standing committees, which are elected by representatives of U.S. member institutions.

Under separate funding from the NSF Division of Earth Sciences, scientists in the COMPRES community are pursuing three grand challenge collaborative research programs: growth of large synthetic diamonds by chemical vapor deposition, rheology of Earth materials, and elasticity of Earth materials—all at high pressures and temperatures.

While these grand challenge programs are formally independent of the COMPRES core grant, they are intellectually related, as they provide prime examples of the scientific problems that can be addressed using the community facilities operated by, and the technological developments funded by, COMPRES.

Communication within the mineral physics community includes monthly letters from the president, quarterly newsletters, an active Web site (http://www.compres.us), and an annual meeting. The 2005 annual meeting of COMPRES was held in New Paltz, New York, on 16–19 June and attracted 108 participants; it included focus sessions on the mantle, the core, and geochemical evolution, with keynote talks followed by group discussion. The meeting also featured reports from the Community Facilities operations and Infrastructure Development projects and poster presentations highlighting some exciting recent scientific achievements.

Acknowledgments

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Arctic Ocean Study: Synthesis of Model Results and Observations

PAGES 368, 371

Model development and simulations represent a comprehensive synthesis of observations with advances in numerous disciplines (physics; mathematics; and atmospheric, oceanic, cryospheric, and related sciences), enabling hypothesis testing via numerical experiments. For the Arctic Ocean, modeling has become one of the major instruments for understanding past conditions and explaining recently observed changes.

In this context, the international Arctic Ocean Model Intercomparison Project (AOMIP, http://fish.cims.nyu.edu/project_aomip/overview.html) has investigated various aspects of ocean and sea ice changes for the time period 1948 to present. Among the major AOMIP themes are investigations of the origin and variability of Atlantic water (AW) circulation, mechanisms of accumulation and release of fresh water (FW), causes of sea level rise, and the role of tides in shaping climate.

This article presents several hypotheses based on the synthesis of model results with observations, and it delineates major directions for modeling studies during the International Polar Year (IPY) 2007–2008.

Atlantic Water Circulation

The puzzle of AW circulation at 200–800 m depth has been studied by generations of Arctic scientists. AW penetrates into the Arctic via Fram Strait and St. Anna Trough (Barents Sea). Under extensive surface cooling, it sinks to intermediate depths and forms the relatively warm Atlantic Layer ($\Theta > 0°C$, where Θ represents potential water temperature). This layer is covered by low-density surface waters and is thus prevented from undergoing heat and momentum exchange with the atmosphere.

The most widely accepted theory postulates that AW circulates counterclockwise in the Arctic basins (Figure 1). Among AOMIP models, the simulated AW circulation differs in intensity and sense of rotation: Some models show anticyclonic and some support cyclonic circulation patterns. AOMIP has examined the underlying causes for such inconsistency, identified factors influencing AW behavior, and formulated important implications from these studies.

In an idealized model, J. Yang (Woods Hole Oceanographic Institution; see the AOMIP Web site for all article references) examined how flux of potential vorticity (PV) at the Arctic Ocean boundaries affects the AW circulation direction. Because AW is not directly forced by wind stress, the PV integral over the Arctic basins yields a balance between the net lateral PV inflow through straits and PV dissipation along the boundary. When a layer between two surfaces of constant density receives net positive (negative) PV through inflow or outflow, the circulation becomes cyclonic (anticyclonic) so that friction can generate a flux of negative (positive) PV to satisfy the integral balance.

A significant implication is that the hydrographic structure and transport of AW entering or leaving the Arctic are important for setting the pattern and direction of AW circulation, and that long-term, high-resolution, year-round monitoring of boundary throughflow is needed for understanding and predicting AW characteristics.

A different idea by G. Holloway (Institute of Ocean Sciences, Sidney, Canada) is that eddy generation of entropy drives cyclonic boundary currents around the Arctic basins, implying that the cyclonic circulation should be relatively persistent even under changing boundary conditions.

Furthermore, AOMIP numerical experiments reveal that excessive mixing leads to a breakdown or reversal of AW circulation, because a strong surface anticyclonic Beaufort Gyre can weaken the cyclonic AW flow at mid-depth. It was found that the AW circulation has a pulsating character expressed in the propagation of warm and cold events, varying on seasonal to decadal timescales. Collaborating with the Arctic/Subarctic Ocean Fluxes (ASOF) and Nansen and Amundsen Basins Observing System programs, AOMIP models are being used to elucidate the predictive potential for AW flow. Theoretical and modeling studies are also used to identify specific conditions sufficient to reverse AW circulation.

Mechanism of Fresh Water Accumulation and Release

The meridional overturning circulation in the Atlantic Ocean is significantly influenced by FW fluxes from the Arctic Ocean. The international programs Community-Wide Hydrological Analysis and Monitoring Program (CHAMP) and ASOF were organized with the major goal of investigating these fluxes and the FW balance of the Arctic Ocean. As a participant in CHAMP, A. Proshutinsky, lead author of this article and AOMIP principle investigator, proposed and demonstrated that the Arctic Ocean can accumulate a significant amount of FW during anticyclonic circulation regimes and release this water to the North Atlantic during cyclonic regimes.

The Beaufort Gyre of the Canada Basin contains approximately 45,000 km^3 of FW, a volume 10–15 times larger than the total annual river runoff to the Arctic Ocean, and larger than the amount of FW stored in the sea ice. A release of only 5% of this FW is enough to cause salinity anomalies in the North Atlantic, as observed in the 1970s. Because

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the Beaufort Gyre is the major reservoir of FW stored in the Arctic Ocean, an observing system was deployed there in 2003 (http://www.whoi.edu/beaufortgyre/), and analyses of model results were conducted to help validate Proshutinsky's hypothesis.

An AOMIP model (Figure 2) well reproduces FW dynamics from the 1950s to the 1980s, but it is surprising that the model results do not coincide with observations after the 1980s. These observations indicate an increase and shift of the FW maximum toward Canada. Despite these differences, the AOMIP studies have allowed the formulation of several conclusions relevant to the ASOF and CHAMP projects:

- The FW content of the Arctic Ocean (water, snow, and ice) experiences significant seasonal, interannual, and decadal changes. Monitoring FW fluxes only along the Arctic's lateral boundaries is inadequate for a complete understanding of the variability of the FW budget.
- In addition to FW fluxes through boundaries, observations of sea ice thickness, surface FW fluxes, and ocean salinity are critically lacking and need monitoring in the Arctic.
- Variability of river runoff is too small relative to sea ice and liquid FW reservoir changes to significantly influence processes in the North Atlantic at interannual and decadal timescales.

Causes of Sea Level Rise in the Arctic Ocean

Many AOMIP models have notable difficulties reproducing seasonal sea level variability. The major cause of this problem is the omission of sea level variability associated with changes in atmospheric pressure and water volume fluxes from river runoff. The model results are nevertheless useful as they allow for the study of the causes of sea level change in the Arctic Ocean due only to changes in water temperature and salinity.

AOMIP experiments show that these changes have contributed approximately 0.064 cm/yr to sea level rise. This is smaller than the rate of global ocean thermal expansion estimated in the Third Intergovernmental Panel on Climate Change assessment report.

In the Arctic Ocean, the combination of freshening Arctic seas with warming and salinization of the AW layer led to the rise of sea level along coastlines and the fall of sea level in the central ocean. Sea surface height is an important field for validating AOMIP models. Unfortunately, over the Arctic Ocean this parameter is still unavailable with precise accuracy from satellite altimetry.

Tides and Arctic Climate

Although evidence indicates that tides play a role in establishing environmental characteristics, this effect has been largely ignored in Arctic climate modeling studies because tidal effects were thought to be negligible. It is hypothesized that Arctic climate is substantially affected by tidal mixing and ice motion, whereas large-scale ocean models do not, in general, have tidal forcing, do not reproduce

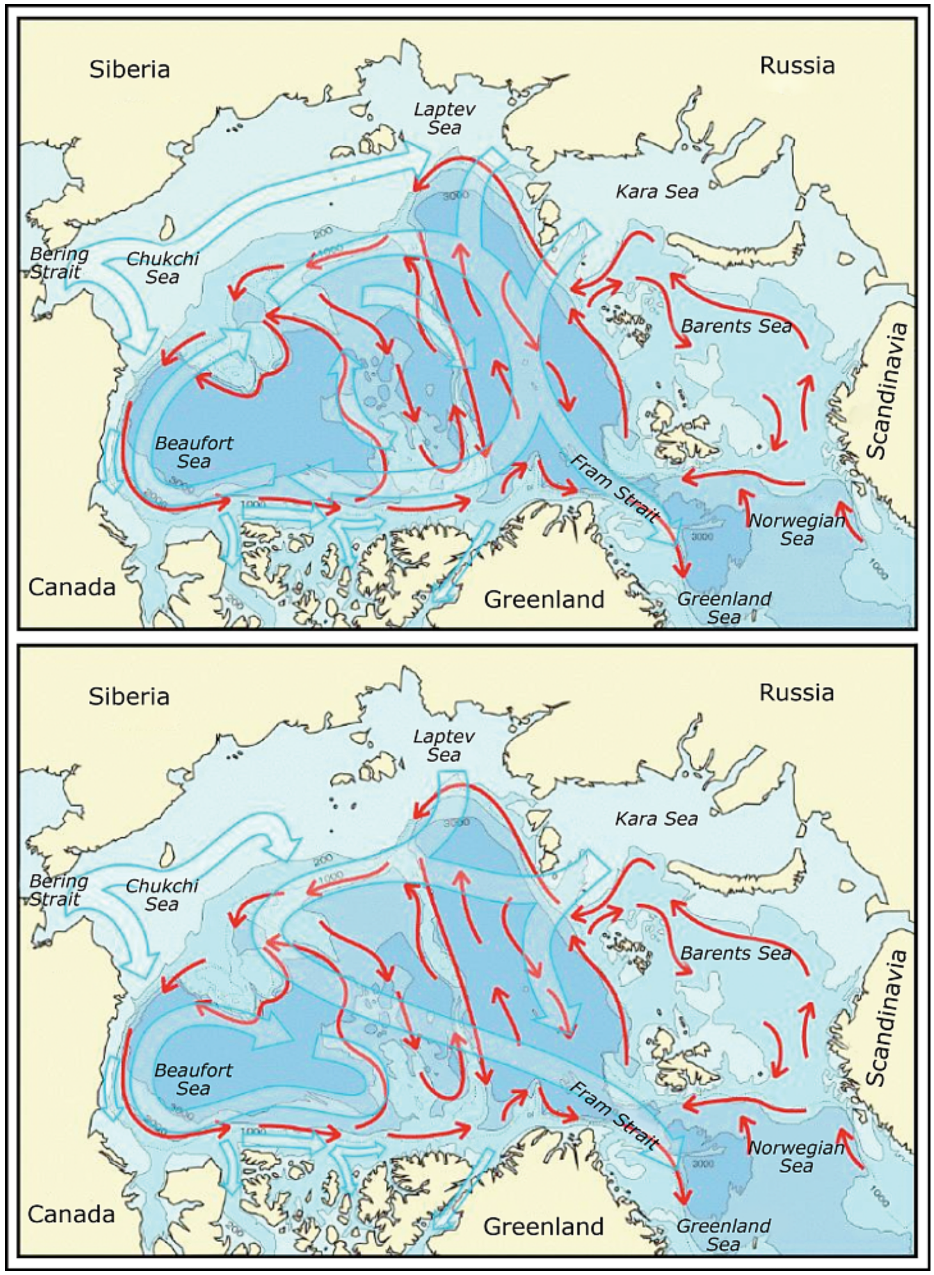

Fig. 1. Circulation patterns of the Arctic Ocean. Two regimes of upper layer circulation (top, anticyclonic; bottom, cyclonic) are shown in wide blue arrows and are well reproduced by all AOMIP models. For Atlantic water (red arrows), observations suggest cyclonic circulation, with which some AOMIP models agree. Other models show anticyclonic Atlantic water motion.

tide-ice interactions, and do not resolve tidal energy dissipation. Consequently, an Arctic system simulated without tides may lack realistic heat fluxes among ocean, ice, and atmosphere.

Tidally-induced ice motion opens and closes areas of open water, generating thick ice via periodic ridging and new ice in exposed surface waters. This process changes surface albedo and regulates brine fluxes and convection, thereby influencing ocean temperature, salinity, and circulation.

AOMIP studies have assessed Arctic tidal effects on the long-term climate of the ocean and ice system. Output from two-dimensional tidal models is used to parameterize vertical mixing, open water production, and the mobility of ice. Results include loss of heat from the AW layer leading to ice reduction, offset by higher ice growth due to ice cover fracturing. W. Hibler (University of Alaska Fairbanks) is developing a more realistic formulation of ice-ocean coupling that includes tides; preliminary results show that ice-tide interaction is significant. With improved model physics, AOMIP plans to investigate the tidal role in shaping Arctic climate.

AOMIP and the International Polar Year

Investigation of Arctic Ocean variability is significantly limited by the paucity of observational data caused by severe Arctic climate conditions, sea ice cover, remoteness, and cost. This limitation will be partly relieved during the 2007–2008 IPY. Historically, IPYs implement new technologies that become sources of vastly increased data from polar regions. For

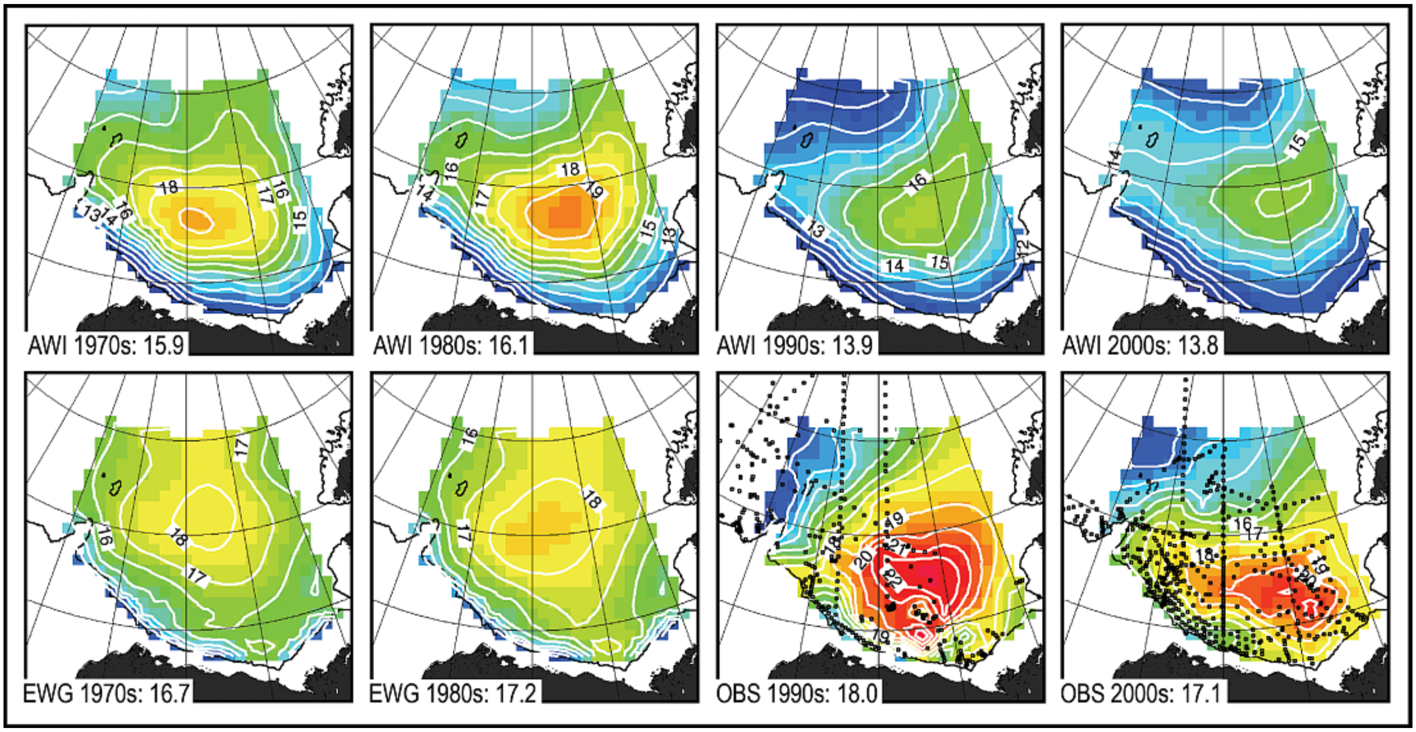

Fig. 2. Summer fresh water content (meters) averaged over decades. The top panel is from an AOMIP model; the bottom panel is based on temperature and salinity fields from the Environmental Working Group Atlas of the Arctic Ocean for the 1950s to the 1980s, and on hydrographic stations (black dots) in the 1990s and 2000s.

instance, the 2007–2008 IPY will have access to observing technologies almost undreamed of in 1957–1958 and will produce observations needed for model improvement, calibration, and validation.

On the other hand, the temporal resolution of IPYs is insufficient to draw robust conclusions regarding oscillations, trends, and natural and anthropogenic change. This information gap can be bridged by numerical modeling.

Model-based experiments can be used at different IPY stages, assisting in the design of the observational network (see recommendations formulated above) and subsequently in diagnosing environmental conditions. Data assimilation techniques will play a major role in reaching these IPY goals. After the IPY, modeling will be used for data reanalysis, near-future predictions, and studies of Arctic change. Employing a diverse suite of Arctic models for internationally coordinated numerical experiments will ensure that the highest-quality and most robust model results are available for an effective contribution to IPY 2007–2008 design, execution, and analysis.

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