



Exchanges

- Selected Research Papers -

A Change in the Summer Atmospheric Circulation over the North Atlantic¹

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1. Introduction

The North Atlantic Oscillation (NAO) has been identified as one of the five principal research areas of the DecCen component of CLIVAR. One reason is that the NAO and its time dependence appear central to the current global change debate. A substantial fraction of the warming of the Northern Hemisphere continents over recent decades is linked to the behaviour of the NAO, in particular a change in the boreal winter atmospheric circulation toward enhanced middle latitude westerly flow (the positive NAO index phase). But what about changes in the Atlantic climate during other times of the year?

The hitherto general focus on the variability of the wintertime Atlantic climate is understandable: the winter months are dynamically the most active, so perturbations in the atmosphere can grow to large amplitudes. However, "climate noise" associated with weather variations is also larger during winter. Because strong climate anomalies can be detected during other times of the year and the noise of natural variability is less, useful insights into the mechanisms responsible for those signals can be obtained. This is especially true of summer, when variability is particularly important from the perspective of droughts and heat waves.

We are examining the annual cycle of climate and climate change over the Atlantic and investigating the mechanisms responsible for the variability through analyses of both observed and climate model data. Coherent fluctuations of surface pressure, temperature and precipitation occur throughout the year, and decadal and longer-term variability is not confined to winter. In the following, we briefly describe one of our more interesting results. A more complete description, including numerical experiments to elucidate physical mechanisms, will be described elsewhere.

2. Results

The spatial pattern of the leading eigenvector of Northern Hemisphere sea level pressure (SLP) during high summer (July-August) is a dipole with a southern center of action extending over the northeast Atlantic across western Europe into Scandinavia and a northern center over the Arctic. This may be viewed as the "summer NAO" (e.g., Hurrell and van Loon, 1997), although the amplitudes of the SLP anomalies are substantially weaker and further north and east relative to winter. A time series of July-August SLP area-averaged over the southern center reveals strong variations on interannual to multi-decadal time scales (Fig. 1). Most striking, perhaps, is the transition from an extended period of below-average SLP to positive SLP anomalies since about 1967 (see also Rodwell and Folland, 2002). The spatial pattern of this change (not shown) reveals locally statistically significant increases in SLP greater than 2 hPa over much of northern Europe during 1967-2001 relative to 1921-1966. This change toward persistent anticyclonic flow during high summer in recent decades is reflected in other variables as well, which increases our confidence that the signal is real. For instance, mean central England surface air temperature (CET) has increased $\sim 0.35^\circ\text{C}$ decade⁻¹ since 1965 during both July and August (more than the mean rate of warming in winter), with the warming concentrated in maximum temperature (Sexton et al., 2002). Over the longer period 1900-1998 high sum-

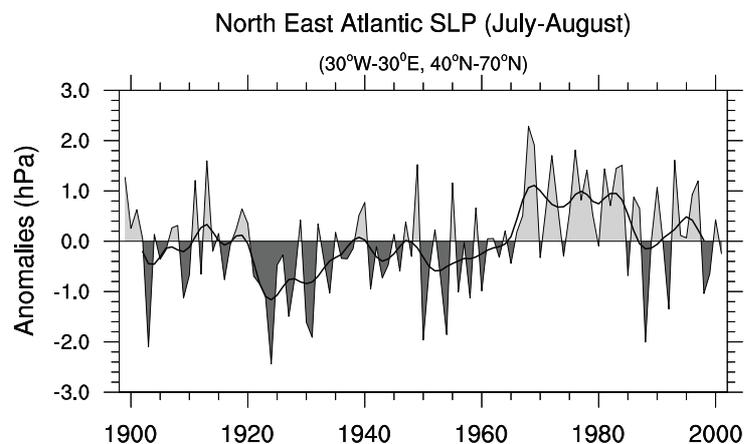


Fig. 1: Anomalies of July-August sea level pressure (SLP) area-averaged over the domain 30°W-30°E, 40°N-70°N from 1899-2001. The heavy solid line represents the SLP variations smoothed with a low-pass filter that eliminates fluctuations with periods less than about 4 years.

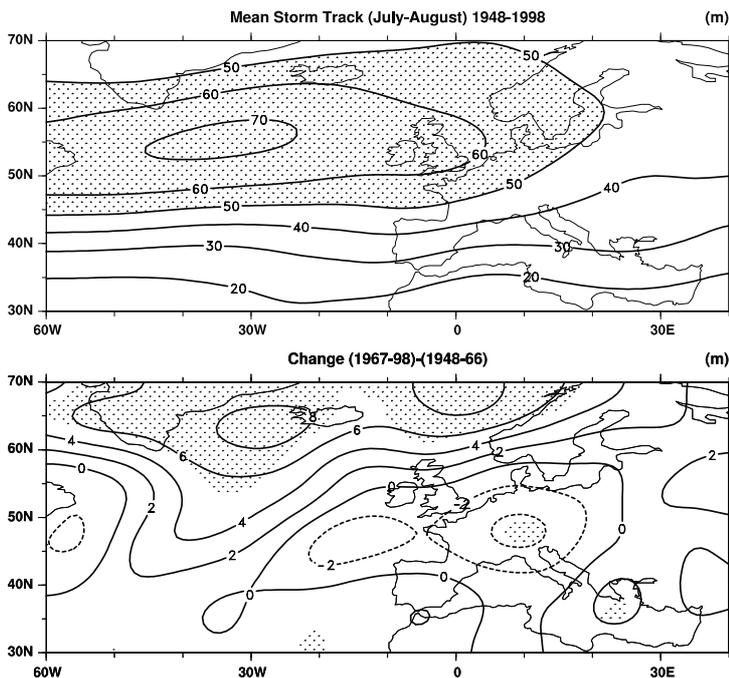


Fig. 2: Mean storm track for 1948-1998 high summers (July-August), and the change after 1966, as revealed by the 300 hPa root mean square transient geopotential height (m) band-pass filtered to include 2-8 day period fluctuations. Differences significantly different from zero at the 5% level using a *t*-test are stippled on the lower panel.

mer CET shows more (significant) warming ($0.09^{\circ}\text{C decade}^{-1}$) than does the annual mean ($0.06^{\circ}\text{C decade}^{-1}$).

The changes in the mean circulation during high summer have been accompanied by a pronounced shift in the storm tracks and associated synoptic eddy activity. We have examined transient eddy statistics from more than 50 years of NCEP/NCAR reanalyzed atmospheric data, band-passed filtered to retain fluctuations on time scales of 2-8 days. The distribution of 300 hPa height variance for July-August reveals a climatological variance maximum near 55°N to the south of Greenland and Iceland (Fig. 2). The change in recent decades has been a northward shift and eastward extension of storm activity, with the largest reduction in variance near 50°N over Europe. These changes in the mean and eddy components of the flow affect the transport and convergence of moisture and, therefore, can be directly related to changes in regional precipitation. Indeed, summer precipitation over much of northern Europe has been about 15% lower compared to earlier decades (e.g., Fig. 3). An analysis of more than 200 years of data from stations throughout England and Wales reveals a significant drying trend since the 1950's with several of the driest high summers on record occurring since 1970 (not shown).

A regression of July-August streamfunction anomalies throughout the troposphere onto the SLP time series of Fig. 1 reveals a strong equivalent barotropic

component to the circulation anomalies over the northeast Atlantic and Europe (not shown). At lower latitudes, when SLP is anomalously high over the North Atlantic, the dominant global feature is a lower tropospheric anticyclonic couplet that straddles the equator over the tropical Atlantic and tropical North Africa with a more extensive cyclonic couplet in the upper troposphere. This structure suggests a relationship between changes in tropical Atlantic diabatic heating, including rainfall variations over the Sahel, and extra-tropical Atlantic circulation anomalies during high summer. Indeed, Fig. 3 shows the pronounced drying in recent decades across tropical North Africa that is well documented in the literature, and suggests a possible extension of the drying across the tropical North Atlantic.

The long record of precipitation over the Sahel is well known as one of the clearest examples of a regional, interdecadal climate signal. This region receives most (80-90%) of its annual mean rainfall (100-500 mm) during July to September. The linear correlation between annual Sahel rainfall and the SLP time series of Fig. 1 is -0.53 over 1901-1998. A plot of the squared coherence between the two time series reveals that variations on interdecadal time scales (periods greater than 20 years) contribute the most to the observed correlation, as the squared coherence is greater than 0.7 at these lower frequencies (not shown; see also Ward, 1998). The lower correlations on sub-decadal time scales are to be expected, given the internal variability of the extra-tropical atmosphere.

3. Discussion

The causes of observed seasonal rainfall variations over tropical North Africa, and the Sahel region in particular, have been of interest for a long time, and a large body of literature exists on the topic. Of particular interest on decadal time scales has been the association between Sahel rainfall and a leading mode of global, seasonal sea surface temperature (SST) variability that describes a tendency for out-of-phase variations between Northern Hemisphere and Southern Hemisphere SST anomalies (e.g., Folland et al., 1986; Palmer, 1986; Ward, 1998). The correspondence between the record of Sahel rainfall and a time series of the interhemispheric SST mode is quite strong ($r \sim 0.6$ over 1901-1998), especially on interdecadal time scales (not shown). But are such SST variations fundamental to the observed link between Sahel rainfall and high summer circulation anomalies over the extra-tropical North Atlantic?

We are addressing this question in part through analysis of several different atmospheric general circu-

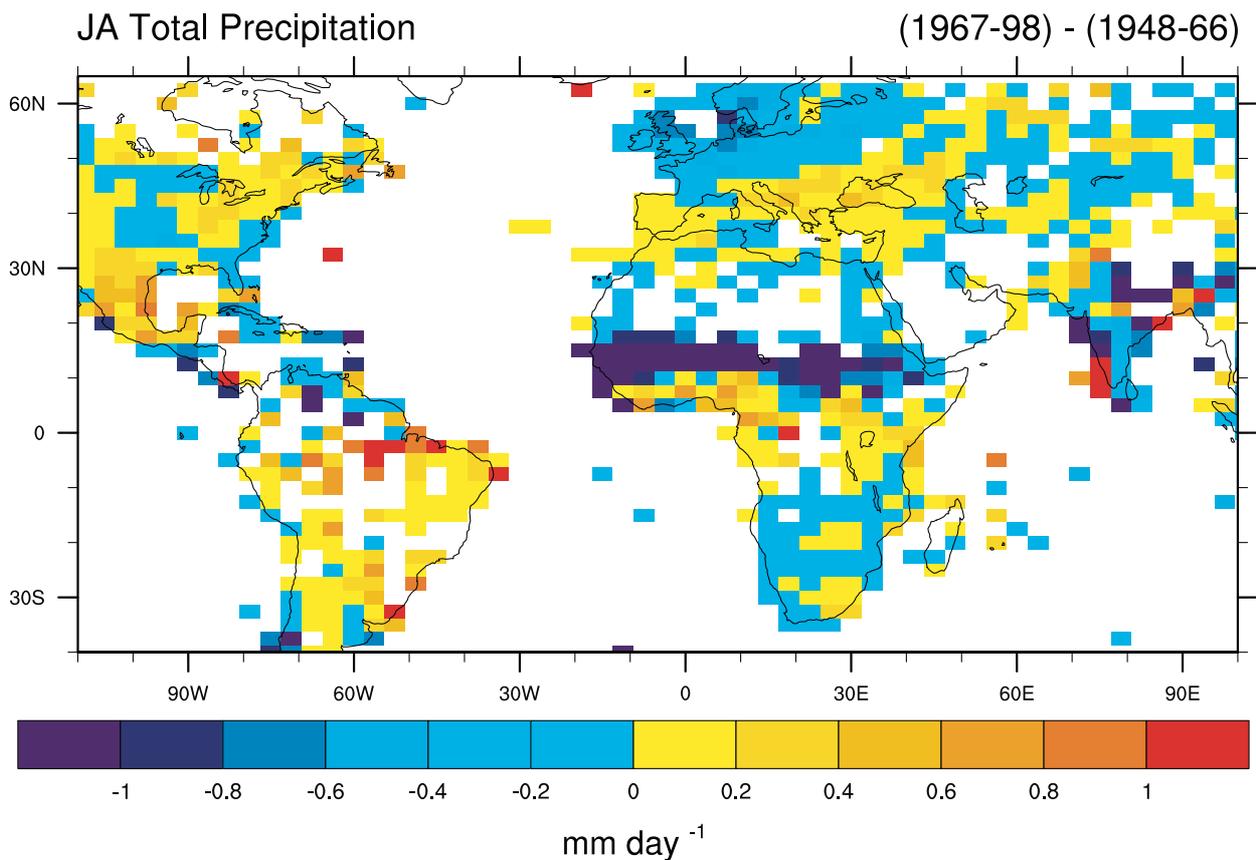


Fig. 3: The change in high summer (July-August) total precipitation (mm day^{-1}), 1967-1998 minus 1948-1966, estimated from land surface records ('g55wld0098.dat' constructed and supplied by Dr. Mike Hulme at the Climatic Research Unit, Univ. of East Anglia, Norwich, UK).

lation model (AGCM) ensembles, where the AGCMs were forced with the time history of observed SSTs. Most of the models are able to reproduce the observed Sahel-extra-tropical North Atlantic relationship, whereby a summer season of higher-than-average surface pressure over northern Europe is accompanied by reduced rainfall over the tropical North Atlantic and North Africa. Initial results, based on analysis of variance techniques that separate climate variability into forced (i.e., due to SST variations) and unforced (i.e., due to internal atmospheric dynamics) components, suggest the link occurs primarily through mechanisms internal to the atmosphere (D.P. Rowell, personal comm.), whereby variations in the tropical Atlantic and Sahel rainfall force changes in high summer North Atlantic climate through an atmospheric bridge mechanism similar to that over the Pacific sector during ENSO. The observed low frequency changes in summer climate over Europe, then, may arise indirectly from processes that affect tropical Atlantic precipitation on long time scales, such as the inter-hemispheric gradient in tropical Atlantic SST. The results also suggest, however, a weaker direct atmospheric circulation response to SST forcing. This would be consistent with Rodwell and Folland (2002), who argue that the high

summer anticyclonic trend over northern Europe is, at least partly, an ocean-forced signal.

References

- Folland, C.K., T.N. Palmer, and D.E. Parker, 1986: Sahel rainfall and worldwide sea temperature 1901-1985. *Nature*, **320**, 602-607.
- Hurrell, J.W., and H. van Loon, 1997: Decadal variations in climate associated with the North Atlantic Oscillation. *Clim. Change*, **36**, 301-326.
- Palmer, T.N., 1986: The influence of the Atlantic, Pacific and Indian Oceans on Sahel rainfall. *Nature*, **322**, 251-253.
- Rodwell, M.J., and C.K. Folland, 2002: Atlantic air-sea interaction and model validation. *Annali di Geofisica*, in press.
- Sexton, D.M.H., Parker D.E., and C.K. Folland, 2002: Natural and human influences on Central England temperature. *J. Climate*, submitted.
- Ward, M.N., 1998: Diagnosis and short-lead time prediction of summer rainfall in tropical North Africa at interannual and multidecadal timescales. *J. Climate*, **11**, 3167-3191.