# THE IMPORTANT ROLE OF FEEDBACK PROCESSES FOR CONTRAIL CIRRUS CLIMATE IMPACT

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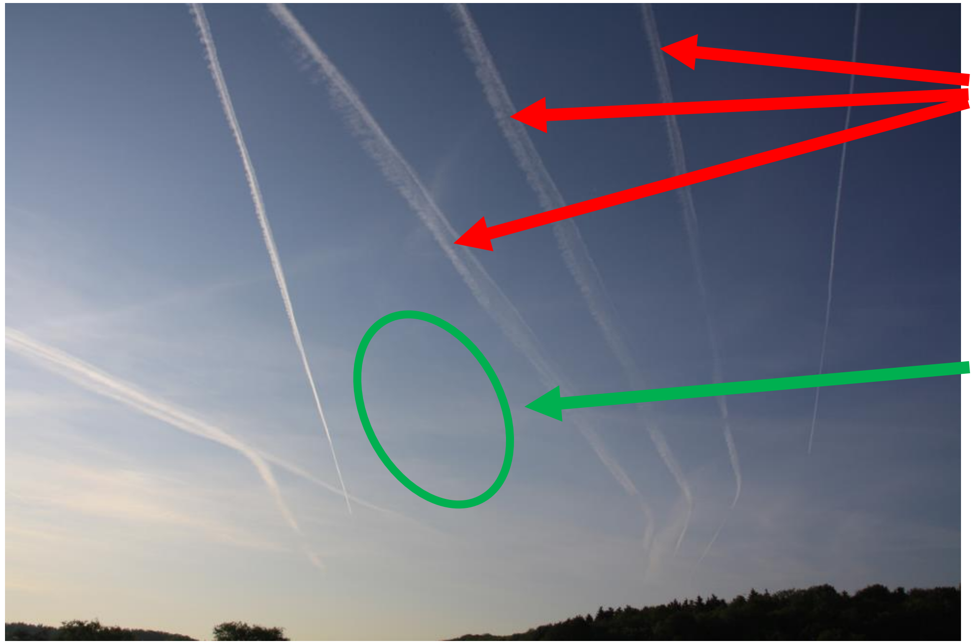
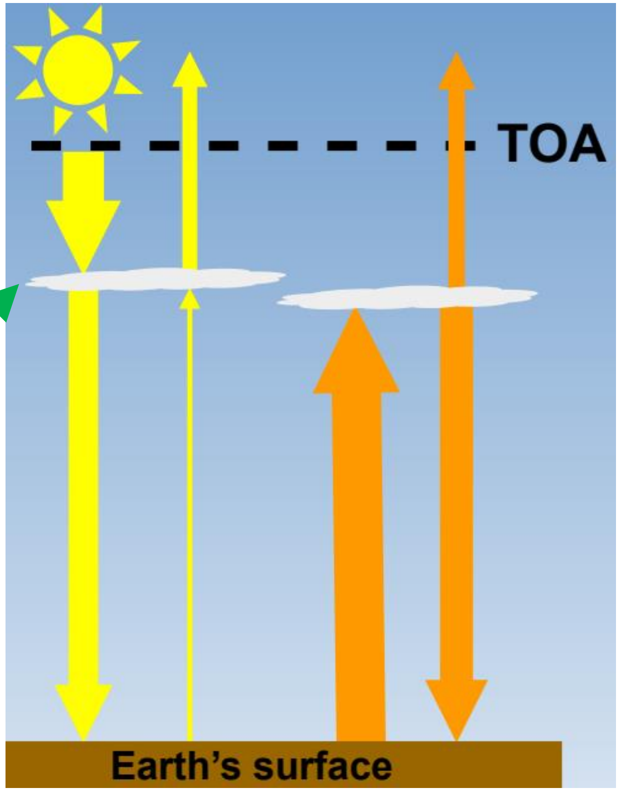
DLR

# Contrail cirrus climate impact



linear contrails

contrail cirrus




RF

Reflection of Shortwave radiation → **cooling**

Trapping of Longwave radiation → **warming**

In the net contrail cirrus **warm** the troposphere-surface-system

- aircraft emit water vapor which may freeze and form **linear contrails** (according to the Schmidt-Appleman contrail formation criterion)
- linear contrails may spread over large areas when the humidity of the atmosphere is large enough and transition into **contrail cirrus** (parameterized for global climate model)

**But how strong? Feedbacks!**

# Climate model setup

- EMAC / MESSy climate model, resolution 2.8° (horizontally), ~600m (vertically)
- Contrail cirrus parameterization of Bock and Burkhardt (2016)
  ↳ „Two-moment cloud scheme“ (ice water content and ice crystal number conc.)
- AEDT 2050 air traffic dataset 12× scaled (air traffic density and water vapor emissions)

**FSST simulations:**

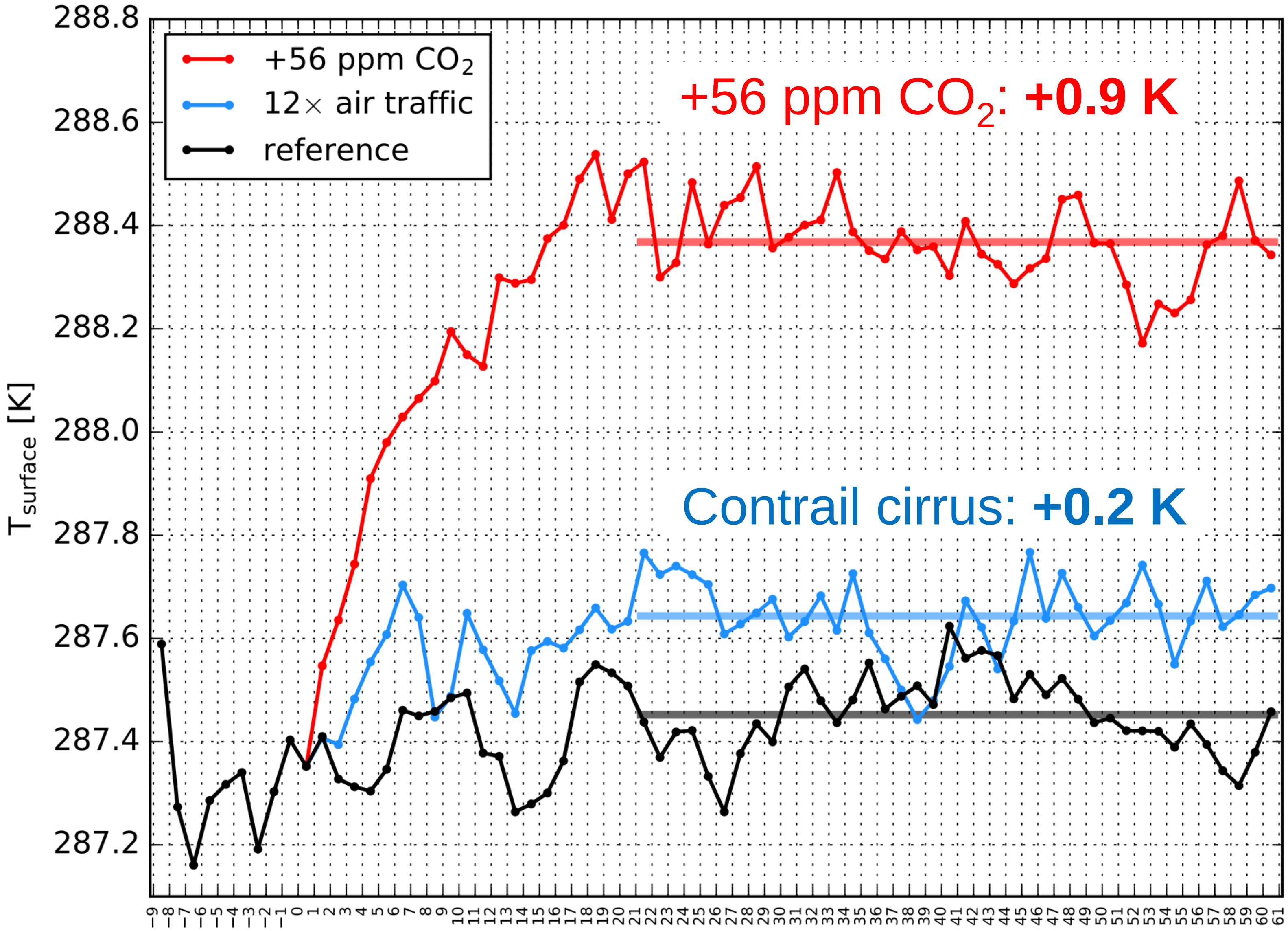
- sea surface temperatures fixed by climatology (FSST)
- Radiative forcings ($RF_{inst}$, $RF_{adj}$, ERF)
- Rapid radiative adjustments (“fast feedbacks”)

**Interactive ocean simulations:**

- Coupled mixed layer ocean (MLO)
- surface temperature change
- Slow feedbacks

# Surface temperature change

$RF_{Contrail\ cirrus}$: 858 $mWm^{-2}$
$RF_{+56\ ppm\ CO_2}$: 854 $mWm^{-2}$
same size



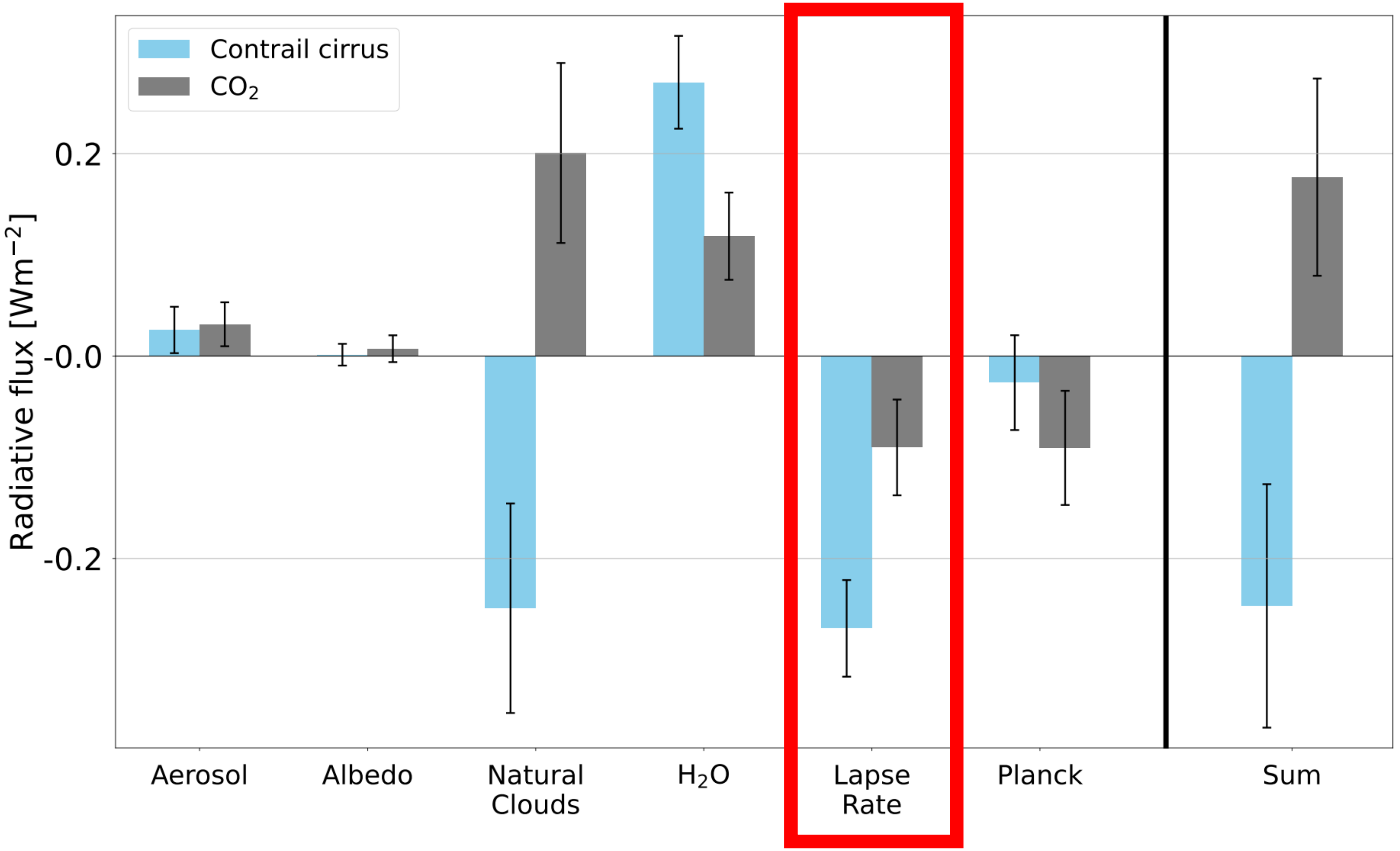

Contrail cirrus and $CO_2$ radiative forcing exhibit a different efficacy to induce surface temperature changes (contrail cirrus efficacy: **0.21**)

**Why?**

**Different Feedbacks!**

# Rapid radiative adjustments (“fast feedbacks”)

- PRP feedback analysis applied to FSST simulations → rapid radiative adjustments

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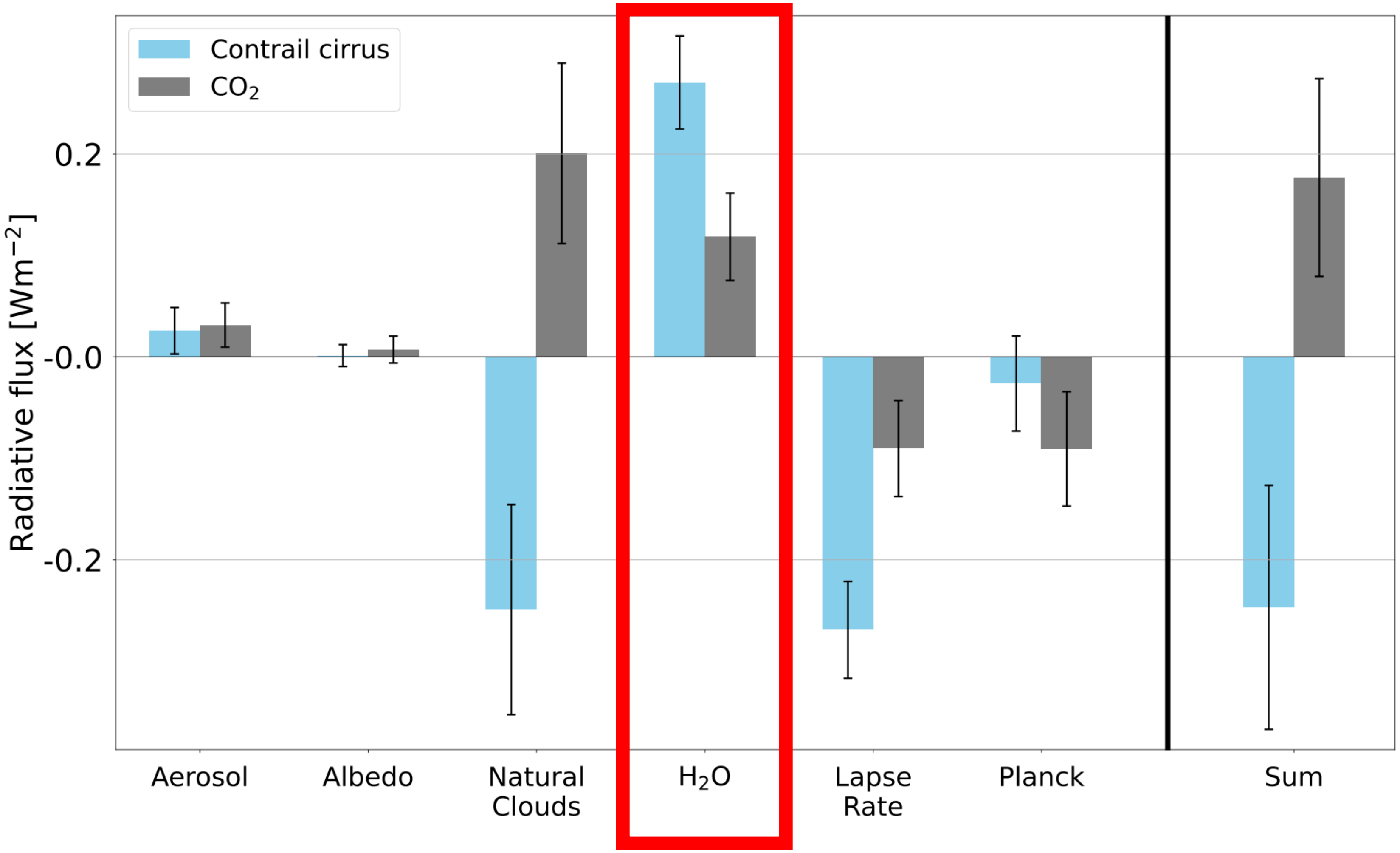


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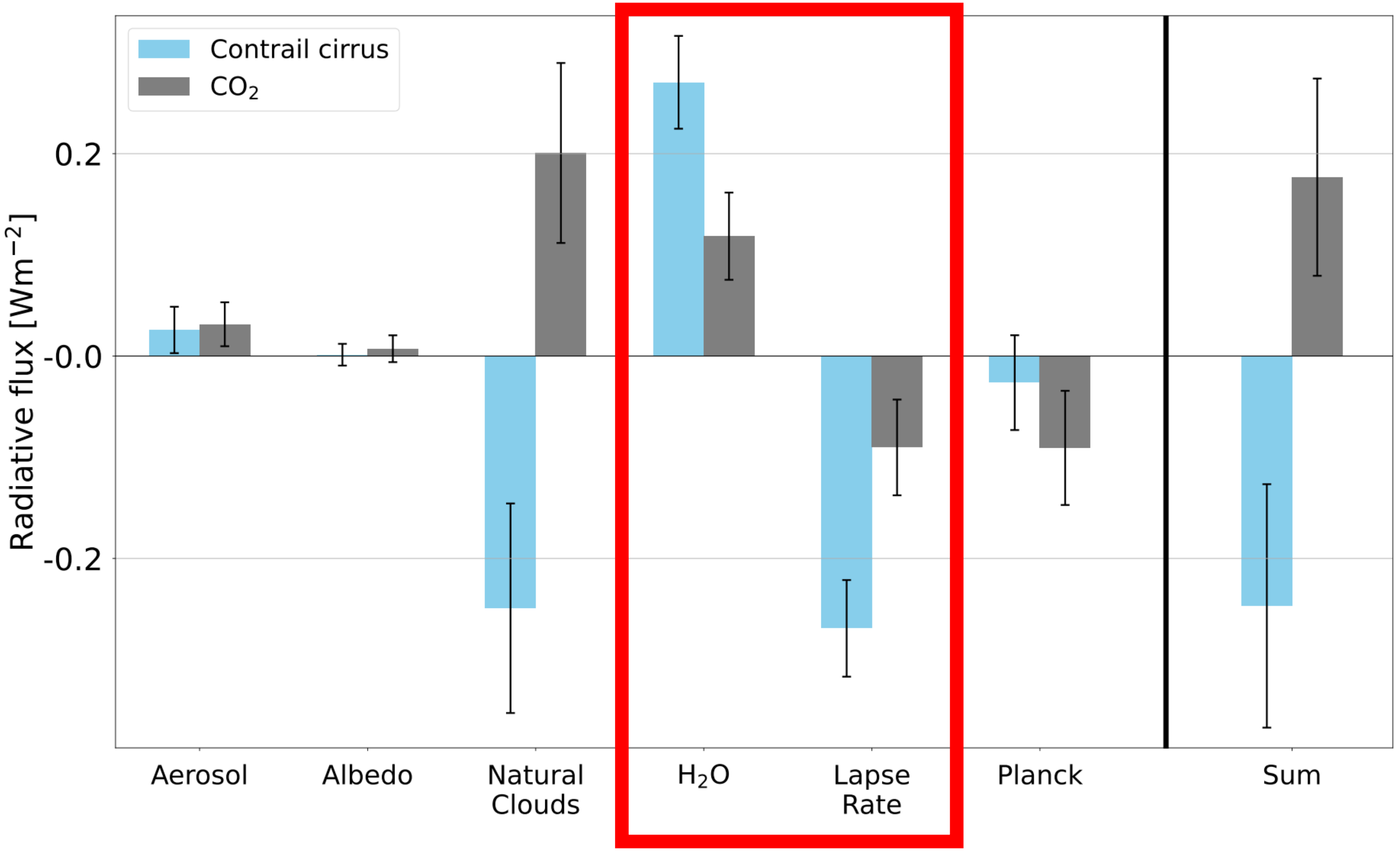


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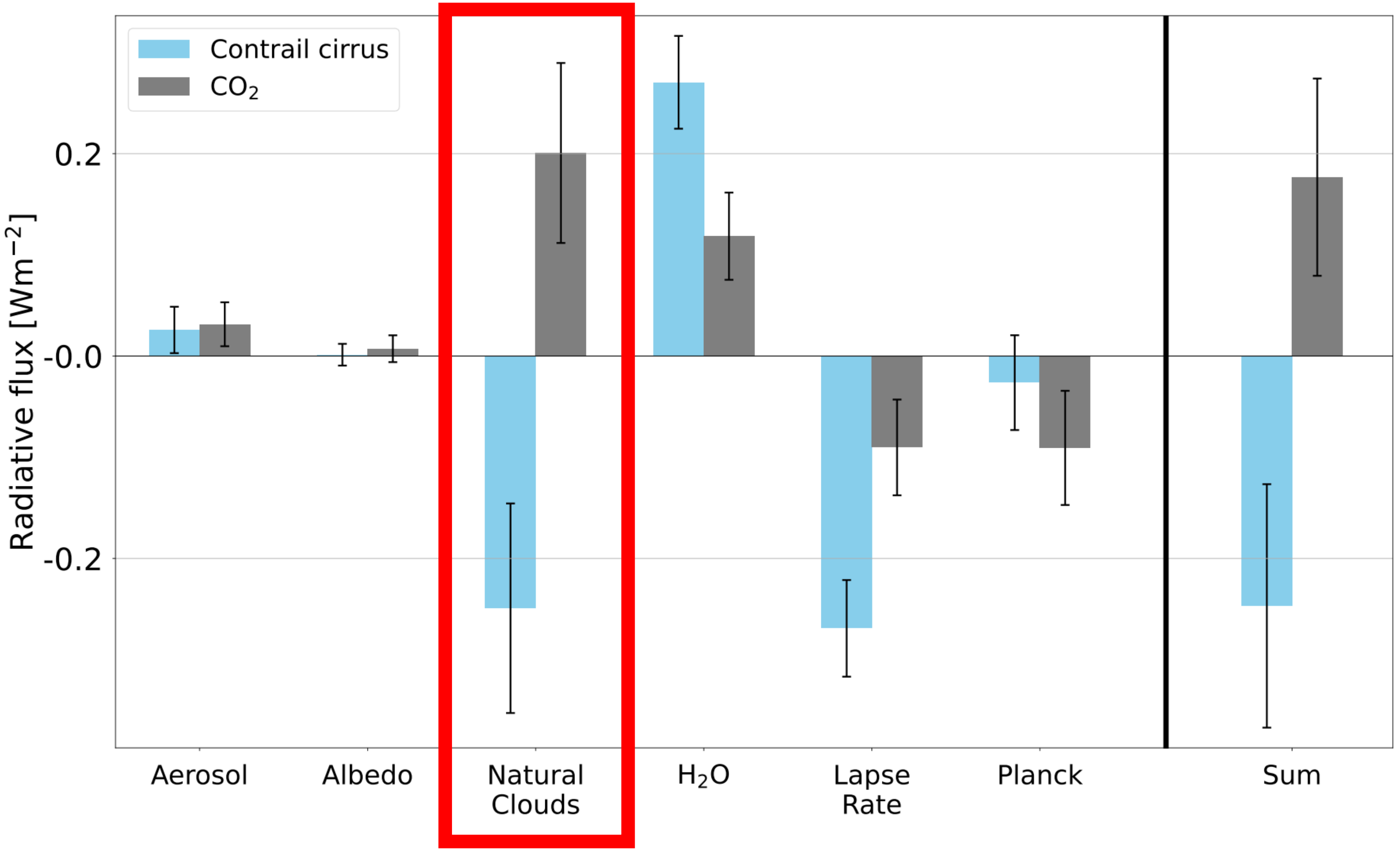


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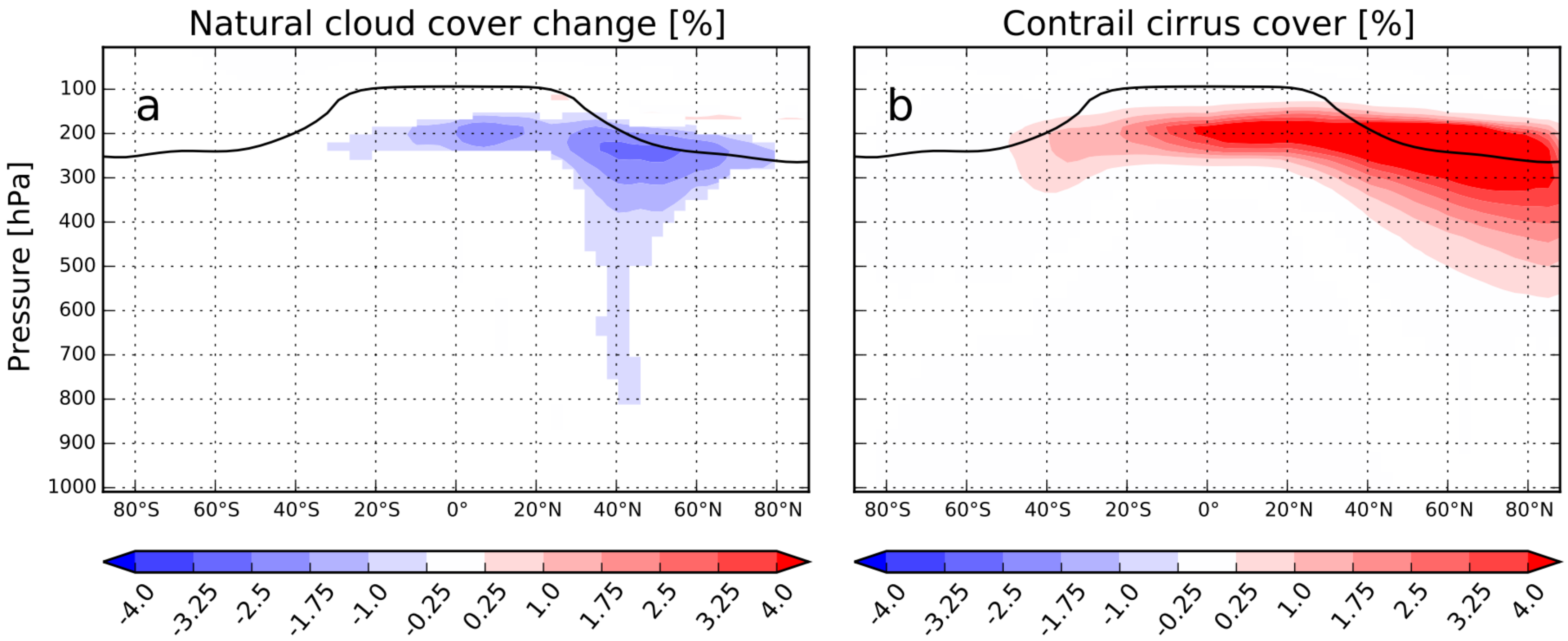
→ **Natural cloud rapid adjustment** most important

# Natural cloud rapid radiative adjustment



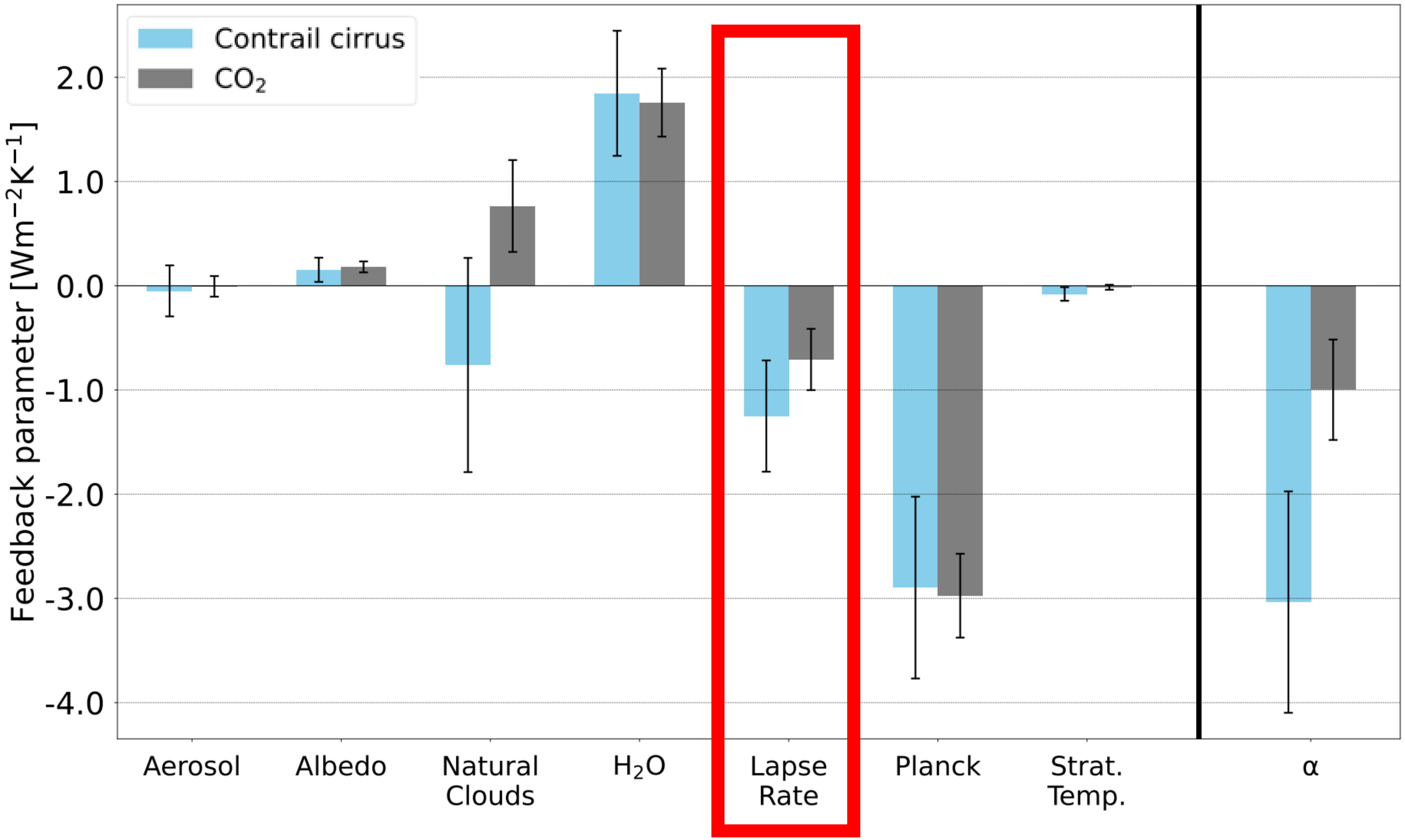

- Natural cirrus cover decreases due contrail cirrus absorbing large parts of ambient water vapor

→ negative natural cloud rapid adjustment

- Contrail cirrus formation almost exclusively on northern hemisphere where the majority of air traffic operates and clearly correlated with natural cloud cover decrease

# Slow feedbacks

- PRP feedback analysis applied to MLO simulations → slow feedbacks




- **Lapse rate slow feedback** (induced by changes of the vertical temperature profile): again due to the strong non-homogeneous warming of contrail cirrus directly below the cloud base

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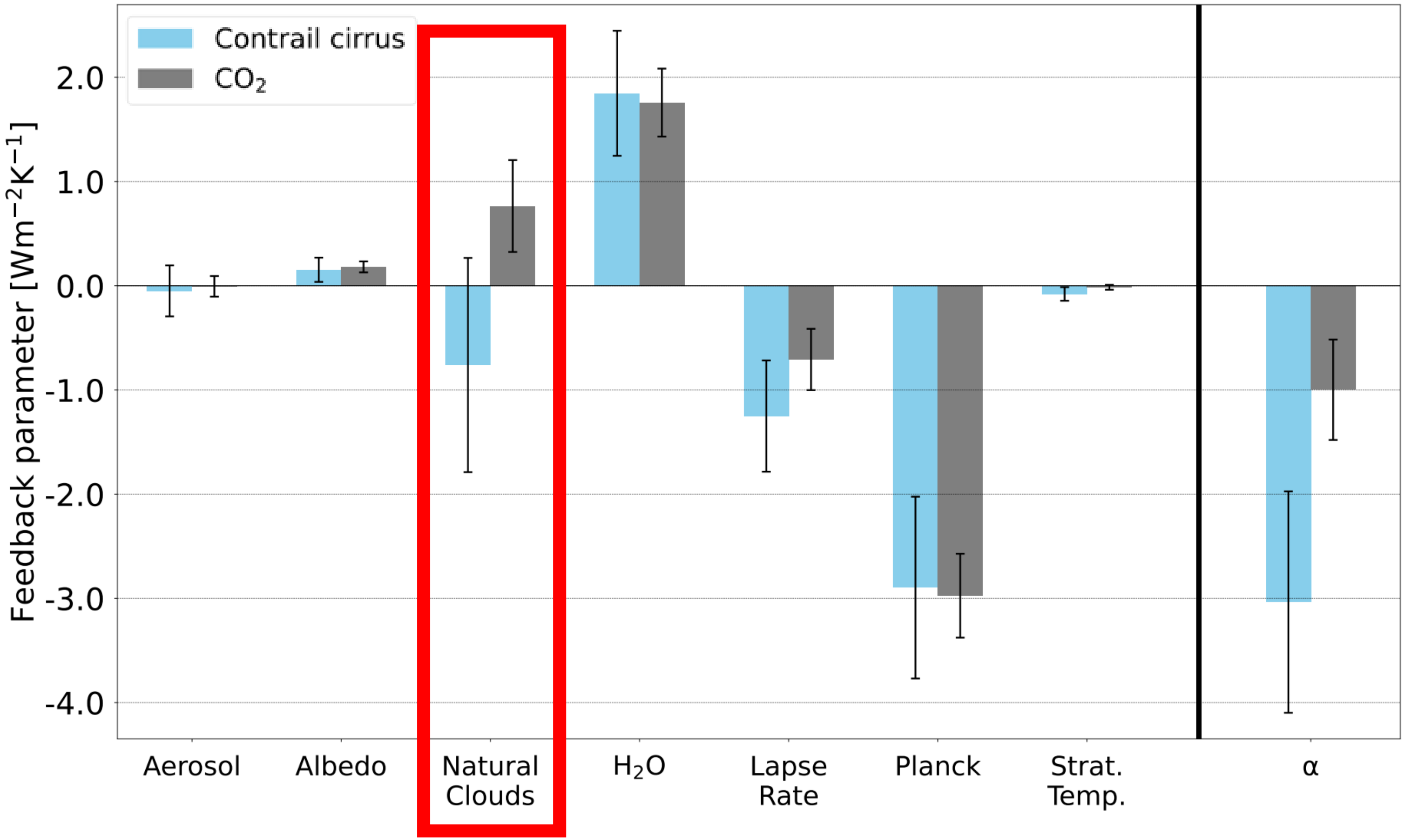
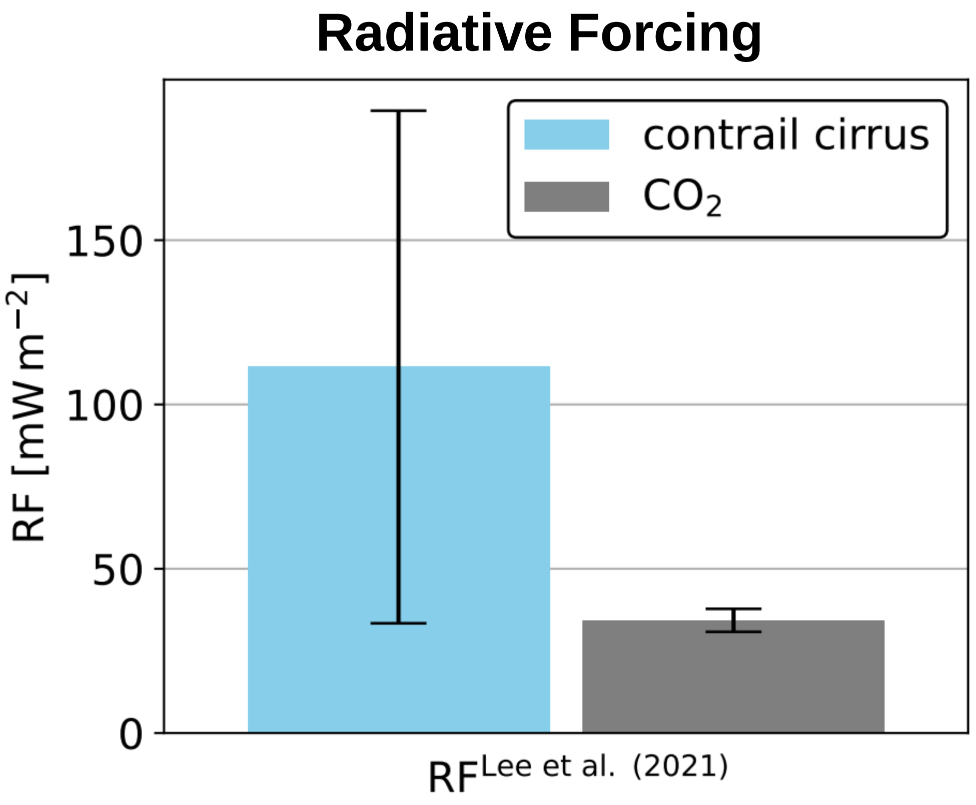
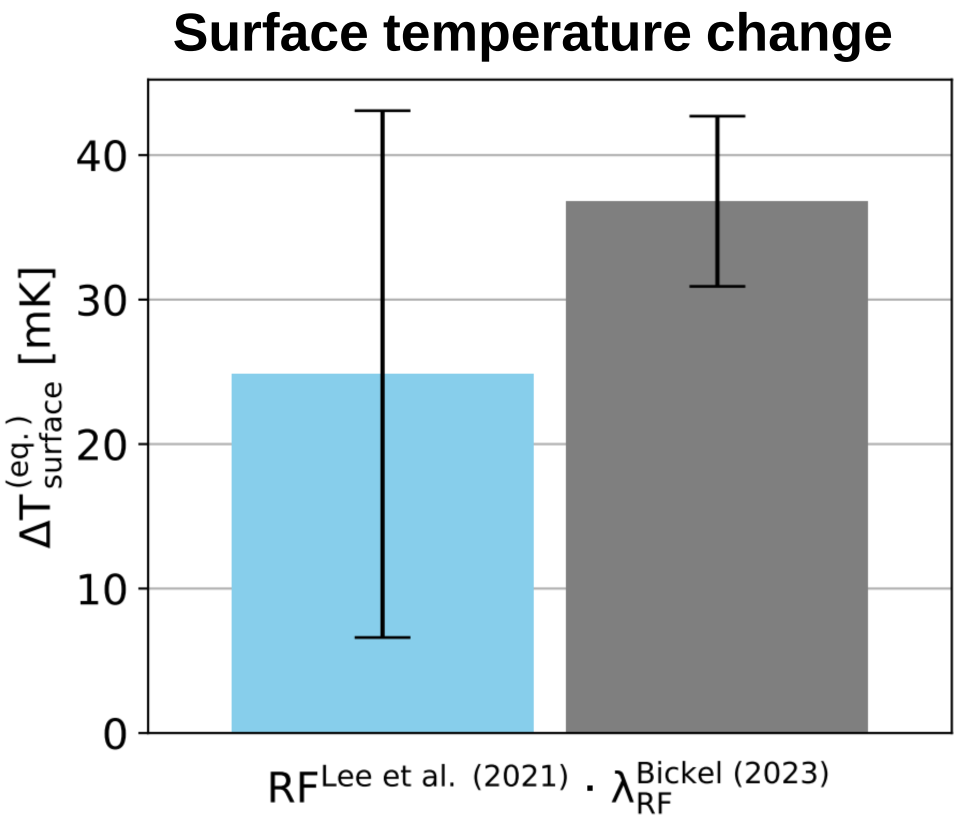



- **Lapse rate slow feedback** (induced by changes of the vertical temperature profile): again due to the strong non-homogeneous warming of contrail cirrus directly below the cloud base
- **Natural cloud slow feedback:** low- and mid-level clouds are decreasing for $CO_2$ and increasing for contrail cirrus

# Consequences: Actual climate impact of contrail cirrus for 2018




- So far, based on Radiative Forcings, contrail cirrus has been regarded as the largest contributor to aviation induced climate impact
- However, based on surface temperature change, air traffic induced $CO_2$ emissions dominate the climate impact of aviation

**→ Feedbacks play an essential role for contrail cirrus climate impact**

# Summary

- Different radiative forcing agents induce different feedbacks, with potentially large impact on their specific global warming contribution (climate sensitivity)

- For comparably sized radiative forcings of contrail cirrus and $CO_2$ the surface warming is strongly reduced for contrail cirrus
  → very small efficacy to induce surface temperature changes: **0.21**

- Determination of the physical origins using feedback analysis reveals different responses between contrail cirrus and $CO_2$ for

  - natural cloud, lapse-rate and water vapor rapid radiative adjustments

  - natural cloud and lapse-rate slow feedbacks

- Actual climate impact (global warming contribution) for contrail cirrus may be smaller than for aviation $CO_2$, in contrast to what RF estimates suggest

  → The alleged leading role of contrail cirrus for aviation induced climate impact has become questionable

**For further information see:**

*Bickel, M., et al., 2025:* ***Contrail Cirrus Climate Impact: From Radiative Forcing to Surface Temperature Change****, Journal of Climate, 38, 1895 – 1912*