Weather types associated with flood, windstorm and synergic events in the Catalan coast

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Abstract: The aim of this work is to analyze the weather types following the Jenkinson and Collison methodology that have produced flood, windstorm and synergic events that have affected the Catalan coast during the period 1981-2015. To do this, the events to be analyzed were first selected from various databases and their distribution and temporal evolution were analyzed. In total, 186 flood events, 37 windstorms and 35 synergic events have been identified. The results point to the predominance of the cyclonic weather type in the three types of events and that the most damaging effects are those produced by synergic events.

I. INTRODUCTION

The Mediterranean coastal zone is an especially vulnerable and sensitive area to natural risks and climate change ([1], [2], [3]), therefore it is considered a hotspot. For instance, in September 1962 there were floods in the Vallès country that caused more than 800 deaths [4], while in October 1970 there was a catastrophic episode of heavy rains in Genoa, Italy, claiming 44 lives [5]. In 1966, there was a sea storm on the Venetian coast that was characterized by the existence of a strong pressure gradient that led to the formation of a southwestern sirocco wind that produced a large amount of warm and humid air, giving rise to the largest storm ever recorded to date on the Venetian coast [6]. Given that flood episodes are especially damaging both in human and economic losses in Catalonia [7], this work will focus on this region.

Until now, various studies have been carried out for the types of weather associated with episodes of intense precipitation and floods in various regions of the Iberian Peninsula. In 2008, Martin-Vide et al. [8] studied the types of weather associated with episodes of torrential precipitation in the northeast of the Iberian Peninsula during the period 1950-2005, and the influence of the WeMo (Western Mediterranean Oscillation) circulation pattern. Gilabert and Llasat [9] reached the conclusion that the weather types associated with flood events that affected Catalonia in the period 1900-2010 were relatively cyclonic and from the SE, which corroborated the thesis of the high presence of a low, defended in the MEDEX project [10]. Llop Garau and Almoar Garau [11] determined the types of weather associated with episodes of precipitation greater than or equal to 100 mm in the Catalan coastline and in the Balearic Islands, in the 1950-2005 series. Various studies have also been carried out on windstorms in the Mediterranean region. Thus, Pirazzoli and Tomasin [12] investigated the possibility of appreciable changes in surface wind patterns in the central Mediterranean area and looked for a correlation between wind, pressure levels at sea level and SST. Nissen et al. [13], studied the frequency and intensity of cyclones associated with windstorms that can affect the Mediterranean region simulated in a scenario of increased greenhouse effect. However, there are very few papers on synergic events, or what is known today as “compound events.” In 2018, Pescaroli and Alexander [14] suggested how “compound risks” could be used as inputs for further analysis and decision tools designed to support the implementation of the SFDRR (Sendai Framework for Disaster Risk Reduction), and Leonard et al. [15] proposed the use of influence diagrams to determine the risk of synergic events as an alternative to modeling due to the difficulty involved. In this context, the M-CostAdapt project [16], in which this Final Degree Work is framed, aims to «carry out an analysis of the adaptability to climate change and the natural risks of the Mediterranean coast», and «to propose a response strategy based on the design of adaptation routes».

The aim of this work is to provide knowledge about the weather types associated with episodes that have generated damage on the Catalan coast and their temporal evolution (floods, windstorms and synergic events). The study focuses on the period 1981-2015. The episodes have been classified according to their impact in both people and infrastructure ([17], [9]).

The work begins with a brief description of the study area and the databases that have been used in section II. Section III explains the methodology according to the classification criteria according to impact and weather types, and the results are shown in section IV. The work ends with the conclusions.

II. DATA AND AREA OF STUDY

The analysis focuses on the study of sea storms and floods that affected the Catalan coast between 1981 and 2015. In this case, the coastal fringe is described as that defined by all the municipalities that face towards the sea. In total there are 70 municipalities.

For this, the INUNGAMA database has been used. Created by the GAMA group ([18], [7]) INUNGAMA is a database associated with a GIS (Geographical Information System), which gathers documentary and instrumental information on the flood events that have affected Catalonia, between 1900 and 2015 [19]. The press news base on natural risks and climate change, PRESSGAMA ([20]) has also been consulted. It is worth mentioning that throughout my contract of curricular internships for the Physics degree, I have collaborated in the compilation and analysis of news corresponding to the years 2012 and 2015. From PRESSGAMA, the news related to sea storms that have affected the Catalan coast was obtained.

From the selected episodes, a reading of the surface pressure values is made from the maps provided by the NCEP/NCAR Reanalysis project [21], for a nine-point grid with extreme vertices at 10ºW-10ºE, 45º-35ºN and an approximate resolution of 2.5º x 2.5º latitude and longitude. The NCEP/NCAR Reanalysis project is a joint product of the

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National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR), which aims to produce atmospheric reanalysis using historical data, as well as produce analyzes of the current atmospheric state. To do this, it uses a state-of-the-art analysis and forecast system to assimilate data using past data from 1948 to the present.

III. METHODOLOGY

A. Impacts

Each type of episode has been classified according to the level of impact it produced ([22], [23], [24]). In summary, the catastrophic episodes are those that have produced the destruction of some infrastructure or building in addition to numerous economic damages and usually deaths; the extraordinary ones are those in which the damage has been minor and there has been no total destruction of buildings or infrastructure; finally, in ordinary episodes, the impacts are usually flooding of the shallows or winding of objects as a result of the flood.

B. Weather types

Weather types (WT) are classified in this work following the Jenkinson and Collison criteria [25], which consists of 27 types of weather based on surface pressure. These are grouped as follows:

- 8 pure advectives: N, NE, E, SE, S, SW, W, NW
- 1 cyclonic: C
- 1 anti-cyclonic: A
- 8 cyclonic hybrid advectives: CN, CNE, CE, CSE, CS, CSW, CW, CNW
- 8 anti-cyclonic hybrid advectives: AN, ANE, AE, ASE, AS, ASW, AW, ANW
- 1 undetermined: U

of which the weather types of the cyclonic hybrid advectives have been grouped into a single type (C), and the anti-cyclonic hybrid advectives into a single type (A).

The procedure followed is the implementation of a 9-point mesh located on the Iberian Peninsula based on the criteria used in [8], Fig.(1). From each point of the grid, the surface pressure values are obtained, to which a series of algorithms are applied to obtain the eight variables necessary to estimate the WTs. The algorithms have not been exposed in this work due to their length.

The values of the surface pressure have been obtained from the implementation of an average pressure field during the days of the episode.

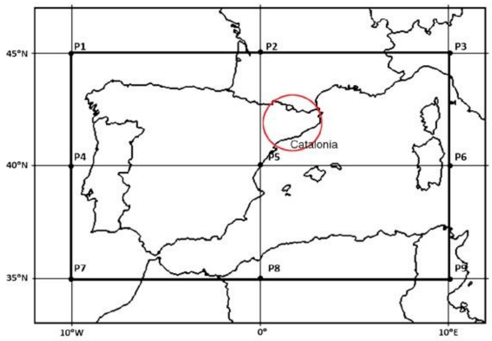

FIG. 1: Map of the Iberian Peninsula with mesh points. Source: [8].

IV. RESULTS

A. Distribution of floods and storms on the Catalan coast 1981-2015

In total, 258 episodes have been identified, of which 186 are floods, flash-floods or surface water floods ([24]), 37 are windstorms and 35 are synergic episodes.

Fig.(2) shows that the year with the highest number of flood episodes was 2005 (11 episodes) followed by 2003 (9 episodes), while for the highest occurrence of windstorm events occurred in 2012 and the highest synergic ones happened in 2011.

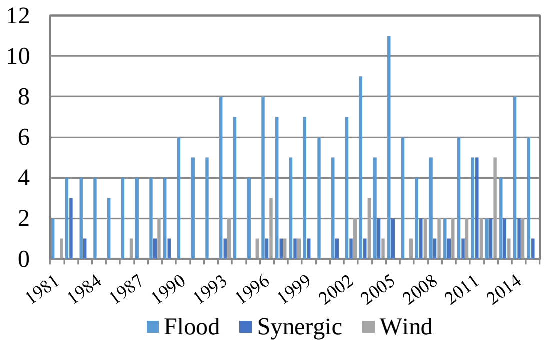

FIG. 2: Number of episodes organized by type of event throughout the period 1981-2015.

In Fig.(3), episodes have been grouped every 5 years. An increase in the number of flood episodes is observed from 2001-2005, but after 2005 that positive trend disappears. Synergic episodes and windstorms increased throughout the period of time studied.

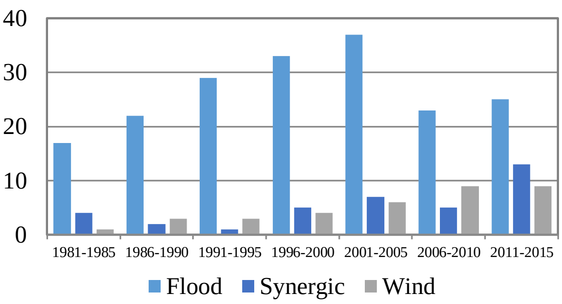

FIG. 3: Number of episodes organized by type of event throughout the series 1981-2015 grouped by time lapses of 5 years.

Flooding episodes are especially frequent during the month of September, followed by August and October, while synergic events have a greater presence between August and November and in the month of March. The episodes of windstorms are relevant between the months of October to April, Fig. (4).

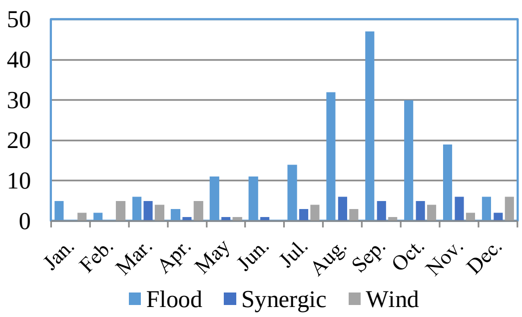

FIG. 4: Monthly distribution of number of episodes by type of episode.

B. Distribution of weather types on the Catalan coast 1981-2015

The predominant weather type is the cyclonic with 167 events, followed by the pure advective with the NE component with 22 episodes and the anti-cyclonic with 20 episodes.

There is an increase in the number of episodes produced by the cyclonic weather type and no appreciable trend for the other types of weather, Fig.(5).

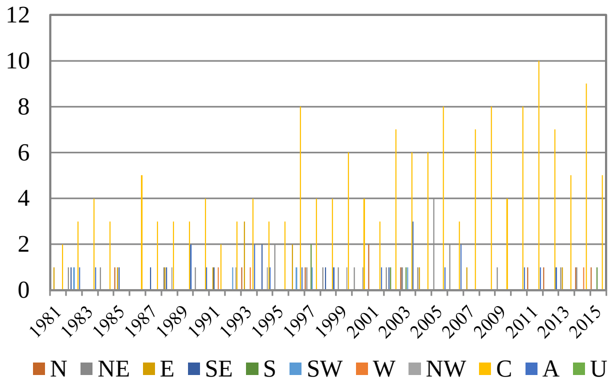

FIG. 5: Number of episodes produced by their correspondent weather type during the period 1981-2015.

The cyclonic weather type has caused the highest number of events in September, followed by October and August, while the pure advective with NE component has the highest incidence in August, followed by September and July. The anti-cyclonic system is notable between the months of July and October, Fig.(6).

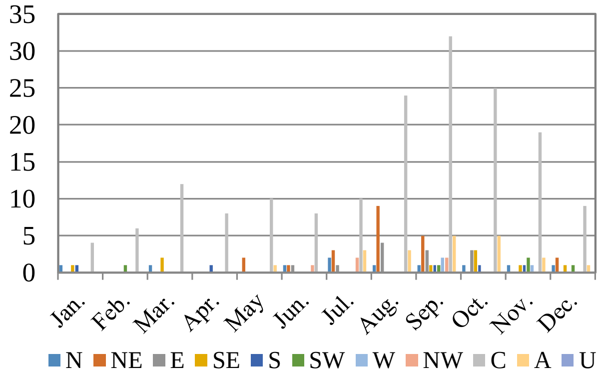

FIG. 6: Monthly distribution by weather types.

C. Distribution of weather types by type of events on the Catalan coast 1981-2015

The most common weather type in flood episodes is the cyclonic, followed by the pure advective with NE component and the anti-cyclonic. As for the remaining weather types except the undetermined, all have led to flood events. The weather types associated with synergic events have been the cyclonic type, and the pure advective with components NE, N, SW and E, while all weather types have caused episodes of windstorms with the exception of the pure advective with component W and the undetermined, Fig. (7).

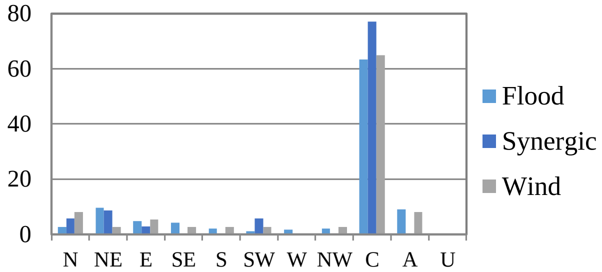

FIG. 7: Ratio as a percentage of the number of episodes produced by each weather type and type of event, by the number of episodes produced by each type of event.

D. Distribution of weather types and events in episodes of catastrophic category on the Catalan coast from 1981-2015

If only catastrophic episodes are considered, 18 have been due to flooding, 4 due to synergism and 2 due to windstorms. Most episodes have been caused by a cyclonic system, Fig.(8).

Although the highest number of catastrophic episodes corresponds to floods, the percentage of catastrophic synergic episodes (43%) is the highest of the three types (37% in floods and 20% in wind storms), therefore, it is concluded that the synergic episodes have a greater impact. No trend is observed in the number of catastrophic episodes, although the years of 1982 and 2005 standout with a total of 3 episodes, Fig.(9).

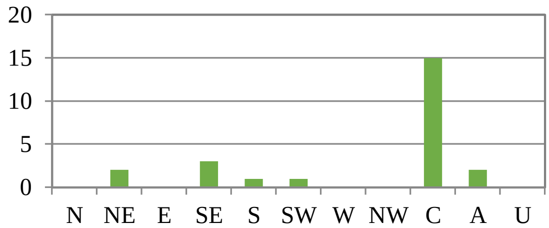

FIG. 8: Number of episodes by weather type in the catastrophic event category.

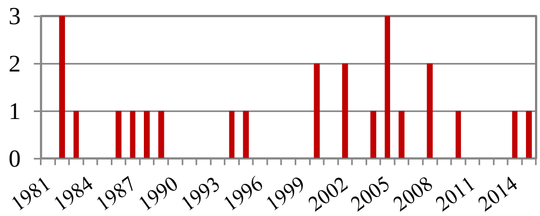

FIG. 9: Number of catastrophic episodes throughout the 1981-2015 series.

E. Surface analysis of three catastrophic cyclonic weather type episodes

Three representative episodes of the cyclonic weather type that caused a catastrophic flood, windstorm and synergic event have been chosen.

In October 1986, there was a flood episode, in which there was the presence of a relative low of 1014.5 hPa in the W of the Iberian Peninsula, and the wind that affected Catalonia was from the SE, providing humid and probably warm air from the Mediterranean, hitting the coast perpendicularly and forcing a rise due to the Litoral Mountain Range. There was rainfall of up to 430 mm in 24 hours in Cadaqués and the overflow of Llobregat de l'Empordà, Fig.(10).

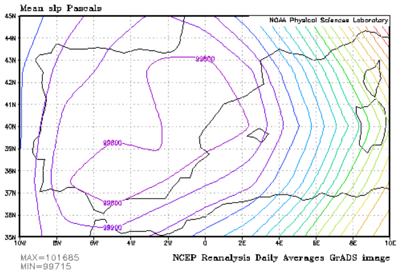

FIG. 10: Map extracted from NCEP/NCAR Reanalysis of the episode of October 12-15, 1986.

In February 2004, there was a windstorm episode that was characterized by a low on the Iberian Peninsula of 998 hPa, with a marked pressure gradient in the west-east direction that favored a strong south-component wind over the Catalan coast. The storm took a good part of the sand off the beaches of Barcelona and Cabrera de Mar, and caused damage to infrastructure. There were strong winds in Alt Empordà (120 km/h in Portbou, 65 km/h in Cadaqués) and waves of up to 8 m (according to testimonies), Fig.(11).

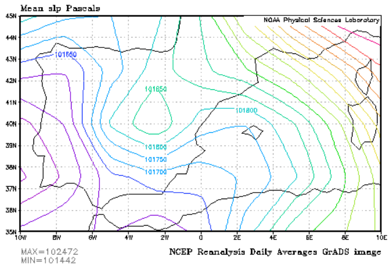

FIG. 11: Map extracted from NCEP/NCAR Reanalysis of the episode of February 2l, 2004.

In December 2008 there was a synergic episode with the presence of a low at 1001 hPa over the Balearic Islands. It was a Levante wind over the N of Catalonia that could have advected humid and warm Mediterranean air (it was autumn, which implied a warm sea) giving rise to heavy rains on the coast. There were waves of up to 8 m in the Golf de Roses, the sand disappeared from the beaches of Roses and l'Estartit, and part of the sand from Vilassar de Mar, Cabrera and Premià was carried away. The intense rains with total rainfall greater than 300 mm, caused flooding in La Jonquera, Fig.(12).

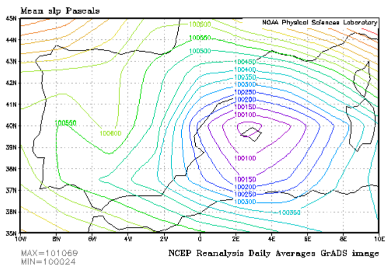

FIG. 12: Map extracted from NCEP/NCAR Reanalysis of the episode of December 26-27, 2008.

V. CONCLUSIONS

In this work, the Jenkinson and Collison methodology has been applied in order to determine the weather types that have caused flood episodes, windstorms and synergic episodes. Likewise, episodes have been classified according to the type of episode, the weather type and the impact produced, both throughout the time series and in monthly frequencies.

The most important points that this work concludes are presented below.

- There has been a total of 258 flood, windstorm and synergic episodes comprised in the 1981-2015 time period. 2005 was the year with the highest number of flood episodes, 2012 with the highest occurrence of windstorms and 2011 with the highest synergics, with an increase throughout the series in episodes produced by windstorms and synergics. In the case of floods, the increasing trend stopped in 2005.
- September was the month with the most cases of flood episodes, while windstorms were grouped between the months of October to April and the synergic ones from August to November and the month of March.
- The weather type that has caused the most episodes is the cyclonic, followed by the pure NE component advective and the anti-cyclonic. This result is consistent with the results of the MEDEX project [10]. This cyclonic weather type predominates between August and November with a peak in September and is much more marked in catastrophic episodes. Usually these are situations in which the low creates a circulation that provides humid air from the Mediterranean or winds from the north or east, depending on where it is located.
- When synergic episodes are recorded, the probability that they are catastrophic is higher than, in the other cases, due to the synergy of the two components of hazard, wind and rainfall.

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