Extreme precipitation events in the Mediterranean region: Their characteristics and connection to large-scale atmospheric patterns

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Motivation

- The Mediterranean region has substantial population, strong contribution to global economy, and locations of global natural, historical and cultural significance.
- Extreme Precipitation Events (*EPEs*) lead to severe negative impacts on society, environment and economy.
- Better understanding of their characteristics and drivers can support improved forecasting, reducing related risks.

Data

- ERA5: Global gridded dataset for the period 1979–2019[i].

Selected Variables	Selected Spatial Resolution
Daily Total Precipitation (*TPr*)	0.25° X 0.25°
Daily Mean Seal Level Pressure (*SLP*)	1.00° X 1.00°
Daily Mean Temperature at 850 hpa (*T850*)	1.00° X 1.00°
Daily Mean Geopotential Height at 500 hpa (*Z500*)	1.00° X 1.00°

Methodology

- Select 31 locations around the basin (Fig. 1: red circles).
- Calculate areal-average TPr over extended areas (Fig. 1: black squares) and identify EPEs based on Q99–Q97 percentiles.
- Analyse seasonality and temporal dependency of EPEs (Figs. 9, 10).
- Assess spatial connections between the identified EPEs and Q99 extremes at each grid cell (Figs. 2, 6).
- Generate composites of SLP, Z500, T850 anomalies for the identified EPEs in the extended domain 10N/70N, 60W/80E and analyse statistical significance (Figs. 3, 4, 7).
- Perform Empirical Orthogonal Function (EOF) analysis for Z500 anomalies in the Mediterranean (26N/50N, 11W/41E) and project the EPEs on the six (6) first Principal Components (PCs)[iii, iv] (Figs. 5, 8, 11).

Future Pathways

- Use TPr data derived from high-density observations.
- Analyse evolution of atmospheric patterns connected to EPEs in the Mediterranean.

KEY FINDINGS

- **West/East divide: Most extremes occur during autumn (winter) for the west (east) Mediterranean** (Fig. 10)
- **Orography enhances precipitation and modulates spatiotemporal connections between locations** (Figs. 2, 6, 10)
- **For most areas, more than 25% (50%) of the Q99 (Q97) events occur within 15 days from the previous Q99 (Q97) event** (Fig. 9)
- **Negative (dipole) anomalies of SLP, Z500 (T850) over (around) the affected area are observed during extreme events** (Figs. 3, 4, 7)
- **EOF analysis corroborates the statement about West/East divide, and can possibly contribute in analysing extremes** (Figs. 5, 8, 11)

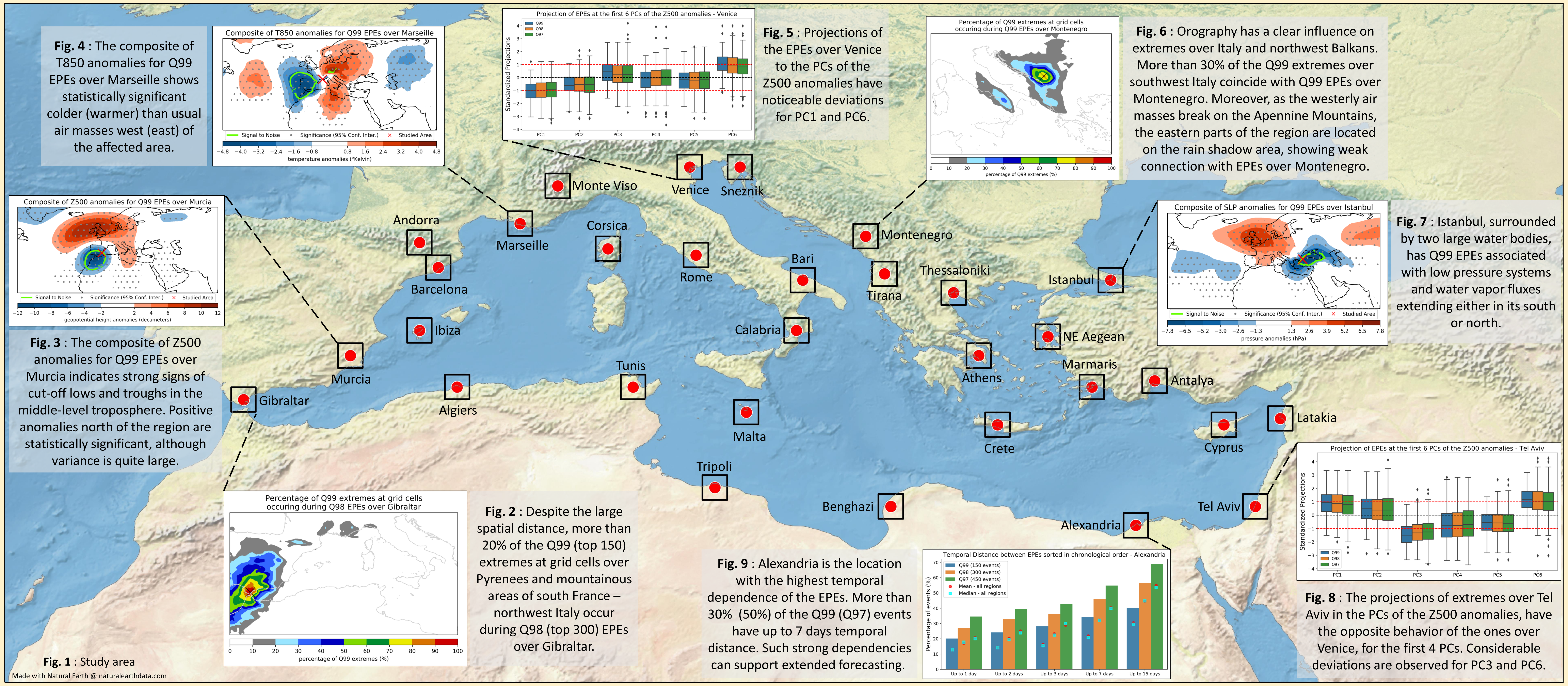

Fig. 1 : Study area

Fig. 2 : Despite the large spatial distance, more than 20% of the Q99 (top 150) extremes at grid cells over Pyrenees and mountainous areas of south France – northwest Italy occur during Q98 (top 300) EPEs over Gibraltar.

Fig. 3 : The composite of Z500 anomalies for Q99 EPEs over Murcia indicates strong signs of cut-off lows and troughs in the middle-level troposphere. Positive anomalies north of the region are statistically significant, although variance is quite large.

Fig. 4 : The composite of T850 anomalies for Q99 EPEs over Marseille shows statistically significant colder (warmer) than usual air masses west (east) of the affected area.

Fig. 5 : Projections of the EPEs over Venice to the PCs of the Z500 anomalies have noticeable deviations for PC1 and PC6.

Fig. 6 : Orography has a clear influence on extremes over Italy and northwest Balkans. More than 30% of the Q99 extremes over southwest Italy coincide with Q99 EPEs over Montenegro. Moreover, as the westerly air masses break on the Apennine Mountains, the eastern parts of the region are located on the rain shadow area, showing weak connection with EPEs over Montenegro.

Fig. 7 : Istanbul, surrounded by two large water bodies, has Q99 EPEs associated with low pressure systems and water vapor fluxes extending either in its south or north.

Fig. 8 : The projections of extremes over Tel Aviv in the PCs of the Z500 anomalies, have the opposite behavior of the ones over Venice, for the first 4 PCs. Considerable deviations are observed for PC3 and PC6.

Fig. 9 : Alexandria is the location with the highest temporal dependence of the EPEs. More than 30% (50%) of the Q99 (Q97) events have up to 7 days temporal distance. Such strong dependencies can support extended forecasting.

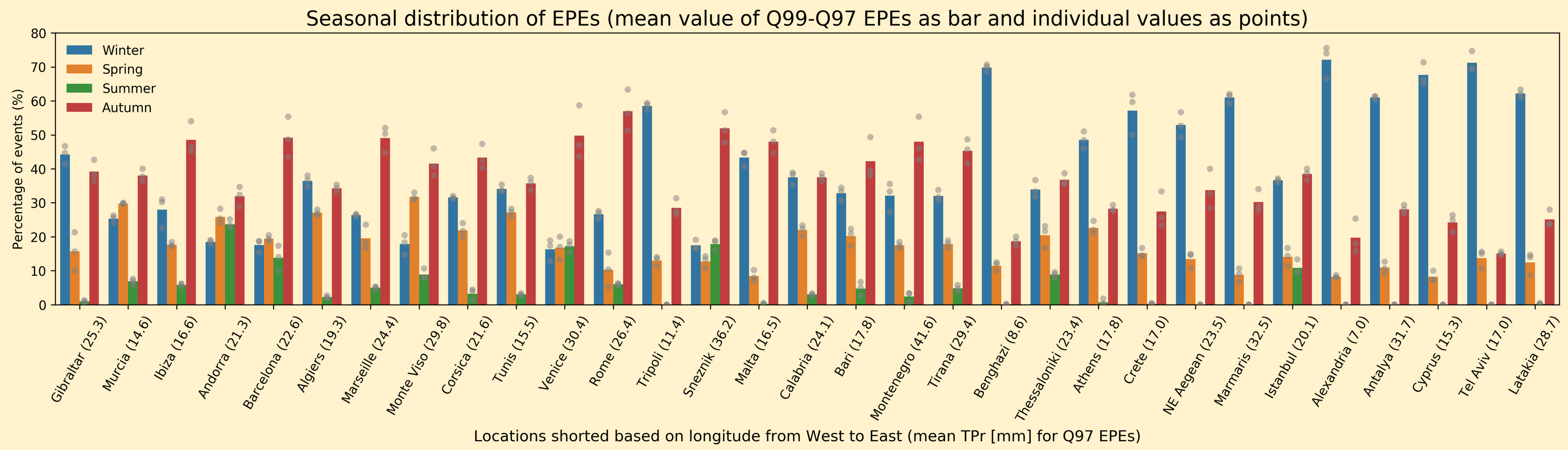

Fig. 10 : West/East divide in EPEs seasonality. For locations in central Mediterranean (e.g. Malta, Sneznik), statistics for south (north) regions have a closer resemblance to locations in East (West) Mediterranean (agreeing with EOF1 & EOF2,Fig. 10). The distinct behaviors for Gibraltar and Istanbul can be associated to the significant influence of the Atlantic and the Black Sea, respectively. In general, locations at northern latitudes (e.g. Barcelona vs. Algiers), as well as at higher altitudes or with mountain ranges in their vicinity (e.g. Antalya vs. NE Aegean), have higher average TPr for EPEs.

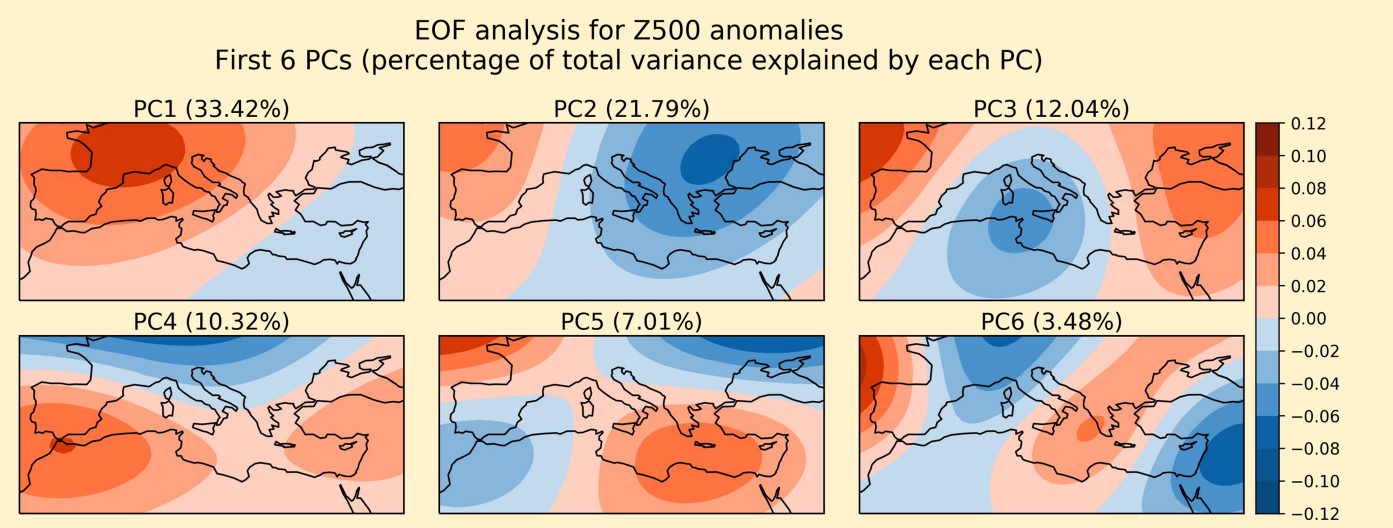

Fig. 11 : EOF analysis for the Z500 anomalies (based on all daily data for period 1979–2019) clearly demonstrates a west (northwest)/east (southeast) divide, with the first two EOFs explaining more than 50% of the total variance. The patterns agree with the known oscillations within the region (Mediterranean Oscillation; West Mediterranean Oscillation[ii]).

References:

[i]Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service Climate Data Store (CDS). https://cds.climate.copernicus.eu/cdsapp#!/home; [ii]Vicente-Serrano, S. M. et al. Daily atmospheric circulation events and extreme precipitation risk in northeast Spain: Role of the North Atlantic Oscillation, the Western Mediterranean Oscillation, and the Mediterranean Oscillation. J. Geophys. Res. 114, D08106 (2009); [iii]Ulbrich, U. et al. Climate of the Mediterranean. in The Climate of the Mediterranean Region 301–346 (Elsevier, 2012). doi:10.1016/B978-0-12-416042-2.00005-7., [iv]Xoplaki, E. et al. Large-Scale Atmospheric Circulation Driving Extreme Climate Events in the Mediterranean and its Related Impacts. in The Climate of the Mediterranean Region (ed. Lionello, P.) 347–417 (Elsevier, 2012). doi:10.1016/B978-0-12-416042-2.00006-9.

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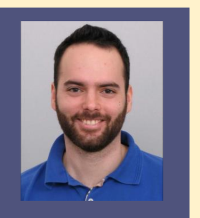

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CAFE Climate Advanced Forecasting of sub-seasonal Extremes

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Supplementary information – Methodology

Extreme Precipitation Events (EPEs):

- The selected spatial scale for the identification of EPEs is a square box of 25 grid cells (Fig. 1: black squares), centred in the area of interest (Fig. 1: red circles). This selection accounts for areas approximately 15,000 km^2. It reduces uncertainties associated with reanalysis data, when it comes to the magnitude and spatial extend of EPEs covering small areas. Moreover, the selected scale provides information for events that severely affect extended domains simultaneously, which makes the response of civil protection very challenging.
- The area-weighted daily average Total Precipitation (*TPr)* was calculated for 31 regions around the basin (Fig. 1: black squares). The influence of latitude in the grid-cell size, was taken into consideration during the calculation of the TPr. The selected regions cover a range of longitudinal and latitudinal domains within the Mediterranean and have different orographic characteristics, with coastal areas, as well as mountainous regions. This gives the opportunity to analyse EPEs at locations with distinct climatic characteristics.
- The EPEs were identified based on Q99-Q97 percentiles. Because of the selected large spatial domain, and due to significant differences in the number of dry days between north/south, wet-days-derived EPEs were not preferred, and the analysis was performed based on all daily data. As the number of days analysed is 14,975 the total number of selected events are 150, 300, and 450 for Q99, Q98, and Q97 respectively.
- The seasonality and temporal dependency of the identified events were analysed (Figs. 9, 10).
- The spatial connections between the identified EPEs and Q99 extremes at each grid cell was assessed (Figs. 2, 6). For this part of the analysis, the dates of the Q99 events for each individual grid cell were derived. The percentage of total Q99 events at grid cell level that occur during the Q99-Q97 EPEs over each of the 31 selected regions was calculated. Such analysis can provide information about the common characteristics of extended areas during EPEs.

Composites

- The daily anomalies of mean Sea Level Pressure (SLP), mean Temperature at 850 hpa (T850) and mean geopotential height at 500 hpa (Z500) were calculated for the domain 10N/70N, 60W/80E. The selected domain provides information about the configuration of the synoptic scale weather, and the influence of the large water and land masses surrounding the case study. SLP and Z500 were selected for providing information about the dynamics of the atmosphere in the lower and middle troposphere, while T850 can be used for identifying fronts. The climatology of these variables was calculated with a 5-day smoothing window. For deriving the anomalies, each day of the 1979-2019 period was subtracted from its corresponding daily climatology.

- The composites[i] of the anomalies for the identified EPEs of each region were generated and their statistical significance was assessed (Figs. 3, 4, 7). Two methods were selected for deriving information about the significance, namely the signal-to-noise ratio, and significance based on bootstrapping. Signal-to-noise refers to *abs(mean)/standard deviation.* Values larger than 1 indicate stronger level of signal compared to background noise. Areas with such values can therefore be considered as the "spatial centre of gravity" of the common characteristics of the identified EPEs. Bootstrapping (with replacement) is performed for 95% confidence interval after analysing 2000 randomly resampled data, based on the subset of days corresponding to EPEs at each location. Grid cells that have the same sign for both 50th and 1950th value (after sorting their values in ascending order) are considered statistically significant, as they are always larger/smaller than zero, which is the expected climatological anomaly.

Empirical Orthogonal Function (EOF) analysis

- The EOF analysis (on the covariance matrix) was performed for the derived daily Z500 anomalies of the full period (1979-2019) on the extended Mediterranean domain (26N/50N, 11W/41E) (Fig. 11). Z500 was selected as it shows a clear connection with EPEs over the study area and is free from local influences of orography, unlike the SLP.

- The identified EPEs were finally projected on the six (6) first Principal Components (PCs) (Figs. 5, 8). The first 6 PCs account for more than 88% of the total variance of the domain and can provide the vast majority of the information related to the influence of the domain in the dynamics of the patterns generating the EPEs. Information about the influence of more extended/distant domains and phenomena (e.g. North Atlantic Oscillation, Rossby Waves, Atlantic storm tracks) was out of the scope of this study and will be addressed at future works.

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[i]A composite is the average of a subset of data with similar characteristics. It can be used for analysing the relationships among different variables and identifying structural characteristics of atmospheric phenomena.