Understanding atmospheric and cloud property variability toward TOA spectral radiance closure

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Outline of this talk

- Error source of longwave fingerprinting
- TOA LW spectra modeling
- Comparison of broadband radiances with CERES
- Effect of small-scale variability on broadband radiances
- Correlation among atmospheric and cloud properties

Error source of LW fingerprinting (TOA closure)

- Instrument calibration
- Modeling error (inputs, assumptions in radiative transfer etc.)
- Non-linear effects $\sum_j \sum_k \frac{\partial^2 I}{\partial x_j \partial x_k} \overline{\Delta x_j} \overline{\Delta x_k}$ (can be included in a signature matrix)
- Vertical resolution in building the signature matrix or missing elements in it.
- Correlations present at a small-scale spatial and temporal resolution that affect observed spectral radiances (focus of this talk)

TOA nadir view spectral radiance computations

- Spectral radiance using PCRTM with a 0.5 cm^{-1} spectral resolution and 20 km spatial resolution.
- July 2006 through Aug. 2009.
- Clouds and aerosols: CCCM (CALIPSO, CloudSat, and MODIS).
- Temperature and humidity: Reanalysis (MOA: GEOS4 and GEOS5).
- Instantaneous nadir radiance.
- Modeled spectral radiance changes are used to investigate atmospheric and cloud property variability.

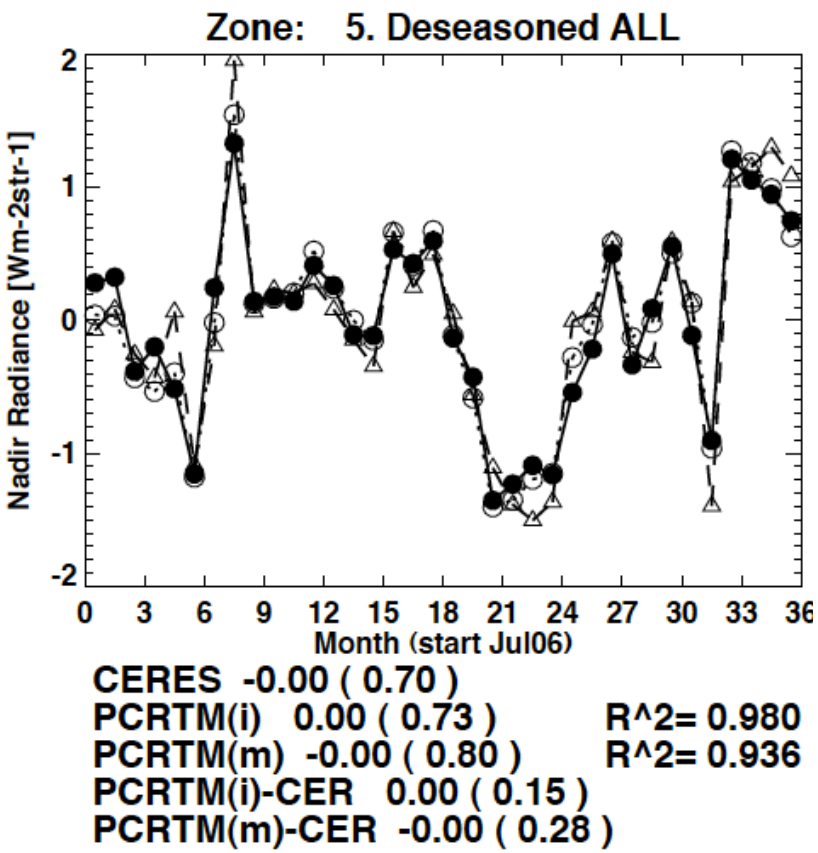
High resolution versus monthly mean computations

- To express the spectral radiance change by the sum of contributions of atmospheric and cloud property changes

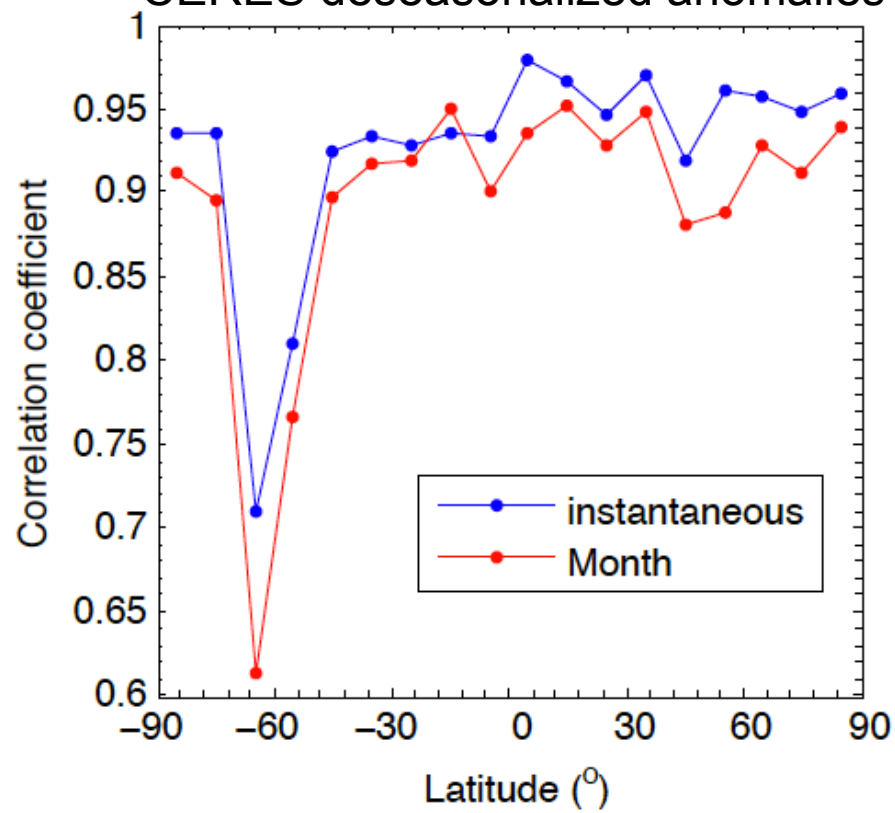
$$\overline{\Delta I} = \sum \Delta I(\overline{x}_i)$$

- Compare
  - Mean of instantaneous radiances $I(\overline{x})$
  - Radiance computed with monthly mean properties $\overline{I(x)}$

Comparison of deseasonalized anomalies with CERES observed LW radiances



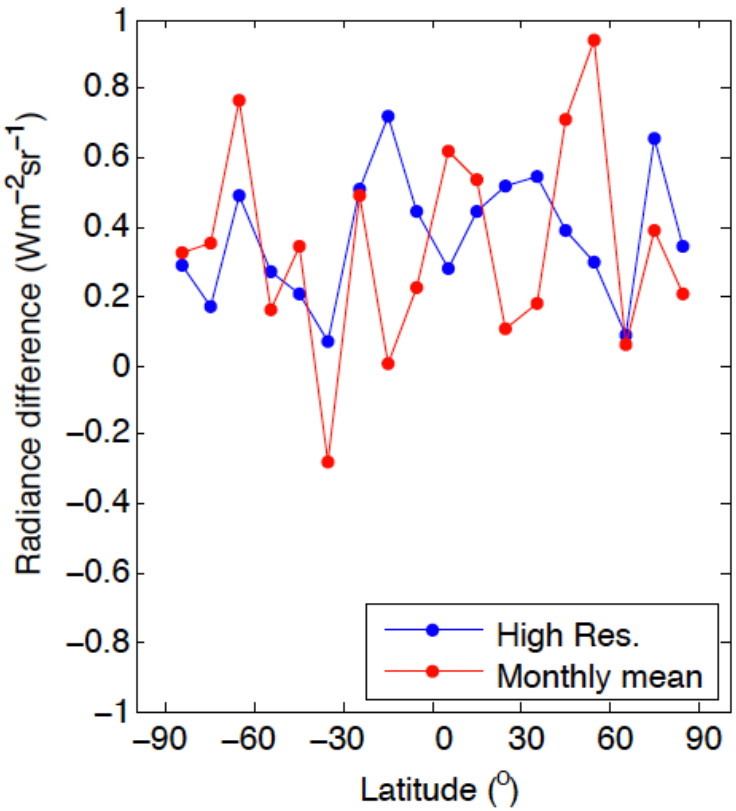
Correlation coefficient with CERES deseasonalized anomalies



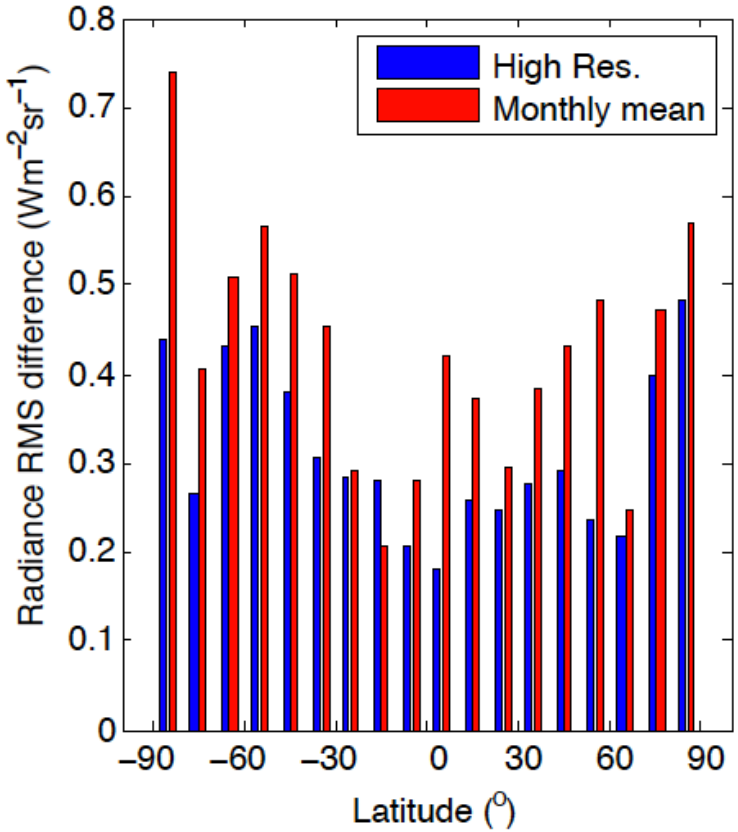
Closed circle: CERES
Open circle: Instantaneous resolution
Open triangle: Monthly mean calculations

2007 - 2008 difference

Radiance difference, 200801 – 200701
Model – CERES,
10°zonal monthly mean difference



RMS difference 2008 – 2007
Model - CERES

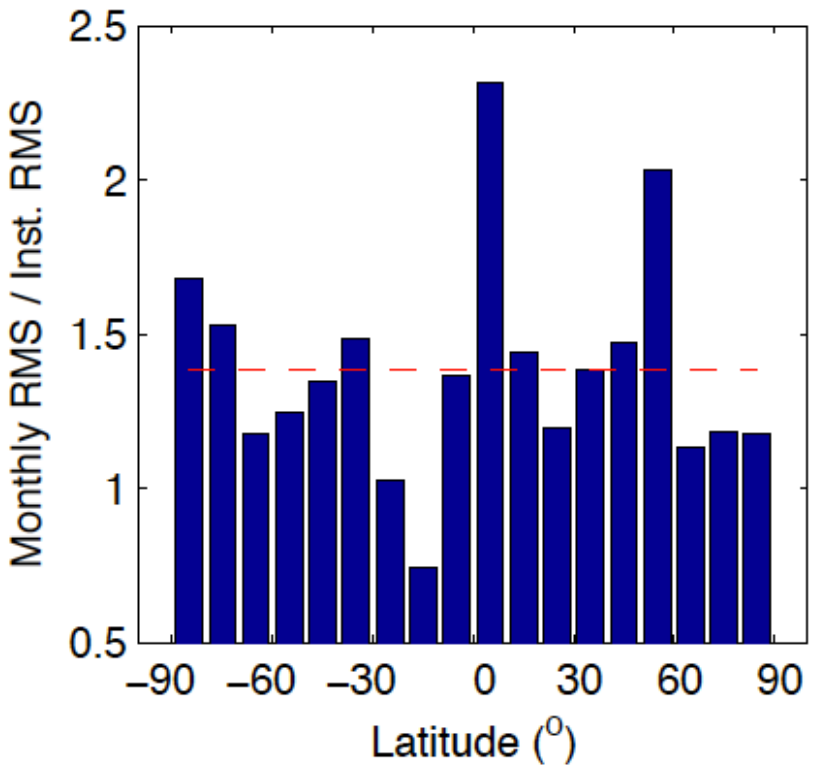


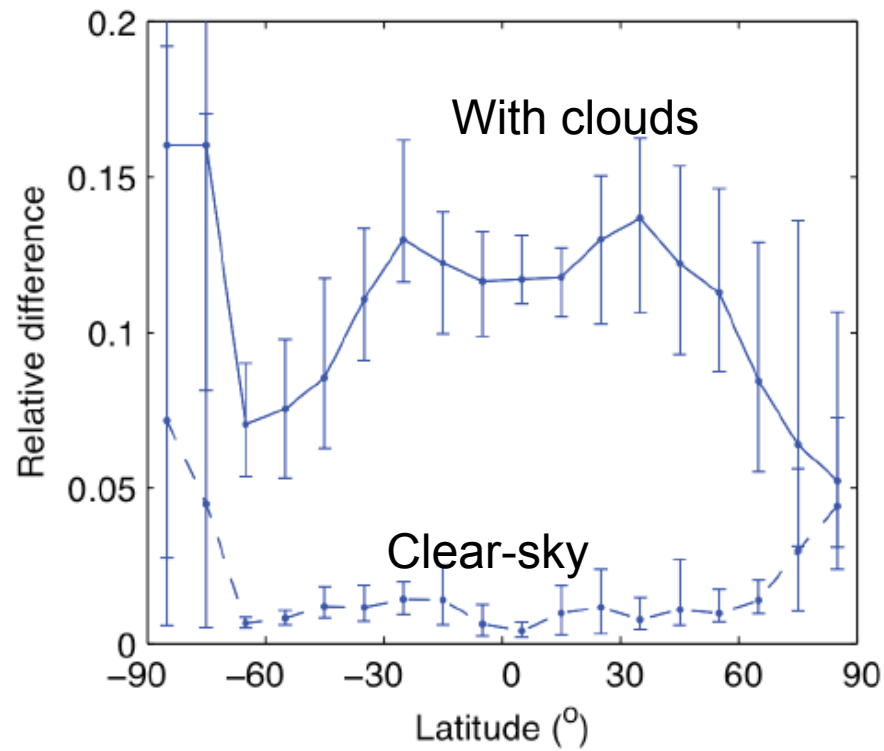
Correlations among atmospheric and cloud properties occurring at a high resolution affect TOA radiances

Small-scale correlation Contribution

$$\frac{\sqrt{\sum\left\{\left[I(\bar{x})-CERES\right]_{2008}-\left[I(\bar{x})-CERES\right]_{2007}\right\}^2}}{\sqrt{\sum\left\{\left[\overline{I(x)}-CERES\right]_{2008}-\left[\overline{I(x)}-CERES\right]_{2007}\right\}^2}}$$

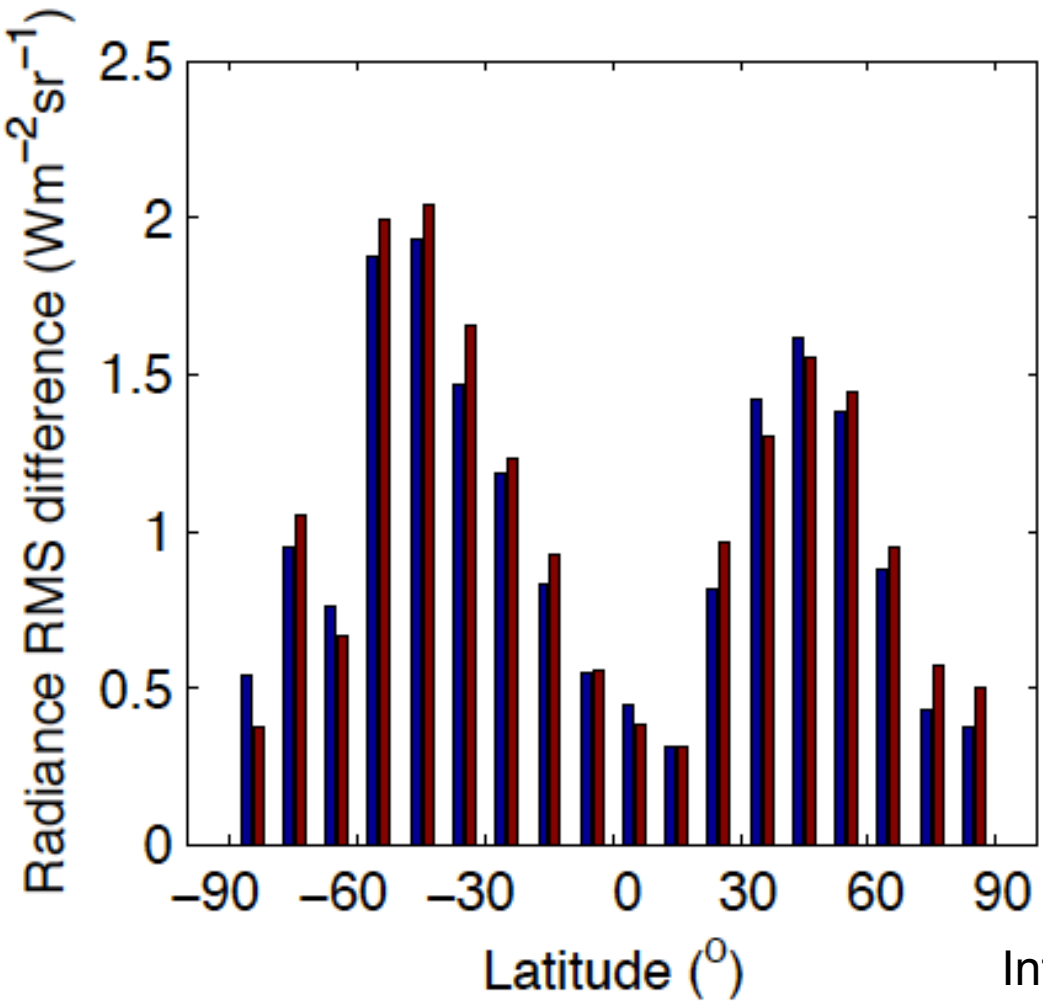
$$\sqrt{\frac{1}{n}\sum\left[\Delta I(all)-\sum\Delta I\right]^2}$$





Small-scale correlation increases RMS 30 to 40 % while the non-linear term contributes 10 to 15%

Modeled radiance difference



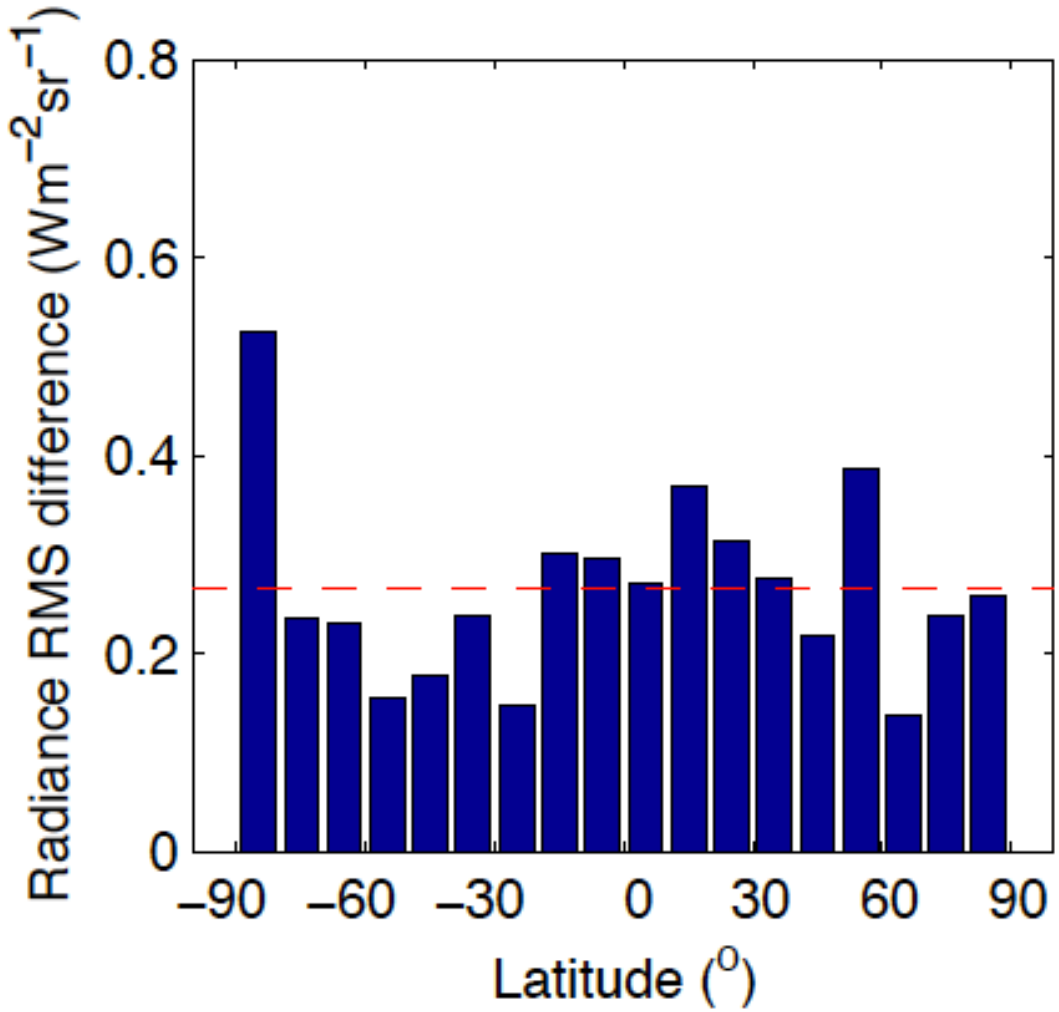
$$\sqrt{\frac{1}{n}\sum\left[I(\bar{x}) - \overline{I(x)}\right]^2}$$

Blue: 2007
Red: 2008

Interannual variability of the RMS is smaller than the modeled radiance difference

2008 – 2007 difference

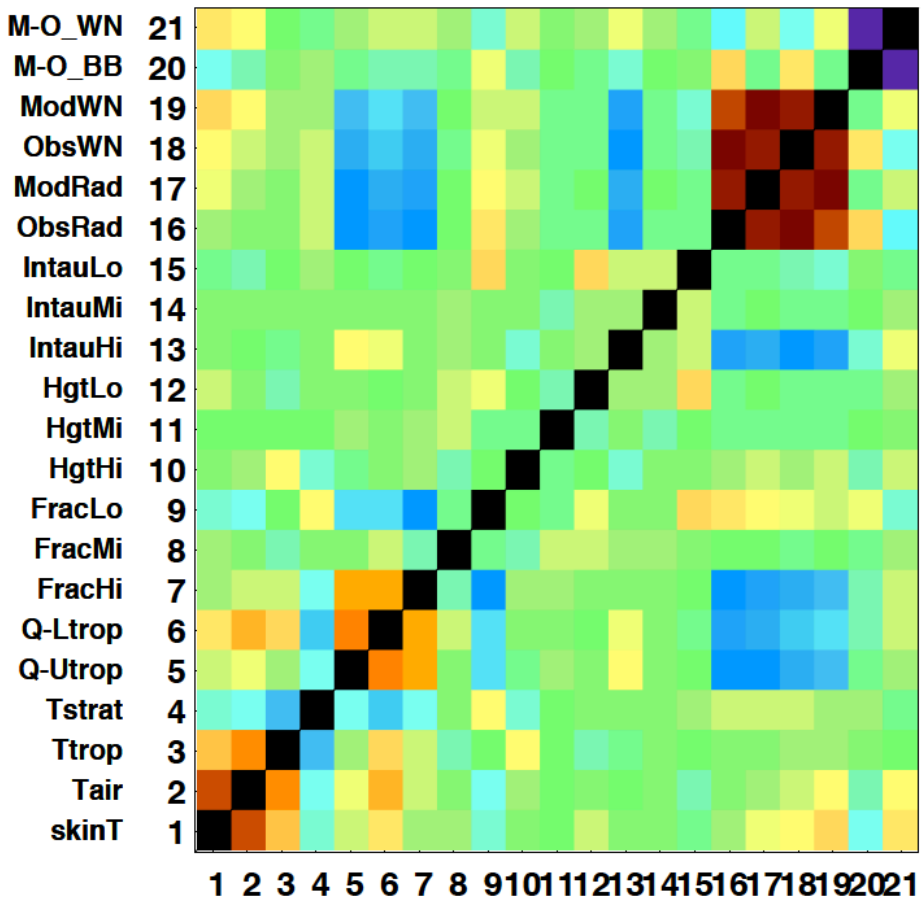
$$\sqrt{\frac{1}{n}\sum\left\{\left[I(\bar{x})-\overline{I(x)}\right]_{2008}-\left[I(\bar{x})-\overline{I(x)}\right]_{2007}\right\}^2}$$



Relatively smaller zonal broadband radiance difference

Correlation matrix

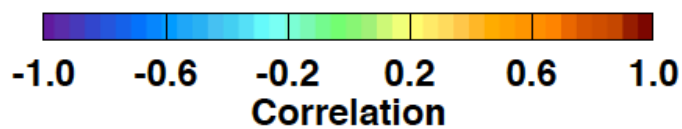
Latitude:-20°S to -10°
36 months average



- Correlation coefficients computed from inputs used for high resolution spectra computations for a month

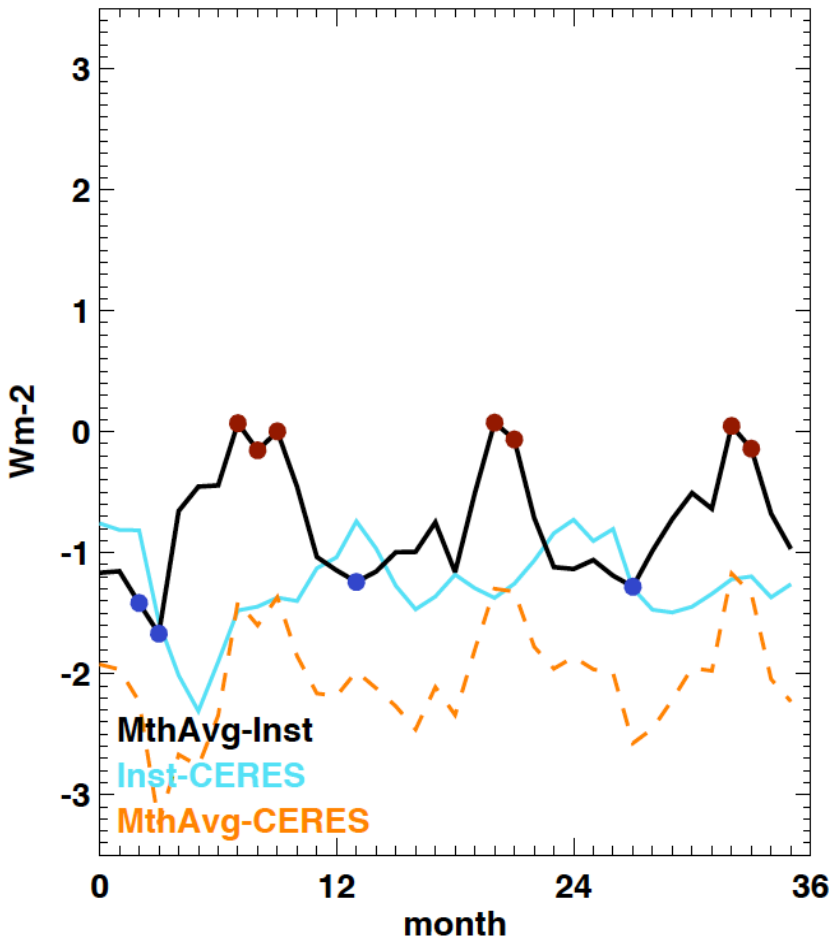
$$\left(\frac{x_{ij}-\bar{x}}{\sigma_i}\right)_i\left(\frac{x_{kj}-\bar{x}_k}{\sigma_k}\right)'$$

- Both spatial and temporal correlations are included

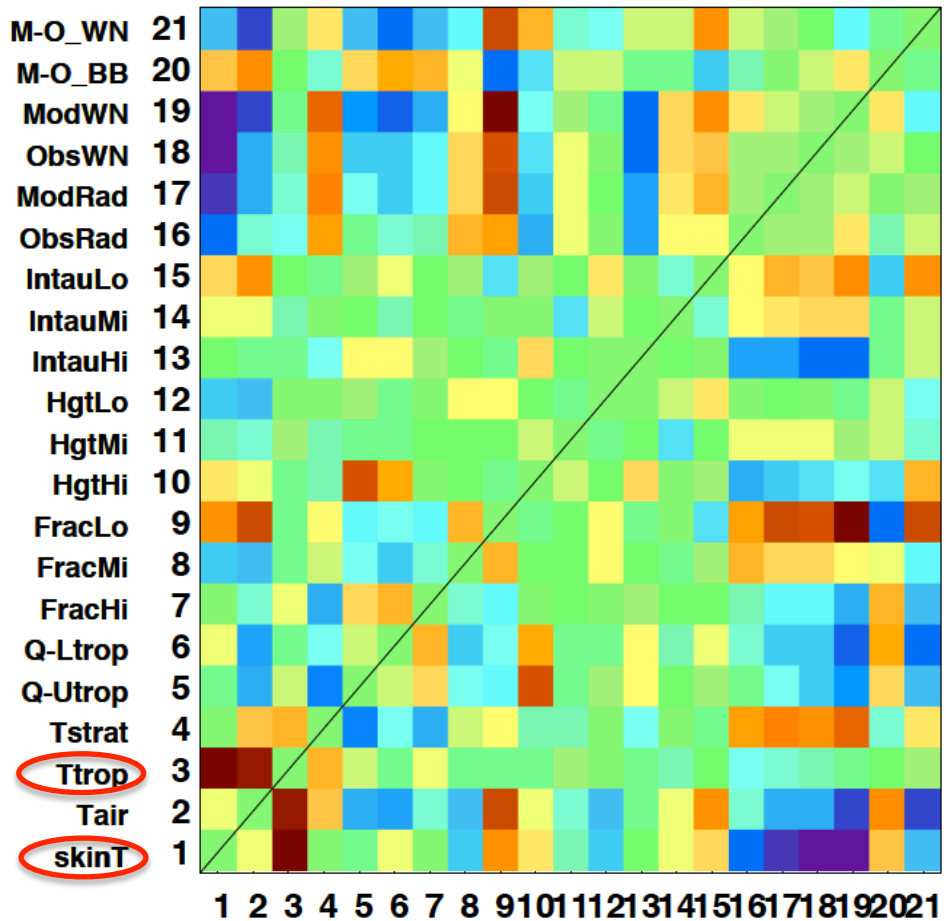


Correlation coefficient difference

Radiance difference
Latitude 20°S-10°S



Good agreement (red) – Bad agreement (blue)



Correlation coefficient difference

	1	2	3
Arctic	T_trop & T_strat (0.326)	T_trop & Tstrat (0.312)	T_trop & C_taulo (0.285)
NH Mid-latitude	T_skin & Q_Ltrop (0.584)	T_air & Q_Utrop (0.531)	T_air & Q_Ltrop (0.517)
Tropics	T_air & Q_Ltrop (0.403)	T_skin & T_trop (0.284)	T_skin & Q_Ltrop (0.266)
SH Mid-latitude	T_trop & T_strat (0.465)	T_air & T_strat (0.377)	T_skin & T_strat (0.372)
Antarctic	T_trop & T_strat (0.825)	T_strat & Q_Ltrop (0.596)	T_skin & T_strat (0.567)

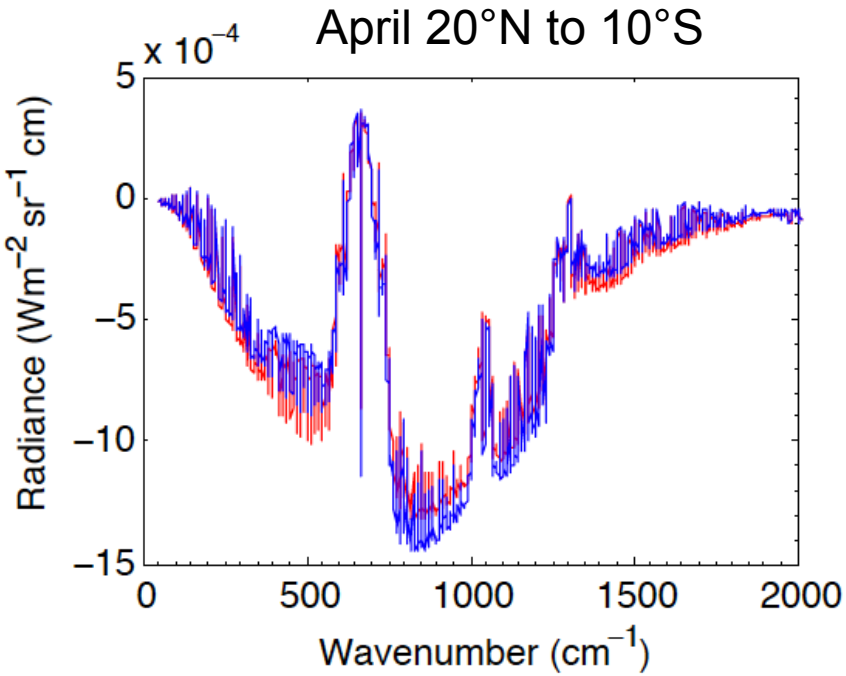
T_trop: Tropospheric temperature (Surface to 200 hPa)
T_strat: Stratospheric temperature (200 hPa to 10 hPa)
T_skin: Skin temperature
T_air: Surface air temperature
Q_Ltrop: Surface to 500 hPa water valopr
Q_Utrop: 500 hPa to 200 hPa water vapor
C_taulo: low-level cloud optical depth (log)

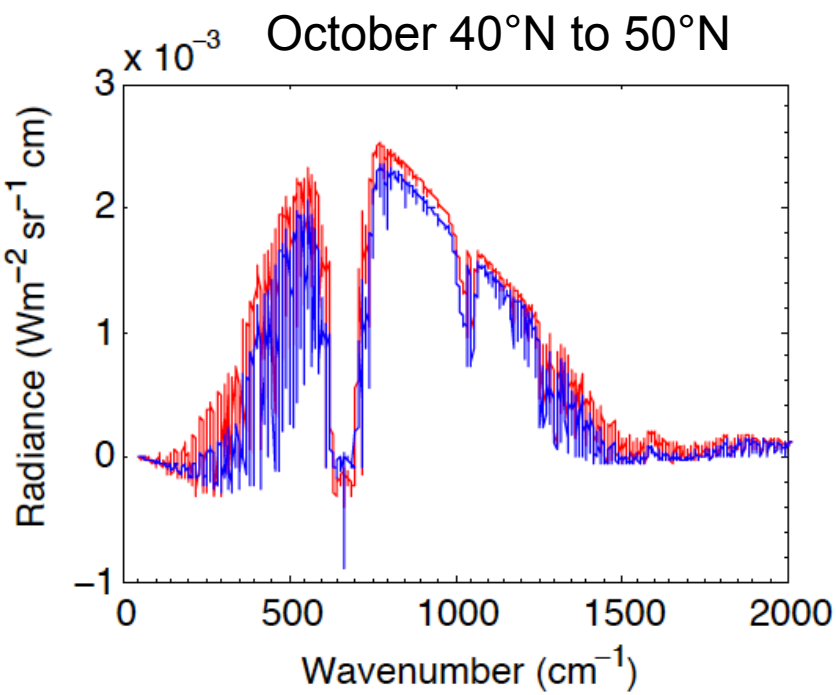
Summary and future work

- Small-scale correlations increase the difference of the 10° zonal monthly mean broadband radiance from two different years by 30 to 40%.
- Correlations among temperature and water vapor appear to be responsible for the increase but need more investigations.
- Future work
  - Quantify TOA spectral radiance contribution due to small-scale correlations
  - Spectral kernel modeling

Back-ups

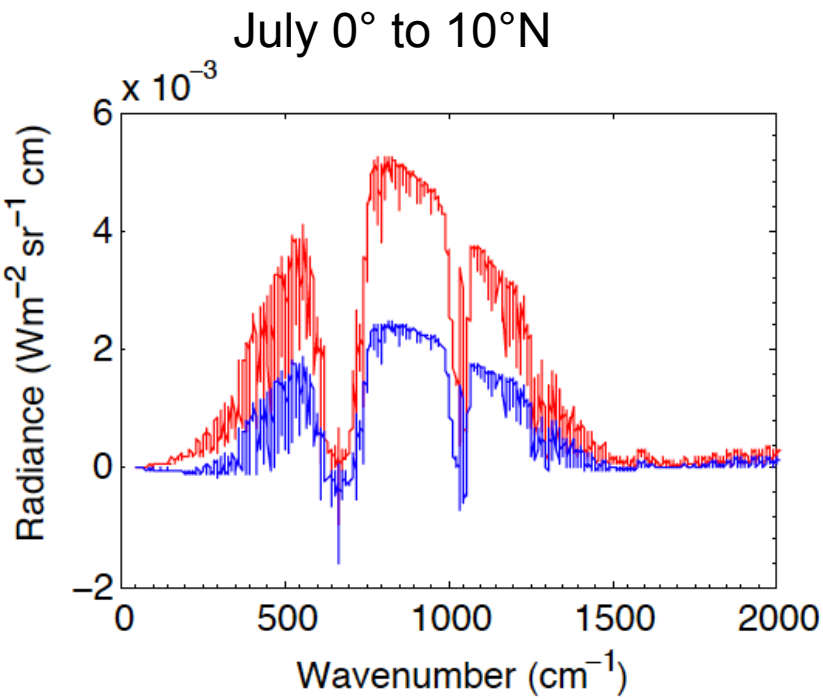
When broadband LW irradiance differences agree

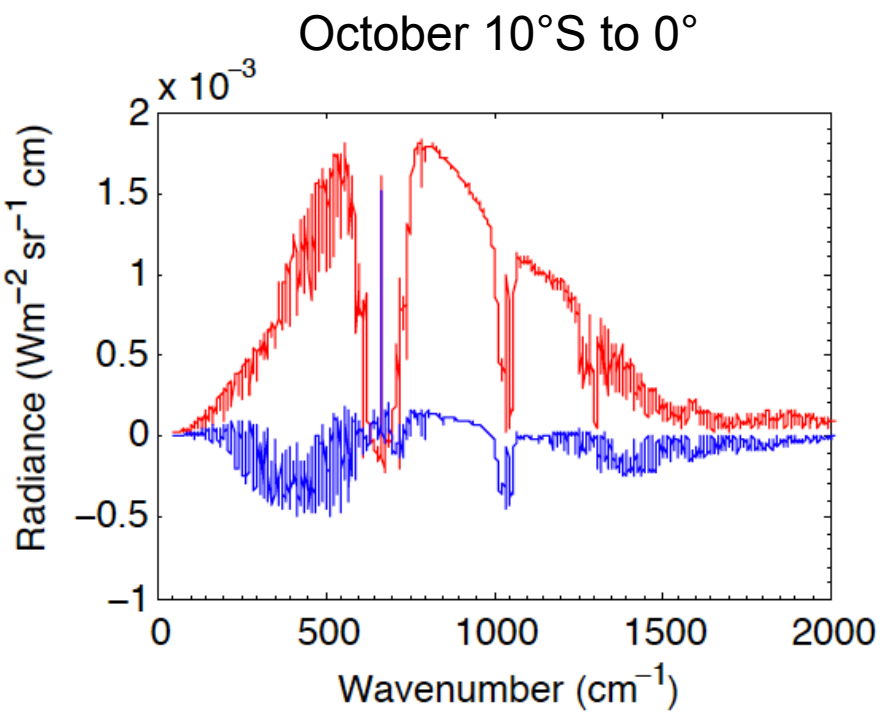




Red line: instantaneous computations
Blue line: monthly 1°×1° mean computations

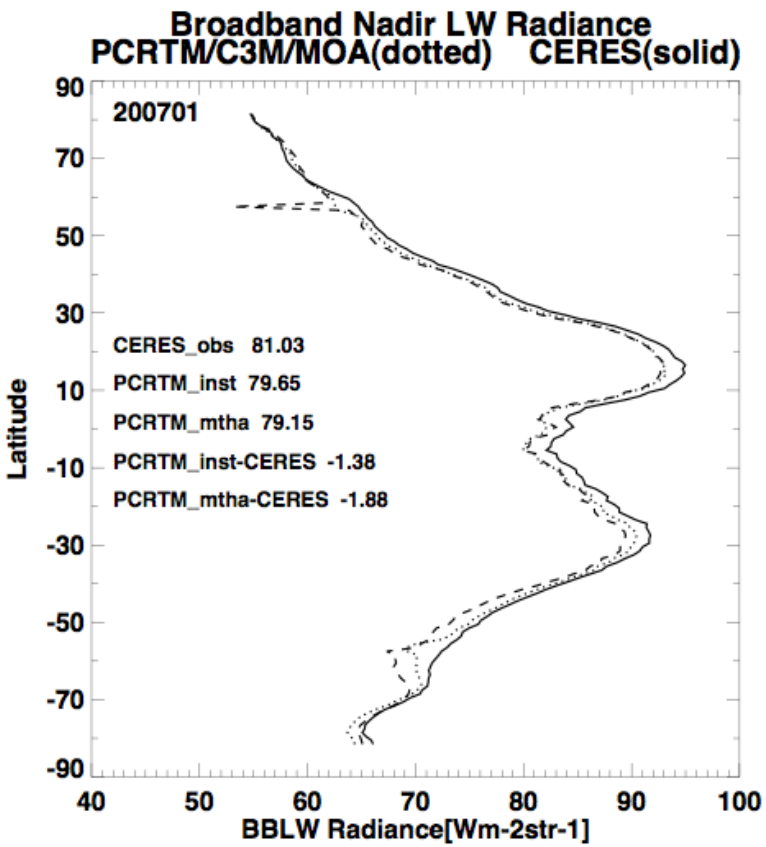
When broadband LW radiance differences disagree

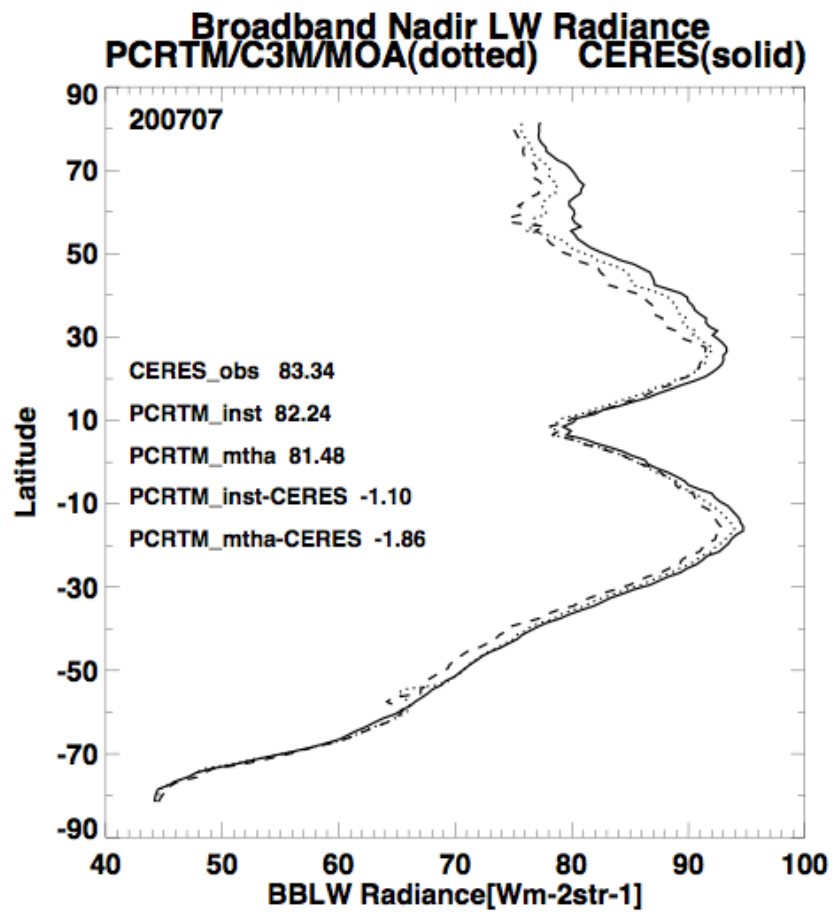




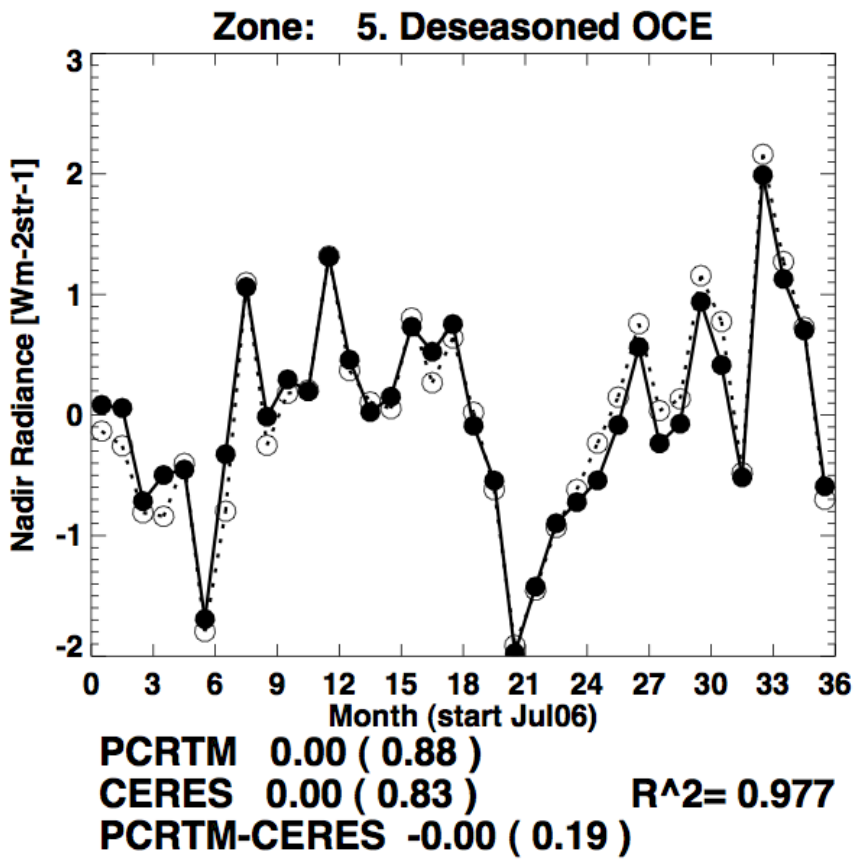
Red line: instantaneous computations
Blue line: monthly 1°×1° mean computations

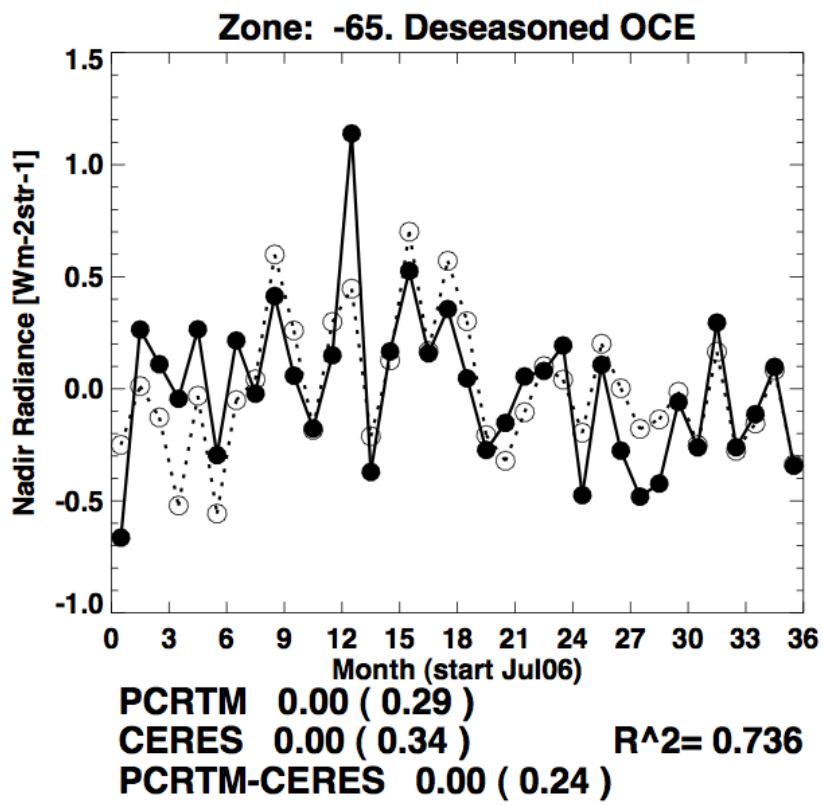
Zonal broadband



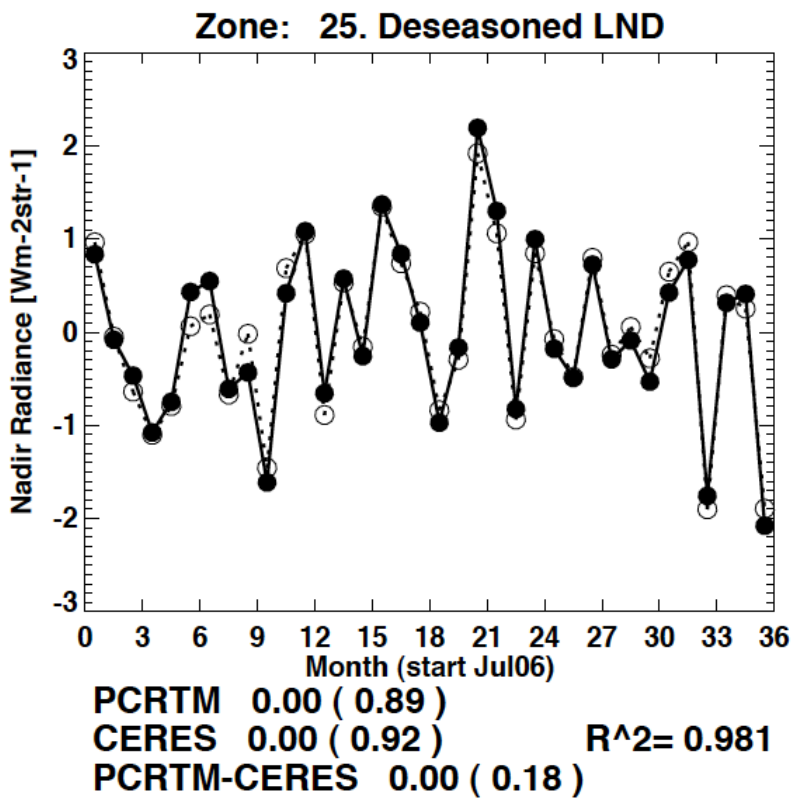


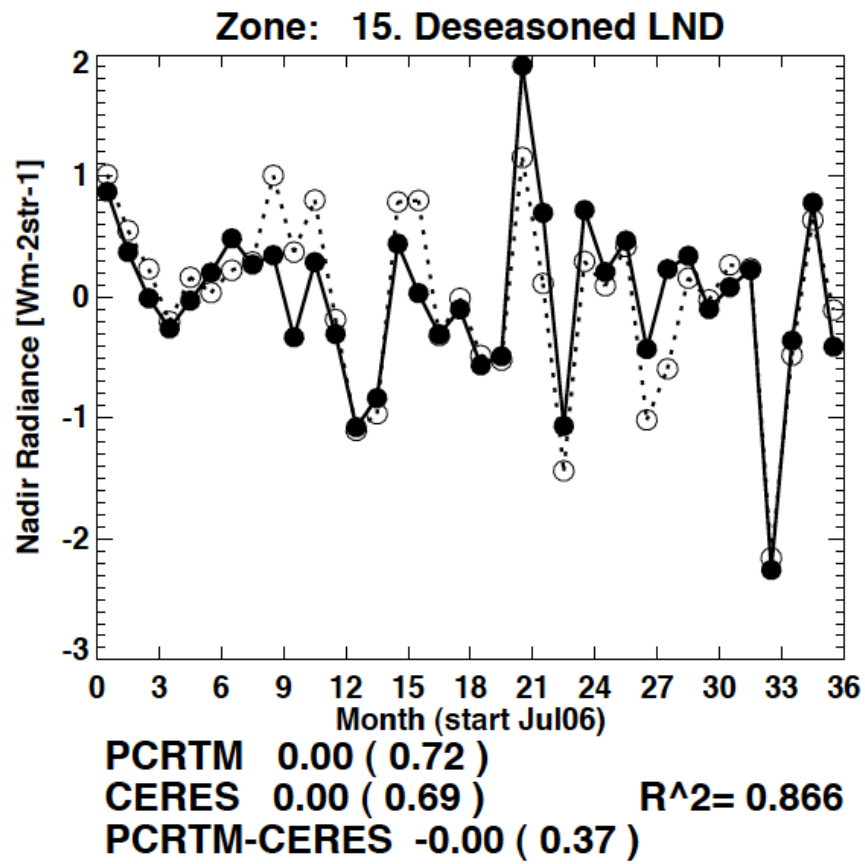
Anomalies over ocean



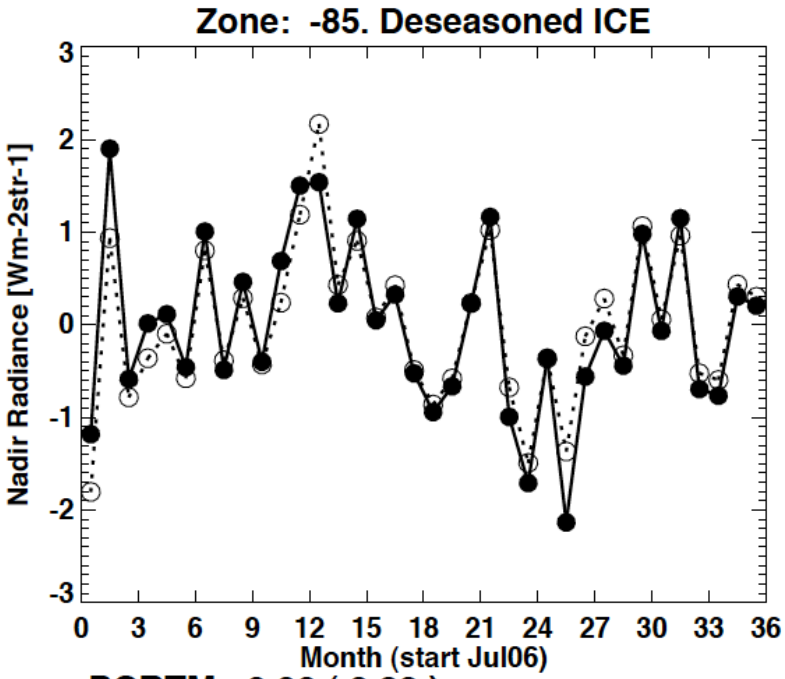


Anomalies over land

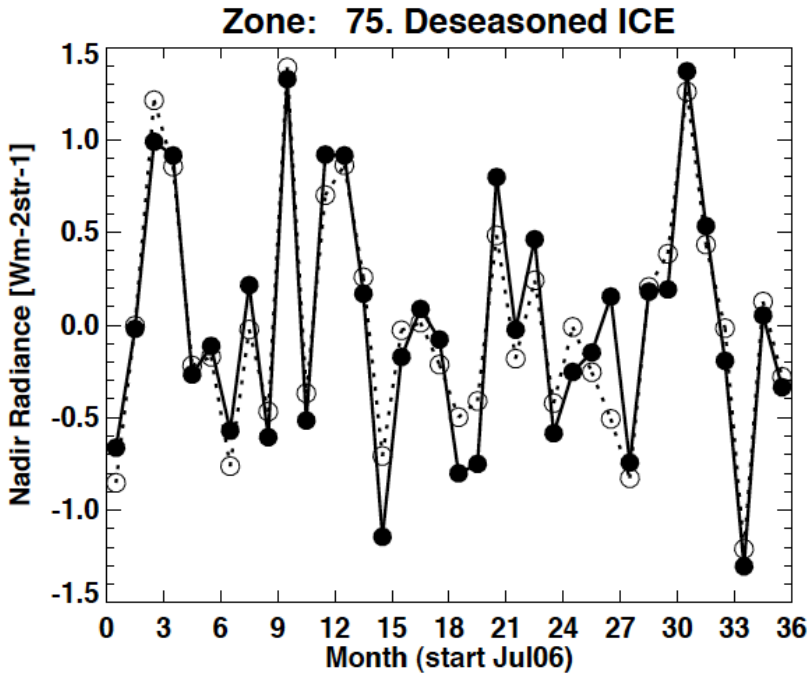




Anomalies over snow/ice



PCRTM 0.00 (0.83)
CERES -0.00 (0.92) R^2= 0.936
PCRTM-CERES -0.00 (0.32)



PCRTM -0.00 (0.61)
CERES 0.00 (0.66) R^2= 0.948
PCRTM-CERES -0.00 (0.21)

CERES LW anomalies

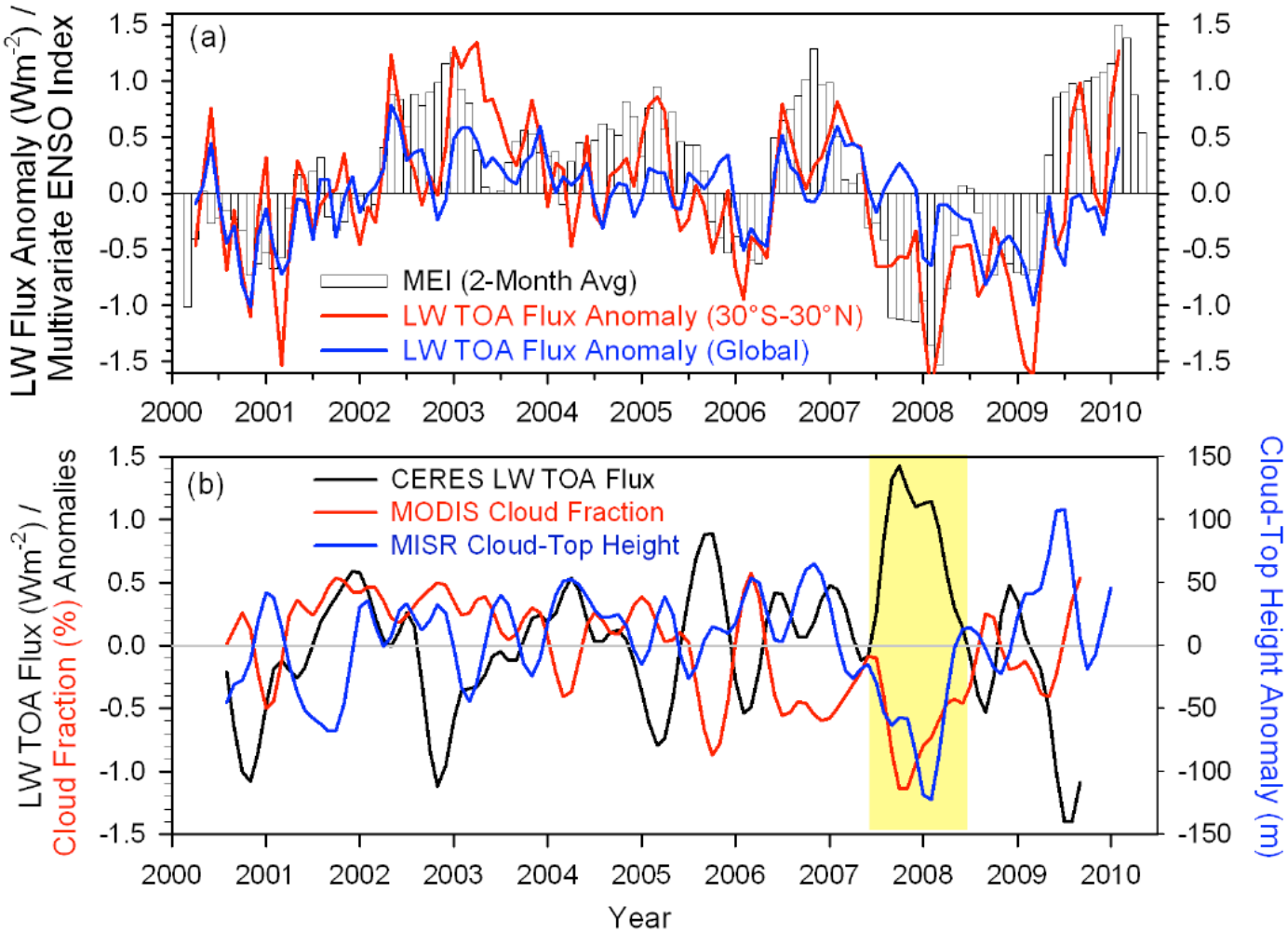
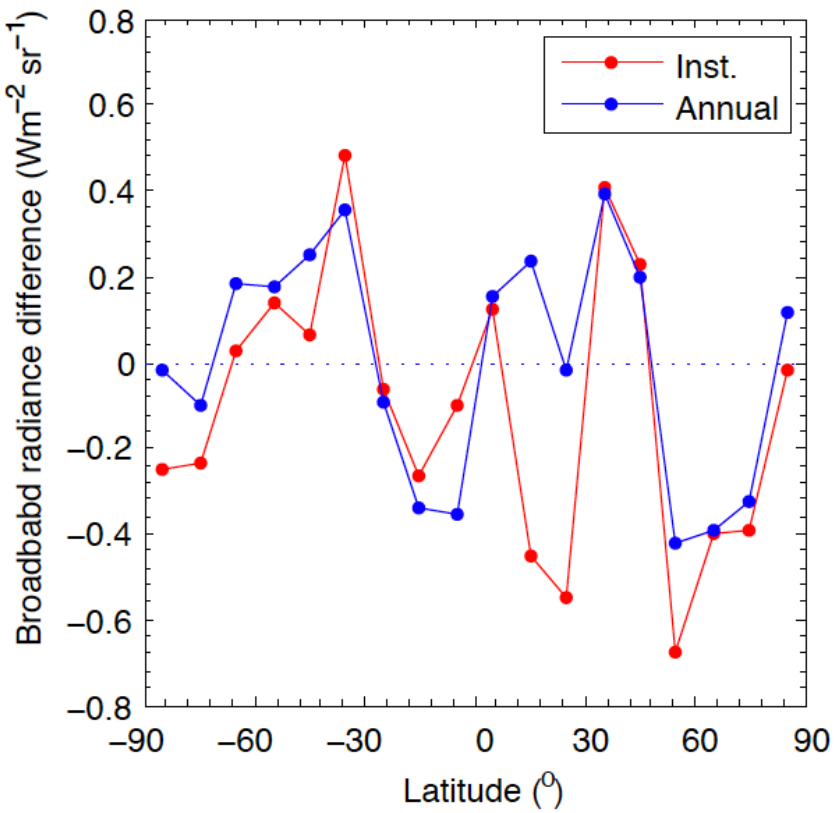
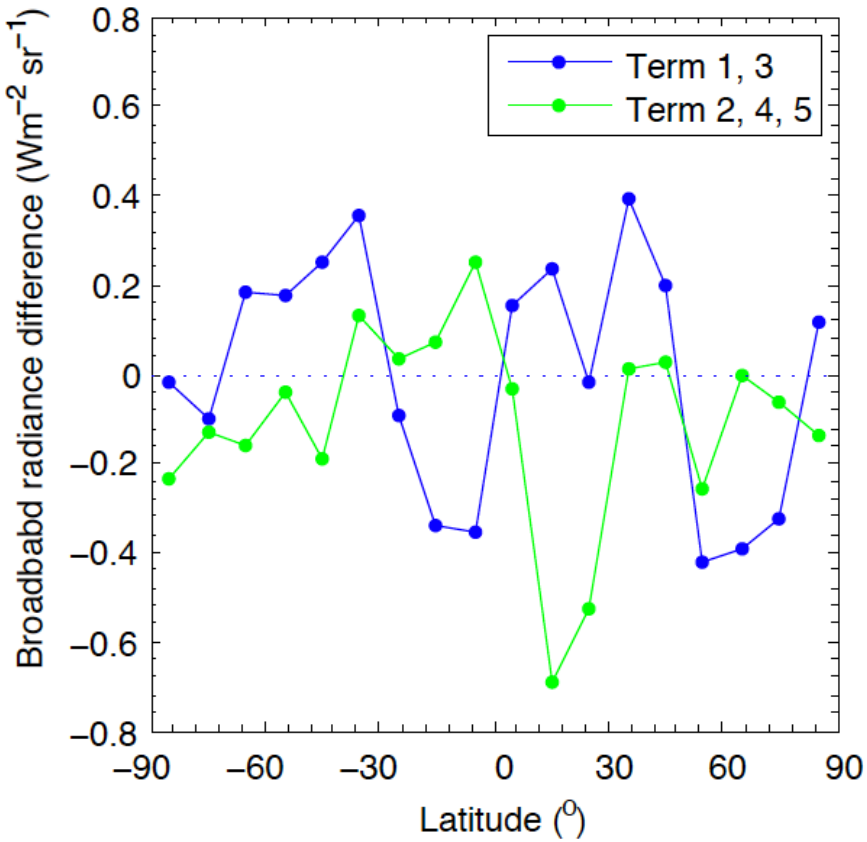


Figure 5 (a) Deseasonalized anomalies in tropical (30°S-30°N) and global CERES LW TOA flux together with the multivariate ENSO Index (MEI). A 2-month running average is used to determine the LW TOA flux anomalies. (b) Deseasonalized anomalies in midlatitude (30°S-60°S and 30°N-60°N) mean CERES LW TOA flux, MODIS cloud fraction, and MISR cloud-top height. An 11-point 6-month low-pass Lanczos filter is applied to the monthly anomalies.

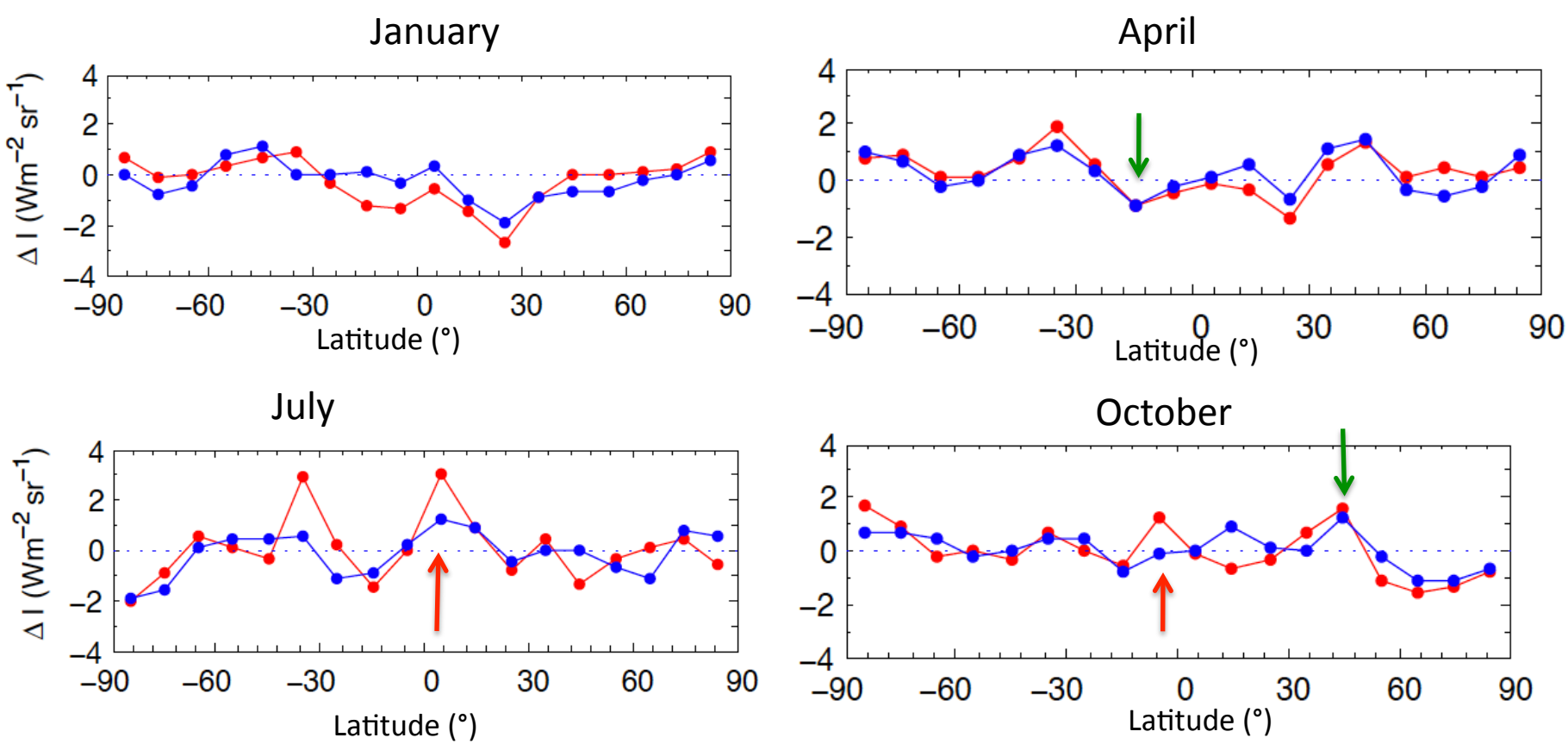
Loeb et al. 2011

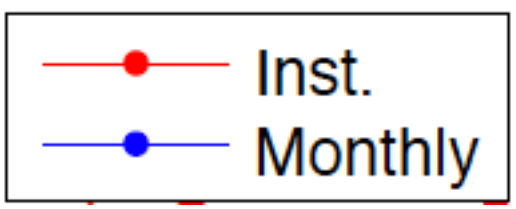
Annual zonal broadband radiance difference





Modeled broadband monthly mean differences (2004 – 2003)





Monthly: Spectral radiances are modeled using monthly mean gridded atmospheric and cloud properties (nadir view sampled grid box only)