Clouds and Sensitivity in AM4/CM4

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Outline

• Clouds in AM4
  - Focus on AMIP period (1979-2016)
  - Emphasis on Satellite simulators and observational products for GCMs.

• Sensitivities of the Simulated Climate Across a Hierarchy of GFDL Models
Outline

• **Clouds in AM4**
  - Focus on AMIP period (1979-2016)
  - Emphasis on Satellite simulators and observational products for GCMs.

• **Sensitivities of the Simulated Climate Across a Hierarchy of GFDL Models**
  - AM4: Zhao et al., 2018 a,b. *JAMES*
  - CM4: Held et al., 2019 *JAMES* (in revision)
  - CM4, TCR & ECS: Winton et al., 2019 *JAMES* (submitted)
### Total Cloud Fraction

<table>
<thead>
<tr>
<th></th>
<th>ISCCP (2000-2007) 65.3 %</th>
<th>CALIPSO (2007-2016) 67.3 %</th>
</tr>
</thead>
</table>

- Bias according to ISCCP: -15.2%
- Bias according to CALIPSO: -11.89%

For similar comparisons with CAM4, CAM5, and E3SM see Kay et al., 2012; Zhang et al., 2019
Cloud Fraction (%) as seen by ISCCP and MODIS

- AM4 underestimates the low-level clouds, especially the optically thin ones
- Good job with thicker low-level clouds
- Too few mid-level clouds
- Observational uncertainty is large
- This partly justifies the motivation to focus on optimizing quantities like TOA fluxes rather than cloud amount.

- See also Pincus et al., 2012; Klein et al., 2013

Zhao et al., 2018a
Vertical Structure of Clouds

- CALIPSO data: 2007-2016
- Upper level bias: -2.8 %
- Mid level bias: -4.9 %
- Low level bias: -10.2 %
- Most of the issues with low level clouds are between +/- 30

Solid: CALIPSO
Dashed: AM4.0
Optimizing AM4 to observations

It is easy to claim that GFDL, and most other GCM have the same problems in simulating clouds as they have had for a long time.

But it is important to realize that we could simulate better clouds, such as low-level tropical clouds... if that was our number one priority.

<table>
<thead>
<tr>
<th></th>
<th>Bias</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM4.0</td>
<td>-0.77</td>
<td>7.35</td>
</tr>
<tr>
<td>AM3</td>
<td>-4.11</td>
<td>11.46</td>
</tr>
<tr>
<td>AM2.1</td>
<td>-3.16</td>
<td>12.93</td>
</tr>
</tbody>
</table>

Zhao et al. 2018a
AM4.0 TOA radiative fluxes: Cloud Radiative Effect

Loeb et al., 2009
Loeb and Doelling, 2018
Sensitivities of the Simulated Climate Across an ensemble of GFDL Models

- Problems with Cess (uniform +2K warming)
  
  Cess Climate Feedback Parameter
  
<table>
<thead>
<tr>
<th>Model</th>
<th>Sensitivity (K W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM4</td>
<td>0.57</td>
</tr>
<tr>
<td>AM3</td>
<td>0.67</td>
</tr>
<tr>
<td>AM2.1</td>
<td>0.54</td>
</tr>
<tr>
<td>AM4</td>
<td>0.52</td>
</tr>
</tbody>
</table>

- Contrary to former expectations, the Cess Feedback Parameter (Cess Sensitivity) is not proportional to TCR, and it is not constant in time.
- The ‘Pattern effect’ is important. Clouds and the ocean heat uptake depend on the pattern of SST

Cess et al., 1989; Senior and Mitchell, 2000; Golaz et al., 2013; Stevens et al., 2016; Gregory and Andrews, 2016; Zhou et al., 2016; Silvers et al., 2018, Andrews et al., 2018; Zhao et al., 2018 a,b
## Different measures of Sensitivity: The Semantic Wars

<table>
<thead>
<tr>
<th></th>
<th>Cess</th>
<th>TCR</th>
<th>Eff CS (1-150)</th>
<th>Eff CS (51-300)</th>
<th>Equilibrium CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM4/CM4</td>
<td>2.1K</td>
<td>2.1 K</td>
<td>3.9 K</td>
<td>5.0 K</td>
<td>?</td>
</tr>
<tr>
<td>AM3/CM3</td>
<td>2.5K</td>
<td>2.0 K</td>
<td>4.0 K</td>
<td>4.3 K</td>
<td>4.8 K</td>
</tr>
<tr>
<td>AM2.1/CM2.1</td>
<td>2.0K</td>
<td>1.5 K</td>
<td>3.4 K</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>AM4*</td>
<td>1.9K (fixed drop number)</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>ESM2M</td>
<td>1.3 K</td>
<td>2.4 K</td>
<td>2.9 K</td>
<td>3.3 K</td>
<td></td>
</tr>
</tbody>
</table>

Stouffer et al., 2006; Randall et al., 2007; Andrews et al., 2012; Golaz et al., 2013; Paynter et al., 2018; Winton et al., 2019
Global and Time Mean Radiative Feedback Values

Initial comparison is consistent with Ringer et al. 2014
Initial comparison is consistent with Ringer et al. 2014
Changing clouds in *amip-future4K* and *amip-p4K*?

- Clouds are almost identical between the p4K and Future 4K experiments.
- Mid-level clouds decrease with warming at most latitudes.
- Upper-level clouds increase with warming poleward of 50.
- In the Tropics warming slightly increases upper level clouds and decreases low level clouds.
- Very little difference in high-latitude cloud fraction between warming experiments.
Changing clouds in *amip-p4K* and *amip-m4K*?

- The response to +/- 4K SST perturbations is fairly symmetric
- Strong polar response of clouds to SST. We don’t have good observations there. Important implications for polar amplification
Relative Changes of Cloud Fraction in *amip-p4K* and *amip-m4K*

- Changes at all heights
- At mid-levels there is a lack of change in tropical clouds
- Large differences in Arctic for low-level clouds
What are we learning?

- AM4 simulates fewer than observed clouds at most levels and latitudes but primarily in the tropical low-level clouds.
- The latest GFDL models compare very well to observed TOA radiative fluxes, clouds are less constrained.
- The pattern of warming can change the sensitivity of the climate.
- The diversity of climate sensitivities can be discouraging...
  - Idealized models are a critical tool for understanding cloud responses.
  - High sensitivity GCMs: Will things get worse before they get better?
- Can we develop a consensus on critical cloud constraints for model developers?
Thank You

Questions about GFDL CFMIP data? Please email me.

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Cloud Radiative Effect

Black: Net CRE
Blue: SW CRE
Yellow: LW CRE