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# Optimal excitation of asymmetric perturbations on an axisymmetric barotropic vortex with piecewise constant vorticity

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Regarding the hierarchal structure seen in natural and artificial vortices, where the multiple secondary vortices revolve around the core of their parent vortex, a linear singular value problem is formulated and solved analytically based on the axisymmetric barotropic vortex consisting of three piecewise constant vorticity regions: i.e. from the non-divergent barotropic vorticity equation linearized around the basic tangential flow with three regions of piecewise constant vorticity, the simultaneous ordinary differential equation on the vector, whose components are the amplitude of the Rossby waves evoked by the vorticity discontinuity of the basic flow. This equation is solved as an initial value problem, and the resultant resolvent matrix is applied to obtain the singular values and the corresponding forward and backward singular vectors under the L2 norm.

The results can be categorized into the two kinds based on the shape of the basic vortex. For Michalke & Timme's vortex characterized by a ring of high vorticity, the forward and backward singular vectors and the growing eigenvector are rather similar in shape with each other. On the contrary, for Syono's vortex incorporating a negative vorticity region surrounding the positive vorticity core, the shape of the forward singular vector is quite different from that of the backward singular vector and the growing eigenvector. Some results in the case adopting energy norm are also introduced.

Keywords: optimal excitation, singular value, singular vector, barotropic vortex, multiple vortex