Parallel Computing of Cloud Resolving Storm Simulator (CReSS) for Simulation Experiments of Severe Storms

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1. Introduction

Convective clouds and their organized storms are highly complicated systems of flows and hydrometeors. Their structure and dynamics are determined by a nonlinear interaction between the fluid dynamics and the cloud microphysics. In order to simulate an evolution of a convective cloud storm, it is essential to formulate cloud physical processes as well as the fluid dynamic and thermodynamic processes. A detailed formulation of cloud physics requires many prognostic variables even in a bulk method such as cloud, rain, ice, snow, hail and so on. If we categorize size distributions of each type of hydro-meteors, the number of prognostic variables could be very large. It is impossible to perform this type of simulation of cloud systems without a huge memory and parallel computing.

The purposes of this study are to develop a cloud resolving model and its parallel computing to simulate cloud-scale to storm-scale phenomena. A thunderstorm which is an organization of convective clouds produces many types of severe weather: heavy rain, hail storm, downburst, tornado and so on. The simulation of the thunderstorm will clarify the characteristics of dynamics and evolution and will contribute to the storm-scale prediction.

The cloud model which we are now developing was named CReSS (the Cloud Resolving Storm Simulator). In this paper, we will describe the characteristics and some results of numerical experiments of CReSS. The source code of CReSS and its documents were now opened to the public.

2. Characteristics of the cloud resolving model and parallel processing strategy

CReSS is formulated in the non-hydrostatic and compressible equation system. In order to include the effect of orography, the coordinate system is a terrain-following coordinate in a two or three dimensional geometry. Prognostic Variables are three-dimensional velocity components, perturbations of pressure and potential temperature, subgrid-scale turbulent kinetic energy (TKE) and mixing ratios for water vapor and several types of hydrometeors. We adopted a finite difference method for the spatial discretization (explicit both in horizontal and vertical or explicit in horizontal and implicit in vertical) and the leap-frog time integration with the Asselin time filter for time integration. Turbulence is one of the most important physical parameterization in a cloud model. At present, CReSS includes the first order closer and 1.5 order closer with TKE. Cloud physics is another important physical process. It is formulated by a bulk method of cold rain. Prognostic variables are mixing ratios for water vapor, cloud water, rain water, cloud ice, snow and graupel. Radiation of cloud is not included. Numerical smoothing is the second or forth order computational mixing. Parallel processing is performed by the Massage Passing Interface (MPI).

A large three-dimensional computational domain (order of 100 km) is necessary for the simulation of thunderstorm with a very high resolution (order of

1km∼ 100m). For parallel computing of this type of computation, we adopt a two dimensional domain decomposition.

3. Simulation experiment of a squall line

3.1 Experimental design

A squall line is a significant mesoscale convective system. It is usually composed of an intense convective leading edge and a trailing stratiform region. We chose an observed squall line which will describe in the following sub-section with the following experimental design of CReSS. The horizontal and vertical grid sizes were 400 m and 300 m, respectively with a domain of 170 km × 120 km. Cloud microphysics was the cold rain type. An initial condition was provided by a dual Doppler analysis and sounding data. A horizontal cross section of the initial field is shown in Fig.1. The boundary condition was the wave-radiating type.

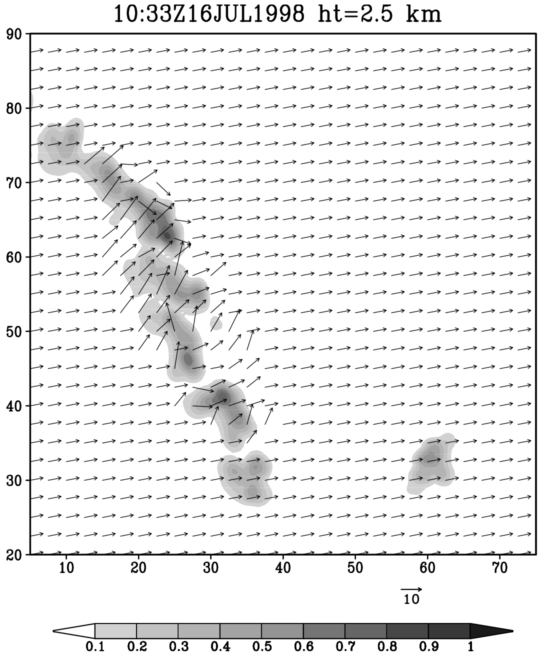

Figure 1: **Horizontal cross section of the initial field at a height of 2.5km at 1033 UTC, 16 July 1998. The color levels mixing ratio of rain. Arrows show the horizontal velocity obtained by the dual Doppler analysis and sounding.**

3.2 Observation of the squall line

An intensive field observation (IFO) of GAME/HUBEX (GEWEX Asian Monsoon Experiment/Huaihe River Basin Experiment) was performed in the Huaihe River Basin, China during the period from 11 June 1998 to 22 July 1998. During IFO, a significant squall line was observed by three Doppler radars. The squall line approached the radars from the southwest around 10 UTC, 16 July 1998. It passed over the radars at 1130 UTC and moved northeastward with decaying. The squall line extended from the northwest to the southeast with a width of a few tens kilometers. Radar echo showed that the squall line consisted of intense convective cells and its leading edge was clear (Fig.2). Most convective cells were located along the leading edge. Some of cells reached to a height of 17 km. After the squall line passed over the radar sites, a stratiform precipitation was extending behind the convective leading edge.

3.3 Result of simulation

The result of the simulation experiment shows that CReSS successfully simulated the development and movement of the squall line (Fig.3). The convective reading edge was maintained by the replacement of new convective cells and the simulated squall line moved to the northeast which is similar to the behavior of the observed squall line. Convective cells reached to a height of about 14 km with large production of graupel above the melting layer. The rear inflow was significant as the observation. A stratiform region extended with time behind the leading edge. Cloud extended to the southwest to form a cloud cluster.

4. Summary

We now develop the Cloud Resolving Storm Simulator (CReSS). We performed the simulation experiment of the observed squall line using CReSS with very high resolution in a large three-dimensional domain. The inhomogeneous initial field was given by the dual Doppler radar observation and the sounding. The result showed that the development process and structure of the observed squall line were successfully simulated by CReSS.

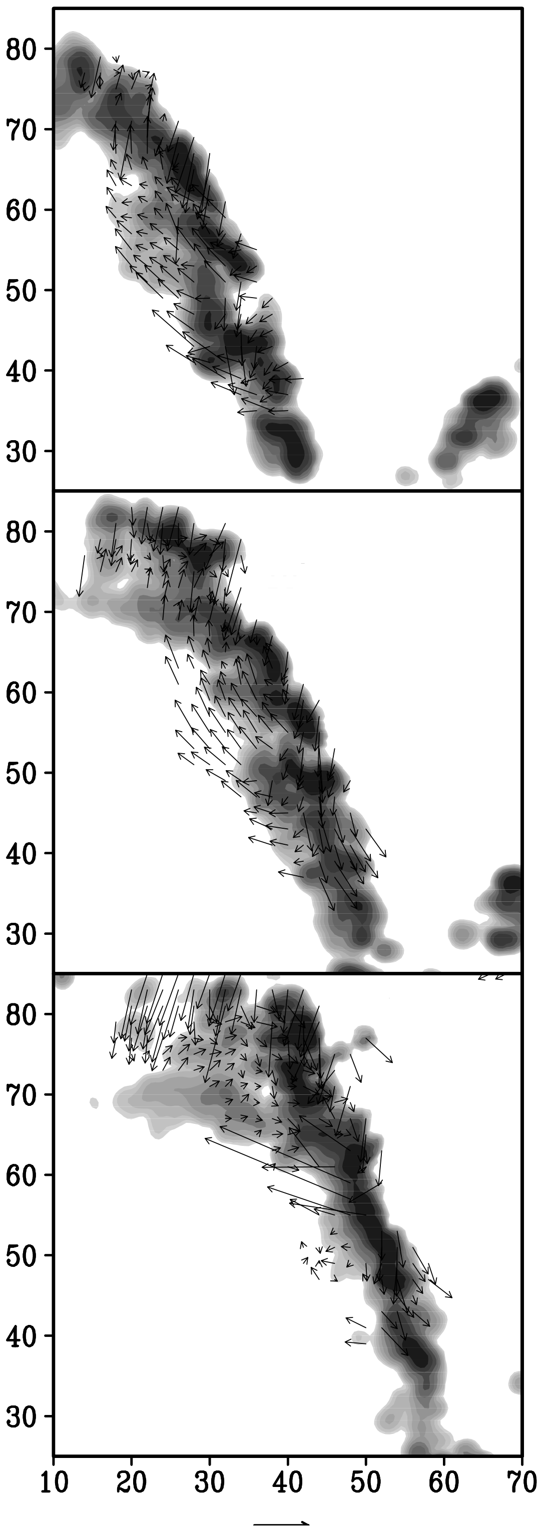

Figure 2: **Time serise of horizontal displays of echo intensity and velocity field of the observed squall line at a height of 2 km. Time goes from the top to the bottom: 1040 UTC, 1054 UTC and 1108 UTC, 16 July 1998.**

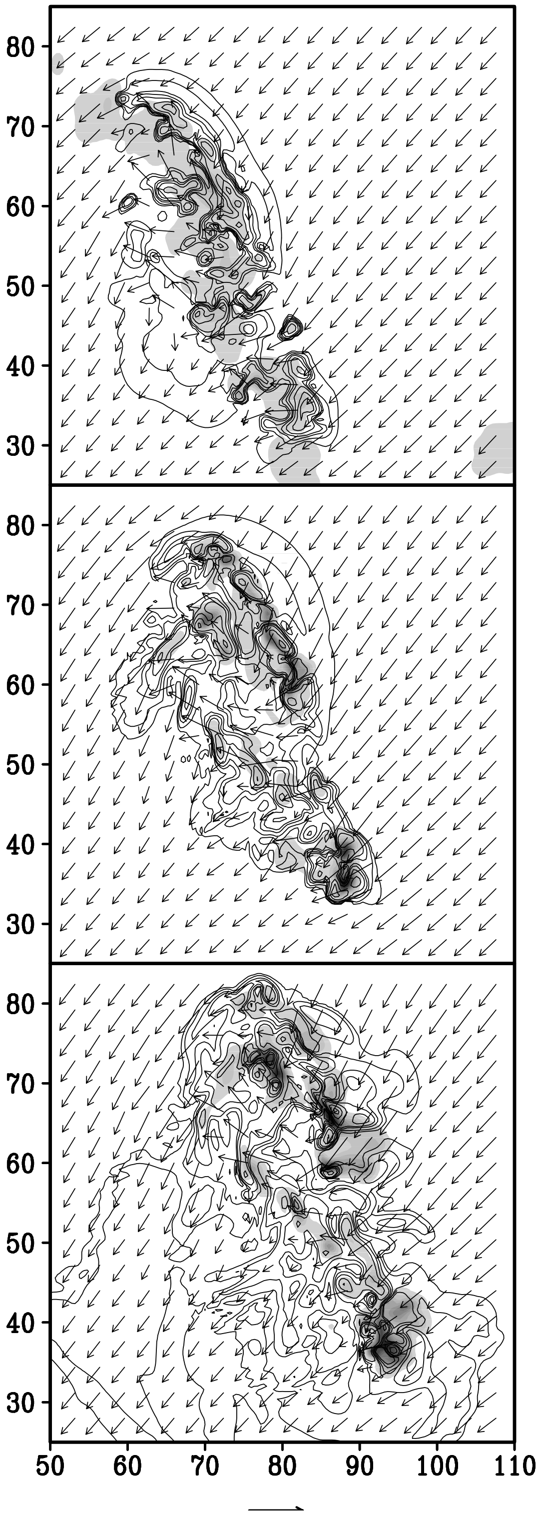

Figure 3: **Time serise of horizontal displays of simulated squall line. Color levels indicate total mixing ratio of rain, snow and graupel. Contour lines indicate total mixing ratio of cloud ice and cloud water. Arrows are horizontal velocity. Time goes from the top to the bottom: 1038 UTC, 1053 UTC and 1108 UTC, 16 July 1998.**