COST Action CA19109 "MedCyclones" – Working Group 1

Deliverable D1.4

Mid-term report describing scientific production so far and setting research orientations

10 November 2022

Activities are organized in cooperative research initiatives, each involving several participants and led by a coordinator. These activities have reached to a different degree of maturity and for each of them, we provide in the following a brief description of the scope, main scientific results so far and perspectives. We also highlight connections and synergies among different activities, even across the WGs.

1. DynForMed (lead: Platon Patlakas and Florian Pantillon)

Aim

The initiative is dedicated to the Dynamics and operational Forecasts of Mediterranean cyclones. The main goal is to develop a prototype website with operational forecast information on Mediterranean cyclones, that is a central platform with predicted cyclone track and intensity for researchers, forecasters and stakeholders. As a reference, the National Hurricane Center delivers trajectories, intensity and categories for tropical cyclones over the North Atlantic. Currently, there is a lack of such information for the Mediterranean. The goal is not to replace weather services, but to provide a prototype platform for information on Mediterranean cyclones for scientists, forecasters, stake holders and potentially also the general public.

Scientific production

Currently, deterministic forecasts up to 7 days ahead from 8 operational systems (from both weather services and research institutions) are provided daily by members of the DynForMed initiative and a tracking algorithm is routinely applied for cyclones over the Mediterranean up to 7 days ahead. The resulting tracks and intensities are available on the web site (at present only for Action participants and password protected). Also, also warm conveyor belts and upper tropospheric systems which are responsible for cyclogenesis, are shown on the website, together with additional forecast products (winds and precipitation) aimed to provide some hints about the impact of Mediterranean cyclones.
This research initiative is thus providing an intercomparison test bed that allows participating stakeholders to assess the performance of their prediction systems with the ones of their peers through a novel framework where the quality of simulations is assessed on the basis of physical processes. This is a step forward compared to model assessments based on comparison of atmospheric variables since it allows a more detailed interpretation of the results.

It is worth saying that the performance of such an intercomparison has stimulated interesting discussions during the forecasting round table within the first MedCyclones workshop and it is regarded as a first step for building a common protocols for the assessment of weather predictions.

Research orientations
This activity is building a database that can be used as a forecasting benchmark for whoever wishes to contribute and can be really valuable for operational centres willing to assess their model performance. In the future, we are planning to enrich the website on the intercomparison of weather forecasts with additional diagnostics and impact-oriented information. Furthermore, we plan to invite more stakeholders to share their forecast outputs and thus allow to the users to acquire a more comprehensive intercomparison of forecast results. Moreover, outcomes from WG2 research initiative devoted to cyclone classification will provide additional contributions for process-oriented intercomparison. Finally it is planned to apply the ”best-track” methodology developed within the research initiative 3T for cyclone tracking (WG2).

2. Model intercomparison (lead: Florian Pantillon and Silvio Davolio)

Aim
The aim of this initiative is to perform a model intercomparison for case studies of Mediterranean cyclones, in order to better understand their dynamics and predictability, which are often linked. The rationale behind the model intercomparison is to adopt a common model setup (details are provided in Deliverable 1.1) and investigate on the one hand the systematic response of changes in the representation of physical processes (e.g. convection, cloud microphysics, air-sea interactions) among a range of models and configurations; on the other hand, understanding the processes responsible for weak model performances in cyclones intensity and tracks, so to provide guidelines and priorities for model development and implementation.

Scientific production
The recent tropical-like cyclone Ianos that hit Greece in mid September 2020 was chosen as a first case study and to prepare the technical framework of the intercomparison. Several additional cyclones were discussed as potential case studies and will be addressed in the future by following the same procedure. Currently, about 20 participants are running 5 different models and several different configurations of WRF, all with two different horizontal grid spacing, 10 km (parameterized convection) and 2 km (explicit convection), initialized from both IFS and ERA5 data at various times. Several meetings were organized to elaborate on the results, discussing the potential impacts of the cyclone and assessing the physical reasons for good or weak model skill in weather prediction.
The main focus so far has been on the sensitivity to initial conditions and horizontal resolution. Some interesting indications have been provided by the results of the initiative:

- The use of high spatial resolution analysis (e.g. IFS-ECMWF) fields as initial and boundary conditions to drive mesoscale models generally provides 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, producing a

failure in the predictions. 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 results in an improved track and a deeper cyclone. Higher resolution appears to enhance convective activity and favorably precondition the upper-level dynamics. Investigation of this complex feedback is ongoing.
- 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 some recent papers have shown similar results for Mediterranean cyclones. This aspect deserve more analysis.

It is also worth mentioning that the database populated with model simulation outputs concerning Ianos case study has been exploited by WG3 ImCyCoast research initiative, to assess the response of coastal sea level (storm surge) and sea state (waves) to Mediterranean cyclones.

Research orientations

In the future, since many WRF configuration are available, it is planned to perform an investigation aimed at identifying possible parameterization schemes that turn out to be more accurate in simulating physical processes in Mediterranean cyclones. It is also expected to exploit results from the "DynForMed" and "3T" initiatives and also to enlarge the participation, including other modelling systems and even coupled systems that are not available for operational forecasts.

A first important milestone will the submission of a collaborative paper expected within the third year of the Action. However, our aim is to go further and deepen our analysis to the physical interpretation of the models performance. For this reason a second paper is planned to be submitted towards the end of the Action. In this paper, we will focus on the representation of specific cyclone-related processes as a function of different model setups. In addition, this WG1 initiative together with WG2 initiative on cyclone classification, is expected to assist in establishing priorities on the representation of key processes in cyclones reproduction. For instance, systematic failure of weather models to place cyclones in a specific cluster of upper tropospheric forcing suggests the need for a better representation of large-scale atmospheric processes.

3. Medicane definition (lead: Mario Marcello Miglietta)

Aim

The purpose of this initiative is the definition of what exactly is a "Mediterranean tropical cyclone" (TLC), aka Medicane. In the literature, the term "Medicane" has been adopted in different ways, depending on the purpose of the study and the tool adopted for the analysis. A commonly agreed definition is critical and necessary to assess the ability of climatological datasets to reproduce this type of cyclones their climatology, as well as to better understand the evolution of Mediterranean cyclone categories and their related processes in a changing climate.

Scientific production

Although there is still no consensus on the definition, Medicanes are generally considered to be baroclinic cyclones that evolve into vortices with structural characteristics similar to tropical cyclones, i.e. axisymmetric, deep warm core with a windless center surrounded by strong winds. The synergy between baroclinic instability and diabatic processes is fundamental for the intensification of a Medicane. Stimulating discussion emerged in several online meetings and in the round table organized within the 1st Action Workshop. The need to differentiate a definition for the general public (including morphological characteristics and possibly the definition of a wind speed threshold) from a definition more appropriate for the academic environment, was underlined. The latter one should include adequate diagnostics, including the Hart diagram and a tool (to be defined) to discriminate diabatic from baroclinic processes. A consensus was reached about the issue that Medicanes with tropical characteristics should be differentiated from weaker Mediterranean subtropical cyclones. The latter cyclones differ from the former category by the different convective cloud cover, the fact that a significant part of their energy is received from baroclinic sources and that the maximum wind radius is farther from the center.

Research orientations

The discussion within this initiative has stimulated a number of works (in progress) related to the characteristics of the Medicanes, analyzed both using remote sensing tools and reanalyses fields. ERA-5 reanalyses and microwave satellites have been used to identify structural and morphological characteristics of Medicanes at different stages of their lifetime. On the other hand, limited area model numerical simulations are currently in progress (in collaboration with other initiatives) to identify their mechanism of development, using different diagnostic algorithms (surface pressure tendency, PV budget analysis). The role of air-sea interaction is also investigated exploring the role of the sea surface temperature and the structure of the ocean mixed layer.

4. Building a first inventory of cyclone simulations in convection-permitting scales

Aim

This initiative recently started aims to study cyclone dynamics and impacts through a large ensemble of case study simulations at convection permitting scales adopting WRF model and an innovative modelling framework. Our purpose is to use the high-resolution simulations for a better understanding of cyclone dynamics and relevant impacts to coastal areas. The simulations will not be solely limited to Mediterranean cyclones but also to other systems so that comparison studies are allowed.

Scientific production

In the Leashed modelling framework, a parent domain tightly encompasses a preselected cyclone track from ERA5. The atmospheric fields within this domain are strongly nudged at every grid point by ERA5, in order to assure that the simulated tracks will not diverge from the ones in ERA5. The simulation duration is almost equal to the duration of the track. A small nested domain will be activated and move in time to follow the cyclone centre, according to the preselected track of ERA5. The nested domain will not be nudged by ERA5 and thus the model will be free to resolve cyclone dynamics. The computational cost for this endeavor is substantially large and therefore only a limited number of simulations is possible for a relatively small group of about 20 members. For

this reason, this initiative submitted a special ECMWF project (www.ecmwf.int/en/research/special-projects/spgrflao-2023). If successful the needed resources will be assured by ECMWF and the production of simulations will be carried out for a total of more than 1500 cyclones.

Research orientations

This initiative is still on the level of design, pending the outcome of the project evaluation by ECMWF. Up to now about 12 projects are proposed by the participants of this initiative that aim to take advantage of the simulations for specific research objectives. Here follows a non-exhaustive list of envisaged projects:

1. Use the ensemble of simulations to understand cyclone dynamics from the perspective of a "process-wise" PV budget.
2. Use the ensemble of simulations to understand cyclone impacts across resolutions.
3. Use PV budget in extreme cyclones for Eastern Europe; Mediterranean cyclones that re-enhanced over the Black Sea; windstorms and sting jet in intense Mediterranean cyclones and diabatic contributions in developments towards flood conditions over Eastern Europe
4. Determine how the size and location of the wind footprint and the intensity, timing and location of wind gusts depends on the large-scale background environment, the classical dynamical measures of cyclone strength (e.g. vorticity, MSLP) and the type of cyclone as determined by considering its spatial structure / location on a phase diagram (potentially identified by clustering)
5. Use the ensemble of simulations to improve the understanding of the dynamics of explosive Mediterranean cyclones and medicanes
6. Use of the ensemble to better understand the role of diabatic vs baroclinic forcing in the development of Medicanes
7. Use the ensemble to assess the relative importance of different diabatic processes for the cyclone evolution using offline diagnostics
8. Use the ensemble of simulations to investigate the formation of Diabatic Vortices and whether all medicanes experience explosive deepening.
9. Use of the high-resolution dataset of simulated Mediterranean cyclones as ground truth of present climate for comparison to corresponding pseudo-global warming simulations
10. Use the ensemble of simulations to understand cyclone dynamics and to better understand the role of diabatic vs baroclinic forcing in the development of Medicanes

5. Data Assimilation (lead: Dorita Rostkier-Edelstein)

Aim and perspectives

During the 1st Action Workshop, several participants running convection permitting data assimilation systems (3DVar, 4DVar and EnKF) discussed the possibility to start a research initiative devoted to Mediterranean cyclone forecasting. Besides comparing and developing suitable assimilation procedure, several groups proposed also to contribute with observations that are not available from public/free sources.

The research initiative will start in the course of the third year of the Action. The first meeting planning is ongoing in these days.