13. CONTRIBUTION OF ATMOSPHERIC CIRCULATION TO WET NORTH EUROPEAN SUMMER PRECIPITATION OF 2012

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Introduction. Northern Europe witnessed anomalously high precipitation rates during the year 2012, especially during summer. The goal of this paper is to put those regional events into the context of long-term variability. In Europe, studies have highlighted that recent temperatures have been systematically warmer than expected due to the North-Atlantic dynamics, which control their intra-seasonal to interannual variability (e.g., Cattiaux et al. 2010; Vautard and Yiou 2009). Here we investigate the contribution of large-scale circulations to the precipitation anomalies of 2012 using the same flow-analogue approach as in the analysis of 2011 temperatures done by Cattiaux and Yiou (2012).

Data. We used in situ measurements provided by the European Climate Assessment dataset at more than 4500 stations over the period 1948–2012 (Klein-Tank et al. 2002). We computed anomalies relative to a 1971–2000 climatology. The daily climatology is obtained by averaging over each calendar day in 1971–2000, then smoothing by splines. We selected 351 stations on the basis of (i) an altitude lower than 800 m, longitudes between 8°W and 40°E and latitudes between 30°N and 72°N, (ii) the availability of more than 70% of daily values between 1 January 1971 and 31 December 2000 for a reliable estimate of the climatology, and (iii) more than 90% of daily values between 1 January 2012 and 31 December 2012 for a reliable estimate of the 2012 anomalies. We averaged precipitation values over Northern Europe (50°N–72°N, 8°W–35°E) after selecting (iv) only one station per 0.5° × 0.5° latitude/longitude box for spatial homogeneity, leaving 142 stations in that region. Although we mainly focus on cumulated precipitation, we also computed the precipitation frequency (or fraction of wet days) for each month, as in Vautard et al. (2007) and Vautard and Yiou (2009). The precipitation frequency is the empirical probability in a given month of observing a daily precipitation rate larger than 0.5 mm. It provides an indicator of the temporal continuity of precipitation.

Observed rainfall anomaly. Anomalously high precipitation rates were observed in Northern Europe (France, Scandinavia, Netherlands, Germany, UK) in June–July 2012 (Fig. 13.1, upper panels). The high precipitation rates extended to August and September in Scandinavia and the United Kingdom, although with a smaller spatial extent. Those wet conditions contrast with drier than usual conditions in Southern Europe (Spain, Balkans, Eastern Europe). The precipitation frequency during summer 2012 also had positive anomalies in Northern Europe, indicating that the rain episodes lasted for prolonged periods of time (Supplementary Fig. S13.1). Therefore, the generally wet conditions mainly concerned the northern part of Europe for summer 2012, with variable conditions (from wet to dry) in France and on the northern coast of Norway.

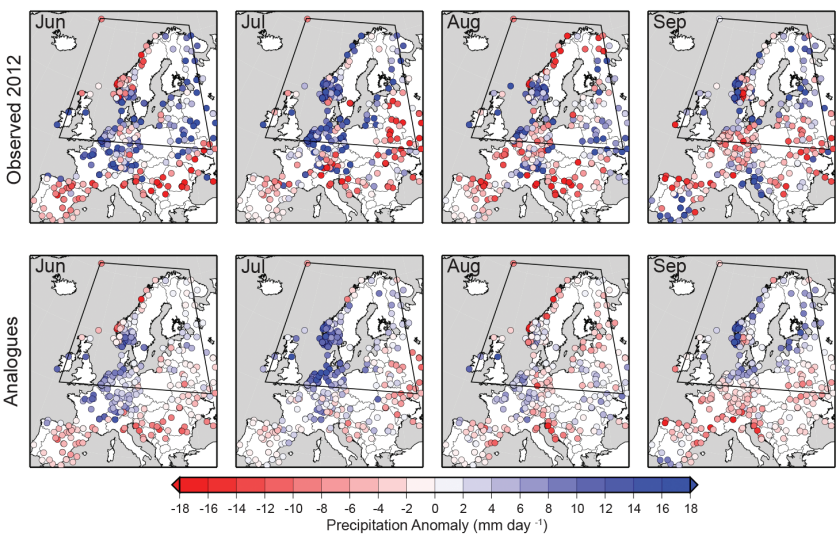

Fig. 13.1. Anomalies of precipitation over Europe (in mm day^{-1}) for the summer months in 2012 (Jun–Sep). The colored points represent the 351 ECA&D stations we retained. The polygon outlines the region over which the averages are computed (50°N–70°N, 8°W–35°E). The upper panels represent observed precipitation anomalies; the lower panels represent the mean precipitation obtained from 20 analogues of circulation.

The highest daily precipitation rates in northern Europe occurred in January and October, although high precipitation rates were also observed in June and July (Fig. 13.2a). The longest spell of precipitation in summer was in July.

The time series of seasonal cumulated precipitation for averages of stations north of 50°N and between 8°W and 35°E are shown in Fig. 13.2b. Although the average precipitation anomaly was positive in summer 2012, it was not exceptional over the 1948–2012 period. The records of summer average precipitations occurred in 2011 and 1988, and the 2012 summer is the 13th wettest summer since 1948.

Contribution of the atmospheric circulation. The contribution of the large-scale dynamics to the temperature anomalies of 1948–2012 was estimated from the same flow-analogue approach as used in Cattiaux and Yiou (2012). For each day, we selected the 20 days with the most correlated atmospheric circulation among days of other years but within a moving window of 60 calendar days to account for seasonality (for details, see Yiou et al. 2007). Circulations are derived from sea level pressure (SLP) anomalies of NCEP/NCAR reanalyses (Kistler et al. 2001) and considered over the period 1948–2012 and the area 22.5°N–70°N, 80°W–20°E.

For each station and each day, we computed the mean of the 20 analogue composites. Mean analogue precipitations (averaged over 20 analogue days) are higher than usual in northern Europe, both in terms of precipitation amount (Fig. 13.1) and frequency (Supplementary Fig. S13.1). Spatial patterns of analogue precipitation follow the observed ones, albeit with lower amplitudes (Fig. 13.1). The spatial correlations are 0.61, 0.56, 0.32, and 0.44 in June to September, respectively. On a daily time scale

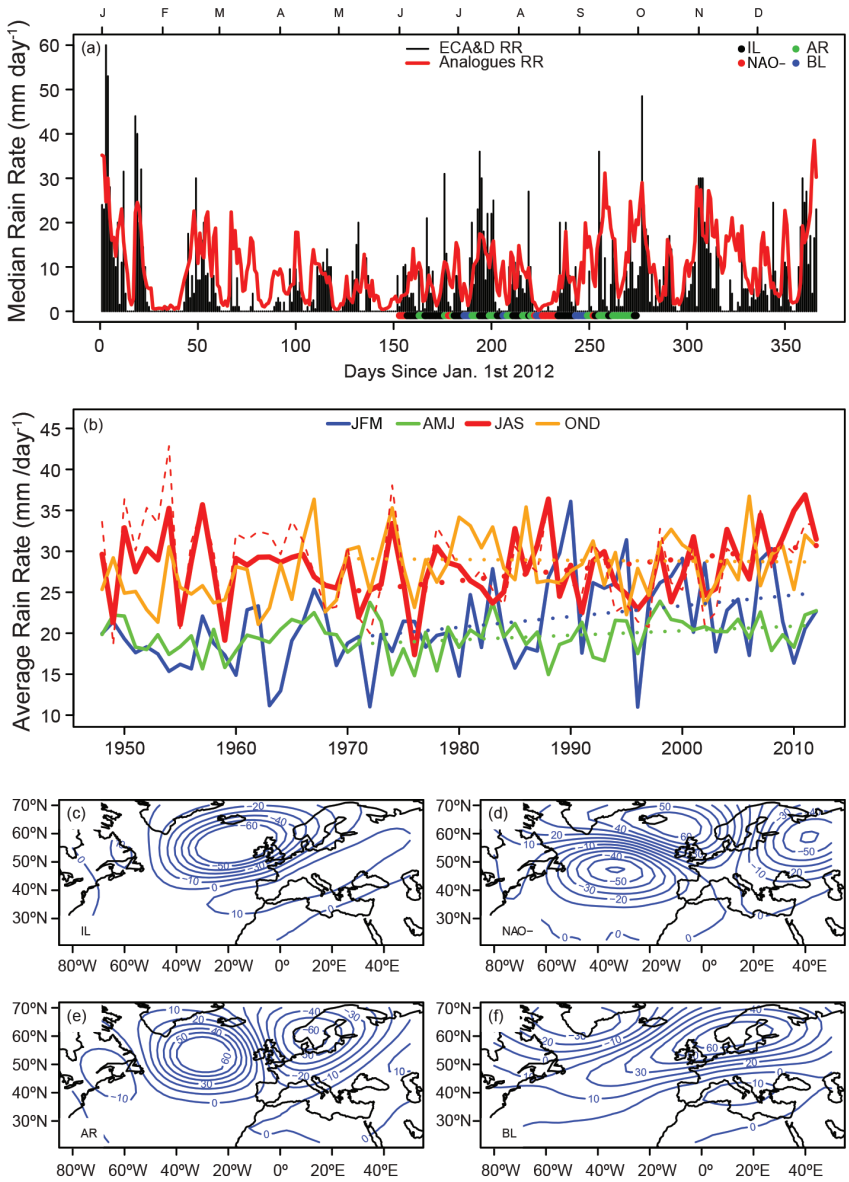

Fig. 13.2. Temporal evolution of precipitation in the outlined northern Europe region and summer weather regimes. (a) Temporal evolution of precipitation in 2012 (black vertical lines). The thick red line represents the median of analogue composites across stations and the 20 analogues. The colored points at the bottom of the panel indicate the daily weather regime. (b) Time series of average precipitation for winter (JFM, black), spring (AMJ, green), summer (JAS, red), and fall (OND, blue) between 1948 and 2012. Dotted lines are the linear trends between 1971 and 2012. The red dashed line represents the mean over northern Europe stations of the upper 75th quantile of analogues. (c)–(f) Summer weather regimes computed from a classification of NCEP sea level pressure data. We use the terminology of Cassou et al. (2005): Icelandic Low (IL), negative North Atlantic Oscillation (NAO), Atlantic Ridge (AR), and Scandinavian Blocking (BL). The isolines (contour intervals every 10 hPa) represent anomalies with respect to a 1971–2000 climatology.

over the northern Europe region, the precipitation analogues follow the observed averages closely (Fig. 13.2a; r = 0.62; p-value $<10^{-15}$). This shows that the precipitation rates are influenced by the large-scale atmospheric circulation.

In order to describe the circulation patterns of summer 2012, we used the clustering approach of Yiou et al. (2008) to derive the four preferential summer weather regimes over the North Atlantic region and the period 1948–2012. The rationale for this analysis is to visualize the atmospheric circulation temporal variability and associate episodes of high precipitation with circulation patterns (Fig. 13.2a). This complements the analysis of flow analogues. The weather regimes are computed from SLP anomalies during 1948–2012. These four weather regimes correspond to modifications in the flow and affect the advection of temperature and humidity (Fig. 13.2c–f). We find that the wet spells over Northern Europe correspond with episodes of the Icelandic Low and Atlantic Ridge [following the terminology of Cassou et al. (2005)], which both yield low pressure centers near Scandinavia (Fig. 13.2a). When the circulation reverts to anticyclonic patterns over Scandinavia (Blocking or NAO-), precipitation rates fall to low values.

Trends of precipitation. We computed the linear trends of the seasonal average precipitation over the outline region (Fig. 13.2b) for the period between 1971 and 2012. A significant increasing trend is found for summer and winter precipitation (p-value $<2.10^{-3}$). The trends for other seasons are not statistically significant (p-values >0.1). The mean analogue precipitation for summer is well correlated (r = 0.86, p-value $<10^{-15}$) with the observed average (Fig. 13.2b), and the analogue also yields a positive summer trend found in the observations, although it is not statistically significant (p-value = 0.14).

Conclusions. Our analysis suggests that the high precipitation rates were caused by the cyclonic conditions that prevailed during the early summer (June and July) over Scandinavia. Such conditions brought moist air over northern Europe. This conclusion is drawn from the significant correlations over Europe between the observed and the analogue precipitation, deduced from the north Atlantic atmospheric circulation.

The trend in summer precipitation over northern Europe is significantly positive but is marginally reproduced by analogues of circulation (with no statistical significance), although the precipitation analogues are correlated with the observations on daily to seasonal timescales. The frequency of cyclonic regimes over Scandinavia (Icelandic Low and Atlantic Ridge) has also increased, albeit not significantly (not shown).

Hence, we cannot attribute this upward summer precipitation trend since 1971 to changes in the atmospheric patterns themselves, because the frequency of cyclonic patterns has not significantly increased nor have the analogue reconstructions of precipitation. This suggests a contribution of climate change to precipitation rate in northern Europe. We conjecture that such a trend could be due to precipitation rates within the cyclonic patterns, which convey more moisture because of increased temperatures. This is consistent with recent process studies of convective precipitations (Berg et al. 2013), although this requires more studies on fine-scale precipitation processes.