Importance of the Ocean Heat Convergence and Air-Sea Exchanges to Arctic Amplification

W. Maslowski[1], Y. Lee[1], J. Clement Kinney[1], A. Craig[*], R. Osinski[2], M. Seefeldt[3], M. Veneziani[4], H. Wang[5], M. Watts[6], W. Weijer[4]

[1]Naval Postgraduate School, Monterey, CA; [2]University of Colorado, Boulder, CO; [*]Contractor, [4]Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Contact: maslowsk@nps.edu

ABSTRACT: Studies of the oceanic contribution to Arctic amplification (AA) have been challenging due to limited measurements, historically limited model capabilities for representation of critical mesoscale processes controlling northward transport of mass and heat, and air-ocean coupling, including in the presence of sea ice. We use several global and regional Earth system models at increasingly high resolution to address such challenges and to advance understanding of the ocean's role in AA. In particular, we have examined a subset of models participating in Phase 6 of the Coupled Model Intercomparison Project (CMIP6), including contributions to the High Resolution Model Intercomparison Project (HighResMIP) as well as the Energy Exascale Earth System model (E3SM) with refined resolution in the pan-Arctic region (E3SM-Arctic) and the Regional Arctic System Model (RASM). We have evaluated the sensitivity of oceanic heat fluxes and heat convergence to model resolution and their integrated impact on the Arctic sea ice cover and on AA. In this presentation, we focus on the North Atlantic heat transport into the Arctic Ocean and air-sea heat exchange along the transport pathways. Findings of this study may serve as guidance for future observations required for better constraining ocean models and for process-level improvements critical to the model representation and projections of Arctic climate change.

1. Background and motivation

- **CMIP6 models have limited skill in representing the Arctic sea ice cover[1].**

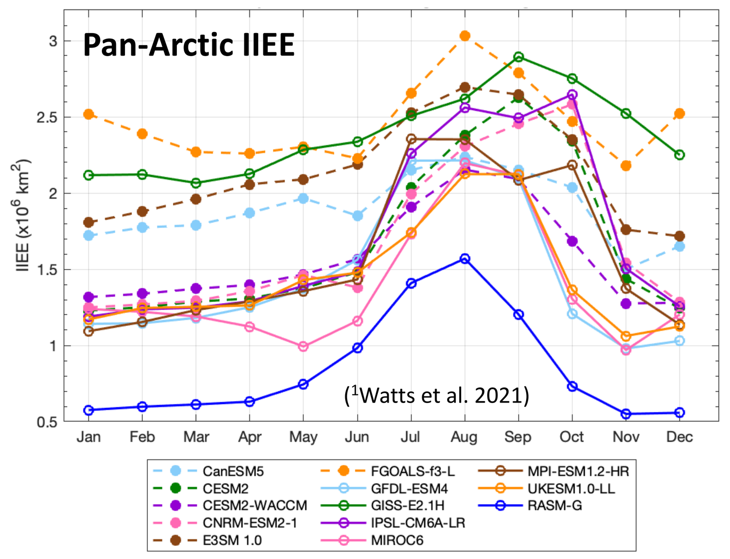


Figure 1. The long-term (1980-2014) mean total CMIP6 Integrated Ice Edge Error (IIEE)

- **Modeled sea ice thickness is more sensitive to model physics compared to sea ice extent/area.**

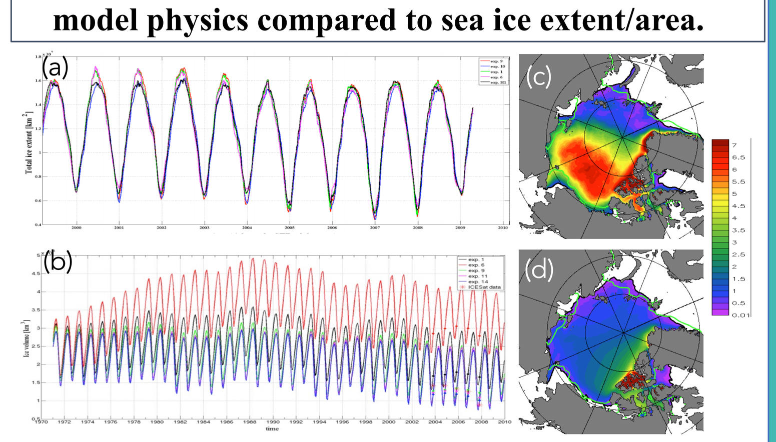


Figure 2. Timeseries of sea ice (a) extent and (b) volume from 5 RASM experiments. The 2000-2004 mean September sea ice thickness distribution (m) from (c) 'red' and (d) 'blue' experiments.

2. The Regional Arctic System Model

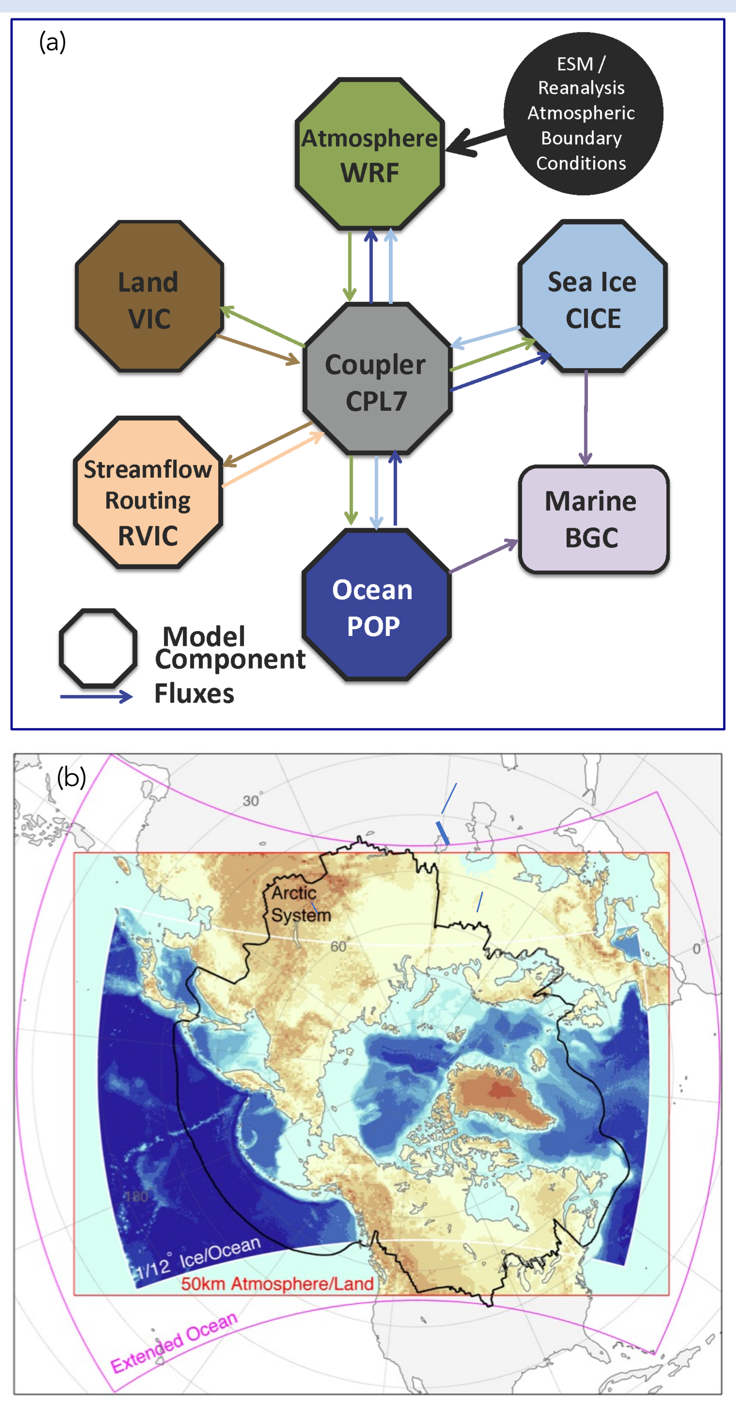


Figure 3. RASM (a) components and wiring diagram and (b) domains and topo-bathymetry

The RASM is a limited-domain, fully-coupled, high-resolution atmosphere, ocean, ice, and land model. The primary components are the Weather Research and Forecasting (WRF3.7), Los Alamos National Laboratory (LANL) Parallel Ocean Program (POP2) and Sea Ice Model (CICE6), the Variable Infiltration Capacity (VIC) land hydrology model, and a streamflow routing (RVIC) model. These components are coupled using the Community Earth System Model (CESM) coupler (CPL7) (Fig. 3a). The RASM domain includes the Arctic Ocean and surrounding marginal seas as well as the sub-Arctic North Pacific, including the Bering Sea, Sea of Okhotsk, and Gulf of Alaska, and the sub-Arctic North Atlantic, including the Nordic and Labrador seas, Baffin and Hudson bays (Fig. 3b).

3. RASM Sensitivity Experiments

- **RASM results suggest linear relationships between the heat and volume fluxes through the Barents Sea Opening (BSO) as well as between the heat flux at BSO and the oceanic heat convergence over the Barents-Kara seas.**

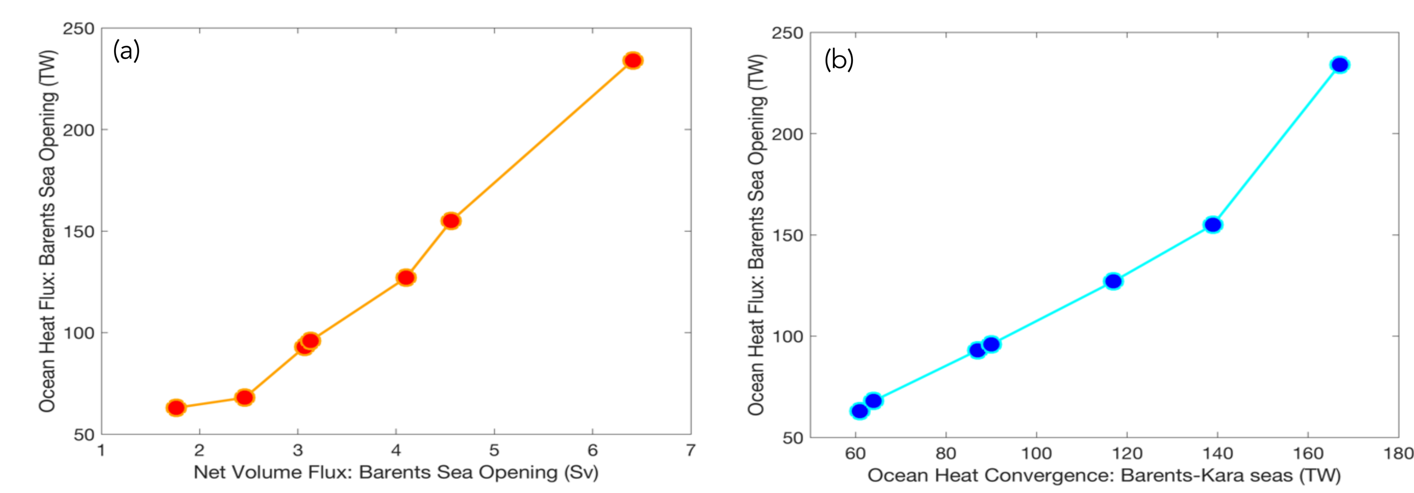


Figure 4. Relationship between varying oceanic fluxes: (a) heat (y-axis) and volume (x-axis) across BSO and (b) heat (y-axis) flux across BSO and oceanic heat convergence (x-axis) over the Barents and Kara seas.

4. Barents Sea Opening fluxes from the E3SM-Arctic-SIO

- **E3SM-Arctic-SIO forced with JRA55 simulates comparable magnitudes of the BSO fluxes to RASM forced with JRA55**

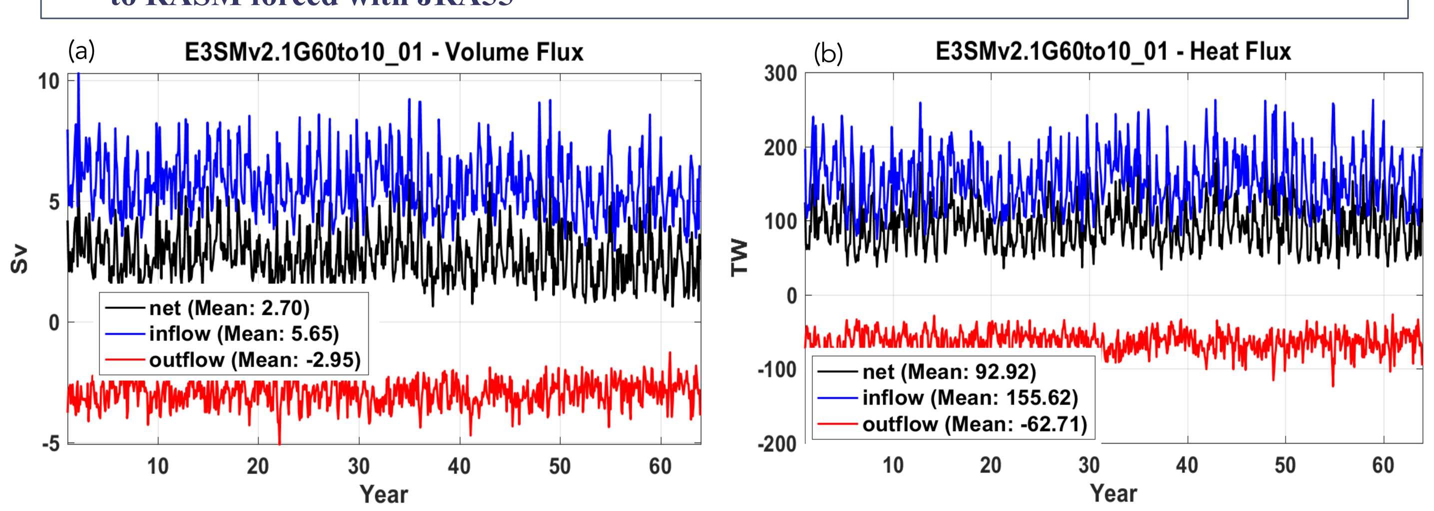


Figure 5. Timeseries of BSO (a) volume and (b) heat fluxes from the 60to10 E3SM-Arctic-SIO simulation forced with JRA55 reanalysis

5. Barents Sea Opening fluxes from the fully coupled E3SM-Arctic

- **Fully coupled E3SM-Arctic simulates higher BSO fluxes (~17%) compared to E3SM-Arctic-SIO forced with JRA55**

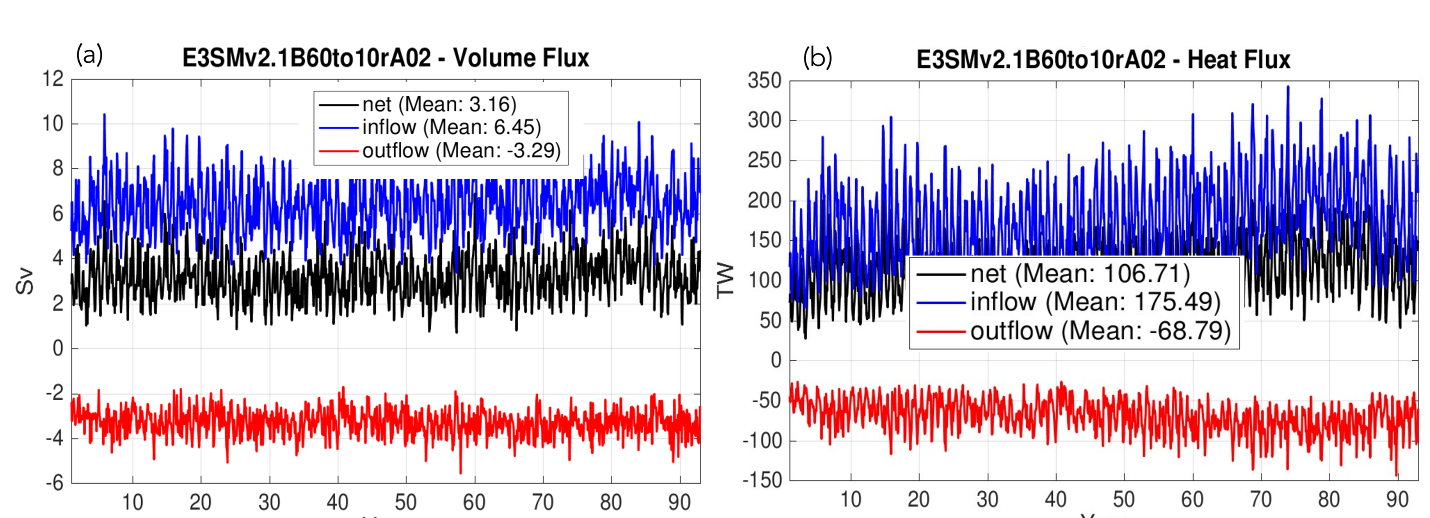


Figure 6. Timeseries of BSO (a) volume and (b) heat fluxes from the fully coupled 60to10 E3SM-Arctic simulation forced with the constant 1950s.greenhouse gas forcings.

6. BSO Hydrography from RASM simulations

- **Only high resolution RASM simulations (left) realistically represents the T/S and flow structure at BSO, including the NCC**
- **The Norwegian Coastal Current (NCC) may account for about half of the volume and heat fluxes into the Barents Sea**

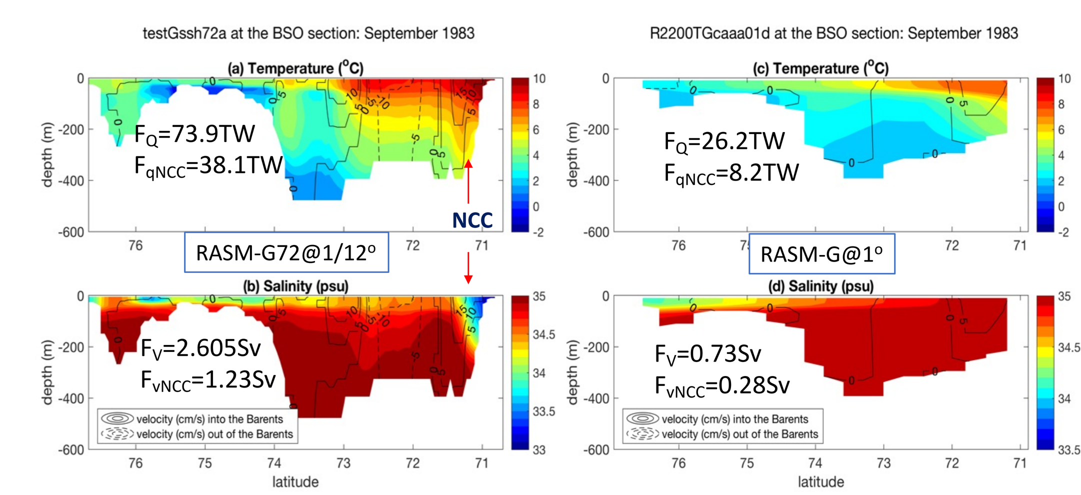


Figure 7. Cross-sections of (top) temperature, (bottom) salinity, with eastward velocity (contours) across the BSO from Norway (left) to Svalbard (right) from (left) 9-km and (right) 1-degree RASM-SIO simulations forced with JRA55. The Norwegian Coastal Current (NCC) is present only in RASM-G@9km.

7. RASM-G@9km Oceanic Heat Convergence (OHC)

- **The oceanic heat convergence (OHT) in the Barents Sea accounts for >80% of the pan-Arctic OHT.**

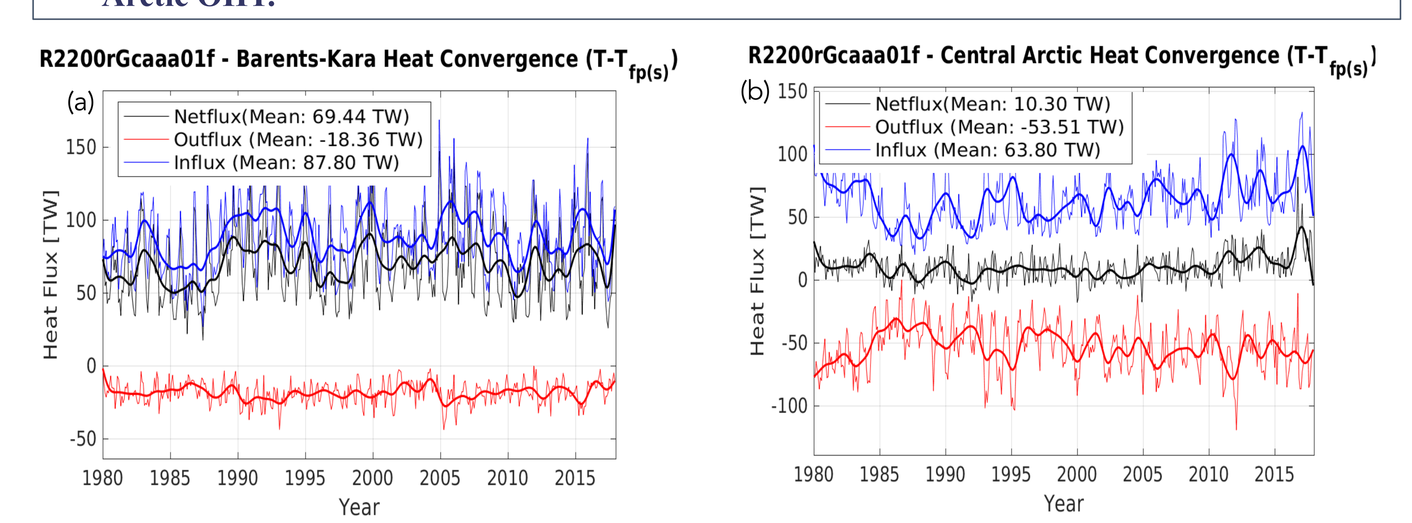


Figure 8. Timeseries of OHT from RASM-G@9km over (a) the Barents Sea and (b) the Central Arctic reference to freezing temperature. The influxes into the region are shown in blue, outfluxes in red and the net fluxes are in black.

8. RASM-G@1° Oceanic Heat Convergence

- **Much reduced OHT in the Barents Sea (<30%), increased OHT in Central Arctic in coarse resolution (ocean) models..**

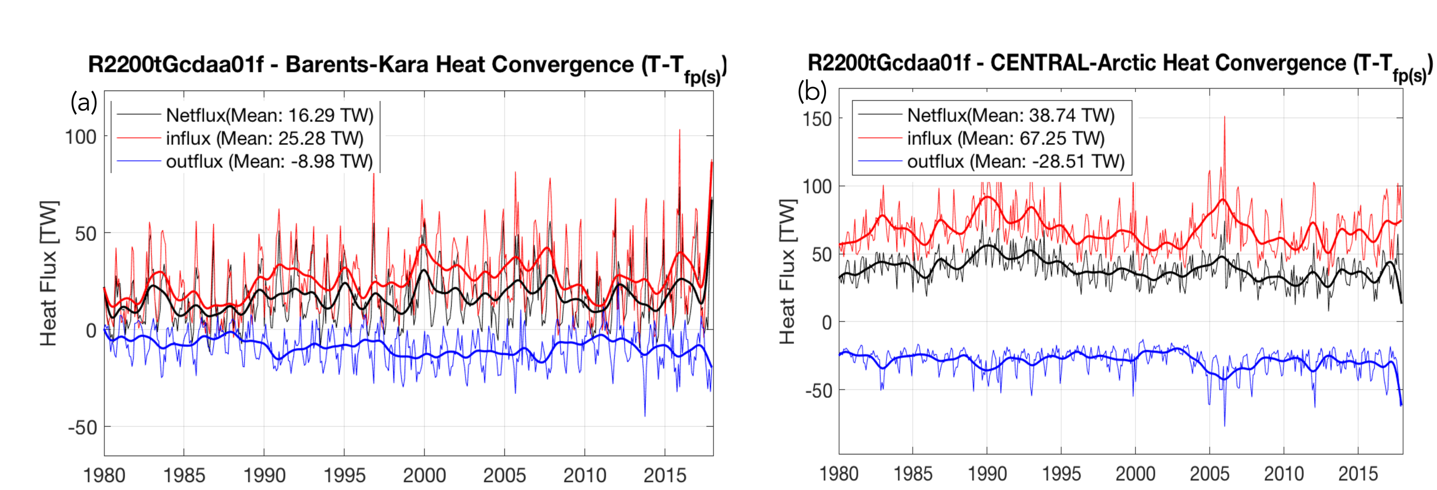


Figure 9. Timeseries of OHT from RASM-G@1° over (a) the Barents Sea and (b) the Central Arctic reference to freezing temperature. The influxes into the region are shown in blue, outfluxes in red and the net fluxes are in black.

9. Impact of Oceanic Heat Convergence (OHC) on Sea Ice

- **35-40TW of heat flux into the central Arctic, melt sea ice in summer in RBR9x-45**

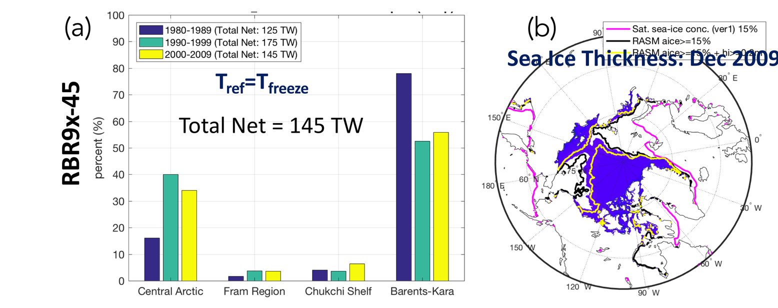
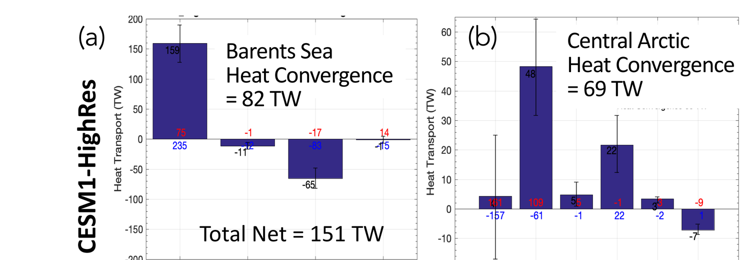


Figure 10. (a) Decadal OHC for the Barents Sea and Central Arctic from RASM sensitivity simulation with dramatically increased OHC into the Central Arctic; (b) Sea ice thickness distribution from the end of that RASM simulation in December 2009 showing freshly forming sea ice after the nearly ice-free summer.



- **Similar effect in CESM1-HighRes with 69TW**

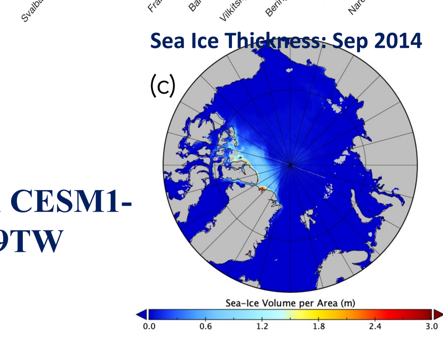


Figure 11. (a) Mean OHC for the Barents Sea and (b) Central Arctic from the CESM1-HighRes historical simulation with similarly increased OHC into the Central Arctic as in RASM above; (c) Sea ice thickness distribution from the same CESM simulation for September 2014 with nearly ice-free summer.

10. RASM air-sea fluxes

- **Mesoscale ice-ocean dynamic impacts air-sea fluxes in the Nordic/Barents seas**

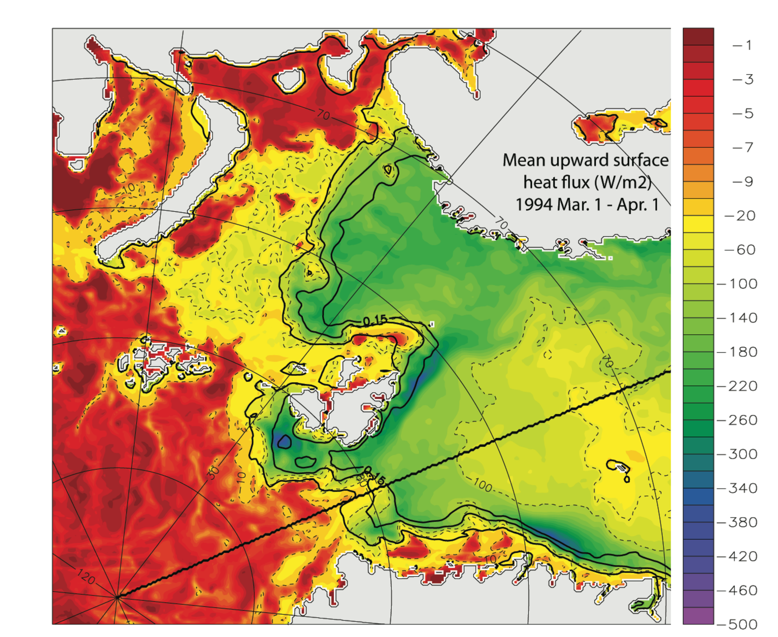


Figure 12. RASM mean March 1994 upward heat fluxes (W/m²), magnitudes of which are likely not represented accurately in coarse resolution ESM, nor AMIP-type simulations. Black contours are for sea ice concentration.

11. Summary

1. Large uncertainties remain in modeled **oceanic heat convergence over the Barents Sea and Central Arctic.**
2. **Observational estimates of ocean volume and heat fluxes are insufficient** to constrain models, e.g., NCC.
3. **Mesoscale ice-ocean dynamics is critical in ocean-sea ice-atmosphere interactions** in these regions.
4. Improved modeling and **observations are needed to quantify their contribution to Arctic amplification.**

Acknowledgments: This work has been supported by the DOE Regional and Global Model Analysis, ONR Arctic and Global Prediction, and DOD High Performance Computing Modernization programs.