Toward detection of atmospheric changes in spatially and temporally averaged infrared spectra observed by CLARREO

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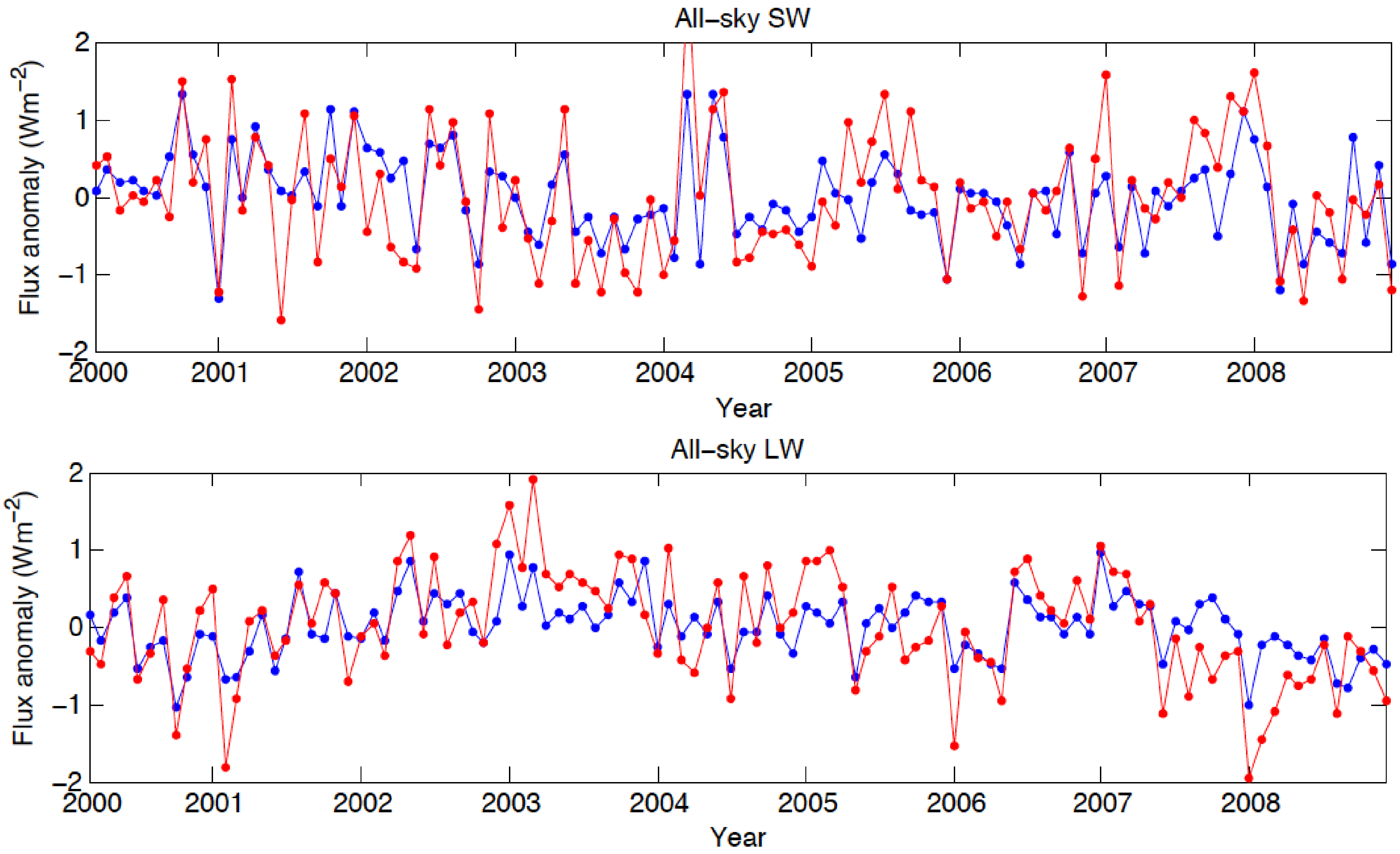
Outline of this talk

- CERES TOA deseasonalized anomalies (understanding natural variability)
- Nadir view spectral radiance simulation
- Cloud effect on non-linear term
- Relationship between atmospheric and cloud properties and spectral radiance change
- Retrieval simulation and error estimate
- Effect of small-scale variability on spectral radiance difference
- Future work

TOA flux anomalies from CERES

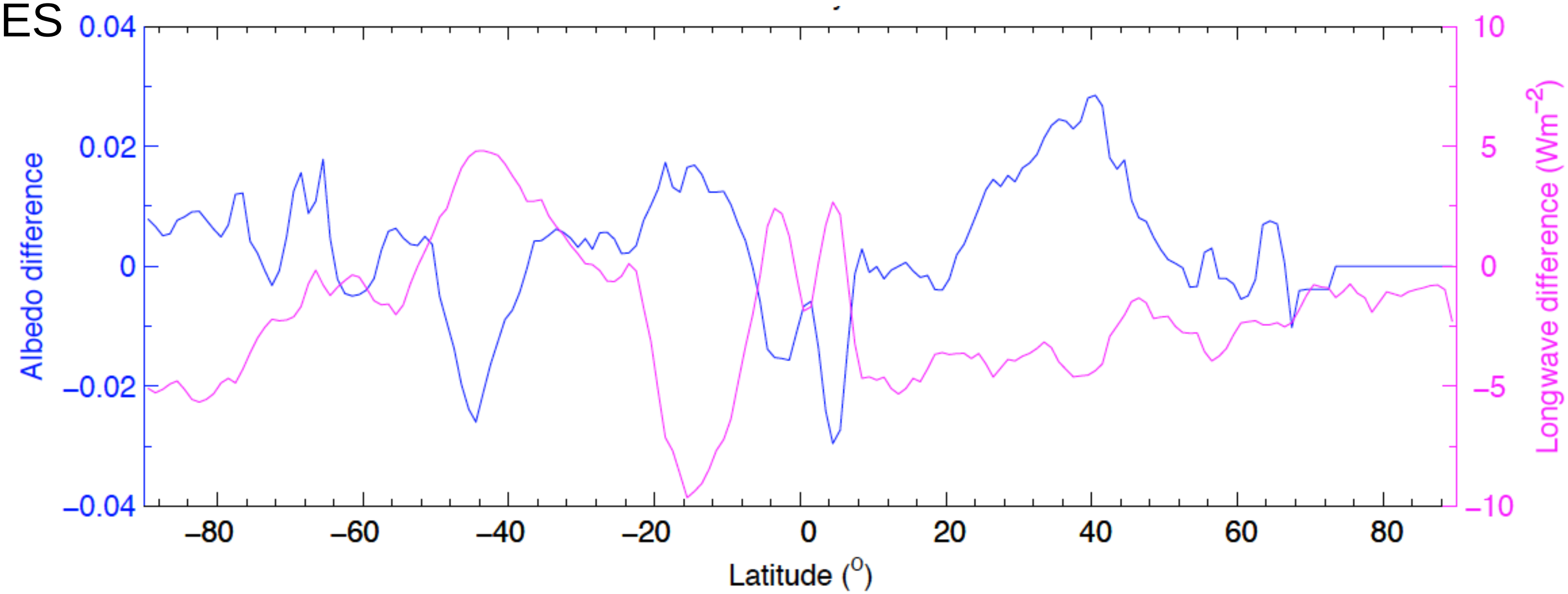


Blue line: global

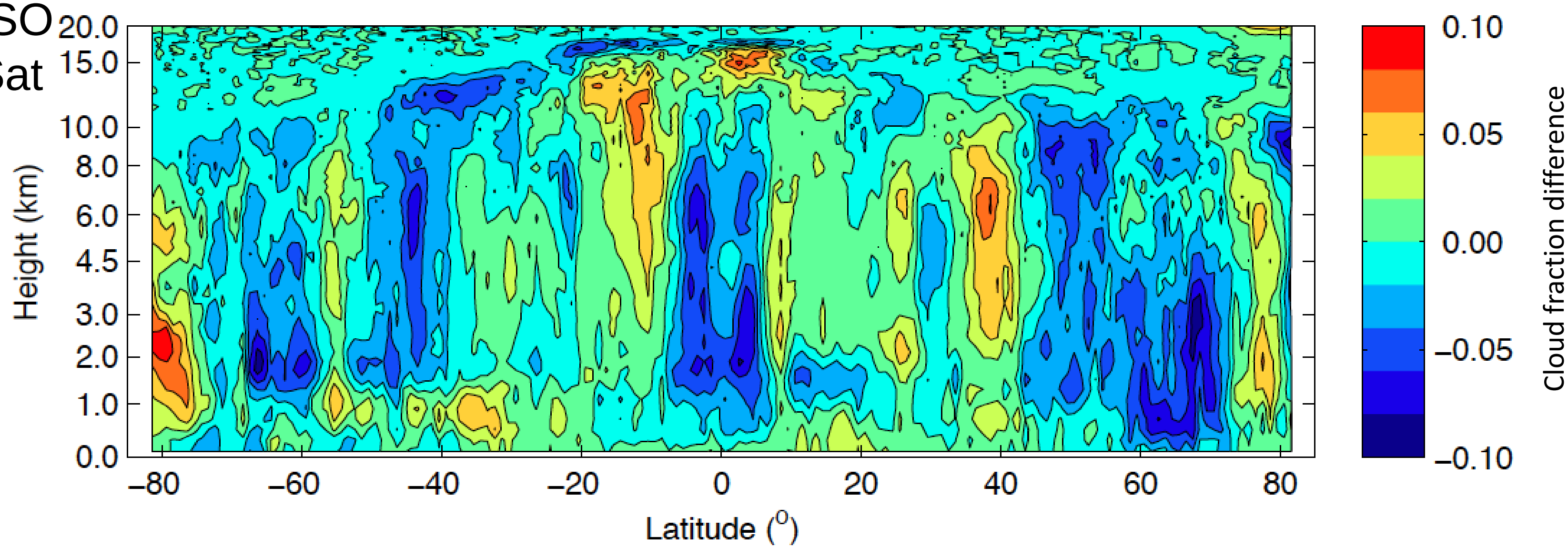
Red line: tropics 30S to 30N

200801 – 200701 TOA Albedo and Longwave radiative flux and cloud fraction differences

CERES



CALIPSO
CloudSat



Cloud fraction is computed for 200 m × 1° latitude grid boxes

Spectral radiance computations

- MODIS (by Ed2 CERES cloud algorithm) derived cloud properties
- Temperature and humidity profiles are from GEOS-4 (reanalysis)
- Control (unperturbed) run is from 2003 and2004
- Nadir view only
- Spectral radiance change is computed by perturbing 2003 and 2004 atmospheres
- TOA spectral radiances are computed with a 20 km spatial resolution for every CERES nadir view footprints
- Emphasis on understanding variability at a high temporal resolution

Mean spectral radiance

Spectral radiance averaged over Time Period 1 (reference)

j: Atmospheric and cloud properties, *i*: samples, δx_{1ij}: high temporal (instantaneous) variability

$$\overline{I_1(\mathbf{x_1})} = I(\bar{\mathbf{x}}_\mathbf{1}) + \sum_j \frac{1}{n_1} \sum_{i=1}^{n_1} \left[\frac{\partial I(\bar{\mathbf{x}}_\mathbf{1})}{\partial x_j} + \sum_k \frac{\partial^2 I(\bar{\mathbf{x}}_\mathbf{1})}{\partial x_j \partial x_{ki}} \delta x_{1ki} \right] \delta x_{1ji},$$

Time period 2, instantaneous

k: Atmospheric and cloud properties,

$$\Delta x = \overline{\Delta x} + \delta x$$

$$I_2(\mathbf{x_2}_i) = I(\bar{\mathbf{x}}_\mathbf{1}) + \sum_j \left[\frac{\partial I(\bar{\mathbf{x}}_\mathbf{1})}{\partial x_j} + \sum_k \frac{\partial^2 I(\bar{\mathbf{x}}_\mathbf{1})}{\partial x_j \partial x_{ki}} \Delta x_{ki} \right] \Delta x_{ji},$$

Spectral radiance averaged over Time Period 2

$$\overline{I_2(\mathbf{x_1} + \Delta \mathbf{x})} = I(\bar{\mathbf{x}}_1) + \sum_j \frac{1}{n_2} \sum_{i=1}^{n_2} \left[\frac{\partial I(\bar{\mathbf{x}}_1)}{\partial x_j} \overline{\Delta x_j} + \sum_k \frac{\partial^2 I(\bar{\mathbf{x}}_1)}{\partial x_j \partial x_{ki}} \Delta x_{ki} \overline{\Delta x_j} + \frac{\partial I(\mathbf{x_2})}{\partial x_{ji}} \delta x_{2ji} \right]$$

Atmospheric and cloud property change retrieval

Spectral radiance difference, Time period 2 – Time period 2

$$\overline{\Delta I} = \sum_j \left\{ \underbrace{\frac{\partial I(\bar{\mathbf{x}}_1)}{\partial x_j}\overline{\Delta x_j}}_{\text{Term 1}} + \underbrace{\frac{1}{n_1}\sum_{i=1}^{n_1}\sum_k \frac{\partial^2 I(\bar{\mathbf{x}}_1)}{\partial x_j \partial x_{ki}}\delta x_{ki}\overline{\Delta x_j}}_{\text{Term 2}} + \underbrace{\sum_k \frac{\partial^2 I(\bar{\mathbf{x}}_1)}{\partial x_j \partial x_k}\overline{\Delta x_k}\,\overline{\Delta x_j}}_{\text{Term 3}} + \underbrace{\epsilon_{4j}}_{\text{Term 4}} + \underbrace{\epsilon_{5j}}_{\text{Term 5}} \right\}$$

where

$$\epsilon_{4j} = \frac{1}{n_2}\sum_{i=1}^{n_2}\frac{\partial I(\mathbf{x_2})}{\partial x_{ji}}\delta x_{2ji} - \frac{1}{n_1}\sum_{i=1}^{n_1}\frac{\partial I(\mathbf{x_1})}{\partial x_{ji}}\delta x_{1ji} \qquad (5)$$

Small scale variability difference

and

$$\epsilon_{5j} = \frac{1}{n_2}\sum_{i=1}^{n_2}\sum_k \frac{\partial^2 I(\bar{\mathbf{x}}_1)}{\partial x_j \partial x_{ki}}\delta x_{2ki}\overline{\Delta x_j} - \frac{1}{n_1}\sum_{i=1}^{n_1}\sum_k \frac{\partial^2 I(\bar{\mathbf{x}}_1)}{\partial x_j \partial x_{ki}}\delta x_{1ki}\overline{\Delta x_j}$$

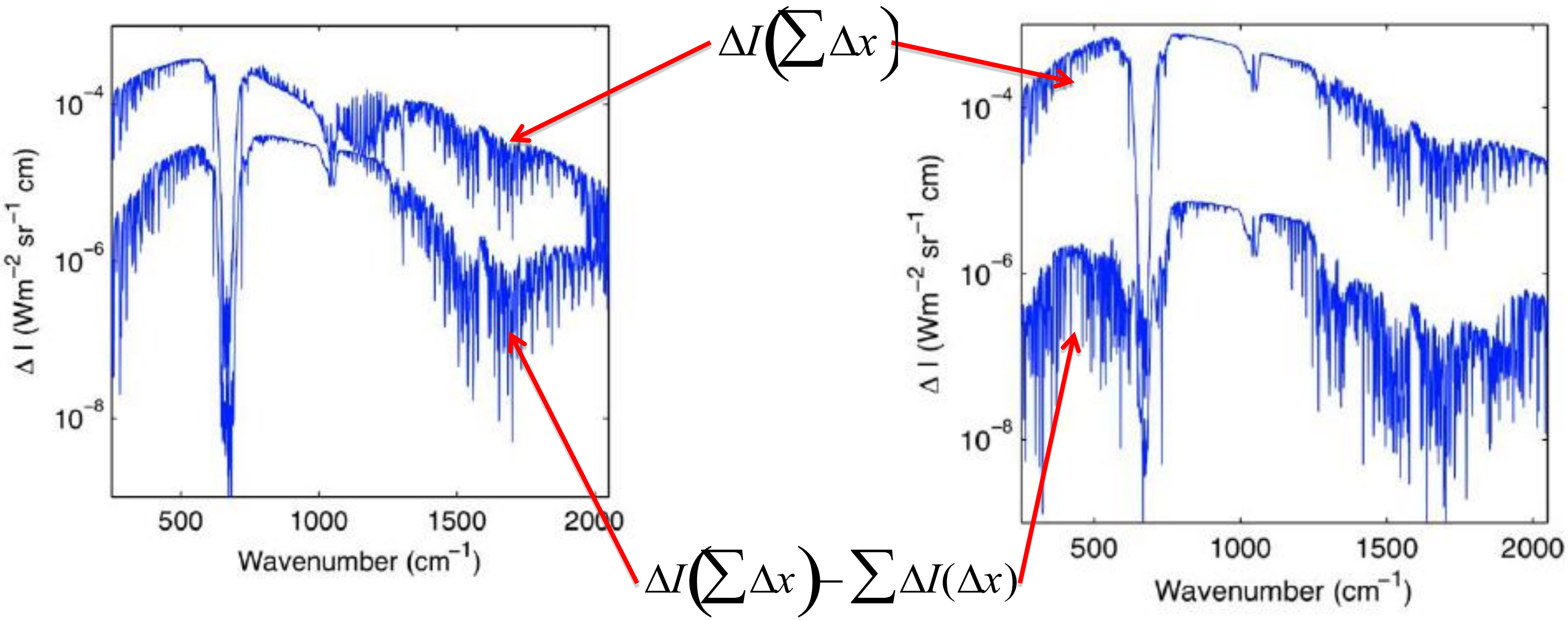
Kernel variability

Kernel to retrieve mean atmospheric and cloud changes is Term 1 + Term 2
Term 3(non-linear term) can be included in the kernel.
Term 4 and Term 5 are noise.

Non-linear term (annual global mean)

Cloud fraction change is included

Cloud fraction change is excluded

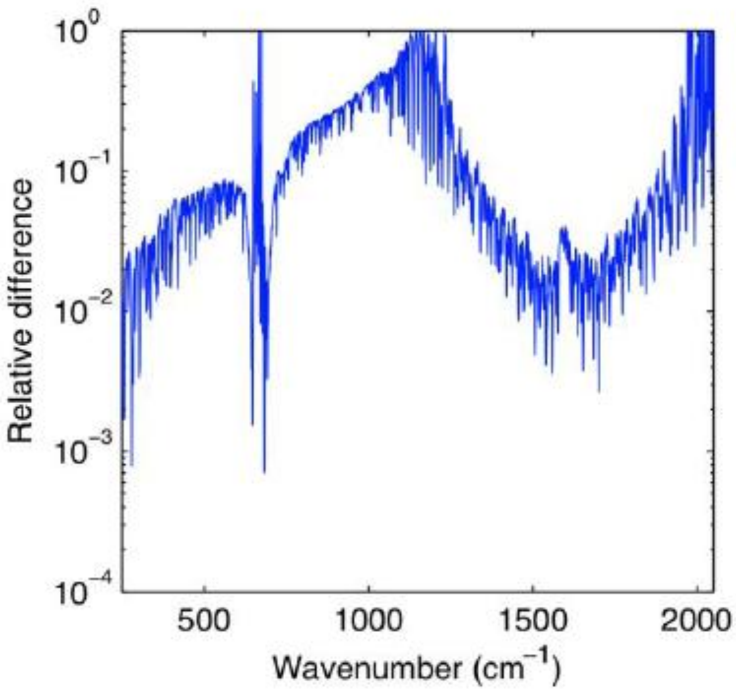


$$\Delta I\left(\sum \Delta x\right)$$

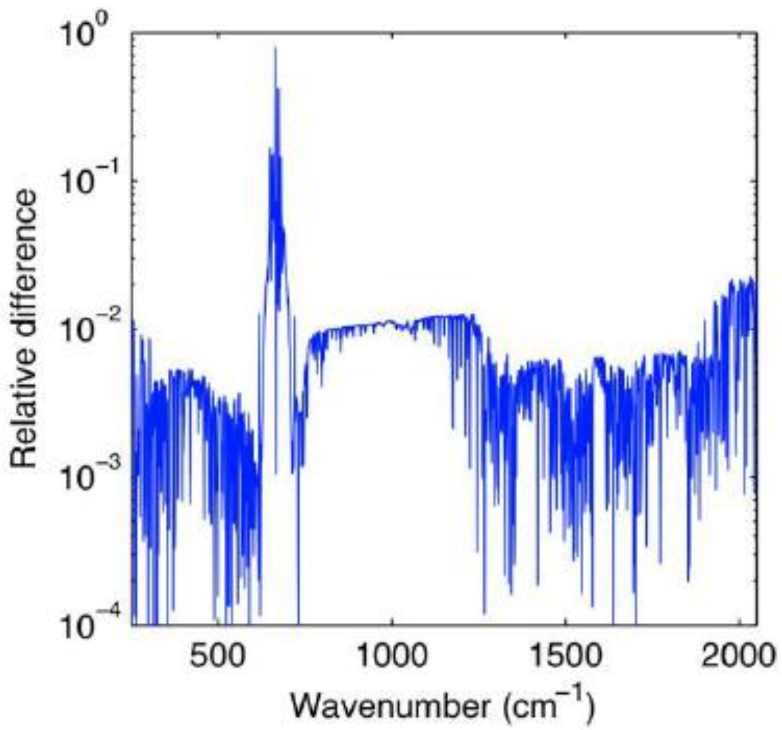
$$\Delta I\left(\sum \Delta x\right) - \sum \Delta I(\Delta x)$$

Cloud fraction change significantly increases the non-linear term

Cloud fraction change is included



Cloud fraction change is excluded

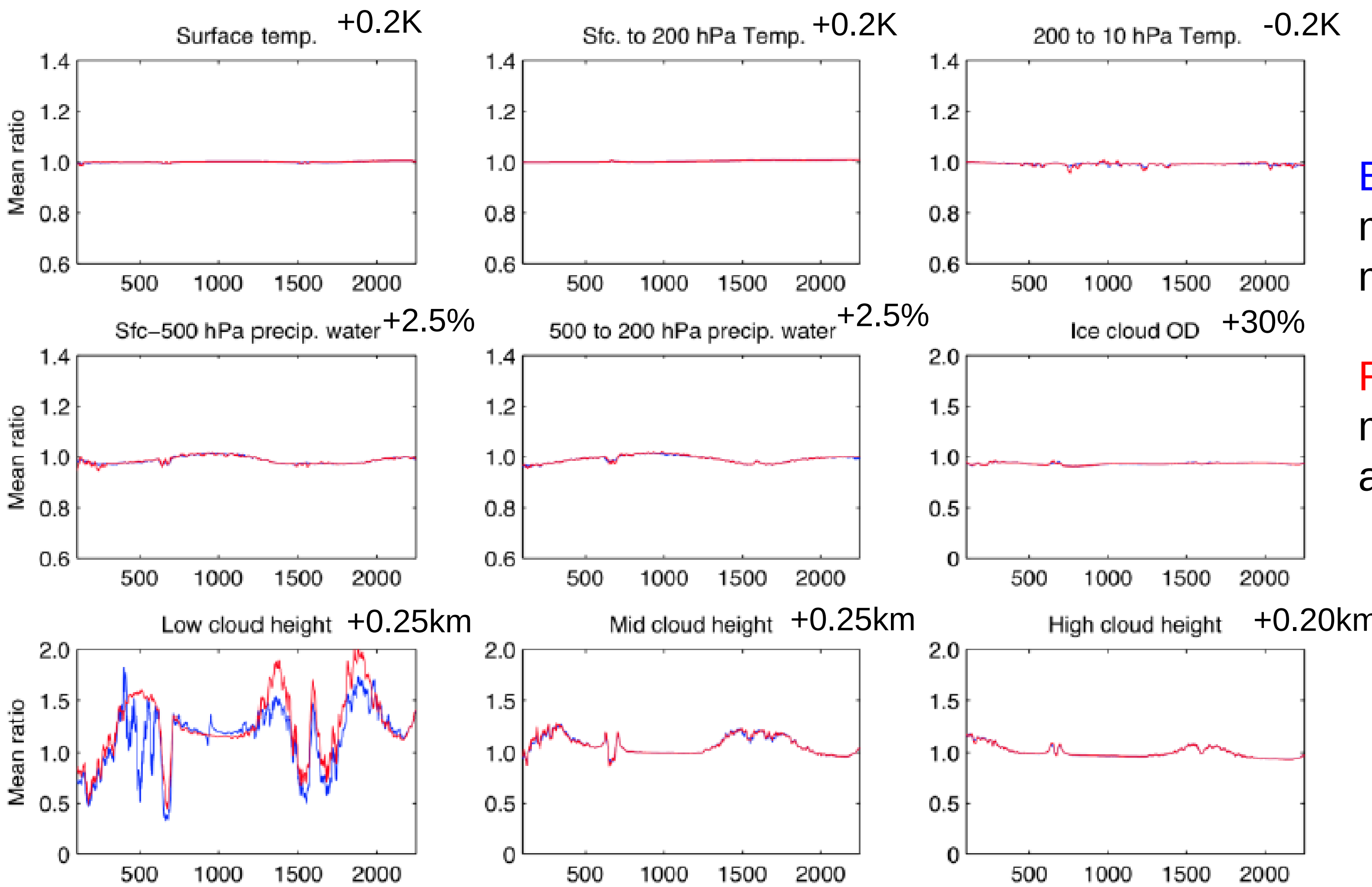


$$\frac{\Delta I\left(\sum \Delta x\right) - \sum \Delta I(\Delta x)}{\Delta I\left(\sum \Delta x\right)}$$

Relationship between atmospheric and cloud changes and TOA spectral radiance change

$$\frac{\Delta I(2\Delta x)-\Delta I(\Delta x)}{\Delta I(\Delta x)}$$

ΔI: 10° zonal monthly radiance change



Blue: mean of monthly 10°

Red: mean of annual 10°

Error ($\varepsilon_4+\varepsilon_5$) term estimate

$$\overline{\Delta I} =$$

$$\sum_j \left\{ \underbrace{\frac{\partial I(\bar{\mathbf{x}}_1)}{\partial x_j}\overline{\Delta x_j}}_{\text{Term 1}} + \underbrace{\frac{1}{n_1}\sum_{i=1}^{n_1}\sum_k \frac{\partial^2 I(\bar{\mathbf{x}}_1)}{\partial x_j \partial x_{ki}}\delta x_{ki}\overline{\Delta x_j}}_{\text{Term 2}} + \underbrace{\sum_k \frac{\partial^2 I(\bar{\mathbf{x}}_1)}{\partial x_j \partial x_k}\overline{\Delta x_k}\ \overline{\Delta x_j}}_{\text{Term 3}} + \underbrace{\epsilon_{4j}}_{\text{Term 4}} + \underbrace{\epsilon_{5j}}_{\text{Term 5}} \right\}$$

Mean spectral radiance change computed with high temporal resolution (Terms 1,2,3,4, and 5)

- Mean spectral change computed with annual mean atmospheres (Terms 1 and 3)
- Term 2 (estimated form perturbed run of the time period 1)

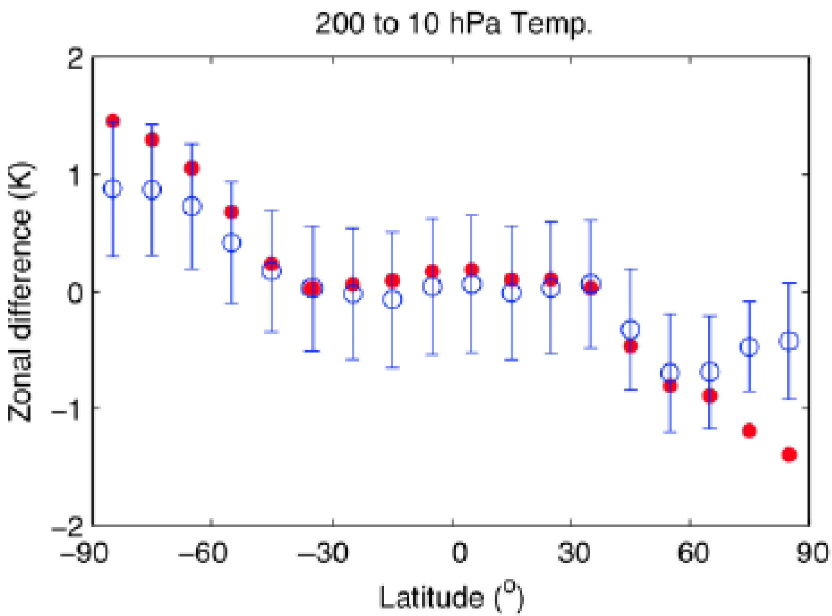
$$\mathbf{a_c} = \left(\mathbf{S^T S} + \lambda \mathbf{H}\right)^{-1} \mathbf{S^T} \Delta \mathbf{I}$$

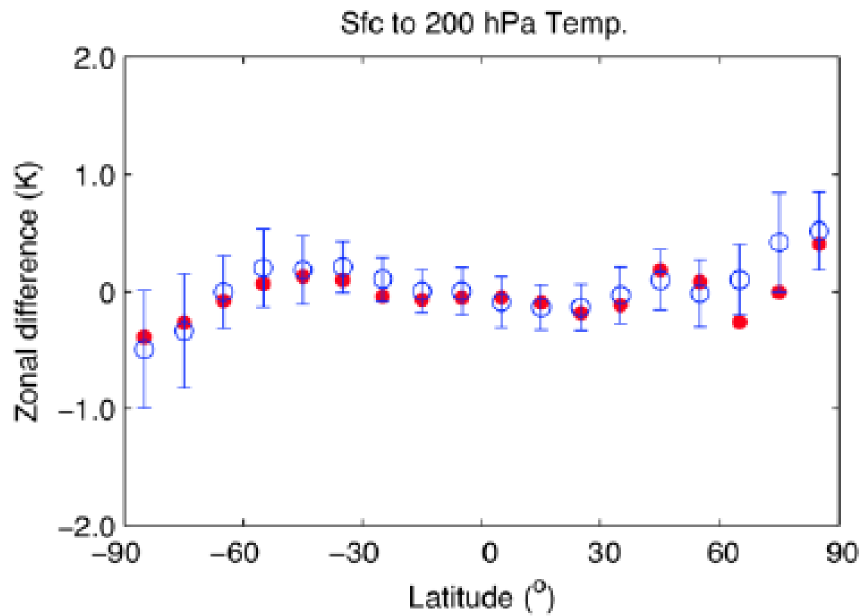
$$Var(\mathbf{a_c}) = (\mathbf{S^T S} + \lambda \mathbf{H})^{-1} \mathbf{S}^T \left(\varepsilon' \varepsilon'^{\mathbf{T}}\right) \mathbf{S} (\mathbf{S^T S} + \lambda \mathbf{H})^{-1}$$

When λ=0, $\left[\mathbf{S}^T \left(\varepsilon' \varepsilon'^T\right)^{-1} \mathbf{S}\right]^{-1}$

Temperature retrieval
(2003 2004 annual mean difference)

Retrieved from 10° zonal annual mean spectra

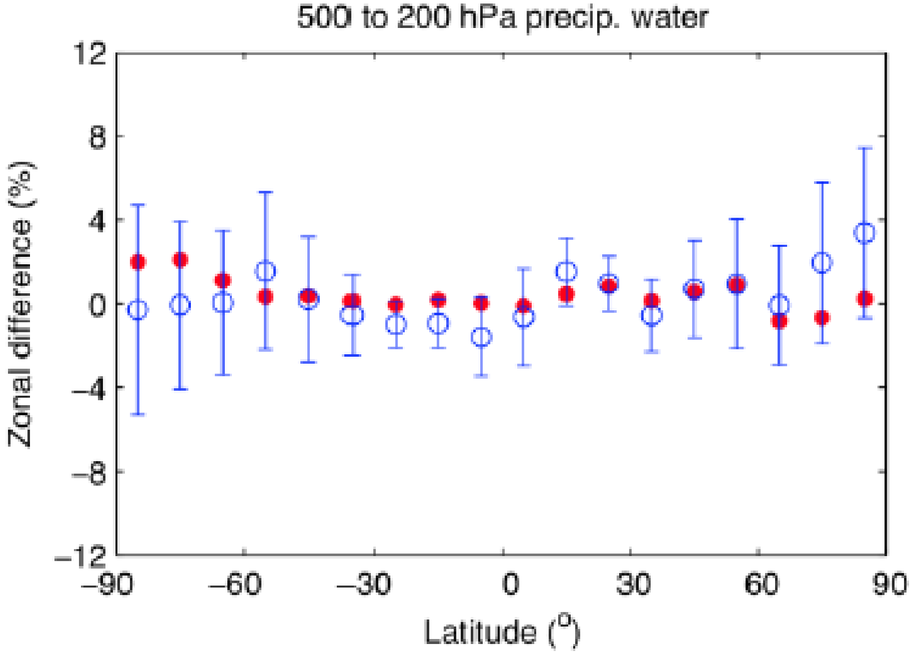




Red: true values
Blue open circles: retrieved values
Error bars: Uncertainty in retrieved values

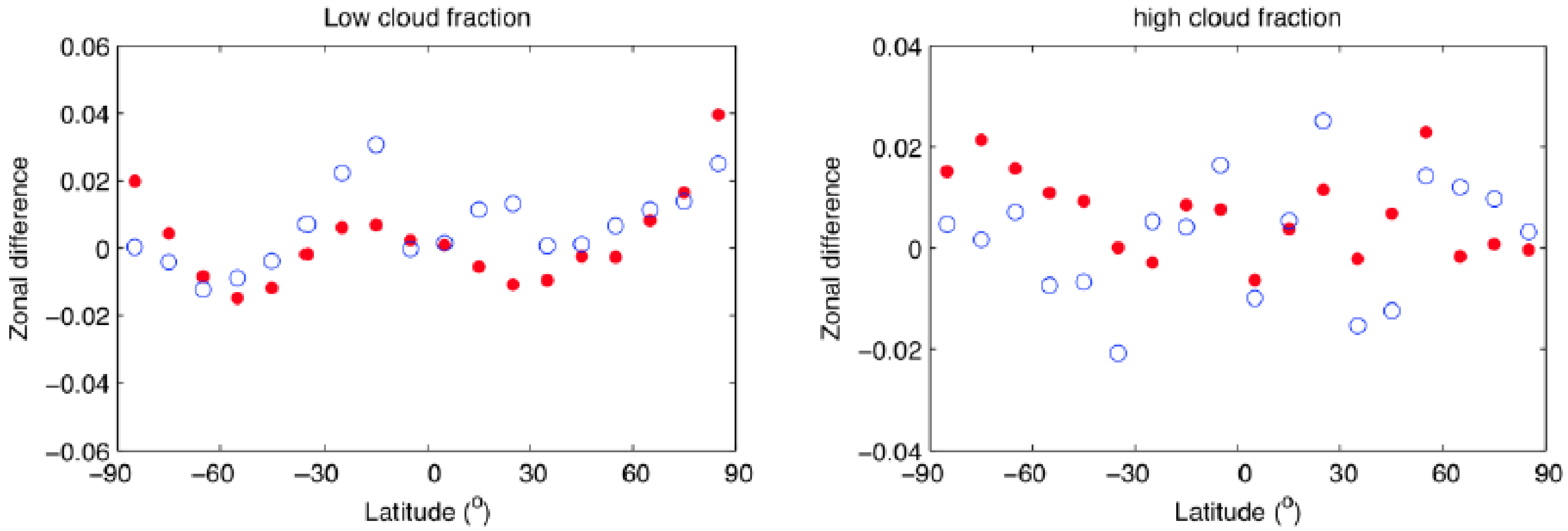
Upper tropospheric water vapor (2003 2004 annual mean difference)

Retrieved from 10˚ zonal annual mean spectra



Red: true values
Blue open circles: retrieved values

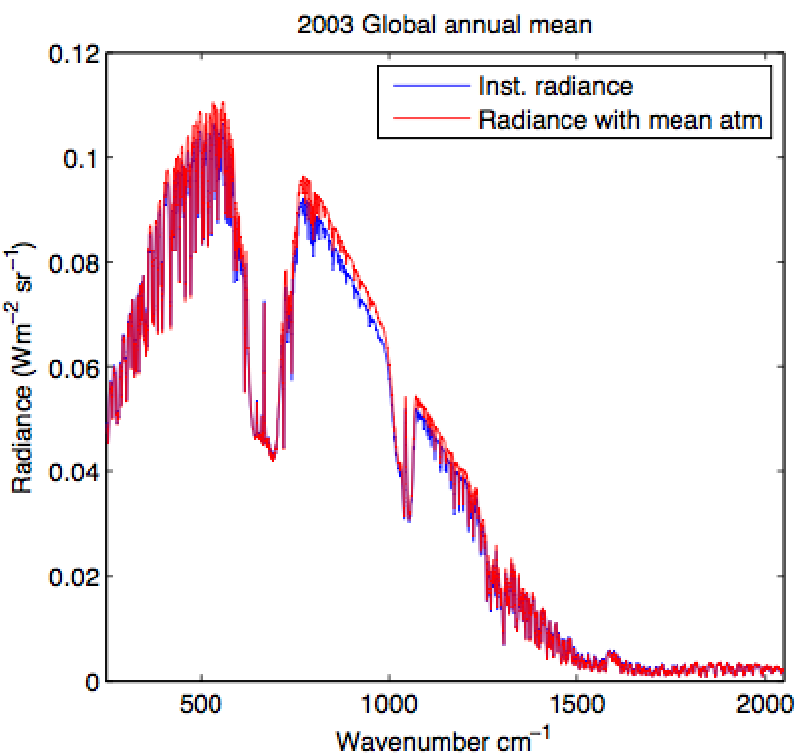
Cloud fraction retrieval
(2003 2004 annual mean difference)

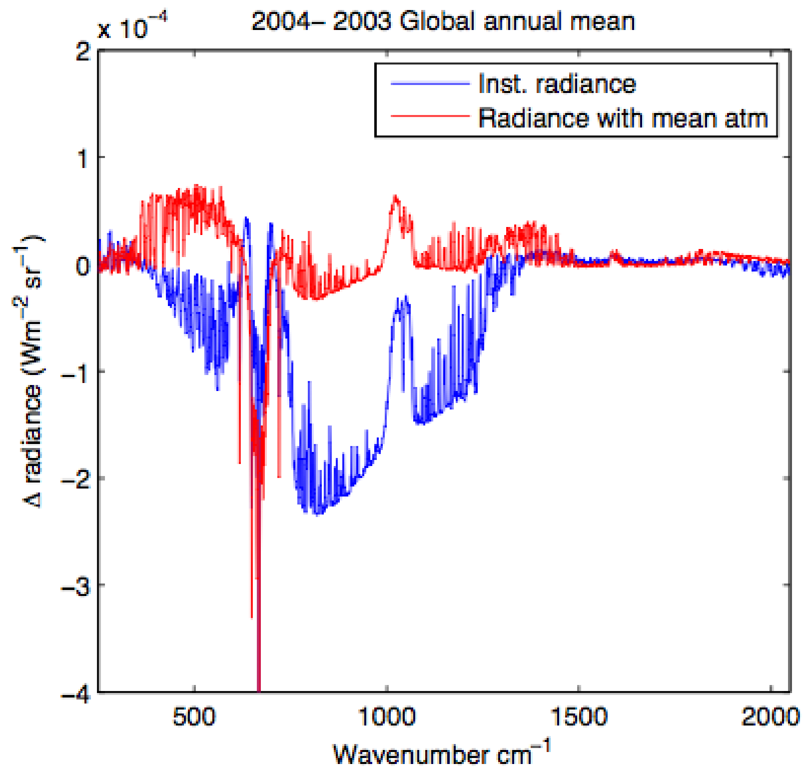


The uncertainties averaged over 18 10° zones are:
Low cloud height: ±2.0 km
Low cloud fraction: ±0.2
High cloud fraction: ±0.4
Because of Terms 4 and 5

Red: true values
Blue open circles: retrieved values

Effect of averaging atmospheric and cloud properties

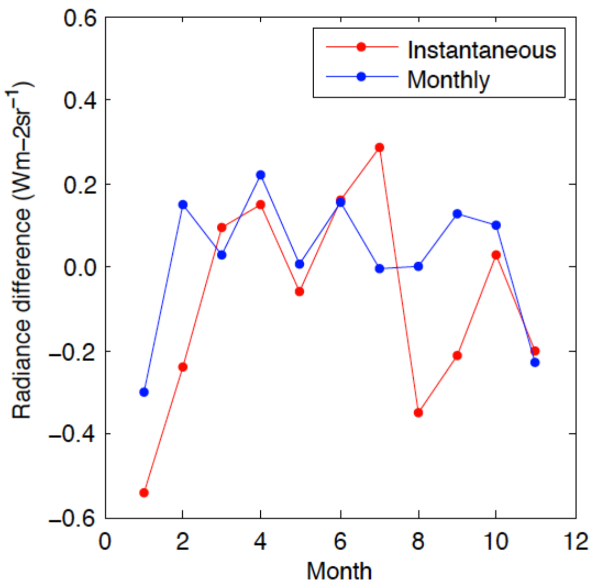




Instantaneous spectrum computations: compute spectra for all 20 km footprints
Monthly mean: compute spectra with monthly mean atmospheric and cloud properties
Terms 2,4, and 5 are not included

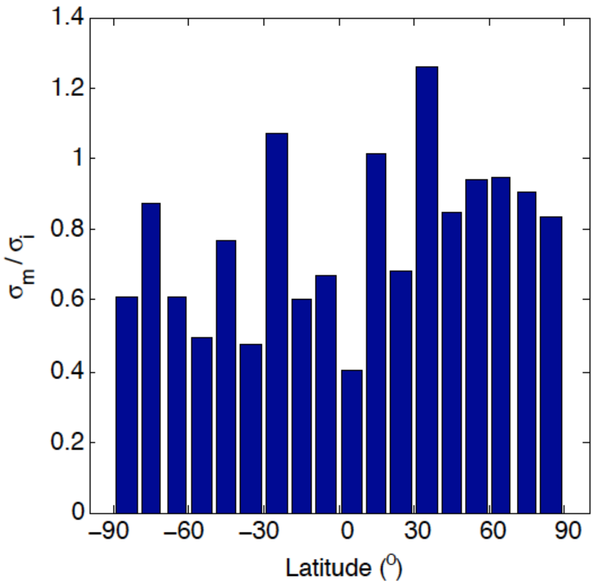
Modeled natural variability comparison

Global annual mean difference

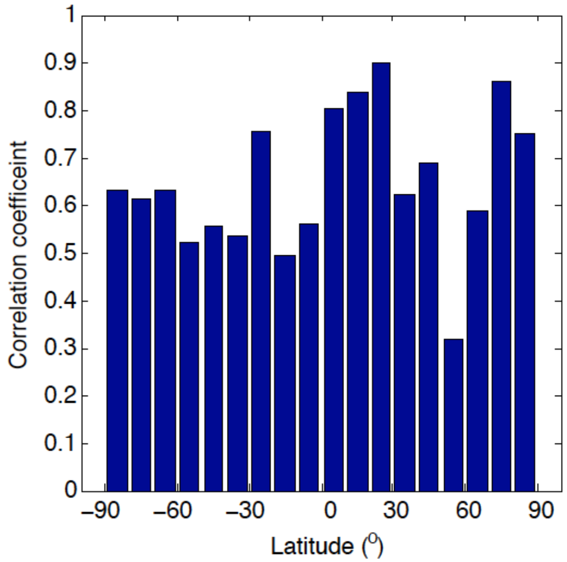


Standard deviation ratio

Monthly 10° zonal $\frac{\sigma_{Monthly}}{\sigma_{Inst.}}$



Correlation coefficient



Nadir view radiance difference, 2004 – 2003

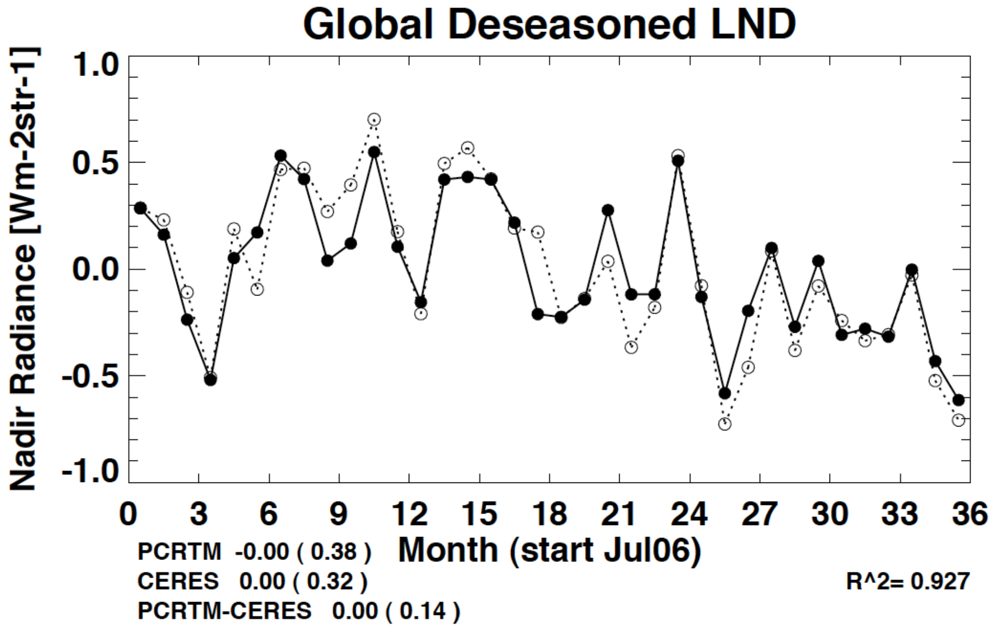
Red: Computed with instantaneous 20 km footprints (high temporal resolution) σ_i

Blue: Computed with monthly mean atmospheric and cloud properties σ_m

Simulation with CALIPSO/CloudSat derived cloud properties

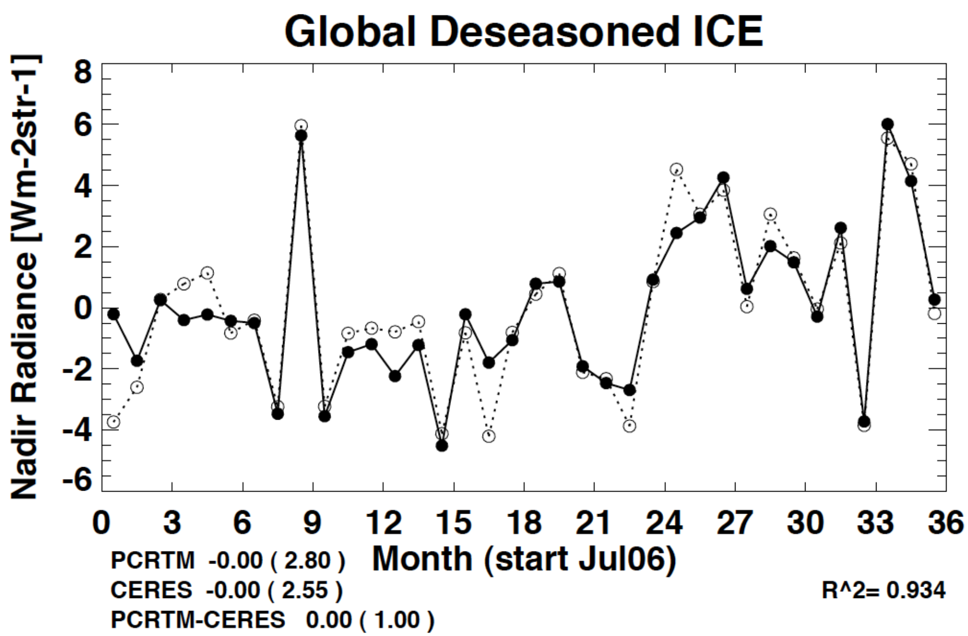
- Understand spectral shape and size of all terms (instantaneous spectrum computations & spectrum computations with mean atmospheric and cloud properties)
- 44 months of data (from July 2006 through Feb. 2010)
- Spectral radiative kernels

Comparison of LW broadband variability

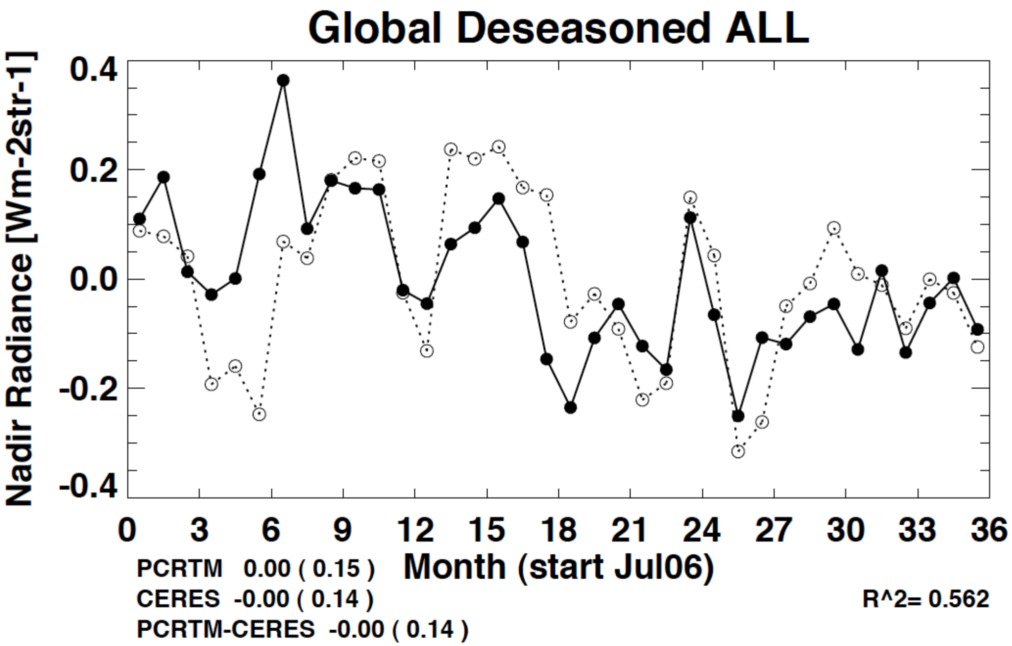


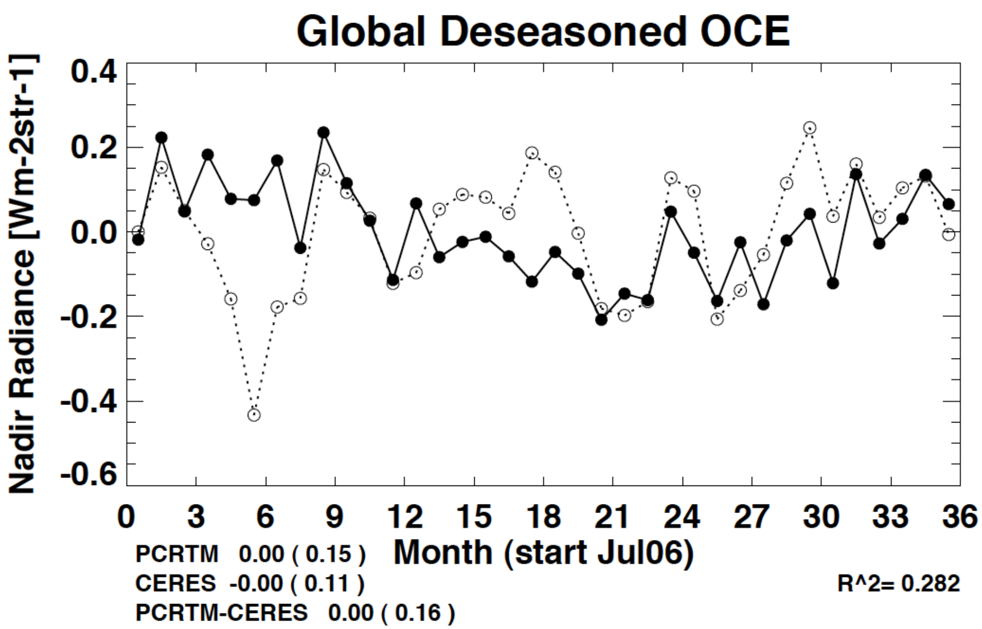
Closed circles: CERES

Open circles: Model



Variability comparison





Closed circles: CERES

Open circles: Model

Summary and future plan

- Demonstrated the importance of small scale variability in inferring atmospheric and cloud property changes from temporally and spatially averaged longwave spectral radiances.
- Use CALIPSO/CloudSat/MODIS derived cloud fields to model spectral radiances.
- Compare natural variability with AIRS observations.
- Reducing retrieval error by treating bias error terms (all-sky, clear-sky, subtracting bias etc.)

Back-ups