What if the Earth had an Adaptive Infrared Iris?

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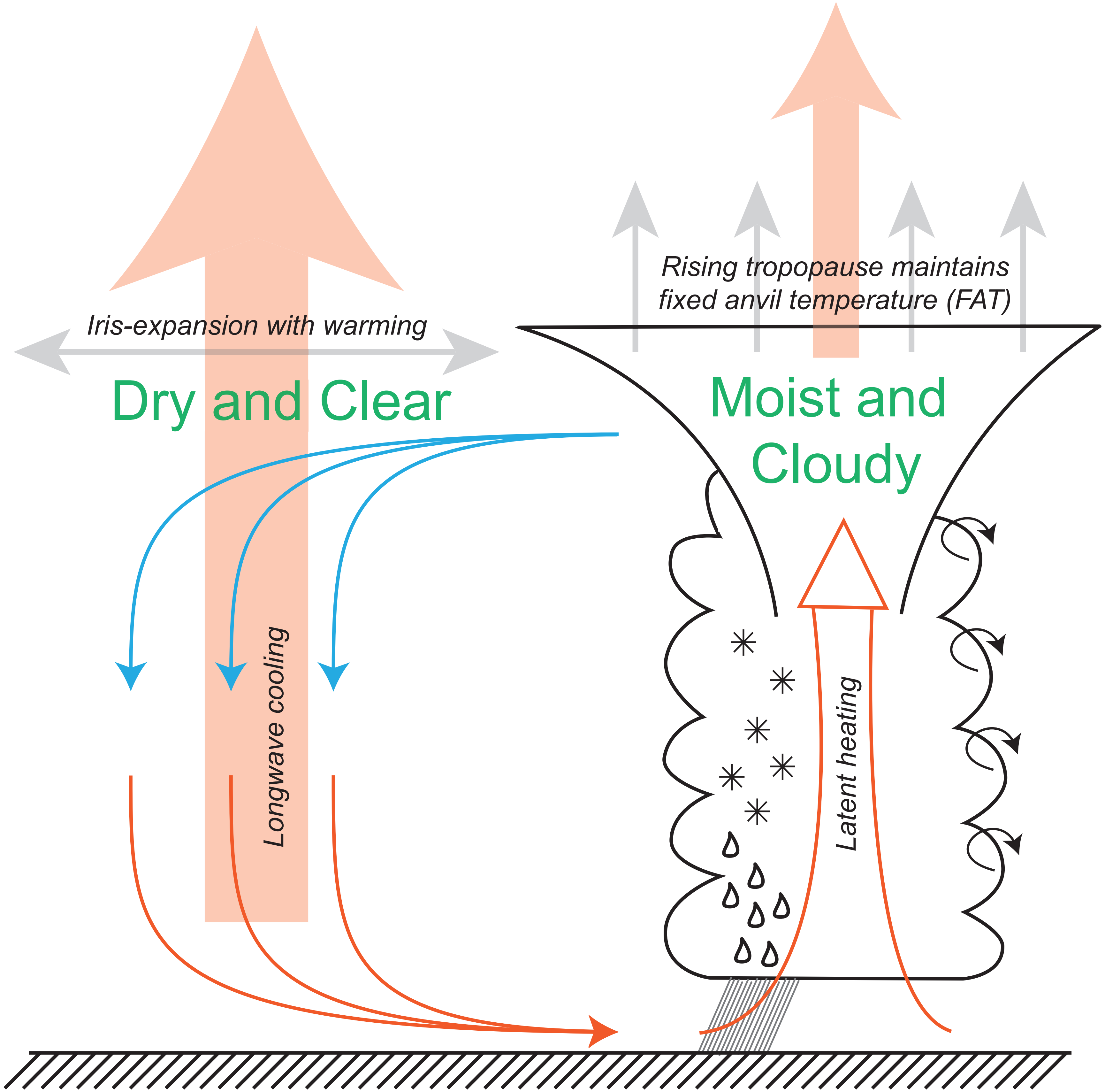
If precipitation efficiency increases in a warming climate, then fewer convective clouds are needed to sustain the atmospheric energy balance, which constitutes a negative longwave feedback

Freely from Lindzen et al. (2001)


Iris-expansion with warming
Dry and Clear
Longwave cooling
Rising tropopause maintains fixed anvil temperature (FAT)
Moist and Cloudy
Latent heating

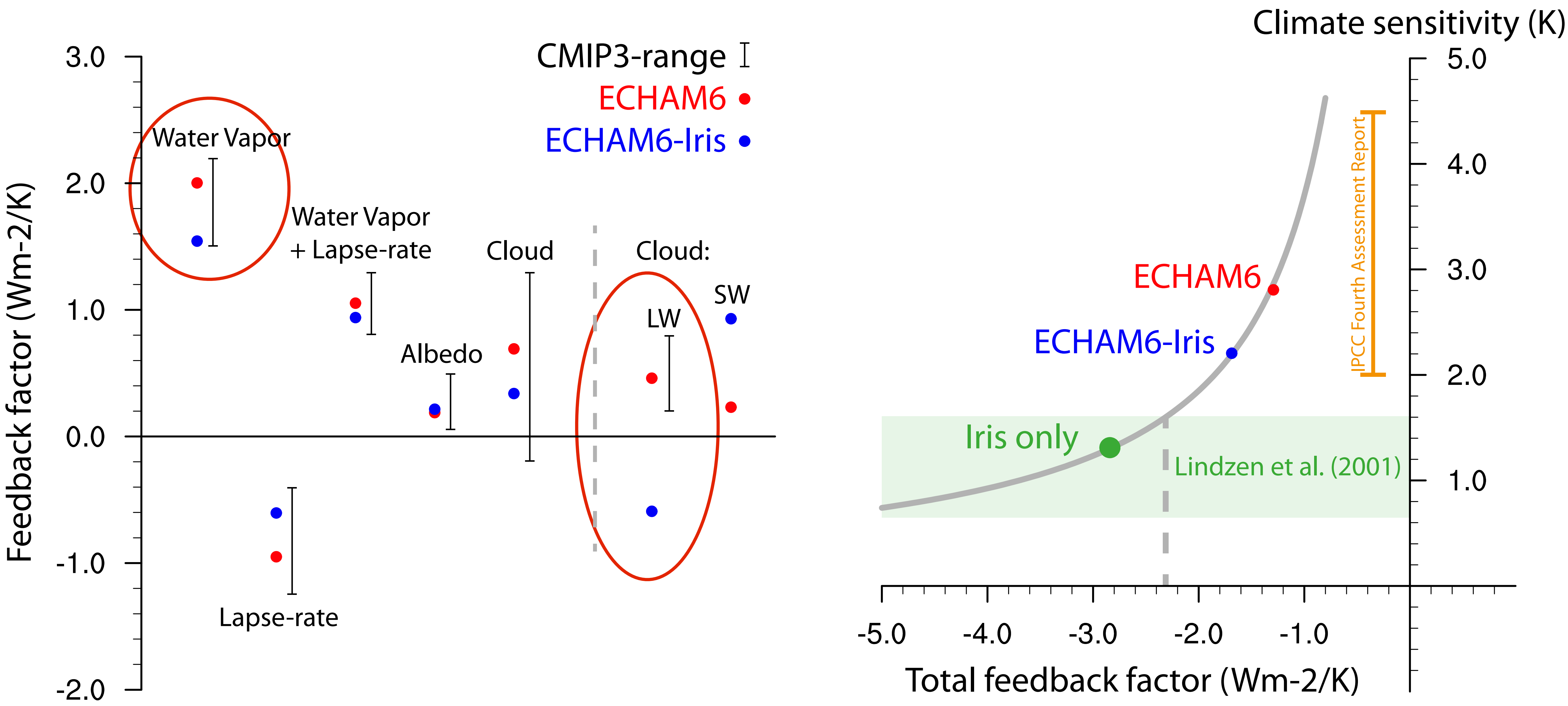
In models:

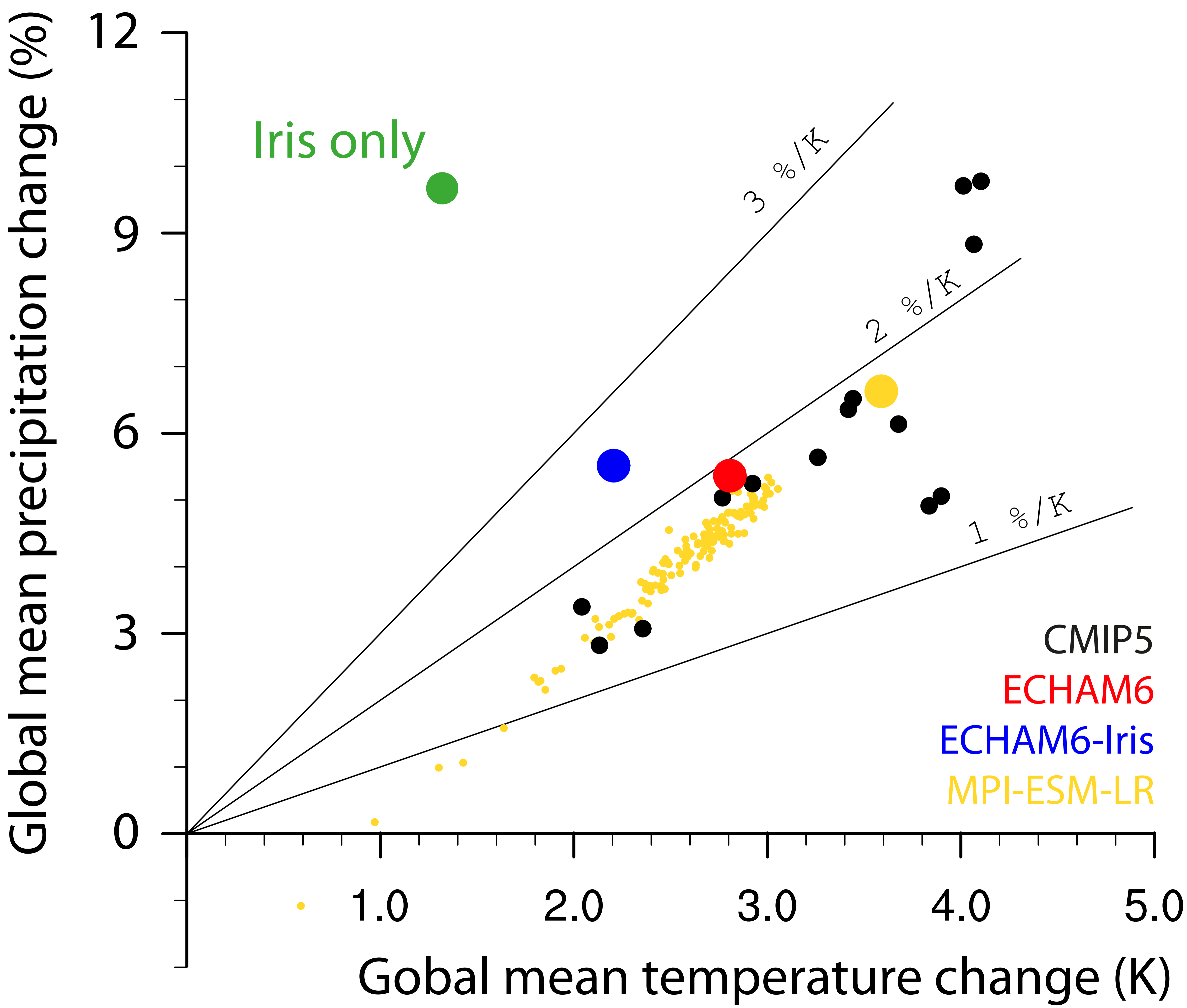
- Inflow temperature increases, outflow temperature stays the same (Emanuel) ✓
- Organization of convection increases ✗
- Microphysical conversion is in enhanced ✗

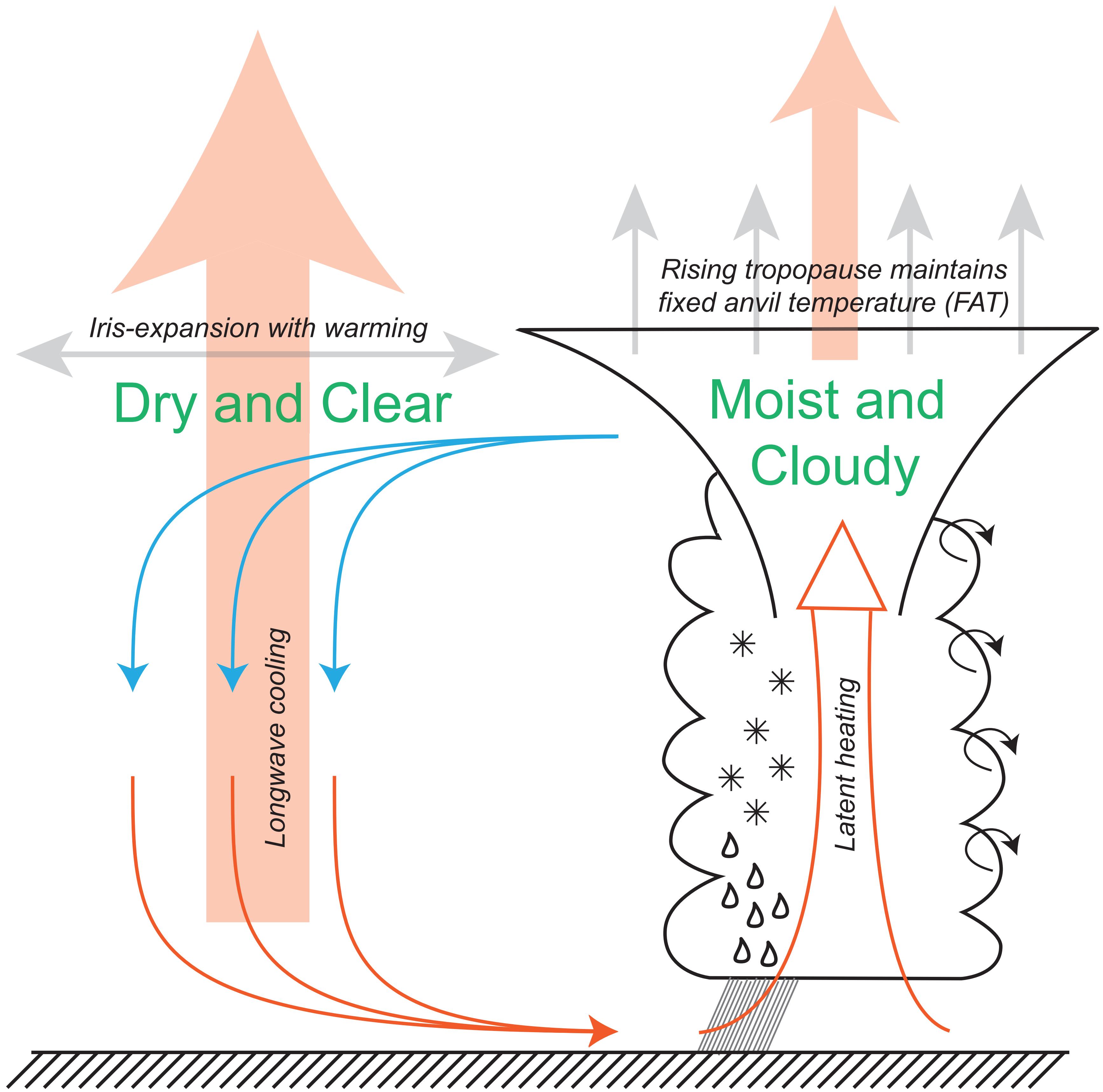
A microphysical Iris-effect:

$$C_p(T_s) = C_o \cdot (1 + I_e)^{T_s - T_o}$$

ECHAM6
T63L47 (LR)
Coupled to mixed-layer ocean
2xCO2


CMIP3-range
ECHAM6
ECHAM6-Iris
Feedback factor (Wm-2/K)
3.0
2.0
1.0
0.0
-1.0
-2.0
Water Vapor
Water Vapor
+ Lapse-rate
Albedo
Cloud
Cloud:
LW
SW
Lapse-rate
Climate sensitivity (K)
5.0
4.0
3.0
2.0
1.0
ECHAM6
ECHAM6-Iris
Iris only
Lindzen et al. (2001)
IPCC Fourth Assessment Report
-5.0
-4.0
-3.0
-2.0
-1.0
Total feedback factor (Wm-2/K)


Iris only
3 %/K
2 %/K
1 %/K
CMIP5
ECHAM6
ECHAM6-Iris
MPI-ESM-LR
12
9
6
3
0
1.0
2.0
3.0
4.0
5.0
Global mean precipitation change (%)
Gobal mean temperature change (K)


Rising tropopause maintains
fixed anvil temperature (FAT)
Iris-expansion with warming
Dry and Clear
Moist and
Cloudy
Longwave cooling
Latent heating

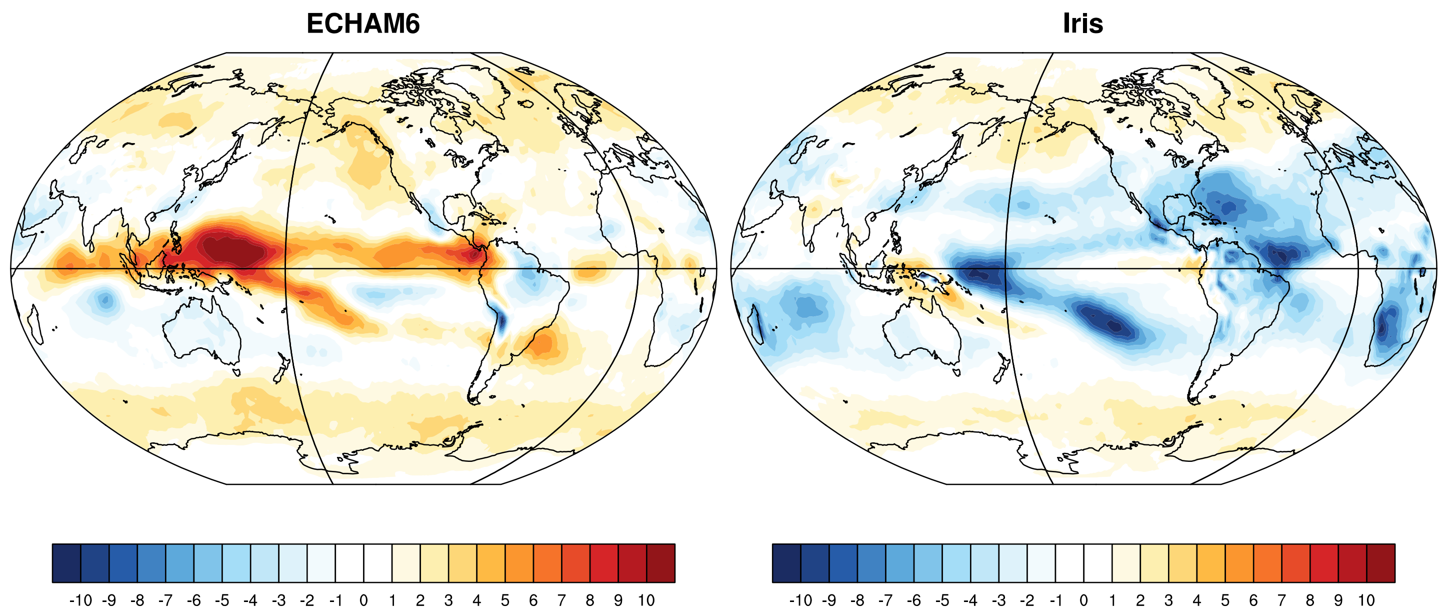
Conclusions

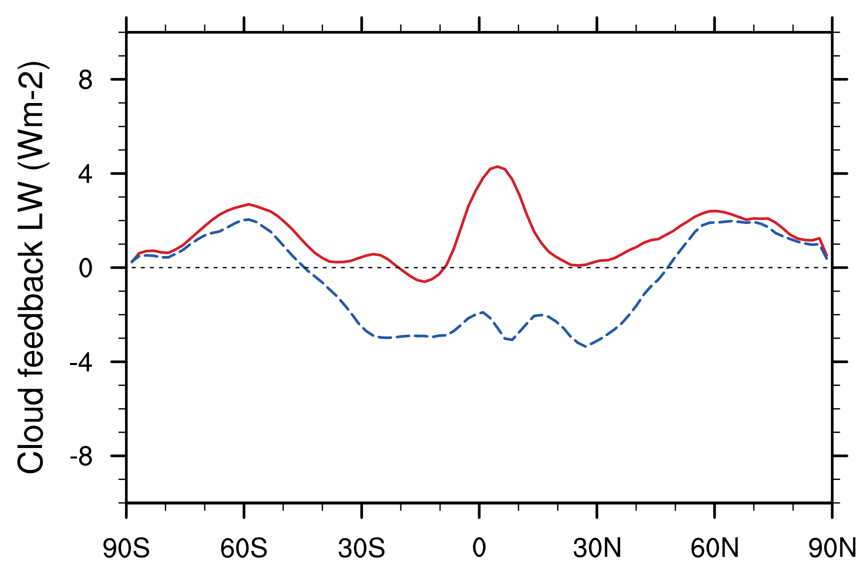
We implemented an artificial strong micro-physical Iris-effect in ECHAM6:

- Climate sensitivity is only lowered from 2.8 to 2.2 K due to well-understood compensation mechanisms
- Hydrological sensitivity increases with an Iris-effect due to enhanced atmospheric cooling

Further, it appears inevitable that hydrological sensitivity would rise further, should compensation be weaker on Earth than it is in ECHAM6

Cloud feedback (LW)

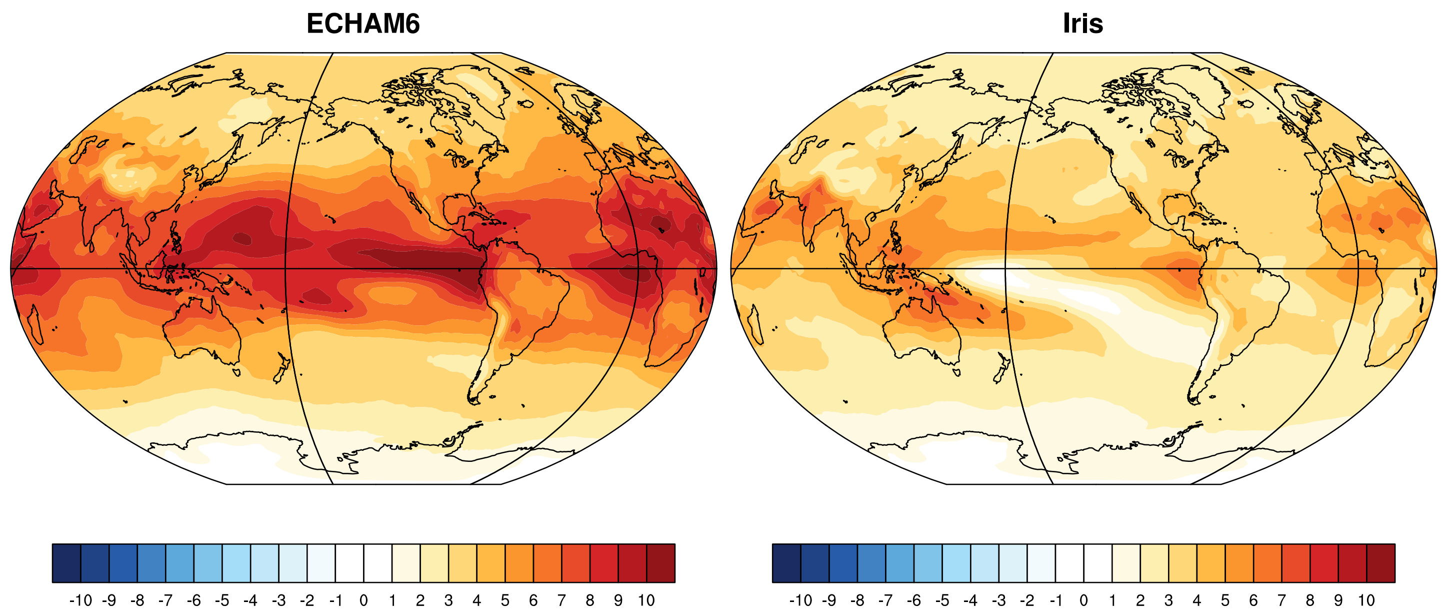


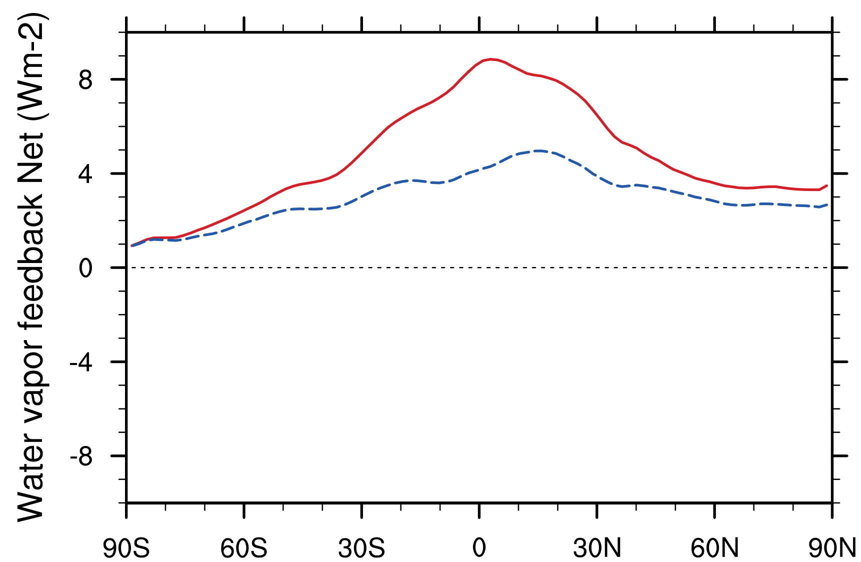


ECHAM6
Iris

Feedback factor reduced by -1.1 Wm-2/K

Water vapor feedback

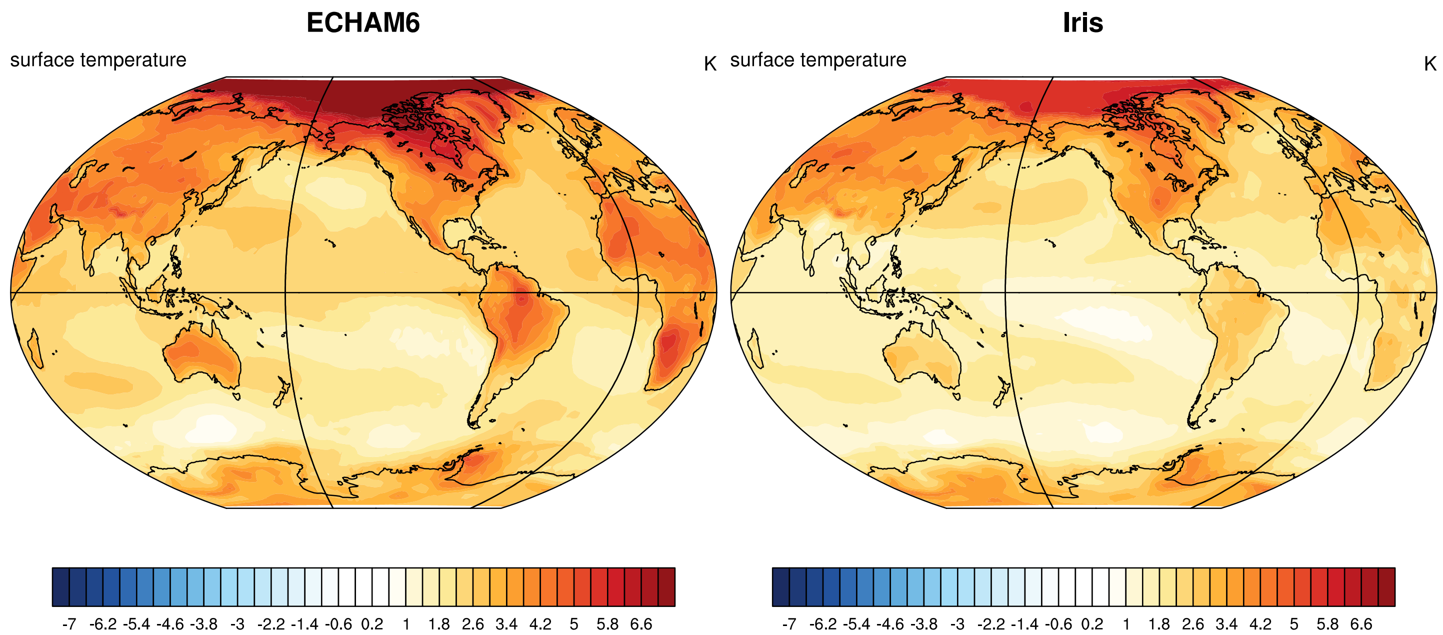


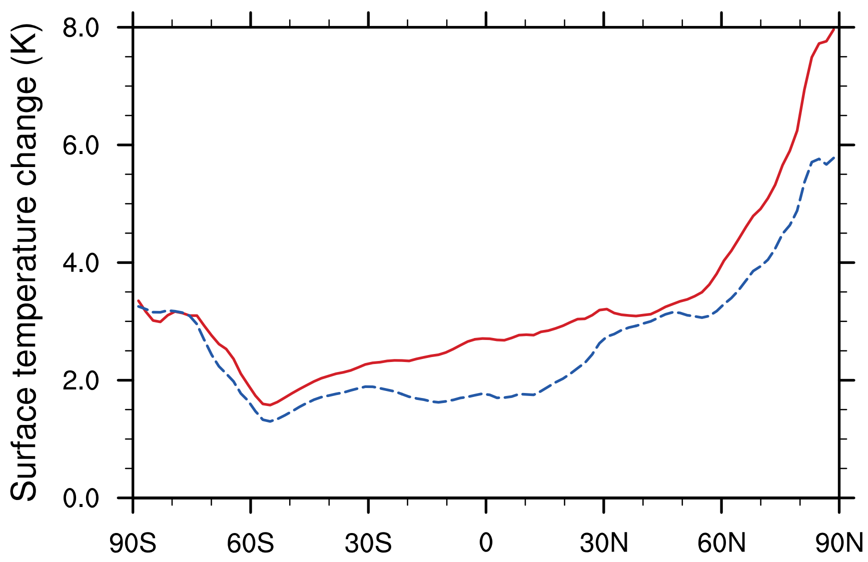


ECHAM6
Iris

Feedback factor reduced by -0.6 Wm-2/K

Climate Sensitivity

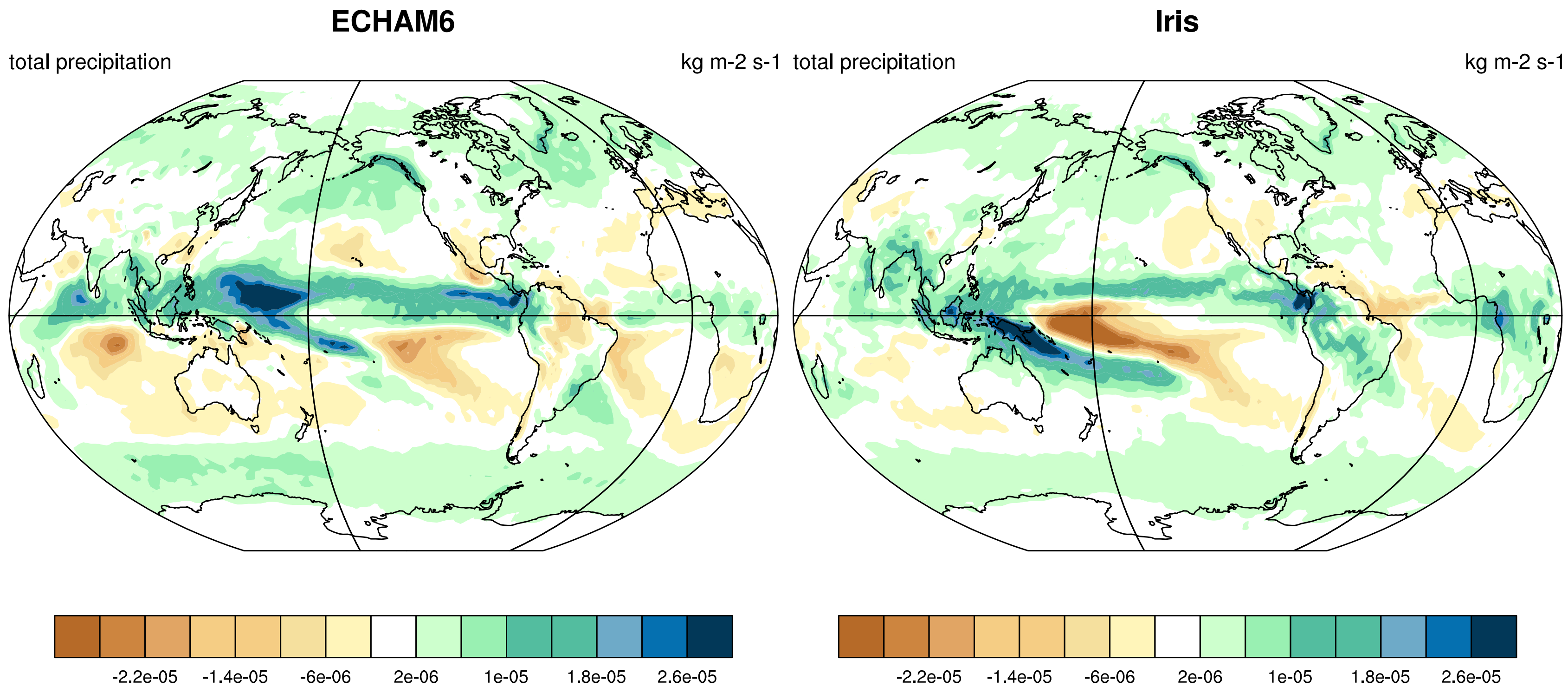


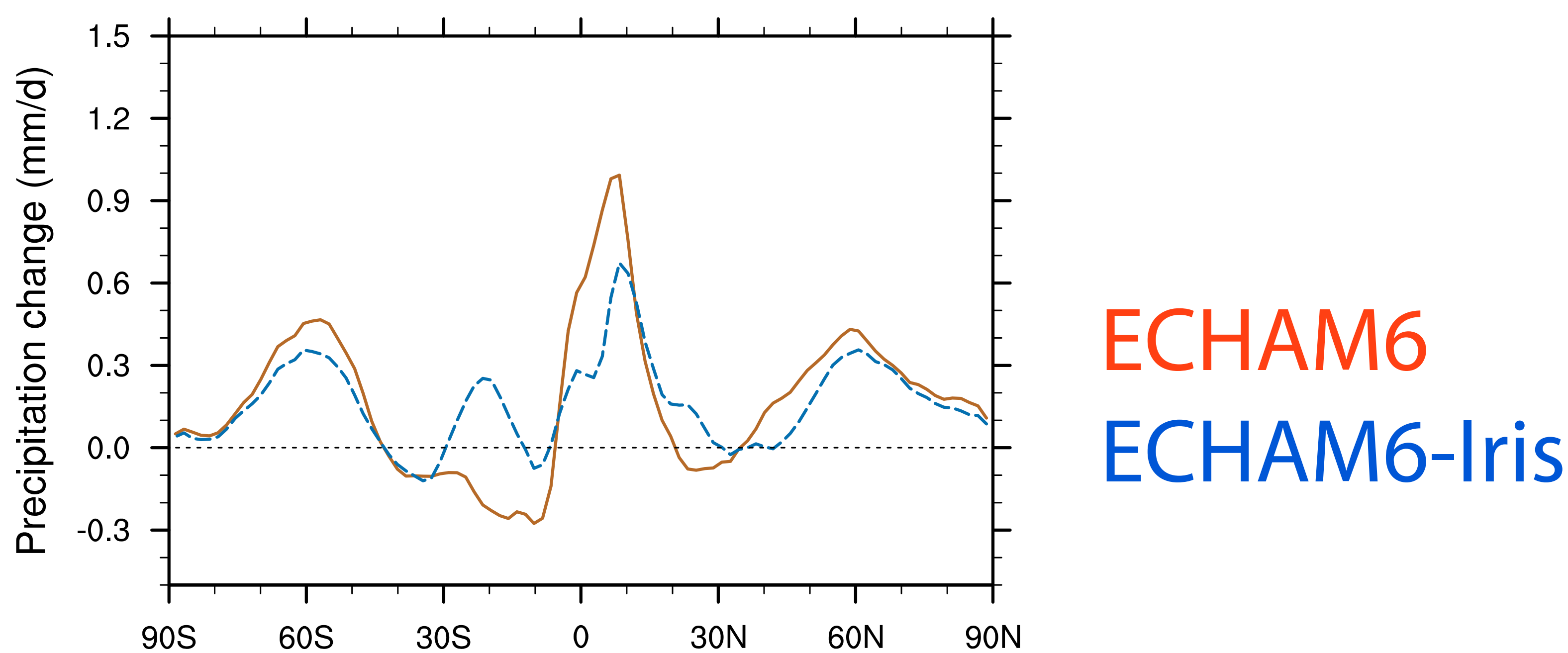


ECHAM6
Iris

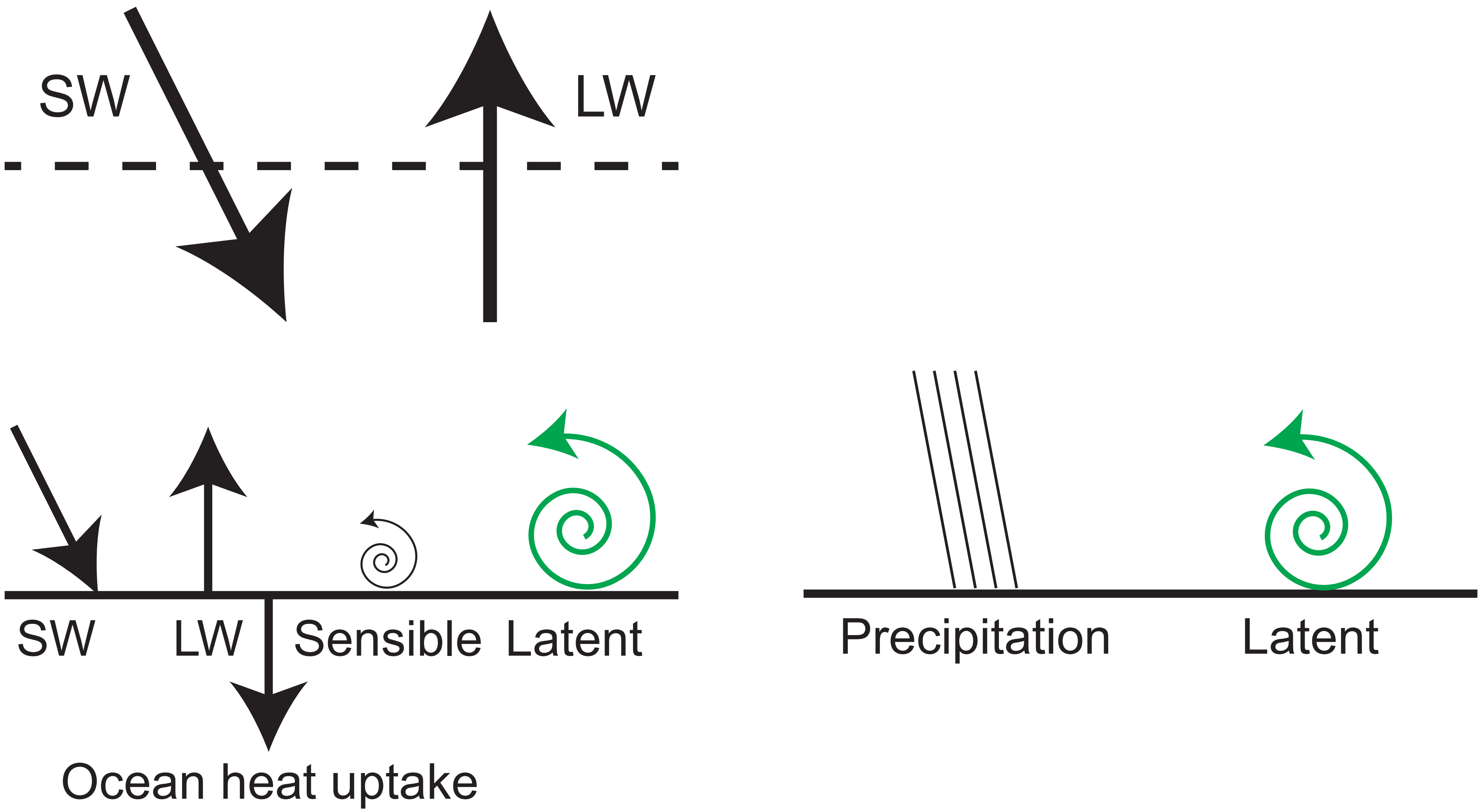
Reduced from 2.9 K to 2.3 K

Hydrological Sensitivity

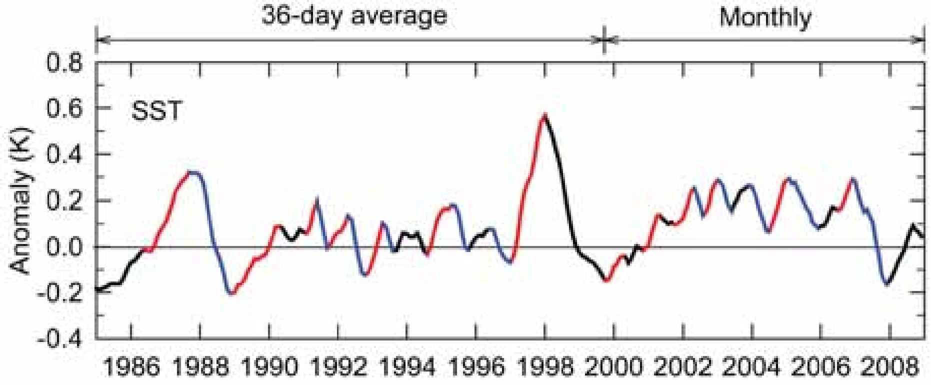


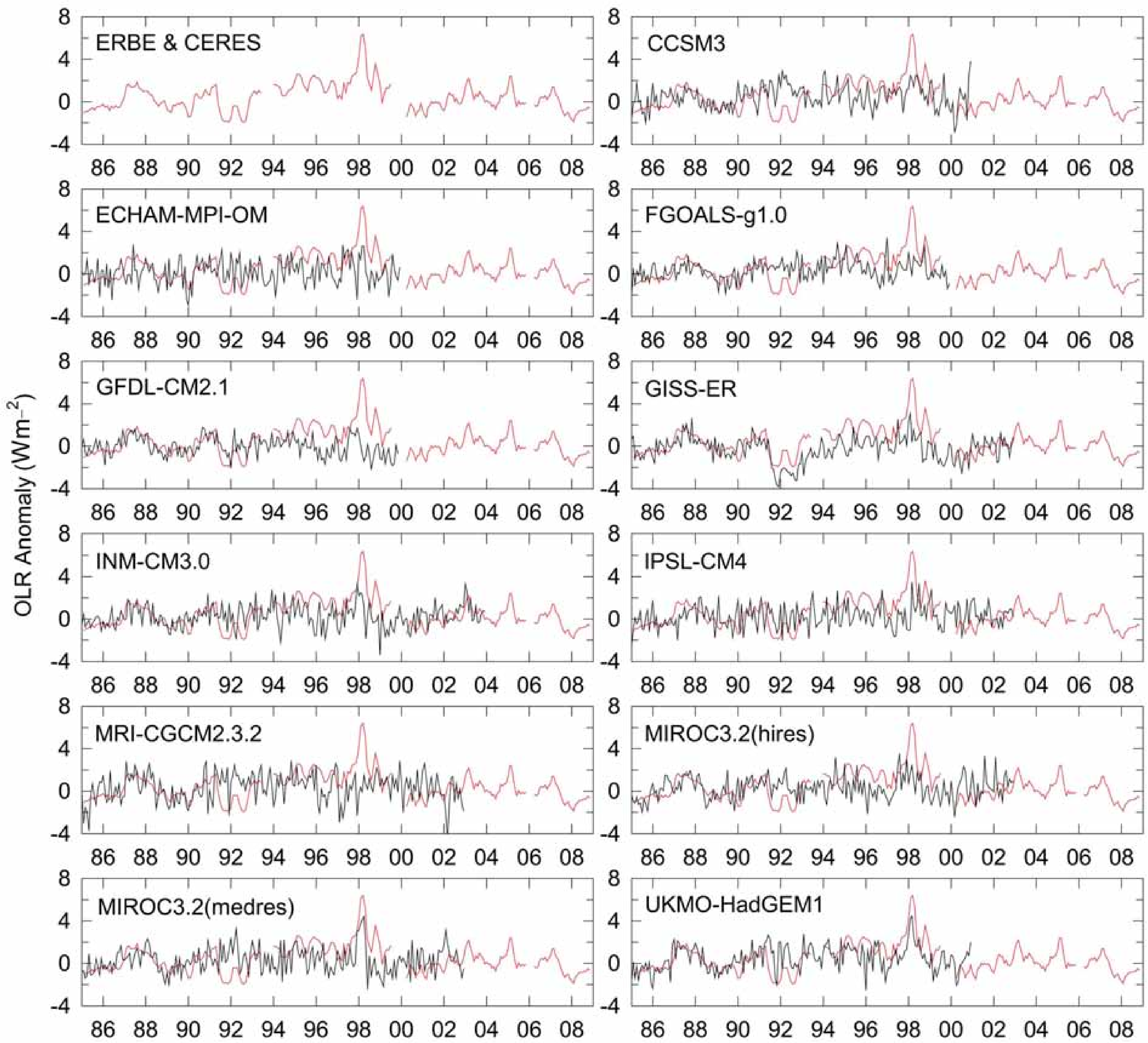


Energy and Water budgets



Observations





Lindzen and Choi (2011)

Observations

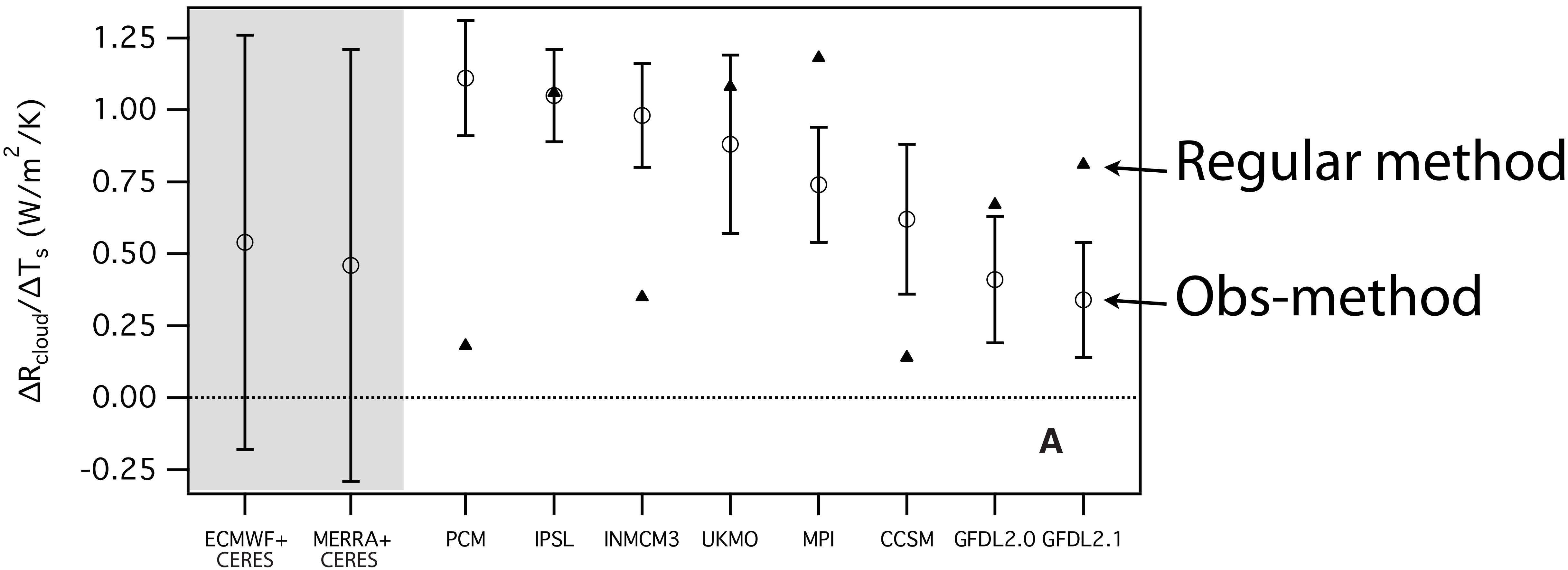
Models	IPCC AR4	Method:
	Sensitivity	Sensitivity
CCSM3	2.7	8.1
ECHAM5/MPI-OM	3.4	1.7
FGOALS-g1.0	2.3	7.9
GFDL-CM2.1	3.4	2.2
GISS-ER	2.7	2.5
INM-CM3.0	2.1	2.7
IPSL-CM4	4.4	10.4
MRI-CGCM2.3.2	3.2	Infinity
MIROC3.2(hires)	4.3	2.2
MIROC3.2(medres)	4	2.4
UKMO-HadGEM1	4.4	1.7

Correlation = -0.11

Lindzen and Choi (2011)

Observations

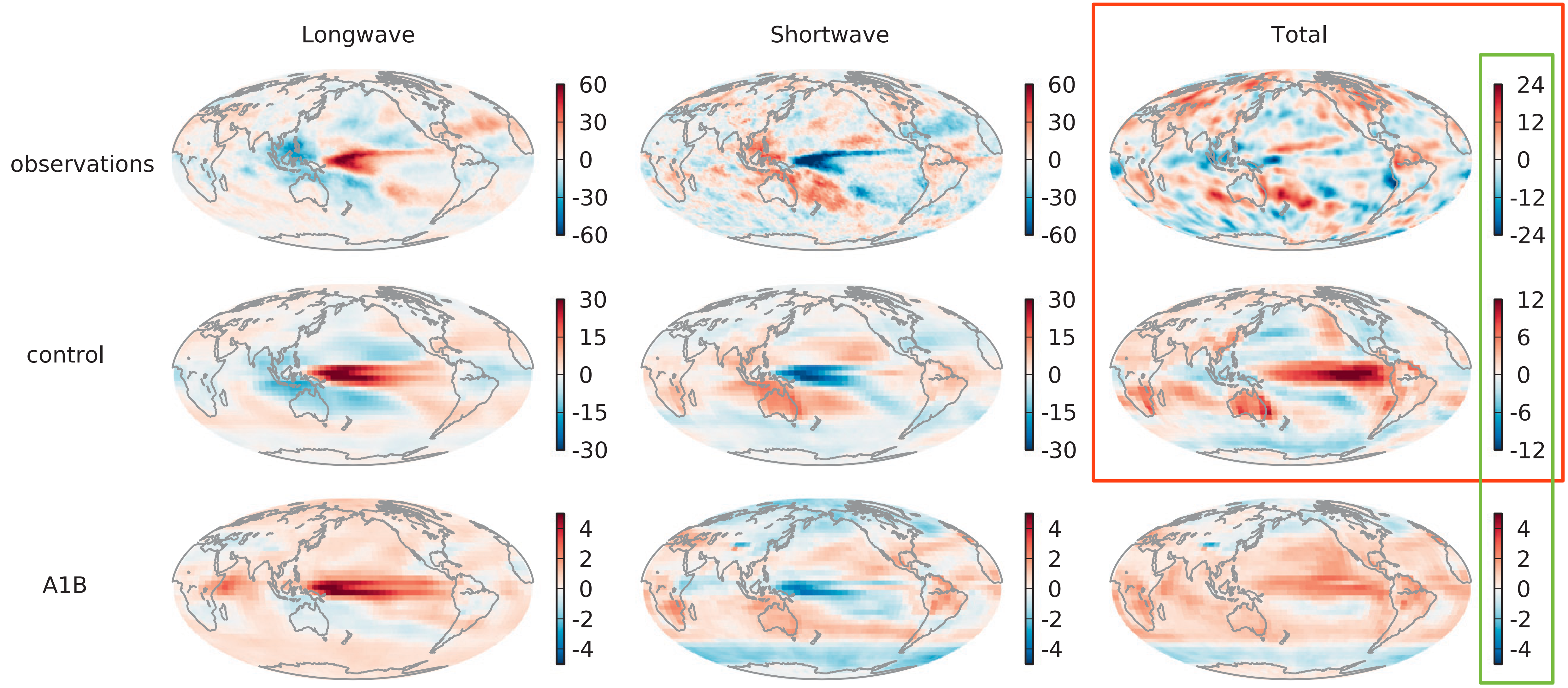
Cloud feedback factor:



Dessler (2010)

Observations

Dessler (2013), cloud feedback:



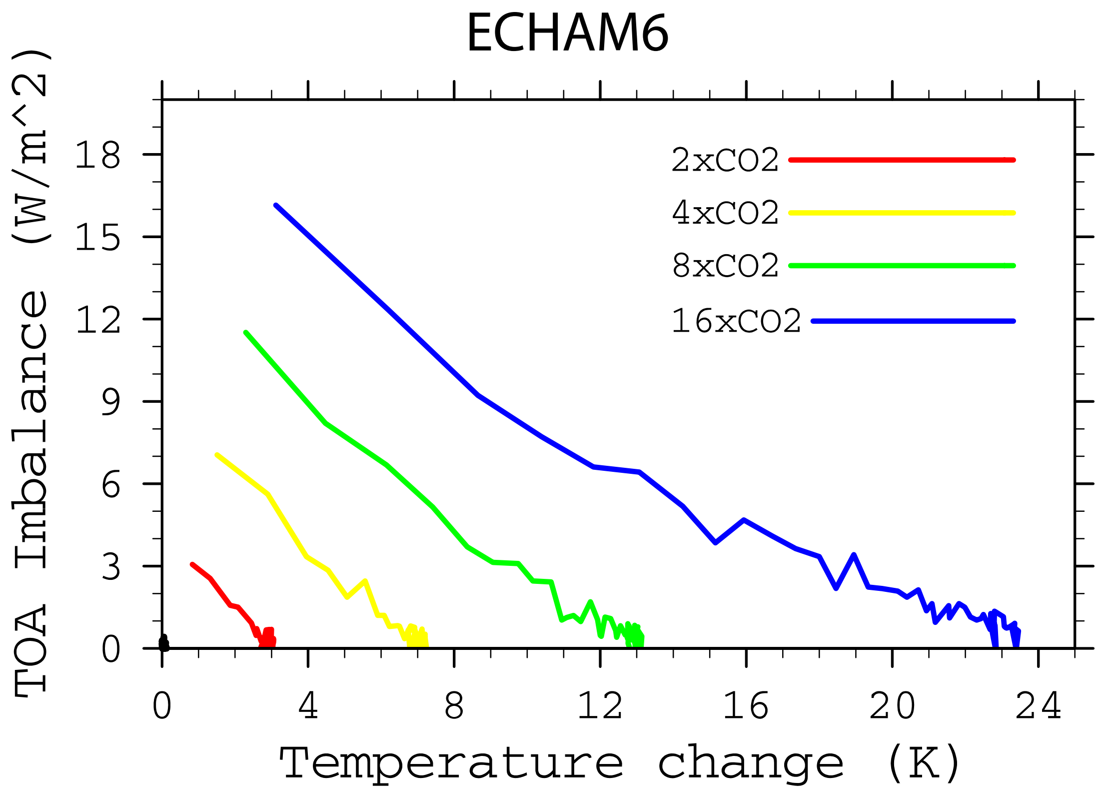
Faint young Sun problem

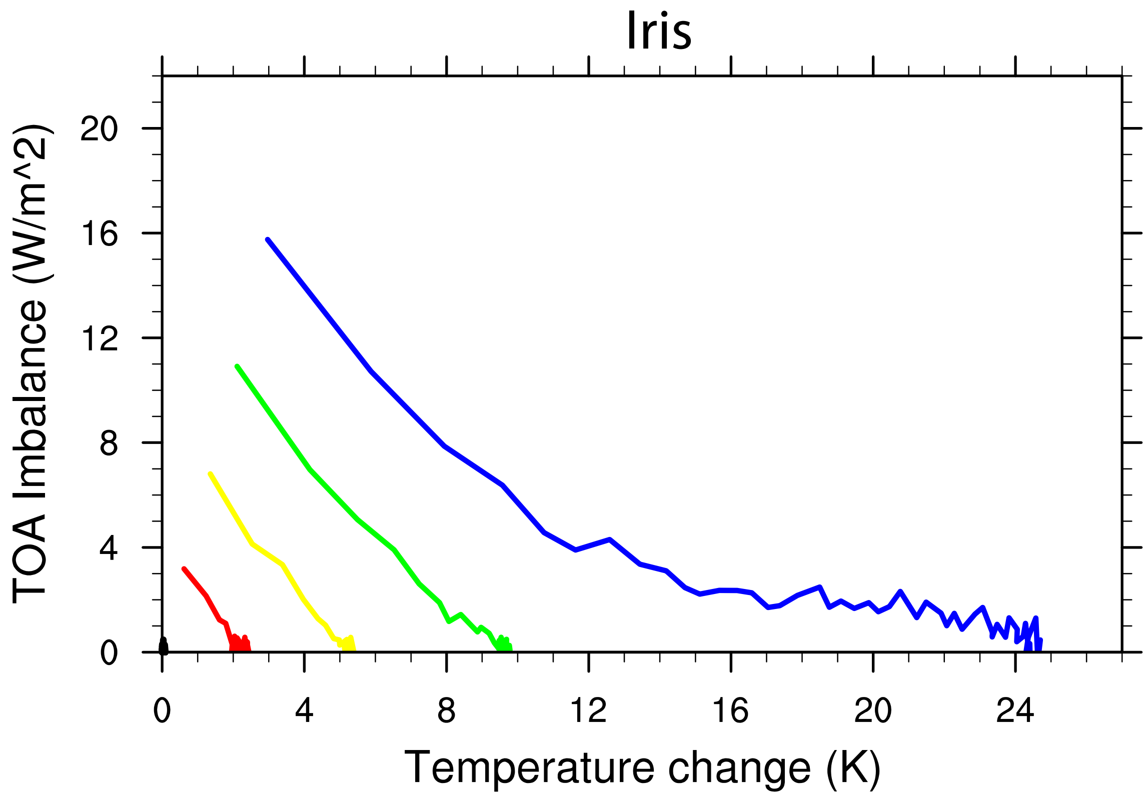
Early Earth had Solar constant equal 0.75 of present, yet Earth was not covered with ice.

Climate models have had trouble reproducing this state at the 'observed' 60.000 ppm CO_2 (e.g. Keinert et al. 2012).

One hypothesis is that Earth was covered with Cirrus clouds, thereby reducing the outgoing longwave radiation to space (Rondanelli and Lindzen 2010).

Non-linear climate sensitivity





$$\Delta R = F + \lambda \Delta T$$

Analysis pending...

Conclusions

We implemented an artificial Iris-effect by doubling the conversion rate in convective clouds for a 1 Kelvin warming in ECHAM6, and coupled it to a mixed-layer ocean. We find:

1. While cloud LW and water vapor feedback change as hypothesized, cloud SW and lapse-rate feedbacks naturally counteract the Iris-effect, to yield merely a 20 percent reduction in climate sensitivity
2. Global precipitation sensitivity instead increases, which can be understood as a response to increased atmospheric cooling being compensated by latent heat release, and hence more precipitation

Outlook

- I aim to prepare an **MPI-ESM2-Iris** to participate in CMIP6 for public evaluation

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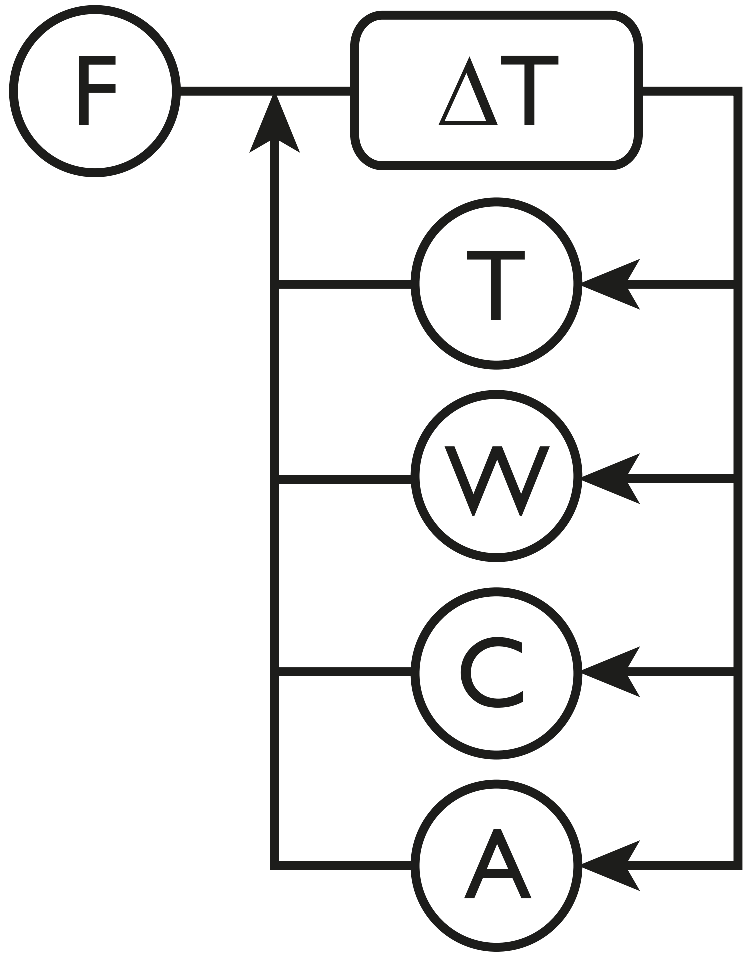
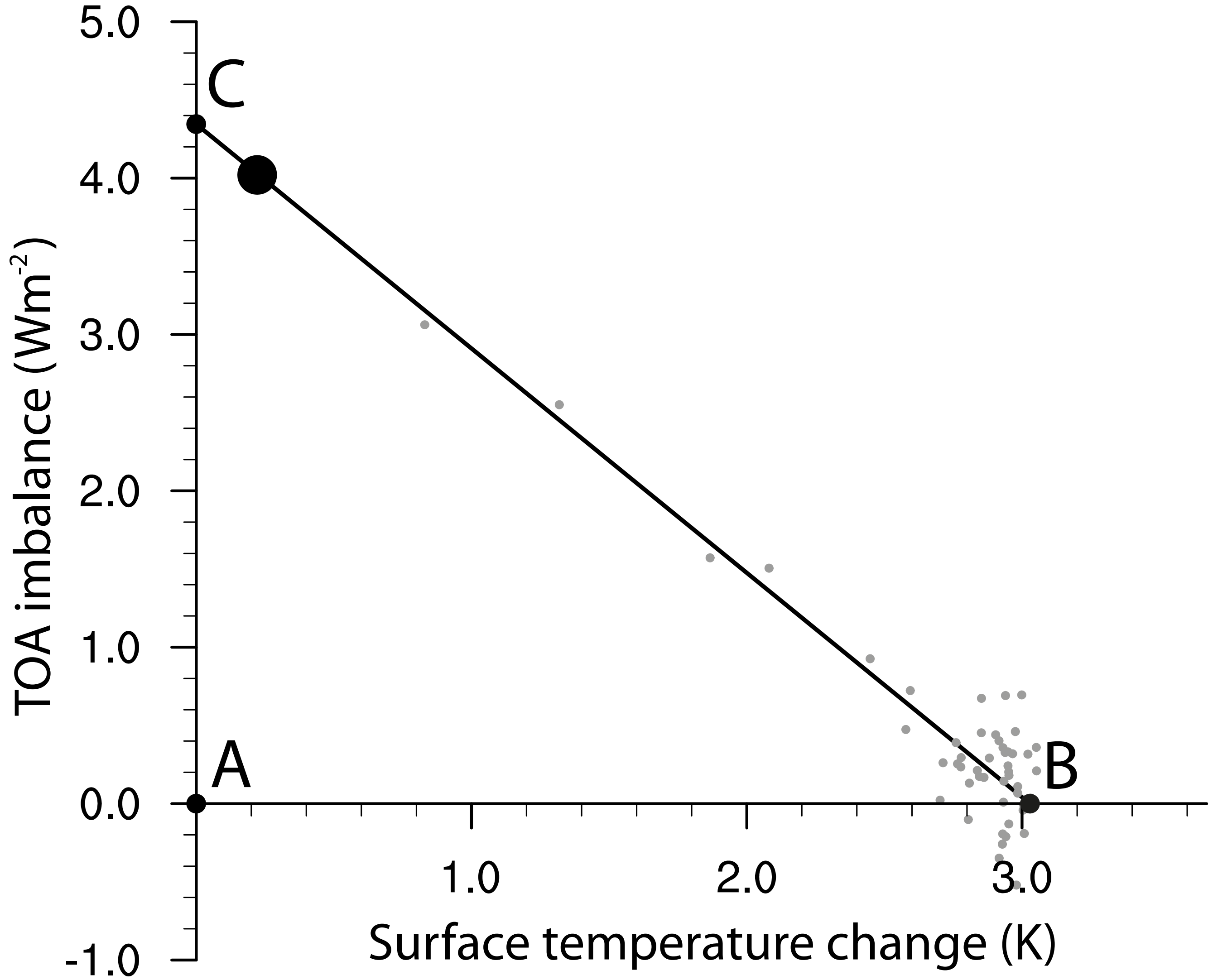
- Can we understand thermal run-away?
- Or the precipitation distribution change?
- How well does the model with Iris-effect couple to the ocean?
- Implications for variability and predictability?
- Is a better representation needed at process-level?
- Large-domain resolved radiative-convective equilibrium, whenever computers and ICON are ready for it...

$$\Delta R = F + \lambda \Delta T$$



$$\lambda = \lambda_T + \lambda_W + \lambda_C + \lambda_A$$

$$\Delta R = F + \lambda \Delta T$$



ECHAM6, abruptly doubled CO2, mixed-layer ocean

External forcing

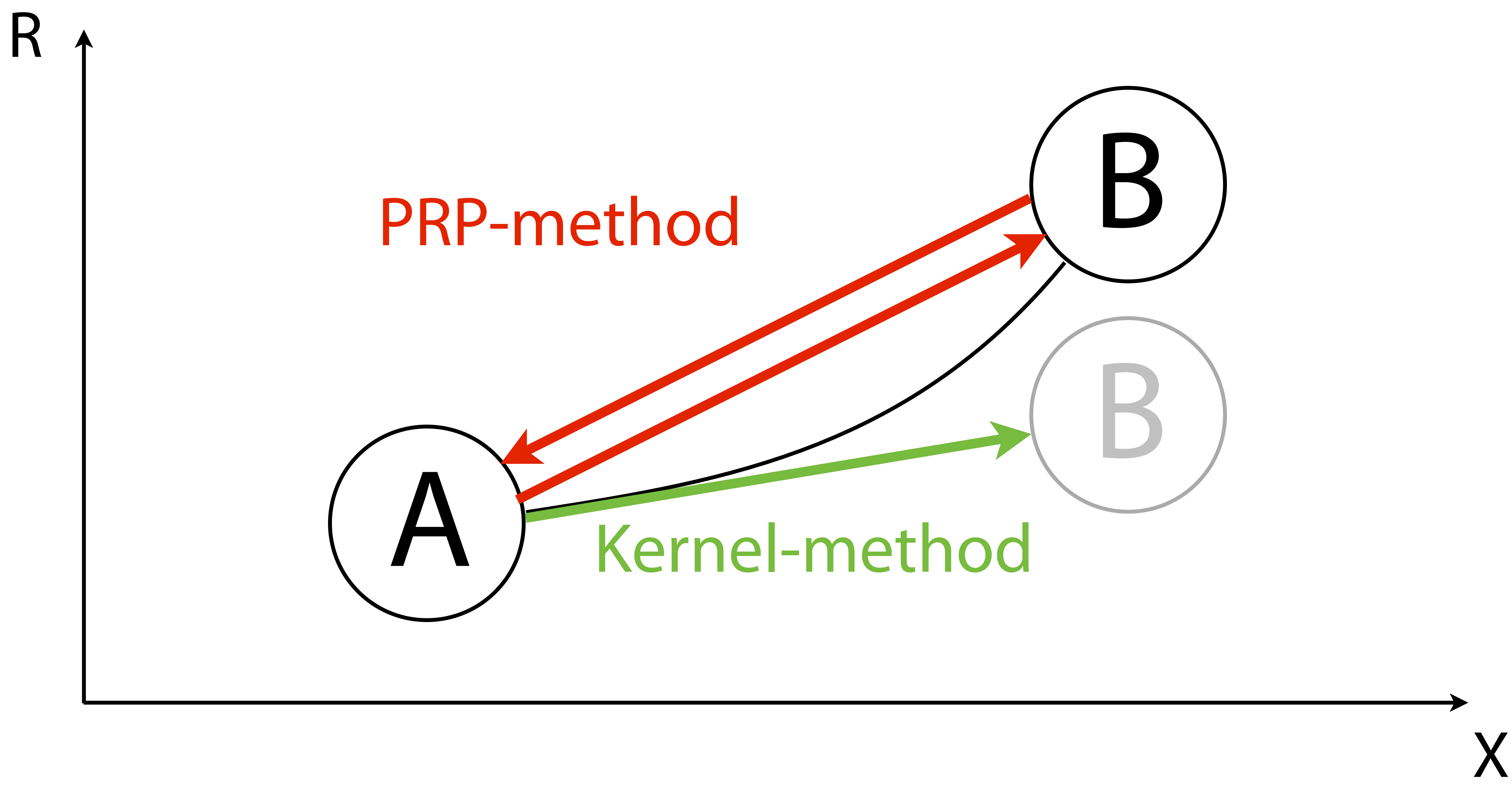
Temperature change

$$\Delta R = F + \lambda \Delta T$$

TOA imbalance

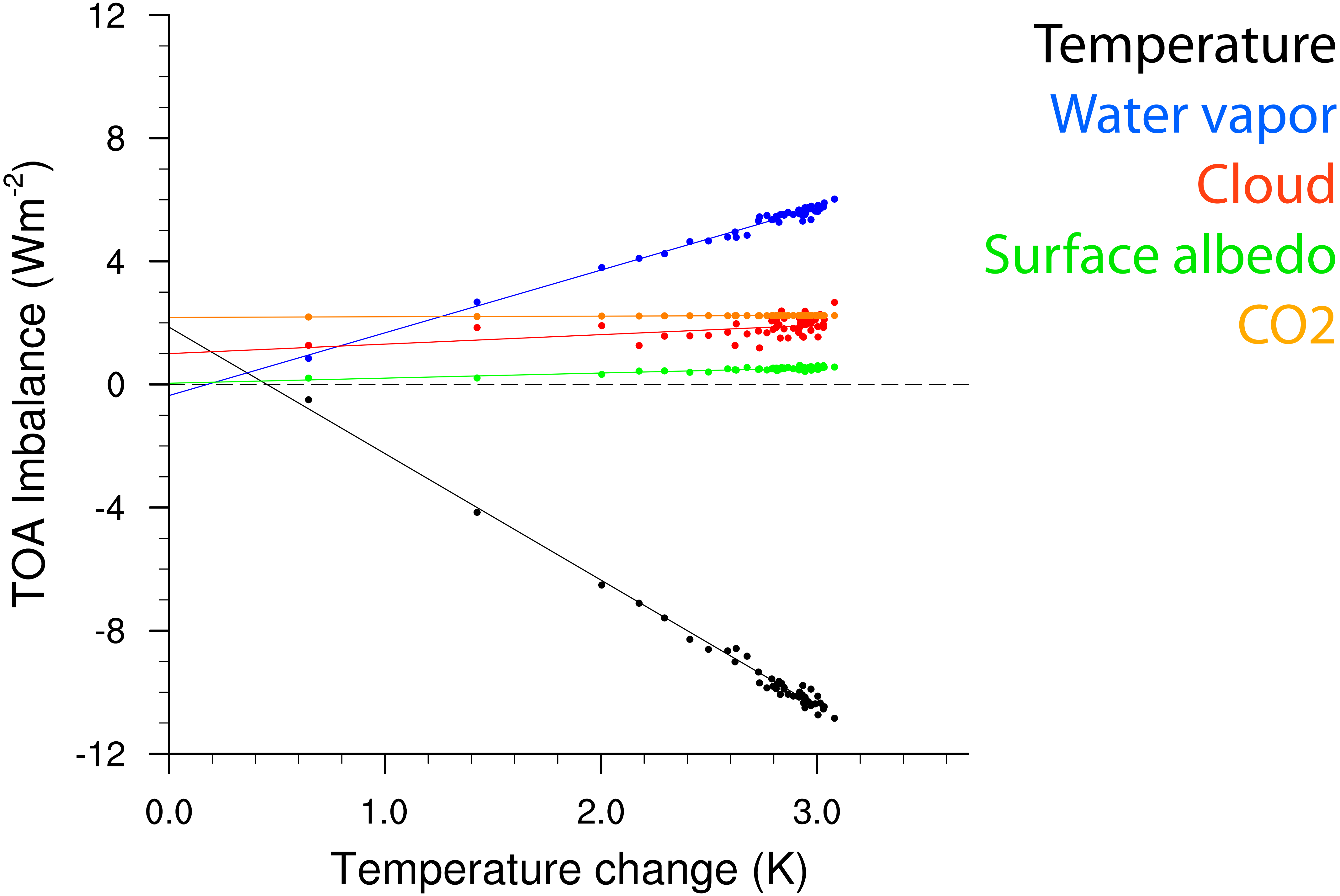
Feedback factor

$$\Delta R = F + \lambda \Delta T$$



3) What causes the non-linearity?

$$\Delta R = F + \lambda \Delta T$$



3) What causes the non-linearity?