SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2026 (2nd year of the project)
Project Title:	Deep ocean heat uptake on equilibrating time scales (DEEPNESS)
Computer Project Account:	spitvent
Principal Investigator(s):	Ventrucci Chiara
Affiliation:	University of Bologna, Department of Physics and Astronomy (DIFA) National Research Council, Institute of Atmospheric Sciences and Climate (CNR-ISAC)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	//
Start date of the project:	01/01/2025
Expected end date:	31/12/2026

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	12,200,000	11,245,594	15,350,000	8,749,969
Data storage capacity	(Gbytes)	16900	0	38,350	3,300

Summary of project objectives (10 lines max)

This project aims to study the response of Earth's climate system to the increase of greenhouse gases concentration in the atmosphere. We run and analysed some idealized experiments with the general circulation model EC-Earth4. We choose to work with a low-resolution version of the model to compare multiple scenarios at a significantly smaller computational cost. Experiment setup includes a change in the structure of the ocean, through the realization of a small perturbed parameter ensemble (OPPE).
The focus of this project is on how the oceanic component influences the atmospheric response, as two key factors shaping the warming pattern and the associated climate feedbacks are the added and redistributed heat, respectively stored in the ocean according to background ventilation pathways and to changes in ocean circulation. Regions of interest for our analysis are the midlatitudes, both in the Southern Ocean and the North Atlantic.

Summary of problems encountered (10 lines max)

None so far.

Summary of plans for the continuation of the project (10 lines max)

For the remaining months of 2026, we plan on continuing the analysis of the simulations realized through this project.
We also plan on using the remaining computer resources for making the analysis more robust. Possible options are:

- extend some preindustrial control runs, to better assess variability,
- run transient warming experiments from different initial years of the preindustrial control to assess dependence from initial conditions,
- run warming experiments with abrupt CO_2 increase to analyse climate sensitivity dependence to ocean parameter perturbations in quasi-equilibrium conditions.

List of publications/reports from the project with complete references

None so far.

Summary of results

We explored and revisited Q2 of the project (What is the role of ocean circulation and ocean stratification in determining the deep ocean uptake?), focusing on the controls of OHU at a global scale.
We worked with the low-resolution configuration of EC-Earth4 v4.1.4, build with the TL63L31 grid of OpenIFS (2.8°x 2.8° resolution) for the atmospheric module and the ORCA2L31 grid of NEMO (2° x 2° resolution) for the ocean module.

We started with testing the sensitivity of the ocean properties to parametrization parameters using v4.1.0. Playing with the tuning of the model, we identified some the most influential parameters in NEMO source code for mixing parametrizations using 50 years long simulations in a preindustrial setup.

The perturbed processes are eddy-induced mixing (through Gent&McWilliams parametrization), lateral diffusion of tracers, vertical turbulent kinetic energy, Langmuir cells strength, vertical momentum diffusion, double diffusive mixing, internal wave mixing, horizontal and vertical diffusion.

Figure 1 shows the change for some key ocean variables at the end of the 50 years test run. Selected variables are sea surface temperatures in the global mean (TOS), Southern Ocean (TOS SO), and North Atlantic (TOS NA), sea ice extent and volume in the Northern Hemisphere (SIC N and SIV N), sea ice extent and volume in the Southern Hemisphere (SIC S and SIV S), maximum mixed layer depth in the North Atlantic (MLD NA) and maximum AMOC strength (AMOC). Values are shown as differences with the simulation with a reference parameter set, reported in the right gray column.

Figure 1. Sensitivity tests for OPPE with EC-Earth4 for key climate variables for years 30-50 of the simulations.

Based on the sensitivity results, we selected 14 configurations. Values are summarized in Table 1.

Exp	Parameter	New value	Ref value	Process
01cc	rn_eiv_scale	3	1	Eddy diffusivity (Gent&McWilliams)
02cc	nn_etau	1	0	ML TKE
03cc	rn_lc	0.4	0.2	Langmuir cells
04cc	rn_aht_scale (nn_aht_ijk_t = 21)	2	1	Tracers diffusivity
05cc	nn_etau	2	0	ML TKE
06cc	rn_lc	0.05	0.2	Langmuir cells
07cc	rn_eiv_scale	2.5	1	Eddy diffusivity (Gent&McWilliams)
08cc	nn_etau + rn_lc	1 + 0.4	0 + 0.2	
09cc	nn_etau + rn_aht_scale	1 + 2	0 + 1	
10cc	nn_etau + rn_lc	1 + 0.05	0 + 0.2	
11cc	nn_etau + rn_eiv_scale	1 + 2.5	0 + 1	
12cc	nn_etau + rn_lc	2 + 0.4	0 + 0.2	
13cc	nn_etau + rn_aht_scale	2 + 2	0 + 1	
ctl0				

Table 1. Summary of parameter perturbations in final OPPE.

For each setup, the following experiments were run:

- Spin up with preindustrial forcing for 1000 years;
- Preindustrial control run for 150 years;
- Transient warming run with CO_2 concentration increasing with a rate of 1%/year for 150 years;
- Atmosphere only run with preindustrial forcing for 150 years;

- Atmosphere only run with CO_2 concentration increasing with a rate of 1%/year for 150 years.

One example is shown in Figure 2 for the evolution of global air surface temperature in the coupled runs.

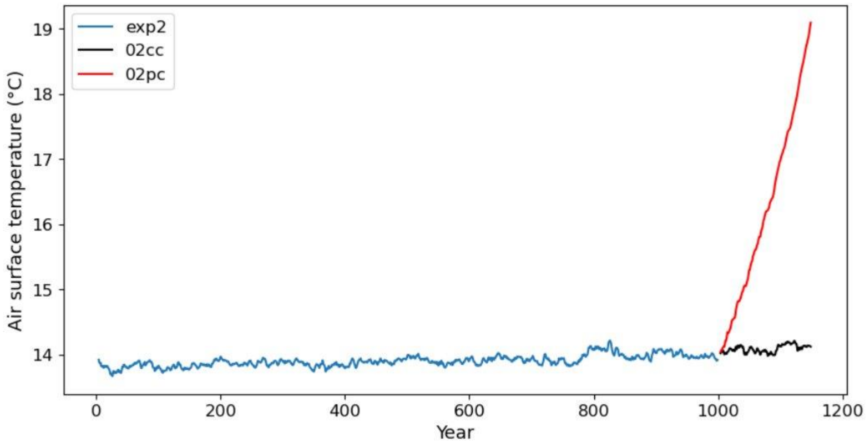

Figure 2. Atmospheric surface temperature evolution for one parameter configuration.

We then analysed the experiments focusing on transient climate change metrics. The evolution with time is different across experiments, resulting in different global mean values of Transient Climate Response (surface air temperature change at the time of CO_2 doubling), ocean heat uptake efficiency and climate feedback parameter.

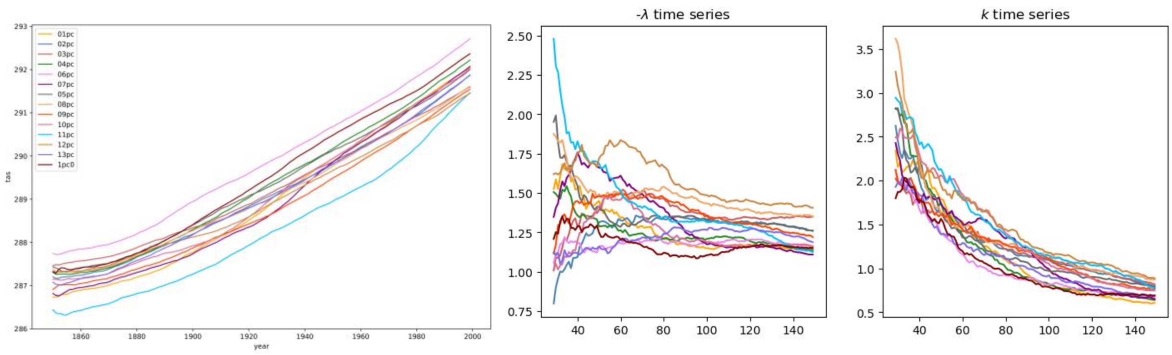

Figure 3. Timeseries of surface temperature (K), ocean heat uptake efficiency and climate feedback parameter (W/m2/K) in OPPE members.

The analysis is now focusing on understanding the regional changes and the connections between these metrics, both in terms of time evolution and ensemble spread.