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Theoretical Analysis and Numerical Study on the Development Mechanism of Squall Line in the Northeast Cold Vortex in China

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Northeast cold vortexs (NECVs) which may cause heavy natural hazards in the North and Northeast China are cutoff lows essentially. Cutoff lows (COLs) are isolated cyclonic vortices in the middle and upper troposphere developed from a deep trough in the westerly (Palmén and Newton, 1969; Gimeno et al., 2007). COLs significantly contribute to extreme precipitation events when accompanying abundant moisture flow within the lower to middle troposphere (Hirota et al., 2016).

The cloud model 1 (CM1) which is a three-dimensional, non-linear, time-dependent numerical model designed for idealized studies of atmospheric phenomena, solves the nonhydrostatic, compressible equations of the moist atmosphere (Shi et al., 2019; Marion et al., 2019; Belik et al., 2018; Oreskovic and Savory, 2018; Bryan and Fritsch, 2002).

Based on the dynamic frame of CM1 model, the necessary conditions for the occurrence and development of severe convective weather are obtained by theoretical derivation and scale analysis. A typical squall line process under the background of Northeast Cold Vortex (NECV) is selected, and the numerical simulation and contrast tests are carried out with a high precision horizontal grid distance of 200m. The theoretical results are verified and the conditions for the formation of a squall line under the NECV are obtained. Through the scale analysis of mode data, we can get that the horizontal and vertical advection and the hydrometeor precipitation have the greatest influence on the change of moisture variables in squall line system, the influence of water vapor phase change is the second, and the turbulence effect is relatively small, so the emergence of squall line needs the cooperation of water vapor distribution and the ascending air flow. The simulation of different regions of NECV verifies the results of theoretical analysis. In the southwest side of the NECV, upper layer is affected by the cold air, combined with the warm advection in lower layer, the unstable stratification occurs, and then combined the humidity field with transverse gradient, squall line can be formed. Under the influence of water vapor concentration and temperature, strong radar echo can easily formed in the middle and high level with strong updraft, and affected by precipitation, strong radar echo can also be found in the lower layer.