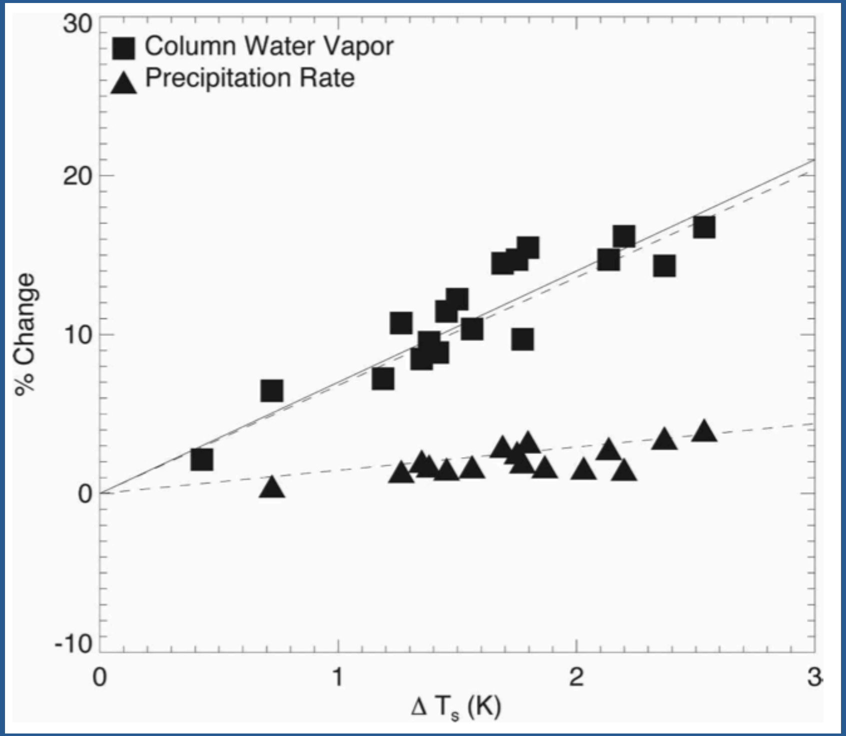
The sensitivity of global mean precipitation to natural versus anthropogenic climate change

Ryan J. Kramer
Brian J. Soden

University of Miami/RSMAS

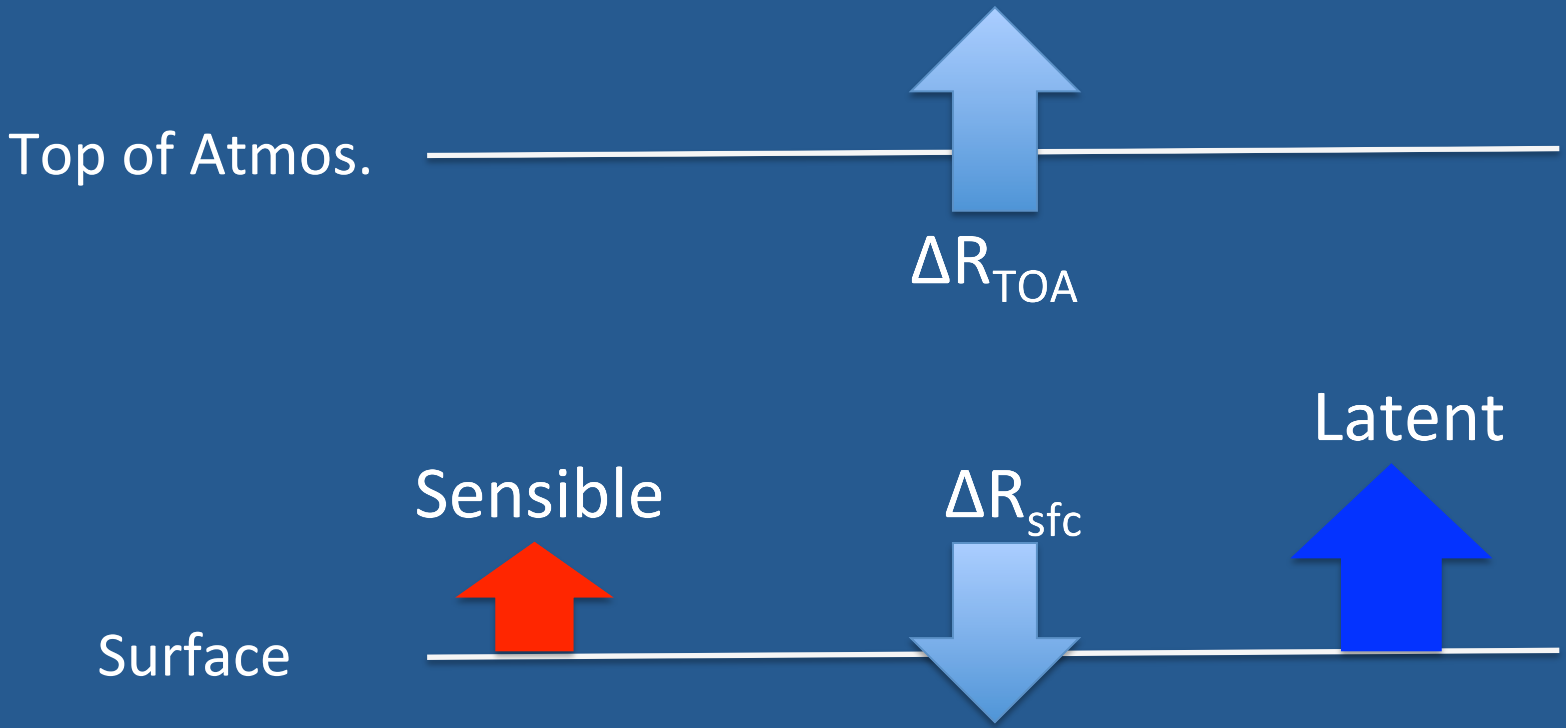
Atmospheric energy budget controls precipitation

- Water vapor (ΔW) sensitivity to surface warming (ΔT_s)
  - Clausius Clapeyron Equation = ~7 %.K^{-1}
- Precipitation (ΔP) sensitivity to ΔT_s
  - Energy Budget = ~1-3%.K^{-1}



Stephens and Ellis (2008)

Energy budget constrains global mean precipitation change



$$\Delta R = L\Delta P + \Delta SH$$

Global mean precipitation increase. Which is “correct”?

<u>Models</u>

1-3 %.K^{-1}

Allen and Ingram (2002)
Lambert and Webb (2008)

<u>Observations</u>

6-7 %.K^{-1}

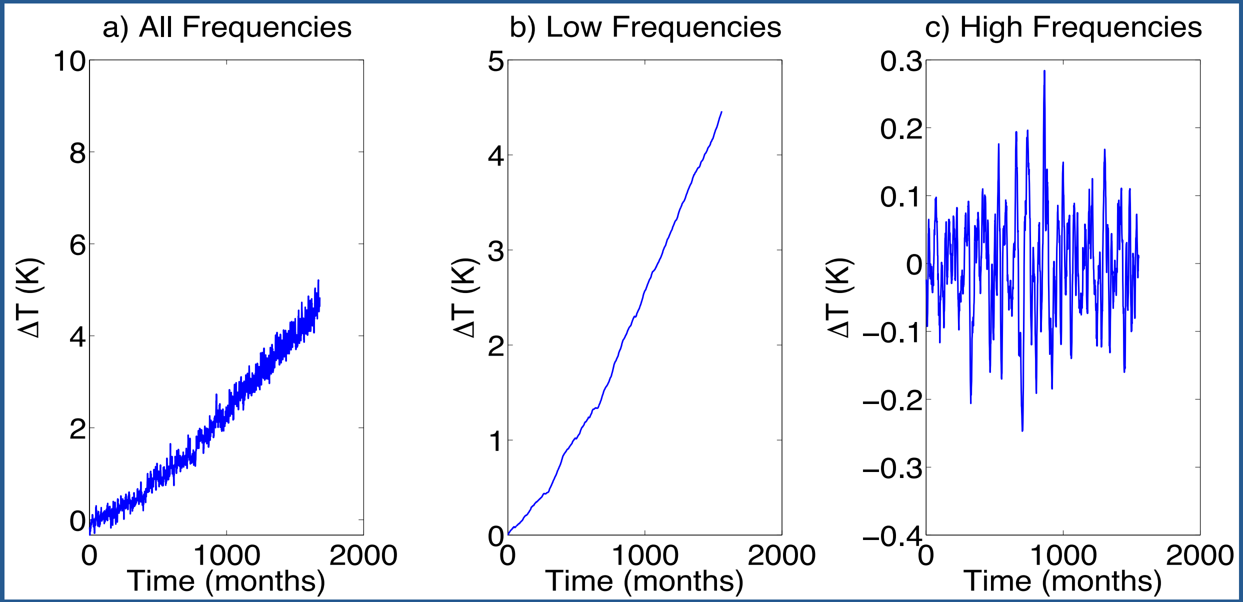
Wentz et al. (2007)

- Does a difference in the physical constraints on ΔP exist between anthropogenically-forced climate change and internal variability?

Use model simulations to compare natural and anthropogenic change

- 29 CMIP5 models are used
  - "1pctCO2" – 1% annual increase to quadrupling from pre-industrial values (~140 yrs).
  - "Low" frequency = Anthropogenic Climate change
  - "High" frequency = Internal Variability

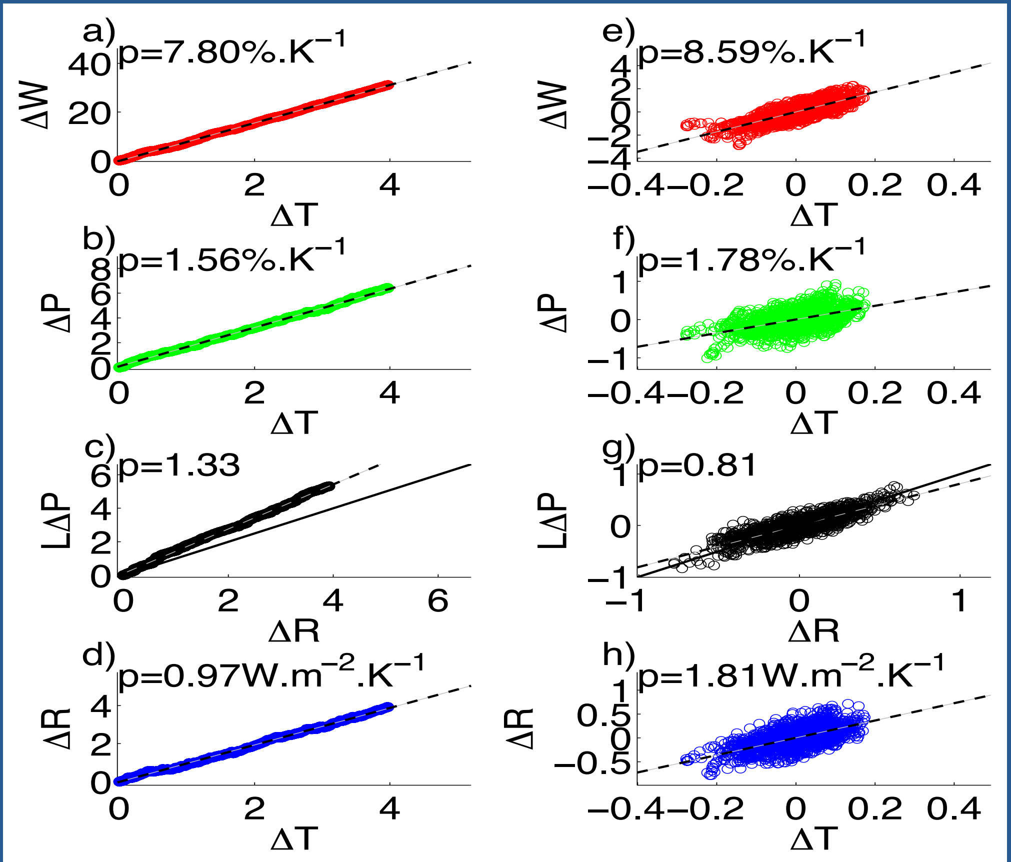
ΔT_s timeseries at all, low and high frequencies



Linearly regress model variables to calculate "sensitivity"

- Difference in slope magnitude
  - Anthropogenic change (left) and internal variability (right).

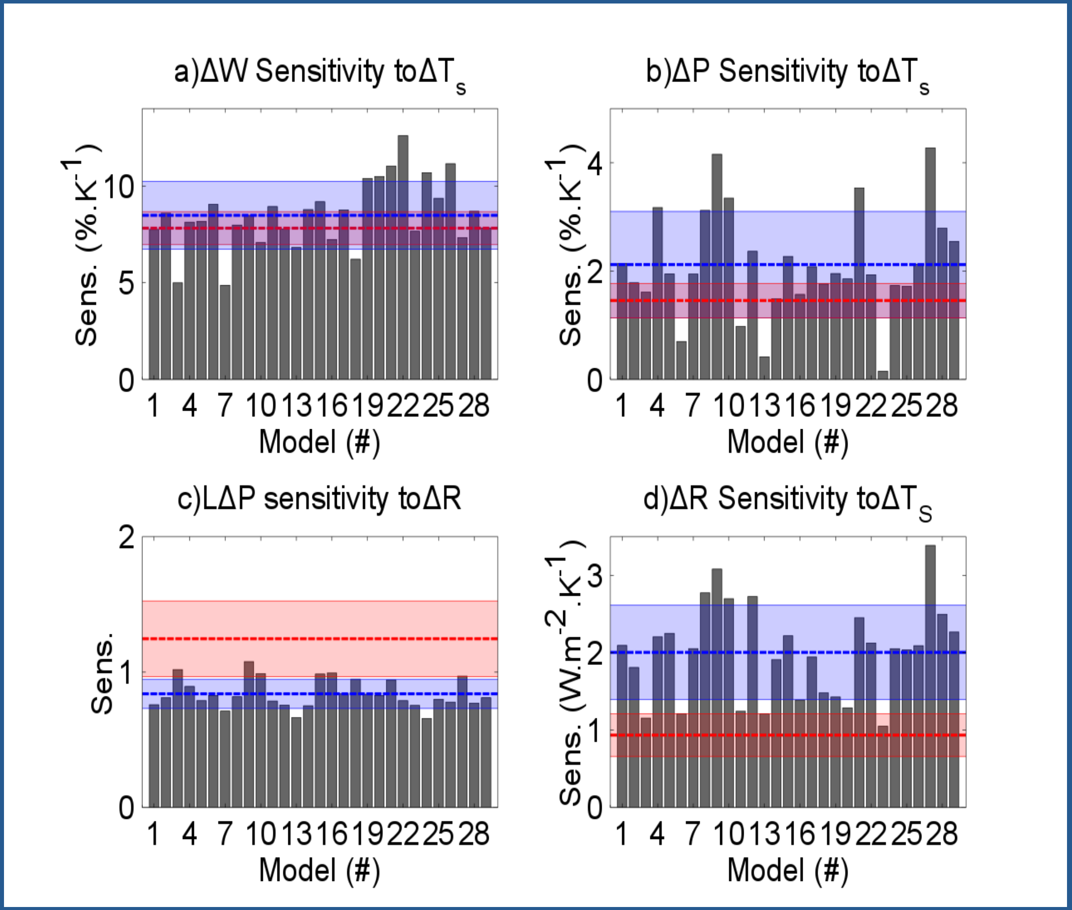
1. ΔW vs. ΔT_s
2. ΔP vs. ΔT_s
3. $L\Delta P$ vs. ΔR
4. ΔR vs. ΔT_s



ACCESS1-3 model. Low (left) and High (right) frequencies. "p" is regression slope

Model sensitivities – High frequencies

- ΔP sensitivity to ΔT_s is greater for internal variability
  - ~1.5:1 ratio of high vs. low frequency sensitivity.
- ΔR sensitivity to ΔT_s is greater for internal variability
  - ~2:1 ratio of high vs. low frequency sensitivity.
- $L\Delta P/\Delta R$ <1 for internal variability, >1 for anthropogenically forced change

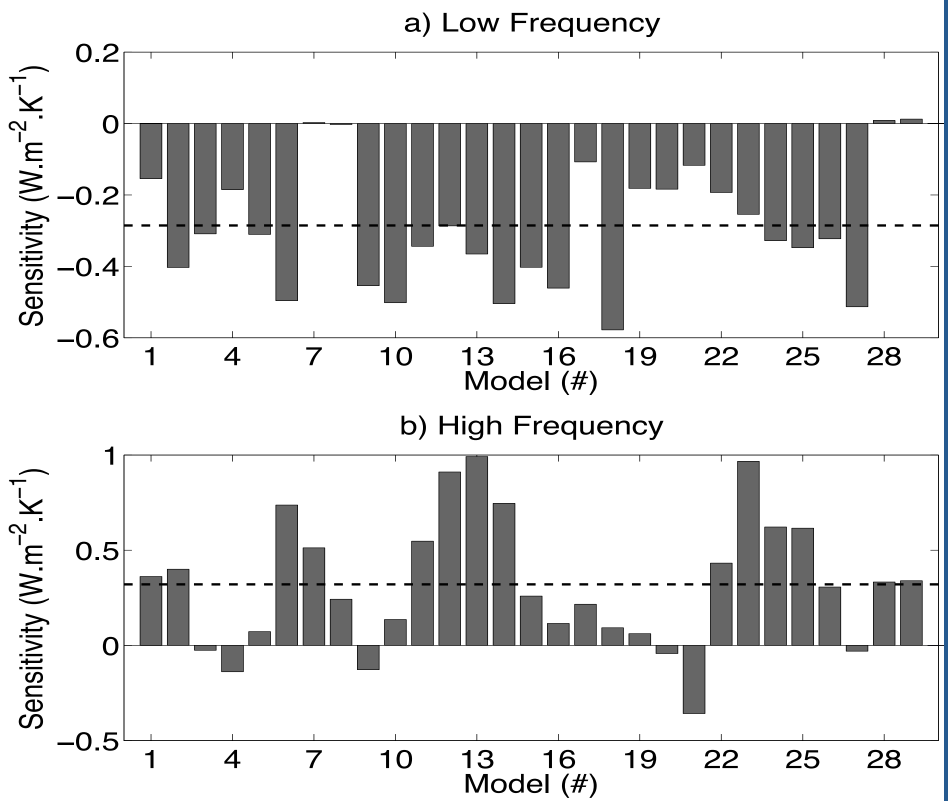


High freq. sensitivities shown for each model

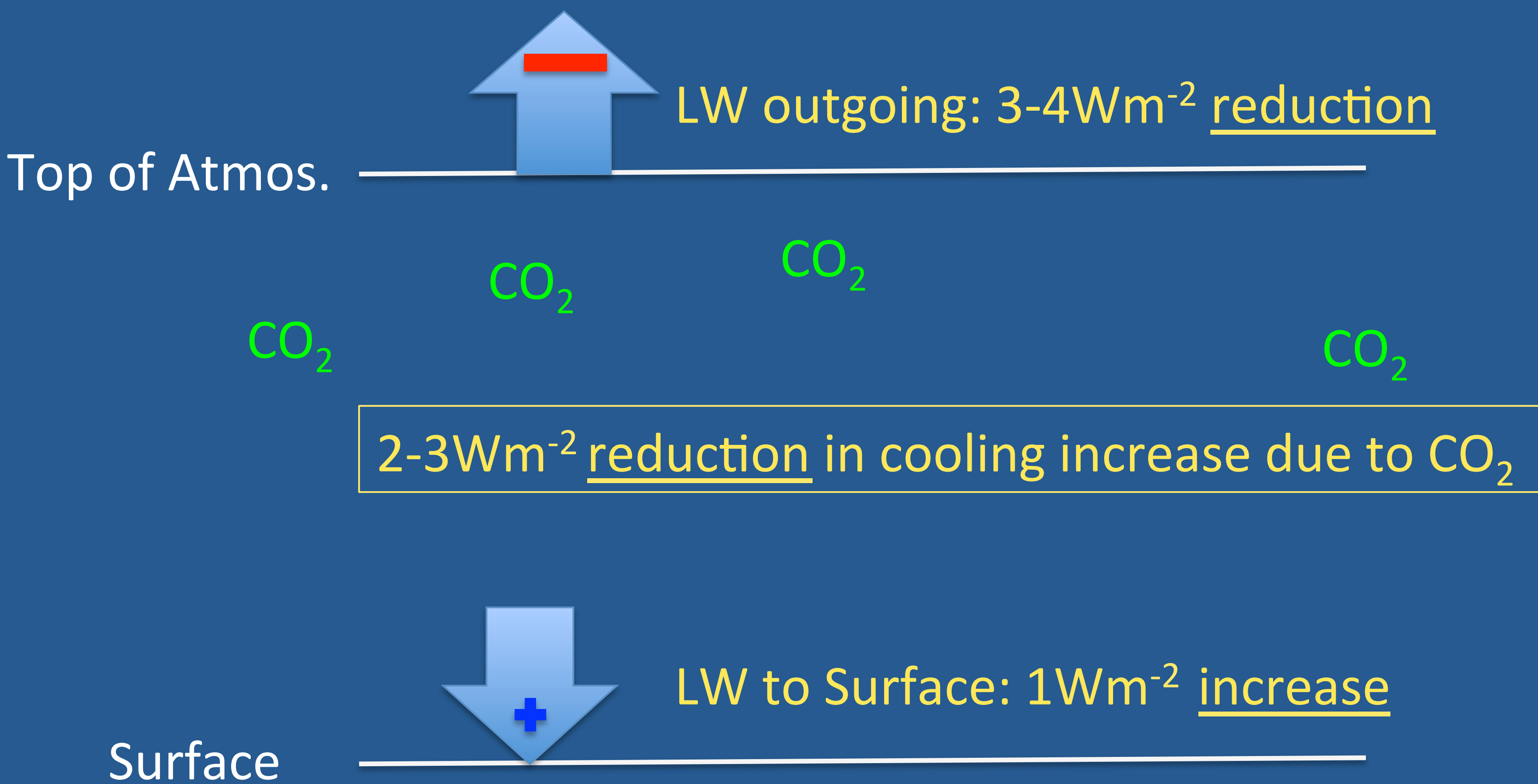
Sensible heat flux sensitivity – sign difference

ΔSH Sensitivity to ΔT_S

- ΔSH sensitivity to ΔT_s
  - Anthropogenically forced change < 0
  - Internal variability > 0



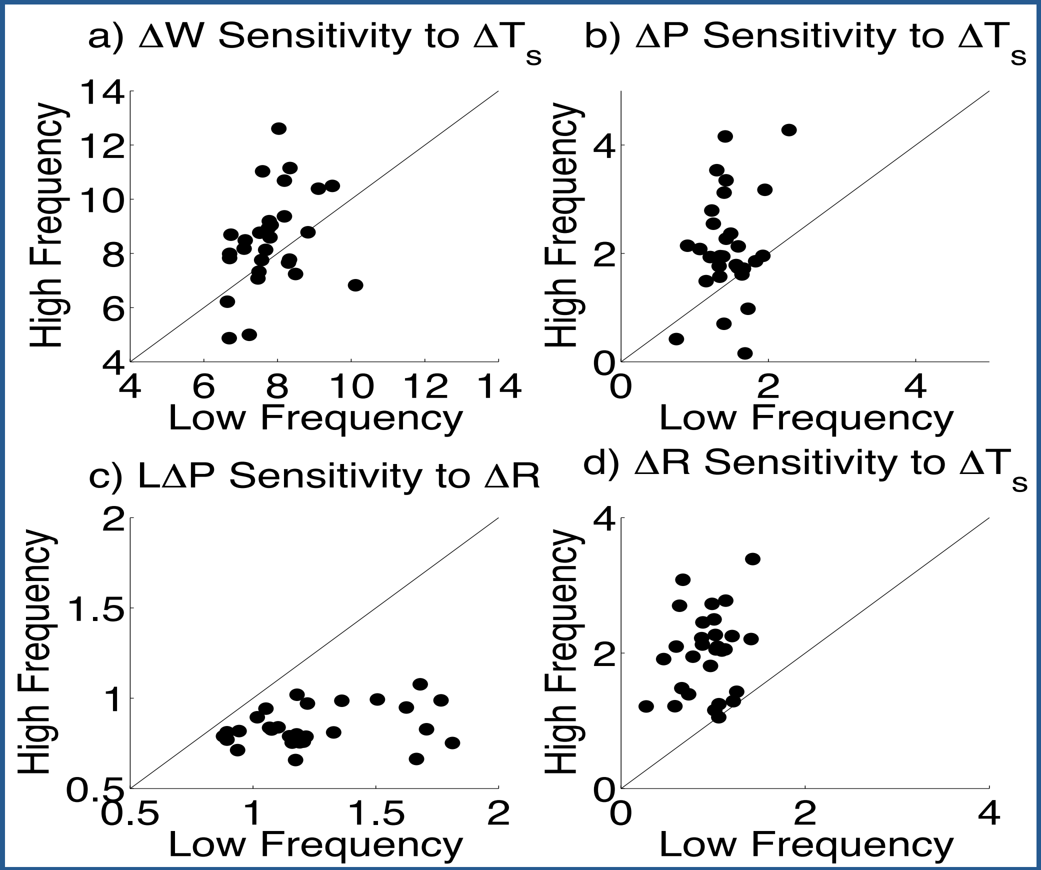
CO_2 affects sensitivities at low frequencies



Values from Allen and Ingram (2002)

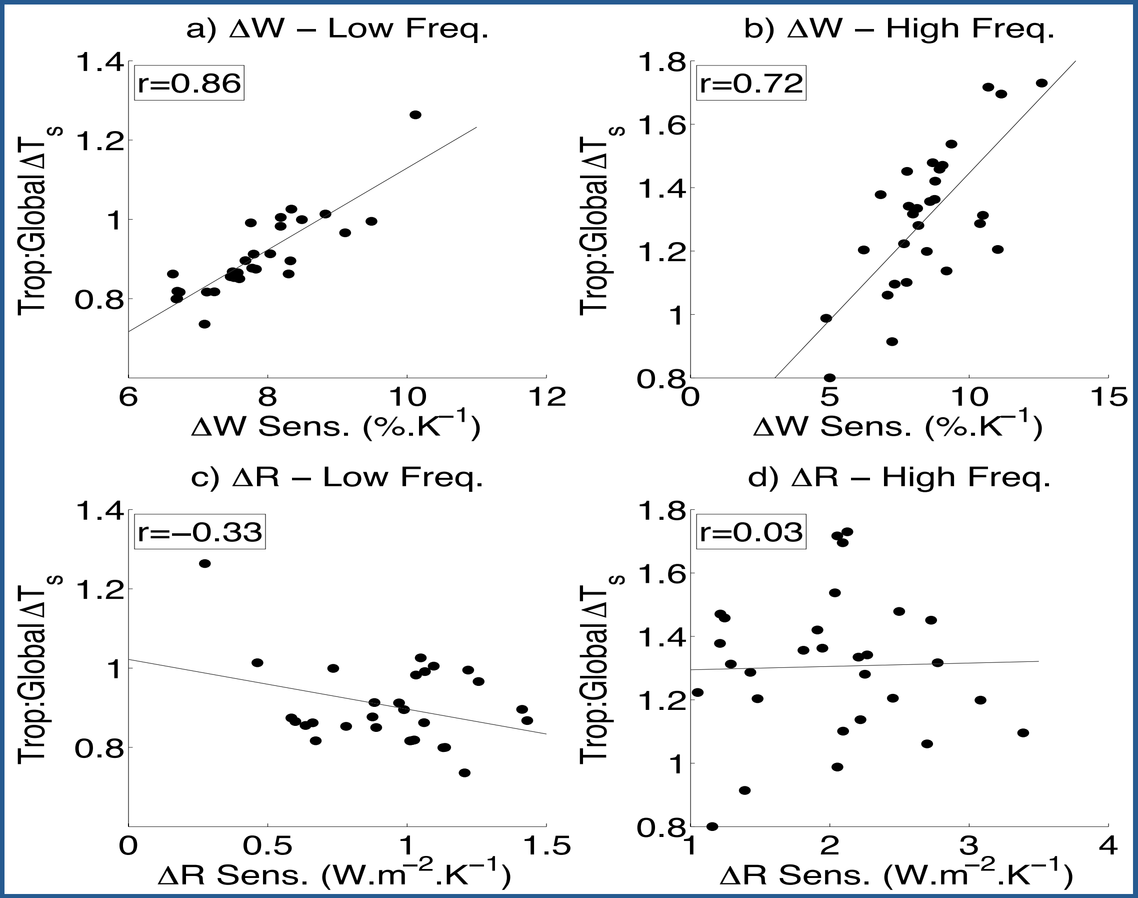
Model spread difference between time scales

- Model spread is greater for internal variability for sensitivities of:
  - ΔW to ΔT_s
  - ΔP to ΔT_s
  - ΔR to ΔT_s



Low vs. high frequency sensitivities. One point represents a single model. 1:1 line shown

Spatial warming patterns explain water vapor sensitivity spread



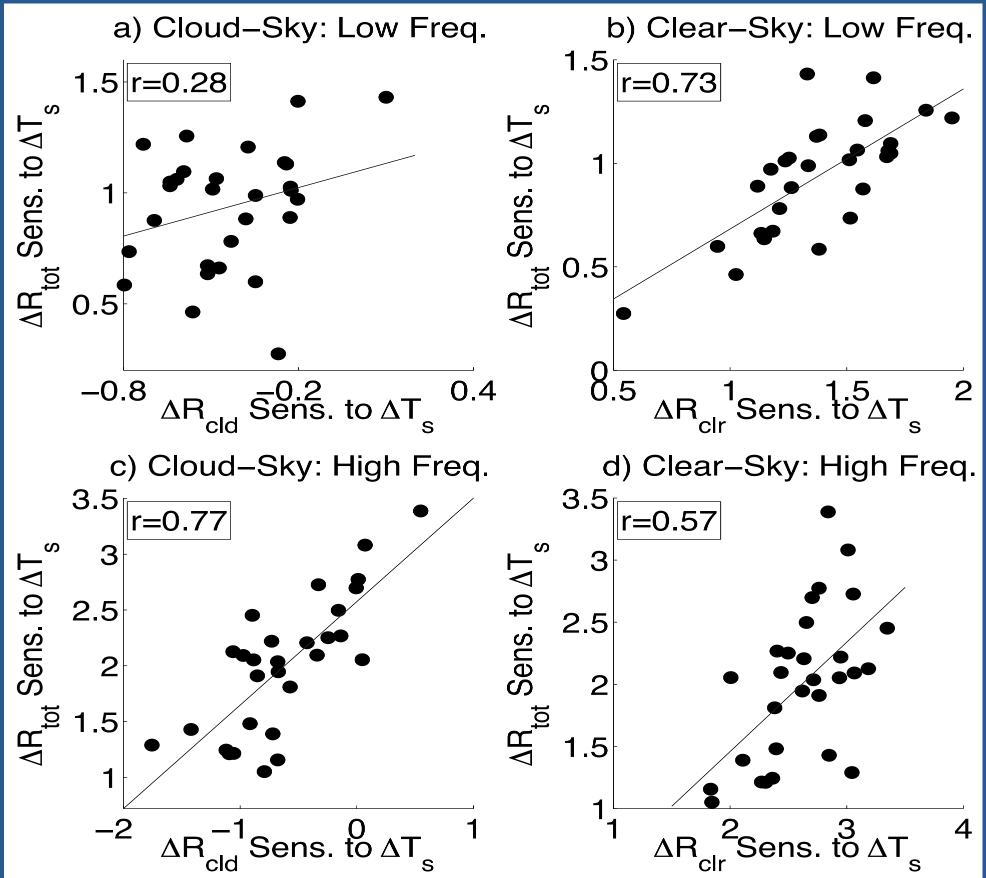
ΔW sensitivity vs. Tropical: Global Sfc. Warming ratio

ΔR sensitivity vs. Tropical: Global Sfc. Warming ratio

Each point represents a single model.

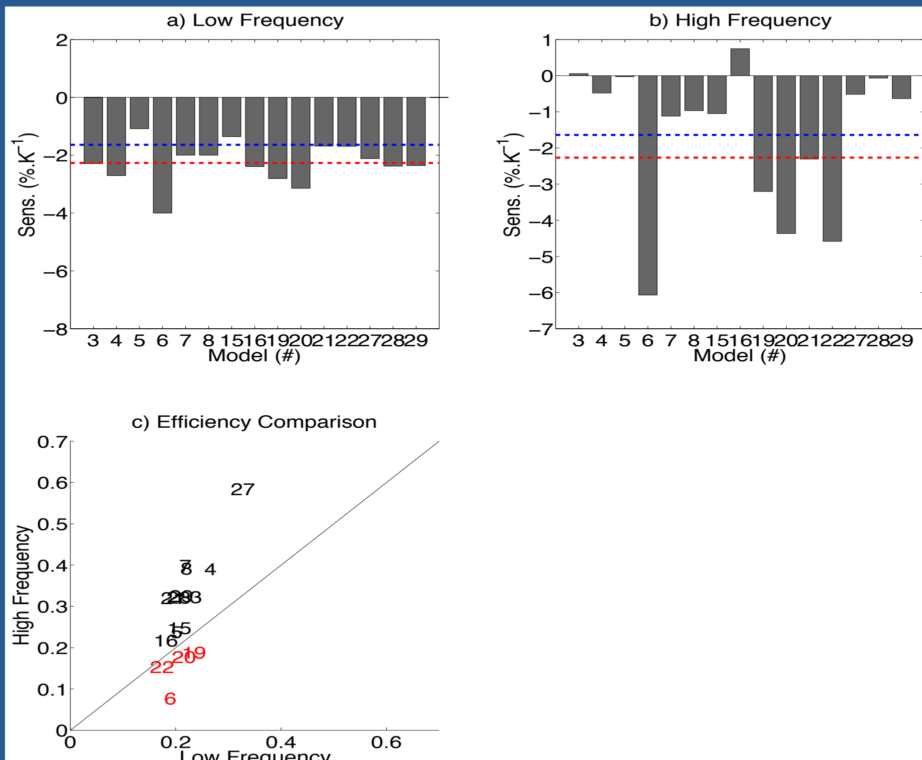
Clouds affect ΔR sensitivity spread more so with internal variability

- Clear –sky component explains much of “total”-sky radiative cooling sensitivity model spread for anthropogenic climate change



Clear-sky (left) ΔR sensitivity or cloud-sky (right) ΔR sensitivity versus total-ΔR sensitivity for each model

Overturning circulation weakens less under natural climate change



Note: Red dashed line is low freq. ensemble mean. Blue dashed line is High freq. ensemble mean

- Δ Strength ~ Change in convective Mass Flux (ΔM)

$$P \sim M*W$$

- Strength ~ Efficiency of converting water vapor to precip.:

$$\varepsilon = \frac{W}{P}\frac{\Delta P}{\Delta W}$$

- $\varepsilon_{low} < \varepsilon_{medium}$

Long term precipitation change cannot be detected with short term observations

- CO_2 causes a reduction in the global-mean precipitation response to anthropogenic climate change.

- Precipitation responds directly to temperature change and to greenhouse gas forcing with long term change

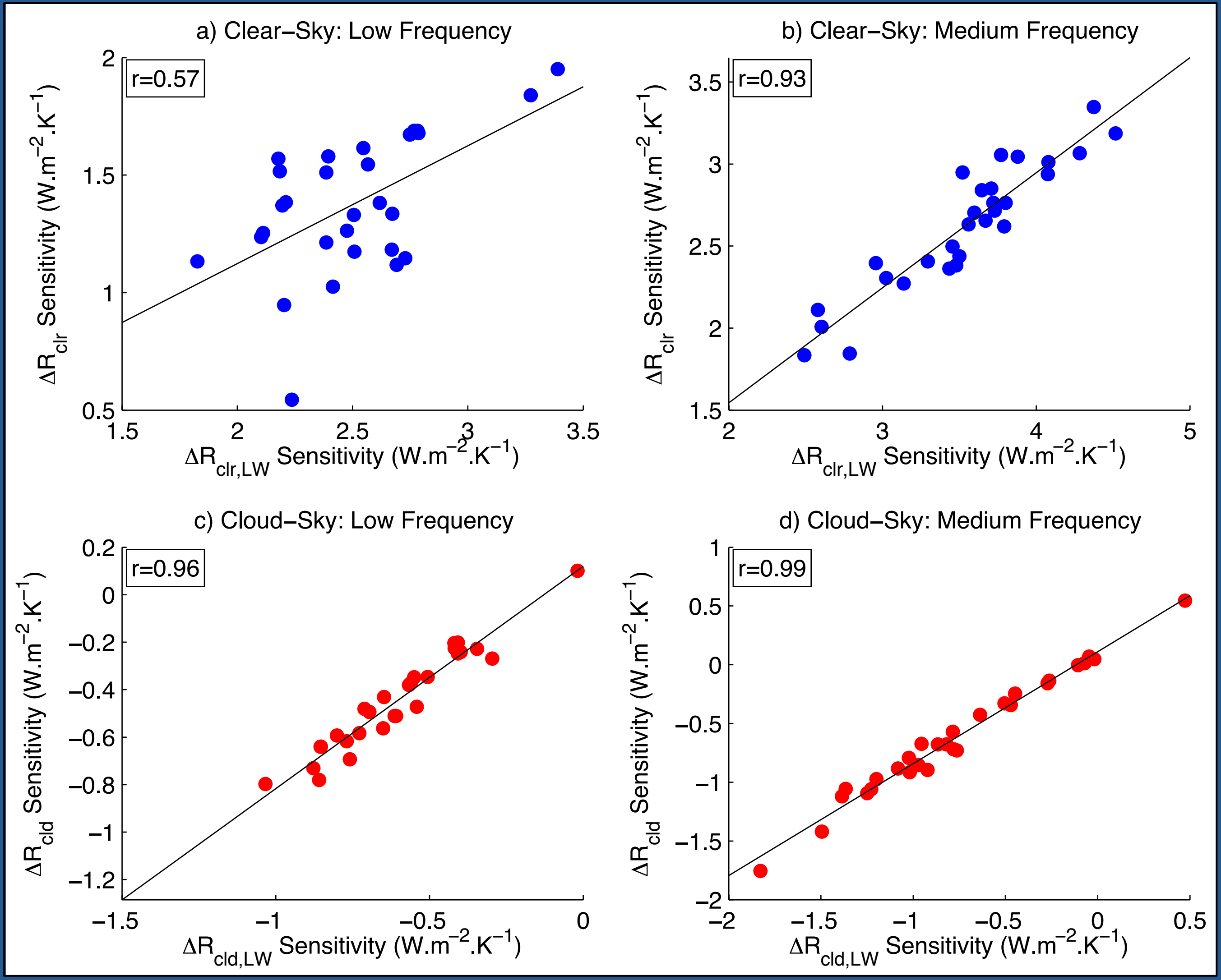
- The ability of CLARREO to detect trends in low frequency variability is necessary to understand global mean precipitation change with anthropogenic climate change.

Future Work

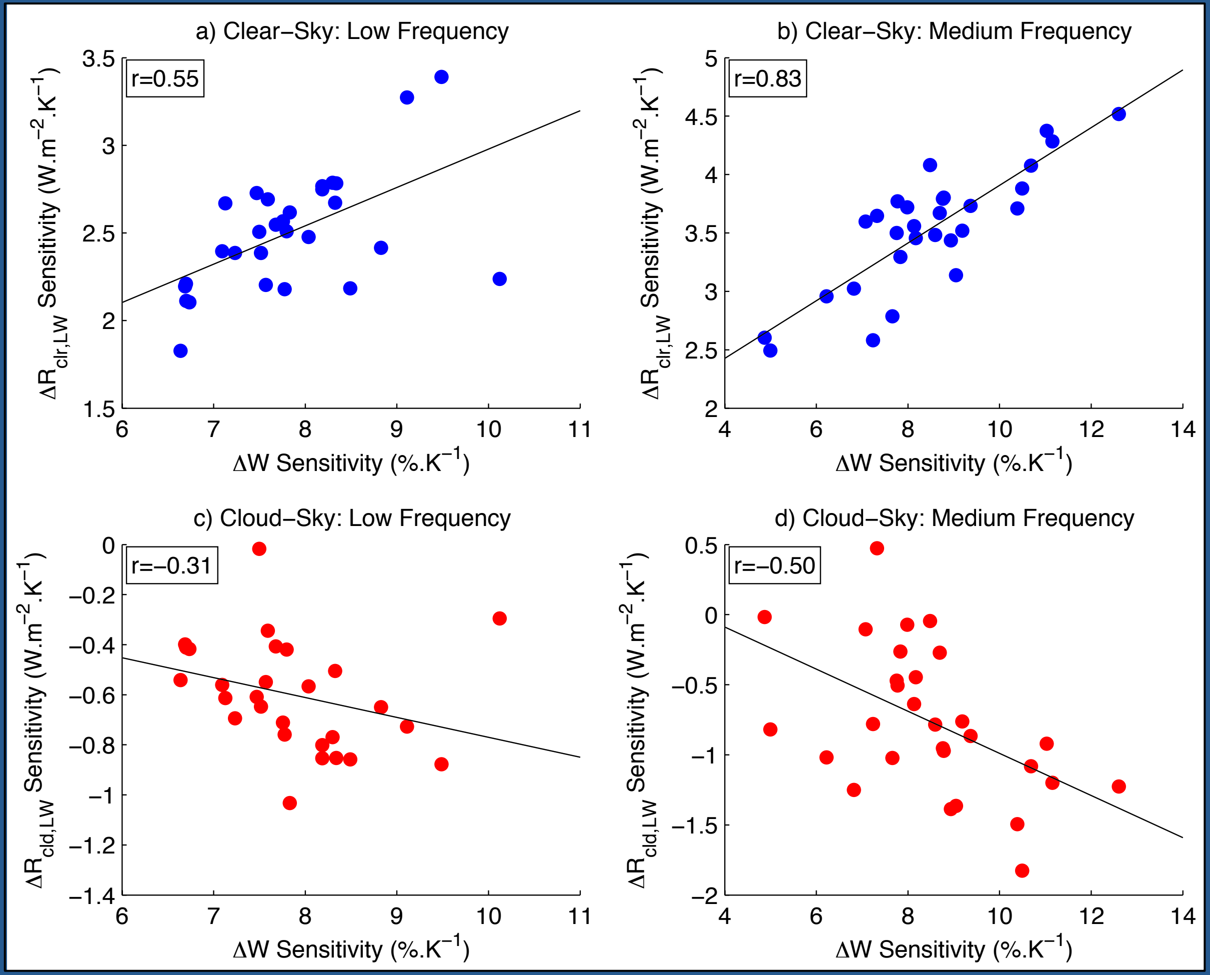
- Use additional CMIP5 experimental simulations to futher analyze the role of CO_2 on precipitation responses to warming
  - Ex: Abrupt CO_2 simulations
- Use radiative kernel technique (Soden et al. 2008; Previdi 2010) to compare climate feedbacks on the precipitation response to internal variability versus anthropogenic climate change.

Extra Slides

LongWave-Only Rad. Cooling Component



ΔW sensitivity vs. ΔRad Cooling – LongWave only



Summary

- During anthropogenic climate change (low frequencies) CO_2 suppresses increases in radiative cooling, thereby reducing global mean precipitation increases with surface warming
  - CO_2 does not affect water vapor changes

- Larger model spread in precipitation sensitivities for natural climate change
  - Clouds have greater effects on spread at these time scales