# 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** | 2025 |
| **Project Title:** | Mapping the continuum of cyclone dynamics in the phase space of diabatic and baroclinic forcing |
| **Computer Project Account:** | sprgflao |
| **Principal Investigator(s):** | Emmanouil Flaounas |
| **Affiliation:** | Hellenic Centre for Marine Research |
| **Name of ECMWF scientist(s) collaborating to the project** (if applicable) | |
| **Start date of the project:** | 1/1/2025 |
| **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) | | | 8,000,000 | 2,455,919 |
| **Data storage capacity** | (Gbytes) | | | 50 Tb | 40 Tb |

## Summary of project objectives (10 lines max)

There is a theoretical continuum between tropical cyclones (TC) and Extratropical cyclones (ETC) which connects purely diabatically and purely baroclinically driven systems. Nevertheless, this theoretical continuum has not been demonstrated in detail and it is yet unclear whether baroclinic and diabatic forcings to cyclones development is balanced or biased towards one end of the continuum for specific groups of ETCs. While it is common knowledge that convection and baroclinic forcing are the main processes characterising the two ends of this continuum, the leading processes implicated within the whole range of cyclones is still an open question. Therefore, this project aims to perform a dedicated modelling analysis that replies to this fundamental gap in atmospheric dynamics

## Summary of problems encountered (10 lines max)

Up to now, there are minor issues related to the implementation of the simulations' framework. This mainly concerns the failed simulation of complete cyclone tracks when the storms are approaching the polar latitudes where Lambert projections are not adequate for a displaced nested domain. Failed simulations have been omitted.

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

The project plans to produce as many simulations as possible. Based on the resources used so far, we expect to create around 1,000 simulations of North hemisphere cyclones. These simulations will likely use all the SBUs allocated for 2025 and 2026.

## Summary of results

In this project, we use a large set of cyclone tracks identified from the ERA5 reanalysis dataset (Hersbach et al., 2020). For each cyclone track, we perform a dedicated two-domain simulation. The parent domain is designed to closely encompass the entire path of the cyclone, while a nested square domain measuring 4,000 km on each side follows the cyclone center throughout its evolution. This nested domain is large enough to capture all key dynamical features of the cyclone, including tropical cyclone convective eyewalls, frontal structures, and the associated airstreams.

The two domains are configured with different horizontal resolutions: the parent domain uses a resolution of 30 km, and the nested domain uses a finer resolution of 10 km. This higher resolution aligns with the anticipated capabilities of future Ensemble Prediction Systems (EPSs). The nested domain consists of roughly 400 x 400 grid points and includes about 61 vertical levels, allowing for detailed representation of the cyclone's vertical structure.

To ensure that the simulated cyclones follow realistic tracks and maintain life stages consistent with observations, the wind field in the parent domain is strongly nudged toward ERA5 data. This nudging constrains the large-scale atmospheric flow and helps reproduce cyclone behavior comparable to reanalysis. In contrast, the nested domain is intentionally left without nudging. This allows the model to resolve important fine-scale processes autonomously, such as mesoscale convective systems and intricate dynamical interactions within the cyclone core.

This approach forces the Weather Research and Forecasting (WRF) model to simulate cyclones with similar tracks and life cycles to those in ERA5, while still capturing cyclone dynamics with "optimal skill" and effectively minimizing model errors in the large-scale circulation.

Figure 1 illustrates an example of all the cyclone tracks selected for a one-month period in May 2020. These tracks span the entire Northern Hemisphere, reflecting the wide range of cyclone types included in this study. Our dataset covers a rich diversity of systems, including tropical cyclones, Mediterranean cyclones, polar lows, subtropical systems, mid-latitude storms, and other less commonly studied cyclones that develop over land.

To date, we have already completed an ensemble of approximately 200 simulations covering a period from January to May 2020, and we are continuing our efforts to produce as many additional simulations as possible to support further research on cyclone dynamics. Large part of the project so far was devoted to the implementation of our simulations methods and the validation of the tracks as calculated in ERA5 reanalysis. More detailed results on cyclone dynamics are expected to be produced by the end of 2025 showing a first ensemble of potential vorticity analysis, aiming thus to show the climatology of cyclone systems from the perspective of atmospheric processes that contribute to the systems' development.

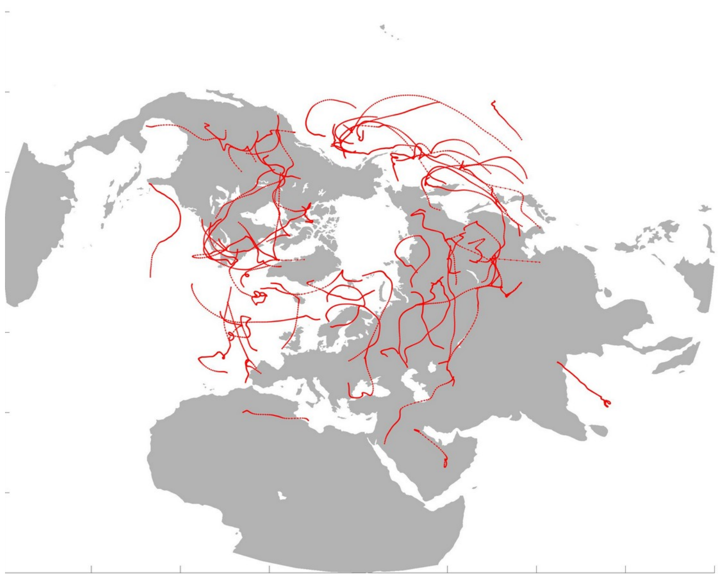

**Fig. 1** Cyclone tracks in May 2020, simulated by WRF in the context of the current project.