Inventory of Observing Sites, Systems & Networks

Finnish Arctic and sub-Arctic environmental and climate monitoring programs and sites north of the Arctic Circle

DRAFT REPORT, 9 November 2009

This report describes the main monitoring stations and continuous observation programs in the region of Finnish Lapland.

1. Sodankylä-Pallas super site of the Finnish Meteorological Institute (FMI)

Name and acronym:	Sodankylä-Pallas
Contact person (e-mail):	Jouni Pulliainen (jouni.pulliainen@fmi.fi)
Web site:	http://fmiarc.fmi.fi/

Main objective of the network:
Atmosphere monitoring, cryosphere monitoring, atmosphere-biosphere interaction

Type of activity:
In situ monitoring with automatic and manual systems (e.g. synoptic meteorological observations since 1908), measurements with ground-based reference systems of space-borne remote sensing instruments

Theme(s):
- Atmosphere
- Terrestrial ecosystem
- Cryopshere
- Space physics
- Earth science

Location(s):	Sodankylä (centre 67°21.712′ N; 26°38.270′ E) Pallas (centre 67°58.400′ N; 24°06.967′ E)

Geographical coverage:
Region with a total size ~150 x 200 km including two main stations

Data archive/centre, including Web site:	http://litdb.fmi.fi/
Data availability:	Open database for research purposes

1.1 Introduction and objective

Dense ground-based observation networks monitoring atmospheric and surface environmental characteristics only exist in densely populated areas. However, in remote regions, such as arctic, sub-arctic and boreal zones of Eurasia and North America, the monitoring networks are typically sparse. In contrast to the general case, the Sodankylä-Pallas site (as well as the whole region Finland), is covered with dense weather, hydrological and environmental monitoring networks and specialized research stations. The Sodankylä-Pallas site is located in northern Finland north of the Arctic Circle and it is a good representative of boreal and sub-arctic Eurasian environment in a transition zone from marine to continental climate (a transition from marine to continental in the west to east direction). The site provides *in situ* monitoring and high spatial resolution land cover data sets that are not available for other regions north of the latitude of 60°. A special feature of the site is that it is the westernmost part of the Eurasian taiga belt that reaches close to the Pacific Ocean in its easternmost extent. As the Russian *in situ* environmental and climate monitoring network has declined since the early 90's, the Sodankylä-Pallas site provides data and a research infrastructure (available e.g. for measurement campaigns) that are not available elsewhere in that particular ecological and climate region. Sodankylä-Pallas site has also an ideal location for studies of upper atmospheric (ionospheric) coupling with near-Earth space phenomena as the site passes every night below the auroral oval.

The data sets available for the Sodankylä-Pallas region include the weather and atmospheric parameter monitoring data from the Finnish Meteorological Institute (FMI), land cover characteristics and hydrological monitoring and modelling data from the Finnish Environment Institute (SYKE), and selected data sets form other Finnish research institutes and universities.

Intensive stations equipped with a large variety of atmospheric sampling, profiling and automatic surface parameter measurement systems are located near the town of Sodankylä (Arctic Research Centre of FMI with a permanent staff of around 30 persons), and at/in the vicinity of Pallas Mountain 100 km north-west from Sodankylä. Additional data sets are available from *in situ* and aerial monitoring campaigns, e.g. brightness temperature and reflectance data sets by Helsinki University of Technology (TKK). Ionospheric observations are collected with the MIRACLE network comprising ~30 stations distributed in Fennoscandian mainland and Svalbard (Janhunen et al., 2000). MIRACLE network is maintained as an international collaboration under the leadership of FMI.

The available data sets range from point-wise monitoring observations to regionally distributed information. The data sets are relevant for space-borne remote sensing instruments with a high or coarse spatial resolution, as well as for atmosphere or surface monitoring instruments. The available reference data also enables the analyses of mixed pixel effects that are highly relevant for the utilization of satellite observations with a coarse spatial resolution.

The Sodankylä-Pallas satellite calibration and validation site is coordinated by the Arctic Research of the Finnish Meteorological Institute (FMI-ARC) and the activities of the site are related e.g. to the Global Atmosphere Watch (GAW) network of WMO, and to the Long Term Ecological Research (LTER) activities coordinated in Finland by the Finnish Environment Institute (SYKE). Currently, FMI-ARC receives processes and delivers MODIS and OMI data from NASA EOS Terra, Aqua and Aura satellites. FMI-ARC also facilitates ESA Envisat GOMOS ozone monitoring instrument's data processing and satellite data archives related to EUMETSAT O3SAF.

1.2 Site characteristics and available land cover data

The Sodankylä-Pallas site is a typical representative of Eurasian taiga belt characterized by a mosaic of sparse conifer-dominated forests and open/forested bogs. The landscape is generally relatively flat or gently rolling although small mountain regions (fjelds) are typical. The map on the cover letter shows the location of the site with intensive research stations at the town of Sodankylä and Pallas Mountain indicated. The land use map of the region provided by SYKE is shown in Fig. 1.1 (land cover and forest characteristics with a spatial resolution of 25 m). Figs. 1.2 and 1.3 show typical aerial and ground-based views of the region.

Fig. 1.1. Land cover map by SYKE on the Sodankylä-Pallas site (with a spatial resolution of 25 m). Coniferous forests on mineral soil are depicted by dark green colour. Light green colour depicts sparse coniferous dominated forests (mainly on peat soil) and open bogs are depicted by grey. Open rock and barren areas (fjells) are shown by brownish colours and open water by blue. Buildings and urban regions are depicted by red.

Fig. 1.2. Spring-winter view on small mountains and boreal forests north-east of Sodankylä.

Fig. 1.3. Examples of forests and bogs of the region.

1.3 Available surface and atmospheric parameter monitoring data sets

FMI operates research stations at Sodankylä and Pallas regions as well as distributed weather station network throughout the region. While the Sodankylä monitoring operations are based on the FMI-ARC research facility located near the town of Sodankylä, the Pallas station is geographically distributed into five separate monitoring sites. Coordinates of the main intensive sites are listed in Table 1.1.

Table 1.1. Coordinates (WGS-84) of selected intensive monitoring areas.

	Latitude	Longitude	Altitude above the sea level
Sodankylä Scots pine forest at FMI-ARC	67°21.712′ N	26°38.270′ E	179.3
Kenttärova spruce forest at Pallas	67°59.234′ N	24°14.583′ E	347
Sammaltunturi fjeld at Pallas	67°58.400′ N	24°06.967′ E	565
Lompolojänkä at Pallas	67°59.832′ N	24°12.551′ E	269

1.3.1 Sodankylä data and measurement program

The Sodankylä monitoring program includes:

- synoptic weather observations performed both automatically and manually (manual observations on a continuous basis starting from 1908);
- solar radiation and albedo and measurements;
- meteorological mast experiment with extensive monitoring of soil-vegetation-atmosphere interaction parameters including CO2 flux measurements (also changes in vegetation and soil carbon storages are monitored);
- remote sensing CAL-VAL-mast experiment with surface spectral reflectance monitoring and multi-channel microwave brightness temperature observations accompanied with soil and snow characteristics monitoring;
- ground based UV, ozone, water vapour and aerosol optical depth observations;
- balloon-borne monitoring of tropospheric and stratospheric profiles of various parameters;

- radioactivity measurements;
- distributed snow observations and other hydrological measurements and
- ionospheric electrodynamics observations.

Examples of the experimental monitoring instrumentation are shown in Figs. 1.4 and 1.5. The spectrometer system of the remote sensing CAL-VAL mast experiment is installed into the 30-m-high mast is shown in Fig. 1.4, whereas the meteorological mast experiment is depicted in Fig. 1.5. The meteorological mast experiment is actually a part of an intensive boreal forest monitoring site primarily dedicated for carbon flux observations. However, the vertically distributed meteorological observations at the mast are also used e.g. for the validation and further development of limited area weather prediction model (HIRLAM). The mast-based spectrometer system has been used e.g. for the investigation of reflectance characteristics of snow covered forested terrain. Detailed monitoring information on winter-time snow cover has been collected starting from the year 2006 (vertical profiles of snow pack including e.g. snow grain size information).

The data available for the Sodankylä site are summarized in Tables 1.2 and 1.3. Note that ionospheric observation sites of Table 1.3 are distributed over a larger region, see Fig. 1.6. The newest instrumentation installed in the end of 2008 is a Fourier-transform interferometer infra-red band spectrometer (FTIR) for the observation of columnar CO2 of atmosphere, see Fig. 1.7. The system is part of the global TCCON network for CO2 monitoring.

Long-term radiosonde measurements as shown in Table 1.2, have been made in Sodankylä since 1949, which is one of the longest records in the European sector of Arctic. Regular profile measurements by balloon-borne ozonesondes started in year 1989. The ozonesonde data from Sodankylä have been used in trend studies, process studies of the Arctic stratospheric chemistry and in a number of satellite validation studies.

Fig. 1.4. The spectrometer installed into the 30-m-high mast. The measurement head is located on the top in a boom 3.80 meter distance from the mast. The boom is rotated by a turning the pole during a measurement in order to measure a forested target area and a forest opening. As a result forest and open area VIS/IR reflectance spectra are obtained. The spectrometer is installed into a weather resistant cover box. The measurement head has a 25 degrees field-of-view, and it is directed 11° off the nadir. A large-view control/reference image acquisition camera is also included into the system. A special moving white reference panel provides on-site calibration. Reference measurements within the mast area include continuos automatic observations ground surface temperature and soil moisture, snow depth and snow water equivalent (SWE).

Fig. 1.5. Micro-meteorological tower experiment at Sodankylä. The mast with a height of 48 m is installed into a Scots pine forests on sandy soil measuring eddy-covariance fluxes of CO_2, latent and sensible heat and momentum, radiation components, and gradients of the CO_2 concentration, temperature and wind. Soil, vegetation and snow parameters are also monitored in the forest region around the tower.

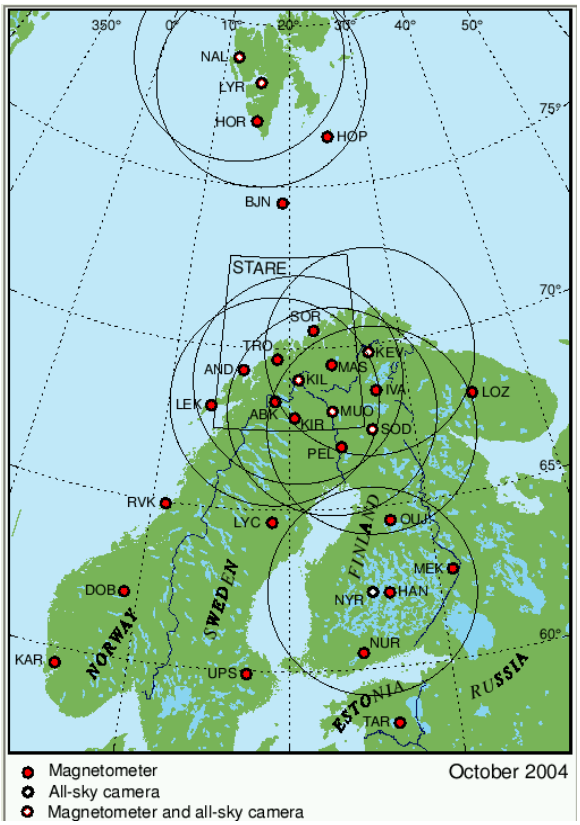

Fig. 1.6. Stations of the MIRACLE network. The field-of-views of the auroral cameras and STARE radar are shown with the black circles and trapezoid.

Fig. 1.7. Sun-tracker of the FTIR CO2 measurement system.

Table 1.2. Observations at FMI-ARC, Sodankylä (excluding reference instruments for space-borne sensors).

Ground weather observations	Starting year	Description
Temperature, Air pressure, Air relative humidity, Wind speed and direction, Visibility, Precipitation, Soil temperature, Snow cover	1908	Ground
Air chemistry: Radon-222 (Aerosol Beta activity, Alpha counting)	1996	Ground
Solar radiation observations		
Global- , reflected-, diffuse- and direct component of solar radiation, sunshine hours	1957	16 m Tower
Aerosol optical depth	2004	16 m Tower
Ground based UV- and Ozone observations		
Global UV-radiation, Spectral UV-radiation, Total column ozone	1990	Ground
Total column Ozone, Total column Nitrogen Dioxide	1990	Whole atmospheric pillar
Balloon borne observations		
Temperature, Air pressure, Air relative humidity, Wind speed and direction from radiosondes	1949	Ground to 30 km
Ozone concentration from ECC sonde	1988	Ground to 30 km
Water vapour concentration from frost point hygrometer	2003	Ground to 30 km
Aerosol backscatter coefficient from backscatter sondes	1994	Ground to 30 km
Meteorological Mast Experiment		
Soil temperature- and moisture profiles, RH% at 10 cm, leaf (needle) wetness, heat flux	1999	Ground
Snow depth, Snow temperature profile, air temperature and relative humidity 10 cm above soil or snow	1999	Ground
Sonic wind speed, direction , temperature, friction velocity, heat vertical flux at 3 ,8,32 and 47 m	1999	48 m high meteorological mast
Temperature, Relative humidity, Wind 3,8,18,25,38,47 m, water vapour vertical flux	1999	48 m high meteorological mast
Global- , Reflected-, Diffuse- component of solar radiation, Net radiation , Photo-synthetically Active Radiation (PAR)	1999	48 m high meteorological mast
Long-wave radiation , Outgoing long-wave radiation, Radiation temperature of canopy	1999	48 m high meteorological mast
Eddy-covariance fluxes of CO_2 and gradients of CO_2 concentration	1999	48 m high meteorological mast
Other observations		
Snow observations along a 4 –km snow course		Ground

Table 1.3. Observations at the distributed ionospheric/magnetic observation sites (MIRACLE network coordinated by FMI-ARC).

Ionospheric electrodynamics	Starting year	Description
Variations in the geomagnetic field	1982	A network of magnetometers (called IMAGE) which started with 6 stations and today has 26 stations
Intensity of auroral light, wavelengths 557.7, 427.8 and 630.0 nm	1996	A network of digital auroral cameras with 5-8 sites depending on year.
Ionospheric plasma convection	1998	Bi-static VHF- radar system (called STARE) which operated until 2005.

1.3.2 Pallas data and measurement program

The functions of the intensive measurement sites of Pallas are the following: The first unit, the *Sammaltunturi* station (Fig. 1.9) on a barren mountain top focuses on the continuous *in situ* sampling of aerosol particles and *in situ* analyses of atmospheric gas composition, e.g. carbon dioxide concentration. Open bog measurement station of *Lompolojänkä* collects soil surface and soil to atmosphere gas, e.g. methane, exchange data. The third station, *Kenttärova*, focuses on the monitoring of soil (including snow) characteristics and boreal forest canopy to atmosphere gas exchange characteristics related to the carbon cycle. Coordinates of the main intensive sites are listed in Table 1.1 and the site is illustrated in Fig. 1.8. The fourth station, *Matorova,* is located in a spruce forest. It is used mainly for sampling of gases, aerosol particles and precipitation for subsequent laboratory analysis. Heavy metals (e.g. lead and cadmium), inorganic components (e.g. sulphate and ammonia), and organic pollutants (e.g. PAH compounds). All these four stations are equiped with automatic weather stations. The fifth station, *Laukukero,* is located on a barren mountain top 765 m above sea level. It is used for air chemistry measurements on a campaign basis. The station also incorporates an automatic weather station that measures temperature and humidity profiles along the hill slope in addition to the mountain top. The data available from FMI for the Pallas station are summarized in Table 1.4.

Table 1.4. Observations at the Pallas GAW site.

Meteorology	Starting year	Description
Full set of meteorological data from about 300 m, 500 m, 560 m, 660 m, 720 m, 790 m above sea level	1992	Automatic weather stations at the Pallasjarvi lake and on the surrounding hill sides
Air chemistry at Sammaltunturi		
Gases: O_3, SO_2, CO_2,N_2O,CH_4, Volatile Organic Compounds	1992	560 a.s.l
Aerosols: Condensation nuclei, Particle Size Distribution, Aerosol scattering Coefficient, Black Carbon , Radon-222 (Aerosol Beta activity, Alpha counting)	1992	560 a.s.l
Solar Global Radiation, NO_2 Photodissociation Frequency, **J**(NO_2)	1992	560 a.s.l
Air chemistry at Matorova forest site		
Gases: Nitrate+_nitric acid, Ammonium+ammonia, Heavy metals,Mercury (particulate, gaseous)	1995	340 a.s.l
Precipitation chemistry: pH conductivity, major ions, Heavy metals, Mercury, Persistent Organic Compounds	1995	340 a.s.l
Flux and surface measurements at Kenttärova boreal forest site		
CO_2 flux, air temperature, soil moisture, soil temperature, snow depth		
Flux and surface measurements at Lompolojänkä open bog		
CO_2 flux, temperature		

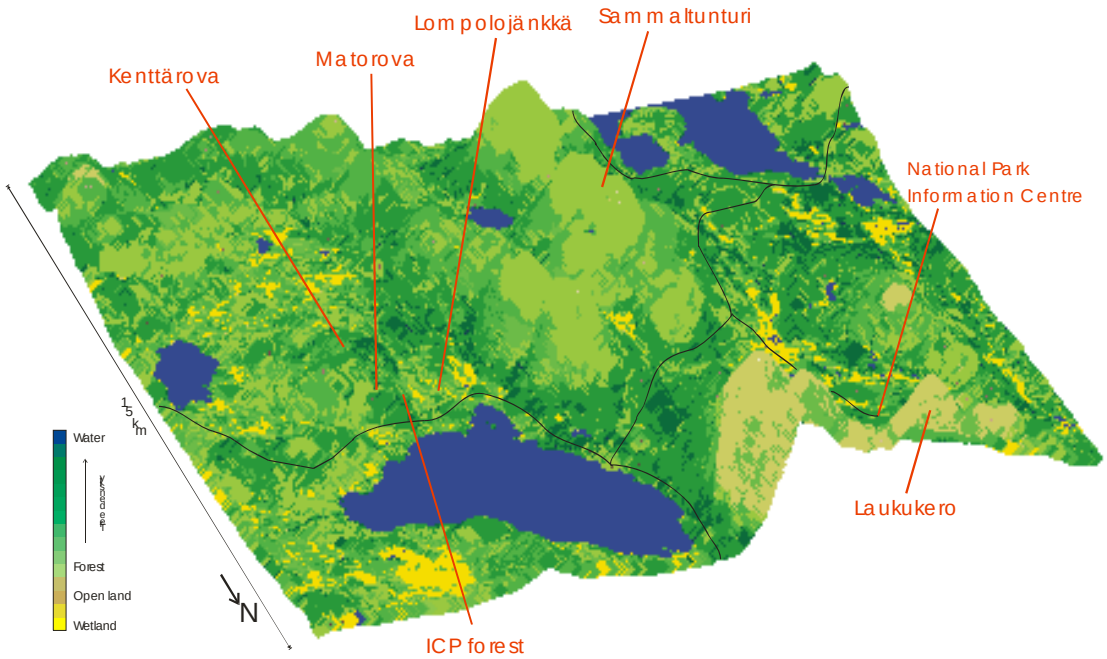

Fig. 1.8. Pallas site with distributed observation stations.

Fig. 1.9. The Sammaltunturi station at the Pallas site.

2. Värriö sub-arctic research station of University of Oulu and University of Helsinki

Name and acronym: Värriö Subarctic Research Station, Värriö

Contact person (e-mail): Prof. Pertti Hari (pertti.hari@helsinki.fi)

Web site (if any): www.mm.helsinki.fi/varrio

Main objective of the network:
SMEAR-I station for measuring ecosystem-atmosphere relations

Type of activity:
Automatic and manual monitoring of atmosphere and biosphere (incl. SMEAR I –station and synoptic weather observations) as well as tracking and monitoring wide range of flora and fauna (e.g. game, insects and berries).

Theme(s):
- Atmosphere
- Terrestrial ecosystem

Location(s): 67°76N; 29°61E

Geographical coverage:
Värriö Strict Nature Reserve, with an area of 125 km^2

Data archive/centre, including Web site:

Data availability: No open database

2.1 General information

SMEAR I –station (Station for Measuring Ecosystem – Atmosphere Relations) was built in 1991-1992 at the side of Värriö Subarctic Research Station to monitor the pollution originating from Kola Peninsula. Continuous measurements of trace gases, aerosols, photosynthesis growth of Scots pines and meteorology have been carried on by the University of Helsinki since 1992. The station is located at the northern border of Salla municipality, some 6 km's from the Russian border and built on top of a 390 m high forested hill. A 16 meter high weather mast is mounted next to the measurement cabin.

The closest source area for air pollutants are the mining and metallurgical industry at the Kola Peninsula with the most important point sources being Nikel, Montcegorsk and Zapolyarny, respectively. In addition to the measurements carried on by the University of Helsinki, Finnish Meteorological Institute (FMI) has been measuring both sulphates and heavy metals using filter sampling techniques. Also, respiration and photosynthesis of the soil has been measured campaign wise in the vicinity of the station.

Trace gases have been measured at four different levels (2, 6.5, 9 and 15 m) above the ground until recently the three highest sampling levels were taken off. The sulphur dioxide concentration is measured with a pulsed fluorescence analyzer. Nitrogen oxides (most importantly NO and NO_2) are measured with an analyzer that is based on chemiluminescence and ozone is measured with a photometric analyzer. Total aerosol concentration has been measured since 1991 and the particle size distribution since 1997. The cut-off diameter of the size distribution measurements was changed from 8 nm to 3 nm in 2003. The total concentration is measured using CPC (Condensation Particle Counter) and the size distribution with DMPS (Differential Mobility Particle Sizer) system. Photosynthesis of Scots pines is measured from living twigs using chambers placed on top of the trees. Also, the growth in width and length are measured. A wide range of meteorological parameters are measured at five different levels (2, 4, 6.6, 9, 15 ja 16 m).

Below is a list of parameters measured at the station (the beginning of the measurements given in parenthesis if not 1992):

Trace gases: SO_2, O_3, NO, NO_x, CO_2 (-2000)

Scots pines: CO_2 and H_2O –exchange, temperature, PAR (photosynthetically active radiation), growth in thickness (2004 onwards) and length

Aerosols: total particle concentration (-2005) and the particle size distribution (1997-)

Meteorology: PAR, global radiation, UVA, UVB, temperature, relative humidity, soil temperature, wind speed, wind direction, air pressure, rainfall, precipitation (indicative).

Fg. 2.1. Tower of SMEAR-I station at Värriö.

3. Meteorological observation network of the Finnish Meteorological Institute (FMI)

Name and acronym: FMI weather station network

Contact person (e-mail): keijo.leminen@fmi.fi

Web site (if any): www.fmi.fi

Main objective of the network:
To produce weather observations for weather services and climatological research and service

Type of activity: Automatic operational weather station observations

Theme:
- Atmosphere

Location(s): Distributed network (about 180 sites over Finland)

Geographical coverage:
Coverage over Finland mainly according to WMO recommendations including all Finnish polar regions

Data archive/centre, including Web site: Data archived in database

Data availability:
Available for research purposes, partially from the open database at fmiarc.fmi.fi (http://litdb.fmi.fi/); Data available in real time.

3.1 General information

The distribution of weather stations of FMI in northern Finland is shown in Fig. 3.1. Some of the stations also include automatic daily snow depth observations and soil moisture monitoring instrumentation.

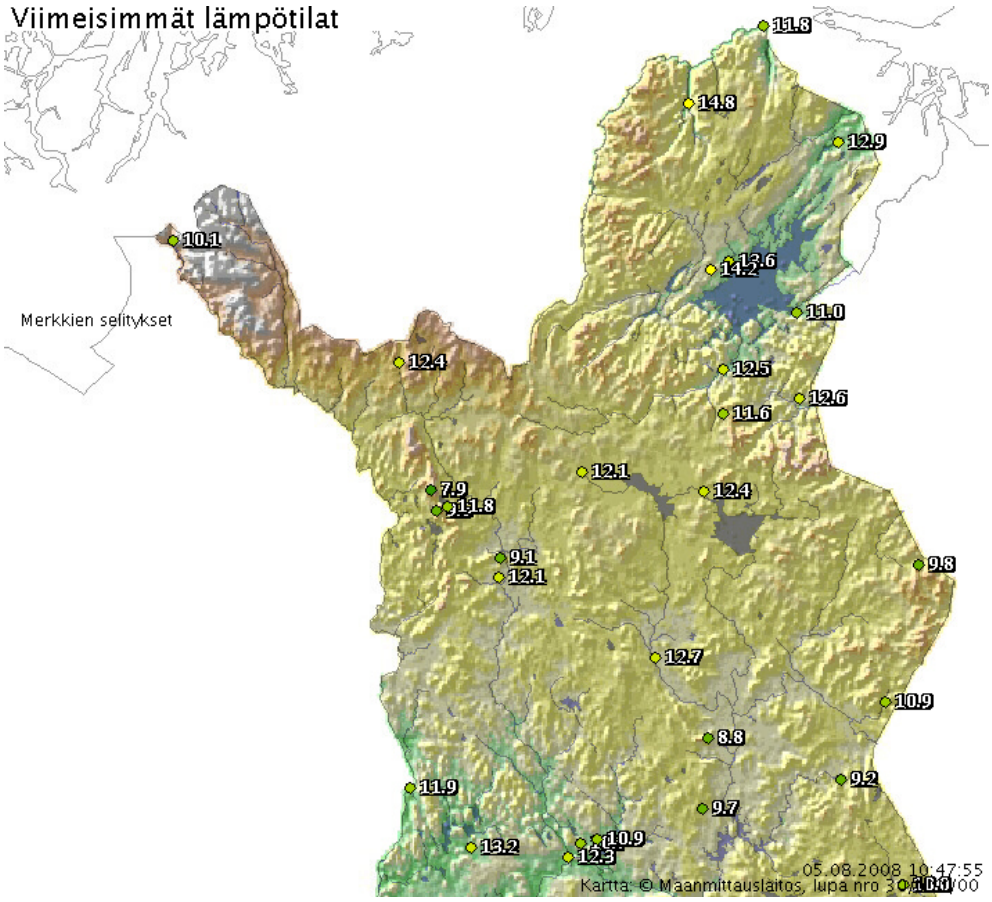

Fig. 3.1. Weather station network of FMI in northern Finland.

4. Hydrological observation network of the Finnish Environment Institute (SYKE)

Name and acronym: Hydrological observation networks

Contact person (e-mail): Markku Puupponen (markku.puupponen@fmi.fi)

Web site:
http://www.ymparisto.fi/default.asp?contentid=66123&lan=en

Main objective of the network:
To collect hydrological data to be used for a wide range of purposes in the utilization and management of water resources (e.g. in watercourse regulation and in flood protection), in water pollution control and in environmental research.

Type of activity: Hydrological in-situ monitoring

Theme:
- Hydrology

Location(s):

Geographical coverage: Finland

Data archive/centre, including Web site:
SYKE's environmental information system (www.ymparisto.fi/oiva)

Data availability: Open database, free of charge by self service

4.1 General information

The national program of hydrological monitoring is managed by the Finnish Environment Institute (SYKE), which is responsible for keeping the monitoring networks representative, for giving instructions concerning observations and measurements, for collecting the results into a database and for information services concerning the water situation. Regional environment centers are responsible for the field work needed for maintaining the monitoring stations, but they also have their own regional monitoring programs and information services.

The data available from SYKE for northern Finland also include a land cover classification covering the region with a spatial resolution of 25 m. Actual hydrological monitoring observations are available e.g. on snow water equivalent, snow depth, snow density, fraction of snow covered area, soil frost depth, lake and river ice, water temperature, river discharges and water levels. Fig. 4.1 shows the monitoring network for the whole region of Finland. The snow data include monthly or bimonthly observations at fixed snow courses (each course is track of 2 to 4 kilometres providing an estimate on regional snow cover characteristics separately for open and forested areas (actually for six land cover categories). Also water quality (including some optical characteristics) monitoring data are available from selected lakes of northern Finland.

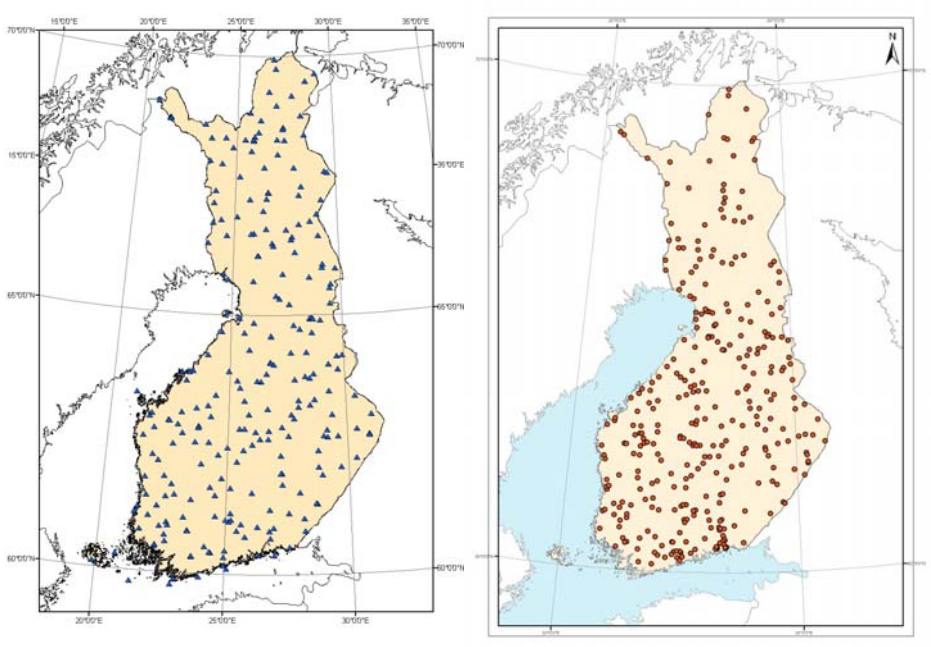

Fig. 4.1. Right: Snow course network of SYKE. Left: River discharge monitoring stations of SYKE.