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	………2024-2025…………
Project Title:	The impact of Stochastic physics in North Atlantic Climate…… ……………………………………………………………………
Computer Project Account:	……spityang……………………………………………
Principal Investigator(s):	……Chunxue Yang………
Affiliation:	Institute of Marine Sciences, National research Council of Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	…………………………………………………………………… ……………………………………………………………………
Start date of the project:	………01/01/2024………………………………………
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)	9M	7,5M	9M	11,7M
Data storage capacity	(Gbytes)	0	0	0	0

Summary of project objectives (10 lines max)

The project focuses on improving the representation of key oceanic physical processes in the North Atlantic-Arctic-Mediterranean region, which is critical for understanding and predicting regional and global climate change. In particular, we would like to understand if including stochastic physics would improve the representation of ocean physics in moderate resolution NEMO models compared with high resolution models because running high resolution model is very costly. Current models struggle to accurately simulate these processes due to limitations in vertical mixing and subgrid-scale variability. By implementing stochastic physics through the STOPACK system in coupled ocean-climate models, the project seeks to improve simulations of ocean mixing and circulation. This could lead to better predictions of climate variability and change. We use regional configurations of NEMO, CREG025 and CREG12, which include the North Atlantic Ocean, Arctic Ocean and Mediterranean Sea at 1/4° and 1/12° of horizontal resolution, respectively.

Summary of problems encountered (10 lines max)

The major problems we encountered are the storage. When we wrote the proposal, we did not apply for the storage, and now it becomes critical because of the following reasons:

- We are saving daily output because we need high temporal resolution to do meso-scale ocean eddy detection and daily output is huge for high-resolution (1/12 resolution).
- To save the computing time, we do not use the XIOS I/O library, which means that we need to rebuild the data afterwards.
- We save daily and monthly data, and daily only could be saved in ECFS and monthly data in our local machine

Therefore, it is time consuming to rebuild the data and transfer data to our local machine, which is the major problem we have encountered that slows down the project process. For example, we still need to rebuild the CREG12 simulations in order to understand the results.

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

In terms of the plans for the project, we have the following tasks to carry out to reach our objectives:

- We will continue the CREG12 simulations to finish the whole time period and perform postprocessing
- We have tested the runs with stochastic physics implemented, however still not successful due to blow-up the experiments, so the next step we will test the stochastic physics runs and run the ensembles experiments
- We will perform analysis of the experiments to understand the impact of stochastic physics

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

During the process of the special project, we have performed the following experiments with NEMO model:

(1) Control run with the CREG025 for the period of 1993-2020
(2) Control run with CREG12 for the period of 1993-2009 (the post-processing is not finished yet, like rebuild the files, so in this report, we only show the analysis of CREG025)

Additional to the experiments, we have performed eddy detection by using different NEMO-based reanalyses that use data assimilation. The objective is to understand the impact of resolution on eddy activities. Similar analysis will be applied to the experiments we performed (will be performed) within this special project.

The outcome of the special project up to now is summarised in the following section.

1. **Evaluation of CREG025 with observations**

To understand the performances of the CREG025, we have compared the SST with ESA-CCI SST v2 (Figure 1 and Figure 2).

The simulated sea surface temperature (SST) from NEMO CREG025 model shows that, as expected, there's a strong latitudinal SST gradient, with warm temperatures in the subtropical Atlantic (~26°N) and cold SSTs in the Arctic. The subpolar gyre and Nordic Seas exhibit cooler SSTs, aligning with known oceanographic structures. The observational dataset from ESA-CCI exhibits a broadly similar SST pattern to CREG025, with warm subtropical waters and cold polar waters. However, ESA-CCI likely offers higher fidelity in regions influenced by satellite observations, particularly near sea ice margins and coastal zones.
The differences between CREG025 and ESA-CCI show positive anomalies (green to yellow-red) in parts of the Nordic Seas, Barents Sea, and eastern subpolar North Atlantic suggest that CREG025 tends to underestimate SST in these regions and negative anomalies (light blue to dark blue) near the western subpolar gyre and parts of the Arctic suggest a tendency to overestimate SST there.

The biases are generally within ±1°C in most areas, which is acceptable for many climate applications, but systematic biases (e.g., cold bias in the subpolar gyre) may point to model deficiencies in ocean mixing, heat transport, or surface flux parameterizations.

The timeseries of the SST in CREG025 and ESA-CCI highlights that in general CREG025 slightly overestimates the SST value in summer, likely due to over-estimated stratification, and underestimates in winter, due similarly, to over-estimated mixing and deep convection

Additionally, we have compared the SLA from CREG025 with ESA-CCI SLA (Figure 3). The differences of SLA is larger compared with SST, in particular the CREG025 SLA shows a linear increasing trend that the ESA-CCI SLA does have slightly weaker negative trend. Without data assimilation, indeed, the model can hardly represent low-frequency variations of the sea surface height; however, the representation of the eddy population is not affected by this.

What we have shown here are preliminary evaluation of the CREG025 and further analyses are needed to understand better the performances of the model simulation.

2. **Eddy detection**

Mesoscale eddies play a critical role in the North Atlantic. We used py-eddy-tracker to detect eddies in AVISO DUACS SLA data and ocean reanalyses from the Copernicus Marine Service. This forms a baseline for analyzing the effect of resolution on eddy activity and will guide the evaluation of our project simulations.

Figures 4 and 5 present results from the mesoscale eddy detection analysis using satellite altimetry (AVISO) and ocean reanalyses (GLORYS12). Figure 4 illustrates a snapshot of the eddy population detected on a specific day, showing the spatial distribution of eddies across the North Atlantic. It is evident that GLORYS12 (1/12°), which has higher spatial resolution than AVISO, captures a larger number of eddies, particularly smaller-scale features that may not be resolved in the coarser satellite data (1/4°). This demonstrates the impact of model resolution on the ability to resolve mesoscale dynamics.

Figure 5 shows the time series of eddies with lifetimes longer than 70 days, offering insight into the persistence of eddy structures. The results indicate that: GLORYS2V4 detects fewer long-lived eddies compared to AVISO, likely due to its relatively lower resolution and weaker representation of mesoscale energy. In contrast, GLORYS12V1, with its finer resolution, detects a higher number of long-lived eddies than both GLORYS2V4 and AVISO, reflecting improved simulation of eddy life cycles and dynamics.

These findings suggest that higher-resolution reanalyses provide a more detailed and realistic depiction of mesoscale processes. However, discrepancies in eddy lifetimes between model outputs and satellite observations highlight the need for further validation.

As a next step, we plan to incorporate SWOT (Surface Water and Ocean Topography) satellite altimetry data – for the short period SWOT is available –, which provides higher spatial and temporal resolution than traditional altimetry missions. This will enable a more robust comparison with ocean reanalyses of varying resolution and help assess the performance of models in resolving mesoscale and submesoscale eddy dynamics.

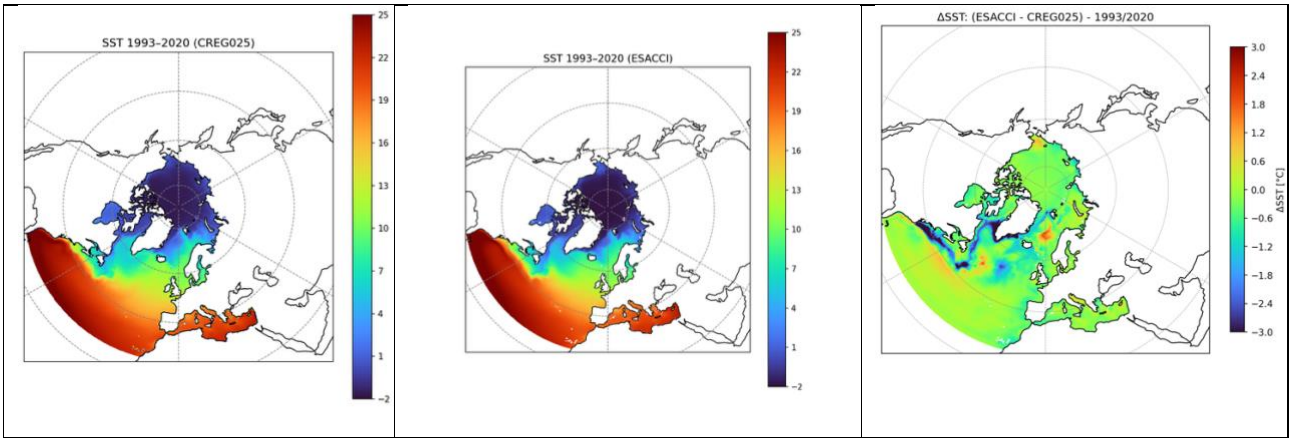


Figure 1, SST climatology in CREG025, ESA-CCI and differences between ESA-CCI and CREG025

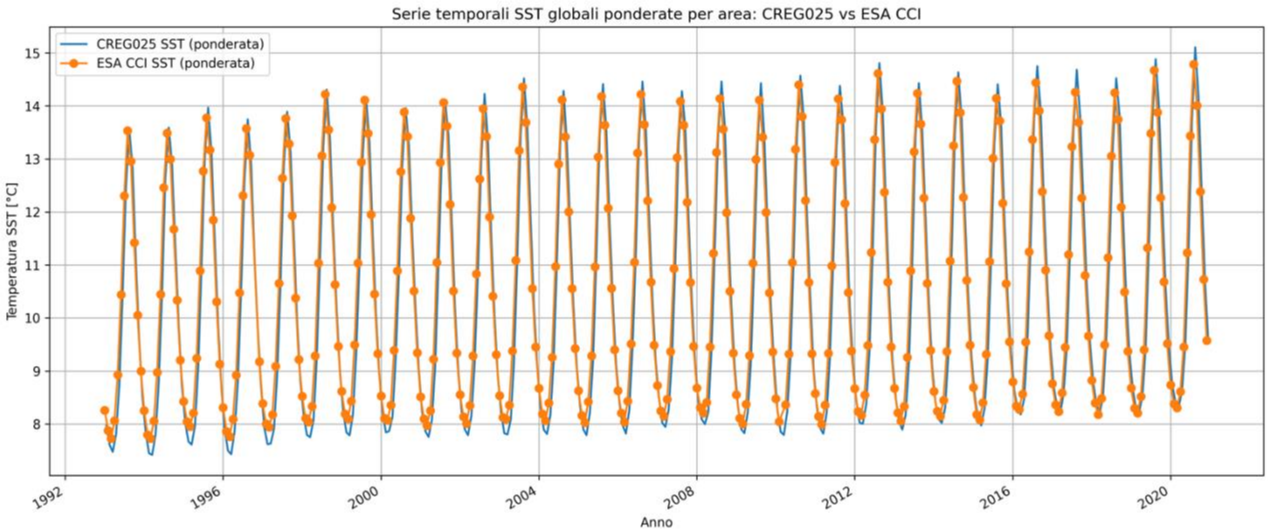


Figure 2 Area mean of the SST in CREG025 and ESA-CCI SST.

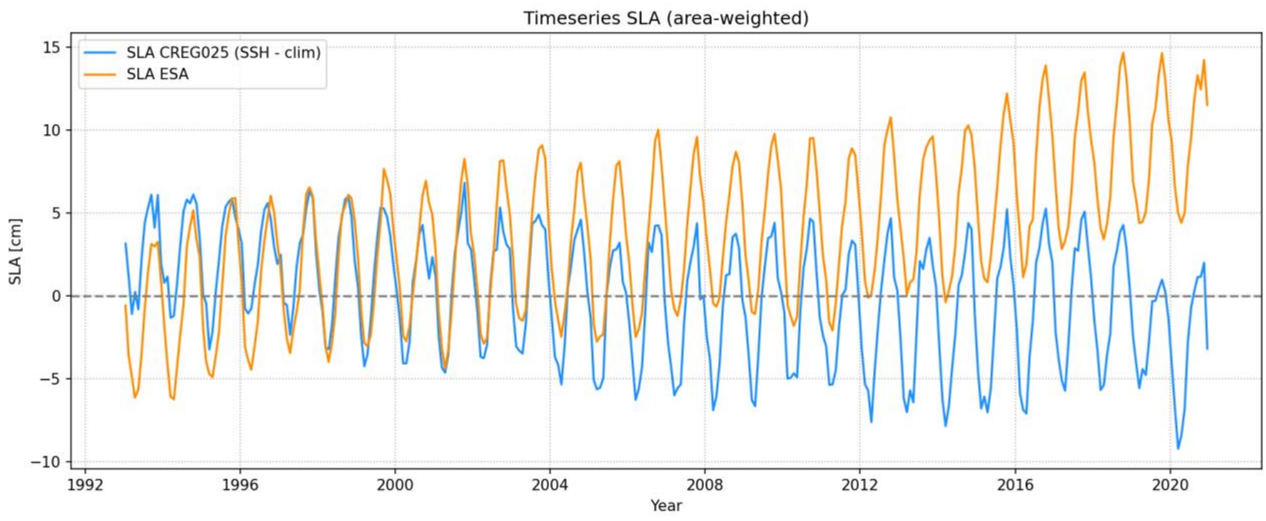


Figure 3 the sea level anomaly in CREG025 and ESA-CCI SLA.

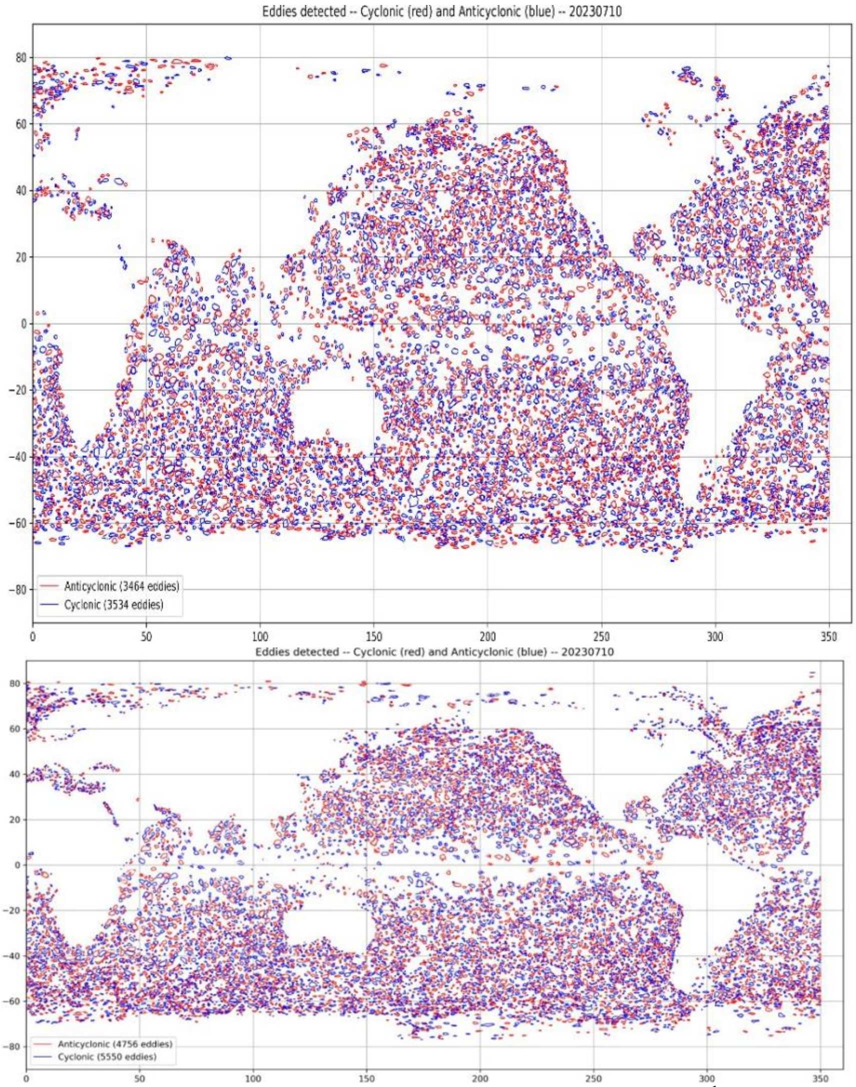
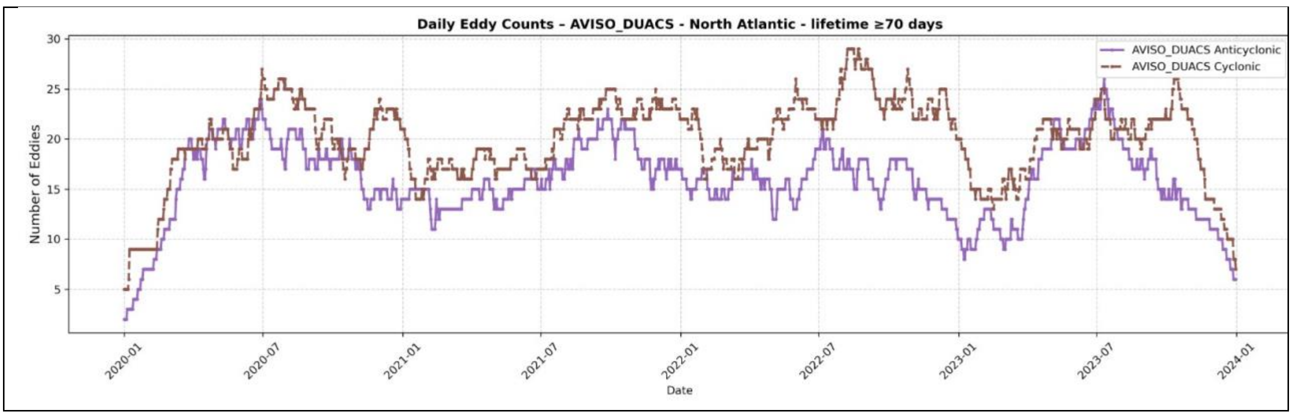


Figure 4 Eddy population in AVISO DUCAS and GLORYS12 on 10th July 2023



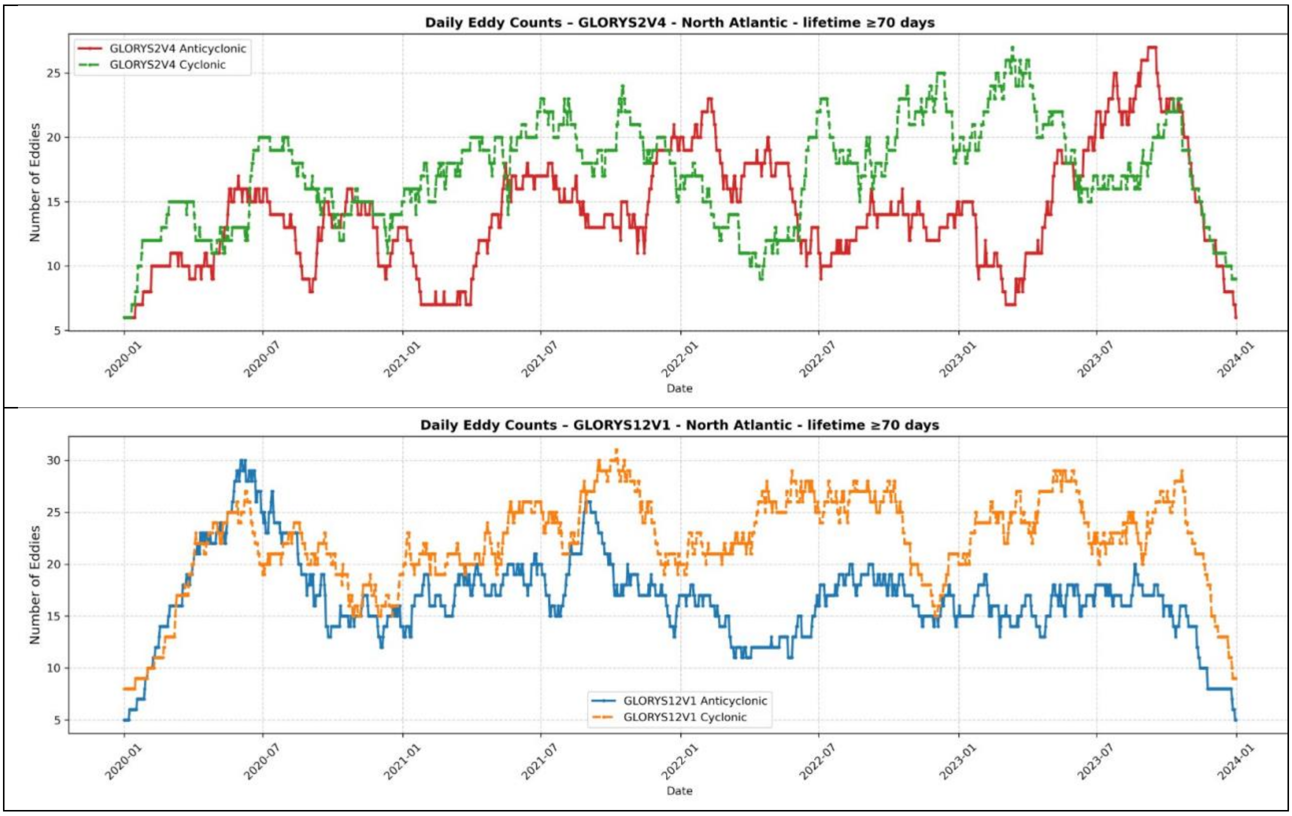


Figure 5 Eddy population in AVISO DUCAS, GLORY2V4 and GLOYRS12