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	2023
Project Title:	Understanding dynamics and impacts of cyclone systems through a comprehensive dataset of convection-permitting simulations
Computer Project Account:	spgrflao
Principal Investigator(s):	Emmanouil Flaounas
Affiliation:	Hellenic Centre for Marine Research (HCMR)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Helena Flocas, Maria Hatzaki, Platon Patlakas, Ioannis Pytharoulis, Juan Jesus Gonzalez Aleman, Mihaela Caian, Diego Carrió, Stavros Dafis, Samira Khodayar, Mario Marcello Miglietta, Georgios Papavasileiou, Dorita Rostkier-Edelstein, Victoria Sinclair, Heini Wernli
Start date of the project:	1 January 2023
Expected end date:	31 December 2025

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	2,115,080
Data storage capacity	(Gbytes)			50,000	

Summary of project objectives (10 lines max)

Given the multiple scales of atmospheric processes involved in cyclones development, high resolution simulations are irreplaceable research means to address open questions in dynamics and impacts. This project aims to fulfil a twofold objective:

- to build a first-of-its-kind comprehensive dataset of cyclone simulations at convection-permitting scales;
- to use this dataset for the ends of better understanding cyclone dynamics and impacts through research projects which have been proposed by the community, especially in the context of the MedCyclones COST Action.

Summary of problems encountered (10 lines max)

The implementation of this project has encountered a series of challenges which are already resolved at large extent. From the technical perspective, much of the first year was devoted to the optimal configuration of the WRF model, the automation of simulations' production chain and the compilation options that make the model cost efficient. Additional challenges were related to the post processing of simulations, where two Lagrangian models are combined to provide air parcel trajectories for the needs of specific research projects. Finally, current -and final- works are devoted to the conversion of model outputs from netcdf format to grib2. This is done to reduce storage. We estimate this final issue to be resolved within the next weeks.

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

The project estimates the production of a series of simulations. According to the resources consumed so far we estimate the production of about 200 simulations of Mediterranean cyclones and about 400 simulations of North Atlantic cyclones. Simulations are expected to use the entire allocated amount of SBUs for 2023 and 2024. In short term (within few months), we aim at completing post-processing and make available the simulations to the community. Until the end of 2023, we aim at starting research projects that take advantage of the simulation outputs. In the year to come (2024), we will continue the intensive production of simulations and will promote this project to the community aiming at increasing scientific production on cyclone dynamics and impacts.

List of publications/reports from the project with complete references

There are no specific publications or scientific outcomes yet. Nevertheless, the project implementation has been discussed extensively in a parallel session of the 1st MedCyclones workshop.

Hatzaki, M., and Coauthors, 2023: MedCyclones: Working Together toward Understanding Mediterranean Cyclones. *Bull. Amer. Meteor. Soc.*, **104**, E480–E487, https://doi.org/10.1175/BAMS-D-22-0280.1.

Summary of results

This is the beginning of the project and main results are of technical nature. They focus on the development of the automatic chain of tools and models that produce the simulations and post-process their outputs. This production chain is mainly composed by (1) the limited area model WRF, (2) the WRF pre-processing system (WPS), (3) the Read/interpolate/plot (RIP) program (a post-processing tool adapted to WRF outputs), and (4) the Lagrangian model LAGRANTO.

The operational chain for the production of simulations starts with a prescribed number of cyclone tracks from ERA5, produced by the method of Flaounas et al. (2014). Each track is provided as an input to a Fortran program that produces the size and coordinates of the parent domain (at 14 km of horizontal resolution). The parent domain tightly encompasses the cyclone track. Then the program calculates the size of the nested domain (2.8 km), the directions and times of its predefined movements to always follow the cyclone centre. WPS is provided with all this information to produce the necessary input fields for WRF. The model will eventually perform simulations for each cyclone track using two-way nesting. Spectral nudging is applied to the parent domain with a strength that increases linearly from the mid-troposphere to the model top at 50 hPa. Spectral nudging is necessary to force the cyclone in the parent domain not to diverge from the prescribed track from ERA5.

After the model integration is finished, we use the RIP (read/interpolate/plot) program to release 10,000 air mass trajectories every ~11 km (every 4 grid points) within the nested domain. Trajectories are released forward and backward in time for 48 hours in each time direction at 950, 850, 800, 700 and 600 hPa (so 50,000 trajectories in total per release time). If the time of maximum intensity of the cyclone (deepest MSLP according to ERA5) is set at t_0, then release times are set at t_0-24h, t_0-12h, t_0 and t_0+12h. This makes a total of 4 datasets per cyclone. Each dataset includes a maximum of 50,000 trajectories where each trajectory runs for a maximum of 96 hours (we only retain trajectories that do not start below ground, and have tracked air parcels for at least 12 hours before leaving the domain). All trajectories eventually escape the nested domain. Therefore, we extend them in the parent domain using LAGRANTO backwards and forward in time for 48 hours. The change of model for the parent domain was necessary for computational reasons. Being adapted to WRF outputs, RIP takes into account that nested domains are moving in time. Nevertheless, RIP was found to have a rather slow performance and requires one release time per run. The latter issue is inconvenient when extending the trajectories in the parent domain since air parcels escape the nested domain in different times.

As an example of the usefulness of the simulations and the post-processing routines, Fig. 1 shows air mass trajectories that correspond to sting jet of storm Brendan (2020) as simulated in the framework of this project. Sting jets are important airstreams for the understanding of storm impacts but due to their fine-scale structure, the identification of a sting jet requires Langragian models applied to high resolution simulations of frequent model outputs. Numerous simulation tests have been conducted in the beginning of the year and currently we have already produced about 60 Mediterranean cyclones and 20 North Atlantic cyclones. Several scientific projects are thus expected to start after the completion of a first round of simulations in late Autumn 2023. Already produced material will be soon provided to the community for scientific research.

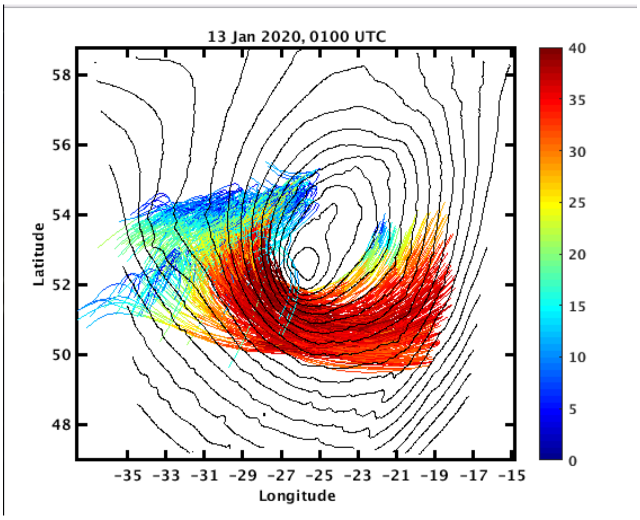

Figure 1 Air parcel trajectories that satisfy the condition of exceeding wind speed of 36 m s^{-1} below 700 hPa when they are close to the cyclone centre. We show only trajectory parts from 12 January 2020, 1900 UTC to 13 January 2020, 0700 UTC. Colorbar depicts wind speed in m s^{-1} and contour depicts the mean sea level pressure (cyclone centre is ~950 hPa).

References

Flaounas, E., Kotroni, V., Lagouvardos, K., and Flaounas, I.: CycloTRACK (v1.0) – tracking winter extratropical cyclones based on relative vorticity: sensitivity to data filtering and other relevant parameters, Geosci. Model Dev., 7, 1841–1853, https://doi.org/10.5194/gmd-7-1841-2014, 2014.

Gray, S.L., Martínez-Alvarado, O., Ackerley, D. and Suri, D. (2021), Development of a prototype real-time sting-jet precursor tool for forecasters. Weather, 76: 369-373. https://doi.org/10.1002/wea.3889