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
- Terrra 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

$$Flux_{all} = Flux_{clr} (1 – f) + Flux_{cld} f$$

$Flux_{all}$	all-sky flux (LW, SW, Net)
$Flux_{clr}$	clear-sky flux (LW, SW, Net)
f	total cloud fraction
$Flux_{cld}$	cloudy-sky flux (as if grid box were overcast)

Derivation of Cloudy-Sky Flux

$$Flux_{cld} = Flux_{clr} + (Flux_{all} – Flux_{clr}) / f$$

Caution

- $Flux_{cld}$ 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 $Flux_{cld}$

Linear Perturbation Analysis

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

Long term mean

$$\langle Flux_{all} \rangle = \langle Flux_{clr} \rangle (1 - \langle f \rangle) + \langle Flux_{cld} \rangle \langle f \rangle$$

Perturbation

$$\Delta Flux_{all} = \Delta f (\langle Flux_{cld} \rangle - \langle Flux_{clr} \rangle) + \Delta Flux_{clr} (1 - \langle f \rangle)$$
$$+ \Delta Flux_{cld} \langle f \rangle + \Delta FLux_{cld} \Delta f - \Delta Flux_{clr} \Delta f$$

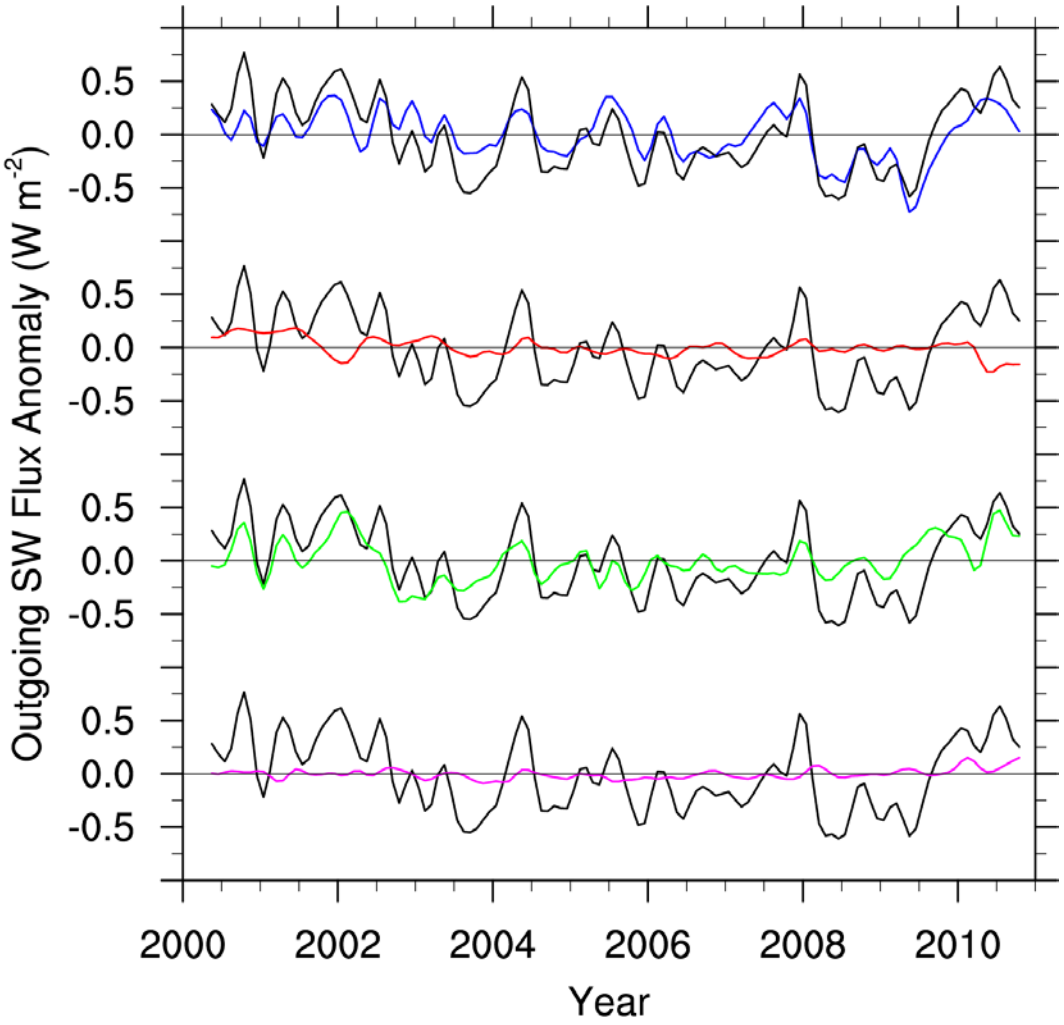
cloud fraction contribution

clear-sky contribution

cloudy-sky contribution

higher-order terms

90°S-90°N SW Time Series



Black: all-sky SW

Blue: cloud fraction component

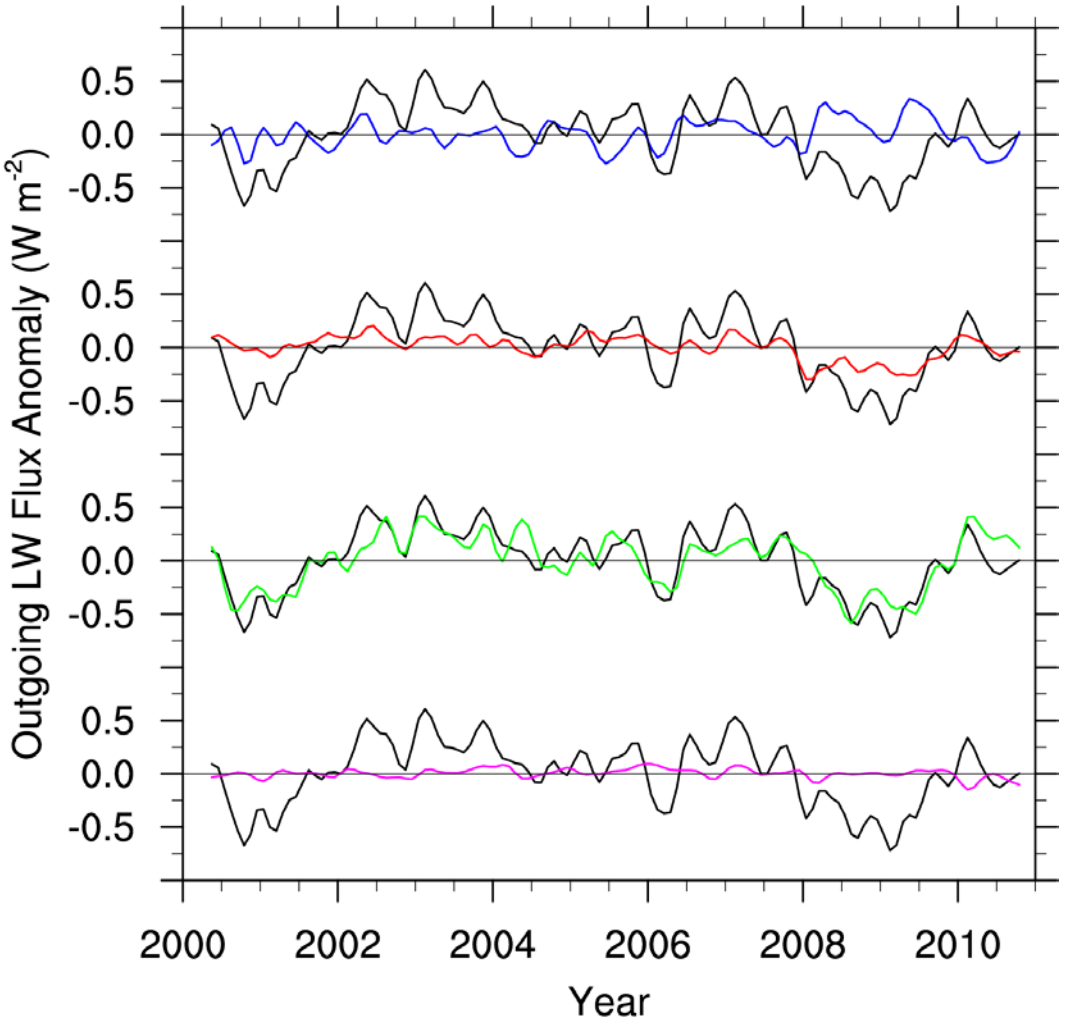
Red: clear-sky component

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

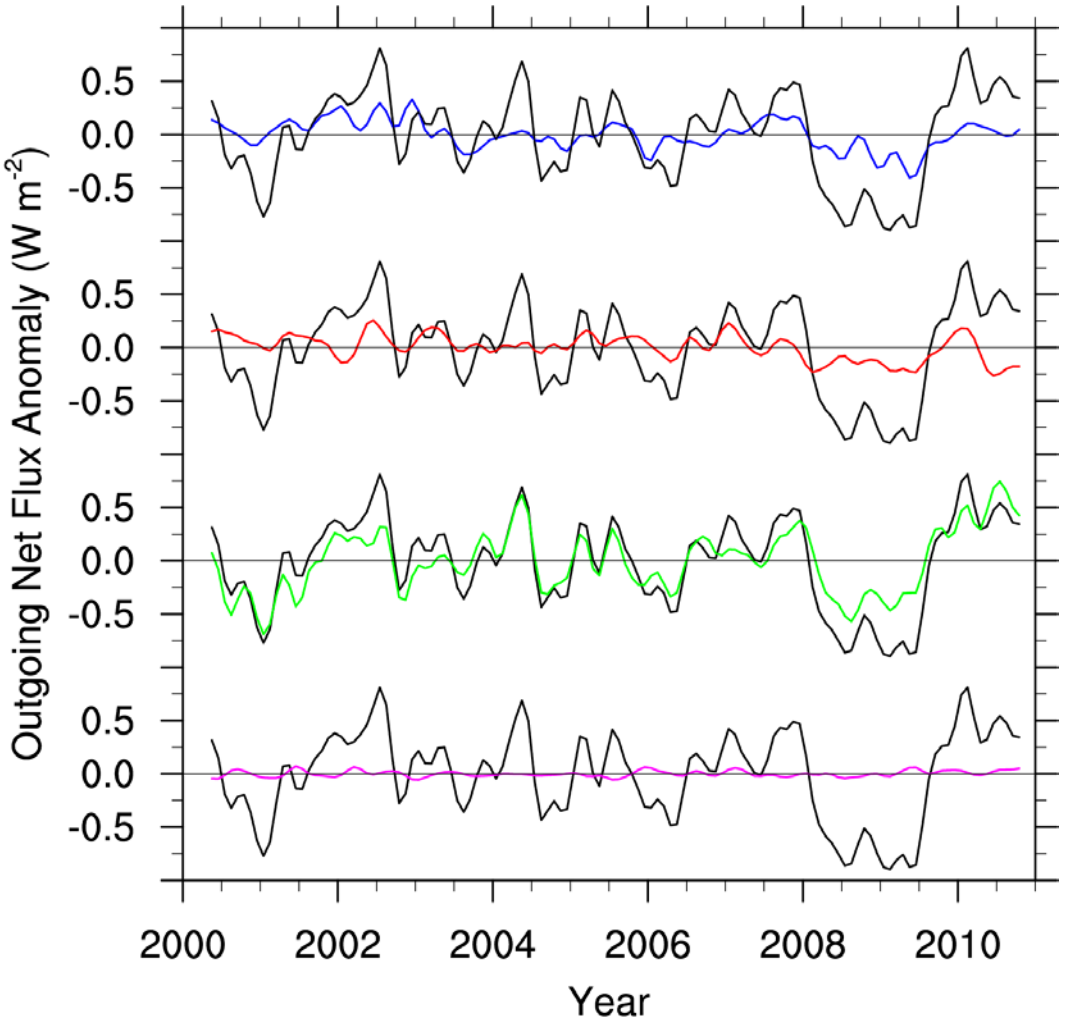
Red: clear-sky component

Green: cloudy-sky component

Magenta: higher-order

Cloudy-sky is dominant contributor to LW anomalies

90°S-90°N Net Time Series



Black: all-sky Net

Blue: cloud fraction component

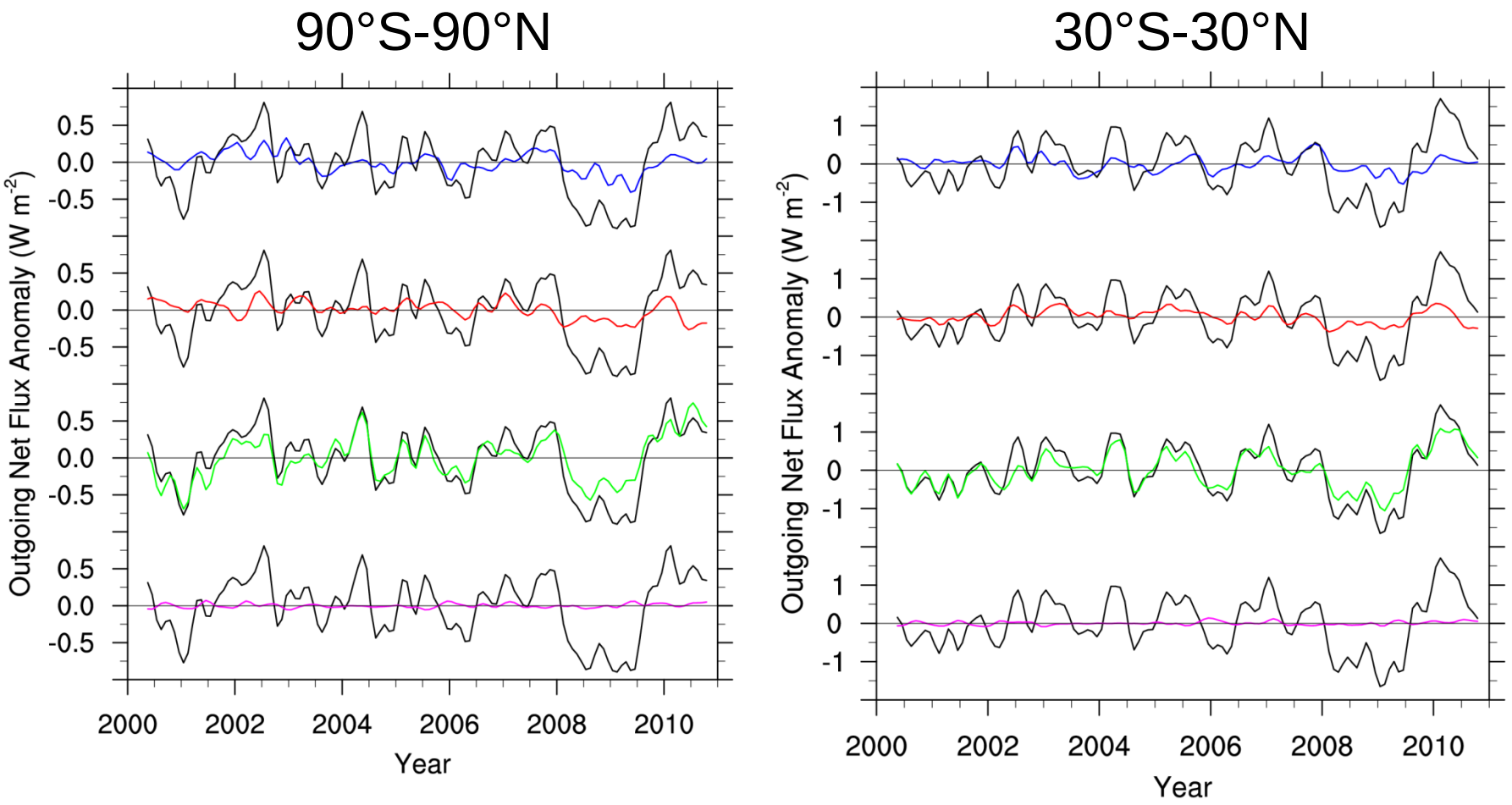
Red: clear-sky component

Green: cloudy-sky component

Magenta: higher-order

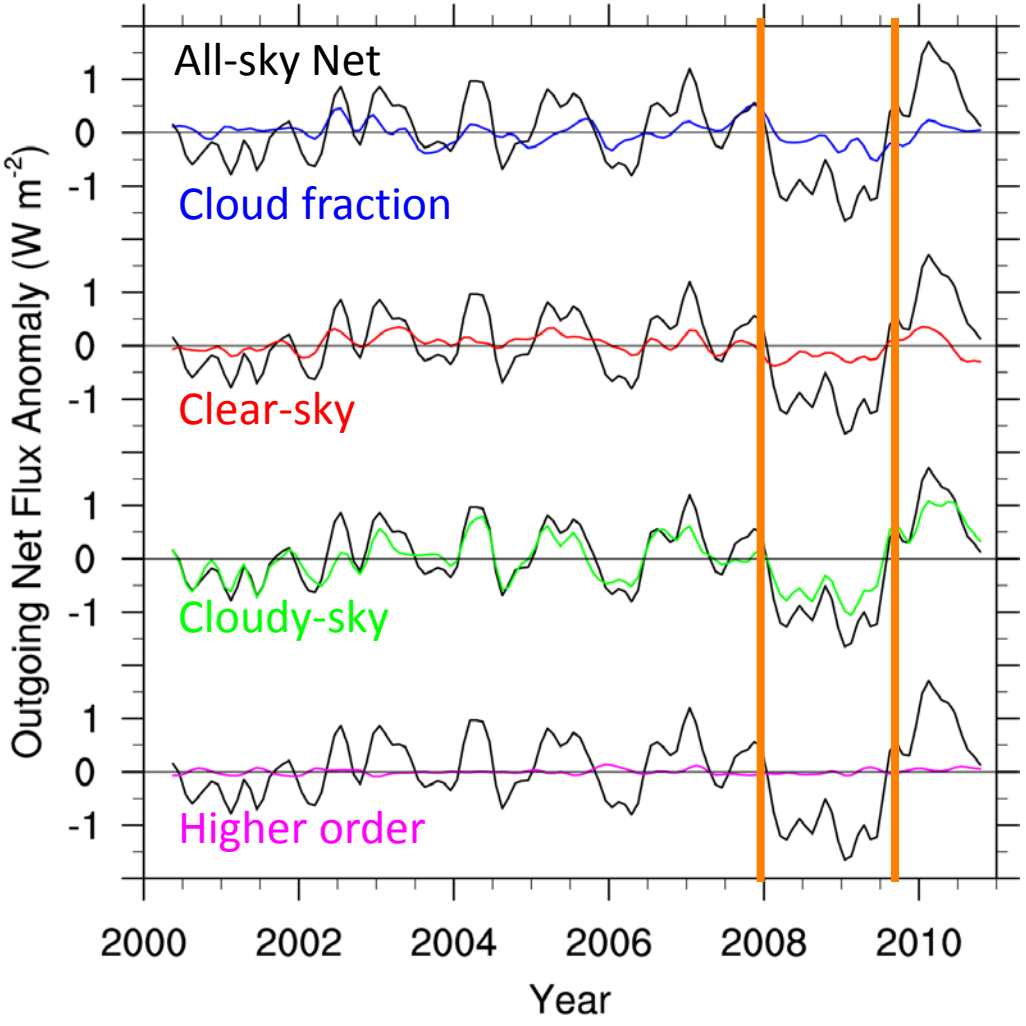
Cloudy-sky is dominant contributor to Net anomalies

Net Time Series



Global anomalies are mostly produced by low-latitude anomalies partially offset by higher latitude anomalies (note different axis scales)

30°S-30°N Net Time Series



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

$$LW_{clr} = \varepsilon_{sfc} \, \sigma \, T_{sfc}^{4} \, G_{clr}$$

LW_{clr}	cloudy-sky LW
ε_{sfc}	temporally constant surface emissivity
T_{sfc}	surface skin temperature
G_{clr}	atmospheric effect (derived from LW_{clr} and T_{sfc} and will include a compensating error if error is present in LW_{clr} and/or T_{sfc})

Linear Perturbation Analysis

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

Long term mean

$$\langle LW_{clr} \rangle = \varepsilon_{sfc}\, \sigma \langle T_{sfc} \rangle^4 \langle G_{clr} \rangle$$

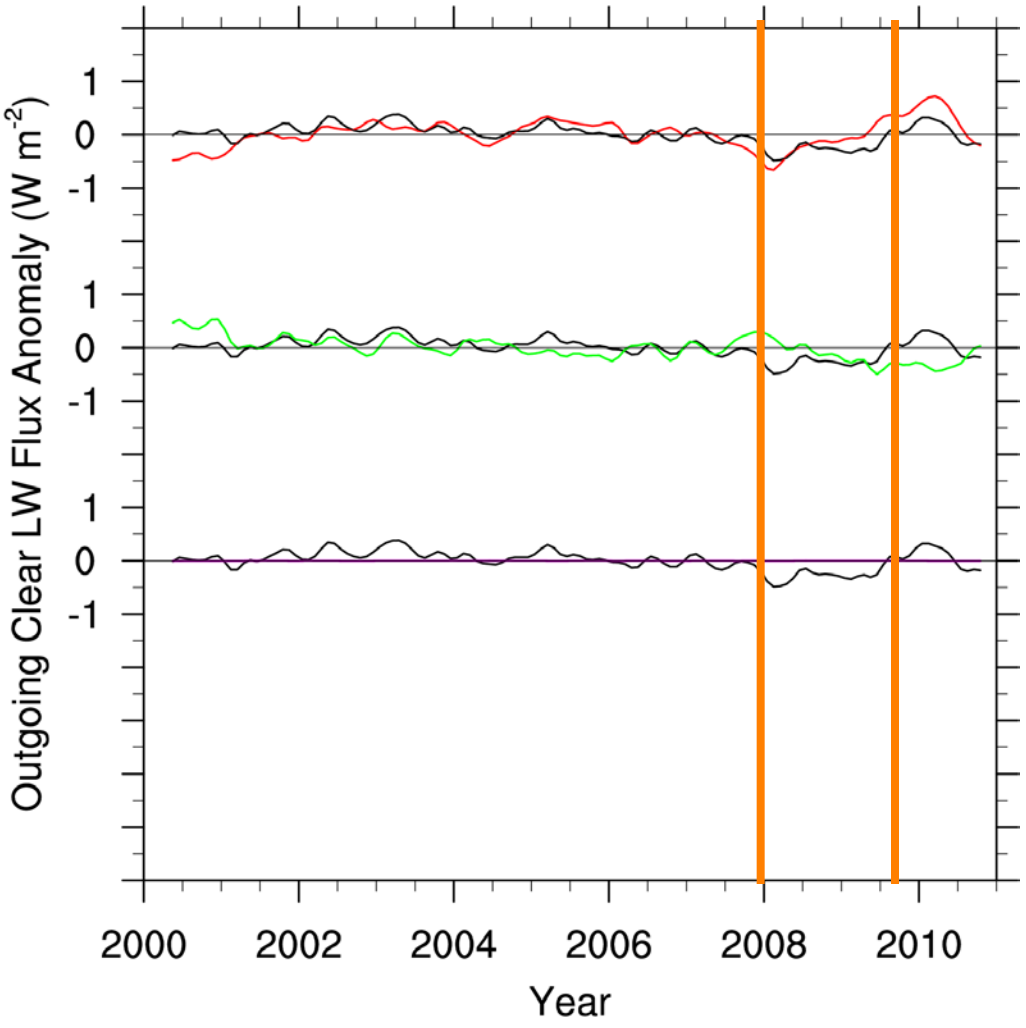
Perturbation

$$\Delta LW_{clr} = 4\, \varepsilon_{sfc}\, \sigma \langle T_{sfc} \rangle^3\, \Delta T_{sfc} \langle G_{clr} \rangle + \sigma \langle T_{cld} \rangle^4\, \Delta G_{clr} + \text{higher order}$$

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

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

$$LW_{cld} = \sigma T_{cld}^4 G_{cld}$$

LW_{cld}	cloudy-sky LW
T_{cld}	cloud effective temperature (assume opaque)
G_{cld}	cloud/atmosphere emissivity/greenhouse effects (derived from LW_{cld} and T_{cld})

Linear Perturbation Analysis

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

Long term mean

$$\langle LW_{cld} \rangle = \sigma \langle T_{cld} \rangle^4 \langle G_{cld} \rangle$$

Perturbation

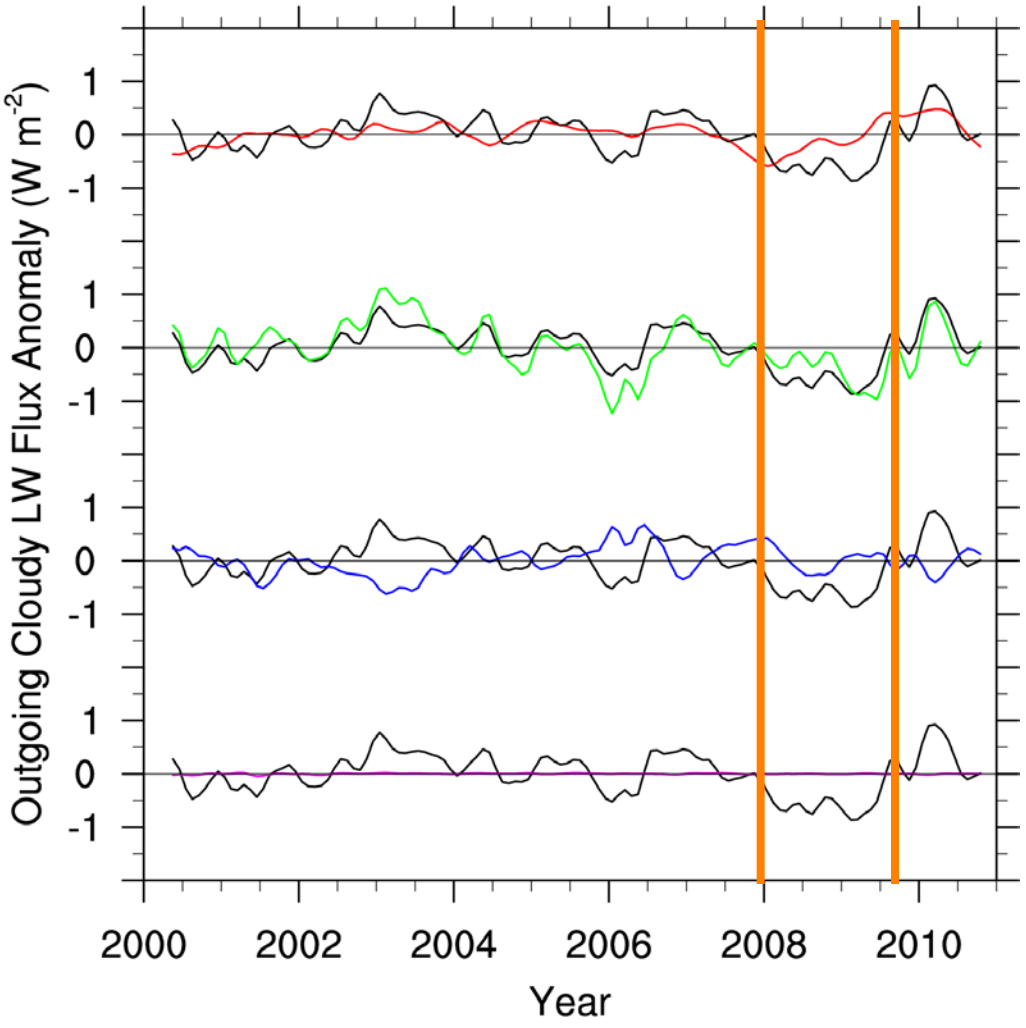
$$\Delta LW_{cld} = 4 \sigma \langle T_{cld} \rangle^3 \Delta T_{sfc} \langle G_{cld} \rangle + 4 \sigma \langle T_{cld} \rangle^3 (\Delta T_{cld} - \Delta T_{sfc}) \langle G_{cld} \rangle$$

$$+ \sigma \langle T_{cld} \rangle^4 \Delta G_{cld} + \text{higher order}$$

surface temp contribution cloud-surface temp difference

cloud/atmosphere emissivity/greenhouse contribution

30°S-30°N Cloudy-Sky LW Time Series



Black: cloudy-sky LW

Red: surface temperature component

Green: cloud-surface temperature difference component

Blue: cloud/atmosphere emissivity/greenhouse

Magenta: higher-order

Cloud temperature is 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

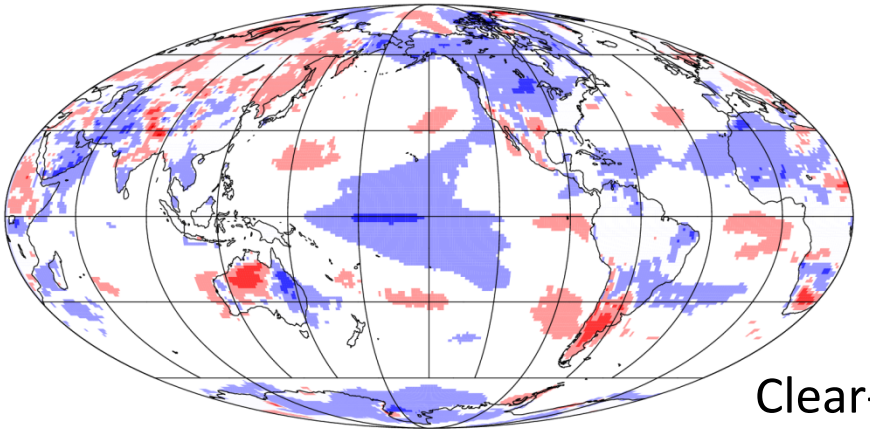
- This approach provides a simple method for investigating consistency between radiation flux and contributing factors
- Independent surface temperature datasets suggest that clear-sky LW flux probably should have increased more over 2000-2010 than has been reported by Terra (and Aqua)
- ~0.5 W m^{-2} 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!

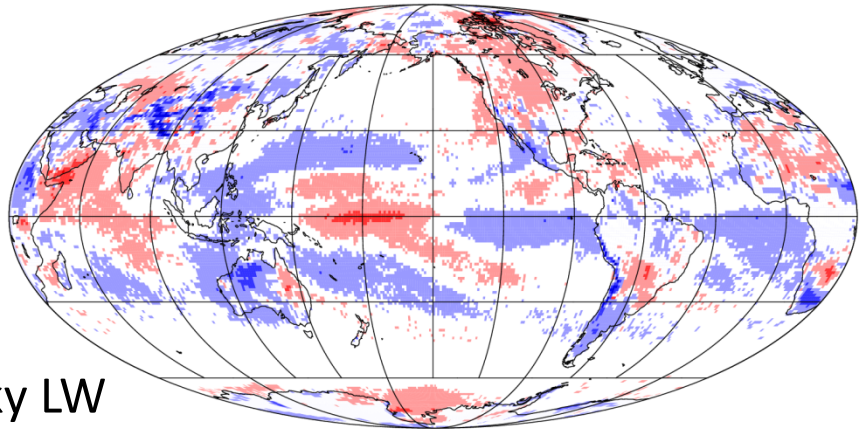
Anomaly Maps

Jan08 – Jun09 Clear-Sky LW Anomaly

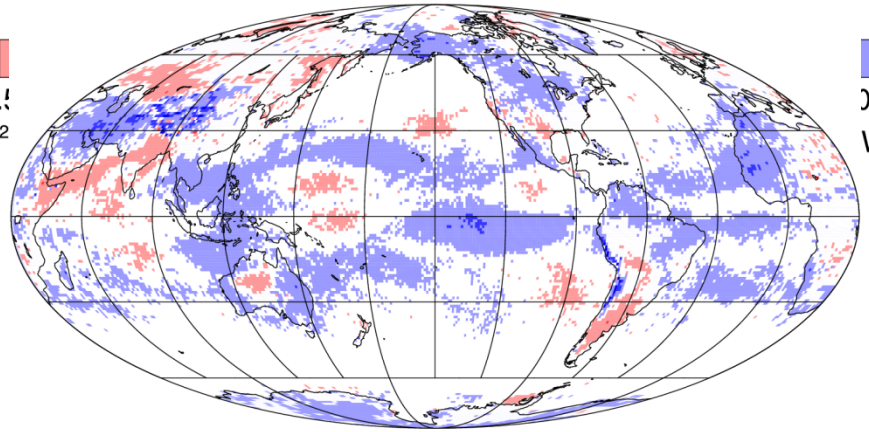
Surface temperature LW

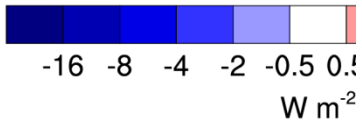


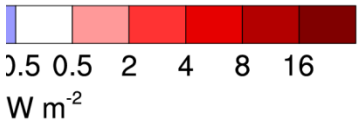
Atmospheric LW

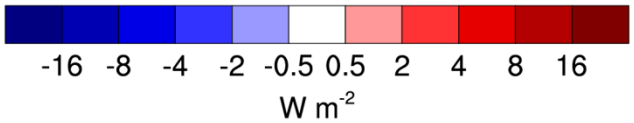


Clear-sky LW



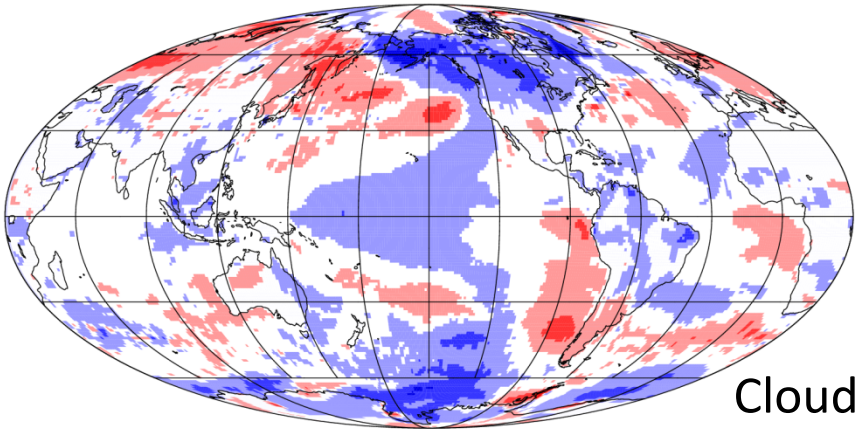




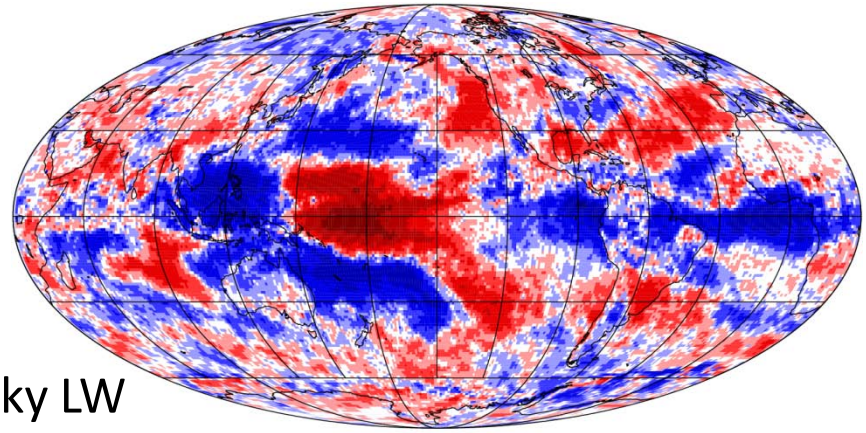


Jan08 – Jun09 Cloudy-Sky LW Anomaly

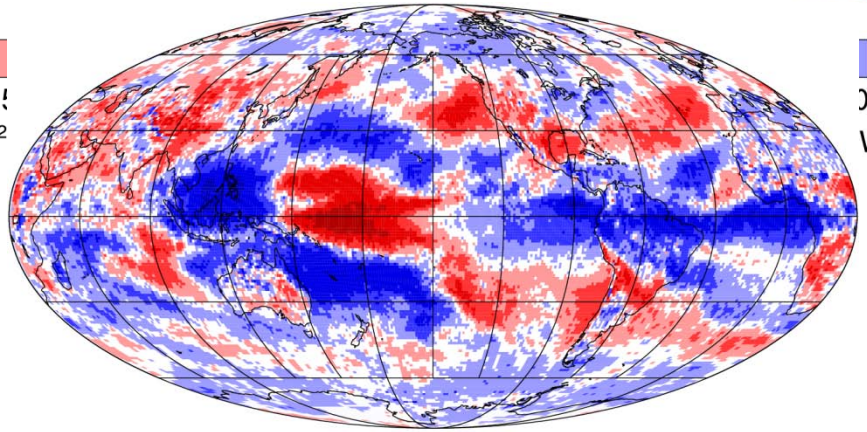
Surface temperature LW

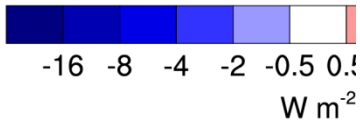


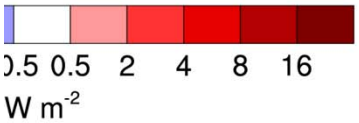
Cloud temperature LW



Cloudy-sky LW

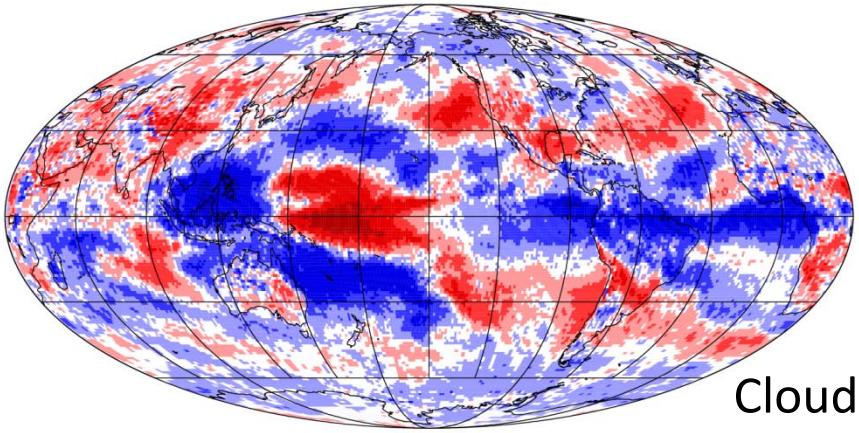




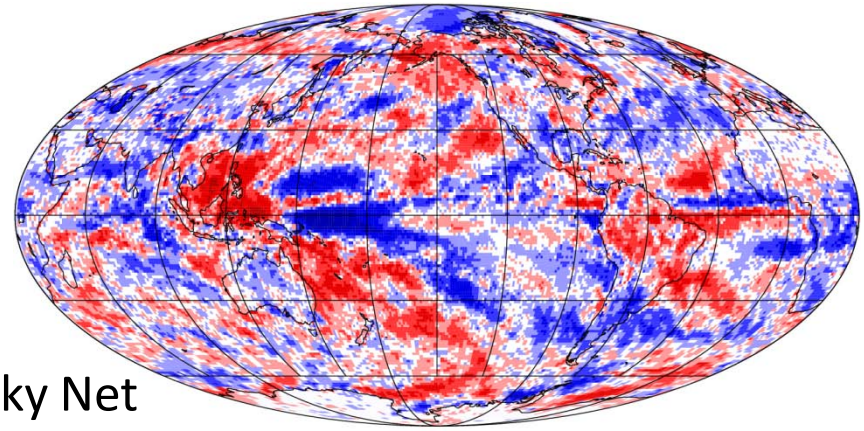


Jan08 – Jun09 Cloudy-Sky Anomaly

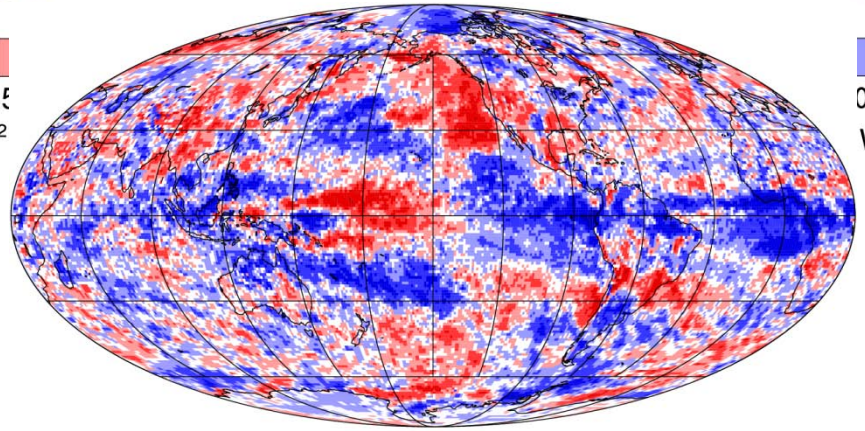
Cloudy-sky LW

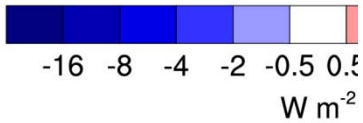


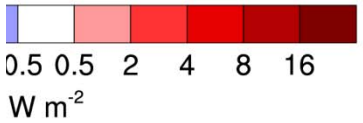
Cloudy-sky SW

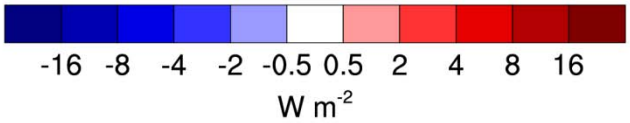


Cloudy-sky Net



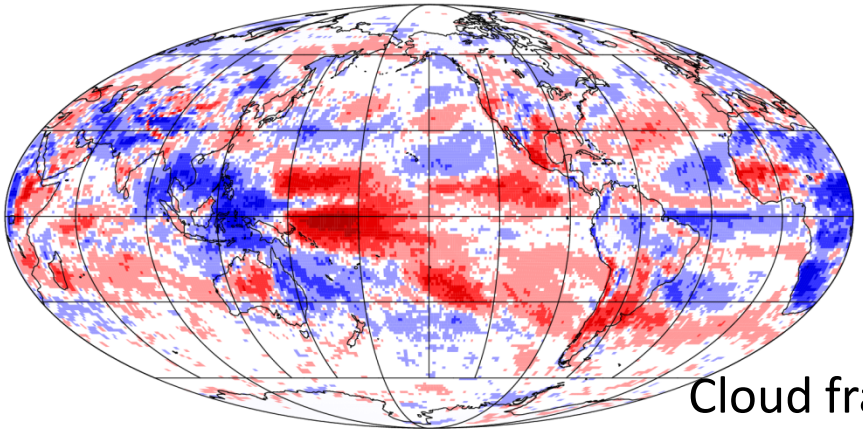




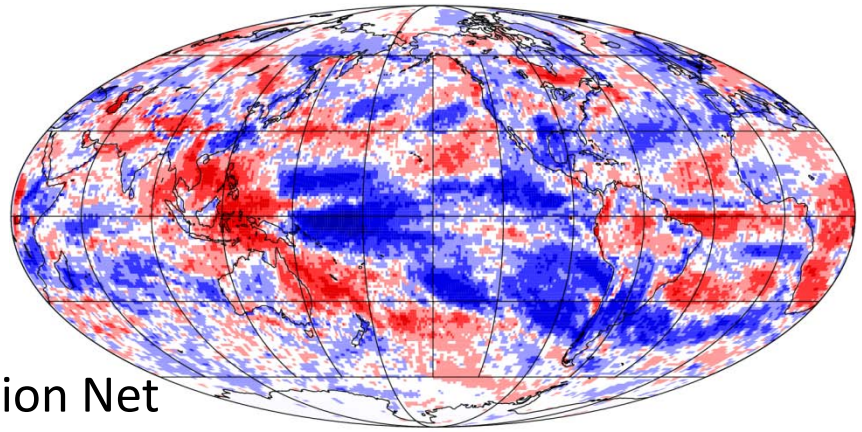


Jan08 – Jun09 Cloud Fraction Anomaly

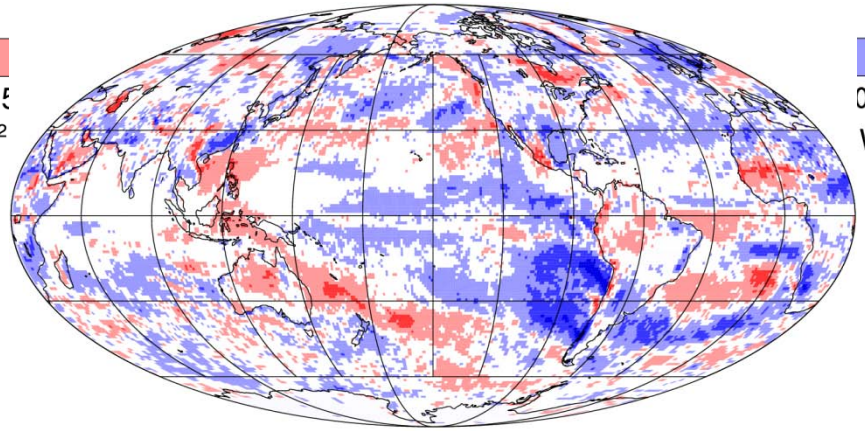
Cloud fraction LW

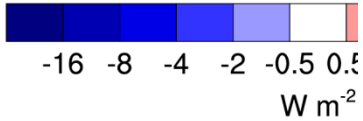


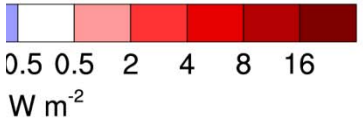
Cloud fraction SW

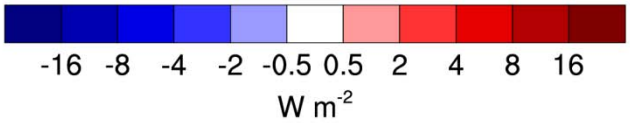


Cloud fraction Net



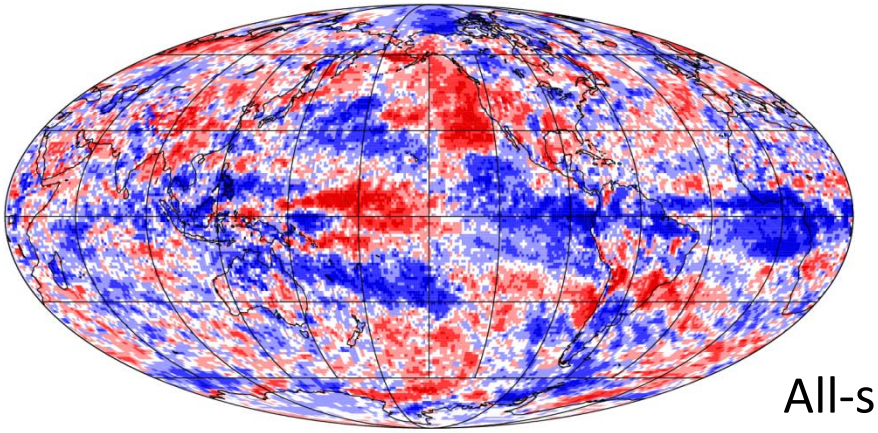




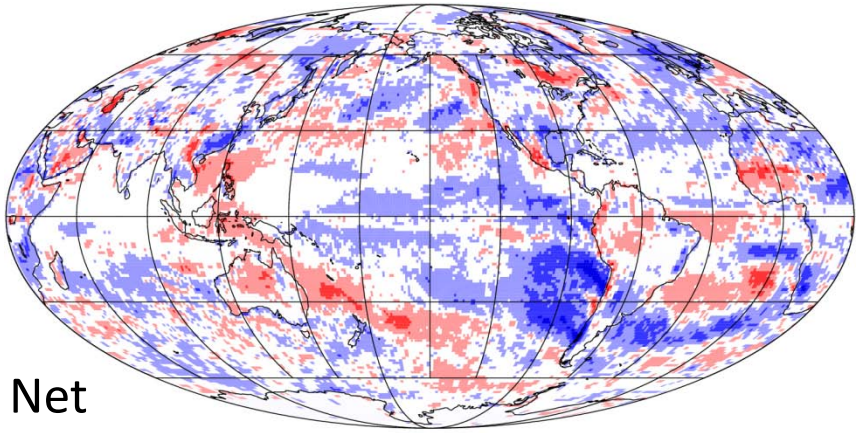


Jan08 – Jun09 Outgoing Net Anomaly

Cloudy-sky Net



Cloud fraction Net



All-sky Net