Evaluating Drizzle Formation Parameterization Using Ensemble Cloud Retrievals from the MAGIC Campaign

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Importance of warm rain observations

• Direct impact on the maintenance of parent clouds

• Impact on Earth’s radiation budget and water cycle

• One of the key variables to constrain cloud-aerosol-precipitation interactions in climate models
Known issues about precipitation in models

- Too frequent by a factor of 1.5 – 2
  
  - Stephens et al. (2010)
  - Ahlgrimm and Forbes (2014)

- Too light by a factor of ~2 in general, but too heavy in marine Sc regions

Abel and Boutle (2012)
Two (entwined) problems - representation of clouds and representation of precipitation

Many studies try to tackle the problem of clouds or clouds and precipitation

Isolate rain formation processes from cloud issues
Ship-based observations from MAGIC in 2013

- Ensemble Cloud Retrieval (ENCORE; Fielding et al., 2014; 2015):
  - Combine cloud radar, lidar and shortwave zenith radiances
  - Use the Iterative Ensemble Kalman Filter as an optimal estimation framework

![Graph showing ENCORE cloud/rain water content](image)
Cloud/drizzle statistics from MAGIC

- **LWPC Median:** 97.1204
- **LWPd Median:** 5.9488

**Water path (g m^{-2})**

- **Cloud**
- **Drizzle**

- **Median:** 0.42

- **Median:** 12.3733

**Droplet number concentration (cm^{-3})**

- **Median:** 60.6781

**Geometric height (km)**

**Optical depth**
Schemes for warm rain formation

- Either diagnostic or prognostic

Autoconversion term + Accretion term

Sedimentation term
(fall speed, rain drop size distribution)
Time to reach steady state

- Use all observed cloud profiles
- steady state: less than a 1% change in the cloud base rain rate
- 95% of time periods shorter than 40 min

\[
\frac{\partial q_r}{\partial t} = \left( \frac{\partial q_r}{\partial t} \right)_{\text{autoconversion}} + \left( \frac{\partial q_r}{\partial t} \right)_{\text{accretion}} + \left( \frac{\partial q_r}{\partial t} \right)_{\text{sed}}
\]
Case selection

- Cloud fraction greater than 0.5

- Cloud water path variability (standard deviation/mean) less than 0.5

- Rain water path variability less than 1.0

- About fifteen 40-min long data (retrieval available at 5-sec resol.)
Coefficient optimization for autoconversion and accretion

\[ V_{r,k} q_{r,k} - V_{r,k-1} q_{r,k-1} = C_1 \cdot q_{c,k}^a \cdot N_d^b \cdot \Delta z_k + C_2 \cdot \left( q_{c,k} \cdot q_{r,k} \right)^c \Delta z_k \]

- sedimentation
- autoconversion
- accretion

- Give a set of coefficients \((C_1, a, b, C_2, c)\)
- Minimize difference between the left and right hand sides using observations
## Optimized coefficients

### Autoconversion

\[ C_1 \cdot q_c^a \cdot N_d^b \]

### Accretion

\[ C_2 (q_c \cdot q_r)^c \]

<table>
<thead>
<tr>
<th></th>
<th>( C_1 )</th>
<th>a</th>
<th>b</th>
<th>( C_2 )</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution</td>
<td>1270 ± 86</td>
<td>2.83 ± 0.16</td>
<td>−1.17 ± 0.14</td>
<td>63 ± 8</td>
<td>1.11 ± 0.01</td>
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<tr>
<td>KK</td>
<td>1350</td>
<td>2.47</td>
<td>−1.79</td>
<td>67</td>
<td>1.15</td>
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<tr>
<td>Solution 2</td>
<td>1270 ± 88</td>
<td>2.68 ± 0.18</td>
<td>−1.67 ± 0.17</td>
<td>59 ± 9</td>
<td>1.11 ± 0.01</td>
</tr>
</tbody>
</table>
The prognostic equation for warm rain

\[
\frac{\partial q_r}{\partial t} = \text{advection} + \left( \frac{\partial q_r}{\partial t} \right)_{\text{autoconversion}} + \left( \frac{\partial q_r}{\partial t} \right)_{\text{accretion}} + \left( \frac{\partial q_r}{\partial t} \right)_{\text{sed}}
\]

\(-\vec{V} \cdot \nabla q_r\)

horizontal gradient of rain properties is missing in current observations!!
Summary

• New observations of in-cloud rain water content allow us to better understand process rates of warm rain formation.

• Observations suggest that autoconversion models may be too sensitive to cloud droplet number concentration, but two possible optimal coefficients remain.

• Measurements of rain horizontal gradient will be invaluable to help constrain the autoconversion rate.