Spectrally resolved cloud radiative feedbacks from model and observations: some thoughts on the kernel approaches

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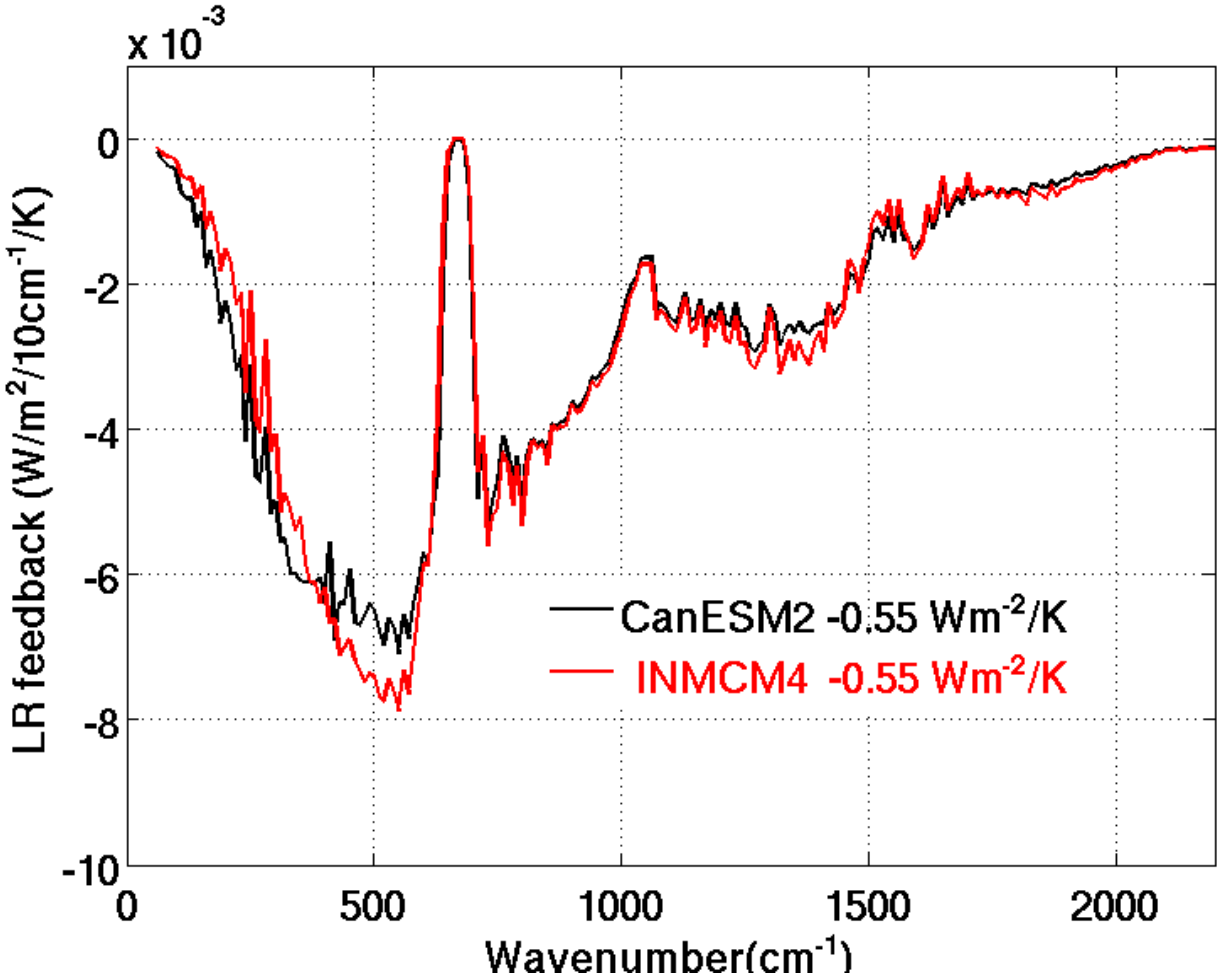
Outline

- Motivation
  - A follow-up from my last CERES STM talk
  - Spectral decomposition of cloud radiative feedbacks
  - Adjust method vs. kernel approach
- Methodology
- Modeling results: long-term cloud radiative feedbacks
  - Short-term cloud radiative feedbacks (fluctuations): model vs. obs in 2003-2013
- Conclusions and discussion

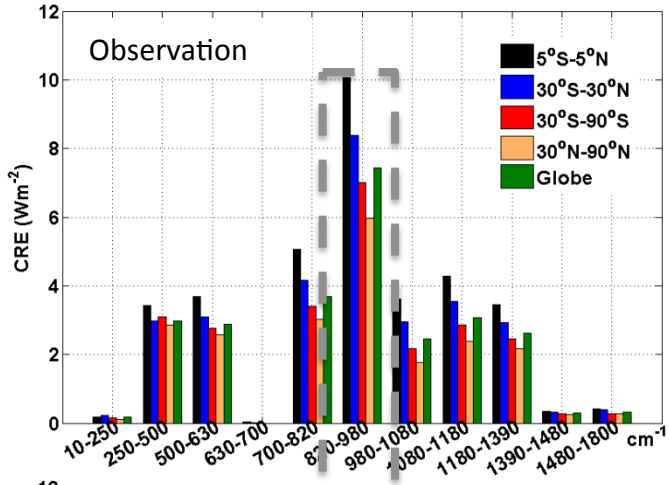
What spectral dimension can offer?

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

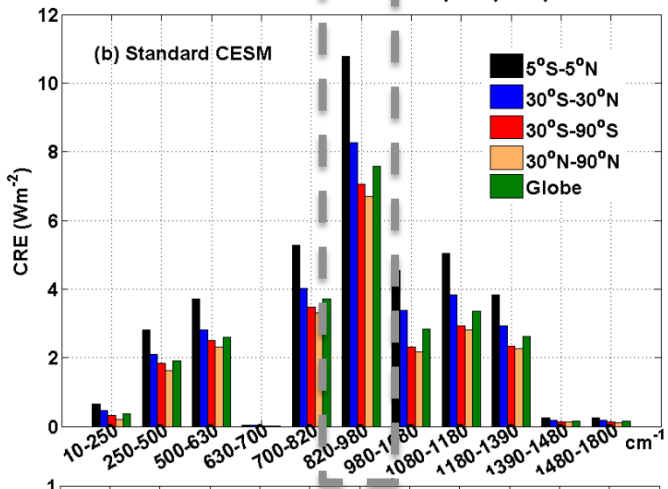


Spectral decomposition of broadband lapse-rate feedback
(Huang et al., 2014, GRL)

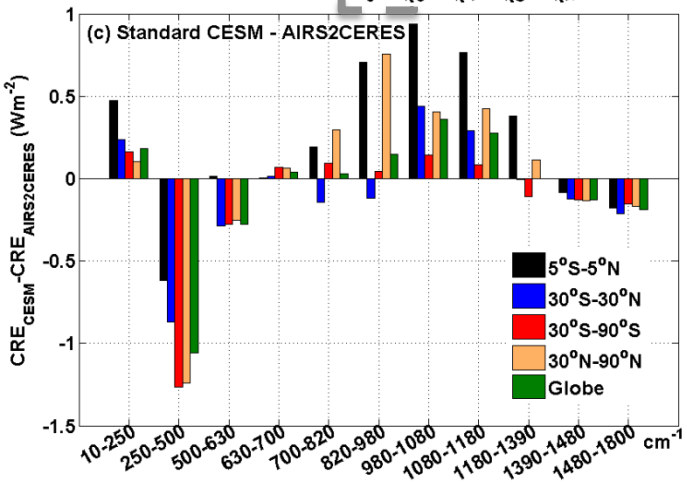
Band-by-band CRE (RRTMG_LW bandwidths)



Observed averages of 2003-2015 using Spectral flux derived from AIRS and CERES collocated observations.



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



Differences of Model - Obs

Cloud Radiative Kernel

- Zelinka et al. (2012) pioneered this approach in τ-CTP dimension.
- Yue et al. (2016) derived cloud radiative kernels solely from observations (CERES, AIRS, MODIS) without use of offline RT calculations.
- Similar methodology can be applied to GCM simulations as well.
- Broadband and band-by-band cloud radiative kernels can be derived in such way without any offline RT calculations.
- A consistent method for data-model comparisons in terms of cloud radiative feedbacks

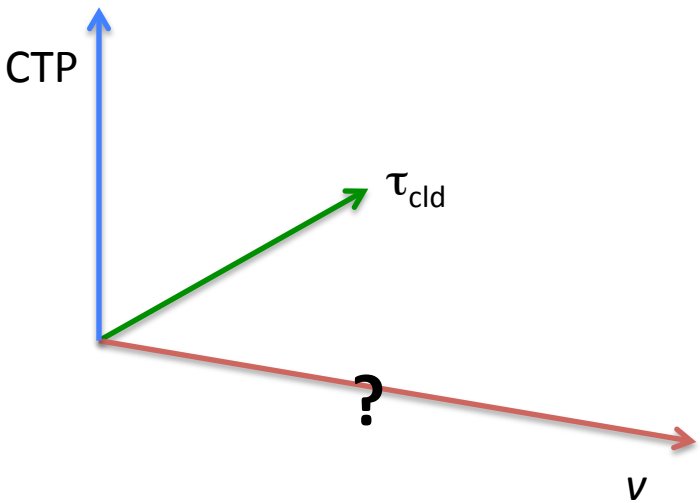
Cloud Radiative Feedback: kernel vs. adjust method

- Kernel approach: pre-build a Jacobian
- Adjust method: taking all-sky and clear-sky difference into account (dC_{RF}: diff in cloud radiative effect)

$$\delta_c R = dC_{RF} + (K^0{}_T - K_T)dT + (K^0{}_W - K_W)dW + (K^0{}_a - K_a)da + (G^0 - G). \quad (25)$$

- Are two approaches consistent with each other: broadband and spectrally?
  - Using CESM to test out

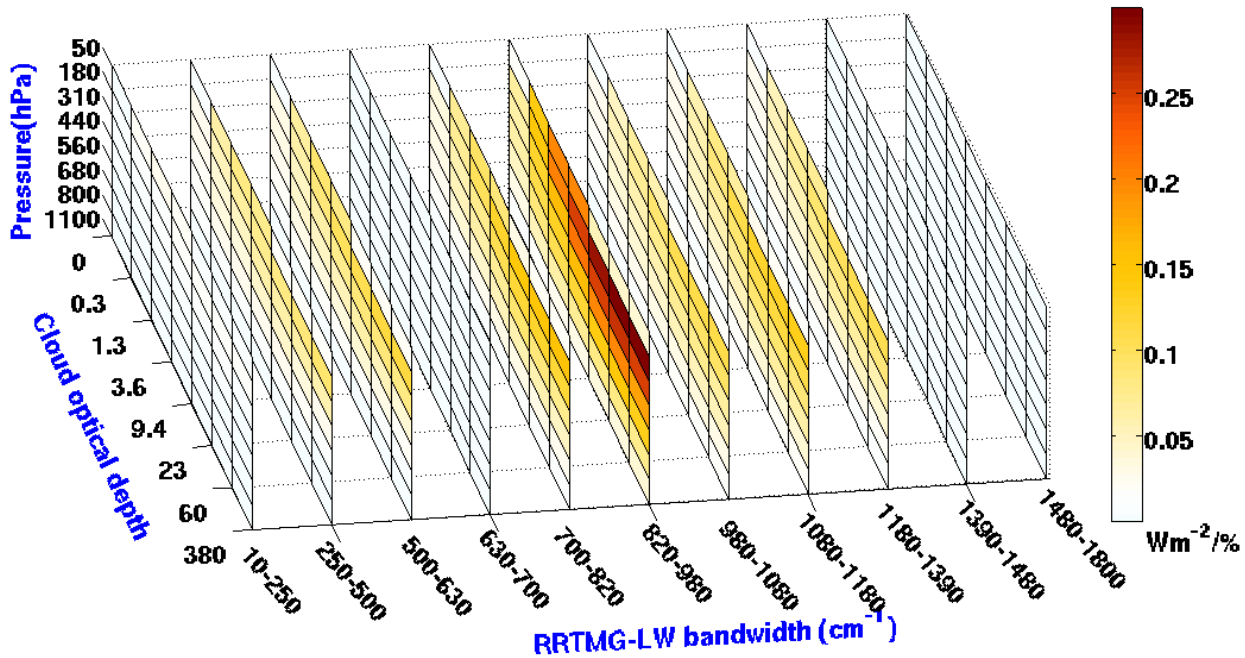
- *Are two methods, adjust vs. CRK, consistent with each other, broadband and spectrally?*
- *How different the spectral decompositions of cloud feedbacks are w.r.t. different warming scenarios?*
- *What does it imply for data-model comparison? Any spectral band provide best synergy w.r.t. broadband studies?*

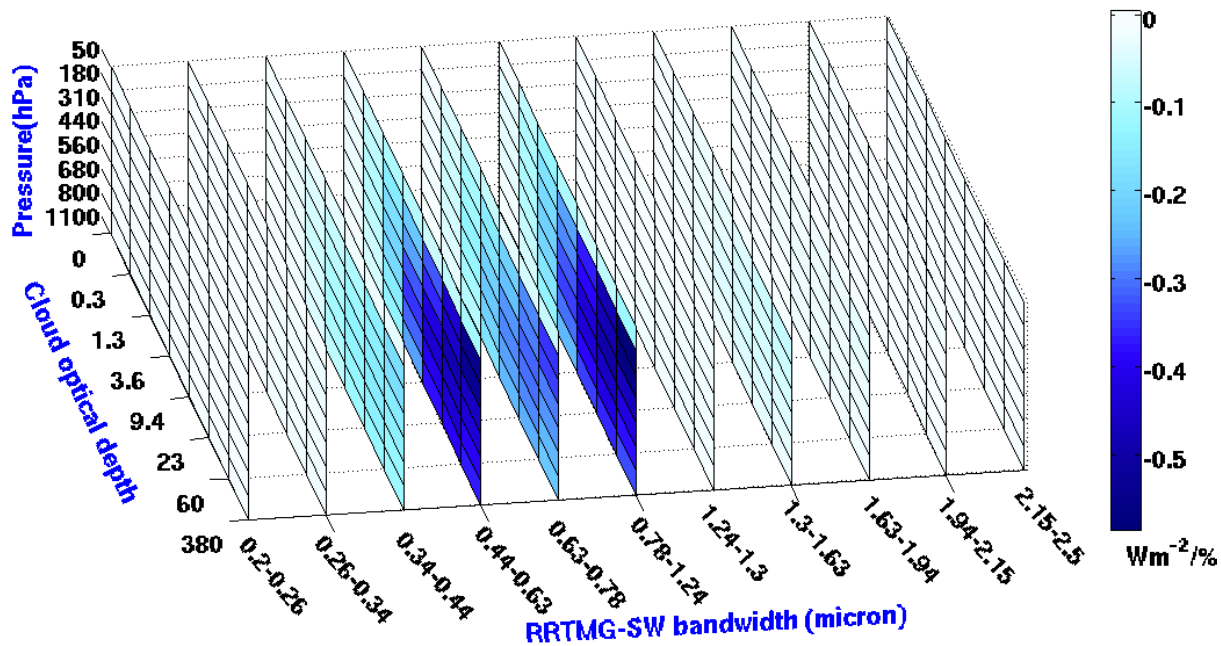


Methodology

- 3-hourly output from CESM simulations
  - Control run, $2xCO_2$, $4xCO_2$, +2K SST run.
- Build CRK for each run: for each run and each grid, following Yue et al. (2016) approach
  - Derive monthly-mean ISCCP-like histograms of cloud fraction and CRE from 3-hourly output
  - Compute cloud radiative kernel for each grid and each calendar month
  - For both broadband and RRTMG_LW/SW bands

Band-by-band Cloud Radiative Kernel based on CESM runs (global avg)





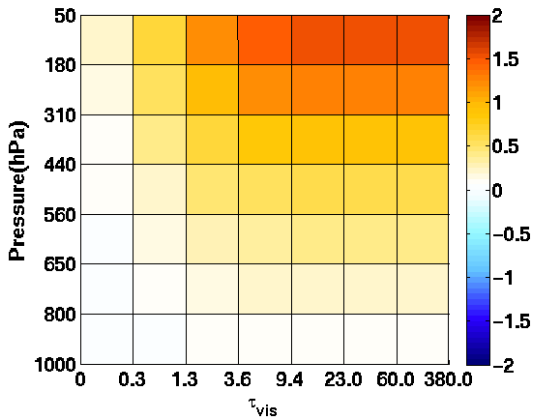
Derived LW cloud radiative kernels (global average)

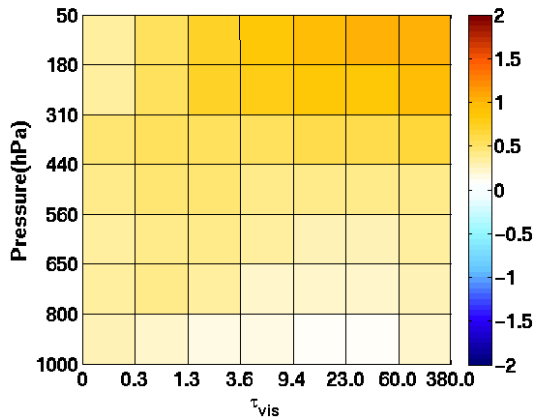
RT-based kernel (Zelinka et al., 2012)

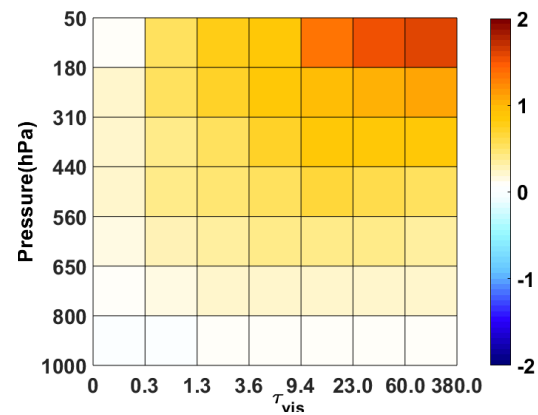
MODIS/AIRS-based kernel (Yue et al. 2016)

CESM-based kernel following Yue et al. (2016)

January

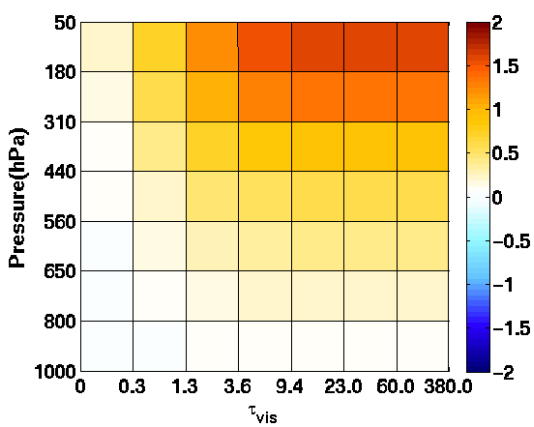


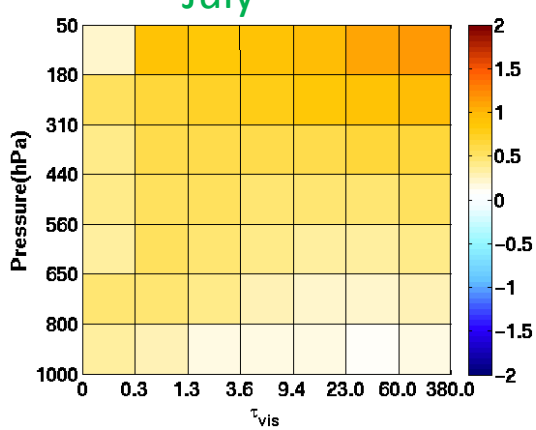


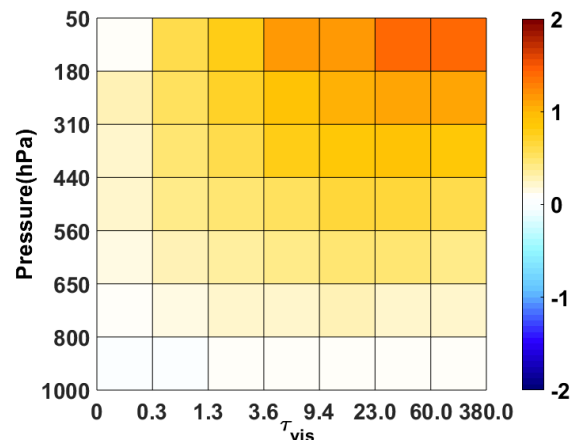


$Wm^{-2}/\%$

July







$Wm^{-2}/\%$

Derived LW cloud radiative kernels (January)

$Wm^{-2}/\%$

RT-based kernel (Zelinka et al., 2012)

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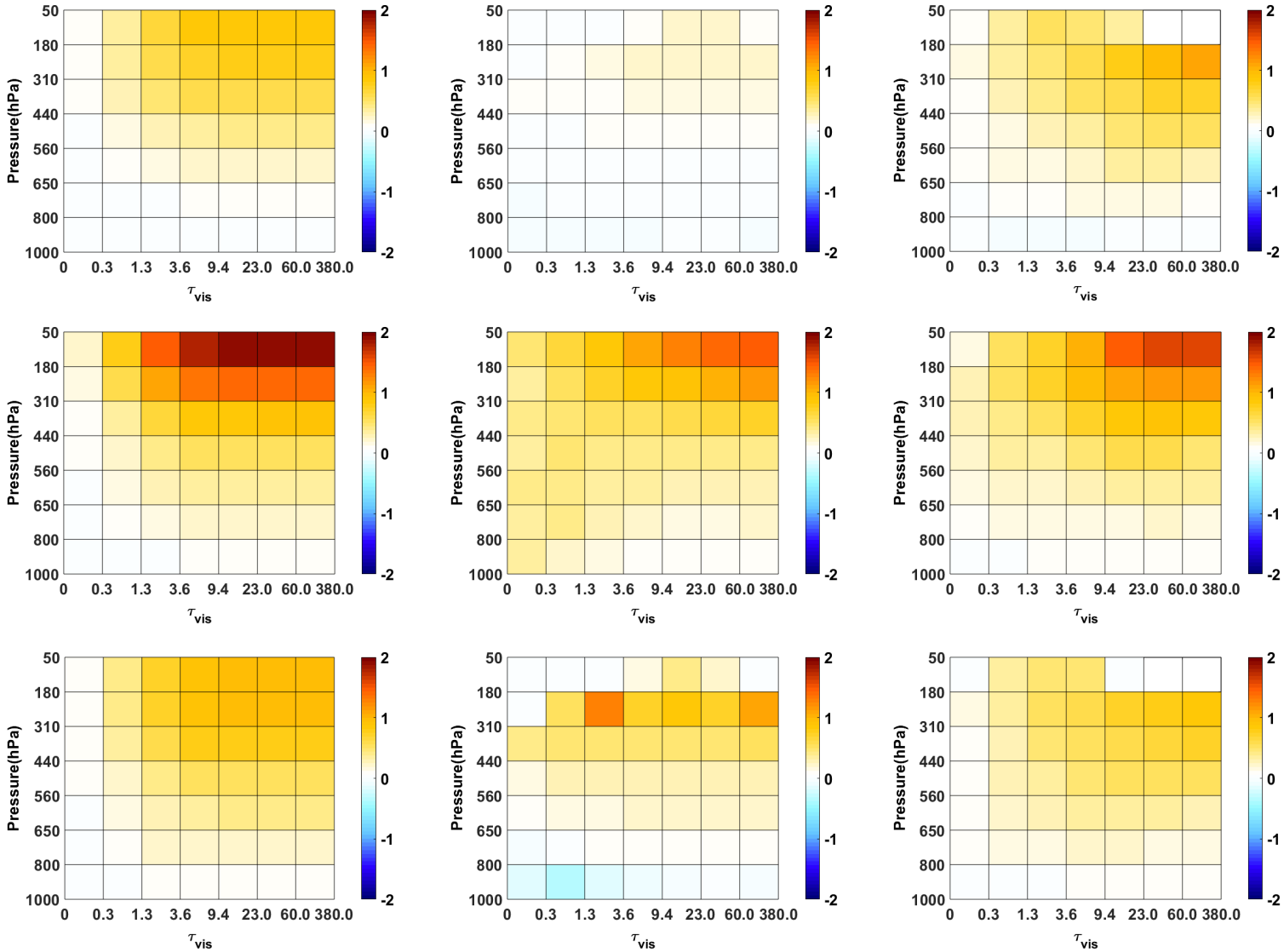
CESM-based kernel following Yue et al.

60°N-90°N

10°S-10°N

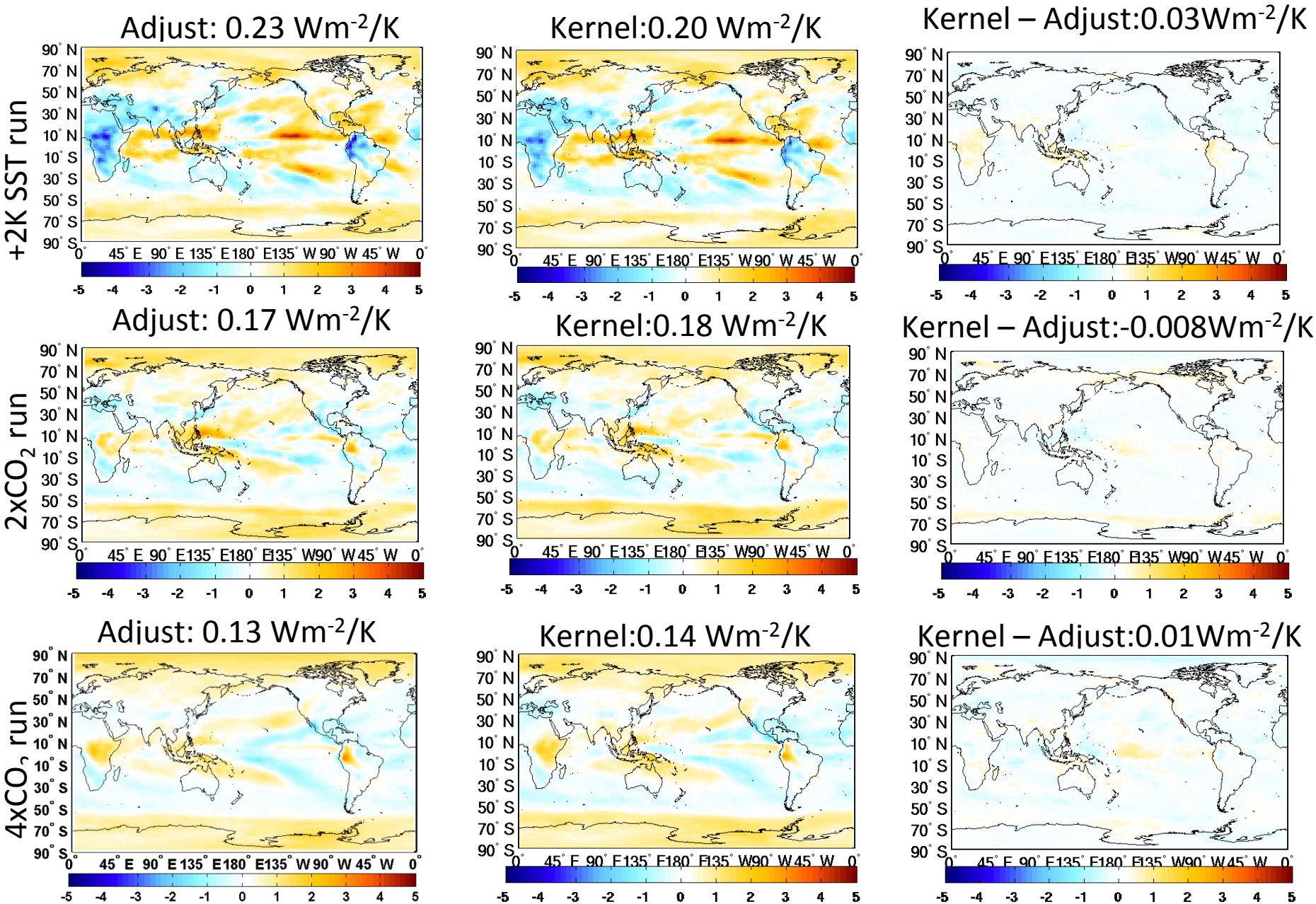
60°S-90°S



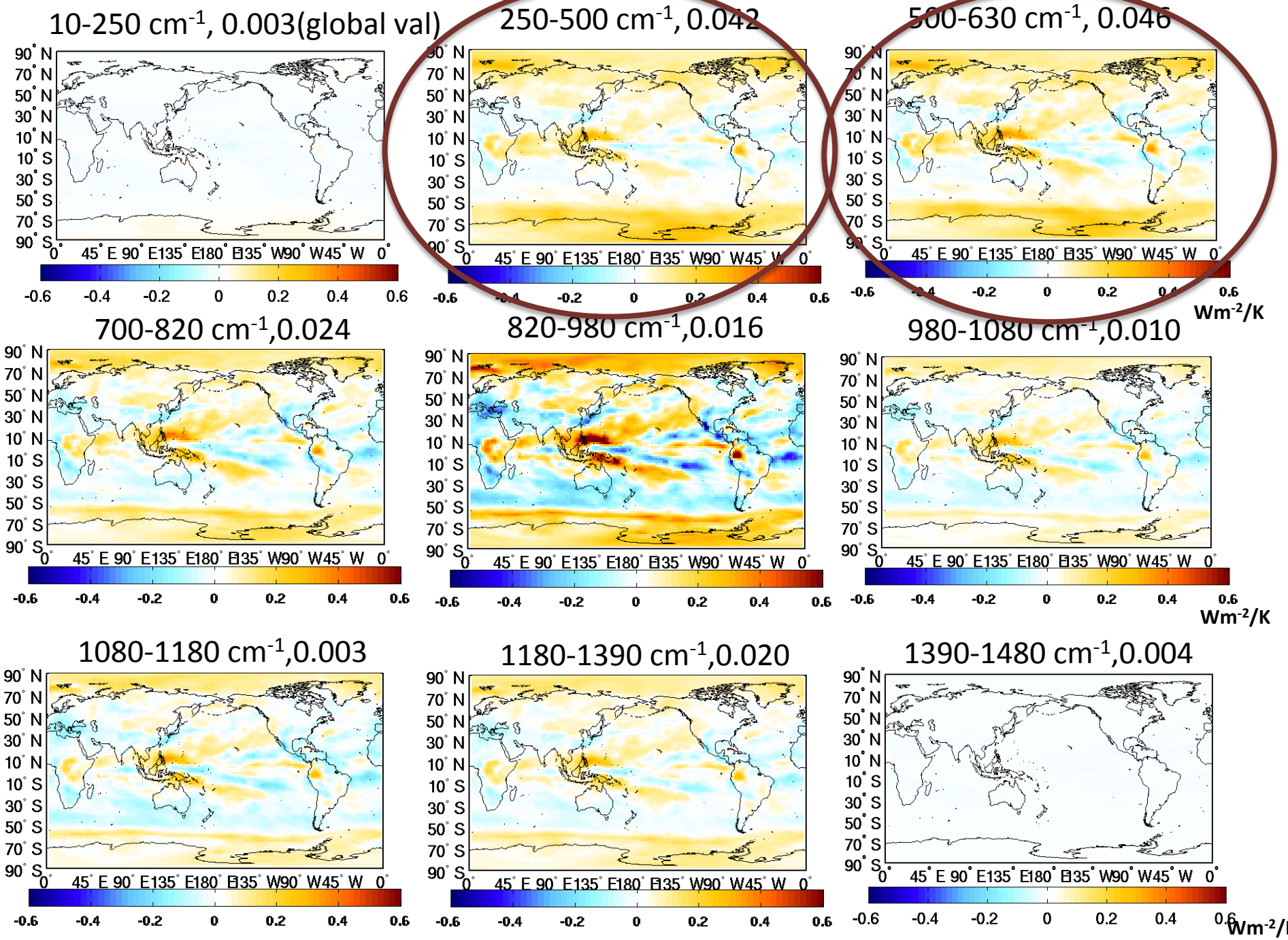
slab, average of control and 2xco2

LW cloud radiative feedback: Kernel approach vs. adjust method

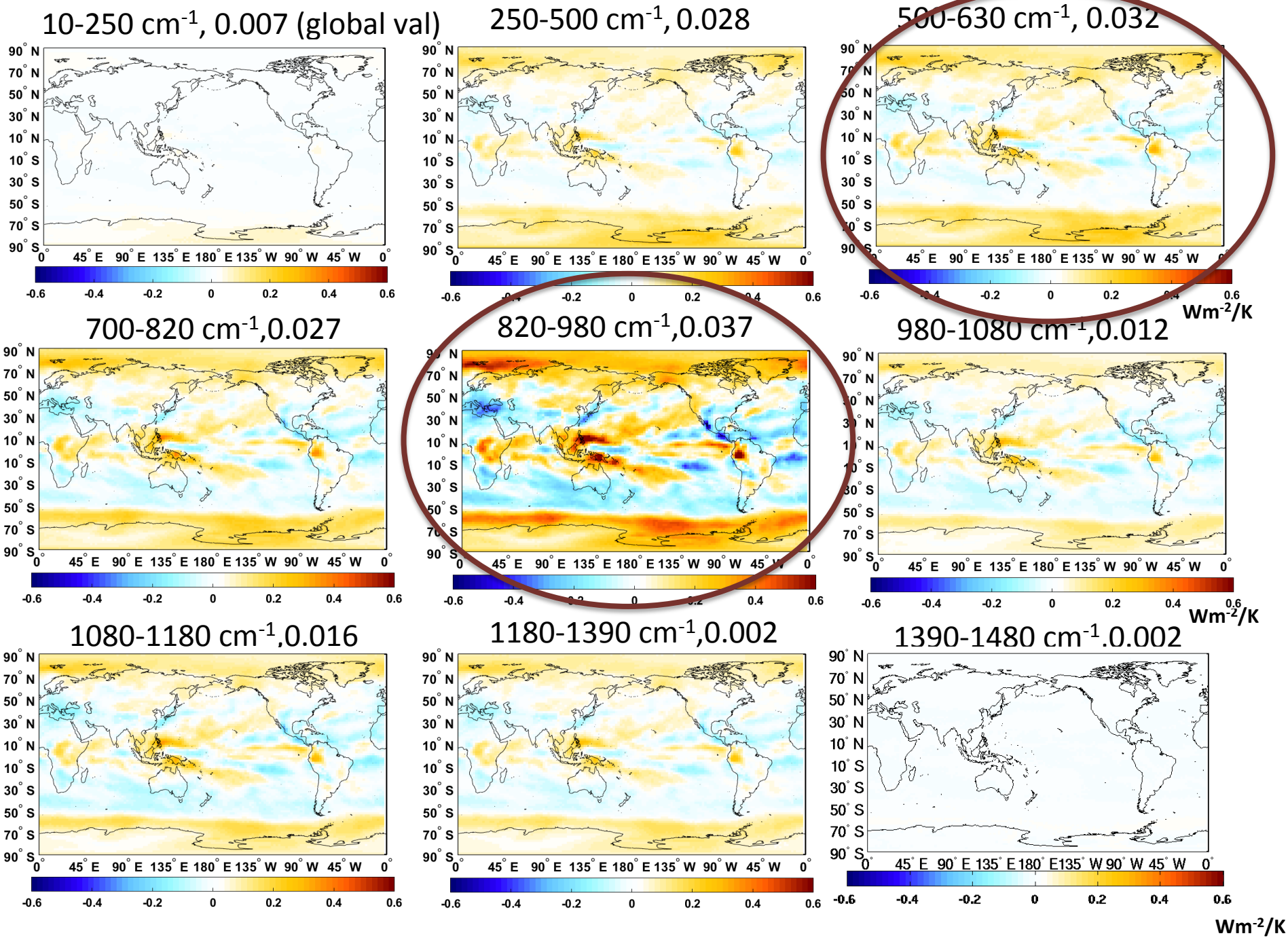
LW broadband cloud feedbacks from two methods: adjust vs. kernel



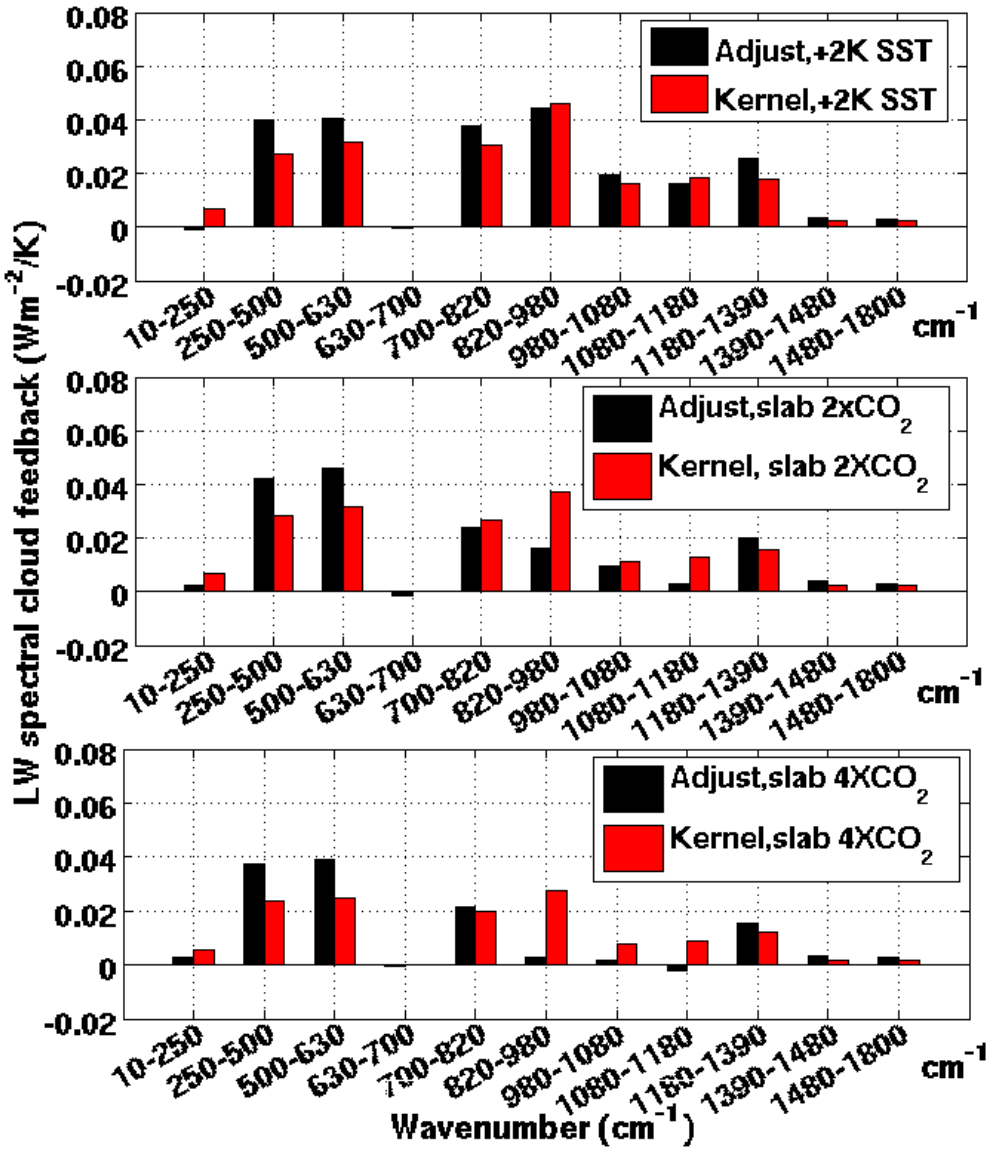
LW band-by-band Cloud radiative feedback from 2×CO_2 run (Adjust method)



LW band-by-band Cloud radiative feedback from 2×CO_2 run (kernel method)



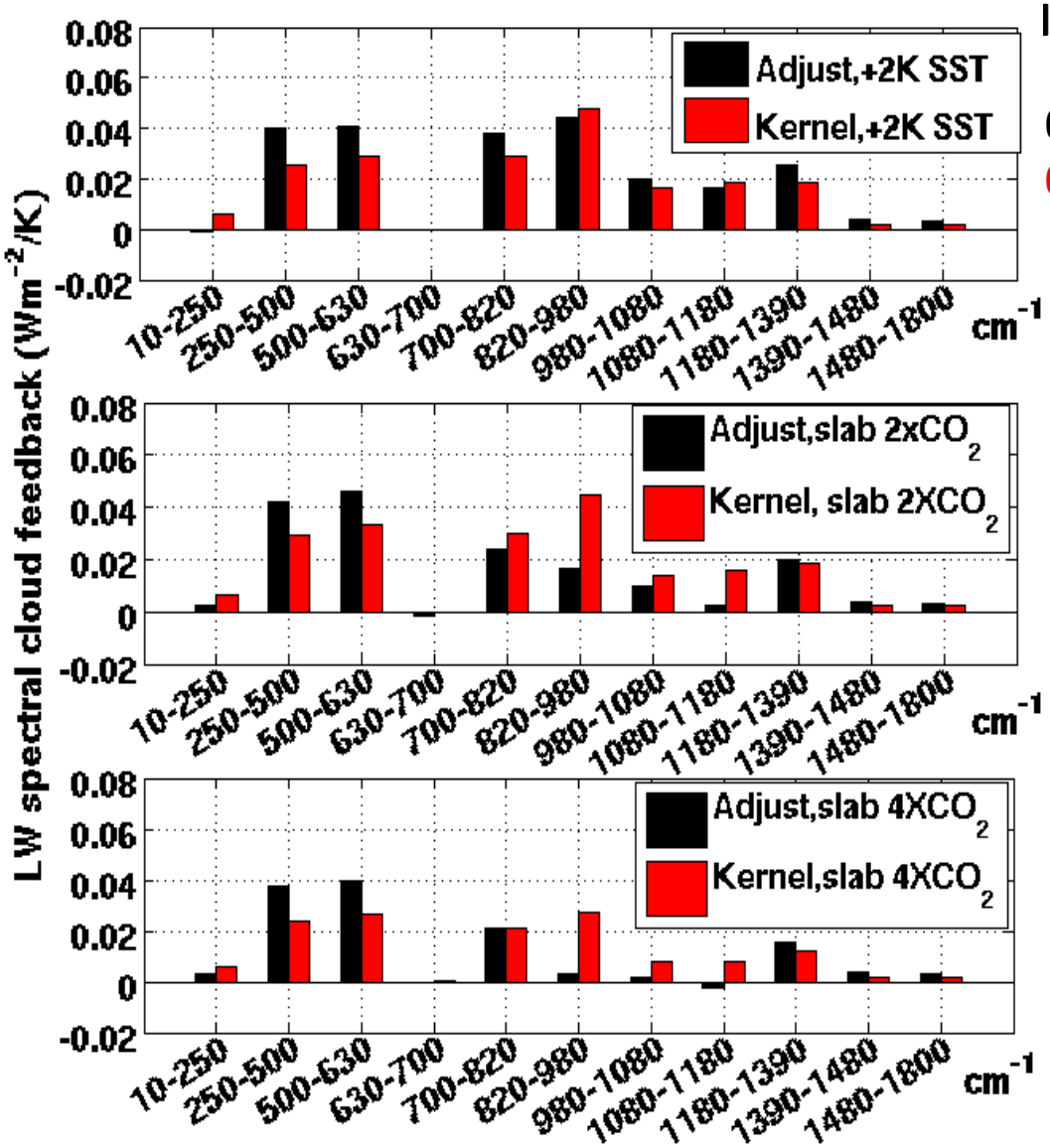
Band-by-band LW cloud feedback in the NCAR CESM



Broadband LW cloud feedback	Kernel	Cloud response
0.23 Wm^{-2}/K 0.20 Wm^{-2}/K	Mean of control and +2K	+2K - control
0.17 Wm^{-2}/K 0.18 Wm^{-2}/K	Mean of control and $2XCO_2$	$2XCO_2$- control
0.13 Wm^{-2}/K 0.14 Wm^{-2}/K	Mean of control and $4XCO_2$	$4XCO_2$- control

- **Two methods have different band-by-band decompositions for CO_2 runs**

Sensitivity to the choice of kernel

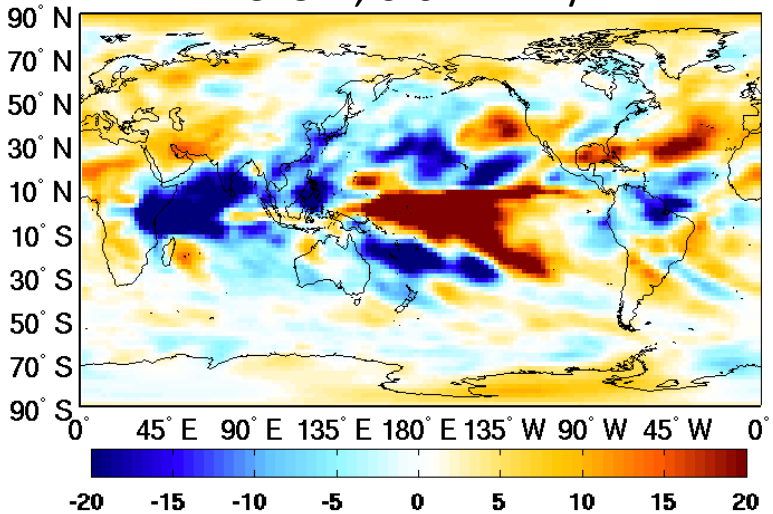


Broadband LW loud feedback	Kernel	Cloud response
0.23 Wm^{-2}/K 0.20 Wm^{-2}/K	Slab 2XCO$_2$	+2K - control
0.18 Wm^{-2}/K 0.20 Wm^{-2}/K	Slab 2XCO$_2$	2XCO$_2$- control
0.13 Wm^{-2}/K 0.14 Wm^{-2}/K	Slab 2XCO$_2$	4XCO$_2$- control

Short-term LW cloud feedback (2003-2013)

adjust method

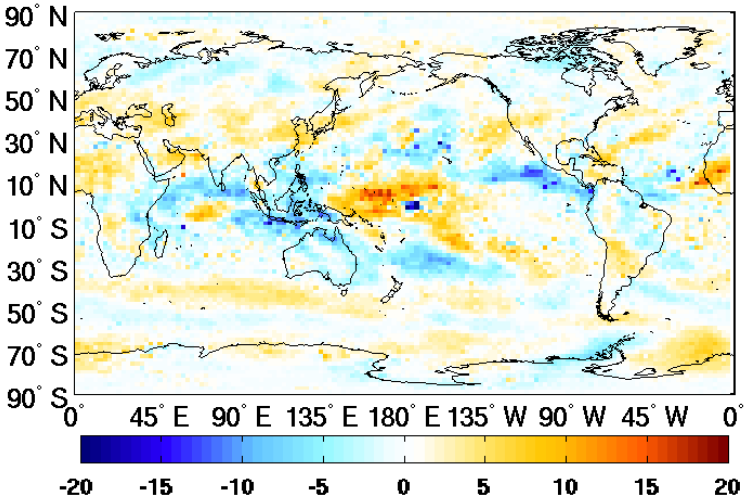
CESM, 0.61Wm^{-2}/K



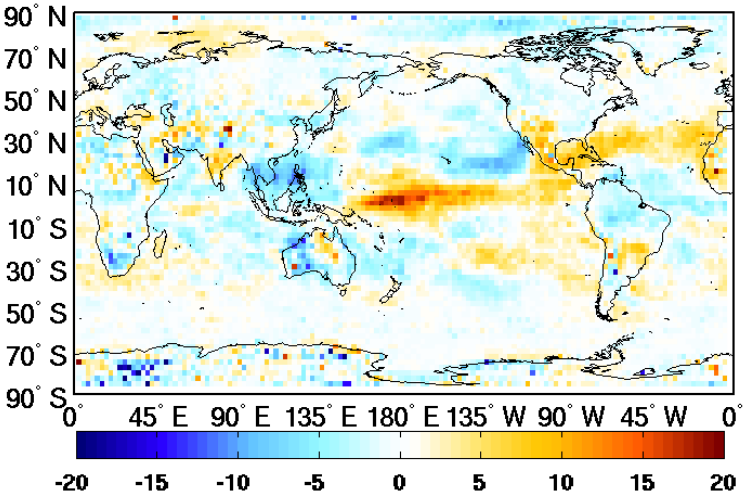
- CESM forced SST monthly output
- For obs
  - CERES EBAF are used
  - Spectral flux from AIRS and CERES using Huang algorithms

Kernel method

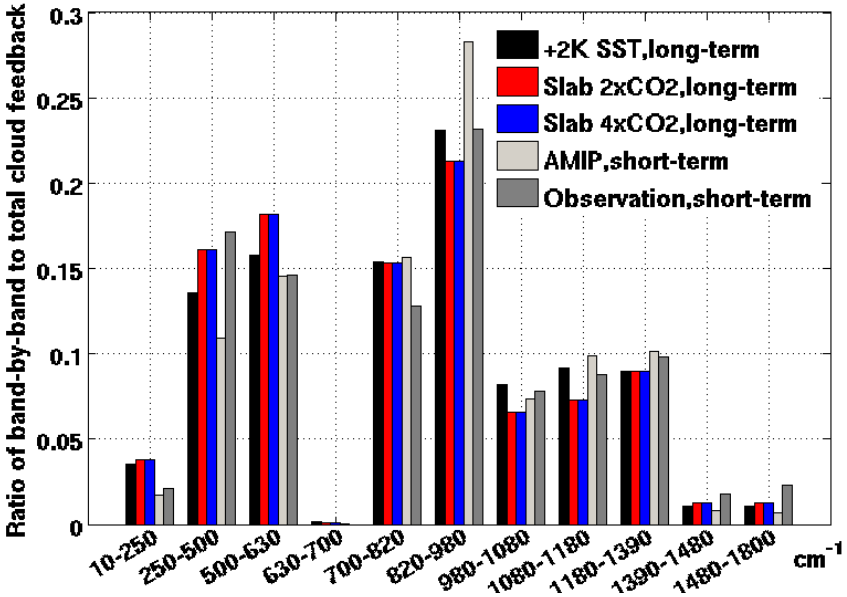
CESM: 0.20Wm^{-2}/K

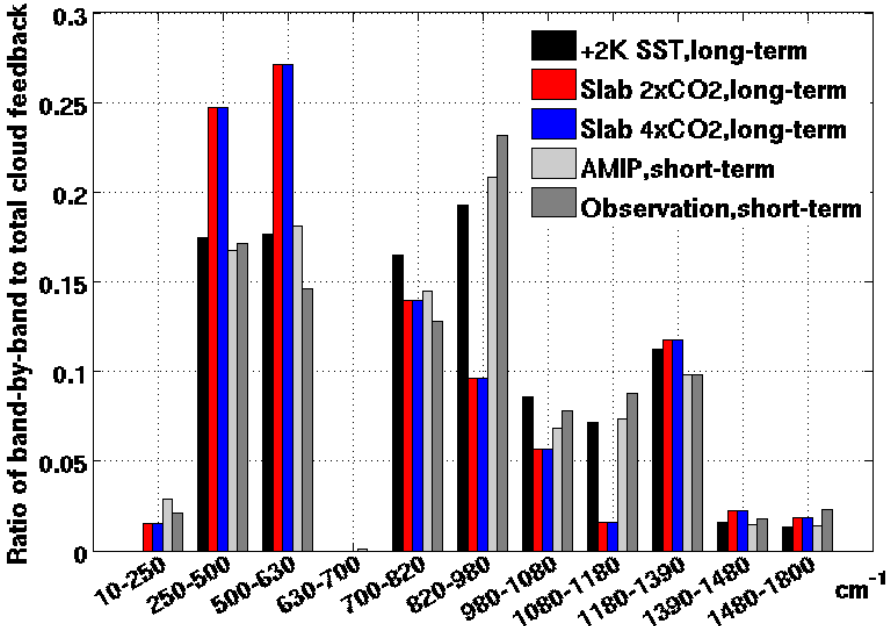


Obs, 0.13 Wm^{-2}/K



Fractional contribution to CRF from each RRTMG_LW band





Broadband LW cloud feedback
+2K SST run (kernel): 0.20 Wm-2/K
Slab 2xCO_2 run (kernel): 0.18 Wm^{-2}/K
Slab 4xCO_2 run (kernel): 0.18 Wm^{-2}/K
AMIP short-term(kernel): 0.20 Wm-2/K
Observation (kernel): 0.13 Wm^{-2}/K

Broadband LW cloud feedback
+2K SST run (adjust): 0.23 Wm-2/K
Slab 2xCO_2 run (adjust): 0.17 Wm^{-2}/K
Slab 4xCO_2 run (adjust): 0.17 Wm^{-2}/K
AMIP short-term(adjust): 0.61 Wm-2/K
Observation (kernel): 0.13 Wm^{-2}/K

Conclusions and discussions

- Construct cloud radiative kernel for obs and mod in a consistent way
- Even the broadband LW cloud radiative feedbacks from adjust and kernel methods are similar, the band-by-band decomposition is different
  - Adjust: far-IR contributes the most
  - Kernel: comparable contributions from far-IR and window region
- Window vs. far-IR bands
- Follow-up: extend to the SW

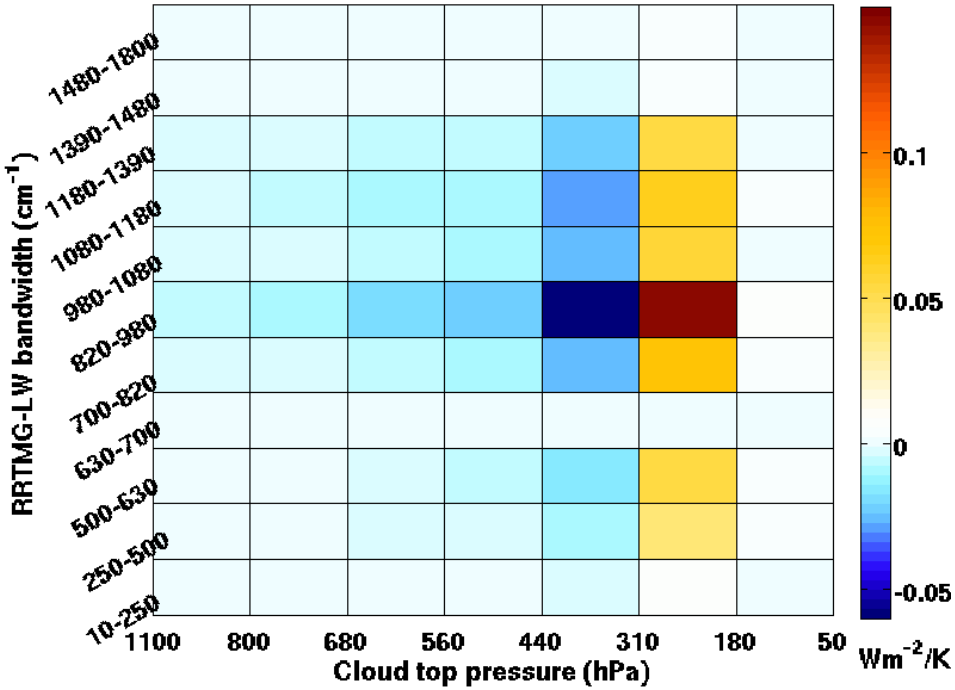
Thank You!

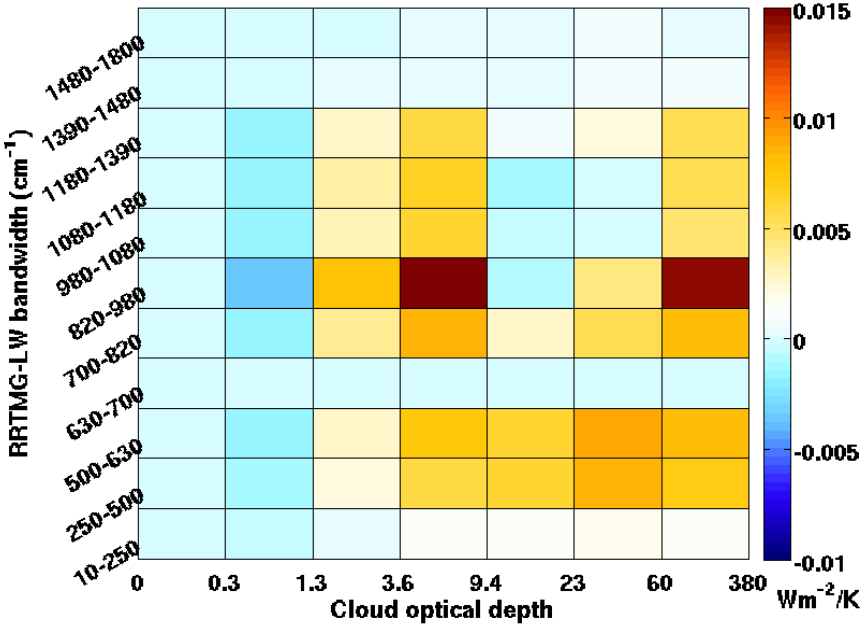
References:

1. 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.
2. 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.
3. 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.

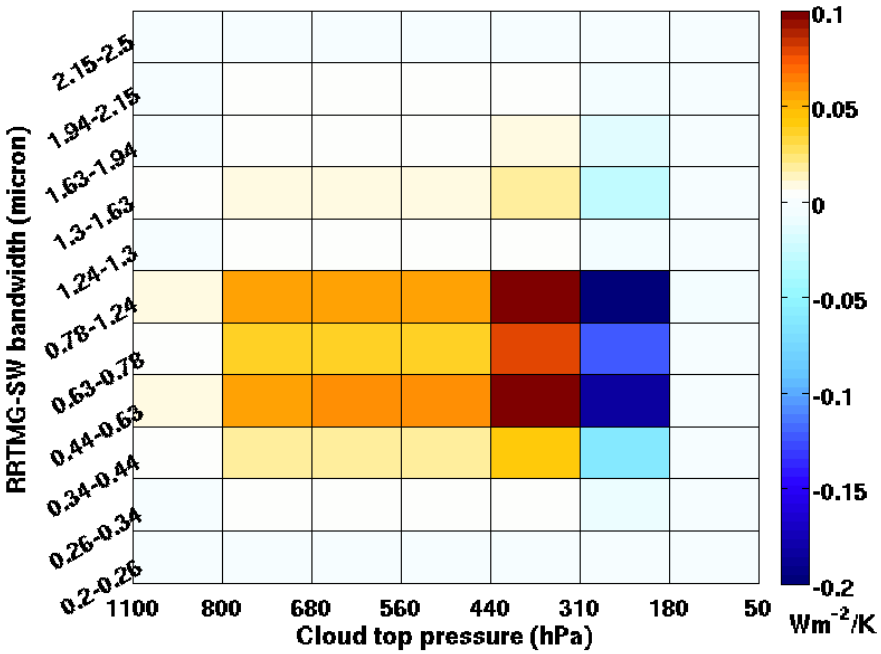
Monthly gridded spectral flux and CRE are available via http://www-personal.umich.edu/~xianglei/datasets.html.
The spectral radiative kernels are available upon request.

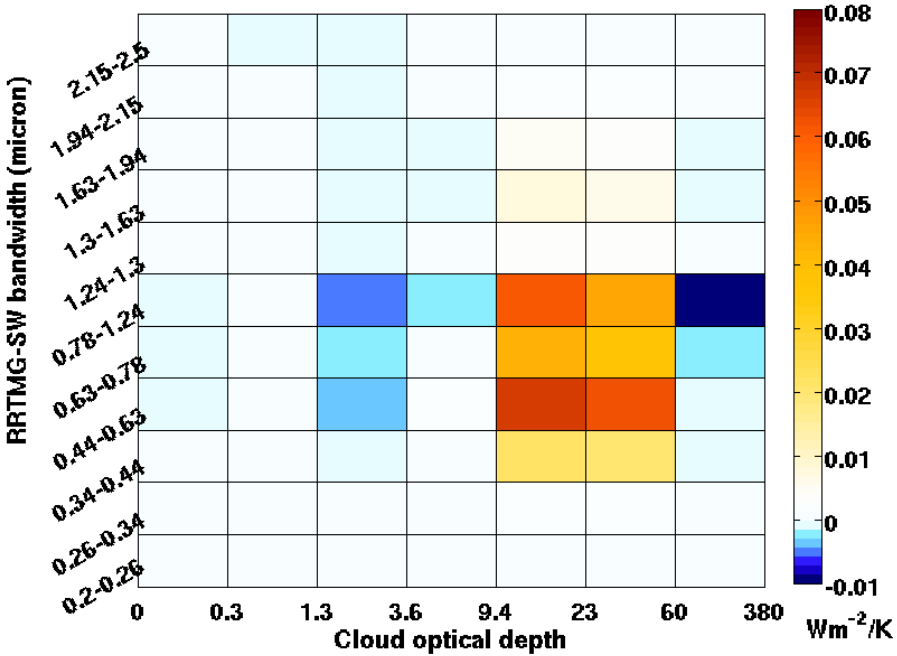
LW cloud feedback (kernel method, slab 2xCO2)





SW cloud feedback (kernel method, slab 2xCO2)





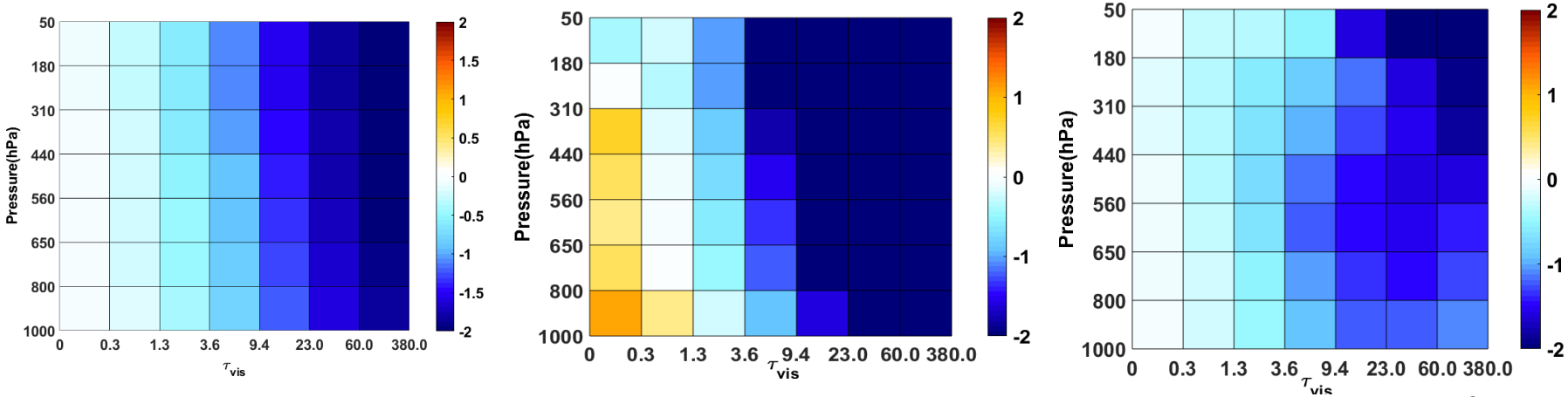
Derived SW cloud radiative kernels

RT-based kernel (Zelinka et al., 2012)

MODIS/AIRS-based kernel (Yue et al. 2016)

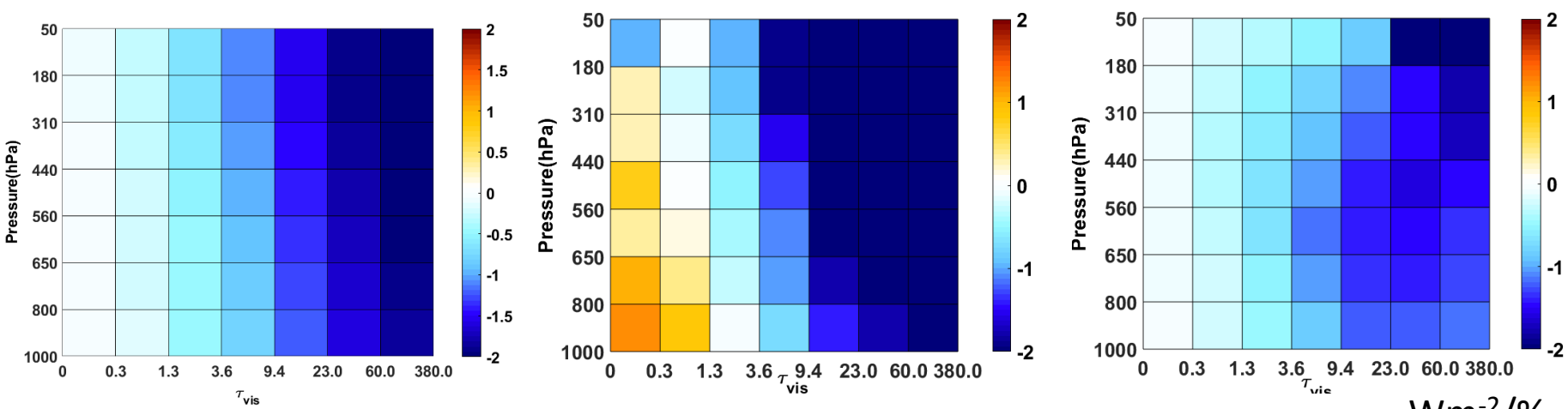
CESM-based kernel following Yue et al. (2016)

January



$Wm^{-2}/\%$

July



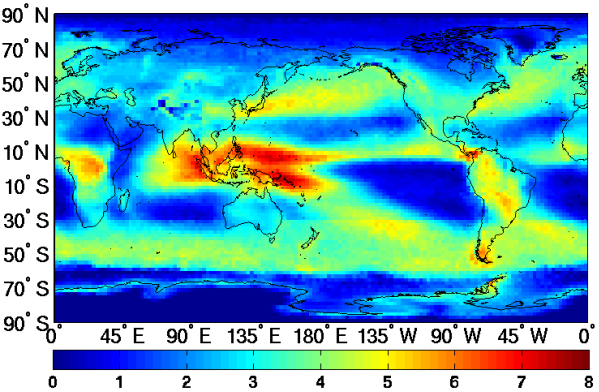
$Wm^{-2}/\%$

Observation: 2003-2015

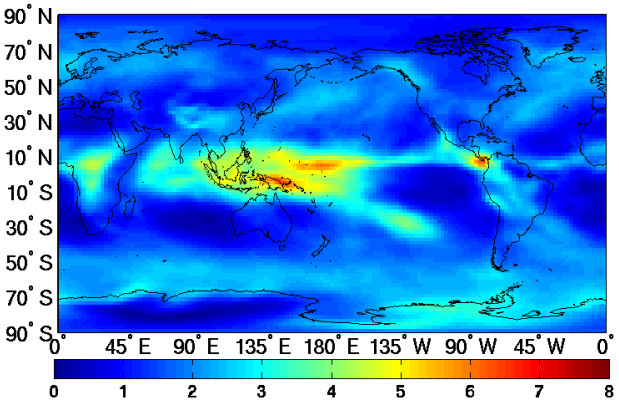
CAM5 forced by observed SST 2003-2015

CAM5-Obs

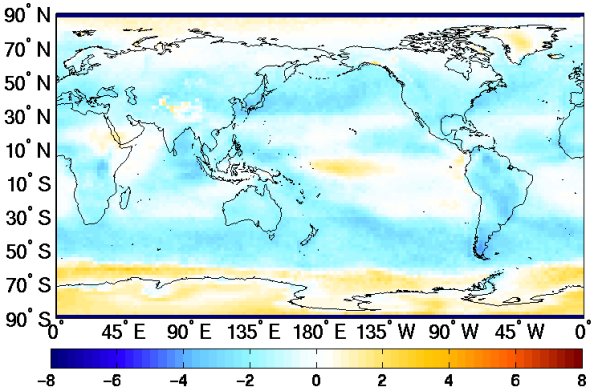
250-500 cm^{-1}, 2.99



250-500 cm^{-1},1.92

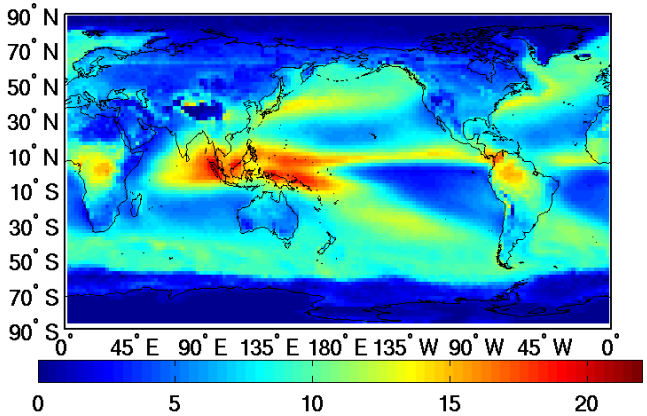


250-500 cm^{-1}, -1.07

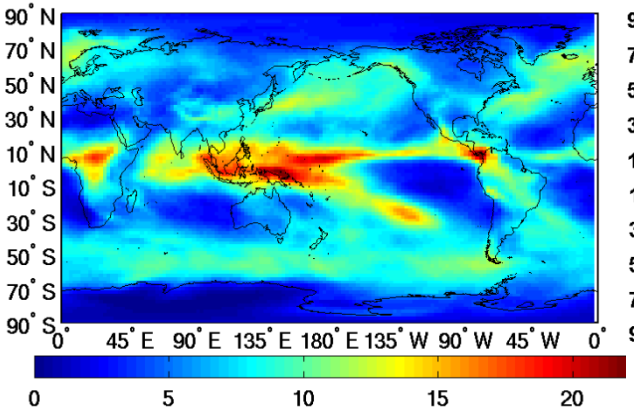


(Wm^{-2})

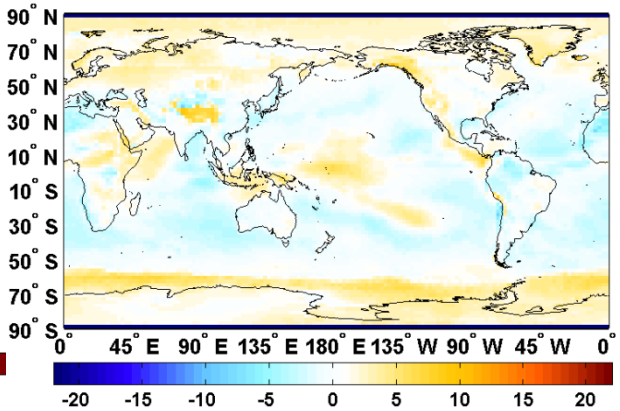
820-980 cm^{-1},7.48



820-980 cm^{-1},7.59



820-980 cm^{-1}, 0.11



(Wm^{-2})

Conclusions and Discussion

- Spectral decomposition helps revealing compensating biases.
  - Compensating biases (t; x, y, **p**) vs. (t; x, y, ***v***)
- Different ways of estimating cloud feedbacks can lead to different spectral decomposition.
- The long-term vs. short-term cloud feedbacks have different spectral decomposition
  - Implications for emergent constrains

Updates on Feb. 8
Our cloud histogram method

For a 3-hourly profile at a grid (lat, lon, time),

1) Divide the grid into several sub-columns (ncol is the number), clouds are assigned assuming maximum-random overlapping method;

2) For each subcolumn, compute IR cloud top pressure.

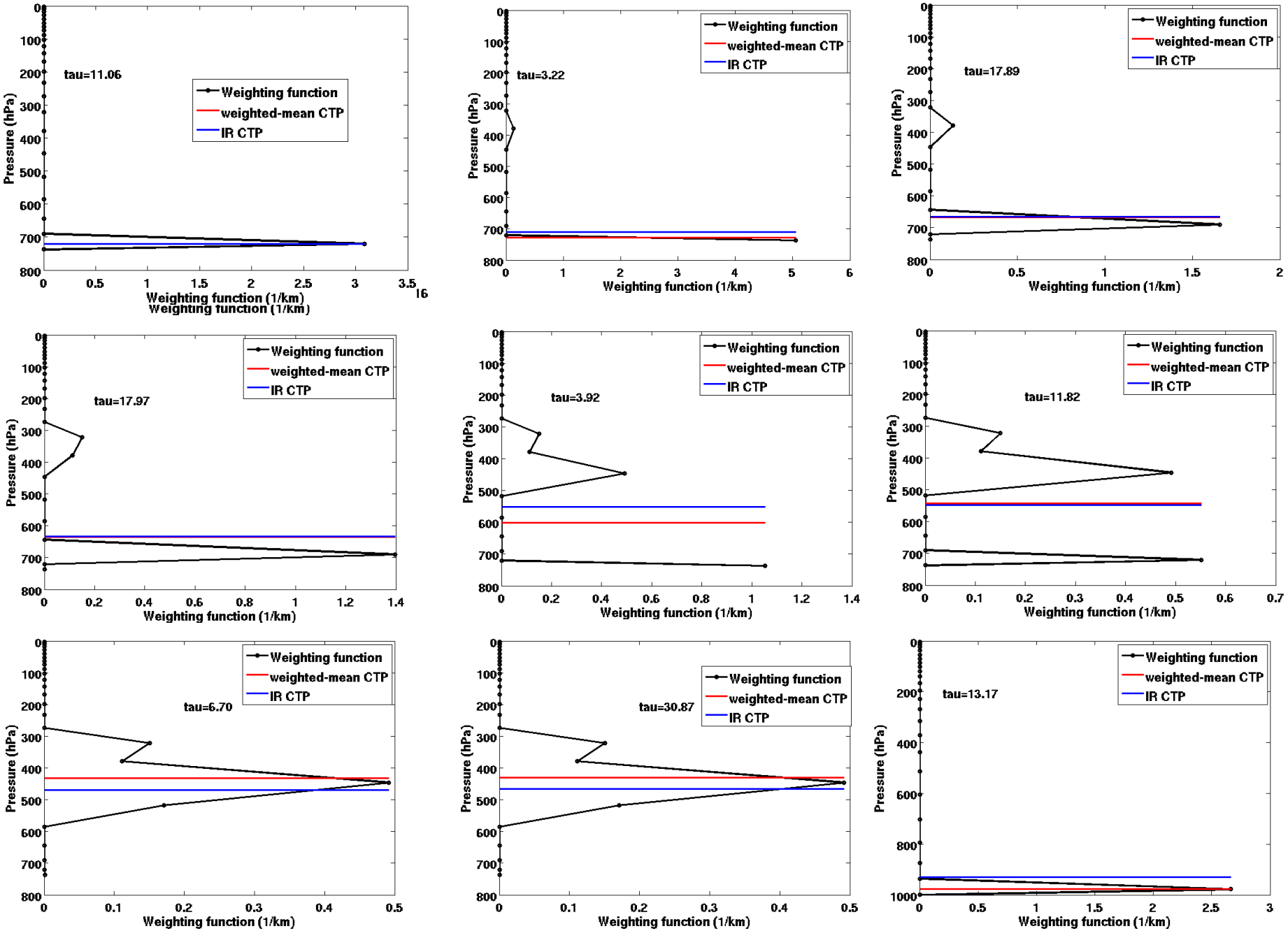
3) For each subcolumn, optical depth is the sum of dtau for all layers with cloud assigned;

4) For all subcolumns covered by cloud in the grid, average to a mean_cloud_top_pressure and a mean_cloud_optical_depth (first convert to albedo, then get mean albedo, then convert back to cloud optical depth).

5) Based on mean_cloud top pressure and mean_cloud optical depth in 4), ISCCP histogram box is located and total cloud fraction and cloud radiative forcing (CRF) is put in the box.

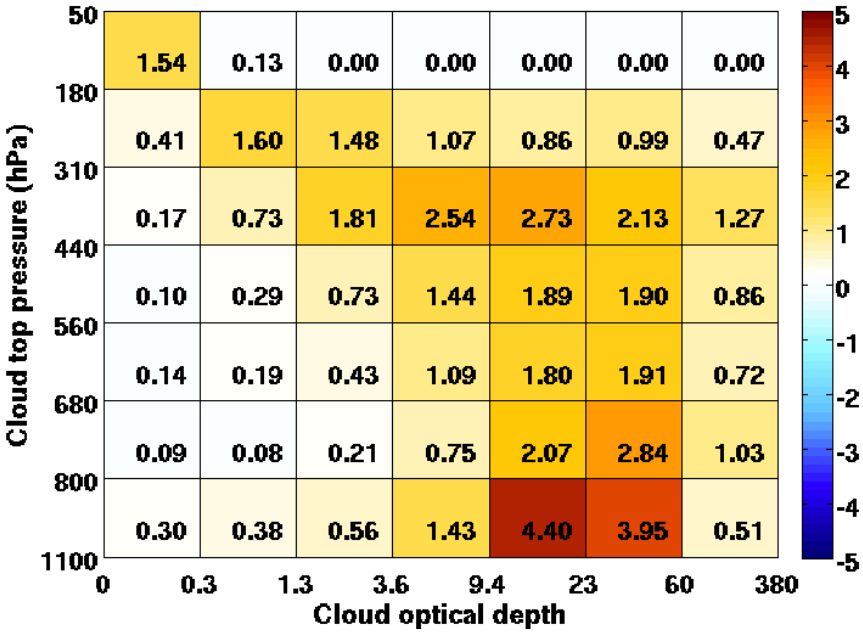
6) Do the same as in 1-5) for all 3-hourly profiles, and get a monthly-mean ISCCP histogram of cloud fraction and a monthly-mean ISCCP histogram of CRF for the grid (lat, lon). Then I compute cloud radiative kernel for the grid.

Black line: weighting function, red line: weighted-mean cloud top pressure



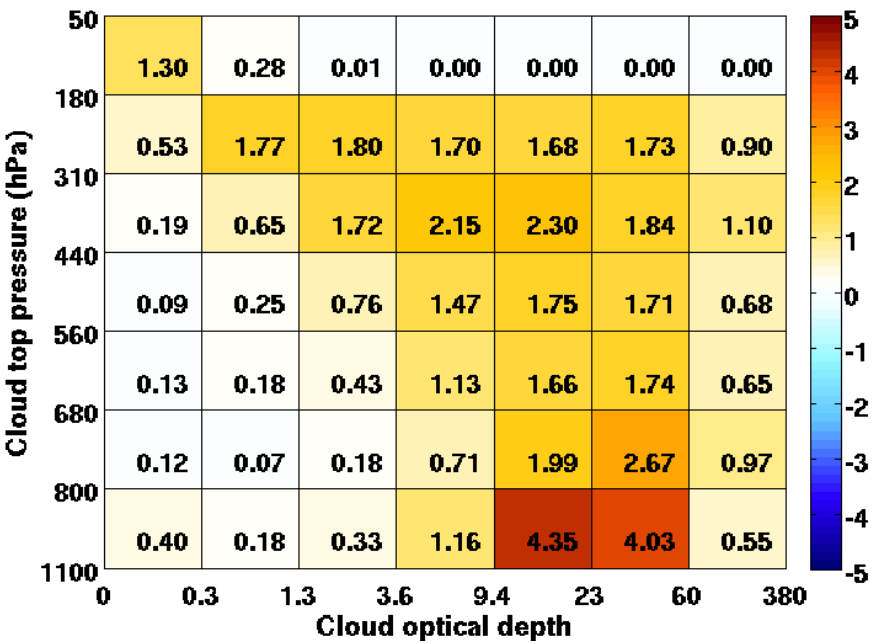
Monthly-mean cloud fraction histogram in Jan. 2003

Obtained by doing IR cloud top pressure



%

Obtained by doing weighted-mean cloud top pressure



%

Derived LW cloud radiative kernels (January)

$Wm^{-2}/\%$

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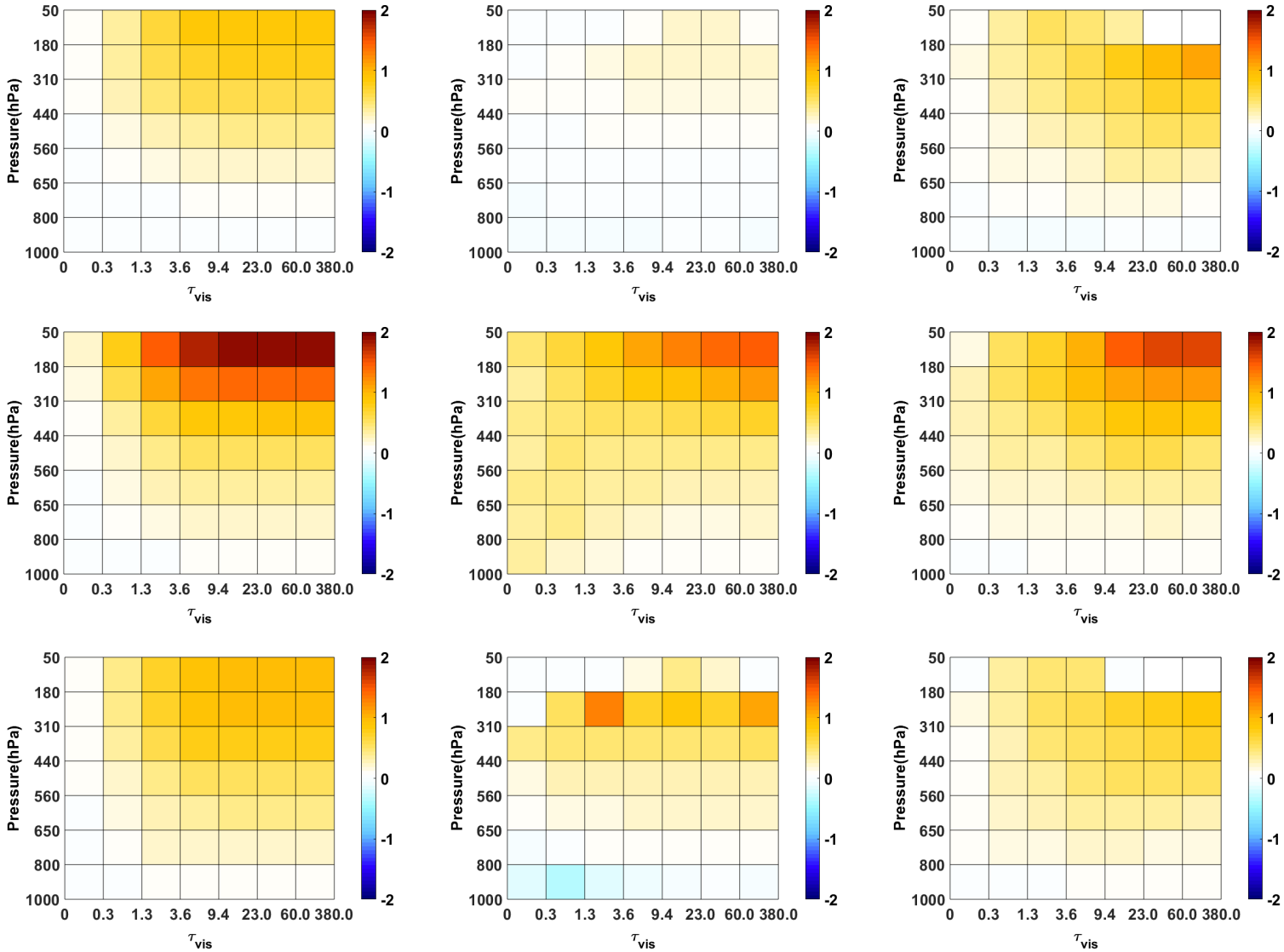
MODIS/AIRS-based kernel (Yue et al. 2016)

CESM-based kernel following Yue et al.

Arctic (60N-90N)

Tropics (10S-10N)

Antarctic (60S-90S)



slab, average of control and 2xco2

Derived LW cloud radiative kernels (July)

$Wm^{-2}/\%$

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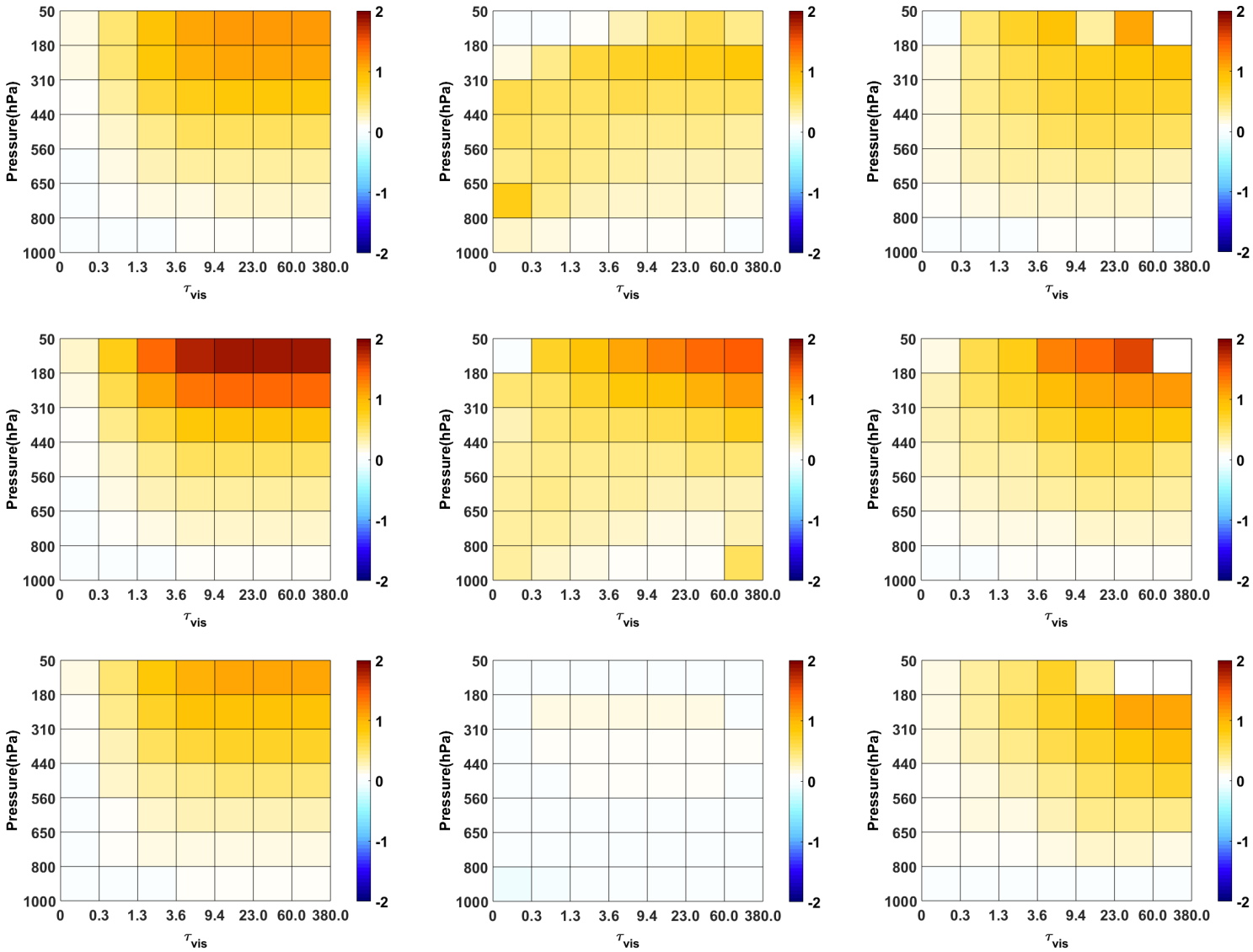
CESM-based kernel following Yue et al.

Arctic (60N-90N)

Tropics (10S-10N)

Antarctic (60S-90S)



slab, average of control and 2xco2

Derived SW cloud radiative kernels (January)

$Wm^{-2}/\%$

RT-based kernel (Zelinka et al., 2012)

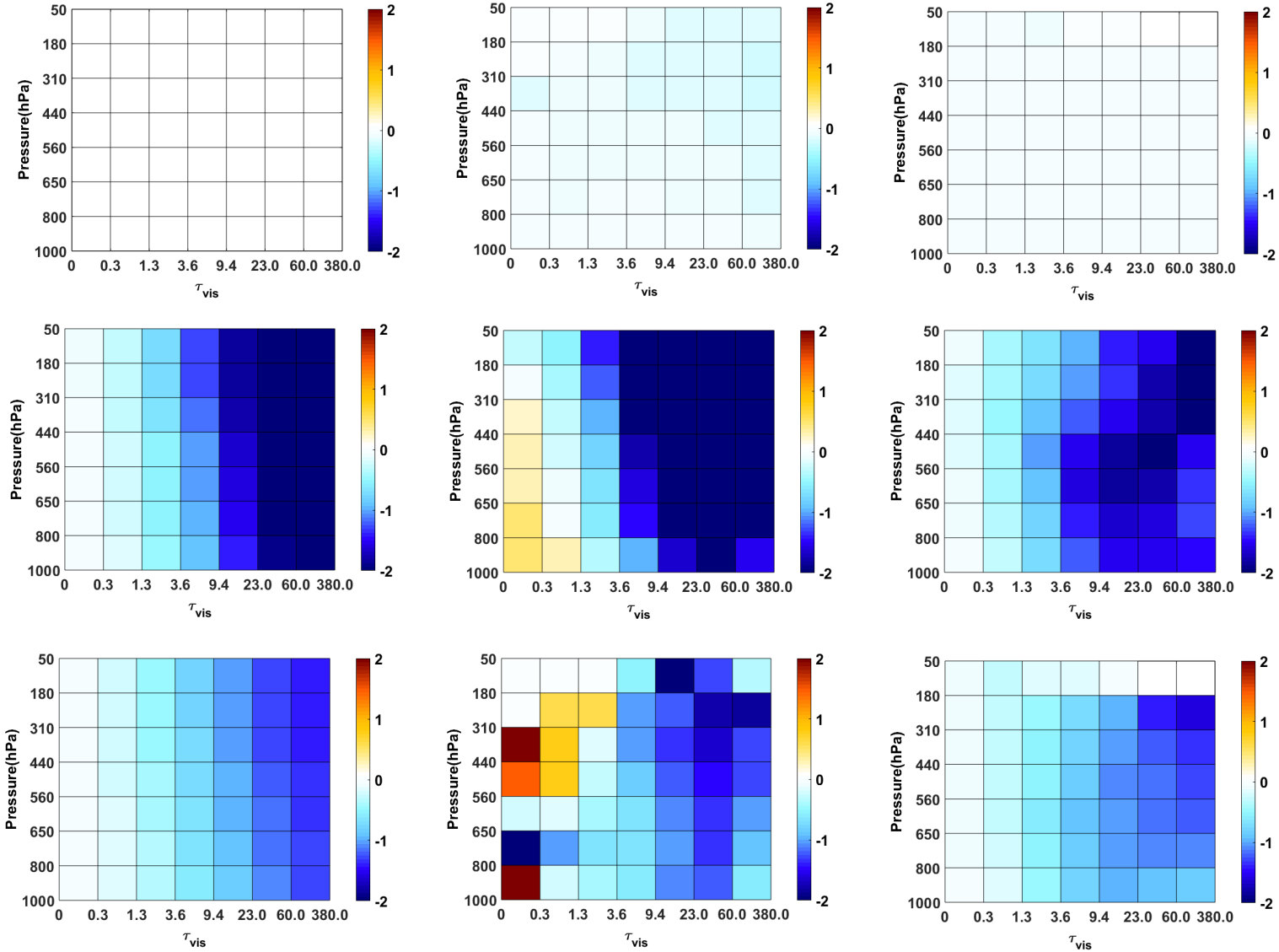
MODIS/AIRS-based kernel (Yue et al. 2016)

CESM-based kernel following Yue et al.

Arctic (60N-90N)

Tropics (10S-10N)

Antarctic (60S-90S)

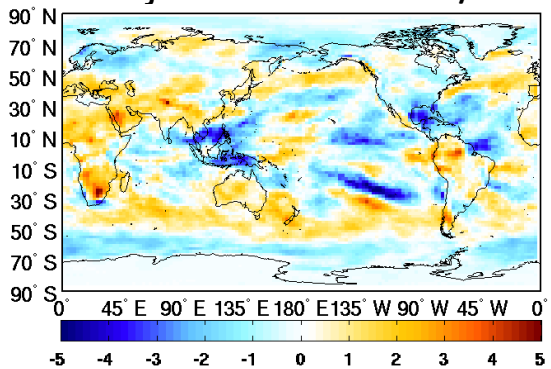


slab, average of control and 2xco2

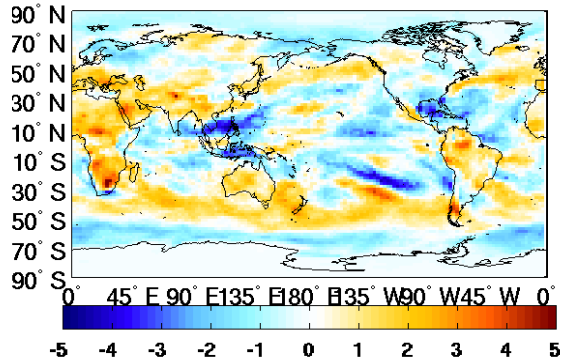
SW cloud feedbacks from two methods: adjust vs. kernel

+2K SST run

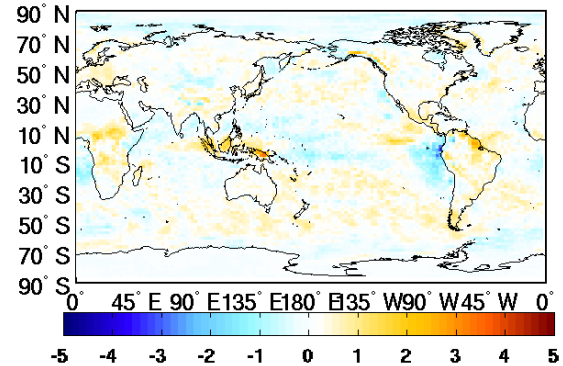
Adjust: -0.10 Wm^{-2}/K



Kernel:0.01 Wm^{-2}/K

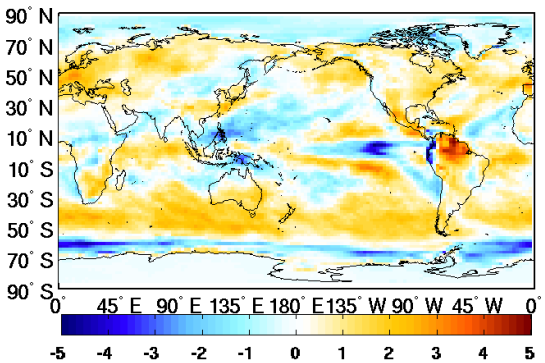


Kernel – Adjust:0.11Wm^{-2}/K

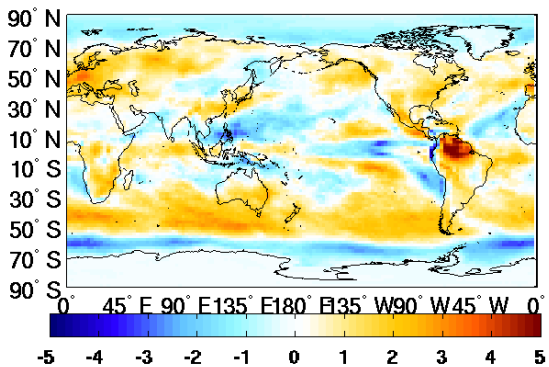


$2XCO_2$ run

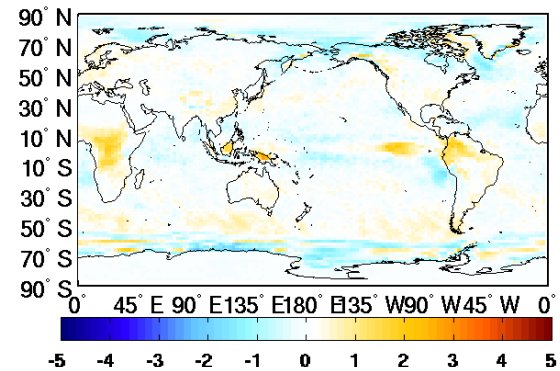
Adjust: 0.34 Wm^{-2}/K



Kernel:0.37 Wm^{-2}/K

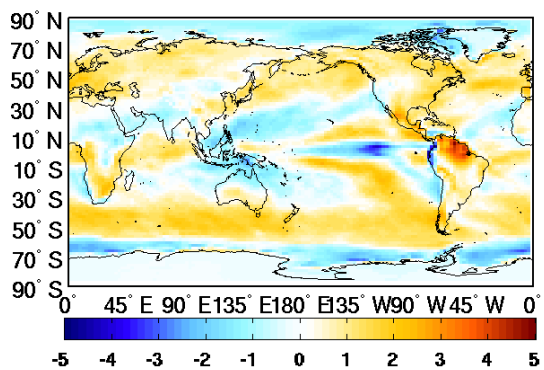


Kernel – Adjust:-0.03Wm^{-2}/K

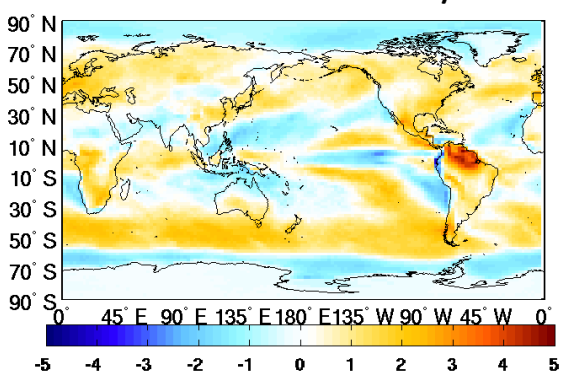


$4XCO_2$ run

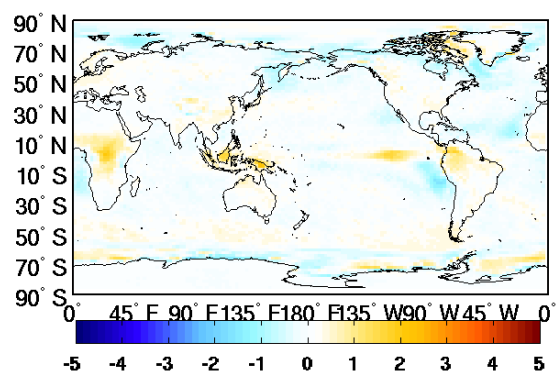
Adjust: 0.34Wm^{-2}/K



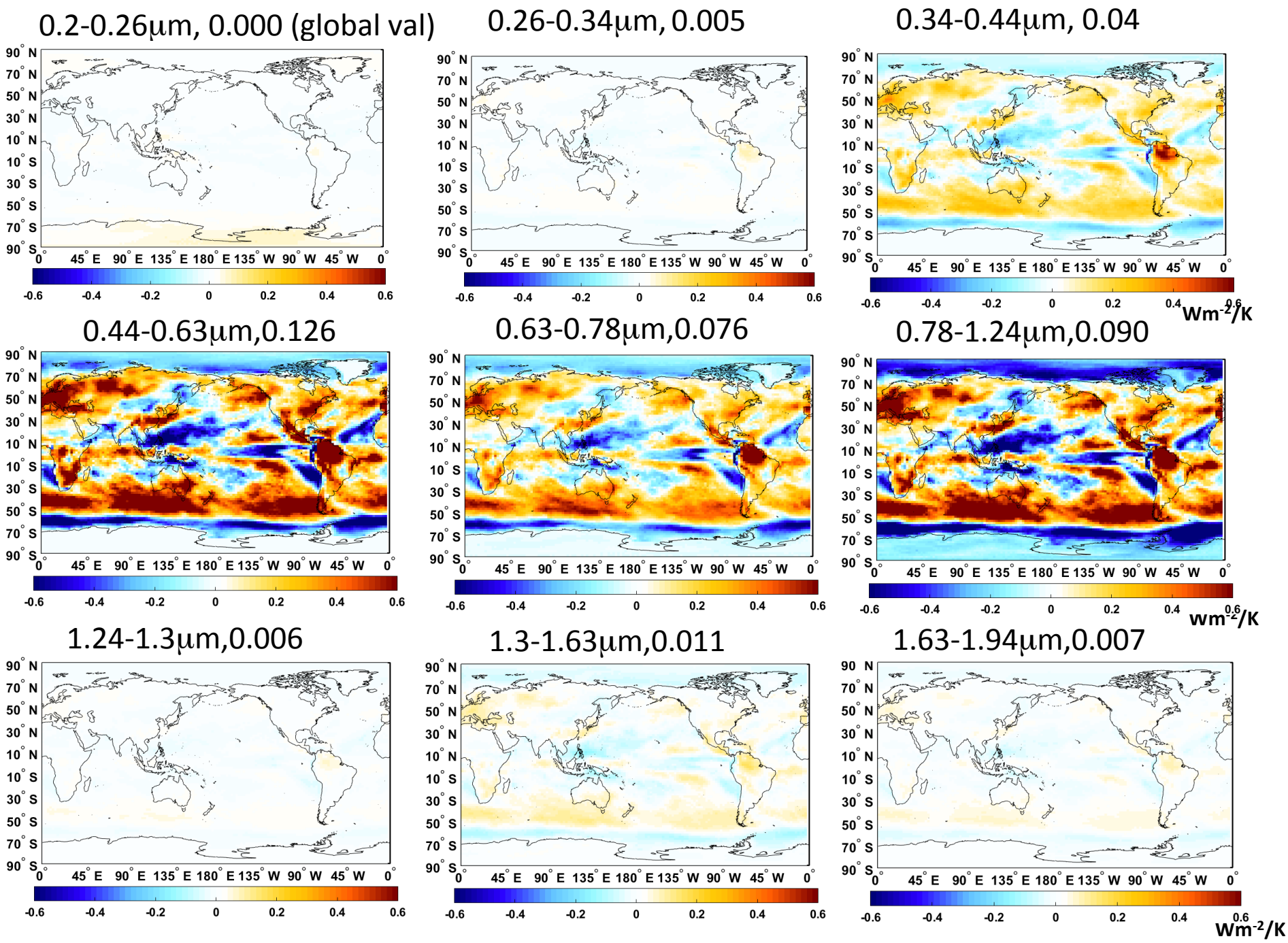
Kernel: 0.38Wm^{-2}/K



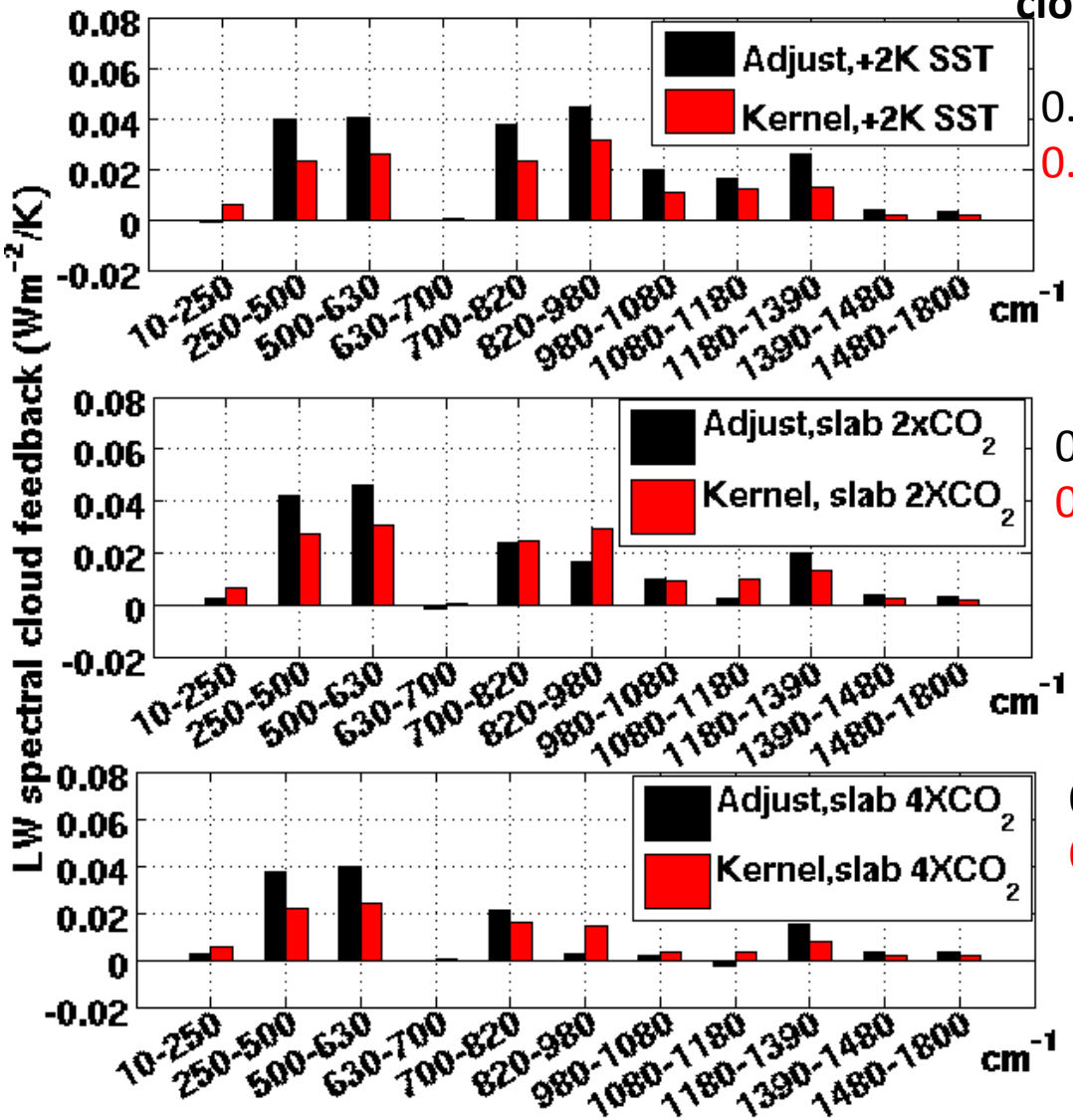
Kernel – Adjust:0.04Wm^{-2}/K



SW and-by-band Cloud radiative feedback from 2×CO_2 run (kernel method)



Band-by-band LW cloud feedback in the NCAR CESM (same kernel)



Broadband LW cloud feedback	Kernel	Cloud response
0.23 Wm^{-2}/K 0.15 Wm^{-2}/K	Slab control	+2K - control
0.18 Wm^{-2}/K 0.16 Wm^{-2}/K	Slab control	2XCO$_2$- control
0.13 Wm^{-2}/K 0.10 Wm^{-2}/K	Slab control	4XCO$_2$- control