Spectral Decomposition of Cloud Radiative Effect and Cloud Radiative Feedbacks

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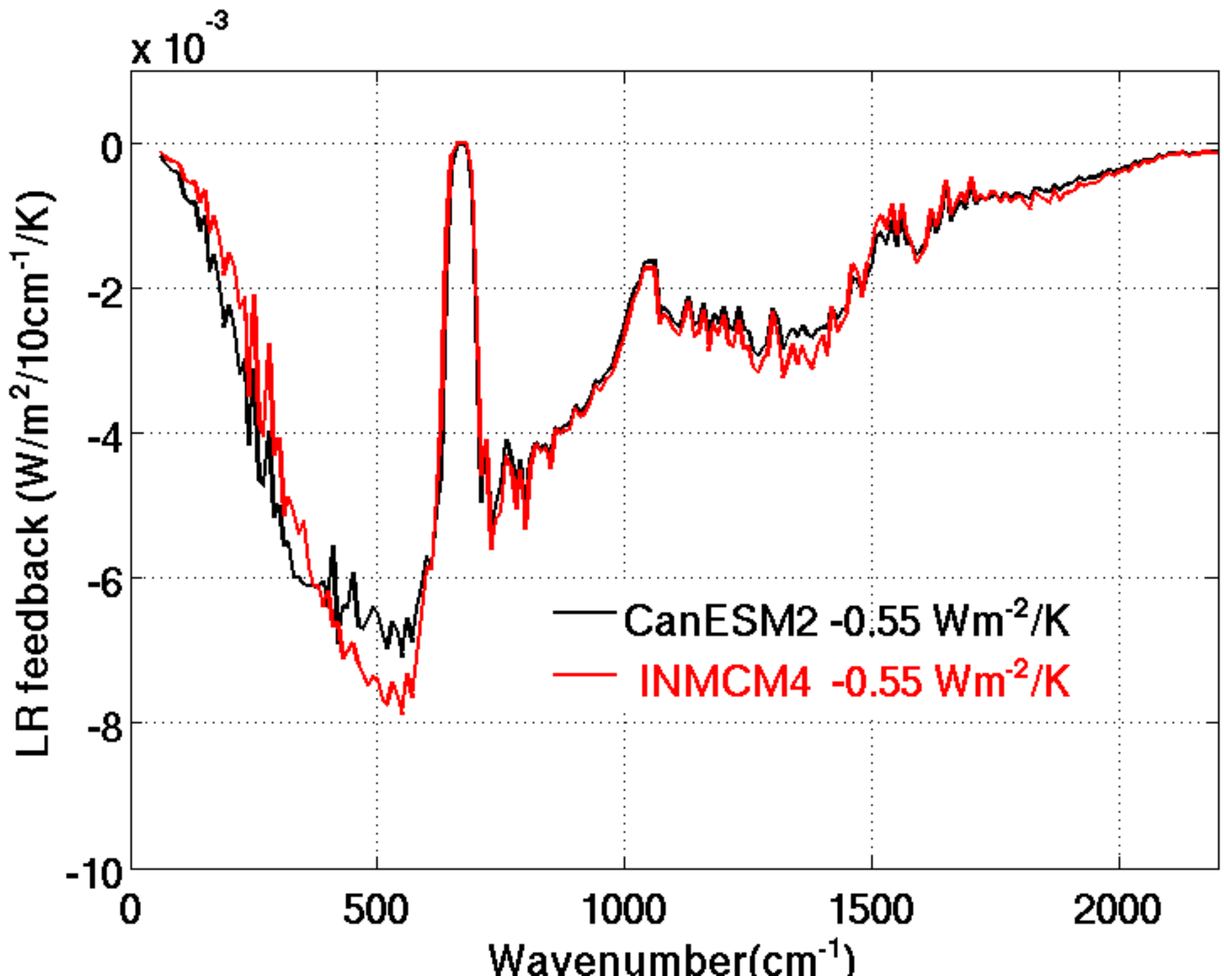
Outline

- Why go from broadband to spectral?
  - Two examples
- Traits in the spectral decomposition of CRE
- Band-by-band LW CRE: CESM vs. obs
- Band-by-band LW cloud feedbacks: 2xCO_2 CESM simulations
- Band-by-band LW short-term cloud radiative feedbacks (fluctuations): model vs. obs in 2003-2013
- Discussion and Conclusions

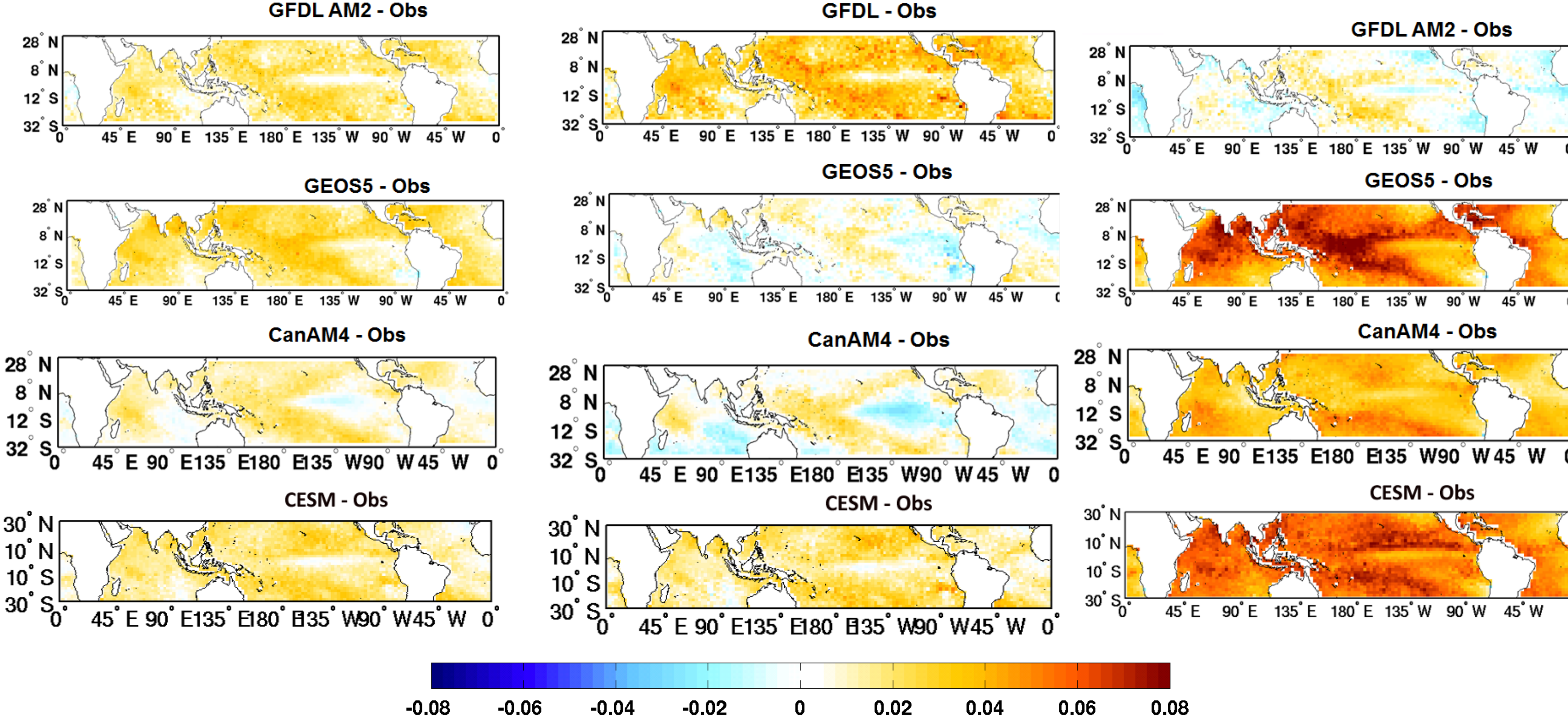
What spectral dimension can offer?

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



Spectral decomposition of broadband lapse-rate feedback
(Huang et al., 2014, GRL)

LW Broadband | **H_2O bands (0-540cm^{-1}, >1400 cm^{-1})** | **window region (800-980cm^{-1})**



clear-sky green-house efficiency

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

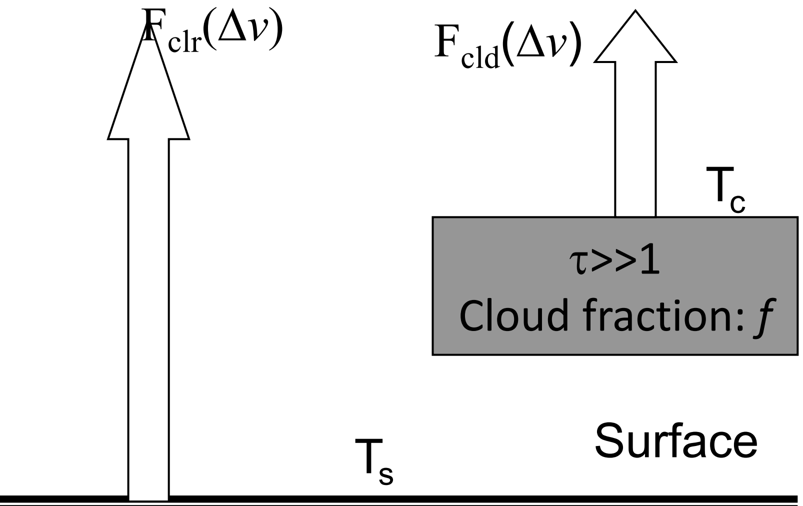
AMIP runs forced by observed SST

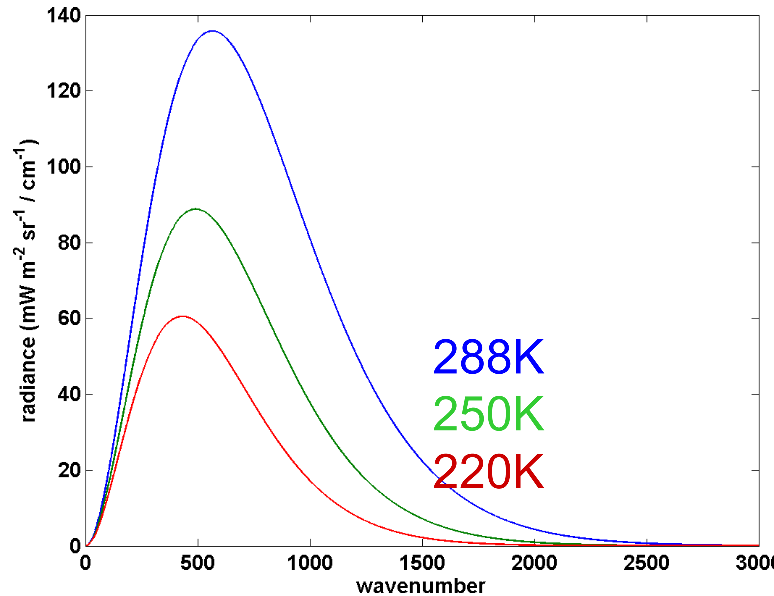
Obs from collocated AIRS and CERES (Huang et al., 2008; Chen et al., 2013)

(GEOS5 simulation provided by L. Oreopoulos et al; CanAM4 provided by J. Cole)

A trait of spectral (band-by-band) CRE

1. Blackbody cloud
2. Ignore atmospheric absorption





r(Δv) changes with T_c

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

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

Fractional contribution

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

Band-to-Band ratio: sensitive to CTH but not cloud amount

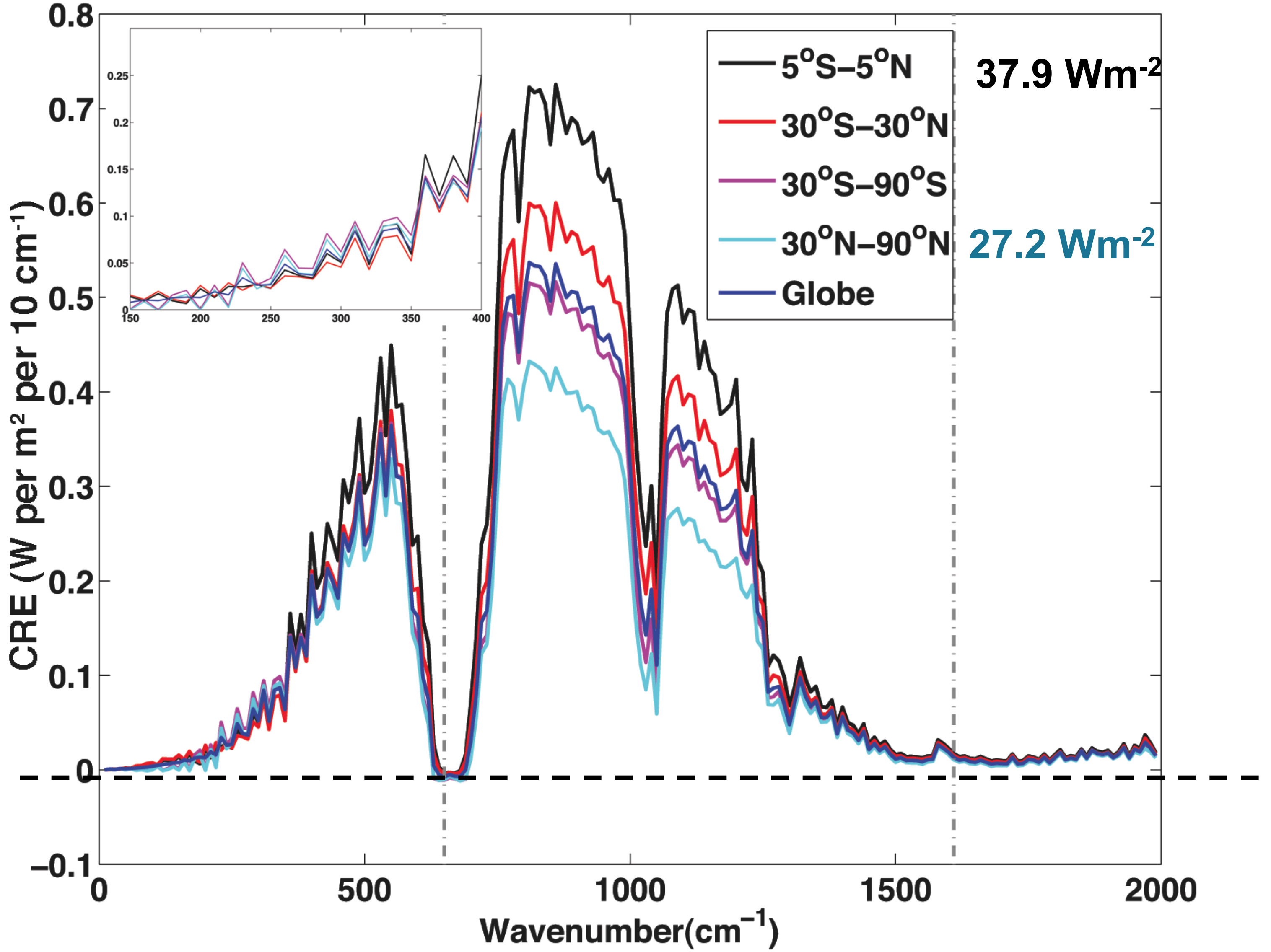
LW CRE: sensitive to both CTH and cloud amount

Outcome: ratio-then-broadband approach (Huang et al., 2014, J Climate)

Derivation of spectral fluxes/CRE/feedbacks

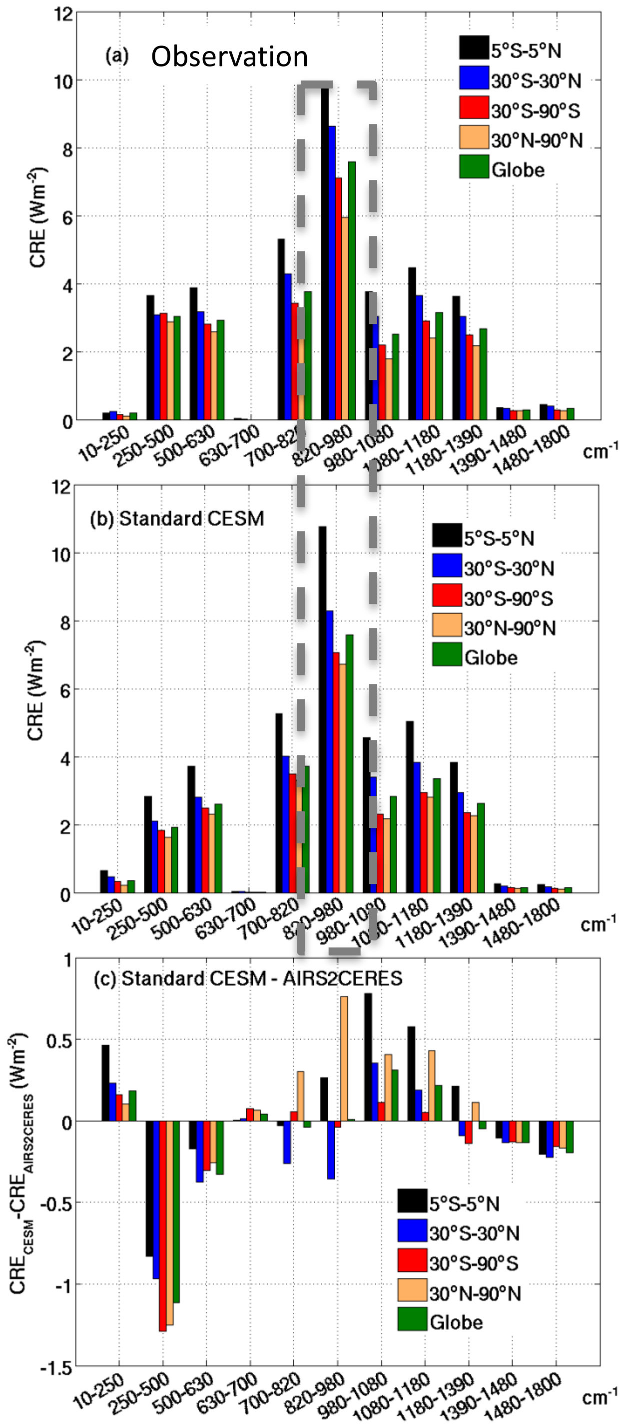
- Observations
  - Invert from AIRS radiances following the scene type classification of CERES (Huang et al., 2008; Chen et al, 2013; Huang et al., 2014)
  - Outcome: spectral flux at $10 cm^{-1}$ interval over the entire LW spectrum (09/2002 to present)
  - Observation-based cloud radiative kernel (Yue et al., 2016)
- Models
  - Simple code modification to output band-by-band fluxes
  - Spectral radiative kernels (Huang et al., 2014, GRL) to derive spectral details of Planck/Lapse-rate/WV feedbacks
  - Adjustment methods to get spectral cloud radiative feedbacks

10-year mean spectral CRE over the different climate zones



(Huang et al., 2014, J Climate)

Band-by-band CRE (RRTMG_LW bandwidths)



Observed averages of 2003-2015

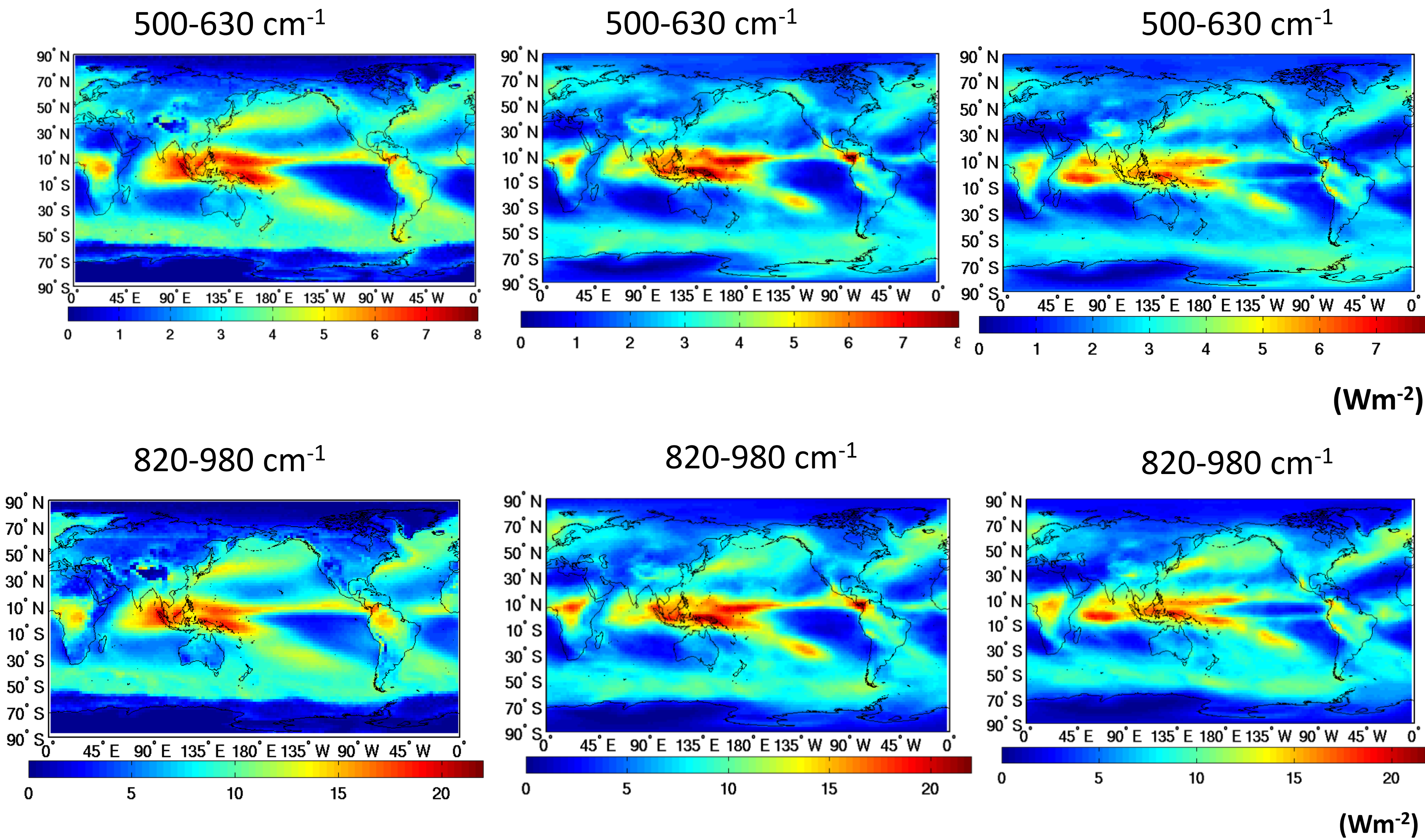
CAM5 forced with observed SST from 2003 to 2015 (total run 2000-2015)

Differences of Model - Obs

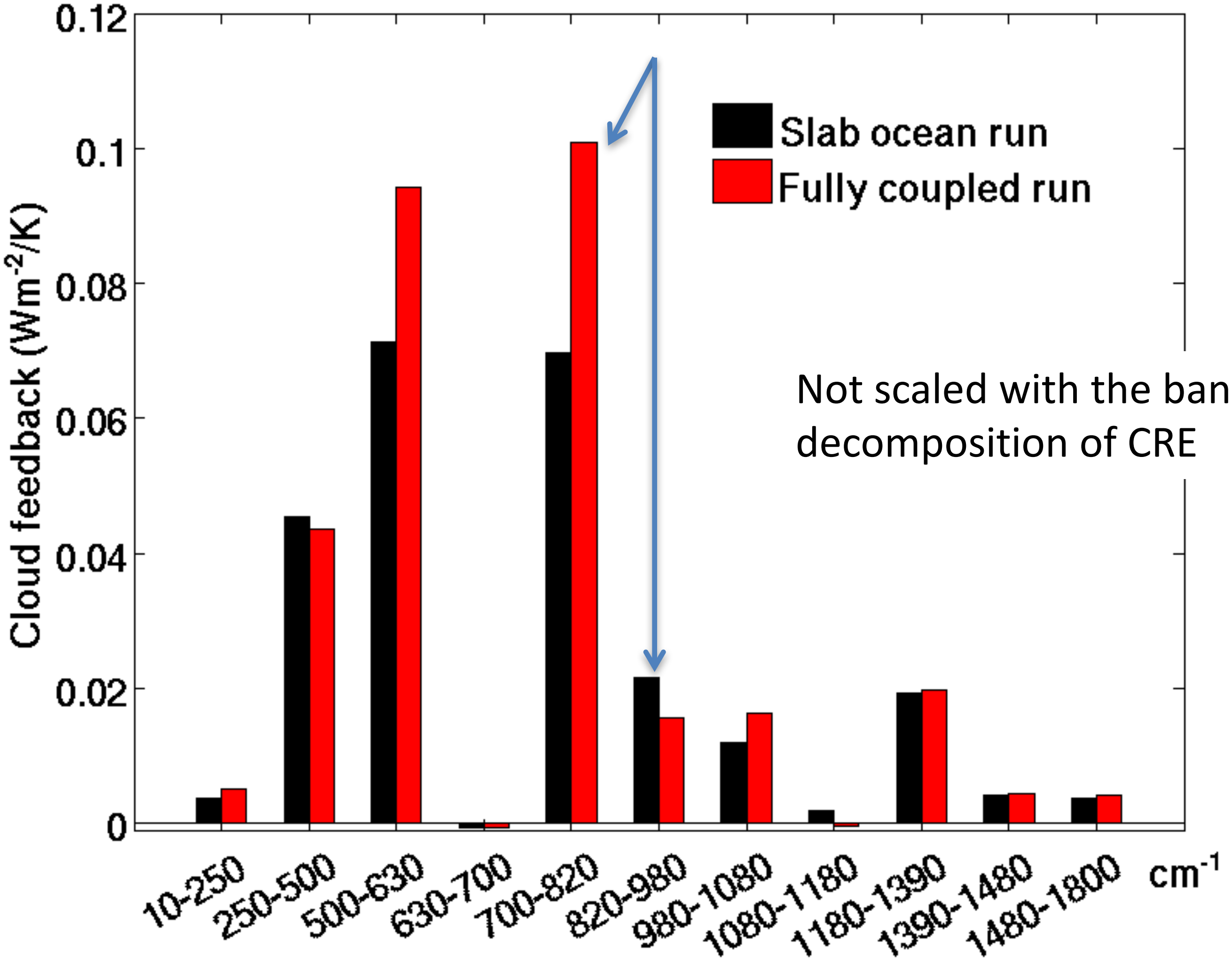
Observation: 2003-2015

CAM5 forced by observed SST 2003-2015

CESM fully-coupled run 30-year mean



Band-by-band LW cloud feedback in the NCAR CESM (2xCO_2 run)

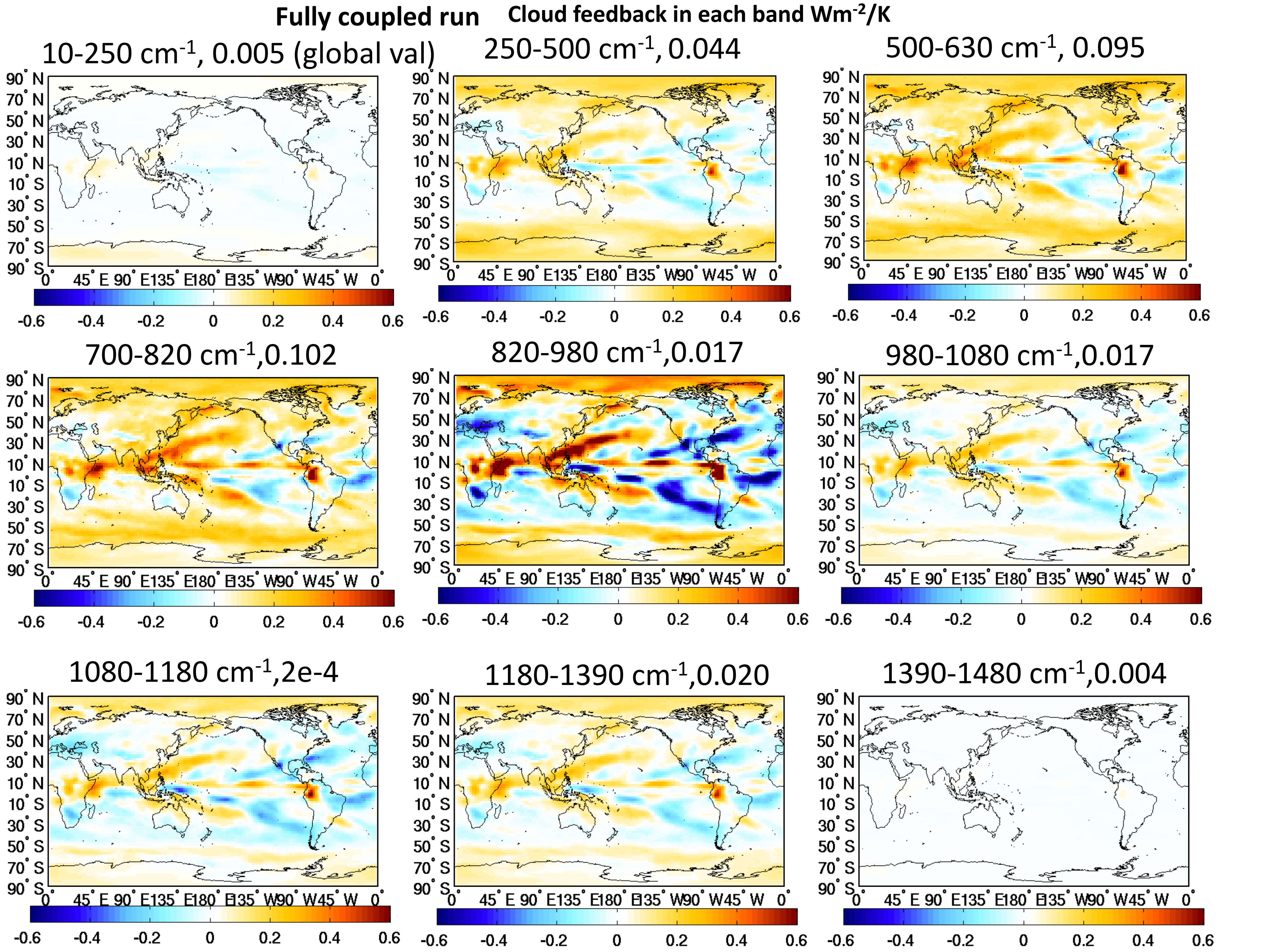


Not scaled with the band-by-band decomposition of CRE

Broadband LW cloud feedback

Slab ocean run: 0.25 Wm^{-2}/K

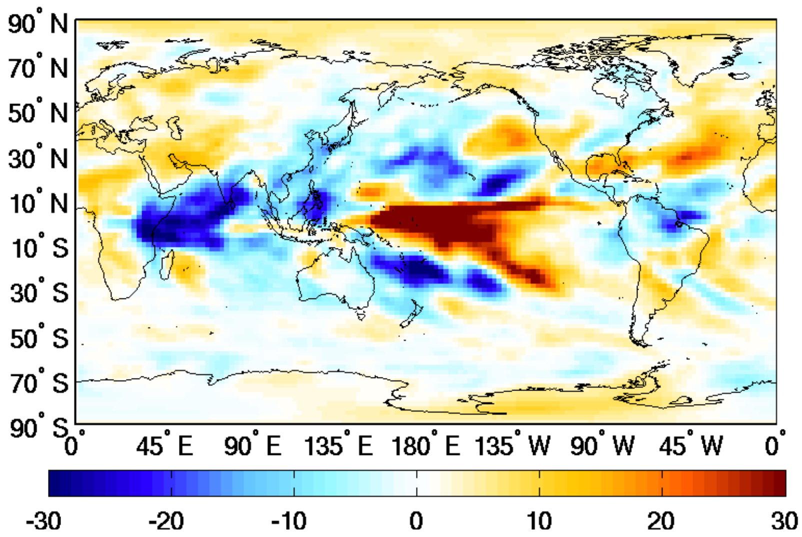
Fully coupled run: 0.31 Wm^{-2}/K


Fully coupled run
Cloud feedback in each band Wm-2/K
10-250 cm-1, 0.005 (global val)
250-500 cm-1, 0.044
500-630 cm-1, 0.095
700-820 cm-1,0.102
820-980 cm-1,0.017
980-1080 cm-1,0.017
1080-1180 cm-1,2e-4
1180-1390 cm-1,0.020
1390-1480 cm-1,0.004
90° N 70° N 50° N 30° N 10° N 10° S 30° S 50° S 70° S 90° S
0° 45° E 90° E135° E180° E135° W90° W45° W 0°
-0.6 -0.4 -0.2 0 0.2 0.4 0.6

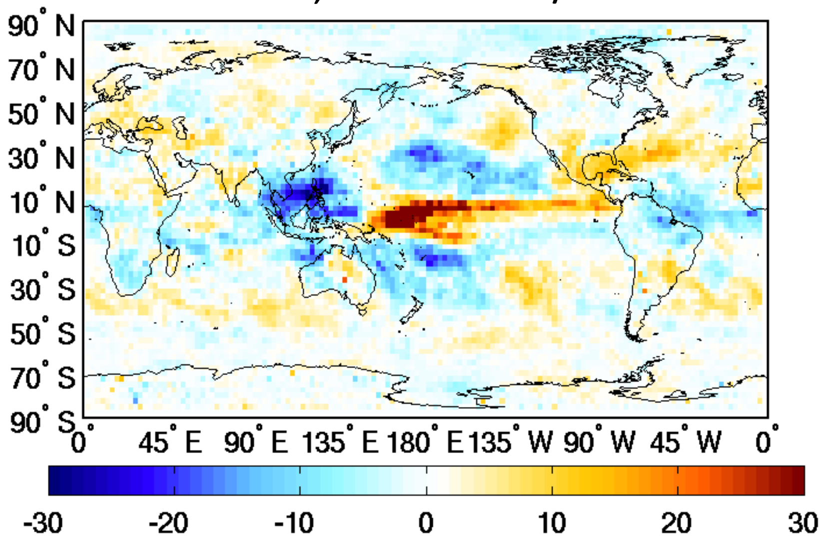
Short-term fluctuation of 2003-2015 (Preliminary)

- CESM simulation: using Dessler's method to obtain an estimation of short-term cloud feedback
- Observation: applying Yue et al. (2016) to MODIS, AIRS and CERES data to obtain the same quantity

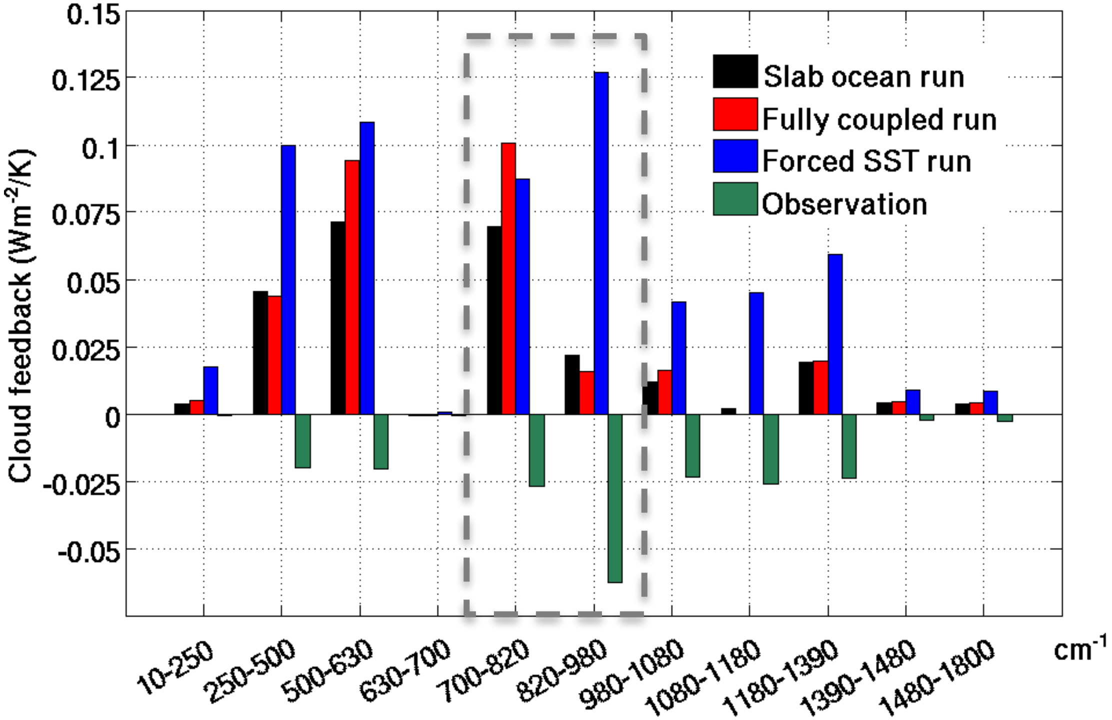
CESM, 0.61 Wm^{-2}/K



Obs, -0.21 Wm^{-2}/K



Long-term vs. short-term contrast



Broadband LW cloud feedback

Slab ocean run: 0.25 Wm^{-2}/K

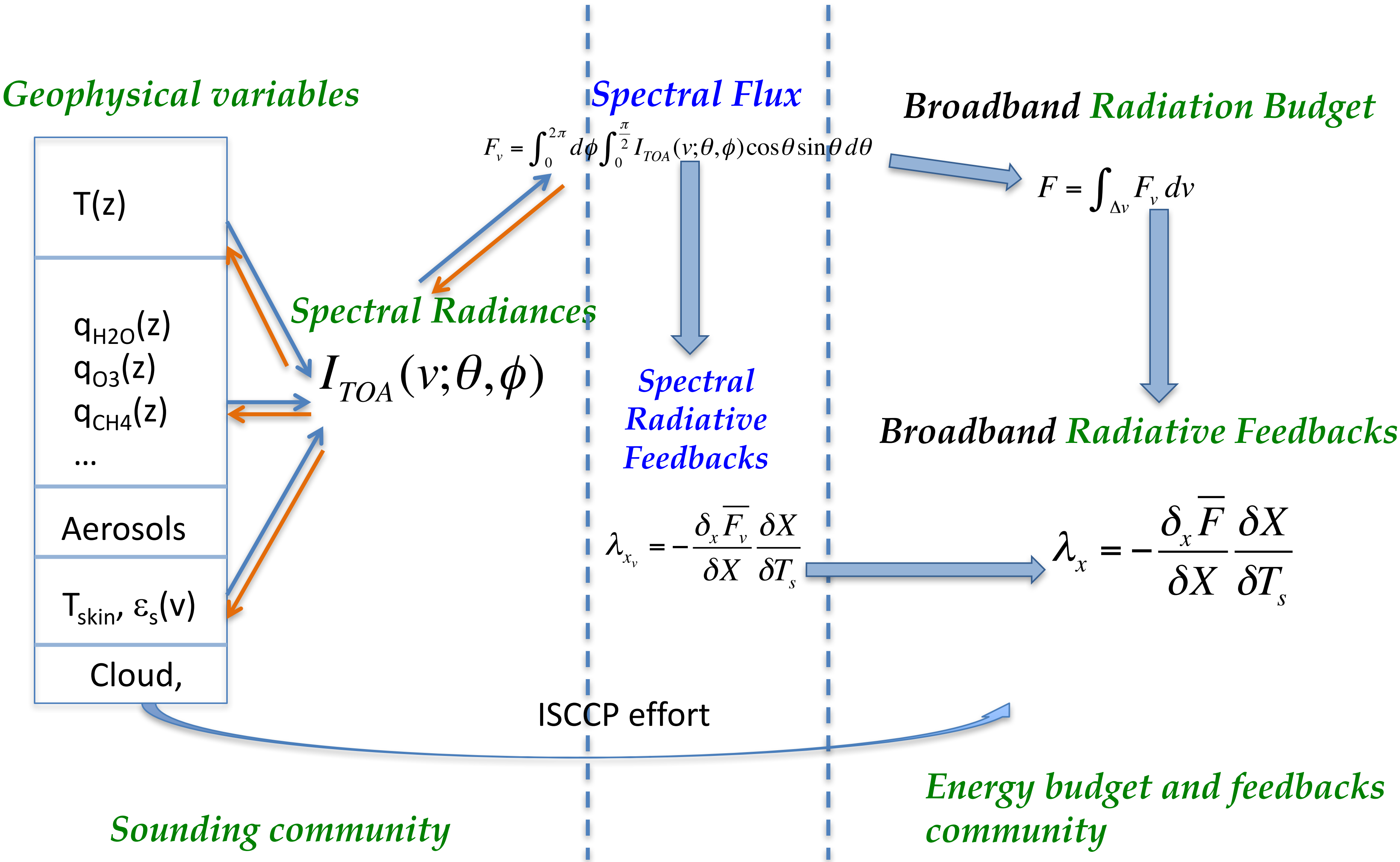
Fully coupled run: 0.31 Wm^{-2}/K

Forced SST run: 0.61 Wm^{-2}/K

Observation: -0.21 Wm^{-2}/K

Conclusion and Discussion

- Spectral decomposition helps revealing compensating biases.
  - For cloud, it helps untangle the biases in CTH and cloud amount
- For RRTMG bandwidths, 820-980cm^{-1} contributes most to the CRE. But 700-820 cm^{-1} contributes most to the cloud feedback (2xCO_2 run)
- The long-term vs. short-term cloud feedback has different spectral decomposition
  - Implications


Geophysical variables
T(z)
$q_{H2O}(z)$
$q_{O3}(z)$
$q_{CH4}(z)$
…
Aerosols
T_{skin}, $\varepsilon_s(v)$
Cloud,
Spectral Radiances
$I_{TOA}(v;\theta,\phi)$
Spectral Flux
$F_v = \int_0^{2\pi} d\phi \int_0^{\frac{\pi}{2}} I_{TOA}(v;\theta,\phi)\cos\theta\sin\theta\, d\theta$
Spectral Radiative Feedbacks
$\lambda_{x_v} = -\frac{\delta_x \overline{F_v}}{\delta X}\frac{\delta X}{\delta T_s}$
Broadband Radiation Budget
$F = \int_{\Delta v} F_v\, dv$
Broadband Radiative Feedbacks
$\lambda_x = -\frac{\delta_x \overline{F}}{\delta X}\frac{\delta X}{\delta T_s}$
ISCCP effort
Sounding community
Energy budget and feedbacks community

Thank You!

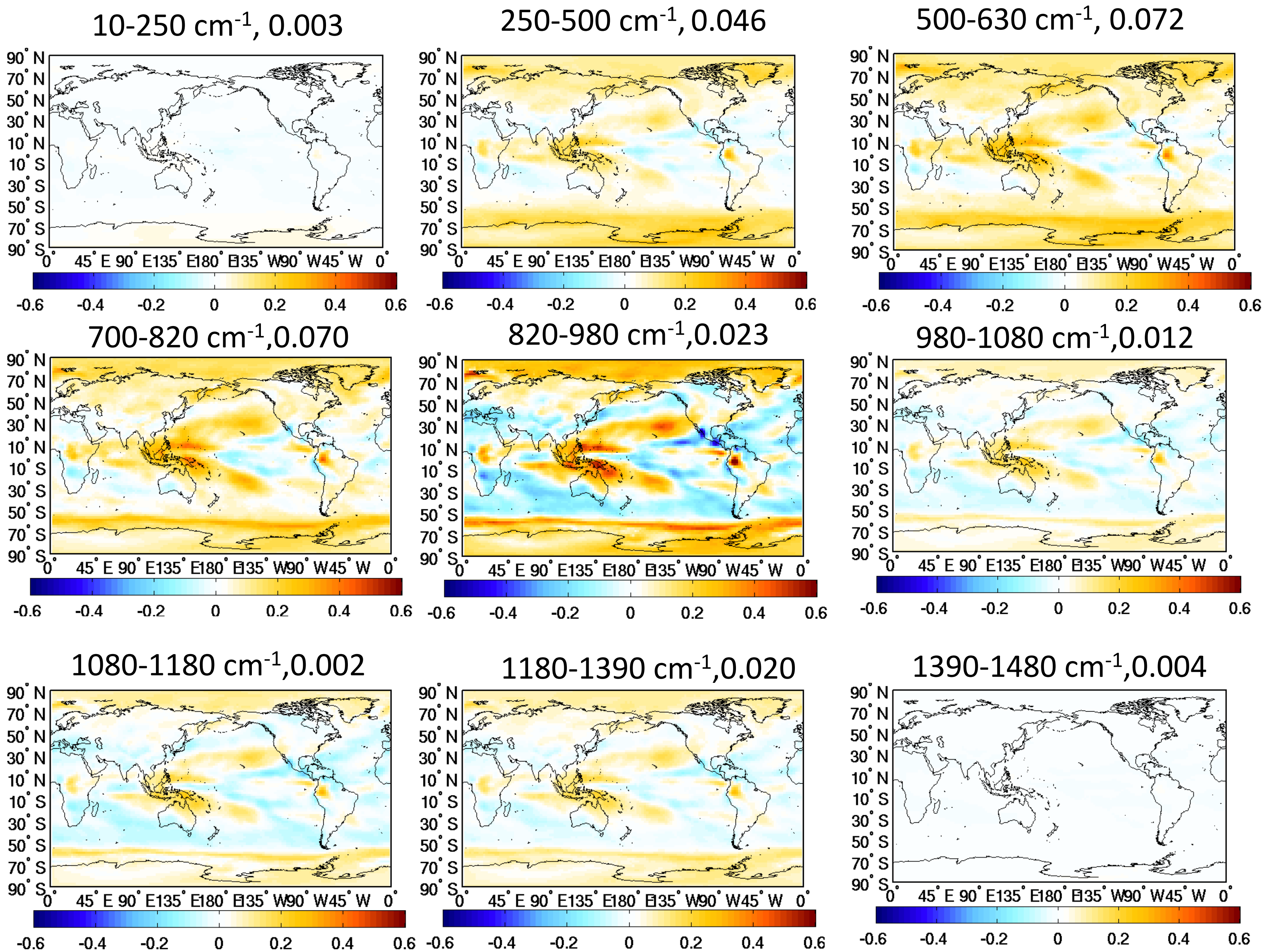
References:

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. 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.
3. 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.
4. Huang, X. L., X. H. Chen, B. J. Soden, X. Liu, 2014: The spectral dimension of longwave feedbacks in the CMIP3 and CMIP5 experiments, *Geophysical Research Letters*, 41, doi:10.1002/2014GL061938.
5. Yue, Q., B. H. Kahn, E. J. Fetzer, M. Schreier, S. Wong, X. H. Chen, X. L. Huang, 2016: Observation-based Longwave Cloud Radiative Kernels Derived from the A-Train, Journal of Climate, 29, 2023-2040.

Monthly gridded spectral flux and CRE available via http://www-personal.umich.edu/~xianglei/datasets.html.
The spectral radiative kernels available upon request.

Backup slides

Cloud feedback Wm^{-2}/K Slab ocean run, 6-35 yr



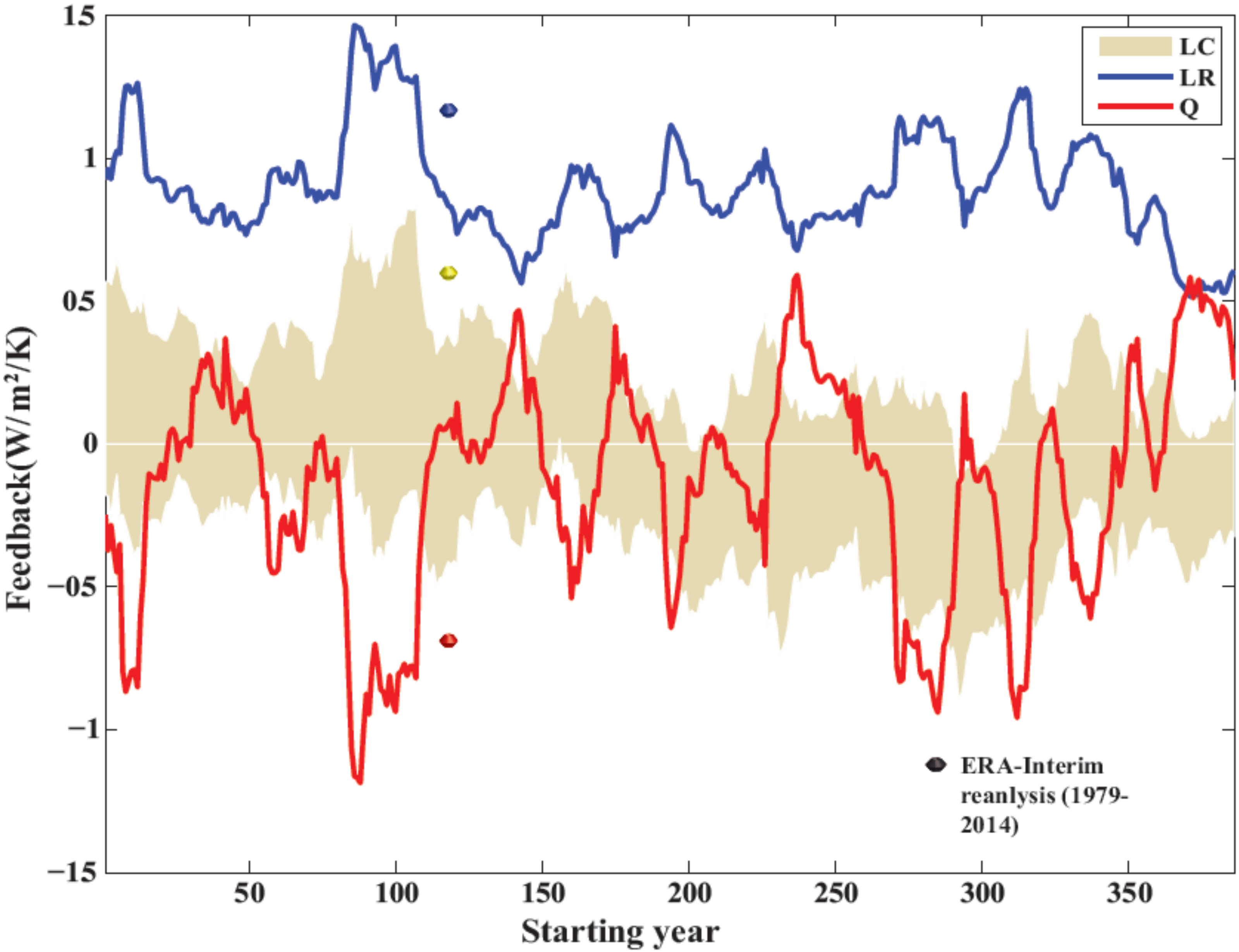


Fig 3. Short-term longwave cloud feedback (LC), lapse-rate feedback (LR), and water vapor feedback (Q) derived from different segments of 35-year CM3 simulations.

All collocated clear-sky observations in 2004 (80° S-80° N)

Surface Type	Daytime	Nighttime
	OLR_{AIRS_Huang}-OLR_{CERES} (Wm^{-2})	OLR_{AIRS_Huang}-OLR_{CERES} (Wm^{-2})
Forest	0.58±1.43	-0.42±1.41
Savannas	-0.03±2.52	0.68±1.50
Grasslands	0.19±2.61	0.63±1.65
Dark Desert	-0.71±2.85	0.36±1.74
Bright Desert	1.67±2.62	1.42±2.28
Ocean	1.09±1.55	0.90±1.26

(Chen et al., J Climate, 2013)

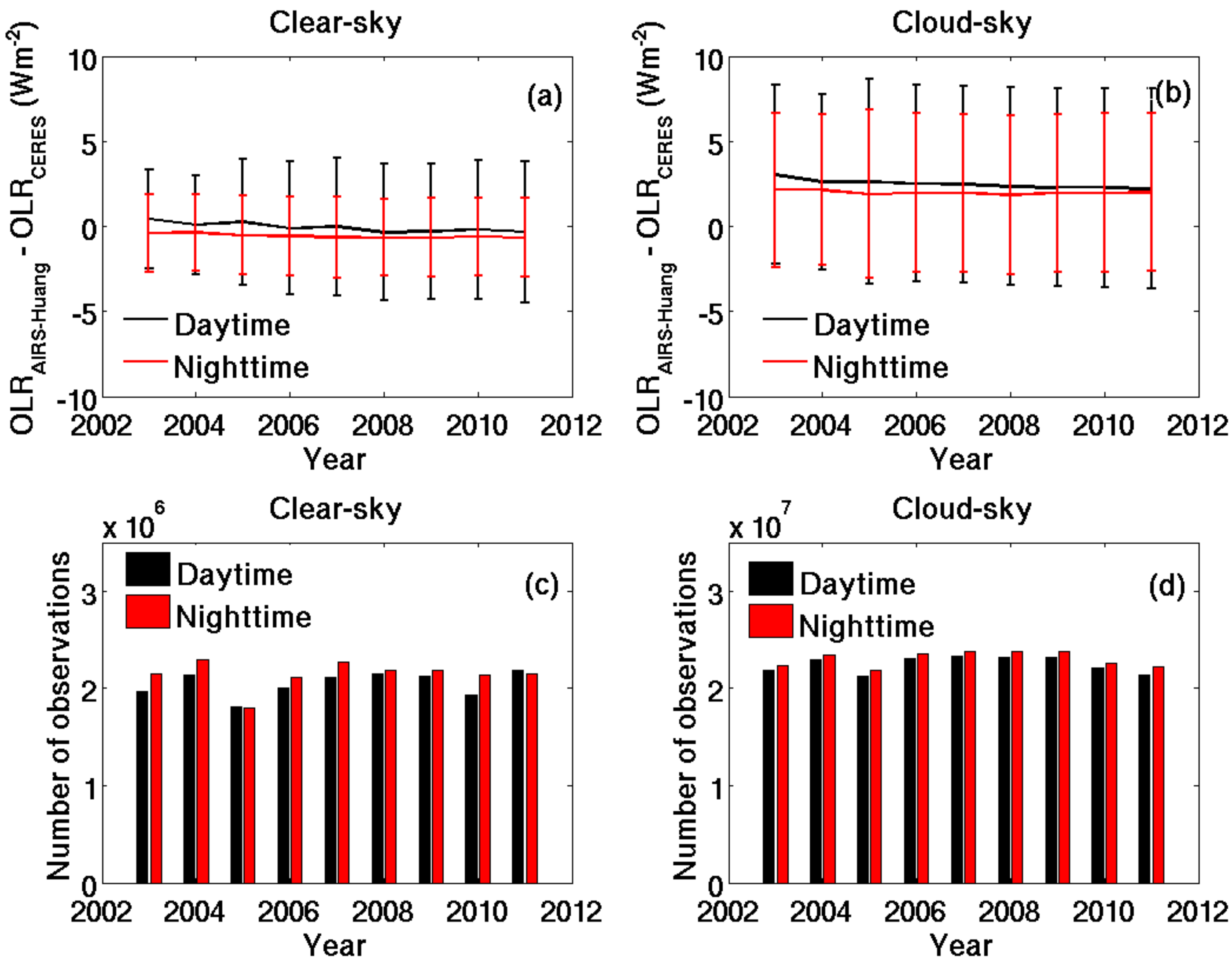
CERES 2σ radiometric calibration uncertainty: 1% (i.e. ~ 2.5W m^{-2})

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

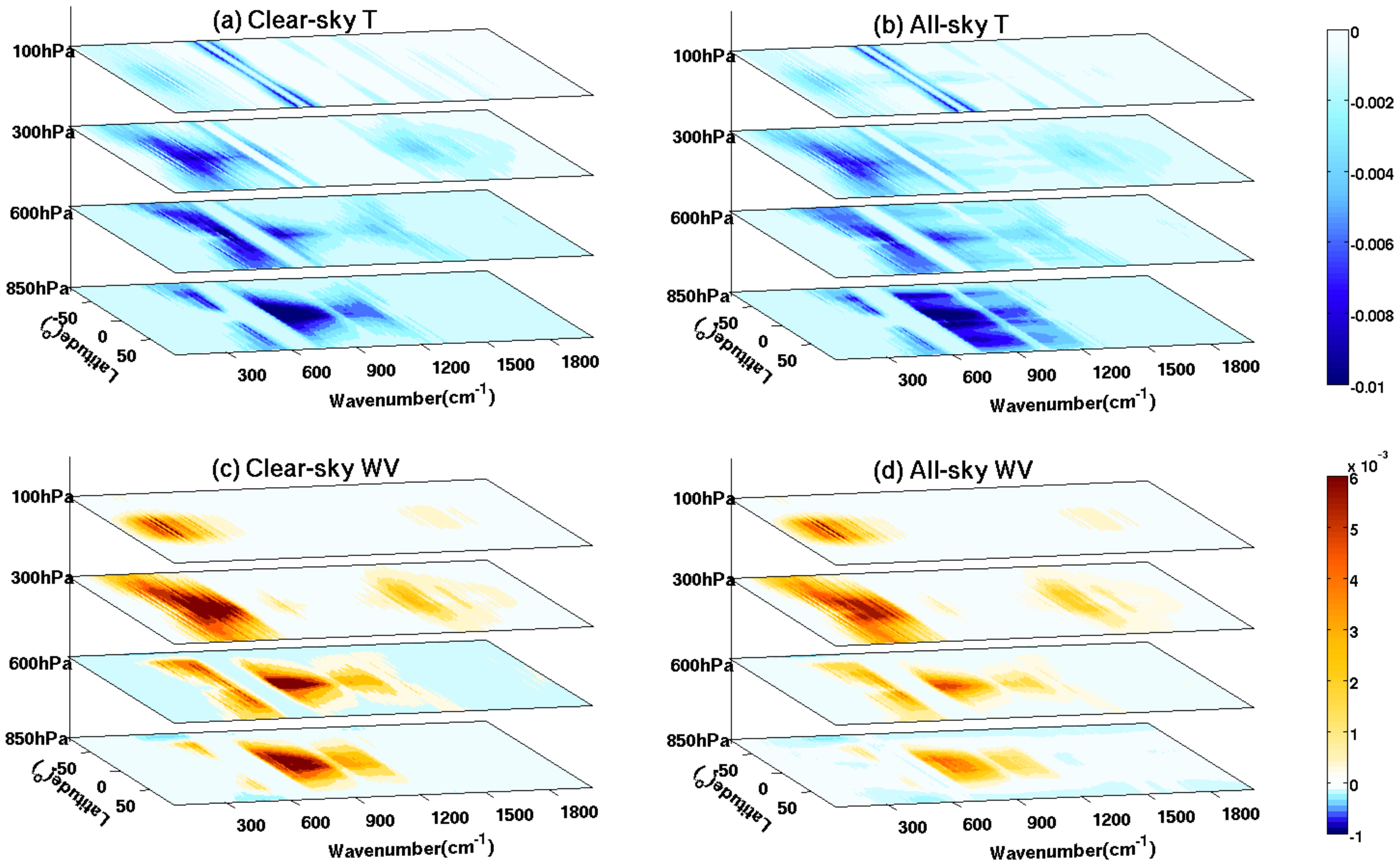
f \ ΔT_{sc}	Over deserts			Over non-desert lands		
	<15k	15K-40K	>40K	<15k	15K-40K	>40K
0.001-0.5	**2.44±3.79 (0.9%)**	**3.25±5.12 (1.2%)**	**1.49±7.61 (0.5%)**	**2.34±2.86 (0.8%)**	**3.62±4.48 (1.3%)**	**2.84±5.94 (1.0%)**
0.5-0.75	**2.79±4.16 (1.1%)**	**3.34±7.80 (1.3%)**	**1.39±12.75 (0.5%)**	**2.90±3.86 (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})

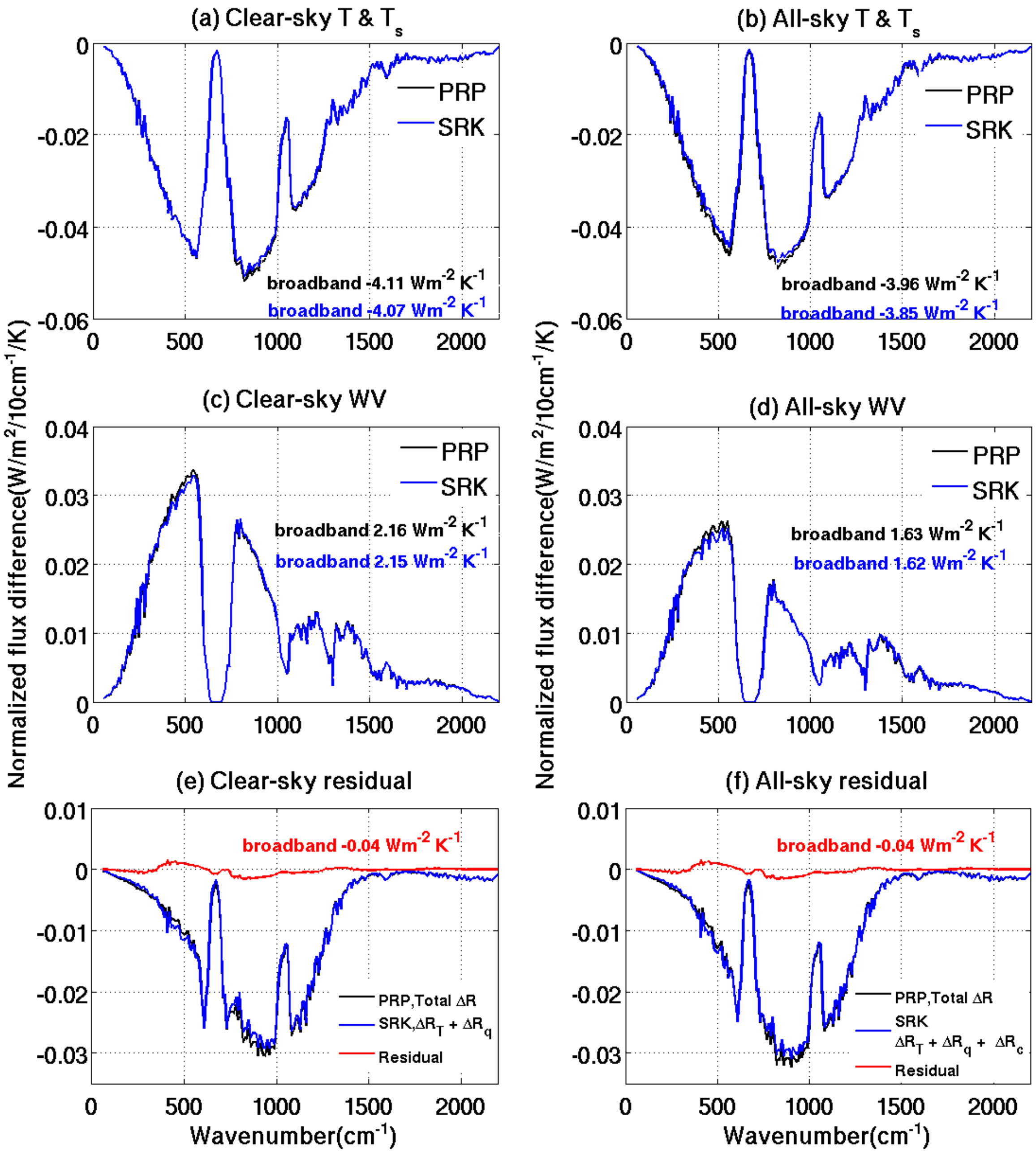
Global OLR_{AIRS_Huang}-OLR_{CERES}: annual means and year to year changes



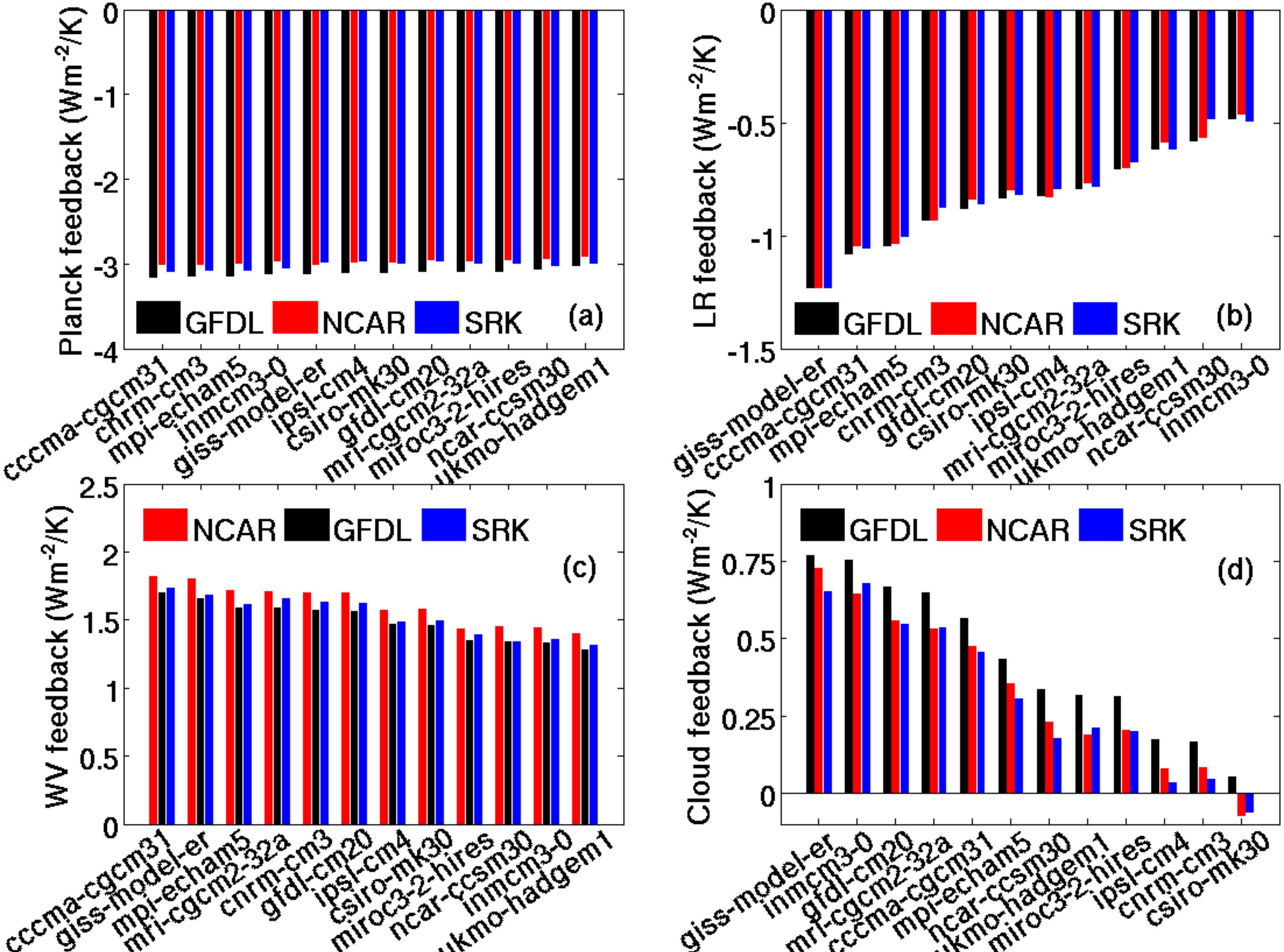
Construction of the SRK

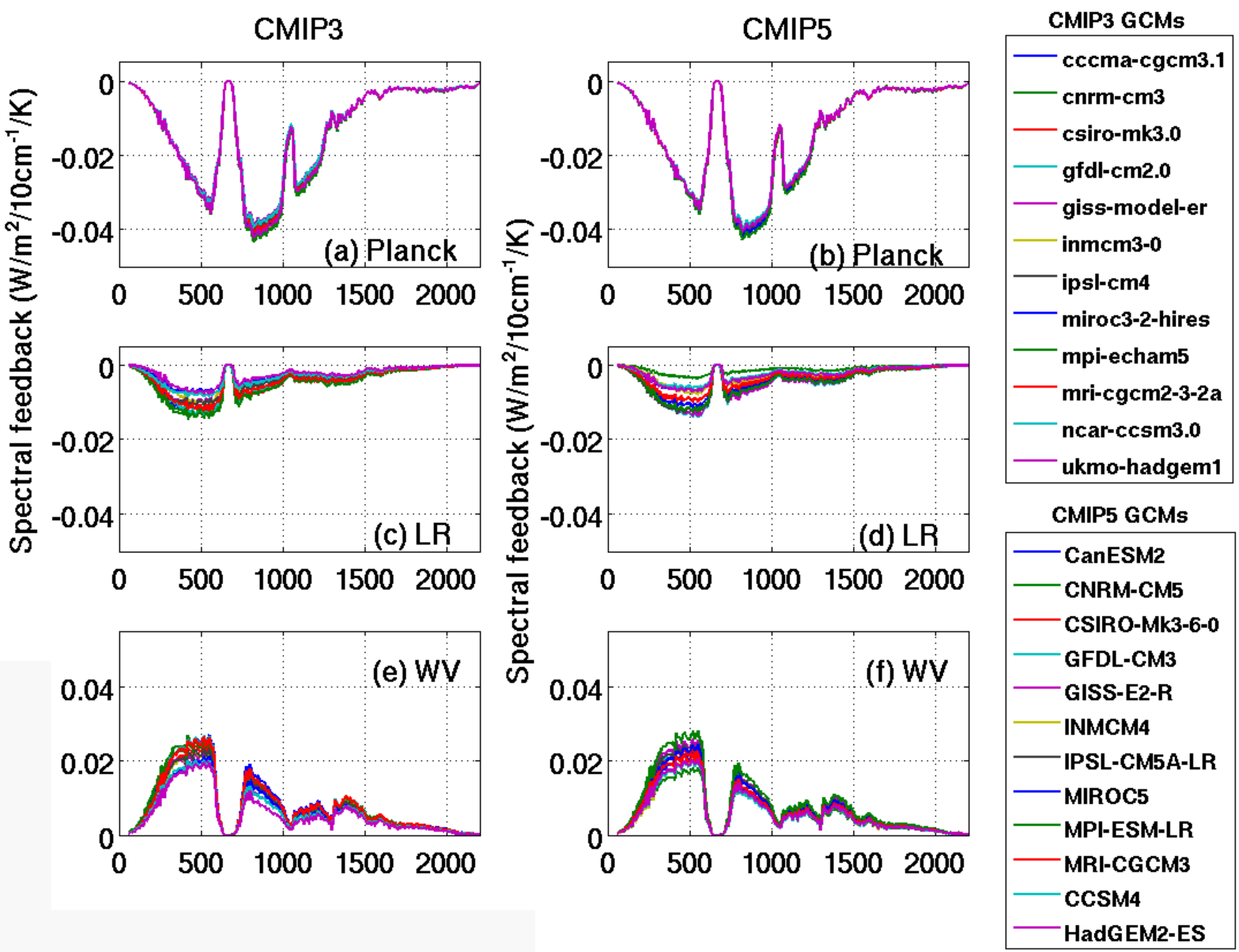


Validation: comparisons with the PRP results



Validation: comparisons with the PRP results




CMIP3
CMIP5
Spectral feedback (W/m2/10cm-1/K)
(a) Planck
(b) Planck
(c) LR
(d) LR
(e) WV
(f) WV
0
-0.02
-0.04
0.04
0.02
500
1000
1500
2000
CMIP3 GCMs
cccma-cgcm3.1
cnrm-cm3
csiro-mk3.0
gfdl-cm2.0
giss-model-er
inmcm3-0
ipsl-cm4
miroc3-2-hires
mpi-echam5
mri-cgcm2-3-2a
ncar-ccsm3.0
ukmo-hadgem1
CMIP5 GCMs
CanESM2
CNRM-CM5
CSIRO-Mk3-6-0
GFDL-CM3
GISS-E2-R
INMCM4
IPSL-CM5A-LR
MIROC5
MPI-ESM-LR
MRI-CGCM3
CCSM4
HadGEM2-ES