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METEOROLOGY

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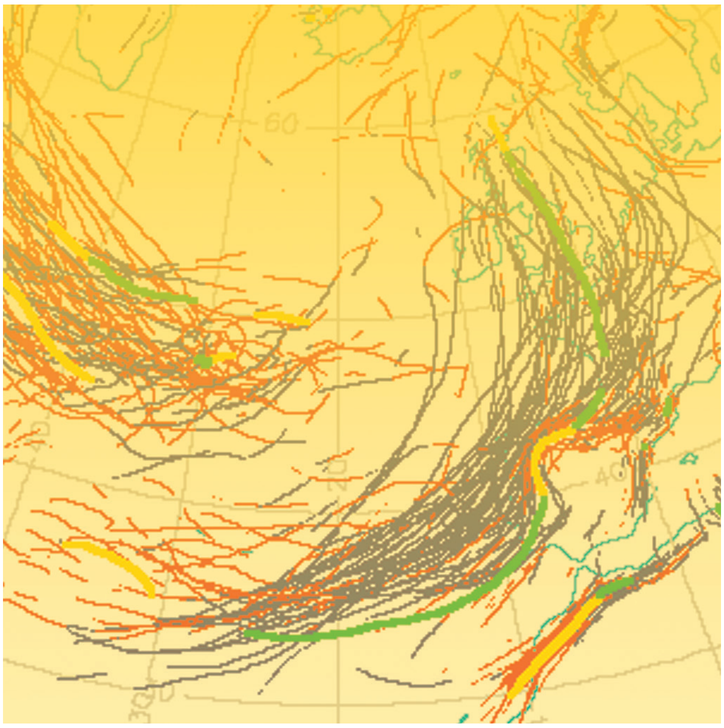

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An experiment with a 46-day Ensemble Prediction System

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The ECMWF monthly forecasting system has been operational since October 2004. It was originally based on 32-day integrations of a coupled ocean-atmosphere system that were produced once a week with an atmospheric horizontal resolution of T159. Initially this system was run separately from the Ensemble Prediction System (EPS) and the seasonal forecasting system. Since March 2008, the monthly forecasting system has been merged with the EPS.

The aim of this article is to describe an investigation into the possibility of extending the length of the mid-month monthly forecast from 32 days to 46 days so that it fully covers the next calendar month. It was recognised that this approach might produce a more accurate and reliable outlook for the second calendar month than the ECMWF seasonal forecasting system for the following reasons.

- More up-to date forecasts (the ECMWF seasonal forecasts are issued 15 days behind real-time, whereas the monthly forecasts are issued the same day as the forecast starting date).
- A more up-to-date model cycle - the seasonal forecasting system uses a frozen version of ECMWF's Integrated Forecast System (IFS).
- Higher resolution of the atmospheric model.

Here, the forecast skill of the 46-day EPS will be compared to the skill of the current seasonal forecasting known as System 3 (*Anderson et al.,* 2007).

Experimental setup

A series of 46-day hindcasts has been performed for the 20-year period from 1989 to 2007. The hindcasts start on the 15th of each month and are 46-days long to fully cover the next calendar month. The 15th of the month was chosen because it is the date the seasonal forecasts from System 3 are disseminated. For each starting date, the hindcasts consist of an ensemble of 15 members: a control and 14 perturbed forecasts. In this investigation, only the first 10 perturbed forecasts will be considered to be consistent with the System 3 hindcasts.

The version of IFS used in this experiment is Cy32r3, which was operational from November 2007 until June 2008. The configuration of the hindcasts is the same as the one used for operational monthly forecasts at ECMWF, except for the length of the forecasts (46 days instead of 32 days for the operational monthly forecasts). In this configuration, the IFS is first integrated for 10 days with a resolution of T399 (about 50 km resolution) and 62 vertical levels. At day 10, the horizontal resolution is lowered to T255 (about 80 km resolution) till the end of the forecast. During the first 10 days, the IFS is forced by persisted SST anomalies. After day 10, the IFS is coupled to the HOPE oceanic model every 3 hours. The initial conditions are taken from the ERA-40 reanalysis till 2001 and ECMWF operational analysis thereafter. The ensemble perturbations are produced in the same way as in the operational monthly forecasts. More details about the model configuration can be found in *Vitart et al.* (2008).

In this investigation, we will compare the 46-day EPS forecasts of the next calendar month with the seasonal forecast from System 3 starting on the 1st of the month but available on the 15th of the month (same day as the monthly hindcasts). For instance for the month of June 2007, we compare the month 2 of the seasonal forecast starting on 1 June 2007 (available on the 15 June 2007) to the EPS forecasts for days 16–46 starting on 15 June 2007.

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Probabilistic scores

We now compare the probabilistic scores for month 2 of System 3 with those obtained with the 46-day EPS. Figure 1 shows the relative operating characteristic (ROC) diagrams of the probability that the 2-metre temperature averaged over the next calendar month is in the upper tercile for the northern extratropics (Figure 1a) and the tropics (Figure 1b) in winter. According to Figure 1, the EPS forecasts are more skilful for predicting 2-metre temperature probabilities than month 2 of System 3. The difference is statistically significant within the 5% level of confidence according to the Wilcoxon-Mann-Whitney test. The 46-day EPS forecast also provides better scores than month 2 of System 3 for other variables such as precipitation and mean-sea-level pressure. Similar results are found for the other seasons.

Another way of assessing the skill of probabilistic forecasts is to use reliability diagrams (observed frequency as a function of forecast probability). Figure 2 shows the reliability diagram of the probability of the 2-metre temperature being in the upper tercile for the 46-day EPS forecasts and month 2 of System 3 over the northern extratropics. These results show that the 46-day EPS forecasts are more reliable than month 2 of System 3.

Increasing the horizontal resolution from T159 to T255 had some positive impact on the probabilistic scores for the extended EPS forecasts (*Vitart et al.*, 2008), but the improvement was significantly lower than the difference displayed in Figures 1 and 2. Therefore most of the difference in skill between the 46-day EPS and System 3 is likely due to the EPS forecasts benefiting from more recent initial conditions and also from a more recent model cycle. It is not clear at this point which of those two factors makes the most important contribution on the probabilistic scores.

It is possible that the skill of the 46-day EPS to predict 2-metre temperature anomalies of the next calendar month comes from day 16–30 forecasts and that there is no skill beyond day 30. To test this hypothesis, the anomalies of day 16-30 have been persisted to predict the 2-metre temperature anomalies of day 31–45. Results (not shown) indicate that persisting day 16–30 anomalies provides significantly less reliable probabilistic forecasts than day 31-45 of the EPS forecasts. This indicates that extending the EPS forecasts until day 46 is useful.

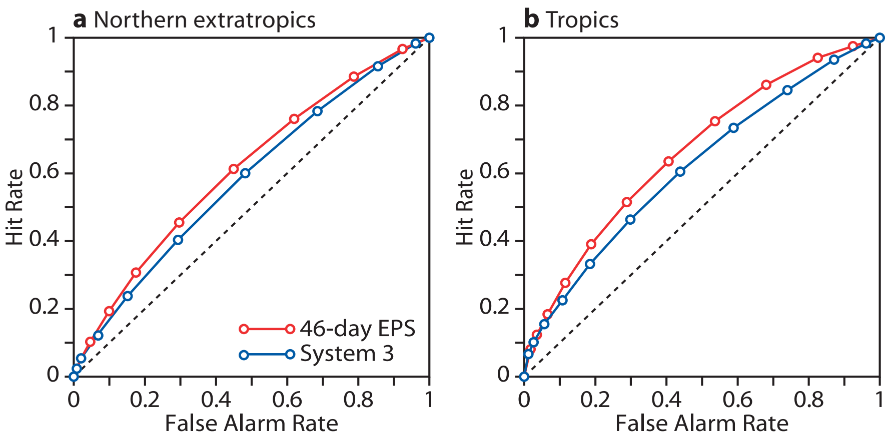

Figure 1 ROC diagrams of the probability that the 2-metre temperature is in the upper tercile for (a) northern extratropics and (b) tropics for the next calendar month for the 46-day EPS and month 2 of System 3 for the period December to February. Only land points have been scored. The further the curve is towards the upper left-hand corner the more skilful the forecast.

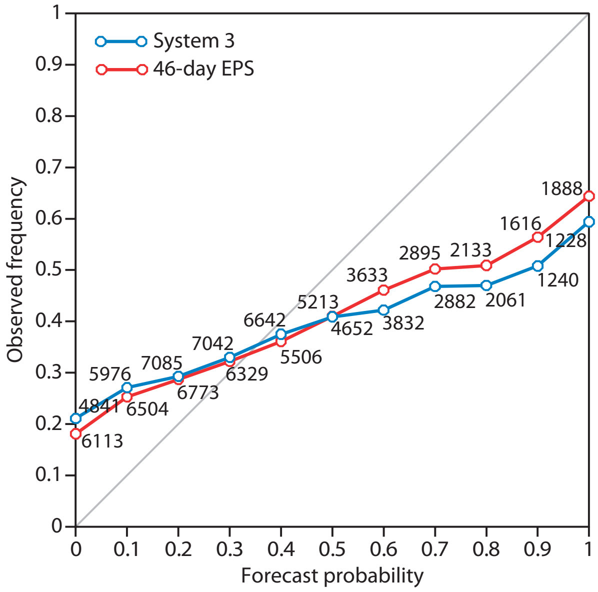

Figure 2 Reliability diagram of the probability that 2-metre temperature over the northern extratropics is in the upper tercile for the next calendar month for the 46-day EPS and month 2 of System 3 for the period December to February. Only land points have been scored. The closer the curve is to the diagonal the more reliable the forecast.

Two examples concerning extreme events

We will now discuss two specific cases of extreme events over Europe: the heatwave over Europe in the summer of 2003 and the unusually wet summer of 2007 in England.

Heatwave over Europe in the summer of 2003

The heatwave in the summer of 2003 killed about 35,000 people in Europe, and is therefore a particularly important case for monthly forecasting. Here we focus on August 2003, when the 2-metre temperature monthly mean anomalies were the highest and exceeded 4°C. For this specific case, the size of the 46-day EPS hindcasts starting on 15 July has been increased to cover the 30-year period from 1978 to 2007.

It is interesting to consider the ensemble distributions of the seasonal forecasts from System 3 starting on 1 July and the 46-day EPS forecasts starting on 15 July. Figure 3 shows the interannual variability of the ensemble mean, 25% and 75% values, and maximum and minimum of the ensemble distributions. In the seasonal forecast starting on the 1 July (Figure 3a), August 2003 does not stand out as being an exceptional month. However, in the 46-day EPS forecast (Figure 3b), August 2003 is predicted as being exceptionally warm. It is indeed predicted as being the warmest month of the 30-year period, although the predicted anomalies are still lower than observed. This suggests that the 46-day EPS could have been of value as an early warning for this heatwave over Europe.

To assess the impact of the horizontal atmospheric resolution on the 46-day EPS forecast, an additional EPS forecast has been produced with the same model version, but with a T159 resolution (same resolution as System 3). In this set of low-resolution EPS forecasts, August 2003 is no longer predicted as the warmest month of the 30-year period. This suggests that part of the improvements in the 2-metre temperature forecasts for August 2003 from the 46-day EPS compared to that from System 3 (Figure 3) is due to the higher resolution of the EPS.

Wet summer of 2007 in England

July 2007 was exceptionally wet over England, with record precipitation that led to significant flooding over Southwest England, particularly during the week of 16–22 July 2007. On the other hand, this month was particularly dry and hot over most of southern Europe, mostly in Southeast Europe as illustrated by the reanalysis (Figure 4a).

Figure 4b shows the probability of a positive anomaly of precipitation over Europe in the 46-day EPS forecasts starting on 15 June 2007. The anomalies have been calculated relative to the 1989–2006 model climatology. These results show that the 46-day EPS forecasts starting on 15 June were successful at predicting a high probability of a wetter than normal July 2007 over England, although the precipitation anomaly does not extend as far east as in the reanalysis (Figure 4a). The low probability of a wetter than normal July over Southeast Europe is also consistent with the reanalysis. On the other hand, the System 3 hindcasts starting on 1 June 2007 (Figure 4c) do not predict a higher probability than normal of a wet month over England. The probability of a dry July over Southeast Europe is also much smaller than in the 46-day EPS forecast. This result suggests that the 46-day EPS forecast would have provided a much better warning for those severe events than the System 3 forecast starting on 1 June.

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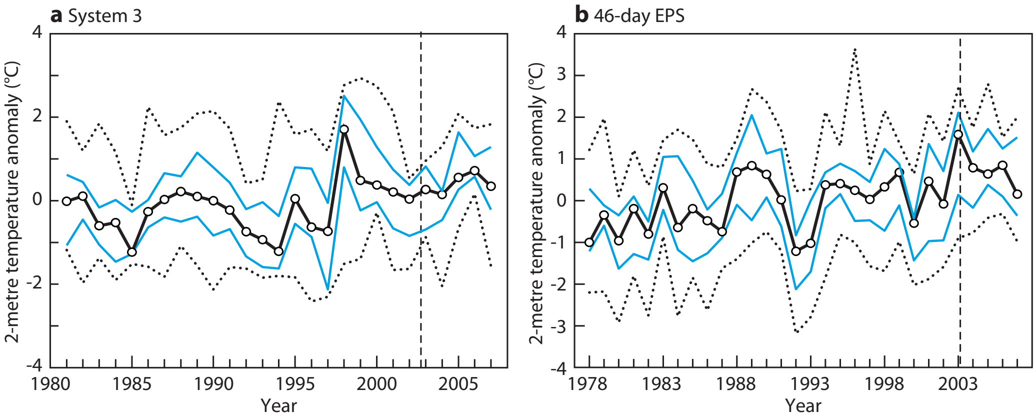

Figure 3 2-metre temperature ensemble distribution for (a) System 3 starting on 1 July and (b) 46-day EPS starting on 15 July. The solid black line represents the median. The blue line represents the 25% and 75% distributions. The black dotted lines represent the maximum and minimum of the distribution. The 2-metre temperature anomalies have been averaged over the area: 0–20°E, 40–50°N.

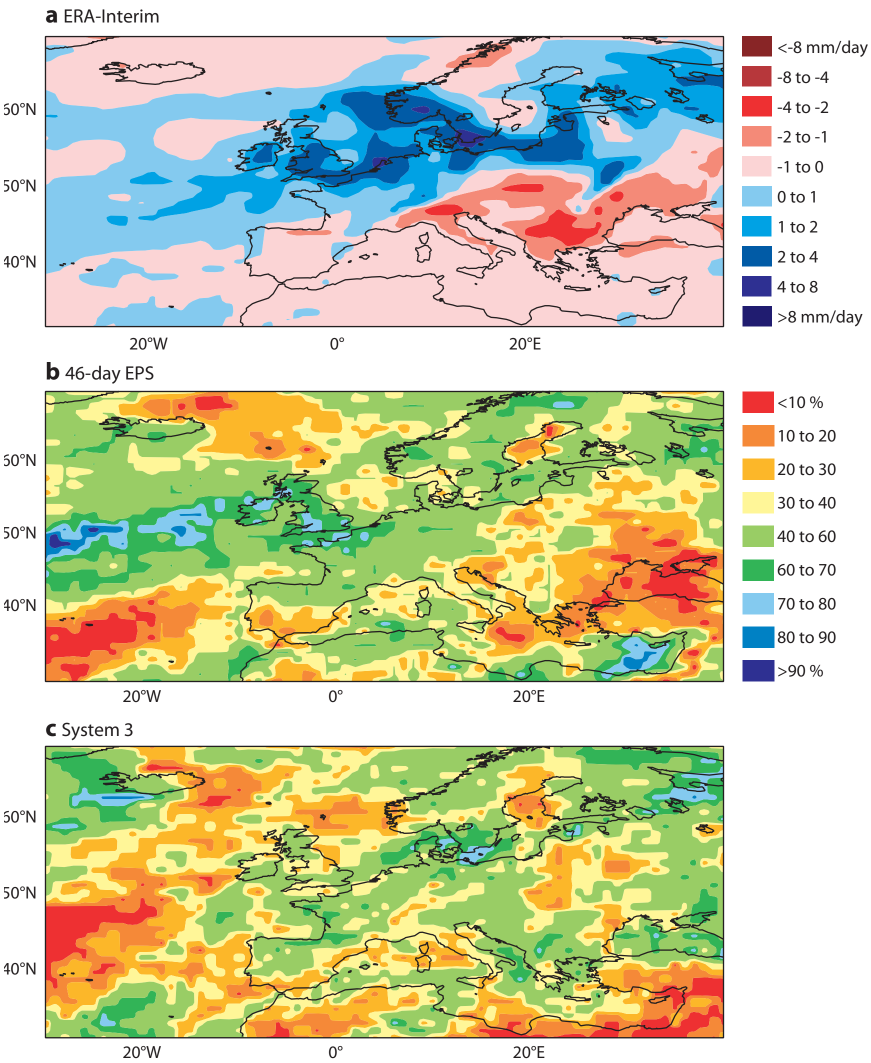

Figure 4 (a) The precipitation anomaly for July 2007 in ERA-Interim. The anomalies are relative to the period July 1989-2006. (b) The probability of a positive anomaly of precipitation (wetter than usual month of July) from the 46-day EPS forecasts starting on 15 June 2007. (c) The probabilities from System 3 starting on 1 June 2007. In all the three panels, the red contours represent dry conditions and the blue contours indicate wet conditions.

Atlantic hurricanes

The prediction of extreme events, such as hurricanes, is likely to benefit from a higher horizontal resolution. It is therefore expected that the higher resolution of 46-day EPS forecasts should produce more accurate hurricane forecasts than month 2 of System 3.

Figure 5 shows the climatological density of tropical storm tracks taken from observations (panel a), 46-day EPS forecasts for days 16–45 (panel b) and forecast for months 2 and 1 from System 3 (panels c and d). The 46-day EPS and System 3 forecasts tend to produce too many storms in the Atlantic at those extended time ranges. The patterns of the tropical storm density tracks are more realistic in the 46-day EPS than in System 3: in the 46-day EPS climatology, there is significant tropical cyclone activity in the mid-Atlantic and in the Gulf of Mexico, whereas most of the tropical cyclone activity in System 3 is concentrated between 10° and 20°N in the Atlantic. This is the main area where easterly waves develop into tropical storms. This difference in model climatology is not due to the 46-day EPS forecasts having a shorter lead time than month 2 of System 3: month 1 of System 3 shows a similar climatology to month 2 (compare Figure 5d with Figure 5c).

Sensitivity experiments have been performed to show that the difference in tropical cyclone climatology between System 3 and the 46-day EPS is mostly due the difference in model cycles.

The 46-day EPS shows a higher skill at predicting the interannual variability of the number of Atlantic hurricanes in individual months (Table 1) than not only month 2 of System 3, but also month 1 of System 3 that starts 15 days after the 46-day EPS. This improvement in the prediction of hurricane is essentially due to the higher resolution of the 46-day EPS compared to System 3. At the System 3 resolution (T159), the number of hurricanes simulated over a month by the model is too low to produce meaningful statistics. However, at T255, the number of hurricanes, although still lower than observed, is large enough to produce a realistic interannual variability.

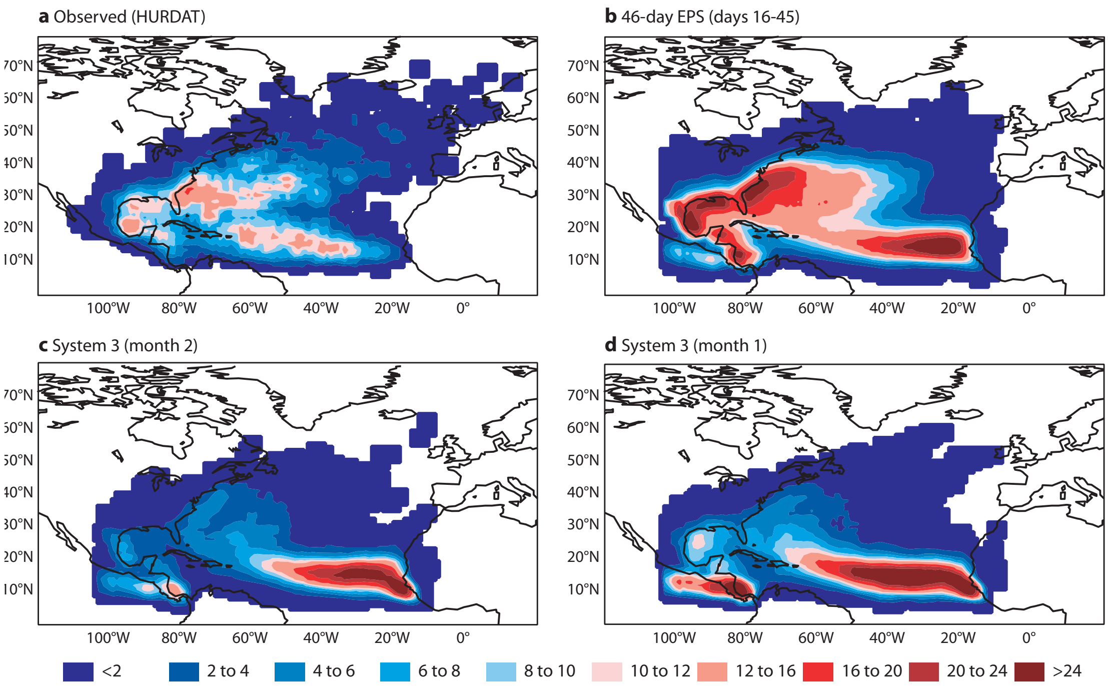

Figure 5 Density of topical storms (×1000) from (a) Atlantic basin hurricane database (HURDAT), (b) days 16–45 of the 46-day EPS forecasts, (c) month 2 of System 3 and (d) month 1 of System 3 for August to September 1989–2007. The density of tropical storms is defined here as the number of tropical storms per day passing within 200 km.

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Forecast system	August	September	October
46-day EPS	0.77	0.37	0.69
System 3 – Month 1	0.31	0.33	0.18
System 3 – Month 2	-0.03	0.23	0.18

Table 1 Correlation between the interannual variability of hurricanes for the period 1989–2007 from an Atlantic basin hurricane database (HURDAT) and 46-day EPS forecasts starting on the 15th of the previous month (forecast range: days 16–45), month 1 of the seasonal forecast starting the 1st of the month and month 2 of the seasonal forecast starting the 1st of the previous month for August, September and October.

Forecast system	Start date	Correlation	RMS error
46-day EPS	15 May	0.62	0.90
System 3– Month 2	1 May	0.40	1.15
System 3– Month 1	1 June	0.52	0.96

Table 2 Correlation and root-mean square (RMS) error between the interannual variability of June rainfall over India (only land points are used in the calculation) for 1989 to 2007 for the 46-day EPS, month 2 of System 3 starting on 1 May, and month1 of System 3 starting on 1 June. The observed data is the 1°×1° gridded daily rainfall data from the India Meteorological Department (Rejeevan et al., 2006, Current Science, 91, 296–306).

Early monsoon rainfall prediction

The prediction of Indian rainfall in June represents a particularly difficult challenge. During the month of June, the level of Indian rainfall is strongly linked to the onset of the monsoon, which is usually difficult to predict more than two weeks in advance. The skill of System 3 to predict monsoon rainfall has been evaluated by *Molteni et al.* (2008). They found that this dynamical seasonal forecasting system displays some skill at predicting monthly-mean precipitation over India after July, but has surprisingly low skill at predicting the June precipitation over India.

Table 2 shows that the correlation between the interannual variability of June precipitation over India predicted by System 3 starting on 1 May (time range: month 2) is only 0.40 for the period 1989–2007. On the other hand the 46-day EPS starting on 15 May has a correlation of 0.62 that is significantly higher than that for System 3. The root-mean-square error is also significantly lower in the 46-day EPS than with System 3. Interestingly, the 46-day EPS also outperforms the forecast from System 3 starting on 1 June (15 days later than the 46-day EPS) – see Table 2. The difference, although smaller than between the 46-day EPS and System 3 starting on 1 May, is statistically significant (within the 1% level of significance using a 10,000 bootstrap re-sampling procedure). Those results are consistent with those found by *Vitart & Molteni* (2009), which used a previous version of the IFS (Cy32r2).

The fact that the 46-day EPS produces more accurate indications of early monsoon rainfall than System 3 cannot be attributed to the more up-to-date initial conditions, since they also outperform seasonal forecasts starting 15 days later. In order to establish if this improvement is due to the increased resolution, the 46-day EPS experiment was repeated but with a T159 resolution (same resolution as System 3). The scores obtained with this low atmospheric resolution were very close to those obtained with System 3. This suggests that the monsoon rainfall forecasts for June benefit from the higher resolution of the 46-day EPS.

Benefits of using the 46-day EPS

In this short article, we have presented results from an experiment where the EPS forecasts have been extended to 46 days. The main conclusion is that extending EPS forecasts can lead to more accurate and reliable forecasts of the next calendar month than with the current seasonal forecasting system (System 3). It has been shown that the probabilistic scores are better with the 46-day EPS forecasts than with month 2 of System 3. In particular, the prediction of severe and extreme events like the 2003 heatwave over Europe, the wet July 2007 over England, the frequency of hurricanes and early monsoon rainfall is significantly more accurate with the 46-day EPS than with System 3.

The forecast improvements are due to different factors: the improvements in the probabilistic scores are due mostly to the more up-to-date initial conditions and model cycle. However, the forecasts of hurricane frequency or early monsoon rainfall produced by the 46-day EPS are more accurate than the System 3 forecasts starting 15 days later (month 1). For those severe events, the increase of the atmospheric resolution seems to be the main factor explaining the improvement. The benefits from a more recent IFS cycle were shown in the case of the Atlantic tropical storm climatology, which is much more realistic in the 46-day EPS than in System 3. Therefore, more up-date model cycle, more up-to-date initial conditions and higher resolution are factors which together help to produce better forecasts of the next calendar month.

At the moment no decision has been taken on the possibility to operationally extend the EPS beyond the current 32 days. In any case, such an extension should be seen as a complement to the seasonal forecast: the next version of the ECMWF seasonal forecasting system (System 4) will remain separate from the EPS. Further research will be performed to investigate the potential benefit of extending the EPS and to determine its optimal overlap with the seasonal forecasting system.

Further Reading

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