SST-driven changes in cloud radiative heating in RCEMIP models and observations

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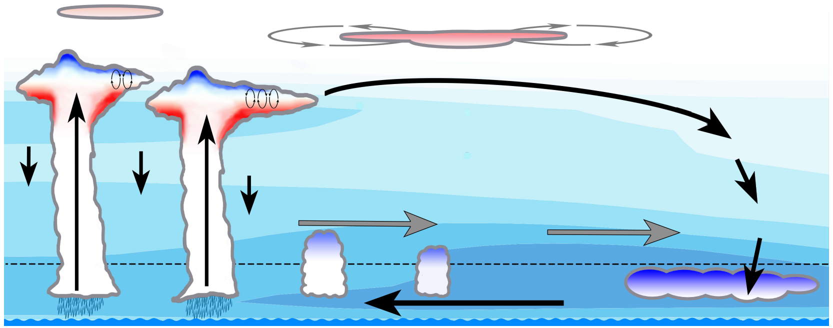
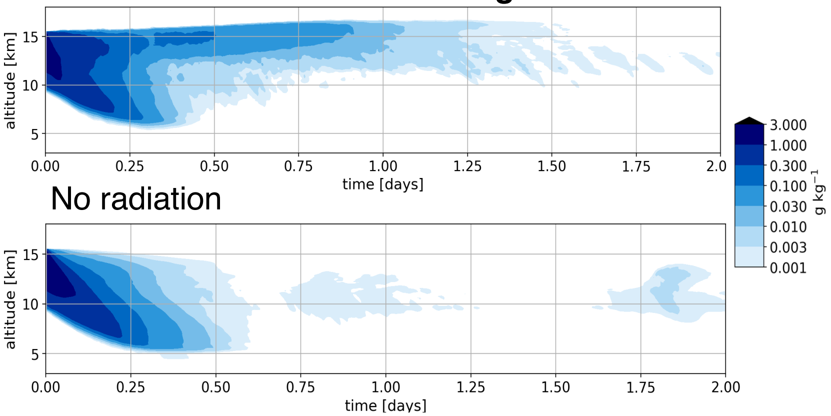
Cloud radiative heating modulates climate processes and their responses to global warming

1. Cloud radiative heating influences large-scale dynamics and circulation response to global warming (e.g. Voigt et al., 2021, Dinh et al., accepted)



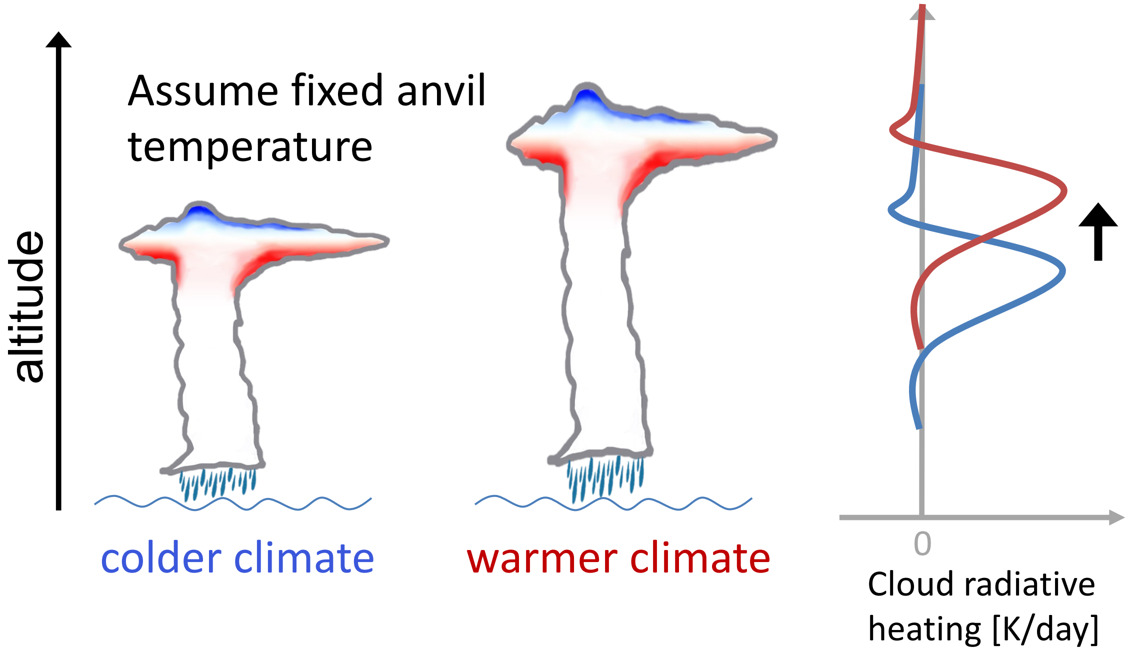
Dinh et al., accepted

2. Cloud radiative heating prolongs single high cloud evolution



Hartmann et al., 2018

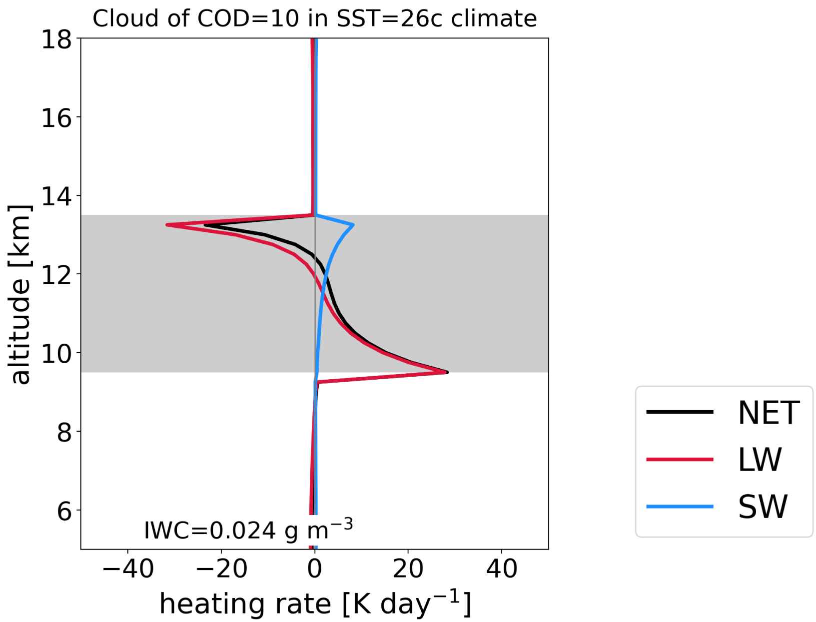
Changes to cloud radiative heating with warming



Zero hypothesis:

Cloud radiative heating shifts to a higher level

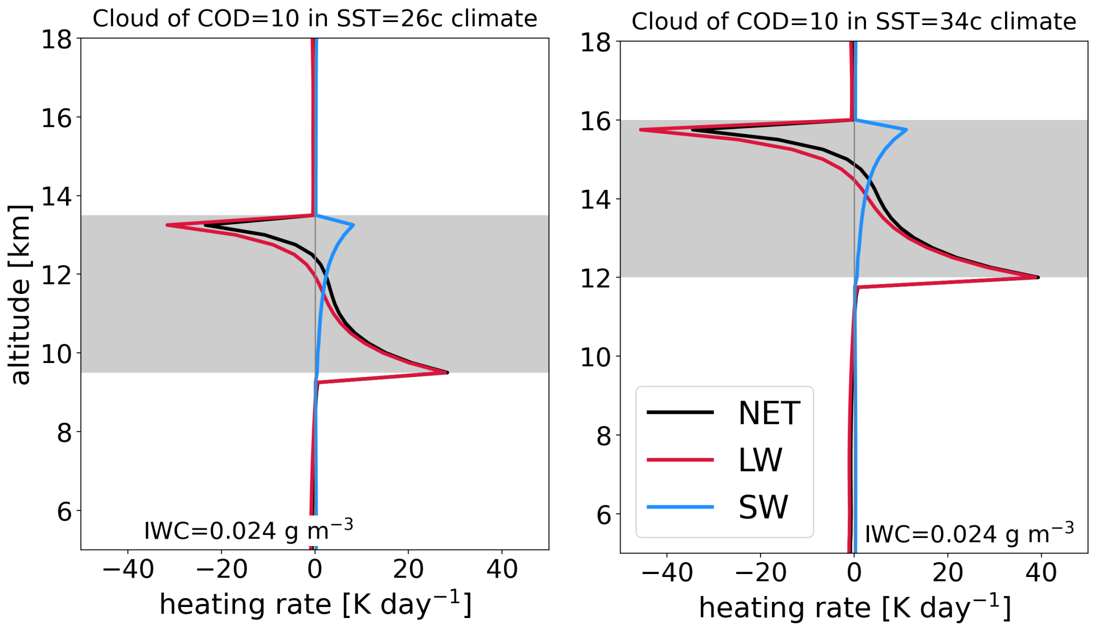
Radiative calculations show an increase in CRH



Cloud of **FIXED** properties
(cloud optical depth = 10,
ice water path = constant)
<u>Fixed cloud top temp.</u>

Radiative code fed in with equilibrium temperature and moisture profiles from RCE simulations at SST=26°C and SST=34°C

Radiative calculations show an increase in CRH

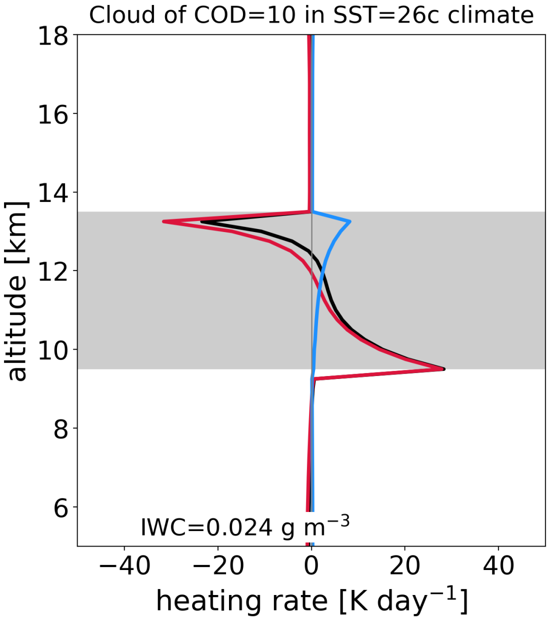


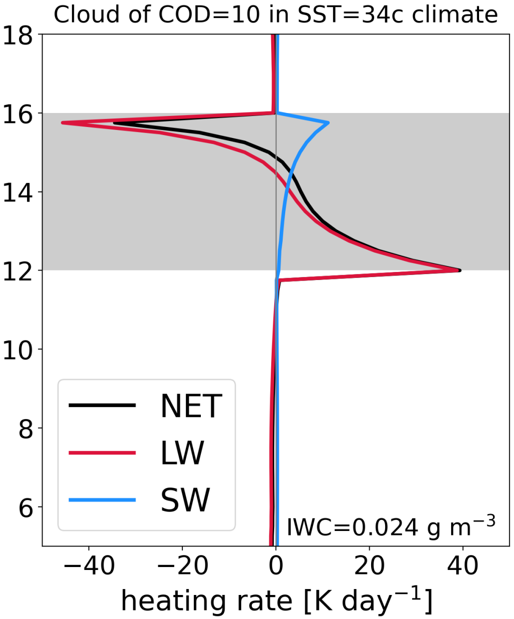
Cloud of **FIXED** properties (cloud optical depth = 10, ice water path = constant)

<u>Fixed cloud top temp.</u>

Radiative code fed in with equilibrium temperature and moisture profiles from RCE simulations at SST=26°C and SST=34°C

The increase is explained by a change in density





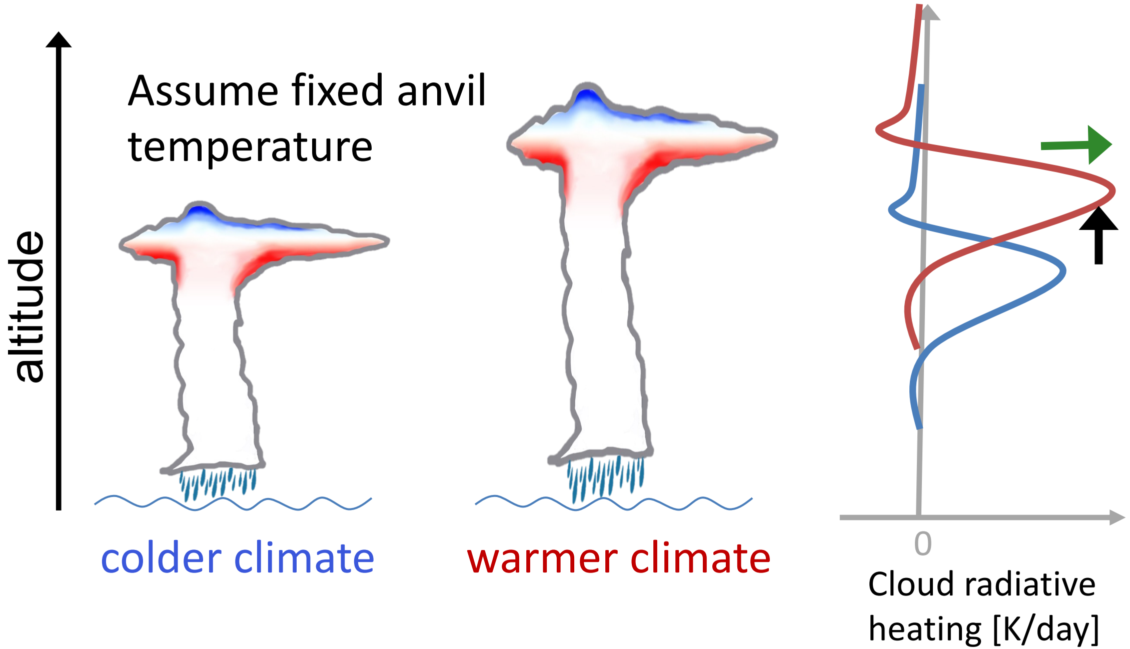
Quantity	SST34/SST26
Max CRH ratio	1.37
1/density at CRH peak	1.35

Approximately fixed

$$\frac{\partial T}{\partial t} = \frac{g}{\rho c_p} \frac{\partial F}{\partial z}$$

Shift in altitude: density decreases

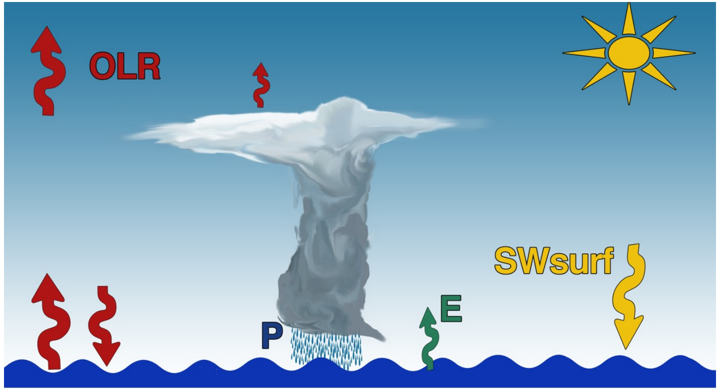
So we need to fix our zero hypothesis



Zero hypothesis

Cloud radiative heating shifts to a higher level and increases in magnitude

Use RCEMIP to test the updated zero hypothesis

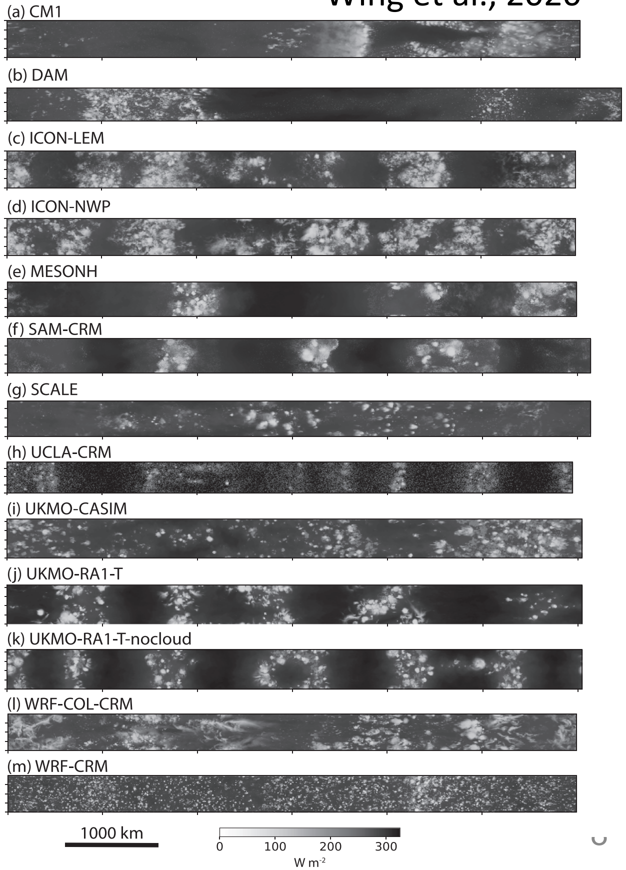


Radiative-convective equilibrium (RCE): The most idealized representation of the tropical climate

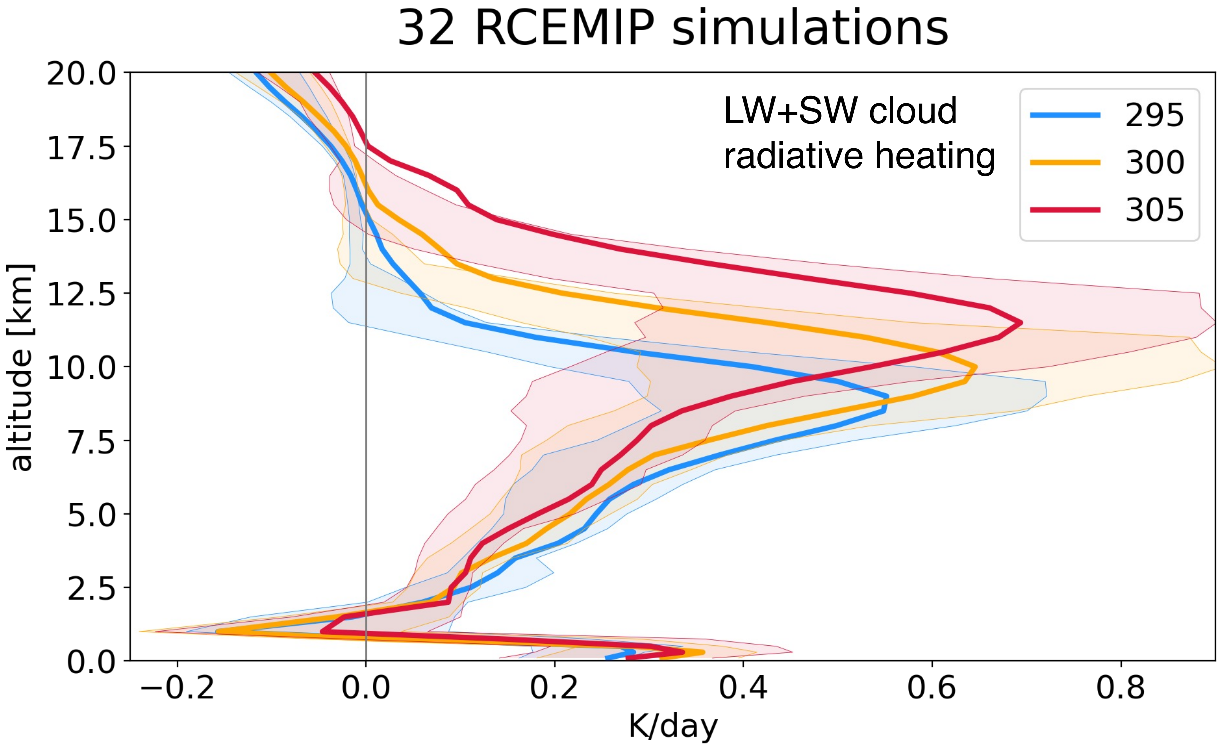
RCEMIP = RCE modeling intercomparison
>30 different models (GCM, SCM, CRM, LES, GCRMs), simulations at 3 different SSTs

Wing et al., 2020

Simulated OLR from RCE large models

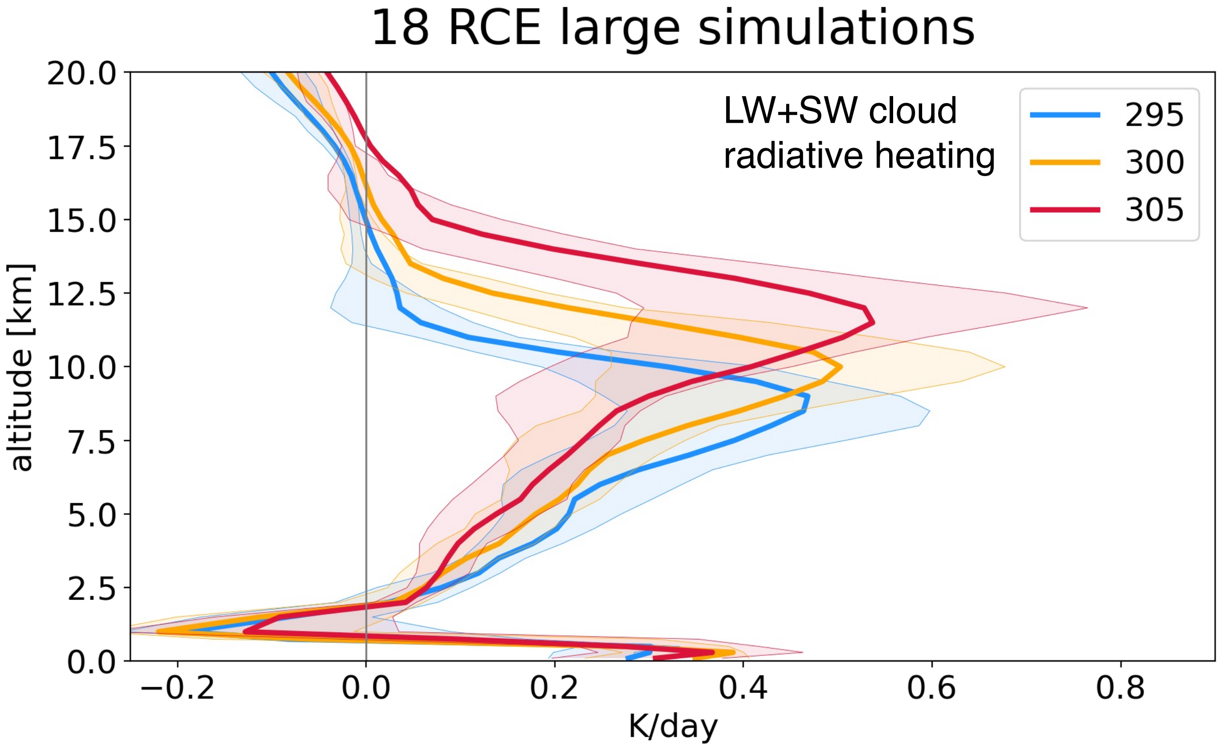


RCEMIP ensemble: vertical shift & intensity increase



18 RCE_large and 14 RCE_small sets of simulations with clear and full-sky flux profiles

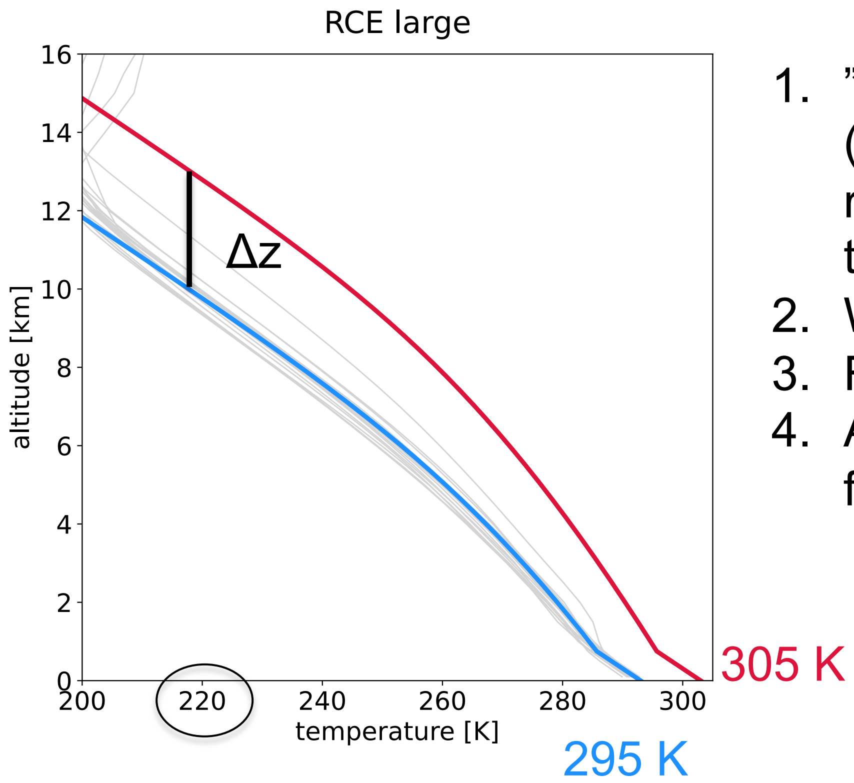
RCEMIP ensemble: vertical shift & intensity increase



Similar behavior when considering only large domain simulations

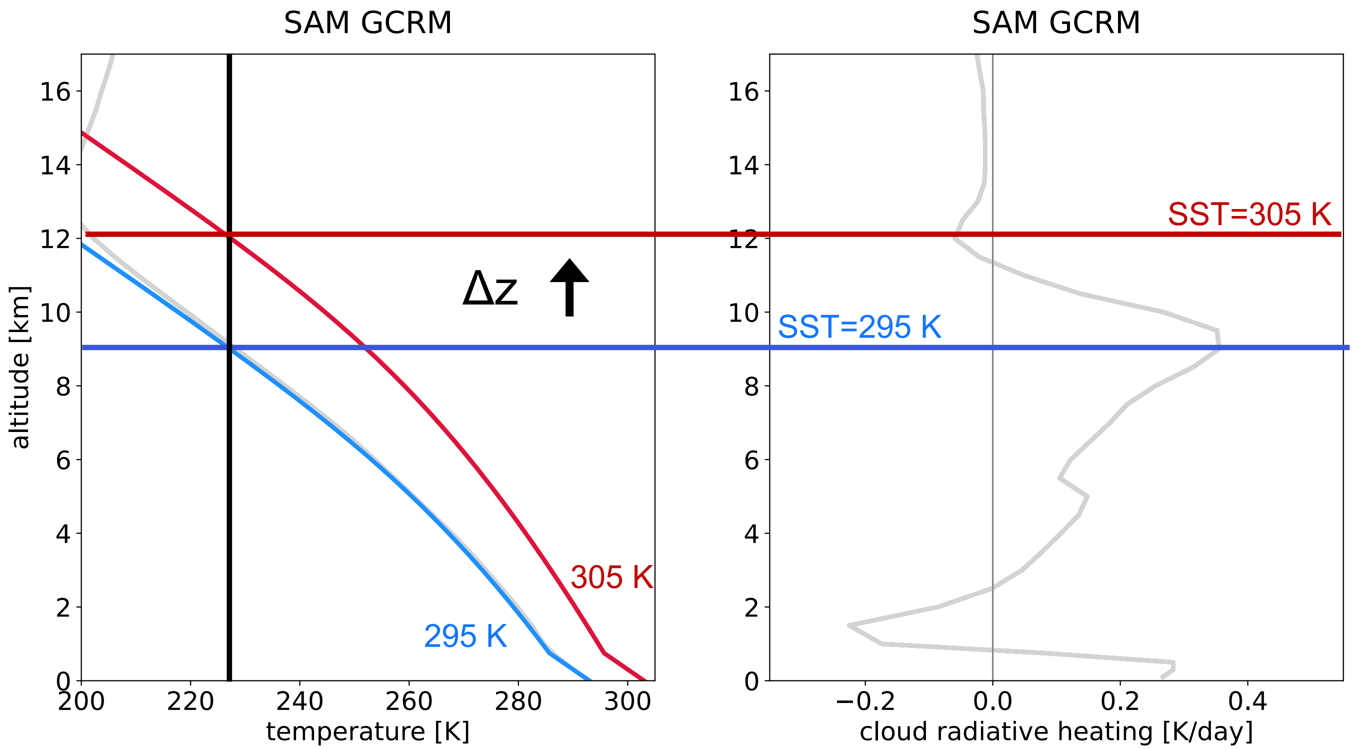
Can we predict the CRH in a changed climate state based on the control climate state only?

How far we come by vertical shift & density terms?

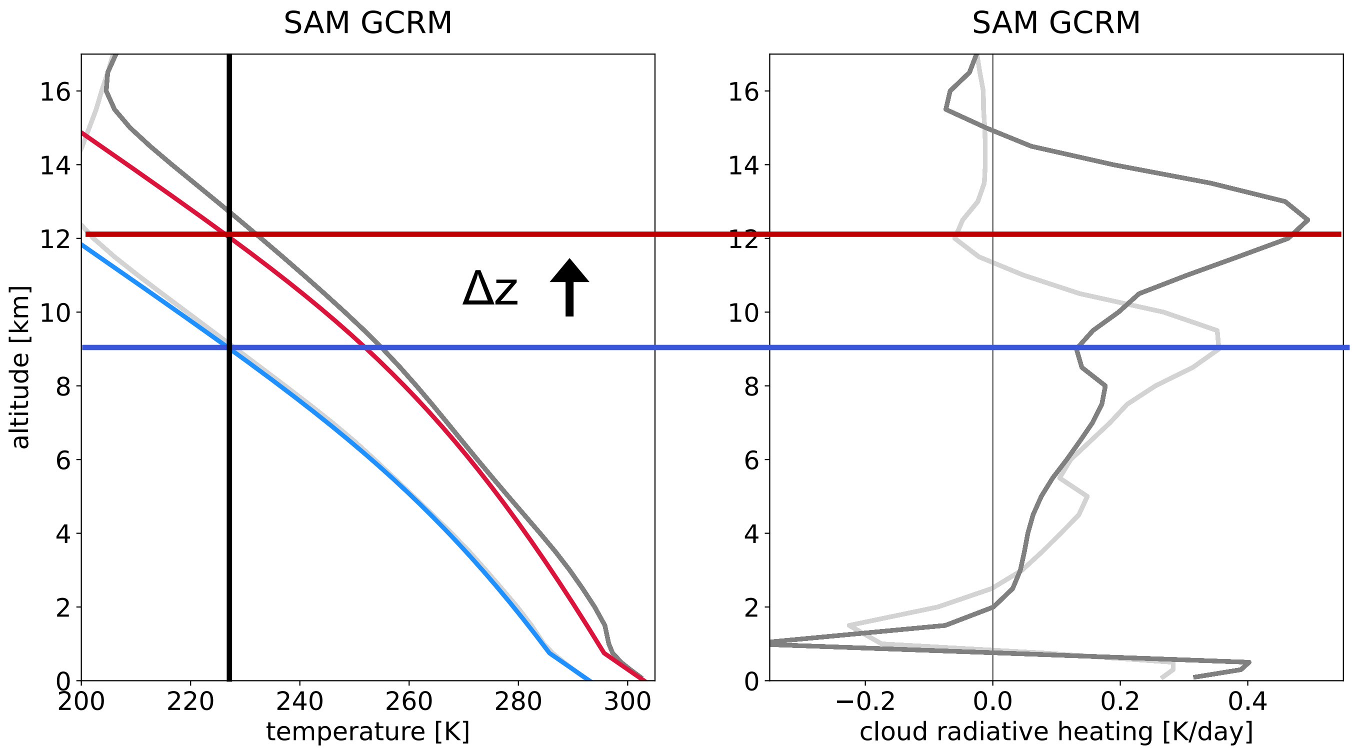


1. ”Fit” a diluted moist adiabat (assuming 90% RH) so that it roughly reproduced the RCEMIP model temperature profiles
2. Warm it by 10°C (at the surface level)
3. Find the temperature of peak CRH
4. Assuming no change in temperature, find the vertical displacement in km

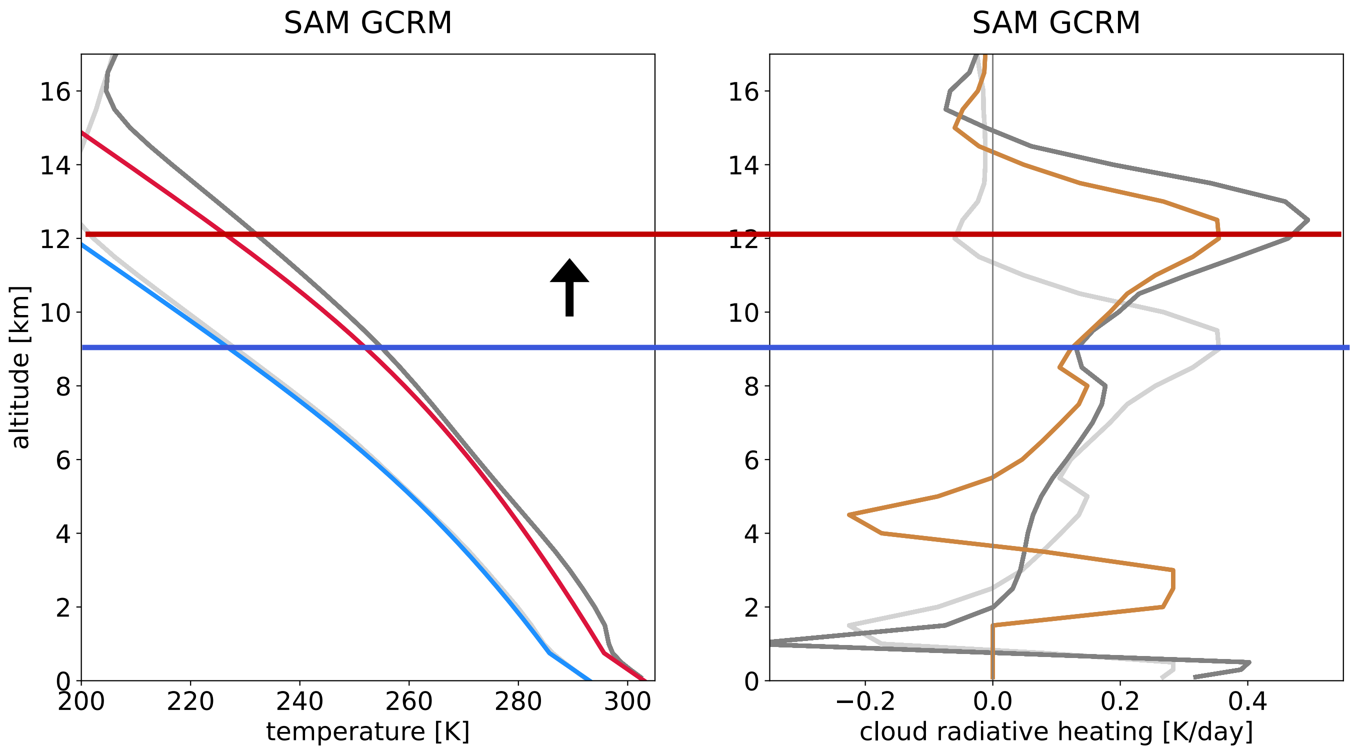
Example: 1. Find the vertical shift



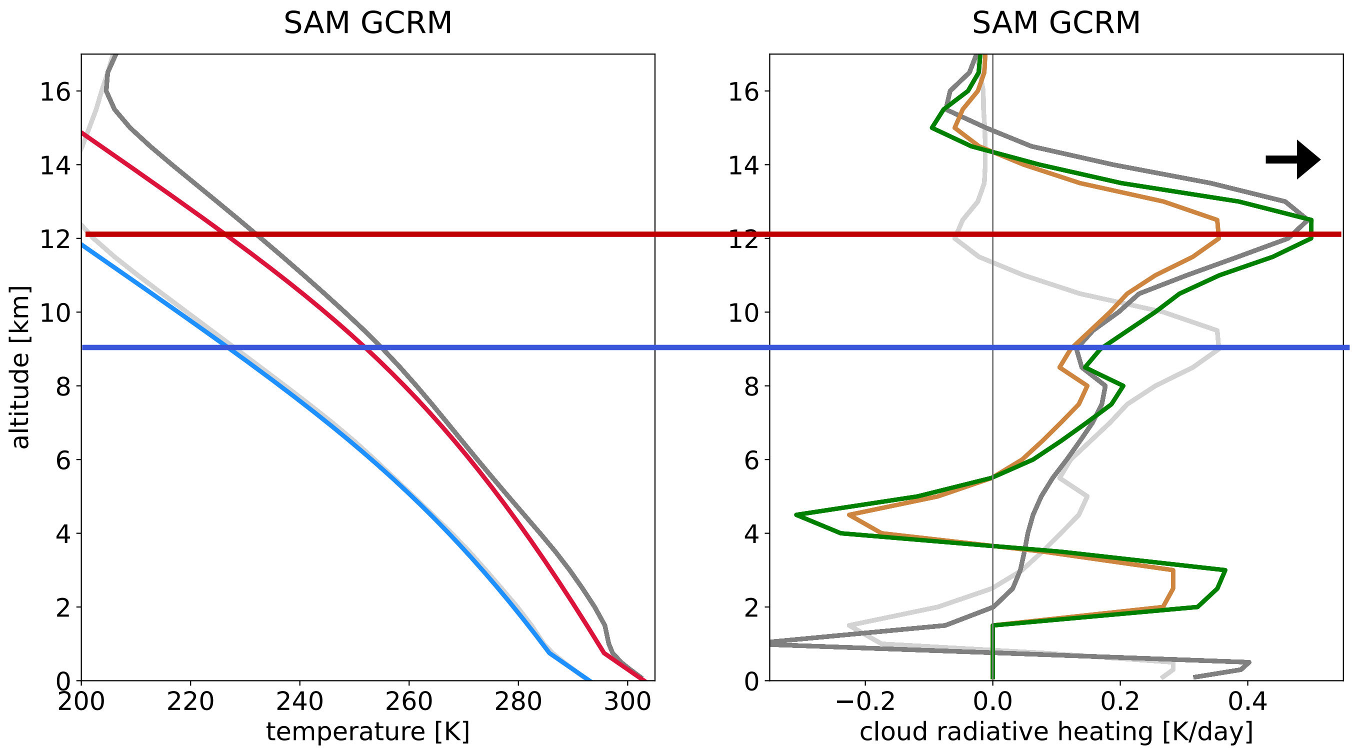
Example: Vertical shift



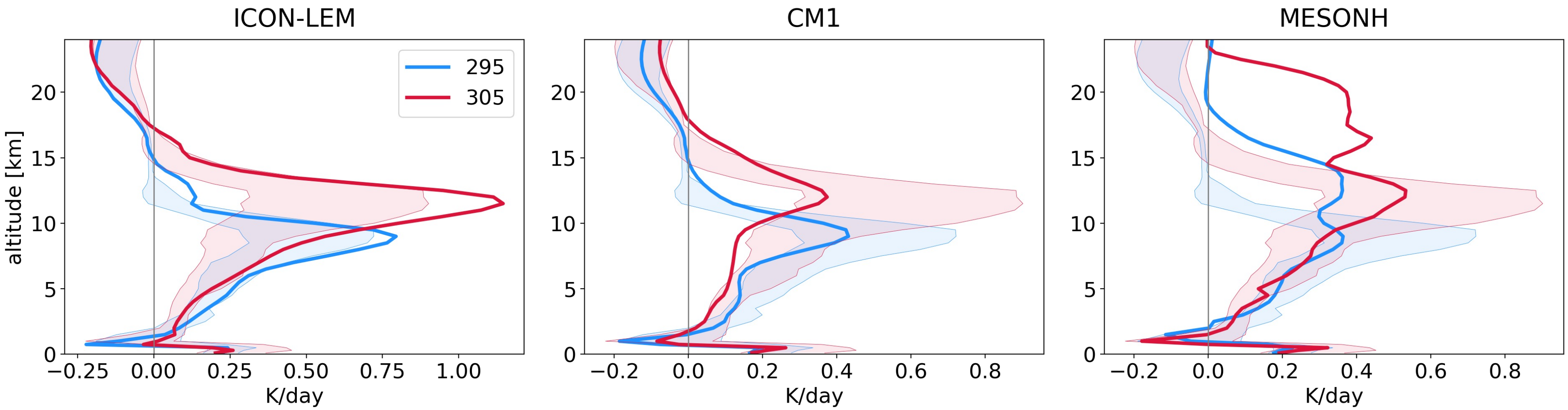
Example: Vertical shift – about 300 m bias



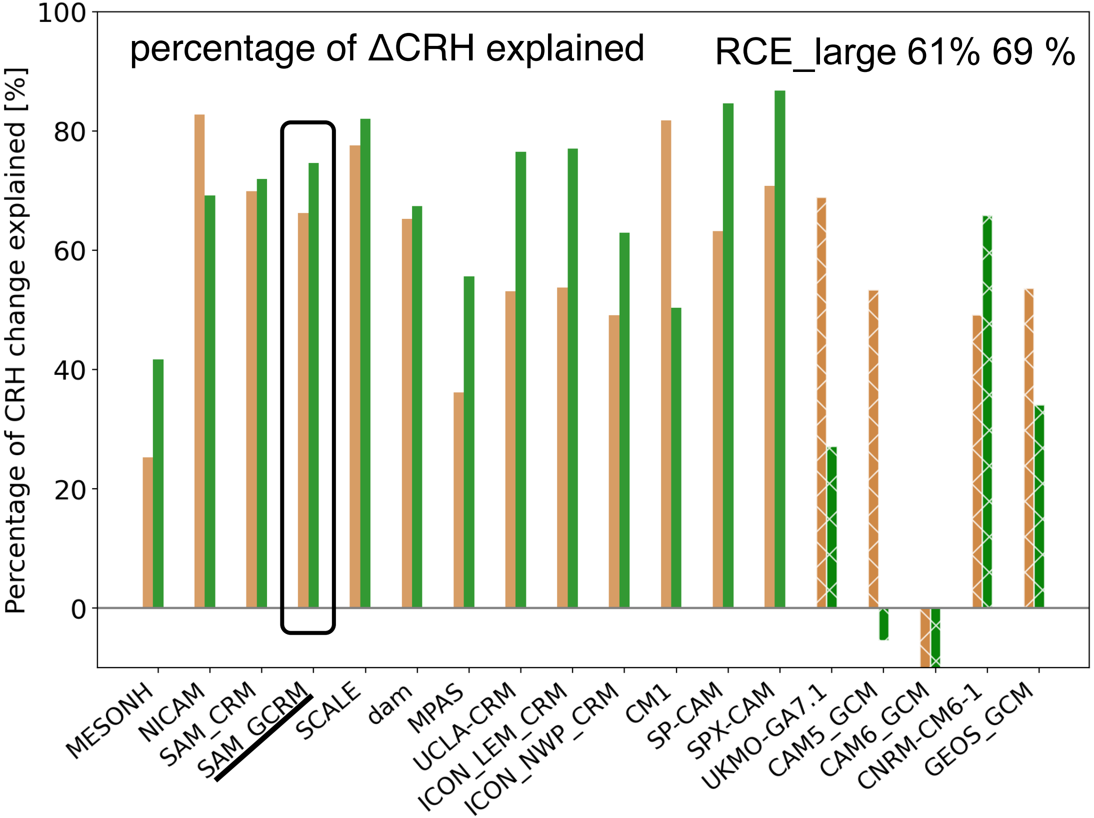
Example: Density factor – quite accurate



Caveat: RCEMIP models point at a large CRH spread



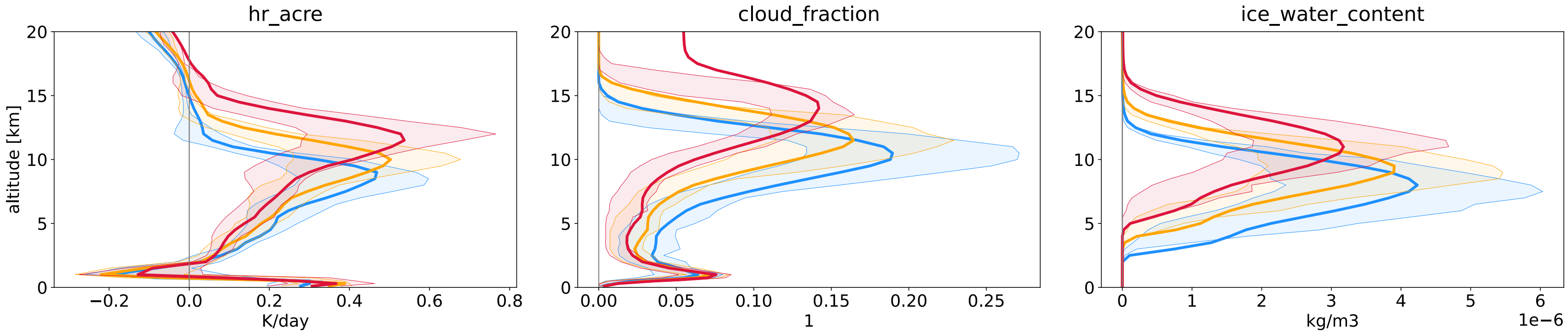
The change can be well explained by a vertical shift (~60%) and the density change (~10%)



1. Vertical shift
2. Density change

General message:
Climate change would be an easier problem if models would accurately reproduce the present-day cloud radiative heating

Where does the missing 30% of the spread comes from?



Large spread!

$$\frac{\partial T}{\partial t} = \frac{g}{\rho c_p}\frac{\partial F}{\partial z}$$

Changes in cloud fraction and ice water content are responsible for the rest of the spread

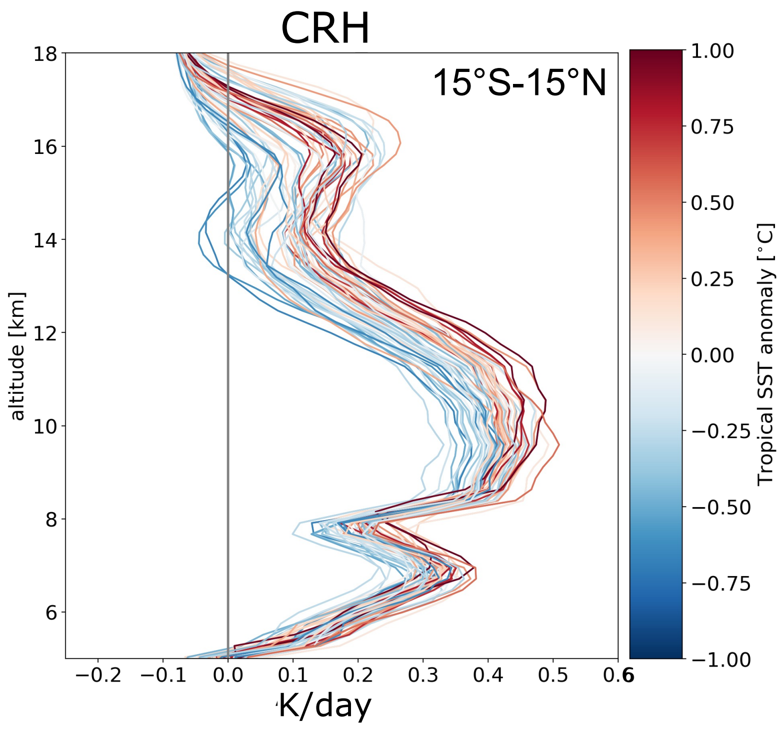
Is it possible to assume an apriori “iris” term?

Shift in altitude: density decreases

What about the real tropical atmosphere?

Can we detect a cloud radiative heating signal from the interannual variability?

1. CloudSat-CALIPSO-derived CRH looks promising!

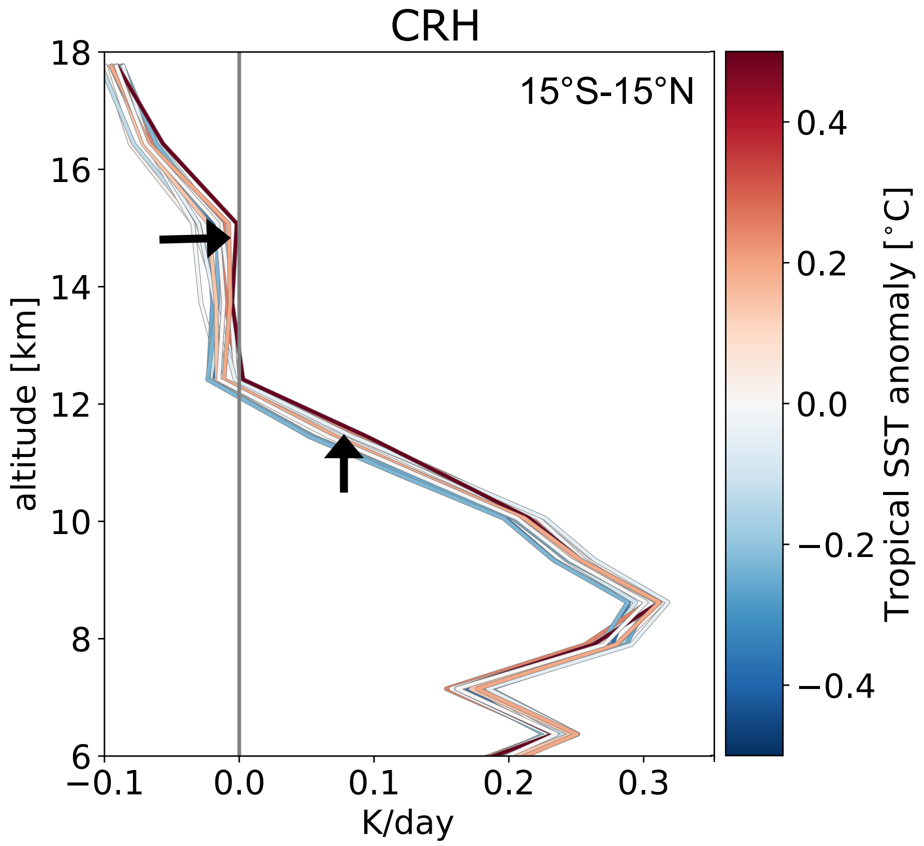


About 6 years of monthly CloudSat-CALIPSO derived heating rates

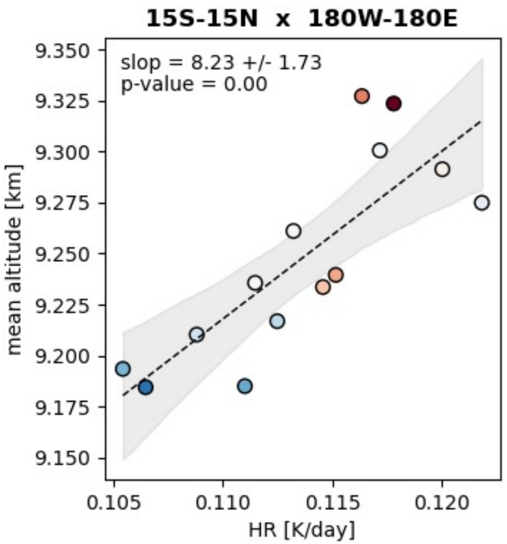
Color: Tropical SST anomaly from the selected 6-year mean

Caveats:
1. mixing up seasonal shifts and interannual variability!
2. Only 6-year long timeseries of this product

2. IR-sounder-derived CRH: not that clear signal

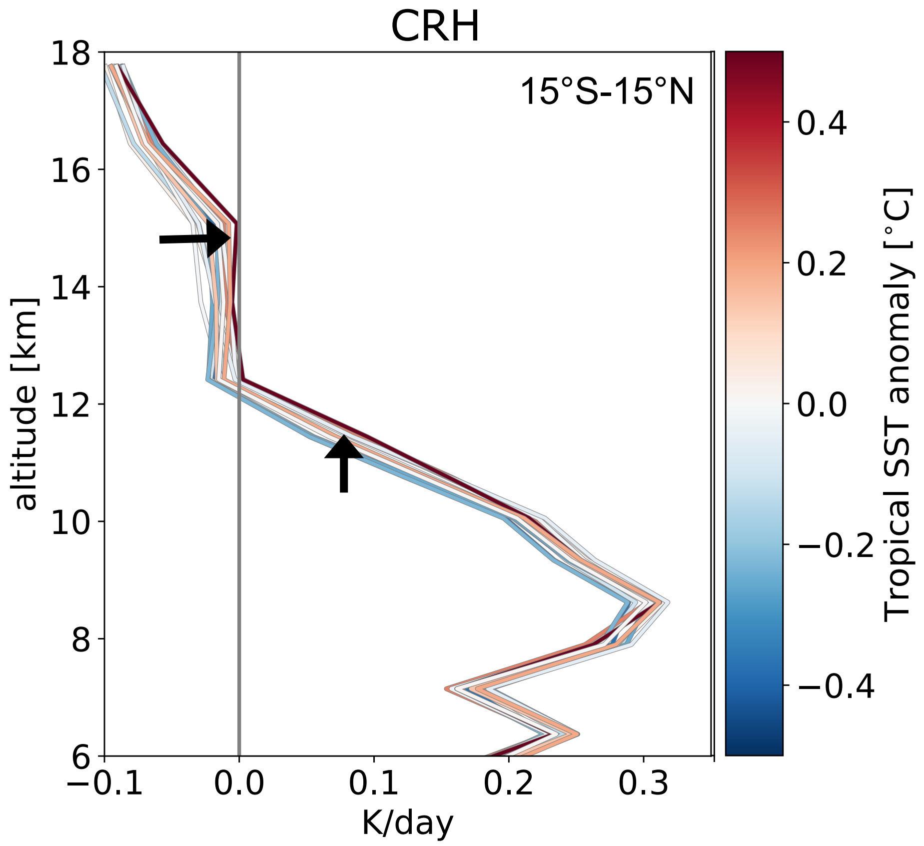


15-year long CRH dataset (Stubenrauch et al., 2021) based on AIRS data trained on the CloudSat-CALIPSO from the previous slide



Upper tropospheric heating rates increase in magnitude in warmer years, peak shifts to higher altitudes

2. IR-sounder-derived CRH: not that clear signal



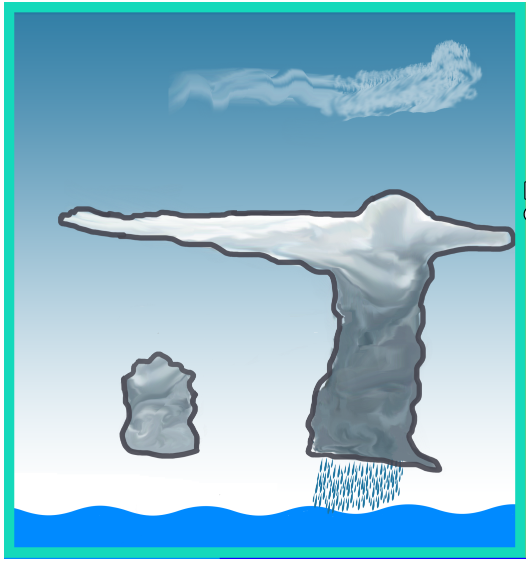
15-year long CRH dataset (Stubenrauch et al., 2021) based on AIRS data trained on the CloudSat CALIPSO from the previous slide

Caveats:

1. Clear-sky cooling may be mixed into the cloud radiative heating
2. Vertical resolution

Conclusions

1. Theory: If clouds behave according to FAT/PHAT, their CRH increase when they shift higher in altitude/lower in density
2. RCEMIP simulations: Well explained by an isothermal shift on a diluted adiabat + density factor
   What about the GCMs?
3. Observations: vertical shift + intensity increase
   [cannot be explained by density alone]



If we know the control climate state we can to a large extent predict its shift in a warmer climate

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