The International Arctic Buoy Programme (IABP) – A Model for Sustaining Arctic Observing Networks

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Introduction

Our ability to predict weather and sea ice conditions requires *in situ* observations of surface meteorology and ice motion. These observations are assimilated into Numerical Weather Prediction (NWP) models that are used to forecast weather on synoptic time scales, and into the many long-term atmospheric reanalyses (e.g., NCEP/NCAR and ERA Interim Reanalyses) that are used for innumerable climate studies. The impact of these *in situ* observations can be seen in Fig. 1, in which *Inoue et al*. (2009) report that the standard deviation in gridded sea level pressure (SLP) reanalyses fields over the Arctic Ocean was over 2.6 hPa in areas where there were no buoy observations to constrain the reanalyses, and this uncertainty in the SLP fields spreads to cover the entire Arctic when the observations from buoys are removed from the reanalyses. The buoy observations also help constrain estimates of wind and heat. *In situ* observations of sea ice motion are also important for estimating the drift of various areas and types of sea ice, and for understanding the dynamics of ridging and rafting of this ice, which changes the thickness distribution of sea ice. **Over the Arctic Ocean, this fundamental observing network is maintained by the IABP.**

This network of drifting buoys was recommended by the U.S. National Academy of Sciences in 1974. Based on this recommendation, the Arctic Ocean Buoy Program was established by the Polar Science Center, Applied Physics Laboratory (PSC/APL), University of Washington in 1978 to support the Global Weather Experiment. Operations began in early 1979, and the program continued through 1990 under funding from various agencies. In 1991, the IABP succeeded the Arctic Ocean Buoy Program, but the basic objective remains – to maintain a network of drifting buoys on the Arctic Ocean to provide meteorological and oceanographic data (e.g., Fig. 2) for real-time operational requirements and research purposes including support to the World Climate Research Programme, the World Weather Watch Programme, and the Arctic Observing Network (AON).

The IABP is composed of 32 different research and operational institutions from many countries (http://iabp.apl.washington.edu/Participants.htm). The IABP is funded and managed by the participants of the program. Management is the responsibility of the IABP Executive Committee, and operation of the program was delegated to the IABP Coordinator Ignatius Rigor.

Contributions to the IABP from each country vary widely, some countries contribute buoys through research projects, others provide substantial logistics support, many contribute both equipment and logistics. The United States contribution to the IABP is coordinated through the USIABP, which is managed by the PSC/APL and the NIC. The USIABP is a collaborative program that draws operating funds and services from many U.S. government organizations and research programs, which include the Office of Naval Research (ONR), Coast Guard (CG), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), Naval Oceanographic Office (NAVO), National Ice Center (NIC), and Shell Exploration and Production Company (SEPC). From these contributions the USIABP acquires and deploys buoys on the Arctic Ocean, and supports the research, coordination, data management and enhancement of the IABP by the PSC/APL.

Contributions to the IABP from Europe range from research driven deployments by the Alfred Wegener Institute in Germany, to contributions of buoys from the European Meteorological Network which are deployed by logistics of opportunity provided to the IABP, for example, deployments by the German R/V Polarstern, and the Russian R/V Akademik Treshnikov during the primarily U.S. funded Nansen and Amundsen Basin Observing Network cruises.

Research Highlights of the IABP AON

Dramatic changes in Arctic climate have been noted during the past two decades. It should be noted that many of these changes were first observed and studied using data from the IABP, which are analyzed and made available to the research community by the PSC/APL. For example, IABP data were fundamental to Walsh et al. (1996, e.g. Fig. 3) showing that atmospheric pressure has decreased, Jones et al. (1999) and Rigor et al. (2000) showing that air temperatures have increased (e.g. Fig. 4); and to Proshutinsky and Johnson (1997), Steele and Boyd, (1998), Kwok, (2000), and Rigor et al. (2002) showing that the clockwise circulation of sea ice and the ocean has weakened (Fig. 3).

The integrated affect of all these changes were studied by Rigor and Wallace (2004), who showed that the average age (thickness) of sea ice has decreased dramatically, which may help explain the recent run of record low summer sea ice extents. All of these results relied heavily on IABP data. And, as such, maintaining and enhancing the IABP has been identified as a priority for the Study of Environmental Arctic Change (SEARCH).

In addition to supporting these studies of climate change, the IABP observations are also essential for:

1. ***Forecasting weather.*** Observations of SLP, which may not be obtained by any other means except by *in situ* drifting buoys, are critical for forecasting weather by the National Weather Service. Estimating the strength and trajectory of Arctic storms would be difficult to predict without observations from the buoys.
2. ***Forcing, assimilation and validation of global weather and climate models.*** For example, the sea level pressures and temperature fields from the IABP were used as forcing, and IABP ice motion data were assimilated by Zhang et al. (2003) to improve model estimates of sea ice thickness, and the IABP data has been used to validate the IPCC AR4 model simulations (e.g. Liu et al., 2007). These data are also assimilated from the World Meteorological Organization

(WMO) Global Telecommunication System (GTS) into the weather and forcing fields produced by Naval Research Laboratory (NRL) to force the Polar Ice Prediction System (PIPS), and are used to validate the ice motion fields from PIPS.

3. ***Validation of satellite retrievals of environmental variables.*** For example, the buoy data are used to validate satellite estimates of sea ice motion (e.g. Kwok, 2008; Lindsay and Stern, 2003), and surface temperatures (e.g. Comiso, 2003).
4. ***Predicting sea ice conditions.*** Our ability to accurately forecast sea ice conditions depends on observations of sea level pressure, surface air temperature and sea ice motion over the Arctic Ocean.
5. ***Assimilation into atmospheric reanalyses.*** The Arctic also plays an important role in the global climate system, primarily through its role in the global heat balance and by its effect on the global thermohaline circulation (Aagaard and Carmack, 1994). Therefore, data from the IABP are also critical for global assessments of the atmosphere and ocean, and are thus assimilated into the global reanalyses, e.g. Inoue et al. 2009 (Fig. 1), and NCEP/NCAR Reanalysis (Kalnay et al. 1996).

The data collected by the IABP support both research and operations, i.e. the data are posted on the WMO GTS (e.g. Fig. 2) where operational weather and ice forecasters may collect the data and assimilate this information into their weather and ice forecasts, and into the forcing fields used to drive numerical models such as PIPS.

Over 800 papers have been written using data from the IABP (A growing list of these citations can be found at http://iabp.apl.washington.edu/publications.html.). This number does not include the countless papers that have used the various reanalyses products (e.g the NCEP/NCAR reanalysis, Kalnay, et al. 1996). Needless to say, the observations and datasets of the IABP data are one of the cornerstones for environmental forecasting and research in the Arctic. For example, the decrease in SLP over the Arctic shown by Walsh et al. (1996) using IABP data is probably the first indication of Arctic climate change (Fig. 3), and recently Inoue et al. (2009) showed the impact of the buoy observations on the SLP field reanalyses (Fig. 1).

Evolution of the IABP Arctic Observing Network

The Participants of the IABP observe the Arctic Ocean to forecast weather and sea ice conditions, and to understand the Arctic and global climate system. Towards these goals, the Participants are actively involved in the research and development of new instruments to monitor the Arctic. For example, given the retreat of Arctic sea ice, the IABP has been deploying Surface Velocity Program (SVP) buoys which are routinely deployed in all the other worlds “wet” oceans. These buoys follow ocean currents and are designed to measure sea surface temperature and air pressure. The IABP started deploying these buoys in the Arctic in 2006, and continues to analyze the observations from these buoys in comparison to the traditional weather stations that the IABP deployed which measure air temperature. The IABP has also been developing buoys which are designed to survive in the increasing area of seasonal ice such as the Airborne Seasonal Ice Beacon (AXIB).

When possible, the meteorological buoys are collocated with buoys, which monitor the temperature, salinity and currents of the upper ocean. For example, Ice Mass Balance (IMB) buoys deployments by the Canadian CCGS Louis St. Laurent, and German R/V Polarstern are collocated with ocean buoys provided by the Japan Agency for Marine-Earth Science and Technology Center and the Woods Hole Oceanographic Institute forming "Automated Drifting Stations", which monitor a myriad of geophysical variables at the air, ice and ocean interface. These enhanced data sets are collected as part of the data management tasks of the IABP (i.e. the IABP strives to collect all data collected by buoys deployed in the Arctic); this data are made available to the operational and research communities through the WMO/IOC GTS, the IABP web pages, and through various external data archives.

Arctic Observing Experiment (AOX)

Accurate observations of the fundamental meteorological parameters: temperature, air pressure, and wind are critical for the AON. The USIABP/IABP continually assesses the accuracy of the instruments that we deploy, but given the increased heterogeneity and seasonality of the Arctic the IABP has had to quickly adapt to these changes by developing the AXIB buoy and by deploying buoys typically deployed in the "wet" global oceans, e.g. the SVP buoy. But how accurate are these instruments in the polar environment, and how do measurements of air temperature (Ta, the primary temperature variable that the IABP historically strived to measure), compare to the surface temperature (Ts) measurements of an SVP buoy? Accurate temperature measurements are also necessary to validate and improve satellite measurements of surface temperature across the Arctic. As we deploy more AXIB buoys, which measure both Ta, and Ts, we will be able to answer this question. And in 2013, the USIABP established the IABP AOX test site at the DOE Atmospheric Radiation Measurement, and NOAA Climate Monitoring and Diagnostics Laboratory in Barrow, Alaska to assess our ability to measure these fundamental parameters. The AOX is primarily funded using contributions from U.S. DOE, NOAA and NSF, Environment Canada, and the Alfred Wegener Institute.

Summary

Sustaining the Arctic Observing Network to collect the fundamental observations of sea level pressure, air temperature and ice motion that are required by the operational and research communities for a myriad of purposes is a challenge that requires a well coordinated program to manage all the disparate pieces. These pieces include: 1) funding to purchase equipment; 2) logistics to deploy buoys; 3) manpower to coordinate the pieces, to assure the quality of the data and produce the research databases; etc. Thus maintaining the network requires interagency and international support and collaboration, since no single agency or country has the resources to maintain the whole network. The Participants of the IABP work together to maintain the fundamental observations what we all need from the Arctic Observing Network.

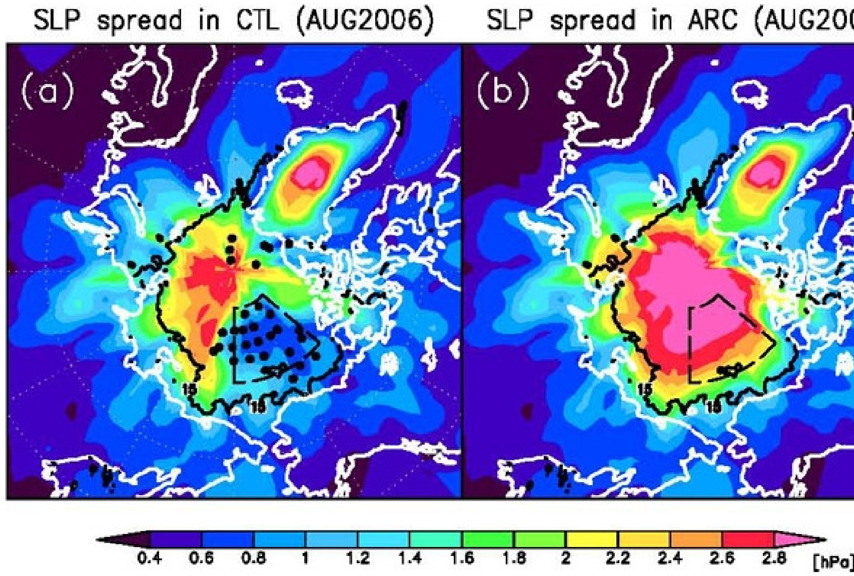

Figure 1. Standard deviation (SD) of sea level pressure measurements from various atmospheric reanalyses. The SD is low in areas where there are buoy observations (left). The spread increases to cover the whole Arctic when the observations from the buoys are removed from the reanalyses (right). Adapted from *Inoue et al*. (2009).

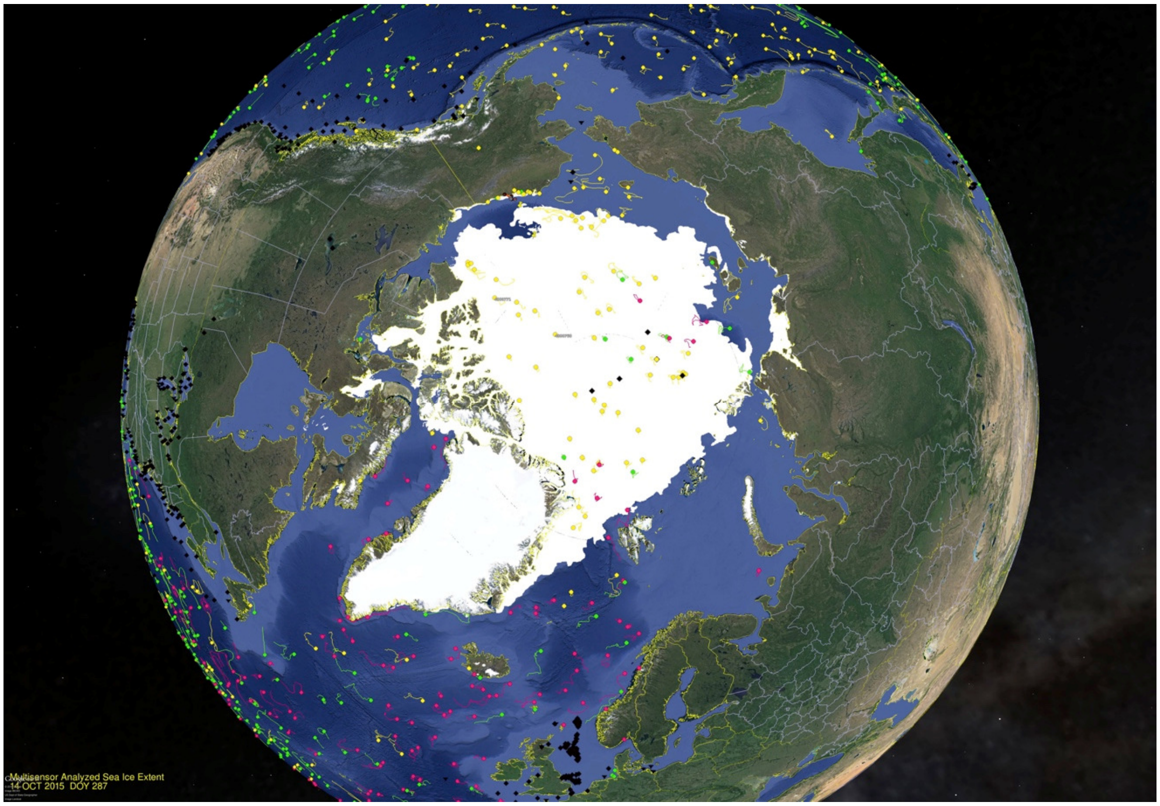

Figure 2. Map of IABP buoys reporting on the World Meteorological Organization (WMO) Global Telecommunications System (GTS) on October 15, 2015 as reported by the Meteo France. The U.S. National Ice Center's (NIC) Multisensor Analyzed Sea Ice Extent (MASIE) denotes areas of sea ice on the Arctic Ocean. The pink dots show buoys contributred to the IABP by the European Meteorological Network (EUMETNET), while the yellow dots show other buoys which report pressure, and the green dots are buoys without barometers. Black diamonds denote subsurface moorings. This map shows over 200 buoys reporting on WMO/GTS over the Arctic Ocean. Automated drifting stations (ADS) with clusters of ocean buoys, ice mass balance and other buoys are shown only by the USIABP/IABP meteorological buoy in these ADS.

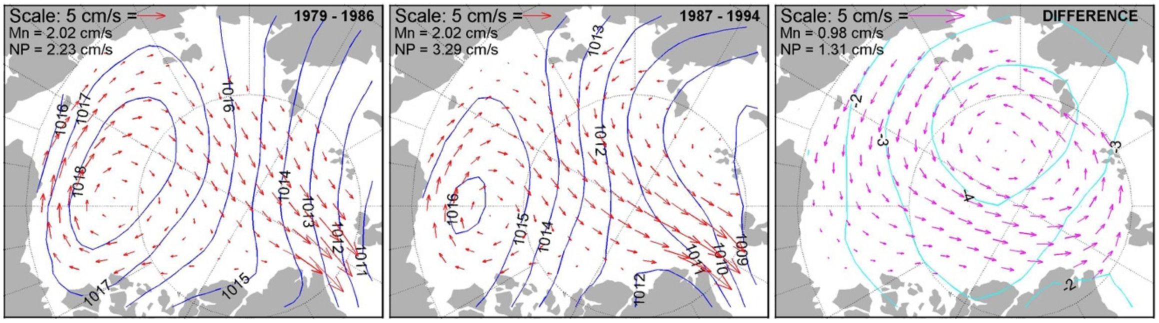

Figure 3. Using IABP data, Walsh et al. (1996) showed that sea level pressure (SLP) over the Arctic Ocean decreased by over 4 hPa (right), when he took the difference between SLP from 1979 – 1986 (left), and 1987 – 1994 (middle). These changes in SLP (winds), drive a cyclonic anomaly in ice motion (vectors), e.g. Rigor, et al. (2002).

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