Study on the Stratiform Cloud Numerical Model and Actual Observation

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1. Introduction

As known to all, nowadays there are two modes to describe the drop spectra. One is parameterisation, and the other divides the drop spectra into many categories and focuses on the interactions between the categories.

In the early 1960s, scientists such as Berry¹ and Kovert² did researches on the evolution of the raindrop spectra with the drop category model. In the 1980s, Xiao Hui³ et.al used a cloud drop category model to simulate the evolution of drop spectra in the process of condensation and coalescence. Meanwhile, Xu Huibin⁴ in his paper particularly covered the problems of the applicability of the category model.

In this paper, with the help of the improved one-dimensional stratiform cloud raindrop category model developed by the Chinese Institute of Atmospheric Science, we have simulated the three different precipitations in Changchun, Jilin Province, on June 21, 2005 and made a comparison between the results and the data obtained through actual observation, taking advantage of the stratiform cloud raindrop category model in calculating the raindrop spectrum and the natural development of the precipitation intensity.

2. Improvement of model microphysical processes

The microphysical processes are introduced in paper 1 and 2 in detail. In this part, we aim to introduce the improvement of the microphysical processes.

2.1 The automatic cloud transformation method

In the original model, the Kessler case is used to describe the cloud automatically transforming to raindrops, such as:

\[
\begin{cases}
A_0 = K(q_c - q_o) & q_c > q_o \\
A_0 = 0 & q_c \leq q_o
\end{cases}
\]

We changed the \( q_o \) from 0.75 to 0.35 g • kg⁻¹. And the liquid water transforming from the cloud is distributed into raindrop categories through the following method:

\[
Q_o = \frac{1}{\rho_i} \int_{\rho_i}^q m(D)N_o e^{-\lambda D} dD
\]

In this equation, \( Q_o \) denotes the liquid water content of raindrops, which transforms from the cloud drops during the automatically changing process. \( m(D) \) is the raindrop mass with the diameter \( D \), \( \rho_i \) is air density. \( \lambda \) is a constant equated to 90. And the unit of raindrop diameter is centimetre. We can easily derivate the following equation:

\[
Q_o = \frac{\pi}{6\rho_i} \int_{\rho_i}^q N_o D^3 e^{-\lambda D} dD
\]

\[
Q_o = \frac{\rho_i}{6\rho_c} \left\{ \frac{1}{\lambda} \exp(-\lambda) \right\} \left\{ (\lambda D)^0 + 3(3D)^1 + 6(3D)^2 + 6 \right\}
\]

\[
N_i = \frac{\rho_i}{6\rho_c} \left\{ \frac{1}{\lambda} \exp(-\lambda) \right\} \left\{ (\lambda D)^0 + 3(3D)^1 + 6(3D)^2 + 6 \right\}
\]

2.2 Numerical solution of the raindrop spectra evolution

The diameters in each category, defining a series of length interval, were chosen to form an exponential progression, which is denoted as \( D(I) = D_o \exp((I-1)/I_1) \).

In order to keep the conservation of mass and quality of whole raindrops, we reprogrammed the numerical solution of the raindrop spectra evolution by means of a simple method derived from the K-0 case, which can be simply written as:

\[
N_i' = N_i + N_i \frac{D_{i+1} - D_i}{D_i - D_{i-1}} - N_i \frac{D_{i+1} - D_i}{D_{i+1} - D_i}
\]

\( N_i' \) is the quantity of raindrop in category \( j \) after collecting with cloud, and \( N_i \) is the one before collecting. \( D_i' \) denotes the raindrop
diameter in category \( j \) after collecting with cloud, and \( D_j \) is the one before collecting.

3. Comparison between the numerical simulation and actual observation

In this part, we simulated three stratiform precipitations in Changchun, Jilin Province, China, on June 21, 2005, comparing between the results and the data observed by Doppler radar, vessel of rain gauge and the raindrop size distribution. As is shown in Fig.1, the top of the cloud is about 7000m, with the \( 0^\circ \text{C} \) level of 3500m.

![Fig.1 The contour chart of the Doppler radar echo at 0808 BT on June 21, in Changchun, Jilin Province](image)

The sounding data of Changchun, Jilin province at 0808 BT on June 21 is used as the initial field of the model simulation. The time step is set to 2s and the vertical grid length to 100m. And the updraft is supposed to be invariable during the numerical simulation.

Fig.2 indicates the evolution of the distribution of the ice crystal concentration and the water content at different periods of time. The three updrafts are set to 0.12m·s\(^{-1}\), 0.18m·s\(^{-1}\) and 0.28m·s\(^{-1}\); the evolutions of ice crystal above zero-temperature level with different updrafts is alike: a high ice crystal concentration area formed at 6000 m height after IN nucleation, and then ice crystals fell into the lower layer and kept growing by collecting the super cooling water near the zero-temperature level.

Finally, the ice crystals melted after falling into the warm area. The IN nucleation rates and other microphysical processes changed significantly with different updrafts.

The concentration of the ice crystal near the \( 0^\circ \text{C} \) level is 1.2L\(^{-1}\), 0.8L\(^{-1}\) and 0.5L\(^{-1}\), while the water content of ice crystal is about 0.6g·kg\(^{-1}\), 0.3g·kg\(^{-1}\) and 0.2g·kg\(^{-1}\). From the fig3 we can see that the dBZ profiles simulated by the model and that of the actual radar observation under the zero-temperature level is similar when the updraft is set to 0.12 m·s\(^{-1}\), 0.18 m·s\(^{-1}\) and 0.28 m·s\(^{-1}\), and the radar echo simulated by the model near the ground is 21.86 dBZ, 26.51 dBZ, 28.56 dBZ after 80 min which are similar to the radar echo calculated by the raindrop size distribution observed on the ground.

Fig 5 shows the evolution of the raindrop size distribution from zero-temperature level to the ground. Which indicates the raindrop spectra changed a little under the \( 0^\circ \text{C} \) level. The collection between the raindrops and cloud contribute to the rain intensity is about 10% in this case.

4. Conclusion

a. In this paper, an improved 1-D stratiform cloud model is used to simulate three precipitations in Changchun, Jilin Province, China, on June 21, 2005. The results show that the improved model tends to be much more stable in calculating and it can simulate the raindrop spectrum closest to the actual precipitation spectrum.

b. It is shown in the comparison between the actual observation and the modelling that the rain intensity could increase about 10% after collecting with cloud water in the warm area.

c. In this model, we only focus on the collection with cloud drops and evolution of raindrop, both of which lead to the great variation of raindrop spectra from zero-temperature level to the ground.

d. The method of parameterisation remains to be used in the cold cloud processes, including the nucleation, multiplication and accretion of ice particles, all of which remain intangible.
Fig. 2 The contour chart of water content and density of ice particle in three schemes of updraft.
Left graphics are contour charts of density of ice particles, m$^{-3}$.
Right graphics are contour charts of water content of ice particles, µg kg$^{-1}$.

Fig. 3 The comparison between the dBZ profile simulated by the model and that of the actual radar observation:
(a) 0720 LST on 21 Jun, Wmax=0.12 m s$^{-1}$
(b) 0845 LST on 21 Jun, Wmax=0.28 m s$^{-1}$
(c) 0905 LST on 21 Jun, Wmax=0.18 m s$^{-1}$
Acknowledgements

We grateful to my teachers for their helpful suggestions and comments. This research partially funded by the Chinese academy of Sciences Knowledge Innovation Program under contract KZCX3-SW-22

References

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Fig 4 The ground raindrop size distribution simulated and observed. D for diameter of raindrop, N forthen concentration of raindrop
(a) 0720 LST on 21 Jun, Nmax=0.12 m⁻³ (b) 0845 LST on 21 Jun, Nmax=0.29 m⁻³ (c) 0905 LST on 21 Jun, Nmax=0.18 m⁻³

Fig 5 The comparison between raindrop size distribution in the bottom of cloud and 0°C level Real line for the spectrum of rain drops at cloud base and the dashed for the spectrum of rain drops at 0°C level