

# A Numerical Study of Cloud Development Using Silver Iodide Cloud Seeding Module

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**Abstract:** *Based on the IAP-LACS multiple-parameter cloud microphysical scheme which has been coupled into WRF model, Sensitivity tests are designed to study the influence of AgI doses on cloud seeding processes. By coupling the AgI cloud seeding module to the IAP-LACS scheme, the effects of AgI catalyst with different doses on ice crystal formation and precipitation are simulated. The results of ideal sensitivity tests show that, with the increase of the AgI dose, the overall cloud rain show a trend of increasing firstly and decreasing secondly, which corresponds to the fact that appropriate amount of catalyst enhances precipitation while excessive catalyst suppresses precipitation.*

## 1. Introduction

The cloud microphysics scheme is a numerical scheme to describe the microphysical processes such as aerosol activation and the source-sink transformation of various hydro condensates (cloud, rain, ice, graupel, hail). The scheme can simulate the evolution of the particle size distribution of various water condensates, and then calculate the precipitation rate and various cloud parameters (such as effective radius, cloud albedo, cloud water volume, etc.). Based on the description of particle spectrum, the cloud microphysics scheme can be divided into two schemes: the bin parameterization scheme and the bulk parameterization scheme (Khain et al,2015).

At present, the bulk parameterization scheme is widely used in regional numerical weather prediction models and global climate models to simulate cloud microphysical processes. The overall water scheme uses specific functions (i.e. gamma, normal distribution, exponential function) to characterize the spectral distribution of aerosol and cloud particles, so only dozens of forecasts need to be considered, which saves computational resources and runs faster, so it can be applied to weather forecasting and climate effect research. However, in the numerical simulation research, the uncertainty of simulation results owing to different cloud parameterization schemes is high. According to the number of moments used in the parameterization scheme, the overall parameterization scheme can be divided into single parameter scheme, double parameter scheme and multiple parameter scheme. The single parameter scheme only contains a single slope parameter, which can be diagnosed by the mass mixing ratio of the condensate. The double parameter scheme further considers the intercept parameter, and the multiple parameter scheme introduces the third or more moment reflectivity factor to diagnose the spectral parameters (Chen and Tsai, 2016).

A new multiple-moment scheme (IAP-LACS) is presented to describe the growth of a population of cloud drops and ice crystals deposition processes more accurately (Zhang et al., 2022). In the deposition of ice crystal shape, based on the growth model of ice crystal deposition proposed by Chen and

Lamb (1994). It makes the numerical simulations of condensation and warm rain formation inaccurate. The IAP-LACS scheme is a multi-parameter cloud microphysics scheme, which is assumed to be superior to existing single-parameter and two-parameter schemes in simulating cloud and precipitation development. Therefore, it can be applied to the simulation of precipitation over Liupan Mountain Area, southern Ningxia.

Furthermore, large eddy simulation (WRF-LES, WRF large eddy simulation) is an important method for simulation research. Large eddy simulation uses energy cascade which divides turbulence into vortices by different scales. Large eddy simulation (WRF-LES, WRF-large eddy simulation) is currently an important method in fluid numerical simulation research (Moeng et al.2007). Large eddy simulation uses the concept of energy cascade, dividing turbulence into vortices of different scales. The Larger vortices are responsible for the exchange of physical quantities between turbulence and the outside world as well as the generation of kinetic energy, while smaller vortices mainly dissipate energy. Owing to the high resolution, this method can develop convective clouds with only initial thermal disturbances, and can resolve the development of turbulent vortices. Therefore, it is superior in theoretical research on cloud microphysical schemes

In this study, the ideal numerical experiment was conducted, and the simulation effect of the four-parameter ice crystal deposition scheme coupled into WRF was tested.

## 2. Models and Methods

### 2.1 Model Description: Dynamic Framework

The Weather Research and Forecasting (WRF) numerical model developed by the National Center for Atmospheric Research (NCAR) is used as dynamic framework to drive microphysical processes. Apart from operational usage, Advanced Research WRF(ARW) version is also advantageous for scientific research owing to its ability of multiple physical processes integration (cloud microphysics, cumulus convection, boundary layer physics, land surface

processes, and radiative transfer, etc.). Besides small and medium-sized real weather cases, ideal cases are also frequently conducted using WRF(ARW).

## 2.2 Model Description: IAP-LACS Microphysical Scheme

IAP-LACS microphysical scheme is jointly developed by the Institute of Atmospheric Physics, Chinese Academy of Sciences and the Department of Atmospheric Science, School of Physics, Peking University. The scheme includes three core parts: (1) cloud droplet condensation and growth scheme, (2) raindrop formation scheme and (3) ice crystal condensation and growth scheme. There are five particle categories in IAP-LACS scheme: cloud drops, raindrops, ice crystals, cloud graupels and cloud hails. This new scheme has significantly improved the accuracy of precipitation prediction through high-resolution simulation.

This scheme adopts a multi-parameter approach that provides a more accurate description of particle size distribution. Compared to single-parameter schemes (i.e. Lin scheme) that only describe the mass mixing ratio or two-parameter schemes (i.e. Thompson scheme) that include both the mass mixing ratio and number concentration (Lin et al., 1983; Thompson et al., 2004).

## 2.3 Description of Cloud Seeding Module

The AgI dispersed in cold clouds will mainly affect the initial activation process of ice crystals in the IAP-LACS scheme which correspond to the primary ice nucleation part in the program, the design of the AgI cloud seeding module is mainly based on the three physical processes activated by AgI: collision nucleation of cloud droplets, contact freezing nucleation of raindrops, and vapor deposition nucleation. The above three processes correspond to the transformation of cloud droplets into ice crystals, raindrops into ice, and water vapor into ice crystals, respectively. By adding the effect of AgI activation in the calculation of the number concentration, mixing ratio, and radar reflectivity of particles in each phase state, and the results are used for four-parameter deposition scheme in the next stage, which is the overall design concept of the AgI cloud seeding module.

Based on the IAP-LACS microphysical parameterization scheme, a cloud seeding module is added to the scheme, and the scheme is used to simulate ideal experimental cases. The effects of different AgI seeding doses on cloud processes and precipitation are analyzed.

## 3. Ideal Simulation Tests for Cloud Seeding

### 3.1 Design of the AgI Cloud Seeding Simulation Tests

The multi-parameter microphysical scheme has a larger computational burden and thus a slower processing speed. For instance, in a five-layer-nested case simulation, it takes approximately 7 to 10 days. Therefore, if we use actual case simulations to study cloud processes, a significant amount of computing resources would be consumed. In contrast, ideal experiments can simplify computing processes by eliminating orographic factors, which reduces temporal and spatial scales of the simulation significantly and shortens the simulation

time to only several hours.

The IAP-LACS scheme mentioned above will be used to simulate the 20-minute growing process of a convective thermal bubble. The simulation area has a horizontal area of 10x10 km and a vertical height of 10 km, with a grid resolution of 100x50 m. A thermal bubble is initiated at the center of the simulation area, with a temperature disturbance of 3K and a radius of 300m. The sounding curve is adopted from Yau (1980), which represents typical deep convective atmospheric conditions (Figure 1). Under the effect of the thermal bubble initiation, deep convection will develop and cloud droplets can fully condense during the condensation process, which facilitates the comparison of parameterization schemes and stratification up to approximately 10 km in height.

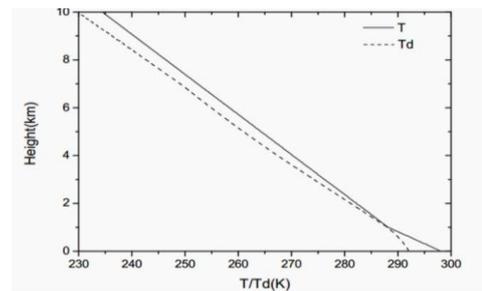


Figure 1: The atmospheric sounding profiles of temperature(T) and dew point ( $T_d$ )

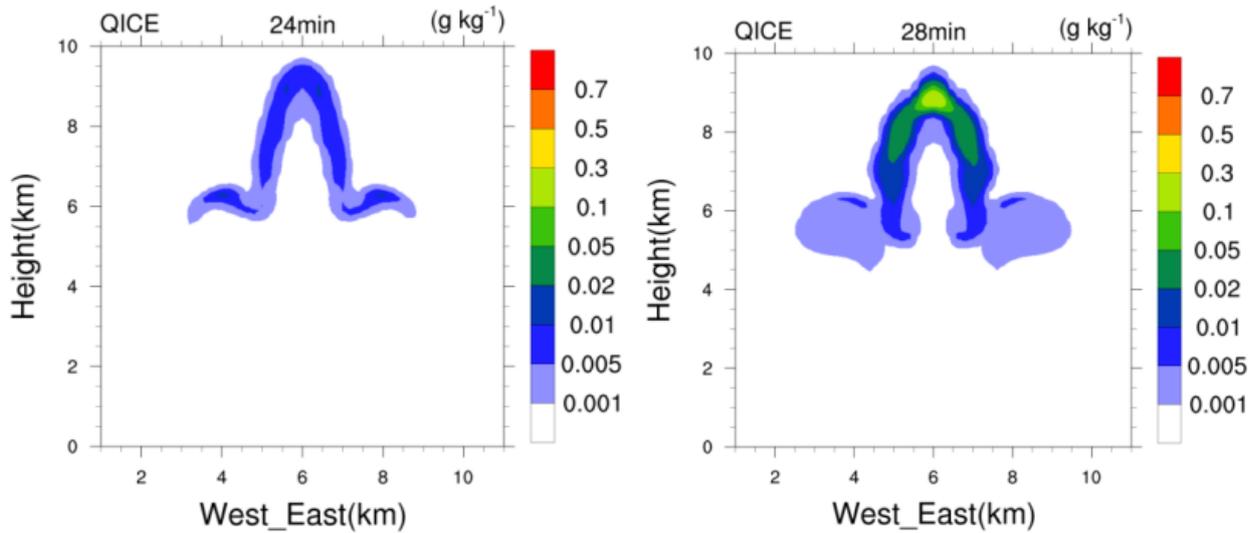
## 3.2 Discussions

### 3.2.1 Results of Control Test

Control test is the simulation test without any AgI cloud seeding. After 40 minutes of simulation, the air bubble develop into mature monomer cloud which generates ground precipitation in the last stage. Figure 2 depicts the number concentration of cloud ice in the control test at representative time points.

The representative time points are selected as follows: The growth of cloud ice related to the cold cloud ice phase process mainly needs to focus on 24min and 28min. Following the activation and formation of cloud ice, cloud graupel is formed through collision and coalescence. Graupel is an important intermediate stage in the formation of hail. The growth of graupel mainly occurs on 36min. With continuous warm cloud process, cloud graupels grow into hail through "dry and wet growth" cycles caused by continuous updraft. After falling to a temperature layer over 0 °C, a part of the cloud hails melt into liquid raindrops, cloud hail and cloud rain particles mainly occur in the middle and late stage of cloud microphysical process, which corresponds to simulation time at 36min and 40min.

In Figure 2, the number concentration distribution of ice crystals presents an inverted V-shaped distribution pattern, which is mainly caused by updraft. Although cloud ice is mainly generated in supersaturation large value area (cloud top) through the growth of condensation, the vortex within cloud carries the cloud ice to both sides, forming a large value band area of cloud ice. Apart from that, with boundary vortex developing, hook shaped distribution areas of cloud ice occur on both sides of the cloud.



**Figure 2:** Profiles of cloud ice number concentration at 24min and 28min

**Table 1:** Description of AgI Seeding Dose sensitivity tests

Test ID	Seeding Dose Factor (NIFA)	Seeding Period	Seeding Height	Range of Temperature
Test-A1	2.0E4	1310-1320s	K=6500-7000m	-8°C<T<-3°C
Test-A2	4.0E4	1310-1320s	K=6500-7000m	-8°C<T<-3°C
Test-A3	6.0E4	1310-1320s	K=6500-7000m	-8°C<T<-3°C
Test-A4	8.0E4	1310-1320s	K=6500-7000m	-8°C<T<-3°C
Test-A5	1.0E8	1310-1320s	K=6500-7000m	-8°C<T<-3°C

Once ice crystals are formed through homogeneous or heterogeneous nucleation processes (i.e. condensation and freezing), if the environment is still in a relatively saturated state, they will continue to diffuse and grow, cloud graupel will be generated through microphysical processes like primary ice crystal nucleation and condensation growth. With cloud hails grow continually, a fraction of loud hail particles will fall and melt into liquid raindrops. Therefore, the number concentration of cloud hails can reflect the total precipitable water in the late stage of cloud development.

### 3.2.2 Results of Cloud Seeding Sensitivity Tests

Sensitivity tests are set to study the effects of different AgI doses on cloud and precipitation processes via tracking the concentration and spatial distribution of cloud water, cloud rain, cloud ice, cloud graupel, cloud hail and other characteristics in different stages of cloud development.

After the catalytic horizontal area and height range are determined, AgI is spread on the corresponding WRF space grid points at a specific rate within the catalytic time. When the AgI emission rate is set to zero, it can be seen as control test. On this basis, five groups of sensitivity tests were conducted by adjusting the AgI emission rate (Table 1). The AgI seeding dose factors (NIFA) in the four groups of sensitivity tests of A1-A5 are  $2.0 \times 10^4$ ,  $4.0 \times 10^4$ ,  $6.0 \times 10^4$ ,  $8.0 \times 10^4$ ,  $1.0 \times 10^8$ , respectively. AgI seeding time and seeding height are 1310-1320s and 6.5-7.0km in each test.

Similar to the control test, the number concentration distribution of ice crystals at 24min and 28min, cloud graupel at 36min, cloud hail and cloud rain at 40min are chosen as representative time points, the number concentrations of

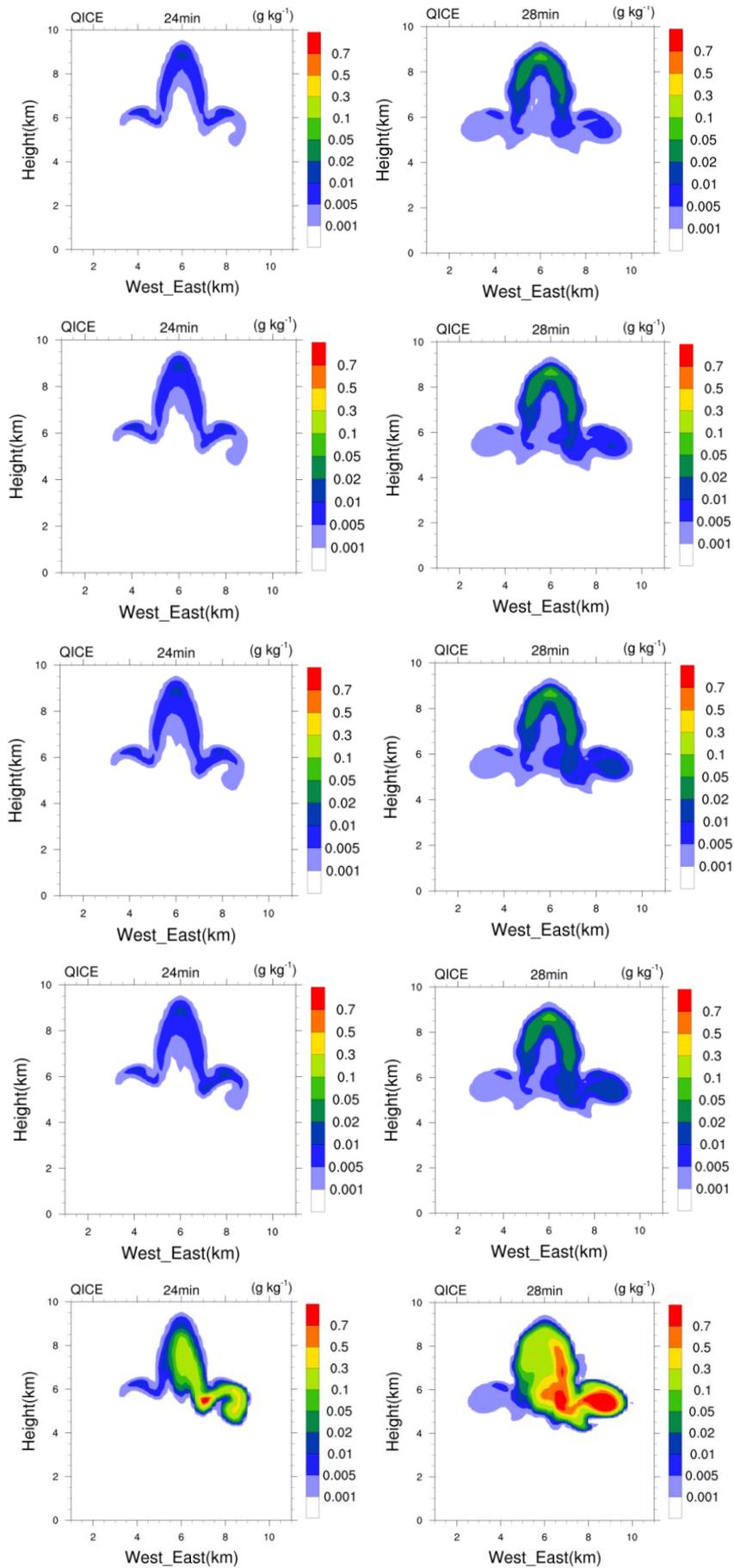
cloud ice and cloud rain in each sensitivity test are drawn in Figure 3 and Figure 4, respectively.

After AgI is spread into the altitude layer of 6.5-7km, the formation of ice crystals in the altitude layer below 7km will be affected, which include two microphysical processes: (1)Contact freezing and nucleation of AgI and cloud droplets caused by Brownian motion or inertial collision; (2)Condensation nucleation of water vapor in the cloud caused by supercooled water in the cloud, which mainly occurs in the altitude below 6km.

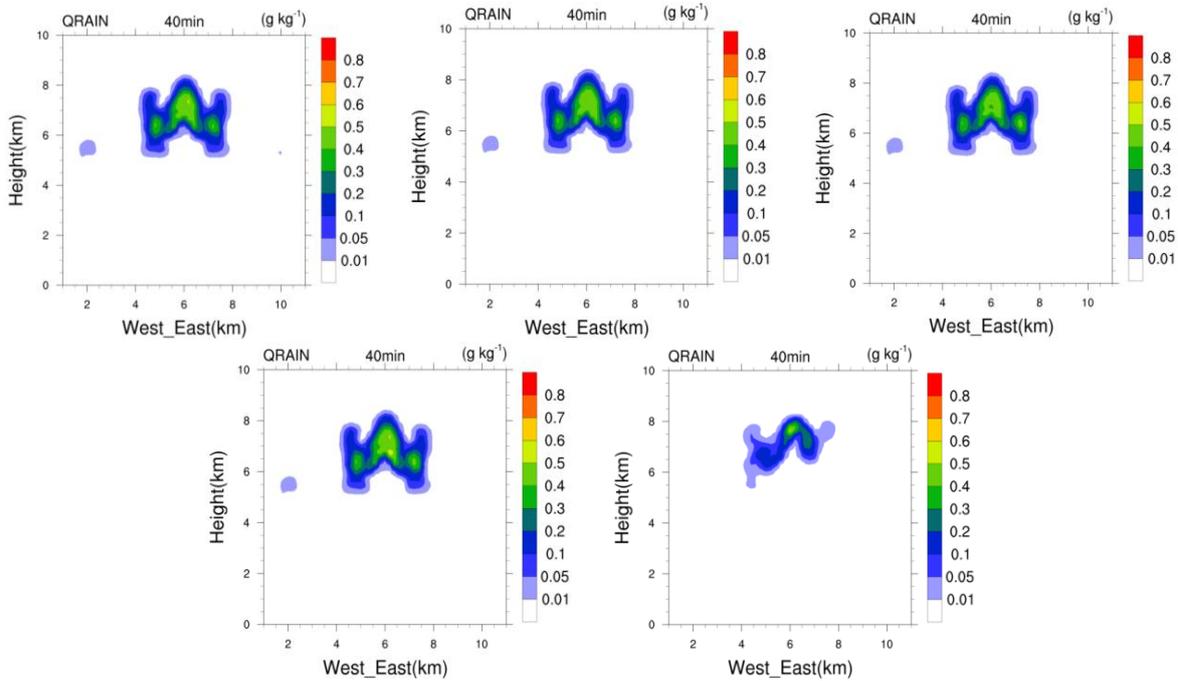
At 24min, the number concentration of ice crystals is relatively limited. The AgI cloud seeding does not directly increase the number concentration of cloud ice particles, but will extend the range of cloud ice particles to a height of 4.5-5.5km. In that case, the AgI cloud seeding will advance the genesis of ice crystal particles in the lower part of the cloud.

At 28min, with the development of the cloud, an ice crystal high value area gradually formed at the top of 8km. From the comparison between the control test and the sensitivity test, the area where ice crystals above 7km is basically not affected. Below 7km, after the spread of AgI, it can be seen that the area with increased ice crystals was mainly in the part below 6km in the right side of the cloud, while the change of ice number concentration in the altitude area of 6-7km is relatively small.

The results of an extreme AgI seeding case (A5) is given as well, in which cloud ice particles increase significantly (Figure 3), however, the super-cooled water in the cloud is not adequate for these ice particles to grow in the following stages (Figure 4).



**Figure 3:** Profiles of cloud ice number concentration in AgI Seeding Dose sensitivity tests (seeding dose factors are 2.0E4, 4.0E4, 6.0E4, 8.0E4, 1.0E8, respectively,  $i=30, j=32$ )



**Figure 4:** Profiles of cloud rain number concentration in AgI Seeding Dose sensitivity tests (seeding dose factors are 2.0E4, 4.0E4, 6.0E4, 8.0E4, 1.0E8, respectively,  $i=30$ ,  $j=32$ )

#### 4. Conclusions

By adding an AgI catalytic module to the IAP-LACS scheme, the effects of different doses of AgI catalyst on ice crystal formation and precipitation were simulated. In the ideal sensitivity tests for different AgI catalyst doses, as the amount of catalyst increased, the mean cloud rain showed an increase at first and a decrease later, which is consistent with the rule that moderate catalyst enhances precipitation while excessive catalyst suppresses precipitation.

#### Acknowledgments

This research is funded by scientific research launch project for high-level talents in Ningxia Hui Autonomous Region (2023BSB03060) and Key R & D project of Ningxia Hui Autonomous Region (2022BEG02010).

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