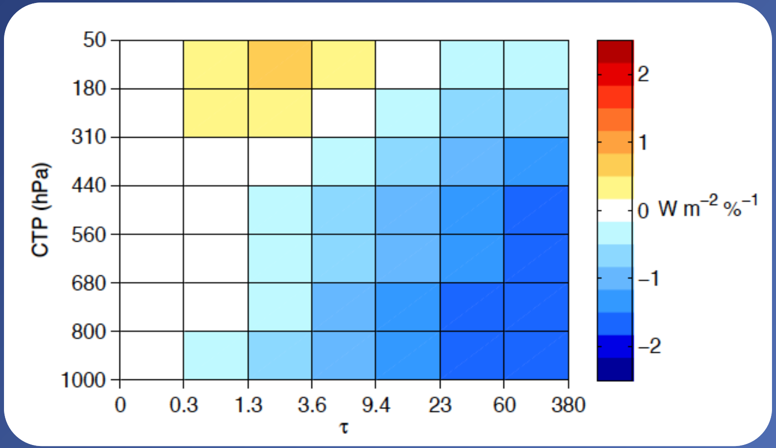
COMPUTING AND PARTITIONING CLOUD FEEDBACKS USING CLOUD PROPERTY HISTOGRAMS



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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)

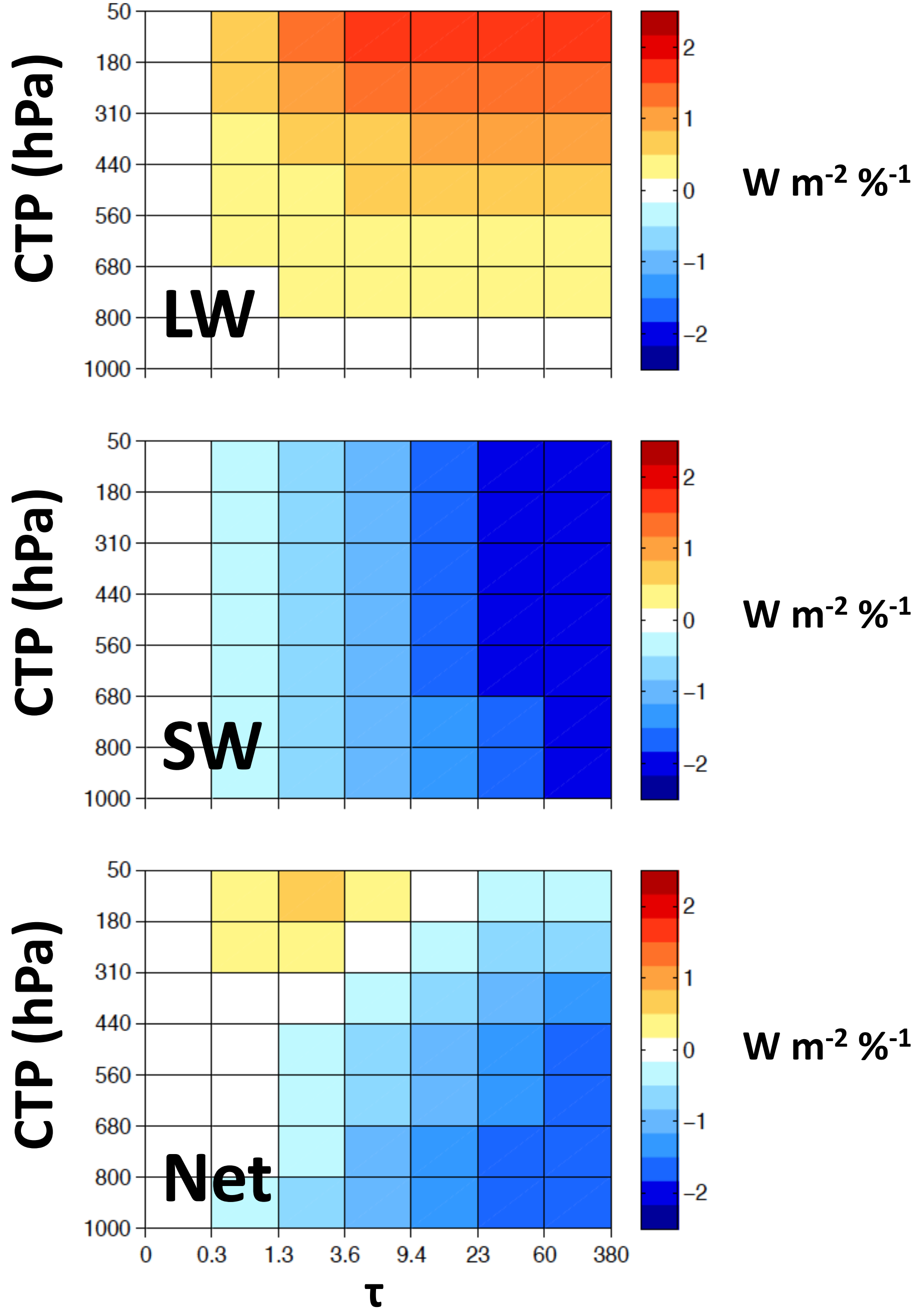
Data & Methodology

- Doubled CO_2 equilibrium slab ocean model simulations from 12 GCMs as part of CFMIP1
- ISCCP simulator 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
- 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 histogram 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

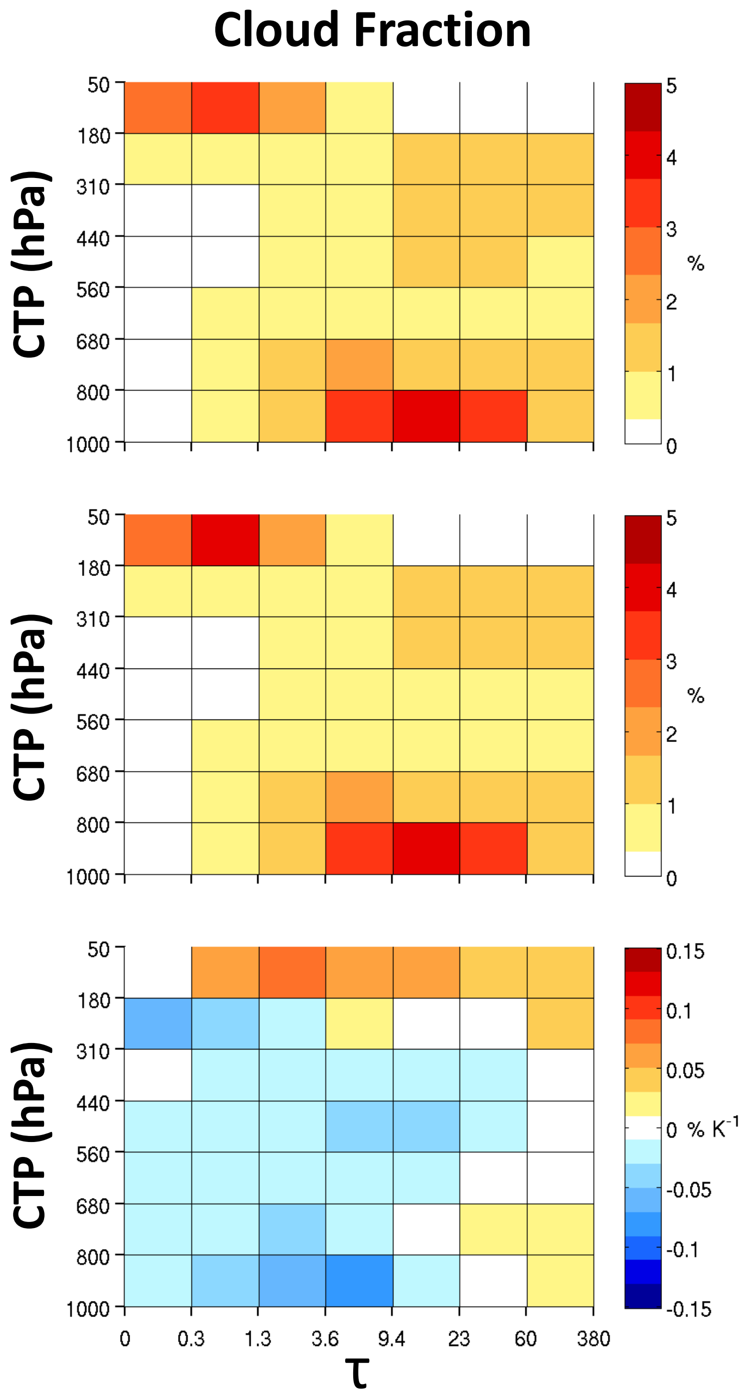
Global Annual Mean Cloud Kernels



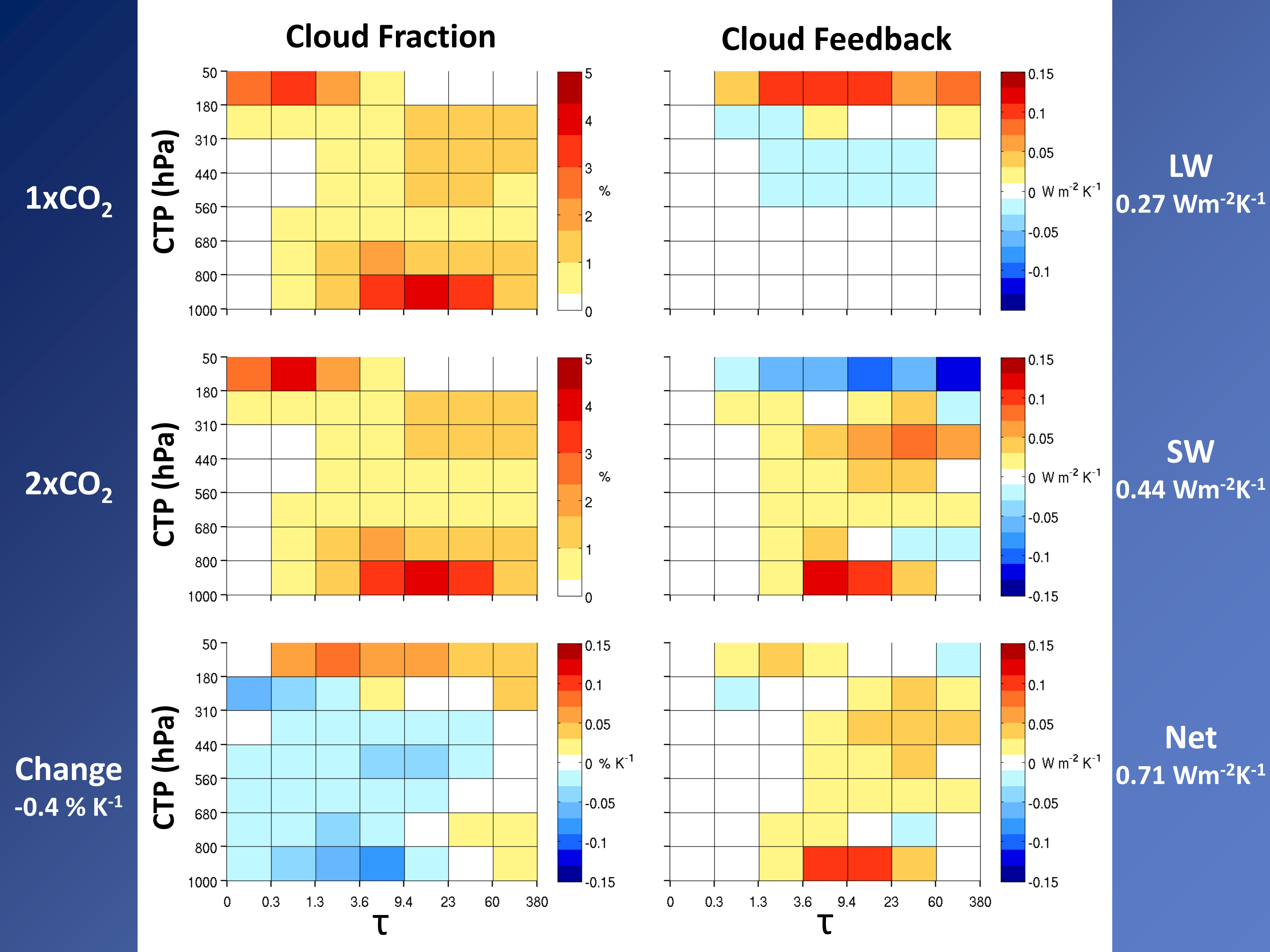
1xCO_2

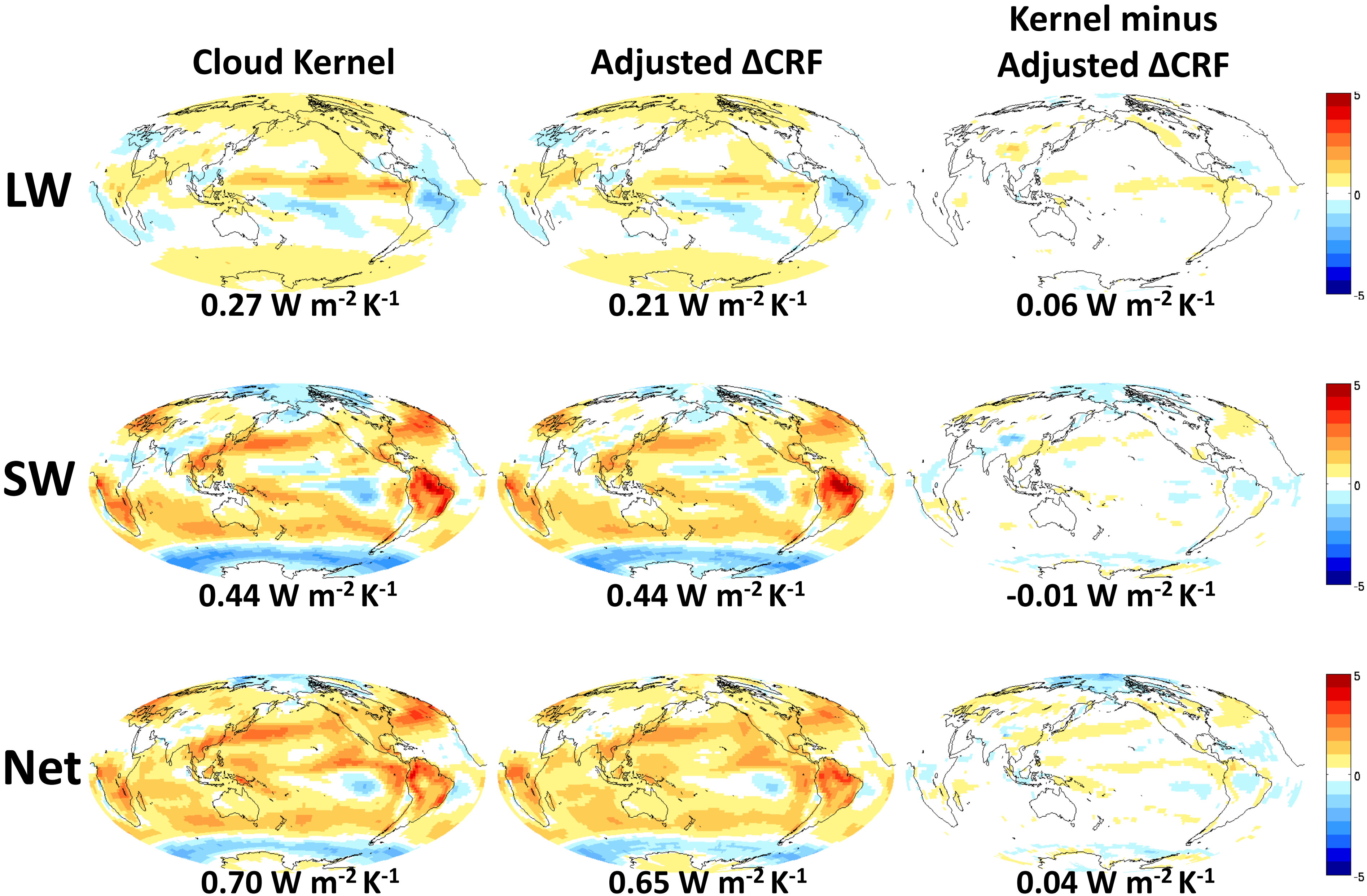
2xCO_2

Change
-0.4 % K^{-1}

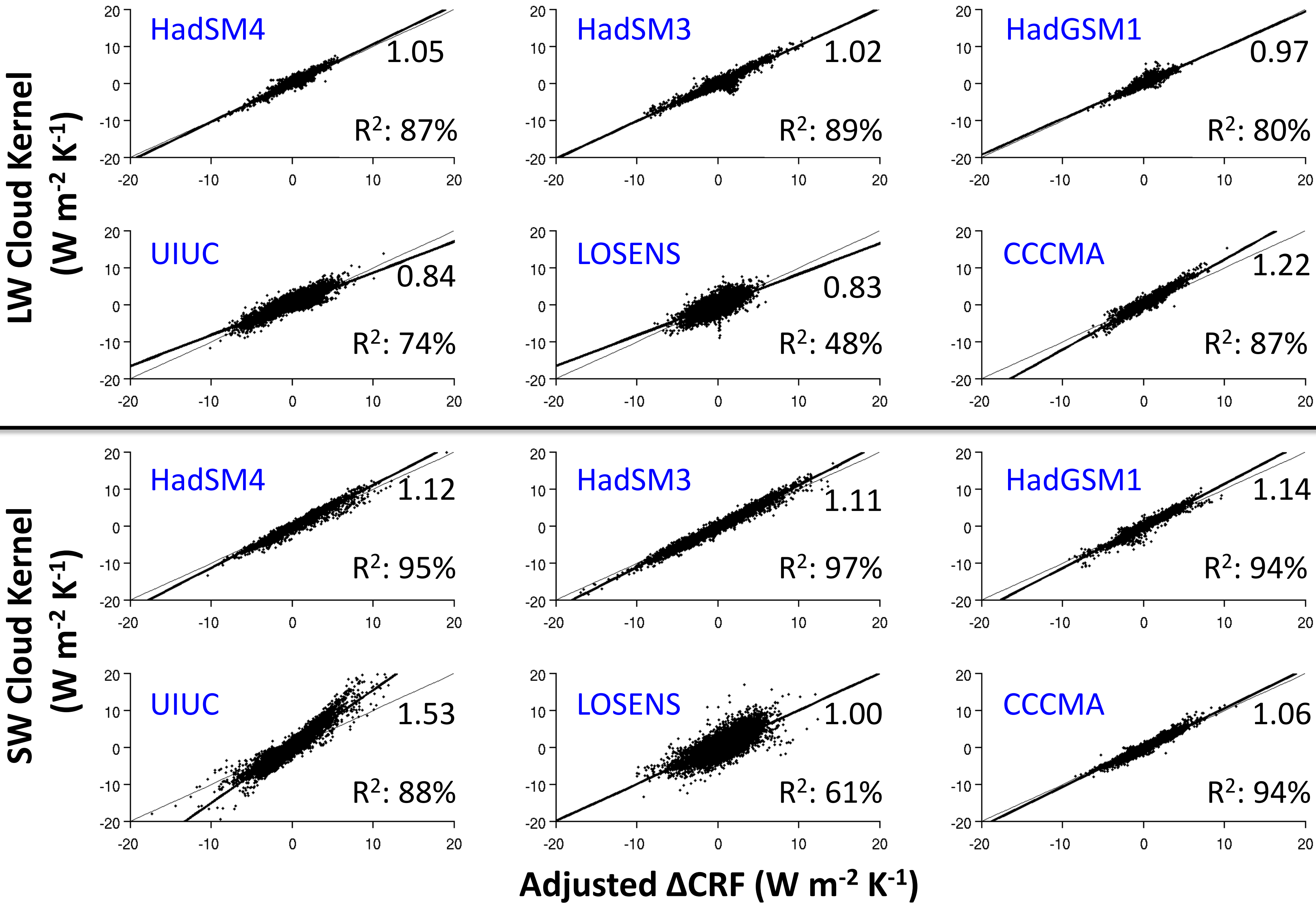


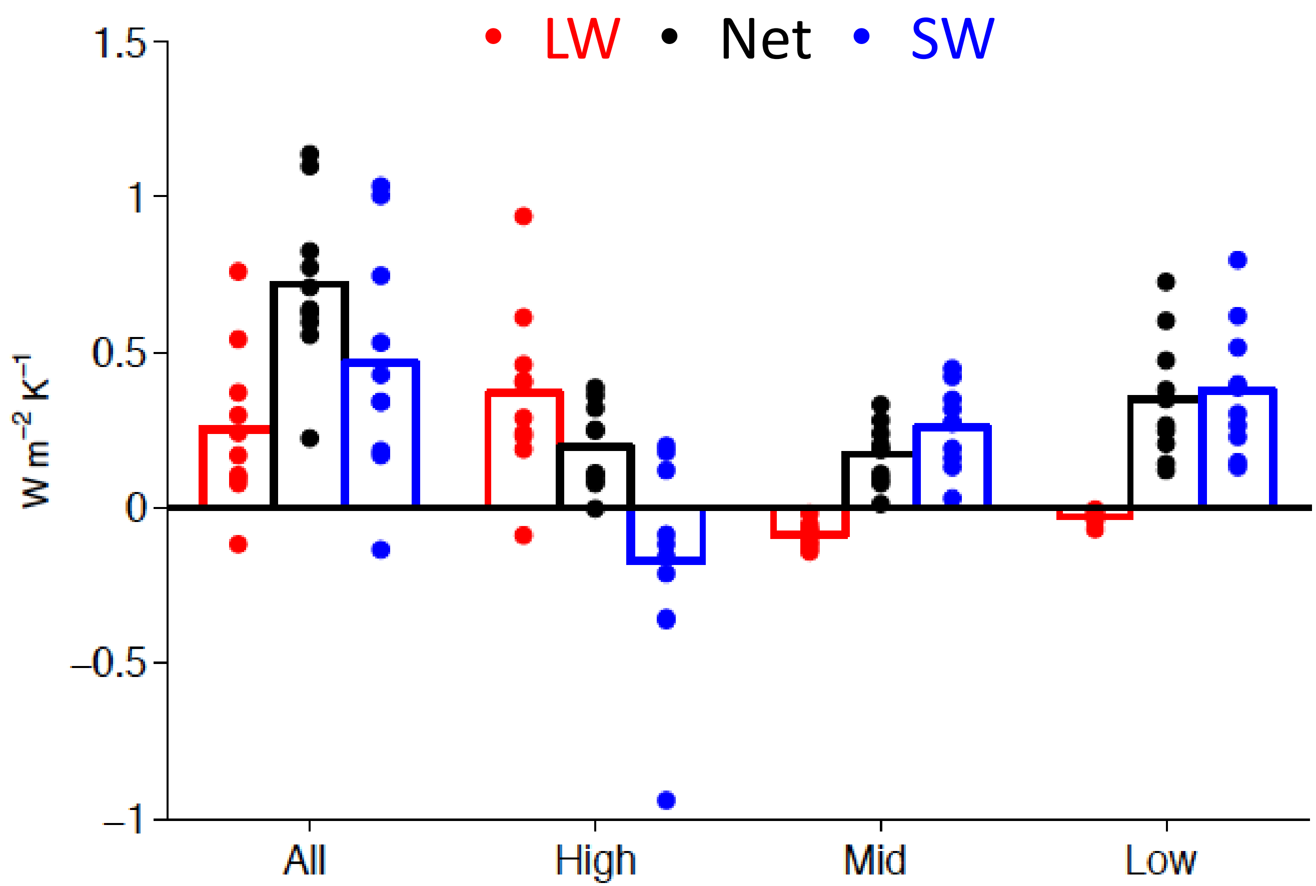
x Cloud Radiative Kernels
at each location and month,
then averaged annually,
globally, and across models…


Cloud Fraction
Cloud Feedback
1xCO2
2xCO2
Change
-0.4 % K-1
LW
0.27 Wm-2K-1
SW
0.44 Wm-2K-1
Net
0.71 Wm-2K-1
CTP (hPa)
τ
%
0 % K-1
0 W m-2 K-1
50
180
310
440
560
680
800
1000
0
0.3
1.3
3.6
9.4
23
60
380

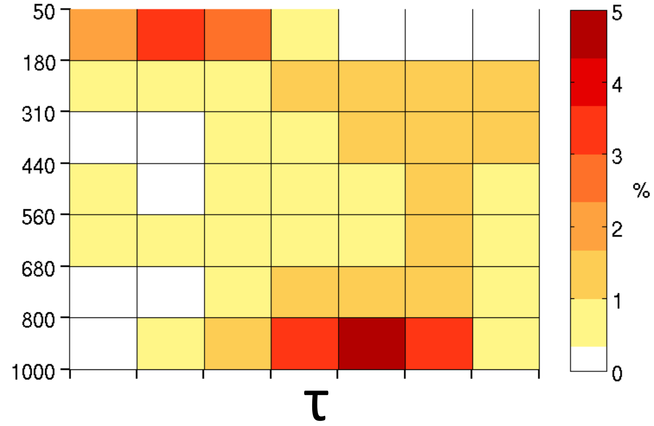


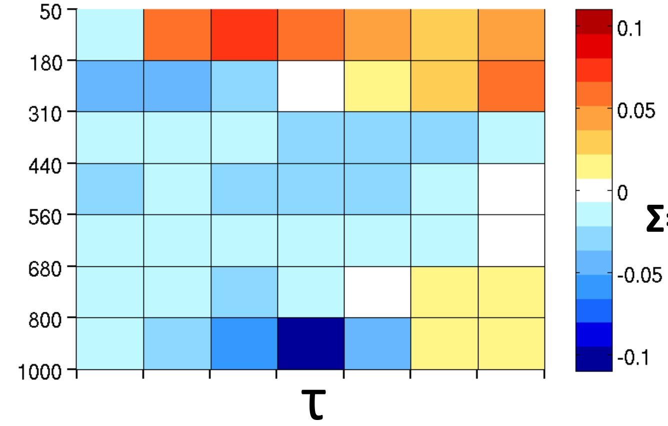
Cloud Kernel
Adjusted ΔCRF
Kernel minus Adjusted ΔCRF
LW
0.27 W m-2 K-1
0.21 W m-2 K-1
0.06 W m-2 K-1
SW
0.44 W m-2 K-1
0.44 W m-2 K-1
-0.01 W m-2 K-1
Net
0.70 W m-2 K-1
0.65 W m-2 K-1
0.04 W m-2 K-1
5
0
-5


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

Mean Cfrac
Σ=52.5 %





ΔCfrac
Σ=-0.42 %K-1

- Decompose the cloud changes into

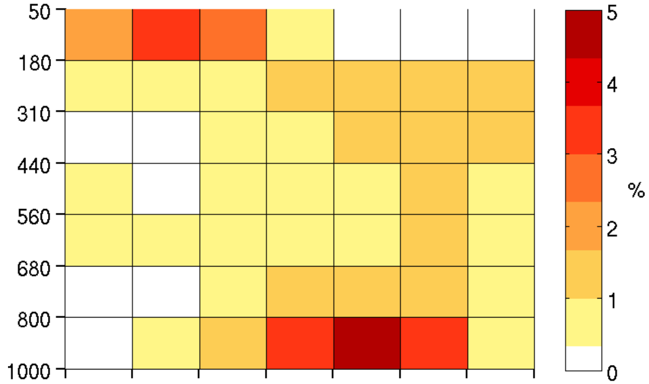
ΔAMOUNT

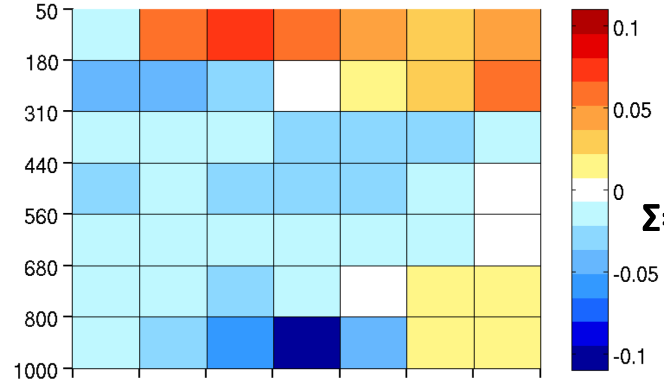
ΔALTITUDE

ΔOPTICAL DEPTH

Mean Cfrac

Σ=52.5 %



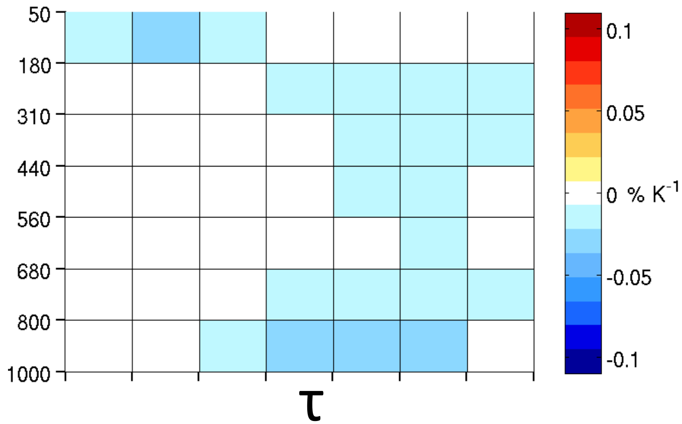


ΔCfrac

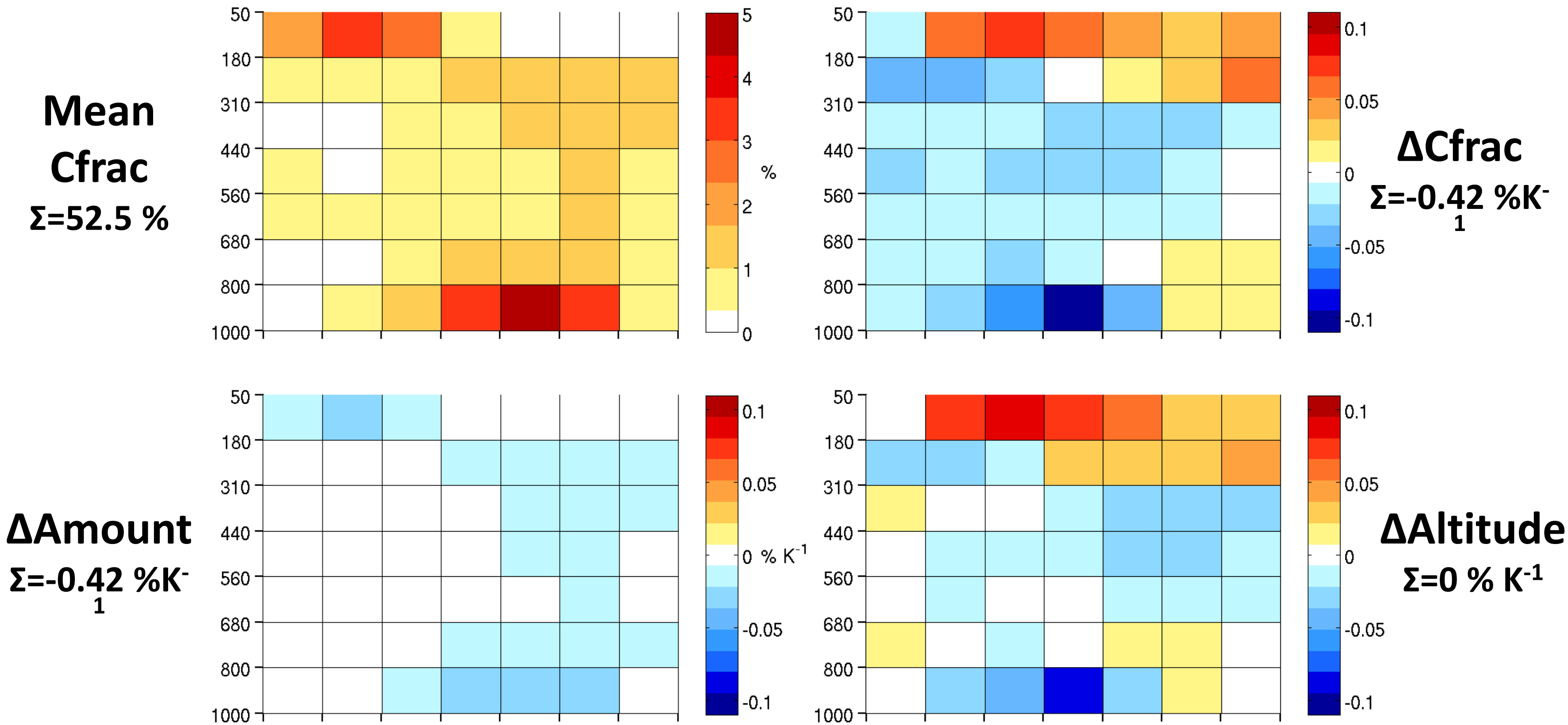
Σ=-0.42 %K^{-1}

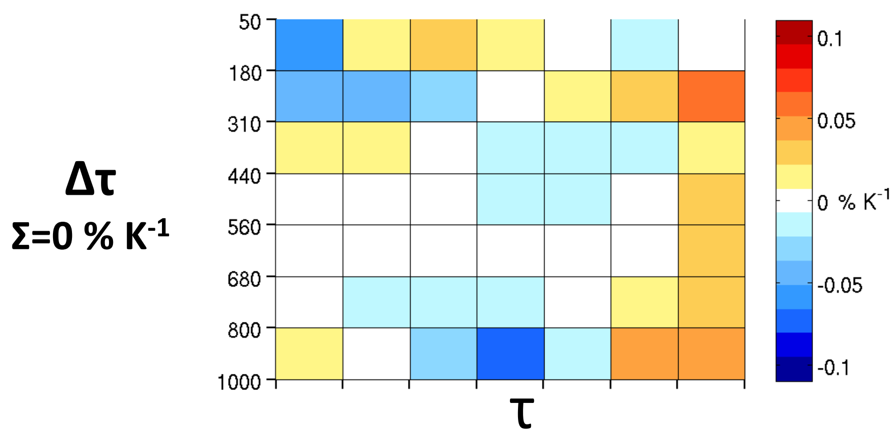
ΔAmount

Σ=-0.42 %K^{-1}



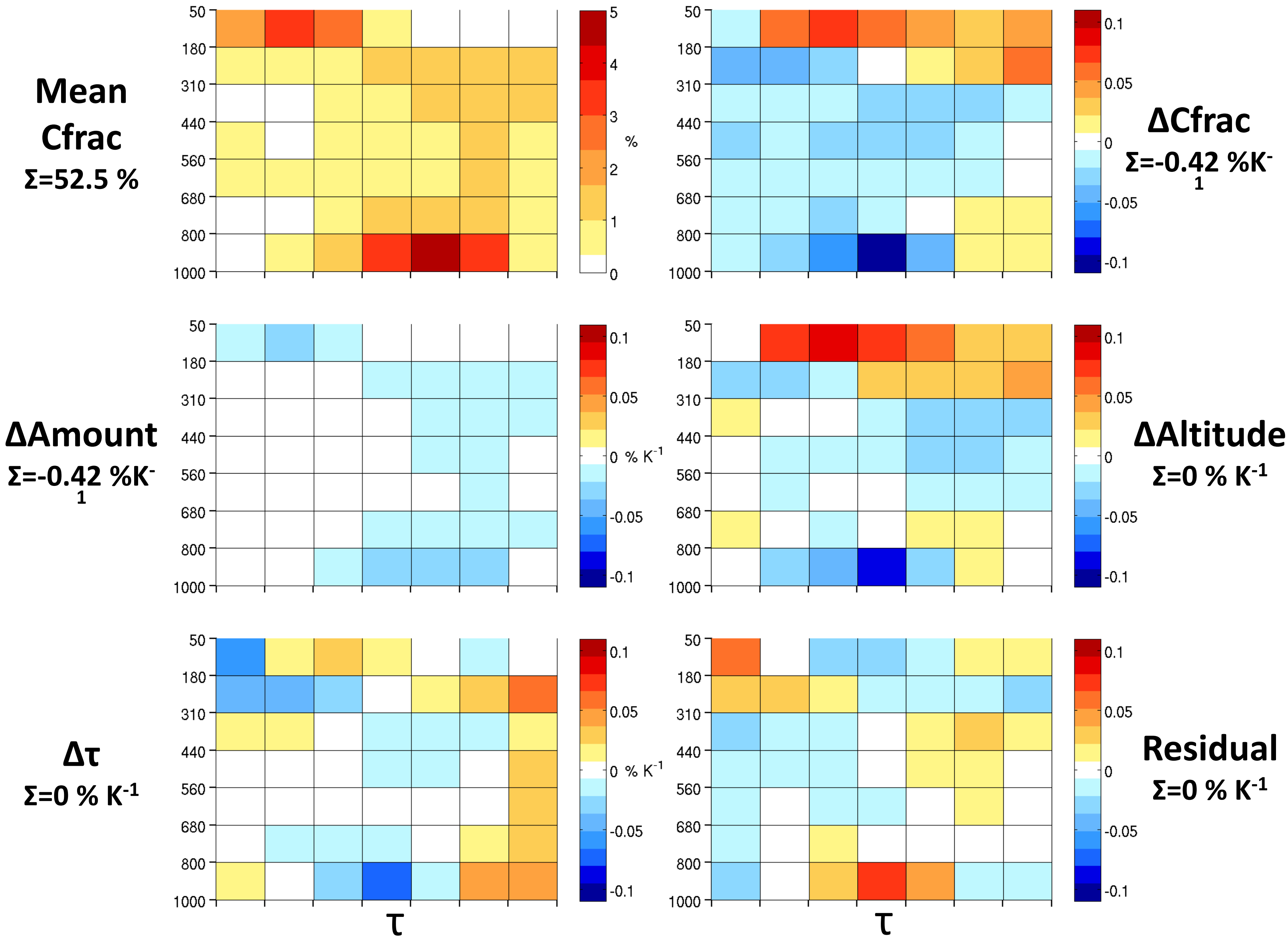
ΔAMOUNT = cloud fraction altered in proportion to amount in 1xCO_2 histogram; no change in vertical or optical depth distribution





ΔALTITUDE = anomalous vertical distribution within each τ bin

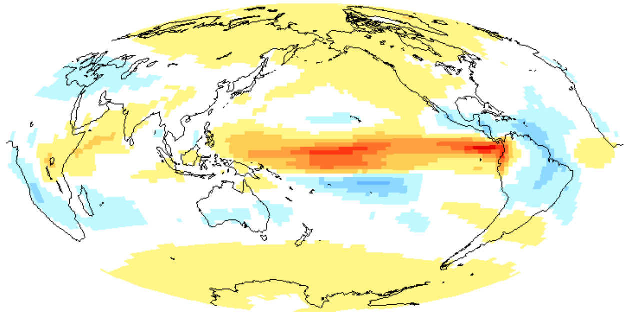
ΔOPTICAL DEPTH = anomalous optical depth distribution within each CTP bin



Mean Cfrac
Σ=52.5 %
ΔCfrac
Σ=-0.42 %K-1
ΔAmount
Σ=-0.42 %K-1
ΔAltitude
Σ=0 % K-1
Δτ
Σ=0 % K-1
Residual
Σ=0 % K-1
%
% K-1
τ
τ
50
180
310
440
560
680
800
1000

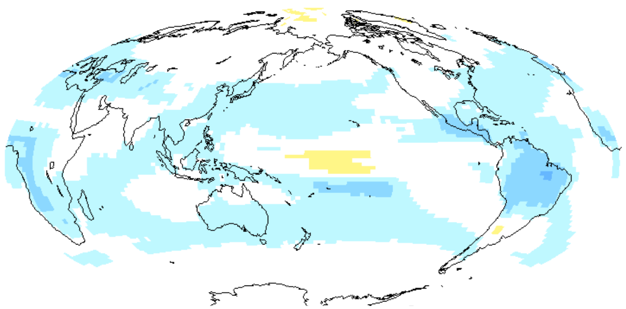
LW Cloud Feedback

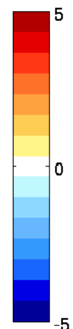
0.26 W m^{-2} K^{-1}



Amount

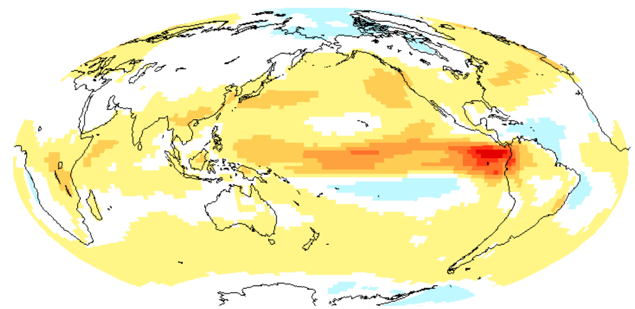
-0.30 W m^{-2} K^{-1}





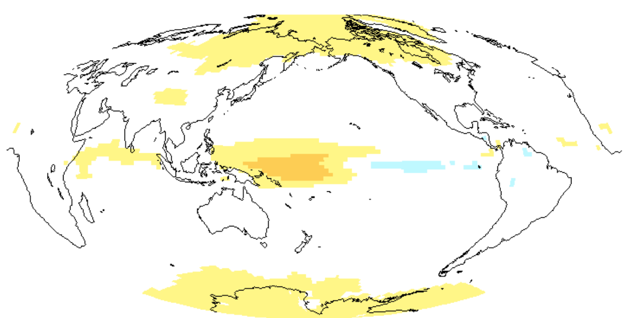
Altitude

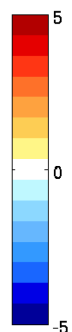
0.44 W m^{-2} K^{-1}



Optical Depth

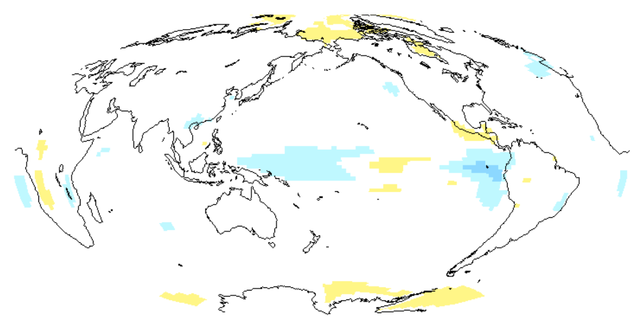
0.16 W m^{-2} K^{-1}





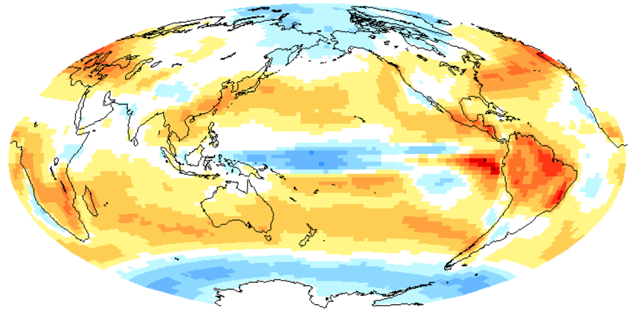
Residual

-0.04 W m^{-2} K^{-1}



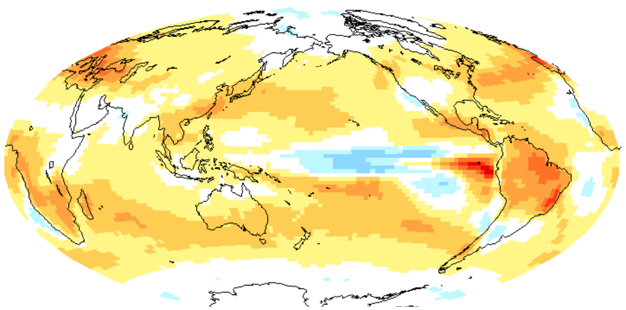
SW Cloud Feedback

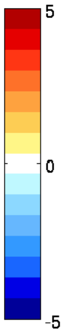
0.46 W m^{-2} K^{-1}



Amount

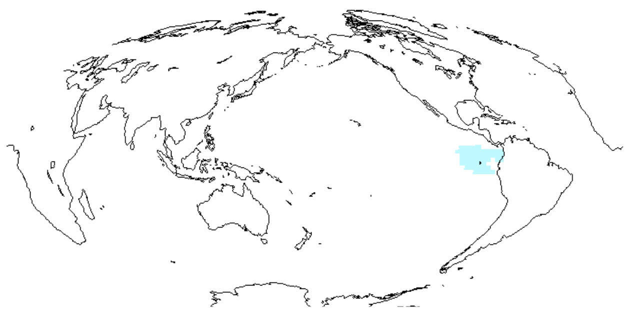
0.66 W m^{-2} K^{-1}





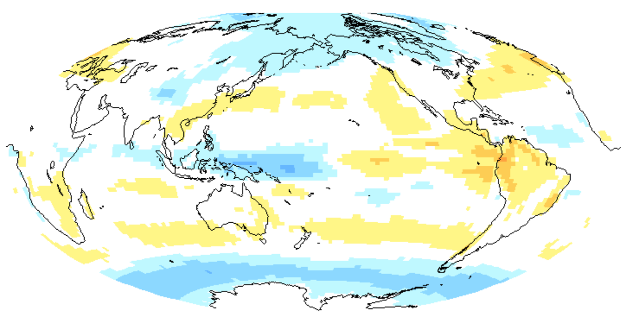
Altitude

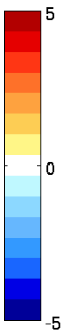
-0.03 W m^{-2} K^{-1}



Optical Depth

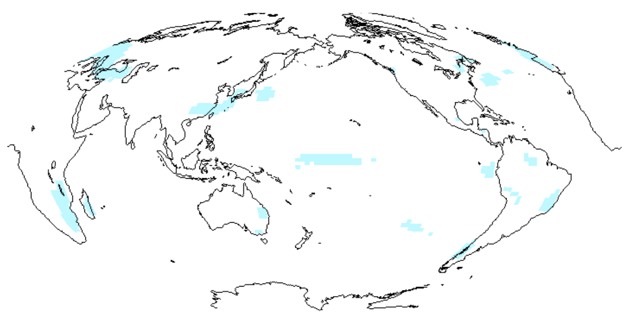
-0.05 W m^{-2} K^{-1}

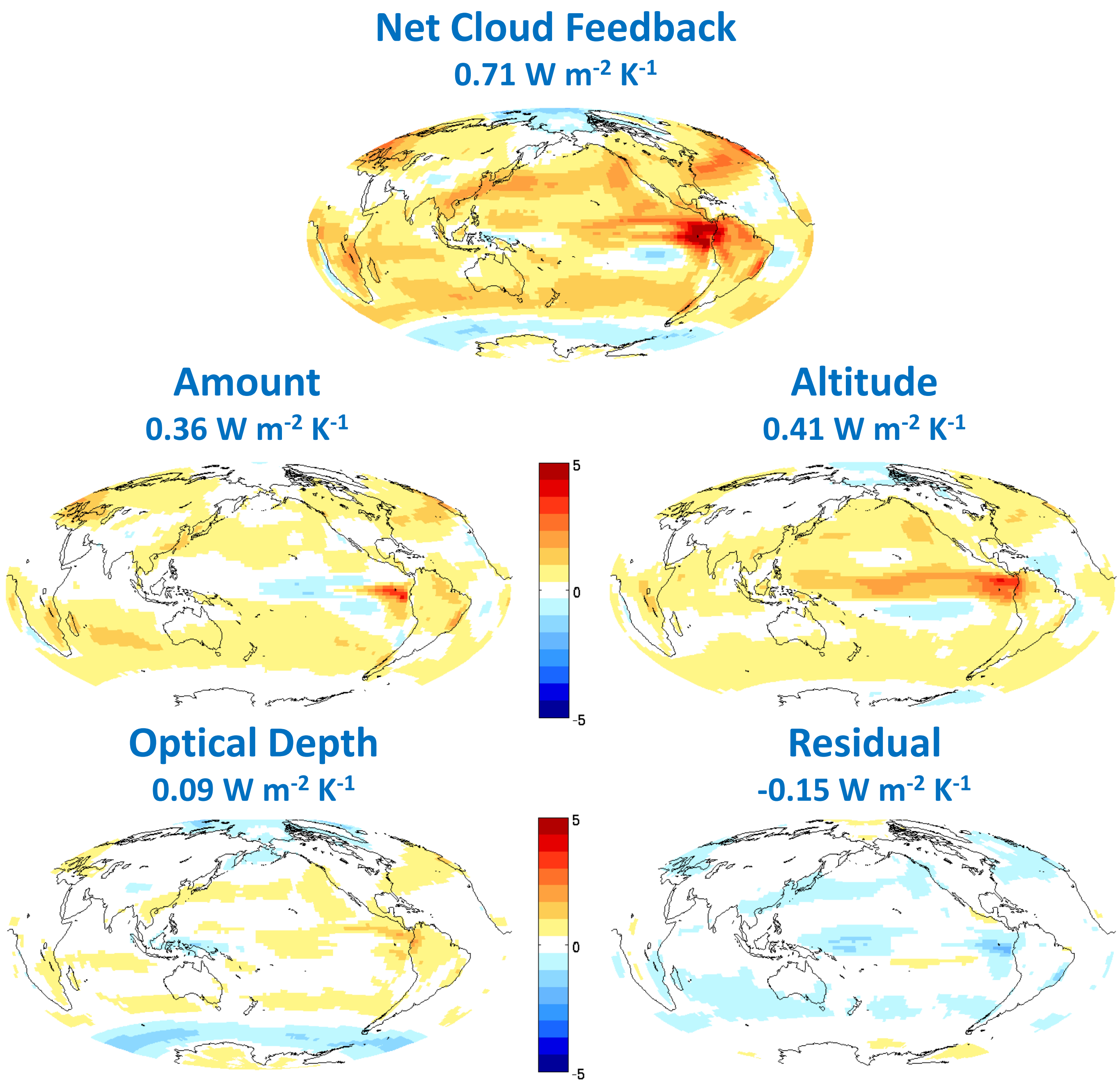




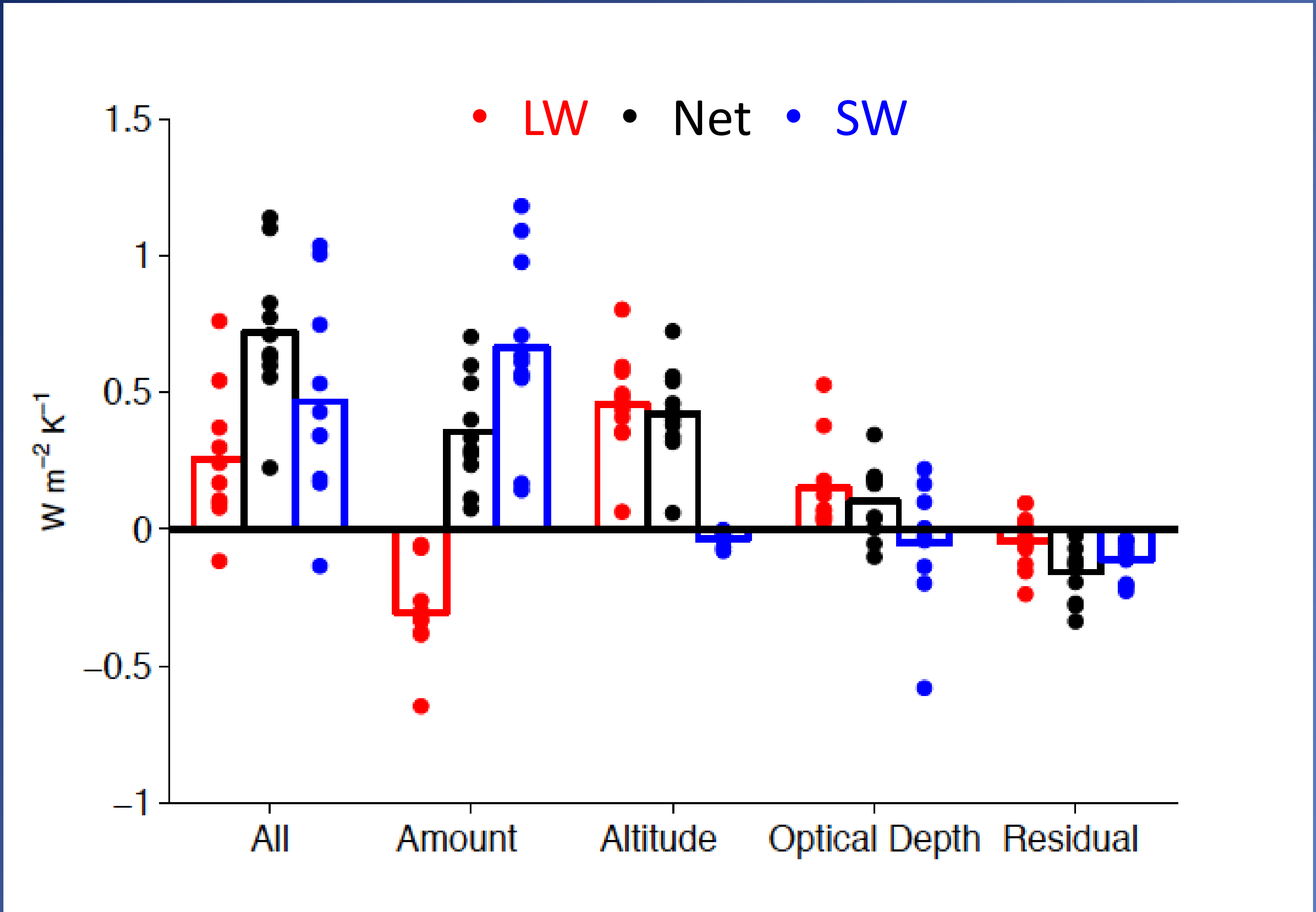
Residual

-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
Optical Depth
0.09 W m-2 K-1
Residual
-0.15 W m-2 K-1
5
0
-5
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 (1 of 2)

- Cloud radiative kernels allow computation of cloud feedback directly from cloud property histograms generated by ISCCP simulator
  - Standard radiative transfer and definition of "cloud" across models
  - Non-cloud changes are automatically excluded (no adjustments necessary)
  - Relatively simple calculation (multiply two matrices) on monthly mean output
  - Ability to quantify contribution to feedback from individual cloud types

- Feedbacks computed with cloud kernels compare very well with those computed by adjusting the change in cloud forcing [Soden et al. (2008)]

- Ensemble (10 model) mean results:
  - LW and SW cloud feedbacks are positive, with SW nearly twice as as large as LW
  - 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

Conclusions (2 of 2)

- ***Increasing cloud top altitude*** is dominant contributor to the ***positive global mean LW and net cloud feedbacks (positive in every model)***
  - Positive impact of rising clouds is ***50% larger*** than negative impact of reductions in cloud amount on LW cloud feedback (but ***varies considerably across models)***
- ***Decreasing total cloud fraction*** is dominant contributor to global mean ***positive SW cloud feedback (positive in every model)***
  - Inter-model ***spread is greater*** than for any other feedback component
  - Overall cloud amount reductions have ***2x as large*** an impact on SW as on LW fluxes
- ***Large negative net cloud feedback at high latitudes*** is caused by ***increased optical depth***, not increased cloud amount
  - Results from ***increased cloud water content and phase changes from ice to liquid***
- Draft of paper: email zelinka1@llnl.gov or Google “Mark Zelinka”