High cloud radiative heating increases with warming and can be predicted by simple physics

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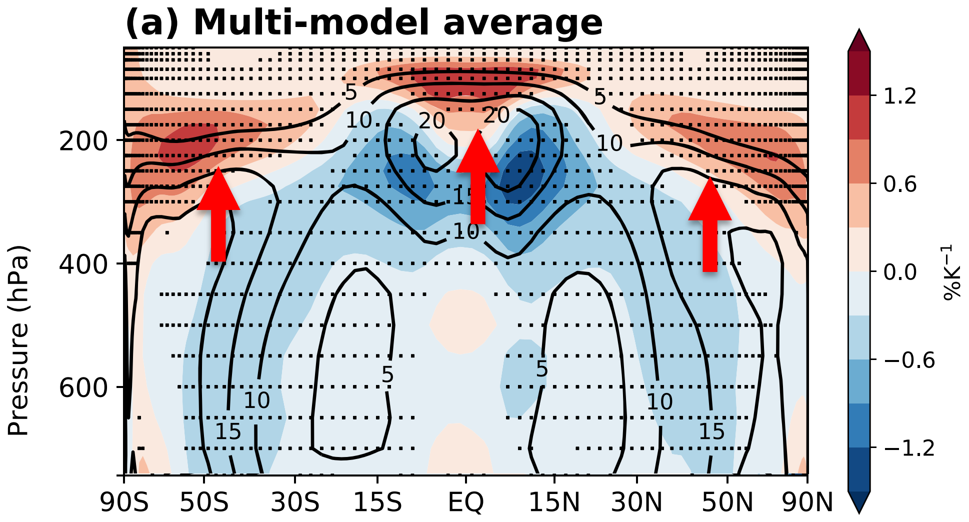
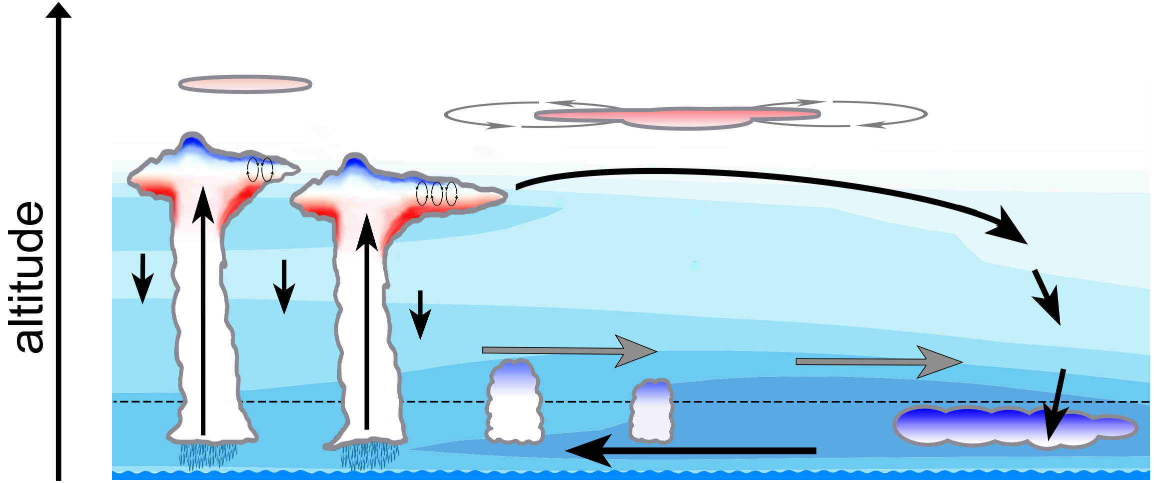
Increase in altitude of high clouds is the most robust cloud response to global warming



Mean warming response (colors) of cloud fraction from 20 CMIP5 models (Sherwood et al., 2020)

Positive cloud feedback, with a value of 0.2 ± 0.1 W m^{-2}/K (Zelinka et al., 2016; Sherwood et al., 2020)

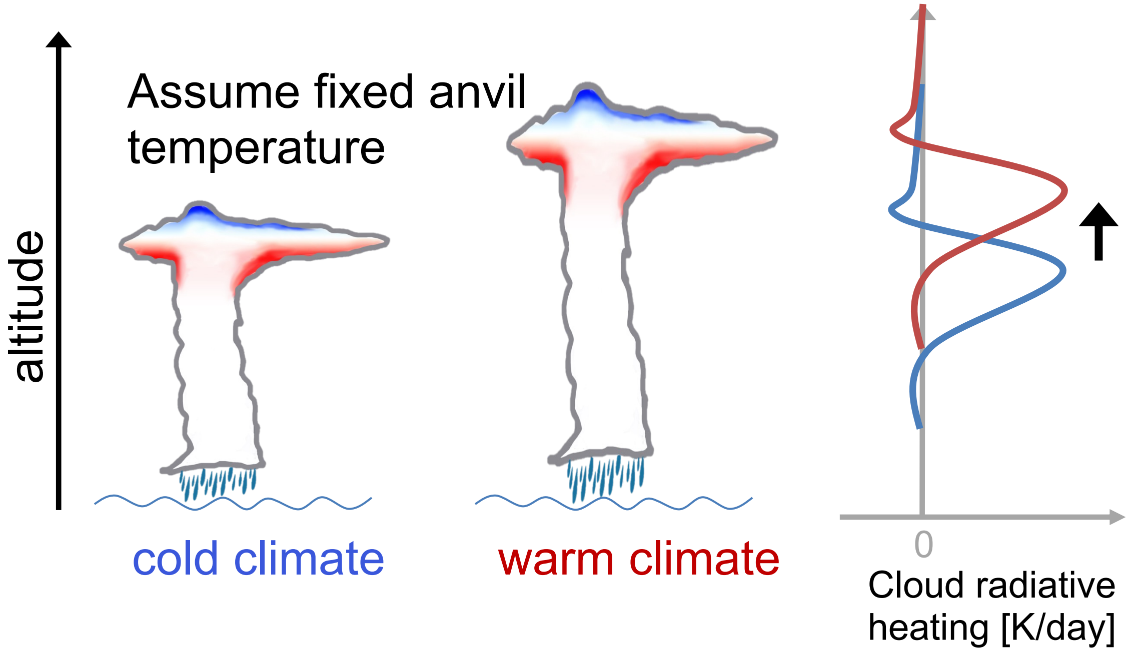
Cloud radiative heating modulates circulations and their responses to global warming



Dinh et al., accepted

Cloud radiative heating drives large-scale dynamics and its response to global warming (e.g. Voigt et al., 2021, Dinh et al., accepted) and mesoscale circulations (e.g. Gasparini et al., 2022)

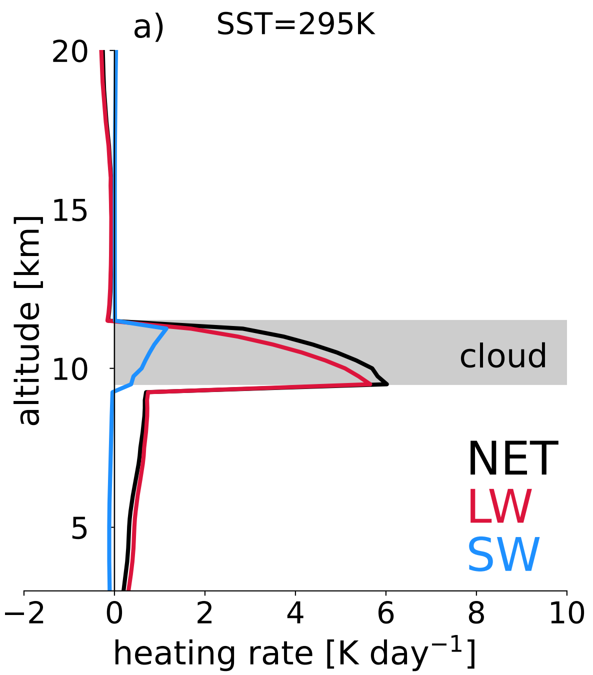
Changes in cloud radiative heating (CRH) with warming



Zero hypothesis:

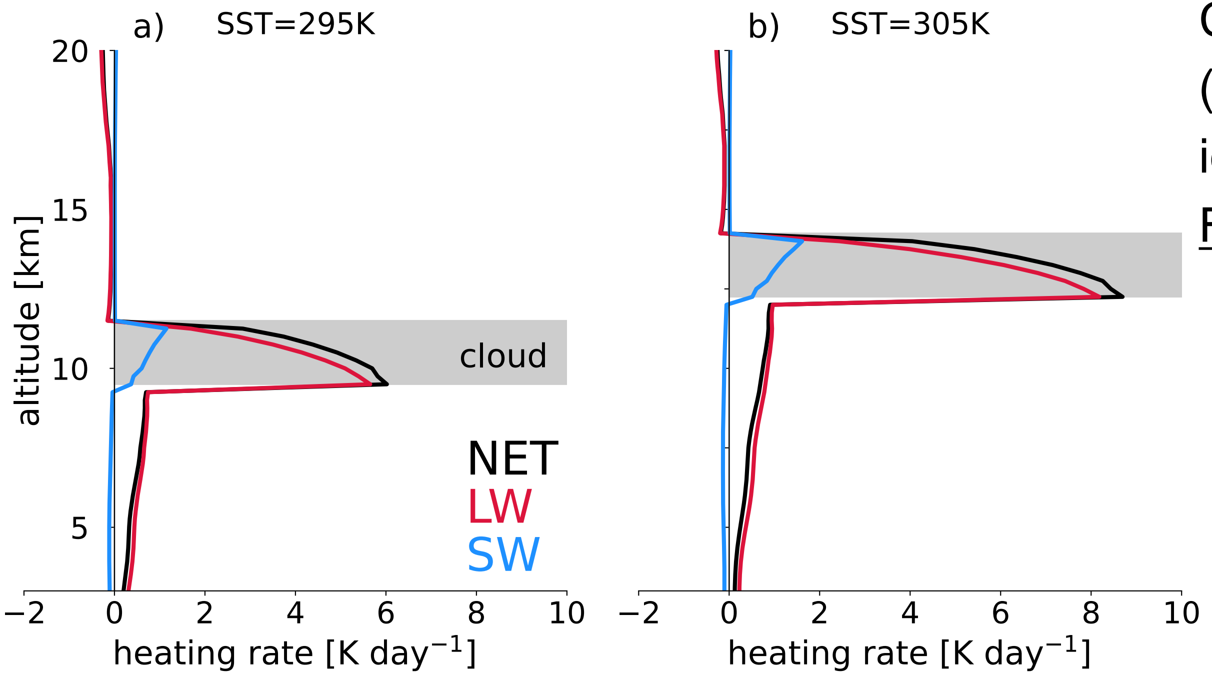
Cloud radiative heating shifts to a higher level

Radiative calculations show an increase in CRH



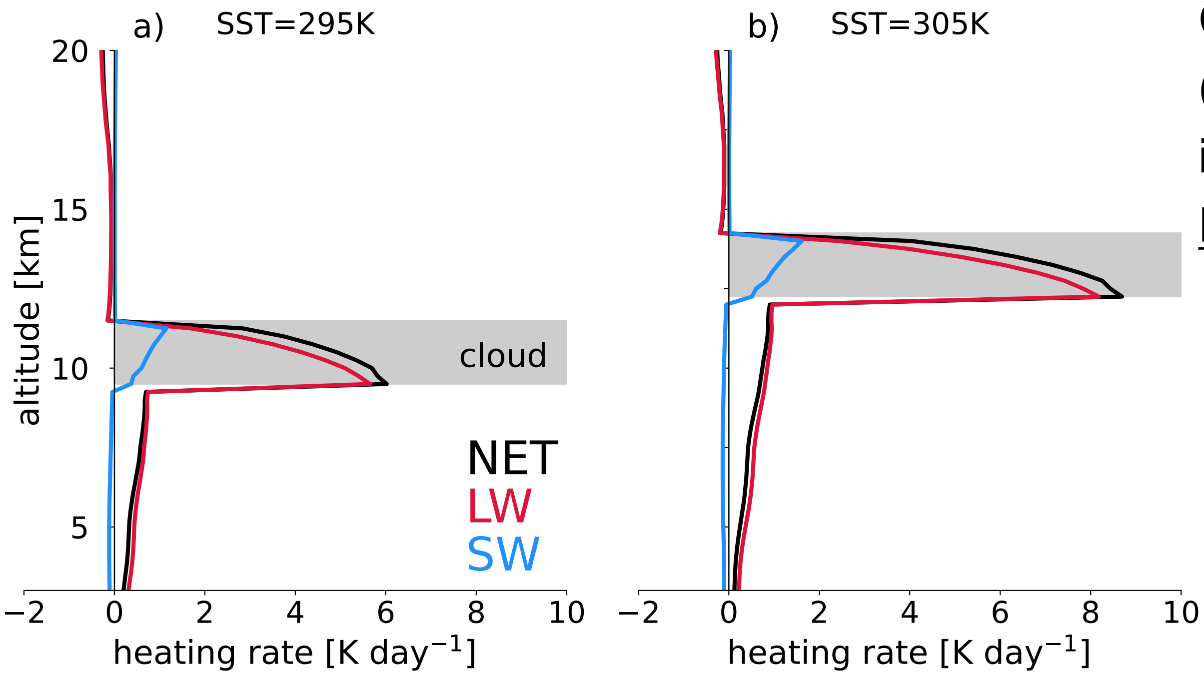
Cloud with **FIXED** properties
(cloud optical depth = 1,
ice water path = constant)
<u>Fixed cloud base temp.</u>

Radiative calculations show an increase in CRH



Cloud with **FIXED** properties
(cloud optical depth = 1,
ice water path = constant)
<u>Fixed cloud base temp.</u>

The increase in CRH is explained by a decrease in density



Cloud with **FIXED** properties

(cloud optical depth = 1,

ice water path = constant)

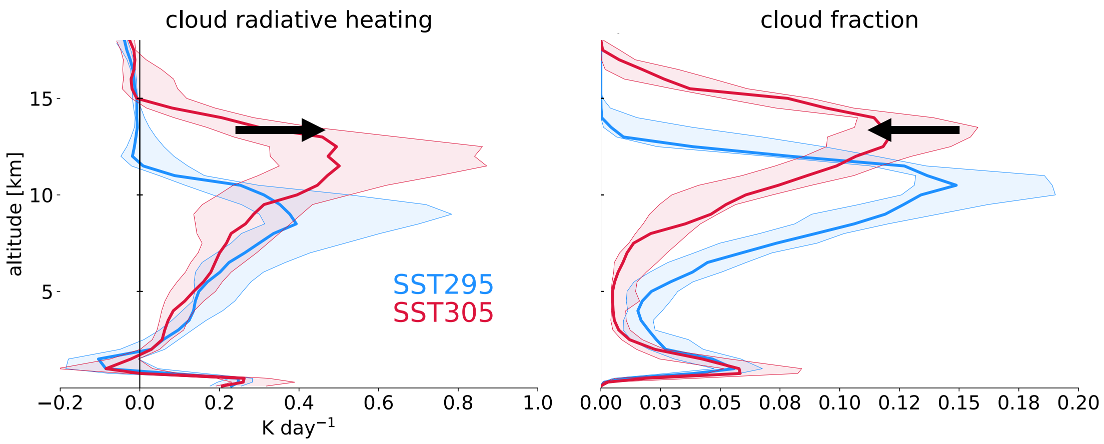
<u>Fixed cloud base temp.</u>

Approximately fixed

$$\frac{\partial T}{\partial t} = \frac{1}{\boxed{\rho} c_p} \boxed{\frac{\partial F}{\partial z}}$$

Shift in altitude:
density decreases

RCE simulations are consistent with this picture

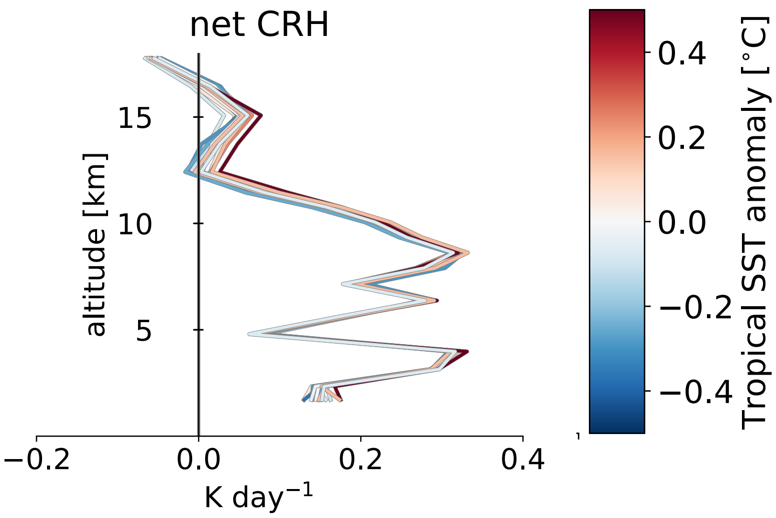


RCEMIP data

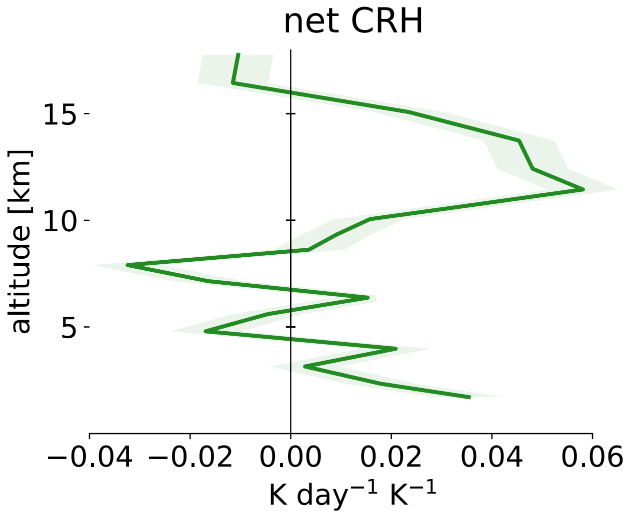
RCE_large domain simulations from 13 cloud resolving models (Wing et al., 2020)

Despite a mean cloud fraction decrease, cloud radiative heating increases!

Satellite data also show an increase in upper tropospheric CRH in warmer years

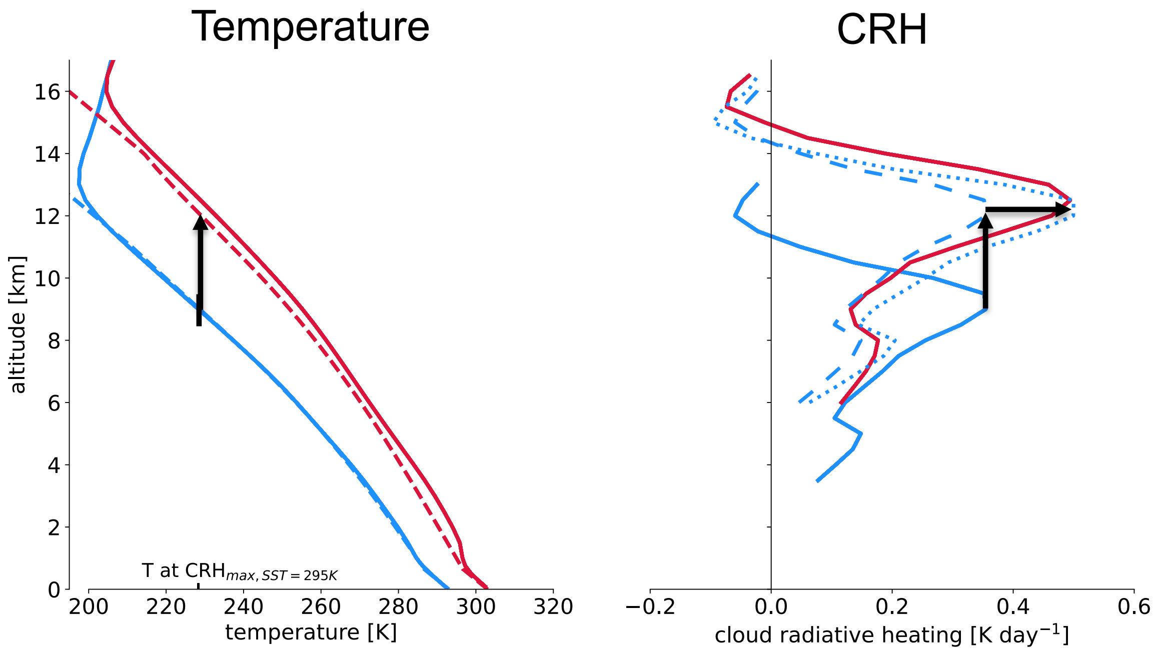


15-year satellite dataset based on infrared sounder data trained on 2B-FLXHR (Stubenrauch et al., 2021)



Response of satellite retrieval to warming comparable to CRH changes in models

Prediction based on “FAT” and diluted moist adiabats

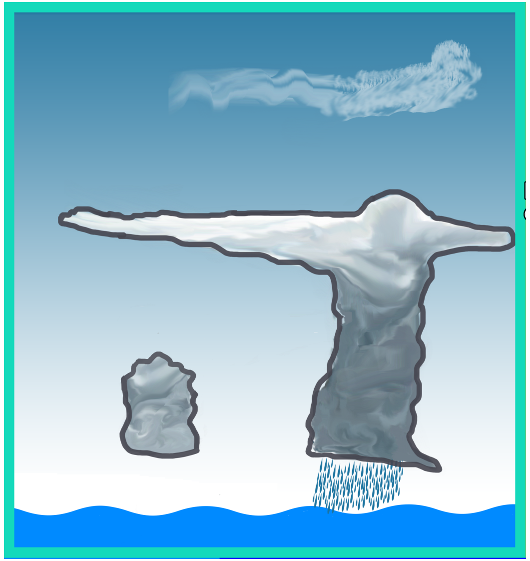


1. Fit a diluted moist adiabat
2. Find the temperature at peak CRH
3. Increase its surface value by 10°C
4. Assume no change in temperature at peak CRH, find the upward shift
5. Apply the density correction

Example for SAM GCRM model

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
3. Observations: same mechanism detected in interannual CRH variability



If we know the present day CRH we can predict its response to surface warming

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