Observing the Inflow of Pacific Water to the Arctic

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Although the importance of the Arctic in global climate change is widely recognized, a critical component of the Arctic system has been largely overlooked – the inflow of Pacific Water. Pacific inflow from the Bering Strait is a source of freshwater, carbon, and nutrients for the Arctic Ocean. However, before reaching the Arctic this water must first transverse the shallow Chukchi Sea (roughly 50 meters deep). Along its journey, Pacific water may be modified by air-sea interactions, input from rivers, mixing, and the freeze-thaw cycle of the ice. In addition, the inflow varies seasonally in both its rate and water mass properties. In particular, there is a need to understand the processes by which Pacific Water flowing through the Bering Strait is modified in the Chukchi Sea and then transported to the western Arctic basin. The most important transport is that which occurs in winter beneath the ice cover. This transport establishes the hydrographic conditions in the upper 200 meters of the Arctic basin, and may profoundly affect the thickness and extent of Arctic sea ice. The narrow passage between Point Barrow, Alaska, and the flank of Barrow Canyon is a critical "choke point" of the system, where a significant portion of the Pacific Water inflow is concentrated (Figure 1).

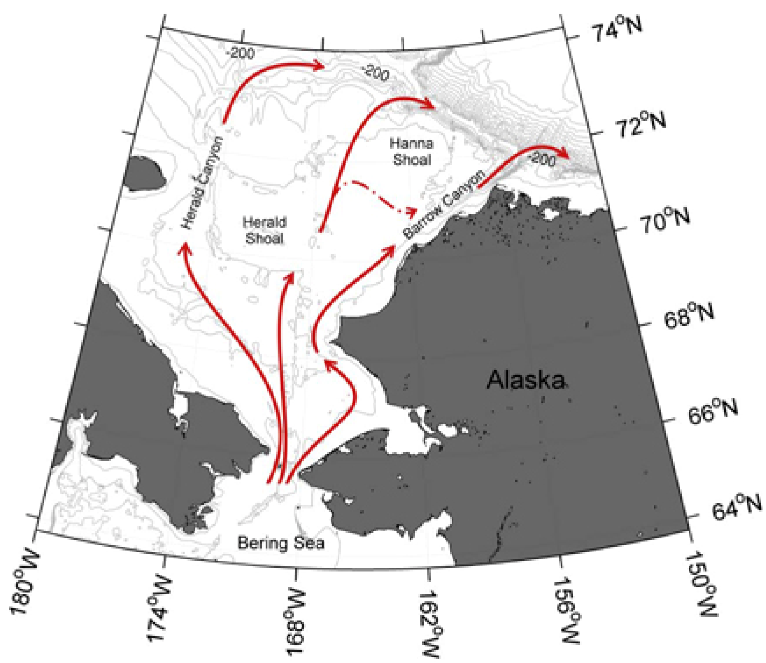

Figure 1: One of the pathways in which a significant portion of Pacific Water flows into the Arctic system is between the coast of Alaska and Barrow Canyon (far right arrow).

With funding from the Comer Science and Education Foundation we conducted a summer field project in 2005 to deploy an autonomous underwater vehicle REMUS (Remote Environmental Monitoring UnitS) to sample the water column across the choke point. The goal of this initial deployment was to assess whether or not the vehicle would be potentially capable of operating under the ice cover in this region during the winter. There were several technical areas of concern, including the acoustic environment, strong currents and navigation issues. For example, due to the acoustic properties of the area, we found that we could only contact the vehicle when it was near the surface. This could have important implications for the winter work, where “homing” transponders deployed through ice-holes near the surface were envisioned, because they would likely have only intermittent contact with the vehicle. We also experienced problems with the navigation system. Despite the unanticipated technical problems, we were able to gather important scientific data, including measurements of temperature, salinity, pressure, velocity, acoustic, and fluorescence data.

The project period was extended to allow further technical developments, which were completed in 2007. Although we determined that the REMUS was well suited to be used in the harsh environment, improvements to the navigation system and the development of a through-ice launch and recovery system were necessary to allow the vehicle to operate successfully in winter. Based on the field experience and technical advancements of this project, the goal of under-ice AUV transects to measure the Pacific Water inflow to the Arctic in winter has been pursued in a follow-on project supported by WHOI’s Arctic Research Initiative.

Support from the Comer Foundation allowed us to pursue an innovative but risky new observational approach, put us ahead of the curve relative to the overall research community, and has leveraged several other research projects.

Greenland Ice Sheet: Surface Melting and a Slippery Bottom

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Should the polar ice sheets melt in response to rising global temperatures, dramatic effects are predicted in the form of higher sea-level and the alteration of ocean circulation patterns. The Greenland Ice Sheet is more than a kilometer thick in most places, and until recently, many believed that it would take over a thousand years for temperature variations at the surface to reach the bed of the ice sheet.

Recent observations from Greenland, however, suggest that ice sheets have the potential to respond much more rapidly to climate change than was previously believed. New data show that ice-flow acceleration can occur within hours or days following the onset of melting at the surface. This surprising finding suggests that meltwater might be draining through the ice sheet rather than running off the surface, thereby rapidly lubricating and warming the bed. This would result in a quicker movement of the ice sheet toward the coast and ultimately into the ocean. If we are to fully grasp the effects of increased ice melting on ice sheet flow and its effects on sea-level change, we need to understand where and how the meltwater gets to the ice sheet bed.

One mechanism that has been proposed to quickly transport meltwater from the surface to the bed of an ice sheet is the propagation of water-filled fractures beneath lakes that form annually on the surface of the ice sheet. While theoretical models suggest that the draining of supraglacial lakes through fractures in the ice is a plausible transport mechanism, water-filled cracks that reached the bed had never been observed in the thick, subfreezing ice sheets. However, in an NSF-funded project to study the behavior of supraglacial lakes (see *Oceanus* article: Tracking an Ocean of Ice Atop Greenland) we found that large lakes do in fact drain rapidly—some in a matter of hours—through an apparent fracture-driven process (see front cover). This study represented the first glimpse into the pathways and time scales of surface-to-bed water flow.

Figure 1: Glaciologist Sarah Das contemplates a huge river of meltwater flowing on Greenland's ice sheet.

Our next step has been to monitor the fracture process with field based measurements to determine the location and timing of fracture events and test our numerical model results.

To accomplish this, we designed an observational network to measure seismicity around seasonally draining supraglacial lakes. Our experiment was designed to determine the rate and extent of water-filled crack propagation. We expected that crack propagation would be accompanied by enhanced seismicity near the crack tip.

During our field expedition in July 2007, we deployed a network of seismometers around two lakes on the Greenland Ice Sheet. We used Global Positioning System receivers and seismometers to measure ice movement, water pressure loggers to detect changes in lake levels, and meteorological sensors to precisely measure surface melting. Data from these instruments confirmed the water filling large glacial lakes can build up enough pressure to crack their bottoms, creating conduits that penetrate the ice sheet and could send torrents of water all the way to the bedrock. The water acts as lubrication between the ice and ground, speeding up the glacier's flow toward the ocean. Evidence collected from the instruments showed that cracks, reaching the bedrock, had suddenly drained the lakes. These measurements provided some of the first direct observations of the mechanisms behind rapid meltwater transport from supraglacial lakes to the bed of the Greenland Ice Sheet.

Line W: Sustained Measurements of the North Atlantic Meridional Overturning Circulation

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The global ocean plays a fundamental role in Earth's climate system by exchanging heat, freshwater, carbon, and other substances across the interface between air and sea at some locations and then transporting and releasing them back to the atmosphere in other places. A major agent in this transport process is the Meridional Overturning Circulation (MOC), manifested in the North Atlantic by the flow of warm surface waters (principally within the Gulf Stream) toward the poles and a return flow of colder, denser subsurface waters toward the Equator. The latter is concentrated in a current called the Deep Western Boundary Current (DWBC), which "hugs" the U.S. Eastern Seaboard.

The Line W Program is dedicated to obtaining a ten-year record of changes in transport by the DWBC at a logistically-accessible site southeast of Woods Hole, Massachusetts (Figure 1). Line W is named in memory of Val Worthington, a physical oceanographer at WHOI who devoted a considerable part of his career to measuring and understanding the properties and flows in the Gulf Stream and DWBC. Our research goals include characterizing the nature of the anomalies of water property transport seen at Line W and relating them to fluctuations at other latitudes and ultimately, to variations in air-sea exchange at latitudes where the deep waters are exposed to the atmosphere. We hope that greater accuracy of climate models and improved understanding of the physical processes responsible for MOC variability and its impact on Earth's climate system will result.

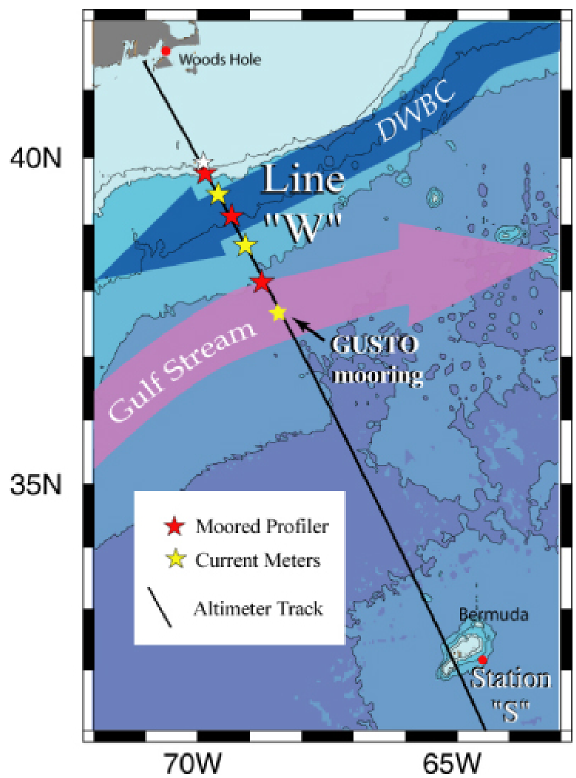

Figure 1: Line W is an array of moorings that monitor changes in the Deep Western Boundary Current (DWBC) and the Gulf Stream. Sensors on the Line W moorings take measurements of water salinity, temperature and velocity along both currents.

Operationally, we are observing the DWBC and Gulf Stream at Line W by utilizing a combination of moored instrumentation and periodic shipboard sampling. Building on a significant archive of historical observations from the region, the modern measurement program was initiated in 2001 with seed funding from The G. Unger Vetlesen Foundation. That support allowed us to deploy one mooring for two sequential one-year periods (2001-2002 and 2003-2004) and conduct some shipboard sampling of the DWBC water properties.

In turn, we were able to parlay that seed money into two substantial grants from the National Science Foundation (NSF). The first of these supported an initial four-year sampling effort (Spring 2004-Spring 2008); the second is providing partial funding for six more years of measurements. In these times of tight science funding, we were required to significantly trim our initial funding request to NSF in Principal Investigator (PI) time to analyze the acquired data. Therefore, we are very grateful that the Comer Science and Education Foundation, through WHOI's Ocean and Climate Change Institute, has provided supplemental support for the Line W science team. With this funding, the Line W scientists will be able to oversee the collection, processing and distribution of the basic observations, as well as perform scientific analysis of those data over the next few years.