Singular vectors for tropical cyclone-like vortices in a nondivergent barotropic framework

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1. Introduction

Singular vectors (SVs) are widely used in the tropical cyclone (TC) forecasting and research communities as a generator of initial perturbations in an ensemble prediction system (EPS) and sensitivity analysis guidance for adaptive observations. The growth of SVs has been studied in many contexts. However, given the weight of the prior work on SVs for mid-latitude dynamics, the basic properties of SVs targeted for TCs are still not fully understood. In this study, SVs are computed in a nondivergent barotropic framework on an *f*- and *β*-plane. Using a nondivergent barotropic model is a good starting point for understanding the basic properties of SVs in the vicinity of TCs.

2. Singular vectors on an *f*-plane

SVs are calculated for TC-like vortices that do and do not satisfy a necessary condition of barotropic instability of normal modes, that the vorticity gradient changes sign. It is found that, in the case where the initial vortices do not meet the condition, 1) SVs are tilted against the shear of the background angular velocity as seen in Fig. 10 of Nolan and Farrell (1999), indicating the SVs grow through the Orr mechanism, 2) Singular values increase with the maximum tangential wind speed (*Vmax*) and decrease with the radius of the maximum wind (*RMW*), 3) The SV location moves outward with increasing *RMW*, 4) The SV location moves outward with increasing *Vmax*, and 5) The azimuthal wavenumber of SVs is sensitive to viscosity and *RMW*. In the case where the initial vortices allow barotropic instability, SVs are found to be able to capture the instability. The SVs are initially tilted against the background shear and exhibit transient growth during the early period while keeping the same structure after that time. At a certain time during the initial growth, the SV “locks in” to a normal mode structure and stays there so that it can continuously grow with time.

3. Singular vectors on a *β*-plane

Different from the SVs on an *f*-plane, the SVs on a *β*-plane appear around the initial vortices locally, and the extent of the local asymmetry increases as the strength of the beta gyres increase. It should be emphasized that all the *β*-plane, leading SVs calculated in this study have an azimuthal wavenumber one structure at the optimization time, though the extent of the local asymmetry of SVs at the initial time is different among them. Note that an azimuthal wavenumber one structure displaces the vortex. It should also be emphasized that the second SVs also have an azimuthal wavenumber one structure at the final time, but the direction of the vortex displacement is orthogonal to that by the leading SVs. These results indicate that the linear combination of the initial 1st and 2nd SVs can produce the displacement of vortex in any direction at optimization time. It would be of particular importance to consider such wavenubmer one perturbations for the purpose of track forecasting of TCs (Fig. 1).

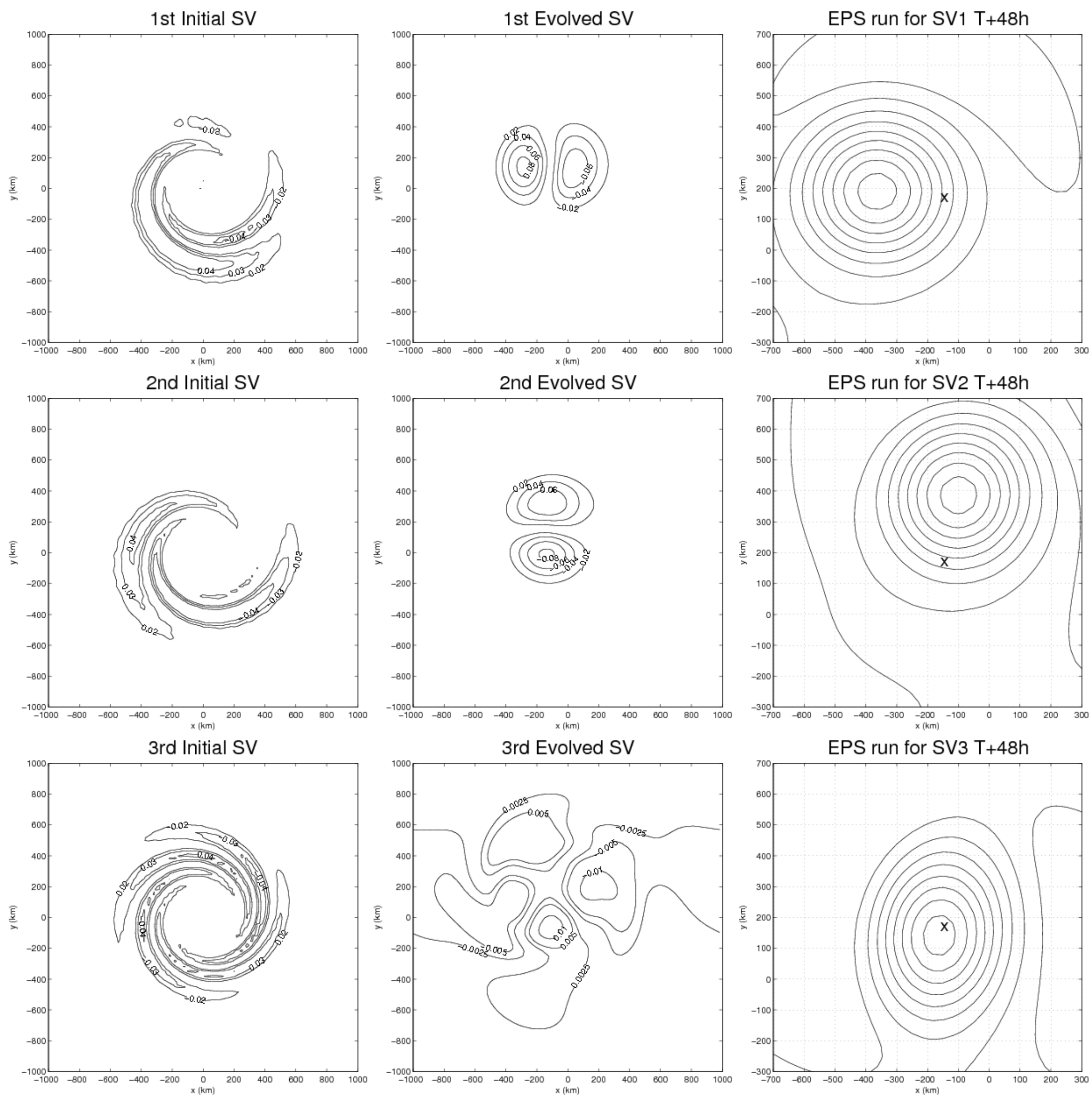

Fig. 1. Left: Initial singular vectors (vorticity fields), Middle: Final singular vectors (vorticity fields), Right: Vorticity fields of 48-h numerical integrations where the initial singular vector is used as an initial perturbations. Figures on the top, middle, and bottom are for the 1st, 2nd, and 3rd singular vectors for an initial vortex with *Vmax*=35 ms−1, *RMW*=100 km, and *b*=1.0, respectively. Optimization time is 48 hours. The x mark on the right figures represents the storm center (defined by the maximum vorticity location) of the control (non-perturbed) run.