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THE STRUCTURE OF SINGULAR VECTORS ASSOCIATED WITH EXTRATROPICAL TRANSITION OF TROPICAL CYCLONES

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1. INTRODUCTION

Extratropical transition (ET) of tropical cyclones is associated with a reduction of predictability both of the ET system itself and downstream due to the high sensitivity of the forecast to the evolution of both the upper-level midlatitude flow and the tropical cyclone. Physical processes associated with latent heat release constitute a further source of uncertainty. Strong error growth can occur in regions of the atmosphere that are unstable to small-amplitude perturbations. Singular vectors (SVs) can be used to identify such regions and indicate the structure of the fastest growing perturbations over a given time interval. For that reason the structure of singular vectors associated with the extratropical transition of a tropical cyclone could provide valuable information on the important dynamical and physical processes during such an event.

In the European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble prediction system (EPS) SVs targeted on tropical cyclones are operationally calculated with linearized diabatic physics and an optimization interval of 48 hours (Puri et al. 2001; Leutbecher and Palmer 2008). The optimization area is located around the forecast track of the tropical cyclone in the EPS. The calculations are performed with respect to a total energy norm. The singular vectors are optimized from the surface to 500 hPa (Barkmeijer et al. 2001).

2. STRUCTURE OF INITIAL SINGULAR VECTORS

In this study the initial singular vectors are investigated for the western North Pacific Typhoons Man-Yi (2007), Usagi (2007), Nari (2007), Ewiniar (2006), Chanchu (2006), Maria (2006), Banyan (2005), Nabi (2005) und Saola (2005) for a total of 133 initialization times. Through comparing the sensitivity index (Peng and Reynolds 2006) for all cases characteristic structures could be identified for the different phases from pre-recurvature through ET. During the tropical phase the sensitivity is located initially around the typhoon and subsequently associated also with the subtropical high. In the recurvature phase sensitivity is still seen around the typhoon but now also associated with the upstream midlatitude trough. Similar features to those described here for the tropical and recurvature phase were discussed by Peng et al. (2007). During the ET phase sensitivity is located around the typhoon, in the upstream trough, and in the downstream midlatitude ridge.

3. GROWTH OF SINGULAR VECTORS

In order to understand the impact of the characteristic structures described in section 2 we consider the evolution of individual singular vectors between the initial time and the optimisation time. To this end modifications were made to ECMWF cycle 32r3 by which the SV and the trajectory variables could be outputted at 3 hourly intervals during the optimization period. The SVs were recalculated for Man Yi, Nabi and Usagi. Here we describe the evolution of the SVs for Man Yi during the tropical phase (initialized on 9 July 2007 12 UTC), the recurvature phase (initialized on 12 July 2007 00 UTC) and the ET phase (initialized on 14 July 2007 12 UTC).

In the tropical phase the horizontal structure of the first SV (SV1) is primarily wavenumber one when viewed in cylindrical coordinates centred on the tropical cyclone. (Fig. 1a,c,e). The vertical structure is dominated by a barotropic component, although the SV rotates cyclonically with height at the initial time and rotates during the optimization period to give an anticyclonic rotation with height. The initial SV1 is located between the subtropical anticyclone and the typhoon. During the optimisation the structure moves around and towards the centre of the typhoon. After 48 h SV1 represents a displacement of the typhoon and the western region of the subtropical high. The second SV exhibits a similar evolution to that of SV1 but is rotated in the horizontal. In contrast, the third SV (Fig. 1b,d,f) has a wavenumber 2 spiral structure. During the optimisation period the spirals lose their upshear tilt and the wavenumber 2 structure is deformed somewhat. After 48 h this SV results in a rotation of the typhoon. Singular vector amplitude is seen in association with the midlatitude flow only for

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the fifth SV. The evolution of the SVs described here for real cases can be related to the idealized study of Nolan and Farrell (1999).

In the recurvature phase SV2 has amplitude both near to the typhoon and in the midlatitudes (Fig. 2). The SV in the midlatitudes is tilted against the shear in the vertical and horizontal. The wavenumber one structure near the typhoon is again predominantly barotropic. A wave train develops in the midlatitudes and moves towards the typhoon. After 48 h SV2 represents a displacement of the southern region of the 500 hPa trough in which Man Yi is embedded and a strengthening of the ridge downstream of Man Yi. The upper tropospheric jet is displaced northwards and strengthened.

In the ET phase SV1 develops in the region between the subtropical high and the midlatitude westerlies (Fig. 3). The SV structure is tilted horizontally and vertically against the shear. Towards the end of the optimisation a wavenumber one structure develops near the typhoon. The ridge downstream of Man Yi is strengthened so the eastwards motion of the ex-typhoon is reduced.

4. SUMMARY

In the tropical phase the fastest growing SVs are located around the typhoon and are predominantly barotropic. Strong growth is observed in the region between the typhoon and the subtropical high. The SVs influence the motion of the typhoon.

In the recurvature phase the first SVs are similar to those of the tropical phase. The following SVs are located both near the typhoon and in the midlatitude westerlies and grow through barotropic and baroclinic processes. The SV structures that are initially in the two separate regions move together during the optimisation period resulting in strong growth in the optimisation region.

In the ET phase the SVs are dominated by structures near the midlatitude jet and influence both position and intensity of the ex-typhoon.

In all three phases the kinetic energy increases strongly during optimisation. A strong increase in potential energy of the SVs is seen only in the recurvature and ET phases.

Due to the resolution used to calculate the SVs, the structure and intensity of the typhoon in question cannot be well represented in the SV calculation. In future work we will investigate the sensitivity of the SVs to the horizontal resolution with which they are calculated.

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REFERENCES

Barkmeijer, J., R. Buizza, T. N. Palmer und J.-F. Mahfouf (2001). Tropical singular vectors computed with linearized diabatic physics. *Q. J. R. Meteorol. Soc.* **127,** 685–708.

Leutbecher, M. und T. N. Palmer (2008). Ensemble forecasting. *J. Comp. Phys.* **227,** 3515-3539.

Nolan, D. S. und B. F. Farrell (1999). Generalized stability analyses of asymmetric disturbances in one- and two-celled vortices maintained by radial inflow. *J. Atmos. Sci.* **56,** 1282–1307.

Peng, M. S. und C. A. Reynolds (2006). Sensitivity of tropical cyclone forecasts as revealed by singular vectors. *J. Atmos. Sci.* **63,** 2508–2528.

Peng, M. S., R. N, Maue, C. A. Reynolds, and R. H. Langland, 2007: Hurricanes Ivan, Jeanne, Karl (2004) and mid-latitude trough interactions. *Meteorol. Atmos. Phys.* **97,** 221-237.

Puri, K., J. Barkmeijer and T.N. Palmer, 2001: Ensemble prediction of tropical cyclones using targeted diabatic singular vectors. *Q. J. R. Meteorol. Soc.* **127,** 709-731.

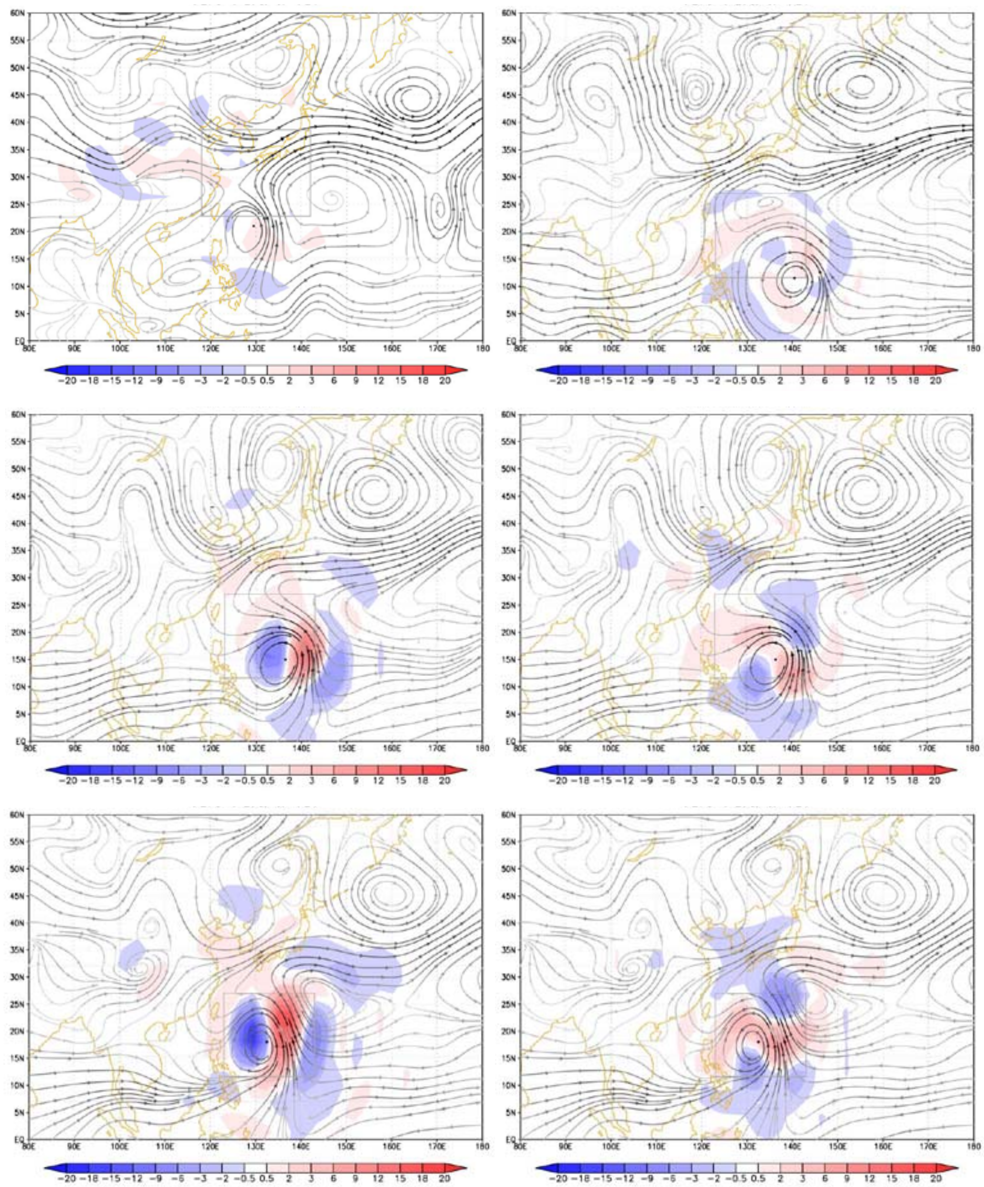

Figure1. Streamlines of the trajectory and perturbation vorticity (in colour) at model level 40 (approx. 650 hPa) of SV1 (left) and SV3 (right) for Man Yi (Tropical Phase) after 0 (top), 27 (middle), 48 (bottom) hours. Darker streamlines indicate higher windspeed.

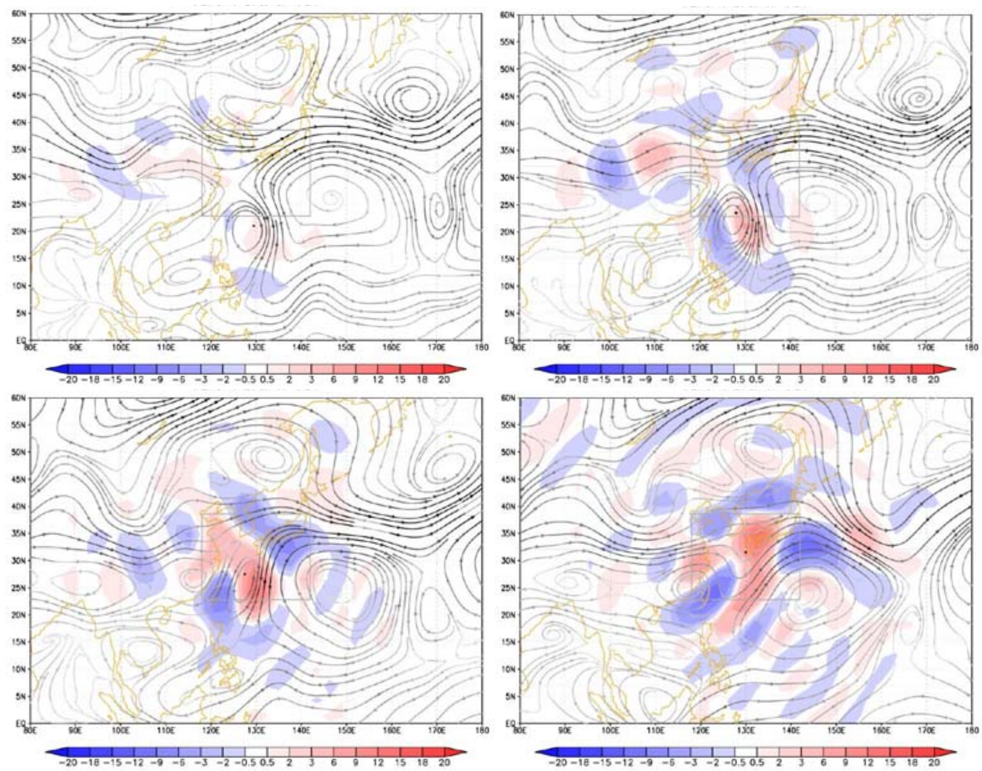

Figure 2: As Fig. 1 for SV2 of Man Yi (recurvature phase) at 0 (top left), 9 (top right), 27 (bottom left), 48 (bottom right) hours.

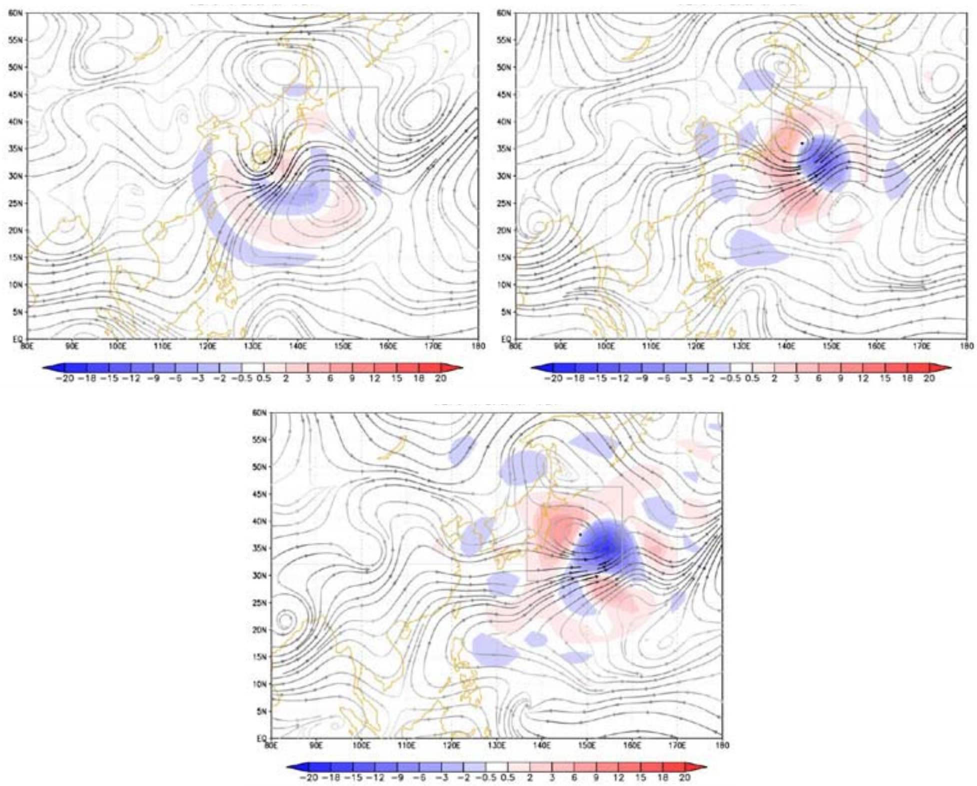

Figure 3: As Fig. 1 for SV2 of Man Yi (recurvature phase) at 0 (top left), 9 (top right), 27 (bottom left), 48 (bottom right) hours.