An Update on LW Band-by-Band Flux and CRF study: Observations versus GCMs

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Outline

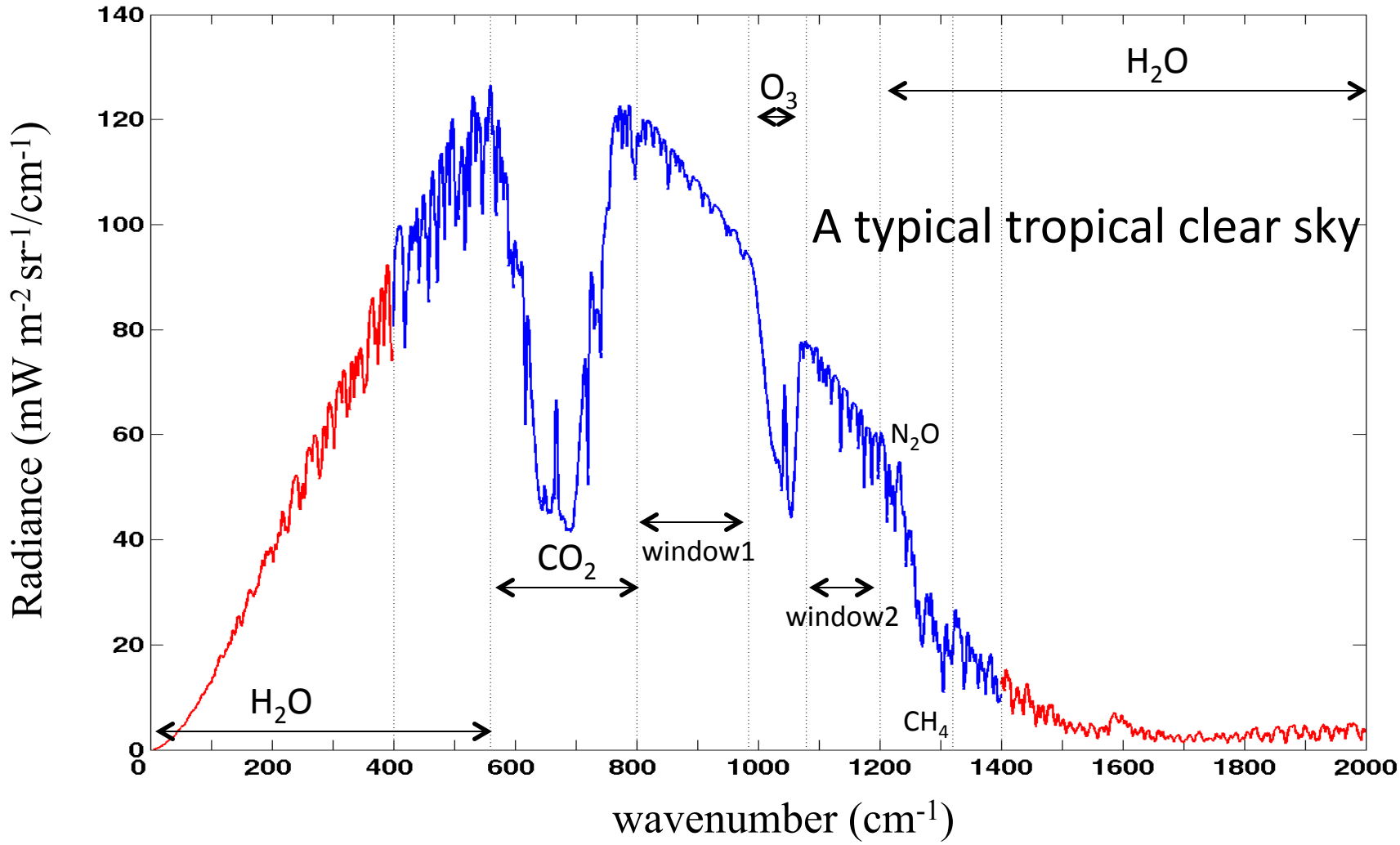
- A quick review of LW band-by-band flux and CRF
  - Why cares about them?
  - How to get them?
- Deriving band-by-band flux and CRF from collocated AIRS & CERES obs.
- Observation vs. multi GCMs
  - Band-by-band clear-sky greenhouse effect
  - Band-by-band CRF
    - Annual mean
    - Seasonality
- Discussions and Conclusions

Huang et al. (2008) and (2010): one year ⟹ multi years
one GCM ⟹ multi GCMs

OLR: important player in radiation budget, CRF, radiative forcings, and thus in climate change

$$F = \int_{\Delta\nu} d\nu \int_0^{2\pi} d\varphi \int_0^{\frac{\pi}{2}} I_{TOA}(\nu;\theta,\varphi)\cos\theta\sin\theta d\theta$$

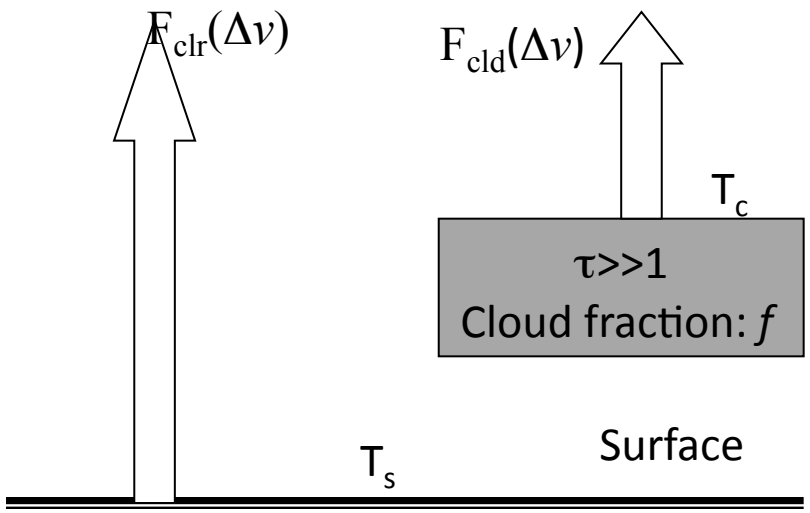
Total flux (wm^{-2}) 52.5 52.2 58.0 59.7 18.0 23.5 12.4 4.5 7.7 =288.5



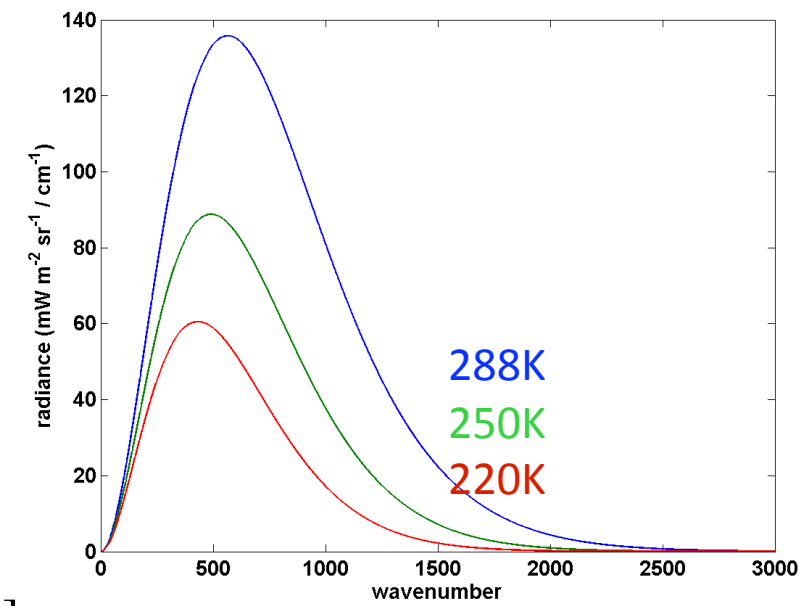
Why go band-by-band?

- Practical reasons (for model evaluation):
  - Compensating biases for simulated broadband CRF and fluxes
  - Band-by-band quantities are directly computed by each GCM
  - Observationally it is possible to derive them
- Also
  - Band-by-band CRFs provides more insights

Why go band-by-band: Toy model A



1. Blackbody cloud
2. Ignore atmospheric absorption



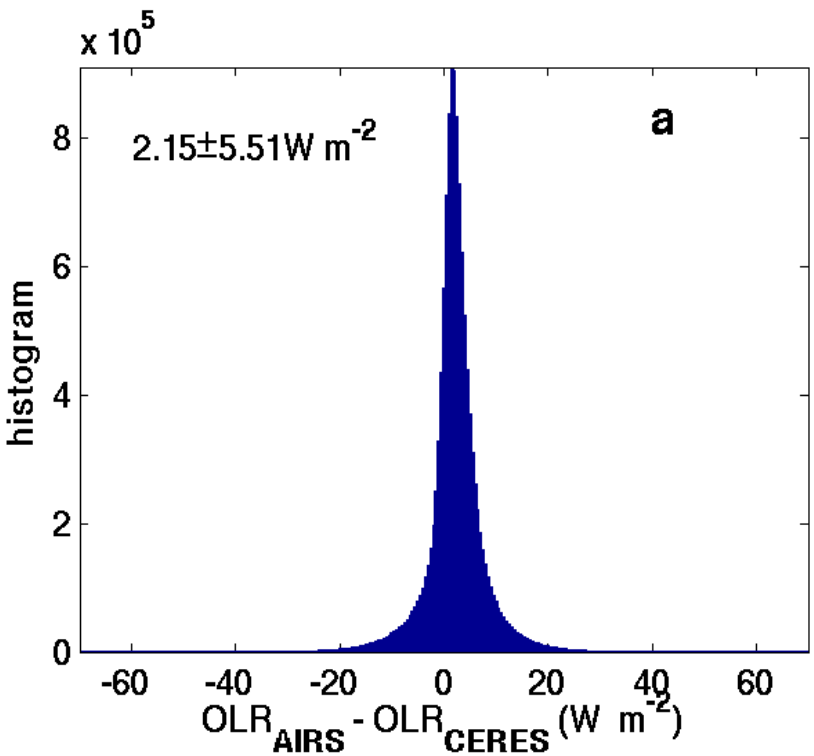
$$CRF_{LW} = \sigma T_s^4 - [f\sigma T_c^4 + (1-f)\sigma T_s^4] = f[\sigma T_s^4 - \sigma T_c^4]$$

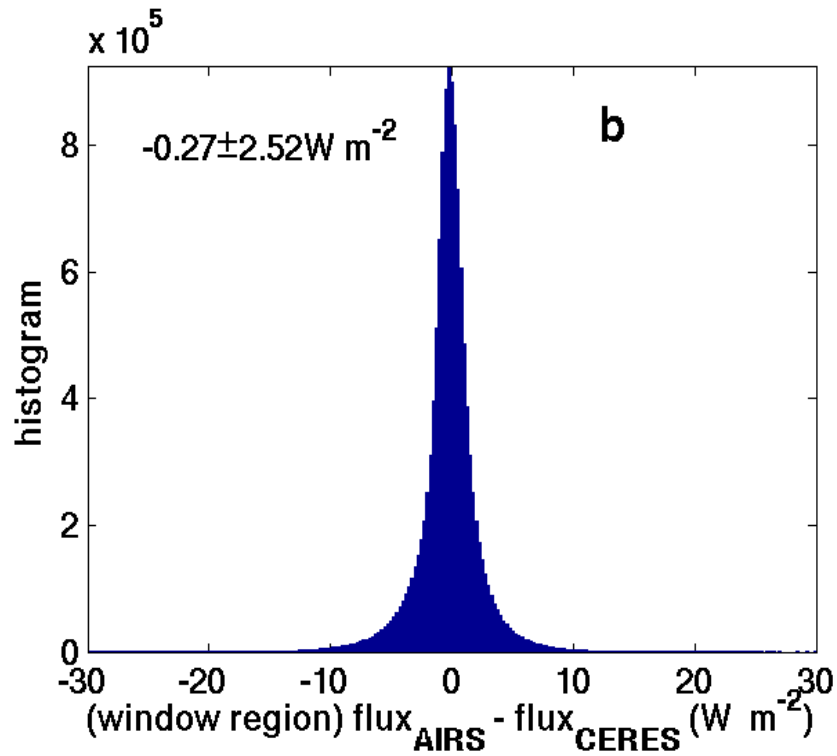
CRF_{LW} sensitive to both f and T_c

Observation of band-by-band flux and CRF

- Huang et al. (2008) and Huang et al. (2010) developed and validated spectral ADM/algorithms for deriving such quantities
  - Build spectral ADM based on CERES scene type def.
  - Compute spectral flux from collocated AIRS observation
  - For open oceans only in these studies

Cloudy sky over the tropical ocean, year 2004





Extending to 2003-2007: OLR_{AIRS}-OLR_{CERES}

Clear sky over the ocean

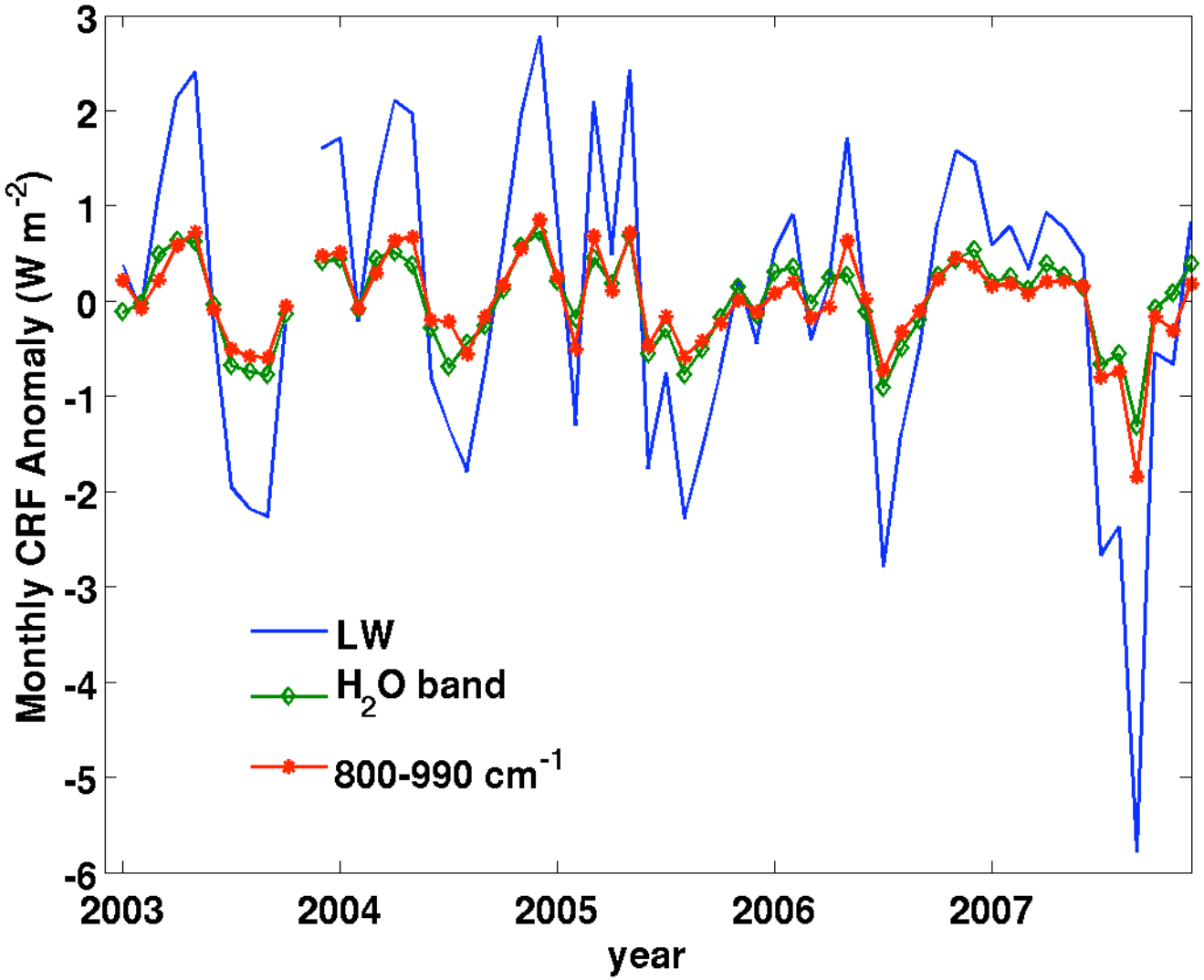
	Nighttime (W m^{-2})	Daytime (W m^{-2})
2003	0.80±1.34	0.86±1.72
2004	0.52±1.29	0.79±1.67
2005	0.93±1.35	1.81±1.81
2006	0.86±1.38	2.10±1.81
2007	0.83±1.40	2.45±1.87

Cloudy sky over the ocean

	Nighttime (W m^{-2})	Daytime (W m^{-2})
2003	1.63±5.22	3.73±5.94
2004	1.33±5.16	3.00±5.73
2005	1.75±5.32	4.06±6.03
2006	1.58±5.42	4.35±6.08
2007	1.50±5.37	4.57±6.06

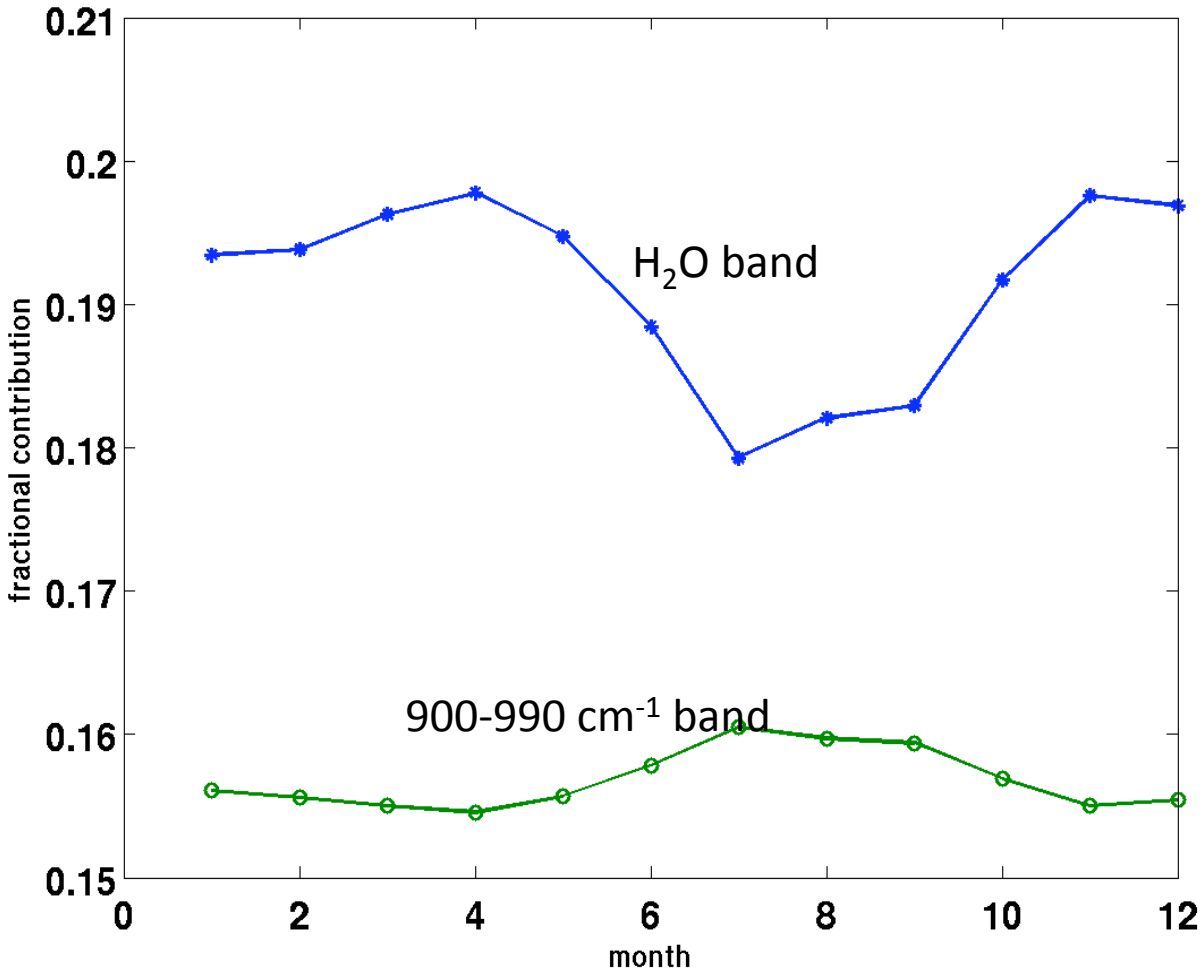
- Standard deviation changes little from year to year
- Daytime seems having a drift w.r.t. nighttime (this is Edition 2 SSF)

Time series of CRF anomaly (tropical ocean average)



As for the absolute value of CRF (W m^{-2}), all band closely tracks LW broadband

Seasonal Cycle of fractional contribution of each band CRF



In terms of fractional contribution, albeit its small variation with time

- CO_2 band tracks H_2O band (r = 0.41)
- Window bands negatively correlation (r = -0.986 ~ -0.996)
- O_3 band positively correlates with window band (r ~ 0.72)

For tropical mean: **small** variation at both seasonal and interannual timescale (H2O band, std ~ 3%; other bands, std < 1%)

GCMs

- GFDL AM2: Ramaswamy & Schwarzkopf
- NASA GEOS-5: M.D. Chou
- CCCma CGCM3.1 (T63): Li & Barker
- AMIP runs with observed SSTs over the AIRS/ CERES era
- Modification of codes to directly output band-by-band quantities

Rearrange of GFDL AM2 and NASA GEOS-5 LW Bands for comparison

New band	GFDL AM2 Band ID	GEOS-5 Band ID	CGCM3.1 Band ID	
0-560 and > 1400	Band 1 (0-560 and > 1400)	Band1-2 (0-540) Band8-9 (>1380)	Band 1-3 (>1400) Band 8-9 (0-540)	H_2O
560-800	Band 2 (560-800)	Band3&10 (540-800)	Band 7 (540-800)	CO_2
800-980	Band 3-4 (800-990)	Band4 (800-980)	Band 6 (800-980)	WN
980-1100	Band 5 (990-1070)	Band5 (980-1100)	Band 5 (980-1100)	O_3
1100-1215	Band 6 (1070-1200)	Band6 (1100-1215)	Band 4 (1100-1400)	WN + $N_2O/CH_4/H_2O$
1215-1400	Band 7 (1200-1400)	Band7 (1215-1380)		

Color coding:

Green: AM2 and GEOS-5 Bandwidth Difference within 20cm^{-1}

Orange: AM2 and GEOS-5 Bandwidth Difference between 20 and 40cm^{-1}

CGCM 3.1 band widths and ranges are more aligned with GEOS-5, except the band of 1100-1400cm^{-1}

Clear-sky flux comparison

Using the green-house parameter to make the comparison.

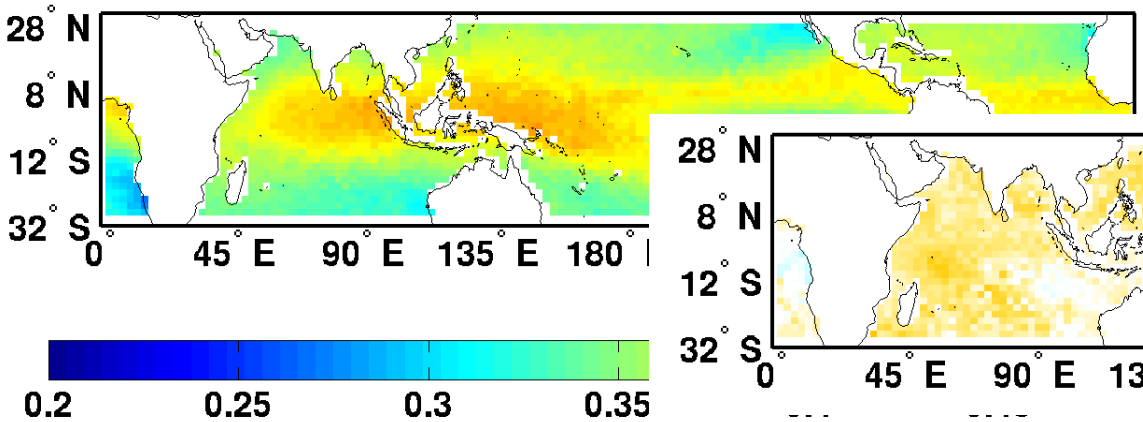
Green-house parameter (efficiency)

$$g_{\Delta v} = \frac{\int_{\Delta v} B_v(T_s)dv - F_{\Delta v}(TOA)}{\int_{\Delta v} B_v(T_s)dv}$$

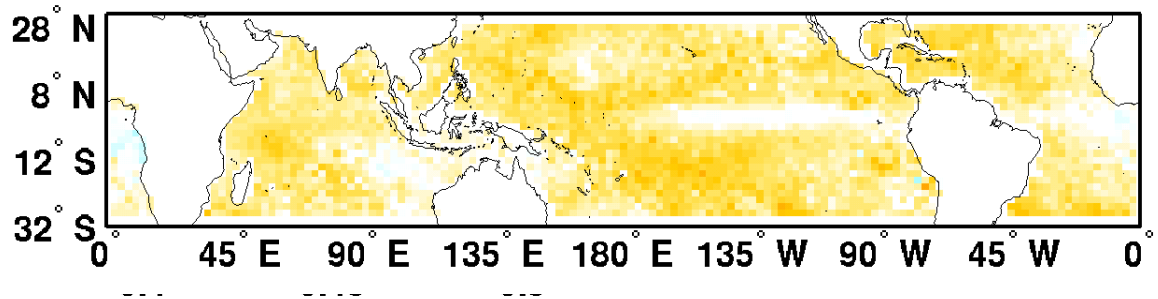
Physical Interpretation: Fraction of radiant energy over a given band that originates from surface but gets trapped within the atmosphere

Collocated AIRS & CERES obs. LW broadband

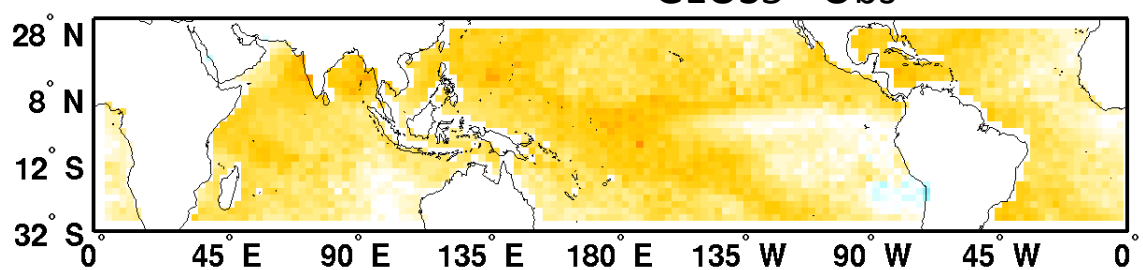
2004 Annual Mean



GFDL AM2 - Obs

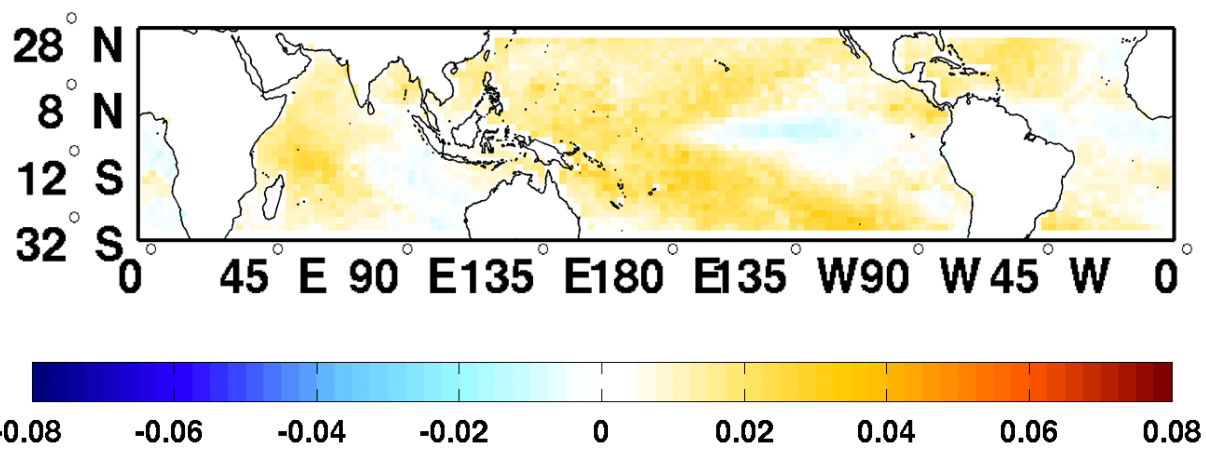


GEOS5 - Obs

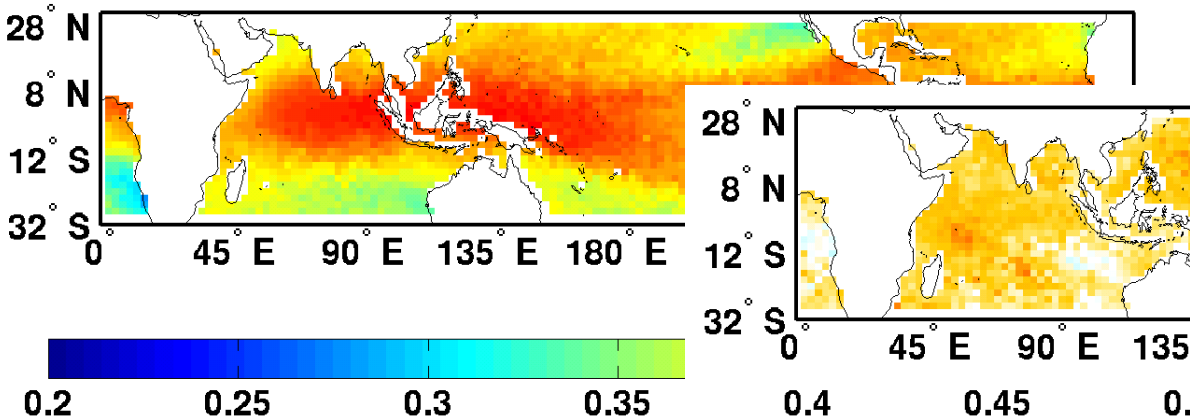


Obs	289.5 W m^{-2}
GFDL AM2	283.3 W m^{-2}
GEOS5	281.0 W m^{-2}
CGCM3.1	286.6 W m^{-2}

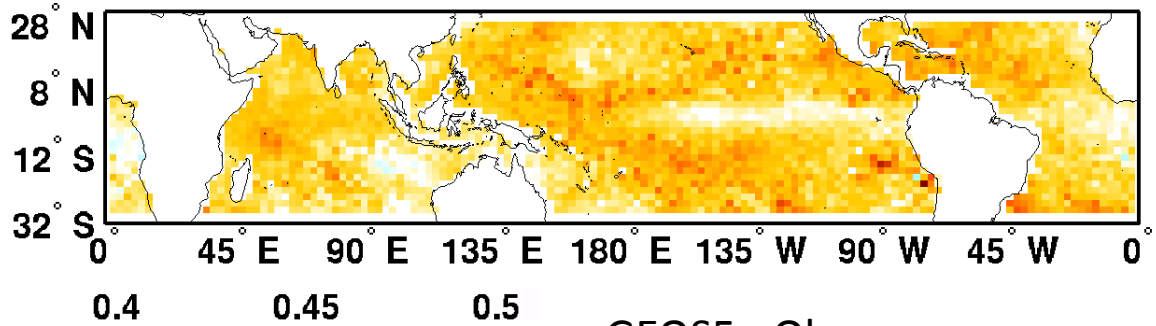
CGCM3.1 - Obs



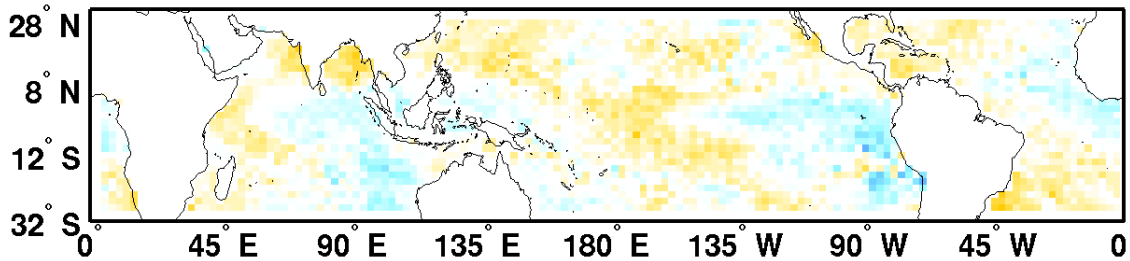
Collocated AIRS & CERES obs. H_2O bands (0-540cm^{-1}, >1400 cm^{-1})



GFDL - Obs

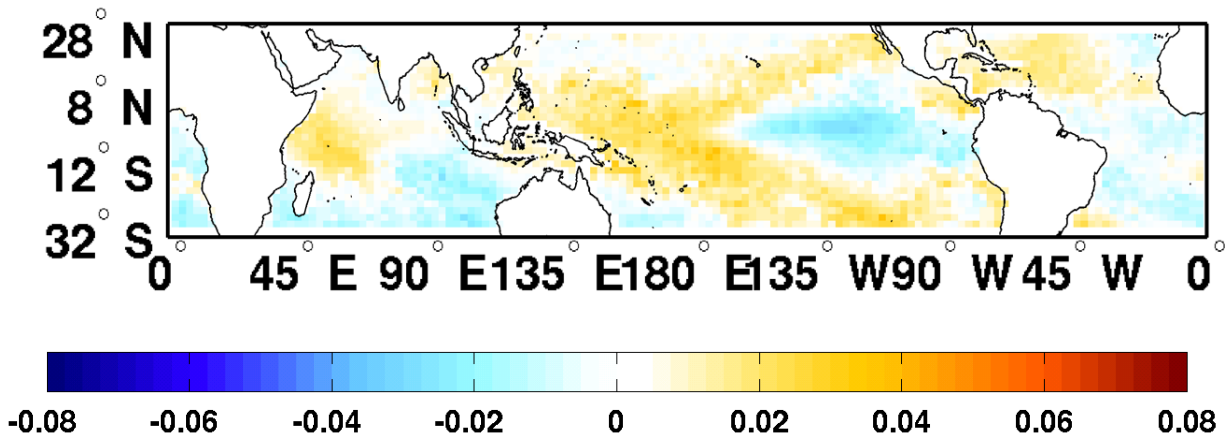


GEOS5 - Obs

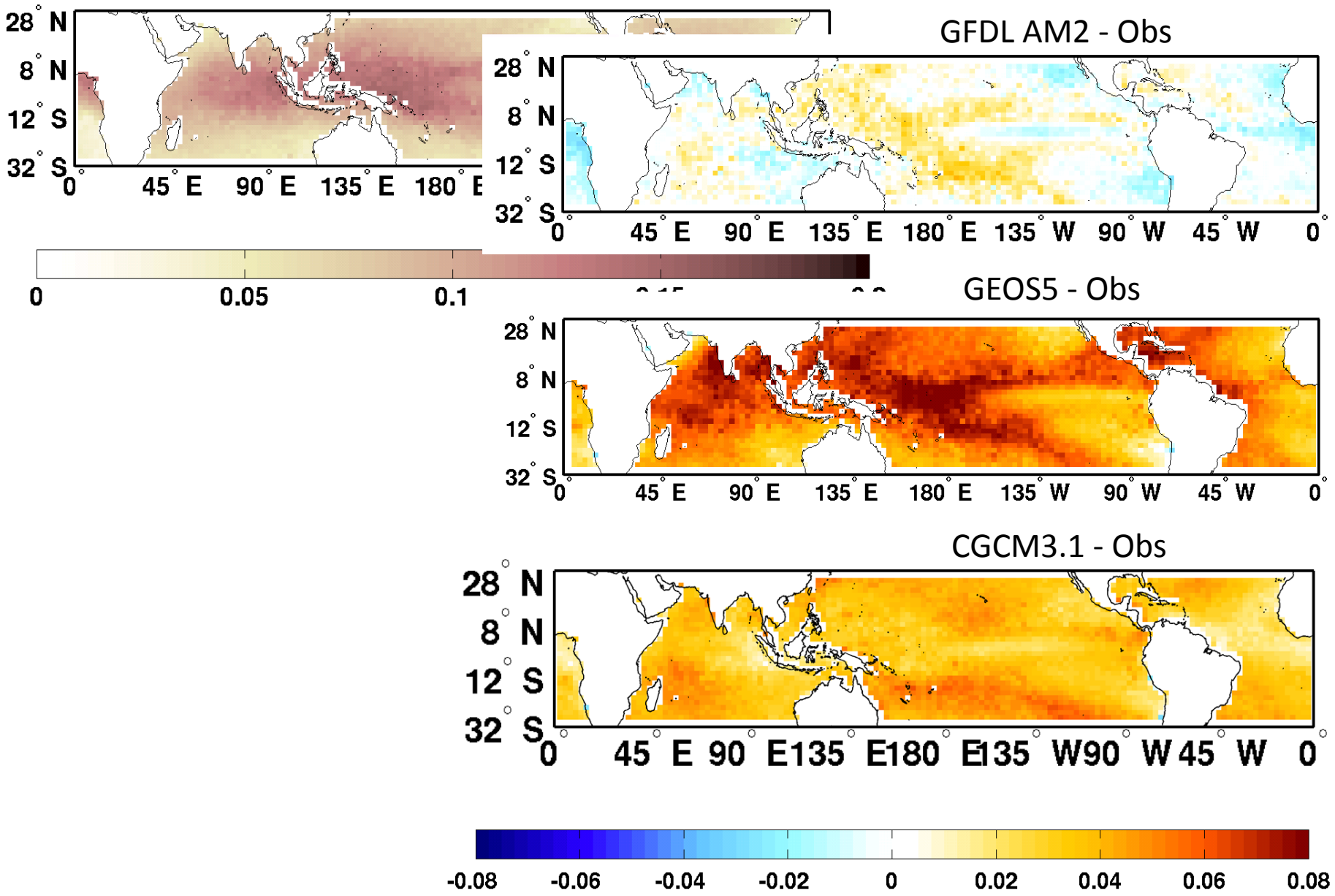


CGCM3.1 - Obs

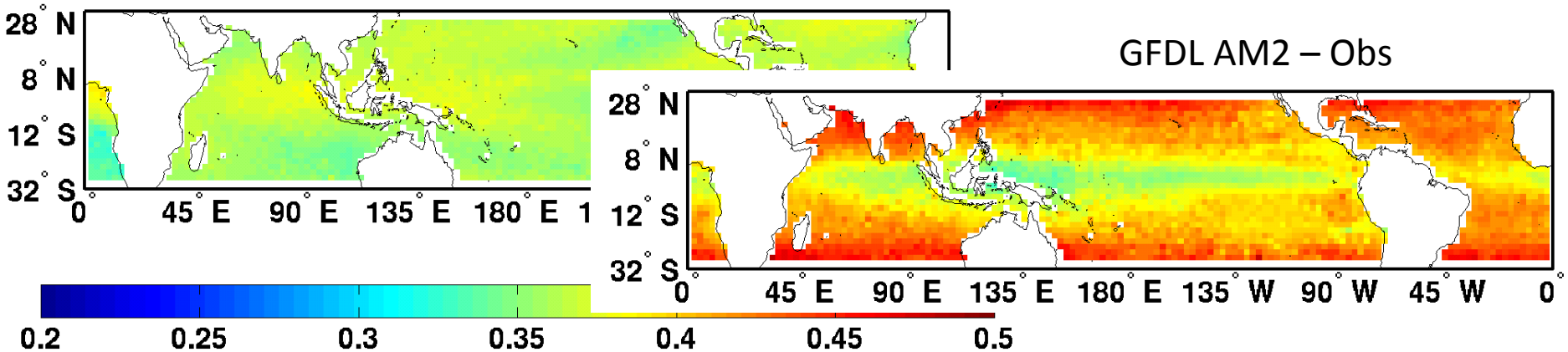
0.02 in fraction ~ 2.7 Wm^{-2}



Collocated AIRS & CERES obs., window region (800-980cm^{-1})

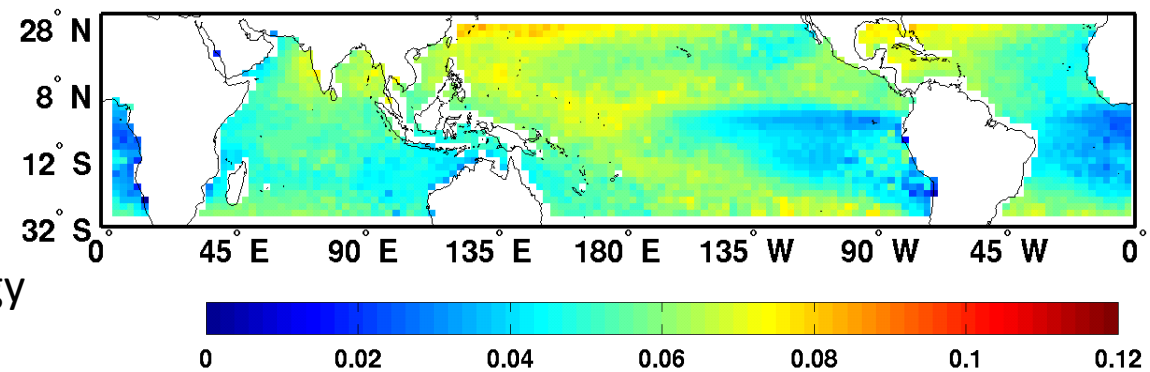


Collocated AIRS & CERES obs., ozone band (980-1070cm^{-1})



GFDL AM2 – Obs

GEOS5 – Obs



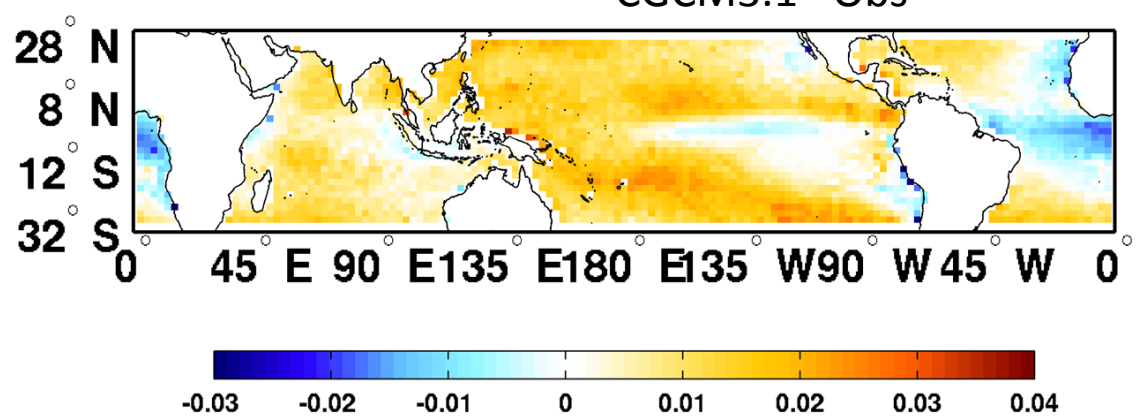
O3 treatment

AM2: prescribed monthly climatology

GEOS5: on-line ozone (PCHEM)

CGCM3.1: time varying, AR5 forcing

CGCM3.1– Obs

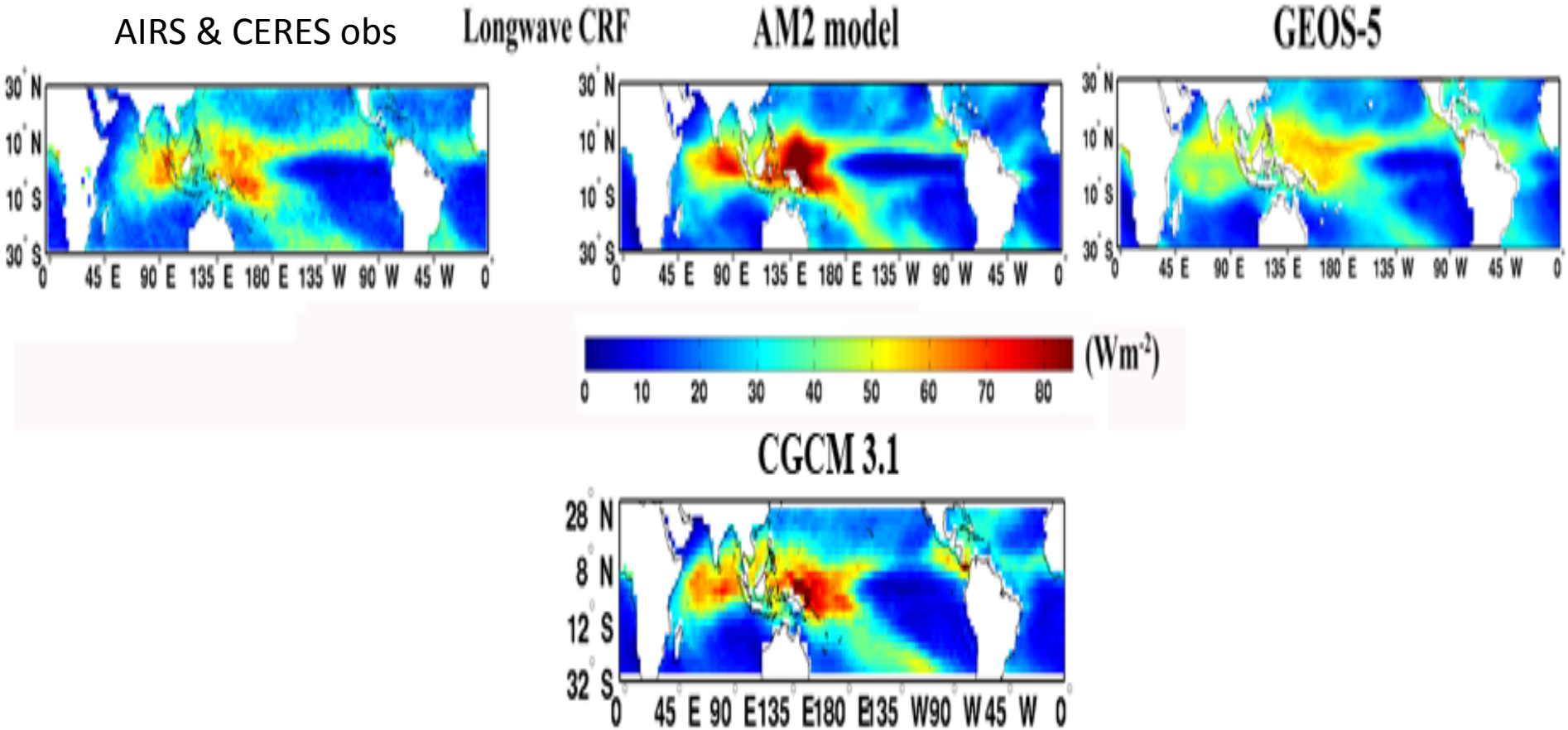


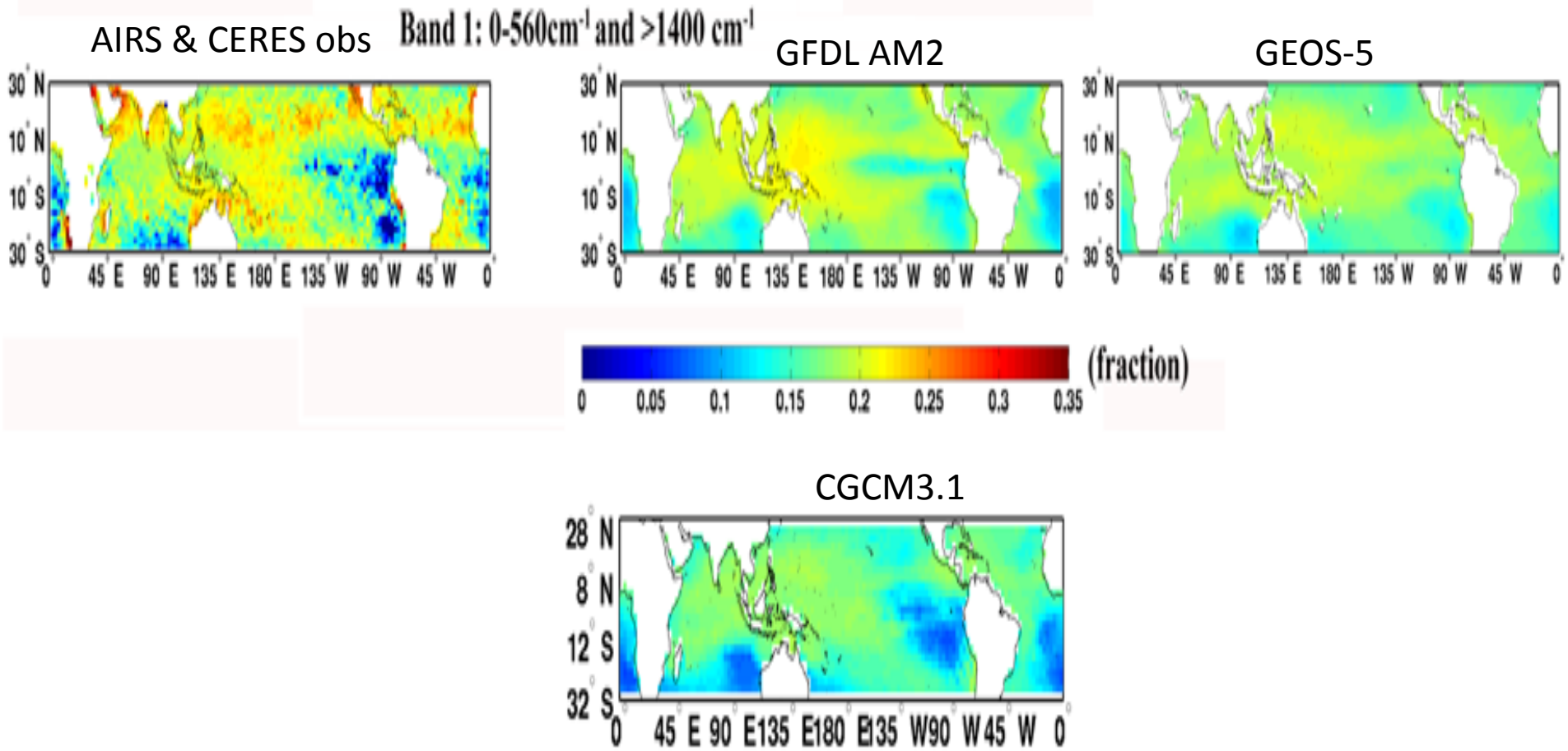
Annual-mean CRF in 2004 (Tropical oceans)

		AIRS&CERES observed CRF (Wm^{-2})	AM2 simulated CRF (Wm^{-2})	GEOS-5 simulated CRF (Wm^{-2})	CGCM3.1 simulated CRF (Wm^{-2})
	LW broadband	27.45 (100%)	28.13 (100%)	28.30 (100%)	27.27 (100%)
H_2O	0-560cm^{-1}; >1400cm^{-1}	5.36 (19.5%)	5.33 (19.0%)	5.08 (17.9%)	4.45 (16.3%)
CO_2	560-800cm^{-1}	4.18 (15.2%)	3.74 (13.3%)	5.15 (18.2%)	4.82 (17.7%)
WN	800-990cm^{-1}	9.35 (34.1%)	10.03 (35.6%)	9.06 (32.0%)	8.78 (32.2%)
O_3	990-1070cm^{-1}	2.02 (7.0%)	1.68 (6.0%)	3.62 (12.8%)	3.73 (13.7%)
WN H_2O NO_2 CH_4	1070-1400cm^{-1}	6.53(23.8%)	7.34 (26.1%)	5.43 (19.1%)	5.48 (20.1%)

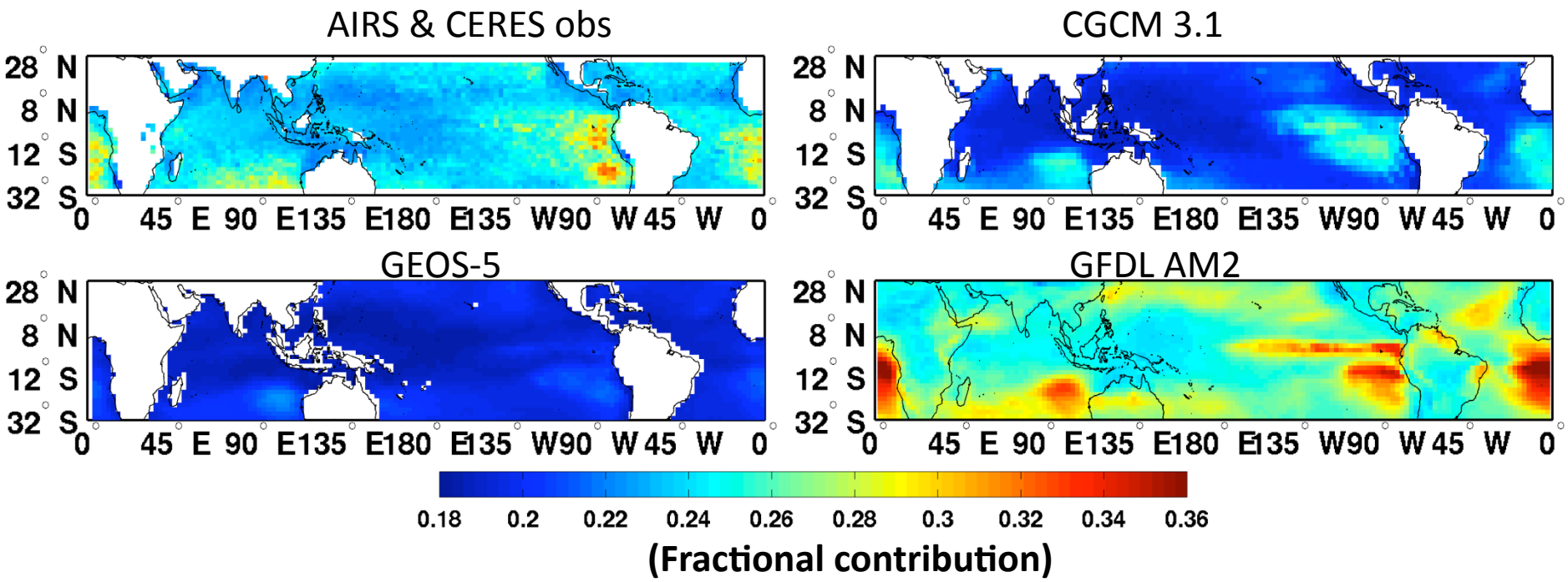
- LW CRF differs ~ 1 Wm^{-2}
- CRF of Individual band can have difference as large as that, or even larger

Annual-mean CRF map




Band 1: 0-560cm-1 and >1400 cm-1
AIRS & CERES obs
GFDL AM2
GEOS-5
CGCM3.1
30° N
10° N
10° S
30° S
0
45 E
90 E
135 E
180 E
135 W
90 W
45 W
0
(fraction)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
28° N
8° N
12° S
32° S

Annual-mean CRF map: 1070-1400 cm^{-1}



GEOS -5: lower than obs. and a narrow range: 0.18-0.22

GFDL AM2: higher than obs.

Seasonality

	$r(frac\_CRF_{H2O}, frac\_CRF_{CO2})$
AIRS obs	0.41
GFDL AM2	0.99
NASA GEOS-5	0.53
CCCma CGCM 3.1	0.96

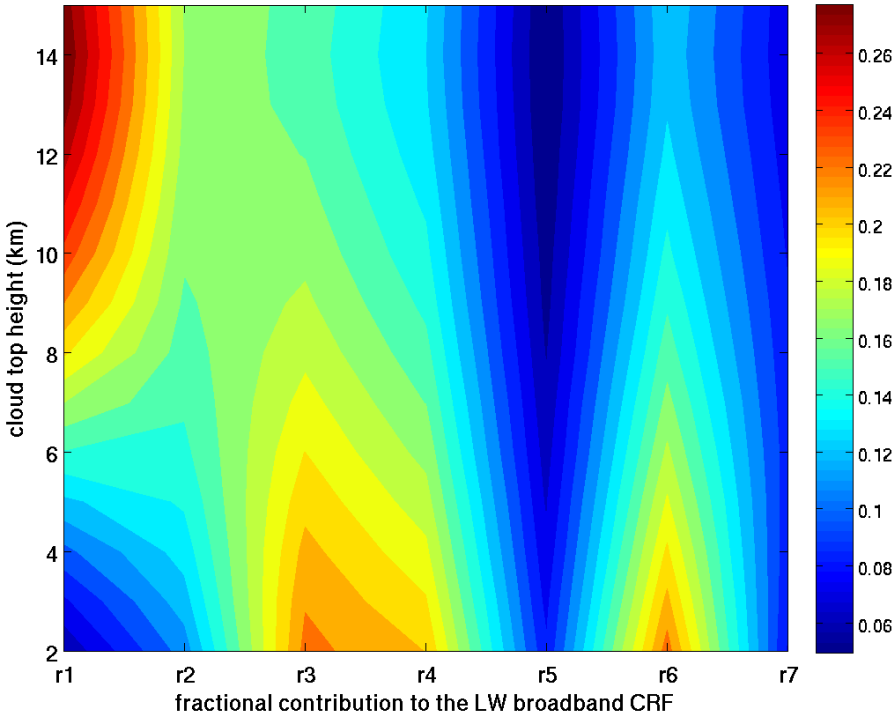
Conclusion and Discussion

- Spread of modeling results in terms of band-by-band fluxes and CRFs
  - Compensating biases can be revealed
  - Ozone band is interesting and a challenge
- The discrepancies in band-by-band comparison is larger than that those in broadband
  - Good thing: variation is small
  - GCM tuning works for broadband, not that much for band-by-band quantities
- How band-by-band biases are related to climate change projection of each GCM?
- Future work
  - Including land: spectral ADM and flux estimation
  - Conceptual model studies: spectral radiative forcing and spectral CRF
  - Similar analysis to CMIP5 models

Thanks for your attention!

- **Huang, X.L.**, N.G. Loeb, and W.Z. Yang, Spectrally resolved fluxes derived from collocated AIRS and CERES measurements and their application in model evaluation: 2. cloudy sky and band-by-band cloud radiative forcing over the tropical oceans, *JGR-Atmospheres*, 115, D21101, doi: 10.1029/2010JD013932, 2010.
- **Huang, X.L.**,W.Z. Yang, N.G. Loeb, and V. Ramaswamy, Spectrally resolved fluxes derived from collocated AIRS and CERES measurements and their application in model evaluation: 1. clear sky over the tropical oceans, *Journal of Geophysical Research-Atmospheres*, 113, D09110, doi: 10.1029/2007JD009219, 2008.

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)

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

Band4: 900-990 cm^{-1} (WN)

Band5: 990-1070cm^{-1} (O_3)

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

Band7: 1200-1400cm^{-1} (N2O, CH_4)

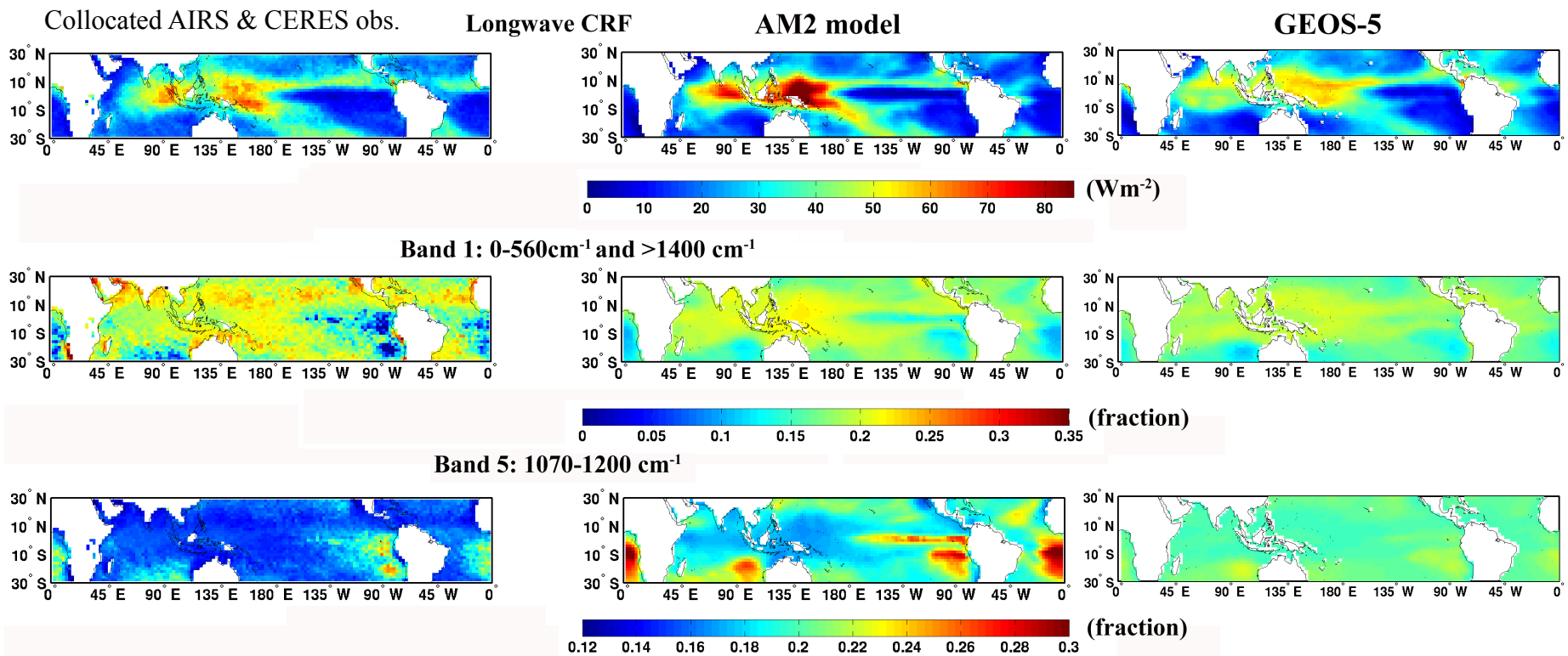
Toy model fit: AIRS&CERS 24.8%, 9.2 km

AM2 25.4%, 9.4km

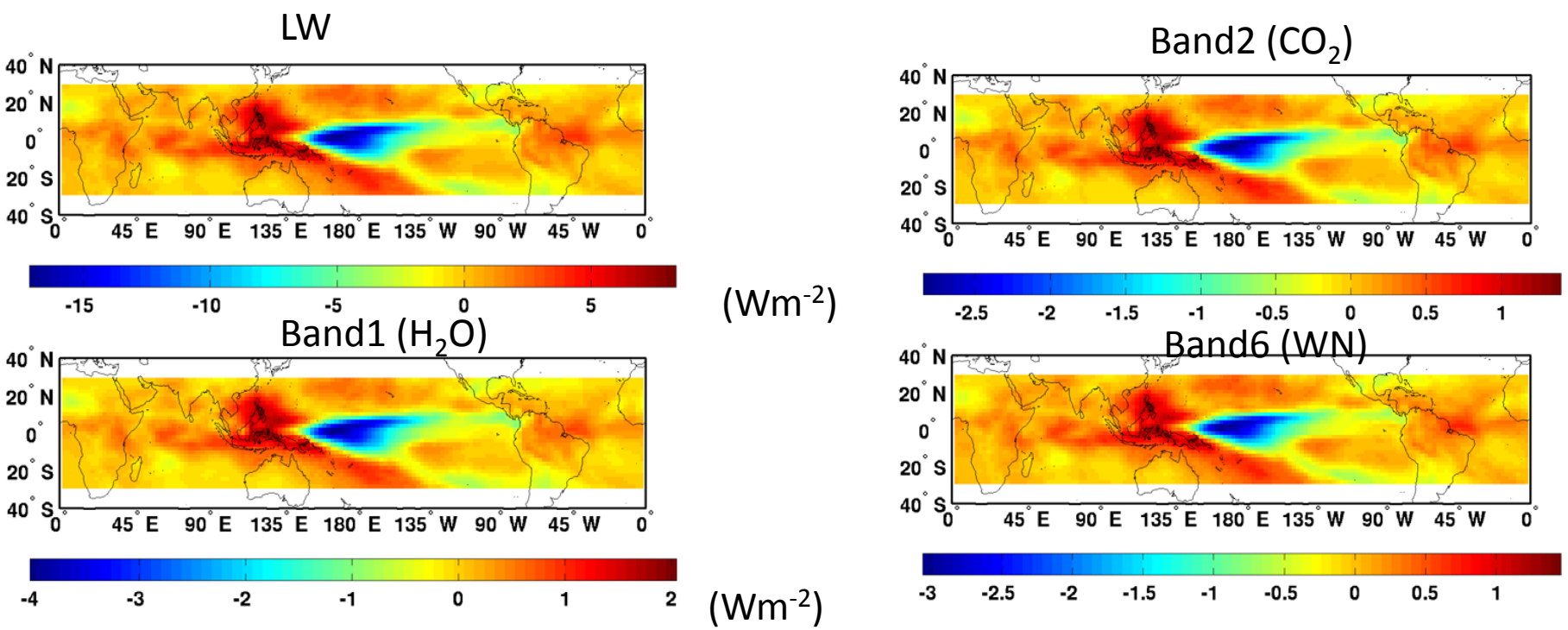
GEOS-5 25.8%, 9.0km

CGCM3.1 24.6%, 9.1km

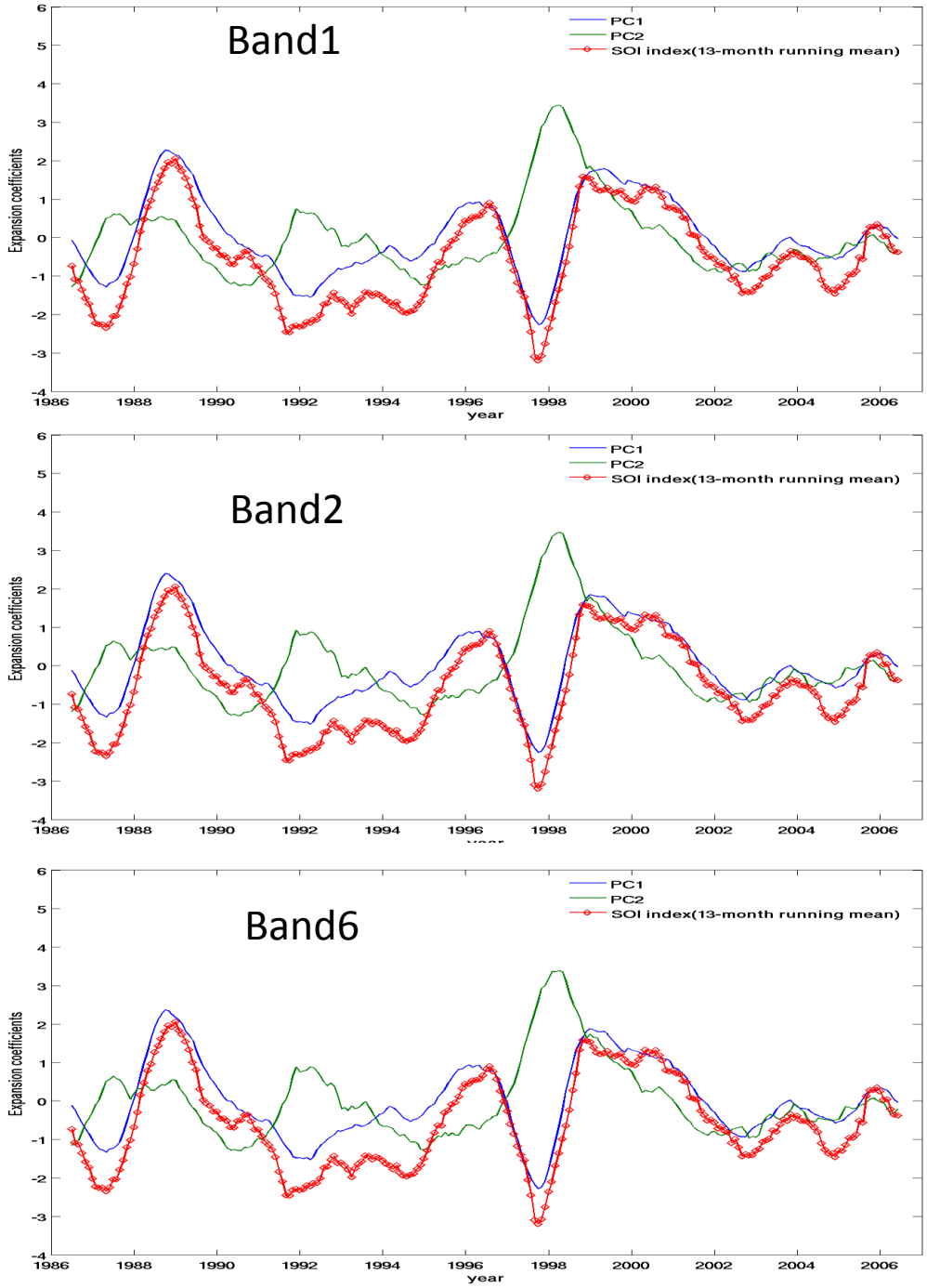
Annual-mean CRF map



Maps of PC1 (~40% variance)



- El Nino year
  - Expansion coefficient <0,
  - For CP, absolute ΔCRF >0 for all bands (ΔCRF =EC * PC1)

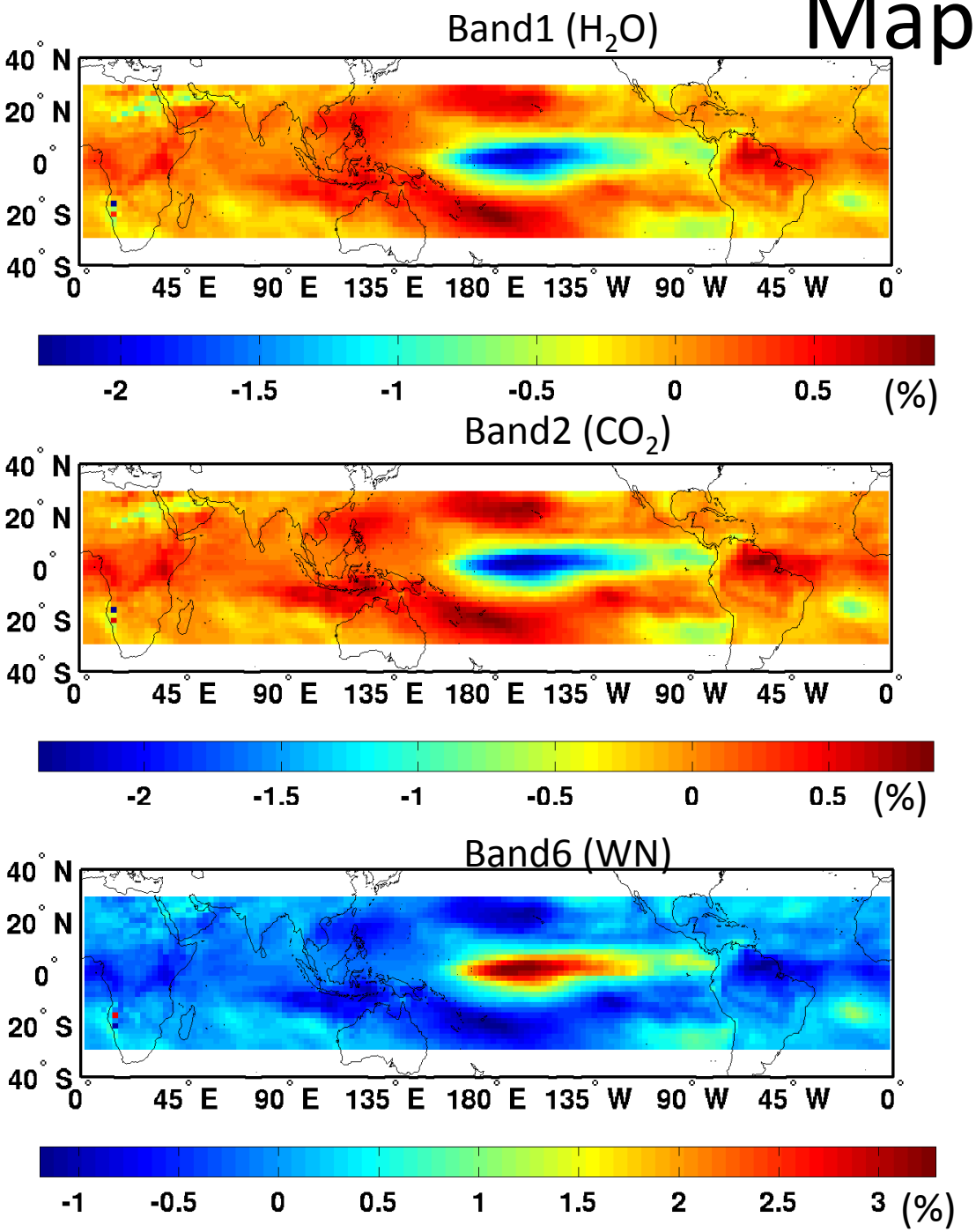


PCA of fractional contribution (r) of each band

Time series almost same as those of PCA of band CRF

But…

Map of PC1



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

Δf_{CRF}=EC * PC1