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Extreme weather events in summer 2010: how did the ECMWF forecasting systems perform?

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Extreme weather events in summer 2010: how did the ECMWF forecasting systems perform?

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The weather over Europe and Asia during July and August 2010 has been rather unusual.

During the second half of July and beginning of August, a blocking anticyclone over Russia dominated the weather pattern in Europe. Figure 1 shows the analysed geopotential height at 500 hPa and the winds at 200 hPa averaged for the period 15 July to 10 August. The blocking high is visible in the geopotential height field while the jet meanders around it. At the end of July, it is this jet that drives cold air towards the Indian Ocean which interacts with low-level warm and humid air and initiates the heavy rainfall in Pakistan. During the blocking period the position of the anticyclone favoured a cold northerly airflow that ended the warm spell over Western Europe. At the same time warm air from Africa reached Russia leading to a heat wave with temperatures rising to unprecedented levels.

Both the Russian heat wave and the severe rainfall in Pakistan will be discussed with the focus on the performance of the ECMWF's deterministic forecasts and Ensemble Prediction System (EPS).

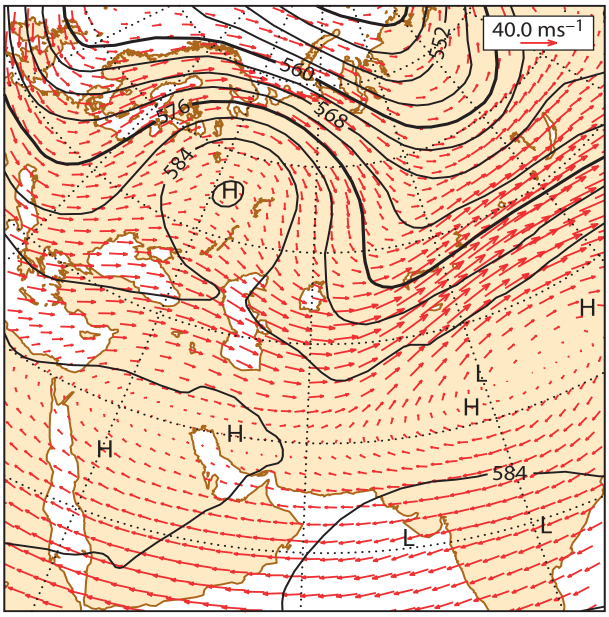

Figure 1 Geopotential height at 500 hPa and wind at 200 hPa averaged over the period 15 July to 10 August 2010.

Russian heat wave

ECMWF's model suites (deterministic and ensemble forecasts) were consistently forecasting the onset and persistence of the blocked pattern both in the medium-range and monthly forecasts. The blocking pattern during the first week in August was forecast four weeks in advance with the monthly forecasting system displaying positive anomalies of geopotential height at 500 hPa over Russia from the forecast run from 8 July 2010. Subsequent forecasts consistently indicated the presence of positive anomalies over Russia which became stronger as the forecast lead-time decreased.

Figure 2 illustrates the forecasts of 2-metre temperature weekly anomalies in Russia and the weekly mean for the geopotential at 500 hPa. Three weeks before the event the anomalies of 2-metre temperature from the monthly forecast (Figure 2a) indicated unusually warm conditions during the first week of August, with this signal being consistent in subsequent forecasts (Figures 2b and 2c). A verification of the heat wave anomalies indicates that the forecast anomalies were only slightly less pronounced than those analysed.

The highest observed temperatures occurred during the last week of July and the first week of August when temperatures soared to record values of up to 39°C at Moscow Domodedovo airport and Moscow Observatory. The ECMWF EPS forecast the heat wave on 29 July as illustrated by the four-day forecast

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of the extreme forecast index (EFI) shown in Figure 3. This shows an extensive area with high values from the Ural Mountains to the western border of Russia. The EFI for Moscow (black dot in Figure 3) is close to 1 (corresponding to the highest probability of temperatures above the climate values) and a significant risk of extremely hot weather is also forecast for southern Finland.

The shorter-range EPS forecast also indicated maximum temperatures well above climate values (the climate used refers to an 18-year model climate) for an extended period as shown in the 15-day EPSgram for a location close to Moscow (Figure 4). Indeed the EPSgram shows maximum temperatures exceeding the 99th percentile of the climate by 4° to 5°C, i.e. a very extreme event.

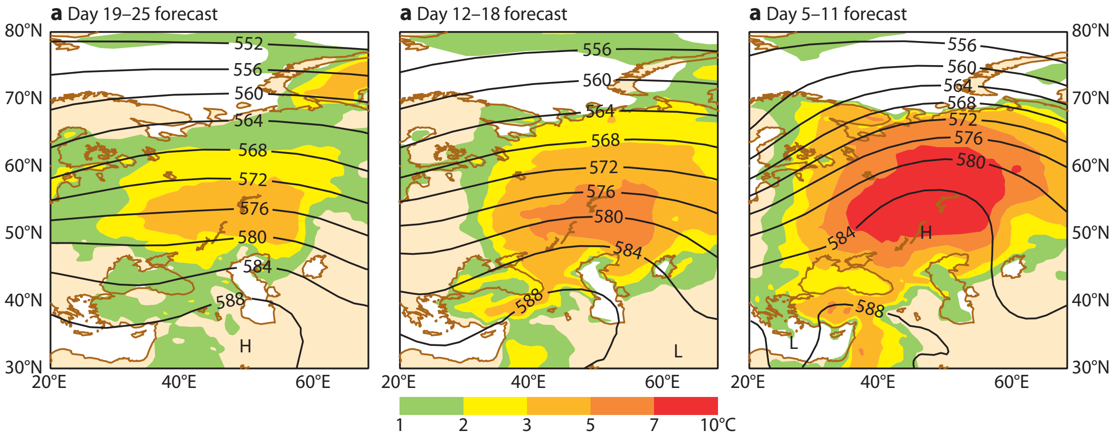

Figure 2 Forecasts of 2-metre temperature weekly anomaly (°C) for the first week in August based on forecasts for (a) days 19 to 25, (b) days 12 to 18 and (c) days 5 to 11. The anomalies are shaded as in the legend and the mean weekly forecast for the geopotential at 500 hPa is contoured.

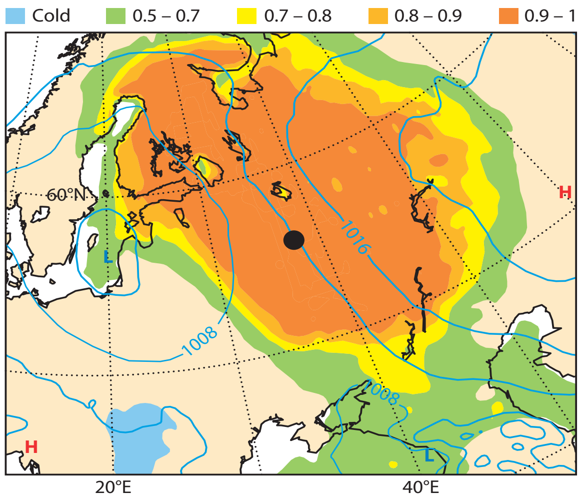

Figure 3 Four-day forecast of EFI values from 00 UTC on 25 July 2010 for the Russian heat wave. The black dot indicates the location of Moscow.

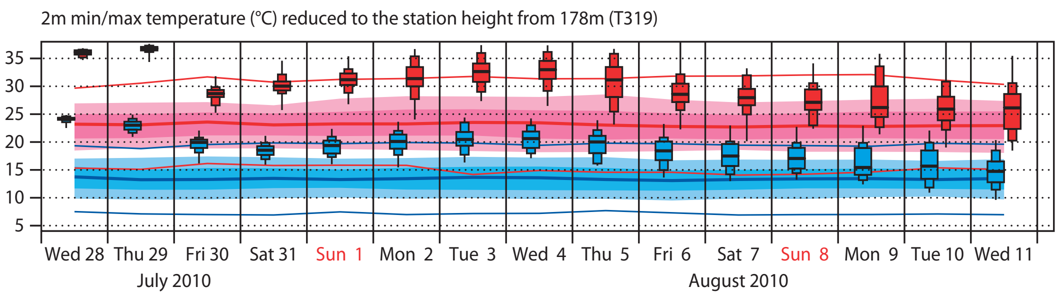

Figure 4 Extract from the 15-day EPSgram for a location near Moscow (55.88°N, 37.50°E). The maximum of temperature (Tmax) and its climate distribution are shown in red. The shaded area is the climate and the lines represent the 1st and 99th percentile. The minimum temperature and its climate distribution are also included (blue).

The rarity of extreme weather events can be expressed in terms of their return period; rarer events have longer return periods which can be assessed statistically from their frequency of occurrence in long time series. Figure 5 shows the EPS probability (at day 4) of exceeding the temperature extreme at each location that statistically would be expected to occur on average once in any 20-year period, i.e. the temperature with a 20-year return period. During the Russian heat wave, the EPS predicted 20-year extreme temperatures with very high probability on 29 July. To generate this probability forecast in terms of return period, the following steps are performed.

- The daily maximum temperature values are extracted from the 18-year EPS model climate at each grid point and used to fit a statistical frequency distribution function appropriate for the analysis of extremes (*Coles*, 2001).
- At each location, the temperature value associated with any given return period (e.g. 20 years) is obtained from those distributions.
- The forecast probability of exceeding the n-year extreme temperature is computed at each location as the number of EPS members with the event divided by the size of the ensemble (i.e. 51 for the current EPS).

In Figure 5 probabilities higher than 80% can be seen in eastern Finland and northern Russia where the 20-year extreme temperature was indeed exceeded in several places as shown by the contoured areas. In some locations the EPS even indicated a high probability of exceeding the 75-year extreme temperature, thereby conveying a high level of confidence for the very unusual temperatures four days in advance.

As the heat wave relentlessly influenced the life of millions of Russians, correctly forecasting the end of the blocking became of crucial importance, as a breaking of the anticyclonic conditions implied cooler air being allowed in over Russia. Figure 6 shows the Hovmöller plot of a 20-day analysis followed by a 10-day forecast from 12 UTC on 18 August 2010. It indicates the time evolution (on the ordinate) of geopotential anomaly at 500 hPa averaged over a range of latitudes (35°N to 60°N) versus the longitude. The red area (positive anomaly) centred at 50°E indicates the analysed stationary blocking pattern. On the 18th, the short-range forecast correctly shows the breaking of the blocking with negative anomalies moving into Russia as the forecast range progresses (blue area, backward tilted). Indeed, indications of the end of the blocked flow were evident in the deterministic high-resolution forecast run from 12 August 2010; that is the end of the blocking was forecast with a 6-day lead-time.

The 6-day EPS forecast based on 12 August 2010 indicated a circulation change. The spread of the ensemble associated with this circulation change was small suggesting a forecast with a high degree of confidence. Moreover, the monthly forecasts showed the weakening of the warm anomaly over Russia in the period 16–22 August, 3 weeks in advance.

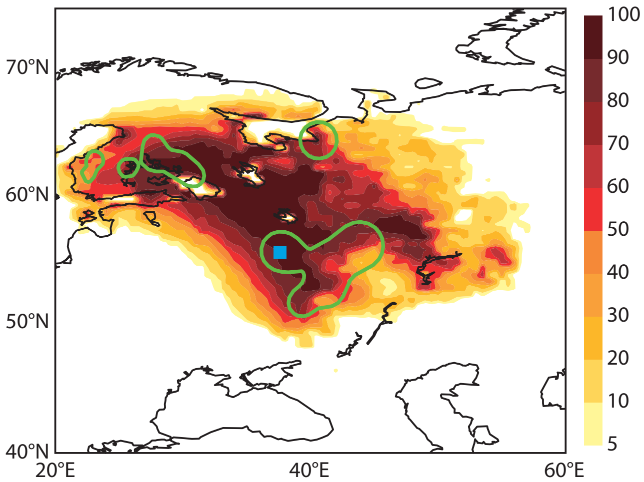

Figure 5 90-hour probability forecast (%) of the 20-year extreme temperature for the forecast started at 00 UTC on 26 July and valid for 18 UTC on 29 July 2010. The areas bounded by green lines represent the ‘radius of influence’ for the SYNOP stations reporting a 20-year return period to highlight observed events at each station. Moscow is marked by a blue square. Return values are obtained from the European Climate Assessment & Dataset Project.

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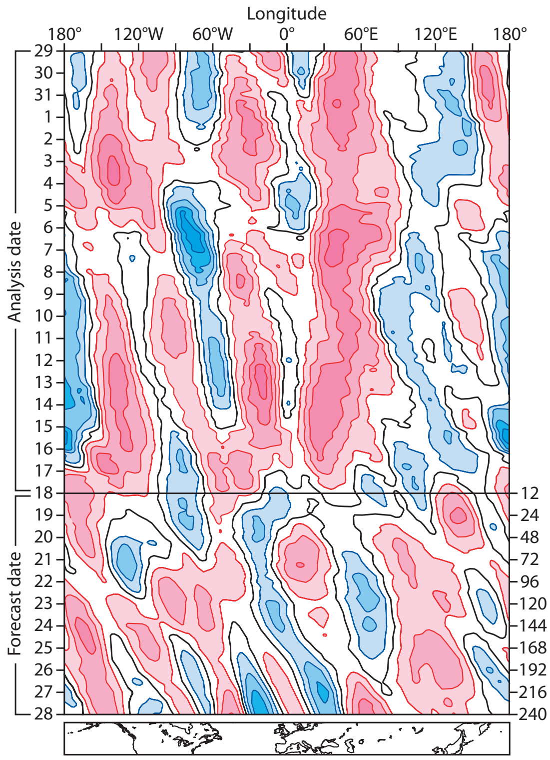

Figure 6 Hovmöller plot of geopotential anomaly showing the 500 hPa geopotential anomaly averaged over 35°–60°N for the analysis from 12 UTC on 29 July to 12 UTC on 18 August followed by the forecast from 12 UTC on 18 August 2010.

Rainfall in Pakistan

The devastating floods that hit Pakistan at the end of July cannot simply be ascribed to a particularly active Indian Monsoon. This is illustrated by the amount of precipitation received in a single day which exceeded half of the annual rainfall (see *'Extreme weather in August 2010'* by Julia Slingo available from:

- www.metoffice.gov.uk/corporate/pressoffice/toolkits.html)

The rather unusual weather pattern during the last week of July, with cold air at higher levels and warm and humid air at low levels, triggered excessive amounts of rain which caused severe flooding along the river Indus. Comparing the satellite images of Pakistan in August 2009 (Figure 7a) and in August 2010 (Figure 7b) gives an indication of the severity of the flooding.

The ECMWF high-resolution deterministic forecast indicated with great consistency the influx of warm and humid air from the ocean 5 days ahead of the event, with accumulated precipitations over 4 days of 400 mm along the river Indus; this is in good agreement with the reported rainfall amounts.

The EFI had a clear signal with values close to 1 (maximum risk) for precipitation well above climate values. A sequence of three plots showing the EFI values for Pakistan and neighbouring parts of India depicts the build up of the heavy precipitation event from 27 to 29 July (Figure 8).

Figure 9 shows the probability of exceeding 100 mm over a period of 4 days. The shaded areas correspond to different probability thresholds while the contours serve as indicators of the orography. The regions of high probability located over the Indian Ocean and the western side of the Indian peninsula correspond to areas affected by the monsoon which is active during the summer season (May through to September). Areas of large probability of exceedance are also located in the mountainous areas (Hindu Kush and Karakoram ranges) of Pakistan and India and along the river Indus where the probability was already up to 40% nine days before the event. Subsequent forecasts (shorter range) see this probability of exceedance increase to 50%.

The monthly forecast predicted exceptional rainfall over Pakistan (during the last week in July) well in advance. Four weeks before the event the predicted weekly anomaly was between 30 to 80 mm depending on the area. These values compare well with the analysed precipitation (the short-range forecast is hereafter used as a proxy for the observed amounts) for the period. Figure 10a shows the precipitation analysis for the last week in July and the four forecasts verifying on the analysis are given at Figures 10b, 10c, 10d and 10e.

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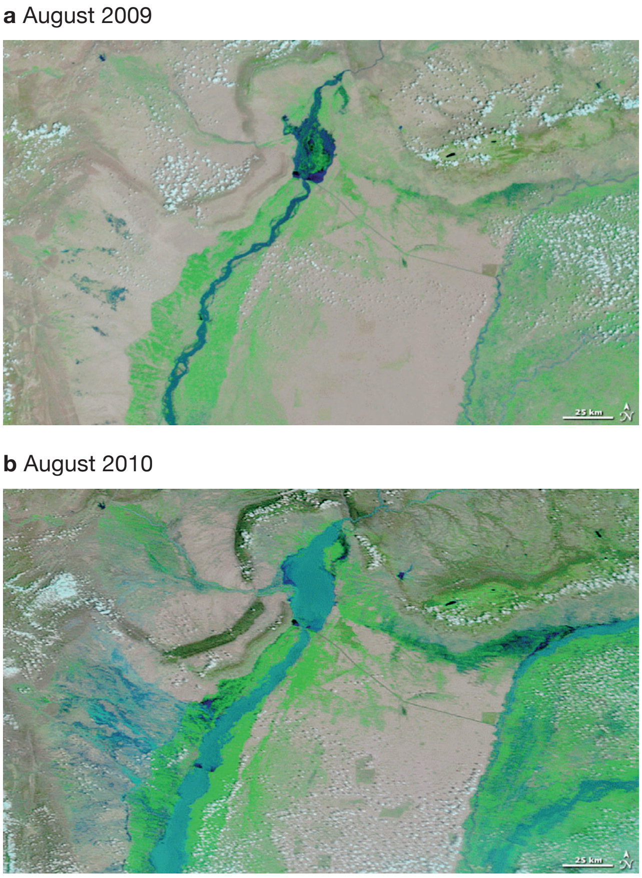

Figure 7 Satellite images of the catchment of the river Indus for (a) August 2009 and (b) August 2010.

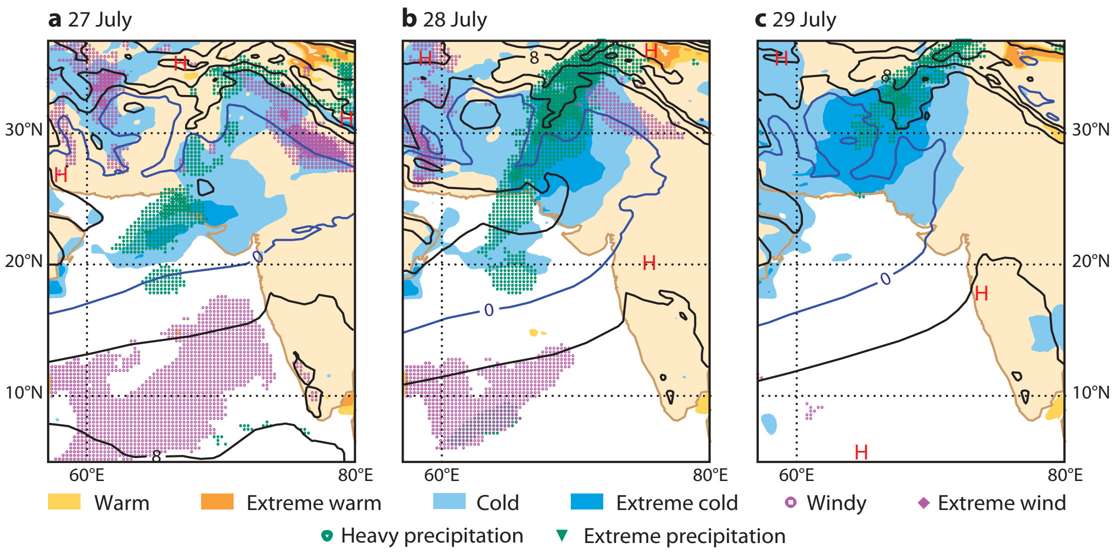

Figure 8 EFI categories for Pakistan and neighbouring India for three consecutive days: (a) 27 July, (b) 28 July and (c) 29 July 2010. Green dots/triangles: heavy/extreme precipitation; Light/dark blue shading: anomalous cold temperatures; Magenta dots/diamonds: windy/extreme wind.

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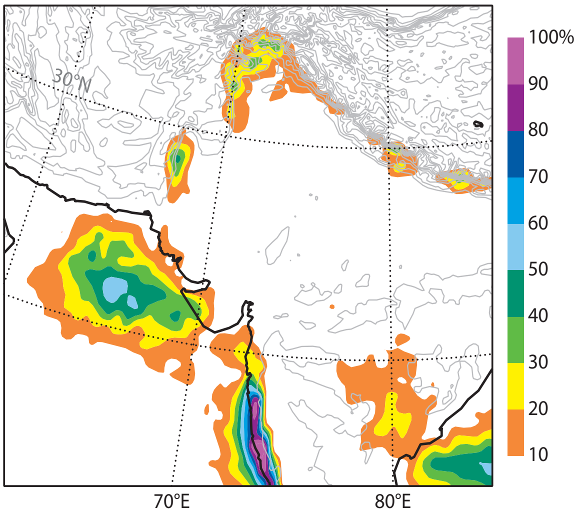

Figure 9 Day-9 probability of rainfall exceeding 100 mm over four days (accumulated from day 5) for Pakistan based on the forecast from 00 UTC on 22 July 2010 along with the contours of the orography.

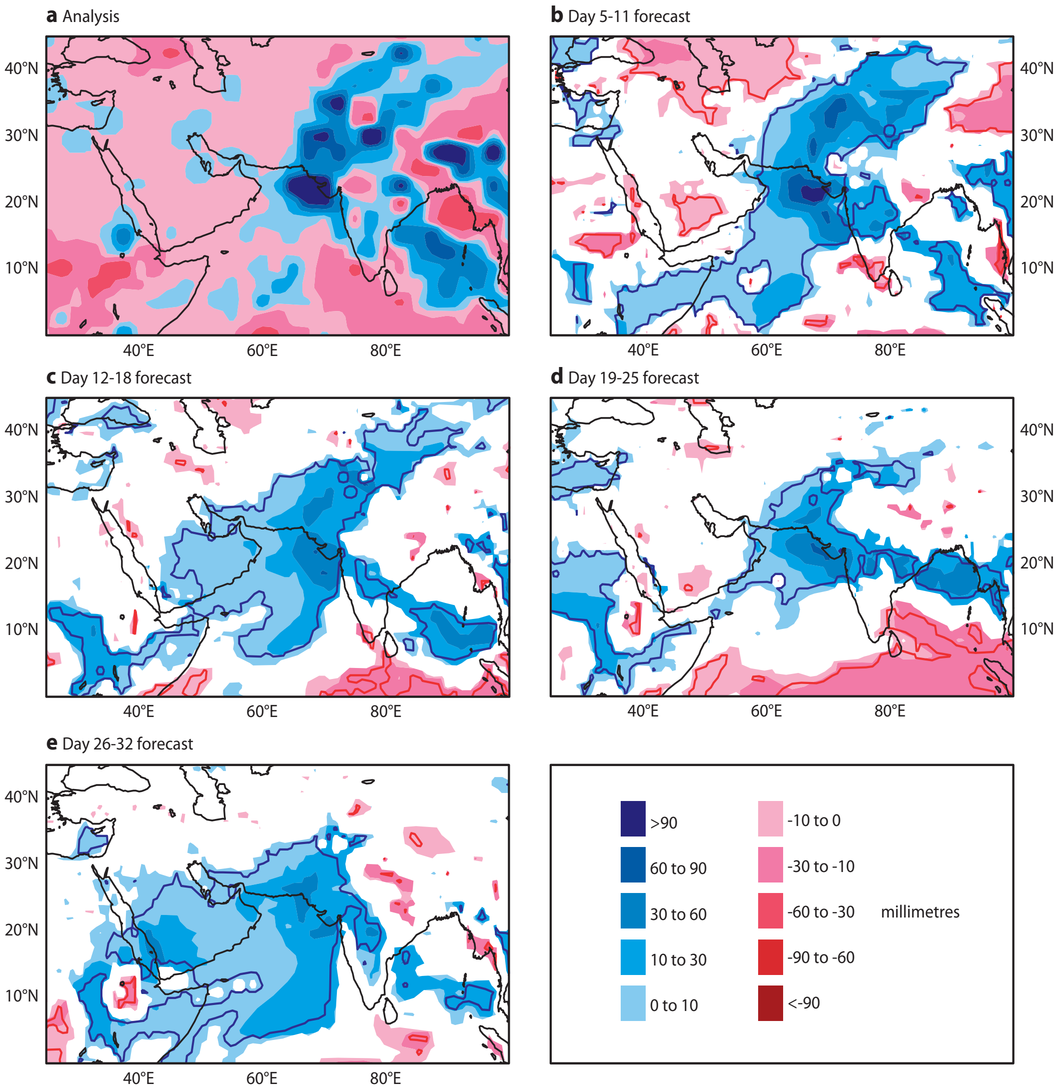

Figure 10 (a) Analysed precipitation anomaly (mm) for the last week in July (the 24-hour forecast has been used as proxy for the analysed values) and the corresponding forecasts for (b) days 5 to 11, (c) days 12 to 18, (d) days 19 to 25, and (e) days 26 to 32 that all verify with the analysed field. The shaded areas are significant at the 10% level.

Forecasting extreme weather events

The extreme weather events in summer 2010 were well predicted by ECMWF forecasting systems. The monthly forecasting system gave a good indication of the temperature anomaly over Russia three weeks in advance and high temperatures were consistently forecast in the medium range. Indeed the EFI gave a good indication of the risk four days ahead and the return period signalled the severity of the event. It is noteworthy that the crucial identification of the breaking of the blocking was also forecast with a high level of confidence by the EPS with a six-day lead-time.

Both the EPS and deterministic models forecast the heavy precipitation in Pakistan with a high level of accuracy, at least in terms of spatial distribution and timing. The exceptional nature of the situation was signalled by the EFI five days before the event. However, a more extensive evaluation of the performance is more difficult because of the lack of observations in the area

The early warning of severe weather events is one of the key goals of ECMWF and in these severe events the ECMWF EPS and deterministic model gave useful guidance at least five days in advance. The monthly forecasts were also very successful and demonstrated the added value they can offer to the medium-range forecasts.

ECMWF strives to offer quality forecasts in the medium and longer time scales. Regular increases in horizontal and vertical resolutions as well as improved data assimilation and representation of physical processes are such that this quality can be achieved and pushed to higher levels. In addition, further developments in providing a better representation of model and initial condition uncertainties will undoubtedly provide more accurate probability forecasts.

Further reading

Coles, **S.**, 2001: *An Introduction to Statistical Modelling of Extreme Values.* Springer-Verlag

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