P35 USING WRF-ARW BASED REGIONAL SHORT-RANGE ENSEMBLE FORECAST TO DRIVE THE MULTI-COLUMN 1D ENSEMBLE CLOUD-SEEDING MODEL

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1. INTRODUCTION

There is high demand for rain enhancement operation in north-east China, where it is always suffering from water shortage. Funded by the Chinese National Science Foundation (CNSF), this project aims to develop a probabilistic based operational cloud-seeding forecasting prototype through a two-tier ensemble forecast system. This system consists of a comprehensive fine-scale regional short-range ensemble weather forecasting component and a multi-column ensemble cloud-seeding modeling component. A WRF-ARW model based ensemble forecasting system, as the first component, has been developed in the Institute of Atmospheric Physics of Chinese Academy of Sciences (called LACS_REFS) by Zhu et al. (2010). The WRF ensembles will provide model soundings and vertical velocity profiles from individual members at multiple grid locations. In this study, the feasibility of using WRF model output soundings to drive a sophisticated mixed-phase one-dimensional (1-D) cloud-seeding model is investigated. The best strategy to use the regional ensemble forecast outputs (e.g. model sounding profile, vertical velocity, the mass concentration and number concentration of the hydrometeor species) to drive the 1-D cloud-seeding model has been presented. Numerical experiments were conducted for a real stratiform precipitation event occurred on 4-5 July 2004 in Northern China.

2. MODEL AND CASE DESCRIPTION

2.1 Synoptic description and measurements for the precipitation case

Precipitating stratiform clouds were observed on 5 July 2004, and the production of precipitation was associated with the Northeast China cyclone. The precipitation process lasted for nearly nine hours. This was a typical stratiform precipitation case characterized by clear radar bright band echoes, but with uneven rainfall distribution. The detailed features of the precipitation cloud were described in Hu et al. (2007). Plan Position Indicator (PPI) images were obtained from the 5-cm wavelength Doppler radar located at the Changchun station (longitude:125.3°E; latitude: 43.9 °N; altitude: 294 6m ASL), and the precipitation rates were recorded by the tipping-bucket rain gauges at Changchun station. Twenty rain gauges are located on a 10 km by 10 km grid，and thirteen of them reported the precipitation data during 4-5 July 2004. (Unrealistic values were removed during quality-control procedures).

2.2 The One-Dimension Stratiform Cold (1DSC) cloud model

The One-Dimension Stratiform Cold (1DSC) cloud model is a simplified version of the two-dimension slab-symmetric mixed cloud system (MCS) model. It is a time-independent cloud model with detailed microphysics of both the warm and cold rain processes (Hong 1996, 2005). This sophisticated mixed-phase 1D cloud model will form the base for the multi-column ensemble cloud-seeding model component driven by the soundings from WRF ensembles. 1DSC model assumes that cloud is evenly distributed horizontally, with a given distribution of vertical flow. The vertical spatial height and resolution are 11km and 0.2km, respectively, and the time step is 5 seconds.

In previous applications using this model, a cloud is initiated by given upward motion with the formula:

$$w = w_0 \sin^2\left(\frac{\pi}{2}\frac{k-m}{h}\right)$$

Where k is the vertical grid level number, w0 is the maximum vertical velocity and (h+m) is the grid level of w0, k≥21, h=30, m=10. With such kind of initialization, simulated clouds always reach a steady state after a spin-up period because of the lack of dissipating forces. Thus their life spans are infinite. This is unreasonable and not feasible to be used in cloud-seeding study. A solution will be presented in Section 3 by applying WRF model predicted soundings and w-profiles directly to drive the 1D cloud model.

2.3 The Weather Research and Forecasting (WRF) model

The WRF-ARW version 3.1.1 was used in this study. A detailed model description was given by Skamarock et al. (2008).The WRF model with explicit microphysics was used as the cloud-resolving model to simulate a stratiform cloud precipitation case over north-east China. The grid size of the model was set to 155×135 horizontal grid points at 12 km grid spacing and 40 vertical eta-levels. The time step for all the processes was 90s. The cloud microphysics scheme use in WRF forecast is similar to the one in the 1DSC model. It is worth mentioning that the microphysical processes were solved using a relatively accurate numerical scheme: Morrison two-moment scheme. The capability of a two-moment bulk scheme to represent most of these processes was documented in Morrison and Grabowski (2007).

3. INITIATION STRATEGY AND RESULTS

3.1 1DSC simulations using WRF input at Changchun station

3.1.1 One-time initiation at the initial time (20 UTC 4 July 2004)

Five numerical experiments with 1DSC are conducted. Because the observed sounding data are restricted to twice-daily (00 UTC and 12 UTC), interpolation to consistent observation times is preprocessed. Table 1 outlines the configurations for

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each individual experiment. Experiment a1 refers to the control run, driven by the given w profile (labeled as ‘artificial’ in Table 1) and observed soundings at the initial time. Experiment a2 is the same as a1 except for using WRF output vertical velocity profile. Experiment a3 differs from a1 by using sounding profiles of WRF. Experiments a4 and a5 are driven by both WRF output soundings and vertical velocity profiles, with a5 adding additional influences of Qx and Nx from the WRF output into consideration. Here, Qx represents the grid volume average of mixing ratios of various water substance in cloud，and Nx is the grid volume average of numerical concentration, where the subscript “x” stand for cloud water (c), rain water (r) , ice crystal (i), snow (s) and graupel (g), and in the case of mixing ratios also for vapor (v).

Exp ID	Exp Scheme
a1(Ctrl)	observed sounding + artificial vertical velocity (w) profile
a2	observed sounding + WRF w profile
a3	WRF sounding + artificial w profile
a4	WRF(sounding + w profile)
a5	WRF(sounding + w profile + Q_x + N_x)

Table 1. The configurations for sensitivity experiments (a1-a5)

3.1.2 Profile-updating initiation

Experiments b1-b3 are the profile-updating versions of a5. Instead of one-time application of sounding and w profile, these set of experiments update the sounding and profile at a given time interval throughout the 1D cloud model simulation. The only difference among b1, b2 and b3 is the time interval for the updating (see Table 2).

Exp ID	time step for updating
b1	1 hour
b2	30 minutes
b3	90 seconds

Table 2. The different time interval for sounding and profile updating used in 1DSC simulations (b1-b3)

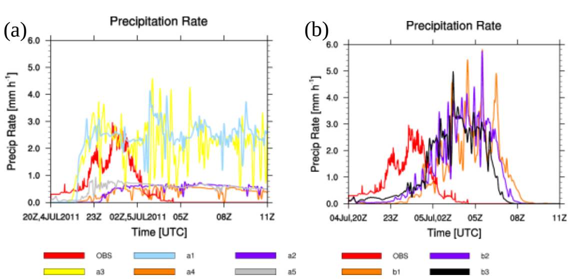

Figure 1. Time evolutions of simulated precipitation rates (colored lines) at Changchun station from 1DSC with sensitivity experiments of different schemes shown in Table1 (a) and Table 2 (b). The observation is presented in red line.

As can be seen in Fig. 1(a), we can safely conclude that vertical velocity profile plays a very significant role in the 1DSC model. As given in Fig. 1(b), the temporal trend of observed rainfall can be simulated by the improved 1DSC. After WRF input updating at a prompt time step, the cloud develops right after the model integration. And when the downward motion is included, precipitation rate is intensified and eventually dissipates as can be seen in Fig.1(b). Compared to the red line (observation), the black line (Experiment b3) shows the best agreement to the observed precipitation curve than the other two (Experiments b1 and b2). However, it shows a time lag behind the observation for about 2 hours, suggesting that precipitation location error inherited in the regional WRF forecast may cause such lags.

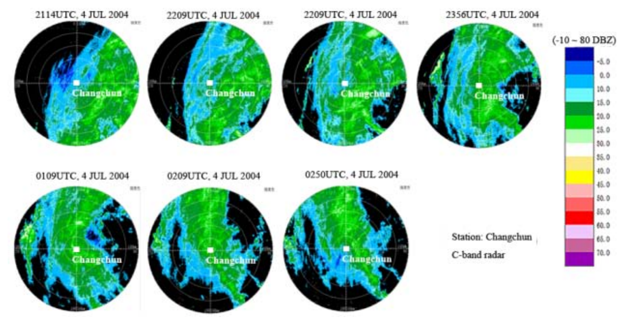

Figure 2. Plan Position Indicator (PPI) (Units: DBZ) displays of radar reflectivity obtained at different valid times. The radar position is marked (Changchun，43.9°N，125.3°E) and the range ring interval is 30 km

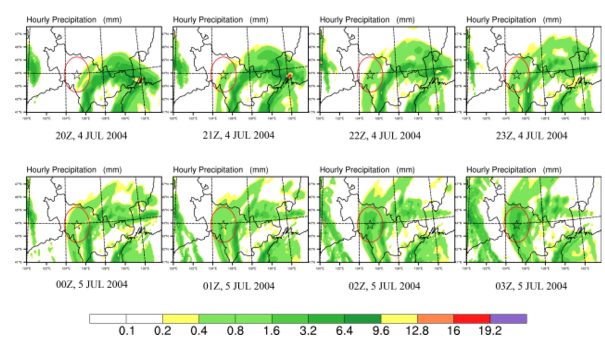

Figure 3. The hourly maps of simulated precipitation rate for 20 UTC 4 July - 03 UTC 5 July 2004. The pentagrams represent Changchun, and the red circles show the radar range.

3.2 1DSC simulations using WRF soundings at nearby grid points

Fig. 2 shows the horizontal displays of radar reflectivity obtained from the C-band radar at Changchun station at different valid times. The hourly maps of simulation precipitation rate are given in Fig. 3. Comparing the two figures, there is a time lag of simulated precipitation rate with WRF model at Changchun station. The simulation rainfall rates at grid points south-east to Changchun station seem more consistent with the observation. Due to the uncertainties and model errors in the WRF model，nearby grid points may be more representative than Changchun station in the WRF simulations. Given our ultimate goal is to use a full set of WRF regional ensemble members to drive the 1D cloud seeding forecast, it is legitimate to try using nearby w-profiles and soundings from a single (deterministic) WRF simulation to see if the 1D cloud model can reproduce the observed precipitation variations.

Spatial distribution of nearby grid points chosen for 1DSC simulation inputs are given in Fig. 4, and the comparisons between WRF simulation results and the observations are shown in Fig. 5. Finally, experiment b3 is rerun using the WRF sounding and w-profile at the grid point N5.

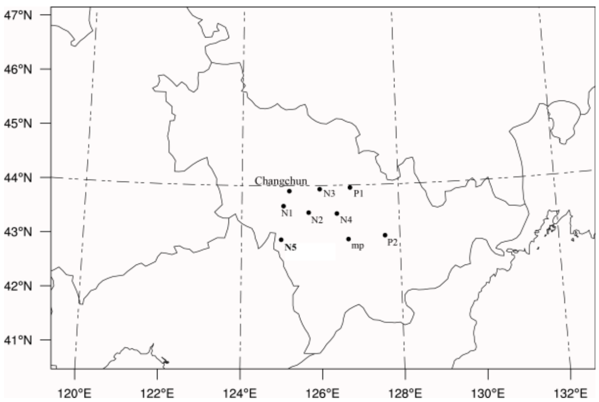

Figure 4. Spatial distribution of grid points chosen for 1DSC simulations

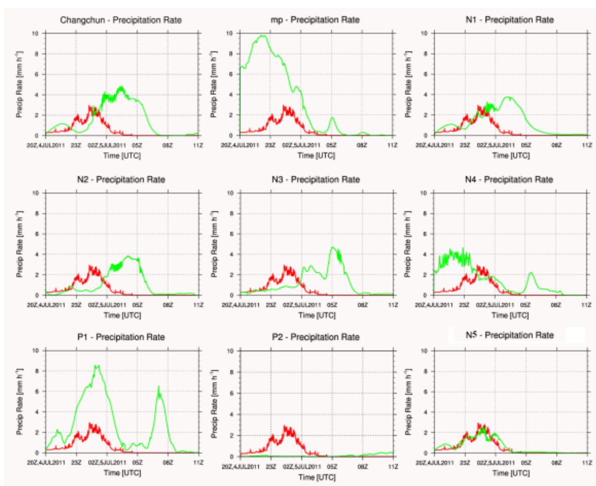

Figure 5. Time evolutions of observed (red line) precipitation rate at Changchun station and rainfall rate simulated by WRF (green line) at different grid points (Units: mm h^{-1})

Although models are still far from being able to simulate all the complex processes in clouds, they can be used to evaluate the sensitivity of the natural processes of rain formation to parameters such as the concentrations and size spectra of ice particles and cloud drops (Reisin, Tzivion et al. 1996). As shown in Fig. 6, the rainfall rate simulated by 1DSC shows that by using the WRF model results as inputs and updating in 90 second interval, 1DSC is capable of reproducing the major features of the precipitation.

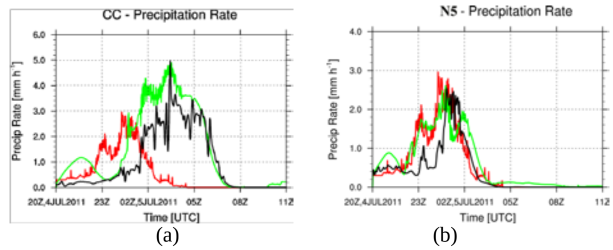

Figure 6. Time evolutions of WRF (green line) and 1DSC simulating (black line) precipitation rates (Units: mm h^{-1}) at Changchun station (a) and at the point N5 (b). The observed precipitation rate at Changchun station is presented in red line.

4. DISCUSSIONS

The preliminary results presented in this paper are based on eight sensitivity studies of a stratiform precipitation event at Changchun station in north-east China. By using the WRF-ARW model generated sounding, w-profile and Qx&Nx profiles as background fields, and by updating sounding and w-profile in 90 sec interval, the 1-D cloud seeding model can produce a much more realistic precipitation pattern than that simulated by using pre-specified static vertical velocity profile. With the static sounding and w-profile, 1-D cloud model produces lagged precipitation which eventually reaches static state without dissipation. By updating using the WRF produced profiles at 90 sec interval, the 1-D cloud model simulated precipitation starts right after the model initiation, with the precipitation rate intensified and eventually dissipated as in observation. Although a single case study does not provide any significance in a statistical sense, the positive results show that by using the WRF model generated sounding and w-profile as background and updating in 90 sec interval, the 1-D cloud seeding model tuned itself to produce a far more realistic precipitation pattern than traditionally used static vertical velocity profile.

Next step of the research is to perform cloud-seeding simulations to study the impact of different WRF sounding locations on the cloud-seeding influence in terms of precipitation enhancement, and to fully apply the model forecast sounding and vertical velocity from individual ensemble members to the 1-D ensemble cloud-seeding modeling component and to obtain probability distribution of certain rain enhancement potential.

5. ACKNOWLEDGMENTS

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