Numerical Simulation of a Hailstorm Event of April 2015 in Eastern China: Hailstone Size Forecast, Microphysical Budget, and Convection Initiation Mechanism

Liping Luo[1], Ming Xue[2] , Kefeng Zhu[3]

1:College of Atmospheric Science, Nanjing University, China

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

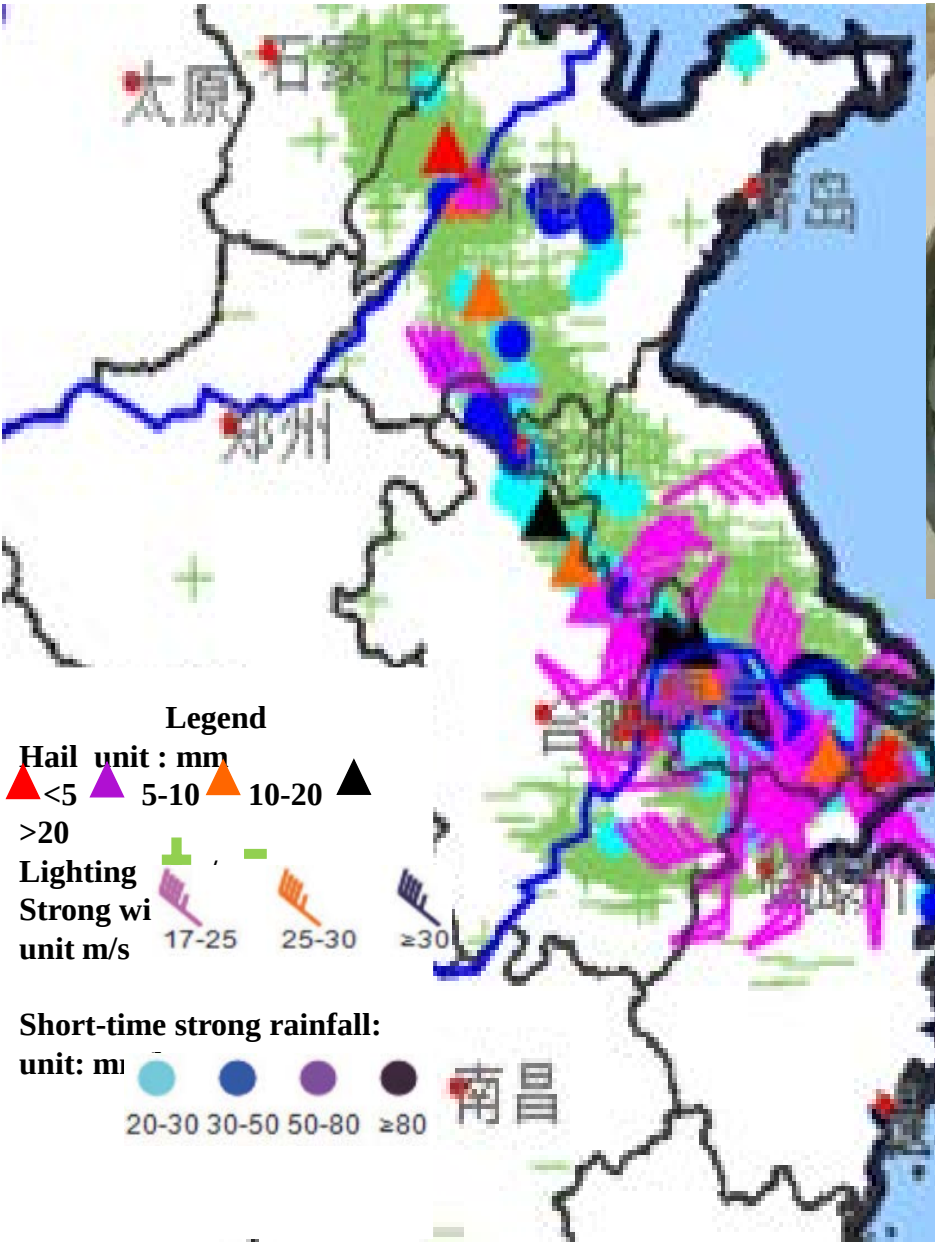
3:College of Atmospheric Science, Nanjing University, China

November 8th, 2016

Motivation

- **The forecasting of hailstone size or intensity poses big challenges.**
- Current NWP models rely on bulk microphysics parameterization schemes (BMSs) to represent cloud microphysics and hail formation processes.
  -Milbrandt and Yao(2005a,b)
  -Morrison and Milbrandt (2010)
  -Nathan Snook and Xue(2015)
- **Few studies have tried to explicitly predict hail sizes or study the main processes contributing to hail growth in real cases.**

Hailstorm Case - 28 April 2015 in Jiangsu Province China



---produced large quantities of golf-ball sized hailstones

---Hail, strong winds and lightning

--- Lasting for seven hours

Questions we try to Answer

- **How skillful is the hailstorm forecasting for this case?**
- **Model skills in terms of Hail size and intensity?**
- **Which processes make dominant contributions to hailstone growth?**
- **What is the Convection Initiation mechanism of this long-lived severe hail storm?**

Experiments set up WRF3.6.1 — ARPS 5.3

WRF3.6.1

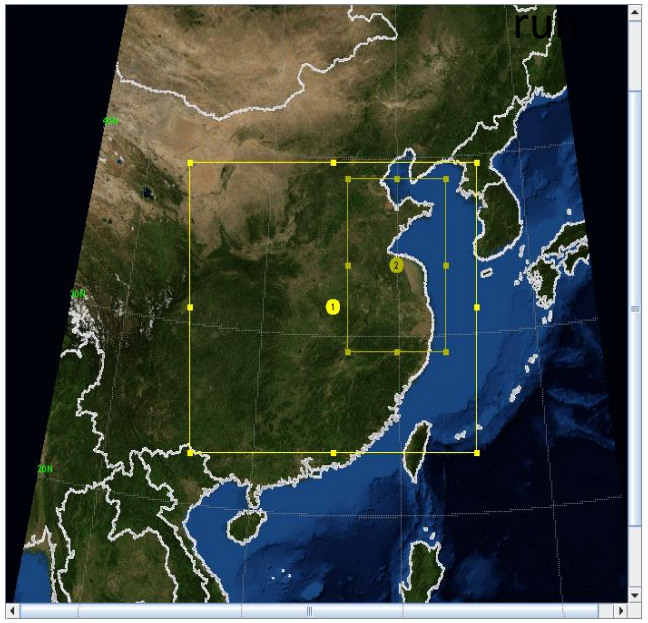
Domain (2-way nesting)	D01 :660 x 600 x 50 grid points . 3km horizontal grid spacing D02: 979 x 1000 x50 . 1km
Initial field	FNL data， 1 degree 6-hourly boundary conditions
Forecast period	2015.4.27:1200~28.1600UTC
Parameterization	Microphysics Schemes . HUJI spectral Bin scheme . Milbrandt and Yao(2005) - MY2 double moment . Morrison double moment . Lin et al.(1983) - LIN single moment . NSSL 1 mom . NSSL 2 mom

ARPS 5.3

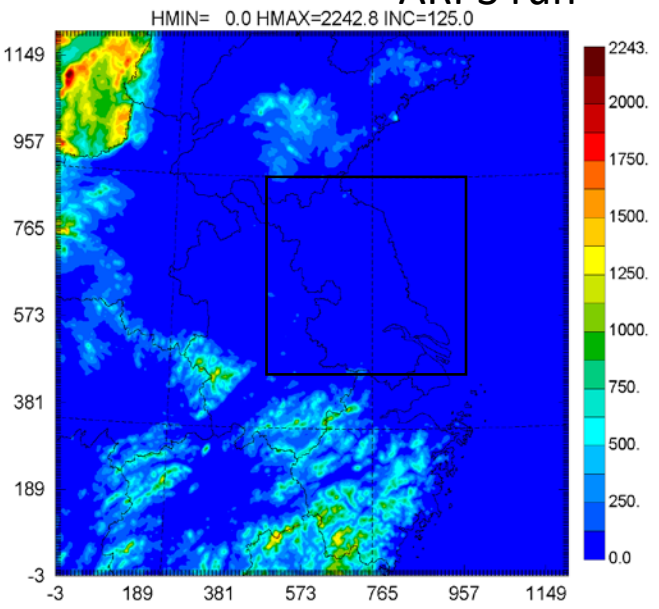
Domain (1-way nesting)	D01 :403 x 403 x 53 grid points . 3km horizontal grid spacing . Stretching in the vertical (min dz=50m) D02: 463 x 463 x 53 . 1km . Stretching in the vertical (min dz=50m)
Parameterization	Microphysics Schemes . Lin et al.(1983) - LIN single moment . Milbrandt and Yao(2005) - single moment - double moment (shape parameter fixed or diagnosed) - Triple moment

Grid configuration

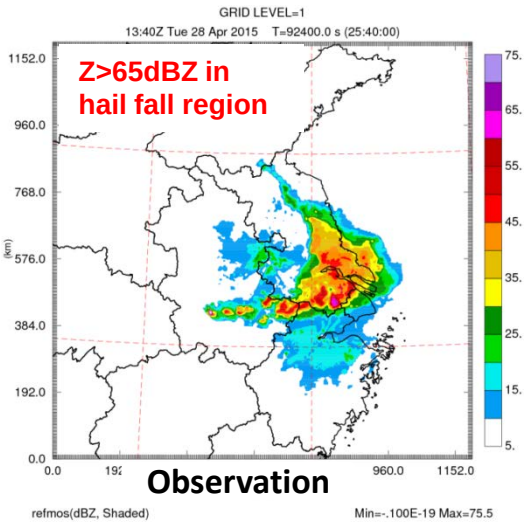
WRF run



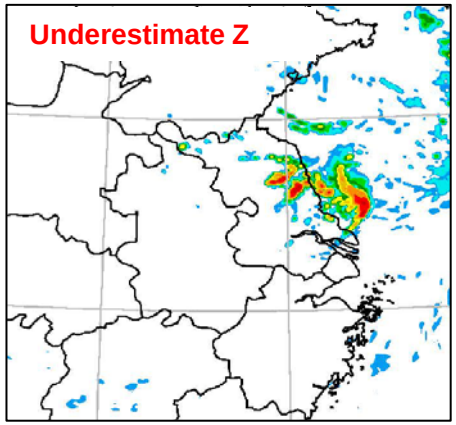
ARPS run



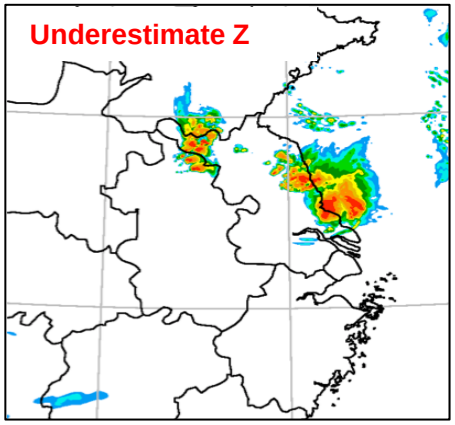
WRF 25h 40 min forecasts with different MP schemes



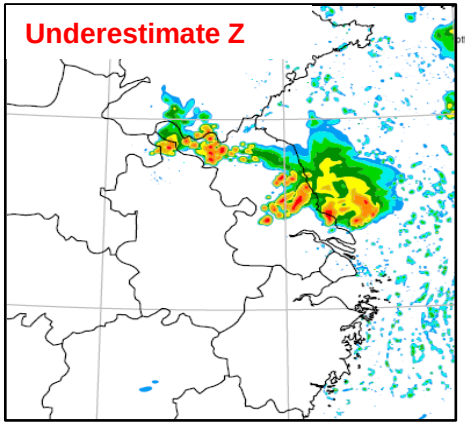
Observation



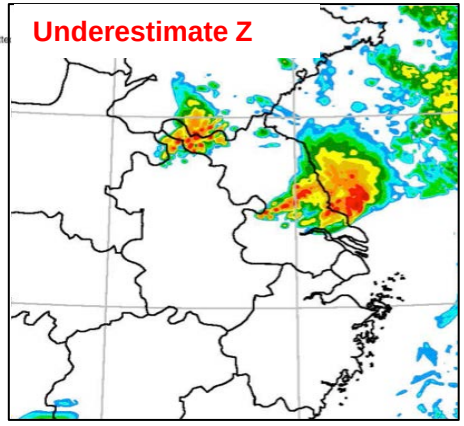
Lin scheme



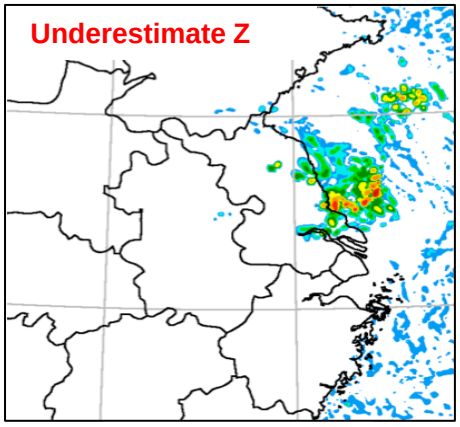
Morrison scheme



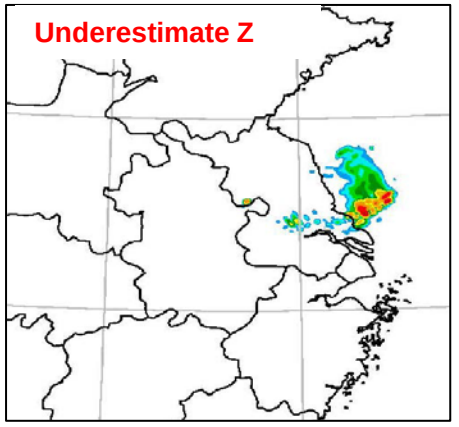
M&Y 2mom scheme



Bin scheme



NSSL- 1mon

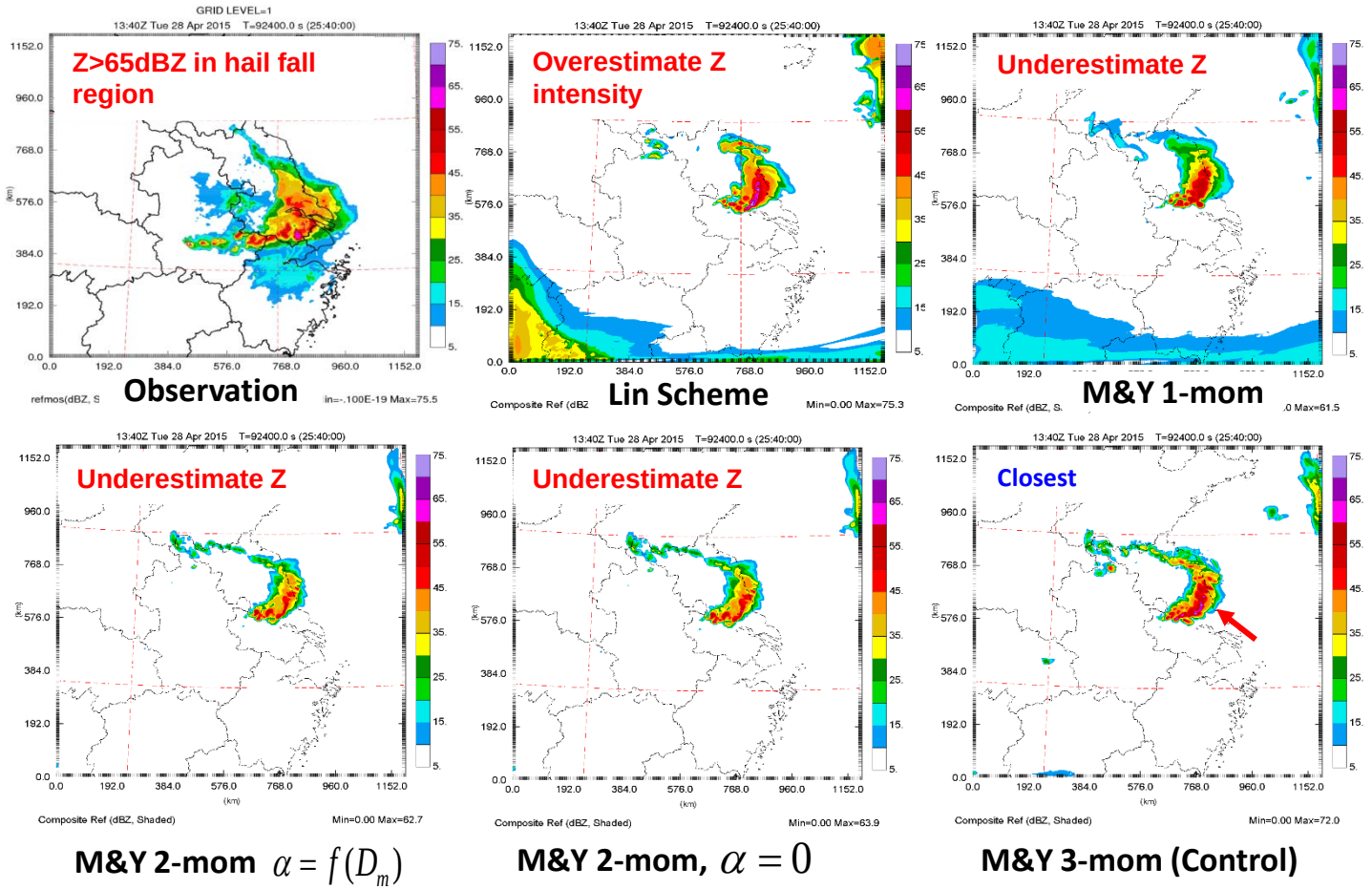


NSSL- 2mon

Lin / Morrsion / M&Y 2-mom / NSSL 1-mom / NSSL 2-mom / Bin scheme: underestimate Z intensity

Generally poor organization of the hail storm

ARPS 25h 40 min forecasts with different MP schemes



M&Y 1 and 2-mom: **underestimate** Z intensity

LIN : **overestimates** Z intensity

M&Y 3-mom： **Reasonable** results with Z>65dBZ in hail fall region

Reasonable prediction of the bow-shaped echo of the hail storm

Questions we try to Answer

- **How skillful is the hailstorm forecasting for this case?**
- **Model skills in terms of Hail size and intensity?**
- **Which processes make dominant contributions to hailstone growth?**
- **What is the Convection Initiation mechanism of this long-lived severe hail storm?**

Hailstone Size Forecast

To determine the presence of hail larger than a given size reaching the ground, we calculate the parameter,

ACC-Nt --- Ground Accumulated Hail Number Concentration larger than D*

1. Total number concentration of hailstones larger than D*

$$N_h\{D^*\} = \int_{D^*}^{\infty} N(D)\,dD$$

2. Terminal velocity of a given size hailstone; Ferrier(1994)

$$V_h(D) = ra_h \times D^{b_h} \times \exp(-f_h D), \mathrm{r} = \left(\frac{\rho_0}{\rho}\right)^{1/2} \quad a_h = 206.89, b_h = 0.6384, f_h = 0$$

3. Surface Flux of Hailstones larger than D*

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

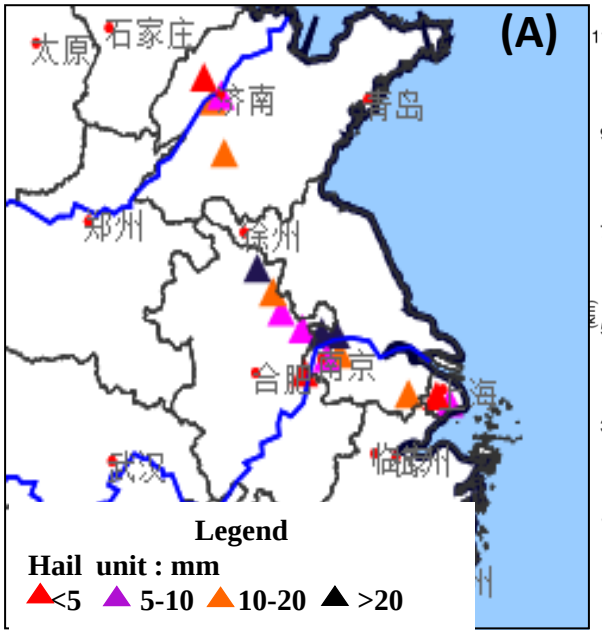
4. Time integration of hailstone flux at surface to obtain the accumulated field

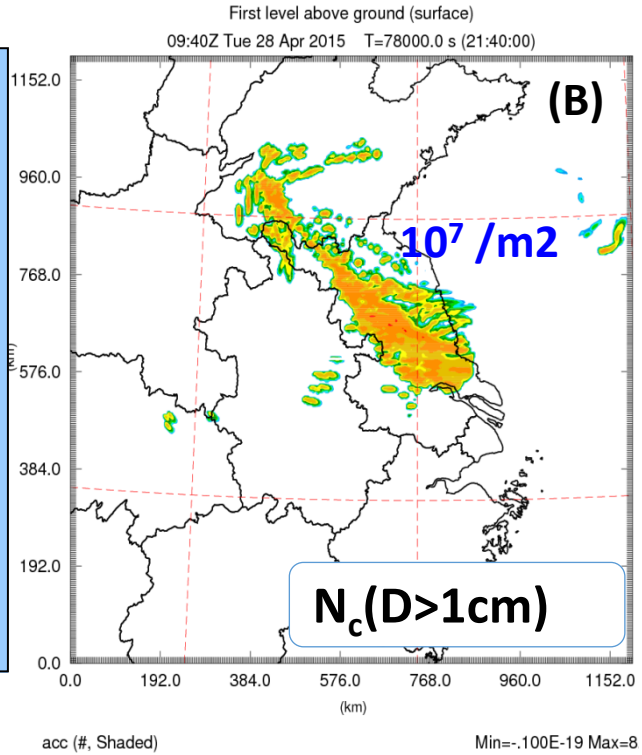
at 60-second interval during hail burst period

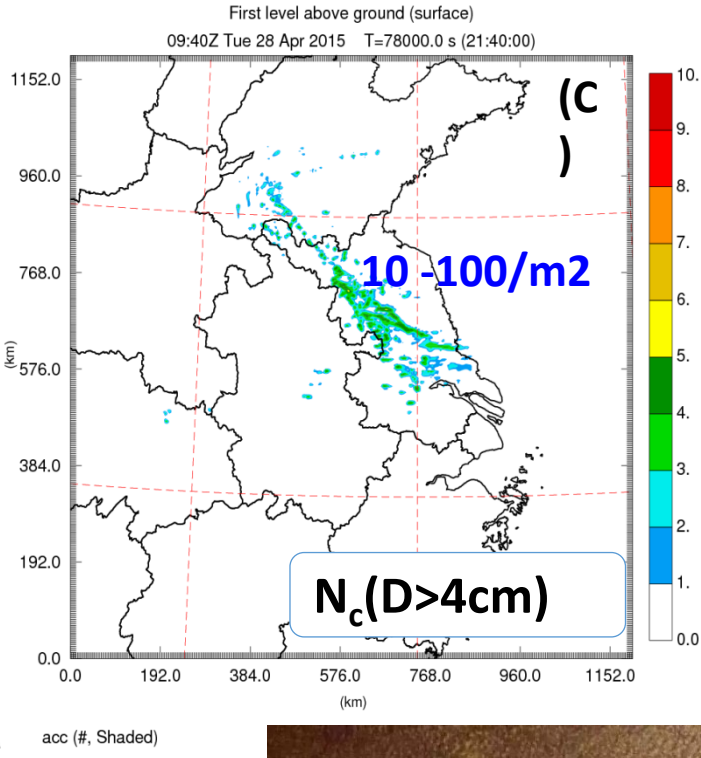
$$Acc\_Nt\{D^*\} = \sum_{T\min 0}^{T\min 1} R_h\{D^*\} * 60$$

ACC-Nt - Ground Accumulated Hail Number Concentration from 2807-1500UTC

Severe weather reports







Swath of ACC-Nt is in good agreement with observation, although a little bit scattered.

CNTR experiment using 3 moment microphysics scheme can produce the largest hailstones, those having diameters exceed 4 cm or larger, about the size of an egg.

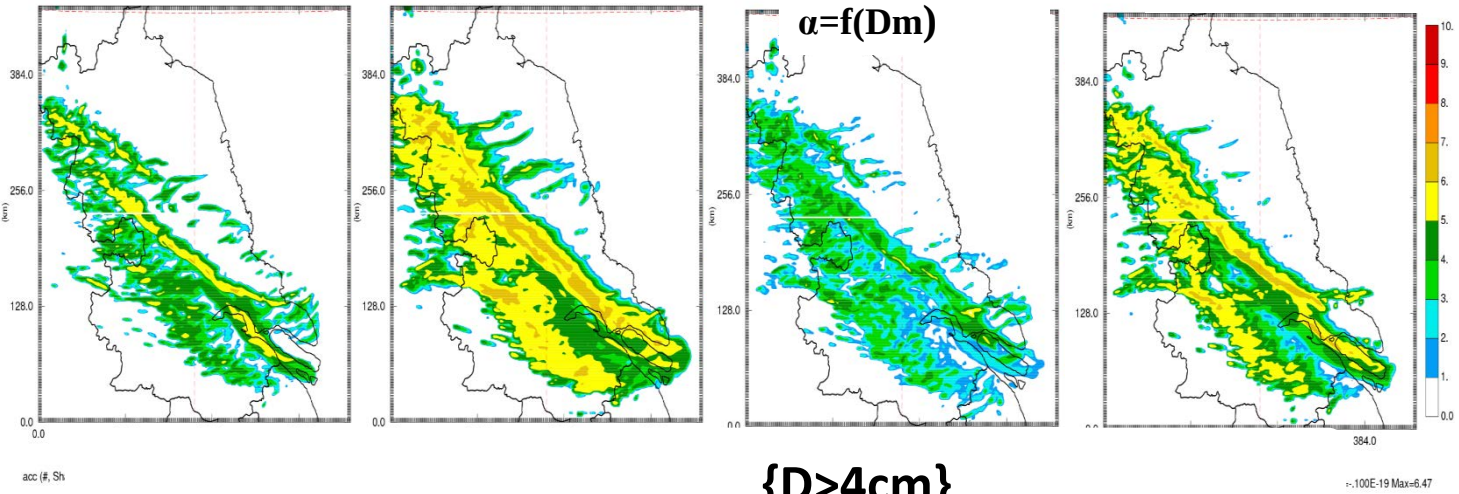
Ground Accumulated Hail Number Concentration

ACC-Nt{D>2cm & D>4cm}

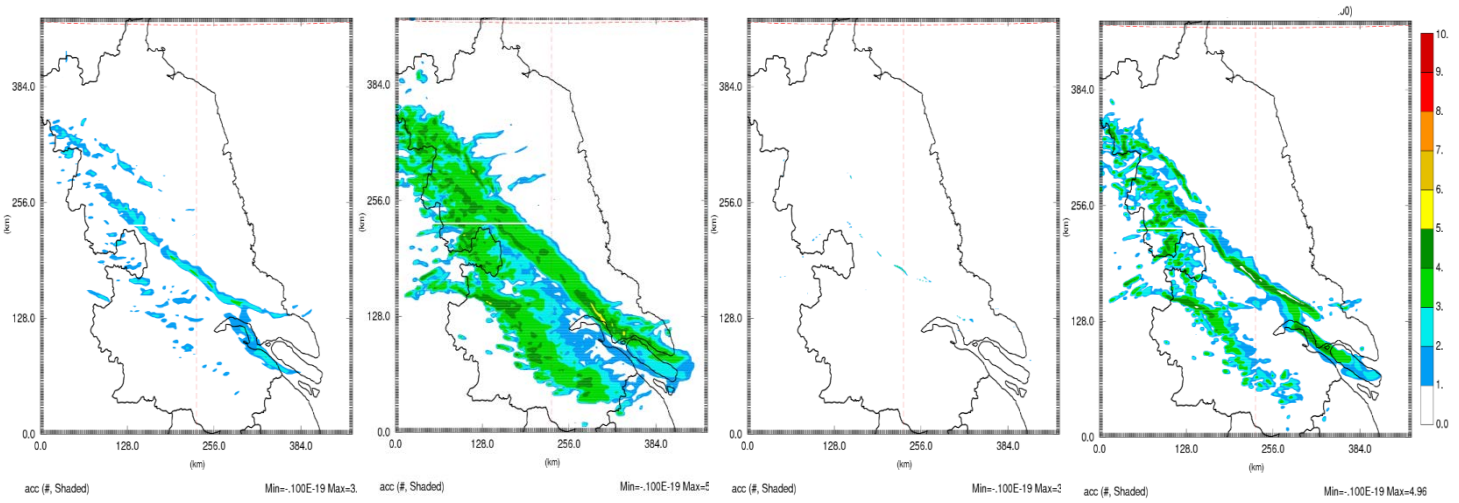
2807—2815 UTC

ACC-Nt{D>2cm}

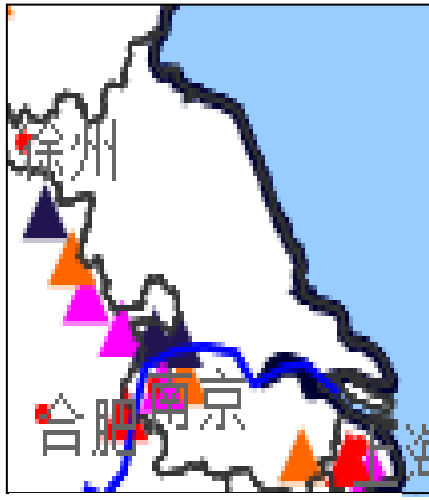
MY1 | MY2 α= 0 | MY2 α=f(Dm) | MY3



{D>4cm}



Severe weather reports



-**MY1 and MY2_diag** **underestimate** the size and intensity of hail

-**MY2_fixed** **overestimate** the spatial extent of larger hailstones

-**MY3** captures the **closest** ACC_Nt signature to observation

Questions we try to Answer

- **How skillful is the hailstorm forecasting for this case?**
- **Model skills in terms of Hail size and intensity?**
- **Which processes make dominant contributions to hailstone growth?**
- **What is the Convection Initiation mechanism of this long-lived severe hail storm?**

Microphysics Budget

To investigate the dominant processes contributing to hail growth, we conduct microphysics budget analysis based on the equation of tendency for the hail mass content in M&Y microphysics scheme,

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

Hail collect of cloud

Hail collect of rain

Hail melt to rain

*Totally **11 source and sink terms** on the right side of equation, namely:*

{Ice to rain & rain to ice } collection freezing between ice and rain to producing hail

{snow to rain & rain to snow } collection freezing between snow and rain to producing hail

{graupel to rain & rain to graupel} collection freezing between graupel and rain to producing hail

Cloud to hail >collection

Rain to hail >collection

Ice to hail >collection

Snow to hail >collection

Water vapor to hail >diffusional growth

Hail to rain >melting

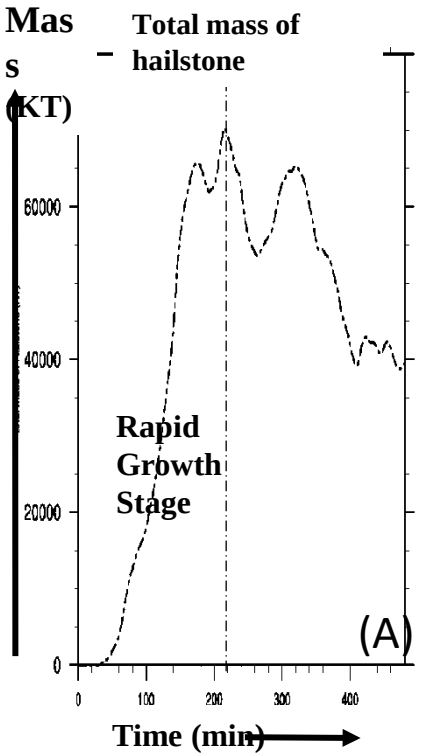
Rain to hail > freezing

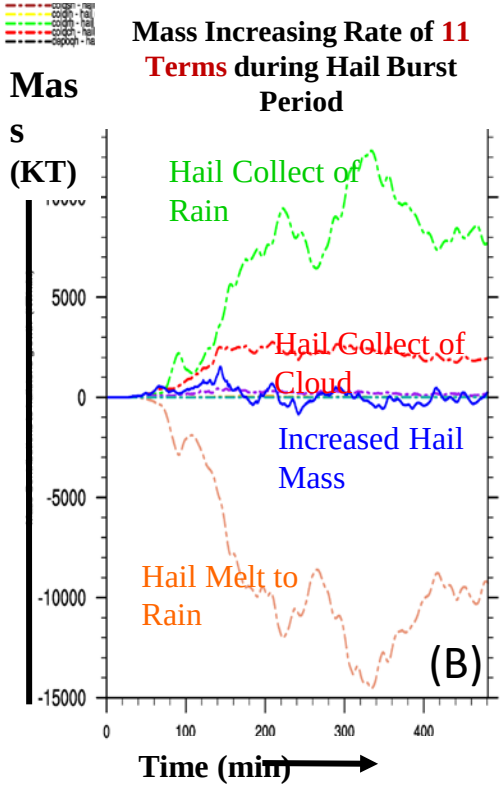
Graupel to hail >conversion

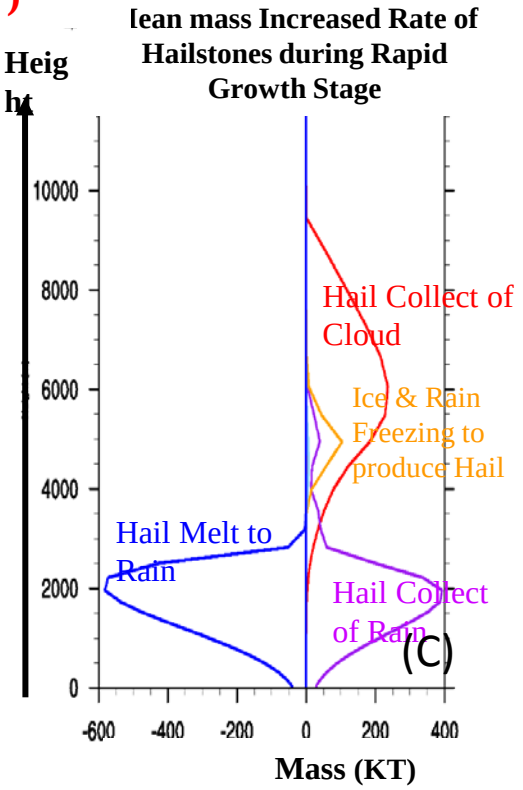
Processes Contribute to Hailstone Mass Growth

Microphysics Budget Analysis

CNTR run --- MY3 (2807 ~ 2815 UTC , dt=60s)



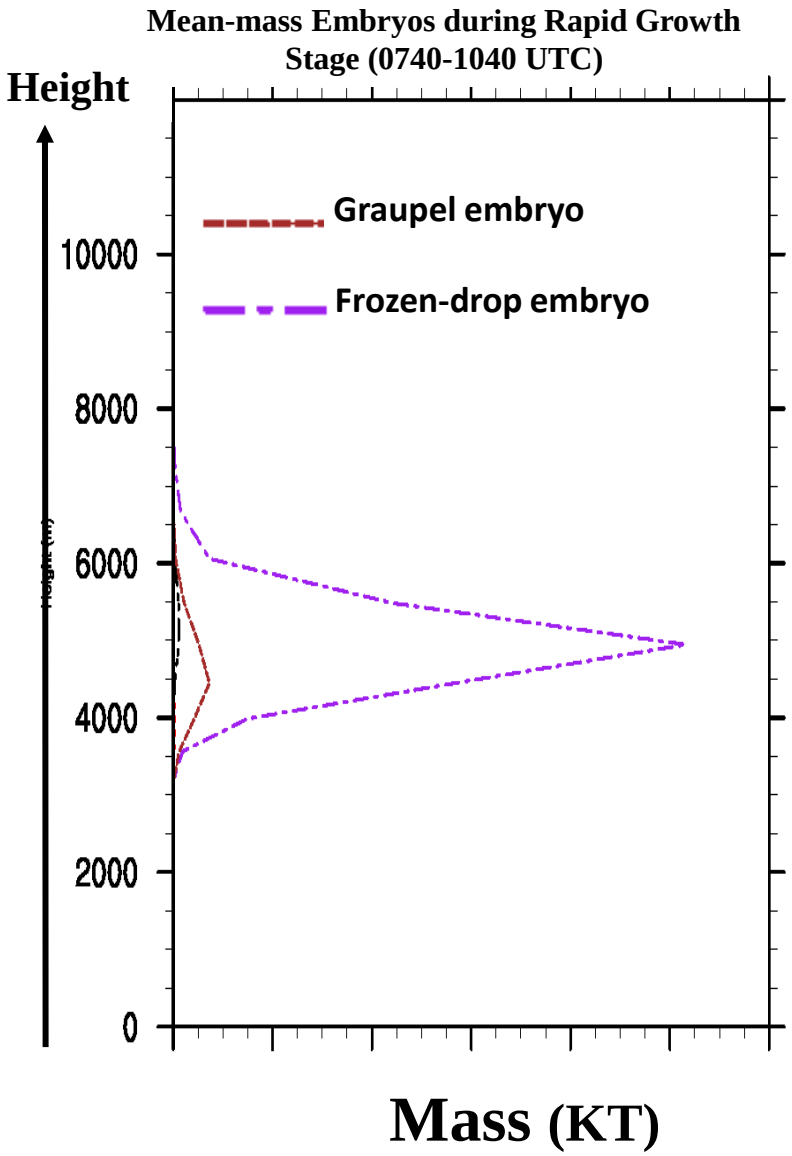




- Rapid growth stage of hailstones from 07:40 to 10:40 UTC
- Hail collect of cloud & hail collect of rain contribute most to the hailstone growth. Dominant sink of hailstone is hail melt to rain.
- Hail collect of cloud mainly happens nearly 6 km. Below the melting layer, hail collect of rain and hail melting to rain. Maximum occurs at 2 km , cloud base

Microphysics Budget Analysis

CNTR run --- MY3 (2807 ~ 2815 UTC , dt=60s)



- Relatively humid and maritime climatology originated from the frozen-drop embryos
- Richest embryos zone between **4-6 km**

Summary on Hail Prediction and Growth

- The ARPS with multi-moment MY schemes can predict the general evolution of the hailstorm better than with single-moment scheme, with the three-moment scheme performing the best.

- The MY three-moment scheme has certain skill in hail size forecasting. The predicted size and number concentration at ground appear consistent with limited observations.

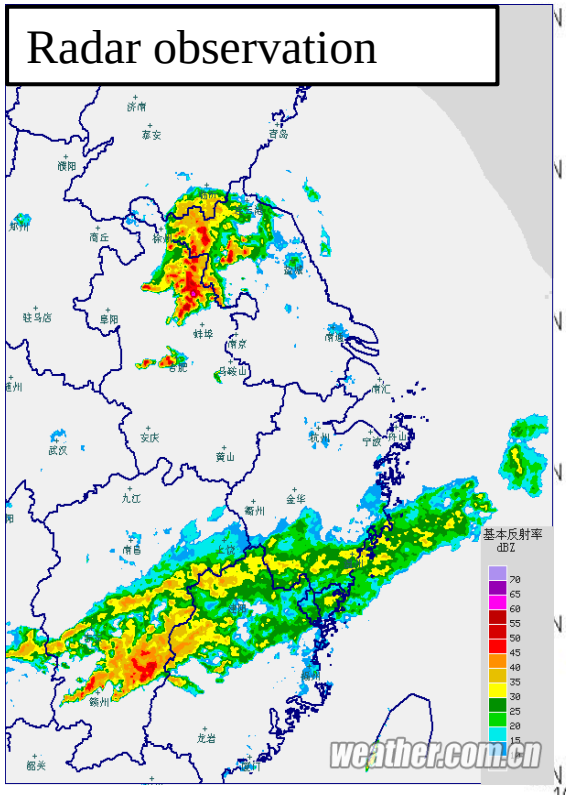
- Due to the relatively humid coastal and maritime air mass in this case, hailstones mainly originate from frozen-drop embryos.

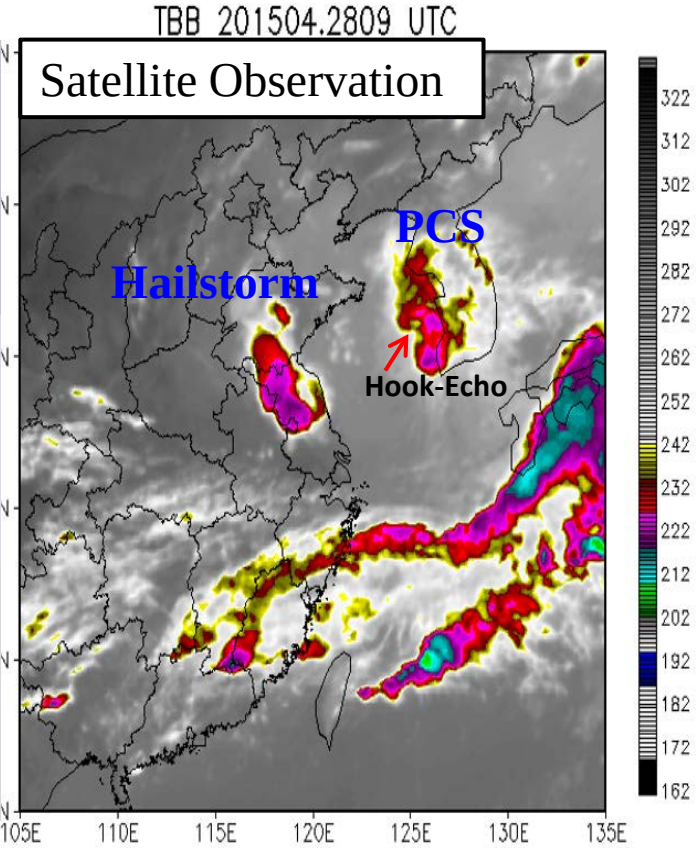
- Dominant sources contributing to hail growth are hail collection of rain and cloud, and the main sink is hail melting to rain.

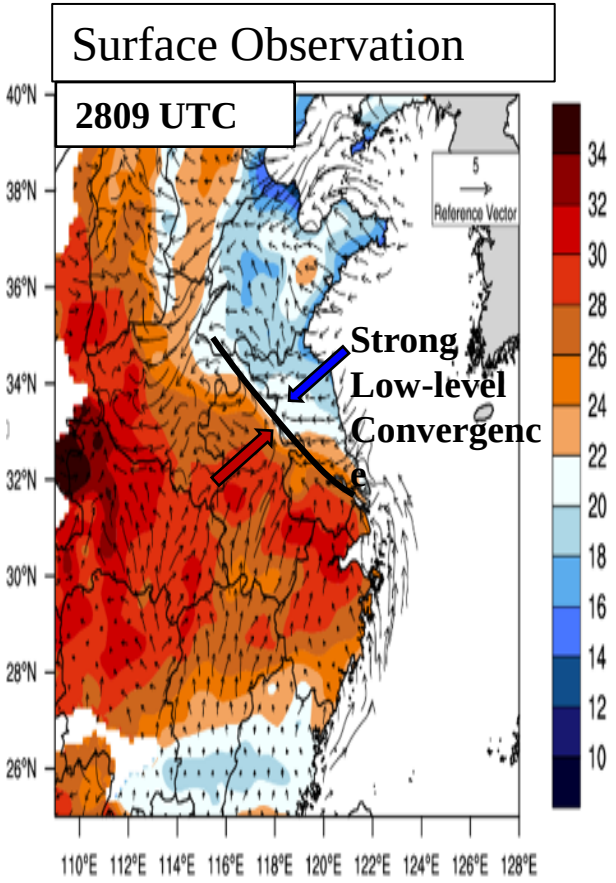
Questions we try to Answer

- **How skillful is the hailstorm forecasting for this case?**
- **Model skills in terms of Hail size and intensity?**
- **Which processes make dominant contributions to hailstone growth?**
- **What is the Convection Initiation mechanism of this long-lived severe hail storm?**

Convection Initiation Mechanism



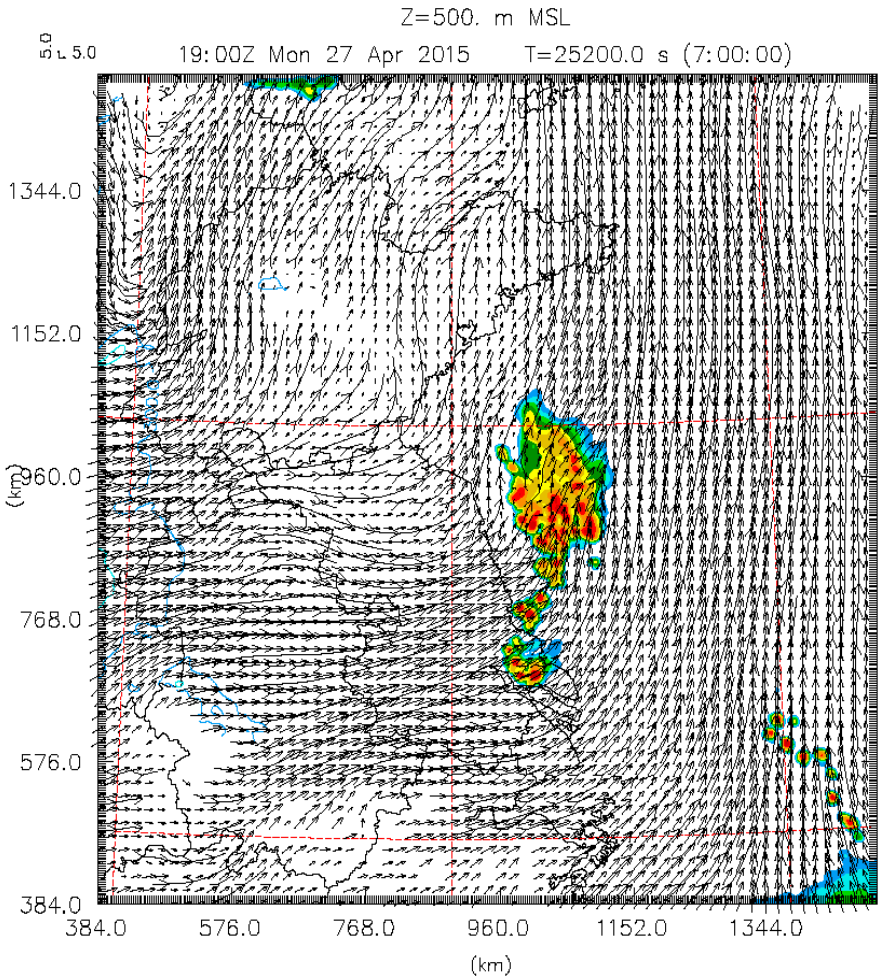




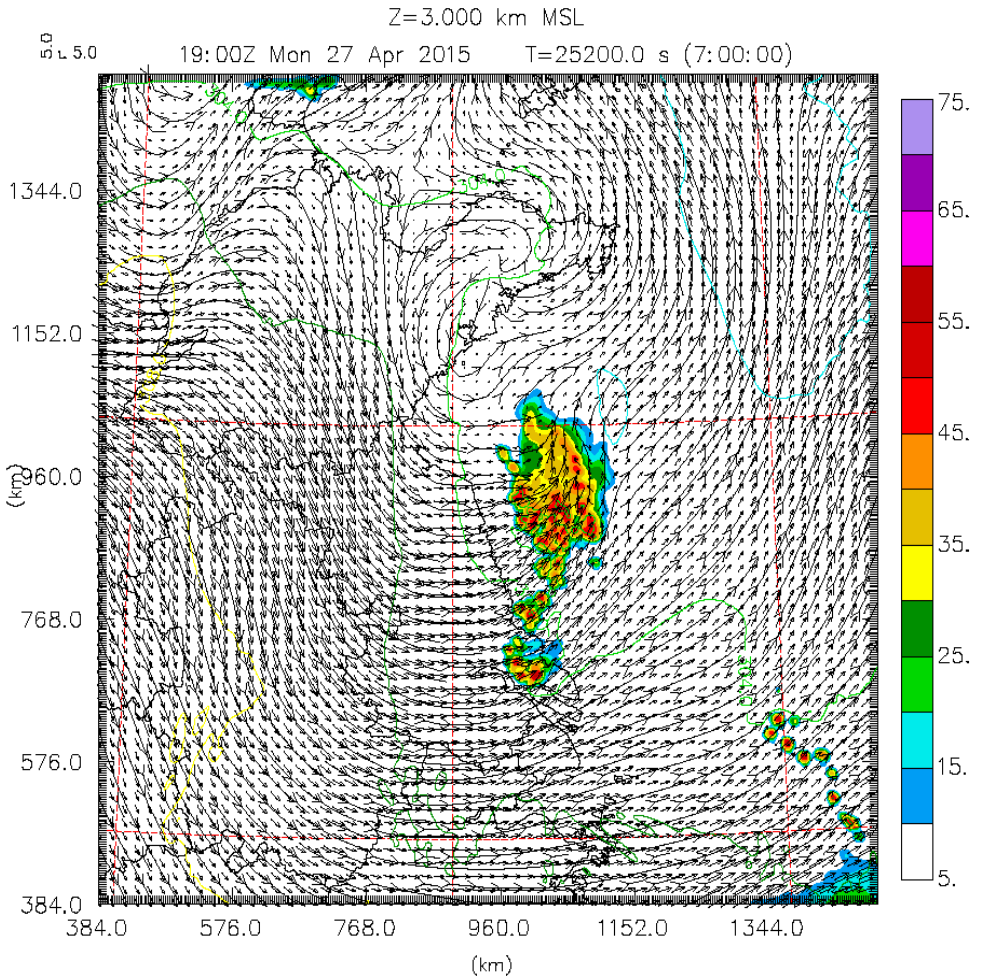
- **PCS** --- Proceeding convective system generated at the night of 27 April and continued moving eastward to the sea.
- **Hailstorm** --- hailstorm swept Jiangsu Province in 7 hours, producing golf-sized hailstones.
- **Strong convergence line along the east coast of China**

ARPS model simulation

500 m MSL



3 km MSL

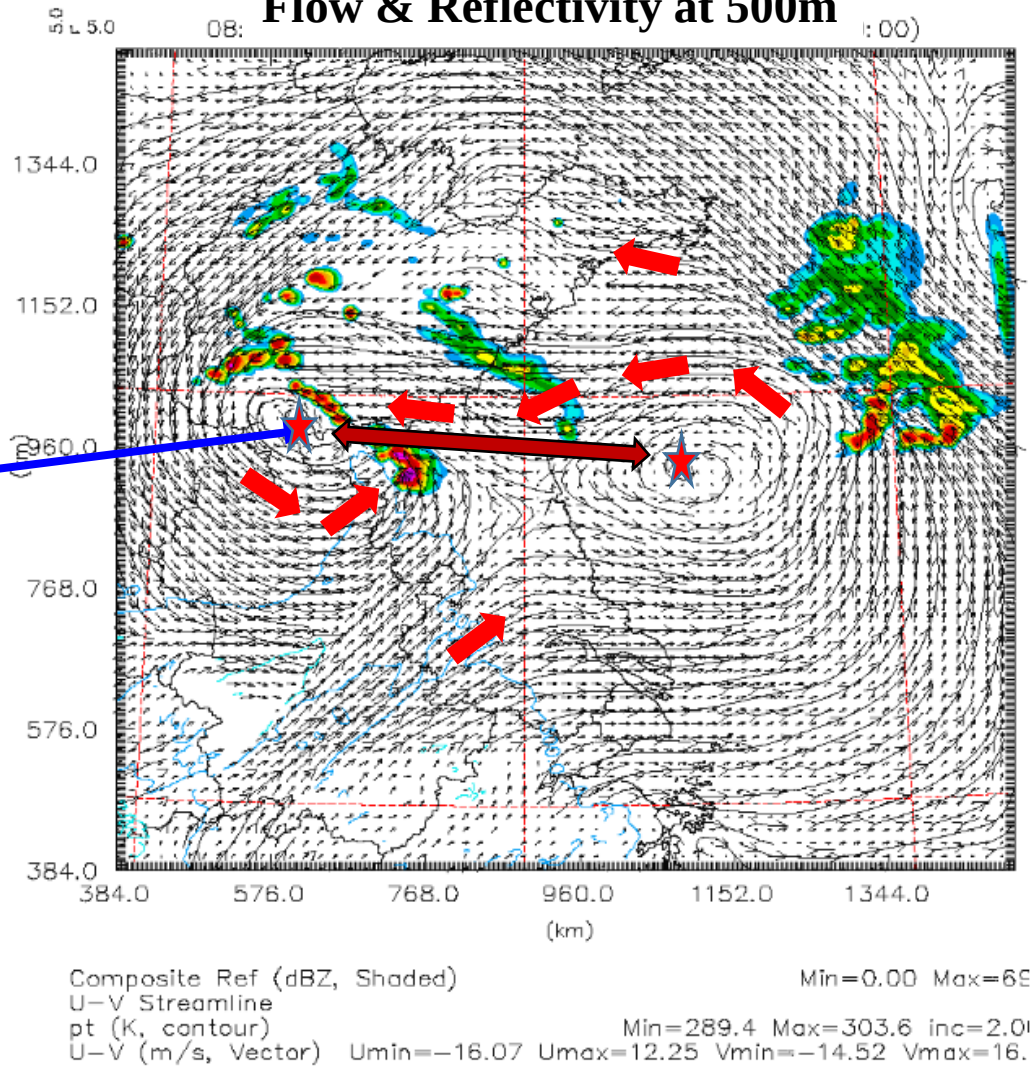


- 500 m MSL, strong developing mesoscale vortex behind the PCS
- **Strong low-level convergence comes from vortex over eastern China and vortex circulation over sea**
- 3 km MSL, another mesoscale cyclonic vortex on the northern end of the PCS

Flow & Reflectivity at 500m

Strong Low-level convergence from one vortex couplet

Severe convection was initiated



Questions

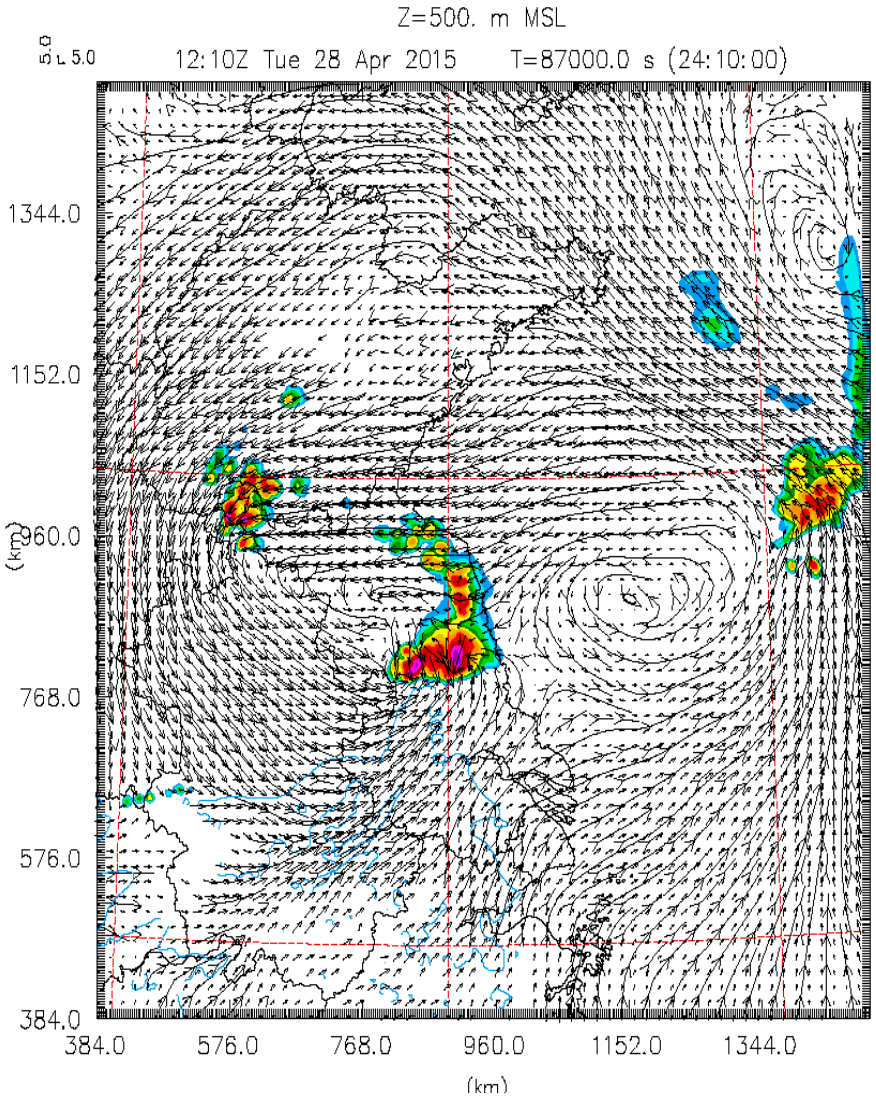
- What is the role of the proceeding convective system (PCS) in the evolution of the hailstorm?

- Where is the origin of the low level vortex over the sea?

A Dry-Moist sensitivity experiment – the same as CNTL, but with moist processes turned off throughout the life of the proceeding convection.

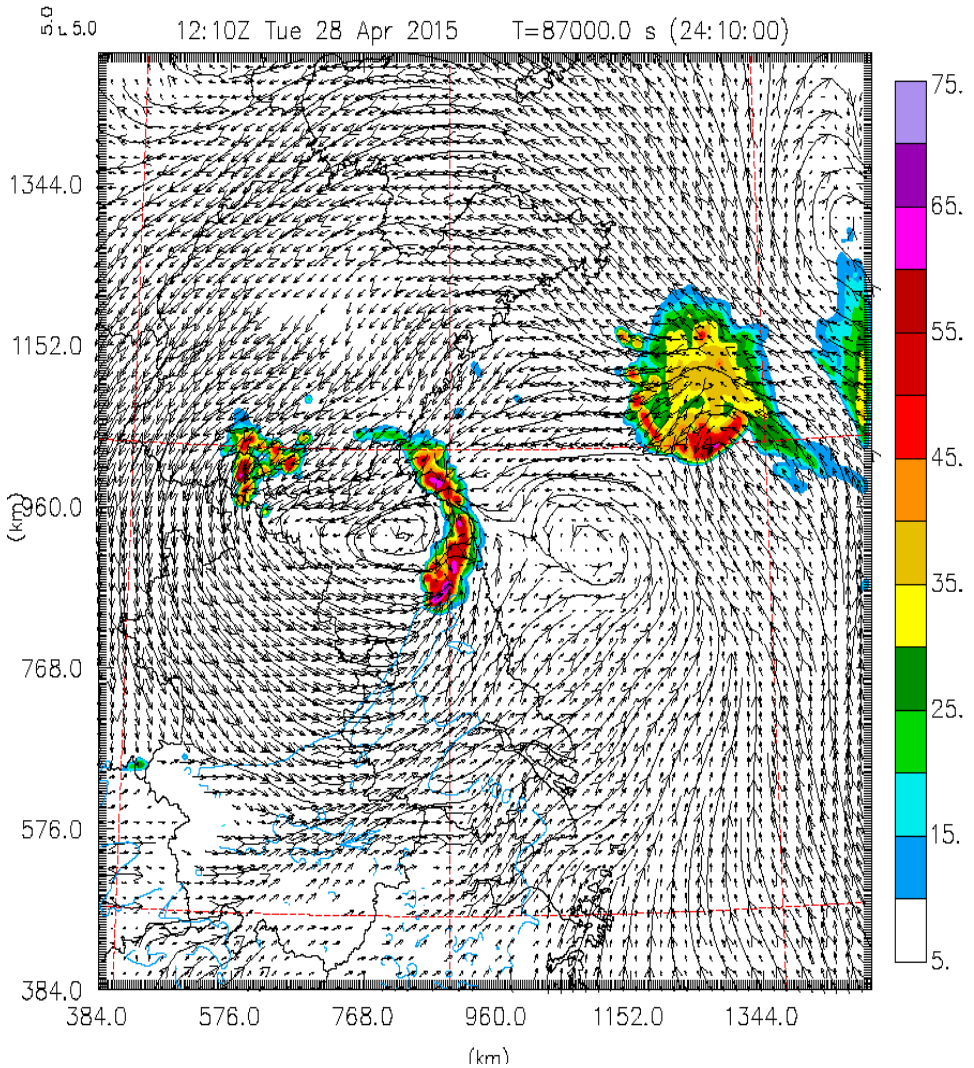
12:10 UTC 500 m

CNTR Moist Run



Dry-Moist Run

Dry run +moist run from 2806 UTC, nearly one hour before CI of the Hailstorm



Dry-Moist run exhibits significant discrepancy:

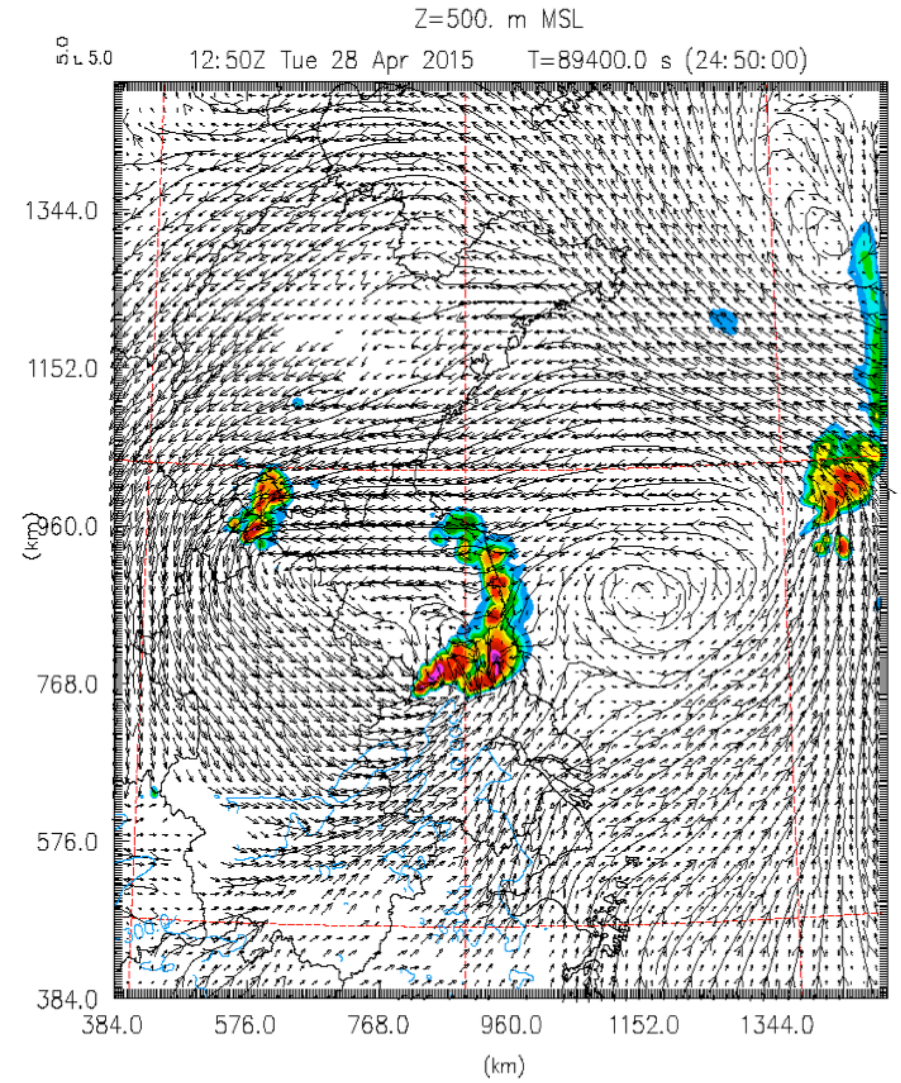
- Hailstorm is still initiated, but is somewhat delayed, and is not as strong as in the CNTR.
- After initiation, the hailstorm moved mostly eastward, instead of southward as observed.

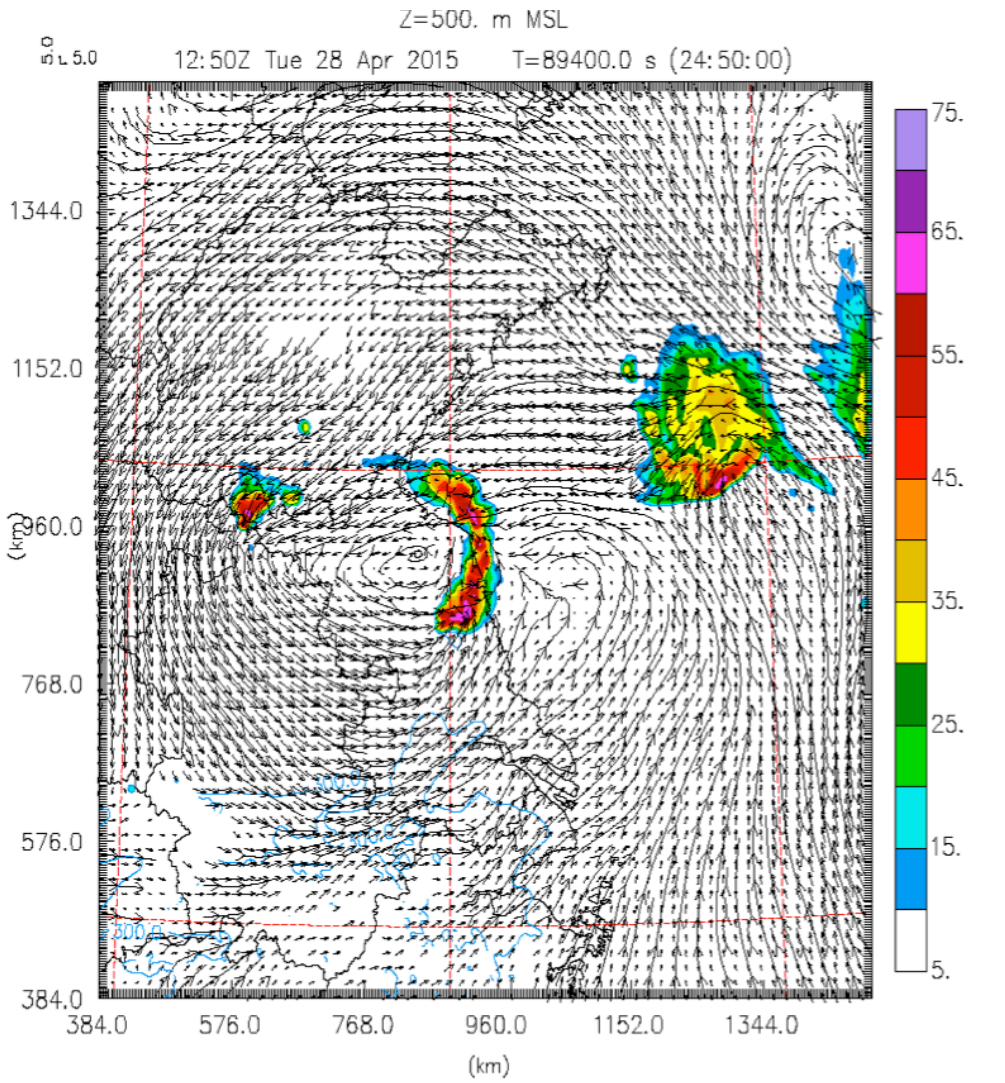
12:50 UTC 500 m

CNTR Moist Run

Dry-Moist Run

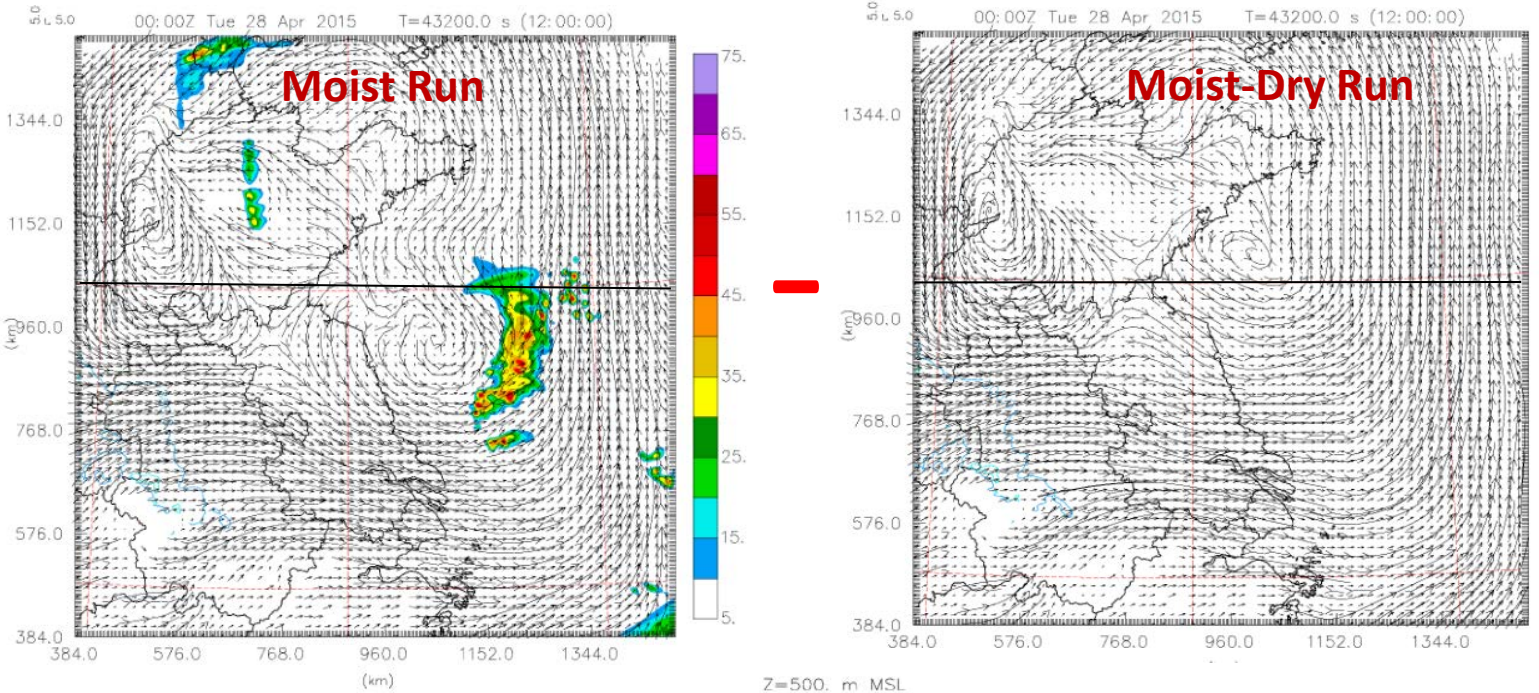
Dry run +moist run from 2806 UTC, nearly one hour before CI of the Hailstorm

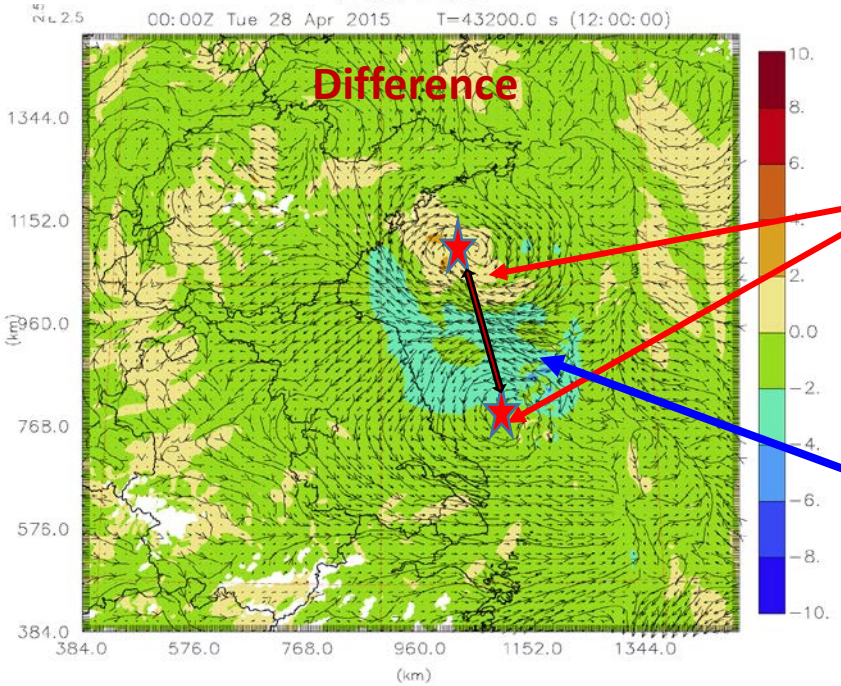




Dry-Moist run exhibits significant discrepancy:

- Hailstorm is still initiated, but is somewhat delayed, and is not as strong as in the CNTR.
- After initiation, hailstorm propagate eastward, instead of southward as observed.

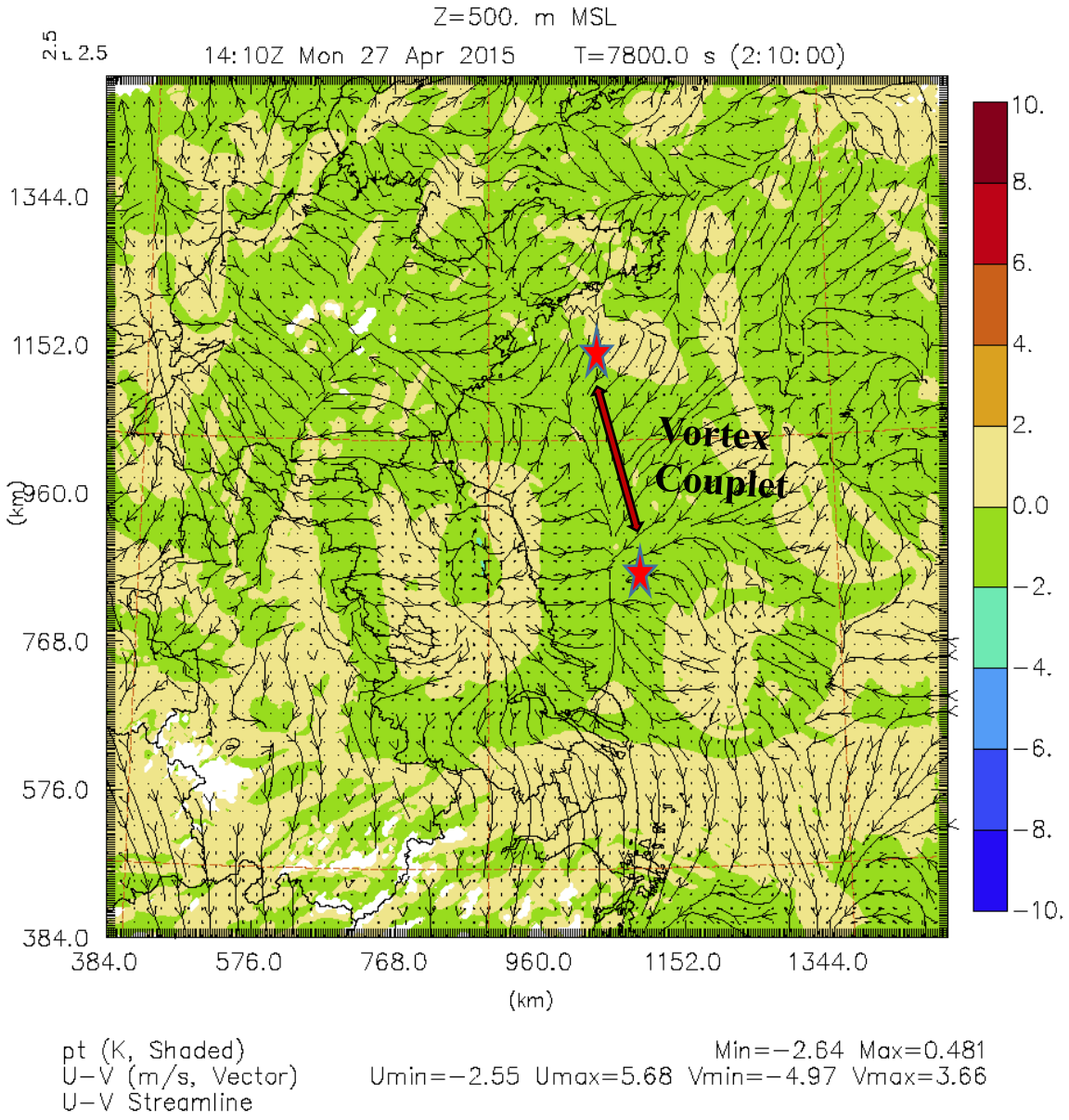




Vortex Couplet

Produced by the rearward spreading cold pool.

Difference



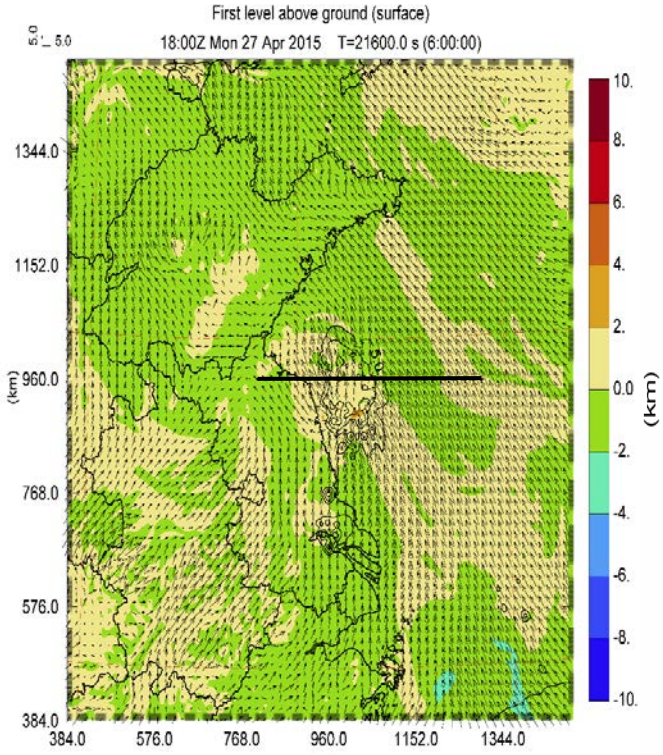
Rearward spreading cold pool generated gust front with strong outflow.

Together with the strong environmental vertical wind shear, long-lived **vortex couplet** are produced at the leading edge of the rearward cold pool outflow boundary.

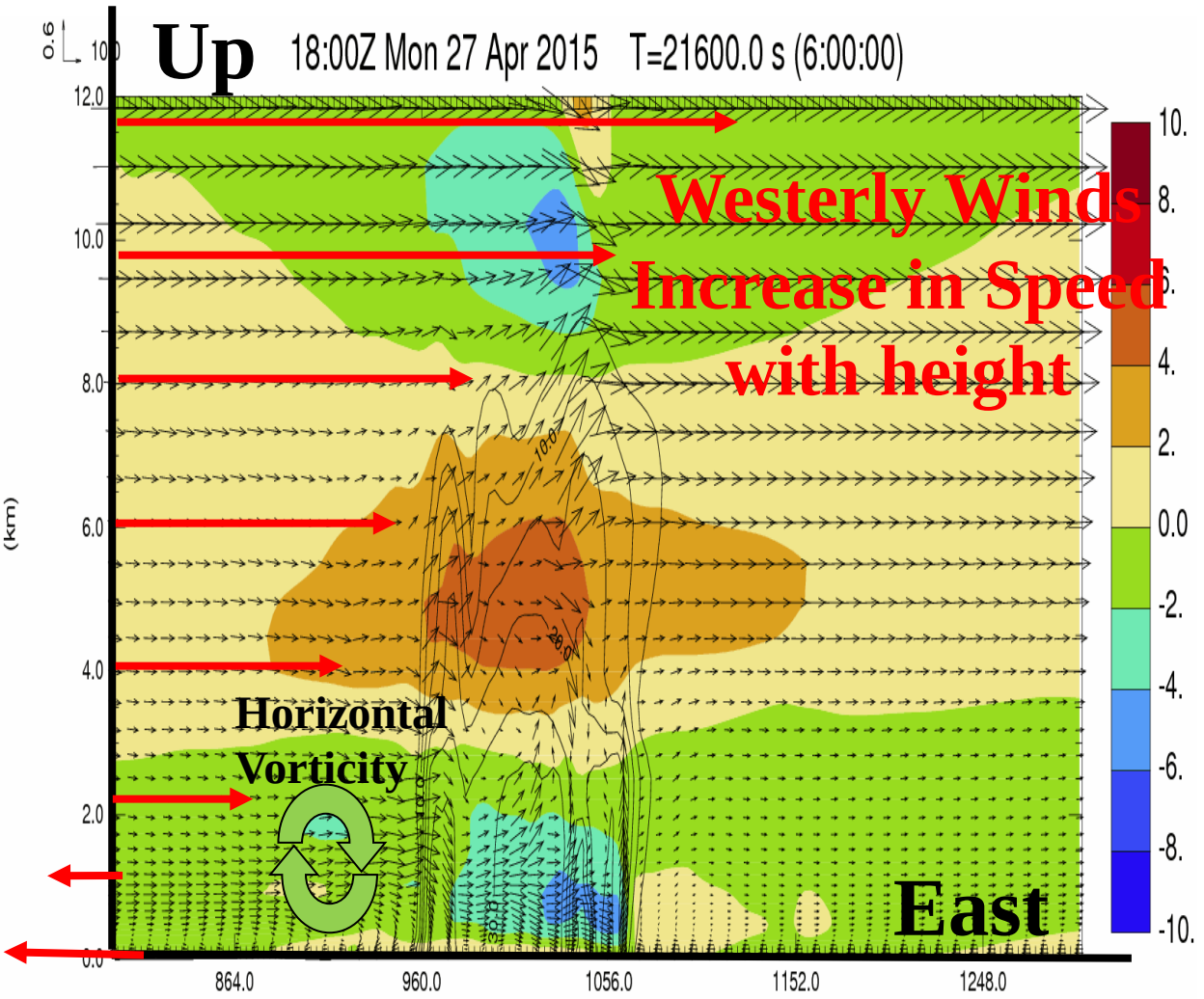
The anticyclonic member of the vortex couplet on the north end of the gust front, acts to counteract with the environmental cyclone over northern part, while the southern cyclonic member becomes stronger, and contributes to the long-lasting convergence line along the east coast of China.

Origin of the vortex couplet

Development of Low-Level Rot

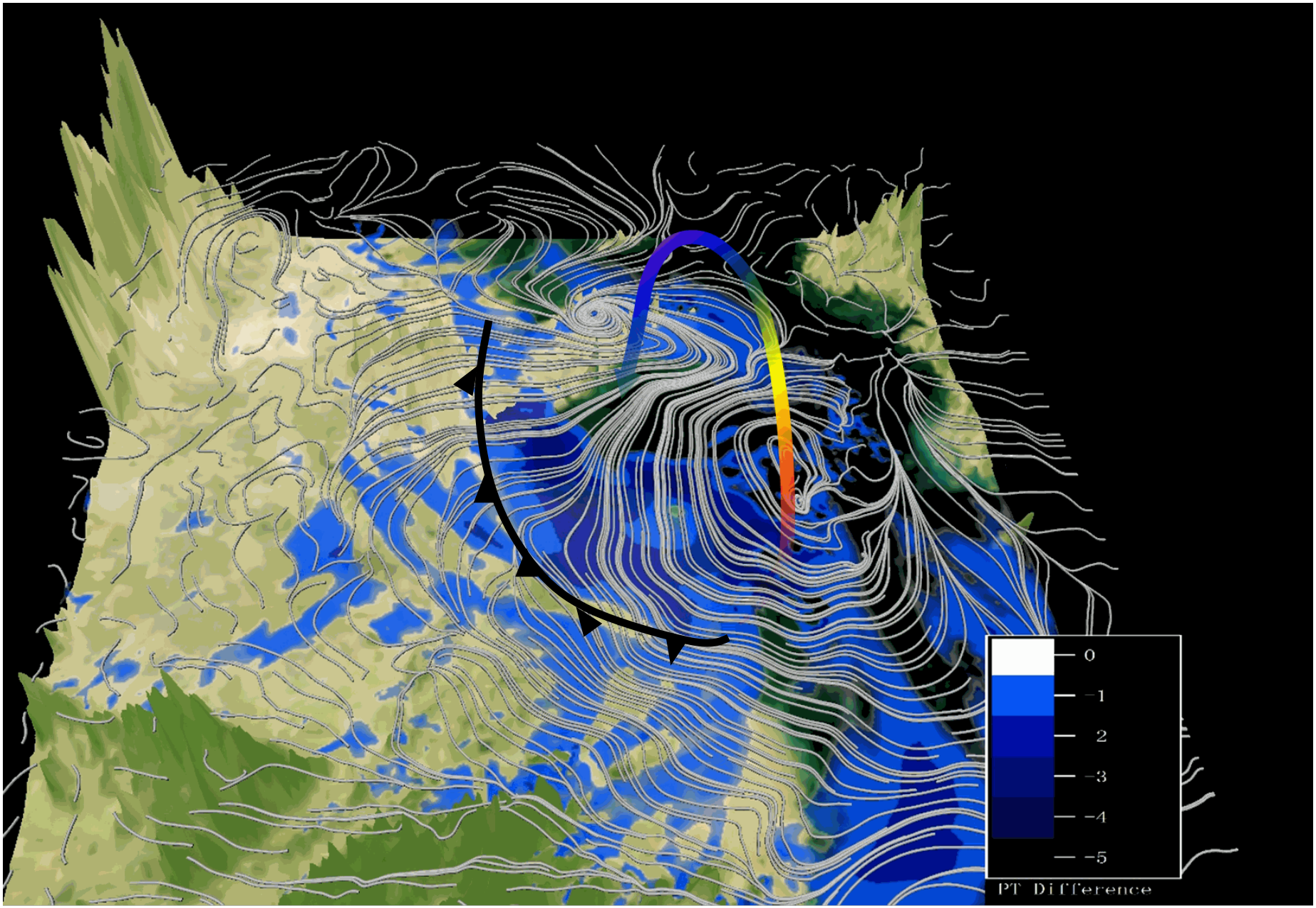


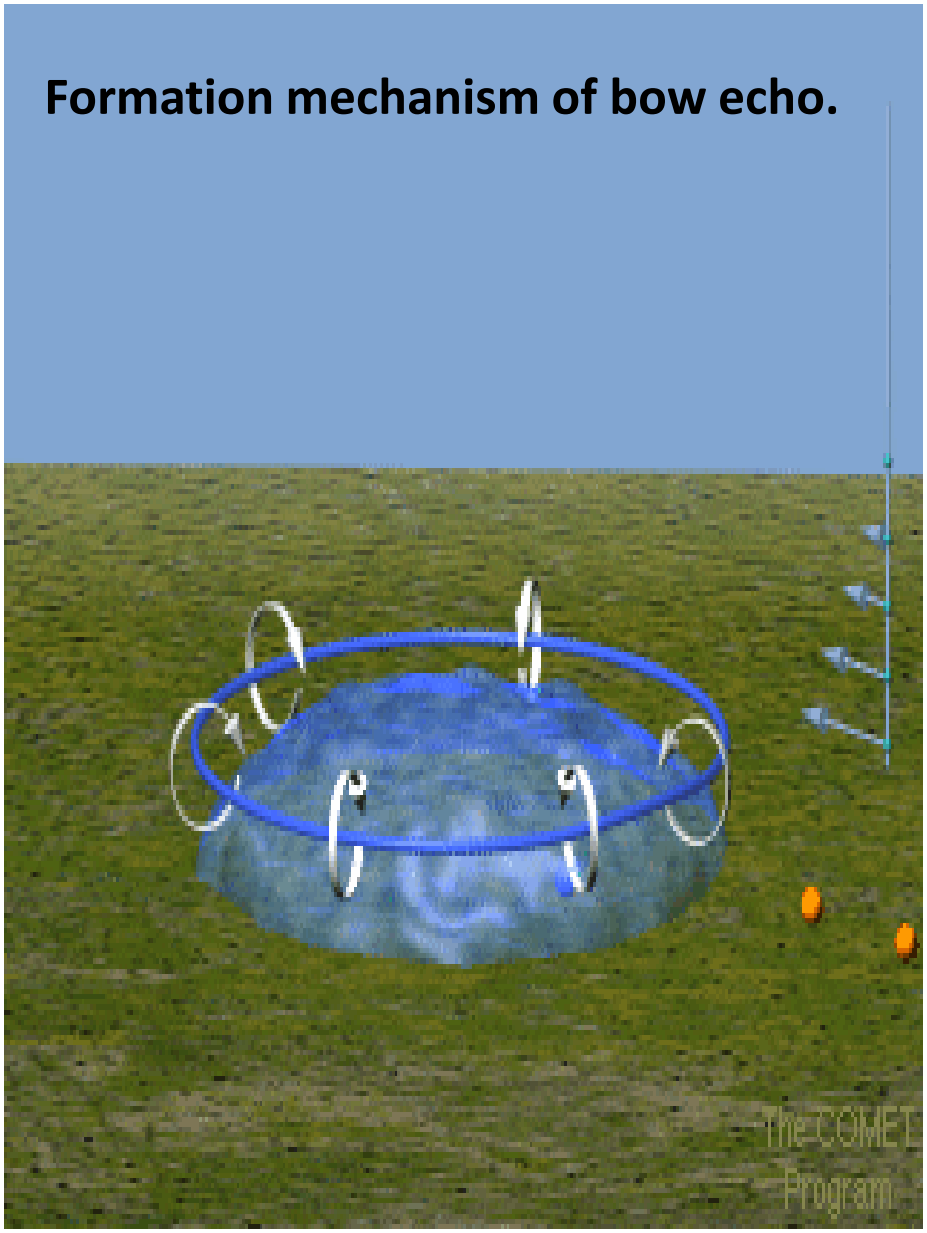
West-east cross section through the cente developing PCS



- Negative potential temperature at low levels ---- Strong cold pool spreading rearward
- The vortex couplet is produced by tilting of the horizontal baroclinic vorticity produced by the cold pool.

Potential temperature (Blue shaded) and wind streamline difference at different levels





Horizontal vorticity in connection with the cold pool tilted by the strong inflow in front. That vortex couplet can be generated

Rearward spreading cold pool can also generated strong vortex couplet.

Never to neglect!!!

Summary on CI and Role of PCS

- 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.

- **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, which initiated the convective cells that evolved into a bow-shaped hailstorm.

Thank You!
Questions!

Email: lpingluo@yeah.net