Project: **1474**

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

Principal investigator: **Nils Hutter**

Report period: **2025-11-01 to 2026-10-31**

## Scope and Aim of the Project

OceanWeather investigates the impact of mesoscale ocean eddies on the mean state and variability of the climate system using ensembles of coupled AWI-CM3 simulations (OpenIFS TCO319L91, FESOM2 ORCA25). The kinetic energy backscatter scheme in FESOM2 provides near eddy-resolving behavior at eddy-permitting cost. Comparing ensembles with backscatter (Eddies), with standard viscosity (Reference) and with the legacy CMIP6 viscosity (Dampened) isolates the role of eddy activity in an otherwise identical model setup. In parallel, we develop a machine-learning (ML) ocean emulator to further extend the ensembles at low cost.

## Summary of Work Conducted in 2026

### 1. Completion of the Historical Ensembles

Building on the spin-up and first historical runs from 2025, we completed the historical ensembles (1950–2014) with one control run and four ensemble members per configuration. The Eddies and Dampened ensembles are complete with five members each. Of the Reference ensemble, three members are complete and two have reached 1981 and 1985 and will be finished with the remaining 2026 resources. Completed runs are post-processed, and archiving to tape started in October 2026.

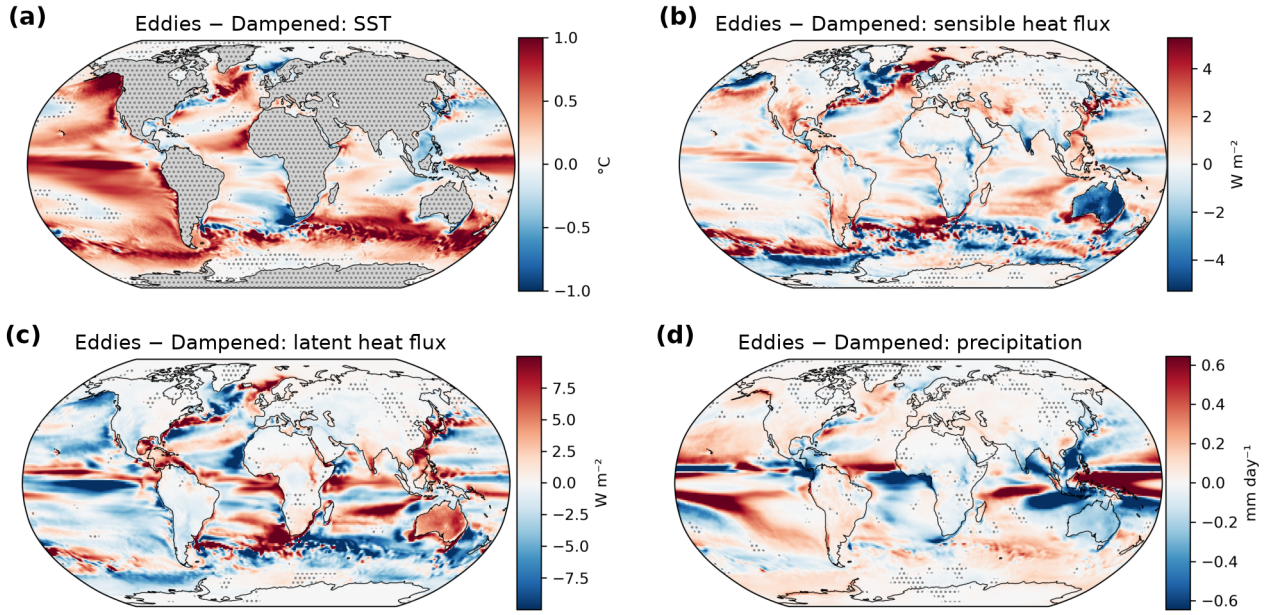



*Figure 1: Ensemble-mean differences Eddies − Dampened (1950–2014) of (a) SST, (b) sensible and (c) latent heat flux (positive downward), and (d) precipitation, from the preliminary analysis of the ensemble members completed by spring 2026. Stippling: more than 25 % of member pairs disagree in the sign of the difference. For brevity, only this pair of configurations is shown.*

### 2. Analysis Framework and First Results

We developed a tested Python analysis package for the native FESOM2 and OpenIFS output, including a significance test based on pairwise sign agreement of all ensemble member combinations. First results, based on the members completed by mid 2026, were presented at EGU and COMMODORE 2026 (Section 5). They focus on relative changes between the configurations, which isolate the effect of eddy activity independently of high latitude biases in the coupled baseline:

- Eddy variability increases from Dampened to Reference and further to Eddies: the variability of sea surface height rises along the western boundary currents, in the northern Southern Ocean and in the tropical Pacific, and the variability of surface velocities rises almost everywhere.
- Shifts of the western boundary currents and of the equatorial dynamics change the mean SST by up to about 1 °C, which imprints on the surface heat fluxes, 2 m temperature and precipitation (Fig. 1). For example, the Agulhas Current retroflects earlier, Australia becomes warmer and drier, and the equatorial

Pacific warms, accompanied by changes in winds, thermocline depth and zonal currents. Changes at high latitudes are largely caused by differences in the sea-ice mean state.

- The deep-ocean drift is reduced in the Eddies ensemble. Most changes are systematic across the three configurations, with the largest step from Dampened to Reference, except in the tropics.

These results are currently being finalized for a publication planned for close submission.

### 3. Machine-Learning Ocean Emulator RánCast

Using about 3,200 GPU node hours, we developed RánCast, an ML emulator of the global three-dimensional ocean that adapts the transformer-based weather model ArchesWeather to the ocean. It is trained on the kilometer-scale coupled FESOM–IFS NextGEMS simulation, regridded to 1.5° with 13 depth levels. Five main experiments tested atmospheric surface forcing and a learnable residual connection per variable and depth level. RánCast produces stable daily forecasts of temperature, salinity, velocities and sea surface height over more than least two years. A two-year global rollout takes 4.5 minutes on one GPU node. With prescribed atmospheric forcing, an ensemble of 24 two-year rollouts closely follows the global-mean SST and reproduces the mean surface circulation and its variability with biases mostly below 0.05 m/s (Fig. 2), whereas unforced rollouts lose the seasonal phase within months. As new ensemble members require an atmosphere that is not prescribed, we will couple RánCast to ArchesWeather and retrain it on the OceanWeather ensembles (see request for 2027). The results are currently being finalized for a publication to be submitted within the next half year.

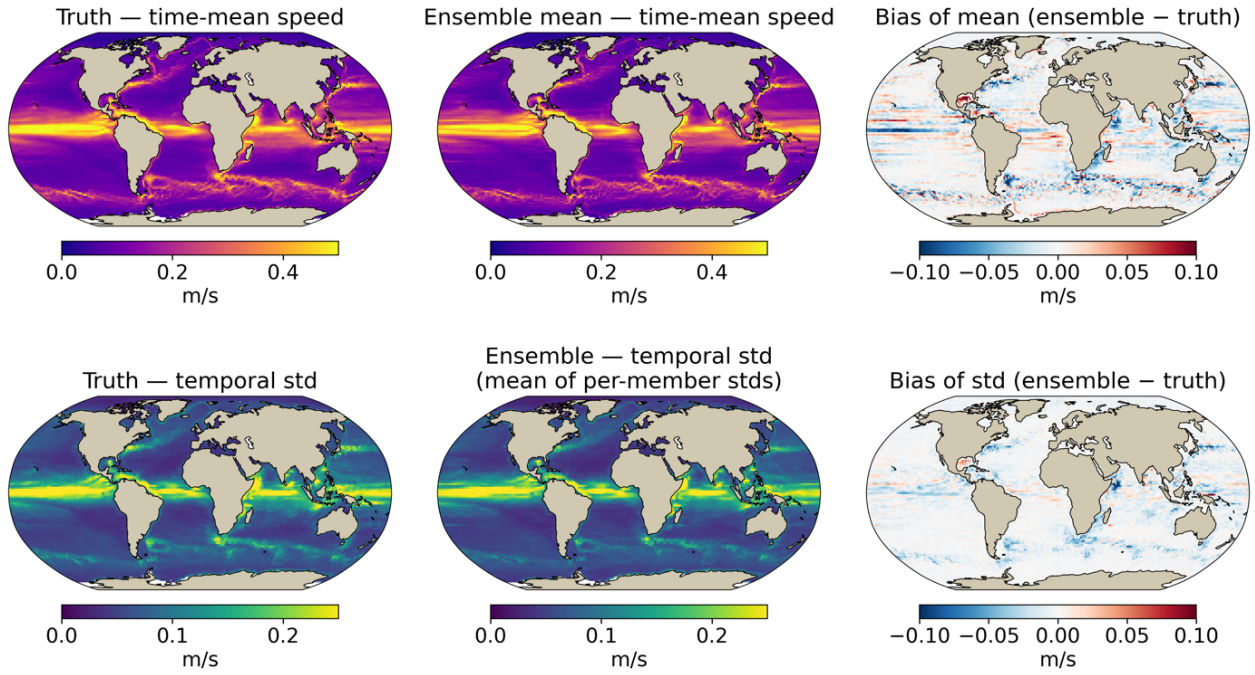



*Figure 2: Time-mean (top) and temporal standard deviation (bottom) of surface current speed in the forced RánCast ensemble (middle) and the nextGEMS reference simulation (left), and their difference (right).*

### 4. Resource Usage and Outlook

CPU resources were used for the generation and analysis of the ensembles, GPU resources for the training of RánCast. Part of the CPU allocation remained unused: the simulations were halted at the beginning of the year for a preliminary analysis of the existing members, and unforeseen Levante downtimes in late summer prevented the planned continuation. The remaining ~18,000 CPU node hours will complete the two outstanding Reference members (about 65 simulated years) and fund the analysis of the ensembles. Since October 2026, restart files and run directories of completed members are being moved to the archive. This will be finalized by the end of the year to free disk space for the ensemble leaves planned for 2027.

### 5. Dissemination and Collaboration

- S. Juricke, N. Hutter: *Ocean eddies in the climate system*, highlight poster, EGU General Assembly 2026, Vienna; S.
- Juricke et al.: *The role of eddy parameterizations in ocean modelling*, talk, COMMODORE workshop 2026, Trieste.
- J. Rhein et al.: *Leveraging km-scale simulations for low-cost data-driven emulation of the global 3D ocean state*, poster, Ocean Sciences Meeting 2026, Glasgow;
- J. Rhein et al.: *RánCast: A global 3D ocean emulator trained on kilometer-scale simulations*, poster, MLESM workshop 2026, Bonn.
- Simulation output has been shared with Ian Grooms (University of Colorado Boulder).