Representing aerosol effects in cumulus physics parameterization in WRF

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Introduction

- Aerosols can significantly influence convection and potentially alter the timing and intensity of precipitation, with feedbacks on the large-scale circulation.
- Cumulus parameterizations generally do not include cloud microphysics so aerosol-cumulus cloud interactions are not fully represented.
- Song and Zhang (2011) incorporated a two-moment microphysics scheme in the Zhang and McFarlane (ZM) cumulus parameterization, so aerosol effects on microphysical and dynamical processes in cumulus clouds can be more realistically simulated.

Using the new ZM cumulus parameterization implemented in WRF, we will investigate the following scientific questions.

🔹 Scientific Questions

1. What are the effects of microphysics in the ZM cumulus scheme?
2. How do aerosols affect regional climate?
**Experimental Design**

- **Model:** WRF-CHEM Version 3.4.1
- **Integration period:** 23 June ~ 31 July 2008
- **Grid spacing:** 36km
- **Physics:** CAM5 physics package

- Cumulus scheme: *Zhang and McFarlane (ZM) scheme with microphysics (Song and Zhang, JGR, 2011)*
- Microphysics scheme: Morrison and Gettelman
- Planetary boundary layer scheme: CAM5 UW
- Shallow cumulus scheme: CAM5 UW
- Long wave and Short wave radiation schemes: RRTMG

**Chemistry and Aerosols model and data**

- Chemistry and aerosol packages: CBMZ and MAM3
- Emission data: CBMZ and MOSAIC for the period of July 2008
- Boundary condition for chemistry and aerosol: CAM5 with MAM3 aerosol model for aerosols and MOZART for other chemistry species

![Model Domain](image-url)
Microphysics processes in ZM scheme

- **Precipitation Production rate in ZM scheme**
  
  **Original ZM scheme**
  \[ \text{PRD} [\text{s}^{-1}] = C_0 M_u q_{c,i} \]

  **New ZM scheme with microphysics**
  \[ \text{PRD} [\text{s}^{-1}] = \frac{M_u}{w_u} S_{R,S}^q \]

- **Source/sink terms for Snow**
  \[ S_s^q = \text{P}_{\text{auto}}^q + \text{P}_{\text{accs}}^q + \text{P}_{\text{accr}}^q + \text{P}_{\text{fhet}}^q + \text{P}_{\text{fhm}}^q - \text{P}_{\text{fallout}}^q \]

- **Source/sink terms for Rain**
  \[ S_r^q = \text{P}_{\text{auto}}^q + \text{P}_{\text{accs}}^q - \text{P}_{\text{accr}}^q - \text{P}_{\text{fhet}}^q - \text{P}_{\text{fhm}}^q - \text{P}_{\text{fallout}}^q \]

- **Cloud water and Cloud ice production rate in ZM scheme**

  **Original ZM scheme**
  \[ \frac{\partial}{\partial z} (M_u q_{c,i}) = -D_u q_{c,i} + C_u - C_0 M_u q_{c,i} \]

  **New ZM scheme with microphysics**
  \[ \frac{\partial}{\partial z} (M_u q_{c,i}) = -D_u q_{c,i} + C_u + \frac{M_u}{w_u} S_{c,i}^q \]

- **Source/sink terms for Cloud water**
  \[ S_c^q = \text{P}_{\text{cond}}^q - \text{P}_{\text{auto}}^q - \text{P}_{\text{accs}}^q - \text{P}_{\text{accr}}^q - \text{P}_{\text{fhet}}^q - \text{P}_{\text{fhm}}^q - \text{P}_{\text{Berg}}^q \]

- **Source/sink terms for Cloud ice**
  \[ S_i^q = \text{P}_{\text{cond}}^q - \text{P}_{\text{auto}}^q - \text{P}_{\text{accs}}^q + \text{P}_{\text{fhet}}^q + \text{P}_{\text{fhm}}^q + \text{P}_{\text{Berg}}^q \]
1. What are the effects of microphysics in the ZM cumulus scheme?

- **Surface Rain (during 1 month of July)**
  - OBS (TRMM)
  - OBS (CMA)
  - ZM_MP (with MP)

- **Statistics for Surface Rain**

<table>
<thead>
<tr>
<th></th>
<th>ZM_MP</th>
<th>ZM_NOPMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIAS</td>
<td>-15.70</td>
<td>-48.32</td>
</tr>
<tr>
<td>PC</td>
<td>0.34</td>
<td>0.14</td>
</tr>
<tr>
<td>RMSE</td>
<td>106.50</td>
<td>129.15</td>
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</tbody>
</table>

- **Total Rain**
  \[ \text{Total Rain} = \text{Large-scale} + \text{Subgrid-scale Rain} \]

- **Large-scale Rain**
  - from Microphysics scheme

- **Subgrid-scale Rain**
  - From Cumulus scheme
Effects of microphysics in the ZM scheme

Simulation with ZM cumulus scheme with microphysics shows better agreement with observation in terms of surface precipitation and radiative properties.

..What causes these improvements?
Analysis to answer for the increasing large-scale precipitation in ZM_MP

Increased detrainment from ZM_MP run is responsible more precipitation production due to the accretion process.
1. What are the effects of microphysics in the ZM cumulus scheme?

- The ZM cumulus scheme with microphysics produces better simulation of surface precipitation and radiative properties.

- Increased detrainment from ZM scheme was responsible for more precipitation production with the ZM cumulus scheme including microphysics.

- Cloud fraction and frequency of higher clouds in ZM_MP improved surface precipitation and radiative properties, relative to ZM_NOMP.
2. How do aerosols affect the regional climate?

- **ZM_MP_CLEAN**: Experiment that mimics the clean environment

- **Aerosols**
  - Aerosol number concentrations
  - **Observed AOD (MISR)**
  - **ZM_MP**
  - **ZM_MP_CLEAN**
  - **ZM_MP - ZM_MP_CLEAN**

- **Surface rain**
  - **OBS**
  - **ZM_MP**
  - **Total precipitation**
  - **Large-scale precipitation**

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Difference: ZM_MP - ZM_MP_CLEAN
Changes in rain rate between the ZM_MP and ZM_MP_CLEAN

Number concentrations and Mixing ratios of hydrometeors
Over the large-scale precipitation dominant region

Large-scale precipitation is dominant over the monsoon period!!
SW, LW, and net radiative cloud forcing of aerosol indirect effects in ZM

\[
\text{SW}_\text{TOA} + \text{LW}_\text{ATM} = \text{NET}_\text{SFC}
\]

<table>
<thead>
<tr>
<th>Region</th>
<th>SW</th>
<th>LW</th>
<th>NET</th>
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</thead>
<tbody>
<tr>
<td>TOA</td>
<td>-1.9</td>
<td>2.4</td>
<td>0.5</td>
</tr>
<tr>
<td>ATM</td>
<td>-1.0</td>
<td>2.7</td>
<td>1.7</td>
</tr>
<tr>
<td>SFC</td>
<td>-0.9</td>
<td>-0.3</td>
<td>-1.2</td>
</tr>
</tbody>
</table>

2. How do aerosols affect the regional climate?

- During summer monsoon season over China, large-scale precipitation is dominant.
- Under polluted environment, precipitation decreases with cloud life time effect, in which precipitation conversion from cloud water becomes more inefficient due to increase of smaller drops.
Conclusions and Further Research Plans

- We can assess the aerosol indirect at the regional scale by implementing of the cumulus scheme having microphysics in it.

- Both microphysics processes in cumulus and explicit cloud microphysics parameterization scheme are connected with the aerosol activation process developed by Abdul-Razzak and Ghan (2000).

- Ensemble run is on the way to assess statistical significance of our results.
Thank you!

Any question?

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Observation: Surface precipitation comparison

TRMM3B42 (0.25°)

TRMM3B43 (1°)

TRMM3A46_SSMI (1°)

GPCP (2.5°)

CMAP (2.5°)

TRMM3B31_TMI_PR (5°)