DON'T COUNT ON IT: REASONS TO DOUBT A STRONG NEGATIVE CLOUD FEEDBACK

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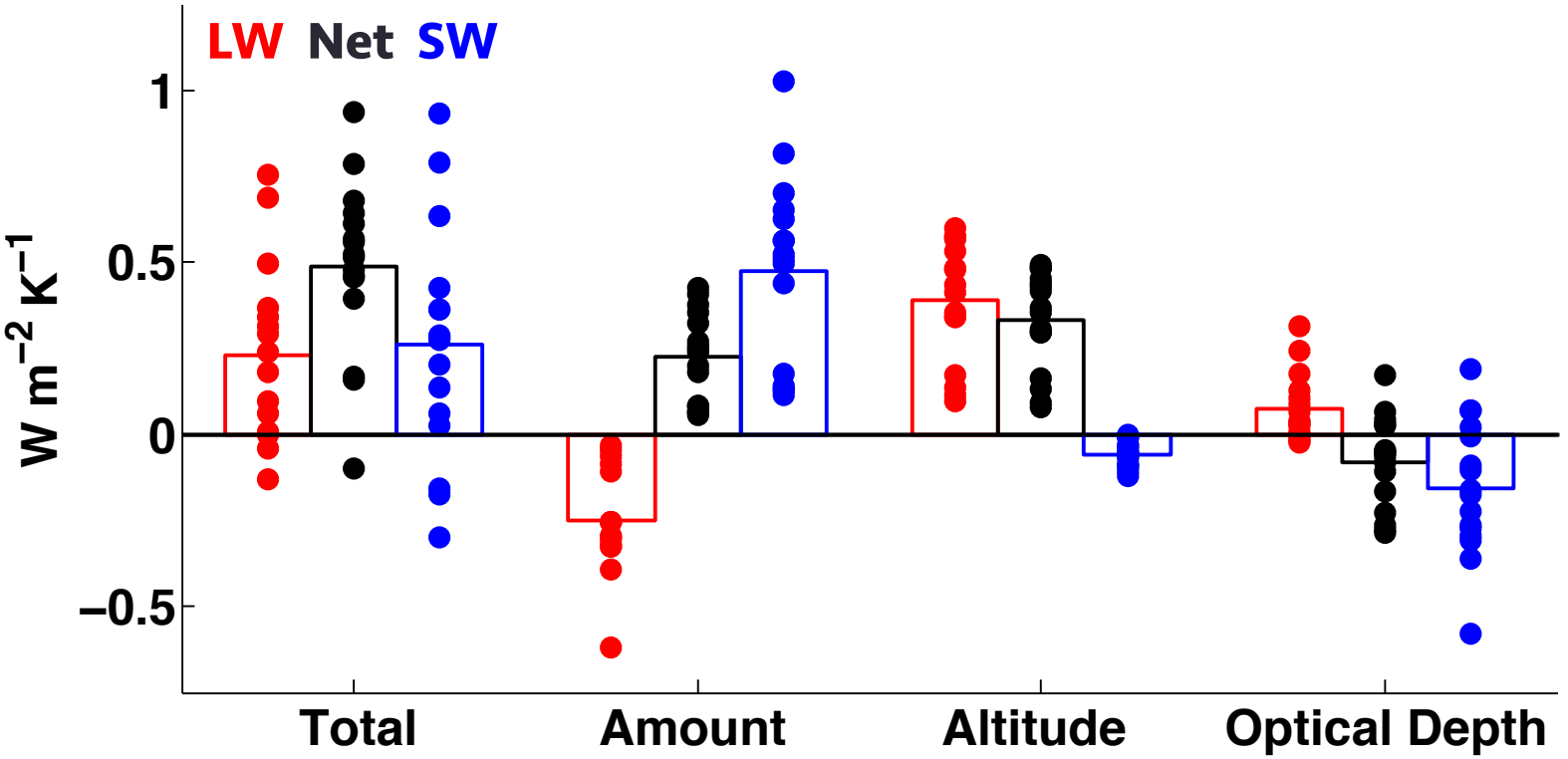
Global mean cloud feedbacks



CMIP3/5 from Zelinka et al. (2012, 2013)

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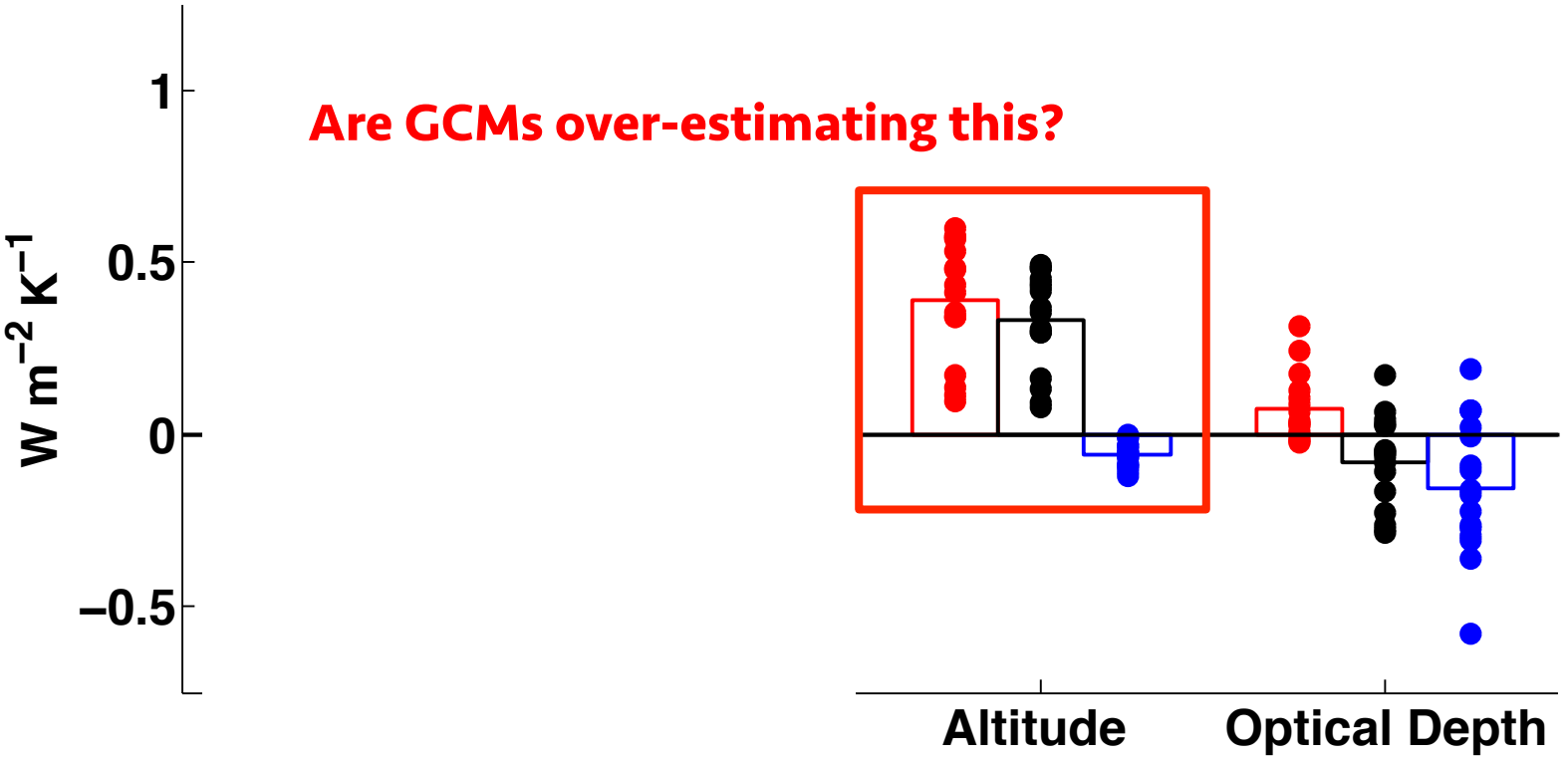

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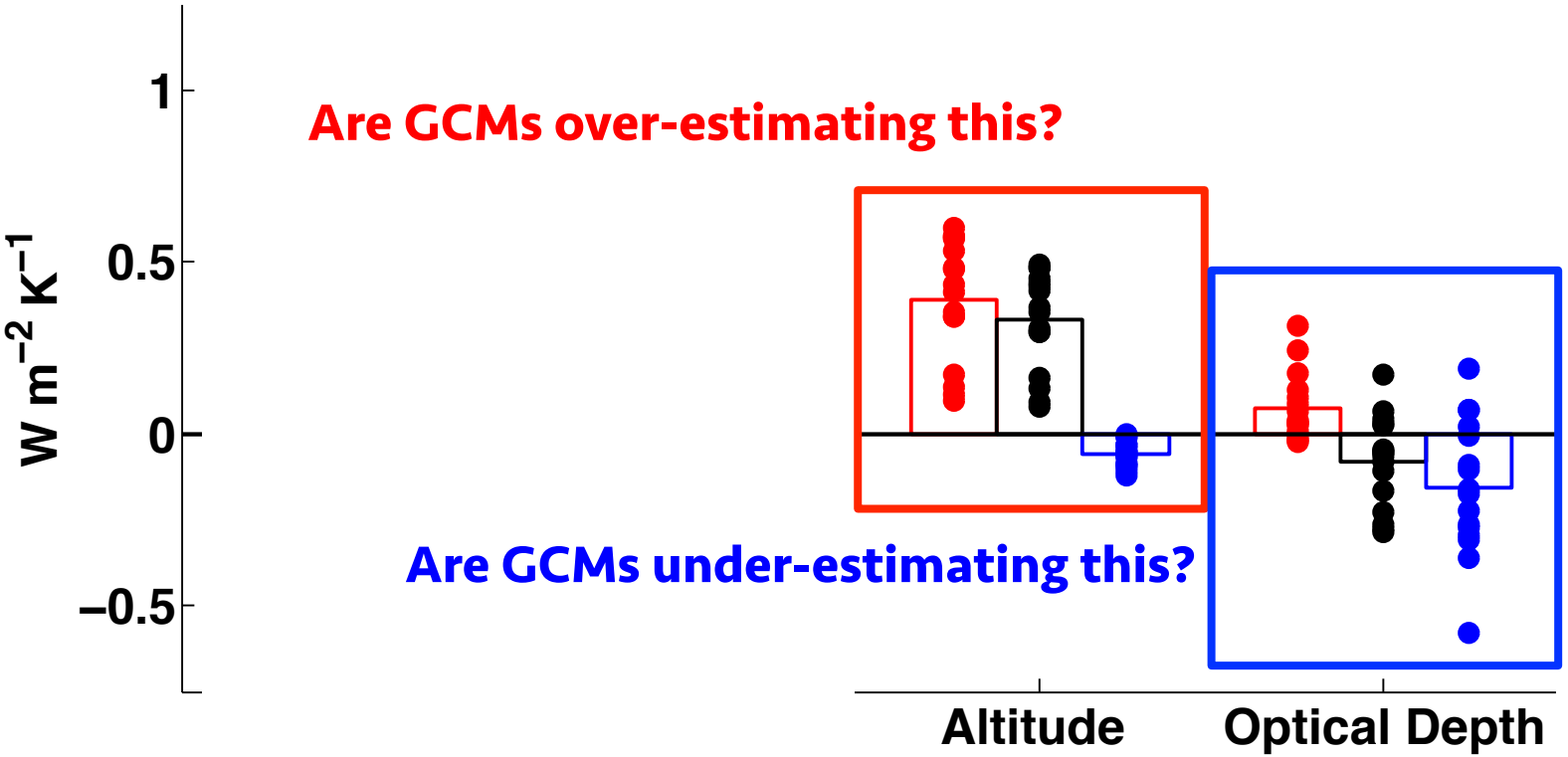

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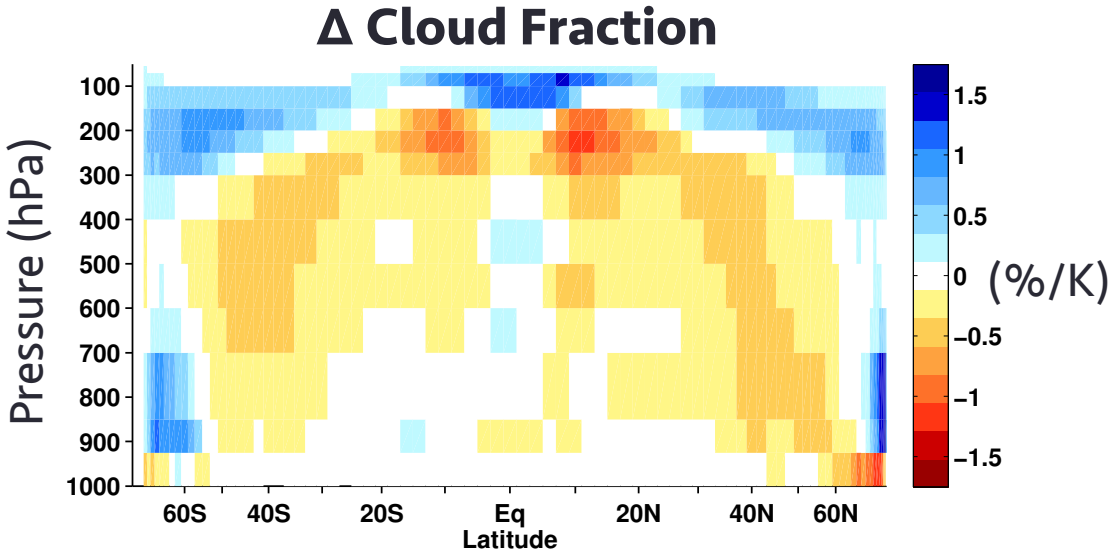
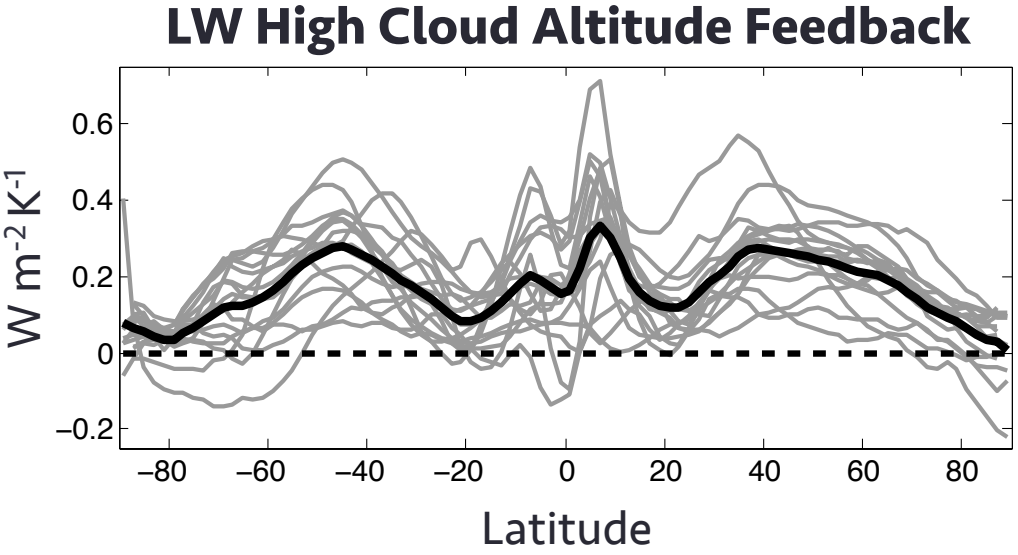




Individual Models

Model Mean

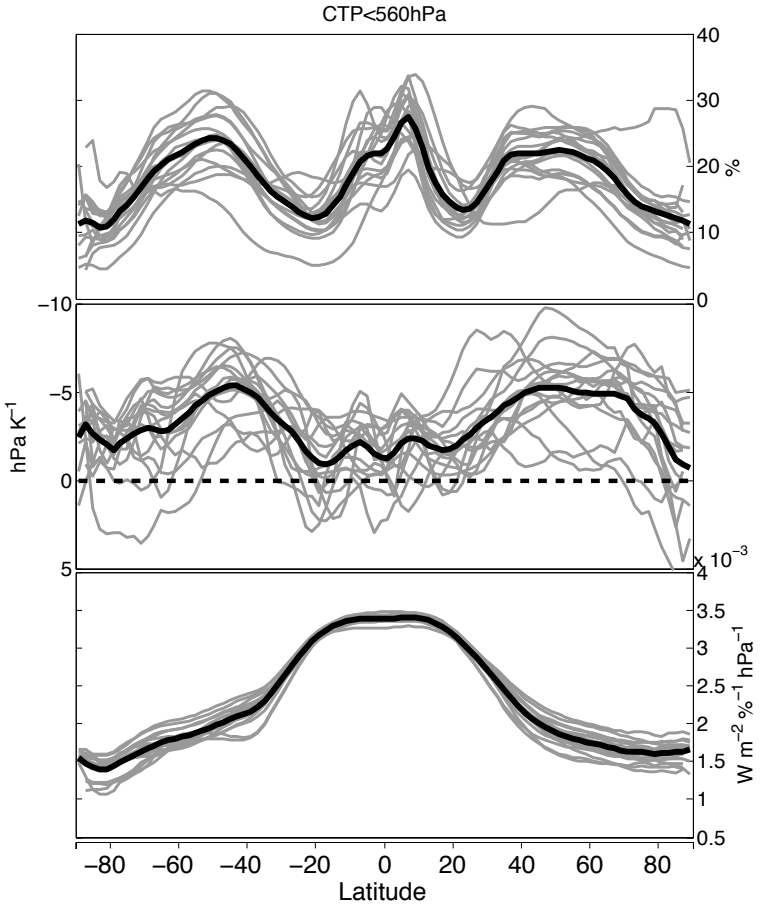
A scalar predictor

$$C_{hi}^{eff} * \frac{\partial CTP_{hi}}{\partial T} * \frac{\partial OLR}{\partial CTP_{hi}}$$

Amount of high clouds

How much they shift upwards

Sensitivity of OLR to ΔCTP



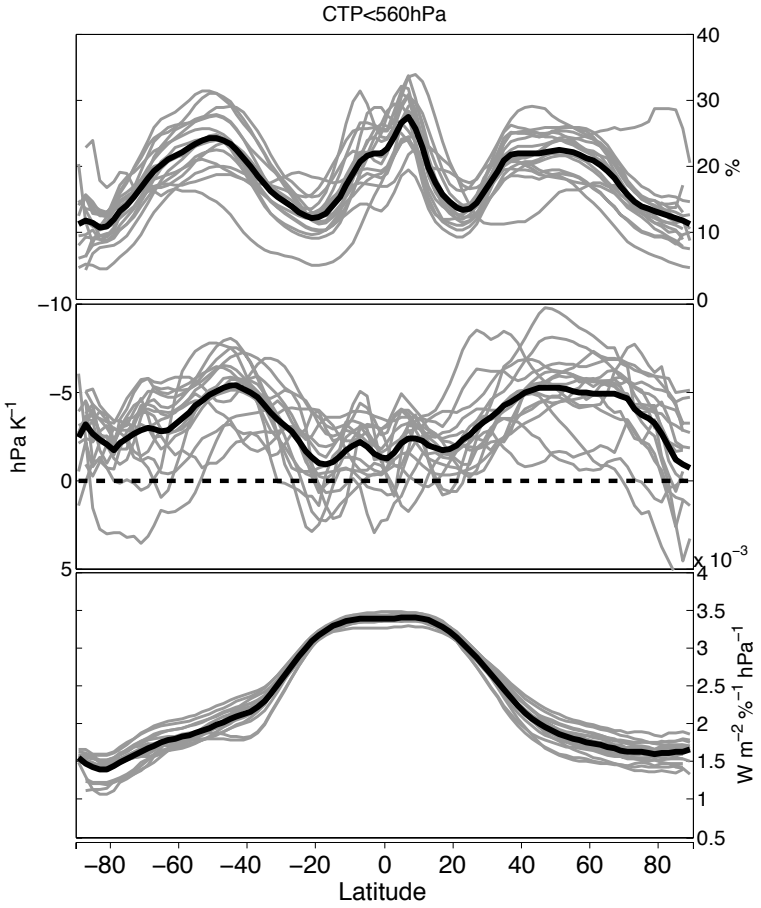
Are models overestimating this feedback?

$$C_{hi}^{eff} * \frac{\partial CTP_{hi}}{\partial T} * \frac{\partial OLR}{\partial CTP_{hi}}$$

Amount of high clouds
Too large in GCMs?

How much they shift upwards
Too large in GCMs?

Sensitivity of OLR to ΔCTP
Too large in GCMs?



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Not tested here, but unlikely.

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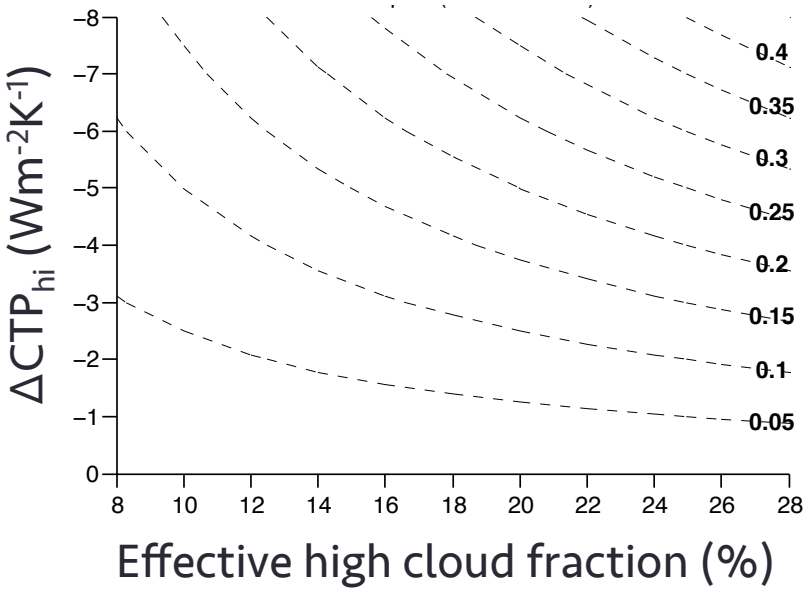

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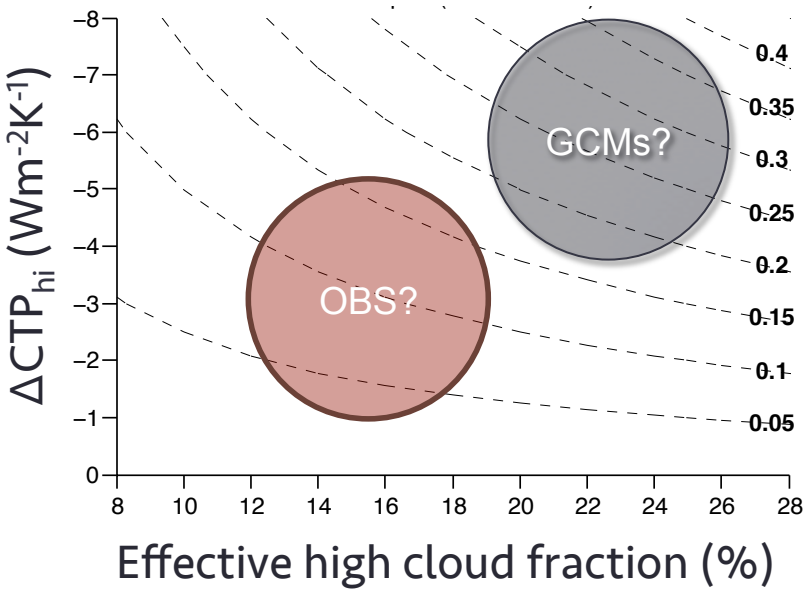

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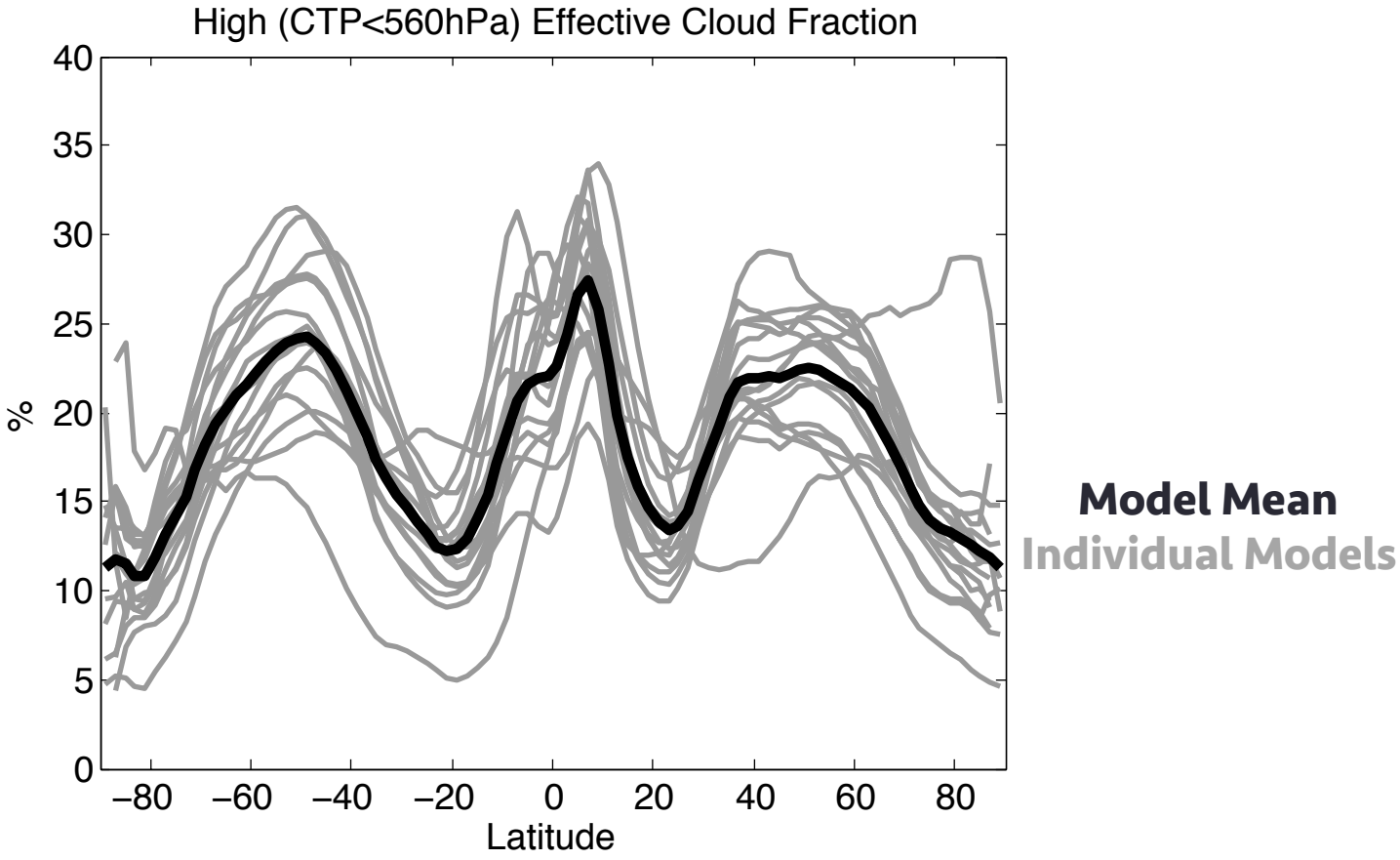
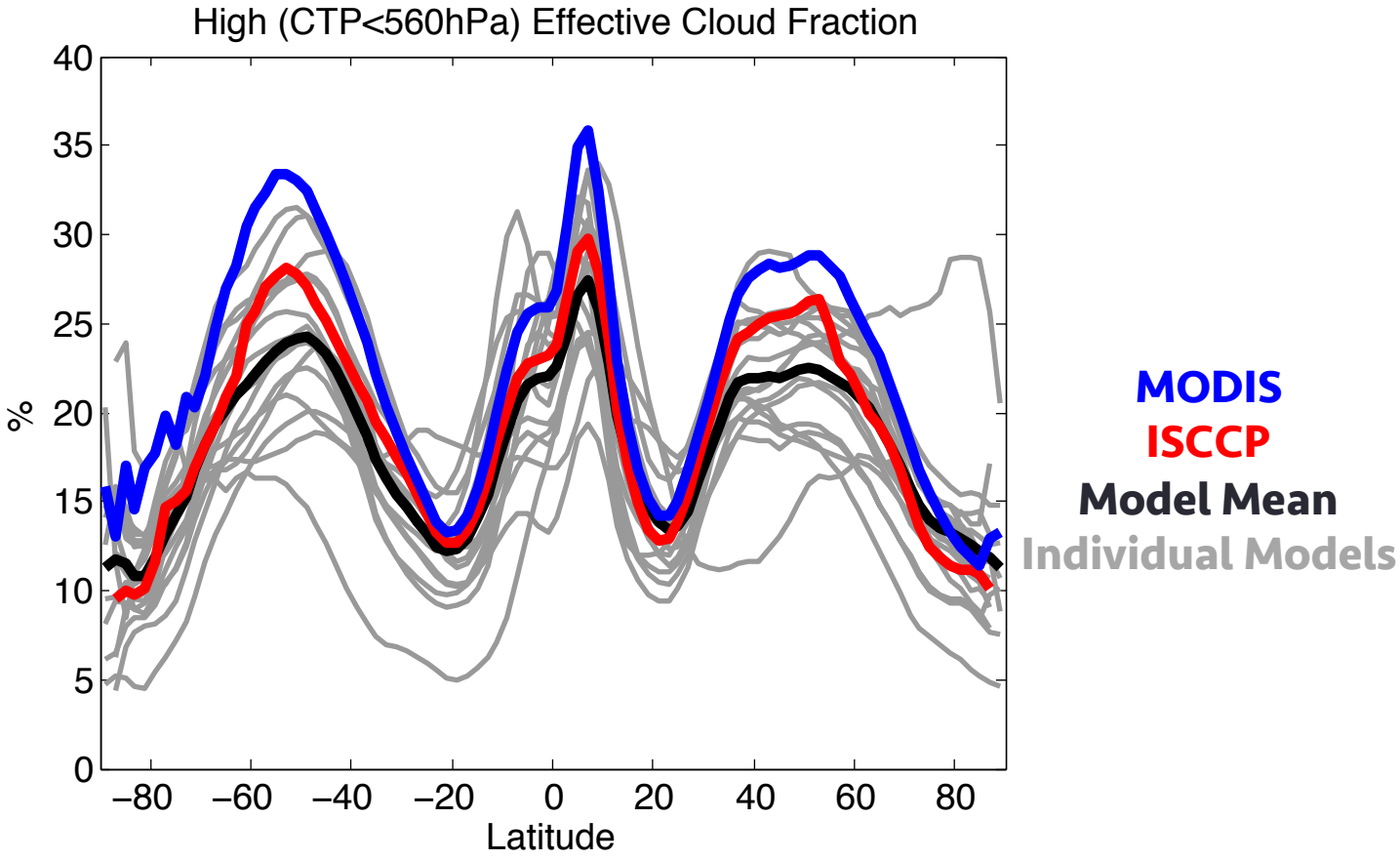
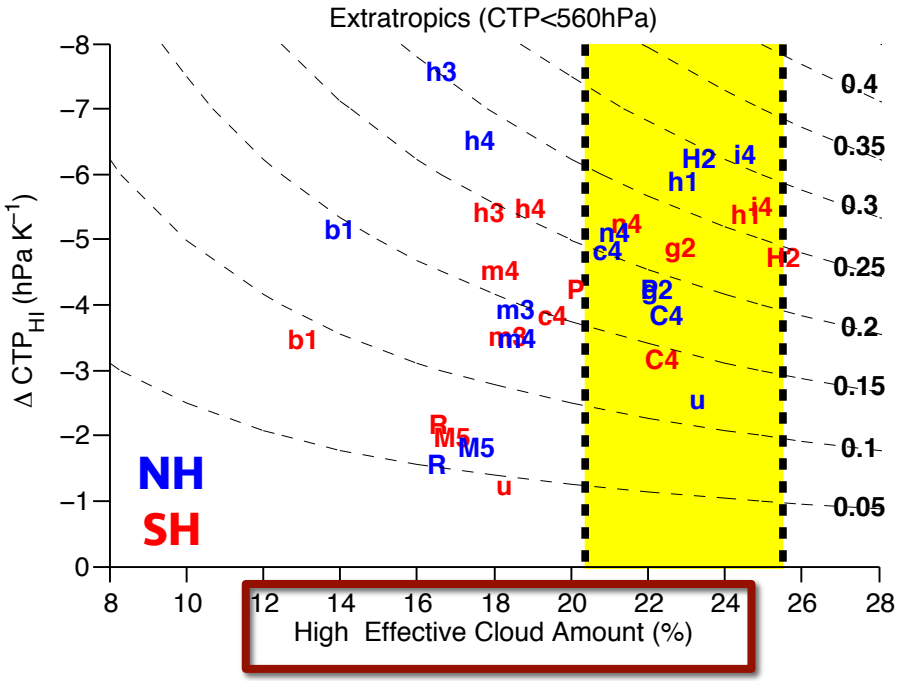

High (CTP<560hPa) Effective Cloud Fraction
%
Latitude
0
5
10
15
20
25
30
35
40
−80
−60
−40
−20
0
20
40
60
80
Model Mean
Individual Models

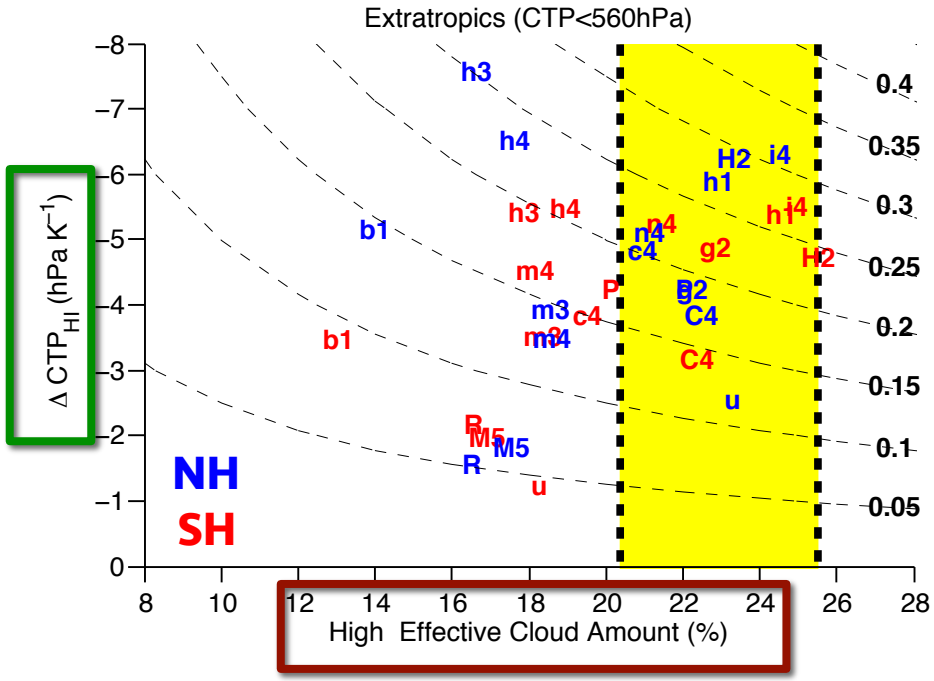


No systematic overestimate of high effective cloud fraction.
Rather, most GCMs ***underestimate*** it.

"It is possible that the underestimate of the RFO of anvil and cirrus regimes ... could lead to an underestimate of the magnitude of their longwave feedbacks with global warming."
Tsushima et al. (2013)



Most models *underestimate* the amount of high clouds
None overestimate the amount of high clouds



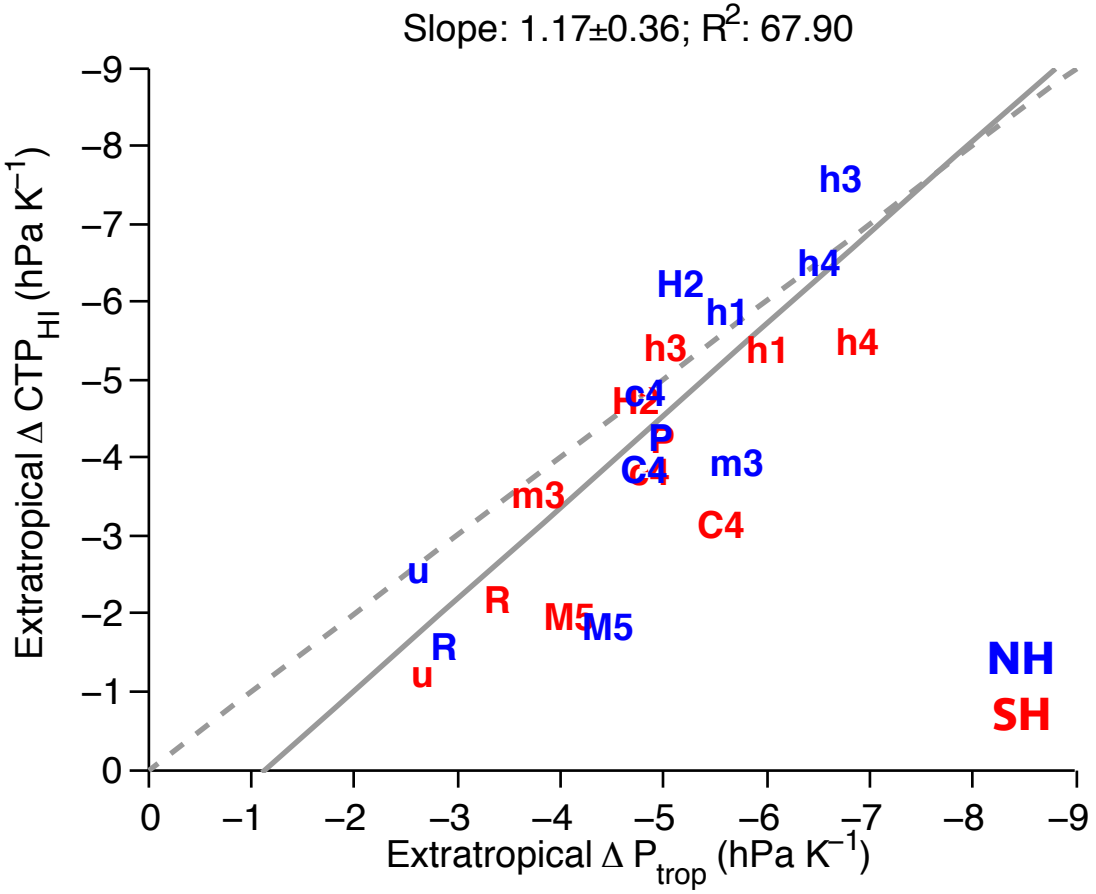
Most models *underestimate* the amount of high clouds
None overestimate the amount of high clouds

What governs ΔCTP_{hi}?

Tropics: radiatively driven divergence → FAT/PHAT

Extratropics: tropopause height → UT warming / LS cooling

$$\frac{\partial CTP_{hi}}{\partial T}$$



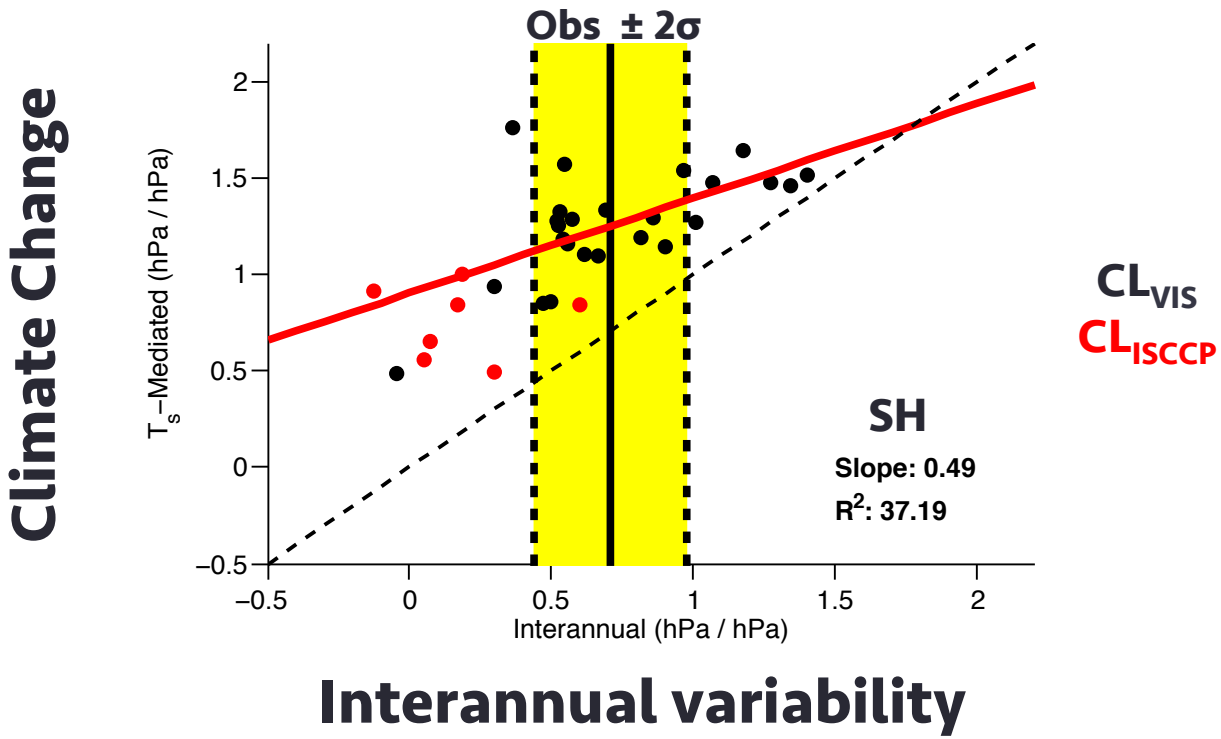
$$\frac{\partial p_{tropopause}}{\partial T}$$

Change in CTP_{hi} is well-explained by change in tropopause pressure

Do observations support this on short timescales?

Are short-term fluctuations predictive of future changes?

$$\frac{\partial CTP_{hi}}{\partial p_{tropopause}}$$



Modeled short-term fluctuations of CTP_{hi} & tropopause pressure are fairly realistic.
Estimates using ISCCP simulator suggest model CTP_{hi} response is too small.
Not perfectly timescale invariant though.

Are models overestimating this feedback?

$$C_{hi}^{eff} * \frac{\partial CTP_{hi}}{\partial T} * \frac{\partial OLR}{\partial CTP_{hi}}$$

Amount of high clouds
Too large in GCMs?

No. It is likely too small.

How much they shift upwards
Too large in GCMs?

No. They shift upwards in a manner consistent with expectations and with observations.

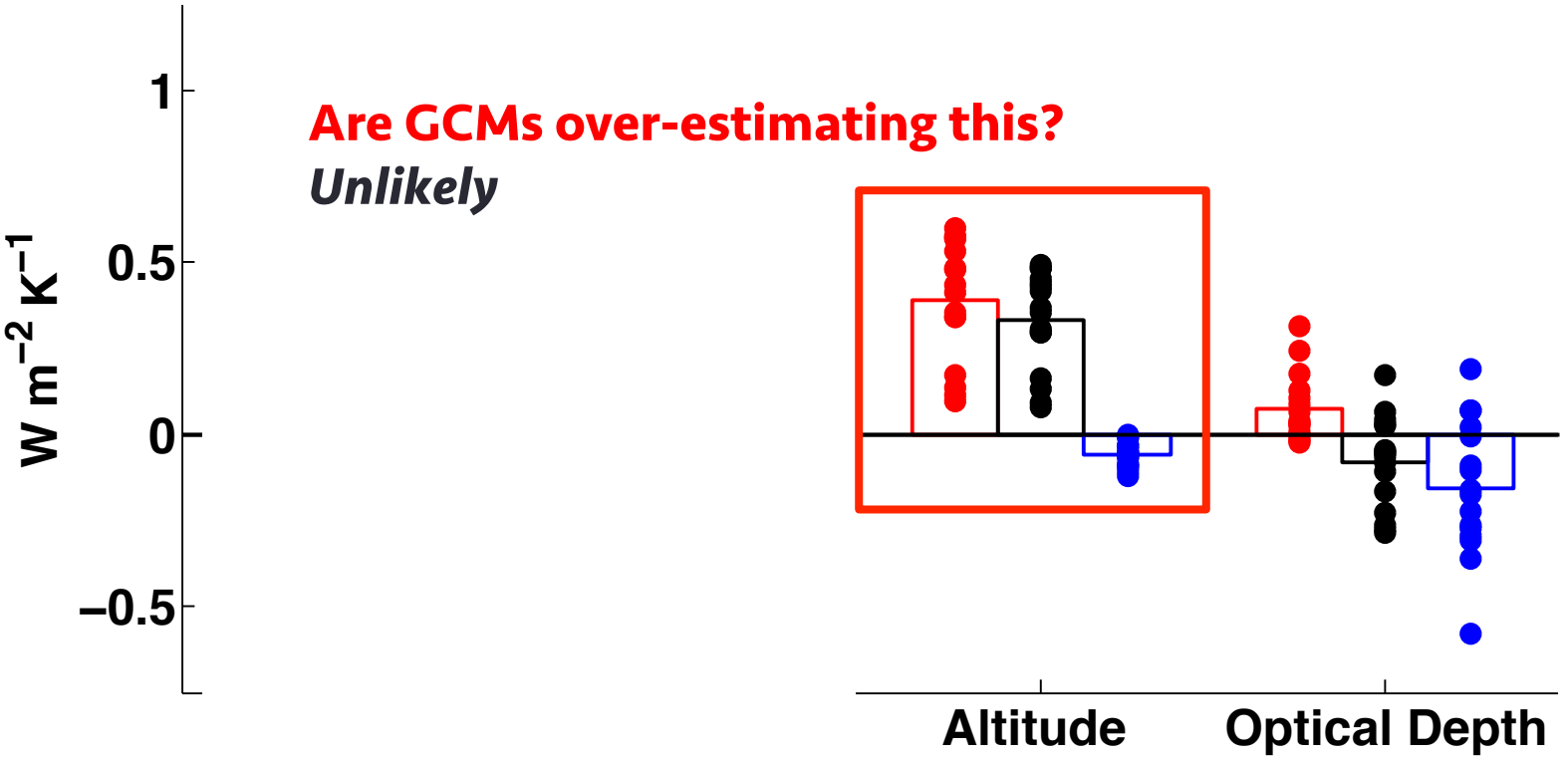
Sensitivity of OLR to ΔCTP
Too large in GCMs?

Not tested here, but unlikely.

Other considerations for LW high cloud altitude feedback

- Does non-interactive ozone in most CMIP runs suppress the ability of cloud tops to rise? (e.g., tropical clouds are **PHAT** rather than FAT)
  - Harrop and Hartmann (2012): "The effect of the model's fixed ozone profile on stability creates a pressure-dependent inhibition of convection, leading to a small warming in cloud-top temperature as SST is increased."
  - Nowack et al. (2014) 4xCO_2 simulations with interactive minus fixed ozone → large impacts on UT cirrus lead to more positive LW cloud feedback

Global mean cloud feedbacks



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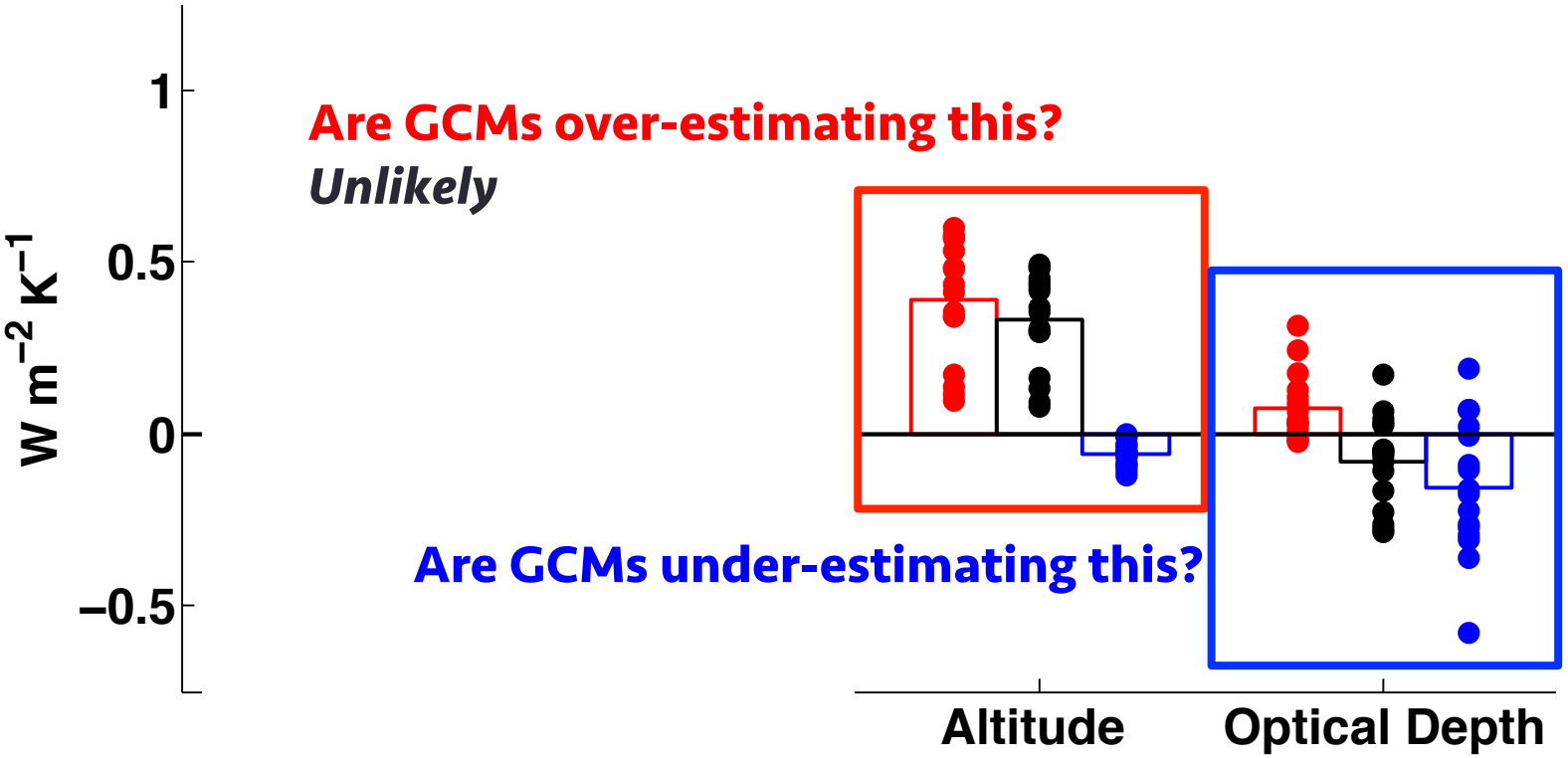

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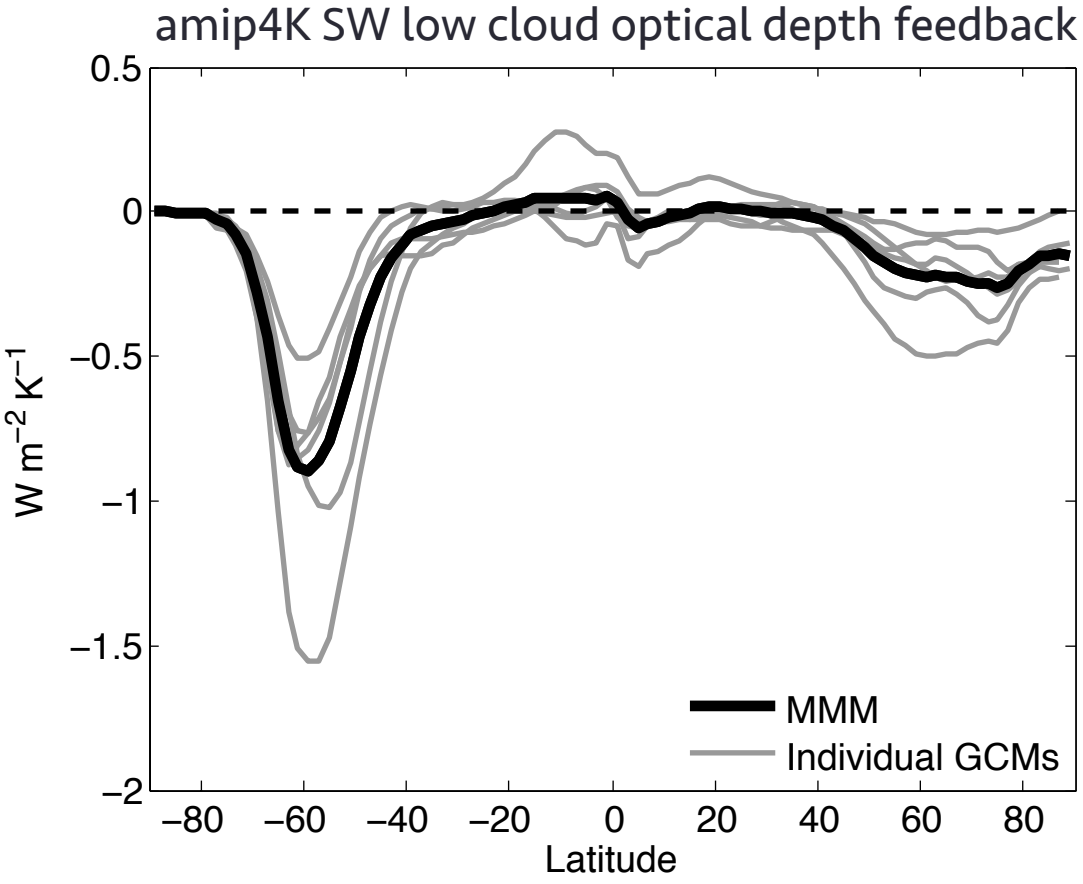


Support for cold clouds becoming more reflective with warming:

Theoretical: Betts & Harshvardan (1987)

Observational: Feigelson (1978), Somerville and Remer (1984), Tselioudis et al. (1992), Tselioudis & Rossow (1994), Chang and Coakley (2007), Eitzen et al. (2011)

Are models underestimating this feedback?

$$C_{lo} \times \frac{\partial \ln(\tau_{lo})}{\partial T} \times \frac{\partial SW^{\downarrow}}{\partial \ln(\tau_{lo})}$$

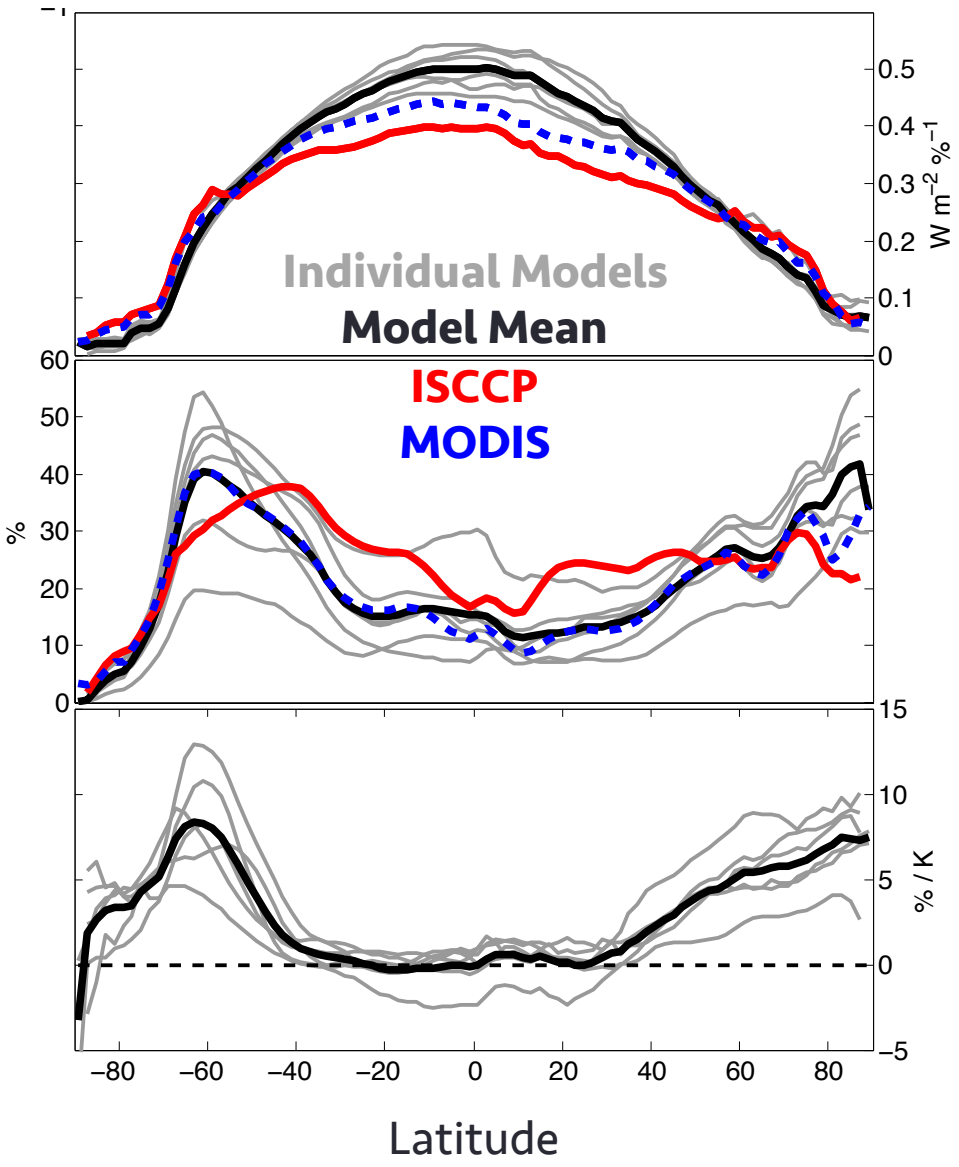
Is low cloud fraction too small* in GCMs?

Do GCMs underestimate the increase in $\ln(\tau_{lo})$?

Is albedo too insensitive to $\ln(\tau_{lo})$ changes* in GCMs?

**where $\ln(\tau_{lo})$ increases*

$$abs\left(\frac{\partial SW^{\downarrow}}{\partial \ln(\tau_{lo})}\right)$$



Too small in GCMs?

$$C_{lo}$$

Too small in GCMs?

$$\frac{\partial \ln(\tau_{lo})}{\partial T}$$

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Is low cloud fraction too small* in GCMs?

No.

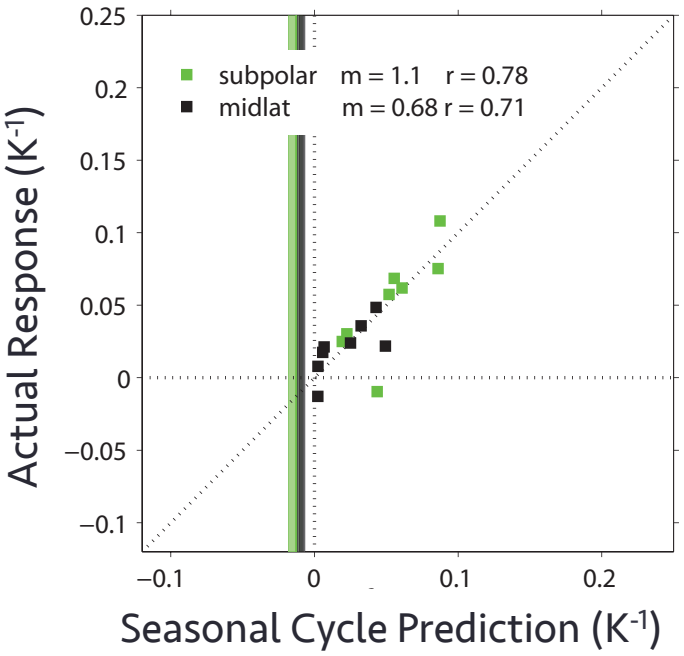
Do GCMs underestimate the increase in $\ln(\tau_{lo})$?

Is albedo too insensitive to $\ln(\tau_{lo})$ changes* in GCMs?

Yes, slightly. But it does not seem to matter much.

**where $\ln(\tau_{lo})$ increases*

$$\frac{\partial \ln(\tau_{lo})}{\partial T}$$



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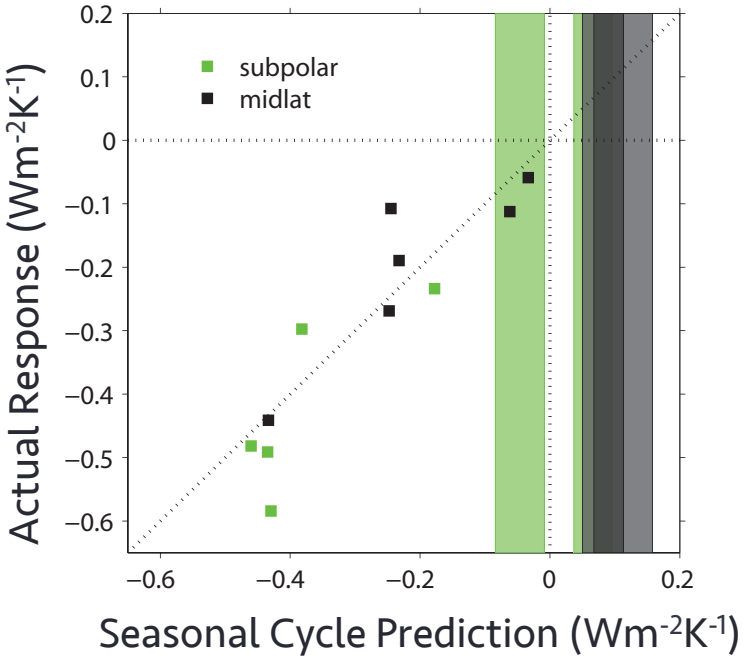


Credit: Chris Terai
Update of Gordon and Klein (2014)

1) The response of $\ln(\tau_{lo})$ to seasonal ΔT is predictive of its future changes.
2) Models tend to overestimate the response of $\ln(\tau_{lo})$ to seasonal ΔT.
3) The models' mid- to high-latitude SW τ_{lo} feedback is too negative.

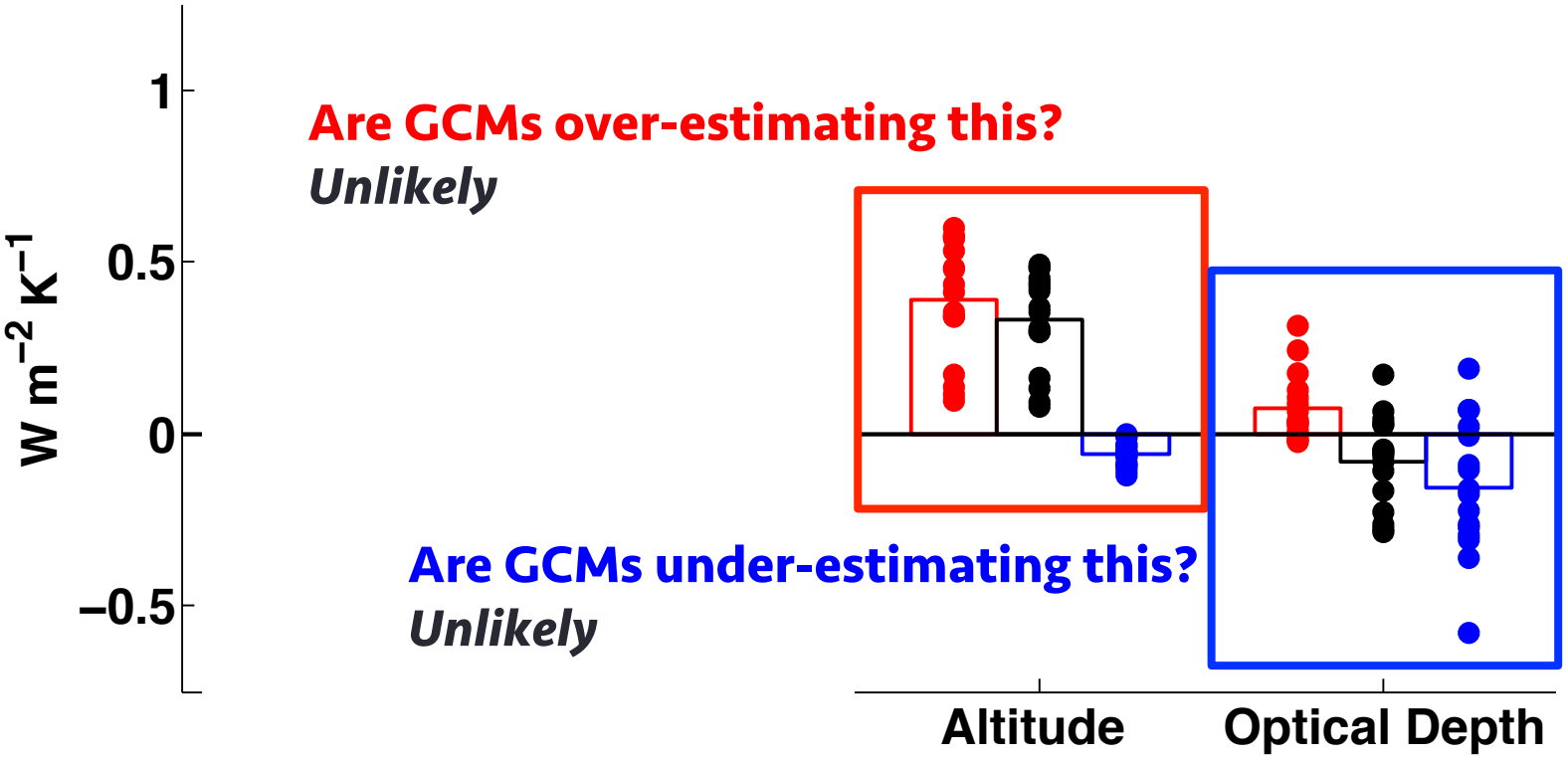
Are models underestimating this feedback?

$$C_{lo} \times \frac{\partial \ln(\tau_{lo})}{\partial T} \times \frac{\partial SW^{\downarrow}}{\partial \ln(\tau_{lo})}$$

Is low cloud fraction too small* in GCMs?	**No.**
Do GCMs underestimate the increase in $\ln(\tau_{lo})$?	**No. They overestimate $\Delta\ln(\tau_{lo})$ for seasonal ΔT.**
Is albedo too insensitive to $\ln(\tau_{lo})$ changes* in GCMs?	**Yes, slightly. But it does not seem to matter much.**

**where $\ln(\tau_{lo})$ increases*

Conclusions



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Thanks!

Caveats

- We have mainly considered a small subset of models (those that correctly implemented the ISCCP simulator)
- Maybe we shouldn't trust ISCCP too much, esp. at high latitudes
- Maybe we shouldn't trust MODIS too much since only a subset of clouds represented in their histograms [Pincus et al 2011]
- We still lack a theoretical understanding of the links between cloud variations on different timescales
  (seasonal cycle vs interannual vs climate change)