COST Action CA19109 “MedCyclones” – Working Group 2

Deliverable D2.4

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 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 try to highlight connections and synergies among different activities, even across the WGs.

1. MedCyClass - Mediterranean Cyclone Classification (lead: S. Raveh-Rubin)

Aim

The purpose of this initiative is to classify Mediterranean cyclones to categories, based on the governing processes that lead to their development. This activity represents the main research initiative carried out in the framework of WG2 and has been carried out by a team efforts of more than 20 researchers.

Scientific production

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. In the first phase, to classify cyclones into categories based on these processes, diagnostic data, including identified feature-based products from members who joined the initiative were collected in a common database. A detailed description of the dataset is available in Deliverable 2.1.

The classification of the full dataset, for the years 1979-2020, was carried out based on the composite tracks data delivered by the 3T initiative (see below). These tracks have been classified into different clusters according to the upper tropospheric conditions (i.e. the precursor of cyclogenesis). The analysis performed so far is based on the use of ERA5 reanalysis which may be considered as "observations" for the needs of analysing cyclone dynamics and as such are detailed enough to consider potential-vorticity-based diagnostics, and Lagrangian feature identification. More precisely WG2 members have classified cyclone tracks at the time of cyclones mature stage according to the morphological shape of the trough that initially triggered cyclogenesis. 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.
Current activities include (i) the refinement of the dataset by performing sensitivity tests to the classification algorithm. The resulting data product entails the tracks, each attributed to a cyclone category, from 1 to 9; (ii) 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 and the presentation of the approach and the classification results have been already disseminated among the WG2 community, on the website and during the 1st MedCyclones workshop.

Research perspectives
The second phase of the initiative will be devoted to investigate and classify the processes that further develop cyclones into catastrophic storms mainly focusing on convection. From the perspective of cyclone dynamics, a cyclone might be initially formed by upper tropospheric disturbances (i.e. exterior processes to the cyclone), but its development and intensification is tuned by convection (i.e. processes internal to the cyclone system). In turn, convection is also tuned by sea surface temperatures (SST), the proximity of cyclones to orography, the degree that large scale ascent is favorable for further development and other factors. Therefore, a further analysis of the 9 cyclone categories will be undertaken in light of the emergence of convection in the vicinity of the cyclones. Both upper tropospheric disturbances and convection will explain in large the processes that synergistically develop cyclones into catastrophic storms. First results in this direction indicate that mid-tropospheric diabatic heating occurs preferentially in certain clusters and almost absent from others, suggesting that upper-tropospheric forcing and convection are not independent factors.
Another critical perspective of this research initiative concerns the application of the developed classification tool to both operational forecasting models (in conjunction with WG1 models intercomparison initiative (see Deliverable 1.4)) and to climate simulations already produced and available by other projects (e.g. IPCC simulations). In terms of numerical weather forecasting, our goal is to automatically assign imminent cyclones to specific clusters, whereas in terms of climate simulations, our goal is to assess the similarity of cyclones climatology with the reanalysis of ERA5. This step requires a challenging step, since it will be necessary to infer the cyclone category with only partial availability of atmospheric data, compared to ERA5. For example, this requires to develop a conceptual approach for attributing cyclones to categories based on their geopotential height field at selected pressure levels only (see also Deliverable 2.2 for more details).

2. 3T - MedCyclones Tracks Task Team (lead: E. Flaounas)

Aim
A key and critical issue in verifying forecasts of Mediterranean cyclones concerns the identification of cyclone tracks, since it is very sensitive to the tracking algorithm. As a consequence, there is no reference dataset of tracks for Mediterranean cyclones such as for tropical cyclones. Moreover, all cyclone tracking methods have limitations which are outcomes of the diagnostics used to identify cyclone centres in gridded datasets and track them in time. This initiative has a twofold objective:

first to combine a wide number of cyclone tracking methods in order to provide a climatological "best tracks" dataset and second, to develop a methodology that performs daily tracking of cyclones, applied to forecast simulations.

Scientific production

A group of about 20 participants contributed with 10 different cyclone tracking methods. E. Flaounas developed a new tool that combines the cyclone track outputs from different tracking methods and rejects the ones that were only identified by single methods.

First, for a rather short target period of one month (September 2006), it was demonstrated that the new tool was able to reject a high number of "bogus" tracks. Most of these tracks were artifacts of the tracking methods and did not correspond to organized mesoscale vortices. As a result, the tool was shown to be promising for reasons of operational forecasting and for providing a climatological dataset of cyclone tracks.

In the second phase, the methodology was applied to a 42 years climatology derived from ERA5 in the period 1979-2020. Results confirmed the capacity of combined cyclone tracking methods in providing a climatological dataset that reduces dramatically "bogus tracks" and includes all major cyclone cases in the region.

Therefore, the 3T research initiative has developed a new diagnostic tool that combines different cyclone tracking methods provided by the participants in order to produce a common cyclone tracks dataset. This "best tracks" dataset is composed only by composite cyclone tracks that concentrate the agreement of ten different cyclone tracking methods. Therefore, the final product of 3T concerns the “best” outcome of combined cyclone tracking tools and provides also a confidence level of the tracks. This methodology allows to overcome the known lack of consensus among different cyclone detection and tracking methods that has jeopardized the production of a commonly accepted reference dataset of extratropical cyclone tracks.

The dataset has been recently released and a paper submitted to an international peer reviewed journal.

Research perspectives

Given the advantage of the developed methodology in producing cyclone tracks with physically meaningful, distinctive life stages and including a minimum number of bogus tracks, the composite tracks is proposed as reference datasets for climatological research in the Mediterranean.

Future application are foreseen in activities of all the WGs, since the method will applied to operational forecasting, tailored to the needs of WG1 (e.g DynForMed initiative), but also to any gridded dataset for climatological purposes and impact studies.

3. MedCPM - MedCyclones in convection-permitting models (lead: S. Berthou)

Aim

The purpose of the initiative is to analyse Mediterranean cyclones in a set of hindcast simulations first and then in future simulations at km-scale resolution with explicit convection. Such simulations are increasingly available (e.g. CORDEX FPS - Convection over the Alps and H2020 EUCP simulations) for at least part of the Mediterranean.

Scientific production

Four simulations are already available for the Mediterranean by members of the Action participating in this initiative: (i) GUF COSMO (MedCordex 3km; 10y); (ii) Météo France AROME (Western Med; 30y); (iii) MOHC-HadREM3 2.2km (REU-3 domain; 20y); and (iv) Uni. C. Louvain: WRF (30y).
As a first step a common tracker (Aragão & Porcù (2021) algorithm) was adapted to km-scale resolution and run on the Met Office HadREM3-2.2km hindcast simulation. Analysis of the resulting cyclone tracks shows 84% matching of the tracks compared to ERA-5, for cyclones with central pressure lower than 1000 hPa.

Research perspectives
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.

4. AIR-SEA - Effects of air-sea interactions on Med Cyclone intensity and rainfall (lead: C. Pasquero)

Aim
In regions with a stable atmospheric boundary layer, as usually in the Mediterranean, sea surface temperature structures, such as eddies and thermal fronts, influence the buoyancy of the overlying air and modify the stability of the air column favoring or inhibiting the vertical fluxes between the surface and the free troposphere. As a consequence, surface winds are generally stronger, due to a more intense vertical mixing, over warm than over cold patches. Winds blowing from a warm to a cold sea surface are thus associated with convergence and viceversa. The link has been shown to be relevant on long term averages that remove synoptic scale variability and recently also at the daily time scale and in presence of strong wind convergence, such as in occluding cyclones (Meroni et al. 2020). Strong wind convergence tends to occur preferentially over SST fronts, resulting in increased cloudiness and rainfall when winds blow over a warm to cold SST front (Desbiolles et al. 2021). This suggests that frontal rainfall, even in very intense cases, can be impacted by small scale SST structures and that those structures should be considered when forecasting intense precipitation events.
On sub-daily timescales, cold air advection over the warmer Mediterranean sea (such as in the cyclone cold sector, Givon et al. 2021) induces turbulent ocean heat loss (sensible and latent), locally lowering SST and warming the lower troposphere. It is yet unclear how this air-sea heat exchange affects the cyclone life cycle and precipitation impact.
The purpose of this action is to study the above described air-sea interactions in Mediterranean cyclones on variable timescales. To this aim, Med-CORDEX simulations and 9 additional high resolution simulations, either coupled or run with high resolution SST boundary conditions, are collected and/or under production.

Scientific production
This initiative is planned to start in the next period of the Action.