Climate Driven Destabilization of Arctic Watersheds and a New Reactivity Paradigm for Carbon Cycling in Arctic Rivers

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The Arctic Ocean is a semi-enclosed basin surrounded by immense watersheds that drain the polar and sub-polar regions of Europe, Asia and North America. Each year, rivers deliver proportionately more freshwater to the Arctic Ocean than to any other ocean basin. Over the past three decades, a gradual warming of the arctic climate has increased precipitation and river discharge, decreased the duration and extent of lake and river ice cover, advanced the timing of the annual ice/snow melt to earlier in the year, and is beginning to thaw the arctic permafrost. Recent studies suggest that these changes are accelerating. Climate change is both impacting how the arctic hydrological cycle functions, and altering feedbacks from the Arctic to the global climate system.

One of the potentially most significant impacts of climate driven change in the Arctic is the transfer of organic carbon and nutrients from the continents to marine ecosystems. Nearly half the global inventory of organic carbon stored in soils is sequestered in arctic watersheds. Presently, through erosion and weathering, Arctic rivers annually deliver some 30-50 x 10^{12}g of this carbon to the coastal zone. The current view holds that the organic carbon found in this soil is the residue of carbon cycling in terrestrial ecosystems, and is therefore old and nonreactive. If Arctic soil carbon is not reactive, it will cycle passively through the Arctic Ocean with little impact on the ecosystem or on global climate. However, new observations suggest that a large fraction of Arctic river carbon is reactive and can be degraded by bacteria, which convert organic carbon to carbon dioxide. If these observations prove to be correct, introduction of organic carbon and nutrients will act to fertilize and restructure the Arctic Ocean ecosystem, and may be a significant new source of carbon dioxide to the atmosphere.

With funds from the WHOI Arctic Research Initiative (ARI), we measured the composition and reactivity of organic carbon in arctic rivers. Our plan was to collect samples of particulate and dissolved organic matter from arctic river water. In addition to analyzing the chemical composition of these samples, we exposed them to bacteria to measure the amount of carbon that could be converted to carbon dioxide. In particular, we wanted to answer the question: Is most of the river water carbon old and nonreactive, or is it reactive carbon that has been temporarily frozen in arctic soils but will now enter the carbon cycle as the arctic permafrost melts? Our project has been a collaboration between WHOI scientists with expertise in different aspects of ocean geochemistry (Drs. Tim Eglinton and Dan Repeta), and microbiology (Dr. Benjamin van Mooy) and Dr. R. Max Holmes of the Woods Hole Research Center, an expert on contemporary arctic climate change. We sampled two large Russian Rivers, (Lena, Ob) and two North American Rivers (Mackenzie and Colville) during the high flow in spring, when most carbon is delivered to the ocean. We also returned to the Mackenzie in the late winter and to the Colville in late summer, during their low flow periods for comparison (Figure 1, next page).

Figure 1: Photographs from sampling trip (May/June 2008) to the Mackenzie River Delta. (a) River just prior to break-up of the ice on the river; (b) water samples showing the high concentrations of dissolved (note color, left) and suspended (note turbidity, right bottle) materials carried by the river during this time period.

For the field programs during high river flow, sampling was conducted from the river bank, whereas sampling in winter was undertaken by drilling through the ice. Large volume water samples were collected in clean plastic bottles (Figure 1) and processed within a few hours of collection. Water samples were filtered on site to remove all bacteria, cooled and quickly returned to WHOI. In the lab, we inoculated each sample with a small amount of unfiltered river water to introduce bacteria back into the water, and then we incubated the samples for several weeks to monitor changes in carbon, nutrients, and bacteria. If carbon in the river water was old and not very reactive, we expected little change in the amount of bacteria or carbon in the water. This result would mean that the carbon in arctic rivers could not be consumed by bacteria, and would probably have little impact on the ocean carbon cycle. If the carbon in river water was reactive, we expected to see a large increase in the number of bacteria cells and a decrease in the amount of carbon, as bacteria used it as food and converted it to carbon dioxide.

Our results showed a clear and dramatic loss of carbon and an increase in bacterial cell numbers during our incubation of springtime high flow samples. In contrast, we saw only a small loss in carbon and a small increase in bacterial cell numbers during incubations of low flow samples. A good example of our results is given in Figure 2 for the Colville River on the Alaskan North Slope. We collected high flow samples in early June, at the time when the ice on the river was breaking up (Figure 1) and the springtime "freshet" as snow melt was flooding through the river. Dissolved carbon concentrations at this time were very high, about 6,300 µg/L (micrograms per liter). However, bacteria were able to reduce this concentration to 3,700 µg/L in only three months, a reduction of slightly more than 40%. The dissolved carbon concentrations for August, a low flow period, were dramatically lower. We measured only 3,070 µg/L in the river water. This carbon was also not very reactive; therefore, it was not a good food source for bacteria. After three months of degradation, bacteria were only able to reduce the amount of carbon in the river to 2,520 µg/L, a loss of only 18%. When viewed in absolute carbon terms, the difference is even more dramatic. The springtime samples lost 2,600 µg over three months of degradation, compared to only 550 µg in the summer.

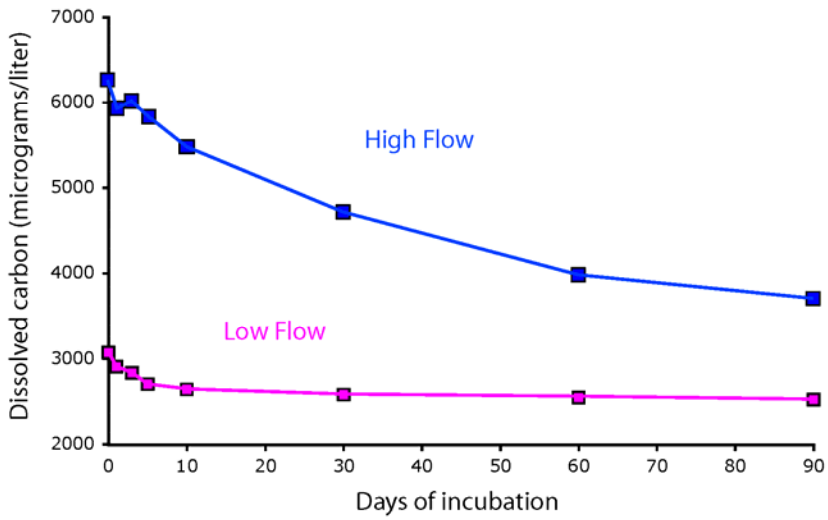

Figure 2: Plot showing the bacterial degradation and loss of carbon over a three month period for Colville River water collected during the high flow springtime freshet (June 3) and during the low flow summer months (August). Both samples were collected from the same site.

Our results present a new paradigm for carbon cycling with climate change in the Arctic. Most water and carbon are discharged over a very short period in the spring, when the snow melts and the ice cover of rivers disappears. The carbon transferred from the arctic landmass into the Arctic Ocean during this time is very different from the carbon that is discharged during normal, low flow periods – it is much more reactive to biological degradation. As a result, carbon transfer from terrestrial sources to the Arctic Ocean may be a much larger source of greenhouse carbon dioxide to the atmosphere than earlier measurements suggest. Our future work will include examining how the chemical composition of the carbon is related to its reactivity so that we can better understand the biogeochemical processes involved.

This project had an unusually rich mix of outreach activities that included extensive interaction with indigenous students and their communities at our Siberian study sites, as well as public presentations and exhibitions in the United States. These activities were designed with several objectives in mind: first, to partner with local citizens to investigate “their” rivers in a collaborative manner; second, to gain insight into the changing Arctic through stories told by local people, particularly the elders of the communities, of environmental changes that have been observed; and third, to convey the importance and excitement of Arctic research to the public.

Figure 3: WHOI co-investigator Max Holmes (center) and Jon Waterhouse , Director of the Yukon River Intertribal Watershed Council (left) training students in the use of water quality monitoring equipment in Zhigansk, Siberia, along the Lena River.

One such group with which we spoke were the residents living along the Lena River in Siberia in the community of Zhigansk, in the Sakha Republic of Siberia. The population of Zhigansk is predominately Evenki, an Arctic indigenous group that numbers less than 20,000 people. Traditional activities of this group include fishing, hunting, and reindeer herding, and these activities still are an important part of their semi-subsistence way of life. The Lena River and Zhigansk have been focal points of Max Holmes' Arctic research for several years, and funds provided by the WHOI Arctic Research Initiative allowed increased collaboration with the people of this remote Siberian outpost. Zhigansk was visited three times – in March 2007, May-June 2007, and May-June 2008.

Zhigansk children and their teachers participated in sample collection during all of the trips that we made to the Lena River. They also collected samples in the intervals when we could not be on site, allowing better characterization of seasonal variation of the Lena River's biogeochemical fluxes. Perhaps as important, elders and community leaders shared their observations of environmental changes in their region, including descriptions of changing snow and ice conditions, thawing permafrost, and altered migrations of fish and other animals upon which they depend. The reindeer herders noted many changes in snow cover and the abundance of lichens, a principal winter forage for their large wandering reindeer herds. This "traditional ecological knowledge" reinforces the rapidly evolving scientific understanding of the impact of global warming in the Arctic.

We have been very pleased with the way that our collaboration with the people of Zhigansk has helped us tell the story of the Arctic and climate change to a wider audience. Perhaps our most effective outreach activity has been an art exhibition featuring paintings done by Siberian schoolchildren, mainly from Zhigansk. The exhibition is centered on the children's paintings but also includes photographs and descriptions of how climate change is directly impacting the traditional way of life in the Arctic. In the past year, the exhibition has been seen by hundreds of thousands of people at the United Nations and the American Museum of Natural History in New York City, and at the American Association for the Advancement of Science headquarters in Washington, DC, as well as at museums and galleries in Moscow, Alaska, Woods Hole, Minnesota, and Vermont.

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