

SIOS Gap Analysis Working Group 2: The coupled Arctic geophysical system

Editor: Georg Hansen, Research Council of Norway

General remarks

A major first step in developing Svalbard towards an “Integrated Arctic Earth Observing “system” is to perform a gap analysis with regard to important scientific questions, the suitability of Svalbard to address these questions, the available resources and new means needed to address the identified issues adequately.

At the first international meeting on the SIOS project in February 2009, five working groups were established to address these questions in their respective field. The approach chosen in the establishment of the groups was a mixture of “traditional” discipline boards and a first steps to address issues in an integrated way. The latter aspect is most evident in working group 2 “The coupled Arctic geophysical system: atmosphere-ocean-ice”. On the other hand, this also makes the work of this group most challenging. The following questions are dealt with in this document:

- 1) What are the crucial scientific questions related to the coupled climate and tracer transport system?
- 2) For which of those is Svalbard naturally suited as a field laboratory?
- 3) What infrastructure is available/what is needed to address the above questions adequately?
- 4) How can the infrastructure be best organised?
- 5) What can be the role of the Knowledge Centre in your field?

The working group consisted of the following members (A: atmospheric scientist, O: ocean scientist; I: ice scientist):

- Georg Hansen (Research Council of Norway, convener)
- John F. Burkhart (NILU – Norway) - A
- Carl E. Bøggild (UNIS – Norway) - I
- Ilker Fer (GFI-University of Bergen – Norway) - O
- Sebastian Gerland (Norwegian Polar Inst. - Norway) - I
- Øystein Hov (Meteorological Institute - Norway) - A
- Roland Neuber (AWI – Germany) - A
- Euan Nisbet (RHUL – UK) – A
- Tymon_Zielinski (IOPAS – Poland) - O
- Sergey Priamikov (AARI – Russia) - O
- Joachim Reuder (GFI-University of Bergen – Norway) - A
- Stein Sandven (NERSC – Norway) - I
- Angelo Viola (ISAC-CNR – Italy) - A
- Finlo Cottier (SAMS – UK) – O

Further input was provided by Jon-Ove Hagen (University of Oslo) and Jacek Jania (University of Silesia, Poland), both glaciologists, and Kjetil Melvold (NVE, Norway), hydrologist.

1 State of knowledge and key questions

Introduction

The Arctic geophysical climate system has experienced dramatic changes in the recent decade, affecting all relevant compartments: atmosphere, ocean, sea ice and terrestrial cryosphere (see, e.g., State of the Arctic Report 2006, Arctic Report cards 2007 and 2008, <http://www.arctic.noaa.gov/reportcard/about.html>, and references herein):

- Both winter/spring and autumn air temperatures (monthly means) have been up to 5 degrees above long-term means;
- Sea ice extent at the late summer minimum was up to 40% below the long-term average (1979-2000) with a record of about 4 mill. km² in 2007;
- Multi-year sea ice is reduced drastically since 1996
- Sea water temperatures have risen markedly over a substantial depth range both in the Atlantic sector and in the Bering region
- Glaciers and ice caps in Greenland, Svalbard and in the Canadian archipelago have been melting at unprecedented rates, causing increased land uplift, e.g., in the Fram Strait region.

Although the direction of changes was predicted by climate models, the rate of change is much faster than expected, and the processes causing these discrepancies are not well understood. The near-surface geophysical system in the Arctic is characterized by a heterogeneous pattern of ice-covered ocean, open ocean, land masses with a strong variation in albedo with seasons due to snow cover and ice caps of largely varying size, overlaid by an atmosphere of large meridional and zonal variability. It is a complex system with strong feedback mechanisms within the single and between the different media. This poses severe challenges to modelling efforts of this coupled system and equally large challenges to provide the observational input needed to verify model results.

The challenge of observation systems is to provide characterization of the fluxes of momentum, heat (latent, sensible, radiative), moisture and mass (e.g., important trace gases) within the atmosphere and the ocean and between the main media atmosphere, ice/snow and ocean. These fluxes are to be quantified with a temporal and spatial resolution determined by the research issues to be studied. The heat exchange related to leads and melt ponds on sea ice are examples with a demand for high-frequency flux observations in short duration field studies. The characterization and trends and variability in the physical climate require observational capabilities over very long time periods with a careful protocol for observational quality and with a temporal and spatial resolution which is adequate for the research purpose.

In the following, key scientific topics related to the coupled Arctic geophysical system are posed; detailed discussions are, e.g., found in the ISAC Draft Science Plan 2009: http://www.arcticchange.org/isac2009/attachments/059_ISAC%20Science%20Plan%2030%20March%2009a.pdf, and in the SEARCH Implementation Plan 2005: http://www.arcus.org/SEARCH/downloads/SIW_Report_FINAL.pdf. These have to be discussed with respect to the suitability of Svalbard as a natural place to study them. Moreover, the infrastructure already available and the one needed ideally to study these processes are described.

Key Scientific Topics

1. Sea ice in the Arctic: studies of processes and fluxes through the gateways

In the last decades, Arctic sea ice has changed significantly, from being dominated by thick multiyear ice to first-year ice. The most predominant changes are the retreat of the summer ice area and the reduction in thickness of the multiyear ice. Sea ice is a sensitive

component of the climate system, influenced by conditions in both the atmosphere and ocean. Variations in sea ice have impact on climate by altering the surface albedo, one of the dominant factors in the poleward amplification of global warming. Sea ice is also important for the exchange of heat, moisture, and momentum between the atmosphere and ocean, and for the upper ocean stratification in areas of deep water formation. Changes in sea ice cover have impact on oceanic and atmospheric processes, leading to fundamental changes in the Arctic climate system.

To study the seasonal and inter-annual variability of the Arctic sea ice is one of the most pressing research topics in the Arctic. Forecasting of sea ice from daily to seasonal and inter-annual time scale is a requirement from many users, but the present ice models are only able to provide forecasts for 10 days ahead. The main limitation in the forecasts is the atmospheric forcing, which is only good for a few days. Development of better atmosphere-ice-ocean models requires improved observing systems across the Arctic. For sea ice, the main deficiency is lack of in situ and underwater sensors that can measure ice thickness and other key ice parameters. Several new methods to observe sea ice thickness have been developed, but are not yet implemented as part of an operational monitoring system. Observations of sea ice with in situ instruments are technically challenging and require further development of platforms and instruments that can operate automatically, year-round and in different locations on the ice and under the ice. Svalbard has a unique location for deployment of sea ice observing platforms and instruments in the European sector of the Arctic where many of the key processes can be studied, such as:

- 1) The ice export through the Fram Strait as a measure for the total sea ice budget of the Arctic Ocean
- 2) The ice thickness north of Svalbard and Greenland needed to estimate the total amount of multi-year ice in the Arctic Ocean
- 3) Ice circulation in the Arctic basin and on the shelves
- 4) The ice budget of the Barents Sea with freezing/melting and inflow/outflow
- 5) Sea ice in fjords characterizing year-to-year variability due to local ocean and atmospheric conditions, including the Storfjorden polynya as a formation area of high salinity water masses
- 6) Sea ice processes in the Marginal Ice Zone (MIZ) and their effects on meteorological and marine processes.

Sea ice research includes a number of other topics that can benefit from SIOS: (i) ice mechanics where studies of ice deformation, ridge formation and ice strength can be conducted in field and laboratory experiments. (ii) air-sea interaction studies in leads and polynas, (iii) snow cover of sea ice and albedo studies, (iv) sea ice as transport agent for sediments and pollutants, (v) sea ice and atmospheric chemistry, and (vi) sea ice as habitat for marine mammals.

2. Oceanographic processes in the Svalbard region and the Fram Strait: small scales - large impacts on regional climate and the Arctic Ocean as a whole

The Arctic Ocean forms an important part in the northern hemispheric hydrological cycle by capturing and redistributing 10% of the global continental runoff. The fresh water has an important role in stabilizing the upper ocean and triggering exchange of heat and substances between the intermediate waters and the surface. The stabilizing effect influences also the potential of the Arctic Ocean convection and thus its role in the Atlantic-wide meridional overturning circulation (DAMOCLES, 2009).

The oceanic circulation, transporting heat and water masses in the Arctic Ocean, is driven by a combination of wind and thermohaline forcing. The air pressure distribution is basically determined by a high-pressure system over the Beaufort Sea and low pressure over

the Nordic Seas leading to an anti-cyclonic circulation pattern. Relatively warm and saline water enters into the Nordic Seas from the Atlantic Ocean, is advected through Fram Strait and the Barents Sea into the Arctic Ocean. It circulates within the Arctic Ocean along different paths whereby it undergoes extensive modifications. The Arctic Ocean is covered by a seasonally varying ice cover, which moves by wind forcing and ocean currents. The anti-cyclonic circulation in the Beaufort Gyre and a less well-established cyclonic counterpart over the European Arctic feed into the Transpolar Drift, which provides the major export of sea ice through Fram Strait into the Nordic Seas. The waters coming out of the Arctic Ocean supply the source waters for the formation of North Atlantic Deep Water, which plays a significant role in the global thermohaline overturning circulation. The Fram Strait has a key role, representing the only deep-water connection between the Arctic Ocean and the Nordic Seas. This strait is characterised by a northward flow of deep waters from the Greenland and the Norwegian Sea entering the Arctic Ocean, and deep waters from the Arctic basin flowing southward to the Nordic Seas

One of the most critical, yet challenging, aspect of Arctic oceanography is quantifying the oceanic flux of heat to the Arctic and its subsequent modification and redistribution. The role of boundaries, shelves, continental slope and bathymetric features are particularly important. Shelf-basin interaction is a means of transporting dense waters formed in polynyas deeper into the Arctic and both maintain the halocline and ventilate the deeper layers. Addressing this key question requires a network of moored observations and dedicated process studies that are planned and proposed as a part of SIOS.

Observation of ocean heat and volume transports through the Fram Strait has been done for more than 10 years using an array of 17 moorings with about 40 instruments along 78°N 50'. The horizontal extent of the array is ~300 km and the distance between consecutive moorings is 10-30 km. The circulation in the Fram Strait is characterized by intensive meso-scale eddies, and the spatial resolution of the moorings is too coarse to resolve the variability. To improve the ocean observing system in the Fram Strait, an acoustic tomography system is currently being installed. Data from this system can be inverted into averaged temperature and current fields, which (on a long-term basis) is a useful and cost-effective tool to observe seasonal and climate variability in the ocean. Navigation of gliders by use of acoustic signals from the tomography sources will also be developed. The tomography system is implemented under the EU projects DAMOCLES and ACOBAR. Results of these projects will be used to improve the ocean observing capability in the polar oceans.

The West Spitsbergen Current (WSC) is assumed to be of special regional importance, influencing environmental processes and climate system of the Svalbard archipelago. Analysis of the spatial and temporal variability of this current from transect (Oceania) and mooring campaigns (HAUSGARTEN and ARCTOS) revealed significant meso-scale variability components. Therefore, oceanographic observations have to be carried out at adequate spatial and temporal scales, and not only during the summer period, which is the usual schedule of activities so far.

3. The Arctic troposphere - boundary layer – surface system and its impacts on arctic climate in a region with large natural variability

The Arctic PBL poses a severe challenge to all models due to its persistent stable stratification and the important role of ice phase microphysical processes in the formation of boundary layer clouds. Moreover, forcing factors as radiation, conduction, turbulence, subsidence and advection processes increase the complexity of the system. Heat, moisture and momentum are transported through the boundary layer by penetration of a warm, moist updraft through the sea/land surface - and boundary layer directly into the free troposphere and by the induced turbulence upward from the ice-air interface and downward through the

top of the inversion from the free troposphere. The balance between mechanical generation of turbulence and damping by stability varies greatly, creating relatively thin stable boundary layers that range from well mixed to non-turbulent. The upper part of the boundary layer can sometimes be decoupled from the surface forcing and properties. Boundary Layer mixing processes are very important to determine aerosols characteristics and depositional processes.

Due to its geographical location, Svalbard can be alternatively under the influence of air mass coming from polar or mid-latitudes. However, the strong orographic obstacles there can disturb the development of a stable ABL and make the interpretation of measurements more difficult. Therefore, an offshore station over flat sea ice, or in a flat coastal area (e.g., Kap Linné) would be desirable.

The typical ABL height in Arctic regions is less than 500 m. Observations of temperature, moisture and trace gases at ground level in Ny-Ålesund, on the 30 m Climate Change Tower and at Zeppelin Observatory (475 m.a.s.l.), supplied by profiles from balloon-borne instruments and lidars, will provide the ABL characteristics and permit year-round studies of mixing and exchange processes all the way from the surface layer to the lower stratosphere. This will add crucial information about transition phases and will help to improve ABL parameterization schemes in climate models as well as to reduce uncertainties of long range transport models. Similar pilot observations have been started at Hornsund Station in southern Spitsbergen. It should also be considered to establish small autonomous instruments at further sites, such as close to Longyearbyen and Barentsburg (influence of local pollution), and at very remote places, e.g. Nordaustlandet, and in connection to existing meteorological stations on Bear Island and Hopen. Ship-based activities should include also include air-sea interaction, with a special focus on the marine atmospheric boundary layer as well as conditions in polynyas and over sea ice.

Arctic aerosols are of great importance for cloud properties and the atmospheric radiation balance. They influence climate directly through changing albedo. In areas covered by snow and ice, aerosols may produce appreciable warming at the surface, if highly absorbing particles are suspended on these bright surfaces. Natural aerosols of marine origin may play an important role in the future due to radically changing ice conditions in the Arctic Ocean. Black carbon particles deposited on snow and ice can significantly decrease the albedo of these surfaces leading to enhanced melting of Arctic land and sea ice, but no data exists yet to quantify this effect. While such effects are due mainly to the direct scattering and absorption of incoming solar radiation, exchange of thermal radiation between the surface and atmosphere enhances heating below dense aerosol layers. It is important to determine the radiative properties of particles within the entire atmospheric column to evaluate accurately the radiative forcing induced by the mixture.

Cloud cover is a crucial parameter influencing the energy balance of the lowermost atmosphere and its exchange with the ocean and the cryosphere, and thus ultimately atmospheric dynamics. This parameter has proven to be very challenging to simulate in climate models, which fail both with respect to average cloud cover percentage, its seasonal variability and the distribution between liquid and solid phase. Little observational data exist on Arctic clouds, especially during the dark winter season, and this limits the understanding of Arctic cloud properties and their impact on radiation fluxes.. Ground-based lidar and radar measurements as well as use of new techniques to detect cloud information for basic radiation measurements are necessary in order to fill this gap and provide validation data for satellite and airborne observations.

4. Terrestrial cryosphere, weather and hydrology in the Svalbard region

Svalbard holds more than 90% of the European ice masses and is located in a region with extreme variability of weather conditions due to the large gradients in crucial parameters

influencing weather, such as sea ice, atmospheric circulation and ocean currents. At the same time weather in the Svalbard region affects weather and climate in a much larger region, including Northern Europe.

The land areas of Svalbard are dominated by the terrestrial cryosphere components; glaciers/ice caps, snow and permafrost (which is addressed in more detail by working group 4). This has a profound impact on the hydrological system. The runoff from melting of snow and ice is concentrated to the summer season. The water stored in the glaciers may give large additional runoff to the fjords and nearby oceans and has a direct impact on marine ecosystems, the local fjord circulation pattern and contributes to global sea level changes. The changes in Svalbard can be used as an indicator of overall Arctic changes. Svalbard is one of the few areas in the Arctic with long term monitoring of the glacier mass balance. It is unique field observatory of mechanisms of physical glacier processes which can be used for modelling in wider scale on Greenland and Antarctica.

In the order of 20-30 % of the mass loss to the oceans from the glaciers and ice caps is caused by calving of icebergs, and data on this mechanism of mass loss by calving are sparse. Changes in ice dynamics likely have a strong effect on iceberg fluxes to the ocean. Surge-type glacier behaviour, in which flow velocities change abruptly between “active” and “quiescent” phases, is common in Svalbard. There is a great need to be able to quantify the calving flux. This requires a better understanding of the dynamics; the calving processes and surge behaviour, including stimulation of calving by such events. It is also of great importance to design a future monitoring programme in such a way that it is truly representative for the whole of Svalbard, e.g., via a stronger focus on the East and the South of the archipelago.

Recent developments in automatic techniques have facilitated mass balance estimates of snow and glacier masses on land. These are basically full energy balance stations (AWS) with additional sensors to measure both melt and snow accumulation (AMS) and can also be used as platforms for automatic monitoring of other parameters, such as aerosols. Land snow is a water storage as well as a strong climate forcer via its albedo and feedback to temperature. Hence, monitoring snow extent and volume is important also for better characterization of the total precipitation on Svalbard.

Changes in the freshwater budget are of crucial importance for both land and sea processes, and are a direct effect of precipitation. However, neither the true amounts of precipitation nor the long-term trends in Arctic precipitation are captured by the present measuring systems. Gauge undercatch is substantially larger for solid than for liquid precipitation. Rising temperatures have led to reduced annual fractions of solid precipitation and increased liquid fractions. Thus the gauge undercatch is reduced, and a fictitious positive trend is superimposed on the real precipitation trend. This has significant implications for the monitoring of present and future precipitation amounts. Additional ground monitoring of snow accumulation in long profiles may give more reliable estimates of the snow precipitation than gauge stations. This can be done by repeated high frequency radar scans and validated by single point direct measurements, or, locally with repeated terrestrial laser scanning. There is also a need of reliable and accurate hydrological data such as runoff, not only for climate change studies, but also for the management of the environment and water resources. This requires water balance studies, including monitoring of runoff, and snow and soil water properties, in different catchments, both glaciated and glacier free. Since rain-on-snow events during winter have significant impacts on both the ecological system and on the water balance the studies should also include soil-snow interface temperature monitoring at spatial scale.

In operational meteorology, the forecasting of polar lows - peculiar intense weather features which can occur in the North Atlantic sector of the Arctic - and Arctic fronts is of particular interest. Because of their severity for the expanding human activities, there is a

need for improving the understanding and forecasting of these phenomena in the region. This can only be achieved by an upgrade of the sparse network of conventional observations, combined with observations from polar orbiting satellites. New instrumentation on meteorological satellites provides new and promising sources of information for the Arctic atmosphere, but these need to be collocated and verified with independent observations, either ground-based or air/balloon-borne.

The development and the placement of meteorological, hydrological and terrestrial cryosphere observation capacity have to be closely coordinated with efforts of the terrestrial ecosystem community which needs geophysical data as input to their studies.

5. Arctic Greenhouse gas budgets on- and offshore: jokers in the Arctic climate system

The Arctic has the potential to significantly influence the budget of the most important greenhouse gases besides water vapour: CO₂, CH₄ and (tropospheric) ozone. With regard to CO₂, the North Atlantic already is and the Arctic Ocean may become an important sink with a rapidly shrinking ice cover. There are, however, also strong indications that due to the rapid increase of atmospheric CO₂ and increasing water temperature, the sink function or buffer capacity of these ocean areas may decrease rapidly in the next decades. Another consequence of CO₂ uptake in the Arctic Ocean, which is receiving increasing attention from the scientific community, is a gradual decrease of ocean water pH values (ocean acidification). According to first model predictions, this parameter could reach a level critical for marine ecosystems in the European Arctic already by about 2030.

With respect to methane, the Arctic contains two large reservoirs which might destabilize in case of continuous atmospheric and ocean warming. One of these is the vast carbon reservoir in high-latitude frozen soils. Depending on temperature, humidity, soil conditions and other environmental changes, these may decompose and cause large methane or CO₂ emissions. Furthermore, there are large methane reservoirs in the form of clathrates and free gas trapped under clathrates at the seafloor of the large shallow seas in the Arctic Ocean and along the shelf edge. These may destabilize in case of a substantial ocean warming as predicted by global models. In fact, field campaigns in recent years, such as the International Siberian Shelf Study (ISSS) 2008, have revealed increased release of methane from the Siberian shelf and other areas, e.g., the Fram Strait. There is also evidence that recent increases in levels of atmospheric methane are due to releases from boreal/subarctic terrestrial ecosystems (marshlands). The only way to perform a proper source apportionment of atmospheric methane, are isotope ratio measurements, which will require the implementation of a Trace gas and Mass Spec (GC-IRMS), so far missing in Svalbard.

Tropospheric ozone has in addition to its atmospheric oxidizing capacity a strong radiative forcing impact. Today ozone is mostly transported to the Arctic from polluted areas at lower latitudes, and this process may increase in case of a marked warming especially in spring. Another potential future source is the envisaged strongly increasing transpolar ship transport, in case the sea ice coverage in the Arctic Ocean continues to decrease. This locally or regionally produced ozone may become an important regional driver of further Arctic warming.

6. Vertical Atmospheric coupling from the surface to space

The importance of stratospheric ozone as a climate active gas has long been recognised. However, current IPCC models do not include interactive stratospheric chemistry and can, therefore, not assess the effect of interactions between the stratospheric ozone layer and Arctic surface climate. From observations it has been shown that anomalies in the Northern Annular Mode (the Arctic Oscillation, AO) propagate from the stratosphere down to the surface on time scales of a few weeks. Polar ozone loss results in amplification of the AO

in the stratosphere but the potentially significant dynamical effect of this amplification of the AO on the surface climate is not clear. Full inclusion of the chemical, radiative and dynamical interactions between the stratosphere and surface climate in global climate models is especially dependent on a better understanding of the Arctic coupling processes. This requires a comprehensive characterization of the full range of the large natural inter-annual variability in the Arctic, which can only be achieved by long-term measurements at least of the key species.

Due to the transient nature and relatively short lifetimes of satellite platforms, continuous and homogenous ground based measurements are needed for this important task. Svalbard is a unique place to achieve long-term observations in the high Arctic. No other place in the central Arctic is as accessible as Svalbard and accessibility is the key for long-term continuous measurements. Many observations of important stratospheric species started on Svalbard in the early nineties, much earlier than at any other place that far north. Also the comprehensive set of instruments currently employed in Svalbard is unique. For making progress in understanding the interaction between the Arctic ozone layer and surface climate it is crucial to better characterize the variability on time scales of years to decades, i.e., to extend data sets, and to combine the data with modelling of the interactions. Based on the observations, numerically less demanding semi-empirical modelling approaches of stratospheric polar chemistry need to be developed so that stratospheric chemistry can be added to Atmosphere-Ocean General Circulation Models without the prohibitively large numerical overhead of current approaches.

Very few efforts have been taken (in the model community) to extend the vertical atmospheric coupling beyond the stratosphere. There are, nevertheless, indications that this is an important issue in polar regions. Polar stratospheric warmings which completely change stratospheric winter circulation and possibly also the circulation in the troposphere, have been found to propagate into or even originate from the mesosphere. Ozone, which is of crucial influence on thermal state of the stratosphere, can in periods be severely disturbed by ionospheric processes following solar particle storms. There is evidence that basic ionospheric parameters, e.g., the altitude of the F layer maximum has changed significantly and systematically during the last 60 years. The reason for this is unknown, and it has been speculated that this may be caused by climate change or other long-term changes, such as the gradual attenuation of Earth's magnetic field.

Svalbard is a unique place to investigate these cross-cutting topics, both because of its geographical location and the already existing extensive instrumentation for upper atmosphere/ionosphere studies.

2 Which issues can be addressed in Svalbard?

Svalbard is located in a region of the Arctic with a large natural variability and strong geophysical gradients. This is very suitable to perform process studies, with a focus on how physical parameters influence important geophysical processes. E.g., the large variations in weather conditions even in mid-winter, with polar conditions followed by mild episodes, enable researchers to study the whole scope within short time periods. Critically, the large natural variability also impedes detection of long-term changes. In selected fields, such as precipitation measurements, small changes, e.g., a shift in the precipitation phase, may even produce artificial trends.

Svalbard is also located in a region where fundamental arctic processes take place: the main Atlantic inflow into the Arctic basin via the West Spitsbergen current, the sea ice and freshwater export from the Arctic through the Fram Strait, and oceanographic shelf processes such as formation of cold, saline water masses in the Storfjord region. The contrasting

oceanographic setting of the fjords offers unique opportunity for process studies relating to ice-ocean interactions. Logistically, Svalbard is an ideal location for operating and maintaining the oceanographic instruments used to address key topic 2, due to available lab facilities, personnel and ship expeditions from Longyearbyen, Ny-Ålesund and Barentsburg. Kongsfjorden and Isfjorden are exemplary sites where shelf-basin exchange processes can be studied with relatively easy access.

Ny-Ålesund, which maintains observatories at sea level, on a tower and at almost 500 m elevation offers a unique opportunity to study the Arctic boundary layer on a continuous, long-term basis, while the combination with ship-based campaigns allows for studies of marine boundary layer properties contrasting to conditions on land with complex topography. Similar opportunity on proportional scale has got and can offer the Hornsund station in different geographical setting.

Svalbard is also a unique place to study vertical atmospheric coupling issues, both due to its location under the cusp region of the Earth's magnetic field, and due to the excellent instrumentation which already exists today. Although these processes are not regarded as key aspects of the ongoing environmental change, this is a vital basic research activity with a number of very interesting "non-main-stream topics" related to climate change that deserve attention.

3 Existing infrastructure and needs for additional equipment and observation programmes

An overview of existing instruments, operators and monitoring programmes addressing the six key topics, as well as planned and proposed instrumentation in order to complement ongoing activities are listed in tables 1 and 2 at the end of this document. On a general level, a fourfold structuring is proposed:

- (1) A few "super-sites" providing a large number of parameters on a continuous, near-realtime basis. The best candidates are the existing main stations: Ny-Ålesund, Longyearbyen, Hornsund and Barentsburg.
- (2) A (larger) number of quasi-autonomous minor land-based stations providing a limited set of parameters, especially within meteorology, hydrology and cryosphere science. E.g., automatic cryospheric stations are becoming more common and have proven useful in very remote areas such as Greenland. Since they are placed on snow and ice the environmental impact is minimal and they can be used as platforms for other automatic environmental measurements requiring little maintenance. This network should provide a representative picture of changes on the archipelago, including the small islands (Hopen, Bear Island). Also in this group, existing field stations and settlements should preferably be used: Kap Linné, Pyramiden, Svea, Kaffiøyra, Kinnvika, Rjipfjorden etc.
- (3) A small number of comprehensive cabled moorings, providing continuous monitoring of oceanic and sea ice information. For logistical reasons these will have to be limited to the areas off the west coast of Spitsbergen (Longyearbyen – Ny-Ålesund).
- (4) Regular campaign-based data acquisition, by vessels, autonomous moorings, and recoverable systems, such as ice-tethered buoys. These have the potential to cover all off-shore areas around Svalbard.

Issues (3) and (4) require a careful inventory of vessel availability and a coordination of cruises in order to achieve an optimum coverage of the offshore areas.

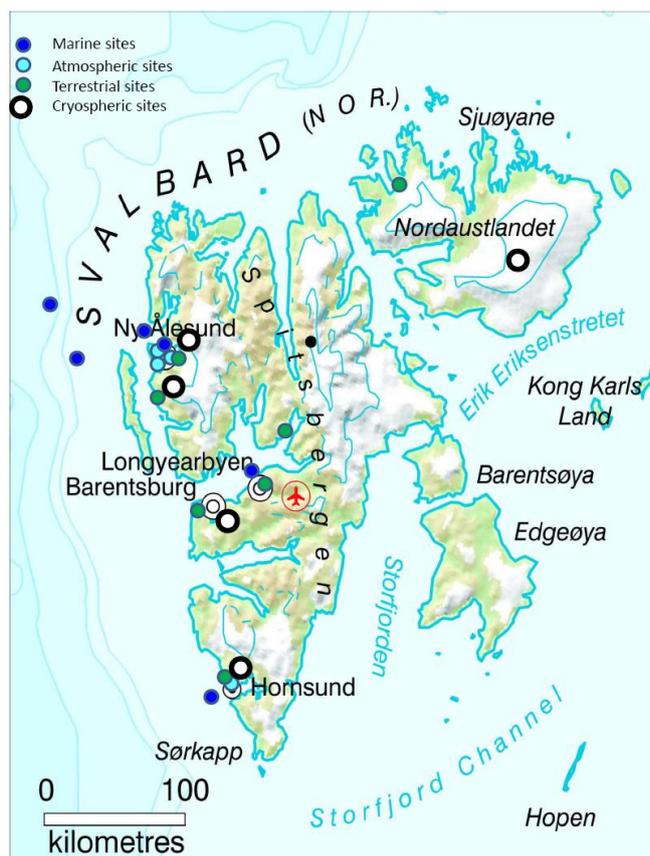


Figure 1. Infrastructure sites included in this report (atmospheric, marine, terrestrial, cryospheric).

Estimates of necessary investments as indicated in Table 2 are only in an initial phase. The total specified investment sum amounts to approximately 5.5 million Euro, with contributions ranging from less than 20 000 Euro to 800 000 Euro per instrument. It is expected that this amount will increase considerably when the existing gaps are filled. A major general infrastructure investment related to the marine activities is the cabling of seafloor observatories and mooring stations off the west coast of Spitsbergen. The optical fibre cable will be applied for in connection with the upgrade of the Geodetic Observatory/VLBI station in Ny-Ålesund, and costs for that are estimated to amount to about 60 mill. NOK (7.5 mill. Euro). For the subsea observatories, in addition a power cable is required, the costs of which are not yet estimated.

4 How should the infrastructure be best organised?

At present, most of the infrastructure is organized as national stations or even at institute level. This partially mirrors geographical sites (especially Barentsburg and Hornsund), but in the case of Ny-Ålesund there are several independent Norwegian activities and 8 other national stations in an area of less than 5 km radius. Exceptions are the German-French collaboration in Ny-Ålesund (AWIPEV Base), and to some degree the coordination of all the stations through the Ny-Ålesund Science Managers Committee (NySMAC). The following models were discussed for a future organization of the infrastructure:

- (1) In disciplines: atmosphere – ocean – ice – land

This is a traditional way of organizing, being advantageous for scientific communication within the various disciplines. The challenges are the wide geographical dispersion of the various platforms and the lack of incentive for cross-disciplinary work. A problem will also arise from organizing cryospheric observations (sea ice, land ice, snow, permafrost). On the other hand, this organizational structure encourages international cooperation and over-critical mass of activities.

- (2) In platforms: land-based – sea-borne – air-borne

This is an alternative based on practical aspects, mainly logistics. Also here, the geographical dispersion will be a challenge, in addition the non-traditional grouping with respect to scientific topics. On the other hand, logistical aspects are of great importance in the Arctic, and this way of organizing will help to optimize the use of resources. It will also facilitate greater opportunities for cross-disciplinary work.

- (3) Geographically: Ny-Ålesund – Longyearbyen – Barentsburg – Hornsund – Hopen/Bjørnøya - off-shore

Also this organizational structure offers practical advantages, as infrastructures are organized most easily as single sites. On the other hand, this structure does not function in an straightforward integrative way, especially given the starting conditions with two single-nation stations and two multi-nation stations.

(4) Topically:

This is an organizational structure that is most natural for scientific purposes, but it is most challenging in practical terms (geographical dispersion, interdisciplinary, logistically) and it requires high flexibility over time and, thus, a considerable amount of (re-)organisation efforts.

Alternative 4 is supported by several members of the group, as it is regarded as the model which guarantees the integrating aspect in the best way. However, we are conscious of the multi-dimensional nature of the issue:

- operation needs to be organized locally (geographically)
- research needs to be organized according to topics or disciplines
- investments needs to be organized by institutes or special-purpose consortia (e.g. for big installations)

Ocean, sea ice and atmospheric research in sea areas will to a large extent use common infrastructure, primarily ice-going and open water ships, helicopters, fixed-wing aircraft and ice buoys. Underwater moorings will be used both for sea ice and oceanographic research. Several observing sensors can be mounted on the same moorings or moving platform such as gliders. Ocean moorings or seafloor installations will be available in fixed locations, where new observing sensors can be added.

5 What can be the role of the Knowledge Centre in your field?

A knowledge centre (located in Longyearbyen) could have various roles in parallel. A central function would be to develop expertise on and provide support to field observations. This could, e.g., include tests of instruments, installations, development and maintenance of measurement set-ups, as well as retrieval, processing and validation of satellite data from SvalSat at Longyearbyen. Links to the Svalbard Research Centre (Forskningsparken: UNIS, NPI-Longyearbyen, the Svalbard Museum) and the Svalbard Science Forum (SSF) appear natural.

For an interdisciplinary field such as the one addressed by working group 2, a data archiving and outreach centre as envisaged for the SIOS Knowledge Centre would be a novelty. In fact, the existing data centre of AMAP also has an interdisciplinary character, but it is thematically focused (environmental pollution). There are also station databases at some Arctic sites, e.g., Point Barrow (<http://www.baidims.org/>). Furthermore, there are a number of thematic databases on specific measurements, with Arctic stations being part of global networks. The major repository for atmospheric composition data can be found at <http://ebas.nilu.no> where data from a large number of international monitoring programmes (including AMAP and EMEP) and research projects can be accessed (after signing specific access protocols if restrictions apply). Two atmosphere related networks are the AERONET network, measuring Aerosol Optical Thickness (AOT) by means of sun photometers all over the globe, with – so far - 3 sites in Svalbard (http://aeronet.gsfc.nasa.gov/cgi-bin/type_piece_of_map_opera_v2_new), and NOAA's Earth System Research Laboratory, collecting flask samples from all over the world to analyse greenhouse and other trace gases (<http://www.esrl.noaa.gov/gmd/ccgg/iadv/>).

Working group 2 has divergent opinions on how far the data base role of the knowledge centre should go. There is agreement that SIOS should not establish redundant structures, but rather function as a portal structure to existing physical databases. At a

minimum, the Knowledge Centre should house a meta-database, but it could also function as a supplementary database for parameters/scientific fields, which are not caught by operational databases at present. In any case, the Knowledge Centre should adopt existing guidelines or data storage protocols, e.g., those from IPY (DOKIPY) or, in case of oceanic data, those of the IPY project DAMOCLES, considering already developed and potentially extended glaciological databases (related partly to the IPY GLACIODYN project). Further proposals for functions of the Knowledge Centre are:

- The KC should focus on utilizing knowledge of local and regional conditions. It could be the main service provider of this knowledge to visiting scientists and research groups.
- The KC could play an important role in developing new technologies for Arctic observations by testing new instruments in-situ.
- A mission of the SIOS KC can be to continuously test out such new sensors on Svalbard as they arrive on the market and judge their suitability before they are brought into operation. Such sensors can be tested on the cryospheric stations. Application and utilization of observation data: focus on niches/areas not yet addressed by operational networks. E.g., it could include the Arctic Regional Ocean Observing System (Arctic-ROOS), which is established for promotion and development of operational ocean monitoring and forecasting in the Arctic and sub-Arctic seas, by 15 member organisations who are all involved in producing ocean data and modelling results for the Arctic areas. A good model to develop such a system could be the Canadian Polar Data Catalogue (<http://www.polardata.ca/login.ccin>).
- The KC should be a discussion forum for researchers to organise their work, set goals, distribute tasks, publish results in common etc.
- The KC should aim at becoming a meeting place bringing together top scientists working on Arctic issues. This should include lectures, discussion rounds etc., as well as stipends for post docs and senior scientists to give them the possibility to work with the best infrastructure at an inspiring Arctic location.
- Satellite earth observation data processing and archiving facility for the Arctic areas. Several processing systems are available for different disciplines, but there is not yet any interdisciplinary satellite data service for the Arctic regions. Here, the proximity to SvalSat is a great advantage.

Table 1. List of instruments – Svalbard Integrated Arctic Earth Observing System (SIOS) – WG 2

Instrument	Parameters observed	Location	Operated since	Respons. inst.	Country	KT
SBE49	CTD towed probe	r.v. Oceania Svalbard	2003	IOPAS	Poland	1
VM ADCP RDI 150	Current profile	r.v. Oceania Svalbard	2003	IOPAS	Poland	1
RDCP 600 with SBE37SM x2 mooring	Current profile with CTD	south-western Svalbard shelf	Summer 2009	IOPAS	Poland	1
Multi-parameter mooring	Temperature, salinity, currents, sediments, fluorescence, added biological sampling	Kongsfjorden	2001	SAMS	UK	1, 2
Multi-parameter mooring	Temperature, salinity, currents, sediments, fluorescence, added biol. sampling	Northern Svalbard Shelf	2006	SAMS	UK	1, 2
Seabird CTD with microCond, Sontek ADV	High frequent time series of ocean current, temperature and salinity	Under-ice boundary layer	2002-	UNIS	Norway	1, 2
Sontek ADP	Current profiles synchronized with the high frequent time series	Under-ice boundary layer	2002-	UNIS	Norway	1, 2
Soot photometer	Particle light absorption	Zeppelin Obs., Ny-Ålesund		SU	Sweden	1, 3
MMP (SBE52, ACM) – mooring	CTD and current profile	Fram Strait	2008	IOPAS	Poland	2
SBE9+/11 with LADCP	CTD, fluorescence, O ₂ current profile	r.v. Oceania Svalbard	1999/2008	IOPAS	Poland	2
Oceanic microstructure profilers	Turbulent mixing in the water column	Ship-board	2001	GFI-UIB	Norway	2
Aandraa RCM9 and Seabird microCats	Ocean current (205m 120m), T and salinity (150m, 90m) at 78.83°N and 8.86°E	F0: Eastward continuation of the AWI/NPI mooring section in Fram Strait	2007-2010 iAOOS-Norway (prop. cont.d)	UNIS	Norway	2
Acoustic Arctic Laboratory with the following components:	Ocean acoustic data (multi-disciplinary use)	Fram Strait, deep sea part	Partly funded 2008-2012,	Nansen Centre (NERSC)	Norway	2
Single-track tomography moorings	Mean ocean temperature	Fram Strait: Westspitzbergen Current	2008	Nansen Centre (NERSC)	Norway	2
Bottom frames with acoustic Doppler current profiler	Ocean current profiles and bottom temperature and salinity	Storfjorden sill and shelf-break off Sørkapp	2004-2010 (prop. cont.)	GFI-UIB	Norway	2
ARGO Floats	CTD	Fram Strait	2009	IOPAS	Poland	2
Tekran Hg monitor	Mercury air concentration	Zeppelin Obs., Ny-Ålesund	2000	NILU	Norway	3

Ozone analyzer	Ambient ozone	Zeppelin Obs., Ny-Ålesund	1991	NILU	Norway	3
GC-HgO	Ambient Hydrogen	Zeppelin Obs., Ny-Ålesund	2005	NILU	Norway	
Filterpack	Aerosol inorganic chemistry	Zeppelin Obs., Ny-Ålesund	1989	NILU	Norway	
Meteorology	Wind, temp, RH,	Zeppelin Obs., Ny-Ålesund	1989	NILU	Norway	
Eppley Precision spectral Pyranometers	Solar radiation fluxes	r.v. Oceania/ Svalbard	1993	IOPAS	Poland	3
Kipp&Zonen net radiation meter	Upward and downward radiation fluxes	r.v. Oceania/ Svalbard	2000	IOPAS	Poland	3
Lidar LB 10 (532 nm)	Aerosol profiles	r.v. Oceania/ Svalbard	2009	IOPAS	Poland	3
Microtops II sunphotometers	AOD	r.v. Oceania/ Svalbard	2001	IOPAS	Poland	3
PMS laser particle counter CSASP-100	Coarse aerosol size distribution and conc.	r.v. Oceania/ Svalbard	1993	IOPAS	Poland	3
Sun/moon/star photometer	Aerosol optical density	AWIPEV Base, Ny-Ålesund	1990	AWI	Germany	3
Condensation Particle Counter (CPC)	Particle number density	Zeppelin Obs., Ny-Ålesund		SU	Sweden	3
Differential Mobility Analyzer (DMA)	Particle size distribution	Zeppelin Obs., Ny-Ålesund		SU	Sweden	3
Nephelometer TSI 3563	Aerosol light scattering	Zeppelin Obs., Ny-Ålesund		SU	Sweden	3
BSRN station	Direct, diffuse, global radiation, UV, upward/ downward long-wave radiation, solar spectrum,...	AWIPEV Base, Ny-Ålesund	1991	AWI	Germany	3
miniaturized 532 nm elastic backscattering and depolarization lidar MULID	particle backscatter coefficient - particle depol. ratio	10 m asl (AWIPEV station – observatory building	UPDATE 2008	ISAC-CNR (CCT Integr. Proj.)	Italy	3
TSI Condensation Particle Counter	Fine mode aerosol concentration	r.v. Oceania/ Svalbard	2007	IOPAS	Poland	3
Laser ceilograph	Cloud base	AWIPEV Base, Ny-Ålesund	1991	AWI	Germany	3, 4
Met-tower	p, T, wind, RH at 2/ 10 m	AWIPEV Base, Ny-Ålesund	1991	AWI	Germany	3, 4
Aerosol Raman lidar	Aerosol profiles	AWIPEV Base, Ny-Ålesund	1994	AWI	Germany	3, 4, 6
Tethered balloon	Vert. profiles of met. Parameters	AWIPEV Base, Ny-	2006	AWI	Germany	3, 4

		Ålesund				
GILL acoustic anemometer	Wind speed pulsations	r.v. Oceania/ Svalbard	2007	IOPAS	Poland	3, 4
Meteo-station	Meteorological parameters	r.v. Oceania/ Svalbard	1993	IOPAS	Poland	3, 4
Automatic Weather Stations (AWS)	T, RH, wind speed & direction, p, snow height, global/reflex radiation, albedo, upward/ downward LWR, net radiation	Hansbreen	2007-present	UoS, IGF PAN, UWt	Poland	3, 4
Automatic Weather Station (AWS)	Global/ reflex radiation, albedo, upward/ downward long-wave radiation, net rad.	Hornsund	2008-present	UoS, IGF PAN	Poland	3, 4
Synoptic met. station (partially automatic)	T, p, wind, RH, prec., snow depth, clouds, visibility	Ny-Ålesund	operational	Met.no	Norway	3, 4
Radiosondes	Vertical profiles of T, p, wind, RH	AWIPEV Base, Ny-Å.	1990	AWI	Germany	3, 4, 6
ozonesondes	Vertical profiles of ozone	AWIPEV Base, Ny-Å.	1988	AWI	Germany	3, 4, 6
CO monitor	CO	Zeppelin Obs., Ny-Ålesund	Sept. 2001	NILU	Norway	3, 5
Dual UV spectro-radiometer	UV-A, UV-B spectra	AWIPEV Base, Ny-Ålesund	1994	AWI	Germany	3, 6
Microtops II ozonometer	Ozone profiles	r.v. Oceania/ Svalbard	2001	IOPAS	Poland	3, 6
UV-RAD ISAC radiometer (7 channels: 300, 306, 310, 314, 325, 338, 364 nm)	UV fluxes at 300-380 nm - Ozone content - Erythemal/DNA dose rates	10 m asl (Sverdrup station)	UPDATE 2008	ISAC-CNR	Italy	3, 6
Synoptic met. station (manual)	T, p, RH, prec., snow depth, clouds, visibility, radiosonde	Bear Island	operational	Met.no	Norway	4
Synoptic met. station (partially automatic)	T, p, RH, prec., snow depth, clouds, visibility, radiosonde	Jan Mayen	operational	Met.no	Norway	4
Synoptic met. station (manual)	T, p, RH, prec., snow depth, clouds, visibility, radiosonde	Hopen	operational	Met.no	Norway	4
meteorological station (automated)	T, p, RH, wind	Edgeøya, Verlegenuken, Karl XII Land	p.d. not operational	Met.no	Norway	4
meteorological station (automated)	T, p, RH, wind	Svea	operational	SNSK	Norway	4
Synoptic met. station (partially automatic)	T, p, wind, RH, prec., snow depth, clouds, visibility, etc.	Svalbard lufthavn Longyearbyen	operational	AVINOR	Norway	4
Automatic Weather Station (AWS)	Ice temperature profile: 30m	Hansbreen	2008-present	UoS, IGF PAN	Poland	4
Glaciological Stations (UBC): Subglacial, englacial and supraglacial sensors	: Basal water pressure, basal sliding indicator, icequake counts, vertical ice, atm. p, snow depth	Hansbreen	2006-present	UBC,UoS	Canada, Poland	4
Ground penetrating radar (GPR)	Snow precipitation, glacier thermal structure and mass balance	Hornsund areas	2007 - present	UoS, IGF PAN	Poland	4
GPS-stations-automatic	Glacier dynamics	Hansbreen	2003 - present	UoS, IGF	Poland	4

				PAN		
Time-lapse cameras	Glacier dynamics Scow cover distribution on tundra	Hansbreen and selected glaciers	2007/2009	UoS, IGF PAN	Poland	4
Runoff station	Water discharge and temperature, suspended sediments (in-organic, organic)	Ny-Ålesund, De Geerdalen, Londonelva	1989, 1990, 1992	NVE	Norway	4
Snow and soil monitoring stations	Soil water level, soil moisture, soil temperature, snow depth, snow temperature	Ny-Ålesund	2008, 2009	NVE	Norway	4
MST radar	Wind field in tropopause region, upper atmosphere	Adventdalen		University of Tromsø	Norway	4, 6
NDIR radiometer	Carbon dioxide	Zeppelin Obs., Ny- Ålesund	1988	Univ. of Stockholm	Sweden	5
	Radon	Zeppelin Obs., Ny- Ålesund		SU/Univ. of Heidelberg	Sweden/ Germany	5
ADS-GCMS	Volatile hydrocarbons	Zeppelin Obs., Ny- Ålesund	Spring 2000	NILU	Norway	5
GC-FID	Ambient methane	Zeppelin Obs., Ny- Ålesund	1998	NILU	Norway	5
FTIR spectrometer	columns of stratospheric trace gases: ozone, HCl, HF, NO ₂ , HNO ₃ , ClONO ₂ , CFCs, ...	AWIPEV Base, Ny- Ålesund	1991	AWI + Univ. Bremen	Germany	5, 6
DOAS	Ozone, NO ₂ , OClO, BrO, IO (column abundance)	AWIPEV Base, Ny- Ålesund	1994	Univ. Bremen	Germany	5, 6
SAOZ	Total ozone, NO ₂	Sverdrup Station, Ny- Ålesund	1991	NILU/CNRS	Norway/ France	6
GUV	UV irradiance, total ozone	Sverdrup Station, Ny- Ålesund	1996	NILU	Norway	6
Sun photometer	Aerosol optical depth, PFR	Sverdrup Station, Ny- Ålesund	2001	NILU/Davos	Norway	6
Precipitation collector	Inorganic chemistry	Sverdrup Station, Ny- Ålesund	1980	NILU/Davos	Norway	6
Stratospheric ozone lidar	Vertical profiles of ozone, PSCs, strat. T, density	AWIPEV Base, Ny- Ålesund	1988	AWI	Germany	6
Microwave radiometer	trace gases in the stratosphere and lower mesosphere	AWIPEV Base, Ny- Ålesund	1991	Univ. Bremen	Germany	6
Brewer No. 05	Ozone Content - UV spectra	Dirigibile Italia Station, Ny-Ålesund	UPDATE 2008	IDAC-CNR	Italy	6

Abbreviations: UoS – University of Silesia, Poland, IGF PAN – Institute of Geophysics, Polish Academy of Sciences, Uwr - Wrocław University, Poland, UBC – University of British Columbia, Canada

Table 2. Planned and proposed instruments

Instrument	Parameters	Location	Status	Respons. inst.	Country	KT	Est. invest. [kEuro]	Est. op. costs [kEuro]
RDGP 600 with SBE37SM x2 mooring	Current profile with CTD	Hornsund	Planned 2010-2011	IOPAS	Poland	1	---	90
VM ADCP	Current profile	r.v. Oceania Svalbard	Proposed	IOPAS	Poland	1	75	
Automatic weather stations	T, p, wind, RH, web cam monitoring	On ice buoys	proposed			1	325 (65/station)	
Upward looking ADCP meas.	Sea ice drift	Sub-ice moorings	Proposed			1		
Upward looking sonar	Ice thickness	Sub-ice moorings	Proposed			1		
Cabled mooring	Temperature, salinity, fluorescence	Kongsfjorden	Proposed	SAMS	UK	1, 2	>600	
Autonomous Vehicle	Temperature, salinity, fluorescence, currents, turbulence	Various locations as required	2010	SAMS	UK	1, 2		50 per campaign
Upgrading of existing coastal moorings	Temperature, salinity, currents, sediments, fluorescence, added biological sampling	Kongsfjorden and northern shelf	2012	SAMS	UK	1, 2	200	
Mooring array (3 moorings)	Temperature, Salinity, currents	Northern Svalbard slope	Proposed	SAMS	UK	1, 2	500	
Array with 4 moorings	Profiles of ocean current, temperature and salinity	Yermak Branch of WSC (west flanks Yermak Plateau)	Proposed	GFI-UIB	Norway	1, 2	700	
Mass balance buoys	Sea ice mass balance	Sea ice buoys	proposed			1, 4		
ROVs, AUVs	Spatial sea and ice meas.	t.b.d.	Proposed			1, 2		
UAVs	Spatial atmosphere and surface meas.	t.b.d.	proposed			1, (2), 3, 4, 5, 6		
Triangle tomography moorings	Mean ocean temperature and currents, acoustic signals for glider navigation	Fram Strait	Planned 2009-2012	Nansen Centre (NERSC)	Norway	2	250	
Passive acoustic listening system	Marine mammals and ambient noise	Fram Strait	Planned from 2010 (proposal)	Nansen Centre (NERSC)	Norway	2	300	
2 Seagliders		Continental shelf and slope west of Spits-	Proposed	GFI-UIB	Norway	2		

		bergen, Yermak Plateau						
Array with 3 moorings incl. 6 Arctic Bottom Press. Recorder, moored profiler, current meters	Ocean currents, temperature, bottom pressure (inferred heat & vol. transport)	Smeerenburg Section (north of Svalbard)	Proposed	UNIS	Norway	2		
2 Seagliders	Profiles of ocean temperature and salinity and	Smeerenburg Section (north of Svalbard)	proposed	UNIS	Norway	2		
Arctic bottom pressure recorders	Sea bottom pressure	Shelves	Proposed	UNIS	Norway	2		
McLane profilers		Between mooring stations	proposed	AARI	Russia	2		
Upper looking ADCP +2CTD mooring	Current profile with CTD/ fluorescence	south-western vbalbard slope	Proposed	IOPAS	Poland	2	90	
Currentmeter, thermistor chain, buoy, releaser, undersea trans-mission system	Thermal structure, marine circulation in Kongsfjord	Deployment offshore NYA, Acq. based in the Marin Lab	Spring 2010	ISMAR-CNR (CCT Integrated Project)	Italy	2		
Bottom frames with acoustic Doppler current profiler	Ocean current profiles and bottom temperature and salinity	Storfjorden sill and shelf-break off Sørkapp	Proposed	GFI-UIB	Norway	2		10 / year
Multi-wavelength Elastic & Raman Scattering LIDAR	Profile of backscattering and extinction coefficient for 355, 532, 1064, 387 and 407 nm (aerosols, clouds, water vapour)	Hornsund Station	Planned September 2009 -	IGF PAN	Poland	3	>800	
TSI particle counter	Aerosol size distribution and concentration	r.v. Oceania/ Svalbard	Proposed	IOPAS	Poland	3		
TSI nephelometer	Aerosol light scattering	r.v. Oceania/ Svalbard	Proposed	IOPAS	Poland	3		100
TSI 3896 Scanning Mobility particle sizer (SMPS) Diffuse mobility analyzer	aerosol size distribution in the range 3 - 1000 nm	NYA To be decided	planned in 2010	Florence University (CCT IP)	Italy	3	200	
PSAP absorption photometer (one wavelength)	aerosol absorption coefficient at 532 nm	NYA To be decided	planned in 2010	ISAC-CNR (CCT IP)	Italy	3	(included in sum above)	
M903 Radiance Research nephelometer	aerosol scattering coefficient	NYA To be decided	planned in 2010	ISAC-CNR (CCT IP)	Italy	3	(included in sum above)	
aerosol sampling systems (single stage-multistage)	size segregated aerosol samples	NYA to be decided	planned in 2010	Florence Univ. IIA-CNR	Italy	3	(included in sum above)	

				(CCT IP)				
Sun photometer	Aerosol optical depth	Svalbard	Proposed	IOPAS	Poland	3	(included in sum above)	
4 propeller anemometers 05106	Wind speed, wind direction	CCT	Fall 2009	ISAC-CNR (CCT Integr. project)	Italy	3, 4	43	
4 thermo igrometers Vaisala HMP45	Temperature, humidity	CCT	Fall 2009	ISAC-CNR (CCT IP)	Italy	3, 4	(included in sum above)	
Barometer CS100	Pressure	CCT	Fall 2009	ISAC-CNR (CCT IP)	Italy	3, 4	(included in sum above)	
Flux plate HFp01	Thermal flux into snow	CCT	Fall 2009	IBIMET-CNR (CCT Integr. project)	Italy	3, 4	(included in sum above)	
2 PT100	Soil temperature	CCT	Fall 2009	IBIMET-CNR (CCT Integr. project)	Italy	3, 4	(included in sum above)	
IR sensor	Snow surface temperature	CCT	Fall 2009	ISAC-CNR (CCT Integr. Project)	Italy	3, 4	(included in sum above)	
CNR-1 Net Radiometer	four components radiation budget	60 m asl CCT	Fall 2009	ISAC-CNR (CCT Integr. Project)	Italy	3, 4	(included in sum above)	
CMP11	upwelling shortwave flux surface albedo (joint to CNR-1)	60 m asl CCT	Fall 2009	ISAC-CNR (CCT Integr. Project)	Italy	3, 4	(included in sum above)	
CGR4	upwelling longwave flux	60 m asl CCT	Fall 2009	ISAC-CNR (CCT Integrated Project)	Italy	3, 4	(included in sum above)	
Advanced precipitation gauge network	precipitation	all existing met stations	proposed	Met.no	Norway	3, 4	480 (80/station)	
Tethered ballon sounding	Met profile	NYA To be decided	To be planned	ISAC-CNR (CCT Integr. Project)	Italy	3, 4		
Doppler Minisodar	Thermal structure & wind profile	NYA To be decided	To be planned	ISAC-CNR (CCT Integr. Project)	Italy	3, 4		
Micrometeorological station	Turbulent fluxes	NYA To be decided	To be planned	ISAC-CNR (CCT Integr.	Italy	3, 4		

				Project)				
Microwave Radiometer MTP5 -P	Temperature profile	NYA To be decided	To be planned	ISAC-CNR (CCT Integr. Project)	Italy	3, 4		
Automatic Weather Station (AWS)	T, RH, wind speed & dir., p, snow height, global/reflex/ net radiation, albedo, upward/ downward LWR	Hansbreen, Werenskjooldbreen	planned in 2010	UoS, IGF PAN, UW r	Poland	3,4	130 (65/station)	
Glaciological Station	Subglacier water pressure, ice temperature profile	Hansbreen	planned in 2010	UoS, IGF PAN, UW r	Poland	4	80.- (40/station)	
30 m borehole for permafrost monitoring	ground temperature profile	NYA to be decided	2010-2011	Insubria Univ. (CCT I P)	Italy	4		
Snow level SR50	Snow height	CCT	Fall 2009	IBIMET-CNR (CCT IP)	Italy	4		
Run-off monitoring instruments	Run-off	Several glacier outlets, major rivers	proposed	Met.no, NVE UoS, IGF PAN, UNIS	Norway Poland	4	200.- (20/set)	
In-situ photogrammetry	Glacier mass balance	Selected glaciers	proposed	UNIS, UiO, NP, UoS, IGF PA N	Norway Poland	4	20	
Automatic Weather Stations (AWS)	Modelling glacier mass balance	Selected glaciers	proposed	UiO, UNIS, NP, UoS, IGF PAN	Norway Poland	4	150 (6 st. a 25)	
Automatic cryospheric mass balance stations (AMS)	Glacier mass balance	Selected glaciers	proposed	UNIS, UiO; UoS, IGF PAN ...	Norway Poland	4	240 (6 st. a 40)	
Ground penetrating radars (GPR)	Snow precipitation, glacier mass balance	Selected areas	Proposed Planned extension for Polish party	UiO, UNIS, NP, UoS, IGF PAN	Norway, Poland	4	30	
GPS-stations-automatic	Glacier dynamics	Selected glaciers	proposed	UiO	Norway	4	20	
Time-lapse cameras	Glacier dynamics	Selected glaciers	proposed	UiO, UoS, IGF PA N	Norway Poland	4	20	
Snow monitoring stations	Snow water eq. & depth, T, snow properties,	Stations to be selected on land, sea ice	proposed	UNIS, NVE (land)		4	200 (10 stat. a 20)	
Fiber optic spatial temperature sensor	Ground-snow interface temperature at spatial scale	Selected land sites	proposed	UNIS	Norway	4	300 (6 stations a 50)	

Runoff monitoring instruments	Runoff	Several glacier outlets, major rivers	proposed	NVE, UNIS, UoS, IGF PA N	Norway Poland	4	150 (5 stat. a 30?)	
Automatic gauge station and sampler	Continuous monitoring of water chemistry and sediment transport in river	Werenskioldbreen river catchment	proposed	UoS, IGF PA N, UW _r	Poland	4	100.-	
Ground interferometric radar ranger	High precision glacier geometry changes and dynamics	Selected glaciers	proposed	UoS, IGF PA N, UNIS	Poland, Norway	4	300,- (150/set)	
High-resolution high-precision GHG monitors	GHG concentrations (high time res., precision)	Ny-Ålesund	proposed	NILU, RHUL, ITM-SU		5	150	
Isotopic GHG monitoring	CH ₄ , CO ₂ isotope conc.	Ny-Ålesund	proposed	NILU, ITM-SU		5	176	
Mobile GHG sampling instruments	CH ₄ , CO ₂ conc. On- and off-shore	Sites t.b.d.	proposed	NILU		5		
Mini- AMS	Aerosol Mass Spectrometer	Zeppelin	Proposed	NILU, ITM-SU		4	120	30
MAAP	Multichannel Aerosol Absorption Photometer	Zeppelin	Proposed	NILU, ITM-SU		4	80	10
NO _x /NO _y /PAN		Zeppelin	Proposed	NILU, ITM-SU		5	50	10
Optical particle counter	OPC	Zeppelin	Proposed	NILU, ITM-SU		4	30	10
CCNC	Cloud Condensation Nucleus Counter	Zeppelin	Proposed	NILU, ITM-SU		4	50	10
INC	Ice Nucleus Counter	Zeppelin	Proposed	NILU, ITM-SU		4	unknown	unknown
HTDMA	Hydroscopicity growth Tandem Differential Mobility Analyzer	Zeppelin	Proposed	NILU, ITM-SU		4	140	50
Mobile ozone sonde launches	Ozone profiles	On-board research vessels	Proposed	AWI		6		