Eos

Addressing Arctic Challenges Requires a Synoptic Ocean Survey

A coordinated effort involving trailblazing science—and icebreaking ships—from many nations is needed to fill gaps in our understanding of the Arctic Ocean and how it's changing.

By **Ø. Paasche**, **A. Olsen**, **M. Årthun**, **L. G. Anderson**, **S.-Å. Wängberg**, **C. J. Ashjian**, **J. M. Grebmeier**, **T. Kikuchi**, **S. Nishino**, **S. Yasunaka**, **S.-H. Kang**, **K.-H. Cho**, **K. Azetsu-Scott**, **W. J. Williams**, **E. Carmack**, **S. Torres-Valdés**, **T. Tyrrell**, **K. Edelvang**, **J. He,** and **H. M. Kassen**
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In this 2007 photo, the Swedish icebreaker *Oden* (left) runs a seismic cable in the wake of the Russian nuclear-powered icebreaker *50 Let Pobedy*, which is plowing through heavy ice north of Greenland. The Synoptic Arctic Survey team plans to launch a coordinated multinational campaign using icebreaker ships to gather data in the Arctic Ocean beginning in 2020. Credit: Leif Anderson

Since the International Polar Year (which actually lasted from 2007 to 2010), two truths about the changing Arctic have emerged. First, the ongoing rapid transformation of the Arctic environment will continue for decades, regardless of future global carbon dioxide (CO_2) emission levels. Second, the scientific challenges and consequences arising from this transformation are too large to be addressed by a single country alone and too complex to be properly understood through single-discipline research approaches.

These observations are interconnected and constitute a new reality for the Arctic [e.g., *Moore and Grebmeier*, 2018] that is far from understood and that presents challenges to stakeholders and decision-makers alike. Expanding fisheries, exploration, shipping, and tourism all must be managed well. But how do we best manage such enterprises when the environments in which they operate change faster than we can observe and understand with the present levels of commitment?

> *A coordinated, multinational pan-Arctic Ocean research effort using icebreakers and research ships is scheduled to become a reality in 2020 and 2021.*

Science-capable icebreakers, the backbone of polar marine science, have a long history of gathering the data necessary for answering such questions. These ships typically follow national priorities or research initiatives and traverse selected areas of the Arctic Ocean, obtaining full-depth ocean data that cannot be collected in any other way. Historic expeditions explored previously unsurveyed locations, but these expeditions were isolated regionally and temporally. Consequently, the inventory of Arctic observations is scattered, fractured, and incomplete.

In response to the need for a more complete data set, an international team of scientists with expertise in Arctic Ocean (AO) physical, carbon, and ecological systems gathered in 2015. At the inaugural Synoptic Arctic Survey (SAS) workshop at the Norwegian Embassy in Washington, D.C., this team explored how to coordinate a pan-AO research effort using icebreakers and research ships. This vision is scheduled to become a reality in 2020 and 2021, with a coordinated multinational campaign to gather ocean data in the Arctic.

A Pan-Arctic Approach

The inertia of the climate system and the long atmospheric residence time of CO_2 released by human activities drive the long-term transformation of the Arctic environment. A rapidly growing number of changes highlight the resulting challenges and consequences: freshening surface waters, seasonally altered light penetration into the ocean surface, dwindling sea ice coverage, increased energy and carbon exchange between the ocean and the atmosphere, ocean acidification, changes in planktonic and sympagic (sea ice–dwelling) communities that modify the biological carbon pump, altered migration patterns of fish, and northward range expansion of species.

Because existing AO studies show inherently large interannual variability in the properties they characterize, and because there are sparse baseline data on which to draw, the scientists at the 2015 workshop concluded that a synoptic Arctic survey of marine physical, carbon, and ecological systems is critically needed. The word synoptic, meaning “seen together,” denotes a broad approach that integrates information from many sources.

In heavy sea ice conditions, a powerful icebreaker becomes a necessity. This aerial view shows the smaller Swedish icebreaker *Oden* following the Russian nuclear-powered icebreaker *50 Let Pobedy*. Credit: Leif Anderson

Since 2015, the SAS group has held successive international workshops in Japan, Russia, Sweden, and the United States. And in June 2018, the group published a comprehensive, peer-reviewed **science plan** that includes information about the ships involved, proposed cruise tracks, and the measurements to be made. National teams have been established, and proposals have been submitted or funded. In October 2018, an SAS Scientific Steering Committee was established at a meeting at Woods Hole Oceanographic Institution.

The SAS group consensus is that our understanding of the AO will be greatly advanced through a pan-Arctic, multination, multiship campaign based on updated sampling and analytical protocols and strategically selected ship tracks. Ideally, the efforts making up this campaign will all take place during the same season and year (mostly in the summer and fall of 2020 but with some in the summer and fall of 2021). This approach will allow for a synoptic view of the changes occurring in the AO and provide integrated data sets to advance model development and prediction.

Facilitating Arctic Science and Education

The SAS science plan builds on one overarching question: What are the present state and major ongoing transformations of the Arctic marine system? The plan also poses nine supporting questions, three each in the focal areas of the SAS: physical oceanography, marine ecosystems, and the carbon cycle and ocean acidification. Addressing these nine questions, which illustrate the interconnected nature of AO systems, will provide input toward the overarching question.

With respect to fundamental drivers of ocean processes, including ocean circulation and the distributions of sea ice and water masses, we are looking to address the following: What are the present states of the heat and freshwater budgets in the AO? How are water mass circulation patterns responding to changes in forcing, and how are water mass sources responding? And to what degree does ice cover hamper light and gas exchange between the ocean and the atmosphere, and thereby influence biological production and carbon cycling?

These questions connect intimately to others about how Arctic marine ecosystems are shifting. For example, how do **primary production** and the flow of energy and biomass between various levels of a food chain vary across different regions of the AO? How will new species invade parts of the AO when **hydrographic** conditions change, and will native species be wiped out?

Ongoing environmental changes are also affecting the carbon cycle in the AO, the ocean's contribution to sustaining the global CO_2 ocean reservoir, and the rate of ocean acidification. Disappearing perennial sea ice is enabling a stronger flux of CO_2 and acidification in the northern Barents and Kara Seas (Figure 1), heralding changes that will occur over the entire AO under unabated global warming [*Harada*, 2016].

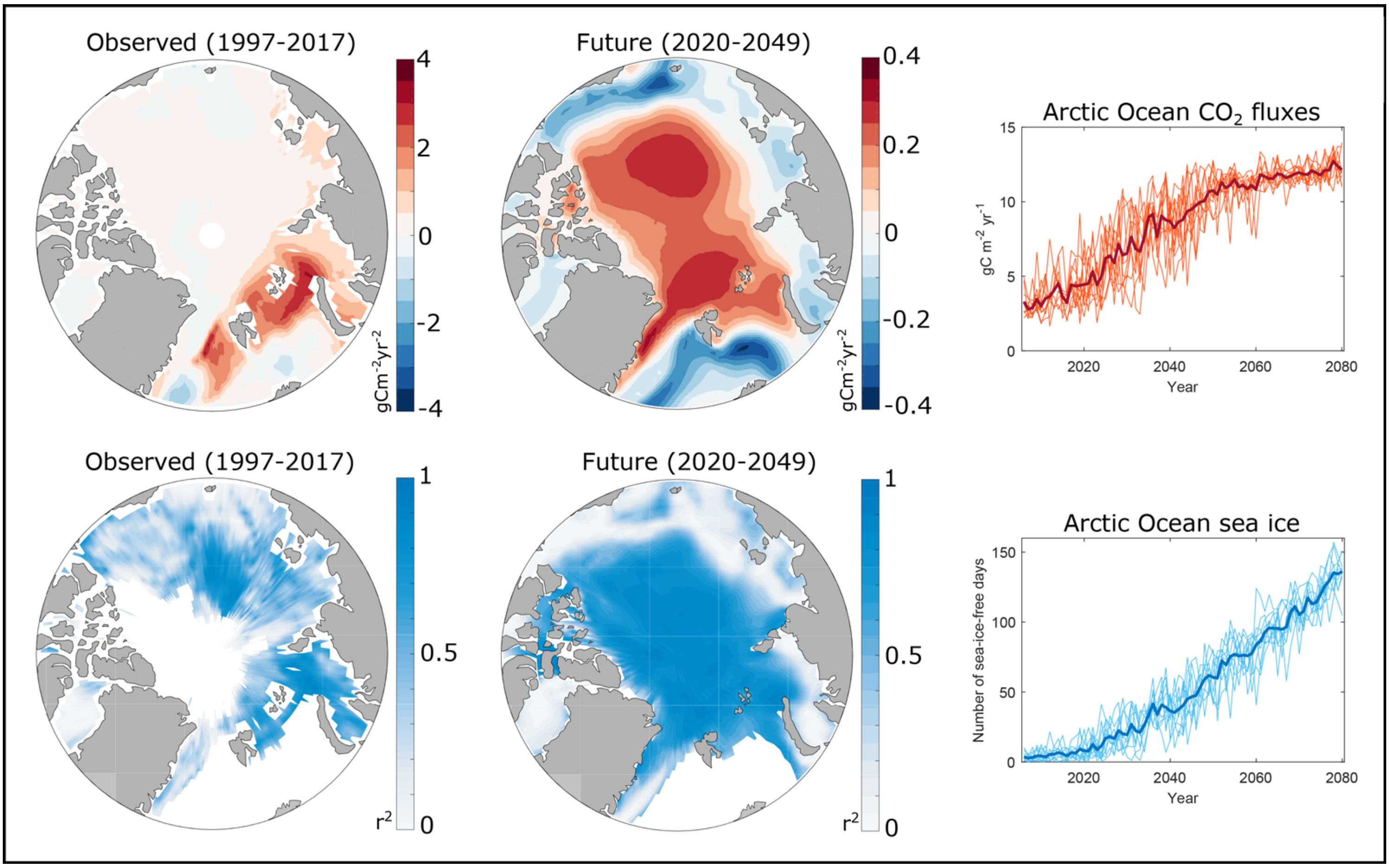

Fig. 1. Shown at left are the observed trends from 1997 to 2017 in annual mean air-sea CO_2 flux (top; grams of carbon per square meter per year; positive values represent fluxes into the ocean) [*Yasunaka et al.*, 2018] and the correlation (r^2) between CO_2 flux and number of ice-free days per year (bottom; higher values correspond to more correlation between open ocean days and CO_2 flux). Observed sea ice concentrations are from the National Snow and Ice Data Center [*Cavalieri et al.*, 1996]. The corresponding projections for the period 2020–2049 in the middle diagrams are based on the Community Earth System Model large ensemble [*Kay et al.*, 2015] under the Intergovernmental Panel on Climate Change's Representative Concentration Pathway 8.5 emission scenario (average of 10 ensemble members). At right are projected trends, extending to 2080, for area-integrated CO_2 fluxes (top) and sea ice–free days (bottom) north of 80°N. The bold curves are the ensemble means, and the thin curves represent individual ensemble members. An ice-free area is defined as having sea ice coverage of less than 15%.

The effort to answer these and other scientific questions will benefit our understanding of how the AO operates and will also help foster the next generation of Arctic researchers. The SAS will provide opportunities for early-career scientists to participate in the field effort, learn from their peers, and participate in subsequent workshops during the data synthesis period. In its efforts to facilitate education, it will also create new constellations of collaboration, a critical aspect of the needs of a new Arctic.

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SAS will not specifically address other important aspects related to Arctic change, such as socioeconomic questions. However, we foresee that new discoveries and better scientific understanding of the AO will influence policy and decision-making at national and international levels.

A Data Set Built to Last

It is of utmost importance that measurements made today are still useful as trusted benchmarks 100 years into the future. Thus, the SAS will adopt proven methods with established accuracies that rely on ship-based, in situ, high-quality measurements to quantify a wide range of ocean physical, carbon, and ecosystem characteristics.

SAS will also benefit, however, from ocean observing systems that are currently being revolutionized with the development of unmanned, high-tech platforms and sensors (e.g., sea ice-going Argo floats) and that are transforming our understanding of how the ocean works and evolves in concert with a changing climate. Thus, the data generated will also provide a unique and valuable validation for new technologies.

Salinity, temperature, oxygen, nutrients, and carbon chemistry are key determinants of ecosystem structure and function, and observing these core ocean characteristics will allow us to gauge ecosystem connectivity across the AO. The coordinated pattern of ship tracks spanning the entire AO planned by SAS also offers a unique opportunity to collect novel data types. One such novel data source, environmental DNA, is extracted from environmental samples (e.g., seawater) and contains information about multiple organisms. Other novel approaches will include a reference collection of biodiversity data across the AO—which will provide a baseline for future comparisons—as well as echograms from acoustic surveys that help illuminate plankton and **fish distributions**.

International Polar Leadership

> *Ultimately, we must know how the Arctic system functions to assess risks and to develop policies that allow effective management.*

The challenge of understanding the changing Arctic belongs to all countries. Various recent efforts have underscored a growing commitment to enhance international collaboration across nations. For example, China, Japan, and South Korea held a high-level dialogue about the Arctic in 2017 [***Ministry of Foreign Affairs of the People's Republic of China***, 2017]. Also in 2017, the eight nations of the Arctic Council signed **an agreement** to enhance scientific cooperation. This agreement entered into force in May 2018, and although it must be rigorously tested before it can be hailed as a success, it may provide a useful framework to stimulate and facilitate collaboration among polar researchers from different countries.

Ultimately, we must know how the Arctic system functions to assess risks and to develop policies that allow effective management. Providing this knowledge is the utmost motivation for SAS, because it will testify to the value of international collaboration and of furthering our scientific understanding of the AO.

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Author Information

Øyvind Paasche (oyvind.paasche@uib.no), Are Olsen, and Marius Årthun, Bjerknes Centre for Climate Research, University of Bergen, Bergen, Norway; Leif G. Anderson and Sten-Åke Wängberg, University of Gothenburg, Gothenburg, Sweden; Carin J. Ashjian, Woods Hole Oceanographic Institution, Woods Hole, Mass.; Jacqueline M. Grebmeier, University of Maryland, College Park; Takashi Kikuchi, Shigeto Nishino, and Sayaka Yasunaka, Japan Agency for Marine-Earth Science and Technology, Yokosuka; Sung-Ho Kang and Kyoung-Ho Cho, Korea Polar Research Institute, Incheon; Kumiko Azetsu-Scott, William J. Williams, and Eddy Carmack, Department of Fisheries and Oceans, Dartmouth, N.S., Canada; Sinhué Torres-Valdés, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany; Toby Tyrrell, University of Southampton, Southampton, U.K.; Karen Edelvang, National Institute of Aquatic Resources (DTU Aqua), Technical University of Denmark, Kongens Lyngby; Jianfeng He, Polar Research Institute of China, Shanghai Shi; and Heidi Marie Kassens, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany

13 November 2019: This article has been updated to clarify that interannual variability in Arctic Ocean data is not the same as noise in the data.

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