Combining the MODIS COSP product with CERES gridded data to evaluate the radiation budget of the GEOS model

Dongmin Lee
Lazaros Oreopoulos
Nayeong Cho

Climate and Radiation Laboratory
NASA-GSFC
Motivation and approach

• Breakdown of cloud radiative effect (CRE) errors in GCMs by cloud class provides insight on model performance
  • Is there cancelation of errors among cloud classes?
• We use cloud regimes (CRs) as cloud classes
  • Defined as having similar CF histograms in CTP-COT space
  • MODIS “COSP” product includes such CF histograms and provides observed CRs used as reference
  • The MODIS simulator (in COSP package) produces counterpart CF histograms in GCMs
• Ultimately we compare observed (CERES SYN1deg) and modeled CREs by CR
MODIS Joint CTP-COT cloud fraction histograms

MODIS cloud regimes are obtained by k-means clustering of such histograms

Daytime only!

1 km for \( \tau \) (COT), 5 km (true) for CTP (every 5th pixel is sampled)

Courtesy of Jackson Tan
MODIS COSP product and Cloud Regimes (CRs)

- Daily (daytime) CF histograms in CTP-COT space, merged Terra-Aqua
- Dec 2002 to Nov 2020
- Subject to k-means clustering, K=11
- Similar CRs as Cho et al. (2021)

Global CF ≈ 56%
**GEOS Cloud Regimes**

- Jason 2.0 tag, 2M µphysics, Dec 2002 to Nov 2016, prescribed SST
- Daily (daytime) CF histograms in CTP-COT space from MODIS simulator
- Assign to closest (by Euclidean distance) observed CR
- Centroids will look similar, but not their frequency of occurrence (RFO)

Global CF ≈ 50%
A closer look

**Observations**

More frequent in model, less cloudy

**Model**

Model does not distinguish between CR7 and CR8
\[ \Delta CRE = (\bar{f} \times \Delta r) + (\bar{r} \times \Delta f) + (\Delta r \times \Delta f) \]

Error contribution due to erroneous regime radiative properties under correct (observed) mean RFO

\[ \Delta CRE = \text{overall CRE error for CR examined} \]
\[ \bar{f} = \text{mean observed frequency (RFO)} \]
\[ \bar{r} = \text{mean observed CRE (from CERES SYN1deg daily)} \]
\[ \Delta f = \text{RFO error} \]
\[ \Delta r = \text{CRE error when regime occurs} \]

“Covariance error”; contribution due to combinations of erroneous regime RFO and CRE

Dec 2002 to Nov 2019
Most error comes from frequency biases $\bar{f} \times \Delta f$

Error cancellation

(Gray $\approx$ 0, red $\approx$ -blue also gray SW $\approx$ -gray LW)

CRE error bar graph: interpretation

- All CREs are derived from (down – up) fluxes
- Positive values: Model underestimates
Full CRE error decomposition

TOA

8.28

similar errors

ATM

0.94

Compensation among CRs

0.42

SFC

7.34

SFC errors bigger

too few of these low clouds

SW

-2.71

LW

5.57

some SW-LW compensation

SFC

LW

TOTAL

Compensation among CRs

Wm-2
Q: Why not use EBAF?

A: Cloud Regimes are defined daily, need to pair them with daily fluxes.
Q: Why not use (daily) FBCT*?

A: To derive the cloud regimes or to also perform the full model validation?

Q: Why not for both?

A: I can indeed derive FBCT cloud regimes, but I cannot repeat the analysis I’ve shown

Q: Why not?

A: I don’t have CRE for overcast grid cells (no clear-sky flux) and I don’t have SFC fluxes

Q: Is there anything you can do with FBCT then?

A: Well, I can combine FBCT Cloud Regimes with SYN1deg fluxes. But let me first compare COSP MODIS vs FBCT MODIS clouds

*CERES FluxByCldType product
Compare MODIS COSP with MODIS FBCT (1)

- Assign ("force") FBCT CF histograms to MODIS COSP centroids
  - Centroids will look (kinda) similar by design (backup slides), but RFOs will differ

**Hard to find CR1 and CR2, too much CR6**
• Assign (“force”) FBCT CF histograms to MODIS COSP centroids
  ○ Centroids will look similar by design, but RFOs will differ

% of time FBCT gives CR4 when MODIS COSP is CR4
% of time FBCT gives CR11 when MODIS COSP is CR2

CR (dis)agreement matrix
• Composite (average) CERES CF histograms for occurrences (location, time) of MODIS CRs
  o RFOs by definition will be the same, but mean histograms (centroids) will look different

FBCT CFs are larger! Globally, ~65% vs ~56%

Full comparison in backup slides
FBCT MODIS Cloud Regimes

Can repeat evaluation of GEOS, but still with SYN1deg fluxes (backup slides).

k-means clustering, K=11
Take-home messages

• A regime-based decomposition of GEOS CRE errors is more insightful
  o Can get CRE errors by cloud class
  o For full picture need *daily* CREs at both TOA and SFC
• MODIS FBCT clouds appear different from those in MODIS COSP
• Can derive FBCT Cloud Regimes
  o But cannot do (full) model evaluation using solely FBCT (CRE not always available, no SFC fluxes)
Questions?
Backup Slides
Nayeong’s results using FBCT JH:
Those datasets are not very close.
Total CF 66.17 vs 56.87

CERES: 2002.7 – 2018.12 monthly data
FluxByCldTyp Cloud Amount - Total

Global (area weighted) mean Total CF

MODIS AQUA and TERRA C6.1, Period: 2003.1.1 – 2018.12.31 (16 years), Equal-angle L3 data (as is)

DAILY MODIS

Daily MODIS definition = Average of Terra and Aqua centroids.
if (Aqua GE 0) and (Terra EQ 'Nan') = Aqua centroids
if (Aqua EQ 'Nan') and (Terra GE 0) = Terra centroids
• Assign ("force") FBCT CF histograms to MODIS COSP centroids
  o Centroids will look (kinda) similar by design, but RFOs will differ

Compare MODIS COSP with MODIS FBCT (1)
**Composite (average) CERES CF JHs based on MODIS CR occurrences (location, time)**

- RFOs by definition will be the same, but mean histograms (centroids) will be different.

**FBCT CFs are larger!**

---

### CERES CF JHs

<table>
<thead>
<tr>
<th>CR</th>
<th>CF</th>
<th>Family</th>
<th>JHs</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR1</td>
<td>CF 95.5</td>
<td>2.0 (3.0)</td>
<td>1.8 (2.9)</td>
</tr>
<tr>
<td>CR2</td>
<td>CF 77.1</td>
<td>3.0 (4.0)</td>
<td>3.2 (4.2)</td>
</tr>
<tr>
<td>CR3</td>
<td>CF 35.6</td>
<td>1.9 (2.9)</td>
<td>1.8 (2.8)</td>
</tr>
<tr>
<td>CR4</td>
<td>CF 82.0</td>
<td>2.3 (3.3)</td>
<td>2.4 (3.4)</td>
</tr>
<tr>
<td>CR5</td>
<td>CF 89.1</td>
<td>3.0 (4.0)</td>
<td>2.9 (3.9)</td>
</tr>
<tr>
<td>CR6</td>
<td>CF 85.0</td>
<td>2.0 (3.0)</td>
<td>2.1 (3.1)</td>
</tr>
<tr>
<td>CR7</td>
<td>CF 88.4</td>
<td>2.1 (3.1)</td>
<td>2.2 (3.2)</td>
</tr>
<tr>
<td>CR8</td>
<td>CF 93.6</td>
<td>3.1 (4.1)</td>
<td>3.2 (4.2)</td>
</tr>
<tr>
<td>CR9</td>
<td>CF 81.0</td>
<td>2.6 (3.6)</td>
<td>2.7 (3.7)</td>
</tr>
</tbody>
</table>

---

### FBCT CFs

<table>
<thead>
<tr>
<th>CR</th>
<th>CF</th>
<th>Family</th>
<th>JHs</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR1</td>
<td>CF 98.4</td>
<td>3.0 (4.0)</td>
<td>3.1 (4.1)</td>
</tr>
<tr>
<td>CR2</td>
<td>CF 94.1</td>
<td>4.0 (5.0)</td>
<td>4.1 (5.1)</td>
</tr>
<tr>
<td>CR3</td>
<td>CF 91.8</td>
<td>3.0 (4.0)</td>
<td>3.1 (4.1)</td>
</tr>
<tr>
<td>CR4</td>
<td>CF 92.6</td>
<td>3.0 (4.0)</td>
<td>3.1 (4.1)</td>
</tr>
<tr>
<td>CR5</td>
<td>CF 95.3</td>
<td>3.0 (4.0)</td>
<td>3.1 (4.1)</td>
</tr>
<tr>
<td>CR6</td>
<td>CF 92.0</td>
<td>3.0 (4.0)</td>
<td>3.1 (4.1)</td>
</tr>
<tr>
<td>CR7</td>
<td>CF 91.0</td>
<td>3.0 (4.0)</td>
<td>3.1 (4.1)</td>
</tr>
<tr>
<td>CR8</td>
<td>CF 96.3</td>
<td>3.0 (4.0)</td>
<td>3.1 (4.1)</td>
</tr>
<tr>
<td>CR9</td>
<td>CF 84.7</td>
<td>3.0 (4.0)</td>
<td>3.1 (4.1)</td>
</tr>
</tbody>
</table>

---

**FBCT CFs are larger!**
GEOS forced (July 2002 ~ June 2016) to FBCT CRs
CR CRE comparison between FBCT and GEOS

(a) TOA CREs
(b) ATM CREs
(c) SFC CREs
CR CREs x RFOs comparison between FBCT and GEOS

(a) TOA CREs

Bars: CERES, SW, LW, Total, GEOS

(b) ATM CREs

(c) SFC CREs
CRE Error decomposition, GEOS with FBCT

a) TOA SW

b) TOA LW

c) TOA Total

d) ATM SW

e) ATM LW

f) ATM Total

g) SFC SW

h) SFC LW

i) SFC Total

6.80

-1.86

4.94

1.04

0.86

1.90

5.76

-2.72

3.04