9C.3 SENSITIVITY EXPERIMENTS FOR ENSEMBLE FORECASTS OF EXTRATROPICAL TRANSITION

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1. INTRODUCTION

A tropical cyclone (TC) transforming into an extratropical system often causes a decrease in predictability. Ensemble prediction presents an appropriate means to provide information about the predictability of a given atmospheric scenario. The dispersion with time of the initially very similar atmospheric scenarios shown by the ensemble members gives a measure of the uncertainty in the forecast and of the extent of possible error growth.

The ensemble prediction system (EPS) of the European Centre for Medium-Range Weather Forecasts (ECMWF) is initialized by adding 50 small perturbations, so called initial perturbations, to the analysis. These symbolize uncertainties in the initial conditions of a forecast arising, for example, through insufficient or regionally and temporally heterogeneous data coverage over the globe.

The initial perturbations are constructed at the ECMWF using singular vectors (SV) which describe the fastest error growth over a finite time intervall (Farrell, 1982). SV growth is optimized for the extratropical domain (polewards of 30°) and for the tropical domain separately. To describe the high uncertainty in the forecast introduced by ET SVs are required to be in the vicinity of TCs to generate enough spread (Puri et al., 2001). As targeting SVs on the whole tropical strip would not guarantee that fast-growing SVs will also be in the region of a TC, SVs are targeted on regions around TCs, called optimization region.

In a perfect model all uncertainties would be described by the initial perturbations. However, in every model additional uncertainties arise during the model runs due to small-scale physical processes that are not resolved by the model grid and therefore have to be parametrized. The ECMWF ensemble takes these into account by perturbing the ensemble additionally through multiplying the parametrized tendencies of every ensemble member with random numbers at every grid point. This procedure is called stochastic physics.

The role of an ET for the reduction of predictability is quantified in this study by investigating the influence of initial perturbations in the environment of an ET event on the ensemble forecast. The dispersion and downstream propagation of these initial perturbations yield a measure of how far the reduction of predictability due to an ET can reach.

During ET parametrized processes play an important role in the forecast as the convective core of a TC and turbulence in the upper troposphere caused by the outflow of the TC are not resolved by the grid. The sensitivity of the growth of uncertainties due to parametrized processes to the presence of an ET event and the downstream propagation of these uncertainties is shown in this study as well.

2. EXPERIMENTS

Typhoon Tokage (2004) was chosen for the experiments because it seemed to have a strong influence on the midlatitude flow pattern. A high uncertainty in the ECMWF ensemble forecast could be attributed to the ET of Tokage (Anwender et al., 2008).

In the experiments new 10 day ensemble forecasts during Tokage's life cycle were calculated with the ECMWF EPS using the configuration with the T255L40 resolution. The SVs were recalculated using the T42L40 resolution in order to be consistent with the model cycle used for the experiments (29r2). At the ECMWF the optimization region around a TC is determined such that a rectangular box is placed around the TC positions forecast for the optimization time, i. e. 48 hours, by the most recent ensemble forecast. A minimum

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extension of the box of 5° in latitudinal and 7° in longitudinal direction is imposed (Leutbecher and Paulsen, 2004).

Fig. 1 shows the temperature component of the leading initial SV (SV1), at 500 hPa for 16 October 2004 12 UTC (4 ½ days before Tokage's ET) and at 12 UTC 18 October 2004 (2 ½ days before Tokage's ET).

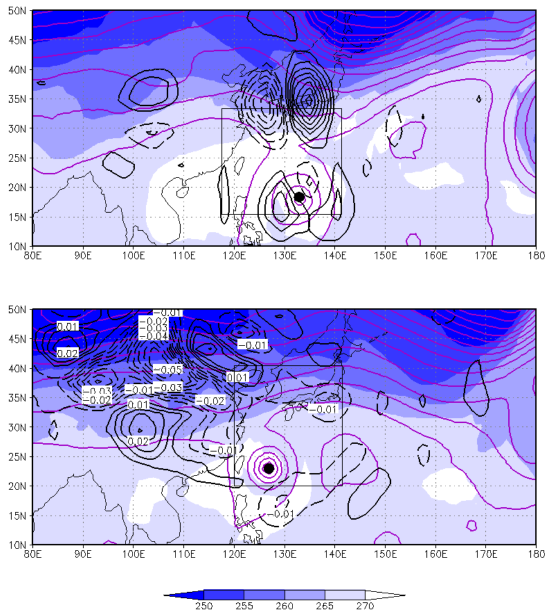

Fig. 1: Temperature component (K, black) of the leading initial SV targeted on Tokage at 500 hPa on 12 UTC 16 October 2004 (top) and on 12 UTC 18 October 2004 (bottom). Geopotential height of the control forecast (m, purple) and temperature (K, shaded). Tokage is marked by a black dot. Optimization regions for Tokage are shown as black boxes.

On 16 October large parts of SV1 are located in the midlatitudes north of Tokage. However, distinct structures are seen around the TC as well. On 18 October almost all of the SV1 structures are in the midlatitudes upstream of Tokage. Only small structures are seen in the vicinity of the TC and the subtropical high to the east of Tokage. Hence, on 16 October Tokage seems to play an important role in the generation of the initial perturbations.

In this study we concentrate on ensemble forecasts initialized on 16 October 2004. In the first experiment a new EPS run without the perturbations targeted on Tokage was performed and compared to a new EPS run with the same configuration but with targeted perturbations. To confine the differences between the two runs solely to that associated with the targeted perturbations the stochastic physics was switched off.

In the second experiment the representation of uncertainties due to parametrized processes is investigated by examining the impact of the stochastic physics. The EPS was run without the targeted perturbations around Tokage but with stochastic physics.

3. RESULTS

The aim of the EPS experiments was to compare the influence of targeted perturbations, stochastic physics and higher resolution on the track and intensity forecasts, the representation of overall spread during an ET, the downstream propagation of uncertainties introduced by an ET event and the grouping of the ensemble members in the regions of uncertainties.

The EPS experiments showed that sufficient ensemble spread in the track and improved spread in the intensity forecast depends strongly on the additional perturbations targeted on Tokage. Without these, the track spread in the forecasts, especially that around the recurvature and ET of Tokage, was underestimated and the analysis was not contained within the ensemble members (Fig. 2).

In general, the targeted SVs are expected to be appropriate to perturb larger scale features associated with the track forecast. The stochastic physics are needed to perturb small scale processes that determine the intensity, such as convection in the inner core of the TC (Puri et al., 2001).

In our case, however, the stochastic physics mainly yields sufficient spread in the intensity for the forecast times before ET. At ET time and following the targeted perturbations were responsible for weakening while the stochastic physics led to more deepening than seen in runs with neither targeted perturbations nor stochastic physics (not shown).

Tokage weakened considerably shortly after its landfall on Japan. The extent and rapidity of the weakening was not contained in the ensemble forecasts with targeted perturbations or with stochastic physics. The weakening, which was probably associated with the landfall in Japan, appears too severe a challenge for a global model.

The new high resolution model cycle with targeted perturbations shows the best spread in track and intensity forecast. More members show a quick movement of Tokage. This is,

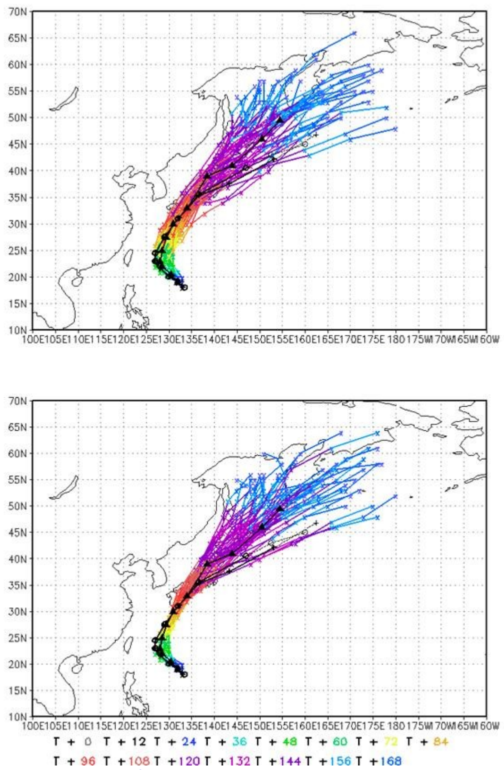

Fig. 2: Tracks for Tokage based on the location of minimum sea level pressure for the runs with (top) and without (bottom) targeted perturbations on the TC. ECMWF analysis (black, circles), best track (black, crosses), deterministic forecast (black, triangles) and ensemble forecast (colors) from 12 UTC 16 October 2004. Analysis and best track dashed after analyzed ET.

however, due to other innovations rather than to the higher horizontal resolution as was shown by test runs with the new model cycle and the lower horizontal resolution used in the old model cycle. Even with the new model cycle with high resolution and with the targeted perturbations on Tokage the ensemble forecast of the intensity does not encompass the analysis over the 24h period of weakening.

The impact of the SVs targeted on Tokage propagates downstream with the group velocity of a Rossby-wave-train that has been excited by the interaction of Tokage with the midlatitudes (Fig. 3, top). The amplitude of the wave packet determines the transport of wave energy which can trigger cyclogenesis far away from the ET event. At 20° per day the group velocity is slightly smaller than that found by Szunyogh et al. (2002).

The growth and downstream propagation of the impact of the targeted SVs on Tokage yields a good measure of the rapidity and the extent of the downstream propagation of errors growing in association with ET. The results indicate that an ET event can reduce the predictability over an entire ocean basin.

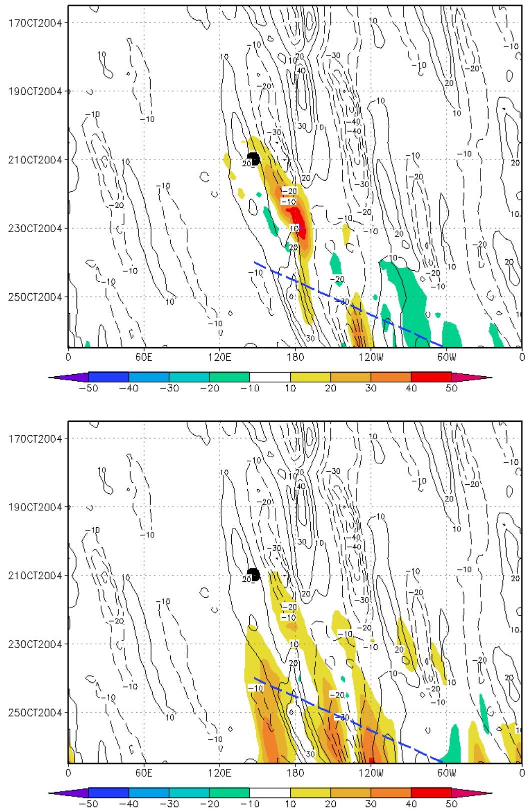

Fig. 3: Hovmoeller plot of RMSD difference (m, shaded) of the geopotential height between the ensemble runs with and without targeted perturbations on Tokage (top) and with and without stochastic physics (bottom) at 200 hPa averaged between 30° - 60° N. Analyzed meridional wind component (m/s, contours) at 200 hPa. 10-day forecast from 12 UTC 16 October 2004. ET position is marked by a black dot. Rossby wave train excited by Tokage is marked by a black dashed line.

The strong growth of the effect due to the stochastic physics in the vicinity of the ET and the partial downstream propagation of this effect demonstrates that there is a distinct reduction of predictability due to parametrized processes associated with the ET (Fig. 3, bottom). Stochastic physics can have an influence on the downstream predictability through perturbations caused by Tokage's outflow impinging on the midlatitude jet. The uncertainties due to parametrized processes continue growing beyond the medium range.

The use of the EOF/cluster analysis (Harr et al., 2008) showed that 4 clusters were obtained only in the runs with targeted perturbations (Fig. 4). With stochastic physics alone or with high resolution alone, 3 clusters were found.

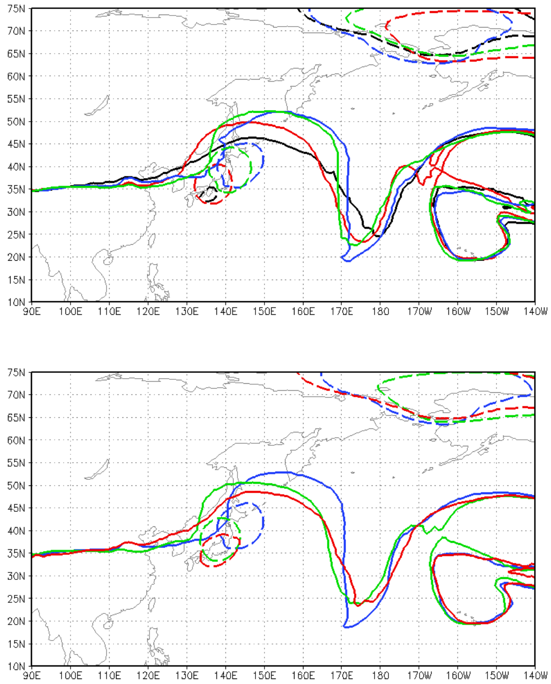

Fig. 4: Spaghetti plots of the cluster means of the 350 K isentrope and the 995 hPa mean sea level pressure isobar. Ensemble forecast for Tokage with (top) and without (bottom) perturbations targeted on Tokage from 12 UTC 16 October 2004 valid on 00 UTC 21 October 2004.

Only the targeted perturbations with the old model cycle yield one cluster that shows no ET and, hence, is weaker than the analysis. The reason for the decay of Tokage in this cluster, however, was not the landfall as in the analysis, but that the TC was too far south of the midlatitude baroclinic zone. Even with the higher resolution and with targeted perturbations on Tokage only one cluster showed the weakening due to the landfall. However, in this cluster the ex-TC re-intensified subsequently, as in all the other clusters. This is in contradiction to the analysis.

4. OUTLOOK

We have demonstrated that experiments with an operational EPS can yield insightful information about the sensitivity of numerical forecasts to an ET event and about the impact which such events can have in remote regions. Further experiments examining different ET cases are needed to test the robustness of these results given the large variety in ET development. Testing the representation of model uncertainties by a new stochastic physics scheme which has been developed recently at the ECMWF are necessary as well. A future study will consider the influence of higher resolution on both SVs and EPS forecasts.

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