Using satellite retrievals to constrain the low-cloud optical depth feedback in climate models

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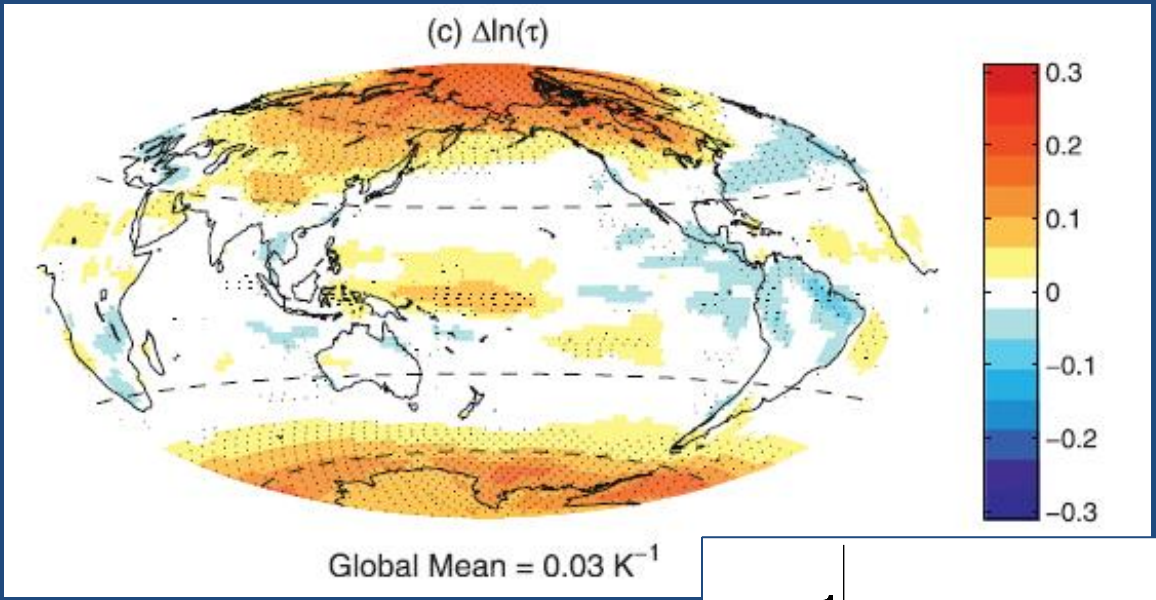
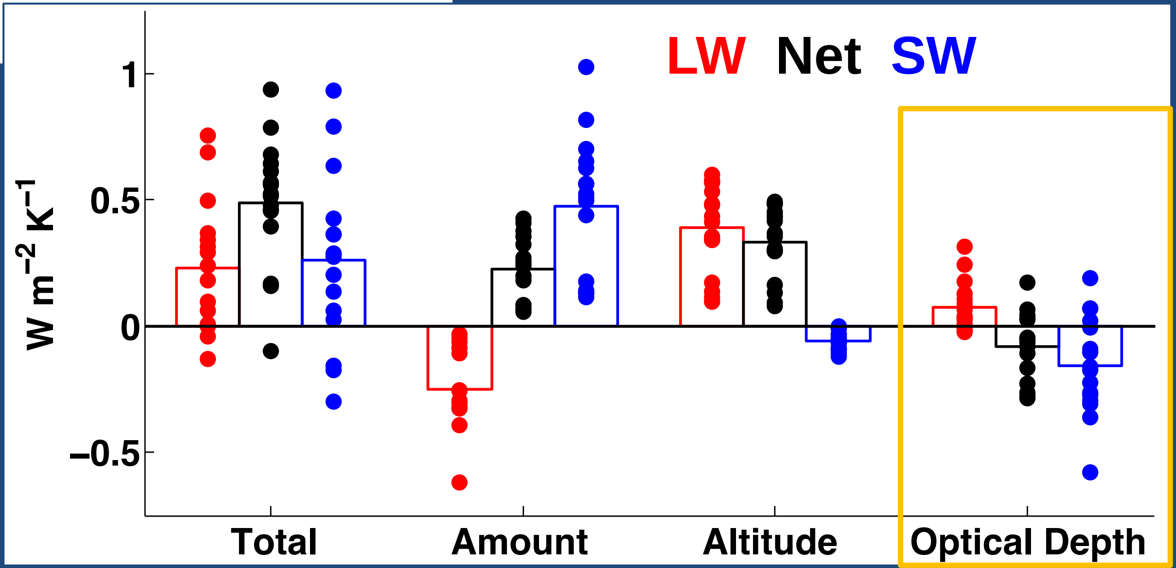
Most models predict *increase* in optical depth at mid and high latitudes *but* disagree on the strength



Annual and ensemble mean change in ln(τ) per degree change in CFMIP1 models



Global and annual mean cloud feedback estimates from CMIP3/5 models

Zelinka et al. 2012, 2013

Questions to address:

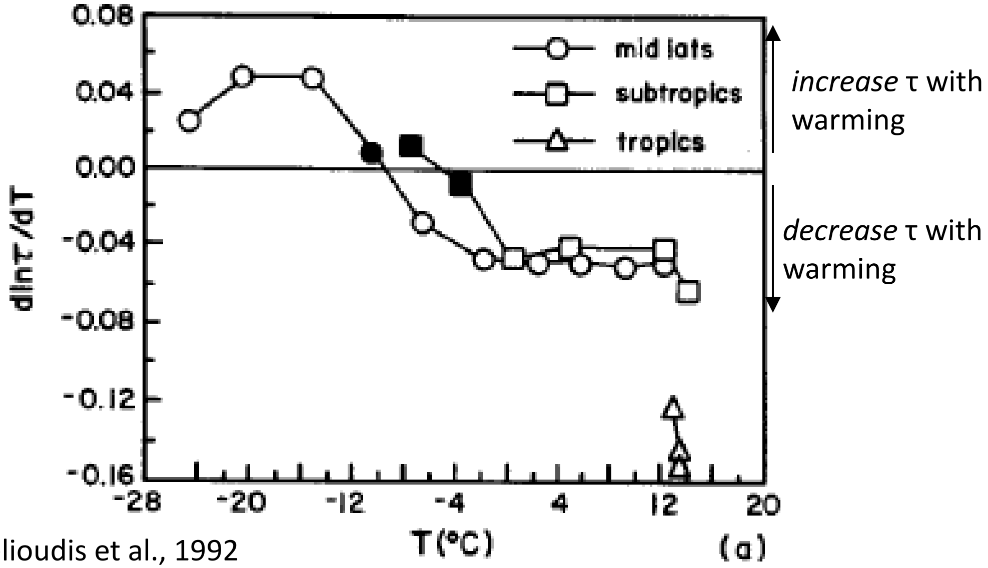
Does the response of optical depth due to global warming physically relate to and scale with the response of optical depth at the monthly to interannual timescales?

Can we use satellite retrievals from ISCCP and MODIS to constrain the low-cloud optical depth response in models?

If we find a discrepancy, what does it suggest about the intermodel mean optical depth feedback?

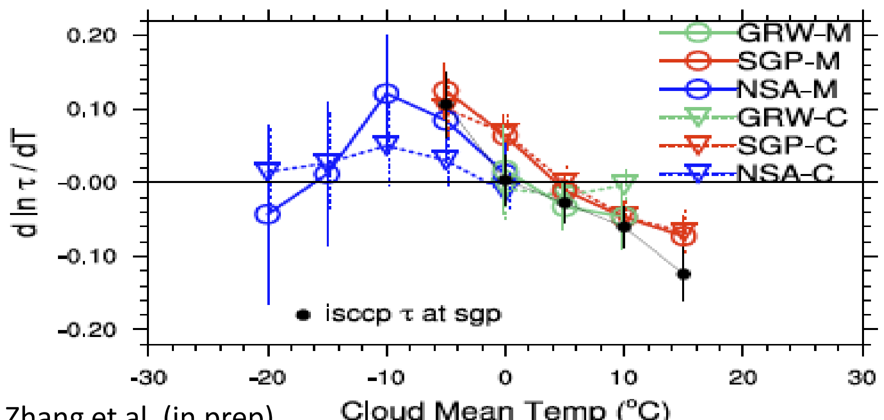
At cold temperatures, observations show low-clouds increase in optical depth with temperature

Low clouds over land from ISCCP (1984)



Tselioudis et al., 1992

Ground-based measurements of low clouds over ARM sites



Y. Zhang et al. (in prep)

Physical mechanisms for increase in optical depth at cold temperatures

- Increase in adiabatic liquid water content of clouds (Betts and Harshvardhan, 1987; Gordon and Klein 2014)
- Reduction of precipitation efficiency (Senior and Mitchell, 1992; Tsushima et al., 2006)
- Change in radiative properties from ice to liquid (McCoy et al. 2014)

Briefly on data and methods

Experiments

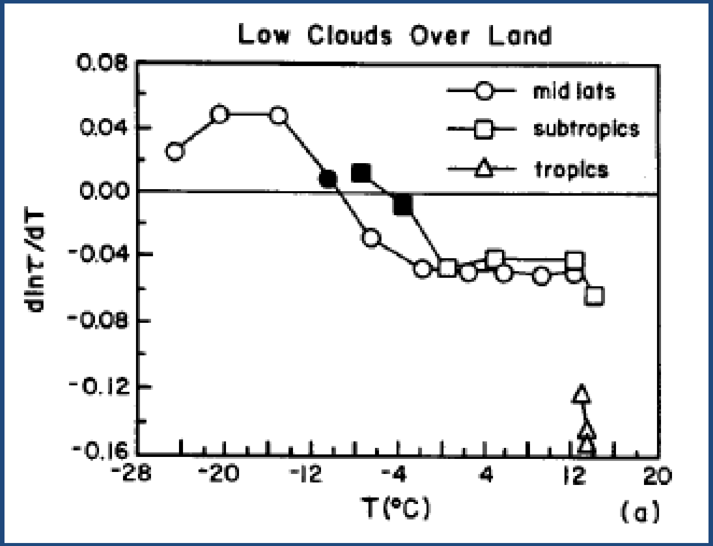
cmip5 AMIP, AMIP4K

Variables (monthly output)

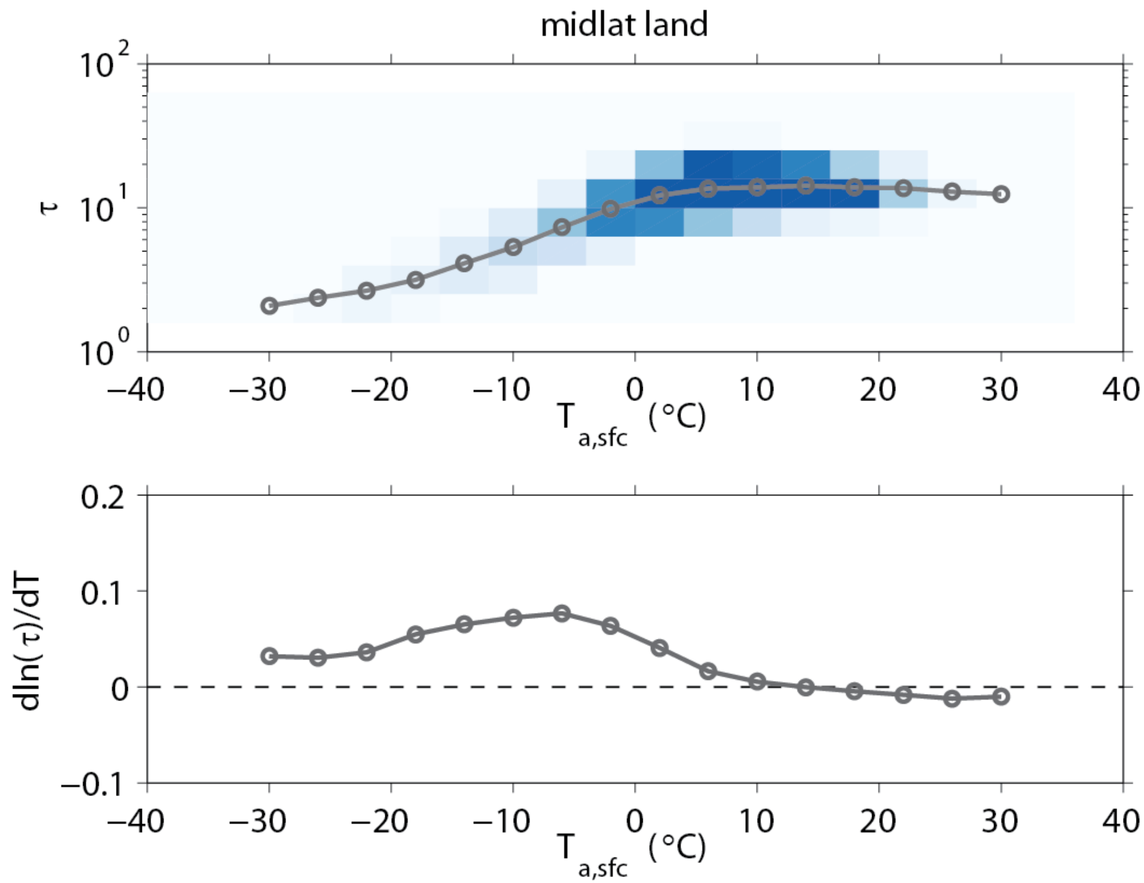
clisccp (ISCCP simulator)

-> calculate monthly-mean low cloud optical depth

tas – surface air temperature



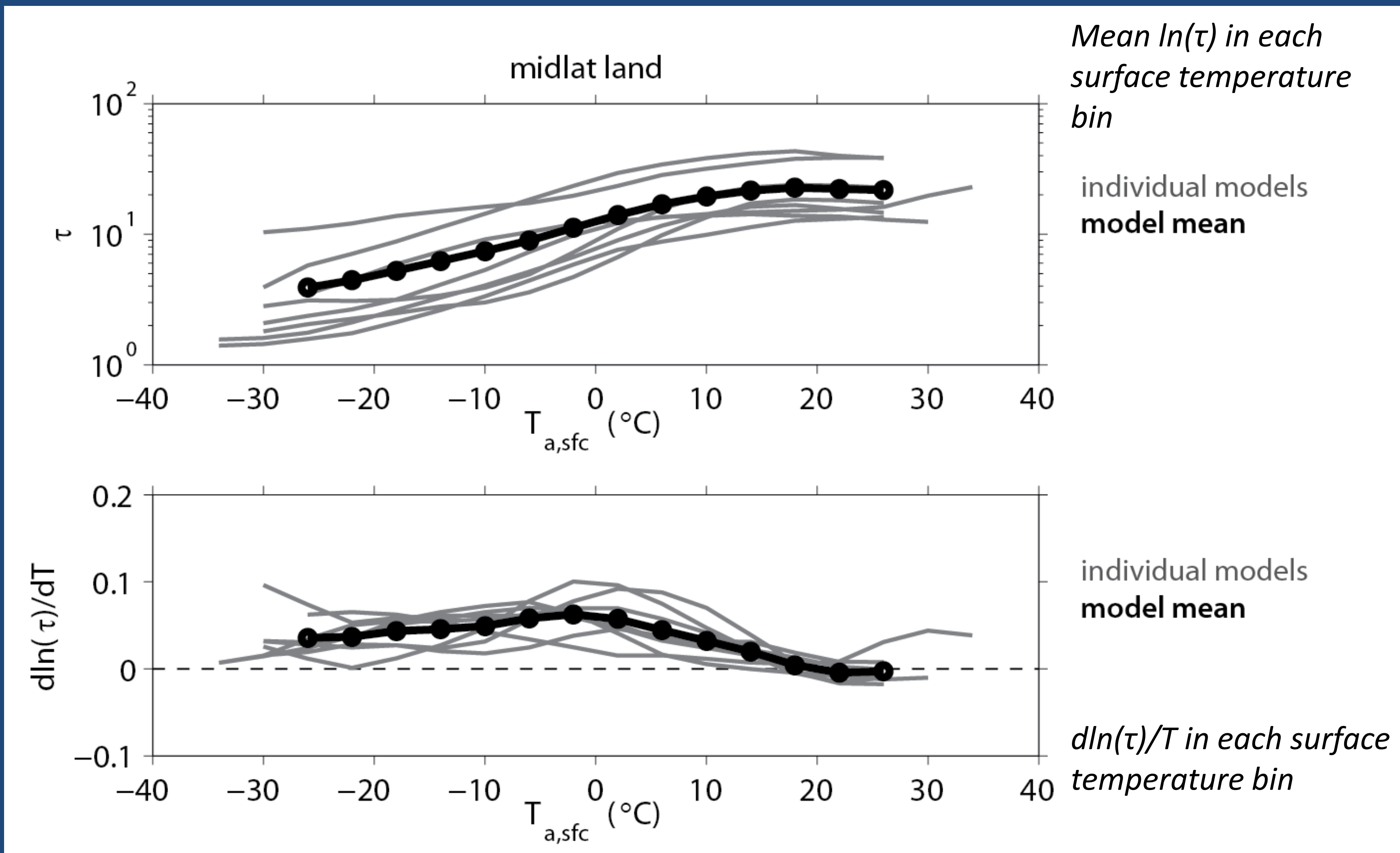
Optical depth response as a function of temperature in AMIP model



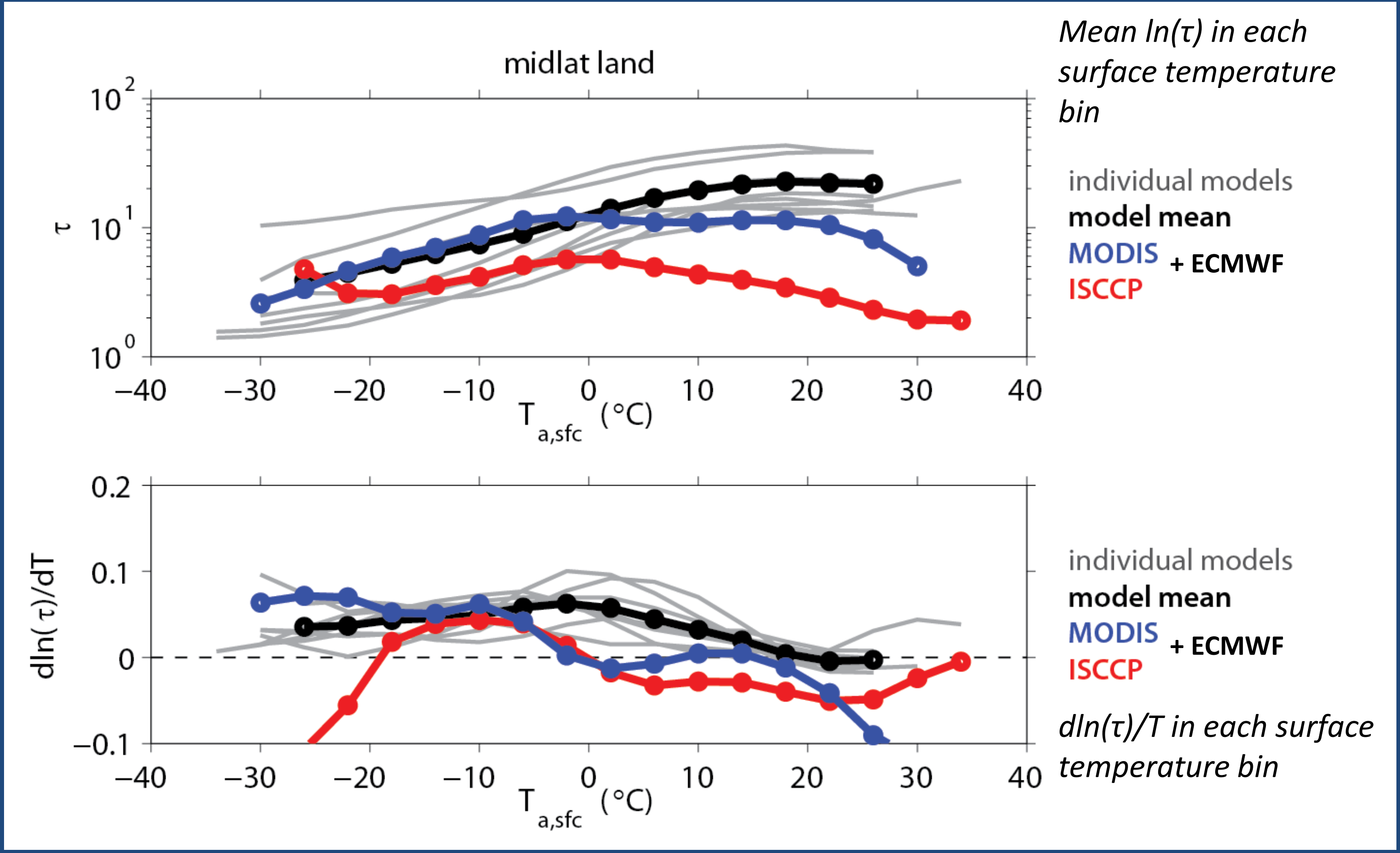
Mean ln(τ) in each surface temperature bin

dln(τ)/T in each surface temperature bin

Optical depth response as a function of temperature in AMIP models



Optical depth response as a function of temperature in AMIP models + satellite



Regional mean optical depth response: predicted vs. actual

f_{predict} = *regional mean*

$$\left(\frac{\partial \ln \tau}{\partial T_l}\right)\left(\frac{\Delta T_l}{\Delta T_G}\right)$$

from **_cntl run_**

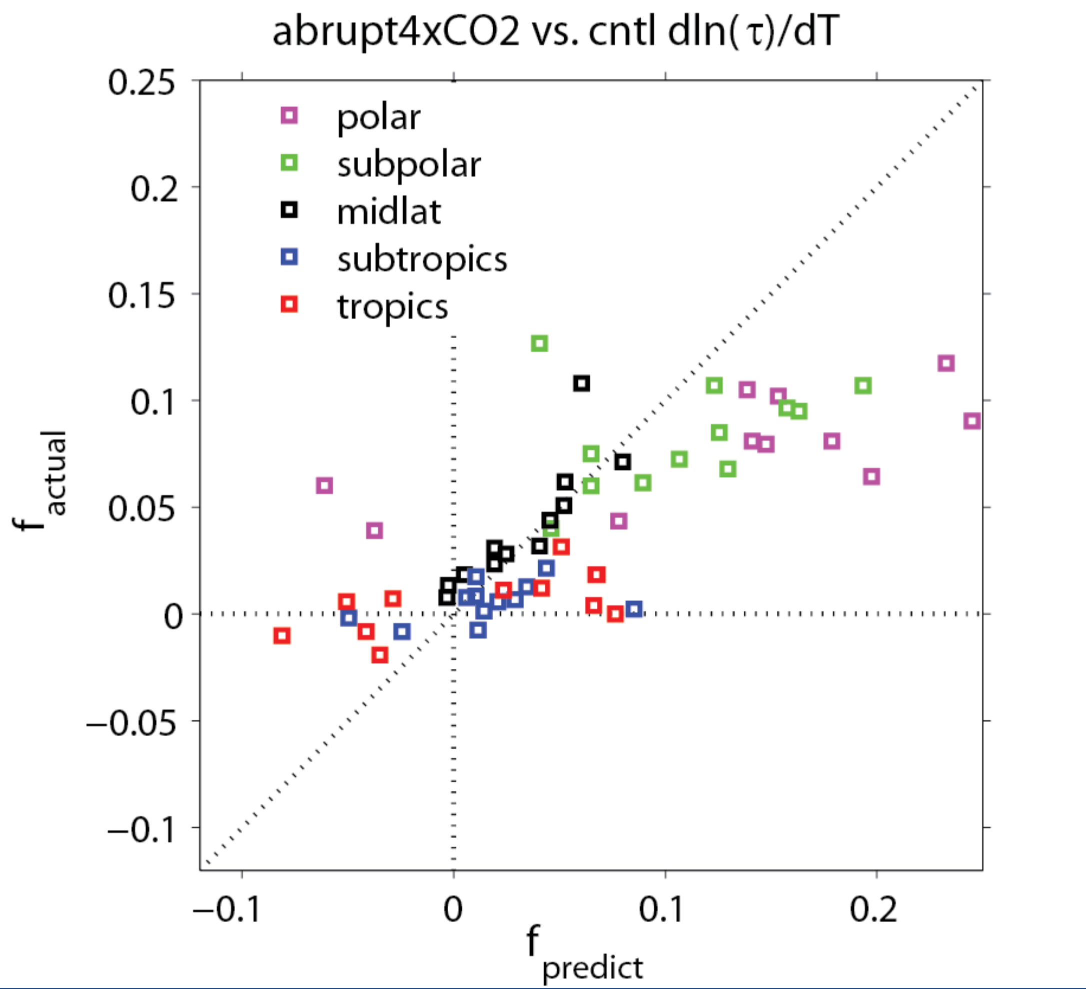
from *CC - cntl*

f_{actual} = *regional mean*

$$\left(\frac{\Delta \ln \tau}{\Delta T_G}\right)$$

from *CC - cntl*

Response of optical depth in short term correlates with global warming response in coupled runs



Actual response

Predicted response

f_{predict} = *region mean*

$$\left(\frac{\partial \ln \tau}{\partial T_l}\right)\left(\frac{\Delta T_l}{\Delta T_G}\right)$$

from ***cntl run***

from *future* -cntl

f_{actual} = *region mean*

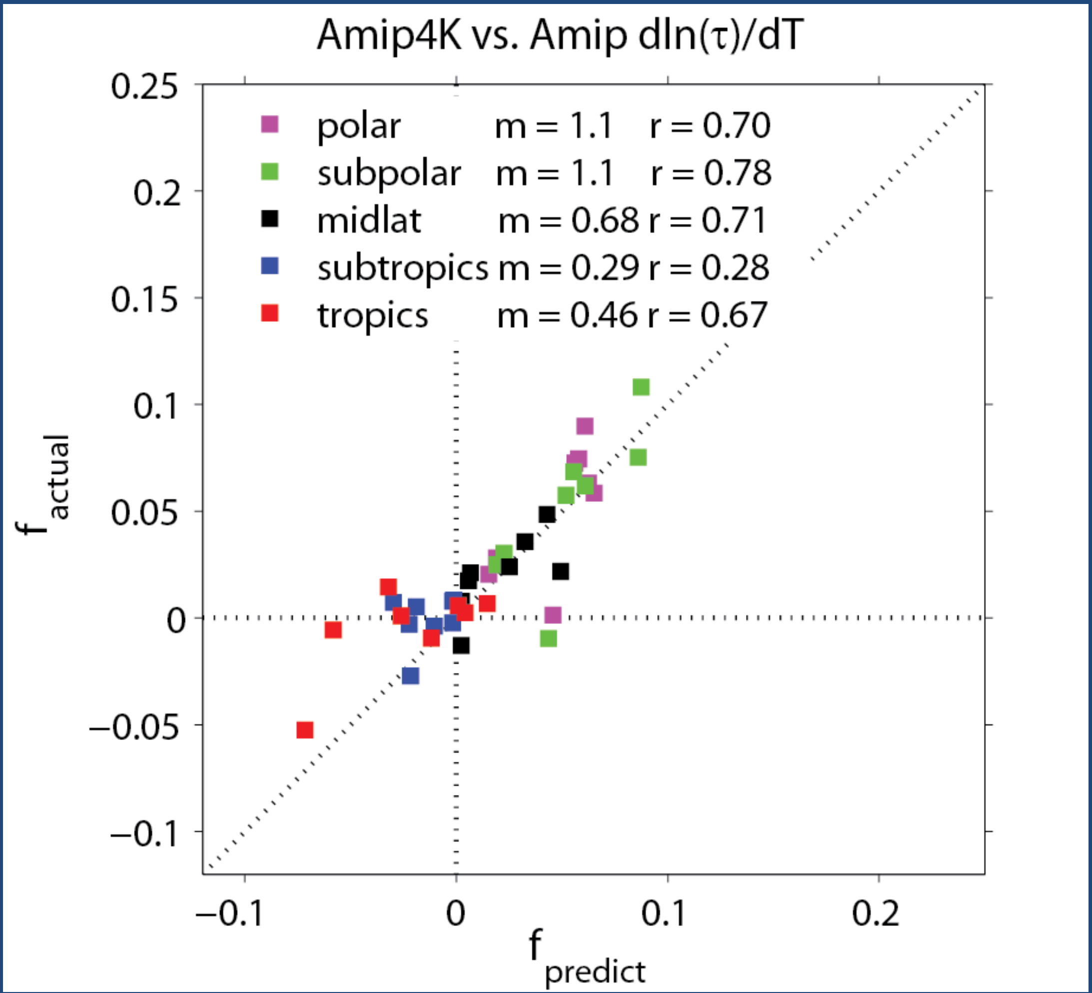
$$\left(\frac{\Delta \ln \tau}{\Delta T_G}\right)$$

from *future* - cntl

Predicted and actual τ response to global temperature increase

Adapted from Gordon and Klein (2014)

Response of optical depth in short term nearly equals global warming response in AMIP runs



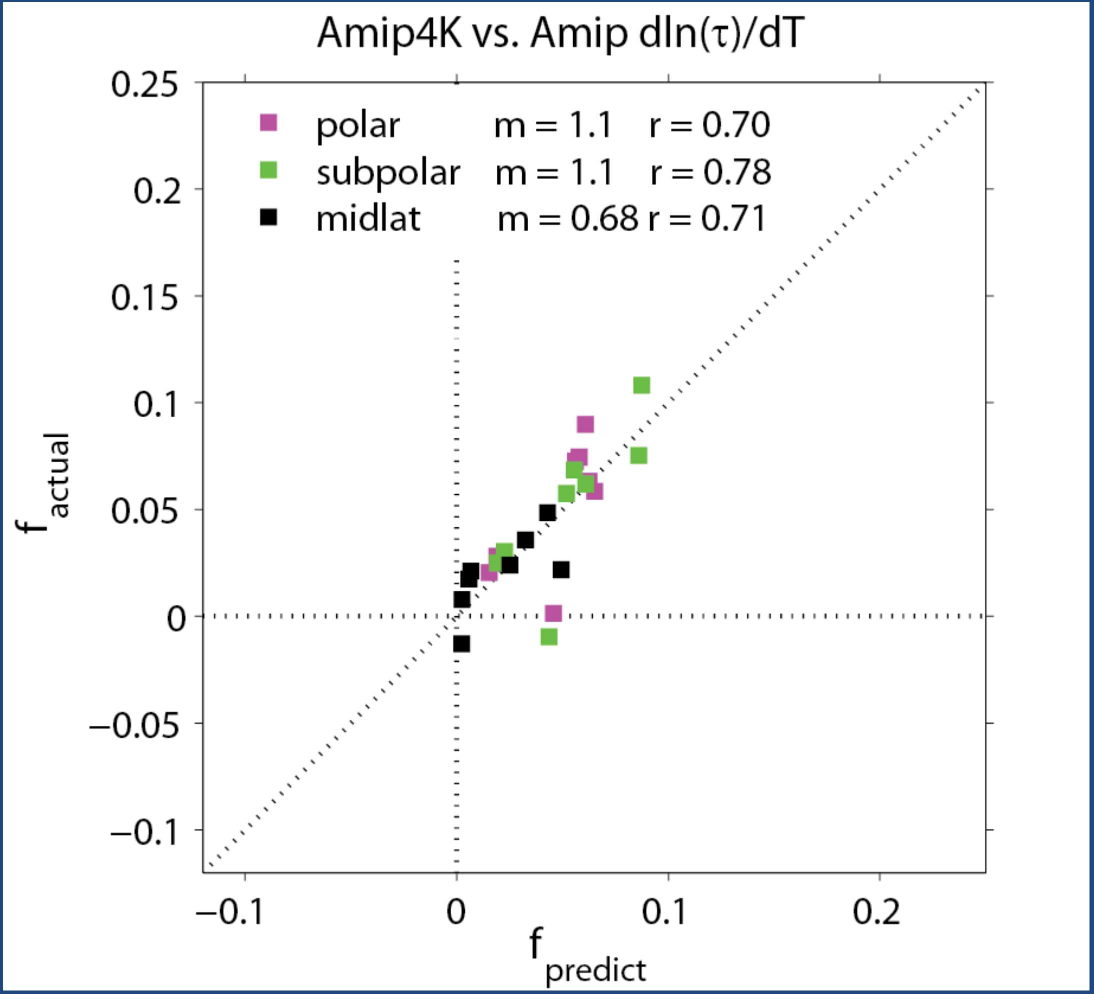
Actual response

Predicted response

Predicted and actual τ response to global temperature increase

Models used:
CanAM4
CCSM4
CNRM-CM4
HadGEM2A
MIROC5
MPI-ESM-LR
MRI-CGCM3
Bcc-csm11

Response over mid and high latitudes can be constrained using short term response



Predicted and actual τ response to global temperature increase

Models used:
CanAM4
CCSM4
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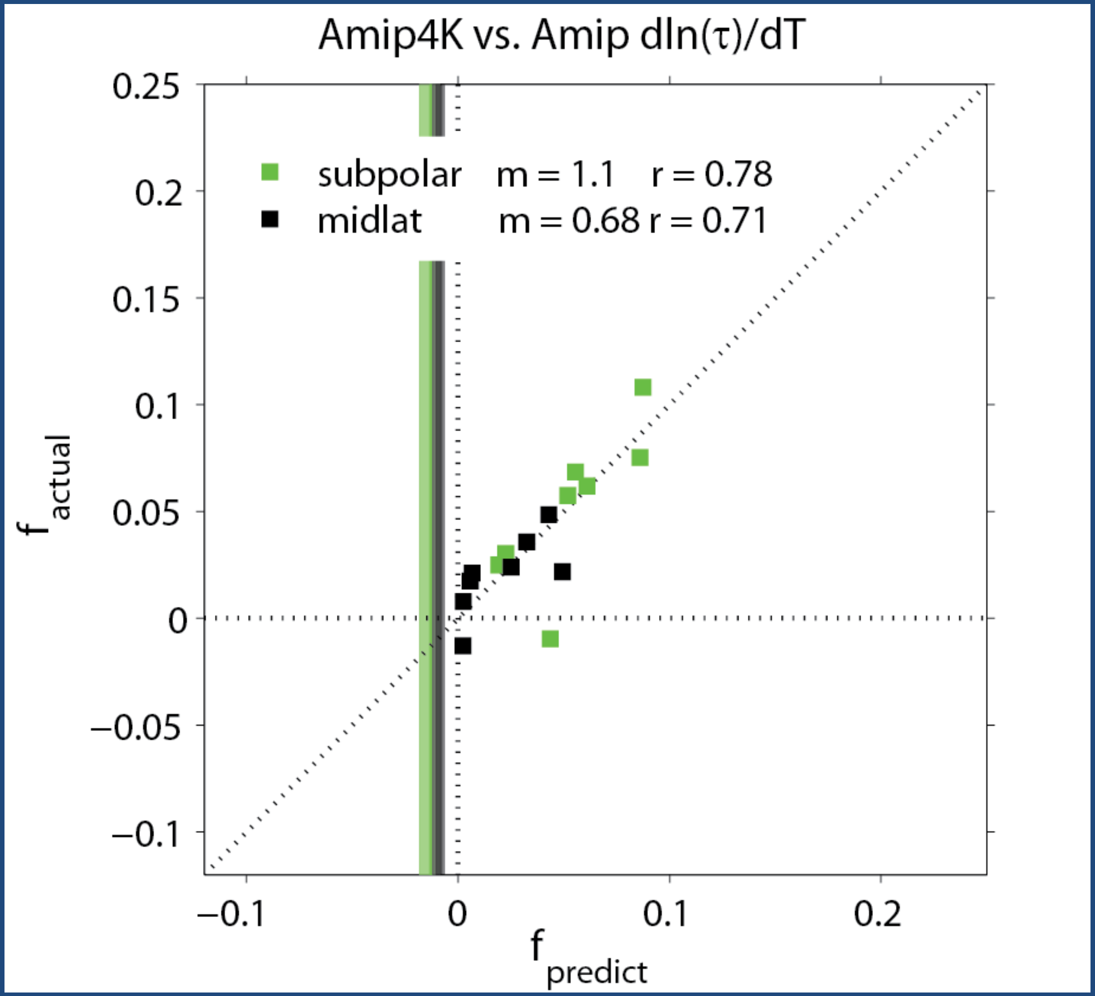
MIROC5
MPI-ESM-LR
MRI-CGCM3
Bcc-csm11

Response over regions with satellite retrievals show that response is over-estimated in models



$f_{\text{pred,sat}}$ = *region mean*

$$\left(\frac{\partial \ln \tau}{\partial T_l}\right)\left(\frac{\Delta T_l}{\Delta T_G}\right)$$

from ***satellite***

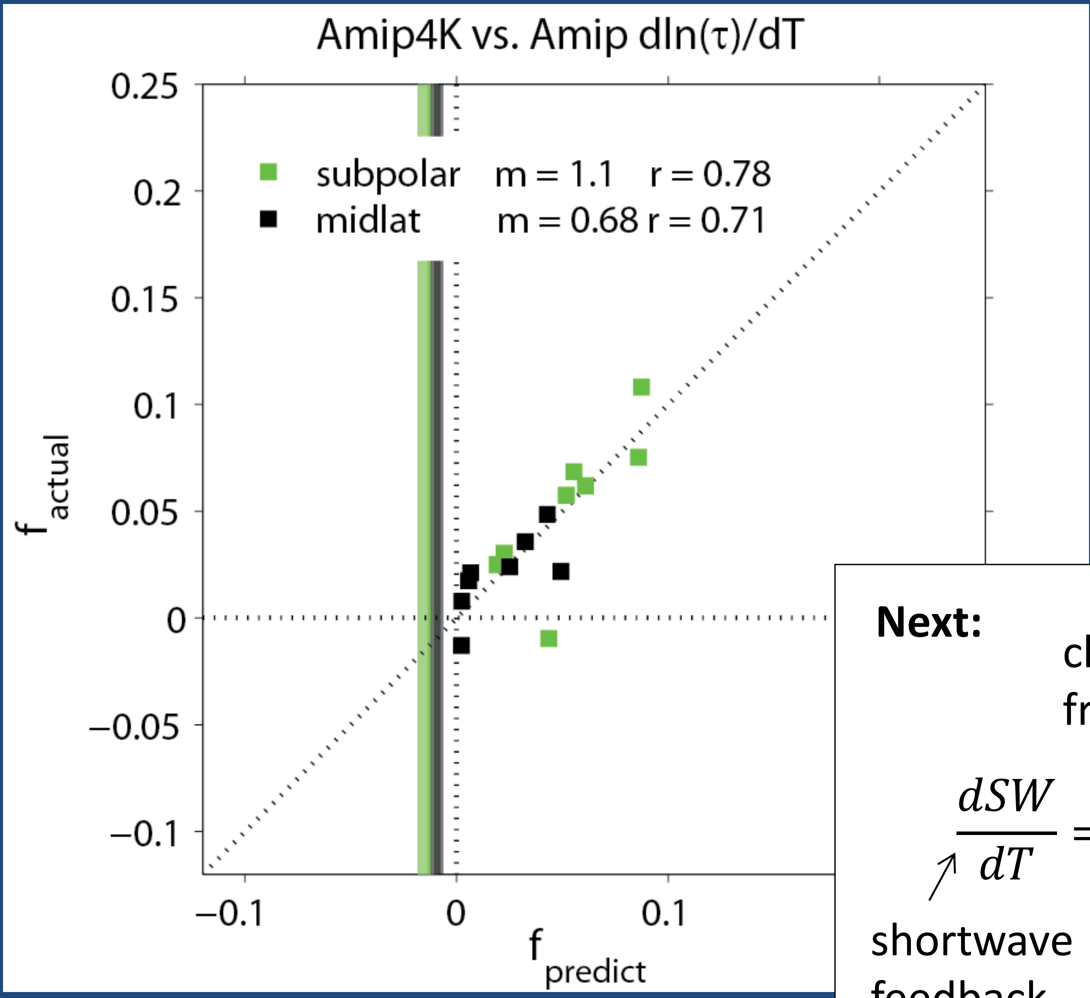
from CC -cntl

Satellite retrievals:
ISCCP (1983 – 2009)
MODIS (2001 – 2014)

Models used:
CanAM4
CCSM4
CNRM-CM4
HadGEM2A
MIROC5
MPI-ESM-LR
MRI-CGCM3
Bcc-csm11

Predicted and actual τ response to global temperature increase with satellite estimates

Response over regions with satellite retrievals show that response is over-estimated in models



$f_{pred,sat}$ = *region mean*

$$\left(\frac{\partial \ln \tau}{\partial T_l}\right)\left(\frac{\Delta T_l}{\Delta T_G}\right)$$

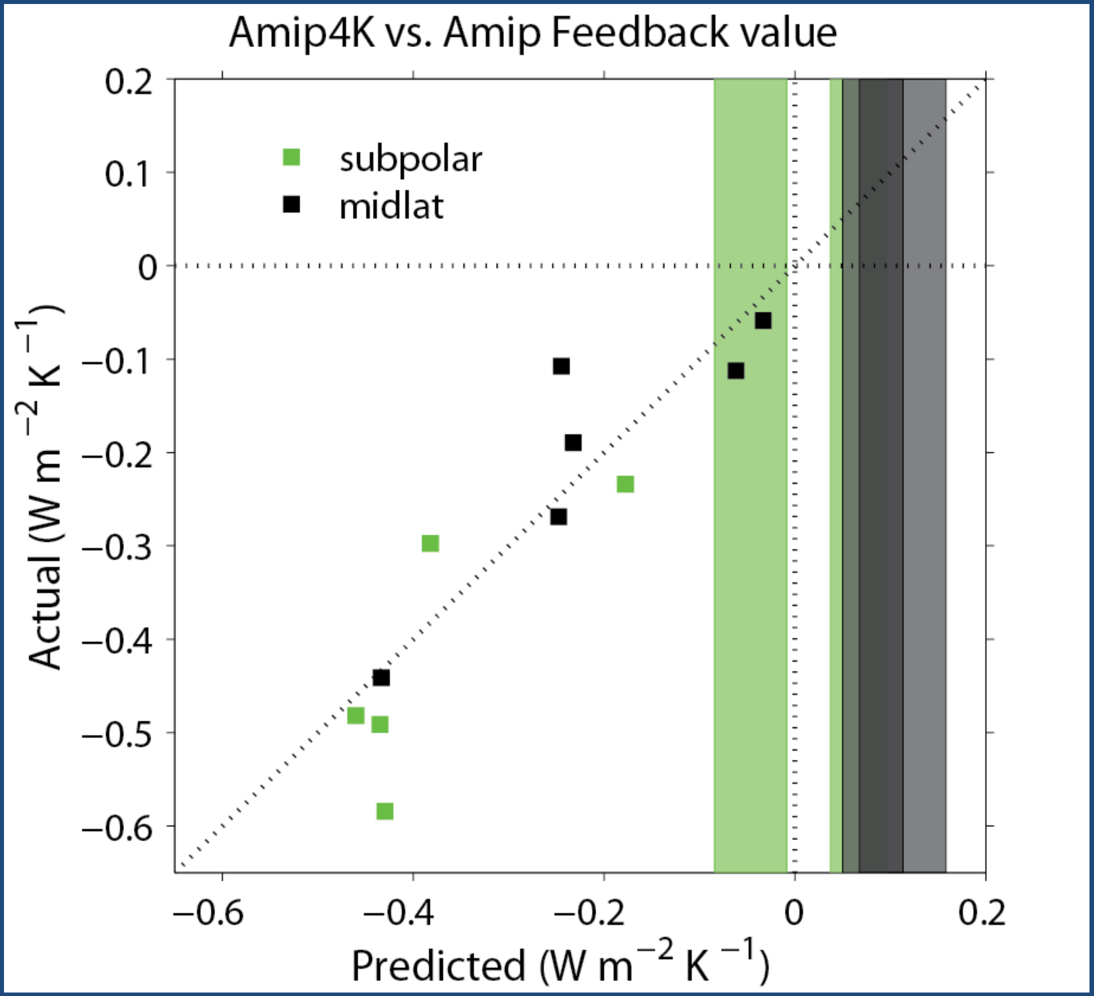
from ***satellite*** | from CC -cntl

Satellite retrievals:
ISCCP (1983 – 2009)
MODIS (2001 – 2014)

Next:

$$\underset{\text{shortwave feedback}}{\frac{dSW}{dT}} = \overset{\text{cloud fraction}}{f}\ \underset{\text{shortwave response to changing } \tau}{\frac{dSW}{d\ln\tau}}\ \overset{\tau \text{ response to temperature}}{\frac{\Delta \ln \tau}{\Delta T_G}}$$

Based on the satellite retrievals, the local feedback strength is overestimated by about 0.3 W m^{-2} K^{-1} in models



Predicted and actual shortwave cloud feedback response to global temperature increase

Satellite retrievals:
ISCCP (1983 – 2009)
MODIS (2001 – 2014)

Models used:
CanAM4
CNRM-CM4
HadGEM2A
MIROC5
MPI-ESM-LR
MRI-CGCM3

Conclusions

Does the response of optical depth due to global warming physically relate to and scale with the response of optical depth at the monthly to interannual timescales?

A. Yes, over the mid and high latitudes.

Can we use satellite retrievals from ISCCP and MODIS to constrain the low-cloud optical depth response in models?

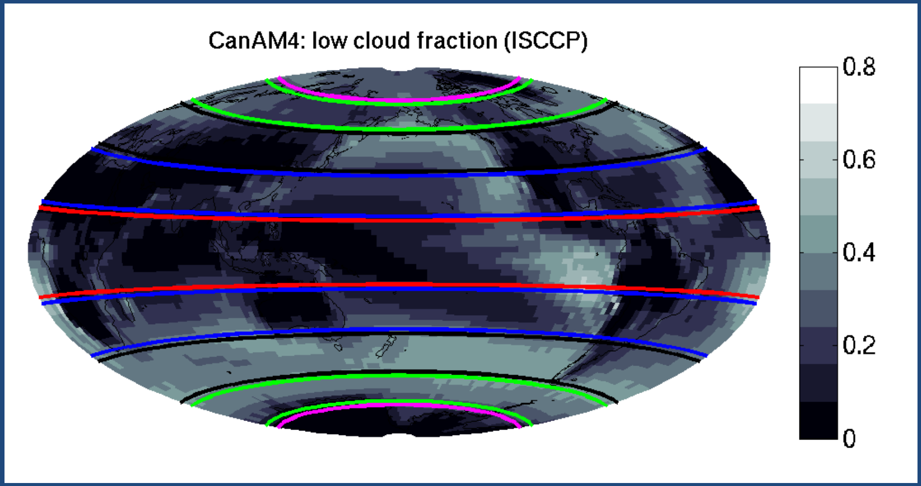
A. Both satellite datasets suggest that the low-cloud optical depth response is overestimated in models.

If we find a discrepancy, what is the model mean bias in the discrepancy?

A. The magnitude of the discrepancy is ~ 0.3 W m^{-2} K^{-1} locally, which corresponds to ~0.1 W m^{-2} K^{-1} globally

Extra slides

Briefly on data and methods



Experiments

cmip5 AMIP, AMIP4K

Variables (monthly output)

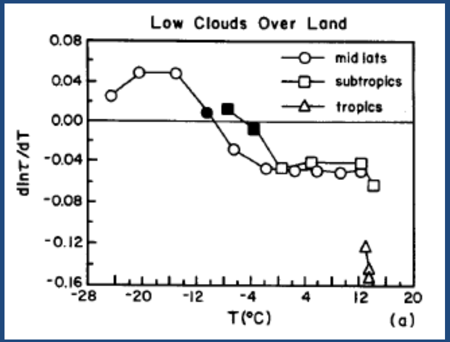
clisccp (ISCCP simulator)

-> calculate monthly-mean low cloud optical depth

tas – surface air temperature

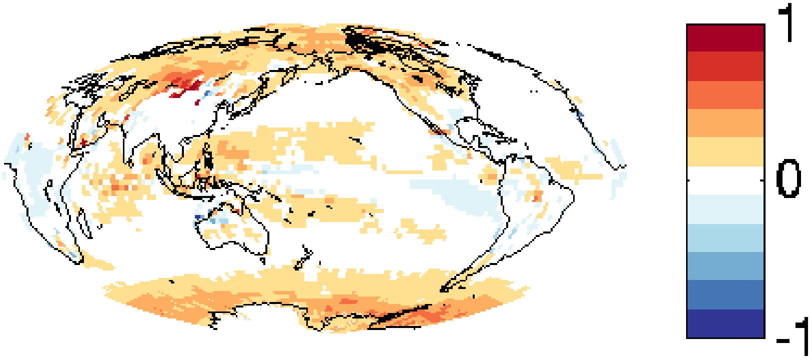
Regions

Global, but perform analysis in latitude bands and separate over land and ocean

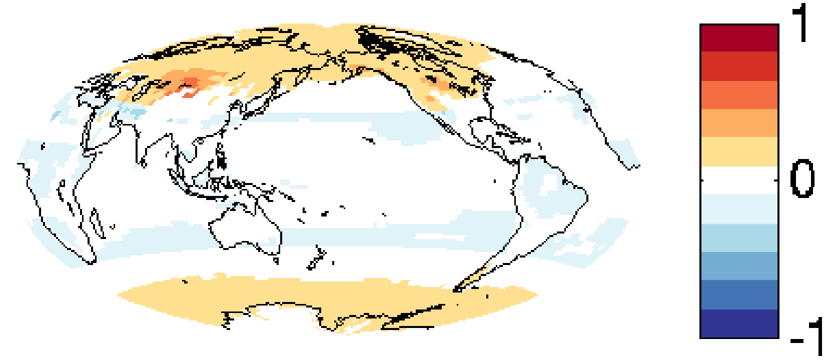


Calculating the radiative bias from dln(τ)/dT

CanAM4 ACTUAL Δ log(τ)



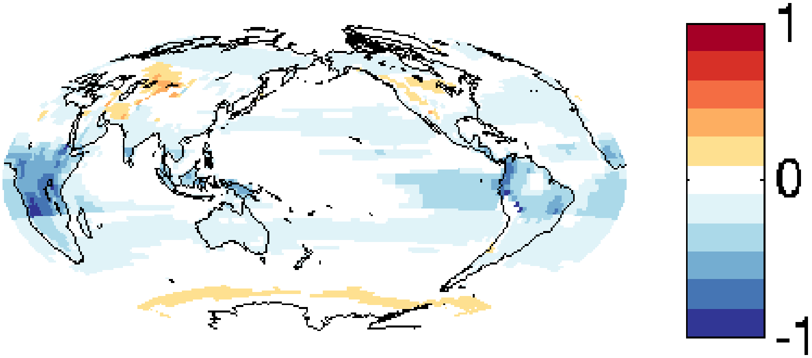
CanAM4 PREDICTED Δ log(τ)



$$\Delta \ln(\tau) = \left[\overline{\frac{\partial \ln(\tau)}{\partial T}}\right]_{amip} \Delta T$$

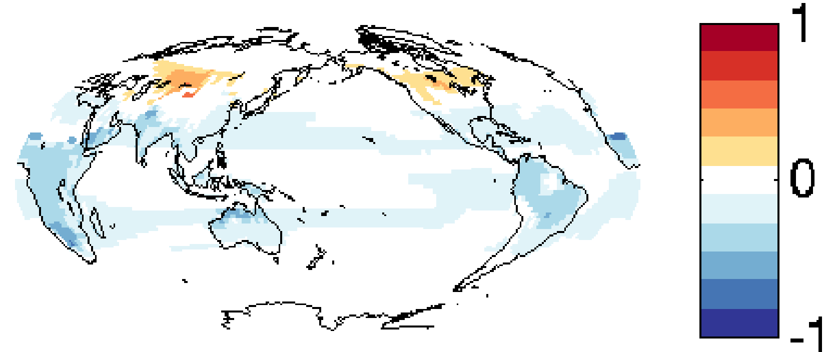
Maps of predicted *f* and actual *f*
Δ = AMIP4K - AMIP

CanAM4 Δ log(τ) ISCCP



$$\Delta \ln(\tau) = \left[\overline{\frac{\partial \ln(\tau)}{\partial T}}\right]_{ISCCP} \Delta T$$

CanAM4 Δ log(τ) MODIS



$$\Delta \ln(\tau) = \left[\overline{\frac{\partial \ln(\tau)}{\partial T}}\right]_{MODIS} \Delta T$$

Calculating the radiative bias from dln(τ)/dT (step 2)

$$\frac{dSW}{dT} = f \frac{dSW}{d\ln\tau} \frac{\Delta \ln\tau}{\Delta T_G}$$

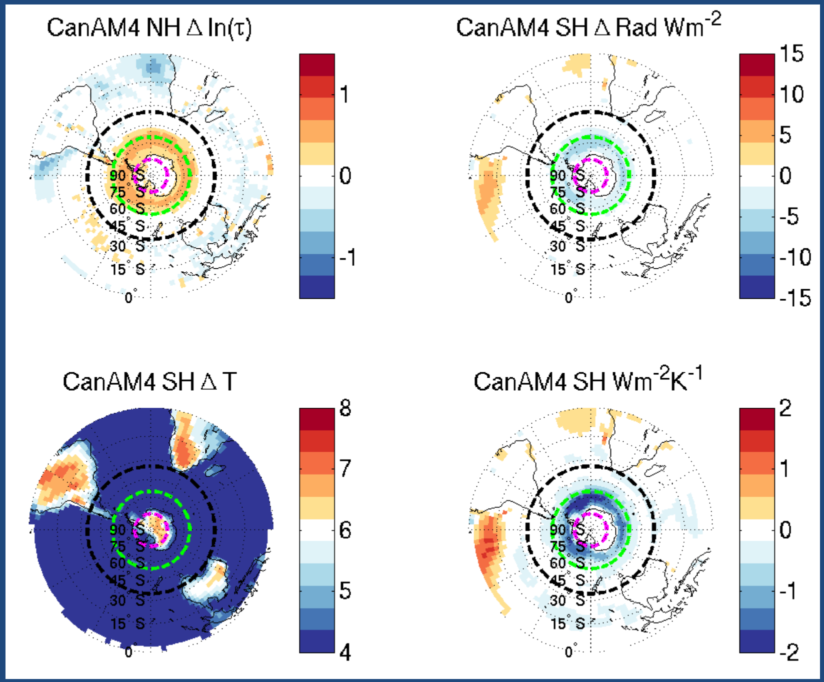
obtained using actual differences, model-predicted differences, satellite-predicted differences

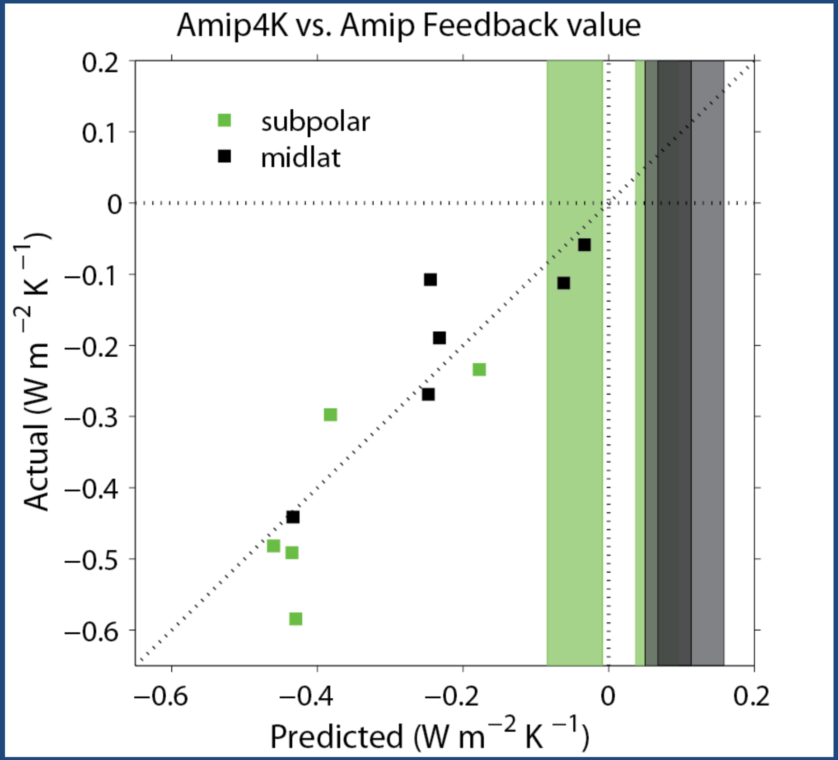
radiative feedback estimate (W m^{-2} K^{-1})

obtained from amip and amip4K runs

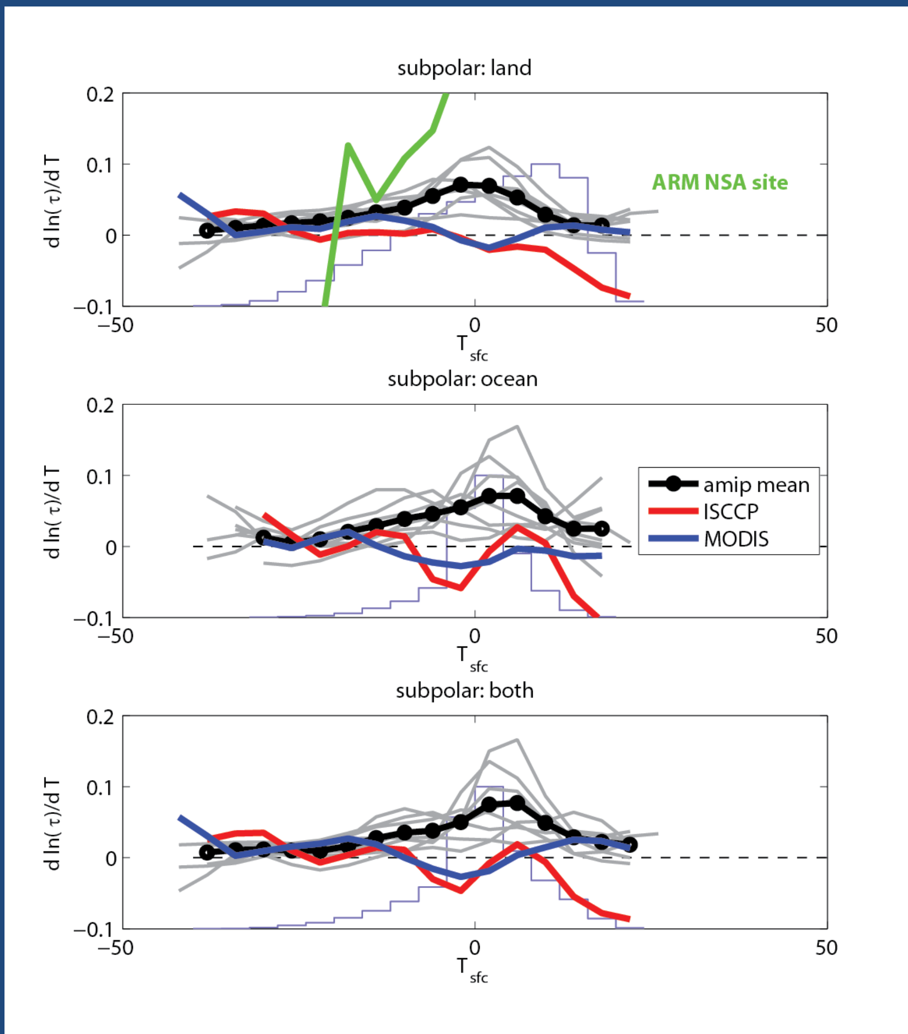
calculated using radiative kernels

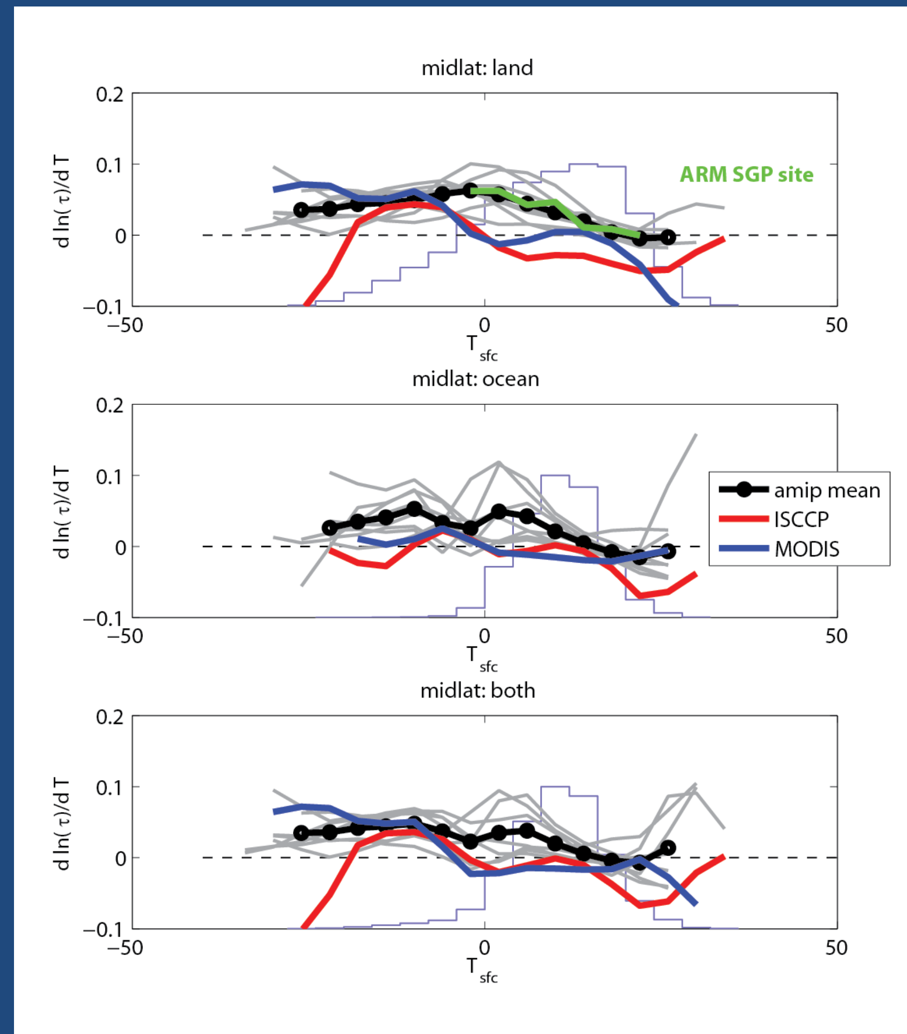
low cloud fraction



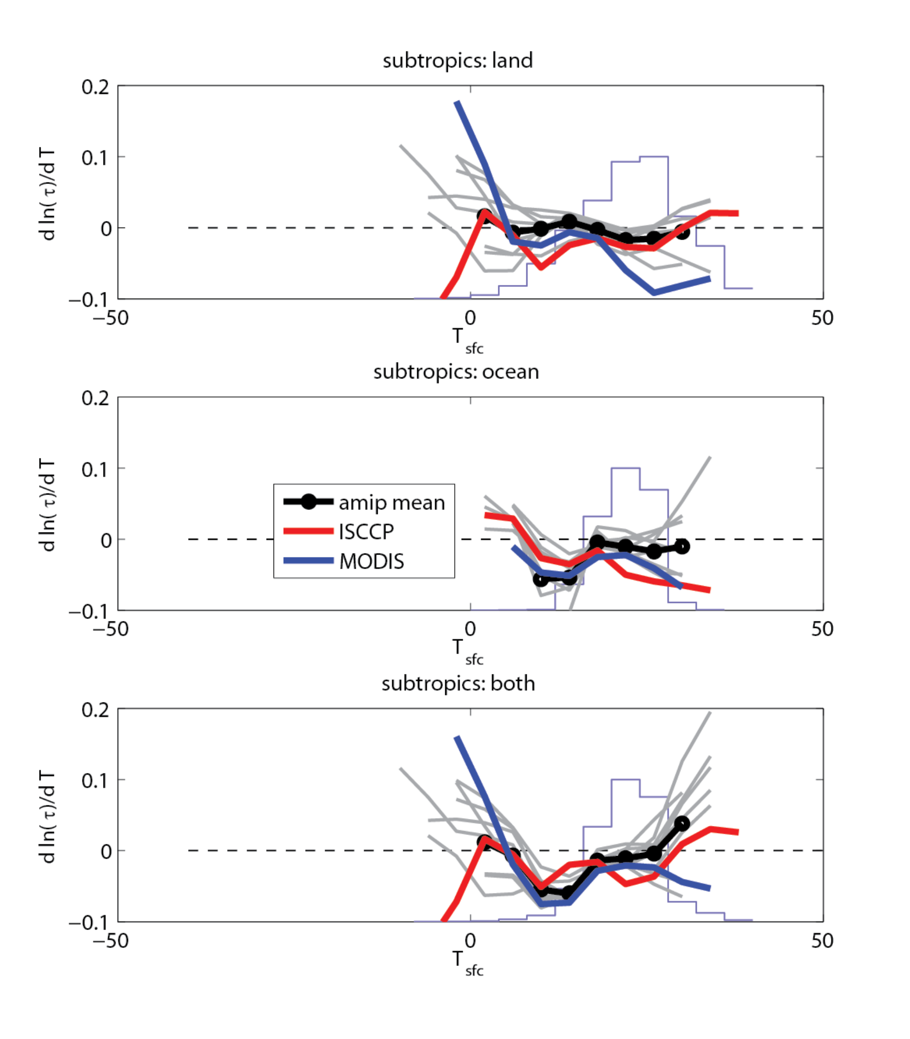


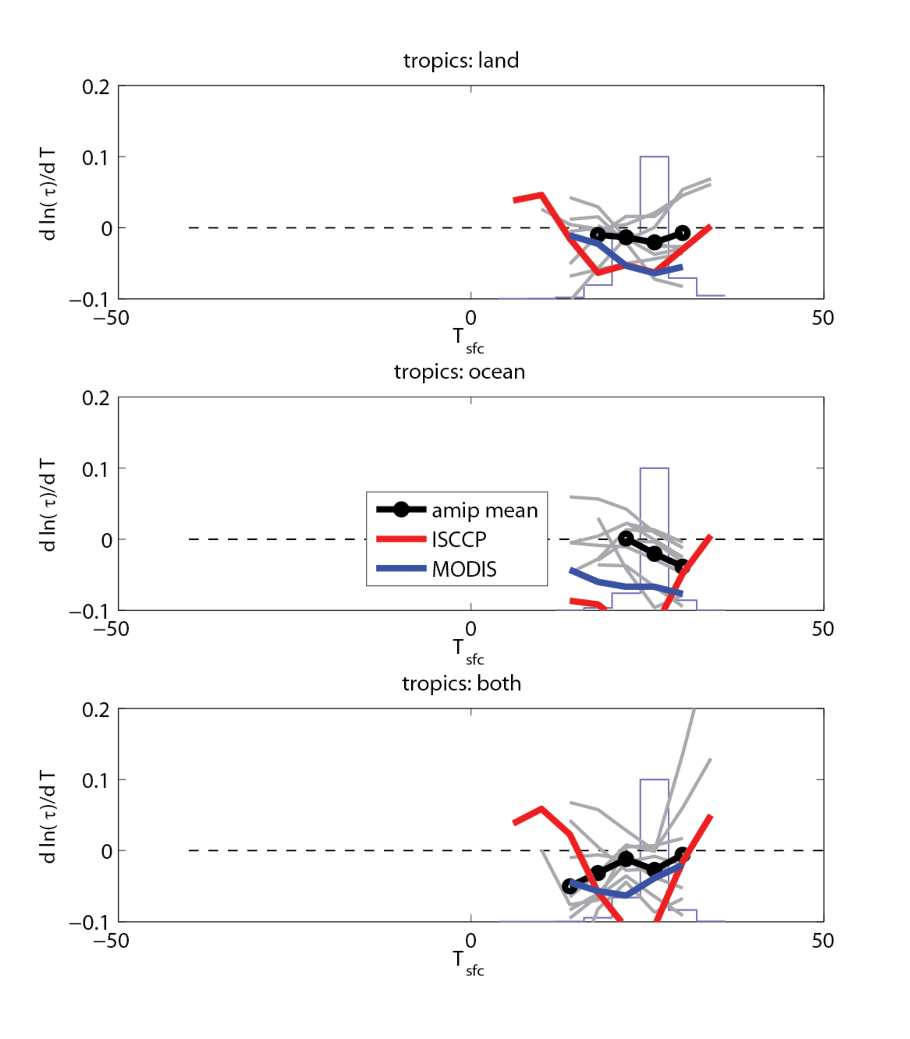
Regional dln(τ)/dT over land and ocean subpolar and midlatitudes



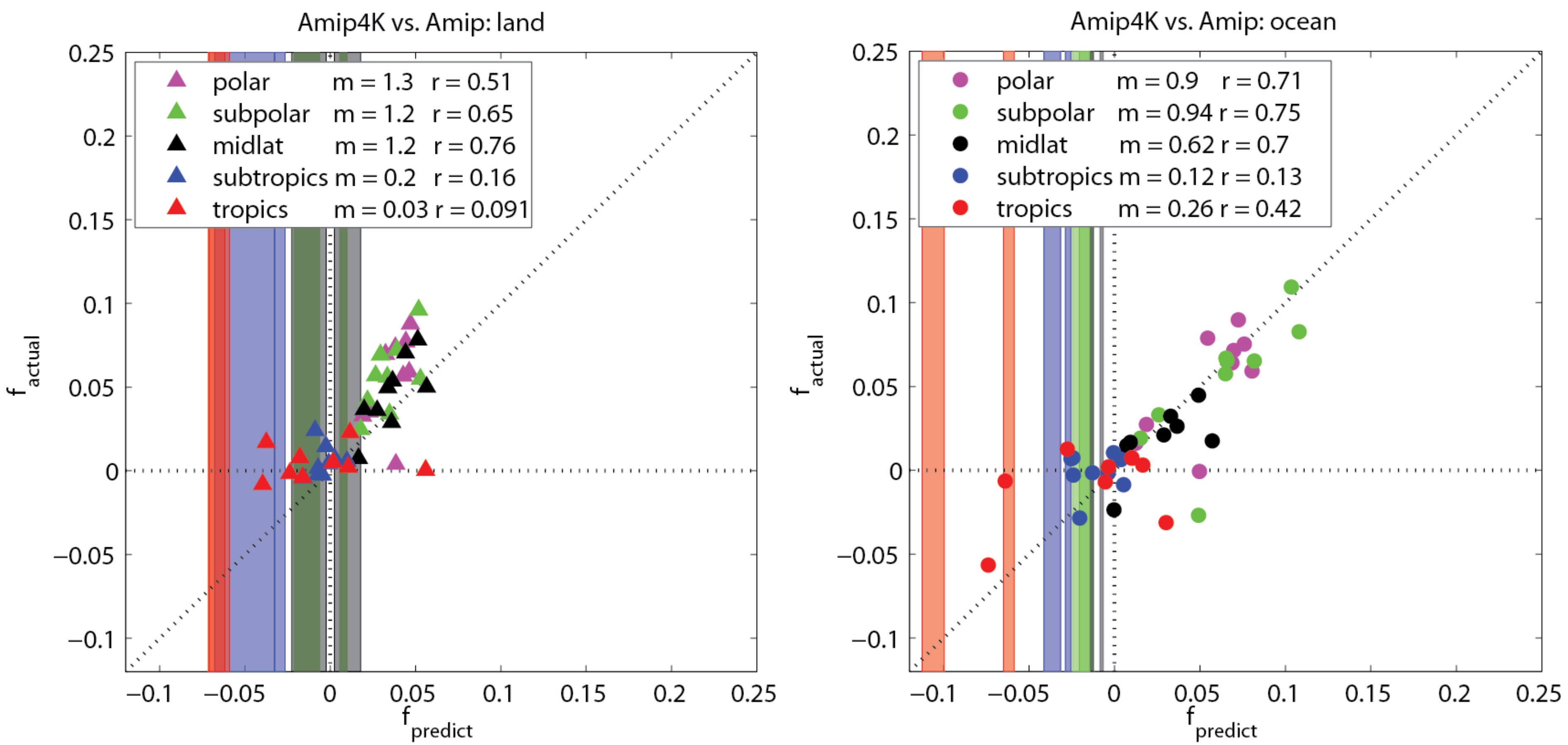


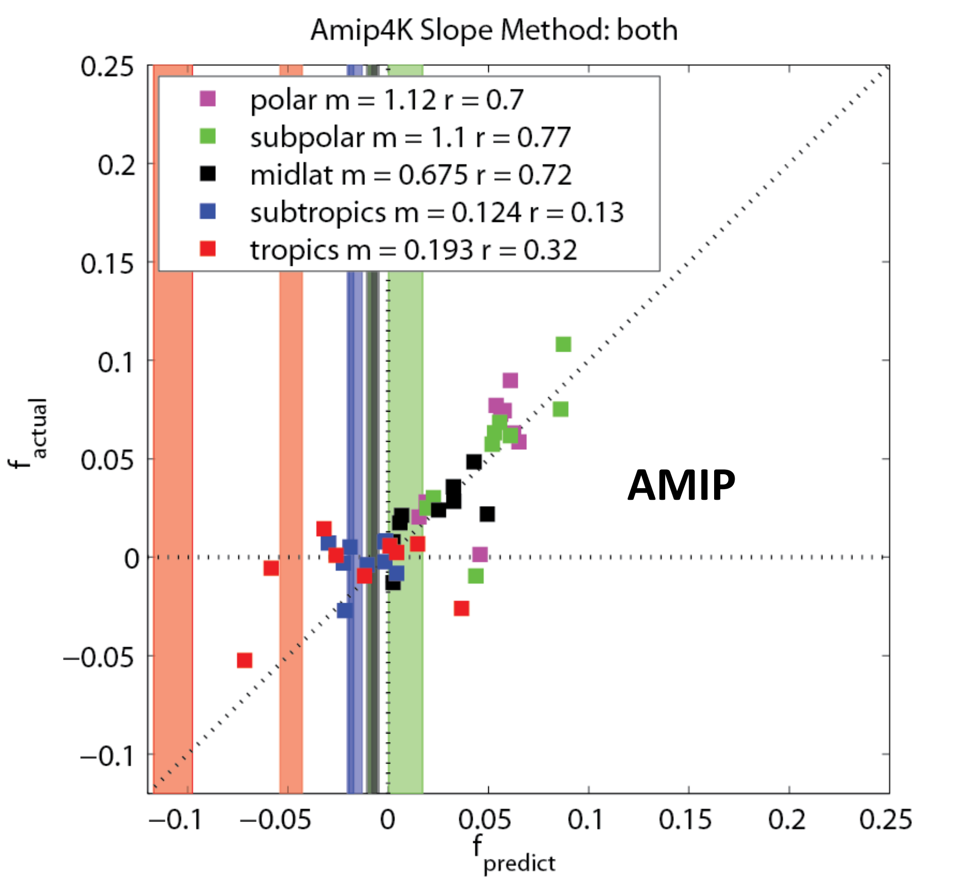
Regional dln(τ)/dT over land and ocean subtropics and tropics

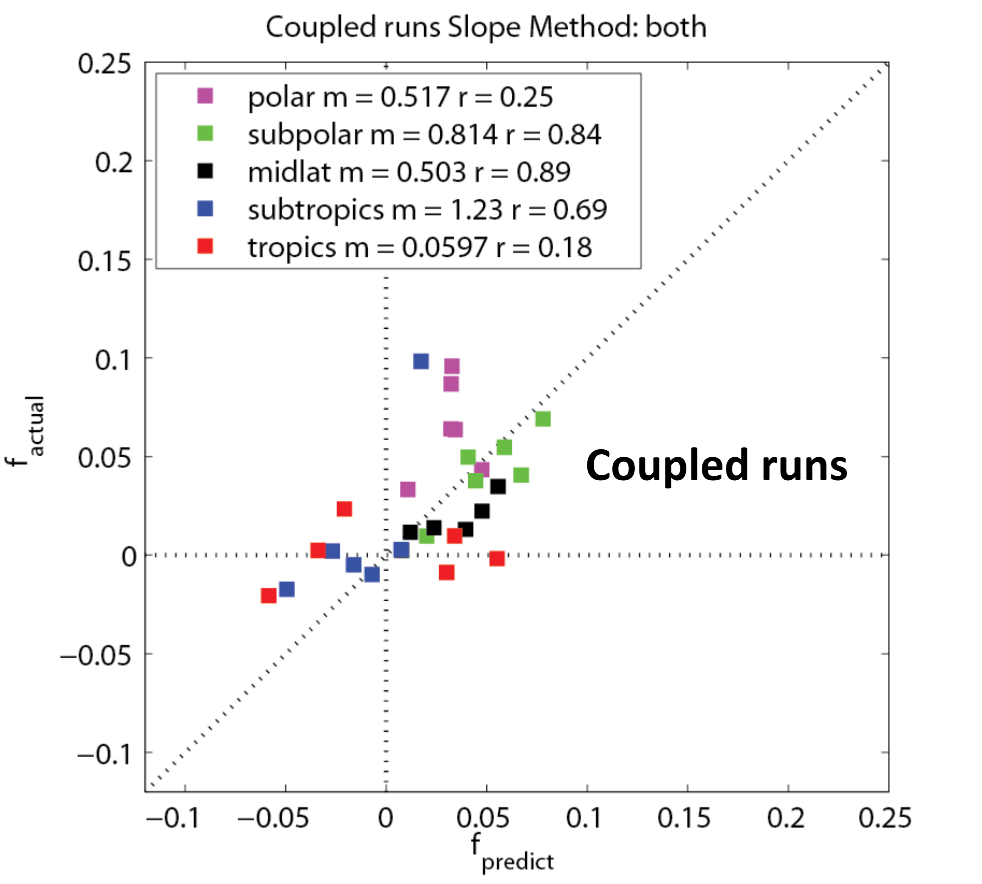




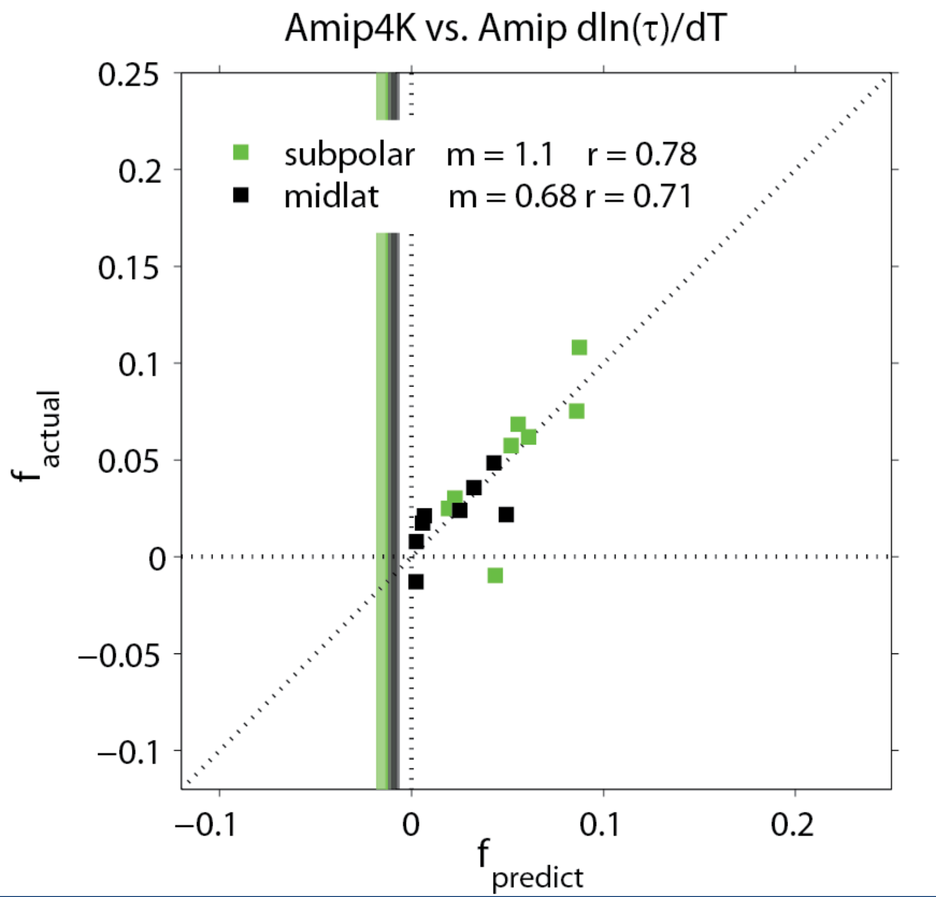
Land vs. ocean response

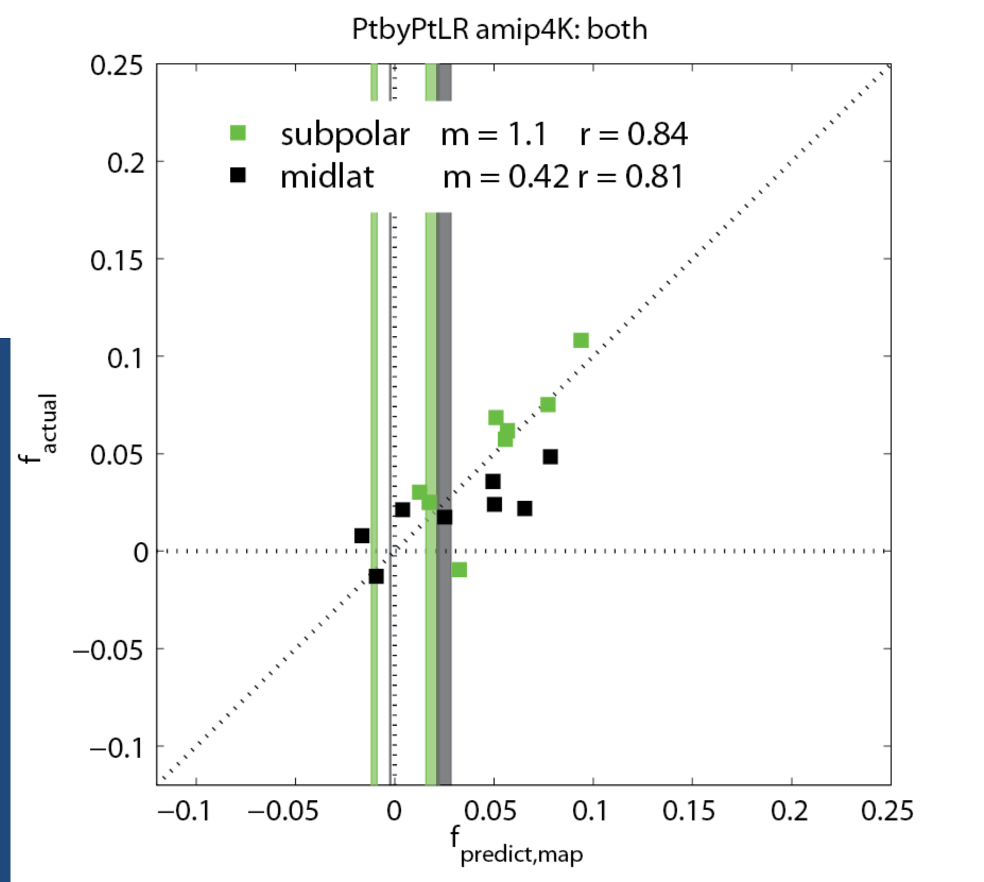






Coupled monthly data do not look that off of the 1-to-1 line.





Using point-by-point linear regression instead of method of Tselioudis