Tropical fingerprints of low and high sensitivities in CMIP5 models

Olivier Geoffroy, Steve Sherwood

Thanks to Mark Webb, Sandrine Bony, Jean-Louis Dufresne

UNSW THE UNIVERSITY OF NEW SOUTH WALES SYDNEY · CANBERRA · AUSTRALIA
Climate Change Research Centre (CCRC)
Faculty of Science

Context

- Tropical cloud feedback → major source of uncertainty for projections *(e.g. Vial et al., 2013)*
- Feedback related to circulation: - mean state strength *(e.g. Fasullo and Trenberth, 2012)*
  - response *(Su et al., 2014)*
  - shallow circulation *(Sherwood et al., 2014)*
- Importance of shallow convective mixing (via humidity) *(Zhang et al., 2014, Sherwood et al., 2014)*, turbulence *(Qu and Hall, 2015)*

Fasullo and Trenberth (2012)

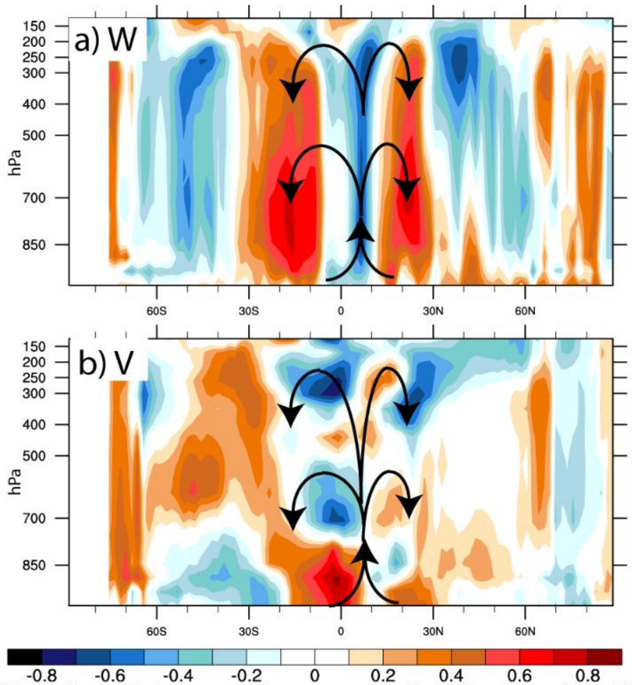
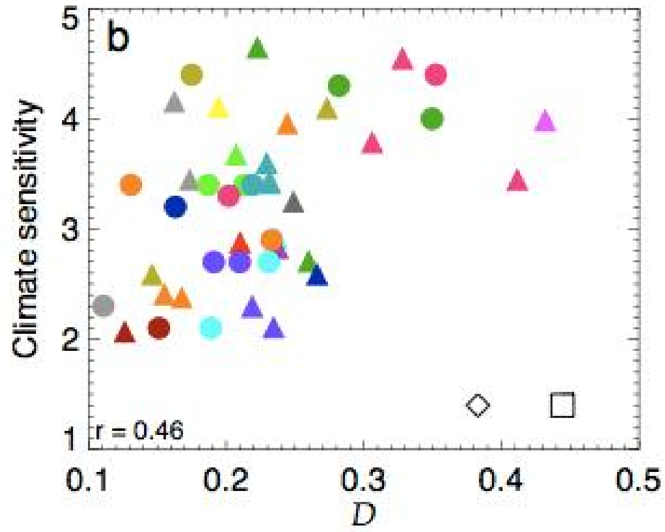


Fig. S2: Correlation between zonal mean ocean a) vertical (W) and b) meridional (V) velocities in the present day simulations of models in the CMIP3 archive and ECS. The results suggest that RH correlations with ECS in the moist and dry regions (Fig 3) are coupled through the depth and intensity of the simulated tropical circulation.

Sherwood et al. (2014)



$wap_{850-700} - wap_{400-500-600}$

Outlines

I. (Constraint with the) mean climatological state

Relationships valid in a simple dynamical regime decomposition? Other relationships? Explanations?

→ CMIP5 Coupled & AMIP models analysis

II. (Constraint with the) annual cycle

Relationship with spatial changes in the annual cycle (and interannual variability)

→ CMIP5 Coupled & AMIP models analysis

Outlines

I. (Constraint with the) mean climatological state

Relationships valid in a simple dynamical regime decomposition? Other relationships? Explanations?

→ CMIP5 Coupled & AMIP models analysis

- Tropics (30°S-30°N)
- Only ocean, ascending and subsiding regions (wap_{500})
- 19 CMIP5 models (1 version per model)
- λ_{trop} : tropical radiative response parameter from Gregory linear regression in the tropics

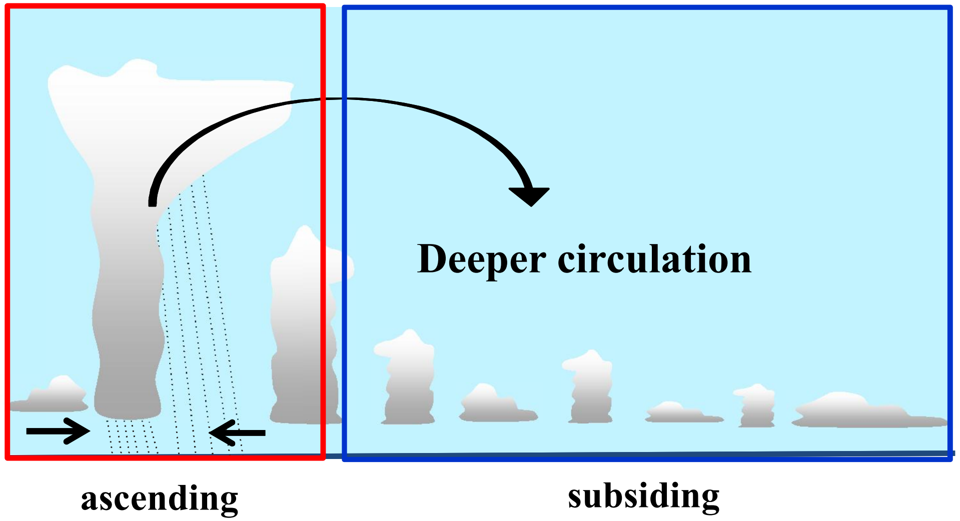
II. (Constraint with the) annual cycle

Relationship with spatial changes in the annual cycle (and interannual variability)

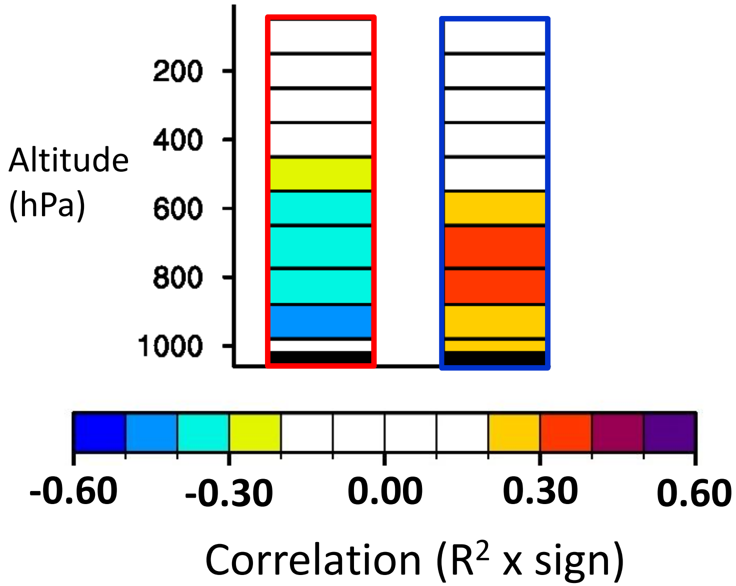
→ CMIP5 Coupled & AMIP models analysis

Tropical feedback vs tropical circulation

High sensitivity models characterized by:



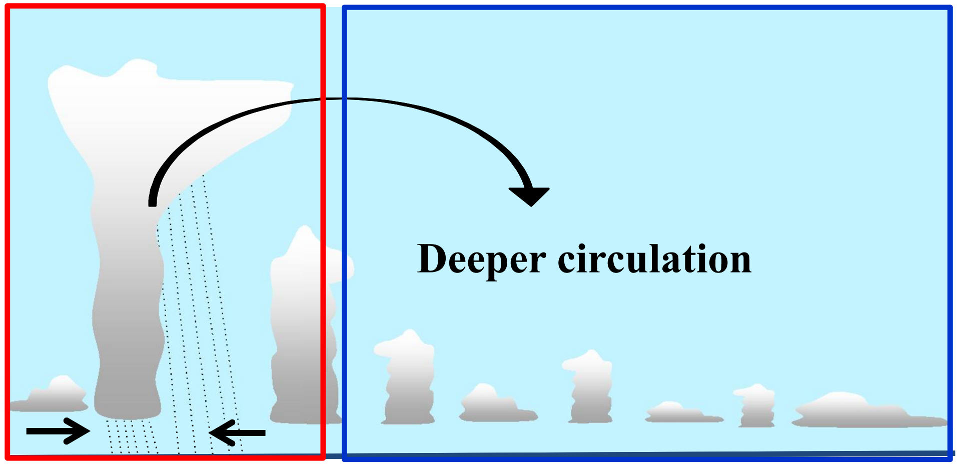
Correlation **wap vs λ_{trop}** per level



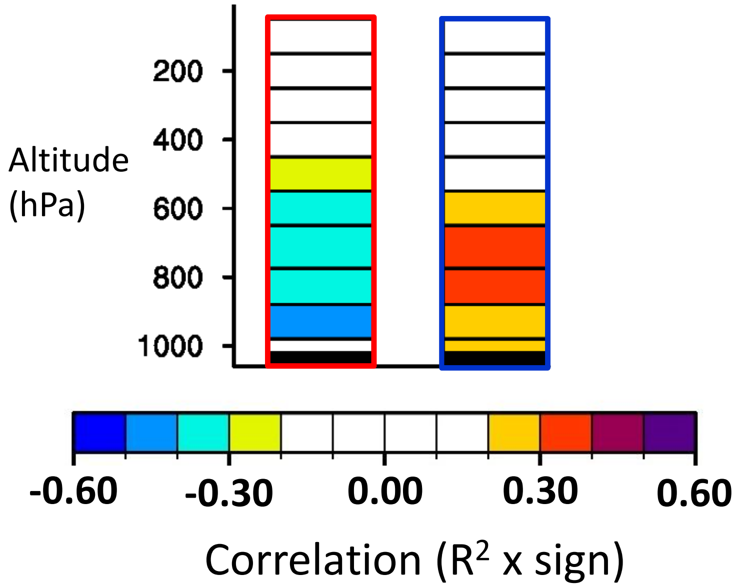
Correlation with $dCRE_{trop}/dT_{trop}$ ↘

Tropical feedback vs tropical circulation

High sensitivity models characterized by:



Correlation **wap vs λ_{trop}** per level



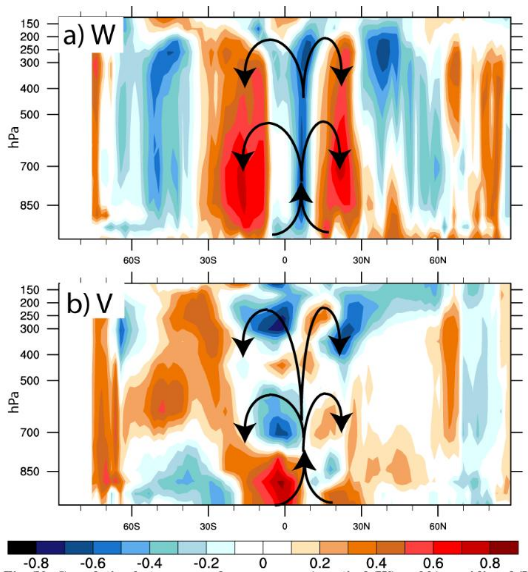


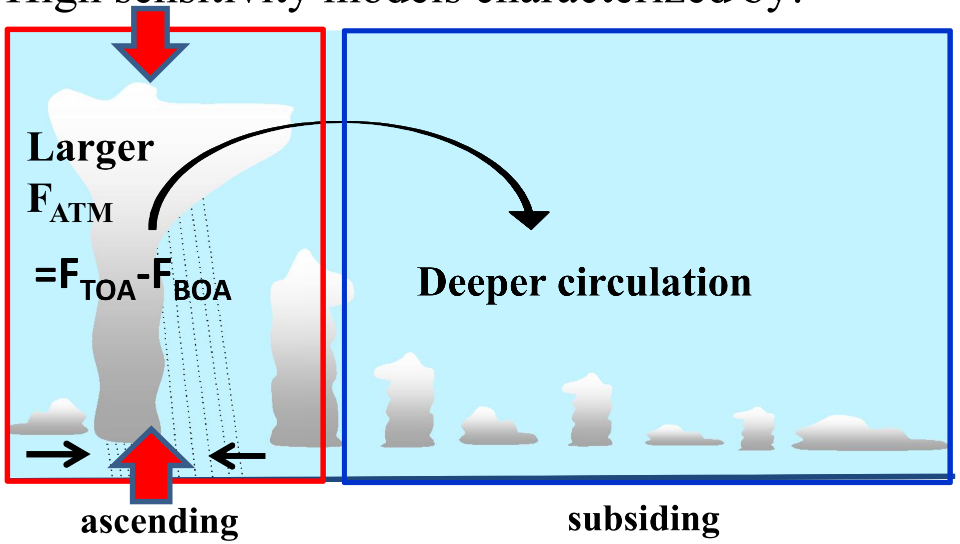
Fig. S2: Correlation between zonal mean ocean a) vertical (W) and b) meridional (V) velocities in the present day simulations of models in the CMIP3 archive and ECS. The results suggest that RH correlations with ECS in the moist and dry regions (Fig 3) are coupled through the depth and intensity of the simulated tropical circulation.

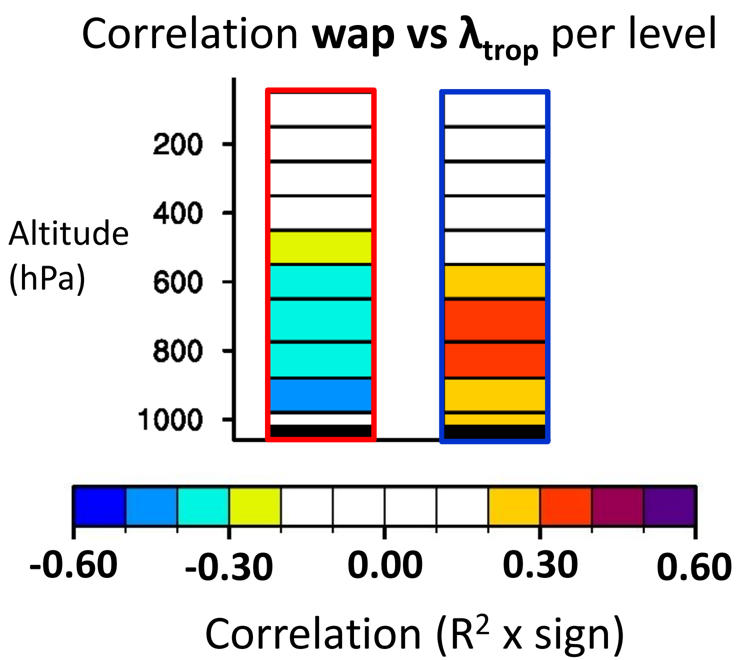
Correlation with $dCRE_{trop}/dT_{trop}$ ↘

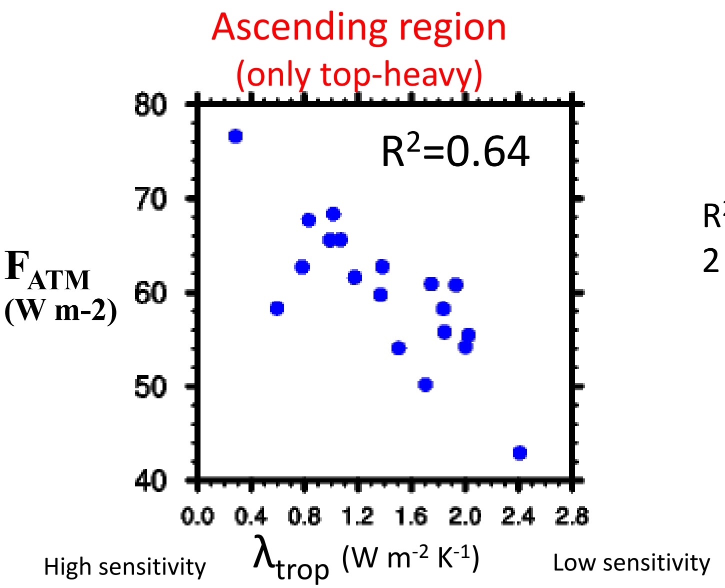
In agreement with with
Fasullo and Trenberth (2012)

Tropical feedback vs tropical circulation

High sensitivity models characterized by:



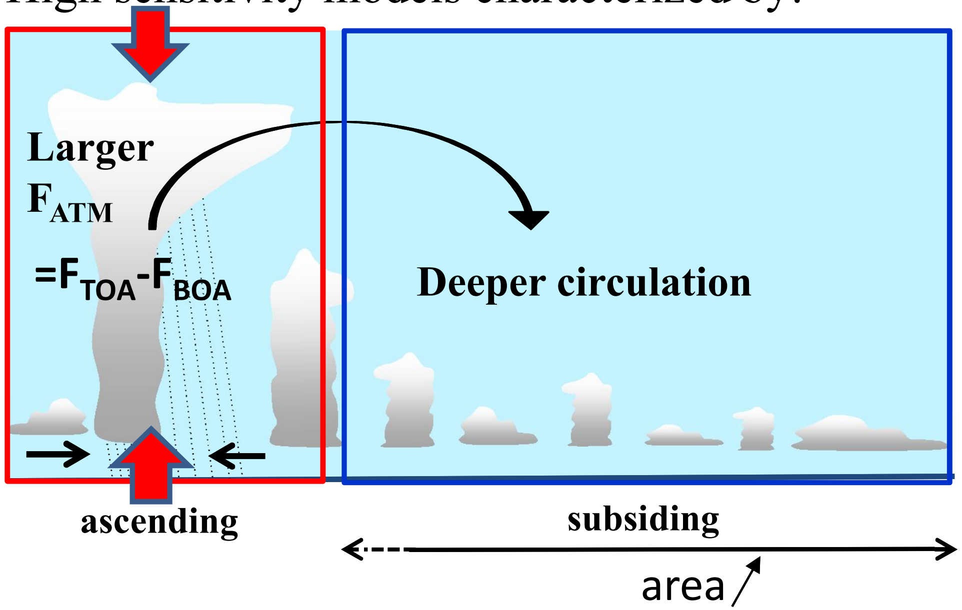


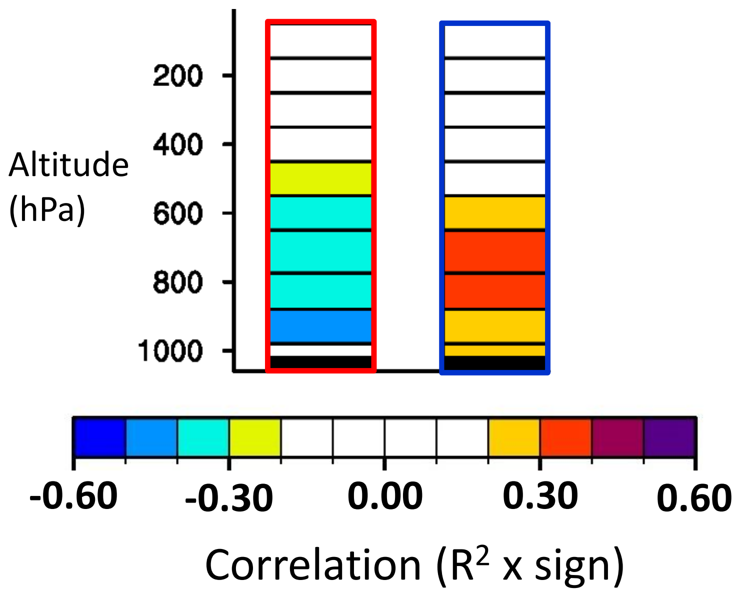


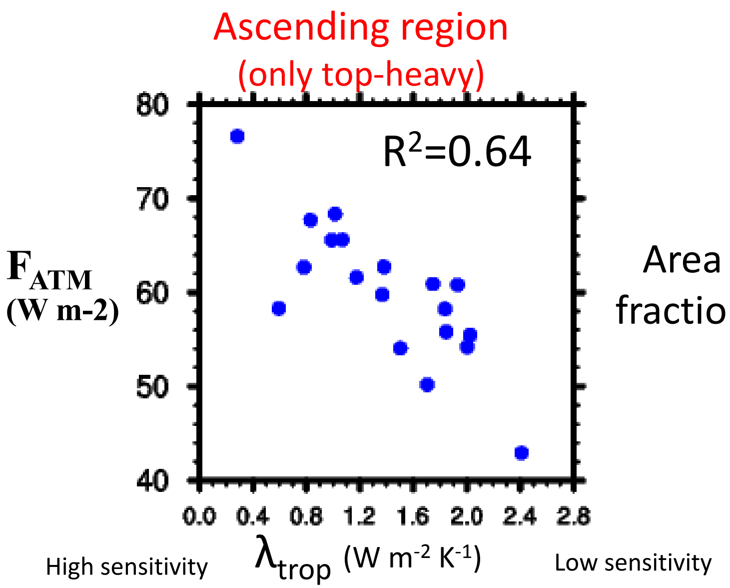
R^2 = 0.40 without the 2 extreme AOGCMs

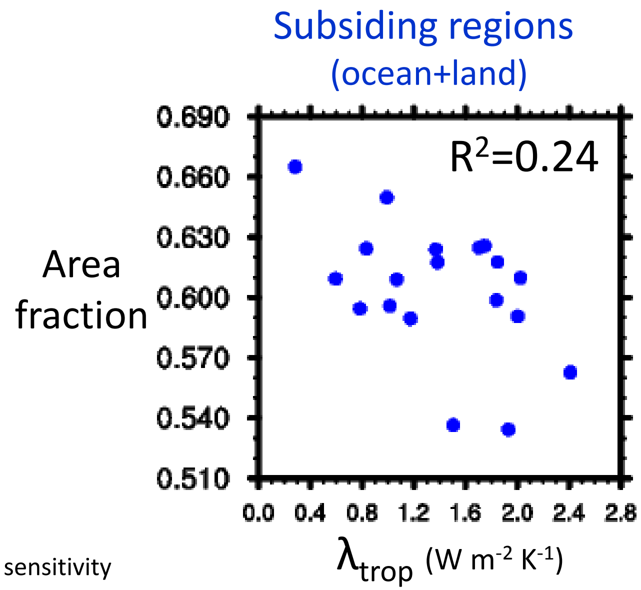
Tropical feedback vs tropical circulation

High sensitivity models characterized by:



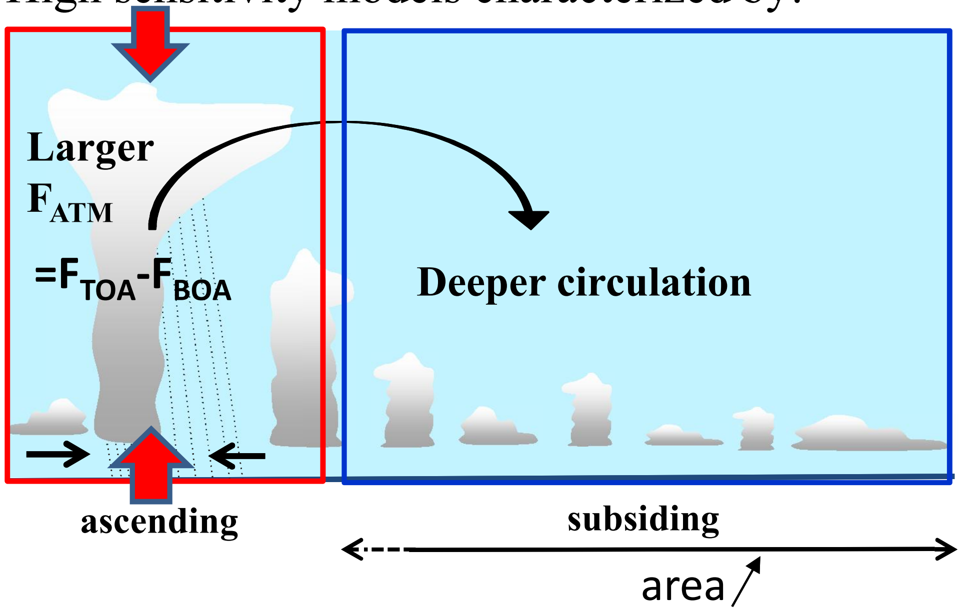




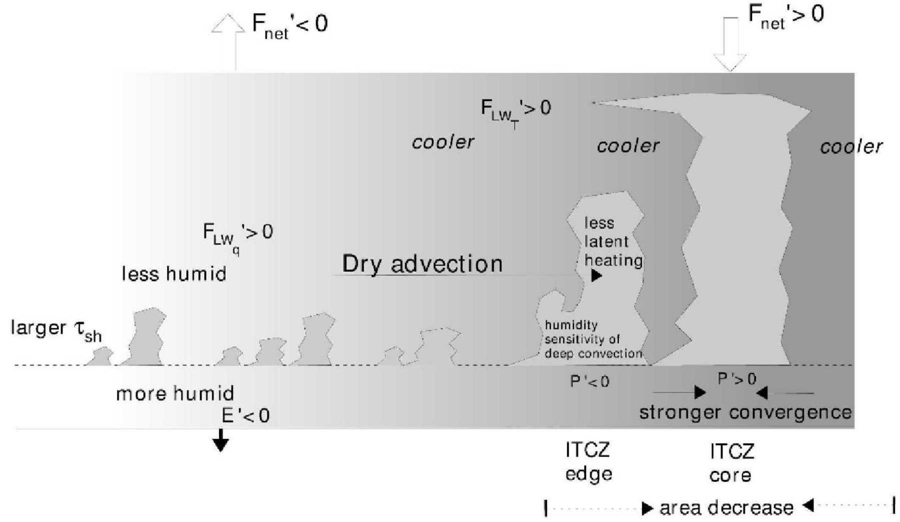


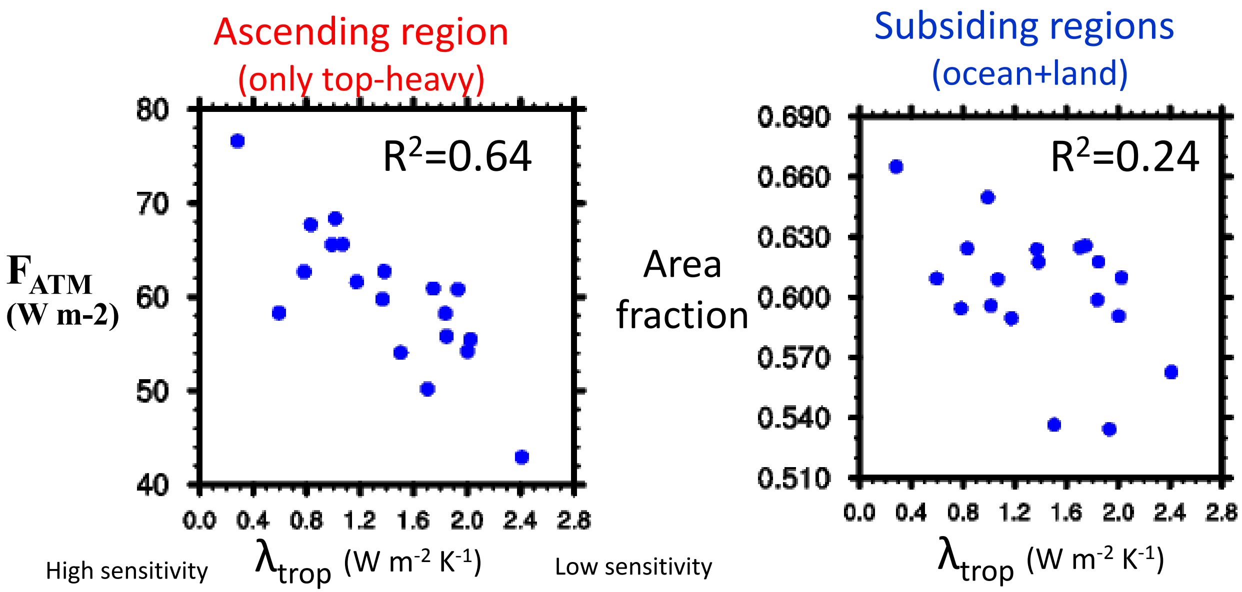
Tropical feedback vs tropical circulation

High sensitivity models characterized by:



Effect of a decrease of shallow vertical transport in a QTCM (*Neggers et al., 2007*):

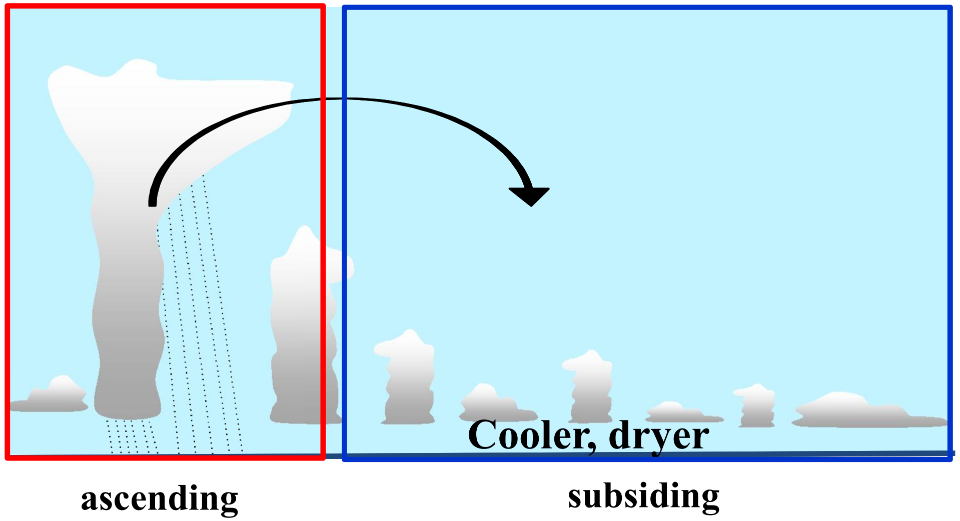




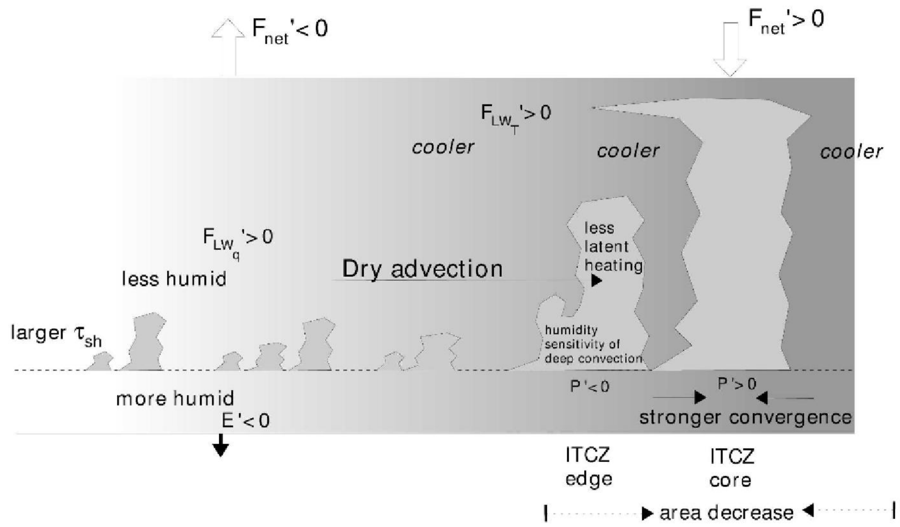
Similar to Neggers et al (2007) results

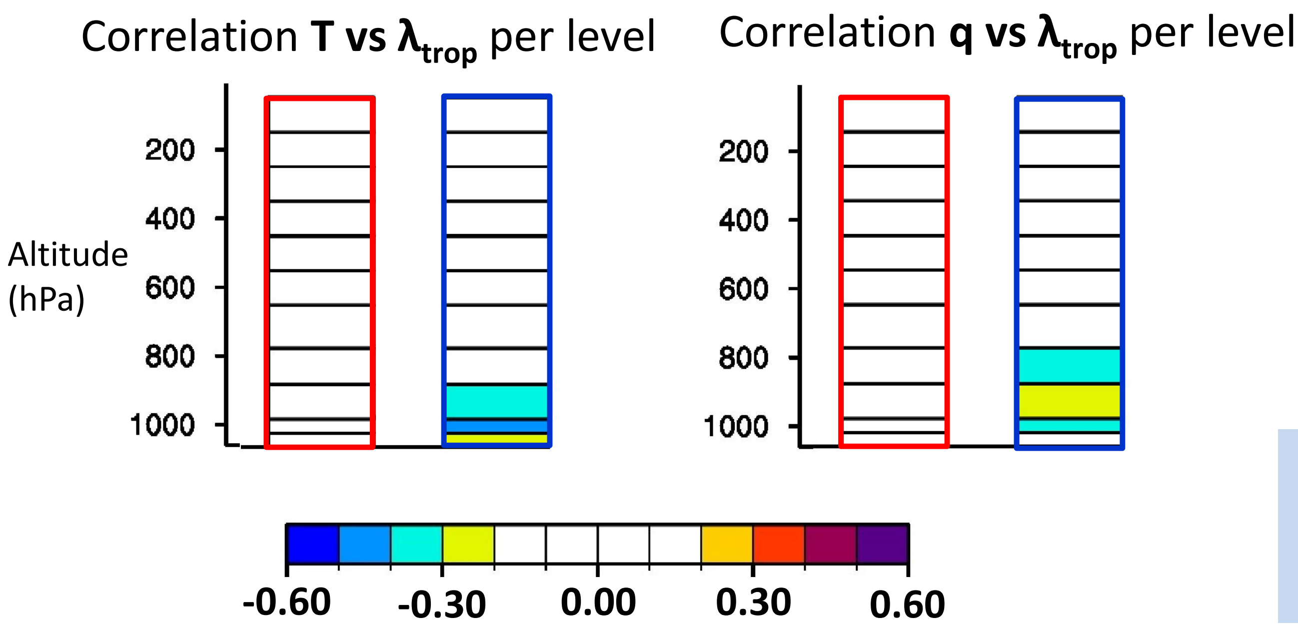
BL and cloud layer thermodynamic

High sensitivity models characterized by:



Effect of a decrease of shallow vertical transport in a QTCM (*Neggers et al., 2007*):

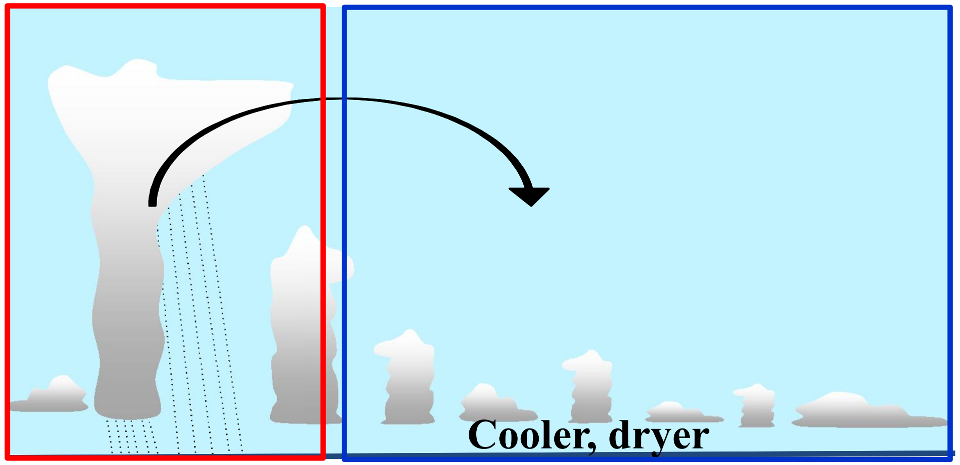




Similar to Neggers et al (2007) results
but not for q in BL

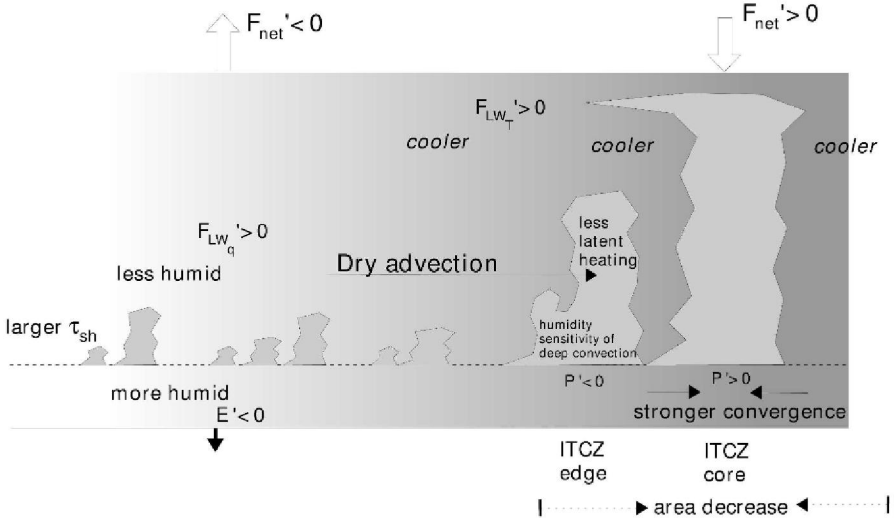
BL and cloud layer thermodynamic

High sensitivity models characterized by:

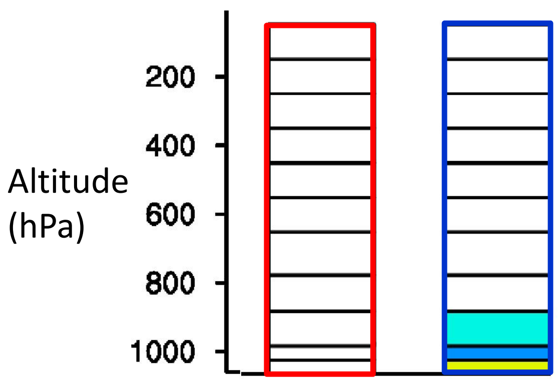


ascending subsiding

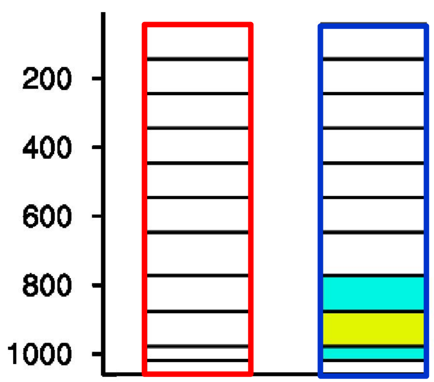
Effect of a decrease of shallow vertical transport in a QTCM (*Neggers et al., 2007*):

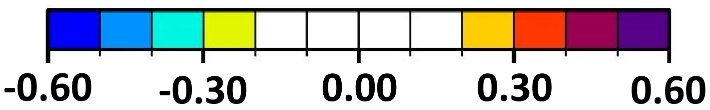


Correlation **T vs λ_{trop}** per level



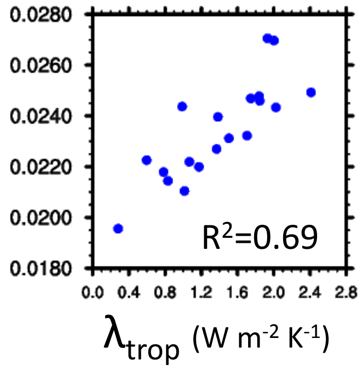
Correlation **q vs λ_{trop}** per level





Bulk equation (Betts and Ridgway)

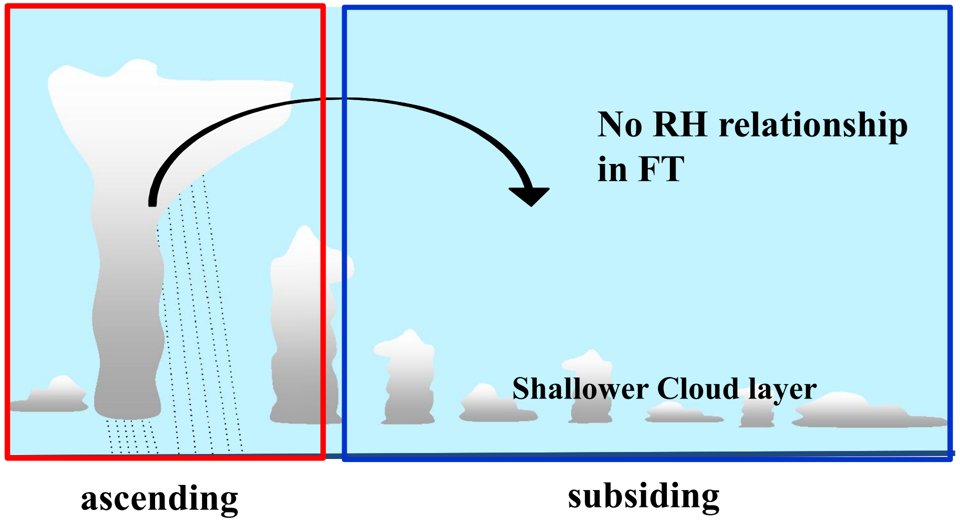
$$\overline{q_{BL}} = \frac{\overline{LHF}}{\overline{\omega_{775}}} + \overline{q_{700}}$$



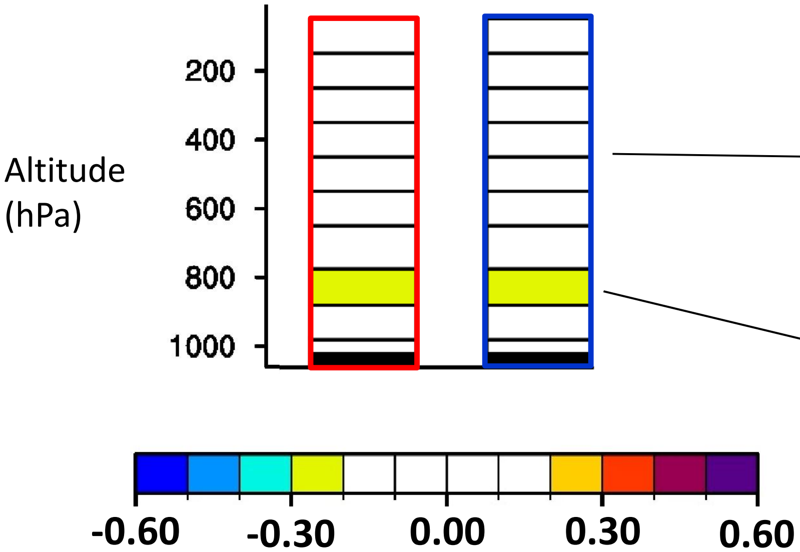
Similar to Neggers et al (2007) results
but not for T and q in BL

Relative humidity

High sensitivity models characterized by:



Correlation **RH vs λ_{trop}** per level

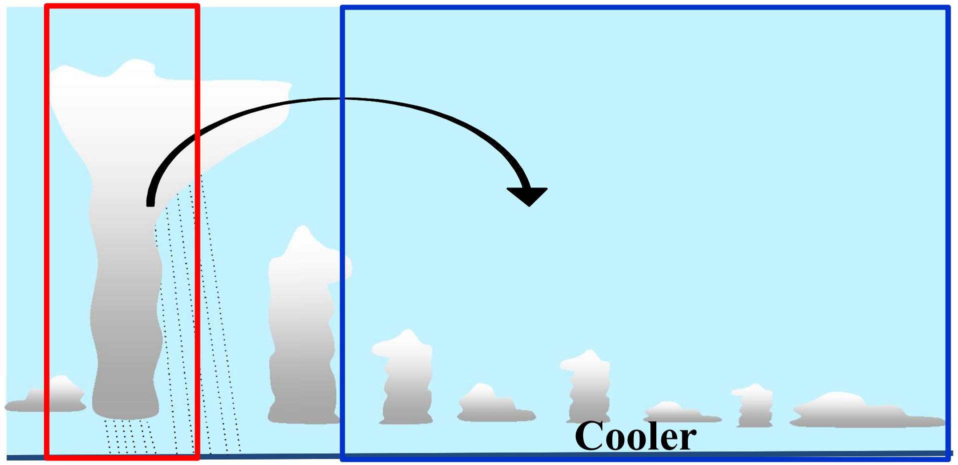


- No correlation with free troposphere RH (Fasullo and Trenberth, 2012) in such decomposition

- Consistent with shallower cloud layer (Brient et al, 2015) but small R^2

Surface air T, warm and cold pools difference

High sensitivity models characterized by:

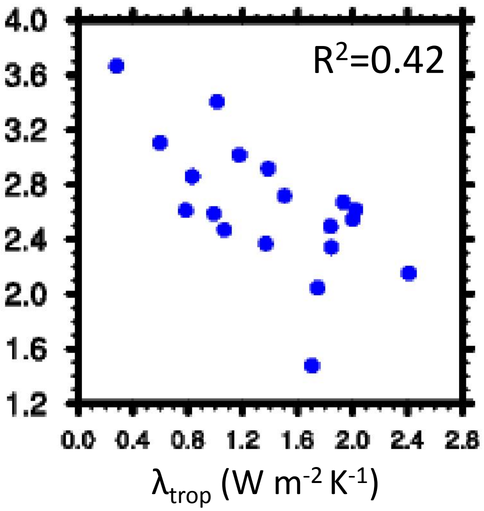


ascending **subsiding**

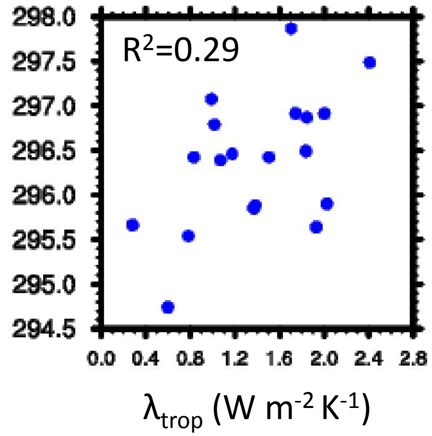
Larger surface air T gradient: $T_{as}^{\uparrow} - T_{as}^{\downarrow} \uparrow$

$T_{as}^{\uparrow} - T_{as}^{\downarrow}$ (K)

(Only in top-heavy regions)

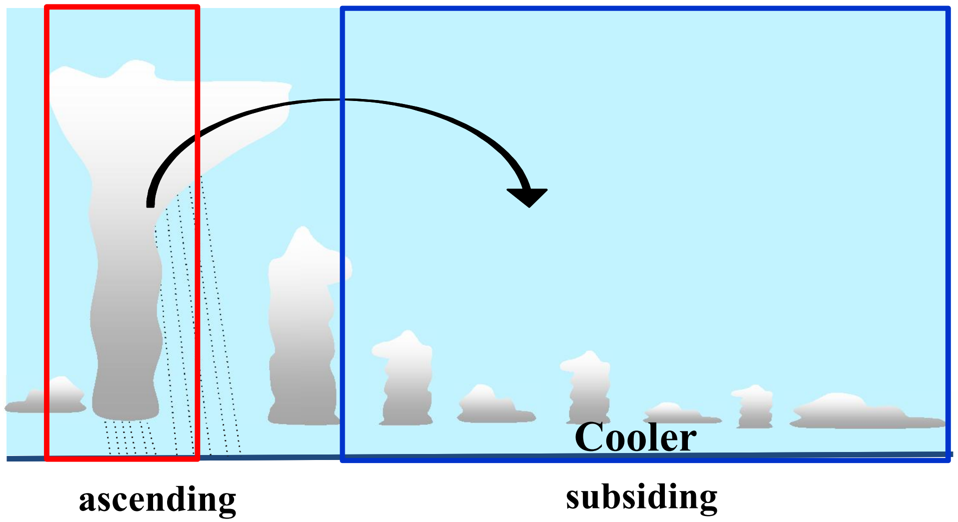


→ mainly due to lower $T_{as}^{\downarrow}$ **(K)**



Surface air T, warm and cold pools difference

High sensitivity models characterized by:

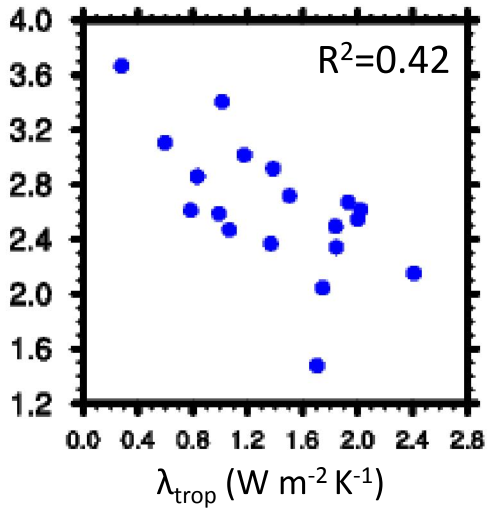


Larger surface air T gradient: $T_{as}^{\uparrow}-T_{as}^{\downarrow}$ ↑

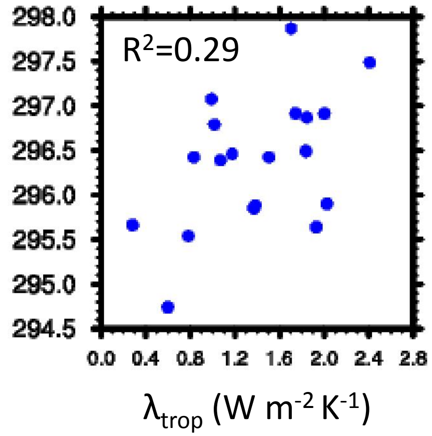
Other fingerprints associated with differences in $T_{as}^{\uparrow}-T_{as}^{\downarrow}$?
→ Analysis of AMIP (Same SST pattern)

$T_{as}^{\uparrow}-T_{as}^{\downarrow}$ (K)

(Only in top-heavy regions)

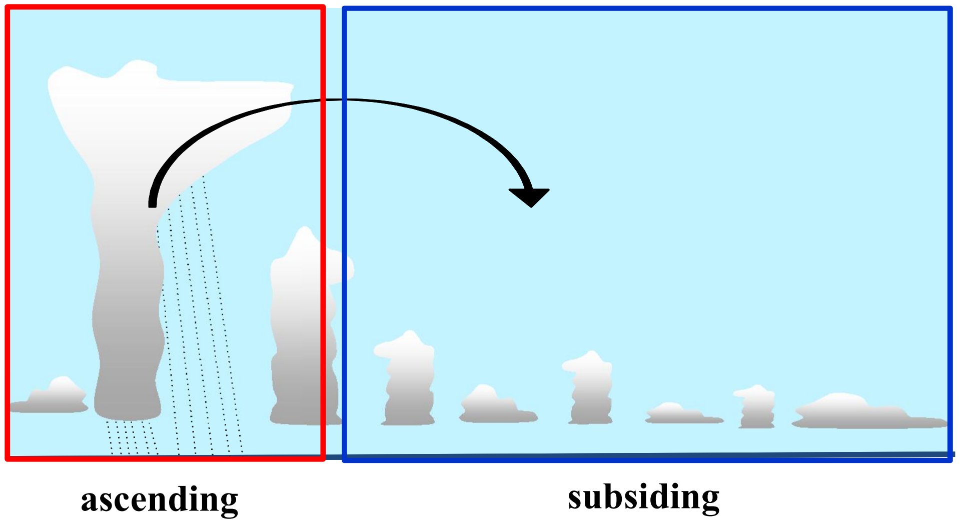


→ mainly due to lower $T_{as}^{\downarrow}$ (K)



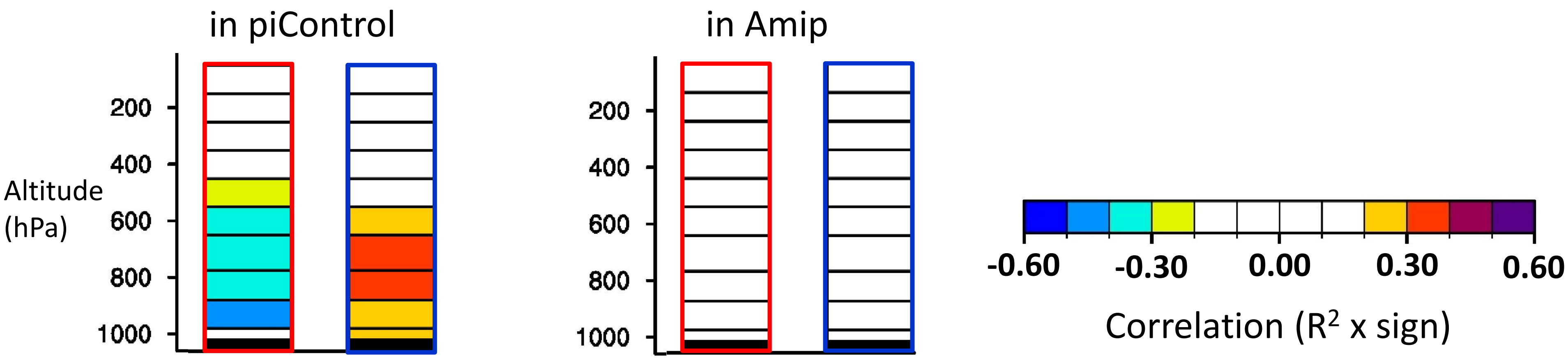
Surface air T, warm and cold pool difference

High sensitivity models characterized by:



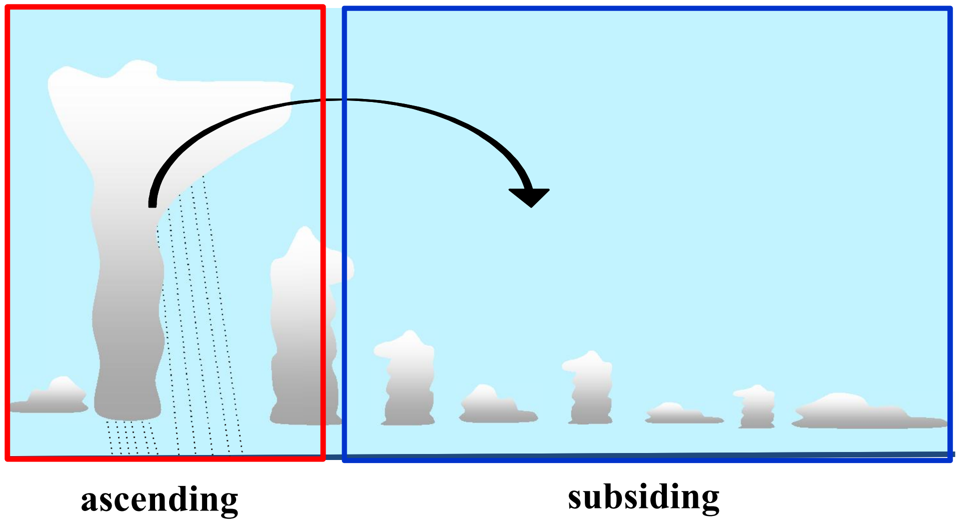
Other fingerprints
associated with differences in $T_{as}^{\uparrow}$-$T_{as}^{\downarrow}$?
→ Analysis of AMIP (Same SST pattern)

Correlation **wap vs λ_{trop}** per level



Surface air T, warm and cold pool difference

High sensitivity models characterized by:

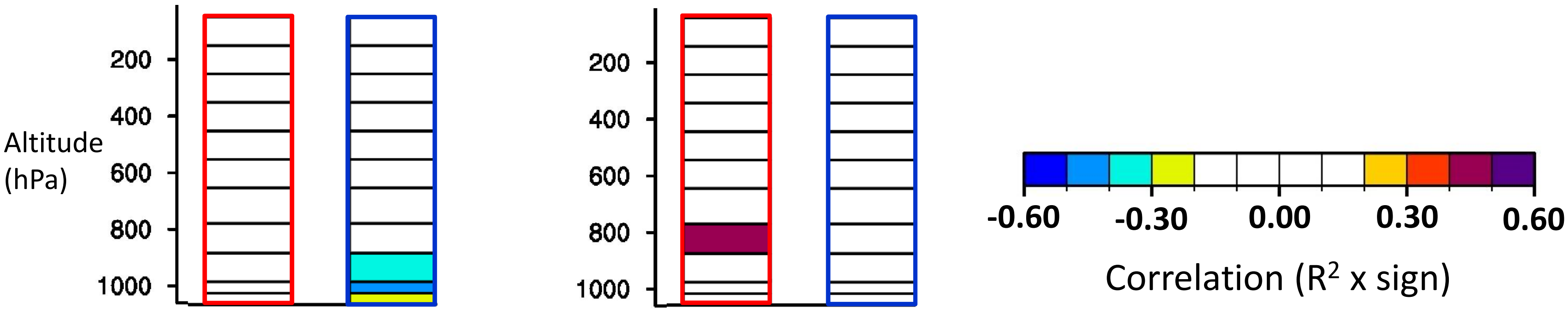


Other fingerprints
associated with differences in $T_{as}^{\uparrow}$-$T_{as}^{\downarrow}$?
→ Analysis of AMIP (Same SST pattern)

Correlation **Temperature vs λ_{trop}** per level

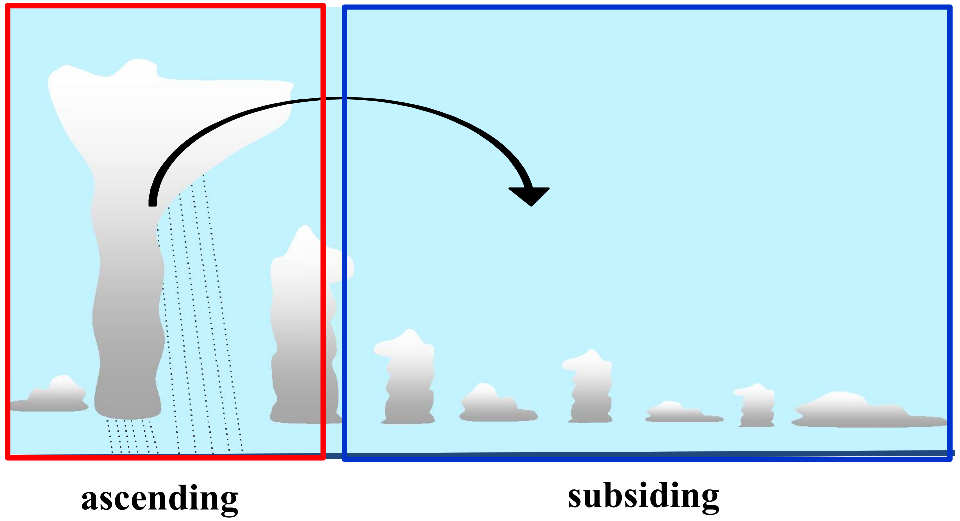
in piControl

in Amip



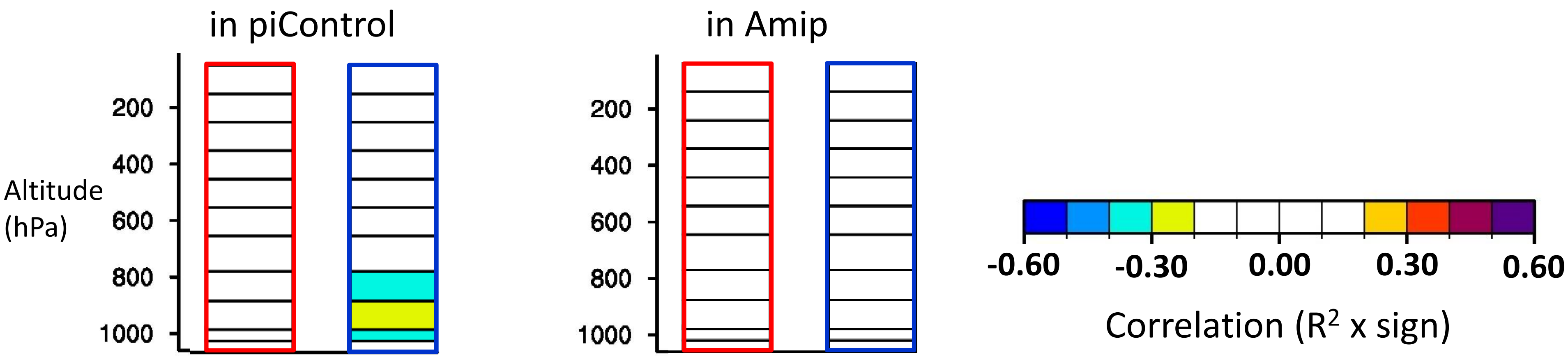
Surface air T, warm and cold pool difference

High sensitivity models characterized by:



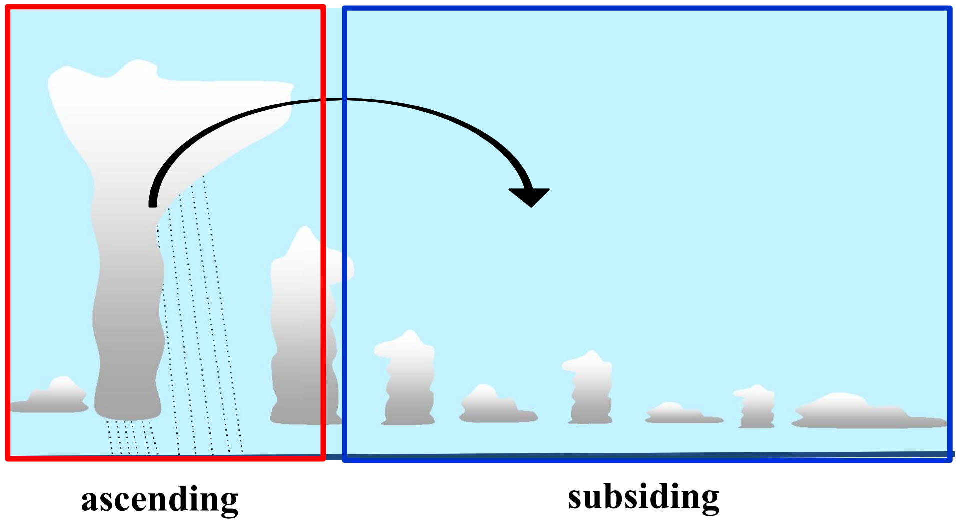
Other fingerprints
associated with differences in $T_{as}^{\uparrow}$-$T_{as}^{\downarrow}$?
→ Analysis of AMIP (Same SST pattern)

Correlation **specific humidity vs λ_{trop}** per level



Surface air T, warm and cold pool difference

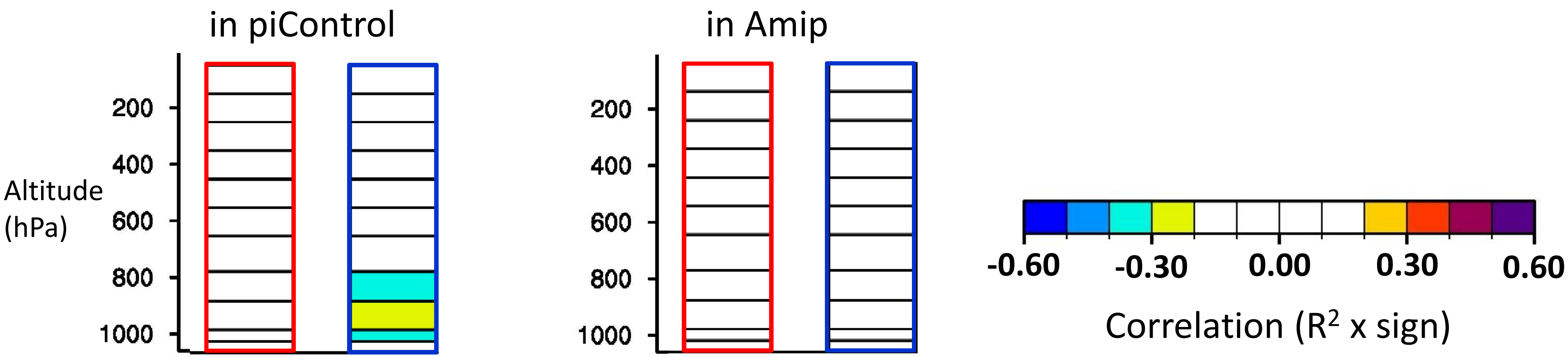
High sensitivity models characterized by:



Other fingerprints associated with differences in $T_{as}^{\uparrow}$-$T_{as}^{\downarrow}$?
→ Analysis of AMIP (Same SST pattern)

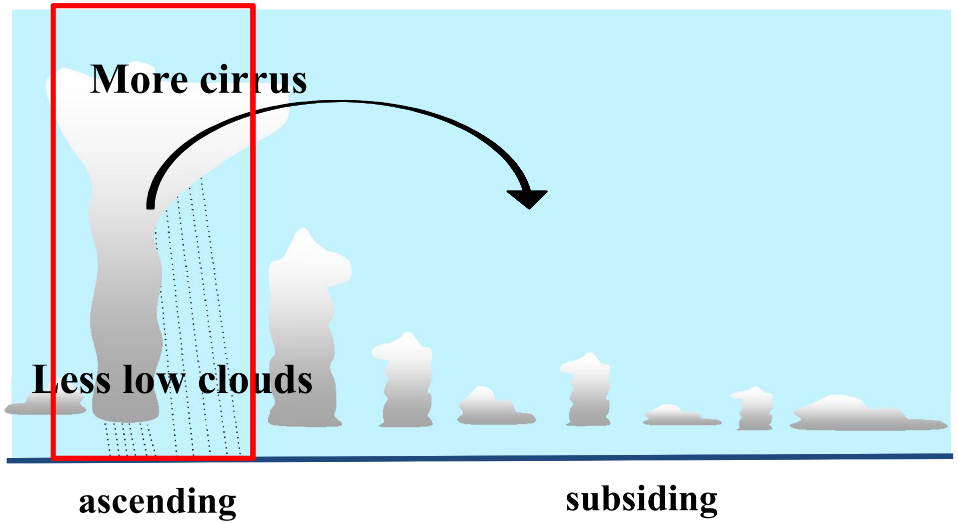
Relationship not in AMIP
→ Suggest important role of $T_{as}^{\uparrow}$-$T_{as}^{\downarrow}$
→ Why larger $T_{as}^{\uparrow}$-$T_{as}^{\downarrow}$?

Correlation **specific humidity vs λ_{trop}** per level

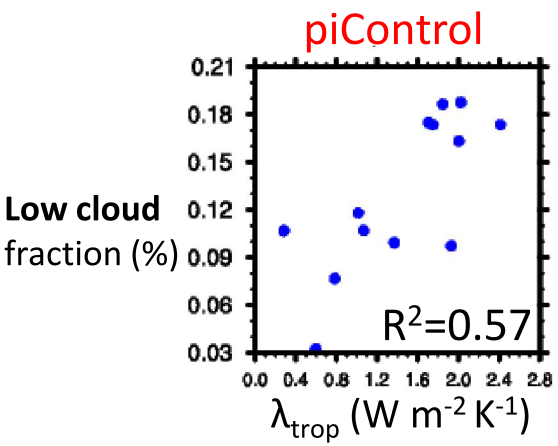


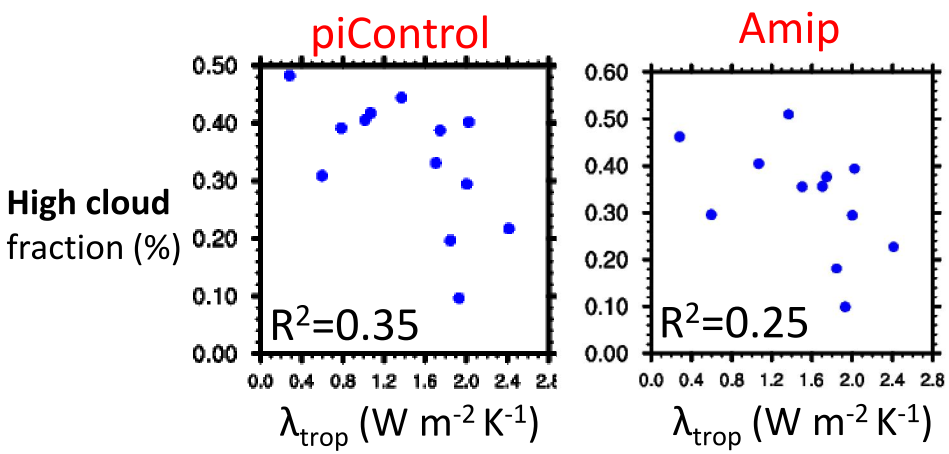
CRE in ascending region

High sensitivity models characterized by:



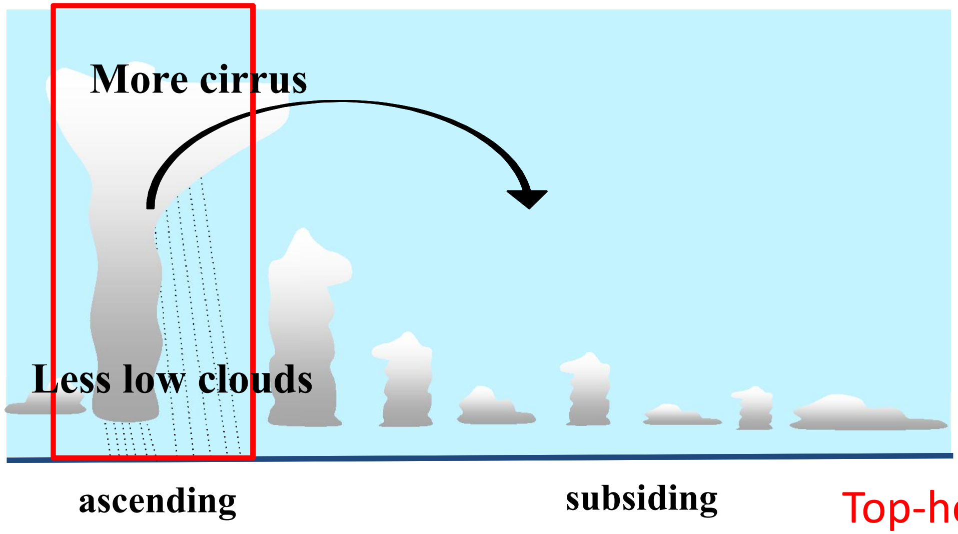
- Less low clouds
- More cirrus





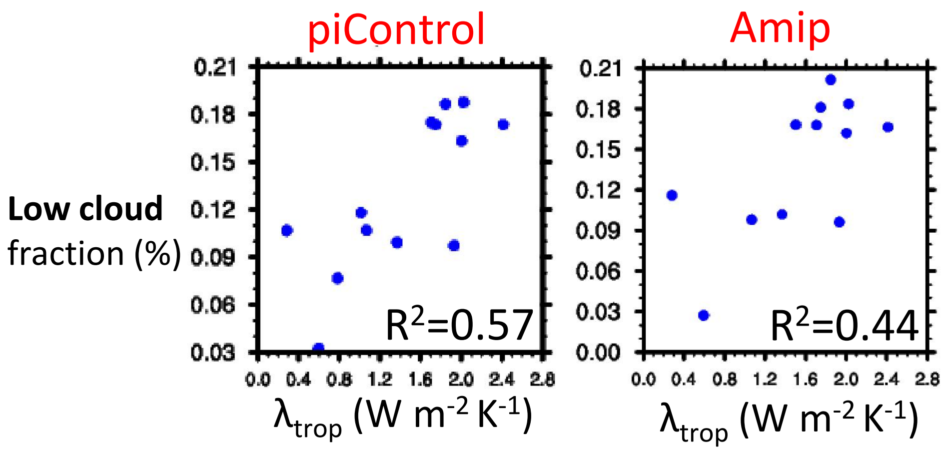
CRE in ascending region

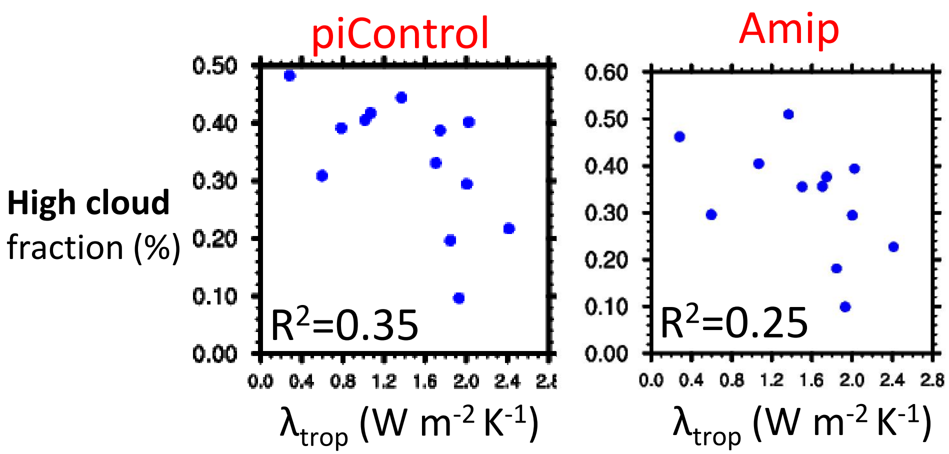
High sensitivity models characterized by:



- Less low clouds
- More cirrus

Top-heavy ascents





- with λ_{glob}	R^2=0.37	R^2=0.27	R^2=0.60	R^2=0.51
- with $dCRE_{trop}/dT_{trop}$	R^2=0.66	R^2=0.56	R^2=0.21	R^2=0.21

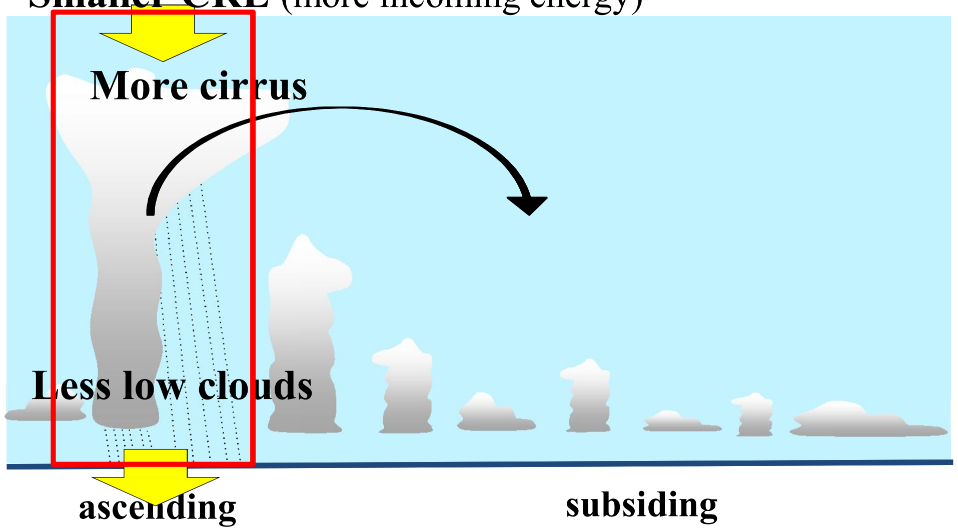
correlation improved with $dCRE_{trop}/dT_{trop}$

correlation improved with λ_{glob}

CRE in ascending region

High sensitivity models characterized by:

Smaller CRE (more incoming energy)



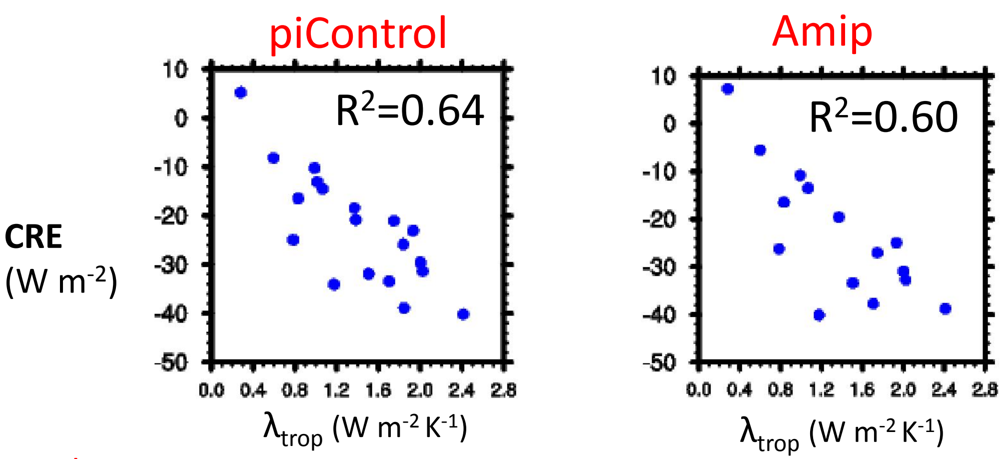
Possible mechanism

- Less low clouds
- More cirrus

↓

CRE in ascending region ↘
TOA flux in ascending region ↗

Top-heavy ascents

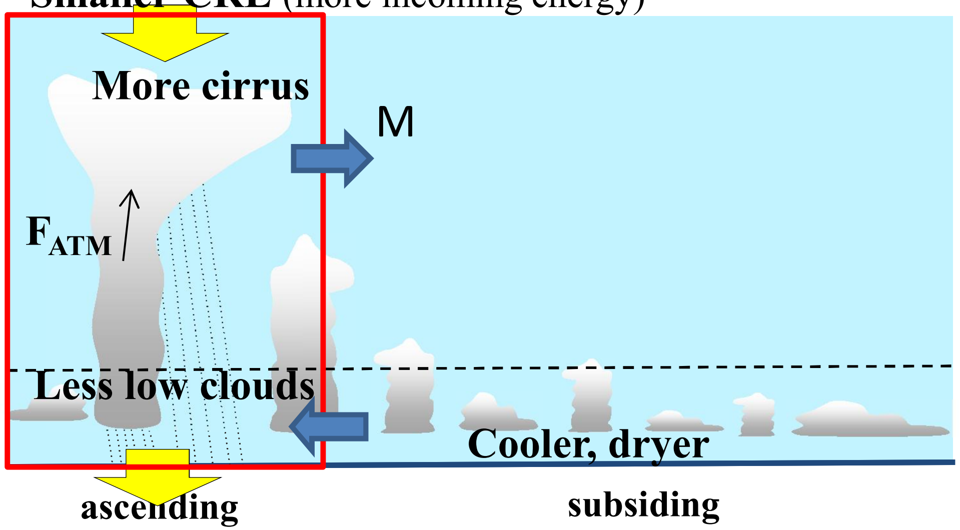


- with $dCRE_{trop}/dT_{trop}$ R^2=0.70 R^2=0.71

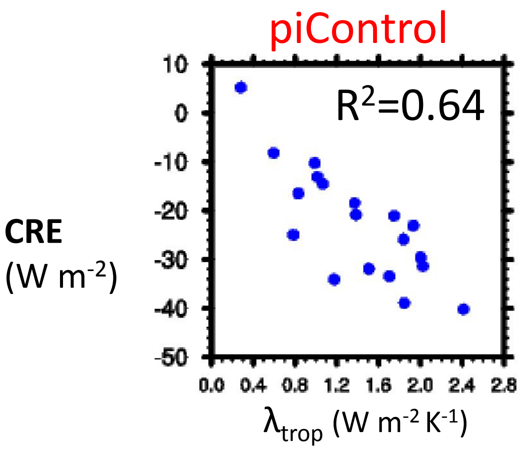
CRE in ascending region

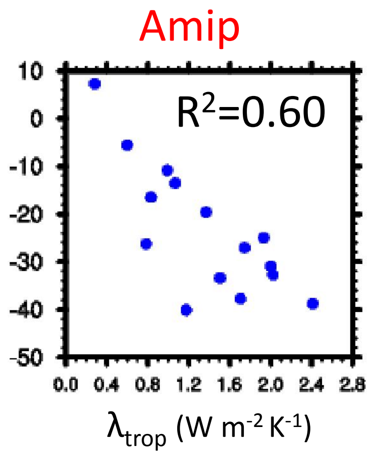
High sensitivity models characterized by:

Smaller CRE (more incoming energy)



Larger surface air T gradient: $T_{as}\uparrow - T_{as}\downarrow \uparrow$





- with $dCRE_{trop}/dT_{trop}$ — R^2=0.70 — R^2=0.71

Possible mechanism

- Less low clouds
- More cirrus

↓

CRE in ascending region ↓
TOA flux in ascending region ↑

amip → Lost in ocean

coupled → F_{ATM} ↑

$F_{ATM}=M(mse_{BL}\uparrow - mse_{BL}\downarrow)$

(Miller et al. 1997)

M ↑ $mse_{BL}\uparrow - mse_{BL}\downarrow$ ↑

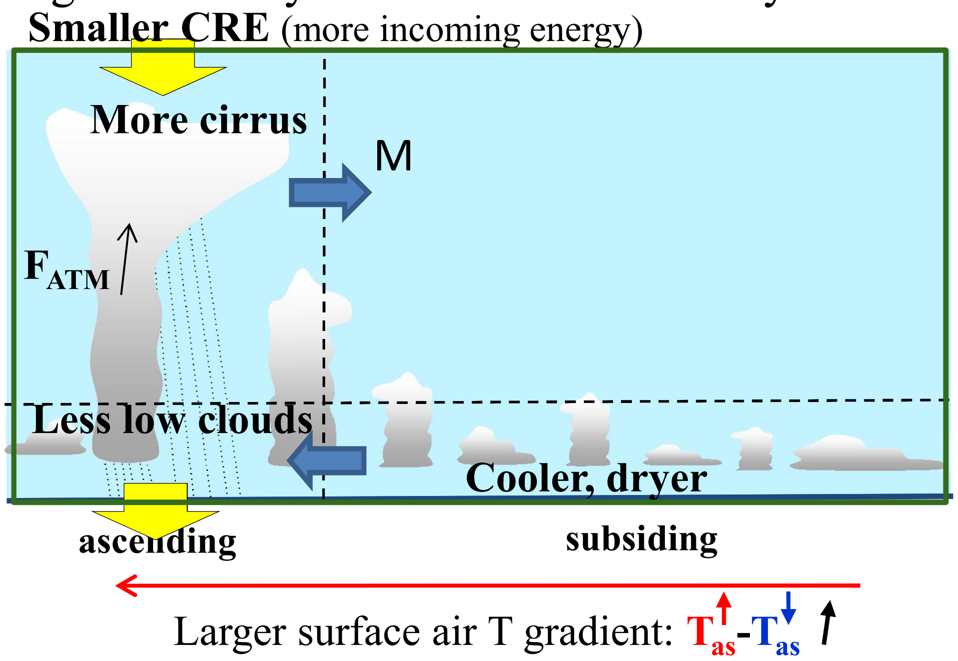
$T_{as}\downarrow$ ↓ $q_{BL}\downarrow$ ↓

More low clouds in subsiding region in comparison with amip

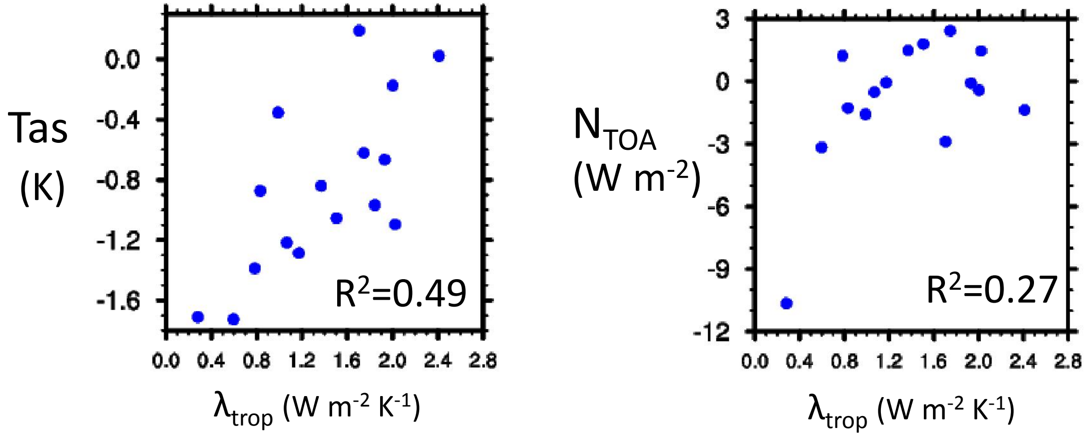
Correlation with mse_w-mse_c ↓ (R^2=0.38)
→ maybe better with T due to less radiative cooling in ascents

Clouds in ascending region

High sensitivity models characterized by:



piControl minus amip, all tropics



Possible mechanism

- Less low clouds
- More cirrus

↓

CRE in ascending region ↓
TOA flux in ascending region ↑

amip → Lost in ocean

coupled → F_{ATM} ↑

$F_{ATM} = M(mse_{BL}^{\uparrow} - mse_{BL}^{\downarrow})$

(Miller et al. 1997)

M ↑ $mse_{BL}^{\uparrow} - mse_{BL}^{\downarrow}$ ↑

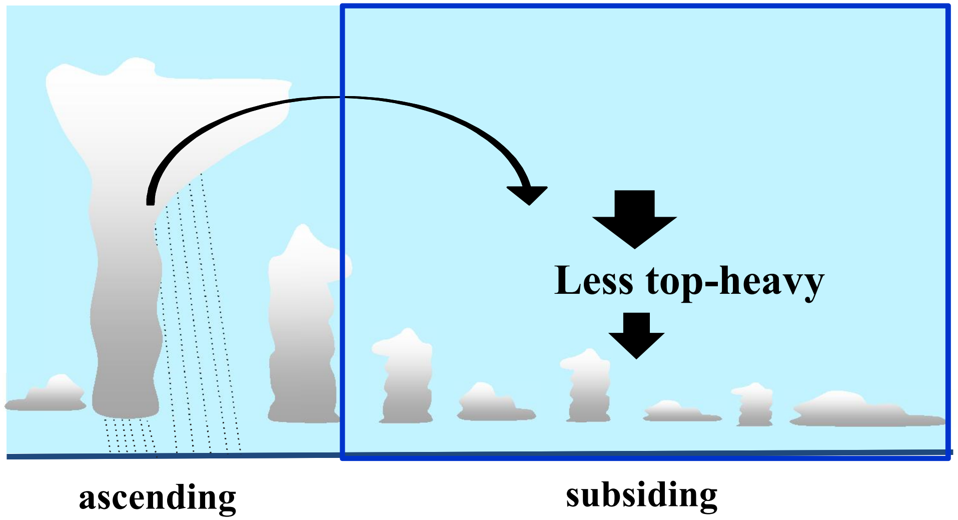
$T_{as}^{\downarrow}$ ↓ $q_{BL}^{\downarrow}$ ↓

More low clouds in subsiding region in comparison with amip

Correlation with $mse_w - mse_c$ ↓ (R^2=0.38)
→ maybe better with T due to less radiative cooling.in ascents

Top-heaviness of velocity profile

High sensitivity models characterized by:



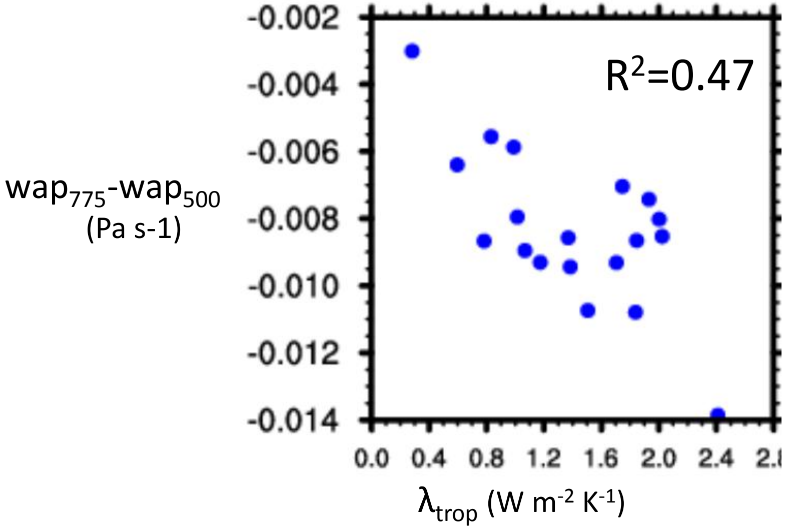
500 hPa

775 hPa

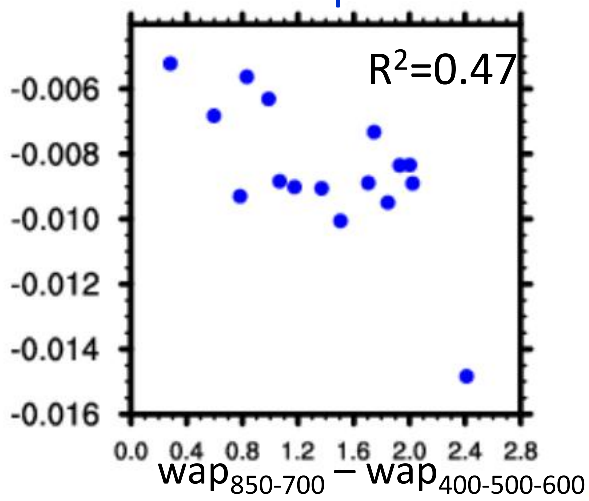
- Related to temperature difference between subsidence region and ascending region?

Subsiding regions (ocean+land)

piControl

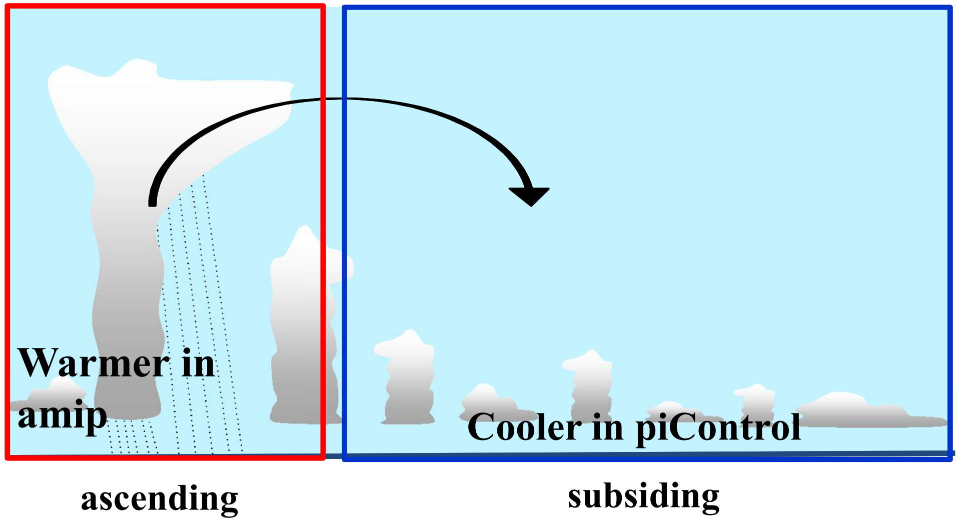


amip

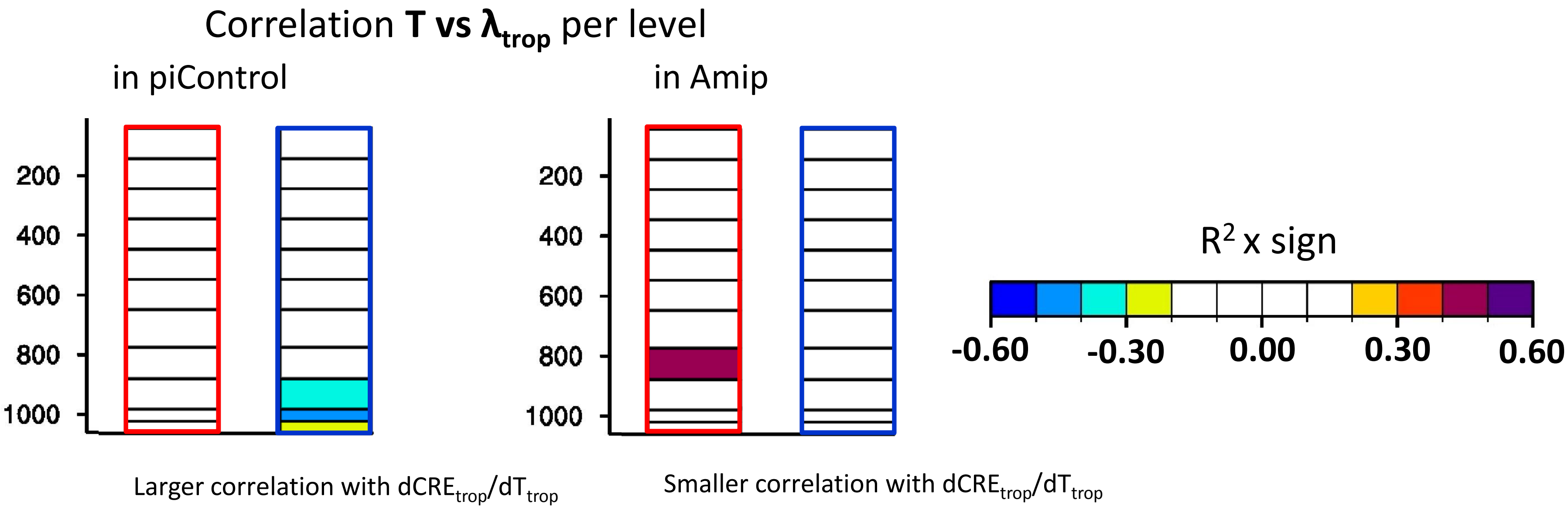


Temperature lapse rate in the BL

High sensitivity models characterized by:

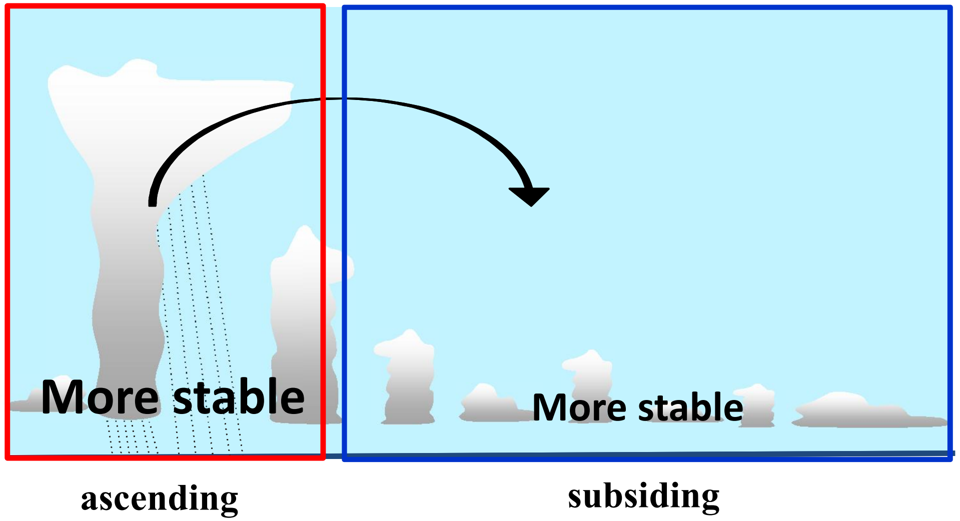


- Consistent with less radiative cooling



Temperature lapse rate in the BL

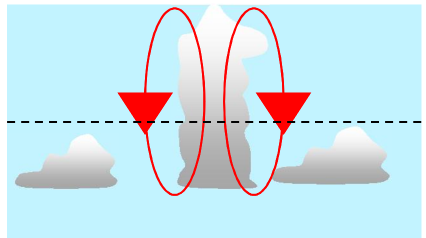
High sensitivity models characterized by:



- Consistent with less radiative cooling
But correlation also in subsiding region

- Consistent with shallower cloud layer

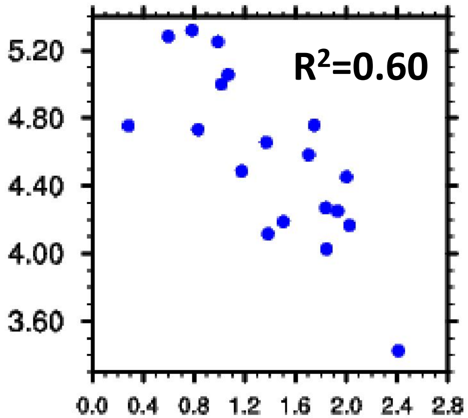
- Related to differences in shallow convective mixing and/or turbulence?



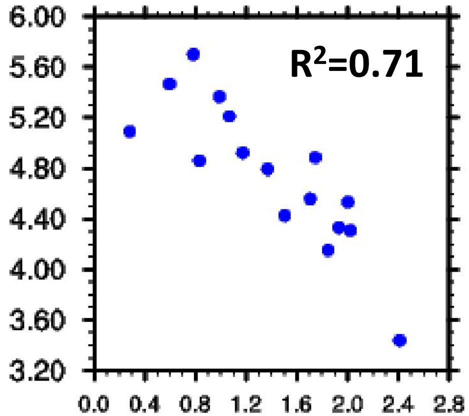
piControl (top-heavy ascents)

Amip (top-heavy ascents)

θ_{850}- θ_{1000} (K)



λ_{trop} (W m^{-2} K^{-1})



λ_{trop} (W m^{-2} K^{-1})

- with $dCRE_{trop}/dT_{trop}$	**R^2=0.78**	**R^2=0.78**
- in subsiding region	R^2=0.57	R^2=0.36

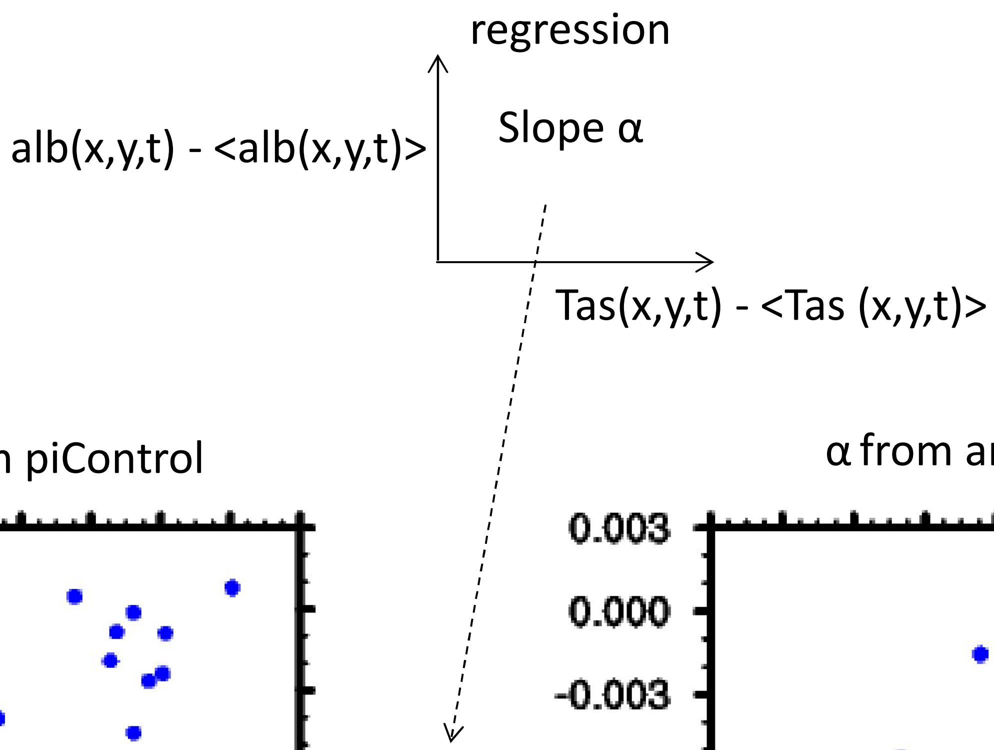
Outlines

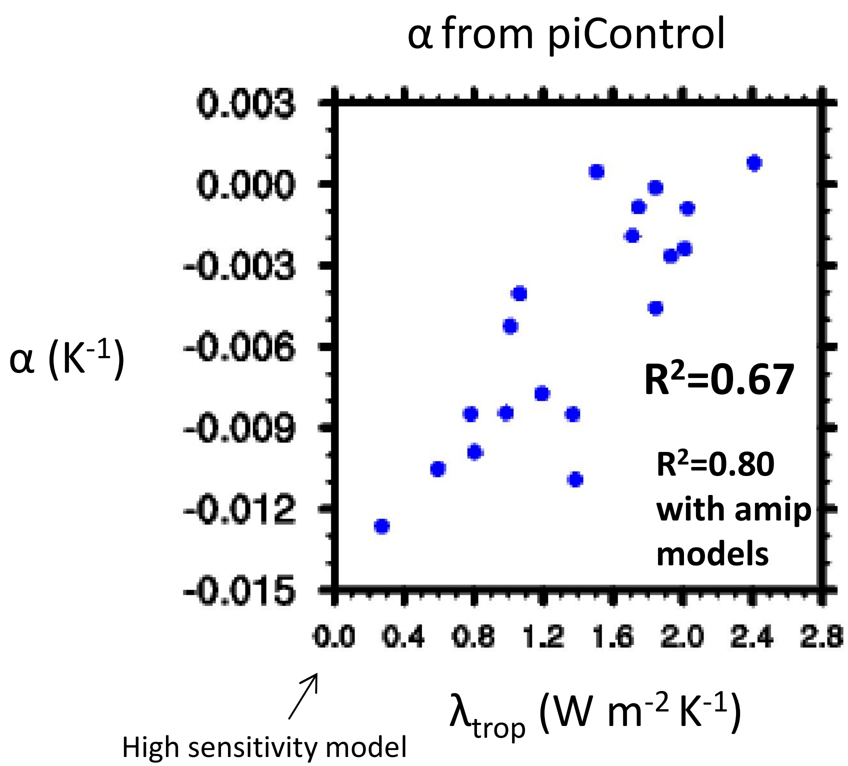
I. (Constraint with the) mean climatological state
Relationships valid in a simple dynamical regime decomposition? Other relationships? Explanations?
→ CMIP5 Coupled & AMIP analysis

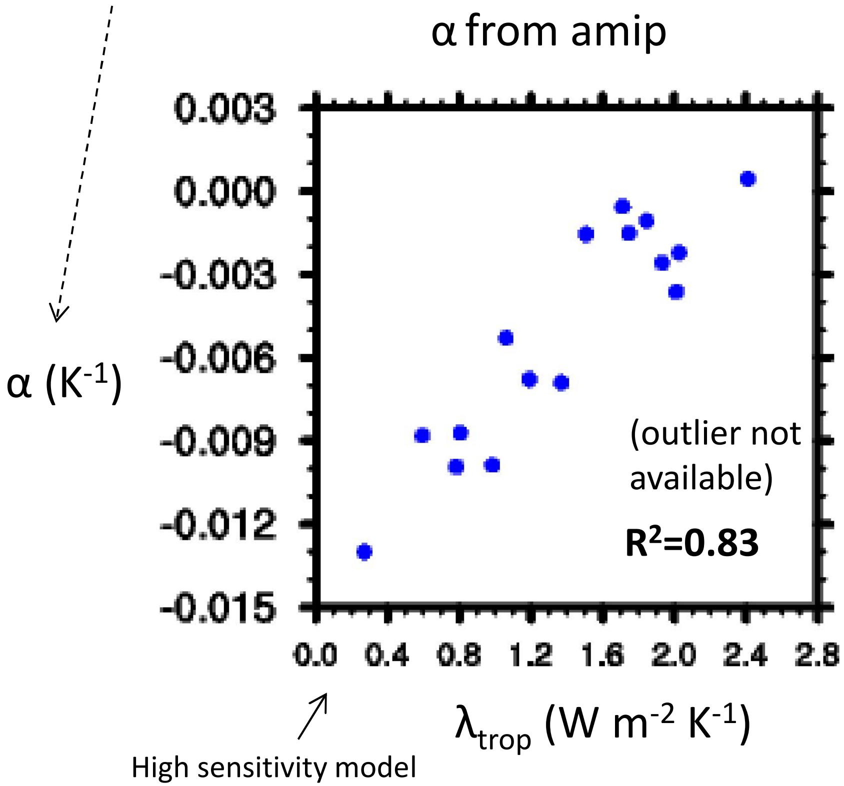
II. (Constraint with the) annual cycle
Relationship with spatial change in annual cycle (and interannual variability)
→ CMIP5 Coupled & AMIP analysis

Tropical feedback vs local monthly albedo response index α (annual cycle)

Region: **30°S-10°S, ocean**
Time period: **15years**







Less good with other metrics (eg ECS)

→ Consistent with Gordon and Klein (2014)

Summary

Coupled models with larger tropical radiative feedback have:

- Deeper circulation, larger atmospheric energy export from ascents to subsiding regions.
- Cooler and drier BL in subsiding regions
- Larger Tas difference between ascending and subsiding regions

→ May be explained by smaller CRE (larger incoming energy) in ascending regions

- Smaller CRE in ascending regions consistent with less low clouds (less reflective) and more high clouds (more greenhouse effect). Feature of both amip and picontrol.

- Relationship between low cloud response to SST change at local and monthly scale (mainly annual cycle) and cloud feedback in forced climate change

→ These results suggest that low cloud in GCMs primarily responds to local SST

In both piControl and amip, large sensitivity model:
- have Less top-heavy ω profile in subsiding regions → related to BL processes? Midlevel clouds ?
- are more stable in the BL → related to shallow convective mixing / turbulence ?

BL and cloud layer thermodynamic

High sensitivity models characterized by: