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:	Exploiting Coupled, High-resolution modelling to simulate severe mediterranean cyclOgenesES (ECHOES)
Computer Project Account:	spitricc
Principal Investigator(s):	Antonio Ricchi
Affiliation:	University of L'Aquila
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)	-	-	60mln	15.457.373
Data storage capacity	(Gbytes)	-	-	26TB	50TB

Summary of project objectives (10 lines max)

ECHOES aims to improve the understanding and simulation of extreme Mediterranean cyclones through high-resolution, coupled atmosphere-ocean-wave modelling. The project will reforecast 10 major historical events using both uncoupled and fully coupled simulations to assess the added value of coupling. It will then perform a 30-year atmospheric reforecast and two ocean-wave hindcasts using ROMS-WW3 and SHYFEM-WW3. The simulations will produce high-resolution datasets (up to 500 m at coastlines) for climatological analysis and machine learning applications. Particular focus will be given to air-sea interactions, flux parameterizations, and the role of ocean heat content and sea state in cyclone evolution. The project extends the previous ASIM-CPL work and targets both scientific advances and societal applications like early-warning and coastal risk assessment.

Summary of problems encountered (10 lines max)

To date, the only issues that have arisen pertain to the organisation of the 5 km atmospheric reanalysis simulations and a few minor technical aspects related to the use of the coupled modelling approach in ensemble mode. None of these problems have hindered the implementation or continuation of the work. All simulations scheduled for the first six months have been completed. Any simulations or post-processing operations affected by errors or minor issues have been revised and successfully rerun, without significant delays or failures.

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

Over the next six months, the reanalysis simulations over the Mediterranean will be completed, transitioning from a 5 km to a 3 km horizontal resolution (convection-permitting setup using WRF). This phase will include numerical configuration tests over both a representative winter and summer quarter, to enable a direct comparison with the 5 km reanalyses. Additional ensemble runs for selected extreme events will be conducted. Further simulations targeting specific extreme events (e.g., DANA over Valencia) will be carried out. Coupled simulations for the selected events will be finalised using the WW3–SHYFEM coupled modelling system. Finally, the implementation of a 500 m resolution setup will be configured and tested.

List of publications/reports from the project with complete references

Talk at Conferences:
Carrie Carrió, D. S., Serafini, P., Pantillon, F., Dafis, S., Menna, M., Martellucci, R., and Ferretti, R.: On the role of air-sea-wave interaction in developing destructive Tropical-Like Cyclones DANIEL, EMS Annual Meeting 2025, Ljubljana, Slovenia, 7–12 Sep 2025, EMS2025-421, 2025.

Ferretti, R., Miglietta, M., Sancho, C., and Ricchi, A.: On the role of ocean structure in Valencia Flood development., EMS Annual Meeting 2025, Ljubljana, Slovenia, 7–12 Sep 2025, EMS2025-352, 2025.

A.Ricchi, R. Ferretti, Pantillon, F., Serafini, P., Dafis, S., Menna, M., Martellucci, R. and Carrió Carrió, D. S.,: On the role of air-sea-wave interaction in developing destructive Tropical-Like Cyclones DANIEL, MetMed 2025. Tolouse (France) 19-21 May 2025.

Chiara Favaretto, Francesco Barbariol, Rossella Ferretti, Christian Ferrarin, Alvise Benetazzo, Antonio Ricchi, Piero Ruol. An ensemble-based Early-Warning Index for coastal flooding alerts in low-lying littoral areas. 4th Internationa workshop on Waves, Storm Surges, and Coastal Hazards.

Serafini, P., Ricchi, A., Marsigli, C., and Ferretti, R.: Multi-model high resolution analysis of Mediterranean Hurricane Daniel with WRF and ICON, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-19128, https://doi.org/10.5194/egusphere-egu25-19128, 2025.

Summary of results

The project *"Exploiting Coupled, High-resolution Modelling to Simulate Severe Mediterranean Cyclogenesis (ECHOES)"* is designed to develop a convection-permitting atmospheric reanalysis for the Mediterranean, to quantify the added value of explicit ocean–wave coupling during extreme episodes, to assemble a multi-model archive suitable for climatological and machine-learning studies, and to benchmark both deterministic and ensemble strategies for high-impact weather and meteo-marine hazards.

Step 1 – Atmospheric reanalysis with WRF

During the first six months we completed a continuous hourly reanalysis spanning 1993–2024 with WRF version 4.5.1 on a 5 km mesh that covers the entire Mediterranean basin. The vertical discretisation comprises sixty hybrid levels, with the lowest level centred at 30 m, while the physics suite employs double-moment microphysics, Kain–Fritsch convection, a non-local PBL scheme and hourly ERA5 SST updates supplied through external NetCDF files. A bespoke reduction of the surface drag coefficient over waters shallower than 50 m, based on GEBCO bathymetry, has also been implemented. Preliminary validation against scatterometer winds and both CERRA and ERA5 reveals skill comparable to these reference products, although winds exceeding 25 m s^{-1} remain marginally underestimated. In the coming semester we shall migrate to a 3 km convection-permitting configuration, test it over representative winter and summer quarters, and regenerate the associated climatology.

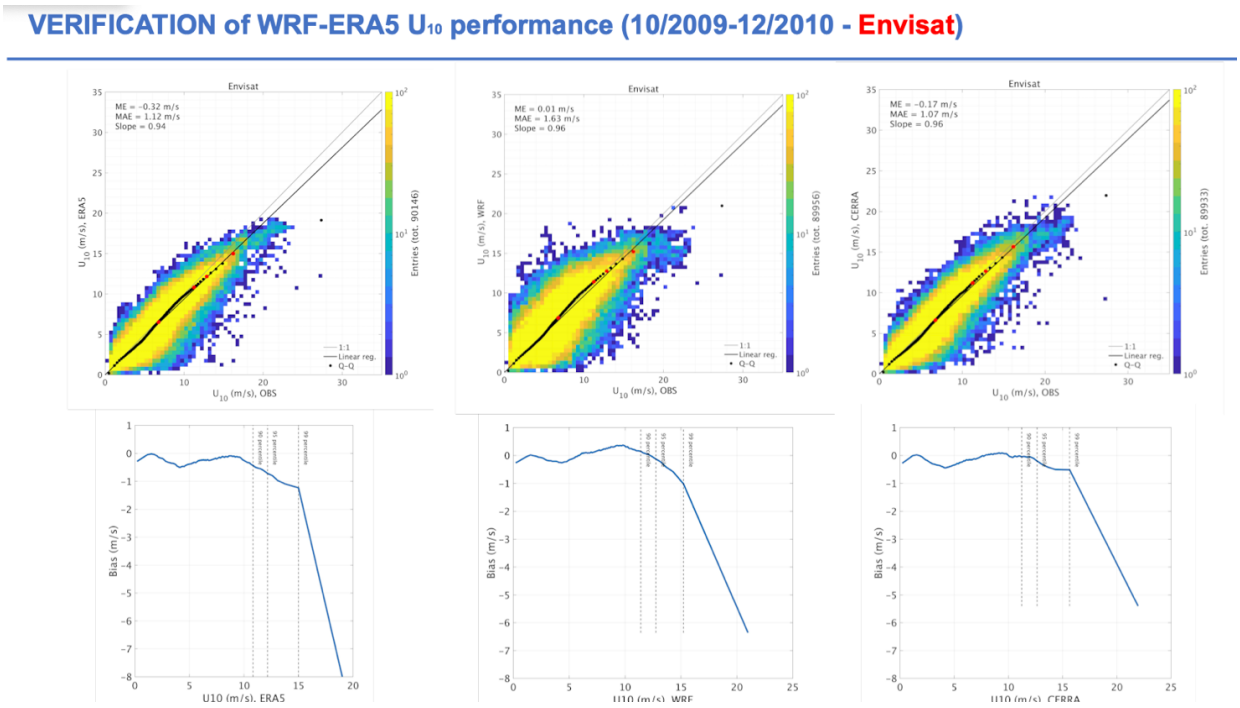

Figure 1. The figure shows the wind distribution at 10 m from our reanalysis, ERA5 and CERRA, compared to satellite observations.

Step 2 – Coupled ocean–wave hindcast (SHYFEM + WW3)

A companion hindcast has been produced with the SHYFEM ocean model coupled to WAVEWATCH III on an unstructured mesh that ranges from 8 km offshore to 500 m along key coastlines. The system is initialised from the CMEMS 4.5 km reanalysis and forced with the WRF fields described above. Roughly seventeen per cent of the allocated CPU budget (user *ecme7224*) has been consumed so far; diagnostic post-processing is in progress. Once the 3 km atmospheric forcing becomes available, additional hindcast periods will be recomputed to assess improvements in coastal storm-surge skill.

Step 3 – Extreme-event simulations with WRF

We have simulated a first set of severe cases, using both a deterministic configuration and a 50-member ensemble driven by IFS boundary conditions (9 km outer grid and 3 km nested grid over Italy as showed in Figure 2.). Initial results indicate that the ensemble spread captures the observed intensity and track, thus providing a robust basis for probabilistic risk assessments.

Studied selected extreme events:

Vaia 2018-10-28 h 00 -> 2018-10-30 h 00
Bora 2015-02-04 h 12 -> 2015-02-06 h 00
Detlef 2019-11-11 h 12 -> 2019-11-13 h 12
Meteotsunami 2023-07-22 h 00 -> 2023-07-23 h 00
Neverin 2024-04-15 h 12 -> 2024-04-17 h 00

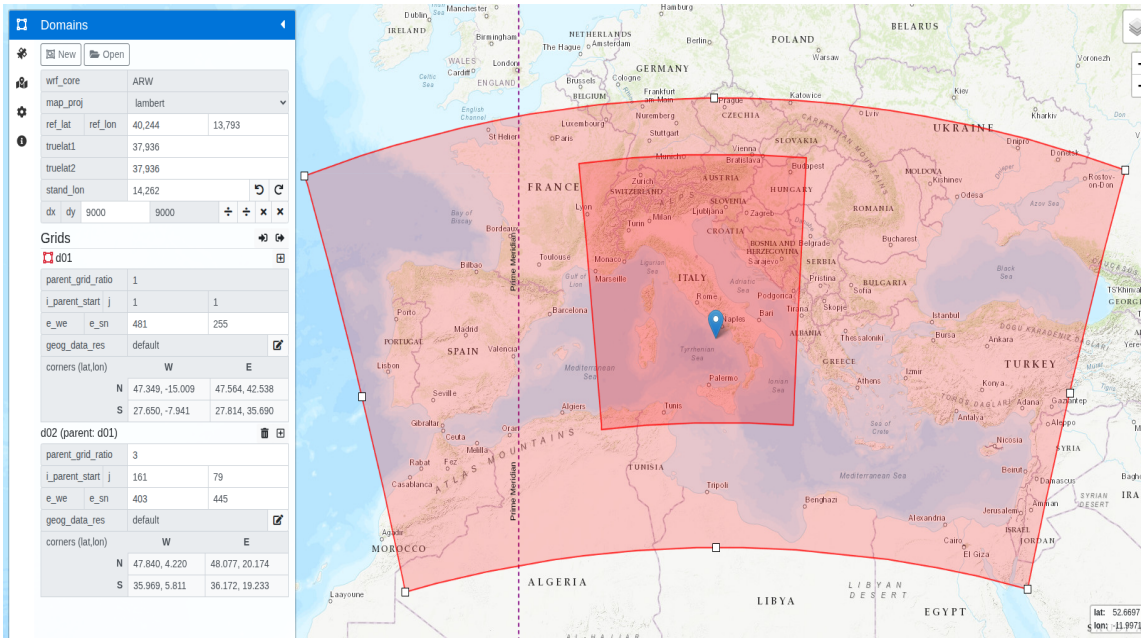

Figure 2. WRF nested domain scheme for ensemble study of selected extreme events

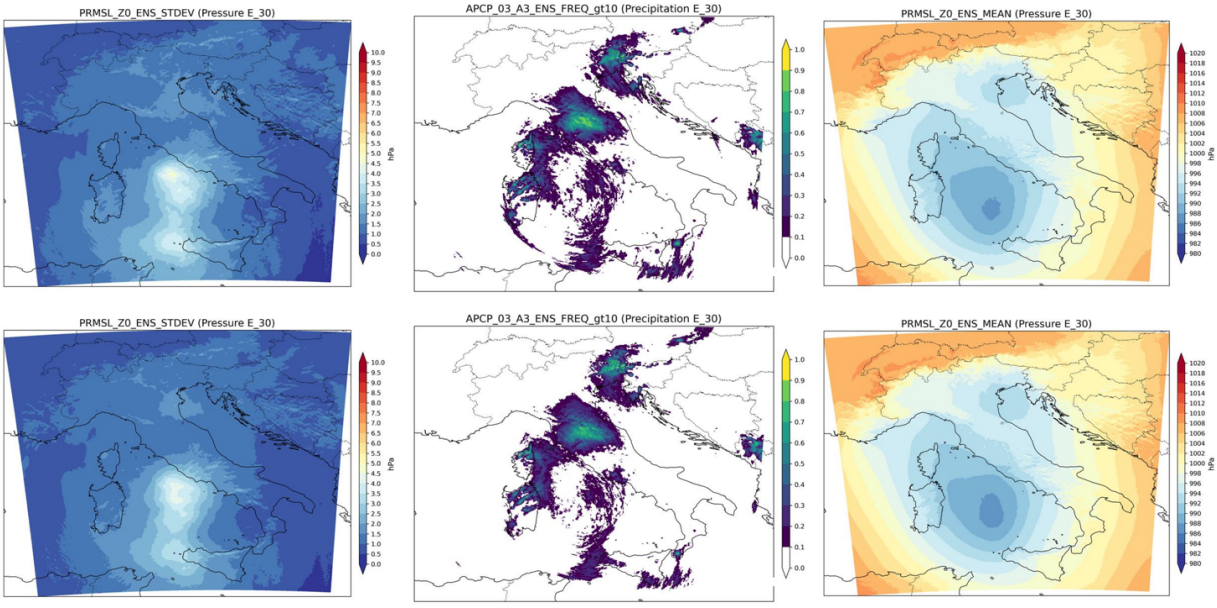

Figure 3. shown mean and standard deviation of sea pressure 30 hours after the start, at 6 p.m. on 12 November 2019, with 50 and 25 members selected, respectively.

For brevity, we present only the Detlef storm, which affected the Venetian Lagoon in November 2019, causing one of the most severe storm surges in recent history. Figure 3 shows preliminary results for this case study, illustrating the ensemble mean sea-level pressure, the standard deviation of sea-level pressure 30 hours after the initial time (i.e., at 6 p.m. on 12 November 2019), and the relative frequency of 3-hour accumulated precipitation exceeding 10 mm.

Step 4 – Ensemble ocean–wave coupling for case studies

For the same events the SHYFEM + WW3 chain has been integrated with all fifty WRF ensemble members. Post-processing of these output files focussing on wave crest statistics, surge percentiles and air-sea flux diagnostics is under way and will be reported in the next milestone.

Step 5 – First tests with the fully-coupled COAWST system

In parallel we have reproduced MEDICANE **Daniel** (September 2023) and MEDICANE **Ianos** (September 2020) with the COAWST framework, coupling WRF, ROMS and WW3 in accordance with project specifications. The experiments confirm the feasibility of the coupled set-up and highlight the sensitivity of intensification to air–sea flux parameterisations and also Figure 4 shows the track and intensity of cyclone DANIEL (Tropical-like cyclones) simulated with different numerical approaches, uncoupled with different Sea Surface temperatures, and coupled using different ocean model configuration approaches.Over the next semester we shall extend this exercise to the remaining events listed in the proposal together with several additional, less-documented tropical-like Mediterranean cyclones to create a homogeneous benchmark suite.

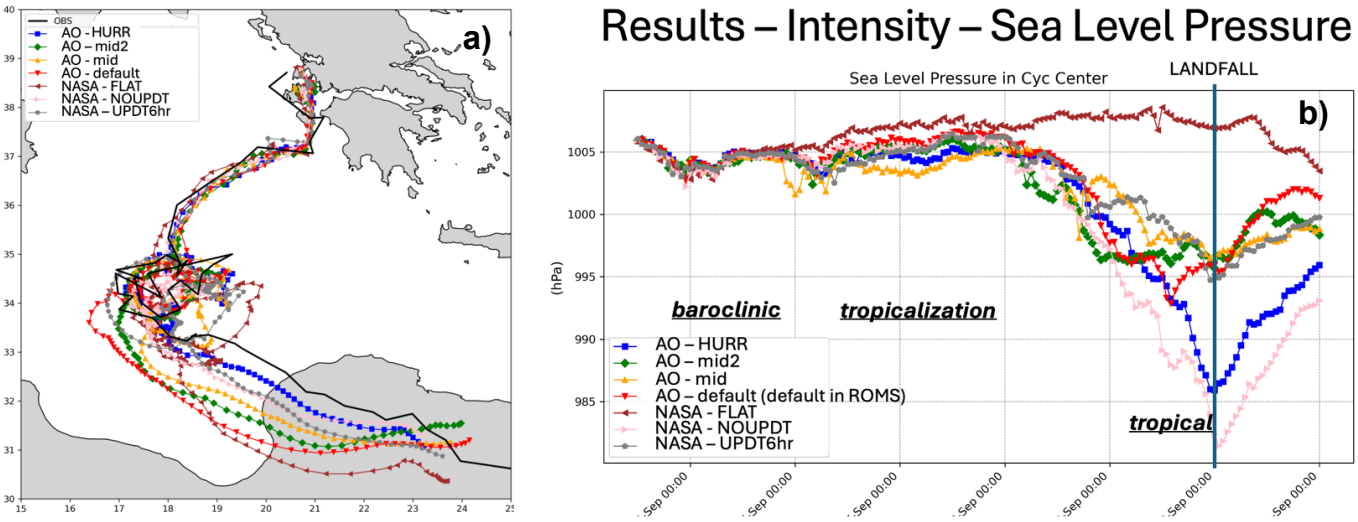

Figure 4 shown in panel a) track and b) intensity of simulated storm DANIEL.