Svalbard Integrated Arctic Earth Observing System (**SIOS**)

SIOS Infrastructure Optimisation Report

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Lead Authors

Cynan Ellis-Evans (NERC-BAS) and Kim Holmen (NPI)

Contributors:

Terry Callaghan, Swedish National Academy; Finlo Cottier, Scottish Association of Marine Science, UK; Robert Dickson, CEFAS, UK; Mark Drinkwater, ESA, Netherlands;
Martin Heimann, MPI Jena, Germany; Silke Kroeger, CEFAS, UK;
Bo Andersen, Norwegian Space Centre

SIOS Infrastructure Optimisation

Executive Summary

The Arctic is warming more rapidly than almost anywhere else on Earth and this is resulting in equally rapid environmental change. The Arctic research community is still struggling to keep pace with the scale of these changes and the complexity of the processes, interactions and feedbacks that underlie the changes. The current environment of funding research for no more than 3-5 years in most cases and with relatively limited overall coordination of efforts, either nationally or internationally, is not a particularly effective approach to understanding rapid change in the Arctic and its vital significance for the Earth System.

The Arctic is of enormous importance and yet is still a comparatively data-poor region. Arctic science needs to establish a coordinated, integrated monitoring programme that can address Earth System variables at relevant temporal and spatial scales. This means a more regional approach and decadal time scales for study. It is recognised that this will need an international cooperative effort as individual nations cannot realistically take on the challenge.

Svalbard is ideally and perhaps uniquely placed to become the major regional monitoring site in the High Arctic. It has important geographical assets (proximity to major Arctic Ocean inflow/outflows, extensive and productive shelf seas, visibility for all polar orbiting satellites), substantial research and logistical infrastructure and a long established and expanding international research community, albeit one that has not routinely interacted. The development of a SIOS programme to effectively coordinate these capabilities could transform our knowledge of the region and make unique contributions to Earth System science, leading to better operational forecasting and more effective management of change.

The proposed overarching approach of the SIOS monitoring programme is to
(a) involve as many of the nations operating there as possible in the monitoring programme,
(b) integrate the monitoring of vertical coupling through the entire atmosphere, down to the Earth surface and into the ocean,
(c) integrate measurements of horizontal transfer of Earth System relevant variables across the archipelago and within the surrounding ocean and
(d) monitor changes in the land-based environment and its biodiversity.
The intention is that a clearly defined set of sites, across Svalbard and in the surrounding ocean, be recognised, with each site contributing, where possible, to a number of Earth System science questions to facilitate better integration and optimisation of sampling and data collection. The involvement of remote sensing satellites, development and deployment of autonomous vehicles and the use of low carbon footprint field facilities are important features of the proposed monitoring programme.

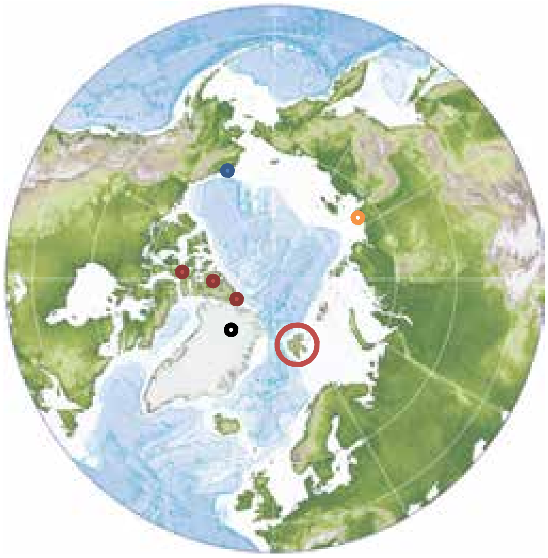
Much of the required infrastructure for a very capable Earth System monitoring programme is already in place but a world-leading Arctic monitoring capability could be facilitated by upgrading certain instrumentation and adding new research capabilities and these are identified here. The integration of SIOS science, closely coupled with the Operation Centre and the Knowledge Centre data portal will provide nations with greater access to both the full range of facilities on Svalbard and

much larger integrated data sets appertaining to globally significant research challenges that an individual nation could not easily address. Membership of SIOS should provide access to unique research opportunities, as well as substantial added value and leverage to national investments on and around Svalbard.

It is recognised that not all existing activities on Svalbard will be designated a role within the core monitoring programme that is outlined in this document. This does not mean that such research falls outside the remit of SIOS as the core observing activity will absolutely require complementary process oriented and experimental studies to explain the long term monitoring results. In some cases these additional research activities could feasibly develop into a relevant core activity for SIOS as the programme evolves over time but they will certainly be able to contribute understanding to the data emerging from core monitoring activities.

SIOS will actively support such studies through its infrastructure access scheme (a focus of WP 4 and to some extent WP 3), which will organise regular Calls each year for proposals to work either on or around Svalbard utilising the research facilities and opportunities of the archipelago.

Introduction



Long term environmental studies in the High Arctic have developed at a number of locations, notably Resolute, Eureka and Alert, in Arctic Canada (*red dot*); Barrow, Alaska (*blue dot*); and Summit, Greenland (*black dot*), as well as at some new locations, notably Tiksi, Siberia (*orange dot*), but Svalbard is also highly regarded internationally and, importantly, is the one truly international and scientifically diverse site, albeit there has been relatively limited interaction between nations to date. There is increasing awareness of the complexity of the Arctic system and its global teleconnections as an integral part of the Earth System. This and the geopolitical/economic elements of a changing Arctic have prompted several new Arctic research nations to establish in Svalbard. Earth System observations and, more recently, Earth System modelling are now a focus for much of the international observational research currently being developed pan-Arctic and Svalbard is well placed to contribute. Such studies are not readily achieved by any one nation and there is now recognition that international cooperation is essential to successfully address regional and global scale questions in the Arctic.

A major challenge for the FP7-funded SIOS-PP Infrastructures project is the establishment of the framework for an Earth Observing System for Svalbard, by late 2013. The backdrop for this EO system is the still poorly understood Arctic region itself, but also the rapid changes now being seen there and the linkages between the Arctic and lower latitudes, much of which can be seen in an Earth System context. The SIOS Vision document (Holmen and Ellis-Evans, 2012) presented to the SIOS Steering Committee meeting in Montreal in May 2012 specifically identified the need to "establish a regional observational system for long term acquisition and proliferation of fundamental knowledge on global environmental change (GEC) in an Earth System Science perspective in and around Svalbard".

The Vision document highlighted that, for mass exchange and transformation, most couplings between GEC entities (energy, various active species and environmental state variables) occur through the interfaces between the various Earth spheres (ocean, atmosphere, land, and biosphere). These entities can be active over various time scales and SIOS will prioritise measuring representative variables whose couplings with other entities are hypothesized as being significantly active in Svalbard over decadal and shorter time scales. It is recognised that not all of these identified measurements are easily made so SIOS will necessarily need to address and develop methodologies appropriate to the polar environment for quantifying boundary fluxes of the observed entities. As the most accessible High Arctic location Svalbard could provide a major focus for development and testing of polar-capable methodologies, sensors and equipment.

Both the extensive SIOS Gap Analysis study undertaken early in the SIOS Preparatory Phase and the synthesis report that was subsequently prepared to bring together the outcomes of the various working groups, illustrate the enormous breadth and diversity of observational studies currently undertaken by various nations on Svalbard. The report identified eleven key topics (or areas) and recognised a further cross-cutting monitoring topic of meteorology and hydrology. For each of these topics, the gap analysis groups identified science opportunities and lists of new and upgraded infrastructure requirements to tackle these opportunities were prepared.

Whilst these group activities assembled much useful information and guidance there were shortcomings in both the gap analysis and synthesis reports. Notably it was unclear what the core Earth System questions should be or how the science outlined under each key topic would interact with that of other topics. The substantial lists of proposed new or upgraded infrastructure under each topic were not prioritised either within each particular key topic or across the topics. Whilst some remote sites have been established on the north and east coasts, most of the existing land-based study sites, notably glaciers and permafrost sites, have been historically located in convenient proximity to research stations on the west coast and it was not clear if these were therefore scientifically the most relevant locations for Earth System studies. The listings of existing infrastructure also illustrated a known shortcoming - the lack of integration between national programmes in instrument deployment for certain research areas. This is further manifested in the limited degree of basic data sharing between nations and the recognition that a fundamental ambition of SIOS should certainly be the far greater integration of instrumentation and data throughout the archipelago.

A group of largely independent experts, in part drawn from the SIOS Advisory Panel, was assembled to consider the infrastructure listings and the Key Topic science proposals in the context of the SIOS Vision and Infrastructure Prioritisation documents, to reassess the proposed science outlined in the Gap Analysis and, where necessary, suggest alternatives that more closely aligned with Earth System Science. The group comprised:

Cynan Ellis-Evans (chair) and Kim Holmen (SIOS Steering Committee representatives)
Mark Drinkwater (SIOS Science Advisory Committee) – cryosphere/remote sensing
Martin Heimann (MPI Jena) - biogeochemical cycling, Earth System Modelling
Bob Dickson – (SIOS Science Advisory Committee) - Arctic Ocean Observing System

Finlo Cottier (SAMS) – fjord/shelf oceanography
Silkie Kroeger (CEFAS) – marine chemistry and bio-sensors
Terry Callaghan (SIOS Science Advisory Committee) – terrestrial studies
Alan Rodger (BAS and SIOS Policy Board) - space and upper atmosphere physics

Bob Dickson provided valuable written input for the meeting but had to withdraw late on so Finlo Cottier provided a very competent replacement.

Relevant Features of Svalbard for ESS Research

The workshop recognised that Svalbard has several valuable features:

- It is set in a High Arctic location remote from the major northern land masses where the other major Arctic monitoring sites are all located.
- It is well placed to observe polar atmospheric circulation and atmospheric chemistry, including long distance pollutant transport and has infrastructure to study both the upper and lower atmospheric layers
- It is located close to the major marine inflows and outflows for the Arctic Ocean in an area where important boundary fluxes (between atmosphere, ocean and sea-ice) are occurring.
- It is flanked by both deep water (west) and shallow shelf sea environments (east) and exhibits significant East-West and North-South environmental gradients, where cryosphere/atmosphere/ocean interact.
- There is already a substantial, research infrastructure established on broadly national lines on Svalbard (Ny Alesund international science village, UNIS and Longyearbyen, Hornsund and Barentsburg , as well as some facilities at the coal mine sites of Svea and Pyramiden).
- From a practical viewpoint
    - researchers on Svalbard are able to "see" all the polar orbiting satellites observing the Arctic region and it follows that the satellites also see Svalbard on more less all orbits
    - there is a sophisticated infrastructure to utilise this capability and undertake other science activities, including a substantial fibre-optic data communications capability, which benefits both the main settlement, Longyearbyen, and, from 2014, also the research village at Ny Alesund.
    - There are airfields and port capabilities to support various polar research vessels at both locations and further port facilities at the Russian settlement of Barentsburg.

All twelve key topics emerging from the synthesis report were discussed over the course of the meeting and the following general points emerged from the discussions:

- Integrated Earth System Science (ESS) relevant monitoring studies should be the core activity of SIOS, with a focus on regionally relevant variables that exhibit change and facilitate change over timescales of years to decades.
- This focus for SIOS on ESS related monitoring should not prevent other research being undertaken on Svalbard and interlinking with SIOS monitoring activities. Indeed such research would be essential in interpreting the core monitoring data and should be supported within SIOS, particularly through its infrastructure access mechanism.

- The twelve key topics were a source of valuable information but were not regarded as the most appropriate means in themselves to structure an integrated SIOS programme.
- It was particularly striking how uniquely well placed researchers on Svalbard were to undertake integrated research at high latitudes focussed on both vertical and horizontal coupling of Earth System variables and that this capability should be at the heart of the monitoring objectives.
- Most of the research on Svalbard was still run with a national focus. Whilst a case could be made for a broad programme of polar science continuing to be driven simply by national priorities it was agreed that ESS research was more effectively addressed through greater international cooperation and integration.
- Temporal and spatial scale issues were not addressed by the earlier reports and would need to be resolved within the monitoring protocols to ensure effective comparison across data sets. It was not feasible to go into that level of detail across the entire infrastructure at this point but generic scaling considerations were possible.
- The problem of effectively quantifying snow and its distribution in the Arctic was recognised as a major shortcoming of current monitoring across the Arctic that could be particularly usefully addressed in a SIOS monitoring programme. Effective monitoring of snow was one obvious target for technological developments.
- There was a strong case made for the use of distributed observatories to complement and extend the work currently focussed at Zepplin, Longyearbyen, Hornsund and Barentsburg. Where possible these remote observatories would be mobile, use green energy options, have a small footprint and include satellite communications to reduce service trips.
- It was accepted that work in the eastern part of the archipelago was necessary, despite its protected environment status and that this should be seen as an opportunity to develop new technical capabilities for working with minimal environmental impact.
- Each of the key topics in the synthesis report identified different east coast research locations and there was limited integration. The workshop participants proposed that if possible the number of sites be more restricted and utilised by a number of research topics to facilitate more effective cross linking of data sets.
- It was recognised that remote satellite sensing could play a very important role in SIOS monitoring activities and the SIOS work package (WP7) on remote sensing should be closely linked with the proposed core monitoring programme development.
- There was broad support for increased use of autonomous vehicles (UAV, AUV) both to reduce current reliance on expensive ships and manned aircraft and increase the temporal and spatial coverage for monitoring of the environment in and around Svalbard.
- It was recognised that other infrastructure programmes, such as ICOS (integrated Carbon Observing System) are also planning long term activities in the Svalbard region and that SIOS should ensure linkages with these programmes as they develop to optimise infrastructure development and core ESS measurements in the region.

Identifying ESS issues relevant for Svalbard

All the components of the Arctic System must be observed across time and space to understand the scope and evolution of change. Understanding how the system functions and projecting future changes requires models using data that flow from an Arctic Observing System and in the case of the

Svalbard region, primarily through the core ESS measurements within SIOS. Moving beyond description to understanding change in the past, present and future will require further research including extensive palaeo investigations, process studies and Arctic System Modelling. The data portal of a SIOS Knowledge Centre will play an important role in facilitating this modelling.

Svalbard does not represent the whole Arctic but it does constitute a very important area of the Arctic and provides particular opportunities to tackle major questions not easily addressed elsewhere. In particular Svalbard offers unique opportunities to holistically address vertical and horizontal coupling of Earth System relevant entities in and around the archipelago. As a starting point for ESS studies it is proposed that this and the various Earth spheres (atmosphere, hydrosphere, cryosphere, pedosphere) provide an underlying focus for organising SIOS core monitoring measurements and complementary shorter term research.

Atmosphere

There is a vertical layering of Arctic (and global) atmospheric processes which needs to be considered as these layers can contribute to the dynamic patterns and variability seen at the Earth's surface. In most Earth System studies to date the main focus has been the troposphere, where most of the weather systems are manifested. However, from numerical modeling of weather and the latest large scale prediction models it has become clear that larger parts of the atmosphere have to be considered to obtain the most reliable predictions. Meteorological models, such as the new Earth System Model developed at the Max-Planck Institute for Meteorology (MPI-ESM), for example, includes the atmosphere from ground to 120 km, and they have achieved a much better representation of the middle atmosphere than previous. However, this type of model will need comparisons with actual measurements in the whole height range to facilite its improvement and verification. The need for *in situ* small scale 3D measurements of waves, structures and turbulence in the altitude range 40-120 km by a structured programme of sounding rockets is likely to be essential to make progress on understanding the vertical transport of energy and mass flow dynamics, including the role of meteor components. Atmospheric physics is a mature field, and the missing links in revealing coupling and feedback mechanisms between the spheres are now considered to be hidden in the chemistry and micro-scale physics.

The vertical coupling between the troposphere and the overlying stratosphere is very important, particularly in relation to interactions of Arctic surface climate and stratospheric ozone which can propagate effects downwards over timescales of weeks and varies substantially on interannual scales. Stratospheric noctilucent clouds are also relevant subjects for monitoring as they are becoming more common with atmospheric cooling and could have an important role in radiative forcing. Recent studies indicate that their formation is linked with meteoric smoke from the upper atmospheric layers.

Noctilucent Clouds – G Paulsen, NASA

Whilst there has been increasing awareness of the need for tropospheric studies to also recognise stratospheric connections there are still very few studies of vertical coupling through the entire atmosphere. The middle and upper atmospheric layers are also part of the Earth System, are relevant elements of Sun-Earth connections and will certainly be interacting with the lower atmosphere so we should be considering the whole atmosphere when studying ESS and this may require a combination of approaches that Svalbard science can facilitate.

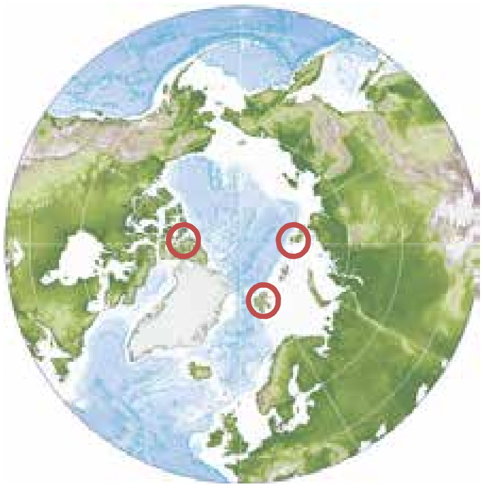
The presence of noctilucent clouds (NLC) and polar mesospheric summer echoes (PMSE) at around 80 kilometers indicate significant gravity wave activity that may influence several of the important vertical atmosphere fluxes. New instrumentation has recently shown similar weak radar reflections in the 50-70 km region but ground-based monitoring of these regions is difficult and the deployment of sounding rockets (already feasible on Svalbard) are likely to be required to provide the necessary detailed information. Regions higher in the atmosphere can be investigated by ground based and satellite remote but would also benefit from the use of sounding rockets for essential detailed process measurements as well as other supporting information. There is therefore a case for a full understanding of the physics, chemistry and dynamics of the whole atmosphere being best achieved with the complementary use of rockets alongside ground-based and remote sensing instrumentation. However whilst the spatial resolution of sounding rockets is unsurpassed, the costs are far too large to allow for high temporal repetition. Rockets should only therefore be used where the added value justify the costs, either directly scientifically or as a required complement to the much higher temporal resolution of ground based instrumentation.

Geomagnetically Svalbard is at a latitude where much solar wind energy enters the Earth's environment and is transmitted to and then dissipated in the upper atmosphere (60-500 km altitude). It also has extended intervals of darkness allowing long periods of observation by low light instruments and it is often is located within the polar vortex, and hence sees significant downward transport of chemically active species in winter (e.g. NO_x) that cause further changes e.g. loss of ozone and impact on the dynamics and structure of the middle and lower atmosphere. Svalbard is also remarkably well placed technically as it experiences very low light pollution and atmospheric pollution so is good for optical viewing and is a substantial distance from significant man-made electrical noise sources so is excellent for very sensitive radio receivers.

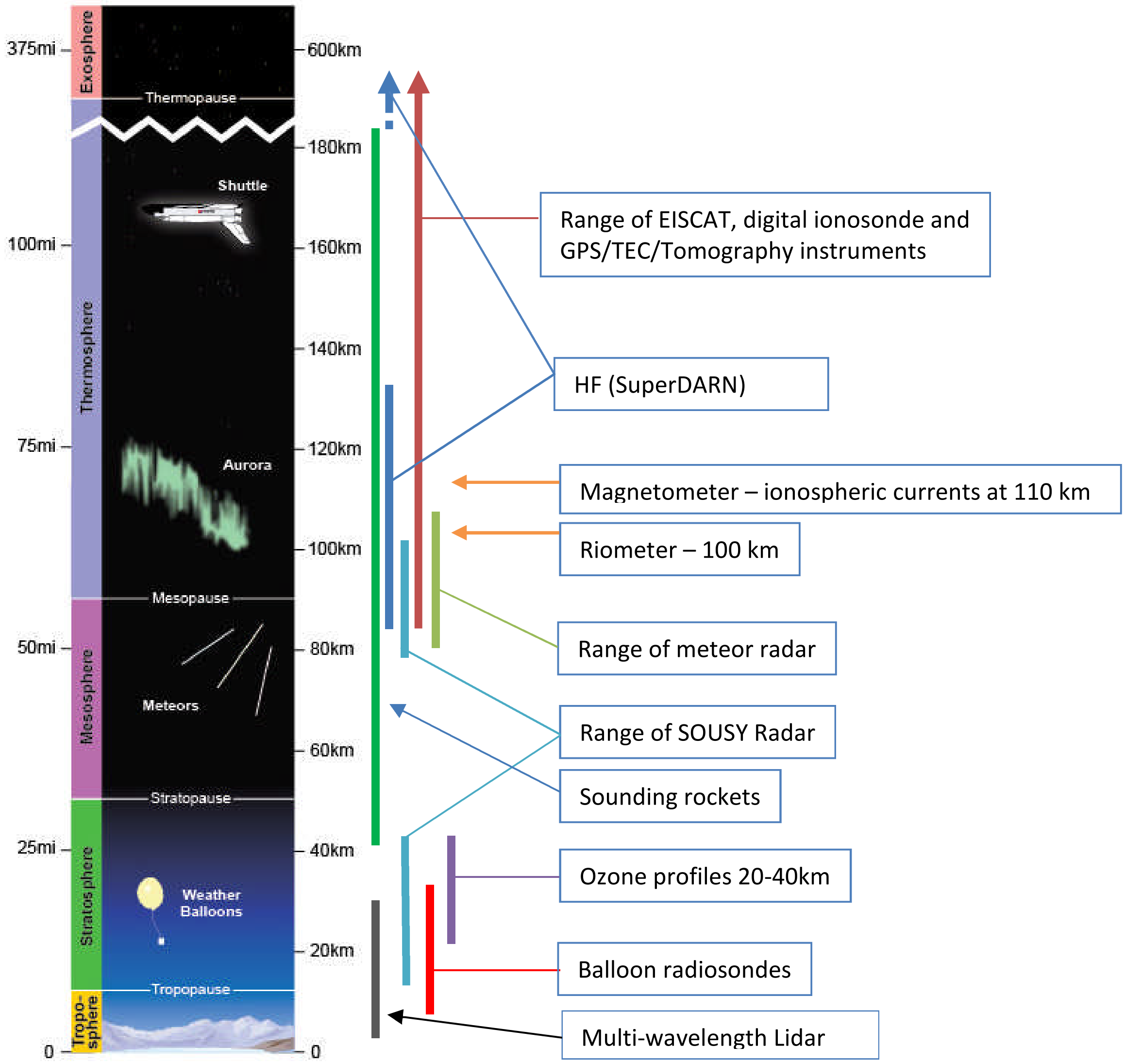
Greenhouse gases cause warming of the troposphere but cooling of the stratosphere and mesosphere because these gases reflect part of the solar short wave radiation absorbed by the middle atmosphere back into space. As a result the middle atmosphere is shrinking and the dynamics/aeronomy of the entire atmospheric column is being affected. Vertical coupling processes in the troposphere-stratosphere-mesosphere system are likely to undergo secular change and climate changes are already being observed in the ionosphere. It is unclear if the effects have anthropogenic, geomagnetic or solar origins so detailed long term measurements are required and the infrastructure on Svalbard can address this significant Earth System scale challenge.

Further relevant atmospheric coupling questions include the role of gravity waves in driving the upper atmosphere and how vertical gravity waves and horizontal planetary waves interact and relate to climate issues on the planet. These questions provide an example of the significant scale issues associated with Earth System studies as whilst gravity waves can be studied at different heights in the atmosphere by distributed ground observatories located at intervals of 100 or 300 km across Svalbard, planetary waves moving horizontally would require stations thousands of kilometres apart – essentially a pan-Arctic scale collaboration between different monitoring stations.

With Svalbard being located at such high latitudes there are limited available sites for other stations. However relevant planetary wave studies at sites around 80˚N latitude to link with those on Svalbard could be established (see right) at the Eureka atmospheric research station in the Canadian Arctic (Ellesmere Island) whilst a station located somewhere in the Severnaya Zemlya archipelago in the Kara Sea region could offer opportunities for Russian involvement.



The diagram below does not include all instrumentation available (particularly at Ny Alesund) for tropospheric studies but it does illustrate the capability of Svalbard infrastructure to study all the various atmospheric layers in significant temporal and spatial detail and this can be complemented in some cases by satellite remote sensing over larger spatial scales, albeit at lower resolution.



Instrumental capabilities on Svalbard for lower, middle and upper atmosphere monitoring

The presence on Svalbard of the Svalsat Satellite Ground Station (see below) offers a unique capability for accessing the full range of polar orbiting satellites and its redundant fibre-optic cable link to mainland Norway provides a powerful communication facility for Svalbard researchers to access other remote sensing resources. The installation in 2014 of a fibre optic communication link between Longyearbyen and Ny Alesund will extend the computing capabilities on the archipelago to its most significant and diverse research hot spot. This will dramatically enhance links to the SIOS Data Portal in Longyearben, provide opportunities to run sophisticated modeling programmes from within Ny Alesund and support the German led proposal for a fibre optic cable network extending from Kongsfjord to the Hausgarten undersea observatory and the MASOX methane venting observatory in Fram Strait.

Svalsat Ground Station, Svalbard

A major requirement for vertical coupling studies is that of all the different research groups putting their sampling strategies and data together to produce an integrated data set. This can be achieved in large part through the Knowledge Centre and the SIOS Science Advisory Committee. There is an opportunity to get far better spatial resolution than at present and this can be achieved by networking existing and new sites across Svalbard in appropriate spatial configurations. The passive instruments in particular, such as optical instruments, really benefit from networking. The EISCAT radars on Svalbard are very powerful facilities and are routinely used in campaign mode but have been used in continuous use during the recent International Polar Year. Other atmospheric observing instruments benefit if used in conjunction with these radars.

Focussing in more on the lower atmosphere it is widely acknowledged that global climate change is substantially anthropogenically driven but it is far from clear how much the remarkable changes observed in the Arctic are driven primarily by external processes (including Sun-Earth connections) or due to internal Arctic System processes, such as local and regional feedbacks (ACIA, 2004). This is a fundamental question to which SIOS can contribute. The external processes include emissions into the global atmosphere of increased amounts of greenhouse gases and changes in aerosols that are then transported horizontally to the Arctic through the lower atmosphere. These include short-lived climate forcers such as methane, and aerosols, particularly black carbon (soot) with its potentially more direct albedo impact in the Arctic. There are of course also many pollutants transferred in similar fashion to the High Arctic and this transport is already being monitored at Svalbard and could now be updated to a more coordinated study.

Water vapour is a major greenhouse gas and changes in the moisture content of the global atmosphere modifies Arctic climate through transport of water vapour into the Arctic from mid-latitudes, causing changes in cloudiness and thus the radiation balance. Atmospheric circulation exhibits natural modes of variability (the North Atlantic and Arctic Oscillations; the Pacific Decadal Oscillation and the recently identified Arctic Rapid Change Pattern), and these have significant roles in the meridional fluxes of heat and moisture into the Arctic, thereby altering temperatures over timescales of days to decades. The effects of these modes often swamp the direct radiative effect of slowly increasing greenhouse gas forcing and can represent a very substantial internal variability which needs to be monitored. Isotopic composition of water vapor and precipitation provides a "tag" for the processes controlling (Arctic) hydrologic balance.

At the bottom of the vertical atmospheric column the Arctic Planetary Boundary Layer (APBL) and boundary layer clouds interact with the Earth's surface which is a key interface area, particularly in relation to radiation. There are important transfers through APBL from the sea or land surface of heat, moisture and momentum which are key elements in Arctic system models of climate. The APBL is also closely associated with long range pollutant transfer. Arctic clouds are critical in influencing energy exchange between ocean and cryosphere surfaces but there is little in the way of detailed observational data, particularly in winter, and this is severely constraining climate models so SIOS could play a valuable role in facilitating year-round measurements that meet international monitoring standards.

The role of snow in the interactions between atmosphere, land and ice is another key question in understanding Arctic variability but snow is particularly difficult to quantify and monitor over time and so again the models are currently not portraying snow effectively. Part of the problem is the technical challenge of assessing snow depth distribution on appropriate horizontal scales to fit into current models as isolated point measurements add little value in themselves. There is a need to also understand snow structure and composition, so new technical approaches, new technologies and more extensive networks of measurements are required to gain better understanding of this critical variable and its relevance to other variables. Snow has to be an important component in the suite of Earth System observations made within SIOS

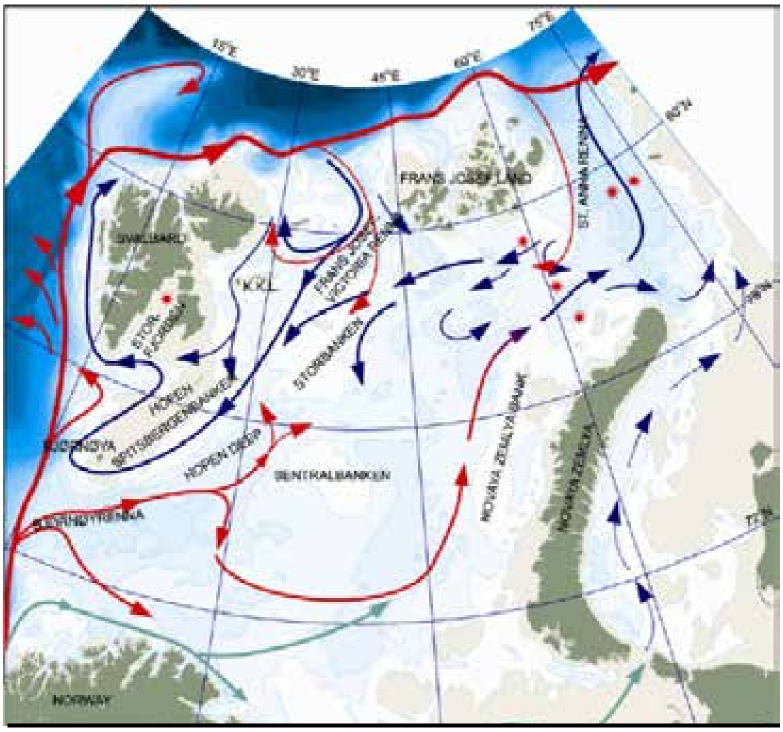
Aerosols are key components of the APBL and are related to cloud properties and radiation balance and influence climate directly through changing albedo. They include natural aerosols of marine origin and anthropogenically derived particles such as black carbon. Determining the distribution of aerosols within the atmospheric column is essential to evaluate radiative forcing and build effective models. SIOS can undertake vertical profile studies of aerosols, monitor change as aerosols move across the archipelago and provide a point along the timeline of aerosol (and pollutant) transport across the Arctic, linking with other monitoring sites.

Svalbard has extensive infrastructure in place (see above) to undertake long term measurements in the upper, middle and lower atmosphere and can address both vertical coupling of atmospheric layers and horizontal transport through the atmosphere between the Arctic and lower latitudes. Eureka Station on Ellesmere Island was one genuinely high latitude location that could match the capabilities of Svalbard in various areas but that has recently reduced to campaign mode activities whereas Svalbard can address full time monitoring of many parameters. It is therefore proposed that a major component of SIOS core measurements should be observations of atmospheric coupling through the entire atmospheric column and the relevant links to ocean/land surfaces. The existing infrastructure on Svalbard is fairly comprehensive but there are a number of research areas where its capabilities could be upgraded to more modern instruments. Equally, certain sites, such as Hornsund, which could be a valuable location in a network but is currently poorly equipped with optical instruments for upper atmosphere studies could be upgraded. There are also issues with the current distribution of major study sites on the west coast as they do not constitute a full 360˚view and this would need to be addressed to provide a world leading capability. The solution is to have one or more sites in a network located on the eastern side of Svalbard.

Ocean and Sea-ice

As with the atmosphere, the ocean has substantial horizontal transport components as well as a vertical component that can couple surface waters with ocean depths and the lower atmosphere. There is an interaction across the all-important surface interface with the atmosphere which is seasonally and interannually modified by the presence/absence of sea-ice. These are fluxes of ESS relevance but the scale of the components varies substantially and needs care in establishing monitoring across different parameters that can all ultimately feed into both regional and Arctic System scale models.

The substantial variations in the oceanic transport of heat into the Arctic, through North Atlantic pathways and the Bering Strait, are likely significant players in Arctic change. Svalbard is located (see diagram below) close to a major oceanic gateway to and from the Arctic, where warm, saline Atlantic water passes through the Nordic Seas and is advected through both the Fram Strait (along



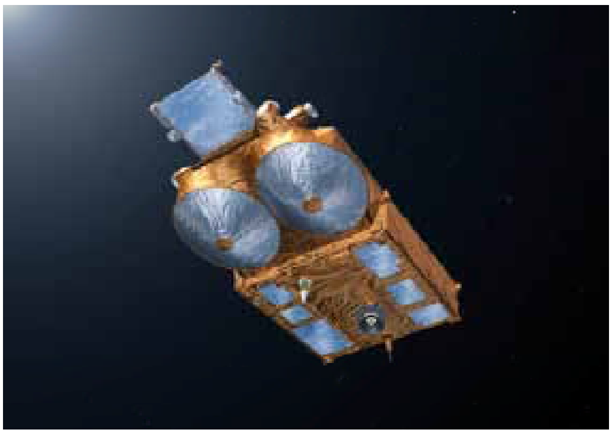
Pathways of Atlantic Water into the Arctic
Atlantic Water (red), Arctic Water (blue) Coastal Water (green)

the west coast of Spitsbergen) and the Barents Sea. There has already been a significant amount of marine infrastructure put in place to study the two branches and their spatial complexity, as well as temporal variability, particularly in the waters around Svalbard itself. However there needs to be a more detailed and coordinated monitoring programme to capture this complexity and variability and also understand the role of boundaries, shelves, continental slopes and bathymetric features.

Recent work has raised the question as to the relative importance of the two main Atlantic inflow branches—the Fram Strait Branch (West Spitsbergen Current) and the Barents Sea Branch - in carrying ocean climate 'signals' horizontally from the Nordic Seas into, around and through the Arctic deep basins. This transport of water around the Arctic Ocean can take decades. Much of the ocean ventilation occurs in the Barents Sea and is tied in with dense (saline) water formation, particularly in the region of Novaya Zemlya and Storfjorden in Svalbard. It has been proposed that the colder, fresher Barents Sea inflow branch may be the branch that dominates the Arctic Ocean beyond the Nansen Basin, with the warmer saltier Fram Strait branch, notably the Yermak sub-branch which flows along the north coast of the archipelago, seldom penetrating beyond the Lomonosov Ridge.

Norwegian and US scientists deployed a mooring array across the Yermak branch in 2012 at around 30°E where the Atlantic Water boundary current flows along well-behaved bathymetry and is free of the re-circulations seen in the Fram Strait and further east between Kvitoya and Frans Josef Land . The moorings are located at 10-15km separations to pick up the variability in salinity across the current. Comparing its seasonal and annual variability and comparing it to Barents Sea branch measurements would allow the relative importance of the two branches to be assessed. SIOS could take over and maintain these moorings and so contribute to Arctic System science as well as monitoring the transfer of heat around the boundary of the Svalbard shelf. This mooring could also be used to monitor other elements of horizontal transport, both chemical and biological.

Both atmospheric and oceanic processes in the Arctic are influenced by changes in sea-ice cover and studying the seasonal and inter-annual variability of Arctic sea-ice is a major focus at this time with such substantial changes in sea-ice extent, thickness and composition occurring in recent years. There is growing evidence that the Arctic heat budget is changing rapidly as a result of increased summer open water and that it is causing major changes in weather patterns.



Cryosat II - ESA

Whilst satellite remote sensing, particularly now from Cryosat II, provides large scale information on sea-ice change there is still a requirement for ground-based studies to provide more detail on variability, to evaluate for example the role of snow cover on sea-ice and the role of sea-ice, as a barrier/interface for ocean and atmosphere linkages, particularly in the poorly studied Marginal Ice Zone (MIZ) which is growing in significance as a location for exchange.

It is inappropriate to treat either the heating of the ocean by the atmosphere or the autumn release of heat to the atmosphere as forcing elements in isolation; the upper ocean/sea ice/atmosphere must be considered as a continuum. Current atmospheric measurements over the Arctic Ocean are insufficient to pin down the energy fluxes either in the atmosphere or between the atmosphere and the ocean or to determine how these fluxes might vary due to vertical stratification, changes in water vapour and clouds, or aerosol concentrations. The measurements are particularly poor for the lower troposphere so there is little to no information on the lower troposphere vertical structure, clouds and their properties (which in the Arctic to a large extent are lower troposphere features) or surface energy fluxes. Long-term observations of the surface energy balance components over the Arctic Ocean are essentially non-existent. To keep track of this whole cycle of heat input, storage and delayed release that will determine ocean-atmosphere heat exchange as the sea-ice dwindles away needs ice based and ocean platforms. SIOS could contribute to this using existing and developing technologies such as the ice tethered profiler being deployed by iAOOS France which can profile the lower atmosphere, sea-ice and upper ocean. It currently does not monitor all the required variables in the atmosphere as certain sensors still need significant power but SIOS could assist in further development and particularly testing.

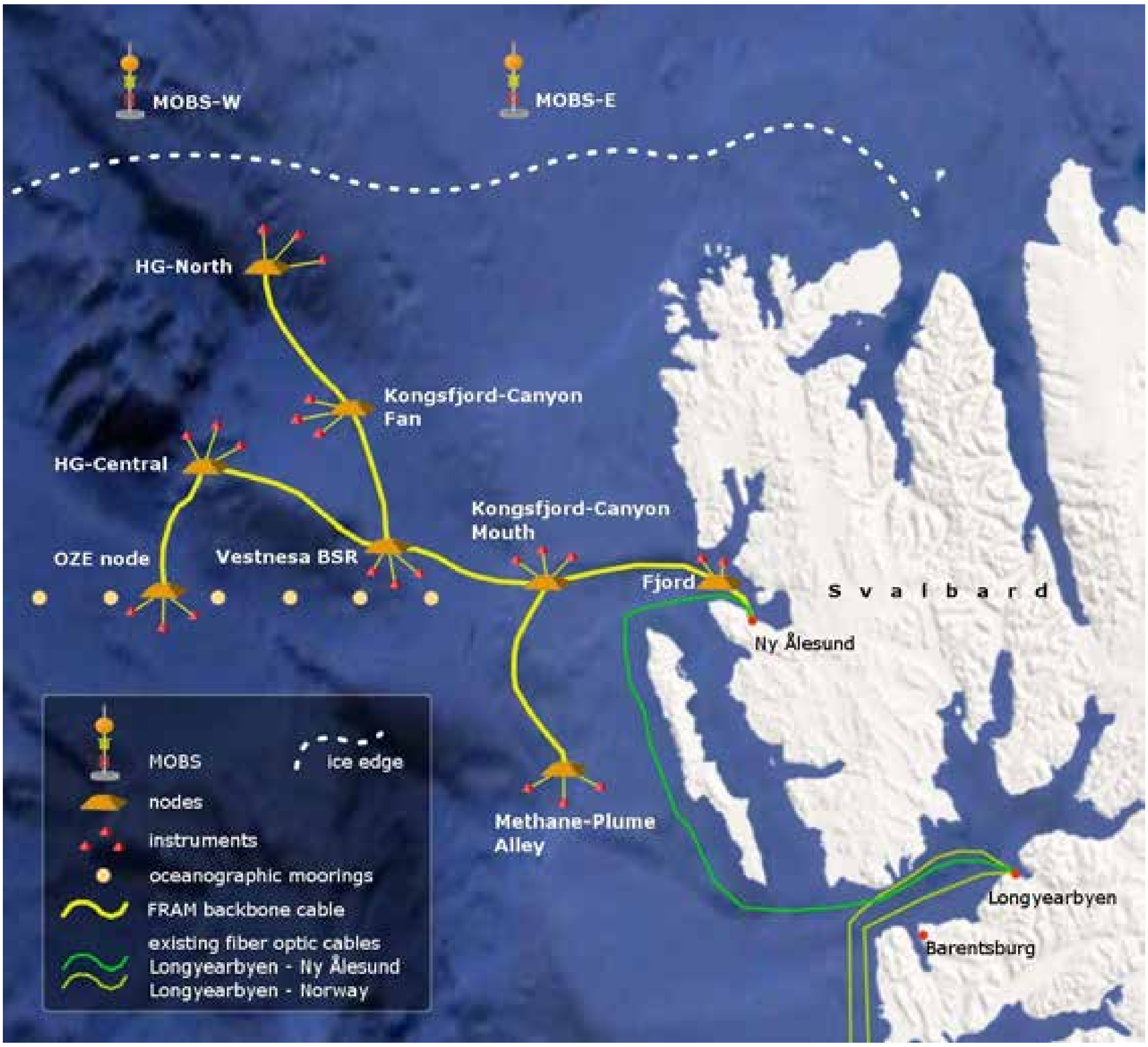
The changing dominance of sea ice in the Eastern Svalbard region (Barents Sea) is an important issue for a variety of oceanographic parameters and is currently not studied in the necessary detail. Shelf-basin interaction is a means of transporting dense waters formed in polynyas deeper into the Arctic and both maintain the halocline and ventilate the deeper ocean layers. Coastal polynyas are a widespread phenomenon throughout Arctic shelf seas such as the Barents and Storfjorden on the eastern side of Spitsbergen provides a convenient model system to monitor temporal variability in a changing shelf sea setting. The brine enriched water from this persistent wind-driven polyna emerges as a cascade of dense water over the sill and is transported northwards into the Arctic Basin, linked with ocean ventilation and thermohaline circulation. Changes in the sea ice conditions in Storfjorden will affect its polynya dynamics and therefore the underlying larger scale physical oceanographic processes with which it is associated.

A key biological feature of sea-ice retreat is increased light penetration bringing more radiant energy to warm Arctic waters but also facilitating more primary production. This has already been manifested in shallow shelf seas such as the Barents Sea where increased light and longer growing seasons have seen massive blooms of coccolithophorids as well as other phytoplankton. These take up carbon dioxide and so contribute to carbon cycle fluxes but can also generate organic sulphur (DMS) aerosols that contribute to cloud formation which influence climate.

Svalbard is also located in the interface area between Atlantic and Arctic climate and biogeographic zones where both Atlantic and Arctic waters and species can co-occur. The northward currents are subject to highly variable meteorological forcing and so there are substantial interannual variations in ocean climate which are reflected in chemistry, physics and biology. The inflowing currents bring heat energy and observations suggest that the Arctic Ocean is in transition to a warmer state. This transition will be associated with high variability at not only annual but also decadal and multi-decadal scales due to large scale atmospheric weather patterns. Comparison of north-east coast (Ripfjorden) and west coast (Kongsfjorden) fjords offer excellent systems to compare genuine Arctic and mixed Atlantic/Arctic locations and ecosystems and monitor change over time.

There are links between the atmosphere and the pelagic and benthic environments of the Arctic Ocean and the fluxes between the two spheres are influenced by sea-ice. Of particular interest here is the carbon cycle in the Arctic as cold polar oceans can be a major carbon sink. The EU-funded infrastructure project ICOS (Integrated Carbon Observing System) is establishing one of its sites for multi-year monitoring of carbon cycling in the vicinity of Svalbard and this will be linked to the long term Hausgarten benthic observatory established by German researchers west of Svalbard. Changes in sea-ice extent, warming of the Arctic Ocean and ocean acidification will all change the balance of carbon fluxes and impact on Arctic organisms (e.g. the coccolithophorids currently benefitting substantially from reduced sea-ice will be highly susceptible to future acidification) so long term monitoring will be needed and both Hausgarten/ FRAM array and the developing ICOS initiatives will be key elements to integrate within SIOS.

Ocean currents also bring nutrients, pollutants and "alien" Atlantic organisms which may penetrate further into the Arctic as its waters warm. There is currently only limited monitoring of nutrients, pollutants and biota by marine platforms (mainly ships) as these pass through the Svalbard region. There are proposals for enhancing studies of these variables within SIOS but this could also offer an opportunity for deployment of suitably "ruggedized" bio-sensors, which are currently being developed, on the moorings and tethered profilers to monitor biologically relevant variables more effectively and, with molecular tools, actually monitor individual types of organisms and their transport through the system. The use of acoustic monitoring to study larger marine organisms could also be undertaken from oceanographic moorings (or autonomous vehicles). This would provide detailed long term information on ecosystems and biogeochemistry alongside the existing physical/chemical measurements network.



Proposed FRAM Array Cabled Network for Svalbard (HG = Hausgarten)

There is already a long established benthic observation platform at Hausgarten that has been operating for a decade in conjunction with the annually occupied oceanographic stations and moorings mentioned earlier. There are also new proposals (the FRAM Array) to substantially extend the benthic (and pelagic) observing capability, link it to the methane venting site on the Svalbard shelf (currently the focus, through the MASOX demonstration project, of an international marine observatory organised by the EU funded EMSO/ESONet initiatives) and to existing and planned Fram Strait/ Kongsfjorden oceanographic and biogeochemical moorings as illustrated above. This is decribed in greater detail in Work Package 5, Deliverable D5.2. but the science opportunities is outlined in brief here.

Fram Strait Cabled Marine and Seafloor Observatory Network (FRA Array)

Sites	**Science Opportunities**
Kongsfjord	Fresh water outflows, warm Atlantic water inflow, physical oceanography, effects of freshwater vs. marine waters on marine ecology, climate impacts
K-Canyon Mouth	Land-Ocean interactions, Atlantic water influences, marine ecology, marine mammals, physical oceanography
K-Canyon Fan	Sediment transport, cascade effects, deep water renewal, slope stability
Methane Plume Alley	Quantification of gas seepage, diurnal/temporal seepage variability, gas hydrate stability in warming waters, seafloor fluids, seep fauna, water column properties, ocean-climate dynamics
Vestnessa BSR	Plate tectonics, gas hydrates, micro-seismicity, sediment transport, seafloor fluids, seep fauna and microbes
Hausgarten Central	Deep sea ecosystems, polar deep sea microbes, particle flux in high Arctic ice free conditions, ocean-climate dynamics, sediment biogeochemistry
Hausgarten North	Particle flux in the marginal ice zone, ocean-climate dynamics, deep sea ecosystems, marine ecology
Oceanography Node	Integration and linkage of oceanographic mooring array, underwater technology test bed.

A key objective here is to network this entire infrastructure with a fibre-optic cable that comes ashore at Ny-Alesund. This FRAM array project, which would create the first high latitude cabled marine observatory in the world would significantly enhance the world class status of a Svalbard Integrated Observing System. Other infrastructure programmes (notably ICOS) as well as large biological research groups such as ARCTOS, already working around Svalbard, could work collaboratively with SIOS to develop biogeochemical and benthic monitoring of this key region of the Arctic Ocean. The FRAM array is primarily a German initiative for now but there is also a proposed Norwegian initiative in the Greenland/Norwegian Seas and it would clearly be advantageous for SIOS if both schemes cooperated to optimise the monitoring infrastructure in Fram Strait and shared the financial outlay, hopefully with several international partners.

Cryosphere, Pedosphere (and Geosphere) and Biosphere

The land mass of Svalbard is on a different scale to the atmosphere and ocean and is subject to the influence of both these spheres, but also impacts on them both to some degree and there can be substantive fluxes at the interfaces. The substantial Svalbard glaciers and ice caps are distributed along significant environmental gradients, east-west and north-south so the archipelago offers an excellent location to study the interaction of cryosphere, geosphere, pedosphere and terrestrial biosphere with atmosphere and ocean along a continuum of change.

To date much of the glaciological studies have been constrained to relatively small glaciers located conveniently close to the main research stations and similarly most hydrological and permafrost studies have been undertaken near to settlements. There needs to be an assessment made of their representativeness for Earth System studies rather than simply continuing with these established studies. There are a number of large tidewater glaciers on Svalbard that have direct linkages with the ocean, as well as very many surge glaciers and some sizeable ice caps, which would likely link more realistically to climate and be more relevant to system modelling. These also need to be assessed as potential locations for core monitoring.

There is currently a lack of information on the total mass of ice across the archipelago, the mass balance components of the large tidewater glaciers, surge glaciers and ice caps and of glacier mass loss through calving. Much of this can be undertaken by satellite remote sensing but ground-based studies provide valuable information at higher resolution for smaller spatial scales which could enhance modelling efforts. This particularly relates to issues such as energy balance and snow cover.

Existing NMA Geodetic Laboratory, Ny Alesund

A valuable feature of the Svalbard infrastructure which is of relevance to the above is the presence of the Geodetic Laboratory located outside Ny Alesund and operated by the Norwegian Mapping Authority. The facility includes VLBI (very-long-baseline interferometry} antenna, a super conducting gravimeter, a permanent GPS station and a tide gauge and will be upgraded with a new Observatory in 2017. The observatory provides a high latitude location for work on mapping reference frames, of broad relevance to much of Svalbard science, and contributes to global collaborations on monitoring the planet. In particular it supplies data that helps to monitor post-glacial rebound, changes in sea levels, currents and the Earth's mass balance.

There are a number of ground-based geodetic networks in polar regions, most notably the bipolar POLENET network (www.polenet.org), that developed in the IPY and is operating in Greenland and Antarctica. There are also facilities on Svalbard, notably the French DORIS station in Ny Alesund, permanent GPS on Bjornoya and Hopen, a GPS receiver at Hornsund and a tide gauge facility at Barentsberg . The NMA has suggested developing an expanded ground-based geodetic network on

Svalbard that could extend across the archipelago and map onto the SIOS observational network and this has been incorporated into the infrastructure plan.

As mentioned earlier, snow is vital component of Polar Regions but is arguably one of the most difficult parameters to measure reliably and representatively for incorporation in system. Svalbard could be a location to develop new and refine existing methodologies for realistic snow cover estimation. The deployment of sensor systems "tuned" to warm ice and snow on board UAV and manned aircraft could provide important data on the temporal and spatial variability of snow cover in relation to atmospheric processes. The same methodologies could also be deployed over sea-ice.

There are also opportunities for studying interfaces with different spheres. For example, increased seismic activity observed in recent years seems to coincide with retreat of glaciers and ice caps. The marine environment in front of tidewater glaciers are seasonally hotspots for marine biological activity. There is also hydrological connectivity with shelf seas and transport of sediment and freshwater into the near-shore environment and these interactions are all subject to climate changes over annual and decadal scales.

Much of the permafrost research on Svalbard has been undertaken in western Svalbard and close to major settlements and there should really be a site in north/east Svalbard to pick up the patterns of thermal seasonality within permafrost in a true High Arctic site. The scale of much of the current activities does not fit well with existing model scaling but the variety of landscape on Svalbard affords opportunities to develop tools such as inSAR (Interferometric Synthetic Aperture Radar) for more widespread use in characterising permafrost studies and scaling up from the site to landscape level. Successful deployment of inSAR in aircraft would ultimately broaden its spatial coverage to relevant ESS scales and provide valuable comparison to existing satellite-based SAR data which is by contrast much coarser.

In the terrestrial biosphere there is connectivity with permafrost, glacial hydrology, the atmosphere and the marine environment (nutrients from seabirds) but on Svalbard there is very limited impact at the scale of Earth System science as the vegetation is sparse and large scale carbon sequestration, typical of terrestrial areas such as Siberia, is relatively insignificant so GHG production/release to the atmosphere is not that notable, though clearly there are opportunities for process studies that could be linked to SIOS core monitoring variables. The biotic resource on Svalbard is its biodiversity and this is being subjected to significant environmental changes so this would need to be a priority for SIOS. As an archipelago Svalbard has biogeographical relevance and there is already a substantial inventory of its biodiversity, which should be updated and referenced against environmental change, colonisation of glacier forelands and the impacts of alien invasion by regular monitoring at representative sites across Svalbard. The monitoring of the many migratory birds, particularly in relation to timing of arrival and availability of food choices against weather patterns and snow distribution would contribute usefully to system modelling.

Legacy pollutants in the terrestrial sphere are generally lipid associated so there is little significant exposure (and bioaccumulation) for Svalbard terrestrial biota but various other emerging pollutants such as mercury, metals and radionuclides are not lipid associated and could accumulate in these biota. There are potential direct links with long range transported pollutants and atmospheric processes and Svalbard could provide a valuable remote reference site for monitoring change.

Earth System Science questions for SIOS to address

The gap analysis synthesis report and the ideas outlined above can be used to generate a number of Earth System Science scale questions that can then be applied using the framework of measurements relating to vertical coupling and horizontal transport and incorporating those relating to the terrestrial cryosphere, pedosphere and biosphere to form the basis for the core monitoring activities. The questions and/or the measurements will need to be assessed after an appropriate time to establish if they are appropriate and if not to modify them to optimise the monitoring programme.

Vertical Coupling

> *"What are the primary coupling processes that connect the troposphere, stratosphere, mesosphere and lower thermosphere and how is this coupling changing over seasonal and multi-year timescales?"*

> *"What controls changes in the vertical structure of the Arctic atmosphere and the ocean?"*

> *"How are changes in the extent of sea-ice cover in the Arctic impacting biogenic emissions from open water, notably in shelf seas, and what are the implications?"*

> *"Is there evidence of change in Arctic marine ecosystem structure through warming, breakdown in vertical mixing and reducing sea-ice extent and age structure?"*

Horizontal Transport

> *"What roles do oceanic exchanges of heat between the Arctic and lower latitudes play in Arctic-global climate linkages?"*

> *"What is the significance for Arctic climate of the substantial natural variability and feedbacks associated with high latitude winds and ocean currents?"*

> *"To what extent are emissions of short lived greenhouse gases and aerosols (e.g. methane and 'black carbon') outside the Arctic affecting Arctic change?"*

> *"How are the horizontal influxes of sensible heat, nutrients and particulate matter to the Greenland and Barents Seas altering over time and what are the regional consequences?"*

> *"How are the patterns and sources of long-range transported pollutants changing over time and how are these patterns manifested in Arctic ecosystems?"*

Svalbard land mass and biota interactions with changing climate

> *"What are the impacts of climate change on Arctic landscape and terrestrial ecosystems?"*

> *"What ecological changes are accelerating?"*

General ESS questions that the SIOS infrastructure can help address include:

> *"Why are many aspects of Arctic change amplified with respect to global conditions"*
>
> *"What are the most important feedback mechanisms for amplification and are they specific to the Arctic System?"*
>
> *"What is the relative importance of anthropogenic forcing for Arctic change, especially on the regional and local scales?*
>
> *"What is the status of the Arctic water cycle and how are the different components (transport from low latitudes, atmosphere/ocean/sea ice exchange, ice sheets, glaciers, ecosystem exchange) that are contributing to the budget changing?"*
>
> *"Will natural variability, particularly the interannual to multi-decadal modes of variability, be affected by anthropogenic forcing in the future?"*

All of these ESS questions can be addressed in and around Svalbard with the existing infrastructure so we can continue to obtain value from the current facilities and potentially use them more effectively. However for the goals of SIOS this infrastructure would benefit from some enhancements of existing facilities as well as provision of some completely new instrumentation. With a focus on integrating vertical and horizontal coupling observations and the establishment of a coordinated distributed network of sites to capture the necessary resolution SIOS could in time provide a detailed monitoring capability unique in the High Arctic.

Monitoring Locations in and around Svalbard

An observing programme involves a set of questions to address the objectives and appropriate methodologies and monitoring sites, within a coordination framework that provide the means to answer these questions. Sampling strategies are an issue as these will influence the quantities of data collected and the resource needed to operate infrastructure acquiring data but this cannot be easily addressed here and is possibly more relevant to WP 8) . There will inevitably also be logistical support required but that is addressed elsewhere in SIOS-PP (e.g. WP 5) and is therefore only flagged here but clearly there will need to be an interaction of science and logistics going forward.

Whilst the basic science infrastructure required is fortunately already largely in place on Svalbard there is a recognized need for upgrading and currently this does not work in an integrated manner. There is a need for nations to agree to work in partnership to put the various, currently independent sites together in a coordinated manner, to adopt similar observational protocols and to put their data into repositories where the separate datasets can be brought together for synthesis, analysis and modeling. This will make for more effective distribution of the costs of SIOS research and provides opportunities to access more effective integrated data sets.

Certain new infrastructure can be identified that would allow SIOS to develop an even more significant world-class observational system. It is recognized that some of this identified new infrastructure cannot realistically be in place at the launch of SIOS in 2013 and will in some cases be installed several years into the future. The SIOS infrastructure will evolve over time as new capabilities become available and new questions arise and this can be coordinated and managed by the SIOS organization.

Much of the monitoring infrastructure on Svalbard is associated with **Longyearbyen** and **Ny Alesund** and both sites have a significant breadth of instrumentation. **Hornsund** is also reasonably equipped in certain science areas and there is also monitoring equipment in **Barentsburg**. All of these sites are on the warmer western side of Svalbard and lie largely on a north-south line so they are not entirely representative of all areas of Svalbard but do have a useful degree of spatial separation (10's of kilometers) that can facilitate valid inter-comparisons for many relevant variables. Two more distant manned sites are located on **Hopen** and **Byornoya** (still within the Svalbard Treaty area) and a variety of unmanned, study sites (some automated), often with a specific instrumental focus, are distributed across the archipelago, as well as in fjords and in the open ocean. These are operated by various nations but not currently centrally coordinated.

Map of Svalbard Archipelago and past sea-ice distribution

Most of the upper atmosphere monitoring infrastructure is located near Longyearbyen and is in reasonable proximity to the Svalsat facility, which provides access to the fibre-optic communication cables linking to mainland Norway. It is most cost effective to maintain Longyearbyen as the central hub for atmospheric studies but there are certain upper atmosphere facilities at Ny Alesund and the research village will also have a fibre-optic communication capability by 2014.

It is not proposed to dramatically change the positioning of these particular facilities though some instruments (particularly with respect to certain atmospheric measurements) that are currently duplicated on several of the stations could arguably be used more effectively if they were redeployed to somewhere such as Hornsund (which, for example, lacks the optical instruments present at other stations) and so, at low cost, build it into a third major site for atmospheric studies. This spatially separated set of integrated instrumentation would substantially increase the value of the data obtained.

Hornsund, Longyearbyen and Barentsburg provide year round sites for atmospheric studies as well as seismic and meteorological measurements and biodiversity (marine and terrestrial) studies. The Hansbreen tidewater glacier near Hornsund has been a subject of study by Polish and other researchers for many years and would provide a west coast site for glaciological studies. Barentsburg and Longyearbyen also offer locations to monitor pollution, ecosystems and biodiversity and this could be repeated at Pyramiden which offers a more central location in the archipelago where human impact has again occurred and climate change is having an impact.

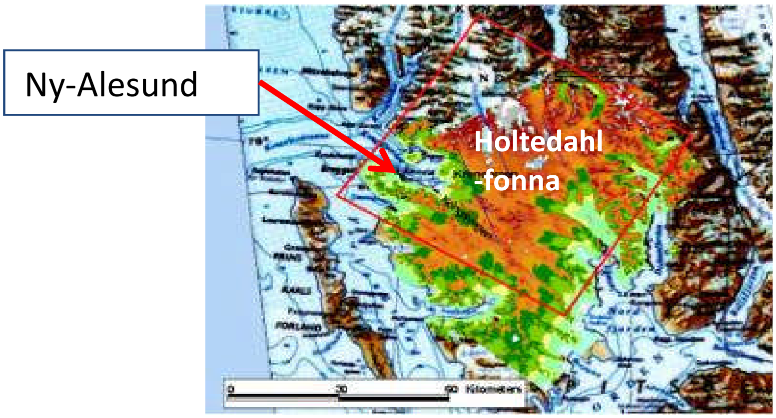
The **Zepplin Observatory** (475 m asl) above Ny Alesund has an internationally recognized status for polar atmospheric chemistry, an extensive range of instrumentation for lower atmosphere and long range pollutant transport studies and has the capability to be upgraded to a more modern instrumentation set. Measurements currently include stratospheric ozone, greenhouse gases, tropospheric ozone, persistent organic pollutants and various aerosols. There are further relevant instruments located closer to sea-level (notably at Sverdrup and AWIPEV stations) and on a 30m Climate Change Tower (Gruvebadet), operated by the Italian station, which together with Zepplin could form a "supersite" for lower/middle atmosphere studies.

Hopen meteorological station

Svalbard is generally a very mountainous location. Both Zepplin Station and the Ny Alesund sites below it are subject to some disruption by the substantial orographic obstacles and the atmosphere monitoring facilities at Hornsund are similarly compromised. The Zepplin site operating alone is also unable to capture the history of atmospheric components as they move horizontally across Svalbard.

This can be addressed by establishment of a remote station located at sea level without orographic obstructions. Kapp Linne was proposed in the Gap Analysis Synthesis Report as a coastal site and it has a certain convenience due to its relative proximity but it is also not without its short-comings so we suggest the use of the island of **Hopen** which has the necessary power, communications and a year-round manned meteorological programme in place to support an atmospheric chemistry facility. It is also located north of the Arctic Front and lies on the eastern side of the archipelago so provides a valuable eastern comparison site which could accommodate instrumentation to study the middle and lower atmosphere, long-distance pollutant transport, and seismicity for the SIOS monitoring infrastructure. The presence of technical personnel could also facilitate the deployment of a marine chemistry mooring/ buoy in the vicinity, serviced from Hopen.

Ny Alesund has extensive terrestrial monitoring sites in place for seismicity, permafrost, carbon fluxes, pollution monitoring and biodiversity monitoring. The site is also close to two large tidewater surge glaciers (**Kongsbreen, Kongsvegen**) associated with a sizeable ice cap, **Holtedahlfonna**. These three sites have all already been the subject of earlier glaciological/hydrological studies and, together with the very well-studied Hansbreen tidewater glacier near Hornsund, could provide primary and secondary west coast sites for SIOS glaciological monitoring and interactions with atmosphere, ocean and geosphere, with appropriately upgraded and extended monitoring facilities.



Kongsbreen/Kongsvegen study area

Turning to terrestrial research at Ny Alesund, there is a growing issue with the high levels of field research activity supported out of the research village which constitutes a substantial geographical area of human disturbance that could potentially compromise future terrestrial research. The immediate area of Ny Alesund is particularly heavily impacted and the transit routes to and from various popular study sites around Ny Alesund (e.g. Midre Lovenbreen glaciology and hydrology site) up to several kilometres away are also increasingly compromised. In the past, work on the south side of the Brogger Peninsula or the northeast side of the Kongsfjord, both of which have interesting science opportunities, were restricted by the difficulties of safe, reliable access.

With the availability of more capable boating support in recent times it would seem prudent to consider establishing new and uncompromised satellite study sites in these areas, more remote from Ny Alesund but easily accessed by boat travel to reduce footfall impacts on local hydrology and terrestrial biology. The provision of small research/accommodation huts would make for safe and comfortable locations for field work in these more pristine conditions and, with appropriate controls on numbers of users, would incur minimal human impact whilst maintaining the Ny Alesund as a "honeypot" for international research.

Ripfjorden is located on the northern side of Nordauslandet in eastern Svalbard an represents a true High Arctic site. It could be the primary land-based location for East Svalbard, being close to the large ice cap of Austfoss and to tidewater glaciers. It should at the minimum host an advanced meteorological station with a glaciological/meteorological station on the adjacent ice cap to provide further complementary data. The proposed site lies within a national park which places considerable constraints on access and stresses the need to minimise impact on the environment so any work there would need extensive permissions to establish infrastructure. However, this could be an opportunity for designing a field facility with a small environmental footprint and utilising green energy power that could provide a model for research elsewhere in polar regions.

With the appropriate framework in place the Ripfjorden site could in due course also potentially host instrumentation for upper and lower atmosphere monitoring, long range pollutant transport monitoring, seismicity monitoring, geodetic measurements. It could provide a valuable location for a deep permafrost borehole and certainly a glacial hydrology station linked to drainage from the icecap. These might not be of the same level of sophistication of other sites on the west coast but would transform the value of data collected on east Svalbard for Earth System studies.

Mooring in Ripfjorden

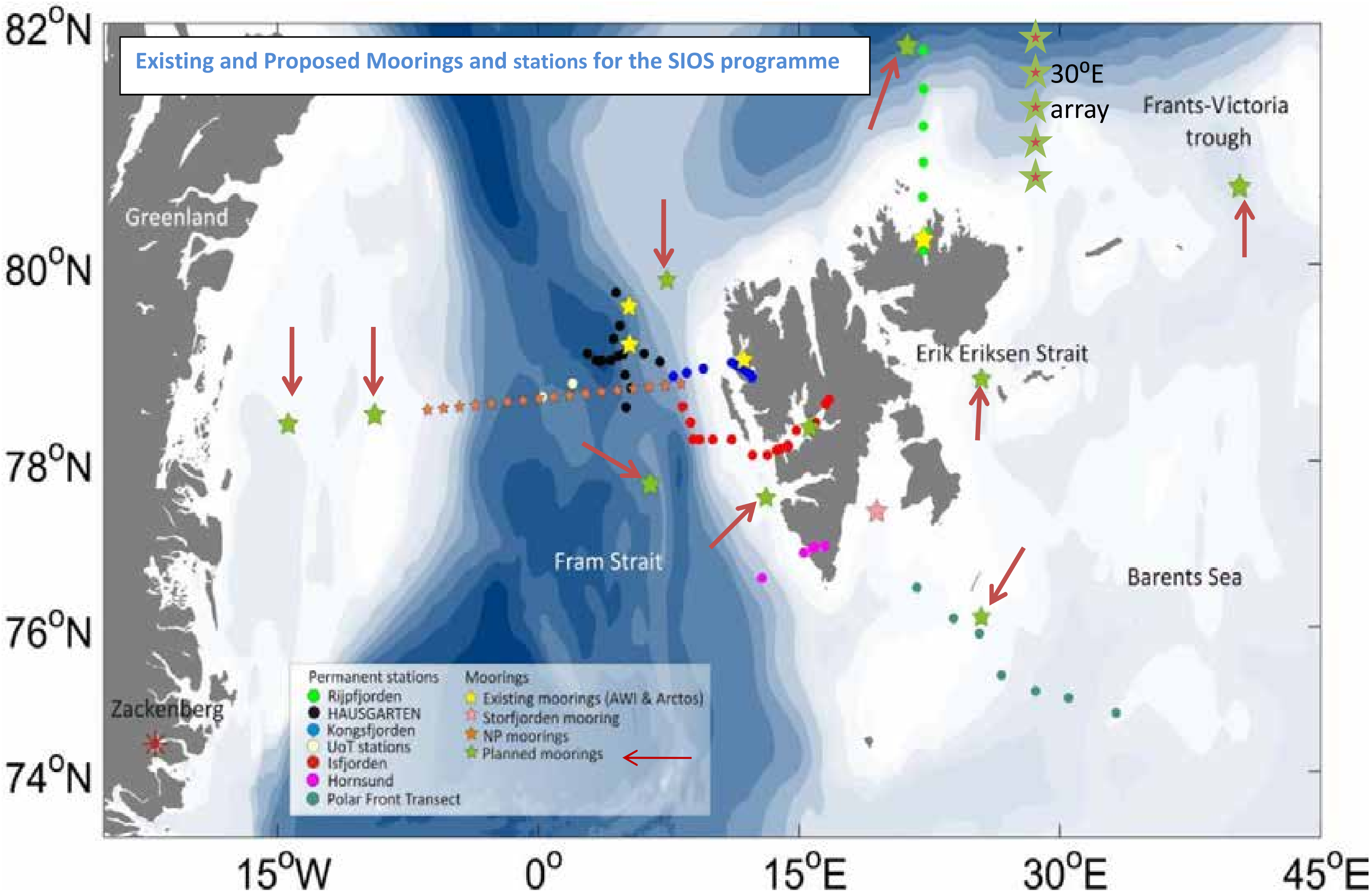
A north-eastern marine location is further proposed at **Ripfjorden** where there is already an established UK/Norwegian mooring to monitor oceanographic/biological parameters in the fjord and there is also an array of further marine stations extending northwards from the fjord., faces north and is much more representative of High Arctic conditions than west coast sites, with little evidence of any influence of advected warm Atlantic water, and a zooplankton community dominated by true Arctic species. Recent winter water temperatures were around -1.4°C. It would be a very relevant eastern location for the deployment of various forms of autonomous underwater vehicle (AUV's).

In terms of marine sites, **Kongsfjorden** provides a useful warm fjord comparison with Ripfjorden. It is west facing and so receives a strong pulsed influx of relatively warm Atlantic Water. Kongsfjorden has remained ice free for most recent winters and during the winter2006-07 the water temperature never fell below 0°C. Its resident zooplankton population contains both Arctic and boreal species. It already is the site of a long term mooring which could be linked to further offshore moorings and marine platforms such as Hausgarten with the development of the cabled FRAM array. It is in relative proximity to Ny Alesund and its substantial infrastructure so offers a useful easy access site.

Coastal polynas are frequently encountered in Arctic shelf seas and **Storfjorden** on the south-eastern side of Spitsbergen is a remarkable example that could offer a third fjord site. The dynamic responses of polynas to changing sea-ice conditions and the formation and transport of dense saline water northwards could be monitored at Storfjorden with appropriate moorings and this valuable data incorporated into system models. It could also provide a useful eastern location for studying the marine/atmospheric boundary layer fluxes.

Within the open ocean around Svalbard there are number of moorings and ship observation stations which intercept the major ocean inflows and outflows and help us understand the fluxes of heat, salinity and freshwater in and around the archipelago. The focus for oceanographic time series has traditionally been the transport of Atlantic Water into the Arctic with sites in the Barents Sea Opening, the Sorkapp Section across the West Spitsbergen Current, the Fram Strait and, more recently, the North Svalbard Slope. Existing permanent stations around Svalbard (see diagram on page 25), include those associated with Hausgarten (black dots), Kongsfjord (blue dots) and Hornsund (purple dots) and further stations on the West Spitsbergen Current and the West Svalbard Slope (red dots). Annual ship cruises (Norway, Germany, Poland) occupy the various stations each summer. To the south, permanent stations are occupied regularly in the Barents Sea (aquamarine dots) and a further line of stations extends northward from Ripsfjorden (light green dots).

Seventeen moorings (orange stars) are located (see diagram on page 25) across the deep section of the Fram Strait monitoring the flow out of the Arctic Ocean. There are two further Fram Strait moorings (yellow stars)are situated in proximity to the Hausgarten benthic observatory, as well as moorings in Kongsfjorden and Ripsfjorden, which are maintained by AWI, UNIS, SAMS and ARCTOS. It is recognised that more detailed monitoring is needed to understand both the complex flow of waters around Svalbard where recirculation is common and to monitor ecosystems.


Existing and Proposed Moorings and stations for the SIOS programme
82°N
80°N
78°N
76°N
74°N
15°W
0°
15°E
30°E
45°E
Greenland
Zackenberg
Fram Strait
Erik Eriksen Strait
Barents Sea
30°E
array
Frants-Victoria
trough
Permanent stations
Rijpfjorden
HAUSGARTEN
Kongsfjorden
UoT stations
Isfjorden
Hornsund
Polar Front Transect
Moorings
Existing moorings (AWI & Arctos)
Storfjorden mooring
NP moorings
Planned moorings

Networking Infrastructure for System Monitoring

Marine - The diagram of marine platforms and stations on Page 25 is the basis of a network identified by the SIOS Gap Analysis and capable of observing the marine environment around Svalbard in both the vertical and horizontal plane utilising existing station/moorings which still have relevance for ESS horizontal transport monitoring. The diagram also shows new moorings (green stars, red arrows), which were also proposed in the Gap Analysis. Some extend existing lines of moorings or provide a year round monitoring capability in conjunction with existing permanent stations. One mooring is proposed in Storfjorden to provide more detailed full seasonal studies of a key ocean area whilst another is located east of Svalbard in the Frants Victoria Trough close to the recently established border between Norway and Russia. A set of seven moorings (green/red stars) is being installed by the Institute of Marine Research, Bergen at around 30^{o}E, north of Svalbard (see diagram above) to monitor Atlantic Water in the Yermak branch during 2012-13 and these could possibly be adopted and maintained by SIOS to monitor flow and features of that branch long term.

It has been highlighted that various existing Svalbard moorings have the potential to be employed as sites for further sensor deployments beyond just physical oceanography. This is particularly with respect to newly emerging technologies for chemical (including pollutant) sensing, acoustic monitoring and, in the near future, identification of biota, using molecular biology approaches which will have relevance for alien species invasions and northward migration of warmer water organisms The new moorings and the increased use of technologies such as gliders (see below) and AUV's have been proposed to address this issue. These were considered sensible proposals by the infrastructure prioritisation workshop participants and have remained in the optimisation plans.

The need for an acoustic tomography network in Fram Strait was one of the outcomes of IPY and the EU-funded project DAMOCLES. This network provides averaged temperature and current fields useful for seasonal variability monitoring but also generates acoustic signals from the tomography sources which would assist with glider navigation. The growing technical capability of gliders to deal effectively with ice conditions would fill gaps between moorings and allow additional measurements to complement fixed site studies.

Slocum Glider on ocean surface

The prioritisation workshop also highlighted the value of utilising ice tethered profiling (ITP) platforms in the pack-ice north of Svalbard equipped with both atmosphere and ocean monitoring capabilities which have sensors to not only monitor the upper layers of the ocean and sea-ice parameters but also begin to address boundary layer meteorology and therefore more realistic ocean-atmosphere fluxes. The first of a number of platforms in the Arctic Basin are currently being installed by iAOOS France and versions of these would allow SIOS to make a valuable contribution to full vertical coupling of ocean and atmosphere for Earth System modelling. There are still shortcomings in ITP measurements due to technological challenges in monitoring some key parameters, e.g. the power consumption of the required sensors and spray freezing on sensor surfaces, but SIOS could assist with these challenges.

Atmosphere - The diagram on Page 28 illustrates how measurement sites can be selected across the archipelago to provide a high spatial resolution network for upper atmospheric studies and how it would integrate with many other ESS-relevant measurements sharing these sites. Vertical coupling studies made at these sites would integrate with and complement the marine stations.

The hub for the atmospheric column studies would be established on the most instrumented site (Longyearbyen) and the various spokes are close enough to a 100 km radius to form an effective network for higher spatial resolution studies for both upper and lower atmosphere studies. All the sites indicated, except the east coast site of Ripsfjorden, have sufficient power to operate standard instruments. The east coast site will necessarily involve a more limited instrumentation set capable of operation with green energy options and more restricted power. Without it, the network would still be significantly better than the current independent site approach used but there would not be the opportunity to obtain a balanced 360^{o} view of the upper atmosphere – a unique research capability that would attract international researchers to Svalbard.

Terrestrial/Ice – The diagram on page 28 illustrates a broader range of study sites across the archipelago which includes an extensive network of meteorological stations that are associated with the proposed main monitoring sites (*blue circles*) and with additional locations (*orange circles*) to provide a multidisciplinary network facilitating east-west and north-south transects and allowing researchers to describe the complex topographic setting of Svalbard most effectively. Additionally marine meteorological platforms on buoys located around the archipelago could further extend this coverage. Three meteorological/ glaciological sites located outside Ny Alesund and Hornsund and on the eastern site of Ausfonna provide the main glaciological monitoring foci and link into the broader meteorological network illustrated by the orange circles.

The main study sites are (with the exception of Pyramiden) existing locations of scientific activity on Spitsbergen so SIOS would building on established capabilities but coupled with East Svalbard sites in Ripfjorden and on Hopen to provide a more complete climatic framework and geographical spread, whilst Bjornoya provides a southern site in the Barents Sea. Pyramiden offers a more central location for monitoring in the archipelago and offers a useful site for monitoring local environmental pollution. All 8 locations can be linked to the marine observing network and to the various topics originally identified in the gap analysis s through the integrative themes outlined here.

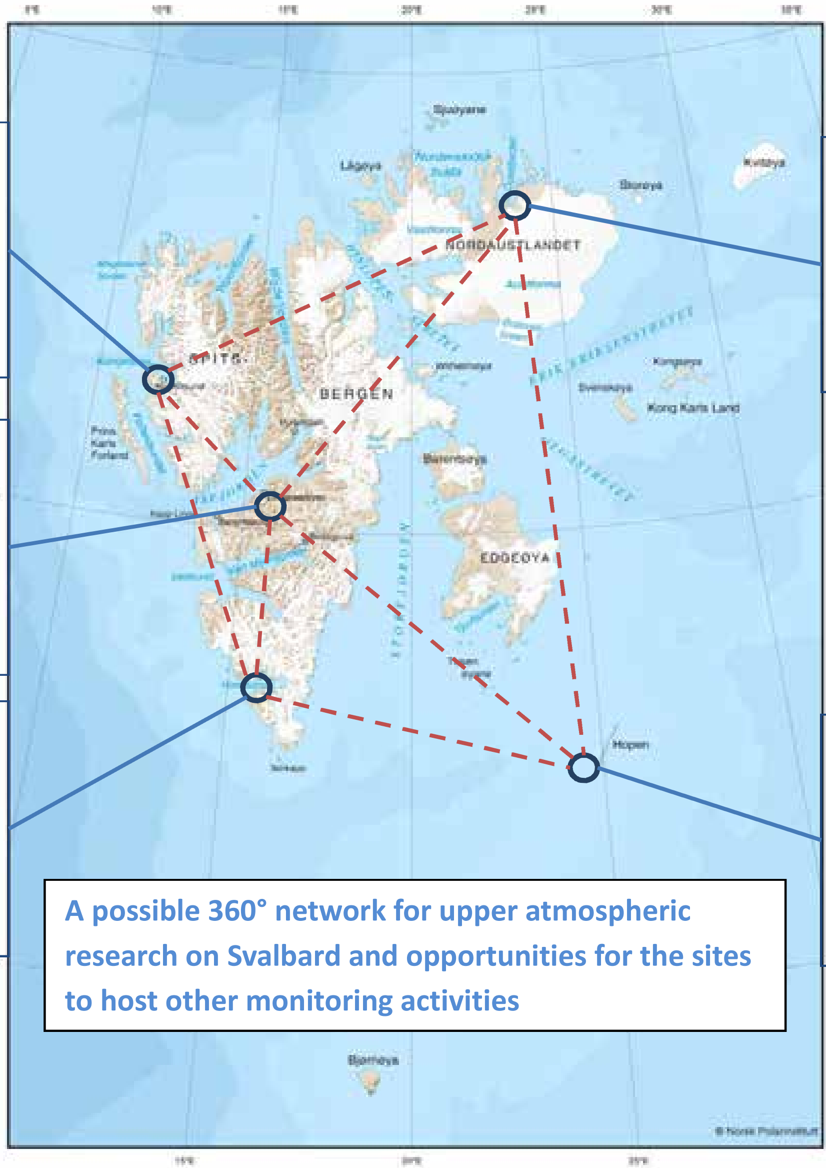
Sampling Strategy

The first element of a sampling strategy for SIOS is the establishment of the network of sites to ensure effective coverage across the archipelago and the surrounding ocean to capture horizontal transport of key variables. Similarly, the establishment of a network of sites across the archipelago to provide a balanced 360° view of events in the vertical column of the atmosphere is required. These are outlined on page 28 and provide a basis for the establishment of instrumentation in a structured framework. However there is also a need to identify variables to be measured and the sampling frequencies for these variables. Earth System relevant variables are the focus of SIOS and these will be changing over seasonal and decadal time scales, which need to be factored into SIOS when it becomes a full blown integrated observational system. There is further the need to sample

Ny Alesund
Upper/Lower Atmosphere coupling
- Advanced Meteorological station
- Land/ice/atmosphere exchange
- Fjord/Shelf seasonality (inc. sea ice)
- Long range transport
- Permafrost seasonality
- Seismicity/geodetic Network site

Longyearbyen (Hub)
Upper/Lower Atmosphere coupling
- Advanced Meteorological station
- Land/ice/atmosphere exchange
- Fjord/Shelf seasonality
- Long range transport
- Permafrost seasonality
- Seismicity/Geodetic Network site

Hornsund
Upper/Lower Atmosphere coupling
- Advanced Meteorological Station
- Land/ice/atmosphere exchange
- Fjord/Shelf seasonality
- Long range transport
- Permafrost seasonality
- Seismicity/Geodetic Network site



A possible 360° network for upper atmospheric research on Svalbard and opportunities for the sites to host other monitoring activities

Ripfjorden
Upper/Lower atmosphere coupling
- Advanced Meteorological station
- Land/ice/atmosphere exchange
- Fjord/Shelf seasonality
- Long range transport
- Permafrost seasonality
- Seismicity/Geodetic Network Site

Hopen
Upper/Lower Atmosphere coupling
- Advanced Meteorological Station
- Long range transport
- Seismicity/Geodetic Network site
- Biodiversity monitoring
- Seismicity/Geodetic Network site
- Ocean monitoring

Automated Meteorological Station
Geodetic Network Site

Ny Alesund
Upper/Lower Atmosphere coupling
Advanced Meteorological station
Land/ice/atmosphere exchange
Fjord/Shelf seasonality (inc. seaice)
Long range transport
Permafrost seasonality
Seismicity/Geodetic Network site
Biodiversity monitoring

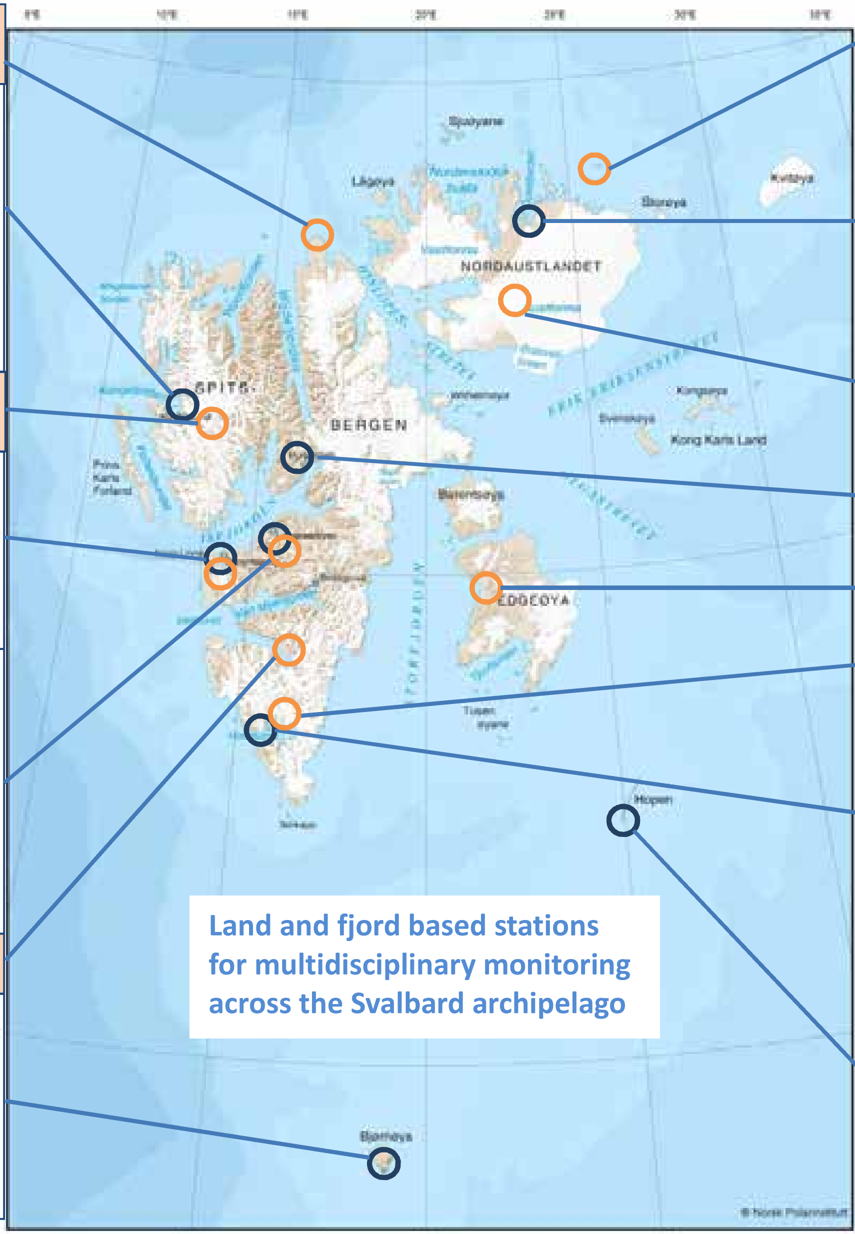
Kongsbreen/Kongsvegen
Automated Met/Glacio Stations

Barentsburg/Kapp Linne
Advanced Meteorological Station
Land/ice/atmosphere exchange
Fjord seasonality (inc. seaice)
Pollution monitoring
Seismicity/Geodetic Network site

Longyearbyen/Adventalen
Upper/Lower Atmosphere coupling
Advanced Meteorological station
Land/ice/atmosphere exchange
Fjord/Shelf seasonality
Long range transport
Permafrost seasonality
Seismicity/Geodetic Network site
Biodiversity monitoring

Geodetic Network site (Sveagrua)

Bjornoya (Bear Island)
Upper/Lower Atmosphere coupling
Advanced Meteorological station
Long range transport
Seismicity/Geodetic Network site
Biodiversity monitoring
Ocean monitoring



Land and fjord based stations for multidisciplinary monitoring across the Svalbard archipelago

Automated Meteorological Station

Ripfjorden
Upper/Lower atmosphere coupling
Advanced Meteorological station
Land/ice/atmosphere exchange
Fjord/Shelf seasonality
Long range transport
Permafrost seasonality
Seismicity/Geodetic Network site
Biodiversity monitoring

Automated Meteorological/
Glaciological Station

Pyramiden
Automated Meteorological Station
Seismicity and geodetic network
Pollution/Biodiversity Monitoring

Automated Meteorological Station

Automated Meteorological/
Glaciological Station

Hornsund
Upper/Lower Atmosphere coupling
Advanced Meteorological Station
and ice/atmosphere exchange site
Fjord/Shelf seasonality
Long range transport
Permafrost seasonality
Seismicity/Geodetic Network site
Biodiversity monitoring

Hopen
Upper/Lower Atmosphere coupling
Advanced Meteorological Station
Long range transport
Seismicity/Geodetic Network site
Biodiversity monitoring
Ocean monitoring

at time Intervals that can capture the scale of variability in the signals. These need to be agreed across all relevant instrumentation and can be established and regularly reassessed by the SIOS Science Advisory Board in conjunction with the research community.

Linking Ground-based Measurements with Remote Sensing Measurements

A major asset for Svalbard is that it is uniquely seen by, and can see, all the polar orbiting remote sensing satellites. This provides a very substantial addition to the observing capabilities of SIOS already outlined above. The combination of satellites, balloons, rockets, aircraft (manned and unmanned) and ground based facilities provide data at different spatial and temporal scales, different types of detail and facilitate application of various sensing systems that in combination allow a more effective means to understand Earth System Science issues. The challenge is to integrate all these capabilities into an coordinated approach to Earth System monitoring and whilst there has been progress and significant technological advances there remains much to be done to link the different observing systems on a scale appropriate for long term observation and to make the data sets equally available. One of the most impressive outcomes of the recent International Polar Year was that all the major space agencies agreed to cooperate to make a wide range of relevant satellite data products available in common formats to the polar science community. They further interacted with an IPY project in which remote sensing researchers could generate requests for satellites to look in particular directions or switch on sensors at specified times over particular parts of the Polar Regions. This IPY initiative has fortunately continued, currently with ESA chairmanship and coupled with a growing number of polar relevant satellites is transforming the research capabilities of Arctic scientists.

A range of high and low altitude satellites are available or planned to provide valuable additional data, albeit not necessarily as detailed as that provided by ground based observatories. Satellites instead provide a broader scale of observation or an integration offering valuable context. One example would be the ESA **SWARM**, a constellation of three satellites that will be studying the Earth's magnetic field. Within the atmosphere future ESA missions such as **ADM-AEOLUS**, studying wind profiles on a global scale and **EARTHCARE,** which will address the question of how clouds and aerosols influence incident solar radiation and infrared radiation from the Earth's surface. At the Earth surface satellites can be particularly valuable in providing landscape scale observations that cannot be easily matched by other observing platforms such as aircraft. This is particularly illustrated in monitoring of sea-ice where the presence of **CRYOSAT-2** is producing remarkable information on not only sea-ice extent but also sea-ice thickness.

The **SMOS** satellite is monitoring ocean salinity and soil moisture, providing insights to the global water cycle whilst the other satellite in ESA's Explore family, **GOCE** is being used to study ocean circulation, changing sea level and processes in the Earth's interior. Satellites also have a role in monitoring sea surface temperature and ocean fluorescence. In future, satellites could be a valuable means for studying precipitation and even snow, one of the most difficult variables to currently assess and of profound significance for permafrost, sea-ice and biology for example. SIOS Work Package 7 has carefully assessed remote sensing and the satellite monitoring capabilities outlined in its reports can be matched against the ground-based infrastructure discussed here.

Optimising the deployment of SIOS Infrastructure in Earth System Monitoring

It was proposed in the SIOS Vision document to classify Svalbard infrastructure through a simple three level system that would identify the minimum level of infrastructure needed (**Level 1 - must have**) to obtain an operational and comprehensive observational system in Svalbard. Secondly, what would be needed for the observational system to deliver on a world class level (**Level 2 - should have**) and infrastructure which would provide useful observations (**Level 3 - nice to have**), but which are a more local scale not essential to SIOS core observational measurements or representing more process focused measurements that help understand the monitoring data. There is therefore two levels that comprise the core monitoring measurements and a third level that and in effect surrounds and supports the core activities. This is the type of research that could be a significant element of the planned SIOS Access to Facilities scheme.

It was further recognized that each of the countries would likely primarily contribute within the scientific field where they already are leading scientifically. Those infrastructures are in most cases already part of a nationally funded monitoring activity and therefore part of existing funding plans. The assigned levels of prioritization are to assist the consortium partners to can identify the significance of the infrastructures they manage and help indicate high priority instruments that be underfunded and should be the subject of proposals to their funding agencies for ongoing funding of these facilities. The prioritization also identifies new infrastructure to upgrade the monitoring capabilities of SIOS and possible nations to lead in obtaining these new facilities. Whereas it is very difficult to cost existing instruments as some have been in use for decades or more and others are simply not available off the shelf, we have attempted to assess costs of purchasing new infrastructure.

The core observational programme of SIOS aims to provide a comprehensive set of interlinked systematic observations that are guaranteed to be available over time through mutual commitment by the consortium participants. It is therefore important that each country/consortium participant commit themselves to funding the infrastructure/deliverable data over a minimum timeframe of 10 years.

Listings of existing infrastructure on Svalbard have been assessed in terms of addressing:

(a) vertical coupling and horizontal transport in and around Svalbard,

(b) cryosphere and geosphere interactions relevant to ESS and

(c) responses to climate change of biodiversity and ecosystems.

This has led to some infrastructure already present on Svalbard not being classified as a Level 1 core measurement but instead being regarded as of more specific interest. For example the CABI Ionosonde which measures electron density profiles in the ionosphere is very relevant to vertical coupling studies and merits a level 1 rating. In contrast infrastructure such as the SPEAR radars are classified as level 3 as they are designed to study plasma physics which is not seen as directly related to the observational theme of vertical coupling. This does not mean that such infrastructure is outside SIOS, it is simply that it does not provide observational data on key variable in relation to the Earth system questions being posed at the outset of SIOS. In future it is perfectly feasible that a particular level 3 infrastructure could become relevant to an evolving core observational programme and be reclassified. For the present its data is still of interest to SIOS in more general terms. For example process studies are not considered core measurements but we need such process understanding to decipher some of the core data.

Categorizing infrastructure is not straightforward and needs some practicality applied at times. Existing ground-based instrumentation cannot observe the 40-60 km height range of atmosphere effectively and rockets are currently the only way to get any detailed information for this region. In the future satellites will provide coarse spatial information with high cadence but rockets are likely to remain the key means for understanding the fine scale details at 40-60 km range. With an unlimited access to funds the rockets would clearly therefore be defined as level 1 in the evaluation. However, practicality rules that there would be an unacceptable funding disparity across SIOS if rockets were deployed frequently and so these should only be used where the added value justifies the costs, either directly scientifically or as a required complement to the much higher temporal resolution of ground based instrumentation. This capability therefore characterizes rockets as being level 2.

The EISCAT radar facility is not set up for long term monitoring, though during International Polar Year it was run continuously for a year with very impressive results. It does not merit level 1 status but it is a “honeypot” instrument, which when coupled with other radars and radio receivers can generate new insights from the collected instrumental data and so the possible future operation of this instrument in continuous mode would also merit a level 2 rating.

A further atmosphere example of the range of issues associated with infrastructure is the proposed upgrade of SUPERDARN radars on Svalbard. These are very powerful research tools but if the focus of the SIOS core monitoring measurements is the vertical column above Svalbard, then it is the SUPERDARN radars in northern Norway that will be looking at this column, not the equivalent radars on Svalbard which are studying further north. Thus it could be argued that the proposed upgrade of SUPERDARN radars on Svalbard be considered level 3 – exciting process based science, but not directly necessary to the core monitoring elements of the SIOS programme. However the prioritisations can and should be reviewed regularly and certainly access to SUPERDARN radars through funding support from the proposed SIOS infrastructure access Calls should be possible as these will not simply be focussed on monitoring but rather on shorter term objectives.

The fact that certain infrastructure is identified as level 3 or indeed is not included in the following tables does not prevent these facilities continuing to be funded by the relevant national funding body. It can be undertaking excellent science on Svalbard and contributing that data to relevant data archives which can be accessed through the SIOS Knowledge Centre data portal. As mentioned above, some of these activities/facilities initially proposed to be outside the core body of monitoring infrastructure may in due course become an integral part as the relevant scientific questions and research priorities alter.

Within the following tables all the significant research infrastructure currently identified (from the gap analysis records) as being present on and around (moorings, stations) the Svalbard archipelago are listed but here reassigned, based on the prioritisation workshop discussions. Costs for upgrading instruments or purchasing new instruments are included in the tables but costs of existing instruments are not listed, as explained above. The upgrades and new instruments identified (blue background cells) have been drawn largely from the gap analysis synthesis document as much thought had already been given to this by various researchers and purchase costs and estimated running costs (where available) are given. Nation(s) that can be associated with particular infrastructure due to existing activity in the relevant field are indicated but this does not exclude other nations contributing and equally does not represent a firm commitment by a nation.

The infrastructure workshop discussions identified some further gaps in infrastructure when applying the foci of vertical and horizontal coupling and this led to additional suggestions for new instrumentation capability (green background cells) which can be further considered by the SIOS Science Advisory Committtee. Examples of some particularly exciting possibilities for monitoring on more relevant spatial scales, and in more detail than satellite remote sensing offers, include novel uses of UAV's, AUV's and aircraft particularly to access remote, difficult sites for repetitive measurements. The gap analysis groups did suggest a number of these items and we would concur that the UAV/AUV/aircraft option would provide a flexible means to tie together a number of more static measurement systems within the core measurement framework. However these items need to be considered in terms of specific issues they can address so that compelling cases can be made for their purchase at some point in the future. They currently do not represent critical items of infrastructure but would certainly enhance a future observing system.

The assessment has revealed a number of instances where the same instruments are being deployed in close proximity by different nations, which in terms of an integrated Svalbard infrastructure is clearly not the most effective use of such infrastructure. This is highlighted where appropriate in the tables in column 6 and needs to be discussed and resolved by the relevant nations to establish which instrument could be most usefully included in the SIOS listing as a core instrument. Duplicate instruments could possibly be redeployed – for example Hornsund does not have optical instruments for upper atmosphere studies and could be a repository for reassigned duplicate instruments and so make for a more effective distributed network overall. Clearly this suggestion might not necessarily sit comfortably with individual nations and their chosen research location on Svalbard but it is not efficient to have similar instruments collecting the same data at a given site. If funding agencies make an assessment of locations such as Ny Alesund such replication would surely not be well regarded.

In the ocean similar spatial scaling to that outlined for atmospheric measurements can be usefully applied but is in practice difficult to achieve. A number of sites are in existence or proposed as new developments and a significant number of new measuring capabilities can be usefully deployed on these platforms to get a more integrated observing platform. The deployment of more sophisticated communications and power capabilities, with the deployment also of new generation sensors will offer an opportunity for much more comprehensive monitoring of ESS relevant variables through the region.

Topics such as permafrost and periglacial studies as well as the tectonics studies are on either local spatial scales or too long (geological) a temporal scale. Only a subset of the infrastructure under these topics has been considered relevant for Earth System scale monitoring in this document. It has been accepted that core measurements would not include process-based studies although many of these were suggested in the gap analysis. The focus here has to be on observational measurements that will address regional rather than local scale issues. Pollution transported to and across the region and effecting or being effected is of appropriate scale whereas, for example, pollution generated within individual Svalbard settlements is not the correct scale for SIOS core measurements, though it is clearly relevant for Svalbard. This does not prevent local pollution data being referenced within the Knowledge Centre and linked with long range pollutant transport data sets as it helps identify what is a long range transport influence but at this time such local data is not a core monitoring activity. Similarly there is a significant temporal element to observational studies and so whilst plate tectonics is a substantial scientific topic in the Arctic it is on too long a time scale to be relevant to the SIOS core monitoring framework. All of these identified infrastructure items should be subject to regular assessment and evaluation in the context of changing questions as knowledge is acquired and technical developments emerge to achieve more effective monitoring.

Infrastructure Prioritisation

- Both existing and proposed new infrastructure are listed below.
- Existing Priority 1 infrastructure needed for the basic core monitoring facility in *gold*
- Recommended new infrastructure items from the gap analysis are highlighted in *blue*.
- New infrastructure proposed by the prioritisation workshop is highlighted in *green*
- Sites within national parks where access permissions will be needed are shown in *red text*.
- Purchase cost estimates are shown where available for proposed upgrades or new purchases as it is impractical to accurately cost most existing infrastructure.
- Each item is also awarded a priority level (1-3) described earlier and possible lead nation(s).

1. Vertical coupling measurements

Location	Parameters	Platform	Possible Lead Nation	Budget -k€	Priority (1, 2, 3)
Radars and Radio Receivers					
Longyearbyen, EISCAT	TEC and ionospheric scintillation	Ionospheric Scintillation Receiver	International	Existing	2
Longyearbyen, EISCAT	Electron density profiles in ionosphere	Dynasonde	International	Existing	2
Longyearbyen, EISCAT	Electron density profiles in ionosphere	Upgrade of Dynasonde	International	100	2
Longyearbyen, SPEAR	Electron density profiles in ionosphere	CADI Ionosonde	UK	Existing	1
Longyearbyen, SPEAR	Active/passive expts. in ionosphere	SPEAR (Phase II upgrade)	Norway, UK	2000	3
Longyearbyen, KHO	Cosmic noise absorption maps (1 s)	64-beam Imaging Riometer	Denmark/ Norway	Existing	1
Longyearbyen, KHO	0.3-6 MHz auroral radio emiss. (1 s)	Auroral Radio Spectrograph	Japan	Existing	1
Longyearbyen, KHO	Doppler spectra of HF radio stations. Remote monitoring of Tromso heater, SPEAR and HAARP	HF acquisition system (Doppler HF receiver)	Ukraine	Existing	1
Longyearbyen, SOUSY	Winds in upper troposphere/lower stratosphere and mesosphere, PMSE, PMWE	MST radar	Norway	Existing	1
Longyearbyen, SOUSY	wind, temperature, 80-100km	Meteor Wind Radar	Norway, Japan	Existing	1
Longyearbyen, SOUSY	TEC and ionospheric scintillation	Ionospheric Scintillation Receiver	Italy	Existing	1

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Longyearbyen, SOUSY	PMSE, wind, temperature 80-100 km, cosmic noise absorption	Upgrade of SOUSY and riometer	Norway	300	2
Ny Alesund	Winds in upper troposphere/lower stratosphere and mesosphere, PMSE, PMWE	MST radar and meteor scatter radar	?	?	2
Ny Alesund	Electron density in ionosphere	Ionosonde	?	?	2
SvalRak, Ny-Ålesund	E/B-field waves, electron density, particles (sub-meter resolution)	2 middle atm. + 1 upper atm. rocket per year for 7 years (i.e. 21 rockets)	Norway, Germany, Sweden, USA, France, Japan	24000 (includes running costs over 7 years)	2
Ny-Ålesund, Chinese Station	Cosmic noise absorption (38.2 MHz)	Imaging Riometer	China	Existing	1
Ny-Ålesund, Chinese Station	TEC and ionospheric scintillation	Ionospheric Scintillation Receiver	China	Existing	1 but Italy have same capability
Ny-Ålesund, Italian Station	TEC and ionospheric scintillation	Ionospheric Scintillation Receiver	Italy	Existing	1 but China have the same
Barentsburg	TEC and ionospheric scintillation	Ionospheric Tomography Receiver	Russia	Existing	1
Barentsburg	Amplitude of cosmic noise absorption (0.1s)	30 MHz riometer	Russia	Existing	1
Barentsburg	Amplitude of signals from St. Petersburg (time delay-frequency, every h.)	Oblique ionospheric sounding receiver	Russia	Existing	3
Hornsund	Electron density profiles in ionosphere	Digital Ionosondes (vertical and oblique)	Poland	Existing	1
Hornsund	Cosmic noise absorption	30 MHz Riometer	Canada	Existing	2
Svalbard & Northern Norway	Horizontal plasma velocity in iono-sphere around Svalbard	SuperDARN HF ionospheric radars	UK	1500	3
Optical Instruments					
Longyearbyen, EISCAT	Images of 427.8, 562.0, 673.0, 732.0 and 777.4 nm emissions in 42m radar beam (20-32 fps, 3x3 deg FOV)	Auroral Structure and Kinetics Imagers (ASK)	UK, Sweden	Existing	2

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Longyearbyen KHO	General purpose bushbroom hyperspectral imager 400-700nm (VIS)	FS-IKEA	Norway	Existing	2
Longyearbyen KHO	Near Infrared emission (OH 6-2 airglow)	All-Sky Airglow Imager	Norway	Existing	2
Longyearbyen, KHO	Images of 427.8, 557.7 and 630.0 nm emissions (3-4 fpm, wide FOV)	All-Sky Imager	Finland	Existing	2 only need one at LBY
Longyearbyen, KHO	High-speed monochrome movie of the sky (25 fps, wide FOV)	All-Sky Camera	Norway	Existing	2, only need one at LBY
Longyearbyen, KHO	High-speed monochrome movie of the sky (30 fps, wide FOV)	All-Sky Camera	USA	Existing	2 , only need one at LBY
Longyearbyen, KHO	RGB color images of the sky (every 5 min, wide FOV)	All-Sky Colour Imager	UK	Existing	2, only need one at LBY
Longyearbyen, KHO	RGB color images of the sky (2-12 fpm, wide FOV)	All-Sky dSLR Camera	Norway	Existing	2, only need one at LBY
Longyearbyen, KHO	NIR spectrum (every 2 min, near zenith)	CCD Spectrograph	USA	Existing	2
Longyearbyen, KHO	NIR image (>2 min exposure, wide FOV)	NIR All-Sky Imager	Norway	Existing	2
Longyearbyen, KHO	Spectrum of 7250-8650 nm emissions, i.e. OH airglow (every 5 min, near zenith)	1 m “Silver” Ebert-Fastie Spectrometer	USA	Existing	2
Longyearbyen, KHO	Spectrum of proton aurora, variable range in UV-NIR (every 8-300 s, near zenith)	1 m 'Green' Ebert-Fastie Spectrometer	USA	Existing	2
Longyearbyen, KHO	Spectrum of proton aurora, variable range in UV-NIR (every 8-300 s, near zenith)	1/2 m 'Black' Ebert-Fastie Spectrometer	USA	Existing	2
Longyearbyen, KHO	Spectrum of proton aurora, variable range UV-NIR (every 12-300 s, along meridional)	1/2 m 'White' Ebert-Fastie Spectrometer	Norway	Existing	2
Longyearbyen, KHO	Thermospheric winds/temperatures (every 30 s, several directions)	Imaging Fabry-Perot Interferometer	UK	Existing	2

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Longyearbyen, KHO	Thermospheric winds and temperatures (every 1-2 min, wide FOV)	Scanning Doppler Imager	UK	Existing	2
Ny-Ålesund	Thermospheric wind/temperature (vectors, every 1-2 min, wide FOV)	Scanning Doppler Imager	?	300	2
Longyearbyen, KHO	Measurements of fine-scale aurora in narrow FOV along B; movie (25 fps), spectrum, and 4 photometers	Spectrographic Imaging Facilities	UK	Existing	2
Ny-Ålesund, Sverdrup Station	Intensity of 2 auroral lines along the meridian (20 s)	Meridian Scanning Photometer	Norway	Existing	2
Longyearbyen, KHO + Ny-Ålesund	Measurements of auroral emissions in sunlight (wide FOV)	2 daylight auroral imagers	Norway	1000	2
Longyearbyen, KHO + Ny-Ålesund	Measurements of atmospheric airglow (wide FOV)	2 airglow imagers	Norway	200	2
Longyearbyen, KHO	Spectrum of all visible aurora (0.1 nm res./every 5 s, and 10 nm res./every 0.1 s, along meridian)	High spectral and time resolution auroral spectrographs	Sweden, UK	1000	2
Ny-Ålesund, Sverdrup Station	Images of 557.7 and 630.0 nm emissions (4-6 fpm, wide FOV)	All-Sky Imager	Norway	Existing	2
Ny-Ålesund, Chinese Station	Images of 557.7, 630.0, and 427.8 nm emissions (10 fpm, wide FOV)	All-Sky Imagers	China	Existing	2
Ny-Ålesund, Italian Station	Images of 427.8, 557.7 and 630.0 nm emissions (6 fpm, wide FOV)	All-Sky Camera	Italy	Existing	2
Ny-Ålesund, Dasan Station	Mesospheric Temperature (OH layer)	FTIR spectrometer	South Korea	Existing	2
Barentsburg	Monochrome movie of the sky (wide FOV, VHS format, ~6 fps)	All-Sky Television Camera	Russia	Existing	1? – too close to LBY?
Barentsburg	Emissions at 557.7 & 630.0 nm (at 25 ms)	4-channel Photometer	Russia	Existing	1? – too close to LBY?
Barentsburg	Sky luminosity (730-890 nm, 4 fpm)	Near-infra-red Spectrometer	Russia	Existing	1? – too close to LBY?

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
KHO/Barentsburg	VIS	All-sky hyperspectral cameras	Norway, Russia	Existing	1? – too close to LBY?
Hornsund	Suite of optical Instruments	There is no optical capability at Hornsund	?	?	2
Magnetometers					
Longyearbyen, KHO	ULF magnetic wave activity (2 axes, 0.1s)	Search-coil Magnetometer	USA	Existing	2
Longyearbyen, KHO	Magnetic field (3 axes, every 10 s)	Fluxgate Magnetometer	Norway	Existing	2
Ny-Ålesund	ULF magnetic wave activity (2 axes, 0.1 s)	Search-coil Magnetometer	USA	Existing	2
Barentsburg	Magnetic field wave activity (3 axes, 0.1-20 Hz, every 25 ms)	Induction Magnetometer	Russia	Existing	2, only need one
Barentsburg	Magnetic field wave activity (3 axes, 0.1-20 Hz)	Induction Magnetometer	Finland	Existing	2, only need one
Barentsburg	Magnetic field (3 axes, every 0.1 s)	Fluxgate Magnetometer	Russia	Existing	2, only need one
Barentsburg	Magnetic field (3 axes, every 0.1 s)	Fluxgate magnetometer	Russia	Existing	2, only need one
Hornsund	Magnetic field (3 axes, every 1 s)	Fluxgate Magnetometer	Poland	Existing	2
Hornsund	ELF electomagnetic field wave activity (Schumann resonance, 1-33Hz, every 0.01 s)	Induction Magnetometer and Electric Ball Antenna	Poland	Existing	2, only need one?
Hornsund	ULF magnetic wave activity (2 axes, 0.1 s)	Search-coil Magnetometer	USA	Existing	2, only need one?
Isfjord	ULF magnetic wave activity (2 axes, 0.1 s)	Search-coil Magnetometer	USA	Existing	2
Bjørnøya, Hopen, Jan Mayen	Magnetic field (3 axes, every 10 s)	Fluxgate Magnetometer	Norway	Existing	2
Other Instruments					
Ny-Ålesund, Blue House	Neutron flux and energy spectrum	Neutron Monitor (Bonner Sphere spectrometer)	Germany	Existing	3
Barentsburg	Cosmic rays (every 10 s)	Neutron Monitor	Russia	Existing	3
Hornsund	TEC and ionospheric scintillation	3 Spaced GPS Receivers	Poland	Existing	2

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
		Radiation and Atmospheric Chemistry			
AWIPEV Base, Ny-Ålesund	Trace gases in the stratosphere and lower mesosphere	Microwave radiometer	Germany	Existing	1
AWIPEV Base, Ny-Ålesund	Vertical profiles of ozone	Ozonesondes	Germany	Existing	1
AWIPEV Base, Ny-Ålesund	Vertical profiles of ozone, PSCs, strat. T, density	Stratospheric ozone lidar	Germany	Existing	1
AWIPEV Base, Ny-Ålesund	Columns of stratospheric trace gases: ozone, HCl, HF, NO_2, HNO_3, $ClONO_2$, CFCs	FTIR spectrometer	Germany	Existing	1
AWIPEV Base, Ny-Ålesund	Column abundance Ozone, NO_2, OClO, BrO, IO	Differential Optical Absorption Spectroscopy	Germany	Existing	1
Sverdrup Station, Ny-Ålesund	Total ozone, NO_2, PSC	SAOZ	Norway/ France	Existing	1-another measure of ozone
Sverdrup Station, Ny-Ålesund	UV irradiance, total ozone	GUV	Norway	Existing	1 – another measure of ozone
Sverdrup Station, Ny-Ålesund	UV fluxes (300-380 nm), Ozone Content	UV-RAD ISAC Radiometer	Italy	Existing	1 –
Rabot Station, Ny-Ålesund	Total ozone - UV spectra	Brewer No. 50	Italy	Existing	1 – another measure of ozone
Ship based	Vertical ozone profiles	Ozonesondes	Germany	Existing	1
RV Oceania/ Svalbard - summer	Ozone profiles	Microtops II ozonometer	Poland	Existing	1
AWIPEV Base, Ny-Ålesund	Direct, diffuse, global radiation, UV, upward/ downward long-wave radiation, solar spectrum	BSRN station	Germany	Existing	1 Primary radiation site
AWIPEV Base, Ny-Ålesund	UV-A, UV-B spectra	Dual UV spectro-radiometer	Germany	Existing	1 Similar to below
Sverdrup Station, Ny-Ålesund	UV fluxes at 300-380 nm - Ozone content - Erithemal/DNA dose rates	UV ISAC radiometer (7 channels: 300, 306, 310, 314, 325, 338, 364 nm	Italy	Existing	1 Similar to above
Hornsund	Global/ reflex radiation, albedo, upward/ downward long-wave radiation, net radiation	Automatic Weather Station (AWS)	Poland	Existing	1

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
RV. Oceania/ Svalbard - summer	Solar radiation fluxes Upward and downward radiation fluxes	Eppley Precision spectral Pyranometers	Poland	Existing	1
Aerosol and Cloud Observations					
Zeppelin Observatory, Ny-Ålesund	Particle light absorption	Soot photometer	Sweden	Existing	1
Zeppelin Observatory, Ny-Ålesund	Particle number density	Condensation Particle Counter (CPC)	Sweden	Existing	1
Zeppelin Observatory, Ny-Ålesund	Particle size distribution	Differential Mobility Analyzer (DMA)	Sweden	Existing	1
Zeppelin Observatory, Ny-Ålesund	Aerosol light scattering	Nephelometer TSI 3563	Sweden	Existing	1
Zepplin Observatory	Particle density, CCN density, ice nucleus density number, hygroscopicity growth, aerosol mass spectrum, aerosol absorption coefficient	Instrument upgrade to replace above	Norway/Sweden	420	2
Sverdrup Station, Ny-Ålesund	Aerosol optical depth	PFR Sun photometer	Norway	Existing	1 – similar to below?
AWIPEV Base, Ny-Ålesund	Aerosol optical density	Sun/moon/star photometer	Germany	Existing	1 – similar to above?
AWIPEV Base, Ny-Ålesund	particle backscatter coefficient, particle depolarization ratio	miniaturized 532 nm backscattering and depolarization lidar (MULID)	Italy	Existing	1
AWIPEV Base, Ny-Ålesund	Cloud base	Laser ceilograph	Germany	Existing	1
AWIPEV Base, Ny-Ålesund	Aerosol profiles	Aerosol Raman lidar	Germany	Existing	1
Gruvebadet, Ny-Ålesund	aerosol size distribution in the range 3 - 1000 nm	TSI 3896 Scanning Mobility particle sizer (SMPS) Diffuse mobility analyzer	Italy	Existing	1
Gruvebadet, Ny-Ålesund	aerosol absorption coefficient at 532 nm	PSAP absorption photometer (one wavelength)	Italy	Existing	1
Gruvebadet, Ny-Ålesund	aerosol scattering coefficient	M903 Radiance Res. nephelometer	Italy	Existing	1
RV. Oceania/ Svalbard - summer	Aerosol profiles	Lidar LB 10 (532 nm)	Poland	Existing	1
RV. Oceania/ Svalbard - summer	Aerosol Optical density	Microtops II sunphotometers	Poland	Existing	1

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
RV. Oceania/ Svalbard - summer	Coarse aerosol size distribution and conc.	PMS laser particle counter CSASP-100	Poland	Existing	1
RV. Oceania/ Svalbard - summer	Fine mode aerosol concentration	TSI Condensation Particle Counter	Poland	Existing	1
Hopen	Aerosol profiles	Aerosol Raman Lidar	?	150	2
Hopen	Aerosol Optical Density	Sun Photometer	?	30	2
Various locations	Various parameters, e.g. black carbon	UAV platform	?	?	2
Meteorological Observations					
Ny-Ålesund	T, p, wind, RH, prec., snow depth, clouds, visibility	Synoptic met. station (partially automatic)	Norway	Existing	1
Bear Island	T, p, RH, prec., snow depth, clouds, visibility, radiosonde	Synoptic met. station (manual)	Norway	Existing	1
Jan Mayen	T, p, RH, prec., snow depth, clouds, visibility, radiosonde	Synoptic met. station (partially automatic)	Norway	Existing	1
Hopen	T, p, RH, prec., snow depth, clouds, visibility, radiosonde	Synoptic met. station (manual)	Norway	Existing	1
Edgeøya,	T, p, RH, wind	meteorological station (automated)	Norway	Existing	1
Verlegenhuken,	T, p, RH, wind	meteorological station (automated)		Existing	1
Karl XII Land	T, p, RH, wind	meteorological station (automated)		Existing	1
Svea	T, p, RH, wind	meteorological station (automated)	Norway	Existing	1
All above stations	Meteorological parameters, radiation and energy balance parameters, and BSRN upgrade	Meteorological station (upgrade to fully automatic, online)	Norway	25 per station	1
Isfjord, Adventalen, Kapp Linne, Ripsfjorden Austfonna	As above	Full station as above	Norway	25 per station	1
All above stations	Precipitation measurements	Advanced precipitation gauge network	Norway	600	2
Ripsfjorden, Ny-Alesund, Kapp Linne, Adventalen	Snow measurements	Automated snow monitoring – to be developed.	?	200	2
Selected glaciers, rivers, including Ripsfjorden area	Freshwater run-off	Runoff monitoring instrumentation	Norway/ Poland	350	1

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
On ice buoys	T, pressure, wind, RH, web cam monitoring	5 Automatic Weather Stations	Germany, Norway	325	1
Hornsund	Radiation measurements	Automatic weather station	Poland	Existing	1
Hornsund	Upgrade to BSRN and synoptic meteorology	Meteorological station upgrade to automatic, online, BSRN	Poland	30	1
AWIPEV Base, Ny-Ålesund	Vertical profiles of T, p, wind, RH	Radiosondes	Germany	Existing	1
AWIPEV Base, Ny-Ålesund	Vert. profiles of met. parameters	Tethered balloon	Germany	Existing	1
AWIPEV Base, Ny-Ålesund	pressure, Temp, wind, RH at 2 and 10 m	Meteorological tower	Germany	Existing	1
Zeppelin Observatory, Ny-Ålesund	Wind, temp, RH,	Meteorological observations	Norway	Existing	1
Kohlhaven , Ny Alesund (Amundsen- Nobile Tower)	Atmospheric profiles in surface layer (PBL)	Pressure, Temp, RH, wind at 4 heights (3, 7,10, 34 m)	Italy	Existing	1
Kohlhaven , Ny Alesund (Amundsen- Nobile Tower)	Turbulent fluxes of moisture, momentum, temperature	KH-20 fast hygrometer, Gill sonic anemometer	Italy	Existing	1
Additional Meteorological Observations					
Svalbard Lufthavn, Longyearbyen	T, pressure, wind, RH, precipitation., snow depth, clouds, visibility, etc.	Synoptic met. station (partially automatic)	Norway	Existing	1
Barentsburg	T, p, wind, RH, prec., snow depth, clouds, visibility, incoming global radiation	Synoptic met. Station (manual)	Russia	Existing	1
RV. Oceania/ Svalbard - summer	Wind speed pulsations	Gill acoustic anemometer	Poland	Existing	1
Vertical C Transport					
Hausgarten, Kongsfjorden, **Ripfjorden**	Sedimentation in water column	Automatic Sedimentatn' traps. Links with existing moorings (see later)	UK, Germany, Norway	Existing	1
Seafloor Methane Seepage Site (ESONET Demo)	Methane production from hydrates on West Svalbard Slope	AOEM instrument – in future possible part of FRAM project	International	300	2

2. Horizontal transport

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
		Greenhouse Gases			
Zeppelin Observatory, Ny-Ålesund	Carbon dioxide	NDIR radiometer	Sweden	Existing	1
Zeppelin Observatory, Ny-Ålesund	halogenated hydrocarbons	ADS-GCMS	Norway	Existing	1
Zeppelin Observatory, Ny-Ålesund	Ambient methane	GC-FID	Norway	Existing	1
Zeppelin Observatory, Ny-Ålesund	nitrous oxide	GC	Norway	Existing	1
Ny-Ålesund	GHG concentrations (high time res., precision)	High-resolution high-precision GHG monitors	Norway, Sweden, UK	Existing	2
Bayelva, near Ny-Ålesund	fluxes of CO_2, sensible heat, H_2O; snow depth	Eddy Co-variance system	Germany	Existing	1
Dasan Station, Ny-Ålesund	CO_2 flux, heat fluxes	Eddy covariance tower	South Korea	Existing	1
Adventdalen, Kap Linné, Rijpfjorden	CO_2, CH_4, N_2O, sensible and latent fluxes	Meteorological flux towers incl. eddy covariance and chambers measurements	Norway, Sweden	325	2
		Pollutant Transport			
Zeppelin Observatory, Ny-Ålesund	Mercury air concentration	Tekran Mercury monitor	Norway	Existing	1
Zeppelin Observatory, Ny-Ålesund	Ambient ozone	Ozone analyzer	Norway	Existing	1
Zeppelin Observatory, Ny-Ålesund	Ambient Hydrogen	GC-HgO	Norway	Existing	1
Zeppelin Obs, Ny-Ålesund	Aerosol inorganic chemistry	Filterpack	Norway	Existing	1
Zeppelin Observatory Ny-Ålesund	Monitoring of organic pollutants (LRT)	DH80 High-Volume Air Sampler	Norway	Existing	1
Sverdrup Station, Ny-Ålesund	Inorganic chemistry	Precipitation collector	Norway	Existing	1
Longyearbyen, Ny-Ålesund, Svea, Hornsund, Kap Linné	Priority pollutants from settlements (transport, energy production), ships	Emission monitors in settlements, harbours and research stations	?	?	1

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Longyearbyen-Norwegian mainland transect	various marine pollutants (+oceanographic parameters)	Ferry Box automated monitoring on “Norbjørn”	Norway	Existing	1
Barentsburg	POPs (PCBs, OCPs, PAHs), HM	Field sampling/ meteorology	Russia	Existing	1
Barentsburg	CO, CO_2, NO_x, PM, PAH, PCDD, Hg, Heavy metals	Samplers for emission, emission monitors for facilities	Russia	?	2
Barentsburg, Pyramiden	Mercury and POPs concentration in air, water, soil, biota	Stationary monitoring station equipped with automated air mercury analyzer; POPs high volume air sampler and passive samplers; storage of samples; active/passive POPs water samplers; small laboratory for sample materials preparation and exchange	Russia	?	2
Eulerian Marine Platforms					
Kongsfjorden	Temperature, salinity, currents	Multi-parameter mooring (Aanderaa RCM)	Norway	Existing	1
Rijpfjorden	T/S/Currents (profile), sediments, fluorescence, PAR	Single Mooring	UK	Existing	1
Billefjorden	T/S/Currents (profile), sediments, fluorescence, PAR	Single Mooring	Norway	Existing	3
Kongsfjorden and northern shelf	Temperature, salinity, currents, sediments, fluorescence, added biological sampling	Upgrading of existing coastal moorings	UK	?	2
Kongsfjorden	Temperature, salinity, fluorescence	Cabled mooring	UK	?	2
Storfjorden sill and shelf-break off Sørkapp	T/S/Currents (profile)	Single Mooring	Norway	Existing	1
Storfjorden sill and shelf-break off Sørkapp	Ocean current profiles and bottom temperature and salinity	Bottom frames with acoustic Doppler current profiler to replace above	Norway	?	2

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Isfjorden mouth, Kapp Linné	Temperature, salinity, currents, turbidity	Multi-parameter mooring (Aanderaa RDCP and SeaGuard, Seabird SBE37)	Norway	Existing	2
Hornsund	currents, temperature, salinity	2 fjord moorings (each with RDCP 600 and 2 Microcats)	Poland	?	2
Kapp Lee (Edgeøya)	meteorological station (automated - GSM), T, P, wind, sea ice camera	Campbell Scientific	Norway	Existing	2
Barentsburg	CTD, turbidity	CTD RBR X-640	Russia	Existing	2
Barentsburg	Ocean current, T, depth	Vector	Russia	Existing	2
Grønfjorden	T/S, sea ice and snow physical properties (thickness, temperature, salinity, turbidity, sediment concn.)	Winter – from fast ice Summer – small boat"Barentsburg"	Russia	Existing	2
South West Shelf	Temperature, Salinity. Currents	Single Mooring	Poland	Existing	1
Fram Strait	Temperature, Salinity. Currents	Single Mooring	Poland	Existing	1
Fram Strait	Temperature, Salinity. Currents	Mooring Array	Germany	Existing	1
Eastward extension of the AWI/NPI mooring section in Fram Strait	Temperature, Salinity. Currents	Single Mooring	Norway	Existing	1
Hausgarten	Long term records of temperature, salinity, currents, sedimentation	Mooring	Germany	Existing	1
Under-ice boundary layer	High frequency Temperature, Salinity. Currents for ocean microstructure	Sea ice mounted	Norway	Existing	2
Oceanic	High frequency Temperature, Salinity. Currents for ocean microstructure profiling	Ship	Norway	Existing	2

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Fram Strait (Deep)	Ocean acoustic data	Acoustic Arctic Laboratory	Norway	Existing	2
Fram Strait (WSC)	Mean temperature from tomography	Mooring	Norway	Existing	2
Northern Svalbard slope	Temperature, Salinity, currents	Mooring array (3 moorings)	UK	500	1
Yermak Branch of WSC (west flank of Yermak Plateau)	Profiles of ocean current, temperature and salinity	Array with 4 moorings	Norway	700	2
30 deg E array, north east Svalbard	Temperature, Salinity, currents	Array with 7 moorings	Norway	1300	2
Core of the West Spitsbergen Current	Sea current, temperature and salinity profiles	2 profiling moorings (MMP) with 2 Microcats each	Poland	30	1
Isfjorden, Bellsund, off shelf west of Bellsund/Smeeren-burg, offshelf N of Rijpfjorden, Grøn-fjorden,Erik Eriksen Strait, Frans-Victoria Trough, N Barents Sea, E. Greenland Shelf)	Hydrography, Velocity, zooplankton biomass and vertical distribution, sedimentation, Chlorophyll, sea ice thickness	Moorings: CTD Temperature loggers, ADCP, Sediment traps, Fluorometer	ARCTOS	2500	2
Western Svalbard slope	Current profile with CTD/ fluorescence	Mooring (ADCP and 2 Microcats)	Poland	20	1
Fram Strait	Mean ocean temperature and currents, acoustic signals for glider navigation	Triangle tomography moorings	Norway	250	2
Fram Strait	Hydrography, Velocity, sedimentation, Chlorophyll, oxygen, nutrients	Upgrade of Fram Strait moorings with sediment traps and biological sensors	Norway	500	1
Fram Strait and surroundings	Various horizontal transport variables	Cabled networked FRAM observatory	Germany, Norway?	140000	2
Repeat Sections					
West Svalbard	T/S, Currents	RV Oceania	Poland	Existing	1
Fram Strait	T/S, Currents	Polarstern	Germany	Existing	1
Kongsfjord/KongHau	Temp/Salinity	Various Ships			2
Across Fram Strait	Tracers (S, d18O, N:P, alkalinity), revealing sources of Arctic Ocean freshwater components	CTD rosette water samples	Norway	Existing	1

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Across Fram Strait	Temperature and salinity of Arctic Ocean inflow (WSC) and outflow (EGC): Snapshots each September	CTD	Norway	Existing	1
Fram Strait, line along 79 N across the East Greenland Current	Ice thickness and drift velocity across the Transpolar Drift where it exits the Arctic Ocean: Time series	Four Ice Profiling Sonars and four ADCPs	Norway	Existing	1
Fram Strait along the 79 N line across the EGC and over the East Greenland Shelf	Ice thicknesses across the Transpolar Drift where it exits the Arctic Ocean: Snapshots each September	EM bird and EM31 Electromagnetic measures	Norway	Existing	1
Fram Strait, mooring array across the East Greenland Current at 79 N	Time series of Arctic Ocean outflow in the East Greenland Current (EGC) (temperature, salinities, current velocities)	Arctic Ocean Outflow Observatory (AOBS) (16 microcats, 16 RCMs, five ADCPS, one TS string)	Norway	Existing	1
All research vessels; on moorings on selected marine mammal species on a rotational basis	Temperature, Salinity, Density, Pressure++	CTD	International	Existing	2
All marine areas around Svalbard	Currents, particle movement in the water column	ADCP	International	Existing	2
HAUSGARTEN and Kongsfjord transect	Service cruises – pelagic sampling	Polarstern?	Germany, Norway, UK	Operating 750	1
Hornsund, Isfjorden and **Rijpfjorden** transects	Service cruises (incl. pelagic sampling on Barents Sea Polar front Transect)	Oceania, ?,	Norway, Poland, UK	Operating 250	1
Langrangian and Active Marine Platforms					
Fram Strait	Temp/salinity	ARGO Floats	Poland	Existing	2
Greenland Sea Basin and Lofoten Basin	CTD, dissolved oxygen, fluoresence	ARGO Floats	UK/Norway	Existing	2
Eastern Fram Strait (open water), and Hornsund	High res sections of temperature, salinity, oxygen, other biochemical properties	2 gliders and glider port in Hornsund	Poland	280	2

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Isfjorden, **Rijp-fjorden**, Hornsund, Kongsfjorden; Various locations depending on expedition.	Temperature, salinity, chemical, biological (acoustic) and optical parameters (PAR, chlorophyll, fluorescence, oxygen, pH)	Autonomous underwater vehicles (AUVs)	Norway	2800	2
Various locations depending on expedition.	Temperature, salinity, fluorescence, currents, turbulence	Autonomous Underwater Vehicle	UK	50	2

3. Cryosphere/Geosphere interactions and responses to climate change

Seismicity					
Ny-Ålesund	Earth Ground Movement	Seismometer (STS-1. STS-2)	International	Existing	1
Adventdalen (Jansonhaugen)	Earth Ground Movement	Seismic Array (15 CMG-3T)	Norway	Existing	1
Barentsburg	Earth Ground Movement	Seismometer (2 geophone sites)	Russia	Existing	1
Hornsund	Earth Ground Movement	Short period Seismometer	Poland	Existing	1
Hornsund	Earth Ground Movement	Broadband seismometer (STS-2)	Poland / Norway	Existing	1
Hopen	Earth Ground Movement	Short period Seismometer	Norway	Existing	1
Hopen	Earth Ground Movement	Broadband seismometer (STS-2)	Norway	Existing	1
Bear Island	Earth Ground Movement	Broadband seismometer (CMG-3T)	Norway	Existing	1
Isfjord Radio	Earth Ground Movement	Seismometer (analog)	Norway	Existing	1
Ripfjorden	Earth Ground Movement	Seismometer	Norway	50	1
Pyramiden, **Edgeoya, Nordauslandet**	Seismicity, ice quakes, geohazards, Earth structure	Permanent Seismic stations	Russia, Norway	150	2
Bjornoya, Hornsund	Seismicity, ice quakes, geohazards, Earth structure	Permanent seismic arrays (upgrade)	Norway, Poland	800	2
Longyearbyen, Barentsburg	Monitoring of rockfalls, ice wedges, rock glaciers, avalanches at landscape scale	Microseismic network 1 permanent, 1 mobile	Norway	80	3

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Mobile	Positioning, tectonic and glacial movements	10 unit network of GPS receivers and base stations	Norway	90	3
Mobile	Seismicity, icequakes, geohazards, Earth structure	20 mobile seismometers and datalogger	Norway	460	3
Offshore moorings (*see section 4 also)	Monitoring of seismic events and mammal noise	Broadband hydrophones	Norway	200*	2
Deep Permafrost Monitoring					
Adventdalen	Deep borehole temperature Monitoring. Linked to met station with BSRN upgrade	Permafrost boreholes	Norway	Existing	2
Kap Linné	Deep borehole temperature Monitoring. Linked to met station with BSRN upgrade	Permafrost boreholes	Norway	Existing	2
At sea level and in Svalbard mountains	Permafrost temperature profiles	deep permafrost penetrating boreholes	Norway	700	3
Ny-Ålesund area	ground temperature profile	30 m borehole for permafrost monitoring	Italy	40	3
Various locations	Permafrost parameters	UAV or manned aircraft and INSAR	?	?	2
Glacial Monitoring and Hydrology					
Kongsvegen tidewater glacier	T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction	4 x Automatic Weather Stations (AWS) across glacier	Norway	Existing	2
Holtedahlfonna,	T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction	2 x Automatic Weather Stations (AWS) on ice cap	Norway	Existing	2
Kongsvegen	Meteorological parameters, radiation and energy balance parameters, BSRN upgrade	Met Station	Norway	30	2

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Kongsbreen tidewater glacier	Meteorological parameters, radiation and energy balance parameters, BSRN upgrade	Met Station	Norway?	30	2
Kongsbreen tidewater glacier	T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction	2 x Automatic Weather Stations (AWS)	Norway?	50	2
East coast tidewater glacier to be identified	T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction	4 x Automatic Weather Stations (AWS)	?	80	2
Nordaustlandet, Austfonna, Etonbreen	Global/ reflex radiation, albedo, upward/ downward long-wave radiation, net radiation	Automatic Weather Station (AWS)	Norway	Existing	2
Hornsund area	Snow precipitation, glacier thermal structure and mass balance	Ground penetrating radar (GPR)	Poland	Existing	2
Hansbreen	Glacier dynamics	GPS-stations-automatic	Poland	Existing	2
Hansbreen and selected glaciers	Glacier dynamics Snow cover on tundra	Time-lapse cameras	Poland	Existing	1
Hansbreen	Ice temperature profile: 30m	AWS	Poland	Existing	1
Hansbreen	T, RH, wind speed & direction, p, snow height, global/reflex radiation, albedo, upward/ downward LWR, net radiation. BSRN upgrade?	Automatic Weather Stations (AWS)	Poland	Existing	1
Hansbreen	Basal water pressure, basal sliding indicator, icequake counts, vertical ice, atm. p, snow depth	Glaciological Stations (UBC): Subglacial, englacial and supraglacial sensors	Canada, Poland	Existing	2
Various sites See Meteorological Observations earlier	Precipitation measurements	Advanced precipitation gauge network	Norway	Existing	1
Various sites See Meteorological Observations earlier	Snow measurements	Automated snow monitoring – to be developed.	Norway	Existing	1
Various sites - see earlier Met Observations	Freshwater run-off	Runoff monitoring instruments	Norway, Poland	Existing	2

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)

4. Biodiversity and Ecosystems in vertical and horizontal coupling

Repeat Ocean Sections					
Transects KongHAU, Rijpfjorden, Isfjorden, Hornsund	Mesozooplankton (abundance, community structure, taxonomy)	Multi Plankton Sampler (=Multinet)	Norway, Germany, Poland, Russia, Korea, China, Sweden	Existing	2
Transects KongHAU, **Rijpfjorden,** Isfjorden, Hornsund	Mesozooplankton	WP2	Norway, Germany, Poland	Existing	2
Transects KongHAU, **Rijpfjorden,** Isfjorden, Hornsund	Macrozooplankton	WP3	Norway, Germany, Poland	Existing	2
Transects KongHAU, **Rijpfjorden,** Isfjorden, Hornsund	Macro-Megazooplankton, ichtyoplankton	MIK	Norway, Germany, Poland	Existing	2
Transects KongHAU, **Rijpfjorden,** Isfjorden, Hornsund	Water samples for - nutrient analysis - phytoplankton taxonomy, abundance - pigment measurements	Niskin Bottles	Norway	Existing	1
Transects KongHAU **Rijpfjorden,** Isfjorden, Hornsund	phytoplankton taxonomy	Nets	Norway, Poland	Existing	2
Transects KongHAU, Rijpfjorden, Isfjorden, Hornsund	Chlorophyll a, fluorescence	Fluorometer	Norway, Germany	Existing	2
Transects KongHAU, Rijpfjorden, Isfjorden, Hornsund	Light, Photosynthetically Active Radiation (PAR 400-700 nm)	Li Cor PAR sensor	Norway	Existing	2
Kongsfjord, KongHAU, Hornsund, Bellsund	Infaunal macrobenthos (medium size, restricted mobility)	Van Veen Grab	Norway, Germany, Poland	Existing	2
KongHAU	Macro-megabenthos	Agassiz trawl	Germany	Existing	2

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Geographically dynamic	Detailed positional information, behavior of top trophic levels on a year-round basis	Top trophic levels distribution and foraging behavior	Norway et al.	Existing	2
Eularian Platforms (fixed)					
HAUSGARTEN, Kongsfjorden, Bellsund	Sediment, Meiofauna, Macrofauna	Box corer	Germany, Norway	Existing	1
HAUSGARTEN, Kongsfjorden, Bellsund	Sediments, Meiofauna	Multiple Corer	Germany, Norway	Existing	1
Hausgarten	Benthic fauna	Towed underwater camera (OFOS)	Germany	Existing	1
Hausgarten	Temperature, salinity, div. chemical and biological parameters	AUV	Germany	Existing	1
Hausgarten	Experiments, observations and measurements on the sea floor	Freefalling Lander System benthic lander	Germany	Existing	1
Hausgarten	Oxygen and H_2S concentration, pH and electrical resistivity at the sediment-water interface	In-situ microprofiler	Germany	Existing	1
Hausgarten	Bottom water samples for biogeochemical and microbiological investigations	Horizontal Bottom Water sampler	Germany	Existing	1
Isfjorden, Bellsund, off shelf west of Bellsund/Smeeren-burg, off shelf N of Rijpfjorden, Grøn-fjorden, Erik Eriksen Strait, Frans-Victoria Trough, N Barents Sea, East Greenland Shelf	Hydrography, Velocity, zooplankton biomass and vertical distribution, sedimentation, Chlorophyll, sea ice thickness	Moorings: CTD Temperature loggers, ADCP, Sediment traps Fluorometer - link to Kongsfjorden and Ripsfjorden moorings	ARCTOS partners	2500	1
Kongsfjorden, (eventually all others)	Hydrography, Velocity, zoo-plankton biomass & vertical distribution, sedimentation, Chlorophyll, real time transmission	cabled moorings (additional instruments: MMP profilers, Echo-sounder. Link to Moorings in Section 2 above	ARCTOS partners	250	1

Location	Parameters	Platform	Possible Lead	Budget -k€	Priority (1, 2, 3)
Kongsfjorden, Fram Strait	Zooplankton, fish, hydrography , Chlorophyll div. organic and inorganic compounds Benthic fauna Sedimentation	Benthic lander: Echosounder, CTD, Fluorometer, Chem. sensors, video, hydrophones, sediment traps	ARCTOS partners	375	2
Fram Strait	Hydrography, Velocity, sedimentation, Chlorophyll, oxygen, nutrients	Upgrade of Fram Strait moorings (Section 2) with sediment traps and biological sensors	Norway	500	1
Offshore moorings (*See section 3 also)	Monitoring of mammal noise	Broadband hydrophones	Norway	200*	3
Langrangian and Active Marine Platforms					
Isfjorden, Kongsfjorden,Fram Strait, Hornsund	Temperature, salinity, diversity. chemical, biological and optical parameters (PAR, chlorophyll, fluorescence, oxygen, pH)	Underwater robots and sensors, Gliders – link to robots/gliders in Section 2 above	Norway	500	2
Marine mammals Svalbard	Hydrography, mammalian distribution, habitat choice	CTD-PPT tags (animal borne tags)	Norway	400	2 or 3
Terrestrial Infrastructure					
East-West transect for terrestrial monitoring (Ny Alesund, Ripfjorden	Micro-meteorology of sites	Micro-met station linked to met stations	Norway?	50	2
Various sites – Ny Alesund, Kap Linne, Hornsund, Ripfjorden Adventalen		Mobile laboratory Container for biological work	Norway	100	3
Satellite study sites around Ny Alesund	Logistical support for land based fieldwork	Research Huts on Brogger Peninsula	Norway (Kings Bay?)	50	2

The infrastructure listed above represents a first cut of the infrastructure required to establish the core elements of an integrated Earth Observing system. A substantial component of the infrastructure listing proposed here is made up of existing facilities that will be required to work more closely and to channel their data through the portal of the Knowledge Centre. It is anticipated that all the various facilities will be assessed, once SIOS has started, to establish how effectively instrument groupings are addressing relevant questions.

The SIOS infrastructure will evolve over time as system modelling of observations refocuses the key questions and new technologies facilitate different approaches. There are many science issues to address in and around Svalbard and these can contribute to SIOS science but the focus here has been on identifying core observations that deal with Earth System issues, at a regional scale and that are impacting the Arctic and lower latitudes over time scales of years to decades. Variables measured in the core measurement set relate to Earth System scale issues that research on Svalbard appears well placed to address.

Efforts elsewhere to establish regional scale monitoring in the Arctic illustrate that starting from scratch may produce a well-honed observational structure but that it takes many years to bring together and to populate the various infrastructural elements. SIOS therefore has a significant advantage in being already well appointed with monitoring instrumentation.

Some of the shortcomings in existing infrastructure for Earth Observation have been already identified and proposals for upgrades or replacement of some infrastructure have been added to the tables above listing infrastructure. New capabilities (such as the use of gliders or unmanned aircraft (UAV's)) have also been proposed which will significantly enhance the capabilities of SIOS, albeit the specific use these would be put to were not always indicated in the Gap Analysis. Regular review will be necessary to keep abreast of new technical capabilities and changing research emphasis.

The new (and upgraded) infrastructure listed in the following tables on page 56-59 are:

(a) Priority 1 and 2 items extracted from the main tables

(b) Priority 3 items that support and complement the core monitoring activities.

Priority 1 infrastructure is required to fill perceived gaps in the existing monitoring framework and does not require a particularly substantial financial input and could be in place relatively soon. The Priority 2 infrastructure substantially enhances the science capabilities of Svalbard infrastructure but will likely take time to put into place.

Only ten nations are currently identified against these infrastructure items and Norway is identified as a possible lead in many cases as it has significant involvement in all these research areas and a substantial number of independent organisations (NPI, NMA, NMI, NILU, IMR, etc.,) on Svalbard whilst other nations have more limited numbers of individual organisations contributing to Svalbard. This disparity in funding commitment is not appropriate for a genuinely international programme and it is to be hoped that other nations will take the opportunity to invest alongside Norway in the SIOS infrastructure, as in the case of the SvalRak rockets, and so build a truly international world-class set of monitoring facilities.

New or Upgraded SIOS Monitoring Infrastructure		Possible Leads	Nor	Swe	UK	Ger	Pol	Ita	Fra	Rus	Jap	USA	Int
(Priority 1 and 2 items)													
Vertical Coupling	**KEuros**	**Comments**											
Dynasonde	100												
SOUSY upgrade	300												
MST Radar	?	No specific lead											
Ionosonde	?	No specific lead											
SvalRak Rockets (7 years funding but 5 shown here)	16000	Rockets for 5 years											
Scanning Doppler Imager	300												
2x Daylight Auroral Imagers	1000												
2x Airglow Imagers	200												
Auroral Spectrographs	1000												
Optical instruments for Hornsund – to be specified	?	No specific lead											
Zepplin aerosol instrument suite upgrade	420												
Aerosol Raman, Lidar at Hopen	150	No specific lead											
Sun Photometer at Hopen	30	No specific lead											
UAV equipped for black carbon, aerosols, etc.	?	No specific lead											
13 Met stations with BSRN **P1**	325												
Met station/BSRN/Synoptic Meteorology at Hornsund **P1**	30												
Precipitation gauging - 8 sites	600												
5x Ice buoys with AWS	325												
Automated snow monitoring -5 sites	300												
Sea-ice - snow monitoring -UAV based?	300												
Freshwater run-off from glaciers **P1**	350												
Seafloor Methane Site _AOEM instrument	300	No specific lead											
Fram benthic moorings/platforms-C Cycling	36000												
Ripfjorden mooring - sedimentation traps	30												

			Nor	Swe	UK	Ger	Pol	Ita	Fra	Rus	Jap	USA	Int
Horizontal Transport	**KEuros**	**Comments**											
Meteorological flux towers	325	Already in place?											
GHG and Pollutants sampling - Barentsburg	150	150Kpy OC											
Mercury/POPS sampling - Barentsburg/Pyramiden	350	350Kpy OC											
Upgrading of existing moorings, Kongsfjorden/N shelf	350	Over 5 years											
Installation of cabled mooring, Kongsfjorden	1000	Over 5 years											
Current/T/Salinity profiling - Storfjorden/shelf break	50	Over 5 years											
Currents/T/S - 2x fjord mooring, Hornsund	30												
Currents/T/S - 3 moorings - N Svalbard slope **P1**	500												
Array of 4 moorings Currents/T/S - Yermak Branch	700												
Array of 7 moorings Currents/T/S - 30°E array	1300												
2x moorings - Curren/T/S - West Spitsbergen Current **P1**	70	Plus 5 yrs support											
7x Moorings physical/biological – ARCTOS	2500	*Also for biology											
Mooring - ADCP/Microcats - W Svalbard slope **P1**	170	Plus 5 yrs support											
Triangle tomography moorings	250												
Upgrade of Fram Strait moorings- bio sensors/traps **P1**	500												
Cabled networked FRAM observatory	140000	From 2017?											
Hausgarten/Kongsfjord transect – service cruises **P1**	3750	Ship time for 5 yrs											
Service cruises (Hornsund/Isfjorden/Ripfjorden **P1**	1250	Ship time for 5 yrs											
2 gliders/glider port - E Fram Strait/Hornsund	320	And 5 yrs support											
AUV's - various locations	2800	***Link to biology											
AUV - various locations – use existing UK units	50												

			Nor	Swe	UK	Ger	Pol	Ita	Fra	Rus	Jap	USA	Int
Cryosphere/Pedosphere	**KEuros**	**Comments**											
Seismometer – Ripfjorden **P1**	50												
Seismometers - Pyramiden/Edgeoya/Nordauslandet	150												
Fixed seismic arrays upgrade - Bjornoya/Hornsund	800												
Broadband hydrophones on moorings	200	**Also biology below											
Permafrost borehole - Ny-Alesund	40												
Permanent GPS – five sites (NMA)	170	And 5 years support											
Glaciological studies - AWS - Kongsvegen	30												
Glaciological studies - AWS x3 - Kongsbreen glacier	80												
Glaciological studies - AWS x3 - East coast glacier	80												
Biodiversity and Ecosystems													
Moorings for biological studies -7 sites – ARCTOS **P1**	*	See * above											
Kongsfjorden cabled mooring/instruments – ARCTOS **P1**	250												
Benthic Lander and instruments - ARCTOS	375												
Upgrade Fram Strait moorings with bio sensors/traps **P1**	500												
Broadband hydrophones on moorings	200	See **											
Gliders/AUV's with bio sensors - various locations	500	Links to ***											
CTD-PPT tags for marine mammal studies	400												
East-West terrestrial transect - micromet stations	50												
2x Field laboratories - green energy - mobile	100												
Research Huts on Brogger Peninsula - green energy	50												
Total P1 infrastructure costs	**7,745**												
Total P1/P2 excluding Cabled FRAM Array	**78,500**												
Total including Cabled FRAM Array	**218,500**												

New Infrastructure for SIOS Activities (Priority 3 items)		**Possible Leads**	**Nor**	**Swe**	**UK**	**Ger**	**Pol**	**Ita**	**Fra**	**Rus**	**Jap**	**USA**	**Int**
Vertical Coupling	**KEuros**	**Comments**											
SuperDARN HF ionospheric radars for Svalbard	1500												
Horizontal Transport													
AUV's - various locations depending on expedition	2800	***Link to biology											
AUV - various locations – use existing UK units	50												
Cryosphere/Pedosphere													
Microseismic network - Longyearbyen, Barentsburg	80												
20x mobile seismometers and data logger	460												
Broadband hydrophones on moorings, seismics	**200	**Also biology below											
Deep permafrost boreholes, coastal and mountain sites	700												
Permafrost monitoring - UAV- airborne InSAR?	?	No specified lead											
Absolute gravimeter – 10 sites (NMA)	20	And 5 years support											
Glaciological studies - AWS - Kongsvegen	30												
Glaciological studies - AWS x3 - Kongsbreen glacier	80												
Glaciological studies - AWS x3 - East coast glacier	80	No specified lead											
Biodiversity and Ecosystems													
Broadband hydrophones on moorings - mammal noise	**	** Also for seismics											
General Facilities													
Mobile field laboratories – green energy	200	No specified lead											
Total for Priority 3 Activities	**5,300**												

Implementing the SIOS Research Infrastructure

The foundation documents for the SIOS-RI implementation are:

D3.1 – Reports and Synthesis of the Gap Analysis Groups

D3.? – Infrastructure Prioritisation and Optimisation Report

These will form a basis for discussions between the SIOS Coordinator (RCN) and potential partners towards the end of the preparatory phase to explore potential commitments to SIOS infrastructure but the detailed development of the infrastructure across Svalbard and the contributions of the SIOS membership will be undertaken in the subsequent phases leading to a fully operational SIOS.

The suggested time plan for the implementation phase of the SIOS Infrastructure and Observational programme is three years (2015-2017), followed by a 3-year development phase ahead of SIOS becoming fully operational in 2021.

It is assumed here that the implementation work will start with a set of workshops in early 2015, following the completion of the SIOS Preparatory Phase in September 2014, with coordinated observations hopefully being initiated in 2016**.** Since many of the formalities need to be coordinated and supported through the SIOS Knowledge Centre and associated committees, the SIOS KC will have to be established ahead of the infrastructure implementation work beginning.

The prioritisation scheme developed for the SIOS Infrastructure to inform the participants in the programme identifies three categories of prioritisation and the Priority 1 items represent those instruments and facilities that are considered to be necessary for the establishment of an initial observational system within the Svalbard archipelago and its surrounding ocean waters. These would be included with existing infrastructure to form the basis of a credible system in the implementation years of SIOS. This system would then provide a foundation for further development of the Earth System observing system and the subsequent addition of Level 2 priority infrastructure. These would be identified by the SIOS science management structure and approved by the General Assembly to enhance and evolve the observational programme.

Infrastructure Investment

Approximately €8m of Level 1 priority infrastructure investment has been identified. The majority of the 13 Level 1 priority items relate to upgrading of the marine observation infrastructure as much of the required land-based observational infrastructure is already in place.

The prioritised new items have been nominally identified through the gap analysis study as being potentially funded either by Norway or by Norway in conjunction with other SIOS partners. Seven of the priority 1 items have been identified as possibilities for joint funding between Norway, Germany, Italy, UK and the international consortium (ARCTOS).

The three items with no Norwegian financial involvement are:

a) Three moorings on the North Svalbard Slope attributed to UK,
b) Two moorings in the West Spitsbergen Current and further moorings on the West Svalbard Slope attributed to Poland, and
c) Bio-sensor upgrades for existing Fram Strait moorings attributed to Germany.

In some cases the infrastructure is at an institutional rather than funding agency or national level. Organisations such as the Norwegian Meteorological Institute (NMI) and the Norwegian Mapping Authority (NMA) have indicated an interest in purchasing observational facilities (remote weather stations, seismometers) and these facilities map well onto the observational network described in this report. However the majority of the items in the infrastructure prioritisation lists are necessarily the concern of national funding agencies, all of which have their own national priorities but will also have signed up to SIOS and its objectives.

The financial attribution to national partners provided in this document is purely indicative and the large proportion attributed to Norway largely reflects the dominance of Norwegian researchers in the gap analysis groups. Attribution needs to be formally discussed by the SIOS partner nations to establish agreement on the items identified in the prioritisation scheme and to identify which nations take responsibility for delivering each specific infrastructure item.

With Norway there has been a national process to establish its own SIOS infrastructure prioritisation list that has taken account of the lists provided by the current document. This will be made available in the near future. Other nations (e.g. Germany and the FRAM array) have also given consideration to potential infrastructure investments but most nations are yet to undertake the process of evaluating proposed SIOS infrastructure and decide on what facilities they are prepared to contribute to the project.

Implementation of the SIOS-RI Plan

Human Resources to Administer the SIOS-RI Scheme

There is a clear need for a committee to be established that represents the scientific and station/facility assets of SIOS and which can manage the SIOS infrastructure. It has been proposed by Work Package 2 (Governance) that a Research Infrastructure Coordination Committee (RICC) should be created with responsibilities for developing the detailed SIOS observational plan that utilises the research infrastructure and also advises on how this infrastructure evolves over time. Whilst the SIOS Infrastructure Optimisation Report outlines a fully integrated Earth observational structure there are practical requirements in managing such a complex system that WP2 proposes will require some division of the administrative responsibilities. A number of Observatory Operator Groups (OOG) is envisaged, each focussing on a particular broad science area, which would establish a forum

*The **Climate Observatory**, including hydro-meteorological, radiation, and greenhouse gas related observations;*
*The **Solar-terrestrial Observatory**, covering upper atmosphere and solar-terrestrial exchange processes;*
*The **Pollution Observatory**, covering pollution issues in the atmospheric, marine and biota environment;*
*The **Marine Observatory**, including water column, sea-floor and sea-ice observations;*
*The **Geophysical Observatory**, including glaciological, permafrost, geomorphologic, seismological and geodetic observations;*
*The **Terrestrial Ecosystem Observatory**, including soil-related activities.*

for scientific expertise in each field. These Groups would each have an Observatory Coordinator who represented the Group on the RICC. The OOG's can provide a source of detailed information on research questions and on-going management and development of infrastructures that would advise the RICC. It will however be important that the RICC ensures that the infrastructure and research integration at the heart of the SIOS Vision is not compromised by different OOG voices. An independent RICC chair will need to be appointed for a defined period of office, supported by the SIOS-KC science coordinator, acting as committee secretary. The RICC and its chair will also draw on the expertise available from the independent SIOS Scientific Advisory Board (SAB).

Within the SIOS-KC a scientific coordinator post has been identified and he or she would be a full time post playing an important role in organising workshops and meetings of the Observatory Operators Groups and RICC and working with the KC Director and the SAB in the task of reviewing SIOS science and providing advice to the programme. Assuming that the SIOS-KC becomes active early during 2015 and a science coordinator and administrative staff are appointed, there will then be administrative support to organise workshops for the Observatory Groups and the RICC to meet early during the first year of implementation to establish with the SIOS research community the basis for a long term observational programme.

The SIOS-KC staff directly relevant to the RI implementation are recognised within the KC implementation plan and have been costed there. The membership of the RICC and the OOG's is supplied from the membership and the members are responsible for the expenses of their nation's participants to committee meetings. The SAB membership will have expenses in attending SIOS meetings and these are costed into the SIOS-KC implementation plan.

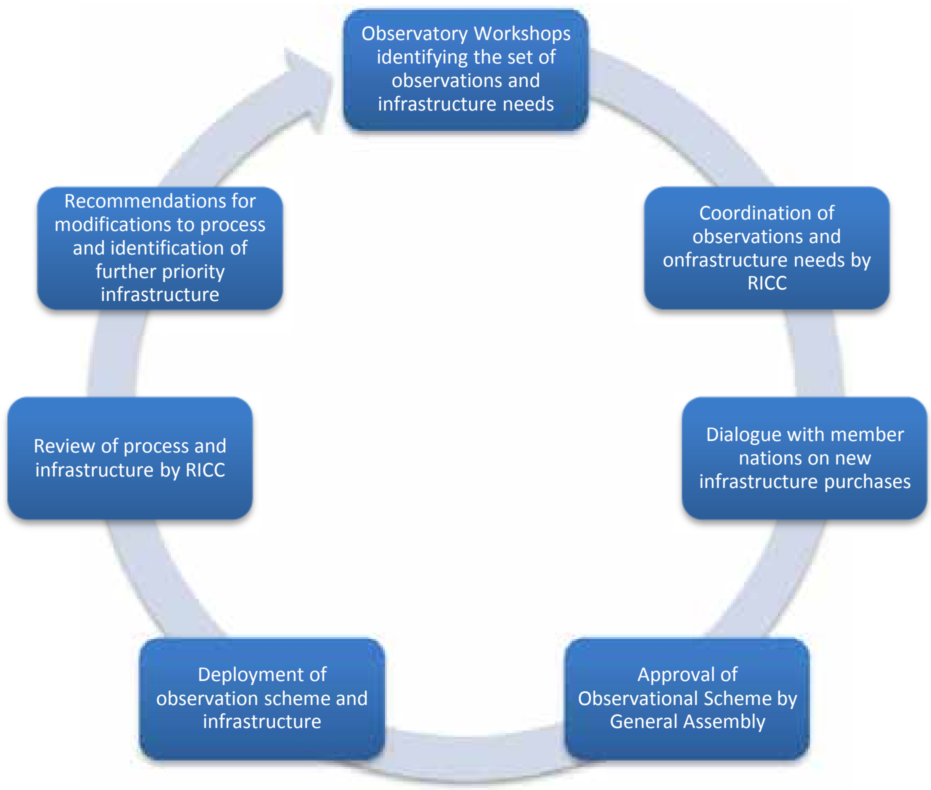
Discussions within the Observatories Groups would identify the forms and quantities of data anticipated to emerge from the initial observational programme work and in conjunction with SIOS-KC data management staff establish a process for the data to be accessible through the SIOS Data Portal. The SIOS-KC implementation plan includes the staffing to support data administration for the observational programme.

Structuring the Observational System

The Optimisation Plan provides a framework for establishing a geographically defined distributed set of instruments across Svalbard and, though the plan is not anticipated to be fully implemented in the first 2-3 years, a basic structure that follows the Plan will be established to begin coordinated observations using identified instruments that already exist on Svalbard.

The Optimisation Plan identifyies a set of first priority (P1) instruments required to augment existing instruments and establish a more coherent observational system and these are suggested as a focus for early purchase and installation during the implementation and development phase. These are few in number and overall costs are around €8m. A number of these instruments (notably the establishment of new or upgraded automated weather stations and geodetic instruments) are already established in the planning of infrastructure developments by NMO and NMA but others are still to be firmly identified as upcoming targets in the financial planning of various nations involved in the SIOS-PP.   Further lists of additional instrumentation (Priority 2 and 3) provided by the Optimisation Plan would allow the range of observations to significantly expand and facilitate further science in later years. Again some of these, such as the proposed purchase of sounding rockets, are already in the early plans of various SIOS-PP members who could be involved in the operational SIOS.

Whilst the Plan provides a workable scheme for establishing an integrated Earth Observing System, it is recognised that with operating experience, it's recommendations will almost certainly not prove entirely appropriate for all circumstances and will need further structuring or tuning to provide the most effective observational solution. It is therefore anticipated that once an observational framework has been set up that the Observatory Groups and the RICC, in conjunction with input from the SAB, regularly monitor the effectiveness of the observational system, consider the need for upgrading of the existing research infrastructure, suggest possible new research instruments and bring a report on the observational system and a prioritised list of new instrumentation to the General Assembly. This process would keep the General Assembly membership aware of the research priorities perceived by the SIOS management and would continue through into the development and operational phases of SIOS in order to steadily refine the observational programme.



Acquisition of Additional Research Infrastructure

The SIOS programme is committed to individual nations having ownership of the research infrastructure on Svalbard. Each member nation has its own distinct national priorities for both research areas and new research infrastructure and they will be looking to identify clear additional value for including scientific instruments/facilities in their national research infrastructure priorities that also make infrastructure contributions to SIOS. A key to this will be the establishment and maintenance of regular communication between SIOS management and the SIOS membership. It is essential that there is an on-going commitment of nations to the SIOS vision, to its focus on decadal scale observational systems and the wide-ranging importance of Svalbard in the Arctic regional research landscape. The latter particularly refers to SIOS being a major component of a multi-hub pan-Arctic observational network where European and Asian nations can genuinely play a leading role through the establishment of the Svalbard Earth observing system.

Most of the instrumentation identified in the SIOS-RI Optimisation Plan can be readily purchased by individual nations and the Plan includes some tentative initial indications of which countries could contribute such equipment though this needs much more detailed consideration through international discussion. Some instruments have relevance to a much broader range of nations and examples of such equipment include sounding rockets, undersea observatories and large radars such as SUPERDARN. The EISCAT radars are another example which is already an established international facility. Again tentative suggestions for possible nations to contribute to such infrastructures are given in the Plan.

Other infrastructure contributions could include nations working cooperatively with their research vessels to occupy a series of oceanographic stations around Svalbard. New ideas for cooperation on observations could involve sharing use of UAV's and AUV assets or providing their own versions of these assets to maintain observations in and around Svalbard and both reduce the pressure on ships and manned aircraft to undertake observations and substantially reduce operational costs whilst potentially increasing the operational window. The proposed deployment of an annual floating sea-ice camp and a fleet of oceanographic gliders from the upcoming new Nord research station on north-east Greenland could be a valuable collaboration for SIOS which could link with various research interests in the Fram Strait ocean system.

There are proposals under the SIOS Access to Facilities scheme to develop projects that address an agreed research topic, such as snow distribution and structure in and around Svalbard and its impact on key environmental processes. Nations would contribute to such a project through supporting the project costs and providing access to relevant instrumentation, logistics etc., but could also use the opportunity to contribute new infrastructural assets that assist the project during the operational window.

Some of the infrastructure suggested in the Optimisation Plan, such as UAV's and AUV's would not necessarily be needed at Svalbard continuously and so, for example, could be deployed by a nation to support a given SIOS project activity for a fixed period and then re-deployed elsewhere in the Arctic (or Antarctic) in support of other projects. These assets need not necessarily have been purchased new for SIOS activities but rather have been re-deployed from activities elsewhere. As such these could represent an in-kind contribution to SIOS.

It is suggested that the RICC bring recommendations for new infrastructure to the General Assembly and member nations can then consider these proposals in the context of their national funding priorities. It takes time to work through a national funding process and so a coordinated timely approach to identifying infrastructural needs to feed into national prioritisation systems must be a requirement for SIOS. Nations can also bring their proposals for infrastructure to SIOS and these should be discussed at the RICC before coming formally before the General Assembly.