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Conditional nonlinear optimal perturbations: behaviors during the evolution of cold vortices over Northeast China

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Conditional nonlinear optimal perturbations (CNOPs) are the initial perturbations that acquire the largest nonlinear evolution at the forecast time with some initial constraint condition. These CNOPs are calculated and examined during the development of two cold vortices with a regional mesoscale primitive equation model. Computation is carried out over a 48-hour optimization time interval with a dry total perturbation energy norm. Attention is given to the CNOPs in terms of structure and evolution. For the particular cases studied, it was found that the CNOPs, similar to the first linear singular vectors, exhibit localness, in which the wind, temperature and surface pressure perturbation fields match the thermal wind balance qualitatively. The primary perturbation regions of CNOPs are closely related to the source regions of high potential vorticity corresponding to the cold vortices. What is more, CNOPs have deep baroclinic structures, which extend throughout the whole troposphere. With time, CNOPs increase their spatial size over larger areas and become quasi-barotropic at the optimization time. In addition, we found that the kinetic energy contributions are much larger than the potential energy contributions to the final perturbation energy. A noteworthy property is that although the dry total energy norm is used to measure the perturbation growth, the moisture perturbation energy appears early on, which is smaller than the kinetic energy but larger than the potential energy in the lower troposphere at the forecast time. The above numerical experiments are helpful for understanding the mechanism of perturbation growth during the formation of cold vortices.