Compound dry and hot extreme events in the Mediterranean region

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Objectives 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 aims of this work is:

- to provide a historical characterization of heatwaves, droughts and CDHEs from 1979 until 2022;
- to identify the driving mechanisms for the development of these events (2022 as a study case).

Data and methodology

Heatwaves were identified when temperatures exceed 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. The nature of the atmospheric circulation was investigated using temperature anomalies at 850 hPa level and geopotential height at 500 hPa level and analyzed based on *DaCamara and Trigo (2000)*. Integrated Water Vapor Transport (IVT) anomalies *(Eq. 1)* and their divergence *(Eq. 4)* for 2022 were analyzed on a seasonal basis. These results were complemented with the study of the correlation between teleconnections and the water vapor that reaches Europe through the western border of the study area.

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

$$Q_\lambda = \frac{1}{g}\int_{SURF}^{TOA} qudp,\ Q_\phi = \frac{1}{g}\int_{SURF}^{TOA} qvdp \quad (2, 3)$$

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

Historical characterization of extreme events

- 2001 – 2022 show a shift towards conditions **favorable to the development of hot and dry events**, with higher temperatures and lower soil moisture *(Figs. 1a, 1b)*. Soil moisture trends are negative with strong influence in **southern Europe** *(Figs. 1c, 1d)*.

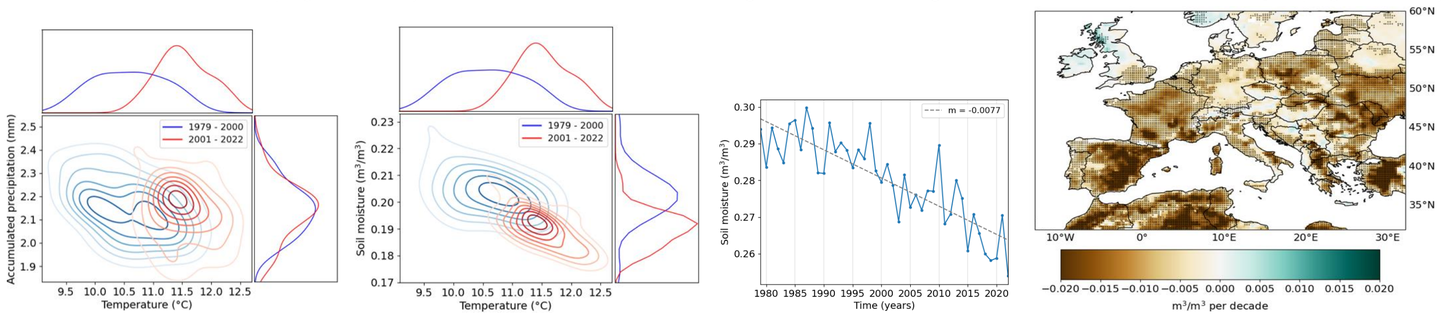


Fig. 1 – Bivariate kernel distributions of the anomalies of temperature and accumulated precipitation (a) and soil moisture (b), interannual variability of soil moisture from 1979 to 2022 (c) and trends of soil moisture (dots depict statistically significant at a 5% level) (d).

- 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)*.

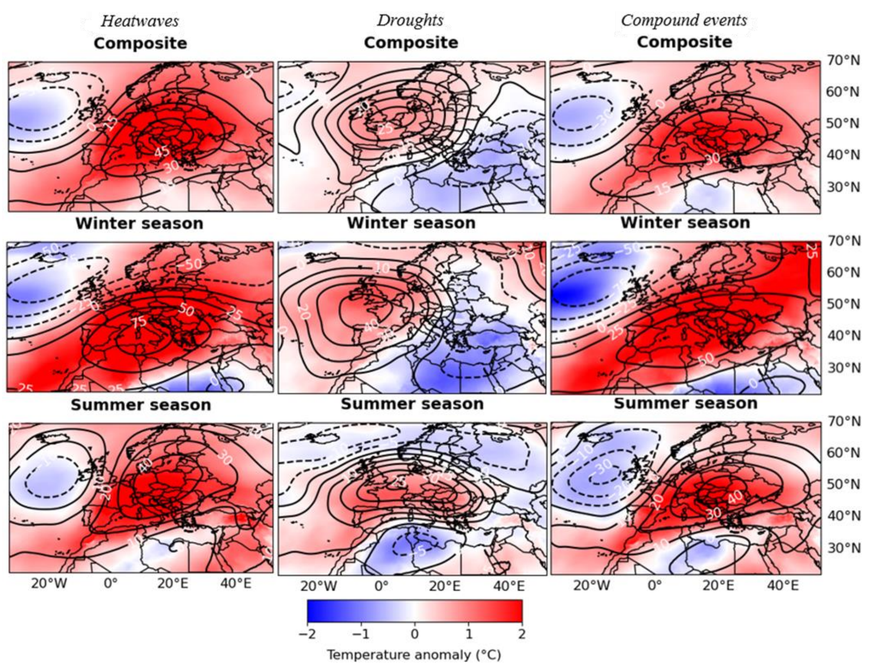
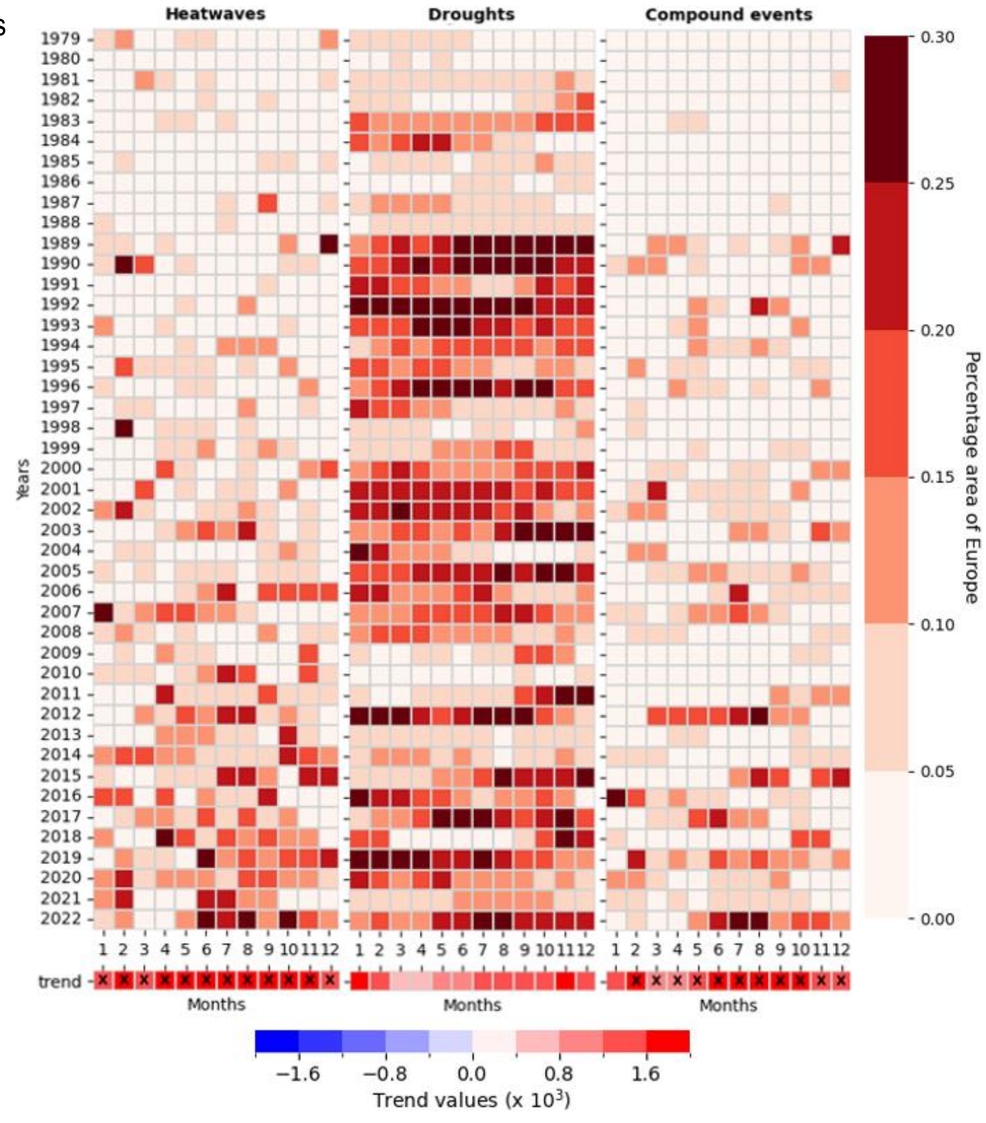


Fig. 2 – Incidence (%) of heatwaves, droughts and CDHEs occurrences in Europe (vertical colorbar), with monthly 1979 – 2022 trends ('X' marking statically significant trends at a 5% level; horizontal colorbar) (a), and mean composite of temperature anomalies at 850 hPa level (color shading) and geopotential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



2022 CDHE as a study case

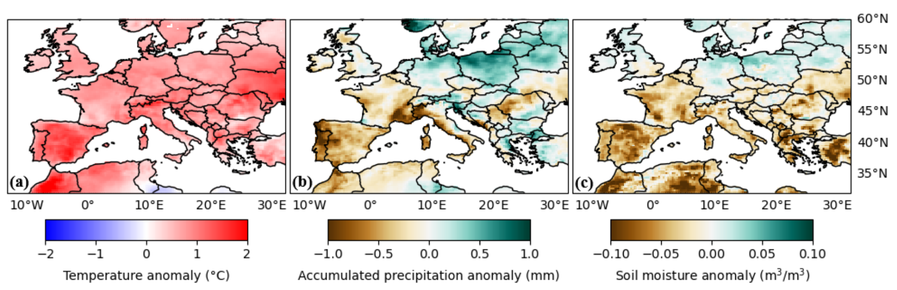


Fig. 3 – Spatial anomalies of temperature (a), accumulated precipitation (b), and soil moisture (c) for 2022.

- In 2022, **strong positive temperature anomalies** were experienced over Europe and **negative precipitation and soil moisture anomalies** were experienced in the Mediterranean region *(Fig. 3)*, accompanied by a **persistent anticyclone over Europe** *(Fig. 4)*.

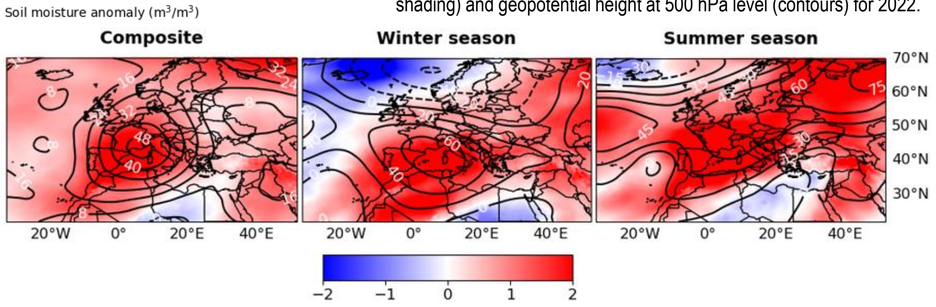


Fig. 4 – Mean composite of temperature anomalies at 850 hPa level (color shading) and geopotential height at 500 hPa level (contours) for 2022.

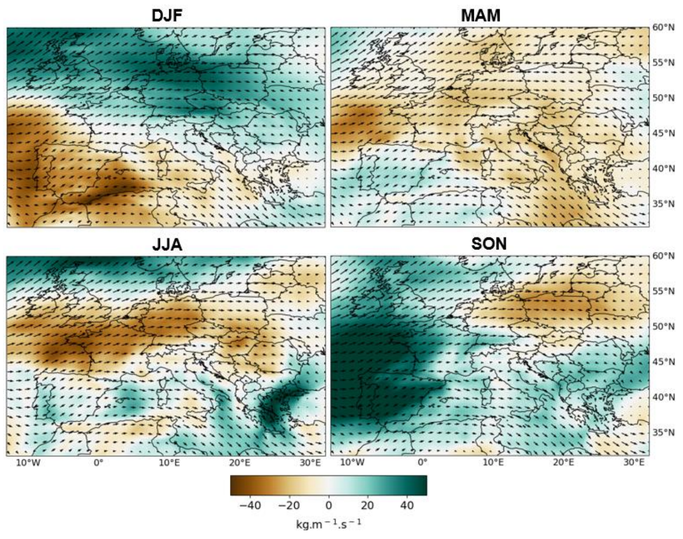


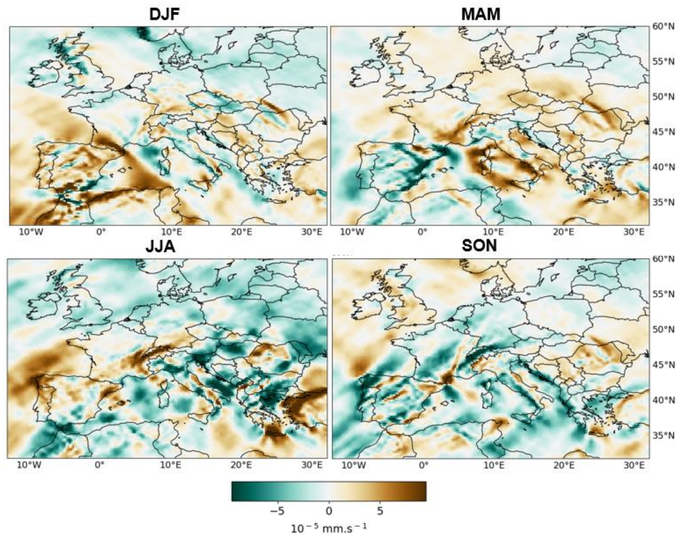
Fig. 5 – Seasonal IVT anomaly (regarding the 1981 – 2010 climatology) during 2022 (absolute field – color shading; direction – vectors).

- 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 *(Fig. 6)*.

Fig. 6 – Seasonal anomalies of moisture divergence (regarding the 1981 – 2010 climatology) during 2022 (absolute field – color shading; direction – vectors).

- **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. 5)*.

- **Enhanced divergence** motions linked to **anomalous subsidence** in the atmosphere led to **water vapor dissipation over central Europe** (Iberia) during MAM (JJA) *(Fig. 5)*. The opposite was observed in Iberia during SON.



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 the severe CDHE in 2022.

References

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