Synoptic Arctic Survey

Report of the Open Planning Workshop

May 15-16, 2019
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts, USA

Report prepared by Carin Ashjian, the US SAS Science Steering Committee, the International SAS Science Steering Committee, and Workshop Participants.

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Executive Summary

A workshop to advance the international Synoptic Arctic Survey (SAS) effort was held at the Woods Hole Oceanographic Institution, Woods Hole, MA USA on May 15-16, 2019. Fifty-nine scientists and science managers participated in the workshop, including 17 early career and 19 international scientists. The workshop reviewed the scientific goals, planned and proposed cruises in 2020-21 and associated measurements of the SAS as well as expanding studies with the SAS Science Plan. Three focal working groups (Physical Oceanography, Marine Ecosystem, Carbon Cycle and Ocean Acidification) refined the core measurements with synergies emerging between the groups. Additional measurements, both ship-based and from non-ship assets, were endorsed if able to be accommodated without compromising the core SAS measurements. Locations of the SAS transects/tracks were discussed relative to the scientific justification for each, including placement relative to key hydrographic features such as boundary currents and relative to previously sampled transects. Key next steps include centralizing information on SAS cruise tracks and establishing connections with regional programs focusing on shelf and near-shore environments. Pre-field synthesis activities should focus on standardization of methodology and centralized cataloguing of available existing data and post-field syntheses would be facilitated through 1-2 international workshops to discuss findings and further collaborations. The value of modeling to the SAS effort was recognized for both pre-field planning and post-field interpretation and future projections. Strategies to involve local indigenous communities in the research and to communicate the SAS plans, progress, and findings were identified, including the participation of indigenous peoples on cruises, working with existing local organizations (e.g., tribal, logistical), using social media to communicate science, community visits or science fairs, following NSF's best practices for Arctic research, and designing attractive marketing materials. The SAS is an excellent opportunity to engage early career scientists in Arctic research and multiple potential activities to nurture this participation were identified. It was recommended that the SAS data management policy stated in the SAS Science Plan should be codified prior to the start of the field season. Data archiving and sharing would be achieved through a network of national data centers, coordinated by a central SAS site and thus virtually linked to provide data access to all SAS participants.

Introduction

The Synoptic Arctic Survey (SAS) has been envisioned by a team of scientists from multiple nations working together to identify fundamental questions, hypotheses, approaches, and joint field efforts to study the status and change of the Arctic ecosystem. This coordinated effort will lead to a better understanding of how variability across the Arctic Ocean is interconnected, how the system responds to environmental forcing and climate change, and how perturbations in one region may cascade to another through physical interconnections. Detection of change requires an understanding of the systems' fundamental structures and functions that is lacking on both local and Pan-Arctic spatial scales. Achieving this understanding requires coordinated scientific studies across multiple pan-Arctic regions near-simultaneously (same year, same season), using common methodologies and sampling strategies.

At the core of the SAS is the premise that a Pan-Arctic, comprehensive, near-synoptic quantification of carbon and eco-system parameters followed by similar activities on a decadal scale will enable us to more holistically describe and understand these systems. We postulate that the SAS sampling effort will allow us to identify trends and perturbations in key chemical and biological parameters that occur in concert with changes in the physical environment, particularly hydrographic structure and currents. This effort in turn will permit projections, both theoretical/conceptual and quantified through coupled physical-biological-chemical modeling, of future trajectories of change and the potential impact of those changes on regional, Pan-Arctic, and even global scales, including on human systems that rely on Arctic ecosystem services.

The SAS is organized around three major research areas: (1) Physical drivers of importance to the ecosystem and carbon cycle, (2) the ecosystem response, and (3) the carbon cycle and ocean acidification. The effort is focused on a single, overarching question: *What are the present state and major ongoing transformations of the Arctic marine system?* Each focal area has three specific questions that cannot be completely answered now because of lack of a baseline or foundational understanding that is key to evaluating ongoing transformations in the system.

Development of the SAS has been ongoing through international collaboration since 2014. The Science Plan was developed in 2016-2017 by a core international group during multiple international workshops and meetings, sent out to the broader scientific community for review in 2017, revised based on those reviews in June 2018 and posted to the SAS website. Multiple presentations of the program have been made at a range of scientific meetings, both within the US and internationally including Arctic Science Summit Weeks in in 2016 - 2019, a Town Hall at the 2016 Ocean Sciences Meeting in New Orleans, LA, at the Ocean Carbon and Biogeochemistry Workshop in Woods Hole in June 2017, and at the AGU meeting in Washington DC in December 2018. The SAS has been presented at the US International Arctic Research Policy Committee (IARPC) Marine Ecosystems Collaboration Team May 2018 Teleconference. The program also is endorsed by the International Arctic Science Committee and the University of the Arctic.

As the next step in the development of the SAS, a workshop was held on May 15-16, 2019 at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA. The overarching goals of the workshop were further developing and planning of the international SAS effort, engaging US participation in that process, fostering international collaborations, synergies, and coordination, promoting participation of international scientists and science managers, and engaging the next generation of Arctic scientists. An additional goal was to include participation of a representative of local Alaskan indigenous communities to identify how to engage those communities in the SAS.

Six of the seven US Science Steering Committee members were present at the workshop. They, together with Øyvind Paasche, chair of the International Science Steering Committee, met on Friday May 17 to discuss US efforts and international coordination.

Workshop Format and Goals

Picture 1. Plenary SAS session

The workshop was held over two full days and comprised plenary and breakout sessions focused on one or more of the twelve specific goals of the workshop (Table1 and Workshop Agenda, Appendix A). Fifty-nine scientists participated in the workshop. Of these, seventeen were early career and nineteen were from international universities or agencies (Appendix B).

The general concept and structure of the SAS program, program governance, and status of field program were presented in an introductory session (Picture 1). This was followed by five-minute country updates from 11 nations. The structure, goals, and outcomes of the workshop were reviewed. Most participants then gave a very brief introduction to their research and interest in the SAS. The workshop then transitioned into three sets of working group sessions of three or four groups each followed by review of the discussions in plenary. The first set of working groups was held on Day 1 with the second two sets held on Day 2. Plenaries focusing on data management (Goal 2) and perspectives and future outlooks also were held on Day 2. A reception was held during the evening of Day 1.

Picture 2. Physical oceanography break-out group.

The working groups focused on twelve specific goals (Table 1) and took advantage of the diverse audience, including scientists from the three scientific focal areas of the SAS. The groups reviewed the scientific questions and planned measurements for each focal area to expand on the existing International SAS Science Plan by identifying additional important topics or approaches and addressing sections that needed elaboration or greater consideration. Each working group was led by an established scientist, many from the US or international SAS science steering committees, and an early career scientist. As can be seen from the agenda, working groups frequently addressed multiple goals in their discussions (Picture 2).

Table 1. Goals of the workshop.

1. Review discipline specific research questions, methods, and measurements including questions of spatial and temporal scale.
2. Data management.
3. Blueprint for nurturing next generation of international Arctic scientists.
4. Elements missing from present SAS science plan (e.g., modeling, synthesis, molecular survey for bar coding, satellite data).
5. Additional possible measurements outside core program components (e.g., atmospheric, cryospheric, geological).
6. Review of planned and potential transects and scientific justification for each.
7. Non-ship assets (e.g., satellites, AUVs, submarine data collections) including questions of spatial and temporal scale.
8. Achieving cross-calibration between programs/ships.
9. Indigenous communities: engagement and participation.
10. Identify potential overlapping interests with other international efforts such as e.g., MOSAiC and YOPP.
11. Education – developing collaborative platforms (focus on PhDs)
12. Outreach. Identify target groups, messages and opportunities.

Outcomes

Workshop summaries are included as Appendix C with key recommendations and observations summarized below.

Working Groups I

The first set of working groups concentrated on discipline specific scientific questions, methods, and measurements including the spatial and temporal scales of sampling required to answer the research questions and how to cross-calibrate methodology between the different ships and nations. In addition, the groups also considered additional measurements and approaches not identified in the existing science plan that could be used, how non-ship assets could be brought to bear, and whether the draft general locations of transects would appropriately address the questions. This latter group of topics also were considered in later break out groups.

Physical Oceanography

Observation: The definition of the baseline pan-Arctic synoptic state that would result from the survey is extremely important and is unique.

Recommendations

- Add an additional research question to the science plan: RQ0 - What is the present basic state, water mass distribution, circulation, heat and freshwater content, and gateway fluxes of the Arctic Ocean?"
- Edits were suggested to the existing RQ1-RQ3 in the science plan.
- All SAS cruises should occur during August-September for seasonal consistency.
- Closer spacing of stations in shelf-break regions.
- Rapid transits of boundary currents.
- International Science Leadership should consider if the present plan samples sufficiently inshore of the shelf-slope transition.
- The core PO measurements identified in the science plan were reviewed. Four additional core measurements (GPS, Bottom Depth, Velocity, and Meteorological) were identified. Six additional non-core measurements were identified (ice morphology, gravity and magnetics, transmissivity, radium isotopes, microstructure, and CDOM). Chlorophyll was also identified as a non-core measurement.
- Non-ship-based assets also were discussed.

Ecosystem

Observation: There is an immediate need for measurements of multiple trophic levels across span-Arctic spatial scales as the Arctic system is undergoing rapid physical and ecosystem change.

Recommendations:

- Satellite data should be an integral component of the scientific plan, as it provides spatial and temporal context for the measurements made through the SAS. Collaborations with NASA supported scientists using satellite data should be developed.
- Collect samples for characterization of biodiversity through molecular/sequencing methods across all trophic levels with size fractionation for lower trophic levels; extra samples should be collected and archived for analysis using future state of the art methods. These collections should be core parameters.
- Establish a reliable repository and database of available samples for scientists planning projects using SAS materials.
- Most process rate measurements should be of lower priority since August-September is past the active growing season and limits on ship time and personnel make process measurements difficult; integrative measures of production across trophic levels are useful (e.g., carbon content, size, stable isotope ratios). However, sediments and benthic populations can provide an integrative measure of water column production and August-September allows for a reasonable measure of seasonal export production to the benthos.
- Develop an updated list of core parameters (see Appendix D).
- Develop a matrix of ship capabilities to identify which measurements can feasibly be done.

- Identify and disseminate sampling and analysis protocols to ensure consistency and comparability of results, drawing on co-occurring, non-SAS expeditions (e.g., MOSAiC, Nansen Legacy).
- Develop synergies with Arctic terrestrial and freshwater-based projects to obtain land-based endmember information.

Note: The list of core parameters was discussed further at the US SSC Committee Meeting on Friday May 17; the updated list is included in Appendix D and should be reviewed by the international SSC.

Carbon

Observation: Components of the carbon cycle in the Arctic connect the atmospheric-seawater and ecosystem with the global carbon cycle that are critical to track under ongoing climate change.

Recommendations:

- Compile a table with recommended measurements and identify which are necessary to answer each of the core carbon questions in the science plan.
- Identify water volume requirements for each core measurement to help with planning.
- If space/time permit, add additional parameters including:
  - Radium isotopes (100-1000 L) for subsea carbon input
  - ^{13}C of dissolved inorganic carbon (DIC) and/or particulate organic carbon (POC) to help distinguish marine - terrestrial sources
  - PIC concentrations on same samples as POC
  - Total organic carbon (TOC) for surface sediments from box corer (opportunistic sampling, benthic program)
  - Atmospheric measurements for carbon dioxide (CO_2) (and methane (CH_4)) flux estimates
- Incorporate sampling with autonomous instrumentation to track seasonality.
- Use of certified reference materials recommended (Andrew Dickson, C; Dennis Hansell, DOC; JAMSTEC, nutrients).
- Overlap some stations of the proposed cruise tracks for cross-calibration.
- The vertical resolution of sampling needs revision.
- The SAS should be repeated every decade.

Working Groups II

The “Pre- and Post-Fieldwork Synthesis” working group focused on identifying elements missing from the present SAS plan, overlap with other international programs, synthesis activities that could be conducted prior to the SAS program to provide greater context, and synthesis activities that should be conducted after the field years. The “Next Generation Arctic Scientists” working group addressed activities that could engage the next generation of international Arctic scientists and increase international collaboration. The “Indigenous Communities” working group discussed how to engage indigenous coastal communities and how to enable their participation in the field work. The "Modeling" working group addressed how modeling can help answer the SAS questions and what modeling efforts would gain from the SAS data.

Pre- and Post-Fieldwork Synthesis

Observation: The SAS program would be strengthened by pre-cruise synthesis activities to identify field sampling locations in relation to past repeat lines and time series stations, along with evaluated past data products. Post-cruise synthesis activities for compare and contrast of SAS data over the pan-Arctic effort to produce products for different stakeholder needs including the science communities, indigenous people ,and decision makers interested in the Arctic system.

Recommendations:

Pre-cruise recommendations centered on the need to collect and standardize the presently-available data before the field program takes place. Post-cruise recommendations focused on synthesizing the metadata, providing legacy conclusions regarding the best sampling and processing procedures, and evaluation challenges and successes.

Pre-Cruise:

- Establish SAS Secretariat to create and maintain central information portal (data, protocols).
- Canvas all SAS national groups to provide information on sites where existing data can be accessed
- Standardize and approve desired parameters and sampling and data protocols prior to field program and create standard operating procedures (SOPs); this should be done by sub-teams within each discipline. Send survey to all SAS participants to create virtual teams and list data archives
- Identify if there are years or sets of years that have sampling coverage similar to the SAS.

Post-Cruise(s):

- Hold a stand-alone meeting during the winter following the first field season to synthesize cruise reports and generate data maps.
- Hold a second stand-alone meeting in 2022 to compare the two field seasons and identify a path forward to develop across-program syntheses, including joint papers or volumes, a data atlas, and a paper providing information for decision-makers.

Action Items:

1) What projects already exist to address the core, high-level SAS questions? Answering this question before the field program will provide an understanding of periods of past data coverage.
2) Task disciplines to generate templates of necessary parameters and SOPs and identify the lead on that discipline's virtual team (response within 1 month).
3) All parties involved in SAS to provide links to core data archives for their discipline. A list of how to access these datasets will then be maintained through the SAS portal, on the meeting website (https://web.whoi.edu/sas2019/)

Next Generation Arctic Scientists

Observation: The SAS program will provide an excellent opportunity to train the next generation of scientists in both national and international collaboration and science activities for Arctic science.

Recommendations:

- Establish a SAS Scientist Training School at which early career scientists (grad students, post docs) or field technicians would be formally trained in the core sampling disciplines. The School would be held annually and would rotate between the 11 participating SAS countries. More information is available in Appendix C.
- Hold a post-processing and data synthesis meeting a year after fieldwork with access available via webinar for those who cannot travel.
- Establish a database of all samples, including unprocessed samples, that were collected, all data generated from the samples, where and how to access the data, and sample/data ownership.
- Improve networking within the SAS group to keep member up to data on e.g., cruise schedules, planning, availability of berths, and points of contact.
- As part of a strategy to educate early career scientists on international funding sources, including a funding list in the network activities.
- Engage early career scientists in social media outreach.
- Encourage the participation and outreach personnel on cruises.

Engagement of Indigenous Communities

Observation: There is increasing interest by indigenous communities to provide their perspective on scientific studies relevant to understanding changes occurring in the Arctic system.

Findings:

Communications and coordination are key
Keep expectations bounded by reality
Community sampling should be community initiated, not community based
There are regional differences in outreach expectations, e.g., US/Canada vs. Europe
Recognize and value the uniqueness of each country, region, village, research entity
Work together with each community to identify what outreach will work for them
Collaboration with local communities is best with locally-derived ideas
Strategies to communicate science to local communities include:
Resident liaisons or points of contact who participate in research (e.g., local observer)
Social Media (e.g., Facebook groups)
Local media such as radio, newspaper
Scientists should be aware of science engagement history and other ongoing science
Follow best practices of Arctic Research promoted by the NSF
Work with existing local organizations to engage local communities
Visit communities

Engage youth (K-12, local universities)
Potluck, BBQ
Community Presentation including door prices
UIC Science BARC Science Fair is an effective forum

Design attractive and informational marketing material

Modeling

Observation: Modeling is recognized as a valuable tool for both developing SAS plans as well as post-cruise evaluation of SAS data. The working group discussed how models could help the SAS effort as well as how SAS can help modelers, summarized below.

a. How models can help SAS effort:
   - Model results, in particular from state-of-the-art climate system (coupled atmosphere-ice-ocean-biogeochemical) models, can be used to put synoptic observations into a broader temporal context.
   - Daily model output can provide an examination of the variability of parameters with time and help interpret SAS measurements that are collected "quasi-synoptically" but within a season.
   - Modeling might help identify the synoptic time scales of variables to help define sampling frequency.
   - Models can inform cruise planning.
   - Models can offer estimates of processes ongoing during earlier, unsampled time periods (e.g., the spring bloom).
   - Synergistic modeling activities with the MOSAiC project can expand temporal coverage of data to use in models.

b. How the SAS can help models:
   - Some models do a very good job of representing sea ice, ocean, and atmospheric characteristics (although they do a less good job on the small scale) but biogeochemical characteristics and the connections between rivers and oceans need improvement. The SAS could provide valuable data for such improvements.
   - The SAS community should engage broader modeling communities.
   - An ensemble modeling approach involving a number of models would be a valuable asset.

Working Groups III

The third set of working groups focused on additional measurements outside the core program, non-ship assets, including questions of spatial and temporal scale, and planned transects and the scientific motivation behind their location.

Additional measurements outside core program

Observation: Additional measurements outside the core program were recognized as important, thought to be critical to measure if possible given constraints of time and space on board, and identified as value added to the program, regardless of whether the measurements are within the core disciplines or complementary.

Recommendations:

- It is important to consider whether there is interference between the different equipment potentially used on SAS cruises (e.g., ADCP, EK80, MB).
- A first step is to census the standard equipment on board each of the participating ships and tabulate that equipment.
- All ships should have the most up-to-date track-map on board and should endeavor covering new ground for mapping purposes (bathymetry, gravity).
- Ice camps would be a good addition but the activities would need to be efficient and desired tools and measurements should be identified.

Additional measurements also were discussed in the discipline specific working groups. All of the suggested measurements from across the workshop are listed in Appendix E.

Non-Ship Assets

Observation: It was recognized that other non-ship assets, such as satellite observations and autonomous vehicles and buoys, could provide valuable information coincident with the SAS ship activities.

Recommendations/Findings:

- Critically important that non-ship efforts do not detract resources from the primary SAS objectives.
- Develop a table listing pan-Arctic non-ship assets (including all countries) that will be deployed during the SAS, deployment durations, measured parameters, and responsible institution/investigator.
- Real-time remotely sensed data (e.g., satellite data, model predictions) should be used to plan at-sea activities.
- In-situ real time/near real-time ocean measurements (satellite-tracked drifters, gliders, SailDrones, HF radar, ice mass buoys, ice tethered profilers, sonobuoys) also can inform and expand data coverage but most measure only a limited subset (usually just physical oceanography) of SAS core parameters.
- Towed-undulation vehicles equipped with sensors could make measurements between stations in open water.
- Airborne and underwater drones also could be deployed.

A comprehensive list is included in Appendix C.

Planned transects and scientific motivation

Proposed sections were reviewed and updated; additional updates were made after the 2019 ASSW meeting in Arkhangelsk, Russia (Figure 1).

Recommendations:

- Updating the map of transects for 2020 and 2021, including the shelf cruises. (e.g., solid lines – confirmed cruises; dashed lines – planed cruises);
- Sharing longitude & latitude of the transects: n-points, regions, etc.;
- Adding the Bering Strait section (note navigation restrictions due to the national boundaries);
- Uploading all the sections on Google Earth and sharing among all (use WHOI portal as a start);
- Determining the cross-over points for cross calibration if there are cruises in the same regions;
- Making a request to cross the boundary currents;
- Reaching out to the regional programs that collect some standard SAS measurements

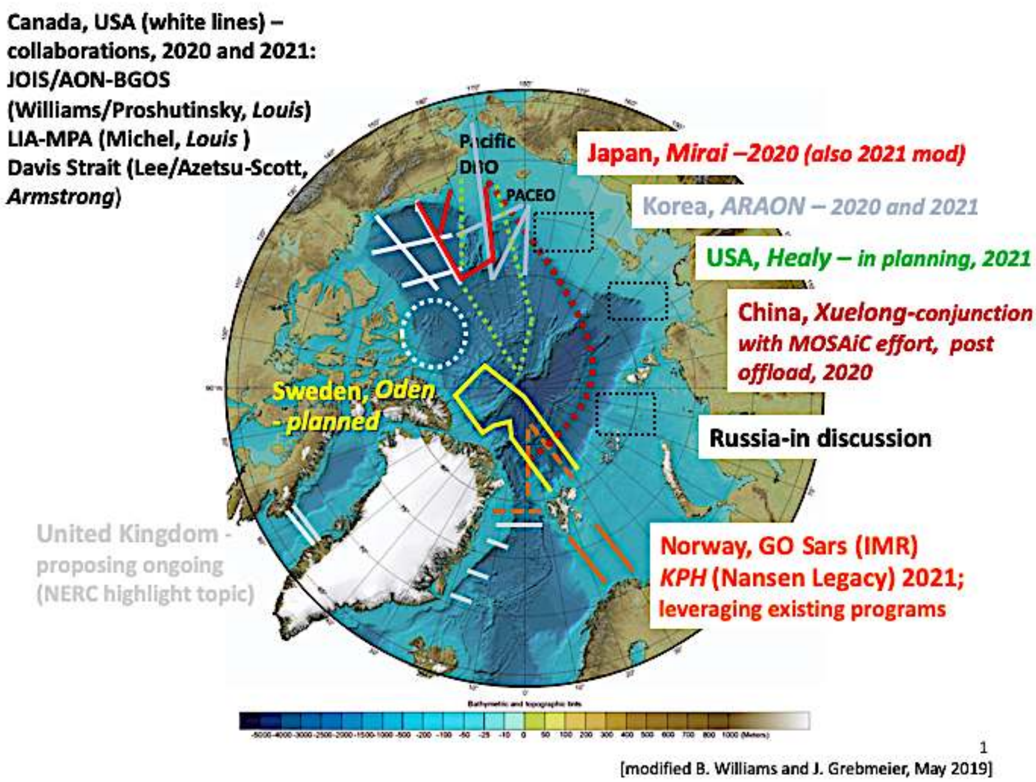

Figure 1. Most recent map of planned SAS transects. Color of text corresponds to annotation regarding country, ship, and year. Solid track lines indicated confirmed cruises; dashed track lines indicated cruises presently being planned or proposed. Additional maps identifying international shelf programs are being generated.

Data Management

Data management was discussed in plenary, led by Jim Swift. It was noted that a draft SAS data policy already is in place and should be codified and endorsed before the field season begins. Data management begins before the field program takes place. It was recognized that it is not imperative to have all of the data in a single location but that a "virtual center" could be established by linking multiple, national data centers together through a central clearing house. It was also recognized that a project office would be extremely useful for networking and tracking data. Data and cruise information should be tracked and documented from conception through collection, management and distribution centers, and ultimately to archives.

As a start, all participating nations should provide links to their data repositories that can be archived on one of the SAS web sites, either the Norwegian site or the satellite WHOI site.

Acknowledgements

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Appendix A. Final Agenda

Synoptic Arctic Survey

AGENDA
Synoptic Arctic Survey (SAS) Open Planning Workshop

Dates: May 15-16, 2019
Venue: Clark Building, 5th Floor, Woods Hole Oceanographic Institution Quissett Campus
360 Woods Hole Rd. Woods Hole Massachusetts USA
Sponsors: US National Science Foundation and the International Arctic Science Committee

Day 1 (May 15)

8:30 Welcome and logistics - Carin Ashjian and Laurence Madin, Deputy Director and Vice President for Research, WHOI

8:40 Overview of the SAS Program – Øyvind Paasche, Chair of the International SAS Science Steering Committee

- -Motivation
- -Timeline of program development
- -Program Components (Physical Oceanography, Carbon Cycle, Ecosystems)
- -International Science Steering Committee Members
- -Core questions
- -Introduction to core measurements
- -Status of the field program – confirmed and planned cruises
- -National efforts

9:15 Five minute Country Updates

Korea – Kyong-Ho Cho presented by Jackie Grebmeier
Russia – Alexander Polukhin
Canada – Bill Williams and Kumiko Azetsu-Scott
Japan – Shige Nishino
China - Jienfeng He presented by Jackie Grebmeier
Swedan – Sten-Åke Wangberg and Leif Anderson
Norway – Øyvind Paasche
Denmark – Karen Edelvang presented by Carin Ashjian
UK – Toby Tyrrell presented by Carin Ashjian
USA – Jackie Grebmeier and Carin Ashjian
Germany – Heidi Kassens

10:00-10:20 Coffee break

10:20 Goals and Outcome of the Workshop – Carin Ashjian and Jackie Grebmeier

-Overall Objectives
-Planned Products
-Review of workshop structure and strategy
-Review of planned breakouts/discussions needed to accomplish workshop goals (not in order; not all require a breakout group)

13. Discipline specific methods and measurements including questions of spatial and temporal scale
14. Data management
15. Blueprint for nurturing next generation of international Arctic scientists
16. Elements missing from present SAS science plan (e.g., modeling, synthesis, molecular survey for bar coding, satellite data)
17. Additional possible measurements outside core program components (e.g., atmospheric, cryospheric, geological)
18. Review of planned and potential transects and scientific justification for each
19. Non-ship assets (e.g., satellites, AUVs, submarine data collections) including questions of spatial and temporal scale
20. Achieving cross-calibration between programs/ships
21. Indigenous communities: engagement and participation
22. Identify potential overlapping interests with other international efforts such MOSAiC and YOPP
23. Education – developing collaborative platforms (focus on PhDs)
24. Outreach. Identify target groups, messages and opportunities.
25. Funding opportunities. Public and Private?

10:35-12:30 Attendees present research areas of interest

Attendees will be asked if they want to present 2 slides in 3 minutes describing their research interests or specialization (e.g., data management) and how they envision contributing to the SAS. Not all attendees need to do so, only those who wish to.

12:30-1:15 Lunch (served) and synergizing

1:15 Working Groups I - Discipline specific methods and measurements – Carin Ashjian

3 groups (physical oceanography, carbon cycle, ecosystems)

Carbon - Clark 509: Leif Anderson and Lisa Bröder
PO – Clark 237: Mary-Louise Timmermans and Maria Pisareva (PO),
ECO - Clarke 507: Carin Ashjian/Jackie Grebmeier and JP Balmonte

Review the discipline specific scientific questions (modifications possible!) and the measurements identified in the science plan. Identify and codify common methods, methods that intercalibration between ships, and additional measurements to add (e.g., ecosystem samples for molecular barcoding). Workshop goals to address:

1) Discipline specific methods and measurements including questions of spatial and temporal scale
8) Achieving cross-calibration between programs/ships
and also consider but note there are dedicated breakout groups for these topics:
4) Elements missing from present SAS science plan (e.g., modeling, synthesis, molecular survey for bar coding, satellite data)
5) Additional possible measurements outside core program components (e.g., atmospheric, cryospheric, geological)
6) Review of planned and potential transects and scientific justification for each
7) Non-ship assets (e.g., satellites, AUVs, submarine data collections) including questions of spatial and temporal scale

3:00 – 3:20 Coffee Break

3:20 Return to Group to pull together conclusions

3:45 Working Groups I Report
- Each working group will present a synopsis of findings
- Group discussion

5:00 – 7:00 Reception – Clark 5 Foyer (outside meeting room)

5:00 - 8:00 Shuttle bus to hotels available

Day 2 (May 16)

8:30 Welcome, logistics, summary of Day 1, and schedule - Carin Ashjian

8:45 Working Groups II
Pre- and Post-fieldwork synthesis –Clark 507: Carin Ashjian, Jackie Grebmeier, and Astrid Pacini
Workshop Goal 4: Identify elements missing from present SAS science plan (e.g., modeling, synthesis, molecular survey for bar coding, satellite data). SAS2030.
Workshop Goal 10. Potential overlap with other international efforts (e.g., MOSAiC, Nansen Legacy, YOPP, Decade of the Ocean)
Next Gen Arctic scientists- Clark 201: Øyvind Paasche and Jennifer Questel
Workshop Goal 3: Blueprint for nurturing next generation of international Arctic scientists
Workshop Goal 11: developing collaborative platforms (focus on PhDs)
Indigenous communities- Clark 237**:** Seth Danielson and Kaare Erickson
Workshop Goal 9: How to engage indigenous communities and identify potential participation
Modeling – MRF 204: Jackie Clement-Kinney and Zhixuan Feng
What can modeling do for the SAS and vice-versa?

10:00-10:30 Coffee break

10:30 Working Groups Report Out

11:30 Working Groups III

Additional measurements outside core program – MRF 204: Carin Ashjian and Anouk Beniest
Workshop Goal 5) Additional possible measurements outside core program components (e.g., atmospheric, cryospheric, geological) including any identified in the discipline specific groups (e.g., molecular)

Non-ship assets – Clark 201: Seth Danielson and Jessica Cross
Workshop Goal 7) Non-ship assets (e.g., satellites, AUVs, submarine data collections) including questions of spatial and temporal scale

Planned transects and scientific motivation - Clark 507: Jackie Grebmeier and Yana Bebieva
Workshop Goal 6

12:30 Lunch (served)

1:15 Data Management – Clark 507: Jackie Grebmeier and Jim Swift

2:00 Working Groups III continued
Additional Measurements – MRF 204
Non-Ship Assets – Clark 237
Planned transects – Clark 507

3:00 Coffee Break

3:30 Working Groups III Report Out and discussion

4:00 Perspectives and future outlook/What we decided and where do we go from here (next international workshop) – Carin Ashjian, Jackie Grebmeier, and Øyvind Paasche
Also: Workshop Goal 12: Outreach – Target Groups, Messages, and Opportunities

5:00 Adjourn. Shuttle buses to hotels.

Post-workshop: Summarize findings in a report that will be made available to funders. decision/policy makers and others interested in the SAS program.

Appendix B. Participants

Synoptic Arctic Survey Attendees

Name ('*' =Early Career)	Affiliation	Email address
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Appendix C. Working Group Summaries (Group Leaders Identified)

Physical Oceanography: Maria Pisareva and Mary-Louise Timmermans

The PO working group included:
Anouk Beniest
Astrid Pacini
Bill Williams
Bob Pickart
Jim Swift
Jessica Dabrowski
Lea McRaven
Maria Pisareva
Mary-Louise Timmermans
Matt Charette
Øyvind Paasche
Yana Bebieva

The group **reviewed and revised the discipline-specific scientific questions** contained in the SAS Science Plan. The group agreed on the need to emphasize that a most valuable outcome of the SAS is that it will provide a baseline pan-Arctic synoptic state. To this end, a new question RQ0 is recommended. Before addressing Arctic *change* (emphasized in questions RQ1-RQ3), a new question regarding the basic state is recommended for two reasons: 1) many fundamental features of the Arctic system are presently not known (e.g., estimates of Transpolar Drift Stream transport, from a PO perspective, and many more in PO and other disciplines) and SAS will allow for such baseline information to be determined; 2) A pan-Arctic synoptic baseline will allow all measurements that have come before (and will come after) to be set in the context of a changing Arctic. The PO group further recommends subtle but important changes to the existing questions RQ1-RQ3, to lead to the following:

Recommended additional scientific question and edits to existing RQ1-RQ3:
RQ0. What is the present basic state, water mass distribution, circulation, heat and freshwater content, and gateway fluxes of the Arctic Ocean?
RQ1. How are Arctic Ocean water masses and circulation patterns responding to changes in sea ice, atmospheric, gateway fluxes and freshwater forcing?
RQ2. What are the changes in heat and freshwater budgets in the Arctic region?
RQ3. What are the changes in water mass sources, sinks and transformations?

The group put forward several recommendations related to **spatial and temporal scales of surveys and sampling**. These are the following:

- For the optimal "synoptic" view, all cruises are recommended to be in August and September (e.g., to avoid significant issues of comparing November measurements and e.g., June measurements in the rapidly seasonally evolving Arctic).

- Near the shelfbreak region, 5-10 km spatial resolution for standard CTD sampling is recommended to fully resolve narrow boundary currents. In the deep basins, station spacing as stated in the Science Plan (20 nm) is appropriate.
- It is recommended that PIs consider rapid crossing (less than 24 h) of boundary currents (i.e., so the full feature is resolved effectively synoptically, before it evolves appreciably).
- While ships are in transit, opportunistic bathymetric mapping (ideally over a track that has not yet been mapped) is recommended.
- The group recommends further discussions and deliberations about how far inshore it is necessary and appropriate for SAS surveys to cover. It is unclear whether the shelf-slope transition is sufficient, or whether further into the shelf is required to capture processes of fundamental importance.

The group **reviewed and revised the core and non-essential measurements** outlined in the Science Plan. In the table below, the recommended core measurements are highlighted in blue, and recommended additions to the existing Science Plan measurements are in bold.

Revised measurement table:
(core measurements in italics, **recommended additions to the Science Plan in bold**)

GPS	
Bottom depth	Multibeam/echosounder
Pressure	CTD
Temperature	CTD + underway?
Salinity	CTD + Niskin + underway?
Velocity	SADCP/LADCP
Dissolved Oxygen	CTD + Niskin
Nutrients (NO3/NO2, PO4, SiO3)	Niskin
Meteorological measurements*	
Ice thickness, concentration, drift	Ice watch, remote sensing
Gravity and magnetic measurements	
Transmissivity	
Chlorophyll	Niskin
Radium isotopes	
Microstructure	
CDOM fluorometer	

** Air temperature, wind speed, humidity, barometric pressure,* PAR.

Finally, the group had a brief discussion on **non-ship-based assets**, classifying them in three overarching categories (below). This was also discussed in an entirely separate working group so is not essential to include, but we put them here for completeness.

Non-ship-based assets:
- Lagrangian (ARGO, ITP, drifters, gliders, sail drones, met buoys, …)
- Fixed platforms (moorings: bottom, water column, ice)
- Remote sensing

Ecosystem Working Group: J.P. Balmonte, Carin Ashjian, and Jackie Grebmeier

Tasked with identifying additional measurements, samples and approaches to be taken for SAS, the Ecosystem working group discussed and agreed on several key points (full list in Table 1). First, satellite data should be an integral component of the scientific plan, as it provides spatial and temporal context for the measurements made through the SAS. Collecting samples for molecular/sequencing work across trophic levels (e.g., bacteria, phytoplankton, zooplankton, fish) was also prioritized to assess biodiversity; size-fractionation is necessary for the lower trophic levels. The group recommended archiving extra sample replicates for future processing and cross-calibration, should the state-of-the-art sequencing technology change, and identified a special need to establish a reliable repository and database of available samples for scientists interested in developing a research agenda using SAS materials. In addition, process rate measurements were heavily discussed, as they are necessary for parameterizing ecosystem models. However, for practical (e.g., limits on ship time, capability, personnel) and scientific reasons (i.e. August not the growing season for many organisms), core rate measurements will be limited to integrative measures of production across trophic levels, though the use of radioactive isotopes needs to be discussed further. Finally, while not a core parameter, an important addition to the SAS scientific plan is understanding the roles of humans in the ecosystem as stakeholders.

This is particularly important in light of the new Arctic Ocean Fisheries Agreement that requires ecosystem assessment prior to considering the development of fisheries. Several actionable items were also identified by the Ecosystem working group. The list includes producing a table/matrix of the science plan versus ship capabilities; this effort would help inform which measurements can be feasibly included in the core parameters. Moreover, protocols need to be identified and disseminated to ensure consistency and comparability of results. Protocols from co-occurring, non-SAS expeditions (e.g., MOSAiC, Nansen Legacy, etc.) can be borrowed (pending permission) for many parameters across all SAS working groups; this approach also allows comparability of results across various Arctic-related research initiatives. Finally, synergies with groups conducting Arctic terrestrial and freshwater-based projects whose goals align with those of SAS need to be identified and developed, to obtain land and aquatic endmember information (e.g., sources of organic carbon, nutrients, dispersed microorganisms, etc.). Potential organizations for these projects include Inter-ACT and ARICE. A separate working group was tasked to identify other collaborative avenues.

Table 1. List of identified core and non-core parameters

Additional core	Not previously present for other groups: Satellite data Already present for other groups: Optics/light, nutrients
Additional non-core, ship/personnel capability-dependent	Nitrogen isotopes, O_2/Ar, Fe, particle flux from sediment traps, ROV, sea-ice and snow measurements, multi-core vs gravity core, acoustics, radioactive isotope-based productivity

Carbon Working Group: Lisa Bröder and Leif Anderson

The key scientific questions in the SAS Science Plan were revisited and agreed upon by the all participants. It was suggested to compile a table with the recommended measurements (Table 4 of the science plan) and note which measurements that are necessary in order to answer each of the research questions (RQ7 to RQ9). It was further suggested to add the water volumes required for each measurement to help with cruise planning. If space and ship time allow, sampling for additional parameters is recommended, the ones mentioned were:

- Radium isotopes (100-1000 L) for subsea C input
- ^{13}C of DIC and/or POC to help distinguish marine - terrestrial sources
- PIC concentrations on same samples as POC
- TOC for surface sediments from box corer (opportunistic sampling, benthic program)
- Atmospheric measurements for CO_2 (and CH_4) flux estimates

Further it was mentioned the great value of complementary measurements with autonomous instrumentation in order to achieve information of the seasonality in the signatures.

For all core parameters, standard methodologies are available. Certified reference materials (for C system by Andrew Dickson, DOC by Dennis A. Hansell, nutrients from JAMSTEC) are strongly recommended to be used on all cruises. A lack of labs that can measure CFCs and SF_6 (dissolved CH_4?) was identified.

For cross-calibration/quality control, it was suggested to overlap some stations of the proposed cruise tracks. In order to do this, all plans of the cruise tracks need to be supplied to the scientific steering committee (responsibility of the scientific steering group).

Spatial and temporal scale were discussed. It was agreed that the horizontal resolution given in the science plan, 20 nm distance between stations for the deep ocean, with a higher resolution on shelves and slopes is desirable for the C system. The suggested vertical resolution (Table 3 of the science plan) needs revisiting for e.g. shelves impacted by river runoff and to allow for sampling for specific features (e.g. chlorophyll max, specific water masses). Generally, the resolution will depend on the number of Niskin bottles on the rosette used. For the temporal resolution a repeated SAS every decade should be aimed for.

Pre- and Post-Fieldwork Synthesis: Jackie Grebmeier, Astrid Pacini)

Workshop Goal 4: Identify elements missing from present SAS science plan (e.g., modeling, synthesis, molecular survey for bar coding, satellite data). SAS2030.
Workshop Goal 10. Potential overlap with other international efforts (e.g., MOSAiC, Nansen Legacy, YOPP, Decade of the Ocean)

Pre-cruise synthesis: This discussion centered on the need to collect and standardize the presently-available data before the field program takes place. More specifically, the group highlighted the need to establish an SAS Secretariat that could create and maintain a centralized portal where scientists can find available datasets and protocols. To this end, funding must be secured. Our plan is to ask all parties involved in SAS to provide sites where their data can currently be accessed and/or planned to be access as part of the SAS effort. Data sampling and protocols must be standardized and agreed upon before the field program begins. This involves identification of past repeat lines or timeseries locations and generation of standard operating procedures (SOPs). To create the SOPs, we think it would be important to create sub-teams (within biology, chemistry, physics etc.) to agree on what the parameters measured and best practices will be. This should be done with periodic virtual meetings in the next 6 months. A survey will be sent to all SAS participants, with a 1-month deadline, to create virtual teams and list data archives.

Additionally, to address SAS core questions that investigate changes in the system, we think it would be valuable to identify particular years or sets of years that have sampling coverage similar to the SAS program. For example, 2015 was well sampled, the time period between 2002-2005 marked the start of the Ice Tethered Profilers (ITP) program, and from 2007 onwards Bulletin of American Meteorological Society (BAMS) reports summarize Arctic data. It would also be important to find a similar period in the 1990s.

Post-fieldwork: We think a crucial post-cruise component of this program will be to have a meeting the winter after the first field season, to synthesize the metadata, to conclude on the best sampling and processing practices, and to acknowledge what went well and what was challenging. We envision this to be a stand-alone meeting (not associated with a large conference), where the cruise reports will be synthesized and data maps can be generated. Similarly, there must be a 2022 meeting to compare the two field seasons, with the goal of producing a joint paper or volume that highlights the program/findings and motivates use of the produced datasets, including for modeling, and for repeating the effort in the future. This document should provide information for decision-makers, produce a data atlas (visual, virtual), and explain how to access the data. One possible platform for this could be the BAMS State of the Climate 2021, which will be produced in summer 2022.

Action items:

4) What projects already exist to address the core, high-level SAS questions? Answering this before the field program will provide an understanding of periods of past data coverage.
5) We task disciplines to generate templates of necessary parameters and SOPs, and we need to identify the lead on that discipline's virtual team (response within 1 month).
6) We task all parties involved in SAS to provide links, in 1 month, to core data archives for their discipline. A list of how to access these datasets will then be maintained through the SAS portal, on the meeting website (https://web.whoi.edu/sas2019/).

Next Generation Arctic Scientists: Øyvind Paasche and Jennifer Questel

Workshop Goal #3: Blueprint for nurturing next generation of international Arctic scientists
Workshop Goal #11: Developing collaborative platforms (focus on PhDs)

To facilitate Goals #3 and #11, the Next Generation Arctic Scientists discussed 5 major topics:

1. SAS scientist field training school

It was proposed that a SAS Scientist Training School / Summer (or winter) workshop should be established. The purpose of this training school would be targeted towards early career scientists (e.g. graduate students and post-docs) or field technicians to be formally trained in the core sampling disciplines required by SAS. This School would be held on an annual basis where host locations would rotate between each of the 11 participating SAS countries. By having SAS trained scientists, they could fill berthing spaces on cruises and assist with any core sampling required of them, regardless of the sampling being a part of their discipling or not. For example, a SAS scientist needing samples could partake in a cruise, collect their samples of interest, as well as fill any other needs of the sampling protocols so that manpower is most efficiently utilized.

During the initial year of the SAS Training School, standard operating procedures (SOPs) could be produced, standardizing sample collection across the SAS core disciplines. These SOPs could then be made available to all scientists on any cruise that would be collecting samples in accordance with the SAS program.

Additionally, opportunities to have classes on communicating science and how to navigate international funding could be given. As the Arctic is a central topic for climate change, Arctic researchers will be engaging with the general public and educating/communicating with them on this important, and sensitive, topic. Regarding funding, a representative from the major funding agencies could attend the School, detailing how to best navigate international funding and what their agency is looking for, or not looking for, in a proposal. This formal training program would also facilitate and capitalize on networking with other students and scientist that work outside of their discipline.

It was also suggested that a post-processing and data synthesis meeting could take place a year after field work. This meeting could also be available via webinar to those that cannot travel.

2. **Database/sample repository**

In conjunction with data management, we as early career scientists would like to have requirements for the database to list all samples that were collected, data generated from these samples, where and how to access these data, and sample ownership. These data would also include any unprocessed samples so that in the future we would know who has what samples and if they would be available for analysis. As technology rapidly advances, it would be beneficial to have access to samples that could be reanalyzed (e.g., extracted DNA or archived specimens) for better cross-comparison with newer updated platforms. Additionally, a record of available data and/or archived samples would provide proof of samples for writing proposals.

3. **Networking**

We believe there is a need for networking amongst the SAS group, either an ECS or more general SAS monthly newsletter detailing any information on cruise schedules for the field season, cruise information (sampling priorities and regions), what cruises have available berths, and point of contact per discipline to coordinate any additional sampling requests.

4. **Funding**

It was of great concern that, in order for the next generation of Arctic researchers to be successful, we would need to learn how to successful navigate international funding sources. As mentioned above, it would be beneficial to have a class during the Training School that was dedicated to this topic. Additionally, a funding source list could be implemented into the suggested monthly SAS newsletter, especially any that pertain to early career scientists. There could also be an ECS section on the SAS webpage that details funding agencies, RFPs, and the ECS Arctic community.

5. **Outreach**

Early career scientists tend to have a strong social media presence and would be ideal candidates for helping in outreach efforts for the SAS program via Facebook, Instagram, Twitter, etc. The central theme in outreach that pertains to the Arctic is being able to broadcast and communicate to peers and the general community on the uniqueness of exploring and researching such remote regions of the world and being out in nature. We also discussed allowing berthing space on cruises that would be dedicated to outreach personnel. Whether that be a teacher-at-sea, an artist, or a scientist who is analyzing data yet never has the opportunity to go out to sea. These individuals could attend the SAS Scientist Training School prior to their respective cruise.

Lastly, we encourage the addition of an ECS representative from the APECS (Association of Polar Early Career Scientists) group as a member of the SAS steering committee.

Engagement of Indigenous Communities- Seth Danielson and Kaare Erickson

Attendees:
- Carin Ashjian, Woods Hole Oceanographic Institution
- Lee Cooper, University of Maryland, Center for Environmental Science
- Seth Danielson, University of Alaska, Fairbanks, College of Fisheries and Ocean Sciences
- Kaare Sikuaq Erickson, Ukpeagvik Inupiat Corporation, UIC Science
- John Farrel, United States Arctic Research Commission
- Laurie Juranek, Oregon State University
- Chelsea Wegner, University of Maryland, Center for Environmental Science
- Jean-Éric Tremblay, Université Laval, Québec City, Québec, Canada

Discussion Topics:

Communication and coordination are key. Discussion centered around the guiding notion that coordination and communication are fundamentally critical to achieving positive research-community interactions. This includes formal and informal settings (e.g., AEWC and AWSC meetings, school visits, community presentations).

Keep expectations bounded by reality. Some opportunities may exist for having local observers fill in data gaps in the coastal realm but many scientists come with misplaced expectations that village residents would welcome employment opportunities to collect occasional samples. Best practices of community sampling dictate that it be community-initiated, not simply community-based.

Recognize regional differences in outreach expectations. The breakout discussion group was comprised solely of US and Canada participants, so we did not get much of a sense for European local community expectations until the report-out. From the report-out discussion it was determined that North American style outreach does not appear to be associated with the same expectations or priorities for the SAS Eurasian partners, but there still may be some good opportunities for educational outreach. Indigenous communities in Greenland, Canada and the US have many cultural linkages. A pan-Arctic outreach events, such as a science fair that entrains local researchers and K-12 youth is an appealing model.

How do we engage the Indigenous communities?
What does it mean to be Indigenous? Due to the varying degree of what "Indigenous communities" means in different countries, members of SAS Scientific Steering Committee might consider using the term "Local communities" (or "Indigenous/Local communities") so that SAS has a more Pan-Arctic engagement plan that includes populations in the Arctic that might not be considered "indigenous" by the varying parameters in each Arctic country.

Each Country is Unique Each village, each region, and each country all have unique characteristics that will require unique engagement efforts tailored for the different situations. However, during the workshop we recognized SAS needs a pan-Arctic outreach plan that provides various ideas or models to be tailored for each situation.

Each research entity participating in SAS is unique Different countries have different obligations to engage with residents of the Arctic. In the US, for instance, the level of engagement with Indigenous/local communities will depend on various contingencies such as location of research and different obligations of funding agencies.

What constitutes "good" outreach? There was acknowledgement that different groups may have different measures of what constitutes good outreach. The best case is when funders, scientists and communities converge upon a mutually satisfactory approach. There is no cookie-cutter formula and what works well for one community may not work well elsewhere. Communication is key. One example of a successful approach to outreach is that of the UIC traveling science fair. This approach aggregates multiple research projects and scientists into a single community visit, thereby cutting down on the over-saturation of community interactions that has been noted with multiple frequent uncoordinated visits. Other successful approaches were noted with the inclusion of community observers on board research vessels, lectures and media outreach when visiting communities, and others. Asking communities what they want is a good first step. There are governmental and nongovernmental organizations that are well situated to help facilitate, coordinate, or guide interactions between researchers and local communities.

It is important to be aware of what priorities an organization may have and to align researcher interactions with those priorities; otherwise the match may not make sense. It is important to be aware of other efforts ongoing so as to not duplicate and to leverage activities where possible. It is important for scientists to get guidance from their funding agencies and it is important that the funders remain well informed.

Are there opportunities for collaboration?
Everything in the Arctic Costs More: As marine researchers, we all know that any type of operation in the Arctic is very expensive. This includes LIVING in the Arctic. Having said this, if SAS projects do not have significant money set aside for local collaboration, the opportunities for collaboration will be very difficult to find.

Locally-derived ideas for collaboration: Ideas for collaboration will need local support from the beginning, as it is very hard to instill local interest in collaborative projects if the ideas solely come from outside entities. Some ideas for collaboration that were discussed during the workshop is included below.

What are the best strategies for communicating our science to local communities?
Resident Liaison (also referred to local observer, marine mammal observer, etc.) – This would consist of local residents physically taking part in various research cruises and acting as liaison to share information about the research operations. The SAS may be able to create a series of positions on vessels that may include duties such as sharing daily updates to social media for local residents and sending a daily email to local stakeholders. A lead scientist on each vessel can be tasked to work with the Resident Liaison to provide daily information from the science research that is understandable in laymen's terms.

Social Media: The SAS should utilize social media to share information to communities in the Arctic. Local Facebook groups, such as North Slope For Sale Market (6,500 members), Nunavut Hunting Stories for the Day (37,000 members), and many more. People make announcements about local Arctic activities in these groups and it is a very effective way to effectively and efficiently share information with thousands of local and Indigenous residents of the Arctic.

Other Local Media: Radio interviews, local newspapers, and local television stations are usually open to letting folks know about large research projects, and this would require SAS researchers to reach out to the local media entities.

Educating the scientists: A critical component to mutually beneficial communication with local and Indigenous communities is to make sure scientists are educated and aware of local contexts such as history of science engagement in different regions as well as current contexts of other science and research projects that occur in and near communities.

Best practices of Arctic research: Focus on the five structural pillars promoted by NSF: Communication, Accountability, Respect, Sustaining Relationships and Environmental Stewardship. A question was raised about the potential benefit of finding a way to better educate researchers about the history of Indigenous communities, colonialism before and after Statehood in Alaska, and related science-village history. Participants could point to past and potential new (e.g., UIC's Suvat Science?) examples of this type cultural-awareness-building training that triggered interest across the discussion group. Especially for researchers in a position to directly interact with communities, such training opportunities would be welcome.

What are the best strategies to interest local communities in our science?
Work with existing organizations: There are many organizations in different regions that already have systems set up to conduct research and assist in relations between visiting scientists and local communities. (I.e. for Alaska, UIC Science and Kawerak).

Visit the communities: One idea that was presented during the breakout session was to make an effort to actually visit several communities in the Arctic to both instill interest in communities and hear feedback from locals in the Arctic. UIC Science provided an example of an outreach model that has successfully worked in northern Alaska.
This model includes:

1. Engage with the Youth – This might include visiting K-12 schools and/or local Universities to take part in fun and educational activities.
2. Potluck/BBQ – Share some sort of food with the community. In smaller communities you might offer BBQ hamburgers and hotdogs. In larger communities you may offer light refreshments and snacks.
3. Community presentation – This is usually incorporated with the potluck/BBQ. Bringing door prizes to give out during the meeting will make things go much smoother as well.
4. UIC Science has hosted the BARC Science Fair in Utqiagvik for several years, which brings coordination and communication to scientists regardless of affiliation. This effort was a response to dozens of science groups coming to Utqiagvik, with each entity wanting to host their own community meetings and outreach activities. This outreach model brought all of these science groups together for a three-day fair. Hundreds of locals take part in the fair, and it provides positive engagement with many different age cohorts in the community. **See example of BARC Science Fair 2018 Agenda below*

Attractive and informational marketing material: This will include utilizing social media and local media resources mentioned above.

A vision for modeling in SAS: Jackie Clement-Kinney and Zhixuan Feng

One of the goals of SAS is to collect a suite of observations across the Arctic. At the same time, participants would like to be able to say something about changes that are occurring over the past few decades. Model results, in particular those from state-of-the-art climate system (coupled atmosphere-ice-ocean-biogeochemical) models, can be used to put synoptic observations into a broader temporal context. Long-term change can be examined in multiple realms including biogeochemistry, sea ice, ocean, atmosphere, and river discharge. In addition, the very best climate models may even be useful for predictive purposes. This could be especially useful for ships that are operating in the Arctic where sea ice frequently limits or even alters cruise track plans. Having a sea ice forecast for several months into the future might be helpful for cruise planning.

Although the plan of SAS is to collect synoptic measurements, the reality may be that measurements are actually collected over the course of a month, or even in separate years. This may be fine for some parameters, but problematic for others. Daily model output can provide an examination of the variability of various parameters with time. We expect that different parameters will show more/less variability due to the specific nature of the parameter in question. We also expect that this variability will differ across the Arctic. For example, parameters that are patchy or highly variable with time will have a shorter synoptic time scale. At the same time, parameters that are more integrative will have a longer synoptic time scale and might not need to be sampled at the highest time frequency. This assessment of the synoptic nature of various parameters might be useful for cruise planning purposes. It was also noted that the timing of the cruises (in late summer) is likely too late in the season to capture the peak of production. If model output compares well with the observed data for the late summer, then models may offer some estimate of the earlier time frame (e.g. the spring bloom) when observations are missing. Because of SAS's limitation in temporal coverage, the group discussed potential synergistic modeling activities with MOSiAC.

We also discussed the strengths and weakness of current climate modeling efforts in relation to the Arctic. We believe that some models are doing a very good job of representing sea ice area and thickness and that this is absolutely critical for modeling of the Arctic Ocean physics and biology. Similarly, ocean and atmospheric general circulation are well represented, although small scale process (e.g. oceanic eddies) may still be missing. There is still room for improvement with certain aspects in biogeochemistry models, including representing the peaks and patchiness of phytoplankton. In addition, the connection between riverine input and the ocean needs improvement. The modelers attending this working group were interested in the SAS observational effort and would like to be included in future work. We suggested that the SAS community could reach out to broader modeling communities, such as FAMOS (Forum for Arctic Modeling and Observational Synthesis). If there is sufficient community interest, an ensemble modeling approach involving a number of models would be a valuable asset.

Additional measurements outside the core program: Anouk Beniest and Carin Ashjian

Besides the measurements already included in the core program, atmospheric, geophysical and ice-related studies may benefit from additional data that can be collected outside of the core-program. This would make the SAS an even more interdisciplinary initiative. These measurements would require equipment such as atmospheric sensors, gravimeter, magnetometer, multi-beam, para-sound, (small) ROV, fluorescence, salinity, oxygen, C-P-O2-systems, nitrate sensors, carbon sensors, drones and ice-cameras.

Most of these measurements could be taken on the go and will not cost a lot of time, however the monitoring for quality data and continuity would require an additional scientist on board. It is important to make sure the different equipment does not interfere with each other. Some of the additional measurements are collected with equipment that require station time such as ROVs and drones. This should be planned carefully. For additional measurements that are mapping related it is important to cover new grounds and every vessel should have an up-to-date track map onboard.
Additional data that could be used during the cruises is LIDAR data and high-resolution SAR.

Our recommendation to proceed with the collection of additional measurements would be to find out what standard equipment is onboard of all vessels (e.g. gravimeter, multi-beam and sensors). Make sure every ship has the most up-to-date track-map onboard. Whenever possible the ships should consider to cover new ground for mapping purposes (of e.g. bathymetry and gravity). To study the ice-camps an overview of the needed tools and wanted measurements is essential to be as efficient as possible when on station. Another great advantage of taking these additional measurements is that they can be combined and compared with other existing programs such as MOSAiC, IBCAO, AGP, etc.

Non-ship Assets: Seth Danielson & Jessica Cross

Non-ship assets provide an opportunity to address many temporal and spatial scales of variability beyond the subsurface ocean observations that the SAS vessels will make. However, it is critically important to make sure that non-ship efforts do not detract resources from the primary SAS objectives.

Year-round moorings, orbiting satellites, passively drifting sensors, and autonomous vehicles all have particular strengths that can help place the core SAS data into a more complete time and space context. Linking non-ship assets amongst the various countries will provide opportunities for pan-Arctic coordination and collaboration activities. We recommend that a table listing pan-Arctic non-ship assets be constructed in order to show proposers and funders what assets are expected to be in the water, what measurement parameters are collected, expected deployment durations, and the responsible institution/investigator.

Real-time remotely sensed data could help inform cruise planning and adaptive sampling by the SAS vessels: ice cover, ocean color, surface altimetry, thermal imagery and other products could provide useful to planning at-sea activities. Such products include the generally available images from large data centers (e.g., Copernicus) as well as specialty image products that some government agencies may be able to produce operationally in support of the SAS mission (e.g. US National Ice Center (NIC) Synthetic Aperture Radar (SAR) imagery). Similarly, atmospheric, ocean and sea ice models can all provide operational support to the SAS fleet.

Examples of in situ real time and near-real time ocean measurements include satellite-tracked drifters, gliders, SailDrones, high-frequency radars, ice mass buoys, ice tethered profilers, and sonobuoys. With a few notable exceptions, all of these platforms specialize in collection of standard physical data only. Their ability to collect the majority of the SAS core observations is extremely limited. There may be opportunities to deploy such platforms to collect ancillary data in the vicinity of the SAS vessels, especially when they are south of the ice edge. Gliders or propelled autonomous underwater vehicles may be deployed to collect microstructure turbulence data or fisheries acoustics data in a “virtual mooring” mode, for example, while other station samplings efforts are underway.

High-frequency radar installations will be deployed at five Alaskan sites, measuring surface currents in Bering Strait and near Barrow Canyon in the northeast Chukchi and western Beaufort Seas. Other land-based measures could come from flowing pumped seawater systems in coastal laboratories or observations of community-based partners. Again, these efforts would generally not be equipped to make most core measurements.

The discussion group also talked non-comprehensively about specialty non-core sensors that could be incorporated into standard sampling approaches and not requiring additional wire time. These could include profiling pCO2/pH sensors, towed undulating vehicles deployed while transiting between stations (open water only), expendable CTD sondes (XCTD), and airborne and underwater drones.

Potential Non-ship assets

- Space-based sensors
  - Passive microwave sea ice concentration
  - Synthetic Aperture Radar (SAR)
  - Sea Surface Temperature
  - Surface altimetry
- Land-based assets
  - High Frequency Radars (Barrow Canyon, Bering Strait)
  - Seawater throughflow in coastal labs
  - Tide gauge stations
- Ice and ocean Lagrangian sensors: many hybrids
  - Profiling floats
  - Satellite-tracked oceanographic drifters
  - Ice tracking beacons
  - Ice Tethered Profilers
  - Ice mass balance buoys
  - Sonobuoys
- Bottom-anchored moorings
  - Of all non-ship assets moorings have perhaps the best potential for multi-trophic level, multi-disciplinary sampling
  - Physical samples are possible (sediment trap, whole water)
  - Requires 2 years of vessel support to deploy & recover
- Autonomous vehicles (Remain south of the sea ice except in special cases; Many payload types are possible)
  - Gliders: Multi-month missions possible
  - Saildrone: Multi-month & fast
  - Wave Glider
  - Other AUV vehicles available with more power, faster & shorter durations
  - UAS Airborne (Oliktok Point UAS flight corridor)
- Vessel-deployed assets
  - XCTDs & XBTs
  - Towed undulating and fixed-depth vehicles (can also bring water to surface)

Planned transects and scientific motivation: Jackie Grebmeier and Yana Bebieva

The proposed sections were reviewed and updated with respect to national goals and sectoral programs; however, some of them are to be discussed and finalized at the upcoming meetings in Russia. Several transects will be further refined based on the existing base of the ship movement from 2010 to 2018 provided by Paul Berkman. Commercial fishing initiatives will be helpful for some of the cruises to be funded.
Recommendations include:

- Updating the map of transects for 2020 and 2021, including the shelf cruises. (e.g., solid lines – confirmed cruises; dashed lines – planed cruises);
- Sharing longitude & latitude of the transects: n-points, regions, etc.;
- Adding the Bering Strait section (note navigation restrictions due to the national boundaries);
- Uploading all the sections on Google Earth and sharing among all (use WHOI portal as a start);
- Determining the cross-over points for cross calibration if there are cruises in the same regions;
- Making a request to cross the boundary currents;
- Reaching out to the regional programs that collect some standard SAS measurements.

Appendix D. Ecosystem Parameters (Revised from Science Plan) and Sampling Notes

Parameter	Methodology	Priority Level
Viruses	Niskins	2
Bacteria (Water Column, Benthic)	Niskins, Box Core or Multicore or other corers	1
Phytoplankton	Niskins, Bio-optical sensors	1
Microzooplanton	Niskins	1
Meso- and Macro- zooplankton	Bongo nets (1), Multinet (1), Optical Instruments (2), Acoustics (2)	1 (2 for acoustics)
Benthic Meio- and Macro- fauna, Sediment parameters	Box Core or Multicore or other corers	1
Benthic Epifauna	Benthic Camera, Beam trawl	1
Epontic Communities	Under-ice imaging, ice cores, sub-ice sampling	1
Ichthyoplankton	Aluette or Tucker Trawls (1000 µm mesh), Acoustics	1
Fish	Trawls, Acoustics	1
Seabirds	Visual observations	1
Marine Mammals	Passive acoustics, visual observations	1
Production from O_2-Ar, O_2 isotopes, nutrients	Niskins	2
Primary Production	Niskins, On-Deck Incubations using C13, Nitrogen, net	2
Respiration	Niskins, Nets, Corers, Incubations	2
Integrative Measurements of Production	Elemental Composition (e.g., C, isotopes)	1
eDNA	Water from Niskins	1
Molecular samples	Samples in ethanol	1

Sampling Notes:

Viruses: Use MOSAiC, Nansen protocols

Bacteria: Use MOSAiC, Nansen protocols. Activity and abundance, molecular detection of composition and metabolic potential

Phytoplankton: Size fractionated chlorophyll, top-ten taxa community composition by microscopy, otpical detection, preservation in RNA Later or frozen

Microzooplankton: Lugols preservation, same method of molecular preservation as phytoplankton, optical methods

Zooplankton: Acoustics is ship or proposal dependent and there are calibration requirements. Multinet preferred, 150 µm mesh. 1000 µm for microzooplankton, 53 µm mesh surface net for smaller zooplankton. Split samples on board for multiple analyses. Organism in ethanol for composition and molecular work.

Benthic Infauna: Multicore preferred, also gravity and piston core occasionally for longer cores. Organism in ethanol for composition and molecular work.
Benthic Epifauna: Depth dependent; potential for dredges
Epontic communities: Ice stations if possible
Ichthyoplankton: 1000 μm mesh nets
Fish: Camera system. Acoustics if possible.
Production from isotopes: MIMS
Primary Production: Need to standardize across vessels
Respiration: Zooplankton, Benthic, Water Column
Integrative Measures: Zooplankton, fish, phytoplankton, bacteria e.g., elemental composition
Nutrients (not on table): Important but to be sampled by carbon team.
Humans: Humans are important stakeholders, not a parameter to be measured by the group

Appendix E. Additional Recommended Measurements Identified during the Workshop

Parameter	Methodology
Core	
GPS	
Bottom Depth	Multibeam/Echosounder
Velocity	SADCP/LADCP
Meteorological measurements	
Biodiversity	Molecular methods, all trophic levels
Satellite imagery	
Desired	
Ice thickness, concentration, drift	Ice watch, remote sensing
Gravity and magnetic measurements	Shipboard instrumentation
Transmissivity	Sensor on rosette
Radium isotopes	
Microstructure	
CDOM	Fluorometer
Nitrogen isotopes	
O_2/Ar	MIMS system
Iron	
Particle flux	sediment traps
Sea-ice and snow	Ice stations
Radioactive isotope-based productivity	Incubations
Radium isotopes	
^{12}C of DIC and/or POC	Niskin
PIC on same samples as POC	Niskin
Surface sediment TOC	Box corer
CO_2 and CH_4 atmospheric flux	
Nitrate	Sensor on rosette or underway system
Carbon	Sensors