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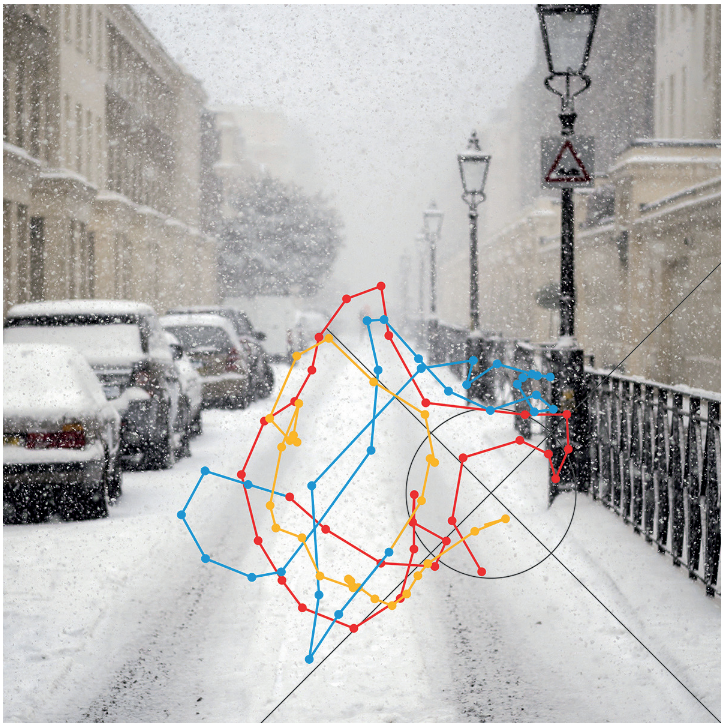
METEOROLOGY

A new product to flag up the risk of cold spells in Europe weeks ahead



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A new product to flag up the risk of cold spells in Europe weeks ahead

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Persistent severe cold temperatures pose serious threats to health and welfare. There is therefore a demand for the development of early warning systems that could allow more time for mitigating actions. In the medium range (up to ten days ahead), predictions of severe temperature conditions can be directly based on temperature forecast probabilities. As forecasts move beyond ten days, on the other hand, increasingly they cannot accurately represent day-to-day weather variability at individual grid points. They may, however, capture large-scale circulation patterns that last more than a week. Early indications of such patterns can help forecasters to identify the potential for temperature anomalies in the extended range. For this reason, ECMWF has developed a new product that visualises extended-range predictions for weather patterns in the Euro-Atlantic region associated with persistent cold spells in Europe. The predictions have been found to have useful skill up to about 2.5 weeks ahead.

Role of persistent highs

In Europe, anomalous surface weather may be the result of persistent high-pressure systems, also called blocking highs. Blocking highs tend to be nearly stationary for more than a week, disrupting the usual eastward progression of weather systems. Severe cold episodes in winter as well as dry spells and heat waves in summer are often associated with the occurrence of blocking. For example, during the August 2003 heat wave, the hot dry tropical continental air mass that characterised this event was pushed over western Europe by a persistent anti-cyclonic system over Central Europe. Similarly, the series of severe cold spells over northern and western Europe that occurred in winter 2009/2010 was associated partly with a blocking high over Scandinavia, and partly with a record persistence of anomalously high pressure over Greenland and low pressure over the Azores, a pattern known as the negative phase of the North Atlantic Oscillation (NAO-). NAO- brings a substantial reduction of the westerly flow across the Atlantic, and in Europe a strengthening of northerly winds from the Arctic. The large spatial scale and the low-frequency nature of such circulation patterns are crucial factors for successful predictions at the extended timescale. The link between flow patterns such as the NAO with tropical forcing and sudden warming events in the lower stratosphere (SSW) is another factor. In fact, during low-frequency phenomena such as El Niño-Southern Oscillation (ENSO), SSW and Madden–Julian Oscillation (MJO) events, the skill of northern hemisphere forecasts is enhanced, creating a window of opportunity for extended-range predictions.

A new product

In order to visualise predicted changes between circulation patterns associated with high-impact temperature anomalies over Europe, we have developed a new product based on two dominant circulation patterns explaining the largest part of atmospheric variability over Europe (Figure 1). The first pattern (Figure 1a) represents the typical structure of the positive phase of the NAO circulation, and the second, with a high centred over Scandinavia and a low to the east over the Atlantic Ocean, describes the anomalous flow during northern European blocking events. The methodology used to identify the two dominant patterns is described by Ferranti et al. (2018).

These two circulation modes can be used to construct a diagram in which any geopotential height anomaly over the Euro-Atlantic region is characterised by the contribution made to it by the NAO± pattern ('NAO') and the blocking/anti-blocking (high/trough over Scandinavia) pattern ('BLO'). To give an example of the use of the NAO–BLO diagram, Figure 2 shows the daily evolution of the analysed 500 hPa geopotential anomalies during the winters of 2009/10 and 2013/14, respectively. Every dot in the diagram shows the amplitude of NAO and BLO anomalies on a given day. For example, the further to the left a dot in the diagram is, the closer the meteorological situation is to the NAO- pattern. The amplitude of the NAO and BLO circulation pattern anomalies is calculated relative to the standard deviation of the respective climatological distribution, which is represented by the circle. Large (small) amplitudes are outside (inside) the circle.

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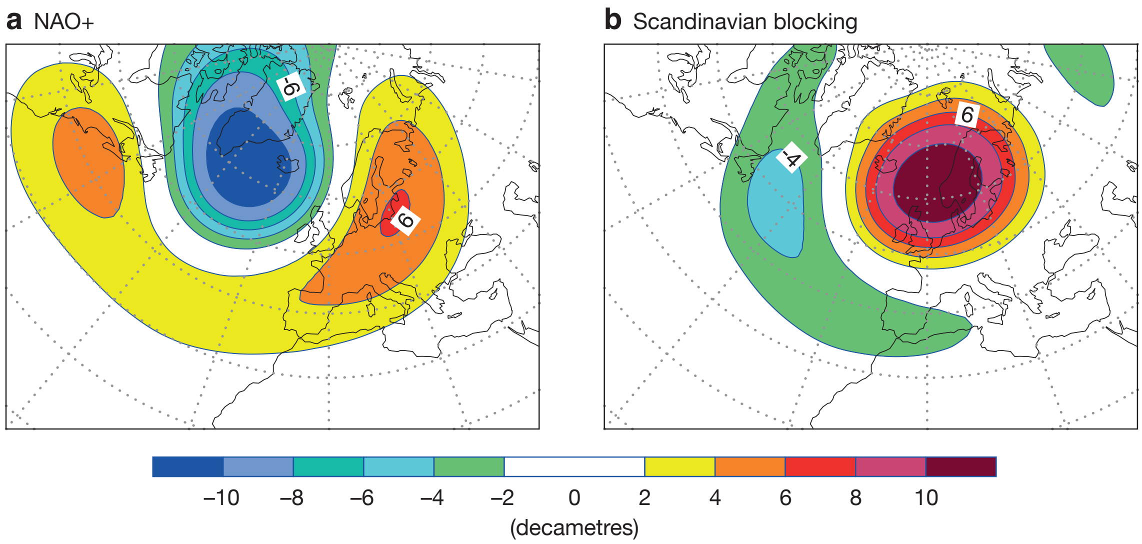

Figure 1 The two dominant wintertime patterns for 500 hPa geopotential height anomalies in the Euro-Atlantic region are (a) NAO+ and (b) Scandinavian blocking.

Figure 2a shows that, during most of December 2009 and February 2010, the flow circulation strongly resembled the negative phase of the NAO pattern, while for much of January 2010 the circulation was characterised by Scandinavian blocking. The persistent southward advection of cold Arctic air or westward advection of cold continental air associated with these patterns resulted in record-breaking cold temperatures over Europe. In contrast, the winter of 2013/2014 (Figure 2b) was dominated by NAO+ and westerly flow anomalies across the Atlantic. Consistent with the anomalous flow conditions, the winter of 2013/2014 saw a series of storms and severe rainfall but rather mild temperatures over Europe.

It might appear that the 2-dimensional NAO–BLO diagram provides a somewhat limited view of the complex structure of extratropical variability. In fact, most of the Euro–Atlantic low-frequency winter variability is typically explained by variations of four climatological regimes represented by the positive phase of the NAO; the negative phase of the NAO; blocking; and Atlantic ridge patterns. Nevertheless, since NAO- and blocking are the patterns typically associated with severe and persistent temperature anomalies, the NAO–BLO diagram provides a more appropriate and simplified framework to help predict temperature extremes.

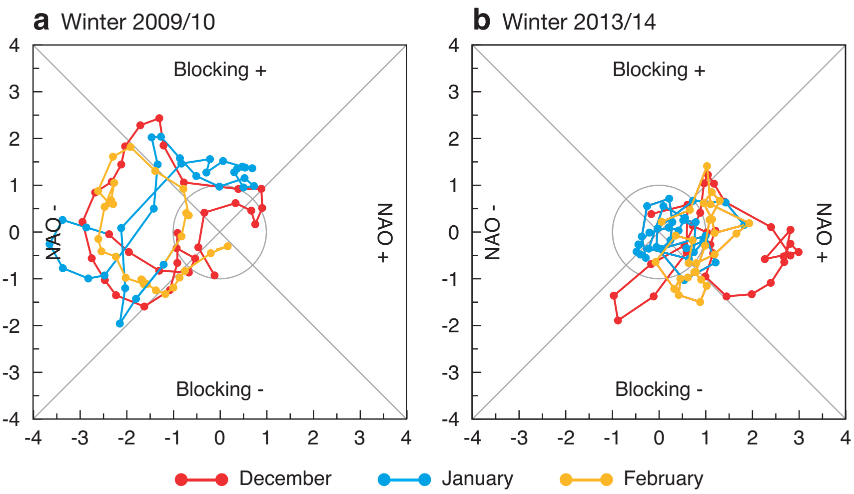

Figure 2 NAO–BLO diagrams showing the daily evolution of the analysis for the two dominant patterns for (a) winter 2009/10 and (b) winter 2013/14.

Relationship with cold spells

The systematic relationship between the NAO–BLO diagram and severe European cold spells is highlighted in Figure 3. The figure shows the distribution of severe cold events in the NAO–BLO diagram for November to February winter periods from 1980 to 2015. The cold events were identified using 2 m temperature reanalysis data. They are shown in the NAO–BLO diagram for nine predefined regions covering the European domain.

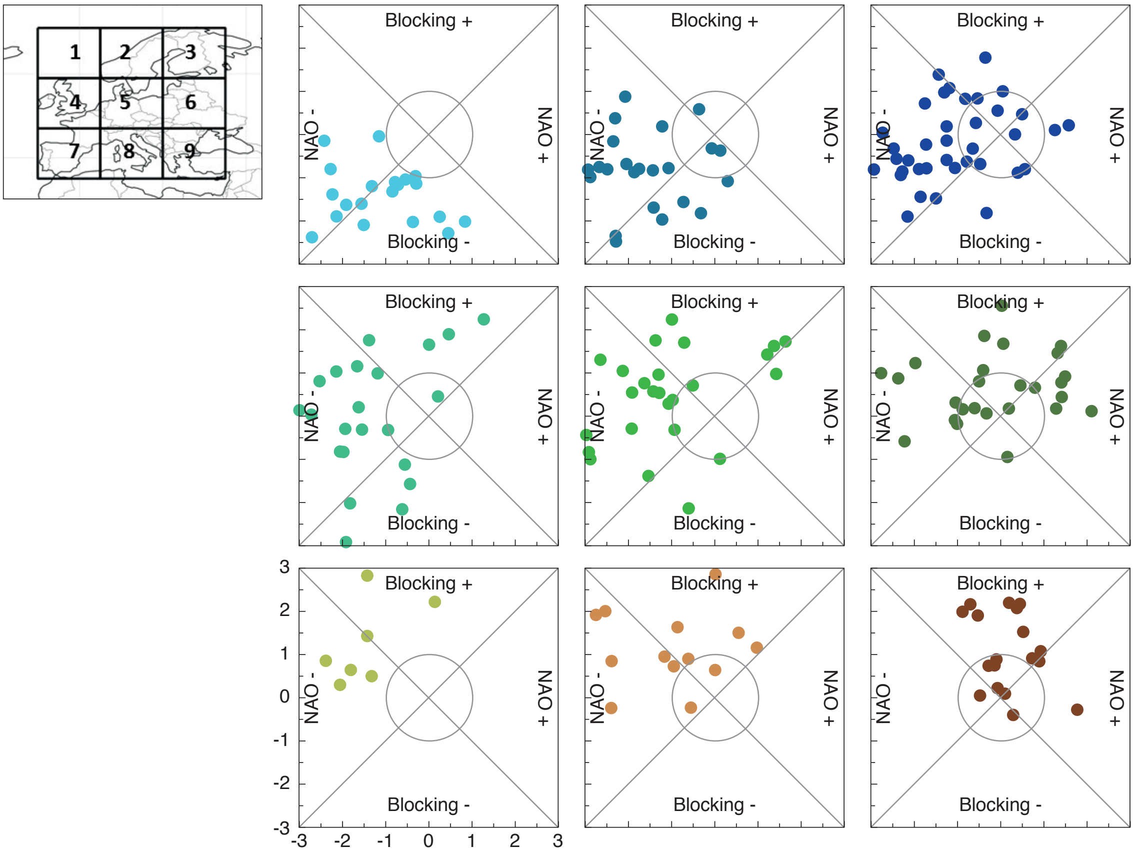

Figure 3 NAO–BLO diagrams for nine European areas. Each diagram describes the large-scale circulation associated with severe cold events that occurred from 1980 to 2015 in the respective area. The severe events are based on 2 m temperature reanalysis, as described in more detail in the text.

A severe event was defined as an event in which daily mean temperatures are cooler than the 10th percentile of the daily climate for at least 60% of the grid points located in the respective region and in which this criterion is satisfied for four consecutive days. The location of each event in the NAO–BLO diagram was determined from the reanalysis 500 hPa geopotential field from the first day of the event. For each of the nine regions, the NAO–BLO diagram shows all events detected in that region. For the northern regions 2 and 3, most severe cold episodes correspond to NAO- events with rather large amplitudes. For region 1, a roughly equal number of cold episodes are characterized by the NAO- and the anti-blocking type of circulation. For the central and southern regions, severe cold events are associated with NAO- and with blocking. The amplitudes in the NAO–BLO diagram are generally very large, indicating that this diagram can be used to describe most severe cold episodes. For the eastern European domain (regions 3, 6 and 9), there is a larger number of cases with relatively small amplitudes. This indicates that for these regions the NAO–BLO diagram is less suitable for representing severe cold spells. However, overall Figure 3 shows that there is a strong link between large amplitudes in the NAO- and BLO sectors and the occurrence of severe cold spells over Europe.

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An illustration of the predicted evolution of atmospheric flow in the Euro-Atlantic region, as represented by ensemble forecast (ENS) trajectories in the NAO–BLO diagram, is given in Figure 4. The forecast trajectories from day 0 to day 10 of the ENS initiated on 23 February 2018 indicate a clear transition from Scandinavian blocking to NAO- by day 5. The evolution of forecast uncertainties (rather low in this case) is well depicted by the NAO–BLO diagram. The verifying analysis and the ensemble mean trajectory match quite closely. Indeed, in late February to early March, a spell of severe low temperatures with significant snowfall was associated with the establishment of a large high-pressure system over Scandinavia, which later developed into a NAO- circulation.

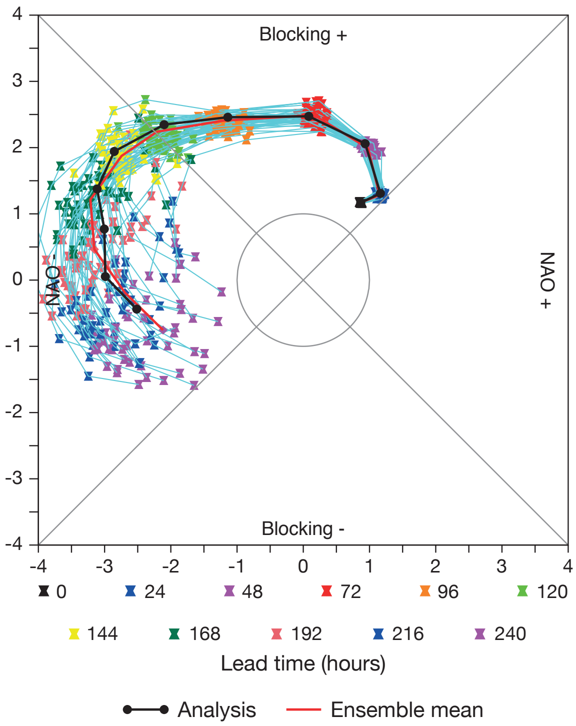

Figure 4 Evolution of ENS forecast up to day 10 in the NAO–BLO diagram. The ENS forecast starts at 00 UTC on 22 February 2018.

In the extended range, the day-to-day trajectories are affected by substantially larger uncertainty. Therefore, the evolution of forecast anomalies is represented by probability density functions (PDF) based on daily values of individual members in a given week.

Figure 5 shows the PDFs for forecasts starting on 15 February and 19 February 2018 for two subsequent target weeks. During the week starting 26 February 2018, the analysed NAO- daily values have very large amplitudes in the tail of the NAO climatological distribution. In that week, mean temperature anomalies ranged between –6°C and –3°C over most of Europe. The PDF for that week for the forecast starting on 19 February indicates high probabilities for strong blocking and extreme NAO- values (Figure 5a). The PDF for the same week from the forecast starting on 15 February has its absolute maximum over the NAO- sector (Figure 5b). It thus provides a strong indication of the likelihood of an NAO- event. However, at this range the amplitude of the event is underestimated, and the uncertainties are rather large. During the subsequent week, starting 5 March, the NAO- persisted while its amplitude gradually reduced. The cold anomalies persisted mainly over Scandinavia and eastern Europe. The PDFs from forecasts for that week starting on 19 and 15 February provide a good indication of the likelihood of NAO- persistence as well as of its reduced amplitude (Figure 5c,d).

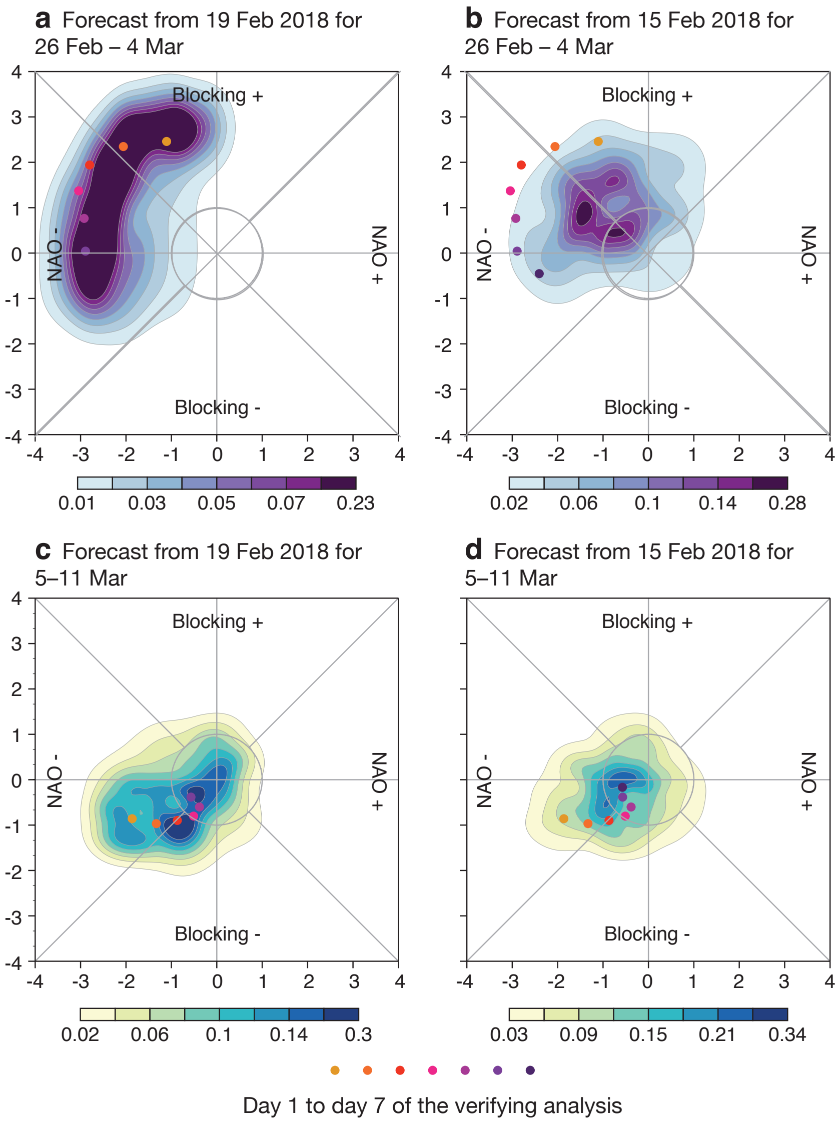

Figure 5 Probability density functions for (a) an ensemble forecast starting on 19 February 2018 for the week starting on 26 February, (b) an ensemble forecast starting on 15 February 2018 for the same week, (c) an ensemble forecast starting on 19 February 2018 for the week starting on 5 March and (d) an ensemble forecast starting on 15 February 2018 for the same week. Daily values of the verifying analysis are represented by dots.

The change in atmospheric circulation that led to the cold spell was predicted about 2.5 weeks in advance. The high level of accuracy in this forecast is likely to be linked to two elements: a very intense MJO event propagating across the West Pacific, and a stratospheric warming event (SSW) that took place around 11 February. The temperature anomaly vertical cross section (not shown) indicates that the SSW was probably not a crucial factor in bringing about the change in circulation although it increased the amplitude of the anomalies.

Skill assessment

First, we assessed the skill in predicting NAO and BLO values separately, then we considered the skill in predicting the evolution in the NAO–BLO diagram to better understand the ability to capture transitions between different flow patterns. Figures 6a and 6b show the skill in predicting the amplitudes of the NAO and BLO patterns, respectively. In this assessment, we considered ECMWF's ensemble forecasts and five additional ensemble systems available from the sub-seasonal to seasonal (S2S) prediction research project archive. The S2S project, established by the World Weather Research Programme/World Climate Research Programme, has constructed an extensive database containing sub-seasonal forecasts (up to 60 days ahead), three weeks behind real time, and reforecasts from 11 operational centres. The skill metric is the anomaly correlation coefficient (ACC) between the observed NAO/BLO amplitudes and the

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NAO/BLO amplitudes predicted by the ensemble-mean forecast, computed for the common period of reforecasts available in the S2S archive covering 12 years (December/January/February 1999–2010). Since beyond two weeks ahead the forecast is not expected to have day-to-day accuracy, a 5-day running mean (centred on the day) was applied to the verifying analysis and the ensemble mean prior to the ACC computation. We use the S2S models to estimate the current range of skill of sub-seasonal predictions.

Looking at the forecast range at which the ACC drops below 0.5, the limit of skill ranges from 11 to 17 days for the NAO predictions and from 9 to 13 days for the BLO predictions. The skill of ECMWF forecasts in predicting BLO drops below 0.5 at about 13 days – a few days earlier than for NAO. Probabilistic skill scores for S2S predictions of NAO and BLO are consistent with the ACC values obtained for the ensemble mean (not shown).

The accuracy of the forecast trajectories in the NAO–BLO diagram is evaluated by assessing the temporal correlation between the predicted and analysed NAO and BLO amplitudes (Figure 6c). This metric, known as bivariate correlation, has been documented by Gottschalck et al. (2010). The bivariate correlation can generally be used to measure the temporal correlation between two vectors defined in a two- or higher-dimensional space. It is thus appropriate for assessing trajectories in the NAO–BLO diagram. Although this score measures only the accuracy of the forecast trajectories without highlighting the prediction skill in terms of strong versus weak events, it provides an objective skill measure for forecasting transitions between the circulation patterns associated with high-impact weather over Europe. The lead times at which the bivariate correlation coefficient drops below 0.5 range from 10 to 15 days for S2S forecasts, indicating some potential to predict the onset of cold spells over Europe beyond the medium range.

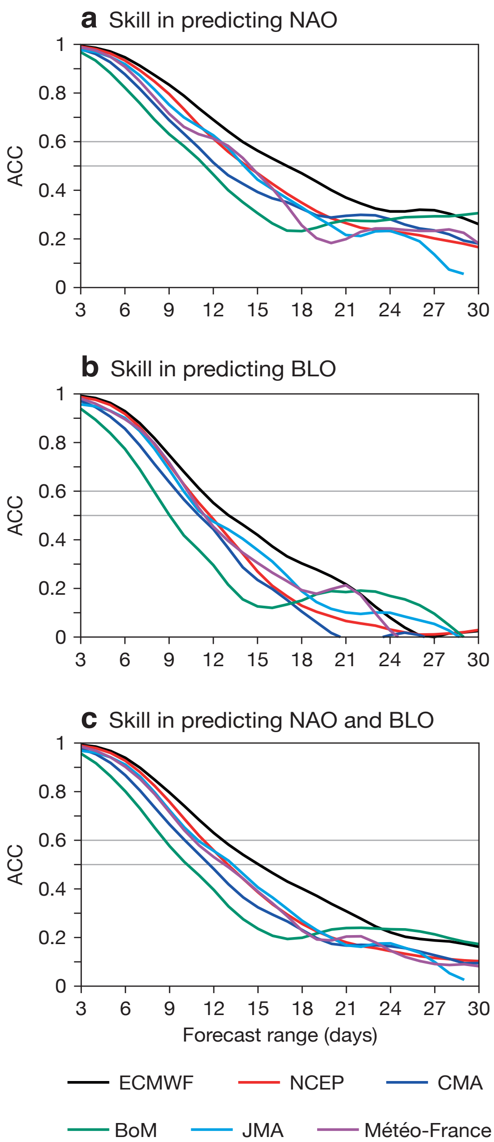

Figure 6 Ensemble mean anomaly correlation coefficient (ACC) as a function of forecast lead time for the prediction of (a) the NAO+/NAO- pattern (westerly/easterly flow across the Atlantic) and (b) the blocking/anti-blocking pattern; and (c) bivariate correlation as a function of forecast lead time for the prediction of the combined pattern. ACC values are based on a 5-day running mean applied to the forecasts and verifying analysis data. Skill scores have been calculated for forecasts produced by ECMWF, NCEP (US National Centers for Environmental Prediction), CMA (China Meteorological Administration), BoM (Australian Bureau of Meteorology), JMA (Japanese Meteorological Agency), and Météo-France.

Conclusion and outlook

The ability to predict the onset of a period with severe temperature anomalies weeks ahead is closely linked with the ability to accurately forecast the evolution of anomalies in the large-scale atmospheric circulation. Therefore, reliable extended-range forecasts of flow patterns such the NAO and blocking can support the prediction of severe cold events over Europe. The NAO–BLO diagram is an effective tool to assess the likelihood of regime transitions associated with the occurrence of severe cold episodes in the exended range. The NAO–BLO forecast trajectory and PDF diagrams are currently available to registered users as test products at: *https://confluence.ecmwf.int/display/FCST/Test+products*. The success of forecasting, weeks ahead, changes in large-scale flow that lead to cold conditions depends on the type of transition. The ECMWF ensemble is able to provide reliable probabilities of cold conditions associated with the establishment of the NAO- pattern beyond the medium range. The predictability of such events is enhanced by tropical–extratropical teleconnections resulting from MJO activity. On the other hand, providing probabilities in the extended range for the occurrence of cold events associated with a transition to blocking presents a bigger challenge. The skill of blocking predictions is not highly sensitive to the existence of an MJO in the initial conditions and, consistent with that, blocking exhibits lower predictability than NAO-. Understanding these flow-dependent variations in forecast skill, and using the new NAO–BLO diagrams, will help users to exploit periods of enhanced extended-range predictability. An assessment of whether it is possible to develop a similar product for European heat waves is planned for 2019.

Further reading

Ferranti, **L.**, **L. Magnusson**, **F. Vitart** & **D.S. Richardson**, 2018: How far in advance can we predict changes in large-scale flow leading to severe cold conditions over Europe? *QJRMS*, **144**, 1788–1802. doi:10.1002/qj.3341

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