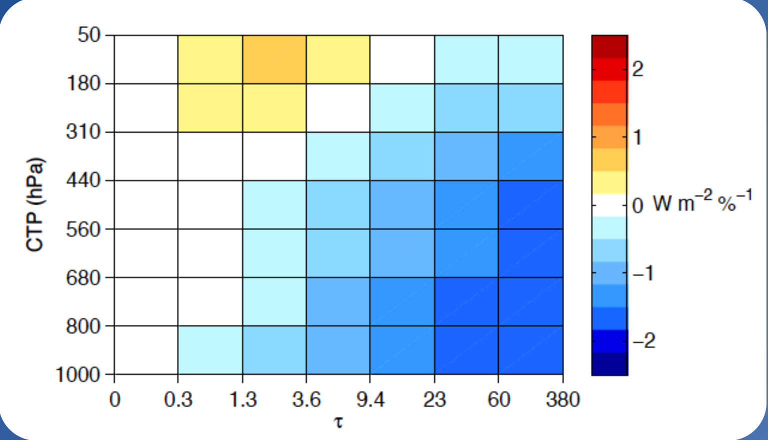
COMPUTING AND PARTITIONING CLOUD FEEDBACKS USING CLOUD PROPERTY HISTOGRAMS



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PCMDI Program for Climate Model Diagnosis and Intercomparison

Atmospheric Sciences University of Washington

Goals

- To provide a clean and simple method of computing cloud feedbacks that is highly informative
- Clean:
  - compute cloud feedback from ISCCP simulator-interpreted cloud changes directly (not inferred)
  - standard definition of "cloud" and radiation code across models
- Simple:
  - no need to correct for non-cloud effects
  - no partial radiative perturbation calculations are needed
  - can use monthly mean model output
- Informative:
  - can **quantify** the contribution to cloud feedback from **changing amounts of individual cloud types** (high, middle, low) and from **individual processes** (Δaltitude, Δoptical depth, Δtotal amount)

Data & Methodology

- Doubled CO_2 equilibrium slab ocean model simulations from 12 GCMs as part of CFMIP1
- ISCCP simulator (Klein & Jakob 1999) run inline during integration
  - Produce distribution of cloud fraction (as function of CTP and τ) that is consistent with how a satellite-borne passive sensor would "view" the model atmosphere
  - Simulated cloud fractions are defined consistently across models

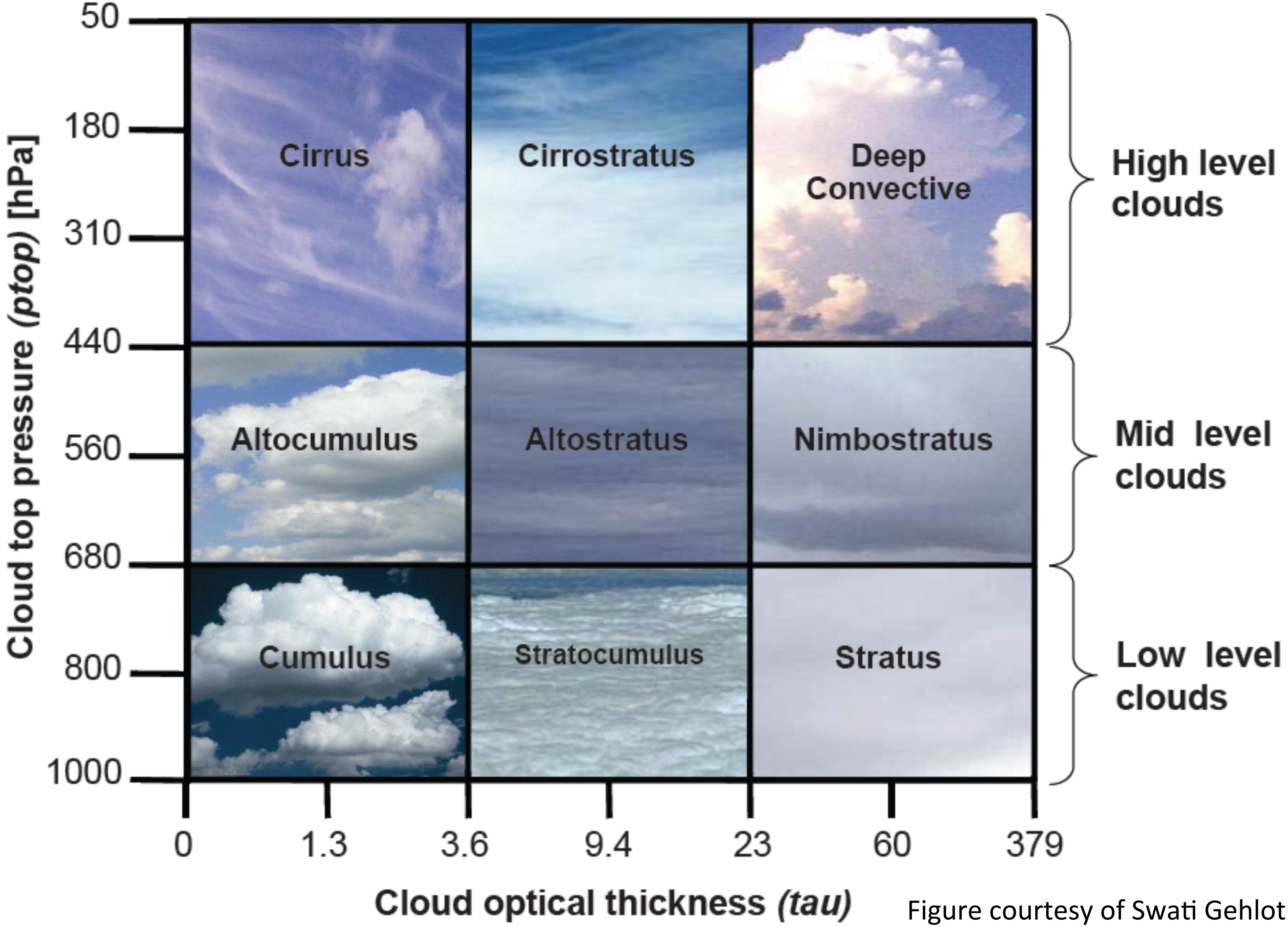

Figure courtesy of Swati Gehlot

Data & Methodology

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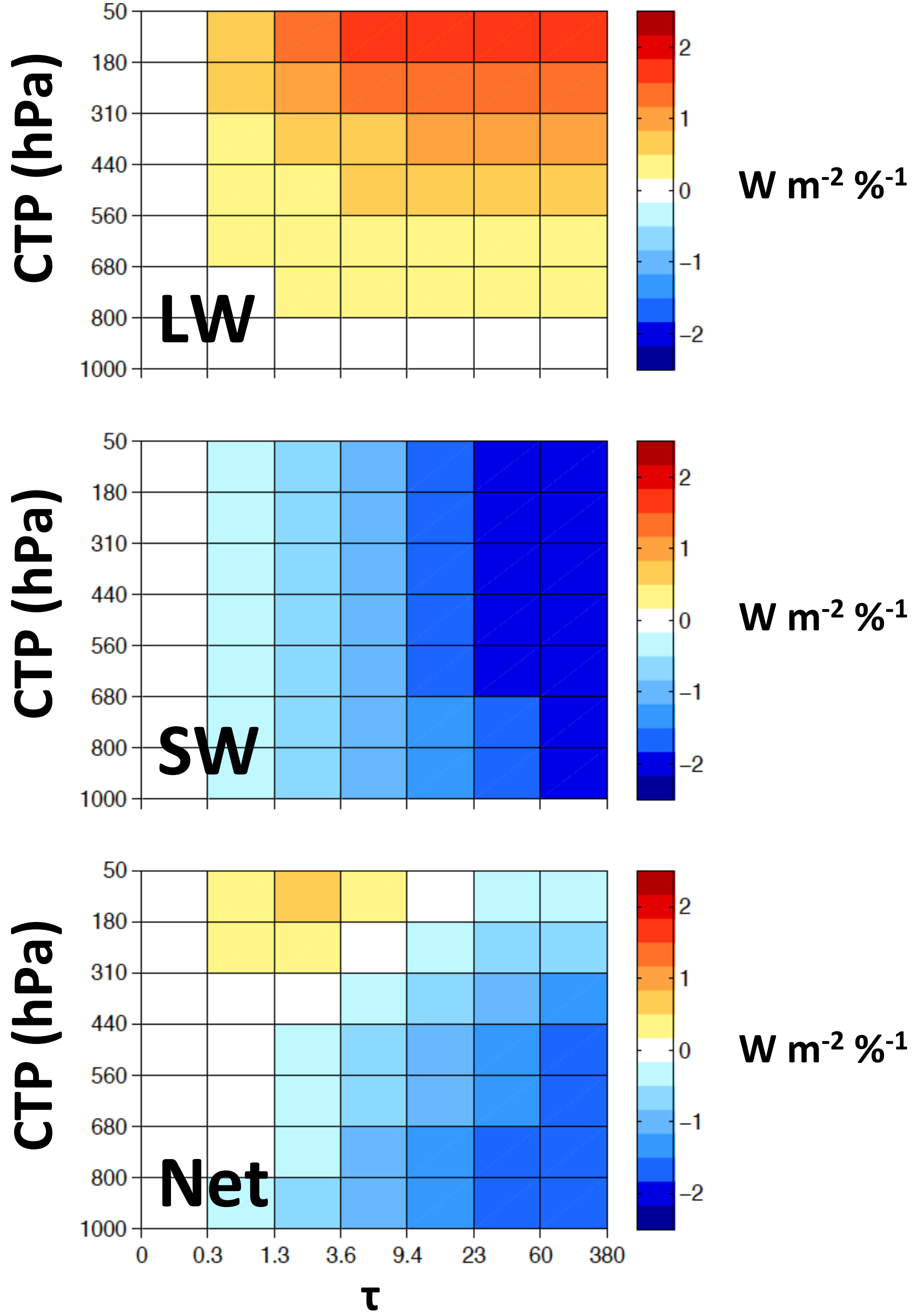
  - Simulated cloud fractions are defined consistently across models
- We compute cloud radiative kernels → sensitivity of TOA radiation to cloud fraction changes in each CTP-τ bin
- Cloud feedback = Δcloud fraction times cloud kernel normalized by ΔT_{sfc}

Recipe for Constructing Cloud Radiative Kernels

- ❑ Input model mean zonal mean T and q profiles to Fu-Liou code
- ❑ Compute clear-sky TOA fluxes
- ❑ Compute overcast-sky fluxes for each CTP and τ bin by setting the LWC / IWC profiles to values appropriate for each cloud type
- ❑ Subtract overcast TOA fluxes in each bin from the clear-sky flux to compute a matrix of overcast sky cloud forcing
- ❑ Divide by 100 to get W m^{-2} $\%^{-1}$
- ❑ Repeat every calculation for 24 solar zenith angles, all latitudes, 12 months, and 10 surface albedo bins between 0 and 1

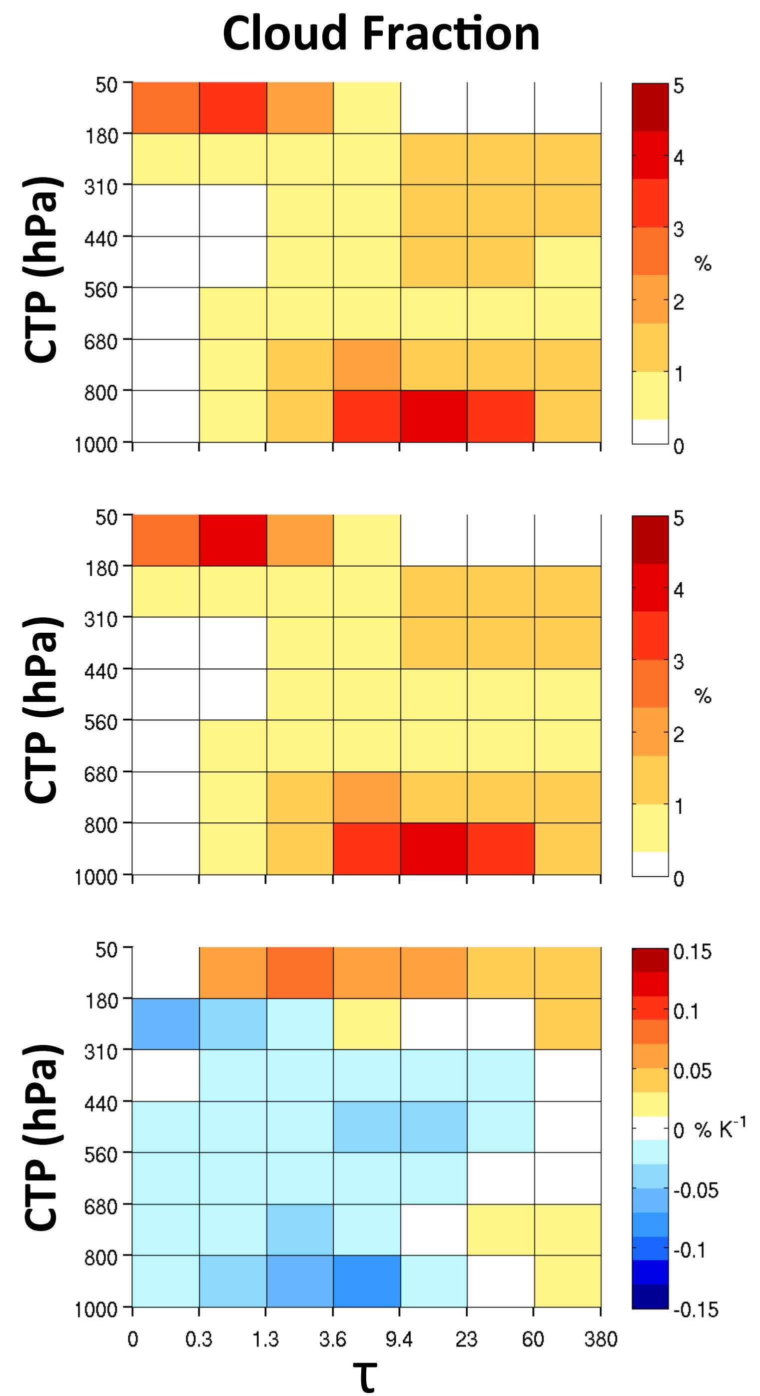
Global Annual Mean Cloud Kernels



1xCO_2

2xCO_2

Change
-0.4 % K^{-1}



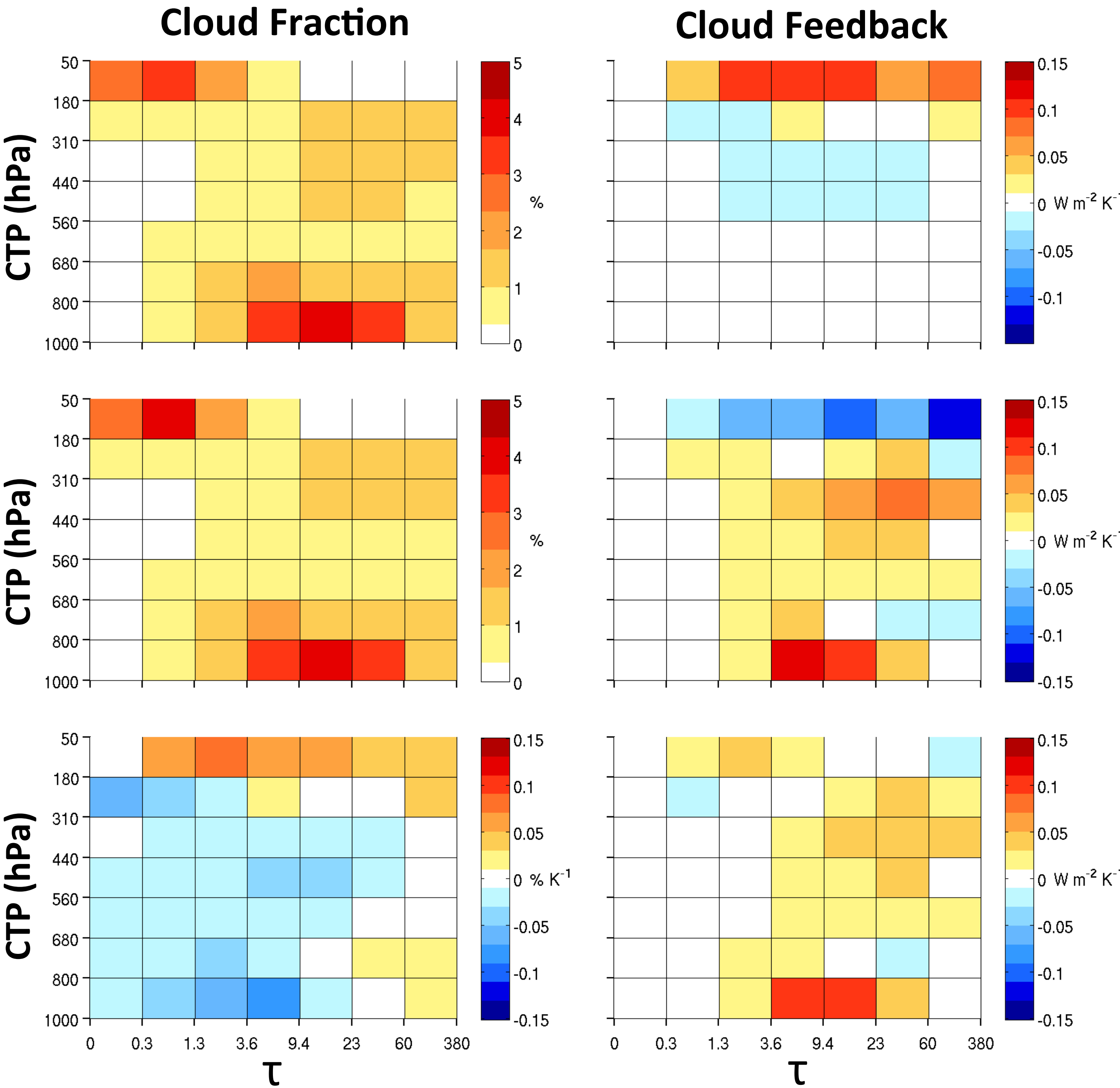
x Cloud Radiative Kernels
at each location and month,
then averaged annually,
globally, and across models...

Cloud Fraction | Cloud Feedback

$1xCO_2$

$2xCO_2$

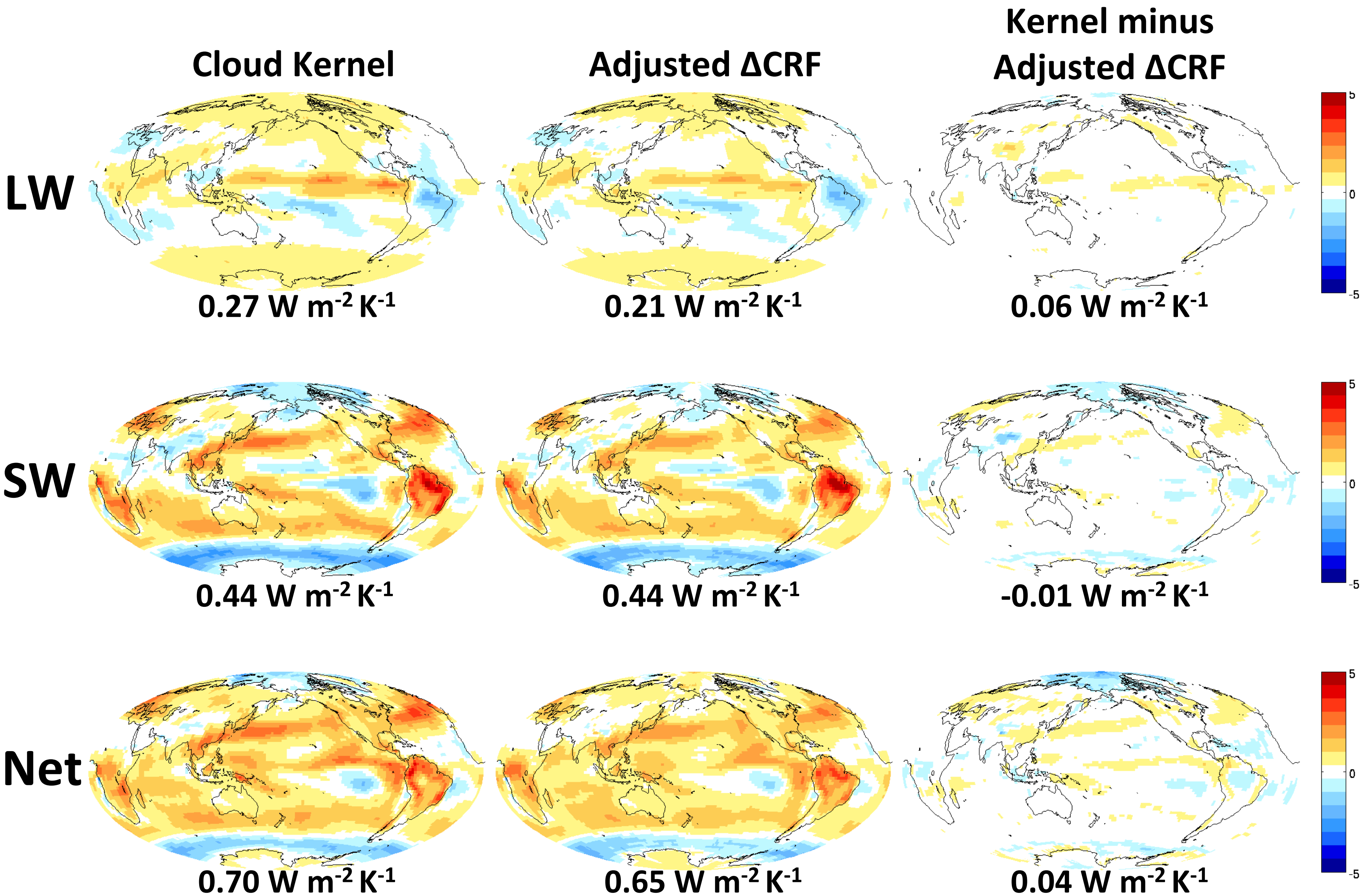
Change
$-0.4\ \%\ K^{-1}$

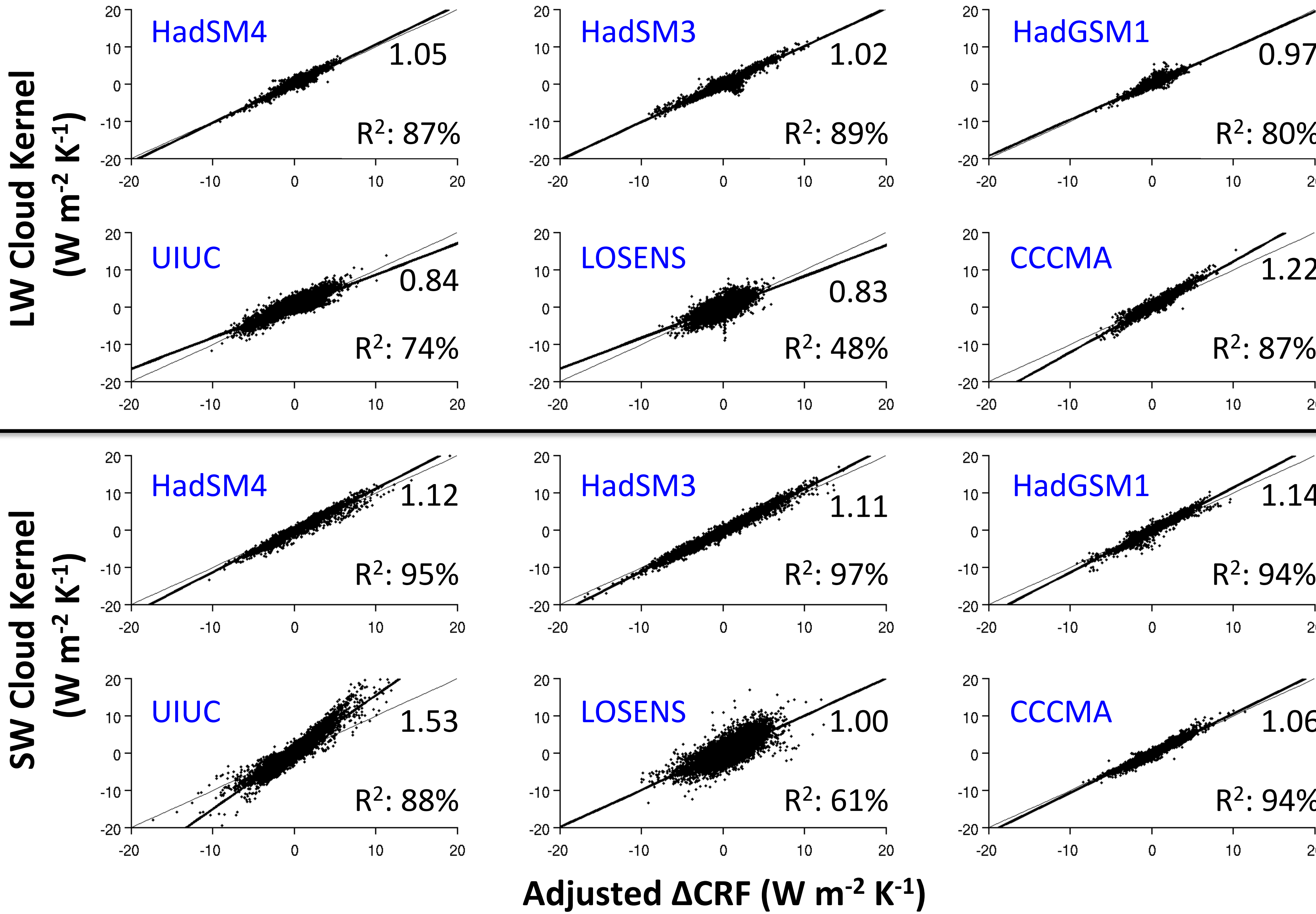


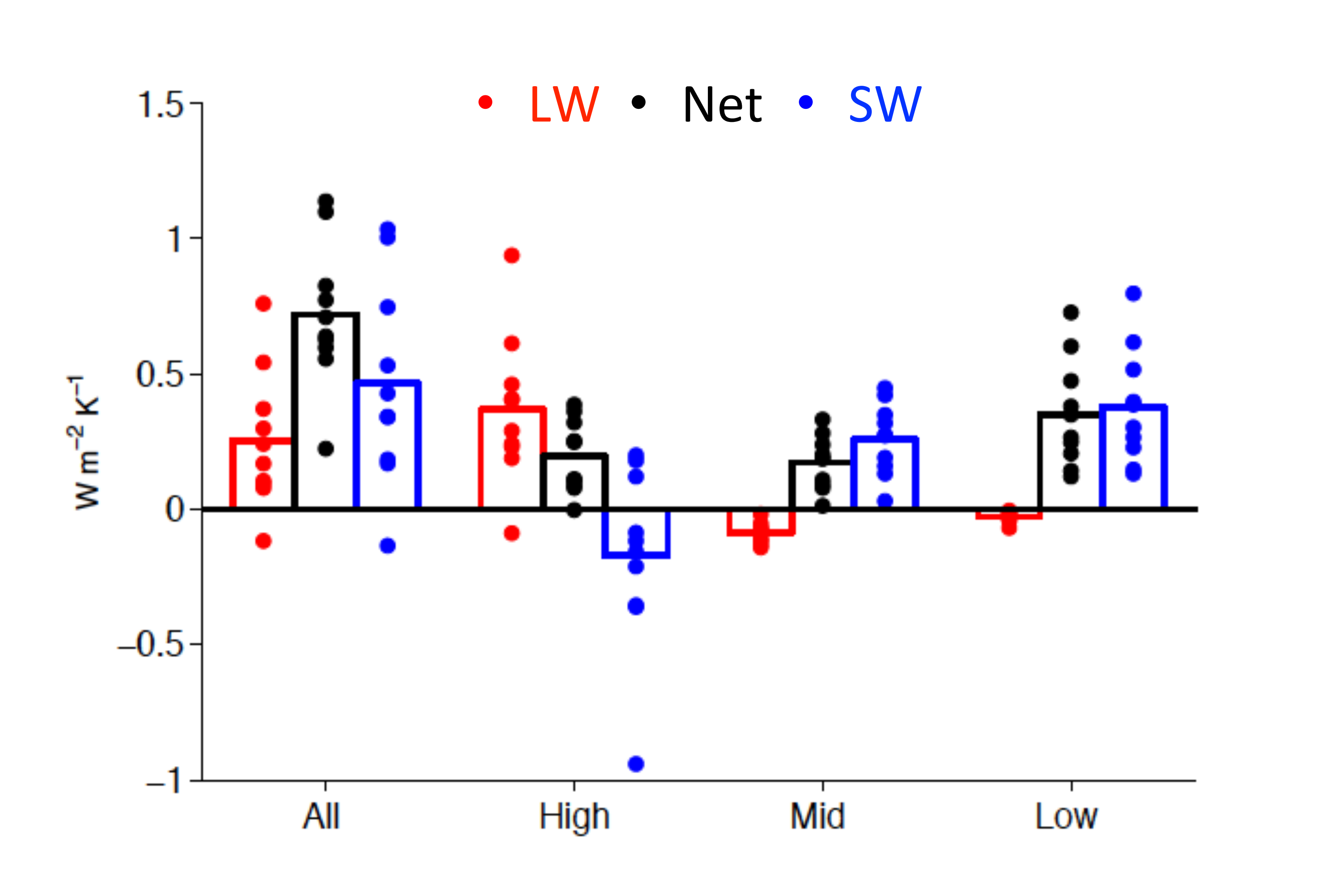
LW
$0.27\ Wm^{-2}K^{-1}$

SW
$0.44\ Wm^{-2}K^{-1}$

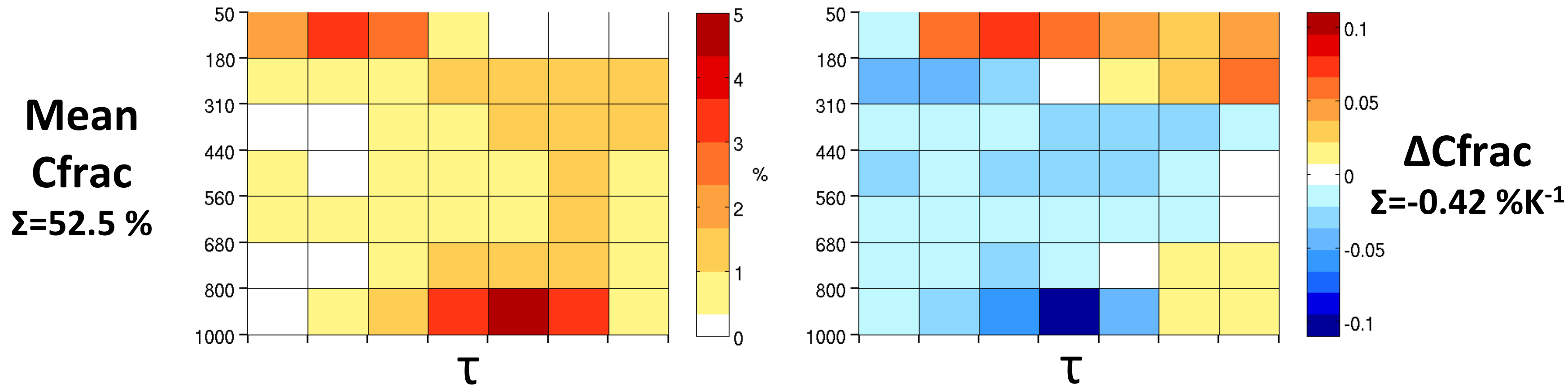
Net
$0.71\ Wm^{-2}K^{-1}$


Cloud Kernel
Adjusted ΔCRF
Kernel minus
Adjusted ΔCRF
LW
SW
Net
0.27 W m-2 K-1
0.21 W m-2 K-1
0.06 W m-2 K-1
0.44 W m-2 K-1
0.44 W m-2 K-1
-0.01 W m-2 K-1
0.70 W m-2 K-1
0.65 W m-2 K-1
0.04 W m-2 K-1
5
0
-5


LW Cloud Kernel (W m-2 K-1)
HadSM4
1.05
R2: 87%
HadSM3
1.02
R2: 89%
HadGSM1
0.97
R2: 80%
UIUC
0.84
R2: 74%
LOSENS
0.83
R2: 48%
CCCMA
1.22
R2: 87%
SW Cloud Kernel (W m-2 K-1)
HadSM4
1.12
R2: 95%
HadSM3
1.11
R2: 97%
HadGSM1
1.14
R2: 94%
UIUC
1.53
R2: 88%
LOSENS
1.00
R2: 61%
CCCMA
1.06
R2: 94%
Adjusted ΔCRF (W m-2 K-1)



LW
Net
SW
1.5
1
0.5
0
–0.5
–1
W m^{-2} K^{-1}
All
High
Mid
Low

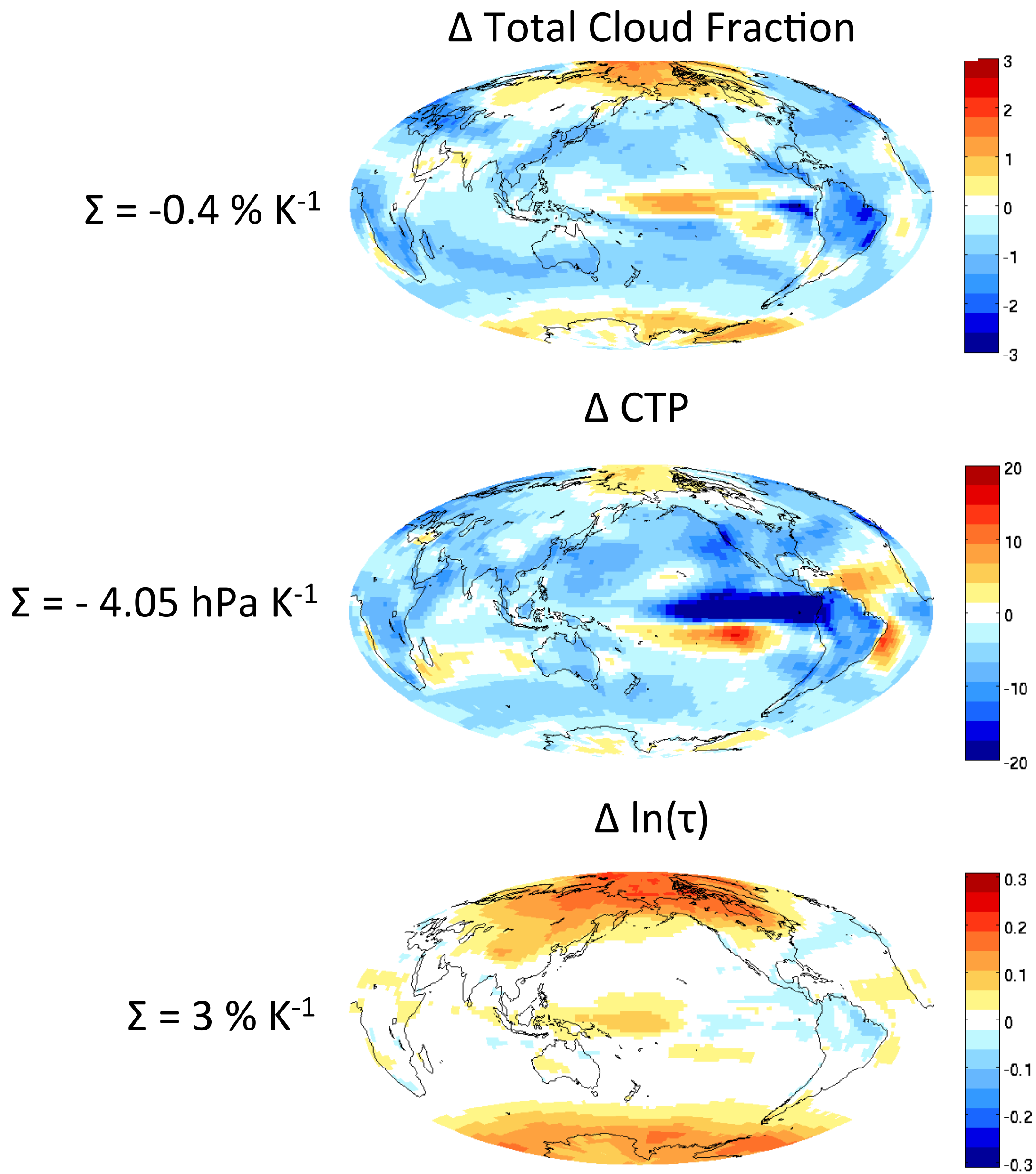


- Decompose the cloud changes into

ΔAMOUNT

ΔALTITUDE

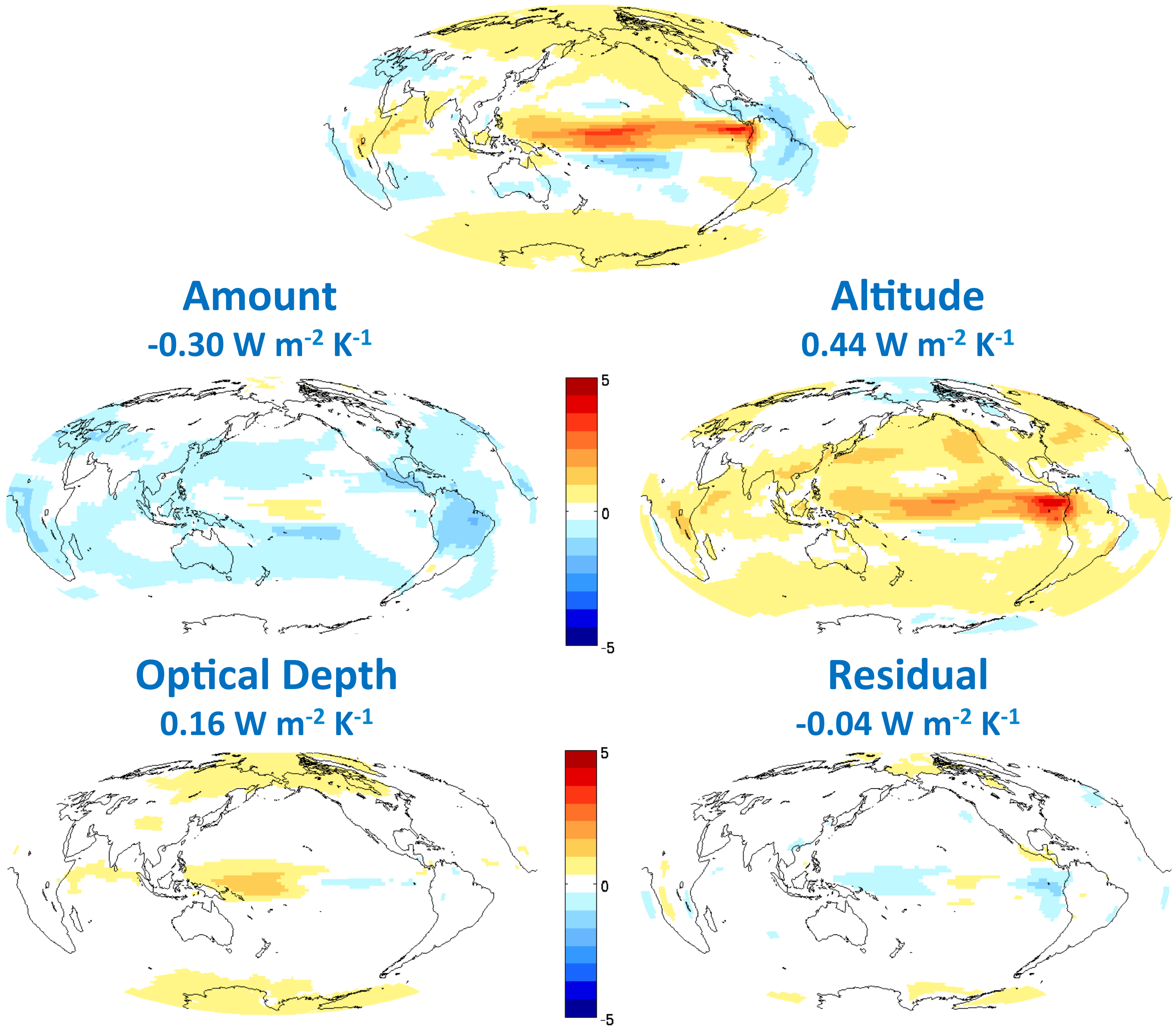
ΔOPTICAL DEPTH



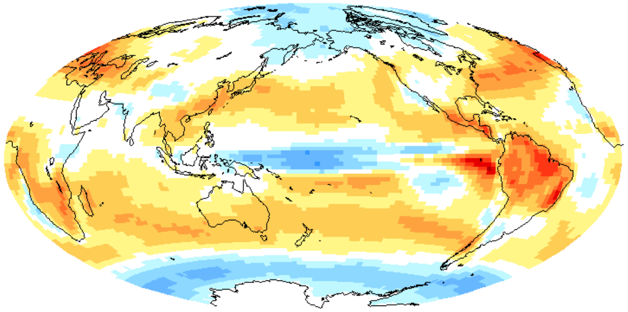
Δ Total Cloud Fraction
Σ = -0.4 % K-1
3
2
1
0
-1
-2
-3
Δ CTP
Σ = - 4.05 hPa K-1
20
10
0
-10
-20
Δ ln(τ)
Σ = 3 % K-1
0.3
0.2
0.1
0
-0.1
-0.2
-0.3

LW Cloud Feedback

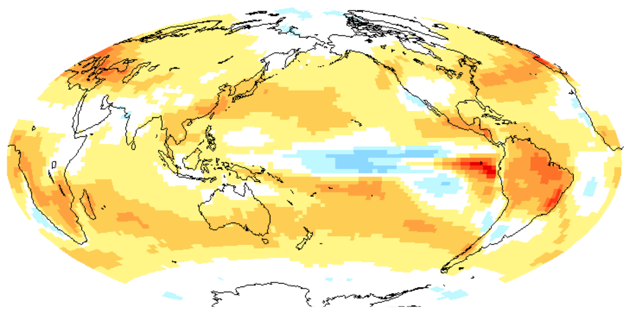
$0.26\ W\ m^{-2}\ K^{-1}$

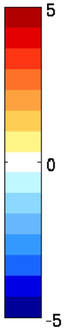


SW Cloud Feedback
0.46 W m^{-2} K^{-1}

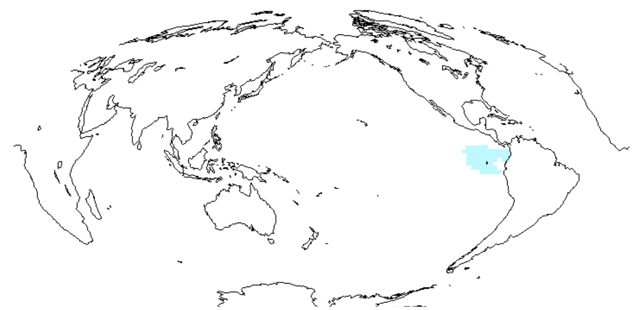


Amount
0.66 W m^{-2} K^{-1}

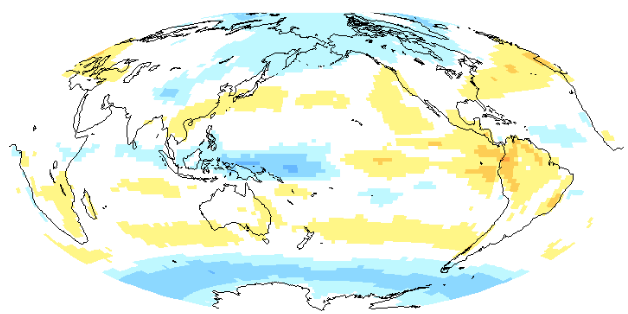


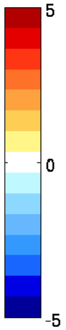


Altitude
-0.03 W m^{-2} K^{-1}

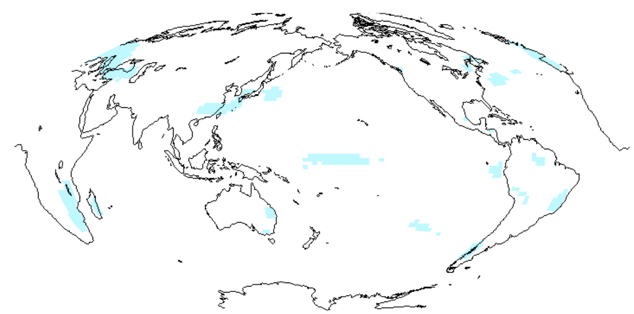


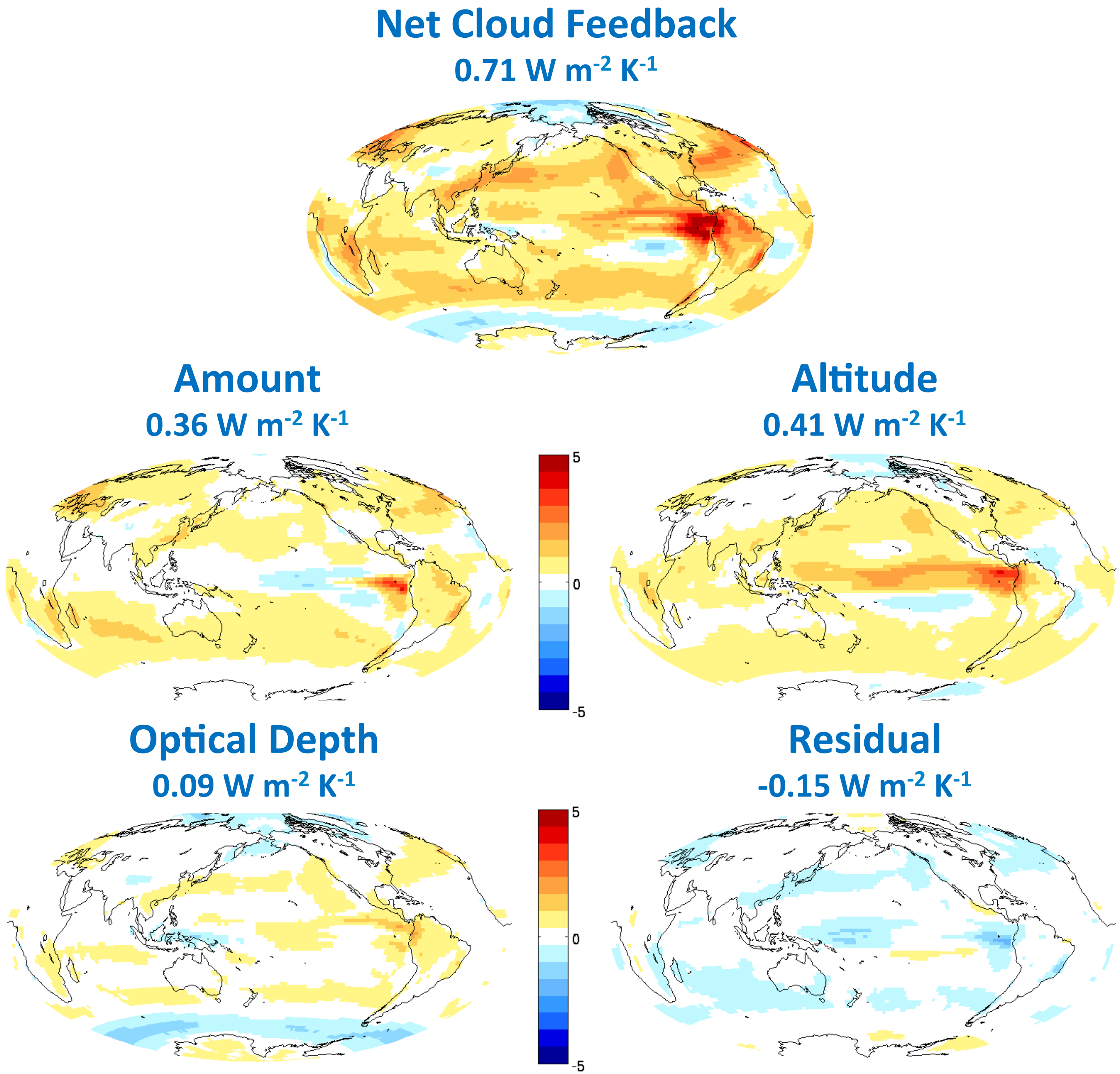
Optical Depth
-0.05 W m^{-2} K^{-1}



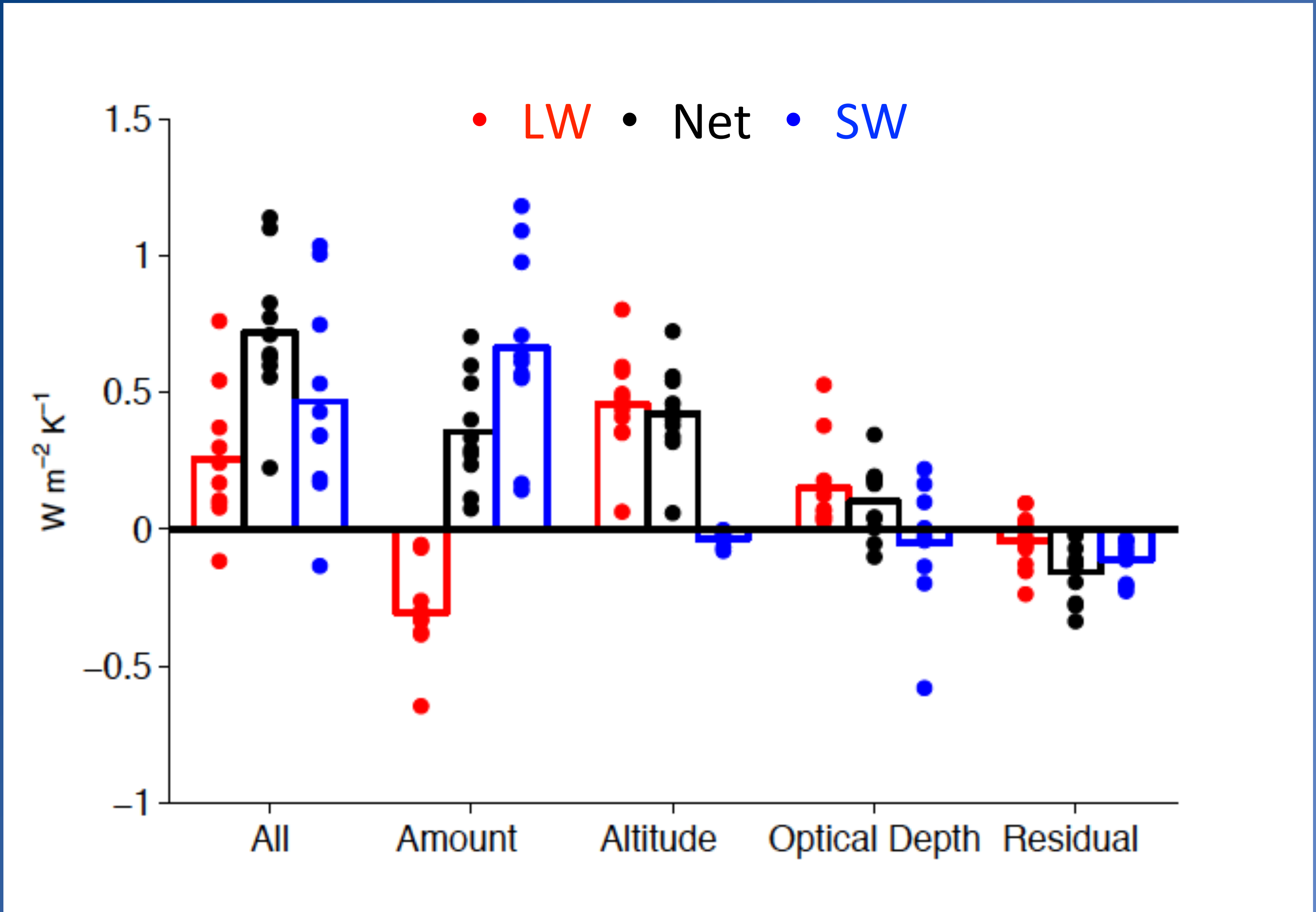


Residual
-0.11 W m^{-2} K^{-1}





Net Cloud Feedback
0.71 W m-2 K-1
Amount
0.36 W m-2 K-1
Altitude
0.41 W m-2 K-1
5
0
-5
Optical Depth
0.09 W m-2 K-1
Residual
-0.15 W m-2 K-1
5
0
-5


• LW • Net • SW
1.5
1
0.5
0
−0.5
−1
W m^{-2} K^{-1}
All
Amount
Altitude
Optical Depth
Residual

Conclusions

- Cloud radiative kernels allow computation of cloud feedback directly from cloud fraction histograms produced by ISCCP simulator
- Feedbacks computed with cloud kernels compare very well with those computed by adjusting the change in cloud forcing
- More than half of the global mean net cloud feedback can be attributed to the combined response of middle- and high-level clouds
- High cloud changes induce wider range of LW and SW cloud feedbacks across models than do low clouds
- Increasing cloud top altitude is dominant contributor to the positive global mean LW and net cloud feedbacks (positive in every model)
- Decreasing total cloud fraction is dominant contributor to global mean positive SW cloud feedback (positive in every model)
- Large negative net cloud feedback at high latitudes is caused by increased optical depth, not increased cloud amount

Thank you!

Drafts of papers: Google "Mark Zelinka"

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