COST Action CA19109 “MedCyclones” – Working Group 1

Deliverable D1.3

Report addressed to Action members and stakeholders, devoted to priorities for improving cyclone prediction (constantly updated)

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On the one hand, the community research initiative on Dynamics and operational Forecasts of Mediterranean cyclones (DynForMed) has focused on developing a prototype website with operational forecast information on Mediterranean cyclones. DynForMed aims to provide a central platform with predicted cyclone track and intensity for researchers, forecasters and stakeholders as a suitable tool to assess model performance at a glance, through comparisons against other modelling systems. Recently, the web site has been updated and migrated to the National and Kapodistrian University of Athens (NKUA) where it is operational and future developments are planned in order to keep it active beyond the end of the Action:
https://medcyclones.eu/dynformed/
One key upgrade that took place during the migration phase is the **Composite Tracks Approach**. This enhancement involves the exploitation and implementation of the "composite tracks" methodology, a concept developed during another scientific initiative developed in the first two years of the Action and named “3T: Tracks Task Team”. This approach (for more detail see https://doi.org/10.5194/wcd-4-639-2023) aims to refine the selection of cyclone tracks by adopting only those with a high level of agreement among different cyclone tracking algorithms. This ensures that users are presented with the most accurate and reliable cyclone track information. It should be mentioned that for the operational needs of this initiative, seven tracking algorithms are adopted.

On the other hand, the research initiative named **model intercomparison project (MIP)** investigated different model setups and tested the sensitivity to advanced model frameworks such as convection-permitting resolution or various couplings. About 15 participants run numerical simulations following a common protocol to look for a systematic response between models and setups. The main focus was on the sensitivity to initial conditions and horizontal resolution.
From the collective study of a specific event, medicane Ianos of September 2020, interesting indications have been provided:

- The use of high spatial resolution analysis (e.g. IFS-ECMWF) fields as initial and boundary conditions to drive mesoscale models generally provided better results than using coarser spatial resolution products (e.g. ERA5) even if the latter has a better time resolution, since they are available hourly instead of every 6 hours.

- For the formation of this medicane, the organization of the convection was critical. This aspect was hardly simulated by the models initialized before cyclogenesis, thus being responsible for poor forecasts. Accurate enough simulations resulted only if the model were initialized at an analysis time when convection was already well-organized.
- For the development and the deepening of the cyclone, the interaction with an upper level disturbance was critical. This points out that a proper vertical resolution in the models is necessary not only in the lower layers, where intense turbulent exchanges occur between the atmosphere and the sea surface, but also in the upper troposphere.
- Increasing horizontal resolution from 10 to 2 km, thus allowing explicit representation of deep convection, generally resulted in an improved track and a deeper cyclone. Higher resolution enhances convective activity, which improves the phasing of the cyclone with an upper-level jet and its subsequent intensification and evolution. This upscale impact of convection matches a conceptual model of upscale error growth in the midlatitudes, while it emphasises the crucial interplay between convective and baroclinic processes during medicane cyclogenesis.
- Even at 2 km horizontal resolution, considered as convective permitting, some models failed to reproduce the correct organization of the intense convection in the initial stage of the cyclone. In such cases, adopting a parametrized convection scheme at this high resolution turned out to be beneficial. This is not a common procedure, but it is in line with some recent papers have shown similar results for Mediterranean cyclones.

Coupled Atmosphere-Ocean and data assimilation

In the course of the last year of the Action, several collaborations grew, aimed at implementing **coupled atmosphere-ocean systems** to improve the forecasts of intense cyclones, in particular Medicanes. Also, the use of high-resolution atmospheric models and the implementation of data assimilation (e.g.: ASCAT data) showed promising results.
This was the context especially of some STSMs, whose main achievements are summarized below and are relevant in terms of indication of priorities to improve cyclone forecasts:

1) Grantee name: Christian FERRARIN, who visited the group of Emmanouil Flaounas (ETHZ)
Title: The marine and coastal hazards of Mediterranean cyclones
The goal of the STSM was to setup a set of high-resolution ocean simulations for assessing the sea conditions in the Mediterranean Sea during the most extreme cyclones. A modelling system is implemented and comprises the finite element SHYFEM hydrodynamic model, two-way coupled with the unstructured WW3 wave model, thus accounting for the wave-current interaction in deep and shallow waters. The hydrodynamic and wave numerical computations are performed on the same spatial domain representing the Mediterranean Sea using an unstructured grid with a resolution varying from 10 km in the open sea to less than 1 km at the coasts.
We successfully implemented a modelling framework composed by the high-resolution meteorological model WRF and the ocean and wave coupled model SHYFEM-WW3.

2) Diego CARRIO, who visited the group of Rossella Ferretti (University of L'Aquila-CETEMPS)
Title: Implementation of Data Assimilation into Regional Coupled Models: Improving the trajectory and intensity of medicane forecasts

This STSM aimed to integrate advanced Data Assimilation techniques with high-resolution coupled Ocean-Wave-Atmosphere models to enhance the accuracy of tropical-like cyclones forecasting. The activity first tackled technical aspects to compile and run the modelling system. Then focusing on three tropical-like cyclones, Ianos, Rolf and Qendresa, several high-resolution simulations using 50 ensemble-members across two nested domains were performed. These simulations involved testing various parameterizations and grid-model resolutions to establish a control simulation, which represents the best possible simulation we can obtain without using coupled models and Data Assimilation techniques. A simulation was designed to assimilate high-resolution scatterometer surface wind observations (ASCAT) over the sea at the beginning of the Qendresa's life cycle, to improve the initial conditions. Finally, further simulations were conducted by assimilating ASCAT observations together with conventional in-situ observations (e.g., radiosondes, maritime buoys). The refined analysis from these assimilations was then used to further enhance the coupled model's performance.

3) Grantee name: Antonio RICCHI, who visited the group of Florian Pantillon (University of Toulouse - Laboratoire d'Aérologie)
Title: Digital twins of the atmosphere and ocean: application to the coupled modeling of tropical-like cyclone Ianos
The research activity of this STSM was based on undertaking coupled modeling simulations of Tropical-Like Cyclone (TLC) Ianos and comparing results from two numerical frameworks: COAWST (Coupled Ocean Atmosphere Wave Sediment Transport system) based on the WRF-ROMS-SWAN chain (performed by the grantee) and MESONH-CROCO-WWIII coupled with OASIS (performed by the host). Coupled simulations were also compared with uncoupled experiments taken as benchmark. The final goal was to structure an analysis tool for coupled ocean-atmosphere-wave simulations in the context of studying a TLC case, the 2020 IANOS event. In addition to the implementation of the tool and the analysis needed to study such a peculiar case, we integrated a structured numerical workflow for intercomparison between two coupled frameworks, COAWST and MESONH-CROCO-WWIII, obtaining interesting results and suggestions not only physical but also numerical (useful for repeatability of experiments by third parties).

Concluding remarks

Most of the activities concerning cyclone predictions, and in particular the MIP initiative, have focused on single case studies. It is not straightforward to generalize the results, since it would have required a large number of tests and the analysis of different Mediterranean cyclone events, possibly characterized by diverse development factors. It is well known in fact that Mediterranean cyclones are sustained by a combination of physical processes, ranging from those typical of extratropical cyclones (e.g. baroclinic instability) to those typical of tropical cyclones (e.g. air-sea exchange and deep convection). Most of the time, several processes are involved in cyclogeneisis and may play different roles during different phases of the development. However, the implementation of several independent modelling systems and their coherent response can provide some robust indications.

(1) Increasing horizontal resolution from 10 to 2 km grid spacing, thus moving from parameterized convection to explicitly resolved convection, clearly improves the cyclone prediction. The error and spread in track are largely reduced and the intensity is closer to observed values, although the

maximum cyclone intensity is not always well constrained (uncertainty still persists and can be even relevant at longer lead times). This behavior has a physical justification, since the correct reproduction of deep convection is crucial not only for local effects, such as intense precipitation, but can have important upscale impacts, modifying the midlatitude circulation in which the cyclone is embedded. A systematic improvement from convection-permitting resolution is not expected in general but only for cases where convection plays an important role. This is not restricted to medicanes only, as for instance an added value of km-scale resolution was also found for a secondary cyclone (Carrió et al., 2020).

(2) Some models may require convective parameterization even at 2-km grid-spacing which is usually considered as a convection-permitting configuration. The parameterization in fact may help in organizing the convective activity especially that preceding the cyclone development, that could result scattered in explicit simulations. Of course, this behavior is strongly model-dependent and also depends upon the characteristics of the convective scheme in terms of interaction with resolved processes and depletion of convective energy and instability.

(3) The clear improvement achieved with explicit convection provides guidance for the next generation of weather and climate models foreseen at the global scale. However, initializing simulations with the ERA5 reanalysis instead of the operational IFS analysis has a detrimental effect, which seems larger on the intensification, which is hardly captured. This aspect should be kept in mind especially when downscaling or reforecasting activities are performed.

(4) High-resolution meteorological simulations have a clear beneficial impact on sea state predictions, run in cascade. Ocean model simulations produce a more realistic representation of the sea conditions during intense cyclone when forced with high-resolution wind fields, thus more severe sea state and higher sea levels closer to observations.

(5) Concerning coupled atmosphere-ocean modelling system at high resolution, results seem non robust yet to provide strong indications. So far what emerged is that these systems are able to provide a more realistic description of the processes, but in terms of forecasts, the improvement seems more relevant for sea state prediction than for the meteorological evolution. Thus, further research along this line are needed and will be performed even after the end of the Action, thanks to the strong collaborations that have been established within the community.