P6.7 PREDICTABILITY ASSOCIATED WITH THE DOWNSTREAM IMPACTS OF THE EXTRATROPICAL TRANSITION (ET) OF TROPICAL CYCLONES

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1. INTRODUCTION

The poleward movement of a decaying tropical cyclone (TC) often results in a rapidly-moving, explosively-deepening midlatitude cyclone. The re-intensification of the remnant TC as an extratropical cyclone depends on the phasing between the decaying TC and a midlatitude environment that is favorable for midlatitude cyclogenesis. Furthermore, the export of low potential vorticity air to the midlatitudes from the upper-levels of the poleward-moving TC may result in excitation and dispersion of Rossby waves that have far-reaching impacts on downstream atmospheric conditions (Fig. 1). Therefore, an extratropical transition (ET) of a TC perturbs the midlatitude flow patterns across individual ocean basins with the potential for nearly hemispheric-scale impacts. The

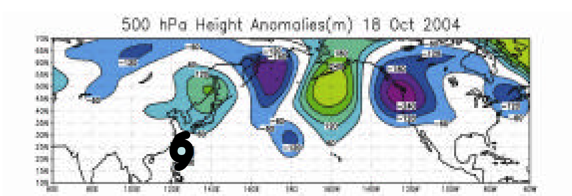

Fig. 1 *Height anomalies (m) at 500 hPa averaged for 0000 UTC and 1200 UTC 18 October 2004. The location of TY Tokage at 1200 UTC 18 October is defined by the tropical cyclone symbol.*

Because of the typical rapid translation speed of the decaying TC, accurate extended-range prediction of the phasing between the remnant tropical circulation and the midlatitude environment into which it is moving is critical.

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The Rossby-wave response associated with the ET of TY Tokage (Fig 1) was aligned such that an anomalous trough was located over western North America. During this period, several powerful early-season storms caused heavy rain and snowfall over central and southern California (Fig. 2).

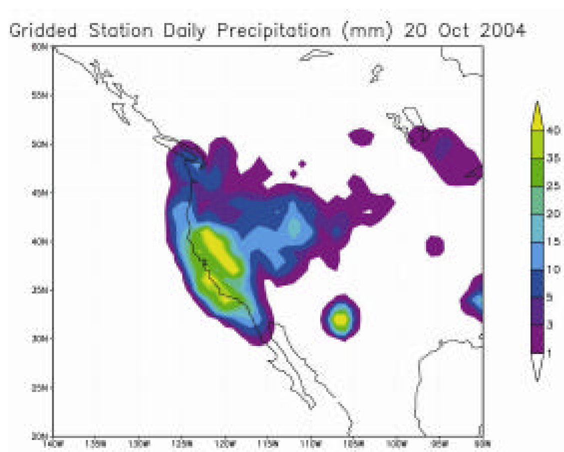

Fig. 2 *Total precipitation over the 24-h period beginning 0000 UTC 20 October 2004. The data are gridded based on precipitation station data.*

The complex physical interactions that occur during the structural changes associated with the ET of the decaying tropical cyclone often contribute to difficult forecast scenarios during ET events. An ensemble forecast system is often used to provide a measure of forecast difficulty or uncertainty in terms of the amount of variability among ensemble members. Often, a plume of increased standard deviation among ensemble members occurs in mid-level geopotential heights downstream of an ET event (Fig. 3). This trait appears to occur in many ensemble prediction systems and represents an uncertainty in the model representation of the downstream response to the ET of the decaying tropical cyclone.

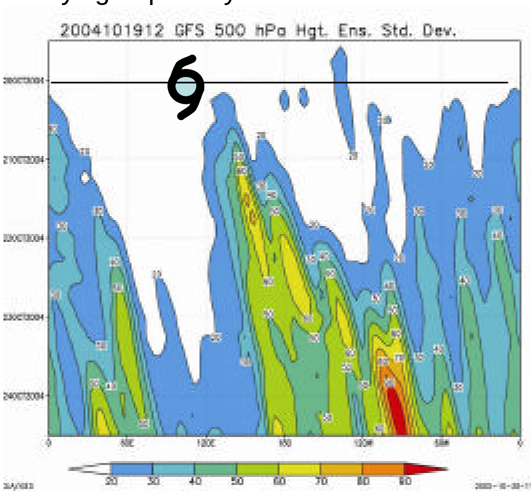

Fig. 3. Time-longitude diagram of the standard deviation in ensemble members for 500 hPa heights for the forecasts initiated at 1200 UTC 19 October 2004 with the Global Forecast System model run at the National Centers for Environmental Prediction. The horizontal line at 0000 UTC 20 October marks the time of the ET of TY Tokage, which is located at the longitude marked by the tropical cyclone symbol. The plume of increased standard deviation among ensemble members in the forecast sequence spreads downstream of the ET in association with a wave train (Fig. 5) that extends over North America.

The ET process is extremely sensitive to complex physical and dynamical interactions between the decaying tropical cyclone and the midlatitude circulation into which it is moving (Harr and Elsberry 2000, Harr et al. 2000, Thorncroft and Jones 2000, Klein et al. 2002, Jones et al., 2003). Although the poleward track of the tropical cyclone may be forecast accurately, the impacts of the ET are often not forecast correctly (Jones et al. 2003). This is especially true at extended forecast ranges. The skill of the 120 h forecasts from the Navy Operational Global Atmospheric Prediction System (NOGAPS) and the Global Forecast System (GFS) global models decreased significantly (Fig. 3) during the ET of TY Nabi between 8-10 September and TY Saola (17W) during 26-28 September. The measure of skill in Fig. 3 is the anomaly correlation at 500 hPa, which represents how well the large-scale pattern has been predicted around the Northern Hemisphere between 20^{o}N-60^{o}N. The sharp decrease in anomaly correlation during ET is often due to the lack of amplitude in the forecasts of the downstream response to the ET or to a displacement in the locations of the downstream ridge and trough pattern, which occurred during the ET of TY Nab (Fig. 4).

In this study, measures of the relative predictability in global numerical weather forecasts with respect to the downstream impacts of ET events are computed based on operational (NCEP and ECMWF) global ensemble prediction systems.

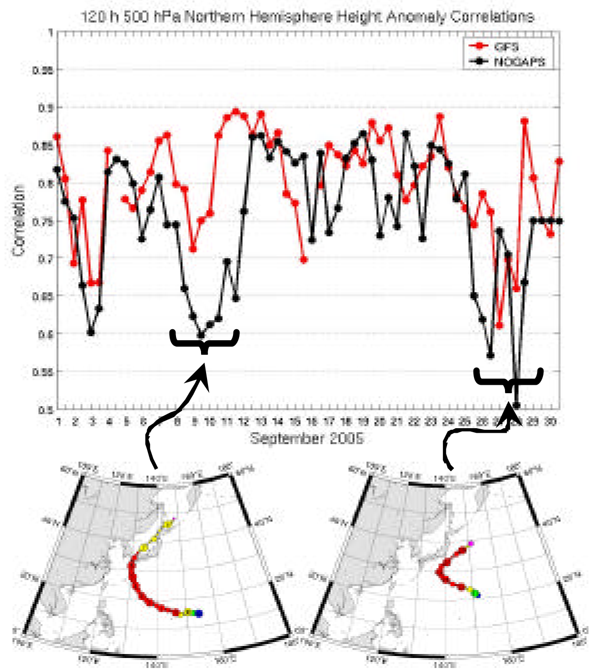

Fig. 4 *Geopotential height anomaly correlations (top) defined for the Northern Hemisphere at 500 hPa between 20^{o}N-60^{o}N from 0000 UTC 1 September 2005 to 1200 UTC 30 September 2005. The periods associated with the ET of TY Nabi (track at lower left) and TY Saola (track at lower right) are marked. Track diagrams from http://agora.ex.nii.ac.jp/digital-typhoon/.*

2. METHOD

Variability among EPS members is characterized by an empirical orthogonal function (EOF) analysis that is applied to 500 hPa geopotential heights and potential temperature on the dynamic tropopause. Principal components computed from the EOF analysis are defined based on the projection of individual ensemble members on the EOFs. The principal components

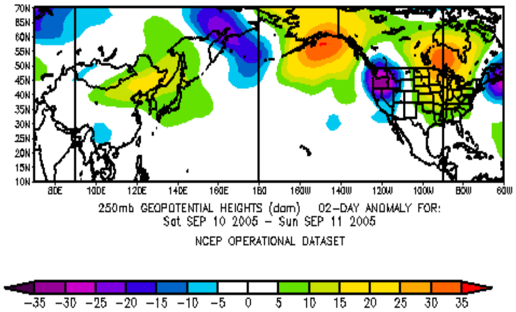

Fig. 5. *Geopotential height anomalies (m) at 250 hPA averaged from 0000 UTC 10 September 2005 to 0000 UTC 11 September 2005. Source: NOAA, Climate Diagnostics center at www.cdc.noaa.gov.*

Provide a framework for a fuzzy cluster analysis, which is applied to identify principal downstream impact scenarios. To identify the temporal change in the variability associated with the forecasts of the ET event and its impacts on the downstream flow patterns, the EOF and cluster analyses are applied successively between 120 h and 24 h prior to the ET time. It is hypothesized that the number of forecast scenarios, which are identified as individual clusters of EPS members, decreases as the uncertainty associated with the downstream impact of the ET is reduced. Furthermore, the EOF and cluster analyses facilitate comparison between ensemble members produced by the NCEP and ECMWF systems. A representative case of variability associated with the ET of Typhoon Saola is presented below.

3. EXTRATROPICAL TRANSITION OF TROPICAL CYCLONE SAOLA (2005)

Typhoon SAOLA reached typhoon intensity on 22 September 2005 06 UTC with a maximum wind speed of 85 kt at the time of its peak intensity. Saola underwent extratropical transition on 25 September 12 UTC and merged with a larger-scale midlatitude cyclone on 26 September 12 UTC. A comparison of the 0000 UTC 25 September ECMWF analysis (Fig. 6a) with the deterministic ECMWF 84-h forecast from 1200 UTC 21 September (Fig. 6b) and the 36-h forecast from 1200 UTC 23 September (Fig. 6c) indicates that the forecasts positions of Saola were too far south and west of the verifying position. Due

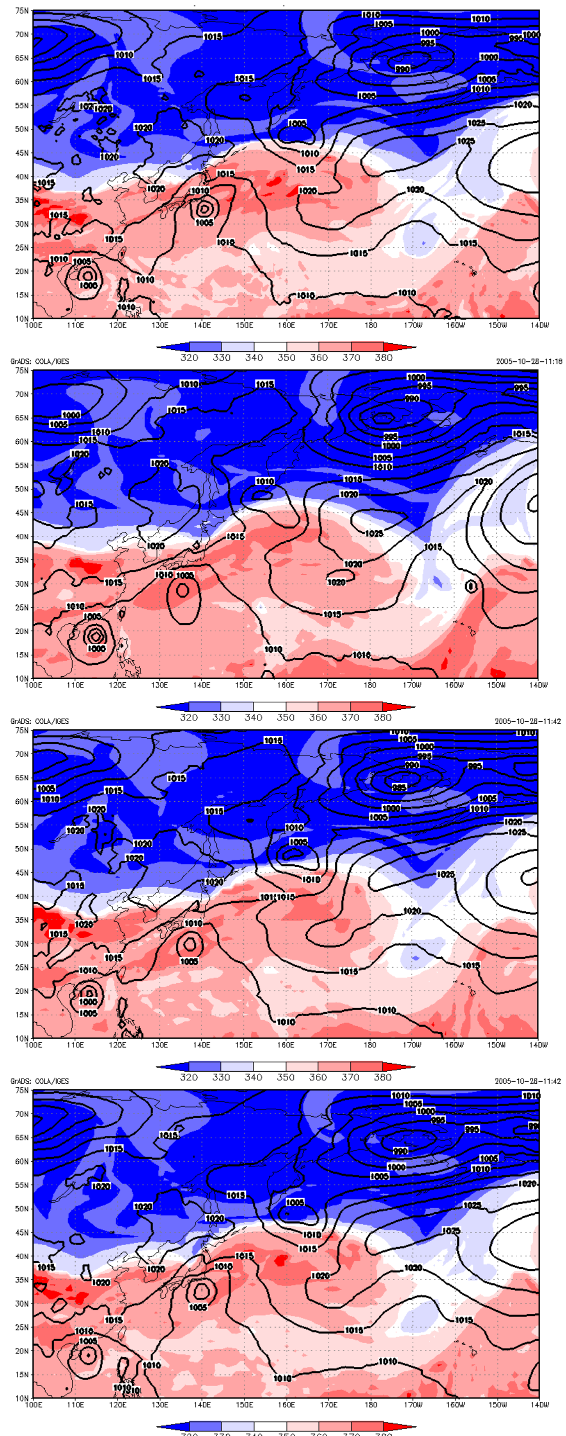

Fig. 6*: Potential temperature on the dynamical tropopause (PVU=2) (shaded) and surface pressure (contours) for 25 September 2005 00 UTC. a) analysis of SAOLA, b) deterministic forecast from 21 September 12 UTC, c) deterministic forecast from 23 September 12 UTC and d) deterministic forecast from 24 September 12 UTC. SAOLA is marked by a white arrow.*

to the more southern position of the tropical cyclone in the 1200 UTC 21 September forecast, the midlatitude trough located directly to the north of Saola does not interact with tropical cyclone, which results in a forecast straight rather than the observed recurvature track. In the deterministic forecast from 23 September 12 UTC (12 h prior to the recurvature) Saola remained stationary as the midlatitude trough passed to the north. This also resulted in an erroneous straight track. The recurvature of Saola was first contained in the deterministic forecast from 0000 UTC 24 September (Fig. 6d).

Comparisons of the ECMWF analysis for 0000 UTC 27 September (Fig. 7a) and the deterministic forecasts form 21, 23 and 24 September 12 UTC indicate the erroneous straight tracks and decaying tropical cyclone in the early forecasts (Figs 7b,c) and the correct recurved track in the forecast from 1200 UTC 24 September (Fig. 7d). Although the forecast from 1200 UTC 24 September correctly depicted the recurvature of Saola, the intensity was too strong (Fig. 7d) and the movement to the northeast was too slow. The slow motion may be due to a slight increase in the amplitude of the midlatitude trough ridge system in the forecast.

Over the entire North Pacific Basin, the 144-h forecast (Fig. 8b) from the 1200 UTC 24 September that verified at 1200 UTC 30 September (Fig. 8a) indicated that the remnants of Saola would move across the North Pacific and result in a deep extratropical cyclone off the west coast of North America. However, in actuality Saola had been absorbed by the large-scale midlatitude deep pressure system east of Japan that results in a weak low-pressure system.

The variability associated with the 500 hPa heights in the ensemble members of the ECMWF for the forecast from 1200 UTC 21 September 12 UTC is identified by a plume of increased standard deviation that extends downstream in time and across the North Pacific. There is a local maximum in standard deviation that begins at 1200 UTC 26 September and extends until 1200 UTC 28 September 12 UTC. The source of the variability among the EPS members is investigated using the combined EOF and

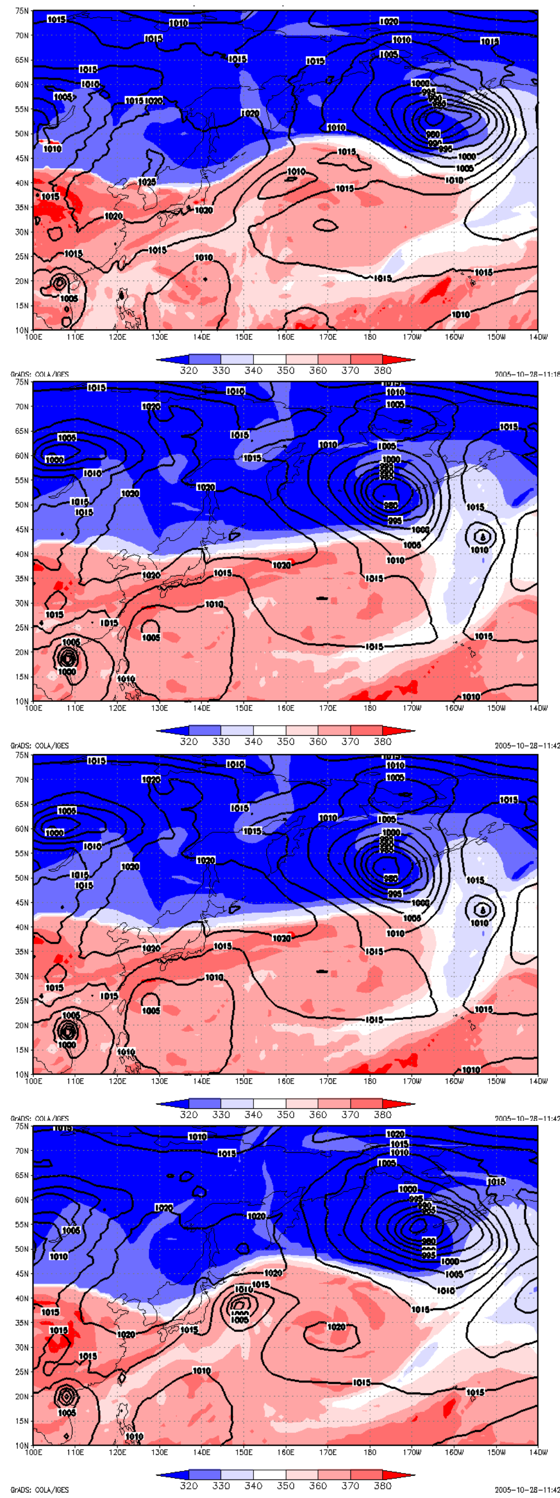

Fig. 7: *As Fig. 9 for 27 September 2005 00 UTC*.

clustering technique. The contribution to variability is investigated with reference to the track variability exhibited by the deterministic forecasts clusters exhibit varying track and re-intensification scenarios

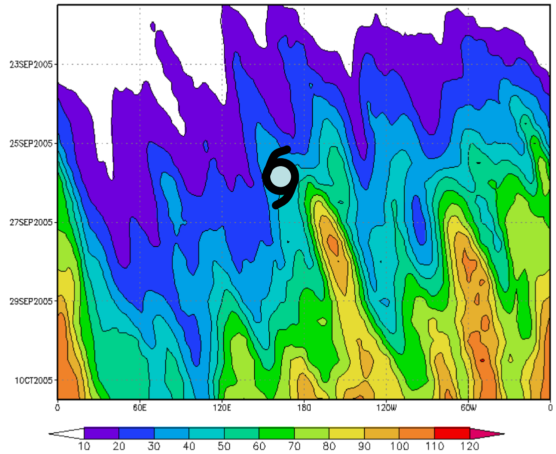

Fig. 8 *Hovmoeller plot of standard deviation of 500 hPa height for 51 ensemble members averaged between 40° - 50° N. Forecast from 21 September 2005 12 UTC. The ET time and location is marked by the tropical cyclone symbol.*

The scenarios identify the source of the variability with respect to the interactions between the decaying tropical cyclone and the midlatitude circulation into which it is moving.

Characteristics associated with the ET of Saola exhibited here in the ECMWF EPS are compared with similar characteristics in the NCEP EPS (Fig. 9), which also exhibit a plume of increased standard deviation downstream of the ET of Saola. Finally, the predictability associated with other ET cases over the North Pacific and North Atlantic is examined.

Acknowledgments

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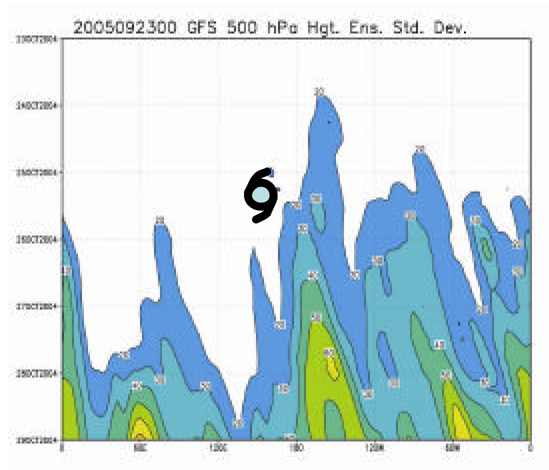

Fig. 9 *Time-longitude diagram of the standard deviation of 500 hPa geopotential heights from the GFS ensemble prediction system on 0000 UTC 23 September 2005. The standard deviation is averaged between 40^{o}N-50^{o}N. The location of TY Saola at 1200 UTC 25 September is marked by the tropical cyclone symbol*

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