Arctic Ice-Ocean Circulation Modeling: Recent Improvements and Application

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Abstract

Regional numerical modeling provides a valuable means to assess important aspects of natural systems when the cost and effort of direct observation is impractical; the Arctic Ocean and its marginal seas and archipelagos represent a domain where such applications abound. We describe the configuration of and results from a set of coupled sea-ice ocean circulation models that are based on the Regional Ocean Modeling System (ROMS). Challenging features include large fresh water fluxes from the major Arctic rivers, seasonal land-fast ice, and ice-covered open boundary conditions in nested models. A broad-scale domain, dubbed the Pan-Arctic ROMS (PAROMS) model, extends from the Aleutian Islands to southern Greenland using a telescoping horizontal grid spacing that varies from 4 km in the Pacific to 8 km in the Atlantic. Higher-resolution domains include nested grids at 3 km and 500 m grid spacing. Coastal discharges are prescribed as lateral inflows distributed over the depth of the ocean-land interface. The model includes tides, sea ice, updated bathymetry, and atmospheric forcing from the MERRA reanalysis. We assess the model's performance with respect to tides, storm surges, wind-driven circulation, and thermohaline fields. A hindcast integrated over 1983-2015 provides a means to assess synoptic, seasonal and inter-annual variability. Applications include investigations of shelf flow field pathways, residence times and advective timescales, and energetics balances.

Arctic ice-ocean circulation modeling: recent improvements and applications

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Introduction

The goal of this project is to produce a ten-year high-resolution hindcast of the coastal Beaufort Sea. The region contains many small barrier islands, driving us to attempt modeling the region at 0.5 km. There is also seasonal landfast ice which has a strong influence on the coastal ocean circulation (Kasper, 2012).

Methods

In order to resolve the features of interest in the Beaufort Sea, we use an offline nesting from a pan-Arctic domain (PAROMS, 5-9 km) to an intermediate domain (3 km) to the target grid at 500 m resolution (Figure 1). All three domains share:

* Regional Ocean Modeling System (ROMS) with Budgell ice
* MERRA atmospheric forcing
* Arctic river inputs from ARDAT (Whitefield, 2015)
* A landfast ice parameterization (Lemieux, 2015)
* Tides from Oregon State

For the offline nesting, we are using daily ocean fields and three-hourly sea-ice fields from a larger domain in an off-line nesting for the boundary conditions, plus nudging to a monthly sea-ice climatology in a narrow band extending 20 gridpoints inwards from the boundaries. The fields being nudged are sea-ice concentration, thickness, snow thickness, and ice internal stress. We also turn off the landfast ice parameterization within the nudging band.

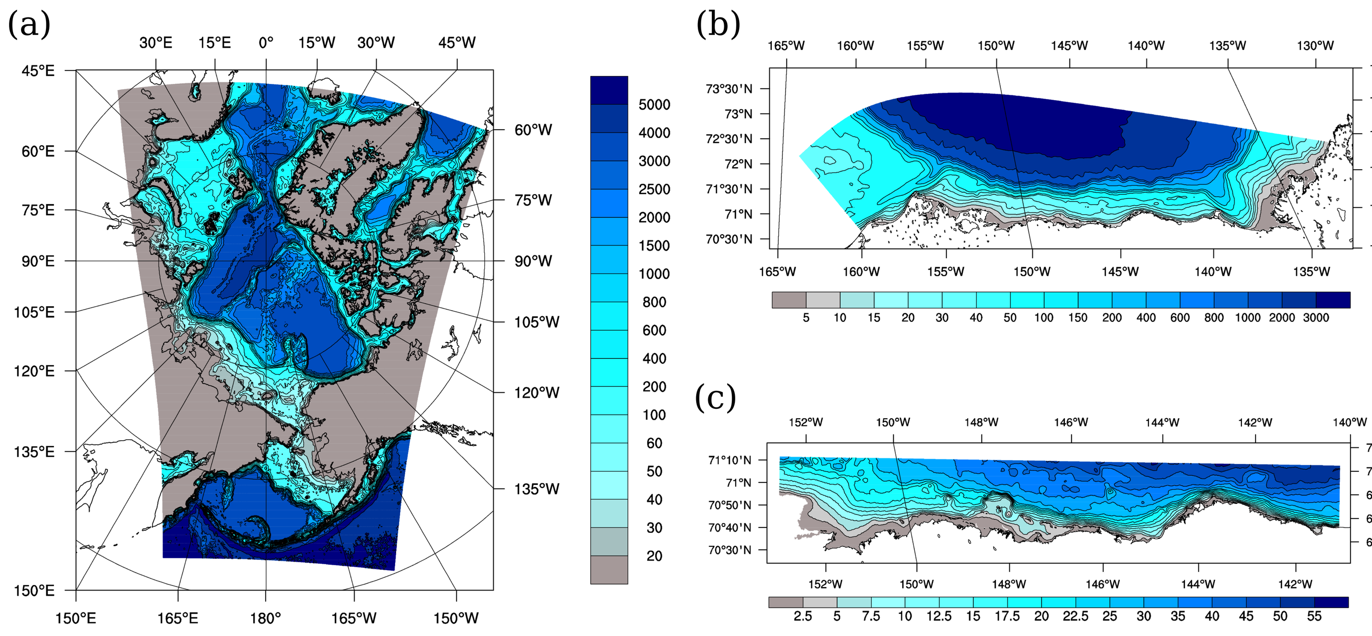

Figure 1. The bathymetry in meters for (a) the pan-Arctic domain (PAROMS), (b) the 3 km Beaufort Sea domain and (c) the 0.5 km Beaufort Sea domain. The latter two are from ARDEM 2.0 (Danielson, 2015) while PAROMS used ETOPO1 (https://www.ngdc.noaa.gov/mgg/global/global.html).

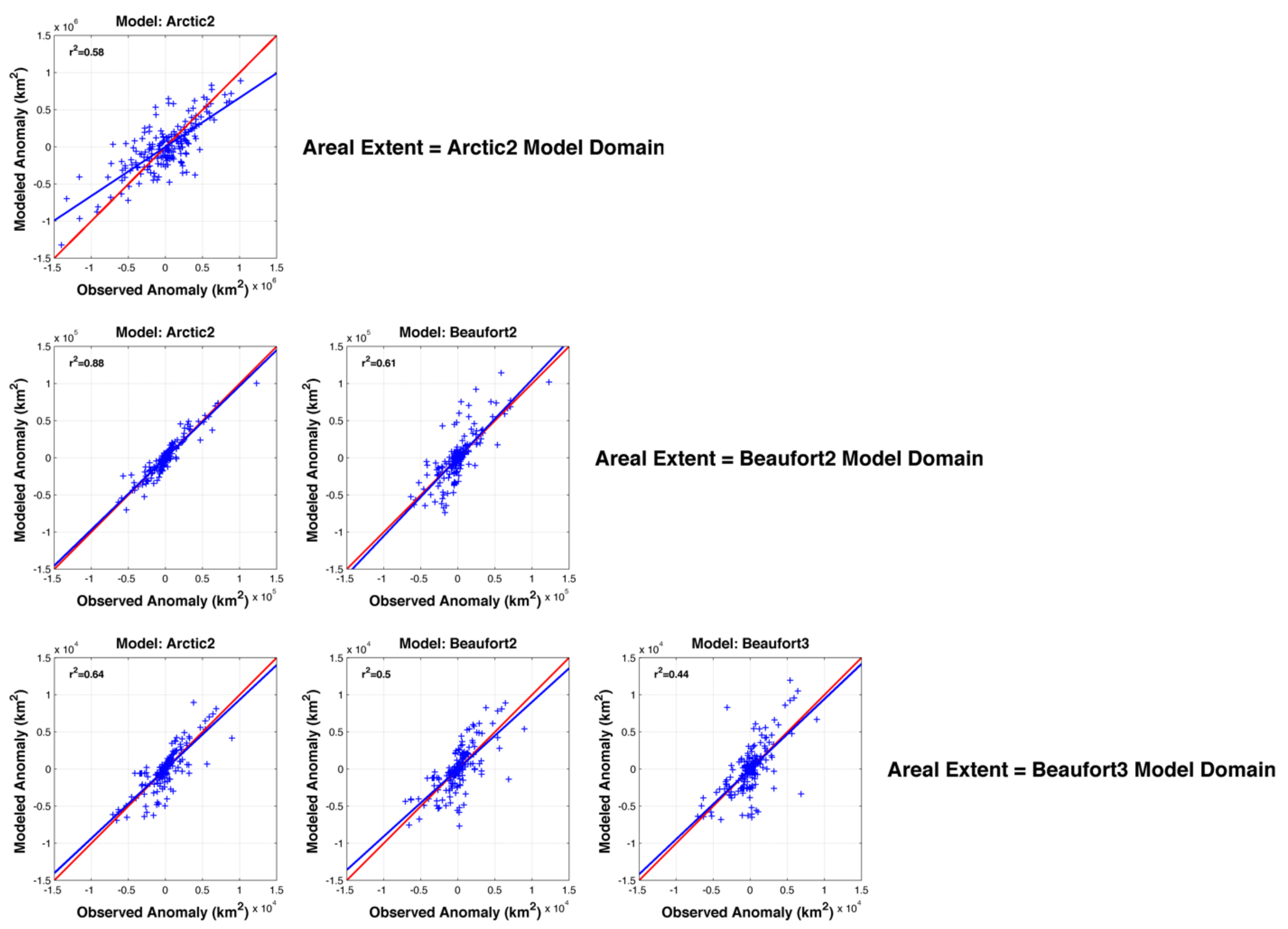

Figure 2. Correlation matrix of ice area anomalies for each of the three model for the Pan-Arctic model domain (top), the Beaufort2 model domain (middle) and Beaufort3 model domain (bottom). The model data that comprise the comparisons are the coarse Pan-Arctic model (left), the medium-resolution Beaufort2 model (center) and the fine-resolution Beaufort3 model (right).

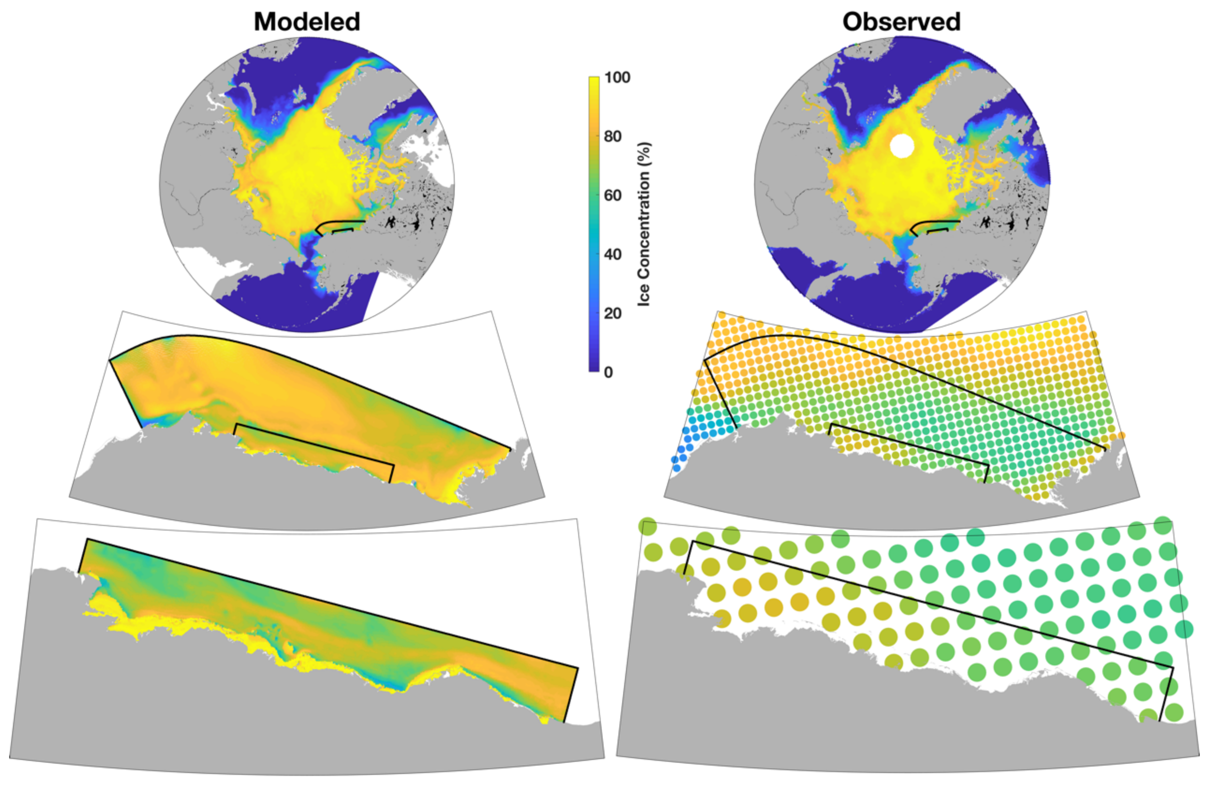

Figure 3. Comparison of modeled (left) and observed (right) ice concentration for the coarse (top), medium-resolution (middle) and fine-resolution (bottom) models.

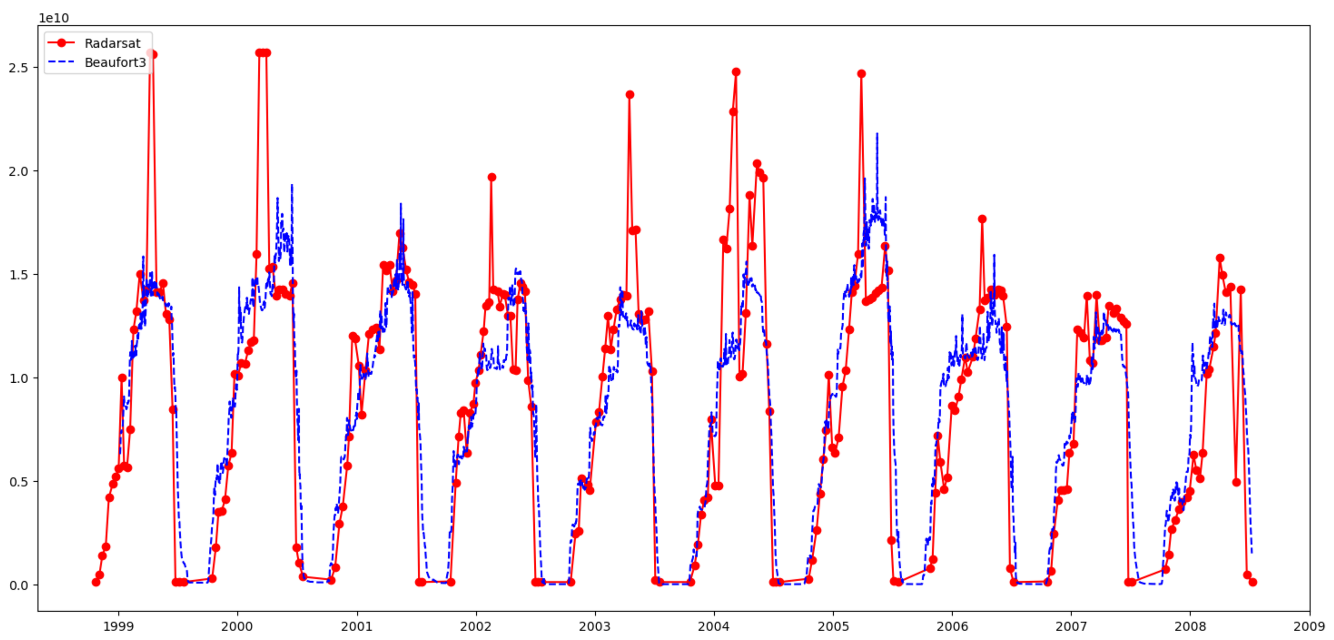

Figure 4. Comparison of observed (dots) and modeled (dashed) landfast ice extent in the 0.5 km domain for the first 9.5 years of the simulation. The observations are from Andy Mahoney, using Radarsat images pieced together to make up cloud-free estimates of ice motion so each dot could represent up to three weeks duration.

Results

Sea-ice extent for the three domains is compared with that from NSIDC (Comiso, 2017) in Figure 2. While the model has some skill, it is perhaps surprising that the Arctic domain is most skillful in the 3 km domain, more skillful than the 3 km domain itself. All three model domains do worse in the 0.5 km region, which might also be surprising until one considers the resolution of the "truth" we're comparing to, shown in Figure 3. Sea-ice contains much smaller features than can be represented by the 25 km gridded product available.

Especially evident in the lower panels of Figure 3 is that the model contains much smaller features, including a narrow band of 100% ice cover right at the shore, likely already landfast in November. We can compare the model's landfast ice extent to Andy Mahoney's estimate based on Radarsat images, see Figure 4. The landfast parameterization does well since it was tuned for the Arctic and is based on the bathymetry. Still, it is clear that the model is missing some large-scale lock-up events. Lemieux has since explored tweaks to the ice rheology to improve its performance in places such as the Kara sea. We would like to bring these tweaks into our model as well.

Figure 5 shows a comparison of volume, heat, and fresh water fluxes across a transect spanning the Bering Strait with data from moorings. The model has considerable skill at reproducing the interannual variability in transport. It does however have biases in the heat and salt transports. Not shown are various other comparisons to tide gauges and other moorings, showing similar model successes and shortcomings.

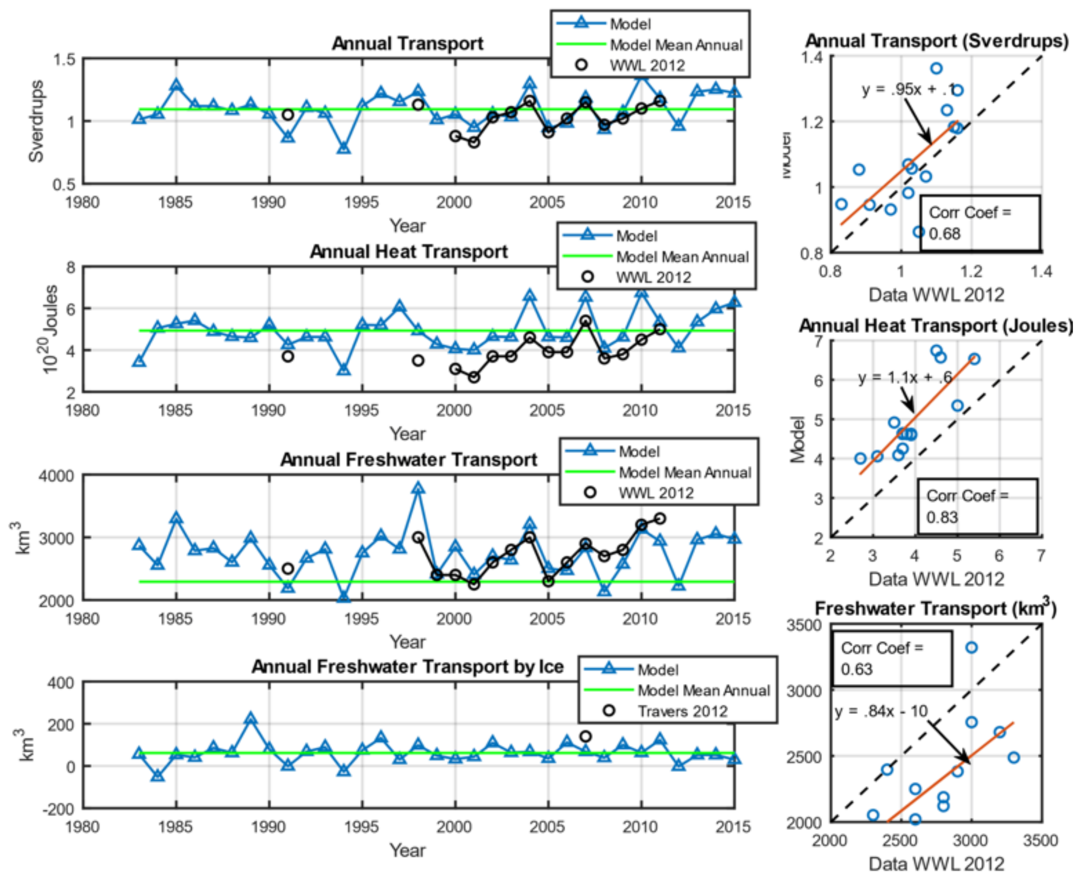

Figure 5. Comparison of annually averaged volume, heat, fresh water and ice freshwater transports (ordered from top to bottom, respectively) as depicted by the PAROMS model and observations. Time series are shown at the left over 1983-2015; scatterplots of the volume, heat and fresh water transports are shown in the right-hand column along with the regression equations and correlation coefficients. Abbreviation: WWL 2012 refers to Woodgate, 2012.

Conclusions

Three model improvements have allowed us to run nested domains with sea-ice for the first time:

* Landfast ice parameterization
* Warm river sources
* Sea ice boundary conditions and climatology nudging

A forthcoming report will contain more model-data comparisons.

Future Plans

We plan to rerun the pan-Arctic domain with improved bathymetry and atmospheric forcing, as well as with changes to the fresh water sources and tweaks to the sea-ice rheology. Also in the works:

* A pan-Arctic simulation with ROMS-CICE and the COBALT biogeochemical model (NSF).
* Adding open boundary conditions to MOM6-SIS2.
* A paper on these simulations.

Acknowledgments

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References

Comiso, J. 2017. Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS. Version 3. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center. doi:10.5067/7Q8HCCWS4I0R.

Danielson, S. L., E. L. Dobbins, M. Jakobsson, M. A. Johnson, T. J. Weingartner, W. J. Williams, and Y. Zarayskaya (2015), Sounding the northern seas, Eos, 96, doi:10.1029/2015EO040975. Published on 29 December 2015.

Kasper, J., and T.J. Weingartner, 2012, Modeling winter circulation under landfast ice: The interaction of winds with landfast ice, J. of Geophys. Res. 117, C04006, pp 14, doi:10.1029/2011JC007649.

Lemieux, J.-F., L. B. Tremblay, F. Dupont, M. Plante, G. C. Smith, and D. Dumont (2015), A basal stress parameterization for modeling landfast ice, J. Geophys. Res. Oceans, 120, 3157–3173, doi:10.1002/2014JC010678.

Whitefield, J., Winsor, P., McClelland, J., & Menemenlis, D. (2015). A new river discharge and river temperature climatology data set for the pan-Arctic region. Ocean Modelling, 88, 1-15. doi: 10.1016/j.ocemod.2014.12.012.