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GAMA Meteorological Hazards Analysis

Compound hydrometeorological risks on the Spanish Mediterranean coast in face of climate, environmental and social change

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OUTLINE

- ✓ **Why** we are interested in analizing compound events in the Mediterranean Region?. Introduction
- ✓ **Where and when**?. Region of study, data and criteria
- ✓ **Which are their characteristics**?. Spatial and temporal distribution of compound flood events
- ✓ Learning from one case: the Gloria event
- ✓ **Conclusions**, future work and messages to take home

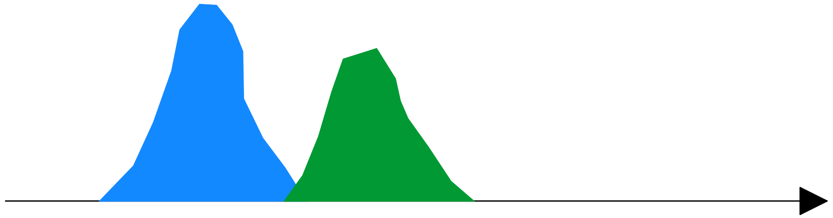
The Mediterranean coastline as a hotspot

- More than **50% of its population is concentrated in the coastal zone,** increasing the risk to human life due to flooding (Vinet et al., 2019) + the **frequency of flash floods** in the region is the highest in Europe (Gaume et al., 2016) + **impacts related to climate and environmental changes are more severe** relative to the global average, with temperatures already reaching 1.5ºC relative to pre-industrial times (Cramer et al., 2018).
- This combination implies an **increase in coastal-storm-induced damage over the last decades** (Jiménez et al., 2012; Garnier et al., 2018).
- **Flash floods induce higher risks in comparison with marine related flooding**, even though they are acting on a smaller spatial scale along the coastline (Ballesteros et al., 2018)
- Although **risk assessments in coastal zones usually consider the impact of sea hazards and climate drivers individually,** they should instead be considered as the result of compounding events
- Mediterranean coasts are the European areas **with the highest probability of compound flooding** under present conditions (Bevacqua et al., 2019).

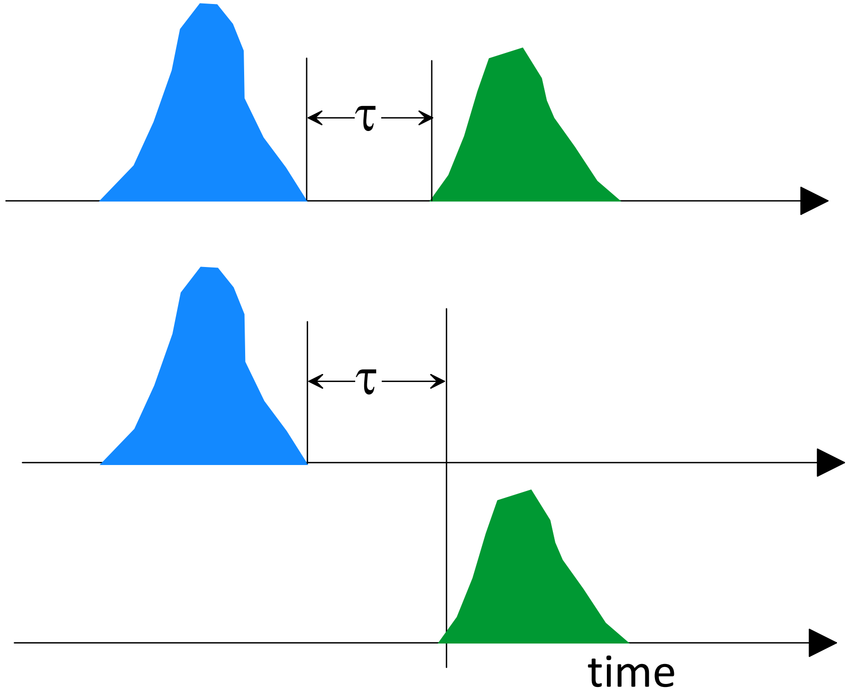
INTRODUCTION. Compound events

Classification of compound events (Zscheischler et al., 2020):

Multivariate compounding events: co-occurrence of hazards from multiple climate drivers in the same geographical region



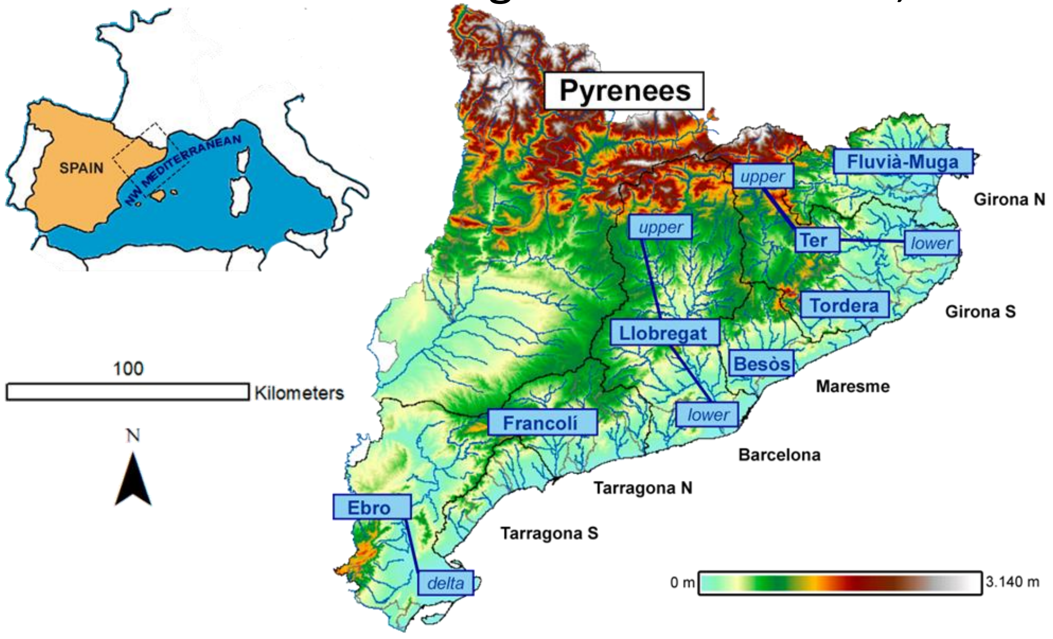
Spatially compounding events: co-occurring hazards from different climate drivers at distant locations within a limited time window.

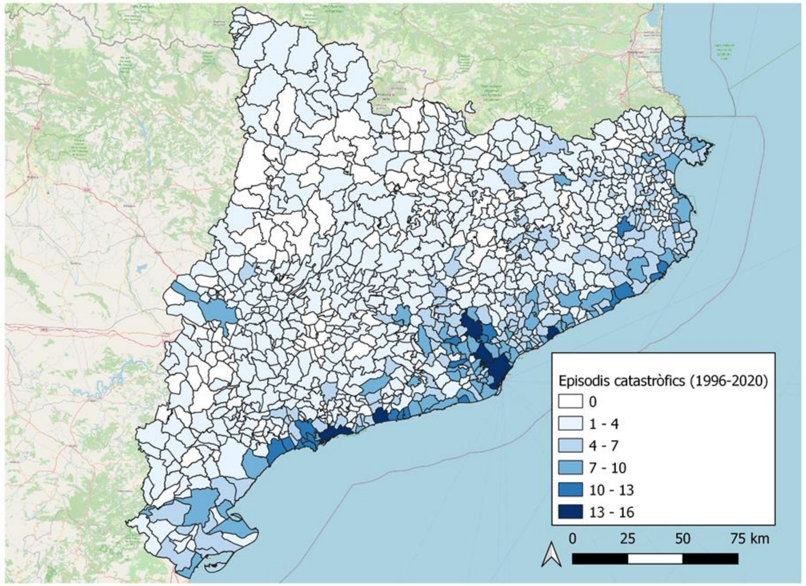


The Catalan coast

It is prone to the development of flash floods and thunderstorms: existence of many small torrential catchments + heavy rains favored by the orographic forcing of Mediterranean air masses with potential instability (Llasat et al. 2016).

600 km of coast (280 km, sedimentary). Great shoreline erosion: decrease in river sediment supplies + current level of urbanization and infrastructure development + natural littoral dynamics (Jiménez and Valdemoro, 2019). Coastal storms: **dominant NE–E extreme waves and , secondary, S–SE** (Mendoza and Jiménez, 2009). Astronomical tidal range of about 0.25 m, meteorological one can arrive until 0,5 m.



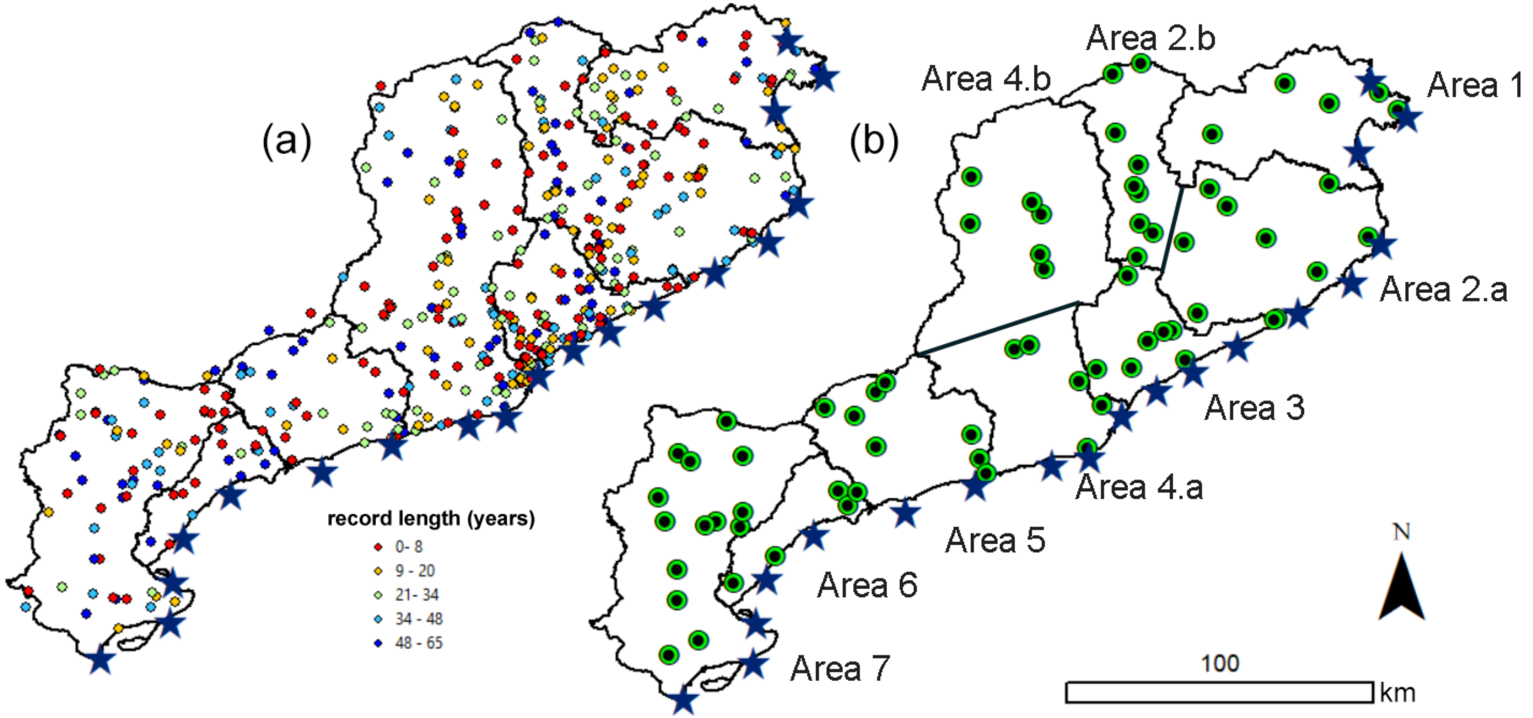


1996-2020: 211 flood events, 62 deaths

Objective

To analyze the occurrence of compound flooding events (multivariate and spatially compound) along the Catalan coast (representative of the NW Mediterranean), their spatial and time distribution and their main features in order to improve the risk management

- Analysis of the occurrence of compound extreme events of **heavy rainfall episodes (as a proxy for flash floods) and coastal storms (using the maximum significant wave height)** along a coastline extension of about 600 km by considering **seven coastal sectors** and their corresponding river catchment basins.
- Spatially and multivariate compounding events are defined by the co-occurrence of heavy rainfall and coastal storms within a **time window less or equal to 3 days.**
- Quantify the **occurrence frequency** of **both types of compound events.** Each compound event is characterized in terms of a **representative Hs** (max. wave height reached during the event) and **P24h** per coastal basin.
- Selected events. POT method: **P24h>40 mm** (Cortès et al, 2019), **P24h>100 m** (Gilabert and Llasat, 2018); **Hs>98th** (storm start-end times, aprox. 2 m), **Hs> 99.5th** (class III storms) (Sanuy et al., 2019).
- Analyze the **spatial variability** of the different types of compound hazards **and the dependence between rainfall and wave height**. Correlation between the magnitude of both components by Spearman coefficient. Identification of **associated weather types**
- Analysis of the **temporal evolution**
- Selection of **remarkable events** (Boudou et al., 2016) considering the significance of their associated impacts in qualitative terms by analyzing after-event press coverage and/or insurance data (Llasat et al., 2009) and emergency management (in progress)



Location of existing rain gauges, AWSs (coloured dots), and wave nodes (stars) in the different drainage basins along the Catalan coast (a). Selected AWSs per drainage basin (areas) along the coast (b).

Daily rainfall, AEMET: 491 AWSs in Catalonia, 1950–2015. Selection criteria: AWSs belonging to catchments in coastal regions with a homogeneous coverage of the 41-year period **1973-2013. 69 stations**

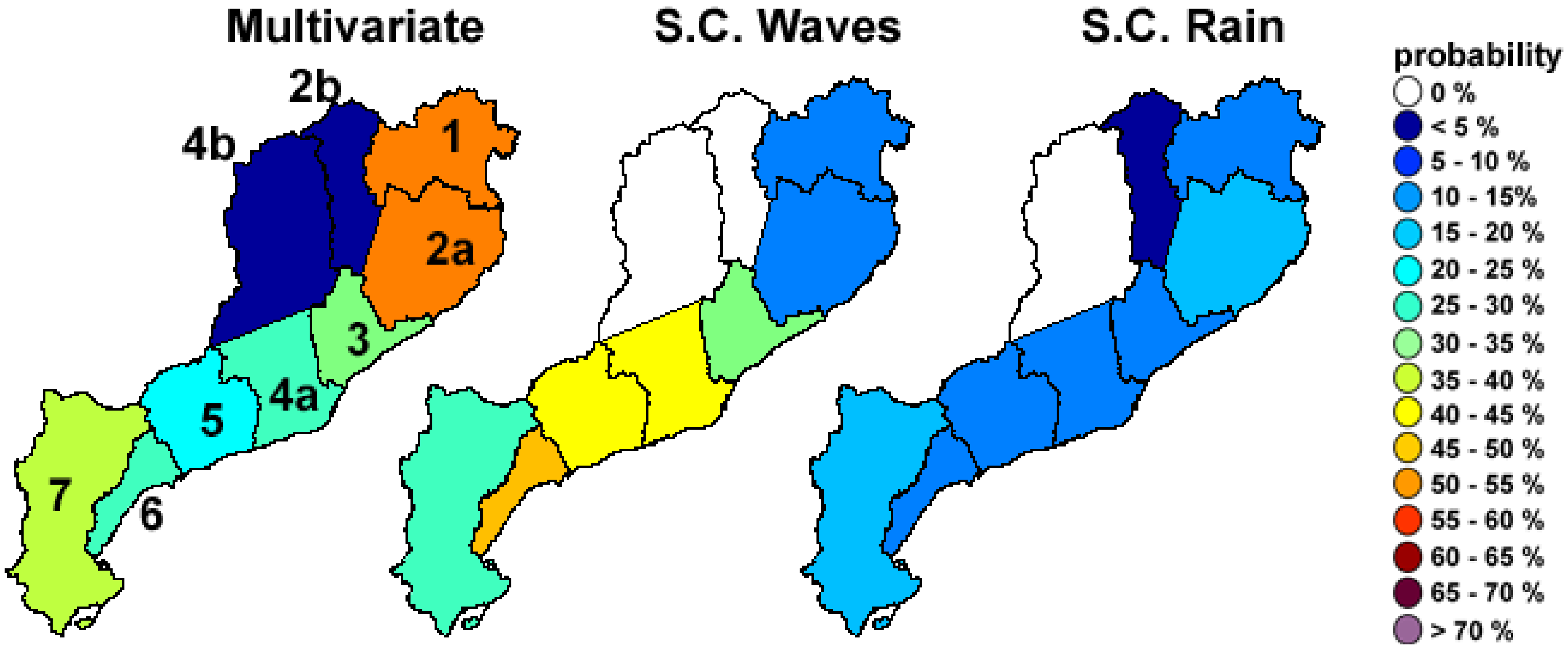
Flood impacts: **INUNGAMA** database 1981-2020.

Wave data: hourly data from the hindcast **Downscaled Ocean Waves (DOW) dataset,** retrieved for **19 nodes** wave height (Hs), wave period, and mean wave direction (1973–2013). Wave records during the Gloria storm (1/2020) from the SIMAR database from Puertos del Estado

Sanuy et al., 2021. Hydrol. Earth Syst. Sci., 25, 3759–3781

1973–2013 period: **225 coastal storms** (CS), **605 heavy rainfall episodes** (HR), 140 compound events (CE). 62% CS and 23% HR are compound events, average frequency of 3.4 CE/year.

The most frequent type: spatially compound, except N sectors where multivariate events dominate and have the highest correlation in the intensity of both hazards.

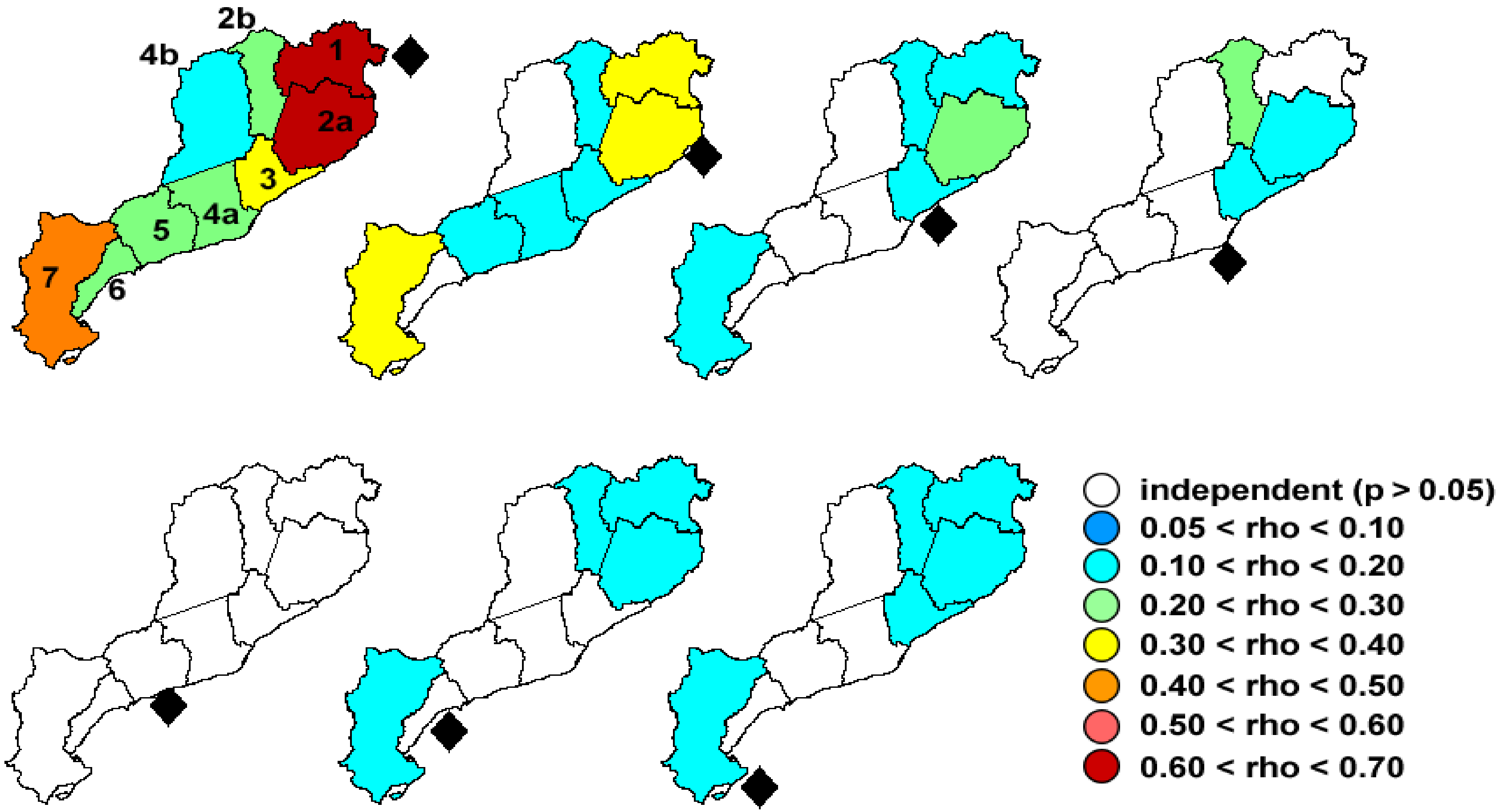


Probability of occurrence of the different types of compound events along the Catalan coast. Multivariate (local simultaneous rainfall and wave storm episodes) SC-waves (local wave storm episodes and simultaneous rainfall in a different area); SC-rain (local rainfall episode and simultaneous wave storm in a different area). Probabilities are given with respect to the presence of a compound event (average occurrence during the period 1973–2013 of about 3.4 events/yr).

Sanuy et al., 2021. Hydrol. Earth Syst. Sci., 25, 3759–3781

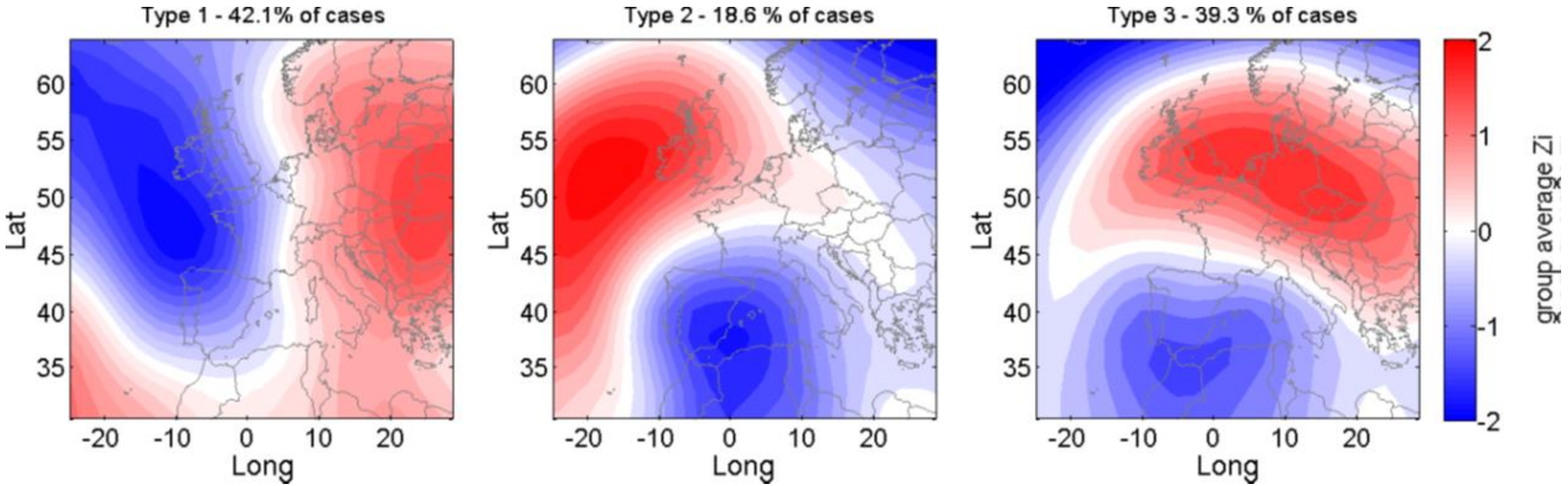
The correlation between the intensity of local wave storms and rainfall across the territory decreases from N to S. The **highest correlation value was obtained for multivariate events in the northernmost area.**
To the south, the correlation between Hs and P24 consistently decreases to very low values.
The **central basins have the lowest correlation** suggesting an independence of storm waves and intense rainfall events.

This correlation is due to the associated weather types



Correlation values (Spearman) between the Hs magnitude and P24h during compound events. Each map shows the correlation between the waves (Hs) in the area indicated by the diamond and rainfall in the other areas. White areas indicate that variables are statistically independent at a significance level of 0.05. Area numbers are specified on the top left map.

Sanuy et al., 2021. Hydrol. Earth Syst. Sci., 25, 3759–3781



Type 1. CE dominated more by HR, especially along the central part of the coast.
Types 2, 3 dominated by CS, especially in the N, where they might also be accompanied by HR.
Type 2 events (Mediterranean cyclones) occur half as frequently as types 1 and 3; mainly associated with the occurrence of H_s>5.5 m at the N and S.
Type 3 events can be as severe as type 2 events in terms of waves, with higher probabilities of compounding simultaneous extreme rainfall.

Sanuy et al., 2021. Hydrol. Earth Syst. Sci., 25, 3759–3781

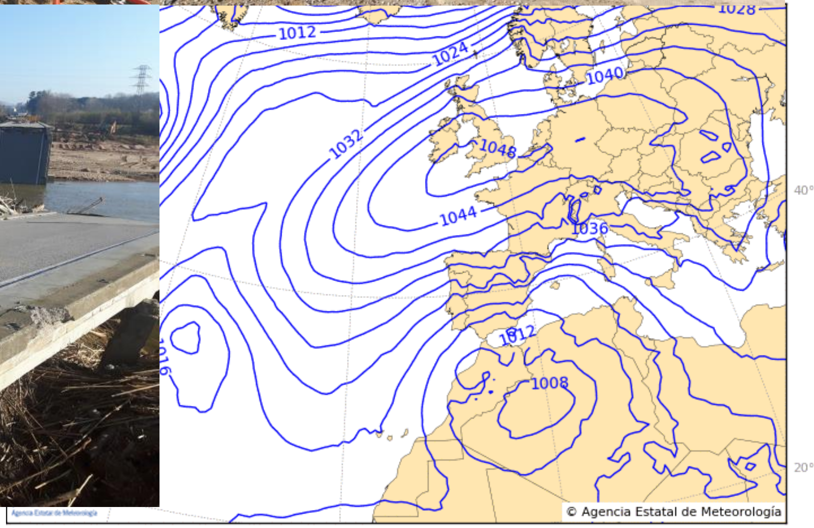
THE GLORIA STORM. 20-23 January 2020

Type 3. From a small superficial depression in the North Atlantic Ocean to a strong dipole Azores anticyclone- Gloria storm. Strong pressure gradient, entry of maritime air over the Catalan coast, high potential instability.

Maximum values of wave heights, moderate storm surge (0.5m), significant erosion at the beaches, with massive overtopping and flooding of low-lying areas, very intense rainfall and thunderstorms, catastrophic flash floods, floods, snowstorms.

Activation of three emergency plans**: INUNCAT, NEUCAT, VENTCAT** (>144 km/h)

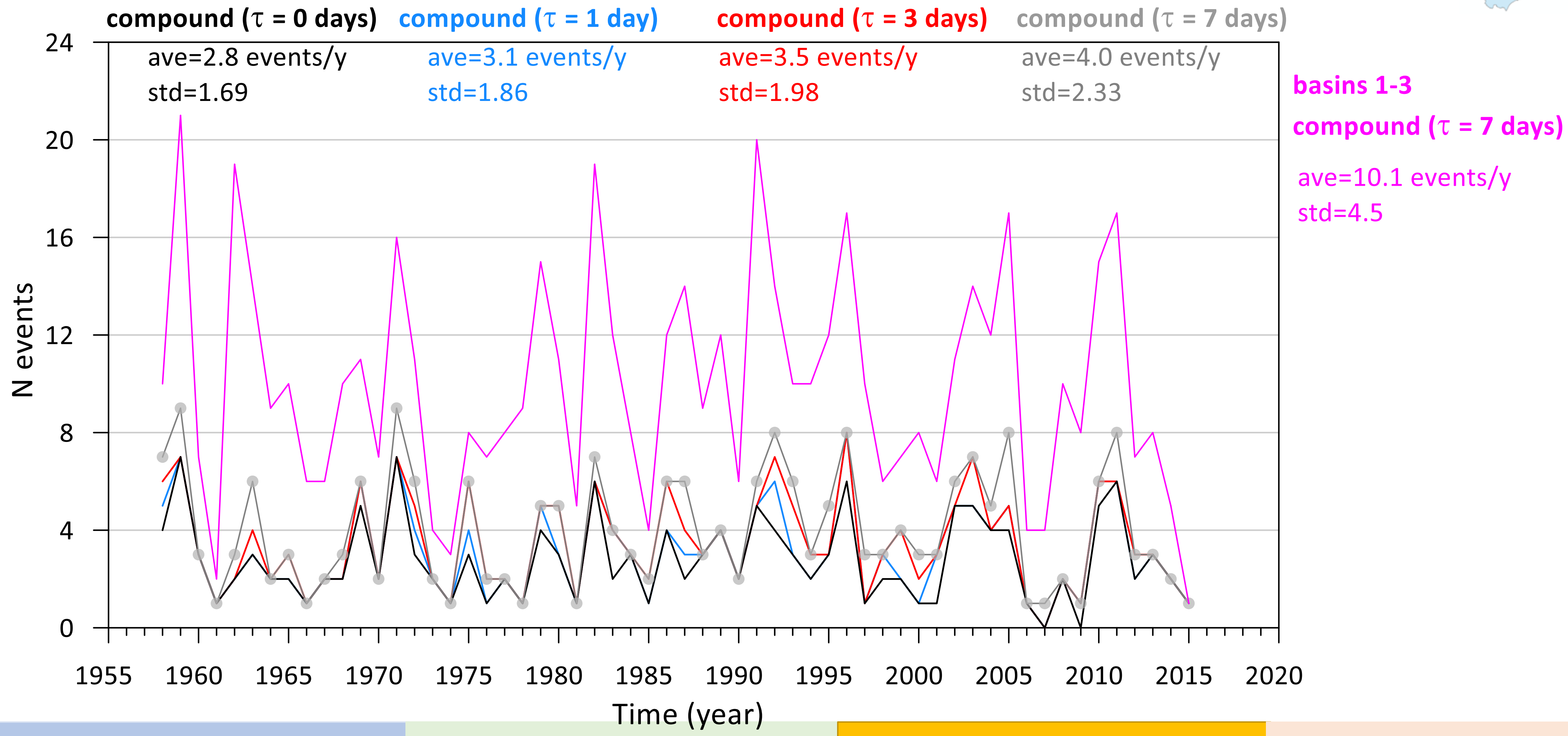
Severe structural damages, cut-offs and damage to roads and railways. **4 casualties** (10 more in the Balearic Islands and Valencia). Payments by CCS: >**EUR51 million**. Inversions to rebuild port infrastructures: >**EUR 17.4** million. Reparation pf damages in the public coastal domain **>6 million**. Damage due to floods in the river margins and flood plain: > **EUR42 million**



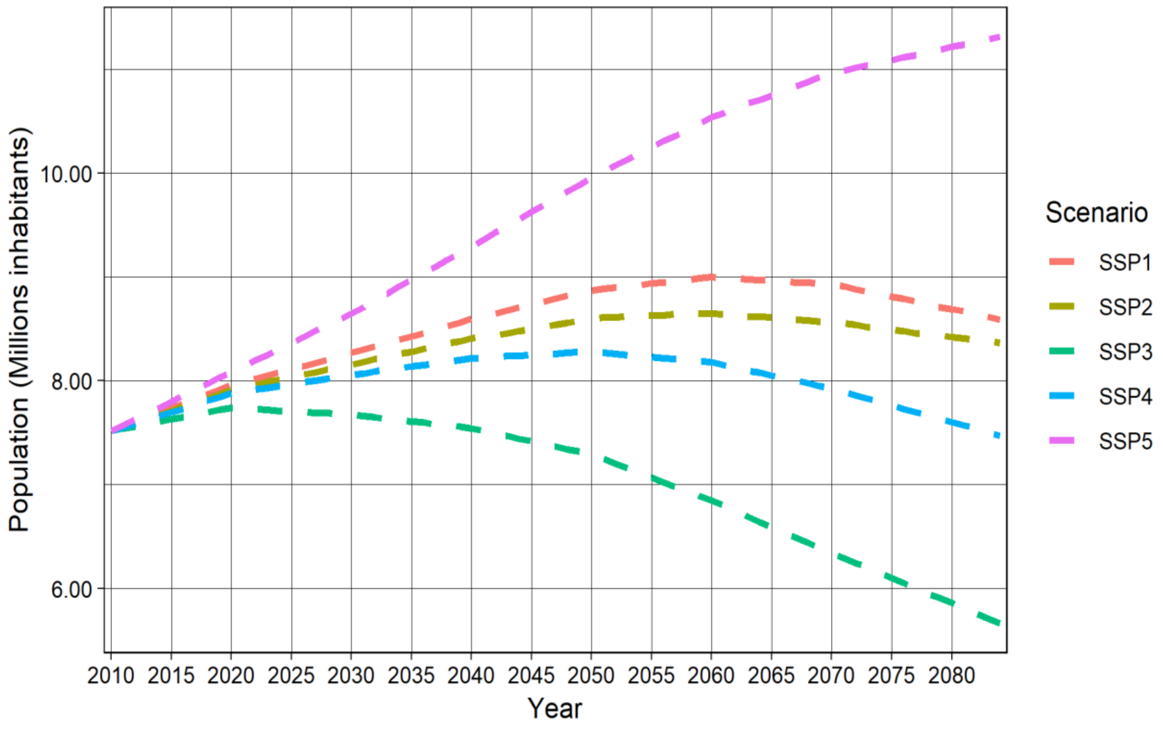
20-23rd: 14,443 calls to 112 and 8,400 fire brigade assistance. 24: 15,034 calls to 112, 2649 from Barcelona.

Sanuy et al., 2021. Hydrol. Earth Syst. Sci., 25, 3759–3781

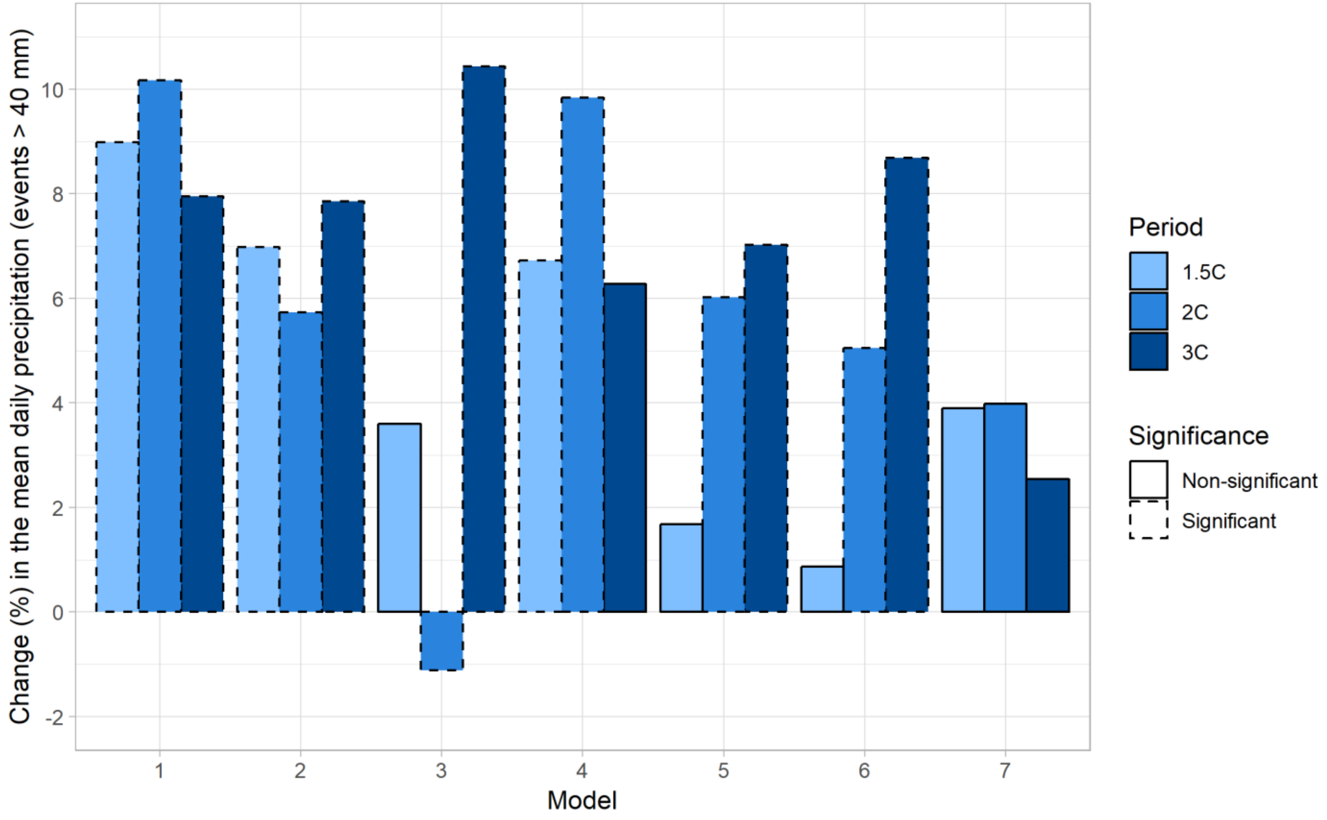
No significant trend for all the region has been identified for the period 1973-2013 (41 years), neither for the period 1955-2015 in the Northern part



HR: Future scenarios

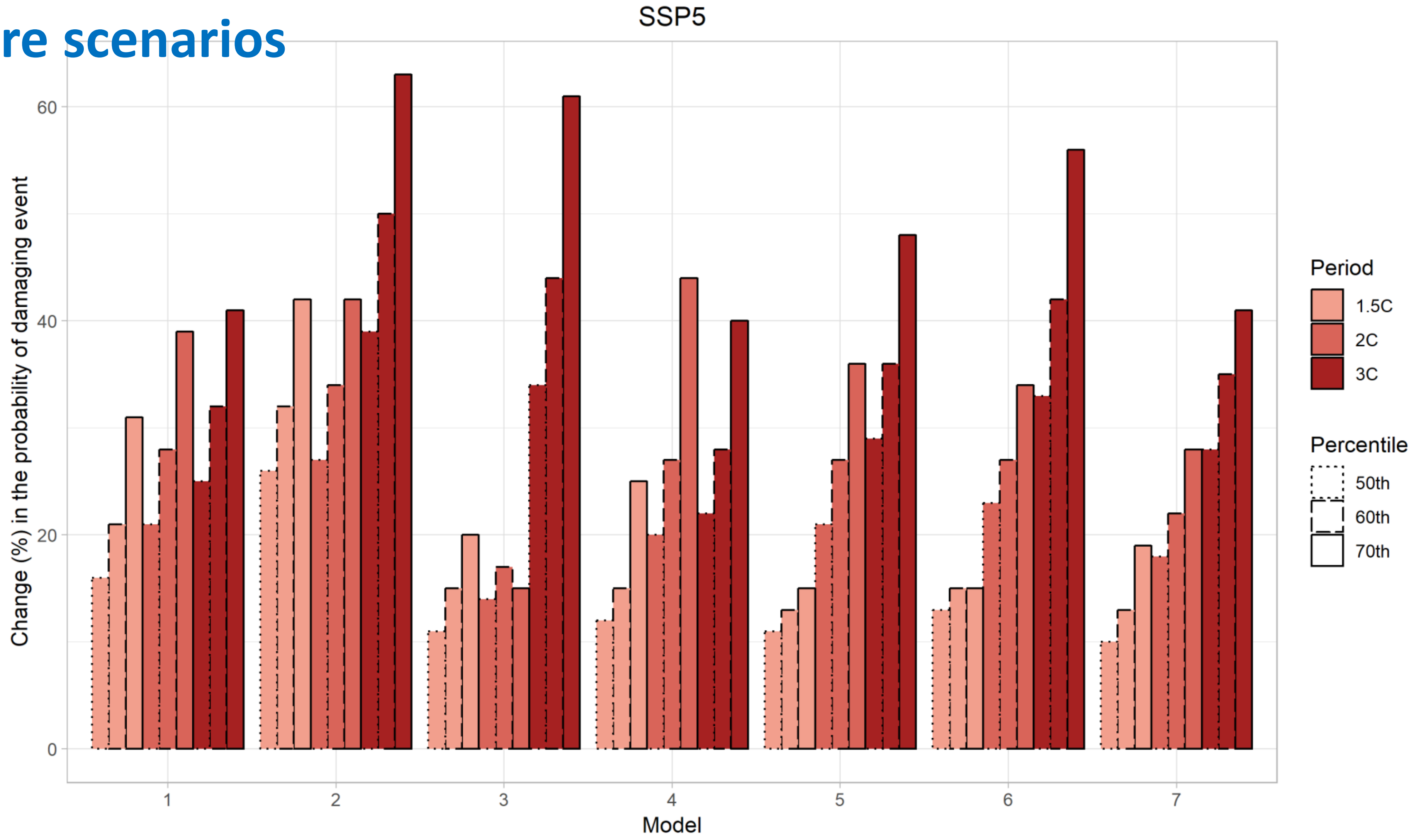


Future population projections for the different SSPs in Catalonia (Cortès et al., 2019)



Change in mean daily precipitation for events>40 mm/day in Catalonia (Cortès., 2020)

HR: Future scenarios



The probability of a damaging event (50th,60th,70th) in Catalonia increases with respect to the reference period (1976-2005) for all the climate models and warming periods when considering the SSP5. The increase is higher when greater warming is considered. The increase in probability is greater for higher percentiles of damage.

CONCLUSIONS. What we have learned?

The NW Mediterranean has a **high probability of experiencing compound extreme events.**

In the study area, when a regional compound event occurs, **wave storms are the "spatially dominant" driver**

The most frequent type being **spatially compound**, except in the northernmost sectors where multivariate events dominate. These **northern sectors also present the highest correlation in the intensity of both hazards.**

From **a risk management perspective**, the relevance of compound events lies in the fact that they can **significantly increase the intensity and/or the spatial and temporal extension of the impact (and damage)** due to the synergic and/or cumulative action of different hazards.

Future scenarios points to an increase of damaging events due to heavy rainfalls, that will affect compound events.

This compounding effect **may overwhelm the capability of emergency-response services ->** they **have to respond to a large number of emergency situations throughout the region at the same time,** and/or they **have to maintain the level of response during a relatively long period**.

It is mandatory for a proper risk management of the Spanish Mediterranean coast to asses **how the risk profile associated with the impact of compound events will change in both magnitude, and spatial distribution.**

From this perspective, it would be important **to incorporate the emergency/recovery services responsiveness** to identify these events, as well as to evaluate their probability of occurrence.

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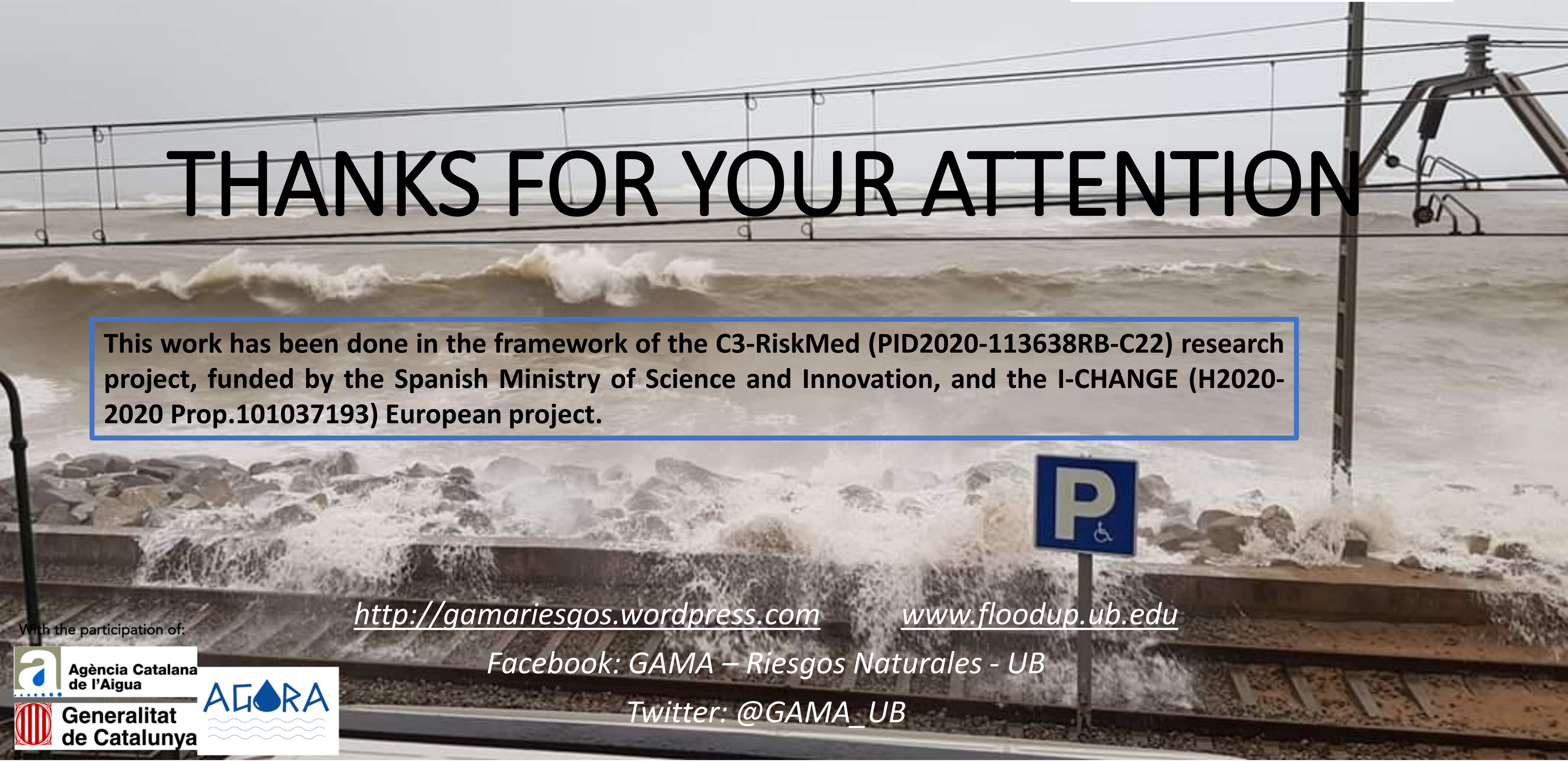

THANKS FOR YOUR ATTENTION

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