Short-term radiation anomalies and feedbacks observed by CERES

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CERES Science Team Meeting
Geophysical Fluid Dynamics Laboratory
Princeton, NJ, October 22-25, 2012
Introduction

Climate state and radiation
- variations in climate states drive radiation changes
- changes in radiation lead climate state variations

Chicken and Egg problem

Climate Studies
- most efforts focus on radiation & surface temperature
- difficulties: no clear signals, various kinds of processes
dynamics/thermodynamics, especially in short time scales
10-yr TOA Radiation Anomaly

Reflected SW
SW = 2.75 – 1.15Ts

Outgoing LW
LW = -6.60 + 3.46Ts

Net Incoming
Net = 4.46 – 2.18Ts

Strip features:
chaotic processes
Observed $T_s$ vs Radiation

TOA Radiation ($W/m^2$)

Surface Skin Temperature ($K$)

Surface Temperature ($K$)
Introduction

Climate Studies
- most efforts focus on radiation & surface temperature difficulties: no clear signals, various kinds of processes dynamics/thermodynamics, especially in short time scales

Cloud observations
- clouds could be used to estimate radiation fields
  However: model cannot predict clouds accurately at least currently

clouds <<<<<< >>>>>>> radiation
the problem in different aspects
radiation anomaly

cld+clr combined

\[ \Delta R \approx -\Delta c \cdot R_{\text{clr}} + (1-c) \Delta R_{\text{clr}} + \Delta c R_{\text{cld}} + c \Delta R_{\text{cld}} \]
Goals

- **Understanding radiation variations**
  - maintaining its base state: especially from LW anomaly
  - relationship with other processes

- **Short-term phenomena**
  - long-term effect may not show up clearly
  - short-term feedback from dynamics/thermodynamics

- Many controlling variables
Radiation Perturbation & Basic Climate Response

\[ R_{net} = (1 - \alpha)S_0 - \varepsilon\sigma T_s^4 \]

equilibrium state: \( \Delta \alpha = \Delta \varepsilon = 0 \)

\[ \Delta R_{net} = -\frac{4\varepsilon\sigma T_s^4}{T_s} \Delta T_s \]

\[ = -\frac{4 \times 237}{288} \Delta T_s = -3.3 \Delta T_s \]

\( f_n = -3.3 \text{ Wm}^{-2}\text{K}^{-1} \) (only for blackbody)

Feedbacks: this feature along with other processes.
Goals

- **Understanding radiation variations**
  - maintaining its base state: especially LW anomaly
  - relationship with other processes

- **Short-term phenomena**
  - long-term effect may not show up clearly
  - short-term feedback from dynamics/thermodynamics

- **Many controlling variables**
Cannot determine total feedback from short-term relationships

\[ f_{\text{tot}} = -6 \text{ W/m}^2 \]
\[ f = -2.7 \quad D=100\text{m} \]
\[ f_{\text{tot}} = -8 \text{ W/m}^2 \]
\[ f = -2.7 \quad D=100\text{m} \quad f_m = -2.0 \]
\[ f_{\text{tot}} = -4 \text{ W/m}^2 \]
\[ f = -2.7 \quad D=100\text{m} \quad f_m = 2.7 \]
\[ f_{\text{tot}} = -2.3 \text{ W/m}^2 \]
\[ f = -2.7 \quad D=100\text{m} \quad f_m = 3.7 \]
Goals

- **Short-term phenomena**
  - long-term effect may not show up clearly
  - short-term feedback from dynamics/thermodynamics

- **Many controlling variables**
  - key parameters and variables for radiation:
    - skin temperature $T$; $T$ gradient: $\Delta T_{\text{LAT}}$, $\Delta T_{\text{LON}}$
    - Column water vapor: $\text{CWV}$; Ozone: $O_3$
    - wind and wind divergence: $W$, $\nabla \cdot W$
    - both linear and 2nd order variations:
      - e.g. $\text{CWV} \cdot W$, $T \nabla \cdot W$, $\Delta T_{\text{LON}} O_3$
  - total 35 variables/parameters/compound terms
Approaches

- 10-years CERES data: 2001 ~ 2010
  - TOA radiation fields & changes
  - anomalies of T and other variables
  - 'climatologies': ten-years means

- Data Processing
  - tropical 23°S to 23°N zonal band
  - SSF1DEG monthly 1° × 1° grid boxes
  - multivariable linear regression
    eliminating statistically insignificant terms,
    until all terms are statistically meaningful
    empirically explain the anomalies in radiation fields
Results

- Time series
  - tropical monthly mean values: SW, LW & Net
  - Gridded results (shown some here)
  - statistical significant terms
  - high confidence on estimated results for the 10-yr data

- Surface temperature effects

- Water vapor effects

- Dynamics: $\Delta T_{\text{lat}}, \Delta T_{\text{lon}}, W, \nabla \cdot W$

- Other variables: e.g. ozone
Empirical Results

Observed Anomaly (W/m$^2$)

Estimated Anomaly (W/m$^2$)

SW = 1.67e-6 + 1.00 * SW$_{est}$
LW = -2.56e-7 + 0.972 * LW$_{est}$
Net = 3.25e-6 + 0.995 * Net$_{est}$
Tropical Mean Analysis

Observed anomalies

Empirical estimates

Time (yr)
Results

- **Time series**
  - tropical monthly mean values: SW, LW & Net
  - statistical significant terms
  - high confidence on estimated results for the 10-yr data

- **Surface temperature effects**

- **Water vapor effects**

- **Dynamics**: $\Delta T_{\text{lat}}, \Delta T_{\text{lon}}, W, \nabla \cdot W$

- **Other variables**: e.g. ozone
Multi-Variable Analysis for LW Radiation Anomaly

<table>
<thead>
<tr>
<th>constant</th>
<th>V</th>
<th>W</th>
<th>( \nabla W )</th>
<th>( \Delta T_{\text{lat}} )</th>
<th>( W^2 )</th>
<th>( \nabla W^2 )</th>
<th>T*W</th>
<th>( \frac{V}{\Delta T_{\text{lat}}} )</th>
<th>W*O₃</th>
<th>( \nabla W^* O_3 )</th>
<th>( \frac{W^*}{\Delta T_{\text{lon}}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.83e-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>coeff</td>
<td>-0.661</td>
<td>0.285</td>
<td>0.184</td>
<td>0.355</td>
<td>-0.143</td>
<td>-0.200</td>
<td>-0.245</td>
<td>0.178</td>
<td>-0.184</td>
<td>-0.214</td>
<td>0.201</td>
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<tr>
<td>corr</td>
<td>-0.449</td>
<td>0.049</td>
<td>0.037</td>
<td>0.141</td>
<td>-0.161</td>
<td>-0.184</td>
<td>-0.009</td>
<td>-0.023</td>
<td>-0.038</td>
<td>0.028</td>
<td>0.123</td>
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<tr>
<td>t_test</td>
<td>10.196</td>
<td>3.530</td>
<td>2.295</td>
<td>5.599</td>
<td>2.203</td>
<td>3.141</td>
<td>3.430</td>
<td>3.010</td>
<td>2.000</td>
<td>2.511</td>
<td>2.997</td>
</tr>
</tbody>
</table>

additional term: blackbody emission: \( f_n \cdot T \)

- **temperature:** blackbody emission; through water vapor
- **water vapor:** absorption/emission; UTH and clouds
- **latitudinal temp. gradient:** general circulation
- **wind speed:** through dynamics & clouds;
## Multi-Variable Analysis for SW Radiation Anomaly

<table>
<thead>
<tr>
<th>Const.</th>
<th>T</th>
<th>W</th>
<th>O₃</th>
<th>ΔT_lon</th>
<th>V²</th>
<th>W²</th>
<th>O₃²</th>
<th>T*V</th>
<th>T*W</th>
<th>T*∇W</th>
<th>V*ΔT_lat</th>
<th>V*ΔT_lon</th>
<th>ΔT_lat*ΔT_lon</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>coeff</td>
<td>-0.159</td>
<td>0.686</td>
<td>-0.273</td>
<td>0.197</td>
<td>-0.301</td>
<td>0.243</td>
<td>0.214</td>
<td>0.577</td>
<td>0.211</td>
<td>0.223</td>
<td>-0.297</td>
<td>0.459</td>
<td>-0.281</td>
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<tr>
<td>corr</td>
<td>-0.203</td>
<td>0.598</td>
<td>-0.122</td>
<td>0.188</td>
<td>0.140</td>
<td>0.232</td>
<td>0.055</td>
<td>0.099</td>
<td>0.001</td>
<td>0.174</td>
<td>0.017</td>
<td>0.080</td>
<td>-0.139</td>
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<tr>
<td>t_test</td>
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<td>11.906</td>
<td>3.951</td>
<td>2.622</td>
<td>2.632</td>
<td>4.034</td>
<td>3.238</td>
<td>3.422</td>
<td>2.449</td>
<td>2.584</td>
<td>2.249</td>
<td>5.438</td>
<td>4.201</td>
</tr>
</tbody>
</table>

**strong links to dynamics & thermodynamics**

- **wind speed**: dynamics; storms; surface reflectivity
- **ozone**: SW absorption; tropo-strato-sphere interaction
- **high order terms**: additional dynamical impacts ??
Multi-Variable Analysis for Net Radiation Anomaly

-2.83e-3

<table>
<thead>
<tr>
<th>Const.</th>
<th>T</th>
<th>V</th>
<th>W</th>
<th>O₃</th>
<th>ΔTₗₐₜ</th>
<th>νW²</th>
<th>O₃²</th>
<th>T*νW</th>
<th>T*O₃²</th>
<th>T*ΔTₜₗ₀</th>
<th>V*ΔTₜₗ₀</th>
<th>νW*ΔTₜₗ₀</th>
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</thead>
<tbody>
<tr>
<td>coeff</td>
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<td>0.440</td>
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<td>0.364</td>
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<td>-0.356</td>
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<td>0.197</td>
<td>0.365</td>
<td>-0.375</td>
<td>-0.217</td>
</tr>
<tr>
<td>corr</td>
<td>0.283</td>
<td>0.150</td>
<td>-0.531</td>
<td>0.041</td>
<td>0.072</td>
<td>0.048</td>
<td>-0.111</td>
<td>-0.130</td>
<td>-0.068</td>
<td>0.175</td>
<td>0.093</td>
<td>-0.114</td>
</tr>
</tbody>
</table>

similar to LW or SW

- temperature: beyond blackbody emission;
- wind speed: dynamics; storms; both LW & SW
- water vapor: trap LW radiation; clouds with UTH
- ozone: shortwave absorption; interaction
Wind Speed and SW Anomalies

2002 Moderate El Nino

2009 Moderate El Nino

2007 Moderate La Nina

2010 Strong La Nina

Wind Speed (m/s)

2002 Mod El Nino

2009 Mod El Nino

2007 Mod La Nina

2010 Strong La Nina

CERES Anomaly (W/m²)
Water Vapor and Net Anomalies

2002 Moderate El Nino

2009 Moderate El Nino

2007 Moderate La Nina

2010 Strong La Nina

Column Water Vapor (kg/m²)

CERES Anomaly (W/m²)
Short Term Feedbacks

- **LW** ( - )
  - - : blackbody emission (or temperature) & dynamics
  - + : water vapor
  - + : others

- **SW** ( + )
  - - : dynamics, especially along longitudinal direction
  - + : temperature & ozone (slow down dynamics ??)

- **Net** ( - )
  - - : blackbody emission; dynamics
  - + : water vapor, temperature, ozone
Potential Long Term Impacts

Assuming with $T$ increasing: $V$ increasing, $W$ decreasing, $\Delta T_{\text{lon}}$ decreasing

- **LW** (−)
  - −: blackbody emission
  - +: water vapor
  - ?: dynamics more likely (−)

- **SW** (+)
  - +: dynamics (slow down dynamics)
  - ?: ozone

- **Net** (+)
  - −: blackbody emission
  - +: water vapor, dynamics
Summary

• Short term radiation changes are one of the keys in maintaining climate basic states.
• Short term radiation variations with meteorological variables cannot be used to predict long-term climate feedbacks.
• The fundamental negative radiative feedback from blackbody emission is the neutral point of the climate system. Other feedback processes should be considered on top of this process.
• The tropical monthly means of water vapor, wind speed, ozone, and temperature gradients are by far the most important meteorological variables for radiation when the blackbody emission effect is removed.
Summary (conti.)

• High order terms of meteorological variables have significant impacts on radiation fields. More study on them is needed.

• Due to the average of entire tropics, wind divergence may not have a strong relation with radiative fluxes. Selection over certain areas may lead better results.

• Short term feedbacks for LW, SW and Net are likely negative, positive, and negative, respectively.
Thank You!