EXPECT Science explainer

Uncovering the impact of land surface interactions on weather and climate extremes

HEAT WAVE FEEDBACKS | SOIL MOISTURE | LAND–ATMOSPHERE INTERACTIONS

FULL NAME

Stefano Materia

INSTITUTION & DEPARTMENT

Established researcher at Barcelona Supercomputing Center

EXPERTISE

Ph.D. in Geophysics, University of Bologna

SUMMARY

Heat waves are triggered by atmospheric circulation, while land surface modulates the near-surface response. In EXPECT, we explore this dialogue - how water, energy, and vegetation interact across seasons to influence climate extremes. From dry soils to forested or deforested landscapes, human and natural factors together decide whether the land amplifies or eases the intensity and duration of extreme heat.

How do land surface conditions influence the formation of heat waves?

Stefano Materia: Land surface conditions such as soil moisture, vegetation, and terrain heterogeneity affect how water and energy are exchanged with the atmosphere. When soil is dry, less water is available for evaporation, reducing cooling and causing surface temperatures to rise. Conversely, moist soils enhance evaporation, cooling the air near the ground *(Figure 1)*. These interactions determine whether heat waves intensify or remain moderate, showing how the land acts as both a driver and a regulator of extreme heat.

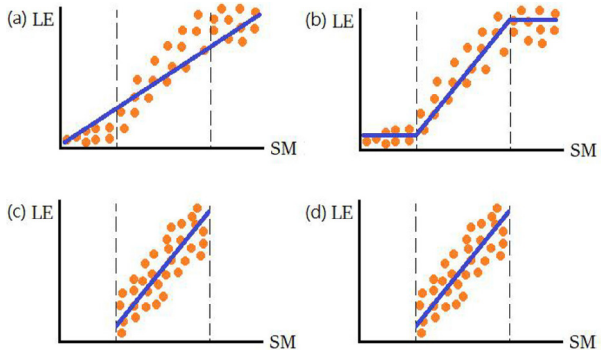
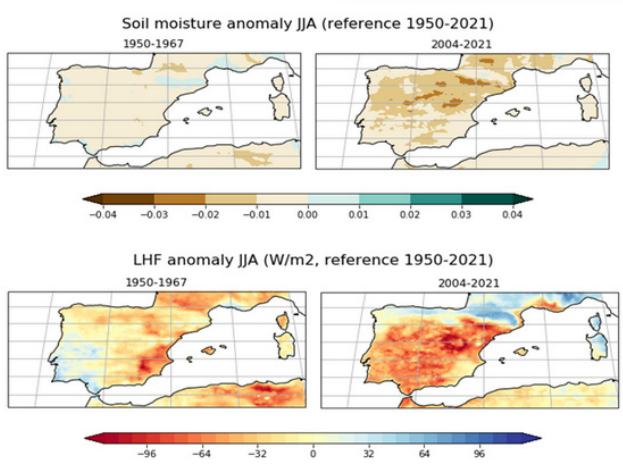


Figure 1: Soil moisture (SM) in x-axis, latent heat (evaporation) in y-axis (LE). Below the wilting point, soil water is not sufficient for plants' physiological activity. Above the critical threshold, radiation and wind totally control evaporation. In between, soil water controls the partition between sensible and latent heat fluxes, therefore the evaporation. Hsu, H., & Dirmeyer, P. A. (2022).

Why are spring-to-summer feedbacks important for understanding Mediterranean heat waves?

S.M.: In Mediterranean climates, soil moisture scarcity in the spring likely persists across the summer, leaving little capacity for evaporative cooling in summer. As solar radiation increases, the land heats faster, triggering stronger heat waves and soil stress. In contrast, wet spring soils enhance evaporation, which cools the lower atmosphere and buffers heat extremes *(Figure 2)*. Understanding these seasonal feedbacks helps scientists predict the severity of summer heat waves and anticipate their local impacts.



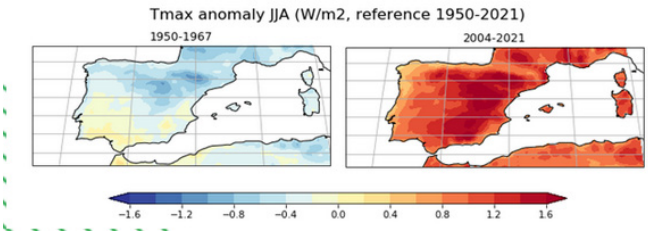


Figure 2: Soil moisture, latent heat flux and 2-meter temperature in the western Mediterranean in 1950-1967 and 2004-2021 (Materia et al., in preparation)

How can artificial intelligence support land–atmosphere research?

S.M.: AI and machine learning can reveal new drivers of land–atmosphere interactions by analysing complex data patterns that traditional models might overlook. These tools can identify relationships between soil, vegetation, and heat extremes, supporting better prediction of weather events (Figure 3). However, AI must be guided by sound physical understanding to ensure meaningful insights. Combining data-driven approaches with classical climate science helps improve accuracy and bridge knowledge gaps.

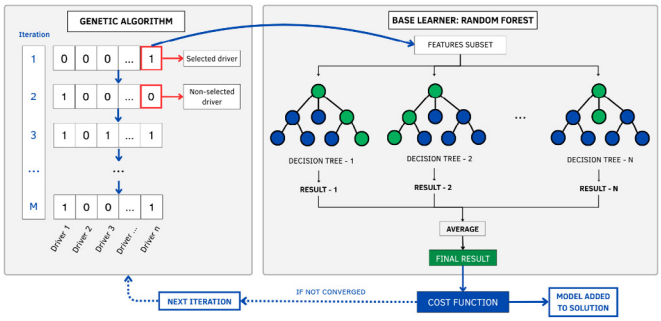


Figure 3: Machine Learning architecture, based on a feature selection algorithm (Guided Hybrid Genetic Algorithm) wrapped around a base learner (Random Forest). (Materia et al., in preparation).

LOOKING FORWARD

Gaining a clearer understanding of how land–atmosphere interactions influence heat waves can greatly improve predictions and responses to extreme weather. Establishing clear boundaries and fostering co-production between scientists and stakeholders ensures transparency, trust, and practical outcomes. The next step lies in integrating land physics and biogeochemistry with advanced modelling to refine local insights. To move forward, we must invest in collaborative, data-driven research that bridges science and society in addressing climate extremes.

WHY A SCIENCE EXPLAINER

Through short, focused questions, project researchers share what they study, why it matters, and how their investigations lead to real-world findings.

By opening up the day-to-day challenges and thinking behind climate research, these explainers make science more accessible, transparent, and trustworthy for other researchers and decision-makers alike.

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