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Temperature at 500hPa, energy budget and the 2003 summer heatwave over Western Europe: a triple-decomposition approach

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Heatwaves represent a major health hazard, as was the case for the 2003 summer heat wave, responsible for more than 70 000 deaths in western Europe. The interplay of mean flow, quasi-periodic and random fluctuations — associated with the westerly jet, Rossby and gravity waves, and eddies — of the large-scale temperature field results in complex heat wave–related amospheric conditions. Understanding how the different physical processes interact is thus crucial for prediction of heat wave events.
In this study, we use the triple decomposition of turbulent flow (Hussain and Reynolds, JFM, 1972) to compute mean, quasi-periodic and random energy fluctuations of the temperature field, that is the 1-point energy budget of temperatures. This decomposition takes into account all interactions between the zonal jet, Rossby waves, gravity waves, and eddies. Both spectral and dynamical systems analyses are applied to the computed terms. More specifically, the concept of extremal length (Ahlfors, Vol. 371, AMS, 2010) is integrated into the equations to quantify how each term of the energy budget equations contributes to the "trapping" of temperature anomalies over Europe.

Results show that, amid positive sea surface temperatures and negative soil moisture anomalies, during the first half of August, i.e., the hottest days of the heat wave, quasi-periodic oscillations of polar air increased, resulting in meridional migration of cold air over Canada, and subsequent mixing with warmer air coming from North America. This mixing triggered baroclinic instabilities that led to production of turbulent eddies, which by August 5th suddenly stopped their eastward progression, creating a cyclonically stalled regime over the Mid-Atlantic; this stationary cyclone interacted positively with North African warm air propagating northward over Europe, thus sustaining the dry conditions over France and much of Western Europe. The cyclonic block finally disappeared, stopping the warm air advection from North Africa, with temperatures falling just after that.
The study reveals that interactions between quasi-periodic and random processes of production, diffusion and dissipation of a scalar field's energy play an important role in the evolution of a major heatwave. Hence, the 2003 event was not just the result of a superposition of Rossby waves and eddy anomalies. Extremal length analysis thus reveals that the zonal advection of temperature anomalies was blocked by interactions between quasi-periodic and random

production and diffusion processes.
This study highlights the complex turbulent interactions that lead to major heat wave events, and the fact that each such event is thus unique.