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SENSITIVITY OF ENSEMBLE FORECASTS OF EXTRATROPICAL TRANSITION TO INITIAL PERTURBATIONS TARGETED ON THE TROPICAL CYCLONE

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1. INTRODUCTION

The reduced predictability associated with the extratropical transition of tropical cyclones presents a severe challenge for numerical weather prediction. Guidance with respect to the uncertainty associated with extratropical transition can be obtained from ensemble prediction systems that calculate a certain number of forecasts from perturbed initial conditions in addition to the deterministic forecast. This allows probability forecasts to be made. In the ECMWF Ensemble Prediction System (EPS) 50 initial perturbations for the ensemble members are obtained by calculating extratropical singular vectors that identify all regions in the atmosphere polewards of 30° where maximal error growth is possible in a certain time interval. In addition singular vectors are calculated with linearised diabatic physics only for areas targeted around tropical cyclones. In order to avoid double counting singular vectors the target areas used to be restricted to the tropical belt (25°S – 25°N). However, a tropical cyclone often exists polewards of 30° especially when it undergoes extratropical transition. In the recent upgrade to the ECMWF EPS the calculation of the initial perturbations targeted on tropical cyclones has been modified so that they can be applied to tropical cyclones as they move into the midlatitudes.

Tests of the new configuration as implemented on 28 September 2004 have been conducted at ECMWF for certain tropical cyclones. In the case of FABIAN (2003), for example, calculations of the tracks with the new configuration show a splitting of the ensemble members in two distinct branches which cannot be seen in the calculation with the old configuration (Fig. 1). The monomodal distribution of tracks changes to a bi-modal one. Furthermore, a larger number of ensemble members can be found close to the observed track.

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In this paper we present experiments designed to investigate the impact of the new initial perturbations on the extratropical transition of tropical cyclones and the downstream flow in ensemble forecasts. In experiments with the ECMWF EPS we want to separate the effect of the initial perturbations on the EPS forecast from the other changes made in the new configuration.

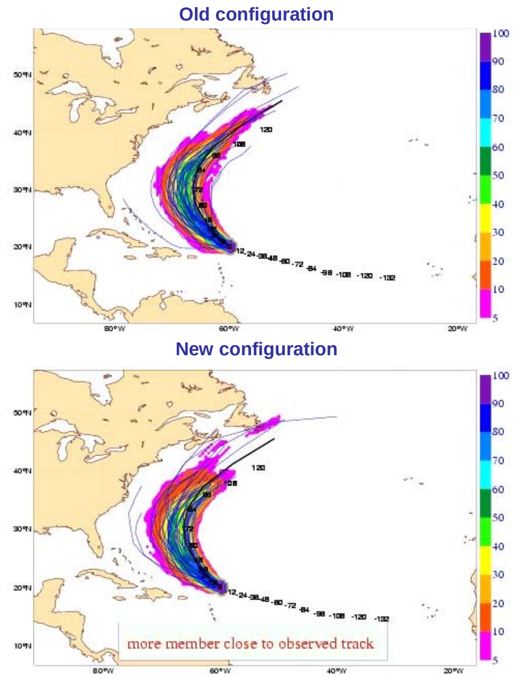

Fig. 1: 2 September 2003 12 UTC. Probability that FABIAN will pass within 120 km radius during the next 120 hours. Tracks: black=analysis, green=contol, blue=ensemble prediction system numbers: observed positions at t+ ..h

2. EXPERIMENTS

In experiments with the ECMWF model system we reran EPS forecasts for the tropical cyclone MAEMI (2003) using the new configuration with the resolution TL255 and 40 levels. In order to identify the impact that is caused by the initial perturbations alone we switch off the stochastic physics for all experiments. This is important because the influence of the stochastic physics cannot be assigned clearly either to the tropical cyclone or to the midlatitude flow. We ran experiments without initial perturbations targeted for MAEMI and compared them to the runs with perturbations.

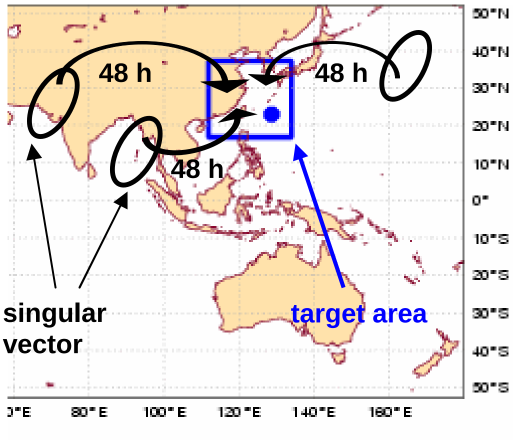

Fig. 2: Target area (blue square) assigned to MAEMI (blue dot). The initial time location of 3 of the leading 5 singular vectors optimised for this area is marked by black ellipses.

In the tropics the initial perturbations for tropical cyclones are calculated with singular vectors (T42, 40 levels) which give maximum growth after an optimisation time of 48 h in target areas assigned to the particular tropical cyclone (Fig 2). These areas are determined from the positions of the tropical cyclone in the latest ensemble forecast which is the reason why the target area is not centred on the reported tropical cyclone position.
In Fig. 3 the temperature fields of two different singular vectors (black contours) targeted on MAEMI (red dot) for 9 September 2003 12 UTC, one at 200 hPa and one at 500 hPa, are shown exemplarily together with the 500 hPa geopotential (blue contours).
These are initial singular vectors that will have grown maximal after 48 h. It is obvious that at this time the singular vectors at 500 hPa cover a wider area than the 200 hPa singular vectors. Furthermore especially at 500 hPa but also at 200 hPa it can be seen that the main part of the singular vectors originates both in the area of the tropical cyclone and in the upstream trough. The singular vectors further upstream and downstream of MAEMI show that singular vectors optimised for the target region of MAEMI can originate far from the cyclone though their main part in this case comes from close areas.

The root mean square difference (RMSD) averaged over 40° - 50° N of the ensemble members (a measure of the ensemble spread) is presented in Hovmoeller plots of 200 hPa (left) and 500 hPa (right) heights in Fig. 4. Downstream of the ET of MAEMI (black dot) a local maximum of the RMSD can be seen both in the 200 hPa and in the 500 hPa plot at about 180° E at 15 and 16 September. At 200 hPa it becomes smaller again at 17 September

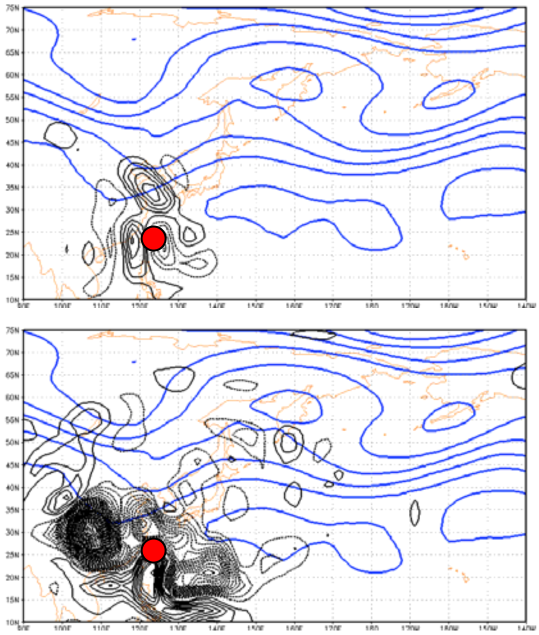

Fig. 3: Singular vectors (black contours) at 200 hPa (left) and 500 hPa (right targeted on MAEMI (red dot) on 9 September 2003 12 UTC plotted on 500 hPa geopotential.

which indicates that the 5- and 6-day forecasts for this region are worse than the 7-day forecast. In Spaghetti plots of the ensemble members (not shown) it becomes clear that this uncertainty is associated with different representations of a trough downstream of MAEMI. After 7 days the flow becomes more zonal again in all the ensemble members.
To identify the influence of the initial perturbations targeted on MAEMI the difference between the RMSD relative to the control forecast with and without perturbations has been calculated for forecasts from 9, 10 and 11 September 2003 12 UTC. The results for 9 September are shown in Hovmoeller plots in Fig. 3. A signal which originates at the ET time and position of MAEMI propagates downstream and broadens with increasing forecast time (Fig. 3).
Particularly in the 200 hPa (left) plot quite high values can be seen in an area including the Typhoon itself (black dot) and an existing downstream ridge. The values of these differences are almost entirely positive until 17 September, indicating an increase of the

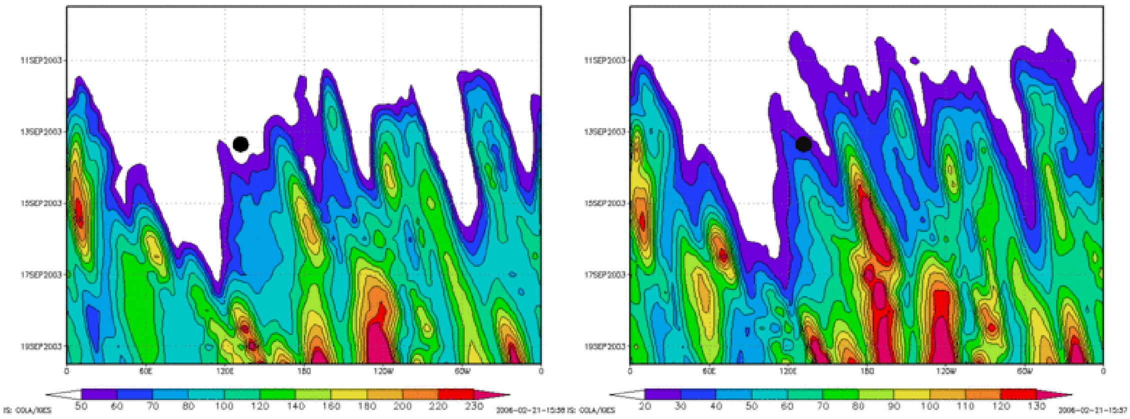

Fig. 4: Forecast from 9 September 2003 12 UTC: RMSD of ensemble forecast with perturbations averaged over 40° - 50° N for 200 hPa (left) and 500 hPa (right).

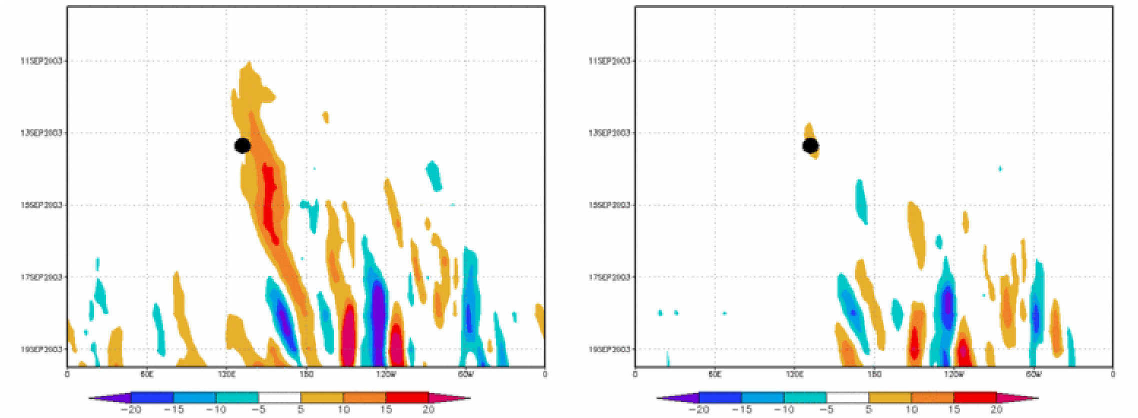

Fig. 5: Forecast from 9 September 2003 12 UTC: RMSD of ensemble forecast with perturbations minus RMSD of ensemble forecast without perturbations around MAEMI at 200 hPa (left) and 500 hPa (right).

ensemble spread in the run with perturbations. From 17 September on they show an alternate pattern of positive and negative values. This indicates a displacement of waves between the runs with and without perturbations. The maximum of the differences at 200 hPa on 15 September makes up 25 % of the RMSD of the forecast with perturbations (Fig. 5 left). The absolute values of the signal at 500 hPa (Fig. 5 right) are smaller then at 200 hPa though if compared to the runs with perturbations on this level (Fig. 4 right) it can be seen that the signal in the region of MAEMI represents 20 % of the values on the same position in Fig. 4 (right). In the same plot of differences at 500 hPa (Fig. 5 right) with smaller scales (not shown) it can be seen that the values of the signal are mostly positive until 15 September 12 UTC. After that time the same alternating pattern of positive and negative values like at 200 hPa can be seen. The signal reaches the West coast of North America (120° W) 2 days after the ET for both levels.

It is of interest to investigate the structure of the individual ensemble members to see whether in the model runs with perturbations they form more distinct groups like we saw in Fig. 1 (bottom) or if some outlying members are missing for the runs without perturbations.

This can be quantified using a principal component analysis with clustering of the principal components. The first step of this method is to find the locations of maximum variability of a certain variable for the 51 ensemble members (perturbed + control forecast) over a certain area. The principal components show the contribution of each of the 51 ensemble members to these patterns. The second step consists of the clustering of the principal components. Thus we group together ensemble members which contribute in a similar way to the dominant atmospheric flow patterns.

3. RESULTS

The variable which has been used for the investigation is the 200 hPa height. 5 clusters are found for the 5-day forecast from 9 September 2003 12 UTC (verification time is 14 September 2003 12 UTC) of both runs with and without perturbations. Clusters of the runs with perturbations are shown on the left and those without perturbations on the right side of Fig. 6.

The number of ensemble members and the standard deviation between the ensemble members in each cluster is marked in white on the bottom of each panel. In the interest of clearness the runs with perturbations are referred to as “PERT” and the runs without perturbations as “NOPERT” in the following.

In a short comparison it can be seen that the 200 hPa flow can be split up in two different patterns. One is quite “wavy” and has a clear trough-ridge-trough pattern between 130° E and 170° W at about 35° - 60° N. It is referred to as “meridional” in the following. The other one is rather zonal west of 160° E and has a sharp trough at about 180°. It is referred to as “zonal” in the following. In PERT three meridional and two zonal flow patterns can be found, while we counted two meridional and three zonal in NOPERT. It is characteristic for the zonal flow patterns that they do not show the downstream deep pressure system that can be found in all the meridional flow patterns.

The location of the ET-system is represented quite differently in the clusters. However, all the meridional flow patterns have in common that they show the ET location further in the west than the zonal patterns. The meridional oriented ridge at about 150° - 160° E seems to inhibit the ET system from propagating too fast in the meridional patterns.

The minimum pressure of the ET system in the clusters ranges from 1005 hPa to 985 hPa for PERT (Fig. 6 b), left) and for NOPERT (Fig. 6 b), right) from 1005 hPa to 990 hPa. The cluster that shows the strongest ET (Fig. 6 a)) cannot be found in NOPERT. This is a small cluster with only three members. Fig. 6 c), left, shows a weak deep pressure system in the location where the ET system should be. In further time steps (not shown) it can be seen that this system is in the process of decaying. This is the only cluster that shows a decay after recurvature. A cluster like this cannot be found in NOPERT. Even the cluster in Fig. 6 c), right, reintensifies in a later time step (not shown).

We can conclude that the range of possible developments in PERT is larger than in NOPERT so that the probability that the analysis lies outside the ensemble is reduced.

The standard deviation within each cluster gives an indication of how well defined the clusters are. We found that in the region of the ET system and the downstream ridge the standard deviations were highest. The values are on average 10 meters, that is approximately 30%, higher in NOPERT. The small cluster in PERT that shows the strongest ET is the only exception. Here the high value of 100 m standard deviation results from the fact this cluster contains only three members.

We conclude that the clusters are better defined in the runs with perturbations than in the runs without perturbations and therefore a higher probability can be assigned to the individual clusters.

4. OUTLOOK

It has been shown that the initial perturbations modify the ensemble in the way that the spread is larger, i. e. more atmospheric developments are possible and the ensemble members group together more distinctively for the tropical cyclone MAEMI.

Now we plan to conduct these experiments with the ECMWF model system for other tropical cyclones with different characteristics. It is of interest how targeted initial perturbations influence weak tropical cyclones undergoing ET which have nevertheless a high impact on the forecast accuracy.

Furthermore, we want to test the latest configuration implemented in February 2006 that has a higher horizontal and vertical resolution (TL399, 62 levels).

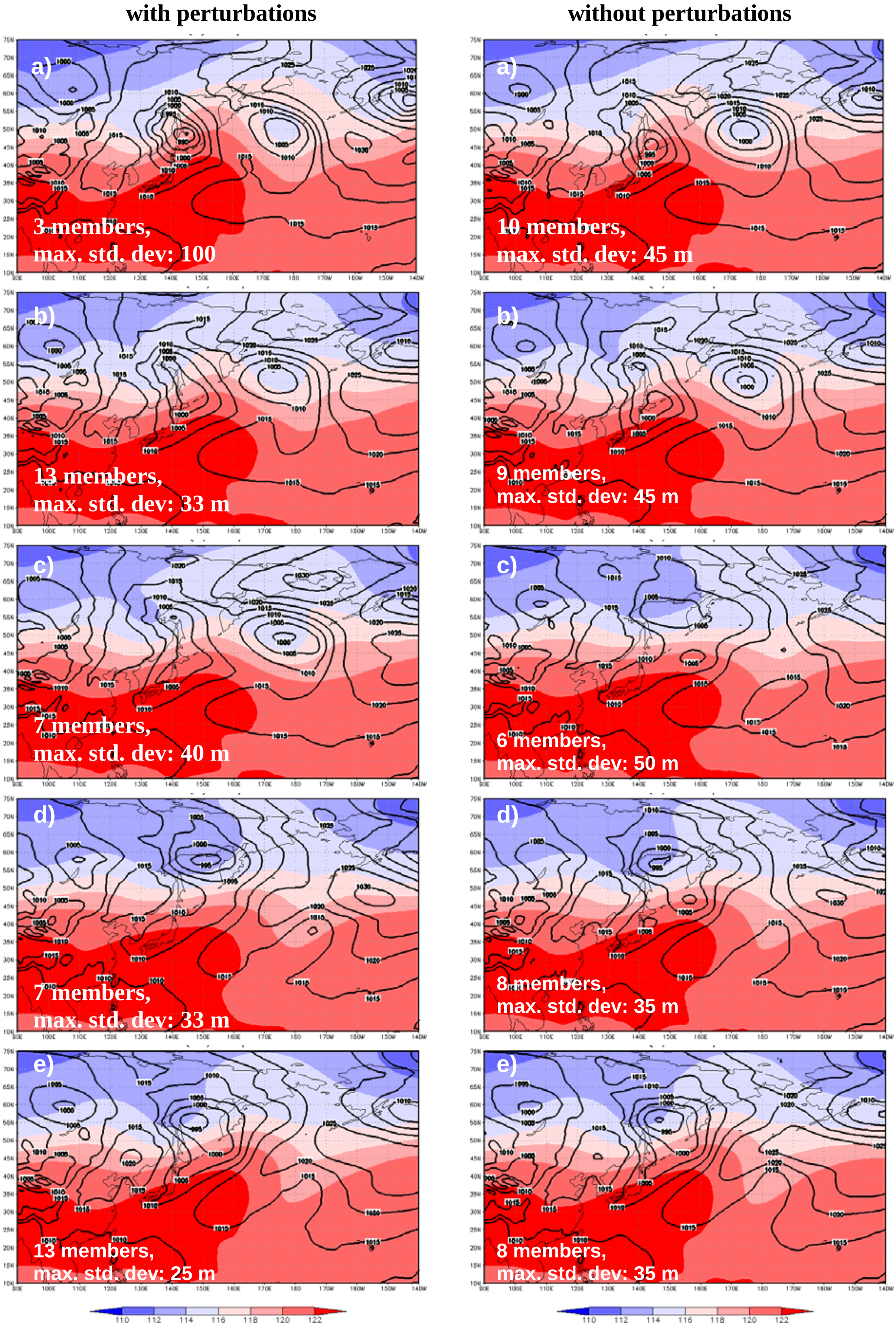

Fig. 6: Comparision of the 5 clusters in the ensemble calculated with (left) perturbations and without (right) perturbations around MAEMI. Number of members and standard deviation of the members in each cluster is marked in white at the bottom of the figures.