Characterization of compound events on the northern Girona coast

Author: Laia Pau Guitart
Advisor: Maria del Carmen Llasat
Facultat de Física, Universitat de Barcelona, Diagonal 645, 08028 Barcelona, Spain.*

Abstract: The aim of this article is to study the phenomena associated with strong wind and compound events where this hazard intervenes in the region of North Girona. Of the two blocks in which this work is divided, the first one focuses on the synthesis of the literature about the most common winds in L'Empordà, floods and compound events. The second one focuses on the analysis of the situations that have affected the area based on rainfall (1950-2015), wind (1997-2018) and coastal storm (1973-2013) data provided by the M-CostAdapt project. The compound events that have been taken into account are the combination of two or three of these hazards. In total, 116 compound events took place between 1997 and 2013, mainly in September and October. The most common type was composed by heavy rain and Tramuntana wind, with a maximum wind gust between 45 and 75 Km/h. One of the strongest storms that affected Catalonia in recent years, storm Gloria, has also been analyzed.

I. INTRODUCTION

The catalan territory enjoys a varied and complex orography, that causes a characteristic climate prone to storms, flash floods and strong winds [1]. In particular, the coastal regions of Girona, are frequently affected by Tramuntanades and Llevantades. If these hazards occur in synergy with other ones, the damages can be catastrophic. These situations are recently known as compound events, and they are objects of numerous studies such as [1] or the COST DAMOCLES project [2], whose objective is to understand, describe and project future scenarios of compound events.

The storm Gloria is a good example of numerous damages in coast line due to storm surge and floods. The Trabucador bar disappeared because of the rise of the sea level [3], and a sand bar appeared in front of the mouth of La Tordera [4]. Some experts and media consider this storm as a direct impact of climate change, describing it as exceptional. A few links are shown in bibliography ([5], [6], [7]).

In Catalonia, temperatures have increased by an average of 0.28ºC per decade, and are expected to increase by 1.4ºC between 2031 and 2050 [8]. Likewise, in the Mediterranean basin, this increase could be much greater during the summers, where some projections predict an increase of between 6 and 6.5ºC by the end of the century [9].

These increases have already been observed in sea temperature, which rose by 1.1ºC between 1970 and 2012, and also in sea level rise, which has been rising sharply since 2006 at a rate of 3.6 cm per decade in L'Estartit [10].

In this context, the objectives of the national M-CostAdapt project [13], in which this study is conducted, are the development of efficient strategies to adapt the territory to natural hazards and climate change [9].

This article shows a synthesis of the characteristics of strong wind situations affecting L'Empordà, focusing on compound events and the particular case of storm Gloria.

II. STUDY REGIONS

The north coast of Girona is characterized by strong winds and heavy precipitation events that occur favored by the proximity of the Pyrenees to the coast.

The region of interest of this work, Fig.(1), is described in [1] and is mostly formed by the Alt Empordà region.

FIG. 1: Region of study, N Girona. Source [1]

The climate of N Girona can be considered Mediterranean, with high summer temperatures and mild winters [10]. The two rivers that flow into this region, La Muga and El Fluvià are responsible for most of the floods caused by overflowing [12]. Tramuntana is the most characteristic wind and 650 mm can be collected annually, especially in autumn [13].

III. BIBLIOGRAPHIC SYNTHESIS

A. Wind storms characterization

The wind storms that can affect the study region are [14]:

- Mestral (NO): The Gulf of Lyon and the Balearic Islands are affected by strong storms surges offshore, but coastal effects are minimal.
- Tramuntana (N): Strong winds with few effects in the coastal area but with impacts in the open sea between the Balearic Islands and the Gulf of Lyon.
- Llevant (E): Strong storm surge with rising seas and huge waves. Large rain accumulations.
- Gregal (NE): They come from N or E windstorms, with moderate, dry and cold continental winds.
- Xaloc (S): Light winds with little disturbance to the sea state.

The Tramuntana, a strong, cold and dry wind, with its maximum in the Gulf of Lyon is the most frequent wind storm. There are 5 synoptic patterns that produce it [15]:

- Conf. A: High pressure over the Atlantic Ocean and low pressure over the Tyrrhenian Sea.
- Conf. B: Strong anticyclone over Russia and the Atlantic Ocean with low pressures over Iceland, the British Islands and the Mediterranean Sea.

* Electronic address: `lpauguit7@alumnes.ub.edu`

- Conf. C: Low pressure over northern Europe with a secondary low in the Gulf of Genoa. High pressure at west Portugal.
- Conf. D: Rhombohedral anticyclone in central Europe, surrounded by four lows.
- Conf. E: High pressure over Scandinavia and the Mediterranean Sea.

Tramuntana is formed by the pressure gradient generated at the synoptic scale. It also suffers mesoscale effects due to the orographic dipole and the Foehn effect, which turn the Pyrenees into its accelerator. ([15],[16]). From the PYREX experiment, a shear line was discovered between the Catalan coast and the Balearic Islands [15].

The most damaging windstorm are the Llevantades. They are difficult to detect but there are two synoptic patterns [17]:

- High pressures over central Europe with the Iberian Peninsula at the lower end.
- Low pressures over the British Islands with a secondary low over the Mediterranean Sea.

No trend has been discovered regarding windstorms but, it has been seen that cyclones, a fundamental part for their development, have decreased their frequency, especially in winter and spring [8].

B. Flood characterization

Storm surges, river overflows or heavy rains can cause flash floods resulting in severe damage. According to the intensity of these, we can classify them as follows [18]:

- Catastrophic: Severe damage, with partial or total destruction of infrastructures. Severe losses in agriculture.
- Extraordinary: Partial destruction of hydraulic infrastructures and buildings near the river.
- Ordinary: Floods in restricted areas with minor damage to hydraulic infrastructures.

The usual synoptic pattern for these situations is a strong anticyclone over the Mediterranean and/or central Europe that favors the formation of a moist and warm air mass at low levels. In the 80% of the cases, there are near surface low pressures that help to reorganize the incident flow, which together with convergence lines and mountain barriers, can trigger latent instability [19].

The most common origin of these episodes is the Mediterranean, but if the rainfall is extreme and extensive, as in November 1982, most of the moisture comes from the Atlantic Ocean [20]. The frequency of floods has increased by an average of one episode per decade, especially between August and October [18]. On the coast, this may be due to an increase in short-duration torrential events [21].

C. Compound events

We can define compound events as the combination of multiple hazards or meteorological drivers that contribute to a social and environmental risk ([2], [22]). They can be classified into two groups [1]:

- Multivariate compound events: Climate drivers or hazards occur at the same time and place.
- Spatially compounding events: Climate hazards or drivers occur successively over a period of maximum 3 days in different areas.

The hazards that affect the most the coastal zone and on which this work is based are heavy rainfalls, storm surges and windstorms. The most common synoptic situations that generate them are [1]:

- Type 1: (42.1%) Low pressure to the northwest, over the Atlantic, with high pressure in central Mediterranean. It may cause the appearance of a mesoscale orographic dipole.
- Type 2: (18.6%) Low pressure in the southeast of the peninsula with an anticyclone to the northwest.
- Type 3: (39.3%) Deep low in the peninsular south with an anticyclone in central Europe.

Configuration number 3 coincides with the synoptic pattern for Llevantades and is the one that generates more instability [1]. The areas with the highest probability of being affected by compound events in respect to the frequency of individual hazards, should be taken into account. These are the so-called hotspots and Europe is one of them due to the increase of strong winds [23]. Climate change has affected these processes making their prediction more difficult, since not only has the probability of occurrence changed, but also the relationship between two or more hazards, generating new conditions for which we are not prepared [22].

IV. DATA AND METHODOLOGY

A. DATA

The development of this work has been based on the article [1] from which the N Girona zone described above is selected. The rainfall data series studied covers the period (1950-2015), for wind (1997-2018), and (1997-2013) for coastal storms. The storm data and daily significant wave height (Hs) from the buoy located in the Gulf of Roses have been provided by the UPC team of the M-CostAadapt project. In addition, rainfall and wind data from the weather stations of the AEMET (Agencia Estatal de Meteorologia) network in the study area and the press information, as well as the damages, have been provided by the UB team of the same project. In total we have worked with 16 rainfall stations and 7 wind stations.

B. Methodology

In order to determine the compound events that took place in N Girona for the period 1997-2013, we must first select those days where the limit of 40 mm in 24 hours is exceeded. This limit has been chosen because of [24] and is the minimum above which flash floods can be recorded in the Catalan coast. We must also select the maximum wind gust and classify it according to the wind thresholds, chosen from the criteria of the M-CostAdapt project. These are ≤ 45 Km/h, 45-75 Km/h, 75-95 Km/h, 95-135 Km/h and > 135 Km/h. Finally, we also have to make a selection of the days with coastal storm. The significant wave height (Hs) must be greater than 2 m and a class III storm must occur [1] (Hs less than 4.4 m, approximate wave period of 11.6 s and duration of 77h) [25].

For this work, only the maximum daily record has been selected and the compound events have been determined from the coincidence of two or three hazards in a maximum period of 3 days, taking into account the following combinations of hazards: rain - wind, wind - surge, rain - surge and rain - wind - surge. We have also analyzed the storm Gloria.

V. RESULTS

A. Rainy days selection

The established threshold of 40 mm in 24h was exceeded in the N Girona area 655 times between 1950 and 2015. Fig.(2) does not show any annual trend of increase or decrease, but it shows an average of 10 episodes per year.

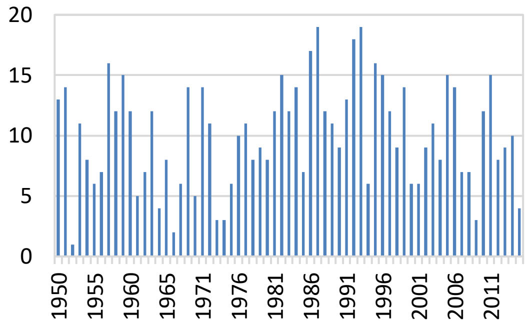

FIG. 2: Number of days with precipitation greater than 40 mm.

In Fig.(3) we can observe that October, with 19.08% of the episodes, is the rainiest month and July the driest, with only 1.52% of the episodes.

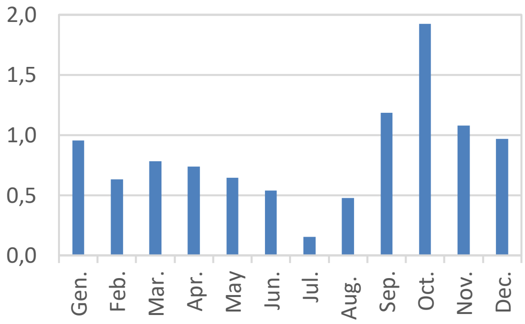

FIG. 3: Days per month with precipitation greater than 40 mm.

B. Wind days selection

From Fig.(4), which studies the period from 1997 to 2018, it is observed that the most common record is the lowest, ≤45 km/h, representing 65.4% of the cases studied. It is also observed that February is the month in which the highest gusts are most likely to be recorded.

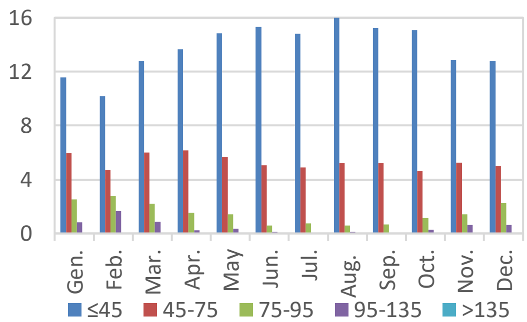

FIG. 4: Average number of cases per month according to the threshold exceed.

In Fig.(5) we can observe that the Tramuntana (N) is the dominant wind except for the first threshold, where Xaloc (S) is the prevailing wind.

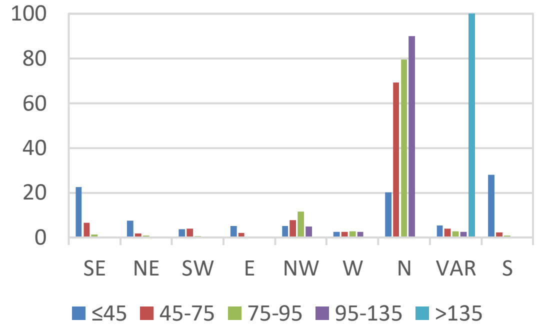

FIG. 5: Percentage cases by wind direction and thresholds.

C. Rain and wind compound events

From 1997 to 2013, 74 wind and rain compound events were detected. They usually occur between September and October. In Fig.(6), the most frequent compound event is the one formed by a maximum gust of Tramuntana between 45 and 75 km/h.

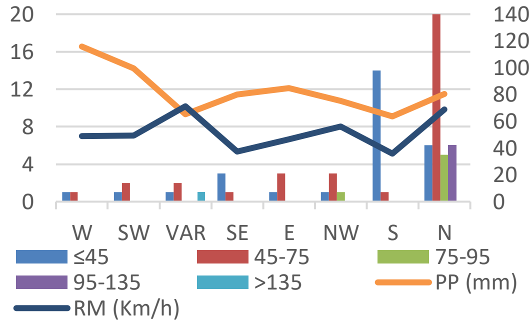

FIG. 6: Number of compound events according to wind direction (left ordinate axis). Average precipitation and wind by type of compound event (right ordinate axis).

D. Coastal storm compound events

Compound events involving only rain and waves are a minority, with only 5 cases detected, one in 1998 and two in 1999 and 2003 with an average Hs of 3.42 m. The 47.62% of those that involve waves are formed by wind and surge. Their Hs average is 2.95 m. Finally, those involving all three hazards simultaneously represent 40.48% of the cases and their distribution throughout the year is more homogeneous than in the previous cases. Their average Hs is 4.06 m.

E. Most common compound events

In Fig.(7), the most common compound event is composed of wind and rain hazards, representing the 63.79% of the events and with an annual average frequency of 4 episodes.

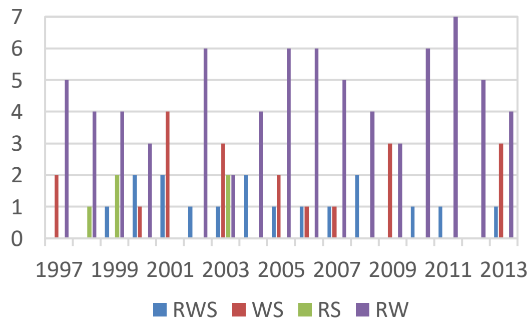

FIG. 7: Number of events consisting of rain, wind and surge (RWS), wind and surge (WS), rain and surge (RS) and rain and wind (RW).

Another fact to consider is the effect of compound events. Fig.(8) shows a comparison of cases with flood effects, wind damage, synergy effects and non-occurrence of effects. Out of a total of 116 events studied, 54 have affected the region and 62 have not, which does not allow us to establish a clear trend, although if there are any effects, it is due to flooding in one out of every two cases.

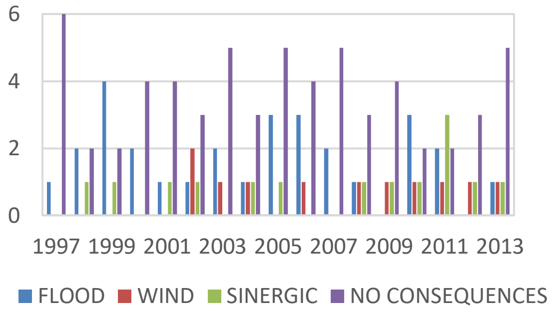

FIG. 8: Number of compound events according to the produced effects.

F. Storm Gloria

Storm Gloria has been described as exceptional by many experts. Synoptically, its formation occurred between January 17th and 18th of 2020 when the vortex located near the island of Newfoundland moved towards the peninsular north where a surface low was forming [26]. This low, moved in a southeasterly direction, until it became storm Gloria (Fig. (9)) with the center in Ibiza on January 19th [26].

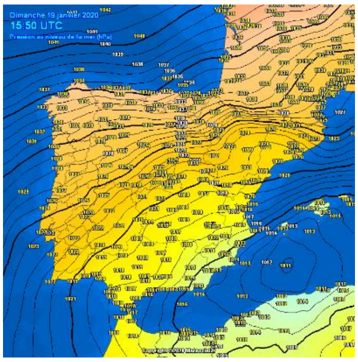

FIG. 9: Sea level pressure on January 19th 2020 at 15.50 UTC. Map extracted from Meteociel.fr.

The intensity of this storm was not due to its pressure, of 1011hPa, but to the presence of a strong anticyclone of 1050 hPa which was attached to the south of the British Islands and caused a strong pressure gradient. [26].

The following day, on January 20th, storm Gloria was absorbed by a deeper low over the Alboran Sea [26] and the effects of the storm lasted until its disappearance on January 24th [3].

The records of this storm were very high, with wind gusts reaching 144.4 km/h in Puig Sesolles, accumulations in Lliurona, a town located in N Girona, up to 516 mm [27] and a strong coastal storm with waves that reached 7.9 m on average on Costa Brava [3]. In N Girona, the maximum wind gust reached 96.8 km/h in Portbou [27] and waves reached 7 m at the buoy of Roses.

We can define storm Gloria as a multivariate compound event, with the presence of the three hazards studied, rain, wind and waves, located at the fourth threshold, between 95 and 135 km/h in the N Girona region. The floods can be considered catastrophic and the synoptic configuration was type 3.

VI. CONCLUSIONS

- The most common gusts in the area of N Girona, are those form Xaloc (S), Garbí (SE) and Tramuntana (N) with maximums below 45 Km/h. They usually occur at any time of the year but there is a small increase in the hottest months.
- Tramuntana is the mainly direction for all others thresholds, and for the highest ones, starting from 75-95 km/h, February is the month with the highest probability of occurrence, while in the warmest months this probability is practically inexistent.
- The most common compound event in the area of N Girona is the one composed by wind and rain hazards. The maximum gust is usually from the north (Tramuntana), and can be located in the threshold between 45 and 75 Km/h. From the data studied in this work, the average maximum gust is 69.05 Km/h combined with 80.33 mm of precipitation in 24 h. They usually occur in autumn, between September and October.

The N Girona region is often affected by compound events, which have a greater impact than if the hazards occurred separately. It is not certain that Gloria was due to climate change, but it is a paradigmatic example of how these compound situations may increase in the future due to global warming or even occur at unusual times of the year.

Acknowledgments

First of all, I would like to thank my tutor, Maria del Carmen Llasat, for her advice, encouragement and dedication during the completion of this work. I would also like to thank Tomeu Rigo, Marc Sanuy and José Antonio Jiménez for providing me with the data and their explanations and also Inés Montoya, for her table of territorial effects. Finally, I would like to thank my family and partner for always believing in me and encouraging me always. This work has been done in the framework of the M-CostAdapt (CTM2017-83655-C2-1&2-R) research project, funded by the Spanish Ministry of Economy and Competitiveness (MINECO/AEI/FEDER, UE).

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