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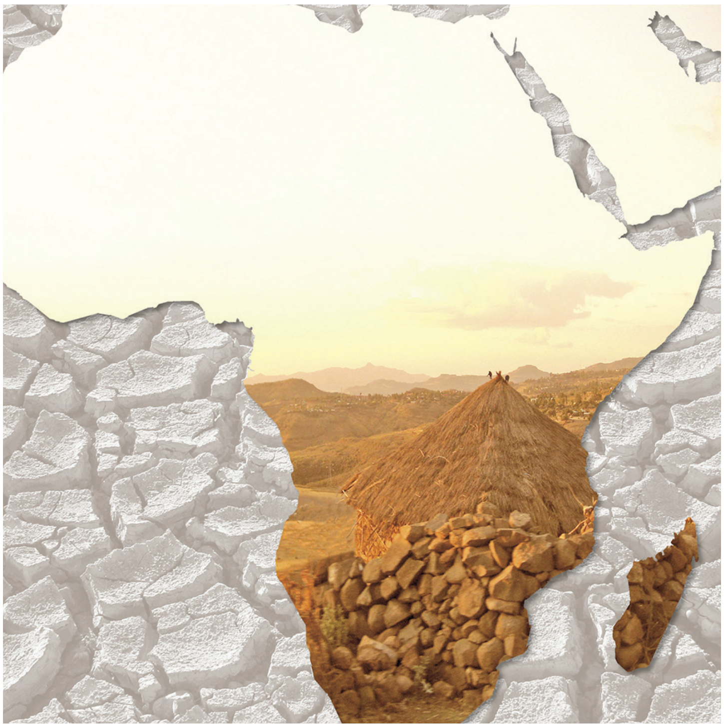
METEOROLOGY

Characteristics of occasional poor medium-range forecasts for Europe



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Characteristics of occasional poor medium-range forecasts for Europe

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A feature of medium-range weather prediction is the occasional strong dip in forecast skill. Such events are often referred to as 'drop outs' or 'busts'. Although frequencies have decreased, even a single bust is inconvenient for users of ECMWF products, and it can have a significant impact on seasonal-mean scores. The ECMWF Working Group on Diagnostics has carried out a study aimed at understanding the nature of forecast busts over Europe, and exploring possibilities of further reducing their frequency or severity.

This article outlines what has been found out about the general characteristics of European busts. It is established that a large proportion of these busts are associated with increased forecast uncertainty, particularly associated with blocking onset. Much of this uncertainty, particularly in spring, appears to arise from sensitivities to initial conditions over the United States and, in agreement with *Grazzini & Isaksen* (2002), mesoscale convective systems (MCSs) over the USA play a key role.

A companion article in this edition of the *ECMWF Newsletter* shows how the bust of 10 April 2011 corresponds to the general characterisation found here. It then examines this case in more detail with a view to identifying key factors that could help reduce the frequency or severity of forecast busts.

Background

European busts are defined here as occasions on which both the following conditions apply to the day-6 forecast of 500 hPa geopotential height (Z500) for Europe.

- Mean root-mean-squared-error (RMSE) is greater than 60 m.
- Spatial anomaly correlation coefficient (ACC) is less than 40%.

These two conditions ensure that a bust is associated with errors of a sufficient magnitude and also involve a pattern or phase discrepancy.

Figure 1 depicts a bust in the spring of 2011. It shows the time series of ACC for day-6 forecasts of Z500 over Europe from several of the world's forecast centres during spring 2011. In general, scores fluctuate around the 80% level, but around 10 April a bust occurs. On this particular occasion all centres suffered, with the UK Met. Office (UKMO) recovering earliest.

Over the years, significant progress has been made in reducing the frequency of busts. Figure 2a shows that annual totals for the ECMWF operational forecast have decreased from around 70 per year in 1990 to around 5 in 2011. But even this low level of busts causes problems for users of NWP products. Note that, as indicated by Figure 2b, busts occur throughout the annual cycle, not just in spring.

It would be most beneficial to understand busts in recent cycles of the ECMWF Integrated Forecasting System (IFS), but this means that there are very few busts to investigate. The approach taken here is to first use forecasts made within the 'ERA-Interim' reanalysis project. Figure 2a shows that bust frequency for the ERA-Interim forecast only decreases slightly over the last 22 years – owing to the use of a fixed IFS cycle (which was operational in 2006; note that the curves should not necessarily intersect in 2006 because the resolutions were different). Using all 22 years' worth of data from this stable forecasting system allows us to characterise the busts. Later we check whether these characterisations are still valid for more recent IFS cycles.

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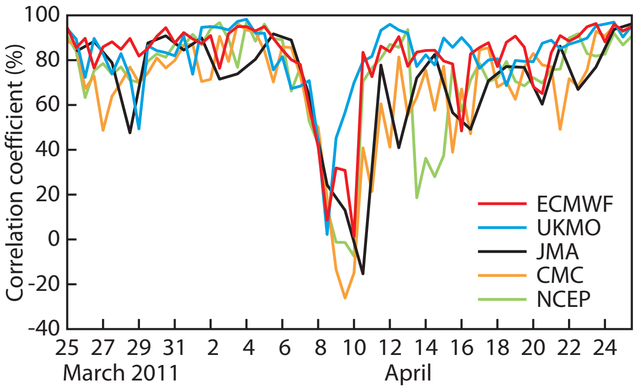

Figure 1 Time series of the spatial anomaly correlation for day-6 forecasts of Z500 over Europe from some of the world's leading NWP centres (within the 'TIGGE' programme): UK Met Office (UKMO), Japan Meteorological Agency (JMA), Canadian Meteorological Centre and National Centers for Environmental Prediction (NCEP), The dates correspond to the start of the forecast.

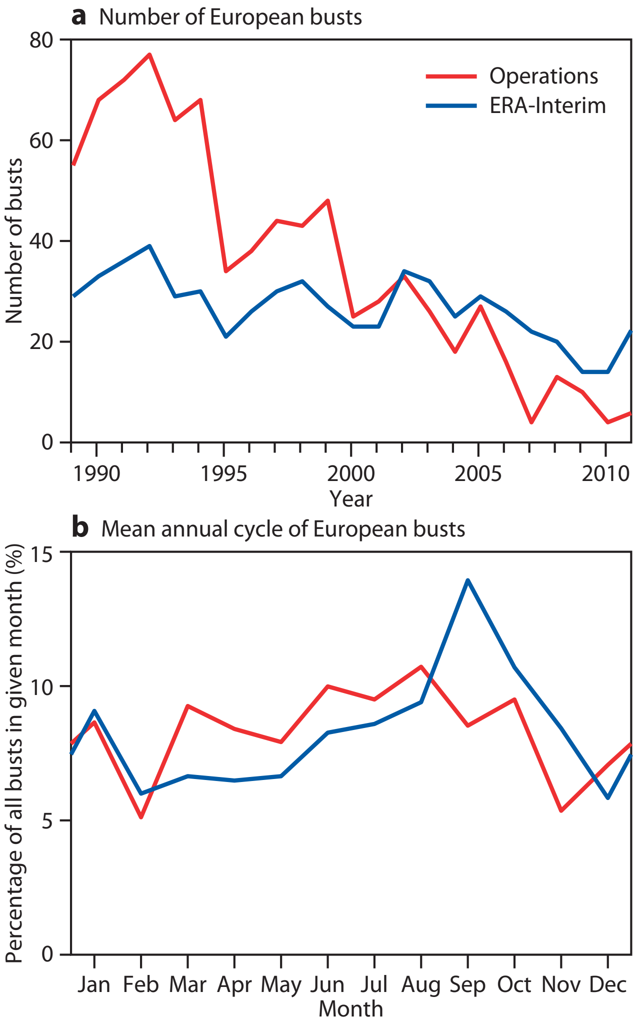

Figure 2 European busts at day 6 from the operational forecast and ERA-Interim reanalysis project for 1989 to 2011. (a) Time series of annual totals (b) Mean annual cycle. Results are based on forecasts started at 12 UTC since operational forecasts were not made at 00 UTC before 2001. Since operational annual totals have decreased, the operational mean-annual cycle will emphasise the early part of the record.

Conditions when a bust occurs

To characterise the scenario most clearly associated with busts, a 'bust composite' is made using all 584 dates for which the ERA-Interim forecast had a European bust during the period 1 January 1989 to 24 June 2010. This period was before implementation of a significant change to the initialisation of the Ensemble Prediction System – this is discussed later.

Figure 3 shows the Z500 mean verifying analysis for the bust composite. Bold colours indicate mean values that are statistically different from zero at the 5% level. Despite only defining busts by their gross scores, it appears that there is a particular verifying analysis associated with many busts – it includes a high-pressure 'block' over northern Europe and a low centre over the Mediterranean; this might be part of a larger wave-train that stretches across the Atlantic.

Initial conditions of the forecast preceding a bust

We can use the same bust composite to search for the key features in the initial conditions of these poor forecasts. Figure 4a shows that the statistically significant features in the Z500 mean initial conditions are not over Europe, but include a 'Rockies trough' embedded in an apparent Rossby wave covering the USA, and a northern 'Canada High'. Over northern Europe, there is a weak and statistically insignificant low centre in the composite initial conditions. This might indicate that busts are often associated with a particular difficulty in developing the northern European block 6 days later.

Previous studies and internal reports have linked busts to MCSs over the USA, particularly around the Great Lakes region. Figure 4b shows the convective available potential energy (CAPE) in the composite-mean initial conditions (throughout this article 'analysed CAPE' is actually a 6-hour forecast, since this is what is archived). While each grid-point is not individually statistically significant at the 5% level, there is a coherent region of increased convective instability over the USA that stretches north to the Great Lakes and beyond. The question arises as to whether a situation of convective instability ahead of a trough over the Rockies leads to increased forecast error and uncertainty in more recent IFS cycles.

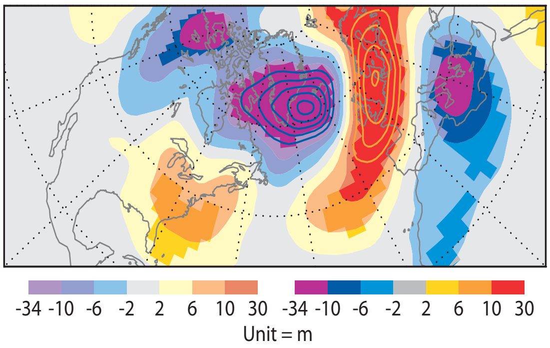

Figure 3 The composite mean Z500 verifying analysis anomaly averaged over 584 European bust events produced by the ERA-Interim forecast system from 1 January 1989 to 24 June 2010. Anomalies are relative to the ERA-Interim climatology for 1989–2008. Statistical significance at the 5% level is indicated through the use of bold colours.

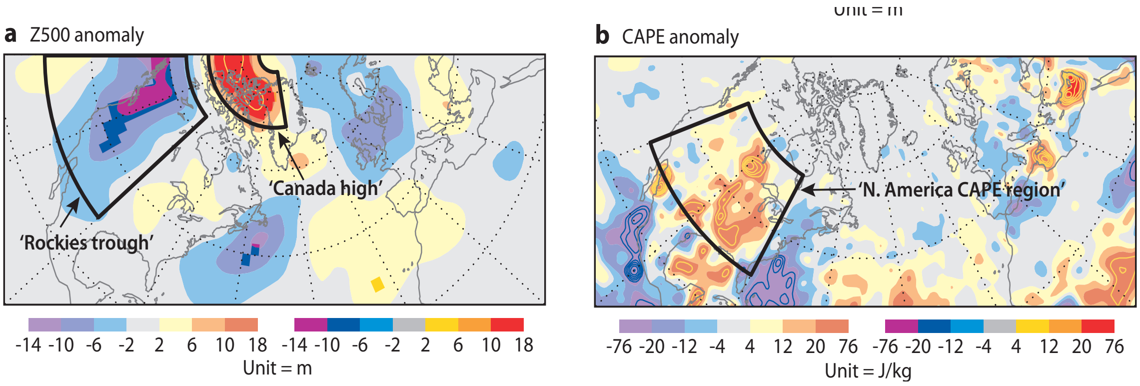

Figure 4 The composite mean initial condition anomalies of (a) Z500 and (b) CAPE leading to the same busts used in Figure 3 Anomalies are relative to the ERA-Interim climatology for 1989–2008 Statistical significance at the 5% level is indicated through the use of bold colours.

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Forecast error and uncertainty

The trough/CAPE regime was identified above from deterministic forecasts from the ERA-Interim IFS cycle. To quantify forecast error and uncertainty associated with this regime in more recent IFS cycles, we now turn to the Ensemble Prediction System (EPS). Since there was a major change to the initialisation of the EPS on 24 June 2010 (with the involvement of the 'ensemble of data assimilations'; EDA) and subsequent changes on 9 November 2010 (that affected our representation of uncertainty estimates), we focus on the period from 10 November 2010 to 20 March 2012. Note that this period is also designed to be independent of the dates used to generate the bust composite, thereby ensuring statistical rigor. We wish to identify dates in this new period when the trough/CAPE regime occurs in the forecast initial conditions. To do this we project the 00 and 12 UTC operational Z500 analyses (actually analysis anomalies from climatology) onto the patterns within the highlighted regions shown in Figure 4, and select dates for which the trough has a projection coefficient greater than 3 and the CAPE has a projection coefficient greater than 1. This means that, if a Z500 analysis anomaly had exactly the same spatial pattern as that shown in the 'Rockies trough' box in Figure 4a, it would need to have three times the magnitude. The CAPE threshold was set lower because Figure 4b indicates small-scale uncertainties in the pattern. Using this approach, 84 date/times are selected – including, incidentally, the major busts of 10 April and 10 May 2011. Note that results are not sensitive to the precise choices of these thresholds.

Figures 5a and 5c show ensemble 'spread' and ensemble-mean RMSE averaged over the 84 incidences of the trough/CAPE regime. (Here, spread is actually the ensemble standard deviation, scaled so that long-term means of spread and RMSE would be equal in a reliable system.) Figures 5b and 5d show corresponding 'background' spread and error, respectively, for days when at least one of these projection thresholds was not exceeded.

The results in Figure 5 show that error is indeed enhanced (by around 30% over Western Europe) in trough/CAPE situations. Spread is also increased, particularly around Iceland, but more data or better techniques may be required to assess whether this increase is sufficient to match the increased error.

The dates used to generate the trough/CAPE composite tend to be concentrated in northern spring– suggesting a different cause for the autumn busts seen in Figure 2b. Note that the 'Canada High' does not appear to be so crucial for increasing error or spread. Hence it would appear that for recent IFS cycles, the same trough/CAPE situation over North America is a highly unstable situation as far as day-6 forecasts for Europe are concerned. One can perhaps think of this situation as being close to a bifurcation point on Lorenz's 'butterfly diagram'.

The trough/CAPE situation also leads to a very similar mean flow anomaly at day 6 to that seen in the bust composite in Figure 3 – including the Northern Europe high. However, a similar pattern is also seen at day 1, and would appear to be associated with the simple extension of the Rossby wave that incorporates the Rockies trough.

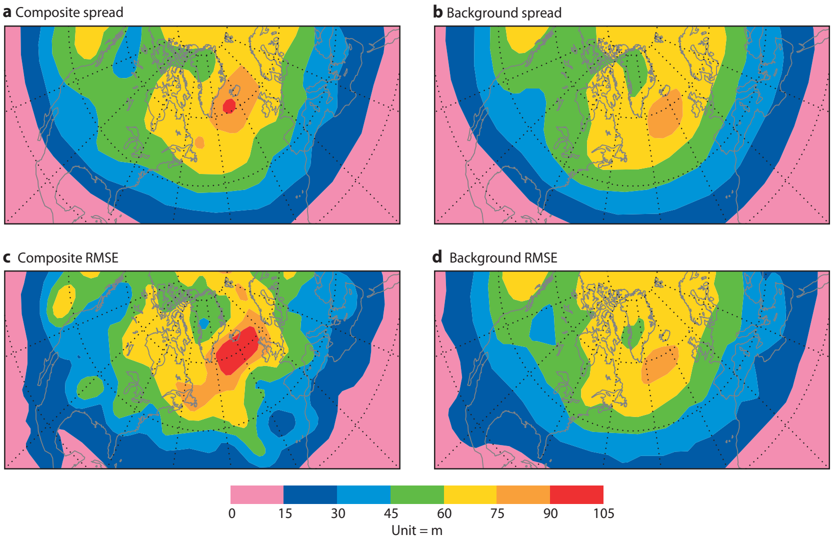

Figure 5 Spread and error results for Z500 at day 6 from the EPS. (a) Ensemble spread for the trough/CAPE composite. (b) Background spread. (c) Ensemble-mean RMSE for the trough/CAPE composite. (d) Background RMSE. Results are based on all 00 and 12 UTC forecasts from 10 November 2010 to 20 March 2012. To ensure a fair comparison, spread and error, for each month of the year, are given the same weight in the background composite as they are given in the trough/CAPE composite.

Mesoscale convective systems over the USA

The above results indicate that a trough/CAPE situation can lead to forecast busts over Europe. Such trough/CAPE situations also lead to MCS events over the USA, so one would expect correlations between busts and MCS events. It is clearly possible, however, that the MCS events play a more active role in the forecast busts. As an attempt to quantify one aspect of this role, the Potential Vorticity (PV) budget on the 330 K isentropic surface (approximately at 250 hPa) is calculated. The aim is to assess whether the time-evolution of the trough (and the Rossby-wave feature in which it is embedded) is consistent with simple adiabatic advection, or whether diabatic/frictional effects are essential.

Since we calculate this budget for the operational deterministic analysis, we are not constrained by the issue of the EPS initialisation and so can extend the period of investigation back to the end of the period used to construct the bust composite. Figure 6a shows, contoured, the anomalous PV calculated using all 95 trough/CAPE events from 25 June 2010 to 20 March 2012. The trough over the Rockies is clearly evident as a positive PV anomaly. The ridge over the eastern USA is also evident. Shading in Figure 6a shows the anomalous local time-tendency of PV. The ridge is strengthening to its northeast while little tendency is evident on the leading (eastern) edge of the trough.

Shading in Figure 6b shows the anomalous adiabatic advection of PV. Since the advection anomalies lie east of PV anomalies of the same sign, this advection clearly acts to propagate the Rossby wave eastward, and accounts for much of the local time-tendencies found in Figure 6a. Nevertheless there are non-negligible differences, and these must be attributed to the combined effects of anomalous diabatic and frictional processes.

The diabatic plus frictional PV tendency (i.e. the difference between Figures 6a and 6b) is shown in Figure 6c. This term is seen to oppose the adiabatic advection term, and thus slows-down the eastward propagation of the wave and, indeed, virtually halts the eastward propagation of the leading edge of the trough. Since the budget is based on analyses, this term is likely to be reasonably consistent with the observations and, to some extent at least, model-independent. The term includes diabatic advection, diabatic changes in stratification, diabatic tilting, surface friction and turbulent mixing. A major component of this term may well be the ‘destruction’ of PV above the maximum in convective heating (associated with stratification changes). This would explain the negative values seen over central North America in Figure 6c. On the other hand, frictional effects on southerly flow along the eastern flanks of the Rockies would be more likely to lead to positive vorticity forcing, and so are probably of secondary importance.

Based on the results given in Figure 6, it seems likely that MCSs do play an active role in the evolution of the trough – they slow it down.

General characteristics of busts

It has been shown that busts tend to occur when there is a high over northern Europe, and are often associated with a trough in the initial conditions over the Rockies. To the east of the trough there is warm, moist, southerly flow and high convective available potential energy (CAPE). Using independent data, it has been confirmed that this flow regime tends to occur in northern spring, and does lead to increased medium-range errors over Europe and, to a lesser extent, increased ensemble spread. Hence the trough/CAPE regime can be thought of as being a ‘bifurcation point’ (i.e. close to the body of Lorenz’s butterfly) as far as European medium-range forecasts are concerned. Using Potential Vorticity budgets, it has also been shown that the MCSs – that accompany the high CAPE – act to slow-down the eastward propagation of the trough, thereby perpetuating the trough/CAPE regime. The representation of convection in the model could, therefore, affect the analysis and the forecast evolution of the trough (and the Rossby-wave it is embedded in, which also includes the north European high). Baroclinic instabilities over the North Atlantic are likely to magnify the errors that eventually develop over Europe.

The difficulty with predicting the north European high is well supported by dynamical studies of flow mechanisms in connection with blocking situations. For example, *Mauritsen & Källén* (2004) demonstrated that ECMWF ensemble spread systematically increases a few days ahead of the onset of a European block – thus indicating a bifurcation point with increased sensitivity to the initial conditions. Since the Rockies trough is an integral component of the negative Pacific-North-American (PNA) pattern, the present findings are also consistent with the results of *Corti & Palmer* (1997) who demonstrated that the amplitude of the PNA pattern over North America influences the onset of European blocking.

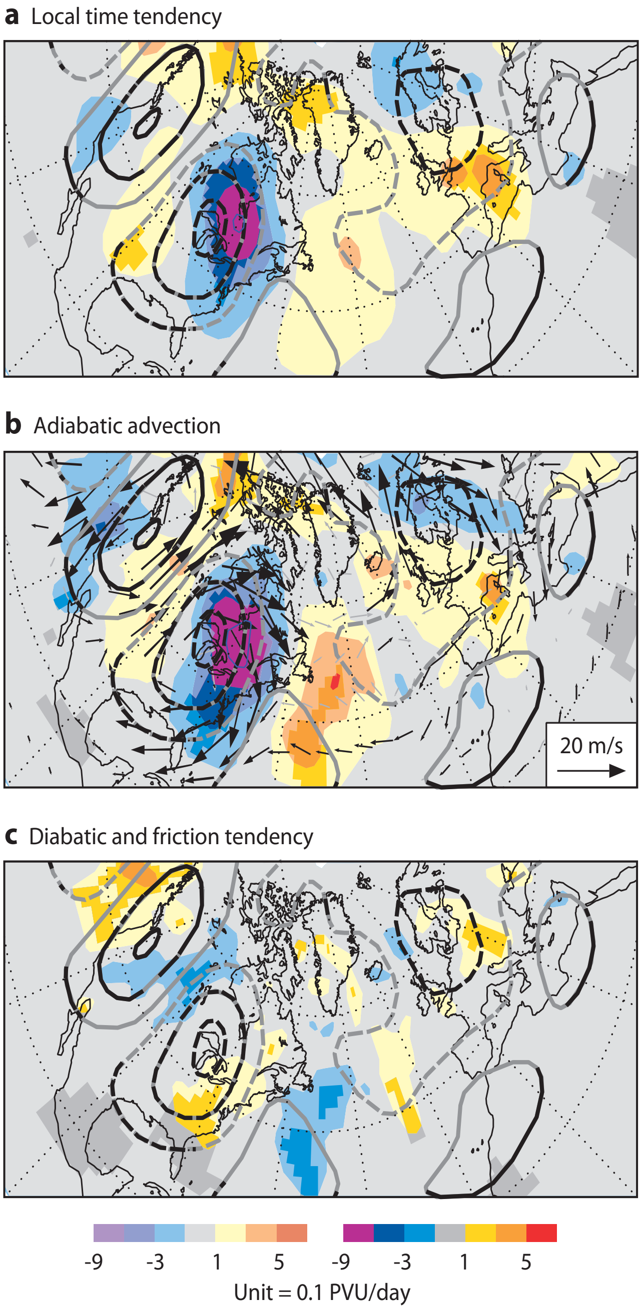

Figure 6 Mean PV anomaly (contoured) and anomalous PV budget terms (shaded) for the trough/CAPE composite on the 330 k isentropic surface in operational analyses from 25 June 2010 to 20 March 2012. (a) The local time-tendency calculated as the central difference of analyses displaced by ±6 hours. (b) The adiabatic advection of PV calculated using IFS spectral transforms, together with anomalous horizontal winds. (c) The diabatic plus frictional PV tendency, deduced as the difference (a) minus (b). All components were calculated using the full set of spectral coefficients in the analysis and a filter on total wavenumbers greater than 10 has been applied to the fields. PV anomalies are contoured with interval 0.4 PVU, and with contours smaller or equal to -0.2 PVU dashed. Statistical significance at the 5% level is indicated through the use of bold colours and black vectors and contours. Anomalies are relative to a climatology made using the same days of the year, from the preceding three years.

Case studies

Although the dominant flow regime that gives rise to European busts was obtained by constructing large composites, it is not feasible, from a technical and computational resources point of view, to apply analysis and forecast experiments to a large set of bust and 'no-bust' cases. Hence an assessment has been made of how well the busts of spring 2011 (primarily the 10 April bust) fit the general characterisation described above. The results of this investigation are described in the companion article '*A case study of occasional poor medium-range forecasts for Europe*' in this edition of the *ECMWF Newsletter*.

Further reading

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Grazzini, F. & **L. Isaksen,** 2002: North America Increments – a problem in 2002. *ECMWF Tech. Memo. 674.*

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