Use of cluster analysis to identify the meteorological patterns associated with hail phenomena in Campania (Southern Italy)

Master di II livello in Meteorologia e Oceanografia Fisica

Sabrina Veltri[1]

Supervisor: Vincenzo Capozzi[2]

[1] Università del Salento, [2] Università degli studi di Napoli "Parthenope"

1. Introduction

Hail is one of the most diffuse and harmful meteorological hazard, causing damages to crops, transport activities, buildings and infrastructure. Therefore, improving hail forecast is a crucial task to preserve assets and human life, especially in metropolitan areas, whose infrastructure and settlements are more and more vulnerable to severe convective events. The aim of this work is to analyze the relationship between hailstorm occurrence and atmospheric circulation patterns in Naples metropolitan area (Campania Region) over the period from 1988 to 2021. Multivariate statistical techniques, including Principal Components Analysis and Cluster analysis have been applied to some meteorological fields obtained from ERA5 reanalysis. The atmospheric pattern classification has been carried out after partitioning the available hail events according to their period of occurrence, i.e. warm season (May to September) and cold season (October to April). Finally, two case studies related to the hailstorms occurred on January 30, 2015 and August 25, 2021 have been examined, in order to investigate the synoptic and mesoscale conditions and to validate the results obtained from Cluster Analysis.

2. Data and methods

The dataset includes 170 severe convective events, 85 of which were characterized by the presence of hail. The meteorological configurations associated with hail events were obtained from ERA5 reanalysis, which provides hourly estimates of many atmospheric quantities on pressure levels with a horizontal resolution of 0.25 degrees. We chose data at 12:00 UTC as reference pattern. There were selected some meteorological fields, including: (i) the 500-hPa geopotential height (Z500) and temperature (T500), (ii) the 850-hPa specific humidity (SH850), (iii) the 700-hPa vertical velocity (VV700) and (iv) the 1000-hPa horizontal winds (HV1000). As other authors have done, multivariate statistical techniques were used (e.g., Aran et al. 2011; Houssos et al. 2008; Esteban et al. 2006).

- Firstly, Principal Components Analysis (PCA) in R-mode was performed, using days as variables and reanalysis grid points as observations.
- Finally, we have applied the Cluster Analysis (CA) to the components extracted from PCA. For this study, it has been chosen the k-means algorithm method, which classifies groups of data according to their similarities using the Euclidean distance.

3. Results

Taking into account the 85 hail days, PCA and CA were separately applied to the warm and cold season. Four and three patterns were obtained, respectively.

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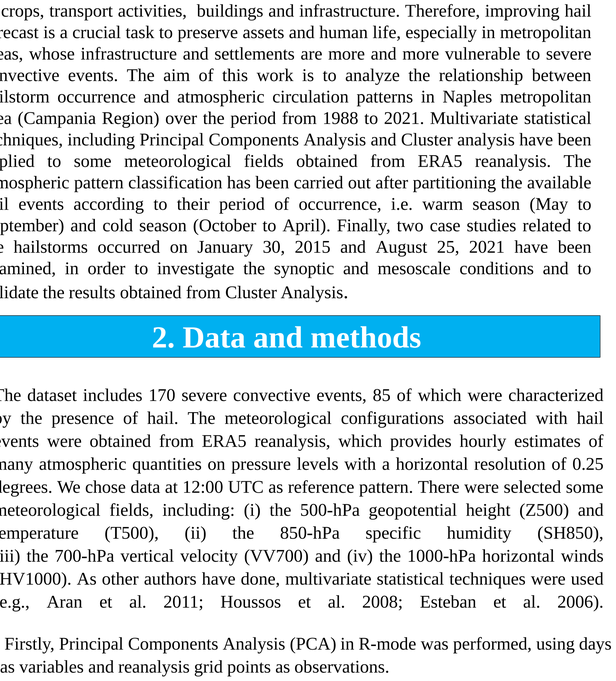

Fig.1 Frequency of occurrence of each cluster for every month of (a) the warm season and (b) the cold season.

3.1 Circulation types for warm season

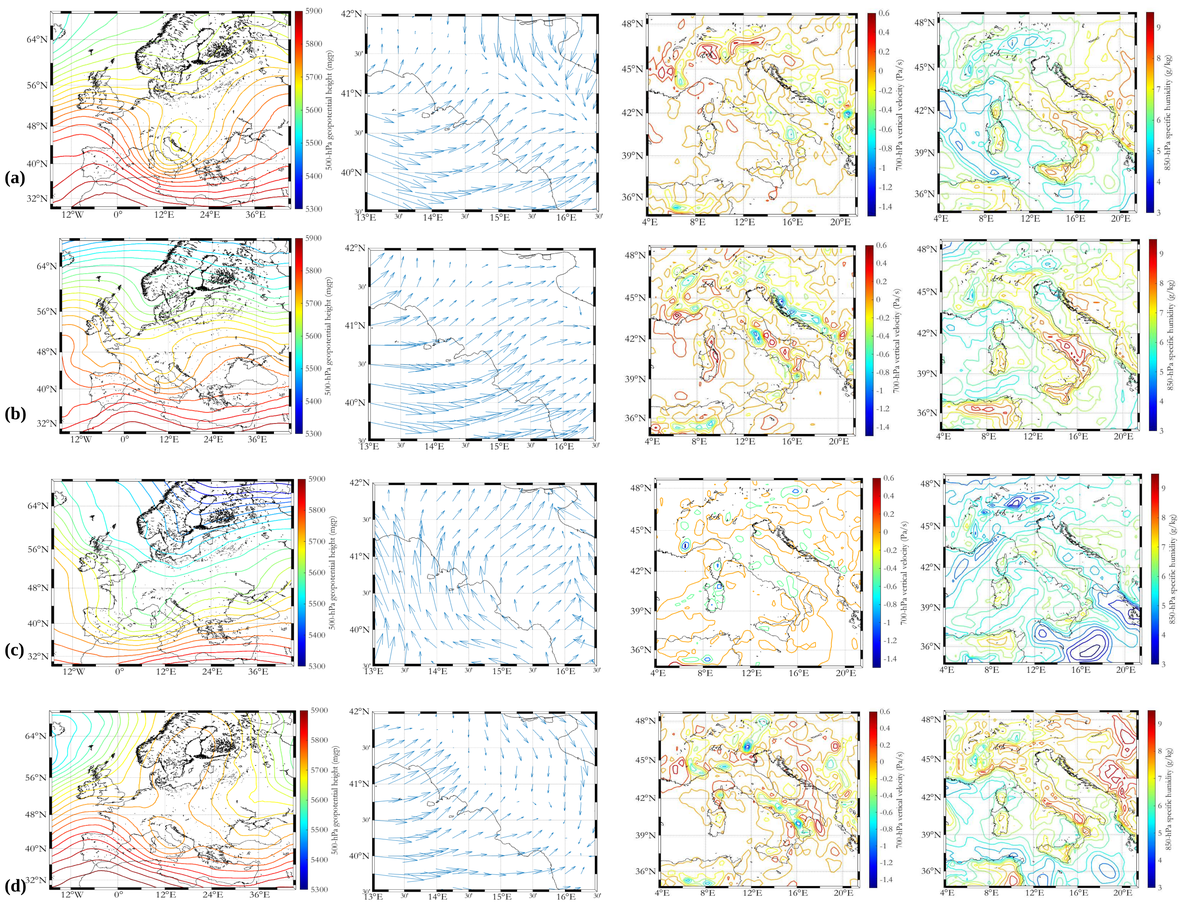

Fig. 2 From left to right: map of Z500, HW1000, VV7000 and SH850 for (a) Cluster 1, (b) Cluster 2, (c) Cluster 3 and (d) Cluster 4.

- Hailstorms occurred during hail events within Cluster 1 and 4 **(Fig. 2a,d)** are associated with the interaction between the synoptic low-pressure system and low-level convergence of winds, while hail days described by Cluster 2 and 3 **(Fig. 2b,c)** appear to be due to the interaction between the large-scale pattern at upper level and moist air masses coming from Tyrrenian Sea.

3.2 Circulation types for cold season

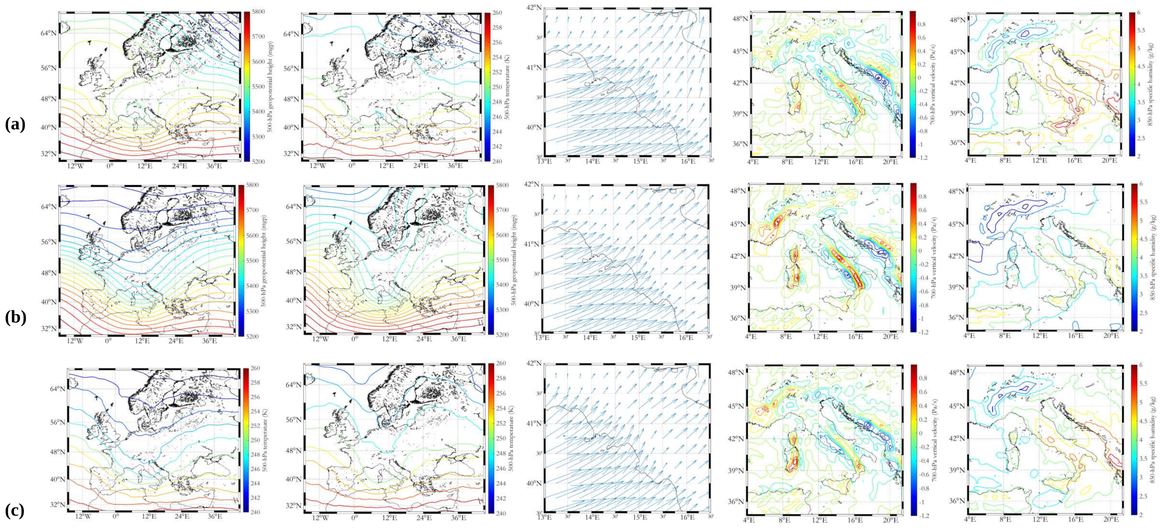

Fig. 3 From left to right: map of Z500, T500, HW1000, VV7000 and SH850 for (a) Cluster 1, (b) Cluster 2 and (c) Cluster 3.

- Hailstorms were caused by an advection of upper-level cold air mass. The synoptic environment of Cluster 1 shows a closed circulation that resembles the final stage (i.e. cut-off low) of a Rossby wave evolution (**Fig. 3a**), while the pattern of Cluster 2 and 3 represents the mature stage of the Rossby wave associated with the Polar Front oscillation. (**Fig.3b,c**).

4. Cases study

In this section, two hailstorm events, one occurred during warm season and the other occurred during cold season, are analyzed. Within the framework of our analysis, the former belongs to Cluster 1 **(Section 3.1)** and the latter to Cluster 2 (**Section 3.2**).

4.1 Warm season

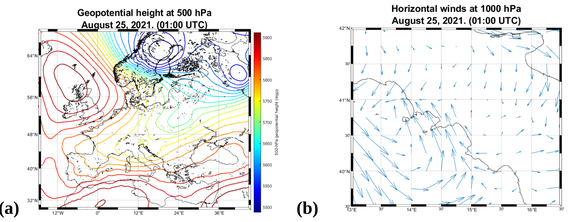

Fig. 4 Map of 500 hPa geopotential height on August 25, 2021 (01:00 UTC). (b) Map of horizontal components of wind at 1000 hPa on August 25, 2021 (01:00 UTC).

- The most interesting feature is the presence of a cyclonic circulation of surface winds over the entire Campania's coast and the adjacent Tyrrhenian Sea, which promotes low-level wind convergence in Naples urban area (**Fig.4b**).

4.2 Cold season

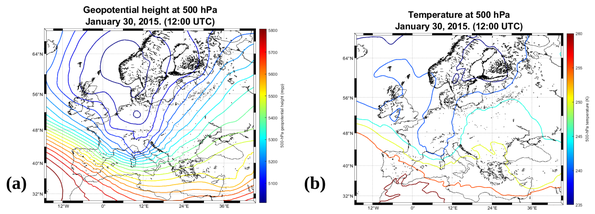

Fig. 5 (a) Map of 500 hPa geopotential height on January 30, 2015 (12:00 UTC). (b) Map of 500 hPa temperature on January 30, 2021 (12:00 UTC).

- The event was determined by an advection of arctic maritime air mass, as shown in the charts presented in **Fig.5a,b**. This configuration promotes the development of convective cells along the relatively warm Tyrrenian Sea that are advected towards coastal area of Campania Region by southwesterly winds.

5. Conclusions

- Hailstorms occurred during warm season are caused by closed cyclonic circulation, which enhanced the convective instability in conjunction with the advection, at low atmospheric levels, of warm and moist winds from the sea and/or low-level convergence between synoptic scale flow and mesoscale circulation (sea breeze), resulting in a strong convective activity mainly in the inland sectors of the study region.
- During cold season, the hailstorms in Naples urban area are generally triggered by wide trough elongated from northern Europe to Mediterranean basins, determining an advection of cold air masses. The latter, crossing the relatively warm Mediterranean sea, enhance the convective instability, causing the formation of thunderstorms events that mainly affect the coastal sector of Campania Region.
- Overall, it appears that the circulation pattern of the two events successfully reproduced the configurations of the cluster in which they were included.
- Future works are needed to assess the significance of the third cluster of warm season, which is only present in the last decade and to build up a more robust and less biased dataset, as well. Moreover, it is evident that additional efforts are required to include in the cluster analysis some instability indices that can be used as hail forecast parameters.

References

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