Factors Contributing to Variability in CERES Radiation Flux

2011 CERES Science Team Meeting

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Data Selection and Processing

- Monthly 1° x 1° values for Mar 2000 – Dec 2010
- Terra Edition 3 radiation fluxes (no geostationary contribution)
- MODIS cloud fraction and effective temperature (Minnis Edition 2 algorithm)
- ERA Interim surface temperature
- 6-month low-pass filter applied to time series for readability
Split All-Sky Flux into Components

\[ \text{Flux}_{\text{all}} = \text{Flux}_{\text{clr}} (1 - f) + \text{Flux}_{\text{cld}} f \]

\[
\begin{align*}
\text{Flux}_{\text{all}} & \quad \text{all-sky flux (LW, SW, Net)} \\
\text{Flux}_{\text{clr}} & \quad \text{clear-sky flux (LW, SW, Net)} \\
f & \quad \text{total cloud fraction} \\
\text{Flux}_{\text{cld}} & \quad \text{cloudy-sky flux (as if grid box were overcast)}
\end{align*}
\]
Derivation of Cloudy-Sky Flux

$$\text{Flux}_{\text{cld}} = \text{Flux}_{\text{clr}} + \left( \text{Flux}_{\text{all}} - \text{Flux}_{\text{clr}} \right) / f$$

**Caution**

- $\text{Flux}_{\text{cld}}$ is derived from measured parameters and therefore is not independent.
- Any error in all-sky flux, clear-sky flux, and/or cloud fraction will produce a compensating error in $\text{Flux}_{\text{cld}}$.
Linear Perturbation Analysis

For each grid box and calendar month, separate into long-term mean <> and monthly anomalies $\Delta$

**Long term mean**

$$<\text{Flux}_{\text{all}}> = <\text{Flux}_{\text{clr}}>(1 - <f>) + <\text{Flux}_{\text{cld}}><f>$$

**Perturbation**

$$\Delta\text{Flux}_{\text{all}} = \Delta f (<\text{Flux}_{\text{cld}}> - <\text{Flux}_{\text{clr}}>) + \Delta\text{Flux}_{\text{clr}} (1 - <f>)$$

$$+ \Delta\text{Flux}_{\text{cld}}<f> + \Delta\text{Flux}_{\text{cld}} \Delta f - \Delta\text{Flux}_{\text{clr}} \Delta f$$

- cloud fraction contribution
- clear-sky contribution
- cloudy-sky contribution
- higher-order terms
90°S-90°N SW Time Series

Outgoing SW Flux Anomaly (W m⁻²)

Year

Black: all-sky SW
Blue: cloud fraction component
Red: clear-sky component
Green: cloudy-sky component
Magenta: higher-order

Cloud fraction is dominant contributor to SW anomalies
90°S-90°N LW Time Series

Black: all-sky LW
Blue: cloud fraction component
Red: clear-sky component
Green: cloudy-sky component
Magenta: higher-order component

Cloudy-sky is dominant contributor to LW anomalies
90°S-90°N Net Time Series

Black: all-sky Net
Blue: cloud fraction component
Red: clear-sky component
Green: cloudy-sky component
Magenta: higher-order component

Cloudy-sky is dominant contributor to Net anomalies
Global anomalies are mostly produced by low-latitude anomalies partially offset by higher latitude anomalies (note different axis scales)
Jan 2008 – Jun 2009 is a period of sustained strong negative outgoing net radiation anomaly

Why?

Less cloud fraction (SW partially offset by LW)

Less outgoing clear-sky LW (SW negligible)

**Dominant Factor:**
Less outgoing cloudy-sky LW (SW small)
Split Clear-Sky LW into Components

\[ \text{LW}_{\text{clr}} = \varepsilon_{\text{sfc}} \sigma T_{\text{sfc}}^4 G_{\text{clr}} \]

\( \text{LW}_{\text{clr}} \)  cloudy-sky LW

\( \varepsilon_{\text{sfc}} \)  temporally constant surface emissivity

\( T_{\text{sfc}} \)  surface skin temperature

\( G_{\text{clr}} \)  atmospheric effect (derived from \( \text{LW}_{\text{clr}} \) and \( T_{\text{sfc}} \) and will include a compensating error if error is present in \( \text{LW}_{\text{clr}} \) and/or \( T_{\text{sfc}} \) )
Linear Perturbation Analysis

For each grid box, separate into long-term mean <> and monthly anomalies ∆

Long term mean

\[ <LW_{clr}> = \varepsilon_{sfc} \sigma <T_{sfc}>^4 <G_{clr}> \]

Perturbation

\[ \Delta LW_{clr} = 4 \varepsilon_{sfc} \sigma <T_{sfc}>^3 \Delta T_{sfc} <G_{clr}> + \sigma <T_{cll}>^4 \Delta G_{clr} + \text{higher order} \]

- surface temp contribution
- atmospheric contribution
30°S-30°N Clear-Sky LW Time Series

Black: clear-sky LW
Red: surface temperature component
Green: atmospheric component
Magenta: higher-order component

Contribution of surface temperature trend is largely offset by the (presumably spurious) greenhouse trend: 
*temperature increase is too large or clear-sky LW increase is too small*
Split Cloudy-Sky LW into Components

\[ \text{LW}_{\text{cl}d} = \sigma \, T_{\text{cl}d}^4 \, G_{\text{cl}d} \]

- \( \text{LW}_{\text{cl}d} \): cloudy-sky LW
- \( T_{\text{cl}d} \): cloud effective temperature (assume opaque)
- \( G_{\text{cl}d} \): cloud/atmosphere emissivity/greenhouse effects (derived from \( \text{LW}_{\text{cl}d} \) and \( T_{\text{cl}d} \))
Linear Perturbation Analysis

For each grid box, separate into long-term mean <> and monthly anomalies ∆

**Long term mean**

\[ <LW_{cld}> = \sigma <T_{cld}>^4 <G_{cld}> \]

**Perturbation**

\[ \Delta LW_{cld} = 4 \sigma <T_{cld}>^3 \Delta T_{sfc} <G_{cld}> + 4 \sigma <T_{cld}>^3 (\Delta T_{cld} - \Delta T_{sfc}) <G_{cld}> + \sigma <T_{cld}>^4 \Delta G_{cld} + \text{higher order} \]

- surface temp contribution
- cloud-surface temp difference
- cloud/atmosphere emissivity/greenhouse contribution
Cloud temperature is the dominant contributor to cloudy-sky LW anomalies.
2000-2010 Terra Record

What factors contribute to interannual anomalies in net flux?

• Nonlinear higher-order terms unimportant for monthly 1° x 1° grid boxes and limited set of component parameters
• Clear sky contribution is small (cloud-free area is small)
• Cloud fraction contribution is relatively small (partial cancelation between SW and LW)
• Surface temperature contribution is relatively small (more important for decadal trend)
• Cloud temperature contribution is relatively large (cloud height seems to vary more than cloud albedo)
Broader Implications

• This approach provides a simple method for investigating consistency between radiation flux and contributing factors.

• Independent surface temperature datasets suggest that clear-sky LW flux probably should have increased more over 2000-2010 than has been reported by Terra (and Aqua).

• \(~0.5\) W m\(^{-2}\) change over 10 years is climatically important but smaller than the stated uncertainty range for CERES.

• MODIS cloud properties also suffer from spurious temporal changes.
Thank You!
Anomaly Maps
Jan08 – Jun09 Cloudy-Sky LW Anomaly

Surface temperature LW

Cloud temperature LW

Cloudy-sky LW

Legend:

-16 -8 -4 -2 -0.5 0.5 8 16 W m⁻²
Jan08 – Jun09 Cloudy-Sky Anomaly
Jan08 – Jun09 Cloud Fraction Anomaly

Cloud fraction LW

Cloud fraction SW

Cloud fraction Net
Jan08 – Jun09 Outgoing Net Anomaly

Cloudy-sky Net

Cloud fraction Net

All-sky Net