Variations of radiation fields with environmental conditions
Observed by 10-years of CERES

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Introduction

- Climate state variations with radiation changes
  - feedbacks, esp. clouds: model simulations and observations

non-linear, chaotic
variations in
different time scales

Dessler, 2010
Radiation & Temp.

- Observed radiation variations: not only on $T$
  - Climate tendency: maintain its base state
  - Clouds, dynamics/thermodynamics >> $T$ & environmental variables $v_i$

![Graphs showing surface temperature and TOA net radiation](image)

Surface Temperature (K)

Tropics

N. Atlantic

Raw vs. anomaly TOA Net Radiation (W/m²)
climate variability

short-time scale characteristics

maintaining basic state

long-term climate sensitivity

climate forcing
Approaches

- **Radiation measurements**
  - TOA radiation changes: 10 yrs obs.
  - deseasonalized anomalies & perturbation/linearization
  - empirically explain the anomalies in radiation fields

- **Basic relationships**
  - dynamic & thermodynamic influences on radiation
  - environmental conditions: $T$, $w$, CWV, $\nabla \cdot w$, $\nabla T$, $o_3$
  - ENSO index: representing interannual variability

- **radiation change**

\[
R = (1-c)R_{clr} + cR_{cld}
\]
\[
\Delta R = -\Delta c \ R_{clr} + (1-c)\Delta R_{clr} + \Delta cR_{cld} + c \ \Delta R_{cld} + \ldots
\]
\[
= \Delta E_T + \Sigma_i (\partial R / \partial v_i) \Delta v_i + \text{other terms}
\]

*individual variables' influences on radiation*
Blackbody Thermal Emission (climate response function)

\[
Cp \frac{dT_s}{dt} = (1 - \alpha)S_0 - \varepsilon \sigma T_s^4
\]

\(Cp\): equivalent heat capacity

non-feedback status: \(\Delta \alpha = \Delta \varepsilon = 0\)

\[
Cp \frac{d\Delta T_s}{dt} = - \frac{4\varepsilon \sigma T_s^4}{T_s} \Delta T_s = E^0 \Delta T_s
\]

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

\(E^0 \approx -3.3 \text{ Wm}^{-2}\text{K}^{-1}; \ \Delta E_T = E^0 \Delta T\)

At short time scales, this feature is mixed with other processes.
Approaches (conti.)

- 10-years CERES data: 2001 ~ 2010
  - TOA radiation changes
  - variations in T and other variables
  - 10 years 'climatologies'

- Statistical analysis
  - SSF1DEG monthly $1^\circ \times 1^\circ$ grid boxes
  - Tropics: 23°S to 23°N zonal band
  - Global & other regional or basin results
  - multivariable linear regression (no aerosols considered)

- Residuals
  - uncertainty level
  - remaining unexplained
radiation anomaly

\[ \Delta R \approx -\Delta c \, R_{clr} + (1-c)\Delta R_{clr} + \Delta c R_{cl} + c \, \Delta R_{cl} \]
cloud effect

cloudy

clear

red: ΔC  blue: ΔR

Time (yr)
environmental variations

\[ \Delta(T(0^\circ - 20^\circ) - T(20^\circ - 40^\circ)) \]
individual relations

SW (W/m²)

LW (W/m²)

cloud cover (%)
multi-variable relations

\[ \Delta R = \Delta E_T + C_0 + \Sigma_i C_i \Delta v_i / \sigma_i \]

<table>
<thead>
<tr>
<th></th>
<th>C_0</th>
<th>Ts</th>
<th>cwv</th>
<th>w</th>
<th>\nabla \cdot w</th>
<th>E_{index}</th>
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<tbody>
<tr>
<td>SW</td>
<td>-6.60e^{-5}</td>
<td>-0.138</td>
<td>0.243</td>
<td>0.540</td>
<td>-0.107</td>
<td>-0.221</td>
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<tr>
<td>LW</td>
<td>-1.40e^{-3}</td>
<td>-0.276</td>
<td>-0.381</td>
<td>0.136</td>
<td>0.187</td>
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<tr>
<td>net</td>
<td>1.61e^{-3}</td>
<td>0.459</td>
<td>0.134</td>
<td>-0.696</td>
<td>-0.132</td>
<td>-0.005</td>
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<table>
<thead>
<tr>
<th></th>
<th>\nabla T</th>
<th>O3</th>
<th>\nabla \Delta</th>
<th>\sigma_{diff}</th>
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<tbody>
<tr>
<td>SW</td>
<td>-0.122</td>
<td>-0.201</td>
<td>0.73</td>
<td>0.69</td>
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<tr>
<td>LW</td>
<td>0.331</td>
<td>0.105</td>
<td>0.79</td>
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<tr>
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<td>-0.223</td>
<td>0.159</td>
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<td>0.89</td>
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</table>
multi-variable relations

Time (yr)
residuals

\[ \Delta R_{\text{anom}} \ (\text{W/m}^2) \]

Time (yr)
residuals (conti.)
### Cloudy Skies

<table>
<thead>
<tr>
<th></th>
<th>( C_0 )</th>
<th>( T_s )</th>
<th>( cwv )</th>
<th>( w )</th>
<th>( \nabla \cdot w )</th>
<th>( E_{\text{index}} )</th>
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<td>0.463</td>
<td>0.491</td>
<td>0.442</td>
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<td>LW</td>
<td>-1.04e-3</td>
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<td>-0.250</td>
<td>0.185</td>
<td>-0.092</td>
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<tr>
<td>Net</td>
<td>9.41e-4</td>
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<td>-0.331</td>
<td>-0.459</td>
<td>-0.075</td>
<td>-0.046</td>
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<table>
<thead>
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<th></th>
<th>( \nabla T )</th>
<th>( O_3 )</th>
<th>( r^2 )</th>
<th>( \sigma_{\text{diff}} )</th>
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</thead>
<tbody>
<tr>
<td>SW</td>
<td>0.111</td>
<td>0.261</td>
<td>0.59</td>
<td>0.90</td>
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<tr>
<td>LW</td>
<td>0.424</td>
<td>-0.114</td>
<td>0.54</td>
<td>1.04</td>
</tr>
<tr>
<td>net</td>
<td>-0.637</td>
<td>-0.153</td>
<td>0.64</td>
<td>1.16</td>
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</tbody>
</table>
cloudy skies

Time (yr)
Residuals: cloudy

ΔRanom (W/m²)

Time (yr)
Residuals: cloudy

\[ \Delta \text{Ranom} \ (W/m^2) \]

Time (yr)
Summary

- Climate system has different characteristics in different time scales. Current analyses focus on short-time scales (within few years).
- Many variables such as clouds, surface temperature, water vapor, wind, divergence, $O_3$, and temperature gradient have significant influences on the variations of TOA radiation fields in short-time scales.
- According to current results, dynamics (e.g. wind) may dominate the SW radiation variations, while for LW, thermodynamics (temperature & water vapor) along with other factors like $\nabla T$ and ENSO may be the most important factors in determining its variability.
Summary (conti.)

- Current analysis could explain more than 80% changes in the radiation anomalies observed by CERES for all sky conditions. For cloudy skies, the levels of explained variances are slightly lower.

- Although the variances in the residuals of the radiation anomalies are within the uncertainties of satellite measurements, the differences between empirically analyzed results and CERES observations are still not negligible. Influences of additional variables such as aerosols (indirect effects) on radiation anomalies may still exist.

- Further studies are needed.
Acknowledgement

Many people, especially Norm Loeb, Don Garber, and Gary Gibson, have significant supports for this study.