Project: **1474**

Project title: **OceanWeather - Impact of ocean eddies on climate variability in coupled climate simulation ensembles**

Principal investigator: **Nils Hutter**

Report period: **2024-11-01 to 2025-10-31**

Scope and Aim of the Project

The OceanWeather project investigates the impact of mesoscale ocean eddies on climate variability using ensembles of coupled climate simulations. Eddies are fundamental drivers of ocean–atmosphere interactions, redistributing heat, salt, and momentum. Due to their chaotic nature and small spatial scales, their representation in climate models requires either high-resolution modeling or advanced parameterizations. Our work leverages a dynamic energy backscatter scheme in the FESOM2 ocean model, allowing cost-efficient simulations that mimic eddy-resolving behavior at coarser resolution. The project goal is to compare simulations with and without backscatter in a controlled setup to quantify the role of eddy activity in shaping climate variability from 1950–2050.

Summary of Work Conducted in 2025

1. Ocean-Only Simulations for Configuration Testing

A comprehensive suite of ocean-only simulations using FESOM2 forced by JRA55 reanalysis was conducted to evaluate the impact of energy backscatter on various ocean grids. Configurations included HR, Dart, F20, and ORCA25. For each mesh, reference and eddying simulations were run with standard namelist parameters, and maximum time steps were tested. Based on the ability to differentiate mesoscale activity and computational efficiency, the ORCA25 mesh was selected for further coupled simulations. A detailed description of the selection and tuning process can be found in the request for additional resources midterm 2024.

2. Coupled Model Setup and Tuning

AWI-CM3 (v3.3.0) was configured and debugged with the TCO319L91 atmosphere and ORCA25 ocean grid. This configuration provides a balanced trade-off between resolution and performance. Both the reference (no backscatter) and eddying (with backscatter) configurations were tuned and benchmarked on Levante for optimal node load balance. In the final form both setups require 146 Node hours per simulated year and produce 159 Gb output per simulated year.

3. Spin-Up Simulations

A 30-year spin-up (1950-repeated forcing) was completed for the reference configuration following the CMIP HighResMIP protocols. Since both configurations use the same timestep and grid, no additional spin-up was required for the eddying configuration.

4. Historic Ensemble Production

Initialized from the spin-up simulations, we successfully produced so far:

- A full historic run (1950–2014) for the reference configuration
- One reference ensemble branch (1950–2014)
- A full historic run (1950–2014) with backscatter
- One ensemble branch (1950–1990) with backscatter; simulation ongoing

These four production runs together with the tuning runs consumed the bulk of the granted CPU

resources. The simulations are currently post-processed for further analysis and prepared for archiving.

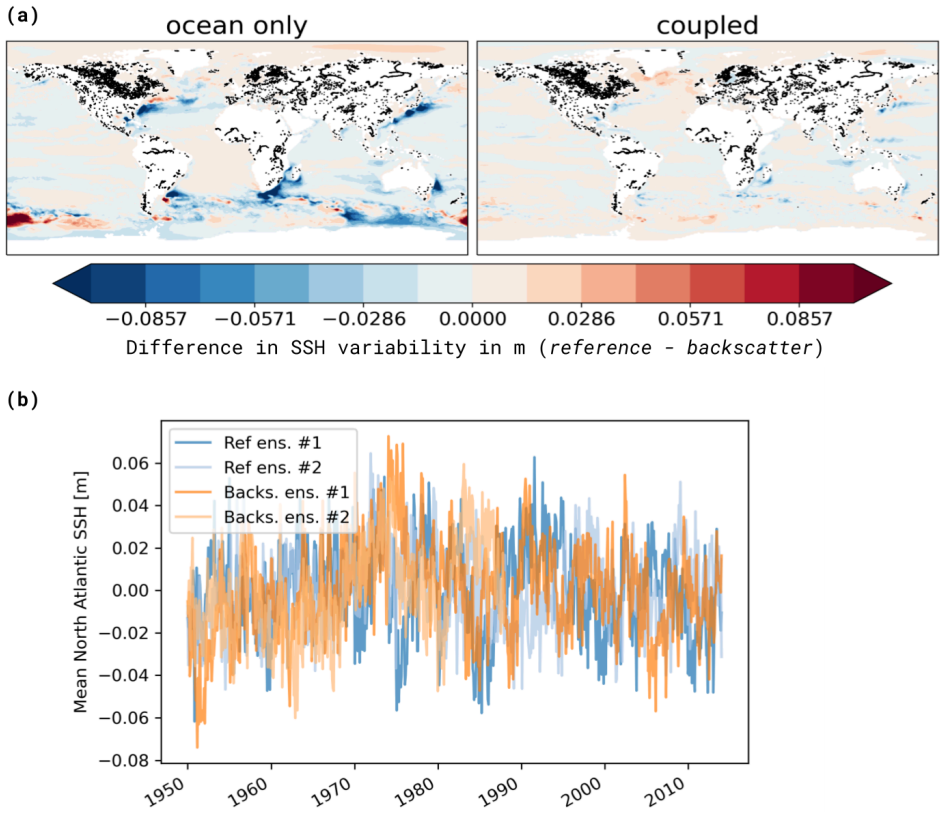

Figure 1:
(a) Comparison of simulated SSH variability between reference and backscatter configuration for ocean-only (left) and coupled simulations (right).
(b) Time series of the SSH anomaly in the North Atlantic (30/50°N and 80/30°W) in both the reference and backscatter ensemble.

5. Machine Learning Applications (Unplanned Work)
We initiated training of a data-driven emulator to learn ocean dynamics from nextGEMS FESOM-IFS outputs regridded to 1.5° by adapting the ML-based atmospheric model ArchesWeather. Training the emulator is GPU intensive, which resulted quickly in exceeding our originally allocated GPU budget. The development of the emulator has been continued with other computing resources and was published in a Master's thesis.

Note on expired resources: In the beginning of 2025 the backscatter scheme had to be re-integrated and adapted following major FESOM code changes, resulting in slower than anticipated progress and unused resources. After resolving these issues, we successfully tested the parameterisation in ocean-only simulations and initiated the first coupled climate simulations using this parameterisation in the second half of 2025.

Outlook and Remaining Work in 2025

The remaining CPU node hours (~36,000 NH) will be used to extend all 4 simulations performed so far to 2050 using CMIP SSP2-4.5 scenario forcing aligning with HighResMIP2 protocol. Also, one additional ensemble branch for the eddying configuration will be performed.