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Glacier depth controls downstream productivity; non-linearity in all Ice Sheet-to-Ocean nutrient fluxes

Mark Hopwood (1), Carolina Cantoni (2), Dustin Carroll (3), Stefano Cozzi (2), Thomas Browning (1), and Eric Achterberg (1)

(1) GEOMAR, Marine Biogeochemistry, Kiel, Germany, (2) CNR-ISMAR, Marine Science Institute, Trieste, Italy , (3) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

It is widely hypothesized that climate change will enhance dissolved macronutrient (NO_3, PO4 and Si) and micronutrient (e.g. Fe) fluxes from glaciers to the ocean and thus potentially enhance future marine primary production. Here we combine a subglacial plume model for a tidewater glacier and datasets of estuarine nutrient distribution from Greenland and Svalbard to investigate how meltwater affects the availability of nutrients in the marine environment. Combining these data with insight from satellite derived fluorescence quantum yields to assess the balance between NO_3 and Fe limitation in the North Atlantic, we also evaluate the likely effect of increased discharge from the Greenland Ice Sheet on future marine primary production.

We show that delivery of macro/micro nutrients from both tidewater and land terminating glaciers is non-linear with respect to increasing freshwater volume. In the case of tidewater glaciers, macronutrient fluxes to the marine photic zone are strongly dependent upon glacier grounding line depth. For a simplified model tidewater glacier, an optimum 'Goldilocks' zone for nutrient delivery into the photic zone for a discharge of 500 m3 s-1 occurs when the glacier sits at around 200-600 m depth. The resulting plume entrains seawater and produces an upwelled NO_3 flux at least two orders of magnitude greater than that from glacial runoff. Runoff itself provides a negligible NO_3 flux in terms of the likely effect on marine productivity. Shoaling of tidewater glaciers decreases downstream fluxes of all macronutrients due to the reduced upwelling efficiency. For example, even with a 10-fold increase in meltwater discharge, the macronutrient flux from our model system is still reduced with a 200 m grounding line relative to a 600 m grounding line. Further non-linearity in all Ice Sheet-to-Ocean nutrient fluxes arises because of non-conservative estuarine mixing behavior for Fe (>80% removal), Si (+12-13% increase) and PO4 (>35% removal) in turbid fjord waters.

Our results emphasize the importance of 3-dimensional processes on Ice Sheet-to-Ocean nutrient fluxes. Nutrient fluxes derived simply from meltwater volume and meltwater nutrient concentration are always positive even though the enhanced stratification which accompanies meltwater delivery into the ocean leads to, in the absence of sub-glacial discharge driven upwelling, reduced NO_3 and PO4 availability for downstream marine primary production.