The tropical stratospheric upwelling sets the tropical ECS by reducing the effective radiative forcing

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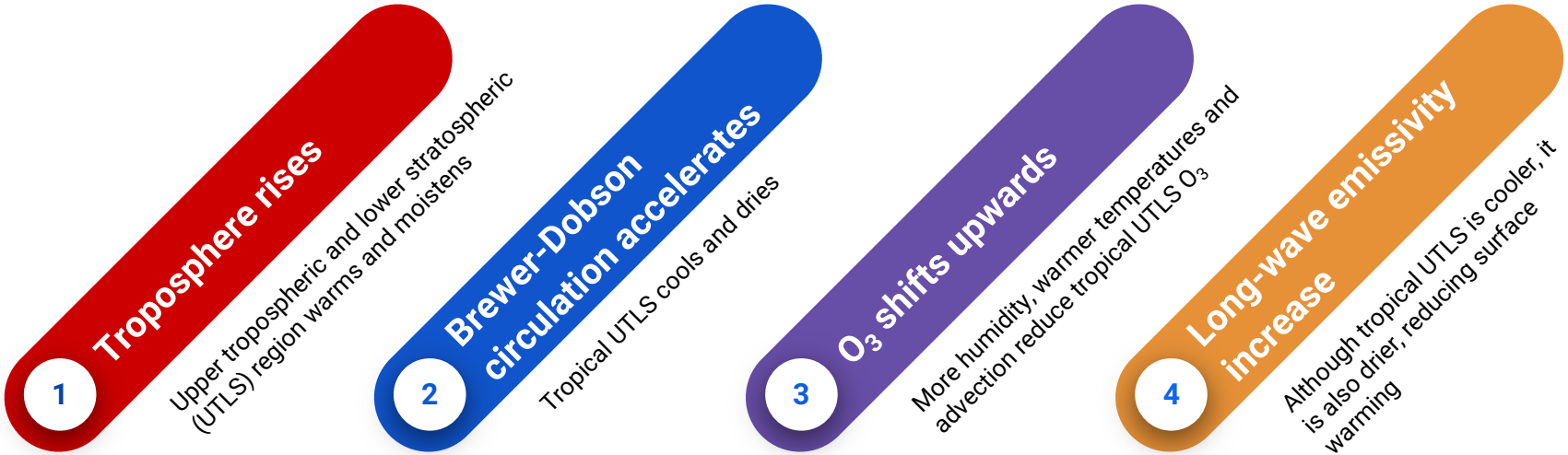
Atmospheric composition feedback



What is the direct impact of changes in the BDC in the tropical ECS?

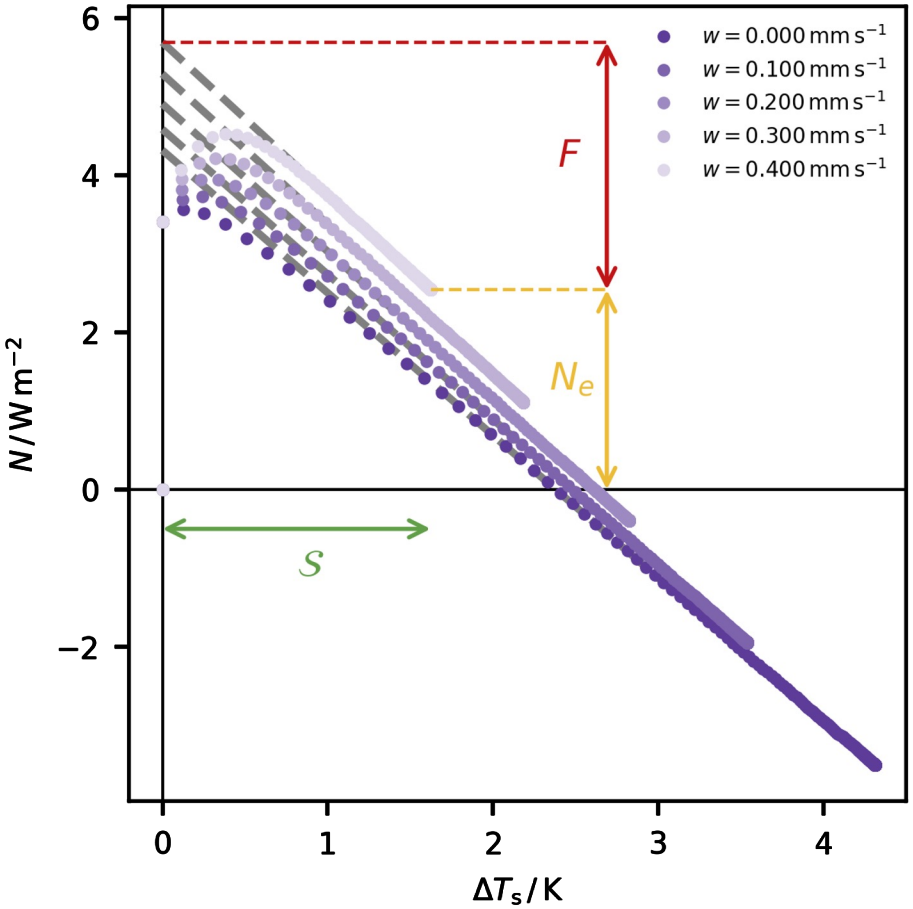
Tropical upwelling change in konrad

$$K = -w\left[(\partial_z T) + \frac{g}{c_p}\right]$$

Stratospheric cooling term: can interact with diabatic processes
Represents a tropical energy export to the extratropics

control	Control experiment with	• Cariolle and Teyssèdre (2007) linearised O_3 • Upwelling speed: 0.2 mm s^{-1}
2xC02	Climate change experiment with	• Upwelling speed change: -0.2 to 0.2 mm s^{-1}

The energy export reduces tropical ECS



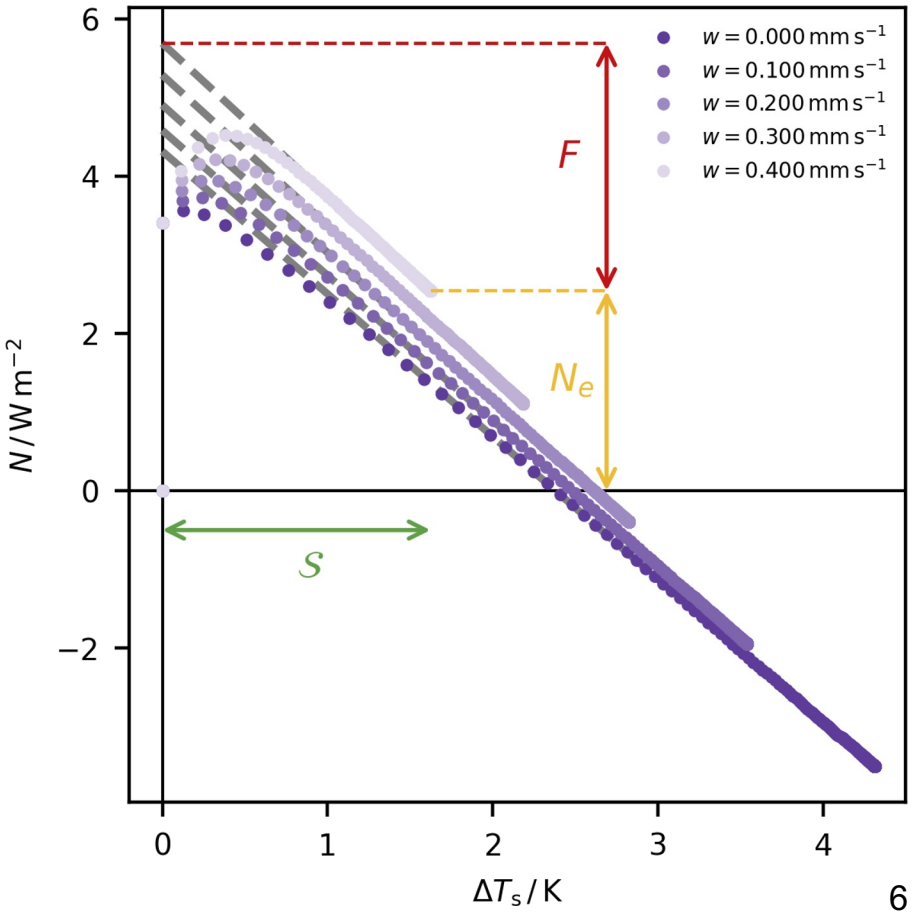
- ***The tropical energy export***
  - increases with stronger ***upwelling***
  - allows the equilibrium at a different TOA net flux
  - dampens ***the tropical effective radiative forcing***…
  - …reducing ***the tropical equilibrium climate sensitivity***

Some more details

- ***The dampened effective radiative forcing*** contributes **from 75% to 90%** to the ***ECS reduction***
- The rest of the ***ECS reduction*** comes from the ***net radiative feedback***
- **The *atmospheric composition feedback*** from interactive ozone only adds **about 25%** to the ***ECS reduction***

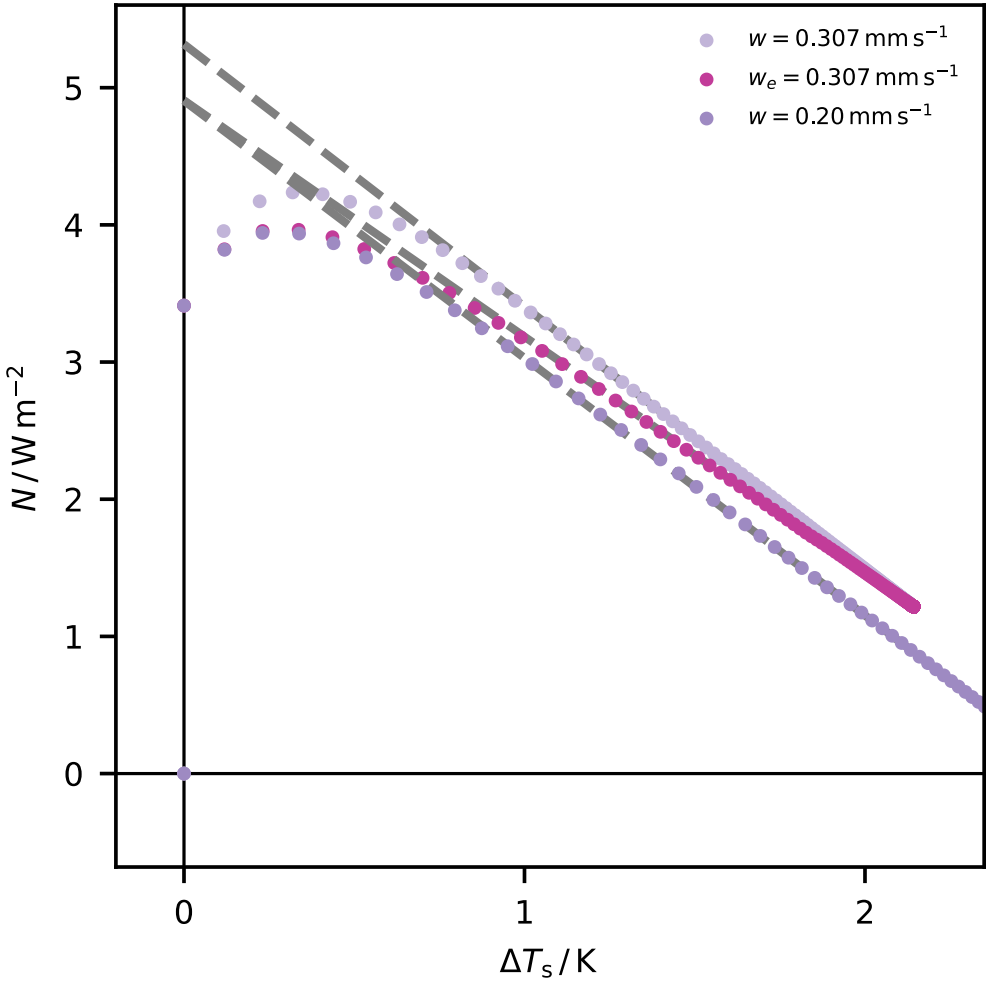
The tropical stratospheric upwelling sets the tropical ECS

- Stronger ***tropical stratospheric upwelling*** increases the ***tropical energy export***
- The increased ***tropical energy export*** reduces ***tropical ECS*** by mainly dampening the ***tropical effective radiative forcing***
- The ***atmospheric composition feedback*** only contributes about 25% to the ***tropical ECS*** reduction



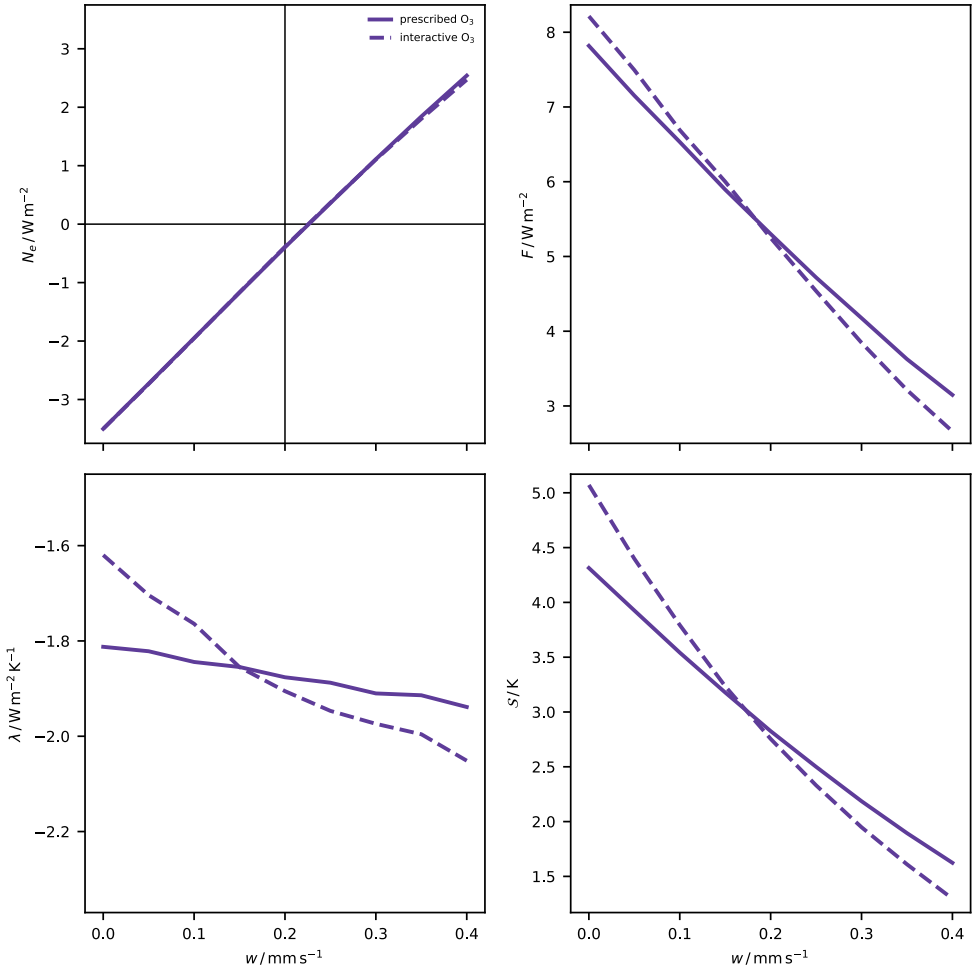
Supplementary Slides

Changing instantaneously and gradually the upwelling speed: the difference



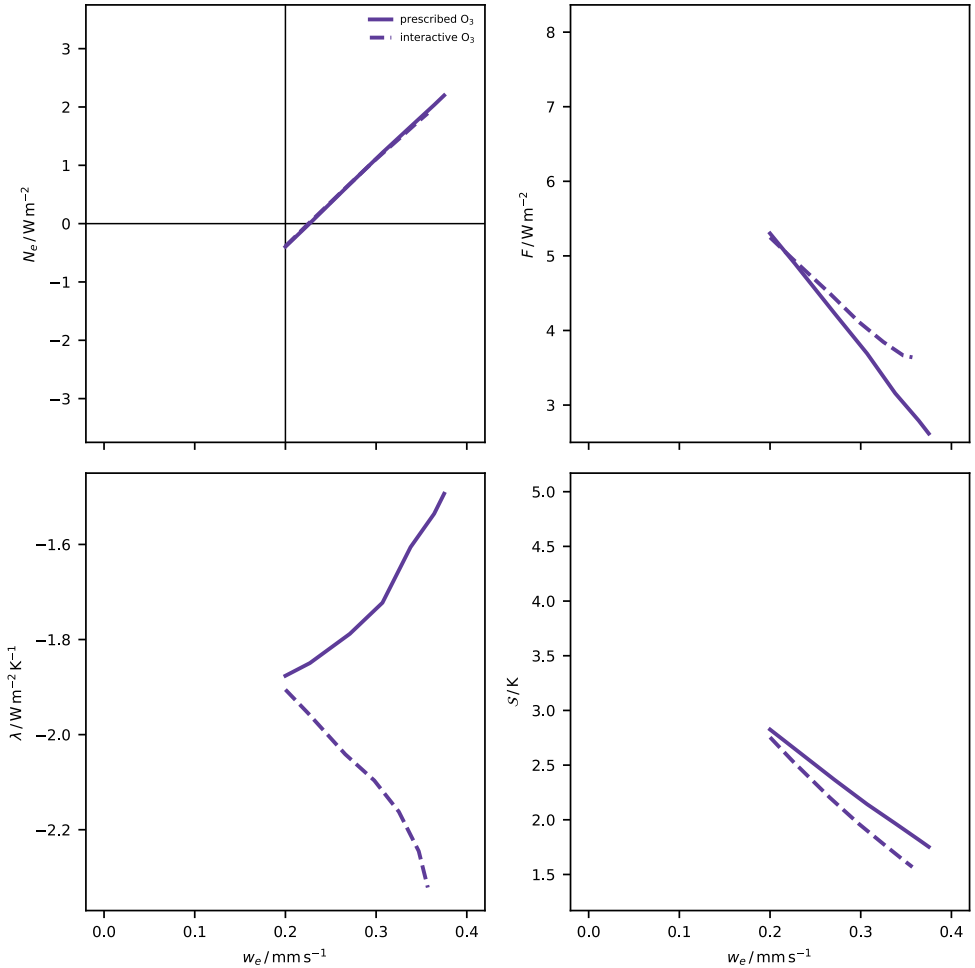
- The ***tropical energy export*** does not depend on how we change the ***tropical stratospheric upwelling***
- The ***tropical net radiative feedback weakens***
- ***The tropical effective radiative forcing dampens*** to compensate
- ***The tropical equilibrium climate sensitivity reduction*** only depend on the ***final tropical stratospheric upwelling speed***

Tropical energy export, net radiative feedback, effective radiative forcing and ECS as functions of the final upwelling speed (instantaneous)



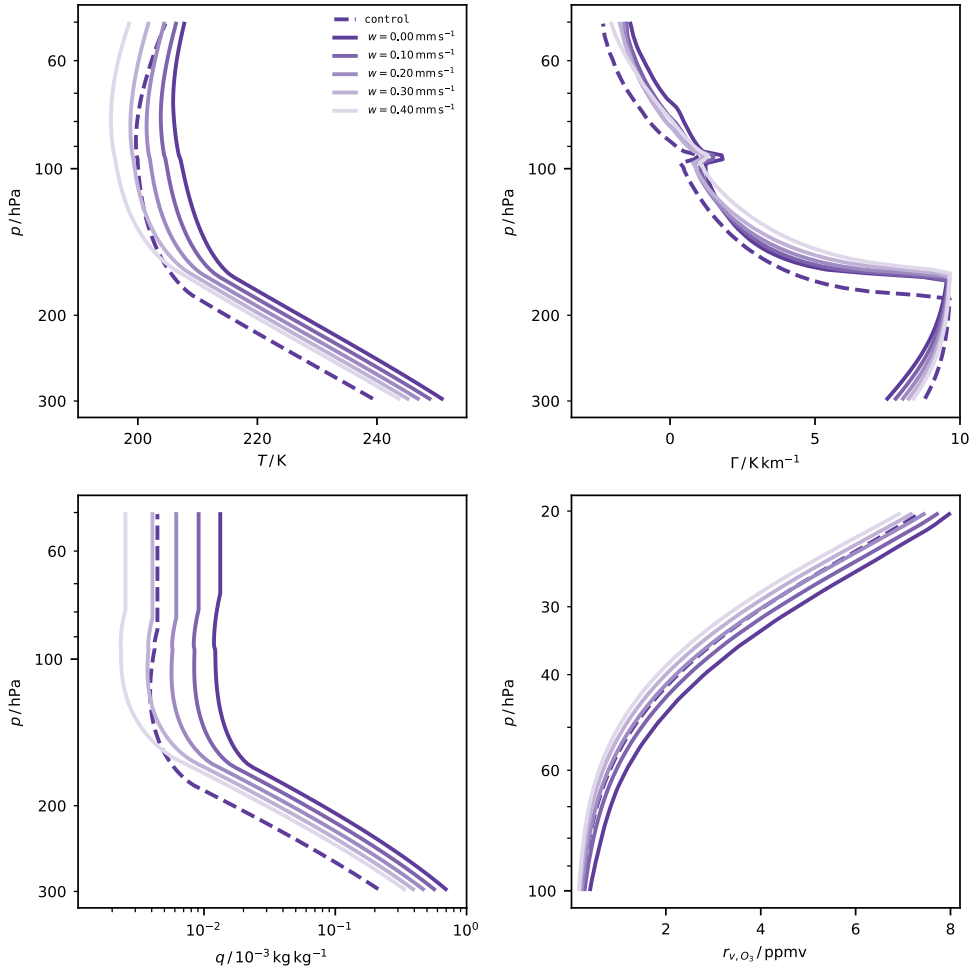
- The *tropical energy export* increases monotonically with increasing *tropical stratospheric upwelling*
- The increased *tropical energy export* dampens the *tropical effective radiative forcing*
- The *tropical net radiative feedback* strengthens slightly due to the *atmospheric composition feedback*
- *The tropical equilibrium climate sensitivity* is mainly set by *the tropical stratospheric upwelling*

Tropical energy export, net radiative feedback, effective radiative forcing and ECS as functions of the final upwelling speed (gradual)



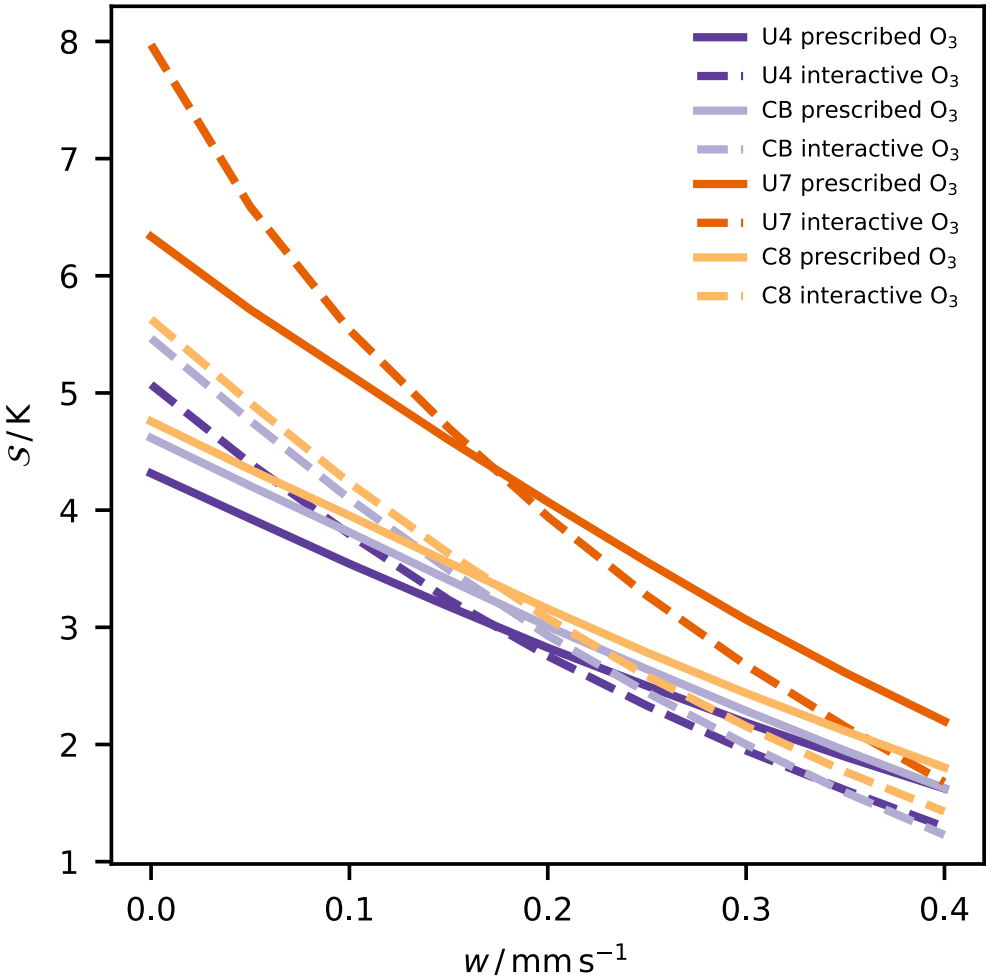
- The ***tropical energy export*** does not depend on how we change the ***tropical stratospheric upwelling***
- ***Without the atmospheric composition feedback***, the ***forcing dampens more*** to compensate for the weaker ***tropical net radiative feedback***.
- ***The tropical equilibrium climate sensitivity reduction*** only depend on the ***final tropical stratospheric upwelling speed***

Tropical profiles of temperature, temperature lapse rate, specific humidity and ozone as functions of the final upwelling speed



- With ***increasing upwelling,*** the UTLS:
- cools…
- …dries…
- …and unstabilizes (here overshooting convection can have a role)
- Interactive ozone changes more due to the ***upwelling***.

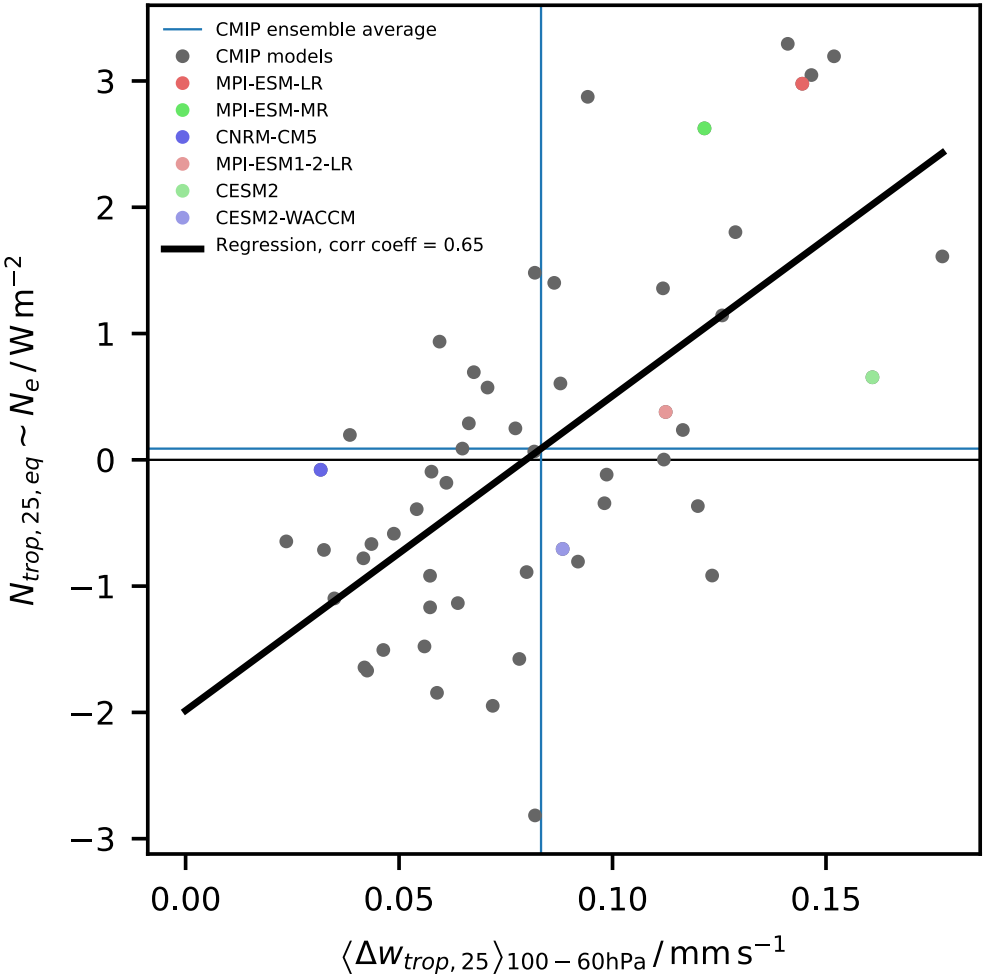
The relative humidity's role



The upwelling effect can allow very humid *palaeoclimates* to be **more stable**

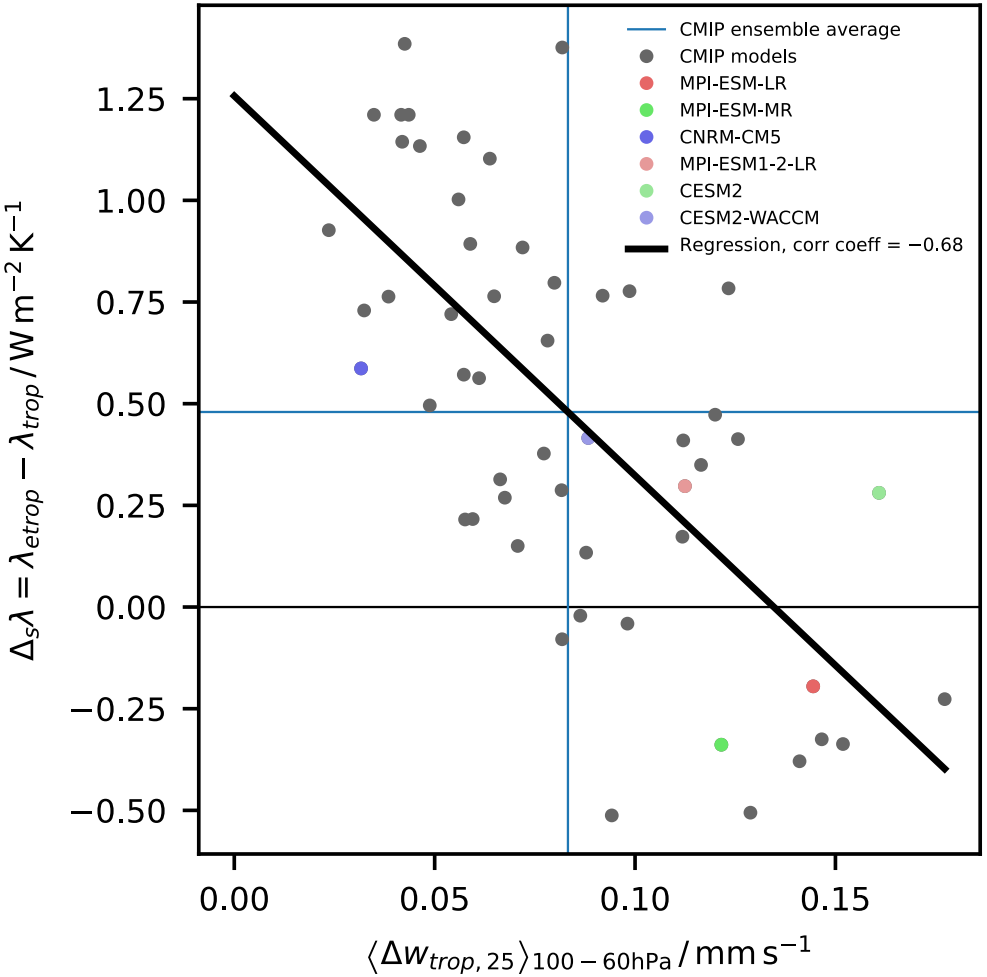
	RH / 1		
Name	Lower	Middle	Upper
U4	0.4	0.4	0.4
CB	0.8	0.3	0.6
U7	0.7	0.7	0.7
C8	0.8	0.4	0.8

CMIP5+6 shows the change in the tropical energy export



- Similar relationship as found with `konrad`
- GCMs with ***stronger upwelling change*** are those with *higher* ***global ECS***
- Without ***the upwelling change***, the ***global ECS*** would be *even higher*.

CMIP5+6 shows the effect in the extratropics



- The ***tropical energy export*** should warm the lower stratosphere in the extratropics
- This warming will lead to stronger extratropical OLR without a strong change in surface temperature: a ***stronger extratropical net radiative feedback***
- GCMs with ***stronger upwelling*** show a ***stronger extratropical feedback***: the difference between tropical and extratropical is reduced.
- Therefore the ***global ECS*** is also affected by the ***upwelling effect***

A weak BDC response to forcing in GCMs would overestimate the ECS

It can also account for the large spread in the strength of the atmospheric composition feedback