Introduction

Because of the lack of thorough observation within hailstorms, until now people still do not know well about the real dynamics and microphysical 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

<table>
<thead>
<tr>
<th>Model</th>
<th>ARPS, Version 5.3.3</th>
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<tbody>
<tr>
<td>Domain</td>
<td>D01: 40°N/40°E/553 grid points, dxdy=km; D02: 46°N/46°E/553 grid points, dxdy=km</td>
</tr>
<tr>
<td>Initial/Boundary condition</td>
<td>MCEF Final Analysis data at 111 resolution</td>
</tr>
<tr>
<td>Microphysics schemes</td>
<td>Mihnean and Tius scheme: - single moment (experiment Single) - double moment (FixA and DiagA) (with final and diagnosed alpha) - triple moment (CNTL)</td>
</tr>
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Results of Sensitivity runs

<table>
<thead>
<tr>
<th>Composite reflectivity-Z</th>
<th>Maximum estimated size of hail-MESH</th>
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<tbody>
<tr>
<td>0.5 km</td>
<td>1.5 km</td>
</tr>
<tr>
<td>1.0 km</td>
<td>2.5 km</td>
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<tr>
<td>1.5 km</td>
<td>3.5 km</td>
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</tbody>
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- MY 2-mom with diagnosed Alpha: Underestimate Z and MESH;
- MY 3-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 R(D) at 60-second intervals during hail burst period from T0 to T1, described as the formula below:

\[ N_{SAHNC}(D) = \int_{0}^{\infty} R(D) dD \]

- 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 northeast to southeast part of Jiangsu Province, which appears to be more realistic.

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_i in MY schemes are conducted.

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 hailstorm hailstones mainly originate from frozen-drop embryos.
- Hailstone size forecast is well performed and can provide a useful guidance for the public to take necessary preparations.
- The rearward spreading cold pool, together with the positive vertical environmental shear, generated strong long-lived vortex couplet.
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