Lapse rate deviations from the moist adiabat in the tropical upper troposphere in climate models

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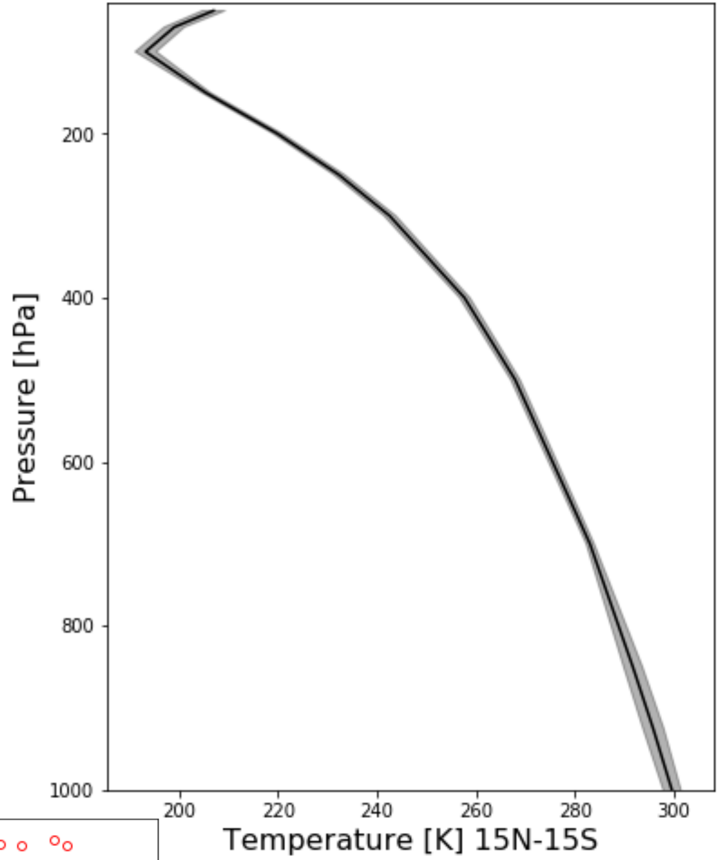
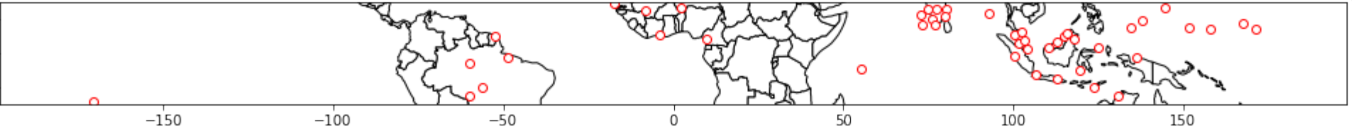
Observed Temperature Profile in the Tropics

Radiosonde data from 46 stations 1990-2018 between 15°N and 15°S

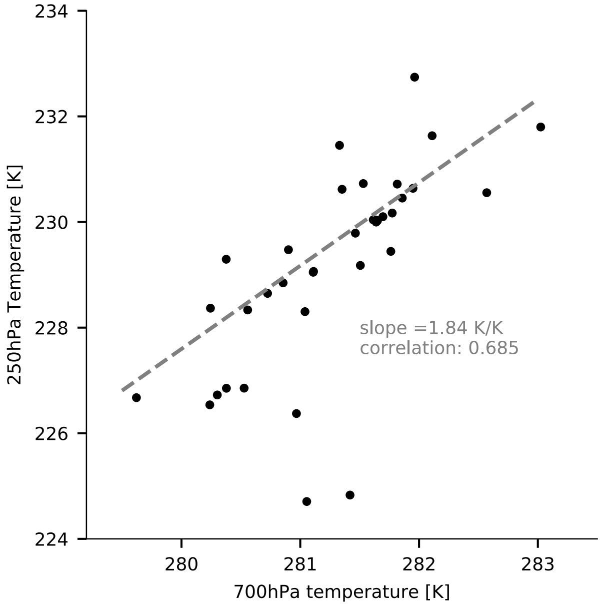
—> The profile follows a moist adiabat
—> Upper tropospheric temperatures mainly set by lower tropospheric conditions



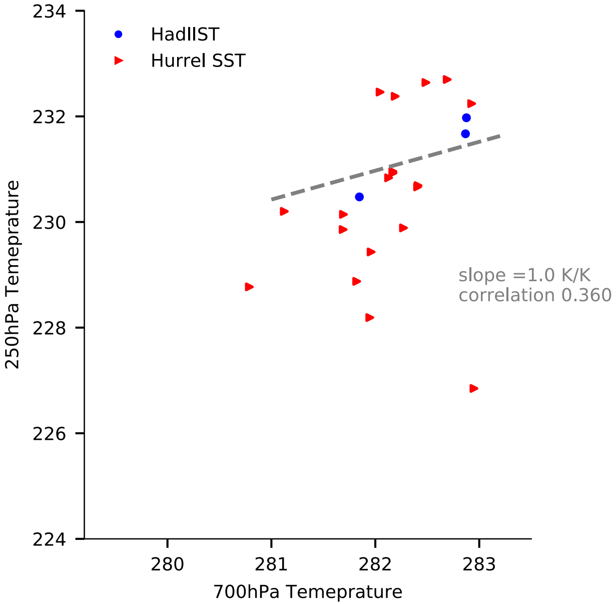


How true is this in CMIP5 models?

piControl CMIP5



AMIP 1979-2008 CMIP5



—> considerable variability in the upper troposphere for the same lower tropospheric temperature

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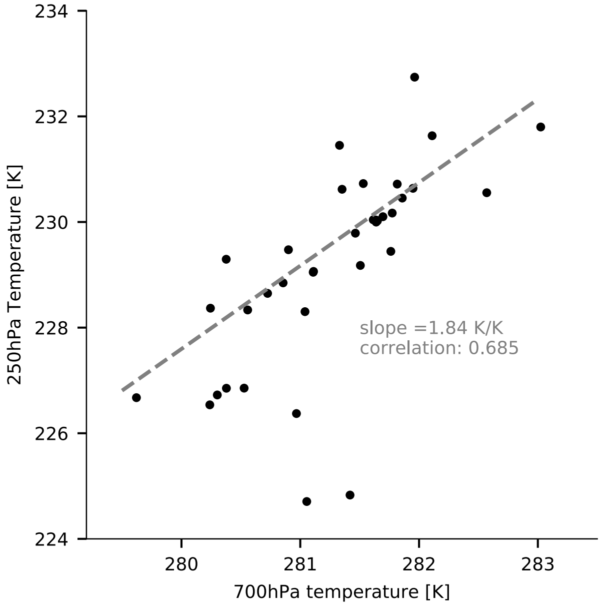
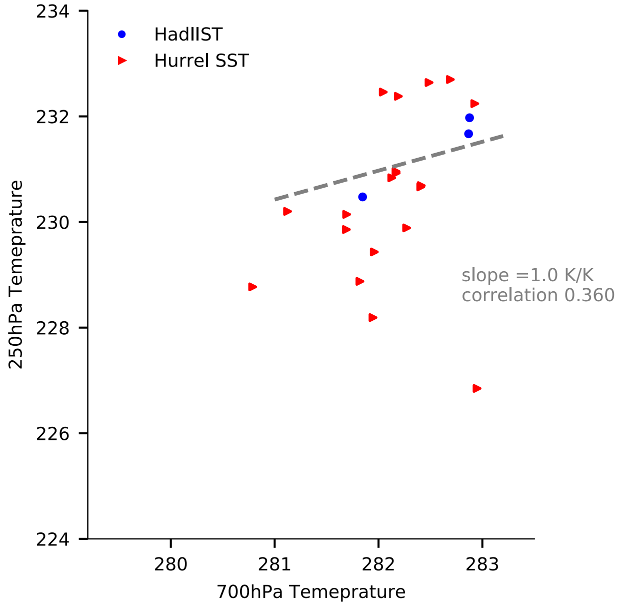


AMIP 1979-2008 CMIP5

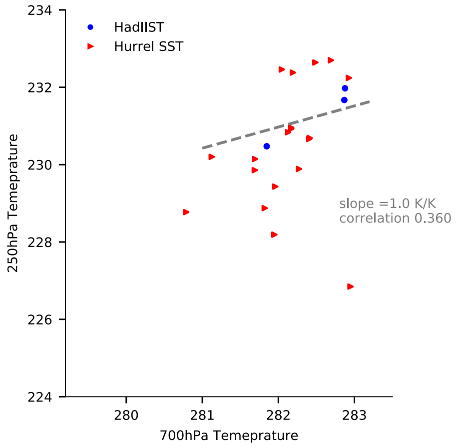


—> considerable variability in the upper troposphere for the same lower tropospheric temperature

Why should we care?

- climate models overestimate upper tropospheric warming (Santer 2005 et al, Santer et al 2017, Suarez Gutierrez et al 2016)
    - Potential impact on lapse rate and water vapour feedback (Kluft and Dacie 2019)

- Upper tropospheric temperatures are connected to global circulation patterns:
    - strength of the Walker Circulation (Sohn et al 2016)
    - atmospheric moisture flux into the Arctic (Lee et al 2019)
    - tropical cyclone intensity (Trabing et al 2019)



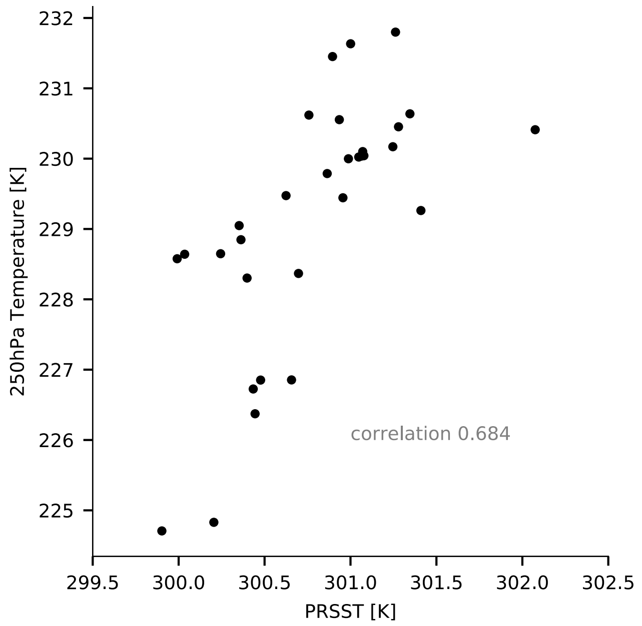
Possible reasons for these variations

1. **Different coupling of SSTs and convection (Fueglistaler et al 2015, Tuel 2019)**

2. Different ways representing moist convection

1. Different coupling of SSTs and convection

Precipitation weighted SSTs can explain differences in the upper tropospheric warming rate (Fueglistaler et al 2015, Tuel 2019).

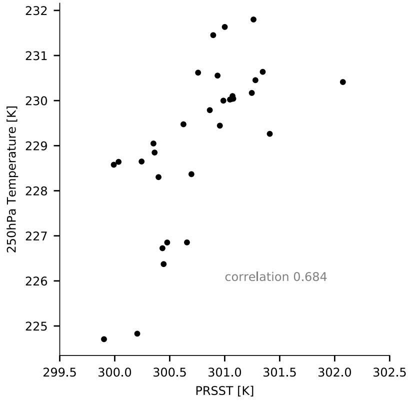


However, this is not the case for differences in the mean state.

Possible reasons:

1. Different coupling of SSTs and convection (Fueglistaler et al 2015, Tuel 2019) :

   Likely has an influence but does not reduce the variation in the upper troposphere



2. Different ways representing moist convection

2. Differences in the representation of moist convection

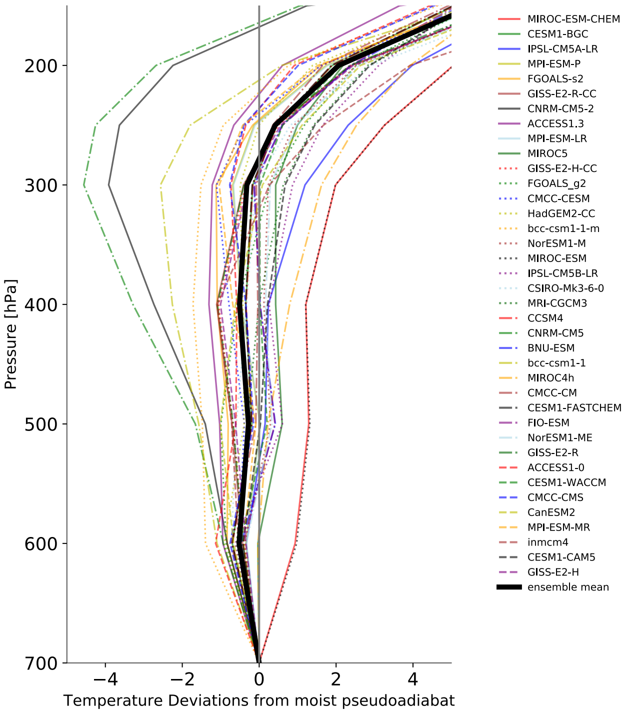
What is the moist adiabat exactly and how do climate models diverge from it?

Moist pseudoadiabat: All condensate precipitates immediately

Calculate idealised moist pseudoadiabat from 700hPa temperature and show deviations to simulated lapse rate:

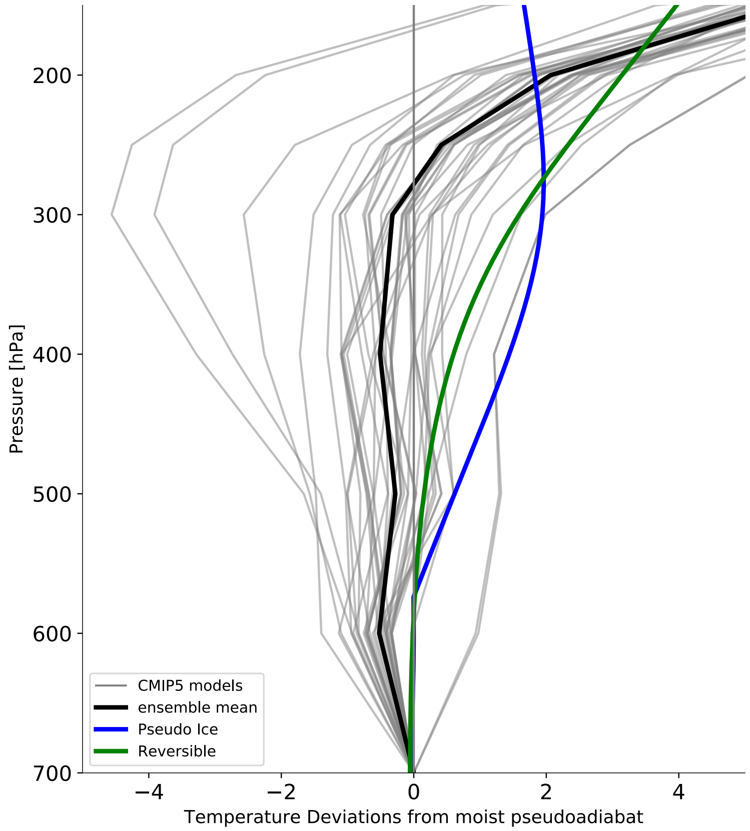
—> Range of different behaviours

piControl CMIP5



Simulated lapse rates vs idealised moist adiabats

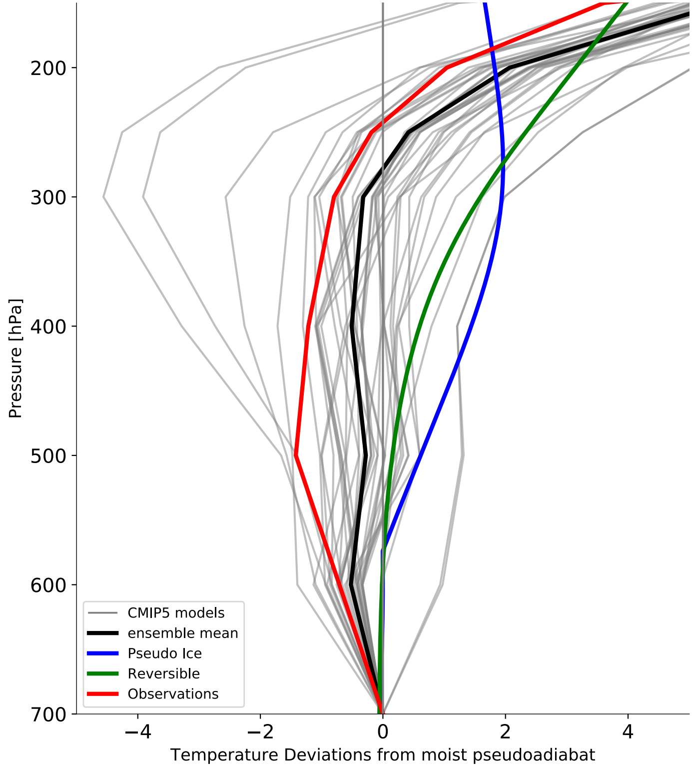
- Moist pseudoadiabat: All condensate precipitates immediately
- Isentropic (“reversible”) adiabat: no precipitation
- Freezing provides additional enthalpy
- Entrainment not considered here, but likely also important!

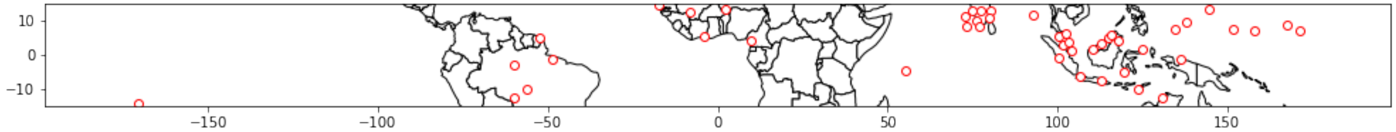


Observations

Observations from 43 radiosonde stations

Even colder than multi-model-mean





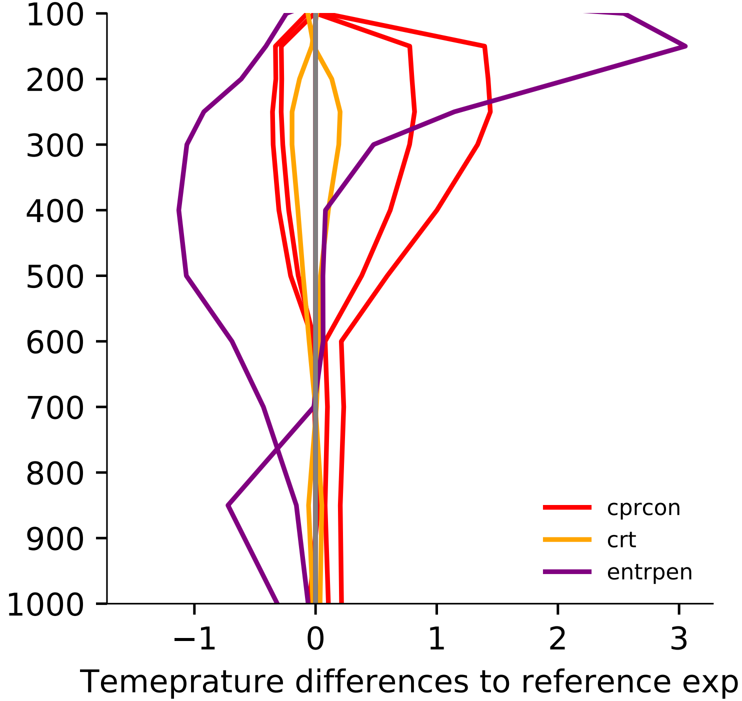
AMIP experiments

Can we reproduce some of these variations?

—> Experiments with the atmospheric circulation model ICON-A at 160km resolution

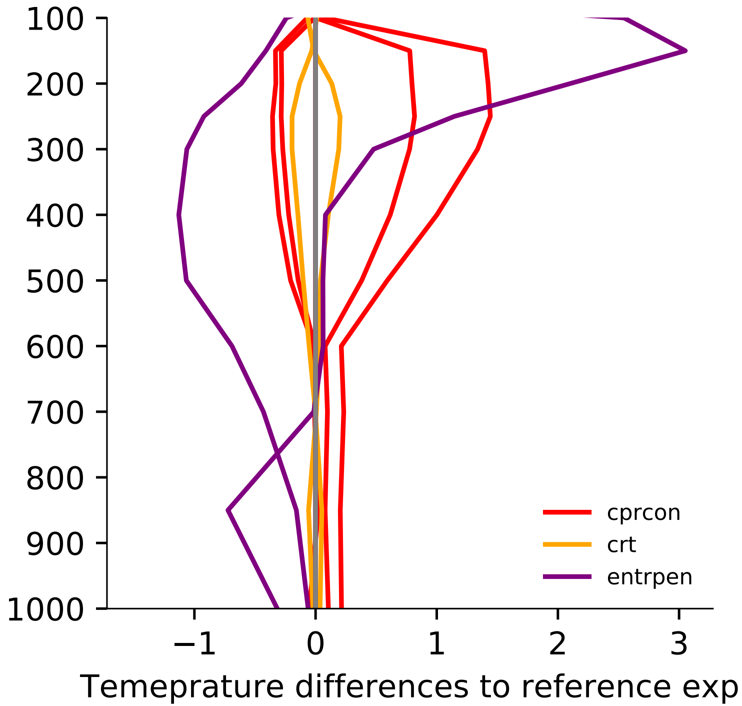
Change some parameters in the convection scheme (Tiedtke 1989):

- **cprcon** "Conversion of cloud water to rain"
- **crt** "Critical humidity aloft"
- **entrpen** "turbulent entrainment rate for penetrative convection"

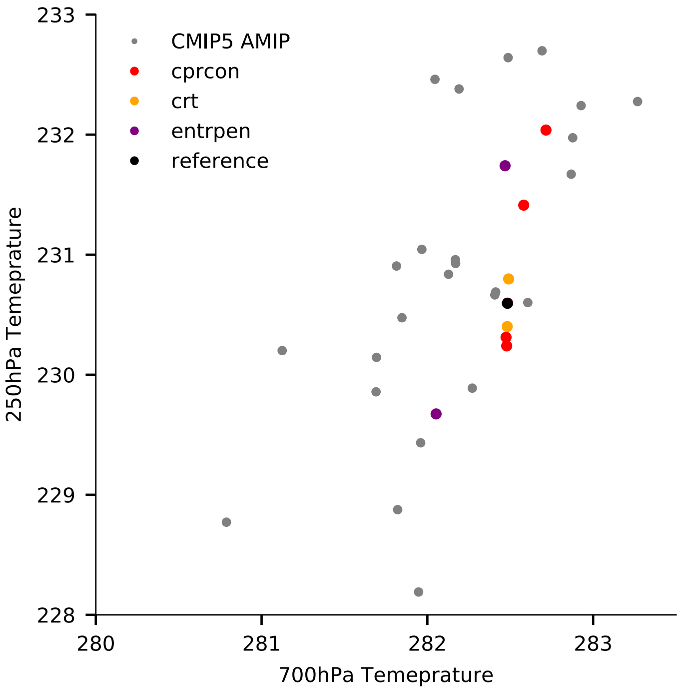


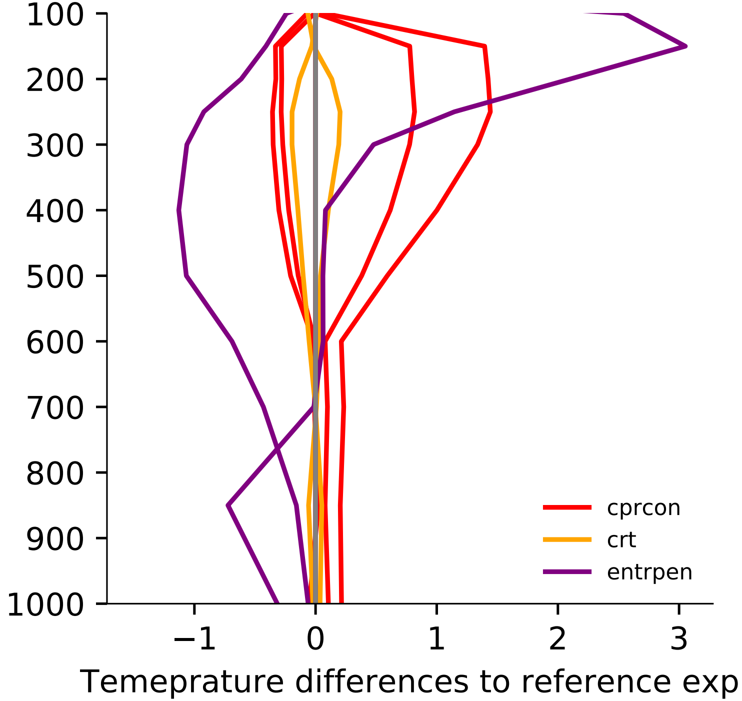
AMIP experiments

- **cprcon** “Conversion of cloud water to rain”
  - Increases (decreases) the lifetime of condensate in the air parcel
  - Thereby the lapse rate is tilted towards a reversible adiabat (pseudoadiabat)
  - Additional warming in the upper troposphere
- crt, entrpen still being worked on



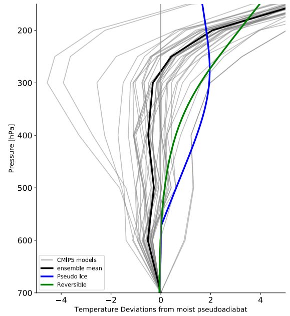
AMIP experiments vs CMIP5



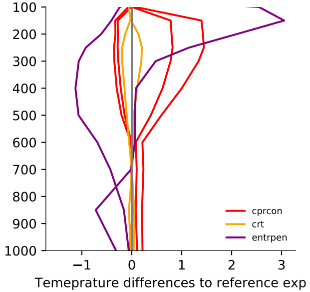


Conclusion

Variations in upper tropospheric temperatures in climate models are related to the representation of moist convection



We can reproduce these variation by adapting the convection scheme



What implication does this have for global warming?

References

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