Finnish National Report on Systematic Observations for Climate

National Activities with Respect to the Global Climate Observing System (GCOS) Implementation Plan

Prepared for Submission to the United Nations Framework Convention on Climate Change (UNFCCC)

Compiled by the
Finnish Meteorological Institute

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SUMMARY

Finland continues its efforts in carrying out, archiving and distributing the most reliable and sustainable systematic observations related to various climate variables. These atmospheric, oceanic and terrestrial observations are based on the regulations of corresponding international organizations. The implementation of systematic observations in Finland is tabulated in this report, which was made in accordance with the revised United Nations Framework Convention on Climate Change Reporting Guidelines on Global Climate Change Observing Systems (2007). Since the foundation of the Global Climate Observing System the climate-related work in Finland has been directed gradually to follow the GCOS climate monitoring principles. The continuation and improvement of these activities are going on as well as climate change-related research.

Framework

This report was prepared in response to conclusions FCCC/SBSTA/2005/10, paragraph 95 (2005) and FCCC/SBSTA/2007/L.14 (2007) of the UN Framework Convention on Climate Change (UNFCCC) Subsidiary Body on Scientific and Technological Advice (SBSTA) and presents the progress in the implementation of GCOS in Finland. Additionally, the requirements especially related to new Essential Climate Variables, ECV's, are taken into account as detailed in the updated GCOS Implementation plan (2022) and encouraged in the conclusion FCCC/SBSTA/2010/L.22.

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N.B. The acronyms used in this report are either explained in the text or can be found in
http://www.wmo.int/pages/themes/acronyms/index_en.html

Cover figure: *Dr. Melander, the director of Finnish Meteorological Institute's predecessor, makes an inspection as weather observations are being carried out in Helsinki in the 1920s.(Credit: Finnish Meteorological Institute's archive)*

Contents

1. COMMON ISSUES

Introduction

Making reliable, continuous and accurate systematic observations lays the groundwork for climate-related studies. High-quality observations are essential in climate change monitoring as well as for understanding long-term climate variations that is needed for climate change adaptation strategies and validation of models.

Established in 1992, the Global Climate Observing System (GCOS) addresses these needs and acts to ensure that observations are carried out and archived in the best possible ways and that they are further made available to a wide array of end-users. GCOS encompasses a wide array of climate-related systematic observations of physical, chemical and biological properties of the atmosphere, the ocean and the land surface.

To implement the GCOS plan in Finland, national coordination is necessary, yet many of the advised mechanisms are already deeply rooted in the everyday workflow at the responsible institutions. As an example continual meetings between the observational unit and climate service group take place to discuss the current issues regarding systematic observations to ensure that they are carried in the most efficient, reliable and sustainable way. In addition several homogenization projects (including Nordic cooperation) are underway to take into account changes in location, surroundings and technology.

The newest and perhaps the most significant change in the past few years in GCOS-related affairs in Finland has been the open data policy at the Finnish Meteorological Institute that was adopted in the beginning of 2013. Already a vast amount of forecast and observational data is freely available to the public with more being added continuously.

The open data policy has emphasized the importance of digitizing past observations as well as further improving the quality control of observations. In addition it has widened the use of systematic observations both in scientific as well as commercial use. Updated observations have been resubmitted for example for various reanalysis projects.

In response to GCOS IP-10, this report presents the progress in the implementation of GCOS in Finland, according to the guidelines adopted at the 13th UNFCCC Conference of the Parties (COP13; Decision 11/CP.13).

National GCOS coordination

Finland's contribution to systematic observations with regard to GCOS has been reported in the National Communications under the framework of UNFCCC.

The national GCOS coordination is taken place by the Finnish Meteorological Institute (FMI). The various observing activities in Finland are carried out as follow:

- The Finnish Meteorological Institute is responsible for the operational and research activities in climatology including climate data-monitoring and applications-services (cf. Ch.2) as well as marine observations (cf. Ch 3).

- Climate-related terrestrial observational activities in Finland are carried out at the Finnish Environment Institute (cf. Ch.4).

- Some climate-related observations are also made in the Natural Resources Institute Finland (Luke), MTT Agrifood Research, and at several universities.

National committees co-ordinate activities in Finland in relation to Intergovernmental Panel on Climate Change and International Geosphere-Biosphere Programme. Finland is operationally taking part in the World Weather Watch (http://www.wmo.int) by the synoptic network of surface and upper-air stations. These stations constitute also the basis for the climatological services, applications and research. This station network is complemented nationally by climatological and precipitation stations.

Finland is also contributing to the Global Atmospheric Watch (http://www.wmo.int). Finland takes part in WMO climate activities mainly through the Commission for Climatology (CCl) and its Open Panel of CCl Experts (OPACE), especially climate data and data management.

Satellite information

Satellite observations are needed to obtain necessary observations of the climate system. Thus, a detailed global climate record for the future depends much on the satellite component within GCOS. Finland has significant activity in the field of satellites and remote sensing covering developing applications, building sensors and satellites and doing high-level research.

Finnish Meteorological Institute’s Arctic Space Centre (ARC) operates Sodankylä National Satellite Data Centre (NSDC). NSDC has four satellite receiving systems that are used to receive satellite data for operational and research purposes. Two 3.7 m antenna systems operate in X/L-band and two 7.3 m antenna systems in X-band but one being also capable to receive and transmit data on S-band. The northern location above 67 latitude makes the site ideal for receiving data from polar orbiting satellites. NSDC’s ground station services are used in a national level and also globally. The site has co-operation with, for example, ESA, EUMETSAT, NOAA and NASA.

NSDC has data center to process, store and disseminate the received satellite data and data collected from over 500 wide in-situ measurement network located in Sodankylä. The data center has state-of-the-art processing capacity including high performance computing (HPC). Most of the services and processes run on virtual environments and the data can be stored and disseminated using could object storage, like S3. NSDC also offers cloud services that makes it possible for external users to do the processing next to the data instead of moving massive datasets from the site.
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Figure 1.1. *FMI satellite data centre at Arctic Research Centre at Sodankylä northern Finland*.

Figure 1.2. *FMI Arctic Space Centre's area. NSDC's 7.3 m antennas are seen on right-hand side and in the left back the 32 m EISCAT radar receiver antenna.*

Since entering the into a contract in 2012 to receive and process Italian COSMO-SkyMed Synthetic Aperture Radar (SAR) satellite constellation data FMI has been supporting Finnish, Swedish and Estonian ice services and ice breakers. The SAR instruments onboard the satellite constellation enables FMI to provide real-time information on ice conditions in the Baltic Sea. Compared to optical sensors, SAR is capable of to provide images independently from atmospheric conditions or available daylight. The received satellite data is processed at NSDC and delivered to ice breakers in 30 minutes.

FMI is ESA's Sentinel Collaborative Ground Segment and provides Sentinel satellite data and products through its FinHub data service. FinHub is a local data distribution point focusing on Finland and Baltic Sea drainage and targets delivering data and products without download limitations and faster compared to global datahubs.

The report of systematic observation requirements for satellite-based products for climate was compiled by the WMO GCOS Secretariat in 2006 as a supplement to GCOS Implementation Plan (GIP-SS; WMO, 2006). Additional refined details related to satellite-based products have also been given in subsequent reports (e.g. GCOS IP-10). Activities related to satellite-products with involvement of Finnish institutions are described in Chapters 2-4 for relevant Essential Climate Variables (ECV, cf. Annex 1).

Palaeoclimatology

Estimates of past climate variability (i.e., palaeoclimatology) can be retrieved from several types of records. Finnish universities and research institutes have extensive activities in palaeoclimatology, and they cooperate in several research areas. Studies are primarily based on abundant natural archives in Finland and polar areas.

At the Environmental Change Research Unit (ECRU), Faculty of Biological and Environmental Sciences of the University of Helsinki, the central research theme is the development and application of empirical, computational and modelling tools to detect global climatic and environmental changes and analyse their ecological and societal impacts. ECRU is particularly interested in centennial to millennial-scale climatic changes with a focus on Arctic environments. The research is largely based on proxies stored in natural archives (peatlands, lake and marine sediments, ice cores). Specific research themes include carbon cycling, past climate development and extreme climatic events, past black carbon deposition in the European Arctic, Arctic sea-ice history, and past peatland, lake and marine ecosystem dynamics.

Intensive data handling and application of big data compilations are a key element of research at ECRU. In addition, monitoring and proxy calibration founded on modern environmental data from peatlands, catchments and ice-covered lake and marine environments plays a central role in past climate reconstruction. The research of ECRU is also a part of wider international research programs and networks (e.g. AMAP, PAGES; The Arctic Society of Finland, Arctic Avenue).

The Department of Geosciences and Geography at the University of Helsinki works on climate reconstructions based on biological indicators in lake sediments. The Geological Survey of Finland studies varved sediments, with an emphasis on their physical properties.

At the Geosciences Research Unit of the University of Oulu, the objectives under palaeoclimatological research are to produce important threshold values in geochemical (incl. isotopic fingerprint) and sedimentological proxy information on past climate warming events and related loss of ice in the Arctic in time scales from hundreds to hundreds of thousands of years.

The research unit has conducted influential research on the glaciation history of Eurasian Arctic. A special emphasis has been to study the dynamics of past ice sheets, evolution of landscape and high-latitude oceans with modern sedimentological techniques and laser scanning imageries of glacial landforms. The studied marine sediment records from the Central Arctic Ocean and the Baltic Sea also document transitions between different climate states well, including abrupt events on timescales of decades to a few centuries. The research is conducted under international research programmes such as the International Ocean Discovery Program (IODP).

The Space Climate Research Unit of the University of Oulu studies the long-term (up to a few hundred years) evolution of the Sun and the effects of solar magnetic activity to the space around the Sun, including the Earth. All possible long-term series of observations made by satellite and ground-based instruments to study solar effects to the Earth’s atmosphere and climate are in use. The solar wind affects the climate and atmosphere, especially at high latitudes. Studies are related to questions like how these mechanisms influence the atmosphere and how relevant they are to climate change.

The Laboratory of Chronology (LC) of the Finnish Museum of Natural History analyses the isotopic and elemental compositions of samples from different environmental archives. The LC has led efforts to construct radiocarbon and stable isotope chronologies from Finnish subfossil materials for the late and mid Holocene times, in cooperation with Luke (see below). The aim is to constrain the temperature-cloud-irradiance interrelationships and their dependence of North Atlantic variability in the ocean-atmospheric circulation. Furthermore, abrupt climatic and environmental anomalies are tracked down by multiproxy methodologies and the interaction between nature and people is addressed.

Natural Resources Institute Finland (Luke) has constructed one of the longest tree-ring chronology in the world (5634 BC to AD 2021) based on mega fossil and living trees recovered from lake bottoms and lakesides. This tree-ring material and its carbon isotope data has been used for reconstructions of past summer temperature and cloud cover changes and variability in the northern climate after the last glaciation period, in cooperation with LC.

In general, Luke contributes to climate research with tree-ring data for reconstructions of past temperature, cloudiness and precipitation variability in Finland and in international cooperation for Hemispheric and global scale reconstructions. Paleoclimate data are used for analysing the impacts of natural forcing factors (solar activity and explosive volcanism) and the effects of ocean-atmospheric circulation on climate variability. The paleoclimate expertise of Luke contains the fieldwork and laboratory work with subfossil wood materials (tree-ring dating, blue intensity/latewood maximum density, wood anatomy) needed to build the long tree-ring chronologies.

Figure 1.3. *These subfossils of Scots pine have preserved several thousands of years in lake sedimentary conditions. This small lake is located beyond the present pine timberline, north of Näkkälä village, Northern Finland (close to the Norwegian border). Photo by Mauri Timonen.*

Capacity building

Investment in the development of hydrometeorological capacity plays a key role in the reduction of weather-related losses. During the years Finland has had extensive capacity building programs around the world. Through the Finnish international development agencies climate data management systems have been implemented in several developing countries with considerable financial and personnel support. The institutional support of the develop programs is channeled mainly through technical aid to strengthen the meteorological observing networks and weather services as well as climatological data bases, expert services and training programs. At the moment, the Institutional Co-operation Instrument (ICI) of the Ministry for Foreign Affairs of Finland remains one of the main funding tools in meteorological capacity building in addition to EU and other development aid funding instruments by World Bank and other international development banks.

FMI has expertise from development cooperation and strengthening of national meteorological services in more than 100 countries since the 1970s and a strong commitment to participate in international cooperation and capacity building as outlined in its strategy. FMI experts have carried out feasibility studies and studies on impacts of hydrometeorological services to different socio-economic sectors for the Ministry for Foreign Affairs of Finland, World Meteorological Organization (WMO), UNDRR, World Bank, etc. FMI has a very strong research sector (weather radar, satellite, observation networks, numerical weather prediction, climate change, applications in sector of renewable energy and air quality) and extensive expertise in commercial services and cooperation with different types of end-users and stakeholders. FMI has also strong internal training unit with close cooperation in training with the University of Helsinki and also a dedicated communications unit and expertise in the communication of weather and other information to the media, general public and customers.

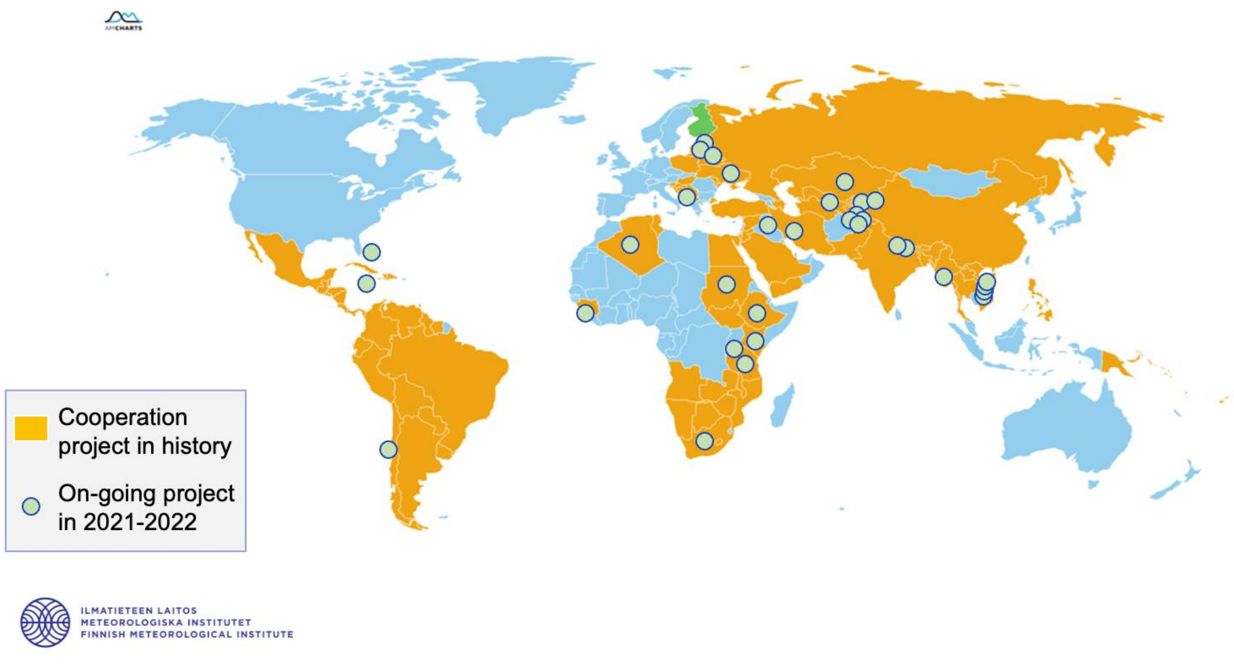

***Figure 1.4** Status of the FMI´s international co-operation projects in 2022*

2. ATMOSPHERE ESSENTIAL CLIMATE VARIABLES

Introduction

In Finland, the prime source of atmospheric observations relevant to climate is the routine surface and upper air weather observations undertaken by the Finnish Meteorological Institute (FMI). FMI also plays an important role in air chemistry observations. The observations are archived in the data bases.

Arrangements and conditions for data provision are consistent with WMO Resolution 40 (Cg-XII) on policy and practice for the exchange of meteorological and related data and products. Appropriate weather observations are forwarded to other countries in real time, through the WMO networks. Finland provides also climate and greenhouse gas monitoring data to international data centers under the WMO/ICSU programs.

Finland has three stations providing data to international data centers as part of the Global Surface Network (GSN), and one station which reports as part of the Global Upper Air Network (GUAN).

Jointly with other Nordic countries Finland is aiming at best possible long-term climatological data records for the study, monitoring and detection of past and future climatic changes in the northern areas. In this work the reliability and homogeneity of the data records and the station records (metadata) are in key roles.

Finland has a few stations providing atmospheric constituent data to international data centers as part of the Global Atmospheric Watch (GAW). Concentrations of carbon dioxide, methane and nitrous oxide, and ozone as well as aerosol properties and non-methane hydrocarbons, are monitored at the Sodankylä/Pallas GAW station.

Weather observations

The Finnish Meteorological Institute makes observations of the atmosphere, sea and space at over 400 observation stations around Finland, and using remote sensing instruments such as radars and satellites. In addition to weather observations FMI monitors e.g. air quality, radioactivity and properties of the upper atmosphere. The most common methods of observation, observation stations and observed parameters are introduced in the following.

Synoptic weather messages are transmitted from automated weather stations every one hour. One surface station is also producing manual observations every three hours. In addition, observations specially related to rainfall and snow are made once a day at precipitation stations.

Mast stations are used for the observation of the vertical profiles of several meteorological parameters. These are being used e.g. when exploring temperature inversions, low clouds and wind shear.

At solar radiation stations several different measurements are made, although some of these stations measure the duration of sunshine hours only. The most common other solar measurements include ultraviolet, global and diffuse radiation.

Radiosondes reveal important information also from the upper levels of the troposphere. This information is vital for both the forecast models and meteorologists. In addition to daily soundings, special ozone soundings are made e.g. weekly in Arctic Research Centre in Sodankylä. Radioactivity soundings may be also carried out if needed.

Lightning detection system consists of several sensors around the country. The system detects the time of arrival and the direction of an incoming electromagnetic pulse generated by a lightning, and then automatically calculates the location of the lightning.

The observations obtained with the help of weather radars and satellites are very important, because they give information on weather conditions from geographically large areas. These data are extensively used in the operational detection of rain and clouds, but also in research activities.

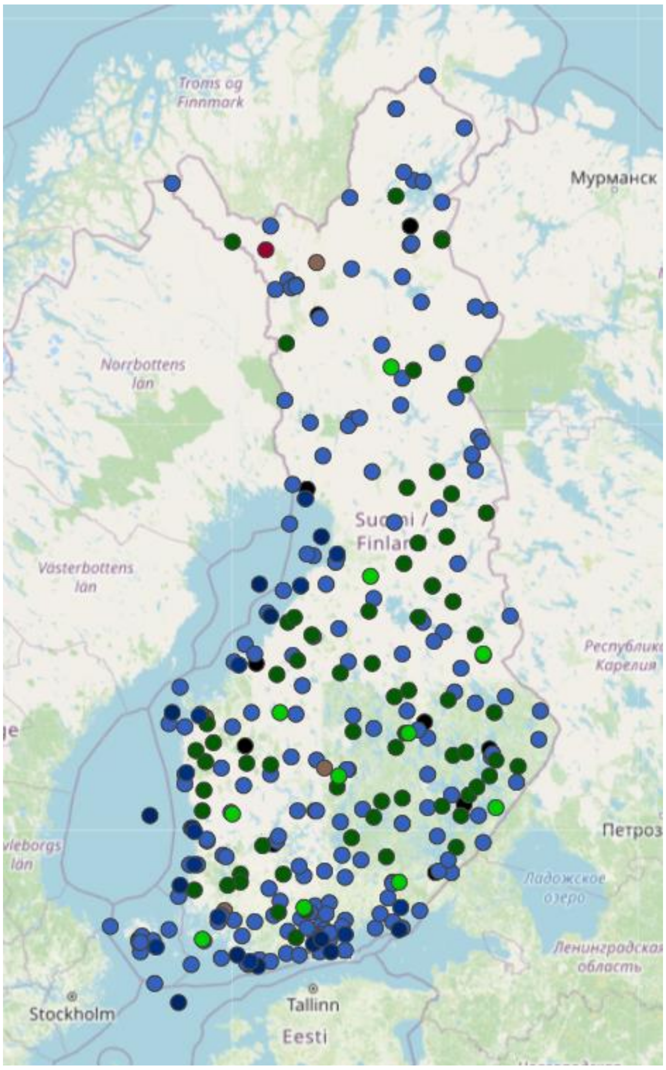

Figure 2.1. *Finnish climate-related observing stations.*

Other measurements include special research observations, testing new methods of observation, other more seldom used measurement techniques and observations obtained from co-operative agencies.

Meteorological observations have been made at several stations in Finland for more than a hundred years. In December 2022, observation network consists of 185 automatic stations, 82 precipitation stations, 24 aviation stations, 2 sounding stations, 11 radar stations, 3 mast stations, 14 marine stations and 14 buoy stations (Figure 2.1.).

Under the GCOS programs, stations in Jokioinen, Jyväskylä, and Sodankylä are included in the GCOS Surface Network (GSN) and Sodankylä in the GCOS Upper-Air Network (GUAN).

Long climatological time series form a necessary basis not only for the climatological research itself but also for estimates on the impacts of climate change. Finnish climate observations have been included for example in the international NkDS and ECA&D datasets, which are Nordic and European collections of reliable long-term climatic observations for climate change research.

The archives are full of observations which only exist in analogue form and would need to be digitized. Digitizing efforts are going on by the FMI with a focus on temperature and precipitation, but the same work remains to be done for other variables such as air pressure, wind and snow cover. Compiling long, daily meteorological series is important for impact studies of extreme events. Moreover, in parallel with global efforts in this direction, such data are needed to produce global historical reanalysis data sets.

Atmospheric composition

Finland participates in the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO) with objective to observe greenhouse gas concentrations and long-range transport of pollutants in the atmosphere. In addition, Finland contributes to the Integrated Carbon Observation System (ICOS) and the Aerosols, Clouds and Trace Gases Research Infrastructure (ACTRIS), and is hosting the head offices for both of these research infrastructures.

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Figure 2.2. *The Pallas station in Lapland is the northernmost GAW-station in continental Europe. It offers unique possibilities for carrying out measurements on atmosphere-biosphere exchange and background air composition.*

Greenhouse gas monitoring

Concentrations of greenhouse gases in the atmosphere have increased significantly from preindustrial-era causing global warming. Estimates of source strengths to the atmosphere from anthropogenic sources, based on emission factors and statistics of activity, have high uncertainties. Atmospheric observations are essential in determining trends and they provide the vital information for estimates of sources and sinks by natural processes and for allocating sinks and sources to marine and terrestrial environments.

Highly accurate and inter-calibrated global measurement networks are the basis for monitoring the global trends. The main network is the Global Atmosphere Watch (GAW) network co-ordinated by the World Meteorological Organization. It consists of 25 continuously monitoring sites around the world. The other important network is the cooperative sampling network by The Carbon Cycle Greenhouse Gases Group of the Earth System Research Laboratory (ESRL) of the U.S. National Oceanic and Atmospheric Administration for which weekly flask samples are collected at the sites and analysed in the central laboratory in Boulder (U.S.). European wide ICOS research infrastructure is established to provide, integrate and analyse data on greenhouse gas observations and to distribute information to user communities.

For monitoring globally and regionally representative trends, observatories should be located in clean, preferably elevated, sites to exclude effects of local pollution.

The Finnish Meteorological Institute maintains Pallas-Sodankylä GAW and ICOS -stations in Lapland. Greenhouse gas concentrations are measured on a mountain top in a national park. Carbon dioxide, methane, nitrous oxide, sulphur dioxide and ozone are measured continuously at Pallas. Continuous measurements of carbon dioxide started in 1996 and of methane in 2004.

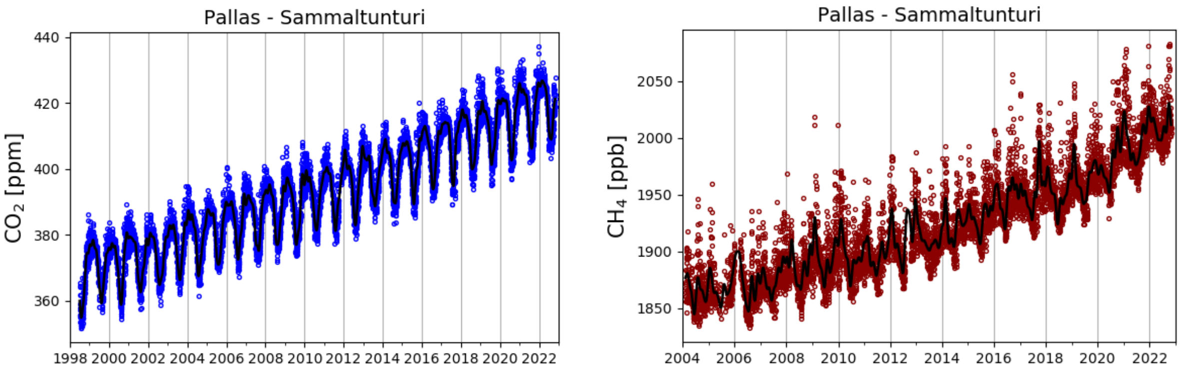


Figure 2.3. *Measurements of CO_2 and CH_4 in Pallas GAW station.*

Flask samples are collected weekly and sent to Boulder to be analyzed by ESRL for CO_2, CH_4, CO, H_2, N_2O, and SF_6 concentration and by Stable Isotope Laboratory of the University of Colorado at Boulder for the concentrations of the stable isotope $^{13}CO_2$. At Sodankylä, ozone soundings in the troposphere and stratosphere are conducted weekly. Regular ozone soundings have been also performed at Marambio (Antarctica) since 1988; the data has been used in scientific publications, and they form a significant contribution to the WMO ozone bulletins. Continuous CO_2 and CH_4 measurements have been performed at Marambio since 2013, CO measurements since 2019.

For assessing global trends and regional sources and sinks, global data integration and earth system modelling are needed. The data is sent to relevant data banks including World Data Centre for Greenhouse Gases in Japan. In Europe, collection and distribution of GHG data is centrally conducted by ICOS Carbon Portal, to which FMI is submitting data.

The trend in atmospheric methane concentrations is a result of many anthropogenic and natural sources of which possible increases of terrestrial and marine sources in Arctic areas have recently raised lively discussion. Warming of the Arctic region will change patterns of methane emissions from wetlands. Huge reservoirs of organic carbon are stored in northern peatlands. According to some scenarios there is a high risk that warming will increase soil respiration turning these long-term sinks of atmospheric carbon dioxide to net sources. Measurements of ambient air concentrations in the high northern latitudes are essential to monitor the effects of environmental changes in this area and to act as early warning guards. The importance of the GAW/ICOS-station of Pallas-Sodankylä is emphasized by the fact that it is the only continuously monitoring site in the northern parts of Eurasia. Variations of ambient air concentrations have source areas of thousands of kilometres integrating various sources and sinks. For monitoring carbon dioxide and methane fluxes at ecosystem level, micrometeorological methods are available. Using high-tech instrumentation we can observe gas exchange of a forest or mire continuously, year round. Presently, the Finnish Meteorological Institute measures continuously methane emissions and carbon dioxide exchange from three subarctic aapa mires and carbon dioxide exchange of two forests in Northern Finland. These data are used to study the effect of climate on seasonal and annual patterns of carbon sink and methane emissions in northern boreal and subarctic regions. The sites belong to the European flux measurement networks (e.g. ICOS) and the observations are analysed together with other global flux networks.

Air quality

Finnish Meteorological Institute is responsible for the national background air quality measurements. The measurement network consists of about twenty stations in different parts of the country. Most of the measurements are part of the international monitoring and research programmes.

The background air quality measurements were started in the beginning of the 1970's. The longest time series from those days include sulphur dioxide and major ions in precipitation. Nowadays monitoring measurements include aerosol mass in PM10 and PM2.5, and the chemical composition (major ions, PAHs, heavy metals) of aerosols and precipitation, mercury in air and in precipitation, and air concentrations of ozone, sulphur and nitrogen oxides and volatile organic compounds. Quality assurance procedures are an essential part of the monitoring routines.

The Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO) provides highly accurate measurement data on the atmospheric composition and other information related to physical characteristics of the background atmosphere from all parts of the globe. In addition to the GAW-functions the Pallas-Sodankylä station is also a part of Arctic Monitoring and Assessment Programme (AMAP) co-ordinated by the Arctic Council. Five stations (Pallas, Ähtäri, Virolahti, Oulanka and Utö) belong to the European Monitoring and Evaluation Programme (EMEP).

The Integrated Monitoring programme (IM co-ordinated by UN/ECE) refers to the simultaneous measurements of physical, chemical and biological properties of an ecosystem over time and across compartments at the same location. There are two IM measurement stations (Kotinen and Hietajärvi). HELCOM's (Helsinki Commission coordinated by the Baltic Marine Environment Protection Commission) objective is to protect the marine environment of the Baltic Sea. There is one HELCOM station; Hailuoto.

The FMI also maintains the monitoring and warning system of the tropospheric ozone concentrations according to the European Union's Ozone Directive (92/72/EEC). There are ten ozone monitoring stations (Utö, Virolahti, Evo, Jokioinen, Hyytiälä, Oulanka, Ilomantsi, Pallas, Sodankylä and Raja-Jooseppi). At three stations a complete measurement programme required by the EU Directives is carried out. Air quality issues in European Union are co-ordinated by the European Environment Agency and in the European Topic Centre on Air Quality.

Aerosols

Aerosols have direct and indirect effects on the atmosphere. The magnitude of these effects, as regards to warming or cooling, remains one of the most significant sources of uncertainty in climate models. In pristine Arctic and sub-Arctic environments even small changes in aerosol properties can have significant climate effects.

As a Finland’s contribution to WMO-GAW program, FMI runs the Pallas-Sodankylä station. Sodankylä is the classical meteorological part of the twin site, homogenized data records date back to 1908. Pallas is a clean air site for air chemistry and aerosol measurements established 1994. The variables measured include the scattering, backscattering and absorption coefficients, number, mass and black carbon concentrations, number size distribution and chemical composition (major ions and heavy metals).

Similar properties are measured by FMI also in Utö atmospheric and marine research station in Baltic and Kuopio research station. Aerosol optical depth (AOD) as well as vertical distribution, microphysical and radiative properties of aerosols in atmospheric column are measured with doppler LIDARs, PFR or Cimel sunphotometers at Sodankylä and Pallas, Jokioinen Observatory, Hyytiälä research station, Utö atmospheric and marine research station and in Kuopio research station.

Data from the GAW station is regularly submitted to World Data Centre for Aerosols (WDCA). FMI is also responsible of similar long term aerosol measurements as in Pallas-Sodankylä global GAW station in Marambio in Antarctica.Another FMI's measurements in Tiksi, Russian Siberia are in unknown status due to current global crisis (Russia's attack to Ukraine in 2022). Pallas, Utö and Marambio also belong to the European ACTRIS research infrastructure.

Aerosol- cloud interactions are measured continuously in two stations, Pallas GAW station and Kuopio research station in Puijo tower.

Table 1a. National contributions to the surface-based atmospheric essential climate

Contributing networks specified in the GCOS implementation plan	ECVs	Number of stations or platforms currently operating	Number of stations or platforms operating in accordance with the GCMPs	Number of stations or platforms expected to be operating in 2025	Number of stations or platforms providing data to the international data centres	Number of stations or platforms with complete historical record available in international data centres
GCOS Surface Network (GSN)	Air temperature	3	3	3	3	
	Precipitation	3	3	3	3	
Full World Weather Watch/Global Observing System (WWW/GOS) surface network	Air temperature, air pressure, wind speed and direction, water vapour	209		211	209	
	Precipitation	119		119	119	
Baseline Surface Radiation Network (BSRN)	Surface radiation					
Solar radiation and radiation balance data	Surface radiation	14		14		
Ocean drifting buoys	Air temperature, air pressure					
Moored buoys	Air temperature, air pressure					
Voluntary Observing Ship Climate Project (VOSClim)	Air temperature, air pressure, wind speed and direction, water vapour					
Ocean Reference Mooring Network and sites on small isolated islands	Air temperature, wind speed and direction, air pressure					
	Precipitation					

Table 1b. National contributions to the upper-air atmospheric essential climate variables

Contributing networks specified in the GCOS implementation plan	ECVs	Number of stations or platforms currently operating	Number of stations or platforms operating in accordance with the GCMPs	Number of stations or platforms expected to be operating in 2025	Number of stations or platforms providing data to the international data centres	Number of stations or platforms with complete historical record available in international data centres
GCOS Upper Air Network (GUAN)	Upper-air temperature, upper-air wind speed direction, upper-air water vapour	1	1	1	1	
Full WWW/GOS Upper Air Network	Upper-air temperature, upper-air wind speed direction, upper-air water vapour	2	2	2	2	

Table 1c. National contributions to the atmospheric composition

Contributing networks specified in the GCOS implementation plan	ECVs	Number of Stations or platforms currently operating	Number of stations or platforms operating in accordance with the GCMPs	Number of stations or platforms expected to be operating in 2025	Number of stations or platforms providing data to the international data centres	Number of stations or platforms with complete historical record available in international data centres
World Meteorological Organization/ Global Atmosphere Watch (WMO/GAW) Global Atmospheric CO2 & CH4 Monitoring Network	Carbon dioxide	1	1	1	1	1
	Methane	1	1	1	1	1
	Other greenhouse gases	1	1	1	1	1
WMO/GAW ozone sonde network	Ozone	1	1	1	1	1
WMO/GAW column ozone network	Ozone	1	1	1	1	1
WMO/GAW Aerosol Network	Aerosol optical depth	6	6	6	6	6
	Other aerosol properties	4	4	4	4	4

3. OCEAN ESSENTIAL CLIMATE VARIABLES

Introduction

The Finnish Meteorological Institute (FMI) maintains a network of measurement stations for sea level, sea state, hydrography and currents in the northern part of the Baltic Sea. Measurements are done with tide gauges, wave buoys, ADCP's, Argo floats and with CTD equipment on-board R/V Aranda and at several fixed locations.

FMI operates 14 tide gauges on the Finnish coast. Thirteen of them were established in 1887-1933 and have been operating since then. The newest station was established in the Gulf of Finland in 2014. The real-time sea level information is available at the FMI web site. Time series data from 1971 onwards is available in the open data portal of FMI. The complete historical record of monthly mean sea levels is available in the Permanent Service for Mean Sea Level (PSMSL) database. Since late 1990's sea surface temperature has also been measured at the tide gauges.

FMI measures sea state at four locations in the northern part of the Baltic Sea with Directional Waverider buoys. Together with the city of Helsinki FMI measures waves also in the Helsinki coastal area (wave buoy locations are given in Figure 3.1). Data is available in real-time at FMI's web pages and in FMI's open data portal. The Northern Baltic Proper wave buoy has been operating since 1996, Helsinki wave buoy since 2000, Bothnian Sea wave buoy since 2011 and Bothnian Bay wave buoy since 2012, excluding the ice season. Historical data are stored at FMI and data measured from 2005 onward can be downloaded from Open data portal (parameters: significant wave height, peak wave period, mean direction at spectral peak, spreading and water temperature).

Baltic Sea monitoring conducted together with SYKE's using research vessel Aranda gives the widest 3D overview of the physical state and nutrients in the open sea. The measurements provide accurate information on the water column including the near bottom layer. The measured parameters include dissolved oxygen that is measured by probes enabling 1-m measuring interval. The parameters indicative of oxygen acidification – pH – is measured by wet analytics from discrete samples. As of 2014, the EU Marine Strategy Framework Directive also requires the routine determination of pCO_2 in the water column.

In addition, there are two kinds of monitoring stations: the intensive monitoring stations near the coast and the open sea stations. During the ice-free season, the intensive stations are measured one to three times a month and open sea stations twice a year. FMI has also established in 2013 one fully automatic measurement station at Utö island located at the outer Archipelago Sea.

ELY-centres (Centres for Economic Development, Transport and Environment) perform coastal monitoring of intensive sites in their river basin districts. Vertical samples cover the basic hydrographical variables such as temperature, salinity, pH and oxygen concentrations. The results are reported annually to the database of HELCOM, which is maintained by ICES. Additionally, Finland is committed to deliver water quality data to EU and to the network of EEA. These reports are important for the implementation of the European water policy.

FMI has used freely floating measuring buoys since 2012 in the Bothnian Sea and Northern Baltic Proper. These Argo-floats measure the water column frequently and send the data by satellite connection to the FMI. The data is freely available in the international Argo data base **http://www.coriolis.eu.org/**

Sea ice drift in the Bay of Bothnia has been measured since 2012 by GPS-buoys. Every ice season Finnish icebreakers deploy one to four buoys, depending on ice conditions. The bouys also measure SST in open ocean conditions.

FMI uses multisensor satellite data in maritime and sea ice services, and in research purposes. , In the Finnish Environment Institute (SYKE) satellite images are used to retrieve information about sea surface temperature, turbidity, algal blooms and a-chlorophyll in the Baltic Sea. ,

SYKE maintains automatic measurement equipments on Ships-of-Opportunity (Algaline). Measurements include temperature, salinity, chlorophyll-a and nutrients. Data is available in real-time at Baltic Sea Portal.

Table 3a. National contributions to the oceanic essential climate variables – surface

Contributing networks specified in the GCOS implementation plan (Ch 5.1)	ECVs	Number of stations or platforms currently operating	Number of stations or platforms operating in accordance with the GCMPs	Number of stations or platforms expected to be operating in 2025	Number of stations or platforms providing data to the international data centres	Number of stations or platforms with complete historical record available in international data centres
Global surface drifting buoy array on 5x5 degree resolution	Sea surface temperature, sea level pressure, position-change based current					
Global reference mooring network	All feasible surface ECVs	5[1]		5[1]	5[1]	
GLOSS Core Sea-level Network	Sea level	14		14	14	14
Carbon VOS	pCO_2, SST, SSS	1				
Sea-ice buoys	Sea ice	10[2]		12		
Satellite IR (polar orbit and geostationary)	SST, Sea ice	3[3]		4[4]		
AMSR-class microwave SST satellite	SST, Wind speed, Sea ice	1[5]		1		
Surface vector wind satellite	Surface vector wind satellite					
Ocean colour satellite (SeaWiFS-class)	Ocean colour; Chlorophyll concentration (biomass of phytoplankton)	2[6]		4[7]		
High-precision satellite altimetry	Sea-level anomaly from steady state, Sea state					
Complementary -orbit (sun-synchronous)	Sea level					

satellite altimetry						
Satellite SAR	Sea ice, sea state	2[8]		5[9]	2[10]	2
VOSClim and VOS fleet	All feasible surface ECVs plus extensive ship metadata for VOSClim					
Ships of Opportunity	All feasible surface ECVs	3		4		

1: Directional Waveriders measuring the sea state.
2: Consists of sea ice buoys for ice drift detection, ice mass balance buoys for thickness measurements and virtual sea ice buoys from coast radar images
3: NOAA/AVHRR, AQUA&TERRA/MODIS
4: Suomi NPP/VIIRS included
5: Used for sea ice detection: AMSR2
6: AQUA&TERRA/MODIS
7: Sentinel 2/MSI and Sentinel 3A/OLCI included
8: Used for sea ice detection: Radarsat-2, COSMO-SkyMed
9: TerraSAR and Sentinel 1 satellites included
10: Ice thickness product distributed to CMS

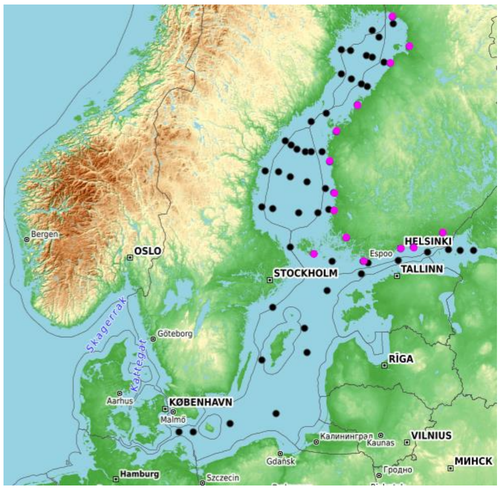


Figure 3.1. *(left) Locations wave buoys (turquoise) and SST-buoys (dark blue) and (right) FMI's tide gauges (purple) and hydrographic open sea monitoring stations (black).*

SYKE's Algaline-project utilises so-called ship-of-opportunity (SOOP) monitoring system, which uses merchant ships as operating platforms. The data collection and water sampling for analytical measurements are carried out with autonomous flow-through measuring systems. Recently, the SOOP-systems of this kind have been increasingly adopted for routine use all over the world as the most cost-effective environmental monitoring system. Algaline is a forerunner in the field of unattended SOOP-monitoring, and currently forms a state-of-the-art environmental monitoring system from data collection and assimilation to Internet applications and products. **http://itameriportaali.fi/en/tietoa/algaline_seuranta/en_GB/algaline_seuranta/**

Table 3b. National contributions to the oceanic essential climate variables – water column

Contributing networks specified in the GCOS implementation plan	ECVs	Number of stations or platforms currently operating	Number of stations or platforms operating in accordance with the GCMPs	Number of stations or platforms expected to be operating in 2025	Number of stations or platforms providing data to the international data centres	Number of stations or platforms with complete historical record available in international data centres
Reference mooring network	All autonomously observable ECVs					
Sustained and repeated ship based hydrography network	All feasible ECVs, including those that depend on obtaining water samples	~ 150		~150	~150	~150
Argo network	Temperature, salinity, current	4	4	4	4	32
Critical current & transport monitoring	Temperature, heat, fresh water, carbon transports, mass					

Role of satellites

FMI uses satellite synthetic aperture radar (SAR) imagery, supplemented with optical imagery, for operational monitoring of the Baltic Sea ice. The SAR imagery is the main data source for the daily ice chart prepared manually. FMI uses also satellite data for developing new remote sensing methods for monitoring sea ice conditions in the Baltic Sea, Arctic and Antarctic. In the Finnish Environment Institute (SYKE) satellite images are used to retrieve information about sea surface temperature, turbidity, algal blooms and a-chlorophyll in the Baltic Sea. The satellite data based Baltic Sea information is distributed through Copernicus Marine Service (CMS). Products are also available through FMI''s and SYKE's webpages.

Remote sensing of ocean

The Maritime Service of FMI uses data from NOAA satellites to provide information about ocean surface temperatures. Other information about the sea state (surface floating algal blooms, water turbidity etc.) is provided with the help of satellite images by the Finnish Environment Institute (SYKE). For example MODIS-Aqua data is used for Baltic Sea chlorophyll-a and turbidity research. Data from Sentinel satellites (Sentinel 2 and Sentinel 3A) is planned to be used in future for obtaining a-chlorophyll and turbidity information. However, for example using satellite altimeters and SAR to measure the wave height operationally in the Baltic Sea is not reliable. This is due to numerous islands and ships and because the satellite data is sparse. The wave buoys and the wave model are used instead.

In Marine research significant wave height from altimeter measurements (Jason-1, Jason-2) has been used to verify the operational wave model. In the Baltic Sea the use of satellite data is restricted by the coarse resolution. Novel wave research is going on where optical photographs of the sea surface are used.

Remote sensing of sea ice

The Finnish Ice Service is responsible for collecting, analysing and distributing sea ice data in the Baltic Sea. During Winter Ice Service provides information about ice condition by producing an ice chart daily.

In sea ice research automatic classification algorithms are being developed in order to estimate sea ice concentration, ice drift, ice deformation, ice thickness, etc., from SAR imagery alone, or together with radar altimeter or microwave radiometer data. The used SAR imagery includes Sentinel-1, Radarsat-2, and COSMO-SkyMed. Operational products have been developed and they are distributed through CMS. For example, an ice thickness chart with 500 m resolution is operationally produced from a SAR image received, using the latest available ice chart as an input, see Figures 3.2 and 3.3.

Radiometer data (AMSR2) or thermal infrared data, (e.g. MODIS, VIIRS) can be used for thin ice detection. Satellite images from altimeters (e.g. altimeter in Cryosat-2 satellite) are used to investigate sea ice thickness estimation in the Arctic. Long satellite data series are used in the research of long term changes in sea ice properties and effects of climate change on sea ice. Information obtained from satellites like ice drift and ice concentration, are used for the validation of models.

The daily ice chart based on satellite images, interpretations and in-situ measurements is presented on the left side of Figure 3.2. The simplified ice chart that is published weekly is on the right. An example of the ice thickness chart is shown in Figure 3.3.

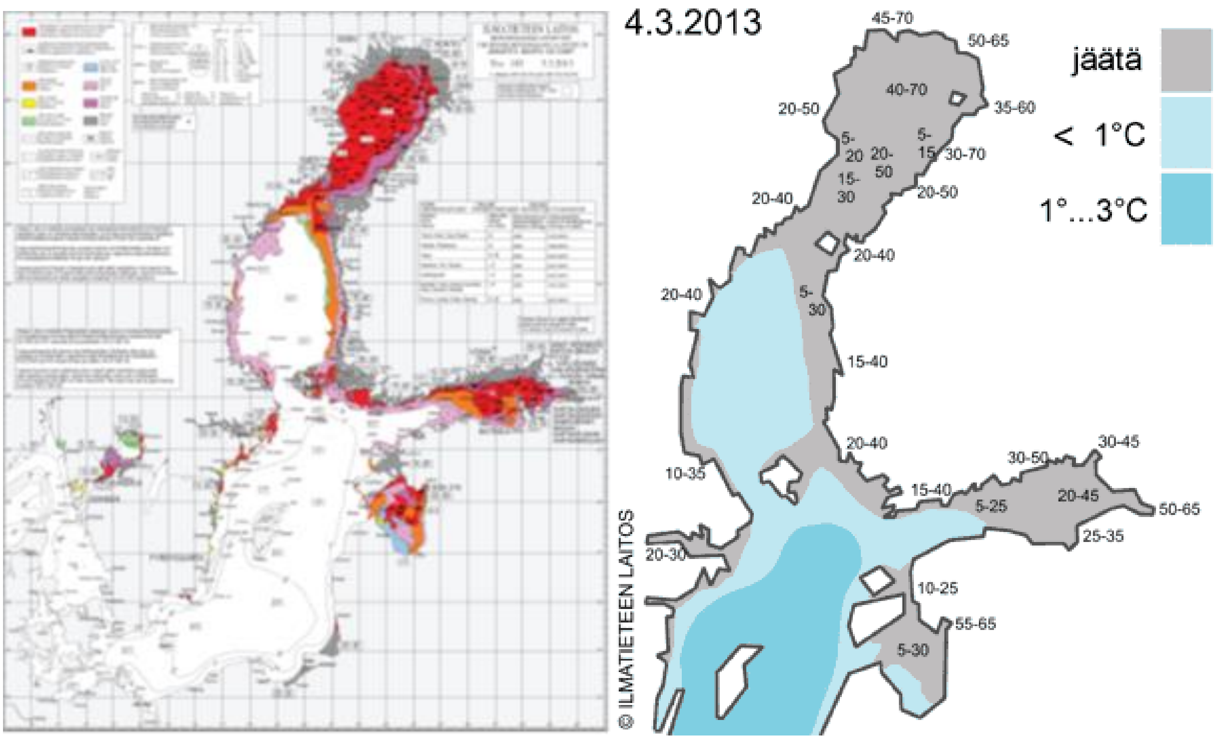


Figure 3.2. *The daily ice chart (5.3.2013) and the simplified ice chart published weekly in Baltic Sea area (4.3.2013) in March 2013.*

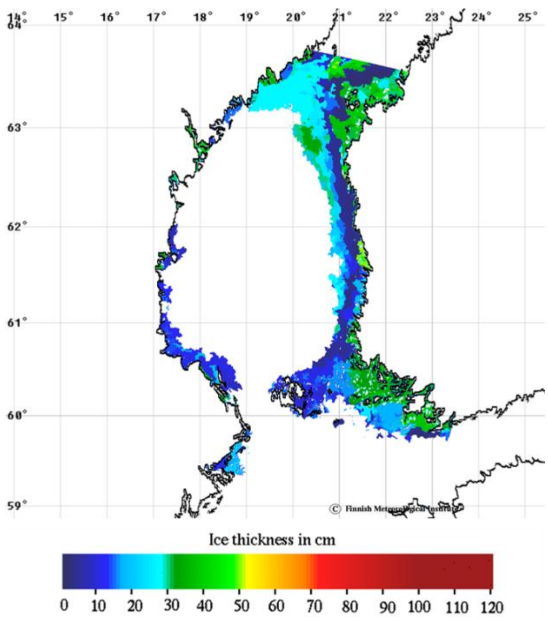


Figure 3.3. *The ice thickness chart 5.3.2013 (based on Radarsat-2 SAR data) produced with the algorithms developed in research.*

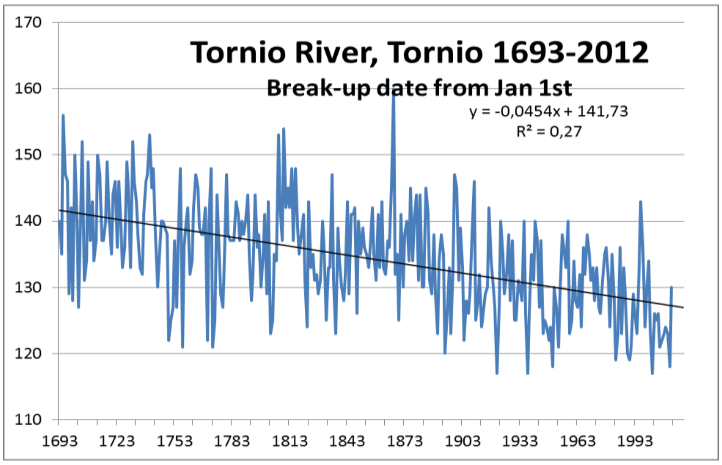
4. TERRESTRIAL ESSENTIAL CLIMATE VARIABLES

Introduction

The Finnish Environment Institute (SYKE) is a national centre for monitoring the physical, chemical and biological state of inland waters in Finland. Terrestrial ECVs and relevant metadata are included in the following registers:

- Hydrology and Water Resources Management Data System (HYDRO)
- Groundwater Database (POVET)
- State of Finland's Surface Waters (PIVET)
- Lake Register
- Information System for Monitoring Land Use Planning.

Of particular interest in climate change studies is HYDRO, because it contains a number of time series dating back to the 1800s. The series on the freezing and breakup dates of Finnish lakes and rivers are particularly long. The longest of them, breakup dates of River Tornio in northern Finland, starts as early as 1693 (Figure 4.1.)



Finland is reporting to the Global Runoff Data Centre (GRDC), located in Koblenz, Germany. The number of stations reported is 136, out of the total of 421. Nordic runoff data centre at SMHI, Sweden, also contains a considerable amount of Finnish runoff data.

Figure 4.1. *Break-up dates from Jan 1st of River Tornio in 1693-2012.*

Finland has one of the densest snow survey networks in the world (Figure 4.2.). Snow depth is measured at 50–80 points and snow density at 8–10 points on each survey line, which have a length of 2–4 km. Snow surveys have been made since the late 1940s, and areal water equivalents of snow have been calculated for all major river basins. Most of these data series extend to the late 1940s.

Cryospheric data from Finland have been reported to the National Snow and Ice Data Center (NSIDC) at Boulder, Colorado. These data include particularly the longest freezing and breakup data series.

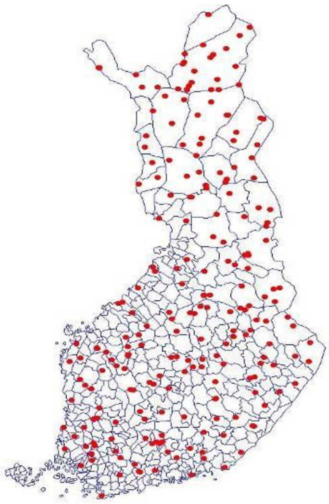


Figure 4.2. *Snow survey network.*

There are no glaciers in Finland. Sporadic permafrost exists in the northernmost part of the country, but no regular observations have been made.

Finland has a network of 72 groundwater stations, also operated and maintained by the Finnish Environment Institute. In addition to groundwater levels, soil moisture and the depth of soil frost are measured. Most stations were established in the 1970s.

Information related to irrigation is not systematically collected, because this type of water use is rather limited in Finland. Sectoral water withdrawals are collected annually for municipal water supply, industry and agriculture.

As to land use, Statistics Finland maintains data registers. The Finnish Forest Research Institute (METLA) performs national forest inventories. The first inventory covering the entire Finland was carried out in 1921–1924, the field work for the eleventh was done in 2009–2013.

As to the soil carbon, a nationwide survey has been conducted three times on agricultural lands. These surveys were made in 1974, 1987, 1998 and 2009, the numbers of plots being 2042, 1362, 720 and 611, respectively. Same plots were sampled, but the number of plots has decreased due to diminishing resources. In forests, soil samples were collected first time in 1985-1986 as a part of the national forest inventory covering the whole country. The plots represent the average Finnish forest in respect of both soil type and tree species distributions. The sampling was repeated in 2006 giving either 11 or 18-20 years between the measurements.

Flood forecasting at the Finnish Environment Institute is based on the Watershed Simulation and Forecasting System (WSFS). Its main component is a hydrological model representing the circulation of water in a catchment. WSFS covers 100% of Finland and is used for forecasting over 85% of the total area of the country. The forecasts are made daily for 800 water level and discharge observation points. The WSFS is used for a number of purposes, including studies on climate change.

In 1998, the European Environment Agency issued instructions for building an observation network for monitoring the quality and quantity of water in EU member states. Together, the national networks form EUROWATERNET, which provides reliable and comparable data on the state of waters all over Europe. In Finland, the new monitoring system was implemented at the beginning of 2000. There are 195 observation points for rivers, 253 for lakes and 74 hydrological sampling stations.

Table 5. National contributions to the terrestrial domain essential climate variables

Contributing networks specified in the GCOS implementation plan	ECVs	Number of stations or platforms currently operating	Number of stations or platforms operating in accordance with the GCMPs	Number of stations or platforms expected to be operating in 2015	Number of stations or platforms providing data to the international data centres	Number of stations or platforms with complete historical record available in international data centres
GCOS baseline river discharge network (GTN-R)	River Discharge	421		421	136	136
GCOS Baseline Lake Level/ Area/Temperature Network (GTN-L)	Lake level/area/ temperature	390 - 34		390 - 34		
WWW/GOS synoptic network	Snow cover					
GCOS glacier monitoring network (GTN-G)	Glaciers mass balance and length, also ice sheet mass balance					
GCOS permafrost monitoring network (GTN-P)	Permafrost Borehole temperatures and active-layerthickness					

Role of satellites

Lakes and Coastal waters

SYKE provides operational satellite-based information about surface waters of the Baltic Sea and Finnish lakes. The materials include surface water temperature, algal blooms, turbidity, chlorophyll a and the absorption of coloured dissolved organic matter. The satellite instruments used for observing water quality parameters and temperature are the Sentinel satellite series (Sentinel-2 MSI and Sentinel-3 OLCI and SLSTR) of the EUs Copernicus programme and USGS Landsat programme (OLI and TIRS onboard Landsat 8 and Landsat 9). NOAA/AVHRR and ENVISAT/MERIS satellites are utilized in analysing long-term changes starting from 2002. The operational products are openly available in SYKE's TARKKA map service (www.syke.fi/tarkka/en). During year 2023, TARKKA will be upgraded to its new version TARKKA+. SYKE has a STATUS database especially designed for satellite observations over the water areas. The information is collected on daily basis automatically including QA by operator. STATUS DB holds information on Finnish lakes and coastal water bodies and open sea areas in 20km grid division covering the Baltic Sea.

Additionally, SYKE together with FMI, and Austrian ENVEO IT GmbH are responsible for Cryospheric theme (Snow and Lake ice) under Copernicus Global Land Service (CGLS). SYKE is the leader of Lake Ice Extent service. Currently, the portfolio includes Northern Europe Lake Ice Extent (LIE-NE) and Northern Hemisphere Lake Ice Extent (LIE-NH) products. The methods for both products are developed at SYKE. Importantly, the ICEmod -method utilized in provision of LIE-NH includes cloud detection and the cloud screening algorithm utilized in LIE-NE is also developed at SYKE. These products provide information on lake ice extent from over 10 000 of lakes all over the Northern Hemisphere. This service undergoes evolution cycles whenever needed; transition from MODIS to VIIRS in Northern European LIE service is realized in early 2023, and further on, to Sentinel-3 OLCI (+SLSTR). LIE-NH is based on Sentinel-3 SLSTR data.

Snow

At SYKE, satellite images by optical sensors have been used in the monitoring of snow melt since 1999. In the beginning, remote sensing of snow was related to SYKE's nationwide hydrological monitoring and forecasting; its major task was to provide information for hydrological forecasting in order to improve the forecasts. The service started utilizing NOAA/AVHRR data but was switched to use Terra/MODIS in 2001. This task is still important; however, SYKE has gained a remarkable role in a provision of Northern hemispheric and European-wide snow cover extent (SCE) service from optical data under above mentioned Copernicus Global Land Service, which is a joint effort of FMI, SYKE and ENVEO. This service undergoes evolution cycles whenever needed; transition from MODIS to VIIRS in Pan-European SCE service is realized in early 2023, and further on, to Sentinel-3 OLCI (+SLSTR). At Northern Hemispheric and global scales, Sentinel-3 SLSTR will the main sensor applied, the current VIIRS serving as a backup sensor. These SCE products feature the Fractional Snow Cover (FSC, also referred to as SCA, Snow Covered Area) for ~500×500 m^2 – 1000×1000 m^2, depending on the applied sensor. In the core of the FSC-calculation is the SCAmod-method developed at SYKE, later adjusted by ENVEO. Cloud screening relies on the SCDA-method also developed at SYKE.

The method development related to the Snow Cover Extent (and very essentially, cloud screening) is also exploited in the generation of Climate Data Records in ESA CCI Snow. Before CCI snow, the snow CDR was generated within ESA DUE-project GlobSnow, in close-co-operation with the Finnish Meteorological Institute (FMI).

SYKE’s own daily snow map service associated to hydrological modelling covers Finland and its neighboring areas, practically the Northern Europe. Currently the SCE product utilizes Terra/MODIS data, ending up as 500×500 m^2 resolution FSC-maps. In addition, for the need of SYKE’s national hydrological modelling, 3rd order drainage basins of Finland are used as calculation unit areas. The basin-wise product enables the practical use of SCA-estimates in the hydrological forecasting models. This daily service uses EO-data receiving facility and computing platform of the Finnish Meteorological Institute, while the methodology development and updates (including cloud detection algorithm) are carried out at SYKE. The transition from MODIS to VIIRS and later to Sentinel-3 OLCI (+SLSTR) will be taken place in 2023-2024.

SYKE is also experienced in in-situ validation of Snow Cover Extent products. This work has been conducted under European Space Agency-funded project SnowPEx and SnowPEx+, where SYKE leads the validation of several continental/global SCE-product against snow depth data from global network of weather stations.

Land Cover and vegetation

SYKE has participated in production of land cover data since the late 1980s. In the European wide Copernicus Land program the Corine land cover and land cover changes of Finland have been mapped by SYKE in six years intervals from 2000to 2018. The method SYKE utilizes rely on data integration by combining satellite and map information with field measurements. In addition, national versions of land cover classification are produced with higher spatial (20 m raster) and thematic accuracy as well as the land cover change layers between consequent Corine versions.

Frequent Sentinel 2 satellite data are used in the seasonal monitoring of vegetation status and phenological events. Parameters describing the seasonal changes in vegetation bring relevant information e.g. for the biodiversity monitoring, in modeling of diffuse nutrient loads into water bodies and carbon balance. Bio-geophysical services are produced globally in Copernicus program.

Environmental data produced by SYKE, including land use/land cover data, are made available through SYKE's open data service (https://www.syke.fi/opendata). In addition, Copernicus Land service by EU provide large number of European wide land cover and vegetation related data products. These include e.g. tree cover density, tree species composition, build-up-areas (imperviousness, Urban atlas), grasslands, wetland and waters (see land.copernicus.eu).

5. ADDITIONAL INFORMATION

More and more emphasis is put on accuracy, reliability and consistency of systematic observations in Finland than ever before. Finland is working hard to maintain the best systematic observations program with the resources available. The most notable changes in the past few years in systematic observations have been the active change to more automated observations and the continuous decline of manual observations.

The automation process has allowed new parameters to be observed, in areas that were not possible previously and much more frequently than before. However in some instances it has been shown that manual observations are also still needed, especially at airports where the accuracy and reliability of observations is of paramount importance. A balance between automated and manual observations is crucial to gain the best possible systematic observations. Finland will continue to keep high standards in its climate-related observing work, and will continue to support the GCOS and its programs in the future, too.

Annex 1

GCOS Essential Climate Variables

The Essential Climate Variables (ECVs) are required to support the work of the UNFCCC and the IPCC. All ECVs are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations. Additional variables required for research purposes are not included in this table. It is emphasized that the ordering within the table is simply for convenience and is not an indicator of relative priority.

Domain	Essential Climate Variables
Atmosphere	Surface Pressure, Surface Temperature, Surface wind Speed and Direction, Surface Water Vapour, Precipitation. Surface Radiation Budget, Upper-air Temperature, Upper-air Wind Speed and Direction, Upper-air Water Vapour, Earth Radiation Budget, Cloud Properties, Lightning, Carbon Dioxide, Methane and Other Greenhouse Gases, Ozone, Precursors (Supporting the aerosol and ozone ECVs), Aerosol Properties
Ocean	Sea-surface temperature, Subsurface Temperature, Sea-Surface Salinity, Subsurface Salinity, Surface Current Sea Level, Sea State, Surface Stress, Ocean Surface Heat Flux, Sea Ice, Oxygen, Nutrients, Ocean Inorganic Carbon, Transient Tracers, Ocean nitrous oxide (N_2O), Ocean Colour Plankton, Marine Habitat Properties
Terrestial	Groundwater, Lakes, River Discharge, Soil Moisture, Terrestial Water Storage [1], Snow, Glaciers, Ice Sheets and Ice Shelves, Permafrost, Fraction of FAPAR, Leaf Area Index, Albedo, Land-Surface Temperature, Above-Ground Biomass, Land Cover, Soil Carbon, Fire, Anthropogenic Greenhouse-Gas Fluxes, Evaporation from Land, Anthropogenic Water Use

[1] New ECV approved by GCOS Steering Committee in 2020

Annex 2

GCOS Climate Monitoring Principles

*Effective monitoring systems for climate should adhere to the following principles**

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.
11. Furthermore, operators of satellite systems for monitoring climate need to:

(a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and

(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term inter-annual) changes can be resolved. Thus satellite systems for climate monitoring should adhere to the following specific principles:

12. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.
13. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
14. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
15. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
16. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
17. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.
18. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.
19. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on decommissioned satellites.
20. Complementary in situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.
21. Random errors and time-dependent biases in satellite observations and derived products should be identified.

(The ten basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.)*