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Atmospheric cloud-radiative heating in CMIP6 and observations, and its response to surface warming

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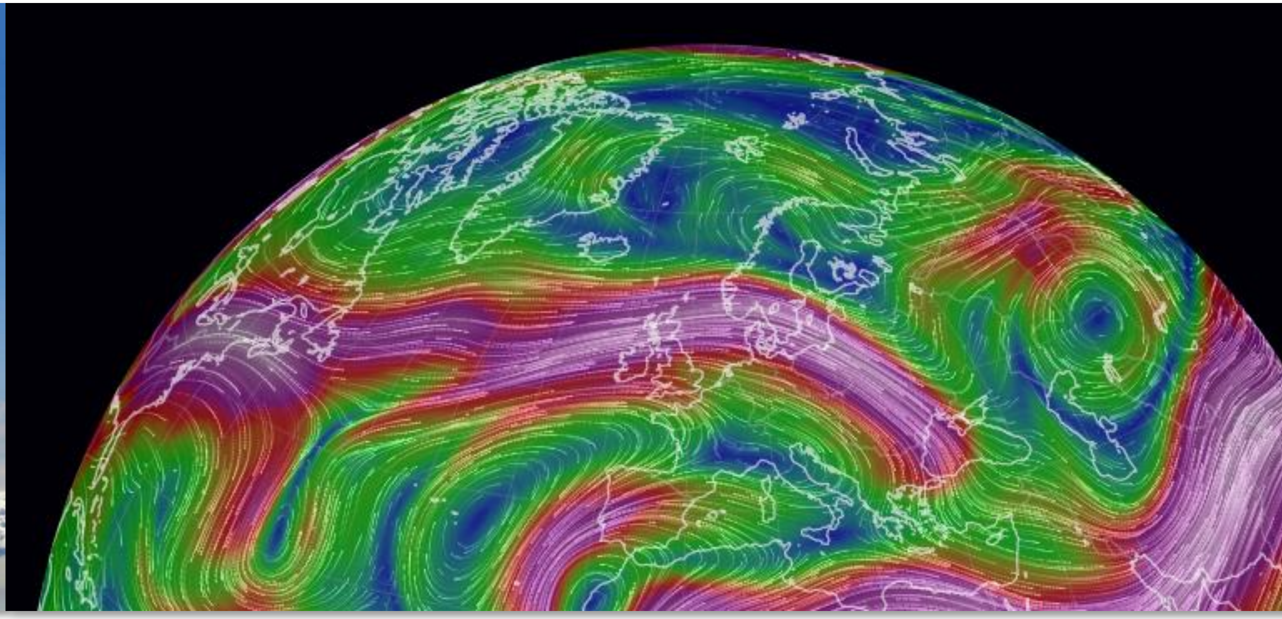
Clouds and radiation

Planetary-scale circulation of the atmosphere



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Key Points:

- Radiative heating from high clouds leads to a stronger cyclone, radiative heating from low clouds leads to a weaker cyclone
- Because of this tug-of-war, the overall effect of cloud-radiative heating can be a stronger or weaker cyclone
- The radiative impact of clouds can be understood from the effect on static stability

Tug-Of-War on Idealized Midlatitude Cyclones Between Radiative Heating From Low-Level and High-Level Clouds

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Abstract We present baroclinic life-cycle simulations with two versions of the atmosphere model ICON to understand how cloud-radiative heating and cooling affect an idealized midlatitude cyclone. Both versions simulate the same cyclone when run without radiation, but disagree when cloud-radiation-interaction is taken into account. The radiative effects of clouds weaken the cyclone in ICON2.1 but strengthen it in ICON2.6. We attribute the disagreement to low-level clouds, which in ICON2.1 are more abundant and show stronger

Cloud-radiative heating, i.e., cloud feedbacks, are crucial for climate and weather.

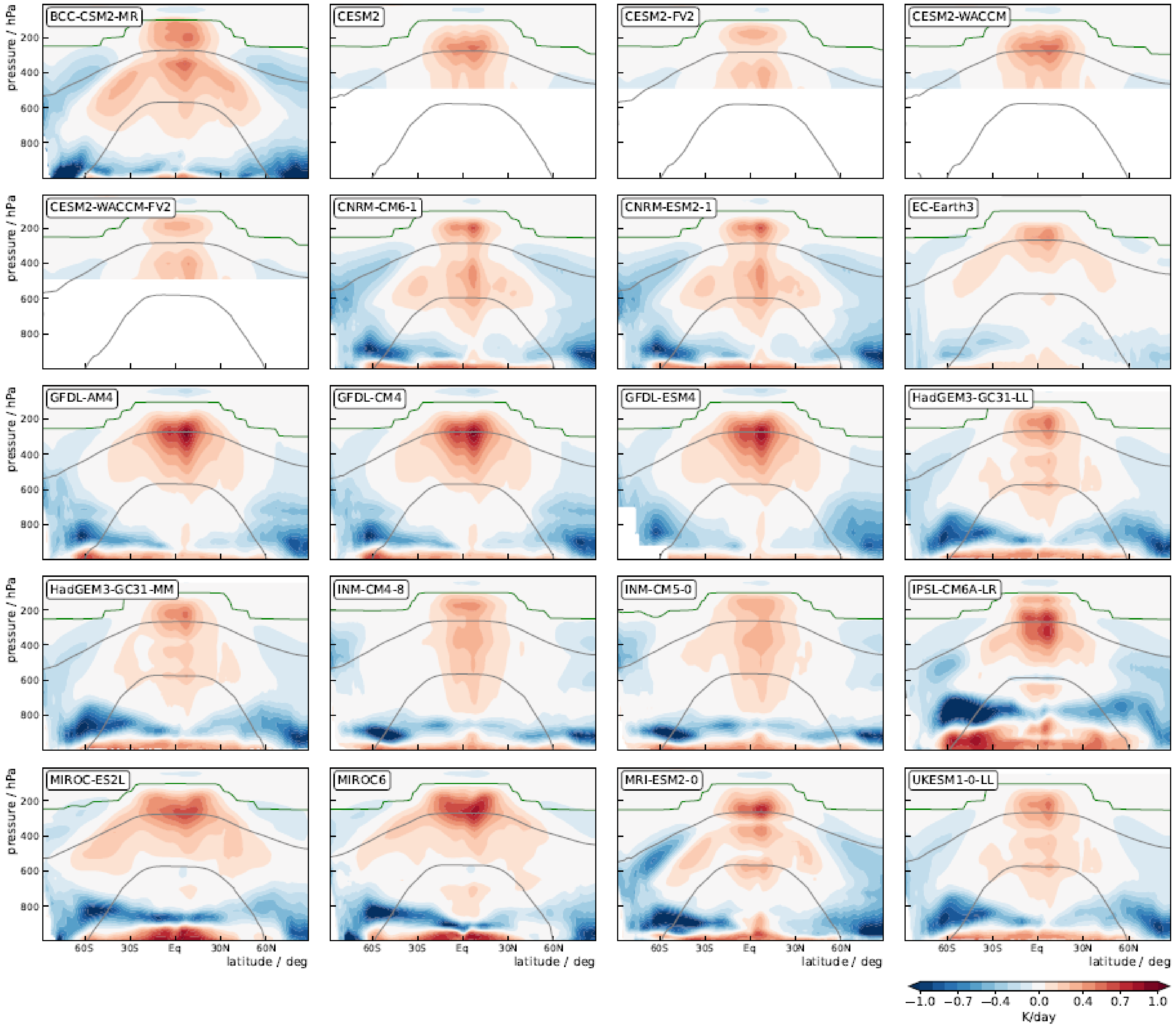
The cloud-radiative impact on the TOA energy balance was studied extensively in obs and models.

But how well do global climate models represent cloud-radiative heating within the atmosphere?

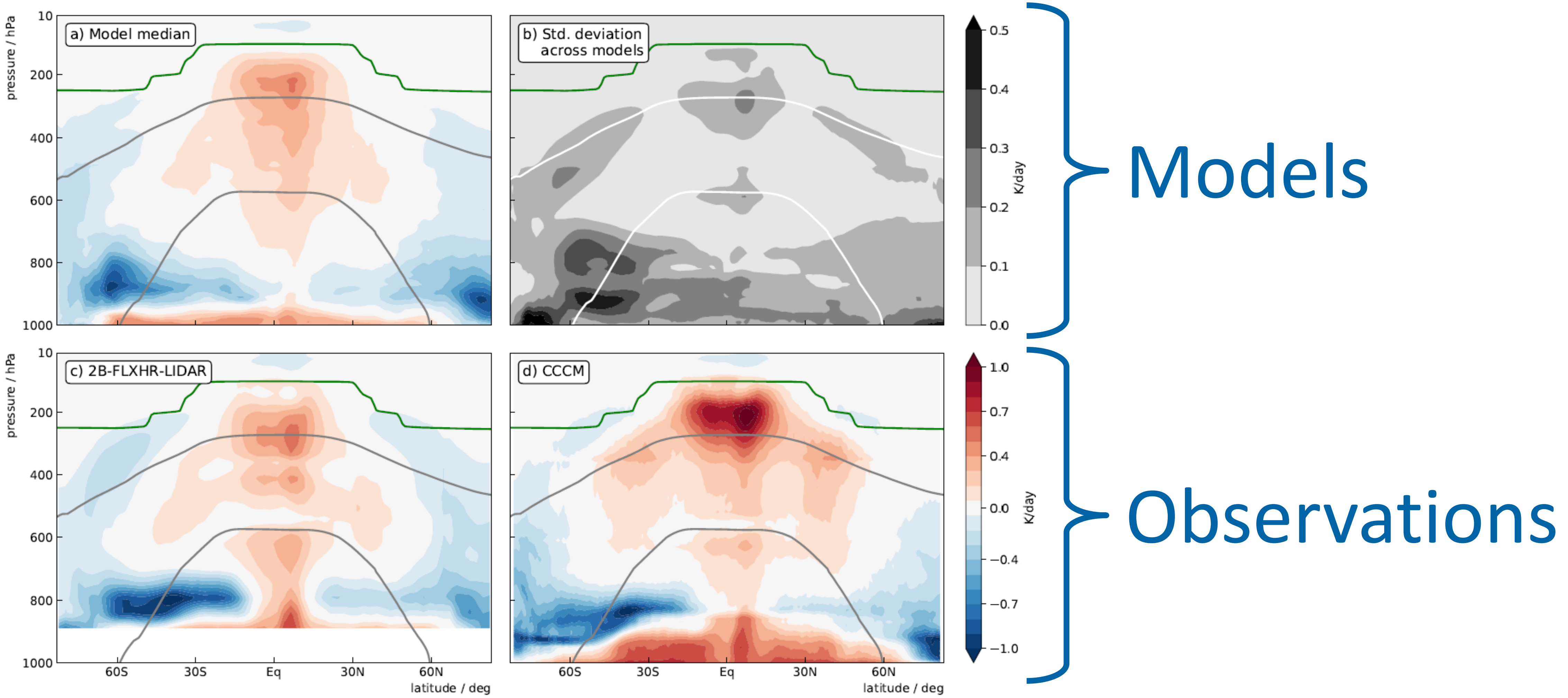
cloud-radiative heating within the atmosphere

$$
\begin{aligned}
CRH &= \left.\frac{\partial T}{\partial t}\right|_{\text{radiation}}^{\text{all-sky}} - \left.\frac{\partial T}{\partial t}\right|_{\text{radiation}}^{\text{clear-sky}} \\
&= -\frac{g}{c_p} \cdot \frac{\partial}{\partial p}\left(F^{\text{all-sky}} - F^{\text{clear-sky}}\right) \\
&= \frac{1}{\rho\, c_p} \cdot \frac{\partial}{\partial z}\left(F^{\text{all-sky}} - F^{\text{clear-sky}}\right)
\end{aligned}
$$

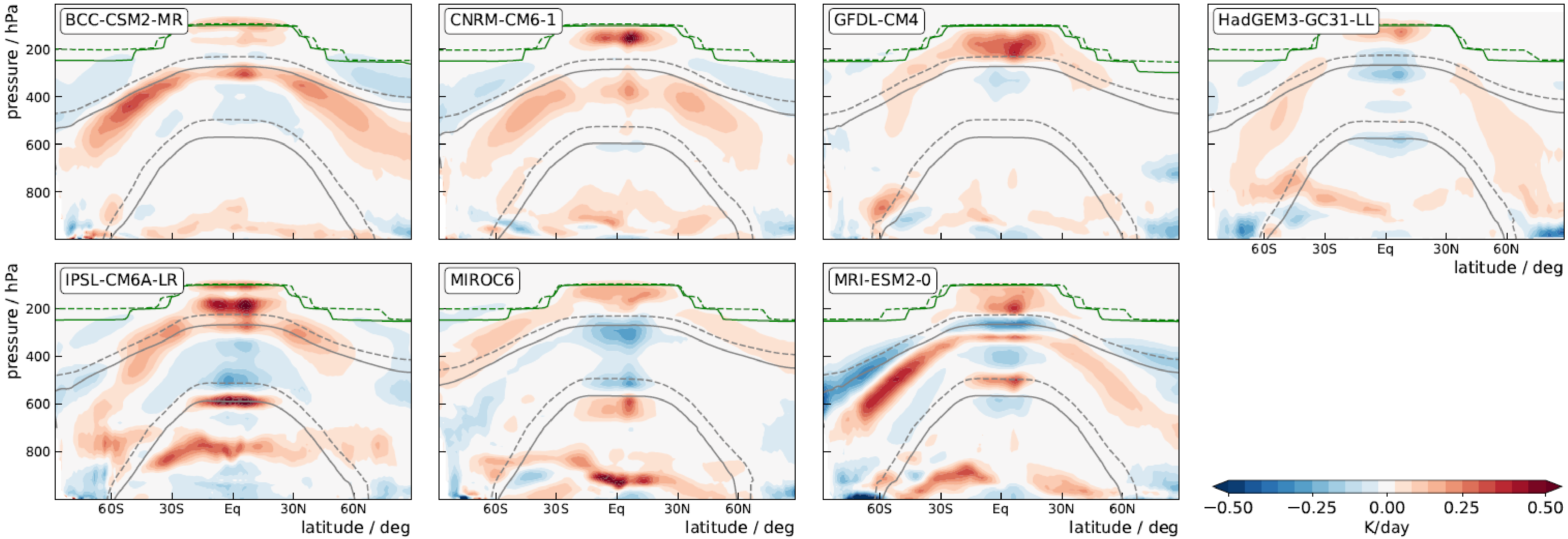
CRH in 20 CMIP6 models



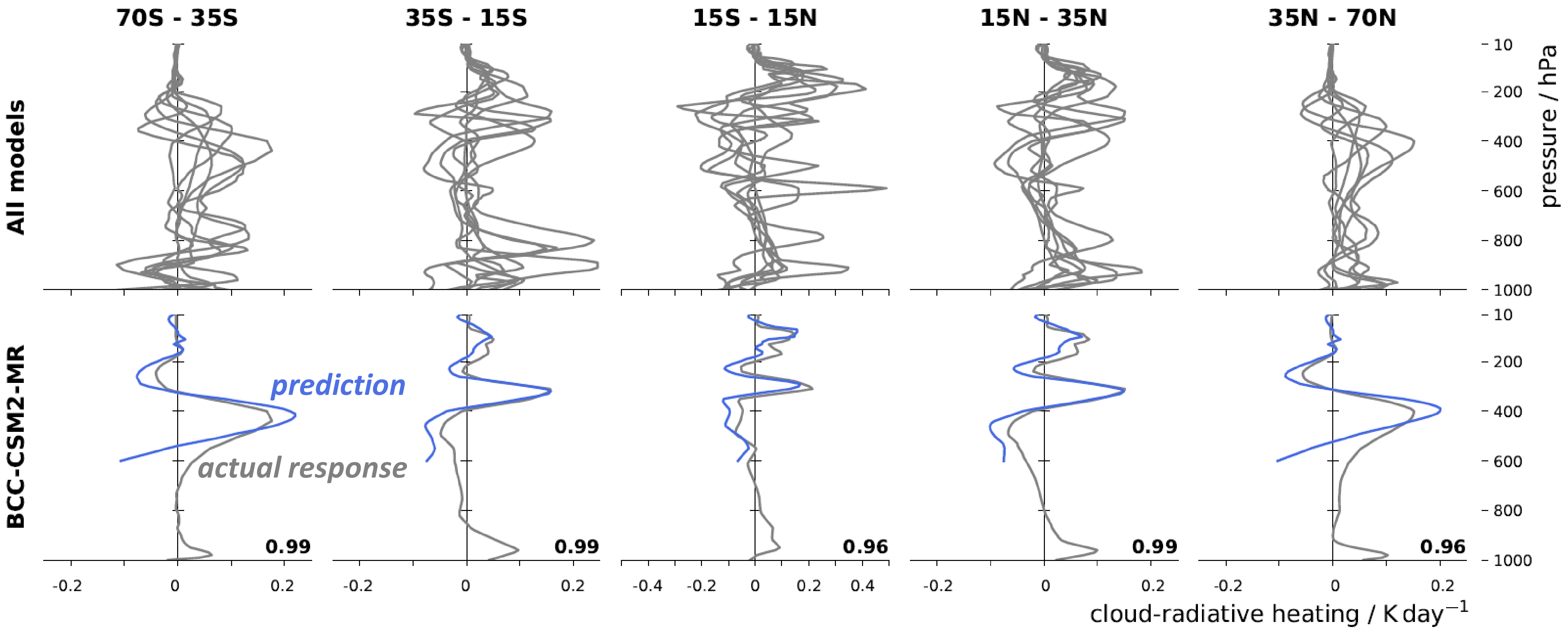
Large model spread in CRH connected to high-level ice clouds and low-level Southern Ocean clouds



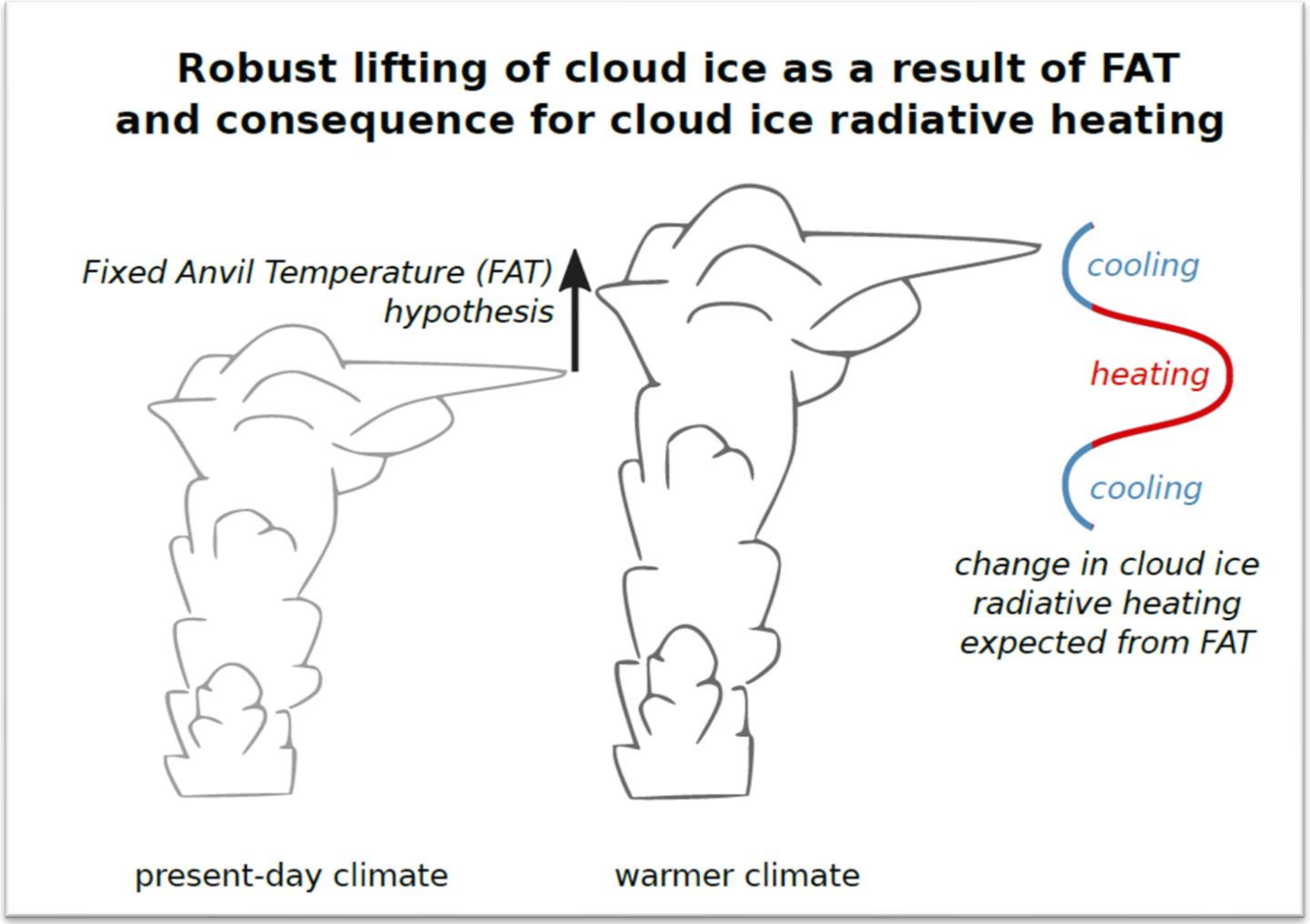
Also large model spread in the response of the models‘ CRH to surface warming. This is not surprising.



However, the response of upper-tropospheric CRH to surface warming is very well predicted by an upward shift of today‘s CRH.



Mechanism



$$dCRH(p, \varphi) = CRH(p, \varphi) - CRH(\beta p, \varphi)$$

response of CRH = upward-shifted present-day CRH – present-day CRH

Take home points (a.k.a. key points of manuscript in review at AGU Advances)

Key Points:

- First assessment of the vertical structure of cloud-radiative heating within the atmosphere in CMIP6 global climate models
- Model differences are largest in the lower and upper troposphere, smallest in the mid-troposphere
- Upper-tropospheric response to warming is predicted by upward shift of present-day heating and independent of pattern of surface warming