The ECMWF medium-range forecasting system: performance and product development

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1 Introduction

The core activity of ECMWF is to provide medium-range weather forecasts to the national meteorological services of its Member and Co-operating States. The ECMWF forecasting system provides users with operational forecast guidance twice daily for the medium range. The high-resolution deterministic forecast is run at 25km resolution (T799 spectral truncation) and has 91 levels from the surface to a height of 80km. Forecasts are started from analyses at 00 and 12 UTC and run to 10 days ahead. To quantify the uncertainty in the forecast, the deterministic forecast is complemented by an Ensemble Prediction System (EPS). This is a set of 50 forecasts, each started from a slightly perturbed version of the operational analysis. The perturbed forecasts represent the range of possible future atmospheric states consistent with the small but sometimes significant uncertainty in the initial state. In addition, small perturbations are also applied during the forecast to represent uncertainty in the model formulation. The EPS uses the same model as the deterministic forecast, but at lower resolution. The EPS is run to 10 days at 50 km horizontal resolution (T399 spectral truncation), with 62 levels. In autumn 2006, the VarEPS system was introduced, extending the EPS range to 15 days, with the portion from 10-15 days run at a reduced 80km resolution (T255).

ECMWF also runs a coupled atmosphere-ocean forecasting system to provide longer-range predictions, providing operational forecasts once a week for a month ahead and once a month out to seven months. A new seasonal forecasting system was implemented in spring 2007. The monthly and seasonal forecasting systems are described elsewhere in these proceedings.

During 2006 and 2007, several major changes to the operational medium-range forecasting system were implemented. These included:

- Substantial increase in resolution for both the deterministic forecast and the EPS (February 2006)
- Changes to the assimilation system (three minimizations in 4D-Var)
- Assimilation of new data sources, most notably IASI from Metop-A
- Major revisions of the model physics
- Introduction of the variable resolution ensemble forecasting system (VarEPS), with forecasts at reduced resolution going out to day 15 (November 2006)

Details of the changes can be found in the ECMWF Newsletter or on the ECMWF web site.

2 Performance of the medium-range forecasting system

The performance of the deterministic forecasts has been consistently good in the last year, with a particularly striking positive trend in the anomaly correlation over Europe (Figure 1). One notable reason for the overall high scores is a continuing reduction in the number of poor individual forecasts and corresponding increase in the occurrence of skilful forecasts. The trend in EPS performance is illustrated in Figure 2, which shows the evolution of the ranked probability skill score (RPSS) for 850 hPa temperature over the northern hemisphere and Europe. As for the deterministic forecast, the EPS skill was consistently good over the last year. The EPS performance benefited substantially from the increase in resolution in February 2006 (T255 to T399).

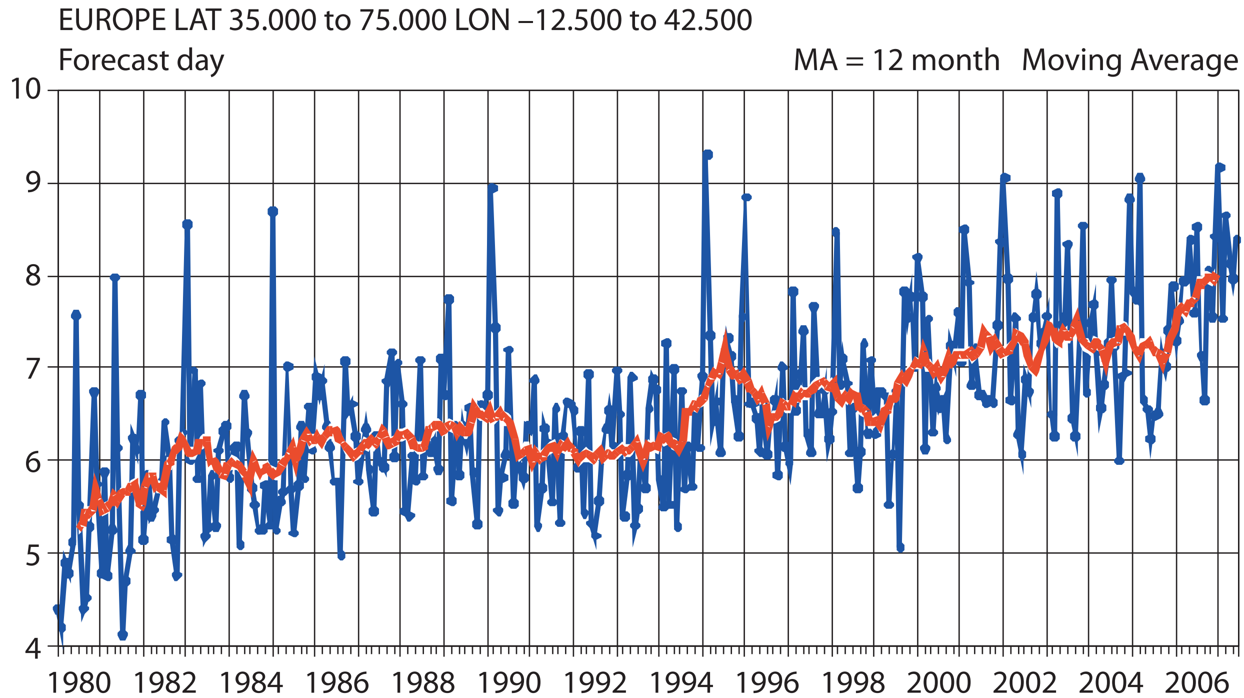

Fig. 1 Monthly mean (blue) and 12-month running mean (red) of the forecast range at which the anomaly correlation for 500hPa height field of the ECMWF operational forecasts falls below 60% for Europe.

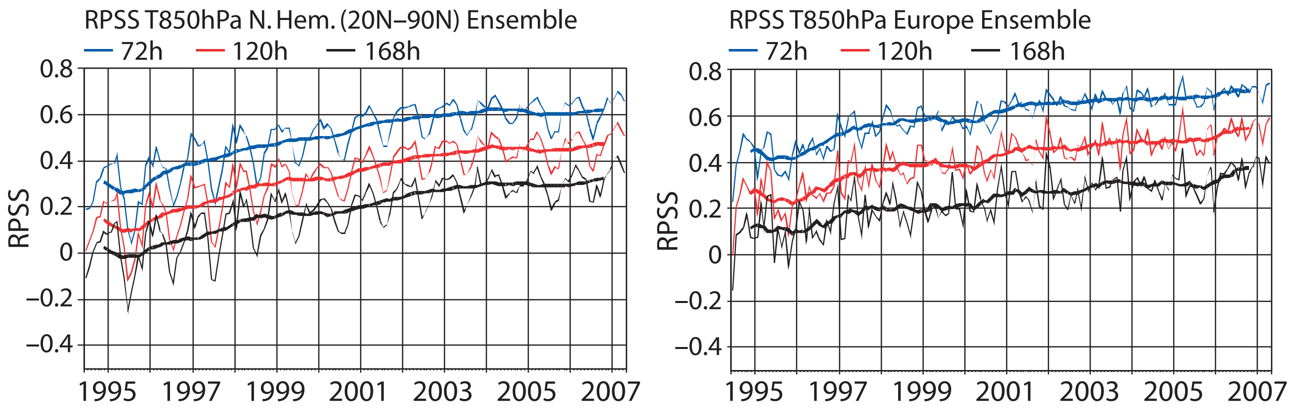

Fig. 2 Monthly score and 12-month running mean (bold) of Ranked Probability Skill Score for EPS forecasts of 850 hPa temperature at day 3 (blue), 5 (red) and 7 (black) for the northern hemisphere extratropics (left) and Europe (right).

Forecasts of surface weather parameters benefited from the improvements to the model physics. As an example, the evolution of precipitation skill for the deterministic forecast over Europe is shown in Figure 3 for precipitation exceeding the threshold of 5mm/day. The improvement in skill following the introduction of the physics changes in cycle 31r1 (September 2006) is particularly striking. Corresponding improvements are also found in scores for the EPS probability forecasts (not shown).

The ocean wave model continues to perform well, as can be seen in the comparison with other models shown in Figure 4. Forecasts from different centres are verified for a common set of northern hemisphere buoys. The wave forecasts from the French naval Service Hydrographique et Océanographique de la Marine, SHOM, are the closest in performance to ECMWF; their wave model is driven by the ECMWF winds.

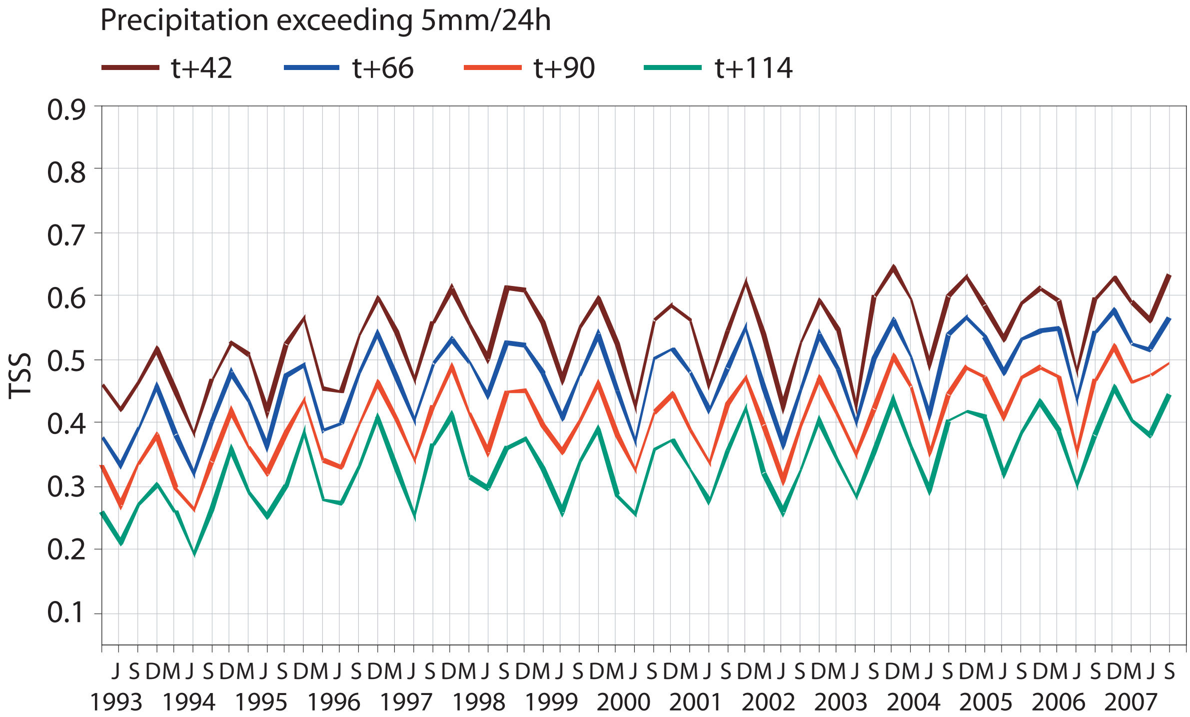

Fig. 3 Time series of True Skill Score (TSS) for precipitation forecasts exceeding 5mm/day verified against SYNOP data on the GTS for Europe. Curves are shown for the 24-hour accumulations up to 42, 66, 90, and 114 hours (from the forecasts starting at 12 UTC). 3-month mean scores (last point is September-November 2007).

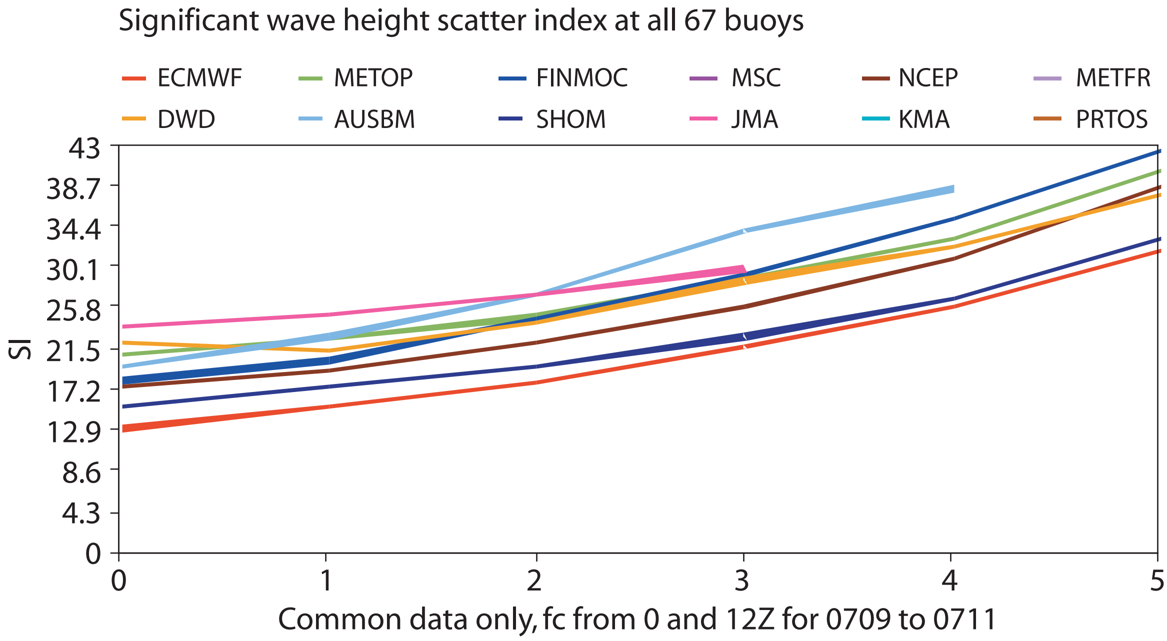

Fig. 4 Verification of different model wave height forecasts using a consistent set of observations from wave buoys. The scatter index (SI) is the standard deviation of error normalised by the mean observed value. Curves show SI for the analysis(day 0) and forecasts for 1-5 days, averaged over September-November 2007.

3 Product development

In November 2006 the variable resolution ensemble system (VarEPS) was introduced, extending the EPS forecast range to 15 days. The last 5 days of the forecasts are run at a reduced horizontal resolution (T255) relative to the first 10 days (T399). The full range of VarEPS model output is archived in MARS and available through the dissemination. The post-processed EPS probability products were extended to 15 days and a new set of probabilities was introduced for the period 11-15 days, based on the thresholds already used for days 6-10. A new 15-day EPSgram was introduced to complement the existing 10-day product. The 15-day EPSgram displays daily values (maximum and minimum for temperature) on the T255 grid. More information on the tails of the EPS distribution was added to both 10-day and 15-day EPSgrams by adding the 10th and 90th centiles. In 2007, the distribution of wind direction was added to the 15-day EPSgram. A 10-day EPSgram for ocean waves is planned to be introduced in 2008.

The range of EPS products displayed on the ECMWF web site has been extended to include plots of the ensemble mean and ensemble spread. Products in development include maps of selected percentiles of the EPS distribution and additional ocean wave products. The genesis of tropical cyclones during the forecast has been noted on several occasions in the operational model. At present operational tracking is only applied when a tropical cyclone is observed and present in the analysis. The tracking of cyclones that develop during the forecast is being investigated.

4 Severe weather

A key part of the ECMWF strategy is to develop products to provide early warnings of severe weather. The following examples demonstrate some of these products for three different types of severe events that occurred in Europe in 2007.

A severe winter storm (Kyrill) affected many areas, crossing from the UK into northern Germany on 18 January 2007. Extreme winds caused extensive damage over large areas. Initial estimates put total losses at €5-7 billion, making this one of the most damaging storm events to affect northern Europe in recent years. Medium-range forecasts gave early warning of a storm affecting the region, with increasing probability of extreme winds as the event approached. Figure 5 shows the strong signal from the extreme forecast index (EFI) for widespread extreme winds from the EPS forecast of 15 January. The EFI compares the distribution of wind speeds in the current EPS forecast with the distribution of speeds in the model climate. A high value of the EFI indicates that there is a strong signal in the EPS for winds to be at the extreme of the range that can be reproduced by the model.

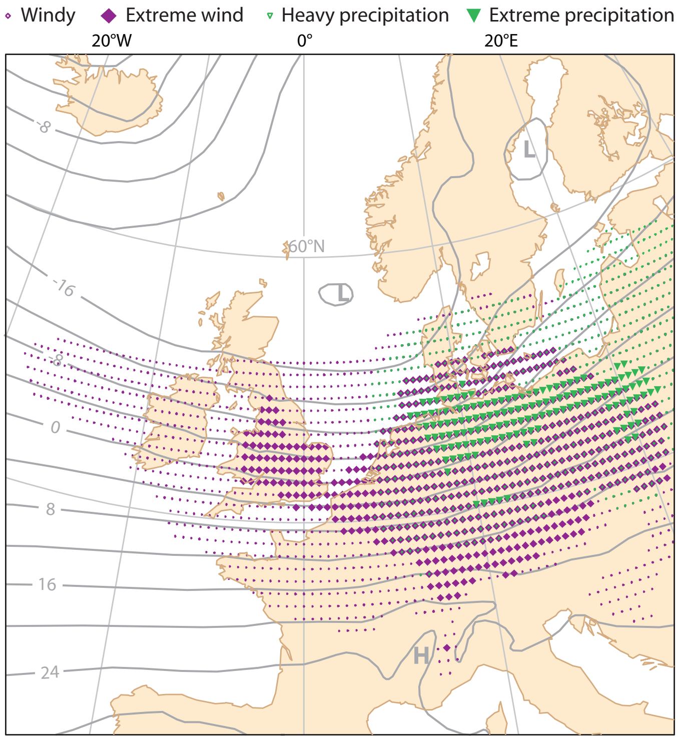

Fig. 5 Storm Kyrill affected large areas of northern Europe on 18 January 2007. The chart shows areas where exceptionally strong winds and heavy rainfall are expected during 18 January, based on the EPS forecast from 00 UTC on 15. Symbols indicate high risk of extreme weather, using the extreme forecast index (EFI) which compares the EPS distribution to that of the model climate, for wind (purple symbols) and precipitation (green symbols). The contours show the 1000 hPa height from the ensemble mean for 12 UTC on 18 January.

June and July 2007 were record wet months in England and Wales, containing periods of intense precipitation that resulted in severe flooding in many areas. The exceptional rainfall over the two-month period was well forecast (Figure 6). Total precipitation predicted over the period was higher than the 30-year maximum of the EFI model climate for forecasts up to day four, while longer range forecasts also generated substantially higher rainfall than average. Figure 7 shows the EFI for precipitation for the forecast from 17 July, warning of extreme precipitation in the south of the UK on 20 July. The event caused widespread flooding in southern England.

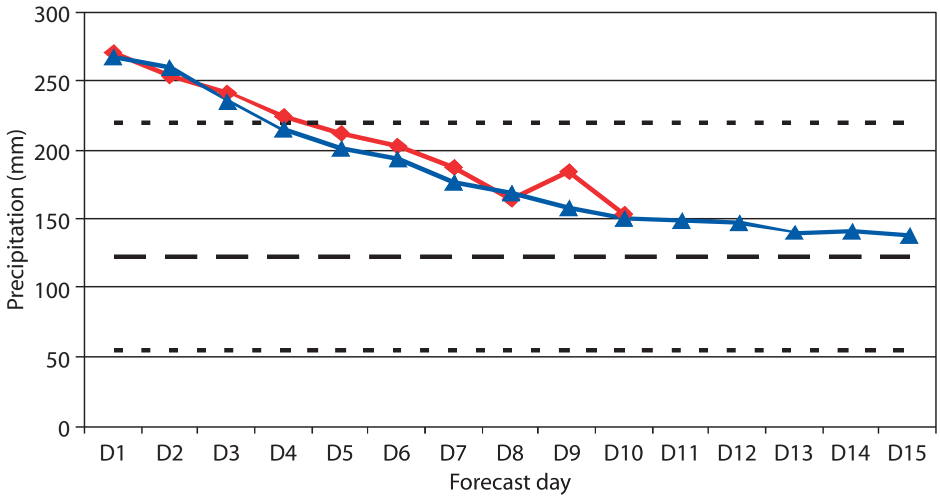

Fig. 6 Total precipitation over England and Wales during June-July 2007. The curves show the total rainfall accumulated over all forecasts verifying during June and July for each 24-hour forecast period from the deterministic T799 (red) and EPS ensemble mean (blue). The climatological range of the model forecasts is shown using the 30-year set of one-day forecasts used to generate the EFI climatology. The minimum, maximum (dotted) and mean (dashed) totals are shown.

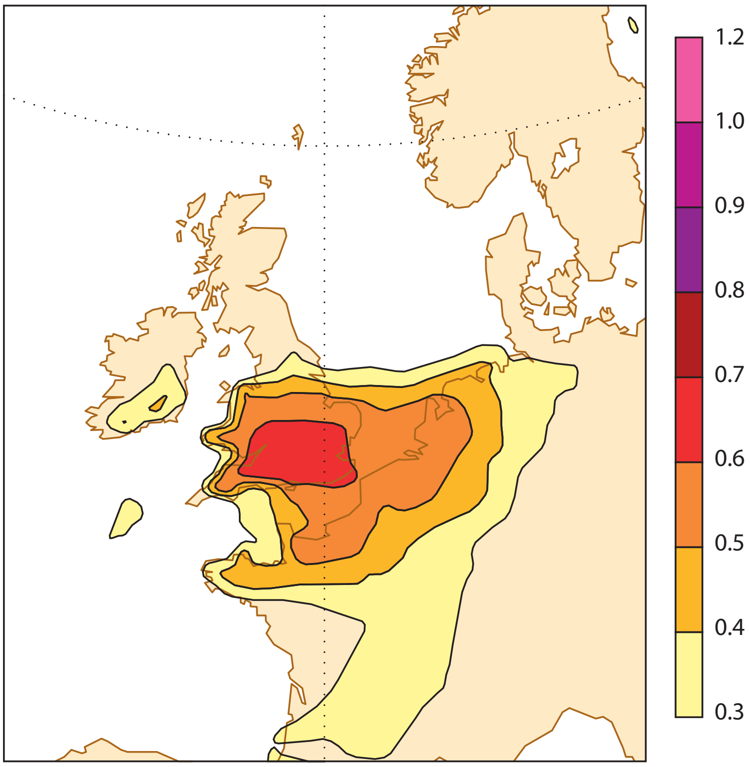

Fig. 7 Heavy rainfall over southern UK on 20 July 2007. Extreme Forecast Index (EFI) gives good indication of an area of exceptional precipitation in 72-hour forecast. Shading shows EFI (higher values indicate more extreme events). The contours show the complementary Shift of Tails (SOT) index.

At the same time, much of south-eastern Europe was affected by a heat wave. The event lasted about one week centred on 20 July 2007, with temperatures rising above 40°C. Many casualties were reported as a result of the sustained high temperatures. The medium-range forecasting system gave good early warnings, already apparent in the 15-day forecast. Figure 8 shows a set of 10-day EPS forecast products for 20th July, showing a strong and consistent signal for the event.

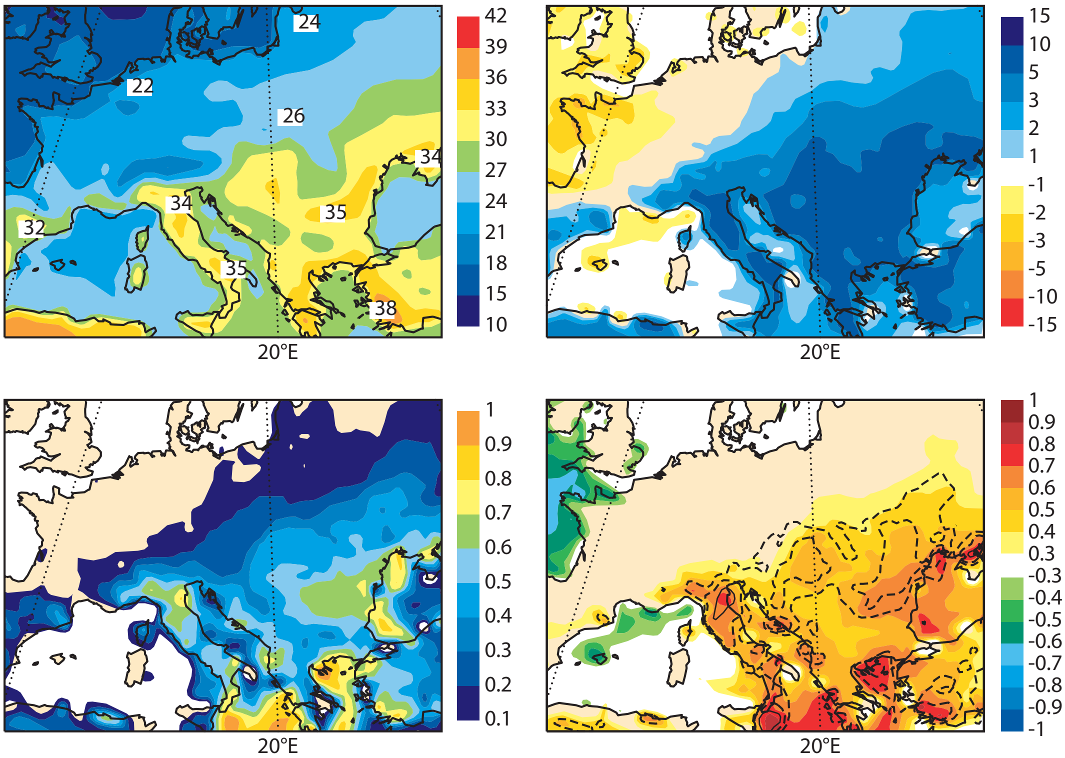

Fig. 8 Heat wave in south-east Europe, July 2007. The four panels show different products from the EPS 15-day forecast made on 5 July for the temperature over Europe on 20 July. The top-left panel shows the ensemble mean forecast of 2m temperature with values in the high 30s in south-east Europe. The top-right panel shows the temperature expressed as an anomaly from climatology. This confirms that these values are several degrees above normal for July. The bottom panels are also useful in assessing how extreme this event may be. The lower-left panel shows the probability that temperatures will be in the top 5% of the climate distribution. More than half of the ensemble members are forecasting such a situation; this is an unusually strong signal at this forecast range, 15 days before the event. The signal is confirmed in the lower-right panel, which shows the Extreme Forecast Index (EFI); this also shows an unusually strong signal for a 15-day forecast.