Synoptic Arctic Survey

Synoptic Arctic Survey (SAS) Inaugural Workshop

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meeting minutes

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Synoptic Arctic Survey (SAS) Inaugural Workshop

Contents

1. Opening and workshop goals

State secretary **Bård Glad Pedersen** of the Norwegian Ministry of Foreign Affairs opened up the workshop and welcomed the participants to the Residence of the Norwegian Ambassador in DC, emphasizing potential future resource harvesting, the importance of international collaboration in research and sovereignty issues, the importance of sustainability in exploration and exploitation, and expressed his support for a multi-national and multi-ship effort to collect oceanographic data generating a baseline for future research and resource management.

Are Olsen presented the overarching idea behind the SAS, to obtain: "A comprehensive snapshot of Arctic Ocean hydrography, biology, chemistry, ice properties and air-sea interaction in one season in one year", and the primary workshop goals:

- Engage the international community by formulating a science plan.
- To identify potential national SAS contributions by getting an overview of resources, interests and planned activities.
- To decide on a reasonable timeline and decide what need to be done, and when in order to realize SAS.
- Discuss need and opportunities for an international secretariat.
- Alert funding bodies and policy makers to the existence and opportunities of SAS.

2. DAY 1

Day one of the workshop was dedicated to overview talks, presenting the grand challenges in Arctic marine research, experiences from earlier internationally coordinated ocean observing projects and to work in breakout groups.

2.1 Arctic Ocean challenges: motivation for synoptic surveys

Leif G. Anderson first summarized recent observations of changes in the Arctic Ocean, that the largest air temperature increase has occurred in the Arctic; changes in the sea-ice cover is unprecedented in modern times and from year 1980 to 2000 seawater temperature has increased by ~1°C in the depth range 200 to 300 m at the North Pole. Next he pointed out some key features that need to be taken into account when planning the SAS; the heavy sea-ice north of Greenland vs. the much lighter on the Pacific-Siberian side; the importance of ocean circulation and frontal systems, that variability in the latter should not be taken as evidence of change (this could also explain some of the temperature increase observed at the North Pole); the challenge of projecting impact of small scale processes to a pan-Arctic perspective and the need for assessing the impact of multiple drivers on the system. SAS should provide us with a good baseline for future research and address the following topics: heat fluxes in the vertical and horizontal, marine organism composition, carbon system and changes in all of these.

2.2 Research front on Arctic hydrography and circulation: a case for a synoptic survey

Eddy Carmack presents his talk "A (Long-Overdue) SAS - a brief look at hydrography". He points out that "Our current view of the Arctic Mediterranean is decidedly 'regional' because historical efforts have focused on regions with the result that we sense the parts but not the whole. A synoptic view of the Mediterranean Arctic Ocean is lacking and is sorely needed." Further, he stresses the global impact of the Arctic Ocean, the Arctic Ocean is the only ocean that can claim to reach every other ocean basin. But most of all we have a question of change, 'The loss of Arctic sea-ice has emerged as a leading signal of global warming and this will affect almost everything'.

For the survey, scale is key to good planning:

- Global (global/climate connection- the 'job' of climate and hydrological cycle-freshwater budget of the Arctic system; waters from the Arctic do circulate into every ocean basin).
- Pan-arctic (circulation of the ocean basin – ocean gyres and four basic ocean layers: (i) surface short residence layer, (ii) halocline, (iii) Atlantic layer and (iv) deep waters. Impacts of water mass distribution on ecology, the need to sort out water masses according to depth, function, geochemistry; shelf breaks and ridges must be emphasized.
- Basin/gyre (Recent changes in Beaufort gyre, oceanic freshwater 2007/2008 as a game changer).
- Process scale (shelf, riverine coastal domain, tides and mixing creating openings in ice -- tidal gardens).

Kathy Crane comments that we need to include atmospheric scientists along with hydrographers to look at more atmospheric coupling questions.

Takashi Kikuchi presents his talk: "Research front on Arctic hydrography and circulation:

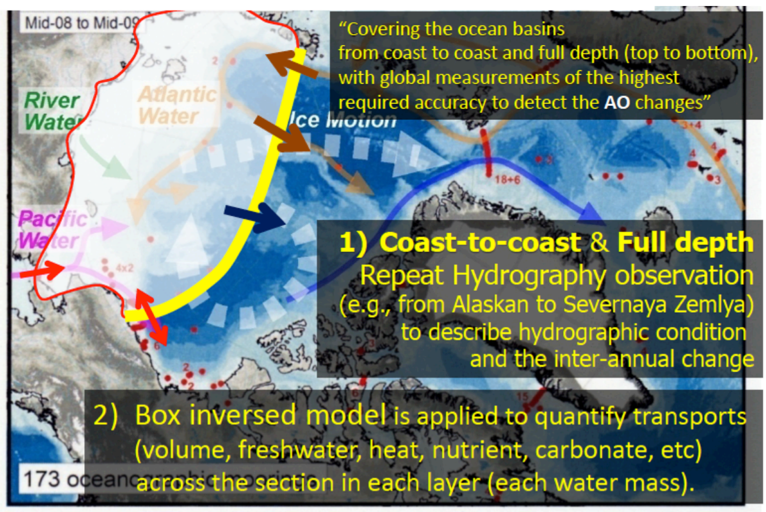

Figure 1: Section Proposal (yellow line) of Takashi Kikuchi

a case for a synoptic survey". He emphasizes that SAS should align itself with GO-SHIP, presents some recent results from expeditions with the RV Mirai and recent observations of change in the Arctic Ocean (strengthening of the Beaufort Gyre after 2004, pulse of Atlantic Water warming in the 2000s).

For the survey the following needs should be emphasized:

- It should cover the ocean basins from coast to coast and full depth, with global measurements of the highest requires accuracy to detect the AO changes, with a concretely suggested section from Alaska to Severnaya Zemlya. (Fig. 1).
- Box inverse models should be used to quantify transports (volume, freshwater, heat, nutrients, carbon etc.) across the section in each layer (water mass).

Kyoung-Ho Cho presents his talk "Research front on Arctic hydrography and circulation: a case for a synoptic survey". In particular he emphasizes the importance of atmosphere-ice-upper ocean interaction in the Arctic and value of buoys, ice-tethered profilers, sea-ice camps and meteorological instruments for investigating these processes.

2.3 Research front on Arctic Biology: a case for a synoptic survey

Carin Ashjian identifies the most important climate change impacts on plankton and benthos:

- Loss of sea-ice substrate and reduction in ice algae.
- Change in water column primary production.
- Changes in seasonality (timing) and growth season length (and mismatch of organism life cycles with production cycles).
- Changes in the ranges of organisms.
- Advection.
- Colonization.
- Changes in the marine food web.
- Changes in dominant organisms.
- Changes in size composition (smaller species more or less important).
- Changes in food web linkages (e.g., more/less predation).
- Changes in allocation of carbon between different components of the food web.
- Change from benthic-dominated to pelagic-dominated and vice-versa.

Carin summarizes some recent evidence for change and approaches for detection (and difficulties):

- Compare abundance, distribution, composition, and rates between present and older studies.
- Compare abundance, distribution, composition, and rates at *synoptic* times between different regions to remove the signal of internal variability and to exploit regional differences in ice conditions.

- Difficult because of paucity of older data from proposed study area and of sampling inconsistencies (gear incompatibility) between older data and present data.
- Use models to run experiments to see how populations and ecosystems change under changing environmental conditions (note: information on key processes to drive model development frequently missing).

Existing data that can be used for comparison is summarized, a key point being: Most recent Trans-Arctic biology expedition was the Arctic Ocean Section in 1994. *There has been no comprehensive effort to do trans-Arctic biology studies! Just pieces to date.*

Carin point out the following directions for SAS:

- Characterization of Arctic hydrography and circulation, carbon uptake and ocean acidification, tracer distribution and pollution, and organismal and ecosystem functioning and productivity.
- Arctic Council biodiversity working group Conservation of Arctic Flora and Fauna (CAFF), CBMP (Circumarctic Biodiversity Monitoring Program) suggested ships of opportunity that are going to cross the Arctic Ocean from the Svalbard outer shelf to the North American coastline provide an opportunity to gather ecosystem information in poorly observed areas; also compare/contrast of common characteristics in a pan-Arctic view.
- Distributed Biological Observatory (DBO)-standardized physical, chemical and biological measurements.
- Pacific Arctic Climate Ecosystem Observatory (PACEO)-standardized measurements.
- Nutrients, chlorophyll, microbial, plankton and benthic biodiversity and population structure.
- Pelagic and Benthic time series measurement.

Jackie Grebmeier presents the more benthos-specific issues. Important stressors on the benthic ecosystem are:

- Changing sea-ice conditions and connection to upper water column production (sea-ice and ice edge bloom).
- Warming water enhancing zooplankton production and enhanced intrusion of Pacific species seasonally, potential increasing grazing that reduces export production.
- Change in surface sediment patterns via hydrographic forcing changes have direct impact on benthic population structure.
- Changing temperature and food supply to benthos is intimately connected to the timing of reproductive events in the benthos that release meroplankton or demersal young annually, with consequences on benthic community composition and structure.

- Ocean acidification has potential for negative impacts on calcium & aragonite producing infauna, such as bivalves, snails, and corals.

Benthic fauna can integrate changes in the overlying water column and provide "first responder" information to changing physical forcing. We need interdisciplinary focal measurements with key physical, hydrographic, biogeochemical and biological variables.

Evaluating and forecasting benthos requires multinational and integrated planning, also based on ongoing and planned time-series transect lines. Synoptic, interdisciplinary, multi-ship shelf-to-basin measurements from marginal seas into/across the basin in one focused year to connect and leverage multiple national programs.
The Distributed Biological Observatory and the Pacific Arctic group research cruises are examples of ongoing activities.

Jackie goes on to possible questions to evaluate pelagic and benthic components in a Synoptic Survey:

- How will lower trophic biodiversity change under variable physical forcing with climate warming?
- What specific sentinel measurements to evaluate changes in faunal abundances, composition and distributions over both space and time and do these biological component influence carbon cycling and higher trophic level populations?
- How will benthic hotspots change over time and space with changes in hydrographic forcing and sediment dynamics, and can these hotspots provide a framework to assess ecosystem response and change?
- How can we assess the impact of key stressors on benthic faunal systems and can we develop models to forecast ecosystem response?

And finally, makes the biological case for a Synoptic Arctic Survey:

- The Arctic environment is changing dramatically and this is likely to have repercussions on the ecosystem.
- Comparisons of synoptic surveys between regions of Arctic that are presently experiencing different ice conditions (timing, extent, age, thickness) may permit us to identify variability in ecosystem functioning (timing of reproduction relative to phenology, shifts in population structures, shifts in community composition) - the comparisons are a model of the different ecosystem responses.
- It has been over 20 years since the last biological assessment in the Central Arctic and that cruise was not even near to synoptic because it was accomplished on a single ship. Also the sampling density was rather low and geographically limited compared to what we could conduct using a collaborative effort with multiple ships.
- Few process measurements were made during that assessment.
- New tools and approaches (genetics, optical instruments) are available.

2.4 Research front on Arctic Carbon Cycle: a case for a synoptic survey.

Leif G. Anderson presents contribution from himself, **Melissa Chierici, Are Olsen** and others. Key messages are:

- Current Arctic Ocean carbon budgets and estimates of anthropogenic CO_2 uptake have unacceptable uncertainties, SAS will allow us to constrain these better.
- Changes in biology will affect export production and associated carbon sequestration, SAS will provide a base line for detecting this.
- Carbon uptake associated with sea-ice and brine formation contributes potentially significantly to a net Arctic Ocean carbon uptake and storage at depth. Its magnitude and climate change vulnerability must be established.
- Global warming will lead to permafrost melt and transfer of terrestrial carbon to the ocean, its impact must be determined.
- The increasing concentrations of carbon leads to ocean acidification, quantification of its present and future magnitude are essential for forecasting future ecosystem effects.

2.5 Lessons from repeat hydrography

Jim Swift first provided an overview of the development and goals of the global repeat hydrography program GO-SHIP. This evolved out of the WOCE hydrographic program, which included a global one-time survey, a repeat hydrography program and time series stations. WOCE enabled the CLIVAR and subsequent GO-SHIP programs. The GO-SHIP is an international repeat hydrography program with sections occupied to specified parameter, quality and data availability specifications. Many of these sections have been occupied approximately every ten years since 1990 (see www.go-ship.org for more info).

Jim pointed out that many pressing ocean science questions can be addressed effectively at present only using repeat hydrography:

- Carbon storage and transport.
- Heat and freshwater storage and transport.
- Ocean ventilation rates and their variability.
- Autonomous sensor calibration.
- Data for model validation and calibration.

There is no repeat hydrography program in the Arctic Ocean. The SAS may initiate this. For planning the SAS Jim suggest that we need to pay attention to:

- Providing a set of oceanic repeat sections needed at a minimum to provide the critical information on shifting hydrography, heat/salt budgets, carbon system and inventories, and large-scale marine biology (ecosystem assessment) of the Arctic Ocean.

- Other likely components of a broader Arctic observing system which may include moored measurements, drifters, gliders, and other non-hydrographic-section measurements, and focus on measurements and data that will not be available through these.
- That the program should reflect lessons-learned, climate monitoring needs, and new frontiers of science.
- That there should be specific objectives and expected program payoffs. Who are the anticipated users/programs of the collected data and how important are these data to their goals?
- Whether new parameters would be included as routine observations? Why?
- Consider how programmatic and financial needs differ from those of GO-SHIP.
- The expectations and likelihood of availability of adequate ship resources.
- The commitment from the international community towards the program. Which countries in particular?
- What can be improved with respect to international coordination?
- How GO-SHIP can facilitate international coordination and what resources are necessary to do so?
- That there are data centers to collect and distribute repeat hydrographic data. Is the community ready to follow international data policies? What is the strategy for improving integrated management (including timely data release)?
- What strategies will support and encourage development of new technologies and assess their effectiveness to achieve hydrography objectives (at reduced cost)?

With respect to governance and oversight the SAS group should also consider:

- To appoint a science committee for supervising the SAS.
- That SAS needs to be coordinated with international GO-SHIP and with the Arctic Observing Network.
- To affiliate itself with CLIVAR and WCRP.
- Coordination and information sharing (and possibly cruise sharing) with other efforts where hydrography is important, e.g. GEOTRACES, ocean acidification and autonomous profiling.

Jim ends with presenting a schematic concept of a pair of one-way (or two way roundtrips) trans-Arctic sections

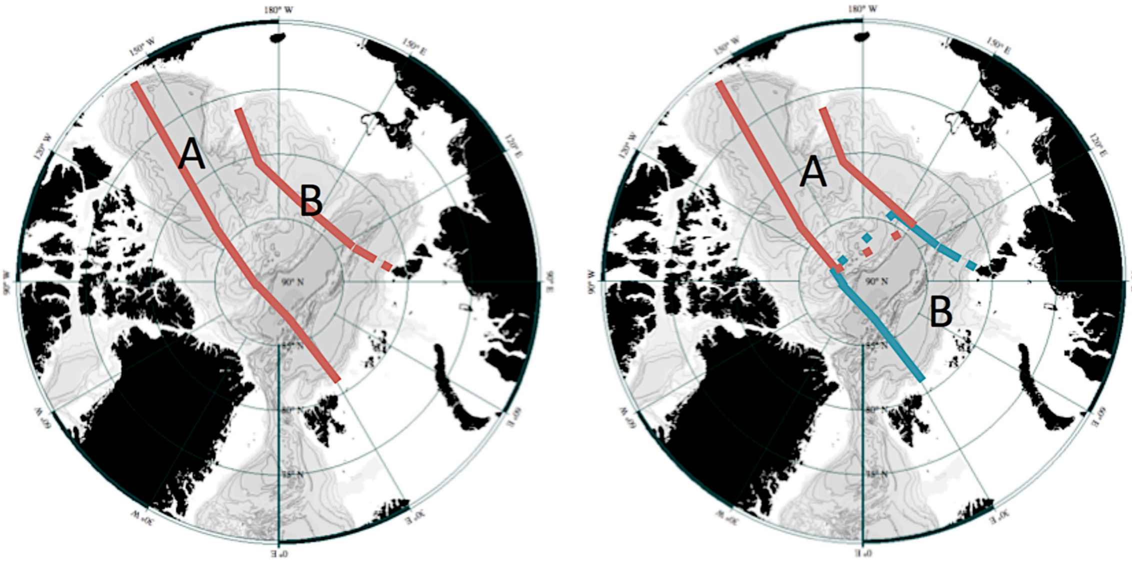

Figure 2: Schematic concept of a pair of one-way trans-Arctic sections in support of global ocean change research. (The dashed line on “B” schematically shows sampling in the Russian EEZ.). The routes in right panel gives the same coverage as those shown in the left, with the added benefit of allowing icebreakers to return to their home port, and also data consistency checks where the two lines meet

2.6 Breakout groups

Three breakout groups were organized, one on hydrography and circulation, one on carbon cycle and one on biology. These should start working on the science plan. The breakout groups continued their work during day 2 of the workshop, and their reports are provided at the end of this document (Appendices B1-B3).

2.7 Plenary discussion

Following the breakout groups we had a plenary discussion, some important insight emerged:

- Completing all aspects of the program would require a large number of scientists on each ship. GO-SHIP for example has 24 people for round the clock measurements (without students). RUSALCA has 52 scientists. Not many ships are large enough to accommodate the people required; we identify Healy, Louis St. Laurent and potential Russian ships. These limitations must be kept in mind during the planning.
- It is important to have students and a mixed generation of polar scientists on board; the students should come as active participants, helping, for example, with sampling or CTD operation.
- We must also consider available lab-space on vessels. Not many ships have enough room for the work involved in a complete biological, chemical and hydrography program; it is important to have efficient use of personnel and

space, post-processing of samples becomes very important to be able to make multidisciplinary cruises possible.

- It is important to have tracks over straits in order to do complete budgets for carbon, heat and similar.
- When planning tracks it is important to link up to existing efforts by e.g. Norway, Russia, Canada, US.
- A closed area on the Siberian side is important in order to do a closed box heat flux model.
- We should have a line where different aged sea-ice is present -this can/will be orthogonal to bathymetry.
- The region of the East Siberian Sea is tremendously undersampled and has a great need for understanding of mixing etc.
- We need to have strong statements and requirements on data management and data sharing up front - for example requirement of being part of WOCE was being part of data management and sharing.

3. DAY 2

Day two of the workshop was dedicated top presentation of each nation's resources, ongoing projects of relevance for SAS, discussions on how we take this initiative further and work in the breakout groups.

3.1 National Resources

3.1.1 Canada

Canada's resources, interests and aligning programs were presented by **Kumiko Asetzu-Scott**. Most of Canadian Arctic research is carried out on board vessels of the Canadian Coast Guard Ships (CCGS). These are not available for rent, but by request from scientific parties to the Canadian Coast Guard, and normally shepherded by Fisheries and Oceans, Canada (DFO). The following Canadian vessels are used for polar research:

- Canadian Coast Guard Fleet (HI-Heavy icebreaker, MI-Medium icebreaker, LI-light icebreaker, IE-Ice enforced)
    - East coast - *Louis S. St-Laurent (HI), Terry Fox (HI), Martha Black (LI), Henry Larsen (MI), Hudson (IE)*
    - Quebec - *Des Grosseilliers (MI), Pierre Radisson (MI) and Amundsen (MI-research)*
    - West Coast - *Sir Wilfred Laurier (LI)*
- chartered vessels
    - *F/V Frosti* (Richmond, B.C.) Non-profit organization vessel
    - R/V Marty Bergmann (Cambridge Bay, Nunavut)

The following three ships are most appropriate for SAS:

- *CCGS Amundsen*- crewed by Coast Guard;
    - Available for research led by ArcticNet from May-December (would need to negotiate with ArcticNet for use)
    - Mid-size ship; 40 ppl berth
- *CCGCS Hudson*
    - Ice enforced; 28-30 scientists on board
    - Can do NW Arctic passage
    - A little older; ice-capability decreasing every year
- *Louis St. Laurent*
    - Heavy icebreaker; 36 ppl capability
    - Have been used in high Arctic

Canada has many time series and process studies that may be components of SAS. These are presented in Fig. 3.

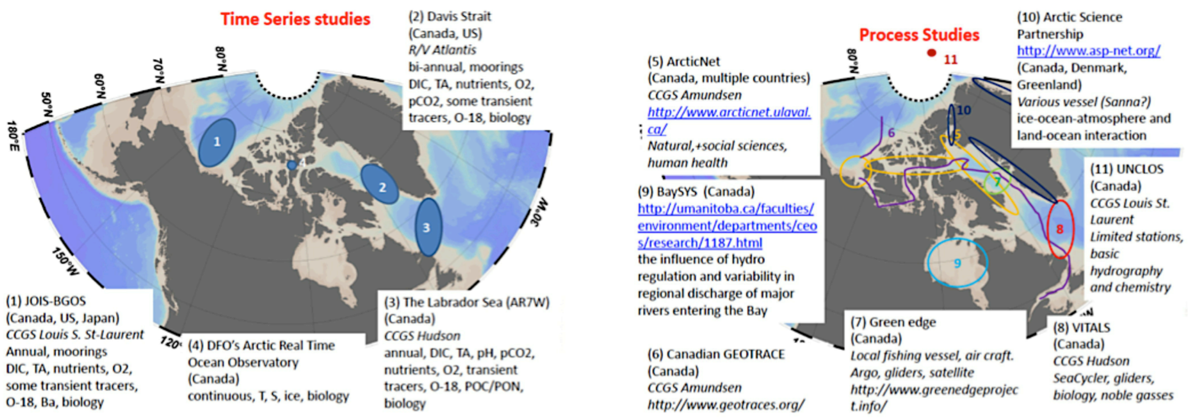

Figure 3: Canadian time-series and process studies

3.1.2 Germany

Heidi Marie Kassens provided an overview of German resources and programs. R/V Polarstern is a big icebreaker operated by the AWI, and would be the most suitable ship for SAS. It has 44 crewmembers and can host 50 scientists who have access to 9 scientific research laboratories and deck space for 5 containers.

The schedule for Polarstern is planned for 5 years at a time, and set until 2020. Hence, if Polarstern should be part of SAS, it has to take place after that time. A new icebreaker is being built, but not many details are known, and SAS should plan for using Polarstern.

Heidi next presented the extensive and successful collaboration that has taken place between Germany and Russia since the early 1990s in the TRANSDRIFT project, and makes it clear that Russia should be an integrated partner in SAS. We all agree.

3.1.3 Iceland

Steingrímur Jónsson presents an overview Iceland's Marine Research Institute, which operates two research vessels, the Árni Fridriksson and Bjarni Sæmundson. The former can take 17 scientists and the latter 13. The Árnin Fridriksson has ice class 1, but doesn't really go into the ice unless they have to. Hence, any Icelandic contribution would have to be limited to waters free of sea-ice.

3.1.4 Japan

Takashi Kikuchi presented the resources and related projects of Japan. The RV Mirai is used in the Chukchi Sea. She is ice-strengthened and not an icebreaker. A total of 46 scientists can be hosted onboard. Cruises to the Arctic (Chukchi Sea) is planned for the next 4 years (2015-2019) in the ArCS (Arctic Challenge for Sustainability) project. Preparation of the 2020/2021 cruise plan for will commence in 2018.

3.1.5 Korea

Kyoung-Ho Cho presented Korea's activities in the Arctic Ocean. Korea operates the icebreaker R/V Araon, which can handle 1 m of ice in 3 Knot and host 56 scientists. In the Arctic it has been operating in the Chukchi and East Siberian Sea since 2010 and the typical expedition period runs from the end of July to the end of September. Korea currently runs the K-PORT project, Korea-Polar Ocean in Rapid Transition, this ends in 2016 and includes both physical oceanographic (hydrography, sea-ice dynamics), chemical (e.g. carbon and nutrients) and biological investigations. They also have extensive international collaboration on buoys and moorings. Phase II of K-PORT will commence in 2016 and have a duration of 5 years. This is certainly a potential element in the SAS.

3.1.6 Norway

Sebastian Gerland presented Norway's new Polar 10 icebreaker Kronprins Haakon, which will start operating in 2018 (tentative). This vessel will be able to host 55 persons and have an endurance of 65 days at cruising speed. It can break ice of 1 m at 5 knots and can operate in multiyear ice. Currently the Norwegian Polar Institute operates the much smaller RV Lance. Its fate after Kronprins Haakon set sails is unclear. Routine areas of operation include the Fram Strait, northern Barents Sea and north of Svalbard. Norway also operates several other - non-ice classed research vessels in the Barents, Greenland and Norwegian Seas.

Sebastian also provided an overview of the MOSAiC project, Multidiciplinary drifting Observatory for the Study of Arctic Climate. This is an IASC coordinated effort including at its center deploying the Polarstern as a drifting icebreaker across the Arctic for one full year.

Finally Sebastian presented the Norwegian Young sea ICE cruise (N-ICE) and the many activities carried out there. During N-ICE the IB Lance was deployed as a drifting observatory in the sea-ice north of Svalbard, an important Norwegian contribution to

Arctic Ocean research (http://www.npolar.no/en/projects/details?pid=b98886ce-590a-48a8-b113-4b96e98c65c8).

Melissa informed on the Ocean Acidification project of the Fram Centre in Tromsø, which includes annual repeat surveys across the Fram Strait.

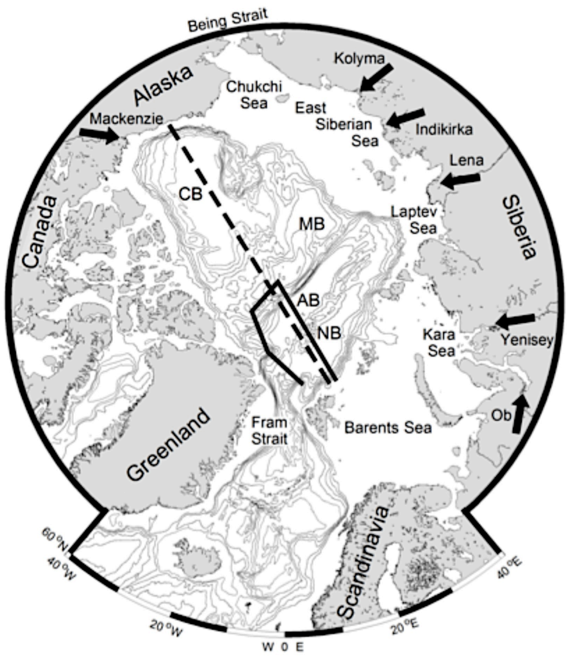

Figure 4: A potential track of a cruise within the US-Sweden program on Oden (solid line). The dashed line is the track of Oden in the 2005 Beringia campaign.

Are mentioned that the University of Bergen/Bjerknes Centre for Climate Research carries out repeat occupations of the 75°N line in an approximately 3-year basis, depending on funding.

3.1.7 Sweden

Leif Anderson presented Sweden's icebreaker Oden. This is a heavy icebreaker capable of handling >2 m of solid ice at 3 knots. The Oden can host 46 scientists, has lab space and several lab-containers can be installed at its deck. It has been extensively used in the Arctic the past decades. Recently a multibeam echosounder and side scanning sonar was installed. An AUV will be purchased, for use from the Oden. There are ongoing discussions for instigating a joint US-Sweden Arctic research program that will use Oden. A pilot cruise is planned for 2018, and this will be followed by cruises every second year. This would be a valuable component of the SAS. A potential cruise track for this program is shown in Fig. 4.

3.1.8 United States

Kathy Crane presents the U.S possible contributions to repeat hydrographic-ecosystem transect of the Arctic. Regarding vessels, US charter a lot of foreign vessels, as they have a real shortage of vessels for Arctic work. Nevertheless Kathy mentions two ships that might take part in the SAS The RV Sikuliaq is owned by the National Science Foundation and operated by Univ. Alaska. This ship can host 26 scientists and operate in single-year sea-ice. The other ship is the USCGC Healy, which is a medium icebreaker with accommodations for up to 50 scientists.
Kathy runs through the many ongoing U.S. Arctic activities. The AON, the Arctic Observing Network. Transects should intersect these stations**.** The strong US interest in Arctic bathymetry, this needs to be kept in mind for the SAS, bathymetry data should be an important deliverable. US have made several contributions to repeat hydrography in particular covering Chukchi Sea and northwards. The RUSALCA project is a fine example

of Russian-U.S. collaboration. The Distributed Biological Observatory covers Bering Sea, Bering Strait and Chukchi Sea; a detection array for identification and consistent monitoring of biophysical resources, where the sites are occupied by national and international entities with shared data plan. Kathy also mentions MOSAiC and the PAG climate observing network. The latter is a long-term plan to address causes and consequences of sea-ice loss, migration of fisheries is a big issue. SAS may link up with that. Distant response to Arctic change (teleconnections) must be kept in mind, for example mediated through changes in the Polar Jet Stream in response to Arctic sea-ice change, a strong atmospheric component in SAS would aid US buy in.

Guillermo Auad presents possible support from BOEM (Bureau of Ocean Energy Management). They have a large pool of ADCPs and buoys, which can be put at SASs disposal during the campaign as long as said instruments are placed on the US OCS (Outer Continental Shelf).

3.2 Plenary Discussion

Everybody agrees that SAS would be a very important, timely, challenging but also doable effort and we discuss the road ahead. The most important points that follow form this discussion is:

- SAS must be science driven, and we need to formulate a science document that outlines the science questions and how SAS will enable us to answer them. This could be in the form of a white paper, and EOS article or similar.
- In the wake of this document a science plan should be formulated.
- We need to strike a balance between observation driven and hypothesis driven approaches to funding proposals.
- Should we push for a repeat Synoptic Arctic Survey or a one-time-off? We agree that the one-time-off is a necessary start, repeat programs can be formulated in its wake.
- Hydrography data will be available this summer, GEOTRACES cruise, and would be a good baseline to start focus efforts.
- What does synoptic mean, just one track across the Arctic, or multiple lines back and forth? We agree that it should be multiple lines back and forth over the course of one (summer) season.

3.3 Next steps

A science plan should be formulated; its first draft should be ready for presentation at OSM2016. This should also be shared with the group of people that have expressed strong interest in the program but weren't able to participate at this workshop. A structure of the science plan was developed this appears in Appendix A.

A science steering committee needs to be established, at the time of the AGU is appropriate.

We need to be present at the Arctic Science Summit Week, March 2016

Important to liaise with Arctic Council (AC), the SAS could be promoted as a potential important outcome of the 2015-2017 US chairmanship, the AC is also important for bringing the Russian community fully on board the SAS initiative.

We need to work with funding agencies to initiate fellowships for young polar researchers. Some initial discussions have already been had with the Norwegian Research Council. This can be an important step towards building a successful SAS.

3.4 Secretariat

Everybody agrees that the administrative load involved in coordinating the SAS will be massive and that a secretariat is sorely needed. We discuss models for organizing and funding this. It will be difficult to get funding from many countries simultaneously, so a rotating secretariat is the likely option. For example, the Pacific Arctic Group secretariat (basically a full time job) is rotated every two years to a different country who is responsible for funding the secretariat based on timing of their chairmanship. There is a potential for obtaining Norwegian funds for the first few years. A secretariat may be linked up with the AMAP. Alternatively we may consider a GO-SHIP coordination model. This is done informally, with different PIs contacting each other regarding what measurements they are doing in order to ensure that there is not overlap between different efforts (In hindsight this is strictly not true, JCOMMOPS allocates some fraction (1/3?) of a position to GO-SHIP coordination.). It is mentioned that it might be important to engage observer countries in the process.

3.5 Collaboration with Russia

Everybody agrees on the important contributions from Russian scientists to Arctic research and emphasizes the need and urgency of fully involving them in the development and execution of SAS. We identify several groups interested in polar research, AARI (St. Petersburg), Russian Academy of Sciences (they are also involved in IASC) and Russian Geographical Society, PINRO (Murmansk). Several connections exists, University of the Arctic, Arctic Council, IMR (Norway) - PINRO collaboration. We agree that a good way ahead is to hold a SAS meeting in Russia, possibly at the German embassy in Moscow. Heidi Marie Kassens agrees to investigate of this is possible.

3.6 Timeline for SAS

Øyvind Paasche summarized the development of SAS until the workshop and continued presenting a suggested timeline for SAS that was briefly discussed. The initial idea of SAS was conceived at the Norway-Japan Science Week held in Tokyo in May 2014. After the DC Workshop he would present SAS at the Year of Polar Prediction (YOPP) meeting to be held in Geneva: 12-15. July. It was further suggested to inform the Arctic Council's

Science Task Force which were to meet in August 2015. SAS had been given space in the upcoming Transatlantic Science Week (TSW2015), which is an annual event that will be held in Boston, 4-6 November in collaboration with WHOI, Harvard and MIT. Are Olsen will present SAS at TSW2015. Efforts should be made to include SAS in the Arctic Council Meeting in Alaska.

Paasche forwarded the idea that in order to ensure continued information flow and secure activity an International secretariat should be formed, preferentially by late Autumn 2015. Regardless of a secretariat, a first-order-draft (FOD) of the Science plans must be completed and circulated to a reference group for the potential inclusion of additional comments. The FOD should be complete a by 15 January 2015. This opens up for input from a wider community prior to the Ocean Sciences Meeting (OSM), 21-26 February 2016. Before October, SAS should file a suggestion for a Town Hall meeting where not only input from a wider community can be given, but it would also be an excellent opportunity for informing and promoting the initiative. During the AGU-meeting a Science Steering Committee (SSC) should be formed. The next large meeting to introduce SAS, and also utilize the possible presence of many of the partners, will be at General Assembly (EGU): 17-22 April 2016. A side-event should be scheduled, and the FOD can be presented.

Parallel to this process an EOS-paper should be submitted by at least August 2016, hopefully before. One should work towards an announcement by the End of the US Chairmanship. Finally, instruments and proposals (ship time-science projects) needs to be submitted no later than 2018 as the timeline for SAS now is 2020/2021.

Acknowledgement. Support for this inaugural workshop was kindly provided by the Norwegian Ministry of Foreign Affaires, the University of Bergen, the Bjerknes Centre for Climate Research and also the Norwegian Ambassador in Washington DC. We also wish to extend our thanks to researchers who were contacted prior to this workshop and who expressed support but were not able to attend.

Appendix A Science plan structure

Science and Implementation Plan

1. Background and Overall Motivation

Provides background information and overall motivation for a Synoptic Arctic Survey
Figures, map, illustration of change (heating, ice, ocean pH (from Leif))

2. Expected outcome

Summarize the findings expected to result from the SAS

3. Key observations for the Synoptic Arctic Survey

Three categories for now (Hydrography, Ecosystem, Carbon Cycle). For each justify each type of observation to be done in program (i.e. Specify the questions and parameters needed to answer them, see example in Appendix B3, notes from carbon group)

3.1 Hydrography

3.2 Ecosystem

3.3 Carbon system including ocean pH

4. Synoptic Survey Requirements

For each category provide very specific time and space sampling requirements

4.1 Hydrography

4.1.1Space and time considerations

Area of specific interest
Seasonal timing
Vertical and horizontal, extent and resolution

4.1.2 Key parameters, sampling, analysis and logistic requirements

4.1.3 Personnel requirements

4.1.4 Requirements on ship time

4.2 Ecosystem

4.2.1S pace and time considerations

Area of specific interest
Seasonal timing
Vertical and horizontal, extent and resolution

4.2.2 Key parameters, sampling, analysis and logistic requirements

4.2.3 Personnel requirements

4.2.4 Requirements on ship time

4.3 Carbon cycle and ocean pH

4.2.1Space and time considerations

Area of specific interest
Seasonal timing
Vertical and horizontal, extent and resolution

4.2.2 Key parameters, sampling, analysis and logistic requirements

4.2.3 Personnel requirements

4.2.4 Requirements on ship time

5. Data Policy

6. Contributions to international and national programs

7. Timeline for implementation of SAS

Appendix B Notes from Breakout groups

B1 Notes from hydrography and circulation breakout group

(Jim Swift, Eddy Carmack, Takashi Kikuchi, Kyoung-Ho Cho, Øyvind Paasche, Guillermo Auad, Steingrímur Jónsson)

Many pressing Arctic Ocean science problems can be addressed effectively at present only using repeat hydrography:

Carbon storage and transport
Ocean ventilation rates and their variability
Autonomous platform sensor calibration

High quality data are also critical for determining heat and freshwater storage and transport and valuable for model validation and calibration.

Global repeat hydrography programs must include one or more sections in the Arctic Ocean because of the major changes occurring in the physical environment there. Many attributes of the Arctic Ocean are well known, including its role as an ocean bridge between the Pacific and Atlantic Oceans, its important contributions to the Denmark Strait Overflow, its receipt of massive loads of terrigenous organic matter from watersheds experiencing permafrost thawing, and its influence on climate through its albedo. Although the essential hydrographic structure of the Arctic Ocean has been known for three decades (e.g., cf. Aagaard et al., 1981; Aagaard et al., 1985), some aspects of its physical environment, such as ice cover, are undergoing unprecedented change.

The Arctic Ocean is not hydrographically static: Swift et al. (2005) found that beginning about 1976, most of the upper Arctic Ocean became significantly saltier, and in addition to the warming of the Atlantic layer during the early 1990s, there were other, less obvious warm events during the 1950s and 1964-1969, possibly related to both enhanced horizontal heat advection and reduced vertical heat loss associated with increased upper-ocean stratification. The silicate maximum in the central Arctic Ocean halocline eroded abruptly in the mid-1980s, demonstrating that the redistribution of Pacific waters and the warming of the Atlantic layer (cf. McLaughlin et al., 1996) were distinct events. Since the late 1980s there have been two prolonged episodes of significant warm anomalies in the Atlantic Water entering the Arctic Ocean (Grotefendt et al., 1998; Polyakov et al., 2005). These have been tracked in the Eurasian sector (Dmitrenko et al., 2008) and took place mostly without density-compensation from salinity. Observations suggest these anomalies may have occurred without significant change in volume transport (Beszczynska-Moeller, et al., 2012). Modeling studies indicate they may be able to reduce the Denmark Strait overflow 15-25 years after their initial entry into the Arctic Ocean (Karcher et al., 2011).

The Arctic also undergoing rapid and dramatic change in its carbon systems. The region makes important contributions to the ocean uptake of anthropogenic CO_2, as low temperatures and low buffering capacity facilitate uptake from the atmosphere (Bates & Mathis, 2009). Quantifying and understanding the dynamics of ocean-atmosphere exchanges of CO_2 in permanently and seasonally ice covered regions has been difficult due to paucity of data (e.g., Bates & Mathis, 2009; Takahashi et al., 2009), with predictions difficult to make because of rapid sea-ice loss. DOC is especially distinctive in the surface Arctic as it has a very strong terrigenous signature (Wheeler *et al*. 1997; Opsahl *et al*. 1999) due to the system being a relatively small basin receiving disproportionate fractions of global river runoff (~10%) and terrigenous DOC (tDOC) export (~13%) (Stein and Macdonald, 2004). 10 to 20% of global vegetative carbon, and up to half the global inventory of upper-soil organic carbon, resides in the Arctic watersheds (Dixon *et al*. 1994; McGuire *et al*., 2009). As such, DOC is highly elevated (>300 μmol/kg) in surface waters most impacted by runoff, such as offshore the outflows of the major Arctic rivers and in the Transpolar Current, which transports DOC originating in Siberian rivers to the North Atlantic. Much of this material is mineralized en route, adding to the exported TCO_2 stock.

It is widely agreed that the impacts of anomalies such as the warm episodes on the hydrographic structure of the Arctic Ocean must be observed (e.g., cf. Mauritzen et al., 2011; Woodgate, 2013). Although hydrographic and tracer sections are being carried out, few span multiple basins, and none yet completely cross the entire Arctic Ocean including the boundaries at each end. Some repeat section work via aircraft is focused on the upper 500-1000m, with water sampling for temperature, salinity, dissolved oxygen, nutrients, some carbon system measurements and a few tracers. The full-depth "reference quality" Repeat Hydrography Level I measurement suite, with only a few region-specific changes, is ideal in terms of defining key physical and ocean carbon system aspects such as multi-year variability, ocean climate and carbon response time scales, and locations of future transects.

Goals for repeated Arctic surveys

"What are the critical elements of the physical environment and ecosystems of the Arctic Ocean, (as related to aspects of global change?)?"
"What are the critical multi-year changes in the physical environment and ecosystems of the Arctic Ocean?"
"How are those related to other aspects of global change?"

1. From a physical standpoint, the SAS program will provide the baseline for the future set of sections. [Note: What is the time scale of "synoptic"?]

2. There are at least two differing needs: to observe change and to understand how those changes came about.

Regarding change, there is the possibility that in addition to long-term trends, that there are multiple air-sea-ice regimes that can shift from one to the other on some time scale. (Think of Eddy's interpretation of the sea-ice record.)

1. What has changed? (Inventories.)
2. Why has it changed? (Process.)
3. How do the changes relate to the other oceans (or, maybe instead, the global ocean-atmosphere-cryosphere system)?

One unifying theme could be understanding fresh water in the Arctic Ocean. With a synoptic survey question #1 can be addressed partly on the basis of determining some degree of inventory, and some of the measurements will meanwhile relate to earlier ones and begin to answer what has changed. The ratios of the components will change over time, and if we are to predict/understand the changes, we need to understand the components and what controls their changes and distribution, sort of #2. (And we did not really discuss #3, which JHS added after the discussion.)

What SAS-compatible observations are underway at present? (E.g., repeated short sections, etc.) What are their principal limitations with respect to SAS objectives?

What science questions are being addressed by present Arctic observing efforts with different measurement approaches than SAS? I.e. consider ice-tethered profilers, ice and surface drifters, moorings, xxx.

Which set of oceanic repeat sections would be needed at a minimum to provide the critical needed information on shifting hydrography, heat/salt budgets, carbon system and inventories, and large-scale marine biology (ecosystem assessment) of the Arctic Ocean?

Note that one does not need to address all of the measurements which are needed to address "shifting hydrography, heat/salt budgets, carbon system and inventories, and large scale marine biology", etc., but only those which are needed in light of other likely components of a broader Arctic observing system which may include moored measurements, drifters, gliders, and other non-hydrographic-section measurements.

Group discussion

What areas do we need to measure in order to address the critical questions?

We need a list of science questions that drive the need for synoptic measurements and/or drive the need for repeated measurements.

What questions important to the climate community (modelers, etc.) can we address with the SAS program that cannot be addressed by ASOF and the like?

For parameters over the basins use the GO-SHIP Priority One list plus 18O minus He/Tr. Over the shelf do not need CFCs. Possibly add barium over the shelves. ADCP (yes?) but not LADCP (no scatterers).

Station spacing maximum 50 km over deep basins (often less as dictated by past studies of a given region) and much closer over and near bathymetric features (to 5 km in boundary currents).

JHS preference is to align SAS with GO-SHIP, including data policies, but look also to differences specific to SAS as needed, such as addition of fresh water tracers (examples might be 18O and Barium) and possibly deletion of He/Tr (as Level 1). (Also possibly deletion of CFCs on shelf-only cruises.)

We suggest that scientific interests requiring a presence on program cruises other than those directly aimed at core program goals can be addressed by requests to the oversight committee, which would considers program priorities, limits on cruise duration, berths, and lab space. We note that in general, programs that add ship time may need long lead times (≥ 1 year) and may be required to support their added time.

We suggest that the core measurement program, to be included on all program cruises except as noted mirror GO-SHIP Level 1 measurements:

Dissolved Inorganic Carbon (DIC)
Total Alkalinity (TAlk)
CTD pressure, temperature, conductivity
CTD oxygen (sensor)
Bottle salinity
Nutrients by standard autoanalyzer (NO3, NO2, PO4, Si(OH)4
Dissolved oxygen (O2)
Chlorofluorocarbon tracers (CFC-11, -12, -113) & SF6 [except on shelf-only cruises]
Tritium - 3He
Total Organic Carbon (TOC)
Total Organic Nitrogen (TON)
Surface underway system: T, S, pCO2
ADCP shipboard

18O of H2O and other program-required tracers of fresh water sources (Barium?)

The program should reflect lessons-learned, climate monitoring needs, and new frontiers of science.

There should be specific objectives and expected program payoffs. Who are the anticipated users/programs of the collected data and how important are these data to their goals?

Would new parameters be included as routine observations? Why?

How do programmatic and financial needs differ from those of GO-SHIP?

What are the expectations and likelihood of availability of adequate ship resources?

What is the commitment from the international community towards the program? Which countries in particular?

What can be improved with respect to international coordination?

How can GO-SHIP facilitate international coordination and what resources are necessary to do so?

There are data centers to collect and distribute repeat hydrographic data. Is the community ready to follow international data policies? What is the strategy for improving integrated management (including timely data release)?

What strategies will support and encourage development of new technologies and assess their effectiveness to achieve hydrography objectives (at reduced cost)?

Oversight typically via program science committee

Coordination with international GO-SHIP

Coordination with Arctic Observing Network

Affiliation with CLIVAR/WCRP?

Coordination & information sharing (and possibly cruise sharing) with other efforts where hydrography is important, e.g., Geotraces, ocean acidification, autonomous profiling.

Such pairings may permit icebreakers to return to their home ports, and also may help with international coordination.

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B2 Notes from biology breakout group
(Carin Ashjian, Jackie Grebmeier, Amalia Almada (remainder members, add your name to this list))

Ideal plan vs. what we can do in addition to hydrography, carbon surveys?

What would make this unique- really long transect lines (3 R/Vs), potentially spoked into the existing transects and observations on the margins

Frequent shallow depth zooplankton tows (0-200m) and less frequent deep tows; box cores every 100 miles

Important to refer to the pan-Arctic survey for Biology in 1994; important to be somewhat consistent with the historical measurements that have been taken with other surveys and observing stations

->where are these data sets? Important to have someone investing time to mine this data to help facilitate what is in the plan. Perhaps this was already done by Russell?

Look at what other synthesis papers recommend in terms of what biological parameters ideal to measure

->can sell the synthesis as part of the research grant (because this takes a lot of effort)

Consider taking bulk samples, ethanol preservation as a way to increase the speed and efficiency of the zooplankton tows

AOS 1994 sampling: box cores, bongo nets (zooplankton from water column), primary production (incld. Chlorophyll),

*big selling point of this survey is the fact that it would have been nearly quarter of a century for pan-arctic biological survey – this could be a big hook

<u>What do we want to know:</u>

- Standing stocks/species composition of the major carbon compartments
- How has the state of the ecosystem changed from what we know?
    - Including range expansion, new species/size dominance, standing stock, changes in functional groups
- Areas of late ice vs. areas of early ice retreat- sea-ice continuum - (do communities develop at different rates – older vs. newer ice has different rates of community development, incld. Life stages)

- Major transportation pathways for fish - Are fish transported with hydrography and different water bodies? Intrusion of fish from the shelves?
- Presence of non-endemics? Intrusion of Pacific or Atlantic species

Measurements:

- Microbes (viruses, bacteria in water column and benthic), zooplankton, phytoplankton (including size distribution), microzooplankton, mesozooplankton, macrozooplankton (fish – use cameras or, meiofauna, epifauna (under ice and on the benthos – use of cameras), ice cores (algae, microbes)
- Important to do observations not processes
- Size fractionation/Lugal's for phytoplankton sizes
- Passive acoustic observations for larger marine mammals, or observations of whales and seabirds during stops of the measurement
- Oxygen/argon ratios, argon techniques
- Underway flow cytometer (image plankton that fluoresced)
- FRFF
- Zooplankton taxonomy (nauplii, adults)

Logistics:

- Is sampling for viruses difficult? Can you freeze the samples?
- Can we use AUVs under ice for some of these observations?
- Potentially share taxonomists between countries?
- Important to take basic measurements so that we can have consistent sampling methods across different research vessels
- Observing vs. 'understanding' – important to appease different funding sources
- Important to leave some instruments in all year and then get the buy-in to go back and bring them back up

B3 Notes from carbon cycle breakout group
(Kumiko Azetsu-Scott, Leif G. Anderson, Melissa Chierici, Heidi Marie Kassens, Are Olsen, Michiyo Yamamoto-Kawai)

The carbon cycle group elected Kumiko Asetzu-Scott as leader, decided what elements should be included in the Science Plan, and assigned responsible scientist for each. The science plan structure with our added elements (highlighed) is provided below.

Science and Implementation Plan
1. Background and Overall Motivation

Figures, map, illustration of change (heating, ice, ocean pH (from Leif))

2. Expected outcome

3. Key Observations for the Synoptic Arctic Survey

3.1 Hydrography

Freshwater dynamics, sources and sinks of freshwaters in the Arctic
Ventilation timescales should be included as elements where biogeochemists can contribute as well.

3.2 Ecosystem

3.3 Carbon system including ocean pH

1. Inventory, transport (vertical and horizontal) and transformation of total and anthropogenic CO_2 (Are)

- Map and integrate DIC and Cant in the Artic
- Determine the horizontal fluxes of the above into and out of the Arctic and relation to water masses
- Determine vertical fluxes associated with watermass transformations (deep water formation)
- Determine vertical fluxes as a result of biological production (Export production)
- How efficient are these vertical transports for carbon storage/sequestration? (time scales for resurfacing)

2. Sea-ice and air-sea exchange of CO_2, ocean pH, $CaCO_3$ saturation (Melissa)

- Pan-arctic effect of ikaite formation in sea-ice (spatial gradients of upper ocean alkalinity anomalies, relation for freshwater contribution)

3. Supply and transformation of nutrients

Future Arctic PP and sustainability and downstream effects (Michiyo))

- Denitrification, N-loss and N_2O production in the Arctic
- Budget to give:
  - Nitrogen fixation in the Arctic.
  - N-loss
  - advective and run-off supplies
  - upwelling supplies
- Export production loss

4. Freshwater impacts (Kumiko)

- Impact of freshwaters on carbon, nutrients, ocean acidification
- Map out freshwater sources, alk end-member concentrations
- Sea-ice melt impacts
- Precipitation effects??

5. Input of terrigeneous carbon and its fate in the Arctic ocean (Leif)

- Map out magnitude of sources
- Determine retention times
- Sedimentary loss
- Transformation of POC and DOC to DIC (and its (the DIC's) fate))
- An Arctic Ocean DOC budget (method remote sensing is a component)

6. Ocean acidification (Melissa)

- Map out preindustrial pH and change with fossil fuel uptake
- Determine current and potential strength of amplification/moderating drivers
- Indicators (e.g. pteropod, distribution, shell thickness, density in relation to water masses)

7. Historical carbon trends (Heidi)

- Microfossils and geochemical tracers

4. Synpotic Survey Requirements

For each category provide very specific time and space sampling requirements

4.1 Hydrography

4.1.1 Space and time considerations

Area of specific interest

Seasonal timing

Vertical and horizontal, extent and resolution

4.1.2 Key parameters, sampling, analysis and logistic requirements

4.1.3 Personnel requirements

4.1.4 Requirements on ship time

4.2 Ecosystem

4.2.1 Space and time considerations

Area of specific interest
Seasonal timing
Vertical and horizontal, extent and resolution

4.2.2 Key parameters, sampling, analysis and logistic requirements

4.2.3 Personnel requirements

4.2.4 Requirements on ship time

4.3 Carbon cycle and ocean pH

4.3.1 Space and time considerations

Area of specific interest
Seasonal timing
Vertical and horizontal, extent and resolution

4.3.2 Key parameters, sampling, analysis and logistic requirements

4.3.3 Personnel requirements

4.3.4 Requirements on ship time

5. Data Policy

6. Contributions to international and national programs

7. Timeline for implementation of SAS

Contributions to international and national programs

An Arctic Ocean DOC budget - GEOTRACES