Explosive Cyclones in the Mediterranean Sea exploiting ERA5 dataset: detection, classification, statistical and synoptic analysis of their occurrence

Cosimo Enrico Carniel[1], R. Ferretti[2], A. Ricchi[2], G. Curci[2], M.M. Miglietta[3], M. Reale[4], P. Serafini[2], E.D. Wellmeyer[2], and D. Zardi[1]

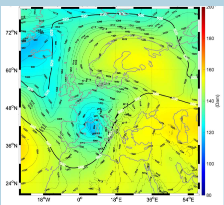
[1]University of Trento, DICAM-Department of Civil, Enviromental and Mechanical Engineering, Trento, Italy

[2]University of L'Aquila, Department of Physical and Chemical Sciences - CETEMPS, L'Aquila, Italy

[3]CNR-ISAC, Padova, Italy, [4]Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS, Trieste, Italy

1 - Introduction

In a time of growing concern related to climate change impacts, the ability to understand and forecast severe meteorological events becomes essential; among all the weather hazards, Explosive Cyclones (EC hereafter) are an eloquent example of a potentially disruptive event, so they are also known as "Meteorological Bombs. Several types of cyclones affecting the Mediterranean region may undergo an explosive deepening, and if they do, consequences can be rather uncomfortable. The Vaia Storm happened in October 2018 really testifies it.



Vaia's synoptic configuration:

- High pressure block from East, West and North
- Inverted Ω configuration
- Proved role of an atmospheric river

Among the causes:

- Baroclinic instability
- Extremely fast deepening
- Cut-off from Atlantic Circulation
- PV variations
- Dry air intrusions from the stratosphere
- Influence of air–sea interaction, latent heat release, SST anomalies

How often and where do these events occur?
Are we able to predict them?

2 - Data

Starting from ERA5 reanalysis dataset 1979-2020, we used an algorithm (*Flaounas et al, 2014)* to detected the tracks of the cyclones and retrieve the hourly data of SLP. All the study is carried out exclusively with these high-resolution (0.25°x0.25°) data.

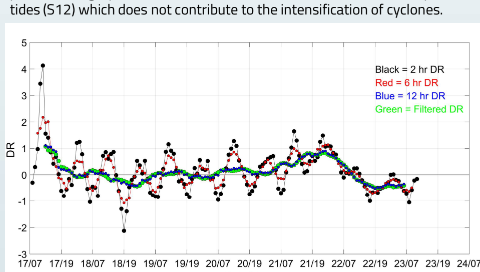
3 - Methodology

Analyses of cyclone intensification, starting from Tor Bergeron and *Sanders and Gyakum* (1980) and more recently, *Zhang et al.* (2017, 2021) have used the deepening rate (DR) of the cyclone center sea level pressure (CSLP) to characterize the rate of intensification. DR is usually normalized for the latitude of the cyclone, by referencing it to a chosen reference latitude. This takes into account the fact that the same radial pressure gradient gives rise to a higher (lower) velocity at lower (higher) latitudes. *Sanders and Gyakum* (1980) chose 60° as the reference latitude and defined the unit of DR in terms of Bergeron, with 1 Bergeron being the deepening rate of 1 mb (hPa) hr^{-1} (or equivalently 24 mb in 24 hr) at 60° latitude. On the other hand, *Zhang et al.* (2017, 2021) chose 45° as the reference latitude so that DR in Bergeron is given by the generalized formula:

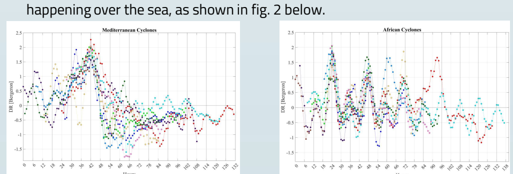
$$DR = \frac{p_{t-\frac{\tau}{2}} - p_{t+\frac{\tau}{2}}}{\tau}\left(\frac{\sin 45°}{\sin\left(\frac{\phi_{t-\frac{\tau}{2}} - \phi_{t+\frac{\tau}{2}}}{2}\right)}\right)$$

In this study, we have used the hourly cyclone CSLP from ERA5 dataset, which enables us to compute the DR at a higher time resolution of τ= 2 hr.

Figure 1 below shows the different methods of DR computation (calculated for every timestep), exhibiting oscillations in τ= 2 hr and τ=6 hr cases with a period of roughly 12 hr. This is the effect of solar semidiurnal atmospheric tides (S12) which does not contribute to the intensification of cyclones.



The S12 contamination is more prominent in Northern african cyclones, due to their development primarily on the land, in comparison with others happening over the sea, as shown in fig. 2 below.



Since spurios tidal signals corrupt DR, they must be eliminated. Therefore, we will use 12-hr DR in our study.

4 - Results

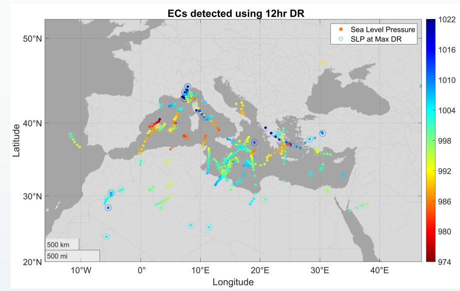


Fig 3. 80 cyclones where identified as EC througout the dataset. Their spatial distribution highlights the Gulf of Geona, where the majority of cyclones derives from the orographyc leap to which baroclinic waves from the Atlantic are subjected crossing the Alps, the Ionian Sea, the typical Cyprus low and developments in the North African region, where the Atlas mountains play the same role as the Alps in the case of Genoa.
NOTE: Coloured points indicate the pressure reached at every timestep along the tracks

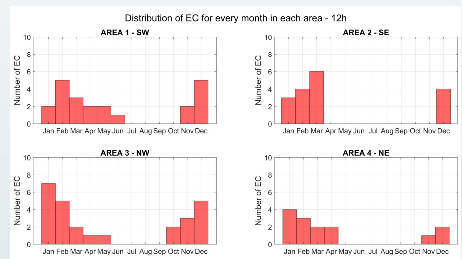


Fig. 4: results show, accordingly to previous studies, that Ecs are essentially a winter phenomenon. In all the four sectors selected from the initial domain, frequency peaks can be readily seen between January and March, with spurios events in early spring especially in the SW sector (North Africa)

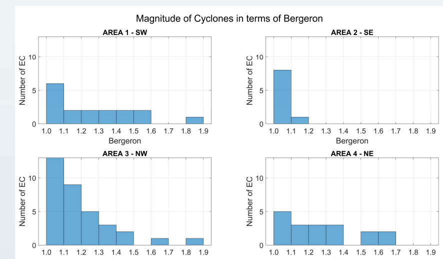


Fig. 5: Intensity of ECs in terms of Bergeron. According to Zhang's intensity characterization, 2 ECs are identified as "Strong" (DR>1.7 Bergeron), these two occurred in November 1991 and December 1998

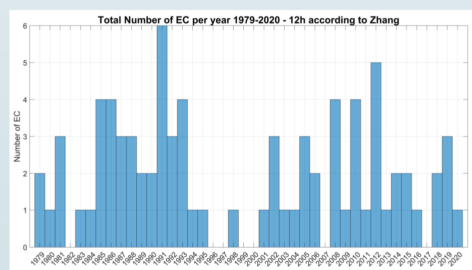


Fig. 6: Total distribution of Ecs 1979-2020. The trend is slightly diminishing from 3 to 2 ECs per year

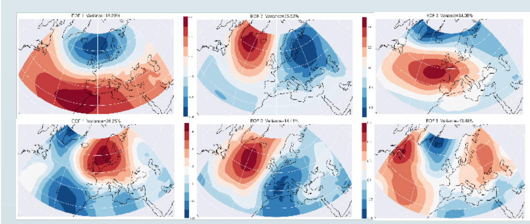


Fig. 7: In contrast to the typical synoptic patterns charaterizing the circulation in the Mediterranean Region (figures in the firs line) - positive NAO (18.29%), the EA-WR (15.92%) and EA (14.08%)- ,the first three EOFs computed using the SLP data belonging to every EC's deepening phase, indicate that deepenings of explosive nature are favoured by, a strong SCAND+ index (accounting for 24.25%), negative NAO (14.41 %) and a SCAND- (13.48%)

5 - Conclusion

- The formation locates in primarily in four geographical areas
- The Ligurian Sea presents the highest density of explosive cyclogeneses, not only developed in situ, but also coming from other regions with genesis not typical of the Genova low
- Highest frequency winter and autumn
- Recurring patterns such as cutoffs from atlantic or northern circulation, fast deepening over the Mediterranean due to high pressure blocks, intrusion of PV, atmospheric rivers (not shown)
- The majority of ECs in entering the Mediterranean are caused by a vast amount of cold air coming from the Atlantic Ocean, in accordance with a Mediterranean sea showing stronger positive SST anomalies in the last 40 years.

Acknowledgements:
Lakshmi Kantha, Emmanouil Flaounas