Predicting severe cold spells over Europe
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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 conditions can be directly based on temperature forecast probabilities. Extended range forecasts 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 severe temperatures. 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 NAO-BLO diagram
In order to visualise predicted changes between circulation patterns associated with high-impact temperature anomalies (e.g., 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. 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 Ferrari et al. (2018).

These two circulation modes can be used to construct a diagram in which any geopotential height anomaly combination over the Euro-Atlantic region is characterized by the contribution made to it by the NAO pattern (NAO) and the blocking anti-blocking (high/low over Scandinavia) pattern (BLO). Figure 2 shows the daily evolution of the analysed 500 hPa geopotential anomalies of 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. 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 over western advection of cold continental air associated with these patterns resulted in record-breaking cold temperatures over Europe. In contrast, the winter of 2014 (Figure 2b) was dominated by NAO+ and westerly flow anomalies across the Atlantic. Consistent with the anomalous flow conditions, the winter of 2014 saw a series of storms and severe rainfall but rather mild temperatures over Europe.

In the extended range, the evolution of forecast anomalies is represented by probability density functions (PDF) based on daily values of individual members in a given week. 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 vertical cross-section indicates that the SSW was not a crucial factor in bringing the change in circulation.

Role of persistent highs
In Europe, anomalous surface weather may be the result of persistent high-pressure systems (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, the series of severe cold spells over northern and western Europe that occurred in winter 2009/2010 was associated 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 and 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 MJO events, the skill of northern hemisphere forecasts is enhanced, creating a window of opportunity for extended range predictions.

Skill assessment
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 subseasonal-to-seasonal (S2S) prediction research project archive. The skill metric is the anomaly correlation coefficient (ACC), computed for the common period of reforecasts available in the S2S archive covering 12 years (1999-2010). A 5-day running mean (centred on the day) was applied to the verifying and ensemble corel cores. The skill 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 Gottschalch et al. (2010). The bivariate correlation provides an objective measure for forecasting transitions.

In Figure 6a, 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 cold temperatures with significant snowfall was associated with the establishment of a large high-pressure system over Scandinavia, which later developed into a NAO-BLO diagram.

The success of forecasting ahead, changes in large-scale atmospheric conditions, 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 extended range. The NAO-BLO forecast trajectory and PDF diagrams are currently available to registered users as test products at: https://confluence.ecmwf.int/display/EC57/Test+products.

Relationship with extreme cold conditions
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 reanalysis data. They are shown in the NAO-BLO diagram for nine predefined regions covering the European domain. 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 events with either 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. For the central and southern regions, 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 domain (regions 3, 6 and 9), there is a large number of cases with relatively small amplitudes indicating that for these regions the NAO-BLO diagram is not as suitable. Overall Figure 3 shows that there is a strong link between large amplitudes in the NAO-BLO diagram and the occurrence of severe cold spells over Europe.

Conclusion
The ability to predict the onset severe temperatures weeks ahead is closely linked with the ability to accurately forecast the evolution of anomalous in the large-scale atmospheric circulation. 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 extended range. The NAO-BLO forecast trajectory and PDF diagrams are currently available to registered users as test products at: https://confluence.ecmwf.int/display/EC57/Test+products.

The success of forecasting 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- beyond the medium range. The predictability if such events is enhanced by tropical-extratropical teleconnections resulting from NAO 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. 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.

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