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Arctic Shelf and Large Rivers Seamless Nesting in Global HYCOM

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LONG-TERM GOALS

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 are unresolved. 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. To assess the fidelity of the inner nests and boundary conditions, we will compare our simulations to all available observations. 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.

OBJECTIVES

The overall goal of this work 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. The technical objective of the proposed work is to implement two-way nesting in HYCOM that 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 in 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.

The above objectives are to be realized in partnership with the Naval Reserach Laboratory (see separate report by P. Hogan)

APPROACH

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. 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 proposed approach will be 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. Then, the benefit of using a nested super-high resolution (< 1 km with less than 500 m near the coast) model of the Arctic shelf seas with the unstructured-grid Finite-Volume Community Ocean Model (FVCOM) instead of a HYCOM-HYCOM nest will be evaluated. Both nested shelf models will have improved representation of the river runoff including mass flux and heat flux associated with river water temperature. The nested modeling systems 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

Task 1: Validation and improvements of existing Arctic HYCOM simulations

The main objective of this task is to evaluate representation of the ocean thermohaline structure and circulation in the Arctic Ocean and Subpolar regions (north of the ~55° latitude) in the 1/12° HYCOM global reanalysis (GLBb0.08) from 1993 to 2012. Thermohaline structure of the Arctic Ocean and North Atlantic controls vertical and horizontal heat fluxes in the ocean and at the ocean surface, water mass formation, freshwater transport to the North Atlantic and convective processes there, sea ice freezing and melting. Previous evaluation of the not-assimilative regional Arctic Ocean HYCOM ("Arctic Cap") identified substantial biases in the thermohaline characteristics of the water masses in the Arctic Ocean. Representation of the Arctic Ocean in the existing global reanalysis has not been evaluated yet. The motivation for this analysis was the necessity to identify biases and their sources in the global reanalysis in order to improve representation of the Arctic Ocean region in the model. Specific goals of this investigation are 1) evaluate representation of the major water masses and their properties in the Arctic Ocean and Subpolar seas compared to climatology, other ocean reanalyses, and in situ observations; 2) evaluate trends in the Arctic Ocean variables (freshwater content and temperature) based on in situ observations; 3) analyze representation of the shelf processes and compare to available in situ observations; 4) compare ocean circulation against Argo floats and SSH-based large-scale geostropic currents. A summary of the preliminary results of the validation study is provided.

- *Reanalysis T/S fields are compared to the GDEM4 climatology*
  - Comparison identified cold and low S biases in the deep Canada Basin of the Arctic Ocean (Figs. 1 & 2), discrepancies in spreading of the Atlantic water in the Arctic Ocean basin (Fig. 3), and salinity biases in the deep layers in the North Atlantic (Fig. 4).
  - T/S profiles from GLBb0.08 were compared to the GDEM4 profiles in several regions The comparison identified substantial biases in the reanalysis fields. For example, in Canada Basin and Eurasian Basin, the temperature has negative bias in the Atlantic layer. In Eurasian Basin, the reanalysis demonstrates some improvement in the temperature of the Atlantic layer In the central Greenland Sea, seasonal variability of thermohaline characteristics is not well captured in the reanalysis compared to the GDEM4.

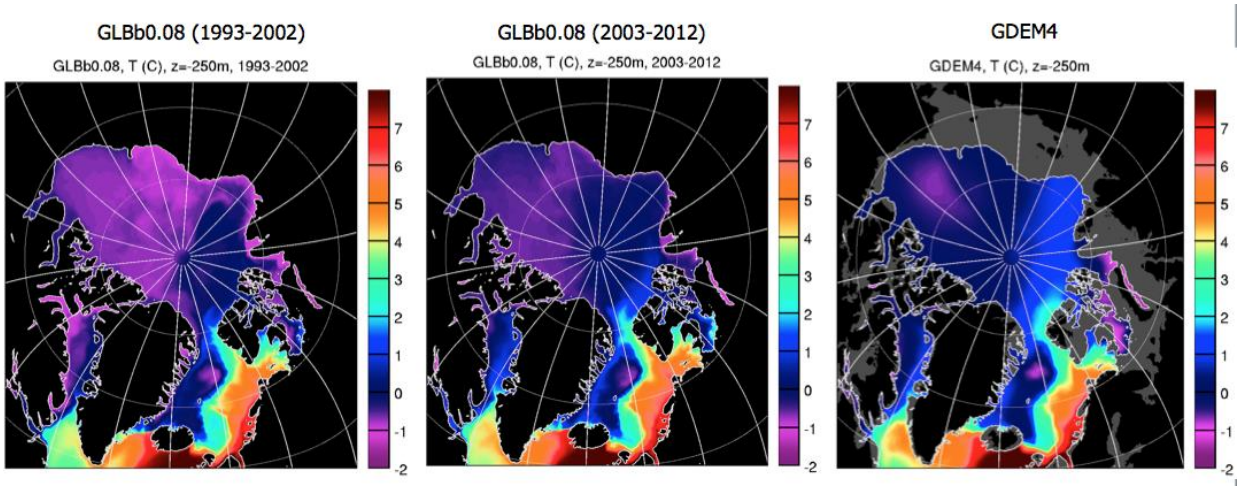

Figure 1. Temperature fields at 250 m from GLBb0.08 averaged over 1993-2002 (left) and 2003-2012 (middle) and GDEM4 (right).

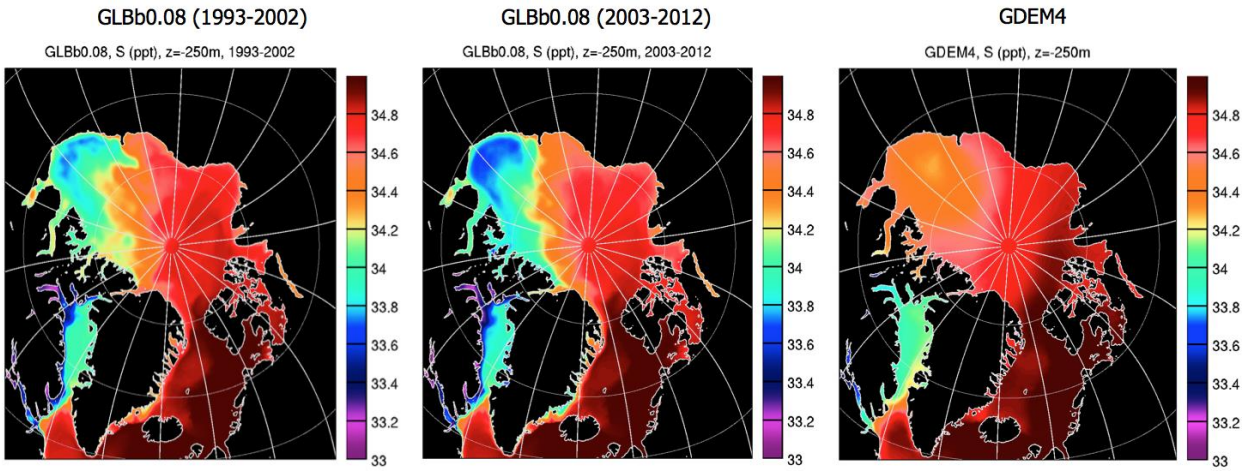

Figure 2. Salinity fields at 250 m from GLBb0.08 averaged over 1993-2002 (left) and 2003-2012 (middle) and GDEM4 (right).

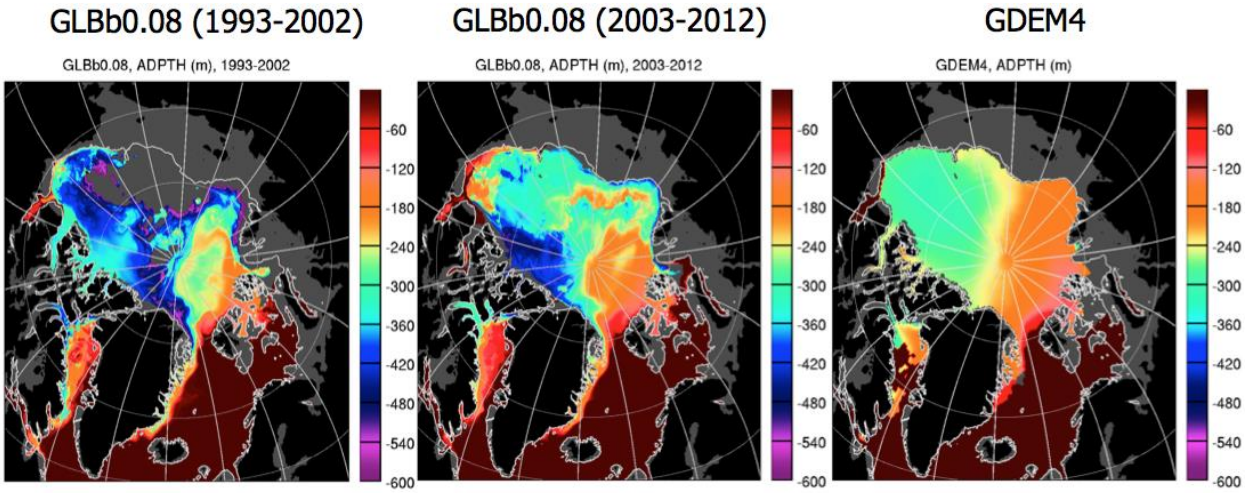

Figure 3. Depth of the top of the Atlantic layer (defined as the uppermost isosurface T>0C below the mixed layer).

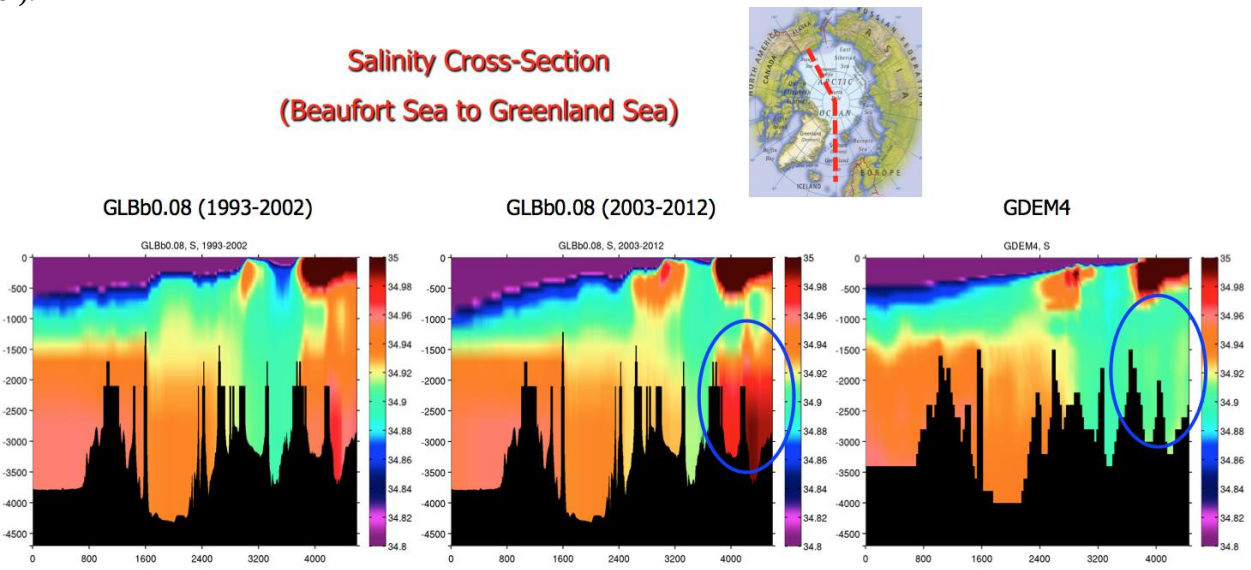

Figure 4. Vertical distribution of S along the Arctic Ocean – North Atlantic section from GLBb0.08 1993-2002 (left), 2003-2012 (middle), and GDEM4 climatology (right).

- *Reanalysis T/S fields are compared to in situ observations to further evaluate discrepancies in the simulated thermohaline fields.*
  - annual freshwater content (FWC) in the Beaufort Gyre was compared to the FWC constructed from BGOS observations. GLBb0.08 reanalysis simulates growing FWC in the Beaufort Gyre in agreement with BGOS observations
  - The FWC maximum is higher and the location of the maximum is shifted compared to the BGOS observations.
  - Reanalysis S profiles in the southern Norway Sea are positively biased (in agreement with Figure 4). The positive S bias increases during the simulation.

- *Representation of thermohaline fields in shelf areas: Reanalysis T/S fields are compared against available in situ observations in the Kara Sea, Laptev Sea, Chukchi Sea, Bering Strait, Beuafort Sea shelf area.*
  - Comparison of the T/S profiles in the shelf seas demonstrates low skills of GLBb0.08 to reproduce major water masses in the shelf areas especially closer to the coast line, estuaries and river sources.

- *In order to determine the source of the T/S biases in the reanalysis fields, the initial T/S fields have been analyzed*
  - The initial fields have strong negative T bias in the Atlantic layer in the Arctic Ocean basin. This resulted in the negative T bias in this layer in the reanalysis (shown in Figs. 1 & 3).
  - The negative S bias in Canada Basin at 250 m (Fig. 2) also exists in the initial fields. However the negative bias strengthens through the reanalysis run. The causes of this negative S drift in this layer are being investigated.

Task 2: Freshwater pathways in the Arctic and sub-Arctic seas

In order to address the above goals, we have been working on setting up the 0.08-degree coupled HYCOM-CICE for the Arctic Ocean domain (hereinafter referenced as AO HYCOM-CICE) with improved bathymetry and vertical grid based on the configuration described in Dukhovskoy et al. (2016). The new configuration of the AO HYCOM-CICE uses topography T11 and 41 hybrid layers similar to the GOFS3.1. The plan is to nest AO HYCOM-CICE within the GLBb0.08 reanalysis. This configuration will be used to study freshwater pathways in the Arctic Ocean and North Atlantic tracking propagation of river and melt water from sources by employing passive tracer capability of HYCOM as in Dukhovskoy et al., (2016). Locations of these "fresh water (FW)" tracer release are shown in Fig. 5. The simulation will be performed for the time period from 1993 – 2014.

Comparison of T09 (used in the old configuration of the AO HYCOM-CICE in [Dukhovskoy et al., 2016]) and T11:
There are minor differences in the topographies in the deep ocean basins. The major difference is the shallower coastline (5 m) in T11 vs 10 m in T09. Both topographic data sets have erroneously closed Fury and Hecla Strait that connects Foxe Basin and the Gulf of Boothia. This influences water exchange between the CAA region and the Labrador Sea. This has to be fixed in the future.

Comparison of 32 and 41-layer vertical grids:

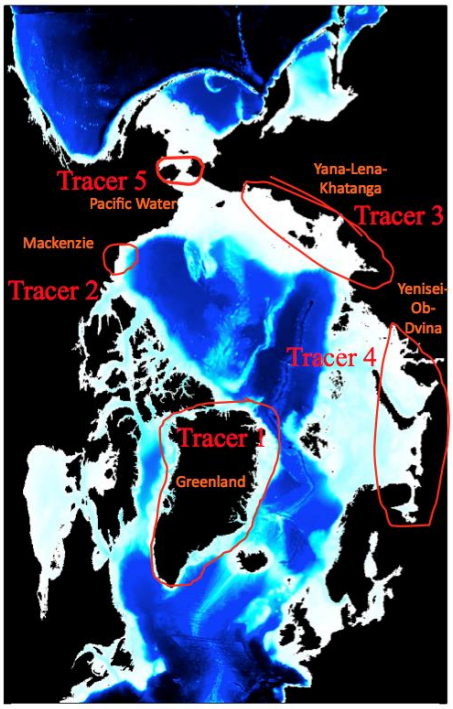

Figure 5. Locations of FW tracer release in the AO HYCOM-CICE experiment to study freshwater pathways in the Arctic Ocean – North Atlantic.

The 41-layer grid has more layers in the upper ocean. Below sigma layer of 35.5, both grids match. Note that the 41 layer grid is still geopotential (z-level) in the Arctic Ocean. In the future, the regional Arctic Ocean HYCOM should use different set of target densities to use the benefit of isopycnal layers for better representation of the Arctic water masses (Fig. 6).

The following tasks need to be completed in order to perform the proposed experiments:

1) GLBb0.08 reanalysis does not provide sea ice fields necessary for initialization of the AO HYCOM-CICE, initial sea ice fields need to be prepared;
2) GLBb0.08 employs topography T07 and has 32 vertical layers, nest fields have to be interpolated into ARCc0.08 grid with T11 topography and 41 hybrid layers.
3) Preliminary results of the validation analysis show substantial biases in the thermohaline fields of the Arctic Ocean (Figs. 1–4), initial fields that better represent the major water masses are needed.

- *For the sea ice initial fields, PIOMAS reanalysis is used to create CICE restart fields*

- PIOMAS fields are interpolated into ARCc0.08.
- PIOMAS sea ice and snow thickness and area are redistributed within the categories and layers according to the CICE configuration used in the AO HYCOM-CICE experiments, iIce and snow enthalpie fields are estimated.
- Test runs with created CICE restart files are currently performed.

- *Development of the GLBb0.08 – AO HYCOM-CICE nesting: an automated algorithm for preparation nest files from GLBb0.08 reanalysis*

- Nest files for the AO HYCOM-CICE simulation are prepared from the GLBb0.08 reanalysis. The algorithm has been developed that can be run offline (preparing nest files before the simulation)

or “on the run” (during the model integration, can prepare individual nest fields for specified date).

- The algorithm includes the following steps:
  (1) GLBb0.08 fields are mapped onto the ARCc0.08 grid;
  (2) Interpolation from T07 to T11;
  (3) Interpolation from 32 to 41 layers.
- The algorithm has been developed and currently nest fields are being prepared
- Test simulations with the new nest files have been successfully performed.

- *FW pathways: experiment with AO HYCOM-CICE*

- A 1-year test simulation with FW passive tracers have been run with constant OB and no cice restart file (Fig. 7).

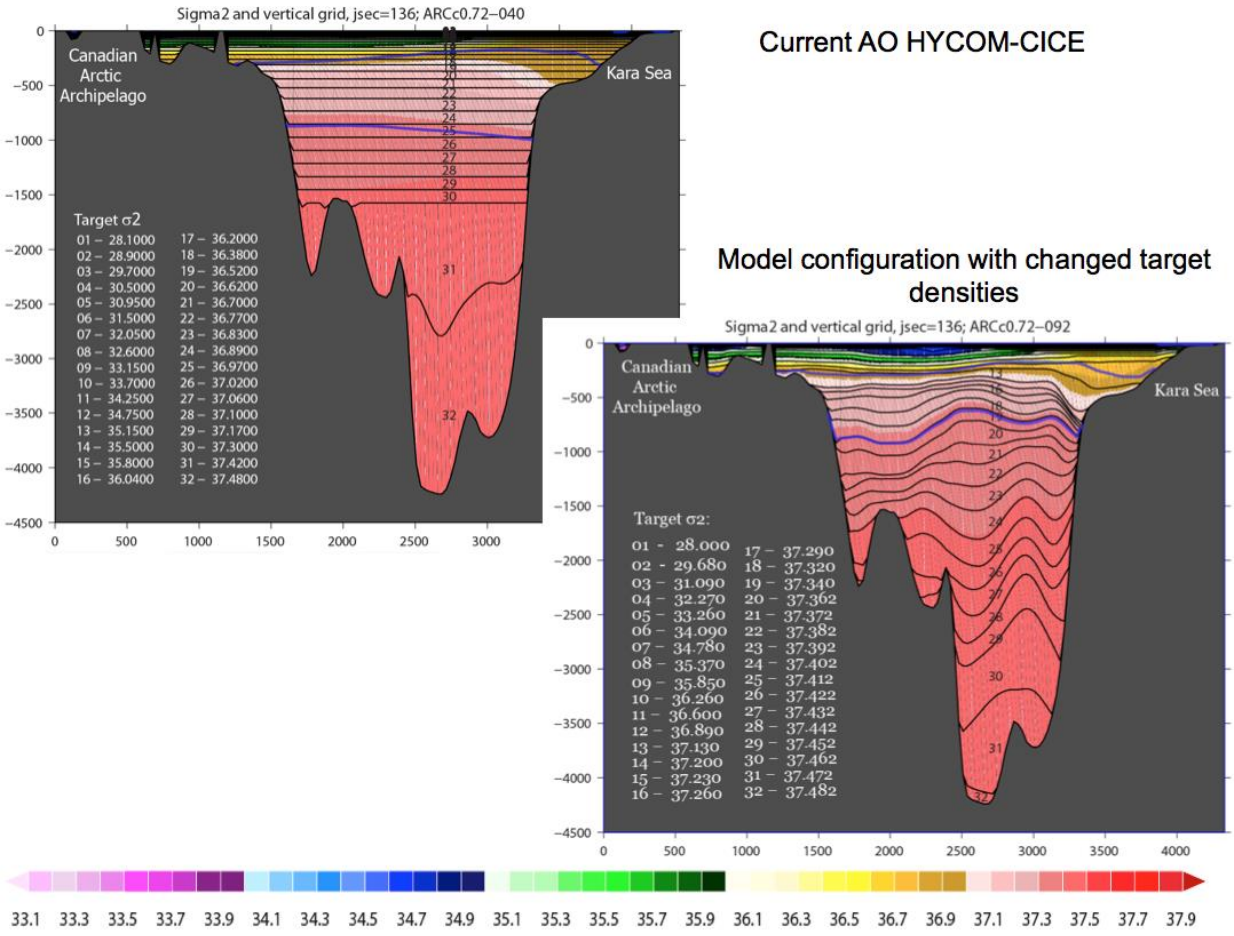

Figure 6. Distribution of the vertical layers with different target densities. Top left: 32 layers in the AO HYCOM-CICE in Dukhovskoy et al. (2016). Bottom right: modified target densities result in isopycnal layers through most of the water column and provide a better representation of the Atlantic layer (blue lines).

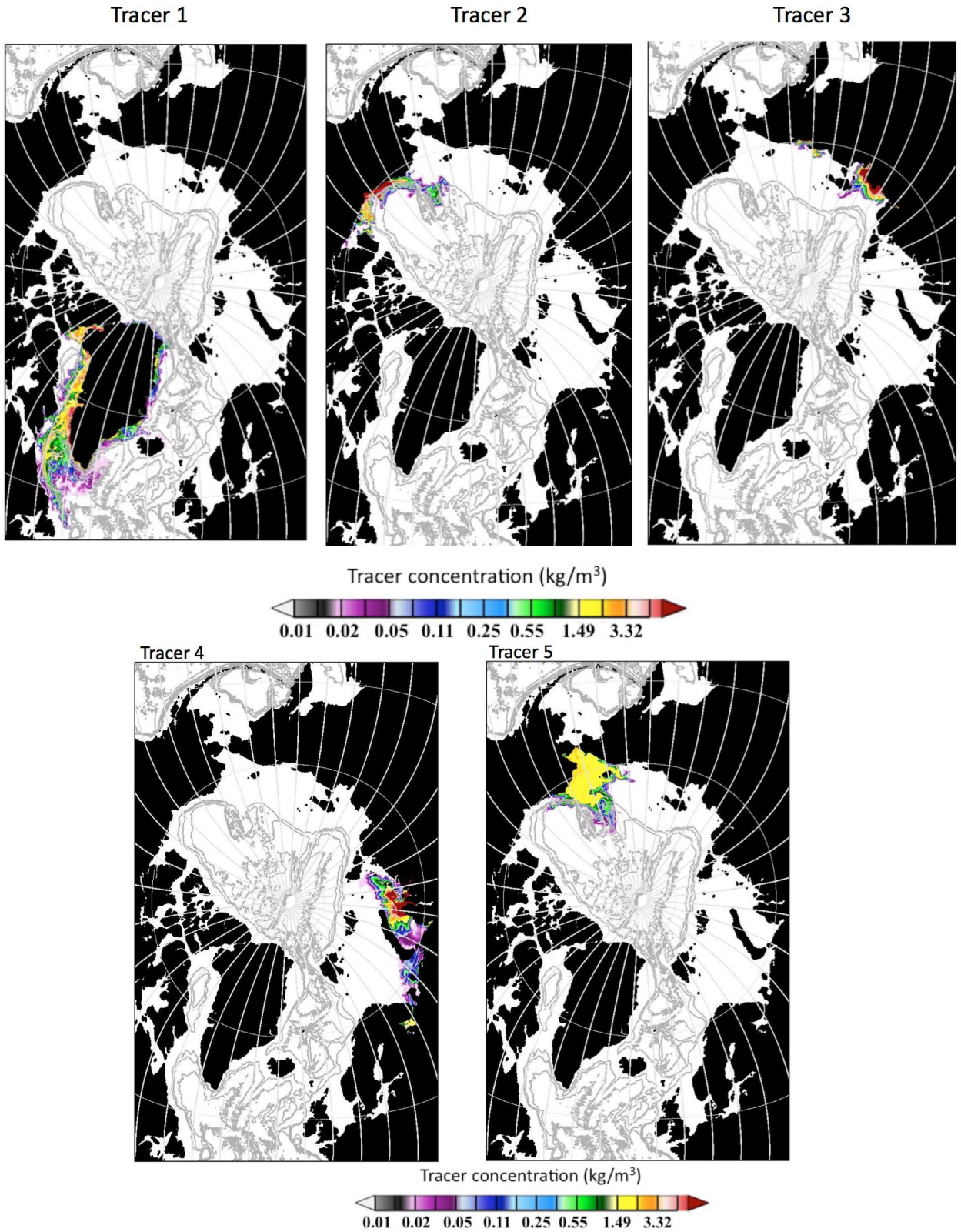

Figure 7. Concentration of passive tracers after 1 year of the test simulation.

RESULTS

- Validation of 1/12° HYCOM global reanalysis (GLBb0.08) from 1993 to 2012.
- Configuration of a 0.08-degree coupled HYCOM-CICE for the Arctic Ocean to study freshwater pathways

RELATED PROJECTS

This project builds on the core model development activities taking place at the Naval Research Laboratory (see annual report by P. Hogan).

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