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ANALYSIS OF THE METEOROLOGICAL SITUATION ASSOCIATED WITH FLOODING IN THE PROVINCE OF VALENCIA ON TUESDAY, OCTOBER 29, 2024

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This precipitation event in the Valencia Region is characterized by its extraordinary severity, attributable to a confluence of various meteorological and climatic factors that have synergistically exacerbated its impact. The persistent positioning of the DANA, in conjunction with moisture influx from the Mediterranean—which continues to exhibit anomalously elevated temperature readings—combined with a topographical advantage featuring mountainous terrains adjacent to coastal areas and urban settlements situated in low-lying regions, has facilitated water accumulation and the subsequent overflow of rivers and ravines. In the absence of a comprehensive and rigorous examination of the incident and the mechanisms that facilitated its occurrence, one may categorize this as a historic storm, ranking among the three most intense meteorological events of the past century in the Valencia Region.

1. OVERVIEW

At approximately 5:00 local time on Tuesday, the 29th of October 2024, within the context of an isolated upper-level depression impacting the Iberian Peninsula since the 26th of October, a stationary convective system manifests directly above the Alzira town area. The resultant disturbance or trajectory of the storm train propagates due to the influence of southeast winds at higher atmospheric strata, advancing in a northwest direction and affecting communities such as Llombai, Buñol, Turís, Chiva, Siete Aguas, and particularly Utiel and the la Atalaya mountain ranges, with natural hydrological flow directed towards the basins of the Magro and Turia rivers (Figure 1). The pronounced advection of easterly winds at the surface, laden with moisture from the Mediterranean, alongside its convergence along the storm line, promotes the formation of intense and sustained precipitation.

Ultimately, the convective cell dissipates around 10:00 local time; however, the convective focus reactivates over the Alzira area at approximately 12:00, maintaining a stationary position and, in this instance, achieving exceptionally high intensities locally, even surpassing 100 mm/h downstream of the principal focus. The expanse of the storm train encompasses adjacent regions to the west of Valencia city, impacting the municipalities of Torrent, Alaquàs, Aldaia, and Riba-roja de Túria. Furthermore, this convective cell extends toward Utiel and the la Atalaya mountain ranges, culminating in flooding within the corresponding river basins. By around 23:00 local time, the convective focus begins to dissipate, and the intensity of precipitation diminishes from coastal to inland regions.

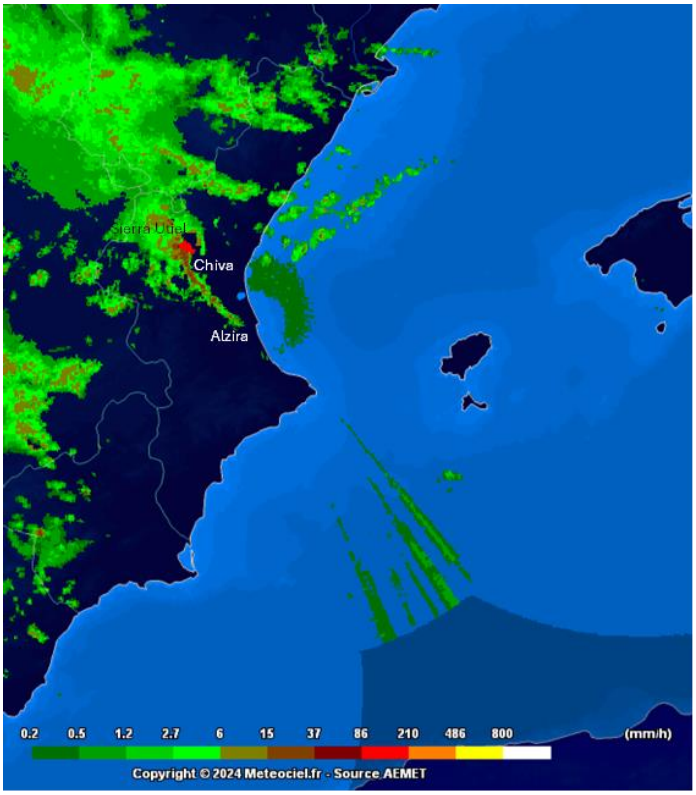


Figure 1: Precipitation intensity at 20:40 local time associated with the storm train with stationary focus in the Alzira area. Source: Meteociel (AEMET).

2. ACCUMULATED PRECIPITATION

Precipitation on the 29th was primarily concentrated along the prelittoral and inland regions, predominantly influencing the areas of Plana d'Utiel-Requena and Foia de Bunyol (Figure 2). Among the recorded daily precipitation totals, rain gauges in Chiva and Chera documented remarkable values of 491.2 mm and 409 mm, respectively, as per data from the SAIH (Sistema Automático de Información Hidrológica) network of the Hydrographic Confederation of Júcar (CHJ). Moreover, it is pertinent to highlight the torrential intensity of the precipitation (exceeding 60 mm/h) at both meteorological stations, which recorded hourly accumulations reaching up to 122 mm in Chiva and 74 mm in Chera. Additionally, significant torrential precipitation has been observed at numerous other meteorological stations located in the prelittoral and inland regions of the Valencia Region, with an exceptional measurement of 630.6 mm recorded in Turís, according to data from the meteorological network of the *Associació Valenciana de Meteorologia* (AVAMET).

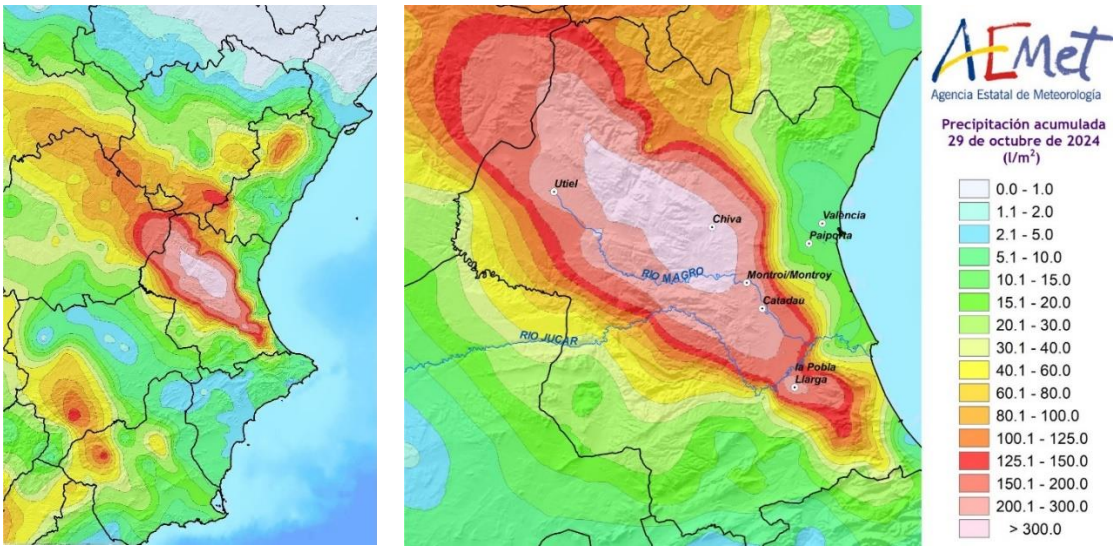


Figure 2: Daily precipitation map for the 29th of October 2024. Source: AEMET (data obtained from AEMET, SAIH-CHJ, IVIA, AVAMET and Inforatge meteorological networks).

The volume of precipitation accrued during this significant precipitation episode exhibits a resemblance to other recent occurrences, such as those on November 4 and 5, 2020, which had a localized impact on the regions of la Ribera Alta and la Ribera Baixa, as well as on September 12 and 13, 2019, particularly impacting the region of la Vega Baja. Nonetheless, this episode is distinguished by its heightened prevalence over inland territories, as heavy precipitation events in this region typically exert their effects predominantly on coastal and prelittoral zones. It is plausible that this distinctive characteristic, in conjunction with the

torrential (even violent) nature of the precipitation, has contributed to the catastrophic consequences of this episode. Indeed, this event can be likened to the two significant episodes of October 1982, during which 900 mm/day was recorded in Cortes de Pallás (unofficial data), and November 1987, which was particularly disastrous in la Safor, where more than 800 mm/day was documented in the urban centers of Gandia and Oliva.

3. SYNOPTIC CONDITIONS

The extreme precipitation episode develops in a meteorological context dominated by the positioning of an isolated depression at upper levels (COL) to the southwest of the Iberian Peninsula (Figure 3). The depression became detached from the general circulation, positioning itself over the center of the Iberian Peninsula, already in October 26, generating heavy precipitation along eastern and southern regions of Spain. Interestingly, the perturbation presented a large extent without a remarkable deepening regarding geopotential values. This positioning of the COL commonly leads to the organization of the different air masses in the form of instability fronts that advance over the Iberian Peninsula progressively. The configuration is especially dangerous for southeastern Spain, since it promotes a strong easterly circulation in surface layers (Figure 4a), favoring the advection of moist air that is incorporated in the convective phenomena associated with the advance of the instability front.

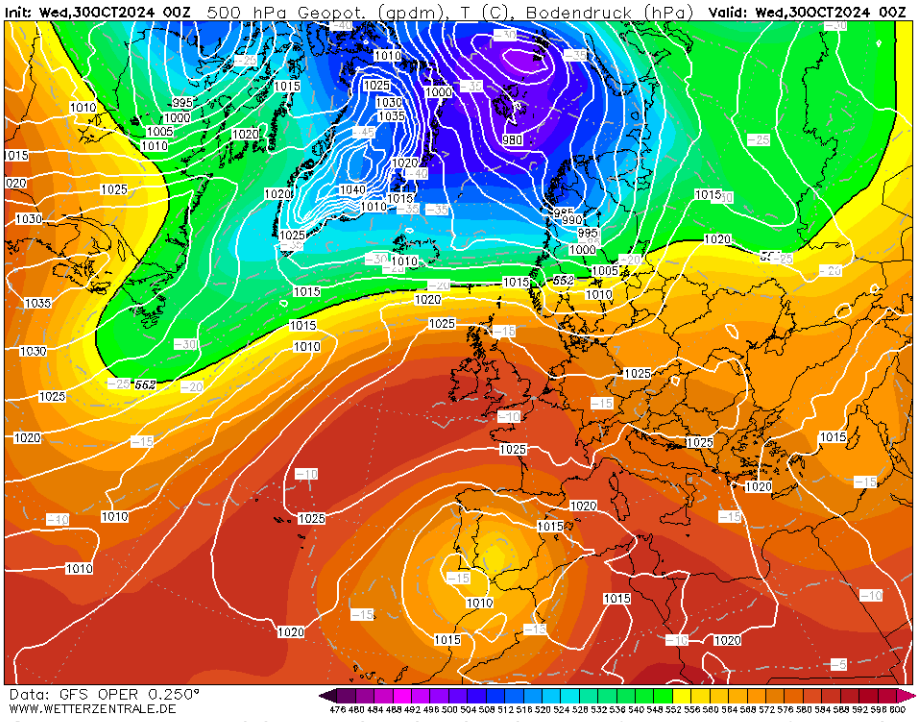
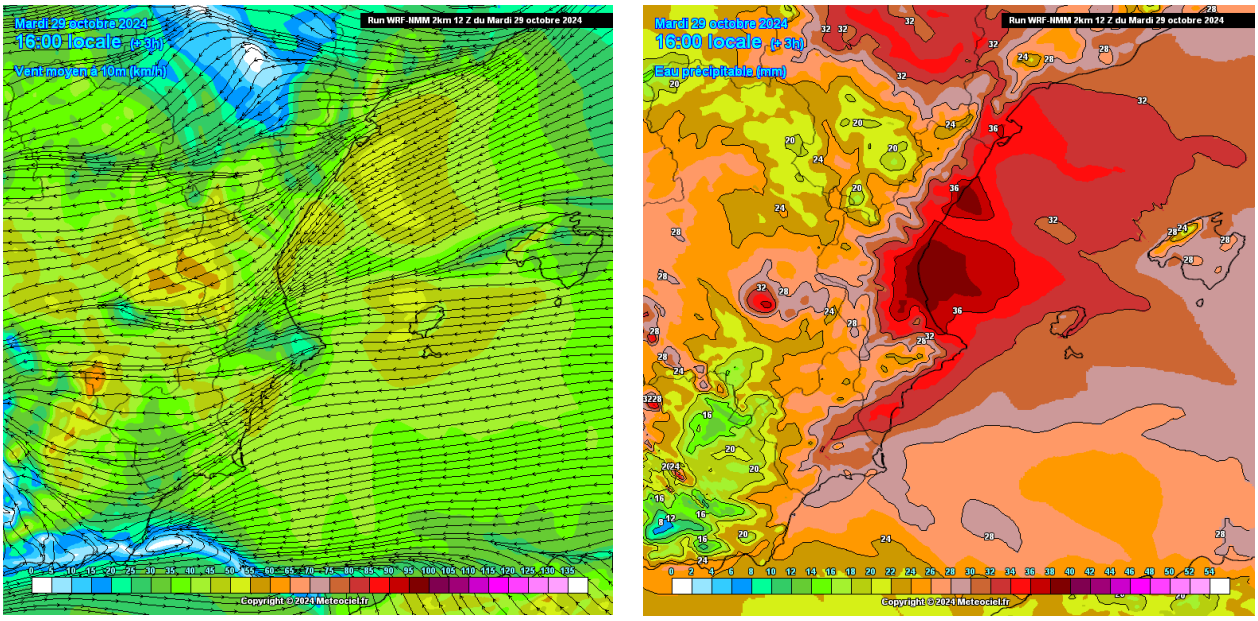


Figure 3: Geopotential at 500-hPa level and sea surface pressure for October 30, 2024, at a las 00:00.

These very moist air masses are observed in the integrated water vapor column (Figure 4b) along the Mediterranean coast displacing toward continental land, with especially high values

in the area of the Gulf of Valencia. These conditions are very favorable for the development of intense precipitation, typically affecting regions along the Mediterranean coast, with a duration according to the progression of the convective fronts.



(a) (b)

Figure 4: Maps of (a) wind at 10m above the earth's surface and (b) total atmospheric water vapor column simulated at 16:00. Source: Meteociel.

4. ATMOSPHERIC WATER VAPOR

In a manner analogous to the necessity of water vapor from the Mediterranean for the formation of precipitation over the eastern Iberian Peninsula, it is imperative to investigate alternative sources that may have contributed during this extreme meteorological event. Consequently, the initiation and amplification of the storm line responsible for the substantial precipitation event may have been affected by the interaction with the influx of an "atmospheric river" across eastern Spain. These phenomena manifest as concentrations of atmospheric plumes containing water vapor originating from distant locales at altitudes exceeding 3000 m, facilitating the rapid transport of moisture. Specifically, the presence of a potential atmospheric river is discernible on October 29, as indicated by elevated relative humidity values at 700 hPa (Figure 5), in stark contrast to those in lower atmospheric strata. The origin of this moisture can be traced to several thousand kilometers away, within the Atlantic equatorial region of western Africa, traversing a significant portion of the Sahara Desert. The arrival of this atmospheric river may furnish the requisite moisture for precipitation formation, while simultaneously inducing greater instability in the atmosphere as a mechanism that increases the advection of moisture that naturally occurs from the

Mediterranean Sea.

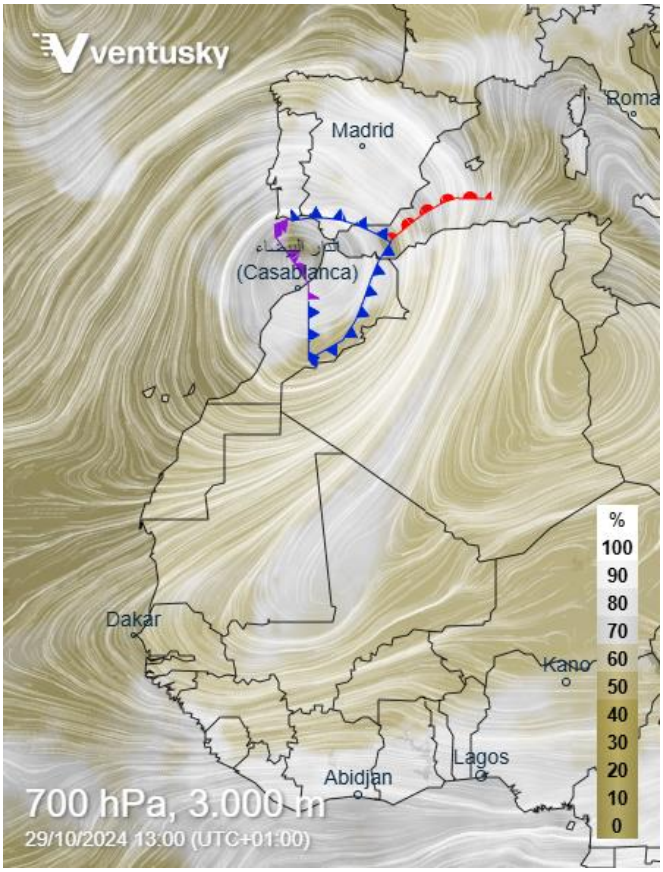


Figure 5: Possible interaction with atmospheric river of Equatorial/Atlantic origin at 700hPa level. The warm (red) and cold (blue) fronts originated by the interaction of the air masses around the COL are also shown.

5. SEA SURFACE TEMPERATURE

Sea surface temperature (SST) constitutes a significant variable that delineates the Mediterranean climate, serving as a crucial determinant in meteorological phenomena such as the genesis of sea breezes during the summer months and the occurrence of torrential precipitation in the autumn season. SST acts as a definitive indicator of energy accumulation within the marine environment, which consequently facilitates the exchanges of heat and moisture that create conducive conditions for the onset of torrential precipitation. SST exhibits a distinctly marked annual cycle, attaining its apex during the month of August, after which it shows a gradual decline towards winter values that are established from December onwards. Throughout the autumn period, notably between September and October, elevated SST values continue to be recorded, particularly in the context of the last few decades.

The average SST of the Mediterranean in 2024 has consistently remained above the climatic mean values established for the period 1982-2011 (Figure 6) across the entirety of the year. This trend has been most pronounced during the summer months, with mean values recorded between mid-July and mid-September consistently ranging from 1 to 1.5ºC above the summer average. In the month of August, the mean temperature in the Mediterranean

surpassed 28ºC, marking the highest value documented since 1982 (a phenomenon only previously observed in 2023). It is noteworthy that temperatures exceeding or closely approaching 28ºC were recorded during August and the initial days of September, further promoting the accumulation of energy within the Mediterranean Sea.

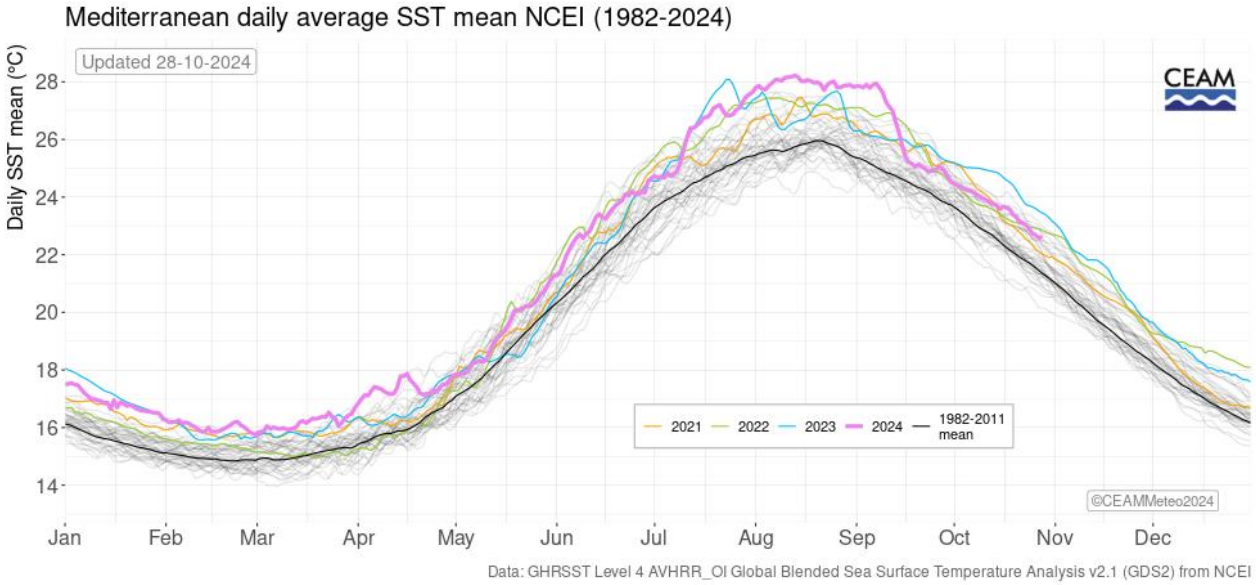


Figure 6: Annual evolution of SST (1982-2024). The black line indicates the average SST value for the period 1982-2011; the colored lines indicate the years 2021 to 2024. Source: NCEI. Prepared by CEAM.

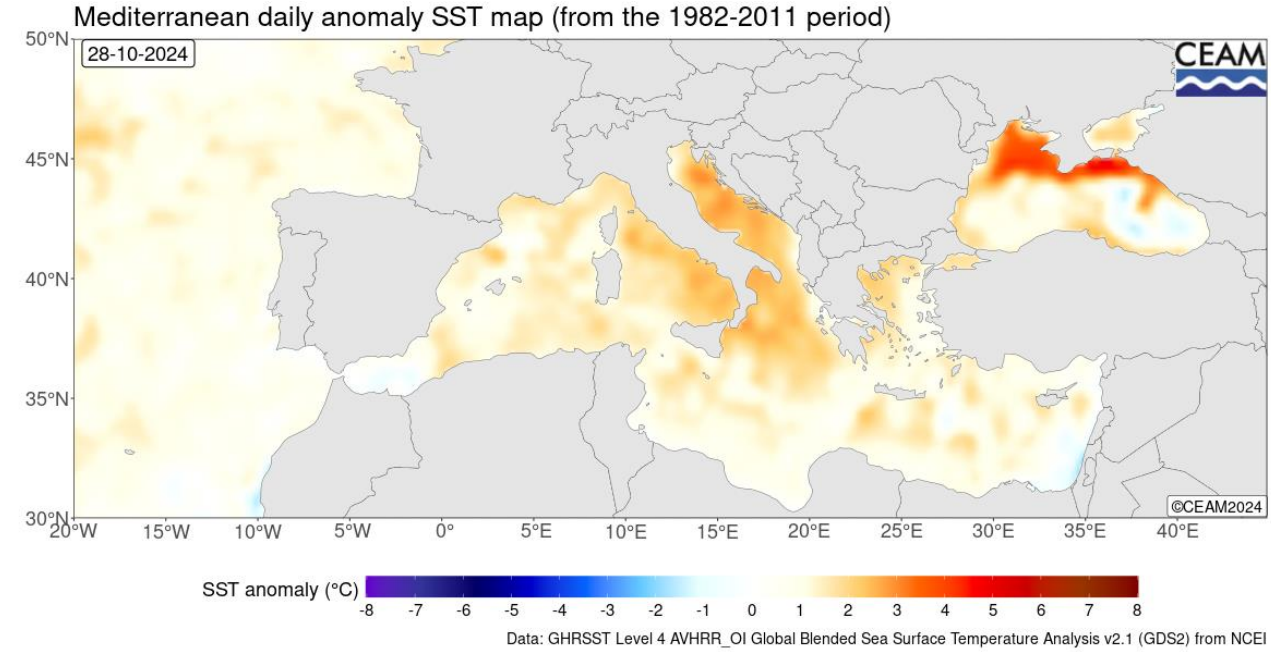


Figure 7: SST anomaly map of the Mediterranean on October 28, 2024. Source: NCEI. Prepared by CEAM.

In the month of October, the Sea Surface Temperature (SST) remained elevated in relation to the climatic norms for this period, commencing with an average temperature exceeding 24ºC and progressively declining to 22ºC by the end of the month, thereby maintaining a temperature approximately one degree above the climatic average. In the days preceding the precipitation event, SST values ranging from 22 to 23ºC were recorded along the coasts of the Valencia Region and the Balearic Sea, exhibiting positive anomalies of approximately 1ºC (Figure 7); however, in the preceding days, these values were marginally higher and more widespread in this region, attaining levels of up to 1.5ºC.

The maritime region situated between the Valencia Region and the Balearic Sea exhibited a behavior analogous to that of the entire Mediterranean Sea during the summer months. Average SST values in this region surpassed the 90th percentile, indicating an exceptionally high SST, from mid-July to mid-September. These elevated SST values precipitated the occurrence of a marine heat wave lasting for a duration of one month between late July and late August (Figure 8), which was classified as moderate for the majority of its duration but escalated to a strong classification around mid-August. Throughout the remainder of the summer, additional instances of marine heat waves were documented in this area, albeit of shorter duration. The persistence of exceedingly high SST values enhances the energy and moisture exchanges from the ocean to the atmosphere, thereby augmenting the atmospheric moisture present at lower atmospheric strata, which facilitates the occurrence of torrential precipitation.

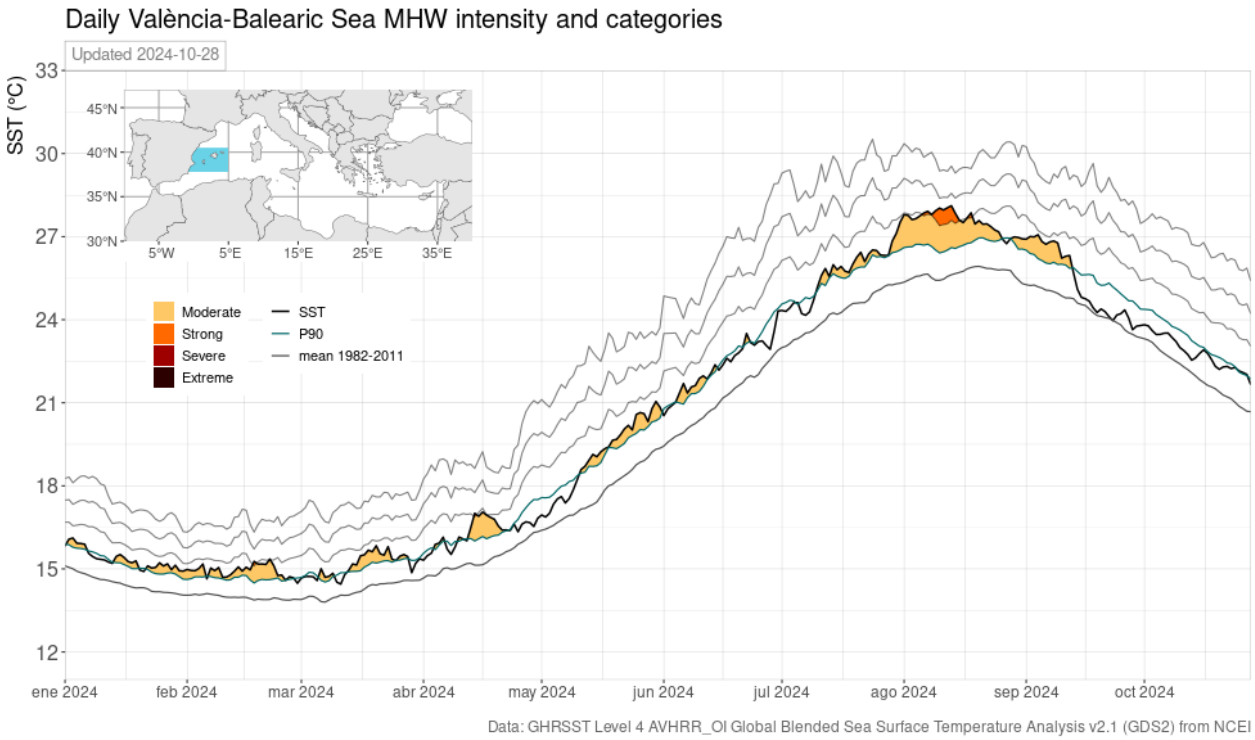


Figure 8: SST evolution in 2024 near the coast of the Valencia Region and Balearic Sea, with the identification of marine heat wave periods. Source: NCEI. Prepared by CEAM.

6. SOCIOECONOMIC IMPACTS

The recent floods in the Valencia Region have had a devastating impact in both human and socioeconomic terms. More than two hundred fatalities and missing people have been reported, with the number of victims being provisional while emergency teams continue rescue and identification tasks in areas of difficult access and with significant damage to infrastructure such as roads and bridges.

Economic losses affect key sectors in the region, such as tourism and agriculture, especially in rural areas that depend on these activities. Torrential precipitation has caused extensive damage to farmland, transportation infrastructure and housing, representing a substantial loss of income for these communities.

This event has once again highlighted the vulnerability of society to extreme weather events. Sustainable infrastructure planning and prevention programs are a priority to avoid human and economic losses of this magnitude in the future.

(a)

(b)

Figure 9: Images of the damage caused by heavy precipitation in Valencia (a) train tracks in *Alfafar* (source: Raquel Segura, EFE), and (b) V-31 highway in *Sedaví* (source: Claudio Álvarez, el País).

7. CONCLUSION

The following factors have increased the magnitude of the floods in the Valencia Region, making it one of the most extreme episodes ever recorded in the region:

1. Intensity and Duration of the COL: The Isolated Upper-Level Depression (COL) has generated deep and sustained atmospheric instability, causing intense and persistent storms concentrated in specific areas. The combination of rapid and focused precipitation saturated the ground and urban infrastructure, surpassing the “gota fría” events typical of the region in terms of persistence and extent.

2. Anomalous Mediterranean Temperature: the Mediterranean Sea has maintained significantly above-average temperatures for months with episodes of marine heat waves,

which has increased moisture availability in the air mass over the east coast of Spain. This warm sea, acting as an additional source of energy, has intensified precipitation in the region, triggering sustained torrential precipitation.

3. Increased Atmospheric Moisture and *Levante* Winds: The accumulation of heat in the Mediterranean, as well as the possible presence of an atmospheric river of subtropical Atlantic origin, has increased precipitable water in the atmosphere, creating ideal conditions for heavy precipitation. The presence of cold air in upper atmospheric levels together with a constant flow of moist air from the sea yielded the formation of deep convective cells generating intense and concentrated precipitation. Besides, easterly wind also intensified the development of these storms, keeping them active for more than 12 hours in the same area.

4. Localized Torrential Precipitation Pattern: During the episode, localities such as *Chiva* recorded extreme precipitation up to 491.2 mm in only 8 hours. The localized distribution and intensity of the precipitation in such a short time caused heavy runoff and accumulation of water collected by rivers and ravines which caused them to overflow leading to urban flooding, severely affecting homes, roads, and basic services in several areas.

5. Climate Change: Climate change is increasing the frequency and intensity of these phenomena in the Mediterranean basin. The increase in sea and atmospheric temperatures creates a favorable environment in the autumn period for episodes of extreme and sudden precipitation. This climatic context adds an element of greater risk and persistence to the COL episodes in the region, amplifying their impacts in vulnerable areas.

These factors - a prolonged and intense COL, the warmer Mediterranean, high atmospheric humidity, and the context of climate change - have made this flood event particularly devastating in the Valencia Region.

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