Svalbard Integrated Arctic Earth Observing System - Infrastructure development of the Norwegian node (SIOS-InfraNor)

Project owner: University Centre in Svalbard (UNIS)

Project leader: Dr Ole Jørgen Lønne (UNIS and Director of SIOS)

Webpage with additional and relevant information: www.sios-svalbard.org

Category

X Advanced scientific equipment/facilities (2-200 mill NOK)
X Participation in international research infrastructure (ESFRI or other)

1. Relevance to the call for proposals

Brief description of the relevance to the call
Environmental change is one of the most important challenges facing humankind and nature today. Global climate models demonstrate that Polar Regions play a crucial role in the Earth's climate system. The Arctic region will probably experience the most severe climate change worldwide with an anticipated warming of four to eight degrees (annual average) and a significant increase in precipitation by the end of the 21st century. Svalbard is consequently an important arena for investigations of environmental and climate change.

The Svalbard Integrated Arctic Earth Observing System (SIOS) is a distributed world-class research infrastructure, included in the ESFRI roadmap, that will develop a regional observational system in and around Svalbard. Based on new and existing research infrastructure owned by its member institutions, SIOS will aid in addressing Earth System Science questions related to Global Change. The proposed project *SIOS-InfraNor* aims to expand and improve the Norwegian node of SIOS. SIOS offers single-point access to infrastructure, tools and services as well as providing continuous development of methods, ground-based observations and a substantial capability for utilizing remote sensing resources. SIOS will link with other observational infrastructures across the Arctic to share data and best practice, thus contributing to a pan-Arctic observational structure that facilitates better regional modelling and understanding of the role of the Arctic in the Earth System.

Relevance of the infrastructure with respect to existing national and international research strategies
Norway proposed SIOS as one of three initiatives for the ESFRI roadmap in 2008. At that time it was estimated that there was a need for investments in the range of 400 MNOK in infrastructure to fulfil the concept of a fully operational regional observation system. SIOS remained on the 2016 ESFRI roadmap update of research infrastructures (http://www.esfri.eu/roadmap-2016), and has the ambition to be an ESFRI landmark infrastructure at the time of the next evaluation (2018). SIOS preparatory phase (2010-2014) was funded by EU as an international infrastructure project with 26 partners from Europe and Asia. The ongoing interim phase (2015-2018) is funded by the Research Council of Norway (RCN), with in-kind contributions from the international member institutions.

SIOS is on the 2016 RCN Norwegian roadmap for infrastructure as a national priority, and Norway has committed itself to establishing the SIOS consortium as an independent legal structure by the end of 2016 (Meld. St. 32 (2015–2016), Stortingsmelding om Svalbard). We consider SIOS to be on track to become an important node in Arctic observing networks and regard SAON (http://www.arcticobserving.org) as an important ally and facilitator.

2. Status of current research and infrastructures

Arctic research and monitoring has a long and strong tradition in Norway. As an example, the atmospheric monitoring programme started in the 1970s and has gradually been extended to cover pollution, aerosols and the whole spectrum of greenhouse gases. Ny-Ålesund is one of the global atmospheric supersites; its data are supplied foremost by the Zeppelin Observatory with strong support from observations by AWI (Germany), CNR (Italy), NIPR (Japan), and KOPRI (Korea). In the field of upper atmosphere research, Svalbard has developed into the foremost platform worldwide for studying high-latitude ionospheric phenomena, especially aurora and dynamics. The most important steps towards this status have been the establishment of the

EISCAT Svalbard Radar and the Kjell Henriksen Observatory near Longyearbyen and the SvalRak rocket launch facility in Ny-Ålesund. Another major and international leading initiative is the establishment of the Climate-Ecological Observatory for Arctic Tundra (COAT), a network for ecosystem observations in Northern Norway and Svalbard, which is integrated with SIOS. In marine science Svalbard has developed into an international research platform, and currently serves as a major node in monitoring the in- and outflow of sea ice and water masses from the Arctic Ocean. In an Earth System Science perspective, Svalbard is a key international arena to monitor, study and understand how climate change is affecting the biosphere, cryosphere, atmosphere and hydrosphere.

However, despite substantial international focus and cooperation, research is still somewhat fragmented and insufficiently coordinated, which reduces its usefulness for Earth System Science. A gap analysis carried out in the early phase of the SIOS initiative (2009-2011) identified 11 key topics SIOS should address, and thus formed the basis for the ensuing process of prioritizing new infrastructure to be implemented through SIOS. The SIOS observing system proposed here builds on these documents and on the existing infrastructure owned by Norwegian and international consortium partners. Developing the research infrastructure relevant for SIOS is a long-term challenge in close interplay with initiatives from the international partners. In this application there is a dual emphasis on upgrading existing and establishing new infrastructure, such that it produces a more coherent dataset among sites with similar instruments. It also focuses on investing in new technology that will reduce the footprint of future scientific activities in Svalbard, e.g. by using unmanned vehicles to map ocean characteristics, see Module 3.

The SIOS observing system is a distributed network of infrastructures that will be substantially strengthened by the proposed infrastructure (Figure 1). The infrastructure is owned by SIOS partners, but coordinated and made available for use by the SIOS Knowledge Centre (SIOS-KC) already established in Longyearbyen.

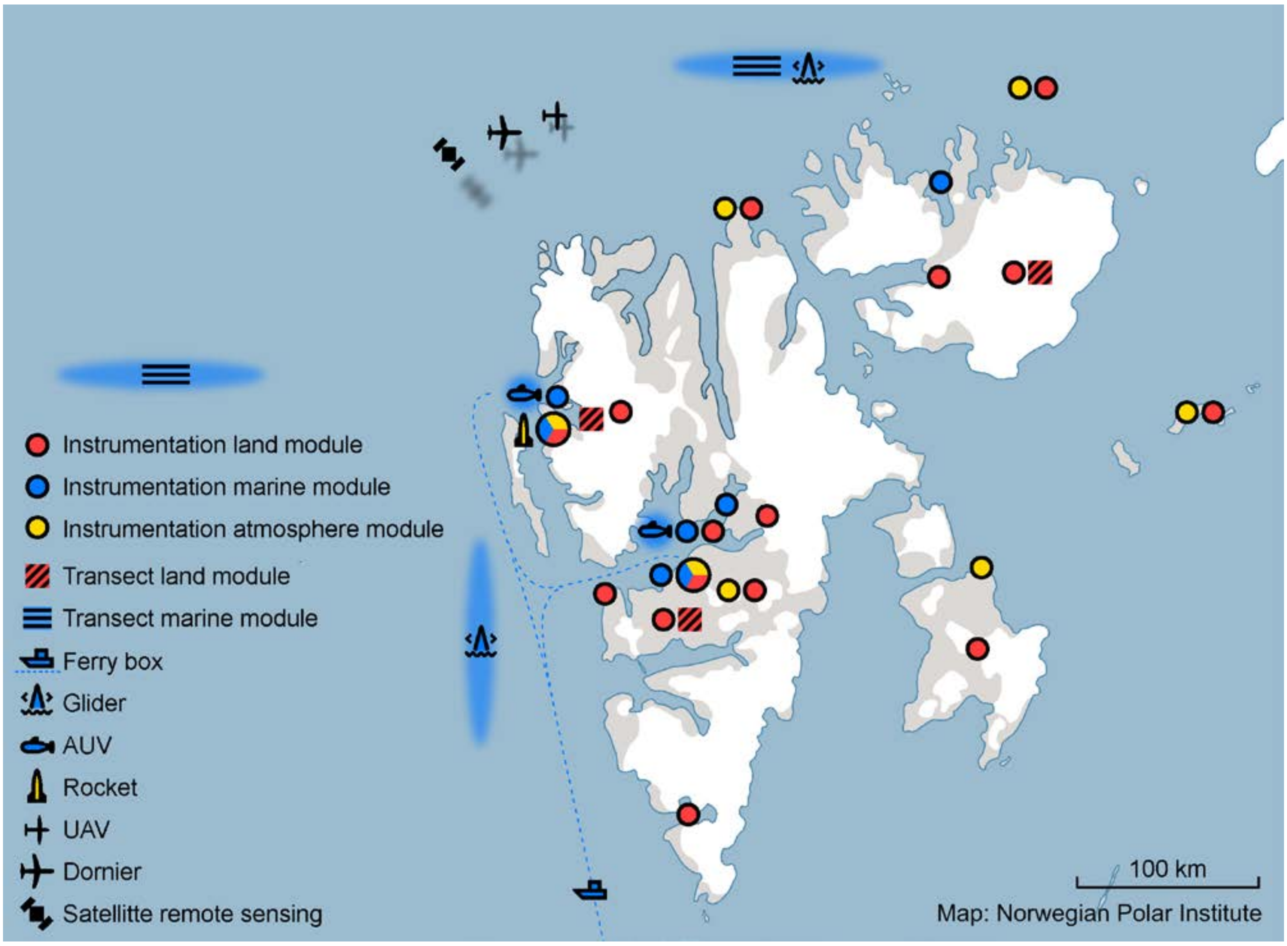

Figure 1: The proposed distributed installations within the atmosphere, terrestrial, ocean and common modules. Map by Anders Skoglund (NPI).

3. Description of the Research Infrastructure

In order to be consistent with the thematic division in the Norwegian SIOS prioritization report (Mehlum et al 2013: Svalbard Integrated Arctic Observing System – SIOS – Anbefalinger fra prioriteringsgruppen for nasjonal forskningsinfrastruktur i SIOS; hereafter Mehlum et al 2013), we divide our proposal into 6 modules: Modules 1-4 (Atmosphere, Land, Ocean and Common infrastructure) contain scientific infrastructure priorities, Module 5 deals with data management and handling, and Module 6 with project management. Within each module, each instrument or instrument-carrying platform has its own owner and responsible institution; only metadata and data access are the responsibility of SIOS-KC:

Module 1: Atmosphere, Leader: Dr GH Hansen (NILU)
Module 2: Land, Leader: Dr G Moholdt (NPI)
Module 3: Ocean, Leader: Professor J Berge (UiT)
Module 4: Common infrastructure, Leader: Professor R Storvold (NORUT)
Module 5: Data management, Leader: Dr Ø Godøy (Met.no)
Module 6: Management, Leader: SIOS-KC director Dr OJ Lønne (UNIS)

The overarching goal of SIOS is to address the coupled Arctic system and support Earth System Models, but for the process of instrument implementation, a discipline-based modular approach is most reasonable. A key innovation within this infrastructure is that the data and remote-sensing module will be designed so that Earth System Science studies in Svalbard will have access to near real-time data (preferably "on-line"), and can be interactively adjusted based on information products with continually updated content regarding the state of the surroundings.

The different infrastructures and the coordination between them have a common set-up phase of five years, followed by a five-year operation phase. This is equivalent to the planned set-up phase of the SIOS-KC. Some infrastructures may need a shorter time to be up and running, but to optimize data harvesting between sensors and activities we find it important that all partners have a common development phase. For all modules, we follow the recommended priorities in Mehlum et al 2013.

3.1 Module 1 - Atmosphere

The proposed new atmospheric infrastructure addresses issues closely linked to the land and ocean modules regarding meteorology, climate, surface energy/radiation processes and their impact on Arctic ecosystems, as well as trace gas and aerosol characteristics and transport. In addition, there is a strong need to better understand the coupling between space and the upper and lower atmosphere. This coupling is most pronounced in the polar cap region, and Svalbard is at a particularly well-suited location for efforts to strengthen understanding. The atmospheric module is organized in four thematic sections.

3.1.1 Network of meteorological/climate observatory stations

State-of-the-art meteorological stations, supplied with additional equipment addressing the radiation climate, are the backbone of any Earth System observation network. The Norwegian Meteorological Institute (MET) is currently operating 9 automatic weather stations (AWS) in Svalbard as part of the operational observing network. The data are of great value for atmospheric, coastal/marine and terrestrial science. We will enhance the utilization of the existing infrastructure by upgrading existing stations with additional sensors: short and long wave radiation sensors (pyranometer, pyrgeometer); sunshine duration sensors; infrared surface (skin) temperature sensors. This requires an upgrade of the energy supply for the stations. Permafrost sensors will be added to selected AWS (see terrestrial module). In addition, we will invest in two mobile AWS that can be deployed in connection with field campaigns on land and on marine vessels.

3.1.2 Vertical coupling processes in the atmosphere from ground to space

Vertical coupling in the atmosphere is a complex interplay of processes over a wide range of spatial (cm to hundreds of km) and temporal scales (seconds to months), some of which, in addition, involve large-scale horizontal transport processes. We will investigate processes that are crucial for vertical coupling. Svalbard is already very well equipped to perform such studies, but to close SIOS knowledge gaps related to "Energy transport through the atmosphere", there is a need for sounding rockets. Multi-scale coupling processes are considered to be of critical importance, and the small scale processes need to be explored further. We suggest covering the ionosphere by sounding rockets with 3D measurements to complement existing ground-based infrastructure (Figure 3). The rockets will be launched from Ny-Ålesund. Each payload will be equipped with 12 daughter payloads, which allow 3D observations. With this innovative technique we can uniquely discriminate between waves and turbulence phenomena, and in particular study the role of turbulence in upper atmosphere layer coupling and energy dissipation. In the ionosphere, instabilities and turbulence (referred to as ionospheric space weather) give rise to disturbances in communication and GPS systems. SIOS rockets will provide key measurements to develop ionosphere space weather forecasts to predict availability and quality of satellite signals.

The primary turbulence parameter in this context is the electron density (N_e). The 4D space module has already been invented by the Andøya Space Center, and UiO has invented the instrument technology. We propose to develop Hotel-Payloads for 2 rockets, where each payload will be equipped with 12 daughter payloads, both to be launched in winter 2018, as part of the Grand Challenge Initiative - Cusp (GCI-Cusp). This campaign comprises one JAXA rocket and five NASA rockets, in addition to the above-mentioned SIOS-rockets, and the aim is to launch configurations of four rockets simultaneously, two from Andøya towards and over Svalbard (horizontal coverage of the energy input from the solar wind) and two vertically from Ny-Ålesund to observe the atmospheric effects of the solar wind energy input. With the two Norwegian rockets the GCI-cusp will cover the altitude range from 60-1200 km. Coordinated rocket campaigns with several rockets in the air at the same time, will offer unparalleled opportunities to conduct 4D space observations (time variation of 3D multi-scale dynamics).

In addition, we will upgrade and extend existing ground-based infrastructure to enhance the value of detailed rocket-borne process studies. This includes refurbishment of the SOUSY MST antenna array, riometers, and two ionosonde antennas, as well as installation of a new scanning Doppler imager to provide ionospheric wind information. The combined investments on rocket-borne in-situ and ground-based observations will provide a unique infrastructure that will be valuable for the GCI-Cusp coordinated campaigns with JAXA and NASA.

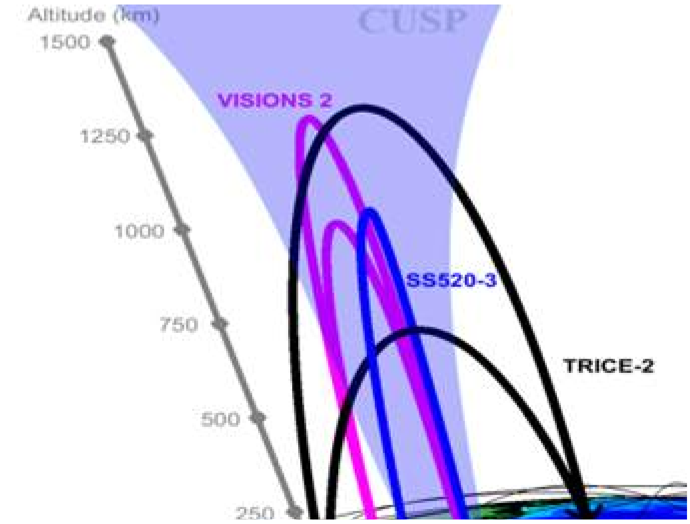

Figure 2: Assembly of rockets to be launched within the framework of the GCI-Cusp program. Rockets and payloads applied for through *SIOS-InfraNor* will add to this program and manifest a strong Norwegian participation in this worldwide cooperation.

3.1.3 Radiation and energy budget in the Arctic troposphere

In the lower part of the Arctic atmosphere, the (near-surface) energy and radiation budget is a highly critical and yet uncertain issue for the future development of the Arctic climate system. Current climate models have severe problems reproducing realistic conditions in this region. *SIOS-InfraNor* will address: (1) Arctic aerosols - formation, composition, physical properties, and their impact on albedo and atmospheric energy budget; and (2) Arctic clouds - formation and development, cloud physics and their importance for the energy budget in the Arctic as well as the vertical stratification of the Arctic troposphere/boundary layer. The aerosol observation programs at Zeppelin Observatory, the AWIPEV NDACC Observatory, Sverdrup Station and other international programmes in Ny-Ålesund are already comprehensive. We will add three instruments to fill important gaps in the observation capacity: (1) A lunar photometer which will provide aerosol optical density (AOD) observations during the polar night in periods of moonshine and thus enhance our knowledge of the development of, e.g., Arctic haze during the winter; (2) An aerosol particle sizer (APS) which will provide size distributions of large aerosols (0.6 to 25 μm), which have so far been missing in the observation program. (3) A UV/visible spectrometer (Pandora) will provide spectral AOD (and trace gas) data, which are centrally processed for a global network and used, e.g., by ESA, in satellite validation efforts. We aim for an extension to a 5-instrument array at a later stage to determine spatial inhomogeneity of aerosols, which is also of great importance for satellite validation.

3.1.4 Atmospheric pollution and trace gas concentrations

Ny-Ålesund has been a global background station in the international atmospheric monitoring networks EMEP and WMO-GAW for several decades. SO_2 and NO_2 are two basic (and mandatory) compounds, which have been monitored at Zeppelin Observatory since 1989. We propose to upgrade the monitoring capacity by replacing the SO_2 instrument at Zeppelin Observatory with a state-of-the-art automated model providing much better time resolution. Furthermore, we propose to set up instruments for both SO_2 and NO_2 in Ny-Ålesund, in order to be able to identify (and exclude) episodes of local pollution and thus improve the quality of the Zeppelin long-range-transport monitoring programme. To improve the capacity to monitor non-methane volatile organic (nmVOC) compounds as an indicator of polluted air arriving from densely populated areas, especially Central Europe, we propose to set up a new GC-FID instrument at Zeppelin Observatory.

The Pandora UV/Vis spectrometer proposed under section 3.1.3 will not only provide new AOD information, but also comprehensive new data on ozone, NO_2, SO_2, formaldehyde, BrO and water vapour, both total columns and vertical profiles.

ID#	***Description***	***Owner***	***Cost***
1	Upgrade of four AWS (Verlegenhuken, Karl XII Land, Kongsøya, Kapp Heuglin)	MET	2520 (1720)
2	New mobile AWS (land) with radiative flux sensors, IR radiometers, thermistor chain, sunshine duration, air p, T, RH, wind sensors	MET	670 (510)
3	New mobile AWS (marine) with radiative flux sensors, IR radiometers, thermistor chain, sunshine duration, air p, T, RH, wind sensors	MET	562 (402)
4	2 ICI Hotel Payloads: 2 × 4D Space sections (for 12 daughter modules), ready to plug in instruments, payload services	UiO	9687 (9357)
5	Rocket campaign from Ny-Ålesund in January 2019	UiO	6673 (6300)
6	Two-stage and one-stage motors configured for the ICI-5 and ICI-6 projects	UiO	7323 (7323)
7,8,9	Upgrading of ground-based instrumentation for middle and upper atmosphere observations (MST SOUSY radar, riometers, ionosondes)	UiT	8233 (8233)
10	Scanning Doppler Imager	UiT	3824 (3824)
11	Aerodynamic particle sizer	NILU	1649 (1649)
12	PFR lunar photometer	NILU	550 (550)
14	Pandora UV/Vis spectrometer for trace gas and aerosol obs.	NILU	1293 (1293)
15,16	3 trace gas monitors (2 × SO_2, 1 × NO_2)	NILU	2650 (2425)
17	GC-FID detector for nmVOC measurements	NILU	1088 (902)
	Total cost (10 years) of Module 1 (allocation from RCN in brackets)		46722 (44488)

Table 1: Infrastructure applied for through the atmosphere module, numbering of items according to budget attachment

3.2 Module 2 - Terrestrial

In this module we suggest establishing a joint Arctic Terrestrial Observatory that combines the following key scientific topics: glaciology, snow, hydrology, permafrost and biosphere. Most infrastructures will be tied to the two SIOS super-site regions of Kongsfjorden and Isfjorden, with additional instrumentation in eastern Svalbard for glaciology, snow and permafrost, consisting of autonomous borehole thermistors, snow sensors and weather stations. This will ensure detailed data for coupled process modelling at the local scale, as well as a basic observational coverage of the west-east climatic gradient in Svalbard for larger scale studies and Earth System models.

Existing monitoring programs for glaciology, hydrology and permafrost will be expanded and strengthened to provide time series of various climatic parameters rather than just averaged results within the respective disciplines. All permafrost data will go into the NORPERM database, and AWS data from glaciology and hydrology will be homogenized with those in the atmospheric module to be useful for meteorological model validation and forecasting. There has so far not been any operational monitoring program for snow and avalanches in Svalbard, and this will now be established through SIOS in Kongsfjorden, Isfjorden and at Austfonna, in connection with the other terrestrial monitoring programs. Biosphere monitoring will be carried out through the Climate-ecological Observatory for Arctic Tundra (COAT, see the attached support letter) with additional remote sensing and calibration-validation through *SIOS-InfraNor*. We will also use remote sensing to extend ground observations of snow parameters and avalanches to the rest of Svalbard. Surface elevation changes related to snow, ice and permafrost will be assessed locally by a new terrestrial laser scanner and regionally by a new digital terrain model to be acquired in 2020 using the proposed aircraft infrastructure in module 4. An overview of all terrestrial infrastructures is provided in table 2.

3.2.1 Glaciology

Glaciers cover about 60% of the Svalbard archipelago and have lost significant mass over the last few decades. An updated spatial and temporal distribution total mass balance of ice across the archipelago is best accomplished through a combination of modelling and remote sensing with support from field data. *In situ* measurements of mass balance are labour intensive and thus limited to a few glaciers. NPI maintains mass balance programs for four glaciers around Kongsfjorden and one glacier on Austfonna, Nordaustlandet, in collaboration with the University of Oslo, all a part of the national programme for Environmental Monitoring of Svalbard and Jan Mayen (MOSJ) In addition, Polish researchers are monitoring two glaciers near Hornsund in southern Spitsbergen. Existing mass balance programs should be maintained in the future to obtain long-term climatological records for both, north, south and east of Svalbard. To make a stronger contribution to SIOS and climate research, we propose to establish a new glacier mass-balance and dynamics monitoring program at Tunabreen in Isfjorden and to upgrade existing AWS at Kongsfjorden glaciers and Austfonna to meet the quality standards for operational meteorological use and climate modelling. The monitoring site at Tunabreen will be developed by UNIS,which has recently initiated a process study of glacier-ocean-atmosphere interactions in the area. In addition, we propose to acquire a set of GPS units to monitor glacier flow for a few dynamically active glaciers in the region. They will record the temporal variability of ice flow between satellite acquisitions (every 2-4 weeks), and provide validation for satellite measurements of glacier velocity available from other research and monitoring projects. Tunabreen will also be instrumented with time lapse camera, seismometer and strain gauges for dynamical monitoring and process understanding.

3.2.2 Snow

Snow is a critical component for Arctic climate and ecosystems, particularly in Svalbard, with a strong oceanic influence. The lack of effective monitoring of snow was highlighted multiple times in Mehlum et al. 2013. By establishing basic and comprehensive field monitoring of snow parameters, and ultimately comparing this information with remote sensing data and output from snow- and climate models, SIOS could make a significant contribution to this field.

A set of fixed snow transects across the two super-site regions (Kongsfjorden and Isfjorden) and at Austfonna will be monitored annually in the late winter-early spring with existing basic snow measurement equipment, ground penetrating radar (GPR), and a new set of accumulation/temperature sensors. Basic snow properties such as snow cover fraction and duration, snow depth, density, snow water equivalent and basal ice on land will be extracted. All sites will also make extensive use of existing and new AWS infrastructure from the atmospheric module and from glaciology and biosphere within this module and COAT. The data obtained from these transects will provide annual maps of snow properties (depth, density, wetness, stratigraphy) showing their spatial variability and the determining scale, as well as time series of selected snow parameters from the continuously operating stations/sensors. These data will provide calibration and validation for snow modelling and remote sensing, which will then be applied to the rest of the archipelago.

A new terrestrial laser scanner will be used to measure the spatial snow depth distribution through time at selected sites, also during the polar night period when major changes occur in the snow cover. The newer models of laser scanners allow measurements over distances of 6 km, so surface analysis can be done over a wide range, and is also applicable to studies of permafrost variation and glacier dynamics/calving. Further near-continuous monitoring of snow distribution, melt-season evolution and avalanches will be done with time lapse cameras installed at key locations during the daylight period.

A designated avalanche monitoring site will be established in Longyeardalen, equipped with an acoustic fibre optic sensor string, time-lapse cameras, pressure sensors and a snow drift measuring station included in an AWS. Cornice development will be monitored using UAV and a second snowdrift station will be incorporated within the already existing AWS at Gruvefjellet. In addition, we will establish an automated snow depth sensor network around Longyeardalen containing 8 automated snow properties measuring stations. Data output will be a full meteorological and snowpack record from all point observation sites on an east-west gradient, and an avalanche activity database, with run-out simulations and avalanche warnings.

Remote sensing data will be used to up-scale detailed snow measurements taken at sites and transects to the rest of Svalbard. Polar orbiting satellites give a particularly high density of observations in the Arctic, and the entire snow cover of Svalbard can be observed daily, or even multiple times daily, with spectrometers and radar satellites. This allows us to monitor the snow cover with high temporal and medium spatial resolution. The lack of light during the polar night period can be overcome by the use of widely available radar satellites. Snow parameters such as snow cover fraction, snow water equivalent and liquid water content in snow will be derived from time series of satellite data available since 2000. For example, MODIS Terra can been used to derive daily snow cover fraction, and wet snow detections from SAR can be used to detect rain-on-snow events and monitor the melting season. The new Sentinel-1/2/3 satellites grant availability of both optical and SAR data for SIOS. Avalanche activity will be monitored effectively using Sentinel-1 data, and methods to retrieve snow water equivalent and snow depth will also be assessed. The project will support delivery of daily snow parameters for all of Svalbard from 2000 to the present, and secure continuation of the time series in the future. Methods and results will be validated using in situ data from sites and transects.

3.2.3 Hydrology

We will establish new and upgraded watershed monitoring sites within the two SIOS super-site regions. This will enable a better-specified water balance parameterization in complex terrain at spatial scales appropriate for development of Earth Observation tools, global climate model downscaling methods and UAV platforms. In this way a range of technologies for high resolution geospatial observation can be integrated with in situ water balance monitoring. The data will also be appropriate for plot- and lysimeter scale process studies within watershed models and for quantitative studies of land-ocean fluxes of water, sediment, organic matter and solutes.

In the Kongsfjorden area we plan to upgrade the hydrological station in Bayelva watershed and to replace the Londonelva station on Blomstrandhalvøya with a new station on the west coast of Brøggerhalvøya (Kjærstranddalen or Taudalen river). In the Isfjorden area, we plan to upgrade the station in De Geerdalen and install a new station at Revneset. The hydrological stations will be maintained by NVE and also equipped with AWS and time-lapse cameras for monitoring of meteorology and snow/ice conditions in the vicinity. The stations will produce records of runoff, suspended sediment, water temperature and electrical conductance along with basic meteorological data. The data will be transferred to NVE via satellite link and deposited to the HYDRA II database (NVE's national archive for hydrological data in Norway and Svalbard).

3.2.4 Permafrost

Permafrost in Svalbard is continuous except under the larger glaciers. It is the warmest permafrost this far north in the Arctic and the longest existing record (from the Janssonhaugen borehole in Adventdalen) shows a warming trend. The thermal state of permafrost in different landforms has only been monitored since the International Polar Year in 2008, and mainly in central Svalbard and the top layers of the permafrost. Very little data had been collected on the amounts and types of ice in the permafrost (cryostratigraphic studies), yet such information is crucial to our understanding of the potential effects of climate change on different parts of the Svalbard landscape. To be able to monitor the thermal conditions not only in the top layer of permafrost (which shows the annual thermal variation), we propose to drill several deeper boreholes and make one that goes through the permafrost in Adventdalen. We plan to obtain and analyse cores from these boreholes to provide information on the ice content, type and age of the permafrost in different parts of the Svalbard landscape. This will be done using the UNIS medium-sized drill rig, which needs to be upgraded to be able to drill in the various sediment types that exist in Svalbard, including coarse-grained slope sediments that we presently cannot core. To determine changes in the Svalbard permafrost landscape, we will compare the proposed new Svalbard digital terrain model (DTM) with earlier DTMs from NPI.

Permafrost temperature monitoring in SIOS will be improved by (1) upgrading one of the existing deep boreholes at Kapp Linne boreholes linking it to the existing AWS, (2) establishing five new 15-30 m deep permafrost boreholes linked to AWS operated by MET at Pyramiden, in Barentsburg and at three sites in eastern Svalbard, (3) upgrading 8 existing boreholes near Longyearbyen by increasing their depth to 25 m and installing temperature instrumentation to function online, (4) establishing one borehole that penetrates through the permafrost to about 200 m depth, and (5) upgrading the UNIS-based drill rig to handle all sediment types in Svalbard.

3.2.5 Biosphere

Arctic ecosystems are complex systems of biological, physical and hydrological components that interact across a wide range of temporal and spatial scales. On the terrestrial side, short-stemmed perennial herbs, low-growing prostrate shrubs, lichens and mosses characterize the vegetation communities. Due to the limited growing season, the nutrient dynamics of individual plants are rapid and complex, and herbivores must respond accordingly for optimal forage intakes. A thorough understanding of the functioning of food webs has been highlighted as a key both for predicting the response of tundra ecosystems to drivers of change and for rational management of terrestrial ecosystems. In response to that, a comprehensive science plan for a Climate-ecological Observatory for Arctic Tundra (COAT) was launched in 2013. COAT is an initiative of the Fram Centre (with institutions UiT, NPI, NINA, UNIS, MET) and has international collaboration with comparable long-term initiatives in Canada (Bylot Island) and Greenland (Zackenberg). Infrastructure in COAT <u>is not included in this proposal</u>, but will be strongly integrated with SIOS (see the attached support letter).

The Biosphere component of this proposal focuses on calibration and validation (cal-val) of biophysical parameters derived from satellite data. Since 2014, there has been one terrestrial cal-val area in Adventdalen close to Longeyarbyen. To expand the coverage to different vegetation types, we propose to establish additional sites near Ny-Ålesund and Kapp Linne, as well as at higher elevation in Adventdalen. Each site will be equipped with sensors/cameras to monitor a range of biophysical parameters, with focus on key parameters such as net primary productivity, length of the growing season, impact on vegetation from extreme weather events, and radiation budget for different vegetation types and ecosystems. The proposed cal-val sites will be part of the Nordic NordSpec infrastructure for spectral data collection, with further links to global terrestrial ecological infrastructure like the EddyCovariance facility (carbon-flux tower) in Adventdalen headed by the University of Lund.

Ongoing monitoring of the growing season in Svalbard within MOSJ is based on coarse resolution satellite imagery. We want to improve current products by intercalibrating time-series of MODIS data with Sentinel-3 Ocean and Land Colour Instrument data and relate the clear-sky time-series to annual primary productivity. The clear-sky time-series of coarse spatial resolution data (MODIS/Sentinel-3) covers the entire archipelago and ensures that the impacts on terrestrial ecosystems across the climatic gradients are monitored.

ID#	***Description***	***Owner***	***Cost***
30, 67-69	Glacier monitoring in Kongsfjorden, Isfjorden (Tunabreen) and at Austfonna: AWS, GPS, cameras, seismometers, strain gauges	NPI, UNIS, UiO	12877 (6250)
35-36	Snow monitoring transects in Kongsfjorden, Isfjorden and at Austfonna: ground penetrating radar, snow properties and accumulation/temperature sensors	NPI, UNIS, UiO	9000 (6000)
33	Avalanche monitoring in Longyeardalen: activity, runout simulations and warning	NORUT, UNIS	2500 (2000)
37	Hydrology monitoring in Kongsfjorden and Isfjorden: 2 new and 2 upgraded stations, including AWS	NVE	3700 (3000)
31-32, 40-41	Permafrost monitoring of new and upgraded boreholes in west/east Svalbard, including an expanded drill rig and one deeper hole in Adventdalen (150 m)	UNIS, MET, NGU	13800 (10500)
55	Terrestrial laser scanner for interannual surface changes of snow, ice and permafrost	UNIS	4500 (4000)
34	Update of Svalbard digital terrain model for surface changes using aircraft infrastructure	NPI	4880 (4680)
42-43	Remote sensing of snow parameters and avalanche activity, including calibration/validation with in situ data	NORUT	7000 (6000)
44-47, 49-53	Remote sensing of biosphere parameters, including 3 calibration-validation sites with instrumented towers	NORUT, NINA, UiT	12645 (7570)
	Total cost (10 years) of Module 2 (RCN allocation in brackets)		70912 (50000)

Table 2: Infrastructure applied for through the terrestrial module, numbering of items according to budget attachment

3.3. Module 3 - Ocean

We suggest a combination of new Arctic ocean observatories replacing existing outdated infrastructure, and extending existing observatories that have a proven track record of suitability for long term monitoring. We also propose investing in a package of autonomous platforms (AUV, gliders and ASV) that will supplement long-term observatories with short-term and high-resolution spatial coverage of target sites. The integration of stationary fixed observatories with mobile autonomous vehicles will provide unique insights into the biological and physical factors influencing and characterizing the dynamics of the marine environment around Svalbard. Observatories will offer the capabilities needed to address the following key topics: (1) physical and biological oceanographic coupling; (2) energy of ocean currents; (3) ocean nutrients and pollutants (horizontally, vertically and through the food chain); and (4) ecosystem resilience to climate seasonal variability and long-term change. Sea ice processes in coastal areas are included through an AUV that is equipped for use under sea ice. It is linked with SIOS through a collaborating infrastructure project (Arctic ABC Development, project number 245923). Moreover, SIOS will provide the infrastructure and opportunity to use the coastal ocean observatories from the coast to the continental slope as reference points for dedicated biological process studies. Through *SIOS-InfraNor*, we aim to concentrate on four main mooring arrays (main responsible institutions in brackets): Arctic Ocean inflow along the slope north of Svalbard (IMR and NPI), Arctic Ocean outflow across the Fram Strait (NPI), shelf regions along the north and west coast of Svalbard (UiT and UNIS) and Arctic Ocean governance of greenhouse gas release monitored by a world class ocean-observatory Kongsberg system for both the shallow and deep Arctic region offshore north Svalbard (CAGE/UiT). In addition, infrastructure includes gliders for oceanographic surveys in and outside the fjords (UiB) and ferryboxes mounted on ships regularly working in the region (NIVA). The proposed infrastructure serves long-term time series for monitoring and research (infrastructure designed to be deployed on a continuous basis) and process-oriented studies (infrastructure subject to funding and collaboration with research projects/priorities).

3.3.1 Oceanographic time series relevant for Arctic Ocean exchange processes (Fig 3c)

The Arctic Ocean is experiencing major transformations with dramatic reductions in the Arctic sea ice cover. Global models have predicted the direction of change, but the speed of change has been underestimated. The major part of oceanic heat is brought to the Arctic Ocean by the warm Atlantic inflow, and recent studies have shown that this oceanic heat has direct impact on the observed ice reductions in the Arctic. Thus, changes in this oceanic heat transport have fundamental influence on high-latitude climate variability and change, as well as profound implications for the circulation, marine resources and ecosystems in the Arctic Ocean. Colonization of new regions by immigrating species is also more likely on this side of the Arctic compared to the Pacific side. The proposed infrastructure will give the opportunity to address the variability in this heat flow and its impact on sea ice, vertical stratification and cross-shelf exchange.

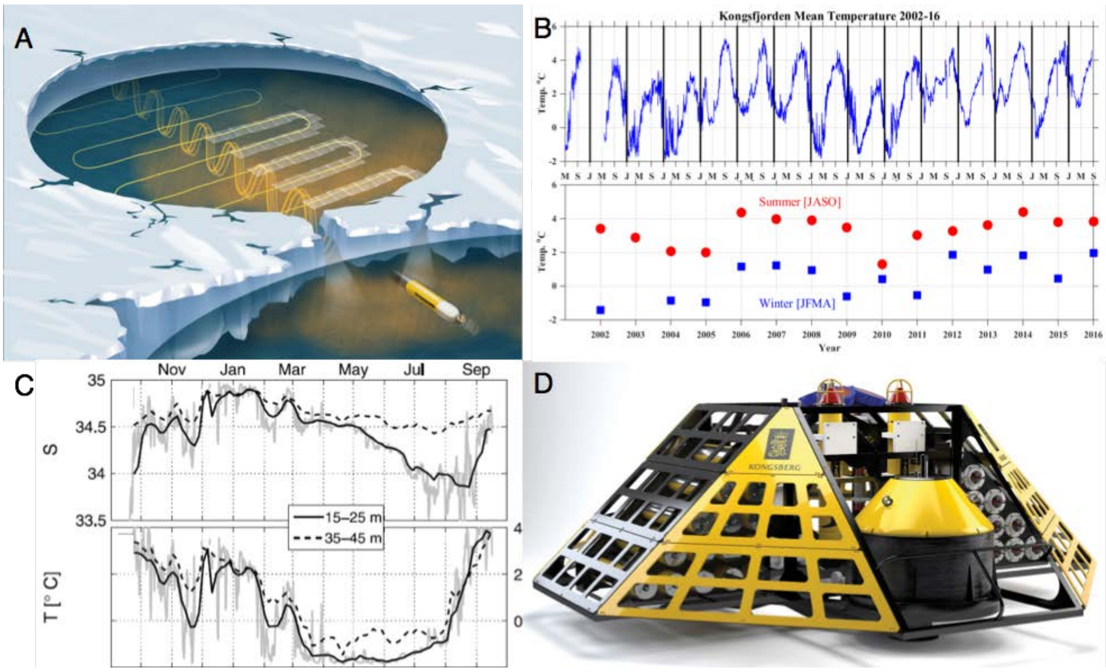

Figure 3. A – Process study of biological and physical oceanography using an AUV under sea ice, B – Time series of temperature in Kongsfjorden since 2002 with a continuous mean temperature of the water column (upper) and averaged mean over four months (lower). C – Time series of salinity (upper) and temperature (lower) in inflowing Atlantic water north of Svalbard, D – K-Lander observatory for monitoring methane seepage

3.3.2 Oceanographic time series relevant for shelf exchange processes (Fig 3b)

Fjords are commonly regarded as the link between the ocean and land through cross-shelf exchange and the circulation dynamics of the fjord's water masses. Propagation of warm oceanic waters onto the shelf and into fjords, with the potential to increase the melt rates of both glaciers and frozen gas hydrates, has been identified as a likely mechanism leading to the acceleration, thinning and retreat of glaciers and greenhouse gas release. Finally, the modification of the density of ocean water in the Arctic through salt release during sea ice formation is a critical process in terms of atmosphere-ice-ocean interactions. Whilst this densification process occurs throughout the Arctic, fjords provide a convenient site to study the underlying physics in a relatively contained natural laboratory. We plan a series of on-shelf observatories equipped with instrumentation that allow for direct comparison of results relevant for both physical and biological parameters. The shelf region array will be situated mainly inside the fjords (Kongsfjorden, Isfjorden, Rijpfjorden). It is our ambition that the observatories in Kongsfjorden and Isfjorden are to be cabled, thus providing real-time data-streaming. In addition, the already installed "Ferrybox" infrastructure operated by NIVA since 2008 will be upgraded and included, to provide a spatially broader monitoring area of physical and biogeochemical measurements. The biological sensors (e.g. acoustics, chl a / nitrate sensors, water samplers) and installations (use of observatories as experimental platforms) will be designed and coordinated to enable comparison of biological activity and production measures, as well as physical parameters.

3.3.3 Process-oriented observational systems (Fig 3a, d)
In addition to the long-term and fixed observatories (sections 3.3.1-2), *SIOS-InfraNor* will also develop sensor and monitoring capabilities that are more process-oriented. Infrastructure with more focused sensor / platform technologies will typically be aimed at linkages between spheres (hydrosphere, biosphere, cryosphere etc). In order to provide a much-needed spatial component to these point measurements, SIOS will build up an infrastructure baseline to accommodate AUV (Fig 3a), gliders and ASV (autonomous surface vehicle) missions by partner institutions with world-leading expertise on autonomous underwater systems (NTNU and UiB). Gliders hold great potential for distributed, but spatially dense observations and contribute both to hydrographic sections and time series observations, and to process-oriented studies. The national facility for gliders (NACO) was initiated with main focus on Atlantic Water in the Norwegian Sea, but now serves a variety of research projects. In order to enable glider use as a regular part of SIOS, we propose to invest in specialized glider hardware dedicated to SIOS, operated through NACO.

UiT's Centre of Excellence CAGE, Centre for Arctic Gas Hydrate, Environment and Climate, working with Kongsberg Maritime, successfully developed, deployed and retrieved two world-class ocean observatories (K-landers) offshore Svalbard 2015/2016. SIOS will allow for long-term commitments towards the governance of greenhouse gases using ocean observatories in a transect from the shelf to the deep sea. CAGE will redeploy one of these K-landers in a relatively shallow area (<400m) within the highest concentration of natural greenhouse gas release. The *SIOS-InfraNor* K-Lander observatory will be deployed in deep-water at ~1200m, where methane release is very active at the mid-ocean ridge. Kongsfjorden is the location for a shallow reference site. These three strategic sites will form a key transect from near-shore to deep sea.

ID#	***Description***	***Owner***	***Cost***
56	Ferrybox onboard M/S Norbjørn for continuous measurements of physical and biological data between Tromsø and Longyearbyen	NIVA	5950 (2300)
57	Mooring array in the Fram Strait to measure Arctic Ocean outflow, sensors of physical, biochemical and biological relevance	NPI	21250 (6500)
58	Mooring array north of Svalbard to measure Arctic Ocean inflow, sensors of physical, biochemical and biological relevance. Combined with #59	IMR	11350 (6500)
59	Mooring array north of Svalbard to measure Arctic Ocean inflow, sensors of physical, biochemical and biological relevance. Combined with #58	NPI	8250 (6000)
60	Oceanographic gliders to operate in the fjords and off-shelf west of Svalbard	UiB	9000 (6000)
61	K-landers to measure methane and other greenhouse gas exchange from the sea floor to the sea surface	UiT	12300 (6000)
62	Oceanographic moorings in Kongsfjorden and Rijpfjorden for physical, biochemical and biological time series studies	UiT	13500 (5000)
63	Oceanographic mooring in Isfjorden for physical, biochemical and biological time series studies	UNIS	11600 (5000)
64	Oceanographic mooring in Adventfjorden for physical, biochemical and biological time series studies	NIVA	1000 (700)
65	Waveglider - a platform with capabilities of carrying biological and physical sensor packages for use in the fjord on the west coast of Svalbard	NTNU	6250 (3000)
66	Autonomous underwater vehicle for use in process studies inside the fjords and under sea ice	NTNU	9900 (6000)
	Total cost (10 years) of Module 3 (allocation from RCN in brackets)		110349 (53000)

Table 3: Infrastructure applied for through the marine module, numbering of items according to budget attachment

3.4 Module 4 - Common Infrastructure

In this module, we introduce new interdisciplinary research infrastructure that will contribute unique data collection capacities through both collection of new data time series and process studies that support the cross-disciplinary priorities in Mehlum et al 2013. The fact that the infrastructure and sensor capacities have multiple applications leads to the creation of the Common Infrastructure Module. The platforms and sensor themselves are not necessarily aimed specifically towards one application. This makes it difficult to assign them directly to individual thematic modules; rather, it is the algorithms used in the geophysical retrieval that are module-specific. In the next sections the contributions to each of the thematic modules will be described.

3.4.1 *Basic infrastructure platforms and sensors*

The module contains one manned aircraft platform and three unmanned platforms. The sensor suit mounted on the manned platform is installed in a pod permanently affixed to the Lufttransport Dornier DO228 aircraft based in Longyearbyen. The aircraft will be equipped with a hyperspectral imager, X-band synthetic aperture radar, high-resolution high sensitivity camera and a laser scanner. The Dornier platform has a range of 2000 km which is covered in about 5-6 hours. The three different unmanned platforms (drones) have all been proven in the Arctic, and are functionally complementary. The largest fixed wing platforms run on petrol; they can carry a payload of 15 kg over a range of 1200 km but cannot land on ships. The smaller fixed wing is electric and has a range of 120 km and 3 kg payload. It can be operated from ships and remote field stations with a very light operational footprint. The octocopter drones can land almost anywhere and with their payload up to 6 kg payload can carry any of the sensors included; their range is 25-45 km depending on payload weight, well suited for ship-based operations.

ID#	***Description***	***Owner***	***Cost***
18	Instruments to be installed in Dornier DO228 POD, airborne SAR, VNIR hyperspectral Imager, vis/NIR aerial camera and laser scanner.	Norut	14682 (10432)
19	UAS Ground Station, communication equipment, basic common metadata sensor and data collection and sensor control system	Norut	10300 (4300)
20	UAS Ocean and land sensors, hyperspectral Imager UV/VIS and NIR/SWIR, Synthetic Aperture radar, Ultra Wide Band Radar, IR Camera	Norut	7180 (6380)
21	UAS Atmosphere Instrumentation. Cloud particle imager (CPI), Aerosol instrument, turbulent flux probe, net radiative flux, met sensors	Norut	5210 (4410)
22	Sea-ice drifting buoys, 3 each year with the following sensors: GPS, P, T, active thermistor chain for one of them	NPI	1500 (750)
23	Satellite SAR wind retrieval, sea-ice drift, sea-ice type, altimetry and gravimetry. Daily and weekly and monthly products, around Svalbard	NERSC	800 (800)
27	Satellite based high resolution chlorophyll concentration, weekly maps	NERSC	200 (200)
24	Back processing of satellite SAR high resolution winds (1991-present)	NERSC	800 (800)
	Total cost (10 years) of Module 4 (allocation from RCN in brackets)		40672 (28072)

Table 4: Infrastructure applied for through the “Common” module, numbering of items according to budget attachment

3.4.2 *Contributions to the ocean module*

The instrumented pod on board the Dornier will contribute to a time-series of high-resolution transects on sea-ice thickness, distribution, drift, and spectral albedo across the Fram Strait as the aircraft flies about 20 transects a year across from Longyearbyen to the Villum Research Station (Station Nord) on Greenland to provide logistical support. Over open water, Chlorophyll-a, algae concentrations, ocean waves and winds can be retrieved. These data can in addition be used for validation of satellite data retrievals. The electric drones can be operated from research vessels and could measure sea-ice properties like sea-ice thickness, snow on ice thickness, albedo, melt pond fractions, surface temperatures, and chlorophyll-a concentrations. We propose deployment of three drifting sea-ice buoys each year in waters near Svalbard. NPI has during the past years regularly deployed measurement buoys in drifting and land-fast Arctic sea ice, partly combined with advanced systems to measure optical properties of sea ice and snow. Buoy deployments are part NPI’s long-term program and of the International Arctic Buoy Programme, where NPI is a partner (http://iabp.apl.washington.edu/). The deployment of sea ice buoys will be closely coordinated with other related programmes such as the infrastructure component of the Arctic ABC cluster.

In support of the SIOS observatories for monitoring Arctic ocean inflow and outflow, the Nansen Environmental and Remote Sensing Center (NERSC) will develop and set up the production of time series of satellite remote sensing ocean products based on satellite SAR data from Radarsat-2 and Sentinel-1 including high-resolution wind, ocean surface currents, altimetry, and gravimetry, and high-resolution sea ice drift and sea-ice types. From optical satellite data from Modis and Sentinel-2, weekly high resolution chlorophyll concentration maps will be created. Provided sufficient resolution, some of these datasets may also be applicable to the shelf region observatories in Kongsfjorden, Isfjorden, and Rijpfjorden. Clearly, the in situ data obtained in SIOS will thus also serve as a valuable validation source for the remote sensing algorithms. Data will be prepared and served using tools developed in the NORMAP infrastructure project, and use of the Scientific Platform as a Service (SPaaS) will be demonstrated.

3.4.3 Contributions to the atmosphere module

The atmosphere sensors installed on the large drones will be important in assessing the spatial variations as well as representativeness of the measurements performed at Zeppelin Observatory and in Ny-Ålesund. Profiles of aerosols and cloud particle properties like concentration, composition, phase, and shape will be retrieved from ground to 4000 metres and long transect flights of up to 1200 km will investigate spatial variations and do Lagrangian studies while following the same air parcels for up to 12 hours. Both the smaller electric drones and the long-range drones can be used for boundary layer research, including ocean-land-atmosphere energy exchange through turbulent sensible and latent heat fluxes as well as radiative flux measurements yielding the total surface energy exchange.

3.4.4 Contributions to the terrestrial module

On regular weekly flights, the Dornier will collect data on snow cover and depth, glacier surface elevation, vegetation, and phenology along predetermined transects between Longyearbyen and Ny-Ålesund and Longyearbyen and Svea. The Dornier will also allow for mapping large areas (about 400 km^2 per hour) for high resolution data terrain models of glaciers, population surveys of marine mammals, vegetation maps and indices, ortho maps, glacier mass balance, and snow cover properties at high resolution. For smaller area studies and ultra-high resolution and high temporal coverage, the unmanned aircraft can be used. In addition, the unmanned aircraft have sensors for both broadband and spectral albedo measurements and measurements of bidirectional reflectance distribution functions, which are particularly important at high latitudes for correction of satellite-based optical observations of snow and vegetation properties and to correct representations of the surface energy balance. The drone UWB radar allows for mapping of ice layers and sub surface glacier properties.

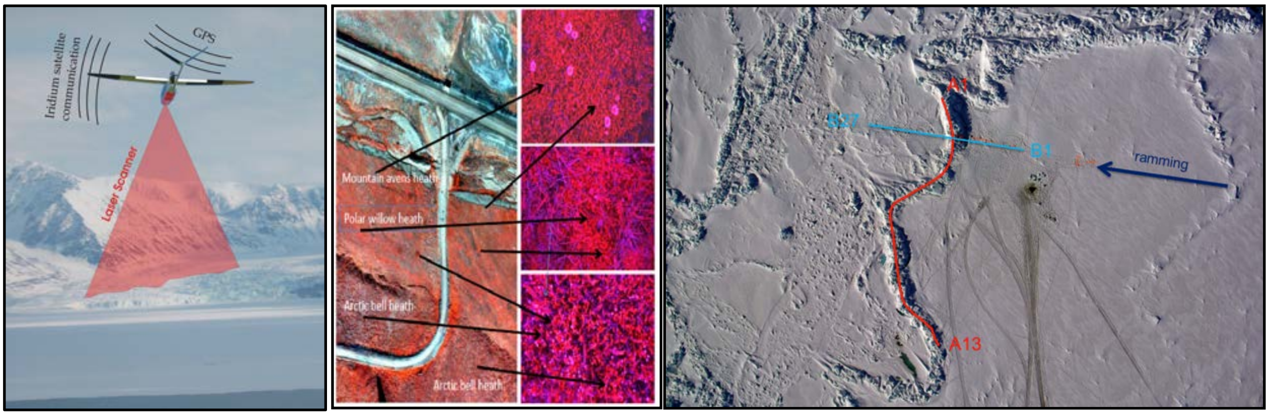

Figure 4. A drone measuring glacier surface elevation. Examples of data collected by drones in Svalbard to investigate plant types and sea-ice thickness and ridging based on multispectral high resolution cameras.

3.5 Module 5 - Data Management

The SIOS Data Policy promotes free and open access to data. It is a requirement that scientists and projects utilizing the SIOS Infrastructure also adhere to the SIOS Data Policy and deposit data in a data centre contributing to the SIOS Data Management System (SDMS).

The main focus of *SIOS-InfraNor* data management is to ensure that the data generated by the proposed instrumentation are properly taken care of and shared through SDMS. This data management system is outlined by documents delivered by the SIOS prepatory phase project, and further refined in the SIOS-KC project. SDMS is a physically distributed data management system that relies on internationally approved standards for documentation of and access to data. Utilization of standards allows integration with discipline-specific (e.g. WMO Information System) and regional (e.g. Copernicus Marine Environmental Monitoring Service) data management systems. Development of the SDMS technical infrastructure is aligned with current efforts of e.g. the combined SAON/IASC Data Committee.

SDMS is a metadata driven data management systems where datasets are documented and encoded using a limited number of standards.

SIOS-InfraNor data management activities are primarily focused on documentation and encoding of datasets, and submission of these to data centres committed to life cycle management of data (including long term data preservation). This allows integration of *SIOS-InfraNor* data streams into the SDMS. In this process *SIOS-InfraNor* relies on existing national infrastructures and their present business models. In the budget outline, costs related to preparation (documentation and encoding) of datasets are included in the modules generating the data. Costs related to long-term data preservation and publishing of data are included in the data management module. The central search interface and data access point of SDMS is already covered by the SIOS-KC project.

Capitalizing on the SDMS and its distributed nature, a software and processing environment will be developed. This is utilizing virtual machines and predefined but extensible software components packaged as a Scientific Platform as a Service (SPaaS). Costs related to SPaaS development are included in this module.

Further description of data management is provided in section 7.

3.6 Module 6 - Project Management

The management module focuses on coordinating the construction and testing of the infrastructure owned by the 15 partners and thematically organized in modules 1-4. It is also the task for the project management to make sure that the *SIOS-InfraNor* project is fully utilizing the SIOS-KC services.

The management module is lead by the project leader (SIOS Director), and the six module leaders (Modules 1-6) together form the project leader group. See Section 9 for further description and information.

4. **Impacts of the Research Infrastructure**

4.1 Research areas benefitting from the SIOS infrastructure

The observation system, towards which this application is a first step, will first and foremost be an important contribution to regional, pan-arctic and global Earth System Science and Management projects and programs. It will produce a coherent set of data that will be essential for the planning and execution of new research projects in the Svalbard/European Arctic region. By making the infrastructure and the information it produces available to the Arctic research community through SIOS-KC, it will secure a more efficient use of the instruments, and reduce the need for duplication of expensive infrastructure.

4.2 Impact of the research infrastructure on Norwegian and international science and innovation

Developing a coherent observing system, and making the information available in a standardized manner to the international scientific community will be a crucial step towards enabling Svalbard science to be of even greater global significance than it is today. Developing and successfully deploying this broad array of platforms and sensors is a bold, innovative and ambitious project and will allow for both scientific exploration and hypothesis testing addressing the entire spectrum of marine, terrestrial, atmospheric and cryospheric science. Also, by fully implementing the infrastructure into the existing SIOS consortium, with 4 Norwegian and 10 international partners, we secure a broad and inclusive use of data among leading Norwegian and international scientists and institutions. All these factors will, *in combination*, ensure that the SIOS infrastructure is both highly *internationalized,* have a *high attractiveness for Norwegian and international researchers and students,* and will, not least, be instrumental in creating *strong new national and international alliances and collaborations*.

4.3 Impact on the recruitment to science

UNIS with partners host a Centre of Excellence in Education (in Biology, BioCEED), which will ensure the very best basis for direct and mutually beneficial integration of research, technological development and education. Both the infrastructure development phase and the operational phase (see sections below) will have strong and direct links with ongoing and planned educational activities at the MSc and PhD level through BioCEED. Moreover, UNIS, in partnership with SIOS educational institutions, plans to establish a new and dedicated MSc / PhD level course in climate research and time series analyses. This course will be directly linked with the SIOS infrastructure and SIOS-KC, and will ensure long-term use of data. The main partner institutions will ensure a basis of students to attract and train a new generation of scientists, engineers and entrepreneurs and improve the retention of highly educated workers in Norway.

4.4 Impact on strengthening of expertise and technology

SIOS will assemble and align the existing intellectual and infrastructural resources from industry, education, and research sectors into a long-term partnership for the development of marine, atmospheric and terrestrial observatories to improve Earth system modelling capabilities and understanding of the Arctic processes. Strong collaboration between Norwegian and international partners will ensure the transfer of expertise. Through the academic and industrial partnerships established between SIOS members, we will provide a platform for the translation of knowledge between business and academia.

4.5 Impact on future value creation, national competitiveness and internationalization of Norwegian science

Any future exploitation of natural resources in the Arctic will require a reliable investigation of potential environmental consequences. SIOS will provide this information in a comprehensive way. The establishment of such a unique combination of instruments covering the whole spectrum of natural sciences also offers a unique opportunity to study the interactions in the natural system on a limited geographical scale, but with global significance and relevance. This will secure a major national and international competitive advantage, and will be instrumental in the planned development of Svalbard as a research platform.

4.6 Impact in relation to societal challenges

SIOS in general and *SIOS-InfraNor* as an important step towards the optimisation of the observing system address one of the foremost challenges the world faces today: global environmental change induced by humanity, especially climate change. Thus, it is of high societal importance. Norway has a particular focus on climate change in the Arctic, and therefore SIOS will be a cornerstone of these efforts. With respect to the Norwegian Svalbard policy, increased research activity on the archipelago will be an important asset to uphold Norwegian activities after the end of the coal mining activities.

5. Importance of the research infrastructure for various user groups

5.1 National importance of the SIOS infrastructure

Norway has a strong national interest in the Arctic, with the exploration, scientific surveying and management of Arctic regions being part of Norway's official high-north strategy. The construction of the new ice enforced national research vessel (RV Kronprins Haakon), initiation of the Nansen Legacy project and the investments in research and research infrastructure in Svalbard (both Ny-Ålesund and Longyearbyen) illustrate the national importance of scientific exploration and monitoring of the Barents Sea, Svalbard and the Arctic Ocean. User groups that will strongly benefit from a successful development and deployment of the SIOS infrastructure include:

Management - through access to data and knowledge regarding a severely understudied ecosystem.
Industry - through combining vital information and validation for remote sensing in regions of increasing interest from petro-maritime industries. Space weather observations – key to predicting availability and quality of communication and navigation signals –are expected to have significant commercial value (prevent accidents and pollution).
Education - through a unique integration of scientific disciplines of interest for Norwegian educational programmes.
Geopolitics - through vital understanding of production regimes in Arctic waters.

The Norwegian government has a stated vision to be a leader in Arctic management and sustainable resource exploitation. With fisheries, oil and gas, and mineral extraction from the sea-floor expanding northwards, ship routes opening up in the north, and previously ice-covered areas opening up for exploration, it is crucial to fill important knowledge gaps and obtain the best possible understanding of the Arctic system. The development of the SIOS infrastructure will provide highly relevant data and technology to address important knowledge gaps that are needed to inform decision makers.

5.2 Estimated use of the infrastructure for research, management and private sector

With a growing concern and interest in environmental monitoring and climate change studies, the *SIOS-InfraNor* infrastructure has significant potential to be much needed and much used during the coming 10-year period. In addition, the infrastructure investments are based on user needs as identified through the gap analysis and Mehlum et al 2013, and will provide the requested support for research and management. As an example, SIOS will contribute to the MOSJ programme, which focuses on environmental information from the Norwegian Arctic that is strategically important for politicians and environmental managers.
The private sector is expected to utilize data and knowledge accrued from the infrastructure in environmental impact assessment work and planning of activities that are dependent on the present and future state of the environment. In addition to serving SIOS, the aircraft-based infrastructure will be an important asset to the new Centre for Integrated Remote Sensing for Arctic Operations (CIRFA) and other more technical and cold climate technology projects. It could support maritime operations, ice management, emergency response operations and search and rescue with high resolution imagery in near real-time. In case of oil spills the aircraft would be capable of detecting and monitoring spills under all weather conditions. Since the Dornier aircraft will carry the sensors permanently, the response time will be down to hours in emergencies. The Dornier could also be used for mineral prospecting and high resolution mapping in the east Greenland-Svalbard region.

6. Plan for access and knowledge management

The new infrastructure will become part of the Norwegian contribution to the SIOS ESFRI project hosted by

Norway. Due to regulations in the Svalbard Treaty, partners in SIOS have to be institutions, not nations. With a successful outcome of this application the number of Norwegian partners in the consortium will increase from four to 15. As a result, the infrastructure available for the consortium will increase substantially above what is included in the application.

6.1. Information about how the research infrastructure and its offers will be disseminated
Information about the research infrastructure will be available on the SIOS and on the Svalbard Science Forum web pages. There is a joint initiative for developing the two entry points such that they will both contain the same information about infrastructure in Svalbard. SIOS-KC has a full time information officer who is the point of contact for all information regarding the SIOS observing system. SIOS-KC distributes newsletters on a regular basis and will utilize Twitter, to attract attention on news on the SIOS website, and be present at relevant conferences. The planned Svalbard conference as part of the annual Arctic Frontiers conference and the regular *Ny-Ålesund Science Manger Committee* (NySMAC) meetings and Ny-Ålesund seminars will be important venues for SIOS.

6.2 Access to the research infrastructure for external users
SIOS-KC has a dedicated position for infrastructure and access management. This position will be filled during autumn 2016 and will have responsibility for implementing the plan for the Infrastructure access service under the SIOS-KC as it was developed in the framework of the SIOS prepatory phase project. Information regarding access to infrastructure and data generated from these infrastructures will be made available on the SIOS website.

6.3 Management of generated knowledge and intellectual property
The partners in this project have all committed themselves to apply for membership in the SIOS consortium. As SIOS members they will all adhere to the SIOS Data policy and Statutes. The policy states in general that data are open and free. The policy is in line with open data policies of Norway (RCN) and the EU (H2020). Intellectual property rights are regulated through the SIOS Statutes which are to be adopted by all members of this proposal. SIOS-KC will play an active role in disseminating the knowledge generated.

7. Data management

The *SIOS-InfraNor* project will adhere to the SIOS data management regulations as given in the SIOS data policy, guidelines on interoperability and operation manuals (www.sios-svalbard.org). Data will be submitted to data centres contributing to the SIOS Data Management System (SDMS). This ensures interoperability at the metadata and data levels, as well as long-term data preservation. The SIOS Data Portal, embedded in the SIOS website, will provide unified data search and retrieval options. *SIOS-InfraNor* will be fully implemented into the SIOS Data Management operations which are funded through SIOS-KC. However, in order to ensure that all data are fully streamlined and compatible with each other and the SIOS data portal, we also include a total of 10 mill NOK (2 mill each year during the first 5-year period) in funding for data management. These costs will, pending on demand and need, be distributed to partners.

The main focus of data management is to ensure that the data generated by the proposed instrumentation is taken care of and published through data centres that are compliant with SDMS. Integration of the physically distributed components contributing to SDMS, is the responsibility of the SIOS-KC. SDMS will rely on infrastructure available at contributing data centres. It is the task of each contributing data centre to ensure that data are properly documented for indexing (e.g. GCMD DIF or ISO19115/ISO19139) and use (e.g. through application of Climate and Forecast Conventions or Darwin Core), to ensure access to data through SIOS standardized interfaces and long term preservation. Data will be managed and served through institutional data centres (which are integrated in national e-infrastructures) and the NorStore archive. Index metadata for such datasets can be hosted by any of the contributing data centres. Quality control and documentation of data is a joint effort between the responsible scientists and the data centre stewarding the data. Scientists document the requirements, standards and best practices and quality control and document their datasets. The contributing data centres enforce the quality control and documentation process and check submitted data for compliance, while the SDMS provides this information to data consumers using the interoperability interfaces agreed and identified. At the national level many institutional data centres are affiliated with three national infrastructures: Norwegian Satellite Earth Observation Database for Marine and Polar Research (NORMAP) - offering higher order services on remote sensing data; Norwegian Marine Data Centre (NMDC) - handling marine datasets; and the Norwegian Scientific Data Network (NorDataNet) - a newly established infrastructure initially focusing on geoscience, but with an interdisciplinary perspective on solutions developed.

7.1 Documentation tools

Tools for documentation and preparation of data are critical for success in communities generating scientific data. Without user-friendly tools, the process of sharing and preserving data is complicated and resource consuming. Standardization on self-documenting file formats with international support simplifies both sharing and preservation of data. Current efforts in this area (e.g., development of the Climate and Forecast convention) are closely linked to semantic interoperability, ensuring that scientists can understand each other across disciplines. Utilization of Open Source Code implies that further development of these tools can be a cooperative effort, reducing development costs and generating tools that are useful for scientists beyond the SIOS community. This proposal relies on tools developed by SDMS, data centres contributing to SDMS, NMDC or NorDataNet.

7.2 Interaction between data centres

Interoperability interfaces for metadata and data are crucial for integration with SDMS. Standardization of such interfaces minimizes the development and maintenance cost for SDMS, as the same interface is used to connect several data centres. Site-specific interfaces must be avoided unless strictly necessary, as they drive costs and reduce the sustainability of solutions. The infrastructure project NorDataNet is committed to supporting SDMS activities and will be used to integrate national data streams towards SDMS. This includes data streams from NMDC and NORMAP.

7.3 Handling of new datasets

This proposal includes large investments in new instrumentation for SIOS activities. While institutional data centres make considerable in kind contributions towards sharing and preserving these data, costs are also caused by initialization of data streams and life cycle management of data. The new datasets will be handled by institutional data centres or through the NorStore archive. An important task in this context is to implement unique and persistent identification of datasets, allowing traceability of data usage and increasing data provider attribution. While most data centres have such identifiers in place they are usually not standardized. Digital Object Identifiers (DOI) have become a de facto standard for such identifiers and are now required by many journals. Consistent implementation of this mechanism will ensure that data providers and SIOS can be cited in a standardized manner, increasing the probability of proper attribution of datasets. A system for issuing DOI has been set up in Norway. Many of the relevant institutional data centres integrating with NorDataNet and implicitly SDMS are developing this capacity. NorStore is already supporting DOI.

7.4 Unified metadata catalogue

Establishing a single end point for SIOS data requires a unified metadata catalogue that harvests metadata from all contributing SIOS data centres in Norway. In order to do so it, must support a certain level of brokering capabilities in both structured metadata and semantic translations (e.g. between controlled vocabularies used by different communities). It will be an important contribution to SDMS. This functionality is under development by the infrastructure project NorDataNet. It will provide the integrated end point for Norwegian SIOS data and feed these into SDMS.

7.5 Handling of remote sensing data

Satellite remote sensing products are an important contribution to the Earth System vision of SIOS, but SIOS will also be a major calibration and validation site for sensors and algorithms being applied under Arctic conditions. The initial focus for satellite remote sensing is on 3 of the 6 core services described in the SIOS Remote Sensing Service. In prioritized order, these are data access, specific datasets and dedicated processing. To give end-users an opportunity to efficiently use SAR data from Sentinel-1, it is suggested to establish an infrastructure for on-demand processing, subsetting, temporal and thematic data fusion. Higher-level products served by other parts of the SDMS can be available as data sources. This functionality is suggested to be collocated with the national collaborative ground segment for Sentinel-1. Processed products from the above on demand processing will be fed into NORMAP. This system is under integration with SDMS and is interoperable with CERSAT. Support for EUMETSAT and ESA catalogue interoperability is under development.

7.6 A Scientific Platform as a Service

To help users exploit the data collected, a Scientific Platform as a Service (SPaaS) will be developed. It relies on the machine interfaces to metadata and data offered by the SDMS and provides easily extensible software for data analysis and processing. The SPaaS will be installed on pre-configured virtual machines containing the necessary processing and visualization tools (e.g., Nansat) for scientific research, and development of new products based on (e.g., collocated) remote sensing, model, and in situ data.

Through courses at the SIOS-KC, users will be trained to use SPaaS. The SPaaS will allow users to search, access and analyze online distributed datasets via the IPython command line. Complementing this, a specific SIOS web page will provide a simple search interface as starting point to access data via the command line or IPython Notebook. Pre-configured virtual machines can be provided on both Windows, Mac, and Linux. Python is selected as programming language and has a well developed standard library similar to tools such as MatLab, IDL, or Mathematica, but is free and open-source.

8. Partners

The *SIOS-InfraNor* project is owned by UNIS, and the consortium of partners include 14 additional Norwegian institutions. As this proposal is to fund the Norwegian node of the ESFRI infrastructure programme SIOS, only Norwegian institutions are included as partners. However, the SIOS consortium contains most major international institutions currently operating research infrastructure in Svalbard, thus securing a solid international basis for the project.

The partner institutions are: The Institute of Marine Research (IMR), Norwegian Meteorological Institute (MET), the Nansen Environmental and Remote Sensing Center (NERSC), The Geological Survey of Norway (NGU), The Norwegian Institute for Air Research (NILU), The Norwegian Institute for Nature Research (NINA), The Norwegian Institute for Water Research (NIVA), The Northern Research Institute (NORUT), The Norwegian Polar Institute (NPI), The Norwegian University of Science and Technology (NTNU), The Norwegian Water Resources and Energy Directorate (NVE), The University of Bergen (UiB), The University of Oslo (UiO), and UiT The Arctic University of Norway (UiT).

Combined, the consortium consists of the most experienced institutions in Norway regarding operation of research infrastructure in Svalbard and in the Arctic in general. In addition, several other Norwegian and international institutions are involved as collaborators. A partner in this context is an institution that own an instrument or host an activity. Their roles regarding infrastructure are listed in Tables 1 - 4. Each partner will have the responsibility to deploy and operate the infrastructure they own. Access to the infrastructure will in some cases be restricted to the data output, but several of the infrastructures will have the capacity to host additional instruments or sensors owned by external users.

9. Project management

The *SIOS-InfraNor* project will from Day 1 take full advantage of SIOS-KC as the coordination unit of the SIOS consortium, but at the same time be managed as a separate project during its construction and implementation phase (the first five years). After five years the *SIOS-InfraNor* project will be fully integrated in the SIOS consortium operation and coordinated by the SIOS consortium management structure.

The project management will be set up in the following manner:

Project owner is Managing Director Harald Ellingsen, University Centre in Svalbard (UNIS). This responsibility will be transferred to the managing director of SIOS AS when the independent legal entity is established and the SIOS consortium enters its next phase.

The project manager is the director of SIOS, Dr Ole Jørgen Lønne. The project manager is head of the SIOS-KC, with administrative, logistical and advisory support staff at his disposal. In addition, a full time technical engineer will be employed through *SIOS-InfraNor*, funded by this proposal. The engineer will assist and coordinate the technical work carried out by the partners. Combined, this support staff will be actively used by the project manager in the day-to-day operation of the project.

A leader group consisting of the SIOS director and the five module leaders (Hansen, Moholdt, Berge, Storvold, and Godøy) will have a coordinating role for the Norwegian SIOS infrastructure. The SIOS director will have main responsibility for coordinating the Norwegian infrastructure with international initiatives. The leader group will be jointly responsible for making budget priorities, ensuring that the implementation plan is followed and making the strategic decisions needed to ensure the success of *SIOS-InfraNor*. The leader group will have regular meetings (web) at least every second week in the initial part of the project; later in the project period, meetings will be according to need. At least two meetings (in person) each year will be hosted by UNIS or other partner institutions. Importantly, in order to ensure the engagement and direct involvement of the module leaders in the management of the project, some salary for the first 5-year period is earmarked through the project (250k NOK per person/year).

The partner group consisting of one representative from each of the partner institutions (IMR, MET, NERSC, NGU, NILU, NINA, NIVA, NORUT, NPI, NTNU, NVE, UiB, UiO, UiT) will function as a "general advisory board" for the project during the first five-year period, during which UNIS will host a joint meeting once a year. During the second five-year period (operational phase), the partners will only meet for a mid-term evaluation and a final closing meeting in 2026. These representatives represent each institution's technical, operational and/or scientific expertise, and are selected by its institutions.

9.1 Competence of the project leader and leader group

All members of the leader group have extensive experience from working in the Arctic and from operating advanced *in situ* infrastructure. Within the SIOS consortium the infrastructure is established, owned and operated by each member institution. All partners in the application will be members of the SIOS consortium, and through this take full advantage of the logistical support and capabilities held by SIOS-KC. All partner institutions in the application are in the international forefront in establishing and operating advanced scientific infrastructure in the Arctic (See institutional LoI and individual CVs).

9.2 Management and organization of the national research infrastructure in the operational phase, subsequent to the project period

The project management team will be operational for the first five years of this project. During this phase they will have the full support of the KC staff (Information, Remote sensing, Logistics and access, Data management services officers, and the Director), and with administrative and economic support services from UNIS. This integration is secured by having the KC data management officer and the SIOS director on the project management team. The management and organization of the new research infrastructure in the operational phase will be an integral part of the SIOS observation system and follow the management procedures as stated in the SIOS statutes (appended).

9.3. Competence of the operational management in terms of operating advanced research infrastructure

See attached CVs from Module leaders and responsible researchers for each piece of infrastructure.

10. **Work plan, time-schedule and deliverables**

Activity	**2018**				**2019**				**2020**				**2021**				**2022**				**2023**	**2024**	**2025**	**2026**	**2027**
RI	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**					
3.1.1																									
3.1.2																									
3.1.3																									
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3.4.1																									
3.4.2																									
3.4.3																									
3.4.4																									
Module 5																									
Module 6	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**					
LGM																									
PGM																									
TechStaff																									
Synthesis & Progress																									
ProgEval																									
AF																									

Figure 5: Time-schedule and milestones phase 1 (2018-2022) – procurement (light grey), validation and deployment (grey) and phase 2 (2023-2027) - operation (dark grey). The activity number refers to the subchapters in chapter 3. LGM: Leader group meetings, PGM: Partner group meetings, TechStaff: Technical staff, ProgEval: Progress Evalua-

tion, AF: Arctic Frontiers conference.

The project period is divided into two phases (1 and 2), both with duration of five years. Phase 1 includes the developmental part of the project during which the infrastructure elements are to be procured, tested and deployed. Phase 2 is strictly an operational phase in which the infrastructure elements are expected to be in full use. Depending on season, access to field sites and available ship-time, the ambition is to deploy the majority of instruments in 2019 and have all installations in an operational phase by the end of 2022. Some instruments will, however, be fully operational already during phase 1.

10.1 Measurable deliverables and criteria for success:

The project has been a success if we by the end of 2018 have all four infrastructure modules in full operation, by the end of 2019 have purchased at least 75% of the proposed infrastructure, by 2020 have successfully deployed at least 50% of the proposed infrastructure, and by 2022 have all four infrastructure modules in full operation and providing data through SIOS-KC.

The major deliverables are the 60 instruments and activities in the attached table. Timing of these deliverables is given in Figure 5.

11. **Risk analysis and mitigation measures**

SIOS-InfraNor is a bold and innovative project aiming at scientific exploration in one of the most challenging and poorly known systems on the planet – the High Arctic. Carrying out such a project will inevitably carry some risk of failure. However, through careful selection of a recognized national team (section 8) that includes world-leading technological competence, the partner group's long and proven track record of operating advanced scientific infrastructure in Svalbard, and not least by defining the entire project in terms of 60 independent components (see Tables 1-4), we are optimally equipped to carry out the proposed work. The last aspect is an especially important part of the risk contingency plan, reducing the risk for the entire project significantly by making the 60 infrastructure components fully independent of each other, which means that failure in any one component does not carry over to any of the other 59 components. It also reduces the financial strain on the project if any of the components turn out to be significantly more expensive than previously estimated.

12. **Cost- and funding plan**

The total financial framework of the *SIOS-InfraNor* proposal is 373 million NOK, of which 200 mill NOK (the exact amount is 199.672k NOK) is sought from RCN through this proposal. The project is divided into a procurement phase (years 1-5) and an operational phase (years 6-10). The total budget for the procurement phase is 258 mill NOK, whereas the total budget for the operational phase is 115 mill NOK:

		2018	2019	2020	2021	2022	Total
Module 1	From RCN	16407	18096	7716	1416	1416	45051
	Total cost	16522	18903	8681	2008	2008	48122
Module 2	From RCN	19384	9951	10645	5025	4995	50000
	Total cost	20610	10754	11437	5726	5756	54283
Module 3	From RCN	29585	14861	3348	2762	2444	52999
	Total cost	32435	19861	7798	7912	6744	74749
Module 4	From RCN	23282	3090	500	500	500	27872
	Total cost	23282	3090	1450	1450	1450	30722
Module 5	From RCN	2000	2000	2000	2000	2000	10000
	Total cost	3500	2500	2500	2500	2000	13000
Module 6	From RCN	3000	3000	2750	2750	2250	13750
	Total cost	7300	7300	7100	7100	6650	35450
Total budget *SIOS InfraNor* Procurement Phase (years 1-5)							258527

Table 5. Total budget overview of *SIOS-InfraNor* during the procurement phase (years 1-5). For an overview of the operation phase, see budget attachment.

SIOS is a decentralized infrastructure where a substantial portion of the "usage" will be access to the data and remote sensing products made available through SIOS-KC. SIOS data policies are clearly “open access” which is not synonymous with “access without cost”. There are structural issues (high Norwegian cost levels compared to the international partners’ national cost levels) as well as a deliberate intention to use SIOS to provide data and services that make Svalbard yet more attractive for international scientific endeavours. These issues are incompatible with a full cost recovery model for data usage. The SIOS infrastructure also contains elements of platforms and facilities for which users may pay an access fee, either directly or through funds released to the facilities from mobility schemes. These access costs will for the most part entail usage fees based on running costs. In the international SIOS consortium, proposed business models for the full SIOS infrastructure fees have never included write off costs for the investments. The infrastructure will deliver products that also private industry and agencies will utilize, but the volumes of usage depends on future, currently unknown developments of trade and commerce in the vicinity of Svalbard. The core program of environmental observations that SIOS will deliver are of paramount importance for all sectors of society but cannot be priced at a cost recovery level.

SIOS will encompass substantial parts of Norwegian and international long-term measurements of environmental entities. The inter-disciplinary coupling of measurements is a fundamental thought behind the SIOS initiative. With the elements contained in the present proposal, SIOS-KC may be in a position to harvest the benefits of the inter-disciplinary. We posit that the role of snow for Svalbard in an Earth System Science perspective can be tackled in a meaningful manner. A down-scaled version would have little credibility as an observation system, and such a limited measurement program would be unlikely to attract the international commitment to the SIOS notion that is a prerequisite for the long term success of Svalbard as a prominent international research platform.

This application consists of 60 discrete packages of scientific infrastructure, and is only a first step in developing the complete SIOS observing system. In total, we apply for 200 mill NOK to implement to proposed research infrastructure in Svalbard. This constitutes only 50% of the total need identified in Melhum et al 2013. As such, *SIOS-InfraNor* is already a downscaled version of the total need for a fully developed Norwegian research infrastructure network in Svalbard. If the application is not fully funded, we will follow the priority list provided by Mehlum et al 2013 (dividing all infrastructure items into a first and second priority). The final decision on which of the 60 items that are to be put on a hold in case the funding does not match the amount sought for rests with the project leader group.

A total funding below 140 mill NOK will, however, impede development of the observing system to such a degree that it would be difficult keep the consortium together. As such, we regard 140 mill NOK as a minimum funding level possible for this proposal. Cuts of up to 60 mill. NOK will result in infrastructure packages given priority two in Mehlum et al 2013 being postponed.

13.**Environmental and ethical perspectives**

During SIOS prepatory phase a detailed description of the environmental rules that the SIOS infrastructure must follow was produced under work package B. All parties to this proposal will adhere to these obligations. In the vision of SIOS, the development of new technology minimizing the environmental footprint has a prominent position. The two leading institutions NPI and UNIS have a long record of operating in Svalbard. No ethical issues are forseen for this infrastructure. Experiments with live animals that may appear under the auspices of SIOS will apply for permission as stipulated by Norwegian law.

The impact on the local environment will therefore be minimal, and one of the overall ambitions of the project is to develop automated and/or autonomous observational platforms that in themselves will reduce the need for larger field campaigns. Also, it is the Norwegian government’s stated vision to be a leader in Arctic management and sustainable resource exploitation. *SIOS-InfraNor* will be instrumental in this by providing the knowledge required for stewardship of the Arctic by a country whose identity is culturally, politically, and economically tied to the region.

14.**Further information**

Further information can be found on the SIOS webpage (www.sios-svalbard-org), including SIOS statutes, SIOS data policy and SDMS, SIOS management, Mehlum et al 2013, and a detailed list of proposed infrastructure.