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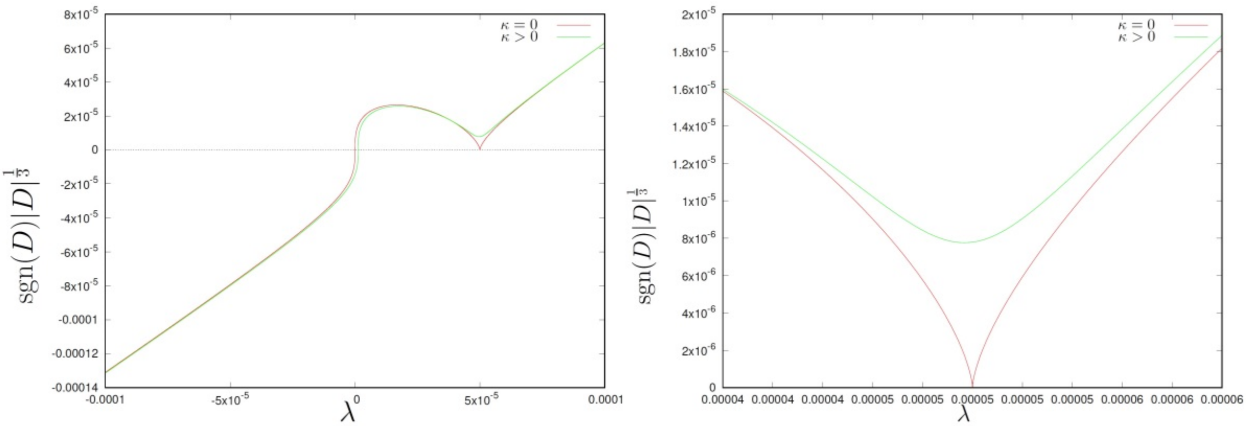

Figure 1: Graphs of $\mathrm{sgn}\,(D)|D|^{1/3}$ for $\kappa = \frac{f\pi}{NH} = 0\ m^{-1}$(red) and $\kappa = \frac{f\pi}{NH} = 2 \times 10^{-6}\ m^{-1}$(green) as functions of λ, where f is the Coriolis parameter, H is the fluid depth, and N is the reference buoyancy frequency. An enlarged view in the vicinity of multiple root for $\kappa = 0$ is shown at the right. The parameter values are set such that the linear growth condition is satisfied.

- Analytically solving the disturbance potential vorticity (PV) equation linearized about an axisymmetric vortex with radially piecewise uniform basic PV, we show that the vortex Rossby waves (VRWs) with azimuthal wavenumber one can grow exponentially in a quasi-geostrophic system (with disturbances projected on the first baroclinic mode) although they cannot do so in a barotropic system.
- The exponential growth of the VRWs, whose temporal dependence is expressed as $e^{i\lambda t}$, is possible when the eigenequation $\mathrm{D}(\lambda) = 0$ has non-real roots.
- For example, in the case of three regions of uniform basic PV, $\mathrm{D}(\lambda)$ is a cubic function whose graph is shown in Figure 1. The red line shows $\mathrm{D}(\lambda)$ in the absence of vertical interaction. Since the graph has two λ-intercepts one of which is degenerate, all the three roots are real. Hence, the VRWs cannot grow exponentially although they grow linearly because of the degenerate two roots. On the other hand, in the presence of vertical interaction which is possible in the quasi-geostrophic system, the graph of $\mathrm{D}(\lambda)$ shown by the green line in Figure 1 has only one λ-intercept, and the degenerate two roots become a complex conjugate pair. Hence, the VRWs can grow exponentially. Also in the case of more regions than three, it is shown in the same way that the VRWs can grow exponentially in the presence of vertical interaction.