White Paper
on
The Need for Sustaining Observations in the North Pole Region

James Morison –PSC (US) - morison@apl.washington.edu

Jeremy Wilkinson – SAMS (UK) – jpw28@bas.ac.uk

Matthew Alkire – PSC (US) - malkire@apl.washington.edu

Frank Nilsen – UNIS (Norway) - Frank.Nilsen@unis.no

Igor Polyakov – UAF (US) - igor@iarc.uaf.edu

William Smethie Jr. – LDEO (US) - bsmeth@ldeo.columbia.edu

Peter Schlosser –LDEO (US) - schlosser@ldeo.columbia.edu

Frederic Vivier –UPMC (France) – fvi@locean-ipsl.upmc.fr

Antonio Lourenco – UPMC (France) - antonio.lourenco@locean-ipsl.upmc.fr

North Pole as an Indicator of the Changing Arctic Ocean

Sustained observations of environmental conditions in the North Pole region, nominally north of 84°N, are critical to understanding changing Arctic Ocean sea ice and circulation and their connections with global climate. The Transpolar Drift is the main conduit of sea ice and freshened upper ocean waters across the Arctic Ocean. It passes over the North Pole region just before passing through Fram and Nares straits on its way to the North Atlantic. The exported ice and freshened water stratifies the sub-Arctic seas and limits the vertical convection of heat that 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 Pole is highly correlated with the basin-average ice thickness [*Lindsay and Zhang*, 2006]. Ocean

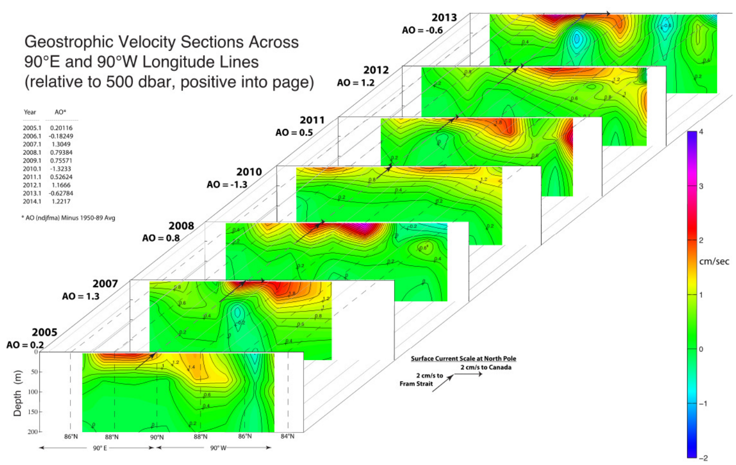

Figure 1. Geostrophic velocity across 90°W and 90°E longitude lines for years from 2005 to 2013. These are computed from dynamic heights relative to 500 dbar derived from Switchyard, NPEO, and NABOS CTD profiles. Positive velocities are into the page, nominally toward Fram Strait. Transpolar drift in the ocean is the positive lens in the upper 100-m centered near the North Pole (90°N on x axis). The winter (NDJFMA) AO index minus the average winter AO 1950-89 is also shown for each year. Arrows show surface geostrophic current at the Pole into and along the section.

bottom pressure (OBP) measured at the North Pole is highly correlated with dominant mode of Arctic Ocean mass change [*Peralta-Ferriz et al.*, 2014b], which 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 reveal 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]. 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 index [*Morison et al.*, 2012].

Hydrographic stations at one degree intervals over the Pole along 90°W and 90°E made by the US National Science Foundation Switchyard, North Pole Environmental Observatory (NPEO) and Nansen and Amundsen Basin Observing System (NABOS) project reveal changes in the geostrophic water velocity of the Transpolar Drift (Fig. 1) that cannot be resolved by buoys moving with the Drift. These sections from 2005 to 2013 indicate a current core of about 2 cm s^{-1} magnitude roughly centered on the North Pole, but with significant structure and interannual variability. The position of the velocity core is shifted towards Canada along 90°W when the previous winter (NDJFMA) AO index is high (e.g., 2007, 2008, 2011, 2012) in qualitative agreement with the cyclonic-anticyclonic paradigm (*Morison et al.*, [2012]). 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. The International Arctic Buoy Program (IABP) is the source of many of the buoys measuring surface atmospheric properties and ice drift. Data from these have contributed to countless successful studies. However, the IABP usually depends on shorter-term projects for buoy deployment, commonly along with new buoys measuring a wider range of variables. These efforts have a distinctly international character. Examples include drifting Polar Ocean Profile Systems from Japan and Canada [*Kikuchi et al.*, 2004; *Kikuchi et al.*, 2005] and Ice Tethered Profilers, Ice Mass Balance, and Arctic Ocean Flux buoys from the US [*Timmermans et al.*, 2011]. Investigators from the France's University of Pierre and Marie Curie (UPMC) have been deploying a new type of ice-mass and ocean flux buoy (Vivier) and an Ice, Atmosphere, Arctic Ocean Observing System (IAOOS) (Gascard), (http://iaoos.ipev.fr/index.php?option=com_content&view=article&id=47&catid=29&lang=en&Itemid=179) in collaboration with investigators from the Norwegian Polar Institute and Scottish Association for Marine Science deploying advanced ice-mass balance and radiometer buoys. The Polar Science Center in the US works with the IAOOS group deploying NPEO Web-Cam buoys that give visual evidence of the seasonal ice melt progression [*Inoue et al.*, 2005; *Perovich et al.*, 2008].

An international suite of satellite remote sensing tools such as ICESat from the US, GRACE from the US and Germany, and CryoSat2 from the EU extend the conclusions from Central Arctic Ocean in situ observations 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 versus hydrography-determined dynamic heights in the North Pole region [*Kwok and Morison*, 2011] (ICESat) [*Kwok and Morison* 2016] (CryoSat2). The hourly in situ ocean bottom pressure 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 Sustaining Observations in the North Pole Region

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 NOAA/BAMS State of the Climate Report (https://www.ncdc.noaa.gov/bams). Process studies and detection of interannual changes are helpful in this. However, detecting and understanding climate change absolutely requires observations at decadal and longer scales. And this is now the crux of the problem that our Arctic Ocean research community is facing. The investigations described above were nearly all conducted with the support of basic research funding agencies around the world. They were funded under grants and programs typically extending a few years.

In the future, national funding efforts such as the US National Science Foundation Arctic Observing Network (https://www.nsf.gov/news/news_summ.jsp?cntn_id=109687) and the EU Integrated Arctic Observing Network (http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/5122-bg-09-2016.html) are positioned to support long-term observations. However, these agencies are 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 there over the decades required for climate science. Given this fundamental problem, how might we build a program of sustained observations in the North Pole region out of what has been 20 years of basic research observations?

In this white paper, 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 International Arctic Buoy Program (IABP) providing support to the World Climate Research Program (WCRP) and the International Arctic Systems for Observing the Atmosphere (IASOA) circumarctic network of meteorological observatories. With this white 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 have to be continued, the sanctioning of these 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; 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. We need 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 the individual funding agencies. Arguably, the help we now provide our international partners investigator-to-investigator 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 the observational effort greater robustness, and ideally immunity, in the face of changing geo-politics. 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 that recognition.

References

Alkire, M. B., J. Morison, and R. Andersen (2015), Variability in the meteoric water, sea-ice melt, and Pacific water contributions to the central Arctic Ocean, 2000–2014, *Journal of Geophysical Research: Oceans*, *120*(3), 1573-1598.

Inoue, J., T. Kikuchi, D. K. Perovich, and J. H. Morison (2005), A drop in mid-summer shortwave radiation induced by changes in the ice-surface condition in the central Arctic, *Geophysical Research Letters*, *32*(13).

Kikuchi, T., K. Hatakeyama, and J. H. Morison (2004), Distribution of convective Lower Halocline Water in the eastern Arctic Ocean, *Journal of Geophysical Research-Oceans*, *109*(C12).

Kikuchi, T., J. Inoue, and J. H. Morison (2005), Temperature difference across the Lomonosov Ridge: Implications for the Atlantic water circulation in the Arctic Ocean, *Geophysical Research Letters*, *32*(20).

Kwok, R., and J. Morison (2011), Dynamic topography of the ice-covered Arctic Ocean from ICESat, *Geophysical Research Letters*, *38*(L02501), L02501.

Kwok, R., and J. Morison (2016), Sea surface height and dynamic topography of the ice-covered oceans from CryoSat-2: 2011-2014, *J Geophys. Res. - Oceans*, *121*, DOI:10.1002/ 2015JC011357.

Lindsay, R. W., and J. Zhang (2006), Arctic ocean ice thickness: Modes of variability and the best locations from which to monitor them, *Journal of Physical Oceanography*, *36*(3), 496-506.

Morison, J. H., R. Kwok, C. Peralta-Ferriz, M. Alkire, I. Rigor, R. Andersen, and M. Steele (2012), Changing Arctic Ocean freshwater pathways, *Nature*, *481*(7379), 66-70.

Peralta-Ferriz, C., J. H. Morison, J. M. Wallace, and J. Zhang (2011), A basin-coherent mode of sub-monthly variability in Arctic Ocean bottom pressure, , *Geophys. Res. Lett.* , *38,* , L14606.

Peralta-Ferriz, C., J. Morison , S. Stalin, and C. Meinig (2014a), Measuring bottom pressure at the North Pole, *Marine Technology Society Journal*, *48*(5), 52-68.

Peralta-Ferriz, C., J. H. Morison, J. M. Wallace, J. A. Bonin, and J. Zhang (2014b), Arctic Ocean Circulation Patterns Revealed by GRACE, *Journal of Climate*, *27*(4), 1445-1468.

Perovich, D. K., J. A. Richter-Menge, K. F. Jones, and B. Light (2008), Sunlight, water, and ice: Extreme Arctic sea ice melt during the summer of 2007, *Geophysical Research Letters*, *35*(11).

Sokolov, A. L. (1962), Drift of ice in the Arctic Basin and changes in ice conditions over the northern sea route, *Probl. Arct. Antarct., Engl. Transl.*, *11*, j1-j20.

Timmermans, M. L., A. Proshutinsky, R. A. Krishfield, D. K. Perovich, J. A. Richter-Menge, T. P. Stanton, and J. M. Toole (2011), Surface freshening in the Arctic Ocean's Eurasian Basin: An apparent consequence of recent change in the wind-driven circulation, *J. Geophys. Res.*, *116*, C00D03.