Influence of a high spatial resolution Arctic/Sub-Arctic river discharge and temperature forcing on modelled nearshore hydrography and sea ice conditions

Jonathan Whitefield(jwhitefield@alaska.edu)[1], Peter Winsor[1], Jim McClelland[2]
[1] Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks
[2] Department of Marine Science, The University of Texas at Austin

Introduction

Compared to the rest of the world's oceans, the Arctic basin receives a large amount of fresh water. Around 10% of the world's river discharge empties in to the Arctic Ocean, an ocean which represents only ~1% of the total world ocean by volume. The Massachusetts Institute of Technology's general circulation model (MITgcm) is a high-resolution (~1/6°) coupled ocean-ice global model (Fig. 1a) that has been used for many Arctic climate related studies, yet the current river discharge forcing has a resolution of 1°, interpolated to the model grid. Subsequently, input from many of the Arctic rivers is mis-located due to land mask constraints, and spatial aliasing of river deltas occurs.

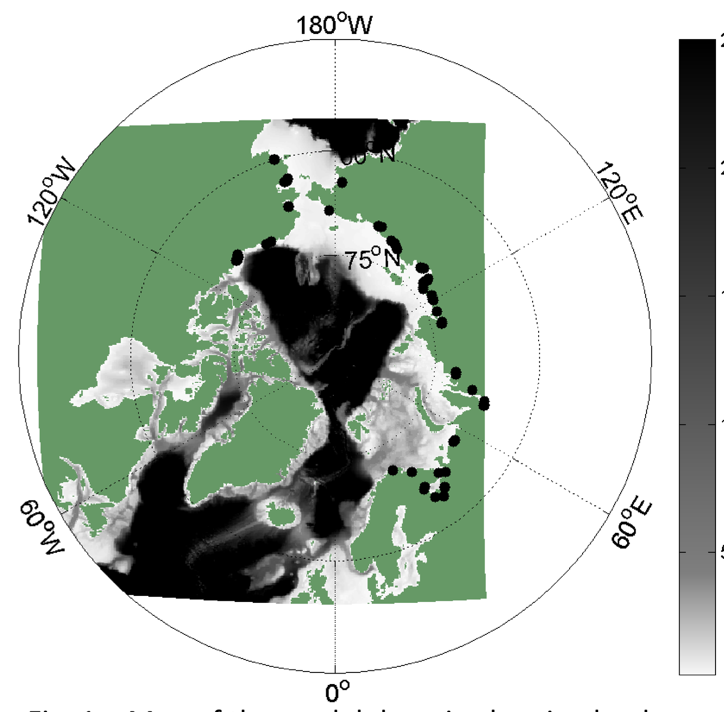

Fig. 1a. Map of the model domain showing land mask in green, model bathymetry as greyscale contours, and river discharge and temperature forcing locations as black dots.

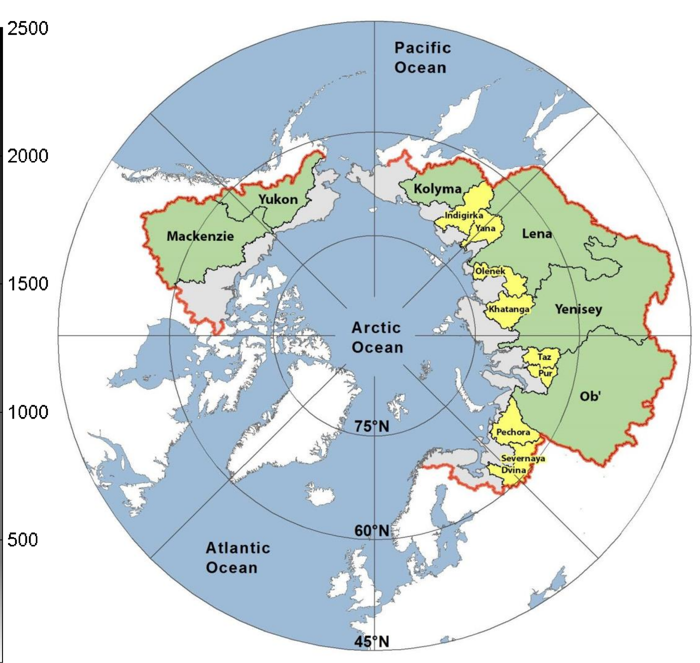

Fig. 1b. Map of the major river basins in the pan-Arctic watershed. Temperatures from major river basins (in green) were applied to other smaller rivers. Adapted from Holmes et al., 2012.

In addition, fresh water is added at ambient ocean temperature, despite many of the Arctic rivers reaching temperatures of >10 °C during May-July. For this improved forcing field, discharge volume and temperature data was obtained from R-ArcticNET, ArcticRIMS, the Arctic Great Rivers Observatory (AGRO), and USGS National Water Information System (NWIS). Discharge temperature was assigned for the nearest large river basin (Fig. 1b). By including the seasonal river discharge temperature, we find that sea surface temperature (SST) increases by 2-3 °C, sea ice thickness around rivers decreases by up to 80%, and sea ice volume decreases by up to 27% during the spring freshet.

Results – changes in temperature and salinity

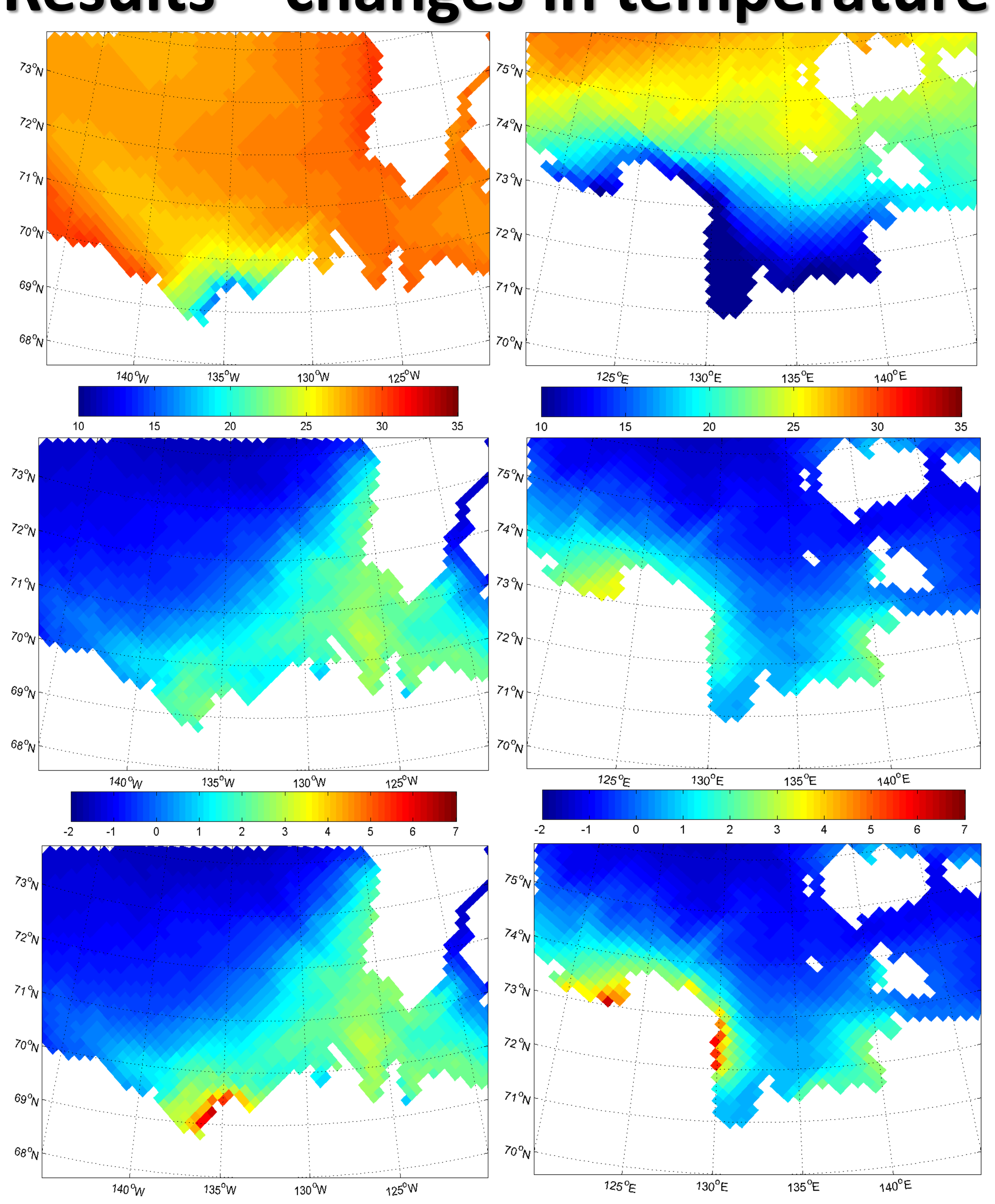

Fig. 2. TOP: Long-term mean June (i.e. peak discharge) sea surface salinity (SSS) for the Mackenzie (left) and Lena (right) deltas. MIDDLE: Long-term mean June sea surface temperature (SST) for the Mackenzie (left) and Lena (right) deltas, using forcing with no river discharge temperature. BOTTOM: Long-term mean June SST for the Mackenzie (left) and Lena (right) deltas, using forcing which includes river discharge temperature. Model land mask is in white.

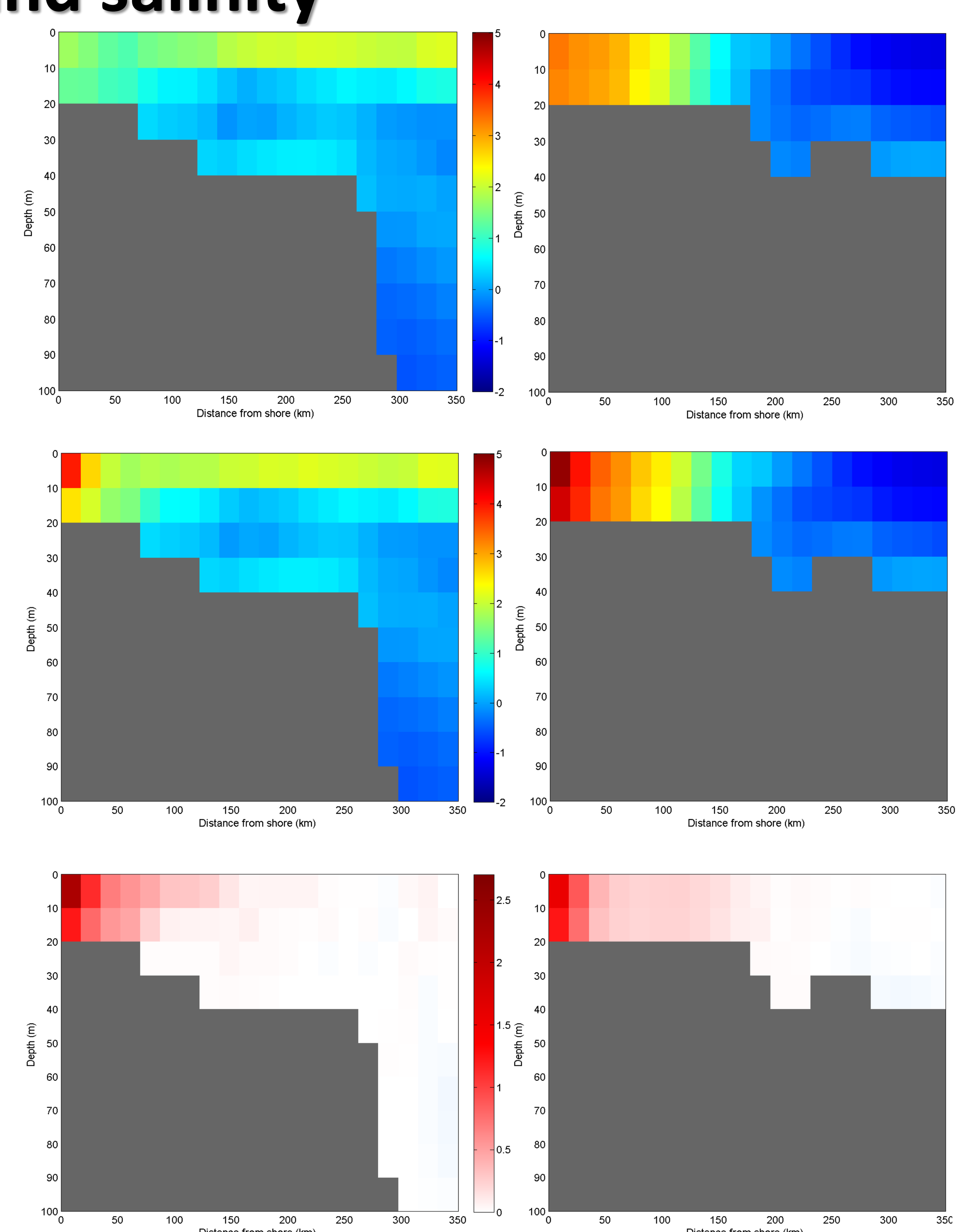

Fig. 3. TOP: Long-term mean June (i.e. peak discharge) temperature along a transect from the Mackenzie (left) and Lena (right) deltas, using forcing with no river discharge temperature. MIDDLE: Long-term mean June temperature along a transect from the Mackenzie (left) and Lena (right) deltas, using forcing which includes river discharge temperature. BOTTOM: Difference in modelled long-term mean June temperature. Model land mask is in grey, and the coastline is to the left for both transects.

By re-writing the discharge forcing field to the same resolution as the model grid, the issues of spatial aliasing of river deltas, and mis-location of river discharge are immediately rectified. For brevity, sea surface salinity (SSS) and temperature (SST) plots of only the Mackenzie and Lena deltas are shown here, although the effects are similar for other rivers in the new forcing field. SSS (Fig. 2, top) is now fresher at the coast, and even spread around river deltas; before, for example, discharge from many rivers were input over the shelf break.

The increase in fresh water close to the coast leads to increased stratification (Fig 3, top, middle), and also increased seasonal heating from shortwave radiation. Previously, the wide area of discharge forcing meant that river plumes were indistinguishable from ocean water in SST plots. With the high-resolution forcing field, river plumes are now visible as plumes of 3-4 °C (Fig. 2, middle). By including a seasonal cycle of river temperature, input to the model as a heat flux where river discharge exists, SST near to the coast increases by an additional 2-3 °C (25-50%) to 6-7 °C (Fig. 2, bottom).

The Mackenzie shelf becomes more stratified within 100km of the coast (Fig. 3, left), but due to the wide shelf around the Lena delta, this warm water is mixed in the top 2 grid cells in the model, and remains well mixed in the within 100km of the coastline (Fig. 3, middle, right).

Results – changes in sea ice

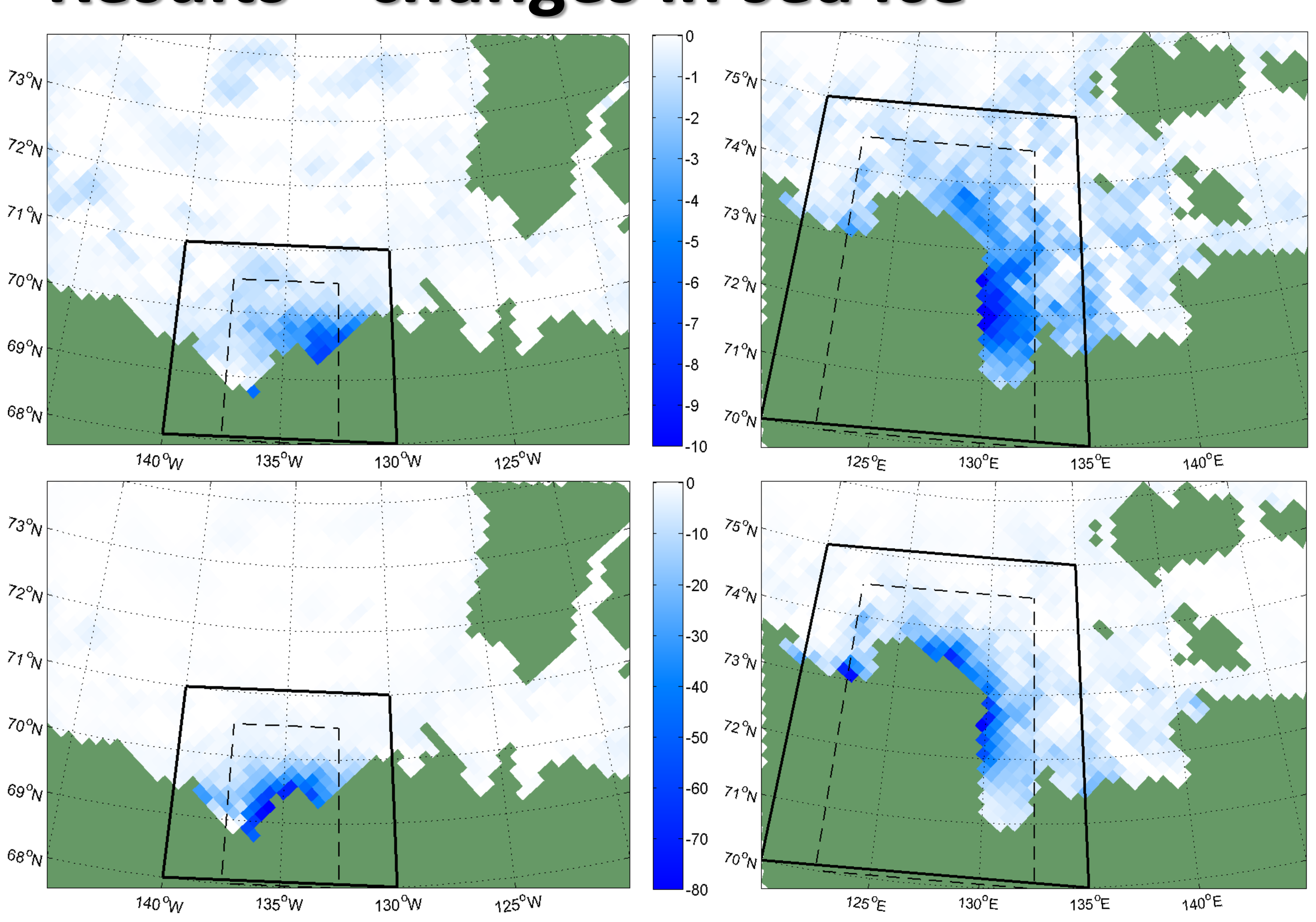

Fig. 4. TOP: Differences (i.e. forcing with temperature – forcing without) in long-term June sea ice percentage area near the Mackenzie (left) and Lena (right) deltas. BOTTOM: Percent change in long-term mean June sea ice thickness near the Mackenzie (left) and Lena (right) deltas. Boxes mark area used to calculate sea ice volume reduction. Model land mask is in green.

Inclusion of river discharge temperature has pronounced effects on local sea ice concentration (Fig. 4, top) and thickness (Fig. 4, bottom). Reduction in long-term mean June sea ice thickness and coverage is large, but by September/October, when discharge is small, differences are <1%.

Integrating a ~50km radius around the Mackenzie/ Lena deltas (M: 2 x 10^4 km^2 L: 6.4 x 10^4 km^2) returns a long-term mean June sea ice volume loss of 27%/17% due to inclusion of discharge temperature. A ~100km radius (M: 6.4 x 10^4 km^2 L: 13 x 10^4 km^2) shows a reduction of 6%/8% over that area.

Conclusions

By increasing the resolution of the discharge forcing field for this regional configuration of the MITgcm, it is now applied to the model without interpolation. Consequently, river discharge now forces the model along the coast instead of on the shelf, or even the shelf break. Away from rivers, shallow bays (e.g. Norton Sound) become fresher and warmer, comparable to observations.

When the river discharge includes a seasonal cycle of temperature, these effects are increased. SST increases by a further 2-3 °C, sea ice retreat begins earlier, and volume decreases by up to 27%. This new high-resolution forcing field will thus have significant impacts on how the MITgcm reproduces local ice melt/formation, and well as affecting biological/chemical models when run in tandem.

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