Investigating the Effects of Changing Atmospheric Forcing Resolution in a Regional Ocean Model of the Northwest Atlantic

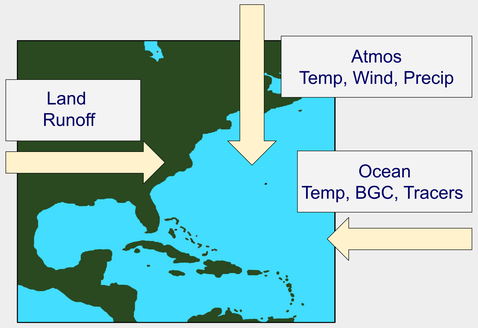
Harris Longfield, Vimal Koul, Andrew Ross, Liping Zhang

harris.a.longfield@gmail.com - hal3@williams.edu

Atmospheric Forcing

At their core, ocean models are a series of differential equations that evolve over time depending on their initial conditions. Regional uncoupled models, like MOM6 NWA12, need to be fed ocean boundary conditions at their oceanic borders, land boundary conditions at its land borders, and atmospheric boundary conditions at its atmospheric border. “Atmospheric forcing,” which this project focuses on, refers to the application of these atmospheric boundary conditions.

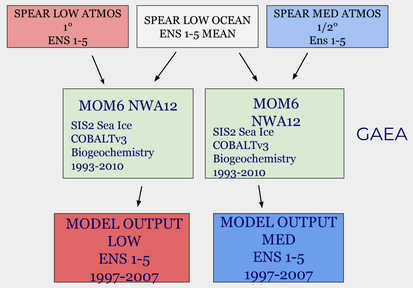
This project seeks to determine whether there is a significant difference between model output when forced by low-resolution atmospheric data and model output forced by medium resolution atmospheric data. If there are differences, where are they most significant and can we error-correct?



Methodology

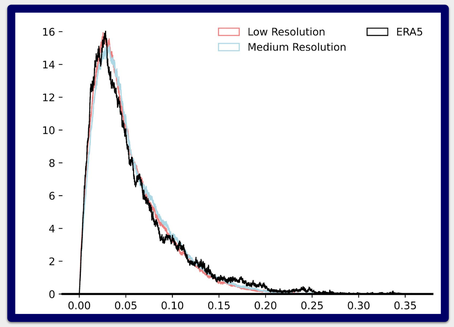
To explore the differences between low and medium-resolution forced MOM6 NWA12 output, we ran 10 simulations: 5 ensembles forced by low-resolution atmospheric data from GFDL's 1 degree SPEAR_lo coupled model and 5 parallel ensembles forced by medium-resolution atmospheric data from GFDL's 0.5 degree SPEAR_med coupled model. In all 10 simulations we used the ensemble mean of SPEAR LO c96 1-degree ensembles 1-5 for ocean initial and boundary conditions. We also used SPEAR LO as atmospheric input. Variables were renamed and regridded to match the model. BGC and LAND utilizes preprocessing from Ross et. al (2023). Although the simulations begin in 1993, to remove initialization bias we only analyze output between 1997 and 2007.

Additionally, this project uses ERA5 Reanalysis-forced output as a benchmark when available.

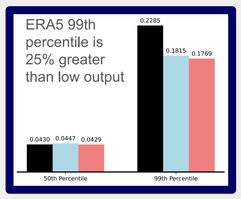


Wind Stress

The primary difference between low and medium-resolution SPEAR is their distribution of wind values, and thus, one of the greatest differences in output is in wind stress, which is proportional to the squared velocity of wind. When compared to medium-resolution, low-resolution atmospheric forcing overrepresented the median wind values and underrepresented the highest echelon values. When compared to ERA5, these trends generally hold, suggesting that the medium-resolution output is more accurate.



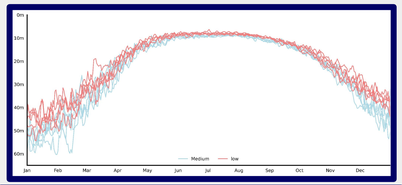
A probability density function of wind stress in the Gulf of Maine (Pa)



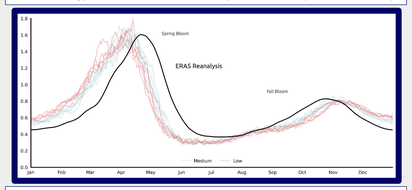
Histogram of 50th/99th percentile wind stress

The mixed layer refers to the uppermost level of the ocean, which can be affected by atmospheric conditions. The differences in wind stress between resolutions should affect the depth of this mixing layer, since stronger winds penetrate deeper into the ocean resulting in a greater mixing depth. This effect is most noticeable during the winter months, when the wind is strongest, resulting in a “stretching” effect of lower-resolution output with less extreme winds.

This effect can be observed through chlorophyll concentration in the water. A deeper mixed layer delays the spring bloom and expedites the fall bloom, causing a similar stretching effect. In this case, we have ERA5-forced output to confirm that this effect is a result of the underrepresentation of the greatest winds.



Climatology of maximum mixed-layer depth in (Gulf of Maine)

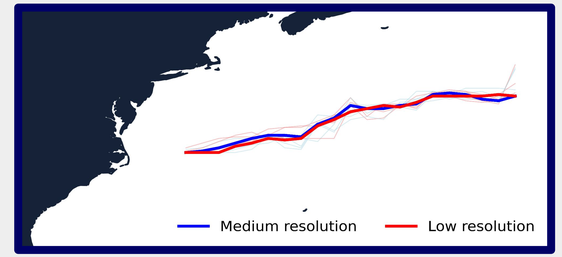


Climatology of chlorophyll concentration in GOM (mg/m^3)

These plots suggest that for diagnostics sensitive to wind stress, the medium resolution forcing is notably better than low-resolution, but still erroneous when compared to ERA5-forced output.

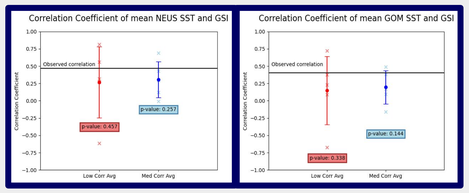
Gulf Stream

The most important structure of NWA12 is the Gulf Stream, which carries warm tropical water from the Gulf of Mexico to the Northeast region of the US. When evaluating a model’s ability to simulate it, we analyze its position and its effect on ocean temperatures, SST. Its average position can be found and indexed by taking SSH anomalies.



Average Gulfstream position for each of the 10 runs and each group’s median position

To evaluate ocean dynamics, we can calculate the correlation between northward shifts of the GS and increases in SST in northern marine ecosystems, specifically the Northeast US and Gulf of Maine. By comparing this correlation to the observed value, we can monitor discrepancies between resolutions.



Values of correlation coefficients in the NEUS and GOM with 95% CI

There is no evidence suggesting that there is a statistically significant difference between the correlation coefficients for low and medium resolution atmospheric forcing, or the observed correlation.

Conclusions

Overall, there were small but significant differences between low and medium resolution atmospheric forced MOM6 NWA12 output. For diagnostics sensitive to wind-stress, like chlorophyll, medium-resolution forcing is notably better, but still inaccurate when compared to ERA5 Reanalysis. For more robust diagnostics, like Gulf Stream dynamics, the difference becomes negligible.

References

Ross, A. C., Stock, C. A., Adcroft, A., Curchitser, E., Hallberg, R., Harrison, M. J., Hedstrom, K., Zadeh, N., Alexander, M., Chen, W., Drenkard, E. J., du Pontavice, H., Dussin, R., Gomez, F., John, J. G., Kang, D., Lavoie, D., Resplandy, L., Roobaert, A., Saba, V., Shin, S.-I., Siedlecki, S., and Simkins, J.: Model source code for "A high-resolution physical-biogeochemical model for marine resource applications in the Northwest Atlantic (MOM6-COBALT-NWA12)", Zenodo [code], https://doi.org/10.5281/zenodo.7893349, 2023b. a

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