Evaluation of GFDL coupled climate models for western Arctic seasonal heat budgets

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Introduction and Scientific Aim

The Arctic is undergoing rapid change with atmospheric and oceanic warming, retreating sea ice, and shifting fish distributions. The greatest losses of sea ice have been in the Beaufort Sea and Chukchi Sea (left, SST from CMIP6 CM4) where approximately two thirds of the sea ice loss is attributed to ocean heat fluxes. (Right) Waters of North Pacific origin transport heat into the Arctic through Bering Strait ($Q_{\text{surface}}$) and that warm, salty water is subducted under the mixed layer in the deep basin ($Q_{\text{sub}}$), forming the warm halocline of the Beaufort Gyre. While the Chukchi Sea plays a critical role in modulating the heat content of Pacific Water subducted into the Beaufort Gyre halocline on seasonal timescales, conflicting observational evidence leaves the Chukchi Sea’s role in this heat transport unclear.

To address this uncertainty, a suite of ocean and coupled climate models produced at the National Oceanic and Atmospheric Administration Office’s (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL) are being utilized to close heat budgets for the Chukchi Sea. Here we present the evaluation of some of these simulations to quantify model biases and identify strengths, weaknesses, and uncertainties for the available configurations.

Model Data and Observations

Two configurations of the NOAA GFDL coupled climate model, CM4, are presented here. For both configurations, the ocean model uses the state-of-the-art MOM6 code with 75 vertical levels utilizing a hybrid vertical coordinate system (Adcroft et al., 2019). CMIP6 CM4 (Held et al., 2019) has a nominal horizontal grid spacing of 0.25°, while High Res (in development) has a spacing of 0.125°. The preindustrial control (PI) simulations are analyzed for both, and the historical simulation is also evaluated for CMIP6 CM4. Simulated ocean heat transport through Bering Strait is evaluated using mooring observations of water properties and the derived mooring transports and fluxes at monthly and annual timesteps. A consistent reference temperature of -1.9°C is used for the observational and model heat flux and transport estimates.

Simulated surface winds are compared with reanalysis outputs from the European Centre for Medium-Range Weather Forecast (ECMWF) ERA5 model (Hersbach et al., 2020). The evaluation uses the direct observations of water properties and the derived mooring transports and fluxes at monthly and annual timesteps. A monthly observations do not include a correction for the ACC transport) (Table below).

Annual mean volume transport ($T_{\text{vol}}$) and total heat transport ($T_{\text{heat}}$) for all three simulations are less than the observational estimates (which do include a correction for the ACC transport) (Table below). While all simulation estimates are low relative to the observations, the High Res PI simulation is in closest agreement with the mooring estimate. The mooring estimate of both quantities also demonstrates a strong positive trend since the year 2000 (below for $T_{\text{vol}}$ and thus the observational estimate is likely an upper bound for any preindustrial estimate. A key feature missing in CM4 Historical is the rapid increase in both $T_{\text{vol}}$ and $T_{\text{heat}}$ since 2000 which will be a source of uncertainty in present-day budget estimates.

Future Work: Beaufort Gyre Heat Content and Water Properties

A remaining step is to evaluate the water properties and heat content of the Beaufort Gyre to provide context and error estimates in the calculation of $Q_{\text{sub}}$. Temperature, salinity and pressure observations from Ice-Tethered Profilers will be used to estimate the heat content within density layers in the Beaufort Gyre and compared with simulated heat content. The difference in layer-by-layer heat content will be used to determine if the simulations subduct a similar quantity of heat into the Beaufort Gyre halocline and how the simulations redistribute that heat relative to the observations.

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