TECHNICAL MEMORANDUM

415

Forecasting of Extreme Seasonal Precipitation : Insight into the ECMWF Potential

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Abstract

Recent studies suggest that European events of extreme seasonal precipitation will become up to five times more frequent in the coming decades. Here we examine the capacity of the ECMWF model to simulate Autumn 2000 extreme rainfall (the wettest autumn ever recorded in the UK) and in the process provide a fresh insight into the ECMWF potential to forecast extreme seasonal events over Europe. A series of ensemble–experiments is undertaken and the sensitivity of the model to horizontal resolution (T63/T159/T255) and sea-surface temperature anomalies is considered. Results indicate that the nature of the model response over Europe varies strongly with both horizontal resolution and localized SST forcing from the warm-pool region; however only in the SST case is the model response significantly improved with a comparatively realistic structure of the northern hemispheric planetary-scale flow. These results prompt questions related to the very predictability of autumn 2000 extreme conditions. However they also suggest (i) a deficiency of the ECMWF model in the representation of warm-pool convection and (ii) a significant connection between warm-pool SSTs and autumn teleconnection patterns.

1 Introduction

In autumn 2000, Europe and the United Kingdom in particular experienced some of the most repetitive and intense rainfall ever recorded in an autumnal season (Fig. 1; seasonal mean about 200% of climatology). This seasonal extreme prompts questions related to climate change and possible early manifestations of its effects. Various numerical studies suggest that daily and seasonal extreme rainfall will become more frequent in the coming decades (eg. Gregory and Mitchell 1995; Jones *et al.* 1997; Hennessy *et al.* 1997; Zwiers and Kharin 1998; Palmer and Räisänen 2002) and thus that events such as autumn 2000 might become less extreme and more commonplace.

Considering the extensive flooding typically associated with extreme rainfall (see eg. Marsh 2001), these predictions illustrate the major challenge that weather services face to improve the quality and reliability of their seasonal forecasts – not only in terms of averages, but of frequency and type of individual weather events.

This promts questions related to the factors affecting the performance of numerical models on the seasonal timescale and in particular to the influence of horizontal resolution (cf. Branković and Gregory 2001; Branković and Molteni 1997; Tibaldi et al. 1990) and sea-surface temperature (SST) anomalies. Indeed localized SST anomalies originating from the equatorial Pacific or the warm-pool region have been shown to possibly impact on midlatitudes (eg. Ferranti et al. 1994; Palmer and Mansfield 1986).

In the present study we assess the current ability and potential of the ECMWF model to simulate Autumn 2000 extreme rainfall and design a series of experiments targetted at examining the foregoing aspects. Although of a single case, this study is expected to highlight some dynamical features and physical processes common to a range of extreme events and whose numerical replication will be required.

Below we briefly introduce salient characteristics of Autumn 2000. The main variables considered are PV (ECMWF ERA15 and analysis) and precipitation (GPCP data). In October and November 2000, regions of marked precipitation anomalies not only included western Europe but also the western North Atlantic and the Indonesian (warm-pool) region in particular (Fig. 1).

Dynamical Background

In this section we briefly introduce dynamical results relevant to the remaining of this study.

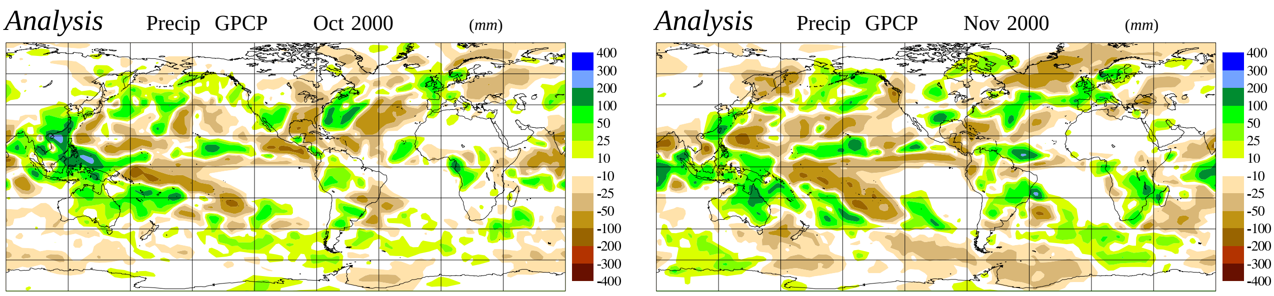


Figure 1: Monthly anomaly-distribution of precipitation for October 2000 (left) and November 2000 (right); from GPCP data, reference period is 1980-2000.

October/November 2000 – Synoptic-scale Anomalies

Inspection of daily fields indicates that individual precipitation events were associated with some distinctive PV-structures at upper-tropospheric elevation. These rain-inducing structures – whose life-time over the UK did not exceed the usual couple of days – appeared to re-generate in a comparatively organized and systematic manner. Typically confluence would form in the North Atlantic as a result of concomitant meridional descent (ascent) of high (low) PV. This confluence would favour the elongation of a high-PV band around $55-60^{\circ}\,N$ that would in turn evolve into a weather system ranging from weak frontal disturbance to major storm (cf. 29th October and 5th November).

Although dynamical aspects of Autumn 2000 are the object of a separate study (Massacand 2003), it is relevant to note here that (i) the foregoing PV features exhibit a comparatively small-scale structure (cf. PV cut-offs south of Newfoundland) and (ii) their recurrent generation in the North Atlantic can be related to large-scale processes and in particular prior events of sub-tropical (Atlantic) convection (cf. trajectory calculations not shown). These features suggest significant interactions between tropical and midlatitude regions on various spatial-scales and thus non-trivial physical processes for climate models to reproduce.

October/November 2000 – Planetary-scale Anomalies

The hemispheric structure of October/November 2000 is commented upon in Massacand (2003) and monthly-anomalies of PV and precipitation are only shown here as a reference (Fig. 2). In short monthly fields of PV exhibit strong anomalies over the Atlantic and Europe but also the Pacific and North America indicating a truly global and possibly teleconnected anomaly-structure. Consistent precipitation signals can be located downstream of the positive PV-centres with distinct maximae off the eastern coast of the US and over western Europe.

How good was the ECMWF Seasonal Forecast ?

ECMWF seasonal predictions for sea-surface temperatures showed warm anomalies similar to the observations over the Pacific and Atlantic oceans north of 30°N. Over the equatorial central-east Pacific and the NINO3 region in particular, observed SST anomalies were weakly negative (about -0.5°C; see http://www.ecmwf.int/products/forecasts/d/charts/seasonal/plumes) and SST predictions were slightly warmer than observations. Overall predicted SSTs were comparatively realistic.

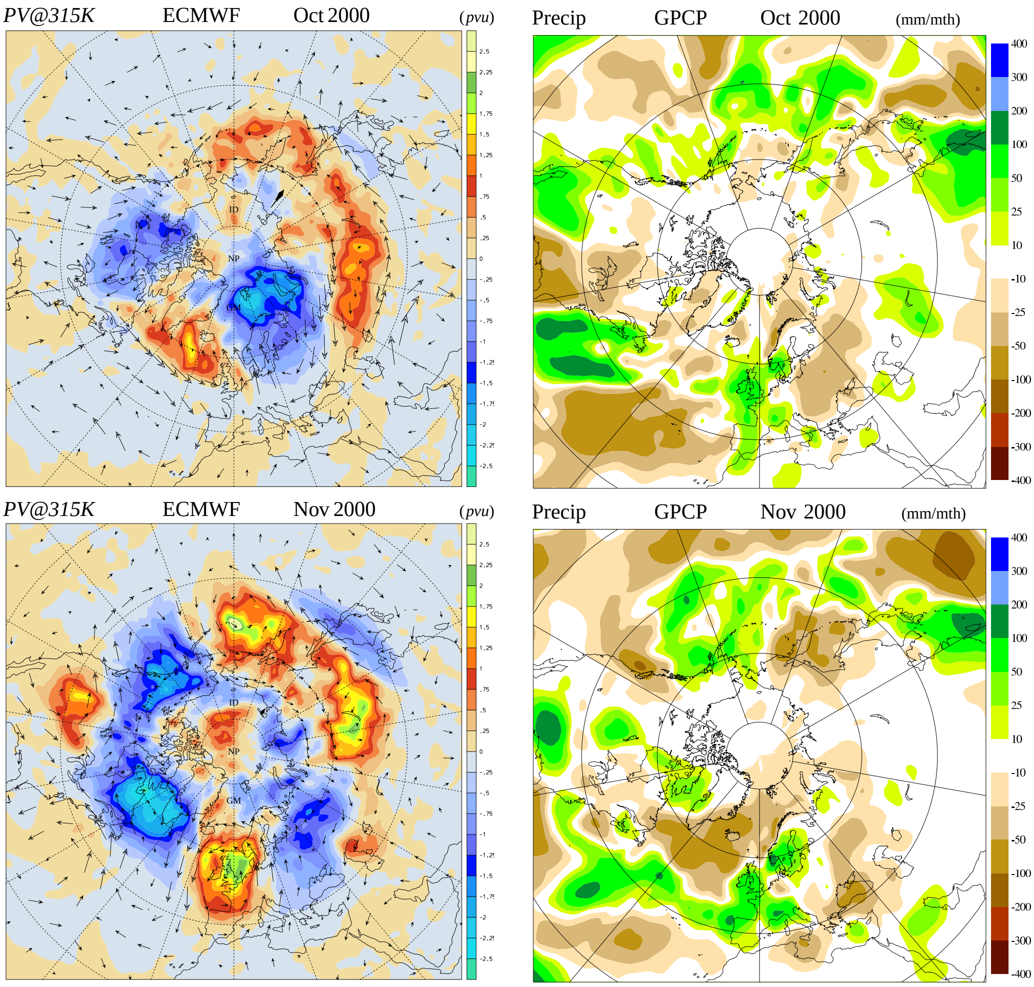


Figure 2: Monthly analysis of PV at 315 K (ECMWF; left panels) and precipitation (GPCP; right panels) for October 2000 (top) and November 2000 (bottom); reference period is October 1980-2001 and November 1980-2001.

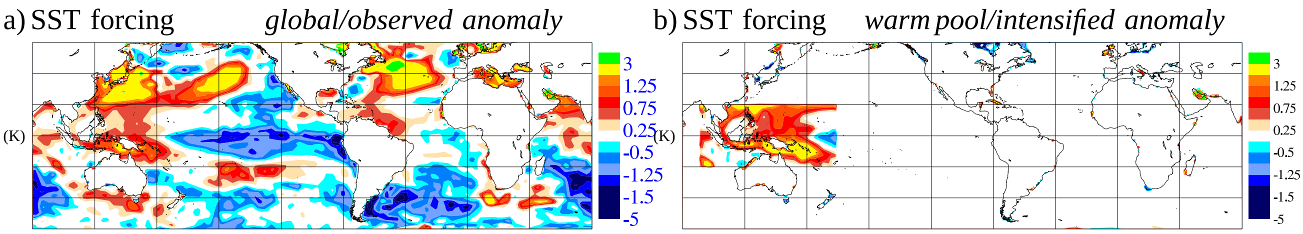


Figure 3: Sea-surface temperature distributions used to force the atmospheric model ie. for November 2000, monthly anomaly global and observed (left panel) and observed anomaly restricted to the "warm pool" region and intensified by a factor two (right panel).

In contrast seasonal predictions of rainfall for autumn 2000 failed to show high probabilities of anomalies over Europe (see http://www.ecmwf.int/products/forecasts/d/charts/seasonal/charts/seasonal_charts). Rather midlatitude rainfall anomalies were predicted to be close to the climatological values, consistently with the weak equatorial SST anomalies. Over the tropical regions rainfall predictions were somewhat more realistic.

The seasonal predictions described above stem from the seasonal forecast version System 1. The atmospheric component of this system is the ECMWF NWP IFS (Integrated Forecast System) model version 15R8, with a T63 spectral horizontal resolution and 31 vertical sigma levels. Cycle 15R8 was used for ECMWF operational medium-range forecasts from Jan-May 1997. In January 2000 the seasonal forecast system was upgraded with the current System 2 version and since March 2003 System 1 has been dismissed.

2 Experimental Design

Six ensemble-experiments are undertaken to examine the sensitivity of the ECMWF model (cy23r3; 60 levels) to horizontal resolution (T63 vs. T159 vs. T255) and to the distribution of the sea-surface temperature field. SST anomalies range from (i) global and observed (Fig. 3a) to (ii) geographically-confined and intensified ie. observed anomaly confined to the "warm-pool" region at double-intensity (Fig. 3b). These six set-ups are summarized below :

1) T63 forced by global/observed SST field

2) T159 forced by global/observed SST field

3) T255 forced by global/observed SST field

4) T159 forced by warm pool/double-intensity SST field (referred to as 2WP)

5) T159 forced by global/observed SST field + warm pool/single-intensity SST field (WP+AN)

6) T159 forced by global/observed SST field + warm pool/double-intensity SST field (2WP+AN)

In addition a control experiment is run at each resolution (atmospheric model forced by the SST climatology). Experiments 1) to 3) above have twenty members and they were started on 18 August until 6 September 2000 for a three-month period. Experiments 4) to 6) have ten members and they were started on 22 August 2000 (until 31st) for a three-month period.

Table 1: *Projection (correlation) of ensemble-mean differences (EXP - CTRL) of PV at 315 K onto corresponding EOFs and ECMWF analysis.*

.	October				November			
Global SST	ANA	T63	T159	T255	ANA	T63	T159	T255
EOF1	0.7	0.12	0.25	-	0.4	-0.15	-0.3	0.3
EOF2	-	-	-0.2	-0.13	0.55	-	-	-
ANALYSIS	1	-0.14	0.2	-	1	-	-0.2	-

3 Performance of the ECMWF Model

In this section we sequentially examine the influence of horizontal resolution and sea-surface temperature anomalies upon the performance of the ECMWF model. In effect both of these aspects are likely to affect the model representation of extratropical dynamics, tropical-extratropical interactions and tropical convection.

3.1 Sensitivity to Horizontal Resolution

Results from the T63, T159, and T255 runs (set-ups 1 to 3 above) are analyzed for the months of October/November 2000 separately and successively compared in the form of ensemble-means and individual members.

3.1.1 Ensemble means

The difference between experiment and control ensemble-means of PV at 315 K and precipitation is shown in Figs. 4 & 5 (left and right column respectively). Notable features from the T63 and T159 runs are described below.

October (Fig. 4). The northern hemispheric structures of the PV (and precipitation) field at T63 and T159 exhibit marked differences over the eastern North Atlantic, Europe and Asia with similar structures however of opposite sign. This reversal in sign is particularly striking over the North Atlantic – European sector where it connotes a change from wet conditions (T63) to dry conditions (T159). Comparison of the foregoing hemispheric distributions with the corresponding ECMWF analysis (Fig. 2; top row) indicates that neither of the two resolutions yields realistic results (cf. Table 1 where each resolution-distribution is correlated with its EOF and analysis counterpart).

November (Fig. 5). T63 and T159 produce comparatively similar distributions of midlatitude PV and precipitation - up to the North American sector where the sign of the west-east dipole is reversed. Over Europe the signal is dominantly (and highly significantly) dry at T63, only with a few (lower significant) wet patches at T159. Again there is little resemblance with the analysis (cf. low correlation values in Table 1).

Hence for both October and November 2000, T159 consistently produces rather unrealistic patterns over both the Pacific and Atlantic regions whereas T63 features patterns comparatively close to the analysis over the North Atlantic/Europe in October and over the Pacific in November. T255 would produce the most realistic forecast for November (projection coefficient onto November EOF1 is 0.3) however the relatively low statistical significance of the signal (conventional T-test) over Europe undermines the relevance of this result. Furthermore an increase of the ensemble-size to twenty members does not corroborate the T255 tendency to produce a wet northern Europe (in contrast ten and twenty-member results are strongly consistent for T63 and T159).

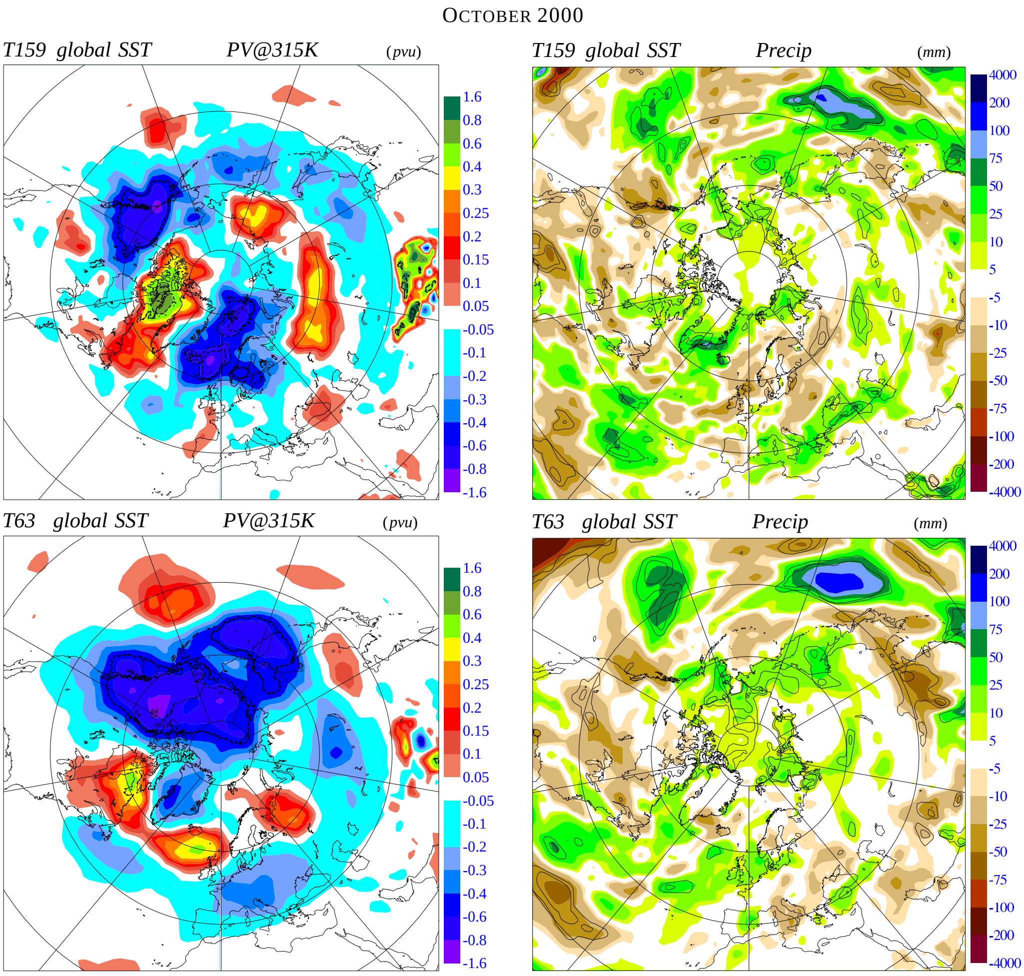


Figure 4: October difference between EXPERIMENT *and* CONTROL *ensemble-means of PV at 315 K (left column) and precipitation (right column) for the global/observed SST runs at T159 (top row) and T63 (bottom row). Significance contours at* 90% *and* 95% *are highlighted in black.*

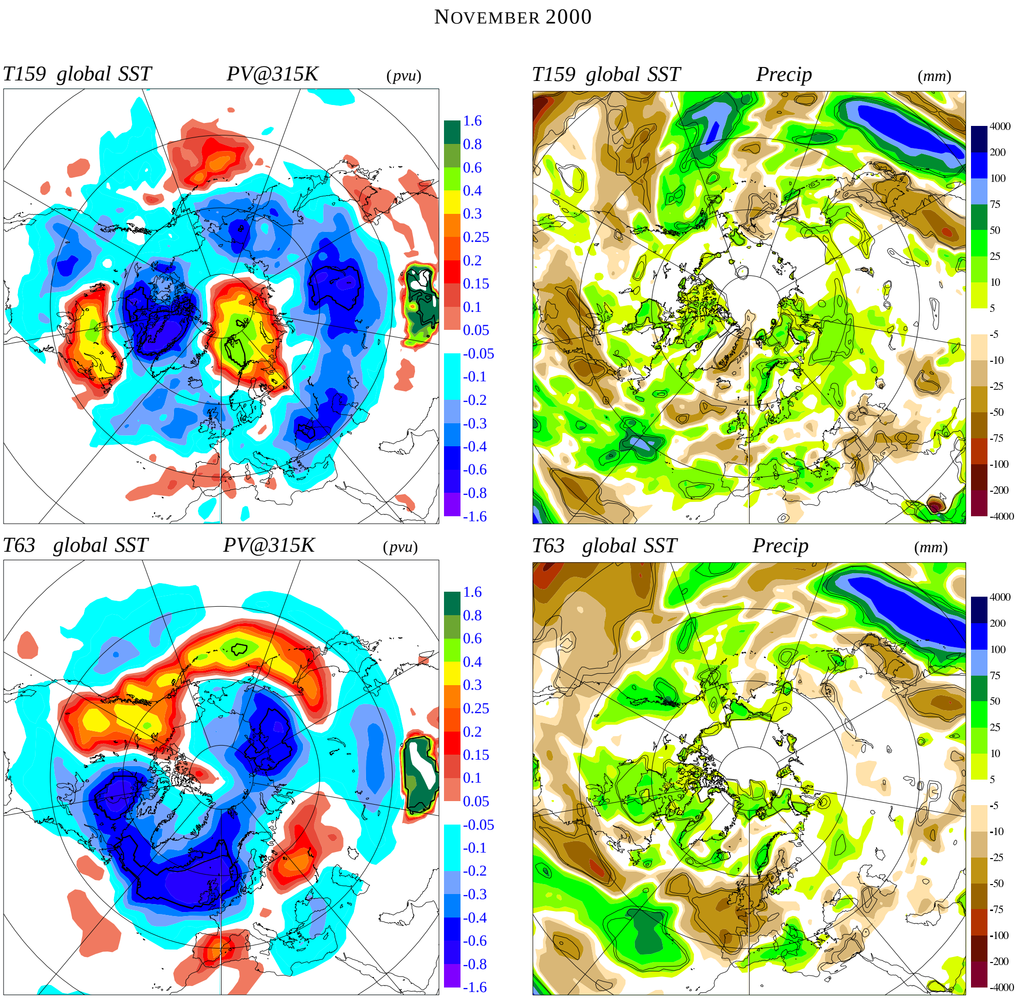


Figure 5: *Same as Fig. 4 for November 2000.*

In the tropics (not shown), intercomparison of T63, T159, and T255 PV and precipitation fields points to little improvement of the model performance at higher resolution. Similar large-scale structures appear with slight differences essentially in the intensity of the anomalies. With respect to ECMWF analysis, the three foregoing resolutions display mixed features that mainly relate to a better representation of land (eg. Indonesian islands) and orography. In effect at the same time as the precipitation error is reduced at T159 or T255 (cf. western and southern part of the Indian Ocean; Indonesia; Andes; North eastern Pacific), it is increased in other regions (north-eastern Indian Ocean; south Pacific and the equatorial band off the coast of Central America). Hence the impact of a resolution increase upon the simulation of Autumn 2000 is not altogether beneficial and the conclusion not straightforward. The change in resolution yields better representations of individual aspects of extratropical dynamics, extratropical-tropical interactions or tropical convection however the end picture remains mixed with zones of local improvements only.

3.1.2 Individual Members

In this section we assess the variance associated with the ensembles above and provide an objective analysis of each ensemble-member (ie. projection of each member's PV distribution onto October/November EOF patterns). This helps clarify (i) the information implicitly contained in the ensemble-mean differences computed above and (ii) whether one model resolution favours the simulation of one particular pattern of variability (and therefore of the physical processes and forcing that this pattern relates to).

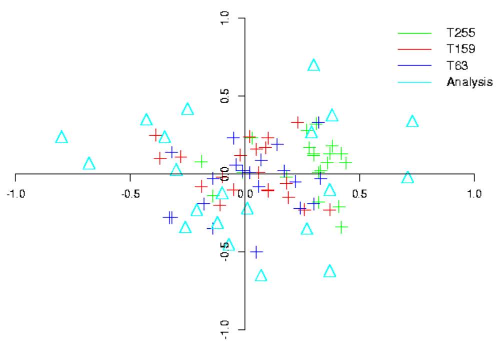
Both control and experimental runs are considered and this also sheds light on the resolution-dependent bias of the ECMWF model. Note for the sake of reference that October ECMWF analysis (blue triangle in upper-right panel; Fig. 6) projects essentially onto October EOF1 whereas November ECMWF analysis (blue triangle in lower-right panel; Fig. 6) is a mix of both EOFs.

October (Fig. 6 upper row). T63 and T159 control runs cover a comparatively wide range of EOF combinations that correspond to the climatology. T255 on the other hand shows a marked preference for the positive phase of EOF1 (wet nothern Europe) hinting at a bias of the model. In the experiments the introduction of the global SST forcing induces a general widening of the spread along the EOF1 axis at T255 however no striking shift at T63 or T159. Eventually T255 produces five experiment-members close to the analysis (however control members tend to be biased towards the analysis).

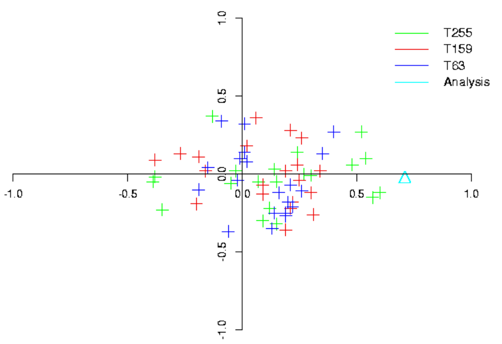
November (Fig. 6 lower row). Control members at all three resolutions exhibit a strong bias towards the positive side of EOF1 (wet northern Europe) and also to some extent for T255 towards the positive side of EOF2 (wet southern Europe). The bias disappears in the experiments that increase the spread and have a much more homogenous/symmetrical repartition (ie. hardly any signal). The only remarkable feature regards the extension of the distribution towards a high positive phase of EOF2 (and thus towards ECMWF analysis) at T255 and T159. However no member combines the two EOF aspects of the analysis.

Hence little improvement can be depicted through the analysis of ensemble-mean differences (experiment minus control) and/or of individual experiment members. However if one considers individual control members and the variance underlying each control-ensemble, a distinct sensitivity to resolution (mean value and spread) appears (October) along with a significant bias of the model towards a wet northern European climate (November; positive phase of EOF1). The foregoing (implicit) features should be kept in mind when interpreting ensemble-mean differences and experiment-member distributions.

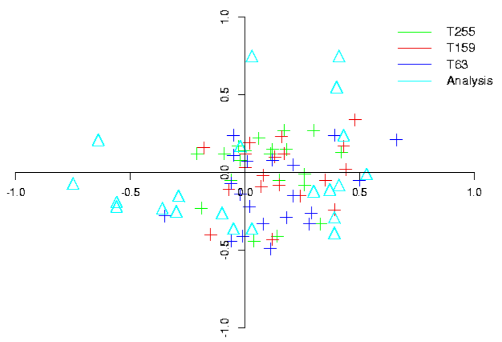
October CTRL



October EXP



November CTRL



November EXP

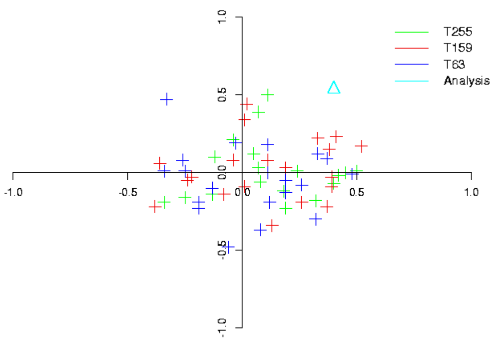


Figure 6: Top row *: Projection onto October PV–EOF1 (abscissa) and PV–EOF2 (ordinates) of PV@315K distributions of control members (left panel) and experiment members (right panel). ECMWF analysis values for 1980-2000 are marked as blue triangles. Bottom row : Same for November.*

Table 2: Projection (correlation) of ensemble-mean differences (EXP - CTRL) of PV patterns at 315 K onto corresponding EOFs and ECMWF analysis.

.	October				November			
Warm Pool SST	AN	2WP	WP+AN	2WP+AN	AN	2WP	WP+AN	2WP+AN
EOF1	0.7	0.46	-	0.5	0.4	-0.14	-0.47	-
EOF2	-	-0.2	-	-0.1	0.55	0.35	-	0.27
ANALYSIS	1	0.33	-0.2	0.63	1	0.2	-0.2	0.24

3.2 Sensitivity to Tropical SST Forcing

We now discuss the implications of modulating the SST forcing for a given horizontal resolution (T159). As illustrated above forcing the ECMWF model with the global and observed SST field at T159 does not provide a satisfactory response. Here we examine whether this can be related to a poor representation of tropical dynamical processes and/or of their transition/interactions in/with the extratropics.

In effect SST covariance maps (not shown) suggest that changes in the representation of convection in the warm pool region might reflect onto the distribution of PV (precipitation) in midlatitudes and the Pacific in particular. Hence the series of T159 experiments whose SST forcing are centered around the “warm-pool” region (cf. Section 2).

3.2.1 Ensemble means

As in the previous section, the difference between experiment and control ensemble-means is shown and compared in the extratropics. Of the three warm-pool settings invoked, two are described in details (2WP and 2WP+AN) following the same structure as above (the WP+AN experiment yields mediocre results that do not justify a detailed descrition of its output cf. Table 2).

October (Fig. 7). The PV distributions out of the 2WP and 2WP+AN runs bear some resemblance particularly over the Pacific and Asia. Over the Atlantic and Europe the structure is roughly similar up to a southward (northward) extension of the positive PV-centre over Greenland (Europe) in the 2WP experiment. Both distributions compare well with EOF1 (correlations of 0.46 and 0.5 cf. Table 2) and 2WP+AN remarkably well with ECMWF analysis. This result contrasts strongly with the T159 run forced by the observed field only (cf. previous section; Fig. 4 upper row).

November (Fig. 8). As for October, the two warm-pool experiments exhibit comparatively similar features only with a broader PV-centre over Europe/northern Japan in the 2WP run (top left panel). This centre however intense is slightly shifted eastwards compared with ECMWF analysis and this has implications for the regional distribution of precipitation over Europe. The two PV-patterns project reasonably well onto November EOF2 however not on November EOF1 and therefore not on ECMWF analysis (cf. Table 2). They also strongly differ from the global and observed T159 experiment (Fig. 5 upper panels) over the Pacific, and for the 2WP experiment over the North Atlantic and Europe. This result hints at a dynamical relationship between the warm-pool region and the North Atlantic/European sector.

Hence inspection of the foregoing runs reveals a substantial sensitivity of the model to the Indonesian region with significant anomalies depictable across midlatitudes. Moreover results indicate a distinct improvement of the hemispheric PV-field compared with the T159 “global/observed” run (Figs. 4 &5) over eastern Asia, the Pacific and the North Atlantic/Europe for November only.

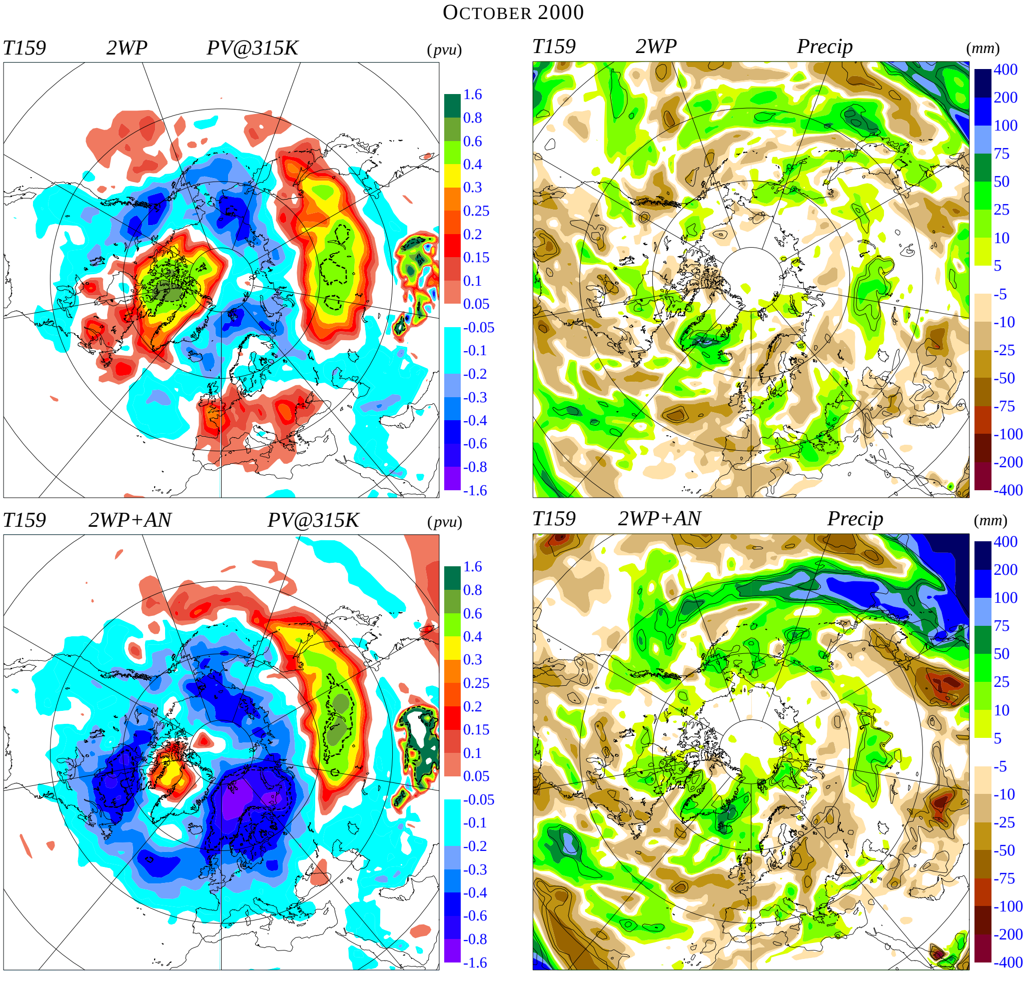


Figure 7: October difference between EXPERIMENT *and* CONTROL *ensemble-means of PV at 315 K (left column) and precipitation (right column) for the warm-pool/intensified SST runs at T159 (top row) and T63 (bottom row). Significance contours at* 90% *and* 95% *are highlighted in black.*

NOVEMBER 2000

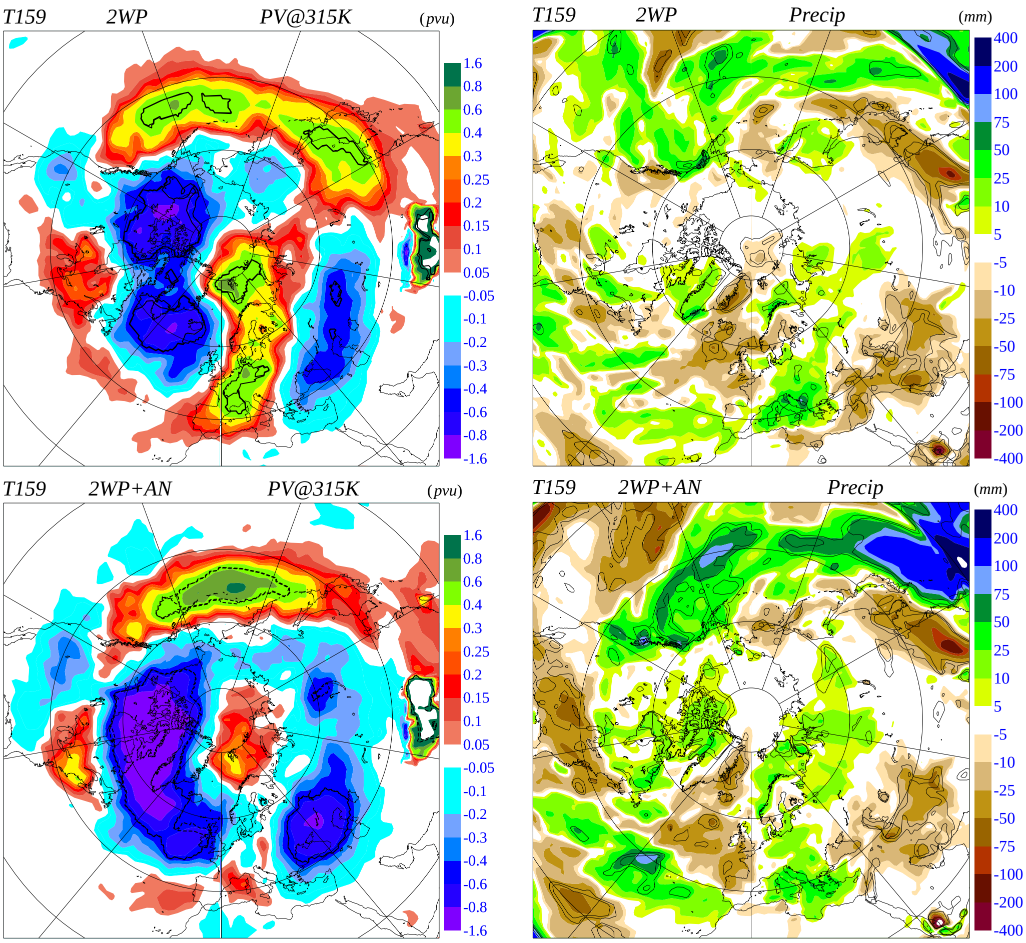


Figure 8: Same as Fig. 7 for November.

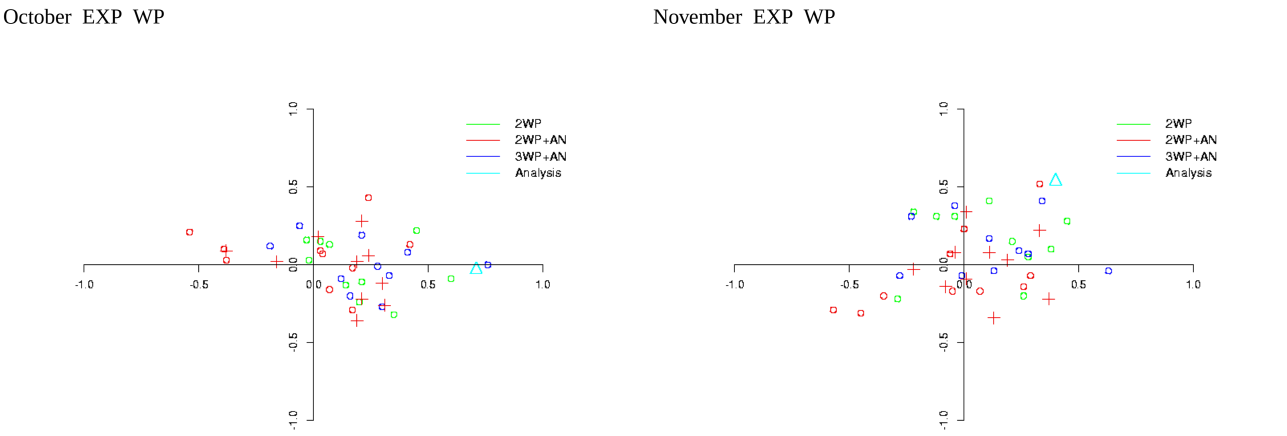


Figure 9: Left panel*: Projection onto October PV–EOF1 (abscissa) and PV–EOF2 (ordinates) of PV@315K distributions of experiment warm-pool members (right panel). Reference ECMWF analysis value for 1980-2000 is marked as a blue triangle* Right panel*: Same for November.*

In the tropics, the warm-pool SST forcing appears to significantly impact upon the representation of tropical PV/precipitation (not shown). Moreover the shape, extent and intensity of tropical anomalies compare better with ECMWF analysis than the ones from the previous T63, T159 and T255 runs. Note also a reduction of the precipitation model-error in the Indian Ocean, the Andes, New Guinea, the Equatorial Pacific and Central America; a feature mainly related to an improved representation of the Walker cell (cf. increased warm pool convection).

3.2.2 Individual Members

Here we examine the variance associated with the ensembles above.

October (Fig. 9 left panel). Compared with the observed SST T159 run (red crosses), the 2WP and 2WP+AN experiments (green and blue circles resp.) have member-distributions clearly shifted towards the positive phase of EOF1 (wet northern Europe) and ECMWF analysis itself (blue triangle). Compelling is that the completion of the 2WP forcing with the observed field (experiment WP+AN; in red circles) deteriorates rather than improves the performance of the 2WP ensemble (green circles).

November (Fig. 9 right panel). The WP+AN ensemble (red circles) is associated with a large spread with values that cover most of the EOF1 spectrum and to some lesser extent that of EOF2. Notwithstanding it also features the closest member to the ECMWF analysis value (blue triangle). With regard to 2WP and 2WP+AN, their member-distributions are both biaised towards the positive phases of EOF1 and EOF2 (wet northern and southern Europe respectively), however not concurrently such that analysis-like values are hardly approached.

4 Discussion

The resolution sensitivity runs above indicate that the ECMWF model performance in midlatitudes is hardly improved by (i) the correction of the SST field (from forecasted to analyzed) and (ii) the increase of the underlying horizontal resolution from T63 to T255.

This result raises questions related to (i) the general ability of the ECMWF model to simulate extreme seasonal rainfall over Europe and (ii) the predictability of this particular event. Indeed it is conceivable that the resolution/SST impact is conditional to the dynamical nature of the event considered. As an example a similar ensemble-experiment (same cycle; T63), but conducted for summer 2002, produces a comparatively realistic simulation of the prolonged heavy rainfall that plagued central Europe in August 2002.

However the relative deficiency of the ECMWF model in the autumn 2000 case might be related to the model representation of tropical convection that do not necessarily improves as resolution increases (cf. parametrization-effects). Indeed results from the warm-pool based experiments suggest that by reinforcing the initial SST forcing in strategic tropical locations, a significant impact/improvement can be obtained in both the tropics and midlatitudes.

According to the foregoing results, the ECMWF model if adequately forced in the warm-pool region replicates comparatively realistically a crucial part of the dynamics involved in the forcing of planetary-scale teleconnection patterns.

5 Summary and Implications

The ECMWF model (cy23r3; 60 levels) was run under six different set-ups (Section 1.3) to examine the influence of horizontal resolution and SST forcing upon the simulation of an extreme seasonal precipitation event (Autumn 2000). Results are summarized below.

(i) Forcing the atmospheric model at T63, T159 or T255 with global/observed SSTs does not improve the European forecast produced by the coupled version of the model. Major discrepancies appear in the PV distribution of the northern hemisphere with eg. broad negative anomalies (ridges) over the North Atlantic/Europe and eastern Asia/Pacific. These conflict with ECMWF analysis and fail to provide the dynamical setting favourable to rain formation over Europe and the UK in particular.

(ii) Forcing the atmospheric model with an intensified "warm pool" SST anomaly at intermediate resolution (T159) does produce a more realistic representation of the PV field. In effect the PV discrepancy over eastern Asia/Pacific is reduced and the midlatitude response downstream towards Europe is improved with precipitation signals depictable over Europe.

(iii) Although improved, the foregoing signals do not appear to capture the full extent of the PV (or precipitation) anomaly over the North Atlantic and Europe. Rather two of the warm-pool forcing settings considered appear to have the numerical ability to capture the dynamical characteristics of specific leading patterns of planetary-scale variability : EOF1 in October and EOF2 in November.

Hence results suggest :

A significant sensitivity of the ECMWF model to horizontal resolution (T63 vs. T159 vs. T255) on the seasonal time-scale, however only conditionally beneficial. In the present case, results display inconclusive features in the extratropics and mixed features in the tropics that essentially relate to differing representations of land/orography and parametrization effects (cf. Branković and Gregory, 2001).

An improvement of the ECMWF model performance under specific SST forcing conditions. The concurrent improvement of the warm-pool region and the extratropical Pacific points to a more realistic representation of both tropical convection and tropical-extratropical interactions in the Pacific region. This result suggests a deficiency in the model representation of warm-pool convection (and related Walker cell).

The physical processes involved in the setting-up of October EOF1 and November EOF2 require a comparatively accurate representation of convection in the warm pool. A rider is that anomalous convection over the warm-pool might be a key dynamical component of Autumn 2000 forcing.

Thus a better representation of convection in the tropics and the warm-pool region in particular might be required to forecast European extremes of autumnal precipitation. To what extent this factor should be more beneficial than a high horizontal resolution might depend on the nature of the event itself and that of the accompanying forcing. In the case of a comparatively weak event, it is conceivable that the present ECMWF model produces a good forecast. Hence part of the interannual variability in the model performance might be inherent in the nature of the seasonal events themselves.

Acknowledgements

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