Clouds and convection in RCEMIP simulations with CAM and a hierarchy of models

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Previous Work:
RCE in CAM

- NCAR’s Community Atmosphere Model version 5 (CAM 5).
- Run with 30 vertical levels is used at the horizontal resolutions at a resolution of ~100 km.
- Full physics in Aquaplanet mode is used, with a simplified ocean covered Earth and constant surface temperatures.
- No rotation effects.
- Diurnally varying, spatially uniform insolation (~340 W/m²).
- Such a setup mimics similar simulations with limited-area or cloud-resolving models, but at a relatively lower resolution.

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[Reed et al. 2015, JAS; Arnold and Randall 2015, JAMES]
Temperature Sensitivity: Precipitation – CAM5

[Image of Earth with temperature sensitivity data]
• This suggests that while the mean state changes gradually, **extreme rainfall depends on organization**!
RCEMIP in GCM Hierarchy

- Model hierarchy used for development:

Increasing Complexity

- 2D Shallow Water Test Cases
- 3D Dry Dynamical Core Test Cases
- 3D Dynamical Core + Moist Simplified-Physics Test Cases
- 3D Aqua-Planet Experiment
- 3D AMIP

Deterministic Tests
Additional Complexities
Tests of Statistical Behavior

[Updated from Reed & Jablonowski 2012, JAMES]
A statistical equilibrium: balance between net radiative cooling and convective heating
Two Sets of Simulations:

1. **RCE_small (295 K, 300 K, 305 K)**
   - 100 km square for CRMs, 1 km horiz spacing
   - Single column or small Earth for GCMs
   - 200 m horiz spacing for LES

2. **RCE_large (295 K, 300 K, 305 K)**
   - 6000 km x 400 km rectangle for CRMs, 3 km horiz spacing
   - Global for GCMs, GCRMs

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[Wing et al. 2018, GMD]
CAM is now fully configured with the RCEMIP specifications!

Utilizes CESM2.1, released mid Dec. 2018, which is the default code base for CMIP6 DECK experiments.

CESM2.1 includes functionality to configure previous versions of CAM. We make use of:

- **CAM5** – CMIP5 version of model *with various updates*
- **CAM6** – CMIP6 version of model

We use single-column CAM output for initialization of full 3D CAM simulations. *This effort was led by I-Kuan Hu (University of Miami).*
CAM5 vs CAM6

- Brief History of CAM Updates and Advances:

<table>
<thead>
<tr>
<th>Dynamics/Grid</th>
<th>Deep Convection</th>
<th>Shallow Convection</th>
<th>PBL/Turbulence</th>
<th>Macrophysics</th>
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<tr>
<td>Hack</td>
<td>Holtslag-Boville</td>
<td>Hack</td>
<td>Holtslag-Boville</td>
<td>Park</td>
<td>Rasch-Kristjansson</td>
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<td>Finite Volume, nominal 1° on Lat-Lon</td>
<td>Zhang-McFarlane</td>
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<td>4 released 1 April 2010</td>
<td>5 released 1 May 2014</td>
<td>6 to be released 2017</td>
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Additional Modification for CAM RCEMIP

Spectral Element (ne30 ~ 1 deg.)

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[CAM timeline courtesy of Brian Medeiros]
RCEMIP CAM Comparison: Monthly Precipitation

[Monthly Averaged]
RCEMIP CAM Comparison: OLR and Precipitation

CAM5

295 K

300 K

305 K

Precipitation (mm/hr)

Upward Longwave Radiation (W/m²)

CAM6
RCEMIP CAM Comparison: Water Vapor Path

CAM5

CAM6

Precipitable Water (kg/m²)

[Hourly Averaged]
Consistent with previous results, but **difference in degree of aggregation** between CAM configurations!
High clouds shift upward with increasing temperature and decrease in extent, but differences in structure.
RCEMIP Model Hierarchy: Small Domain at 300 K

[OLR; Work by Stauffer and Wing]
RCEMIP Model Hierarchy: Large Domain at 300 K

[OLR; Work by Stauffer and Wing]
RCEMIP Model Hierarchy: Large Domain at 300 K
RCEMIP Model Hierarchy: Changes Across SSTs

Anvil cloud fraction decreases with warming across some simulations, but also some with minimal change, and one with an increase.

Changes are not monotonic with SST.
RCEMIP protocols have been implemented in CESM2.1.
We are planning to have these available as an official 'compset' in a future release of CESM2 – making them more user friendly – stay tuned!
Fits well with Simpler Models efforts within NCAR/NSF.
There are noticeable differences between CAM5 and CAM6 RCE state, including the amount of aggregation.
Comparison with other RCEMIP Models is underway!

Special thanks to NCAR (i.e., Brian Medeiros, Gary Strand) and I-Kuan Hu (University of Miami) for CESM2.1 implementation and output specifications.
Adding rotation allows for interesting studies of the controls of tropical cyclone characteristics.

Filling in the model hierarchy!

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[Reed & Chavas 2015, JAMES; Chavas et al. 2017, Nat. Comm.; Chavas & Reed 2019, JAS]