Compound dry and hot extreme events in the Mediterranean region

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1. Objetives and motivation

Recent years have seen an increase in the number, duration and magnitude of heatwaves and droughts, leading to an increase in compound dry and hot events (CDHEs) in southern Europe and the Mediterranean. The aim of this work is therefore to provide a historical characterization of heatwaves and droughts, and to identify the mechanisms responsible for the development of these types of events from 1979 until 2022.

2. Data and methods

Heatwaves were identified when temperatures exceeded the 90th percentile for at least 5 days (Perkins and Alexander, 2013). Droughts were identified when the Standardized Precipitation Index (SPI) is below -1 for at least 2 months (McKee et al., 1993). CDHEs were identified when heatwaves and droughts occurred simultaneously on a pixel basis.

Integrated Water Vapour Transport (IVT) anomalies (Eq. 1) and their divergence (Eq. 4) for 2022 were analyzed on an annual and monthly basis. These results were complemented with the study of the water vapour balance in Iberia.

$$IVT = \left[\left(\frac{1}{g}\int_{SURF}^{TOA} qudp\right)^2 + \left(\frac{1}{g}\int_{SURF}^{TOA} qvdp\right)^2\right]^{\frac{1}{2}} \quad \text{(Eq. 1)}$$

with,

$$Q_\lambda = \frac{1}{g}\int_{SURF}^{TOA} qudp \quad \text{(Eq. 2)}$$

$$Q_\phi = \frac{1}{g}\int_{SURF}^{TOA} qvdp \quad \text{(Eq. 3)}$$

$$\nabla.\vec{Q} = \frac{\partial Q_\lambda}{\partial x} + \frac{\partial Q_\varnothing}{dy} \quad \text{(Eq. 4)}$$

3. Historical characterization

Figs. 1A and **1B** show that the 2000-22 period show a shift towards conditions favorable to the development of hot and dry events, with higher temperatures and lower soil moisture. **Figs. 1C** show a negative decadal trend (-0.0077 m^3/m^3) with inter-annual variability.

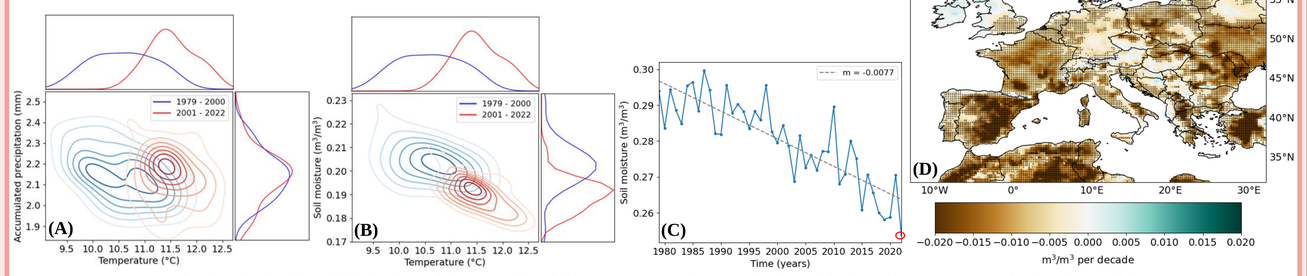

Fig. 1 – Bivariate Kernel distributions of the anomalies of (A) temperature and accumulated precipitation; (B) temperature and soil moisture; (C) interannual variability of soil moisture from 1979 to 2022; (D) and trends of soil moisture (dots depict statically significant trends at a 5% level).

In contrast to droughts, both heatwaves and CDHEs show a significative temporal trend, which are positive and statistically significant for heatwaves and CDHEs. The atmospheric configurations most often associated to the occurrence of heatwaves and CDHEs are similar and are characterized by more intense anomalies (**Fig. 2**).

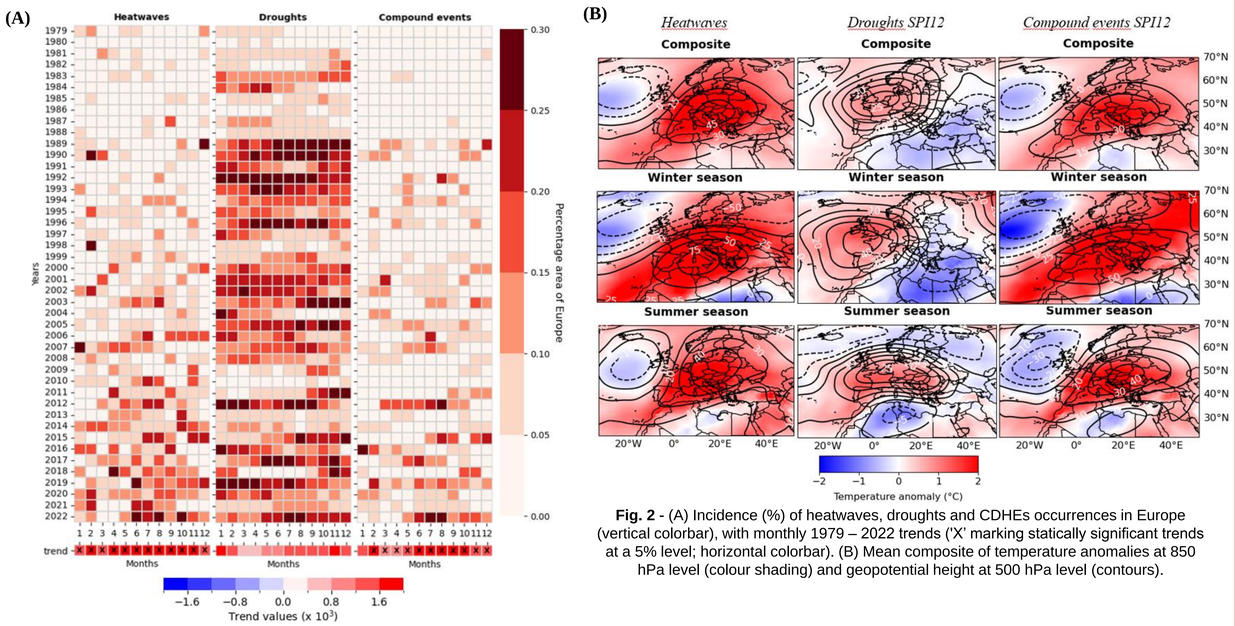

Fig. 2 - (A) Incidence (%) of heatwaves, droughts and CDHEs occurrences in Europe (vertical colorbar), with monthly 1979 – 2022 trends ('X' marking statically significant trends at a 5% level; horizontal colorbar). (B) Mean composite of temperature anomalies at 850 hPa level (colour shading) and geopotential height at 500 hPa level (contours).

4. Driving mechanisms

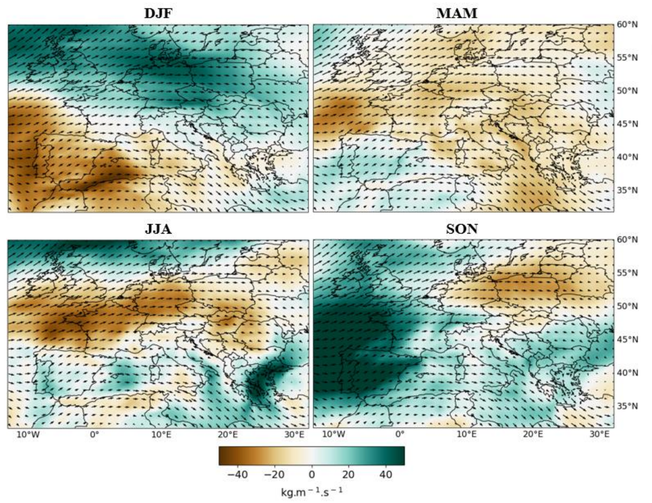

Fig. 3 – Seasonal IVT anomaly (regarding the 1981 – 2010 climatology) during 2022 (absolute field – colour shading; direction – vectors).

- In 2022, strongest negative anomalies of IVT are mainly observed over central Europe during MAM and JJA, while Iberia experienced positive IVT anomalies during all seasons except in DJF (**Fig. 3**).
- Enhanced divergence motions linked to anomalous subsidence in the atmosphere led to water vapour dissipation over central Europe (Iberia) during MAM (JJA) (**Fig. 4**). The opposite was observed in Iberia during SON.

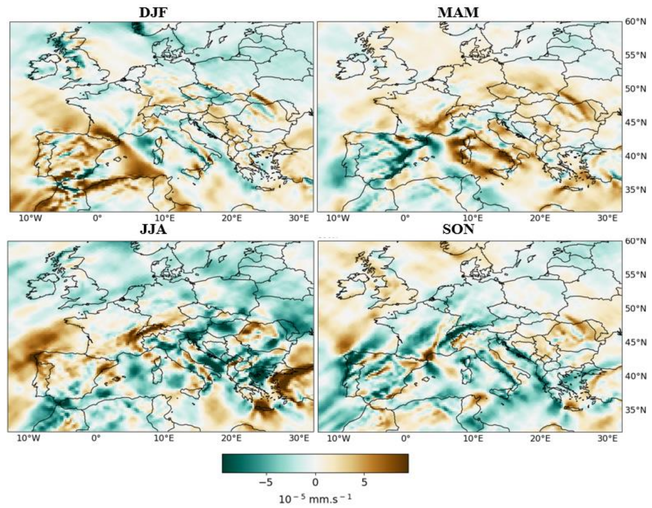

Fig. 4 – Seasonal anomalies of moisture divergence (regarding the 1981 – 2010 climatology) during 2022.

- This lower than expected moisture input and enhance moisture divergence matches the previously observed anticyclonic circulation pattern over central Europe, which was found to be the main dynamical driver to the exceptional hot and dry conditions in this particular year.

5. Conclusions

1) Europe has been witnessing a decrease in the soil moisture level in recent decades, which is related to an increasing incidence of heatwaves, droughts and CDHE.
2) The year of 2022 stands out as an exceptional hot and dry period fitting the previously discussed trend.
3) Deficits in moisture supply and convergence followed by clear-sky conditions, linked to enhanced evaporation and diabatic heating triggered the severe CDHE in 2022.

References

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McKee et al. (1993). https://climate.colostate.edu/pdfs/relationshipofdroughtfrequency.pdf

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