Large-scale climatic control on European precipitation

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1. Introduction

Precipitation variability has a significant impact on society, with sectors such as agriculture and water resources management particularly reliant on timely precipitation delivery. It is important to uncover the large-scale climatic control on precipitation because these hydroclimatological linkages improve process understanding, which may have useful ramifications for precipitation prediction across Europe.

Previous research has mainly used atmospheric indices, such as the North Atlantic Oscillation (NAO), to investigate links between atmospheric circulation and European precipitation. Work by Lavers et al. (submitted) has shown a spatial and seasonal variation of large-scale climatic control on British precipitation. In light of this finding, the aim of this current research is to evaluate whether hydroclimatological linkages vary spatially and seasonally across Europe. To achieve this aim, we use (1) gridded European precipitation and (2) gridded mean sea level pressure (MSLP). MSLP was used as low (high) pressure areas reveal where air ascends (descends) in the atmosphere; this is related to precipitation occurrence.

2. Data and Methodology

Gridded observed European precipitation (E-OBS dataset) at a 0.5º×0.5º resolution across 36.25ºN–74.25ºN and 10.25ºW–24.75ºE was from the ENSEMBLES project (Haylock *et al.*, 2008). MSLP on a 2.5º×2.5º grid (0ºN–90ºN and 90ºW–90ºE) was selected from the ERA-40 reanalysis dataset (Uppala *et al.*, 2005). Monthly time series over September 1957 – August 2002 were used.

Concurrent correlation analysis was carried out by month (n = 45) between the gridded MSLP atmospheric domain and each grid of observed precipitation to assess the detailed spatial variation of MSLP control on European precipitation. The non-parametric Spearman Rank correlation (ρ) was used, as MSLP and precipitation time series were not normally distributed. Note that trends were not found to affect the results presented.

Monte Carlo simulations were used to determine whether the observed significant correlation patterns were greater in size than those expected by chance (field significance; Livezey and Chen, 1983). By correlating a random precipitation time series (from its empirical distribution) with the time series of MSLP at the 2701 grid points in 200 different simulations, an accurate probability density function (PDF) of the number of significant grid points in each simulation was estimated. If the area of observed significant correlation is larger than the 95% percentile of the constructed PDF, then the correlation field is considered significant at the 0.05 level. Field significance was evaluated by month.

3. Results

(a) Precipitation variability

Figures 1a and 1b show the coefficient of variation (CV) in percent (%) of European precipitation in January and July (over 1958-2002) respectively. In January, the highest precipitation variability is found in the Alps and on the Iberian Peninsula (Fig.1a). In July, CV exceeds 100% over the Iberian Peninsula, southern Italy and southern Greece suggesting that these regions experience extremes in summer precipitation (Fig. 1b). Generally there is less variability in precipitation over northern Europe (e.g. British Isles) throughout the year.

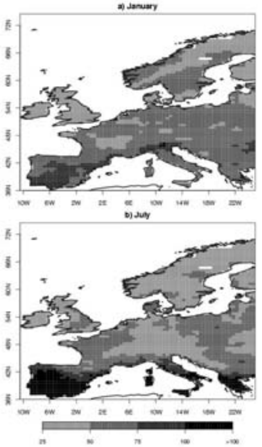


Figure 1: Coefficient of variation (%) in January (a) and July (b).

(b) Field significance

Figures 2a and 2b show the number of field significance months for winter (October to March) and summer (April to September) half-years respectively. In winter, the Atlantic seaboard region (Norway, Western Scotland and the Iberian Peninsula) have the most field-significant months suggesting that large-scale climatic patterns have a large influence on precipitation here (Fig. 2a). Fewer field significant months occur in regions remote from the Atlantic Ocean and in the lee of mountain ranges (e.g. Central Scandinavia). In summer fewer field significant months are found suggesting more local-scale weather systems produce precipitation (Fig. 2b).

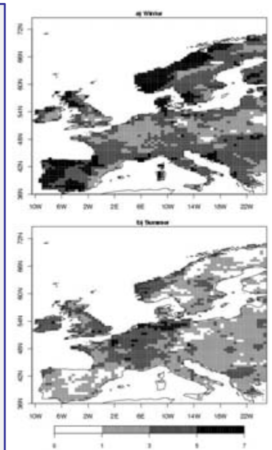


Figure 2: Field significance months in winter (a) and summer (b) half-years.

3. Results (Continued)

(c) Correlation results

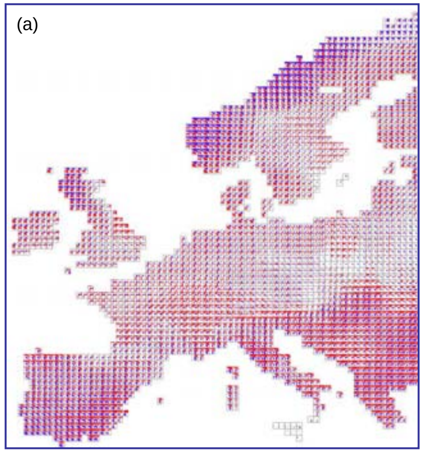
Figure 3 (a-b) shows Europe as a grid, where each grid contains the map of correlations between precipitation and MSLP. In January (Fig. 3a) a statistically significant MSLP correlation dipole (ρ > |0.6|) is found from the western British Isles to western Scandinavia. Negative/blue (positive/red) correlation across the northern (southern) part of the geographical domain relates to the Icelandic Low (Azores High) pressure centre and implies that from the western British Isles to Scandinavia, winter precipitation occurs when MSLP is low (high) near Iceland (the Azores). A similar, but smaller, dipole structure is found from northern France to Finland. This atmospheric pattern, which corresponds to a positive phase of the NAO, causes westerly winds, moisture advection and thus precipitation to occur over northern Europe (Uvo, 2003).

Over Britain and Scandinavia as distance increases from the Atlantic Ocean, the winter correlation dipole shrinks (Fig. 3a). The smaller correlation patterns are likely to reflect the existence of western British and Scandinavian mountains. A similar effect is seen in Central and Eastern Europe (the Alps). In southern Finland, weaker mountain influence on precipitation is seen with stronger correlation present here, indicating the penetration of westerly winds into the European continent.

A reversed winter correlation dipole is found from Central France southwards (Fig. 3a). Over Spain, Portugal and the Mediterranean, negative and positive correlation are centred over the Azores and northern Europe respectively. South-eastern European precipitation has positive MSLP correlation over Asia, which indicates a link with the Siberian High pressure system.

The winter correlation dipole structure uncovered is found in September in Scandinavia compared to December for southern Britain / northern France suggesting that a longer winter season exists in the far North of Europe.

With the onset of summer, the winter North Atlantic correlation dipole weakens and the areas of significant correlation shift in location (Fig. 3b). During summer (June, July, August; JJA) precipitation is generally related to smaller scale weather systems, as seen by fewer red/blue colours in Figure 3b compared to 3a. This is because convective precipitation events are more prevalent in summer (Berg et al., 2009). However, note the strong significant correlation over the Low Countries and the Balkans in July (Fig. 3b); this may relate to the summer NAO pattern (Folland et al., 2009).



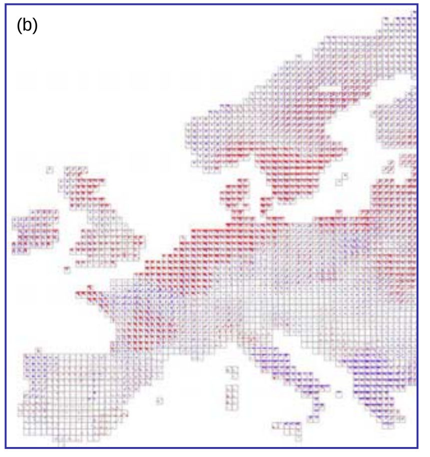


Figure 3: January (a) and July (b)

4. Conclusions

A. Precipitation is most related to the large-scale atmospheric circulation in winter. Western European precipitation is associated with a correlation dipole pattern, which relates to the Icelandic Low and Azores High pressure centres. In northern Europe, precipitation increases with stronger westerly flow; in southern Europe precipitation increases with an easterly or weak air flow. This is consistent with a positive (negative) NAO relationship with northern (southern) European precipitation (Hurrell, 1995).
B. Significant correlation patterns shift in location and change in size during the year highlighting the dynamic nature of the precipitation generating weather systems. Indices with a fixed location definition, such as the NAO, can not capture these spatial variations throughout the year, and are thus not as powerful as the gridded MSLP. In summer, precipitation has fewer significant correlations with the large-scale climatic circulation implying that precipitation is produced by more local-scale weather systems i.e. convection. Note the possible summer NAO teleconnection pattern with Northwest and Southeast European precipitation.
C. Gradients in correlation pattern size exist across Europe (e.g. over Scandinavia) due to mountain chains. Regions in the lee of mountain chains receive less precipitation, as water is precipitated out over the mountains having a drying effect on the air. This phenomenon is most notable in the winter months.

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