The UK record-breaking wet Autumn 2000

September to November 2000 was the wettest Autumn in England and Wales since records began in 1766, with almost double the average seasonal precipitation (196% of the 1961-1990 average) being measured (Hadley Centre data). The sustained wet period lasted from mid-September to mid-December (see Fig.1), being displaced from the 3-month Autumn averaging period of September to November (SON) by only 2 weeks. The wet weather extended to many parts of western Europe from Scandinavia to Iberia, with Oslo and Bordeaux receiving double their climatological precipitation (NOAA Climate Prediction Centre data).

The public debate about the record precipitation and extensive flooding in the UK has raised the question of causality, in particular whether global warming is playing any role, taking the natural climate variability beyond its previous extremes. This could occur through changes in the north Atlantic storm-track or by a warming trend leading to higher absolute humidities and stronger precipitation in individual storms. This article investigates the large scale dynamical aspects of the Autumn 2000 weather.

The anomalous northern hemisphere tropospheric flow for SON 2000 showed an equivalent-barotropic wave pattern extending from the subtropical Atlantic through to Siberia (Fig.2), with low pressure near the UK and a strong Scandinavian ridge. This was associated with a strong, ridged jet across the Atlantic, with the UK positioned on its left-hand exit, upstream of the ridge. Dynamically this location would be preferential for baroclinic development and ascent. Additionally the phase speed of transient weather systems would reduce in the diffluent large-scale flow, possibly leading to long-lasting precipitation events as was observed. The onset and decay of this anomalous pattern coincided with the timing of the 3-month wet period in the UK, though there was also variability on shorter timescales.

What anomalous flow has been associated with wet UK Autumns in the past? The correlation of SON seasonal England-Wales precipitation (EWP) with 500hPa height for the 42 years preceding 2000 is shown in Fig.3, and exhibits a strong similarity to the pattern observed in SON 2000. Correlations for individual months show more variation, some with less directionality in the positive height anomalies about the UK. So wet UK Autumns are not only correlated with low mean pressure (unsurprisingly), but also with a particular change in the large-scale flow pattern.

For much of 2000 there were anomalously warm SSTs in the Atlantic, south-east of Newfoundland (NOAA, 2000). During SON an SST anomaly of magnitude 2K was situated just to the west of the high streamfunction anomaly of Fig.2. ECMWF analyses and 24-hour forecasts suggested anomalous precipitation and deep tropospheric heating over the SST anomaly (not shown).

Correlation of SON seasonal EWP with surface temperature gives weak positive correlations ~0.3 in the mid-west Atlantic, marginally significant at the 95% confidence level (not shown). The correlating pattern of surface temperature anomalies extends from the Atlantic through Eurasia and is similarly marginally significant. Its pattern is consistent with atmospheric forcing of the surface by anomalous meridional thermal advection associated with the flow pattern of Fig.3.

If anomalous heating in the mid-latitude Atlantic was the source of the anomalous flow pattern over Europe, the steady linear baroclinic response to mid-latitude heating (Hoskins and Karoly, 1981) suggests that the local response should be baroclinic, in contrast to an equivalent-barotropic far-field response. The barotropic nature of the observed subtropical anomaly in SON 2000 is not in agreement with such a mechanism.

In the tropics SON 2000 was characterised by weak La Niña conditions but with strong intraseasonal variability (NOAA, 2000). From mid-September convection intensified in the Indian Ocean and was strong over Indonesia throughout October, then again in late November and early December. During these Madden-Julian Oscillation (MJO) events there was evidence of anomalous convergence over tropical south America (NOAA, 2000), giving strong monthly anomalies of velocity potential at 200hPa (Fig.4). Independent precipitation estimates were in agreement with these analyses of divergence (NOAA, 2000). Was the observed pattern a Rossby wavetrain emanating from this tropical convergence anomaly?

To attempt to answer this question, a spectral barotropic model has been run using both idealised and observed anomalous divergence forcing. The 200hPa zonally varying SON climatological rotational flow from the ECMWF Reanalysis (1979-93) has been held fixed as a basic state, by computing the climatological vorticity forcing necessary to hold it stationary against self-advection. Then fully non-linear initial-value experiments have been run, forcing the model with additional divergence anomalies. Fig.5a shows an idealised convergence anomaly, with a peak of $4*10^{-6}s^{-1}$, located over south America. The forcing includes the complete effect of the divergent flow as described in Sardeshmukh and Hoskins (1988). Fig.5b shows the streamfunction response after 15 days, which exhibits a wavetrain propagating north-east from the convergence anomaly and bearing a remarkable resemblance to the patterns of Figs.2-3. Sensitivity experiments suggest that the wavetrain response is reasonably robust to changes in the location of the convergence source. Linearising the divergence forcing in the barotropic model to ($-fD$) still gives rise to the wavetrain response, more clearly isolating this component of the anomalous flow. Using only the zonally symmetric climatological flow as basic state modifies the wavetrain response (Fig.5c), enlarging the low near the UK and weakening the Scandinavian ridge. Forcing experiments using estimates of the anomalous divergence distribution observed in October 2000 have been less successful, all of them giving a strong response to the Indonesian divergence anomaly which alters the flow over north America upstream of the Atlantic sector.

ECMWF seasonal forecasts failed to predict the anomalously wet weather over western Europe and, interestingly, did not appear to capture the anomalous convergence over tropical south America (Tim Stockdale, personal communication). Ensemble hindcast experiments using the Met. Office Unified Model forced by observed SSTs (see the article by Dong et al in this issue) also failed to capture the wet European weather. However, differences between ensembles in which SST anomalies in particular regions were omitted did exhibit flow structures which project strongly onto the observed pattern in Fig.2.

We intend to confirm the barotropic modelling results by performing similar non-linear initial-value experiments in a baroclinic model, using localised heating anomalies in place of tropopause divergence anomalies. This will include any effects of vertical structure in modifying the wavetrain response, in particular its wavelength. A major outstanding question is an explanation of the anomalous equatorial south American tropopause convergence, whether or not it is related to the observed strong MJO activity in the Indian Ocean and west Pacific. This can also be addressed using initial-value baroclinic model experiments.

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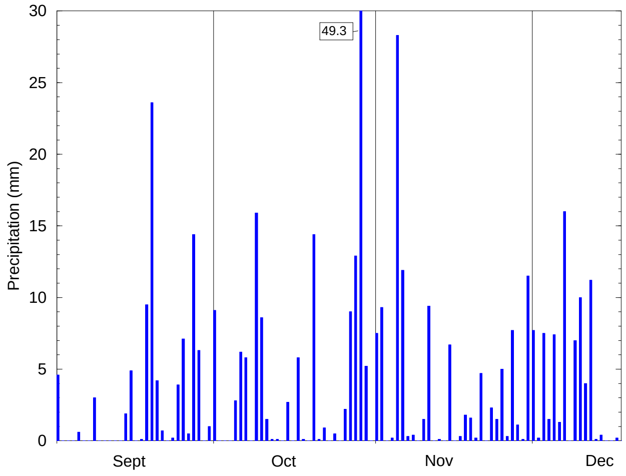
Fig.1 Daily precipitation (mm) at the University of Reading field site for Autumn 2000. Monthly totals were 151%, 253% and 203% of climatology (1971-1995) for September, October and November respectively. 116% of the December climatological mean had been measured by 18th.

Fig.2 Seasonal mean streamfunction at 500hPa for SON 2000 from ECMWF operational analyses (contours, interval $10^7 m^2 s^{-1}$). Anomaly relative to the ERA-15 climatology, 1979-93 (shaded according to colour scale).

Fig.3 Correlation map of SON seasonal mean 500hPa geopotential height against SON seasonal England-Wales precipitation for 1958-99. Correlations in excess of ±0.3 are significant at the 95% confidence level.

Fig.4 200hPa velocity potential anomalies for September, October and November 2000, from ECMWF operational analyses relative to the ERA-15 climatology, 1979-93. Contour $10^6 m^2 s^{-1}$.

Fig.5 (a) Idealised convergence anomaly used to force the barotropic model described in the text (contour $4*10^{-7}s^{-1}$, zero contour omitted). Northern hemisphere streamfunction response after 15 days using as basic state (b) the full SON 200hPa climatological flow and (c) the zonal mean climatology (contour $2*10^6 m^2 s^{-1}$).



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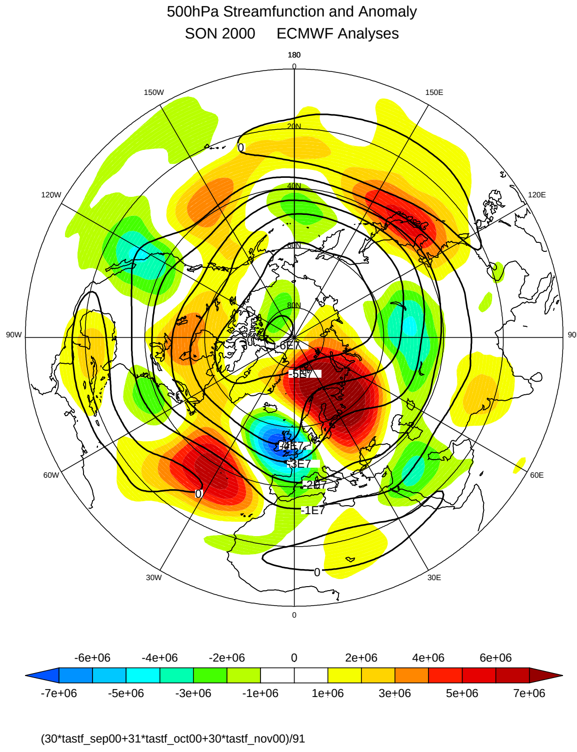

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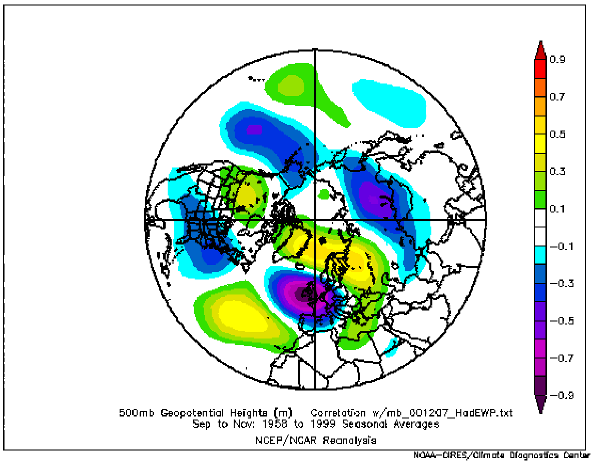

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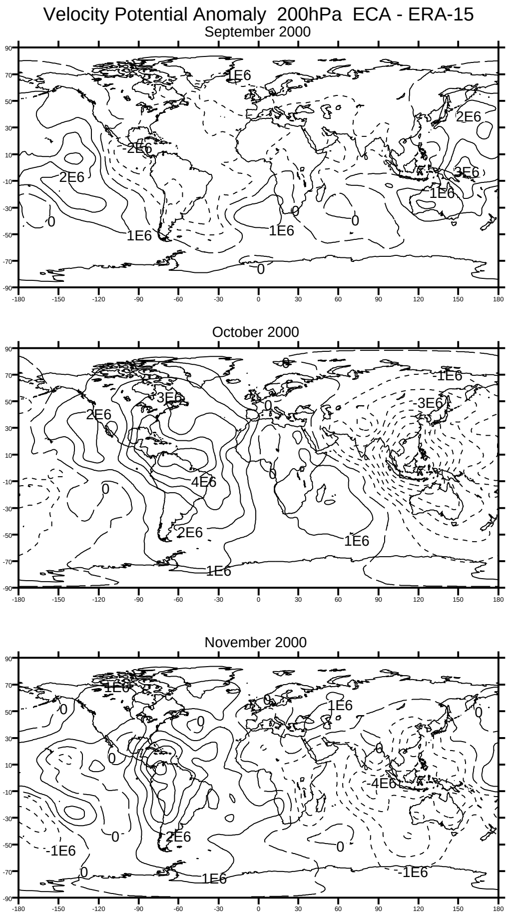

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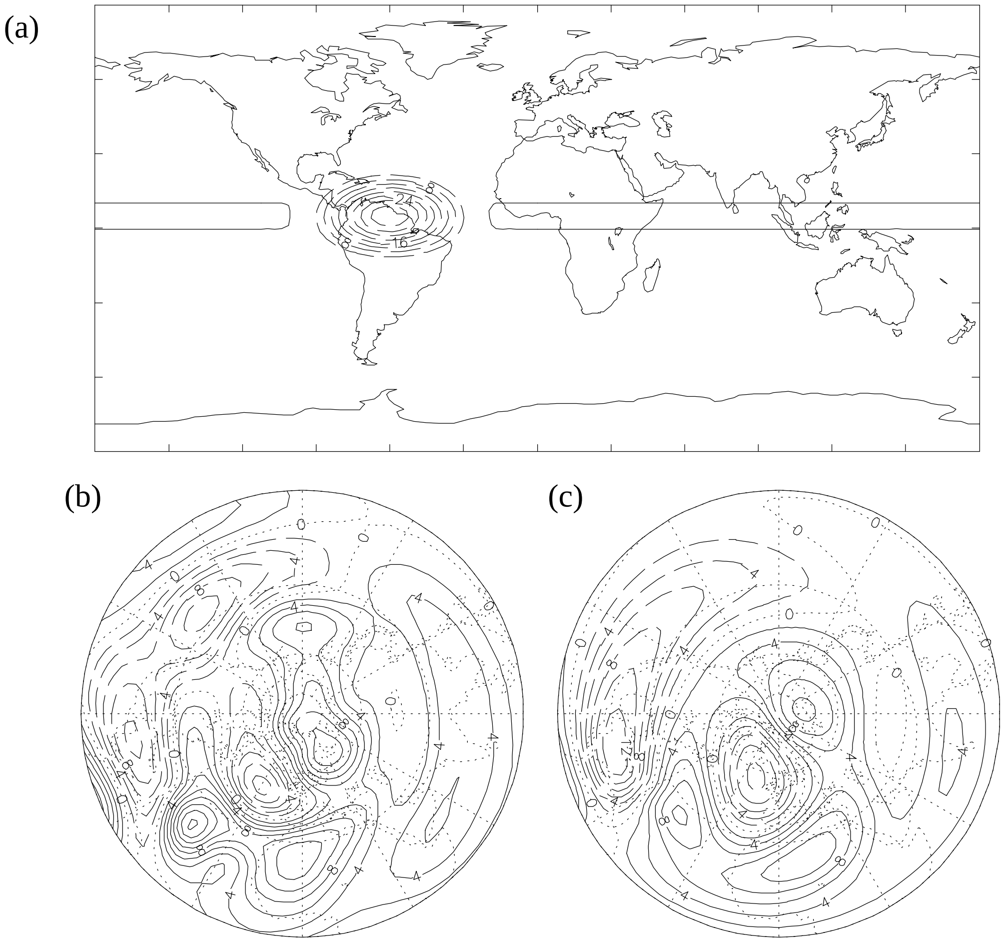

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