PCRTM
(Principal Component Radiative Transfer Model)
Spectral Longwave Simulations with 5 Years of SSF and MOA Data Compared to CERES Observed Broadband Nadir Radiances

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Outline

• PCRTM Model
  – Accuracy
  – Description of Simulation

• Survey of Results
  – Monthly Variability
  – Daily variability example

• Comparisons to CERES Nadir broadband LW radiance

• Radiative kernels
  – CO2 Forcing and possible feedback examples

• Summary
PCRTM

• Principal Component Radiative Transfer Model
  – Xu Liu, William L. Smith, Daniel K. Zhou, and Allen Larar
    • Applied Optics Vol 45, No. 1, 1 Jan 2006
• Spectral longwave radiance (50 - 2760 cm$^{-1}$)
• 0.5 cm$^{-1}$ effective resolution
  – obtained using 280 principal components (FAST !!!)
• Cloud properties (P. Yang)
  – Optical depth, Particle size, Phase ,Effective height
• Includes Multiple Scattering
• Variable Gases: H$_2$O, O$_3$
  - CO$_2$, CH$_4$, N$_2$O, CO can vary in PCRTM but not in this simulation.
  - Other minor trace gas concentrations fixed example: CFC’s
• IGBP based (coarse /12 band) surface spectral emissivity
• No Aerosol in this simulation
Radiance & Brightness Temperature

- An example longwave radiance spectra color coded by brightness temperature
- Plank functions overlaid

Brightness temperature is convenient to highlight variability in spectral regions where emitted radiant energy is small.
PCRTM Accuracy

- PCRTM compared to LBLRTM
- Used 52 ECMWF diverse atmosphere profiles
- Fig 4. Applied Optics (Xu et al 2006)
Five Year PCRTM/SSF/MOA Inputs

• Jan 2001 : Dec 2005 ( 60 Months)
  • Instantaneous NADIR ONLY FOVs ( ie Clarreo simulation)
• Subset SSF : Terra-FM1-MODIS_Edition2B
  – Cloud ( Fraction, Optical Depth, Height, Phase , Re/De)
  – Clear Sky and up to 2 Cloud Conditions per SSF FOV
  – Skin Temperature, IGBP type
• MOA: DAO-GEOS4
  – 6 hourly profiles of Temperature, Humidity (Surface to 0.4 hPa)
  – Daily SMOBA Ozone profile
• Processed on AMI : IBM X86 64 node cluster
  – ~45 Million Instantaneous Nadir Only FOVs
  – 100+ Million Clear and Cloudy PCRTM spectra calculations
  – Output data: 60 month 10degLat PCscore output ~ 6Mb
Monthly Sampling

- Typically
  - 750,000 Global FOV/month
  - 400,000 Ocean
  - 200,000 Snow/Ice
  - 150,000 Land

- June 2001: MODIS issue
  - 15 days missing

- Nov 2002: SMOBA ozone
  - 10 days missing
5 Year MEAN
Zonal/Spectrum
Standard Deviation of Monthly Data (200101-200512)
Seasonal Variability
Deseasonalized Anomaly : What is it?
Example using made up temperature data

Original Data is 5 years of monthly data with a large apparent seasonal component

Canonical Season is the mean of each individual month (Jan, Feb.. Dec) over all available years. In this case 5 years.

Deseasonalized Anomaly is formed by original data minus canonical season

\[
\sigma_{\text{Total}} = \sqrt{\sigma_{\text{Canonical}}^2 + \sigma_{\text{Anomaly}}^2}
\]

\[
19.7 = \sqrt{(18.2)^2 + (7.4)^2}
\]
Standard Deviation of Deseasonalized Anomaly (Jan 2001:Dec 2005)
Global Mean LW Spectral Brightness Temperature Variability

Seasonal variability large in windows surface temperature variability

Deseasonalized anomaly variability large in H$_2$O atmosphere absorption bands
Daily Zonal Mean Variability
Jan 2001
65N -90N Sudden Stratospheric Warming Event Jan-Feb 2001

$\Delta T$ during Jan 2001

- 1hpa $+40K$
- 5hpa $+45K$
- 30hpa $+15K$

Source: http://www.cpc.noaa.gov/products/stratosphere/temperature/
Comparisons of PCRTM simulations to CERES Observations of LW nadir radiances
Global Monthly Means
(Seasonal Variability)

<table>
<thead>
<tr>
<th>Radiance</th>
<th>PCRTM</th>
<th>CERES</th>
<th>PCRTM - CERES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>80.3</td>
<td>80.7</td>
<td>-0.40</td>
</tr>
<tr>
<td>Ocean</td>
<td>80.9</td>
<td>81.3</td>
<td>-0.39</td>
</tr>
<tr>
<td>Land</td>
<td>81.9</td>
<td>82.5</td>
<td>-0.61</td>
</tr>
<tr>
<td>Snow/Ice</td>
<td>72.6</td>
<td>73.1</td>
<td>-0.47</td>
</tr>
</tbody>
</table>

Ocean

Land

Snow/Ice
Monthly Mean Anomaly
(Inter-annual Variability)

<table>
<thead>
<tr>
<th>Anomaly Statistics</th>
<th>$R^2$</th>
<th>PCRTM Stddev</th>
<th>CERES Stddev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>0.75</td>
<td>0.128</td>
<td>0.117</td>
</tr>
<tr>
<td>Ocean</td>
<td>0.81</td>
<td>0.162</td>
<td>0.131</td>
</tr>
<tr>
<td>Land</td>
<td>0.91</td>
<td>0.379</td>
<td>0.362</td>
</tr>
<tr>
<td>Snow/Ice</td>
<td>0.95</td>
<td>1.886</td>
<td>1.600</td>
</tr>
</tbody>
</table>

Global Monthly Mean
Deseasonalized Nadir LW Radiance
Year 2001-2005

Ocean

Land

Snow/Ice

Month from Jan 2001

Month from Jan 2001

Month from Jan 2001
Inter-annual Variability by Lat. Zone
**Daily Zonal Mean 200101 & CERES**

<table>
<thead>
<tr>
<th></th>
<th>75N</th>
<th>45N</th>
<th>25N</th>
<th>45S</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CERES BB</strong></td>
<td>56.2(1.17)</td>
<td>68.0(0.88)</td>
<td>89.2(1.64)</td>
<td>78.3(1.29)</td>
</tr>
<tr>
<td><strong>PCRTM BB</strong></td>
<td>56.3(1.17)</td>
<td>67.5(0.93)</td>
<td>88.7(1.59)</td>
<td>78.7(1.33)</td>
</tr>
<tr>
<td><strong>PCRTM BB-CERES BB</strong></td>
<td>0.1(0.23)</td>
<td>-0.6(0.25)</td>
<td>-0.5(0.18)</td>
<td>-0.5(0.18)</td>
</tr>
<tr>
<td><strong>PCRTM CO2 band 680-720 cm-1</strong></td>
<td>1.5(0.08)</td>
<td>1.8(0.04)</td>
<td>1.9(0.01)</td>
<td>2.1(0.01)</td>
</tr>
</tbody>
</table>
PCRTM & CLARREO
Radiative Kernels
(Partial Derivatives of Spectral LW radiances)
and the Attribution of spectral changes
over time to physical variables
One of upcoming CLARREO mission goals is to detect climate trends.

Example here is a forcing due to a change in CO2 affecting the longwave spectra with a characteristic shape.

Computed using PCRTM for a single day of SSF 20010115 using a CO2 change of 2 ppmv.

But the Earth is vastly more complicated, feedbacks and natural variability exist….
Possible Feedback Responses
(Many others possible)

Low Cloud Height Plus 250m[P23]

Hi Cloud Height Plus 200m[P25]
Summary

• PCRTM/SSF/MOA used to simulate nadir LW radiances
  – Use as a tool for CLARREO

• PCRTM/SSF/MOA show much of seasonal and most of deseasoned variance is from stratosphere CO2, O3 bands.

• PCRTM/SSF/MOA simulations match CERES ED2 broadband nadir radiances to -0.4 (Wm-2sr-1) global 5 year mean
  – High correlations of simulation to CERES deseasoned Anomaly
CERES Global LW FLUX Anomaly
(Norman Loeb Provisional Ed3)

Global CERES & PCRTM RADIANCE Anomaly
(Sized to scale roughly to Flux Anomaly Plot.)

0.753 ± 0.44 Wm⁻² per decade
0.572 ± 0.36 Wm⁻² per decade
D-N: 0.180 ± 0.24 Wm⁻² per decade
Additional Figures

• http://snowdog.larc.nasa.gov/rose/pctrm/ssf/zgm/