SOUTHERN OCEAN OBSERVING SYSTEM

Report of the first SOOS
Amundsen & Bellingshausen Sea Regional Working Group
Korea Polar Research Institute, Incheon, Korea
8-10 May 2019

Report by K. Lowry and Y. Nakayama
Contact: B. Y. Queste (bastien.queste@gu.se)

International Science Council
SCOR
Scientific Committee on Oceanic Research

THE INTERNATIONAL COUNCIL FOR SCIENCE
SCAR
SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

Table of Contents

1. Summary

The Southern Ocean Observing System (SOOS) is a joint initiative of the Scientific Committee on Antarctic Research (SCAR) and the Scientific Committee on Oceanic Research (SCOR); and is endorsed by the Partnership for Observations of the Global Ocean (POGO), and the "Climate Variability and predictability (CLIVAR)" and "Climate and Cryosphere (CliC)" projects of the World Climate Research Programme (WCRP).

The Amundsen and Bellingshausen Sea regional working group is part of the newly formed Regional Working Group Consortium which aims to discuss progress and ideas in the Amundsen and Bellingshausen Sea sector to improve the functioning, development, outputs and outcomes of research, policy and stakeholder groups. This report outlines the terms of reference for the RWG and summarises what representatives of the community highlighted as key questions, topics and priorities for the coming decade in the Amundsen & Bellingshausen Sea sector.

The group is chaired by Bastien Queste, but is intended to be an open forum, such that all members are on an equal footing in all discussions, and all ideas and opinions are welcome.

2. Objectives of the workshop

The objectives of the workshop were to:

- Identify community of active researchers and operators in the Amundsen/Bellingshausen Sector
- Gain consensus on the key drivers of the region
- Develop a picture of the status of multidisciplinary observations in the Amundsen/Bellingshausen Sector
- Discuss key observational gaps, regional priorities, and challenges
- Collate list of upcoming/anticipated work in the region to promote collaborative opportunities

3. Participants

- Co-conveners: **Bastien Queste (UK)**, Tae Wan Kim (Korea), Patricia L. Yager (USA), Anna Wåhlin (Sweden), Povl Abrahamsen (UK), Yoshihiro Nakayama (Japan; APECS Representative)
- Local organizers: Tae Wan Kim (Korea), Hyoung Chul Shin (Korea), Sunhwi Kim (Korea)
- SOOS representatives: Louise Newman (Australia), Phillippa Bricher (Australia)
- Attendees: Peter King (Australia), Marilyn Raphael (USA), Guy Williams (Australia), Lars Boehme (UK), SangHoon Lee (Korea), Youngju Lee (Korea), Won Sang Lee (Korea), Seok-Gwan Choi (Korea), Pierre Dutrieux (USA), Rob Sherrell (USA), Kate Lowry (USA), Luc Rainville (USA), Hilmar Gudmundsson (UK), Julia Wellner (USA), Will Hobbs (Australia), Marius Melin (Sweden)

4. Terms of Reference

The SOOS Amundsen-Bellingshausen Seas Working Group aims to fulfill the following terms of reference:

1. Develop and enable regional-scale observing using SOOS best practice for observing system including areas from which data sets already exist to detect long-term changes.
2. Identify physical, geochemical and biological key processes and their coupling in areas of the Amundsen-Bellingshausen Seas region under climate change and in environmentally stable areas being expected to experience warming and melting of sea-ice in the future.
3. Advocate long-term sustained observations in the region to enable monitoring of changes and understanding variability within the Amundsen-Bellingshausen Seas region.
4. Identify and assemble important legacy data sets and sampling techniques.
5. Based on the experience in the region, identify data gaps and bottlenecks in the observation systems, which until present hinder a comprehensive and better understanding of the physical, geochemical and biological systems.
6. Facilitate coordinated and, where possible, multi-disciplinary observations.
7. Make plans of operations available on the SOOS website to increase collaboration amongst the international community.
8. Facilitate procedures to achieve data availability across the science community according to SOOS data policy, which includes the publication of data and meta-data.
9. Convene focussed sessions at international meetings, including SCAR and SCOR, and facilitate synthesis products, to increase the awareness of the science community to the importance of the Amundsen-Bellingshausen Seas region.
10. Provide support to the International Program Office (IPO) by providing short reports to be available at the SOOS SSC annual meeting, as well as providing content for the IPO website/newsletters on the activities and outcomes.

5. Scientific Presentations and key points

a. Key drivers of the region by topic

Ocean-atmosphere (W. Hobbs)

- Amundsen/Bellingshausen has highest tropospheric variability on planet.
- The dominant atmospheric driver is the Amundsen Sea Low, which is connected to the tropics/Southern Hemisphere.
- Region has inherently ‘warm’ ocean regime
    - Close to Polar Front/ACC
    - Relatively low rates of coastal sea ice production -> shallow Winter Water

Ocean-ice (P. Dutrieux)

- Historical observations demonstrate that water 2-3°C above in situ freezing reaches the grounding line of Amundsen/Bellinghausen terminating glaciers and ice shelves.
- The heat content reaching the ice varies strongly (factor of 2 to 6, depending on the area) on seasonal to decadal timescales, in yet to be quantified connections with sea ice seasonal forcing and decadal atmospheric variability emanating from the tropics.
- The resulting ice melt is structured over a broad range of scales, from tens of meters to tens of kilometers, with implications for the glacial reaction.

- Large questions remain on pathways and processes modulating the oceanic heat content available to melt the ice, the efficiency of melt as a function of oceanic heat, and the resulting discharge and ultimate fate of melt-induced freshwater and nutrients fluxes to the middle to upper part of the water column.
- Observations are required covering broad spatial and temporal scales, both on the continental shelf, in ice shelf cavities, and in the ice/ocean boundary.

Ice shelves (H. Gudmundsson)

- Bathymetry: The importance of bathymetry depends on the situation, but we can only assess this once the bathymetry is known. For example, improvements in the bathymetry around Dotson affect our calculated melt rates. Not that some melt-rate parameterisations, such as the 'plume model,' do not use bathymetry data.
- Ice shelf thickness: Ice-shelf thickness is inaccurate and this affects melt-rate calculations and estimates of ice-shelf buttressing.
- Improved representation of ocean-induced melt: This could (possibly) be achieved by observing melt and oceanic properties at the same time as a few locations. It should be tightly aligned with modelling efforts and focused on improving those aspects that matter for ice-flow.
- Modelling Ice/Ocean interactions is an ongoing task. Currently several groups are exploring different approaches, e.g. plume models, box models, fully coupled. A fully coupled approach might be needed whenever there are significant changes in the ambient water properties.

Sea ice (M. Raphael)

- In the Amundsen Sea, sea ice advances and retreats earlier than other locations around Antarctica.
- ENSO plays an important role in determining the timing of sea ice advance and retreat.

Biogeochemistry (R. Sherrell)

- The Amundsen Sea Polynya bloom is limited by both iron and light.
- The buoyancy-driven overturning circulation within the ice shelf cavities (the meltwater pump) is the key process bringing iron from deeper layers to the upper water column of the polynya, creating an iron-rich coastal current with injections into the central polynya via a rich eddy field.
- A 3D high resolution physical/biogeochemical model suggests that sedimentary sources of iron are more important than glacial meltwater in providing the limiting nutrient to the polynya both over the course of the winter as well as during bloom growth during the summer.
- The same model indicates that the vertical flux of particulate organic carbon resulting from the bloom is diverted to the west of the polynya and is especially intense within the coastal current.

Lower trophic levels (Y. Lee)

- In the Amundsen Sea Polynya, phytoplankton communities were dominated by *Phaeocystis antarctica* with high Chlorophyll *a* concentration (Chl *a)* in January 2014, while diatoms were the major group in the phytoplankton biomass with low Chl *a* concentration in January 2016.
- Low light could be an important limiting factor especially for the growth of *P. antarctica* in January 2016.

- Microscopic investigation of the phytoplankton composition in the Antarctic coastal waters is important.
- Phytoplankton community structure plays an important role in the biogeochemical cycle.
- Multi-year observations of phytoplankton physiology are related to environmental forcing in the Amundsen Sea.
- Trophic links of planktonic food webs are resolved to understand ecosystem dynamics and the carbon cycle.
- The role of zooplankton is quantified to determine the biological carbon pump.

Higher trophic levels (L. Boehme)
- Review of higher trophic levels in the region: seabirds (Antarctic petrels, Southern Giant petrels, South Polar Skuas, Snow petrels, Adélie penguins, Emperor penguins), whales and dolphins (Humpback whales, Antarctic minke whales, Killer whales, Beaked whales?), and Phocids (Crabeater seals, Weddell seals, Leopard seals, Ross seals, and Elephant seals).
- Animal-borne instruments (ABIs) are one of the largest oceanographic data providers from the sea ice zone. Example of 8,800+ CTD profiles in winter 2014. In TARSAN, over 2,000 CTD profiles.
- This strategy works best in conjunction with other observational strategies, including ships, moorings, ITPs, and Argo floats. ABIs can fill in time and space or work as ‘adaptive samplers’.
- Marine animals Exploring the Oceans Pole-to-Pole (MEOP) consists of several national programmes in a consortium to investigate the behavior and well-being of marine animals.
- Future work may include adding biological and biogeochemical sensors as part of the ABI suite.

Climate system dynamics, modeling (Y. Nakayama)
- Review of the Amundsen Sea focused ocean simulations.
- After 10 years of model development, most ocean models show qualitative agreement in on-shelf circulation, Circumpolar Deep Water (CDW) intrusion, as well as glacial meltwater outflow.
- Recent updates include coupling with biogeochemistry model, adding tides, and refinement of ocean model resolution up to 200 m.

b. National marine science activities and priorities

Documenting and sharing national activities and data discovery – DueSouth and SOOSmap (P. Bricher)
- DueSouth - the database of upcoming expeditions to the Southern Ocean is an opportunity to improve international science collaboration by sharing fieldwork plans. The Amundsen RWG is encouraged to enter their fieldwork plans into DueSouth and to use if to find potential collaboration opportunities.
- SOOSmap is a central portal for internationally curated datasets of general interest to the SOOS community, including physical, cryospheric, and biological observations.. New data layers are being added regularly. For suggestions on how to improve SOOSmap, please contact Pip Bricher, the SOOS data officer, data@soos.aq.

Korean Amundsen Sea project (T-W Kim)
- Introduction of Korea's research activities in the Amundsen Sea from 2010 to present.

- 2019/20 field campaign of Korea Polar Research Institute and future plans.

Sweden – current (moorings, AUV) and future plans, and Norway (A. Wåhlin)
- Gothenburg is embedded in the ITGC TARSAN project and is providing AUV capability with its new Hugin vehicle. The next campaign will be winter 20/21.
- Swedish moorings will be taken out of the Amundsen in winter 19/20 due to logistical constraints. One or two of the moorings may be redeployed alongside KOPRI moorings in the future.

USA (non-Thwaites) - current and future plans, overwinter (P. Dutrieux)
- ORBIS project: demonstration of seagliders and float capability for under-ice cavity exploration and overwintering under/near Dotson ice shelf.
- A. Thompson project looking at the Bellingshausen Sea ocean physics using repeat summer CTD and glider sections.
- Many other efforts demonstrate AUV (U Tasmania, U Gothenburg) and glider (A. Forrest, UC Davis) operations under ice, though in other settings and without acoustic navigation.

UK (non-Thwaites) - moorings, current and future (P. Abrahamsen)
- iSTAR is one of the largest UK activities in the Amundsen Sea in recent years, combining physical oceanography measurements from the shelf break up the ice fronts to investigate ocean forcing on the West Antarctic Ice Sheet, with glaciology on Pine Island Glacier ice shelf and tributaries to study the ice shelf response.
- A legacy of this project is five moorings that are being maintained by BAS, two in the troughs at the shelf break leading to PIG, one on the shelf, and two near the PIG ice front.
- Funding is secured to maintain these at least through 2023.

c. Status of multidisciplinary programs

Korean Thwaites Glacier Project (W-S. Lee)
- LIONESS-TG (Land-Ice/Ocean Network Exploration using Semiautonomous Systems - Thwaites Glacier): USD 20M, June 2019-May 2023; closely working with a couple of ITGC projects (e.g., MELT/PROPHET, hopefully more).
- Working toward better projection of SLR with reduced uncertainties by collecting in-situ observation data and using multidisciplinary approaches.
- Mainly focusing on understanding the evolution of the subglacial hydrological system (subglacial lakes and hydrothermal activities, etc.), constraining viscoelastic properties in the upper mantle, and direct access to ice shelf cavity.

ASPIRE / ODEN SO/ other biogeochem historical data (P. Yager)
- There have been multiple recent (past 12 years) US+international efforts to measure biogeochemistry in the Amundsen Sea including: Swedish+US (Oden Southern Ocean 2006-07, 2007-08, 2008-09, 2009-10, 2010-11), culminating in ASPIRE.
- ASPIRE included trace metals; phytoplankton biomass and productivity; zooplankton biomass and grazing rates; POM and particle flux; DOM; microbial abundance, productivity, respiration, and metagenomics; carbonate system (including CO2 flux); physical oceanography (including meltwater tracers); and sea ice observations.

- Other rich data sets are available from underway pCO2 on ships of opportunity (e.g., N.B Palmer and Gould) and Repeat Hydrography.

ApRES / NECKLACE (George VI, PIG, Thwaites, Getz) (P. Abrahamsen)

- The Autonomous Phase-Sensitive Radio Echo Sounder (ApRES) is a novel low-power radar device capable of measuring millimetre-scale changes to ice shelf thickness.
- These have been deployed on Getz Ice Shelf in 2016 and 2018, and on PIG Ice Shelf in 2014; one radar is currently active on Thwaites, and more will be deployed as part of ITGC.
- NECKLACE is the SOOS-endorsed concept of a circum-Antarctic network of ApRES sites to monitor changes in the ice shelves.

CCAMLR and Fisheries activities (S-G. Choi)

- Korea has been approved for research fishing using commercial fishing vessel from members of CCAMLR in subarea 88.3 since 2016 and has established research fishing up to 2019.
- The study items are as follows: 1) Diet composition and feeding strategy, 2) Biological parameter estimation, 3) Reproductive ecology, 4) Trophic niche inferred from fatty acids and stable isotopes. For the study, we collected the samples (stomach, liver, length, weight, otolith, etc.) of Antarctic toothfish and environmental data (temperature and salinity by depth).
- We will continue to conduct research fishing in the same area in the future.

International Thwaites Glacier Collaboration Overview (T. Scambos)

- Thwaites Glacier and the adjacent Amundsen Sea have been selected by several national programs now as the key area for major research on the potential for a rapid increase in ice flux from Antarctica and a consequent change in the rate of sea level rise.
- The US and UK have launched the International Thwaites Glacier Collaboration, a ~50 million dollar effort (science and logistics) to investigate all physical aspects of the glacier and its adjacent ocean, with particular focus on the ice-ocean interface, recent geological history, basal and ice margin geophysics, and improvements in modeling.
- A preliminary ocean-focussed season was just completed, and a major season on the ice-ocean interfaces in the Thwaites and Dotson-Crosson region will begin in November 2019.

ITGC MELT (P. Abrahamsen)

- The MELT project is focused on processes at the grounding line: how should coupled ocean-ice models treat the melt rates at the base of the ice shelves as grounding lines retreat.
- To help improve model parameterizations in these partially grounded cells, a series of measurements will be made across the grounding line, deploying instruments into boreholes from the grounded ice onto the ice shelves (and into the ocean cavities beneath), measuring the ice from the ground using seismics and ApRES, and using airborne radar.

ITGC TARSAN (B. Queste)

- TARSAN is studying how atmospheric and ocean processes are influencing Thwaites, Crosson and Dotson Ice Shelves.
- Ocean and ice components with field components in 2019, 2020 and 2021. Multiyear AMIGOS stations on the ice shelf. AUVs, gliders, and ships for the ocean component.

- Highly successful test season in 2019 with a hydrographic survey, and two under ice deployments of the Hugin AUV.

ITGC PROPHET (H. Gudmundsson)
- Modelling project using ISSM, Ua, and MITgcm (stream ice)

ITGC THOR: THwaites Offshore Research (J. Wellner)
- THOR will investigate drivers of ice sheet, ocean, and climate change recorded in sediments deposited in the ocean near Thwaites Glacier over the last several thousand years and especially the last decades.
- The early 2019 mini cruise on the *RVIB Nathaniel B. Palmer* included coring, bathymetry, sub-bottom profiling, and collaborative work with TARSAN and GHC.
- The early 2020 full cruise will include coring, bathymetry, sub-bottom profiling, and towed seismic. There will also be sub-ice shelf coring in 2020 in conjunction with other on-ice work.

d. Key data streams and tools

SOOS data management and discovery tools (P. Bricher)
- Introduction of SOOS data management tool (http://www.soos.aq/data).

e. Novel platform capabilities

AUVs, coordinating and sharing platform expertise (P. King)
- University of Tasmania has Polar Capable AUV that has completed its first under ice shelf missions
- Broad range of scientific payload, with ability to integrate more
- Eager to collaborate on future Polar deployments

Glider capabilities (L. Rainville)
- We are working on quantifying delivery and fate of oceanic heat to Dotson ice sheet. We have dense (km-scale) and fast (day-scale) measurements of T, S, U, sustained over an annual cycle in front of Dotson, and in the cavity during 2 seasons.
- Autonomous platforms, like gliders and floats, offer the persistence necessary to resolve the wide range of scales relevant to the ice-ocean interaction processes. They allow us to collect measurements in remote regions with unreliable, infrequent access.
- Operating these platforms in an unforgiving operating environment builds on the efforts of many years and an extended development arc.

UAVs (G. Williams)
- UAVs offer new and innovative methodologies for augmenting traditional ship and station based polar research.
- Autonomous photogrammetric surveys have been conducted in conjunction with AUV missions below sea-ice to produce near-coincident maps of total thickness.
- There are now many cost-effective sensor systems (visual, thermal IR, multispectral) and cross-disciplinary applications including clean water sampling and marine mammal biometrics and population counts.

- Key challenge is moving towards 'Beyond Visual Line of Sight' operations in terms of certification and approvals because the technology has quickly developed to greatly exceed the standard 'Visual Line of Sight' operations (<400m).

Airborne gravity measurements over ice shelves (W. Hobbs on behalf of J. Greenbaum)
- [Notes missing]

Surface vehicles, UEA's Autonaut (B. Queste)
- Surface vehicles offer the opportunity for significantly larger payloads and meteorological measurements.
- UEA's new Autonaut is being developed with the Antarctic in mind (ice strengthening, anti ice coatings, ice avoidance technology). The long term aim is to develop a platform capable of carrying a glider in the early season, deploy the glider and collect surface measurements, and then remain until a late season cruise.
- Key challenge is surviving the dangerous surface environment (ice accretion, ice formation and animals).

Seals and platforms of opportunity (B. Queste)
- Seals are currently the larger provider of Antarctic data in the winter months. Miniaturisation developments are leading to new seal tag technologies able to measure temperature, salinity, light levels, ice depth, chlorophyll and backscatter.
- Also providing interesting insights into animal physiology, behaviour and climate change.
- Current challenge is understanding habitats and behaviour to identify reliable opportunities to tag animals.

Modelling: observations required by modelers
Discussion of ocean/biogeochemical modeling (Nakayama/Yager)
- Examples of using ocean/biogeochemical modeling for observational planning and understanding observations.
- Need for opportunities to enhance collaboration between observing and modelling communities.

6. Key scientific priorities and observations needed to address them

We defined four research priorities and their underlying processes and considerations and identified the observations needed to address them. The necessary observations were then categorized as either lacking and in progress, depending on the present data collection stage. The four priorities are:

1. The role of the Amundsen/Bellingshausen Seas heat and freshwater in the Southern Ocean
2. The ocean's role in the stability of the Antarctic Ice Sheet and its future contribution to sea-level rise
3. The role of the Amundsen/Bellingshausen Seas on Southern Ocean carbon uptake and future changes
4. Understanding ecosystem functioning in the Amundsen/Bellingshausen Seas and its sensitivity to global change

We also divided the Amundsen/Bellingshausen Seas region into different sub-areas (Figure 1) to facilitate the discussion. We expect that this map will be useful for future working group meetings.

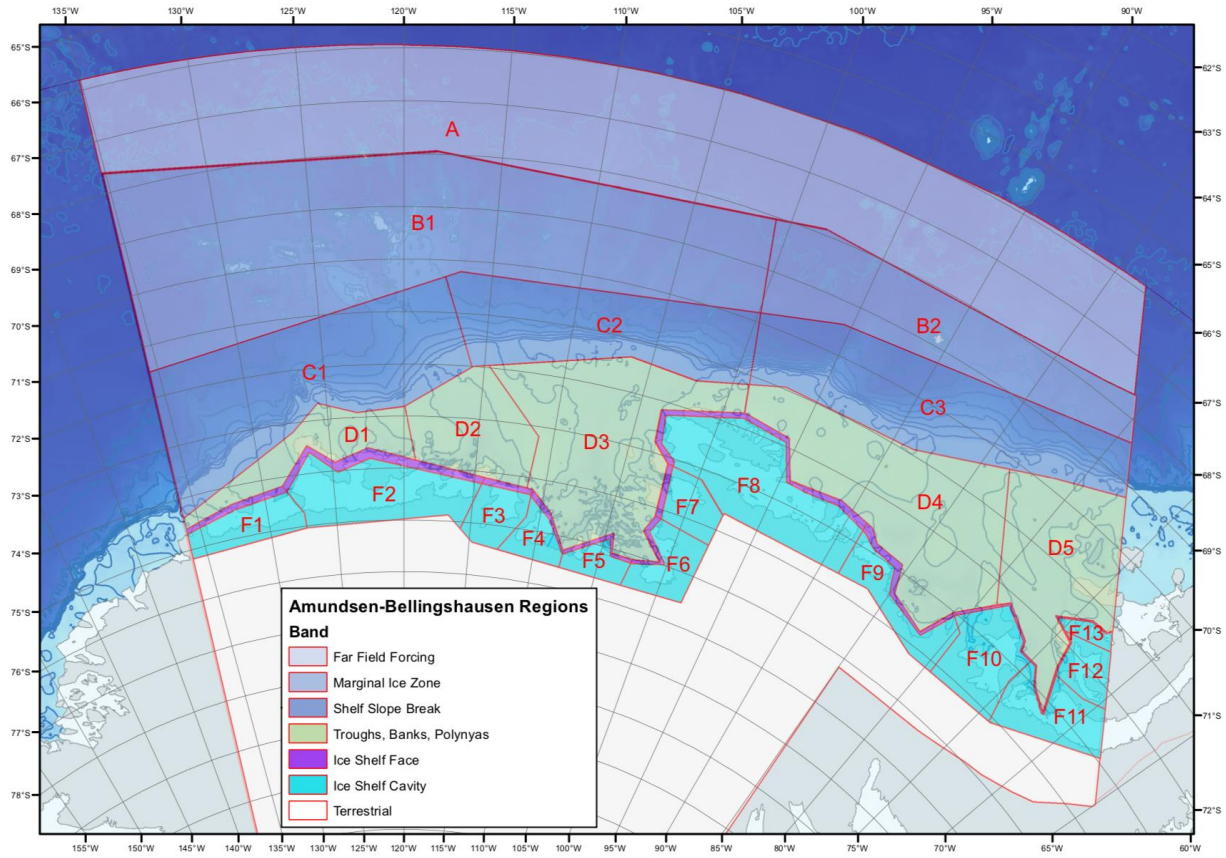

Figure 1: Map of the Amundsen and Bellingshausen Seas illustrating the division to 24 sub-areas

The key processes and considerations and necessary observations that we discussed during the workshop are listed below.

a. The role of the Amundsen/Bellingshausen Seas heat and freshwater in the Southern Ocean

Key processes and considerations

- Role of sea ice
- Contributions of ice shelf meltwater
- Connectivity from Bellingshausen Sea (upstream) to PIG/Thwaites, Dotson, Getz, Ross Sea (downstream)

Observations necessary and lacking (or extremely sparse)

- T/S in the Bellingshausen
- Meltwater fluxes
- Sea ice thickness
- Measurements in the far western region

- Buoyancy fluxes (icebergs, sea ice, precipitation)
- Subsurface salinity time series
- Ocean currents under sea ice

Observations necessary and in progress
- T/S, including under sea ice
- Models including both the Amundsen AND Bellingshausen
- Shelf/slope exchange
- Icebergs

b. The ocean's role in the stability of the Antarctic Ice Sheet and its future contribution to sea-level rise

Key processes and considerations
- On-shelf intrusion and on-shelf transport of CDW into ice shelf cavities
- Ice shelf melt water and its impact on upper ocean stratification
- Ice shelf-ocean interaction
- Role of sea ice

Observations necessary and lacking (or extremely sparse)
- Observations for some small ice shelves (e.g., Abbot, Crosson, etc).
- Weather stations
- Meltwater fluxes (dO18, He)
- Bathymetry under ice shelves
- Bathymetry on shelf
- Higher resolution, persistent T/S
- Cavity geometry (draft/thickness)
- Sea ice thickness
- Additional paleo work for context/background

Observations necessary and in progress
- SSH
- Ice sheet topography
- Ocean surface stress (wind and sea ice)
- Current velocities
- Grounding line movement
- T/S, including under sea ice
- Shelf/slope exchange

c. The role of the Amundsen/Bellingshausen Seas on Southern Ocean carbon uptake and future changes.

Key processes and considerations
- Role of sea ice
- Iron budget in the polynyas and offshore export
- Consequences locally, in the Southern Ocean, and globally

Observations necessary and lacking (or extremely sparse)
- Iron speciation, ligands, flux from sediments (iron everything)

- Weather stations
- Meltwater fluxes (or even just volume fluxes)
- Irradiance and Kd

Observations necessary and in progress

- Photophysiology
- Time series sediment traps, Thorium, etc. (for carbon export)
- Particle dynamics
- Phytoplankton phenology and composition
- Sea ice phytoplankton productivity
- Bacterial remineralization rates
- Sea ice thickness
- Synoptic T/S
- Nutrient concentrations across different water masses
- Shelf/slope exchange
- cf. all of #2

d. Understanding ecosystem functioning in the Amundsen/Bellingshausen Seas and its sensitivity to global change

Key processes and considerations

- Tipping points, regime shifts, and thresholds
- Energy flux through trophic levels (need species abundance, diet, phenology)
- Role of sea ice (e.g. change in annual cycle, extent, thickness)

Observations necessary and lacking (or extremely sparse)

- Bathymetry (and bed type)
- Benthic community
- Species abundance
- Foraging range, diet, phenology, reproductive rates, genetic diversity
- Fishing/tourist effort, location
- Pollution (pathogens, plastics, particulates)

Observations necessary and in progress

- cf all of #1-3 (and sea ice again, because it underpins everything)
- Snow/accumulation (for irradiance and Kd)

7. Next workshop

It was proposed that the next working group meeting would take place in conjunction with the SCAR meeting in August 2020 in Hobart, Tasmania.

8. Next actions

The goal for the next two years is to disseminate this report and to build a contact list of interested parties which will form the membership of the Amundsen & Bellingshausen Sea RWG.