CERES TOA Flux Trends by Cloud Type

Norman G. Loeb\textsuperscript{1}, Seung-Hee Ham\textsuperscript{2}, Tyler Thorsen\textsuperscript{1}, Seiji Kato\textsuperscript{1}, and Ryan Scott\textsuperscript{1}

\textsuperscript{1}NASA Langley Research Center, Hampton, VA
\textsuperscript{2}Science Systems & Applications (SSAI), Hampton, VA
Loeb et al. (GRL; 2021)

- CERES Net radiation & In-Situ PHU show consistent increasing trends with good agreement in year-to-year variability.

**Trend and Uncertainty (Wm$^{-2}$ per decade; 5%-95% CI)**

Trend : $0.50 \pm 0.47$

Trend Diff : $0.07 \pm 0.29$

$R^2 = 0.49$

Note: CERES and Argo+Altimeter are anchored to an EEI of $0.76 \pm 0.1$ Wm$^{-2}$ for 2005-2020 based upon in-situ data.
• ASR trend mainly due to cloud and surface albedo changes.

• Combined changes in clouds, sea-ice, WV and trace gases exceed influence from temperature changes, resulting in a positive overall trend in net TOA flux.
Trend Attribution (Jan-Dec; SH) for 09/2002–03/2020

Absorbed Solar Radiation

Net Radiation

Longwave Radiation

Trend (Wm\(^{-2}\) per decade)
Trend Attribution (Jan-Dec; NH) for 09/2002–03/2020

Absorbed Solar Radiation

Net Radiation

Longwave Radiation
Negative reflected SW TOA flux trends often found in regions with positive SST trends.
Figure S1 Anomalies in MODIS cloud fraction and CERES SW TOA flux for a region over the Eastern Pacific (10°-40°N, 150°-110°W) for 03/2000-02/2020.

Trends
MODIS Cld frac: -1.4 ± 1.1 %/decade
CERES SW TOA: -2.1 ± 1.6 Wm⁻²/decade

Loeb et al. JGR, 2022 (in press)
Use the FluxbyCldType product to determine what cloud types contributed most to the cloud trends in each hemisphere.
Methodology

1) Determine meteorology by cloud type:
   - Read in meteorological variables (EIS, $T_{\text{skin}}$) in SSF1deg-daily for one month.
   - Sort and average meteorology by cloud type categories in FluxbyCldTyp-daily files to produce monthly meteorology by cloud type (6 cloud optical depth, 7 cloud-top pressure).

2) Determine flux by cloud class:
   - Read in monthly meteorology by cloud type from step 1.
   - For each gridbox, determine overall cloud fraction and mean SW TOA flux contribution for the following cloud classes:

<table>
<thead>
<tr>
<th>Cloud Class</th>
<th>Cloud Top Press (hPa)</th>
<th>EIS (K)</th>
<th>Latitude Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratocumulus (Sc)</td>
<td>&gt; 680</td>
<td>&gt; 5</td>
<td>$</td>
</tr>
<tr>
<td>Stratocumulus-to-Cumulus Transition (SCT)</td>
<td>&gt; 680</td>
<td>0 – 5</td>
<td>$</td>
</tr>
<tr>
<td>Shallow Cumulus (Cu)</td>
<td>&gt; 680</td>
<td>&lt; 5</td>
<td>$</td>
</tr>
<tr>
<td>Middle</td>
<td>440 – 680</td>
<td>–</td>
<td>$</td>
</tr>
<tr>
<td>High</td>
<td>&lt; 440</td>
<td>–</td>
<td>$</td>
</tr>
<tr>
<td>Polar</td>
<td>–</td>
<td>–</td>
<td>$</td>
</tr>
</tbody>
</table>

- Determine anomalies and trends for each cloud class (07/2002-12/2021)
Cloud Fraction by Cloud Class (September 2002)

- **Stratocumulus (Sc)**: Global: 6%
- **Sc-to-Cu Transition (SCT)**: Global: 13%
- **Shallow Cumulus (Cu)**: Global: 9%
- **Middle**: Global: 11%
- **High**: Global: 16%
- **Polar**: Global: 11%

![Map showing cloud fraction by cloud class](image)
SW Contribution to Hemispheric Anomalies

SH

<table>
<thead>
<tr>
<th>Area</th>
<th>Std (Wm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear (0-90°S)</td>
<td>0.41</td>
</tr>
<tr>
<td>Low (0-60°S)</td>
<td>0.87</td>
</tr>
<tr>
<td>Middle (0-60°S)</td>
<td>0.33</td>
</tr>
<tr>
<td>High (0-60°S)</td>
<td>0.64</td>
</tr>
<tr>
<td>Polar (60°-90°S)</td>
<td>0.35</td>
</tr>
</tbody>
</table>

NH

<table>
<thead>
<tr>
<th>Area</th>
<th>Std (Wm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear (0-90°N)</td>
<td>0.47</td>
</tr>
<tr>
<td>Low (0-60°N)</td>
<td>0.67</td>
</tr>
<tr>
<td>Middle (0-60°N)</td>
<td>0.37</td>
</tr>
<tr>
<td>High (0-60°N)</td>
<td>0.66</td>
</tr>
<tr>
<td>Polar (60°-90°N)</td>
<td>0.40</td>
</tr>
</tbody>
</table>
- Increase in CLR fraction (SH & NH)
- Decreases in low and middle clouds (SH & NH)

- NH CLR SW flux decrease due to decreases in sea-ice fraction and aerosols
- Middle cloud decreases are main reason for SW TOA flux changes in SH.
- Low cloud decreases are main reason for SW TOA flux changes in NH
Low Cloud Fraction Anomalies

**SH**

- **Sc**
  - Std: 1.3%
  - Year range: 2002-2022

- **SCT**
  - Std: 1.2%

- **Cu**
  - Std: 0.62%

**NH**

- **Sc**
  - Std: 0.67%
  - Year range: 2002-2022

- **SCT**
  - Std: 0.71%

- **Cu**
  - Std: 0.45%
  - Year range: 2002-2022
Low Cloud Trends by Type

**Cloud Fraction**

<table>
<thead>
<tr>
<th>Type</th>
<th>SH</th>
<th>NH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc</td>
<td>-0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>SCT</td>
<td>0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Cu</td>
<td>0.00</td>
<td>-0.25</td>
</tr>
<tr>
<td>All</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**SH:** Weak overall low cloud change due to compensation between SCT and Cu.

**NH:** Sc dominate the low cloud changes.

**SW TOA Flux**

<table>
<thead>
<tr>
<th>Type</th>
<th>SH</th>
<th>NH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc</td>
<td>-0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>SCT</td>
<td>0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Cu</td>
<td>0.00</td>
<td>-0.25</td>
</tr>
<tr>
<td>All</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Summary

• Increase in clear area fraction in both hemispheres
• NH CLR SW flux decreases due to decreases in sea-ice fraction and aerosols
• Middle cloud decreases are main reason for SW TOA flux changes in SH.
• Low cloud decreases (mainly Sc) are main reason for SW TOA flux changes in NH

Next Steps

• Use the C3M data product to compare trends in cloud fraction from MODIS with those from active sensors (CALIPSO & CloudSat) for 2007-2017.
• Analyze active sensor data in a manner analogous to MODIS: examine cloud fraction for the clouds exposed to space (sort clouds according to top layer visible from space).
Global Mean All-Sky TOA Flux Anomalies (Relative to Climatology for 05/2018—06/2019)

- **ASR**
  - EBAF Trends (03/2000-01/2022)
  - \(0.69 \pm 0.20 \text{ Wm}^{-2} \text{ per decade}\)

- **OLR**
  - \(-0.27 \pm 0.21 \text{ Wm}^{-2} \text{ per decade}\)

- **NET**
  - \(0.42 \pm 0.20 \text{ Wm}^{-2} \text{ per decade}\)

- Earth’s heating rate increased markedly since 2000:
  - Avg EEI (03/2000—02/2005): 0.44 Wm\(^{-2}\)
  - Avg EEI (02/2017—01/2022): 1.14 Wm\(^{-2}\)
Clear and Cloud Fraction Hemispheric Anomalies

SH

Clear (0-90°S)
Std: 0.70%

Low (0-60°S)
Std: 0.60%

Middle (0-60°S)
Std: 0.22%

High (0-60°S)
Std: 0.50%

Polar (60°-90°S)
Std: 0.14%

NH

Clear (0-90°N)
Std: 0.67%

Low (0-60°N)
Std: 0.49%

Middle (0-60°N)
Std: 0.28%

High (0-60°N)
Std: 0.50%

Polar (60°-90°N)
Std: 0.23%