Arctic Shelf and Large Rivers Seamless Nesting in Global HYCOM

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LONG-TERM GOALS

The main scientific and technical objective of the proposed work is to implement river mass flux and temperature flux boundary conditions, as well as two-way nesting to improve the representation of large river plumes and Arctic Ocean ice melt water runoff (land ice and glacier) in global HYCOM and to improve the predictability in coastal regions, the Arctic Ocean, and the Atlantic Ocean. This is needed because fresh water inputs such as rivers and ice melt are poorly represented in global HYCOM since many of the processes associated with river plume dynamics and ice melt remain unresolved. Emphasis will be placed on the fresh water plume dynamics and offshore circulation dynamics, as well as how the rivers impact the seasonal ice melt. We anticipate that the more accurate treatment of the river inflow and embedded two-way nested higher resolution local models will translate into improved river plume dynamics. To assess the fidelity of the inner nests and boundary conditions, we will compare our simulations to all available observations.

OBJECTIVES

The overall objective is to investigate the fate and pathways of fresh water in the pan-Arctic system in order to assess the role of fresh water in the current changes of the Arctic ocean-sea ice system. One way this will be achieved is through the implementation of two-way nesting in the Hybrid Coordinate Ocean Model (HYCOM), which will improve the representation of the large river plumes and ice melt water runoff (land ice and glacier) in coastal areas of the global and Arctic Cap HYCOM in order to advance the predictability of coastal regions, the Arctic Ocean, and the sub-Arctic Seas.

The specific objectives are to:

- Evaluate the performance of the GOFS and Arctic Cap using available hydrographic and sea ice observations in terms of ocean basin-scale circulation, distribution of major water masses with particular focus on the Beaufort Gyre, and characteristics of sea ice on the shelf and interior basin.
- Implement river mass flux and temperature flux boundary conditions to HYCOM.
- Develop and evaluate a two-way HYCOM-HYCOM nesting.
- Implement coupled CICE in nested HYCOM system.
- Parameterize land-fast ice in HYCOM.

- Apply two-way nested modeling systems to:
  - investigate and improve the fate and pathways of river and meltwater runoff on the Arctic shelves, coastal region, Arctic Ocean, and sub-Arctic seas;
  - quantify the impact of fresh water on thermohaline processes on the Arctic shelves such as convection and water mass formation, heat exchange between deep and upper ocean layers, sea ice formation and melting;
  - assess the impact of fresh water input on the Arctic Ocean mixed layer (depth, thermohaline characteristics, water column stability).
  - evaluate sea ice formation and melting processes on the shelf under different fresh water content conditions.
  - analyze the fresh water plume dynamics in the two-way nested models and compare it to the current GOFS HYCOM; and
  - explore parameterizations of the fresh water dynamics and mixing implicitly resolved by the high-resolution shelf nests for the coarser global model to improve simulation and predictability of the shelf processes.
- Evaluate the benefit of using a nested super-high resolution (<500 m) model of the Arctic shelf seas with the unstructured-grid Finite-Volume Community Ocean Model (FVCOM) instead of a HYCOM-HYCOM nest.
- Incorporate HYCOM (replacing NCOM) in the COAMPS Arctic System.

To note, the specific objectives include tasks to be divided between NRL and Florida State University, our collaborators on this project.

APPROACH

The approach is to use downscaling (nesting) that include 2-way interaction between grids and more accurate representation of fresh water inputs to improve numerical simulations where processes associated with fresh water inputs are of order one importance, such as the Arctic. Indeed, simulation of the hydrodynamic processes on the Arctic shelves is challenging due to a number of factors. Among these are: coastal line with a complex geometry, presence of land-fast ice, seasonal ice cover, formation of polynyas and formation of water masses. Estimates of the baroclinic deformation (Rossby) radii have small (<1 km) values over most of the Arctic shelves (Fig. 1). In order to adequately describe boundary currents, river plumes, and the eddy field, a model horizontal resolution should be at least two grid points per Rossby radius of deformation. The approach is to use two-way nesting to quantify the impact of a better representation of fresh water pathways on the Arctic shelves and fresh water flux to the Arctic interior. First, a high resolution (O(1 km)) HYCOM-to-HYCOM nest will be implemented, not only to provide better resolution of the shelves but also to improve river mass and temperature fluxes. The configuration will allow for the quantification of the impact of a better representation of fresh water pathways on the Arctic shelves and fresh water flux to the Arctic interior. The nested shelf model will have improved representation of the river runoff including mass flux and heat flux associated with river water temperature. The nested modeling system will be evaluated against in situ and satellites observations (ocean color, sea ice extent). The developed two-way nested modeling system will be employed to: (1) determine transport pathways and fate of fresh water on the shelves, (2) characterize ocean-shelf fresh water flux, and (3) evaluate the influence, over the Arctic shelves, of continental runoff on thermohaline processes and sea ice formation. The results from the

nested models will be compared to the outputs from the current Arctic Cap and global HYCOM in order to assess the benefit of high-resolution nesting of the shelf regions.

WORK COMPLETED

Validation of existing Arctic HYCOM simulations

An evaluation of the water mass properties and circulation pathways in the Arctic Ocean and Subpolar regions was performed using output from a multi-year free-running (non-assimilative) and reanalysis (assimilative) version of 1/12° global HYCOM forced with the NCEP Climate Forecast System Reanalysis (CFSR). These global simulations are based on the GOFS 3.0 configuration, and as such both use an energy loan approximation to account for sea ice rather than a dynamical ice model. The initial evaluation focused on the model's representation of the Atlantic water, both in terms of thickness and depth from the surface (Figure 1).

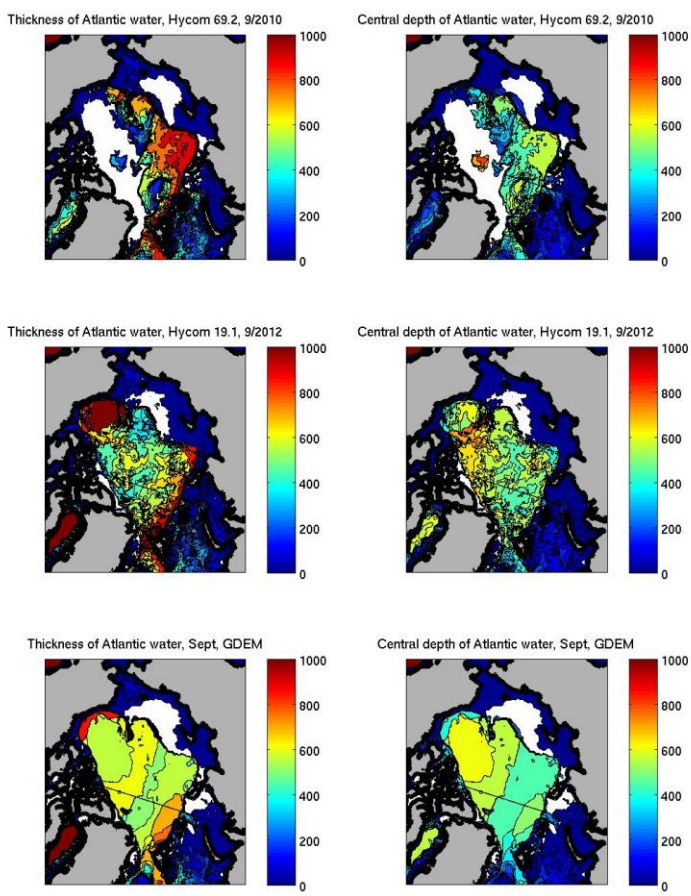

Figure 1. Comparison of the thickness and central depth of the Atlantic Mode Water between non-assimilative global HYCOM (top left and right, respectively), assimilative HYCOM reanalysis (middle

left and right, respectively) and GDEM climatology (bottom left and right, respectively) during September 2010.

In the Arctic, the Atlantic water is characterized by warmer and more saline properties relative to the surrounding ambient water masses. Indeed, by definition the Atlantic water is defined as the water mass bounded by the 0° isotherm (both above and below). As shown in the top panels of Figure 1, the non-assimilative configuration of the global model did not accurately represent the presence of the Atlantic water in the Beaufort Gyre region relative to climatology. The assimilative reanalysis on the other hand (middle panels of figure 1), were in much better agreement with the GDEM climatology (bottom panels of figure 1).

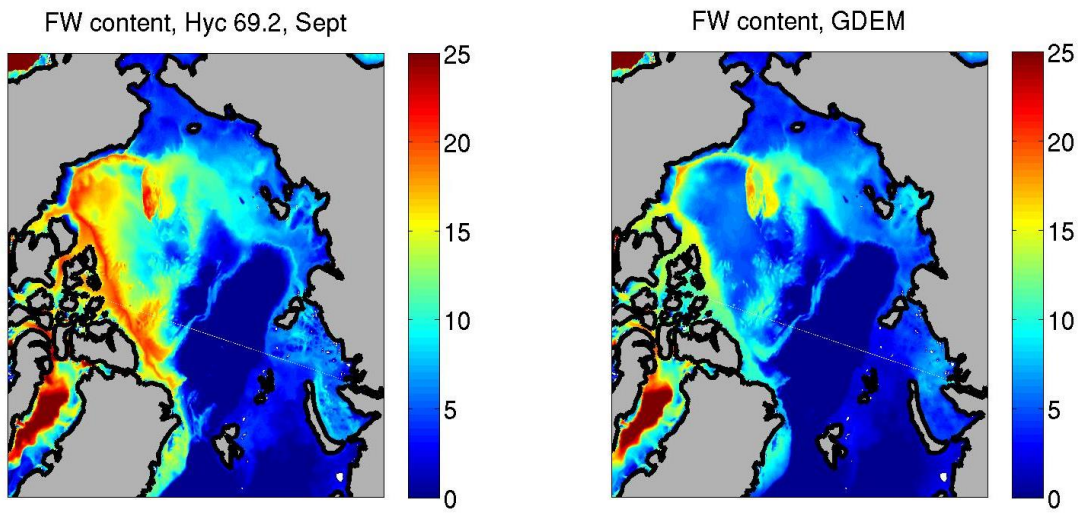

Figure 2. Fresh water content in global HYCOM (left) vs. GDEM climatology (right). For both, the fresh water content is calculated relative to 34.8 PSU.

To evaluate the circulation pathways and freshwater transports through the Arctic, both volume transports and freshwater (FW) transports were examined at all of the input/output sources, as defined by the sections shown in Figure 2. Here, freshwater transports are calculated at each transect relative to a salinity of 34.8 PSU and the cross-transect velocity is used to define the volume transport.

The results averaged over 2003-2012 are as follows:

Bering Strait:

Volume transport from HYCOM: 0.8 Sv
Volume transport from Woodgate et al. (2005): 0.8 Sv
Volume transport from Rudels et al. (2015): 0.8 Sv
Volume transport from Dickson et al. (2007): 0.8 Sv.
FW transport from HYCOM: 0.71 mSv
FW transport (Rudels et al.) 0.78 mSv

Fram Strait:

The transport through the Fram Strait consists of both northward and southward components, as well as episodic recirculation. It is strongly latitude dependent, due to recirculation of portions of the West Spitzbergen Current within the strait.

Volume transport:

Schauer et al. (2004) report the net volume transport at 78.5N is ~9-10 Sv northward and ~12-13 Sv southward, i.e. the net volume transport is ~-2-4 Sv (net outflow)

Rudels et al. (2015) report net volume transport of -2.3 Sv (net outflow).

HYCOM has a net volume transport of ~9 Sv northward and ~10 Sv southward for a net volume transport of ~-1 Sv (net outflow).

FW transport:

Rabe et al. (2013) report net freshwater outflow of 100 mSv.

Rudels et al. (2015) report net freshwater outflow of 100 mSv.

HYCOM has net freshwater outflow of 45 mSv.

Barents Sea:

Volume transport:

Smedsrud (2010) reports 2.0 Sv eastward (net inflow).

Rudels et al (2015) estimate ~3.3 Sv eastward (net inflow).

HYCOM net inflow is ~0.7 SV.

FW transport:

Rudels et al. (2015) estimates net freshwater inflow of 20 mSv.

HYCOM has net freshwater OUTFLOW of -10 mSv: although HYCOM has a net inflow of volume, that volume is saltier than the reference density of 34.8, and thus the net effect is outflow of freshwater.

For the other straits, HYCOM largely agree with the observation, i.e. flow into Baffin Bay through the Barrow and Nares Straits, and flow out of Baffin Bay through the Davis Strait.

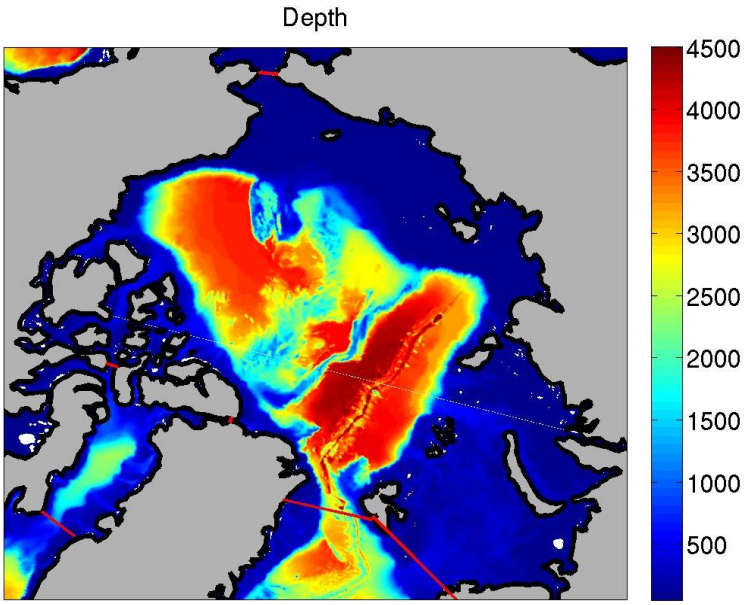

Figure 3. Map showing sections across which the freshwater volume transport has been calculated.

Implementation of Arctic Cap HYCOM consistent with GOFS 3.1

A new 1/12 °Arctic Cap domain has been implemented to be consistent with GOFS 3.1, meaning it is coupled to the CICE ice model and has higher vertical resolution than the version that was consistent with GOFS 3.0. This model was initialized on 02 December 2010 from the GOFS 3.0-like reanalysis (the same simulation shown in the middle panels of figure 1), is forced through the lateral boundaries from the same reanalysis, and is forced at the surface with NAVGEM 1.3 winds and heat fluxes. A depiction of the surface salinity on 27 July, 2012 is shown in figure 4. The impact of fresh water inflows near the river mouths are evident.

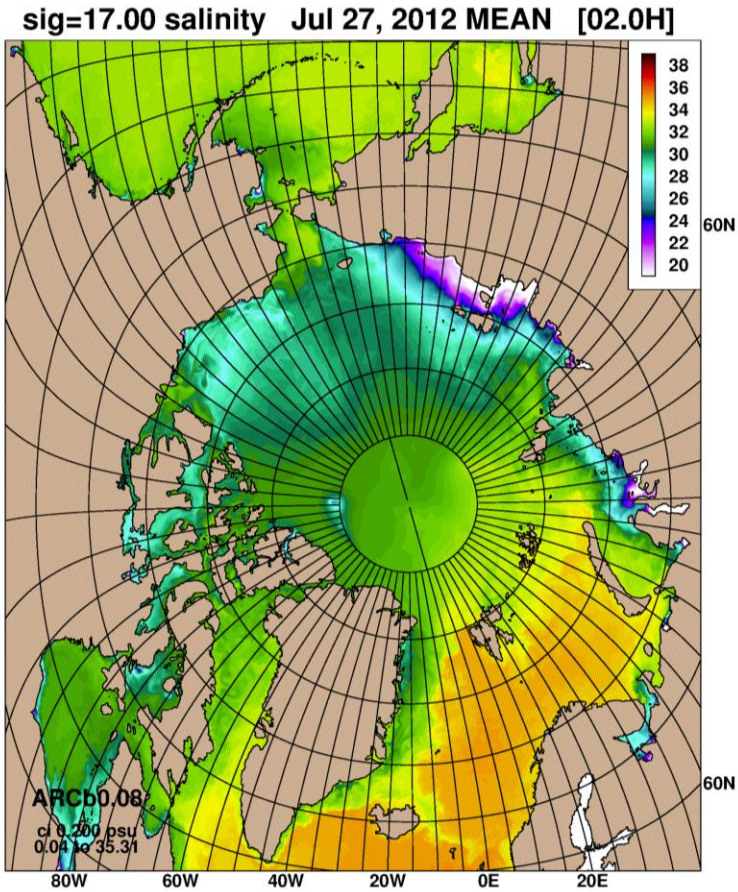

Figure 4. Surface Salinity on 27 July, 2012 from the 1/12° Arctic Cap model.

The Arctic Cap configuration will be used for several purposes, including investigating (1) the freshwater pathways and water mass distributions in the Arctic Ocean, (2) the impact of low vs. high frequency fresh water inputs, (3) implementing higher resolution HYCOM to HYCOM nests near the river mouths and ice melt locations, (4) process studies such as ice dam breaks on downstream circulation impacts.

Implementation and testing of improved fresh water mass fluxes

The current operational version of GOFS (3.0) and the soon to be transitioned GOFS 3.1 treat freshwater (river) flux input into HYCOM is parameterized as a virtual salt flux similar to evaporation and precipitation. The salt flux is distributed across a number of grid points and layers to approximate coastal plume dynamics. To adequately model coastal plume dynamics, the treatment of the riverine freshwater flux has been changed from a virtual salt flux to a mass flux. To date, this is still being treated as a surface flux, but this will be implemented as a lateral boundary flux in FY17. In addition, high frequency (say, daily vs. monthly climatology) freshwater inputs are now allowed in HYCOM. Both the surface mass flux and daily rivers have been implemented and tested in 1/25° configuration of

the Gulf of Mexico. The high frequency freshwater input allows short term fluctuations to be included, which are typically completely missed in climatological inputs (Figure 5).

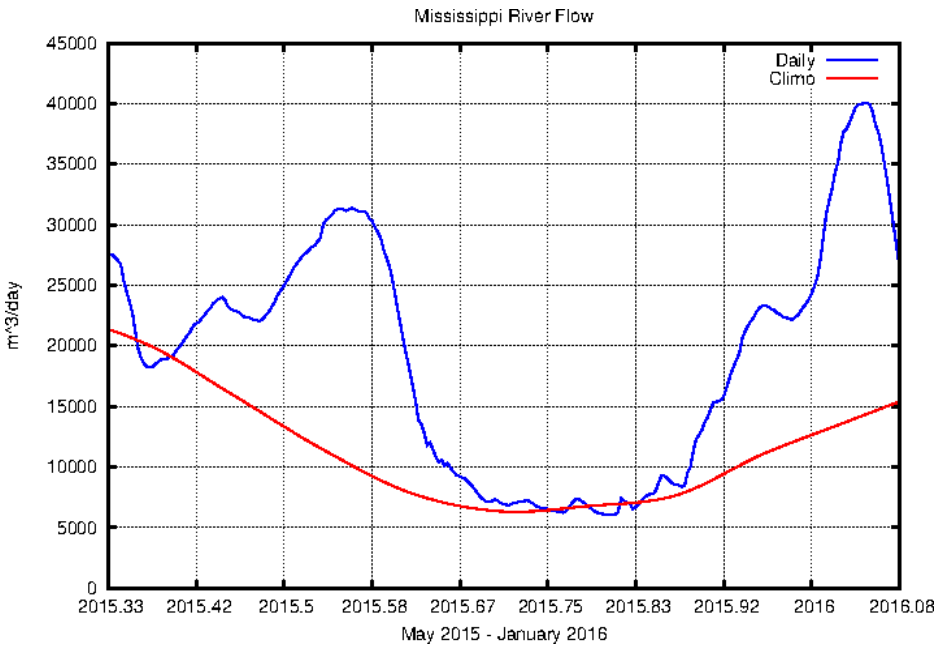

Figure 5. Mississippi River inflow into the Gulf of Mexico derived from monthly climatology (red) and daily rivers from tide gauge stations (blue) during May 2015 – January 2018.

Daily river forcing for the major rivers in the Arctic have been acquired. Time series of the daily vs. monthly inputs are show in figure 6.

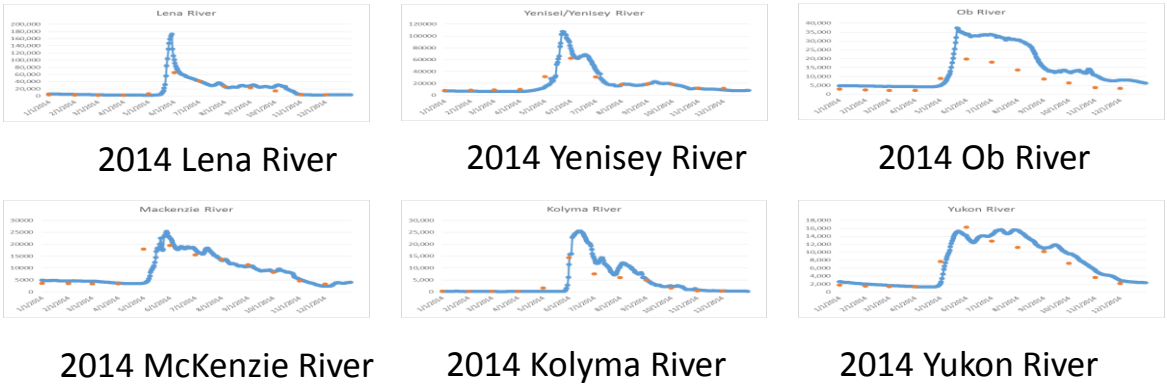

Figure 6. Daily (blue line) vs. monthly average (red dots) for the major rivers in the Arctic region during 2014.

RESULTS

- Assessment of 1/12° assimilative (reanalysis) and non-assimilative (free-running) global HYCOM relative to GDEM climatology.

- Implementation and testing of 1/12° Arctic Cap HYCOM-CICE domain for nesting and process studies.
- Implementation and testing of rivers as a surface mass flux.
- Implementation and testing of high-frequency (daily) river inputs.

IMPACT/APPLICATIONS

N/A

TRANSITIONS

None.

RELATED PROJECTS

This project is a collaborative effort with activities taking place at FSU COAPS under Eric Chassignet. Partnering projects at NRL include 6.1 Determining the Impact of Sea Ice Thickness on the Arctic's Naturally Changing Environment (DISTANCE) and and 6.4 Ice Modeling Assimilation from Satellites. The computational effort is strongly supported by DoD HPC Challenge and NRL non-challenge grants of computer time.

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PUBLICATIONS

None.