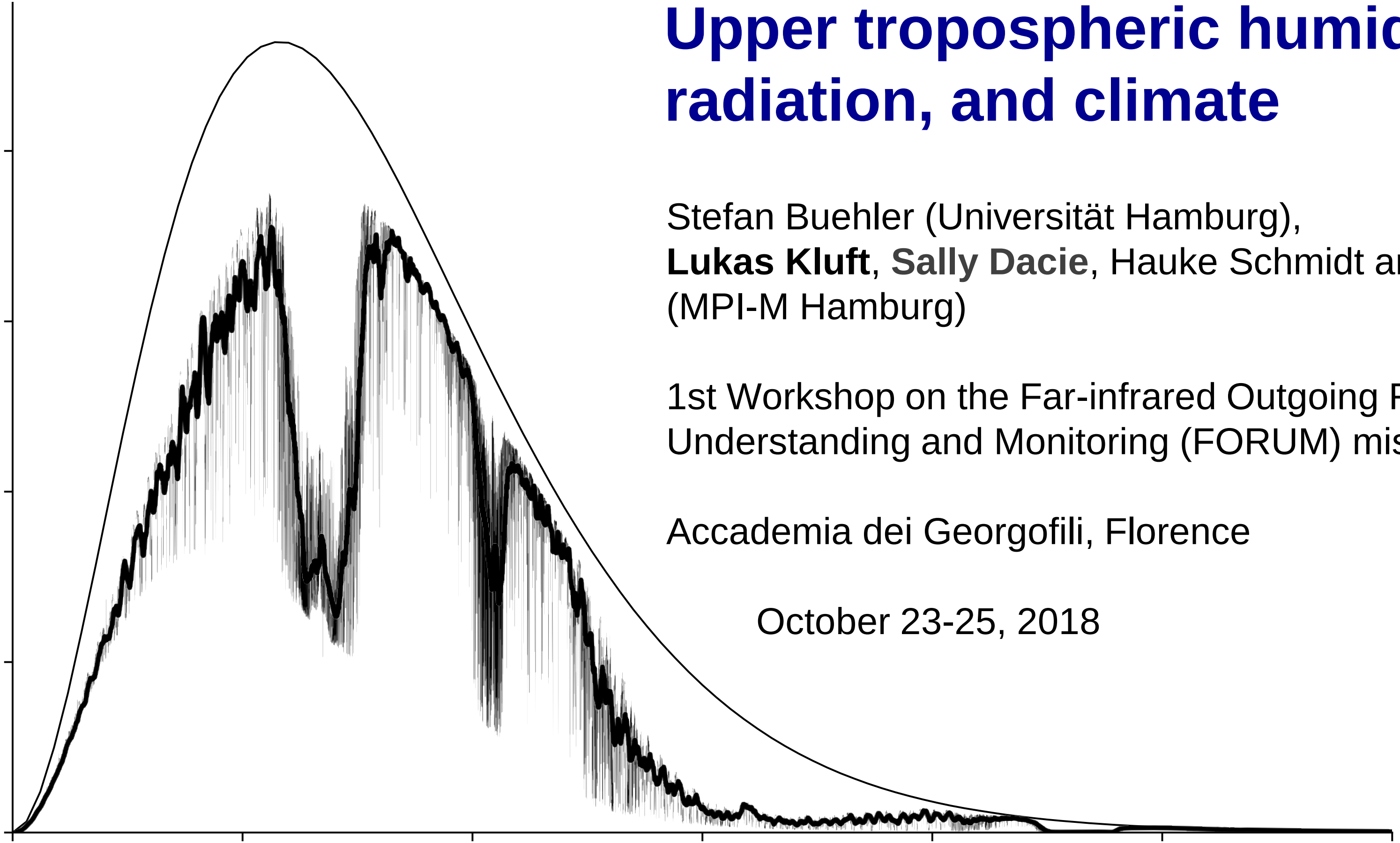

Upper tropospheric humidity, radiation, and climate

Stefan Buehler (Universität Hamburg),
Lukas Kluft, **Sally Dacie**, Hauke Schmidt and Bjorn Stevens
(MPI-M Hamburg)

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Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Overview

- Setting the scene
- The RCE model
- Climate sensitivity
- The spectral view
- FAP, FAT, PHAT
- Summary and conclusions

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Equilibrium **climate sensitivity** (ECS) = change in surface temperature for CO_2 doubling.

The core question of climate research.

Discussed in framework of **forcings** (radiation balance change in W/m^2) and **feedbacks** (in $W/m^2/K$).

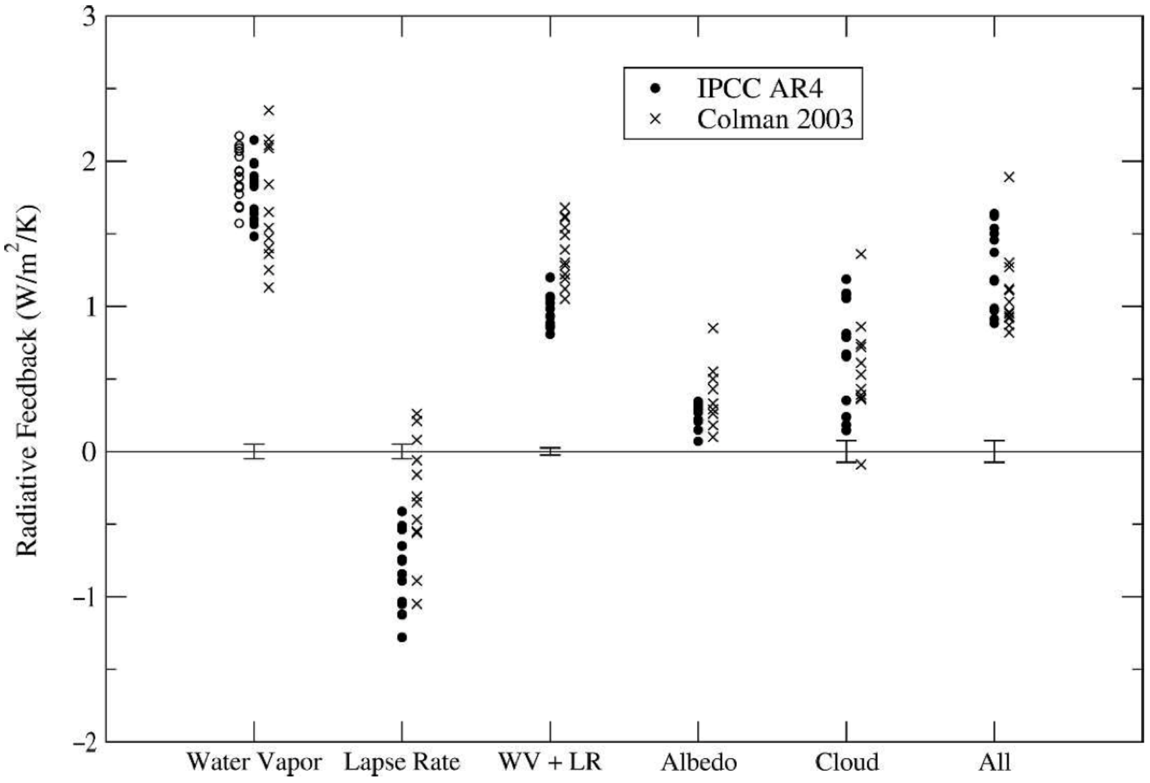
Diagnostic feedbacks

Different methods exist to factor the overall response of complex climate models into individual feedbacks.

Positive **Water vapor** feedback arises because warmer atmosphere contains more of greenhouse gas H_2O.

Negative **Lapse rate** feedback arises because upper troposphere warms more than surface.

Difficult to derive physical/intuitive insight from such diagnostics.



Soden, B. J. and I. M. Held (2006), An assessment of climate feedbacks in coupled ocean-atmosphere models, J. Climate, 19(14), 3354–3360.

As I will show, the simplest possible climate model can give important physical insights.

It can serve as backdrop for thinking about more complex models.

Allows integration to full equilibrium and (in principle) full line-by-line treatment of radiation, promoting a spectral view, appropriate for FORUM.

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Radiative cooling rates

At each altitude, atmosphere absorbs shortwave (UV/Vis from the sun) and longwave (IR) radiation and emits longwave radiation.

Net radiation flux divergence determines if atmosphere is cooled or warmed, cooling dominates in the troposphere.

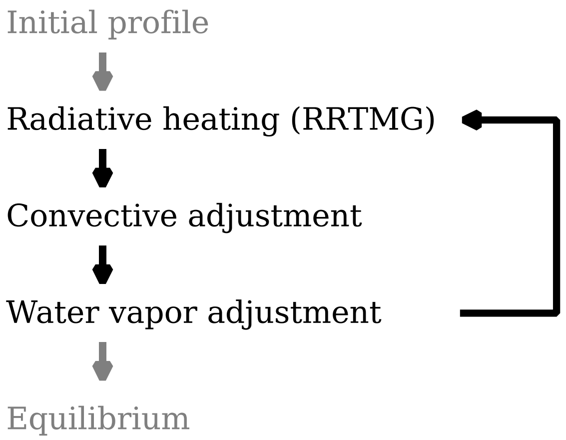
The RCE model

Originally developed by Manabe and Wetherald (1967).

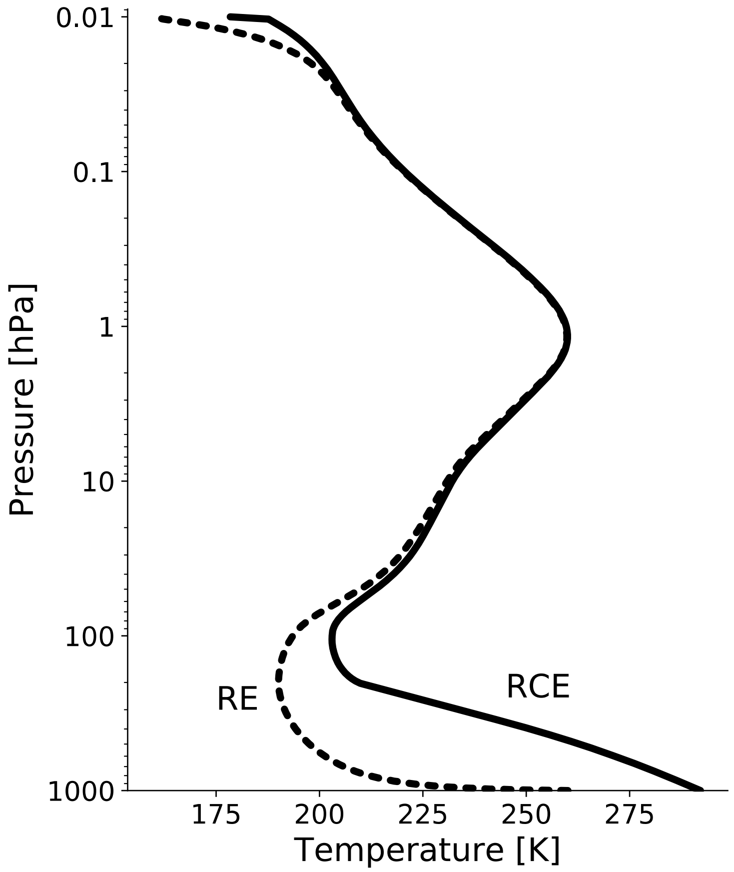
Just calculating radiative equilibrium results in unstable lower troposphere.

Convection is assumed to relax profile back to neutral stability (moist adiabat).

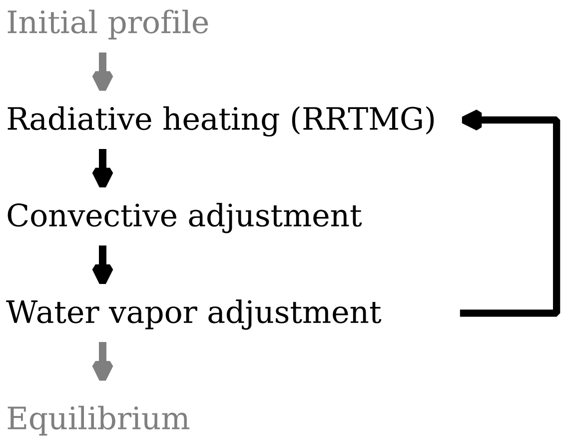
Manabe already realized the importance of treating water vapor correctly (fixed RH).



The RCE model



A good conceptual model of the tropical troposphere, continuously de-stabilized by radiation and re-stabilized by convection.



Basic temperature structure

Manabe & Wetherald

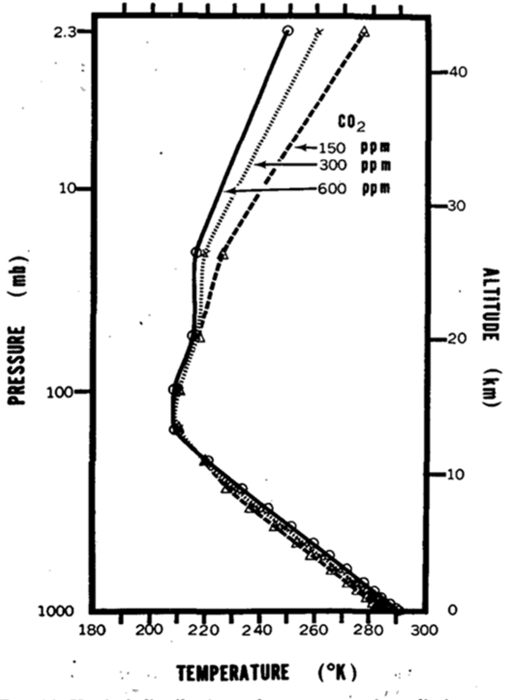
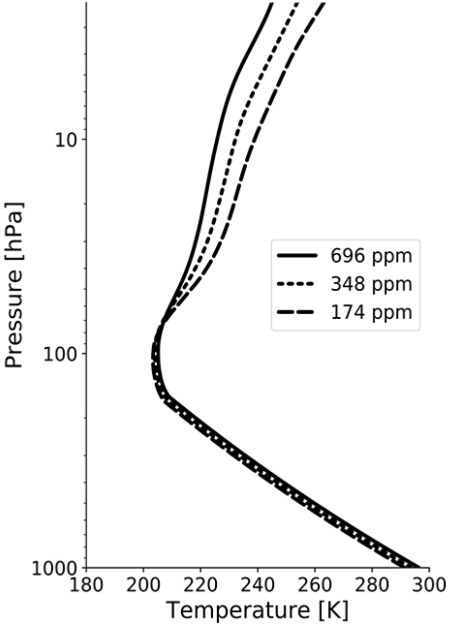


FIG. 16. Vertical distributions of temperature in radiative convective equilibrium for various values of CO_2 content.

New



Syukuro Manabe this year received the Crafoord Prize at the Royal Swedish Academy of Sciences, Stockholm.

Manabe and Wetherald (1967) results stand up remarkably well against new calculation, despite 50 years of progress in spectroscopy.

Even climate sensitivity estimate is very similar.

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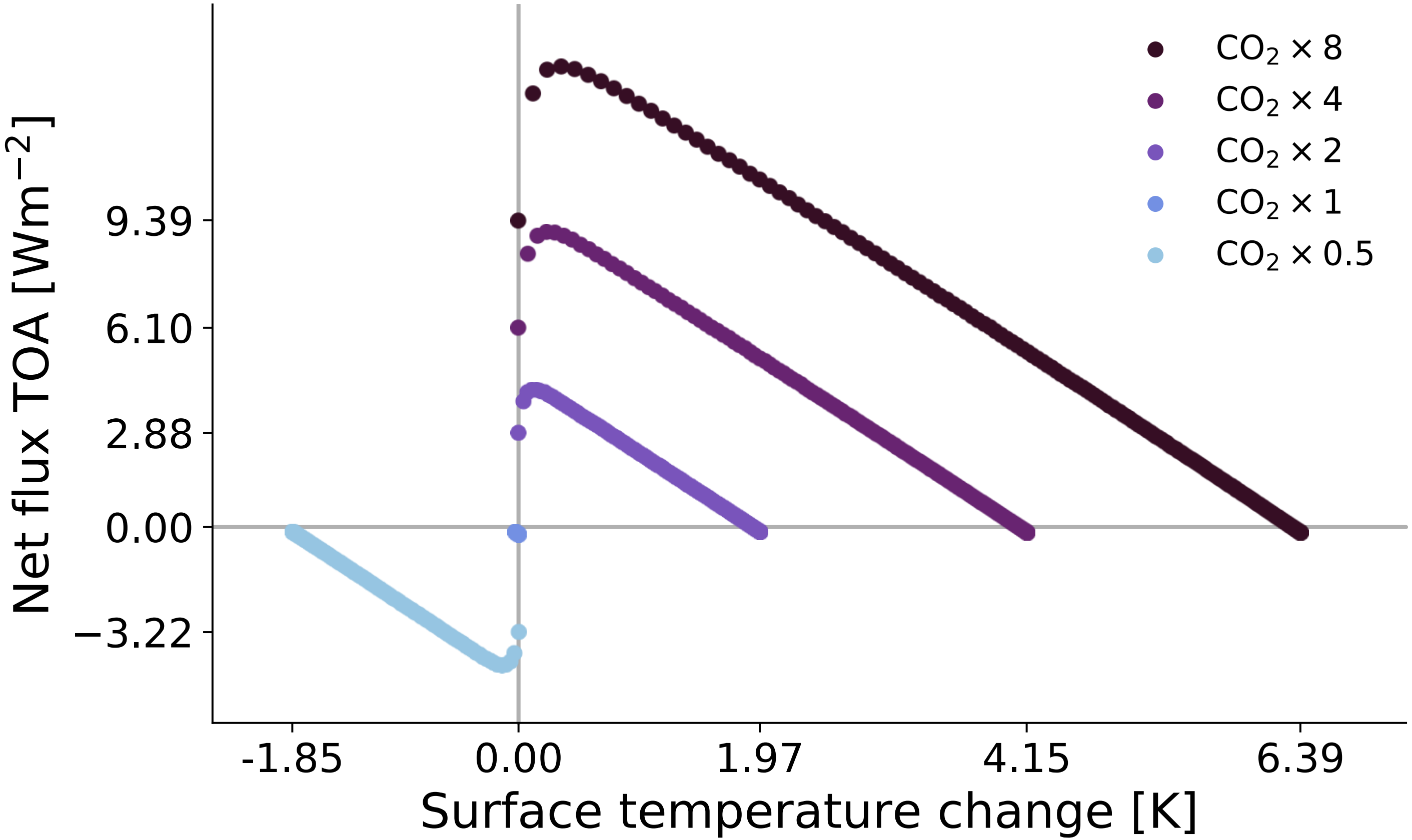
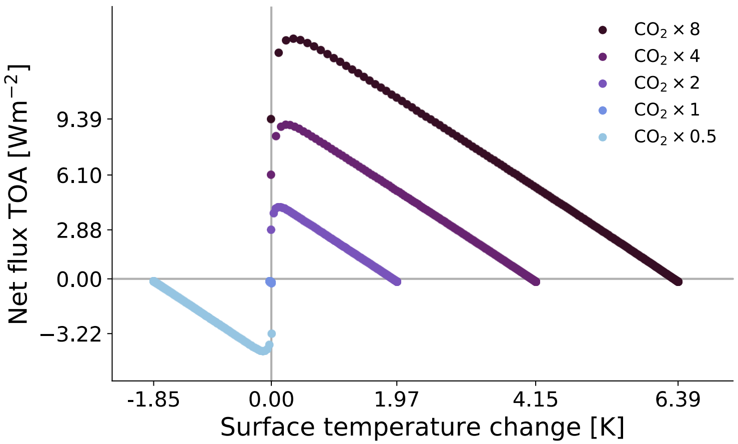
Gregory plots

$$N = F - H = F - \frac{\Delta T}{\lambda}$$



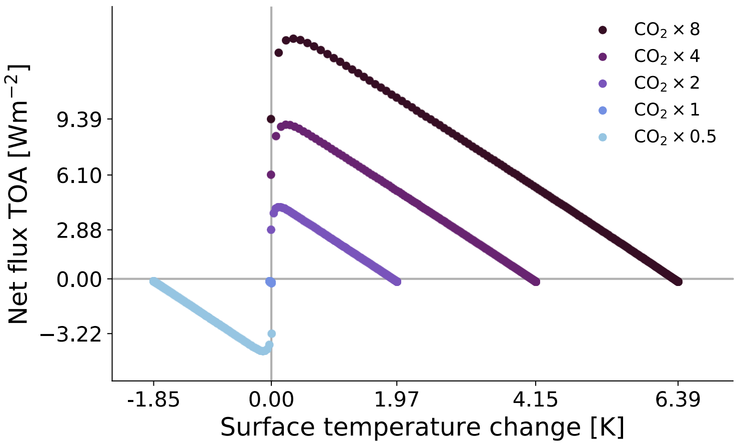
Separating feedbacks



Feedbacks can be separated by running different model configurations.

Model configuration	ECS [K]	
Fixed abs. humidity, constant lapse rate (6.5 K/km)	1.40	Planck
Fixed rel. humidity, constant lapse rate (6.5 K/km)	2.70	Planck+WV
Fixed rel. humidity, saturated isentropic lapse rate	1.97	Planck+WV+LR

ECS and λ



$$N = F - H = F - \frac{\Delta T}{\lambda}$$

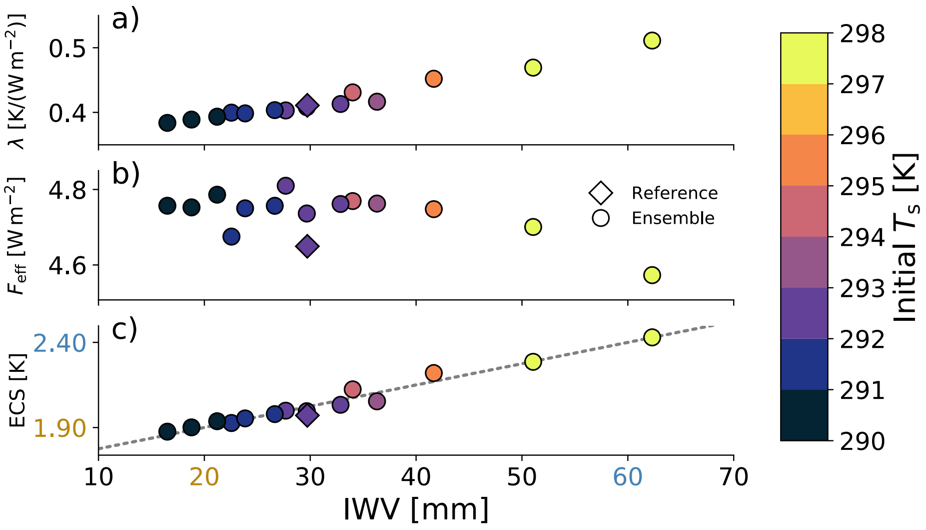
Good agreement of ECS with coupled GCMs is coincidental, our model is strictly clear-sky, resulting in different forcing.

More honest to discuss in terms of λ, the inverse of the slope.

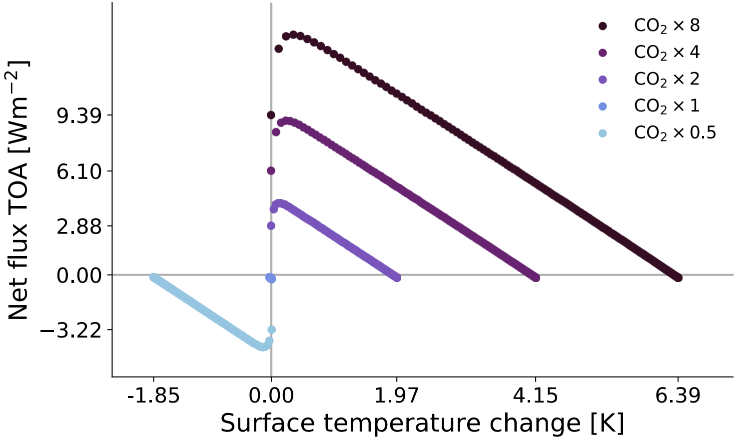
This simple model is then at the lower end of the sensitivity range of GCMs.

Robustness

- Prescribed RH profile is nontrivial aspect of the model.
- Runs with very different RH profiles show that ECS mostly depends on integrated water vapor, not on the vertical structure.



State dependence under CO_2 forcing



CO_2	ECS	λ_{PL}	λ_{WV}	λ_{LR}	λ
×0.5	-1.85	0.271	0.234	-0.097	0.407
×2	1.97	0.277	0.265	-0.132	0.411
×4	4.15	0.283	0.289	-0.161	0.412
×8	6.39	0.290	0.312	-0.193	0.410

Individual λ_x are state dependent, but these compensate to make total λ state independent (under CO_2 forcing).

➔ State dependence of coupled GCMs must have other reasons than these simple feedbacks.

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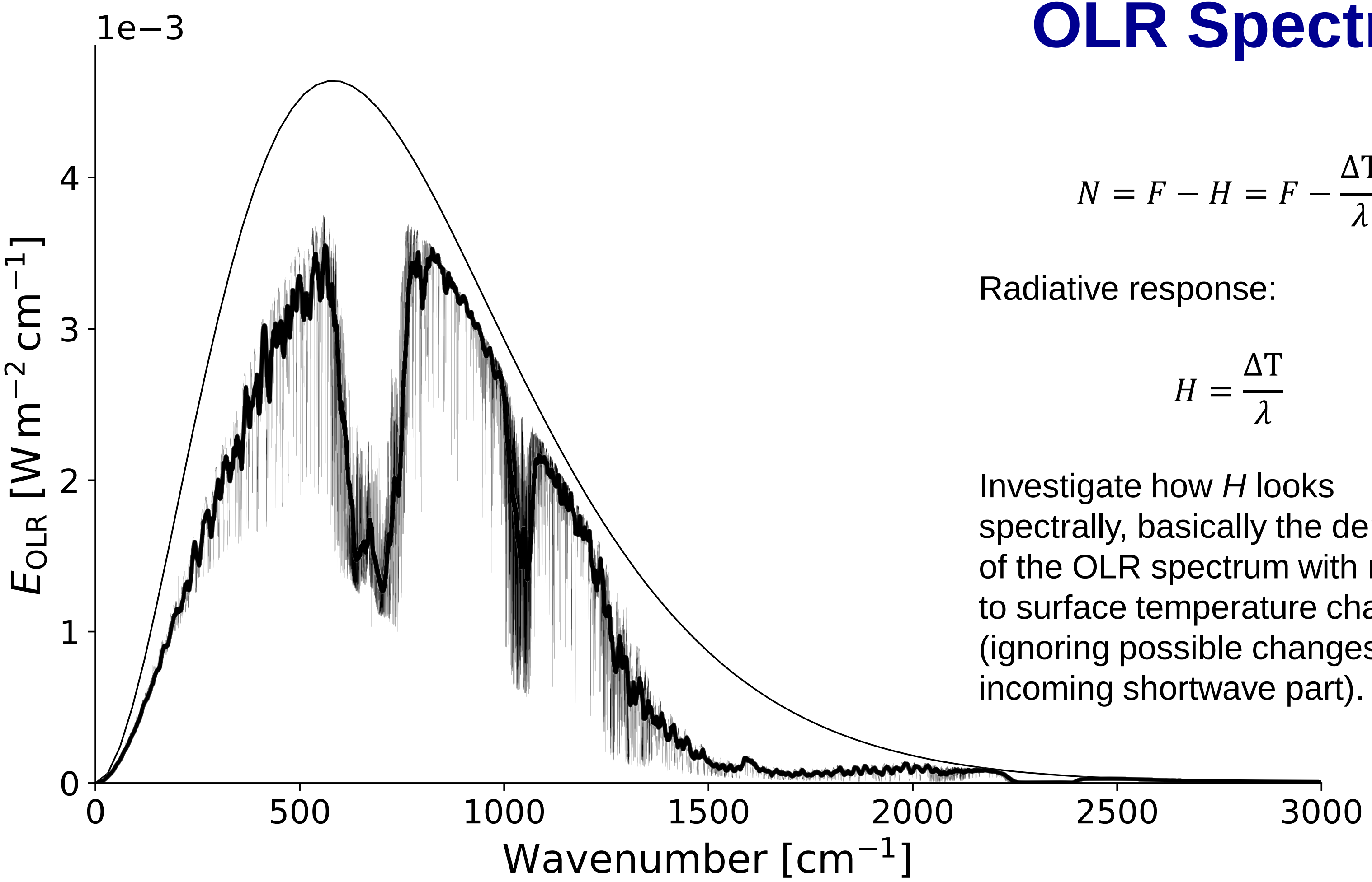
OLR Spectrum



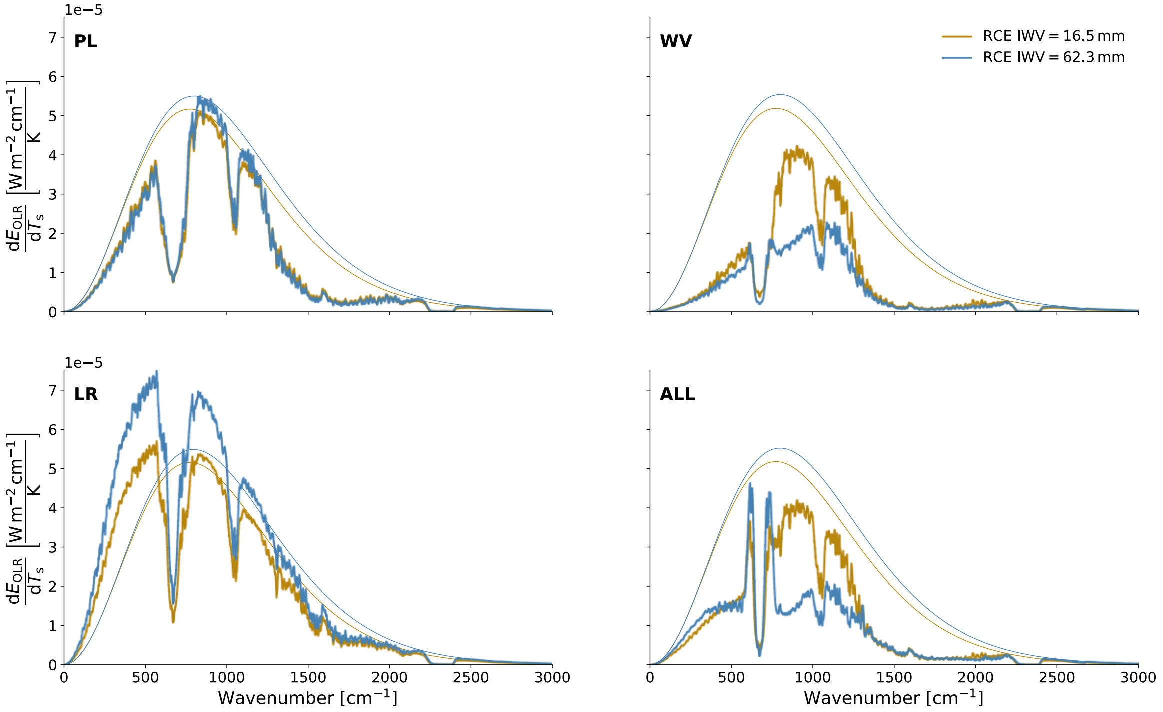
$$N = F - H = F - \frac{\Delta T}{\lambda}$$

Radiative response:

$$H = \frac{\Delta T}{\lambda}$$

Investigate how *H* looks spectrally, basically the derivative of the OLR spectrum with respect to surface temperature changes (ignoring possible changes in incoming shortwave part).

Sensitivity of OLR spectrum to surface temperature changes



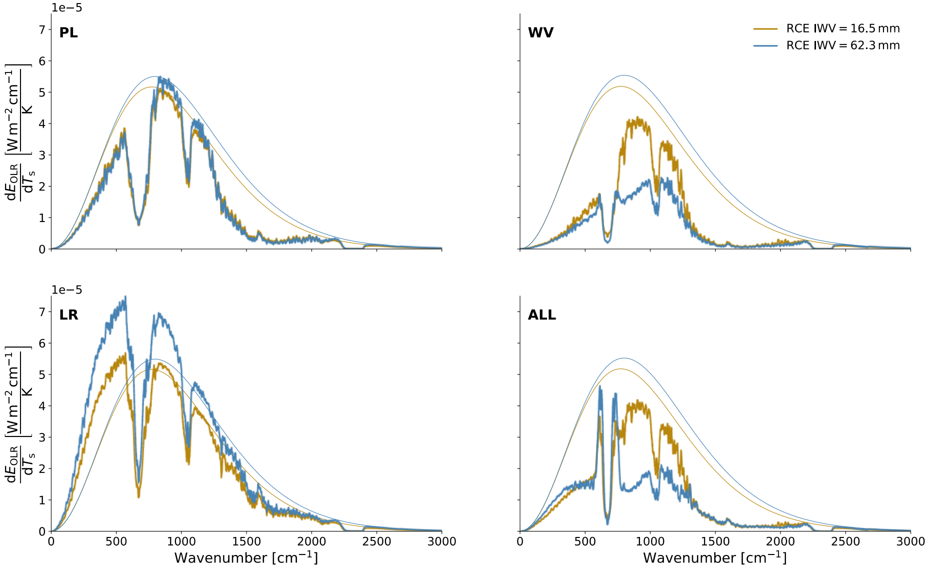
A large part of the LR and WV feedbacks occur in the upper troposphere in the mid-FIR spectral range.

FIR is especially important for the LR response.

ECS estimate depends on whether RT model there faithfully describes reality,

and on the coupling between surface T and UTH changes.

Sensitivity of OLR spectrum to surface temperature changes



To see spectral fingerprint of the WV and LR feedback requires observation of the entire FIR-TIR range.

Although used in context of (slow) climate change, WV and LR feedback mechanism themselves are fast.

Can be tested on natural variability of surface T with a few years of FORUM observations, as has been demonstrated for the PHAT mechanism (e.g., Zelinka and Harmann, 2011).

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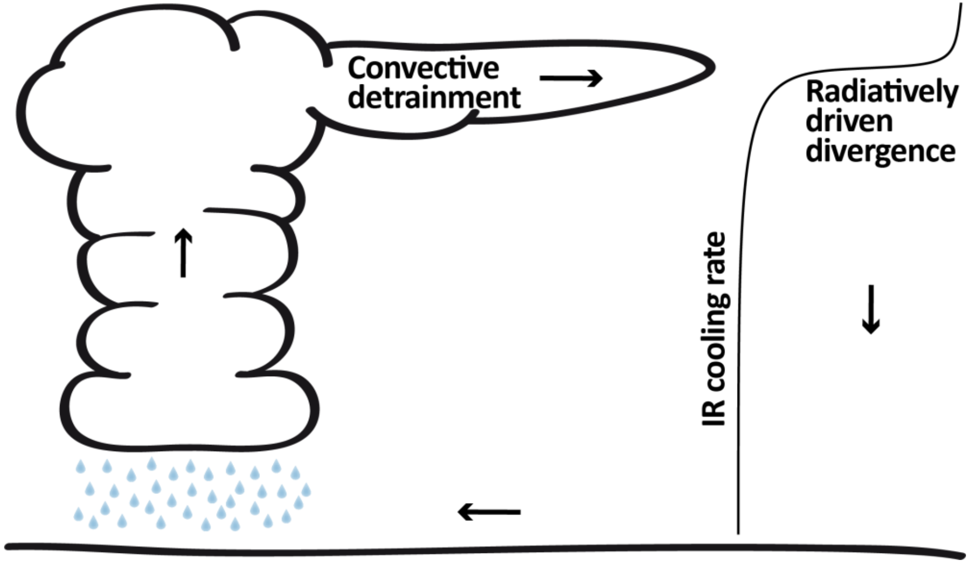
The fixed anvil temperature (FAT) mechanism



Introduced by Hartmann and Larson (FAT, 2002), Zelinka and Hartmann (PHAT, 2010, 2011).

Idea that temperature is the controlling variable for radiation (since it sets absolute humidity) goes back to Simpson (1928), as discussed by Ingram (2010).

Despite the name, this is a pure clear-sky mechanism, and our model allows to study it.

Proportionally higher anvil temperature (**PHAT**):

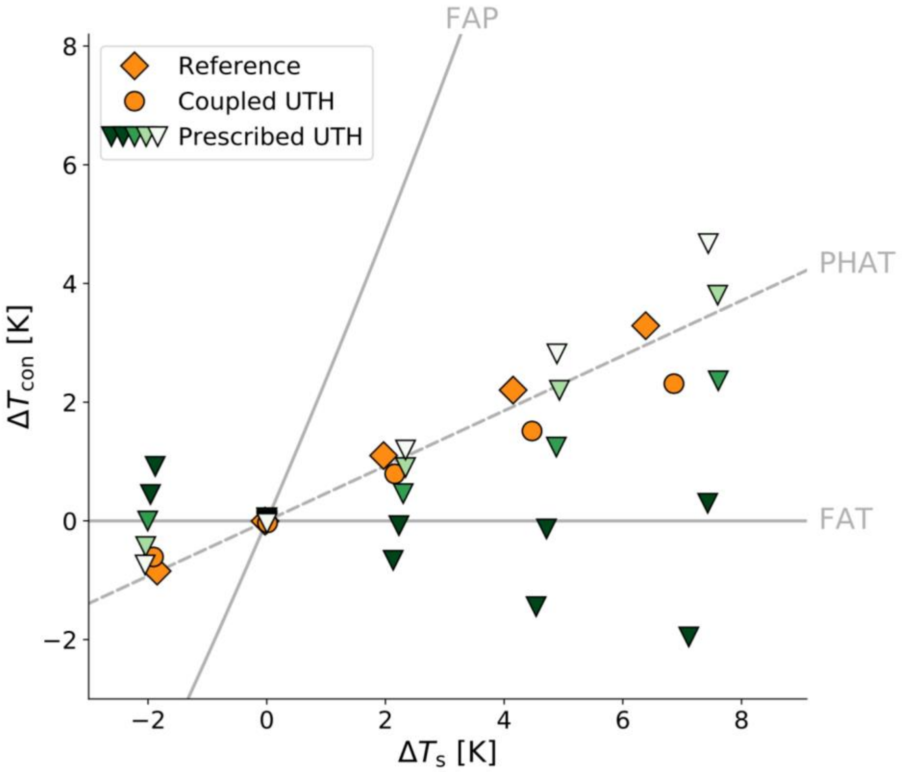
$$\omega = \frac{Q}{\sigma} = \frac{\text{cooling rate}}{\text{static stability}}$$

$$\text{Divergence} = \frac{d\omega}{dz}$$

See how convective top temperature (*T* at the height up to which convective adjustment occurs) changes with surface temperature.

Our model is consistent with PHAT (Zelinka and Hartmann,2010), which takes into account changing stability.

Triangles show experiments with
a peak RH fixed at different altitudes.
This unphysical model setup damages the PHAT mechanism.



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Summary and conclusions

- A simple 1D RC climate model still leads to valuable insights on the robustness of ECS, WV and LR feedback, and PHAT mechanism.
- Original Manabe ECS estimate for this model still valid with modern radiation.
- Supports a spectral view of the radiative response.
- FORUM would allow us to see the full spectral fingerprint of the WV and LR feedback to test our understanding of these two primary climate feedbacks.