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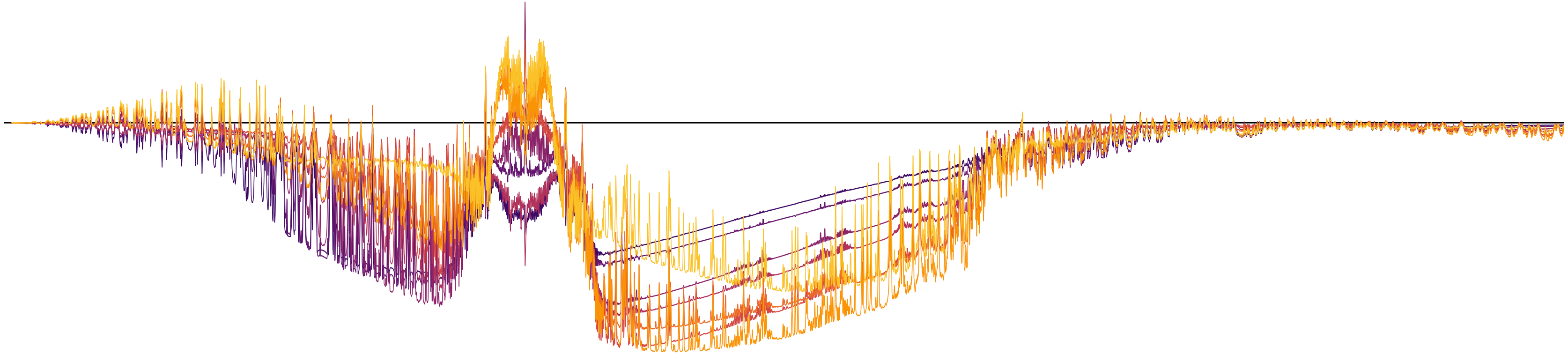


State-Dependence of the Spectral Longwave Feedback

ARTS-Workshop, 06/06/2024 **Florian Roemer,** Stefan Buehler

Climate Sensitivity

2×CO$_2$
radiative
forcing

$$\mathcal{S} = -\frac{\mathcal{F}}{\lambda}$$

ΔT_s for 2×CO$_2$

radiative
feedback $\dfrac{dN}{dT_s}$

Clear-Sky Longwave Feedback: $\lambda = -\frac{d\mathrm{OLR}_{\mathrm{cs}}}{dT_s}$

climate feedbacks λ_i

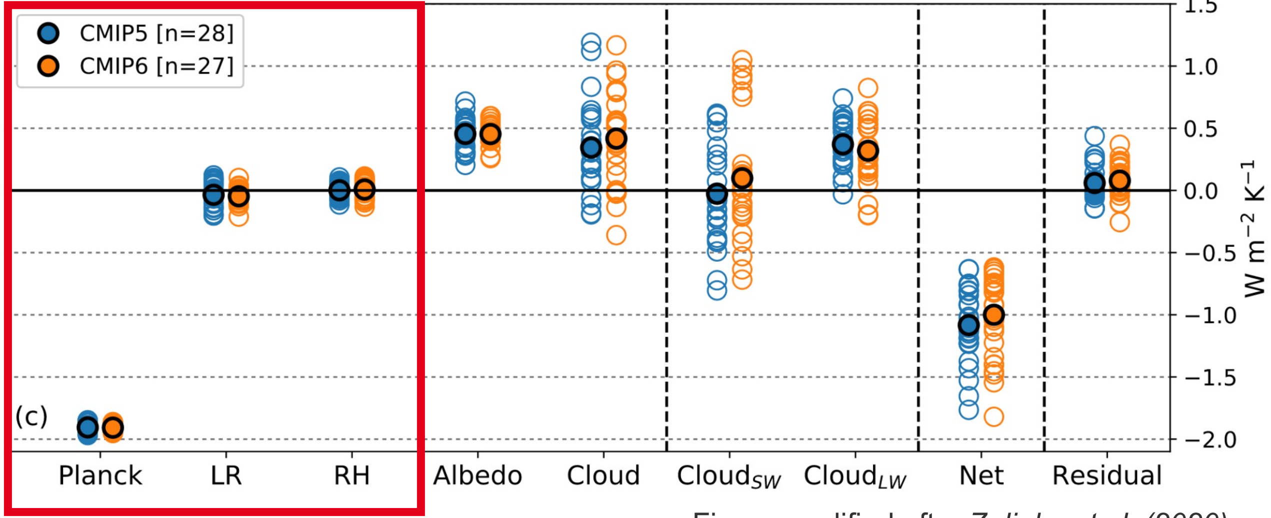
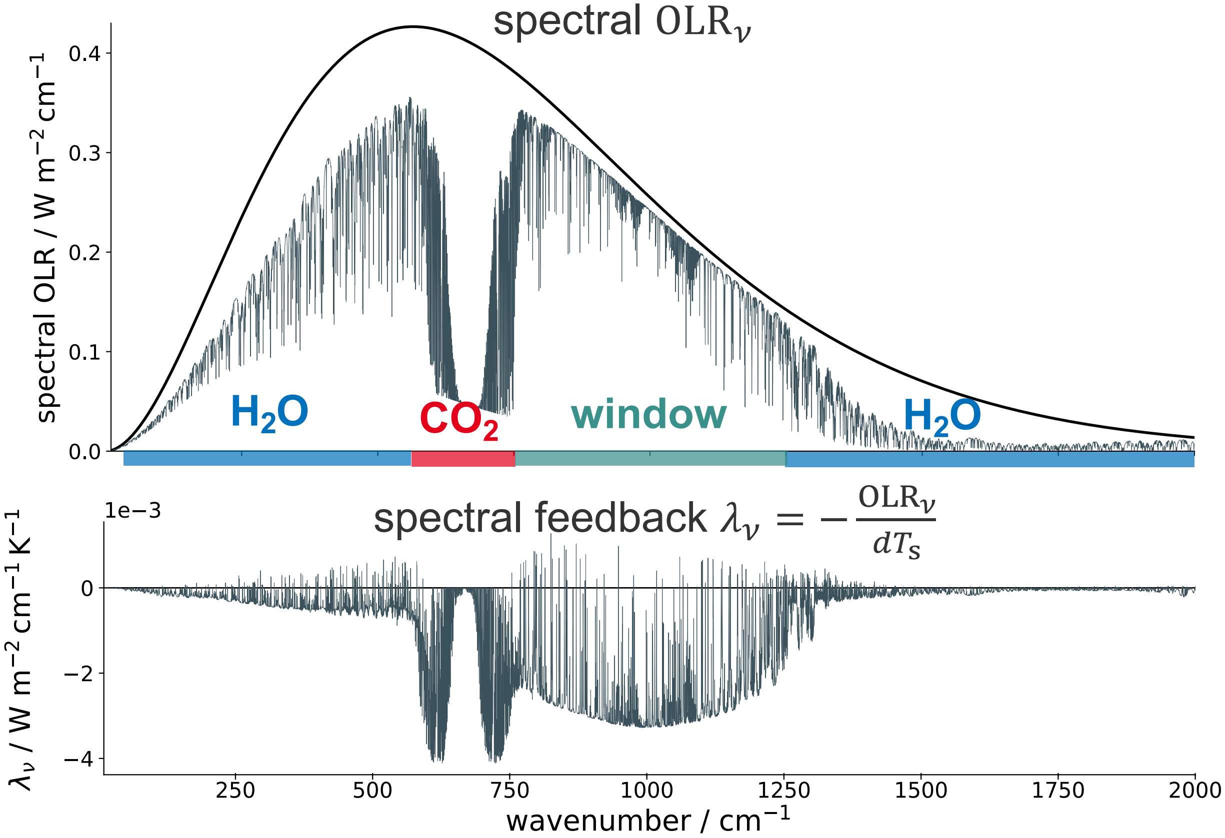


Figure modified after *Zelinka et al. (2020)*

clear-sky
longwave
feedback

The spectral dimension

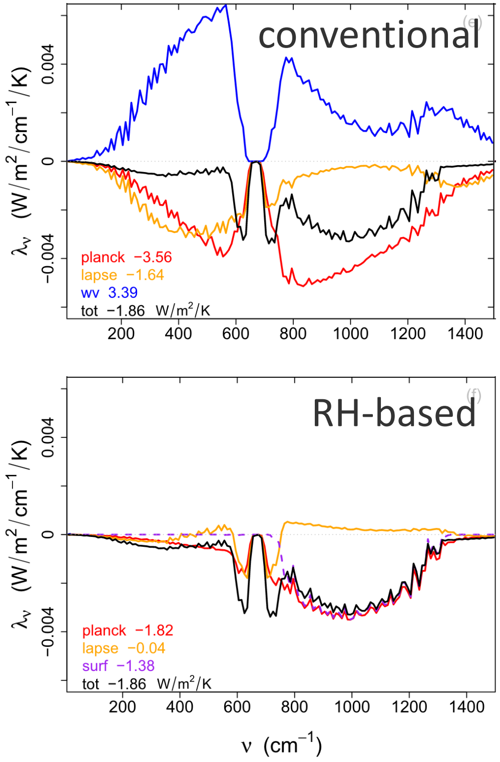


Feedback decomposition

- conventional: feedbacks decomposed into effects of changes in temperature and **absolute humidity q**

- new: feedbacks decomposed into effects of changes in temperature and **relative humidity $\mathcal{R}$** *(Held and Shell, 2012)*

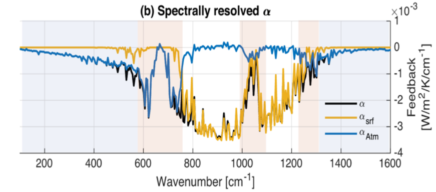
➢ **"Simpson's law":** near-zero feedback in water vapor bands under constant $\mathcal{R}$ *(Simpson 1928; Ingram, 2010; Jeevanjee et al., 2021)*

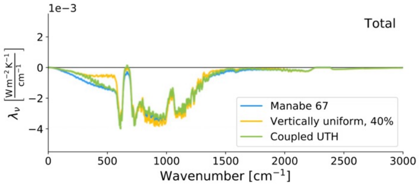


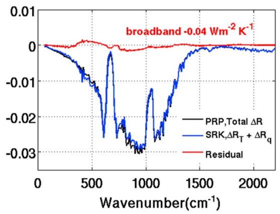
Figures after
Jeevanjee et al. (2021)

Previous studies

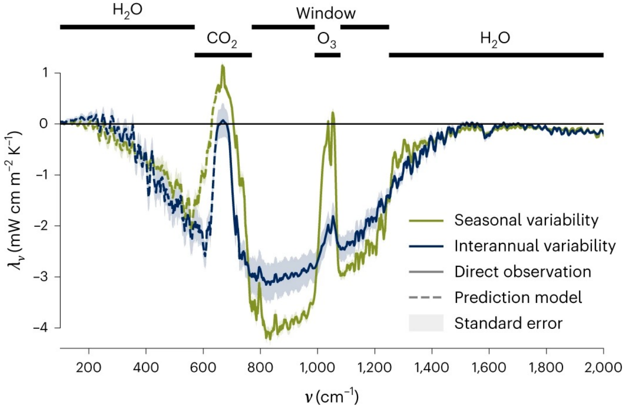
- Most studies use models of different complexity to calculate λ_ν
  (Jeevanjee et al., 2021; Kluft et al., 2019; Huang et al., 2014, Feng et al., 2023)







- Recent study uses satellite observations to derive λ_ν
  (Roemer et al., 2023)

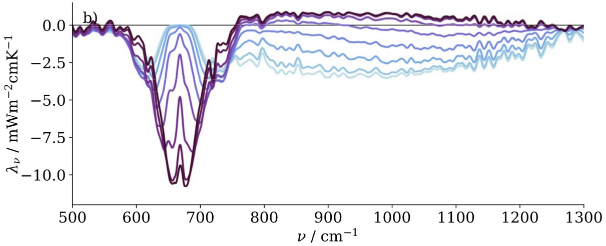


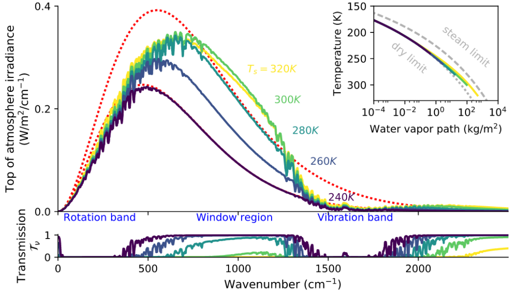
Surface temperature dependence

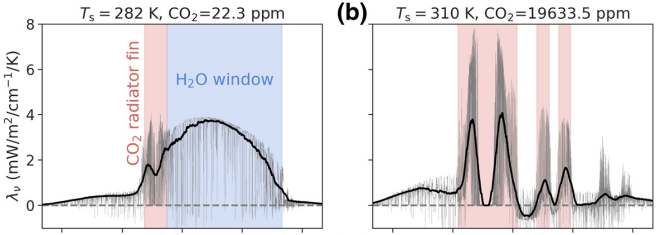
- H_2O concentration increases with surface temperature T_s, affecting λ_ν, particularly in the atmospheric window

- Therefore, T_s dependence of λ_ν has been modeled *(Koll & Cronin, 2018; Koll et al., 2023; Kluft et al., 2021; Seeley & Jeevanjee, 2021)*

➢ **Can we derive this T_s dependence of λ_ν from satellite observations?**



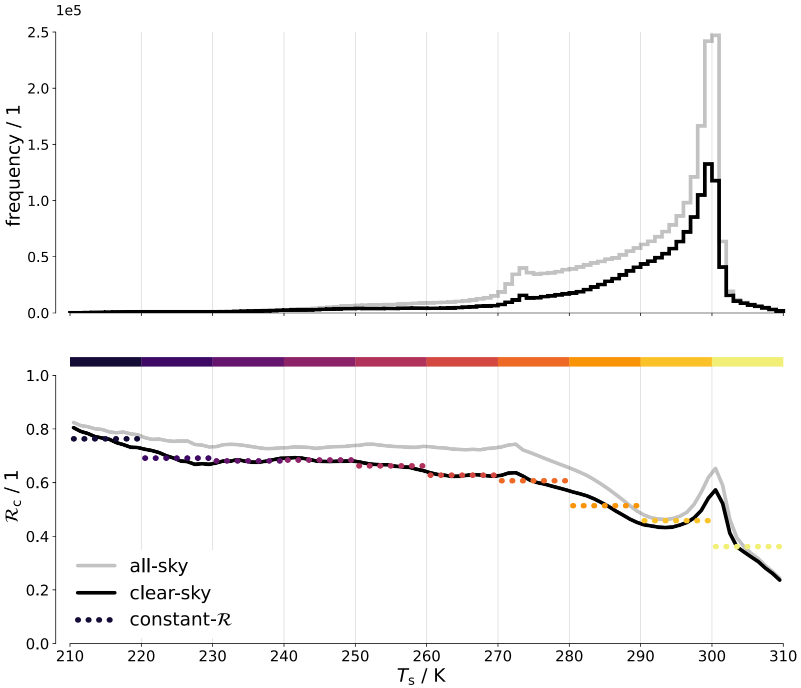




Challenges in observing T_s dependence

- Satellite observations of spectral OLR available for $T_s \in [210\mathrm{K}, 310\mathrm{K}]$
  - Aqua AIRS Level 3 Spectral Outgoing Longwave Radiation (OLR) Monthly dataset *(Huang, 2020).* Spectral resolution: 10cm^{-1}

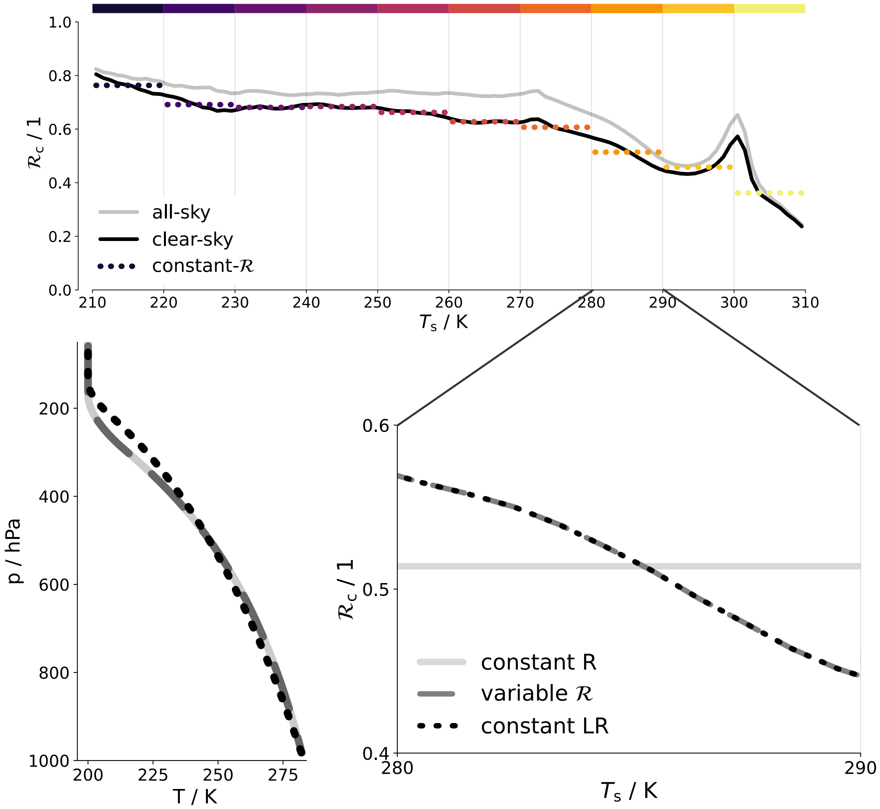
- **BUT**: those observations include radiative signature of variations in atmospheric temperature and humidity with T_s caused by general circulation



How can we disentangle those effects?

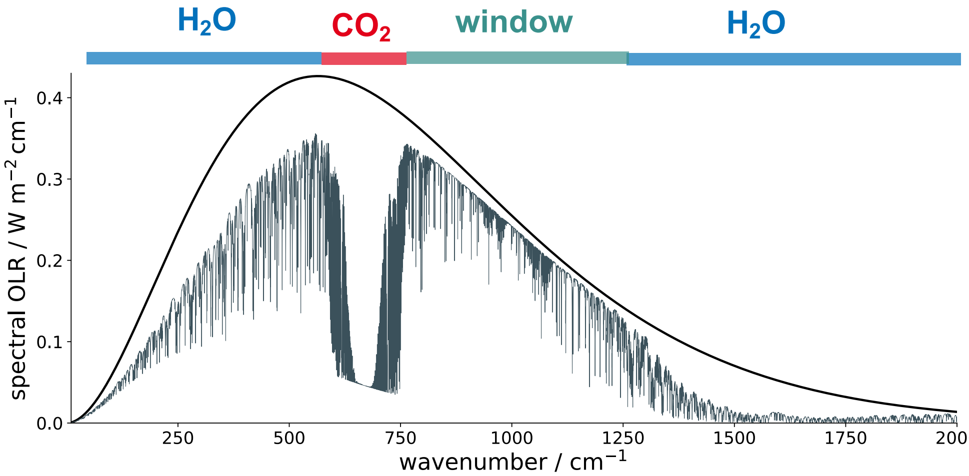
- Simulate λ_ν based on single-column model konrad
  (Kluft et al., 2019; Dacie et al., 2019)
- Input data from ERA5 reanalysis
  (Hersbach et al., 2019)
- Divide T_s range into ten 10K regimes
- Perform different experiments to disentangle effects of atmospheric processes:

constant-$\mathcal{R}$
variable-$\mathcal{R}$
constant-LR
} vertically uniform $\mathcal{R}$
closure



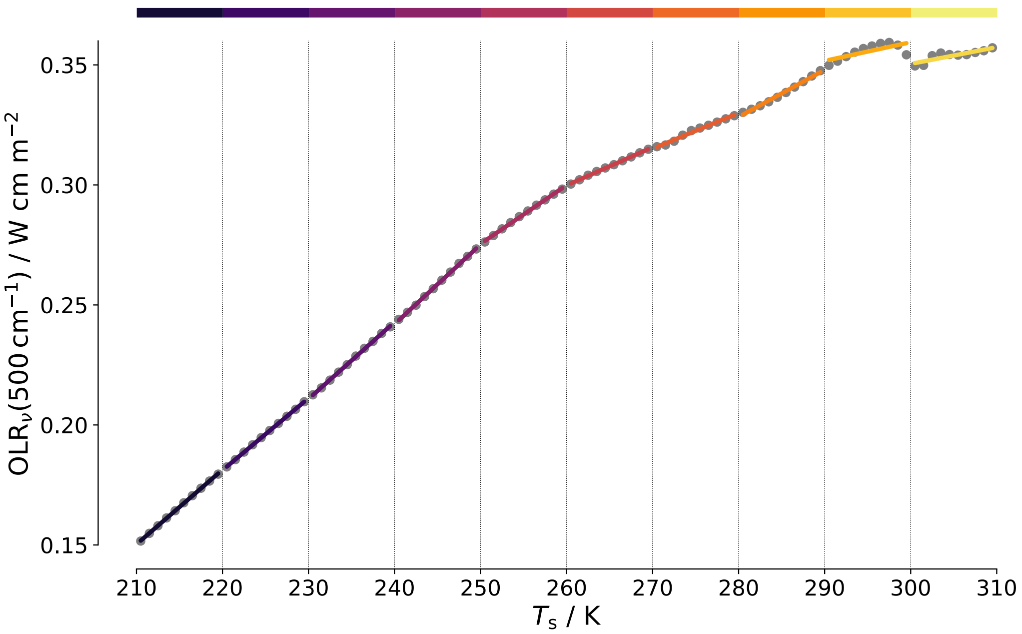
Radiative transfer simulations using ARTS

- Based on these atmospheres: simulate clear-sky OLR_ν using ARTS
  (Eriksson et al., 2011; Buehler et al., 2018)
- Spectral range: 10cm^{-1} to 2000cm^{-1}, with 0.1cm^{-1} resolution
- Absorption species: H_2O, CO_2, CH_4, N_2O (no O_3)
- H_2O continuum: MT_CKD 4.0
  (Mlawer et al., 2023)



Feedback calculation

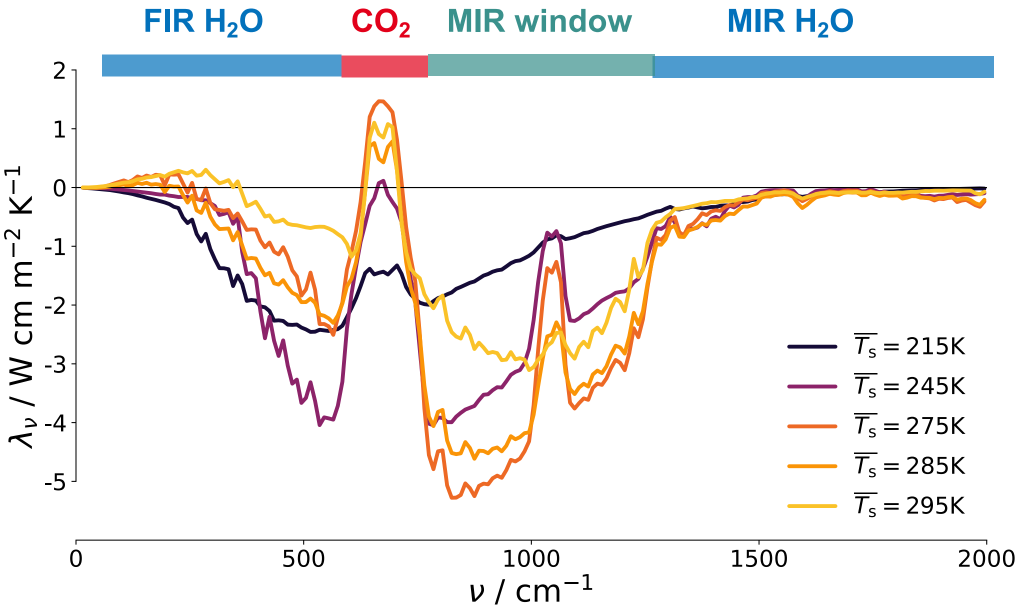
- Observed OLR_ν sorted into 1K T_s bins (210K to 310K)
- Simulate OLR_ν for same T_s range in 1K increments
- Linear regression of OLR_ν against T_s to calculate λ_ν for ten T_s regimes (simulations and observations)



Observed spectral feedback

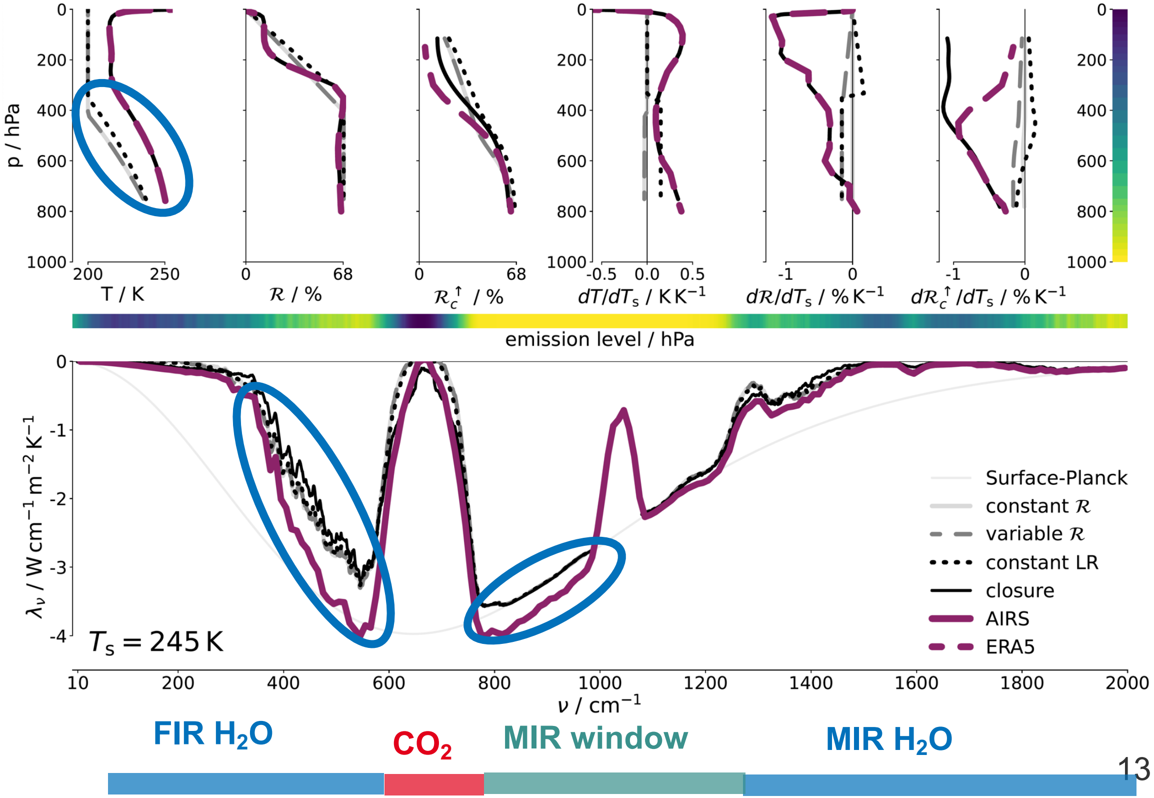
- Far-infrared window ($\approx 400 - 600\mathrm{cm}^{-1}$) already closes at $T_s \approx 260\mathrm{K}$

- Mid-infrared window ($\approx 800 - 1200\mathrm{cm}^{-1}$) starts to close at $T_s \approx 290\mathrm{K}$



Spectral feedback at low surface temperatures

- Atmosphere has little impact on λ_ν
- Simulations underestimate λ_ν in optically thin spectral regions → presumably due to surface processes

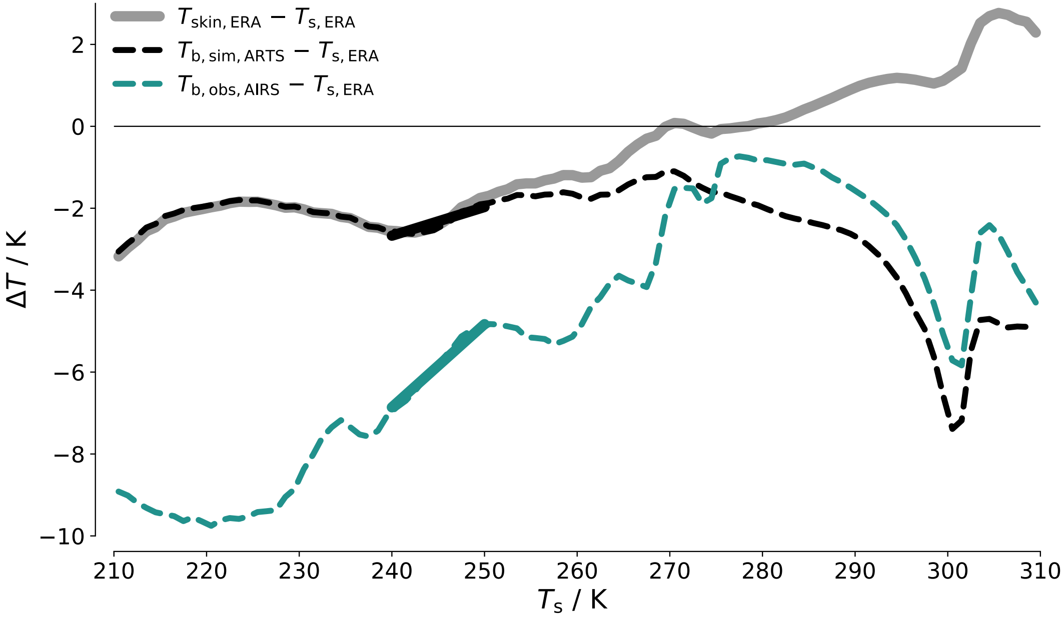


Reanalysis underestimates T_{skin} at low T_{s}

- Simulated brightness temperature $T_{\mathrm{b,\,sim}}$ in window around 5K higher than observed $T_{\mathrm{b,\,obs}}$ below 240K

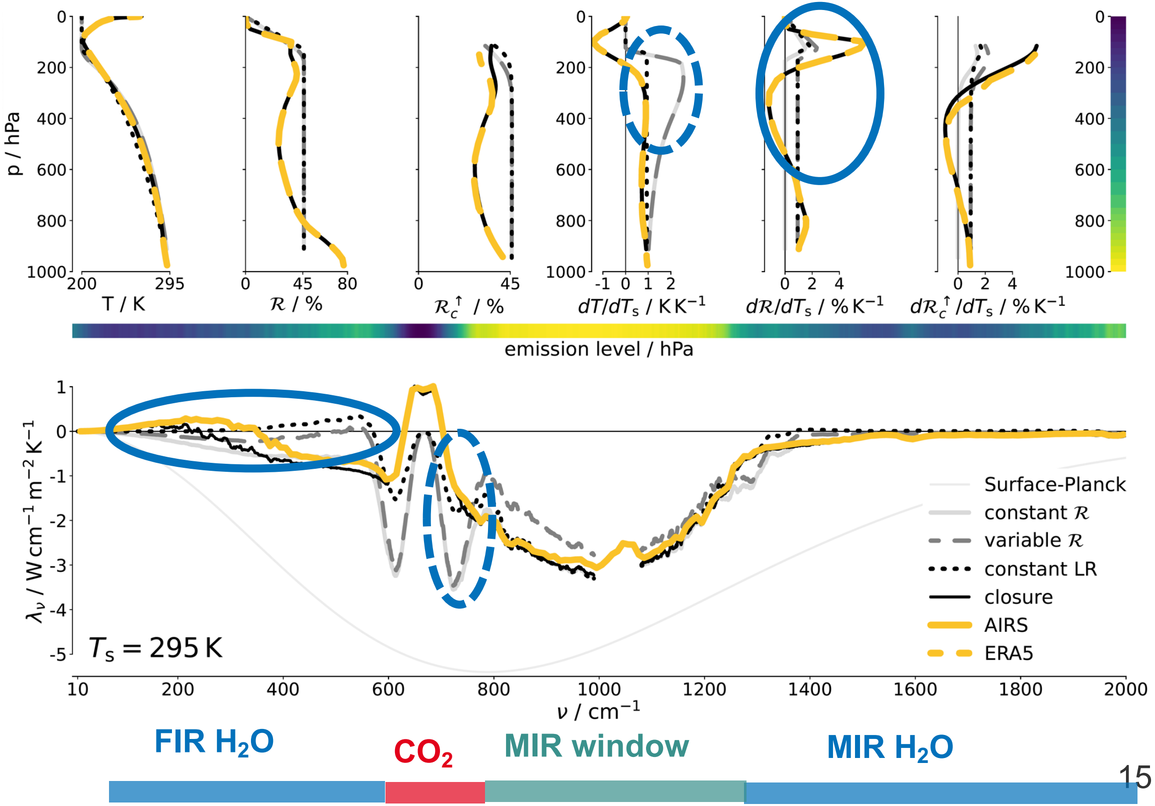
➢ Consistent with erroneous T_{skin} in ERA5 in polar regions *(Muñoz-Sabater et al., 2021)*

➢ Simulations underestimate $\frac{dT_{\mathrm{skin}}}{dT_{\mathrm{s}}}$ and thus the feedback



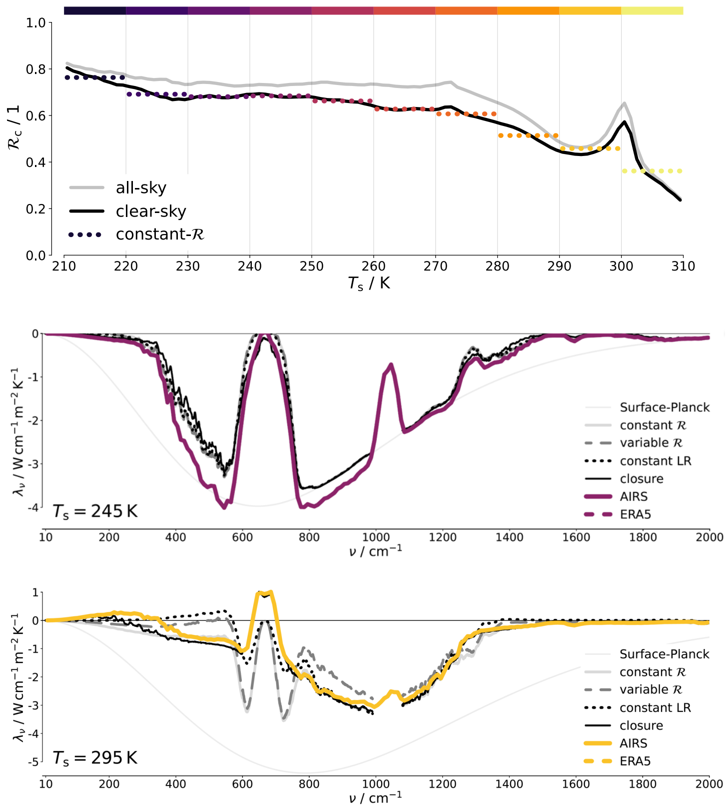
Spectral feedback at high surface temperatures

- Atmosphere plays important role for λ_ν
- H_2O bands: changes in $\mathcal{R}$ profile with T_s
- CO_2 band: T profile change with T_s in upper troposphere and stratosphere



Conclusions

- Clear-Sky spectral feedback λ_ν observed for surface temperatures T_s between 210K and 310K
- Simulated λ_ν used to understand role of circulation-induced atmospheric variations
- λ_ν at low T_s sensitive to biases in skin temperature
- λ_ν at high T_s sensitive to changes in atmospheric temperature and humidity profiles
- conceptional understanding of $\lambda_\nu(T_s)$ can help in studies on paleoclimates and exoplanets



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