The Arctic Great Rivers Observatory (Arctic-GRO): Monitoring Biogeochemical Fluxes from Rivers to the Arctic Ocean

Bruce J. Peterson[1], Robert M. Holmes[2], James W. McClelland[3], Peter A. Raymond[4], Robert G. Striegl[5], Suzanne E. Tank[1]

[1]Marine Biological Laboratory, Woods Hole, MA; [2]Woods Hole Research Center, Falmouth, MA; [3]University of Texas at Austin, Port Aransas, TX; [4]Yale University, New Haven, CT; [5]US Geological Survey, Denver, CO

Figure 1: Map of the catchments of the six Great Rivers monitored by the Arctic-GRO project. Sampling locations are indicated by red dots. The red line demarcates the boundary of the pan-arctic watershed.

Introduction

The arctic system is undergoing rapid terrestrial, oceanic and atmospheric change,[1] and the riverine linkage between land and the Arctic Ocean is playing a central role in this evolution. The Arctic Great Rivers Observatory project (**Arctic-GRO**) measures the flux of water-borne constituents in 6 Great Arctic Rivers: the Ob', Yenisey, Lena, Kolyma, Yukon, and Mackenzie (Fig. 1). Together, these rivers deliver the majority of the continental fresh water to the Arctic Ocean, the most landlocked and freshwater-dominated of the Earth's seas. Arctic-GRO measurements are conducted at downstream locations that capture the vast majority of continental runoff from the major arctic watersheds, in the same manner as Arctic-GRO's antecedent, **PARTNERS** (2002-2007), which was the first comprehensive study of riverine fluxes to the Arctic Ocean. Our observations are being used to test hypotheses about the magnitude, controls and ecological significance of riverine input to the Arctic Ocean, and will provide new information on inter-annual variability and trends in these fluxes. By monitoring constituent flux at these 6 downstream sites, we are beginning to form a time-series of data that is critical to understanding terrestrial and oceanic processes in the arctic system.

Sampling regimen

The Arctic-GRO project samples for numerous water-borne constituents, with a sampling schedule specifically designed to capture conditions during peak flow, base flow, and flows during maximum yearly permafrost melt (Fig. 2).

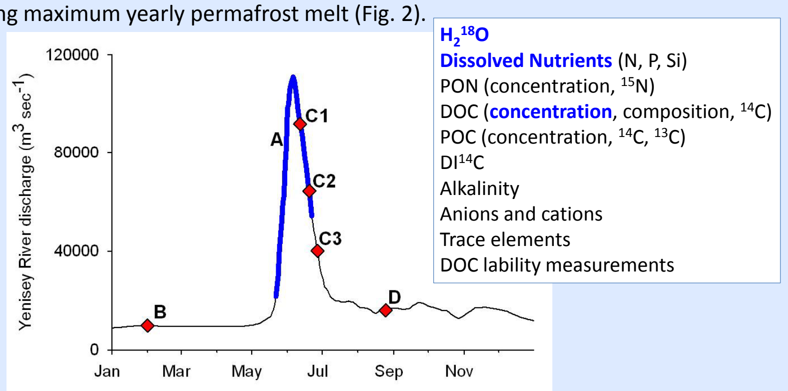


Figure 2: A schematic of the A-GRO sampling schedule, overlaid on average discharge from the Yenisey River, for illustration purposes. (A) Starting as ice begins to break up on the river, and for ~30 days thereafter, samples are taken daily from shore, for the subset of constituents highlighted in blue (inset). Larger samples are taken at 5 key timepoints during the year, for all of the listed constituents: (B) under-ice surface water, between November and April; (C1-C3) a depth /width integrated collection just after ice has cleared from the river, and twice thereafter at weekly intervals, and (D) a depth/width integrated collection in late August. This sampling regimen was specifically designed to capture (A, C) peak flow, (B) base flow, and (D) the point of greatest seasonal permafrost melt.

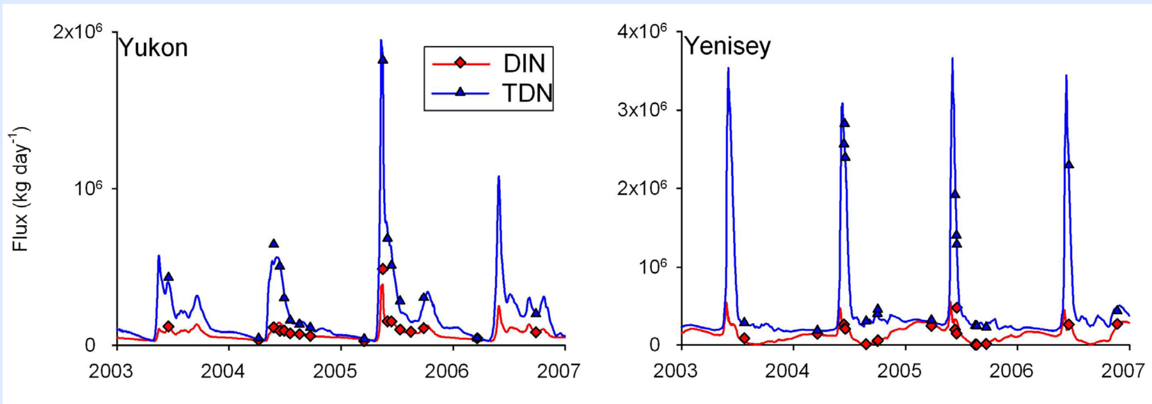
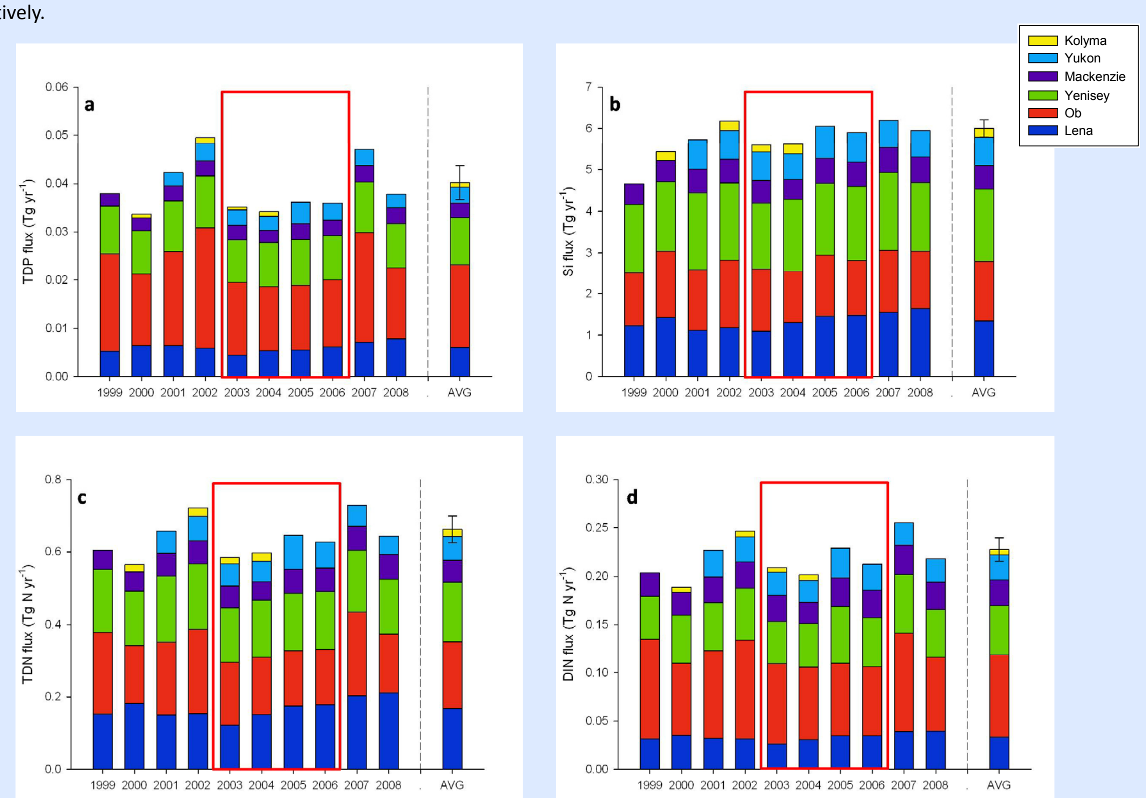


Figure 3: Estimated fluxes of dissolved inorganic nitrogen (DIN) and total dissolved nitrogen (TDN) from 2 of the 6 Great Arctic Rivers, shown for the time span of the PARTNERS project. Fluxes are estimated using the USGS LoadEstimator program, which pairs measured constituent concentration data with daily streamflow data to create a calibration equation for daily flux. Measured fluxes of DIN and TDN are shown as red diamonds and blue triangles, respectively. Estimated daily fluxes are shown as red and blue lines for DIN and TDN, respectively.



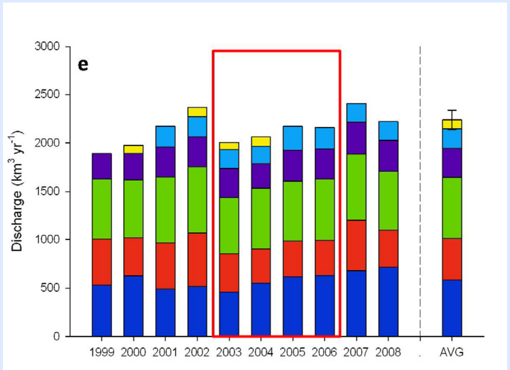


Figure 4: 10-year fluxes of (a) total dissolved phosphorus (TDP), (b) silica (Si), (c) total dissolved nitrogen (TDN), and (d) dissolved inorganic nitrogen (DIN) from the 6 Great Arctic Rivers. Constituent fluxes were calculated in LoadEstimator by creating a calibration equation for the period of the PARTNERS dataset, highlighted by red boxes. Flux estimates were expanded to the 1999-2008 period using measured discharge data (e), to give a decadal mean of constituent flux. Discharge data for the Yukon and Kolyma Rivers are only available for 8 and 4 years of this 10 year period, respectively; thus, these rivers are not included in flux estimates for years when discharge data is unavailable. In each panel, mean fluxes are shown with 95% confidence intervals, which have been adjusted to account for the incomplete Yukon and Kolyma dataset.

Results

Because the Arctic-GRO project began in 2009, initial samples are still being collected and processed. However, work with the PARTNERS dataset continues to increase our understanding of the functioning of the arctic system. For example, the variation of oxygen isotope ratios between these Great rivers has been quantified, and used to elucidate freshwater sources in the Arctic Ocean.[2] Measurements of dissolved organic carbon (DOC) have increased our estimates of DOC flux to the Arctic Ocean, largely as a result of newly-captured high concentration fluxes during spring peak flows.[3] DOC has also been shown to be more labile during the spring peak, when compared to the traditionally sampled, later season period, which has fundamentally changed our understanding of the role of riverine DOC in coastal regions.[4] Current efforts are producing new estimates of riverine fluxes of dissolved N, P and Si (Figs. 3 and 4). Unlike previous work, these pan-arctic flux estimates explicitly incorporate constituent concentrations from the critical high-flow period.

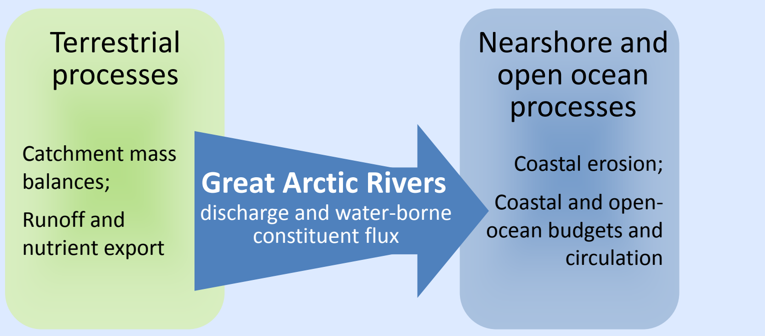


Figure 5: Large, north-flowing rivers serve as a 'linchpin' in the arctic system: integrating processes that occur over vast terrestrial regions, and feeding into key oceanic processes.

Significance

Monitoring circumpolar riverine discharge and constituent flux is critical for understanding environmental change in the Arctic. As an intermediary between vast continental regions and the Arctic Ocean, the Great Arctic Rivers act as a linchpin of the arctic system (e.g., Fig. 5). Sampling of large rivers near their mouth provides one of the most efficient ways to assess changes occurring across vast continental regions that may diagnose environmental change on land. At the same time, riverine fluxes to the Arctic Ocean play an important role in global climate feedbacks: affecting sea ice extent and albedo through inter-annual variability in discharge, trace gas feedbacks through transport of dissolved gases and organic carbon, and ocean circulation through trends in freshwater inputs to the Arctic and North Atlantic Oceans. Previous work by Arctic-GRO team members and others has already shown an increasing trend in Siberian river discharge over the past several decades,[5] which almost certainly indicates recent changes in constituent fluxes. The Arctic-GRO project, and continued monitoring of riverine flux into the future, will help assess the magnitude of this change.

References

1. Arctic Climate Impact Assessment. 2005. 1042 pp., Cambridge Univ. Press, New York.
2. Cooper, L. W., R. Benner, J. W. McClelland, B. J. Peterson, R. M. Holmes, P. A. Raymond, D. A. Hansell, J. M. Grebmeier and L. A. Codispoti. 2005. Linkages among runoff, dissolved organic carbon, and the stable oxygen isotope composition of seawater and other water mass indicators in the Arctic Ocean, *J.Geophys. Res.*, 110, G02013, doi:10.1029/2005JG000031.
3. Raymond, P. A., J. W. McClelland, R. M. Holmes, A. Zhulidov, K. Mull, B.J. Peterson, R.G. Striegl, G. R. Aiken and T. Y. Gurtovaya. 2007. Flux and age of dissolved organic carbon exported to the Arctic Ocean: A carbon isotopic study of the five largest arctic rivers, *Global Biogeochem. Cycles*, 21, GB4011, doi:10.1029/2007GB002783.
4. Holmes, R. M., J. W. McClelland, P. A. Raymond, B. B. Frazer, B. J. Peterson and M. Stieglitz. 2008. Lability of DOC transported by Alaskan rivers to the Arctic Ocean, *Geophys. Res. Lett.*, 35, L03402, doi:10.1029/2007GL032837.
5. Peterson, B. J., R. M. Holmes, J. W. McClelland, C. J. Vorosmarty, R. B. Lammers, A. I. Shiklomanov, I. A. Shiklomanov, and S. Rahmstorf. 2002. Increasing river discharge to the Arctic Ocean. *Science , 298, 2171-2173.*