Mediterranean Storms
(Proceedings of the 4th EGS Plinius Conference held at Mallorca, Spain, October 2002)

A STUDY ON THE FORECAST QUALITY OF THE MEDITERRANEAN CYCLONES

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ABSTRACT

The main general objective of MEDEX is stated to be the improvement of knowledge and forecasting of cyclones that produce high impact weather in the Mediterranean area. So, for this scope one of the intermediate goals of the project concerns the development of an objective method to evaluate the quality of the forecast of the cyclones. The topic of the present study is to investigate the cyclone's forecast errors in that area and to propose an objective methodology to quantify them. An investigation on the performance of the HIRLAM(INM)-0.5 model in the forecast of cyclonic centres has been done. Databases of analysed and forecasted cyclones for the Western Mediterranean have been used in this study. The "distance" between the analysed and forecasted cyclone has been measured calculating the differences in the value of the parameters chosen to describe them at the sea level surface. Results on the characteristics of the errors are shown. An index constructed by means of these differences has been introduced to evaluate the ability of the model forecasting cyclones, and to quantify it. From this index, two others indexes have been derived in order to discriminate if the forecast has overestimated or underestimated some magnitudes in the description of the cyclone. Three different time forecast ranges, H+12,H+24 and H+48, have been considered to investigate temporal trend in their quality. Finally, to check this methodology, it has been applied to some MEDEX cases.

1 INTRODUCTION

The Mediterranean area is affected from time to time by extreme adverse weather events. Although not all extreme weather events are related to cyclones and most of the cyclones do not produce extreme weather, it is plausible to assume that Mediterranean cyclones influence most of the high impact phenomena, at least in an indirect way. Therefore, the improvement on the cyclone forecast probably will contribute to the improvement of these event forecast. The main general objective of MEDEX (Mediterranean Experiment) concerns the improvement of knowledge and forecast of cyclones that produce high impact weather in the Mediterranean area, and in particular, one of the intermediate goals is the development of an objective method to evaluate the quality of the forecast of the cyclones (http://www.inm.es/MEDEX). In the frame of this project the present study has been developed and the topic of this one is to propose an objective methodology to assess the cyclone forecast error and to quantify it. This methodology is applied to investigate the performance of the HIRLAM(INM)-0.5° model in predicting surface cyclones. In order to evaluate the cyclone forecast two cyclone databases have been compared, one, as reference point, obtained from the sea level pressure (slp) analyses of the model and other one from the corresponding slp forecasted fields. First, the number of forecasted cyclones is compared against the number of analysed cyclones and, secondly, the accuracy of the forecast is evaluated, comparing the description of the cyclones in both fields, and quantified, by using an index value, built from the differences in the value of the cyclone features.

2 CYCLONE DATABASES

An automated procedure to detect and characterize surface cyclones in the Western Mediterranean had been developed and a first objective catalogue of cyclones had been obtained from the HIRLAM(INM)-0.5° slp analyses, as it is described in *Picornell et al*. (2001). This procedure has been subsequently modified in some aspects: as well as the cyclone catalogue from the original analyses, able to detect and describe small low-pressure centres, a new cyclone database has been obtained from the smoothed fields (smoothed using a Cressman filter with 200 km of radius), in order to select the more significant cyclones and to obtain an adequate description of them. In the catalogue from the original (smoothed) fields both detection and description of the cyclones by using the original (smoothed) fields are done.
A cyclone is defined as a relative minimum of pressure with a mean pressure gradient around the centre higher than 0.5 hPa/100km in at least six of eight main directions. For each cyclone some magnitudes are collected as data, location, domain, radii, mean geostrophic vorticity and circulation among others. In the new procedure the cyclone domain (defined as the area of positive geostrophic vorticity around the cyclone centre) is obtained looking for the zero-

vorticity line around the low-pressure centre in sixteen directions instead of four in the previous method, in order to obtain a more accurate domain.

A database of forecast cyclones has been obtained from the smoothed forecast fields (with the same Cressman filter) for one year, 1999, by means of the aforementioned procedure and it is compared with the corresponding cyclone database from the smoothed analysis fields. Three different forecast ranges, H+12, H+24 (four forecasts per day 00, 06, 12, 18) and H+48 (two forecasts per day 00 and 12Z) have been considered to investigate temporal trend in the quality.

In this paper the word 'cyclone' is used in a very general sense to refer to the low-pressure centres, not only extra-tropical cyclones but also shallow depressions.

3 VERIFICATION PROCEDURE

The method to objectively investigate the performance of the model on the cyclonic centre forecast follows three steps. As in Atger (1997), in the first one, the ability of the model to forecast the cyclones is assessed by means of some statistic parameters obtained from the number of forecasted and analysed cyclones and, in the second one, the accuracy of this forecast is evaluated comparing some cyclone magnitudes. In the third step, in order to quantify the forecast quality, an index is defined from the differences of some of these magnitudes.

3.1 Detection performance

The first step in this process is to evaluate which rate of low-pressure centres the model correctly forecasts. When the analysed and forecasted fields are compared, an analysed cyclone is regarded as correctly forecast if in the corresponding forecasted field a cyclone is located at a distance shorter than 400 km of them. From this comparison the number of hits, analysed and forecast cyclones (H), false alarms, forecast but not analysed centres (FA), misses, analysed but not forecast centres (M), and correct rejection, number of charts without analysed and without forecast cyclones (CR), are counted and collected in the following contingency table for each forecast range:

	Forecast	Not for.	Total
Observed	H	M	H+M
Not obser.	FA	CR	FA+CR
Total	H+FA	M+CR	

Table 1. Contingency table.

From this table the Hit Rate (HR) and the False Alarm Rate (FAR) have been obtained by means of the following equations 1 and 2, among others verification rates and their values for the different ranges are showed at figure 1.

$$HR = \frac{H}{H+M} \tag{1}$$

$$FAR = \frac{FA}{FA+CR} \tag{2}$$

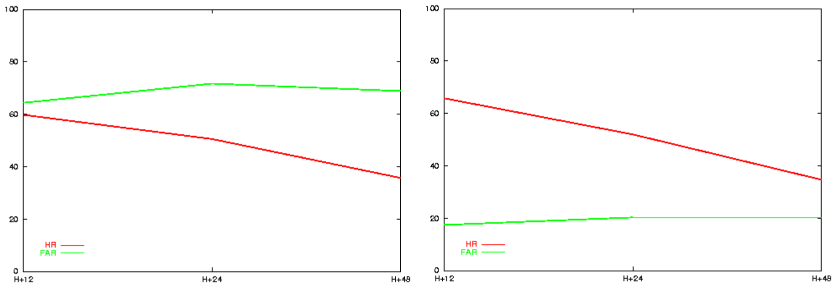

Figure 1. Hits Rates and False Alarm Rates for all cyclones (left) and for intense cyclones (right)

The figure 1 (left) shows that in the shorter 12 h range, around a 60 % of all analysed cyclonic centres are forecast by the model. This rate decreases to 51% and to 36 % when the forecast range increases to 24 and 48 h. On average, the model forecasts a little more than half of cyclones. The value of the FAR is very high. Probably it is difficult to localize some weak and short-living cyclones at the same time in both fields. This agrees with the fact that these results improve looking at the rates if only intense cyclones (with circulation $\geq 4\ 10^7\ m^2\ s^{-1}$) (see fig.1, right). The hits rate not increases very much, but the false alarms rate decreases considerably.

3.2 Forecast accuracy

The second step concerns to investigate the forecast accuracy. To do this, only the hits are considered. To evaluate the forecast accuracy and to study a possible trend to over or underestimate the cyclones some magnitudes of the analysed and forecast cyclones are compared: central pressure value, central geostrophic vorticity, mean geostrophic vorticity, circulation and area. The forecast error has been measured calculating the differences in the value of these parameters. First the location of the cyclones is compared. The distance between the positions of cyclones in the analysis and in the forecast depends on the time forecast range. For the short ranges, in general the forecasted cyclone position is close the analysed cyclone, in particular a 62% for 12h. and 42% for 24h. of the cyclones are forecast nearer than 100 km of the detected cyclones and less than 7% are forecast farther than 300 km. For the 48 h. range on average the cyclones are forecasted at a longer distance from their location, only the 28% of the forecast cyclones are nearer than 100 km of the detected cyclones, a 65% nearer than 200 km. and some of them, a 15.5%, are farther than 300 km.

For the differences of the others parameters the probability distribution, the bias and the root mean square error (RMSE) are calculated (Stanski, 1989). The differences are obtained taking the analysed value away from the forecasted value. Figure 2 shows these results for the central pressure. The distribution is similar for other magnitudes (not shown). A common characteristic of all distributions is the dependence on the forecast range. Accordingly to intuition, they show the decrease of the accuracy of the cyclone model description when the forecast range increases: the curves became larger, so the error (the differences) in the central pressure value, geostrophic vorticity, circulation and area increases with the forecast range. There is not a strong signal of a trend to over or underestimate of the cyclones. The curves are centred at zero and they have a gaussian sharp approximately. Anyway it is possible to observe a little underestimation of all variables but area. Observing the season's distributions (not shown), we note a clear tendency of the model to overestimate the central pressure, that is, to underestimate the cyclone depth, in the warmer seasons and the reverse situation in the colder ones.

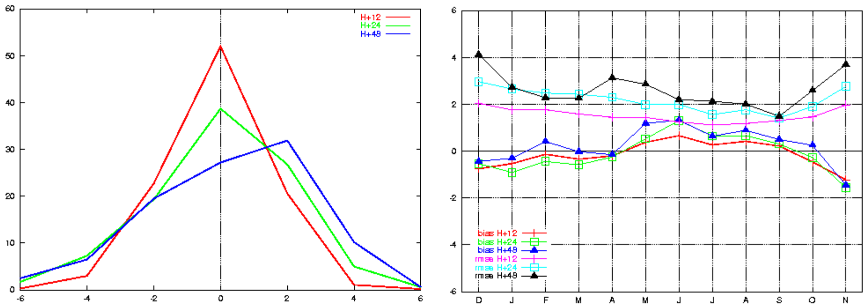

Figure 2. Probability distribution (%, left), monthly bias and monthly RMSE (right) for the difference (forecast - analysis) of central pressure

The bias curve show results that agree with our preliminary conclusions for the distributions. There is no, in general, a tendency to an over or underestimation. The curves lie close to the zero lines, and a clear temporal dependence is not observed. There are some exceptions. The model shows a clear underestimation of the mean vorticity and an overestimation of the area. For the central pressure, the same temporal variation can be observed, as already noted from the seasonal distribution. All of the three forecast range tend to overestimate the pressure during the warmer months and underestimate during the rest of the year (see fig.2, left). The RMSE again increases with the forecast time. The highest RMSE values are reached during the cold months, that is, the model forecast more accuracy during summer. In general the model tends to forecast a lightly less intense and more extensive cyclone than the observed one. Also this behaviour is clearly more evident for the longer H+48 range.

3.3 Index

The third step concerns to an index constructed to evaluate and quantify the accuracy of the model forecasting cyclones. Of course the difference distributions already give us information about the actual mean error in the forecast of the considered variable. Anyway, the quality of a prediction is not a directed consequence of a specific error on a variable, rather it is affected in a complicated way by the errors in all of the parameter, which obviously are strongly related by atmospheric constraints. To try to give some insight to how the errors in the estimate of the variables contribute to collapse the forecast, an index that combine them has been introduced. The index has been constructed in an empirical way combining, after to be adimensionalized, the various errors and weighting them according to the importance the authors believe they have in conditioning the forecast.

For each cyclone j the index I(j) is defined by means of the equation 3 from 19 magnitudes (n=19), the distance (with a weight of 32%, α_1=0.32 in eq. 4) and differences on central pressure (α_2=0.28), circulation (α_3=0.23) and 16 radii ($\alpha_4=\ldots=\alpha_{19}$=0.17/16). Some parameters are introduced, N_i, to obtain adimensional values of the differences, and M, to limit the value of I(j) between 0 and 1 (1 for a correct forecast and 0 for a bad one). The values of these parameters, from the sample of one year, are N_1=137.2 km, N_2=1.6 hPa, N_3=0.8 10^7 m^2s^{-1}, N_4,…,N_{19} range from 130.1 to 186.2 km and M=2.9. These parameters enable to compare forecasts for different ranges.

$$I(j) = 1 - \frac{S(j)}{M} \tag{3}$$

where

$$S(j) = \sum_{i=1}^{n} \alpha_i \frac{|dif\_\mathrm{var}_i(j)|}{N_i} \tag{4}$$

$$N_i = \overline{|dif\_\mathrm{var}_i|}_{H+24} \tag{5}$$

$$M = \max\left(\sum_{i=1}^{n} \alpha_i \frac{|dif\_\mathrm{var}_i(j)|}{N_i} \right)_{H+24} \tag{6}$$

The cyclone distribution as a function of the index shows again the best forecast is obtained for the shorter range (see fig.3, left), accordingly with the previous results. The temporal variability of the forecast's quality, as measured by the index, shows a similar behaviour between the three ranges (see fig.3, right). This could means that it is most due to some intrinsic atmospheric characteristic and to the model ability to capture them, rather than a model error in estimate the actual cyclone. The highest index values are reached during summer, that is, the cyclone forecast is more precise during this season, and the lowest values during winter. It must be take into account that only one year had been studied, a short period to extract definitive results.

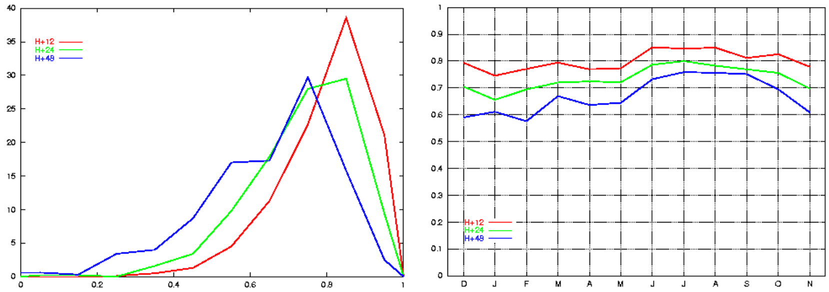

Figure 3. Cyclone distribution as a function of the index value (left) and monthly index values (right)

From this index, two others indexes have been derived in order to discriminate if the forecast has over or underestimated some magnitudes in the description of the cyclone. The distance is not included in these indexes.

4 CONCLUSIONS

A methodology to assess the forecast quality of the Mediterranean cyclones from the numerical model has been developed. This methodology is based on the evaluation of the differences of the cyclone magnitudes between the analysed and the corresponding forecasted cyclone. From the combination of these differences, an index value is obtained as a measure of the forecast quality.

The method has been applied to the HIRLAM model at three different ranges. The model is only able to detect around the half of the analysed cyclones. The accuracy of the forecast decreases as the forecast range increases, accordingly with the intuition. Although a clear temporal trend has not appeared, a certain tendency to the over-estimation or under-estimation of some variables during particular period is present and the authors believe in the need of a greater database to clarify this aspect and to obtain more representative results.

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