An Integration and Evaluation Framework for ESPC Coupled Models

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Award Number: N00014-13-1-0508
http:// http://www.earthsystemcog.org/projects/espc-infrastructure/

LONG-TERM GOALS

To realize its potential, a U.S. Earth system modeling and prediction capability must encompass a network of agencies and organizations that contribute model components, infrastructure, and scientific and technical expertise. The model component contributions must be integrated using coupling software, the coupled systems optimized for emerging computing platforms, and the predictive skill of the resulting models assessed using standard metrics. We propose to provide these integrative functions for the Earth System Prediction Capability (ESPC), using as a reference application a version of the Community Earth System Model (CESM) running an optimized version of the HYbrid Coordinate Ocean Model (HYCOM).

OBJECTIVES

The objectives of our work are:

- To establish an ESPC Coupling Testbed that allows for collaborative research into coupling technologies, and use it to prototype multi-model optimization techniques focused on computing systems with accelerator technologies.
- To support migration of optimization strategies from the ESPC Coupling Testbed to infrastructure packages and coupled model applications, and provide support for coupling of optimized components in the ESPC program.
- To update a newly coupled CESM-HYCOM model configuration with an optimized version of HYCOM and assess the coupled system performance.
- To evaluate the CESM-HYCOM model using standard measures of predictive skill, and promote the usage of standard metrics by other models in the program.
- To extend ESPC-related computational committees to address new requirements driven by changes in computing architectures and program needs, and to initiate scientific committees.

APPROACH

RESULTS

HYCOM was implemented as an ESPC ocean component in a standalone configuration. In order to validate changes in the model, we are configuring and running HYCOM in CESM in several different configurations. Initial work was done using two low-resolution grids: the POP gx1v6 (~1º) grid, that was already available in the CESM set-up, and the HYCOM glbt0.72 (~0.72º) tripolar grid that has been especially implemented in the CESM set-up.

As a first step, the CESM passive ice component DICE was added to the standalone HYCOM. This new option allows HYCOM to evolve with a prescribed ice cover derived from SSMR/SSMI NSIDC climatology (Cavalieri et al., 1997). In addition to those changes, options to use a spatially varying sea surface salinity and/or temperature relaxation as well as a correction of the precipitation based on the global salinity have been introduced to comply with the POP simulation parameters used for comparison. Several 30-year runs of HYCOM have been performed with the CORE normal year atmospheric fields (Large and Yeager, 2009) to assess the sensitivity of the model to several parameters (reference pressure, thermobaricity, and isopycnal smoothing) and find the optimal parameters for HYCOM.

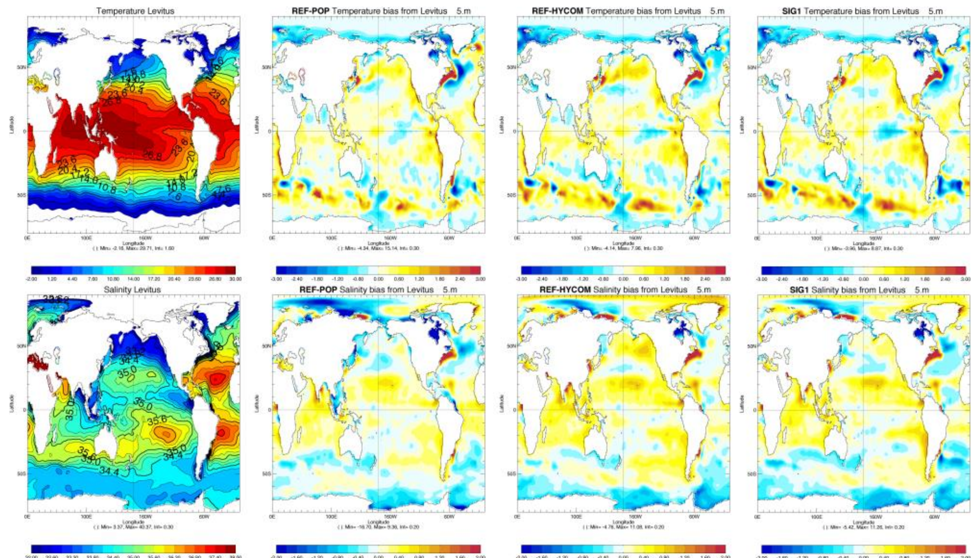

Figure 4. SST and SSS bias from Levitus PHC2 for POP (2nd column) and HYCOM-SIGMA2 (3rd column) and HYCOM-SIGMA1 (right column).

Figure 4 shows the SST and SSS biases of POP and HYCOM with a reference pressure at 2000 and 1000 meters, respectively. The three simulations exhibit similar features and intensity over the most part of the ocean except over the North Atlantic subpolar gyre region where HYCOM shows a cold bias and POP, a warm bias.

As second step, HYCOM was fully implemented in CESM as an alternative ocean component to POP. Starting with version 2.2.35 of HYCOM, we first focused on the proper implementation of the routine responsible for the exchange of fluxes between HYCOM and the ice and atmospheric components. We then updated HYCOM to the latest version available (2.2.98) and connected the river transport component. In addition, we implemented the latest HYCOM-CESM together with the latest version of ESMF (7.0.0beta60) on the NAVY DSRC machines, Kilrain (IBM iDataPlex), Shepard (Cray XC30) and Gordon (Cray XC40). A 20-year experiment forced the CORE normal year climatological fields was performed to ensure that HYCOM-CESM performed as expected when coupled with CICE only (G compset). When comparing HYCOM-CESM to POP-CESM simulations, we find that differences arise over the polar regions (Fig. 5). While the ice cover are in good agreement between the two models, HYCOM-CESM presents a thicker ice sheet on the Beaufort gyre than POP-CESM.

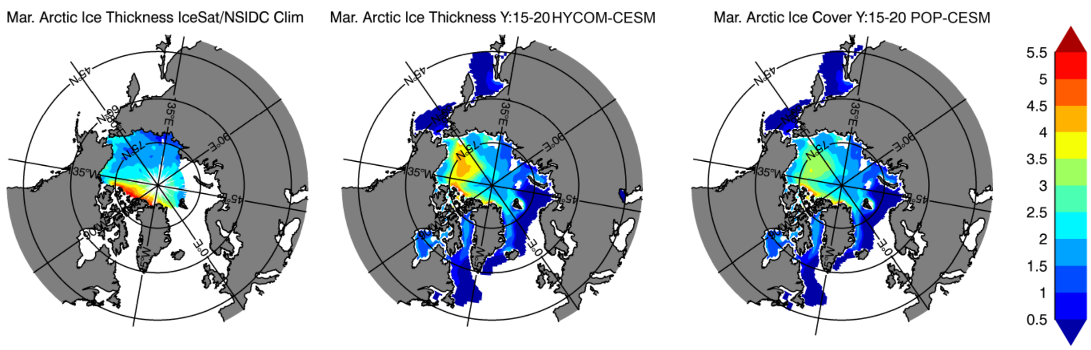

Figure 5. Ice thickness climatology from IceSat (left) and averaged over the last 5 years of simulation for HYCOM-CESM (middle) and POP-CESM (right).

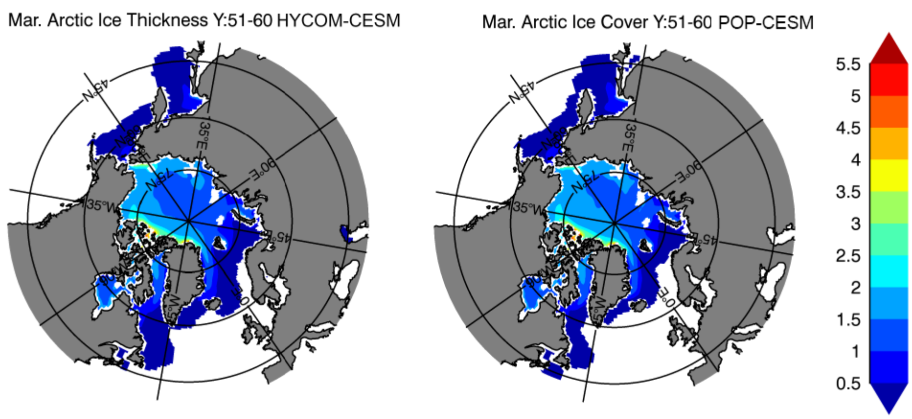

Figure 6. Ice thickness averaged over the last 10 years for HYCOM-CESM (left) and POP-CESM (right).

After performing sensitivity tests on different CICE constants and parameterizations that were set differently between the standalone HYCOM-CICE and HYCOM-CESM (i.e. snowpatch, ustar_scale, shortwave parameterizations), it was established that HYCOM-CESM produced more ice than POP-CESM when using the Delta-Eddington shortwave parameterization under the CORE normal year forcing. To ensure that these differences did not come from a technical mistake in the coupling process, a standalone HYCOM-CICE simulation was performed and compared to a HYCOM-CESM simulation using the same set of CICE parameters. The results showed almost identical ice thickness between HYCOM-CICE and HYCOM-CESM (not shown). Then, in order to properly compare the two models in a more realistic setting, a 60-year simulation was performed using the atmospheric CORE interannual forcing for each ocean model within the CESM (GIAF compset). Unlike with the CORE normal year forcing, the ice thickness averaged over the last 10 years of simulation in

HYCOM_CESM was very similar to the ice thickness in POP-CESM (Fig. 3) with even slightly less ice in the middle of the Beaufort Gyre in HYCOM-CESM compared to POP-CESM. The ice extent was however slightly higher in HYCOM-CESM, especially in the Labrador Sea Region and the Nordic Sea (Fig. 6).

On the ocean part, HYCOM-CESM's global temperature increases by 0.1ºC in 60 years whereas POP-CESM's global temperature stays almost constant over the whole time period (not shown). At the surface, HYCOM-CESM presents a saltier bias compared with POP-CESM but a similar bias in SST except in the North Pacific where HYCOM-CESM is warmer and the North Atlantic subpolar gyre where POP-CESM is warmer (Fig. 7). The maximum of Atlantic Meridional Overturning Circulation (AMOC) at 26.5ºN averaged over the last 10 years of simulations is 17.5Sv for POP-CESM and 9Sv for HYCOM-CESM, in agreement with the CORE-II HYCOM experiments (Danabasoglu et al., 2015) (not shown). In parallel to this study with the gx1v6 POP grid, the HYCOM GLBt0.72 tripolar grid (500x382) was also implemented and tested within CESM and showed overall comparable results with the gx1v6 grid HYCOM simulations.

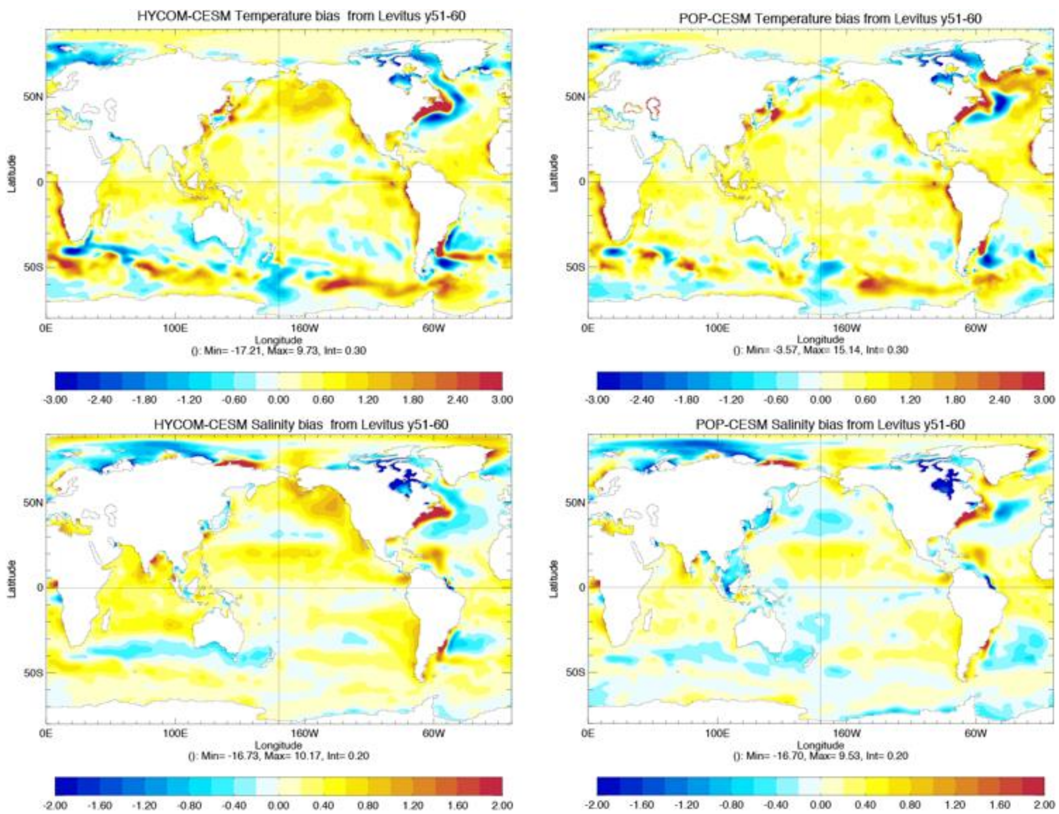

Figure7. SST (top) and SSS (bottom) bias from Levitus averaged over the last 10 years for HYCOM-CESM (left) and POP-CESM (right).

After validating HYCOM in an ocean-ice configuration, we then started to evaluate HYCOM into a coupled ocean-ice-atmosphere configuration. With CAM as an atmospheric model on a 1.9ºx2.5º grid, HYCOM on a gx1v6 grid and a GLBt0.72 grid is compared to POP on a gx1v6 grid. There is a larger ice cover extent in the HYCOM simulations than in POP-CESM especially in the Labrador Sea (not showed). Consequently, HYCOM presents a colder and fresher bias over the North Atlantic subpolar region (not showed). Concurrently, a high-resolution configuration using the 1/10º tx01v2 POP tripolar grid and a 0.47ºx0.63º atmospheric grid was set-up with HYCOM as the ocean model. The goals of this exercise are to 1) compare the HYCOM and POP ocean model in a high resolution framework, 2) to evaluate the HYCOM behavior on the 1/10º tripolar POP grid vs. running on the 1/12º HYCOM tripolar grid and finally 3) quantify the HYCOM 1/12º in CESM vs. ESPC (CAM vs. NAVGEM atmospheric model). The 1/10º tripolar POP grid HYCOM configuration is currently being run by Ben Kirtman (collaboration with the Infrastructure ESPC team.

Finally, we added a low-resolution configuration using a roughly 1º (T119) NAVGEM atmospheric grid and a 0.72º (GLBt0.72) ocean grid to the sample runs of the ESPC system to allow for easier testing (Collaboration with Jim Kinter). The ESPC ice-ocean coupling now allows for a full flux exchange instead of the usual partial coupling initially implemented by NRL. In addition, an automatic resubmission script has been added to the system to be able to run continuously month per month in long-term simulations.

Several performance tests performed with output frequency and configuration similar to the CESM-HYCOM above (i.e. ocean IO every day, ice-atm IO every month and 32 layers instead of 41 layers for HYCOM). We show that, for a 900procs (ocn/ice) + 96procs (atm) configuration, 1 simulated day takes 25-26 CPU minutes, and for a 1800procs + 96procs configuration, 1 simulated day in 19-20 min with a time step of 120 s/5 s. By comparison, 1 simulated day takes 13-14 min for CESM-HYCOM with the same time step.

IMPACT/APPLICATIONS

Through the actions of a succession of infrastructure projects in the Earth sciences over the last two decades, a common model architecture (CMA) has emerged in the U.S. modeling community. This has enabled coupled models to wrap high level model components in community-developed ESMF and NUOPC interfaces. The Earth System Prediction Suite (ESPS), a collection of multi-agency coupled weather and climate systems that complies with these interfaces and can more easily exchange components, is a tangible outcome of this coordination. A publication describing the ESPS, led by Navy contractor Gerhard Theurich, was published in BAMS in July 2016.

The ESPS is a direct response to the recommendations of a series of National Research Council and other reports recommending common modeling infrastructure. Integration of the HYCOM model with CESM contributes to development of the ESPS, and prototyping of interactive and interactive multi-model ensembles looks to a future where experimental model configurations are more readily assembled.

RELATED PROJECTS

Optimized Infrastructure for ESPC, funded by ONR, was a one-year seed project for this effort. Partners also include projects under the program *Advancing Atmosphere-Ocean-Land-Ice Global Coupled Prediction on Emerging Computational Architectures*, described here: http://coaps.fsu.edu/aoli/projects

PUBLICATIONS

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CoG: http://earthsystemcog.org/
ESMF: http://www.earthsystemmodeling.org/
HYCOM: http://hycom.org/
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