COST Action CA19109 "MedCyclones" – Working Group 2

Deliverable D2.2

Documentation addressed to Action members and stakeholders describing the available diagnostic tools, the protocols and techniques for assessing climate simulations

First release: November 2022
Second release: October 2023
Last version: October 2024

Activities have been organized in cooperative research initiatives and short-term scientific missions. Completed datasets and tools are available on the Action website (see also D2.1), and others are currently in production, as detailed in the following.

MedCyClass initiative: Classification of Mediterranean cyclones by processes

The objective of this core initiative is to classify Mediterranean cyclones to categories based on the governing processes. Upper-tropospheric forcing is known to govern cyclogenesis. While considered at the timing of maximum cyclone intensity, diabatic mechanisms often strongly enhance cyclone deepening and modulate its subsequent development and impact. To classify cyclones into categories based on these processes, we collected diagnostic data, including identified feature-based products from over 20 members who joined the initiative, as detailed in the previous report (D2.1).
We have carried out the classification of the full dataset, for the years 1979-2020, based on the composite tracks data delivered by the 3T initiative. **Based on the potential vorticity distribution in the cyclones environment we have classified all ~3600 cyclones into 9 categories using a self-organizing maps algorithm.** The categories represent the range of Rossby wave breaking patterns, as well as heat lows and strongly diabatically-influenced cyclones. The resulting data product entails the tracks, each attributed to a cyclone category, from 1 to 9; composite analysis by cyclone category using additional data provided by the initiative members: sea-surface temperature, surface turbulent heat fluxes, feature-based diagnostics (PV streamers, PV cutoffs, warm conveyor belts, fronts, dry intrusion airstreams) and convective parameters.

The **classification algorithm of potential vorticity in an isentropic layer using the self-organizing maps, is available on the Action website.**
Results have been presented at several conferences, including the **1st MedCyclones workshop in 2022, the 2nd Medcyclones & European Storm Workshop, the MetMed Conference in 2023 and departmental seminars at the Israel Meteorological Service, Hebrew University of Jerusalem and Kyoto University.**

A scientific paper has been published on Weather and Climate Dynamics (Copernicus Ed):
Givon, Y.; Hess, O.; Flaounas, E.; Catto, J. L.; Sprenger, M.; Raveh-Rubin, S. Process-based classification of Mediterranean cyclones using potential vorticity, Weather and Climate Dynamics, 5, 133–162, https://doi.org/10.5194/wcd-5-133-2024, 2024.
The dataset has been already exploited for other research activities related to cyclone impacts, such as:
Portal, A.; Raveh-Rubin, S.; Catto, J. L.; Givon, Y.; Martius, O. Linking compound weather extremes to Mediterranean cyclones, fronts, and airstreams. Weather and Climate Dynamics, 5, 1043–1060, https://doi.org/10.5194/wcd-5-1043-2024, 2024.
and
Rousseau-Rizzi, R.; Raveh-Rubin, S.; Catto, J.L.; Portal, A.; Givon, Y.; Martius, O. A storm-relative climatology of compound hazards in Mediterranean cyclones. Weather and Climate Dynamics, 5, 1079–1101, https://doi.org/10.5194/wcd-5-1079-2024, 2024.
or to study Ocean evaporation characteristics for the different cyclone categories

Protocols for the assessment of climate simulations

It is scientifically interesting and critical in terms of cyclone impacts to evaluate climate model simulations by their skill in representing the emerging cyclone categories. We therefore here aim to construct a consistent approach to do so across models and simulations. Building on the 9 Mediterranean cyclones categories, we create a protocol for the evaluation of climate model simulations by their ability to reconstruct the 9 categories with the same occurrence frequencies in historical simulations. It is expected that different cyclone categories respond to anthropogenic forcing in different ways. Using the same methods, changes to the frequencies and spatio-temporal distribution of cyclone types in each category can be evaluated in future (or past) simulations. The following methodological steps are conceptualized, and will be implemented into historical simulations in the next year:

1. Composite mean geopotential height anomaly fields of the 9 categories will be produced from the classified tracks in ERA5 in the MedCyClass initiative.
2. Cyclones will be identified and tracked in the respective climate model simulation.
3. For each cyclone track, locate the cyclone in the timing of its minimum central sea-level pressure.
4. Record the regional geopotential field at 300 and/or 500 hPa (according to availability) in the ±30-degrees relative to the cyclone centre.
5. Compute geopotential height anomaly from the model climatology.

6. For each track calculate the mean squared differences of the geopotential anomaly field from each of the 9 composite field.
7. Attribute the cyclone track to a specific category by finding the category with least mean distances.
8. Repeat steps 1-7 for each track in historical and future scenario simulations.
9. For each simulation compute for each cyclone category its (i) occurrence frequency, (ii) monthly seasonality, and (iii) geographical heat map of cyclone occurrence.
10. Evaluate historical simulations by comparing the results in step 9 to those for ERA5 from the MedCyClass initiative.
11. Assess the changes to the results in step 9 in future simulations.

This endeavour, which builds on the novel cyclone categories, form the backbone of WG2 activities. This approach is applied to climate simulations by Action members, organized in within the "Mediterranean cyclones in regional climate simulations" initiative and STSMs.

MedCPM initiative

This initiative aims to analyse Mediterranean cyclones in a set of hindcast simulations and in future **simulations at km-scale resolution** with explicit convection. Such simulations are increasingly available within H2020-EUCP project / CORDEX-FPS Convection (ALP-3). Four simulations are already available for the Mediterranean by members of the Action participating in this initiative:

1. GUF COSMO (MedCordex 3km; 10y);
2. Météo France AROME (Western Med; 30y);
3. MOHC-HadREM3 2.2km (REU-3 domain; 20y);
4. Uni. C. Louvain: WRF (30y).

An STSM was offered by the lead of this initiative, S. Berthou at the British Met Office which took place in the first grant period with L. Aragao. Analysis of the resulting first cyclone tracks in HadREM3-2.2km (SLP-6-hourly) shows 84% matching of the tracks compared to ERA-5, for cyclones with central pressure lower than 1000 hPa. Plans for the next year entail the tracking of a second tracking method onto the same model simulations, and further applications to the other simulations which opens up plenty of opportunities for the cyclones' subsequent analysis by Action members.

A recent STSM grant supported Lisa Bernini visit to the Free University of Berlin. The research carried out and planned fit the topic of this initiative, since will exploit a convection-permitting dataset to (i) determine potential feedback explaining the increase in frequency and strength of convective precipitation over land; (i) identify differences in the origin of precipitation associated with Mediterranean extratropical cyclones and tropical-like cyclones. This would give some insight into the physical processes leading to the development of this latter category and increases our understanding on how explicitly simulating convection affects different types of Mediterranean cyclones.

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

This initiative is of interest of both WG1 and WG2 and it aims at understanding dynamics and impacts of cyclone systems through the creation of a unique comprehensive dataset of very high spatial resolution (convection-permitting) cyclone simulations. Researchers working on cyclone dynamics, but also stakeholders interested in weather impacts, have a constantly increasing need to acquire climatological simulations and associated knowledge of cyclones at high resolutions. Such a climatological dataset would provide diagnostics about processes and impacts that cannot be explicitly resolved, or that are not available in reanalysis.
A large ensemble of simulations has been produced in the framework of an ECWMF special project named "Understanding dynamics and impacts of cyclone systems through a comprehensive dataset of convection-permitting simulations" (www.ecmwf.int/en/research/special-projects/spgrflao-2023). It encompasses a wide number of cyclones in the Euro-Atlantic domain, giving priority to cyclones making landfall in Europe. Therefore, this project is expected to substantially promote our understanding of cyclone dynamics and in parallel, to provide deeper insights into the link between atmospheric dynamics and the impacts delivered by precipitation, wind and the sea state.
All simulations have been performed by the WRF model version 4.4 in a moving nest framework. In this framework, a two-domain simulation is performed for each cyclone case study. A parent domain tightly encompasses a preselected cyclone track and a nested domain moves always following the cyclone centre. The displacements of the nested domain is predefined, according to the cyclone tracks, taken from ERA5. To assure that the simulated tracks do not diverge from the ones in ERA5, the wind fields in the parent domain is strongly nudged at every grid point by the same reanalysis. Therefore, cyclones are efficiently resolved (in terms of consistent tracks and life stages as in ERA5), as confirmed by a series of preliminary simulations, already performed by the PI of the project. The nested domain is not nudged into ERA5 and thus the model will be free to resolve cyclone dynamics.
In addition to WRF, this project will be accompanied by the employment of the RIP tool (Read/Interpolate/Plot). RIP has been developed by NCAR and is configured to read directly WRF outputs and produce dedicated diagnostics. Most important, RIP incorporates a lagrangian model that operates directly on WRF outputs and produces air mass trajectories. Being able to identify moving grids, RIP is valuable for producing diagnostics in the moving nested domain about the development of important airstreams for cyclone dynamics such as sting-jets, dry air intrusions, as well as warm and cold conveyor belts.

Mediterranean cyclones in regional climate simulations

This initiative aims to create a useful Mediterranean cyclone tracks composite dataset using Climate Models that will be made available to the Action community. Data of surface pressure and relative vorticity at 850 hPa, taken form a large ensemble of simulations from the CMIP6 projects and from ERA5 reanalysis, have been shared server in a uniform format. All participating algorithm developers have been able to run their tracking algorithms, following a common protocol. The data cover the period 1979-2015 and from 2050-2100 and include the entire northern hemisphere
The research activity is still ongoing and has plan for continuation after the end of the Action.

Once we obtain all tracks, we will build on Flaounas et al. (2023) track composite protocol to create the tracks dataset. There are a few important considerations before the actual work starts. These directly link to the needs of the different groups in the COST-MedCyclones community. For example, which models fit best depending on the availability of data, temporal and spatial resolution, scenarios, adequacy of GCM for the Mediterranean climate, and more. For the historic scenario an ERA5 based tracks will be used to evaluate the CMIP6 based results. By interpolating the ERA5 to fit the same resolution of 1-degree and 6-hourly CMIP6 data we will show how CMIP6 sub-models represent the atmosphere. The tracks extracted for the interpolated ERA5 will be also compared with the former results. This comparison will present an insight on how change in spatial and temporal resolution may have affected on the algorithms ability to identify Mediterranean cyclones. Preliminary results already show difference in detection depending on the main variable used in the cyclone detection and tracking methods, sea level pressure, surface pressure or potential vorticity at 850 mb. The initiative will continue with the COST-ACTION “Future-Med”.

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