Spectrum: An Underutilized Dimension in the Climate Diagnostics and Climate Change Studies

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with contributions from collaborators in Univ. of Michigan, NASA GMAO, Environment Canada, NASA Langley, NOAA/GFDL, and Univ. of Miami

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ECMWF, Oct 21, 2016

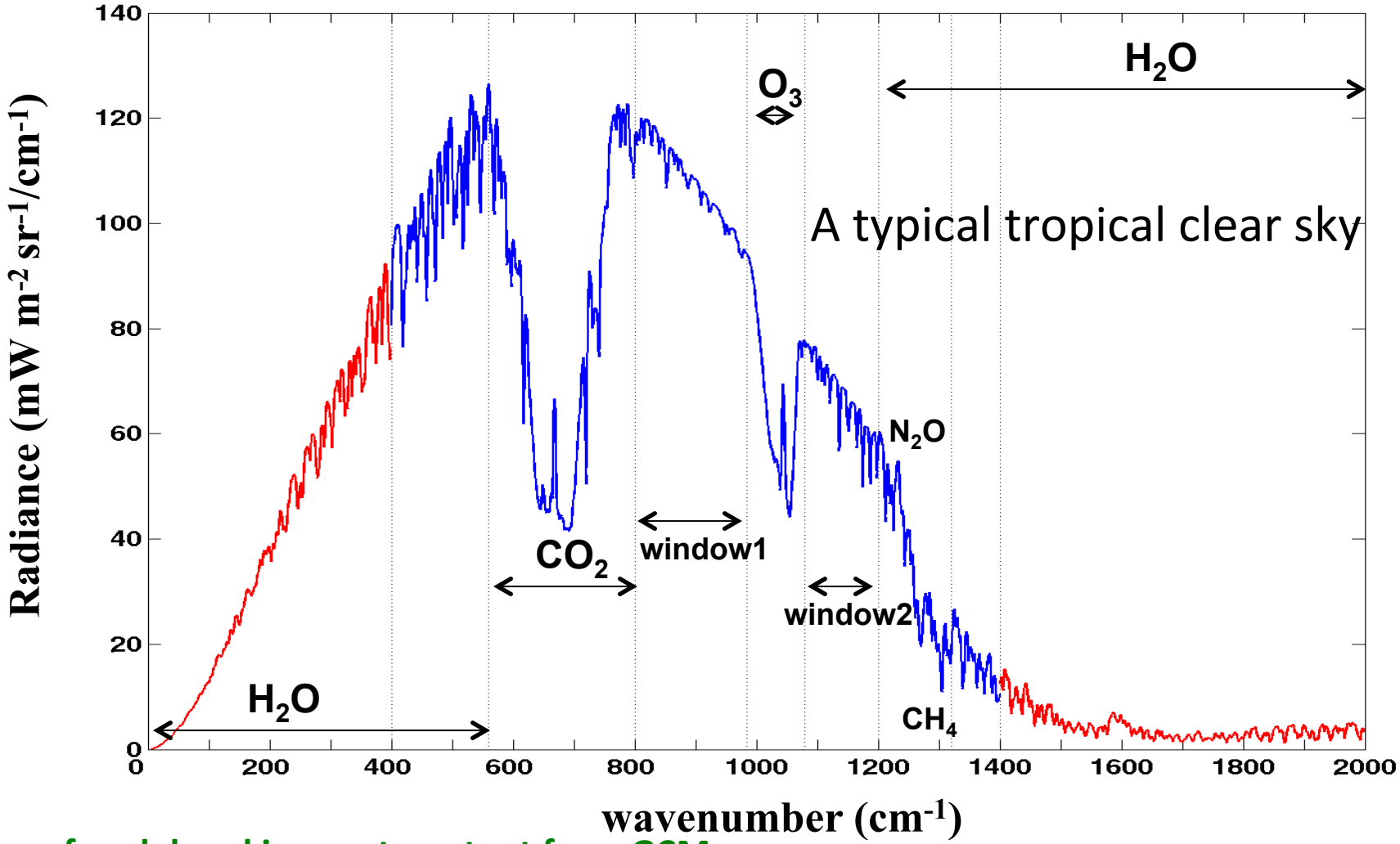
Outline

- Motivations
  - The spectral dimension
  - What additional info it can offer?
  - Two examples:
    - Clear-sky flux diagnostics
    - Radiative feedbacks
- LW spectral flux from collocated AIRS&CERES observations (Sep 2002 to Nov 2014)
- Spectral radiative feedbacks: a kernel approach
  - Developments
  - Applications in the CMIP3 and CMIP5 diagnostics
- Conclusions and discussions

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

$$F = 2\pi \int_{\Delta\nu} d\nu \int_0^1 I(\nu;\mu)\,\mu\, d\mu \quad (\mu = \cos\theta)$$

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



Flux of each band is easy to output from GCMs

What can the spectral dimension offer?

Reveal compensating differences that cannot be revealed in broadband diagnostics alone.

Example 1: clear-sky flux comparison

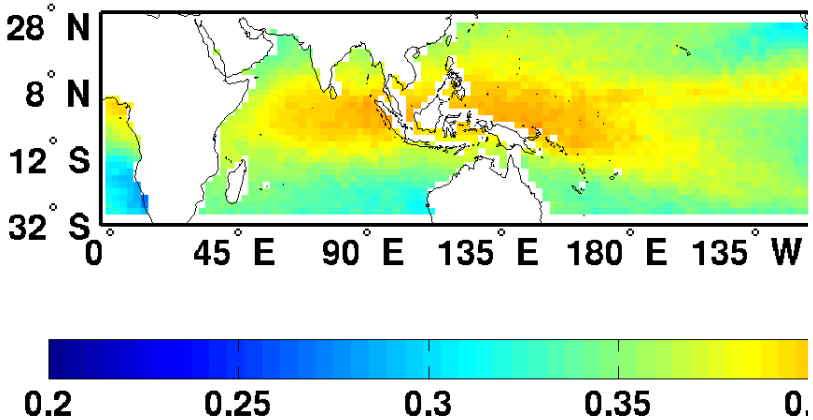
Using the green-house parameter to make the comparison.

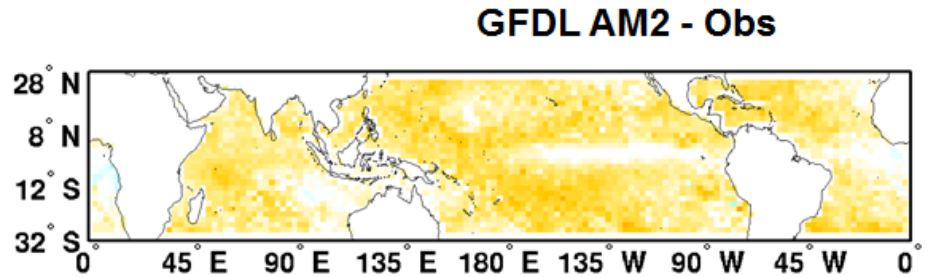
Green-house parameter (efficiency)

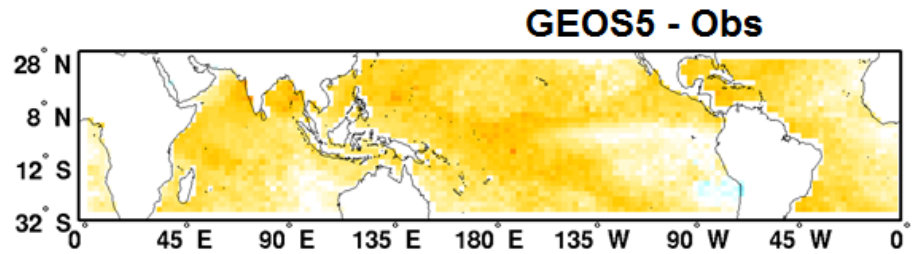
$$g_{\Delta v} = \frac{\int_{\Delta v} B_v(T_s)dv - F_{\Delta v}(TOA)}{\int_{\Delta v} B_v(T_s)dv}$$

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*

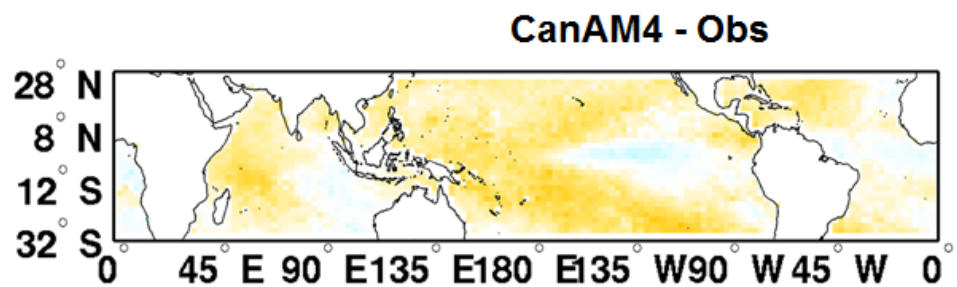


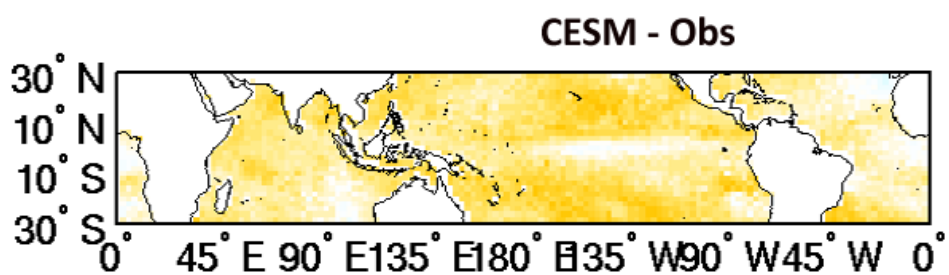


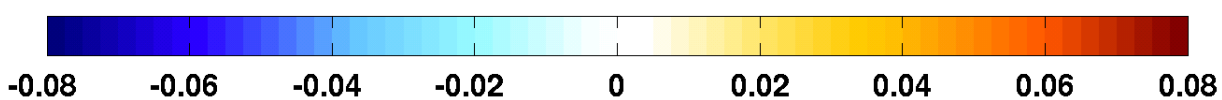


All AMIP runs

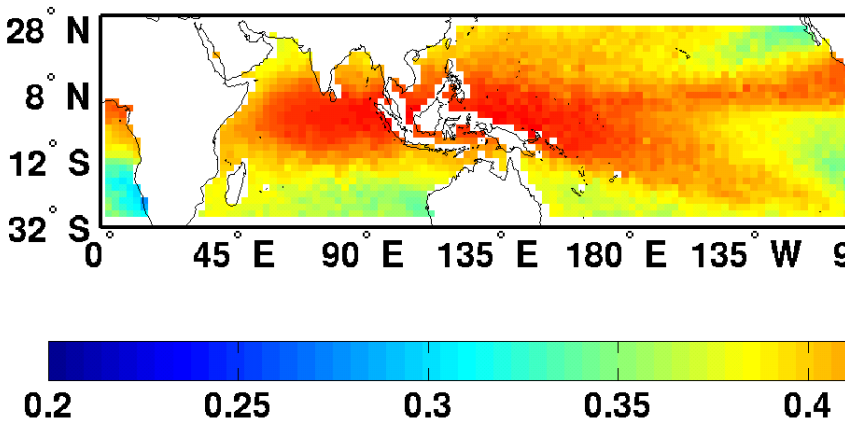
Obs	289.5 W m^{-2}
GFDL AM2	283.3 W m^{-2}
GEOS5	281.0 W m^{-2}
CanAM4	286.6 W m^{-2}
CESM	279.3W m^{-2}

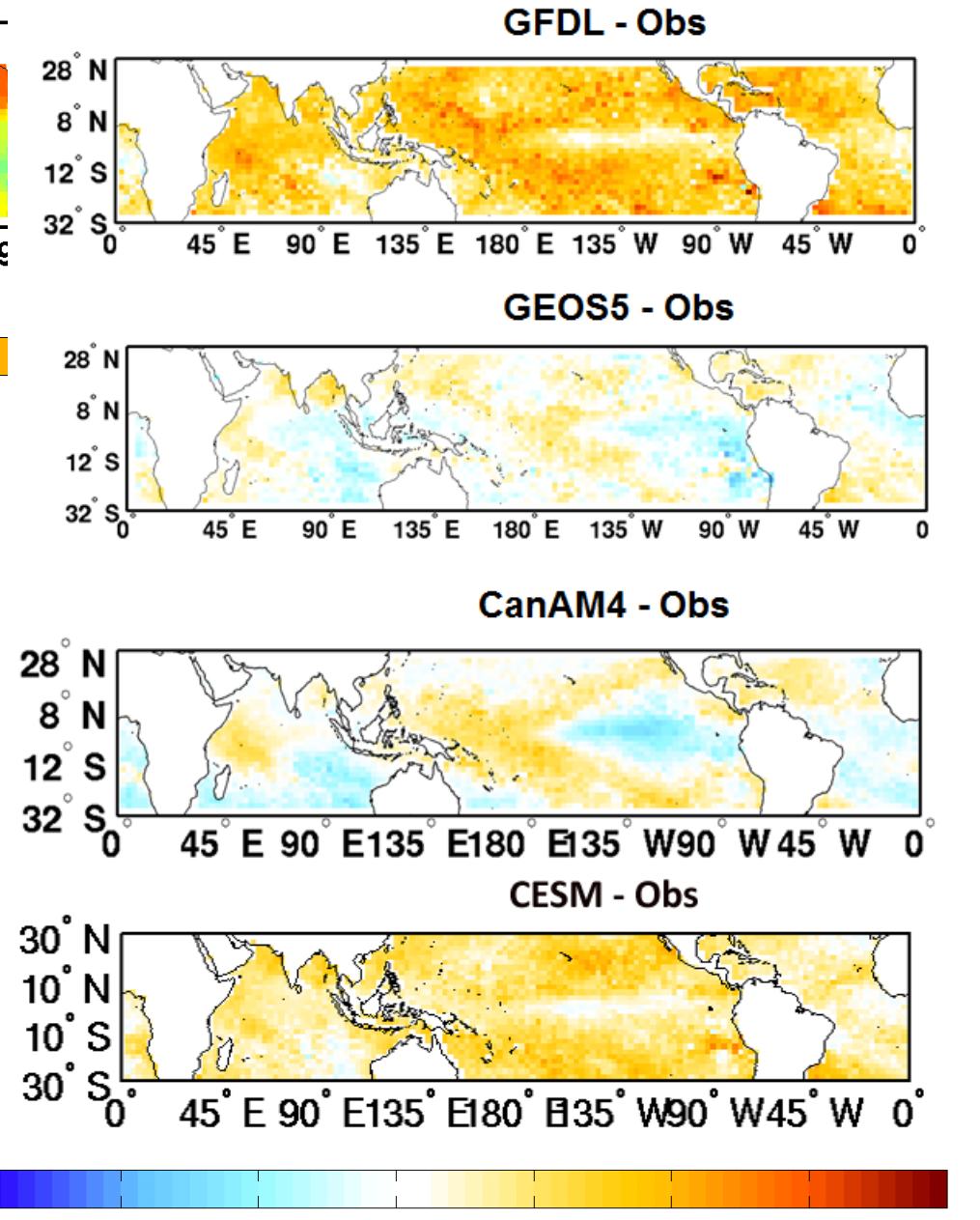






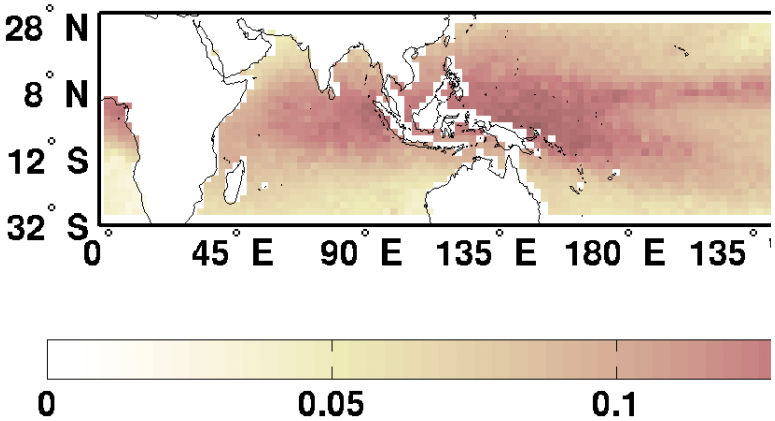
Collocated AIRS & CERES obs. H_2O bands (0-540cm^{-1}, >1400 cm^{-1})

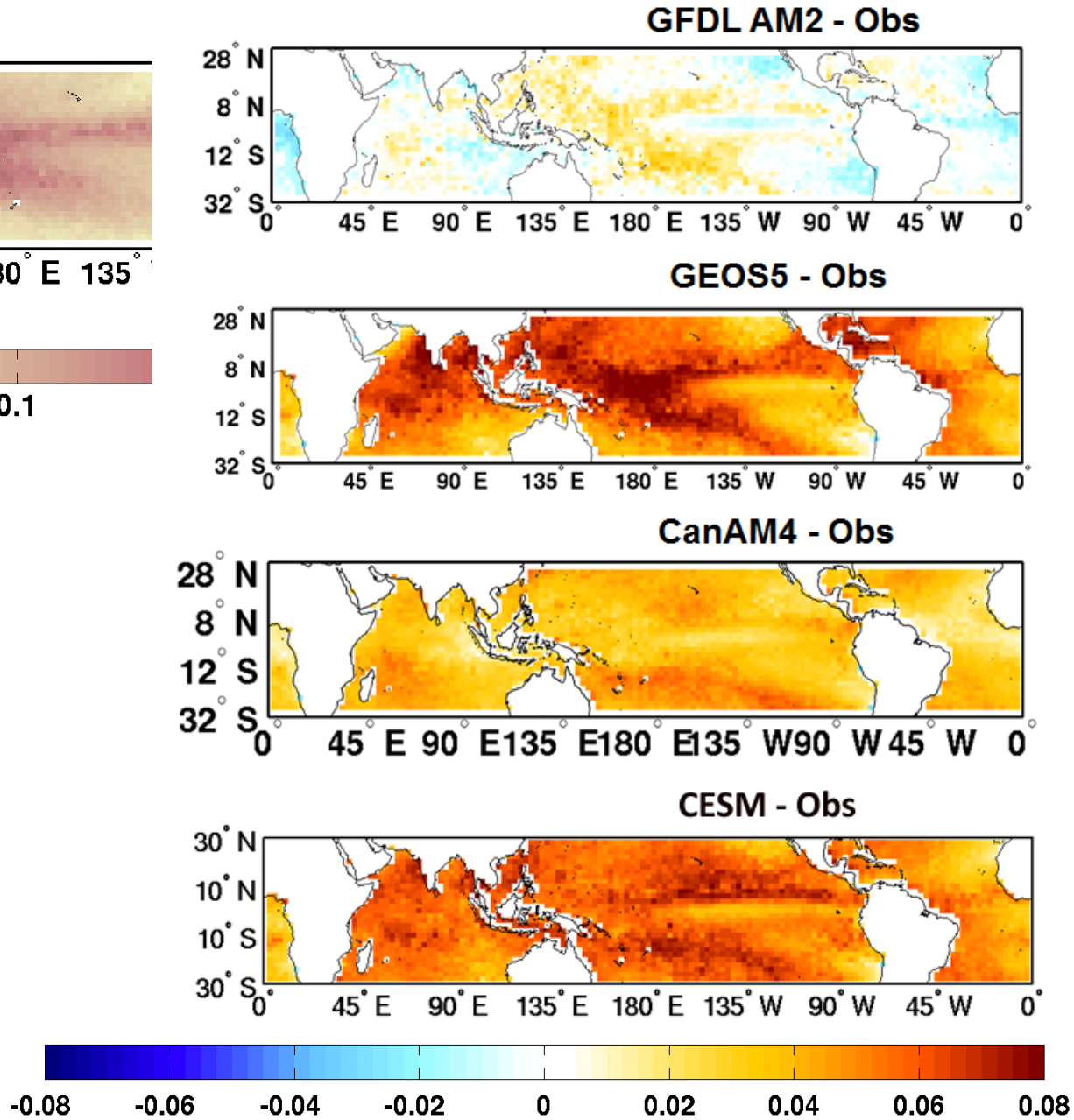




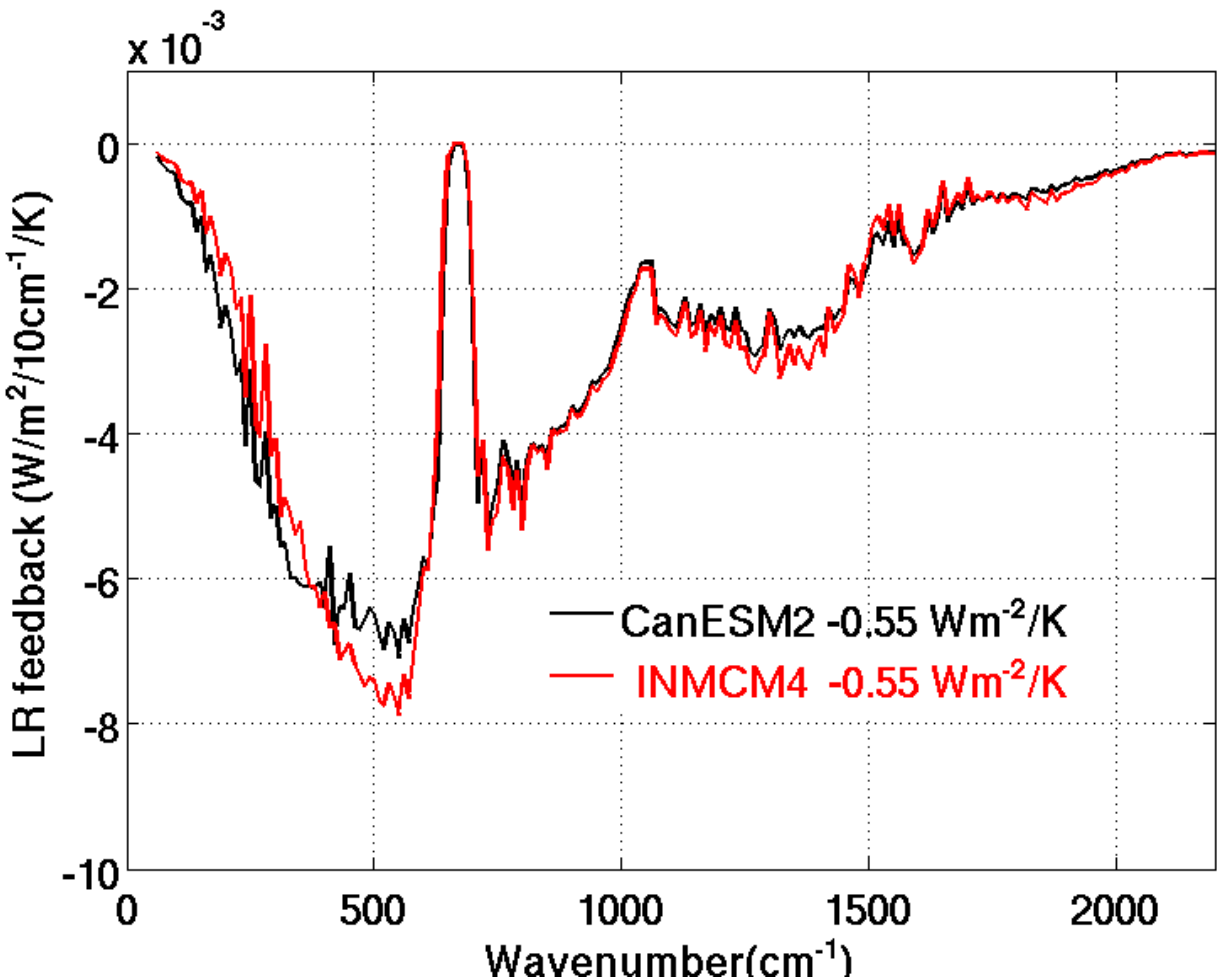
0.02 in fraction ~ 2.7 Wm^{-2}

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





Example 2: Spectral decomposition of broadband lapse-rate feedback



Contribution to ΔTs @2xCO_2

	0-400 LR
CanESM2	-0.08K
INMCM4	-0.04K

Can we get spectral flux from satellite observations? the Spectral ADM approach

Soundings (AIRS, CrIS, IASI, HIRS, etc.): radiance (W m^{-2} per freq per sr.)

Flux (ERBE, CERES, GERB): flux (Wm^{-2})

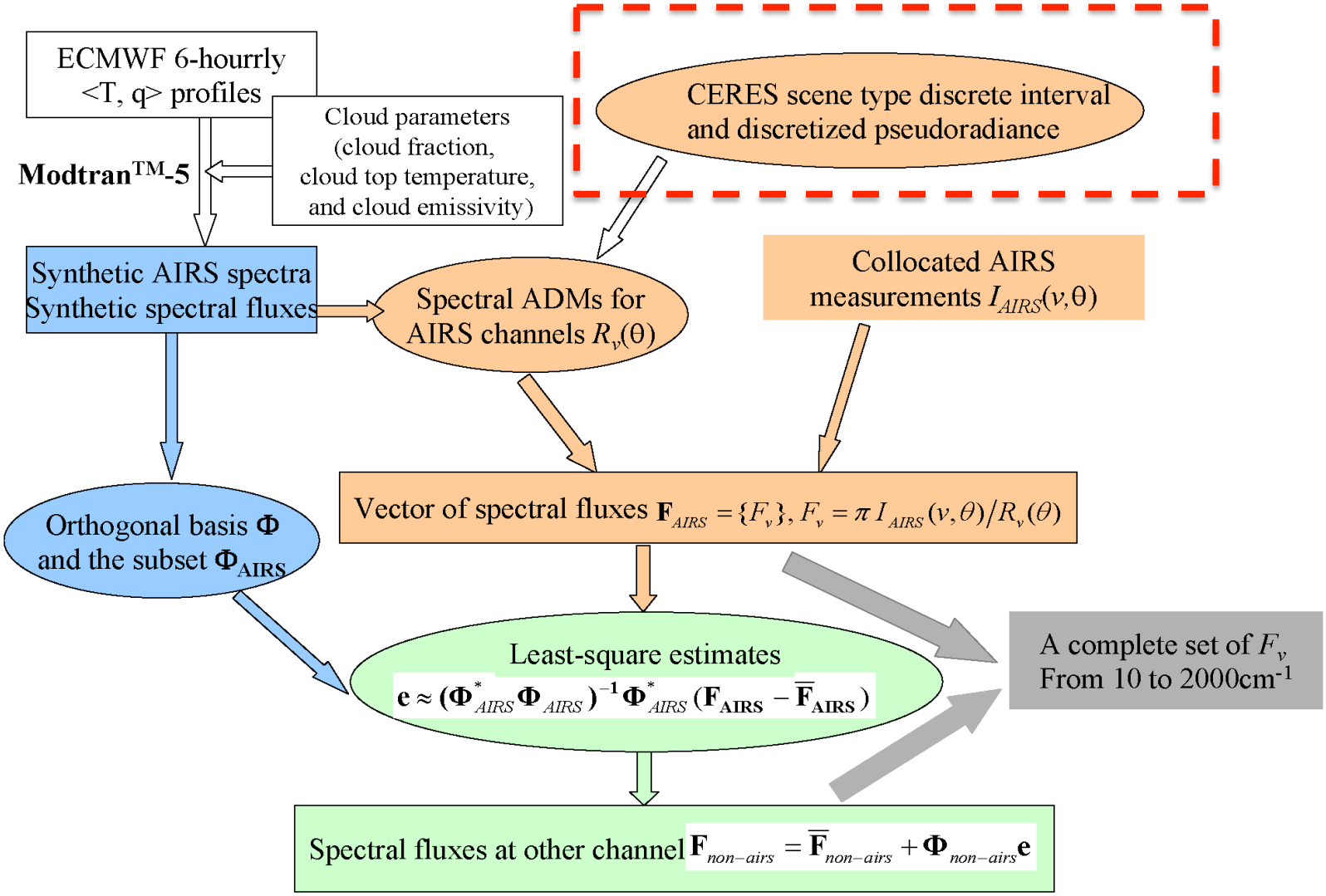
$$F = 2\pi \int_{\Delta v} dv \int_0^1 I(v;\mu)\mu d\mu \quad (\mu = \cos\theta)$$

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

(Huang et al., 2008; Huang et al., 2010; Chen et al., 2013; Huang et al., 2014)

http://www-personal.umich.edu/~xianglei/airs2ceres.html

Obtain spectral flux from observations



CERES flux and radiance are never used. Only ancillary info in the CERES datasets are used.

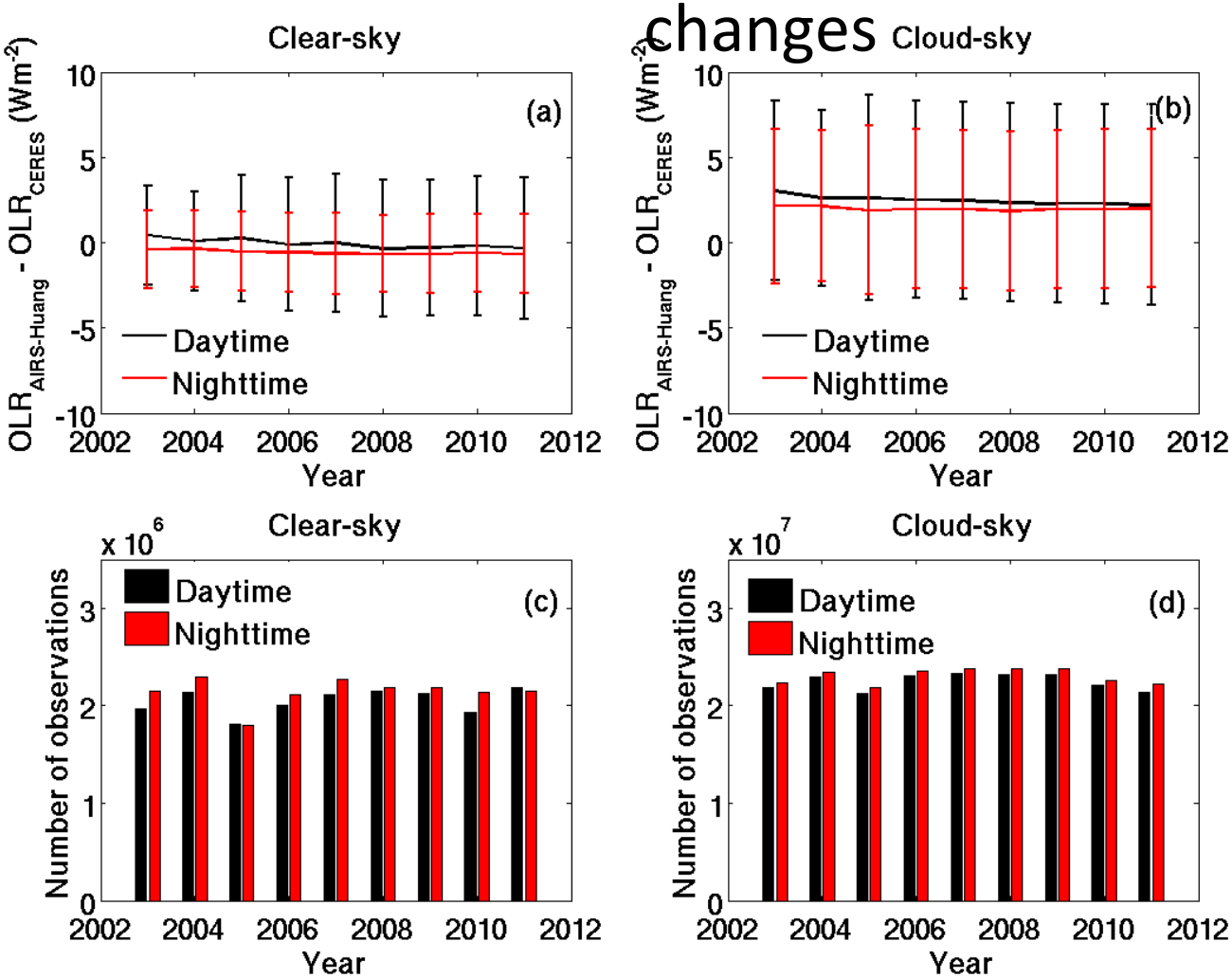
Output: spectral flux at 10cm^{-1} intervals through the entire longwave spectral range

Stratifying OLR_{AIRS_Huang}-OLR_{CERES} (Wm^{-2}): cloudy observations over the lands

f \ ΔT_{sc}	Over deserts			Over non-desert lands		
	<15k	15K-40K	>40K	<15k	15K-40K	>40K
0.001-0.5	2.44±3.79 (0.9%)	3.25±5.12 (1.2%)	1.49±7.61 (0.5%)	2.34±2.86 (0.8%)	3.62±4.48 (1.3%)	2.84±5.94 (1.0%)
0.5-0.75	2.79±4.16 (1.1%)	3.34±7.80 (1.3%)	1.39±12.75 (0.5%)	2.90±3.86 (1.1%)	4.24±7.25 (1.7%)	2.61±11.38 (1.0%)
0.75-0.999	2.67±3.67 (1.1%)	1.45±6.47 (0.6%)	-1.17±10.97 (-0.5%)	2.81±3.56 (1.2%)	3.14±6.68 (1.4%)	0.47±11.45 (0.2%)
0.999-1.0	2.61±2.80 (1.2%)	3.15±4.00 (1.6%)	1.28±6.64 (0.7%)	2.86±2.83 (1.3%)	4.04±4.33 (2.0%)	2.48±7.16 (1.5%)

CERES 2σ radiometric calibration uncertainty: 1% (i.e. ~ 2.5W m^{-2})

Global OLR_{AIRS_Huang}-OLR_{CERES}: annual means and year to year changes



Usages: (1) Model evaluation; (2) Tuning for SARB product; (3) Obs-based cloud radiative kernel (Yue et al., 2016, J Climate)

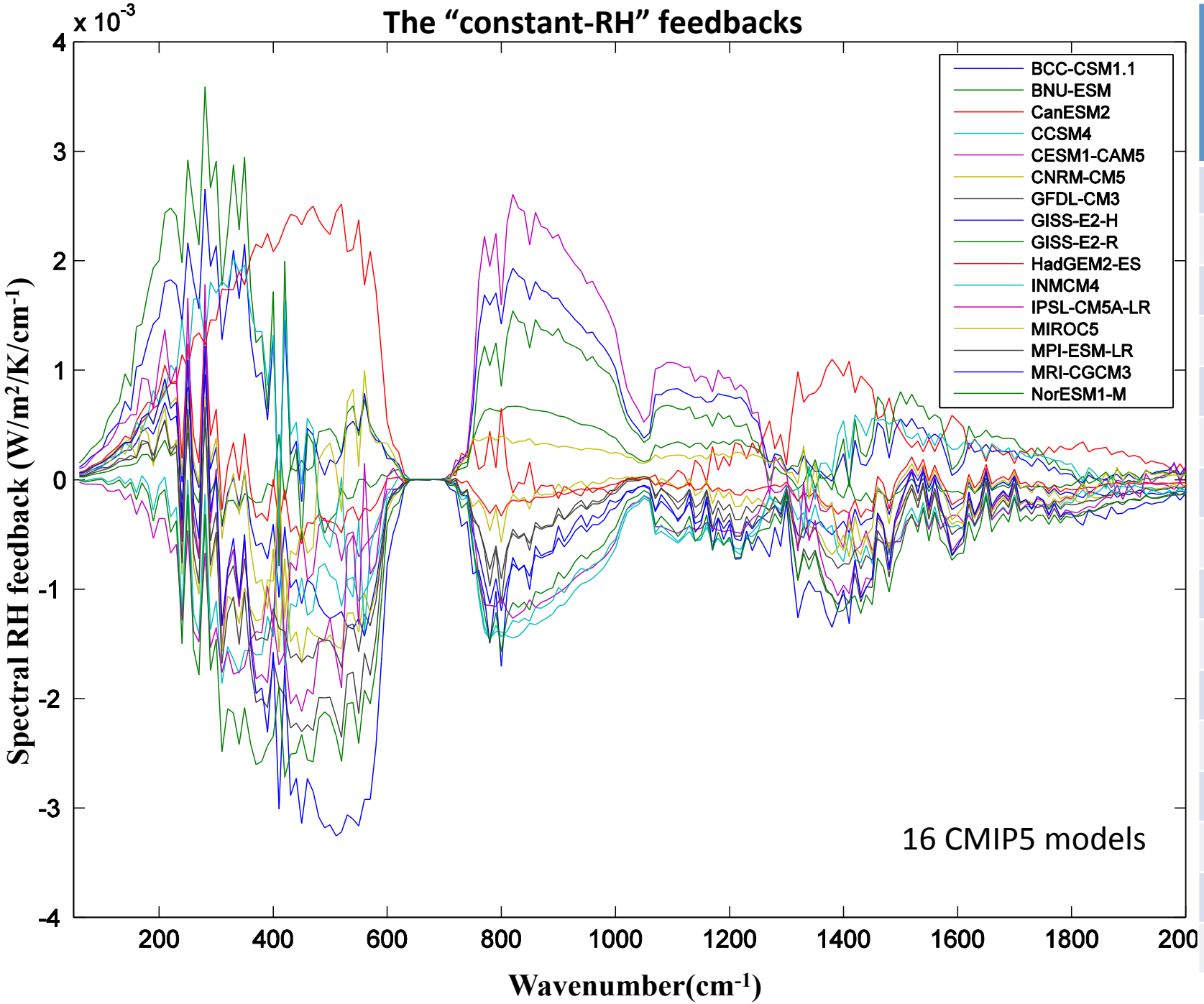
Spectral radiative feedbacks

- Following the broadband radiative kernel approach, we have developed and validated a set of LW Spectral Radiative Kernel (SRK; Huang et al., 2014b)
- With this set of LW SRK, you can derive LW spectral feedbacks from **monthly-mean** CMIP3/CMIP5 archives.

$$\lambda_X = -\frac{\delta_X \overline{R}}{\delta X}\frac{\delta X}{\delta T_s} \quad \mathrm{Wm^{-2}\,K^{-1}}$$

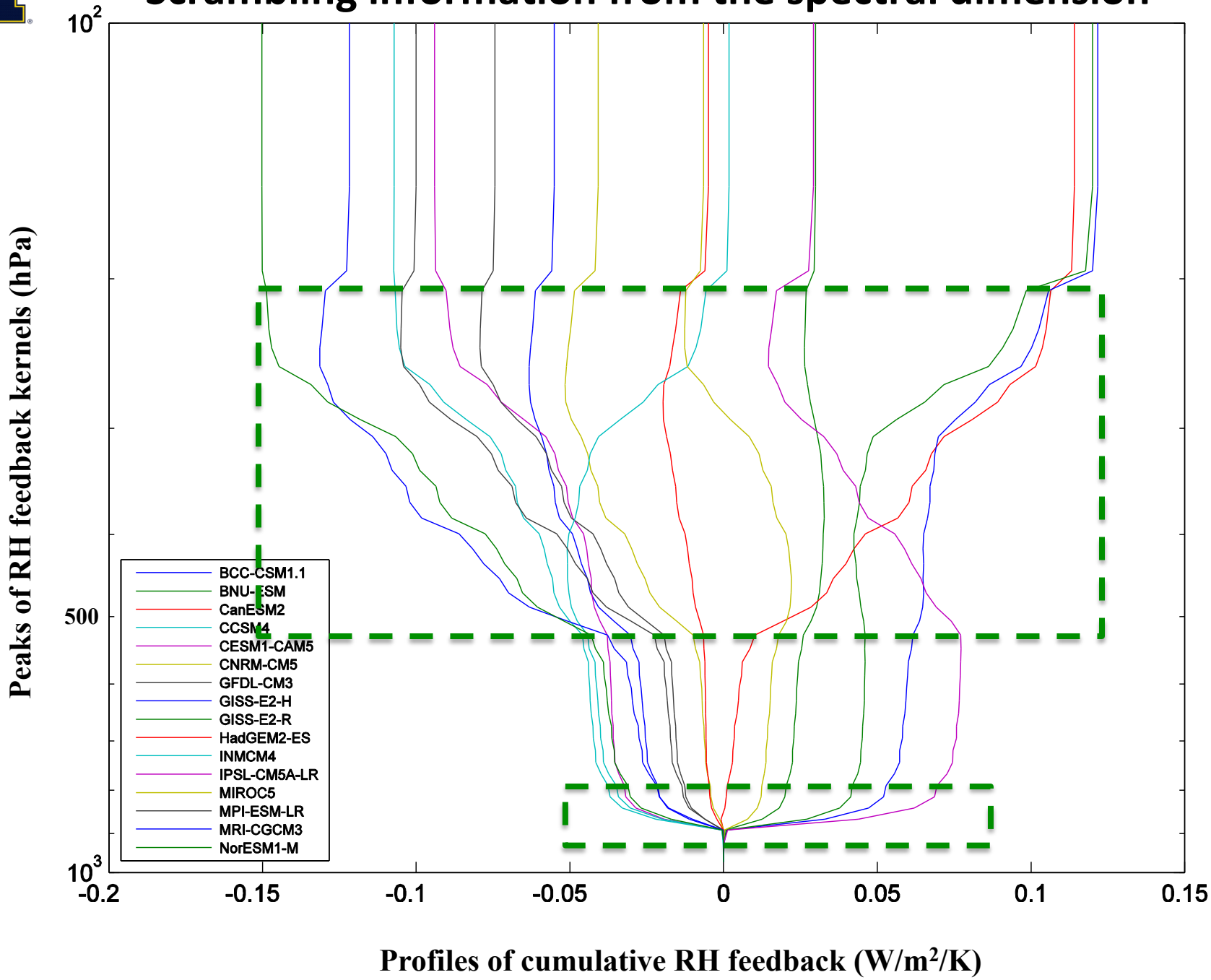
$$\lambda_{x_\nu} = -\frac{\delta_x \overline{R_\nu}}{\delta X}\frac{\delta X}{\delta T_s} \quad \mathrm{Wm^{-2}\,cm^{-1}\,K^{-1}}$$

The LW SRK can be provided upon request



Broadband RH feedback ($W/m^2/K$)
-0.055
0.030
0.114
-0.107
-0.094
-0.041
-0.074
0.122
0.120
-0.005
0.002
0.029
-0.007
-0.100
-0.122
-0.150

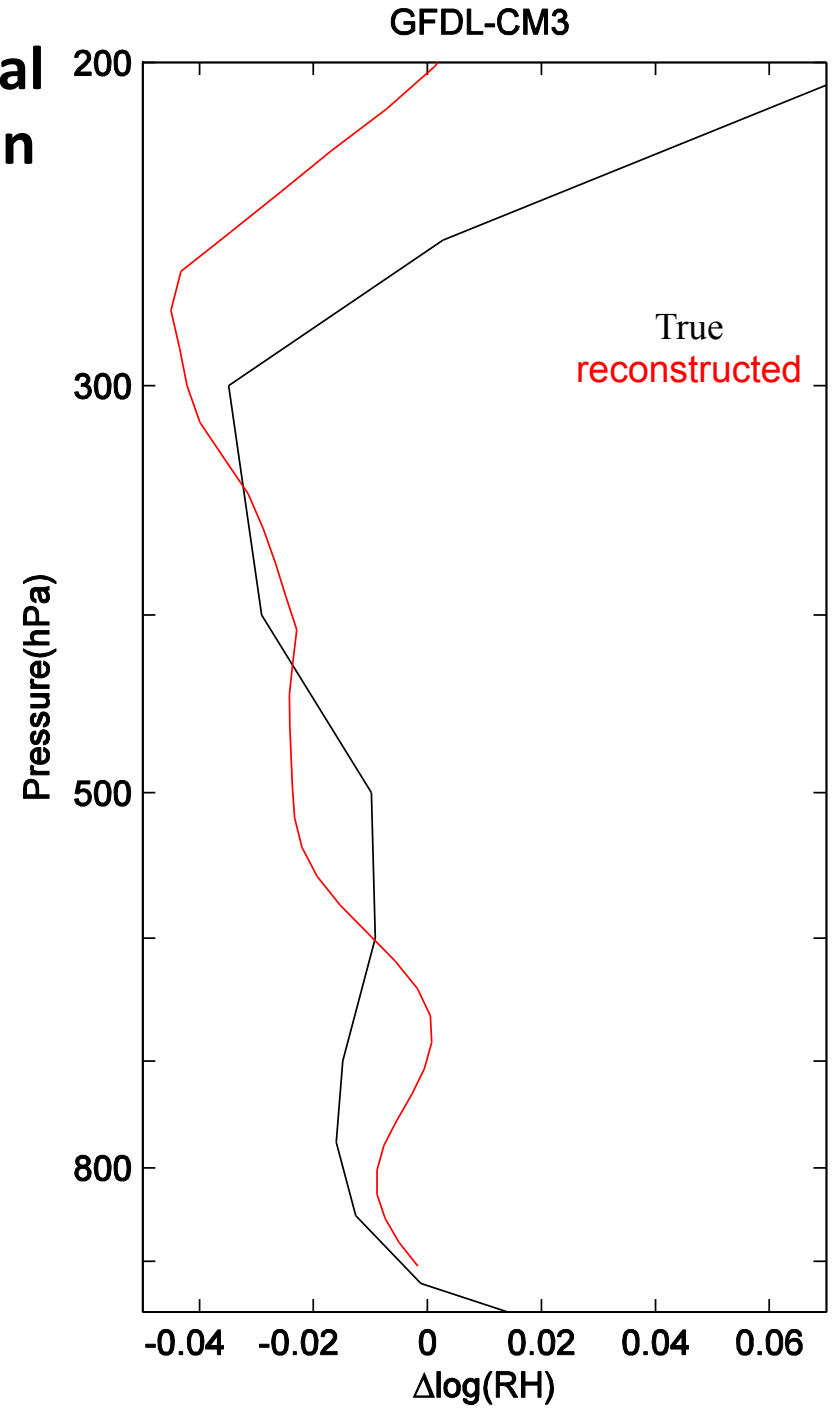
Scrambling information from the spectral dimension



Scrambling information from the spectral dimension: a truncated SVD approach (in progress)

True: actual Δlog(RH)
From CM3 1% CO_2 simulation.

Reconstructed: a truncated-SVD estimate from the CM3 spectral RH feedback (9 leading singular values).



Conclusions and Discussions

- Spectral dimension has its potential in model development and climate diagnostics
  - It can help expose offset biases
  - Available from observations
  - Computable from model archives (or online simulator)
- How to include spectral band info in the tuning of GCM/NWP model?
- Biases in radiation budget and biases in geophysical variables
  - *Can the spectral diagnostics be the bridge to make the closure for error diagnostics in energy budgets and in thermodynamic fields?*

Monthly gridded spectral flux and CRE (Sep 2002 to Nov 2014) are available via http://www-personal.umich.edu/~xianglei/datasets.html.
The spectral radiative kernels available upon request.

Thank You!

References:

1. Huang et al., 2008: Spectrally resolved fluxes derived from collocated AIRS and CERES measurements and their application in model evaluation, Part I: clear sky over the tropical oceans, *JGR-Atmospheres*, 113, D09110, doi:10.1029/2007JD009219.
2. Huang et al., 2010: Spectrally resolved fluxes derived from collocated AIRS and CERES measurements and their application in model evaluation, Part II: cloudy sky and band-by-band cloud radiative forcing over the tropical oceans, *JGR-Atmospheres,* 115, D21101, doi:10.1029/2010JD013932.
3. Huang et al., 2013: Longwave band-by-band cloud radiative effect and its application in GCM evaluation, *Journal of Climate*, 26(2), 450-467, doi:10.1175/JCLI-D-12-00112.1.
4. Chen et al., 2013: Comparisons of clear-sky outgoing far-IR flux inferred from satellite observations and computed from three most recent reanalysis products, *Journal of Climate*, 26(2), 478-494, doi:10.1175/JCLI-D-12-00212.1.
5. Huang et al., 2014: A global climatology of outgoing longwave spectral cloud radiative effect and associated effective cloud properties, *Journal of Climate*, 27, 7475-7492, doi:10.1175/JCLI-D-13-00663.1.
6. Huang, X. L., X. H. Chen, B. J. Soden, X. Liu, 2014b: The spectral dimension of longwave feedbacks in the CMIP3 and CMIP5 experiments, *Geophysical Research Letters*, 41, doi:10.1002/2014GL061938.

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Averages of net TOA **broadband** flux R(x,y;t)

$$\lambda_X = -\frac{\delta_X \overline{R}}{\delta X}\frac{\delta X}{\delta T_s}$$

$Wm^{-2}\,K^{-1}$

Change of global-mean surface temperature

X : [Temp, WV, cloud, albedo]

(Soden et al., 2008)

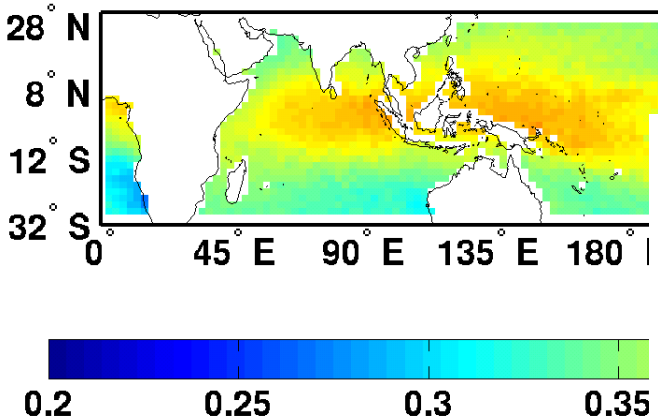
$\overline{R}$ has another dimension, the frequency v

Spectral radiative feedbacks

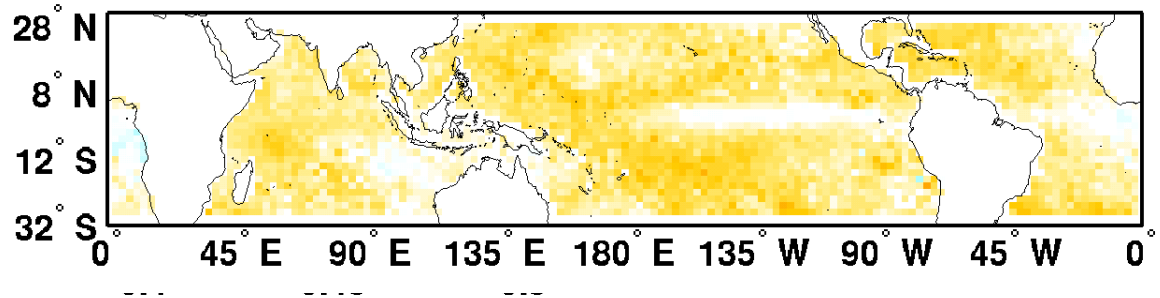
$$\lambda_{x_v} = -\frac{\delta_x \overline{R_v}}{\delta X}\frac{\delta X}{\delta T_s}$$

$Wm^{-2}\,cm^{-1}\,K^{-1}$

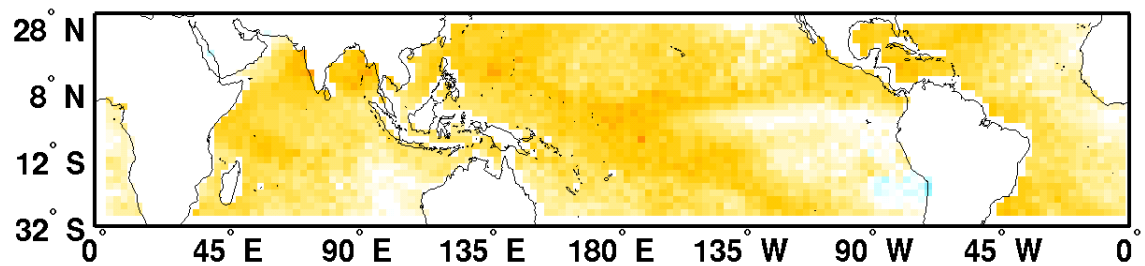
Collocated AIRS & CERES obs. LW broadband *2004 Annual Mean*



GFDL AM2 - Obs



GEOS5 - Obs



All AMIP runs

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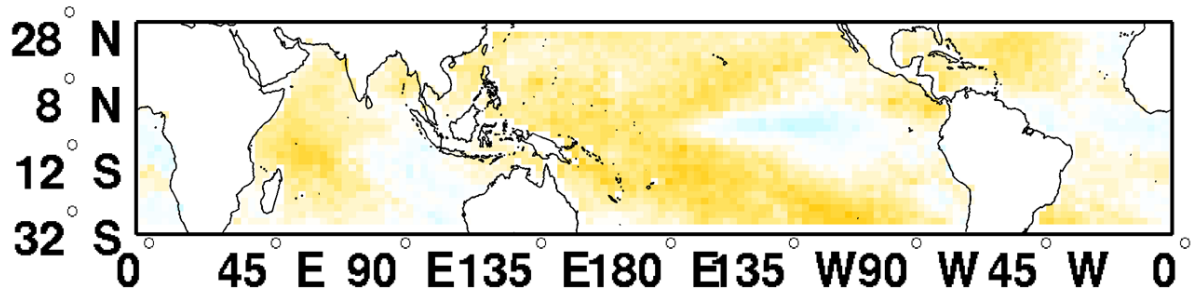
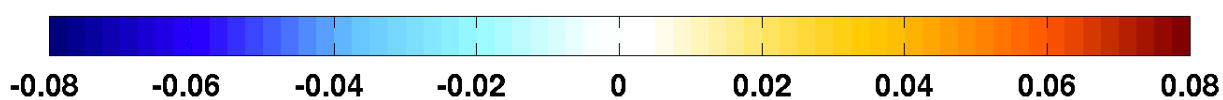
GEOS5	281.0 W m^{-2}
CGCM3.1	286.6 W m^{-2}

CanAM4 - Obs





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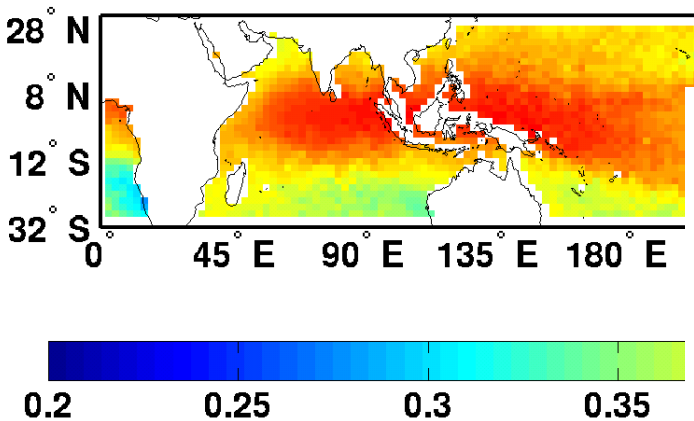

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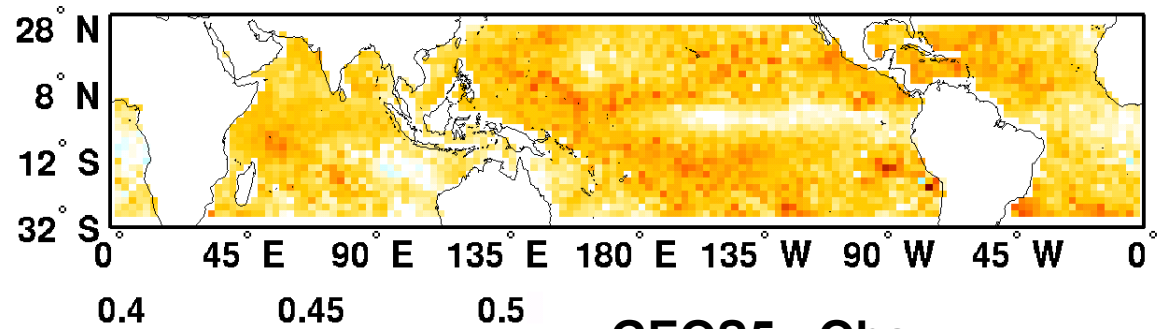

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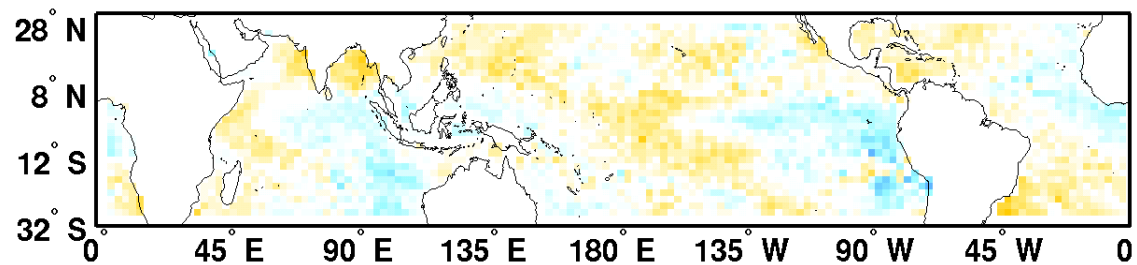
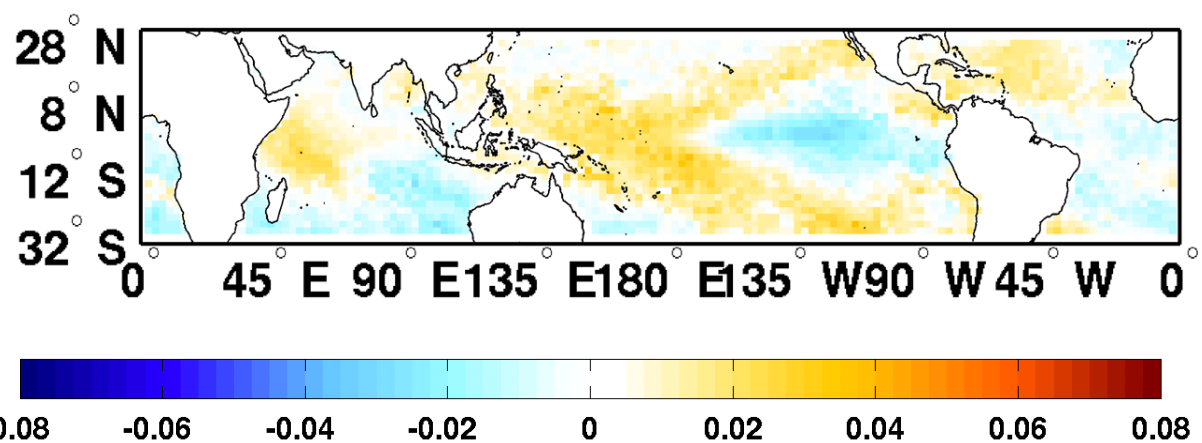
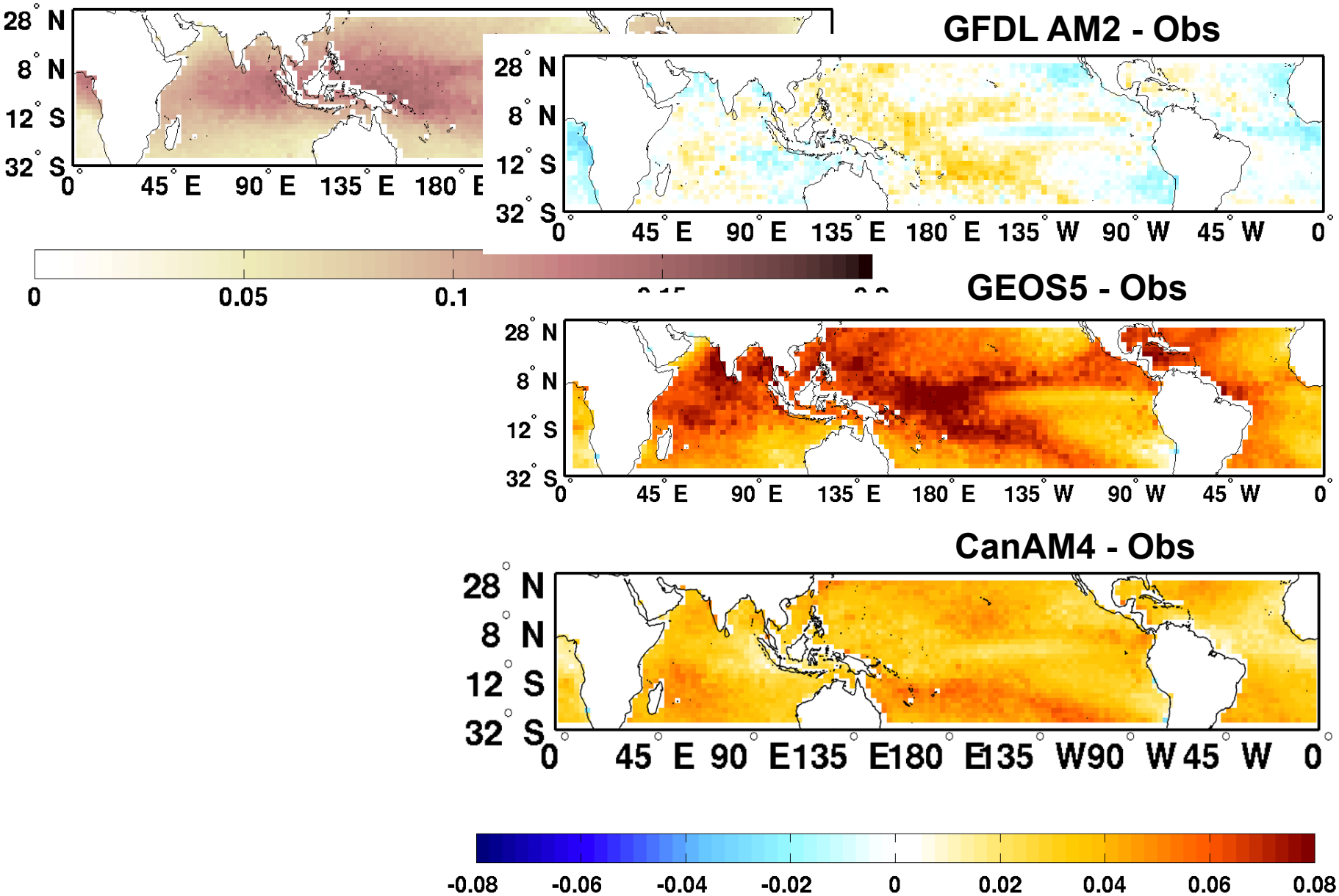


CanAM4 - Obs

0.02 in fraction ~ 2.7 Wm^{-2}



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