Toward deriving cloud property changes consistent with observed radiance change

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Outline

- TOA radiative flux derived from CERES
- Cloud retrieval and in the CERES process (why cloud retrievals are needed?)
- Cloud property and TOA radiative flux closure
- Understanding cloud change through highly averaged spectral radiances (an alternative way to achieve closure)
- Climate data record and process study (Why do we need closure?)

CERES

CERES: Clouds and Earth's Radiant Energy System

Broadband instruments
Measure shortwave, total, and window radiances
Currently, instruments are on Terra and Aqua

Satellite viewing geometry

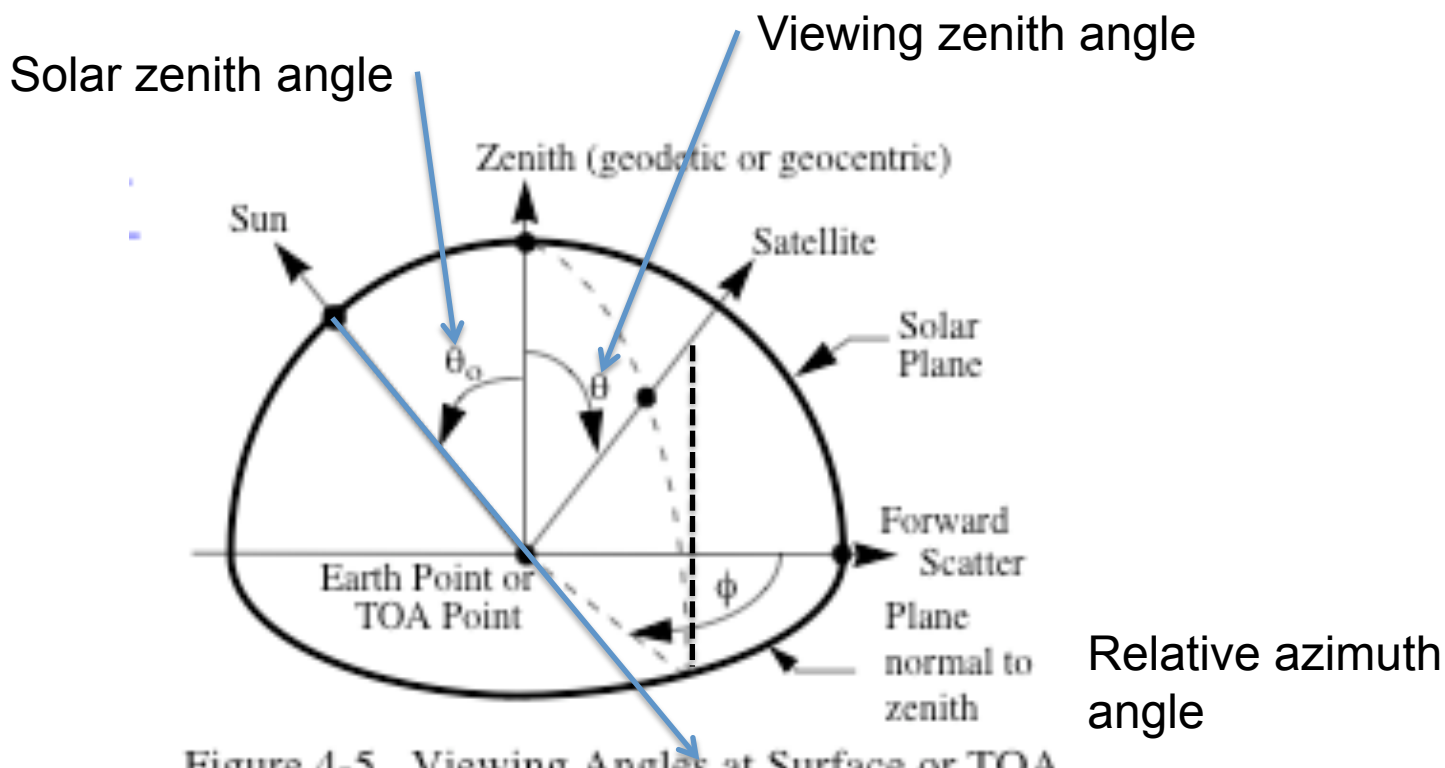
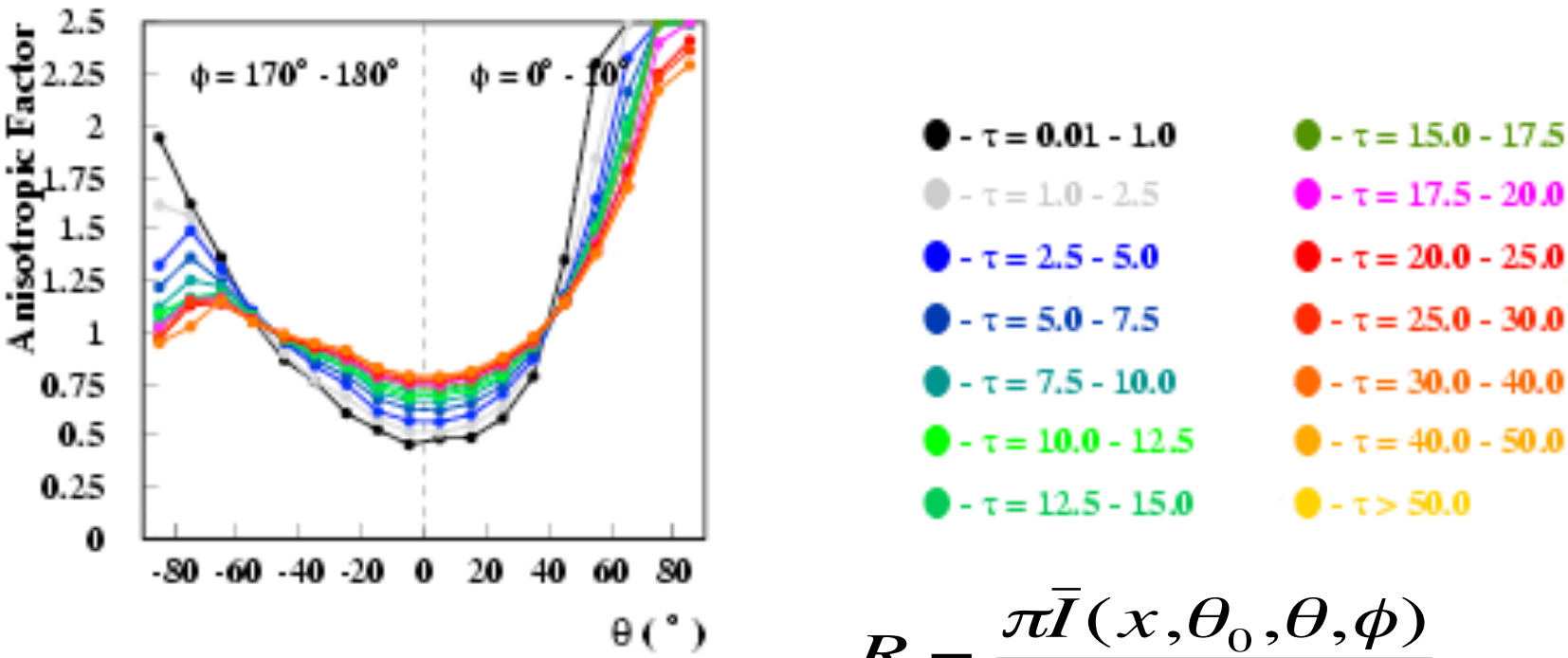


Figure 4-5. Viewing Angles at Surface or TOA

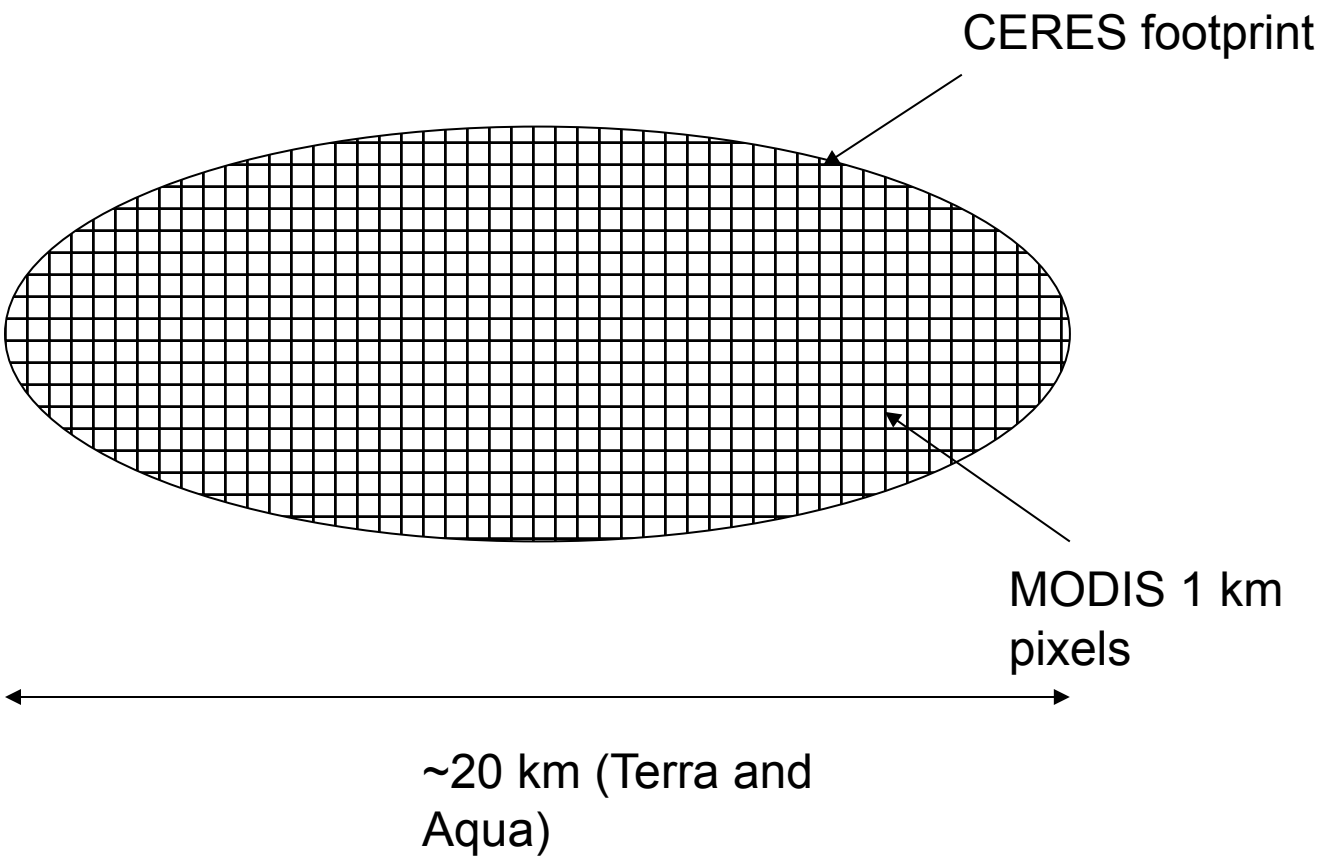
Anisotropic Factor

Water cloud
Cloud fraction 99.0 to 100
Solar zenith angle: 60 to 70°



$$R = \frac{\pi \bar{I}(x, \theta_0, \theta, \phi)}{F_{adm}(x, \theta_0)}$$

Scene Identification

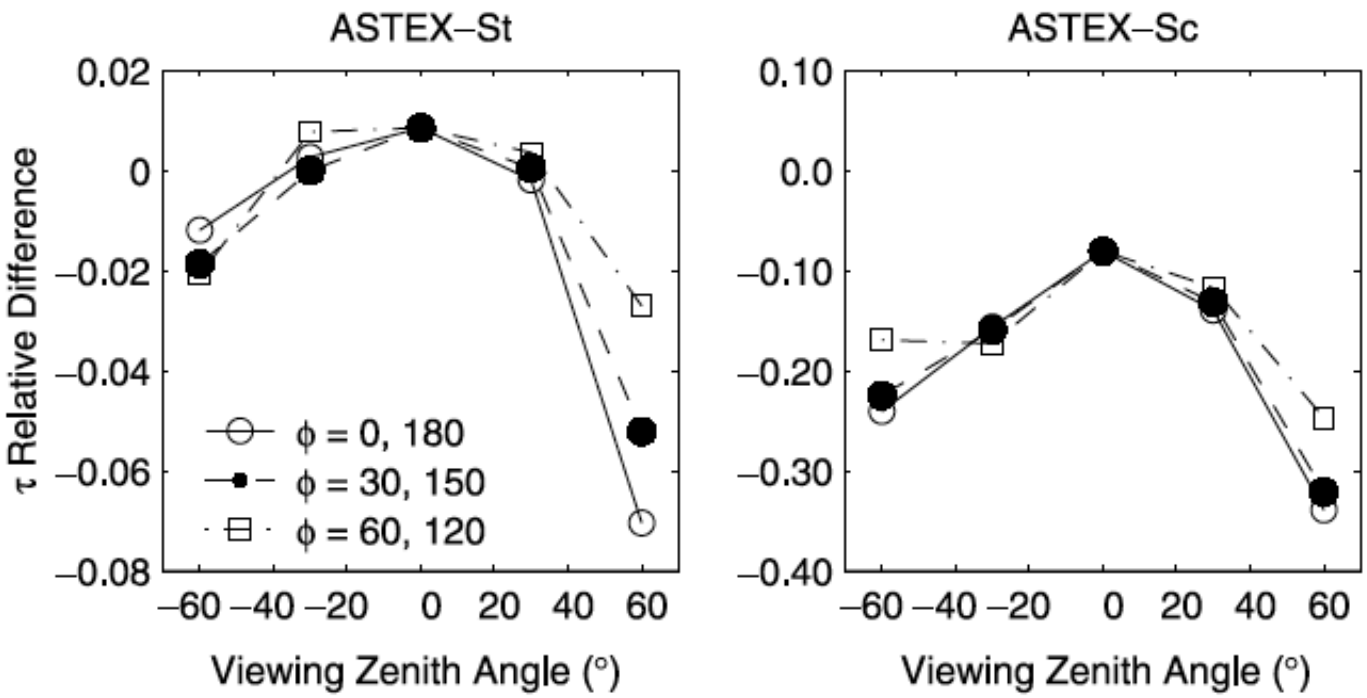


For Climate data record:
MODIS retrievals are needed everywhere all the time
Cloud algorithm need to be fixed

SW ADM Scene Types

Surface Type	Variables	Description
Clear-sky Ocean	Wind Speed	Theoretical aerosol OD Correction
Clouds over Ocean	Phase Cloud Fraction Cloud OD	Fraction and OD are continuous
Clear Land and Desert	1 degree by 1 degree grid box (Monthly)	Fitting by an 8-parameter non-linear function
Cloudy Land and Desert	Land type Phase Cloud Fraction Cloud OD	Fitting by an 8-parameter non-linear function and Cloud Fraction and OD are continuous
Clear and Cloudy Permanent Snow	Cloud Fraction Cloud OD Surface Brightness	
Clear and Cloudy Fresh Snow and Sea Ice	Snow/Ice Fraction Cloud Fraction Cloud OD Surface Brightness	
Unknown Scenes	CERES SW and LW radiances and geometry	Neural Network

Retrieval error (optical depth)

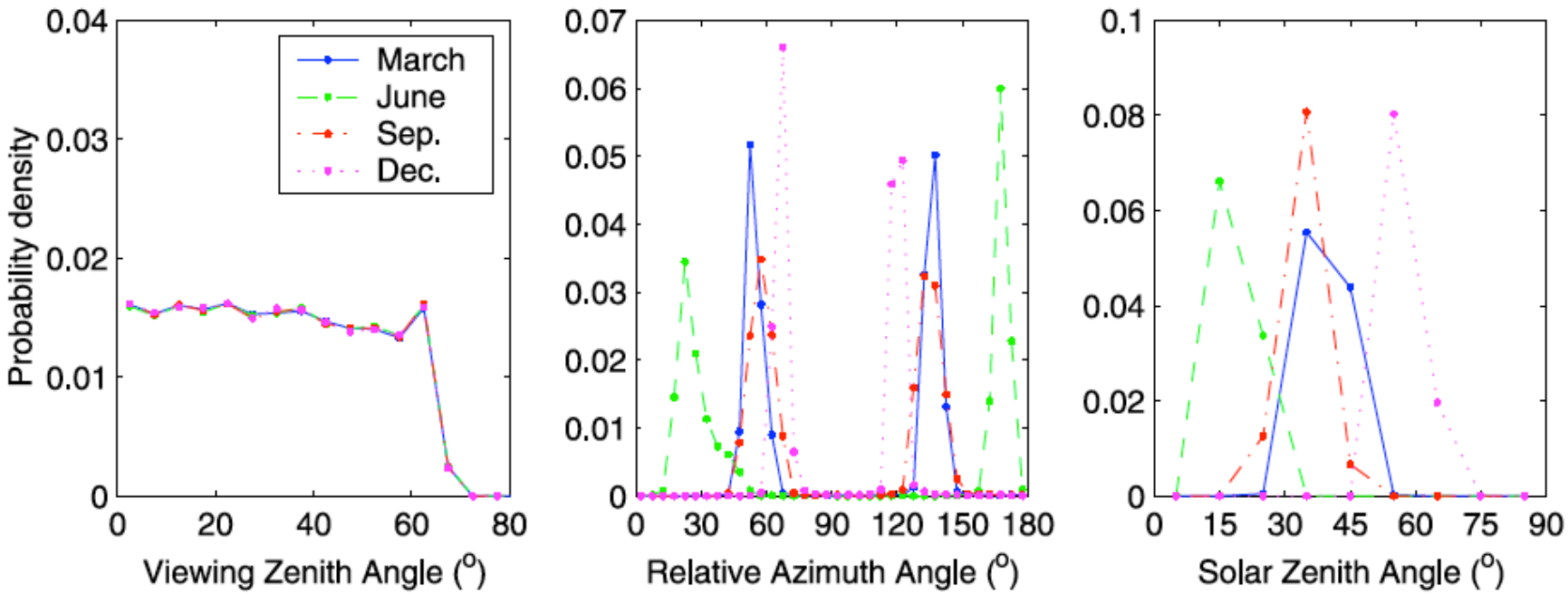


50 degree solar zenith angle

Understanding how instantaneous retrieval errors affect spatially and temporally Averaged cloud properties is needed.

Kato et al. 2006

Satellite viewing geometry



Terra viewing geometry over 1 degree by 1 degree region centered at 32.5N 134.5W
Viewing geometry needs to be considered to understand the error in a mean

Kato and Marshak 2009

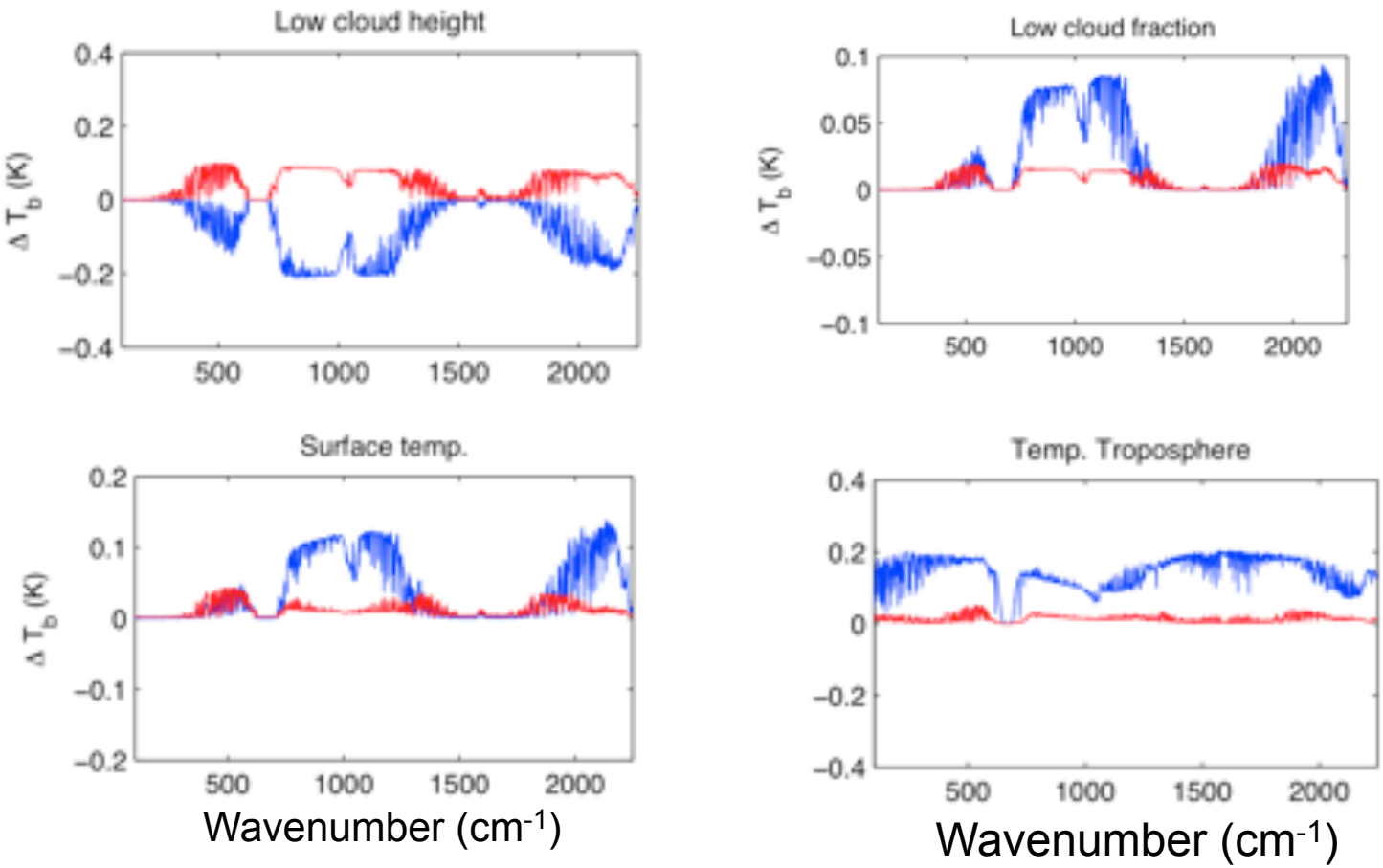
TOA radiation and cloud property closure (current approach)

- Cloud properties are derived from instantaneous radiances
- Compute TOA broadband irradiance and compare with CERES derived irradiance
- There is no simple way to adjust cloud properties when modeled flux does not agree with CERES-derived flux

Alternative approach in CLARREO

- Calibrate other instruments to support current approach.
- Infer atmospheric property changes from highly spatially and temporally averaged spectral radiance.

Spectral radiance change

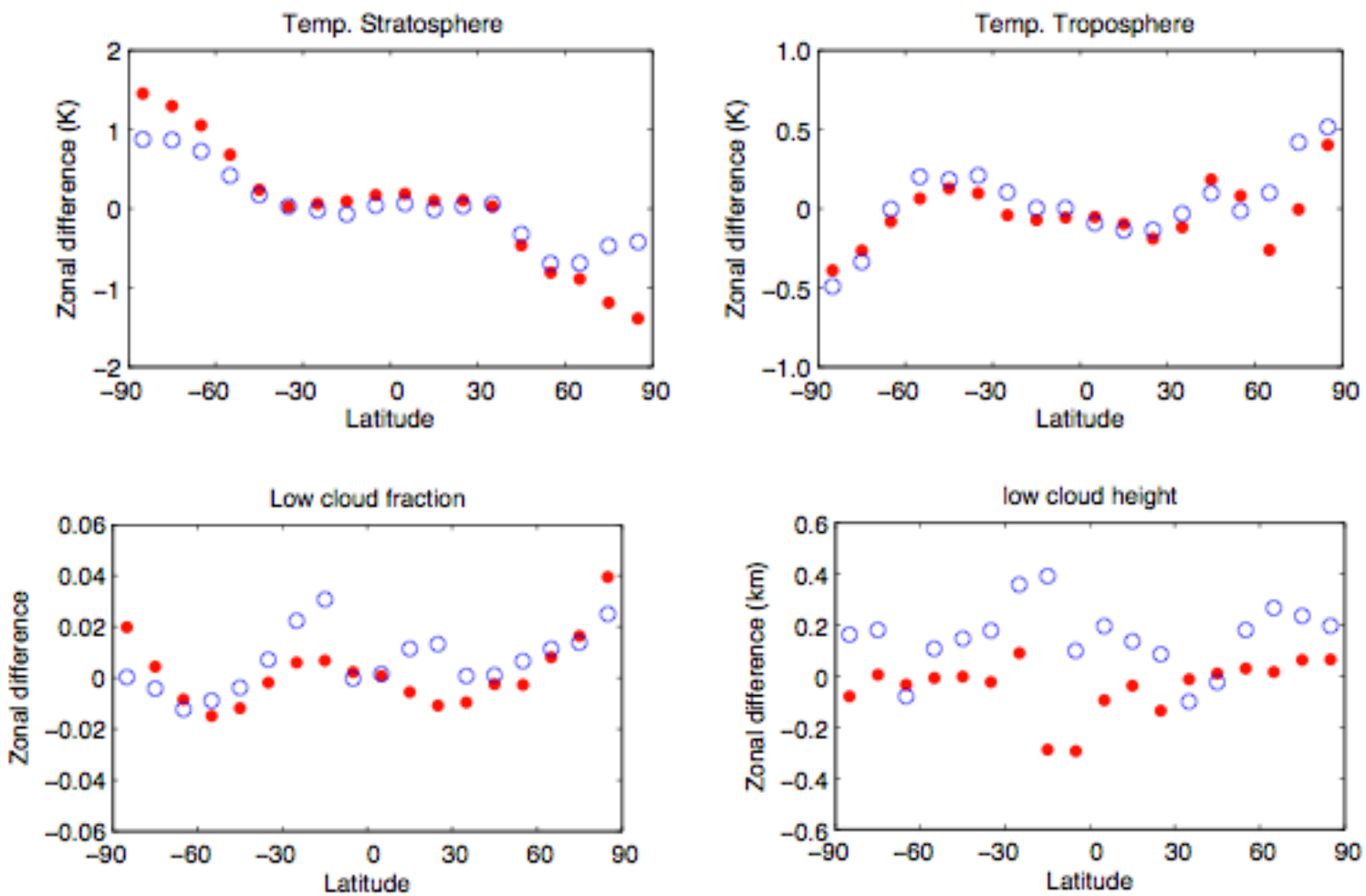


Blue: global annual mean
Red: Standard deviation of monthly global means

Necessary conditions for the retrievals to work

- The sum of spectral changes caused by individual perturbations needs to be approximately equal to the spectral change caused by all individual properties perturbed together.
- The radiance for a given wavenumber needs to change linearly as a response to an atmospheric property perturbation.
- The spectral shape caused by each atmospheric property change needs to be significant to be detectable and unique.

Retrieval result
(retrieved from annual 10 degree mean spectral radiance)



Red: truth, Blue: retrieved

Problems

$$\bar{I}_1(x_1) = I(\bar{x}_1) + \frac{1}{n_1}\sum \frac{\partial I(x_1)}{\partial x}\delta x_1,$$

$$\bar{I}_2(x_1 + \Delta x) = I(\bar{x}_1) + \frac{1}{n_2}\sum \left[\frac{\partial I(x_1)}{\partial x}\overline{\Delta x} + \frac{\partial I(x_2)}{\partial x}\delta x_2\right],$$

$$\overline{\Delta I} = \overline{I_2} - \overline{I_1} = \frac{1}{n_2}\sum \frac{\partial I(x_1)}{\partial x}\overline{\Delta x} + \frac{1}{n_2}\sum \frac{\partial I(x_2)}{\partial x}\delta x_2 - \frac{1}{n_1}\sum \frac{\partial I(x_1)}{\partial x}\delta x_1.$$

The second and third terms do not necessarily cancel out in a short time scale
Do they cancel out in a longer time scale?

Process study and Climate data record

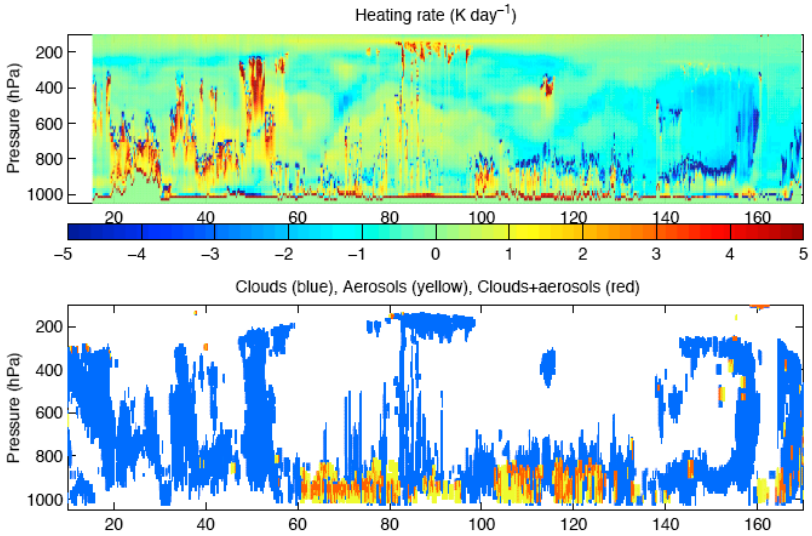
- Understand processes that affect regional and global TOA, surface, and atmospheric radiaiton budget

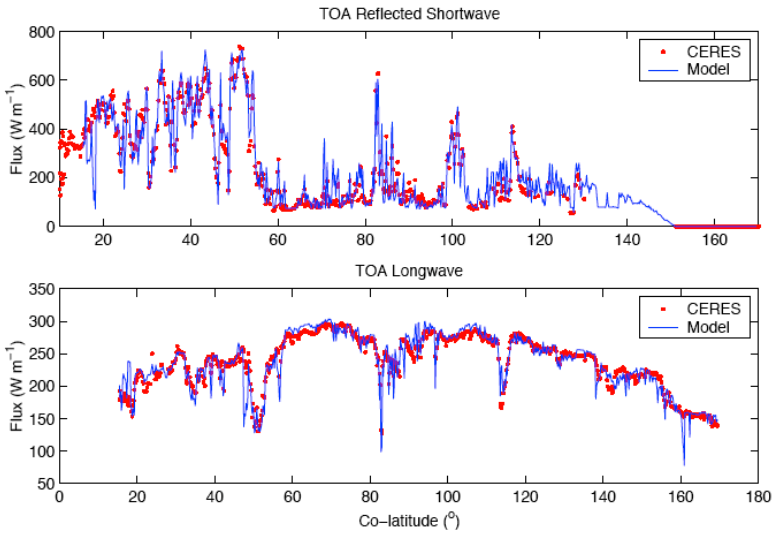
C3M (CCCM) product

- Contains:

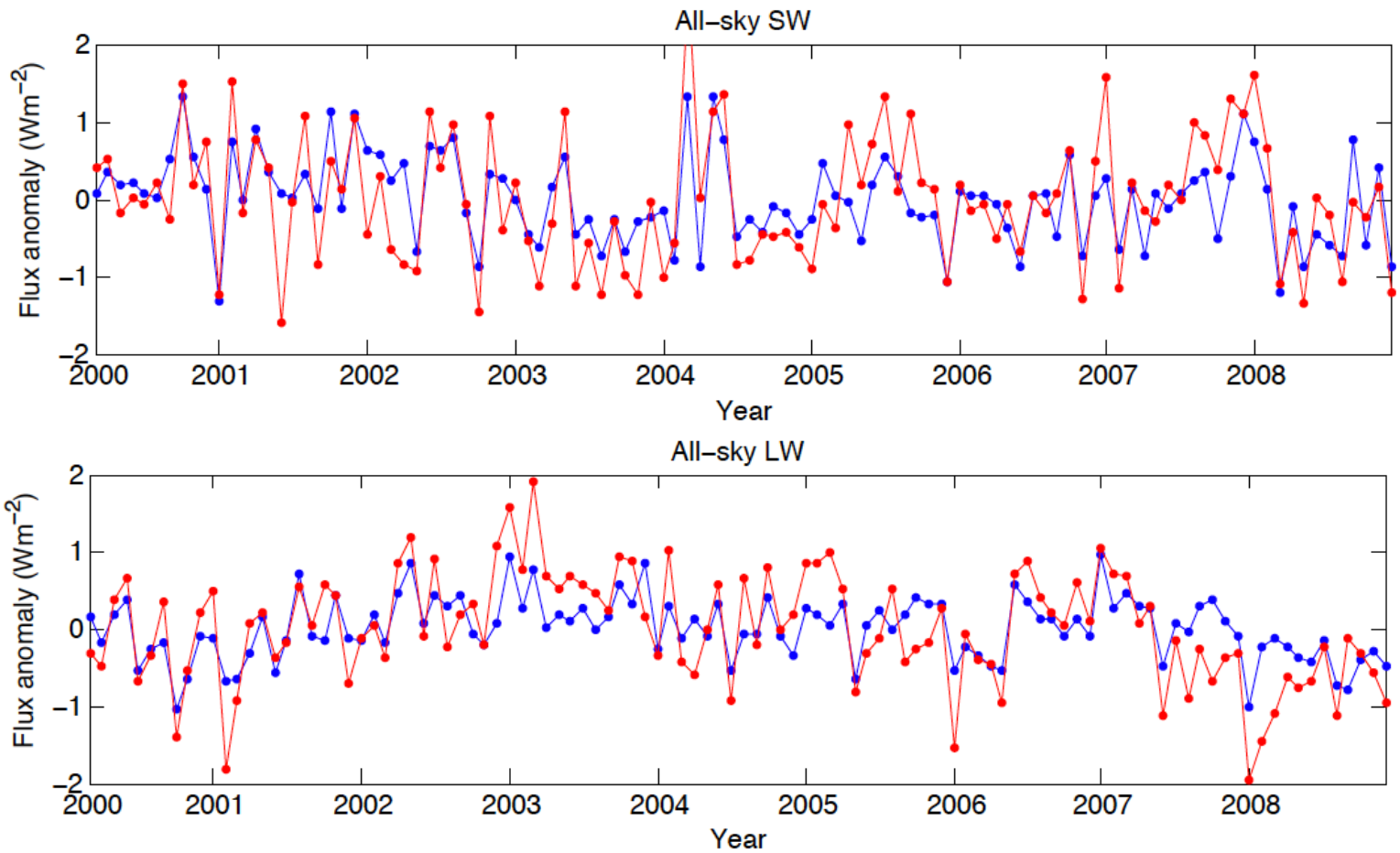
1. Merged CALIPSO, CloudSat derived clouds, CERES TOA radiative flux (SW, LW, and WN), MODIS (CERES_ST) derived cloud properties both along CALIPSO-CloudSat ground-track and over the whole CERES footprint,
2. MODIS derived cloud properties by an enhanced cloud algorithm,
3. CALIPSO and MODIS derived aerosol properties
4. Vertical radiative flux profiles computed with CALIPSO, CloudSat, and MODIS derived cloud properties.

- 2.5 years of Data are available from http://eosweb.larc.nasa.gov/PRODOCS/ceres-news/table_ceres-news.html



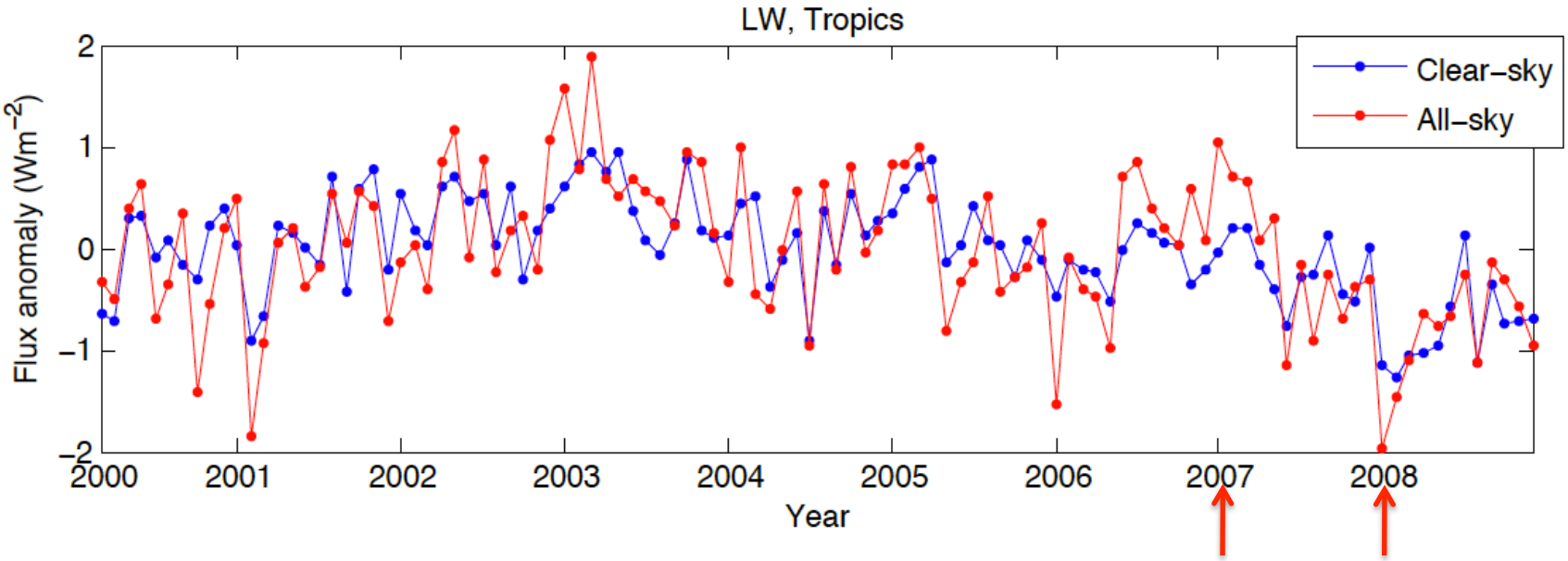


TOA flux anomalies from CERES

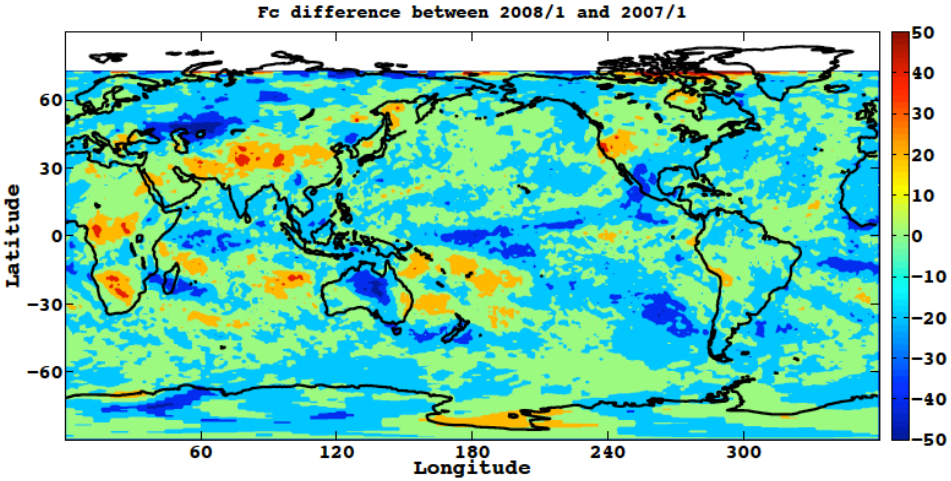


Blue line: global
Red line: tropics 30S to 30N

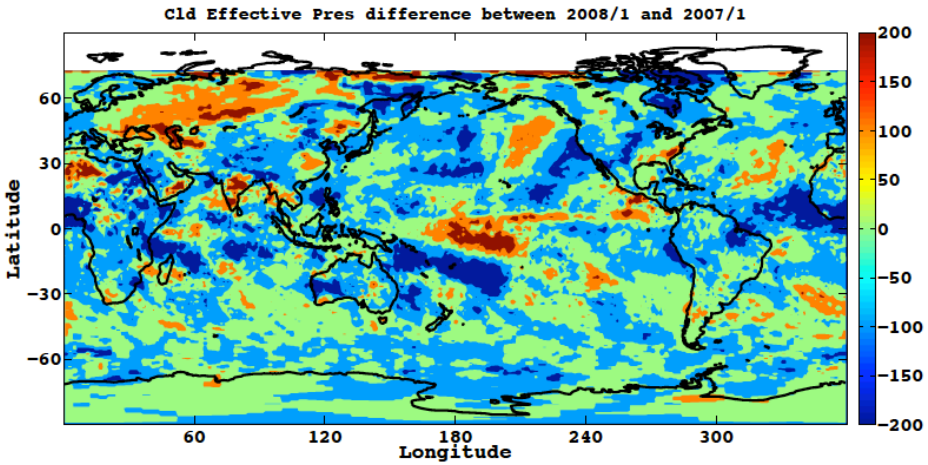
LW TOA anomalies over tropics



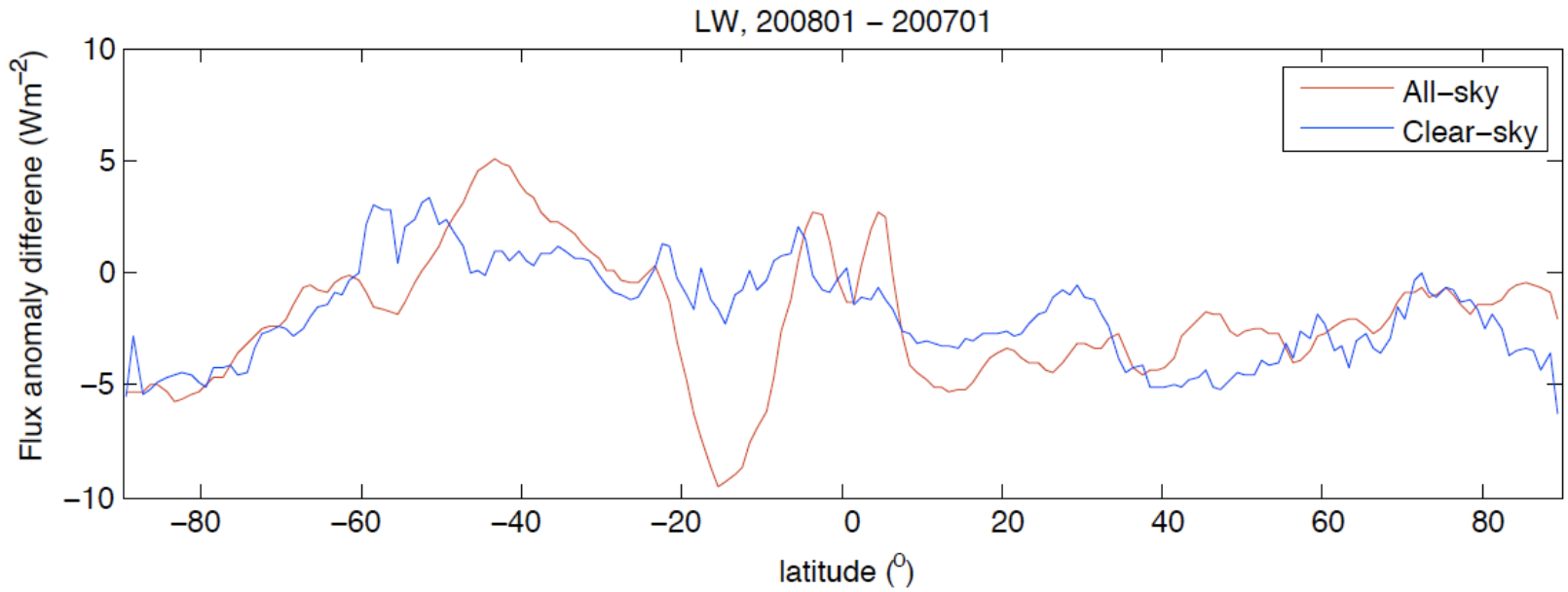
Cloud fraction difference 200801 - 200701

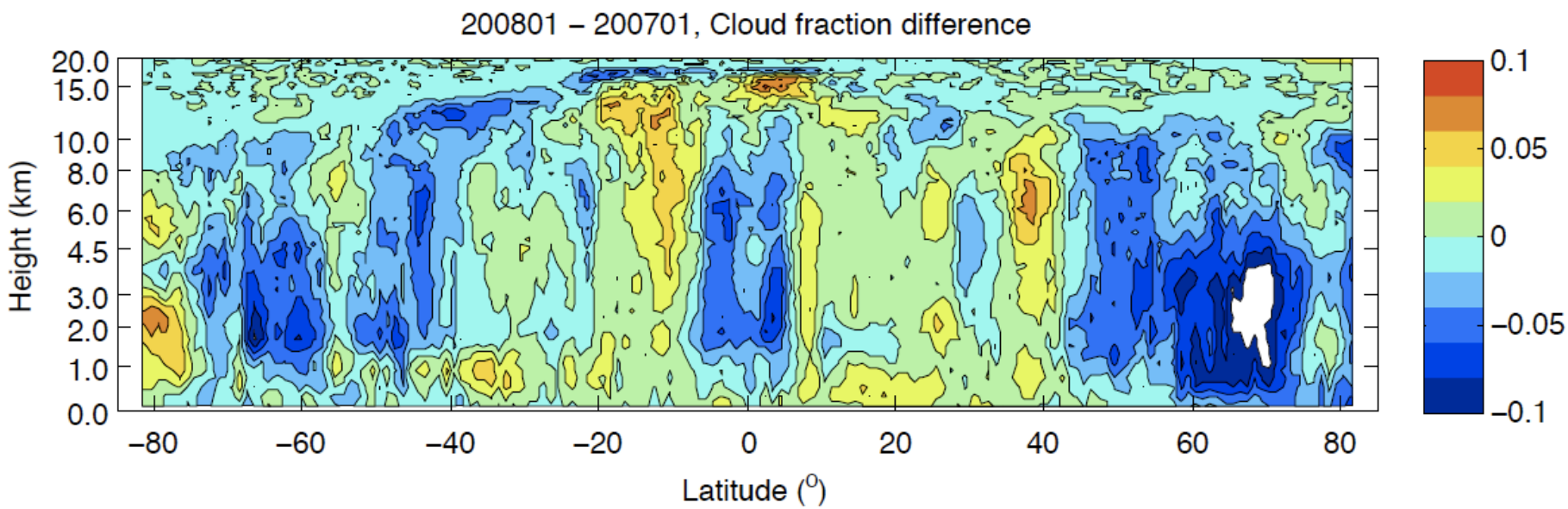


Cloud effective pressure 200801 - 200701

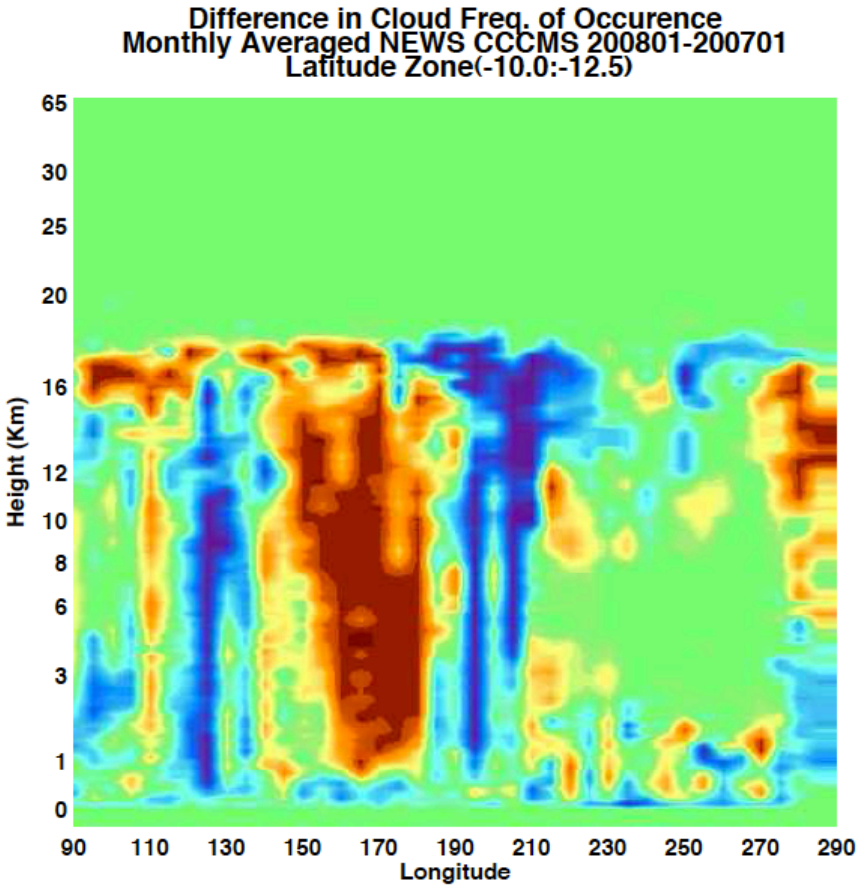


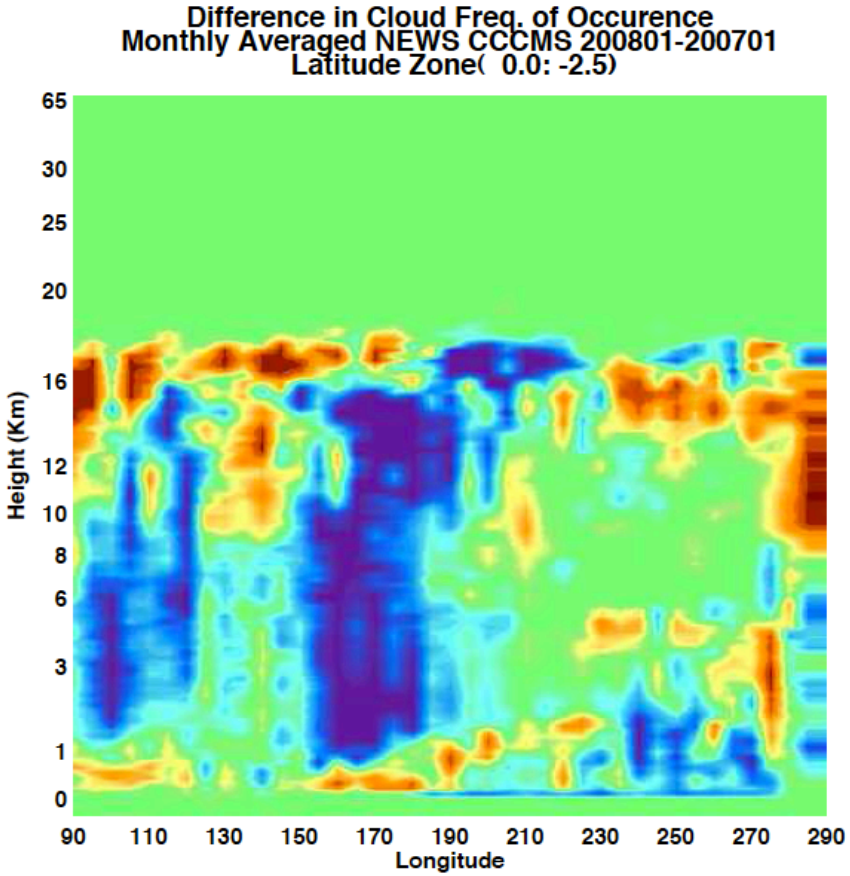
TOA LW anomaly difference and cloud fraction difference



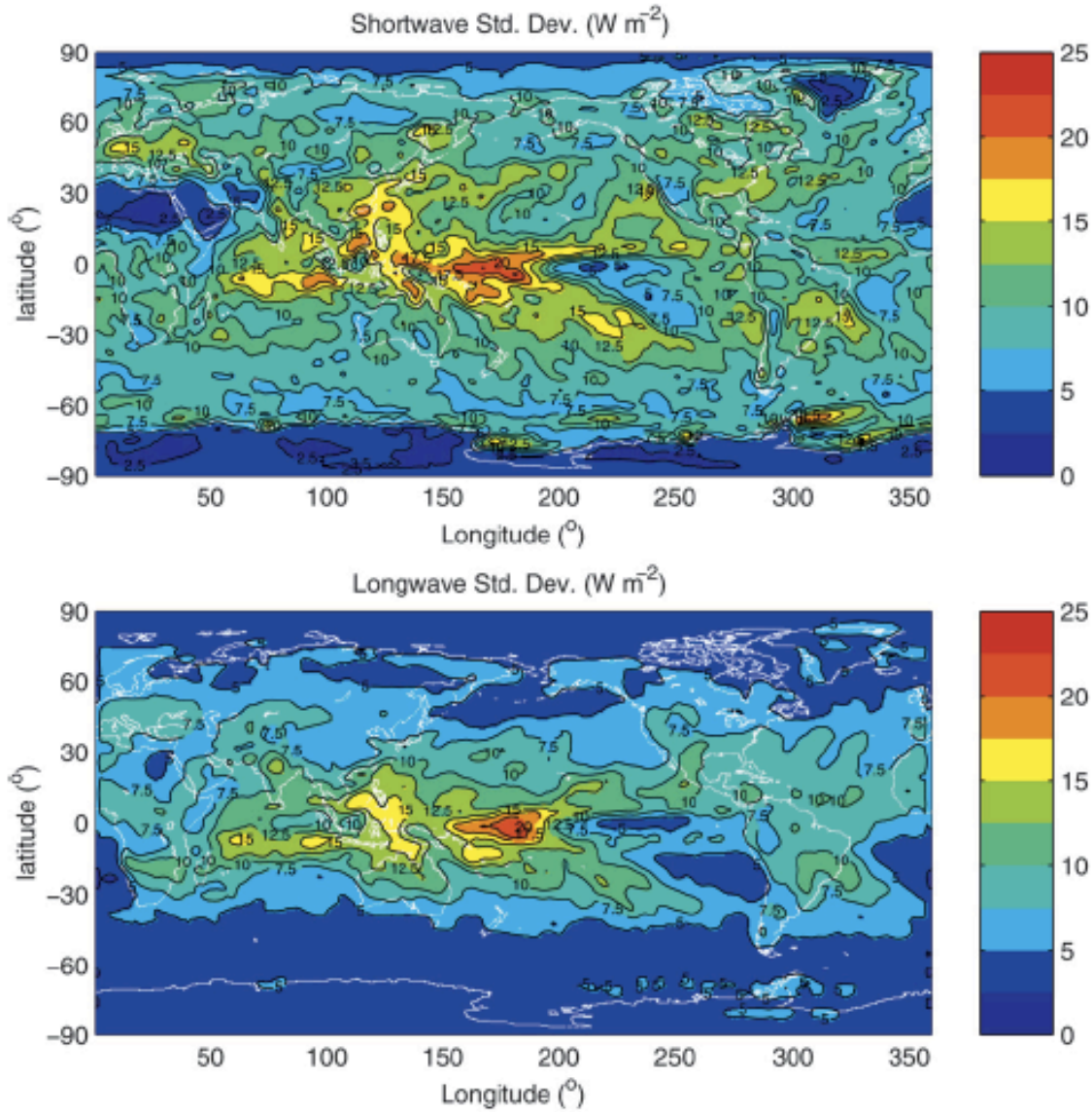


Longitudinal cloud occurrence difference 200801 - 200701



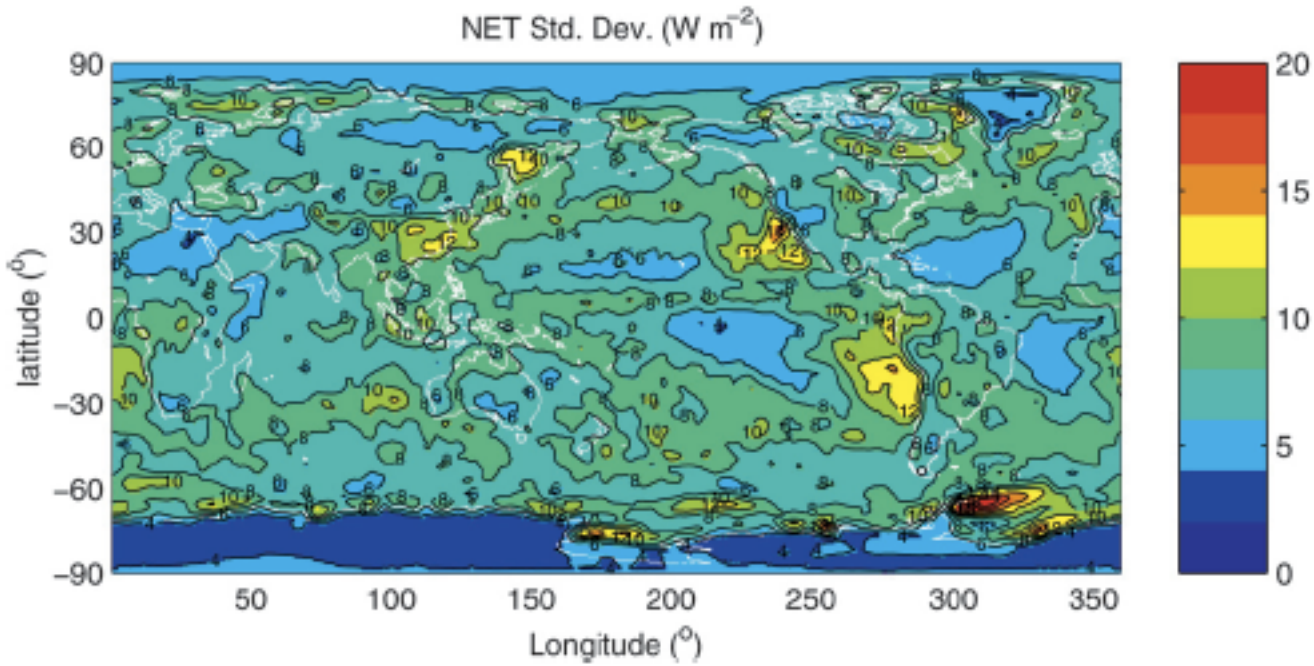


Standard deviation of deseasonalized anomalies



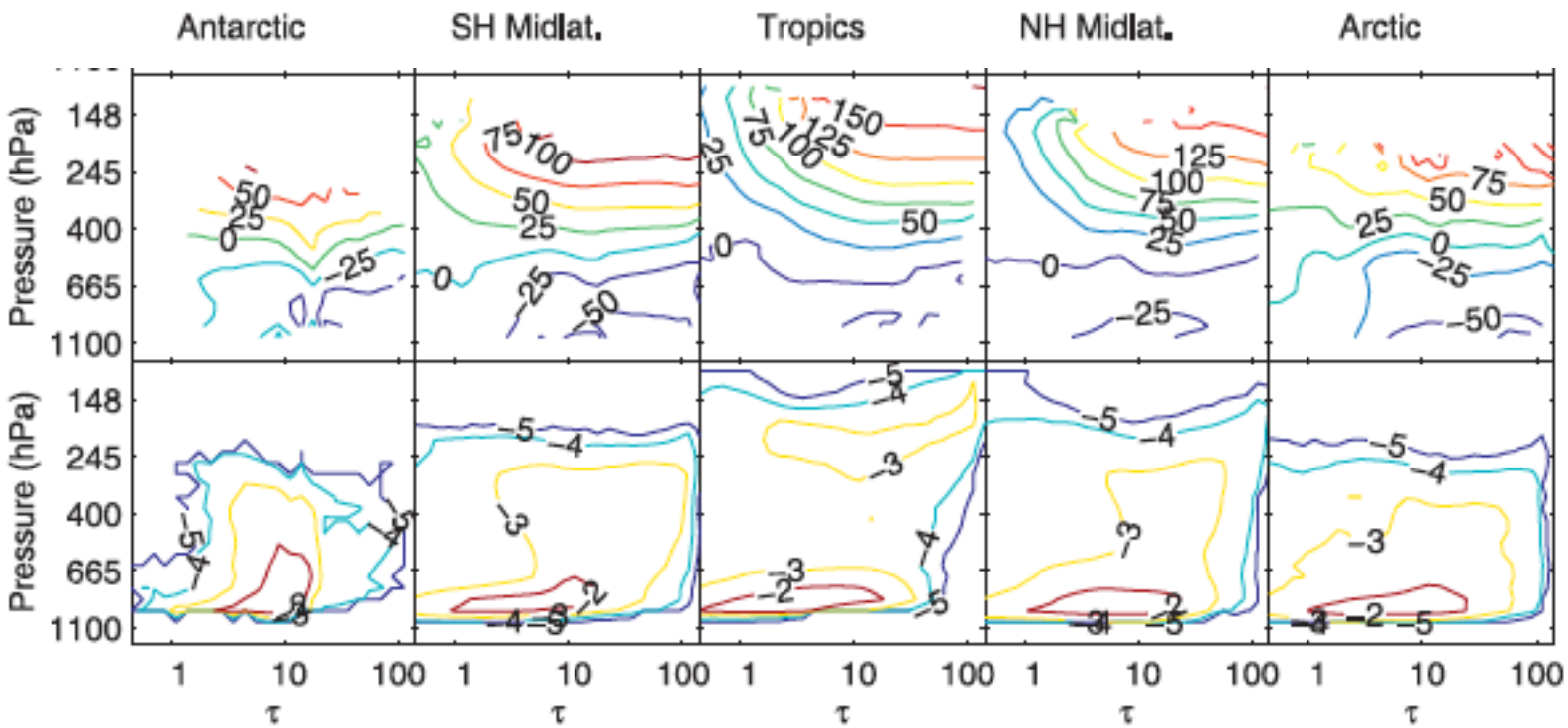
Standard deviations computed from 1° X 1° monthly anomalies

Standard deviation of NET anomalies



Thick high clouds: Negative SW anomalies and positive LW anomalies partially cancel
Low clouds: LW anomalies are small compared to SW anomalies-
Low level clouds contribute variability of TOA NET

NET atmospheric cloud effect



Summary

- Both approaches (instantaneous retrieval + radiative flux modeling and understanding cloud changes from mean radiances) are needed to establish the consistency between cloud property and radiative flux changes.
- To understand atmospheric processes influencing atmospheric energy deposition, other components of energy flux, such as surface sensible and latent heat fluxes, their horizontal advection and atmospheric heating by latent heat are needed.
- Diurnal cycle?