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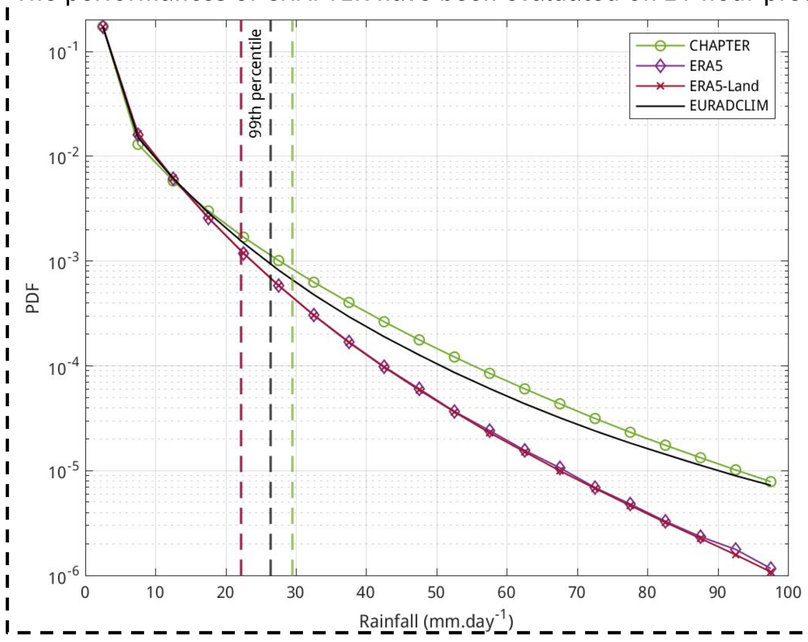
Thermodynamic and Dynamic Contribution in Hourly Extreme Precipitation Changes over Europe and the Mediterranean Basin

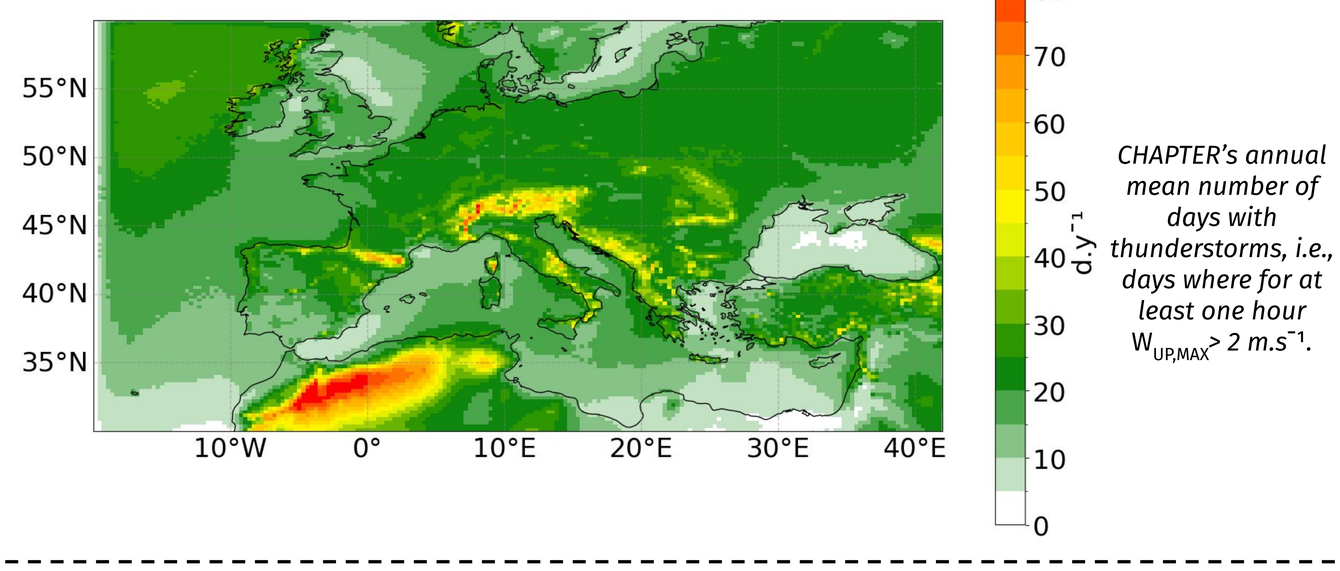
Take Home Message: The high-resolution CHAPTER dataset offers new opportunities to investigate high-impact weather events across Europe and the Mediterranean. Analysis of CHAPTER reveals a significant increase in extreme precipitation over recent decades. A diagnostic has been applied to decompose these trends into two components: a thermodynamic part, driven by the increased moisture-holding capacity of a warmer atmosphere, and a dynamic part, governed by changes in vertical motion. While the thermodynamic component shows a modest positive trend across most of the domain, changes in convective dynamics emerge as the dominant factor, more accurately reproducing the spatial distribution and intensity of precipitation extremes seen in the model. These results highlight the central role of dynamical processes in shaping both observed and changes in regional extreme rainfall.

CHAPTER: A New High-Resolution Dataset

CHAPTER (Computational Hydrometeorology with Advanced Performance to Enhance Realism) is a convection-permitting dynamical downscaling of the ERA5 global reanalysis. CHAPTER has a grid spacing of **3 km by 3 km** and **hourly** temporal resolution for the period **1981-2022**, allowing for detailed and precise simulations of atmospheric phenomena. The performances of CHAPTER have been evaluated on 24-hour precipitation accumulation and 2-m daily mean temperature (Bernini *et al.*, 2025, see QR code).

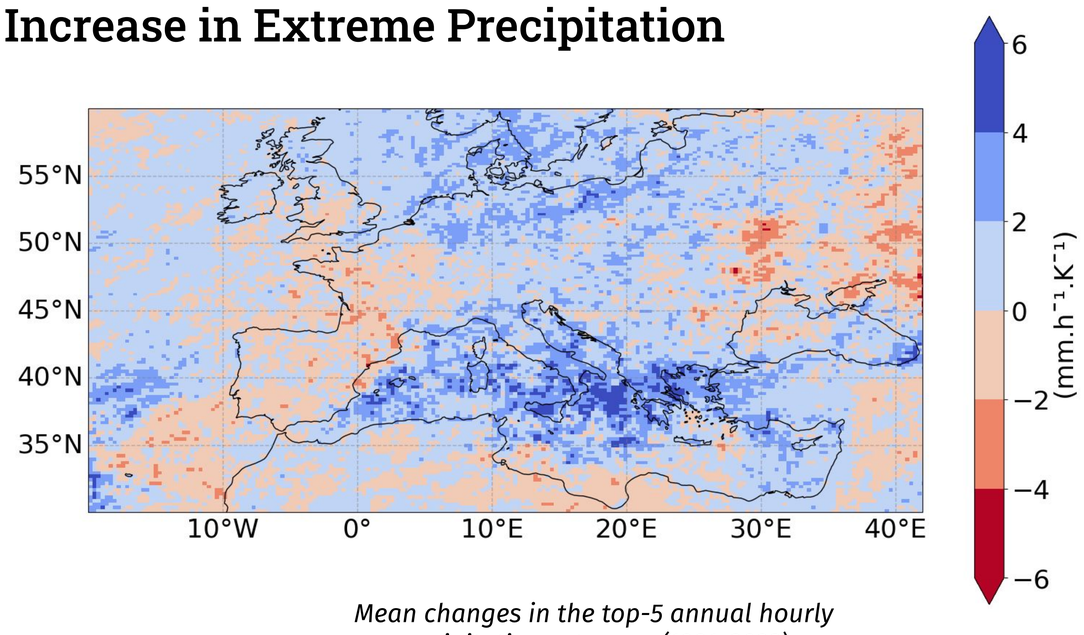


Probability density function of the annual daily mean precipitation for the period 2013-2022 for the datasets: EURADCLIM, ERA5, ERA5-Land, and CHAPTER.



CHAPTER's annual mean number of days with thunderstorms, i.e., days where for at least one hour $W_{UP,MAX} > 2\ m.s^{-1}$.

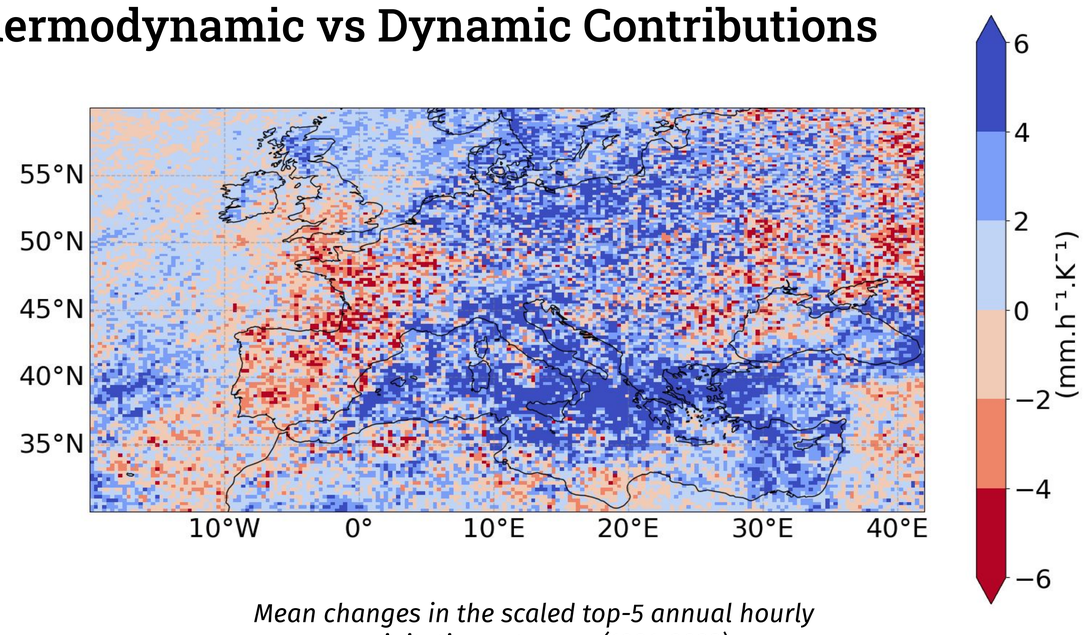
Increase in Extreme Precipitation



Mean changes in the top-5 annual hourly precipitation extremes (1981–2022).

Spatial correlation of 0.73

Thermodynamic vs Dynamic Contributions



Mean changes in the scaled top-5 annual hourly precipitation extremes (1981–2022).

For the period 1981-2022, the average annual maximum precipitation over the entire domain is 12.5 $mm.h^{-1}$. During the same period, the mean temperature increase over the whole domain is **+1.3 K**, and the annual maximum precipitation has increased by **+0.8 $mm.h^{-1}$** (or +1.6 $mm.h^{-1}$ for the positive trends only).
However, different spatial patterns are observed: the positive trends are observed in most of the **Mediterranean and North Sea**, with increases up to **7 $mm.h^{-1}$** (corresponding to **+50%**) , while the western part of France and the border between eastern Europe and Russia experienced negative trends.

Decomposing Extreme Precipitation Drivers

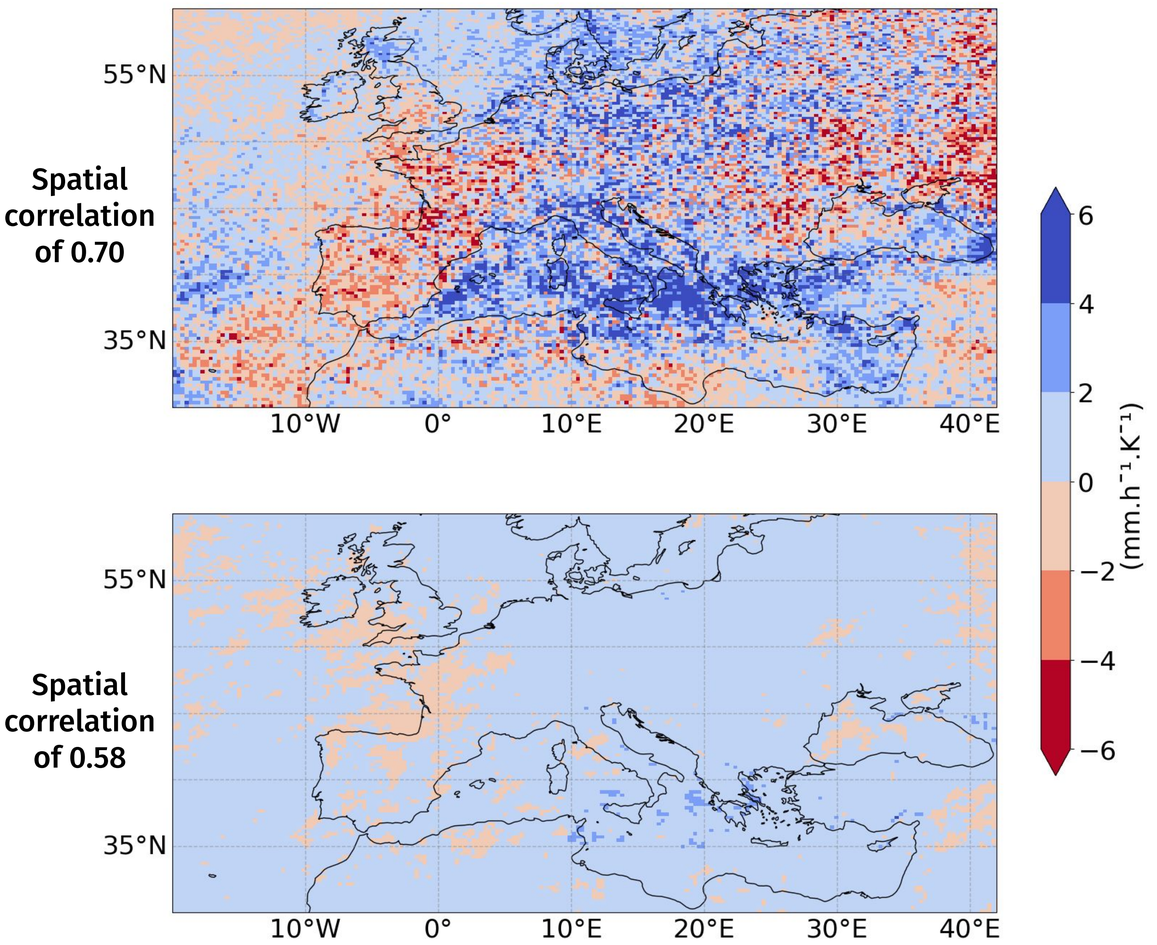
Following O'Gorman and Schneider (2009), Sugiyama *et al.* (2010), and Pfahl *et al.* (2017), the hourly maxima precipitation found in CHAPTER has been approximated with a physical scaling diagnostic. This scaling allows the decomposition of maximum precipitation changes into thermodynamic and dynamic contributions:

$$P_e \sim -\left\{ \omega_e \frac{dq_s}{dp}\bigg|_{\theta*} \right\}$$

Where P_e, the annual maximum daily precipitation at each model grid point, is related to the corresponding vertical pressure velocity ω_e and the vertical derivative of the saturation specific humidity q_s at constant saturation equivalent potential temperature θ^*. Finally, {.} indicates a mass-weighted vertical integral over the troposphere.

Spatial correlation of 0.70

Spatial correlation of 0.58



Mean changes in the dynamic scaling where the temperature is kept constant (top), and in the thermodynamic scaling in which the vertical velocity ω_e is kept constant (bottom).

References: Karger, D. N., Wilson, A. M., Mahony, C., Zimmermann, N. E., and Jetz, W. (2021). Global daily 1 km land surface precipitation based on cloud cover-informed downscaling. *Scientific Data*, 8(1):307. Munoz-Sabater, J., Dutra, E., Agust´ı-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H., et al. (2021). Era5-land: A state-of-the-art global reanalysis dataset for land applications. *Earth system science data*, 13(9):4349–4383. O'Gorman, P. A. and Schneider, T. (2009). The physical basis for increases in precipitation extremes in simulations of 21st-century climate change. *Proceedings of the National Academy of Sciences*, 106(35):14773–14777. Overeem, A., van den Besselaar, E., van der Schrier, G., Meirink, J. F., van der Plas, E., and Leijnse, H. (2022). Euradclim: the european climatological high-resolution gauge-adjusted radar precipitation dataset. *Earth System Science Data Discussions*, 2022:1–34. Pfahl, S., O'Gorman, P. A., and Fischer, E. M. (2017). Understanding the regional pattern of projected future changes in extreme precipitation. *Nature Climate Change*, 7(6):423–427. Sugiyama, M., Shiogama, H., and Emori, S. (2010). Precipitation extreme changes exceeding moisture content increases in miroc and ipcc climate models. *Proceedings of the National Academy of Sciences*, 107(2):571–575.