Simulation Experiment of Squall Line Observed in the Huaihe River Basin, China

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ABSTRACT

A significant squall line was observed on 16 July 1998 during the intensive field observation of GAME/HUBEX. We performed a simulation experiment of the observed squall line using the Cloud Resolving Storm Simulator (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 of the simulation experiment shows that CReSS successfully simulated the development and movement of the observed squall line.

1. Introduction

The energy and water cycle in the subtropical monsoon region of the East Asia is characterized largely by Baiu/Meiyu front in summer. It is one of subtropical fronts and a unique subsystem of the Asian monsoon. Various scale of cloud/precipitation systems are formed in this frontal zone and play major role in the energy and water cycle in the zone. One of purposes of GAME/HUBEX (GEWEX Asian Monsoon Experiment/ Huaihe River Basin Experiment) is to study the evolution of a mesoscale cloud system.

The intensive field observation (IFO) of GAME/ HUBEX 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.

Houze et al. (1989) showed a conceptual model of the kinematic, microphysical, and radar-echo structure of a mid-latitude squall line. Its characteristic features are the convective line with a trailing stratiform precipitation, the rear-inflow, the front to rear flow and a gust front. Biggerstaff and Houze (1993) showed a vertical motion and trajectory of precipitation particles within a mid-latitude squall line. They found a transition zone between the convective line and a mesoscale stratiform precipitation zone. Johonson and Hamilton (1988) found the pre-squall mesolow in front of a squall line, the mesohigh just behind the convective line and a wake low within the stratiform precipitation area. It is not clear that these characteristic features are found in the squall line which developed in the monsoon environment.

In order to reveal dynamics of a squall line, Fovell and Ogura (1988) performed a numerical experiment of a squall line. They found a self-maintaining squall line with a periodical intensification.

The purpose of this study is to clarify the structure and evolution of the squall line developed over the China Continent. We made data analysis of the three Doppler radar observation during the IFO of HUBEX and a numerical simulation using a cloud resolving model. In order to simulate an evolution of a convective cloud storm, we are now developing a cloud resolving model which is named as the Cloud Resolving Storm Simulator (CReSS). We performed a simulation experiment of the observed squall line using CReSS with very high resolution in a large three-dimensional domain.

In this paper, we will describe the observed squall line and show the result of the simulation experiment.

2. Characteristics of CReSS

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$\sim$ 100m). For parallel computing of this type of computation, we adopt a two dimensional domain decomposition.

3. Doppler radar observation

The squall line was observed around 10 UTC, 16 July 1998. The local time of the observation site was advanced for 8 hours to UTC. The squall line, therefore, developed in the late evening as a part of diurnal variation of convective activities due to strong solar radiation.

The squall line was formed outside of the Doppler radar observation range and 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. The CAPPI display of radar echo showed that the squall line consisted of intense convective cells and its leading edge was very much clear (Fig.1). Most convective cells were located along the leading edge. Some of cells reached to a height of 17 km.

Horizontal velocity at a height of 2 km was almost southwesterly, which was found in the environmental wind. The magnitude of the horizontal velocity is rather larger than that of the environment. The acceleration of horizontal velocity was caused by the intense convective activity of the squall line. The relative velocity had a component parallel to the squall line. This parallel component was significant throughout the troposphere when the squall line was extending.

When the squall line was approaching the radar, new cells was formed successively on the southeasternmost part of the squall line. Consequently, the squall line extended southeastward. The parallel component had a vertical shear and its down-shear direction was the southeast. The new cells was formed on the down-shear side of the parallel component.

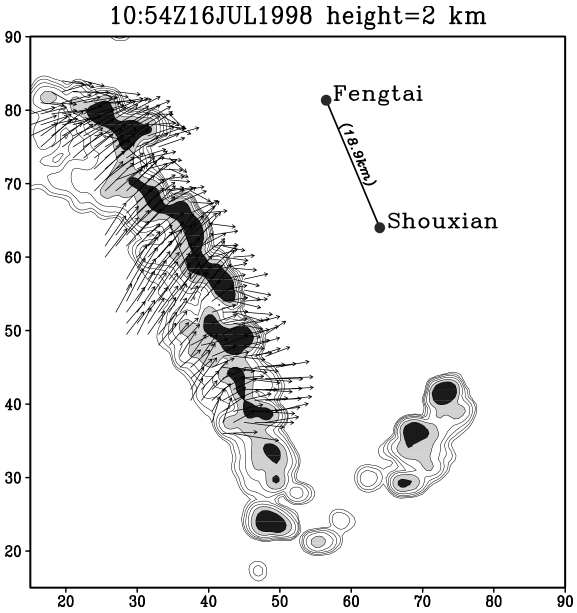
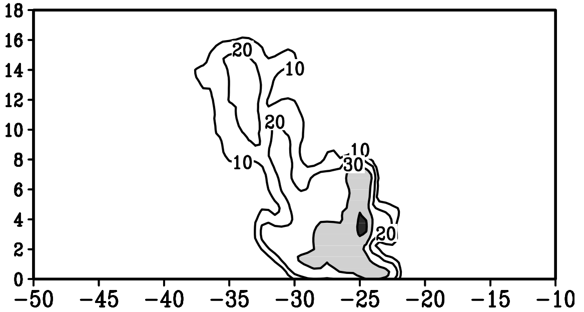


Figure 1: CAPPI display of echo intensity and horizontal velocity at a level of 2 km at 1045 UTC, 16 July 1998. Darkly shadings indicate 35 dBZ and lightly shadings 30 dBZ. Contour lines are drawn every 5 dBZ from 10 dBZ.

After the squall line passed over the radar sites, a stratiform precipitation was extending behind the convective leading edge. A new small squall line developed behind the main squall line. The new line was extended along the same direction of the main squall line. A parallel component of the relative velocity was also significant along the new squall line.

The vertical cross section of echo intensity observed by RHI scan normal to the squall line showed that the convective cell at the leading edge was reached to a height of 8 km and a weaker echo extended to about 16 km in height behind the convective cells (Fig.2a). Doppler velocity showed that a strong forward flow was present whose velocity was larger than 13 m s^{-1} at a level of 4 km (Fig.2b). This is a significant rear-inflow to the squall line. The axis of the maximum of the rear-inflow was descended behind the leading edge. Another maximum of a forward flow was present below a height of 2 km. The negative Doppler velocity which was indicated by shadings in the upper levels means rear-ward flow in the upper levels. The axis of rear-ward flow was inclined to the rear of the squall line. The lower-level convergence at the leading edge and the upper-level divergence behind the leading edge were significant.

(a) echo intensity (dBZ)



(b) Doppler velocity (m/s)

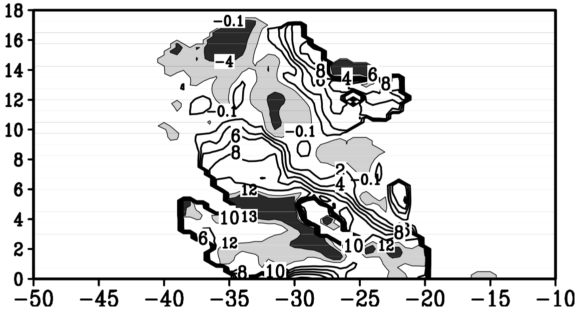


Figure 2: RHI display of (a) echo intensity and (b) Doppler velocity at an azimuth of 235° at 1100 UTC, 16 July 1998.

4. Experimental design of simulation

In the simulation experiment using CReSS, we used the following experimental design. Since the observed squall line composed of the intense convective leading edge, the grid size must be small enough to resolve convective cloud directly.

The both horizontal and vertical grid sizes were 300 m within a domain of 170 km × 120 km. Cloud microphysics was the cold rain type. An initial condition was provided by a dual Doppler analysis with in the storm and sounding data was used to provide a uniform field outside of the storm. A horizontal cross section of the initial field is shown in Fig.3. The boundary condition was the wave-radiating type. In this experiment, no surface processes were included.

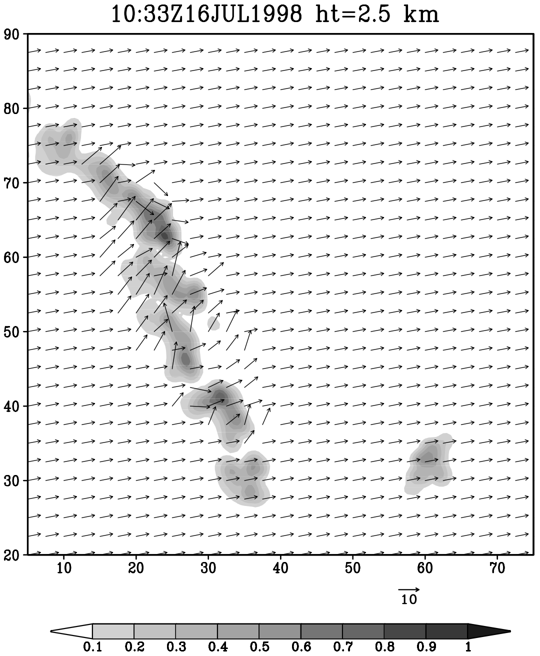


Figure 3: Horizontal cross section of the initial field at a height of 2.5km at 1033 UTC, 16 July 1998. The color levels mixing ratio of rain. Arrows show the horizontal velocity obtained by the dual Doppler analysis and sounding.

5. Result of simulation

The result of the simulation experiment shows that CReSS successfully simulated the development and movement of the squall line. Time series of CAPPI displays of the observed squall line (Fig.4) are compared with the horizontal display of the simulated squall line (Fig.5).

CReSS simulated the convective leading edge to move northeastward with extending stratiform region behind the leading edge. The convective leading edge was maintained by the replacement of convective cells and the simulated squall line moved to the northeast which is similar to the behavior of the observed squall line. The parallel component within the squall line is evident as found in the observation.

Vertical cross-section normal to the squall line (Fig.6) shows that the vertical structure resembles the observed squall line (Fig.2). The convective region was tilted rear-ward and convective cells reached to a height of about 14 km with large production of graupel above the melting layer. The replacement of convective cells at the leading edge was also simulated. The rear-inflow was significant at a height of $4 \sim 5$ km as the observation. A stratiform region extended with time behind the leading edge. Cloud extended to the southwest of the leading edge to form a cloud cluster.

6. Summary

A significant squall line was observed by Doppler radars during the intensive field observation of HUBEX. The squall line was formed within the circulation of a mesoscale low. The southwesterly was prevailed while its vertical shear was weak. The lower troposphere was highly humid and moderately convective unstable.

The squall line was extended from the northwest to the southeast and was maintained for longer than two hours. Dual Doppler radar analysis revealed the echo structure and the characteristics of the flow field of the squall line. The squall line was composed of intense convective cells along the leading edge. After it passed over the radar, a stratiform region was observed behind the convective leading edge. The convective cells at the leading edge were reached to a height of 8 km and a weaker echo extended to about 15 km in height be-

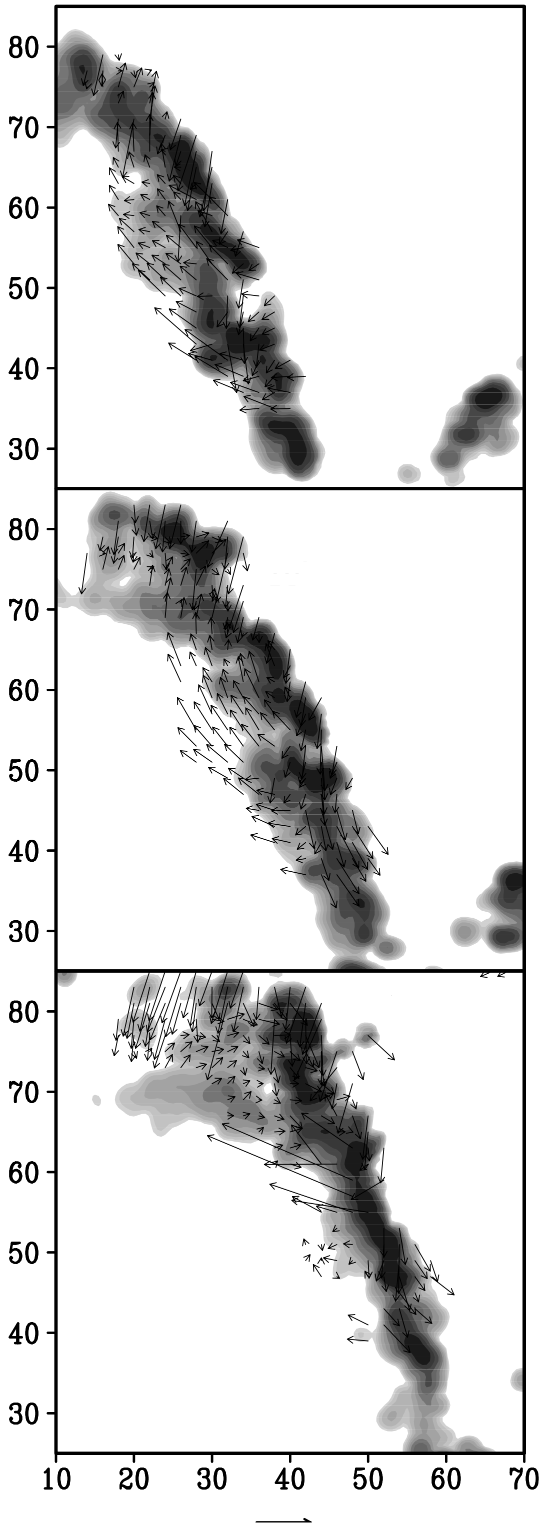


Figure 4: Time series of horizontal displays of echo intensity and velocity field of the observed squall line at a height of 2 km. Time goes from the top to the bottom: 1040 UTC, 1054 UTC and 1108 UTC, 16 July 1998.

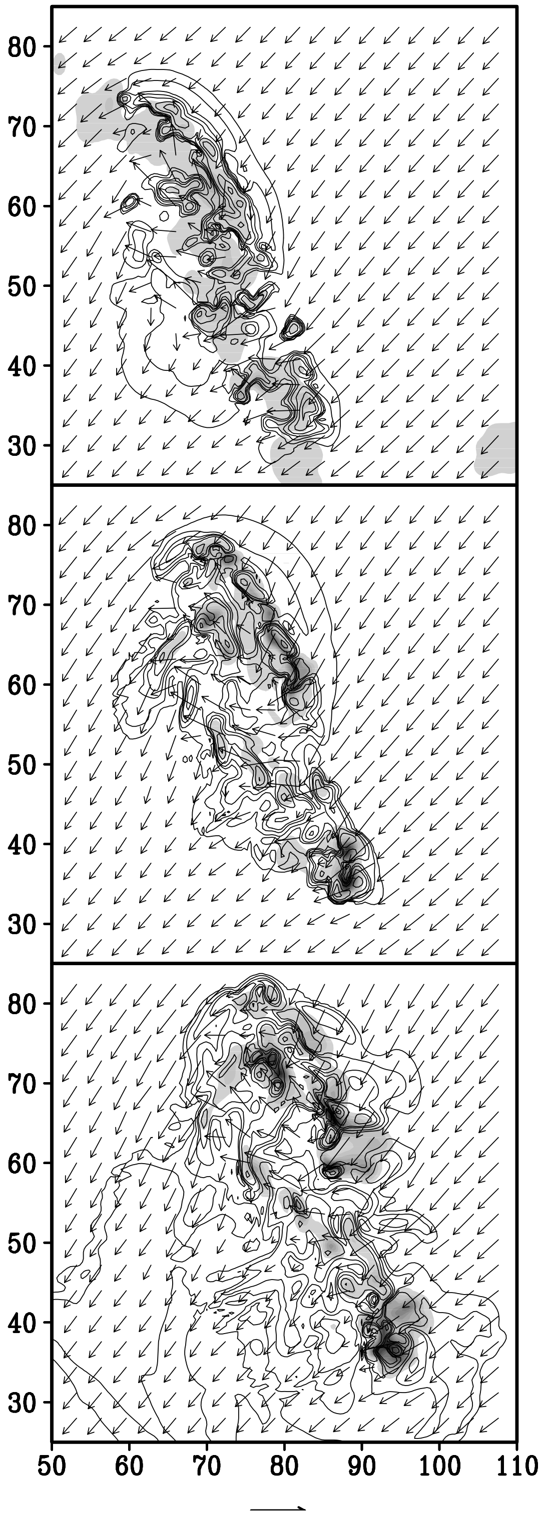


Figure 5: Time series of horizontal displays of the simulated squall line. Gray levels indicate total mixing ratio of rain, snow and graupel. Contour lines indicate total mixing ratio of cloud ice and cloud water. Arrows are horizontal velocity. Time goes from the top to the bottom: 1038 UTC, 1053 UTC and 1108 UTC, 16 July 1998.

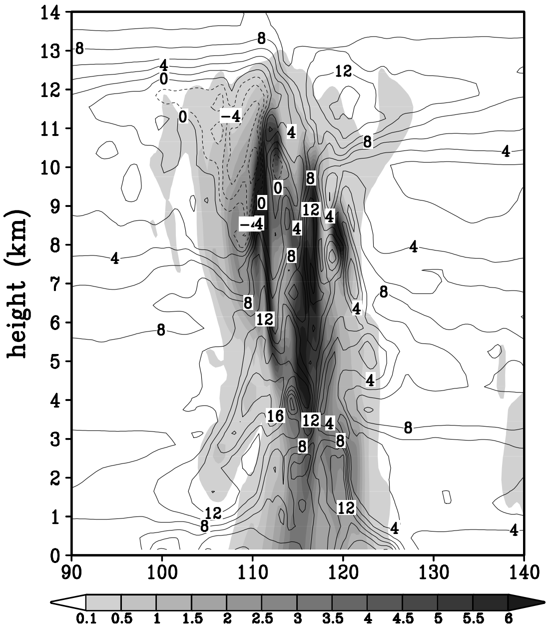


Figure 6: Vertical cross-section of the simulated squall line at 1218 UTC, 16 July 1998. Gray levels indicate total mixing ratio of rain, snow and graupel. Contour lines indicate normal component of horizontal velocity (m s^{-1}).

hind the convective cells. The squall line was tilted to the up-share side. The rear-inflow was significant at a height of 4 km with a maximum velocity of 13 m s^{-1}. Another maximum of the forward flow was present at the surface. The squall line advanced as a result of the successive development of convective cells at the leading edge.

We developed 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. The convective leading edge was maintained by the replacement of 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.

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