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A Lagrangian analysis of upper-level ridges associated with heat waves in Europe

Philipp Zschenderlein (1), Stephan Pfahl (2), Heini Wernli (3), and Andreas H. Fink (1)

(1) Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research, Troposphere Research, Karlsruhe, Germany (philipp.zschenderlein@kit.edu), (2) Freie Universität Berlin, Institute of Meteorology, Berlin, Germany , (3) ETH Zürich, Institute of Atmospheric and Climate Science, Zürich, Switzerland

Heat waves in Europe typically co-occur with upper-level ridges and thus upper-level negative potential vorticity (PV) anomalies. The formation of these upper-level PV anomalies is due to quasi-isentropic advection and cross-isentropic transport of low PV air into upper levels. The latter process is associated with diabatic heating, in particular latent heat release in ascending air streams.

Here, we present a Lagrangian analysis of these processes determining the formation and maintenance of upper-level ridges associated with heat waves in different parts of Europe for the period 1979 – 2016. The main questions to be addressed are (i) how strong is the contribution of the cross-isentropic transport for heat waves in different parts of Europe and (ii) where does the diabatic heating associated with the cross-isentropic transport typically occur?

The upper-level negative PV anomalies associated with heat waves are more intense in northern Europe compared to southern Europe. As quantified from the maximum potential temperature change along backward trajectories in the last three days prior to the arrival of the air parcels in the upper-level ridge, 22 – 44 % of them are heated by more than 2 K. We refer to this set of trajectories as the heated branch. Extending the analysis to the last seven days, the contribution of this branch increases to 51 %, underlining the importance of the latent heating contributing to the formation of upper-level ridges. Ridges over western Russia and Scandinavia experience the strongest influence of upstream latent heating, whereas ridges over the Mediterranean are less affected by diabatic heating. Air parcels with a maximum potential temperature change of less than 2 K in three or seven days are either quasi-adiabatic or experience radiative cooling in the free atmosphere.

Focusing only on the heated branch, we find two regimes that contribute to this branch. Three days prior to their arrival, air parcels in the first regime are located over the western North Atlantic Ocean, whereas air parcels in the second regime are located over north-western Africa or over southern Europe. A composite analysis at the time of maximum diabatic heating reveals that the heating in the first regime occurs ahead of an upper-level PV trough in an extratropical cyclone, where the forcing for ascent is strong. The second regime is less influenced by extratropical cyclones and the heating occurs at the westward flank of the upper-level ridge in an area of elevated convective available potential energy. The first regime is especially important for the formation of the ridge, whereas the second regime becomes more important for its maintenance.

Overall, the results reveal two regimes in the heated branch which presumably has implications on the predictability of heat waves in Europe.