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APPLICATION OF SINGULAR VECTOR ANALYSES TO TROPICAL CYCLONE MOTIONS

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1. Introduction

In general, tropical cyclones (TCs) originate in low latitudes and track westward, either terminating over land, or recurving into mid-latitudes. There are also irregular tracks caused by interactions of storms with near-by synoptic systems. In this study, singular vector (SV) analyses are used to understand the relationship between tropical cyclone structure and its motion, and to examine the influences of the background flow on TC movements. The SVs are based on the adiabatic adjoint system of the Navy Operational Global Atmospheric Prediction System (NOGAPS, Hogan et al. 1991). In recent years, NOGAPS has performed very well in predicting tropical cyclone tracks, making it suitable for the present study. SVs based on NOGAPS forecasts are analyzed to understand where and how the initial conditions most affect the TC motions. One hypothesis is that TCs that have straight tracks may show different sensitive regions in their initial fields than those that recurve or have irregular motions.

2. Singular Vector Analysis

SVs represent the fastest growing perturbations, in a linear sense, to a given trajectory. The SVs are calculated using the Lanczos algorithm applied to the dry forward and adjoint tangent equations of NOGAPS at a T79L30 resolution. A local projection operator is employed to maximize final-time perturbation variances over a region centered near the storm. SV diagnostics have been successfully applied to predictability studies of extratropical systems (e.g., Gelaro et al. 2000). While moist physics plays a key role in the development of tropical cyclones, our focus is on the track, rendering the SVs extracted from a dry system appropriate. Recent study by Reynolds and Rosmond (2003) also suggests that synoptic-scale features can remain significantly linear out to three days. Since TC motions are largely controlled by large-scale environmental flows, the use of linear SV analyses can be justified.

3. Composite of Singular Vectors

Excluding weak and short-lived storms, 79 individual NOGPAS forecasts for 15 TCs during the 2003 season are analyzed. The SVs are constructed such that they maximize dry total energy perturbation growth in a 20 by 20 degree latitude/longitude region centered on the TC position in the 48 hr forecast. The SV perturbation energy at final time is mainly localized around the final (48-h) TC positions. The initial SVs indicate regions where changes in the initial analysis will have the biggest impact on the 48-h TC forecast. Our hypothesis is that the initial SVs may exhibit different characteristics for different types of motion. Based on this hypothesis, the 79 cases are grouped into two categories. The first group contains straight-moving cyclones and the second group contains cyclones that change direction appreciably within 48 h, either by recurving or by interacting with other systems. In some cases, a cyclone remains straight moving for its lifetime while others may be straight moving in early stage and recurve later. The distinction between the two groups is made subjectively. There are 30 cases in the straight-moving group and 49 cases in the recurving group (including erratic motions).

Composites are made of the vertically averaged total energy of the leading initial SVs for the two groups in a 60 by 60 degree longitude/latitude region centered on the initial storm. Such a large area is chosen so as to include cases where the initial sensitivity may occur far from the TC's vicinity. The SV fields are rotated such that the storm motion points northward before the composites are made. For the straight-moving group (Fig. 1a), the composite shows that the final storm's position is most sensitive to the initial fields in the rear and right quadrant of the storm. For the recurving/erratic group, the composite maximum is, roughly speaking, uniformly distributed within an annulus around the center (Fig. 1b). The locations of the maximum of the initial SV vertically integrated total energy for the individual cases are depicted in Fig. 2. These distributions correspond well with the composites, indicating that the composite fields are not dominated by a few cases only. This is especially important for the straight-moving TC group since its maximum is more localized. For both groups, the maximum is located roughly 7 degrees away from the center. The significance of this distance relative to the TC structure will be investigated.

Structures of the individual SVs for the recurving/erratic group are more complicated than the composite indicates. They usually contain more than one local maximum and the region with significant amplitude extends beyond the vicinity of TCs, indicating the influence of large-scale environmental flows and other systems on the movement of TCs in this group.

4. Discussions

Composites of the initial SVs show that the 48-h forecast tracks of straight-moving TCs have different

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initial sensitivities than TCs with recurving or erratic tracks. The results may provide insight into how the structures of storms and the interactions of the storms with environmental flows affect their motions. The results also suggest that different strategies may be applied to the design of reconnaissance flights into TCs based on their projected tracks.

Most of the final SVs show a dipole structure with the axis aligned with the storm's motion. This indicates that the fastest growing perturbation will have more of an impact on the direction of the TC, rather than the speed. The next step is to evaluate the appropriateness of the linear approximation by making SV-based perturbations to the initial analyses and examining the impact on the cyclone tracks in the subsequent forecasts.

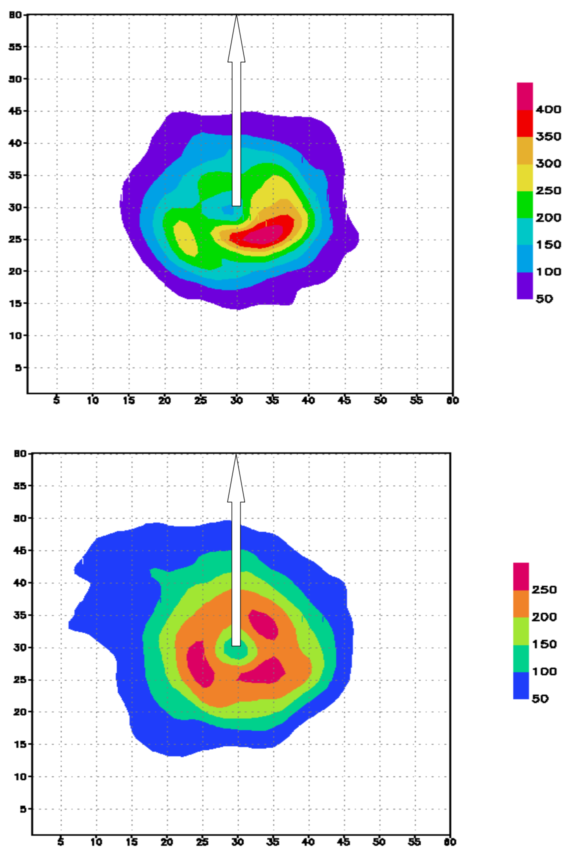

Figure 1. Composite of the vertically integrated total energy of the leading SV at the initial time for a) straight-moving TCs, and b) recurving/erratic TCs. The cyclones are located in the center of the domain and moving toward north based on the prior 12h position change. Arrow indicates the direction of TCs' movement.

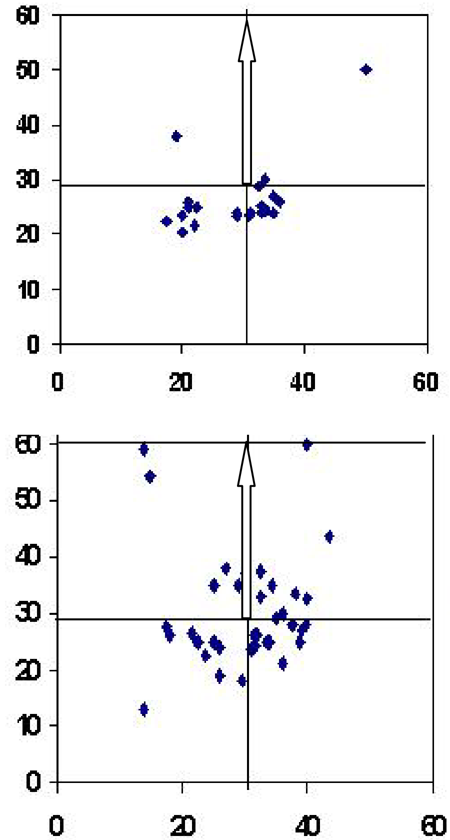

Figure 2. Locations of maximum of the vertically integrated total energy for the leading SVs for the individual cases corresponding to the composite diagrams shown in Fig. 1. Arrow indicates the direction of TCs' movement.

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