US-Swedish Planning Workshop on

Joint Arctic Research using the I/B *Oden*

Workshop Report

Stora Brännbo Hotel & Conference Center, Sigtuna Sweden

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Cover photo: Sven Lidström

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Executive Summary

An adequate understanding of the past and the present Arctic climate, and of the processes that shape it, is key to projecting the future of this unique region, and the climate impact on society including health, social issues and commerce. Over the last several decades, climate change has been larger in the Arctic than elsewhere on Earth, with the most obvious consequence being a rapidly diminishing sea ice extent and mass. There is not yet a clear understanding of the strong feedback mechanisms, local and distant, between climate and sea ice currently debated, or any consensus on their relative importance. One limitation to an improved understanding of important feedback processes is that the Arctic environment is very hostile to all types of modern instrumentation, and to the people trying to perform experiments. An additional limitation is caused by the continuously drifting sea ice, which provides an unstable basis for long-term measurements for long time periods. The high temporal and spatial variability observed necessitates repeating experiments during different years.

An US-Swedish workshop on joint Arctic Ocean research using the Icebreaker (I/B) *Oden* was held in Sigtuna, Sweden in late March 2015. It was funded by the Swedish Polar Research Secretariat (SPRS) and the US National Science Foundation Polar Programs (NSF PLR) Division and jointly organized with the Swedish Research Council (SRC) VR and the Swedish Research Council Formas. The I/B *Oden* is operated for research purposes under a long-term agreement between SPRS and the ship owner, the Swedish Maritime Administration.

Approximately 15 scientists from each nation (selected through an open process), funders, and logistics personnel from the US and Sweden participated. Three objectives were addressed: (1) Prioritization of scientific themes, geographical regions, sampling seasons, international collaborations and future demands on technology in this harsh environment; (2) Scientific priorities, collaboration and synergies for a first expedition focusing on the linkages and feedbacks among surface energy, cloud formation, biological processes and climate in the High Arctic; and (3) A process for joint, international decision-making, funding and logistics.

1 General overview of the workshop

Building on earlier successful cooperation in polar research between Sweden and the US, the aim is to increase scientific collaborations using the I/B *Oden* as a platform for Arctic science, providing a solid base for US and Swedish research in the High Arctic. A multi-year approach will allow for the development of strong bilateral research collaborations, as well as the reliable deployment and retrieval of sophisticated instruments used for monitoring and research. Ship time will continue to be driven by merit-reviewed funded proposals through regular proposal competitions in the US and Sweden, but this workshop provided an opportunity to explore the scientific and interagency context that would enable these collaborations to develop in the future.

The workshop was organized in three main sessions. The first two aimed at identifying scientific demands and possibilities, and was jointly organized by scientists from US and Sweden, with guidance from the funding organizations. One session addressed the scientific priorities, collaboration, and synergies within the 2017/2018 cruise. Another session addressed science themes for multi-year collaboration(s), prioritized seasons, prioritized geographical regions, vessel capabilities and constraints with regards to the prioritized science, monitoring needs, deployment and retrieval of moored/automated equipment, ice/aerial/terrestrial missions, prospects for synergies and multi-platform operations, logistics and equipment, and a view to future demands on technology and innovation.

The third session focused on operational and feasibility issues and was organized by SPRS and NSF in dialogue with all funding organizations. SPRS set the stage with an introduction to existing agreements and intended research directions, funding opportunities, vessel capabilities, and an introduction to the format of the workshop.

2 Scientific motivation

An adequate understanding of the past and the present Arctic climate, and of the processes that shape it, is a key to projecting the future of this unique region, and the climate impact on society including health, social issues and commerce. Over the last several decades climate change has been larger in the Arctic than elsewhere on Earth, and since the mid 1960's the annually averaged near-surface air temperature north of 60°N has increased more than twice as much as the corresponding global average. This is often referred to as the "Arctic amplification".

One of the most obvious consequences of this warming, or Arctic amplification, is a rapidly shrinking sea ice (extent and volume), appearing in all seasons, but most dramatically in late summer when the sea ice has its annual minimum. It is quite likely that the sea ice mass, also taking the ice thickness into account, is diminishing even faster, but thickness is much more difficult to observe. In addition, we see ever-warmer pulses of Atlantic and Pacific waters, early signs of acidification, rapidly increasing land-ice loss from the Greenland Ice Sheet and other glaciers distributed around the Arctic region, and changed patterns of meteorological fields. In spite of the considerable effort that has been invested in understanding both the Arctic amplification and its consequence for the diminishing sea ice and land-ice, there is not yet a clear understanding of the strong feedback mechanisms, local and distant, between climate and the Arctic cryosphere currently debated, or any consensus on their relative importance. One limitation to an improved understanding of important feedback processes is that the Arctic environment is very hostile to all types of modern instrumentation, and to the people trying to perform experiments. An additional limitation is caused by the continuously drifting sea ice and icebergs, which pose a challenge for long-term measurements. The high temporal and spatial variability observed necessitates repeating experiments during different years.

3 Cruises

Collaborative cruises on the I/B *Oden* would provide opportunities for US and Swedish scientists to join on a wide variety of research foci. Summaries of the discussions held at the Workshop are given in Section 4.

A pilot cruise has been approved, the only one yet to have a specific research focus on life cycle of clouds and associated biogeochemical processes in the high Arctic summer, as part of the Swedish Roadmap for Polar Research, and thus prioritized for support from SPRS. Details are provided below (Section 5). This cruise may take place in 2017, but due to the timeline of research proposal competitions in the US and Sweden, the workshop participants agreed that 2018 would allow more time to plan for and develop the research collaboration. This is an open opportunity for Swedish and US scientists to develop a suite of research that complements and supports this research area.

The I/B *Oden* is a Polar 20 class icebreaker that can operate as a research platform in multi-year ice conditions in Polar waters. Research facilities include winches capable of handling CTD-rosette packages, nets for plankton sampling, and sediment coring facilities. There is also an ability to add winches for other types of sampling, such as a trace metal clean system. I/B *Oden* also has a small (60 cm diameter) moon pool. One or two helicopters can be deployed to facilitate on-ice research or personnel transfers to land.

I/B *Oden* has a 90 m^2 permanently installed laboratory that is divided into three units, including one clean room. This laboratory is supplied by seawater from a hull inlet at ~8.5 m depth and has several independent gas lines and manifolds. A larger laboratory is also situated on the 4th deck. In addition, there are options for up to 12 container laboratories (20ft vans) with electric and waste water and specialty gas connections. As I/B *Oden* is not primarily a research vessel, scientists are expected to bring necessary laboratory equipment aboard and install it in the main labs or in containers/vans. There is access to MilliQ equipment, and storage at -80^{o}C, -20^{o}C and +4^{o}C. An atmospheric tower is located in the bow. An advanced multibeam sonar with a sub bottom profiler and a water column sonar are installed on I/B *Oden*.

I/B *Oden* has a well-developed IT infrastructure covering data storage, e-mail and ship navigational data that can be accessed in most areas of the ship. An introduction to I/B *Oden* as a research vessel with drawings and further technical specifications is available here:

http://polar.se/wp-content/uploads/broschyr_isbrytaren_oden.pdf

There are certain science operational constraints:

Technical support: The I/B *Oden* is an excellent ice-breaking platform and with SPRS augmenting the crew for scientific operations, I/B *Oden* is a highly capable science vessel. There is support available from the ship to assist in deck operations, operations of A-frames and winches, but assistance from the science group is necessary. After training, winch control on CTD stations, equipment handling is often operated by the projects. Researchers should take this into account and request personnel for technical support in their proposals. Technical support needs will be re-assessed by US and Sweden once research teams are selected for participation in I/B *Oden* cruises.

Station keeping in open water: I/B *Oden* has limited station-keeping ability in open water. The ship is subject to windage and has a tendency to roll. Over-the-side operations in open water in even moderate conditions are constrained by wire-angle considerations as well as the safety of personnel.

Radioisotope tracers: No tritium is allowed on-board because of the risk of residual contamination that could invalidate subsequent research involving environmental levels of the tracer. Work with carbon-14 radioisotopes may be done in a designated isotope laboratory van. US scientists should follow radioisotope handling procedures for their designated institution, as well as protocols developed by the University-National Oceanographic Laboratory System (UNOLS) and the Swedish Polar Research Secretariat.

Permits: The I/B *Oden* is a Swedish vessel operating under Swedish law. US investigators must also comply with US regulations.

4 Areas for possible future US-Sweden Arctic scientific cooperation involving Oden

Future science programs should take advantage of the special capabilities of the I/B *Oden* to work in regions of Arctic ice. Scientific cooperation would optimize the cruise tracks to fulfill the requirements of the scientific party on each campaign. The following sections consist of very condensed summaries of the discussions in break-out groups and in plenary sessions of the Workshop.

Not all topics are independent and several are connected though physical, chemical, and biological processes, such as the Surface Energy Budget and Consequences of Snow and Ice Transitions as well as the Clouds and associated physical and biogeochemical processes of the 2017/2018 cruise. Other topics could be linked by logistical considerations, either through complementary sampling processes, or discounted by mutually exclusive requirements.

4.1 Arctic Ocean geological history / cryosphere dynamics on different time scales

Research topics include the origin of the Amerasian Basin, specifically the timing and tectonic mechanisms, and the history and role of major gateways, including Bering Strait, Fram Strait, and Nares Strait. Other aspects include the history of a) sea ice and related processes, such as impacts on productivity, circulation, and CO_2 exchange, and their rates of change; b) freshwater, heat and biogeochemical fluxes between glaciers and the ocean; c) marine ice sheet history, including grounded and floating ice and their rates of change; and d) submarine permafrost, especially methane release and climate feedback and their rates of change.

Geological cores taken from the I/B *Oden* in the areas of interest would improve the sampling of poorly observed, but important areas, needed to better understand the origins of the central Arctic Ocean basins, and the exchanges between these areas and the rest of the world's oceans though the major gateways. Cores and samples taken on continental shelves and adjacent deeper waters such as the outlet glaciers of northern Greenland, ice shelves along Ellesmere Island, the Lomonosov Ridge off Greenland and Alpha Ridge represent some of the least explored areas in the Arctic Ocean.

Two icebreakers may be required to fully enter the southern Lomonosov Ridge in the western Arctic and Alpha ridge area; an expedition consisting of a transect from northern Greenland, entering through Nares Strait, to the Canada Basin could provide valuable information, although other areas should not be excluded from consideration.

Some of the research topics would benefit from long term (years) observations involving moorings (ocean properties), weather stations and sediment traps. Mapping and sampling of physical properties of ocean, seafloor and subsurface are key to all research topics; mapping of ecosystems is also of specific interest. Appropriate data sets would be enhanced by the use of Autonomous Underwater Vehicles (AUVs) for under ice mapping, and hybrid AUV-Remotely Operated Vehicles (ROVs).

4.2 Greenhouse Gas Exchange in the Arctic Ocean

The Arctic Ocean is considered to be a sink for CO_2 since measurements show that the partial pressure of CO_2 (pCO_2) in ocean surface waters is generally lower than the concentration in the atmosphere. The processes driving this open water uptake of CO_2 have been stimulated in recent years by the decline of sea ice. In particular, this has strengthened the uptake of CO_2 in the shallow waters of the shelf margin, but future projections are uncertain.

The dynamics of pCO_2 in the ocean water and how this relates to current and future climatic and sea ice conditions would benefit from measurements taken from the I/B *Oden*. CO_2-exchange is not just an open water process; brine expelled during sea ice formation contains dissolved inorganic carbon and, because of its high density, this carbon is transported downwards with the brine. Subsequently, ikaite crystals (hexahydrate of calcium carbonate, $CaCO_3 \cdot 6H_2O$) can form in the ice. Upon ice melt, the dissolution of these crystals increases the pH of surface waters, which in turn lowers the pCO_2. Hence, both the formation and melt of ice may facilitate carbon uptake. This has important implications for the Arctic as a carbon sink, given that more sea ice is formed and melted under seasonal ice cover conditions. These processes are poorly constrained while fieldwork is often limited to fjords. A cruise on the I/B *Oden* in the Arctic Ocean in areas of sea ice formation and melt could vastly improve our knowledge.

The measurement of direct exchange of CO_2 between the ice and the atmosphere could also be done from the I/B *Oden*, using chambers or eddy covariance sensors. Assessed fluxes should be put in perspective according to the ice quality, quantity, and age. Apart from ice-covered areas, open water within the ice pack such as polynyas can also be hot spots for CO_2 uptake.

Processes in the Arctic Ocean related to methane formation, oxidation, and transport (e.g. bubble plumes) are also potential topics for research from the I/B *Oden*. Continuous sampling of the methane concentration in the water, and the use of an eddy covariance tower from the bow would be important tools to determine the flux to the atmosphere. To understand what drives these fluxes, a better categorization of the microbial community responsible for the formation and oxidation of methane in seawater and a focus on benthic processes would be beneficial. Specific issues regarding gas hydrates and how emissions relate to subsea permafrost and sea ice decline are other important areas of interest.

4.3 Ocean-land and land-ice interactions

Substantial input of organic matter through coastal erosion and river runoff and glacial discharge is added to the Arctic Ocean shelves affecting the carbon cycle, the marine ecosystems and the regional air-sea exchange of CO_2. Marine-terminating glaciers (including floating ice shelves) are both affected by ocean (via thermodynamic and mechanical forcing) and affect the ocean through freshwater discharge and discharge of minerals and carbon.

Knowledge of ocean–land and land-ice interactions in the Arctic region is limited and the few measurements are typically from the ice-free period. As a result, predictions of ice sheet change (and hence sea level rise) or the input of land-stored carbon into the Arctic Ocean are highly uncertain. Key to improving this situation is to obtain measurements from the land-ocean/land-ice interface both during the accessible period, but also from the remainder of the year. I/B *Oden* is a suitable platform to reach the margins of the Greenland ice sheet, especially the northern section of Greenland and other Arctic land-ice regions. Access here is possible in spring and summer using I/B *Oden* and offers the opportunity to deploy instrumentation which can collect data from the remainder of the year (e.g. moorings, or on land/ice sensors). In some cases, these would need to be recovered during a subsequent cruise or data can be received through telemetry. Collection of sediment cores, including from the open ocean towards the ice shelf, can provide a historic record of glacier and glacier/ocean interaction. Access to land via helicopters on board I/B *Oden*, in addition, would provide the opportunity to integrate glaciology, and other land-based studies, with ocean measurements.

Similarly, studying other non-glaciated Arctic margins can contribute to our understanding of the input of chemical constituents and their transformation by biogeochemical processes. The shelf seas are heavily impacted by input of terrestrial organic matter, where the majority of that added by coastal erosion occurs in the fall when the seas are mostly ice-free and the winds can be strong. The addition by rivers on the other hand is largest during the spring flood. It is not well known how this large inflow of runoff spreads out in the coastal region, i.e. how is it mixed under the sea ice and to what degree is it flowing on top of the sea ice. This is the time of the year when it is logistically difficult to do investigation using ice camps supplied from land.

Addressing the spreading of the river runoff, assessing the fluxes of dissolved and particulate organic matter by the runoff and the importance of land fast ice in the spreading of freshwater and constituents off the coastal area during the early season is of high relevance. The fate of the chemical constituents during their transport from the coast towards the outer shelf determines the strength of several processes relevant to the cycling of carbon. Nutrient supply from land may add to marine primary production and the microbial decay of terrestrial organic matter increases pCO_2 with subsequent impact on air-sea flux. All of these investigations are only possible with an icebreaking vessel like I/B *Oden*, though operation in depths shallower than 50-100m may be difficult.

4.4 Surface energy budget

The surface energy budget is a critical component of the changing Arctic, both though direct means and though various feedback processes, which might be well described, at least conceptually, but currently lack quantification and understanding of details.

Improving our understanding of the surface energy budget requires measurements of its components, both radiative and turbulent fluxes, but also the use of these measurements to constrain modeling studies. The requirements of modelling studies can also guide measurement strategies. Clouds are critical in modulating the radiative components of the surface energy budget in all seasons, both directly and through cloud-related feedbacks; knowledge of cloud occurrence and formation, microphysical properties, phase partitioning and many cloud processes is inadequate, and consequently these processes are not correctly represented in models. A major problem in characterizing the surface energy budget results from surface heterogeneities, especially in transition regions and periods where open water and sea ice occur on a wide range of spatial scales, most of which are not resolved in current coupled ocean-ice-atmosphere models. An adequate understanding is lacking of the relative importance of local and remote sources of moisture, heat, and particles and how these impact cloud formation. Two-way interactions in leads are important in the exchanges between atmosphere and ocean, and for the energy budgets in the ocean mixed layer, atmospheric boundary layer, and sea ice surface. The vertical mixing processes communicate information across an otherwise stratified atmospheric environment.

Characterizing variability on model grid box scales is a pressing need for the modelling community, specifically how to provide areal integrals in a system where heterogeneity has different scales of importance depending on the domain, sub-system, or relevant process. Ice processes, deformation, convergence-divergence, thickness, energy flux components, moisture fluxes, and cloud properties need to be characterized in the vertical and over a spatial domain, which could be in the range of 10x10km to 50x50km. In addition to data from the I/B *Oden*, remote stations might be used to measure the local meteorology and the surface energy budget in different ice conditions (thin ice, thick ice, marginal zone, open ocean).

Measurements are required in all seasons; winter conditions are especially understudied, particularly the impact of leads on energy exchanges. Data from the transition seasons are needed because of the influence of energy fluxes on forcing the transitions and the changes in energy exchange processes. In the summer, large radiative fluxes have importance for ice melt processes.

4.5 Optical properties of atmosphere, snow, ice and ocean

During the summer, the incident solar radiation plays a critical role in determining the state of the Arctic, influencing ice melt, and, as the solar zenith angle increases at the end of summer, on the rate of ice formation. The presence and properties of clouds modulate the solar radiation incident at the surface. During all seasons, the propagation of thermal, infrared emission through the atmosphere to space is a fundamental heat sink for the earth's climate system.

While the top-of-atmosphere flux of solar radiation, and its spectral composition, can be accurately calculated, interactions with atmospheric gases and particulates, including, ice crystals and water droplets render the surface insolation very variable. The surface albedo, itself a very variable quantity, especially in the transition periods of snow and ice melt, or after snowfall and the start of sea ice formation, determines how much solar energy is reflected back to the atmosphere. The propagation of solar radiation though the snow, underlying sea ice and into the ocean below has important impacts not only on the energy budget of the system, but also on photochemical processes and marine / sea ice primary production. Measurements of optical properties and radiative fluxes, and modelling of the radiative transfer processes from the top-of-atmosphere to the bottom of the euphotic layer, are needed to improve our quantification of the direct consequences of variability in the component layers, and of feedbacks that can accelerate or reduce the rate of change in the Arctic.

The loss of thermal radiation to space in the Polar Regions is an important mechanism for cooling the planet and the transfer of heat from low to high latitudes in the ocean and atmosphere is driven by the polar heat sink. Changes in the Arctic atmosphere will influence the radiative transfer of infrared photons through the atmosphere in ways that are poorly understood and poorly represented in climate models, and which have feedback potentials that can influence the evolution of our climate on a global basis.

4.6 Consequences of snow & ice transitions

Ice and snow cover are changing in the Arctic, and these impact the surface energy budget, biological/ecosystem function, and chemical processes. These systems are highly coupled, with numerous potential feedbacks and interactions.

As an example, changing sea ice regimes, from multi-year to first year sea ice, impact biological systems and productivity, which in turn impact marine aerosol production and trace gas fluxes. These aerosol and gas fluxes (through both primary and secondary processes) will impact cloud condensation nuclei and ice nuclei with potential feedbacks on the surface energy budget, that could further accelerate or reduce sea ice regime changes. There are a number of highly synergistic and interdisciplinary studies that could be organized around such processes and feedbacks in the Arctic that would benefit from measurements taken from the I/B *Oden*, or from instrument packages deployed on or under the ice.

The changing nature of ice and snow influences biological processes, both seasonal transitions as well as changing ice regimes over time (e.g., ice algal blooms / phytoplankton blooms; sympagic to pelagic transitions). Ecological systems are impacted by changes in contaminant transport and fate via acute (toxic) and chronic (bioaccumulation) effects while changes in the marine microbiology influence marine aerosol production (e.g., bio-aerosols, gels, polysaccharides, sea surface microlayer) as well as GHG (greenhouse gas) emissions. Surface photochemistry impacts the flux of gases and particles to/from snow and sea ice and changes in the surface fluxes of chemicals (e.g., GHG, oxidants, halogens, contaminants) influence atmospheric chemistry and also potentially biological functions.

Contaminant transport and fate will be impacted by changing sea ice and snow regimes. In addition to studies of "traditional" species like POPs, Hg, and heavy metals, newly identified emerging contaminants as well as plastic debris/microfibers should be considered.

4.7 Sensors for continuous measurements

Continuous underway measurements are a potentially important component of research supported by the I/B Oden, and these could include a) enhanced meteorological measurements, b) atmospheric gas measurements, c) seawater measurements, and d) sea ice measurements.

Enhanced meteorological measurements would provide information on the spatial distribution of energy, momentum, gas fluxes and clouds. Examples are measurements of downwelling irradiance, cloud heights, cloud liquid water and three-dimension distributions, upwelling radiation and surface albedo. Given that atmospheric depletion events of gases such as O_3 and Hg are coupled with halogen chemistry, measurements of O_3, CO_2, CO, CH_4, halogens, and atmospheric mercury species would be useful. A springtime emphasis may require logistical releases for I/B *Oden* from other ice-breaking obligations.

To constrain reservoirs and fluxes of carbon and primary productivity in the Arctic, underway seawater measurements could be taken, including, for example, particle size (organic and inorganic carbon), chlorophyll and colored dissolved organic matter (DOM), pH and pCO_2, DIC/Alkalinity measurements, dissolved O_2, and nitrate. Underway expendable-CTDs would provide vertical information about the temperature and salinity of the water column.

Better characterization of sea ice conditions is required, and this could be achieved using, for example, a camera system, infrared radiometer, scanning lidar, snow radar, and an electromagnetic ice thickness sensor. Some of these sensors could be deployed from the ship, but others would be better deployed from a helicopter.

4.8 Winter investigations

A recent synthesis effort focused on the western Arctic marine ecosystem (PacMARS: Pacific Marine Arctic Regional Synthesis) as well as ongoing work around Svalbard (Marine Night) have come to the conclusion that our knowledge about winter conditions and processes is very poor, in part as a result of the scarcity of research studies during the winter season.

The capabilities of the I/B *Oden* could support studies in many disciplinary and multi-disciplinary studies at this inhospitable time of the year. Currently, winter physical processes have to be inferred from remnants observed in early spring; of special importance might be studies extending to the end of the freezing period. Shelf processes are of particular importance, especially on the Siberian shelves but also around Svalbard and the northern Barents Sea shelves. In addition to ship or ice-based measurements, those from moorings, perhaps in place throughout the winter, would be of special value.

Little is known about sea ice chemistry through the winter when sea ice could be an important source for many different gases, including halogens, produced from dark chemistry and when poorly understood biological processes play a role in release and uptake of gases including halocarbons and mercury. Given that anthropogenic pollutants accumulate in brine channels, studies are needed in both multi- and first-year ice. Also the role of sea ice in winter in producing sea salt aerosols, reactive halogens, and transformation of contaminants has not been adequately studied.

Good knowledge of winter ecology in the Arctic is lacking, and recent surprising findings suggest that Arctic organisms in surface waters, especially on shelves, remain active in winter, indicating a need for biological process studies to determine, for example, survival rates and strategies, causes of mortality, activity levels, and food sources. Studies could also focus on sympagic, pelagic, and benthic systems, as well as coupling between those systems. The use of acoustic moorings or though-ice sensor strings could provide valuable information. All of these investigations are only possible with a vessel like I/B *Oden*, though winter operations may require logistical prioritization.

4.9 Repeat sections and stations

Repeat ocean sections and stations provide information to help understand the evolution of the Arctic Ocean as a system in times of environmental change. Repeat sections are needed to study trends and variability of the individual components of the Arctic Ocean including its physics, biology, chemistry, as well as the coupling to the sea ice cover, atmosphere, glacial ice masses, and sediments through exchange of heat, water, gases, and particles.

In addition to standard hydrographic parameters (T, S, DOM, nutrients), water samples for analysis of a variety of trace substances, gases, and biological parameters that are important for our understanding of the evolution of the Arctic Ocean as part of the Arctic system should be collected. Underway sampling and measurements, and deployment of moorings and other measurement devices, should be facilitated; helicopter-based studies and work on sea ice can be supported from an icebreaker during section work. Repeated ship sections are seen as complementary to Lagrangian (e.g. ice-tethered profilers) and Eulerian (moorings) measurements.

I/B *Oden* is well suited for pan-Arctic sections, either as a single ship (as the 2005 transect) or by multiple icebreakers through coordinated activities with other agencies and ship operators. Based on available information of trends and variability in the Arctic Ocean, pan-Arctic sections should be repeated every ca. 3 to 5 years. They should be geographically as close as possible to eliminate spatial aliasing. The sections would typically be multi-disciplinary in nature, but each section, or part of one, could be focused on a specific discipline or research focus.

4.10 Satellite geophysical validation

Since the Arctic area is relative inaccessible and hostile to instruments and observers, satellite remote sensing offers a great potential to studying the important aspects of a changing Arctic.

Much of what we know about changing sea ice conditions in the Arctic Ocean has been derived from satellite imagery. Other aspects of the marine and atmospheric variability, such as temperature, phytoplankton concentrations and primary production, coastal sediment loads, cloud properties, and so on, are accessible using satellite remote sensing. Independent information is required both to assess the accuracies of satellite-derived variables and to validate /improve the algorithms used to derive them from the satellite measurements; such data can be derived from instruments mounted on the I/B *Oden* or deployed on ice or in the open water from the ship.

4.11 Human acclimatization to cold environments

Human activity, both physical and psychological, can suffer when done in cold conditions, and the acclimatization to cold environments, while a recognized response, is poorly understood, especially in terms of duration and levels of exposure, and how fast does acclimatization and de-acclimatization occurs

Work in cold environments is a challenge as even moderate chilling of the hands will reduce manual dexterity, while more extreme exposure will involve a risk of frostbite as well as hypothermia. When humans are exposed to cold environments, constriction of peripheral vessels occurs to reduce heat loss and maintain core temperature at around 37^{o}C. This results in a cooling of the extremities, with negative effects of manual dexterity and risk of frostbite. However, 5-10 min after the initiation of cold exposure, blood vessels suddenly dilate which increases finger temperature, after which the vessels constrict again. This is repeated in cycles in an attempt to prevent local sensory loss and frostbite.

Acclimatization to cold occurs on several levels in humans. At repeated exposure, protective responses are enhanced and manual dexterity in cold conditions is improved. While it is clear that changes occur that promote manual dexterity in the cold and also resistance to frostbite, it is less well known how fast this adaptation occurs and what minimum exposure time is required, as well as how long it takes to de-acclimatize. Crew and scientists of I/B *Oden* being exposed to cold could be suitable subjects for research into this study area.

4.12 Synergy with other programs

The scientific worth of the measurements to be taken on multi-year cruises of the I/B Oden will be greatly enhanced though synergy with other observational programs, past measurement campaigns, and through the use of satellite data.

While it is self-evident that the benefit of the I/B *Oden* cruises can be enriched through synergy with other measurement campaigns, modelling efforts and satellite missions, the degree of collaboration and synergy could not be determined at the Workshop, as these will be determined by the research foci of the cruises, their locations and timing. Researchers will be encouraged to seek synergism through collaborations to enhance be scientific value of their measurements and analyses.

5 2017/2018 cruise – "The life cycle of clouds in the high Arctic summer"

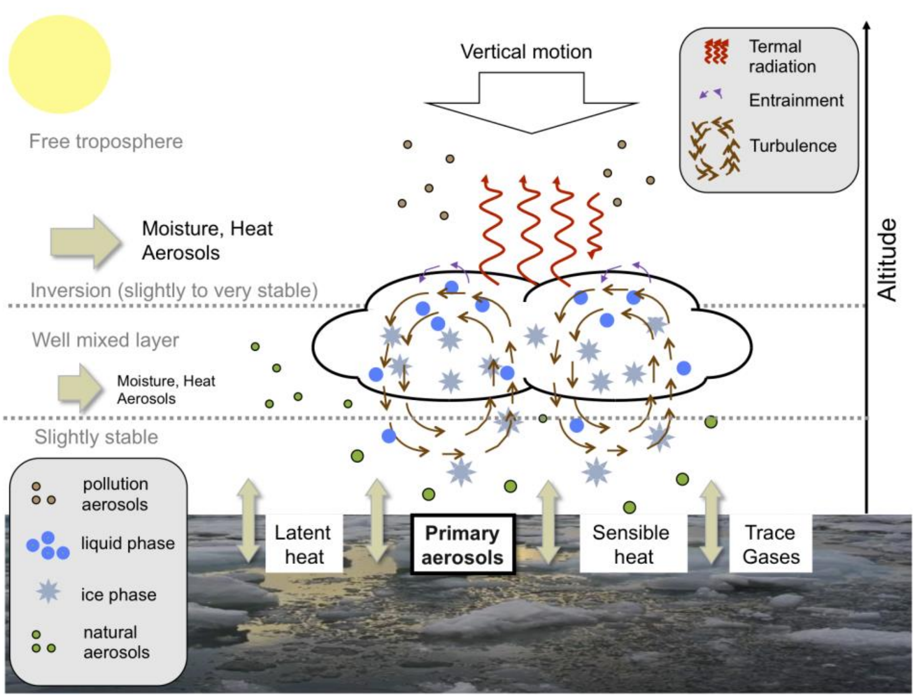

Figure 1. A schematic of the main processes to be studied in the 2017/2018 cruise (modified from A. Ekman and C. Leck, pers. comm.)

5.1 Motivation

The uncertainties in simulating future scenarios of Arctic climate change partly relate to an insufficient understanding of several strong feedback mechanisms believed to involve the ocean, sea ice, snow cover, clouds and radiation and not least ocean biology within the Arctic system, and therefore to an inadequate description of these processes in our models.

The only remedy is to collect in-situ data from the Arctic covering the scales and processes that are important to this system. However, one cannot expect to resolve all possible states of the system with just one experiment or with just a few very limited measurements. The Arctic atmosphere shows a high temporal variability and many degrees of freedom, not only *in situ* but also on inter-annual and inter-decadal time scales. This necessitates repeating experiments during different years that are of sufficient length to observe the entire spectrum of occurring events.

Sweden has a unique capability to carry out science projects in the high Arctic, through access to the I/B *Oden* and the experience of the SPRS. The proposed initiative (section 5.1.2 below) should be viewed as a direct continuation and development of outstanding research carried out in a series of five previous international ice-breaker expeditions to the high Arctic in the years of 1980, 1991, 1996, 2001 and 2008. Each expedition resulted in data that improved our understanding of processes that are important to the Arctic climate system itself and advanced the questions and hypotheses posed by research teams.

With an integrated study, from ocean mixed layer through the ice and the troposphere, the proposed international and interdisciplinary research program for 2017/2018 is designed to identify, quantify and understand controlling factors of optically thin low-level clouds, with links to microbiological life in the ocean and ice. This necessitates combining different expertise in meteorology, aerosol chemistry and physics as well as marine physics, chemistry and biology (Figure 1). It is planned as a comprehensive program and has the overall aim of reducing the uncertainties in climate models in their estimates of climate sensitivity in the Arctic and the response to climate change caused by human activities. The Swedish I/B *Oden* will be moored to an ice floe and drift passively, especially during the biologically most active period into autumn freeze-up conditions, mid-July through September.

The following sections describe the 2017/2018 cruise already in the Swedish Roadmap for Polar Research. They are included here to foster multidisciplinary collaborations among US and Swedish investigators.

5.1.1 A negative feedback involving micro-organism and clouds

The shrinking area of summer sea ice is, as pointed out above, one of the most visible manifestations of Arctic climate change. In summer 2012, ice cover melted to its lowest extent in the satellite record, breaking the previous record low observed in 2007. If this trend continues, the region is likely to witness ice-free summers before the mid-2100s. Sea ice reflects incoming solar radiation, while the open ocean absorbs and stores solar radiation during the summer. Later, during the autumn, this heat is released and further warms the atmosphere. As more ocean is exposed, a positive feedback loop would develop accelerating summer sea ice.

But low-level clouds, while controlling the Arctic surface radiation balance, could potentially counter the warming. For most of the year, such clouds tend to warm the Arctic surface.

However, during the peak-melt season at the end of the summer, low-level clouds may cool the surface and thereby influence the timing of the autumn freeze-up. Earlier freeze-up will cause thicker ice that might melt less during the following summer, surviving into the subsequent winter. If such a process were to recur over several years, it could delay or even prevent sea ice from melting completely during the Arctic summer. In other words, it would constitute a negative feedback.

The most common type of clouds in the Arctic is a mixed-phase cloud where the cloud top contains a relatively thin layer of liquid water that semi-constantly precipitates ice particles [e.g. Morrison et al., 2012]. Neither the processes that control the balance between formation of either liquid or ice water in the clouds, nor those that control the resilience of the clouds and their impact on the vertical structure of the Arctic atmospheric boundary layer are well understood. However, the clouds form first in the liquid phase and are dependent on tiny airborne aerosol particles, known as cloud condensation nuclei (CCN), while the transition to ice is critically dependent on the part of the aerosol population that could form ice crystals, known as ice nuclei (IN). Presently, the exact properties of a good IN are neither well identified nor quantified.

The optical properties of the summer Arctic low-level clouds relate to clean air with its low concentration of cloud droplets. Therefore, the Arctic low-level clouds are often optically thin, that is, have fewer but larger droplets compared to other regions [e.g. Tjernström et al., 2008]. This makes them reflect less shortwave radiation than clouds with numerous but smaller droplets [e.g. Twomey, 1977], everything else being the same. Combined with the semi-permanent ice cover, small changes in either are very important to the heat transfer to the ice and the subsequent summertime ice-melt. An increase in CCN in summer could increase the albedo of the clouds (more reflecting), as the condensed water is distributed over many small droplets rather than over a few large ones, and therefore lead to decreased ice-melt.

A link between CCN and microorganisms has been demonstrated in the Arctic, more specifically via marine biogenic polymer gels [Leck and Bigg, 2005a; Orellana et al., 2011] that are also present in aerosol particles, cloud and fog water. Sea ice microalgae and phytoplankton are likely to be strongly affected by changing sea ice conditions [Wassmann and Reigstad, 2011]. But whereas both groups generate dissolved organic matter and are hence a potential source of airborne gels, their relative importance in the central Arctic Ocean is still not fully understood.

The recent report of an extensive sub-ice phytoplankton bloom by Arrigo and colleagues [2012] strongly suggests increased activity as the Arctic warms. If they are found to be a strong contributor of aerosol precursors [Orellana et al., 2011], phytoplankton might facilitate an increased reflectivity of the low-level clouds, which helps counteract enhanced ice melt. On the other hand, the melting of sea ice might reduce or even eliminate the habitat of ice algae [Leu et al. 2015] and reduce their role as a source of biogenic aerosols.

The presence of sea ice significantly controls wind-driven mixing of the surface layer of the Arctic Ocean. Combined with light availability, this has kept phytoplankton mostly at the surface. Thinner ice or more open ocean areas would allow the wind to mix the surface ocean more effectively, deepening the mixed layer, thereby potentially reducing algal growth. As ice algal DOM was confirmed [Orellana et al., 2011] to be a major source of airborne gels, future warming might imply a reduced supply of CCN and thus very optically thin clouds with enhanced surface warming. On the other hand, ice formation during freeze-up excludes salt brine and other substances, including DOM likely assembled as primary particles that can end up in both the surrounding water and the atmosphere during this crucial period.

How microorganisms in seawater and/or sea ice respond to the melting sea ice [e.g., Arrigo et al., 2012] will thus influence formation of Arctic low-level clouds and their optical properties, and perhaps the rate of future melting.

Clearly, there are too many unknowns at this stage to fully assess the likelihood of a negative feedback involving microorganisms and clouds. But given how sensitive the Arctic is to climate change and how important it is for the regional and global radiation balance, there is a strong rationale for continued research to test this hypothesis. Further, the processes that control potential links between cloud radiative properties and marine primary production are not only in their infancy, they are also "sub-grid scale" in climate models. This means their presence or their impacts on other processes are not resolved by the models projecting future climate.

5.1.2 Specific targets and objectives of the 2017/2018 proposed program

The proposed program is a multi-month field experiment planned for the summer of 2017/2018, with the main activities taking place while I/B *Oden* is moored to an ice floe in the inner pack ice area and drifts passively, during the biologically most active period into autumn freeze-up conditions, roughly mid-July through September. Instruments will be deployed on board the icebreaker and on the ice. Additional sampling will be performed during the transit into the ice before the ice camp is established.

The role of the program will be to provide high quality and unique data on high Arctic boundary-layer, cloud and aerosol processes as well as associated marine biogeochemical processes that do not presently exist in a coordinated manner. To allow for this approach, the program comprises four subprograms: marine planktonic ecology, gas/aerosol chemistry/aerosol physics, meteorology, as well as physical and chemical oceanography. The specific objectives of the program are listed in Table 1.

The efforts will be organized in a novel way around the identified basic needs listed in Table 2. Examples of processes to be quantified for Needs 1 and 2 include microbial community composition and abundance, particle characterization and concentration (air, water, ice, snow), food web analysis as control for DOM release, radiation/ photochemical processes and controls, DOM chemical composition (water, ice, air, fog, clouds simultaneously), sea ice-air gas and aerosol flux measurements, optical characterization of seawater particulate and dissolved components, upper ocean physics, bubble dynamics and composition, and others. Such characterizations require multiple collaborations that were discussed during the workshop.

The third identified Basic need will advance our understanding of the following two key questions: What is the size-dependent fraction of marine biogenic sourced particles in the Arctic aerosol? What is the fraction of biological material in activated droplet of real-world clouds and fogs in the summer Arctic? Answering these needs will include characterization of gas and tracer chemistry, aerosol physical, and aerosol chemistry/biology in air and aqueous phase.

To meet the Basic needs 4, 5 and 6, workshop participants concluded that, at minimum, a suite of surface-based remote sensing instruments will continuously record the state and vertical structure of the lower troposphere. A combination of cloud Doppler radar(s) and lidar will detect clouds, cloud boundaries and cloud phase (liquid or ice). With Doppler and backscatter radar signals, combined with other instruments cloud microphysical properties will be measured. Passive scanning radiometers will determine the temperature, moisture and cloud liquid-water profile through the lowest troposphere, while wind profiler and sodar will monitor the wind profile. The remote sensing instruments will be supported by regular soundings, providing *in situ* profiles of temperature, moisture and winds through the whole troposphere.

Table 1. <u>Specific</u> program objectives

1. To determine the relative role of marine biochemical sources for CCN and IN formation, with emphasis on the open lead surface microlayer, compared to other sources.
2. To explore the vertical structure of the lowest atmosphere and determine the effects of this on aerosol distribution and source apportionment.
3. To determine the evolution of CCN and IN, how they form cloud droplets and ice crystals and partition water between the liquid and solid phase.
4. To determine the role of boundary-layer clouds on the turbulent exchange of heat, momentum, gases and aerosols across the ocean/ice/air interface and with the free troposphere.
5. To provide a comprehensive data set on the high Arctic climate system, for developing and testing of integrated climate models.

Table 2. <u>Basic</u> needs identified

1. To provide a complete description of the microbiology of the water and ice, the nutrients present, productivity and sedimenting material.
2. To determine the properties of the surface microlayer and its probable role in influencing the nature of the particles produced by bubble bursting.
3. To make shipboard measurements of the chemistry and physical properties of the aerosol, trace gases, CCN, IN, radioactive tracers and electrical conductivity.
4. To have lengthy and as continuous as possible series of measurements of P, T, W, RH, clouds, mixing processes in the atmosphere from the surface to above the cloud top.
5. To assess horizontal homogeneity of the near surface atmosphere.
6. To obtain as many vertical profiles as possible of cloud water, aerosols in various size ranges and of trace gases.

While many of the techniques and methods have been well tried and require only modification for the Arctic environment, some are or need to be innovative. The greatest deficiency has been an inability to connect aerosol and cloud properties other than theoretically because of the difficulties of performing *in situ* measurements in super-cooled clouds in a remote and hostile environment.

Providing detailed *in situ* vertical profiling capability in the Arctic environment is a major challenge for state-of-the-art instrumentation and flight safety. There is a clear need for development, such as UAVs (Unmanned Aerial Vehicle), capable of flying in icing conditions with advanced but miniaturized instrumentation.

Investigation of primary aerosol and aerosol-precursor particles, particularly marine gels, and their constituents in the surface microlayer and bulk seawater and their relative contributions to the overlying CCN and IN particle populations, and their air-sea exchange should use an array of "cutting edge" chemical and physical techniques.

A synthesizing need of "scaling" may be addressed via up- and down-scaling for closure in time and space, improving the treatment of microphysics and chemical composition of clouds, examining the heterogeneity of the surface atmospheric layer, melt pond fractions, sea ice influence (MIZ, pack ice as compared to open water) on low level clouds, and aerosol influence on cloud microphysics, among other processes.

In parallel, workshop participants concluded that there is also an obvious need for expanded observations during longer observation periods, covering different seasons, to increase the number of samples, understand processes relevant to other seasons, and to follow the ongoing changes in the Arctic.

5.2 Section 5 References

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6 Data Sharing

Investigators are encouraged to share with other researchers, at no more than incremental cost and within a reasonable time, the primary data, samples, physical collections and other supporting materials created or gathered in the course of the collaborative research on I/B Oden. Privileged or confidential information should be released only in a form that protects the privacy of individuals and subjects involved. Additional data requirements may apply depending on the program or solicitation under which specific awards are made. On I/B *Oden* previous expeditions, data have been shared between scientists on-board, and (meta)data have been published at appropriate repositories. Data collected from the monitoring program on-board I/B *Oden* (e.g., meteorology) are in the public domain.

Appendix A –Report from bi-lateral agency meeting (session 3) and follow up discussion with Workshop participants

Meeting held in Sigtuna, Sweden during US-Swedish Planning Workshop on joint Arctic Research using the I/B *Oden*, April, 1 2015, 9:00-11:30

Present: Eric Saltzman, NSF Arctic Science; Renee Crain, NSF Arctic Science; Magnus Friberg, Swedish Research Council (SRC) VR; Linda Bergqvist Ampel, Formas; Björn Dahlbäck, SPRS; Ulf Hedman, SPRS; Ulf Jonsell, SPRS.

Chair and Rapporteur: Magnus Friberg, Swedish Research Council

Decisions

- It was agreed that collaborative US-SE projects are appreciated, but not a requirement for participation on the joint expeditions.
- It was agreed that the projects should be open to non US and SE scientists. No decision was made whether to have a joint call for non US and SE projects. It is unlikely that this will be possible for the 2017 expedition
- It was agreed that the participants at this meeting constitute the steering committee defined in the signed Letter of Intent (Feb 2015). We are open to inviting other agencies with an interest in the Arctic to participate in the discussions, e.g. NOAA, NASA.
- It was agreed to explore the possibilities for integrated evaluation of proposals, preferably managed by NSF through its merit review process.
- It was agreed to explore the possibilities to postpone the 2017 expedition to 2018 for the reasons given below.
- It was agreed that there will be some form of open data requirements for the participating projects. Most likely the same as now used by the NSF Arctic section with possible addition of sharing data between projects on the expedition.

Summary of discussions

Collaboration and proposals

NSF noted that this collaboration is different from the *Oden* Southern Ocean (OSO) expeditions. The OSO collaboration was driven by the annual logistic needs. Decisions on what we do beyond the 2017 (2018) Arctic expedition need to be taken as cooperation evolves. Formal commitments for ship time beyond 2017 will depend on science priorities, availability of funds, and award of merit-reviewed science proposals.

SRC VR and Formas stated that the message from the Swedish government is different - they pay annually for this cooperation. Given that this continues a longer term planning, at least a 3-year horizon is needed and RSC VR/Formas will want to know that there is such an opportunity before launching calls. A call will be very open and from that the concept chosen. There is currently only the “The life cycle of clouds in the high Arctic summer” proposal on the Swedish Road Map that needs I/B *Oden* in the Arctic. To add projects, it would be good to know if there will be a continuation after 2017 as soon as possible.

NSF informed on the use of pre-proposals/scoping papers as a way of informing the agencies about plans for future proposals. Plans beyond the 2017 (2018) expedition should be included in the scoping paper from this workshop. The proponents for future expeditions should pick a concept and work on it. If the proposals from the scoping workshop are successful, the next cruise is possible in the time-line 2019 - 2021.

At the scientific sessions of the workshop, a better coordination between US and SE was requested. How this could best be achieved for the 2017 (2018) cruise was discussed.

Sweden has decided to start logistic planning for the "High Arctic clouds"-proposal but has not granted research funding to any projects based on I/B *Oden* expeditions. Sweden is reluctant to support big collaborative proposals of versatile projects. We prefer to evaluate each project on its own merits. One evaluation criterion will be societal relevance of the projects since this is a criterion for support from Formas.

Sweden raised the possibility to combine 2017 with IODP 2018 drilling. This would mean delaying the 2017 expedition to 2018 and prolonging the expedition. It was judged as logistically possible by NSF.

Independently, the participants on the scientific sessions of the workshop raised the possibility to delay the 2017 expedition to 2018 to better prepare funding issues and to open up for add-on projects. It is now difficult for collaborative/add-on projects to finalize their planning and securing research funding in time for 2017.

Data management

On *Oden* Southern Ocean data were shared between scientists on-board, and (meta)data were to be published at appropriate repositories. Data collected from the monitoring program on-board I/B *Oden* (meteorology, etc.) are already in the public domain.

The Arctic US-Sweden collaboration will involve some form of data sharing agreement that addresses both sharing of data among PIs and long term public archival and access. The current NSF Arctic section data policy requires data sharing among PIs and archival of metadata and data in publicly accessible archives (either upon collection or after an embargo period depending on the program). Sweden has an ongoing process on open access to data. However, for projects with international cooperation, there are possibilities for separate requirements, if this is agreed upon. Also, it would be preferable to have data sharing agreements between projects on each expedition such that multiple datasets can be utilized by the participating researchers.

U.S Sweden Arctic seminar in Washington in May 2015

Outcomes from this workshop should be presented as bullet points at the meeting at the House of Sweden in Washington.

There is also a need to sign a formal charter/agreement for the 2015 cruise. This should be done at the Washington event.

Appendix B – Workshop participants

List of Participants

Name	Organization	Country
Amanda Grannas	Villanova University	US
Anke Herrmann	Swedish University of Agricultural Sciences	SWE
Axel Meiton	Swedish Polar Research Secretariat	SWE
Birgitta Ekström	Swedish Polar Research Secretariat	SWE
Björn Dahlbäck	Swedish Polar Research Secretariat	SWE
Brice Loose	University of Rhode Island	US
Caroline Leck	Stockholm University	SWE
Don Perovich	Dartmouth College	US
Eric Saltzman	National Science Foundation PLR/ARC	US
Erika Schagatay	Mid Sweden University	SWE
Fiamma Straneo	Woods Hole Oceanographic Institution	US
Frans-Jan Parmentier	Lund University	SWE
Göran Björk	University of Gothenburg	SWE
Henrik Kylin	University of Linköping	SWE
Jack DiTullio	College of Charleston	US
Joseph D. Ortiz	Kent State University	US
Jorijntje Henderiks	Uppsala University	SWE
Katarina Gårdfeldt	Chalmers University of Technology	SWE
Larry Mayer	University of New Hampshire	US
Leif Anderson	University of Gothenburg	SWE
Leonid Polyak	Ohio State University	US
Linda Bergqvist Ampel	The Swedish Research Council Formas	SWE
Love Dalén	Swedish Museum of Natural History	SWE
Magnus Augner	Swedish Polar Research Secretariat	SWE
Magnus Friberg	The Swedish Research Council	SWE
Martin Jakobsson	Stockholm University	SWE
Matt Shupe	University of Colorado	US
Mattias Petersson	Swedish Maritime Administration	SWE
Nina Kirchner	KTH Royal Institute of Technology	SWE
Patricia Matrai	Bigelow Laboratory for Ocean Sciences	US
Peter Minnett	University of Miami	US
Peter Schlosser	Columbia University	US
Peter Sigray	FOI/Swedish Defence Research Agency	SWE
Pär Ljusberg	Swedish Polar Research Secretariat	SWE
Rainer Amon	Texas AM University Galveston	US
Renee Crain	National Science Foundation PLR/ARC	US
Robert Campbell	University of Rhode Island	US
Saewung Kim	University of California	US
Sheila Kirkwood	Swedish Institute for Space Physics	SWE
Ulf Hedman	Swedish Polar Research Secretariat	SWE
Ulf Jonsell	Swedish Polar Research Secretariat	SWE
Wieslaw Maslowski	Naval Postgraduate School	US

Appendix C – Workshop Agenda

Monday March 30

09.00 Petermann 2015 cruise meeting (invited only)

12.00 Lunch for all participants

13.00 Opening of the Workshop

Welcome, workshop background, goals and deliverables	Björn Dahlbäck
Workshop logistics	Sara Paglia
Introduction of the participants	All
Presentations by NSF	Renee Crain Eric Saltzman
Presentations by the Swedish Research Council/Formas	Magnus Friberg Linda Bergqvist Ampel

14.00 I/B *Oden* as a research platform

Possibilities and constraints using I/B *Oden* as a research vessel	Ulf Hedman
What combination of research work well on board?	Mattias Petersson
Recap of Southern Ocean SWE-US partnership	Peter Minnett Martin Jakobsson

14.45 Coffee break

15.15 Session 1 – Process for multiyear, multidisciplinary possibilities
Chairs: Leif Anderson and Peter Minnett

This session will explore and identify scientific demands and possibilities taking advantage of I/B *Oden's* strengths that could be done if there were a multiyear US-SWE collaboration on Arctic science using I/B *Oden*. The discussion should include what combination of research that works well on board, identify prioritized region(s), seasons, research topics, collaboration or overlaps. Further to be discussed are number of cruises, years and frequency.

18.30 Guided Tour of Sigtuna Historic Town (meet at the reception)

19.30 Joint Dinner at Sigtuna Stadshotell (guided tour ends here)

Tuesday March 31

09.00 Session 1 – Process for multiyear, multidisciplinary possibilities - continued
Chairs: Leif Anderson, Peter Minnett

10.30 Coffee break

10.45 Session 1 – Continued

12.00 Lunch

13.00 Session 2 – SWE-US 2017 cruise plan
Chairs: Caroline Leck, Patricia Matrai
This session will address the scientific priorities, collaborations and opportunities in a planned cruise, most likely in 2017, that is based on the framework for the project "The life cycle of clouds in the high Arctic summer" which is part of the Swedish roadmap for polar research. The session will explore possible links to other international upcoming programs and initiatives.

14.45 Coffee break

15.30 Session 2 – SWE-US 2017 cruise plan - continued
Chairs: Caroline Leck, Patricia Matrai

17.00 Session 2 ends

18.00 Joint Dinner

Wednesday April 1

9.00 – 12.00 Session 3 Bi-lateral agency-level meeting (closed)
Discussion on the cooperation - joint science planning, calls, time-lines and evaluation principles.

In parallel:

10.00 Workshop Report writing assignments

Process for multiyear, multidisciplinary possibilities	Peter Minnett
SWE-US 2017 cruise plan	Caroline Leck

12.00 Lunch

13.00 Brief summary of Sessions 1, 2 and 3 — *Session Chairs*

14.00 Session 2– SWE-US 2017 cruise plan – the way towards implementation
Chairs: Patricia Matrai and Caroline Leck

14.30 Session 1– Process for multiyear, multidisciplinary possibilities - the way towards implementation
Chairs: Leif Anderson and Peter Minnett

15.00 Workshop ends