# Numerical Simulation of a Hail Storm Event of April 2015 over Eastern China: Hailstone Size Forecast, Microphysical Budgets and Convection Initiation Mechanism

**Liping Luo[1], Kefeng Zhu[1],Ming Xue[1,2]**

*1:College of Atmospheric Science, Nanjing University, China*

*2:Center for Analysis and Prediction of Storms (CAPS), University of Oklahoma, Norman, OK, USA*

*Corresponding author: Ming Xue (mxue@ou.edu)*

## Introduction

Because the lack of thorough observation within hailstorm, until now people still do not know well about the real dynamics and microphysics processes during the formation of golf ball-sized hailstones. This leads to a large extent of blindness when it comes to hailstone size forecast.

Since 1960, operational numerical weather prediction(NWP) models have improved considerably due to increases in computer power and advanced treatment of physical processes. Currently, models generally use bulk microphysics schemes (BMSs) to parameterize the effects of cloud microphysics. This allows us to see more details in the microphysical processes contributing to hailstone growth.

## Case overview

In the afternoon of April 28, 2015, a multi-cellular hailstorm system swept through almost the entire Jiangsu Province, China, producing golf ball-sized hailstones on the ground. The hailfall over Jiangsu lasted as long as seven hours. Intense lightning and damaging surface winds (>23 m/s) were also reported.

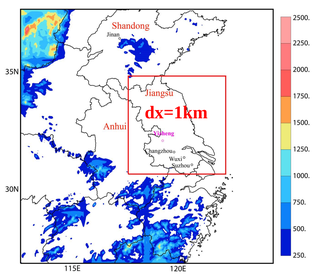

## Aim and methods

The hailstorm is simulated using the Advanced Regional Prediction System (ARPS) at 1-km grid spacing. Different microphysics schemes are used predicting one, two, and three moments of the PSD.

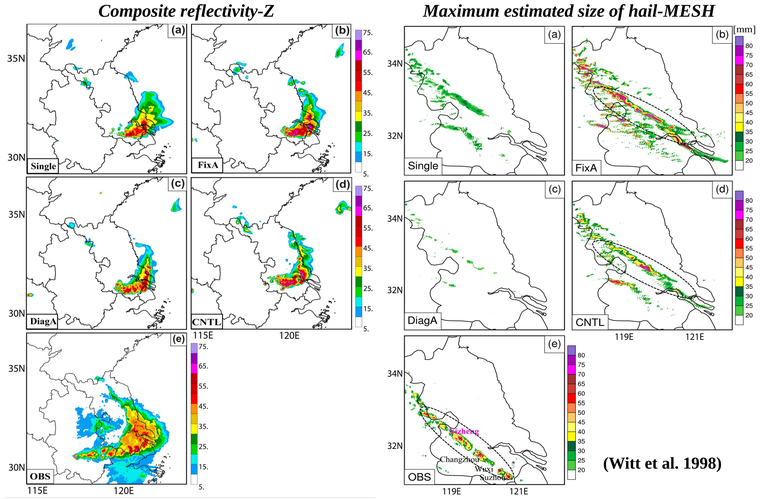
1. To explore the effects of the number of predicted moments in bulk microphysics schemes on explicit hailstone forecast, the hailstone size, accumulated number and mass distribution were examined.
2. Detailed microphysical budget analysis is conducted based on the simulations, to investigate the hailstone growth mechanism.
3. For better understanding of the convection initiation and evolution of this long-lasting severe hailstorm, other sensitivity experiments were conducted.

## Experiments setup

| Model | ARPS, Version 5.3.3 |
|---|---|
| Domain | D01: 403*403*53 grid points, dx=dy=3km<br>D02: 463*463*53 grid points, dx=dy=1km |
| Initial/Boundary condition | NCEP Final Analysis data at 1*1 resolution |
| Microphysics schemes | Milbrandt and Yau scheme<br>-single moment (Experiment Single)<br>-double moment (FixA and DiagA) (with fixed and diagnosed alpha)<br>-triple moment (CNTL) |




## Results of Sensitivity runs




(Witt et al. 1998)

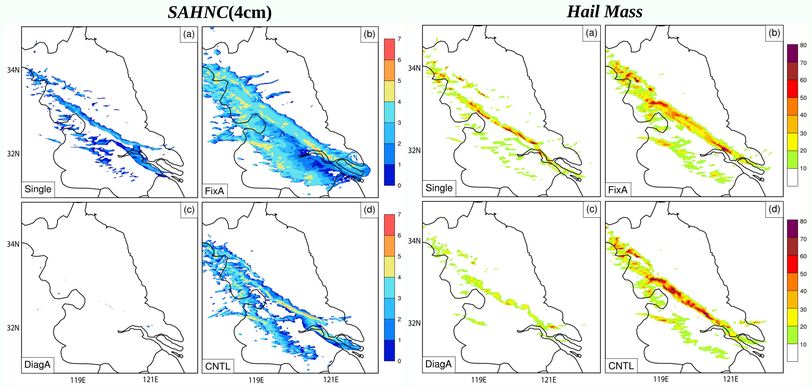
- MY 1/2-mom with diagnosed Alpha: Underestimate Z and MESH;
- MY 2-mom with fixed-Alpha: Overestimate Z and MESH;
- MY 3-mom: Reasonably reproduce the observations, e.g., Z>65dBZ in hail fall region, bow-shaped echo, MESH

## Hail prediction

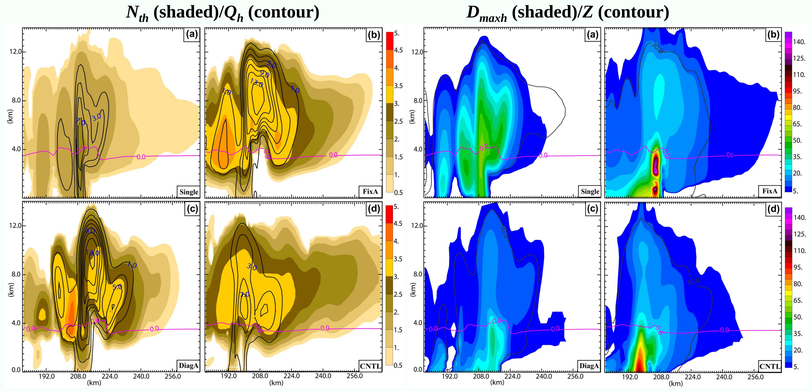
Given that the accumulated hail number is also important for hail prediction, *SAHNC* is proposed to estimate the surface accumulated number concentration of hail larger than a particular size. *SAHNC* is defined as an integration of the flux of large hail Rh(D) at 60-second intervals during hail burst period from T0 to T1, described as the formulas below,

$$N_{Dh}(D)=\int_D^{\infty} N_h(D^*)dD^*; \quad N_h(D^*)=N_{0h}D^{\alpha}e^{-\lambda D}; \quad V_h(D)=\gamma a_h\times D^{b_h}\times e^{-f_h}$$

$$R_h(D)=N_h(D)\times V_h(D); \quad SAHNC(D)=\int_{T_2}^{T_1} R_h(D)dt$$




- DiagA has no forecast skill for hail larger than 4 cm for this case.
- FixA produces more huge hailstones accumulated on the ground than other experiments, and predicting a swath which is almost twice the width of high *SAHNC* swath than CNTL.
- CNTL produces hail mass concentrated along a straight path extending from northwest to southeast part of Jiangsu Province, which appears to be more realistic.

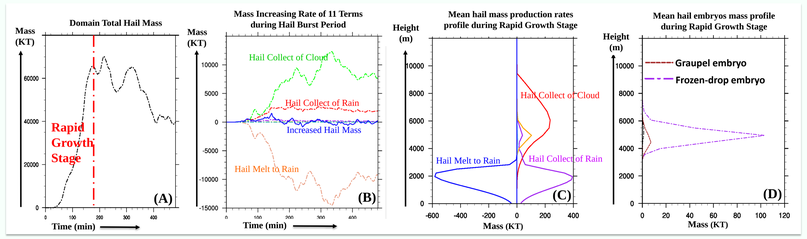



- For Single, vertical distribution of $D_{maxh}$ is consistent with its $Q_h$, and $D_{maxh}$ varies from 20-50 mm.
- FixA and DiagA produce copious hail mass aloft, with peak values of $Q_h$ over 13 g m$^{-3}$, while peak values of $Q_h$ in CNTL and Single are around 7 g m$^{-3}$.
- Larger peak values of $N_{th}$ are predicted by two-moment schemes, especially in the rear part of the cell.
- For multi-moment schemes, different moment-weighted terminal velocities allow for size sorting of particles, making it possible to reproduce more realistic PSD.

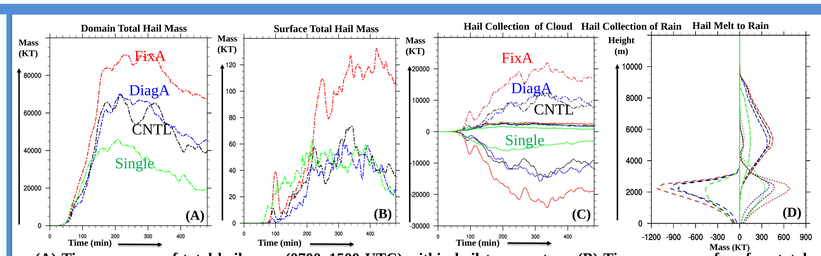
## Microphysical Budget Analysis

In order to investigate dominant processes contributing to hail growth and examine the differences among various microphysical schemes, detailed microphysical budget analysis based on the equation of tendency for the $Q_h$ in MY schemes are conducted.

$$\frac{dq_h}{dt}_S=\left(\delta_{rh}\left(QCL_{hr}+QCL_{ri}\right)+\delta_{sh}\left(QCL_{hs}+QCL_{rs}\right)+\delta_{gh}\left(QCL_{hg}+QCL_{rg}\right)+QFZ_{rh}+QCN_{gh}+QCL_{ch}+QCL_{rh}+QCL_{fh}+QCL_{sh}+QVD_{th}-QML_{hr}\right)$$




(A) Time sequence of total hail mass (0700~1500 UTC) within hailstorm system; (B) dominant microphysical processes contributing to hails growth; (C) profile of the mean hail mass production rates of dominant microphysical processes; (D) profile of hail embryos mass during Rapid hail mass Growth Stage.

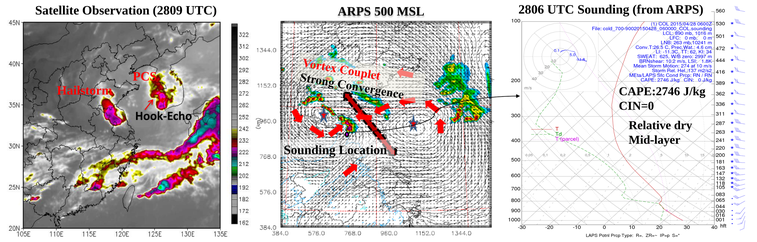



(A) Time sequence of total hail mass (0700~1500 UTC) within hailstorm system; (B) Time sequence of surface total hail mass; (C) Time sequence of dominant microphysical processes contributing to hail growth; (D) profile of the mean hail mass production rates of dominant microphysical processes.

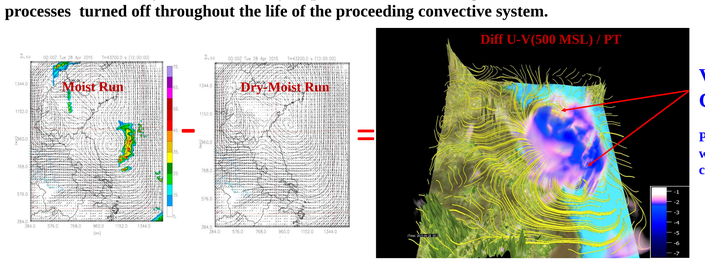
- Collection of cloud and rain contribute most to hail growth. Dominant sink of hail is melting to rain. Maximum rate of cloud collection occurs near 6 km, and maximum rate of rain collection is at around 2 km.
- Because of the humid and maritime environment, hail mainly originate from frozen-drop embryos. The richest embryos zone is between 4-6 km.
- Budget analysis of the sensitivity runs suggest that the different treatment of PSD parameters between the sensitivity runs result in the difference in the terms contributing to hail growth. Results are also consistent with the *SAHNC*, accumulated hail mass at ground, and vertical hail distribution characteristics.

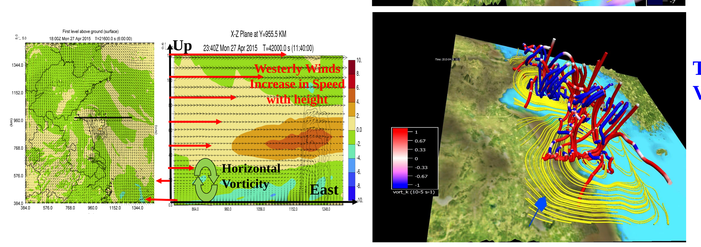
## Convection Initiation Mechanism

We were surprised to find before the day hailstorm happened, another proceeding convective system(PCS) developed intensively and moved eastward to the sea, even with a hook-shaped echo appendage developed near the northern apex of a segment. At the next day afternoon, there existed one strong low-level convergence line along east coast of China and severe hailstorm burst out.




To explain the role of the proceeding convective system in the convection initiation of the hailstorm, we conduct another Dry-Moist sensitivity experiment – the settings are the same as CNTL, but with moist processes turned off throughout the life of the proceeding convective system.




- The rearward spreading cold pool, together with the positive vertical environmental shear, generated strong long-lived vortex couplet.
- The vortex couplet originated from tilting of the horizontal baroclinic vorticity produced by the cold pool.

## Conclusion

- ➢ The multi-moment microphysics schemes have certain skill in hail size forecasting, with the three-moment scheme performing the best.
- ➢ Due to the humid coastal maritime air mass, in this case hailstones mainly originate from frozen-drop embryos.
- ➢ Dominant sources contributing to hail growth are hail collection of rain and cloud, and the main sink is hail melting to rain.

- ◆Strong low-level convergence between the vortex over Jiangsu province and the vortex circulation connected with the rearward spreading cold pool forced deep upwelling of moist air, initiating the convective cells that evolved into a bow-shaped hailstorm.
- ◆The rearward spreading cold pool, together with the positive vertical environmental shear, generated strong long-lived vortex couplet.
- ◆The vortex couplet originated from tilting of the horizontal baroclinic vorticity produced by the cold pool.