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The North Pole Region as an Indicator of the Changing Arctic Ocean: The Need for Sustaining Observations

James Morison,[1,2] Jeremy Wilkinson,[3] Matthew Alkire,[1] Frank Nilsen,[4] Igor Polyakov,[5] William Smethie, Jr.,[6] Peter Schlosser,[6] Frédéric Vivier,[7] Antonio Lourenco,[7] Christine Provost,[7] Jacques Pelon,[7] Cecilia Peralta Ferriz,[1] Michael Karcher,[8,9] Benjamin Rabe[8] and Craig Lee[1]

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ABSTRACT. Sustained observations of environmental conditions in the North Pole region are critical to understanding the changing Arctic Ocean. The Transpolar Drift conduit of sea ice and freshened upper-ocean waters across the Arctic Ocean passes over the North Pole region on its way to the North Atlantic through Fram and Nares Straits. The exported ice and freshened water stratifies the sub-Arctic seas and limits the vertical convection that ventilates the world ocean. Key variables such as ice thickness, bottom pressure, and hydrography in the North Pole region are thus sensitive indicators of changes over the whole Arctic Basin and how these affect the global ocean. Drifting buoys installed in the North Pole region by Great Britain, Canada, France, Germany, Japan, and the U.S. address what would otherwise be a dearth of ocean, ice, and atmosphere observations in the central Arctic. A suite of satellite remote sensing tools such as ICESat/ICESat-2 from the U.S., GRACE from the U.S. and Germany, and CryoSat2 from the European Union extend the conclusions from central Arctic Ocean in situ observations to other regions. Detecting and understanding climate change requires observations over decadal and longer scales. We propose an international program as the key to sustaining these observations in the North Pole region. Such an international program would help immeasurably by 1) facilitating financial sharing of the burden of long-term measurements among several nations, (2) reducing logistics costs through economies of scale, and 3) providing a buffer against national funding, logistics, and geopolitical difficulties.

Key words: Arctic Ocean; North Pole; sustained observations; climate; international effort

RÉSUMÉ. L'observation continue des conditions environnementales dans la région du pôle Nord est essentielle à la compréhension des changements qui se manifestent dans l'océan Arctique. Le courant de la dérive transpolaire déplace la glace de mer et les eaux rafraîchies des couches supérieures de l'océan à travers l'océan Arctique. Il passe par la région du pôle Nord en direction de l'Atlantique Nord en traversant les détroits de Fram et de Nares. La glace ainsi exportée et l'eau rafraîchie stratifient les mers subarctiques et restreignent la convection verticale qui aère l'océan mondial. Des variables-clés comme l'épaisseur de la glace, la pression de fond et l'hydrographie de la région du pôle Nord constituent des indicateurs sensibles des changements dans l'ensemble du bassin arctique ainsi que des indicateurs de leur incidence sur l'océan mondial. Sans les bouées dérivantes installées dans la région du pôle Nord par la Grande-Bretagne, le Canada, la France, l'Allemagne, le Japon et les États-Unis, il y aurait une pénurie d'observations océaniques, glaciaires et atmosphériques dans l'Arctique central. Une série d'outils de télédétection satellitaire comme le ICESat/ICESat2 des États-Unis, le GRACE des États-Unis et de l'Allemagne et le CryoSat2 de l'Union européenne permet d'appliquer les conclusions des observations de l'océan Arctique central faites sur place à d'autres régions. La détection et la compréhension du changement climatique nécessitent des observations à l'échelle décadaire ou plus. Nous proposons un programme international en guise de solution pour poursuivre ces observations dans la région du pôle Nord. Un tel programme international aiderait incommensurablement en 1) facilitant le partage financier du fardeau des mesures à long terme entre plusieurs pays; 2) en réduisant les coûts logistiques grâce aux économies d'échelle; et 3) en offrant une protection contre le financement national, la logistique et les difficultés géopolitiques.

Mots clés : océan Arctique; pôle Nord; observations continues; climat; effort international

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[1] Applied Physics Laboratory, University of Washington, 1013 NE 40th St., Seattle, Washington 98105-6698, USA
[2] Corresponding author: morison@apl.washington.edu
[3] Scottish Marine Institute, Oban, Argyll, PA37 1QA, United Kingdom
[4] University Centre in Svalbard, PO Box 156, N-9171 Longyearbyen, Norway
[5] International Arctic Research Center, University of Alaska Fairbanks, PO Box 757335, Fairbanks, Alaska 99775, USA
[6] Lamont-Doherty Earth Observatory, 129 Comer, PO Box 1000, 61 Route 9W, Palisades, New York 10964-1000, USA
[7] Université Pierre et Marie Curie, 4 Place Jussieu, 75252 Paris cedex 05, France
[8] Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research, Postfach 120161, 27515 Bremerhaven, Germany
[9] Ocean Atmosphere Systems GmbH, Tewessteg 4, D-20249 Hamburg, Germany

BACKGROUND

Sustained observations of environmental conditions in the North Pole region (at a minimum north of 84˚ N) are critical to understanding the ongoing changes to Arctic Ocean sea ice and circulation, and their connections with global climate. Vital environmental processes occur in every region of the Arctic Ocean, yet the North Pole region is unique in that its ocean properties are a cumulative indication of variability over the whole Arctic Ocean. The Transpolar Drift is the main conduit of sea ice and freshened upper ocean waters across the Arctic Ocean, passing over the North Pole region just before passing through the Fram and Nares Straits on its way to the North Atlantic. The exported ice and freshened water from the Transpolar Drift stratifies the sub-Arctic seas and limits the vertical convection of heat, which is a key element in global climate change. As a result, conditions in the region of the Pole are sensitive indicators of changes over the whole Arctic Basin and how these affect the global ocean.

The average ice thickness near the North Pole is highly correlated with the basin-average ice thickness (Lindsay and Zhang, 2006). Ocean bottom pressure (OBP) measured at the Pole is highly correlated with the dominant mode of Arctic Ocean mass change (Peralta-Ferriz et al., 2014b). This basin-wide mass change appears to be forced by northward winds in the Nordic Seas and Fram Strait in what is arguably a lower frequency expression of the sub-monthly mass variation that dominates wintertime Arctic Ocean bottom pressure (Peralta-Ferriz et al., 2011). Annual repeat hydrochemistry stations at the Pole have revealed the contributions from sea ice melt, runoff and precipitation, and the Pacific Ocean to freshwater flux in the Transpolar Drift toward the North Atlantic (Alkire et al., 2015).

The position and orientation of the Transpolar Drift provide a strong indication of whether the Arctic Ocean circulation is in an anticyclonic (clockwise) state dominated by a large Beaufort Gyre, or a cyclonic (counterclockwise) state in which the anticyclonic Beaufort Gyre is balanced against cyclonic circulation on the Eurasian side of the Arctic Ocean (Sokolov, 1962) (Fig. 1, chart inset). The cyclonic mode has been associated with a counterclockwise shift in the orientation of the Transpolar Drift, diversion of Eurasian runoff to the Canada Basin, and high levels of the wintertime Arctic Oscillation (AO) index (Morison et al., 2012) (Fig. 1, chart inset). Measurements of ocean temperature, salinity, density, and chemical constituents in the North Pole region tell us the strength and direction of the current in the Transpolar Drift as well as the resulting heat and freshwater transports toward Fram Strait. The position of the current is thus an indication of the relative strength of anticyclonic and cyclonic circulations in the Arctic Ocean (Fig. 1).

The U.S. National Science Foundation Switchyard, North Pole Environmental Observatory (NPEO), and Nansen and Amundsen Basin Observing System (NABOS) have established hydrographic sections consisting of stations at 1˚ intervals over the Pole along 90˚ W and 90˚ E, which reveal changes in the geostrophic water velocity of the Transpolar Drift that cannot be resolved by buoys moving with the Drift (Fig. 1). These stations indicated a current core of about 2 cm s^{-1} magnitude from 2005 to 2015, roughly centered on the North Pole, but with significant structure and inter-annual variability. The position of the velocity core is shifted towards Canada along 90˚ W when the previous winter (November to April) AO index is high (e.g., 2007, 2008, 2011, 2012) in qualitative agreement with the cyclonic-anticyclonic paradigm (Morison et al., 2012). Unfortunately, there was no hydrographic sampling in 2009, a year of high AO and strong export of freshwater from the Arctic Ocean to the Atlantic (de Steur et al., 2013). The velocity core tends to shift toward the 90˚ E side of the Pole when AO is low (e.g., 2005, 2010, 2013), as we expect under an expanded anticyclonic Beaufort Gyre in the Canada Basin.

Drifting buoys installed in the North Pole region address what would otherwise be a nearly complete lack of near-surface ocean, ice, and atmosphere observations in the central Arctic Ocean. The International Arctic Buoy Program (IABP) is the source of many of the buoys measuring surface atmospheric properties and ice drift. Data from these buoys have contributed to countless successful studies. However, the IABP usually depends on shorter-term projects for buoy deployment, sometimes with the shorter-term projects installing their own buoys making additional measurements. These efforts have a distinctly international character. Examples include drifting Polar Ocean profile systems from Japan and Canada (Kikuchi et al., 2004, 2005) as well as ice-tethered profilers, ice mass balance, and Arctic Ocean flux buoys from the U.S. (Timmermans et al., 2011). Investigators from France's University of Pierre and Marie Curie (UPMC) have recently been deploying a new type of ice-mass and ocean flux buoy (Vivier et al., 2016). In collaboration with investigators from the Norwegian Polar Institute and Scottish Association for Marine Science, UPMC has been deploying an Ice, Atmosphere, Arctic Ocean Observing System (IAOOS; see IAOOS Equipex, 2017) that includes an ocean profiler and advanced ice-mass balance and radiometer buoys. The Polar Science Center in the U.S. works with the IAOOS group to deploy NPEO web-cam buoys that give visual evidence of the seasonal ice melt progression (Inoue et al., 2005; Perovich et al., 2008). The German Frontiers in Arctic Marine Monitoring (FRAM) effort, led by the Alfred Wegener Institute and the Helmholtz Foundation, is developing buoy technology and data streams within an integrated approach to observe parameters in the atmosphere, sea ice and snow, and the upper ocean using autonomous drifting ice-tethered platforms. These observations will contribute to the international observing efforts in the Transpolar Drift.

An international suite of satellite remote sensing tools—such as the Ice, Cloud, and Land Elevation Satellite (ICESat) from the United States, the Gravity Recovery

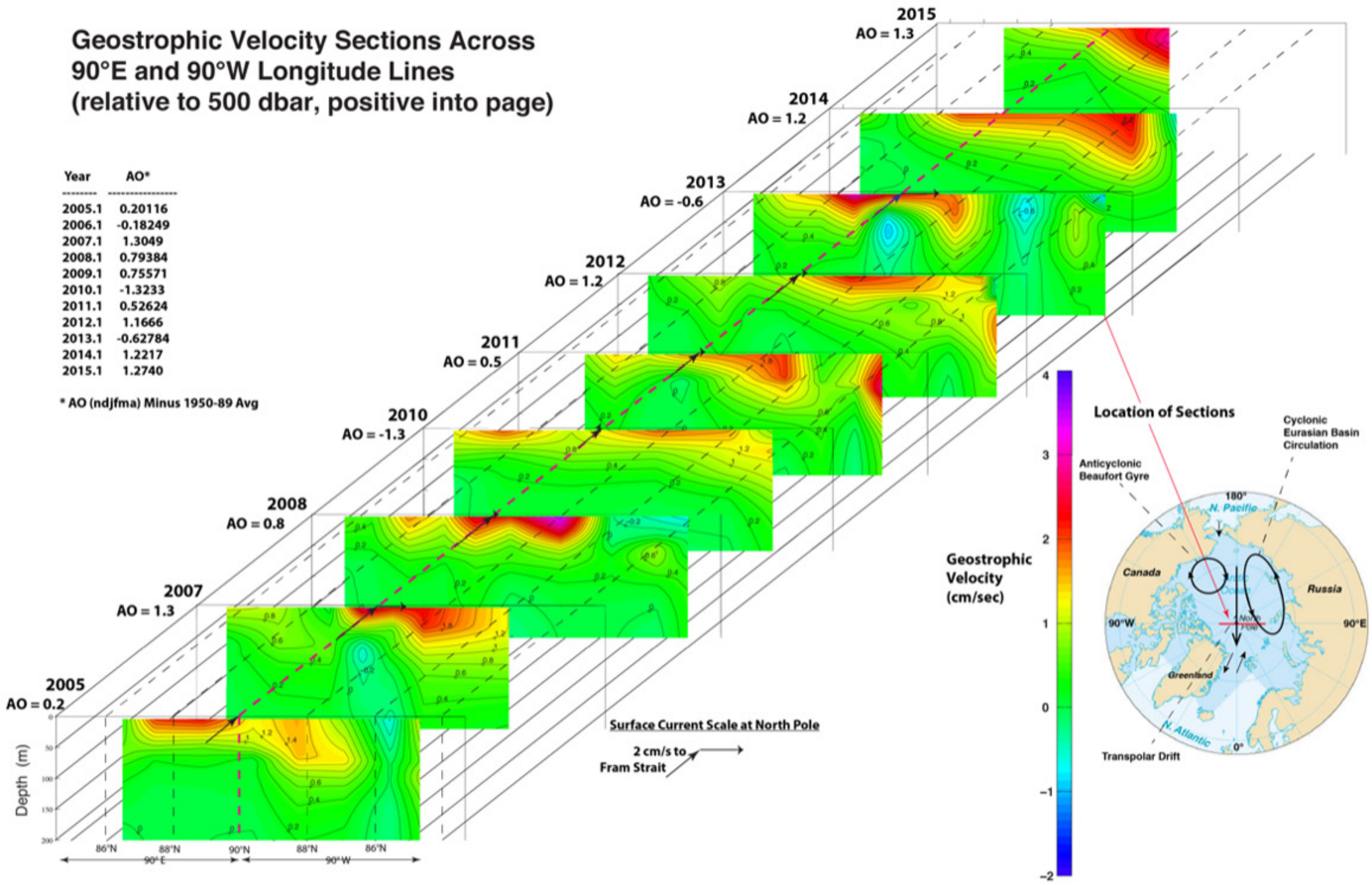

FIG. 1. Geostrophic velocity across 90˚ W and 90˚ E longitude sections (see chart) from 2005 to 2015. These velocities are computed from dynamic heights relative to 500 dbar derived from Switchyard, NPEO, and NABOS conductivity, temperature, and depth (CTD) profiles. Positive velocities are into the page, nominally toward Fram Strait. Transpolar drift in the ocean is the positive lens in the upper 100 m, centered near the North Pole (90˚ N on the x-axis). The winter (November to April) AO index minus the average winter AO for 1950–89 is also shown for each year. Arrows show surface geostrophic current at the Pole into and along the section.

and Climate Experiment (GRACE) from the United States and Germany, and CryoSat-2 from the European Union—extend the conclusions from in situ observations of the North Pole region to other regions. Furthermore, even though all satellite systems have a data hole of some size at the Pole, the high concentration of satellite passes through the larger North Pole region provide many opportunities for ground truth comparisons between satellite remote sensing and in situ observations. For example, satellite altimeter-derived dynamic ocean topography can be validated using hydrography-determined dynamic heights in the North Pole region (Kwok and Morison, 2011; [ICESat], 2016 [CryoSat-2]). The hourly in situ OBP measurements at the North Pole extend the frequency range and validate the monthly average OBP from GRACE (Peralta-Ferriz et al., 2014a).

NEED FOR INTERNATIONAL EFFORT TO SUSTAINING OBSERVATIONS

Nearly all the research efforts noted above are aimed at understanding the role of the Arctic Ocean in climate variability. The North Pole region data have been a regular contribution to the State of the Climate reports from the American Meteorological Society (NOAA-NCEI, 2015). Process studies and detection of interannual changes are helpful for this research. However, detecting and understanding climate change absolutely require observations at decadal and longer scales, which is lacking in the Arctic Ocean research community and is now the crux of the challenge for future research. The investigations described above were nearly all conducted with the support of basic research funding agencies from around the world, which typically provide funding through grants and programs that last only a few years per project.

In the future, national funding efforts such as the U.S. National Science Foundation (2007) Arctic Observing Network and the EU Integrated Arctic Observing Network (EC, 2015) are positioned to support long-term observations. However, these agencies are also under some obligation to fund new investigators with new projects. Thus, it can be difficult for them, particularly given the large logistics costs of operating in the North Pole region, to sustain consistent repeat observations over several decades, which is required for climate science. Given this fundamental problem, how might we build a program of sustained observations in the North Pole region from what has been 20 years of short-term research observations?

We propose that an international program is a key element in sustaining observations in the North Pole region at decadal and longer time scales. Examples of such programs are the IABP, which provides support to the World Climate Research Program (WCRP), as well as the International Arctic Systems for Observing the Atmosphere (IASOA) circum-Arctic network of meteorological observatories. With this paper, we hope to begin establishing endorsements and links with governmental organizations such as the Arctic Council and existing programs devoted to international Arctic research such as Sustained Arctic Observing Networks (SAON) and the International Study of Arctic Change (ISAC).

An international program can help build a sustained North Pole observing program in at least four ways. The first is by facilitating financial sharing of the burden of long-term measurements among several nations. If we can agree on what measurements absolutely must be continued, the sanctioning of these standards by an international body could be a compelling rationale for individual countries to participate.

Second, international coordination of field efforts would reduce the logistics burden of sustaining observations through economies of scale. For instance, the cost of a helicopter flight to the North Pole for deployment of several buoys from several countries is the same as for one buoy from one country, which illustrates the need for establishing a way to share logistics costs among participating countries. Also, this type of logistics sharing, which already happens a great deal at the investigator level, would be better recognized and appreciated by individual funding agencies. Arguably, the help we currently provide to our international partners on an investigator-to-investigator basis may be unknown at the higher levels of our funding agencies.

Third, international support provides a buffer against funding or logistics difficulties in any one program. If one national group has a shortfall for a period of time, partners from other countries can ensure that the critical measurements are maintained.

Finally, the establishment of an international program of sustained observations in the North Pole region by a strong international body would give greater robustness to the effort to maintain research presence, and ideally immunity, in the face of changing geopolitics. To understand the role of the Arctic Ocean in global climate, we need it fully recognized that, at least for climate science, the North Pole region is in international waters. Endorsement by an established international body could give a program of sustained observations in the North Pole region a level of recognition that protects the efforts of international researchers to conduct crucial central Arctic Ocean research in the future.

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