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The Changing Arctic Ocean

An Introduction to the Special Issue on the International Polar Year (2007–2008)

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Over the last few decades, the Arctic Ocean has experienced profound changes. Its summer sea ice is shrinking dramatically, both in thickness and extent. Ever warmer pulses of Atlantic water are circulating within the Arctic basins. Pacific waters are bringing in record amounts of oceanic heat. Freshwater storage in the Arctic Ocean is displaying considerable variability. There are early signs of ocean acidification, and some waters are already corrosive to carbonate minerals important to marine life. Surface air temperature and pressure fields are exhibiting patterns different from those of the last several decades.

Looking forward, modeling studies predict that the Arctic could become seasonally ice-free within a few decades, with profound implications. It seems inevitable that the Arctic Ocean itself will warm, with impacts on local oceanic processes and, coupled with alterations in freshwater cycling, consequences for global climate through Arctic-subarctic linkages. Findings from local studies suggest that significant fractions of the Arctic shelves—particularly in the western Arctic—could shift from benthic-dominated to pelagic-dominated ecosystems, placing growing stress on endemic populations. Arctic warming may also affect the global atmosphere's greenhouse gas inventory through altered CO_2 cycling or methane hydrate stability, whose possible magnitudes are still only poorly known. In addition to the direct effects on local and global climate, reduced sea ice conditions are already opening the Arctic Ocean to resource exploration and extraction, development of new shipping routes, and increased tourism. These activities are focusing attention on maritime safety and national and international security. We must enhance our fundamental knowledge of the Arctic system and improve our predictive skills to better guide future policy decisions. The major changes underway in the Arctic impact marine ecosystems as well as the people of the North who depend on them and are intimately linked to our global climate system. Now is clearly an important time to keep a finger on the pulse of the Arctic Ocean.

These recent changes and the possibility of new discoveries in the under-observed polar regions motivated intense international observational efforts in the Arctic and Antarctic during the International Polar Year (IPY) of 2007–2008. IPY operations were conducted until 2009 to allow observation of complete annual cycles in both the Arctic and the Antarctic. National and international efforts were organized by the International Council for Science (ICSU) and the World Meteorological Organization (WMO), and coordinated by an International IPY Programme Office. This most recent IPY marks the fourth time that the world community has gathered its scientific expertise to assess the state of the Arctic, with previous efforts taking place in 1882–1883, 1932–1933, and 1957–1958 (http://ipy.arcticportal.org/about-ipy). The six main research themes that united this latest effort focused on polar region status, changes, global linkages, new frontiers, unique vantage points, and human dimensions (see ***Carlson***).

Even at this comparatively early stage, it is clear that the recent IPY significantly enhanced our understanding of Arctic and Antarctic systems. As we outline below, this special issue of *Oceanography*—The Changing Arctic Ocean—showcases some of the scientific advances and illuminates the considerable international investments in the 2007–2008 IPY. The volume brings together new and diverse Arctic findings, stretching across and integrating many disciplines and including the human dimension of the Arctic. The articles are aimed not just at Arctic experts, but also at those unfamiliar with the Arctic—given that an important aspect of this IPY is bringing polar regions to those not intimately involved in them.

You will find herein that certainly the most sustained direct human engagement in the Arctic is reflected in the traditions and knowledge of the local Arctic people (***Fienup-Riordan and Carmack***). Alongside this appreciation of change over generations, geological investigations provide a longer-term perspective of regional changes. ***O'Regan et al.*** provide a current synthesis of what is known of the Arctic Ocean over the past 112–140 million years as it transitioned from a warm, ice-free, land-locked sea to the cold, inhospitable environment that it is today. ***Polyak and Jakobsson*** document the development of the modern oceanographic circulation features—the Transpolar Drift and the Beaufort Gyre—within the last 0.5 to 0.7 million years. ***Jennings et al.*** discuss how the retreat of ice from Nares Strait, in northern Baffin Bay, led to the reconnection of the Arctic and the Atlantic Oceans during the warming following the Last Glacial Maximum, approximately 10,000 years ago, while ***St-Onge and Stoner*** reveal remarkable changes in Earth's magnetic field over the past 400 years.

Leading up to and through the recent IPY, extensive resources have also been aimed at documenting and understanding the "vital parameters" of the Arctic Ocean. Satellites and drifting buoys allow an updated assessment of sea ice state and changes (***Perovich***). Through collective, determined national efforts, we gained the first synoptic assessment of exchanges between the Arctic and the rest of the world's ocean, as measured by long-term (multiyear) mooring arrays in key gateways (***Beszczynska-Möller et al.; Münchow et al.***). Multiyear ship-based observations reveal dramatic changes in the distribution and properties of waters of the main Arctic basins (***McLaughlin et al.***), and satellite and modeling data highlight unusual patterns in the atmospheric forcing of the system (***Overland***). New tools, such as autonomous systems measuring ocean physics and relaying data via satellite while drifting with the ice (***Toole et al.***), give us a fresh, broad-scale assessment of Arctic Ocean change. As our understanding of the system improves, we can draw on experience from lower latitudes to foresee increased impacts of wind-driven mixing and internal waves in the currently quiescent Arctic Ocean (***Rainville et al.***). Arctic-wide international model intercomparisons are synthesizing these various field efforts to produce a collective best assessment of Arctic circulation simulations to enhance their ability to understand Arctic physical change (***Proshutinsky et al.***).

The impacts of these changes are multidisciplinary. Sea ice has historically been viewed as a barrier to heat and mass transport, but that view is now being revised to acknowledge its active participation in polar biogeochemical cycles (***Loose et al.***). As such, the Arctic marine carbon cycle and exchange of CO_2 between the ocean and atmosphere appear particularly sensitive to physical and biological changes (*Bates et al.*). Understanding this complexity requires conceptual models of biogeochemical carbon cycling and climate warming at various scales (*Wassmann and Riegstad*). Regional differences in summer distributions of marine animals in the western Arctic Ocean will likely reflect a new balance between northward-moving subarctic fauna, in juxtaposition with Arctic animals that are sea ice dependent, and resilient Arctic species (*Sigler et al.*). Thus, the diversity of Arctic Ocean biota is reflected in its species inventories (*Bluhm et al.*), which show interannual and interdecadal variability.

This special issue includes short reports (sidebars) to highlight some of the extraordinary aspects of IPY, including the extreme challenges of the environment (*Melling; Brigham-Grette et al.*), the particular emphasis on a new generation of polar researchers and an informed public (*Baeseman and Pope; Roof et al.; Richter-Menge; Carlson*), the development of new technologies to study polar regions (*Smethie et al.; Aagaard and Johnson*), and glimpses of some of the work that is growing from the seeds of IPY and enabling future polar research (*Brigham-Grette et al.; Gascard; Edwards and Oliver*).

The science and its dissemination as described in this volume set the stage for the development of sound policy decisions both today and in the decades to come. The challenge we face is developing a policy framework that will balance human interests in the Arctic against the protection of this unique environment. Continued research will provide the mechanism to ensure the validity of evolving policy decisions at national and international levels (*Moran and Farrell*).

One major outcome of this IPY is recognition of the necessity for the world to observe the Arctic routinely, adapting and employing technology now common at lower latitudes to meet the particular challenges of the North. We have a dream for an Arctic observing system where gliders equipped with autonomous sensors patrol the Arctic Ocean, collecting information on an array of ocean properties, ferrying data from lone, heavily instrumented subsurface moorings to land stations or floating ice-based observatories, and beaming all the data back to any computer in the world. Autonomous robotic vehicles undertake seafloor mapping and subsurface seismic work to guide seafloor-drilling systems that extract sediment cores from sites currently inaccessible to surface drilling to provide insights into the long-term geologic history of this largely unexplored region. Ice-drifting observatories are outfitted with systems below, inside, and above the sea ice to collect information on water, ice, and air. An international science team in a virtual control room compiles these sources of Arctic Ocean data, mines weather and ocean prediction models, and redirects glider missions to critical areas of the ocean via satellite connections. The various platforms carry autonomous sensors to observe geological, physical, chemical, and biological processes, all properly calibrated and validated, to enhance understanding of their linkages and feedbacks at higher temporal and spatial resolution. The Arctic observing system services the world with peaceful, sustainable activities and connects classrooms around the globe to an important and inspiring part of our planet.

It is a dream, but not an inaccessible one. The technological components exist and are in play in the lower-latitude oceans—the transition to polar environments is a difficult, multifaceted challenge currently under consideration. We can and should do more with the necessary resources, and we will. Our immediate goal thus should be to define what questions we, as a global community, must address in these times of rapid Arctic change, and from this inquiry find an efficient and economically responsible way forward to connect knowledge to action.

We hope this special issue will bring you an appreciation of the multifaceted face of research in the Arctic Ocean, its challenges, its recent successes, and views toward the future.

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