SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2025
Project Title:	SEVERE CONVECTIVE WEATHER PHENOMENA AND CLIMATE CHANGE
Computer Project Account:	SPESVALE
Principal Investigator(s):	FRANCISCO VALERO
Affiliation:	FACULTAD DE CIENCIAS FÍSICAS. UNIVERSIDAD COMPLUTENSE DE MADRID
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Mariano Sastre (UCM), Javier Díaz-Fernández (UCM), Pedro Bolgiani (UCM), Carlos Calvo (UVA), María Luisa Martín (UVA), Daniel Santos (DMI), José Ignacio Farrán (UVA), Juan Jesús González-Alemán (AEMET), Ana Montoro (UVA), Mauricio López-Reyes (UCM) UCM: Universidad Complutense de Madrid. Spain UVA: Universidad de Valladolid. Spain DMI: Danish Meteorological Institute. Denmark AEMET: Agencia Estatal de Meteorología. Spain
Start date of the project:	01/01/2025
Expected end date:	31/12/2027

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)			1200000	1165057
Data storage capacity	(Gbytes)			10000	10000

Summary of project objectives (10 lines max)

A severe hailstorm that occurred in Spain on 30 August 2022, caused material and human damage, including one fatality due to giant hailstones up to 12 cm in diameter was analyzed by applying the pseudo-global warming approach (PGWA; Martin et al., 2024), highlighting that a marine heatwave and anthropogenic climate change (ACC) affected a unique environment conductive to such giant hailstones. Here, we will apply the PGWA strategy to a wider range of severe convective weather phenomena (tornadoes, hailstorms, and intense thunderstorm outbreaks) that have had significant impacts on populations. The PGWA strategy modifies historical weather event data to reflect future climate conditions, enabling us to simulate and analysed how these severe weather phenomena may change as the climate continues to warm, identifying potential trends and patterns in the frequency, intensity, and spatial distribution of these extreme events under different climate scenarios.

Summary of problems encountered (10 lines max)

No problems have been found except in the simulation, at very high resolution, of some of those selected systems, mainly due to obtaining sub-hourly outputs when using the HARMONIE model.

Summary of plans for the continuation of the project (10 lines max)

In October 2024, Valencia (Spain) experienced rainfall accumulations in a few hours surpassing annual averages (771.8 mm in Turís official weather station) and record-breaking in one hour in Spain (184.6 mm), which promoted devastating flash-floods. This event resulted in 228 fatalities and was the major weather event in losses for contemporary Spain. The associated cut-off low (DANA) will be studied presenting a physical-based attribution study using the WRF model sourced with CMIP6 models to assess the contribution of ACC to rainfall intensity, moisture content, and storm dynamics (i.e., diabatic heating, vertical motions, microphysical processes).

Additionally, the cost-benefit analysis of the nesting approach in the HARMONIE-AROME model will be deeply analyzed when a study case of supercell outbreak in Spain is considered.

Other severe convective weather phenomena will be analyzed throughout the special project development.

List of publications/reports from the project with complete references

Publications

- Díaz-Fernández, J., C. Calvo-Sancho, P. Bolgiani, M. Sastre, M. López-Reyes, S. Fernández-González, M.L. Martín (2025). Effect of complex orography on numerical simulations of a downburst event in Spain. Atmospheric Research, 314, 107821; https://doi.org/10.1016/j.atmosres.2024.107821.
- Calvo-Sancho, C., Díaz-Fernández, J., González-Alemán, J.J., Halifa-Marín, A., Miglietta, M.M., Azorín-Molina, C., Prein, A.F., Montoro-Mendoza, A., Bolgiani, P., Morata, A., & Martín, M.L. (2025). Climate change unleashed: physical-based attribution analysis proves human-induced amplification of Valencia's deadly flooding. Nature Communications. Under Review.

- Montoro-Mendoza, A., Calvo-Sancho, C., González-Alemán, J.J., Díaz-Fernández, J., Bolgiani, P., & Martín, M.L. (2025). Strengthening of favorable environments for North Atlantic tropical cyclogenesis in midlatitudes in a warmer climate. npj Climate and Atmospheric Science. Under Review.
- Díaz-Fernández, J., Calvo-Sancho, C., Bolgiani, P., González-Alemán, J.J., Morata, A., Santos-Muñoz, D., & Martín, M.L. (2025). Case study of a supercell outbreak in Spain and cost-benefit analysis of the nesting approach in HARMONIE-AROME. Atmospheric Research. Under Review.
- López-Reyes, M., Martín, M.L., Calvo-Sancho, C. & González-Alemán, J.J. (2025). The key role of trough-tropical cyclone interaction in the rapid intensification of Hurricane Lidia. Geophysical Research Letters. Under Review.
- García-Miguel, A., Díaz-Fernández, J., Calvo-Sancho, C., López-Reyes, M., Bolgiani, P., & Martín, M.L. (2025). Future changes in wind energy source in Spain. In preparation.
- Calvo-Sancho, C., Rotunno, R., Montoro-Mendoza, A., González-Alemán, J.J., Bolgiani, P., & Martín, M.L. (2025). The role of moist convection and mesoscale processes in achieving the final stage of a tropical transition: Hurricane Ophelia [2017]. In preparation.

Conferences/Meetings:

- Azorin-Molina, C., Granell, F., Gomez-Reyes, J., Calvo-Sancho, C., Barrio-Martín, A., Plaza-Martin, N.P., Prein, A.F., Vicente-Serrano, S.M., Gimeno, L., Nieto, R., Chen, D., McVicar, T.R., Zeng, Z., Pirooz, A., Martínez-Roig, M., González-Alemán, J.J., Martín. M.L.: The DOWNBURST MXO: a real-time downburst monitoring service in eastern Spain, 12th European Conference on Severe Storms, Utrecth, Netherlands, 17–21 November 2025, ECSS2025-55, https://doi.org/10.5194/ecss2025-55, 2025.

- Calvo-Sancho, C., Díaz-Fernández, J., González-Alemán, J. J., Halifa-Marín, A., Miglietta, M.M., Azorín-Molina, C., Prein, A.F., Montoro-Mendoza, A., Bolgiani, P., Morata, A., and Martín, M. L.: Storm Dynamics-based Attribution to the Valencia's deadly floods, 12th European Conference on Severe Storms, Utrecth, Netherlands, 17–21 November 2025, ECSS2025-54, https://doi.org/10.5194/ecss2025-54, 2025.

- Calvo-Sancho, C., Martín, Y., González-Alemán, J. J., Azorin-Molina, C., Martín, M. L.: Supercells and large hail in Spain, 12th European Conference on Severe Storms, Utrecth, Netherlands, 17–21 November 2025, ECSS2025-53, https://doi.org/10.5194/ecss2025-53, 2025.

- Calvo-Sancho, C., Díaz-Fernández, J., González-Alemán, J. J., Halifa-Marín, A., Miglietta, M.M., Azorín-Molina, C., Prein, A.F., Montoro-Mendoza, A., Bolgiani, P., Morata, A., and Martín, M. L.: Anthropogenic Climate Change Attribution to the Valencia's deadly floods, EMS Annual Meeting 2025, Ljubljana, Slovenia, 7–12 Sep 2025, EMS2025-504, https://doi.org/10.5194/ems2025-504, 2025.

- Calvo-Sancho, C. , Díaz-Fernández, J., González-Alemán, J. J., Azorín-Molina, C., Halifa-Marín, A., Montoro-Mendoza, A., Bolgiani, P., Beguería, S., Vicente-Serrano, S. M., Morata, A., and Martín, M. L.: Anthropogenic Climate Change Attribution to a Record-breaking Precipitation Event in October 2024 in Valencia, Spain , EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-15941, https://doi.org/10.5194/egusphere-egu25-15941, 2025.

- Halifa-Marín, A., Calvo-Sancho, C., Gil-Guallar, M., Royo-Aranda, A., Beguería, S., and Vicente-Serrano, S. M.: Reconstructing Extreme Weather Events in the Southeastern Iberian

Peninsula: Lessons from the Winter of 1944/45, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-18487, https://doi.org/10.5194/egusphere-egu25-18487, 2025.

- González-Alemán,J.J., Gómez-Plasencia, P., Calvo-Sancho, C., Martín, M. L: Convective activity behaviour on tropical cyclones impacting Europe in a warmer world. 12th European Conference on Severe Storms, ECSS2025-202, Utrecht, Netherlands – 17 to 21 November 2025.

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

On 29 October 2024, the eastern Spanish region of Valencia experienced one of the most devastating flash flood events in recent history, with record-breaking rainfall rates and accumulations exceeding annual averages in a matter of hours. The hydrological response was overwhelming, promoting extensive flash floods in the metropolitan area south of Valencia. In addition to the heavy rainfall associated with the convective system, 11 tornadoes and large hail were observed (AEMET, 2024). The event resulted in at least 228 fatalities, extensive damage to infrastructure, and economic losses estimated in several billions of euros (Llasat, 2024).

The event was driven by a cut-off low over the Iberian Peninsula (Figure 1a), creating a baroclinic environment where cold air aloft contrasted with warm, moist low-level air advected from the subtropical Atlantic. This strong contrast triggered convective instability and quasi-stationary convective systems (Figure 1b). The DANA or cut-off low enhanced convection inducing upper-level divergence and promoted the intense horizontal moisture advection via atmospheric river-like from the subtropical Atlantic, increasing the supply of humid air and raising the potential for severe storms. This pattern often plays a key role in torrential rainfall events in the eastern Iberian Peninsula (Lorente-Plazas et al., 2020; Beguería et al. 2025).

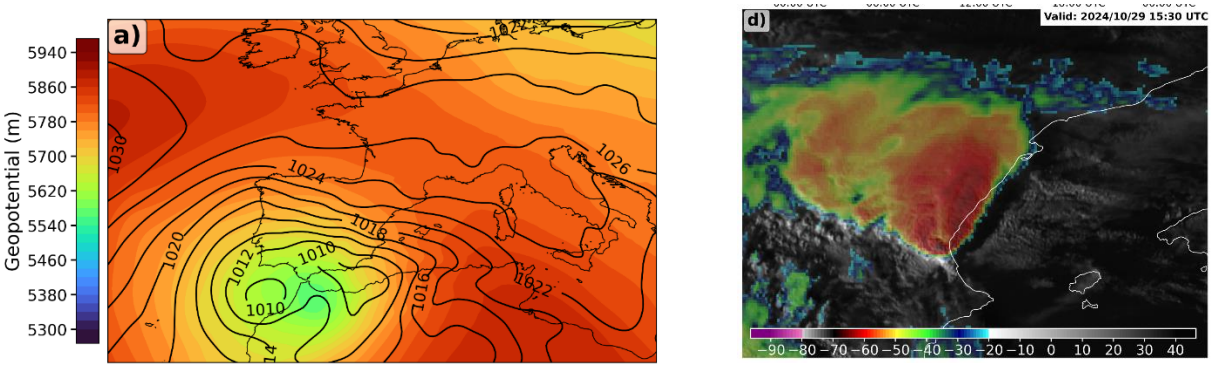


Figure 1: Valencia's deadly floods are the highest impact climate event in recent Spanish history. (a) Geopotential at 500 hPa (shaded) and sea level pressure (contour) on October 29th, 2024, 12 UTC. (b) View of the storm from Meteosat Second Generations taken at 15:30 UTC in the IR10.8 mm channel.

This catastrophe highlights the vulnerability of Mediterranean regions to extreme precipitation events, which seems to be exacerbated in recent years by ACC (González-Alemán et al., 2023; Martin et al., 2024). The anomalously high SST in the western Mediterranean, which keep increasing and reached record levels during summer 2024 (Cheng et al. 2024), likely intensified the event through thermodynamic forcing, increasing atmospheric moisture content and enhancing convective instability (Fischer & Knutti, 2016).

We present a physical-based attribution study using the WRF model sourced with CMIP6 models to assess the ACC contribution to rainfall intensity, moisture content, and storm dynamics (i.e., diabatic heating, vertical motions, microphysical processes). Table 1 shows the CMIP6 models finally selected in the DANA of Valencia case study.

Table 1: CMIP6 models selected for this study case. Further details for each model are available in the references listed in this table.

GCM	Institute ID	Resolution (lat. x lon.)	Reference
AWI-CM-1-1-MR	AWI (Germany)	0.937º x 0.937º	Semmler et al. (2018)
CESM2-WACCM	NCAR (USA)	1.3º x 0.9º	Danabasoglu (2019)
EC-Earth3	EC-Earth-Consortium (Europe)	0.7º x 0.7º	EC-Earth (2019)
FGOALS-g3	CAS (China)	2º x 2º	Li et al. (2020)
GISS-E2-1-G	NASA (USA)	2º x 2.5º	Kelley et al. (2020)
GISS-E2-1-H	NASA (USA)	2º x 2.5º	Kelley et al. (2020)
INM-CM4-8	INM (Russia)	1.5º x 2º	Volodin et al. (2018)
INM-CM5-0	INM (Russia)	1.5º x 2º	Volodin et al. (2018)
IPSL-CM6A-LR	IPSL (France)	1.3 x 2.5º	Boucher et al. (2018)
MCM-UA-1-0	UA (USA)	2.25º x 3.75º	Stouffer (2019)
MIROC-ES2L	MIROC (Japan)	2.8º x 2.8º	Tachiiri et al. (2019)
MIROC6	MIROC (Japan)	1.4º x 1.4º	Tatebe et al. (2019)
MRI-ESM2-0	MRI (Japan)	1.121º x 1.125º	Yukimoto et al. (2019)
NorESM2-LM	NCC (Norway)	1.9º x 2.5º	Seland et al. (2020)
NorESM2-MM	NCC (Norway)	0.94º x 1.25º	Seland et al. (2020)

In this study, a convection-allowing model with 1-km horizontal grid spacing to simulate the event in the present-day (factual, 2009-2038) and pre-industrial-like climate (counterfactual, 1850-1879) is utilized, using the physical-based attribution approach. This methodology enables for a thorough evaluation of how ACC has intensified the extraordinary Valencia floods of October 2024 by examining changes in rainfall intensity and spatial coverage, changes in moisture content, and shifts in the underlying physical mechanisms governing this extreme rainfall event.

Observed climate change led to more intense precipitation and a greater extent of this extreme rainfall event by +20% C-1 in 1-h rainfall rate. Enhanced availability of atmospheric water vapor due to higher Mediterranean and subtropical North Atlantic SST played a central role, while CAPE, diabatic heating, and stronger vertical velocities boosted the convective processes. A deeper warm cloud layer and elevated graupel concentration reveal microphysical mechanisms that enhanced precipitation volumes in a warmer climate (Calvo-Sancho et al., 2025). These results demonstrate that ACC intensifies flash-flood risks in the Mediterranean region, and in this particular case, intensified the 6-h rainfall rate by 21%, amplified the 180 mm total rainfall area by 55% and increased the volume of total rain within the river Jucar catchment by 19% compared to the pre-industrial era. This study highlights the urgent need for effective adaptation strategies and improved urban planning to reduce the growing risks of hydrometeorological extremes in a rapidly warming world.

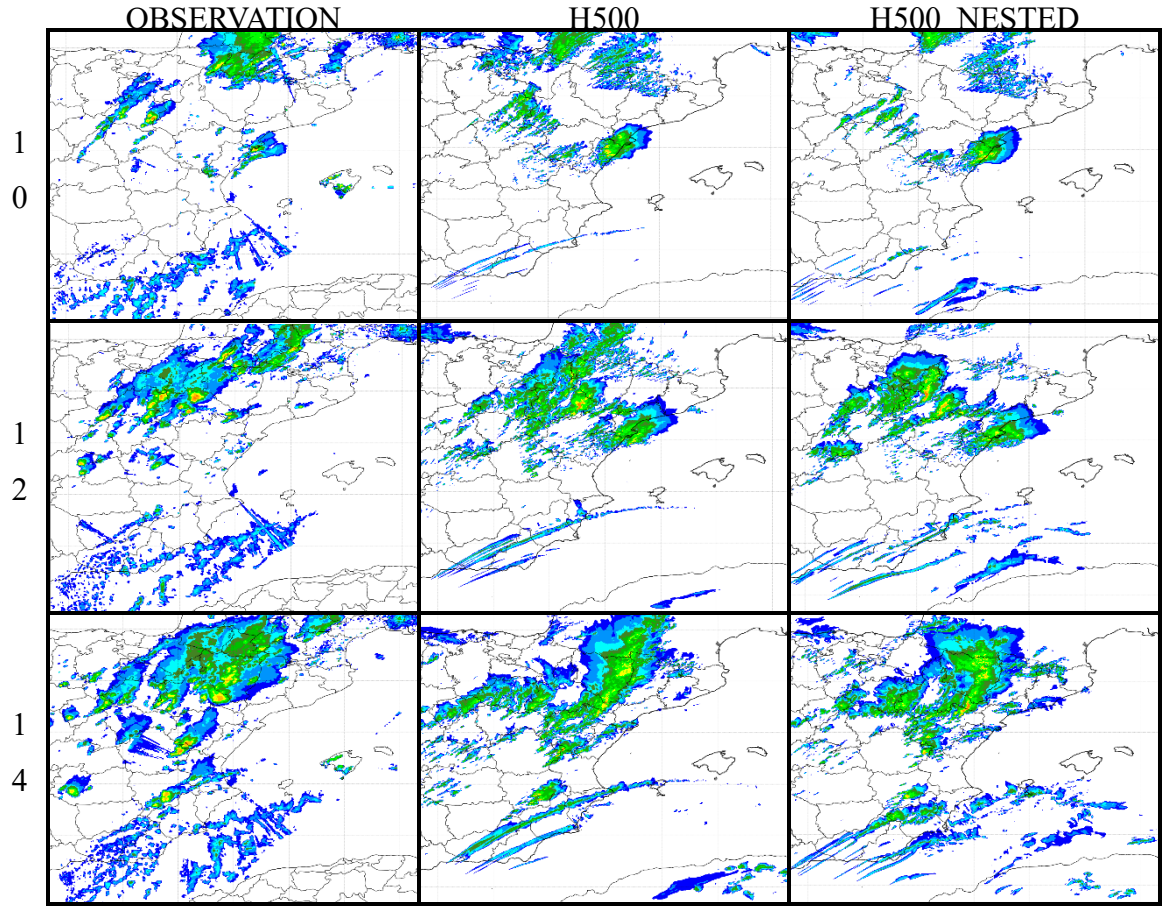
Another extreme event is additionally studied (Díaz-Fernández et al., 2025). A supercell outbreak in Spain (31 July 2015) is analyzed in the behavior of the HARMONIE-AROME model when two different approaches are studied: with nesting (H500 NESTED) and with a single domain (H500). The cost-benefit analysis of the nesting approach is deeply analyzed showing non-necessity of nesting in the model simulation (Figure 2). An observed sounding at Murcia (SE Spain) is considered, to be compared with the two simulation soundings.

Main conclusions can be summarized as follow:

Both, H500_NESTED and H500 show similar overall performance in simulating the supercell event. While H500_NESTED provides a more accurate representation of specific aspects, such as convective core structure, high reflectivity values, and a better approximation to observed temperature and wind patterns, these improvements are marginal. Moreover, H500_NESTED requires 30% more computational resources than H500, making the single-domain H500 configuration a more efficient and cost-effective option for simulating such events.

Both simulations capture the general structure of the atmospheric profile but tend to underestimate instability and helicity, which could impact the accurate prediction of storm intensity and rotation. Although convective parameters such as CIN, WS06, SRH03, and SCP in H500_NESTED are closer to those observed in the Murcia sounding, the improvements do not justify the additional computational cost. On the other hand, the CAPE values simulated by H500 closely match observations.

Given the negligible advantages of the nesting approach in this study, future simulations may prioritize single-domain high-resolution setups like H500 for severe convective event analysis, particularly when computational resources are limited. Also, it would be interesting to investigate the influence of complex orography and a warmer Mediterranean Sea play in these severe convective events.



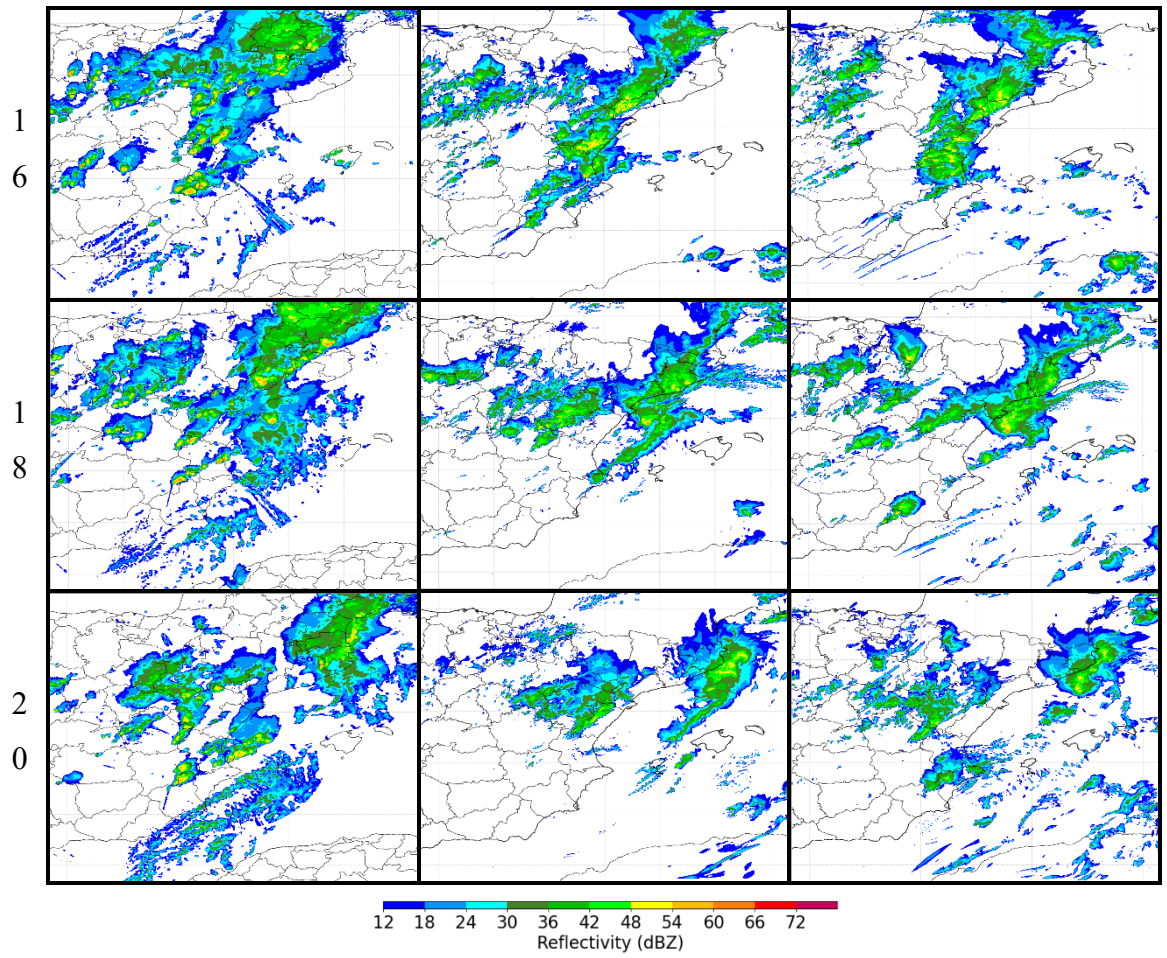


Figure 2. Maximum reflectivity observed (OBSERVATION) and simulated (H500 and H500_NESTED) for the period 10:00 – 20:00 UTC 31 July 2015.

References:

Beguería, S., & Azorín Molina, C. (2024). Ground records and spatial fields of the 2024/10/29 extreme precipitation event in Valencia, Spain [Dataset]. Consejo Superior de Investigaciones Científicas (España). http://doi.org/10.20350/DIGITALCSIC/16716

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Cheng, L., Abraham, J., Trenberth, K.E. et al. Record High Temperatures in the Ocean in 2024. Adv. Atmos. Sci. (2025). https://doi.org/10.1007/s00376-025-4541-3

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Lorente-Plazas, R., et al. Unusual atmospheric-river-like structures coming from Africa induce extreme precipitation over the western Mediterranean Sea. J. Geophys. Res. Atmos., 125 (2020). https://doi.org/10.1029/2019JD031280

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