Evaluation of WRF cloud microphysics scheme using radar observations

Ki-Hong Min$^{1,2,3}$ and Gyuwon Lee$^{1,2}$

$^1$Dept. of Astronomy & Atmospheric Sciences, Kyungpook National University
$^2$Center for Atmospheric Remote Sensing, Kyungpook National University
$^3$Dept. of Earth, Atmospheric, and Planetary Sciences, Purdue University
1. Motivation & Objectives

- Need for accurate weather info
- Uncertainty of clouds in NWP
- Next-gen. NWP model development

Evaluate cloud microphysics (MP)

Improve MP/NWP
2.1 Concept and Data

- **Data Quality Control (QC)**
  - **CFAD** (Contoured Frequency by Altitude Diagram)
    - Radar (dBZ)
    - WRF (qrain, qgraup, qsnow)
  - **Bright Band / Melting Level**
- **Time-Height Cross Section**
  - Radar (dBZ)
  - WRF (qrain, qgraup, qsnow)
- **Vertical Profile**
  - WRF (temperature, relative humidity, qv, qrain, qgraup, qsnow, qcl, qice)

Koch et al. (2005) & Stoelinga (2005): Using simulated reflectivity products to compare model fields with radar have advantage over radar estimated precipitation fields because there is less uncertainty involved in the calculation.
2.2 Background

Schematic vertical profile illustrating significant trends of various microphysical and state parameters through a typical melting layer as deduced by synthesizing the observations (Stewart et al. 1984; Berenguer and Zawadzki 2009).

5-yr climatology in Korea (Lee 2012). The 0°C level occurs above 190 m of the bright band peak reflectivity height (±0.13 km).
2.3 Radar Data Processing

- **UF Data**
  - Data QC (KNU fuzzy algorithm)
  - Convert PPI to CAPPI
  - Radar Calibration (bias removal)
  - Resolution Matching (4km and 12km)
  - Data Extraction (< radius 100km)
  - CFAD Reflectivity
  - Time-height Cross-section

**Raw**

**QC**

**CFAD**

**Time-height**
2.4 WRF v3.5 Model

I.C. & B.C.: FNL (NCEP Final Analysis) from GFS (Global Forecast System)

- Resolution: 1° × 1°
- Time interval: 6 hourly
- 26 pressure levels (1000-10hPa; excluding surface)

Domains

- Grid points:
  - 140 × 146 × 60 (D01)
  - 130 × 136 × 60 (D02)
  - 130 × 169 × 60 (D03)
- Resolution:
  - 36km × 36km (D01)
  - 12km × 12km (D02)
  - 4km × 4km (D03)

Schemes

<table>
<thead>
<tr>
<th>Schemes</th>
<th>WSM6</th>
<th>WDM6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass variables</td>
<td>$q_{\downarrow v}$</td>
<td>$q_{\downarrow v}$</td>
</tr>
<tr>
<td></td>
<td>$q_{\downarrow c}$</td>
<td>$q_{\downarrow c}$</td>
</tr>
<tr>
<td></td>
<td>$q_{\downarrow r}$</td>
<td>$q_{\downarrow r}$</td>
</tr>
<tr>
<td></td>
<td>$q_{\downarrow i}$</td>
<td>$q_{\downarrow i}$</td>
</tr>
<tr>
<td></td>
<td>$q_{\downarrow s}$</td>
<td>$q_{\downarrow s}$</td>
</tr>
<tr>
<td></td>
<td>$q_{\downarrow g}$</td>
<td>$q_{\downarrow g}$</td>
</tr>
</tbody>
</table>

Number variables

<table>
<thead>
<tr>
<th>Number variables</th>
<th>$N_{\downarrow n}$</th>
<th>$N_{\downarrow c}$</th>
<th>$N_{\downarrow r}$</th>
</tr>
</thead>
</table>

$N_{\downarrow n}$: CCN number
$N_{\downarrow c}$: cloud droplets number concentration
$N_{\downarrow r}$: rain droplets number concentration
### 3. Selected cases for this study

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Period</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8/14/2011</td>
<td>Scattered Convection</td>
</tr>
<tr>
<td>4</td>
<td>8/11/2011</td>
<td>Scattered Convection</td>
</tr>
</tbody>
</table>
Case 1) Changma Front (00KST 24 – 03KST 25 June 2011)

60 min. accumulated rainfall of AWS, WSM6 & WDM6

AWS

WSM6

WDM6

- GDK (1000m)
- KWK (600m)
- KSN (34m)
Case 1) GDK : CFAD of Reflectivity

\[
\overline{dBZ_k} = \frac{1}{N_k} \sum_{i=1}^{n} dBZ_i
\]

\[
\overline{dBZ_k} = 10 \times \log_{10} \left( \frac{1}{N_k} \sum_{i=1}^{n} 10^{0.1 \times dBZ_i} \right)
\]
**Case 1) KSN : 반사도 CFAD**

**Radar**

<table>
<thead>
<tr>
<th>Radar</th>
<th>WSM6</th>
<th>WDM6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z(dBZ)</td>
<td>Level (km)</td>
<td>Level (km)</td>
</tr>
<tr>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>20</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>30</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>40</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>50</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>60</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td>70</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>80</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td>90</td>
<td>10.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

**KSN 0° C**
Case 1) GDK : Time-Height Cross Section of Reflectivity

**Radar**

**WSM6**

**WDM6**

GDK 0°C
Case 1) KSN : Time-Height Cross Section of Reflectivity

Radar

WSM6

KSN 0 °C

WDM6
Case 1) GDK : Vertical Mean Profile

Temperature & Relative Humidity

WRF

Q Vapor

Hydrometeors

(unit: g/kg)
Case 2) Scattered Convection (00KST 14 – 24KST August 2011)

60 min. accumulated rainfall of AWS, WSM6 & WDM6

AWS

WSM6

WDM6

- GDK (1000m)
- KWK (600m)
- KSN (34m)
Case 2) KWK : CFAD of Reflectivity

Radar

WSM6

GDK 0°C

WDM6

--- radar
--- model
Case 2) KWK: Time-Height Cross Section of Reflectivity (4km)

**Radar**

**WSM6**

GDK 0°C

**WDM6**
Case 2) KWK : Time-Height Cross Section of Reflectivity (12km)
Case 2) KWK : Vertical Mean Profile

Temperature & Relative Humidity

WRF

Q Vapor

WSM6

WDM6

Hydrometeors
### 4. Melting Level Height of Radar vs. WSM6/WDM6

<table>
<thead>
<tr>
<th></th>
<th>CASE1</th>
<th>CASE2</th>
<th>CASE3</th>
<th>CASE4</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average height (km)</strong></td>
<td>Radar</td>
<td>4.63</td>
<td>5.0</td>
<td>5.1</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>WSM6</td>
<td>4.97</td>
<td>5.2</td>
<td>5.3</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>WDM6</td>
<td>4.8</td>
<td>5.23</td>
<td>5.17</td>
<td>5.2</td>
</tr>
<tr>
<td><strong>Bias (km)</strong></td>
<td>Radar</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>WSM6</td>
<td>0.34</td>
<td>0.2</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>WDM6</td>
<td>0.17</td>
<td>0.23</td>
<td>0.07</td>
<td>-</td>
</tr>
</tbody>
</table>

Both schemes have a tendency to over estimate the height of the melting level when compared to radar observations, but the margin of error is small. However, the identification of B-B location was not distinct showing the growth of ice/snow particles needs to be improved.
5. Summary & Conclusion

- We evaluated WSM6 and WDM6 cloud microphysics schemes using AWS rainfall data, radar CFAD and time-height cross sections, and with the moisture profile for the summer 2011 monsoon and convective cases.

**Monsoon Case:**
- WSM6 scheme has a negative bias - a tendency to simulate reflectivity much smaller than the radar reflectivity below 5 km.
- WDM6 scheme has a positive bias - a tendency to simulate reflectivity greater than the radar, but is in better agreement with the observations.

  From the moisture profile, this tendency is due to WSM6 simulating too little raindrops ($q_{\text{rain}}$) compared to WDM6 below 5 km (0°C isotherm layer), which is related to the lack of sedimentation process of water in WSM6.

**Convection Case:**
- Due to the phase error of location and timing, CFAD did not reveal any meaningful characteristics between WSM6 and WDM6, and there was an underestimate of precipitation.

  Both WSM6 and WDM6 have limitations in simulating summertime convective rain, and there exist a resolution dependency in simulating summer precipitation.

- This study shows the possibility of utilizing radar data to validate mesoscale model’s output and cloud microphysics schemes.

- There are many rooms for improvement of NWP model’s temperature profile, hydrometeor types, and various precipitation aspects (timing, location, and intensity etc.) using radar data.
THANK YOU FOR LISTENING!
Outline

- Introduction
- Methodology
- Selected Cases
- Preliminary Results
- Discussion
- Future Work
## 2.5 WRF Reflectivity Calculation

(Koch et al., 2008)

<table>
<thead>
<tr>
<th>Shape</th>
<th>Rain drops</th>
<th>Snow</th>
<th>Graupel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>( \rho_{lr} = \rho_{ll} = 1000 , kg , m^{-3} )</td>
<td>( \rho_{ls} = 100 , kg , m^{-3} )</td>
<td>( \rho_{lg} = 400 , kg , m^{-3} )</td>
</tr>
<tr>
<td>Distribution</td>
<td>( N(D) = 8 \times 10^{16} \times e^{-\lambda} ) ( D , m^{-4} )</td>
<td>( N(D) = 2 \times 10^{16} \times e^{-0.1} ) ( 2T , m^{-4} )</td>
<td>( N(D) = 4 \times 10^{16} \times e^{-\lambda} ) ( D , m^{-4} )</td>
</tr>
<tr>
<td>Variable</td>
<td>( Z_{lr} ) for rain drops</td>
<td>( q_{snow} (q_{ls}) )</td>
<td>( q_{graup} (q_{lg}) )</td>
</tr>
</tbody>
</table>

Calculation of \( Z_{lr} \) for rain drops

\[
Z_{lr} = \Gamma(7) N_{l0} \lambda^{-7}
\]

where,

\[\lambda = (\pi N_{l0} \rho_{ll} / \rho_{la} q_{lr})^{1/4} \]

for rain drops

Calculation of \( Z_{li} \) for ice particle

\[
Z_{li} = \Gamma(7) N_{i0} \lambda^{-7} \left( \frac{\rho_{ls}}{\rho_{ll}} \right)^{1/2} \alpha_{i2}
\]

\[\alpha_{i} = (\rho_{ll} / \rho_{li})^{1/2} \left( |K|_{ll} / |K|_{li} \right)^{1/2} \]

\[\lambda = (\pi N_{i0} \rho_{li} / \rho_{la} q_{li})^{1/4} \]

for ice particles

\( \lambda \) : gamma function

\( \alpha_{i} \) : dielectric factor of ice

\( |K|_{ll} \) : dielectric factor of liquid water

\( |K|_{li} \) : dielectric factor of liquid water

\( \rho_{la} \) : density of dry air

\( \rho_{li} \) : density of ice particles

\( q_{li} \) : snow or graupel mixing ratio

\( \Gamma \) : gamma function

(\( \rho_{ll} \) : density of liquid water)
Case 1) KSN : Vertical Mean Profile

Temperature & Relative Humidity

WRF

Q Vapor

WSM6
WDM6

Hydrometeors
Case 1: Changma Front (00KST 24 – 03KST 25 June 2011)
Case 2: Scattered Convection (00KST 14 – 24KST August 2011)
Case 3: Changma Front (03KST 03 – 06KST 04 July 2011)
Case 4: Scattered Convection (03KST 11 – 20KST 11 August 2011)
## 4. Melting Level Height of Radar vs. WSM6/WDM6

<table>
<thead>
<tr>
<th></th>
<th>Case1</th>
<th>Case2</th>
<th>Case3</th>
<th>Case4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GDK</strong></td>
<td>Radar</td>
<td>4.7</td>
<td>5.0</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>WSM6</td>
<td>4.8</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>WDM6</td>
<td>4.8</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td><strong>KSN</strong></td>
<td>Radar</td>
<td>4.7</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>WSM6</td>
<td>5.2</td>
<td>5.2</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>WDM6</td>
<td>4.9</td>
<td>5.3</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>KWK</strong></td>
<td>Radar</td>
<td>4.5</td>
<td>X</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>WSM6</td>
<td>4.9</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>WDM6</td>
<td>4.7</td>
<td>5.2</td>
<td>5.2</td>
</tr>
</tbody>
</table>

- Both schemes systematically over estimate the location of the melting level when compared to radar observations.
5.2 Future Work

- Analyze additional cases
- Statistically evaluate WSM6/WDM6 M-P scheme
- Diagnose and improve M-P scheme to improve NWP
- Assimilate radar derived profile to NWP
### 2.5 WRF Model Configuration

<table>
<thead>
<tr>
<th>Model</th>
<th>WRF v3.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulus parameterization</td>
<td>Kain-Fritsch</td>
</tr>
<tr>
<td><strong>Microphysics</strong></td>
<td><strong>WRF Single Moment 6-class (WSM6)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>WRF Double Moment 6-class (WDM6)</strong></td>
</tr>
<tr>
<td>Long-wave radiation</td>
<td>Rapid Radiative Transfer Model (RRTM)</td>
</tr>
<tr>
<td>Short-wave radiation</td>
<td>Dudhia</td>
</tr>
<tr>
<td>Surface-layer physics</td>
<td>Monin-Obukhov Similarity</td>
</tr>
<tr>
<td>Land surface</td>
<td>NOAH LSM</td>
</tr>
<tr>
<td>PBL</td>
<td>YSU scheme</td>
</tr>
<tr>
<td>Horizontal grid spacing</td>
<td>36km (D01) - 12 km (D02) - 4 km (D03)</td>
</tr>
<tr>
<td><strong>Vertical level</strong></td>
<td>60 (top at 50 hPa)</td>
</tr>
<tr>
<td>Initial &amp; Boundary Conditions</td>
<td>1°×1° FNL analysis fields obtained from EMC/NCEP</td>
</tr>
</tbody>
</table>