Assess the heavy rainfall through the integration of remote sensing and in situ measurements

Blanca Arellano (blanca.arellano@upc.edu); Josep Roca;
Qianhui Zheng; Dolors Martínez; & Carina Serra
Universitat Politècnica de Catalunya

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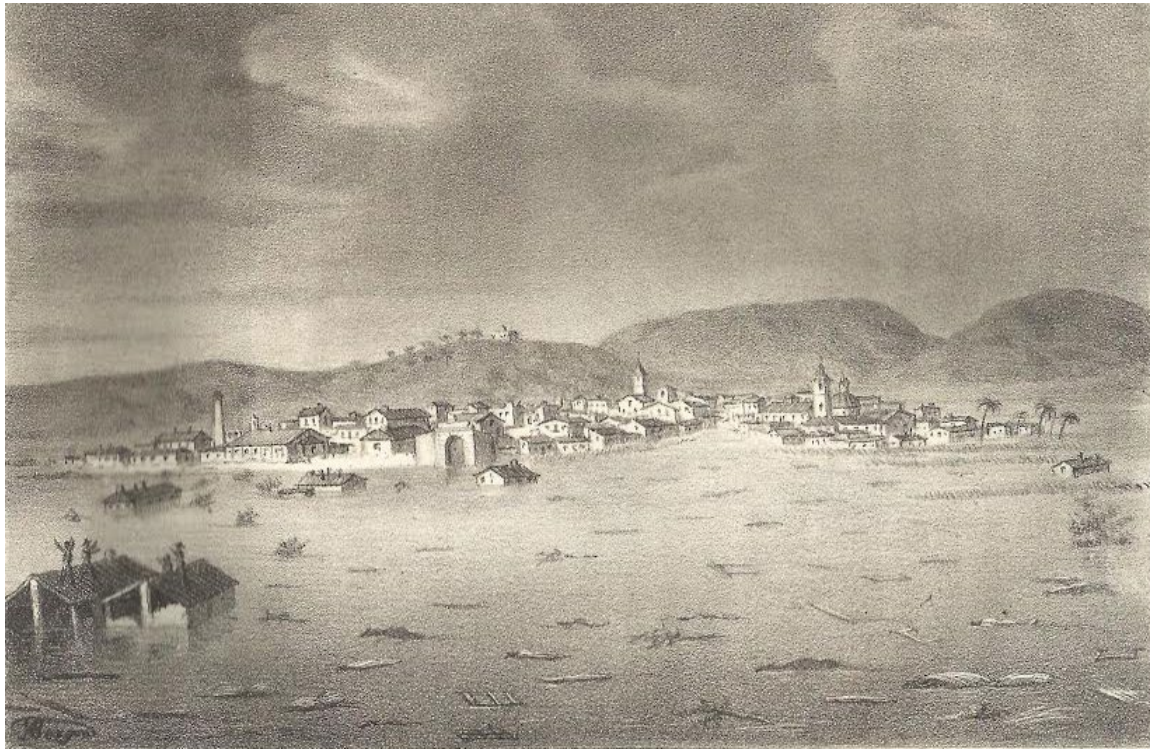
Introduction

- The province of Valencia has suffered torrential rainfall events for as long as recorded memory exists

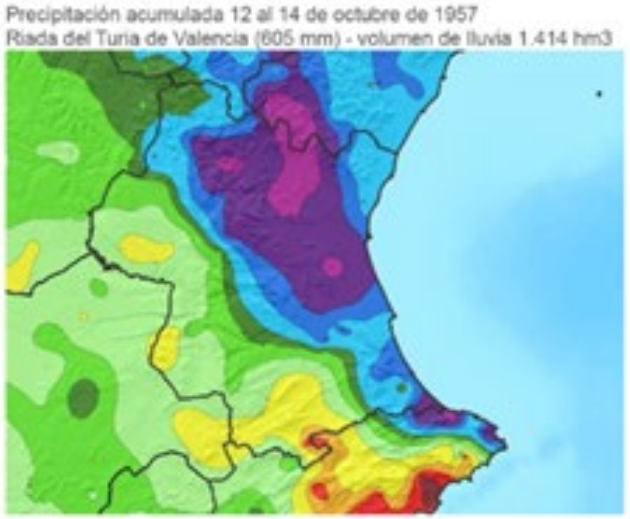
- The extreme rainfall that occurred in Alcira in 1864 is a memory that still remains today. **Valencia is a land where "rain doesn't know how to rain"** (Raimon, Valencian singer, 1984)

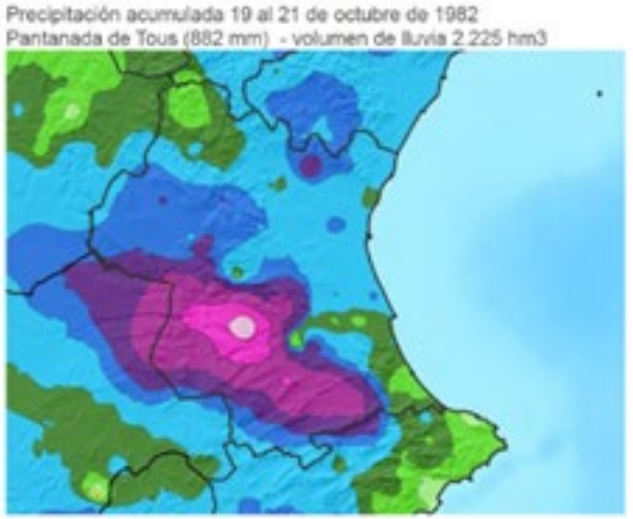


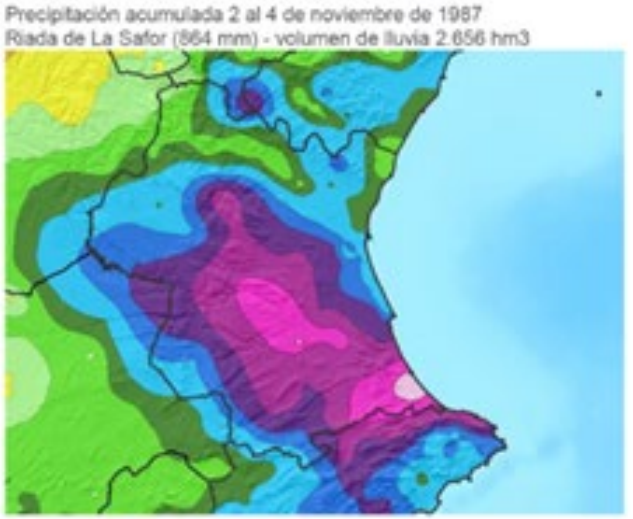
Alcira, 1864

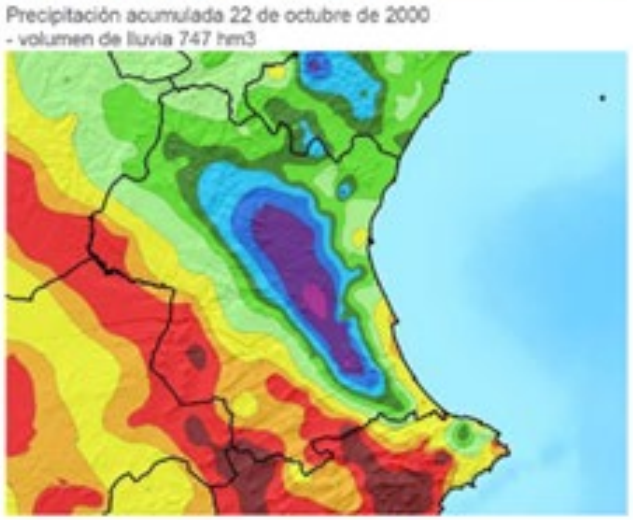
Introduction

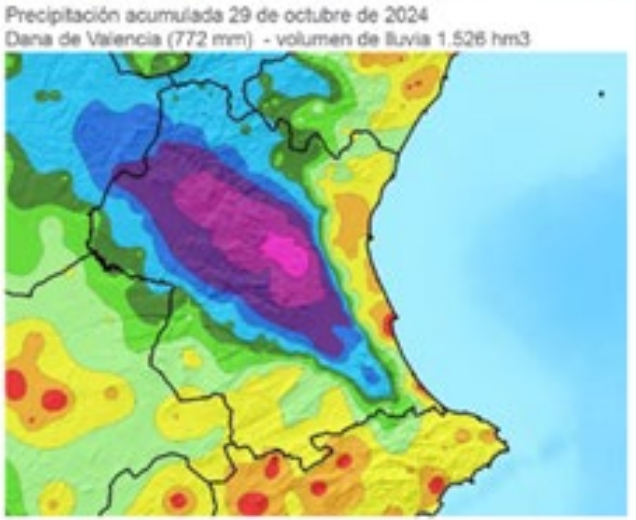
- Since 1850, extreme events have occurred in 1957 (1,414 hm^3), 1982 (2,225 hm^3), 1987 (2,656 hm^3) 2000 (2,196 hm^3) and 2024 (the 1,526 hm^3)





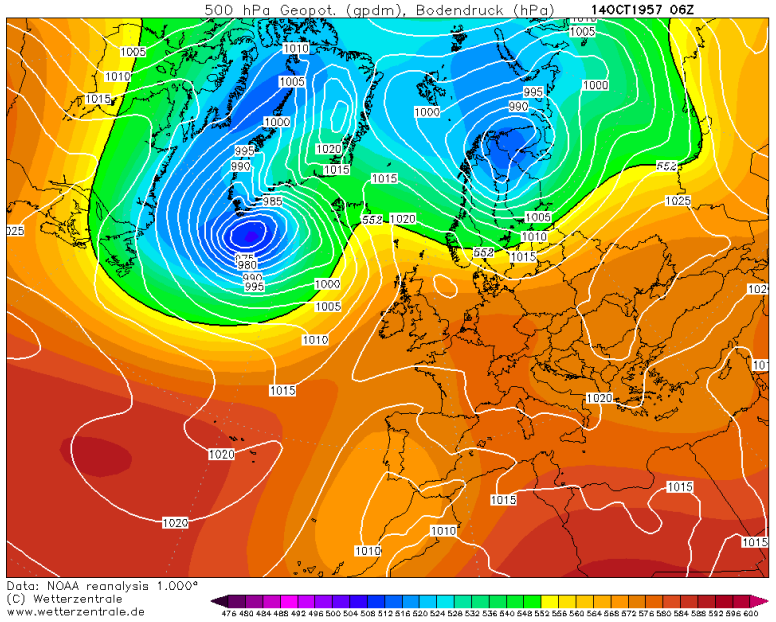


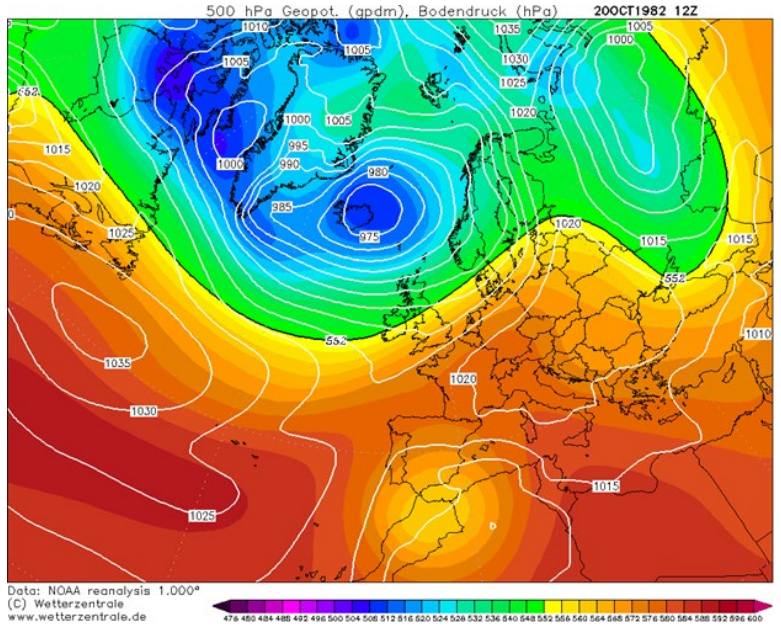


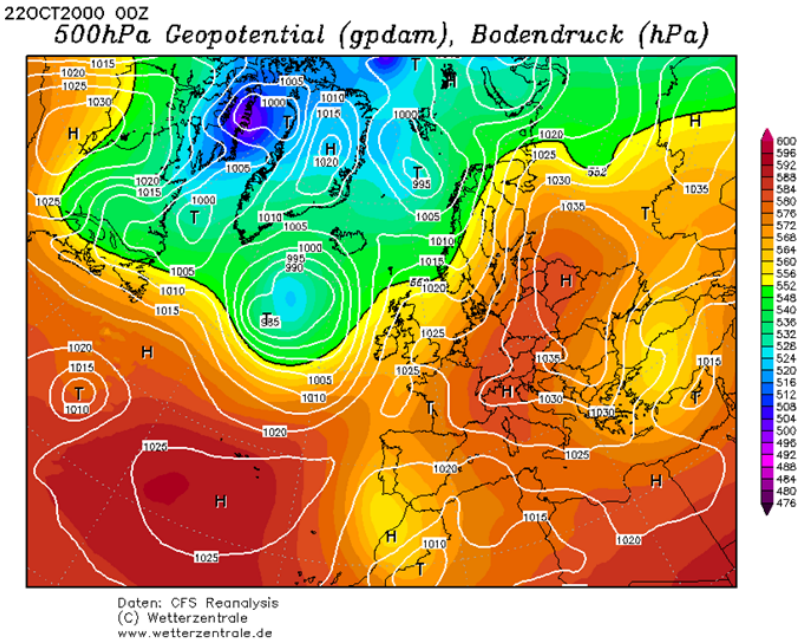


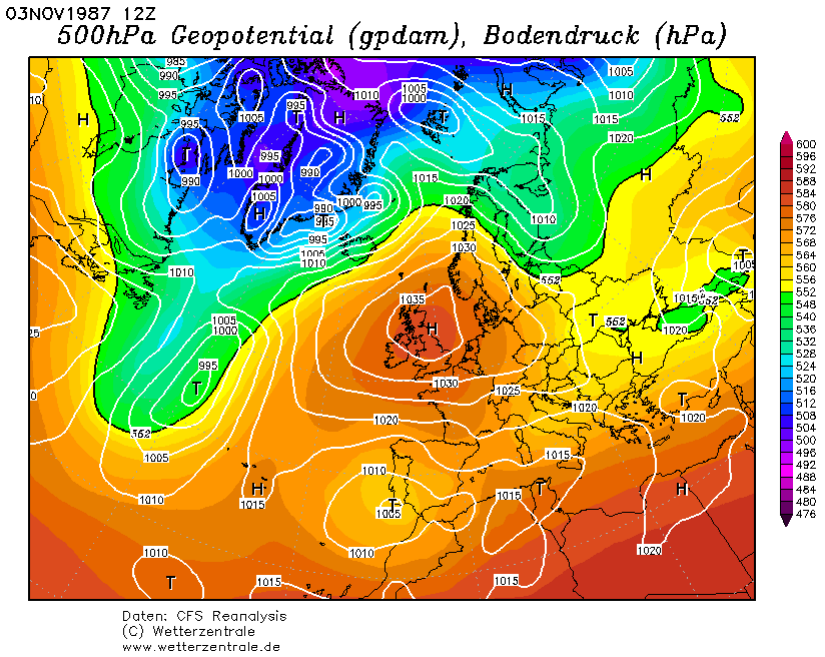
DANAs (57-24)

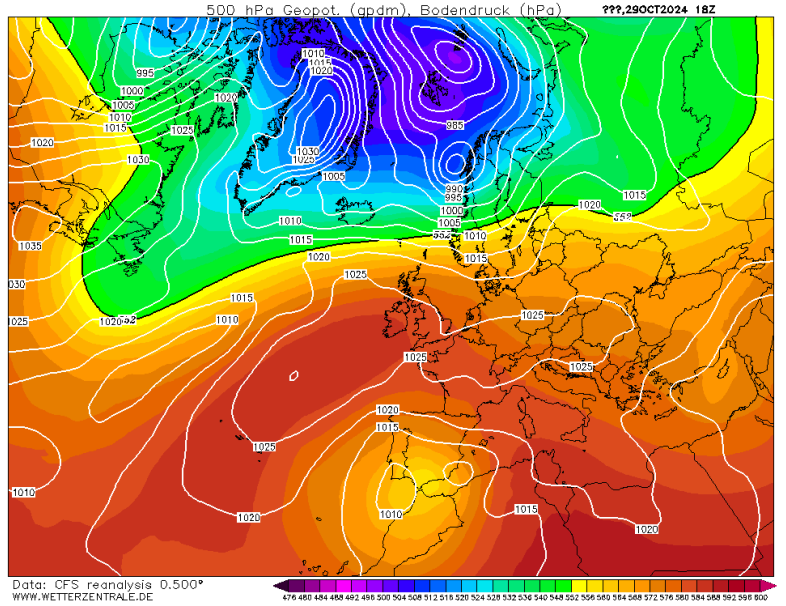
Torrential rains, in which rainfall in 24 hours can exceed that of an entire year, are called DANAs (cold drops) in Spain, or “isolated depressions at high levels.”











29/10/2024 Dana

Spain experienced **the most catastrophic event caused by torrential rains** in recent decades

The mega-rainfalls, as well as the resulting flooding, caused **228 deaths**, as well as extraordinary economic damage

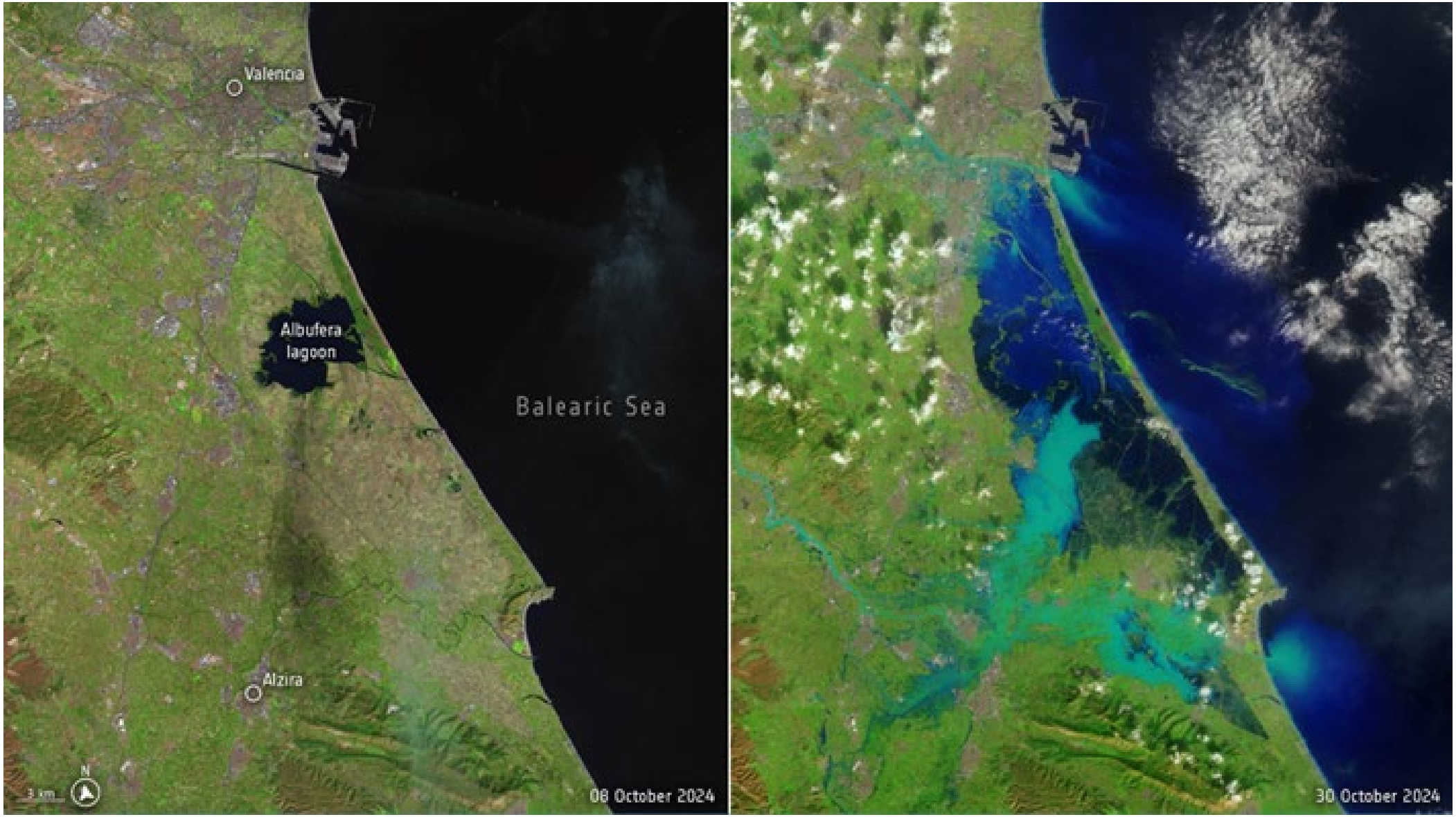
The DANA covered an area of **22,638.6 hectares, affecting 221.9 hectares of built-up areas**, 1,125.2 km of roads, and a population of **81,080 inhabitants** (https://rapidmapping.emergency.copernicus.eu/EMSR773)

The overflowing of rivers, especially ***El Poio*** **torrent, caused flooding of unimaginable magnitude, as well as extraordinary material and economic damage**

Although the Meteorological Agency (AEMET) sent alert messages (highest level) early in the morning, the Autonomous Community of Valencia (equivalent to a state in a federal regime) did not send a danger warning or Alert to mobile phones until 20:11, when the rivers and streams had already flooded

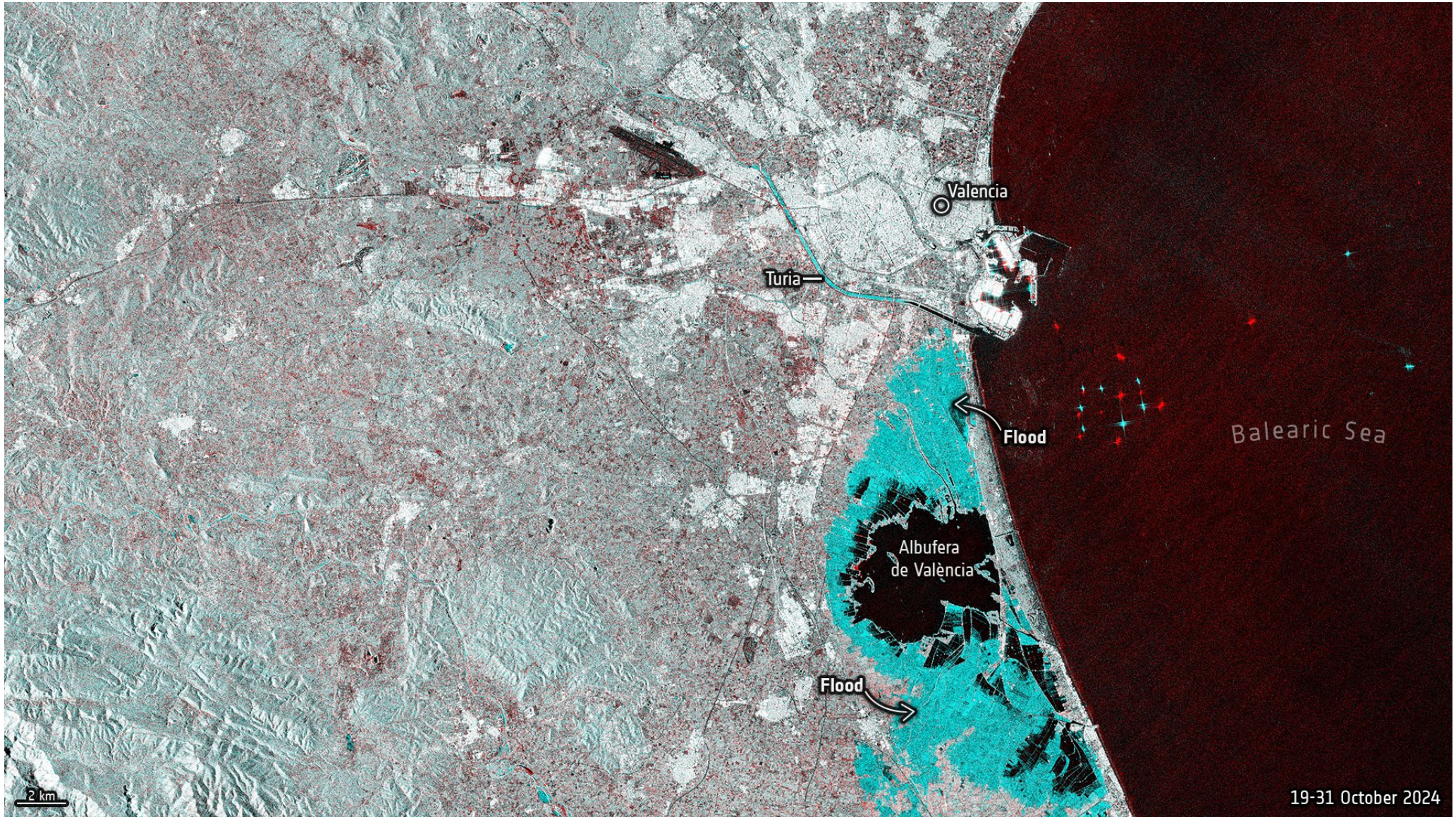
20:11
Neither forgetting
nor forgiving

Images before and after the flood (Landsat 9)



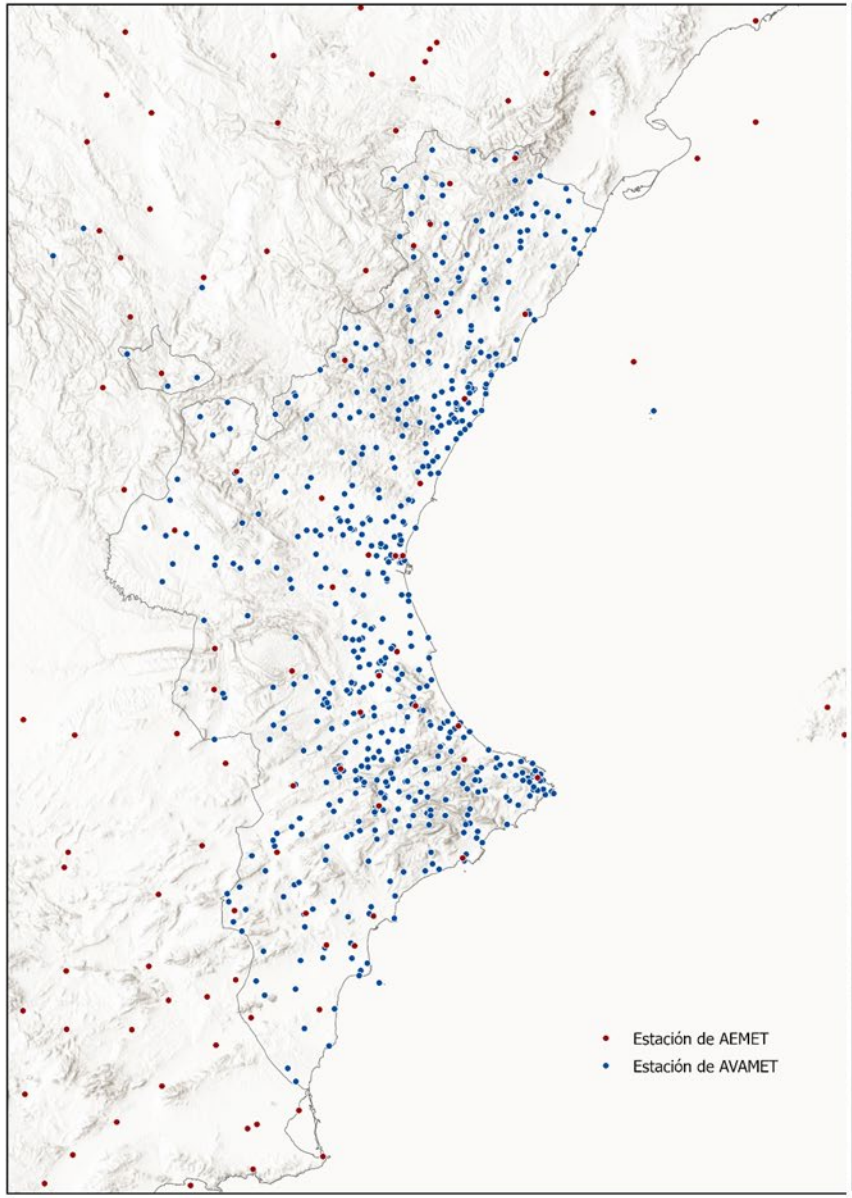
Source: https://esamultimedia.esa.int/images/EarthObservation/Valencia_flood_LC9_20241030_20241008_sbs_ML_v2.jpg

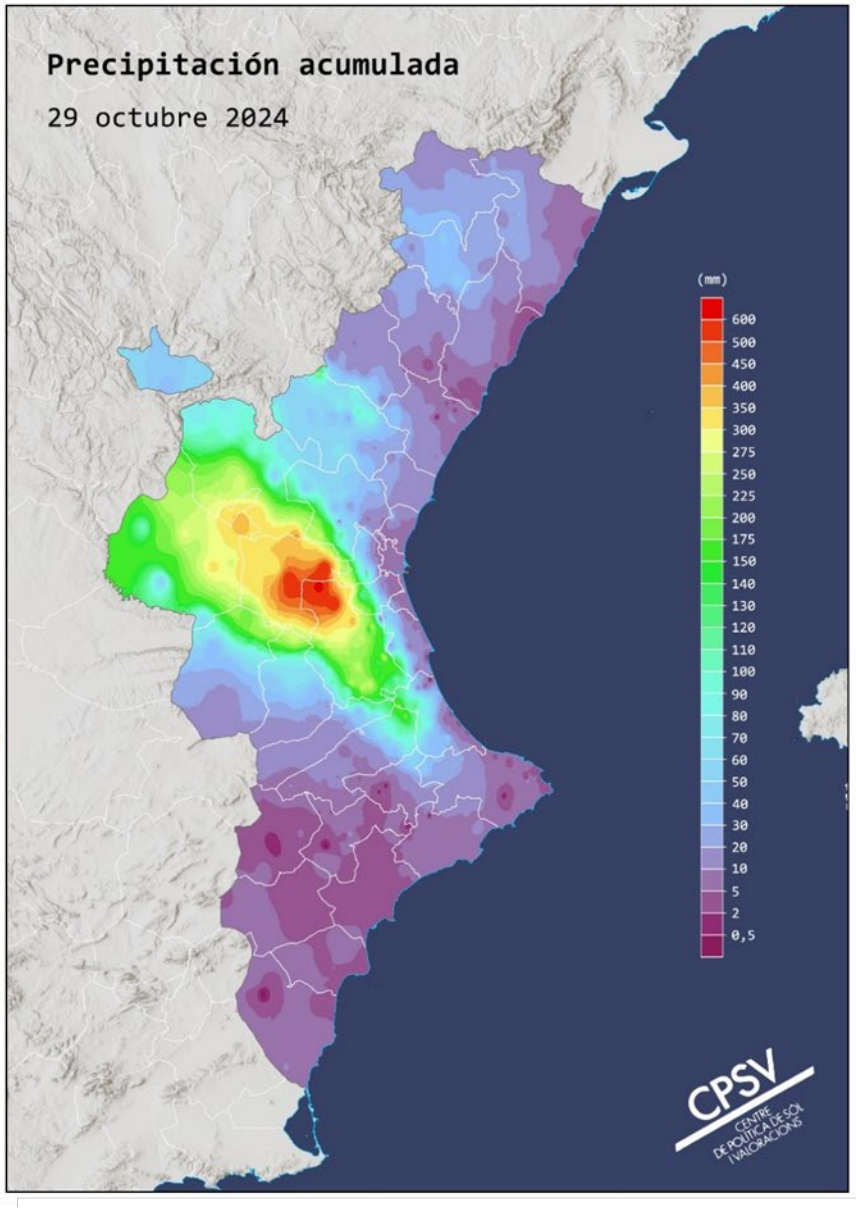
Flooded areas around Valencia (Sentinel-1)



Source: https://www.esa.int/ESA_Multimedia/Images/2024/11/Flooded_areas_around_Valencia_captured_by_Sentinel-1

Spatial distribution of precipitation in situ (10/29/24)





- Using data from AEMET (Agencia Estatal de Meteorología) and AVAMET (Associació Valenciana de Meteorología) meteorological stations, we estimate the spatial distribution of rainfall (10/19/24)
- In the case of AEMET, 375 stations, only 130 operating.
- In the case of AVAMET, there are 251 active stations
- Accumulated rainfall in 24 hours far exceeded 600 mm
- Maximum reached at the Turís weather station (710.8 mm)

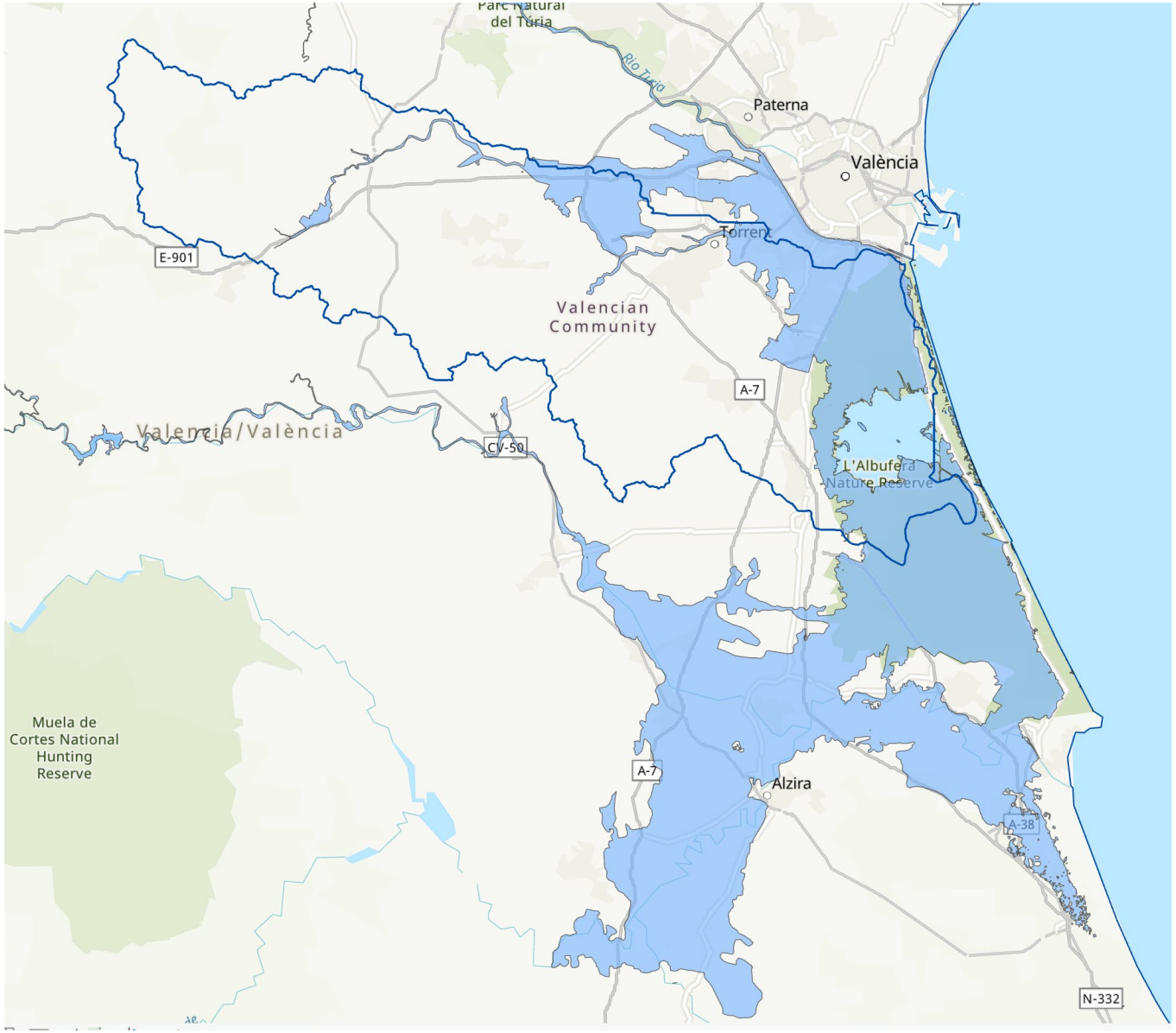
National Flood Zone Mapping System

- The Ministry for Ecological Transition and the Demographic Challenge of the Government of Spain has launched the National Flood Zone Mapping System (SNCZI)

- The SNCZI **maps flood risk at 10, 50, 100, and 500 years.**

- The **500-year return period is used to draw up plans and regulations for the expansion of the city and the construction of new buildings**.

- The comparison between the actual and modeled flood (500 years return) in the SNCZI is important, both to assess the real extent of the event and to estimate the degree of adequacy of the SNCZI

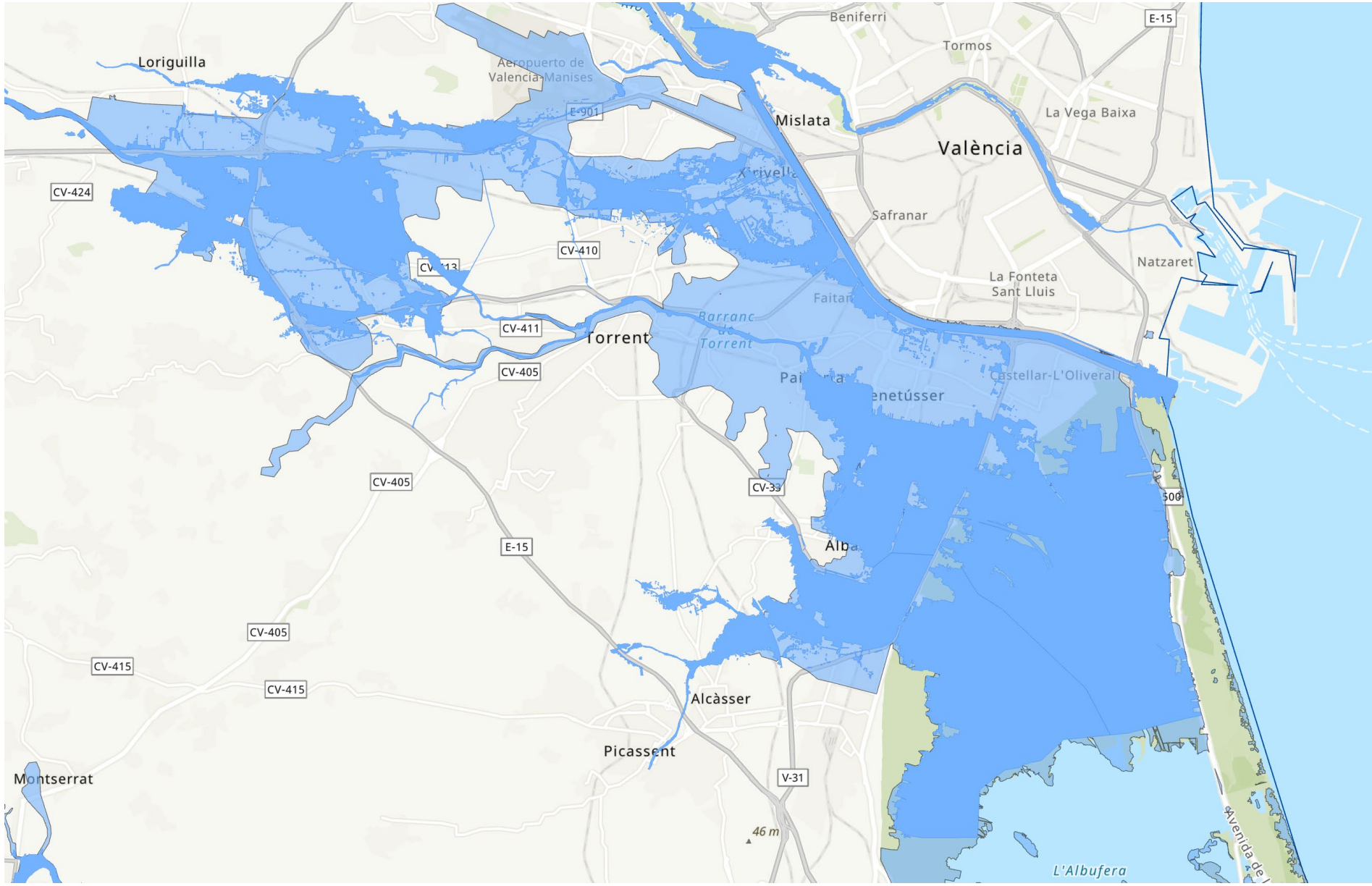


https://www.miteco.gob.es/en/agua/temas/gestion-de-los-riesgos-de-inundacion/snczi.html

2024 Flood vs. 500-year Return period

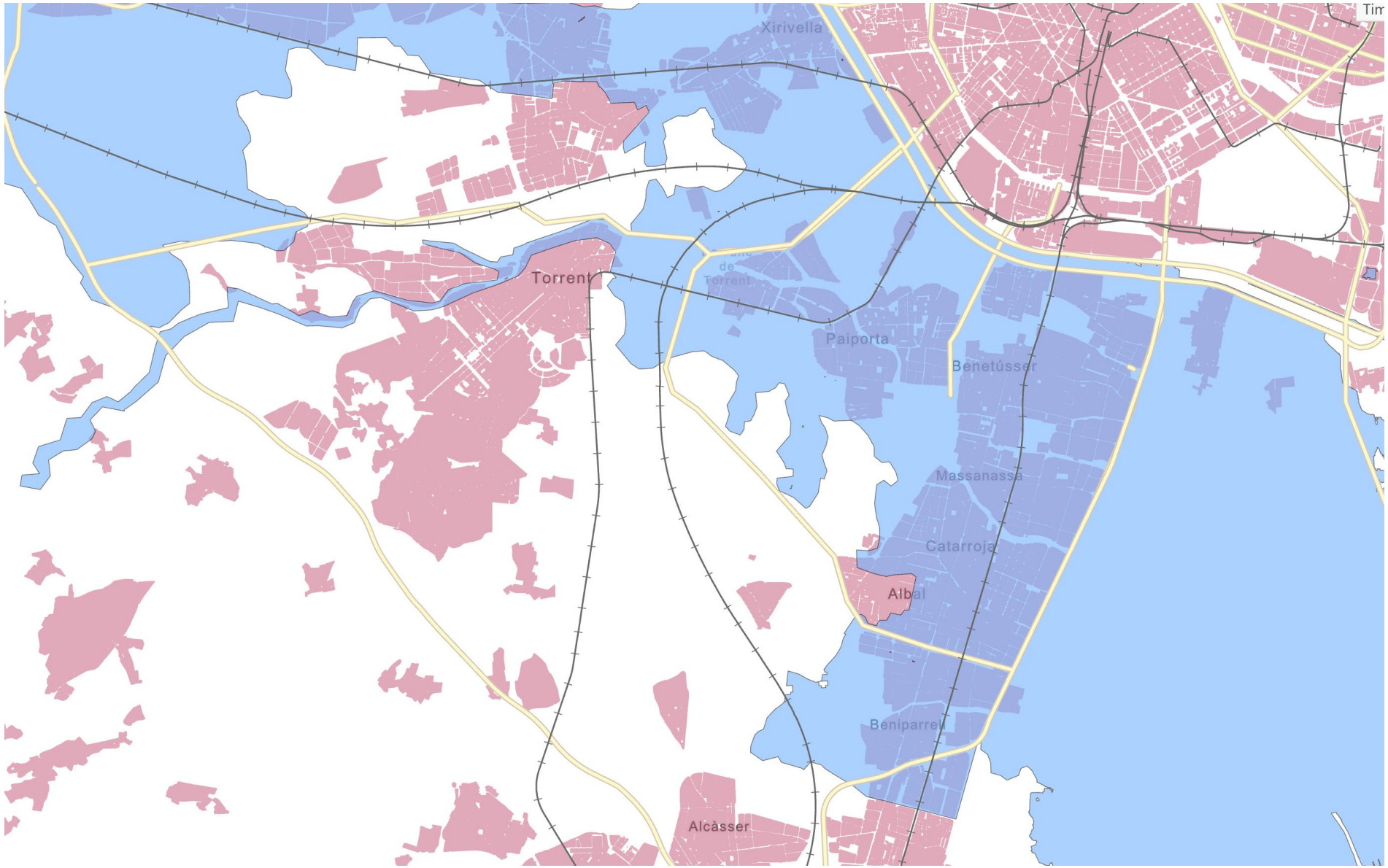
The floods of the DANA on October 29, 2024, exceeded the 500-year Return period risk areas

- 500-year return period of the SNCZI (National Flood Zone Mapping System)
- 2024 flood, modelled by Universitat de València (https://arcg.is/4vnT9)



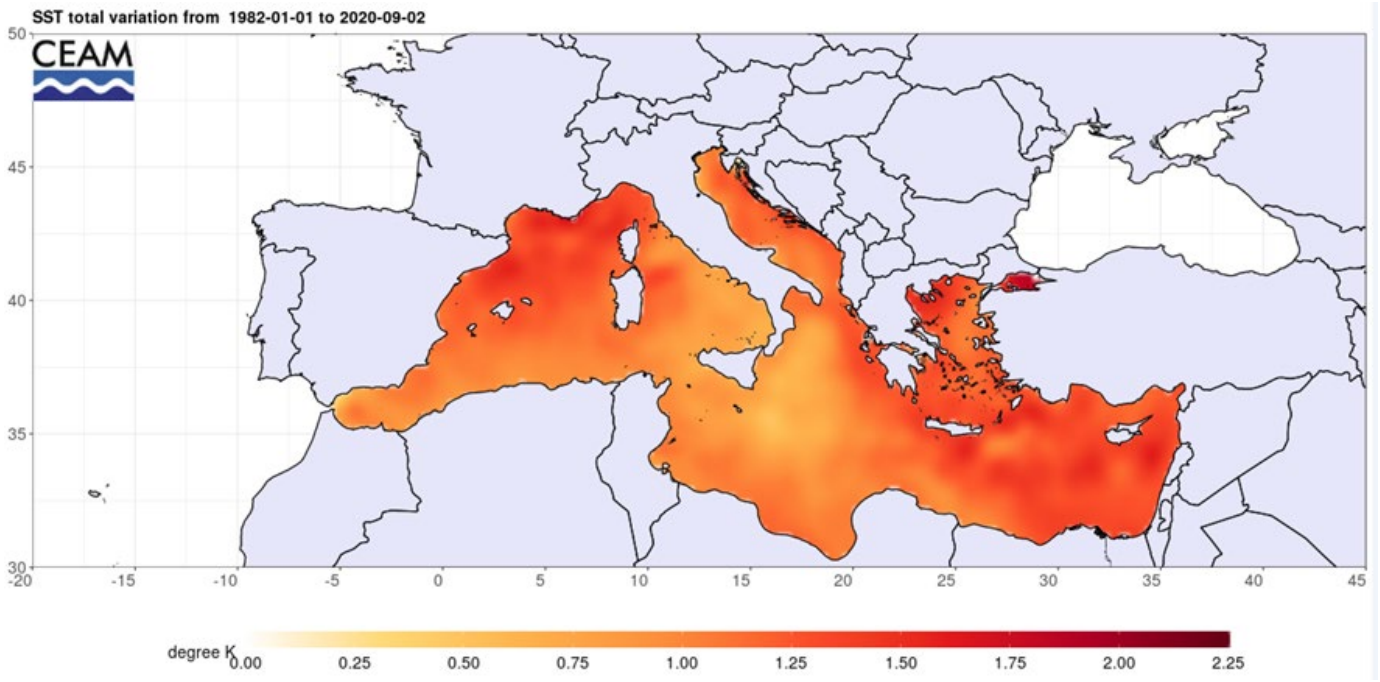
"Ground zero" of the flood

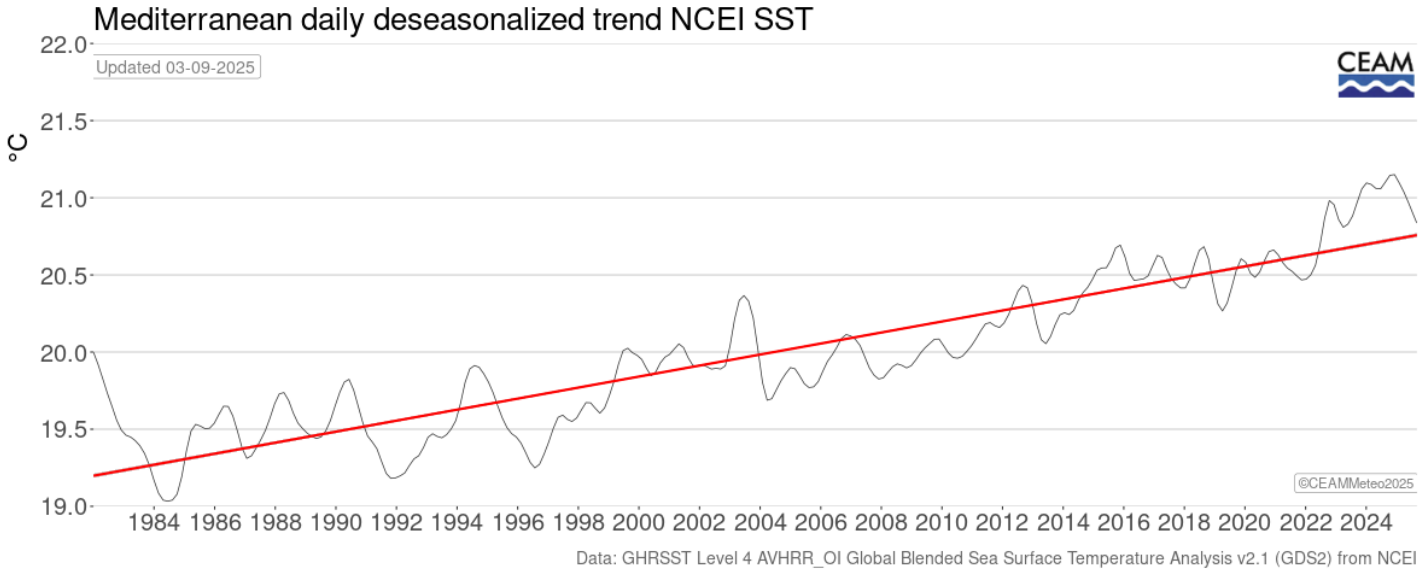
The flood affected widely urbanized areas



Mediterranean warming

- The increase in the temperature of the Mediterranean Sea is a well-established fact.
- The amount of energy accumulated in the sea represents the driving force that powers the DANAs
- The marine buoys measuring water temperature have recorded temperatures above 30°C this year along the Levante coast





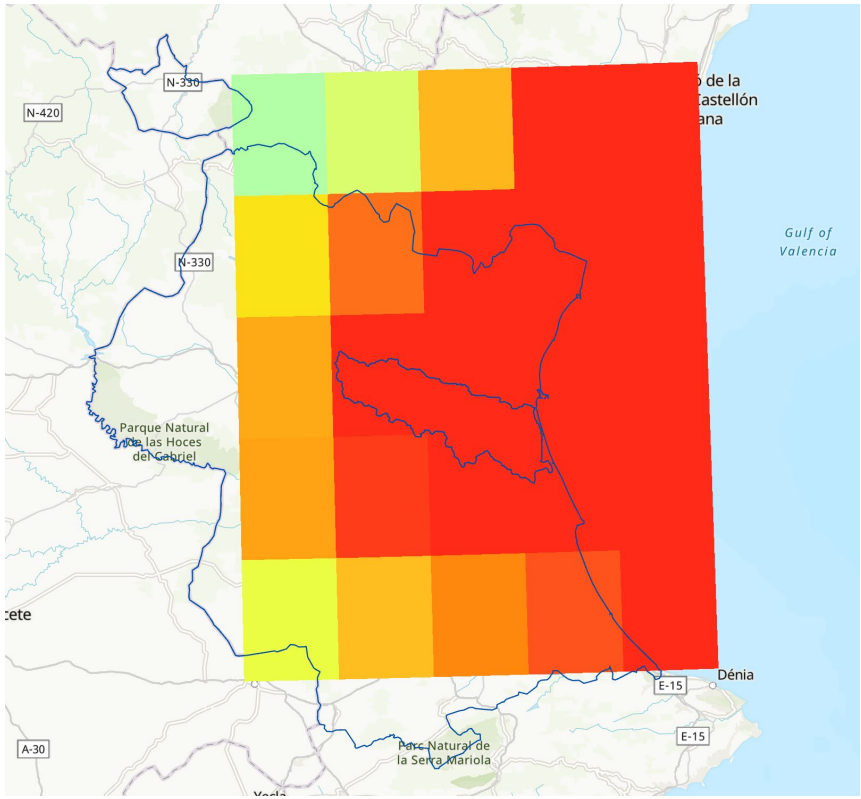
Total water vapour column

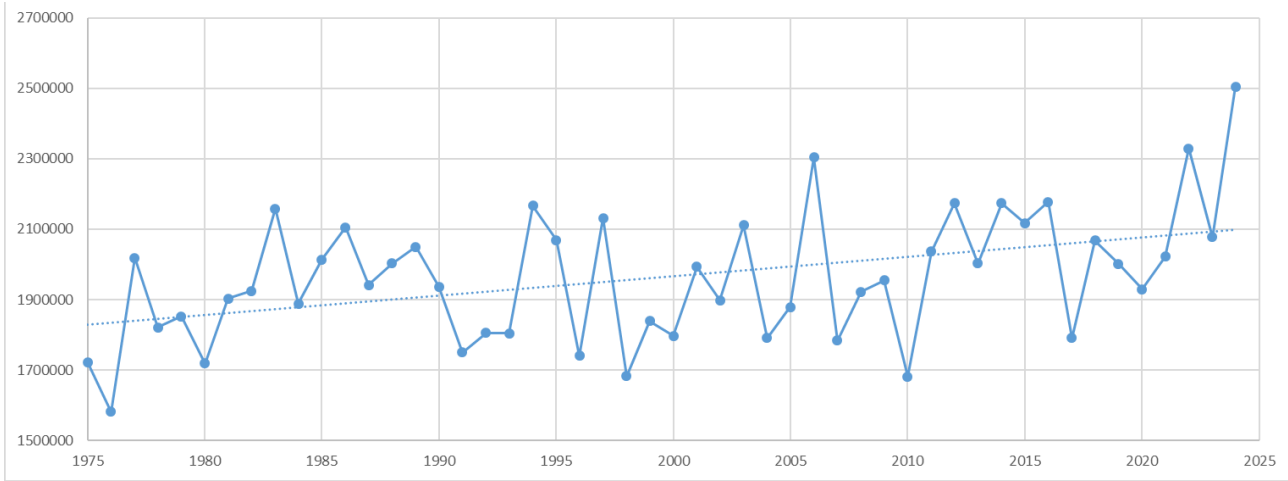
- ERA 5 allows to quantify the *water vapour column*. The absolute total amount of water vapour in a vertical column of air (TCWV) refers to the fact that this amount could, hypothetically, precipitate out. Units are kg/m^2 or mm (like rain)

- **The analysis of the total amount of water vapor in the province of Valencia for the months of October and November between 1975 and 2024 reveals the existence of a continued increase in water vapour, a result of global warming**.

- 2024 and 2022 are the years where the greatest accumulation of water vapor has occurred

- The Mann-Kendall (MK) test confirms the statistical validity (p-value = 0.005208) of the increase in the water vapour column in the months of October and November (1975-2024)





Warmer sea + Increased water vapour ➔ Towards mega-torrential rainfall?

Source: Forschungsinstitut für Wasser- und Abfallwirtschaft an der RWTH Aachen (FiW e.V.)

Towards a mega-torrential rainfall?

The catastrophic events, caused by the DANA on October 29, 2024 in Valencia, lead us to reflect on whether we are facing a trend toward extreme rainfall events never seen before

- How could such a catastrophic outcome have occurred in a country like Spain with a long tradition of weather forecasting?

- Are we facing a mega-event, never seen before? The 1,526 hm^3 accumulated in the province of Valencia in 2024 do not represent a record. However, the torrential rains of October 29, had catastrophic effects. Why?

- **DANAs can occur in areas where they have never occurred before**. According to the Júcar Hydrographic Confederation (the agency responsible for monitoring the river basins of the Valencian Community), **between October 28 and November 4, 2024, *"precipitation with estimated return periods of more than 2000 years was observed"*** .

Objective of the research

➔ The research aims to evaluate the return period of rainfall in *El Poio* torrent basin, where accumulated precipitation in 24 hours exceeded 700 mm

- In order *to clarify whether we are really facing a mega event,* or if, on the contrary, the DANA of 10/29/24 is a normal event in a geographical area, such as the Spanish Levante, where cold drops are normal.

- *It is also necessary to study whether DANAs in the Mediterranean area are becoming more frequent and intense events as a result of climate change*

Methodology

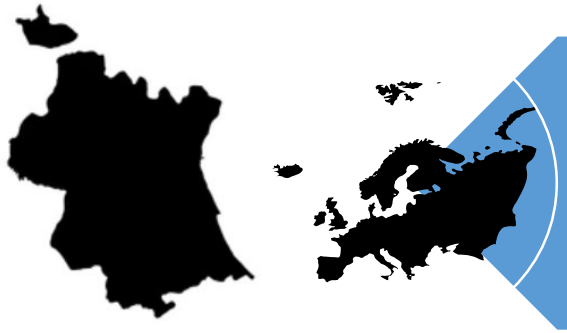
Calculate the return periods using **conventional models*** for precipitation at the Turís station (Turís meteorological station experienced the greatest rainfall on 10/29/2024). This paper analyses annual maximum precipitation over the period 1950–2024, using frequency analysis methods to estimate return levels.

- Gumbel,
- Log-Pearson III (LP3),
- Generalized Extreme Value (GEV), and
- SQRT-ETmax.

*Each distribution was fitted with three parameter estimation methods: Method of Moments (MOM), Maximum Likelihood Estimation (MLE), and L-moments (L-MOM)

Developed our **own method (Log-OLS)** and compare it with the results of conventional models. Since annual maximum precipitation (RRX) modeling offers high variability, our methodology consists of using the logarithm of RRX, which allows a much better model fit.

Methodology



Given the high variability in the location of the different torrential rainfall events produced by cold drops, **an analysis at the scale of the province of Valencia is carried out**. This allows for a much more precise adjustment of return periods and an assessment of the degree of exceptionality of the event of 10/29/2024. The modelling has been carried out using information relating to daily precipitation data (between 1950 and 2024) from 350 meteorological stations throughout the province of Valencia (provided by AEMET)

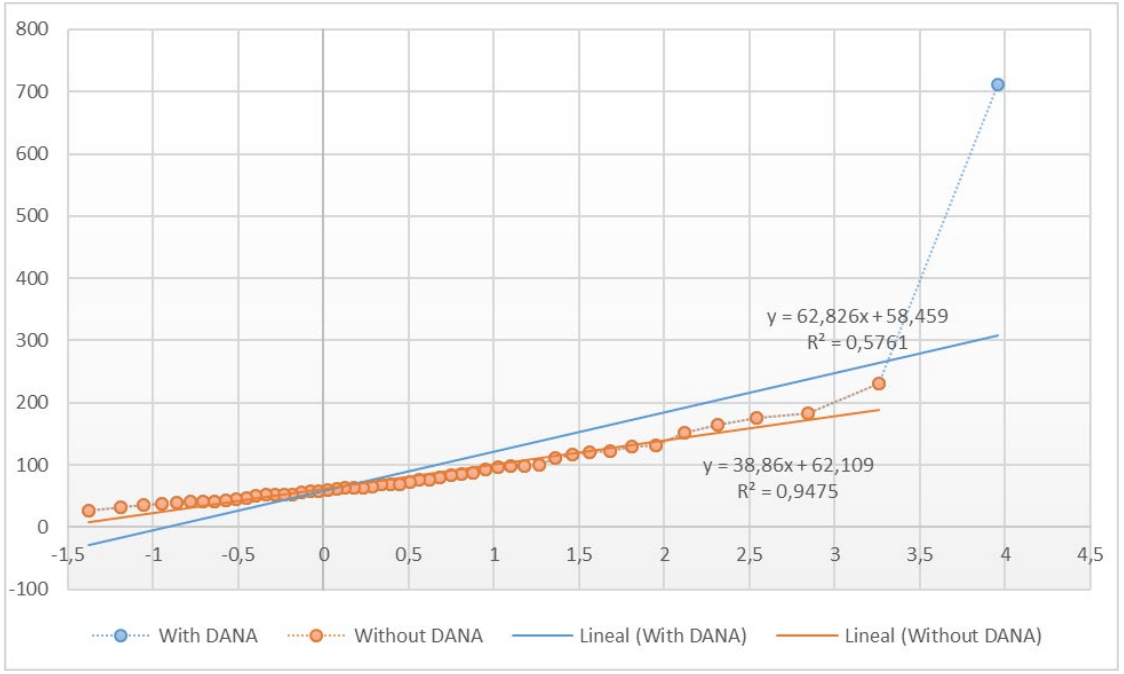
Finally, we analyzed (using the Mann-Kendall test and Kendall-Theil-Sen regression) whether the most extreme annual maximum rainfall events (RRX) tend to increase in frequency and intensity over time.

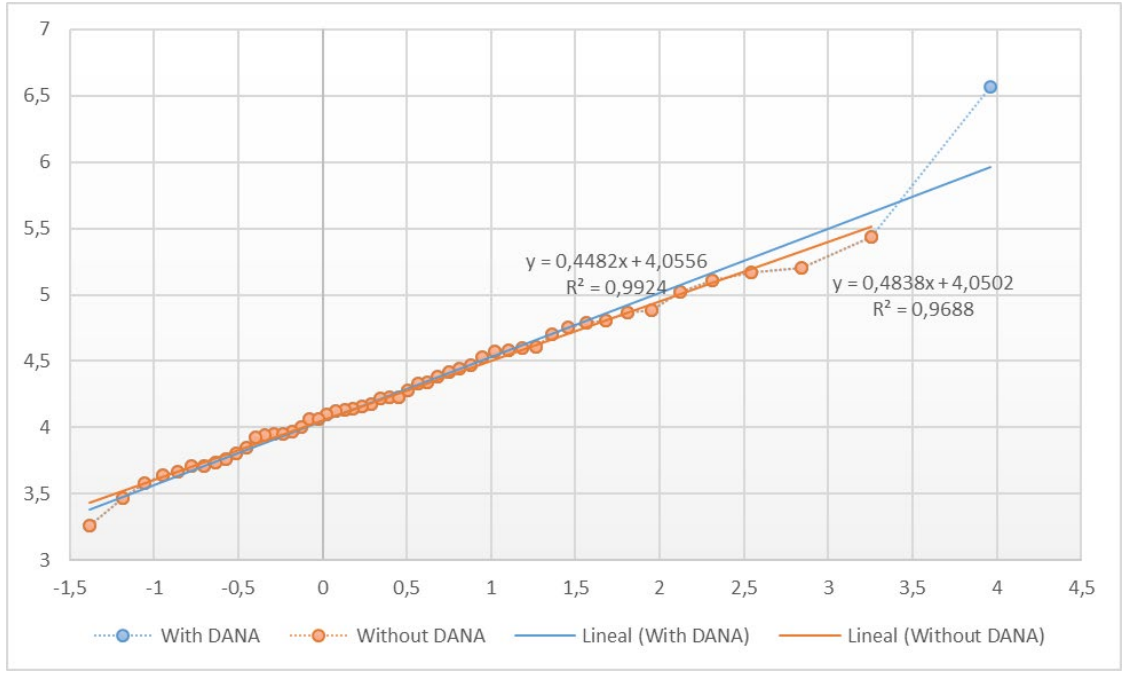
This analysis is compared with a similar study on the trend in torrential rainfall (RR ≥ 60 mm/24 h) to determine whether these trends are a consequence of climate change.

Log-OLS model

- One of the problems with conventional models for simulating extreme rainfall is their **high sensitivity to the occurrence of singular events**. The outbreak of an extreme event in an area where none had previously occurred significantly modifies the analysis of the return period. In the case of Turís, the R^2 of the OLS model between the maximum annual precipitation (RRX) and the reduced probability (Gumbel) decreases very sharply if the DANA of 2024 is not considered and if it is considered

- **When LN(RRX) is considered instead of RRX, the model is much more stable**. The R^2 remains very high, allowing for a more robust estimate





Log-OLS model process

1. First of all, the RRX series is ordered from highest to lowest (rank) and the **probability of occurrence** is obtained: *Likelihood* (L) = 1 - (rank / number of years in the series)

2. Then, as in classical models (Gumbel, ...), the reduced likelihood is obtained: **Reduced Likelihood** (RL) = -LN(-LN(L))

3. **An OLS model is then implemented, with the reduced likelihood (RL) as the dependent variable and the logarithm of RRX (LN_RRX) as the independent variable**

4. From here, we go back until we obtain the return period of each RRX. The predicted value (PRE) by the regression equation resulting from the OLS model is applied to obtain the **predicted probability for each RRX**, using the equation: *Predicted Likelihood* (PL) = EXP(-EXP(-(PRE)))

5. And by means of the equation 1/(1-PL) the **predicted return period** (RP) for each event is obtained.

This allows for calculating return periods of 10-20-50-100-500-1000 years for the Log-OLS method. These results are compared with those obtained by classical models (Gumbel, Log-Pearson III, SQRT-ETmax, and GEV) to assess their suitability for the case study

Results: Turís

- All models predict very long return periods if the 2024 DANA is not included, exceeding millions of years in some cases (Gumbel and GEV)

- If 2024 is included, these return periods are significantly reduced. Even in the most robust statistical model (GEV MLE, without 2024), the timescale is exceeded by 6,000 years

- **The Log-OLS model provides much more stable results and, in general, less extreme values**: a return period for 710.8 mm of precipitation of 261 years if the Mediterranean cyclonic storm (DANA) is not considered, and 157 years if it is

	With 2024	Without 2024
Gumbel_MOM	6503	211959610
LP3_MOM	329	48103
GEV_MOM	396	6107486
Gumbel_MLE	24846278	3691131708
LP3_MLE	870	32545
GEV_MLE	491	6693
Gumbel_LMOM	516321	301499055
LP3_LMOM	577	13494
GEV_LMOM	265	12323
SQRT-ETmax	95	691

Results: Turís

For a return period of 500 years (L-moments method), with or without a DANA event (2024), the results are as follows:

- Gumbel: 267.5 mm (without considering 2024) ➔ 369.1 mm (with 2024)
- Log Pearson III: 374.6 mm (w/o 2024) ➔ 678.1 mm (with 2024)
- GEV: 365.7 mm (w/o 2024) ➔ 974.9 mm (with 2024)
- SQRT-ET max indicates a high degree of variability: from 320.9 mm (w/o DANA) to 2053.1 (with DANA)
- The Log-OLS model forecasts a maximum precipitation of between 954 mm (excluding 2024) and 1,268 mm (including 2024). It fits reality much more accurately, suggesting better performance than the other models

The Log-OLS model also suggests that, in the case of the 2024 DANA, we would not be facing a singularity, as initially seems, but rather an extreme event in the "normal" range for a DANA

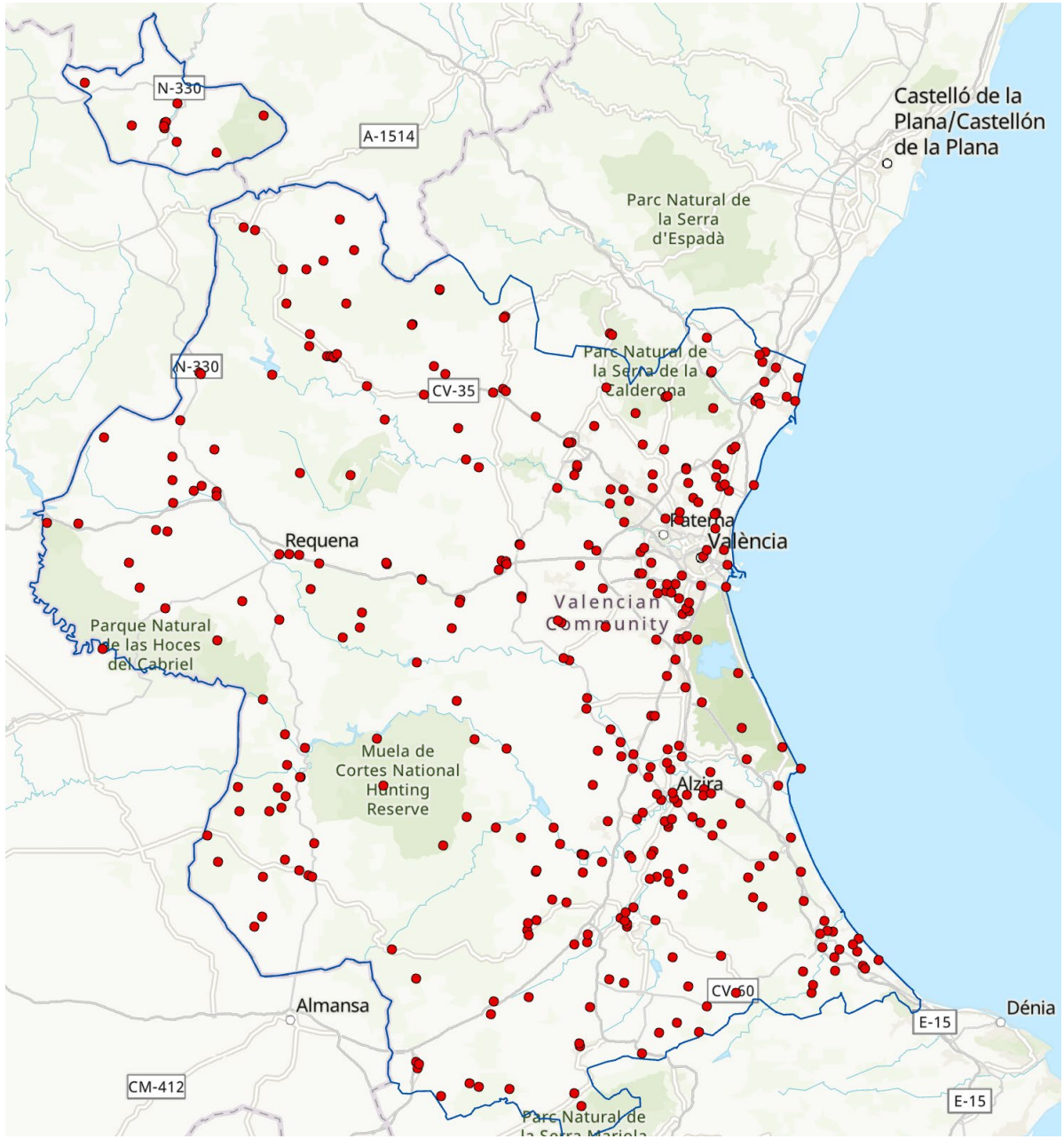
Return period (years)	Gumbel (with 2024)	Gumbel (w/o 2024)	LP3 (with 2024	LP3 (w/o 2024)	GEV (with 2024)	GEV (w/o 2024)	SQRT-ETmax (with 2024)	SQRT-ETmax (w/o 2024)	Log-OLS (with 2024)	Log-OLS (w/o 2024)
10	174	135,5	159,5	137,7	157,5	134,2	154,9	138,4	175,1	159,2
25	220,7	167,1	233	182	242,3	176,1	199,4	177,9	281,2	244,3
50	255,3	190,5	303,8	219,4	333,3	212	379,3	200,2	399,6	335,7
100	289,7	213,7	390,9	260,8	457,2	252,2	742,7	233,6	566,2	460,2
200	323,9	236,9	498	306,5	626,2	297,3	1227,1	269,5	801,5	630
500	369,1	267,5	678,1	374,6	947,9	365,7	2053,1	320,9	1267,6	953,6
1000	403,3	290,6	850,3	432,6	1296,5	425,2	2818,4	362,8	1792,3	1304,5

Results: Province of Valencia

- One of the characteristics of the torrential rainfall of 2024 is that it had never occurred exactly at the headwaters of *El Poio* torrent, which explains not only the terrible consequences for the population but also the failure of traditional adjustment models

- **However, DANAs do not discharge in exactly at the same place. For this reason, annual extreme precipitation events modeling is best done not for a single meteorological station, but for a set of stations across a broader geographical area (the province of Valencia)**

- The modelling has been carried out using information relating to daily precipitation data (between 1950 and 2024) from 350 meteorological stations throughout the province of Valencia (AEMET).



Results: Province of Valencia

Between 1950 and 2024 three events stand out for their extraordinary rainfall (over 500 mm in 24 hours): 1982 (where the so-called "pantanada de Tous" took place, 632 mm), 1987 (Oliva, historical maximum since measurements began, 817 mm) and 2024 (710,8 mm)

➔ **The Log-OLS model forecasts a return period of 70 years for the maximum rainfall (1987), and 47 years for the rainfall occurring in October 2024**

➔ **The Log-OLS model forecasts a precipitation of 925.9 mm for the 100-year return period**; this precipitation, although higher than the maximum recorded so far, is consistent with some estimates indicating that the amount already exceeded 1,000 mm

➔ **The forecast for extreme rainfall for the 500-year return period is 1,627.9 mm; an indicator that should serve as a reference for updating flood zones (SNCZI)**

Return period (yr)	Gumbel-MOM	Gumbel-MLE	Gumbel-L-MOM	LP3-MOM	LP3-MLE	LP3-L-MOM	GEV-MOM	GEV-MLE	GEV-L-MOM	SQRT-ETmax-MOM	SQRT-ETmax-MLE	SQRT-ETmax-L-MOM	Log-OLS
10	411,5	367,7	393,6	390	390,7	390	397,6	388,1	386,1	400,8	375	393,8	407,0
20	483	422,6	457,3	479,2	481,1	477,8	479,5	482,6	477	484,5	445,7	473,2	523,6
50	575,4	493,6	539,7	615,1	619,5	610,6	597,9	635	621,2	603,4	545,3	585,5	725,3
100	644,7	546,8	601,5	734,5	741,5	726,5	697	776,4	752,9	700,1	625,9	676,8	925,9
200	713,7	599,9	663,1	870,6	881,2	857,8	805,3	945,8	908,5	803	711,3	773,8	1180,9
500	804,8	669,8	744,3	1080,5	1097,4	1058,9	964,7	1222,6	1158,8	948,7	831,6	910,7	1627,9
1000	873,6	722,7	805,7	1265,6	1288,9	1235,1	1098,8	1481,1	1388,9	1066,1	928,3	1021,1	2074,9

More intense and frequent torrential rainfall?

- **The study demonstrates that the intensity of the precipitation occurred in 2024 is not an exceptional anomaly, but rather a "normal" event in the climate of the Spanish Levant**

- **The next step is to determine whether the trend toward extreme precipitation is a growing phenomenon over time as a result of climate change:**

  ➔ We used the Mann-Kendall test and the Kendall-Theil-Sen regression to determine whether *the most extreme annual maximum rainfall events (RRX)* tend to increase in frequency and intensity over time

  ➔ A similar study was conducted on the trend of *very intense rainfall (annual sum of daily rainfall ≥ 60 mm)* to determine whether there is an increasing trend in these events as a result of climate change

- The IPCC's Sixth Assessment Report already highlighted how extreme rainfall events are a consequence of global warming in the Mediterranean region. Academic literature has also demonstrated this trend in Spain (Arellano et al, 2025*). The question now remains whether this trend also occurs in the province of Valencia and whether it affects the most intense rainfall (RRX), a result of cold drops.

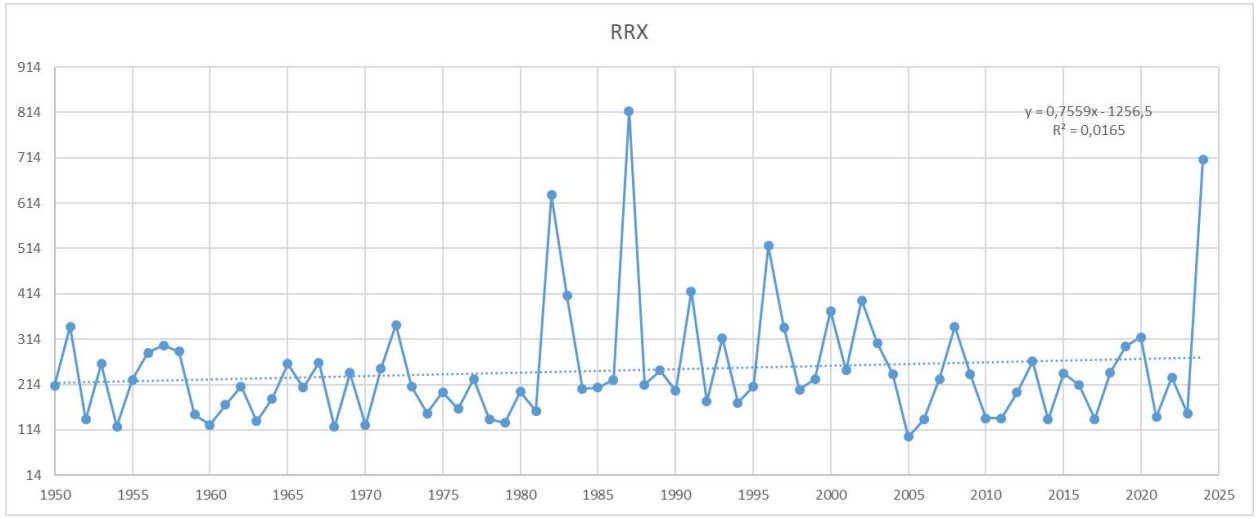
* Arellano, B., Zheng, Q. & Roca, J. Analysis of Climate Change (2025). Effects on Precipitation and Temperature Trends in Spain. Land, 14, 85. https://doi.org/10.3390/land14010085

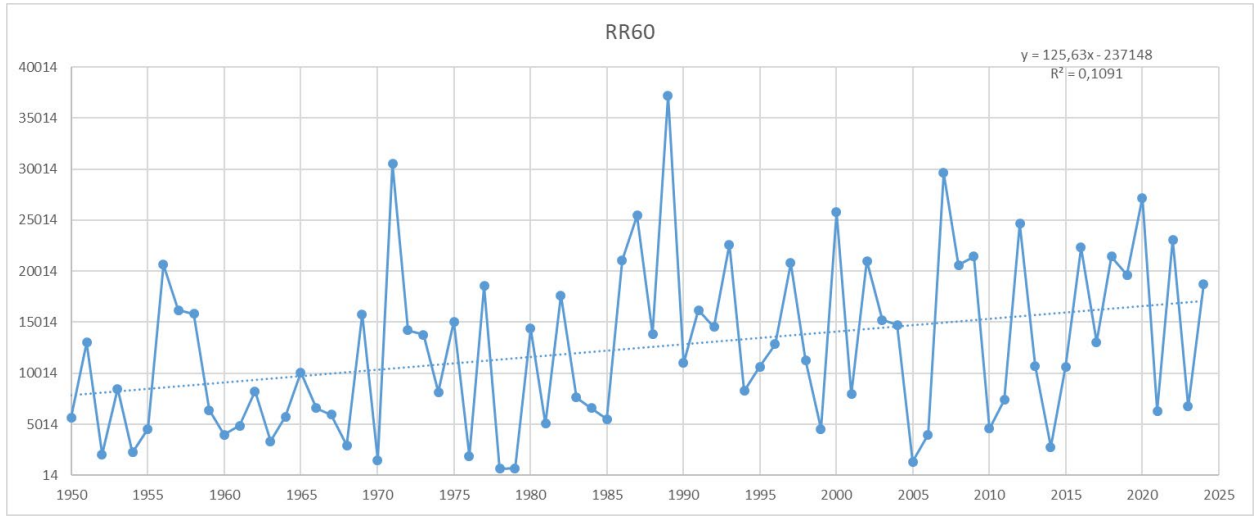
More intense and frequent torrential rainfall?

- **The trend towards an increase in very intense rainfall (RR>=60 mm) is a fact clearly observed in the province of Valencia**. The Sen's slope shows an annual increase of 127.8 mm in the total torrential rainfall. This trend has been statistically verified (MK test) at a 99.6% confidence level

- **This trend is not supported by maximum annual precipitation (RRX)**. Although there is a tendency for precipitation to increase over time (Sen's slope = 0.336 mm/year; 24.9 mm for the entire period 1950-2024), the MK test indicates that this trend only has a 69% confidence level. "More likely than not," in IPCC terminology

- **It cannot be fully confirmed, therefore, that DANAs tend to become more intense over time, although the progressive reduction in return periods seems to indicate that extreme precipitation events will be more frequent**





Discussion & Conclusions

Our study suggests, in one hand, that despite the serious impacts on people and property, the 29/10/2024 DANA was not a mega-event

In the other hand, demonstrates that the extraordinary intensity and frequency of DANAs, not represents an extraordinary rainfall event, because the return periods obtained for the heaviest rainfall events since 1950, considering the province of Valencia as a whole, are less than 100 years.

Discussion & Conclusions

- **The study suggests the relative inadequacy of current flood vulnerability maps (SNCZI), since the actual flooded areas exceed the 500-year return period**.
- It is urgent to produce **updated mapping** that considers a **higher probability of extreme events**. The actual mapping so far has proven insufficient to prevent the risk of the 2024 DANA
- **Spatial and Urban Planning regulations have to be updated** according to extreme events data analysis
- **The research question of whether extreme precipitation events are becoming more intense and frequent, remains open**. The progressive warming of the Mediterranean Sea, as well as the increasing water vapor content, seems to suggest that maximum annual precipitation should become more intense
- This kind of studies, using remote sensing and in situ dataset, helps planners make better

SPIE. SENSORS+ IMAGING

Thanks for your attention!

Blanca Arellano (blanca.arellano@upc.edu)

Josep Roca (josep.roca@upc.edu)

Qianhui Zheng (qianhuizheng0712@gmail.com)

Dolors Martínez (dolors.martinez@upc.edu)

Carina Serra(carina.serra@upc.edu)

Center of Land Policy and Valuations (CPSV-UPC)
Technical University of Catalonia
https://cpsv.upc.edu/en

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

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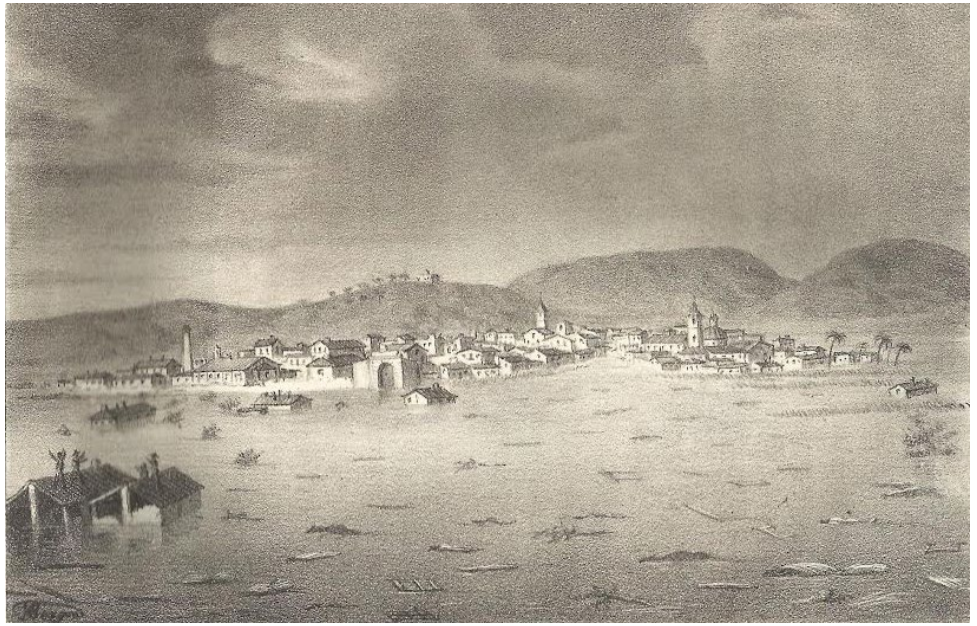

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