Low-cloud optical depth feedbacks in climate models and observations




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PCMDI
Program for Climate Model Diagnosis and Intercomparison

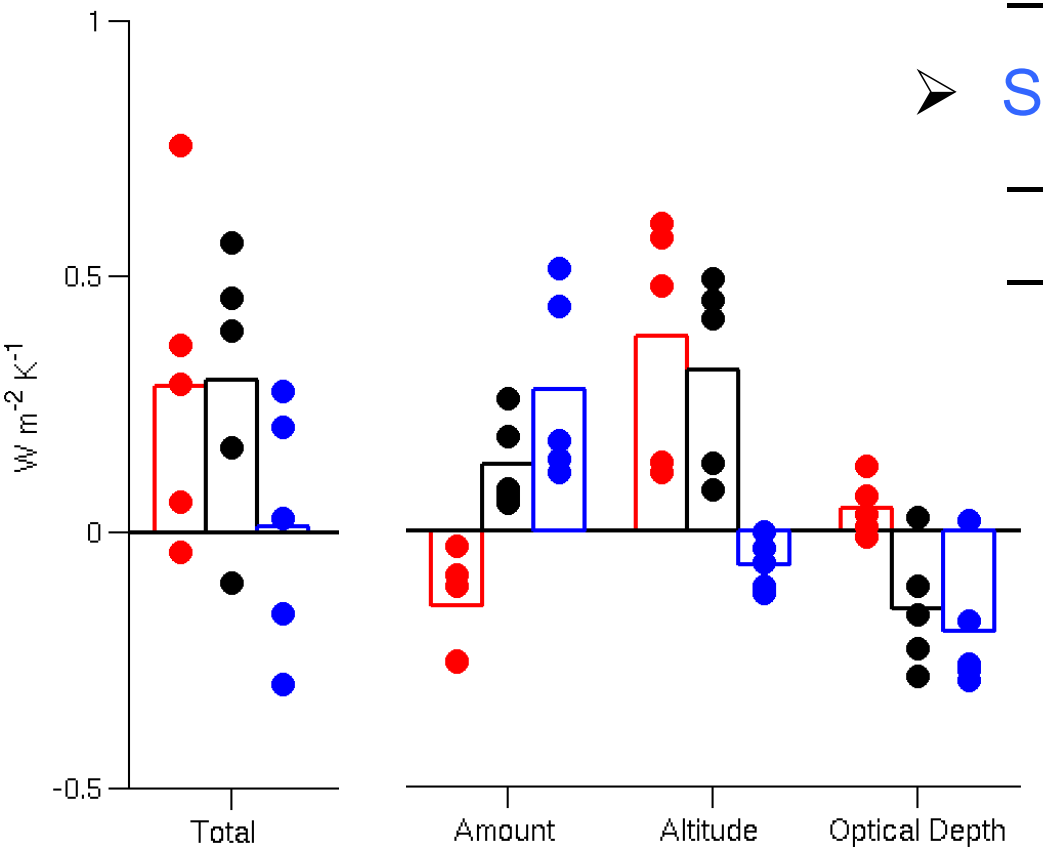
Outline

- *Cloud feedbacks from optical depth changes*
- *Low-cloud optical depth – temperature relationships in the current climate*
- *Responsible physical processes*
- *Is current climate variability a good surrogate for the optical depth feedback?*
- *Take away points*

The role of optical depth feedbacks

Global mean feedbacks in 5 CMIP5 models

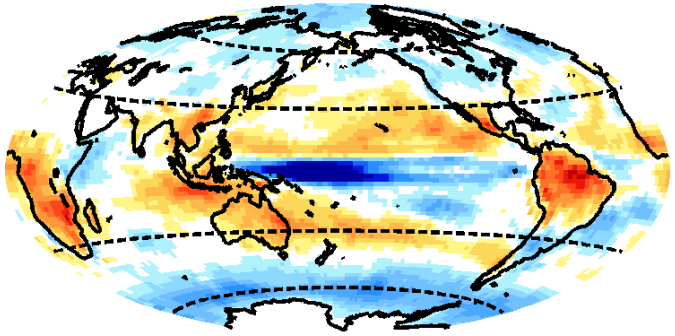
(Zelinka et al. 2013)



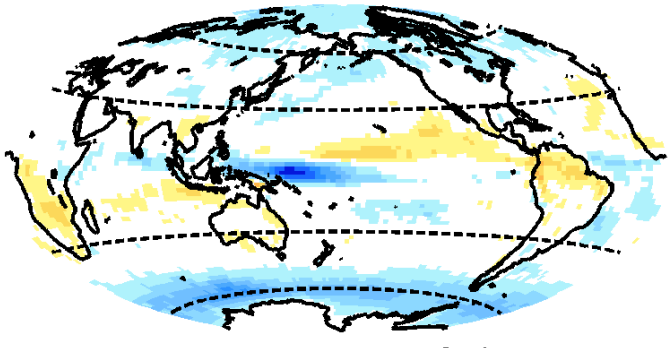
- Longwave feedbacks (+)
  - cloud altitude ↑
- Shortwave feedbacks variable
  - cloud amount ↓ (+)
  - optical depth (τ) ↑ (-)

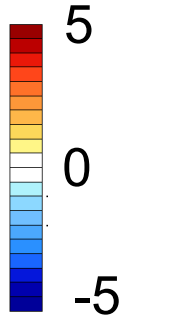
τ feedback geographically

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



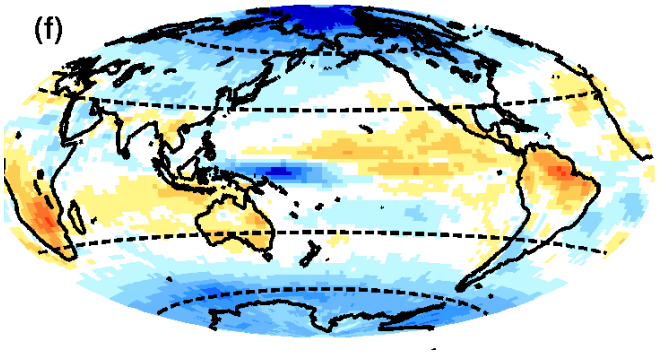
SW Feedback from τ Changes
-0.20 W m^{-2} K^{-1}

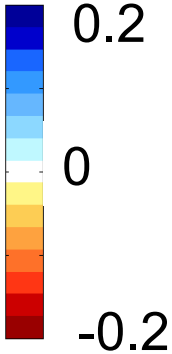




W m^{-2} K^{-1}

τ Changes with Temperature
Δln(τ): 0.02 K^{-1}





K^{-1}

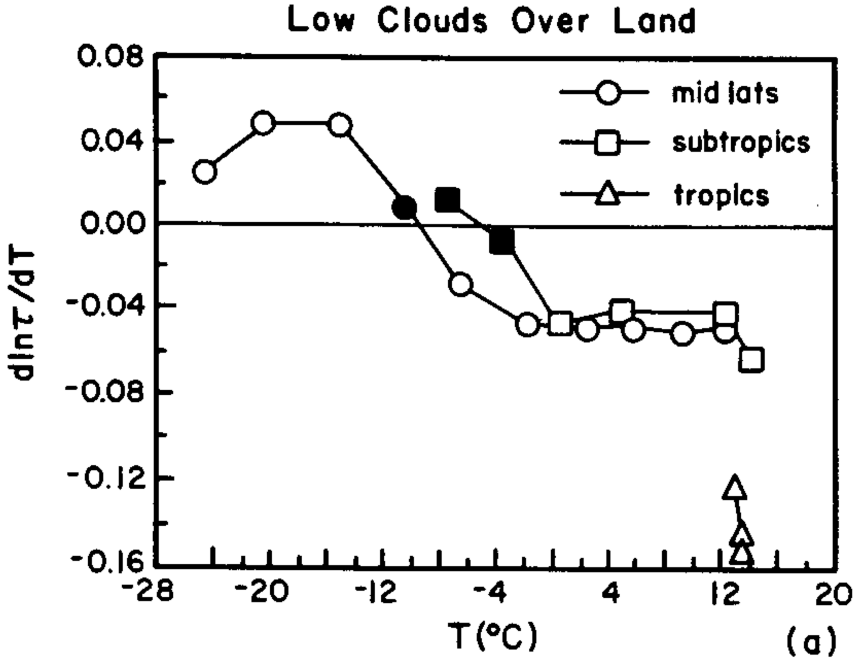
From 5 CMIP5 models

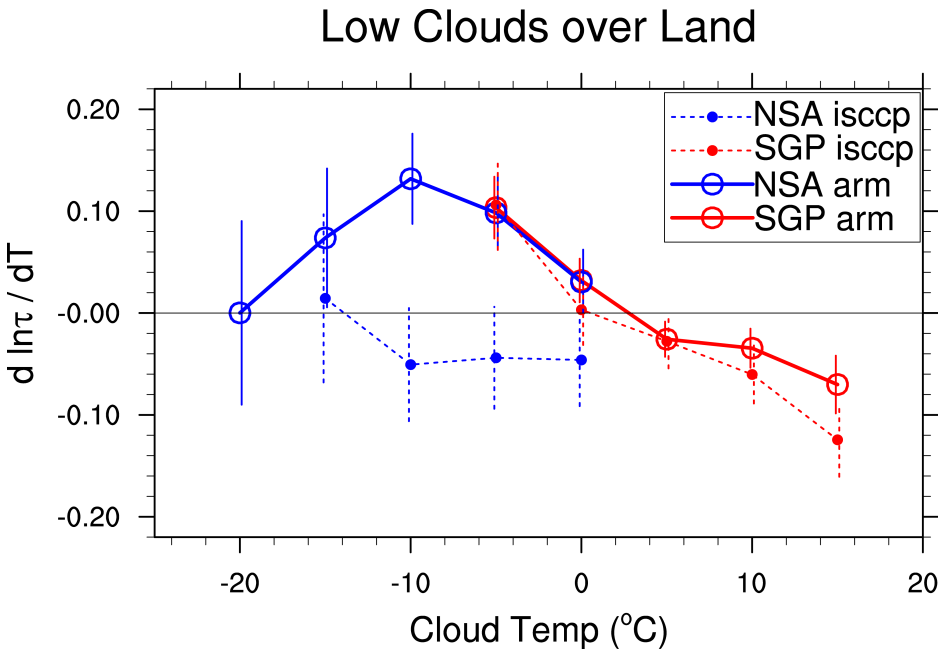
(Zelinka et al. 2013)

- τ increases are strongest at high-latitudes
- τ decreases at low-latitudes
- τ increases occur in low and high clouds

Observed low-cloud τ – temperature (T) relationships

d(ln τ)/dT





From ISCCP Observations

(Tselioudis et al. 1992)

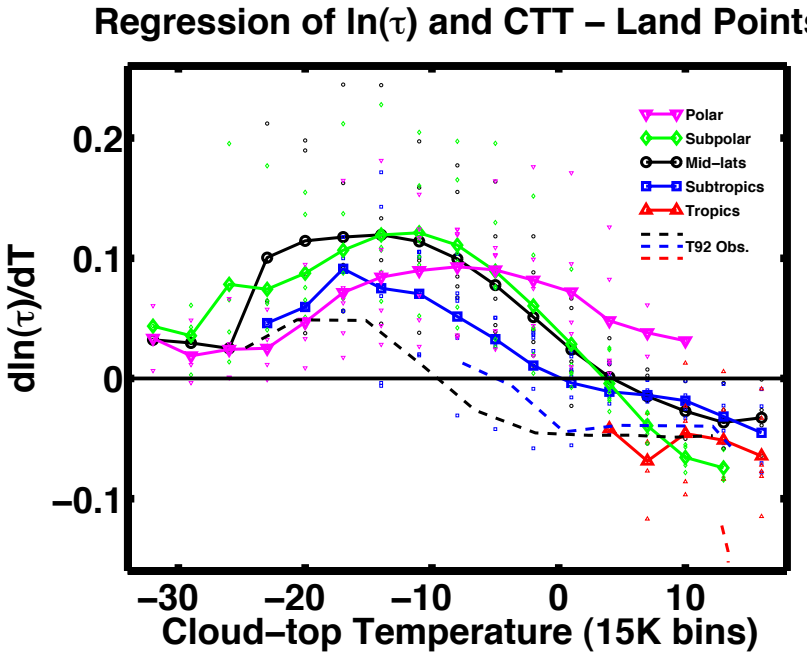
From ARM Sites

(Zhang et al., in preparation)

- *Is this similarity between current climate variability and the climate change responses of models a coincidence?*

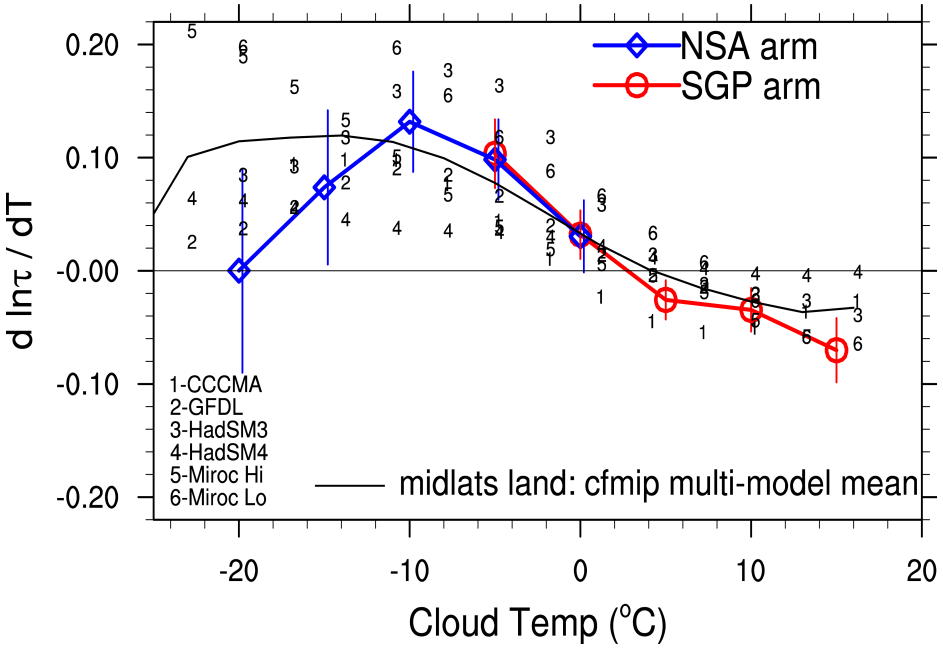
Model low-cloud τ – T relationships

d(ln τ)/dT



CFMIP1 vs. ISCCP

(Gordon et al., in preparation)



CFMIP1 vs. ARM

(Zhang et al., in preparation)

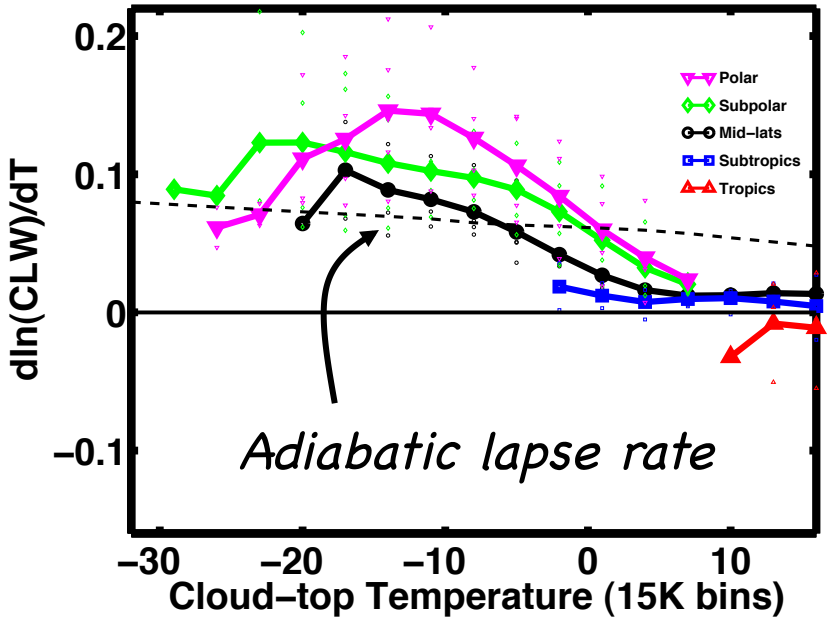
- Model source: Daily CFMIP1 ISCCP simulator output from 7 CFMIP1 slab-ocean models

Responsible physical processes: Models

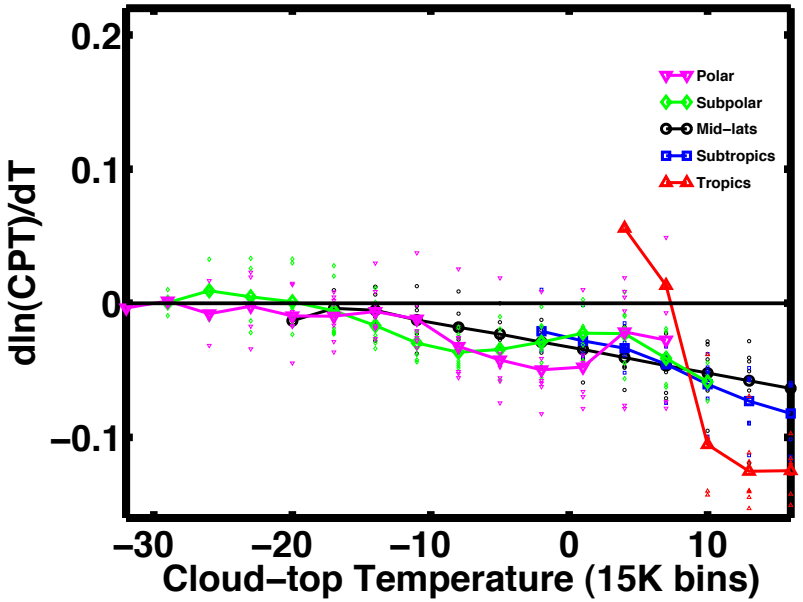
$$\tau = \frac{3}{2}\frac{CWC * \Delta z}{r_e}$$

- CWC available from only 4 models
- r_e not available from any models

d ln(CWC)/dT



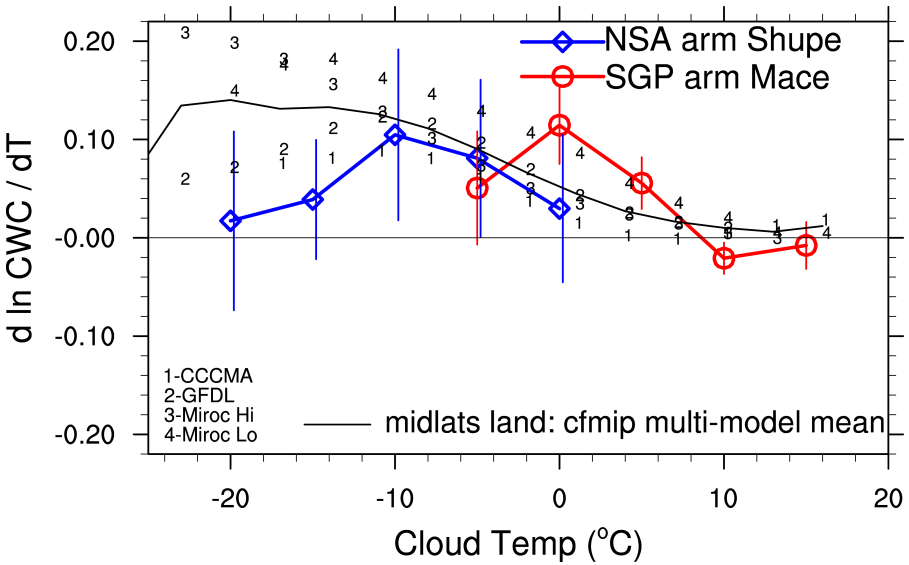
d ln(Δz)/dT



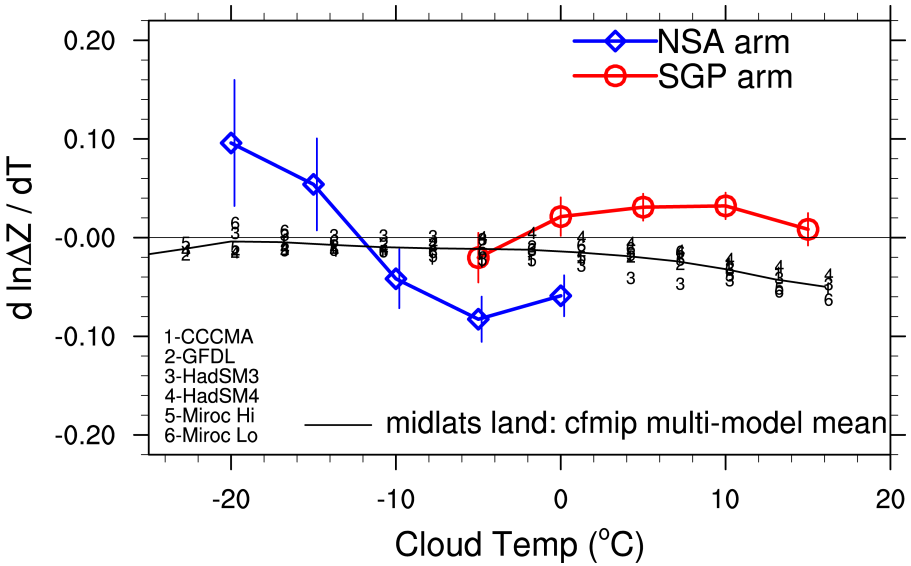
Responsible physical processes: ARM

$$\tau = \frac{3}{2}\frac{CWC * \Delta z}{r_e}$$

d ln(CWC)/dT



d ln(Δz)/dT



Relationship of current climate variability to cloud feedbacks

- Test relationship by examining inter-model spread, as Alex Hall did for snow albedo feedback *(Hall and Qu 2006)*

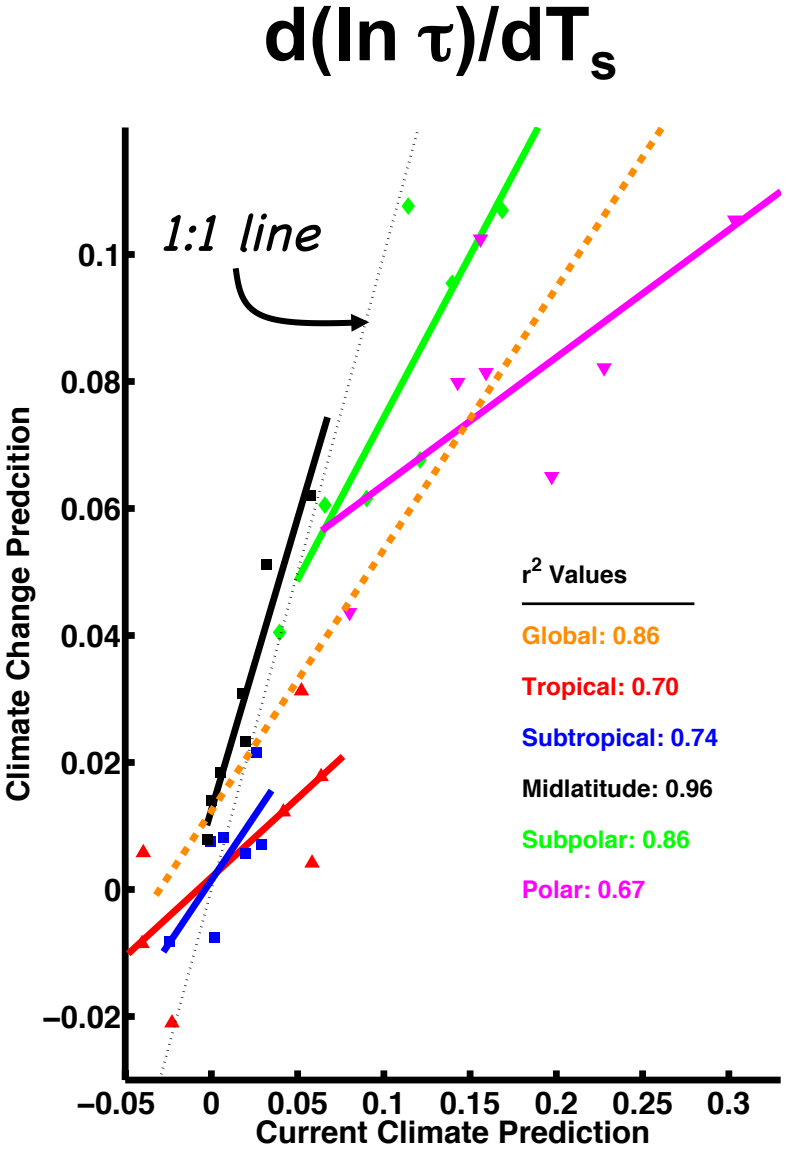
  - Predict τ feedback from current climate variability as

$$\left(\frac{d\ln\tau}{dT_{cloud}}\right)_{current} \times \left(\frac{d\ln T_{cloud}}{dT_{s,local}}\right)_{current} \times \left.\frac{\Delta T_{s,local}}{\Delta T_{s,global}}\right|_{2\times CO_2 - 1\times CO_2}$$

$$= \left(\frac{d\ln\tau}{dT_{s,local}}\right)_{current} \times \left.\frac{\Delta T_{s,local}}{\Delta T_{s,global}}\right|_{2\times CO_2 - 1\times CO_2}$$

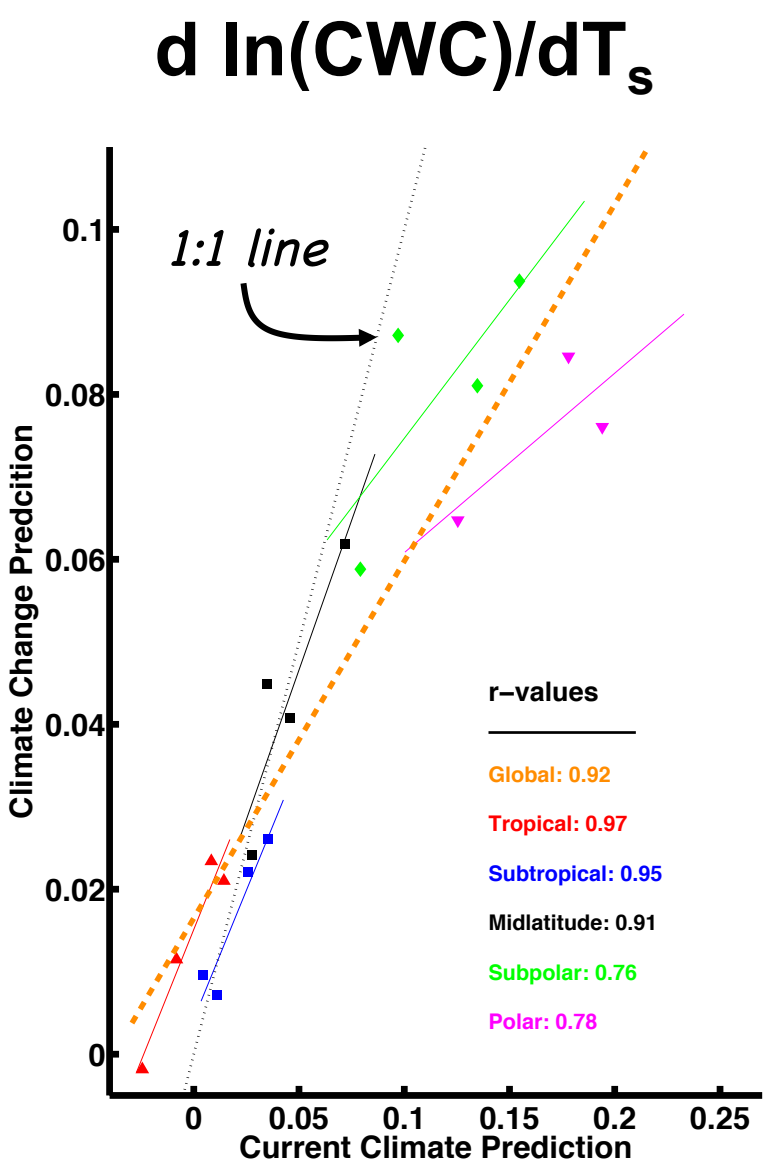
  - Compare to actual feedback → $\left.\frac{\Delta\ln\tau}{\Delta T_{s,global}}\right|_{2\times CO_2 - 1\times CO_2}$

Current climate is partially predictive of future climate



Climate models with stronger increases of τ on temperature in the current climate exhibit stronger increases of τ under climate warming

Current climate is partially predictive of future climate



This correspondence extends to condensed water content

Take Away Points

- τ changes matter for cloud feedbacks
- For climate changes, τ of low clouds increases at high latitudes but decreases or remains the same at low latitudes
- Current climate variability is similar with increases of τ for cold low clouds and decreases of τ for warm low clouds as temperature increases
- Climate models qualitatively reproduce the observed relationships from satellites and ARM data albeit with considerable scatter

Take Away Points

- *For cold clouds, changes of in-cloud water content explain much of the modeled and observed variations of low-cloud τ with temperature*
  - *The water content rise with temperature is qualitatively consistent with the adiabatic lapse rate, although other changes in others factors such as the phase and particle size may contribute to τ variability*
- *For warm clouds, τ decreases with temperature consistent with observations*
  - *Models do this through cloud thickness decreases, not water content changes. It is not clear if this is consistent with observations or LES (Rieck et al. 2012)*

Take Away Points

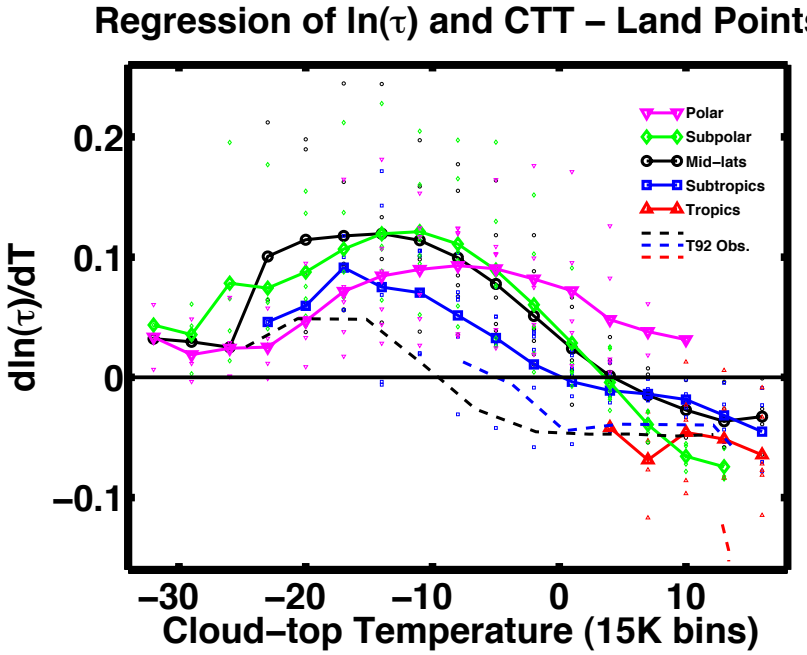
- *The inter-model correspondence of current climate variability to climate change suggests, observations of the relationship of τ and CWC to temperature in the current climate can be used to constrain this cloud feedback (both its bias and inter-model spread)*


Thanks For Your Attention!

Extra Slides

Cloud-top vs. surface temperature

d(ln τ)/dT(cloud)



d(ln τ)/dT(surface)