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:	Exploring high resolution modelling of extreme convective events in the Mediterranean Region with gSAM model
Computer Project Account:	spitsara
Principal Investigator(s):	Paolina Bongioannini Cerlini[1] ; Miriam Saraceni[2]
Affiliation:	1 University of Perugia, Dep.t of Physics and Geology; 2 Dep.t of Civil and Environmental Engineering;
Name of ECMWF scientist(s) collaborating to the project (if applicable)	
Start date of the project:	01/01/2025
Expected end date:	31/12/2027

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)			20.000.000	565.955
Data storage capacity	(Gbytes)			50 TB	483 GB

Summary of project objectives (10 lines max)

The objectives of the project are related to exploring the use of ensembles at different resolutions to understand which type of convective extreme events are more susceptible to the increase of horizontal resolution and why. While this focus has remained, the research has expanded to the possibility of implementing data assimilation with observations from satellites and ground-based meteorological network, mainly because the project is embedded in a collaboration with the regional authorities of Umbria (central Italy) regarding weather forecasting. The new added objective is: Can data assimilation improve forecast of different types of extreme convective events?

This is explored given the same set of observed events:

1. Ianos cyclone (15^{th} –21^{st} of September 2020),
2. the Umbria Mesoscale Convective System (23^{rd} of August 2021)
3. the Umbria flood (11^{th} –14^{th} of November 2012)

This will help to develop a framework coupling a convection permitting model with the IFS analyses to interrogate Mediterranean convective extremes. Another connected goal is to disentangle the roles of self-aggregation, CAPE and moisture-convergence feedback in driving extremes. Our final goal is to produce best-practice guidelines for an operational sub-kilometre ensemble system for Mediterranean feedback prediction. Release open data, reproducible workflows and insights to accelerate European convective-scale research, specifically in our region.

Summary of problems encountered (10 lines max)

The first critical aspect of the work was related to chosen model, gSAM, to carry out the simulations. Indeed, gSAM has proved to be very difficult to adapt for modelling “real” cases. Since it is in its early development stage, gSAM lacks a part of code to successfully achieve the initialization of a “real” case, and in addition the version we planned to use had bugs especially on the surface scheme. Furthermore, in the same version we found that gSAM short-wave/surface-flux restart bug hampers flux-based data assimilation, which becomes important for the new project objectives. Therefore, it was decided to change model and carry out the simulations with the WRF model. The WRF model was chosen because of its easy initialization from reanalysis and other data types and because it allows data assimilation with a specific scheme, WRFDA. In fact, the preliminary simulations carried out with WRF will be presented in the summary of results. A second critical issue was found on the type of initialization chosen. The initialization data chosen were the reanalyses of ERA5. Starting with the first case study chosen, Ianos cyclone, it was realized that the ERA5 resolution is not sufficient to be able to initiate convection from the cyclogenesis phase of the cyclone, i.e., September 15th, 2020. This was found for both the 27-km simulation, the 9-km simulation and the 3-km simulation, which were made with the dynamic downscaling of ERA5 reanalyses. The convection and cyclone were only able to form from already initiated cyclone on September 16 and September 17 of 2020. For this reason, we have decided to change the data for the initialization, as it will be discussed below. Nonetheless we have already obtained some results with these preliminary simulations, which are summarized below.

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

To solve the initialization problems and to continue the research on data assimilation as well, we plan to redo the simulations of the cases study considered from the initialization with the operational analysis of IFS at 9 km. This way we will be able to carry on simulations at 9, 3, and 1 km. We will also add data assimilation for these cases. In the case of Ianos cyclone, the planned data assimilation will specifically involve the assimilation of Sea Surface Temperature (SST) satellite data (from the ESA CCI product), while in the case of the two mesoscale convective systems, the data assimilation will involve the assimilation of 2m temperature, precipitation, and soil moisture data observed from meteorological networks in central Italy, as the one in the Umbria region. We also leave open the possibility of carrying out new test cases of observed convective extreme events in Central Italy.

List of publications/reports from the project with complete references

None

Summary of results

We carried out three different simulations as mentioned of Ianos cyclone, where we enable the change in resolution from 27 km to 9 km to 3 km, within the same initialization date. The three starting dates we chose where from the 15th of September 2020 at 00 UTC to the 17th of September 2020 at 00 UTC. As already mentioned, in this starting case study, initializing WRF with ERA5 reanalysis from the 15th of September does not lead to a cyclone appearance. Thus, here we report the preliminary analysis carried out for the simulations starting from the 16th and from the 17th. First, we tracked the cyclone with a tracking method is based on Picornell et al. (2014) and Saraceni et al. (2023). The algorithm first aims to find the local minima of the sea level pressure field at each time step. Then, for each minimum, the sea level pressure gradient is computed along eight main directions (E, NE, N, NW, W, SW, S, SE) within a circle of radius 200 km. The computed gradient is then chosen to be lower than 5hPa/ 200km in at least 6 directions. After the minimum detection and filtering via selection through sea level pressure gradient, a proximity condition is applied to construct the complete trajectory. Starting from the first-time step, each minimum is connected to the following one, at the following time step, that satisfies the condition of being closer than $\Delta x = V\Delta t$, with $V = 50$km/h and $\Delta t = 3$h. If this condition is met, the two consecutive minima are considered to belong to the same trajectory.

The tracks are reported in Figure 1. There we report the analysis of the tracks at 27 km and at 9 km of resolution. Simulations with higher resolution manage to capture the trajectory better than those with lower resolution regardless of the date of initialization. This result is evident by comparing these simulations with trajectories plotted for the same cyclone in the literature (Saraceni et al. (2023), Saraceni et al. (2025)) and to observations (Panegrossi et al. (2023)).

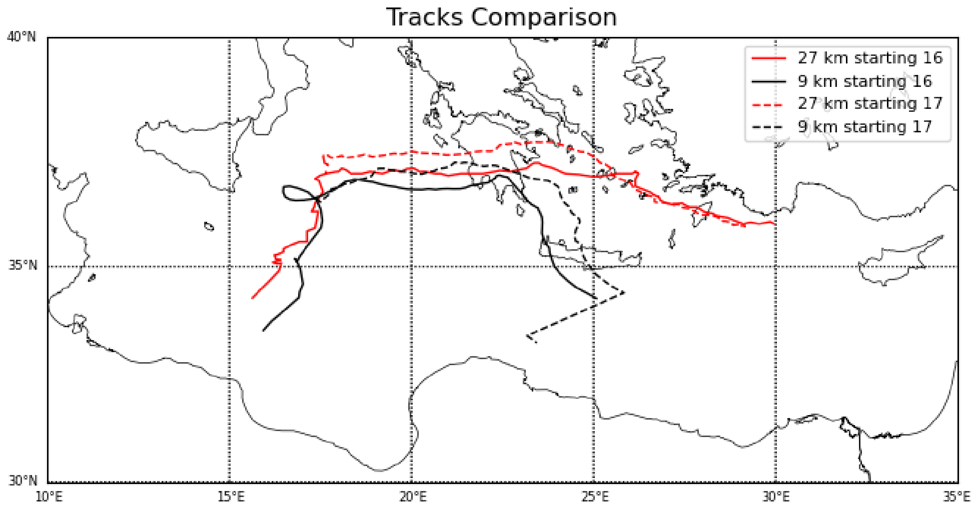

Figure 1: Track comparison between the simulation starting on the 16th at 27 km of resolution and at 9 km of resolution (solid lines) and the simulation starting on the 17th at 27 km of resolution and at 9 km of resolution (dashed lines).

This very relevant aspect is one of the objectives of the special project, exploring the change in resolution in different context and understanding which process is better captured by increasing it. The trajectory being more similar to the observed one with the increase in resolution was an expected result and it is something that will be investigated more thoroughly in the next steps of the project. The results found here are also confirmed by a recent publication that, by analysing Ianos cyclone with various high-resolution models including WRF, obtained similar results on trajectory improvement with increasing resolution (Pantillon et al. 2024).

They pointed out the importance of resolving small-scale convective processes. Indeed, reducing horizontal grid spacing from 10 km with parameterised convection to convection-permitting 2 km further improves the cyclone track and intensity. The intensity of Ianos cyclone is analysed by looking at the central pressure of the tracked cyclone, reported in Figure 2. There, we only report the difference between the simulations starting on the 16th of September of 27 km and of 9 km of resolution. The results show that by increasing the resolution the intensity of the cyclone increases, as one would expect, however, by going to higher resolution the intensity increases alter, contributing to our intuition that increased resolution does not, above a certain threshold, generate improved intensity of mesoscale cyclone-type phenomena, like Ianos. This aspect is explored in Figure 3. In fact, there we present some results regarding the analysis done with respect to the convection improvement with the change with resolution. In Figure 3, the Latent Heat Flux analysed for the simulation starting on the 17th of September, for the three resolutions is shown. Although the heat flux increases with resolution from the 27 km one and the 9 km one, there is little difference between the 9 km and 3 km simulations. This aspect will be studied in more depth in the next simulations, both those with higher resolution and those with data assimilation and different types of convection.

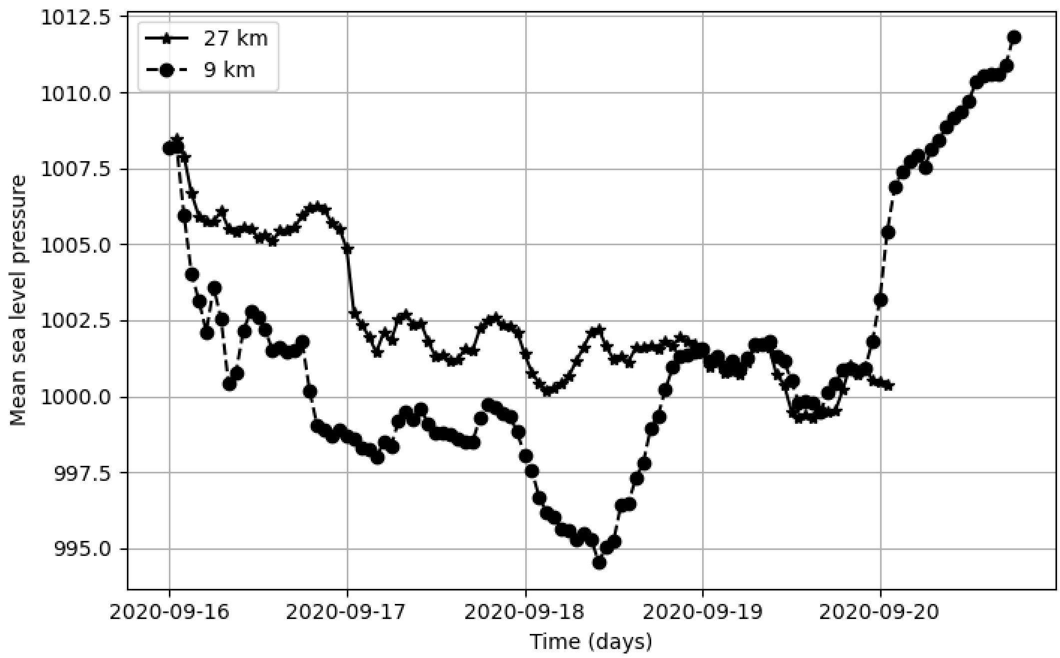

Figure 2: Central pressure of Ianos Cyclone simulation starting on the 16th of September at 00 UTC at 27 km of resolution (solid lines) and at 9 km of resolution (dashed lines).

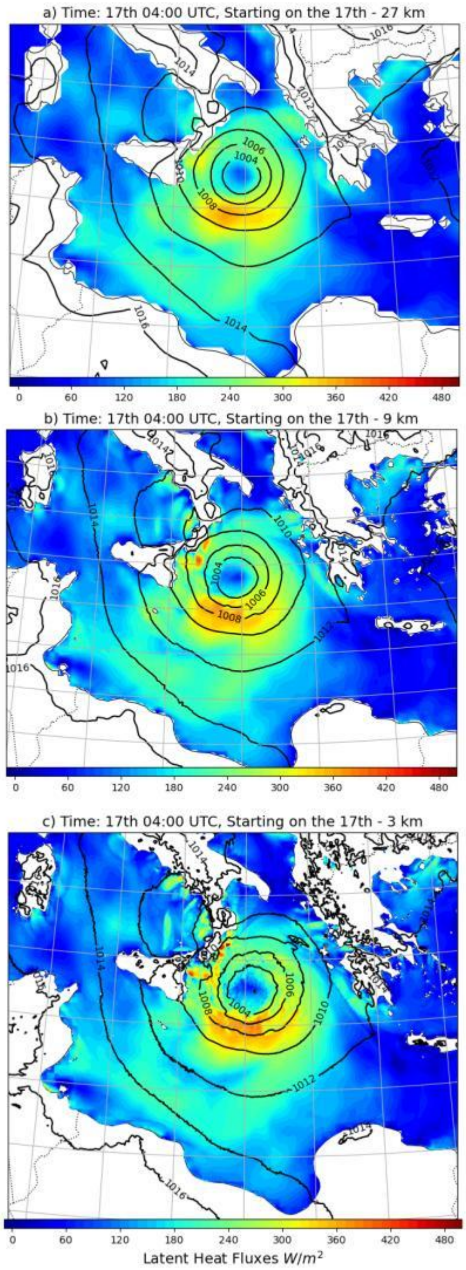

Figure 3: Latent Heat Fluxes comparison on the 17th of September at 04 UTC between simulation starting on the 17th of September at 00 UTC at 27 km of resolution (a), at 9 km of resolution (b) and at 3 km of resolution (c).

Bibliography

Pantillon, F.; Davolio, S.; Avolio, E.; Calvo-Sancho, C.; Carrió, D.S.; Dafis, S.; Flaounas, E.; Gentile, E.S.; Gonzalez-Aleman, J.J.; Gray, S.; et al. The crucial representation of deep convection for the cyclogenesis of medicane Ianos. EGUsphere 2024, 2024, 1–29.

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