CERES Science Team Meeting Fall 09

The Band-By-Band Longwave Cloud Radiative Forcing: Model vs. Observation

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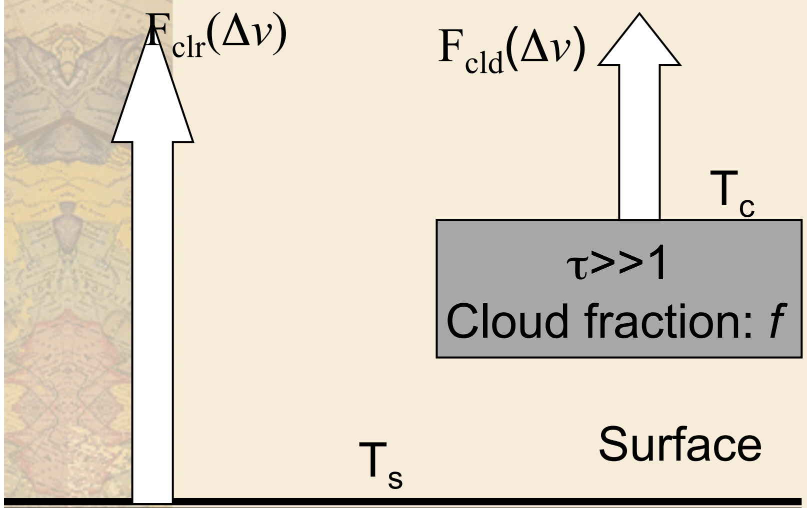
Roadmap

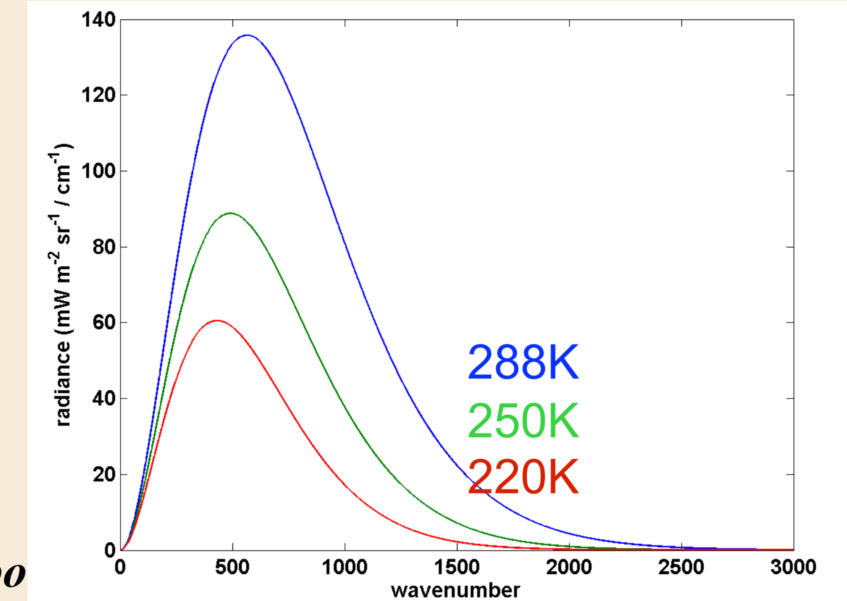
- Motivation: why go band-by-band CRF
  - Toy models
- Datasets and modeling tools
- Derived spectral flux: comparing with collocated CERES OLR
- Band-by-band CRF
  - Annual mean: Obs vs. the GFDL AM2
  - Interannual variability from the GFDL AM2

Take-home message

Why go band-by-band: Toy model A

1. Blackbody cloud
2. Ignore atmospheric absorption





$$CRF_{LW} = f\left[\sigma T_s^{\ 4} - \sigma T_c^{\ 4}\right]$$

CRF_{LW} sensitive to bo

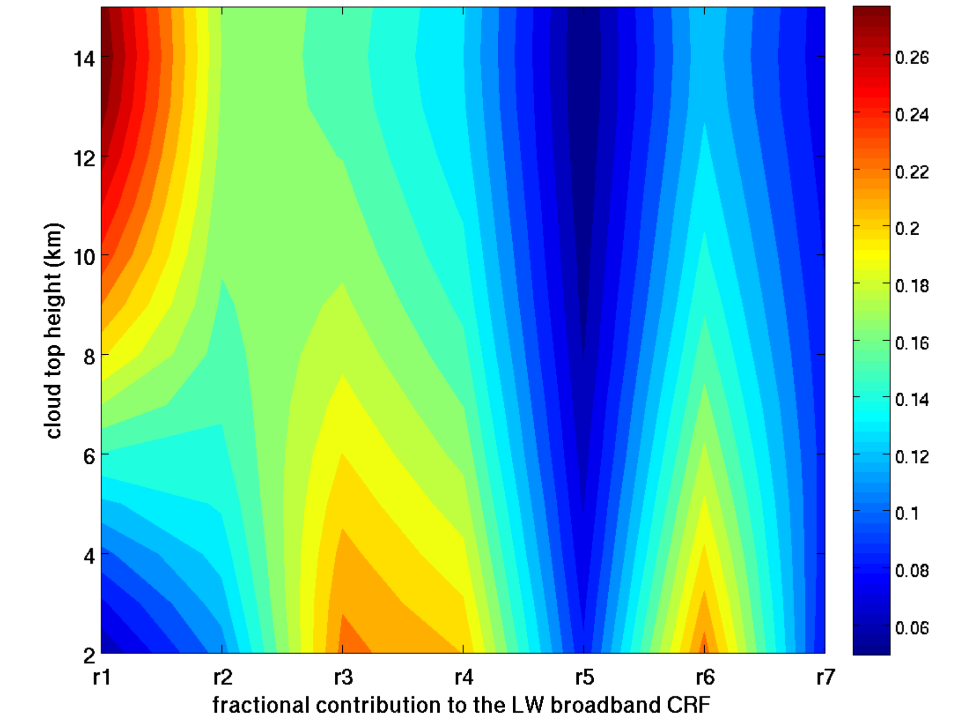
$$CRF(\Delta v) = f[F_{clr}(\Delta v) - F_{cld}(\Delta v)]$$

Fractional contribution

$$\mathrm{r}(\Delta v) = \frac{CRF(\Delta v)}{CRF_{LW}} = \frac{F_{clr}(\Delta v) - F_{cld}(\Delta v)}{\left[\sigma T_s^{\ 4} - \sigma T_c^{\ 4}\right]}$$

r(Δv) sensitive to T_c but not f

Toy model B



- Typical tropical sounding profiles of T, q, O_3, etc ("*McClatchey*" profiles)
- Realistic one-layer cloud (τ>>1) with top varying from 2km to 15km
- 7 bands as used in the GFDL model

Band1: 0-560 and 1400-2500 cm^{-1} (H_2O)

Band2: 560-800 cm^{-1} (CO_2, N_2O) Band5: 990-1070cm^{-1} (O_3)

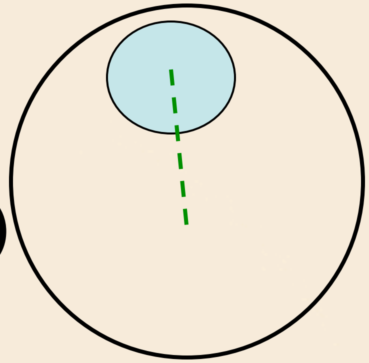
Band3: 800-900 cm^{-1} (WN) Band6: 1070-1200cm^{-1} (WN)

Band4: 900-990 cm^{-1} (WN) Band7: 1200-1400cm^{-1} (N2O, CH_4)

In addition:

- Compensating biases for simulated broadband CRF and fluxes
- Band-by-band quantities are directly computed by each GCM

Datasets

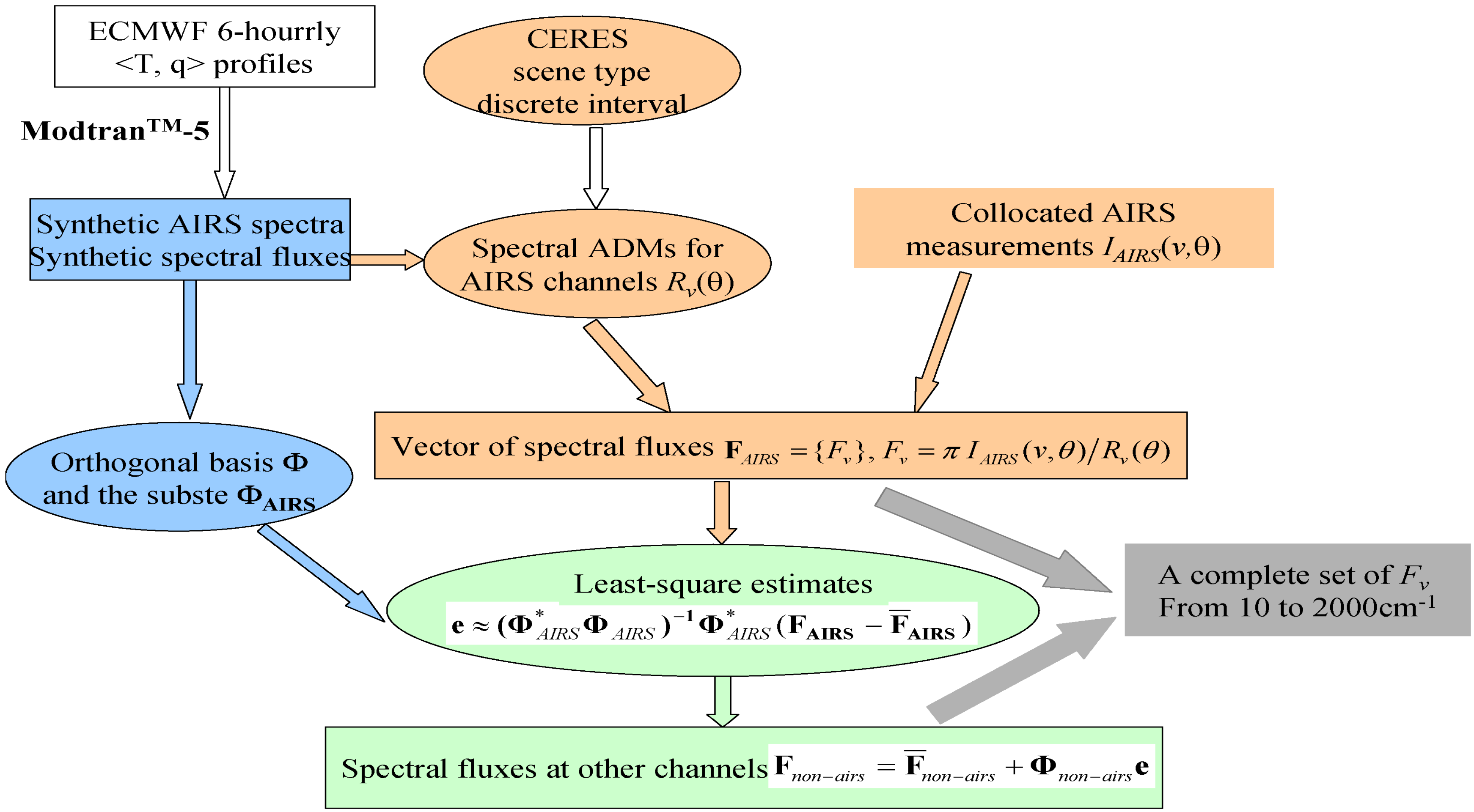


- CERES SSF data product (edition 2A)
  - Cross-scanning mode only
- AIRS
  - 3.74-4.61μm (2169-2673 cm^{-1}) excluded
  - Quality control: filtering out bad channels
- Collocation criteria strategy
  - Time separation ≤ 8 seconds
  - Spatial separation ≤ 3km
- Measurements over the tropical oceans in 2004

Modeling tools

- Modtran^{TM}-5 for forward modeling of radiative transfer
  - Compute spectra at 0.1cm^{-1} resolution
  - Good agreement with LBLRTM
  - AIRS SRF→ synthetic AIRS spectra
- GFDL AM2 (am2p14)
  - 1979-2006 run forced with observed SST and appropriate greenhouse gases (ozone fixed at 1990s)
  - 3-hourly output in 2004
    - further sampled to satellite tracks
  - All band-by-band quantities archived

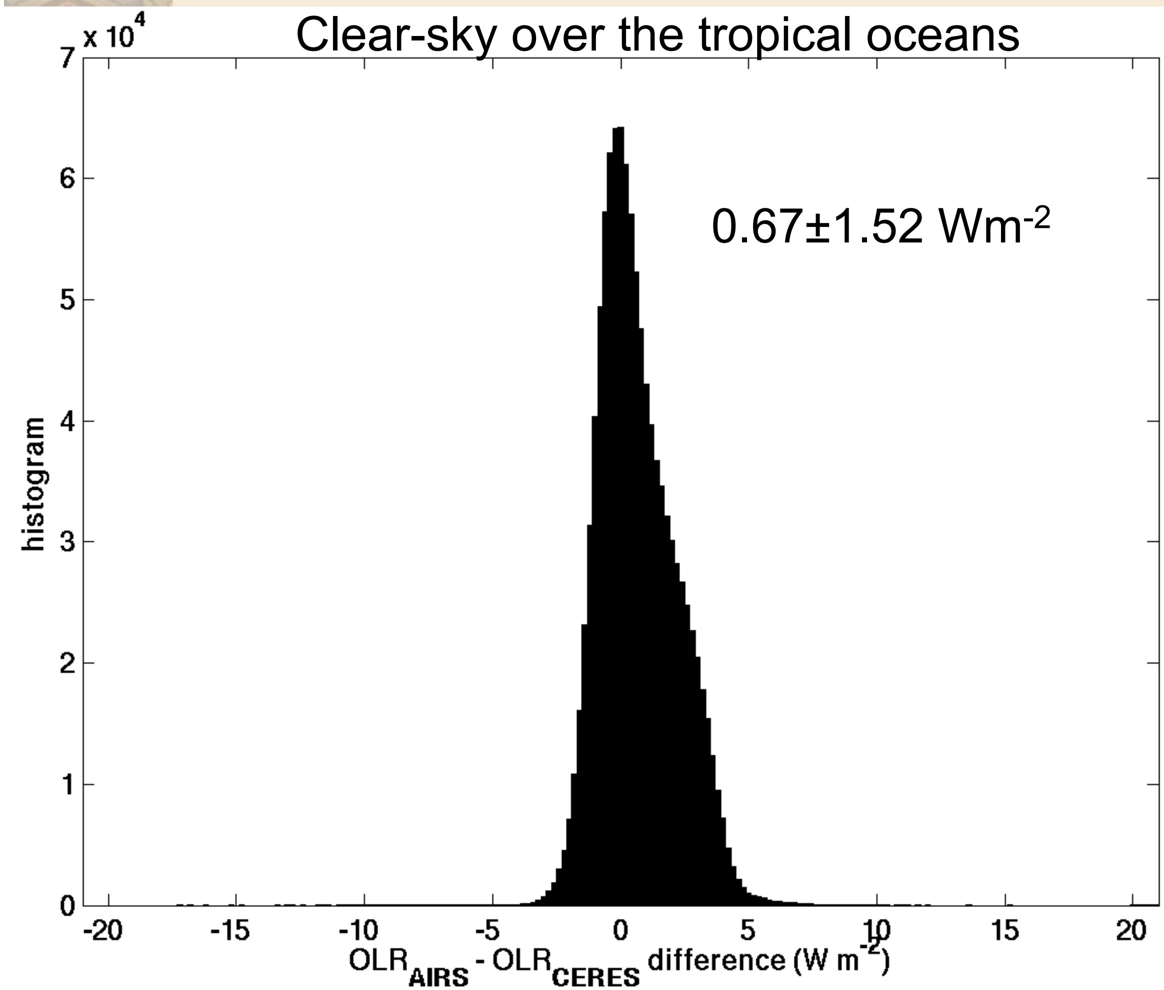
Flowchart for the entire algorithm



Output: spectral flux at 10cm^{-1} intervals through the entire longwave spectral range

OLR_{AIRS}: OLR estimated from AIRS spectra

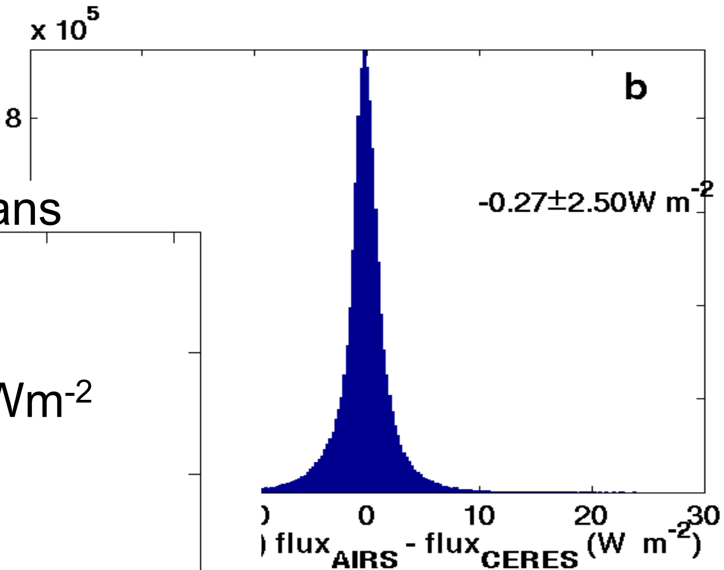
OLR_{CERES}: OLR from collocated CERES observation



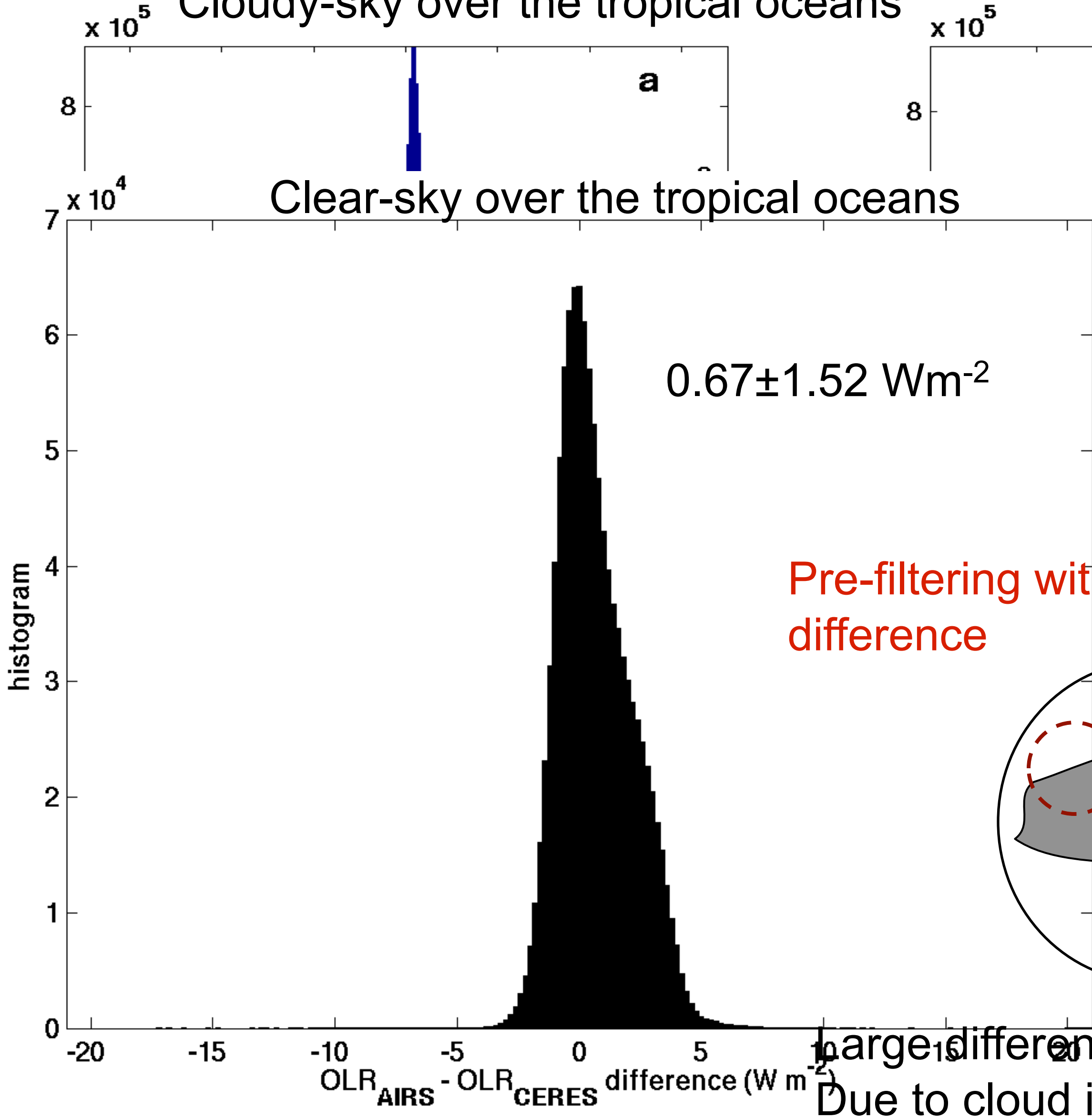
OLR_{AIRS}: OLR estimated from AIRS spectra

OLR_{CERES}: OLR from collocated CERES observation

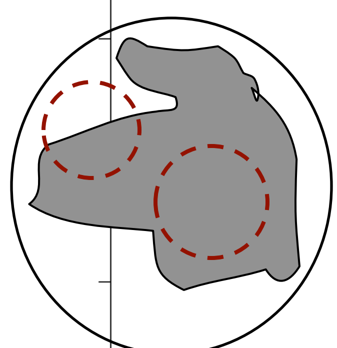
Cloudy-sky over the tropical oceans



Clear-sky over the tropical oceans



Pre-filtering with 2σ window-flux difference

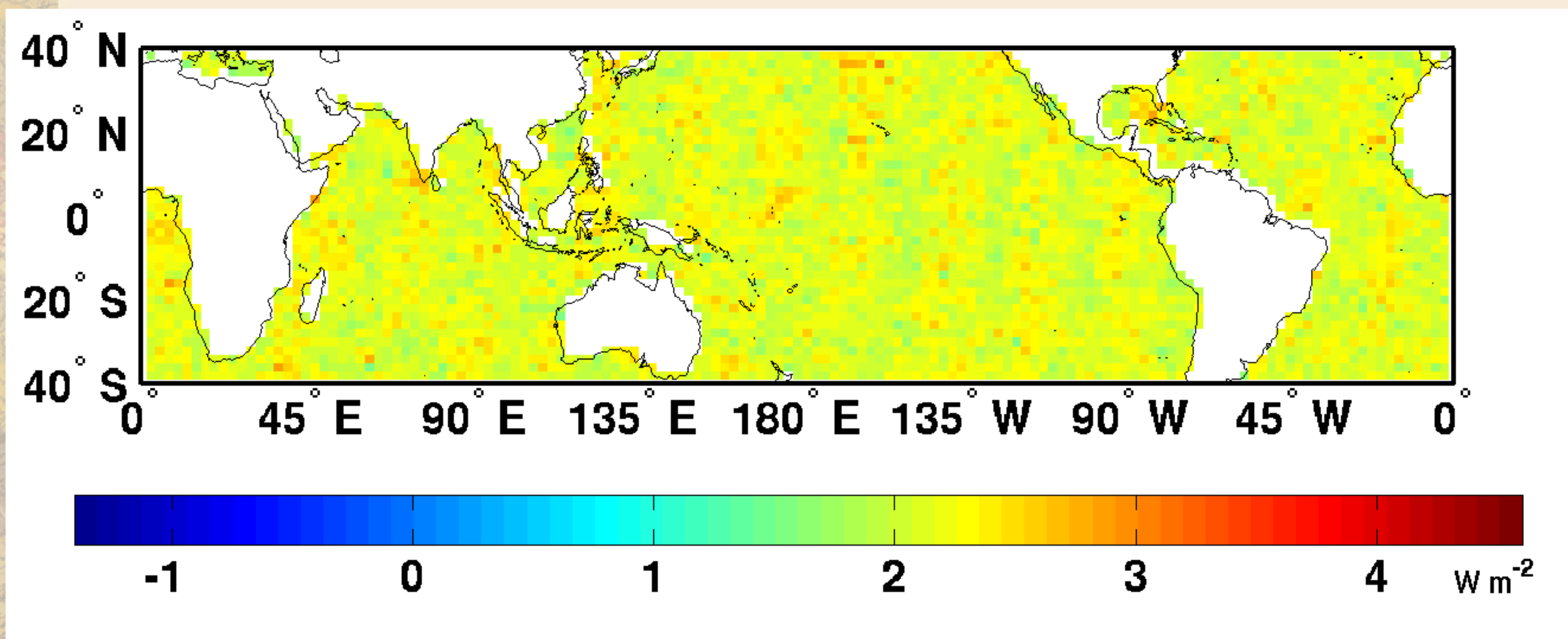


Large difference (>20Wm^{-2}) likely Due to cloud inhomogeneity

OLR_{AIRS}-OLR_{CERES}

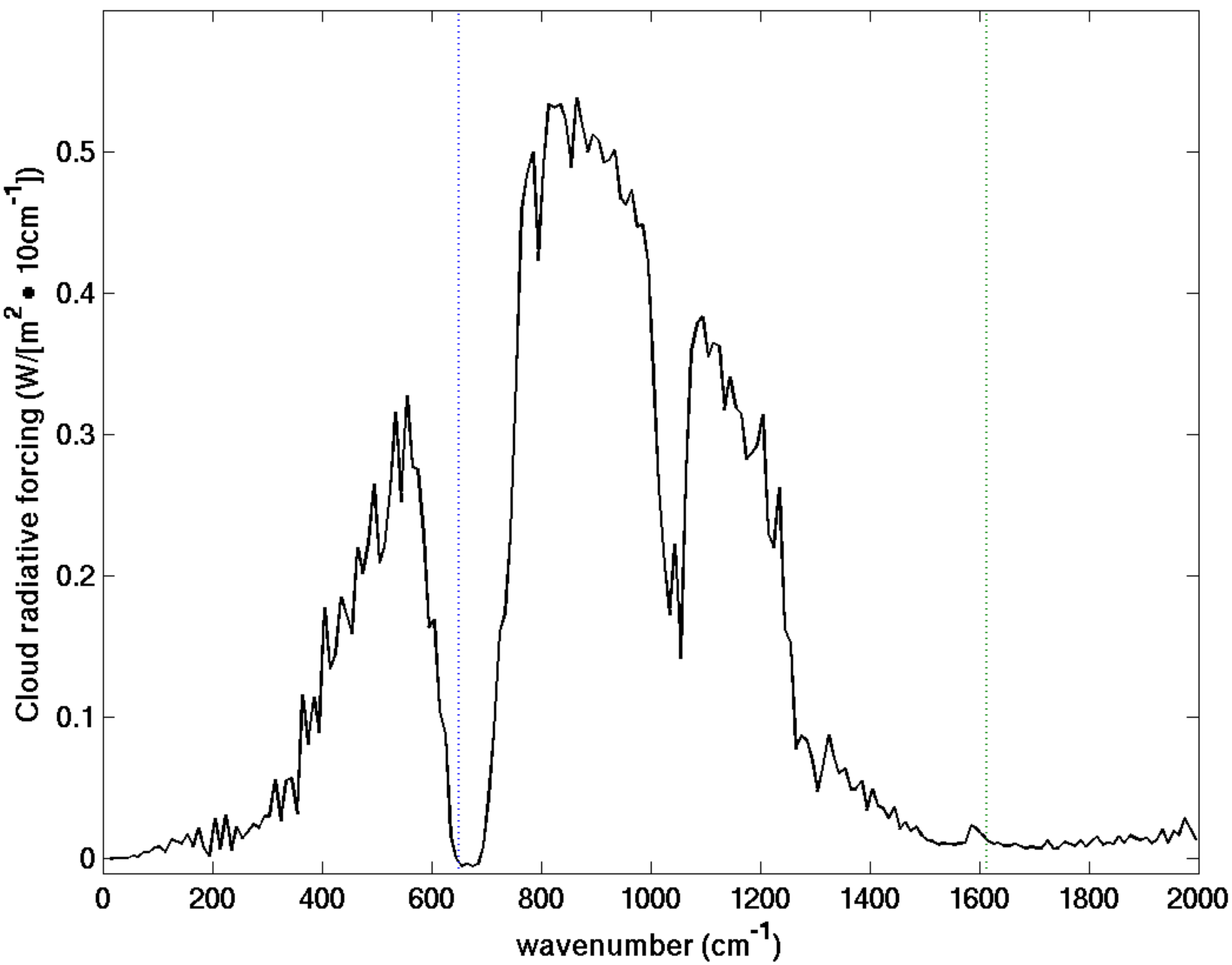
f ΔT_{sc}	<15K	15K-40K	>40K
0.001-0.5	2.63±4.12 (1.90±4.91)	2.30±4.06 (2.14±5.40)	2.21±4.03 (2.10±5.51)
0.5-0.75	2.29±4.03 (2.14±5.47)	2.27±4.03 (2.12±5.40)	2.28±4.04 (2.13±5.50)
0.75-0.999	2.31±4.08 (2.10±5.48)	2.29±4.08 (2.09±5.45)	2.26±4.04 (2.08±5.41)
0.999-1.0	2.30±4.06 (2.11±5.52)	2.29±4.06 (2.12±5.49)	2.28±4.06 (2.14±5.49)

OLR_{AIRS}-OLR_{CERES}
(cloudy-sky, averaged onto 2.5°×2°)



Annual-mean Spectral CRF over tropical ocean in 2004

(Note: 1:30am/pm mean, no temporal interpolation)



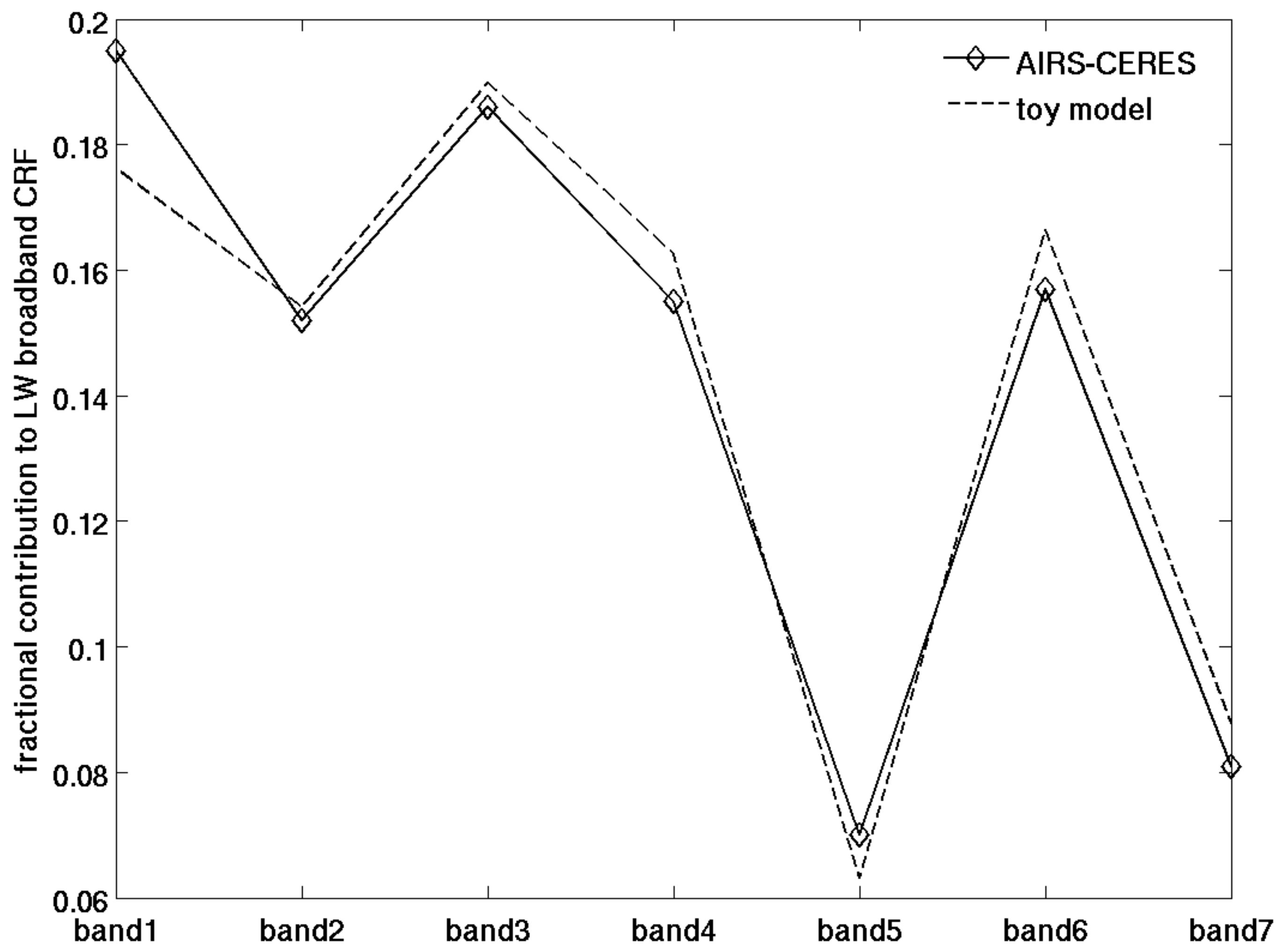
Annual-mean CRF: obs. Vs. model

	AIRS-CERES observed CRF (in Wm^{-2})	AM2 simulated CRF (in Wm^{-2})	AM2 clear-sky flux (in Wm^{-2})
LW broadband	27.45 (100%)	28.13 (100%)	290.88(100%)
0-560cm^{-1}; >1400cm^{-1}	5.36 (19.5%)	5.33 (19.0%)	112.98 (38.8%)
560-800cm^{-1}	4.18 (15.2%)	3.74 (13.3%)	57.52 (19.8%)
800-900cm^{-1}	5.11 (18.6%)	5.32 (18.9%)	35.39 (12.2%)
900-990cm^{-1}	4.24 (15.5%)	4.71 (16.7%)	28.07 (9.7%)
990-1070cm^{-1}	2.02 (7.0%)	1.68 (6.0%)	12.92 (4.4%)
1070-1200cm^{-1}	4.31 (15.7%)	5.33 (18.9%)	28.59 (9.8%)
1200-1400cm^{-1}	2.22 (8.1%)	2.01 (7.2%)	15.43 (5.3%)

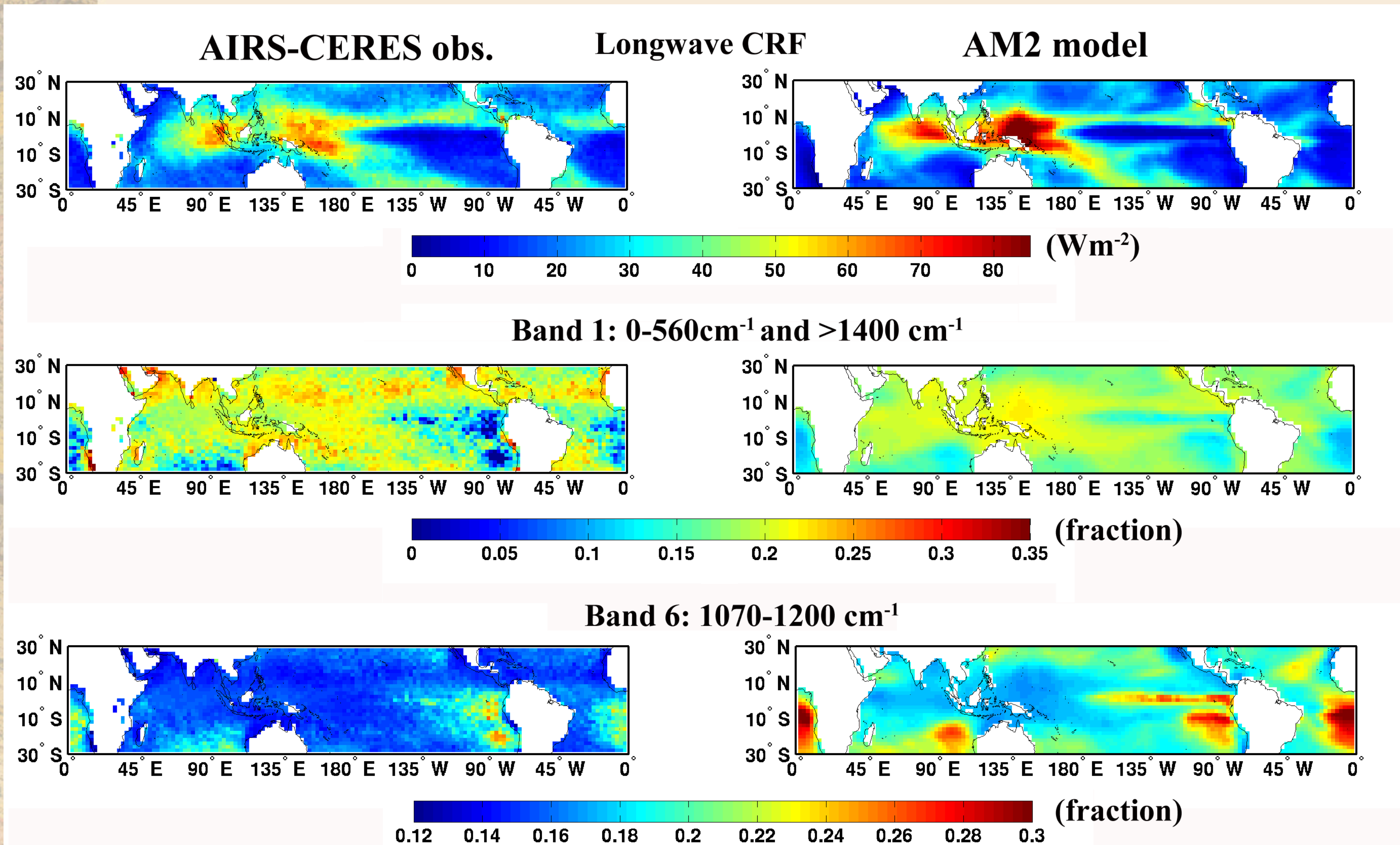
- A fit using Toy Model B

Best fit: cloud top height at 9.3km, cloud fraction 23%

f=CRF/CRF(overcast)



Annual-mean CRF map



Inter-annual anomaly: AM2

- Monthly-mean band-by-band CRF and flux
- De-trended, mean seasonal cycle removed
- 13-month running mean
- Principal component (a.k.a. EOF) analysis
  - Note: statistical pattern not necessarily linked to unique physical pattern

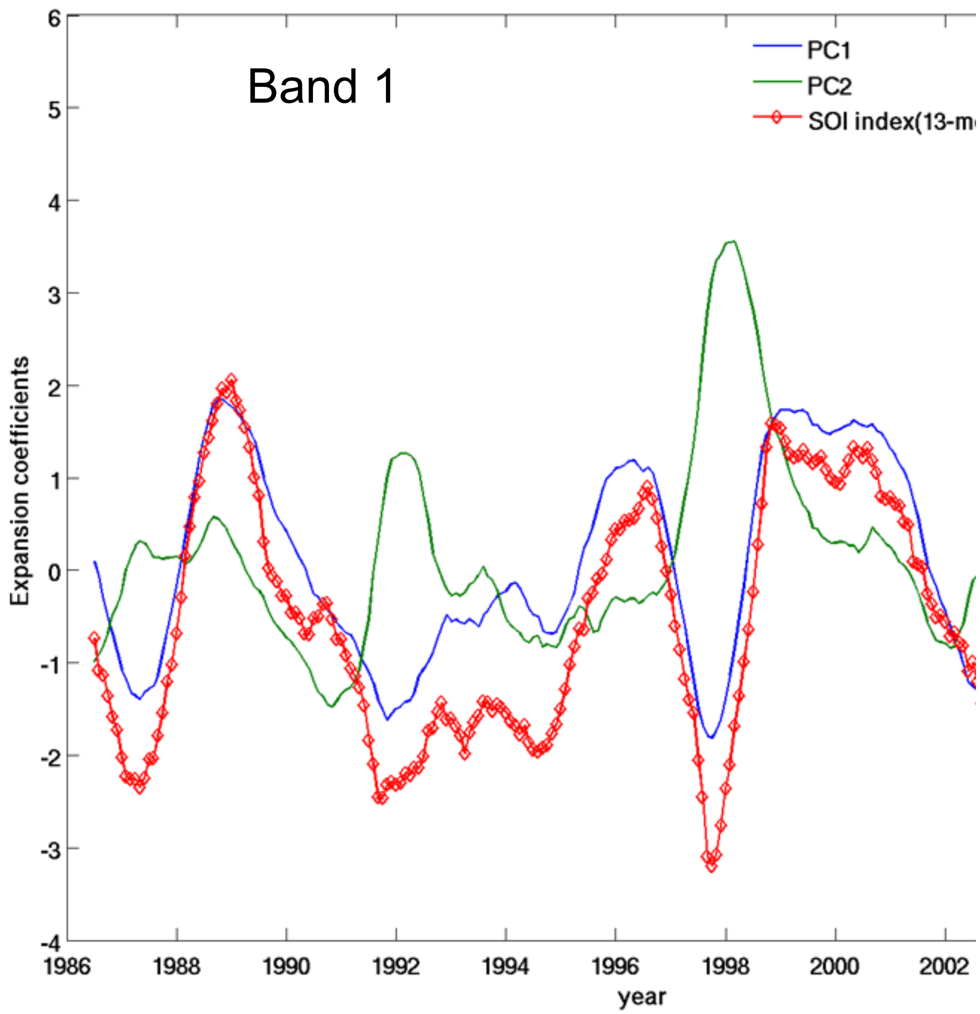
$$CRF(x,y;t) = \sum_{i=1}^{N} e_i(t)\Phi_i(x,y)$$

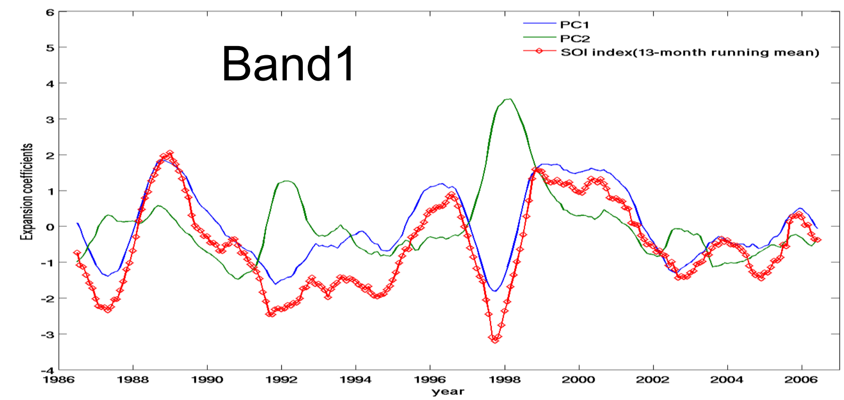
$$<\Phi_i,\Phi_j> = \sqrt{\lambda_i}\delta_{ij} \text{ (}\Phi\text{ has same dimension as CRF)}$$

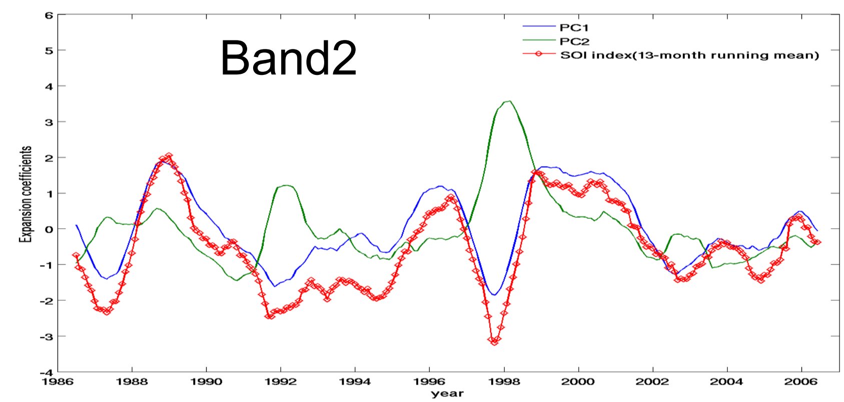
$$<e_i,e_j> = \delta_{ij} \quad \text{(std dev} = 1\text{)}$$

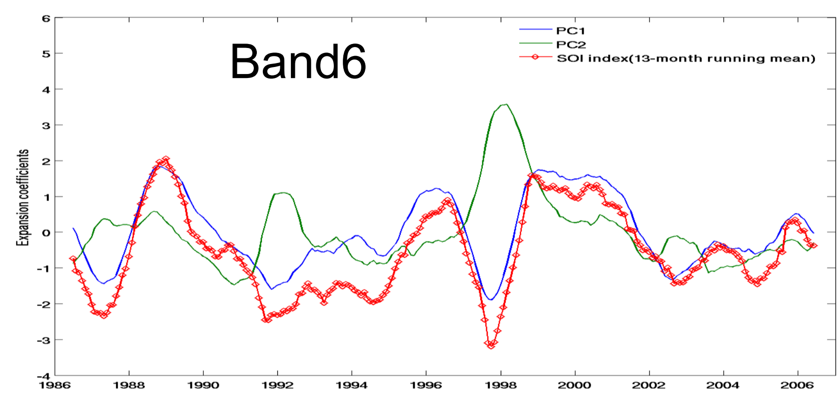
$$\text{Note } (\mathrm{e}_{\mathrm{i},}\Phi_i) \Leftrightarrow (\text{-}\mathrm{e}_{\mathrm{i}},-\Phi_i)$$

PCA of band CRF



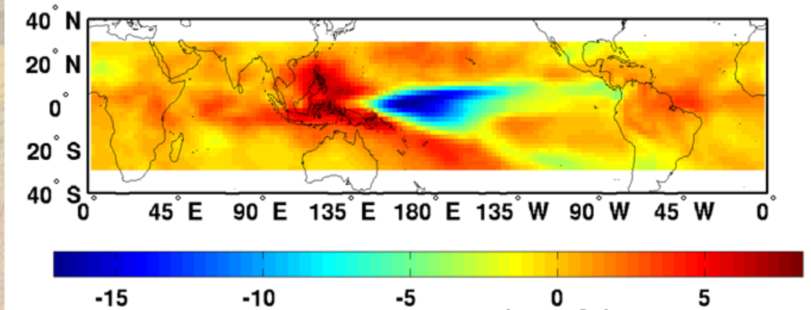




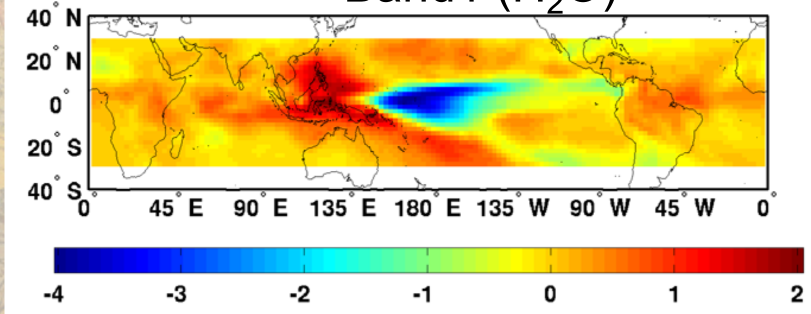


Maps of PC1 (~40% variance)

LW



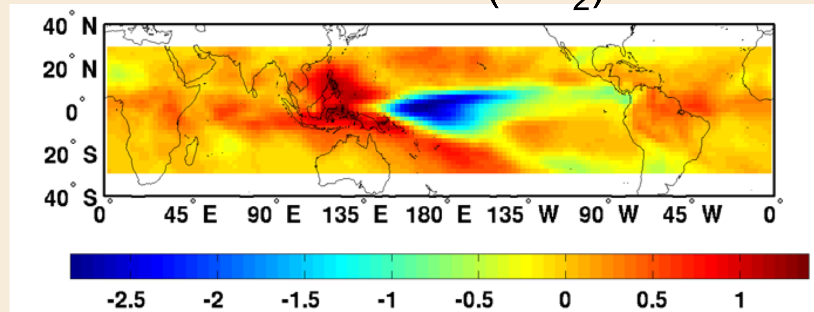
Band1 (H_2O)



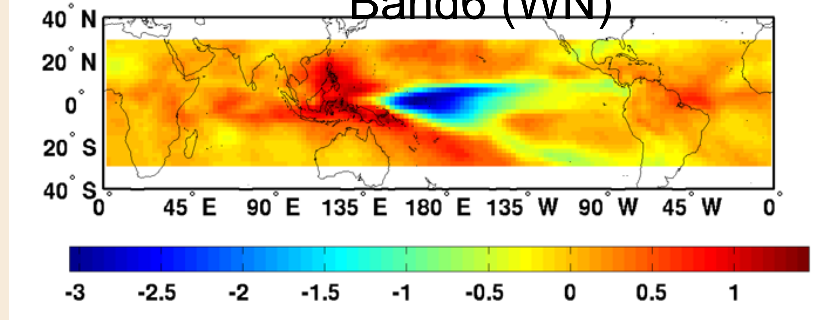
(Wm^{-2})

(Wm^{-2})

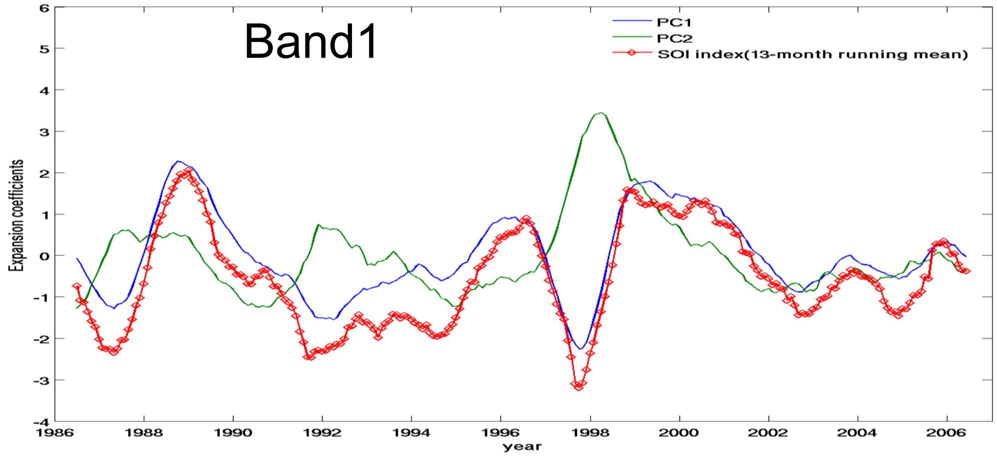
Band2 (CO_2)

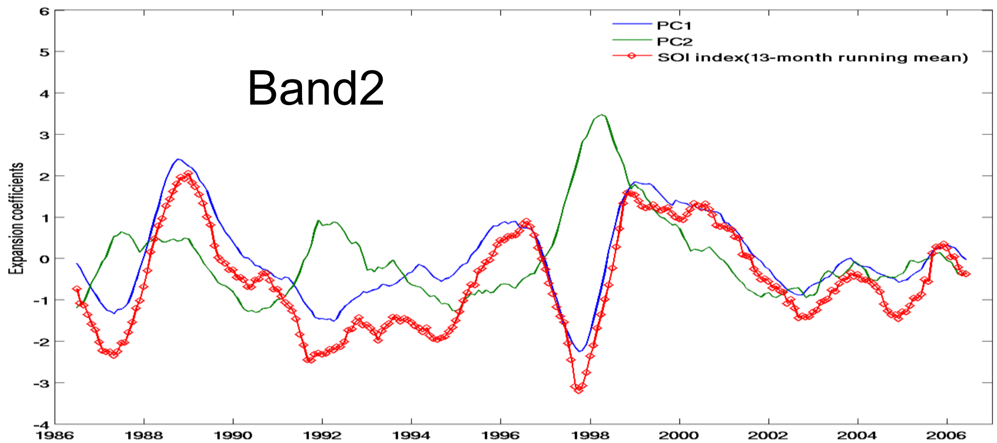


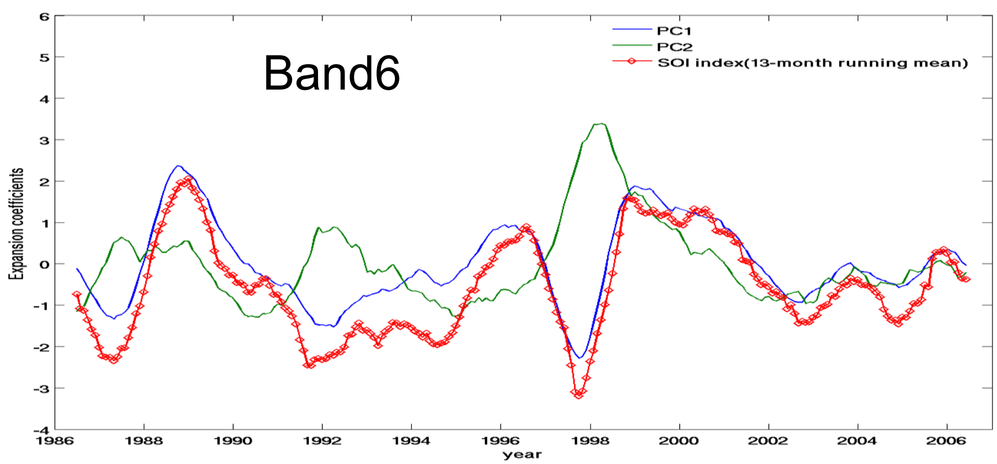
Band6 (WN)



- El Nino year
  - Expansion coefficient <0,
  - Absolute ΔCRF >0 for all bands



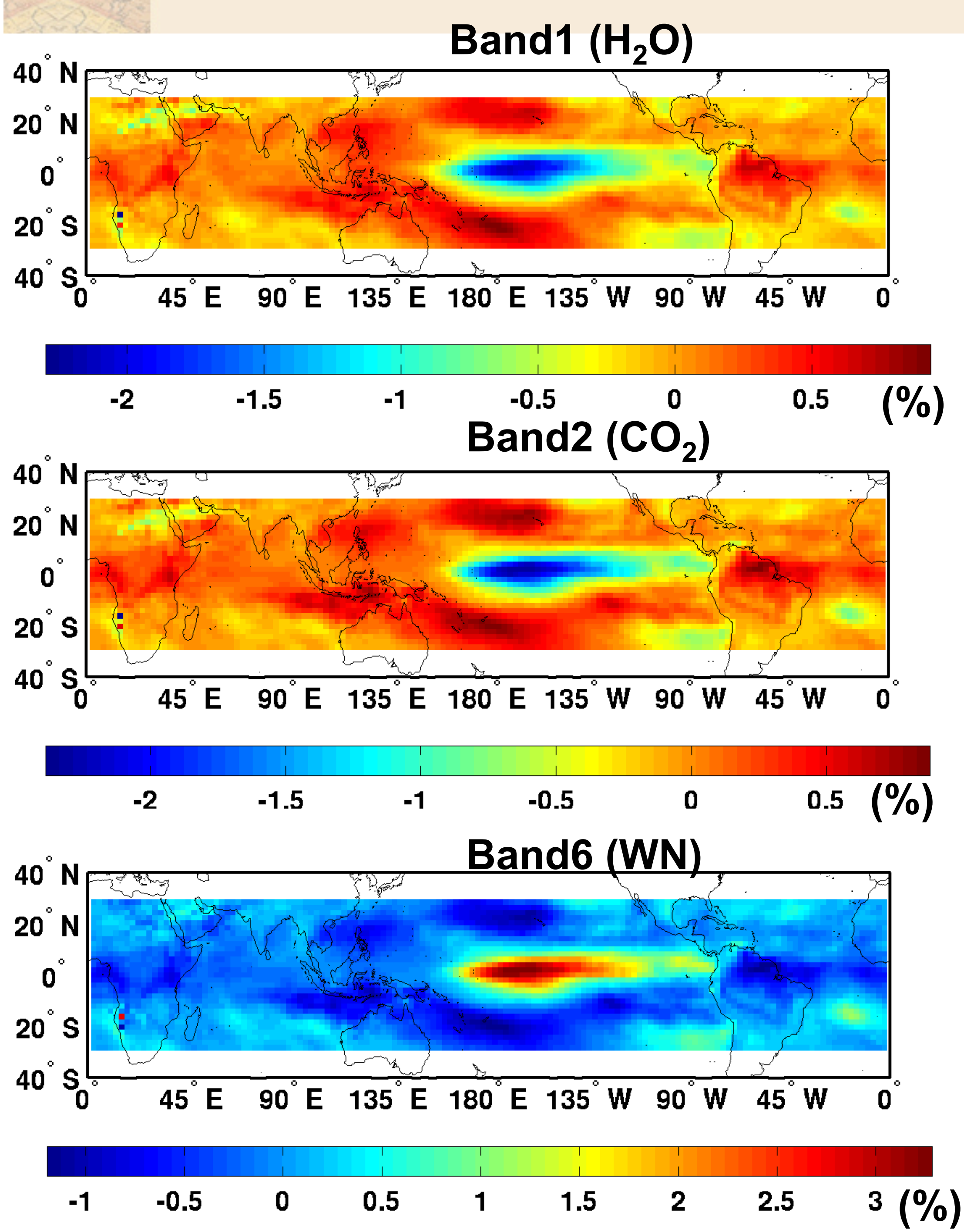




PCA of fractional contribution (r) of each band

Time series almost same as those of PCA of band CRF

But…

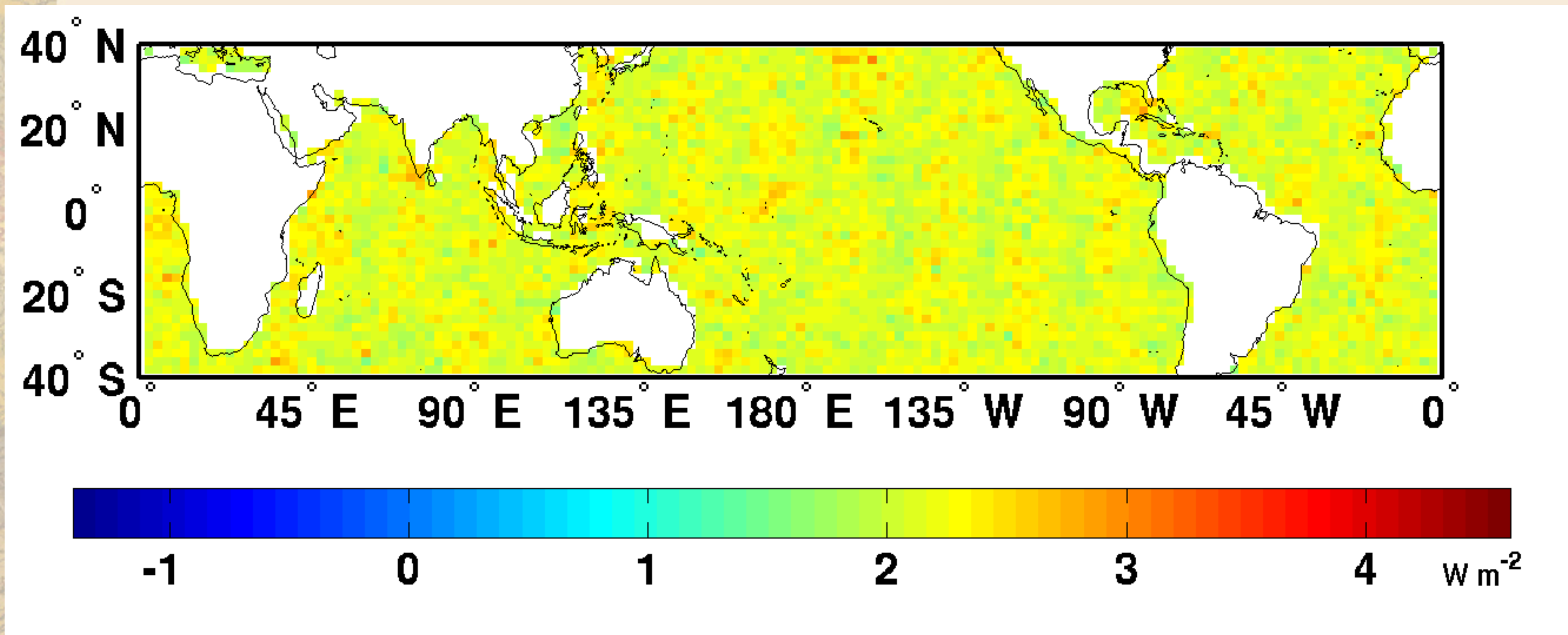


- El Nino year
  - Expansion coefficient <0
  - Absolute ΔCRF >0 for all bands
  - But CTH increases, so Δr_{Band6} indeed becomes smaller and $\Delta r_{Band1-2}$ larger

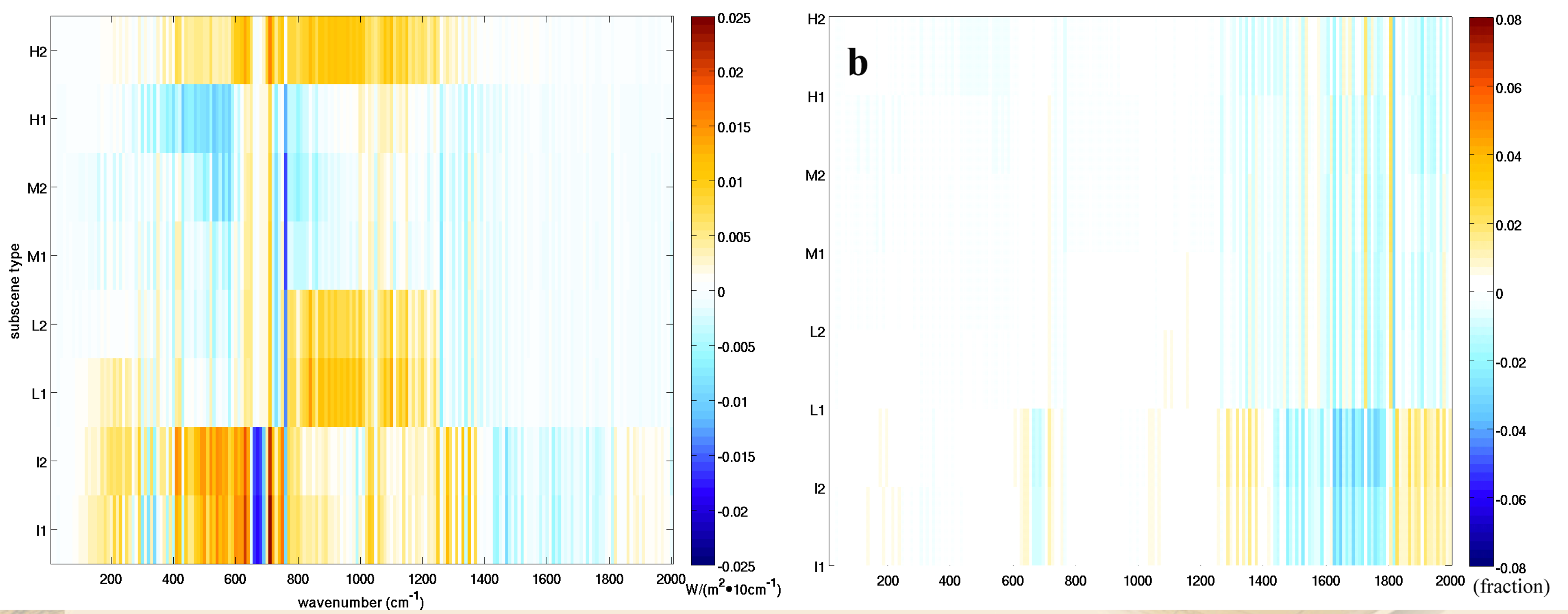
Conclusions

- The algorithm of getting cloud-sky spectral fluxes is robust and insensitive to cloud types or cloud fractions
- Band-by-band fractional contribution is more sensitive to cloud height, less sensitive to cloud fraction
  - Another dimension in model vs. satellite comparison?
- AM2 generally agrees with the AIRS-CERES for the annual-mean band-by-band CRF, but systematic biases are seen over different bands
- What do observed interannual anomalies look like?
- The story of ozone band …

"…understanding cloud feedback will be gleaned neither from observations nor proved from simple theoretical argument alone. The blueprint for progress must follow a more arduous path that requires a carefully orchestrated and systematic combination of model and observations." **Stephens (2005 J Clim)**



40° N
20° N
0°
20° S
40° S
0°
45° E
90° E
135° E
180° E
135° W
90° W
45° W
0°
-1
0
1
2
3
4
W m-2



subscene type
H2
H1
M2
M1
L2
L1
I2
I1
wavenumber (cm^{-1})
W/(m^2•10cm^{-1})
b
(fraction)