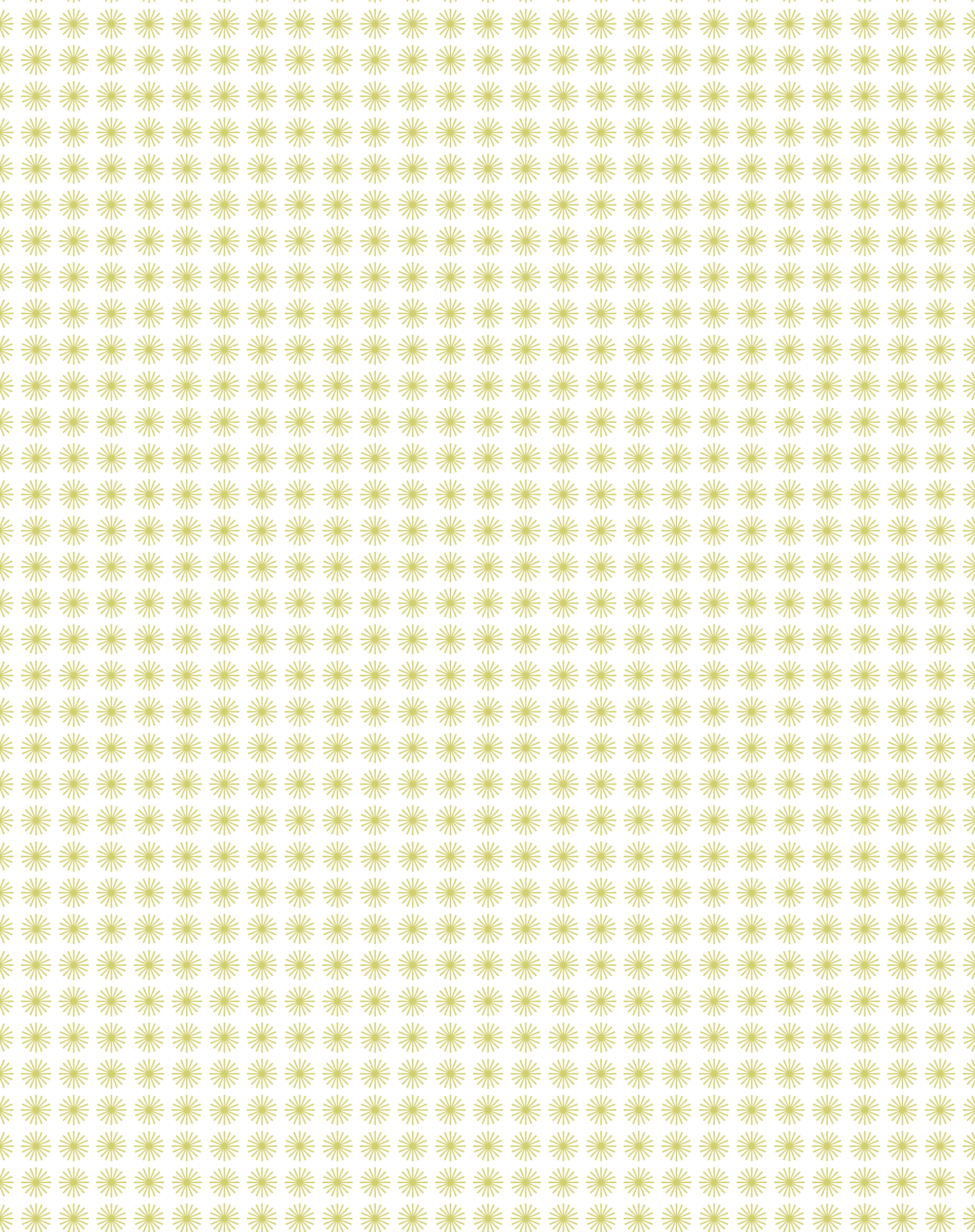
Swedish Environmental Monitoring North of 60°N

Harald Grip and Håkan Olsson



Preface

This report has been commissioned by the Swedish Committee for the International Polar Year 2007–2008 through its special Working Group for Monitoring and Data Management.

During the International Polar Year there has been a rapidly growing interest in the developments in the Arctic, primarily focussed on issues related to global warming and natural resources but also more generally on the Arctic as an arena for political and scientific cooperation in a truly international context. Monitoring and data gathering, storage and accessibility, are issues of prime concern to Arctic affairs as well as a necessary prerequisite for sustainable development in a peaceful Arctic where international cooperation can continue to serve both local residents and the world at large.

Since the Reykjavik Ministerial Meeting of the Arctic Council in the fall of 2004, there is an ongoing effort to improve international cooperation on observation and monitoring. The process has moved forward under the umbrella name SAON, "Sustaining Arctic Observing Networks". The Swedish IPY Committee was proud to host the first SAON Workshop in Stockholm in November 2007. A report from the SAON process with recommendations were submitted to the Arctic Council in early 2009.

This report on *Swedish Environmental Monitoring North of 60°N* should be seen as one of Sweden's contributions to the SAON process and has been commissioned and produced with the explicit purpose to support the efforts to establish a solid international cooperation in monitoring and research in the Arctic region as an instrument to help combat global warming and promote sustainable development in the Arctic. Sweden shares an interest with other Arctic States, as well as local residents, to see sustained Arctic observing and monitoring become a true legacy of the IPY 2007–2008.

We would like to thank in particular the lead author Assoc. Prof. Harald Grip, but also his assisting co-author Professor Håkan Olsson for their work.

Stockholm in August 2009

Sverker Sörlin
Chair, Swedish Committee for the International Polar Year 2007–2008

Lennart Nordh
Chair, Swedish IPY Working Group for Monitoring and Data Management

Note from the authors

This report has been prepared on request from the Swedish National Committee for the International Polar Year (IPY). Harald Grip is the main author and did most of the data collection and text editing. Håkan Olsson contributed mainly to the chapters *Introduction and General Conclusion and Social Dimensions.* Our aim has been to compile an overview of ongoing Swedish monitoring activities to serve as a background for discussions on a Sustaining Arctic Observing Networks, which were initiated during IPY. Our main sources of informations were the websites of the different actors in the environmental monitoring effort in Sweden. In some cases interviews supplemented the website information. We would like to thank those who reviewed and commented on the text. Finally, we would like to thank Anders Clarhäll at the Swedish Research Council for editorial work and finalising the publication.

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Editor and project coordinator Anders Clarhäll, Swedish Research Council

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(published only on the web site **monitoringN60.slu.se**)

Introduction and General Conclusions

Introduction

The Arctic and sub-Arctic areas are in a state of rapid environmental change. Many researchers, research networks, and government agencies are monitoring these changes. However, the coordination of these monitoring efforts across nations and disciplines could improve. Important gaps remain to be filled. The eight foreign ministers of the Arctic Council acknowledged the need for improved arctic monitoring, and in the Salekhard declaration (November 2006) they agreed to: *"Urge Member States and other entities to strengthen monitoring and research efforts needed to comprehensively address Arctic change and to promote the establishment of a circumpolar Arctic observing network of monitoring stations with coordinated data handling and information exchange for scientific data, statistics and traditional knowledge as a lasting legacy of the IPY…".*

As a consequence of the need for improved and more sustained monitoring, which has been identified both by the Arctic Council and the scientific community, the International Polar Year (IPY) and several scientific bodies have initiated a process to make sustained Arctic monitoring a legacy of the IPY. The international coordination process *Sustaining Arctic Observing Networks* (SAON), engaged 350 Arctic researchers, representatives of inter-governmental, national and sub-national government agencies, representatives of indigenous people's organizations, and residents of the Arctic. The SAON-process compiled a set of recommendations for the Arctic Council to consider at their ministerial meeting in April 2009 (www.arcticobserving.org). As a preparation of the process, the Swedish Committee for the International Polar Year initiated this report. The report aims to provide an overview of current monitoring efforts in northern Sweden and to comment on their potential relevance for a future circumarctic monitoring program.

Driving forces behind environmental monitoring in Sweden today are international agreements (EU and UN), national regulations, and other commitments (the 16 environmental goals set by the Swedish Parliament), where monitoring is not focused on the Arctic per se, but is based on national, European, and certain global needs.

The content in this report was guided primarily by the type of variables suggested in the report, *Toward an Arctic Observing Network* (AON, Polar Research Board, 2006, http://www.nap.edu/catalog/11607.html), but we have also included additional variables that we considered relevant. We have concentrated on monitoring activities in Sweden north of latitude 60°N. In a few cases we have also included monitoring conducted by Swedish groups in northern areas outside Sweden. The report, with a few exceptions, does not consider monitoring programs conducted by regional or local authorities. The regional monitoring effort is large and complements the national programs, but it is under revision. Monitoring by nongovernmental organizations (NGOs) is not included. We believe that the report is a useful compilation of information, especially regarding certain monitoring efforts carried out by research groups. However, we must stress that it has not been possible to compile a complete inventory of monitoring programs.

Monitoring generally involves using a measuring device of some sort to observe the state of a system for any changes that may occur over time. This means that other activities, such as mapping, are not a primary aim in this report. However, some activities related to mapping have been included when they relate to the informational needs stated in the AON report.

This report focuses mainly on *in situ* measurements. Satellites, however, are often a well-suited complement for monitoring the atmosphere and also land/vegetation and oceans on scales from global to regional. Satellites in polar orbits (e.g. the Swedish Odin for atmospheric measurements, the French SPOT for land cover, and the European Envisat with multiple sensors) can effectively cover both the Arctic and Antarctic latitudes and provide multiyear time-series on several important parameters. The importance of satellites for long-term monitoring is likely to increase, since more satellites will be put into operation, more parameters will be measured, and more efforts will be made to achieve as long and continuous time-series as possible. Global Monitoring for Environment and Security (GMES), a joint European Commission and ESA initiative, is particularly important in this regard. Satellite monitoring and subsequent data storage/distribution is normally a result of decisions made by international organizations, funded by the participating states.

Layout of the report

General conclusions from the report are presented in the next section. The remaining chapters present a detailed review of how and where different variables are monitored and may be used as an encyclopedia for those interested in specific variables. The final chapter discusses how the current monitoring efforts meet both the AON *key variables* and the *essential climate variables* identified by the Global Climate Observation System (GCOS). Two sets of tables present further details about the variables monitored. One set of tables is printed in the report, and tables 3 to 7 list programs or main sites and subprograms. These tables reference a second set of tables with detailed information about the variables measured and where and when they are measured. The second set of tables is available only on the web site associated with this report: monitoringN60.slu.se. The web site also contains interactively searchable versions of the maps with mon-

Snow-covered Scandinavian Peninsula on 11 March, 2006 captured by European Space Agency's satellite Envisat. European Space Agency. All rights reserved.

itoring sites that are included in this report. A link to web site is also present from the home page of the SAON process: www.arcticobserving.org.

General conclusions

The AON report lists 31 *key variables* that would be relevant to monitor in a circumarctic monitoring program. That list is used as a reference for the following discussion. Table 1 provides a general overview and a subjective judgment of how well the current monitoring activities in Sweden actually meet the monitoring needs mentioned in the AON report. Some of the AON key variables have been slightly modified to be more operationally meaningful. Also, Table 1 omits a few variables, e.g. fresh water flux and sea salinity, since the Gulf of Bothnia is not directly linked to the Arctic Ocean. Swedish researchers are doing many types of measurements in the Arctic Ocean as well, but mostly on a project basis.

We found that national authorities or universities satisfactorily measure most AON variables. Some variables, e.g. albedo, ground temperature, CO_2 flux, and phenology, are however measured by university groups in networks that are sparser and financially unstable. Also, some of the variables measured by the Swedish Meteorological and Hydrological Institute (SMHI) are measured in rather sparse *in situ* networks. One example would be global radiation, which is measured at only 5 sites in northern Sweden. However, the ground-based radiation measurements are combined with satellite measurements. Hence, this exemplifies how increased use of techniques combining satellite data and *in situ* data make it difficult to evaluate an observation network based on information about in situ sites only. There is also a need for a comprehensive radiation station within the extensive Boreal zone, since the radiation balance is a key factor in global climate and would provide a direct measurement of climate change. However, it should be noted that there are few *in situ* physical measurements in the sea, and in the upper air, as well as below ground.

The National Forest Inventory (NFI) and the National Inventory of Landscapes in Sweden (NILS), produce statistics on the state of forests and forest soils, biodiversity and landscape change. General and comprehensive statistics related to the human population is produced by Statistics Sweden, and statistics related to human health is produced by the National Board of Health and Welfare. However, in the present system, it is not possible to identify ethnicity, religion, and language among different groups in society, including the indigenous Sámi population. This is most likely a deliberate choice made by the authorities.

It is essential to build on existing infrastructures, where skilled staff, instrumentation, and facilities are already at hand. The Kiruna area of northernmost Sweden has considerable potential for increased operational measurements since it is home to the Institute for Space Physics (IRF), the EISCAT and ESRANGE facilities for space research, and the Abisko and Tarfala research stations.

Future coordination of measurements and data handling between circumpolar countries would also require harmonization of technical processes and formulation of common definitions. This report does not address those issues. Climatic variables, database structures, and international exchange are already well developed within the World Meteorological Organization (WMO), and harmonization work is progressing in other areas as well, e.g. in the emerging Global Earth Observation System of Systems (GEOSS).

Table 1. Approximate Status of Monitoring Key Variables on the AON List in Sweden that are of Potential Relevance for Arctic Monitoring.

Key Variable or indicator Variable	Agency Measuring and/or Comments
Physical variables	
Albedo	😐 Measured at one site by Lund University
Elevation, at glaciers	😐 Bi-annual terminus mapping of 18 glaciers by Stockholm University. Nation-wide laser scanning is planned.
Ice characteristics	☺ SMHI, from sea and land combined with satellite data
Precipitation	☺ SMHI climate network
Air pressure	☺ SMHI climate network
Solar radiation	😐 SMHI, at 5 sites + integration with satellite data
Snow depth	☺ SMHI climate network
Soil moisture	😐 On project basis by Lund and Gothenburg Universities and SLU at 3 sites each. SLU regular monitoring at 1 site.
Temperature, air, sea, and soil	😐 SMHI climate network, sea surface temp at 4 sites, soil temperature only at a few sites by university groups, upper air temperature by balloon sounding at 2 sites
Wind speed	☺ SMHI climate network
Water vapor	☺ SMHI climate network, balloon sounding at 2 sites
Lake level	😐 Only few found, but many probably exist
Sea level	☺ SMHI, at 6 sites
Land cover	😐 NFI and satellite data analysis, no detailed vegetation maps
Biogeochemical variables	
Aerosol concentration	☺ IVL, monthly at 10 sites
Atmospheric chemistry	☺ IVL, monthly at 15 sites
Biodiversity	☺ NILS, Landscape inventory 1/5 years at 631 sites
Biomass	☺ Sampling based national forest inventory, and satellite data products for forest covered areas
Carbon concentration	😐 CO_2 flux by universities, terrestrial carbon by NFI
Nutrient concentration	☺ Soil surveys by SLU
Contaminant conc.	☺ IVL, at 6 sites
Dissolved oxygen conc.	☺ Made by marine research stations at 33 sites
Phenology and behavior of animals	😐 Sparse phenology network started 2007. Bird migration monitored at a few locations. Extensive reporting from the general public (www.artportalen.se).
Tracer chemistry	😐 Stockholm University at 4 sites
Human-dimension variables	
Human demographics	☺ Statistics Sweden
Human health	☺ National Board of Health and Welfare
Cultural diversity	☹ No regular statistics related to the indigenous Sámi population
Education	☺ Statistics Sweden
Economic indicators	☺ Statistics Sweden

☺ = adequate monitoring program with stable funding
😐 = limited monitoring and / or unstable funding, e.g. through research groups
☹ = no regular monitoring program found
SMHI = monitored by the Swedish Meteorological and Hydrological Institute
NFI = sample plot based National Forest Inventory, carried out by SLU

Atmosphere

The lidar (Light Detection and Ranging) at the Swedish Institute of Space Physics, IRF, in Kiruna is used to make measurements of particles and molecules in the atmosphere. Photo: Uwe Raffalski, IRF

Climate

The Swedish Meteorological and Hydrological Institute (SMHI) performs basic climate measurements (Table 2 and Table 6, #1) in an irregular grid over the country (Fig. 1). For non-commercial research and educational purposes, data from the core services are made available at handling costs only. The meteorological base network (Table 6, ##1.1–1.6) north of 60°N consists of 105 stations; Table 2 lists the different observation programs. In addition to the meteorological base network, SMHI operates several other climate stations with a variety of instrumentation.

The meteorological base network was biased toward lowland in populated areas, originally because potential observers were more likely to be found there. This problem has been partly overcome since the introduction of automated sampling systems. Still there has been a need for climate measurements in forested areas on higher grounds. One such network, operated by the Faculty of Forest Sciences at the Swedish University of Agricultural Sciences (SLU) has 5 climate stations north of 60°N (Table 5, ##6–8, 13, 14). Their standard automated weather stations log air temperature, relative humidity, precipitation, global radiation, and soil temperature. An extensive climate program is also in operation at Abisko Scientific Research Station (Table 5, #1). More advanced climate measurements are conducted at the 12 micrometeorological tower sites (Table 5, ##6, 9, 11, 12, 15, 16–22). Also, at the Institute for Space Physics (IRF) in Kiruna, an automated weather station logging air temperature, humidity, wind, pressure, and UV-radiation has been in operation since 1996 (Table 6, #8.5).

Table 2. Measuring Program at SMHI's Climate Stations North of 60°N.

Variable	Manual station	Automated with PW	MOMS	Simple automated	AWOS	VVIS	Radiation	Total
Precipitation	X	X				X		76
Air temperature	X	X	X	X	X	X		100
Air humidity	X	X	X	X	X	X		100
Wind speed	X	X	X	X	X	X		100
Wind direction	X	X	X	X	X	X		100
Wind maximum		X		X				63
Air pressure	X		X		X			23
Cloud base	X							12
Cloud amount	X							12
Visibility	X	X	X		X			80
Global radiation							X	5
No. of stations	12	57	4	6	7	14	5	105

Weather observation network

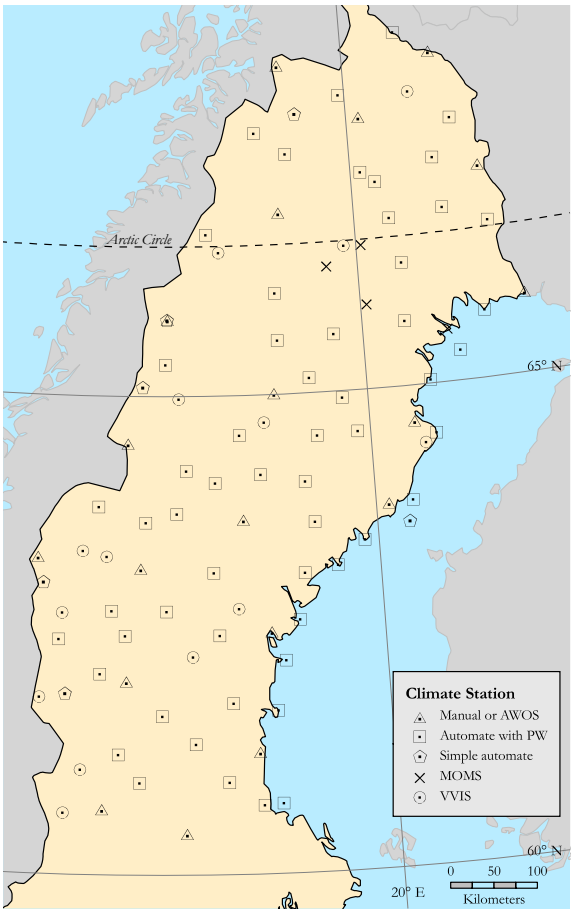

Figure 1. Weather observing network operated by SMHI, the observed variables are for VVIS-stations: air temperature, wind direction, and wind speed; MOMS-stations: as VVIS but with air pressure and visibility added; simple automate stations: as VVIS but with precipitation and maximum wind speed added; automate-with-PW stations: as simple automate, but with visibility added; for the manual and AWOS: as automate with PW, but also air pressure, cloud amount and cloud base, but not maximum wind.

Gas concentrations and fluxes

The monitoring program initiated and sponsored by the Swedish Environmental Protection Agency (SEPA) is guided mainly by the need to follow up on Swedish environmental goals and EU Directives on air quality. It is also important to report to international organizations and conventions. Among the most important are the UN Convention on Air, the Arctic Council, OSPARCOM (Oslo-Paris-Commission) for the Northeast Atlantic Convention, HELCOM (Helsinki Commission) for the Baltic, WMO, and the UN Convention on Climate.

Much of the activity in the area of gas concentrations and fluxes involves basic and applied research of a long-term character. The main issue is to understand exchanges of greenhouse gases between different surfaces of the earth and the atmosphere. The research is typically organized in international networks and programs, for example Fluxnet (see below), and the Nordic Centre for Studies of Ecosystem Carbon Exchange and its Interaction with the Climate System (NECC).

Carbon dioxide and trace gas concentrations

At the Zeppelin Station on Svalbard, Stockholm University, Department of Applied Environmental Sciences (ITM) measures trends in atmospheric carbon dioxide in background atmosphere (Table 4, #1.6, Table 5, ##3–4). In collaboration with NOAA/CMDL in Boulder, USA, air is regularly sampled in flasks for analysis of CO_2, CH_4, CO, $^{13}CO_2$, H_2, N_2O, SF_6, and ^{18}O in CO_2.

At the top of the micrometeorological tower (102 m) at Norunda north of Uppsala, carbon dioxide and methane concentrations are also measured (Fig. 2, Table 5, #5). Other sites for CO_2 measurements are the flux sites described below.

Air samples are taken at 10 sites in northern Sweden for analysis of SO_2, NO_2, and surface-near ozone (Fig. 2, Table 4, #1.2) in the air- and precipitation chemistry network.

Additional atmospheric measurements and measurements in the sea

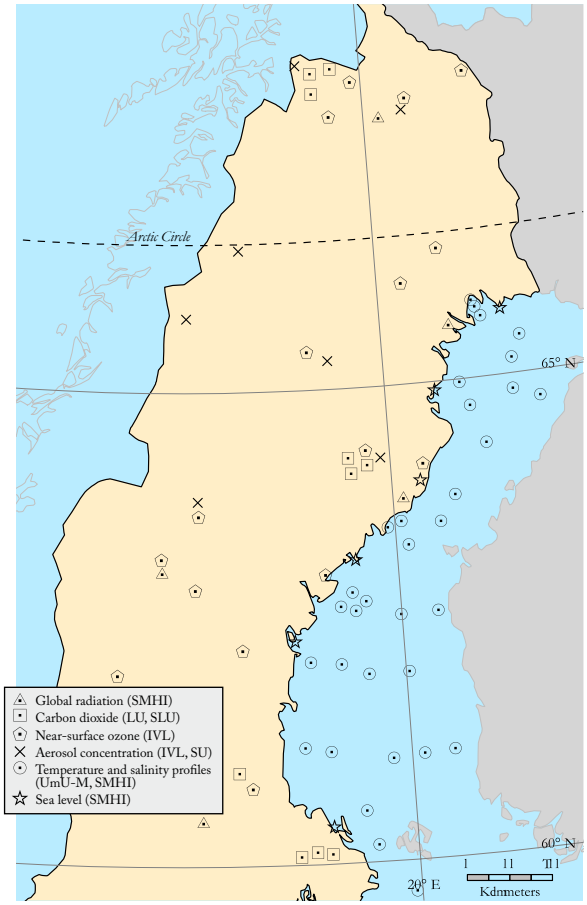

Figure 2. Additional atmospheric measurements and measurements in the sea.

Mass and energy exchange

At present there are about 12 micrometeorological tower sites north of 60°N in Sweden that use eddy covariance techniques to measure the exchanges of carbon dioxide, water vapor, energy, and at some sites methane between terrestrial ecosystem and atmosphere on a long-term and continuous basis (Table 5, ##5, 9, 11, 12, 15, 16–22). Among these tower sites, Norunda is the oldest and most complete (Table 5, #5). Three towers are in use at Rosindal, 70 km northwest of Umeå, in full-scale nitrogen and carbon dioxide experiments (Table 5, #12). In addition, one site is located at Zackenberg on Greenland (Table 5, #22). At the sites, data on vegetation, soil, and meteorological and hydrological conditions are also collected. The Swedish sites are integrated in the international Fluxnet program that assembles more than 400 eddy covariance sites around the world in an effort to better understand land surface – atmosphere interaction and its role in global change. The Swedish micrometeorological towers are presently financed by research councils, viz. Swedish Research Council (VR) and Formas, EU and university faculties. A European research infrastructure for flux measurements, the Integrated Carbon Observation System (ICOS) is being planned and includes Sweden as one of the participating nations.

Deposition

Two networks in Sweden monitor air and precipitation chemistry. They are the Swedish participants in the European Monitoring and Evaluation Program (EMEP) and the Air and Precipitation Chemistry Network. These are operated by IVL Swedish Environmental Research Institute Ltd. (IVL). The history behind the networks lies in their interest to record the deposition of acidifying substances over Sweden. EMEP is an international program within UN-ECE's Convention on Long-range Transboundary Air Pollution (CLTRAP), which consists of monitoring, emission-inventories, and modeling activities to map and evaluate the long-range transboundary transport and deposition of pollutants in Europe. Three of the six EMEP stations are located in low deposition areas in northern Sweden (Table 4, #1.1). Swedish participation in EMEP dates back to the end of the 1970s. The program includes hourly registration of ozone close to the soil surface, daily measurements

of nitrogen and sulfur compounds in the air, and weekly collection of accumulated precipitation for analysis of major inorganic compounds. However, most of the deposition stations are part of SEPA's air and precipitation chemistry monitoring program (Table 4, #1.2) that started 1983. In addition, the county boards also take regional measurements as part of the ICP Forest program (Table 6, #5.3).

The Air and Precipitation Chemistry Network includes about 25 sites (14 in northern Sweden) where precipitation from open accumulating samplers are collected and analyzed for pH, SO_4, NO_3, NH_4, Cl, Ca, Mg, Na, K, conductivity, and amount of precipitation (Table 4, #1.2). At 3 sites (one in northern Sweden) precipitation is analyzed for heavy metals, mercury, and methyl-mercury (Table 4, #1.3).

To integrate the relatively few deposition measurement sites, SMHI has adopted the Mesoscale Atmospheric Transport and Chemistry Model (MATCH) that uses emission data, meteorological data, routines for chemical processes, and a transport model to calculate long-range transport and deposition of air pollutants (Table 4, #1.5). Time series of gridded data over Sweden for deposition of different inorganic chemical compounds calculated with the MATCH-Sweden model are available at SMHI (Appendix, Table 11).

When the MATCH-Sweden model was first tested, the deposition network lacked high elevation sites. Hence, a monitoring program for deposition at higher elevations (Table 4, #1.9) was started. It consists of 4 sites in high elevation forests along the Swedish mountain ridge, where NO_3, NH_4, NH_3, HNO_3, SO_2, SO_4, Na, K, Ca, Mg, Cl, pH, conductivity, and amount of precipitation are analyzed on monthly accumulated precipitation samples.

A notorious problem in deposition assessments is dry deposition on forest canopies. If throughfall is sampled below the canopy it will consist not only of dry and wet deposition, but also of canopy leakage, i.e. exudates and diffusion of substances from within the leaves. However, it has been argued that throughfall sampling, even if not free from problems, may add information to the normal wet deposition sampling. IVL operates a throughfall sampling network comprised of 10 forest sites for sampling, from which monthly samples are analyzed for pH, SO_4, NO_3, NH_4, Kjeldahl-N, Cl, K, Ca, Na, Mg, TOC, conductivity, alkalinity, and amount of throughfall (Table 4, #1.8).

Organic environmental pollutants in air and precipitation are assessed by the Department of Applied Environmental Sciences (ITM), Stockholm University in a program with 3 sampling sites in Sweden and northern Finland. The analyses include 31 variables, comprised of 12 PAHs, 7 PCBs, 3 DDTs, 3 chlordanes, 2 HCHs, 1 HCB, and 3 PBDEs (Table 4, #1.7).

An alternative for metal deposition measurements is to analyze their abundance in mosses since metals bind strongly to cation exchange sites in them. The concentration of metals in mosses would therefore act as an index for metal deposition. It is also assumed that uptake of most water and dissolved substances comes directly from precipitation; even if it has been shown that capillary transport of dissolved metals may be substantial. A national inventory of metals in mosses takes place at 5-year intervals (Table 4, #1.11).

SEPA's monitoring program also includes a subprogram on environmental pollutants in urban environments (Table 4, #1.10). It is less coupled to the Arctic and not dealt with further in this report, but is listed in Table 4 for completeness.

Atmospheric physics

The Swedish Institute for Space Physics (IRF) in Kiruna is one of the 70 worldwide measurement sites for remote sensing research of atmospheric physics and belongs to the Network for the Atmos-

pheric Composition Change (NDACC). The research program comprises studies of the energy balance, electrodynamics, and chemistry of the troposphere, stratosphere, and lower thermosphere. Most of IRF's instruments are involved in IPY projects. Despite its research character, some of the activities aim at monitoring changes over time and are therefore included here.

Total ozone and other trace gases

The total column amount of ozone and other trace gases are measured with mm-wave instruments, FT-IR and DOAS spectrometers, at IRF in Kiruna (Table 6, #8.1). With the sun or moon as infrared light sources, FT-IR spectrometers can quantify the total column amounts of many important trace gases in the troposphere and stratosphere. At present the following species are retrieved from the Kiruna data: O_3 (ozone), $ClONO_2$, HNO_3, HCl, CFC-11, CFC-12, CFC-22, NO_2, N_2O, NO, HF, C_2H_2, C_2H_4, C_2H_6, CH_4, CO, COF_2, H_2O, HCN, HO_2NO_2, NH_3, N_2, and OCS. Together with Russian and Finnish institutes at the same latitude, IRF studies the stratospheric ozone and its dependence on polar atmospheric circulation and precipitation of charged particles. The ground-based instruments are also used to validate satellite measurements of vertical ozone distribution (Odin, SAGE III, and GOME).

SMHI measures the thickness of the ozone layer at 2 sites in Sweden, one at Norrköping in southeast Sweden and one at Svartberget Forest Research Park, Vindeln, 70 km NW of Umeå. At Svartberget a Dobson and a Brewer Spectrophotometer are operational. The measurements are part of SEPA's Environmental Monitoring Program (Table 4, #1.4).

Instruments including a mm-wave radiometer and FT-IR and DOAS spectrometers are deployed on the roof of the optical laboratory at the Swedish Institute of Space Physics, IRF, in Kiruna. Photo: Rick McGregor, IRF

Aerosols and thin clouds

Aerosols and thin clouds are measured at IRF in Kiruna. For example, researchers use Lidars (Light Detection and Ranging) to measure polar stratospheric and noctilucent clouds (Table 6, #8.2).

At Zeppelin Station on Svalbard, Stockholm University, the Department of Applied Environmental Sciences (ITM) measures the amount and composition of aerosols in the background atmosphere (Table 4, #1.6 and Table 5, #3.2). Measurements include particle concentration and size distribution, light absorption and scattering, and, in collaboration with Heidelberg University, radon concentration. Also ITM has a similar measurement program at Aspvreten, 80 km south of Stockholm on the coast of the Baltic Sea (Table 5, #4).

Winds and structures

Winds and structures are measured with ESRAD MST radar at IRF in Kiruna (Table 6, #8.3).

Atmospheric composition

At IRF in Kiruna measurements are used to assess the physical and chemical state of the stratosphere and upper troposphere and the impact of changes on the global climate (Table 6, #8.4).

Polar stratospheric clouds such as these mother-of-pearl clouds over Kiruna form in the winter when cold conditions exist in the stratospere at about 25 km altitude. Photo: Sheila Kirkwood, IRF

Space Physics

Aurora

In and around Kiruna, IRF uses all-sky cameras and other images to detect and record the aurora. The all-sky cameras have 180° field-of-view and take one image per minute. They have been in operation since the International Geophysical Year (IGY) in 1957 (Table 6, #9.1). The Auroral Large Imaging System (ALIS) is a large-scale array of high-resolution monochrome CCD detectors around Kiruna, a network of seven stations within approximately 50 x 50 km. The International Network for Auroral Optical Studies of the Polar Ionosphere, coordinated by IRF, is a forum for planning measuring campaigns, distributing information, and intercalibrating different sets of instruments located in different parts of the world. The network is part of the IPY-endorsed project Heliosphere Impact on Geospace (IPY Cluster #63), with Interhemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research (ICESTAR) and International Heliophysical Year (IHY) as lead projects.

Earth's magnetic field

The Earth's magnetic field is monitored with magnetometers at Fiby (near Uppsala) and at Abisko. The magnetic field fluctuates rapidly depending on solar activity and slowly depending on variations within the mantle of the Earth. The rapid fluctuations are measured every second by a flux-gate magnetometer and the slow fluctuations twice per month by a proton-precession magnetometer (Table 6, #9.2). Data are archived at World Data Center WDC-C1 in Copenhagen, WDC-C2 in Kyoto, and NGDC in Boulder. The Geological Survey of Sweden (SGU) is responsible for the proton-precession magnetometer measurements.

Particle precipitation

Particle precipitation is measured by relative ionospheric opacity meters (riometers) at IRF in Kiruna. Riometers measure the absorption of cosmic noise at 30 and 38 MHz and provide information about particles with energies larger than 10 keV (Table 6, #9.3).

Ionospheric conditions

The electron density of the ionosphere is measured by ionosonds and digisondes at IRF in Kiruna (Table 6, #9.4).

Aurora Large Imaging System (ALIS) is an array of high-resolution monochrome CCD detectors. One of the ALIS stations is situated at the Abisko Research Station. Photo: Rick McGregor, IRF

Terrestrial Conditions

Caterpillar of a Swallowtail butterfly *Papilio machao*. Photo: Sara Cousins

Glaciers

Glaciers in the Arctic are melting at an accelerating speed, and small glaciers appear to melt faster than larger ones. Hence, small glaciers could be regarded as early warning systems that are important to monitor. Glaciers in the Swedish mountain chain would be examples of such systems.

Mass balance

Mass balance measurements started at Storglaciären in the Kebnekaise massif in 1946 (Table 5, #2.1). At present, the measurements comprise a mass balance of 5 glaciers in the area. In calculating one year's mass balance, measurements are taken twice per year (in winter and summer) and mass balances are calculated annually by the Department of Physical Geography and Quaternary Geology at Stockholm University (SU-INK).

Terminus mapping

Measurement of glacier fronts is a simpler alternative to mass balance calculations that could be used as an index for mass balance. Stockholm University (SU-INK) performs such front measurements at 18 glaciers every second year (Table 5, #2.2).

Ice on lakes and rivers

The earliest record of lake ice break-up in Sweden is from as early as 1701, when the ice on Torne River at Haparanda melted on May 31st. Since then SMHI has successively extended the ice observation network. By 1900 the network included about 150 sites, and by 1950 it included over 320 sites (Table 6, #2). By 1950, observations had been terminated at only 9 sites. During the following 50 years 72 new sites were added to the network while observations were terminated at 255 sites. The reason for the extensive network during the latter nineteenth century and the early twentieth century was the use of frozen lakes and rivers for transportation, but also the need to know when spring activities, e.g. floating timber, could commence. The ice broke up on Torne River at Haparanda, on average, on May 20th during the eighteenth century, on May 17th during the nineteenth century, and on May 10th during the twentieth century, indicating a long-term trend of earlier lake ice break up.

Stockholm University monitors mass balance of the glaciers in the vicinity of the Tarfala Research Station. The station and the glaciers are extensively used for educational purposes, mainly for university students, but also for hikers and mountain climbers. Photo: Gunhild Rosqvist

Permafrost

Increasing temperature in the Arctic will increase the soil temperature and decrease the area covered by permafrost. Depending on the situation, microbial decomposition of stored soil organic carbon will increase and release carbon dioxide and eventually methane, two greenhouse gases that may accelerate climate change. Some international programs study permafrost development. At 1540 meters altitude in Tarfala, temperature is measured in one borehole down to 100 m and another down to 15 m below soil surface in the Permafrost and Climate in Europe (PACE) program coupled to the Global Terrestrial Network for Permafrost (GTNP) (Table 5, #2.5). Four more shallow, boreholes near Abisko are suggested candidates for PACE, one managed by Luleå Technical University and three managed by Lund University (Table 5, #1.21).

New holes are drilled for measurements of ground temperature in the vicinity of Abisko Research Station. Drilling is supervised by researcher Margareta Johansson, Lund University. Photo: Frida Keuper

Abisko Research Station carries out manual sonding of the active permafrost layer at Stordalen, an activity on behalf of Geobiosphere Science Center (CGB), Lund University and part of the Circumpolar Active Layer Monitoring (CALM) (Table 3). The active layer has been monitored at 11 sites along an 80 km east-west profile from 1978 to 2002. Eight of these were bog sites situated in a transect from the dry and cold east to the milder and wetter west, all at approximately 390 m altitude.

Permafrost monitoring started in 1972 at Kapp Linné, Svalbard, by the Geobiosphere Science Center (CGB), Lund University (Table 5, #23), and was reported for the period 1972 to 2002. Soil moisture and soil temperature were also monitored. The 10 monitoring sites differed in vegetation cover, elevation, substrate, active periglacial processes, and distance to the sea.

Inventories related to vegetation cover

Remote sensing data sources

The Swedish National Land Survey (www.lm.se) has an ambitious program for government-funded aerial photography. Regular aerial photography programs have been carried out for more than 50 years. At present, each area in the country is photographed on average every 3rd year, using digital air photo cameras. A one-time laser scanning of the nation is also planned to be used to obtain an improved digital elevation model.

Starting in 2008, a database with yearly SPOT, Landsat, or similar satellite data have been established and hosted by the National Land Survey. This archive, called SACCESS, also host historical satellite data from 1972 and onward and is freely available to Nordic citizens (http://saccess.lantmateriet.se/). Both the air photo archive and the satellite data archive will be important sources for future studies of land cover change.

National Forest inventory

The sample plot-based national forest inventory (RIS-RT) has been a continuous activity at SLU (and the forest research organizations existing before SLU) since 1923. All Sweden is included except the subalpine birch forest along the mountain chain. The national forest inventory is part of Sweden's official statistics and is maintained by the Department of Forest Resource Management (SLU-FRM). The sampling strategy combines random and fixed plots and covers the country every 5 years. Each year around 10 000 sample plots are field surveyed nationwide. Approximately 200 variables are recorded for each plot (Fig. 3, Table 6, #10).

Satellite data-based estimates of forest cover

SLU combines the spectral information from SPOT, or similar satellite image data, with the field data information from the national forest inventory plots. The result is a nationwide raster database (pixel size 25x25 m) where each grid cell is coded with the stem volume for the major tree species categories (pine, spruce, deciduous), and tree height. The product, which is called kNN-Sweden after the algorithm used, is repeated every fifth year, starting with images from year 2000. The kNN database can be downloaded free of charge from http://skogskarta.slu.se/

Satellite data-based estimates of clear felling

Swedish forestry practice includes a final clear felling after a rotation of up to about 100 years. To follow up on cutting permits, the Swedish Forest Agency (SST) annually maps all new clear felled areas, using satellite image data from the present and the previous year. This practice, carried out by a government agency, also creates a yearly nationwide database with SPOT or similar satellite image data, which has created the base for the above mentioned SACCESS national satellite data archive

Terrestrial sampling networks

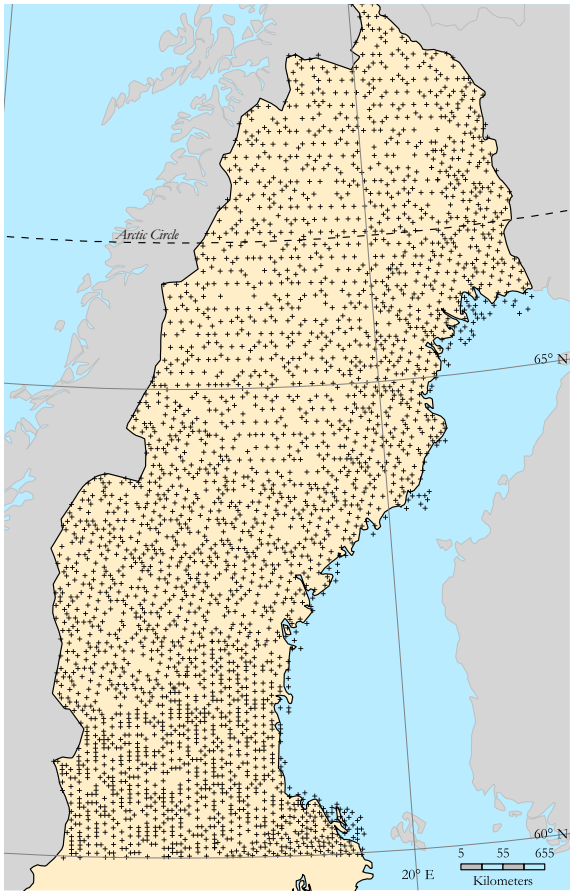

Figure 3. Terrestrial sampling networks. National Forest Inventory tracts (SLU-FRM).

Inventory of landscapes

The National Inventory of Landscapes in Sweden (NILS) is a sample-based, nationwide environmental monitoring program focused on biodiversity. NILS started in full scale in 2003 and is based at the Department of Forest Resources Management, SLU. The program includes all terrestrial environments in Sweden, including agricultural land, wetlands, urban environments, forests, and

mountains. NILS is based on 631 permanent sampling squares of 1 km x 1 km (Fig. 4). Within each square, 12 sample plots are field surveyed and an air photo interpretation is done for the whole area. A more extensive air photo interpretation within wider squares of 5 km x 5 km is also planned. The program will have a rotation time of 5 years. Results from NILS are intended to follow up on the national environmental objectives, land use status and change, and the distribution and area of different biotopes (Table 4, #5.1).

The NILS program is divided into several sub-inventories, i.e. the general landscape (Table 4, #5.1), the mountains (Table 4, #2.1), arable land (Table 4, #4.6), and wetlands (Table 4, #6.3).

Wetland inventories

At present SEPA's program on wetlands is mainly a follow-up on wetland states, e.g. hydrological intactness and biodiversity. On the other hand, wetlands are part of the national inventory of landscape, NILS (see above). Wetland status is embraced by reporting obligations according to the EU Habitat Directive, and SEPA now uses high-resolution satellite data for operational monitoring.

Inventory of Forest Soils

Since 1962, the soil inventory (RIS-MI) and the national forest inventory (RIS-RT) have had a common field organization. The soil inventory investigates soils and collects soil samples for laboratory analysis. It includes several soil variables, e.g. soil type and soil classification, stone and boulder abundance, water relations, and soil chemistry. Simultaneously to the soil inventory, RIS–MI samples the field layer vegetation (Table 4, #3.1).

Soil and Vegetation Inventory of Arable Land

The first sampling for the soil and vegetation inventory of arable land was done in 1994-1995. The program covers arable land in Sweden and is designed to describe the state of Swedish arable land and the quality of the crop in relation to soil status, cultivation measures, and means of operation (Table 4, #4.4).

Fieldwork assistant Anders Malmsten survey plant species abundance for the National Inventory of Landscape in Sweden (NILS). Photo: Bo Karlsson

Terrestrial sampling networks

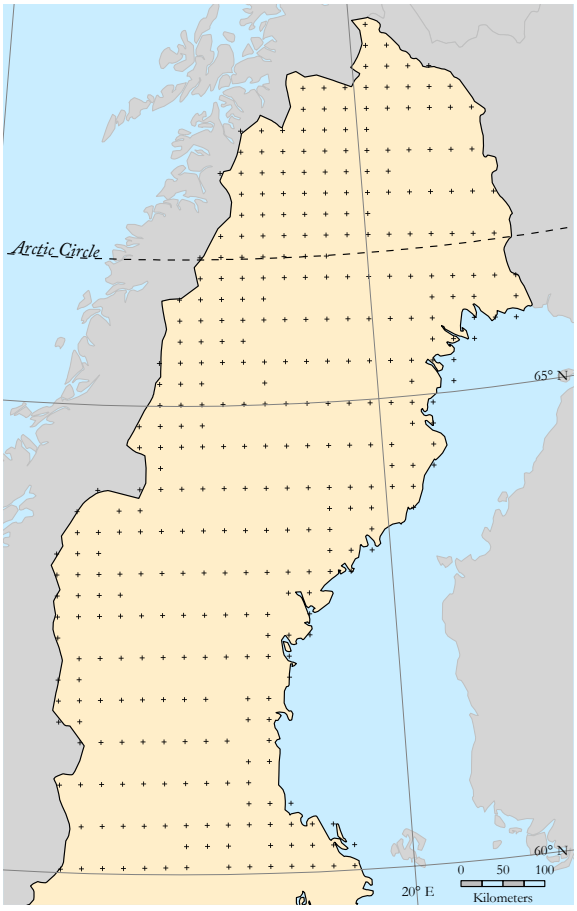

Figure 4. Terrestrial sampling networks. National Inventory of Landscape in Sweden (NILS) tracts (SLU-FRM).

In an inventory of soil compaction on arable land, basic physical variables of soil are monitored on 30 selected, arable fields. One sixth of the fields are sampled annually, and the samples are analyzed for saturated hydraulic conductivity, dry bulk density, porosity, water filled porosity at 1 m suction, and soil penetrability (Table 4, #4.7).

Arable land is also monitored as part of the EU Common Agricultural Policy (CAP) for control of subsidies. The county boards use high resolution satellite images for this purpose.

Other Terrestrial Monitoring

Integrated monitoring

At present, Sweden has 4 integrated monitoring (IM) sites that are part of a European network on integrated monitoring with an extensive measurement program. One of these sites, Gammtratten, situated in central Västerbotten, monitors several variables (Table 4, #3.2). SGU conducts groundwater sampling at 3 of the sites. In total, 18 stations are sampled 4 times per year.

A program for comprehensive information on the state of forests in Europe was launched 1985 in response to acid deposition and fear of forest decline. The program was named the European ICP-Forest Program (International Co-operative Program on Assessment and Monitoring of Air Pollution Effects on Forests operating under the UNECE Convention on Long-range Transboundary Air Pollution, Table 6, #5). ICP-Forest monitors forest conditions in Europe and operates at two levels of intensity. Level I is a systematic 16 km by 16 km transnational grid having around 6 000 observation plots in Europe. Level II is comprised of around 800 sites in selected forests throughout Europe with more intense observations.

The Level I measurements consist of three parts: crown condition assessment, soil condition assessment, and foliar survey. The crown condition assessment includes the degree of defoliation, discoloring, and damage visible on trees. The soil condition assessment addresses possible nutrient imbalances caused by, e.g. acid deposition. The foliar survey assesses foliar nutrient concentrations, because changes in environmental conditions may

affect foliar nutrient concentrations. The Swedish contribution is made by the national forest inventory (SLU-FRM), which estimates the degree of crown defoliation and discoloring on 700 permanent plots around the country.

The Swedish Forest Agency (SST) organizes the Level II observational plots. They manage a program with more than 200 permanent plots throughout Sweden, on which they estimate forest vitality (several measures), forest growth, soil chemistry, and field vegetation. Of these plots, 100 are connected to the international network, and 20 are north of 60°N. Foliage chemistry is determined on 100 plots, deposition and soil water chemistry on 50 plots, air quality on 25 plots, and climate on 14 plots. The sampling intensity varies from once in 5 years to once per hour depending on variable monitored (Table 6, #5.2).

Tree limit

The tree limit has been monitored since 1915 at some sites in the Swedish mountains. The Department of Ecology, Environment, and Geosciences (EMG) at Umeå University, and Jämtland and Dalarna county boards monitored about 300 sites along the Scandinavian mountain chain for upper elevation trees taller than 2 m (Öberg, 2007).

Phenology

Since 2007, SLU has conducted daily phenology observations on forest trees (birch, Scots pine, and Norway spruce) during the spring at four sites in northern Sweden (Fig. 5, Table 5, ##7.2, 8.2, 13.2, and 14.2) In addition, the phenology of 15 plant species is observed at two sites and of birch at one site, all at Abisko (Table 5, #1.11, and 1.12).

Terrestrial monitoring

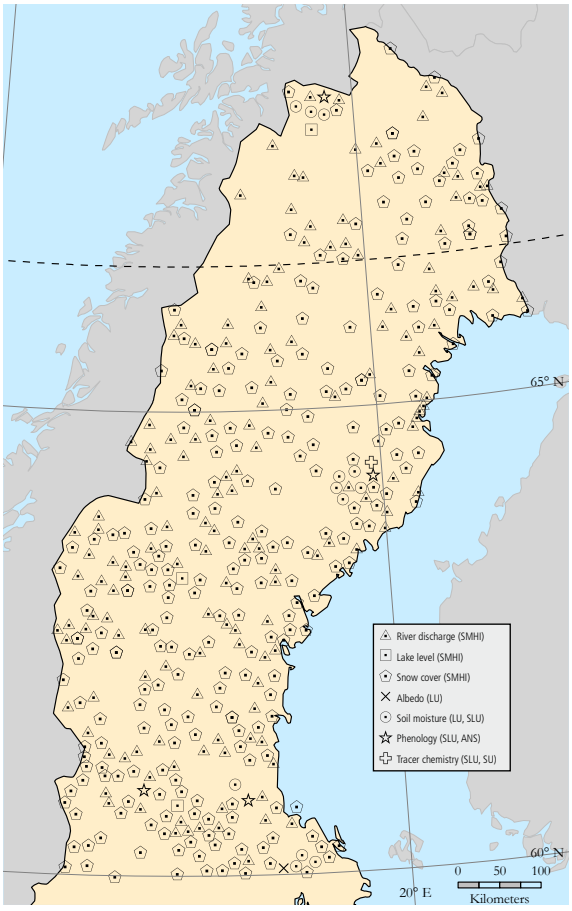

Figure 5. Terrestrial monitoring. (1) River discharge (SMHI), (2) Lake level (SMHI), (3) Snow cover (SMHI), (4) Albedo (LU), (5) Soil moisture (LU, SLU), (6) Phenology (SLU, ANS), (7) Tracer chemistry (SLU, SU).

Metal in mosses

As a way to assess metal deposition, the Swedish Environmental Protection Agency (SEPA) started a program in 1980 to cover all of Sweden every fifth year. Common mosses (preferably *Pleurozium schreberi*, or secondarily *Hylocomium splendens)* were sampled by the national forest inventory

(RIS-RT) with rather high intensity in a grid covering the country. The samples were prepared at the Swedish Museum of Natural History (NRM), and only the growth from the last 3 years was collected for chemical analysis. Surplus material is stored in the sample bank at NRM. The number of samples analyzed per county peaked in 1985 at over 100, but for the past 10 years the figure has decreased to around 40 samples per county and year.

Ecosystem – Fauna

Large animals

A comprehensive overview on monitoring of game is being prepared (oral information, Kjell Danell, SLU, January, 2008). Some monitoring projects, sponsored by SEPA, on metals in animals are under way. Metals in tissue samples from reindeer (Table 4, #2.3) are analyzed at 3 sites along the mountain ridge once per year. Samples in moose (Table 4, #3.4) from Norrbotten and Jämtland counties (and 3 counties in southern Sweden) have been analyzed every autumn since 1996. The Swedish Museum of Natural History (NRM) organizes this work and stores some of the material, and the Swedish Veterinary Institute (SVA) performs chemical analyses on some of the tissues. Hunting associations organize much of the field sampling.

Small animals

Census on small mammals (voles, lemmings, and shrews) are conducted twice per year at 3 sites along the mountain chain (Table 4, #2.2) and at 2 sites in the forest landscape (Table 4, #3.3). Part of the material collected is sent to the environmental sample bank at the Swedish Museum of Natural History (NRM). The Department of Ecology, Environment, and Geosciences (UmU-EMG) at Umeå University is in charge of the program and analyzes the data.

Birds

Bird populations are monitored as part of SEPA's "Landscape" program. The Swedish bird census project determines, once per year, the species and number of birds at about 500 sites throughout the country (Table 4, #5.2). The Department of Zoo-ecology, Lund University, organizes this census.

Ottenby Bird Observatory on Öland is responsible for bird counting and ringing of small birds at Ottenby (Table 4, #5.3), a key location for migrating birds. From August to November the number and species of migrating birds are counted at Falsterbo in southern Sweden. The Department of Zoo-ecology, Lund University, organizes the census (Table 4, #5.4). Falsterbo is a key location for migrating birds of prey.

The Swedish sea-bird inventory is taken place at about 100 sites where these birds spend their winter. Number and species are estimated in January of each year in the internationally coordinated program. The Department of Zoo-ecology, Lund University, conducts the Swedish part (Table 4, #5.5).

The striking appearance of the Mute Swan makes it a well known, and often seen bird along the coast of Gulf of Bothnia. Photo: Sara Cousins

Aquatic Conditions

Photo: Anders Clarhäll

Fresh waters

Soil water

Different programs take samples of soil water for chemical analysis, mostly at 0.5 m below the soil surface, which is below the main rooting zone. Soil water is sampled by municipalities and regional associations for clean air in the ICP-Forest program (Table 6, #5.3). Soil water is also sampled in different forest manipulation experiments where control plots are always maintained. At Flakaliden in central Västerbotten (Table 5, #10.5), soil water chemistry has been monitored for 20 years in control plots and in fertilized, irrigated, or soil-heated plots. Soil water potential is measured at Flakaliden (Table 5, #10.5). Soil water content is measured on a project basis by Lund University and Gothenburg University at three sites each and by SLU at one site. In addition, SLU includes soil water content in its regular monitoring program at one site (Fig. 5, Table 5, #7.3).

Groundwater

Since the late 1960s, the Swedish Geological Survey (SGU) has operated a groundwater network comprising about 400 wells throughout Sweden. The groundwater level is measured twice per month, resulting in maps (published monthly) of the groundwater situation in the country (Table 6, #7.1). Chemical analyses are performed twice per year in 30 wells selected from the network (Table 6, #7.2).

The groundwater sampling network for water quality called "reference stations – groundwater" is split in two parts: one called trend stations (comprised of 80 stations that are sampled a couple of times per year) and the other called periodical stations (comprised of a large number of stations sampled once every 6 years). In total, 528 stations are sampled every 6 years, most of which are natural springs and the rest are groundwater observational wells and municipal water supplies (Table 4, #7.1). Half of the trend stations are situated in small aquifers, e.g. till deposits, while the other half are situated in large aquifers such as sand and gravel deposits in eskers and fossil deltas. Groundwater from all stations is analyzed according to a base program. In addition, complementary analyses are performed for a number of trace elements (Cu, Zn, Pb, Cd, Cr, Ni, Co, As, V and in some cases Hg).

Surface waters

The national surface water monitoring program was revised by SEPA in 2007 to better match the requirements from EU and contains now four main programs and some smaller special programs. The main programs are water quality and bio-indicators in the National Lake Survey and in Trend Lakes, water quality and discharge at River Mouths and in Trend Streams. Sampling and analysis for water chemistry, phytoplankton, bottom fauna and macrophytes are conducted by SLU (SLU-ASA). The test fishing is conducted by the Swedish Board of Fisheries (SFB). These bodies are also data base hosts for their data.

The National Lake Survey (Table 4, #7.4) gives an aerial coverage of water quality in Swedish lakes. Water samples are taken at 0.5 to 2 m depth in a total of 1841 lakes in northern Sweden in a 6-year rotation with about 350 lakes per year. The samples are taken after the lake's complete overturn in the autumn. For water chemistry the samples are analyzed for 20 variables (temperature, pH, NH_4, NO_2+NO_3, Tot-N, Tot-P, PO_4, TOC, Si, absorbance, Fe, Mn, alkalinity, Ca, Mg, K, Na, SO_4, Cl and F) and less frequently for 9 trace metals (Cu, Cd, Pb, Cr, Ni, Co, Ni, V, Al).

In the Trend Lakes program the sampling is more frequent (4 times per year for water chemistry and one time per year for bottom fauna, phytoplankton and macrophytes). The aim of the program is to build time series to detect environmental

changes due to e.g. climate change or large scale changes in deposition load. In this program about 40 lakes are sampled in northern Sweden. For water chemistry the samples are analyzed for the same elements as in the National Lake Survey. In addition test fishing is conducted in 2 of the lakes per year.

Stream water is assessed in two programs in which SMHI conducts most river discharge observations. It has 155 discharge stations in northern Sweden that belong to the Base Hydrological Network (Fig. 5, Table 6, #3.1). SMHI reports daily discharges in 46 rivers north of 60°N to BALTEX (Table 6, #3.2). The size distribution of the catchments is characterized as minimum 30 km^2, median 6 400 km^2 and maximum 33 930 km^2, and the relative area of lakes as minimum 3%, median 6.4%, and maximum 21%. SLU is in charge of the water quality and SFB of the test fishing program.

In the River Mouth Survey the goal is to estimate the element discharge from Sweden to the sea. Monthly sampling is conducted in 23 rivers and the samples are analyzed for pH, conductivity, NH_4, NO_2, NO_2+NO_3, Kjeldahl-N, Tot-N, Tot-P, PO_4, TOC, Si, absorbance (on filtered and non-filtered samples), $KMnO_4$, Fe, Mn, alkalinity, Ca, Mg, Na, K, SO_4, Cl, F, Cu, Zn, Cd, Pb, Cr, Ni, Co, Ni, V, As, Al, Hg.

The primary goal of the Trend Streams program is to build time series to detect eventual environmental changes. The streams are of quite different sizes, with drainage basins from 1 to 10 000 km^2. For water chemistry 37 streams are sampled monthly and the samples analyzed as for the River Mouth Survey. Out of the 37 streams 27 are selected for yearly sampling of bottom fauna and benthic diatoms, and in turn electrical test fishing is performed once per year in 16 of these.

Sea water

Swedish research and monitoring activities in the Arctic Ocean are mainly of a project character, while in the seas around Sweden (i.e. Skagerrak and Kattegatt on the Swedish west coast, and Bal-

Photo: Jakob Halaska

tic Proper, Bothnian Bay, and Gulf of Bothnia on the east coast) several ongoing monitoring projects aim to follow up on large-scale changes, e.g. concerning over-fertilization, metals, environmental toxics, and biodiversity. The main actors around Sweden are SMHI, Gothenburg University (Kristineberg Research Station), Stockholm University (Askö Laboratory), and Umeå University (Umeå Marine Research Center). Only SMHI and Umeå Marine Research Center perform investigations north of 60°N in the Gulf of Bothnia and Bothnian Bay. SMHI hosts the main database, SHARK (Appendix 14).

Gulf of Bothnia and Bothnian Bay

In 2007, SEPA adopted a new monitoring program for coastal areas and the sea. It is coordinated with regional monitoring programs and builds on an earlier program, but has been updated and is described below. Both the Baltic Proper in the east and Skagerrak and Kattegat in the west are entirely situated south of latitude 60°N. Hence, only the monitoring program in the Gulf of Bothnia and Bothnian Bay are described here.

The subprogram, Macro Fauna Soft Bottoms (Table 4, #8.2.1), contains trend and aerial monitoring of soft-bottom fauna in the Gulf of Bothnia. It is conducted by Umeå Marin Research Center (UmU-M) and includes basic sediment investigation and assessment of oxygen concentration in bottom waters. The aim is to observe if, and in what way, the structure of the bottom macro fauna changes. Changes may indicate over-fertilization and oxygen stagnation.

Embryogenes of Amphipod *(Monoporeia affinis and Pontoporeia femorata)* and its environment is studied at 7 sites in Baltic Proper and 5 sites in Gulf of Bothnia as an indicator species of bottom sediment quality (Table 4, #8.2.2).

The Metals and Organic Environmental Pollutants subprogram (Table 4, #8.2.3) will report mainly on environmental toxics in biota in the large sea basins, of which the Bothnian Bay and the Gulf of Bothnia are the farthest north. Sea mussels, fish, and bird eggs are collected and analyzed for the content of metals and organic toxics. The material is then stored at the Swedish Museum of Natural History (NRM) for possible later retrospective analyses.

The Free Water Body subprogram (Table 4, #8.2.4) aims to describe the effects of primarily over-fertilization by means of hydrographical, chemical, and biological methods. One part of the program collects samples as frequently as 18 to 25 times per year at a few sea and coastal stations. Another part collects samples only once per year, during winter, to map the extent of areas with low oxygen content and the size of the nutrient pool, which gives the prerequisites for algal bloom in spring.

The Integrated Coastal Fish Monitoring subprogram (Table 4, #8.2.5) documents the composition of the stationary fish community as well as the growth, general health situation, and reproduction success of perch *(Perca fluviatilis)* and burbot *(Lota lota)* as indicators of environmental toxics. Fish from one site close to Umeå is sent to Gothenburg University for analysis of biochemical, physiological, histological and pathogenic variables in perch.

The Seal and Sea Eagle subprogram (Table 4, #8.2.6) monitors marine top consumers as indicator species to assess harmful effects of environmental toxics. Hopefully, in the long run, the program will show that these species have natural reproduction, health, and population. At present the subprogram has no sampling network. In the Bothnian Bay, the Swedish Museum of Natural History (NRM) monitors grey seals, ringed seals, and European sea eagles. These observations will show the state and trends of population size, development, and health of seals and of reproduction, population size, and development of European sea eagles. The aim of early warning is to detect

changes in reproduction, health, survival, and population trends that may result from changes in the marine environment.

The Swedish Meteorological and Hydrological Institute (SMHI) maps ice extent and type for shipping and weather prognoses (Table 6, #4.1). The ice extent at sea is of great importance for navigation, and assistance from an icebreaker is often needed, especially for harbors in the Bothnian Bay. Hence, ice conditions are mapped daily during the winter period, normally from the end of November until the end of May. Ice meteorologists take advantage of detailed reports about ice type and ice thickness from observers along the coast, e.g. pilots, special ice observers, and from the icebreakers passing through the ice-covered sea. Observations from helicopters are part of the regular icebreaking activities. Satellite images, especially from US weather satellites (NOAA-15, NOAA16 and NOAA-17), complement the ice reports and provide information on the large-scale ice situation on the scale 1 km x 1 km during clear sky conditions. More detailed ice information, down to the scale 20 m x 20 m, can be retrieved from a satellite-based instrument called Synthetic Aperture Radar (SAR). SAR sensors are also found onboard the Canadian RADARSAT (in operation since 1996) and on the European ENVISAT (since 2003) and provide information on the ice situation regardless of weather conditions and time of day. A good description of the ice situation is also needed as input data for weather prognosis models because the extent of sea ice has a major influence on weather (especially in coastal areas), and on temperature, cloudiness, and precipitation. Results from daily ice mapping are saved in a database from which e.g. climate statistics for the Baltic region may be generated.

When lake ice reach a thickness of about 10 cm, it starts transforming into long vertical crystals called "candles." These candles can often be seen when lake disintegrate in spring. Meltwater fills in between the crystals, which begin breaking apart. Lake Lillsjön, Sweden. Photo: Anders Clarhäll

Social Dimension

Photo: Anders Clarhäll

Health-related environmental monitoring

Follow-up on environmental factors that can affect human health.

Biological data

One focus of SEPA's subprogram for human biological data concerns metals in human bodies (Table 4, #9.1). It includes studies on lead concentration in human blood, mercury in hair, and cadmium concentration in urine. Old hair samples have been collected and analyzed for mercury. Methyl mercury may damage the central nervous system, and at the fetal stage effects may occur already after low exposure. A study in Uppsala is investigating persistent organic compounds in breast milk. Concurrently, the young mothers answer a questionnaire, and hair samples are collected to analyze methyl mercury. Cadmium in urine is an indicator of the load on kidneys, and especially women with low iron storage have an elevated risk for increased cadmium uptake. A program on cadmium in women that started in Gothenburg, then expanded to Stockholm, Lund, and Umeå is under way. In 2007, a second round started in Gothenburg. A questionnaire is filled in concurrently with collection of a urine sample.

Organic compounds, especially persistent organic pollutants (POP), are of special interest and are included in one of SEPA's subprograms (Table 4, #9.2). The subprogram includes different groups in the population. On military enlistment, young men are tested for persistent organic compounds in the body. Mercury content is measured in high consumers of fish, and the concentration of flame retardants is measured in samples of breast milk from women who breast-feed. The National Food Administration stores important data from control of pesticides in vegetables, where more than 2 000 samples are taken per year and residues from more than 200 different pesticides are analyzed. To date, no data have been analyzed and reported from this material, but it will be done in the first phase of this SEPA subprogram.

Sampling of breast milk will continue with the intent to monitor organic environmental pollutants. Already existing is a long time series on the concentration of flame retardants and PCB in breast milk. Concurrently, samples will be transferred to the environmental sample bank at the Swedish Museum of Natural History (NRM), which means that samples will be available for comparison in the future.

Air pollutants

Studies of human exposure to cancer-inducing air pollutants (Table 4, #9.3) are being conducted in Gothenburg, Umeå, Stockholm, and other sites. The importance of smoking habits, traffic, and other potential sources will be determined for a better risk evaluation. Measurements will be conducted according to a rolling schedule, with one city at a time and a group of 40 randomly chosen people, 20 to 50 years of age. The background concentrations in air will be followed at the same time.

Exposure to nitrogen dioxide is particularly severe during winter. An estimate of the number of people exposed to nitrogen dioxide concentrations in excess of current limits is performed every fifth year. An improved method of calculation, i.e. the urban model, has been used since winter 2006/2007. The urban model will also be used to calculate the number of people that are overexposed to particles.

Food and drinking water

Estimates of human intake of environmental pollutions via food and drinking water are performed in cooperation with the National Food Administration (Table 4, #9.4). During 2006 an estimation of children's intake of dioxin was finalized. The concentration of pollutants in groundwater wells is studied in cooperation with SGU and the National Board of Health and Welfare.

Environmental toxics – coordination

It is important to consolidate activities that are basic for present and future environmental monitoring and to follow up on environmental goals, e.g. sample storage.

Banking of environmental samples

Repeatedly, retrospective investigations have been shown to be important when new analytical techniques are developed or when diseases are discovered. Hence, it is important to store strategic biological and abiotic samples for possible use in retrospective studies. An environmental sample bank can be defined as a research institution with resources to collect, manage, and maintain samples from the environment. These samples are intended for environmental research and environmental monitoring. The Swedish Museum of Natural History (NRH) keeps the environmental bank for most of SEPA's environmental monitoring program (Table 4, #10.1). SLU banks soil samples from the forest soil inventories and bore cores from the forest inventories.

Screening and retrospective studies

Screening , i.e. to make a perspicuous inventory, is the first step in identifying chemical compounds that may lead to health or environmental problems, and it may be the basis for deciding on which further monitoring or other measures need to be undertaken (Table 4, #10.2). Screening of all compounds listed in the EU Water Framework Directive that started in 2001, was organized by SEPA and included fish from several localities in Sweden. During 2004 and 2005 the concentrations of all compounds in the Water Framework Directive were measured in sediment, fish, and sludge at several sites in Sweden. The program sets aside resources for retrospective studies on materials stored in the bank.

Environmental toxics in urban environment

The screening program investigates the appearance and abundance of different toxic chemical compounds. This subprogram regularly measures metals and organic compounds in sludge from selected sewage treatment plants (Table 4, #10.3).

Photo: Jakob Halaska

Radiation

The Swedish Radiation Safety Authority (SSM) has 32 measurement stations distributed across Sweden, of which 16 are situated north of 60°N (Table 6, #6.1). They mainly measure radiation from radioactive compounds on the soil surface and automatically sound the alarm if the radiation increases. Every seventh month, radioactivity is measured on the soil surface at 4 to 5 spots in every municipality to check eventual radiation changes and to retain knowledge at an acceptable level (Table 6, #6.2). Special programs monitor ^{137}Cs in humans (whole body), reindeer, fish, moose, and roe deer (Table 6, #6.3). The main incentive for this is the remains from the Chernobyl accident in 1986.

Data about the human population

Sweden has a well-developed system for statistics on the human population, but it is not meaningful in the context of this report to recapitulate all the types of human-related data collected. Instead, the text under this heading concentrates on the key human-dimension-related variables listed at the end of Table 4.1 in the report "Towards an integrated arctic observing network (Committee on Designing an Arctic Observing Network, 2006)". The Statistics Sweden website (www.scb.se), for example, provides considerable additional information.

Human demographics

Statistics Sweden has all relevant data related to population size, age structure, gender, births, deaths, and migration. The same types of data are collected for the whole country and are standardized for administrative units. Since the population data also contain the geographical coordinates for the place where each person lives, it is also possible to present the statistics for arbitrary geographical units. However, the official population and health statistics do not contain any information concerning which persons belong to the indigenous / non-indigenous population. In Sweden, this would be of relevance for studies of living conditions among the Sámi population. However, such studies have been conducted only in very specialized research projects based on the researcher's own data collection and carried out in agreement with the Sámi people.

Human health statistics

Detailed information about the health status of the population, e.g. birth weight and causes of death, is available from the National Board of Health and Welfare (www.sos.se). Much of the health data is available directly from their website. Information related to mental illness and information related to the quality of health care in different regions is also available. Data on absence from work due to illness are readily available from Statistics Sweden.

Cultural diversity

No official statistics are easily available about the use of languages or about religious practices in general. For individuals with a foreign background, the country of birth, citizenship, and year of immigration to Sweden are registered. However, the official statistics do not separate the native indigenous from the non-indigenous population. Although the Sámi languages are officially acknowledged as minority languages, the trends concerning the number of people that speak and use them is not systematically monitored.

Education

Statistics Sweden reports on how many individuals enter and complete different levels of education. The statistics can be separated by geographic area.

Economic indicators

Statistics Sweden has data on unemployment and the distribution of incomes in different regions.

Monitoring Program Sustainability

To assess the sustainability of the environmental monitoring programs, Tables 4, 5, and 6 are broadly sorted by purchaser. Table 4 presents the monitoring projects that SEPA has purchased, and which therefore have a relatively stable long-term financial situation. These projects are evaluated every 3 years. Adjustments may be needed, but the basic idea of monitoring is to continue over a longer period. SEPA also purchases database hosts and defines quality criteria to guarantee long-term data sets.

The monitoring listed in Table 6 is mainly part of the normal activities of the different institutions, for example, climate and water discharge measurements performed by SMHI or the National Forest Inventory by the Department of Forest Resource Management at SLU. Government grants fund that activity. The only exception in Table 6 is the Swedish component of EU's ICP-Forest program, which operates on EU grants and is administrated by SST.

Table 5 presents, by measurement site, the monitoring performed on soft money or on faculty grants by universities. Besides the universities and their work at different sites, KVA is a major purchaser of monitoring at its Abisko research station. University projects financed by faculties, EU grants, or research councils are the least stable of the monitoring activities, particularly as regards long-term funding for infrastructure and technical staff.

Abisko Scientific Research Station (ANS, Table 5) has permanent staff paid by KVA. ANS also conducts monitoring for other bodies, e.g. SMHI, IVL, SGU, SEPA, Lund, Uppsala, and Umeå universities, the Swedish Museum of Natural History (NRM), and the Norrbotten County Board (NB). Most of these programs are rather sustainable. Other projects at Abisko, e.g. the eddy covariance mass and energy exchange studies at Stordalen Grassland, Stordalen Forest, and Abisko Delta conducted by the GeoBiosphere Science Center at Lund University (LU-NEC), rely on grants from EU. Nearly all activities at Tarfala operate on faculty grants from Stockholm University allocated for a maximum of 3 years at a time.

Flux measurements at Norunda, Skyttorp-0, -30, and -60 and Zackenberg on Greenland, all run by LU-NEC, operate mainly on EU grants, while flux measurements at Degerö Stormyr, Flakaliden II, and Knottåsen and the Forest Research Parks at Ätnarova, Svartberget, Kulbäcksliden, Siljansfors, and Jädraås are supported by the Faculty of Forest Sciences, SLU. Long-term measurements of atmospheric carbon dioxide and aerosol composition at Aspvreten (south of Stockholm) and at Zeppelin (on Svalbard) performed by the Department of Applied Environmental Research at Stockholm University (SU-ITM) date back 20 years and are based on soft money.

Comparison with AON and GCOS Variables

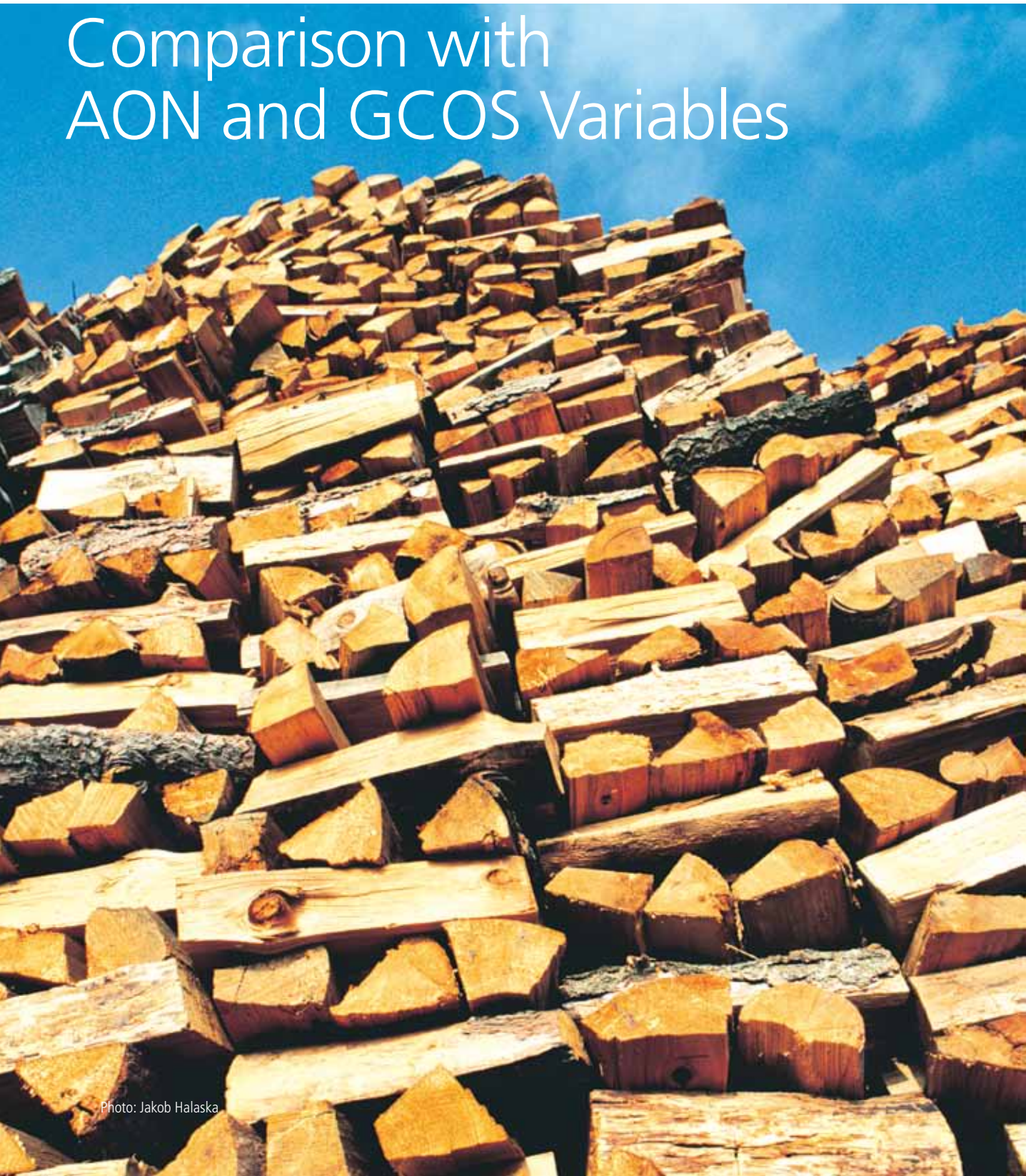

Photo: Jakob Halaska

Atmosphere and climate

GCOS lists the *essential climate variables* (ECV) in a global network for the work of UNFCCC and IPCC. This could be compared with the ongoing monitoring in northern Sweden and with the list of 31 *key variables* suggested by AON (Table 7). Both historical and current observations of these variables need to be internationally exchangeable. In many countries, the national meteorological offices run the observational networks and have international contacts through WMO for data exchange. This is also the case in Sweden, where SMHI does this work. However, in most cases, the national Swedish monitoring networks are much more intensive than what is required for a global network.

Monitoring variables for the near-surface atmosphere listed by GCOS and AON correspond with measurements in northern Sweden. Measurements of basic climatic variables, e.g. air temperature, air humidity, air pressure, precipitation, wind speed, and wind direction are well-covered in the national networks operated by SMHI. SMHI represents northern Sweden with 5 stations in the GCOS Surface Network (GSN, see insert below). In northern Sweden, solar radiation is measured at only 5 sites; and then only the global radiation component.

However, SMHI offers a service (http://produkter.smhi.se/strang/) using the STRÅNG mesoscale model to calculate hourly CIE-weighted UV, global-, direct-, and photosynthetic active irradiance, and sunshine duration in a grid over Sweden. A special run was performed for the period 1980 to 2000, but from 1999 and onward the model has been running daily with a 1-day delay. Since June 2006 the grid size has been 11 km x 11 km (earlier 22 x 22 km). There are no regular measurements of radiation spectra and net radiation in northern Sweden. Considering the importance of the radiation budget in relation to eventual climate change, a good contribution would be to have one such station in the northern boreal zone in Sweden.

For the atmospheric upper-air components, SMHI operates 2 radiosonde stations in northern Sweden, i.e. the airports at Luleå-Kallax and Sundsvall-Härnösand, respectively. These radiosonds measure vertical profiles of air pressure, temperature and relative humidity, but not radiation. GCOS reports on cloud amounts and properties, and they are the only upper-air components listed among AON's 31 key variables. SMHI's basic network includes 12 stations in northern Sweden making these observations.

Components of the atmospheric composition expressed by GCOS are the climate forcing gases carbon dioxide, methane, ozone, and long-lived greenhouse gases (N_2O, CFCs, HCFCs, HFCs, SF_6, and PFCs). AON's list is not so explicit, reporting only "trace gases". Carbon dioxide and methane fluxes are measured at several flux sites in northern Sweden (Table 5). Ozone close to the

Climate Stations in Northern Sweden that SMHI Reports to GSN

Index No	Station Name	Latitude	Longitude	Elevation, m
2120	Kvikkjokk-Arrenjarka	66 53N	18 01E	315
2196	Haparanda	65 50N	24 09E	6
2226	Ostersund Froson	63 12N	14 30E	359
2288	Holmogadd	63 36N	20 45E	6
2410	Malung	60 41N	13 42E	308

ground is measured in networks handled by IVL, and stratospheric ozone is measured at the SLU Forest Research Station in Vindeln (Umeå) on behalf of SMHI and by IRF in Kiruna. Trace gases are measured by Stockholm University (SU-ITM) at Askö (south of Stockholm) and at Zeppelin (Svalbard). Air chemistry is assessed in regional and national networks and analyzed by IVL. The measurements focus on acid gases and constituents in precipitation as major cat- and anions, mineral nutrients, and metals. GCOS does not list these variables, but they are included in the AON list.

Oceanographic variables

The GCOS list of essential variables for the ocean includes surface and subsurface components. SMHI measures sea surface temperature by an automated station at Finngrundet (60°54'N, 18°37'E) and manually at 3 coastal stations in the Gulf of Bothnia (Furuögrund, Ratan, and Järnäs). Sea surface temperature is not one of AON's key variables. UmU-M measures salinity (and other chemical variables) 10 times per year in profiles at 6 stations in the Gulf of Bothnia and the Bothnian Bay. The sea level is also on the GCOS and AON lists and is measured daily at the 3 coastal stations in the Gulf of Bothnia mentioned above and at 3 additional stations. Properties of sea ice is on the GCOS list, but not specified, while it is specified on the AON list. In the Baltic Proper, the Bothnian Bay, and the Gulf of Bothnia properties and extent of sea ice is specified daily during the winter season. The ice is specified according to type, thickness, and extent. Ice reports from SMHI rely on manual observations along the coast and from ships and icebreakers, including helicopter inspections and satellite information, especially from Synthetic Aperture Radar (SAR) onboard Canadian and European satellites, which give a resolution of 20 m x 20 m.

Both GCOS and AON list sea surface and depth profiles of currents as essential variables. However, currents are not monitored in the Bothnian Bay and the Gulf of Bothnia. AON does not list ocean color, but GCOS does. Color is assessed daily by SMHI during the summer from analyses of satellite data, especially using Advanced Very High Resolution Radiometer (onboard NOAA satellites). The GCOS list includes dissolved carbon dioxide in surface water and depth profiles as essential variables. Although AON does not include these among its 31 key variables, UmU-M measures them 10 times per year at the 6 stations in the Gulf of Bothnia and the Bothnian Bay mentioned above.

The AON variables also mention bathymetry. Certainly it is important to better know the bathymetry of the oceans, not least of the Arctic Ocean. It has been part of the task of Swedish Arctic expeditions, and Swedish research vessel Oden now carries a multibeam instrument used during the 2007 expedition to the Arctic. However, if we adhere to the literal definition of "monitoring" presented above bathymetry should not be considered monitoring since we do not expect it to change much with time. Furthermore, for military reasons, Swedish laws do not permit the disclosure of detailed bathymetry near the coast.

GCOS lists sea subsurface nutrient abundance among the essential variables. These nutrients are important for the productivity of the sea and thereby for its carbon cycling. UmU-M measures nutrient concentration profiles 10 times per year at the 6 sites mentioned. The same sampling intensity applies to phytoplankton, and GCOS lists them as well. AON, on the other hand, includes neither nutrients in ocean water nor marine phytoplankton as key variables. However, it lists biomass of the ocean as a key variable. The total biomass does not appear to be particularly meaningful if not related to trophy levels, and the different levels

should be specified. UmU-M for example estimates the phytoplankton biomass, and SBF estimates the fish biomass.

Hydrology and glaciers

Both GCOS and AON identify river discharge as essential. This is well covered in northern Sweden by SMHI's national network, which includes 46 stations in the basic network. At present, Sweden (SMHI) has not responded to the request by WMO to contribute data to a global runoff data center (GRDC) in parallel with GCOS. However, SMHI operates the BALTEX database for all important runoff into the Baltic, which obviously contains the data requested. How we use water influences the natural hydrological cycle. In many countries irrigation is a quantitatively important activity, leading to less groundwater formation and increased evaporation. In northern Sweden irrigation is practically non-existent. However, industrial and domestic water use decrease water quality and may restrict its further usage. Regularly inventories of how water is used are compiled from existing municipal and other data sources of water use and wastewater treatment by the SMED consortium (http://www.smed.se/).

Groundwater is being extracted for domestic use and irrigation at increasing rates worldwide. The depletion of groundwater contributes to the rising sea level. GCOS identifies groundwater as an essential variable, but AON does not. In Sweden, SGU runs a network for groundwater levels and groundwater quality. GCOS and AON include lake water level and snow depth as essential variables. SMHI operates a network for water levels in 20 lakes in northern Sweden and a network for snow depth at more than 250 stations north of 60°N.

Glaciers, especially small glaciers, are melting at an accelerating rate and contributing to the sea level rise. GCOS lists inventory and massbalance of glaciers and ice caps, depth and extent of permafrost and seasonally frozen ground as essential variables, but AON does not. However, in the

A grassland not grazed or mowed for several years has become encroached by deciduous trees and shrubs. The hazel is a remnant from the formerly semi-open grassland. Photo: Sara Cousins

mountains of northwest Sweden, Stockholm University measures glacier mass balance of 5 glaciers, maps the terminus position of 18 glaciers in the Tarfala area, and measures ground temperature down to 100m depth. Further north, near Abisko, Lund University takes additional permafrost measurements.

Radiation

GCOS and AON both recognize albedo and land cover as essential. In northern Sweden albedo is measured on a regular basis only at Norunda, north of Uppsala (by Lund University). However, SLU-FRM is developing a national landscape inventory program, NILS that will provide total coverage every 6 years. Since early last century they have also conducted the national forest inventory. Photosynthesis is the process whereby green vegetation assimilates carbon dioxide to form biomass, thus decreasing the amount of carbon dioxide in the atmosphere. GCOS lists the fraction of absorbed photosyntethically active radiation and leaf area index as essential, but AON does not. In northern Sweden the former is measured at Norunda and Abisko and the latter is measured in connection with different long-lived forest experiments, e.g. by SLU at Flakaliden (northwest of Umeå).

Biomass

Both GCOS and AON list terrestrial biomass as essential. In northern Sweden, forest biomass is accurately assessed by the national forest inventory, and complementary information should be gained from NILS. Worldwide, fire disturbance is a significant pathway for organic carbon to be transformed to carbon dioxide in the atmosphere. GCOS includes frequency, extent and intensity of fire as essential variables, but AON does not. Forest fires are more or less extinct in Sweden, and prescribed burning is actually encouraged in protected areas as a means to preserve biodiversity. In Sweden, such measures are taken on a project basis only. GCOS recognizes soil moisture as an emerging essential climate variable, while AON includes it among its 31 key variables. In northern Sweden it is measured at only a few sites (e.g. Norunda and Flakaliden) and then on a project basis. A soil moisture index is calculated as a by-product of SMHI's runoff prognosis from its HBV runoff model. This index is available at all prognosis stations.

Additional variables

Hereby, we have reached the end of GCOS's list of essential climate variables. AON has partly different foci, e.g. to track changes in northern biological systems and how these changes may affect people, especially indigenous peoples living in the north. Soil temperature is one of the 31 key variables on the AON's list. Albeit infrequent, soil temperature profiles are measured in northern Sweden, e.g. in connection with the permafrost observations in Tarfala and Abisko. In the tower experiments, soil temperature is part of the energy storage component, and hence soil temperature profiles are measured (e.g. at Norunda and other tower sites). For northern Sweden, biodiversity listed by AON should be part of the NILS effort mentioned above.

AON includes carbon concentration among its 31 key variables. Carbon is central, not least from a climate change perspective. In that context, carbon dioxide and methane pools in the atmosphere and net fluxes from the surface of the earth (terrestrial and aquatic) to the atmosphere are of interest, while carbon storage as such is of less interest. However, estimates of carbon storage in the soil are calculated in a 5-year reoccurring program by SLU-FS in the national inventory of forest soils. The same inventory also assesses field layer vegetation. SLU-FRM inventories the forests with the

same intensity. From their data, carbon storage can be calculated. SGU inventoried carbon storage in mires during the last century. However, net changes in such storage are difficult to measure. In the flux towers, net ecosystem exchange of carbon dioxide is measured with the eddy covariance technique. Such measurements are being done at about 10 sites in northern Sweden.

Dissolved inorganic and organic carbon is measured both in lacustrine, fluvial and marine environments. The intensity of these programs is about once per month. Biomass of phytoplankton is estimated concurrently with sampling for chemical analysis. Fish biomass is estimated from trial fishing once per year in selected lakes, rivers, and coastal habitats by the Swedish Board of Fisheries (SBF), who also estimates biomass for open-sea fish populations.

Primary production is driven by the availability of light, water, and nutrients. In terrestrial ecosystems of northern Sweden, nutrient content in soils are assessed by the forest soils inventory. At present, nutrients in forest stands must be estimated from standing volume calculated from the National Forest Inventory and the findings from research projects on nutrient concentrations in different forest stand compartments. In aquatic ecosystems, nutrient concentrations are measured in lakes, rivers, and in the sea about once per month, or less.

Environmental toxics produced by industry have, via various processes, moved successively northward. This can be observed, e.g. from chlorohydrocarbons in polar bear or seal fat. The concentration gradient along Gulf of Bothnia is of interest. Environmental toxics might be best monitored at the highest trophy level, in so-called top preda-

Mattias Ahlström and Caroline Essenberg, Stockholm University, on a fieldwork campaign in the archipelago. Plants and insects are surveyed for several research projects. A larger motor boat is used as a base and the small zodiac is used for transportation between neighbouring small islands. Photo: Sara Cousins

tors. NRM samples, analyzes, and/or stores seals and sea eagles for retrospective studies. In terrestrial ecosystems, samples from moose, vole, and reindeer are collected and sent to NRM for analyses and storage.

The concentration of dissolved oxygen is measured in lakes by SLU and in the sea by Umeå University Marine Research Center. Measurement intensity is about once per month. Regarding the open sea, SMHI conducts a winter sampling to look for eutrophication and anoxic conditions.

Phenological observations and observations of organismal behavior are used as tools for indications of ecosystem change. At a couple of sites, e.g. Abisko, migrant birds are counted and their reproductive success observed. Bud breaking time for trees and the different development stages of trees and other vegetation are recorded. However, the tradition of systematic phonological observations is not well developed in Sweden.

Finally, AON includes tracer chemistry as one of the 31 key variables. Sweden has a long tradition of measuring oxygen and hydrogen isotopes (DHO, THO, $H_2{}^{18}O$) in precipitation and runoff. This program has ended, and the last station was closed in 1995. SSM and the municipalities have measured radioactive isotopes in fish, reindeer, and local people since the Chernobyl accident. Natural or added carbon and nitrogen isotopes are frequently used in ecological research.

Photo: Jakob Halaska

Conclusions

In conclusion, environmental monitoring in northern Sweden meets most needs of GCOS and AON. No Swedish operator measure Earth's radiation budget in the upper air, or environmental tracers in the ocean. Fire disturbance is not explicitly monitored in terrestrial ecosystems, and cultural diversity is not reflected by official statistics. However, monitoring activities are ongoing in northern Sweden for all other essential variables on the GCOS list and on the AON list of 31 key variables. In addition, national networks are often denser than what is recommended in a circumpolar context.

The number of variables monitored in Sweden is more extensive than required by GCOS and AON. The traditional focus has been on environmental conditions in Sweden and causes of change. Long-range transport of air pollutants and effects of their deposition for the environment and for human health have been particularly important. The volume of variables to report to different international bodies, not least to the European Community, has increased with time.

Organization of the databases and the ease of acquiring data differ among database hosts. Databases sponsored by SEPA are generally easy to find and access, but they are not always user friendly and often differ between database hosts. Database hosts with other financing than by SEPA may charge for their data, or demand cooperation for using the data. These cases usually require personal contact with the data owner.

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Table 3. List of Acronyms, Institutions, and Home Pages

Acronym	Full Name	Home Page
ACIA	Arctic Climate Impact Assessment	http://www.acia.uaf.edu/pages/scientific.html
ANS	Abisko Scientific Research Station	http://www.ans.kiruna.se/ans.htm
AON	Arctic Observing Network (programme for observation of the Arctic, led by NSF, USA)	http://www.arcus.org/search/aon.html
BALTEX	Baltic Sea Experiment	http://www.baltex-research.eu/
BV	National Board of Housing, Building, and Planning	http://www.boverket.se
CLTRAP	UN-ECE's Convention on Long-range Transboundary Air Pollution	
DA	Dalarna County Board	http://www.w.lst.se
DkEPA	Danish Environmental Protection Agency	http://www.mst.dk
EU	European Union	http://ec.europa.eu/grants
GB	Gävleborg County Board	http://www.lansstyrelsen.se/gavleborg
GCOS	Global Climate Observing System	http://www.wmo.ch/pages/prog/gcos/index.php
GRDC	Global Runoff Data Center	http://grdc.bafg.de/servlet/is/Entry.987.Display/
GU	Gothenburg University	http://www.gu.se
GU-M	Kristineberg's Marine Research Center, Gothenburg University	http://www.loven.gu.se/stationer/kristineberg/
GU-PES	Department of Plant and Environmental Sciences	http://www.dpes.gu.se/
IPCC	Intergovernmental Panel on Climate Change	http://www.ipcc.ch/
IRF	Swedish Institute of Space Physics	http://www.irf.se
IVL	IVL Swedish Environmental Research Institute	http://www.ivl.se
JA	Jämtland County Board	http://www.lansstyrelsen.se/jamtland
JV	Swedish Board of Agriculture	http://jordbruksverket.se
KI	Swedish Chemicals Agency	http://www.kemi.se
KVA	The Royal Academy of Science	http://www.kva.se
LM	Swedish National Land Survey	http://www.lantmateriet.se/
LU	Lund University	http://www.lu.se
LU-CGB	Center for GeoBiosphere, LU	http://www.cgb.lu.se
LU-ECO	Department of Ecology, LU	http://www.ekol.lu.se/
LU-H	Lund University Hospital	http://www.med.lu.se
LU-NEC	Department of Physical Geography and Ecosystems Analysis, LU	http://www.nateko.lu.se
LU-ZOO	Department of Zoology, Lund University	http://www.zoo.ekol.lu.se/index_en.htm
NB	Norrbotten County Board	http://www.bd.lst.se
NBHW	National Board of Health and Welfare	http://www.socialstyrelsen.se
NFA	National Food Administration	http://www.slv.se
NFI	National Forest Inventory	http://www-nfi.slu.se
NILS	National Inventory of Landscapes in Sweden	http://nils.slu.se/
NRM	Swedish Museum of Natural History	http://www.nrm.se
NRM-PL	Palynological Laboratory, NRM	http://www.nrm.se
SAON	Sustaining Arctic Observing Networks	http://www.arcticobserving.org/
SBF	Swedish Board of Fisheries	http://www.fiskeriverket.se
SBF-FWL	Fresh Water Laboratory, SBF	http://www.fiskeriverket.se
SCB	Statistics Sweden	http://www.scb.se
SEPA	Swedish Environmental Protection Agency	http://www.naturvardsverket.se
SGU	Swedish Geological Survey	http://www.sgu.se
SLU	Swedish University of Agricultural Sciences	http://www.slu.se
SLU-ASA	Department of Aquatic Sciences and Assessment, SLU	http://www.ma.slu.se
SLU-ED	Environmental Data Center, SLU	http://www.md.slu.se
SLU-EKOL	Department of Ecology	http://www.ekol.slu.se

SLU-ESF	Unit for Field-based Forest Research, SLU	http://www.esf.slu.se
SLU-FGPP	Department of Forest Genetics and Plant Physiology, SLU	http://www.genfys.slu.se
SLU-FRM	Department of Forest Resource Management, SLU	http://www.srh.slu.se
SLU-SE	Department of Soil and Environment SLU	http://www.mark.slu.se/
SLU-F&W	Department of Wildlife, Fish and Environment, SLU	http://www.vfm.slu.se
SLU-SF	Forestry Faculty	http://www.sfak.slu.se
SLU-SS	Department of Soil Sciences, SLU	http://www.mv.slu.se
SLU-ESS	Southern Swedish Forest Research Center	http://www.ess.slu.se
SMED	Swedish Methodology for Environmental Data	http://www.smed.se/
SMHI	Swedish Meteorological and Hydrological Institute	http://www.smhi.se
SOS	National Board of Health and Welfare	http://www.socialstyrelsen.se/
SSM	Swedish Radiation Safety Authority	http://www.stralsakerhetsmyndigheten.se/Allmanhet/
SST	Swedish Forest Agency	http://www.skogsstyrelsen.se
STRÅNG	SMHI Radiation Model	http://produkter.smhi.se/strang/
SU	Stockholm University	http://www.su.se
SU-INK	Department of Physical Geography and Quaternary Geology, SU	http://www.ink.su.se
SU-ITM	Department of Applied Environmental Science, SU	http://www.itm.su.se
SU-M	Askö Marine Laboratory, SU	http://www.smf.su.se/
SU-NSF	Natural Sciences Faculty, SU	http://www.science.su.se
SVA	National Veterinary Institute	http://www.sva.se/
TRS	Tarfala Research Station	http://www.ink.su.se
UmU	Umeå University	http://www.umu.se
UmU-EC	Department of Environmental Chemistry, UmU	http://www.chemistry.umu.se
UmU-EMG	Department of Ecology and Environmental Science, UmU	http://www.emg.umu.se
UmU-M	Umeå Marine Research Center, UmU	http://www.umf.umu.se
UNFCCC	United Nations Framework Convention on Climate Change	http://unfccc.int/2860.php
UU	Uppsala University	http://www.uu.se
UU-EBC	Center of Evolution Biology, UU	http://www.ebc.uu.se
UU-ÅL	Ångström Laboratory, UU	http://www.angstrom.uu.se
VB	Västerbotten County Board	http://www.ac.lst.se
VN	Västernorrland County Board	http://www.y.lst.se
VR	Swedish Research Council	http://www.vr.se

Table 4. Environmental Monitoring Programs in Sweden Purchased by the Swedish Environmental Protection Agency (SEPA).

No.	Program Subprogram	Conductor[1]	Table in Appendix
1	**Air**		
1.1	Air- and Precipitation Chemistry in EMEP	IVL, SMHI	21
1.2	Air- and Precipitation Chemistry Network	IVL	21
1.3	Metals in Air and Precipitation	IVL	21
1.4	The Ozone Layer	SMHI	15, 7
1.5	The MATCH-Sweden – Model	SMHI	11
1.6	Climate Forcing Substances and Greenhouse Gases	SMHI, SU-ITM	6
1.7	Organic Environmental Pollutants in Air and Precipitation	SU-ITM	6
1.8	Throughfall Measurements	IVL	21
1.9	Deposition at High Elevation	IVL	21
1.10	Environmental Pollutants in Urban Environment	IVL	21

1.11	Metals in Mosses	IVL	11
2	**Mountains**		
2.1	Mountain Monitoring within NILS	SLU	11
2.2	Small Mammals Screening	UmU-EMG, NRM	26
2.3	Metals in Reindeers	NRM	26
3	**Forest**		
3.1	National Forest Inventory – Soil (RIS-MI)	SLU-SE	11
3.2	Integrated Monitoring (IM)	SLU-EA, SGU, IVL	22
3.3	Small Mammals Screening	UmU-EMG, NRM	26
3.4	Metals in Moose	SLU-W&F, NRM	26
4	**Arable Land**		
4.1	Monitoring Fields	SLU-SE	
4.2	Type areas on Arable Land	SLU-SE	
4.3	Measurement of Pesticides	SLU-SE	
4.4	Soil and Vegetation Inventory	SLU-SE	11
4.5	Pesticides in biota; vegetation and animals	SLU-SE	
4.6	NILS-program	SLU-FRM	11
4.7	Soil Compaction	SLU-SE	11
5	**Landscape**		
5.1	NILS-program	SLU-FRM	11
5.2	Swedish Bird Census (SFT)	LU-ECO	27
5.3	Bird Counting and Ring Marking at Ottenby	LU-ECO	27
5.4	Counting of Migratory Birds at Falsterbo	LU-ZOO	27
5.5	Swedish Sea-Bird Inventory	LU-ZOO	27
6	**Wetlands**		
6.1	Wetlands – Function and State	SLU-SE	
6.2	Biodiversity of Rich Swamps	UU-EBC	
6.3	Biodiversity Monitoring within NILS	SLU-FRM	11
7	**Freshwater**		
7.1	Reference Stations – Groundwater	SGU	20
7.2	Trend Stations – Water Courses	SLU-EA, SBF-FWL	
7.3	River Mouths	SLU-EA	
7.4	National Lake Survey	SLU-EA, SBF-FWL	11, 13
7.5	Lake Resampling Stations	SLU-EA, SBF-FWL	12
7.6	Environmental Pollutants – Sample Banking	SBF-FWL, NRM	
7.7	Environmental Pollutants – Analysis	NRM	
8	**Sea**		
8.1	Arctic Sea	SU	
8.2	Gulf of Bothnia and Bothnian Bay		
8.2.1	Macrofauna Soft Bottoms	UmU-M	14
8.2.2	Embryogenes of Amphipod	UmU-M	14
8.2.3	Metals and Organic Pollutants	NRM	14
8.2.4	The Free Water Body	UmU-M	14
8.2.5	Integrated Coastal Fish Monitoring	UmU-M, SBF	12
8.2.6	Seal and Sea Eagle	NRM	
9	**Health-Related Environmental Monitoring**		
9.1	Biological Data – Metals	LU-H, NFA	
9.2	Biological Data – Organic Substances	SEPA	
9.3	Air Pollutants – Exposition Studies	SEPA	
9.4	Food and Drinking Water	SGU, SOS	
10	**Environmental Pollutants - Coordination**		
10.1	Banking of Environmental Samples	NRM	
10.2	Screening	NRM	
10.3	Environmental Pollutants in Urban Environment	IVL	

[1] See Table 3 for explanation of acronyms.

Table 5. Main Sites for Environmental Monitoring in Northern Sweden and Further North and Their Programs Purchased and Conducted by Universities and Other Research Bodies. The numbers in the "Table" column refer to table numbers in the Appendix.

No.	Program Subprogram	Purchaser[1]	Conductor[1]	Table
1	**Abisko**			1
1.1	Climate 1	KVA	ANS	1
1.2	Climate 2	SMHI	ANS	1
1.3	Climate 3	IVL	ANS	1
1.4	Climate 4	LU-CGB	ANS	1
1.5	Climate 5	UU-ÅL	ANS	1
1.6	Hydrology 1	KVA	ANS	1
1.7	Hydrology 2	SGU	ANS	1
1.8	Hydrology 3	SGU	SGU	1
1.9	Hydrology 4	SMHI	ANS	1
1.10	Hydrology 5	SEPA	ANS	1
1.11	Flora 1	KVA	ANS	1
1.12	Flora 2	NRM	ANS	1
1.13	Fauna 1	LU-ZOO	ANS	1
1.14	Fauna 2	NRM	ANS	1
1.15	Fauna 3	U Petersen	voluntary	1
1.16	Fauna 4	KVA, NRM	ANS, voluntary	1
1.17	Fauna 5	NB	ANS	1
1.18	Fauna 6	KVA	ANS	1
1.19	Physical Environment 1	SGU	ANS	1
1.20	Physical Environment 2	IRF	ANS	1
1.21	Permafrost	LU-NEC	LU-NEC	3
2	**Tarfala**			2
2.1	Glacier mass balance	SU-NSF	TRS	2
2.2	Glacier terminus	SU-NSF	TRS	2
2.3	Climate T1	SU-NSF	TRS	2
2.4	Climate T2	SMHI	TRS	2
2.5	Permafrost	SU-NSF	TRS	2
2.6	Hydrology	SU-NSF	TRS	2
2.7	Elevation	SU-NSF	TRS	2
3	**Zeppelin,** Svalbard		SU-ITM	6
3.1	CO2 concentration		SU-ITM	6
3.2	Aerosol composition		SU-ITM	6
4	**Aspvreten**		SU-ITM	6
4.1	CO_2 concentration		SU-ITM	6
4.2	Aerosol composition		SU-ITM	6
5	**Norunda**			4
5.1	Canopy Flux Density	VR, EU	LU-NEC	4
5.2	Storage Fluxes	VR, EU	LU-NEC	4
5.3	Soil Fluxes	VR, EU	LU-NEC	4
5.4	Meteorology	VR, EU	LU-NEC	4
5.5	Hydrology	VR, EU	LU-NEC	4
5.6	Biology and Physiology	VR, EU	LU-NEC	4
5.7	Structure and Biomass	VR, EU	LU-NEC	4
5.8	Soil Physics and Chemistry	VR, EU	LU-NEC	4

No.	Program Subprogram	Purchaser[1]	Conductor[1]	Table
6	**Ätnarova**	SLU-SF	SLU-SF	7
6.1	Climate	SLU-SF	SLU-SF	7
7	**Svartberget**	SLU-SF	SLU-SF	7
7.1	Climate	SLU-SF	SLU-SF	7
7.2	Phenology	SLU-SF	SLU-SF	7
7.3	Reference Program	SLU-SF	SLU-SF	7
8	**Kulbäcksliden**	SLU-SF	SLU-SF	7
8.1	Climate	SLU-SF	SLU-SF	7
8.2	Phenology	SLU-SF	SLU-SF	7
9	Degerö Stormyr	SLU-SF	SLU-SF	7
9.1	Canopy Flux Density	SLU-SF	SLU-SF	7
9.2	Meteorology	SLU-SF	SLU-SF	7
9.3	Hydrology	SLU-SF	SLU-SF	7
10	**Flakaliden** I	SLU-SF	SLU-SF	8
10.1	Optimum Nutrition exp.	SLU-SF	SLU-SF	8
10.2	Soil Heating exp.	SLU-SF	SLU-SF	8
10.3	Elevated CO_2 exp.	SLU-SF	SLU-SF	8
10.4	Climate	SLU-SF	SLU-SF	8
10.5	Soil Physics	SLU-SF	SLU-SF	8
10.6	Soil Water Chemistry	SLU-SF	SLU-SF	8
10.7	Soil Chemistry	SLU-SF	SLU-SF	8
11	**Flakaliden II**	SLU-SF	SLU-SF	9
11.1	Canopy Flux Density	SLU-SF	SLU-SF	9
11.2	Meteorology	SLU-SF	SLU-SF	9
11.3	Structure and Biomass	SLU-SF	SLU-SF	9
12	**Rosindal**	SLU-SF	SLU-SF	7
12.1	Canopy Flux Density	SLU-SF	SLU-SF	7
12.2	Meteorology	SLU-SF	SLU-SF	7
12.3	Structure and Biomass	SLU-SF	SLU-SF	7
13	**Siljansfors**	SLU-SF	SLU-SF	7
13.1	Climate	SLU-SF	SLU-SF	7
13.2	Phenology	SLU-SF	SLU-SF	7
14	**Jädraås**	SLU-SF	SLU-SF	7
14.1	Climate	SLU-SF	SLU-SF	7
14.2	Phenology	SLU-SF	SLU-SF	7
15	**Knottåsen**	SLU-SF	SLU-SF	7
15.1	Canopy Flux Density	SLU-SF	SLU-SF	7
15.2	Meteorology	SLU-SF	SLU-SF	7
15.3	Structure and Biomass	SLU-SF	SLU-SF	7

➢ **Table 5 continues from previous page.**

No.	Program Subprogram	Purchaser[1]	Conductor[1]	Table
16	**Skyttorp 0**	EU	SLU-EKOL	4
16.1	Canopy Flux Density	EU	SLU-EKOL	4
16.2	Meteorology	EU	SLU-EKOL	4
16.3	Structure and Biomass	EU	SLU-EKOL	4
17	**Skyttorp 30**	EU	LU-NEC	4
17.1	Canopy Flux Density	EU	LU-NEC	4
17.2	Meteorology	EU	LU-NEC	4
17.3	Structure and Biomass	EU	LU-NEC	4
18	**Skyttorp 60**	EU	LU-NEC	4
18.1	Canopy Flux Density	EU	LU-NEC	4
18.2	Meteorology	EU	LU-NEC	4
18.3	Structure and Biomass	EU	LU-NEC	4
19	**Stordalen Grassland**	EU	LU-NEC	4
19.1	Canopy Flux Density	EU	LU-NEC	4
19.2	Meteorology	EU	LU-NEC	4
19.3	Structure and Biomass	EU	LU-NEC	4
20	**Stordalen Forest**	EU	LU-NEC	4
20.1	Canopy Flux Density	EU	LU-NEC	4
20.2	Meteorology	EU	LU-NEC	4
20.3	Structure and Biomass	EU	LU-NEC	4
21	**Abisko, Delta**	KVA	ANS	4
21.1	Canopy Flux Density	KVA	ANS	4
21.2	Meteorology	KVA	ANS	4
21.3	Structure and Biomass	KVA	ANS	4
22	**Zackenberg, Greenland**	EU	LU-NEC	4
22.1	Canopy Flux Density	DkEPA	LU-NEC	4
22.2	Meteorology	DkEPA		4
23	**Kapp Linne, Svalbard**		LU-NEC	3
23.1	Permafrost		LU-NEC	3
23.2	Soil Moisture and Temperature		LU-NEC	3
24	**Latnjajaure**		GU-PES	5
24.1	ITEX		GU-PES	5
24.2	BioGeoChemistry		GU-PES	5

[1] See Table 3 for explanation of acronyms.

Table 6. Climate and Discharge Measurements from Northern Sweden by the Swedish Meteorological and Hydrological Institute (SMHI) and Environmental Monitoring Programs in Northern Sweden Purchased and Conducted by the Swedish Forest Agency (SST), Swedish Radiation Safety Authority (SSM), Swedish Geological Survey (SGU), and Swedish Institute of Space Physics (IRF), and the National Forest Survey conducted by the SLU Department of Forest Resource Management.

The numbers in the "Table" column refer to table numbers in the Appendix.

No.	Program	Purchaser	Conductor	Table
1	**Climate**	SMHI	SMHI	
1.1	Climate, Manual	SMHI	SMHI	15
1.2	Climate, APW	SMHI	SMHI	15
1.3	Climate, MOMS	SMHI	SMHI	15
1.4	Climate, AWOS	SMHI	SMHI	15
1.5	Climate, VVIS	SMHI	SMHI	15
1.6	Climate, Sunshine	SMHI	SMHI	15
2	**Lake Ice**	SMHI	SMHI	19
3	Runoff	SMHI	SMHI	
3.1	Runoff - Base Network	SMHI	SMHI	16
3.2	Runoff - Baltex	SMHI	SMHI	17
4	**Sea**	SMHI	SMHI	
4.1	Sea Ice	SMHI	SMHI	14
4.2	Sea Level	SMHI	SMHI	14
4.3	Sea Algal Situation	SMHI	SMHI	14
5	**ICP-Forest**	EU/SST	SST	
5.1	Level I	EU/SST	SLU-FRM	23
5.2	Level II	EU/SST	SST	23
5.3	Deposition, Soil Water, Air Concentrations for Clean Air	County Boards/ Regional Associations for Clean Air	County Boards/ Regional Associations	21
6	**Radiation**	SSM	SSM	25
6.1	Intense Net	SSM	SSM	25
6.2	Extensive Net	SSM	Municipalities	25
6.3	Biota	SSM	SSM	25
7	**Groundwater**	SGU	SGU	20
7.1	Level	SGU	SGU	20
7.2	Chemistry	SGU	SGU	20
8	**Atmospheric physics**	IRF	IRF	24
8.1	Ozone and Other Trace Gases	IRF	IRF	24
8.2	Aerosols and Thin Clouds	IRF	IRF	24
8.3	Winds and Structures	IRF	IRF	24
8.4	Atmospheric Composition	IRF	IRF	24
8.5	Climate and UV Radiation	IRF	IRF	24
9	**Space Physics**	IRF	IRF	24
9.1	Aurora	IRF	IRF	24
9.2	Earth's Magnetic Field	IRF	IRF	24
9.3	Particle Precipitation	IRF	IRF	24
9.4	Ionospheric Conditions	IRF	IRF	24
10	**Forest Survey**	Gov.	SLU-FRM	11

Table 7. A Comparison of the Global Climate Observing System (GCOS) Essential Climate Variables, the Arctic Observing Network (AON) 31 Variables, and Ongoing Monitoring Activities in Northern Sweden.

		Global Climate Observing System, GCOS	Arctic Observing Network, AON	Monitoring in Northern Sweden			
Domain		**Essential Climate Variables**	**AON's 31 variables1**	**Variables**	**Location**	**Intensity**	**No. of stations**
Atmospheric	Surface	Air temperature	Tempera-ture, air	Air tempera-ture	Network, SMHI	Daily	74
(over land, sea and ice)		Precipitation	Precipitation	Precipitation	Network, SMHI	Daily	68
		Air pressure	Pressure	Air pressure	Network, SMHI	Daily	51
		Surface radiation budget	Radiation	Radiation, global	Network, SMHI	Daily	5
		Wind speed and direction	Velocity, wind	Wind speed and direction	Network, SMHI	Daily	92
		Water vapor	Water vapor concentra-tion	Water vapor concentra-tion	Network, SMHI	Daily	51
	Upper air	Earth radiation budget (including solar irradiance)					
		Upper-air temperature (including MSU radiances)		Air tempera-ture	Balloon sonding		2
		Wind speed and direction		Wind speed and direction	Balloon sonding		2
		Water vapor		Water vapor	Balloon sonding		2
		Cloud properties	Cloud properties	Cloud properties	Network	Daily	17
	Compo-sition	Carbon dioxide	Carbon dioxide	Carbon dioxide	Flux sites	Hourly	8
		Methane	Methane	Methane	Flux sites	Hourly	8
		Ozone	Ozone	Total ozone		Hourly	3
		Other long-lived greenhouse gases	Trace gases	Trace gases	Zeppelin, Aspvreten		2
		Aerosol properties	Aerosol concentra-tion	Aerosol concentra-tion	Network, IVL	Monthly	10
			Atmospheric chemistry	Atmospheric chemistry	Network, IVL	Monthly	15

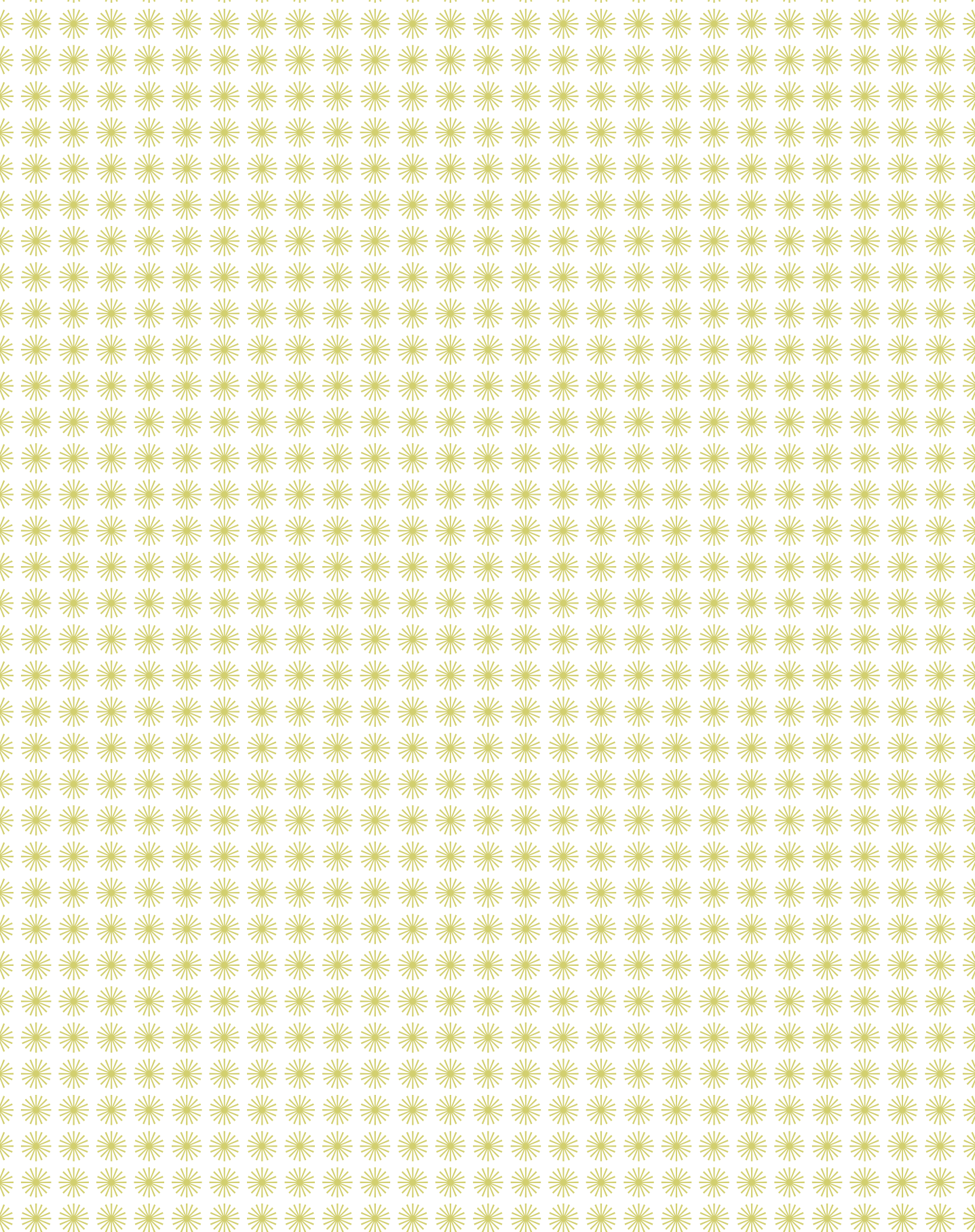
		Global Climate Observing System, GCOS	Arctic Observing Network, AON	Monitoring in Northern Sweden			
Domain		**Essential Climate Variables**	**AON's 31 variables1**	**Variables**	**Location**	**Intensity**	**No. of stations**
Oceanic	Surface	Sea-surface temperature	Sea-surface temperature	Sea-surface temperature	Swedish coast	Daily	4
		Sea-surface salinity	Salinity	Salinity	Sea	10/year	6
		Sea level	Sea level	Sea level	Sw coast	Daily	6
		Sea state					
		Sea ice	Ice character-istics	Ice character-istics	Sea	Daily	aerial co-verage
		Current					
		Ocean color (for biological activity)		Color	Sea	Weekly	aerial co-verage
		Carbon dioxide partial pressure		pCO2	Sea	10/year	6
			Elevation/ bathymetry	Elevation/ bathymetry	Polar sea		
	Sub-surface	Temperature	Temperature	Temperature	Sea	10/year	6
		Salinity	Salinity	Salinity	Sea	10/year	6
		Current					
		Nutrients		Nutrients	Sea	10/year	6
		Carbon		Carbon	Sea	10/year	6
		Ocean tracers					
		Phytoplankton		Phytoplank-ton	Sea	10/year	6
			Biomass	Biomass, Fish	Sea and coast	1/year	6
Terrestrial		River discharge	Freshwater flux	Freshwater flux	Network, SMHI	Daily	46
		Water use		Water use	Munici-pali-ties		
		Groundwater		Groundwater level	Network, SGU	2/month	many
		Lake levels	Lake level	Lake level	Network, SMHI	Daily	3
		Snow Cover	Snow depth/ water equivalent	Snow depth/ water equivalent	Network, SMHI	Daily	>100

➢ **Table 7 continues from previous page.**

	Global Climate Observing System, GCOS	Arctic Observing Network, AON	Monitoring in Northern Sweden			
Domain	**Essential Climate Variables**	**AON's 31 variables1**	**Variables**	**Location**	**Intensity**	**No. of stations**
	Glaciers and ice caps	Glacier thickness	Mass balance, terminus mapping	Tarfala	2/yr 1/2yr	5 mass bal. 18 term. map.
	Permafrost and seasonally-frozen ground		Permafrost and seasonally frozen ground	Tarfala, Abisko		6
	Albedo	Albedo	Albedo	Norunda	1/hour	1
	Land cover (including vegetation type)	Land cover	Land cover	NILS	1/5 years	300
	Fraction of absorbed photosynthetically active radiation (fAPAR)		fAPAR	Norunda, Abisko	1/hour	
	Leaf area index (LAI)		LAI	Flakaliden	1/year	4
	Biomass	Biomass	Biomass, Forest	RIS-IS	1/5 years	1 000
	Fire disturbance			Project basis, SLU		
	Soil moisture	Soil moisture	Soil moisture	SLU, LU	1/week, 1/day	12
		Soil temperature	Soil temperature	SLU, LU	1/hour	15
Biogeochemistry		Biodiversity	Biodiversity	NILS	1/5 year	300
		Carbon concentration	Carbon concentration	SLU 5, Svalbard 1	1/year	6
		Nutrient concentration	Nutrient concentration	P (IVL), R, soil (SLU)	1/month	30
		Contaminant concentration	Contaminant concentration	IVL	1/month	6

	Global Climate Observing System, GCOS	Arctic Observing Network, AON	Monitoring in Northern Sweden			
Domain	**Essential Climate Variables**	**AON's 31 variables1**	**Variables**	**Location**	**Intensity**	**No. of stations**
		Dissolved oxygen concentration	Dissolved oxygen concentration	Marin	10/year	33
		Phenology, organismal behavior, and performance	Phenology, organismal behavior, and performance	Bud breaks Birds	Daily at season	6
		Tracer chemistry	Tracer chemistry	SU-ITM		4
Human dimensions		Human demographics	Human demographics	SCB		
		Health	Health	SOS		
		Cultural diversity				
		Education	Education	SCB		
		Economic indicators	Economic indicators	SCB		

[1] Some of AON's 31 variables have been disintegrated in this list, which now contains 42 variables.



There is an increased awareness that the environment is being subjected to rapid changes. This emphasizes the necessity to further develop and coordinate environmental monitoring efforts. Swedish environmental monitoring activities are extensive, but the knowledge of actors, sites and measured variables is scattered. This report compiles knowledge about environmental monitoring activities in Sweden north of Latitude N60°, and can be complemented by the accompanying web site *monitoringN60.slu.se*. The web site contains a digital version of the report, as well as interactive, searchable maps, and appendices with extensive and detailed lists of monitoring observations in northern Sweden. The report is a contribution to the process of establishing the Sustaining Arctic Observing Networks (SAON, *www.arcticobserving.org*). The SAON process was initiated in 2006 by the Arctic Council as an overarching process emanating from the International Polar Year (IPY). The selection of variables discussed in the present report is guided by the 31 Key variables recommended by the earlier Committee on Designing an Arctic Observing Network, established by the National research council in the USA.

Vetenskapsrådet