera
March 8	Technical flight	400	(x)		
March 30	Technical flight	180 - 400			(x)
April 2	Vertical profiles	180 - 400	(x GPS)	x	x
April 3	Horizontal line and wind rose	1000	x	x	x
April 7	Horizontal line and crosses	400 - 1000	x	x	x
April 10	Horizontal line and crosses	400	x	x	

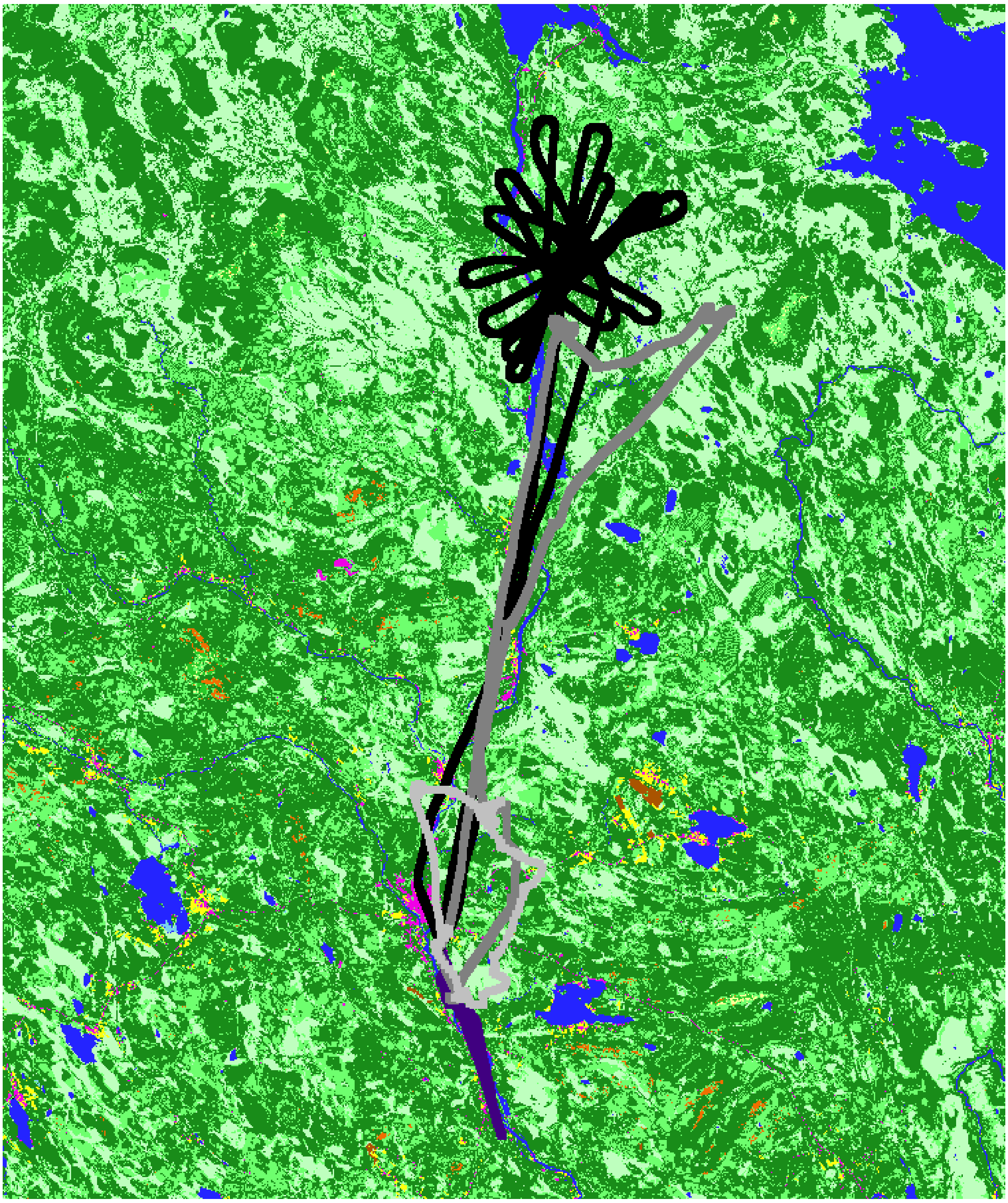

Figure 3. The scientific flight routes of OSIRIS on **April 2**, **April 3,** **April 7** and **April 10, 2008**. The background is the CORINE land cover map (Härmä et al. 2004), the colour scheme of which is: blue – water, pink – urban, yellow – field, brown – rock, green dark green – forest, medium green – sparse forest, light green – open bogs.

In 2009 a typical flight consisted of horizontal transfers from ground measurement site to another. During most of the flights (Table 2, Figure 4, Figure 5) a cross pattern (+) was made at two flight altitudes (Table 2) starting with the helicopter nose pointing to the sun and then turning clockwise in perpendicular directions so that each position was kept for about 30 s. The afternoon flight of April 22 was dedicated to horizontal flying of parallel lines to form a more or less rectangular grid (Figure 5). For the dedicated LAI measurements using the wide optics camera completely overcast sky was required. The flight (March 13, Table 2) itself consisted of vertical profiles above ground LAI measurement sites and horizontal flights at higher altitude (Manninen et al., 2009).

Table 2. Summary of the 2009 flight operations.

Date	Flight type	Altitude above sea level (m)	OSIRIS	Pyranometers and UV sensors	Wide optics camera
March 13	Vertical profiles at LAI sites	170 -330		X	x
March 17	Crosses over test sites	170, 330	x	X	x
March 18	Crosses over test sites	170, 330, 500	x	X	x
April 22 morning	Crosses over test sites	330	x	X	x
April 22 afternoon	Parallel flight lines over test sites	1000	x	X	x
April 24 morning	Crosses over test sites	170		x	x
April 24 afternoon	Parallel flight lines over test sites	1000	x	x	x
May 4	Crosses over sites	400	x	x	
May 5	Long transect	330	x	x	x

Figure 4. The flight routes of OSIRIS on March 17 (yellow) and March 18 (turquoise), 2009, over the extensive snow measurement area.

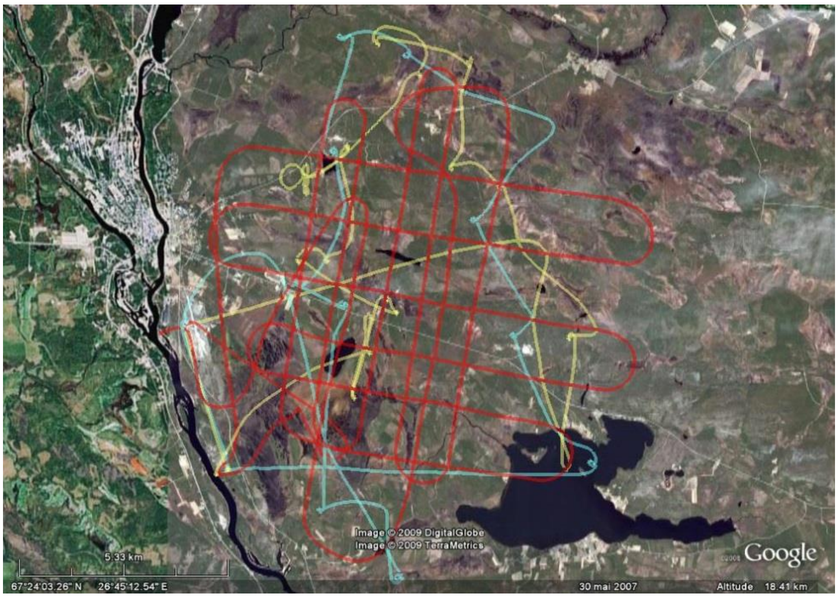

Figure 5. The flight routes of OSIRIS on April 22 morning (blue), April 22 afternoon (red) and May 4 (yellow), 2009, over the extensive snow measurement area.

In 2010 a typical flight consisted of horizontal profiling in a grid pattern at several altitudes, but also vertical profiling was performed as before during the LAI dedicated flight of March 19. This time profiles were located exactly above the LAI measurement sites, which were marked with black crosses.

Table 3. Summary of the 2010 flight operations.

Date	Flight type	Altitude above sea level (m)	AISA	Pyranometers and UV sensors	Wide optics camera
March 18	Horizontal North-South flight lines over lake and aapa mire	800	x	x	x
March 19	Vertical profiles at LAI sites	170 -330	x	x	x
March 21	Horizontal flight lines		x		

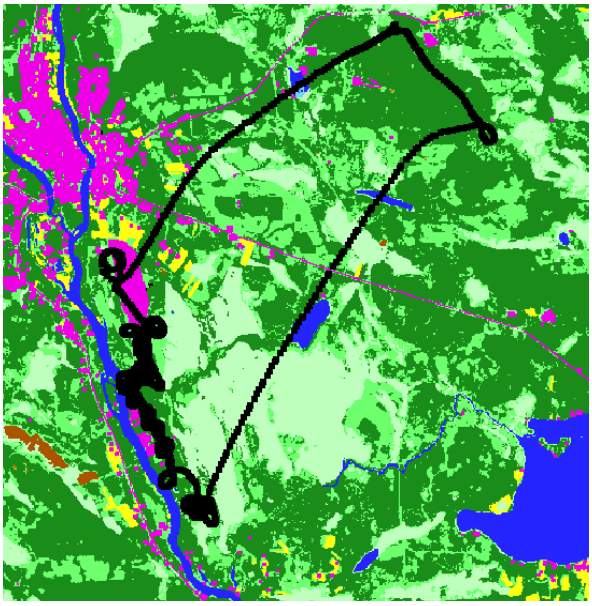

Figure 6. The flight route on March 19 for airborne LAI measurements.

Figure 7. An example of Karhukamera images at about 330 m altitude above sea level on March 30, 2008.

2.2. Instruments

2.2.1. OSIRIS

OSIRIS multi-viewing capability is provided by the sensor displacement along a line of sight. Two different sampling schemes can an option. In the methodology scenario ('Star design'), we focus on a site to get a high density of directional points to sample the Hot spot and specular points. In the validation scenario ('Grid design'), BRDF is sampled over a small region (~10x10 km). Because of low sun elevation, a depointing of the instrument of 20° was necessary.

§ **Telecentric wide-angle lens**
– **Field of view: ±43° x ±51°** – **±57° in the diagonal**
§ **Filters wheel**
– **Interferometric filters** – **Narrow bandwidth** – **440, 490, 670, 763, 765, 865, 910, 940 nm**
§ **Polarizers wheel**
– **Polarizers at -60°, 0° and +60°**
§ **CCD array on focal plane**
– **Size 2/3 "**

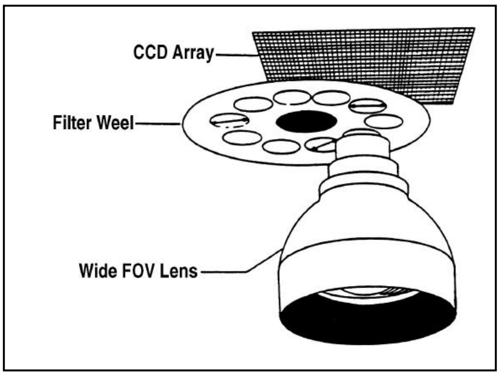

Figure 8. Main characteristics and design of OSIRIS instrument.

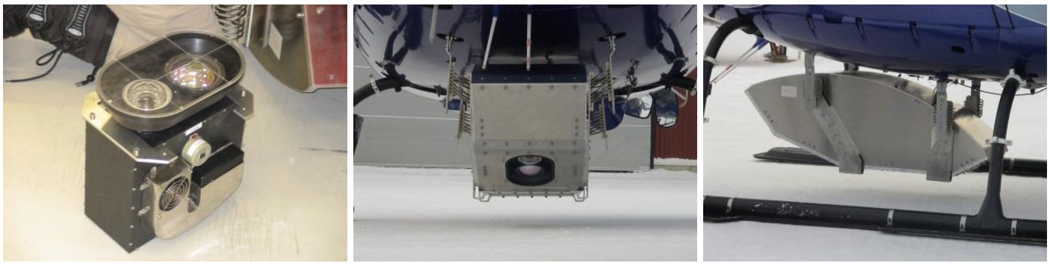

Figure 9. OSIRIS instrument with its platform

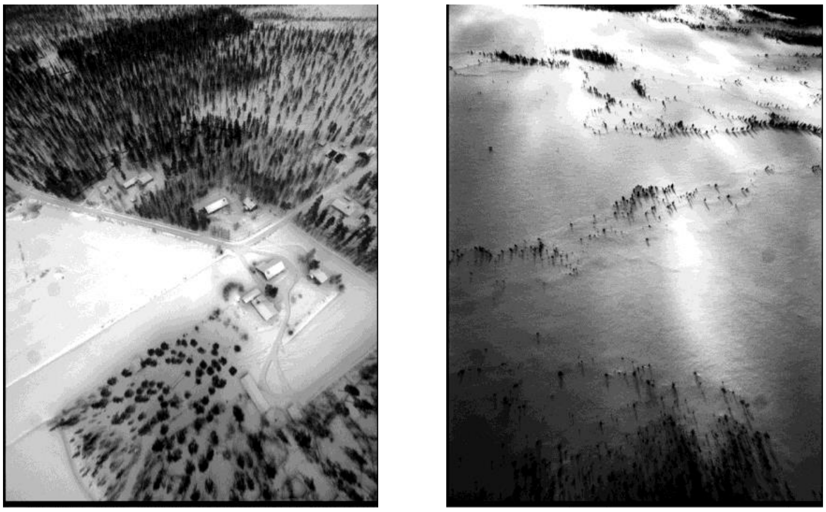

Figure 10. OSIRIS scenes acquired on 3rd April.

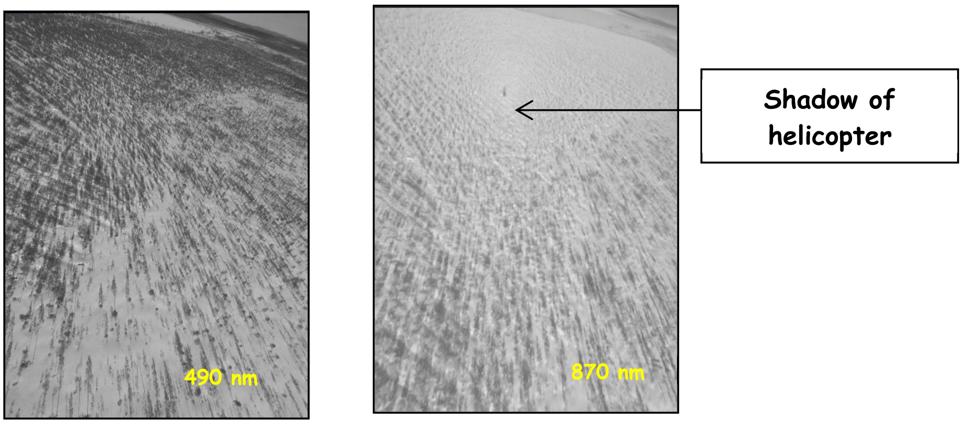

Figure 11. OSIRIS scenes at 490 nm (left) and 870 nm (right) in hot spot configuration.

2.2.2. *Pyranometes, UV sensors, humidity sensor and thermometer (FMI)*

In 2008 two pairs of Kipp & Zonen pyranometers were attached to the helicopter, one pair on either side (Figure 12). The upper pyranometers were measuring the global radiation and the lower the reflected radiation. Beside the pyranometers two pairs of UV sensors (SL501) were attached the same way. The pyranometer data was gathered to a laptop, which was simultaneously recording the GPS coordinates (latitude and longitude) and time. The integration time of the pyranometers and the SL501 sensors was 10 seconds.

Figure 12. The pyranometers and the UV sensors attached on one side of the helicopter. A similar pair is attached to the opposite side. The Pt100 thermometer and the Humicap-sensor are on the left.

In 2009 the pyranometers and UV sensor system was essentially similar to that of 2008, but the GPS height coordinate was recorded as well to help in co-registration of the Karhukamera and the pyranometer data. In 2010 a pressure gauge was added to the system to get more accurate height information than was possible using GPS data only. The instrumental calibration of the pyranometers and UV sensors was checked before the campaigns. The empirical calibration of the pyranometer configuration was carried out flying a wind direction star (the main and intermediate wind directions) close to the meteorological mast at FMI-ARC, where continuous measurements of global and reflected radiation takes place. The altitude was the same as at the mast (about 45 m) so that the helicopter system detects about the same forested area as the mast measurement system. The empirical calibration is needed for clear sky conditions, when the fuselage of the helicopter shades one of the upside looking pyranometers. In white sky conditions the global and reflected radiation on both sides of the helicopter above a homogeneous target is identical (Figure 13). First results are described in Manninen et al., 2012.

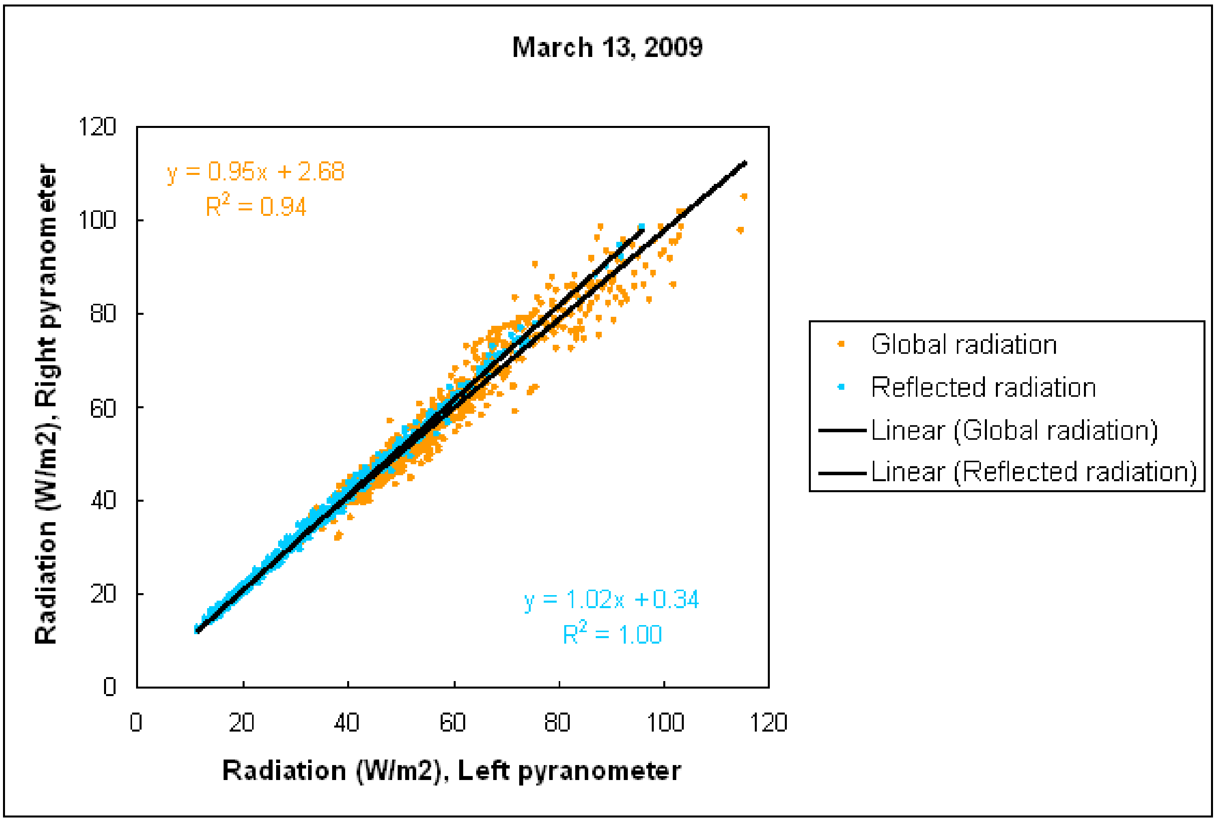

Figure 13. Example of measuring the global and reflected radiation for white sky albedo measurements.

2.2.3. Wide optics camera (FMI)

A normal Canon pocket camera with wide optics (Karhukamera, Figure 14) was attached to the helicopter looking orthogonally downwards (Figure 15). The images were taken every 3 seconds and the GPS coordinates (latitude, longitude and height from sea level) and time were registered for each image frame. The images were stored directly to a laptop used for operating the camera (Manninen et al., 2009, Manninen et al., 2011).

Figure 14. The wide optics camera attached to the helicopter.

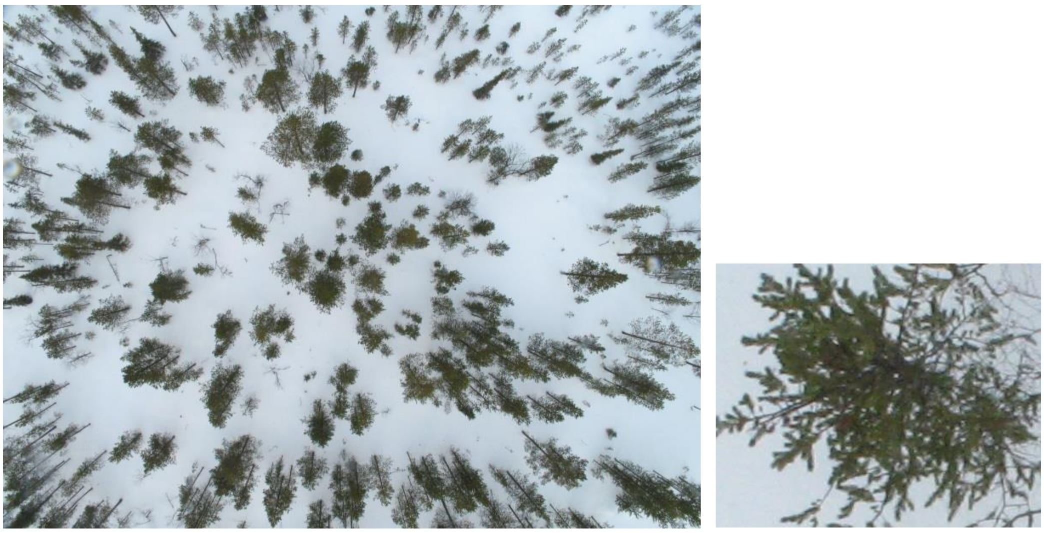

Figure 15. An example of the fish-eye images taken from the helicopter using Karhukamera. A detail is shown on the right.

3. Ground measurements

3.1. Measurement sites

3.1.1. Measurement points in 2008

Various parameters of snow were measured in a wide area in Sodankylä (Figure 16). Altogether 118 measurements were registered (Appendix 1), out of which 23 at the NorSEN-mast in Tähtelä, where the last measurement of each day was made. 30 points outside Tähtelä were measured twice. More than 100 values for the snow depth, density and the snow water equivalent were obtained. In addition crystal size photos, surface roughness photos and photos of the top surface impurities were taken at almost every point. The snow temperature, humidity and density profiles were obtained at 76 points. The broadband albedo of the snow surface was recorded in 44 measurement points including one time series within one day of melting snow at the NorSEN mast. Hemispherical photos were taken in about 10 albedo measurement locations.

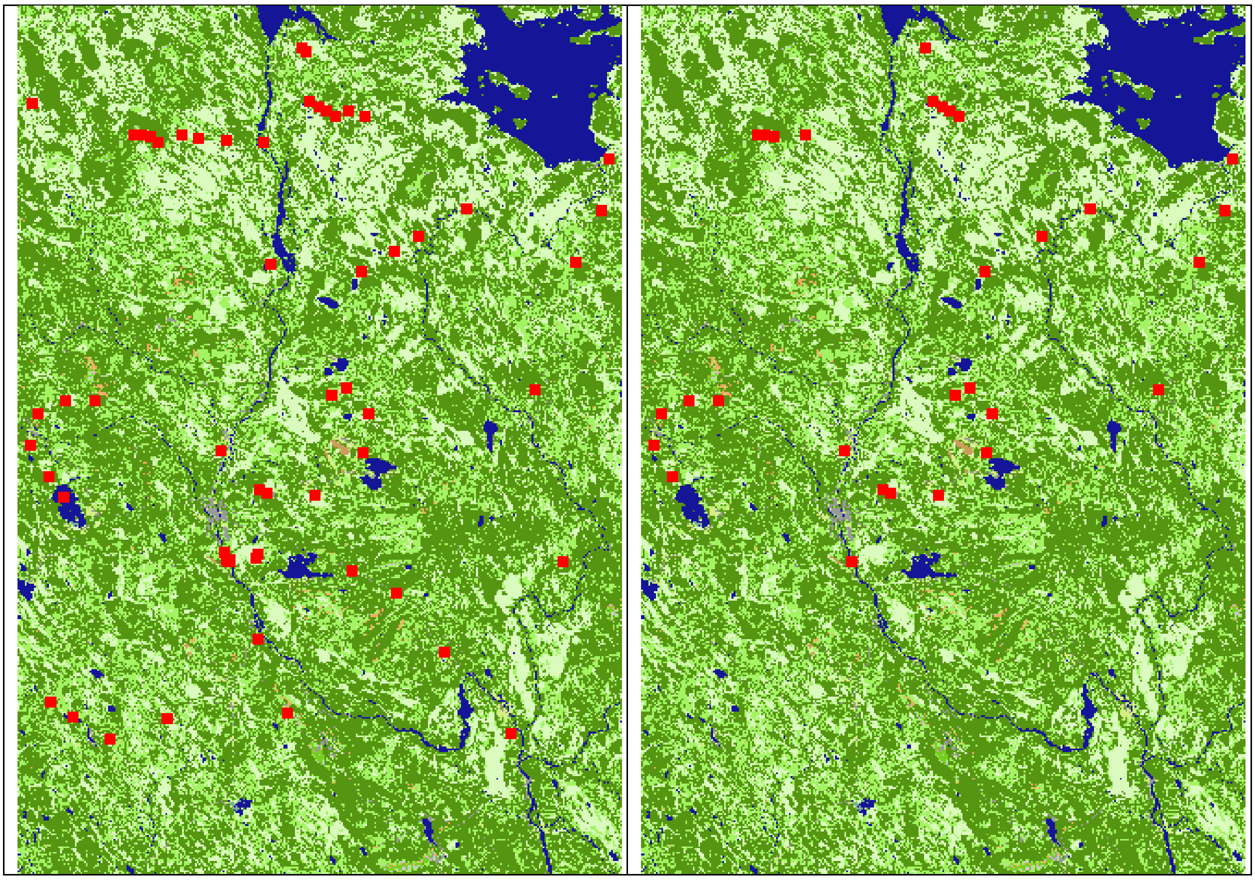

Figure 16. Locations of ground measurements during April 1-9 (left) and April 10-18 (right). The area contains mainly open water (blue), forests (dark green), sparsely forested areas (bright green) and bogs (light green).

3.1.2. Measurement points in 2009

Various parameters of snow were measured in an extensive area in Sodankylä (Figure 17). The area was chosen, because 1) it is close to FMI-ARC, so that time is not spent on transfer, 2) it is relatively flat so that topography is not too problematic for airborne imaging, 3) accessibility of the area by car is good due to the two main roads and some small roads with partial wintertime accessibility and 4) accessibility of the area by snowmobile is good due to the main snowmobile route transect within the area. (Outside the snowmobile routes driving is restricted.) The goal was to cover the area as well as possible carrying out snow measurements each day in different place including both forested and open terrain. Parking of the car is not trivial in the area in winter, therefore the exact location of the measurement points is chosen according to accessibility by car and by foot, which depended greatly on the snow conditions (thickness and hardness of snow cover).

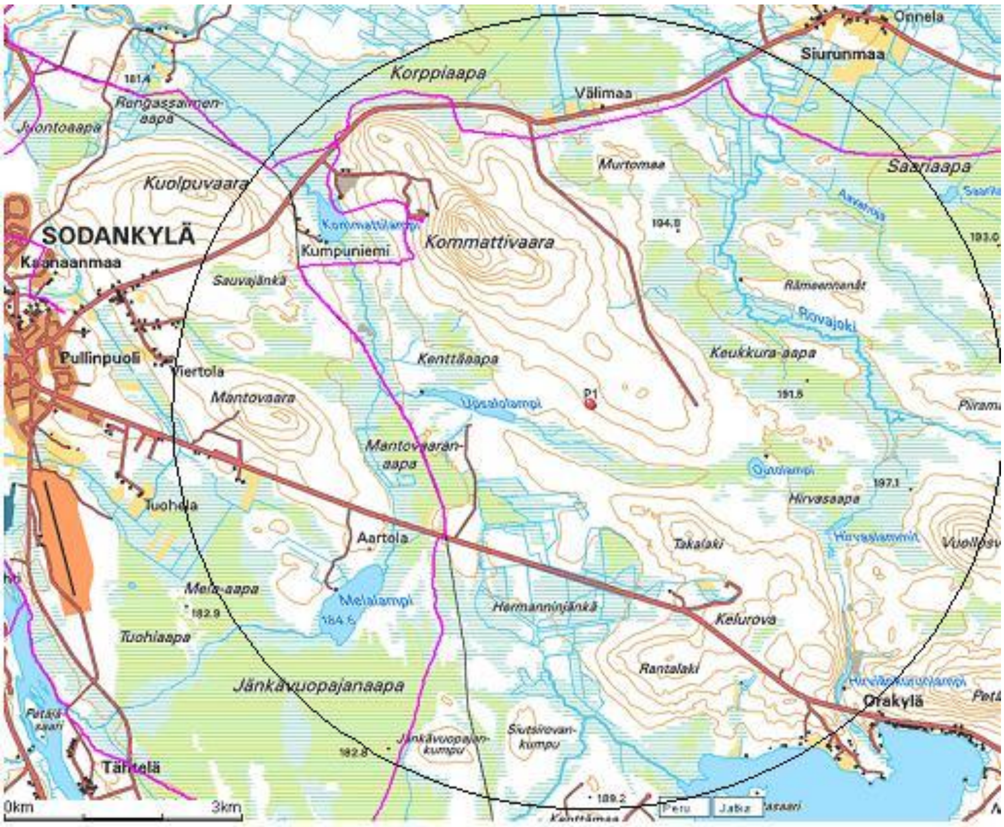

Figure 17. The test area of SNORTEX 2009. The centre point is 67˚ 24.637'N, 26˚ 46.592'E (WGS84). The diameter of the circle is roughly 10 km. The location of FMI-ARC (Tähtelä) is at the bottom left corner and the Sodankylä airport (Heliflite-site) is roughly halfway from Tähtelä to Sodankylä centre. © MML, 2010.

Altogether 118 snow pit measurements in the extensive test area were registered (Appendix 2), out of which 17 at the NorSEN-mast in Tähtelä, where the last measurement of each day was made. 48 points outside Tähtelä were measured twice. Values for snow depth, density and the snow water equivalent were obtained. In addition crystal size photos, surface roughness photos and photos of the top surface impurities were taken at practically every point. The snow temperature, humidity and density profiles were obtained also at all points using a Toikka snow fork. Near infrared photos were taken of the snow profile at 79 points out of which 23 were measured both in March and in April. In addition the snow depth, density and snow water equivalent of the snow pack was measured altogether 70 times in a larger area (a subset of remote points measured in 2008). 26 of the points were measured twice, once in March 17 and once in April 22. Tachymeter and graded plate were used to measure snow surface roughness at the same area as the snowpit locations during expeditions I and II. The albedometer and spectrometer measurements were carried out in the same locations as the snowpit measurements during expedition II. Additional activities (spectrometer calibration, UV measurements, LAI measurements etc.) were sporadically carried out at Tähtelä.

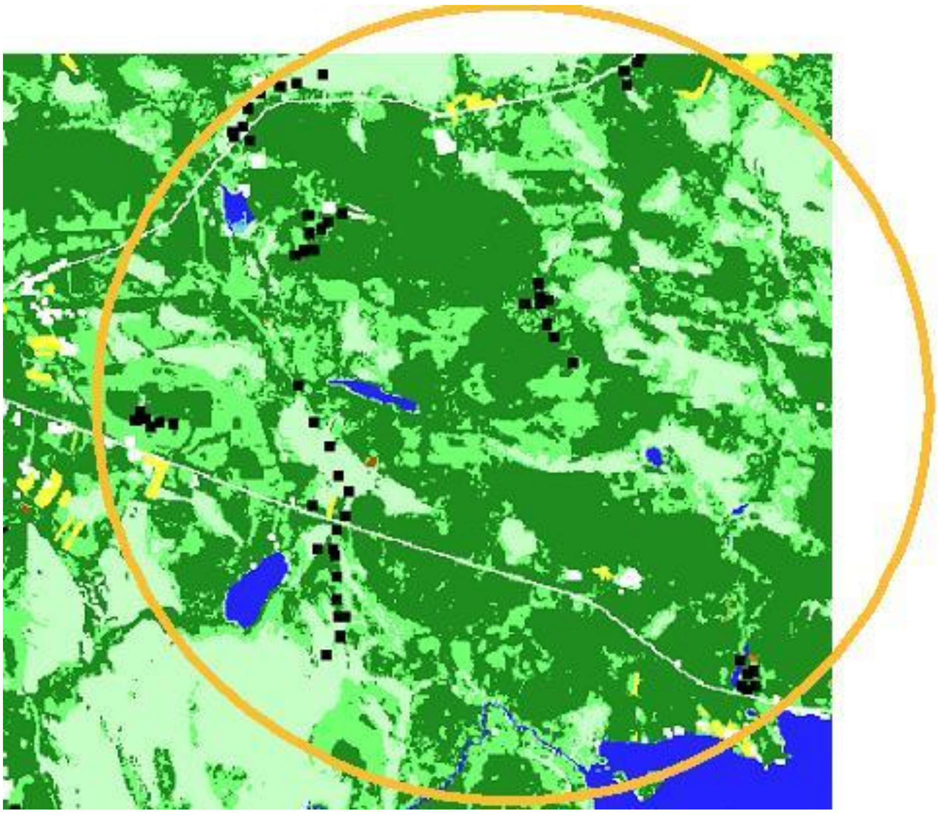

Figure 18. Locations of ground measurements in the extensive area during the field campaigns I and II. The background is the CORINE land cover map. The colour code is: blue – water, yellow – fields, brown – rock, white – urban, dark green – forest, medium green – sparse forest, light green – open bogs.

3.1.3. Measurement points in 2010

In 2010 the snow measurements were carried out in the same extensive area as in 2009 using the same strategy (Figure 19). Altogether 32 snow pit and snow fork measurements in the extensive test area were registered (Appendix 4), out of which 9 at the NorSEN-mast in Tähtelä, where the first measurement of each day was made. 32 values for snow depth, density and the snow water equivalent were obtained. In addition crystal size photos, surface roughness photos and photos of the top surface impurities were taken at practically every point. The snow temperature, humidity and density profiles were obtained also at all points using the snow fork. In addition, one surface specific area (SSA) profile was measured each day using the DUFISSS instrument. A graded plate was used to measure snow surface roughness at the same area as the snowpit locations. The albedometer and spectrometer measurements were carried out in the same locations as the snowpit measurements. UV measurements were carried out at Tähtelä. LAI measurements were carried out in places chosen to cover a wide range of forest types and LAI values. The locations of the measurements (Figure 20, Appendix 11) were marked with black crosses, so that they could be detected using the helicopter.

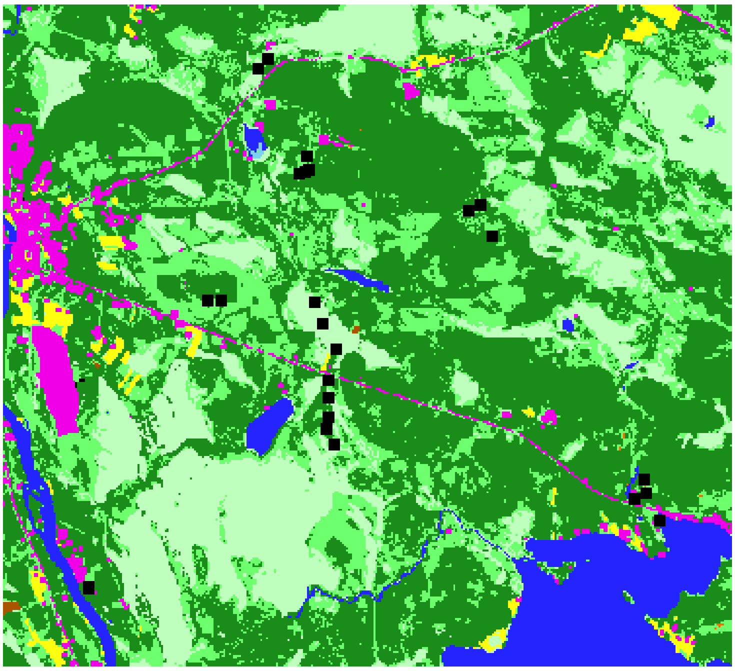

Figure 19. The snow measurements sites in 2010.

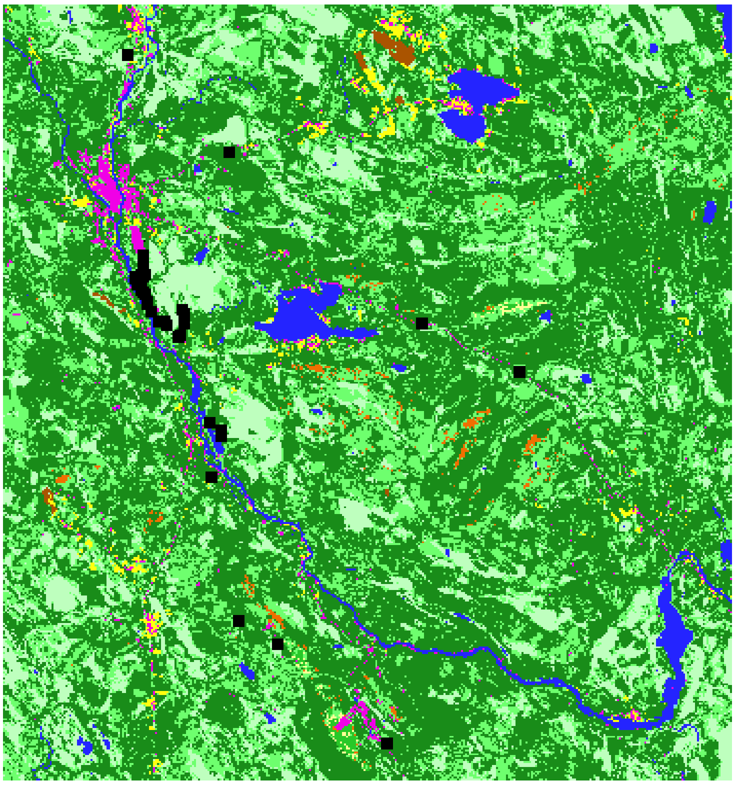

Figure 20. Location of the LAI measurement points in 2010 (marked with black crosses).

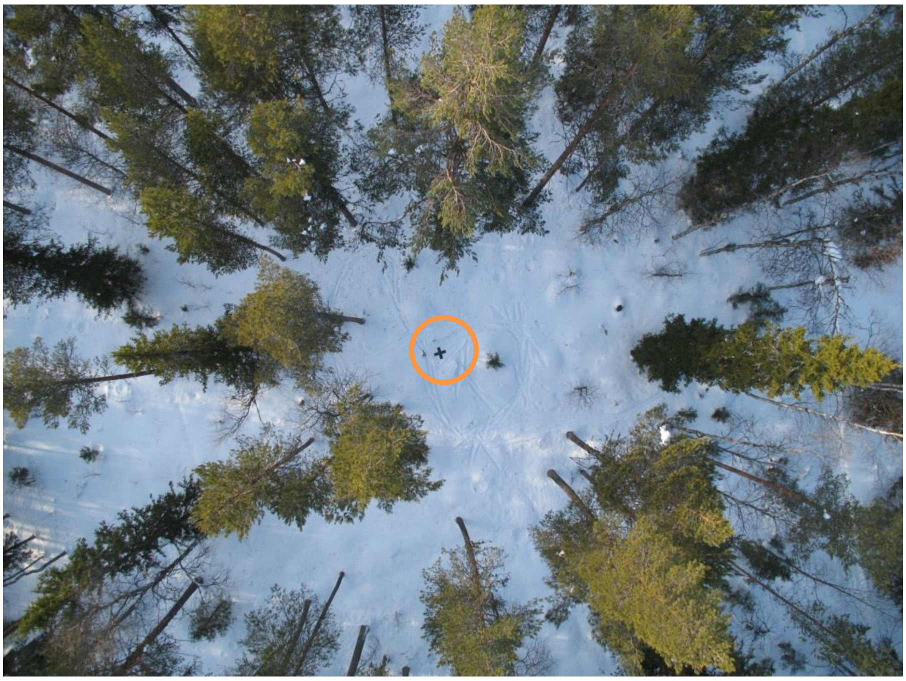

Figure 21. Example of airborne LAI measurement images showing the black cross of ground based LAI measurements.

3.2. Measurement parameters and techniques

3.2.1. Albedo measurements (FMI)

A portable Kipp & Zonen albedometer CM 14 was used to measure the snow surface albedo both in the open areas an at the forest floors. Both the irradiance and the reflected radiation were registered. The location of the albedometer was recorded with a GPS receiver within the data logger and checked with a portable GPS. Both open and forested areas were measured (Figure 22). First the albedometer was leveled, then the GPS system and pyranometers were turned on. for the integration time for a sample was 30 s. In 2008 the measurement time was typically 25 minutes at one point (Figure 23). The main strategy in 2009 was to measure the diurnal variation of the albedo, thus the instrument was on at one location per day while the spectrometer was used both for spatial and temporal sampling (Figure 25). This strategy was also followed during the 2010 campaign. The dates and times of the measurements are given in Appendix 1 for the 2008 campaign, Appendix 6 for the 2009 campaign, and Appendix 7 for the 2010 campaign.

The effect of the measurement set-up (tripod and snow surface disturbance by operator) was tested during the 2008 campaign. The albedometer was fitted at the end of a long boom and swung over a pristine snow pack to measure its albedo. After this, the albedometer was fitted on its tripod and installed on the same spot that the boom set-up observed. The combined tripod and surface disturbance effect was found to be -0.01 in the observed albedo. The test was made in clear-sky conditions when direct-beam solar radiation dominates. The effect is presumed to be smaller during cloudy (diffuse light) conditions.

Figure 22. The albedometer measuring the albedo of the forest floor.

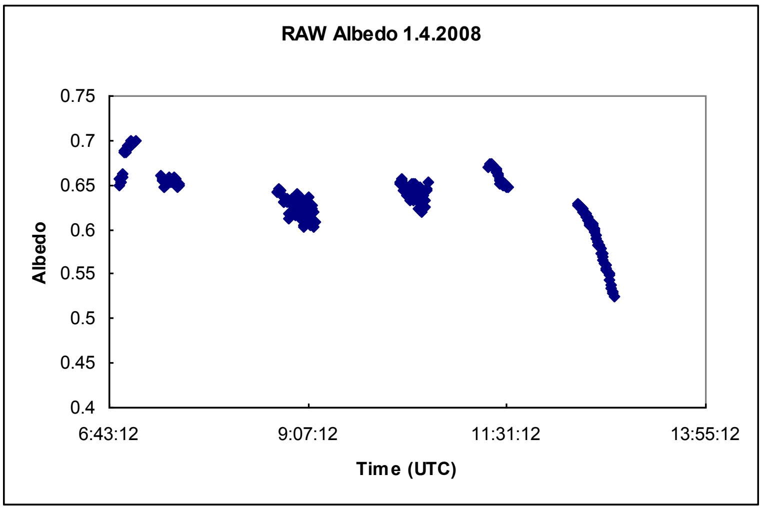

Figure 23. An example of albedo measurements in various locations during one day

3.2.2. Spectrometer measurements (FMI)

A portable spectrometer Analytical Spectral Devices (ASD) Field Spec Pro JR was used in 2008 to measure the global radiation and the reflected radiation of the snow surface at various sites. The dates and times of the measurements are given in the Appendix 1. Altogether 12 sites were measured, out of which 3 at the NorSEN-mast (67˚21.729 N, 26˚38.069 E) in Tähtelä (FMI-ARC). Snow measurements were made at the same site in all cases except one. Both irradiance and the surface reflectance were measured in the range 350 nm – 2500 nm.

At each measurement site the irradiance was measured first (Figure 24). The Remote Cosine Receptor (RCR)-measurement head was leveled before the measurements at the target point without shadows. After the irradiance measurement, pistol grip was leveled to nadir about 30 cm from the snow surface. Radiance and reflectance measurements were done without any foreoptics. The spectral response was optimized using spectralon plate before each measurement. After optimization radiances were measured from the spectralon as well as from the target points at the snow surface. The diverse targets included snow at the sunlight and snow at the shadows of trunks and brunches of different wood species. One saved spectrum was averaged from 10 spectrum measured with integration time of 17 ms. One measurement site was measured in about 20 minutes.

Figure 24. Spectrometer measurements of irradiance (left) and reflectance (right).

In 2009 and 2010, a new portable spectrometer Analytical Spectral Devices (ASD) Field Spec 3 was used to measure the global radiation and the reflected radiation of the snow surface at various sites. The dates and times of the measurements are given in Appendix 6 for 2009 measurements and Appendix 7 for 2010 measurements. The measurements were mostly done using 8-degree foreoptics to minimize small-scale surface roughness effects on observed reflected radiation. Some measurements were made using the 1-degree foreoptic mainly as sensitivity tests.

Most of the spectral measurements in 2009 and 2010 were made during clear-sky conditions. Some few data were collected during diffuse light (fully cloudy) conditions. Measurements were found to be unreliable during broken cloud or snowing conditions, therefore those data were eliminated.

All ASD data went through a manual QA procedure in which the measured data were visually checked for any signs of contamination from a poor calibration or measurement set-up.

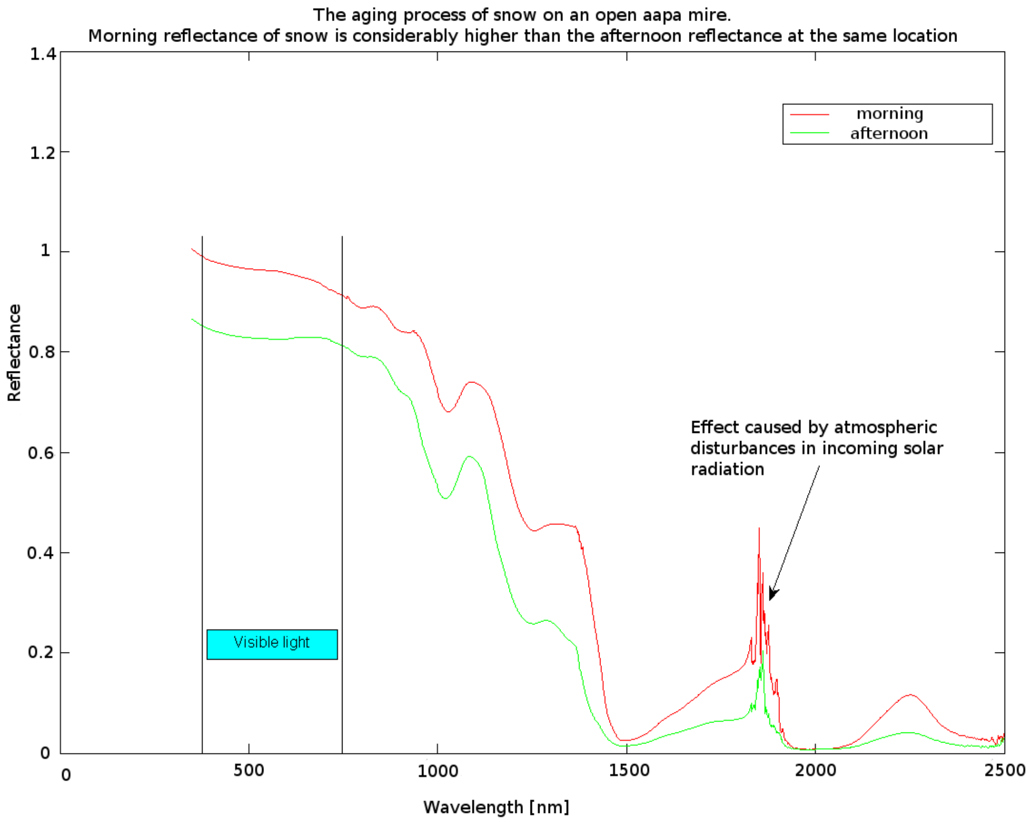

Figure 25. Example diurnal variation of the snow spectral reflectance.

3.2.3. Continuous snow surface temperature measurements (FMI)

A high precision Fluke Pt100 thermometer was used for continuous measurement of the snow surface during the II expedition. Due to an unfortunate technical failure of the instrument data was obtained only for the period April 18 … April 20 (Figure 26). The Fluke thermometer was also used for calibration of the light weight thermometers used for the temperature profile measurement of the snow pits. An example calibration is shown in Figure 27. The calibration was carried out in isopropanol bath, which was first cooled down in a freezer and then allowed to warm up in room temperature.

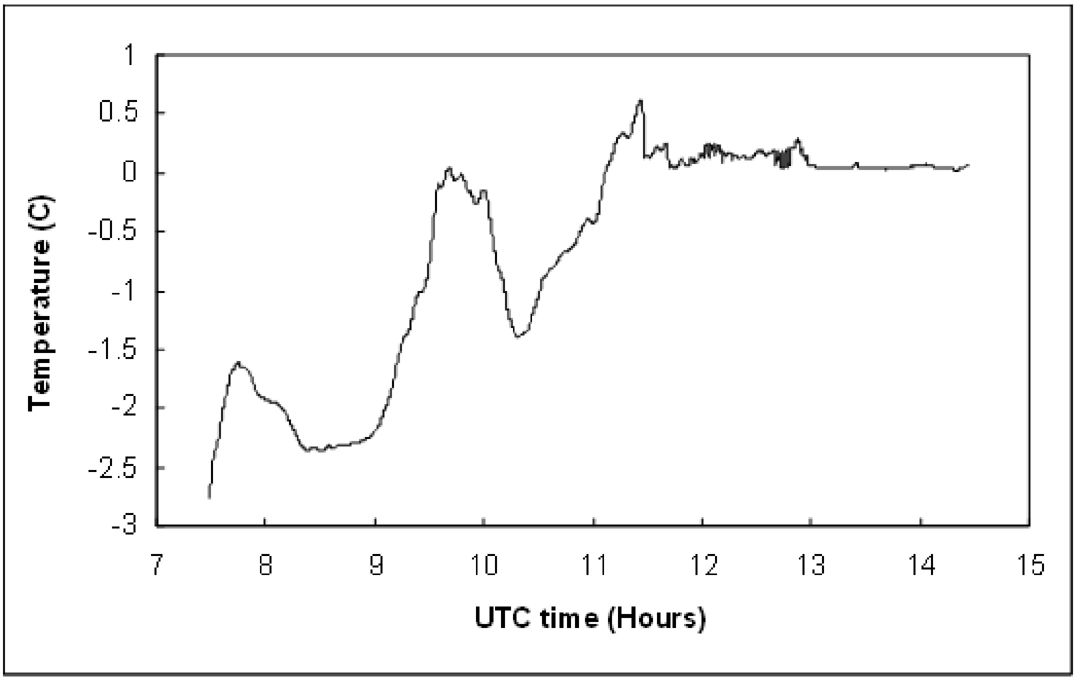

Figure 26. An example of the diurnal temperature variation of snow surface in April 19.

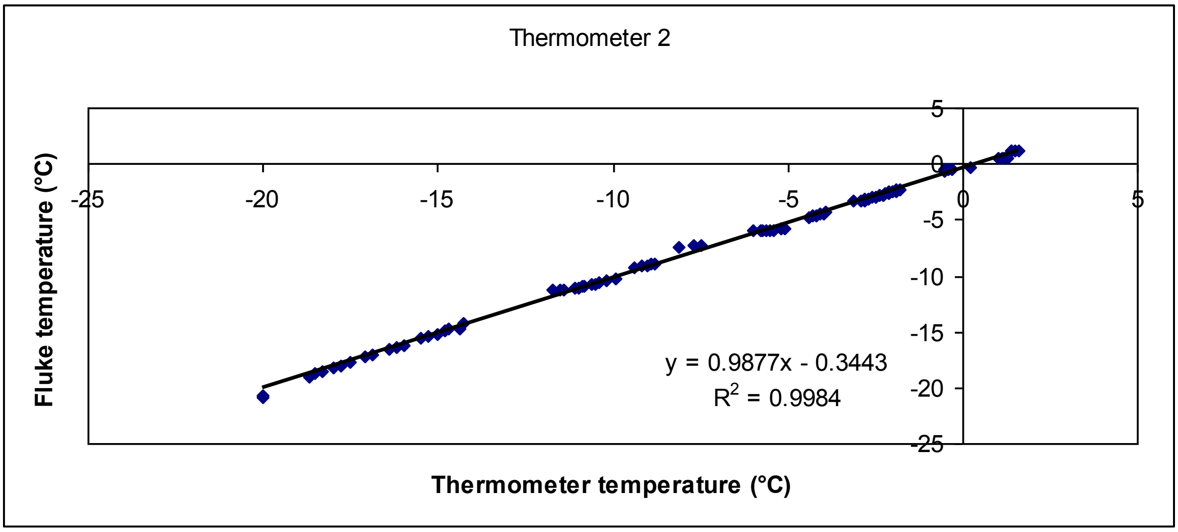

Figure 27. Calibration of a light weight thermometer using the high precision thermometer of Fluke.

3.2.4. Snow pit measurements (FMI, LGGE)

Measurements of snow depth, snow density, snow water equivalent, snow humidity profile, snow temperature profile, snow grain size profile, snow surface roughness and snow surface impurity content were carried out at snow pits located in various open and forested test sites (Appendix 1). Altogether 118 measurements were registered, out of which 23 at the NorSEN-mast (67˚21.729 N, 26˚38.069 E) in Tähtelä (FMI-ARC), where the last measurement of each day was made. 30 points outside Tähtelä were measured twice. More than 100 values for the snow depth, density and the snow water equivalent were obtained. In addition crystal size photos, surface roughness photos and photos of the top surface impurities were taken at almost every point. The snow temperature, humidity and density profiles were obtained at 76 points using a 10 cm interval. The layer structure of the snow pack was analysed and grain size was determined for each layer (also grain size photos were taken). The surface roughness and grain size was determined separately as well as the amount of impurities on the surface.

The depth was measured using an ordinary stick with 1 cm resolution (Figure 28). The snow density was determined using a cylinder and weight. The SWE was calculated from the depth and density. A digital thermometer with a 20 cm long metal stick was used for the temperature measurements. The snow fork model LK based on measurement of the electromagnetic field of the snow pack was used to derive the snow humidity and density profiles.

Figure 28. Snow depth, temperature profile and snow water equivalent measurement.

The snow layers were determined visually and the thickness of each layer was measured with a stick with 1-cm accuracy. Grain sizes were measured using the procedures suggested by Colbeck et al, 1992. A small sample of snow was taken on a snow crystal screen with a 1-mm grid. The maximum diameter of smallest, largest and average-sized grains was estimated visually by comparing the snow sample to the grid. Resolution of 0.25 mm was used. A picture was taken from each snow sample for possible later reanalysis (Figure 29).

Example results are shown in Figure 31.

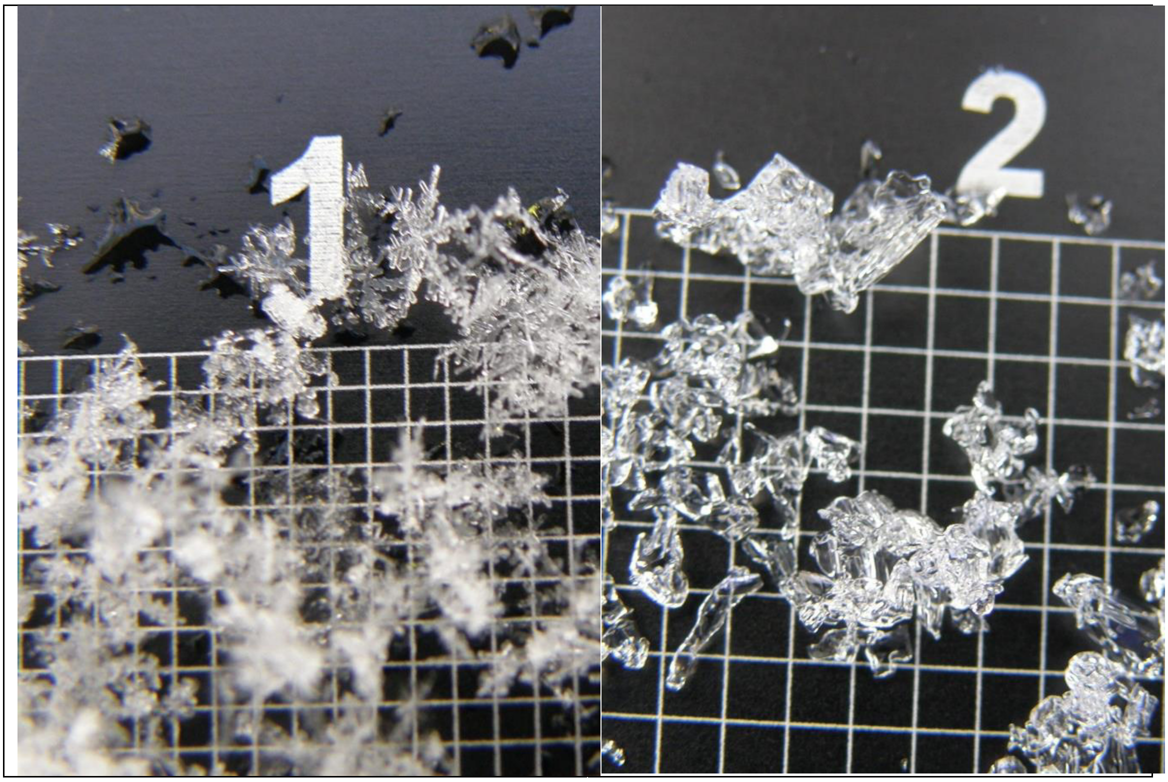

Figure 29. Examples of new (left) and old (right) snow crystals. The grid spacing is 1 mm and 2 mm.

A frame of about 40 cm x 40 cm was used to mark a standard size area in the snow surface impurity photos. The snow surface roughness was recorded taking photos of snow profiles with a graded black plate as the background. Photos of the snow pit surroundings and the snow pit were also taken. In addition, a photo of the sky was taken to store information of the cloud cover conditions during the measurements.

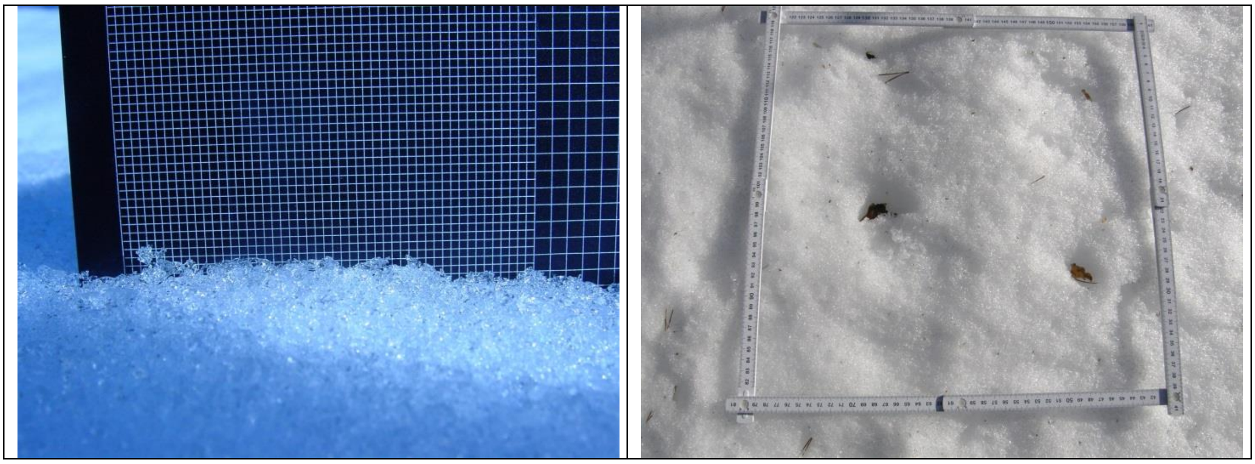

Figure 30. Snow surface roughness profile (left) and impurities on snow surface (right).

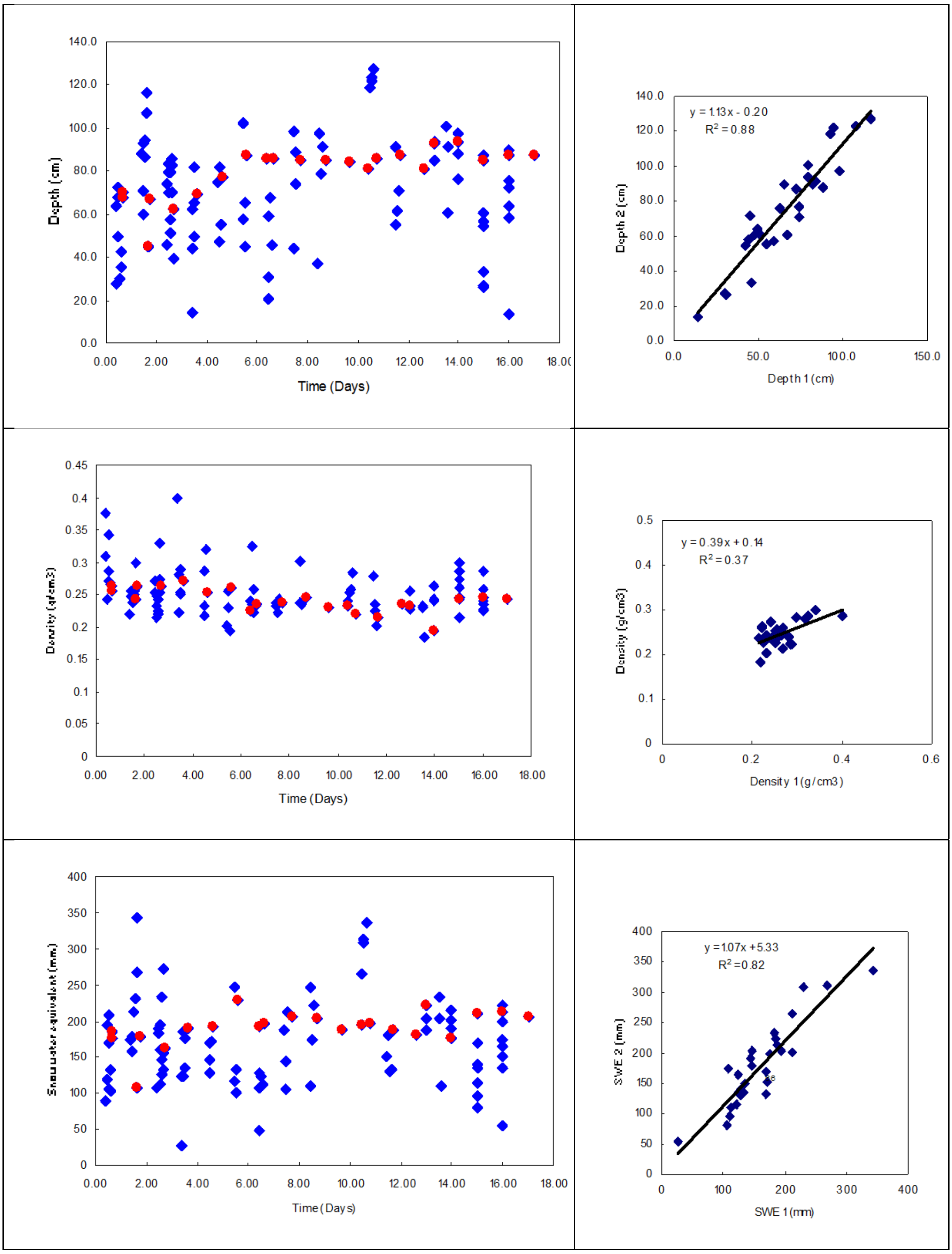

Figure 31. Left: The variation of the snow depth (top), density (middle) and snow water equivalent (bottom) at various test sites. The red symbols correspond to measurements at the extensive test site at the NorSEN mast. Right: The change of the snow depth (top), density (middle) and SWE (bottom) between the successive measurements.

The snowpit measurements of 2009 are listed in Appendix 2. The seasonal variation of the snow density and volumetric moisture content are manifested in the time series measured at the NorSEN mast (Figure 32 and Figure 33). The measured snow temperature values during the two first field expeditions are shown in Figure 34. Examples of the snow depth, density and snow water equivalent (SWE) results are shown in Figure 35.

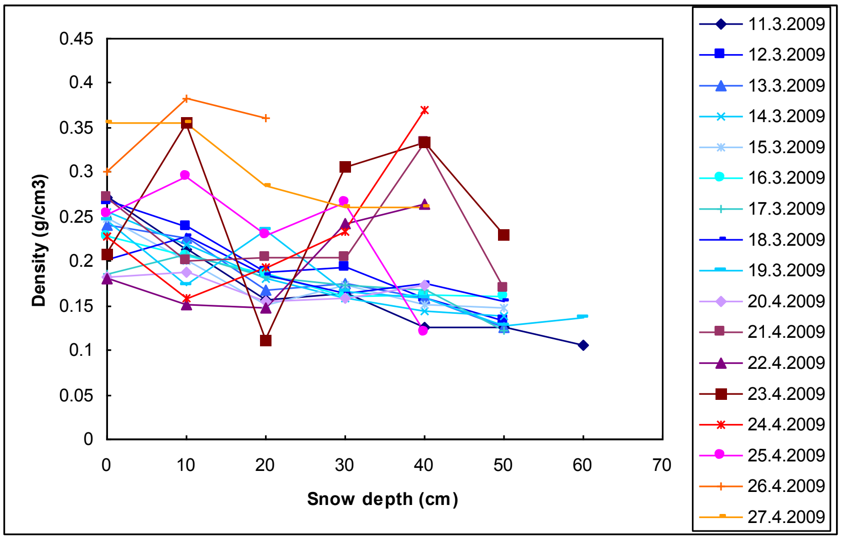

Figure 32. The seasonal variation of the snow density as a function of the snow depth measured at the NorSEN mast.

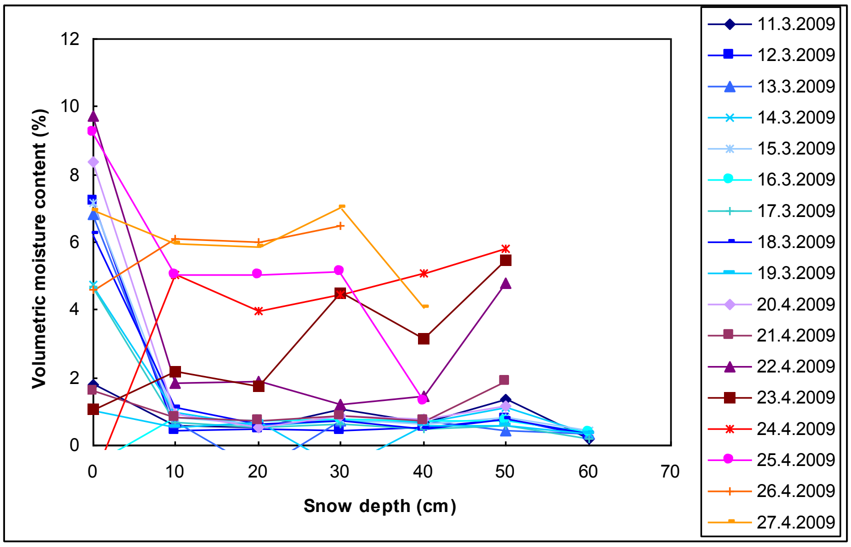

Figure 33. The seasonal variation of the volumetric moisture content as a function of the snow depth measured at the NorSEN mast.

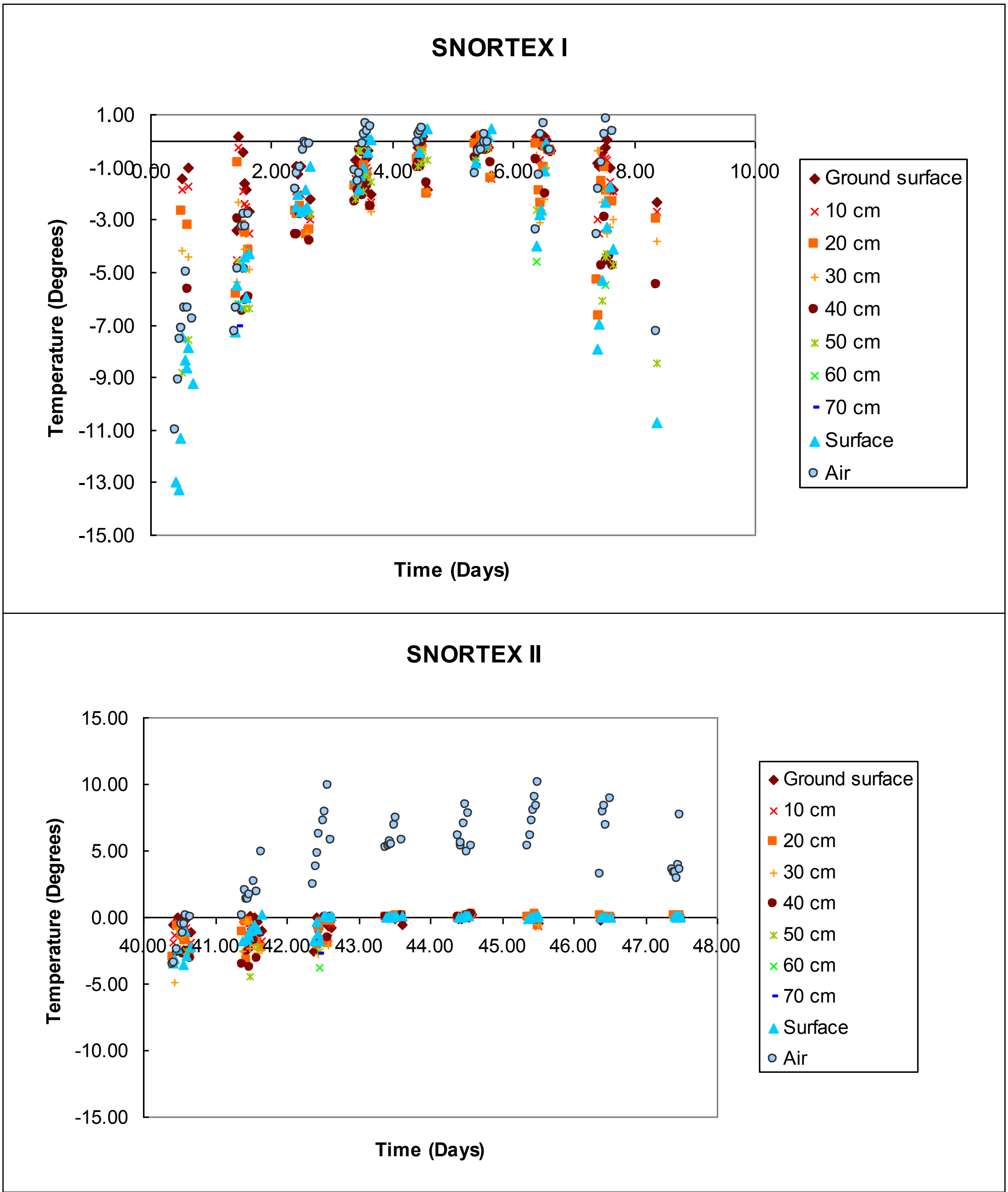

Figure 34. The air and snow temperature at various levels in the snow pack during expeditions I and II. The height is 0 cm at the ground level and increases to the surface of the snow.

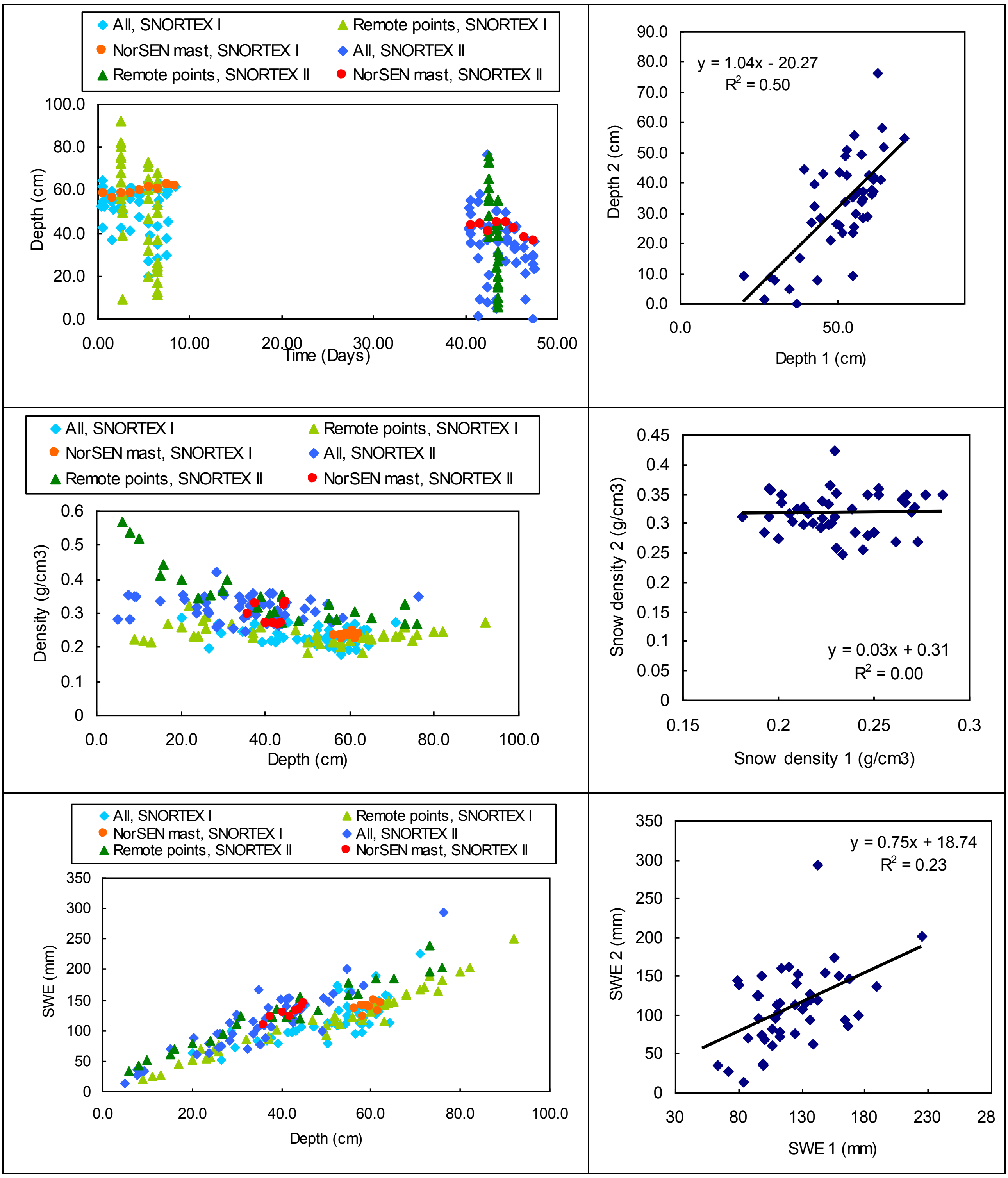

Figure 35. Left: The variation of the snow depth (top), density (middle) and snow water equivalent (bottom) at various test sites. The orange (March) and red (April) symbols correspond to measurements at the extensive test site at the NorSEN mast. Right: The change of the snow depth (top), density (middle) and SWE (bottom) between the successive measurements at the extensive area.

The snowpit measurements in 2010 were carried out in the same sites as in 2009 (**Appendix 4**), but only once during the campaign. Additional snow depth, density and SWE values were measured at the same remote locations as before in March 11-12 and April 8-9. Examples are of snow measurement results are shown in Figure 36.

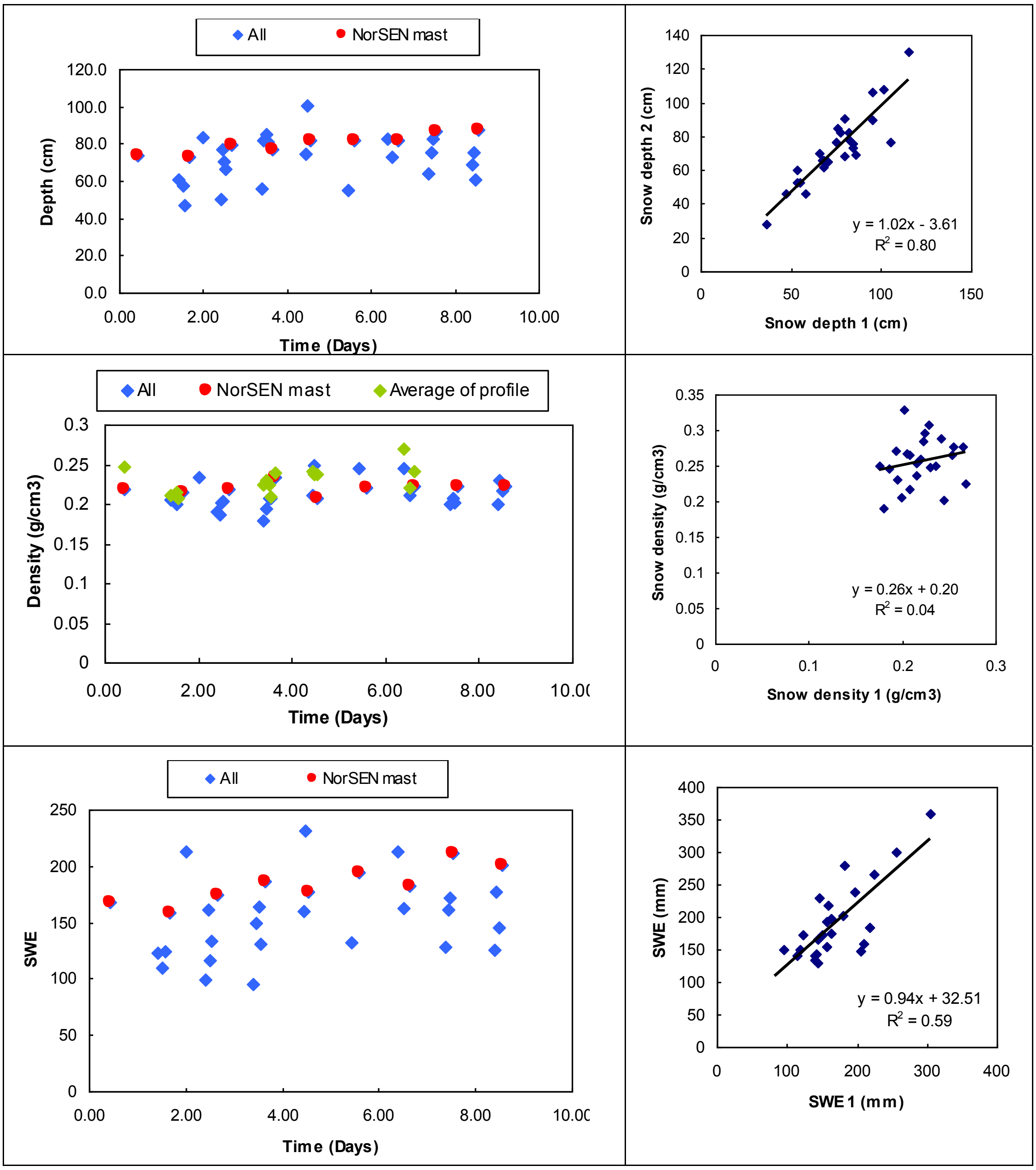

Figure 36. Left: The variation of the snow depth (top), density (middle) and snow water equivalent (bottom) at various test sites in 2010. The red symbols correspond to measurements at the test site at the NorSEN mast. Right: The change of the snow depth (top), density (middle) and SWE (bottom) between the successive measurements of the remote points.

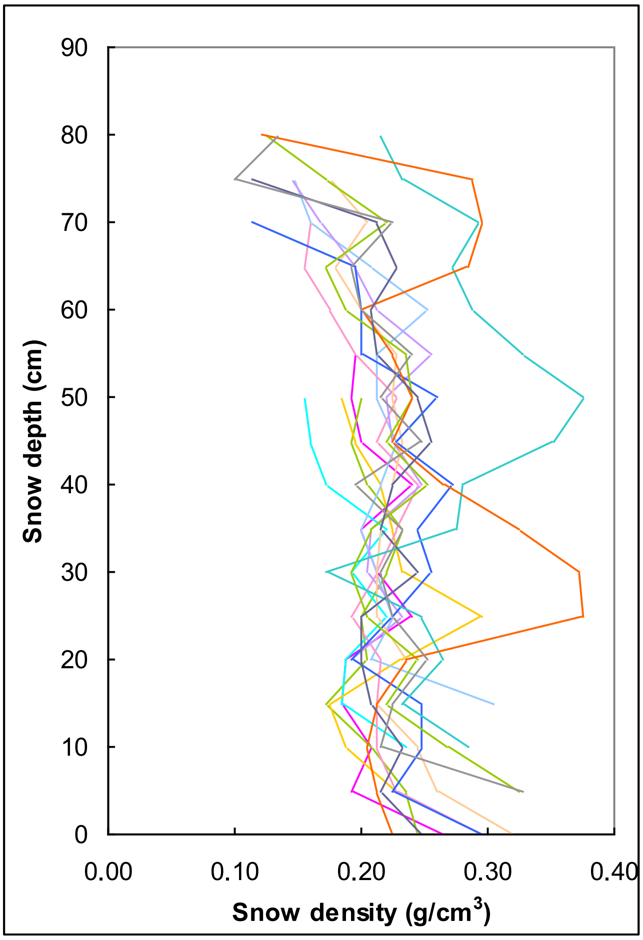

Figure 37. Snow density profiles measured in 2010 using the Toikka snow fork.

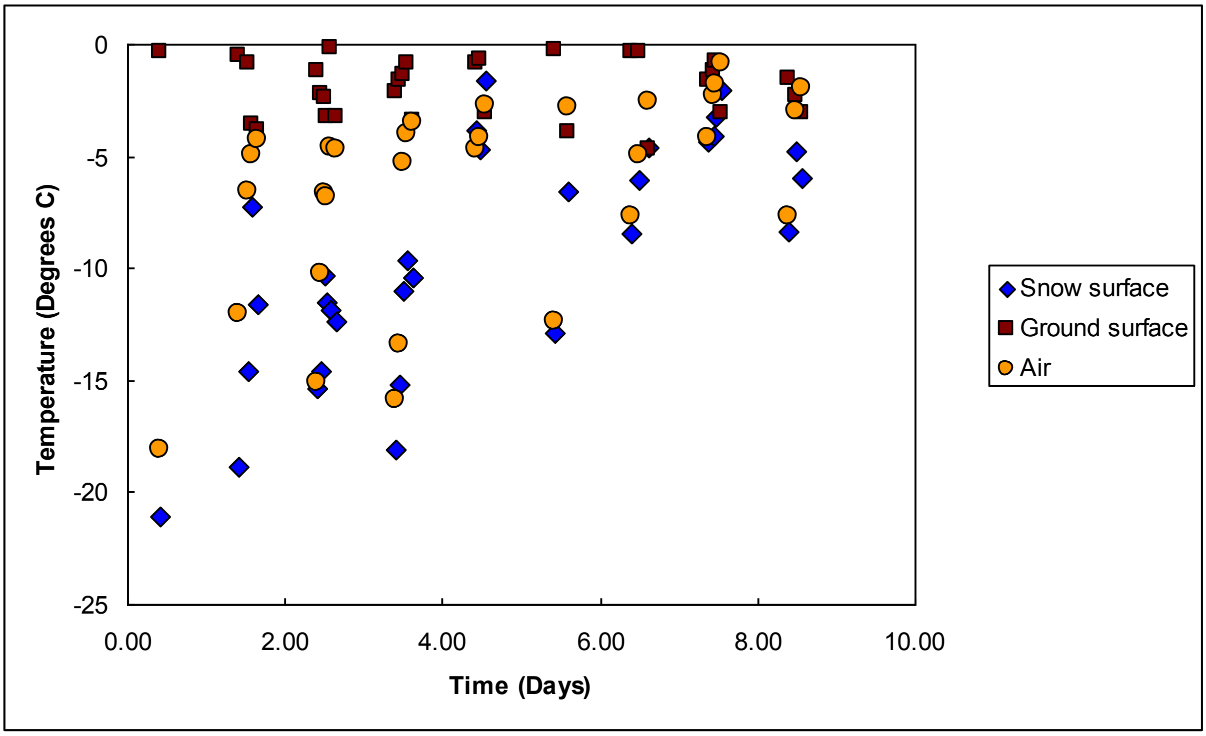

Figure 38. Air, snow and ground temperatures measured in 2010.

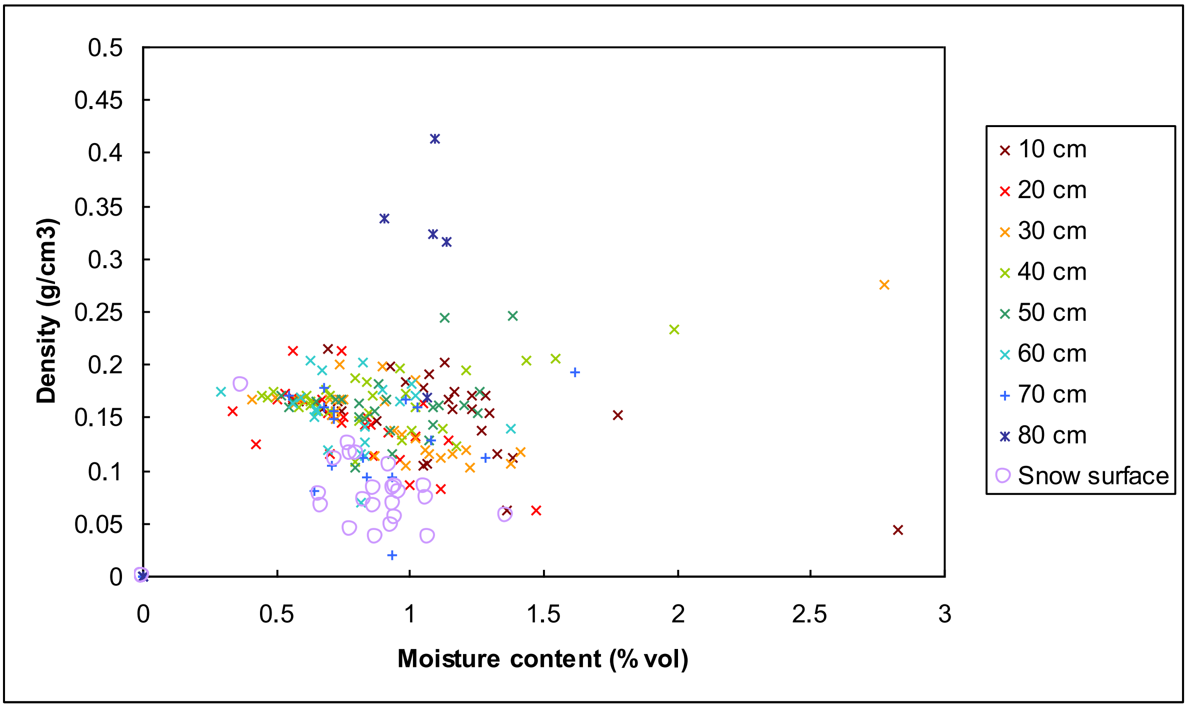

Figure 39. Snow density vs. moisture content in various layers of the snow pack in 2010 based on snowfork measurements.

In 2010 the density profiles of snow pits were recorded using a tube of known size and a balance. An example is shown in Figure 40.

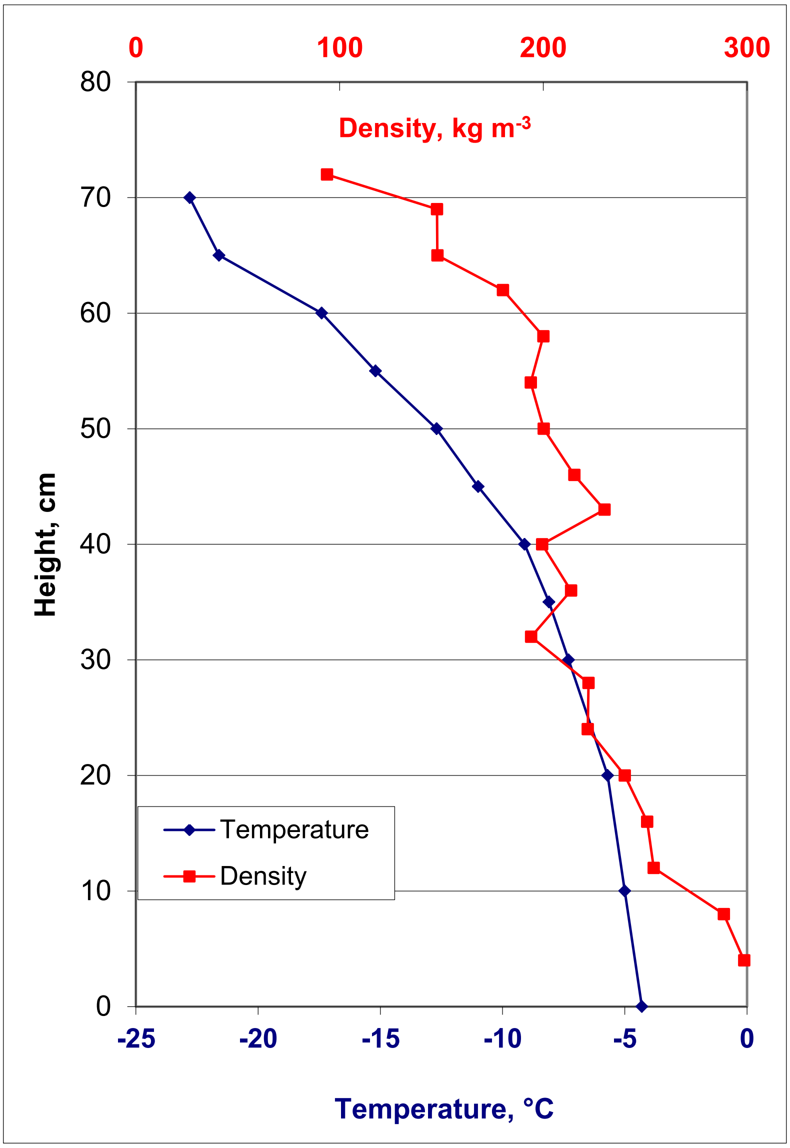

Figure 40. An example of temperature and density profiles of snow.

3.2.5. Near infrared photos

Snow reflectance in the near-infrared (NIR) wavelengths is highly affected by the specific surface area of the snow grains. The use of near-infrared photography has been demonstrated to be useful tool to map SSA (eg. Matzl and Schneebeli, 2006). This method has also been proven to reveal layering of the snowpack. In SNORTEX this method were tested at the snow pits in 2009, but due to this being the first time test, and the nature of Finnish snow (the snow wall couldn't be cut to smooth enough way), the data are not good enough for SSA analysis. Snow layering can still be seen, Fig. 40. The used setup used an entry-level digital SLR camera with a 830 nm IR-pass filter attached to the lens. The camera was mounted on a tripod, and spectralon calibration targets with reflectance of 99 % were fixed to the snow for absolute calibration.

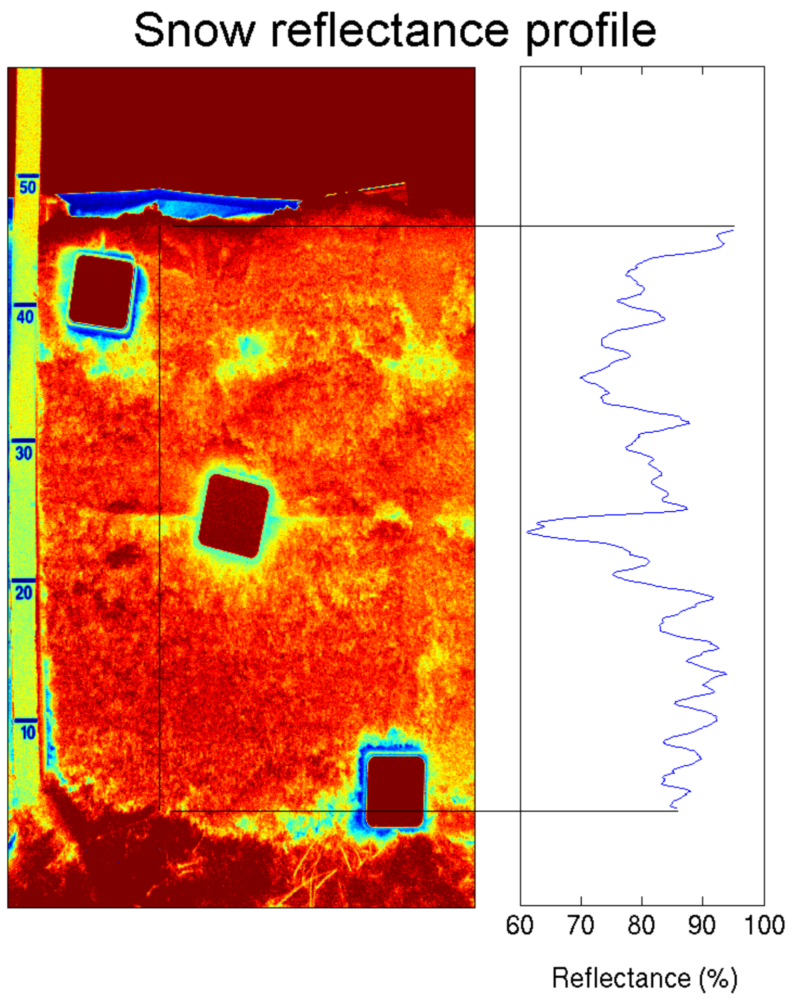

Figure 41. An example of the NIR reflectance profile.

3.2.6. Surface roughness measurements

In 2009 surface roughness measurements were carried out both at 1 m and 50 …100 m scale in the same area as the snowpit measurements (Karjalainen, 2010). The long profiles were obtained using a tachymeter. Complete 3D coordinates were produced for each point, typically 100 points per profile (Figure 42). At the NorSEN mast the same profile was measured every day thus producing a good example of seasonal variation in large scale roughness (Figure 43). Two perpendicular profiles were measured at one point, and a few additional transects per site in March. Roughly the same locations were re-measured in April (Figure 44). Altogether 75 tachymeter profiles and 459 plate profiles were acquired.

Figure 42. Tachymeter measurements of snow surface roughness.

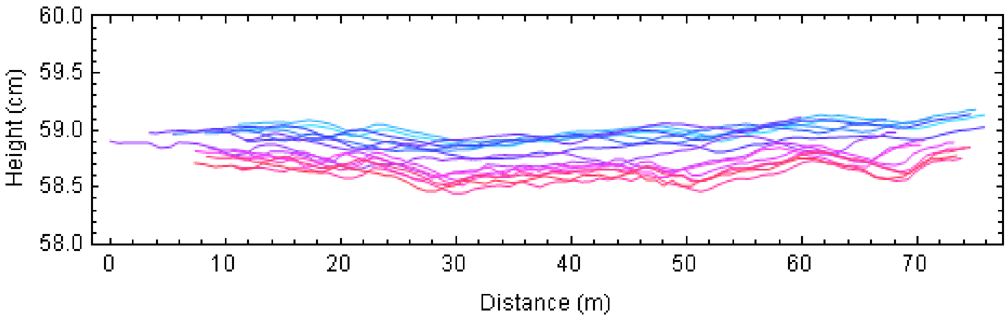

Figure 43. The surface roughness variation at the NorSEN mast during the campaign. (The absolute height level is not calibrated.)

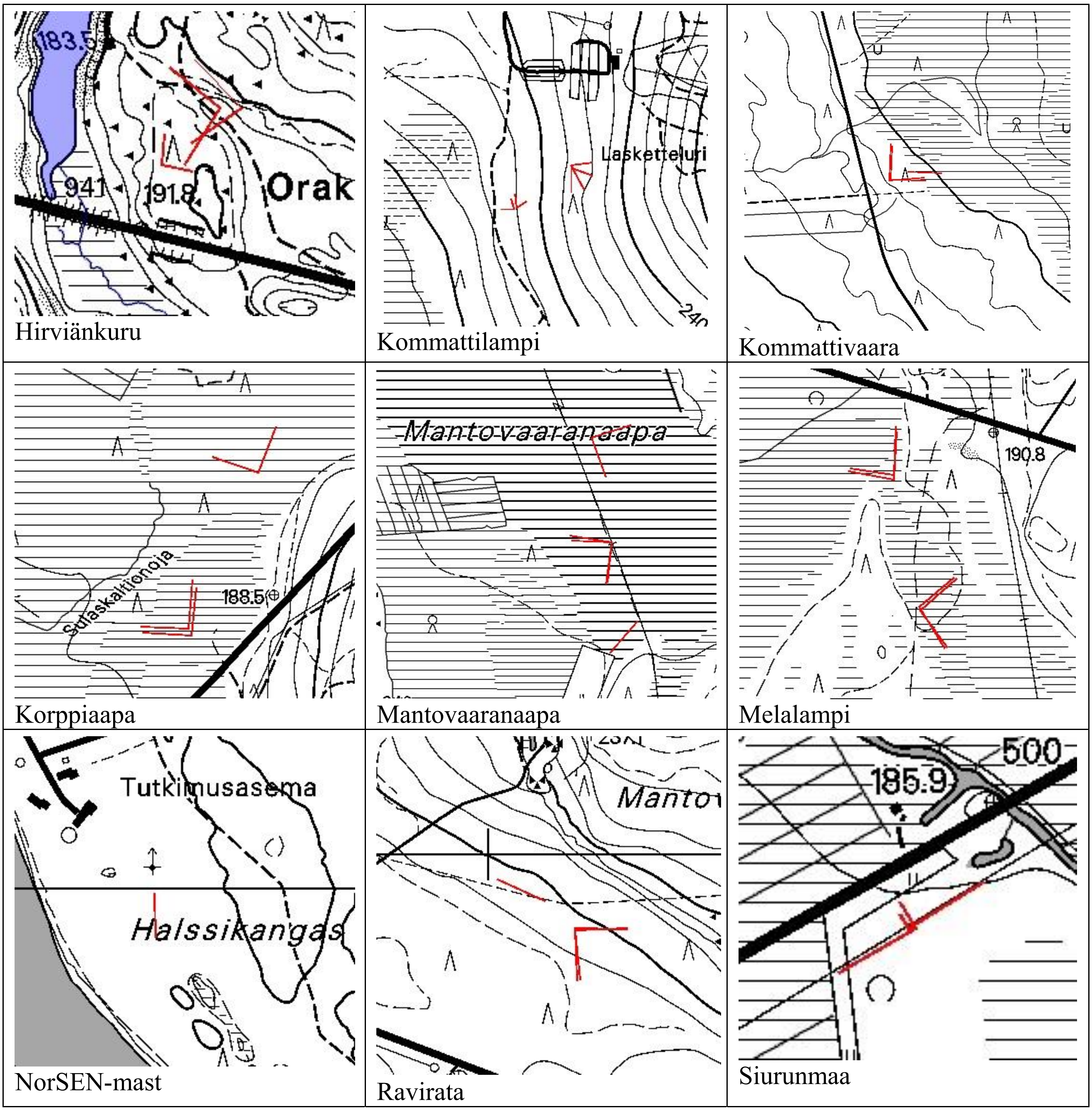

Figure 44. The location of the surface roughness profiles measured using tachymeter. © MML, 2010.

The roughness on 1 m scale was measured by taking photos of a graded plate (Manninen et al., 2012) placed perpendicularly in the snow pack (Figure 45). One profile at each tachymeter measurement point was taken at the remote sites, and one to three at the NorSEN mast every day. The profile was calculated from the photos automatically using image processing technique. The scale at the edge of the plate was detected automatically using pattern recognition methods. The control points were used both for the removal of the barrel distortion of the camera optics and transformation of the pixel coordinates to millimeters (Figure 46). More than 1200 individual profiles were measured.

In 2010 only 1 m roughness scale was measured using the same technique as in the previous year (Manninen et al., 2012). Together about 114 individual profiles were measured at NorSEN mast, every snow pit and along the mobile laser scanning route. The measurements at NorSEN mast were repeated every day in order to get the temporal variability of the roughness. During the days that mobile laser scanning was made roughness profiles were measured along the route right after the scanning. The locations include different environmental settings. These profiles will be used as reference with the mobile laser scanning data. At some measuring points three profiles with different azimuthal orientations were measured. The profiles were at 0°, 45° and 90° angles.

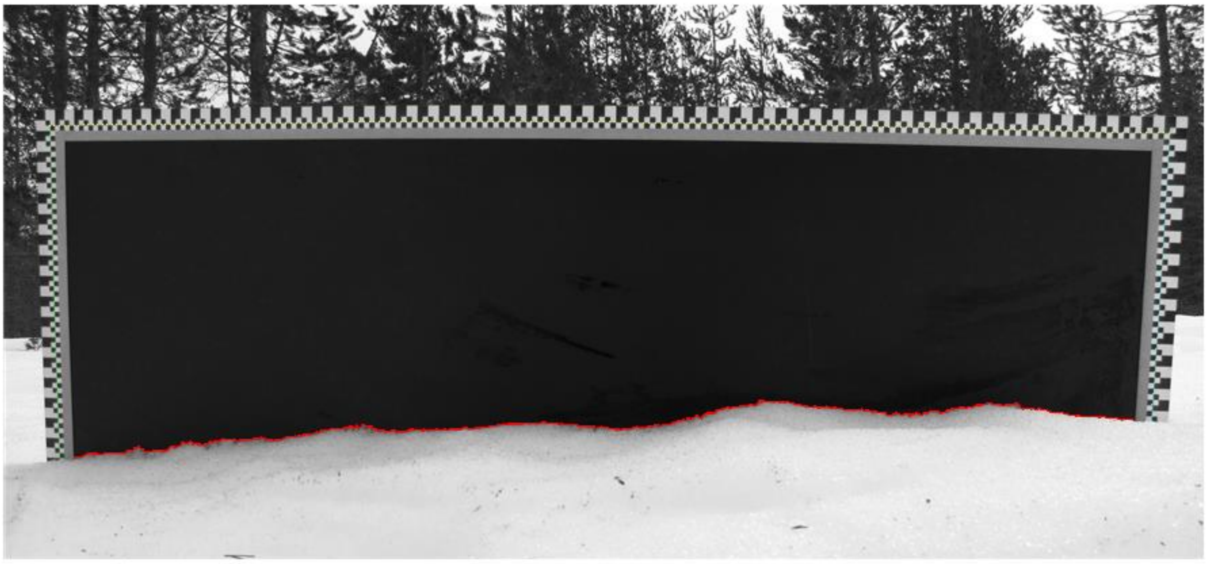

Figure 45. An example of the snow surface roughness profile. The width of the black background is 1 m.

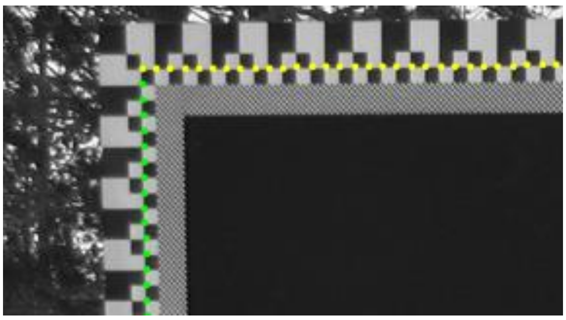

Figure 46. Automatically registered control points used for profile rectification and calibration.

3.2.7. Fractional snow cover estimation

The ground measurements of the fractional snow cover were carried out using a rope marked with 1m intervals and a GPS instrument. The start and end point coordinates of two 100 m long perpendicular lines were registered using the GPS instrument. The snow cover was checked (snow / no snow) at each mark of the rope spread between the end points of the lines thus obtaining a binary statistics of the line. Corresponding areas were covered by the flights of May 5. Examples of the fractional snow cover data are shown in Figure 47 and Figure 48. The ground measurement data is listed in Appendix 9.

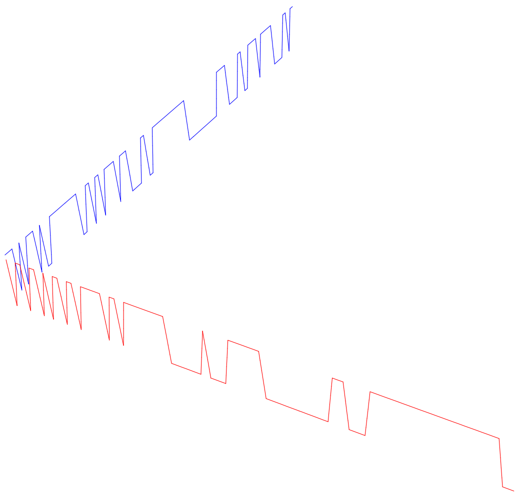

Figure 47. Example of perpendicular binary fractional snow cover profiles.

Figure 48. Example of fractional snow cover as seen by the wide optics camera.

3.2.8. UV measurements (FMI)

For SNORTEX, three types of UV albedo measurements were employed:

1) continuous 1-min in situ broadband UV albedo (years 2008, 2009, 2010),

2) broadband UV albedo from the helicopter side-by-side the pyranometers (years 2008, 2009, 2010), and

3) a campaign of one week producing high quality spectral UV albedo measurement data of intensively melting snow (year 2009).

Sodankylä Arctic snow broadband UV albedo measurements with erythemally weighted SL501 radiometers were started in 2007, as part of the IPY activities (Meinander et al 2008, 2009a). These measurements, with 1-min time resolution, were continued during SNORTEX-2008, 2009 and 2010. These erythemally weighted UV albedo data are analysed with the help of ancillary meteorological automatic weather station (AWS) data on the snow surface temperature, air temperature, beginning of rain, snow depth and cloud cover, as well as snow grain size data produced in SNORTEX.

In addition, similar SL501 sensors, one upwards and one downwards, were used in the SNORTEX-2008, 2009 and 2010 helicopter albedo measurements.

In 2009, the main focus was on spectral albedo measurements of melting snow using a Bentham spectrometer DMc150 (www.bentham.co.uk) combined with simultaneous snow fork measurements of snow liquid content. The spectrometer is equipped with a special two-head optics designed for the albedo measurement from 300 nm to 700 nm. The preliminary results of the Bentham and snowfork measurements were presented in the AGU-2009 fall conference in the context of ground-based Arctic and Antarctic UV albedo data (Meinander et al. 2009b), and published in Meinander et al. (2010).

Figure 1. Year 2009: The first version of the portable setup for snow albedo measurements with the Bentham spectrometer.

3.2.9. Impurity measurements (FMI)

In 2010, a total of 43 snow samples at SNORTEX sites were collected for the analysis of black carbon, organic carbon and total carbon .The first priority was to collect surface snow samples, but some profile samples were collected, too. The carefully collected (avoiding any possible contamination) snow was stored in a freezer. In 2012, some 20 samples were filtered. These filters and melt water samples will be analysed by the Warren group, USA. The other samples, including duplicate samples for those filtered 20 samples, will be analysed at FMI, without filtering, using the SP-method.

3.2.10. Hemispherical photos (FMI)

In 2008 hemispherical photos were taken at 8 test sites where the airborne vertical profiling was carried out (Appendix 1). One example is shown in Figure 49. In 2009 hemispherical photos were taken in individual locations, mostly at the meteorological mast (Appendix 10). In 2010 hemispherical photos were taken in 40 points and marked with black crosses (Figure 50), so that the airborne and ground based LAI measurements could be co-located with high accuracy. Results are described in Manninen et al. 2009 and Manninen et al. 2011.

Figure 49. A hemispherical image from the forest floor upwards.

Figure 50. A hemispherical image from the forest floor upwards (left), and a helicopter view of the same area.

3.2.11. Laser profiling (FGI)

The laser scanning measurements consisted of stationary and mobile measurements. The stationary laser scanning measurements were made using Leica HDS6000 (updated during the campaign to HDS6100). The intensity calibration was made using Spectralon® panel. The measurements were made in at the Norsen-mast (Tähtelä), Sattanen, Petkula, Peurapalo and Ruosselkä in 2009. The same plots were scanned several times to form a time series.
During the campaign a mobile laser scanning method was developed for snow covered surfaces. The measurements were made using FGI ROAMER system with FARO Photon 120 laser scanner (also updated during the campaign), an inertial measurement unit (IMU), a GPS device and a laptop computer to operate the system. The equipment was mounted on a sledge attached to a snow mobile. The scanner head was mounted upwards for vertical profiling to produce across-track swaths. The movement of the snow mobile produces the third dimension for the data. In 2009 the mobile laser profiling was tested in the Kommattivaara area using a stop-and-go mode (a series of stationary scannings). In 2010 mobile laser scanning data was gathered for 3 days. Two strips were measured using official snow mobile tracks in 18^{th} and 19^{th} March. A longer strip of 11.5 km, covering also the previous strips, was measured in 22nd March. Figure 50 shows the ROAMER mounted on a snowmobile sledge during the 2009 SNORTEX profiling. The results from the laser scanning measurements are described in more detail in Kaasalainen et al.2011, Anttila et al, 2011 and Kukko et al., 2012.

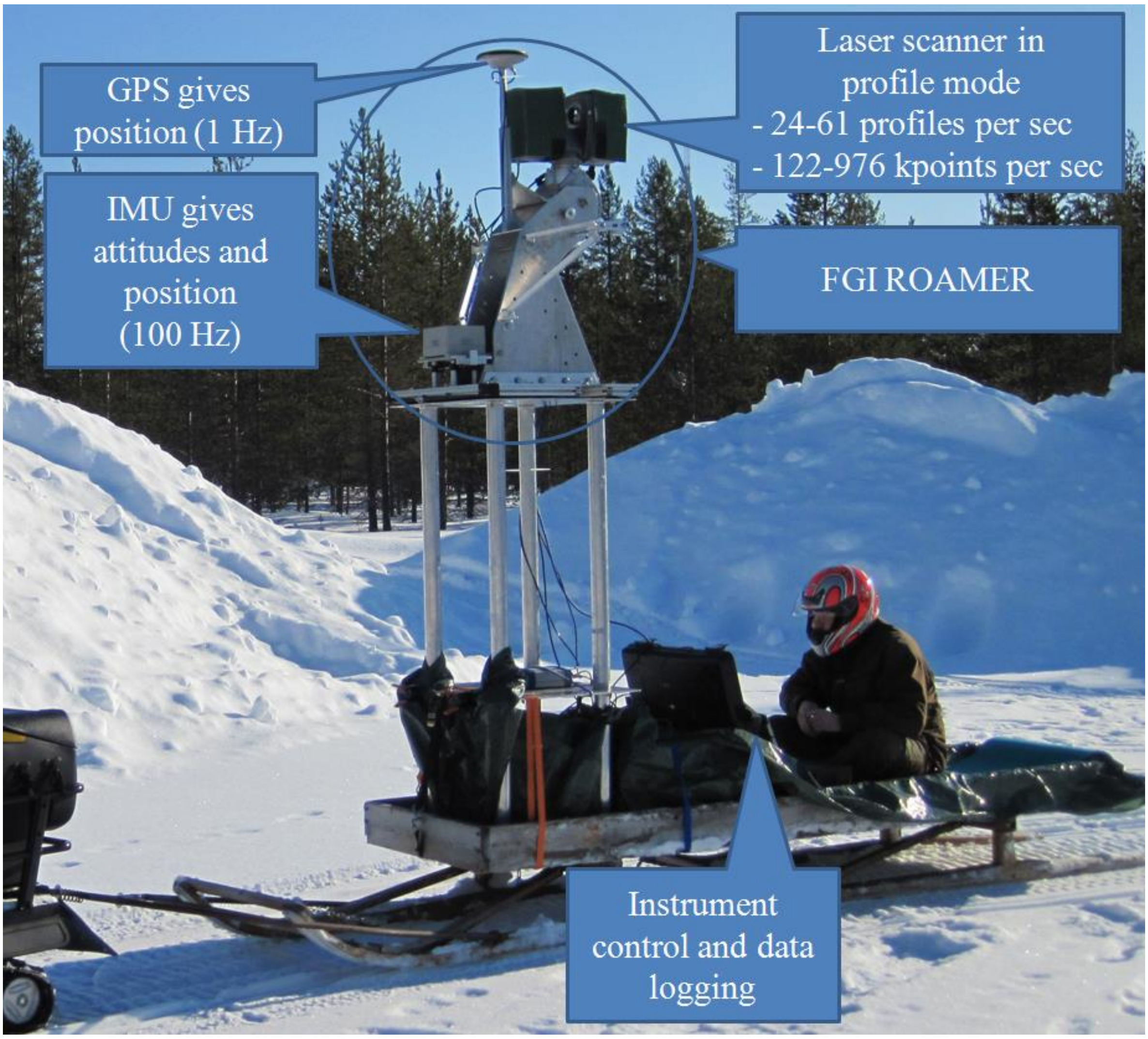

Figure 51. The FGI mobile mapping system, the ROAMER, mounted on a snowmobile sledge in Tähtelä, 2009. The laser scanner (FARO Photon 80, 785nm) and the GPS/IMU systems are in the front of the sledge. Image by Anssi Krooks.

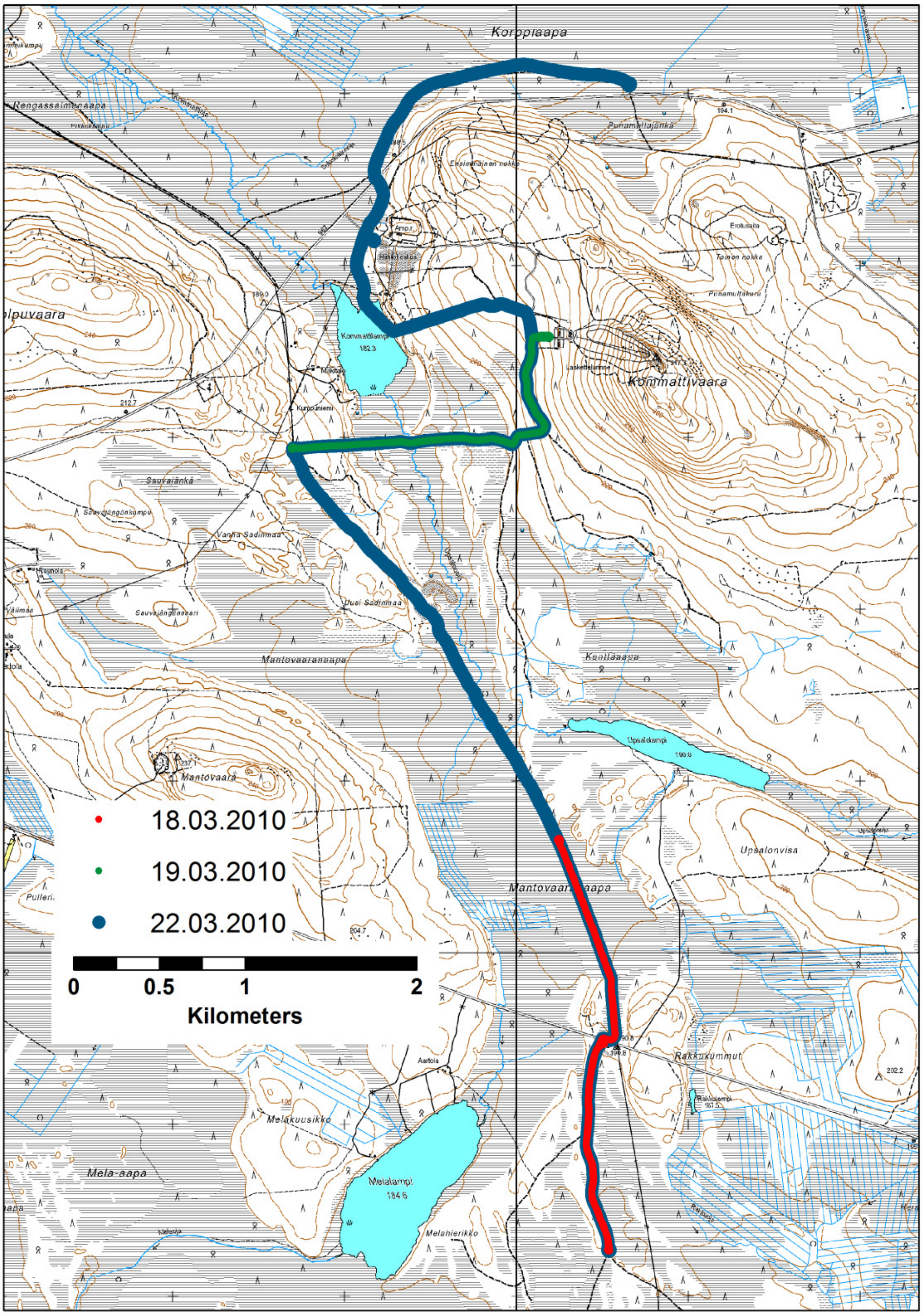

Figure 52. Trajectories of the mobile laser profiling in 2010. The route covers wetlands and forested scenes. © NLS map .

3.2.12. Goniospectrometer measurements (FGI)

The instrument used for BRDF measurements of snow, FIGIFIGO, was the same in all years 2008-2010 (Suomalainen et al. 2009). Resulsts are presented in Peltoniemi et al. 2010. Table TTT lists all FIGIFIGO measurements. Most measurements were taken in sunlight in excellent conditions, only Kommattivaara 20.4.2009 was measured in cloudy conditions, and most Norsen mast measurements were taken using lamp. 17 of total 22 measurements were taken with polarisation. The snow types included new and old snow, dry and melting, clean and dirty. The data are available at www.specchio.ch, and later also at fgi.fi.

Figure 53. FIGIFIGO measurements in Mantovaaranaapa 22.4. 2010. The measurement spot is 50 cm in front of the black box. Foreground left the Spectralon standard, right pyranometer monitoring skylight. The snow is a couple of days old, quite loose and smooth surface.

Table 4: All FIGIFIGO measurements performed during the Snortex campaign. P=polarised, U=unpolarised, L=lamp, D=dry, W= wet, M=moist/melting, grain type according to Colbeck et al 1985

date	location	setup	Solar angles	wetness	Grain type	surface	age
1.4.2008	Norsen	FU	43, 62, 55, 71	D	9lr,1mx	flat	old
2.4.2008	Norsen	FPL	66, 37, 45	D	9lr, 1sf	flat	old
3.4.2008	Norsen	FP	70-62	D	9lr,1sf	flat	old
4.4.2008	Norsen	FPL	35, 55	D	9sd, 1dc	flat	new
5.4.2008	Norsen	FPL	42, 55, 65	D	9nd,1dc	flat	new
20.4.2009	Kommattivaara	FP	57	W	lr		old
21.4.2009	Norsen	FPL	55	D		flat	old
22.4.2009	Mantovaaranaapa	FP	65	M	Sr,cl	smooth	old
22.4.2009	Mantovaaranaapa	FP	60-55	M	mf	rough	old
23.4.2009	Korppiaapa	FP	65	W	mf	rough	old
23.4.2009	Korppiaapa	FP	60	D	bi	rough	old
16.3.2010	Norsen	FP	69	D			days
16.3.2010	Norsen	FP	76	D			
17.3.2010	Mantovaaranaapa	FP	68	D			
18.3.2010	Melalampi	FP	69	D			days
21.3.2010	Orajärvi	FP	68	D			new
21.3.2010	Orajärvi	FU	67	D			new
21.3.2010	Orajärvi	FU	67	D			new
22.3.2010	Korppiaapa	FP	70	D			2 days
22.3.2010	Korppiaapa	FU	67	D			
22.3.2010	Korppiaapa	FU	66	D			
22.3.2020	Korppiaapa	FP	66	D			2 days

Additionally larger areas were measured using UAV ported pocket camera (Hakala et al. 2010).

3.2.13. SSA measurements (LGGE)

SSA profiles were measured using DUFISSS. The resolution of the profiles was 1 to 5 cm with higher resolution at the top of the snow pack. The profiles were measured at same locations as standard snow pit measurements, 1 profile per day. Additional profiles of density and heat conductivity were also measured together with visual mapping of the snowpack structure. The profiles were measured for 8 days covering 7 different locations. The same location (Norsen mast, Tähtelä) was measured at the beginning and end of the field campaign.

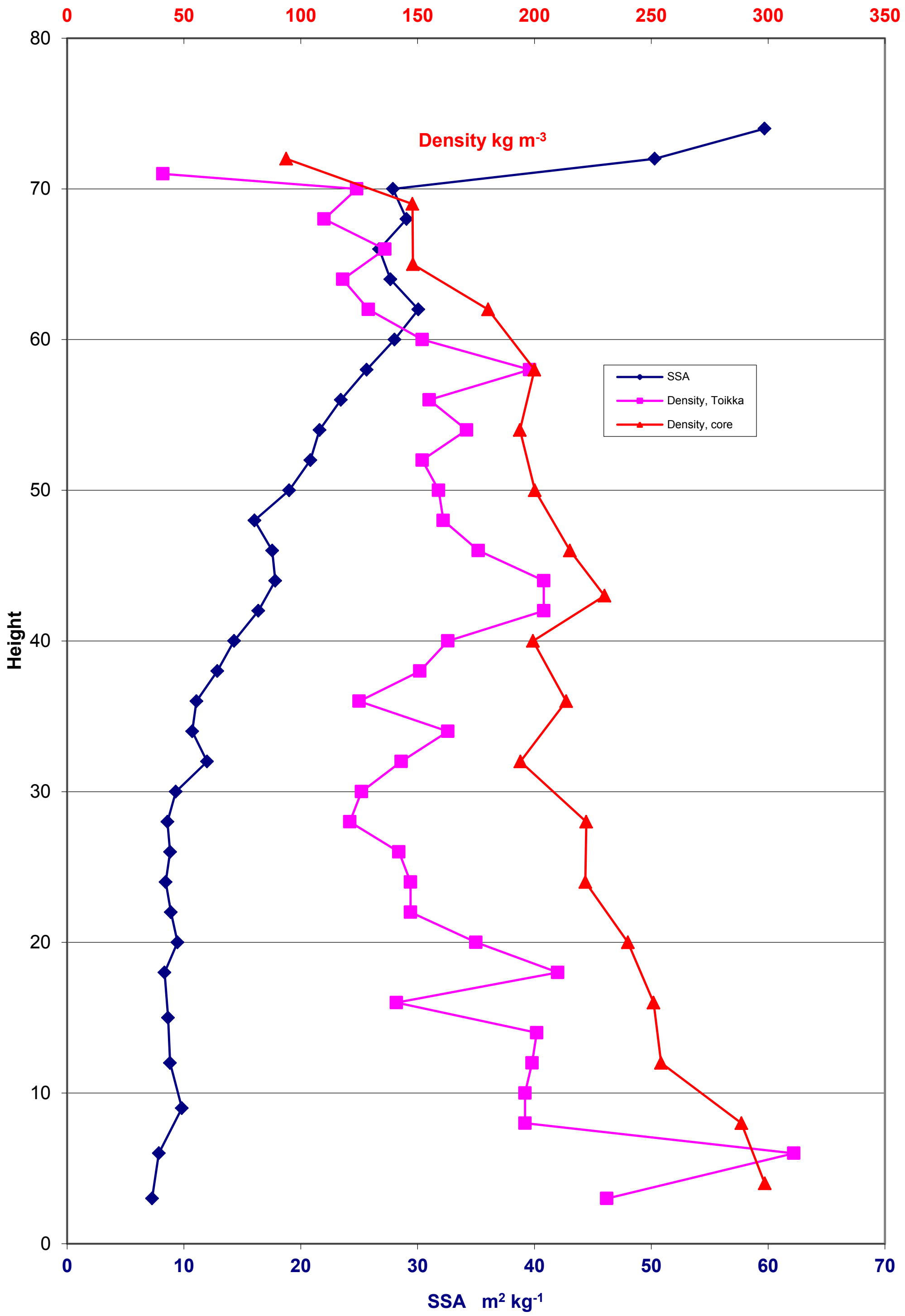

Figure 54. The surface specific area and density profiles measured using DUFISSS and the snow fork at Melalampi in March 16, 2010.

4. Atmospheric measurements (FMI)

The routine measurements are listed in Appendix 12. The AOD is measured at Sodankylä continuously. Results from 2008, 2009 and 2010 are shown in Figure 55.

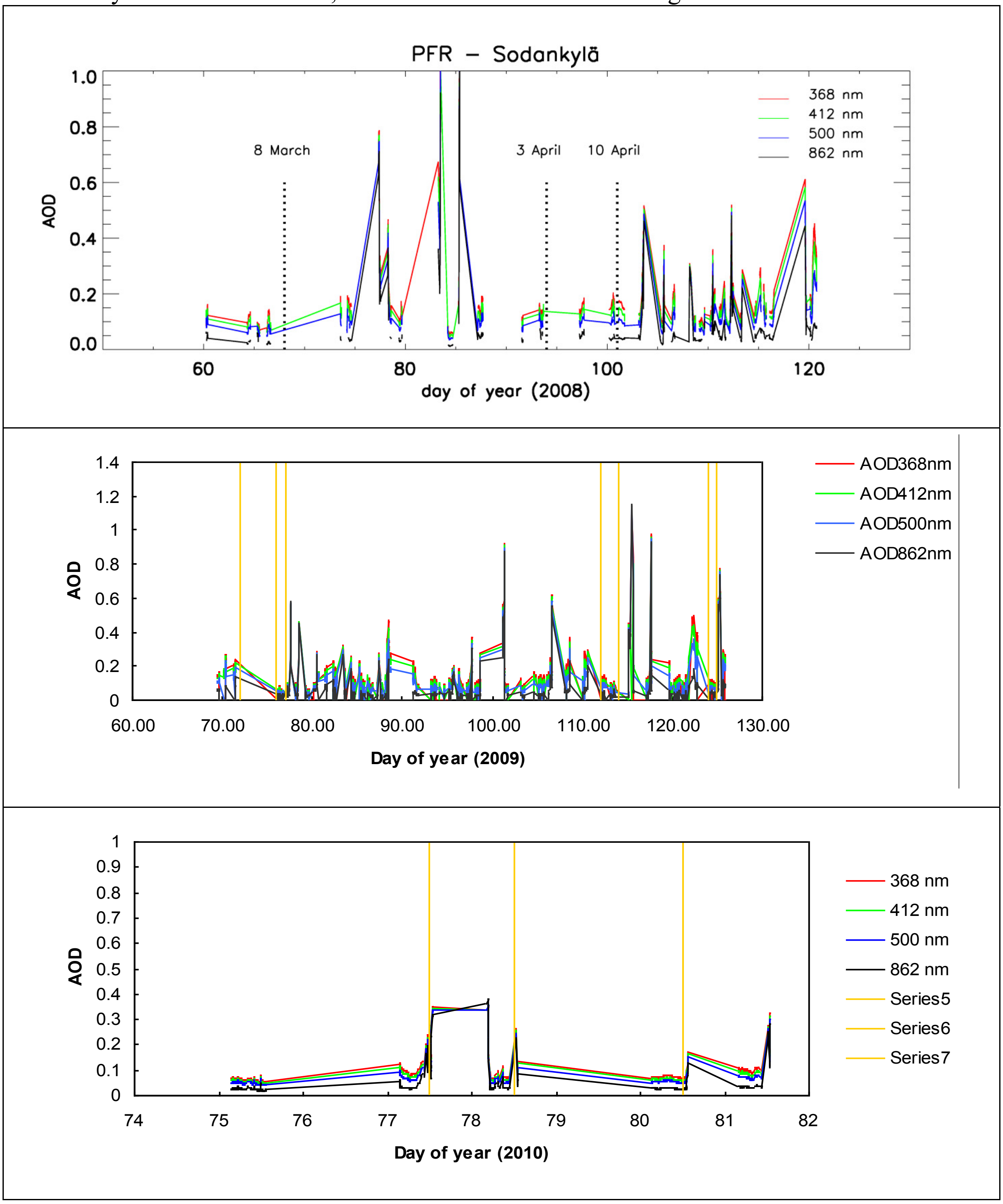

Figure 55. Time series of AOD measured at Sodankylä in 2008, 2009 and 2010. Days of flight are indicated with vertical lines. (Data by V. Aaltonen)

Acknowledgements

Météo-France was financially supported by LapBIAT. Various parts of the campaign were supported by EUMETSAT via the H-SAF visiting scientist funding and via the Climate-SAF and LSA-SAF Federate Activity funding. The authors are grateful to Mr. Antti Poikonen for constructing the power supply and data logging systems for the portable albedometer and Mr. Antti Aarva for the calibration of the pyranometers.

Co-operation with Prof. Pauline Stenberg from University of Helsinki in the LAI work is gratefully acknowledged. The SNORTEX team is grateful to the University of Helsinki (Prof. Pauline Stenberg in 2008-2009 and Prof. Petri Pellikka in 2010) for lending the hemispherical cameras and to SYKE (Finnish Environmental Institute) for lending a portable spectrometer in 2008. FMI wishes to thank M.Sc. Eero Rinne for participation in the technical flights of the Karhukamera system. The contribution of the staff of FMI, FMI-ARC, Heliflite and Vogon-IT is gratefully acknowledged

The SNORTEX participants would like to thank the whole staff of FMI-ARC for support in carrying out the campaign. Specifically the SNORTEX team is grateful to Prof. Jouni Pulliainen for showing green light to the campaign, to Ms. Riitta Aikio for the practical arrangements of lodgings etc., to Timo Pirttijärvi for computer support and to Markku Ahponen, Markku Kivioja, Petri Koivula, Jyrki Mattanen, Veikko Mylläri, Veikko Postila and Sami Suopajärvi for technical support, snow-mobile transportation and for snow depth, density and snow water equivalent measurements (MA, VM and MK) at the remote points in 2009 and 2010.

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Appendix 1: Ground measurement locations in 2008

Point	Name	Date 1	Time 1	N1	E1	Date 2	Time2	N2	E2	Special measurements
MA01	Jänkävuopajanaapa	1.4.2008	9:40	67:21.966	26:43.040					albedometer
MA02	Jänkävuopajankumpu	1.4.2008	10:15	67:22.255	26:43.337					albedometer
SYKE52	Perheluosto	1.4.2008	11:15	67:11.281	26:48.614					spektrometer
MA04	Kommattivaaran tyvi	1.4.2008	12:00	67:26.494	26:44.714	16.4.2008	14:08	67:26.494	26:44.714	albedometer
SYKE53	Perheluosto	1.4.2008	12:05	67:11.277	26:48.573					spektrometer
MA05	Saariaapa	1.4.2008	13:10	67:26.339	26:53.568	16.4.2008	14:52	67:26.339	26:53.568	albedometer
SYKE54	Tammukkatörmä	1.4.2008	14:00	67:16.462	26:43.274	16.4.2008	13:40	67:16.462	26:43.274	spektrometer
MA03	Korppiaapa	1.4.2008	14:10	67:26.763	26:43.510					albedometer
N1	NorSEN-masto	1.4.2008	15:20	67:21.725	26:38.049					albedometer
N2	NorSEN	1.4.2008	15:35	67:21.725	26:38.046					spektrometer
MD14	Kaita-aavan reuna	2.4.2008	9:30	67:50.857	26:37.077					
P36	SGO:n takapiha, plot 153	2.4.2008	10:45	67:22.350	26:37.388					albedometer
MD15	Kaita-aavankuusikko	2.4.2008	11:05	67:51.006	26:32.134					
MD08	Pahtavaarankuusikon laita	2.4.2008	11:45	67:51.293	26:29.112	11.4.2008	10:40	67:51.305	26:29.130	
MD16	Tenniövaara	2.4.2008	12:30	67:50.747	26:24.674					
MD09	Makkaratievat	2.4.2008	13:20	67:51.155	26:23.087	11.4.2008	12:17	67:51.151	26:23.090	
MD19	Tunturipäät	2.4.2008	14:20	67:51.214	26:21.660	11.4.2008	13:25	67:51.216	26:21.659	
MDD01	Rakkavaara	2.4.2008	15:00	67:51.278	26:20.033	11.4.2008	15:20	67:51.275	26:20.036	
NorSEN1	NorSEN-masto	2.4.2008	15:45	67:21.705	26:38.0874					albedometer
N3	NorSEN-masto	2.4.2008	17:20	67:21.724	26:38.045					
AD01	Sattanen	3.4.2008	9:50	67:29.373	26:36.592	17.4.2008	15:47	67:29.373	26:36.592	spektrometer, albedometer
MHH01	Kiveliö 3 km = Mäntypääntie	3.4.2008	10:50	67:57.106	26:51.517					
MH01	Petäjäseljänkummut	3.4.2008	11:50	67:53.609	26:52.436	14.4.2008	12:10	67:53.609	26:52.436	
AD04	Mäntypääntie	3.4.2008	12:10	67:57.105	26:51.514					spektrometer, albedometer
MH02	Kuusi-Lomavaaran tyvi	3.4.2008	12:20	67:53.202	26:54.0908	14.4.2008	12:55	67:53.202	26:54.0908	
MH03	Petäjäselkä	3.4.2008	13:15	67:52.910	26:55.447	14.4.2008	13:53	67:52.910	26:55.447	
AD03	Peurapalontie	3.4.2008	13:50	67:50.716	26:43.957					spektrometer, albedometer
MH04	Heinä-Kiviaapa	3.4.2008	14:00	67:52.585	26:57.196	14.4.2008		67:52.585	26:57.196	
MH06	Vittikko-Lomavaaran tyvi	3.4.2008	14:40	67:52.960	26:59.405					
AD02	Petkula	3.4.2008	15:10	67:42.326	26:45.311					spektrometer, albedometer
MH07	Maaseljän tyvi	3.4.2008	15:20	67:53.352	27:01.345					
MHH02	Maaseljän jänkä	3.4.2008	15:55	67:52.530	27:02.579					
N4	NorSEN-masto	3.4.2008	17:10	67:21.724	26:38.045					albedometer
N5	NorSEN-masto	3.4.2008	18:40	67:21.726	26:38.065					
MC08	Vaalajärvi	4.4.2008	9:25	67:26.179	26:08.128	17.4.2008	9:30	67:26.179	26:08.128	
MC07	Hanhivuoma	4.4.2008	9:40	67:27.492	26:05.554	17.4.2008	9:51	67:27.490	26:05.554	
MC06	Pohjukkavuoma	4.4.2008	10:20	67:29.710	26:02.261	17.4.2008	10:26	67:29.710	26:02.261	
MC05	Isovaara	4.4.2008	11:10	67:31.796	26:03.358	17.4.2008	11:15	67:31.796	26:03.358	
MC04	Kaarrevuoma	4.4.2008	11:45	67:32.798	26:08.424	17.4.2008	12:27	67:32.798	26:08.424	

MC03	Kiimalaen tyvi	4.4.2008	12:15	67:32.792	26:13.800	17.4.2008	11:52	67:32.792	26:13.800	
N6	NorSEN-masto	4.4.2008	15:30	67:21.726	26:38.065					
AJ04	Aitamaan räme	5.4.2008	11:00	67:49.539	27:47.039	12.4.2008	14:35	67:49.539	27:47.039	albedometer 1,2
AJ03	Koutuaavan laita	5.4.2008	11:40	67:45.994	27:45.717	12.4.2008	13:37	67:45.994	27:45.717	albedometer 1,2
AJ02	Ison Angeevaaran tyvi	5.4.2008	12:20	67:42.391	27:40.852	12.4.2008	12:20	67:42.388	27:40.851	albedometer 1,2
AJ01	Suikeloseljännokka	5.4.2008	13:15	67:33.609	27:33.356	12.4.2008	11:13	67:33.609	27:33.356	albedometer 1,2
N7	NorSEN-masto	5.4.2008	15:15	67:21.726	26:38.065					albedometer
AA01	Ruonivaaran tyvi	6.4.2008	10:30	67:21.197	27:00.212					
AA02	Rahkavaaran tyvi	6.4.2008	11:00	67:19.654	27:08.005					
AA03	Tulkkila	6.4.2008	12:00	67:15.571	27:16.742					
AA04	Mukkala	6.4.2008	12:50	67:09.894	27:28.381					
N8	NorSEN-masto	6.4.2008	14:10	67:21.726	26:38.065					
P12	Tähtelä pohjoinen, plot 195	6.4.2008		67:22.6176	26:37.563					albedometer, no snow meas. , LAI image
P24	Tähtelä pohjoinen, pikatie, plot 160	6.4.2008		67:22.6722	26:37.959					albedometer, no snow meas. , LAI image
P8	Halssiaavan reuna, plot 197	6.4.2008		67:21.9024	26:38.6646					albedometer, no snow meas., LAI image
Plot176	NorSEN-masto	6.4.2008		67:21.6876	26:38.0382					albedometer, no snow meas. , LAI image
N9	NorSEN-masto	7.4.2008	9:45	67:21.726	26:38.064					
MF10	Sammakkoaapan kaakkoispää	7.4.2008	10:15	67:29.324	27:02.142	16.4.2008	9:15	67:29.324	27:02.142	albedometer
X01	Kitinen/LIT	7.4.2008	11:00	67:21.925	26:37.525					
MFF11	Tinasenaapa	7.4.2008	11:05	67:31.951	27:03.183	16.4.2008	10:15	67:31.951	27:03.183	albedometer
MFF12	Virnikkasokan juuri	7.4.2008	11:55	67:33.854	26:59.270	16.4.2008	10:34	67:33.854	26:59.270	albedometer
MFF13	Särkivaaran ja -aapan väli	7.4.2008	13:15	67:33.258	26:56.460	16.4.2008	11:10	67:33.258	26:56.460	albedometer
N10	NorSEN-masto	7.4.2008	15:30	67:21.726	26:38.069					albedometer
X02	Luotaamo	7.4.2008	16:43	67:21.987	26:37.771					spektrometer, no snow meas.
MF09	Satovaarankuusikko	8.4.2008	10:20	67:41.843	27:01.977	15.4.2008	10:33	67:41.843	27:01.977	albedometer
MF08	Louejoki	8.4.2008	11:10	67:43.283	27:07.924	15.4.2008	11:41	67:43.283	27:07.924	albedometer
MF07	Melakoskenmaa	8.4.2008	11:55	67:44.325	27:12.304	15.4.2008	12:22	67:44.325	27:12.304	albedometer
MFF14	Pikkupalo	8.4.2008	13:15	67:46.116	27:21.217	15.4.2008	14:01	67:46.116	27:21.217	albedometer
N11	NorSEN-masto	8.4.2008	17:00	67:21.728	26:38.063					albedometer
ME01	Ruikanappa	9.4.2008	10:15	67:10.889	26:27.209					albedometer
ME02	Seipävaaranaapa?	9.4.2008	11:20	67:09.370	26:17.212					albedometer
ME03	Valkkisjärvi	9.4.2008	12:50	67:10.931	26:10.360					albedometer
MEE04	Lavaselkä	9.4.2008	13:40	67:11.925	26:06.484					albedometer
N12	NorSEN-masto	9.4.2008	17:00	67:21.725	26:38.066					albedometer
N13	NorSEN-masto	10.4.2008	15:40	67:21.723	26:38.048					spektrometer, albedometer
N14	NorSEN-masto	11.4.2008	10:30	67:21.726	26:38.064					spektrometer, albedometer
N15	NorSEN-masto	11.4.2008	18:25	67:21.725	26:38.043					spektrometer, albedometer
N16	NorSEN-masto	12.4.2008	16:30	67:21.723	26:38.048					

P29	Käyräsjokisuumaa, plot 186	13.4.2008	11:34	67:16.456	26:43.287					albedometer, no snow meas. , LAI image
P13	Kursala, plot 203	13.4.2008	12:51	67:20.736	26:40.747					albedometer, no snow meas. , LAI image
P33	Halssinkankaannokka, plot 214	13.4.2008	13:41	67:21.046	26:39.729					albedometer, no snow meas. , LAI image
P6	Halssikangas, plot 201	13.4.2008	14:27	67:21.246	26:39.229					albedometer, no snow meas. , LAI image
N17	NorSEN-masto	13.4.2008	15:16	67:21.724	26:38.067					
MHH03	Mäntypää	14.4.2008	10:59	67:57:293	26:50.944					
N18	NorSEN-masto	14.4.2008	16:35	67:21.726	26:38.065					
N19	NorSEN-masto	15.4.2008	17:43	67:21.729	26:38.069					
N20	NorSEN-masto	16.4.2008	16:16	67:21.729	26:38.069					
N21	NorSEN-masto	17.4.2008	16:49	67:21.729	26:38.069					
N22	NorSEN-masto	18.4.2008	8:37	67:21.729	26:38.069					

Appendix 2: Snow pit and surface roughness measurement locations and times in 2009

The dates, local times and locations of the snow pit measurements. The availability of NIR photos is indicated too.

		I expedition					II expedition				
Point	Name	Date 1	Time 1	N1	E1	NIR	Date 2	Time 2	N2	E2	NIR
AIXK1	Kommatti 1	11.3.2009	9:50:00	67°25.265	26°47.514	Yes	20.4.2009	9:45:00	67°25.264	26°47.514	Yes
AIXK2	Kommatti 2	11.3.2009	10:55:00	67°25.275	26°47.494	Yes	20.4.2009	10:30:00	67°25.120	26°47.623	Yes
AIXK3	Kommatti 3	11.3.2009	11:40:00	67°25.285	26°47.667	Yes	20.4.2009	11:20:00	67°24.859	26°48.090	Yes
AIXK4	Kommatti 4	11.3.2009	12:35:00	67°25.267	26°47.247	Yes	20.4.2009	12:42:00	67°25.270	26°47.236	Yes
AIXK5	Kommatti 5	11.3.2009	13:35:00	67°25.041	26°47.764	Yes	20.4.2009	13:20:00	67°25.283	26°47.612	Yes
AIXK6	Kommatti 6	11.3.2009	14:10:00	67°25.128	26°47.616	Yes	20.4.2009	14:00:00	67°25.4	26°47.459	Yes
AIXK7	Kommatti 7	11.3.2009	15:05:00	67°25.408	26°47.481	Yes	20.4.2009	14:31:00	67°25.319	26°47.501	Yes
AIXR1	Ravirata 1	12.3.2009	9:30:00	67°24.400	26°40.455	Yes	27.4.2009	8:55:00	67°24.400	26°40.460	No
AIXR2	Ravirata 2	12.3.2009	10:20:00	67°24.429	26°40.638	Yes	27.4.2009	9:23:00	67°24.427	26°40.627	No
AIXR3	Ravirata 3	12.3.2009	11:00:00	67°24.415	26°40.880	Yes	27.4.2009	9:34:00	67°24.414	26°40.882	No
AIXR4	Ravirata 4	12.3.2009	12:30:00	67°24.453	26°40.362	Yes	27.4.2009	10:10:00	67°24.451	26°40.351	No
AIXR5	Ravirata 5	12.3.2009	13:10:00	67°24.506	26°40.281	Yes	27.4.2009	10:41:00	67°24.505	26°40.277	No
AIXR6	Ravirata 6	12.3.2009	13:50:00	67°24.439	26°40.191	Yes	27.4.2009	11:05:00	67°24.438	26°40.203	No
AIXH1	Hirviäkuru 1	13.3.2009	9:40:00	67°22.605	26°51.425	Yes	25.4.2009	9:47:00	67°22.603	26°51.414	No
AIXH2	Hirviäkuru 2	13.3.2009	10:35:00	67°22.588	26°51.254	Yes	25.4.2009	10:15:00	67°22.587	26°51.260	No
AIXH3	Hirviäkuru 3	13.3.2009	11:25:00	67°22.794	26°51.143	Yes	25.4.2009	10:40:00	67°22.608	26°51.169	No
AIXH4	Hirviäkuru 4	13.3.2009	12:41:00	67°22.611	26°51.169	Yes	25.4.2009	11:05:00	67°22.693	26°51.274	No
AIXH5	Hirviäkuru 5	13.3.2009	13:40:00	67°22.691	26°51.275	Yes	25.4.2009	11:30:00	67°22.713	26°51.375	No
AIXH6	Hirviäkuru 6	13.3.2009	14:15:00	67°22.711	26°51.373	Yes	25.4.2009	12:15:00	67°22.713	26°51.375	Yes
AIXL1	Kommattilampi 1	14.3.2009	9:30:00	67°25.751	26°43.325	Yes	24.4.2009	9:20:00	67°25.747	26°43.324	Yes
AIXL2	Kommattilampi 2	14.3.2009	10:20:00	67°25.777	26°43.522	Yes	24.4.2009	10:12:00	67°25.781	26°43.517	No
AIXL3	Kommattilampi 3	14.3.2009	10:50:00	67°25.828	26°43.660	Yes	24.4.2009	10:36:00	67°25.893	26°43.913	No
AIXL4	Kommattilampi 4	14.3.2009	12:10:00	67°25.639	26°43.393	Yes	24.4.2009	11:12:00	67°25.639	26°43.397	No
AIXL5	Kommattilampi 5	14.3.2009	13:00:00	67°25.626	26°43.207	Yes	24.4.2009	12:00:00	67°25.627	26°43.205	No
AIXL6	Kommattilampi 6	14.3.2009	13:40:00	67°25.602	26°43.074	Yes	24.4.2009	12:25:00	67°25.602	26°43.073	No
AIXL7	Kommattilampi 7	14.3.2009	14:30:00	67°25.872	26°43.297	Yes	24.4.2009	13:01:00	67°25.873	26°43.292	No
AIXS1	Siurunmaa 1	15.3.2009	9:45:00	67°26.995	26°49.314	Yes	26.4.2009	10:00:00	67°26.949	26°49.256	No
AIXS2	Siurunmaa 2	15.3.2009	10:30:00	67°26.949	26°49.248	Yes	26.4.2009	10:35:00	67°26.893	26°49.024	No
AIXS3	Siurunmaa 3	15.3.2009	11:20:00	67°26.892	26°49.014	Yes	26.4.2009	11:05:00	67°26.790	26°49.061	No
AIXS4	Siurunmaa 4	15.3.2009	12:10:00	67°26.791	26°49.051	Yes	26.4.2009	11:35:00	67°26.993	26°49.310	No
AIXM1	Melalampi 1	16.3.2009	9:15:00	67°23.692	26°43.852	Yes	21.4.2009	9:15:00	67°23.691	26°43.849	Yes
AIXM2	Melalampi 2	16.3.2009	10:30:00	67°23.549	26°43.790	Yes	21.4.2009	10:14:00	67°23.548	26°43.481	No
AIXM3	Melalampi 3	16.3.2009	11:15:00	67°23.080	26°44.006	Yes	21.4.2009	10:40:00	67°23.081	26°43.882	Yes
AIXM4	Melalampi 4	16.3.2009	12:30:00	67°22.813	26°43.668	No	21.4.2009	11:22:00	67°22.813	26°43.664	No
AIXM5	Melalampi 5	16.3.2009	13:00:00	67°22.945	26°43.912	Yes	21.4.2009	11:47:00	67°22.942	26°43.916	Yes
AIXM6	Melalampi 6	16.3.2009	13:50:00	67°23.355	26°43.834	Yes	21.4.2009	13:00:00	67°23.203	26°43.84	Yes
AIXM7	Melalampi 7						21.4.2009	14:03:00	67°23.504	26°43.812	Yes
AIXA1	Korppiaapa 1	17.3.2009	9:15:00	67°26.617	26°42.212	Yes	23.4.2009	9:10:00	67°26.615	26°42.199	Yes
AIXA2	Korppiaapa 2	17.3.2009	10:15:00	67°26.767	26°42.782	Yes	23.4.2009	10:00:00	67°26.768	26°42.779	No
AIXA3	Korppiaapa 3	17.3.2009	11:00:00	67°26.850	26°43.549	Yes	23.4.2009	10:25:00	67°26.855	26°43.545	No
AIXA4	Korppiaapa 4	17.3.2009	12:05:00	67°26.794	26°43.085	Yes	23.4.2009	10:50:00	67°26.792	26°43.093	No
AIXA5	Korppiaapa 5	17.3.2009	13:00:00	67°26.720	26°42.410	Yes	23.4.2009	11:17:00	67°26.397	26°42.241	No
AIXA6	Korppiaapa 6	17.3.2009	13:50:00	67°26.485	26°42.098	Yes	23.4.2009	12:00:00	67°26.457	26°41.924	Yes
AIXA7	Korppiaapa 7						23.4.2009	12:44:00	67°26.418	26°41.944	No
AIXV1	Mantovaaranaapa 1	18.3.2009	9:10:00	67°23.956	26°44.058	Yes	22.4.2009	9:00:00	67°23.958	26°44.057	No
AIXV2	Mantovaaranaapa 2	18.3.2009	10:10:00	67°24.263	26°43.702	Yes	22.4.2009	9:40:00	67°24.266	26°43.702	No
AIXV3	Mantovaaranaapa 3	18.3.2009	11:10:00	67°24.684	26°43.127	Yes	22.4.2009	10:15:00	67°24.684	26°43.128	Yes
AIXV4	Mantovaaranaapa 4	18.3.2009	12:20:00	67°24.440	26°43.413	Yes	22.4.2009	11:00:00	67°24.441	26°43.414	Yes
AIXV5	Mantovaaranaapa 5	18.3.2009	13:20:00	67°24.065	26°43.872	Yes	22.4.2009	12:50:00	67°24.065	26°43.872	Yes
AIXV6	Mantovaaranaapa 6	18.3.2009	14:10:00	67°23.784	26°43.989	Yes	22.4.2009	13:43:00	67°23.784	26°43.989	Yes
AIXV7	Mantovaaranaapa 7						22.4.2009	12:30:00	67°23.855	26°43.412	No
NIX1	NorSEN mast	11.3.2009	16:55:00	67°21.725	26°38.069	Yes					
NIX2	NorSEN mast	12.3.2009	15:10:00	67°21.722	26°38.068	Yes					
NIX3	NorSEN mast	13.3.2009	15:20:00	67°21.724	26°38.064	Yes					

NIX4	NorSEN mast	14.3.2009	15:35:00	67°21.727	26°38.064	Yes						
NIX5	NorSEN mast	15.3.2009	13:50:00	67°21.725	26°38.069	Yes						
NIX6	NorSEN mast	16.3.2009	15:15:00	67°21.722	26°38.071	Yes						
NIX7	NorSEN mast	17.3.2009	14:50:00	67°21.727	26°38.068	Yes						
NIX8	NorSEN mast	18.3.2009	15:20:00	67°21.727	26°38.066	Yes						
NIX9	NorSEN mast	19.3.2009	9:10:00	67°21.727	26°38.066	Yes						
NIX10	NorSEN mast	20.4.2009	0:00:00	67°21.725	26°38.065	Yes						
NIX11	NorSEN mast	21.4.2009	15:30:00	67°21.727	26°38.066	Yes						
NIX12	NorSEN mast	22.4.2009	15:05:00	67°21.727	26°38.066	Yes						
NIX13	NorSEN mast	23.4.2009	14:22:00	67°21.727	26°38.066	Yes						
NIX14	NorSEN mast	24.4.2009	14:00:00	67°25.873	26°43.292	Yes						
NIX15	NorSEN mast	25.4.2009	8:30:00	67°21.725	26°38.069	Yes						
NIX16	NorSEN mast	26.4.2009	12:25:00	67°21.725	26°38.069	No						
NIX17	NorSEN mast	27.4.2009	11:45:00	67°21.725	26°38.069	No						

Appendix 3. Remote snow measurement points in 2009.

Point	Name	I set				II set			
		Date 1	Time 1	N1	E1	Date 2	Time 2	N2	E2
MDD01	Rakkavaara	13.3.2009	11:00	67°51.278	26°20.033	22.4.2009	13:38	67°51.278	26°20.033
MD19	Tunturipäät	13.3.2009	11:15	67°51.214	26°21.660	22.4.2009	13:24	67°51.214	26°21.660
MD09	Makkaratievat	13.3.2009	11:30	67°51.155	26°23.087	22.4.2009	13:12	67°51.155	26°23.087
MD16	Tenniövaara	13.3.2009	11:45	67°50.747	26°24.674	22.4.2009	12:45	67°50.747	26°24.674
MDD02	Tenniöhaara	13.3.2009	12:00	67°50.997	26°27.073	22.4.2009	12:33	67°50.997	26°27.073
MD08	Pahtavaarankuusikon laita	13.3.2009	12:15	67°51.293	26°29.112	22.4.2009	12:22	67°51.293	26°29.112
MD15	Kaita-aavankuusikko	13.3.2009	12:30	67°51.006	26°32.134	22.4.2009	12:12	67°51.006	26°32.134
MDD03	Kaita-aavankuusikko, itä	13.3.2009	12:45	67°50.960	26°34.575	22.4.2009	12:03	67°50.960	26°34.575
MD14	Kaita-aavan reuna	13.3.2009	13:00	67°50.857	26°37.077	22.4.2009	11:48	67°50.857	26°37.077
MDD04	Kaita-aapa, itä	13.3.2009	13:15	67°50.558	26°39.303	22.4.2009	11:30	67°50.558	26°39.303
MC08	Vaalajärvi	13.3.2009	15:15	67°26.179	26°08.128	23.4.2009	11:11	67°26.179	26°08.128
MC07	Hanhivuoma	13.3.2009	15:30	67°27.492	26°05.554	23.4.2009	11:03	67°27.492	26°05.554
MCC09	Lehtolanvuoma	13.3.2009	15:45	67°28.283	26°04.125	23.4.2009	10:54	67°28.283	26°04.125
MCC10	Viisakumpu	13.3.2009	16:00	67°29.037	26°03.400	23.4.2009	10:46	67°29.037	26°03.400
MC06	Pohjukkavuoma	13.3.2009	16:15	67°29.71	26°02.261	23.4.2009	10:36	67°29.71	26°02.261
MCC11	Kuohinkivaara	13.3.2009	16:30	67°31.210	26°02.683	23.4.2009	11:43	67°31.210	26°02.683
MC05	Isovaara	16.3.2009	9:30	67°31.796	26°03.358	23.4.2009	11:53	67°31.796	26°03.358
MCC12	Kaaresselkä	16.3.2009	9:45	67°32.107	26°05.888	23.4.2009	12:06	67°32.107	26°05.888
MC04	Kaarrevuoma	16.3.2009	10:00	67°32.798	26°08.424	23.4.2009	12:18	67°32.798	26°08.424
MCC13	Kaareoja	16.3.2009	10:15	67°32.922	26°10.495	23.4.2009	12:26	67°32.922	26°10.495
MC03	Kiimalaen tyvi	16.3.2009	10:30	67°32.792	26°13.800	23.4.2009	13:22	67°32.792	26°13.800
MCC14	Niliselkä	16.3.2009	10:45	67°33.155	26°19.810	23.4.2009	15:03	67°33.155	26°19.810
MCC15	Sisnakka-aapa	16.3.2009	11:00	67°33.043	26°24.135	23.4.2009	14:53	67°33.043	26°24.135
MCC16	Visasaari	16.3.2009	11:15	67°32.282	26°28.047	23.4.2009	14:42	67°32.282	26°28.047
MCC17	Kotiaapa	16.3.2009	11:30	67°30.617	26°32.333	23.4.2009	14:32	67°30.617	26°32.333
MCC18	Känsäsaarenmaa	16.3.2009	11:45	67°28.825	26°35.015	23.4.2009	14:17	67°28.825	26°35.015
MM01	aukea	17.3.2009	9:55	67°26.418	26°50.796				
MM02	aukea	17.3.2009	10:00	67°26.469	26°51.840				
MM03	aukea	17.3.2009	10:07	67°26.070	26°53.064				
MM04	aukea	17.3.2009	10:12	67°25.845	26°53.830				
MM05	aukea	17.3.2009	10:17	67°25.695	26°54.434				
MM06	aukea	17.3.2009	10:20	67°25.620	26°54.646				
MM07	aukean laita, pieniä mäntyjä	17.3.2009	10:25	67°25.428	26°54.340				
MM08	aukean laita, pieniä mäntyjä	17.3.2009	10:35	67°25.572	26°53.993				
MM09	aukea	17.3.2009	10:44	67°25.703	26°53.517				
MM10	aukea	17.3.2009	10:47	67°25.794	26°53.012				
MM11	aukea	17.3.2009	10:54	67°25.797	26°52.087				
MM12	aukea	17.3.2009	10:58	67°25.633	26°51.822				
MM13	aukean laita, pieniä mäntyjä	17.3.2009	11:02	67°25.484	26°51.870				
MM14	mänty- ja kuusimetsä	17.3.2009	11:07	67°25.383	26°51.851				
MM15	nuorehko mäntymetsä	17.3.2009	11:20	67°25.282	26°51.680				
MM16	metsän reuna	17.3.2009	11:26	67°25.420	26°52.006				
MM17	kuusimetsä	17.3.2009	11:32	67°25.551	26°52.408				

Appendix 4: Snow pit and surface roughness measurement locations in 2010

Point	Name	Date	Time	N	E
AXV1	Mantovaaranaapa 1	17.3.2010	10:00	67º23.967	26º44.011
AXV2	Mantovaaranaapa 2	17.3.2010	12:40	67º24.208	26º43.676
AXV3	Mantovaaranaapa 3	17.3.2010	13:40	67º24.404	26º43.508
AXM1	Melalampi 1	18.3.2010	9:40	67º23.530	26º43.837
AXM2	Melalampi 2	18.3.2010	11:00	67º23.338	26º43.849
AXM3	Melalampi 3	18.3.2010	12:00	67º23.230	26º43.825
AXM4	Melalampi 4	18.3.2010	12:40	67º23.082	26º43.992
AXM5	Melalampi 5	18.3.2010	0:00	67º23.689	26º43.834
AXL1	Kommattilampi 1	19.3.2010	9:30	67º25.768	26º43.299
AXL2	Kommattilampi 2	19.3.2010	10:40	67º25.633	26º43.338
AXL3	Kommattilampi 3	19.3.2010	12:05	67º25.630	26º43.246
AXL4	Kommattilampi 4	19.3.2010	13:10	67º25.597	26º43.098
AXR1	Ravirata 1	20.3.2010	10:18	67º24.426	26º40.899
AXR2	Ravirata 2	20.3.2010	11:10	67º24.425	26º41.265
AXO1	Orajärvi 1	21.3.2010	10:30	67º22.392	26º51.848
AXA1	Korppiaapa 1	22.3.2010	9:30	67º26.579	26º42.097
AXA2	Korppiaapa 2	22.3.2010	12:10	67º26.682	26º42.354
AXK1	Kommattivaara 1	23.3.2010	9:10	67º25.030	26º47.790
AXK2	Kommattivaara 2	23.3.2010	10:30	67º25.266	26º47.238
AXK3	Kommattivaara 3	23.3.2010	11:30	67º25.316	26º47.502
AXH1	Hirviäkuru 1	24.3.2010	9:30	67º22.586	26º51.267
AXH2	Hirviäkuru 2	24.3.2010	10:30	67º22.777	26º51.497
AXH3	Hirviäkuru 3	24.3.2010	11:40	67º22.650	26º51.554
NX1	NorSEN mast 1	16.3.2010	10:10	67º21.743	26º38.061
NX2	NorSEN mast 2	17.3.2010	15:40	67º21.742	26º38.062
NX3	NorSEN mast 3	18.3.2010	15:45	67º21.747	26º38.066
NX4	NorSEN mast 4	19.3.2010	15:15	67º21.747	26º38.066
NX5	NorSEN mast 5	20.3.2010	13:00	67º21.746	26º38.070
NX6	NorSEN mast 6	21.3.2010	14:20	67º21.747	26º38.066
NX7	NorSEN mast 7	22.3.2010	15:05	67º21.747	26º38.069
NX8	NorSEN mast 8	23.3.2010	12:45	67º21.747	26º38.077
NX9	NorSEN mast 9	24.3.2010	13:30	67º21.742	26º38.075

Appendix 5. Remote snow measurement points in 2010.

Point	Name	I set				II set			
		Date 1	Time 1	N1	E1	Date 2	Time 2	N2	E2
MDD01	Rakkavaara	11.3.2010	11:50	67°51,278	26°20,033	8.4.2010	10:40	67°51,278	26°20,033
MD19	Tunturipäät	11.3.2010		67°51,214	26°21,660	8.4.2010		67°51,214	26°21,660
MD09	Makkaratievat	11.3.2010		67°51,091	26°23,009	8.4.2010		67°51,091	26°23,009
MD16	Tenniövaara	11.3.2010		67°50,747	26°24,674	8.4.2010		67°50,747	26°24,674
MDD02	Tenniöhaara	11.3.2010		67°50,997	26°27,073	8.4.2010		67°50,997	26°27,073
MD08	Pahtavaarankuusikon, laita	11.3.2010		67°51,293	26°29,112	8.4.2010		67°51,293	26°29,112
MD15	Kaita-aavankuusikko	11.3.2010		67°51,006	26°32,134	8.4.2010		67°51,006	26°32,134
MDD03	Kaita-aavankuusikko, itä	11.3.2010		67°50,960	26°34,575	8.4.2010		67°50,960	26°34,575
MD14	Kaita-aavan, reuna	11.3.2010		67°50,857	26°37,077	8.4.2010		67°50,857	26°37,077
MDD04	Kaita-aapa, itä	11.3.2010		67°50,558	26°39,303	8.4.2010		67°50,558	26°39,303
MC08	Vaalajärvi	12.3.2010	12:15	67°26,179	26°08,128	9.4.2010	10.55	67°26,179	26°08,128
MC07	Hanhivuoma	12.3.2010		67°27,492	26°05,554	9.4.2010		67°27,492	26°05,554
MCC09	Lehtolanvuoma	12.3.2010		67°28,283	26°04,125	9.4.2010		67°28,283	26°04,125
MCC10	Viisakumpu	12.3.2010		67°29,037	26°03,400	9.4.2010		67°29,037	26°03,400
MC06	Pohjukkavuoma	12.3.2010		67°29,71	26°02,261	9.4.2010		67°29,71	26°02,261
MCC11	Kuohinkivaara	12.3.2010		67°31,210	26°02,683	9.4.2010		67°31,210	26°02,683
MC05	Isovaara	12.3.2010		67°31,796	26°03,358	9.4.2010		67°31,796	26°03,358
MCC12	Kaaresselkä	12.3.2010		67°32,107	26°05,888	9.4.2010		67°32,107	26°05,888
MC04	Kaarrevuoma	12.3.2010		67°32,798	26°08,424	9.4.2010		67°32,798	26°08,424
MCC13	Kaareoja	12.3.2010		67°32,922	26°10,495	9.4.2010		67°32,922	26°10,495
MC03	Kiimalaen, tyvi	12.3.2010		67°32,792	26°13,800	9.4.2010		67°32,792	26°13,800
MCC14	Niliselkä	12.3.2010		67°33,155	26°19,810	9.4.2010		67°33,155	26°19,810
MCC15	Sisnakka-aapa	12.3.2010		67°33,043	26°24,135	9.4.2010		67°33,043	26°24,135
MCC16	Visasaari	12.3.2010		67°32,282	26°28,047	9.4.2010		67°32,282	26°28,047
MCC17	Kotiaapa	12.3.2010		67°30,617	26°32,333	9.4.2010		67°30,617	26°32,333
MCC18	Känsäsaarenmaa	12.3.2010	15:10	67°28,825	26°35,015	9.4.2010	14.40	67°28,825	26°35,015

Appendix 6: Albedo, spectrometer and continuous snow temperature measurements during the II expedition in 2009.

Point	name	Date 1	Time 1 (local)	N1	E1	Number of spectra	Albedo data (local)	Temperature data
1	Mantovaaranaapa (050)	16.4.2009	10:30	67.400	26.740	6	10:30-11:40	-
2	Mantovaaranaapa (051)	16.4.2009	12:00	67.400	26.736	3	12:00-14:20	12:10-14:20
3	NorSEN	16.4.2009	15:25	67.362	26.634	-	15:24-16:20	-
4	NorSEN	17.4.2009	10:38	67.362	26.634	-	10:38-19:56	15:20-18:40
5	Mantovaaranaapa	18.4.2009	10:51	67.402	26.738	4	10:51-15:04	10:52-12:06 13:05-13:23 14:35-14:41
6	NorSEN	18.4.2009	16:00	67.362	26.633	1	16:00-16:52	16:32
7	NorSEN	19.4.2009	10:26	67.362	26.635	0	10:26-17:20	10:28-17:26
8	Kommattivaara	20.4.2009	10:00	67.422	26.792	5	10:00-15:10	10:06-14:12
9	NorSEN	20.4.2009	16:07	67.362	26.633	0	16:05-16:51	-
10	Melalampi	21.4.2009	9:37	67.390	26.728	0	9:37-14:50	-
11	NorSEN	21.4.2009	15:34	67.362	26.634	0	15:34-15:58	-
12	Mantovaaranaapa	22.4.2009	9:11	67.400	26.733	23	9:11-14:21	-
12	NorSEN	22.4.2009	15:12	67.362	26.634	3	15:12-15:56	-
13	Korppiaapa	23.4.2009	9:32	67.443	26.7	12	9:32-13:41	-
14	NorSEN	23.4.2009	14:26	67.362	67.634	0	14:26-14:47	-
15	Kommattilampi	24.4.2009	9:31	67.430	26.723	23	9:31-13:20	-
16	NorSEN	24.4.2009	14:05	67.362	26.634	0	14:05-14:28	-
17	NorSEN	25.4.2009	8:37	67.362	26.633	15	8:37-15:26	-
18	NorSEN (forest)	26.4.2009	8:39	67.362	26.638	3	8:39-23:59	-
19	NorSEN (forest)	27.4.2009	0:00	67.362	26.638	5	0:00-12:39	-
20	NorSEN (met.mast)	28.4.2009	10:00-12:00	67.362	26.633	8	-	-

Appendix 7: Albedo, spectrometer, and snow surface temperature measurements in 2010.

Point	name	Date	ASD Start Time (UTC)	N	E	# of spectra	Albedo data (UTC)	Snow Temperature data (UTC)
1	Mantovaaranaapa	17.3.2010	8:47	67º23.967	26º44.011	9	8:10 – 12:34	8:12 – 12:35
2	NorSEN	17.3.2010	-	67º21.72	26º38.04	-	13:40 – 14:25	-
3	Melalampi	18.3.2010	8:26	67º23.530	26º43.837	4	7:46 – 12:45	7:47 – 12:45
4	Kommattivaara	19.3.2010	8:24	67º25.768	26º43.299	5	7:38 – 12:22	10:28 – 12:21
5	NorSEN	19.3.2010	-	67º21.72	26º38.04	-	13:20 – 13:46	13:23 – 13:48
6	Ravirata	20.3.2010	-	67º24.426	26º40.899	-	8:24 – 9:48	8:24 – 9:54
7	NorSEN	20.3.2010	-	67º21.72	26º38.04	-	11:09 – 11:30	11:09 – 11:35
8	Orajärvi	21.3.2010	9:22	67º22.392	26º51.848	3	8:31 – 11:38	8:35 – 13:39
9	NorSEN	21.3.2010	12:51	67º21.72	26º38.04	1	12:30 – 13:03	12:31 – 13:01
10	Korppiaapa	22.3.2010	8:20	67º26.579	26º42.097	5	7:35 – 12:06	-
11	NorSEN	22.3.2010	-	67º21.72	26º38.04	-	13:09 – 14:07	-
12	Aukea-NorSEN	23.3.2010	-	67º21.76	26º38.12	-	7:35 – 15:19	7:37 – 13:23
13	Orajärvi	24.3.2010	7:56	67º22.392	26º51.848	1	-	-
14	NorSEN	24.3.2010	11:41	67º21.72	26º38.04	1	-	-

Appendix 8: Snow surface roughness measurements made using tachymeter in 2009. The starting point coordinates of the lines are (N0, E0) and the end points of the perpendicular lines (N1, E1) and (N2, E2). Once also the 45° direction was measured and the respective end coordinate is added as a second values of (N2, E2). The measurements carried out in April match the areas used in March. The NorSEN mast line was all the time the same. The number of 1 m profiles measure every 10 m along the tachymeter lines (parallel and perpendicular to it) using the graded plate is shown in columns n|| and n⊥.

Point	Name	Date	Time	N0	E0	N1	E1	N2	E2	n||	n⊥
AIXK1s	Kommatti 1s	11.3.2009	10:00	67°25.292	26°47.598	67°25.296	26°47.735	67°25.347	26°47.601	10	13
AIXK2s	Kommatti 2s	11.3.2009	13:50	67°25.305	26°47.667	67°25.303	26°47.802			10	10
AIXR1s	Ravirata 1s	12.3.2009	9:55	67°24.418	26°40.329	67°24.44	26°40.2			9	9
AIXR2s	Ravirata 2s	12.3.2009	12:50	67°24.39	26°40.412	67°24.335	26°40.417	67°24.39	26°40.554	10	10
AIXH1s	Hirviäkuru 1s	13.3.2009	10:00	67°22.643	26°51.399	67°22.615	26°51.297	67°22.682	26°51.303	9	10
AIXH2s	Hirviäkuru 2s	13.3.2009	12:45	67°22.598	26°51.236	67°22.592	26°51.301	67°22.648, 67°22.631,	26°51.23, 26°51.273	5	5, 5
AIXL1s	Kommattilampi 1s	14.3.2009	9:50	67°25.772	26°43.337	67°25.784	26°43.328	67°25.772	26°43.298	5	6
AIXL2s	Kommattilampi 2s	14.3.2009	12:30	67°25.818	26°43.506	67°25.81	26°43.569			6	5, 8
AIXS1s	Siurunmaa 1s	15.3.2009	10:25	67°26.949	26°49.227	67°26.965	26°49.202	67°26°.922	26°49.107	7	11
AIXM1s	Melalampi 1s	16.3.2009	9:35	67°23.652	26°43.738	67°23.707	26°43.746	67°23.662	26°43.6	10	10
AIXM2s	Melalampi 2s	16.3.2009	12:40	67°23.507	26°43.814	67°23.46	26°43.891	67°23.541	26°43.919	10	10
AIXA1s	Korppiaapa 1s	17.3.2009	9:20	67°26.454	26°41.954	67°26.507	26°41.967	67°26°.457	26°41.814	10	10
AIXV1s	Mantovaaranaapa 1s	18.3.2009	9:30	67°23.963	26°43.923	67°23.922	26°43.833			8	
AIXV2s	Mantovaaranaapa 2s	18.3.2009	11.45	67°24.063	26°43.837	67°24.012	26°43.824	67°24.065	26°43.703	11	10
AIXK1s	Kommatti 1s	20.4.2009	10:30	67°25.293	26°47.603	67°25.292	26°47.739	67°25.343	26°47.608		, 16
AIXM1s	Melalampi 1s	21.4.2009	0:38	67°23.658	26°43.738	67°23.714	26°43.744	67°23.665	26°43.606	8	8
AIXM2s	Melalampi 2s	21.4.2009	12:50	67°23.503	26°43.818	67°23.54	26°43.927	67°23.461	26°43.899	3	5
AIXV2s	Mantovaaranaapa 2s	22.4.2009	9:10	67°24.063	26°43.836	67°24.01	26°43.818	67°24.072	26°43.696	3	5
AIXV1s	Mantovaaranaapa 1s	22.4.2009	12:10	67°24.197	26°43.767	67°24.213	26°43.9	67°24.146	26°43.816	9	9
AIXA1s	Korppiaapa 1s	23.4.2009	9:20	67°26°.461	26°41.945	67°26°.515	26°41.957	67°26°.463	26°41.809	7	7
AIXA2s	Korppiaapa 2s	23.4.2009	12:00	67°26°.633	26°42.143	67°26°.683	26°42.192	67°26°.65	26°42.012	9	9
AIXL2s	Kommattilampi 2s	24.4.2009	9:35	67°25.822	26°43.504	67°25.791	26°43.505	67°25.825, 67°25.794	26°43.568, 26°43.544	5	5, 5
AIXL1s	Kommattilampi 1s	24.4.2009	12:10	67°25.773	26°43.345	67°25.789	26°43.339	67°25.781	26°43.374	6	5
AIXH1s	Hirviäkuru 1s	25.4.2009	10:00	67°22.643	26°51.355	67°22.67°5	26°51.251	67°22.598	26°51.282	8	9
AIXS1s	Siurunmaa 1s	26.4.2009	10:15	67°26°.949	26°49.215	67°26°.958	26°49.201	67°26°.977	26°49.334	5	10
AIXR2s	Ravirata 2s	27.4.2009	9:00	67°24.388	26°40.413	67°24.391	26°40.556	67°24.337	26°40.428	8	7
NIX1s	NorSEN mast	12.3.2009	15:20	67°21.723	26°38.077	67°21.767	26°38.073			3	
“	“	13.3.2009	15:45	“	“	“	“			3	
“	“	14.3.2009	15:45	“	“	“	“			3	
“	“	15.3.2009	14:00	“	“	“	“			3	
“	“	16.3.2009	15:35	“	“	“	“			4	
“	“	17.3.2009	11:35	“	“	“	“			3	
“	“	18.3.2009	15:30	“	“	“	“			2	
“	“	19.3.2009	10:00	“	“	“	“			3	
“	“	20.4.2009	15:00	“	“	“	“			3	
“	“	21.4.2009	15:30	“	“	“	“			3	
“	“	22.4.2009	15:10	“	“	“	“			3	
“	“	23.4.2009	14:30	“	“	“	“			4	
“	“	24.4.2009	14:05	“	“	“	“			3	
“	“	25.4.2009	08:35	“	“	“	“			5	
“	“	26.4.2009	12:25	“	“	“	“			6	
“	“	27.4.2009	11:50	“	“	“	“			6	
“	“	28.4.2009	11:45	“	“	“	“			5	

Appendix 9: Locations of fractional snow cover measurements in 2009.

Koodi	Nimi	Kuvaus	Date	Time	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
AIXCR1	Rajala 1	Metsä	5.5.2009	13:40:00	67°37.755	26°17.352	67°37.744	26°17.493	67°37.793	26°17.527
AIXCR2	Rajala 2	Metsä	5.5.2009	14:24:00	67°37.083	26°20.320	67°37.048	26°20.211	67°37.099	26°20.141
AIXCR3	Rajala 3	Metsä	5.5.2009	15:00:00	67°36.036	26°22.946	67°36.060	26°22.824	67°36.085	26°23.017
AIXCR4	Rajala 4	Metsä	5.5.2009	15:30:00	67°35.132	26°26.053	67°35.136	26°25.910	67°35.180	26°26.058
AIXCR5	Rajala 5	Metsä	5.5.2009	16:05:00	67°33.707	26°34.841	67°33.748	26°34.756	67°33.740	26°34.944
AIXCR6	Rajala 6	Metsä	5.5.2009	16:30:00	67°31.394	26°37.184	67°31.448	26°37.263	67°31.373	26°37.312
AIXCK1	Kannusvaarantie 1	Taimikko (ojitettu)	6.5.2009	10:50:00	67°45.317	26°35.395	67°45.373	26°35.374	67°45.315	26°35.538
AIXCK2	Kannusvaarantie 2	Kuusikko/sekametsä	6.5.2009	11:45:00	67°44.994	26°36.952	67°44.954	26°36.920	67°45.000	26°36.799
AIXCK3	Kannusvaarantie 3	Aukea	6.5.2009	12:15:00	67°44.300	26°39.810	67°44.355	26°39.803	67°44.299	26°39.952
AIXCK4	Kannusvaarantie 4	Harva sekametsä	6.5.2009	12:40:00	67°43.213	26°41.353	67°43.266	26°41.400	67°43.190	26°41.480
AIXCK5	Kannusvaarantie 5	Harva sekametsä / hakkuuaukea	6.5.2009	13:04:00	67°42.657	26°42.721	67°42.603	26°42.684	67°42.637	26°42.846
AIXCK6	Kannusvaarantie 6	Sekametsä/taimikko	6.5.2009	13:29:00	67°42.906	26°44.922	67°42.859	26°45.018	67°42.879	26°44.803
AIXCR1	Rajala 1	Mäntymetsä	6.5.2009	14:30:00	67°37.744	26°17.495	67°37.798	26°17.530	67°37.755	26°17.347
AIXCO1	Oratunturi 1, laavu	Harvaa männikköä, metsäraja	7.5.2009	9:30:00	67°21.578	27°04.583	67°21.619	27°04.679	67°21.609	27°04.472
AIXCO2	Oratunturi 2	Harva sekametsä (rinne)/ koivikko	7.5.2009	10:15:00	67°21.665	27°03.737	67°21.721	27°03.698	67°21.656	27°03.590
AIXCO3	Oratunturi 3	Koivikko/sekametsä, alarinne	7.5.2009	10:43:00	67°21.733	27°02.684	67°21.675	27°02.670	67°21.729	27°02.542

Appendix 10: LAI measurement locations and times in 2009.

Place	Date	Time	Latitude	Longitude
Forest at the meteorological mast, left side	19.3.2009	n. 11	6721.71	2638.21
Clearing at the meteorological mast	19.3.2009	n. 11	6721.71	2638.21
Forest at the meteorological mast, left side, 1. spektrometer place	19.3.2009	10:19	6721.71	2638.21
Forest at the meteorological mast, left side, 2. spektrometer place	19.3.2009	10:42	6721.71	2638.21
Forest at the meteorological mast, left side, 3. spektrometer place	19.3.2009	11:05	6721.71	2638.21
Melalampi, road to the snowpit points	21.4.2009	11:28	6723.67	2643.851
Melalampi, road to the snowpit points	21.4.2009	11:28	6723.66	2643.85
Melalampi, road to the snowpit points	21.4.2009	11:28	6723.65	2643.84
Melalampi, road to the snowpit points	21.4.2009	11:28	6723.62	2643.82
Melalampi, road to the snowpit points	21.4.2009	11:28	6723.6	2643.82
Melalampi, clearing at spectrometer measurements	21.4.2009	11:32	6723.56	2643.66
Melalampi, clearing at spectrometer measurements	21.4.2009	11:32	6723.56	2643.66
Melalampi, clearing at spectrometer measurements	21.4.2009	11:33	6723.56	2643.66
Melalampi, clearing at spectrometer measurements	21.4.2009	11:33	6723.56	2643.66
Melalampi, clearing at spectrometer measurements	21.4.2009	11:34	6723.56	2643.66
Melalampi, spectrometer point 1.	21.4.2009	11:42	6721.72	2638.03
Melalampi, spectrometer point 2.	21.4.2009	11:44	6721.72	2638.03
Melalampi, spectrometer point 3.	21.4.2009	11:45	6721.72	2638.03
Melalampi, spectrometer point 4.	21.4.2009	11:46	6721.72	2638.03
Melalampi, spectrometer point 5.	21.4.2009	11:54	6721.72	2638.03
Melalampi, spectrometer point 6.	21.4.2009	11:56	6721.72	2638.03
Melalampi, spectrometer point 7.	21.4.2009	11:57	6721.72	2638.03
Melalampi, spectrometer point 8.	21.4.2009	12:00	6721.72	2638.03
Forest at the meteorological mast, left side, 1. spektrometer place	26.4.2009	12:34	6721.71	2638.21
Forest at the meteorological mast, left side, albedometer place	26.4.2009	12:36	6721.71	2638.21
Forest at the meteorological mast, left side, 2. spektrometer place	26.4.2009	12:44	6721.71	2638.21
Forest at the meteorological mast,right side, 1. forest spectrometer place	28.4.2009	12:45	6721.71	2638.21
Forest at the meteorological mast,right side, 2. forest spectrometer place	28.4.2009	12:46	6721.71	2638.21
Clearing at the meteorological mast	28.4.2009	12:56	6721.71	2638.21
Forest at the meteorological mast,right side, 1. forest spectrometer place	7.5.2009	15:32	6721.71	2638.21
Forest at the meteorological mast,right side, 2. forest spectrometer place	7.5.2009	15:33	6721.71	2638.21

Appendix 11: LAI measurement locations and times in 2010.

Point	Place	Dominant species	Date	Time	Latitude	Longitude
167	Kehtomaa	Scots pine			67.387227	26.630804
168	Kehtomaa	Scots pine			67.382790	26.629745
164	Kehtomaa	Scots pine			67.381989	26.629524
163	Kehtomaa	Scots pine			67.379100	26.631667
160	Kehtomaa	Scots pine			67.377870	26.632649
192	Tähtelä forest	Scots pine			67.376858	26.630158
191	Tähtelä forest	Scots pine			67.377408	26.628907
P12M_195	Tähtelä forest	Scots pine			67.376993	26.626081
198	Tähtelä shore	Norway spruce			67.375560	26.623453
193	Tähtelä shore	Norway spruce			67.376261	26.621026
196	Tähtelä shore	Deciduous			67.375237	26.620260
153	Tähtelä forest	Scots pine			67.372503	26.623291
154	Tähtelä forest	Scots pine			67.370694	26.628759
155	Tähtelä forest	Scots pine			67.369908	26.629434
156	Tähtelä forest	Scots pine			67.368430	26.629821
158	Tähtelä forest	Scots pine			67.367404	26.633841
172	Halssikangas	Scots pine			67.363436	26.636295
171	Halssikangas	Scots pine			67.362881	26.637318
175	Ollinlampi	Scots pine			67.358307	26.640927
P6G_202	Halssinkankaannokka	Scots pine			67.354159	26.652697
174	Halssinkankaannokka	Scots pine			67.353566	26.659538
P33O_214	Halssinkankaannokka	Scots pine			67.351206	26.661885
P13A_203	Kursala	Norway spruce			67.345595	26.679090
P13O_203	Kursala	Scots pine			67.346254	26.679292
UP1_H	Kaikkonen	Norway spruce			67.353188	26.686367
UP1_K	Kaikkonen	Scots pine			67.353841	26.685168
205	Kaikkonen	Norway spruce			67.356710	26.685149
206	Kaikkonen	Norway spruce			67.357616	26.684899
207	Kaikkonen	Norway spruce			67.359623	26.684067
181	Yli-Aavanmaa	Scots pine			67.301665	26.719360
178	Kurkiaapa	Scots pine			67.297778	26.734475
179	Ala-Aavanmaa	Scots pine			67.294853	26.734232
186	Käyräsjokisuumaa	Scots pine			67.274267	26.721457
188	Kiiskimännikkö	Norway spruce			67.199813	26.759702
187	Pyhä-Luosto	Norway spruce			67.187723	26.811198
217	Kiimaselkä	Norway spruce			67.137649	26.954131
AA01_H	Ruonivaara	Scots pine			67.353317	27.002733
AA02_J	Palomaat	Scots pine			67.328468	27.131679
MA04_C	Punamultajänkä	Scots pine			67.441093	26.745143
AD01_G	Heikinpalo	Scots pine			67.490006	26.609191

Appendix 12: Routine measurements operated at Sodankylä station (**http://litdb.fmi.fi/list_of_all_data.php**).

Upper-air data

Column data

Radiation data

Aerosol optical depth

FUVIRC

NorSEN mast

Albedo from the mast

Mast data

Synop data

HIRLAM

Pallas data

SMS data

Webcams

Upper atmospheric data

LIST OF ALL DATA

Name of group	**Instrument**	**Type of data**
Upper-air data	PTU sondes ECC ozone sondes (picture) Stratospheric water vapour sondes (picture) Aerosol backscatter sondes	PTU and wind vertical profile Ozone vertical profile vertical profile of water vapour vertical profile of aerosol backscatter
Column data	Brewer column ozone (picture) Brewer Spectrophotometer SAOZ (picture) GPS total water Radiosonde total water	Column ozone and SO2 Spectral UVB Column ozone and NO2 Total water Total water
Radiation data	Kipp&Zonen CM11 Empley NIP Solar Light SL-501	global, diffuse and reflected radiation direct radiation global UV-radiation
Aerosol optical depth	PFR sunphotometer	Aerosol optical depth at four wavelengths
FUVIRC	FUVIRC (picture)	UV radiation, temperature & PAR
NorSEN mast	ASD spectrometer (picture) Maws data	radiance, irradiance, reflectance soil moisture, snow depth
Albedo from the mast	Kipp & Zonen CM11	global & reflected radiation
Mast data	Mast data (picture) Temperature data (picture) Soil data (picture)	Explanations of mast data - Explanations of soil data
Synop data	Synop observation/AWS Historical synop observations	Explanations of manual synop data -
Pallas data	CO2 measurements Aerosol measurements	CO2 Aerosol

ILMATIETEEN LAITOS, RAPORTTEJA 2014:7
978-951-697-835-5 (PAPERBACK)
978-951-697-836-2 (PDF)
ISSN 0782-6079
Unigrafia
Helsinki 2014

Ilmatieteen laitos
Erik Palménin aukio 1, Helsinki
tel. 029 539 1000
www.ilmatieteenlaitos.fi