The Dynamics of Carbon Export to the Deep Arctic Ocean and its Sensitivity to Climate Change

Tim Eglinton, Marine Chemistry and Geochemistry Department
Richard Krishfield, Physical Oceanography Department
Steven Manganini, Geology and Geophysics Department

The Arctic Ocean is of critical importance to our understanding of the impact and fate of human-induced increases in atmospheric CO_2 on the oceans and on global climate. It has been predicted that these climate changes will occur far more rapidly and be amplified in the Arctic, both on the surrounding continents and in the ocean. Two of the most prominent manifestations of these changes are a decline in sea-ice cover and destabilization of permafrost soils. The latter process and attendant shifts in the hydrologic cycle will release vast quantities of carbon stored in these soils and associated nutrients to the marginal seas. Together with longer open-water seasons over larger expanses of the Arctic Ocean that will promote high biological productivity in surface waters, carbon export to deep basin waters of the Arctic Ocean is likely to increase markedly. However, our knowledge of how the carbon cycle in the Arctic Ocean operates, and its response to changes in the supply of carbon and climate forcing, is severely hampered by the scarcity of information on the flow and fate of biogenic and associated materials exiting the upper ocean.

In a pilot study in 2004 and 2005, we deployed a single sediment trap on a mooring in the Canada Basin in order to collect particles settling to the deep Arctic Ocean. Examination of the recovered samples indicated that the particle flow and most of the material derived from the surrounding margins were very low. In anticipation of dramatic changes to the Arctic carbon cycle, we proposed a project for the Arctic Research Initiative that was designed to provide crucial new insights into the sources, mode of delivery and fate of carbon in the deep Arctic basin. In particular, we sought answers to the following questions:

1. Is the distribution and composition of particles observed in the 2004/5 study typical of the annual cycle in the deep Canada Basin?

2. What is the source and mode of supply of carbon originating from the margins? Specifically, is it terrestrial or marine in origin?

3. What are the likely consequences of climate-induced increases in carbon flow on deep Arctic Ocean ecology and biogeochemistry?

In order to address these questions, we participated in a large scale field program to obtain time-series data on particle flows to the Canadian Basin during 2007-2008. We have also continued this study as part of a 2008-2009 field program. As a component of this work, we have deployed sediment traps on bottom-tethered moorings at different locations within the Canada Basin (Figure 1, next page). Two of these locations are overlain by seasonal ice, whereas as the other two are under permanent ice cover. Our goal is to examine whether the flow and composition of materials accumulating in the traps differ under permanent versus seasonal ice cover. In addition, at one location (Station A), traps are deployed at three different depths in order to follow the changes in flow through the water column.

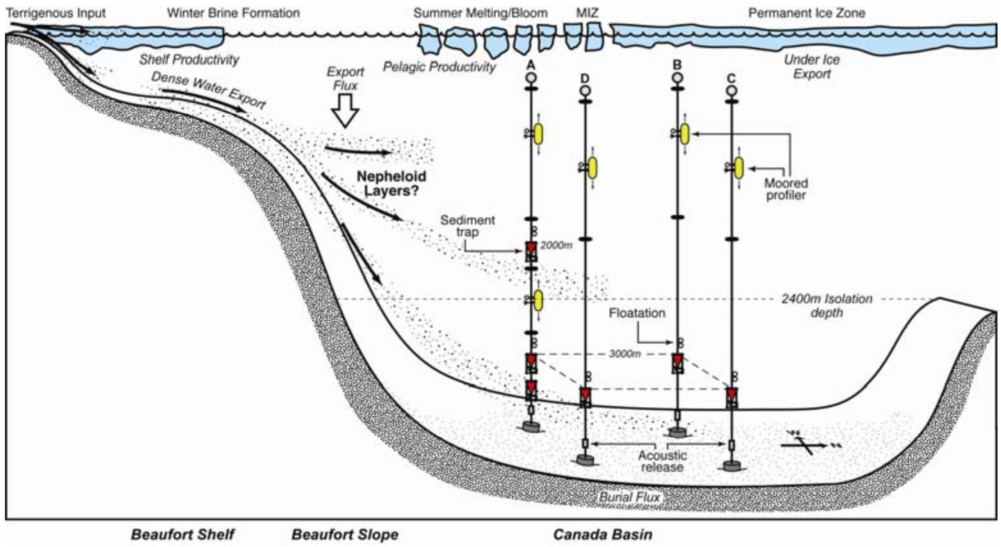

Figure 1: Moored instrumentation (Moored Profilers-yellow, Sediment Traps-red) deployed in the deep Canada Basin at 4 sites (A,B,C,D) and proposed modes of particle transport as suggested by a sediment trap pilot study in 2004-2005. Samples from 6 sediment traps (2007-2008) have been recovered, and the 5 redeployed sediment traps (2008-2009) will be recovered in August 2009.

Interestingly, our 2007-2008 trap deployment coincided with a year that began with record low extent of sea ice in the Arctic Ocean (Figure 2). This dramatic change is superimposed on the long-term decline in sea ice extent that began in the last quarter of the 20th century. We were, therefore, particularly curious to determine how particle flows would respond to this sharp decrease. The sea ice extent at the beginning of the 2008-2009 deployment was also very low. Samples from the latter deployment will be recovered during a cruise in August 2009.

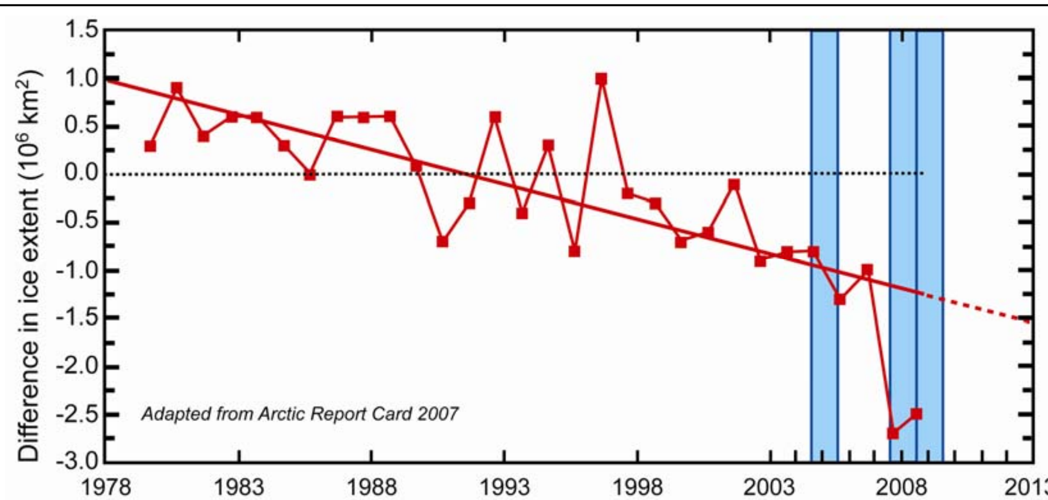

Figure 2: Time series of the difference in September ice extent (the month of ice-minimum) from the average values between 1979-2007. The rate of decrease for the September ice extent was 11.3% per decade (Richter-Menge et al., 2008). The blue shaded bars indicate the time periods for the 2004/2005 and 2007/2008/2009 sediment trap deployments.

Figure 3 shows the geographic extent of September sea ice cover in relation to the different mooring locations. These maps show the overall shrinkage in sea ice extent, and also clearly show that moorings A and D have experienced much greater periods of open surface water during the last two years.

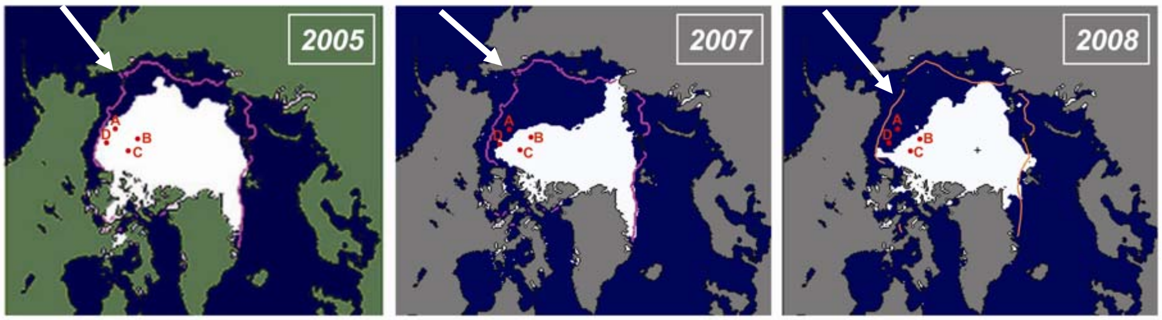

Figure 3. Sea Ice minima during September 2005, 2007, 2008, and mooring locations A, B, C, D. The magenta line (at which white arrows are pointing) indicates the minimum extent of the ice cover for 1979-2000. (Source: http:/nsidc.org/)

Mooring deployments in the Arctic Ocean present considerable logistical challenges. We are enormously grateful to Andrey Proshutinsky and the other members of the Physical Oceanography team at WHOI who have helped with these deployments and have enabled us to build a biogeochemical observation program into their Beaufort Gyre Observing System (BGOS). A particular challenge is in the recovery of the moorings from permanently ice-covered waters (Figure 4). The moorings are hidden under the ice, and the ship must clear a patch of open water so that the mooring can reach (and be located at) the surface.

Figure 4: Recovery of sediment trap mooring from ice-covered waters in the Arctic Ocean during the August 2008 research cruise aboard the *Louis St. Laurent* (Photo courtesy of MIT/WHOI Joint Program student David Griffith). Note yellow "hard hat" floatation balls that have popped up in a gap in the ice made by the ship. The rest of the mooring is lying below, awaiting retrieval. All the moorings were successfully recovered and redeployed.

We have obtained preliminary data on the sediment trap samples from the 2007-2008 deployment collected from the same depth and location as those from the 2004-2005 deployment. Two key observations were made: (i) Particulate carbon flows to the Central Arctic basin were similarly low for both 2004-2005 and 2007-2008; (ii) Surprisingly, maximum flow occurs in the winter with maximum ice cover, implying that it is not linked to primary production in overlying surface waters; (iii) Low values of organic carbon and the abundance of minerals imply that most of the flow reflects sediments resuspended and laterally transported from the surrounding margins.

These observations suggest that, so far, diminished sea ice was not affected by the amount or type of organic matter that was exported from the surface ocean. We suspect that, while a single year of greatly reduced sea ice cover may be insufficient to trigger a change in particle export, sustained low ice cover must ultimately have a profound effect on surface ecosystems. We are, therefore, eager to examine samples from the traps that will be recovered this summer. In addition, the manner in which particles enter the deep waters of the basin remain an enigma, and will only be determined through careful examination of the full suite of samples from the moorings in different locations that have been deployed during the past two field seasons. We also hope that this project will be a springboard for sustained observations of carbon export in the Arctic Ocean; and, we are presently making plans to continue our sediment trap deployments as part of WHOI's Physical Oceanography mooring program beyond 2009. In this way, we will be in a better position to predict how the Arctic carbon cycle may be modified in the face of the climate changes which have been set in motion.

This project has involved the participation and training of both a graduate student and postdoctoral investigator in Arctic oceanography. MIT/WHOI Joint Program student David Griffith participated in the cruise aboard the Canadian research vessel *Louis St. Laurent* in late summer 2008 and was involved in the collection of sinking, suspended and dissolved materials for chemical characterization. Postdoctoral investigator Jeomshik Hwang has performed the radiocarbon measurements shown in Figure 5 and has worked closely with the principal investigators on data interpretation. Overall, we view both the field program and scientific aspects of this project as being a great success. The funds provided by the Arctic Research Initiative were essential in enabling us to conduct this study.