Process-oriented versus energy-based constraints on cloud microphysics: Implication for aerosol-cloud interactions

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Satellite obs offers information about rain formation

Cloud ($Z_e < -15\text{dBZ}$)  Drizzle ($-15 < Z_e < 0\text{dBZ}$)  Rain ($Z_e > 0\text{dBZ}$)

A-Train  MRI-CGCM3  MIROC5.2

- Too frequent occurrence of drizzle/rain in models  

Jing et al. (JGR ’17)
Satellite obs offers information about rain formation

- **Cloud** \( Z_e < -15 \text{dBZ} \)
- **Drizzle** \(-15 < Z_e < 0 \text{dBZ}\)
- **Rain** \( Z_e > 0 \text{dBZ} \)

### Graphs:

- **A-Train**
- **GFDL AM4**
- **ECHAM-HAM**

- Too frequent occurrence of drizzle/rain in models: Common issue
- Why this happens? How to fix?

\( \text{Jing et al. (JGR '17)} \)
Satellite-based insight into the warm rain process

Stephens et al. (‘18) adapted from Takahashi et al. (‘17) based on the CFOODD method of Suzuki et al. (‘10)
What if the model precipitation constrained with satellite?

Satellite Obs.

MIROC (Berry)

MIROC (K-K)

Aerosol Indirect Forcing (PD minus PI)

$P_{\text{auto}} \propto N_c^{-1.0}$ (Berry)

$P_{\text{auto}} \propto N_c^{-1.79}$ (K-K)

Jing and Suzuki (GRL in revision)
What's happening in the model?

\[ P_{\text{auto}} \propto N_c^{-1.0} \text{(Berry)} \]
\[ P_{\text{auto}} \propto N_c^{-1.79} \text{(K-K)} \]

\[ \Delta = (PD) - (PI) \]

\[ + \Delta \text{ Emission} \]
\[ + \Delta \text{ Aerosol} \]
\[ - \Delta \text{ Precip. Eff.} \]
\[ - \Delta \text{ Scavenging} \]
\[ + \Delta \text{ LWP} \]
\[ + \Delta \text{ CRF (Cooling)} \]

Fixed \( N_c \) for scavenging

\( \text{Jing and Suzuki (GRL in revision)} \)
Behaviors of different microphysical schemes

This diagnostic is proposed for **GEWEX/PROES-WR** (Warm Rain) by Jing and Suzuki (In prep)
Possible coupling of direct & indirect effects

Rain formation time scale:

\[ \tau_p \propto (\rho q_c)^{-\alpha} N_c^\beta \]

\[ \Delta AOD \text{ (PD-PI)} \]

\[ \Delta LWP \text{ (PD-PI)} \]

- Switching \( \mu \)-physics scheme changes aerosol loading
- This influences direct as well as indirect radiative forcing
- Possible impact on atmospheric energy balance

Suzuki and Jing (In prep)
Implication for historical change of global precipitation

\[ L\Delta P \approx -\Delta R_{atm} \]

\[ \approx (\alpha \kappa - \lambda) \Delta T_s - \beta \Delta \tau_a (r_{crit}) \]

- WV cooling
- Cloud feedback
- Aerosol radiative heating on ATM

- Cloud \( \mu \)-physical assumption \( (r_{crit}) \) influences the aerosol loading via scavenging process
- Coupling of indirect with direct effect of aerosols perturbs global precipitation

Suzuki et al. (ASL '17)
Possible overestimate of indirect effect in traditional GCMs

Satellite Obs.

NICAM (w/ Berry)

MIROC (w/ Berry)

What’s different b/w MIROC and NICAM?
- Resolution: O(100km) vs O(1-10km)
- DIAG vs PROG rain schemes
- What makes the negative response in NICAM?
  - Enhanced cloud-top evaporation

\[ \frac{\text{d} \ln(\text{LWP})}{\text{d} \ln(N_c)} \]

Y. Sato et al. (Nature Comm. ’18)
Summary

- GEWEX/PROES Warm Rain (WR) is being proposed exploiting satellite-based insight into the process
- Inconsistency b/w “process” and “energy”: A fundamental gap in our understanding of their linkage
- This is amplified through possible coupling of indirect and direct effects of aerosols: Implication for global precipitation change
- Possible overestimate of aerosol indirect forcing by traditional GCM: NICAM shows a promise
What’s happening?

\[ \Delta = (\text{Present-Day}) - (\text{Pre-Industrial}) \]

**Δ CRE**

- KK00
- BR68
- KK00_FN
- BR68_FN

**Δ AOD**

- KK00
- BR68
- KK00_FN
- BR68_FN

**Δ LWP**

Jing and Suzuki (GRL submitted)

- The cloud response is more pronounced in K-K than in Berry
- This happens via wet-scavenging change with precip efficiency

\[ P_{auto} \propto N_c^{-1.0} \quad (\text{Berry}) \]
\[ P_{auto} \propto N_c^{-1.79} \quad (K-K) \]
Uncertainty of cloud microphysics in global models

\[ \frac{\partial (\rho q_c)}{\partial t} = - \frac{\rho q_c}{\tau_p} \]

\[ \tau_p \propto \left( \rho q_c \right)^{-\alpha} N^\beta_c \]

<table>
<thead>
<tr>
<th>Auto-conversion Scheme</th>
<th>Model</th>
<th>( \alpha )</th>
<th>( \beta )</th>
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<tbody>
<tr>
<td>Berry (1968)</td>
<td>MIROC, NICAM</td>
<td>2.0</td>
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<td>Tripoli and Cotton (1980)</td>
<td>UKMO, GFDL</td>
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<td>Khairoutdinov and Kogan (2000)</td>
<td>PNNL/MMF, NCAR</td>
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<td>Beheng (1994)</td>
<td>ECHAM</td>
<td>3.7</td>
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