Can we identify large-scale atmospheric patterns that cause sub-daily extreme rainfall in summer?

Dynamical Drivers of Sub-daily Rainfall Extremes in Europe

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Scan for abstract

WHY?

- Sub-daily extreme rainfall events can cause flash flooding and with global warming these events are predicted to increase in frequency and intensity.
- Improved ability to forecast these events at longer lead times is therefore becoming increasingly necessary.
- But forecast models are not very good at representing the small scale processes linked to sub-daily extremes more than 1 day ahead.

HOW DOES THIS WORK HELP?

- We need more information about the dynamical processes driving sub-daily rainfall extremes. So identifying large-scale atmospheric patterns associated with the extremes is a step towards improving understanding of the dynamical drivers.
- Large-scale dynamics are better represented in forecast models than local-scale conditions, therefore, identifying links between the large-scale patterns and sub-daily rainfall extremes would provide information to increase the lead-time for forecasts of these events.

DATA

- Rain gauge data is from the Global Sub-Daily Rainfall Dataset (GSDR)[1]. Only gauges with >2 complete years of data are included here (Fig 1). All data for summer only (JJA).
- 30 weather patterns developed at the UK Met Office using k-means clustering of mean sea level pressure data from 1850-2003 for the region covering western Europe[2].
- ERA5 reanalysis daily geopotential height at 500 hPa (z500)[3]. Anomalies are calculated from the JJA climatology for 1979-2020.
- The local finite-amplitude wave activity metric[4] (LWA) is calculated using individual 500hPa geopotential height contours[5] and defines the cyclonic and anticyclonic components of non-linear, finite-amplitude Rossby waves. The anomalies of these components show the location of areas with increased cyclonic or anticyclonic activity (indicating anomalous low and high pressure areas). Daily anomalies are calculated from the JJA climatology for 1979-2020.

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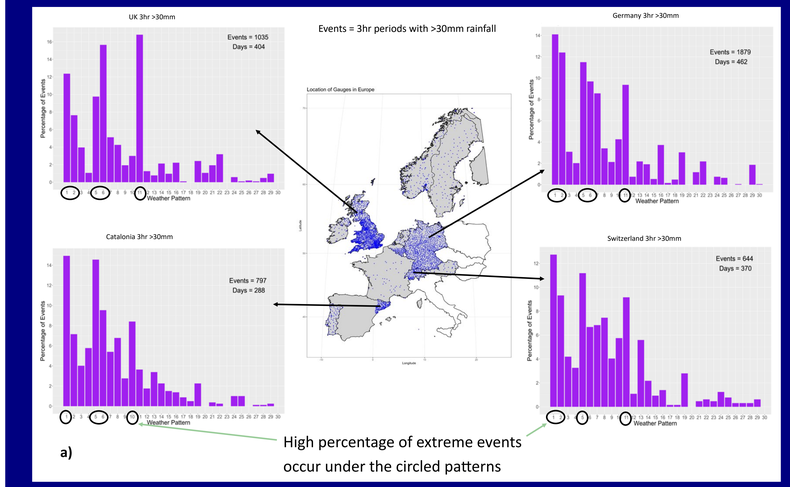
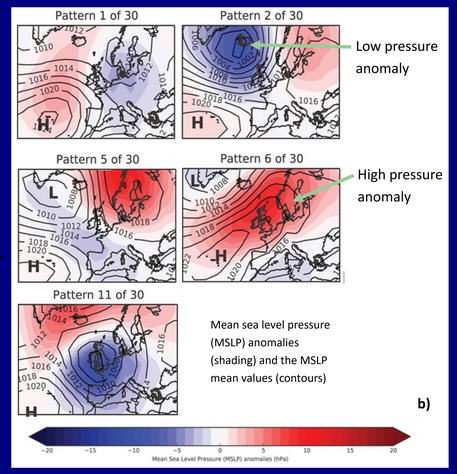
References:

1. Lewis *et al.* (2021) 'Quality control of a global hourly rainfall dataset'.
2. Neal *et al.* (2016) 'A flexible approach to defining weather patterns and their application in weather forecasting over Europe'.
3. Hersbach *et al.* (2020) 'ERA5 hourly data on single levels from 1940 to present.'
4. Huang & Nakamura (2016) 'Local finite amplitude wave activity as a diagnostic of anomalous weather events'.
5. Chen *et al.* (2015) 'Local finite-amplitude wave activity as an objective diagnostic of midlatitude extreme weather'.

1. Sub-daily extreme rainfall events occur much more frequently in conjunction with certain weather patterns across Europe



Out of 30 weather patterns, just 5 are repeatedly important for sub-daily rainfall extremes across Europe



These weather patterns are all associated with southerly flow over Europe.

The weather patterns can be forecast 3-10 days ahead = increased warning time.

Is there something different about the circulation patterns on days with extreme rainfall that could allow more precise forecasting?

Figure 1: a) The percentage of summer 3hr events with >30mm rainfall in each country which occurred under each of the 30 weather patterns, b) The 5 weather patterns most frequently associated with the 3hr 30mm events across Europe

What other large-scale dynamical features might influence the rainfall?

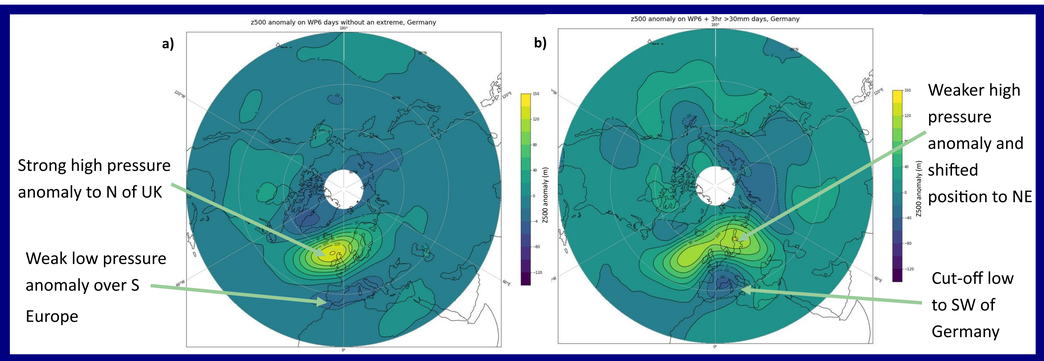
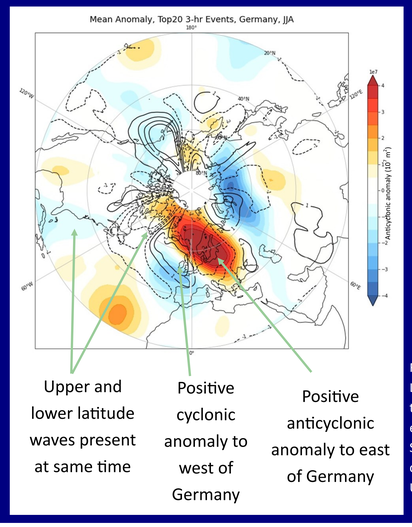


Figure 2: Geopotential height anomalies at 500 hPa on: a) days with WP6 and no 3hr events >30mm in Germany, b) days with WP6 and at least 1 3hr event >30mm in Germany

2. The upper atmosphere anomalies (z500) on days with a certain weather pattern and extreme rainfall events look very different to the anomalies on days without events.

Location and strength of these anomalies can influence location of the rainfall events.

3. Local finite-amplitude Rossby wave activity (LWA) anomalies show distinct patterns on days with sub-daily rainfall extremes in Europe—anticyclonic anomaly to east and cyclonic anomaly to west of the region of interest



If the spatial pattern of waves is anomalous on event days, is the amplitude also anomalous?

Figure 3: Composite of mean LWA anomaly on days with the top 20 strongest 3hr JJA rainfall events in Germany (1996-2015). Shading is anticyclonic anomaly, contours are cyclonic anomaly. Units are 10^7 m^2.

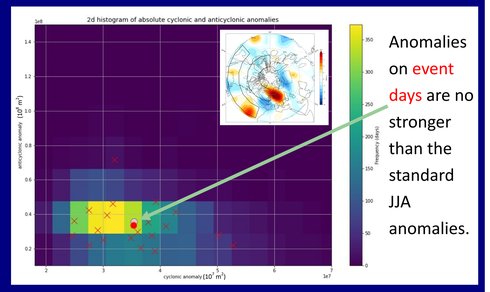


Figure 4: 2d histogram of the absolute anomalies of cyclonic and anticyclonic LWA components within the high (cyclonic) and low (anticyclonic) latitude boxes shown in inset on: all JJA days 1979-2020 (shading), days with a top20 3hr event in Germany (red crosses). The mean of all JJA days is shown by pink circle, mean of all top20 3hr event days by orange circle.

NEXT: is there phase matching of the high and low latitude waves on days with extreme rainfall?

CONCLUSIONS

- Large-scale dynamical drivers associated with sub-daily rainfall extremes have been identified from several different methods.
- The results all show a similar atmospheric pattern associated with the rainfall (high pressure to E, low pressure to W, southerly flow).
- These variables are already (or can be), included in forecasting systems/models, with accurate predictions several days ahead.
- Therefore, these results could be used to improve the synoptic-scale predictability of periods with increased risk of sub-daily rainfall extremes further in advance than is currently possible.