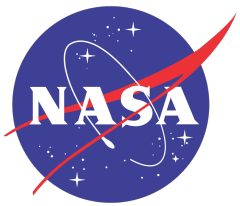
Investigating the role of stratocumulus to cumulus transitions in the extratropical cloud optical depth feedback

Ivy Tan[1,2] Lazaros Oreopoulos[1] Brian H. Kahn[3]
Mark D. Zelinka[4] Daniel T. McCoy[5]

[1]NASA GSFC [2]UMBC [3]NASA JPL [4]LLNL [5]University of Leeds



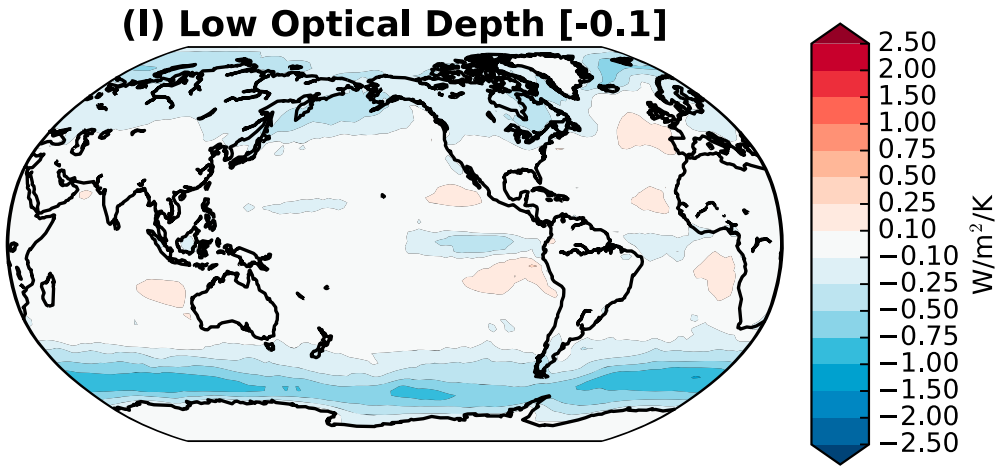
UMBC

UNIVERSITY OF LEEDS

CFMIP Meeting
Mykonos, Greece
October 4, 2019

Background

The net low-cloud optical depth feedback in CFMIP is negative — why?



Zelinka *et al.* (2016), GRL

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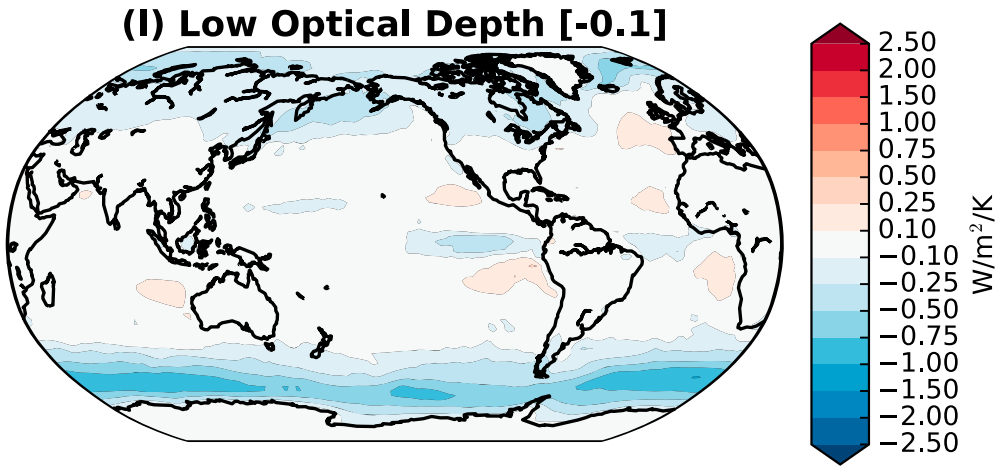
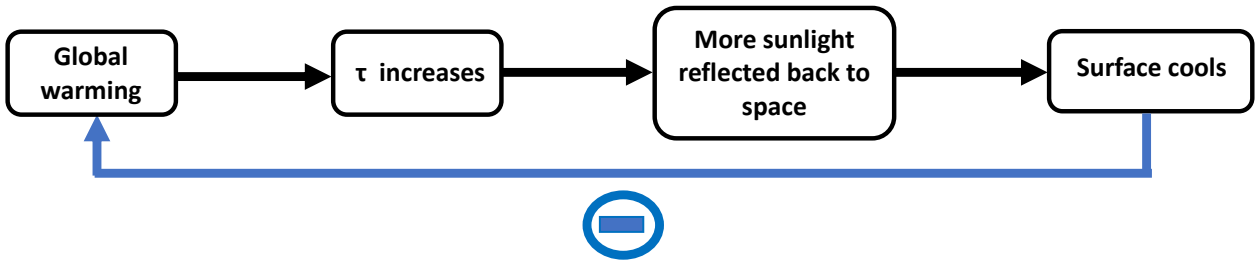


Zelinka *et al.* (2016), GRL



Background

An emergent constraint for λ_τ?

$$\frac{\mathrm{d}\ln\tau}{\mathrm{dT}} \xrightarrow{?} \lambda_\tau$$

(short-term)	(long-term)
−	+
+	−

Background

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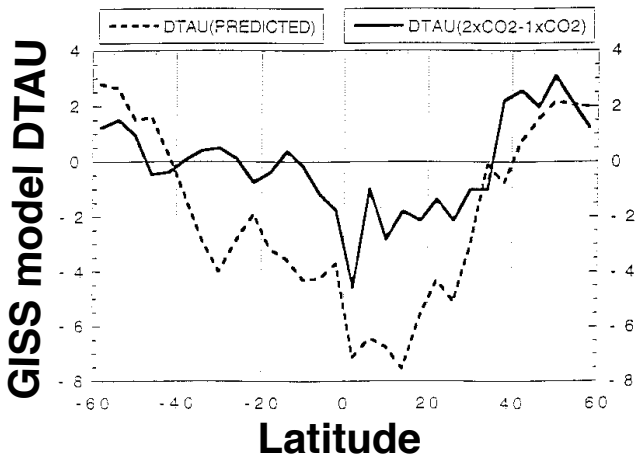
— +

\+ —

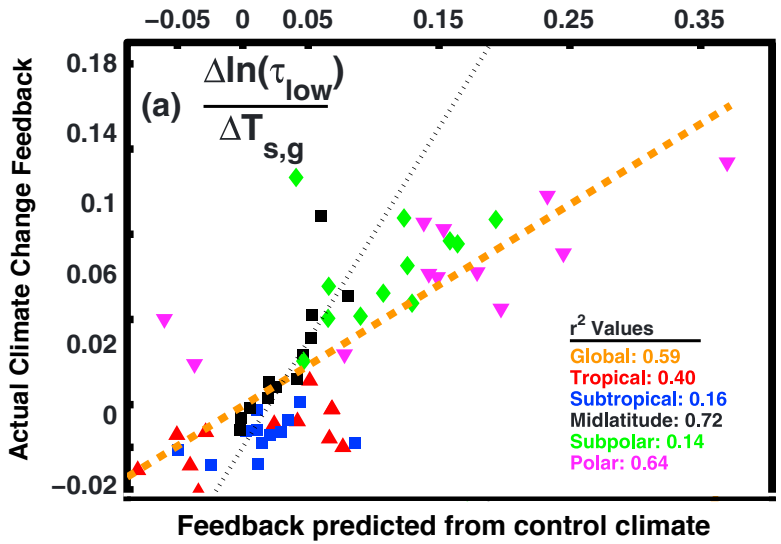


Tselioudis et al. (1998), J. Clim.

Looks promising!

Background

An emergent constraint for λ_τ?



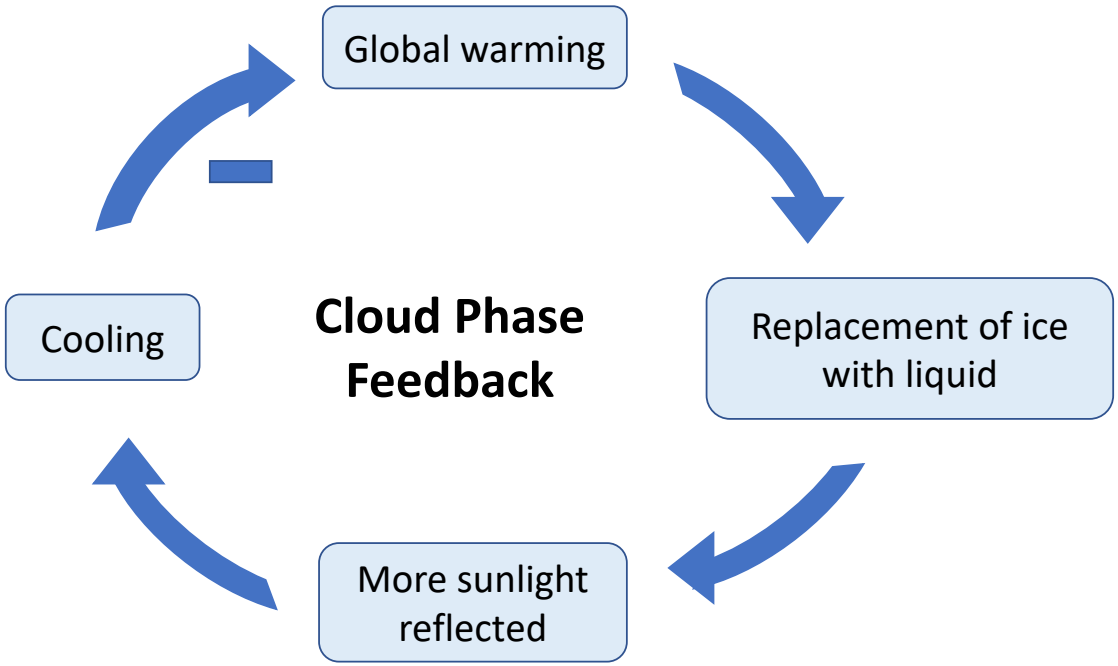
Gordon & Klein (2014), JGR

- Extending the work of Tselioudis et al. to more CFMIP models, Gordon & Klein found that the τ response to warming may be timescale invariant
- $\therefore \frac{\mathrm{d} \ln \tau}{\mathrm{dT}}$ can be an emergent constraint for the cloud optical depth feedback for low-clouds in the extratropics

Background

What causes $\lambda_\tau < 0$ in the extratropics in CFMIP?

Changes in liquid/ice partitioning in mixed-phase clouds



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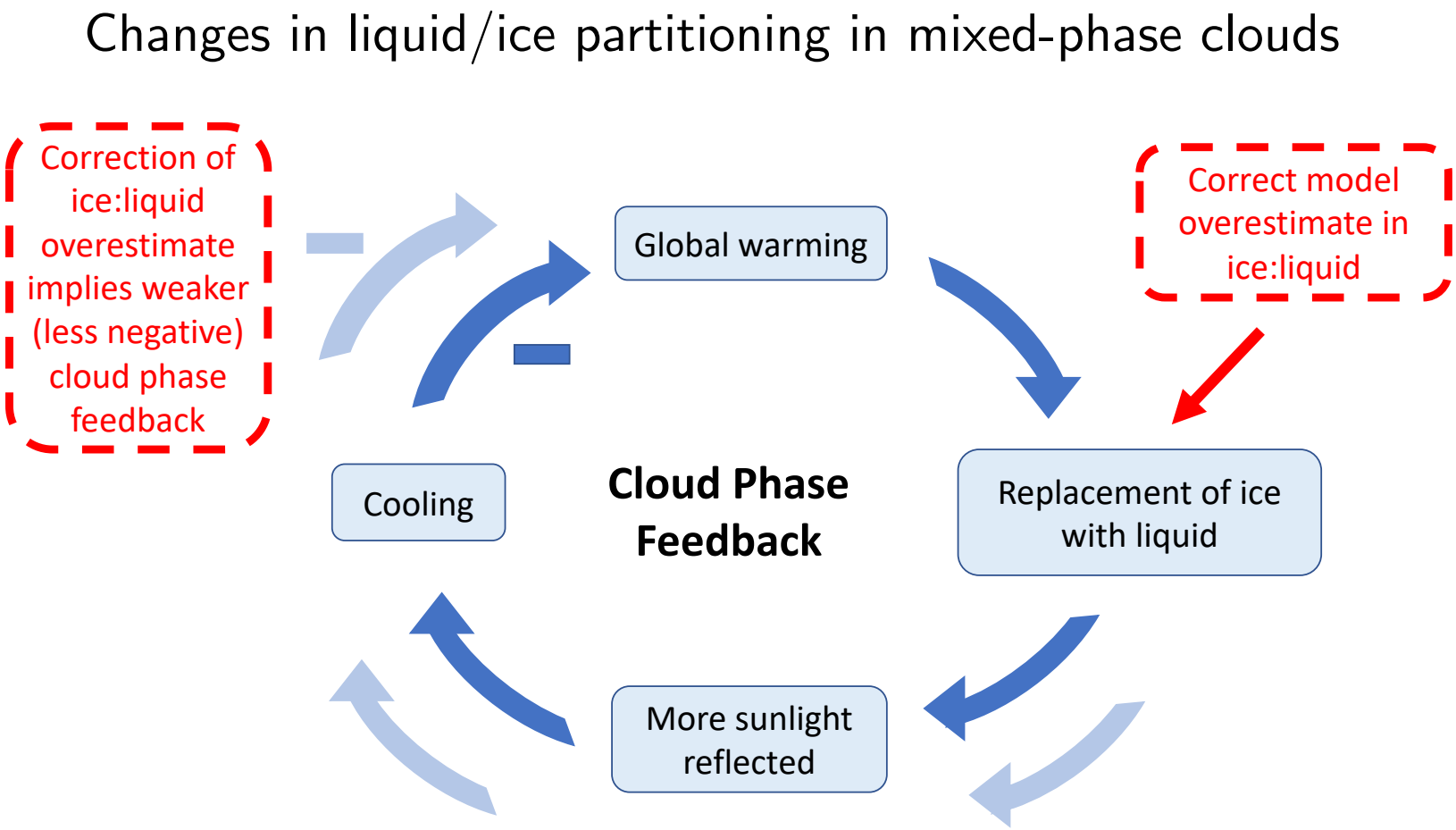
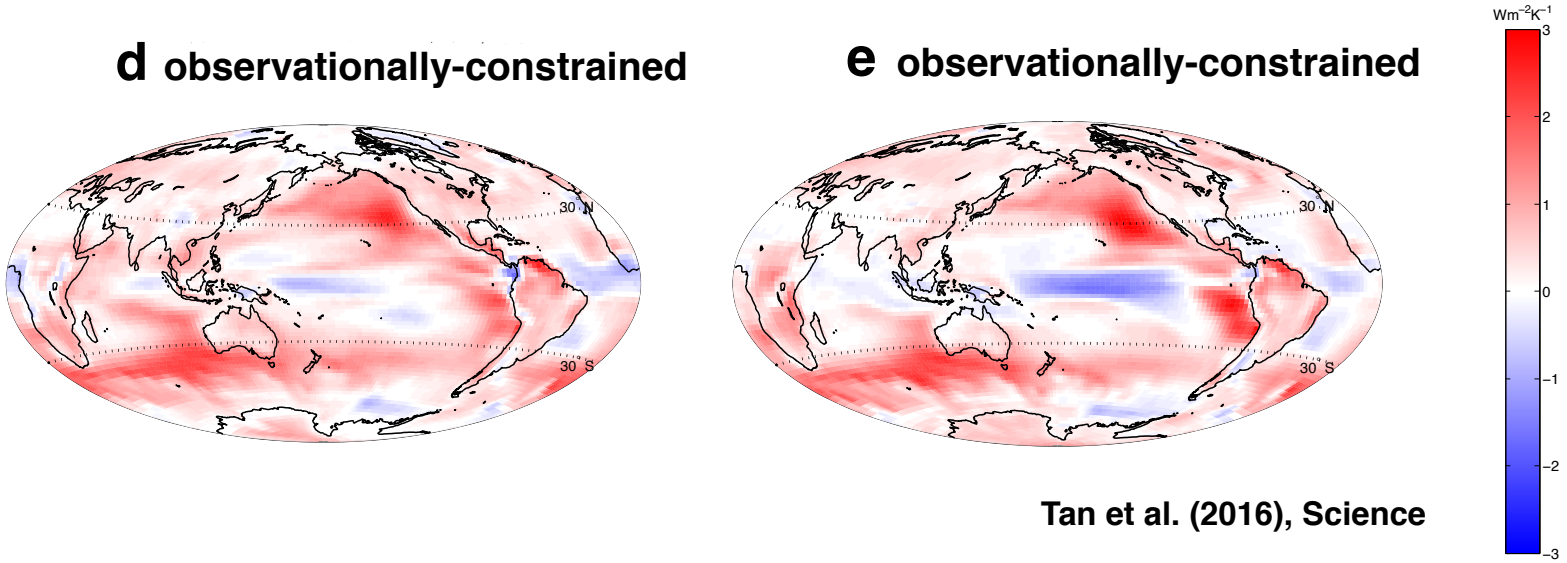


Background

Is $\lambda_\tau > 0$ in the extratropics?

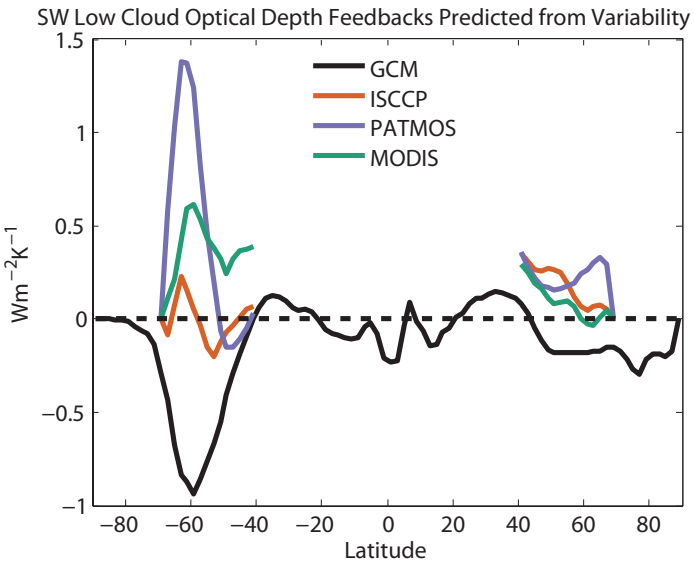
- But λ_τ flips sign and becomes >0 when CESM has more realistic representations of supercooled liquid in mixed-phase clouds — what "cloud optical depth thinning mechanisms" are responsible?
- Are the CMIP models exaggerating the negative cloud phase feedback so much to the point that they are masking an overall positive cloud optical depth feedback?



Background

Is $\lambda_\tau > 0$ in the extratropics?

Terai *et al.* independently computed a positive SW cloud optical depth feedback for low-clouds in the extratropics after constraining the feedback using τ-temperature relationships from multiple satellite observations.

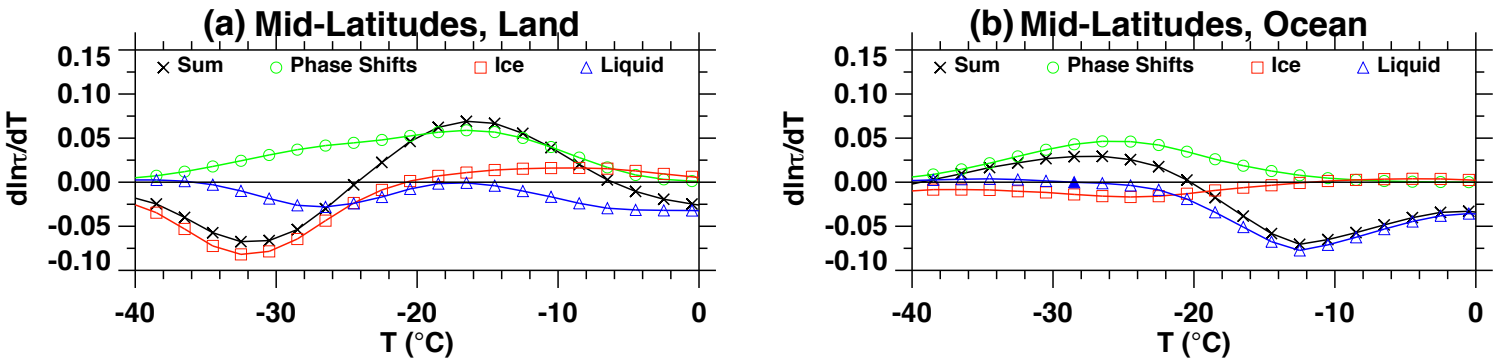


Terai et al. (2016), JGR

Background

What might cause $\lambda_\tau > 0$?

See poster



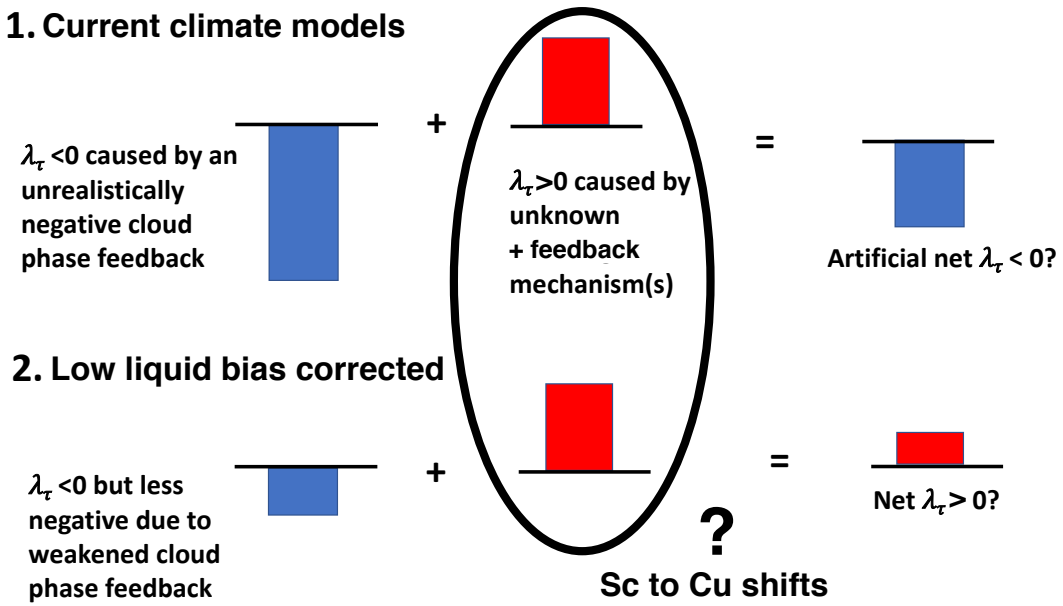
Tan et al. (2019), GRL

- Decomposition of $\frac{\mathrm{d}\ln\tau}{\mathrm{dT}}$ suggests that processes associated with **liquid clouds** always contribute to decreases in τ with temperature, and appear to outweigh the influence of thermodynamic phase shifts over mid-latitude ocean.

Hypothesis

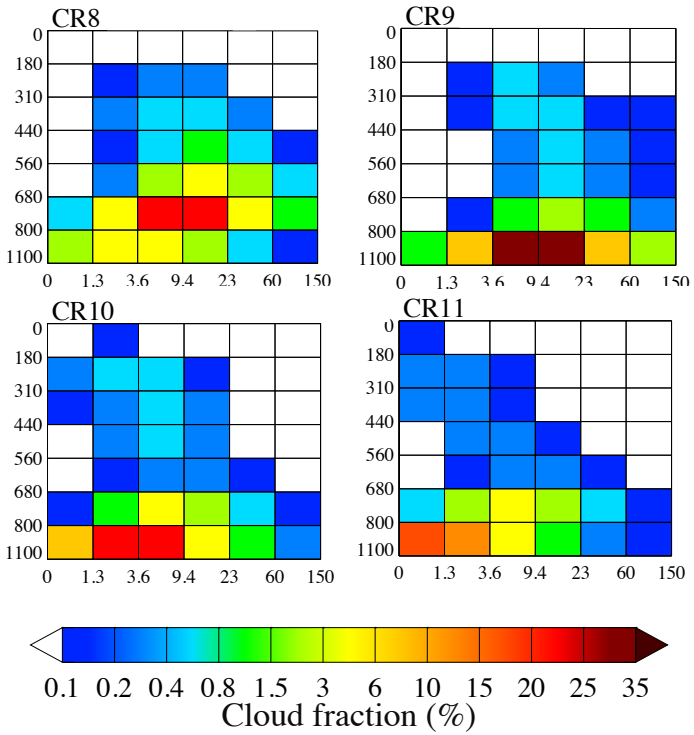
Cloud optical depth thinning mechanism: Shifts from Sc to Cu

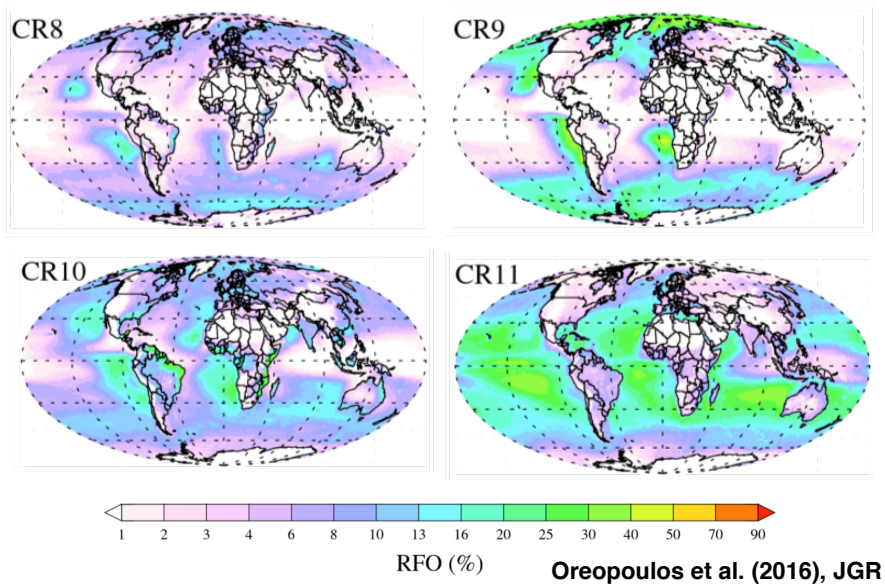
Reductions in τ in a warmer climate due to shifts from Sc to Cu clouds are outweighed by exaggerated increases in optical depth from the cloud phase feedback in the CFMIP models.



MODIS Cloud Regimes (CRs)

— initial approach to extract Sc & Cu and constrain meteorology





Oreopoulos et al. (2016), JGR

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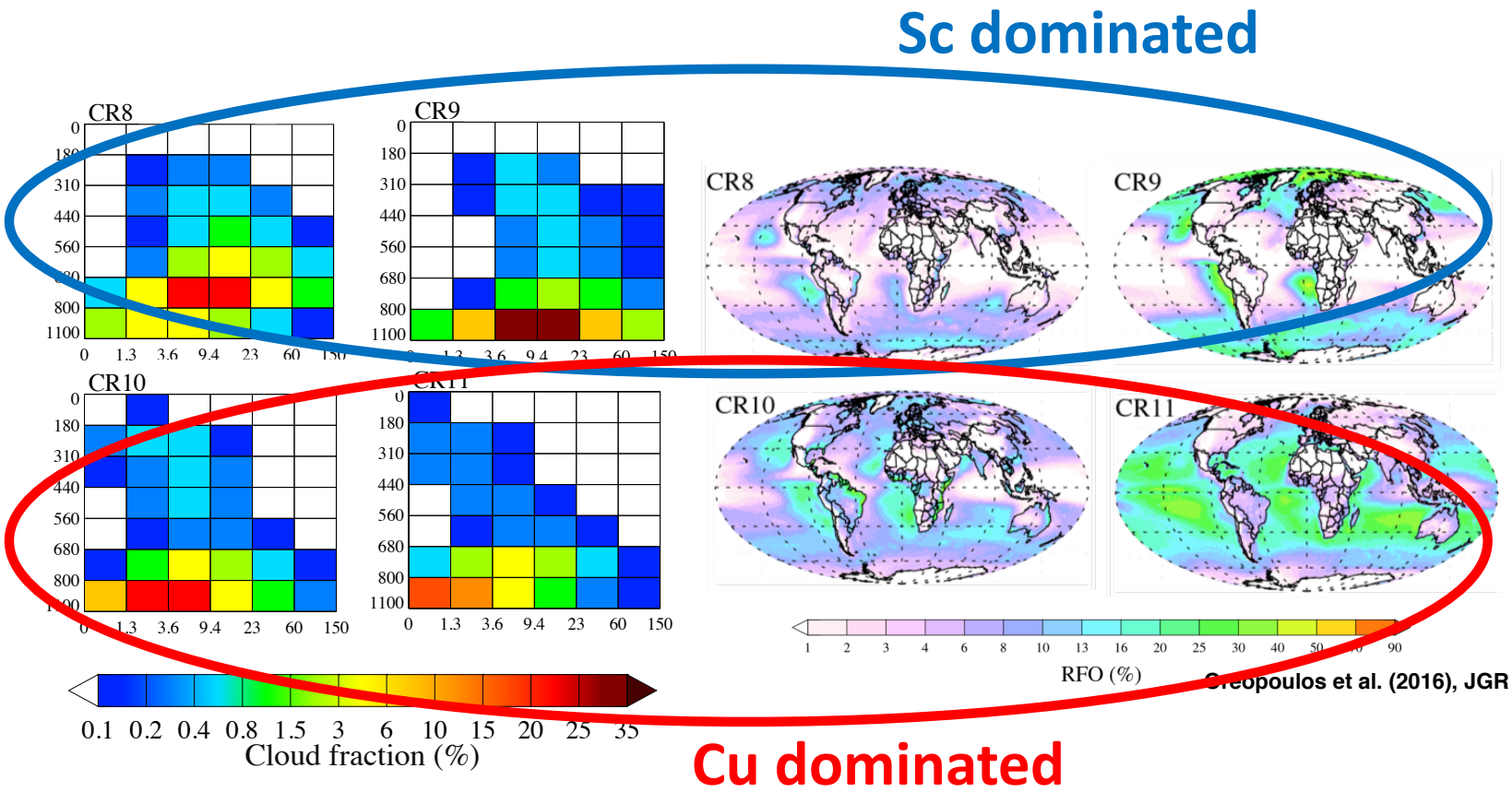


Cleopoulos et al. (2016), JGR

$$\Delta \ln \tau = \sum_i \left(\overline{f_i} \Delta \ln \tau_i + \Delta f_i \overline{\ln \tau_i} \right)$$

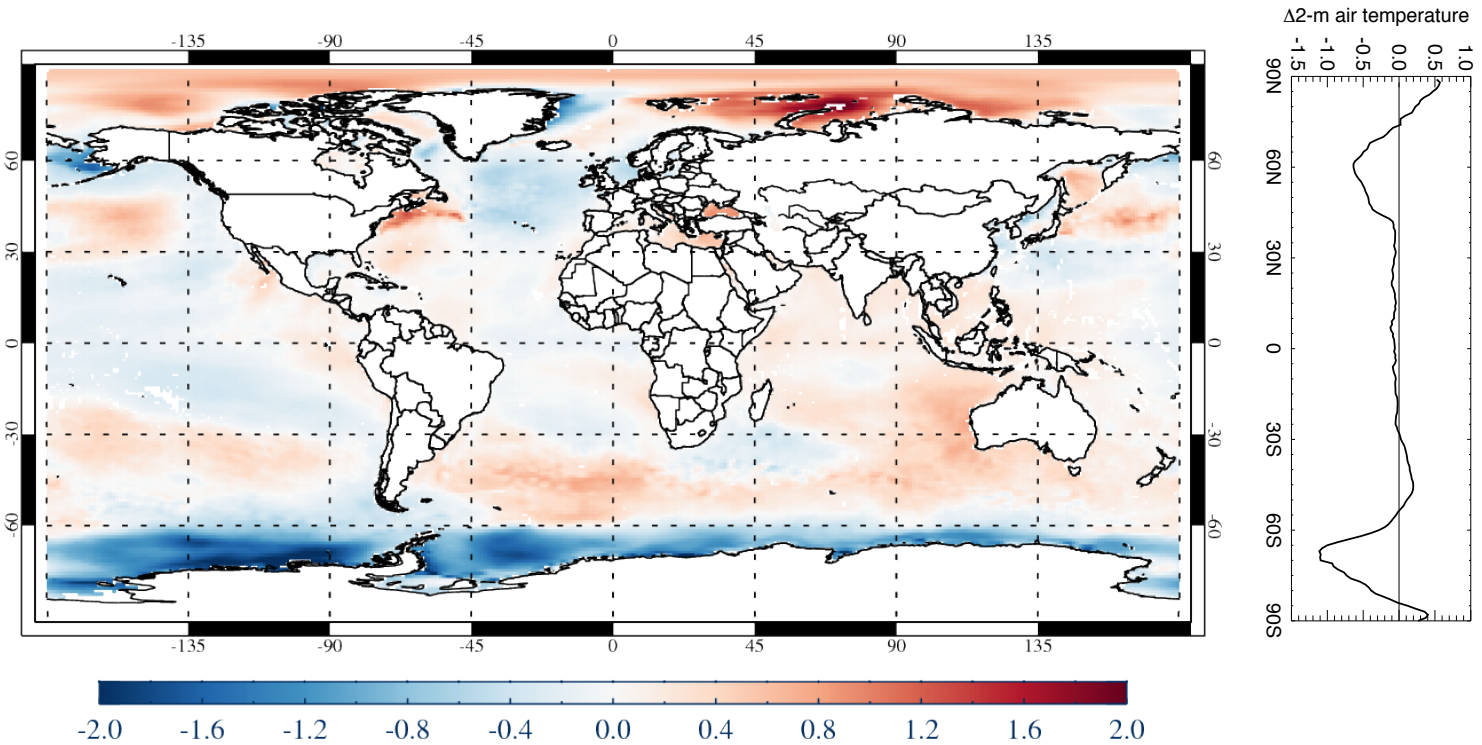
changes within CR

changes between CRs

- Δ with respect to time: (2008 to 2014) $-$ (2002-2008)
- $i =$ CRs 8, 9, 10, 11
- Calculation for every 1° grid cell, monthly timescale
- Statistical significance evaluated at 90% confidence level, using a permutation test, n=5000

MERRA-2 Δ2-m Air Temperature

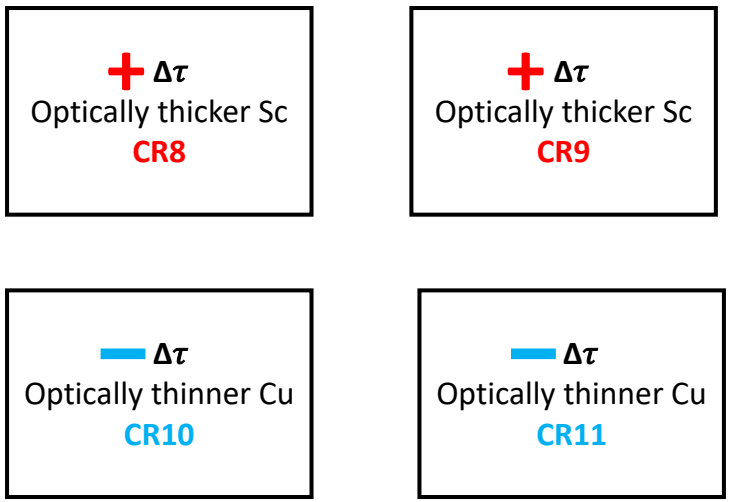
2-m surface air temperature has cooled over the NH and SH mid-latitudes between 2002 to 2014



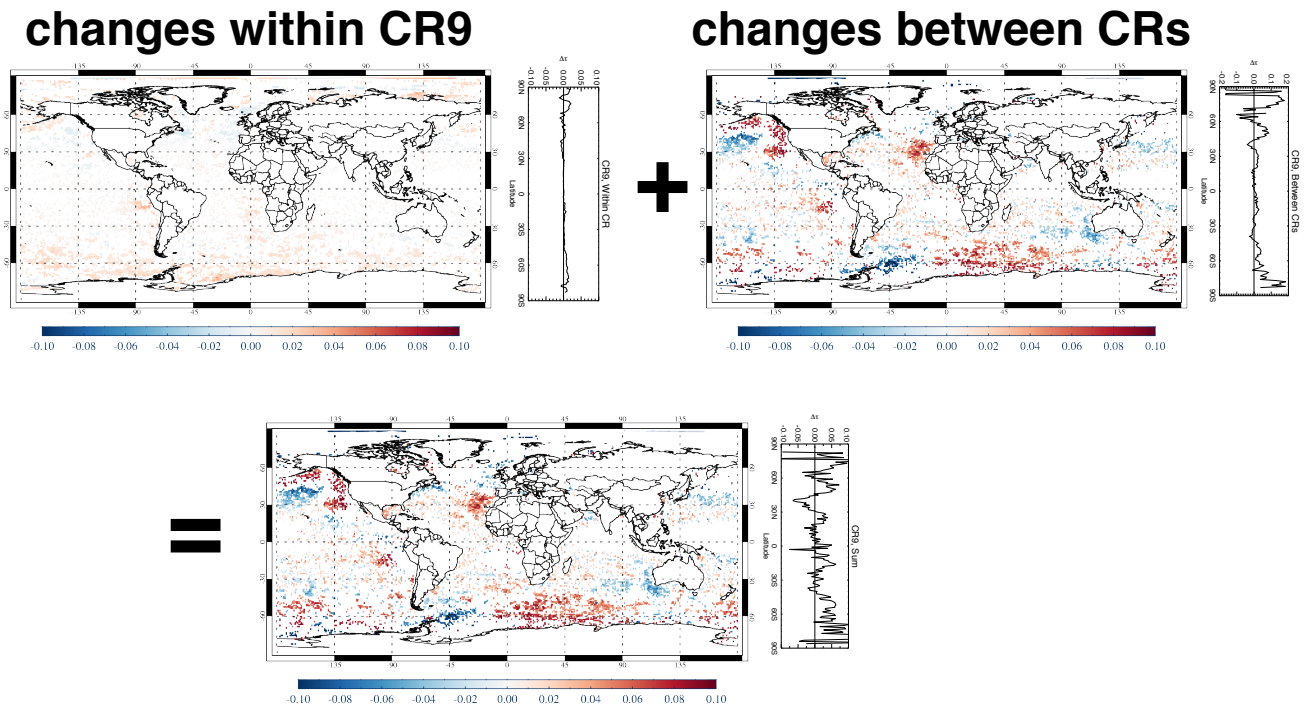
If our hypothesis is correct, then we would expect to see:

- *increases* in τ from optically thicker CRs 8 and 9, and simultaneous *decreases* in τ from optically thinner CRs 10 and 11 over the mid-latitudes

Over the mid-latitudes:

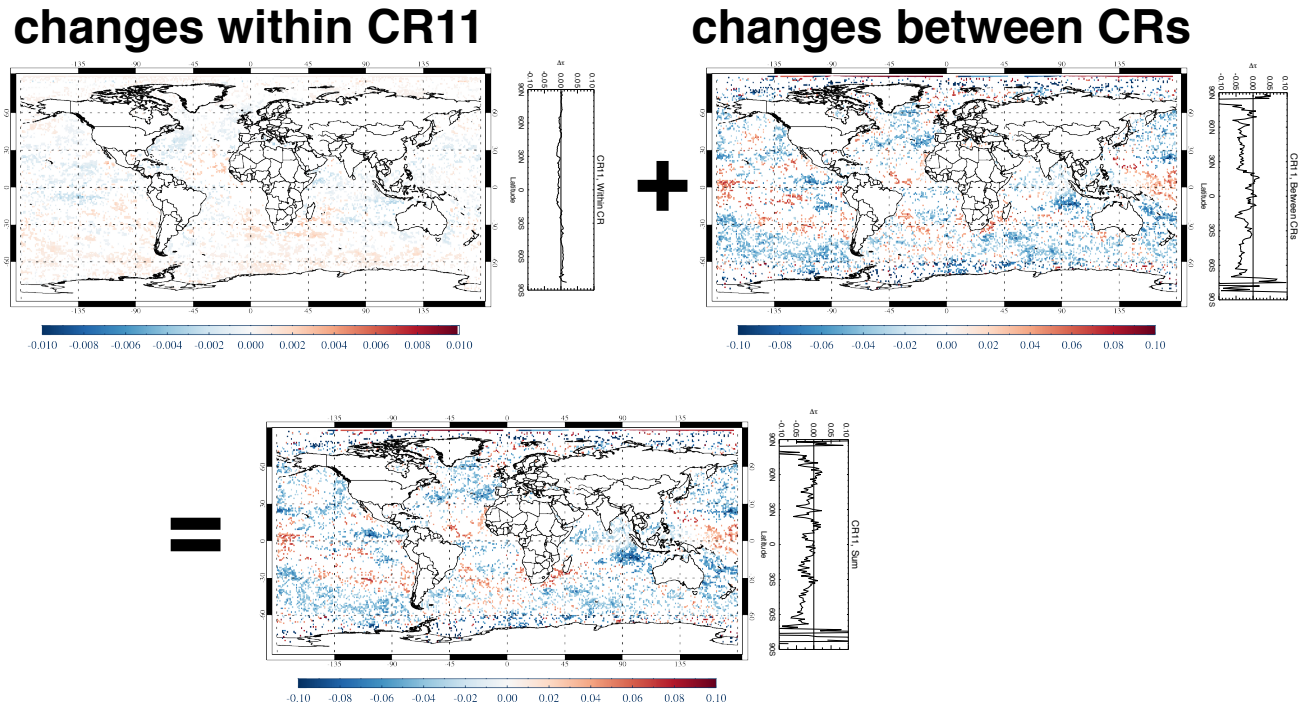


CR9 (Sc-dominated)



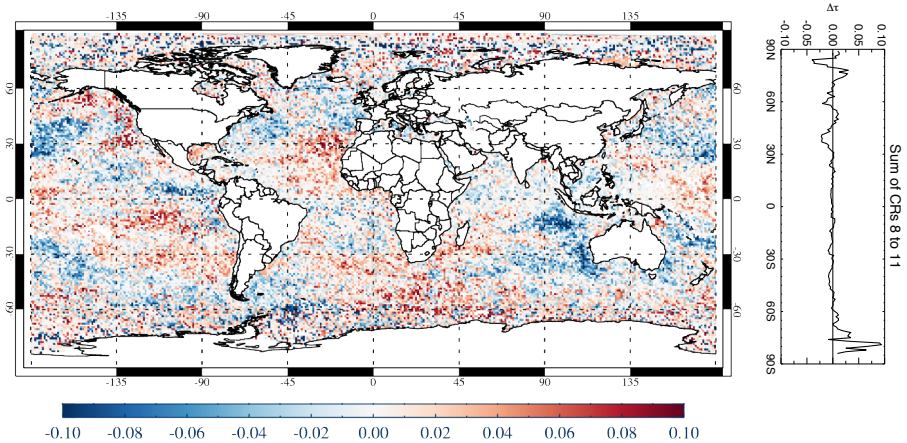
- Changes in frequency of occurrence of CR9 dominates overall $\Delta\tau$
- Increases in τ in zonal mean over Southern Ocean supports hypothesis

CR11 (Cu-dominated)

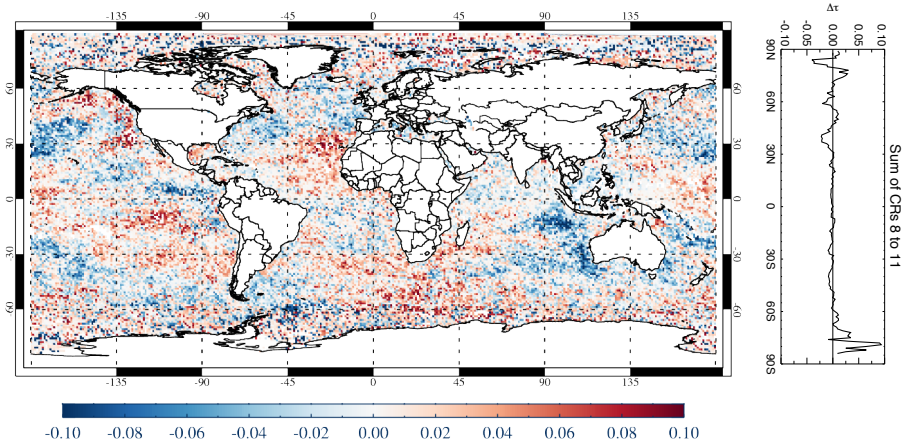


- Changes in frequency of occurrence of CR11 dominates overall $\Delta\tau$
- Decreases in τ in zonal mean over Southern Ocean supports hypothesis

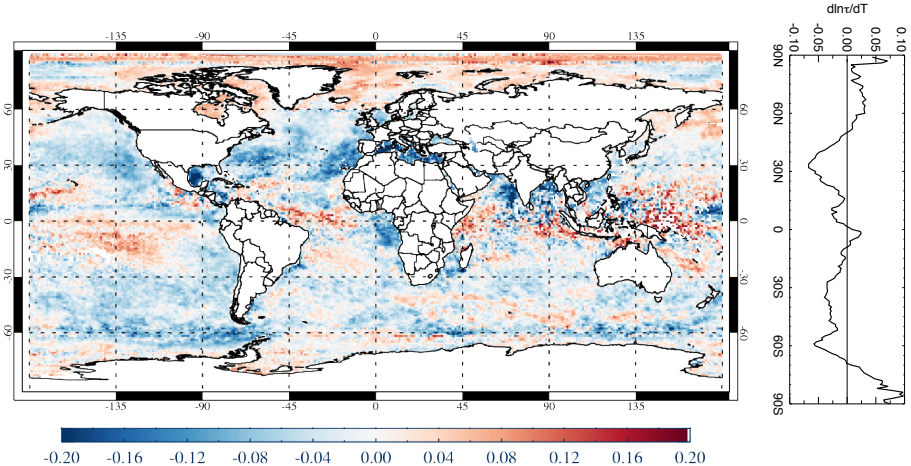
$\Delta\tau$ for CRs 8 + 9 + 10 + 11:



$\Delta\tau$ for CRs 8 + 9 + 10 + 11:



$\frac{\mathrm{d}\ln\tau}{\mathrm{dT}}$ (computed using monthly anomalies):



Summary

Preliminary results suggest that shifts from Sc to Cu clouds constitute a positive cloud optical depth feedback over the Southern Ocean, but the shifts are in the opposite direction in the 12-year period examined because the mid-latitude surface temperature cooled.

Future Work

- Examine Sc and Cu shifts using other datasets that distinguish among various MBL cloud types
- Examine how τ covaries with variables associated with Sc to Cu transitions (e.g. T2M, EIS and PBL depth, wind speed)