Experimental Daily Forecasts of Northern Atlantic Weather Regimes and Heavy Precipitating Events (HPEs) over Southern France with the Meteo France Global Ensemble System PEARP

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Abstract

Introduction

Northern Atlantic atmospheric low frequency variability can be described as mainly evolving through a fixed number of recurrent states. (Vautard, 1990) identified four weather regimes which have a mean persistency about 10 days. Further studies have shown that these can aid comprehension of large scale dynamics, especially as when also considering interactions with the Atlantic jet (Riviere and Orlanski, 2007). In particular, periods of likely regime transitions may have high impact on the sequence and density of mid-latitudes cyclones (Michel and Riviere, 2011).

More recently, as concern on climate change impacts increases, weather regimes are central to new developments in statistical downscaling techniques. Weather regimes may be characterised by applying automatic classification tools over long periods reanalyses. It is then possible to identify local climate properties that occur specifically in association with particular regimes. Global climate models often suffer from a lack of resolution sufficient to describe regional to local atmospheric properties, but they may better reproduce weather regime distributions. An example of such approach is described in Nuissier et al. (2011) over Southern France, which shows that the conditionnal occurrence probability of high precipitation events can be deduced from given regime membership.

In the context of weather forecasting, weather regimes analysis in model forecasts could inform forecasters about the next days' large scale evolution and likely elements of local weather predictability in a more synthetic way. The assumption is that when the regime prediction skill of a model is poor, the predictability of local weather is weak.

We present experimental results concerning the forecasting of the 4 Atlantic weather regimes with the operationnal ensemble forecasting system at Meteo France, PEARP. We also show the results of occurrence probability calculations of Heavy Precipitating Events (HPEs) over Southeastern France in one intense case of 2008 autumn season.

The PEARP Global Ensemble Forecasting System at Meteo France

The PEARP ensemble system runs twice a day at 06UTC (72h forecast range) and at 18UTC (108h forecast range). The horizontal resolution is T538c2.4, giving an approximate mesh size of 15 km over France and 90 km on the opposite side of the globe. In the vertical, the model has 65 levels. The ensemble is composed of 35 members; one unperturbed and 34 having perturbations in the initial state and in the physics of the model. The

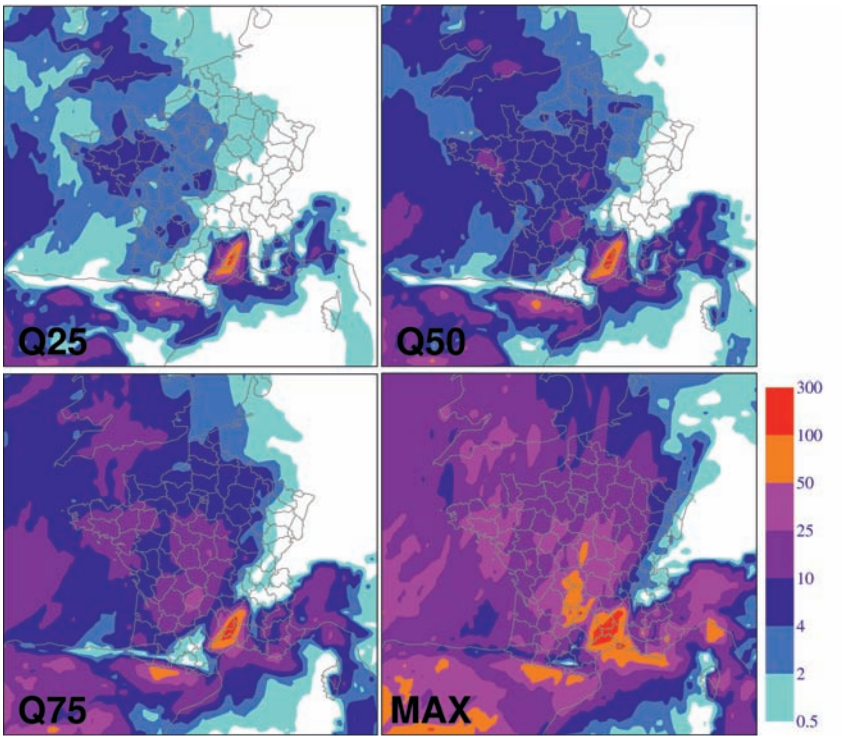


Figure 1

Ensemble quantiles of a 78H PEARP precipitation forecast, from 30th Oct 2011 18H UTC. The quantile are 25% (upper left), 50% (upper right), 75% (lower left) and Max (lower right).

initial perturbations combine Ensemble Data Assimilation (6 members and the assimilation ensemble mean) and singular vectors (TL95c1, 65 levels) targeted on different areas and using different metrics and optimization time windows according to the region (tropical or extra-tropical). The perturbation of the model is performed, for each individual member, by randomly choosing the physical parameterization scheme from a set of 10 different ones, with the constraint that each scheme is not used more than 4 times.

A range of products are provided to the forecasters. Some of them are very "classical" products: probability maps, quantile maps, postage-stamp maps and spaghetti plots. Fig. 1 shows an example of a 4-quantile presentation of one precipitation forecast for the very intense case on 1st Nov 2011. Others products are more specific, for example trajectories of mid-latitudes cyclones or tropical cyclones. Finally, some recently developed products are the result of collaboration with the research department and are dedicated to the detection of particular severe events.

The Atlantic Weather Regimes

During, the 1990s many studies were devoted to weather regimes characterisation. Over the Atlantic domain, major studies (Mo and Ghil, 1988; Molteni et al., 1990; Vautard et al., 1988; Vautard, 1990) identified quasi-stationnary weather patterns based on clustering techniques. Then Michelangeli et al. (1995) reviewed the number of classes and proposed a classification scheme for the North Atlantic consisting of a 4 weather regimes. Within our process of regime calculation, a Principal Component Analysis is carried out over the whole reanalysis (ERA40) and the classification is then performed over the first several components retained. A distance criterion is then defined in the EOFs subspace. After some iterations that minimize the variance intra-cluster (k-means method), each day is allocated to a cluster. The centre of a cluster is defined as the variable average over all its members. Fig. 2 shows an illustration of the centres of the weather regimes we computed. Even though the Northern Atlantic Oscillation is constructed simplier like the projection onto the first EOF only, weather regimes patterns have similarities with the NAO ones. Two broadly equivalent classification scheme coexist then, the original Vautard names are pointed out in the figure, as well as the NAO one.

It may be possible to subjectively identify which regime a current meteorological situation resembles, but we propose here a more objective procedure. In order to estimate to which regime a model forecast should be allocated, we project the forecasts onto the ERA40 first representative EOFs (twenty EOFs correspond here to 97% of the total variance). Then we compute the correlation distance in the EOFs subspace between the forecast and the regime centres for each member at each forecast lead time. In. fig. 3, we can see the results we obtained when applying this technique to one PEARP forecast for 19 Nov 2011. A membership criterion has been validated on the reanalysis, showing that under a correlation threshold the regime membership is predicted with a

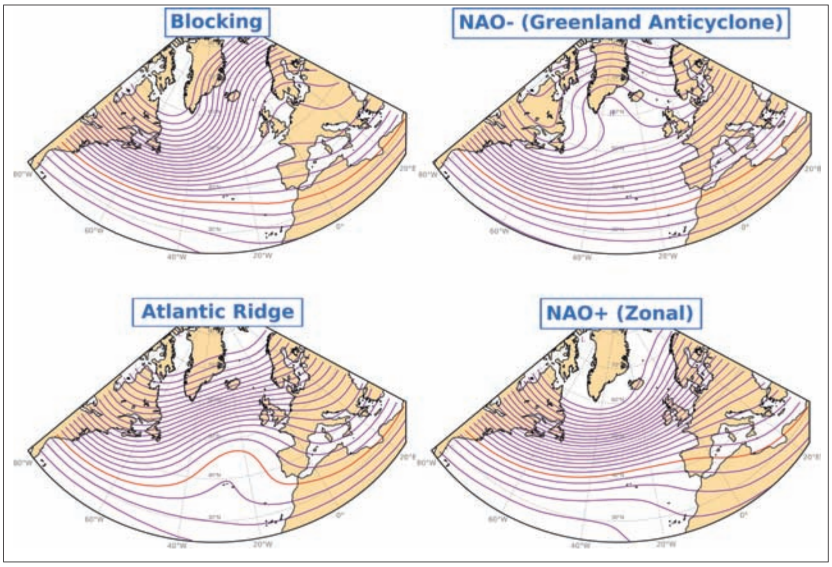


Figure 2

Northern Atlantic 4 weather regimes, composites of geopotential height at 500 hPa

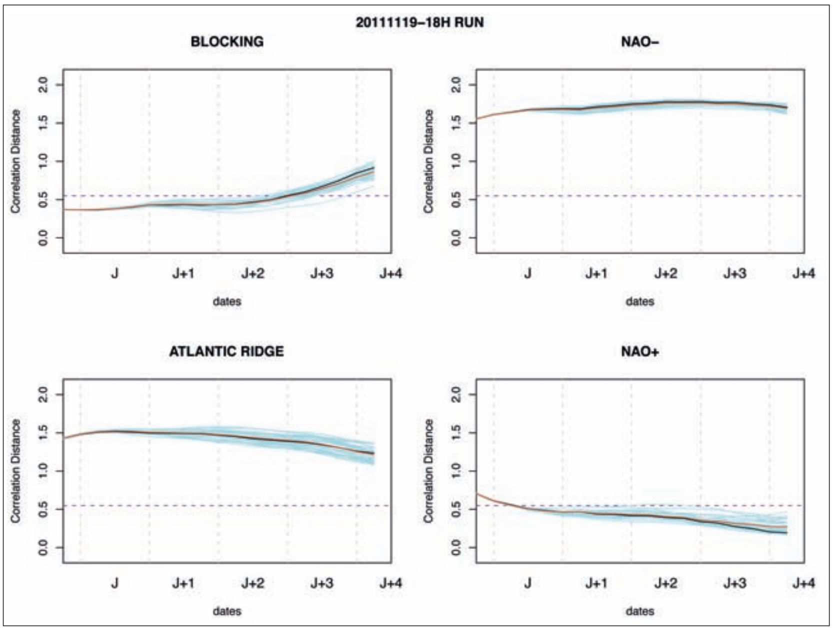


Figure 3

Projection onto the 4 Atlantic weather regimes of the 18 nov 2011 18h UTC PEARP forecast. The dashed line is the significance threshold for regime membership.

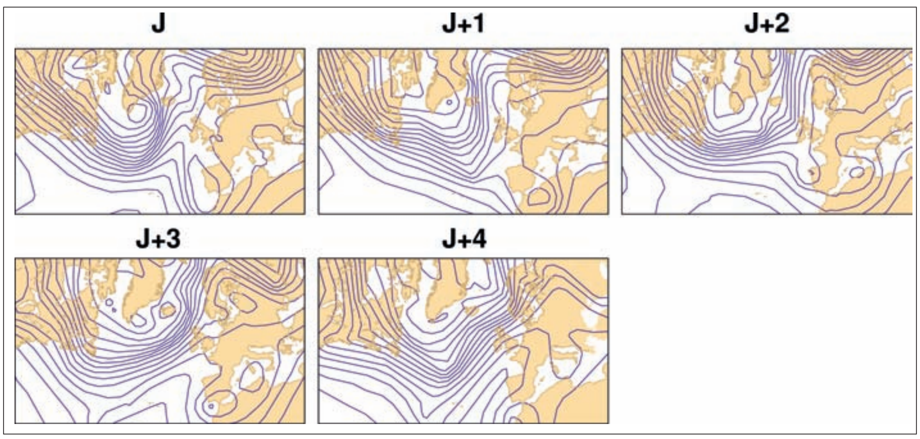


Figure 4

Evolution of the geopotential height at 500 hPa, ARPEGE analysis from 19 nov 2011 00h UTC to 23 nov. 2011 00h UTC

85% score (shown by the dashed blue line). The panels in Fig. 3 show the projection onto each of the 4 regimes versus the lead time of the forecast. The 34 members of the ensemble are drawn in grey lines, whereas the control is the black line, and the mean of the ensemble is the red line. The lower the projection is, the closer the member is to the regime center. At the beginning of the forecast, the Blocking regime is observed. The Atlantic Ridge and NAO- are not likely to occur all along the forecast. We chose this situation because it is a good illustration of a transition between two periods of different regimes, here between Blocking and NAO+, which occurs between J+1 and J+2. Fig. 4 shows the corresponding evolution of the analysed geopotential height at 500 hPa, the blocking is clearly present at the beginning of the period over western Europe, but a strong zonal gradient develops towards Iceland by day 3.

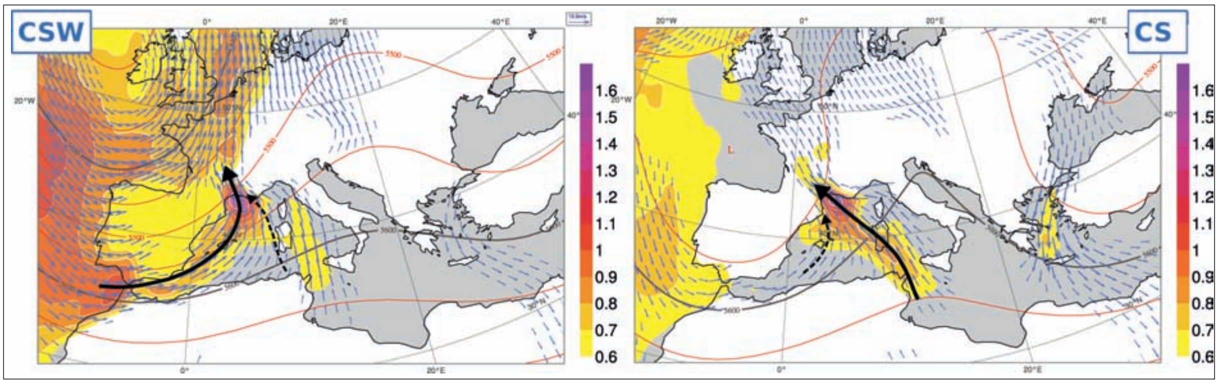
On another hand, one can note that the spread of the ensemble is naturally increasing with time, and so does the uncertainty of the regime prediction. By the way, the increase in spread is not the same for all panels. The anticorrelation of the forecast with NAO- is very strong, with weak spread, wheareas for the other regimes the spread is much larger from J+1. The spread then is not sensitive to the intensity of the correlation.

Forecasting the Occurrence Probability of Heavy Precipitating Events

The CYPRIM French research programme aimed to assess the predictability of HPEs that often hit the French southeastern region during the autumn season. One section of this programme was aimed at defining the large scale circulations (LSC) that favour the occurrence of HPEs. For this purpose, a statistical downscaling technique has been designed, a further description of which can be found in Nuissier et al. (2011). In this study, a classification is performed for the autumn days with significant rainfall and leads to four typical LSC classes. Two of them discriminates the HPEs pretty well : the probability of HPE occurrence increases as the EOFs distance to the center to the LSC is getting low. The composites of these two classes are shown in Fig. 5. Two configurations for humidity anomalies and strong low-level jet hitting the area of interest are underlined. Then, the ability of such atmospheric features to represent sufficient conditions for HPE to occur is assessed. A multivariate linear regression based on LSC distance and low level parameters shows that more than 25% of the HPEs (around two hundred betwen 1960 and 2001) coincide with such conditions with a skill score of 69%. In other words, when these conditions are observed in ERA40, a probability of 69% for an HPE to occur is found. We investigate here the application of this relation in one PEARP3 forecast. The regression is applied on each member of three successive forecasts (Fig. 6) to examine the persistence of HPE detection throughout the forecasts. The example on Fig. 6 is for the 1-2 November 2008 situation which is one of the most severe events in recent years. The left panel shows the ensemble member forecast terms which validate the criterion in red and the others in green. It shows that the event was detected since the 29 October 2008 18 UTC forecast and maintained in the two successive forecasts. In the last forecast, at the lead time corresponding to 2 nov 2008 12-18 UTC, all the members match the

Figure 5

The two patterns favouring HPE occurence. Composites of geopotential height at 500 hPa (red lines), moisture flux anomalies at 925 hPa (shaded colours), and winds (over 5m.s⁻¹) at 925 hPa (blue arrows)



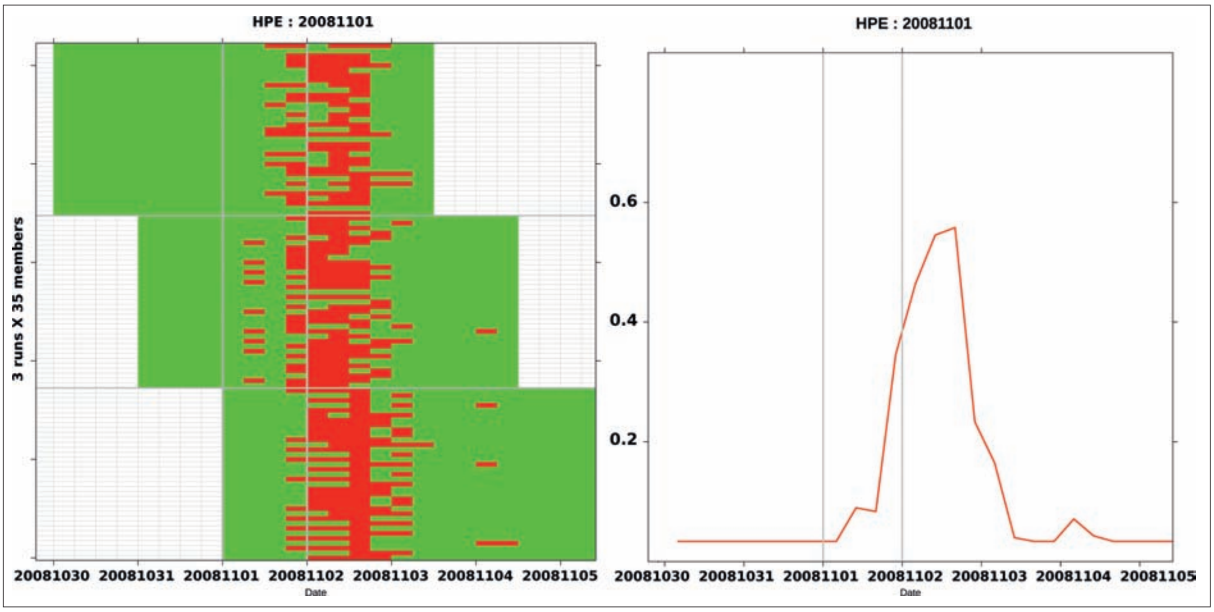
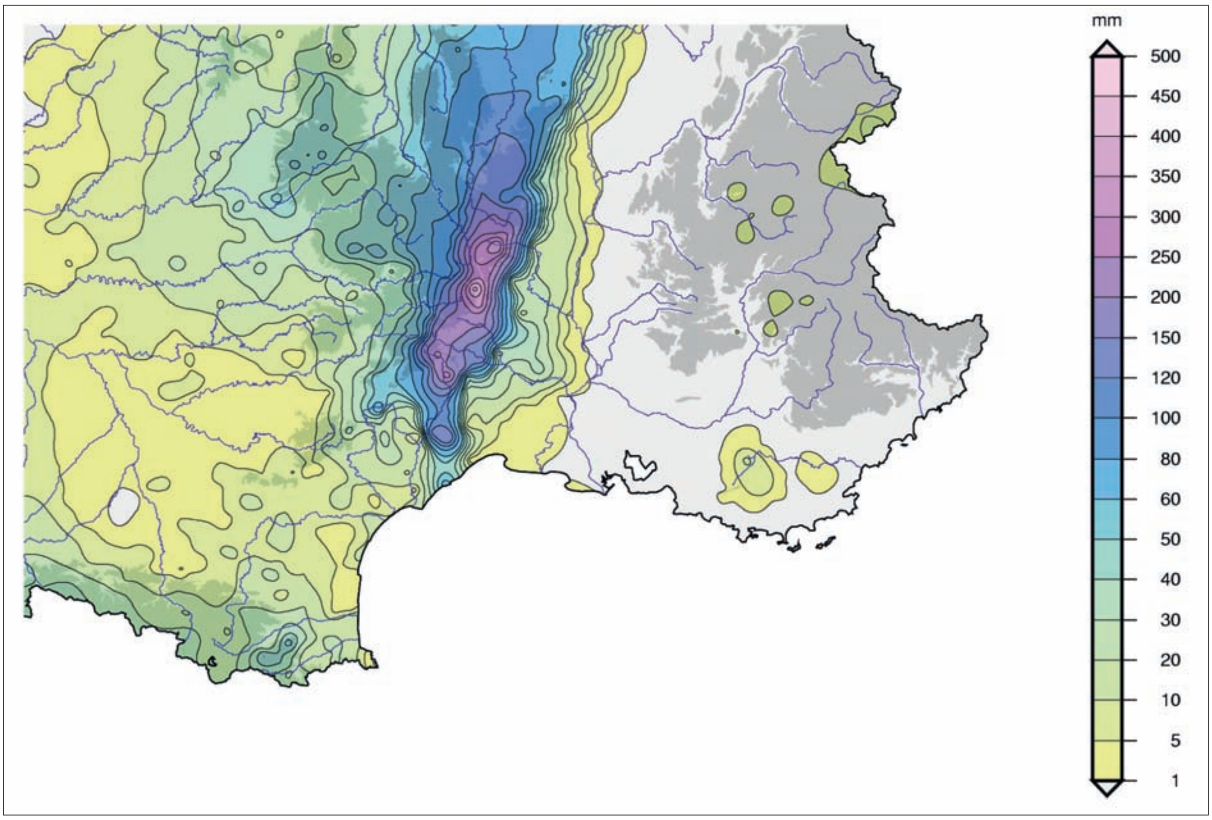


Figure 6

Left panel : HPE index on each term of each member of the PEARP3 on 3 successive runs: red box, the criteria are true, green box the criteria are false.
Right panel : the overall HPE occurrence probability taking into account the HPEs index climatological probability and the ensemble probability

Figure 7
Precipitation daily amount between 31 oct 18 UTC. and 1 Nov 18 UTC



HPE criterion. As previously stated, the highest probability that can be reached with the criterion is about 70%. Then, assuming that the model reliably reproduces the downscaling function, it is possible to compute the forecast probability of HPE occurrence that compounds with the ensemble signal. It can be expressed as:

$$\mathbf{P}_{HPE} = \mathbf{P}^{Clim}_{HPE|Red} \cdot \mathbf{P}^{Ens}_{Red} + \mathbf{P}^{Clim}_{HPE|Green} \cdot \mathbf{P}^{Ens}_{Green}$$

where $\mathbf{P}^{C\,lim}_{HPE|Red}$ is the climatological probability for a day to have an HPE when the criterion is red (i.e about 70%), $\mathbf{P}^{Ens}_{Red}$ is the probability for a term member for being red over the three forecasts, $\mathbf{P}^{C\,lim}_{HPE|Green}$ the probability for a day to be an HPE while the criterion is green, and $\mathbf{P}^{Ens}_{Green}$ the probability for a member term for being green over the three forecasts. The right panel of Fig. 6 shows the probability of HPE occurrence computed in this way. The theoretical maximum of this value is 69%, and in this case it is nearly achieved over the three forecasts. Of course, for other events the probability of HPE can be very weak, this “index“ cannot be considered as an all-in-one predicting tool. However, considering that the technique is designed to detect quasi sufficient conditions it can be considered as a reliable pre-warning index for high impact HPEs.

These results have been derived for one season at this time, and analysed only roughly. However, the procedure has been extended experimentally to the rest of the year, and it might be interesting to extend the validation period to the whole year.

Conclusion

The projection of an ensemble forecast on the Atlantic weather regimes shows the possibility of quickly interpreting the main features of the large scale circulation and its associated predictability. It can help identify likely transition periods in advance, of which some may be associated with high impact weather. The synthetic view provided by this pro-duct could also make the comparison of several models easier, which consitutes a major part of the forecasters role.

The statistical discriminant LSC is explored in the forecast to show the possibility of computing the probability of occurrence of high impact weather. This computation shows a fair ability to anticipate the event detection. By means of an appropriate validation work by comparing with the observations, this HPE index could represent efficient pre-warning information for this kind of event in the medium range.

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