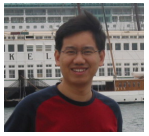
The strength of the tropical inversion and its response to climate change in 18 CMIP5 models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PCMDI
Program for Climate Model Diagnosis and Intercomparison

Outline

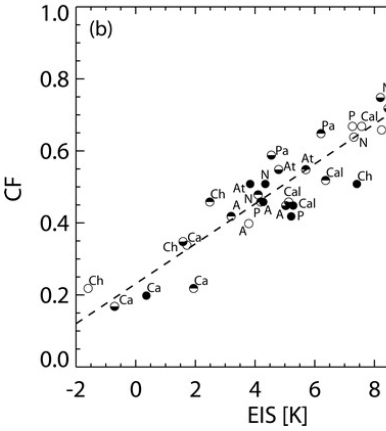
- *Tropical inversion: Its importance*
- *How well do CMIP5 models simulate the present-day tropical inversion strength?*
- *Why do models predict the tropical inversion strength to increase in a warmer world?*
- *Take away points*

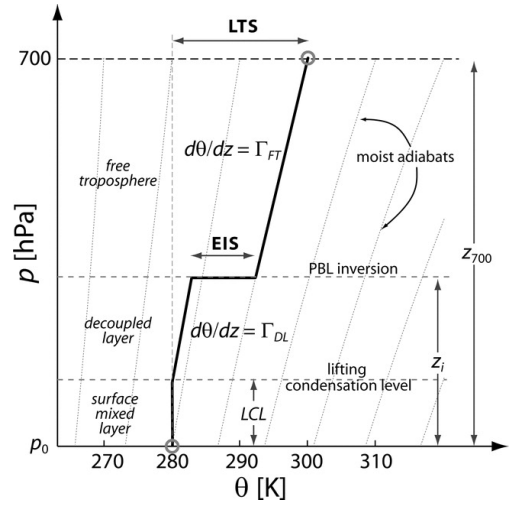
Tropical inversion: Its importance

- The ubiquitous tropical trade inversion and its strength are key factors for subtropical boundary layer clouds
  - The inversion limits the height of boundary layer and its strength limits the entrainment rate of free tropospheric air
  - On seasonal-to-interannual time-scales, low cloud amount is highly correlated with the strength of the inversion
  - Modeling studies suggest the low-cloud response to climate change is sensitive to changes in inversion strength

How well do climate models simulate the tropical inversion strength?

What do climate models predict for changes in inversion strength? And why?

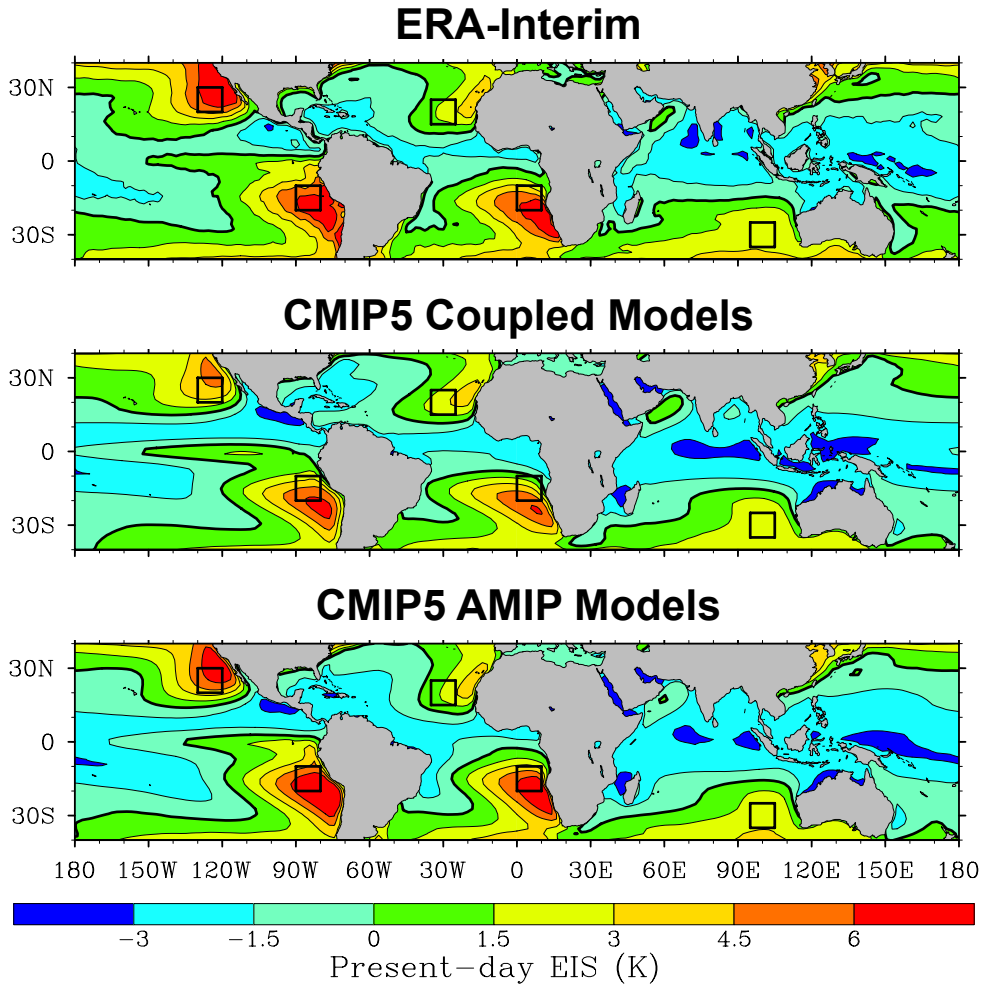




Wood and Bretherton (2006)

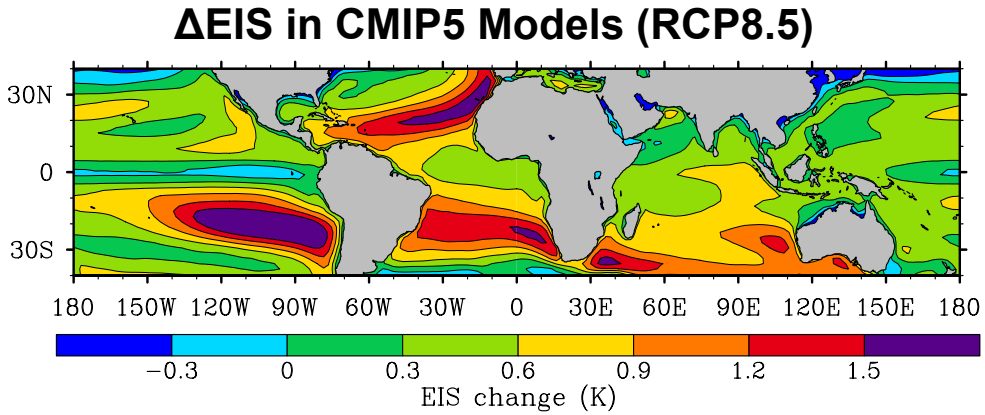
- We use the Estimated Inversion Strength: $EIS = LTS - \Gamma_m^{850} \cdot (z700 - LCL)$

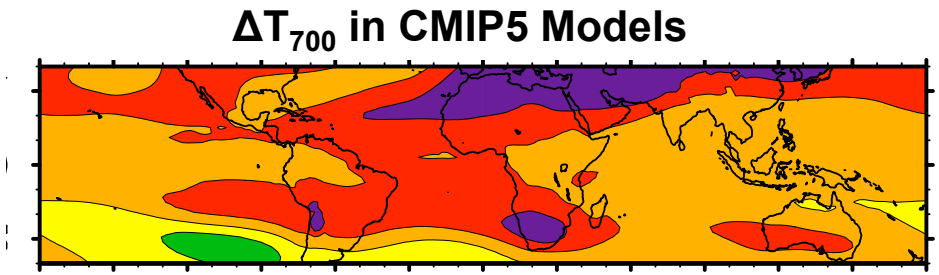
Present-day tropical inversion strength

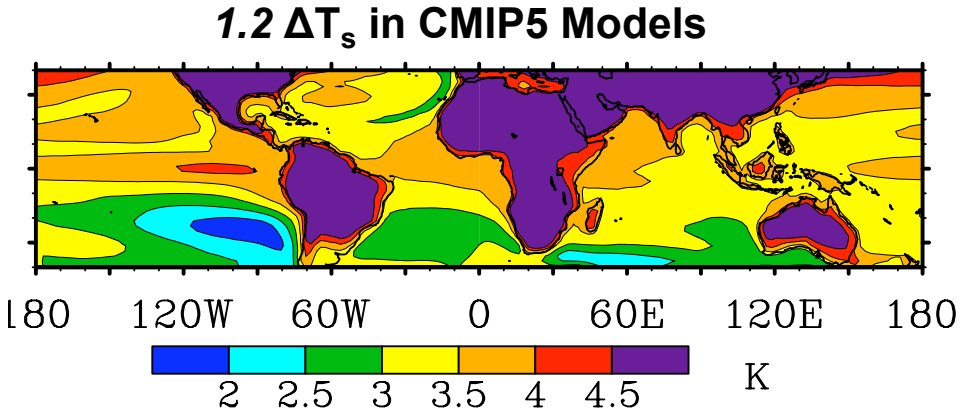


- Very good large-scale geographic correspondence
- Coupled models have a low bias (–1.6 ± 1.2 K) to the inversion strength in stratocumulus (Scu) regions
  - Low bias is mainly attributable to SST warm biases in Scu regions
- Models with prescribed SST have a much smaller low bias (– 0.5 ± 0.6K)
- EIS underestimate likely contributes to low-cloud amount underestimates in Scu regions in CMIP5 models

Predicted 21st century EIS changes





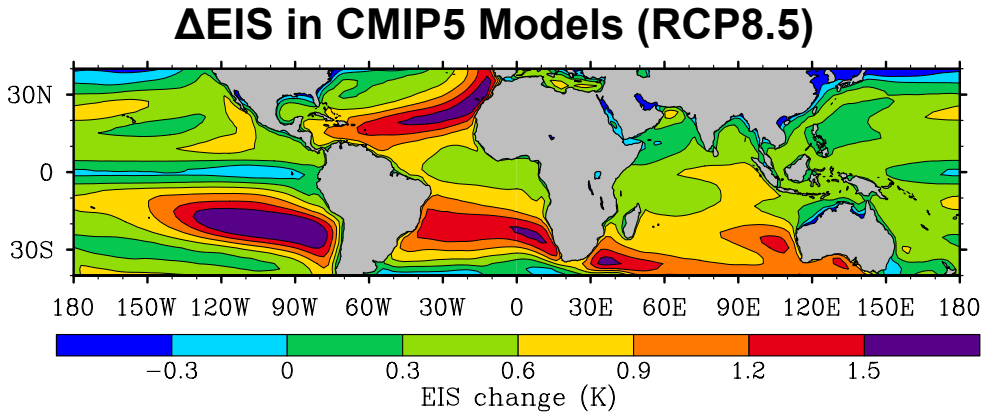


- EIS *robustly* increases in the 21st century simulations particularly in Scu regions and the Southern Hemisphere
  - In Scu regions ΔEIS is +1.0 ± 0.2 K
  - This is contrary to simplified models of the tropics

$$\Delta EIS \approx \Delta T_{700} - 1.2\Delta T_s$$

- ΔT_{700} (Scu regions) ~ ΔT_{700} (land) > ΔT_{700} (warm pool)
- ΔSSTs (Scu regions) < ΔSST (warm pool) < ΔT-surf (land)

21st century vs. Last Glacial Maximum



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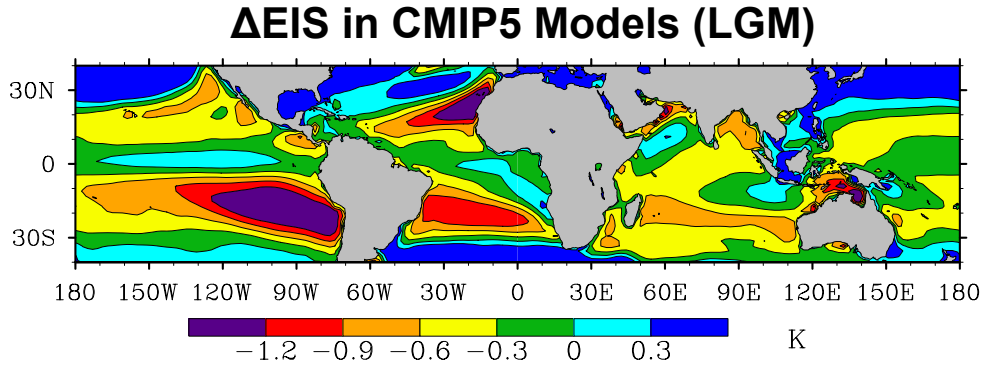


- Predicted EIS changes (in Scu regions) are symmetric with respect to the sign of the climate change

What drives EIS increases?

$$\Delta EIS = \Delta EIS(FR) + \Delta EIS(UOW) + \Delta EIS(\mathrm{Re}\,s)$$

Fast Response (FR)

calculated from *sstclim4XCO2* but scaled for radiative forcing change over 21st century

Residual (Res)

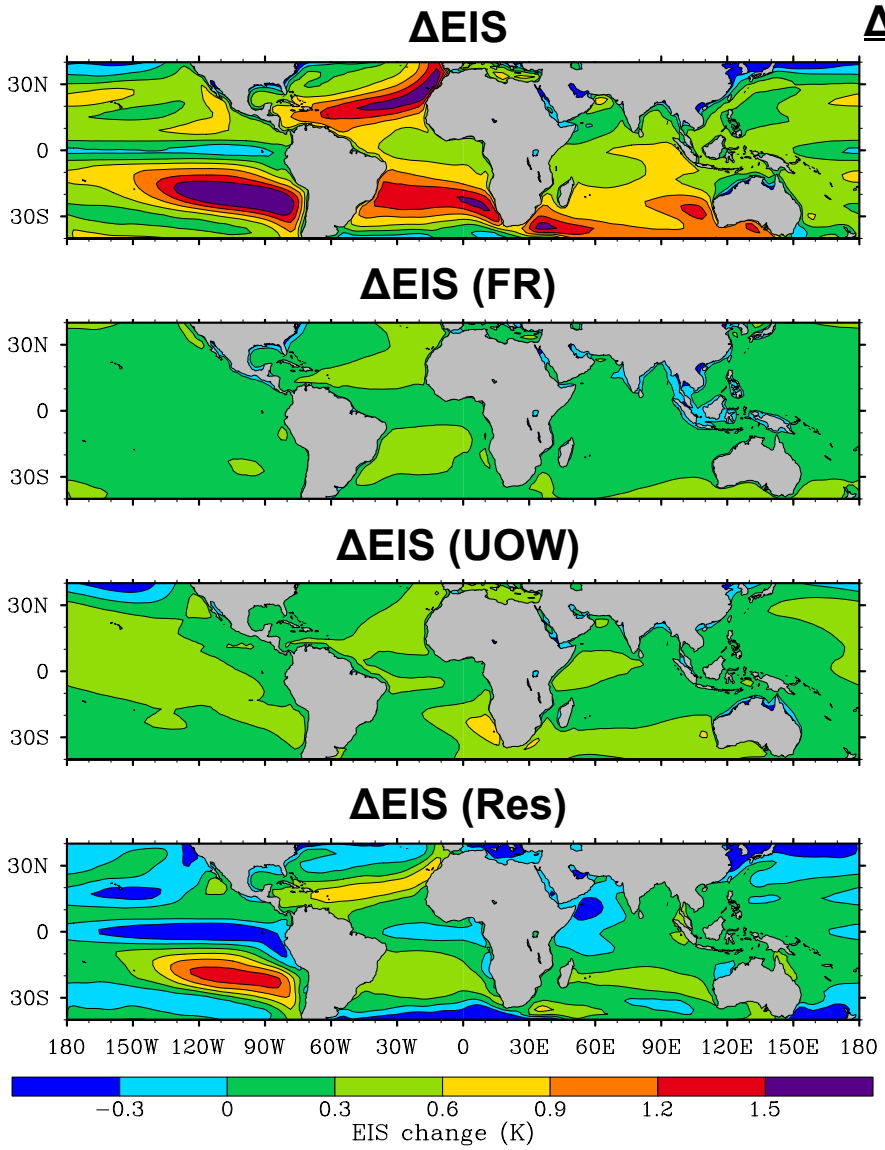
Hypothetically due to non-uniform ocean warming – Compared with scaled *amipFuture* after removing UOW contribution

Uniform Ocean Warming (UOW)

calculated from *amip4K* scaled for the tropical warming over 21st century

Note the power of CFMIP/CMIP → this study utilizes 11 experiments

The contributions to EIS changes



ΔEIS in Scu regions

0.95 K

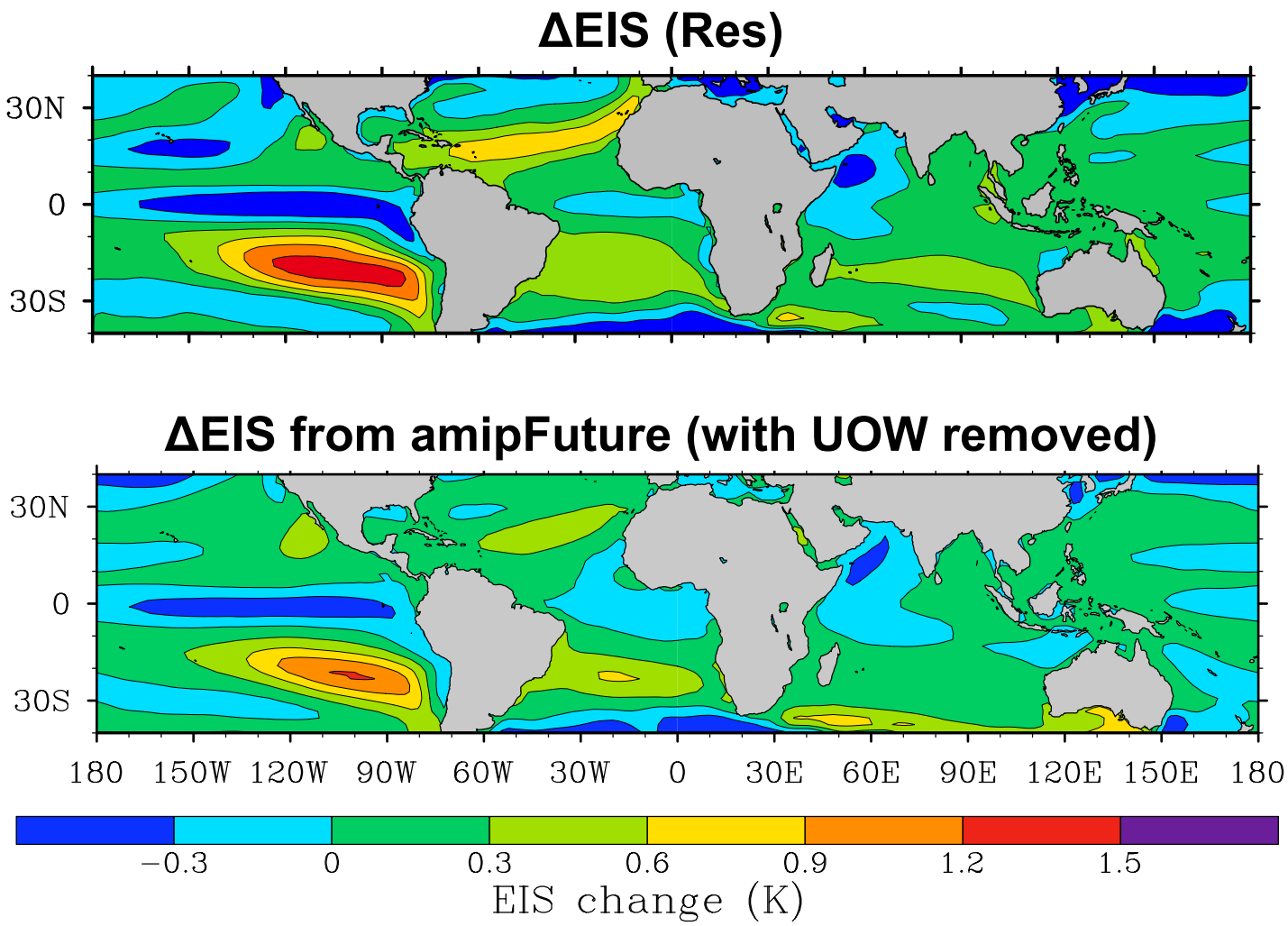
0.30 K

0.38 K

0.25 K

The fast response, uniform ocean warming, and residual each contribute about equally

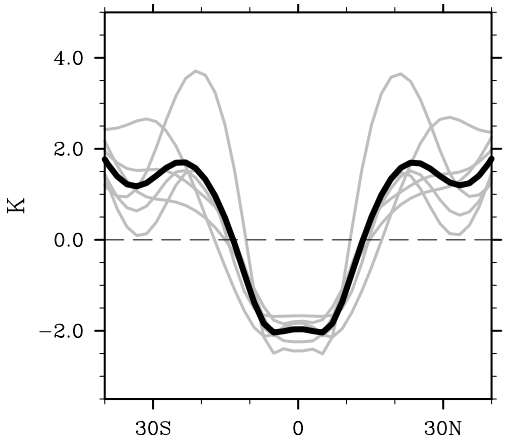
The residual *IS* due to non-uniform oceanic warming



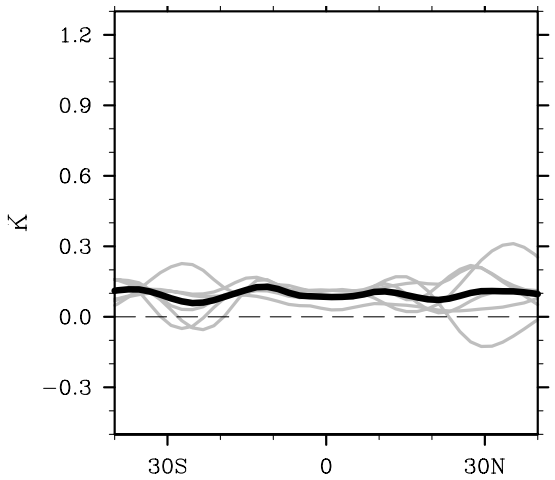
What is the role of land?

Aquaplanets

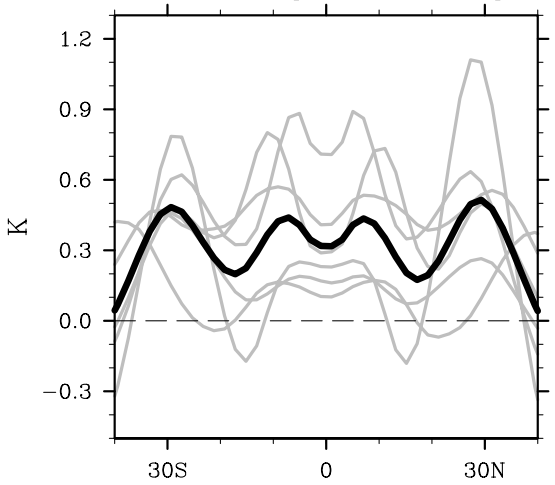
EIS (aquaControl)



ΔEIS (aqua4XCO2)



ΔEIS (aqua4K)



Fast Response

0.1 K << ΔEIS (real)

→ *Land plays a significant role in the fast response, as expected since land warms up but ocean does not*

Uniform Ocean Warming

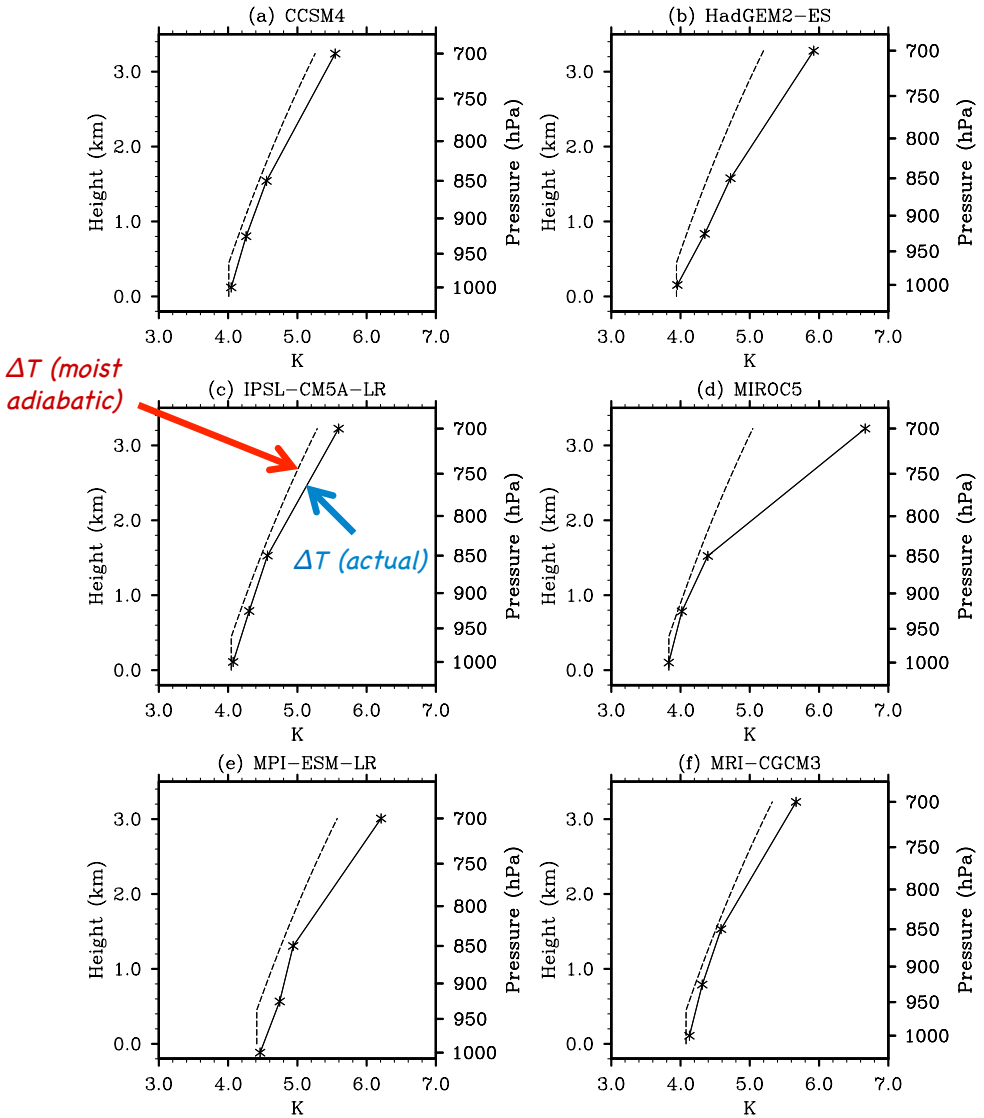
0.3 K ~ ΔEIS (real)

→ *Land does not play a significant role in the uniform ocean warming*

→ *So what does?*

Super - Moist-Adiabatic Warming

ΔT (aqua4K in 10N-10S)



→ *Warming at 700 hPa in the deep tropics exceeds that predict from a moist adiabat (assuming constant RH)*

Why?

→ *This drives the EIS increase in the aqua-planets and the uniform ocean warming simulations (we believe)*

Take Away Points

- *EIS is relatively well simulated in climate models apart from a noticeable underestimate (~1.6 K in Scu regions) resulting from coastal SST warm biases*
- *Climate models simulate EIS increases in a warmer world and decreases in a colder world*
- *EIS increases in a warmer world would encourage greater low-level cloudiness (a negative feedback)*
  - *This increase is expected to be smaller than the decrease directly resulting from the warming*
    (Bretherton et al. 2013, Bretherton and Blossey 2014, Qu et al. 2014)
  - *ΔEIS ~ 40% ΔSST & d(LCC)/dEIS ~ - 1 X d(LCC)/dSST*

Take Away Points

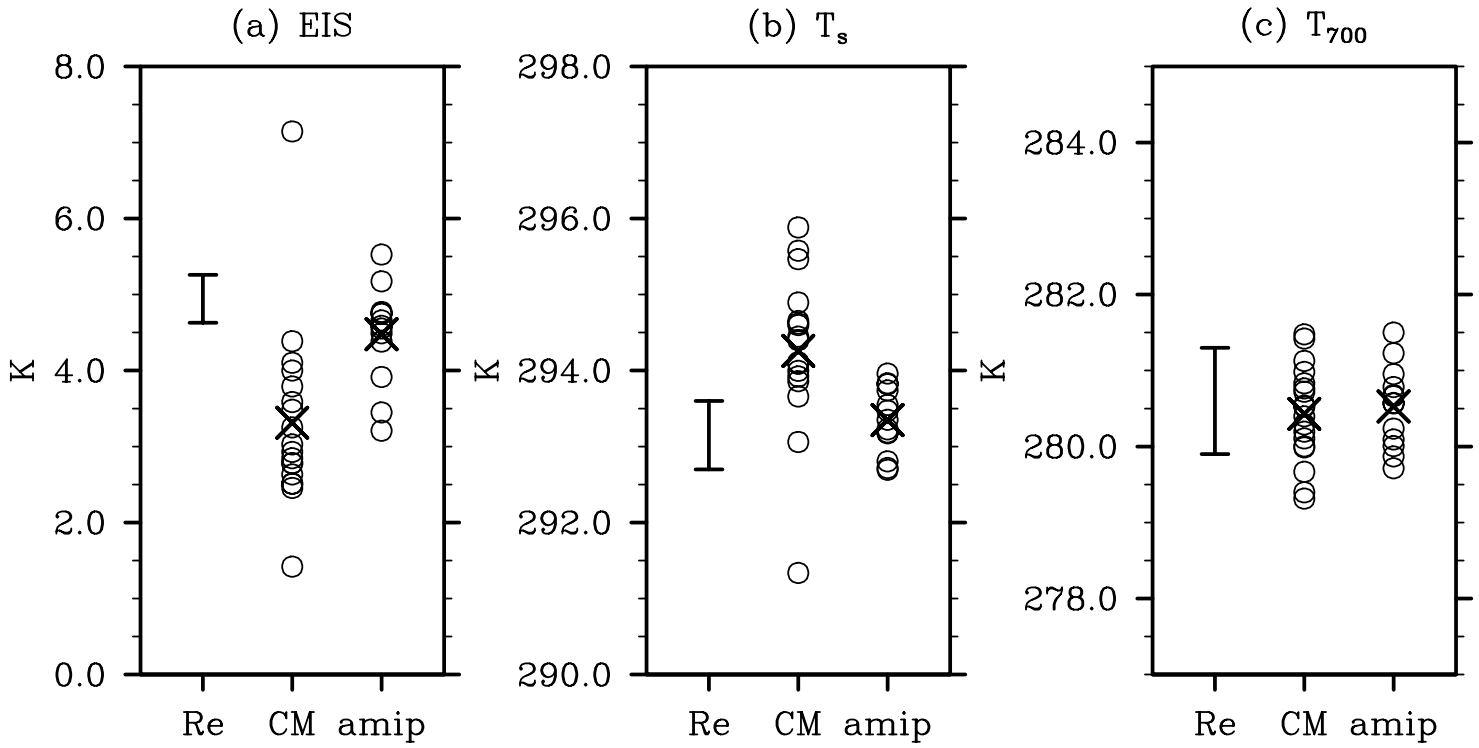
- *EIS increases are a combination of the results of the direct response to CO_2, greater warming over land, a smaller than average SST rises in Scu regions, and a general warming of the planet*
- *Do we believe these climate model predictions for EIS?*

Response	Believable?	Physical Explanation
Direct response to CO2	✔✔	Less lower tropospheric radiative cooling
Greater warming over land	✔	Lower heat capacity over land leads to greater warming of air aloft and which influences T_{700} in nearby marine Scu regions
Increased SST gradient between Scu region and warm pool	?	Greater evaporative damping for a uniform radiative forcing
Super-moist adiabatic warming in deep convection regions	??	Name a reason – please!

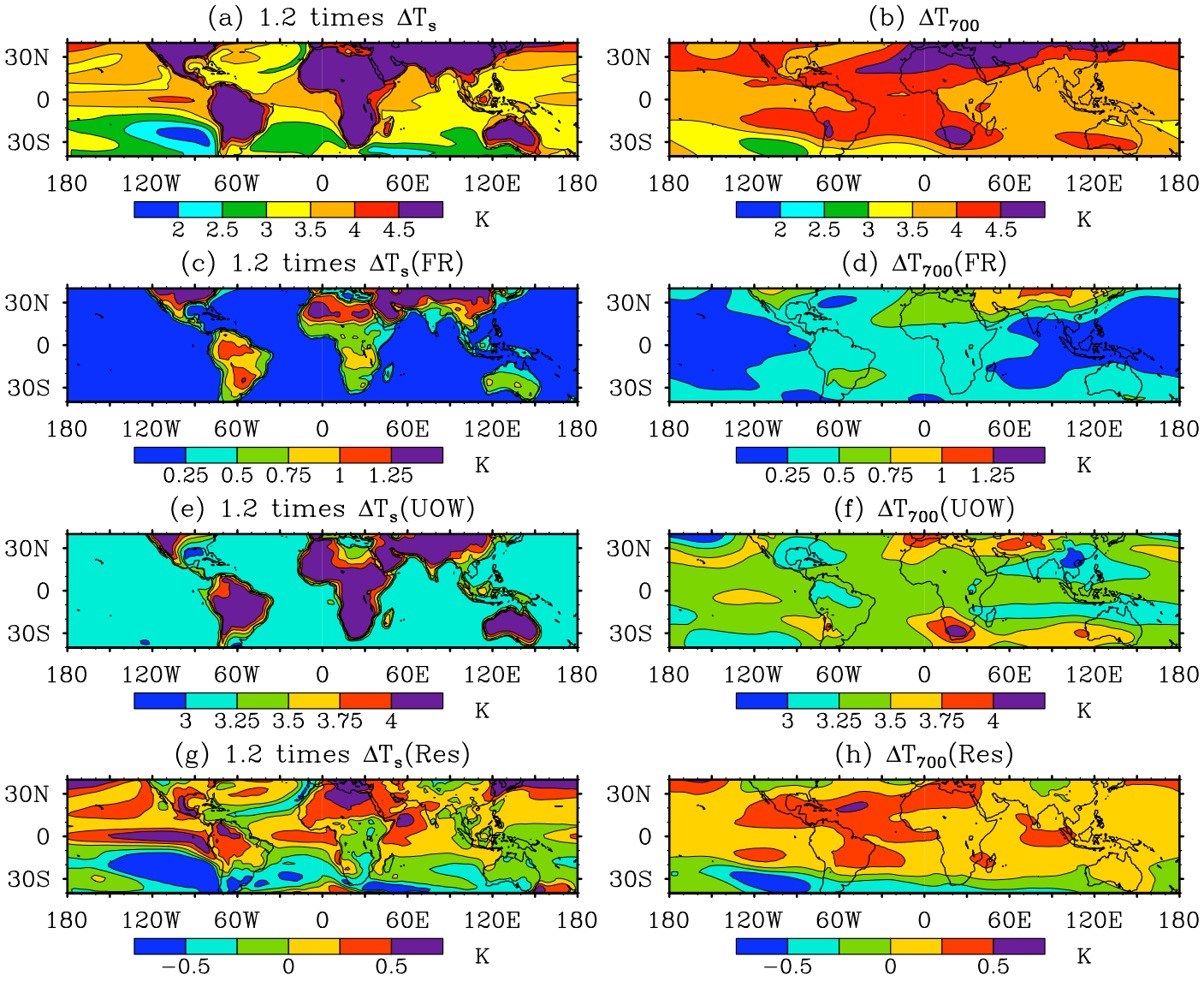
Thank you for your attention!

Extra Slides

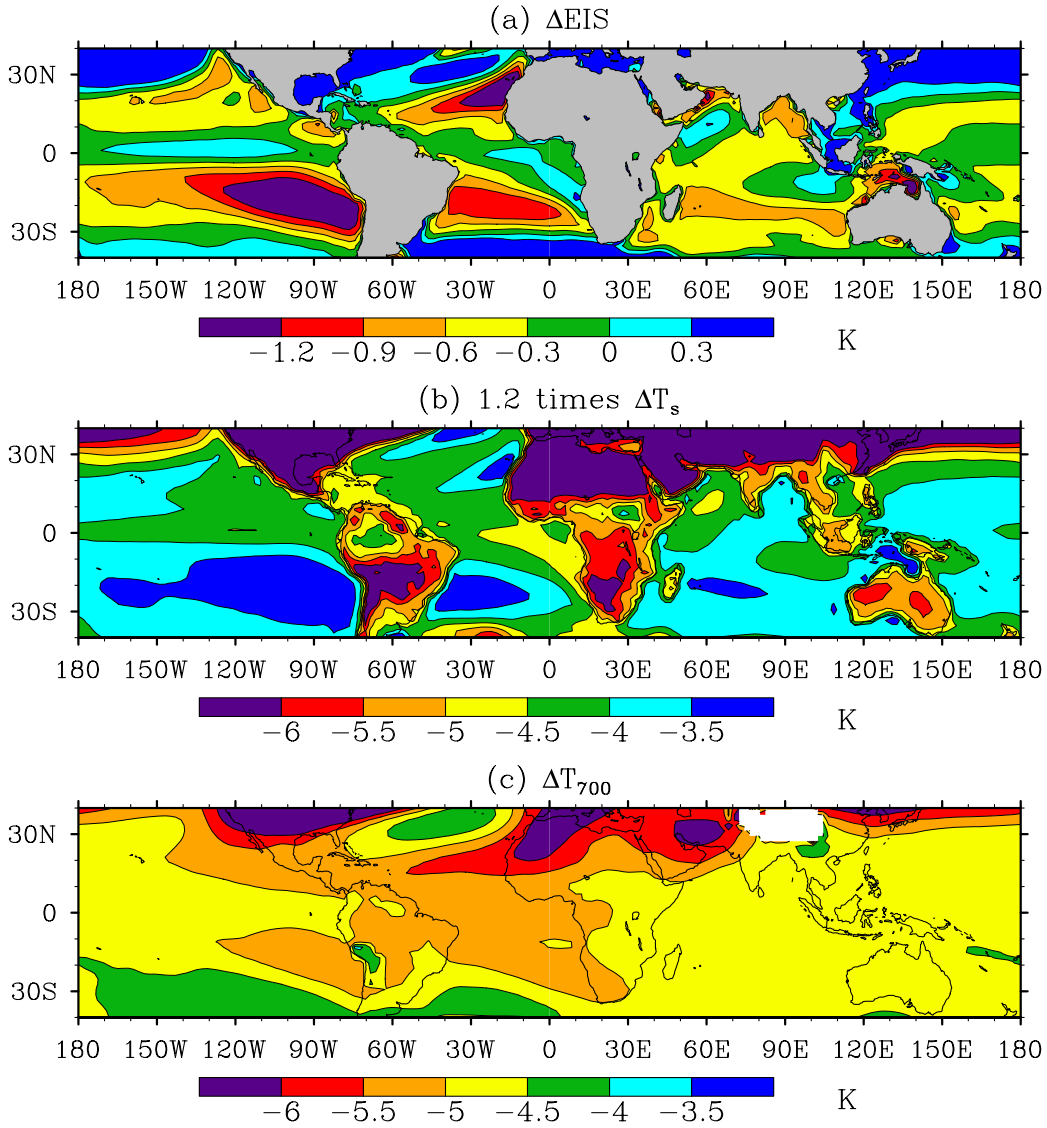
EIS, Ts and T700



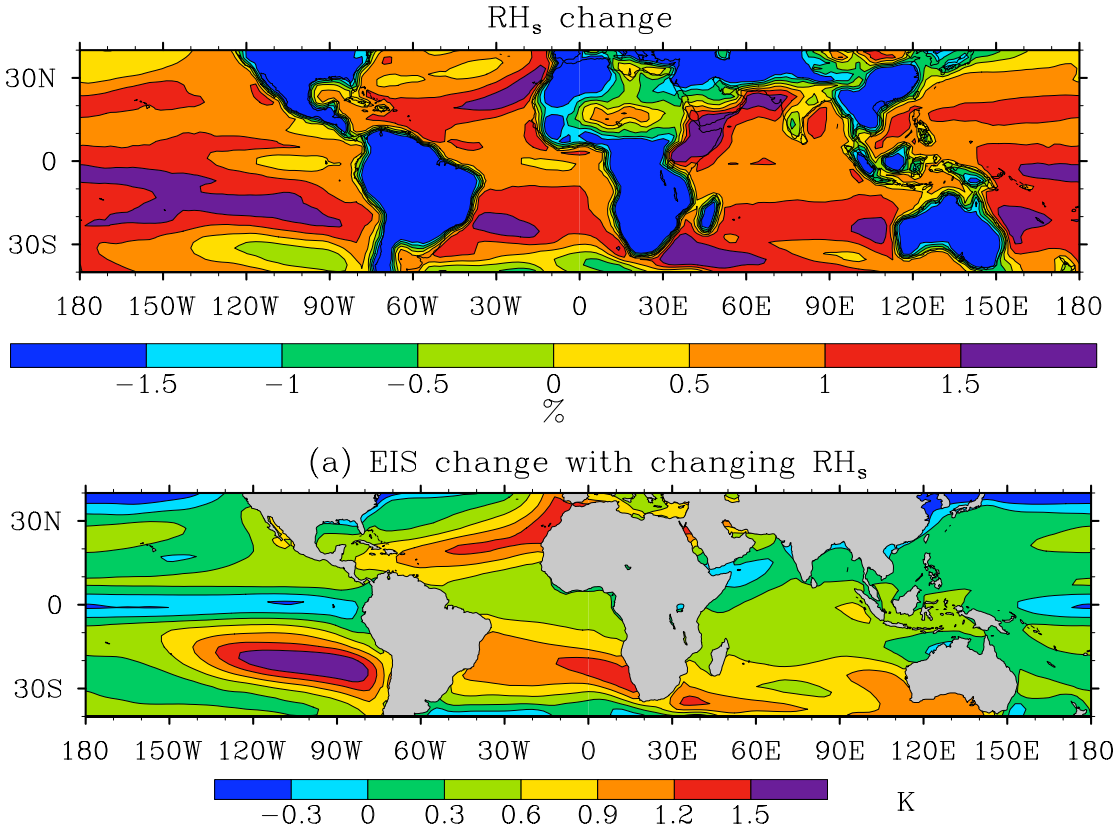
Various contributions to Ts and T700 changes



EIS changes in LGM simulations



The effect of changing ocean surface RH



Equations

$$EIS = LTS - \Gamma_m^{850} \cdot (z700 - LCL)$$

$$\Delta EIS = \Delta EIS(FR) + \Delta EIS(UOM) + \Delta EIS(\mathrm{Re}\, s)$$

$$\Delta EIS \approx \Delta T_{700} - 1.2\Delta T_s$$

$$\Delta T_x = \Delta T_x(FR) + \Delta T_x(UOM) + \Delta T_x(\mathrm{Re}\, s)$$