Numerical Simulation of a Hail Storm Event of April 2015 in Eastern China: Hailstone Size Forecast and Microphysical Budgets

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Introduction

Hailstorm is one of the severe natural disasters in China and many other countries. When it sweeps through, huge loss to agriculture, traffic, communication and buildings will be brought about. Since the lack of thorough observation within the hailstorm, people can not know well about the real dynamics and microphysics processes during the formation of the golf-sized hailstones. This leads to a large extent of blindness when it comes to weather modification.

From 1960s, operational numerical weather prediction(NWP) models have improved considerably due to increases in computer power and advanced treatment of physical processes. And currently models generally use bulk microphysics schemes (BMSs) to parameterize the effects of cloud microphysics because bin-resolving (spectral) methods are expensive and impractical in an operational context.

However, the severe convective hailstorm systems often owe the characteristics of rapidly development, regional features and highly destructive effect, there are still large uncertainties for models to forecast the hailstorms.

Aim

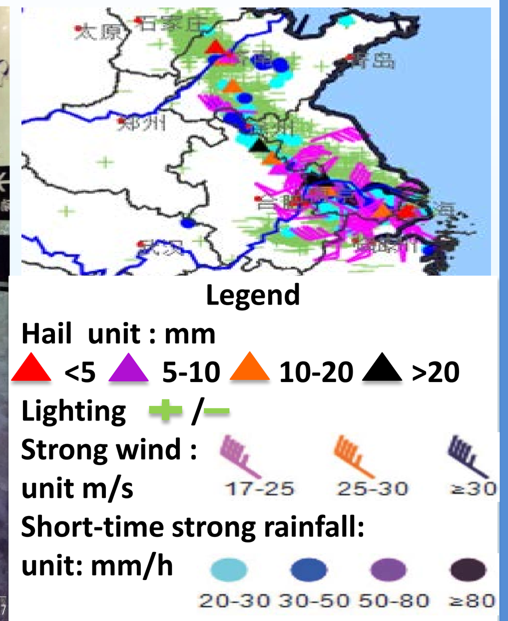
First, based on the Advanced Regional Prediction System (ARPS), several sensitivity runs were performed to explore the effects of the number of predicted moments in bulk microphysics scheme on the simulated results.

Then main focuses are on the calculations of ground hailstones' size, large hailstones' distribution, total number and mass of ground-accumulative hailstones.

Finally, in order to diagnose the contribution of different microphysical processes to the hailstone growth, budget diagnosis analysis of microphysical processes during the hailstorm system develops was done.

Case overview

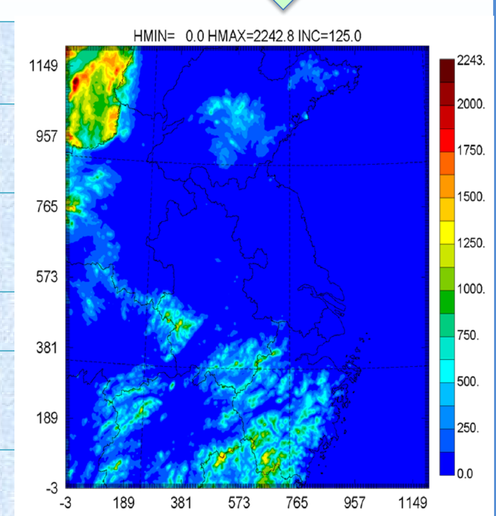
In the afternoon of April 28, 2015, severe hailstorm swept through almost the whole Jiangsu province, China, producing golf-ball sized hails that covered up the ground. The whole process with hail, strong winds and lightning lasted for more than seven hours long.



Experiment set up(ARPS model)

Grid configuration

Grid settings	dX=dY=3km，dZ=500m，nx=403，ny=403，nz=53
Initial field	FNL data，1° X 1°；6-hourly boundary conditions
Microphysics scheme	The three-moment version of Milbrandt & Yau scheme
Forecast period	2015.4.27:1200~28.1600UTC
Advection scheme	fourth order advection in both horizontal and vertical
Soil model	Two-layer Force-restore model



Results compare to observations

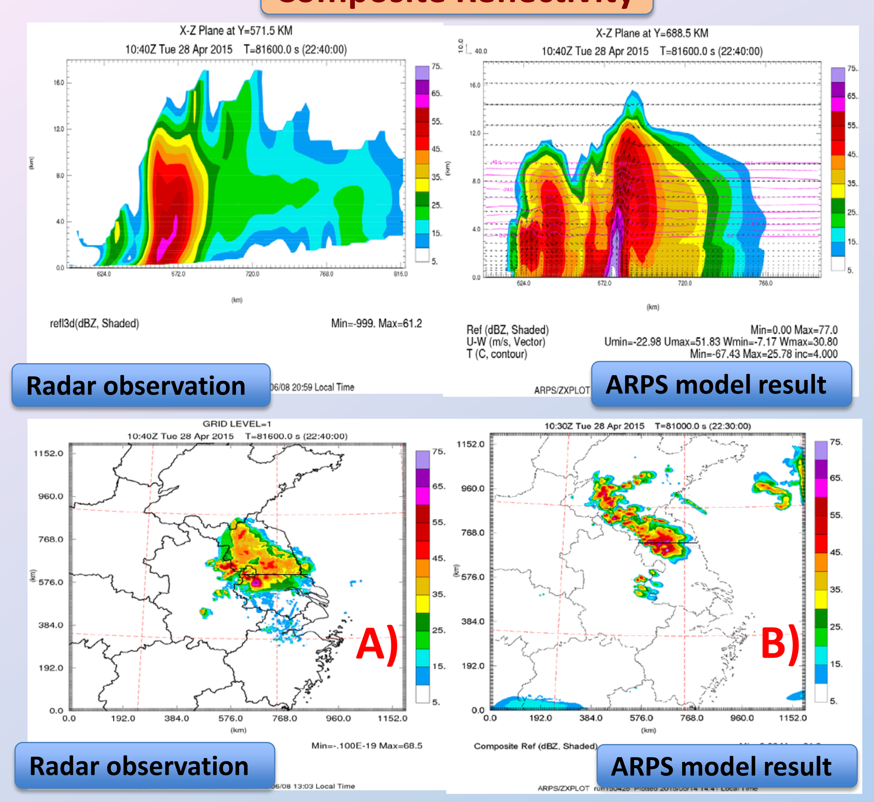


FIG.1.(top A)Vertical cross sections of radar reflectivity along arrows in (bottom A) the composites of maximum reflectivity from the Operational Radar at 1040 UTC 28 April 2015, and ARPS model results(B).

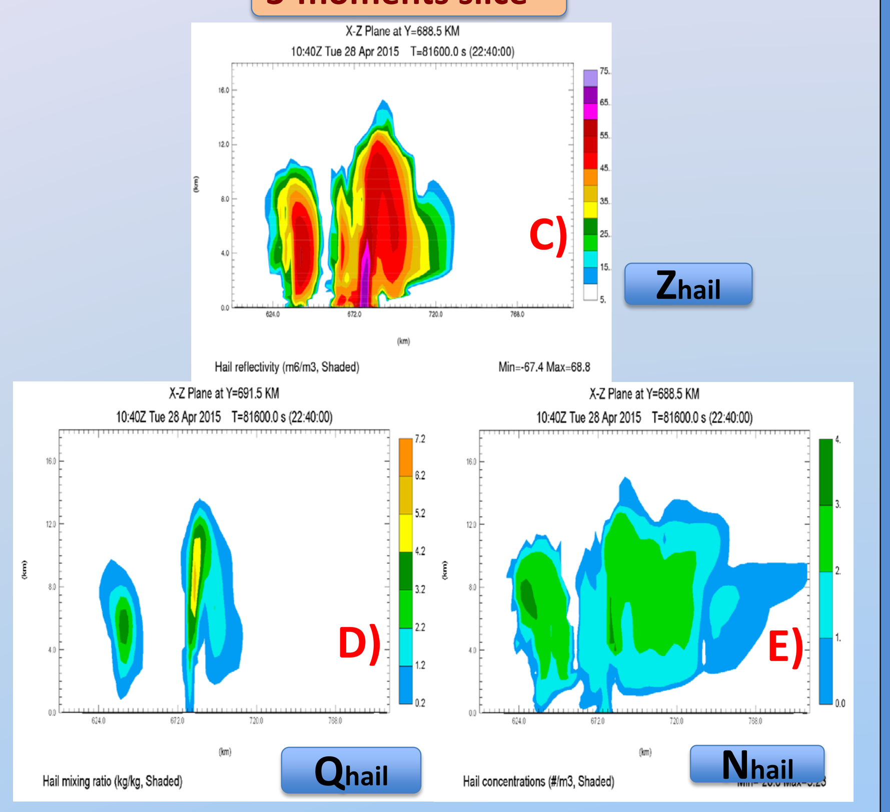


FIG.2.Vertical cross section of (C)reflectivity;(D)mass content;(E)number concentration of hail.

From comparison of the ARPS simulation results with the radar observations at the same time,FIG.1. shows that besides location of storm is a little bit northeast than observation, the simulated storm reproduced several characteristics of the radar observation, such as the direction and speed of propagation, a bounded week echo region and a suspended overhang region.

Based on the forecast of the 3 moments, it can be seen that the Zhail contributed substantially to Z total. From (E) we infer that the large number concentration of hail in the downwind direction is resulted from small size hailstones with small fall velocities which were carried upward in the updraft and transported to the downwind direction And the negligible Qhail in the downwind direction again proves it.

Hail Size Forecast

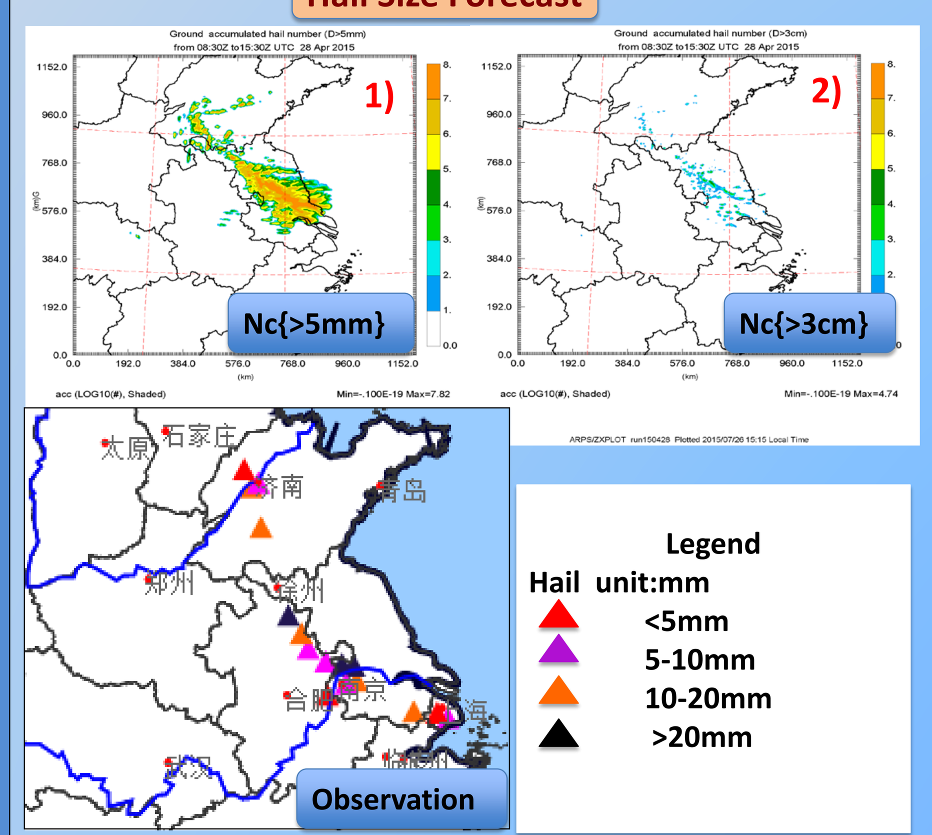


FIG.3.Top,ground accumulated hail number calculated based on the simulated result, form 0830 to 1530 UTC, 1)D>5mm,2)D>3cm;Bottom, observation of hail.

To identify the accumulated number of hail larger than a given size reaching the ground, we calculate the parameter Nc, given by the formula below, where $N_h\{D^*\}$ represents he total number concentration of hailstones larger than D^* in size distribution and V_h is the terminal fall velocity at the surface for a given size hailstone.

$$N_h\{D^*\}=\int_{D^*}^{\infty} N(D)\,dD,\quad V_h(D)=ra_h\times D^{b_h}\times\exp(-f_h D)$$

$$R_h\{D^*\}=N_h\{D^*\}\times V_h(D^*)$$

$$Nc\{D^*\}=\sum_{T\min 0}^{T\min 1} R_h\{D^*\}*60$$

$$a_h=206.89,\ b_h=0.6384,\ f_h=0$$

The ground accumulated hail number distribution during the seven hours(from 08:30 to 15:30UTC) shows that the number of hailstones with D larger than 5mm is about eight root of ten and the almost largest golf ball-sized ones with D larger than 3cm arrive at surface is about 10 per square meter. Such hail size distribution over a given area is consistent with the actual hail observation basically.

This exciting calculation results indicate that the full version 3-moments bulk microphysics scheme has good forecast ability for hail size distribution due to the full diagnose of parameters in the gamma distribution function.

Microphysical budget analysis

In order to investigate the physical reasons for the hailstone growth, the terms of hail mass content (qh) are extracted from the ARPS model and analyzed. We calculate the terms in a cuboid moving together with the hailstorm system.

$$\left.\frac{dq_h}{dt}\right|_S=\left\{\delta_{irh}(QCL_{ir}+QCL_{ri})+\delta_{srh}(QCL_{sr}+QCL_{rs})+\delta_{grh}(QCL_{gr}+QCL_{rg})+QFZ_{rh}+QCN_{gh}+QCL_{ch}+QCL_{rh}+QCL_{ih}+QCL_{sh}+QVD_{vh}-QML_{hr}\right.$$

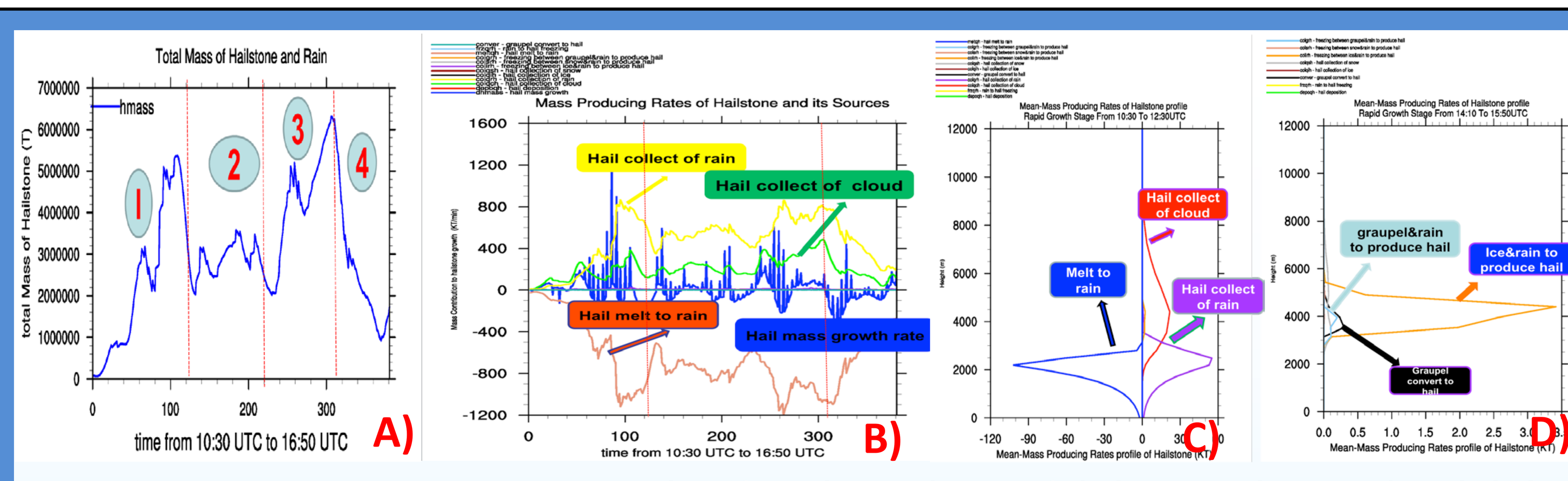
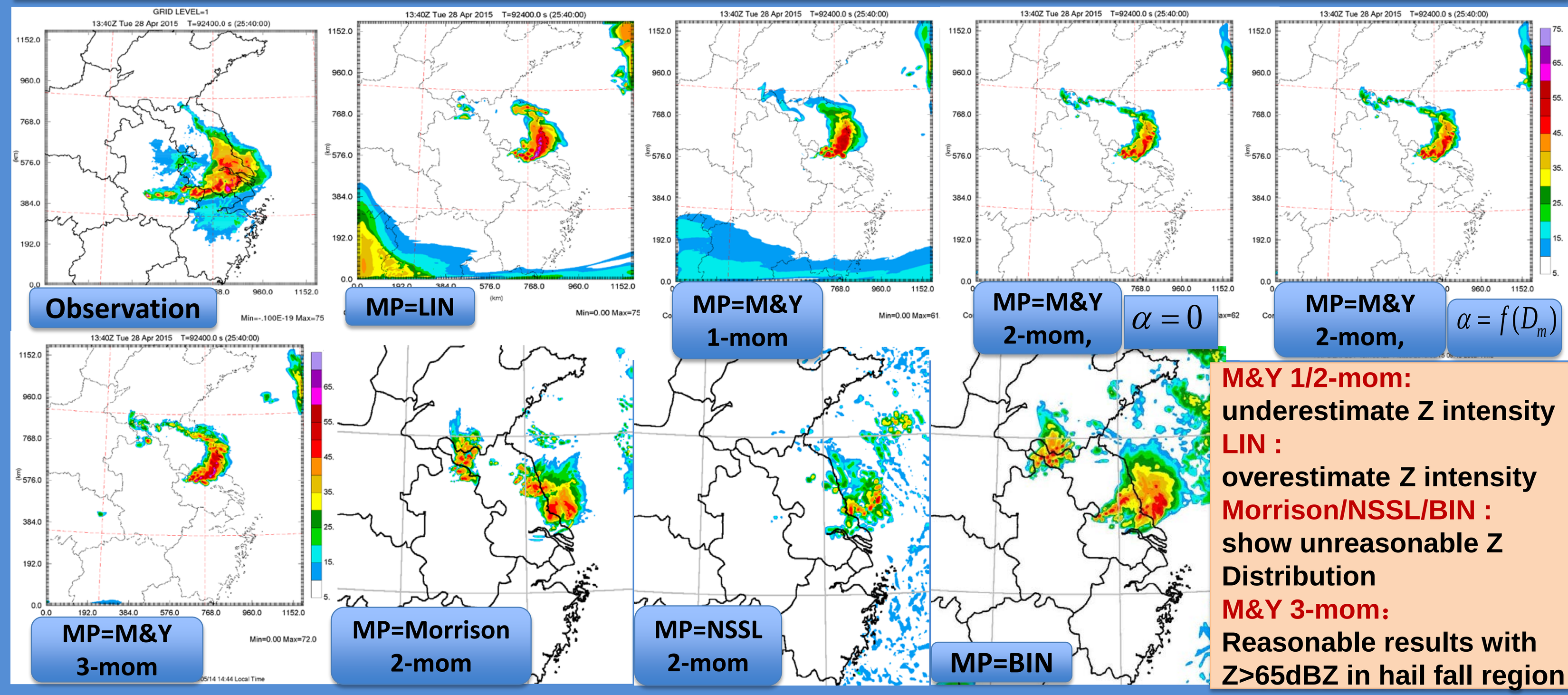


FIG.4.(A)Time series(10:30 to 16:50 UTC, April 28)from the simulations of hail mass;(B)the microphysical budget components;(C)simulated profiles of the microphysical budget terms.

According to the total mass changes of hailstones in the system, in FIG.4. A) we divide the process into four stages, namely Rapid Growth Stage 1, Maintenance Stage, Rapid Growth Stage 2 and Rapid Decline Stage. And in the whole process, the time series of the microphysical budget in B) shown that the dominant contribution terms during hail growth are the hail collect of rain(yellow solid line) and cloud(green solid line) and the main sink term is hail melt to rain(orange solid line), the other sources, such as water vapor diffuse to hail or rain freeze to hail are all relatively too small.

From the profile of the budget terms averaged over the rapid growth stage 1 in C), it is obvious that hail collect of rain and melt to rain dominate below the zero degree layer, and the maximum occurs near 2 km height. While the hail collect of cloud term mainly contributes between 2 to 8 km and the maximum takes place at about 4.5 km, a little bit above the zero degree layer.

What is more, the sources to hail embryo profile is displayed in D).As in the rapid growth stage, the hail embryos mainly come from the collection freezing between ice and rain, followed by the graupel convert to hail and the collection freezing between graupel and rain. And is easy to see these processes all arise between 3 km to 5 km. The result is plausible because this layer is suitable for hail embryo to grow up.



Conclusion

- The simulation using three-moment microphysics scheme exhibited many of the same characteristics as the observed storm, such as the propagation speed and direction, storm structure, including a bounded weak echo region and a suspended overhang region. The magnitudes of radar reflectivity and ground accumulated hail distribution are also well simulated.
- The three-moment microphysics scheme in ARPS model successfully captures the hail fall process between 08:30 and 15:30UTC. And the golf ball-sized hail simulated is in good agreement with observation.
- Major finding based on the microphysical budget is that the main processes contribute to hail growth are the hail collect of cloud above the zero degree layer and below the layer are the hail collect of rain particle as the dominant source terms and then melt to rain as the sink term .

Acknowledgements

- A Multimoment Bulk Microphysics Parameterization. Part III: Control Simulation of a Hailstorm
- High-Resolution Large-Eddy Simulations of Flow in a Steep Alpine Valley. Part II:Flow Structure and Heat Budgets