Project Title: Ocean and Sea Ice and their Interactions around Greenland and the West Antarctic Peninsula in Forced Fine-Resolution Global Simulations

Federal Award Identification Number: DE-SC0014440

Agency Code: 8900

Organization: Office of Biological & Environmental Research

Project Period: 08/01/2015 - 07/31/2019

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FINAL REPORT

1. What are the major goals of the project?

The overarching science objective of the project is to use a series of forced global high resolution numerical simulations based on two ocean general circulation models (OGCMs), each coupled to a thermodynamic/dynamic ice model, to investigate how the interplay of regional processes and decadal changes in local and remote forcing impact the delivery and end member composition of waters over the continental shelves of Greenland and Antarctica. Anomalously warm ocean waters have been implicated as the cause of accelerated ablation along the margin of the Greenland ice sheet, as well as the cause of increasing basal melt rate, mass loss, and grounding line retreat of many Antarctic ice shelves. Specifically, we consider the waters at the mouths of the Greenland fjords and those over the continental shelves in the vicinity of the mouths of ice cavities in Antarctica. To meet our objective, our study needs to be of sufficient length to resolve decadal variability and to capture the changes to the Southern Annular Mode (SAM) in the Southern Ocean, the El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), and the Atlantic Multidecadal Oscillation (MAO) in the tropical and midlatitude North Atlantic over the last 50 years. In addition, the realistic delivery of anomalous water masses over the continental and slope will require the explicit resolution of small scale (~5 km) eddies, fronts, and meanders. To overcome this dichotomy of scales and meet our objective, we use a series of forced global ocean/sea ice simulations that first focus on decadal, basin scales processes and then later on smaller scale processes in shorter duration simulations using ultra-high horizontal meshes.

Our specific project goals are to:

1) Understand how changes and variability in the ocean basins surrounding Greenland and Antarctica affect the composition of the water masses reaching the continental shelf waters of these land masses from 1960-2009. In the case of Greenland, we need to consider upstream conditions in the Arctic and in the North Atlantic. Calculate cross-isobath heat and freshwater transports and determine the dominant dynamics controlling on-shelf property transports. We use an existing 62-year 0.1° global coupled ocean/sea-ice (POP2/CICE4) simulation that was forced with Coordinated Ocean-ice Reference Experiment-II corrected interannually varying forcing (CORE-II CIAF) for 1948-2009 (Large and Yeager, 2009); the simulation is mesoscale eddy resolving equatorward of 50°N/S.

2) Setup and run a new global tripole configuration of the Parallel Ocean Program 2 (POP2) coupled to the CICE5 (sea-ice) model on a grid with ultra-high horizontal resolution around Greenland and the Antarctic continent. The resolution will be roughly 2-3 km over the southeast and west Greenland continental shelf/slope and 2-3 km around the Antarctic shelf. Such ultra-high resolution should explicitly resolve ~5-6 km scale eddies and meanders in both study regions, as well as continuing to resolve mesoscale eddies in the tropical and midlatitude oceans. It will have 60 vertical levels. Like (1) will be forced with CORE-II CIAF. It will include a representation of freshwater fluxes from land-ice

melt. It will be run for several decades to demonstrate the importance of resolving very small scale mesoscale features and mixing processes over these continental shelves.

3) Configure and run regional Arctic Cap 1/25° and 1/50° Hybrid Coordinate Ocean Model (HYCOM)/CICE models forced with interannual forcing. HYCOM uses a hybrid vertical coordinate system that is terrain following near the continental slope/shelf, isopycnal in the interior, and has pressure levels in the mixed layer and unstratified seas. Again, the processes responsible for changes and variability in the delivery and end member composition of the water masses over the Greenland shelf will be examined.

The robustness of the processes responsible for the anomalous high latitude warming in POP and HYCOM models will be challenged and verified by using different ocean models together with available observations.

2. What was accomplished under these goals?

Five publications appeared in international peer-reviewed journals related to the award (see peer-reviewed publication list). All publications acknowledge the support of this DOE award. Two graduate students were supported by this grant at SIO: André Palóczy and Theresa Morrison. Mr. Palóczy has published one paper and has another in preparation (reported here); these papers will constitute two chapters of his Ph.D. dissertation. Similarly, Ms. Morrison's paper in preparation, also reported here, will serve as a chapter of her Ph.D. thesis. Dr. McClean and Prof. Gille co-advise both students. Here we report on:

Goal 1: SIO and FSU
Goal 2: SIO. Effort was collaborative with Dr. Maltrud (LANL), who was unfunded.
Goal 3: FSU - see final report for DE-SC0014378 submitted by Prof. E. Chassignet in 2018.

Goal 1

Southern Ocean

Palóczy et al. (2018) examines the seasonal to multi-decadal variability of heat transport between the Antarctic continental slope (ACS) and the adjacent Southern Ocean (SO) using a global coupled eddying ocean/sea-ice model forced with a realistic atmosphere. Onshore heat transport has the potential to melt Antarctic ice shelves. First, a comparison of temperature and salinity from the Marine Mammals Exploring the Oceans Pole to Pole (MEoP; Roquet et al. 2014) data set and the multi-decadal atmospheric reanalysis-forced (CORE-II CIAF) global 0.1° POP2/CICE4 simulation showed that the model generally represented the temperature/salinity relationships realistically along the 1000-m isobath around Antarctica, although a warm bias occurred in the Circumpolar Deep Water layer found below cold Antarctic Surface Water. The net time mean and eddy components of heat transport across the 1000-m isobath for the entire ACS were then calculated as a function of time and across- and along-isobath distance. The circumpolar integral of the annually averaged mean heat transport is O(20) TW; however the mean heat transport direction fluctuates between on-shore and off-shore while the eddy heat transport is always onshore. The dominant process by which eddies transport heat onshore is by eddy advection and stirring; however advection of heat due to mean flow-topographic interactions and surface Ekman flow can be important at some locations. Weak, but statistically significant, correlations are found between interannual heat transport variability and the SAM and Niño 3.4 climate indices. During positive phases of both climate modes, warming occurs broadly on the bottom of the continental shelf (Fig. 1), suggesting that these climate modes can modulate the transport of heat to the ACS from the SO around Antarctica.

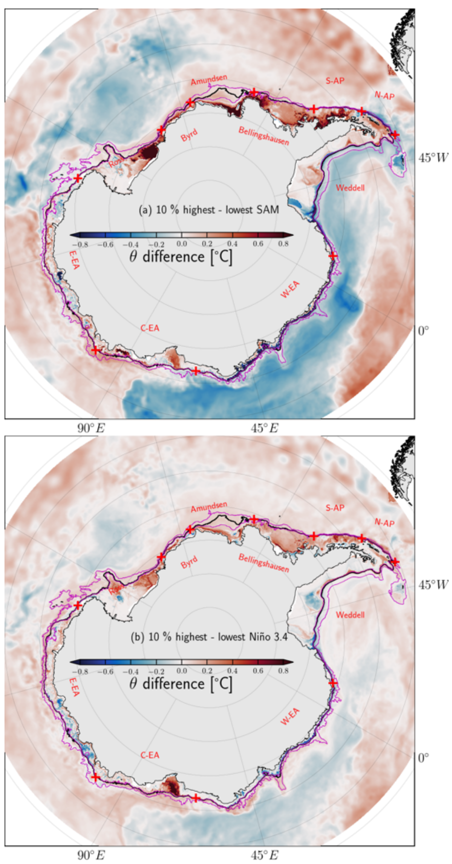


Fig. 1. Spatial structure of the difference in the model potential temperature at 1000 m or the bottom (whichever is shallower), conditionally-averaged in high- and low-SAM years (a) and high- and low-Niño 3.4 years. The high-index and low-index composites are the averages of the years when either index is below its 10th and above its 90th percentile, respectively. Red areas are warmer in high-SAM/high Niño 3.4 years compared to low-SAM/low Niño 3.4 years, while blue areas are colder. The magenta lines are the 800 m and 2500 m isobaths, and the black line is the 1000 m isobath. Note the relative warming from the East Ross Sea to the tip of the Antarctic Peninsula, as well as some areas of East Antarctica for both SAM and Niño 3.4, although the differences associated with SAM are generally larger (after Palóczy et al. 2018; their Fig. 8).

Offshore of the Antarctic continental slope in the SO, the relationship between mixed layer depth (MLD) and the SAM is investigated by Li et al. (2019) using global 0.1° POP forced with CORE-II IAF. The paper also considers variations in the stratification of the ocean interior below the MLD following positive and negative SAM events. Knowledge of the variability of upper ocean stratification in the SO enables us to better understand the variability on interannual time scales in the composition of water types reaching the Antarctic slope. Anomalously strong westerlies occurring during positive SAM phases are found to produce enhanced surface cooling that, in turn, weakens the stratification of the water column. Anomalously deep mixed layers result during spring when the SAM signal is at its strongest. In the following summer, the MLD shallows due to surface warming. However, anomalously weak stratification occurs below it that remains throughout the summer and into the fall. When the surface cools again during fall, the mixed layer deepens easily due to the weak interior stratification. The opposite behavior occurs following negative phases of the SAM, with anomalously shallow mixed layers resulting.

In Palóczy et al. (in prep.), a vorticity budget over the ACS is used to determine the physical processes responsible for the cross-isobath transport of properties. Output from the same CORE-II CIAF 0.1° POP2/CICE4 simulation used in Palóczy et al. (2018) is used here to understand how water in the SO overcomes the dynamical barrier represented by the continental slope to move onto the Antarctic shelf. The key finding is that the flow over the Amundsen and Weddell continental shelves and slopes more closely approximates a Topographic Sverdrup Balance compared to other segments of the Antarctic margin due to their smoother topographies. As a result, wind stress curl can potentially contribute to meridional (roughly cross-shore) transport more easily in regions of smoother topography relative to other segments around the Antarctic shelf. The results apply on large spatial scales and long time scales.

Greenland

In Dukhovskoy et al. (2019), the pathways and fate of surplus Greenland fresh water (representing land ice melt) as well as the propagation and spreading of fresh water from the Arctic Ocean, particularly over the Greenland shelf and adjacent basins, is tracked using passive tracers. A twin numerical experiment was carried out using regional 0.08° Arctic Ocean (AO) HYCOM coupled to CICE4: one experiment included the Greenland surplus freshwater while other did not. A passive tracer was continuously released from freshwater sites around the Greenland continental margin to track the Greenland freshwater anomaly. On the southeastern Greenland shelf, the tracer propagates inshore of the East Greenland Current and is carried by the East Greenland Coastal Current, staying within the shelf break. After the tracer goes around Cape Farewell, it is transported north with the West Greenland Current. The pathway of the Greenland tracer splits into two major branches at the northern Labrador Sea. One branch follows the continental shelf break turning southwestward with the Labrador Current. The other smaller branch continues along the west coast of Greenland, advecting the tracer into Baffin Bay.

Morrison et al. (in prep.) compares the southeast Greenland shelf/slope ocean circulation and water mass composition in the forced 0.1° POP2/CICE4 and the AO 0.08° HCOM/CICE4 simulations, both run without surplus freshwater fluxes. They compare the seasonal cycle of volume transport in the two models through key "gates" such as the Denmark, Davis, Nares, and Fram Straits and also contrast seasonal heat and volume transports across the 800-m isobath encircling Greenland. They then focus on differences and similarities over the seasonal cycle in the broad and narrow parts of the southeast Greenland shelf, as well as comparing water mass compositions both off and on the southeast Greenland shelf. Finally, they are exploring the roles of alongshore wind stress i.e. Ekman-induced downwelling and wind stress curl in the cross-isobath transport of heat onto the continental shelf.

Review article

Both McClean and Chassignet were co-authors of a review article (Hewitt et al. 2017) published in Ocean Modelling that resulted from a workshop at the Met office in Exeter, UK in 2016 that met to discuss the importance of using high-resolution ocean models to study phenomena on time scales ranging from those of weather through to short-term climate (decadal). High resolution in this context means the explicit resolution of mesoscale eddies, narrow boundary currents and their frontal structures, and topographic-flow interactions in the ocean components of global coupled models and forced ocean models. Based on published, albeit limited results, the emerging consensus is that the realistic representation of these features and processes is important for both representing ocean dynamics and coupled prediction.

Goal 2: Configuring and running UH8to2 POP2/CICE5

To meet this goal, we configured a global ocean/sea-ice simulation that explicitly resolves small-scale (~5-6 km) eddies, fronts and meanders over the Greenland and Antarctic continental shelves/slopes, includes a representation of glacier/ice-shelf/iceberg basal melt (by the ocean), and produces responses to change and large-scale natural variability, for the late 20th century and early 21st century. We refer to the simulation as "UH8to2" as the ultra-high grid decreases from 8 km at the equator to 2 km in high-latitudes.

The model consists of the Parallel Ocean Program (POP2) model coupled to CICE5 (sea-ice model) run in the Energy Exascale Earth System Model v0 (E3SMv0) "HiLat" framework for 1975-2009. POP2 is a *z*-level ocean general circulation model (Dukowicz and Smith, 1994) and CICE is a dynamic-thermodynamic model that includes a subgrid-scale ice thickness distribution (Bitz et al. 2001; Lipscomb 2001). CICE5 (Hunke et al. 2015) contains a new anisotropic rheology that results in more realistic sea-ice drift and thickness at high resolution relative to that produced by CICE4 (Roberts et al., 2015); it also has improved thermodynamics. The model components interact and exchange quantities via flux coupler 7 (CPL7; Craig et al., 2012).

UH8to2 was configured on a new tripole grid consisting of 5148x4400 horizontal points. One North Pole is located in Greenland producing 2-3 km resolution over the southeast and west Greenland continental shelves/slopes; the other is located in Siberia. Around the Antarctic shelf, the averaged horizontal grid size is 1-3 km (Fig. 2), while at the equator it is ~8 km. In order for an ocean model to adequately resolve eddy and boundary current scales, the model mesh size should be roughly half the first baroclinic Rossby radius of deformation, the horizontal scale at which rotation effects become as important as buoyancy effects (Tokmakian and McClean, 2003; Hallberg 2013*)*. Over the West Antarctic continental shelf it is about 5 km (Stewart and Thompson, 2012); therefore, this grid is expected to largely resolve small-scale mesoscale structures in our study region, as well as in lower latitudes. The model bathymetry was obtained by interpolating the global 30-arc second General Bathymetric Chart of the Oceans (GEBCO) product onto our vertical grid, which has 60 levels that vary smoothly in thickness from 10 m over the top 200 m of the water column to 250m at the maximum depth of 5500 m. Partial bottom cells are implemented. We also merged in recently acquired bathymetry data (courtesy of F. Nitsche, Columbia U.) over the continental shelf in the Totten Glacier region that were not in the GEBCO data set.

Specifically, we:

- Constructed UH8to2 bathymetry: 5148x4400x60 grid points. This included hand-editing the grid to encourage realistic flow through key passages.
- Created the interpolation and domain files needed by Coupler 7 (CPL7) so it can exchange fluxes among components.
- Created the region mask file.

- Created the chlorophyll files for the model to calculate chlorophyll dependent solar absorption.
- Identified the grid indices that are provided to the model so that it calculates the ~150 volume transports through passages on the fly as part of the model run.
- Constructed a river mask to smooth out river point sources to avoid negative salinities.
- Constructed a new COMPSET for the UH8to2 configuration that includes component namelists with appropriate choices of input parameters for such a high-resolution set up.
- Carried out sensitivity testing at lower resolution (for resolution independent parameters) and consulted with a CICE5 expert (Hunke, LANL) to select these parameters.
- Ported the model to three National Energy Research Scientific Computing Center (NERSC) computering systems – Edison (Cray XC30), Cori (Cray XC40), including Cori-Haswell and Cori-Knights Landing (KNL) nodes to be able to use available DOE computing allocations.
- Tested various processor layouts on the Cori KNL nodes at NERSC to optimize throughput while keeping computational costs viable.
- Optimized throughput is 0.31 simulation years/day or 863,070 processor element-hours/simulated year using 11,264 processors on Cori KNL.
- Created masks to release freshwater fluxes representing land ice melt into the ocean model.

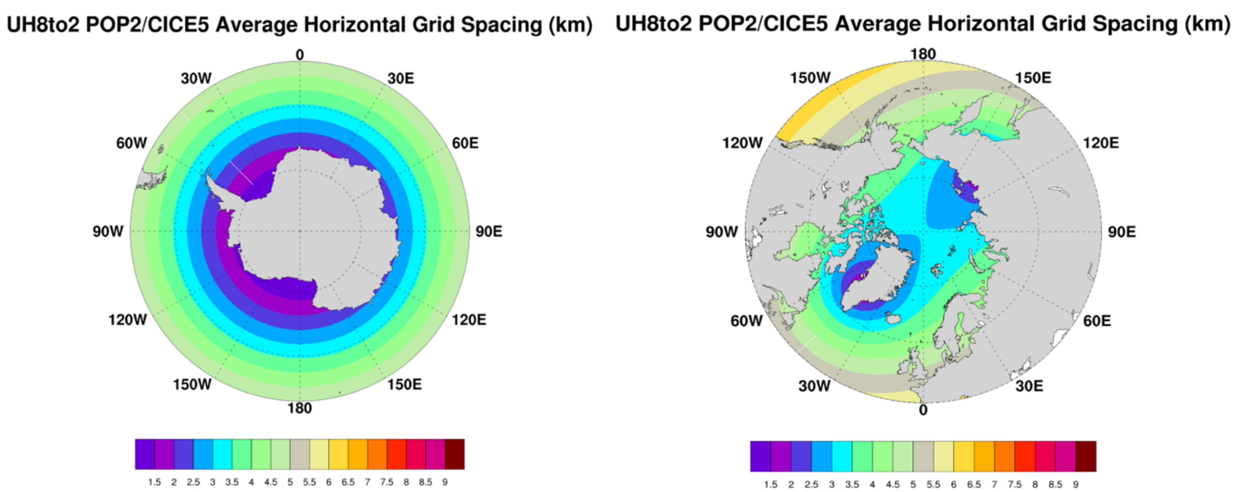


Figure 2. UH8to2 average horizontal grid spacing (km) in the high latitudes of the Southern and Northern Hemispheres.

POP2 and CICE5 are forced with CORE-II CIAFs; these fluxes are available for 1948-2009. As is standard practice for forced ocean models (Yeager et al. 2012), weak (relaxation time scale of 4 years) sea surface salinity restoring to observed climatology is added to the surface freshwater fluxes to limit drift. No sea surface temperature restoring is used, as the CORE data sets were carefully constructed to be almost balanced with respect to the heat fluxes, and our experience has shown that temperature drift is fairly small without SST restoring.

There are no active ice sheets for Greenland or Antarctica in our model. Instead, freshwater fluxes from the Greenland Ice Sheet, both liquid runoff and solid discharge, are represented by spatially distributed freshwater fluxes derived from a reconstruction (1958-2010) of the surface mass balance of the Greenland Ice Sheet in a high-resolution regional climate model and satellite observations, respectively (Bamber et al. 2018). The input consists of monthly estimates and is spatially non-uniform, with an increase in the 1990-2000's. Freshwater is added to POP as a virtual salt flux. The resolution of the UH8to2 grids is insufficient to represent fjord circulations; therefore, the freshwater is released over the Greenland shelf (shallower than 400m) in a uniform vertical profile over the top 200m of the water column. We preserve the spatial inhomogeneity of the Bamber et al. (2018) estimates by remapping the data to the nearest coastal grid cell. In order to avoid unrealistic excessive freshening of a single grid cell, Gaussian smoothing is applied to the freshwater flux. Around Antarctica, we use the Hammond and Jones (2016) multi-year mean freshwater flux field that is based on compiled measurements of ice-sheet melting and calving, iceberg tracking and river runoff for the 2000s. Again, the input is spatially non-uniform around the circumference of Antarctica. It is applied at the surface of the Southern Ocean as a virtual salt flux. In the CORE-II forcing, the Antarctic continental runoff consists entirely of coastal runoff (see Table 1 in Large and Yeager, 2004) derived as the residual from the E-P continental imbalance and the Dai and Trenberth (2009) river runoff data set. To avoid duplicate continental runoff when using the Hammond and Jones (2016) data set, we excluded the Antarctic runoff from the CORE-II data source. The Bamber et al. (2018) dataset includes tundra runoff in the Canadian Archipelago and Svalbard, in addition to Greenland, but the fluxes from those regions are also not used either to avoid duplicate runoff.

Due to the large computational demands imposed by the UH8to2 grid, we started the POP/CICE integration in January 1975 rather than 1948 when the forcing is first available and will run the simulation through 2009. POP was initialized from a short two-month stand-alone POP integration on the same grid, while CICE was initialized from a customized sea-ice state of constant thickness whose ice edge tracks with that from January climatological satellite (Special Sensor Microwave/Imager) observations. The stand-alone POP simulation allowed for the initial adjustment of strong transients that require a very short model time step; this adjustment is best carried out before coupling to sea ice. In turn, the POP short simulation was initialized from rest using climatological observational temperature and salinity. UH8to2 was then run for five years after which time the freshwater fluxes from icebergs and ice sheet melt were turned on (January 1980); this year was chosen as it marks the start of the intensified warming in the late 20th century. The simulation will be allowed to adjust to its initial conditions for 15 years, a typical adjustment period for high-resolution oceans to their initial conditions. As a result, we will have roughly 20 post spin-up years (1990-2009) for our analysis. Since we will be analyzing upper ocean processes on seasonal to interannual time scales, rather than deep and/or very low-frequency processes, this length of spin-up period should be sufficient. Currently, the model is in 1989; the simulation will be completed as part of a new US DOE Office of Science grant.

The Arctic Ocean impacts Greenland continental shelf/slope ocean circulation and sea-ice, so here we show UH8to2 results which indicate that the thickness of the Arctic sea-ice cap and surface circulation have spun-up realistically. Thick (> 5m) sea-ice is seen to the north of the Canadian Archipelago in February-March of 1978 in UH8to2 (Fig. 3; left) in general agreement with ICESat (Fig. 3; right) for February-March 2004-2008 (Kwok and Cunningham, 2008). In the Beaufort Gyre, sea-ice is thicker in UH8to2 than in ICESat as would be expected in the late 1970s. Our winter sea-ice thickness field is in general agreement with that constructed by Bourke and Garrett (1987; their figure 5) from submarine under-ice data from the 1960s through earlier 1980s. The Community Earth System Model (CESM) sea-ice diagnostics package is used to provide a suite of sea-ice diagnostics for both hemispheres for each year of the simulation. In Fig. 4, we show northern high-latitude salinity and currents at 15m for January 1985. The model is reproducing known features of the Arctic surface circulation: the Transpolar Drift flows from the Laptev Sea to exit through the Fram Strait to form the West Greenland Current, the low-salinity clockwise Beaufort Gyre is seen in the eastern basin, and salty water of North Atlantic origin enters the Barents Sea via the eddy-active Norwegian Atlantic Current.

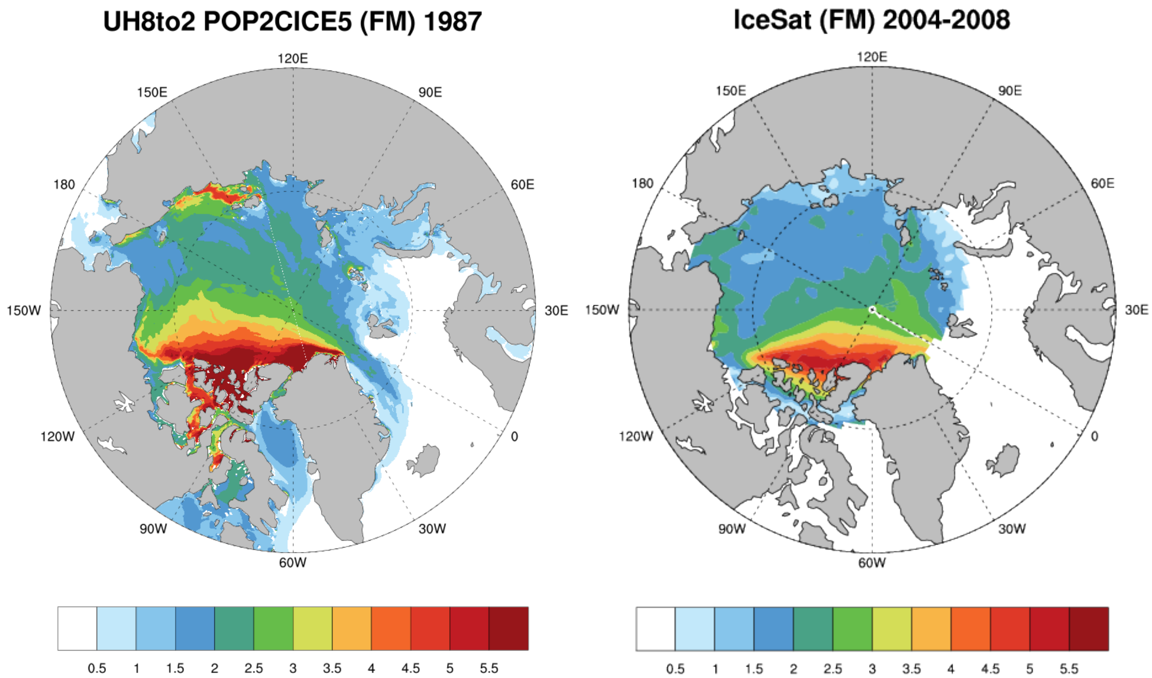


Figure 3: Sea-ice thickness for February and March from (a) UH8to2 for 1987 (left) and ICESat for 2004-2008 (right) from Kwok and Cunningham, 2008. These results indicate that the thickness of the Arctic sea-ice cap has set up realistically. Thick (> 5m) sea-ice is seen to the north of the Canadian Archipelago in general agreement with ICESat. In the Beaufort Gyre, sea-ice is thicker in UH8to2 than in ICESat as would be expected in the late 1980s.

In Fig. 5 we show the meridional overturning circulations (MOCs) *i.e.* the zonally-integrated flow of the global and Atlantic Oceans for 1985 (ten years into the run). The global MOC shows a strong clockwise cell in the upper 2000-3000m of the water column whose southward branch represents the transport of North Atlantic Deep Water. It connects to the Southern Ocean "Deacon Cell" at intermediate depths leading to strong upwelling at 60°S; the strength of the Deacon Cell is 30 Sv. The Atlantic MOC has a maximum overturning strength of about 24 Sv just south of 40°N centered at 1000m. Estimates from the Rapid Climate Change (RAPID) observational array at 26.5ºN for 2005-2016 (Smeed et al. 2019) have a mean of 16.9±1.5 Sv based on annual averages. The UH8to2 value of 24 Sv at this latitude is high relative to the observations, however our value is only for one year and the AMOC does show significant year-to-year variability.

Finally, a pair of global 0.1° POP2/CICE5 simulations, configured equivalently to the UH8to2, except for resolution-dependent parameters, are underway. The "control" simulation does not

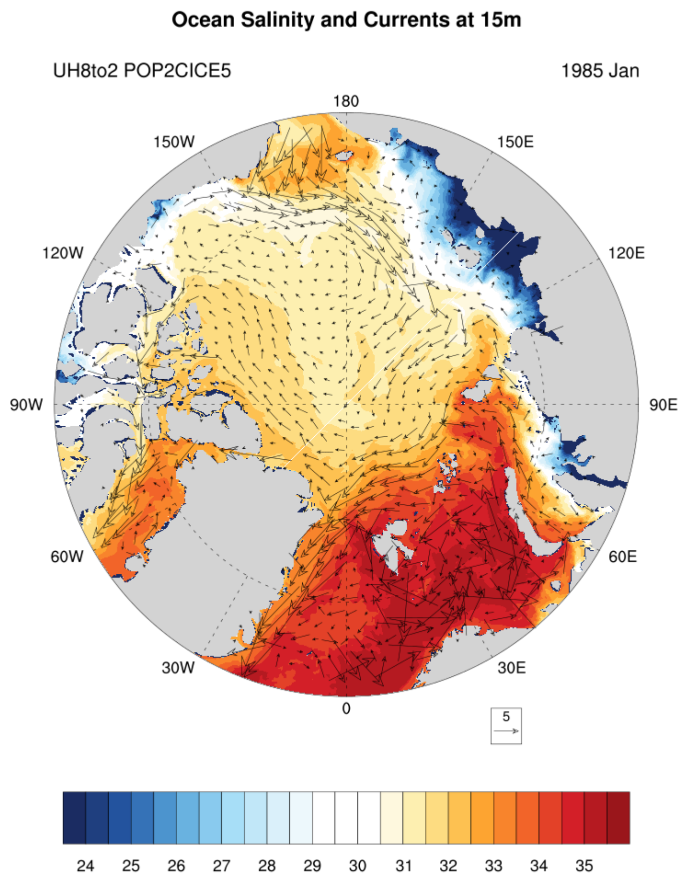
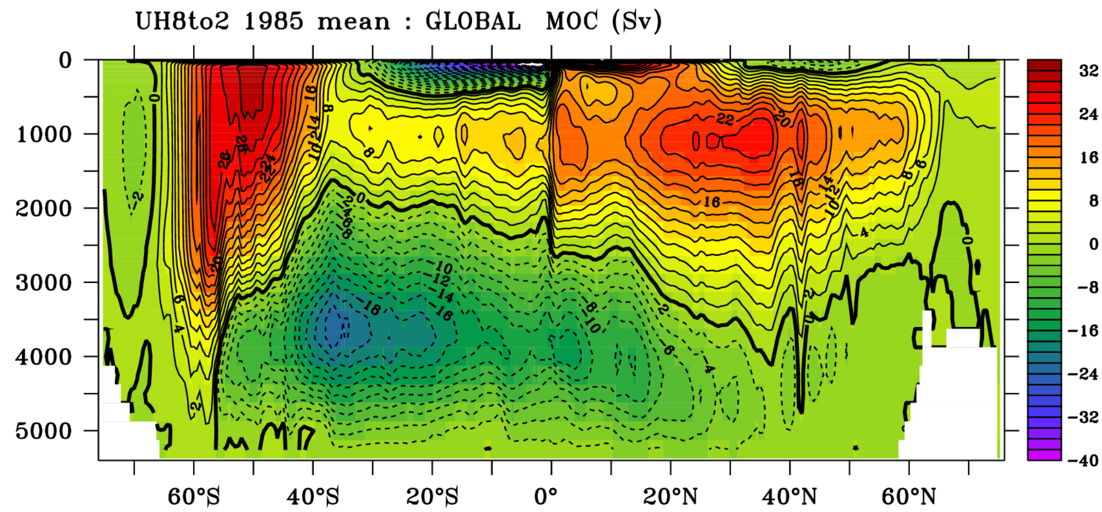


Figure 4: Salinity and currents at 15 m from UH8to2 for January 1985.

contain the freshwater flux releases whereas they are turned on in the other simulation. They have been run through the mid-1980s. Used together with UH8to2, their purpose is the demonstrate the importance of including freshwater flux releases and explicitly resolving mesoscale eddies over the Antarctic and Greenland continental shelves/slopes. These 0.1° POP2/CICE5 simulations are being carried out by Ms. Theresa Morrison (SIO Ph.D. student), who is currently at Los Alamos National Laboratory as part of a DOE graduate fellowship. The comparative analyses of the three simulations described here will constitute a chapter of her Ph.D. thesis and are part of her fellowship studies.



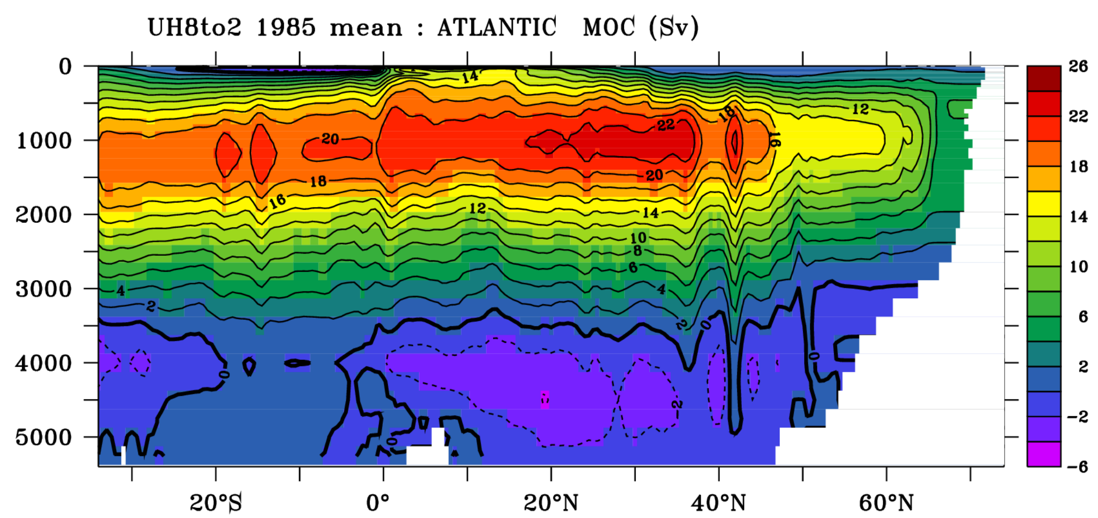


Figure 5*:* Global (upper) and Atlantic (lower) meridional overturning circulation (Sv) for (a) UH8to2 POP2/CICE5 for 1985.

Refereed Publications (DE-SC0014440 and DE-SC0014378):

Chen, R., S.T. Gille, and J.L. McClean, 2017: Isopycnal eddy mixing across the Kuroshio Extension: Stable vs unstable states in an eddying model. *Journal of Geophysical Research-Oceans*. 122: 4329-4345. DOI:10.1002/2016JC012164.

Dukhovskoy, D.S., I. Yashayaev, A. Proshutinsky, J.L. Bamber, I.L. Bashmachnikov, E. Chassignet, C.M. Lee, & A.J. Tedstone, 2019: Role of Greenland freshwater anomaly in the recent freshening of the Subpolar North Atlantic. *Journal of Geophysical Research-Oceans., 124*, DOI:10.1029/2018JC014686.

Hewitt, H. T., M.J. Bell, E.P. Chassignet, A. Czaja, D. Ferreira, S.M. Griffies, P. Hyder, J.L. McClean, A.L. New, and M.J. Roberts, 2017: Will high-resolution global ocean models benefit coupled predictions on short-range to climate timescales? *Ocean Modeling*, 120:120-136. DOI:10.1016/j.ocemod.2017.11.002.

Li, Q, S. Lee S, M.H. England, J.L. McClean, 2019: Seasonal-to-Interannual Response of Southern Ocean Mixed Layer Depth to the Southern Annular Mode from a Global 1/10º Ocean Model. *Journal of Climate*. 32: 6177-6195, DOI:10.1175/JCLI-D-19-0159.1.

Palóczy, A., S.T. Gille, & J.L. McClean, 2018: Oceanic heat delivery to the Antarctic continental shelf: Large-scale, low-frequency variability. *Journal of Geophysical Research-Oceans,* 123, 7678-7701, DOI: 10.1029/2018JC014345.

Papers in Preparation:

Palóczy, A., J.L. McClean, S.T. Gille, & H. Wang. The large-scale vorticity balance of the Antarctic continental margin in a fine-resolution global simulation. *To be submitted to Journal of Physical Oceanography*.

Morrison, T.J., D.S. Dukhovskoy, J.L. McClean, S.T. Gille, & E. Chassignet. Wind-driven regulation of shelf-basin exchange at the southeast Greenland Shelf. *To be submitted to Journal of Geophysical Research-Oceans.*

Published Data:

Chen, Ru; McClean, Julie L.; Gille, Sarah T.; Yulaeva, Elena; Ivanova, Detelina P.; Cerovečki, Ivana (2020). Data from: Effect of atmospheric forcing resolution on simulated mixed layer depth in the North Pacific. UC San Diego Library Digital Collections. DOI:10.6075/J09P3008.

Presentations (DE-SC0014440 only):

Chen, R., J.L. McClean. S.T. Gile, E. Yulaeva, I.Cerovecki., A. Craig, D. Koracin, M. Maltrud, T. McCord, J. Mejia, M. & Hendershott. Effect of atmospheric forcing resolution on the model fidelity of sea level variability in the North Pacific. Abstract OS31B-2015 presented at *2016 Fall Meeting, American Geophysical Meeting*, San Francisco, CA, December 2016.

Ivanova, D.P., T. Morrison, J. L. McClean, S. T. Gille, M. E. Maltrud, A. Craig, J. Ritchie. The Polar Oceans in Ultra-high Resolution Global POPCICE Model Simulations, *Scripps Polar Center Town Hall Meeting*, La Jolla, CA, January, 2019.

McClean, J.L., D. Bailey, C. Papadopoulos, J. Ritchie. Impact of decreasing perennial Arctic sea ice extent on local and remote water masses as depicted by a 60-year forced global coupled 0.1° ocean/sea ice simulation. Abstract GC31A-1159 presented at *2015 Fall Meeting, American Geophysical Meeting*, San Francisco, CA, December 2015.

McClean, J.L., D.C. Bader, M.A. Taylor, M.E. Maltrud, C. Veneziani, Q. Tang, J. Ritchie, M. Branstetter, K. J. Evans. E. Hunke, S. Mahajan, ***Invited,*** *High-Resolution Ocean Modelling for Coupled Seamless Prediction Workshop*, Met Office, Exeter, UK, April 2016.

McClean, J.L., M. Maltrud, J. Ritchie, D. Ivanova, E. Hunke, M. Hecht, & J. Gaukel. Ocean and sea ice and their interactions around Greenland and Antarctica in forced fine-resolution global simulations, *US DOE Regional and Global Climate Modeling (RGCM) RGCM PI Meeting*, Rockville, Maryland, November 2016.

McClean, J.L. High-Resolution Modeling of the Global Ocean and Sea-Ice: Ocean Dynamics and Climate Studies, *Scripps Institution of Oceanography Research Retreat*, Lake Arrowhead, California, September 2018.

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