Understanding atmospheric and cloud property variability toward TOA spectral radiance closure

Seiji Kato\textsuperscript{1}, Fred Rose\textsuperscript{2}, Xu Liu\textsuperscript{1}, and Nipa Phojanamongkolkij\textsuperscript{1}

\textsuperscript{1}NASA Langley Research Center
\textsuperscript{2}Science System & Applications Inc.
Outline of this talk

• Error source of longwave fingerprinting
• TOA LW spectra modeling
• Comparison of broadband radiances with CERES
• Effect of small-scale variability on broadband radiances
• Correlation among atmospheric and cloud properties
Error source of LW fingerprinting (TOA closure)

- Instrument calibration
- Modeling error (inputs, assumptions in radiative transfer etc.)
- Non-linear effects \( \sum \sum \frac{\partial^2 I}{\partial x_j \partial x_k} \Delta x_j \Delta x_k \) (can be included in a signature matrix)
- Vertical resolution in building the signature matrix or missing elements in it.
- Correlations present at a small-scale spatial and temporal resolution that affect observed spectral radiances (focus of this talk)
TOA nadir view spectral radiance computations

- Spectral radiance using PCRTM with a 0.5 cm$^{-1}$ spectral resolution and 20 km spatial resolution.
- Clouds and aerosols: CCCM (CALIPSO, CloudSat, and MODIS).
- Temperature and humidity: Reanalysis (MOA: GEOS4 and GEOS5).
- Instantaneous nadir radiance.
- Modeled spectral radiance changes are used to investigate atmospheric and cloud property variability.
High resolution versus monthly mean computations

• To express the spectral radiance change by the sum of contributions of atmospheric and cloud property changes

\[ \Delta I = \sum \Delta I(\bar{x}_i) \]

• Compare
  – Mean of instantaneous radiances \( I(\bar{x}) \)
  – Radiance computed with monthly mean properties \( I(x) \)
Comparison of deseasonalized anomalies with CERES observed LW radiances

Closed circle: CERES
Open circle: Instantaneous resolution
Open triangle: Monthly mean calculations

Correlation coefficient with CERES deseasonalized anomalies

Zone: 5. Deseasoned ALL

Nadir Radiance [Wm^-2str^-1]

Month (start Jul06)

CERES  -0.00 ( 0.70 )
PCRTM(i)  0.00 ( 0.73 )  R^2= 0.980
PCRTM(m) -0.00 ( 0.80 )  R^2= 0.936
PCRTM(i)-CER  0.00 ( 0.15 )
PCRTM(m)-CER -0.00 ( 0.28 )

Correlation coefficient

Latitude (°)
2007 - 2008 difference

Radiance difference, 200801 – 200701
Model – CERES,
10° zonal monthly mean difference

RMS difference 2008 – 2007
Model - CERES

Correlations among atmospheric and cloud properties occurring at a high resolution affect TOA radiances
Small-scale correlation increases RMS 30 to 40% while the non-linear term contributes 10 to 15%
Modeled radiance difference

\[ \sqrt{\frac{1}{n} \sum [I(\bar{x}) - I(x)]^2} \]

Interannual variability of the RMS is smaller than the modeled radiance difference
2008 – 2007 difference

\[ \sqrt{\frac{1}{n} \sum \left\{ \left[ I(x) - \bar{I}(x) \right]_{2008} - \left[ I(x) - \bar{I}(x) \right]_{2007} \right\}^2} \]

Relatively smaller zonal broadband radiance difference
Correlation matrix

• Correlation coefficients computed from inputs used for high resolution spectra computations for a month

\[
\left( \frac{x_{ij} - \bar{x}}{\sigma_i} \right) \left( \frac{x_{kj} - \bar{x}_k}{\sigma_k} \right)'
\]

• Both spatial and temporal correlations are included
Correlation coefficient difference

Radiance difference
Latitude 20°S-10°S

Good agreement (red) – Bad agreement (blue)
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arctic</strong></td>
<td>$T_{\text{trop}}$ &amp; $T_{\text{strat}}$ (0.326)</td>
<td>$T_{\text{trop}}$ &amp; $T_{\text{strat}}$ (0.312)</td>
<td>$T_{\text{trop}}$ &amp; $C_{\text{taulo}}$ (0.285)</td>
</tr>
<tr>
<td><strong>NH Mid-latitude</strong></td>
<td>$T_{\text{skin}}$ &amp; $Q_{L\text{trop}}$ (0.584)</td>
<td>$T_{\text{air}}$ &amp; $Q_{U\text{trop}}$ (0.531)</td>
<td>$T_{\text{air}}$ &amp; $Q_{L\text{trop}}$ (0.517)</td>
</tr>
<tr>
<td><strong>Tropics</strong></td>
<td>$T_{\text{air}}$ &amp; $Q_{L\text{trop}}$ (0.403)</td>
<td>$T_{\text{skin}}$ &amp; $T_{\text{trop}}$ (0.284)</td>
<td>$T_{\text{skin}}$ &amp; $Q_{L\text{trop}}$ (0.266)</td>
</tr>
<tr>
<td><strong>SH Mid-latitude</strong></td>
<td>$T_{\text{trop}}$ &amp; $T_{\text{strat}}$ (0.465)</td>
<td>$T_{\text{air}}$ &amp; $T_{\text{strat}}$ (0.377)</td>
<td>$T_{\text{skin}}$ &amp; $T_{\text{strat}}$ (0.372)</td>
</tr>
<tr>
<td><strong>Antarctic</strong></td>
<td>$T_{\text{trop}}$ &amp; $T_{\text{strat}}$ (0.825)</td>
<td>$T_{\text{strat}}$ &amp; $Q_{L\text{trop}}$ (0.596)</td>
<td>$T_{\text{skin}}$ &amp; $T_{\text{strat}}$ (0.567)</td>
</tr>
</tbody>
</table>

$T_{\text{trop}}$: Tropospheric temperature (Surface to 200 hPa)
$T_{\text{strat}}$: Stratospheric temperature (200 hPa to 10 hPa)
$T_{\text{skin}}$: Skin temperature
$T_{\text{air}}$: Surface air temperature
$Q_{L\text{trop}}$: Surface to 500 hPa water vapor
$Q_{U\text{trop}}$: 500 hPa to 200 hPa water vapor
$C_{\text{taulo}}$: low-level cloud optical depth (log)
Summary and future work

• Small-scale correlations increase the difference of the 10° zonal monthly mean broadband radiance from two different years by 30 to 40%.

• Correlations among temperature and water vapor appear to be responsible for the increase but need more investigations.

• Future work
  – Quantify TOA spectral radiance contribution due to small-scale correlations
  – Spectral kernel modeling
Back-ups
When broadband LW irradiance differences agree

**April 20°N to 10°S**

**October 40°N to 50°N**

Red line: instantaneous computations

Blue line: monthly 1°×1° mean computations
When broadband LW radiance differences disagree

Red line: instantaneous computations
Blue line: monthly 1°×1° mean computations
Zonal broadband
Anomalies over ocean
Anomalies over land

Zone: 25. Deseasoned LND

Nadir Radiance [Wm-2str-1]

Month (start Jul06)

PCRTM  0.00 ( 0.89 )
CERES  0.00 ( 0.92 )  \( R^2= 0.981 \)
PCRTM-CERES  0.00 ( 0.18 )

Zone: 15. Deseasoned LND

Nadir Radiance [Wm-2str-1]

Month (start Jul06)

PCRTM  0.00 ( 0.72 )
CERES  0.00 ( 0.69 )  \( R^2= 0.866 \)
PCRTM-CERES  -0.00 ( 0.37 )
Anomalies over snow/ice

Zone: -85. Deseasoned ICE

PCRTM 0.00 (0.83)
CERES -0.00 (0.92) \( R^2 = 0.936 \)
PCRTM-CERES -0.00 (0.32)

Zone: 75. Deseasoned ICE

PCRTM -0.00 (0.61)
CERES 0.00 (0.66) \( R^2 = 0.948 \)
PCRTM-CERES -0.00 (0.21)
Figure 5 (a) Deseasonalized anomalies in tropical (30°S-30°N) and global CERES LW TOA flux together with the multivariate ENSO Index (MEI). A 2-month running average is used to determine the LW TOA flux anomalies. (b) Deseasonalized anomalies in midlatitude (30°S-60°S and 30°N-60°N) mean CERES LW TOA flux, MODIS cloud fraction, and MISR cloud-top height. An 11-point 6-month low-pass Lanczos filter is applied to the monthly anomalies.

Loeb et al. 2011
Annual zonal broadband radiance difference

![Graph showing annual zonal broadband radiance difference](image)

Monthly: Spectral radiances are modeled using monthly mean gridded atmospheric and cloud properties (nadir view sampled grid box only)