Use of satellite observations for process-oriented evaluation of cloud microphysics in climate models

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Impact of cloud $\mu$-physics on climate projection

$GFDL \text{CM3}$

$\mu_{\text{crit}}$: Threshold particle radius for warm rain to occur

- Uncertain “tunable” parameter in climate models
- Modulates the magnitude of (2nd) aerosol indirect forcing, leading to severely different climate projections
- How could satellite observations be used to constrain this?
$\mu$-physical processes depicted by satellite analysis

“incipient stage”

$r_e = 5 - 10 \mu m$

$r_e = 10 - 15 \mu m$

$r_e = 15 - 20 \mu m$

$r_e = 20 - 25 \mu m$

$r_e = 25 - 30 \mu m$

“mature stage”

Non-precip

Precip

Vertical $\mu$-physical structure

T. Y. Nakajima et al. (JAS ’10), Suzuki et al. (JAS ’10)
Evaluating climate models selected from CMIP5

\[ R_{\text{top}} = 5-10 \mu \text{m} \]
(a) A-Train/\( r_e = 5-10 \mu \text{m} \)

d) HadGEM2/\( r_e = 5-10 \mu \text{m} \)
(j) CGCM3/\( r_e = 5-10 \mu \text{m} \)

\[ R_{\text{top}} = 15-20 \mu \text{m} \]
(c) A-Train/\( r_e = 15-20 \mu \text{m} \)
(f) HadGEM2/\( r_e = 15-20 \mu \text{m} \)
(l) CGCM3/\( r_e = 15-20 \mu \text{m} \)

CloudSat

MIROC5
Berry

HadGEM2
T-C

CAM5
K-K

CGCM3
T-C

Berry: Berry (’67)
T-C: Tripoli and Cotton (’80)
K-K: Khairoutdinov and Kogan (’00)
Is the cloud “tuning” correct?

Suzuki, Golaz and Stephens (GRL ’13)

“incipient stage”: $R_e = 6-10\mu m$

**GFDL CM3**

Surface air temperature anomaly

- $r_{crit} = 6.0\mu m$
- $r_{crit} = 8.2\mu m$
- $r_{crit} = 10.6\mu m$

Golaz et al. (GRL’13)

$r_{crit}$: threshold radius for rain to occur

- 20th century temperature trend is best simulated by $r_{crit} = 6.0\mu m$
- CloudSat provides a process-based constraint on this: $r_{crit} = 10.6\mu m$
- Dichotomy: compensating errors in the model at a fundamental level?
- What causes this problem?: Resolution vs Physics?
Cloud-to-precipitation process in NICAM

Susceptibility to CCN perturbation:

\[
S = - \frac{d \ln Z_e}{d \ln N_c} \bigg|_{LWP} \approx \frac{1}{3} \frac{d \ln Z_e}{d \ln r_{eff}} \bigg|_{LWP}
\]

- \( S \) (Berry) < \( S \) (K-K) ~ \( S \) (Satellite)
- \( S \) takes peak over different LWPs
- Implication for indirect forcing
Summary

- A particular statistic of satellite observations “fingerprints” signatures of warm rain processes
  - Cloud lifecycle is depicted in the statistic

- The statistic is used as a metric to evaluate the warm rain process in climate models.
  - Some models produce warm rain too fast
  - “Tunable” cloud parameter is constrained with satellite

- The process-based constraint contradicts the “top-down” temperature reproducibility in a climate model

- Global cloud-resolving model also exposes biases in rain formation process depending on microphysics schemes