An overview of the water vapor and cloud feedbacks: What we know and what we don't

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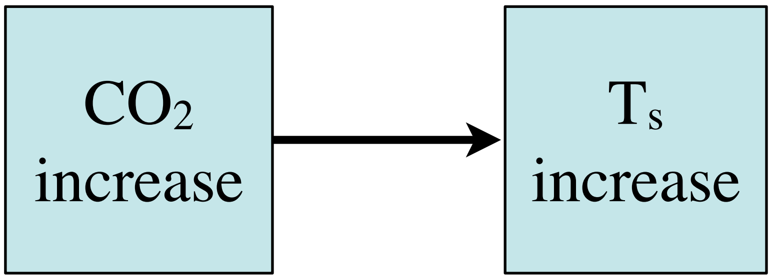
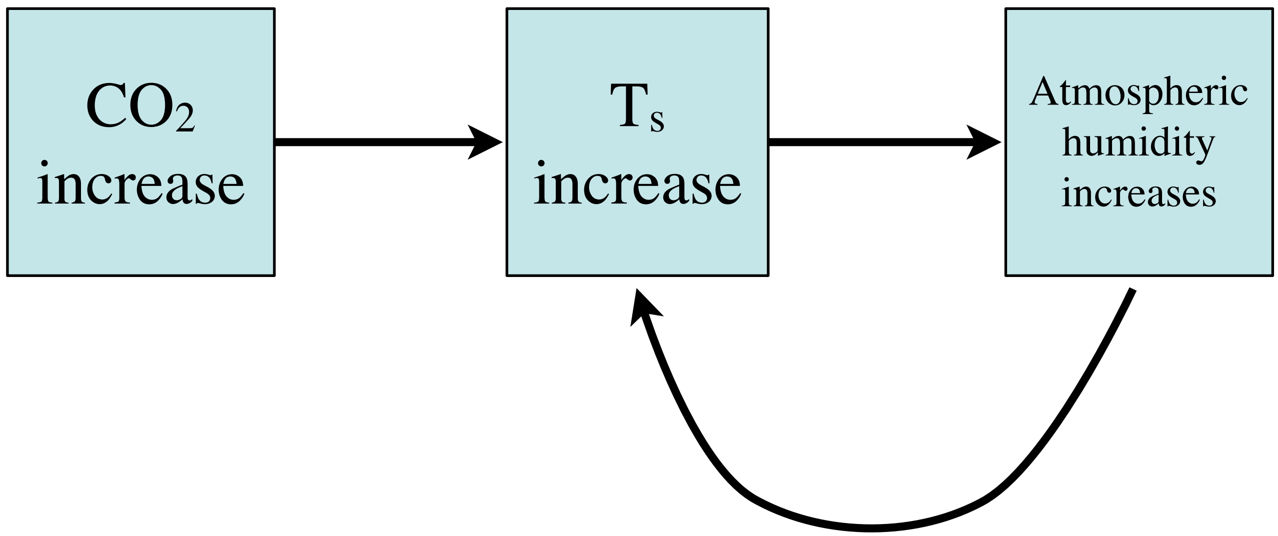
ΔT_i



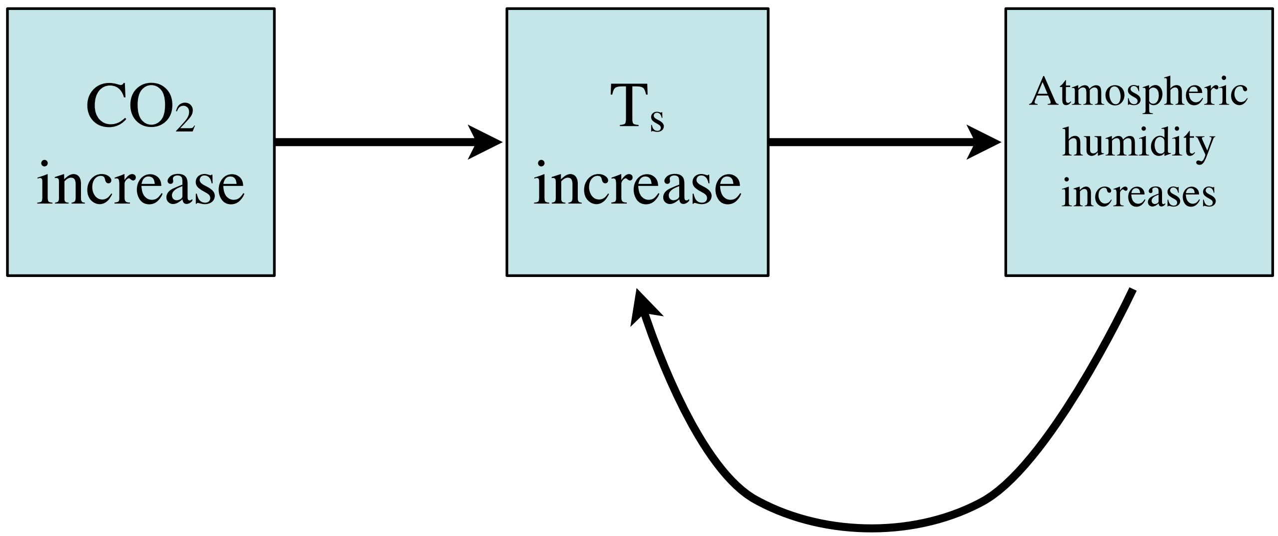
$\Delta T_i \approx 1.2$ K

CO_2 increase $\longrightarrow$ T_s increase

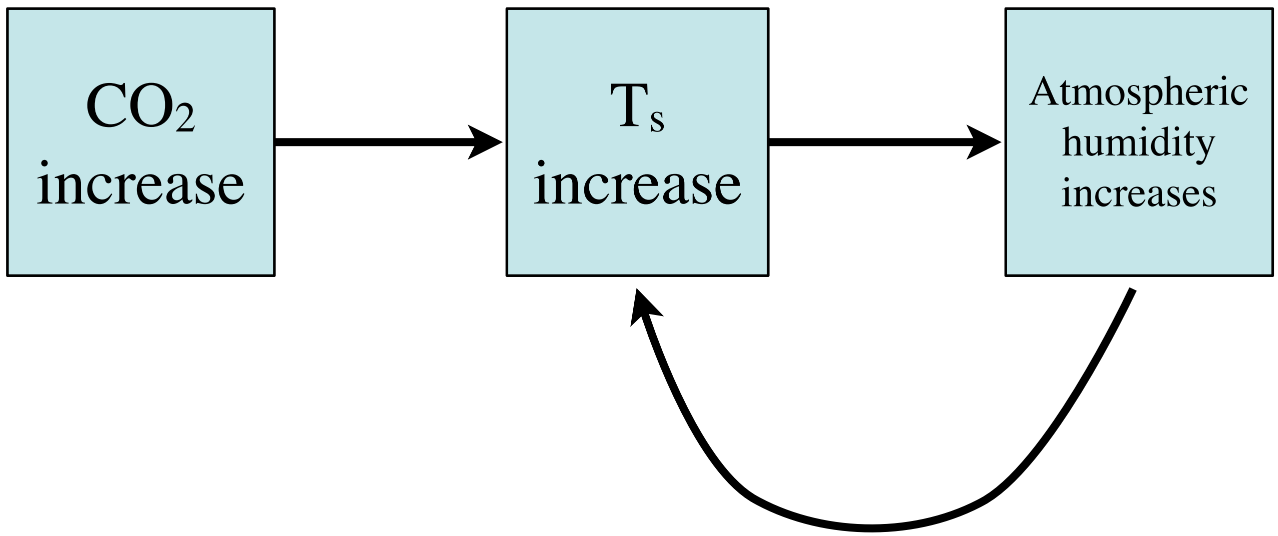
$$\Delta T_i + g\Delta T_i$$



$$\Delta T_i + g\Delta T_i + g^2\Delta T_i$$



$$\Delta T_f = \Delta T_i + g\Delta T_i + g^2\Delta T_i + g^3\Delta T_i + g^4\Delta T_i + \ldots$$



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$$\Delta T_f = \frac{\Delta T_i}{(1 - g)}$$

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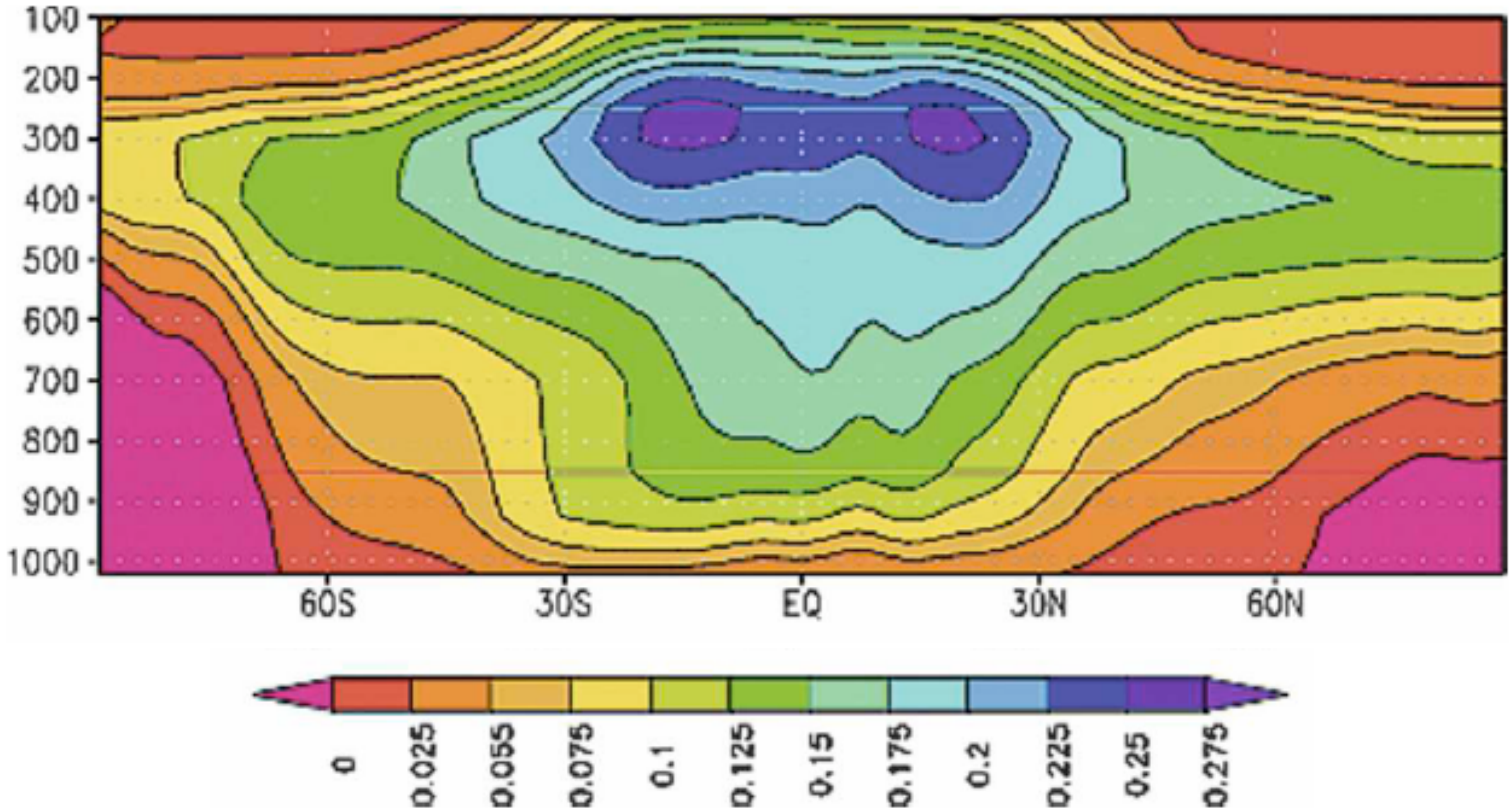
$$\Delta T_f = \frac{\Delta T_i}{(1-g)} \approx 2\text{-}4\ \mathrm{K}$$

$$\Delta T_f = \frac{\Delta T_i}{(1 - g)}$$

$$g = g_{i\text{-}a} + g_{wv} + g_{lr} + g_{cloud} + g_{cc}$$

Soden et al., 2008

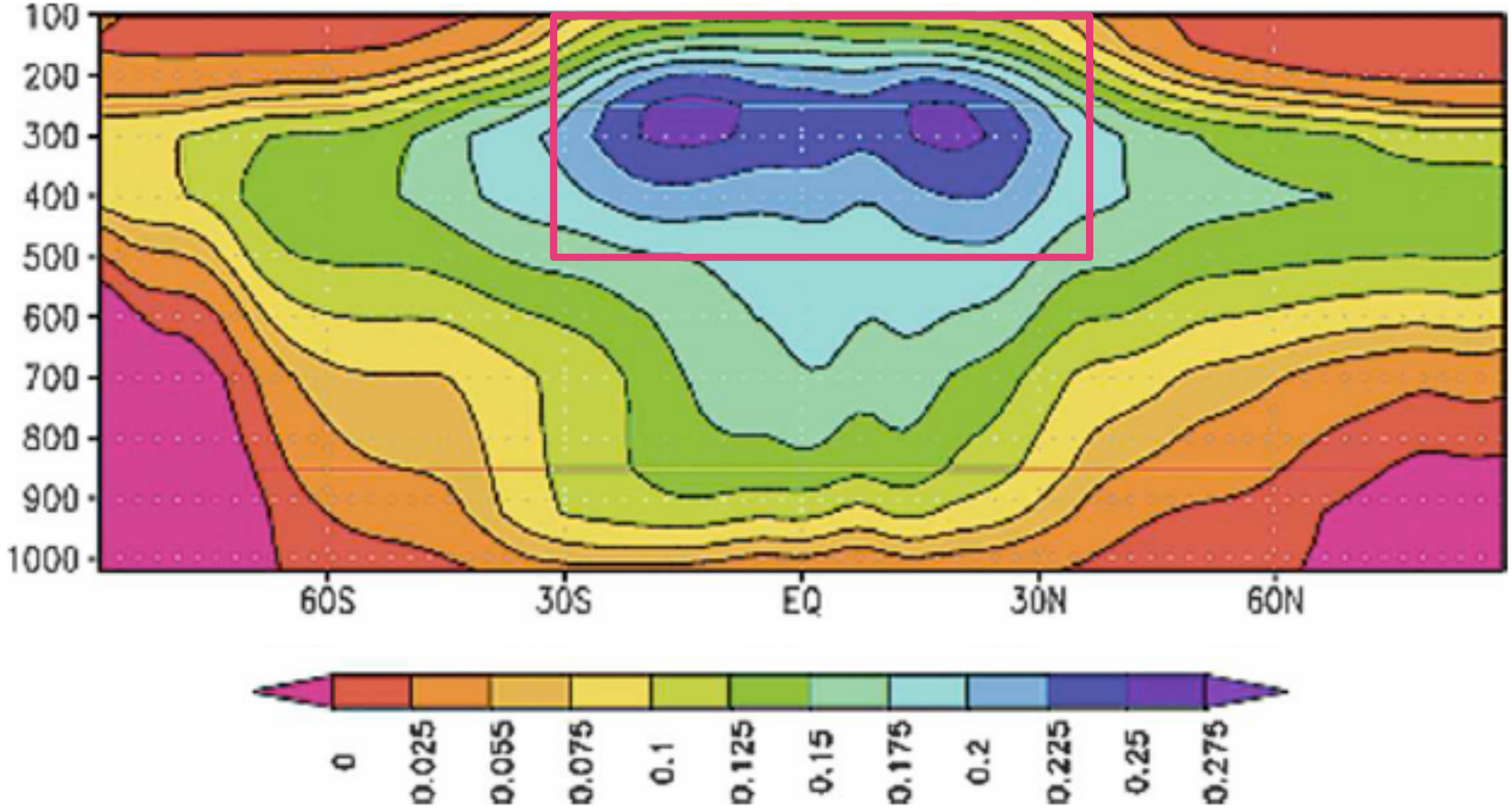


Change in globally avg. OLR in response to Δq(lat,p)

Fig. 2 of Soden et al., 2008

Soden et al., 2008

Water vapor feedback is primarily a "tropical" phenomenon



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1990: "The best understood feedback mechanism is water vapor feedback, and this is intuitively easy to understand."

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1995:

2001:

2007:

Lindzen, BAMS, 1990

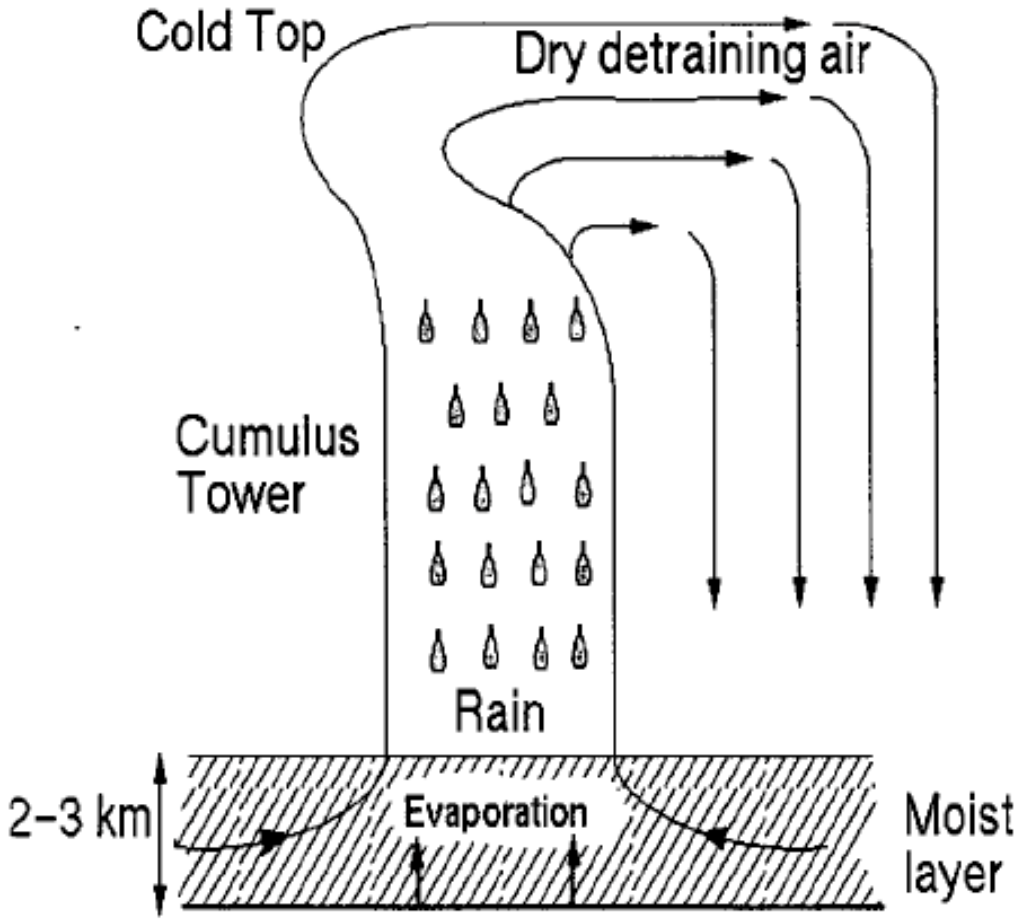
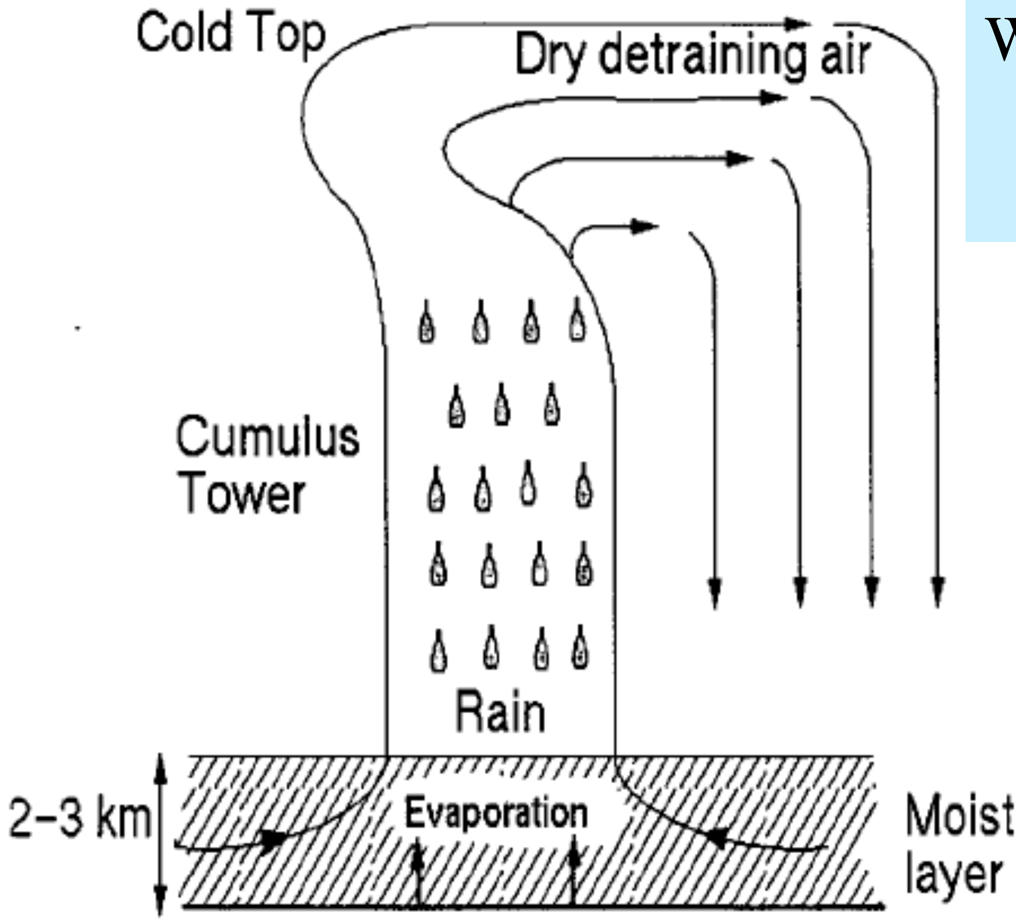


FIG. 7. Schematic illustration of cumulus tower wherein moisture evaporated from the surface and converged into cumulus convection is rained out, leaving dry air to detrain into the environment.

Lindzen, BAMS, 1990



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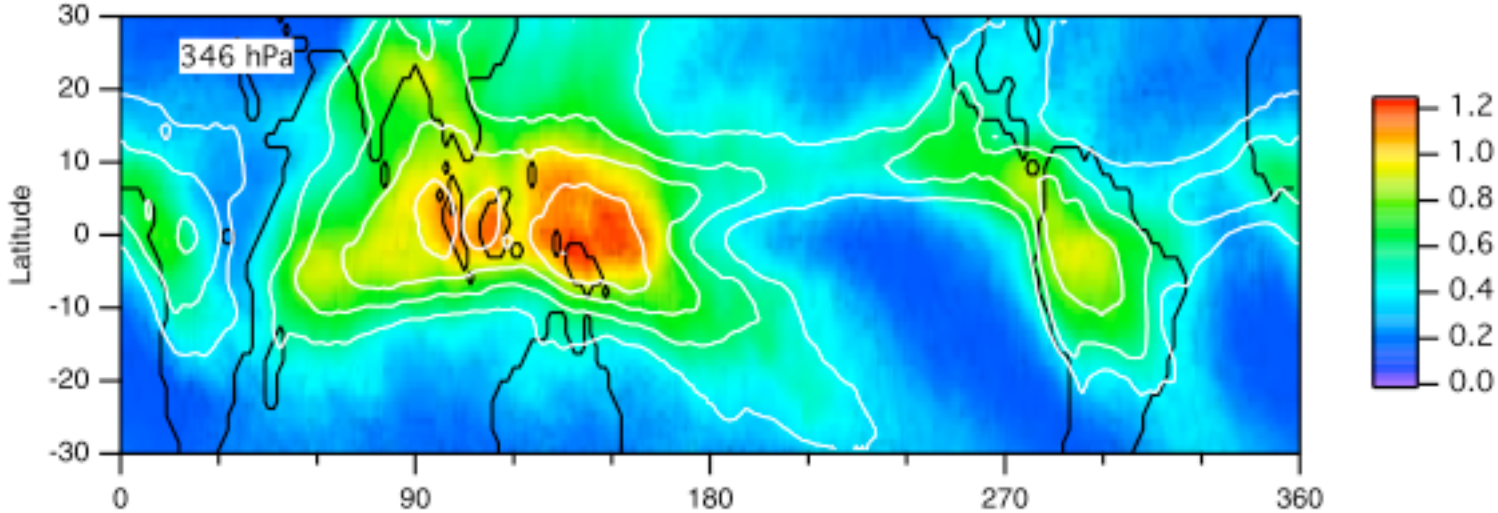
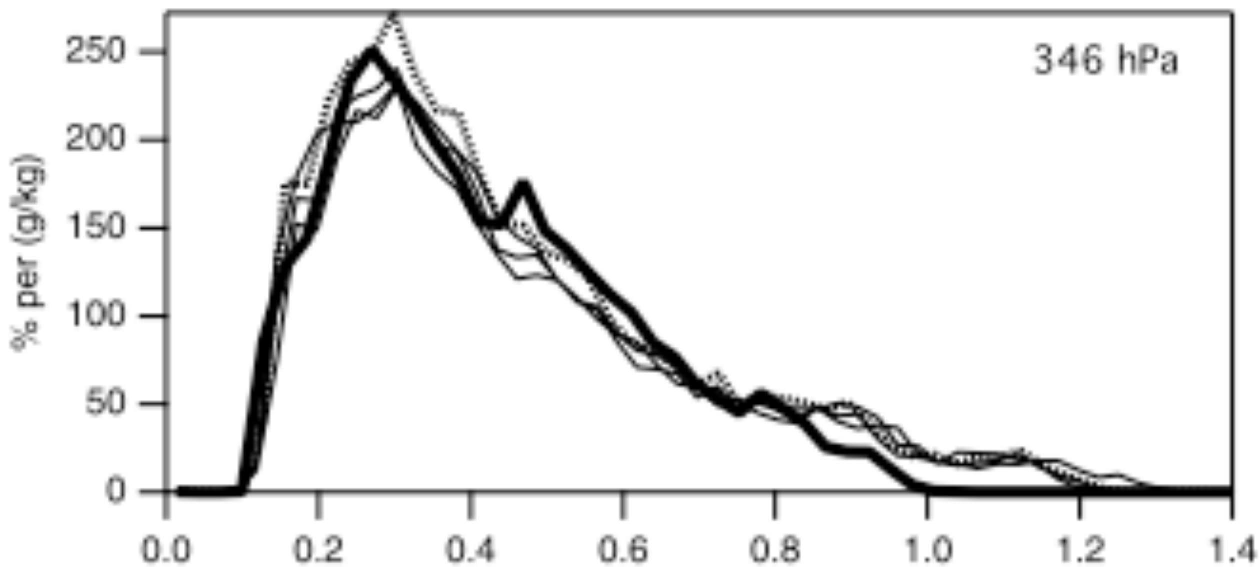
Water vapor in the UT is set by the detrainment temperature in the UT

Large-scale control: Sherwood, Pierrehumbert, Salathe, Dessler, Folkins





Dessler and Minschwaner, 2007

Lindzen, BAMS, 1990

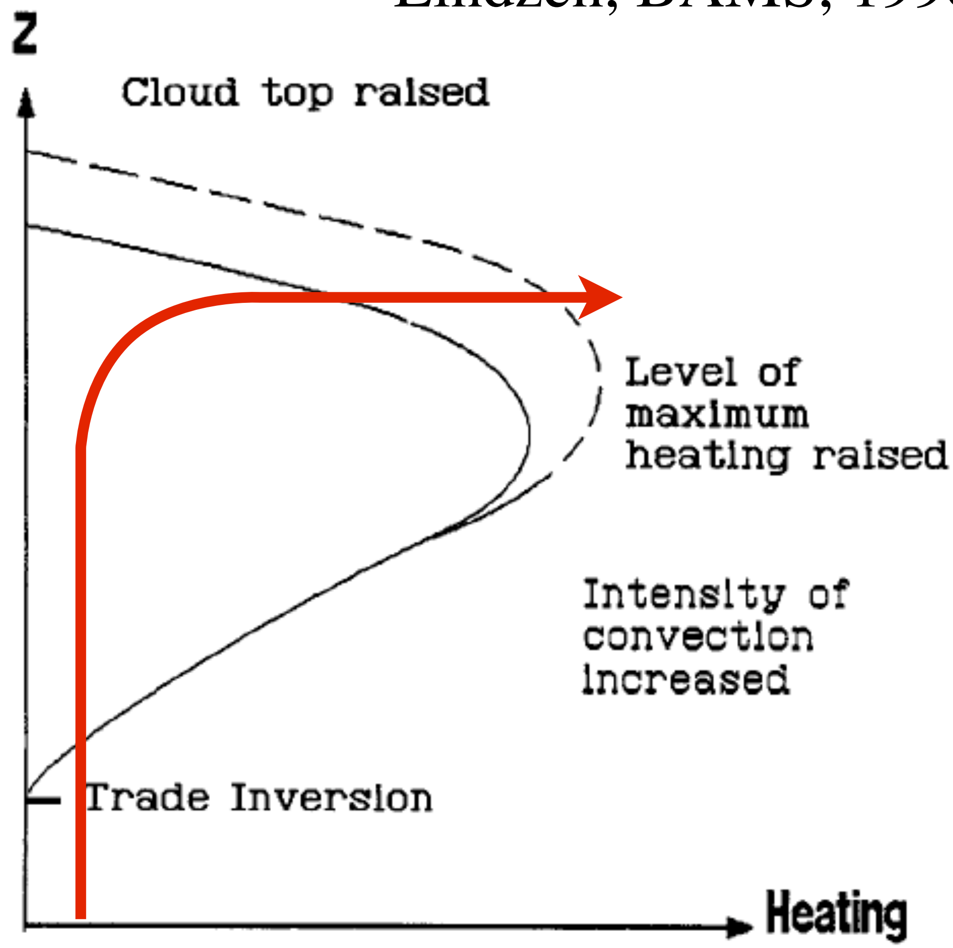


FIG. 8. Schematic illustration of cumulus heating distribution under (solid line) normal conditions, and (dashed line) under conditions of anomalous warming. Warming leads the following effects: 1) cloud tops are raised leading to dryer detrained air; 2) convective intensity increases which leads to the dryer air being pushed down more effectively; and 3) there is an increase in the height at which there is maximum cumulus heating, thus bypassing more infrared absorbers in the atmosphere.

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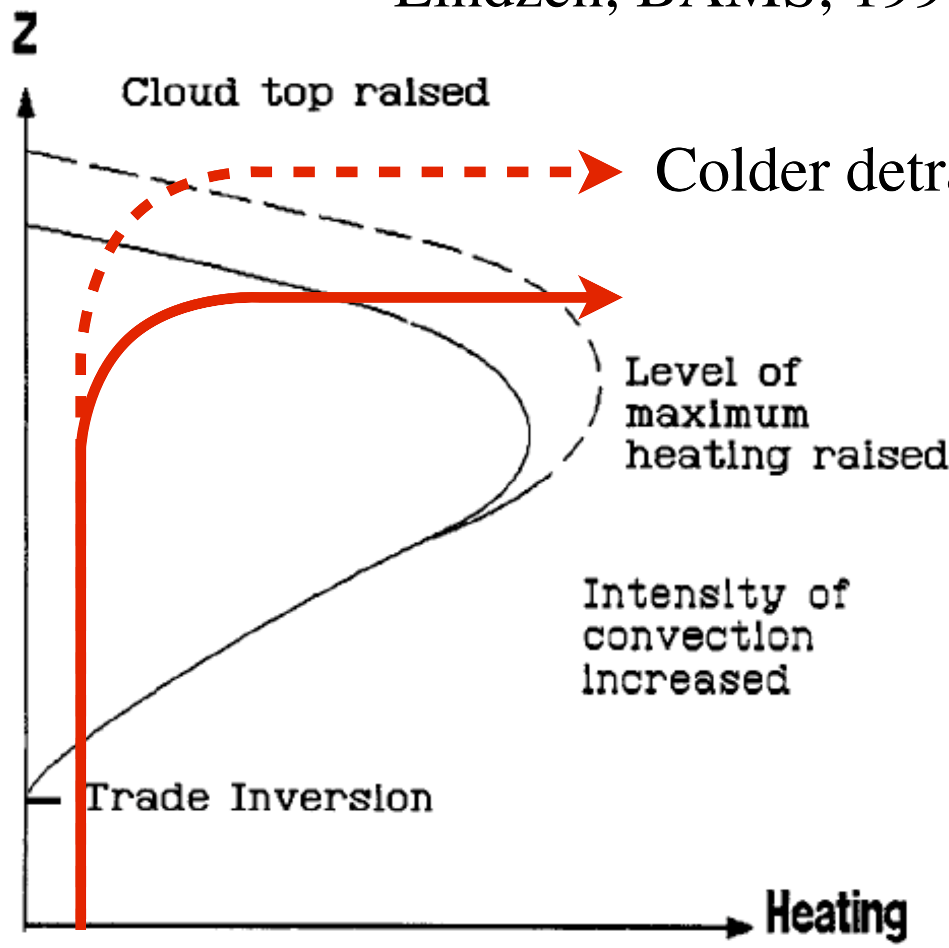

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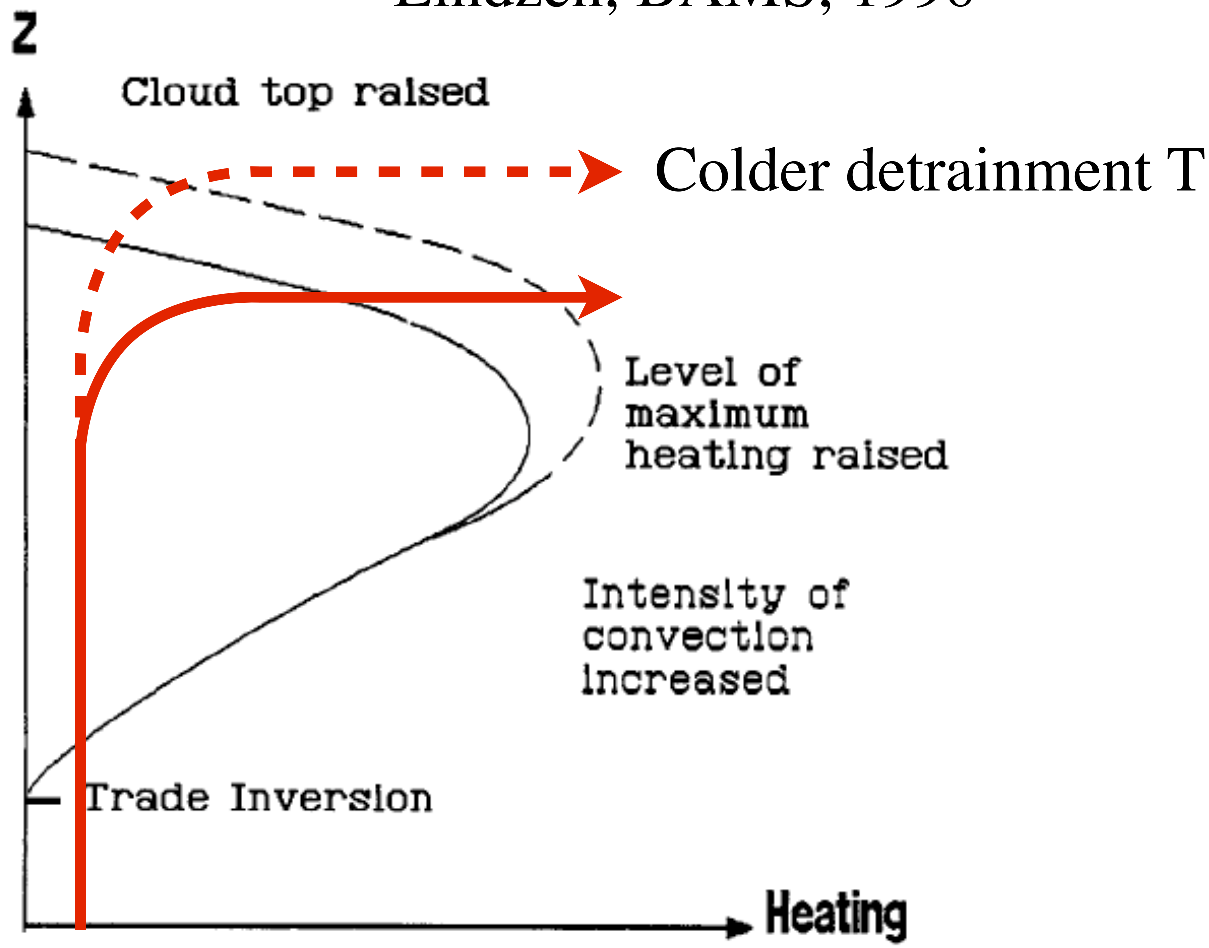

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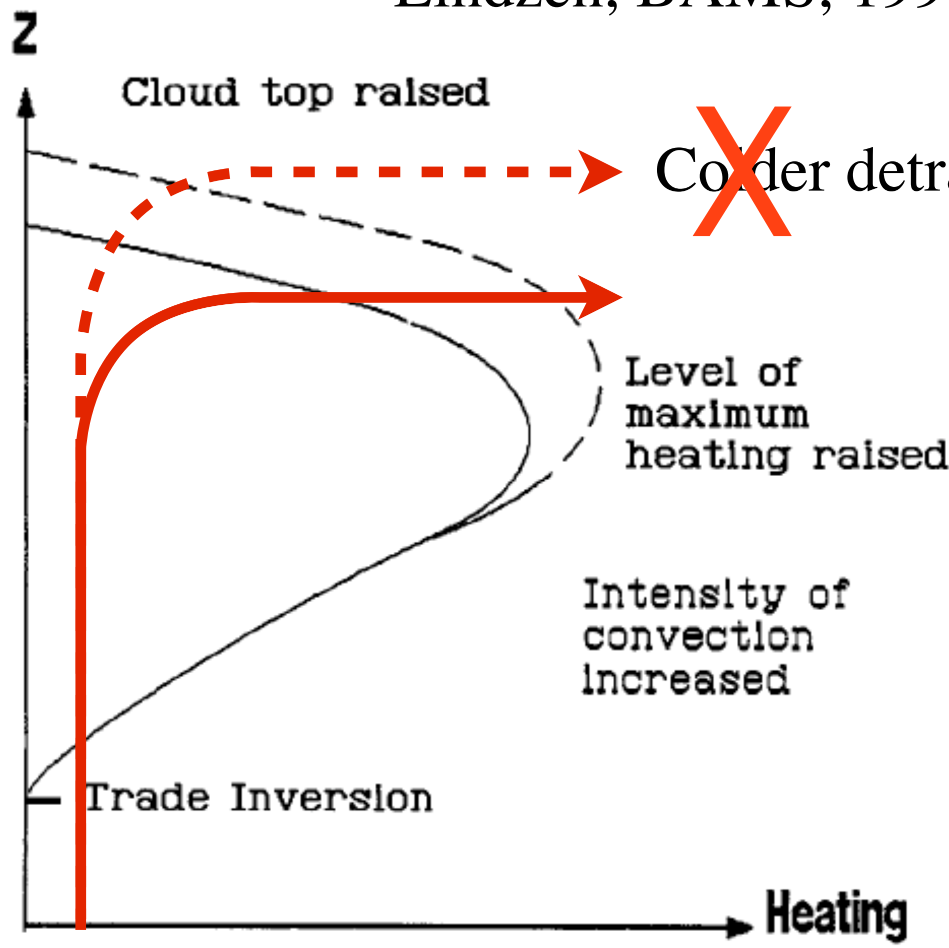

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"cloud tops are raised leading to dryer detrained air"

Downward mass flux

$$M_c = \frac{Q_R}{c_p\left[\frac{dT}{dz} + \Gamma\right]}$$

Continuity equation for q

$$\frac{dM_c}{dz}\left[q - q^*(T)\right] = M_c \frac{dq}{dz}$$

Minschwaner and Dessler, *J. Clim.*, 2004

$$M_c = \frac{Q_R}{c_p\left[\frac{dT}{dz} + \Gamma\right]}$$

$$\frac{dM_c}{dz}\left[q - q^*(T)\right] = M_c \frac{dq}{dz}$$

Minschwaner and Dessler, *J. Clim.*, 2004

- As the climate warms ...
  - Detrainment goes up in altitude
  - Temperature of detrainment also goes up
- Water vapor goes up
- These two parameters cannot be independently varied
- Hartmann and Larsen also found this

Observational tests of the water vapor feedback

Volcano
ENSO+interannual
seasonal cycle
decade-scale warming

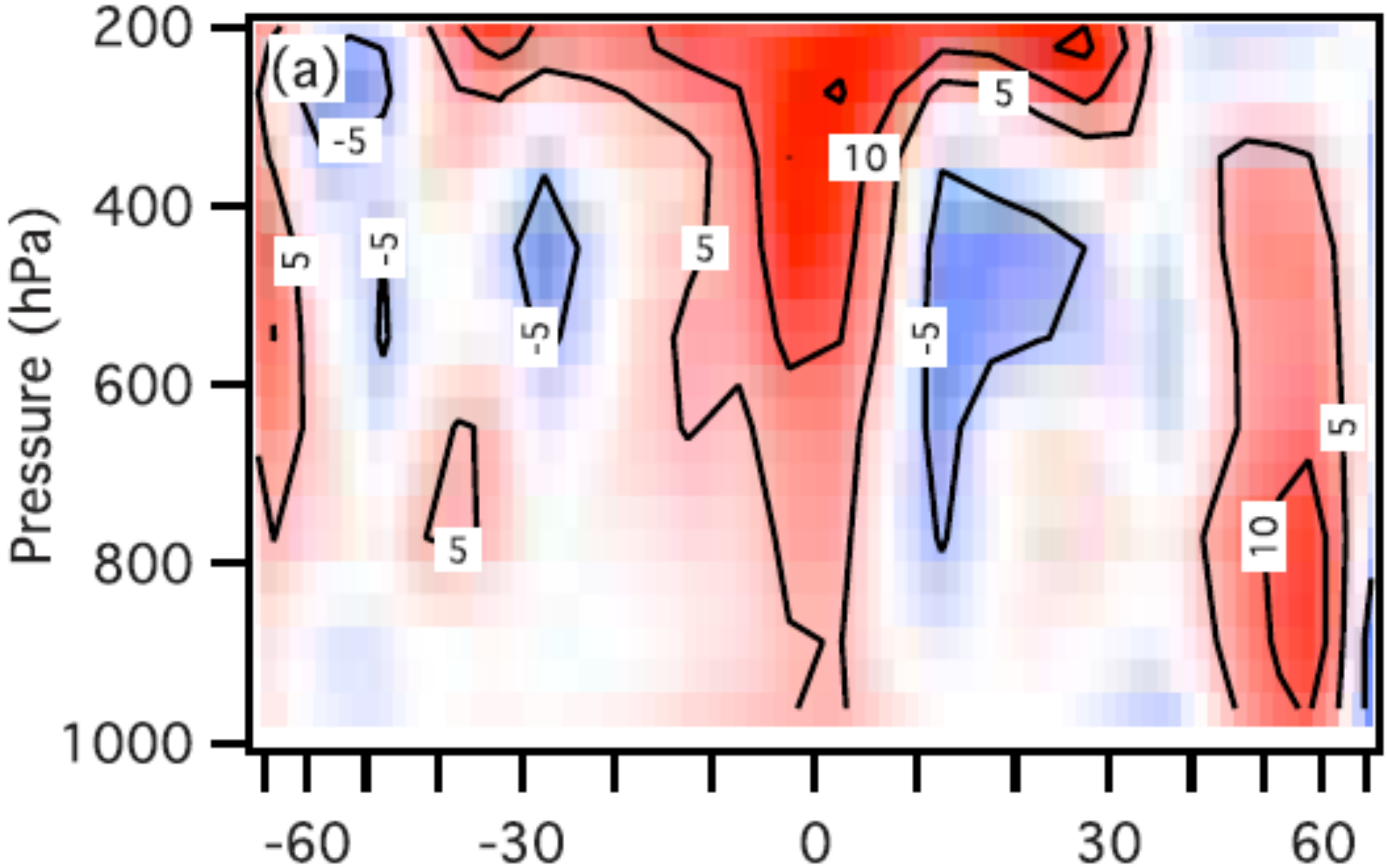
Observational tests of the water vapor feedback

Volcano
ENSO+interannual
seasonal cycle
decade-scale warming

El Nino minus La Nina

% change in specific humidity

AIRS data: D06JF07-D07JF08



Dessler et al. 2008

Verify that the water vapor feedback is strong and positive

Volcano	Soden et al., 2002; Forster and Collins, 2004
ENSO+interannual	Soden, 1997; Minschwaner and Dessler, 2004; Gettelman and Fu, 2008; Dessler et al., 2008
seasonal cycle	Inamdar and Ramanathan, 1998; Wu et al., 2008
decade-scale warming	Soden et al., 2005; Hall and Manabe, 1999

Subtle complexity

Volcano	Forster and Collins: 1.6 $W/m^2/K$
ENSO	Wong and Dessler: AMIP: 2.6 $W/m^2/K$, MERRA: 3.3 $W/m^2/K$, ERA40: 5.0 $W/m^2/K$
decade-scale warming	Soden and Held (models): 1.8 $W/m^2/K$

WARNING

- average "constant RH" is nearly true for both ENSO and for long-term warming

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- but the details of the changes are different

WARNING

- average “constant RH” is nearly true for both ENSO and for long-term warming
- but the details of the changes are different
- this leads to quite different feedbacks

- different strategy to verify feedbacks?

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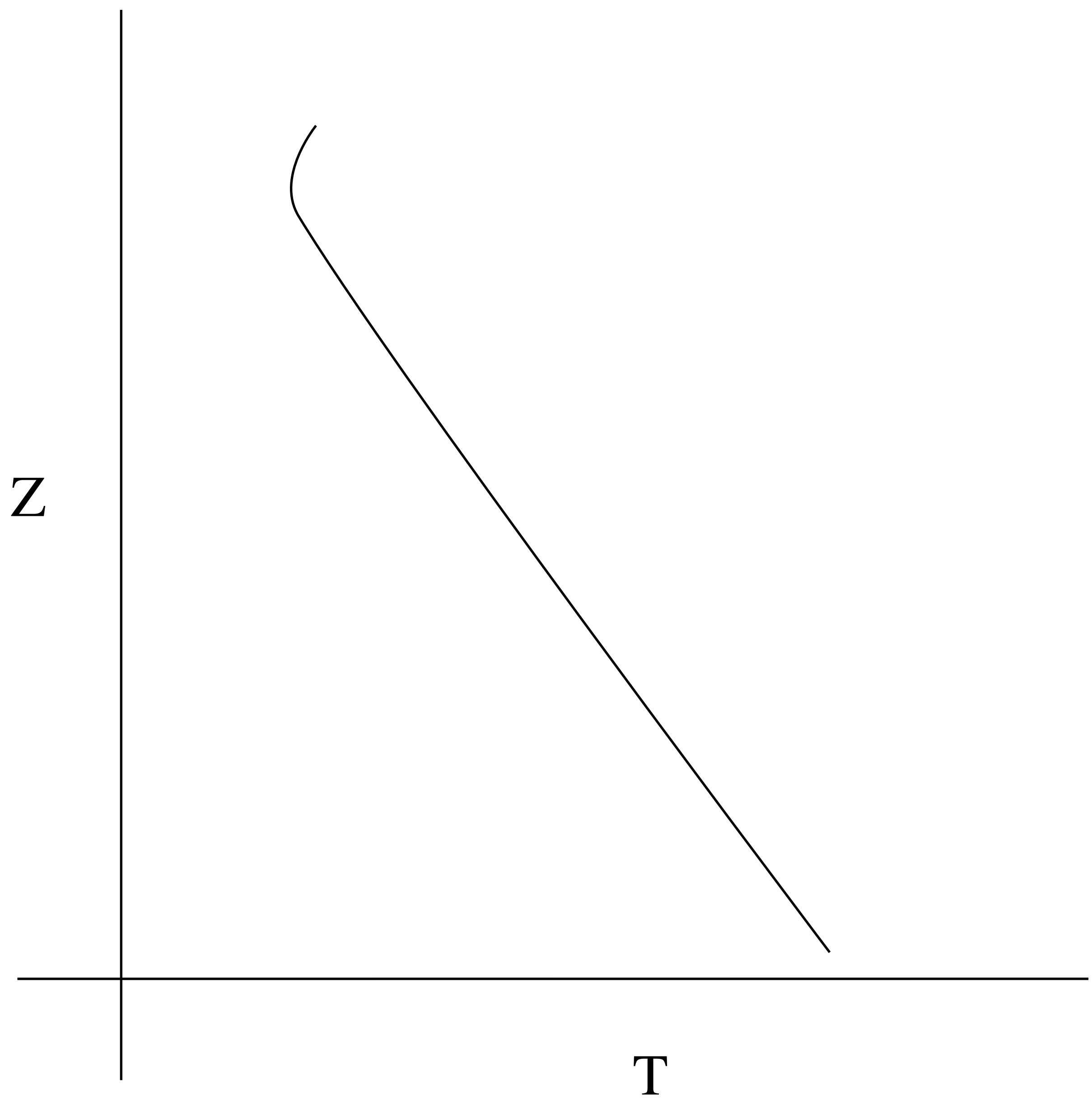
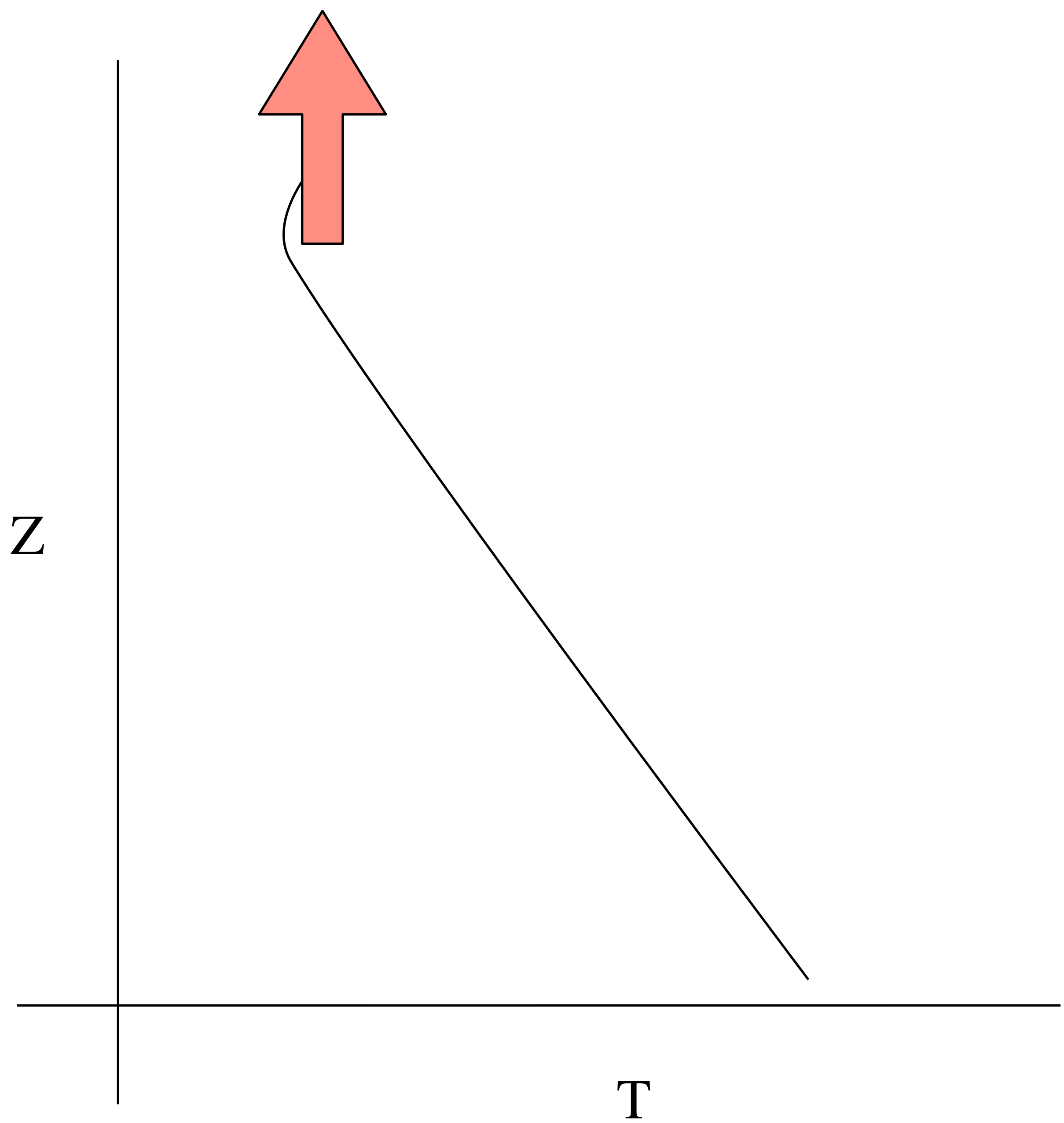
2001: "... the balance of evidence favours a positive clear-sky water vapour feedback of a magnitude comparable to that found in simulations."

2007: "New observational and modelling evidence strongly supports a combined water vapour-lapse rate feedback of a strength comparable to that found in [GCMs]."


Z
T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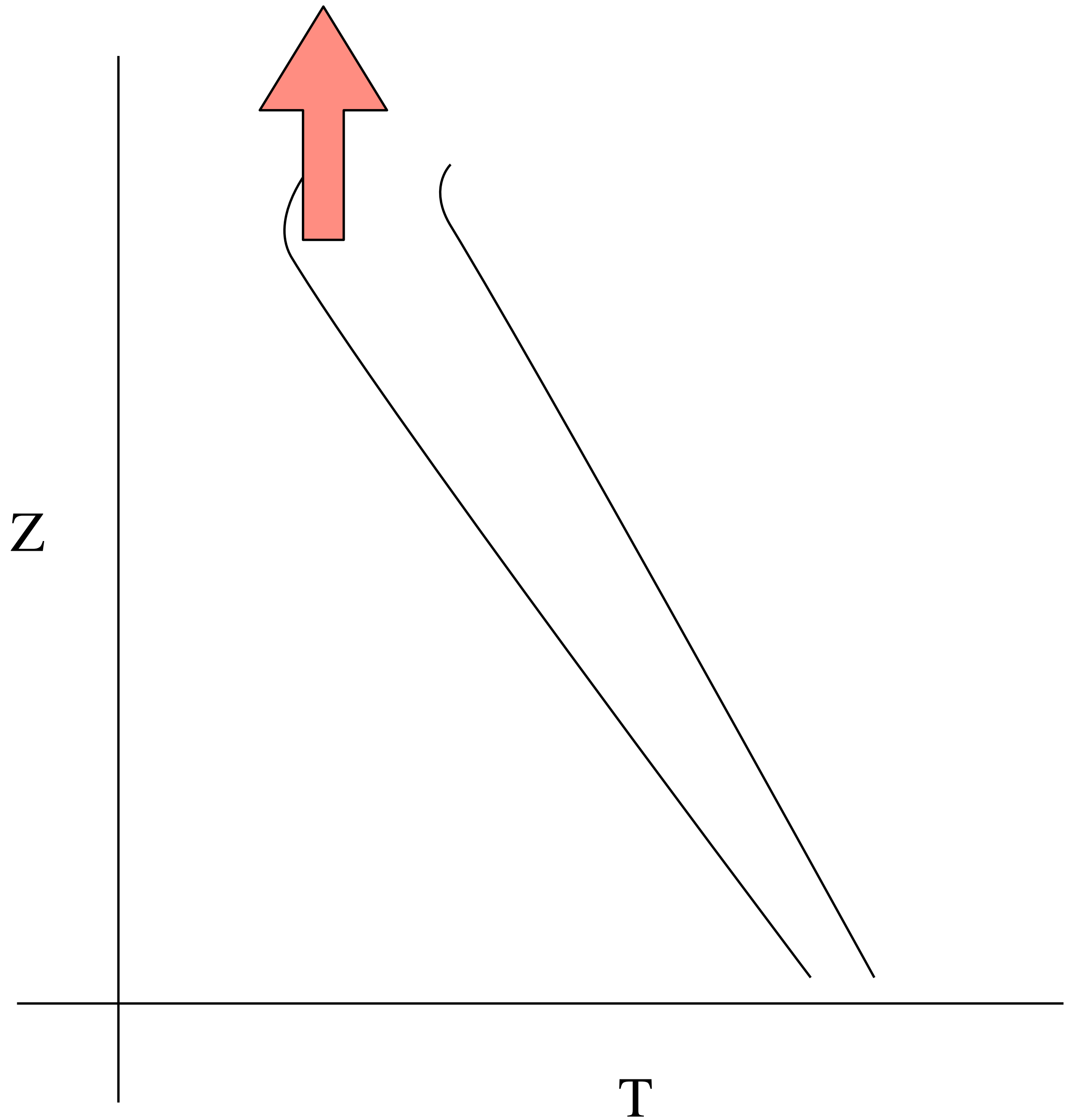
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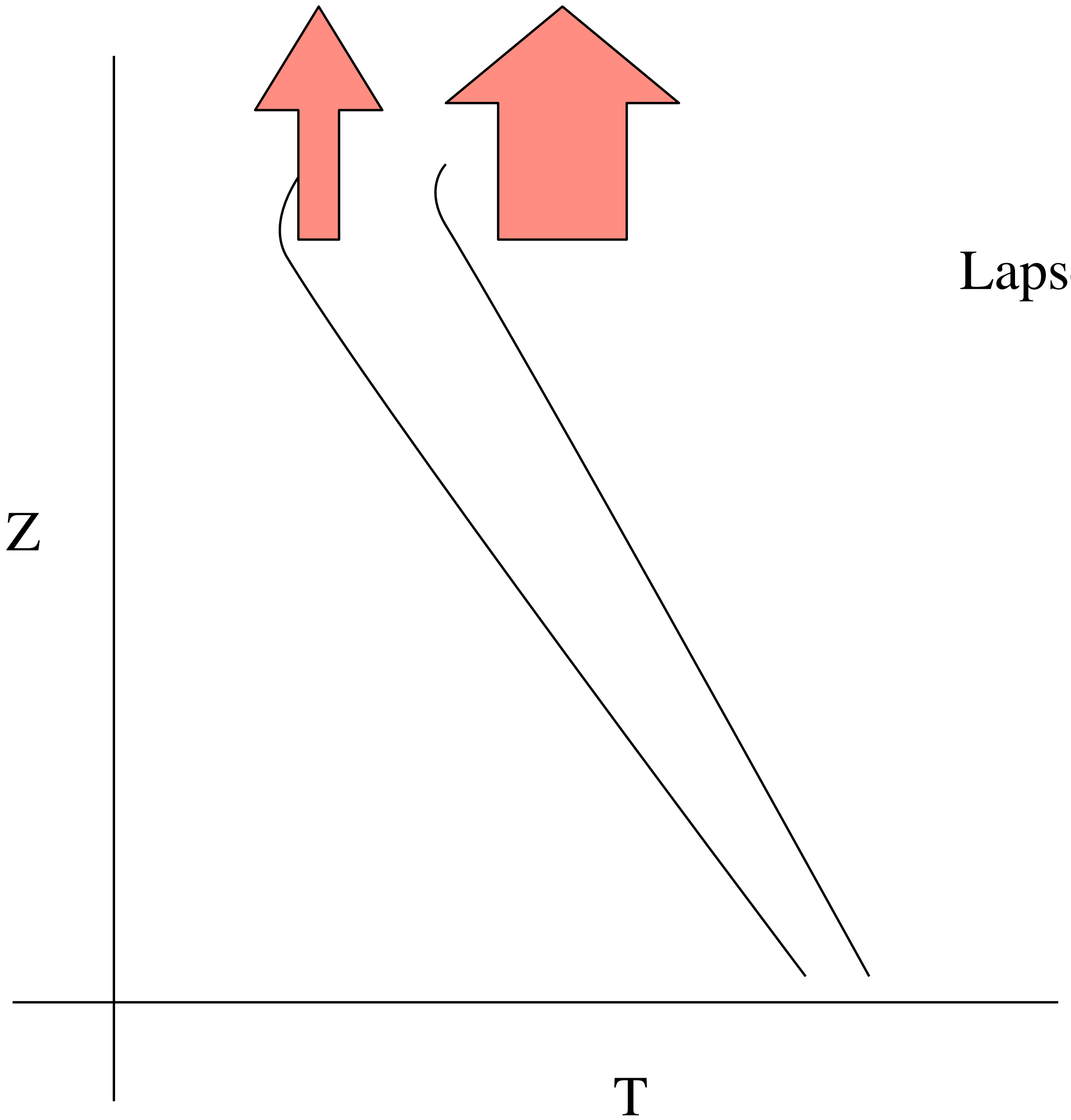
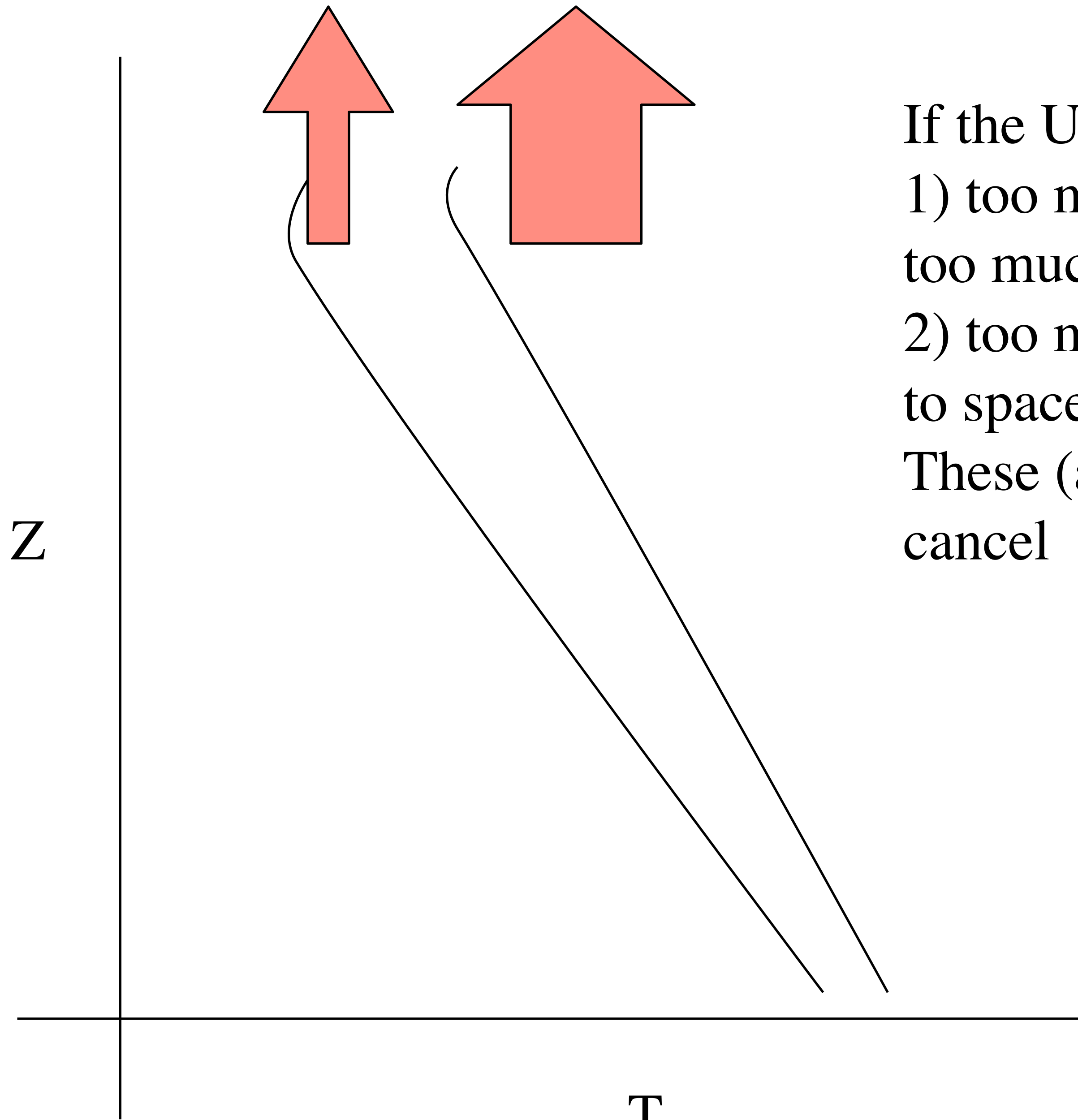


Lapse-rate feedback



If the UT warms too much:
1) too much water, leads to too much trapping of IR
2) too much IR emission to space
These (at least partially) cancel

Soden and Held, 2006
(corrected figure)

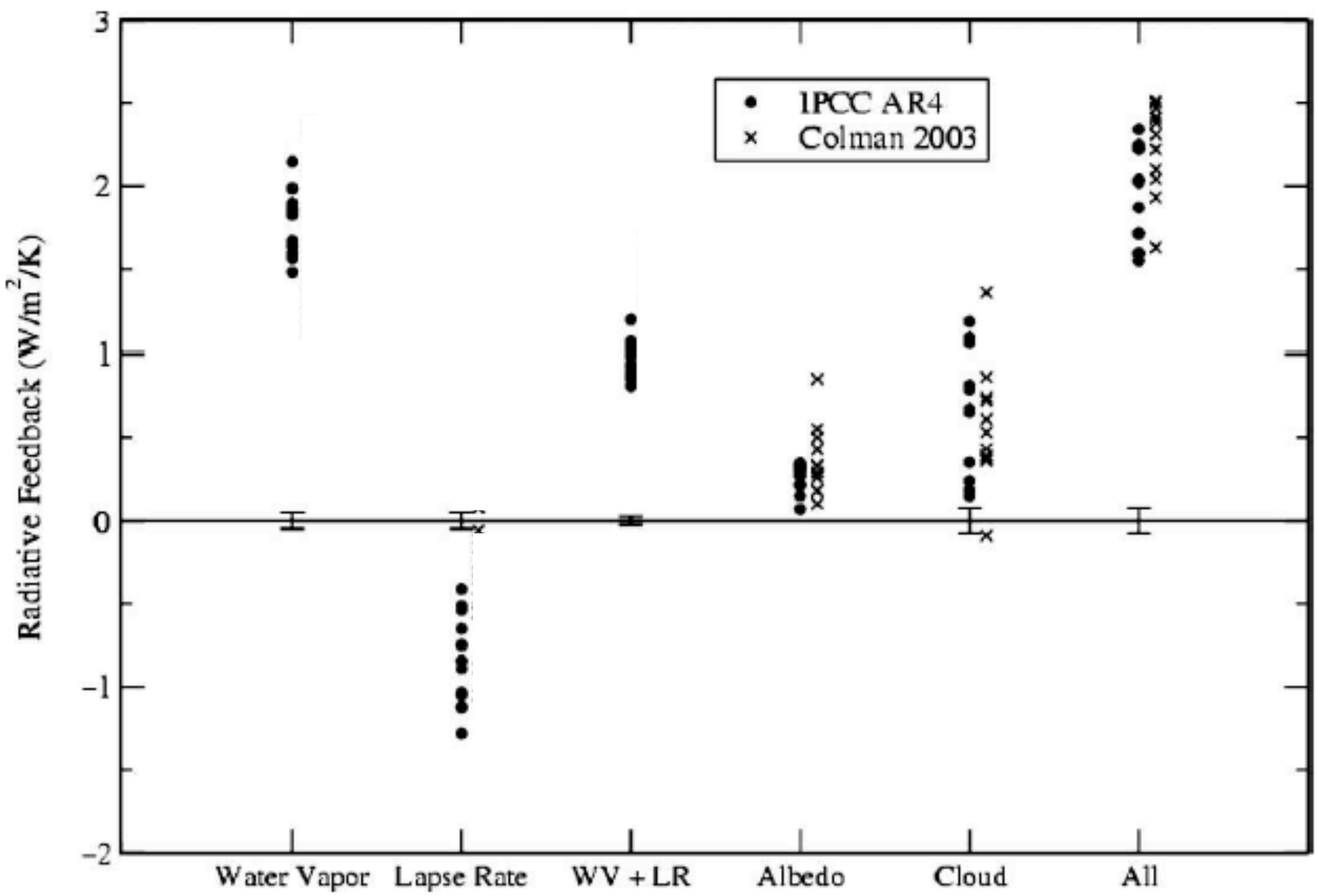


FIG. 1

Corrected version of Fig. 1 of Soden and Held, 2006

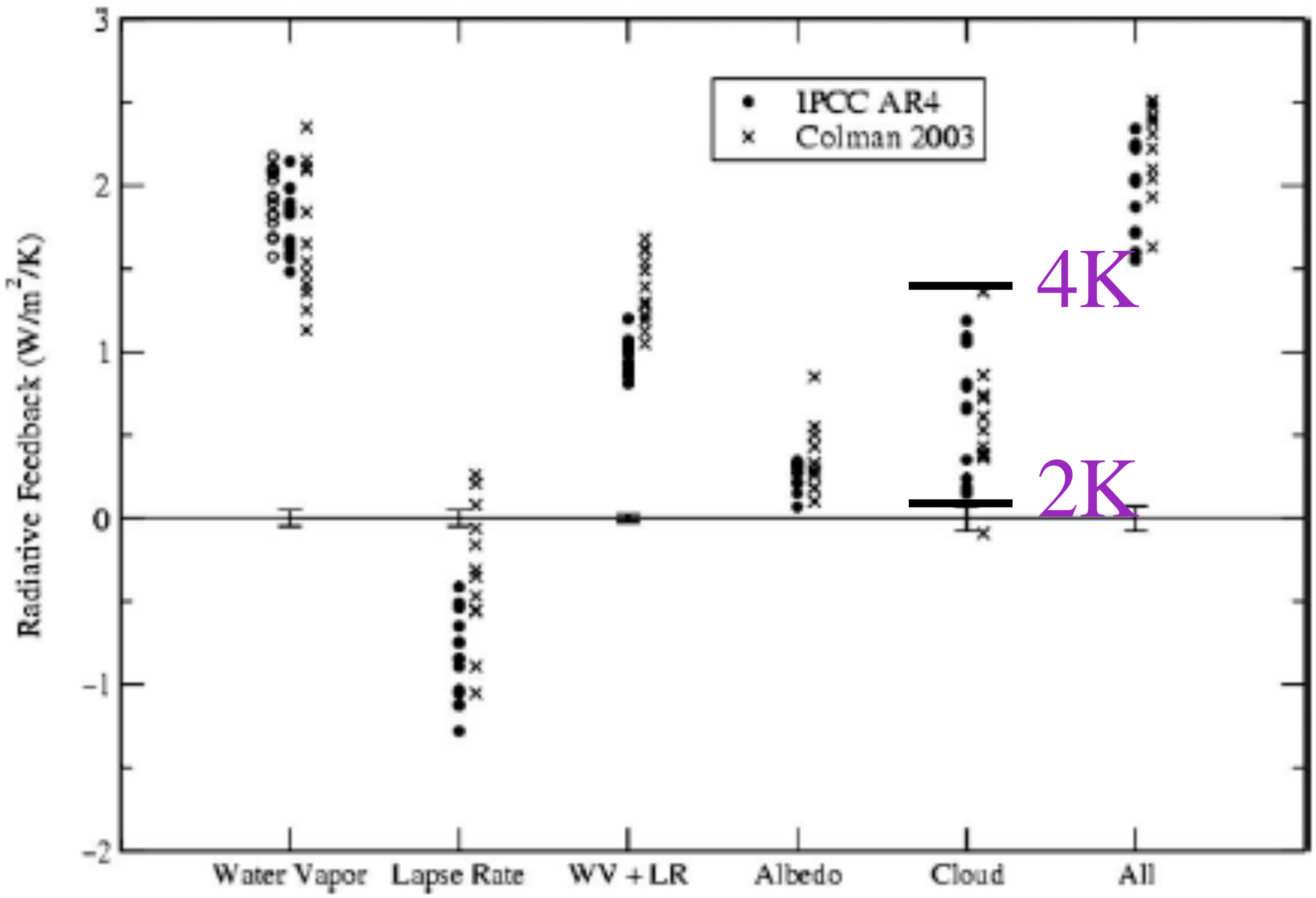
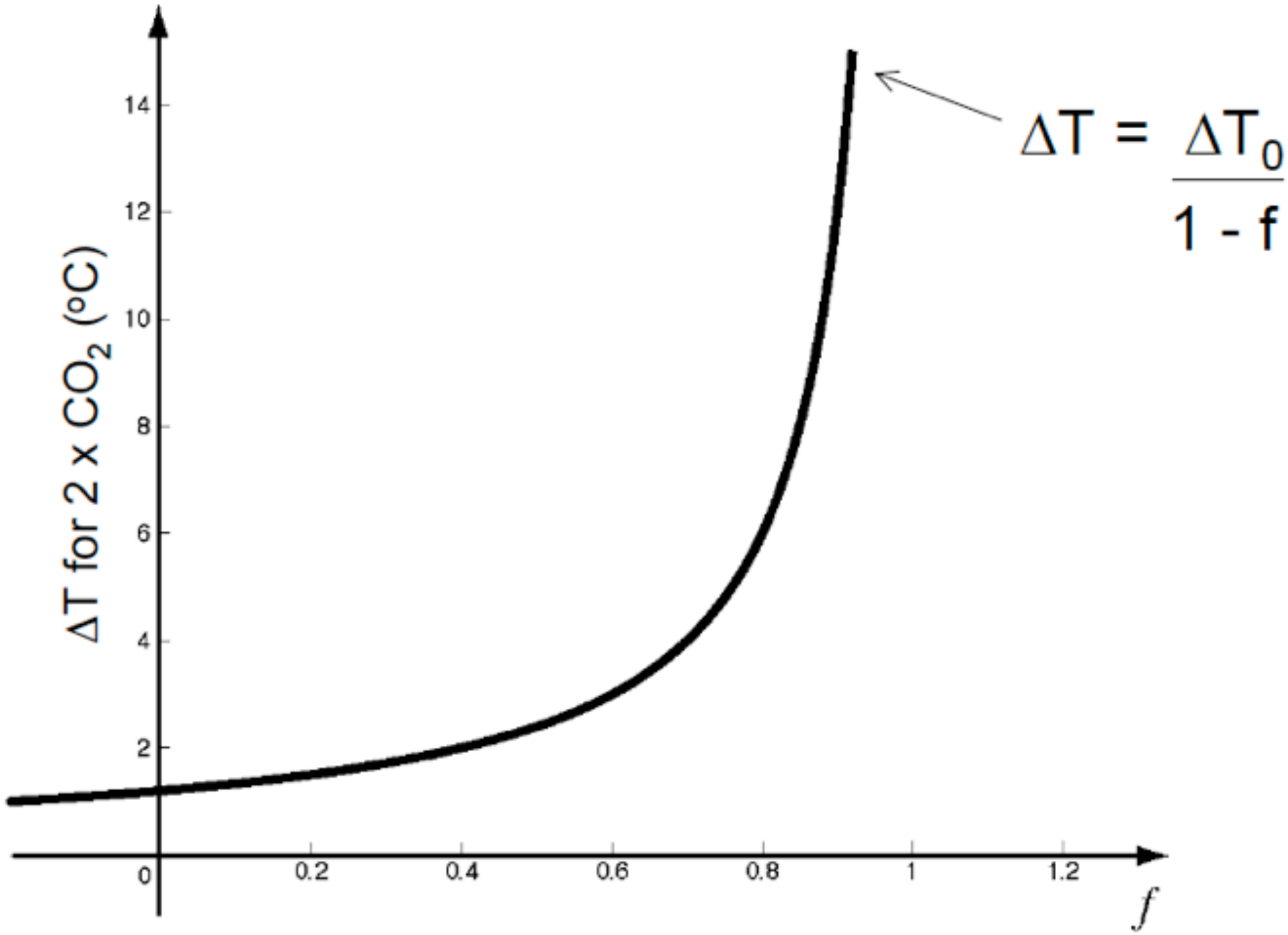
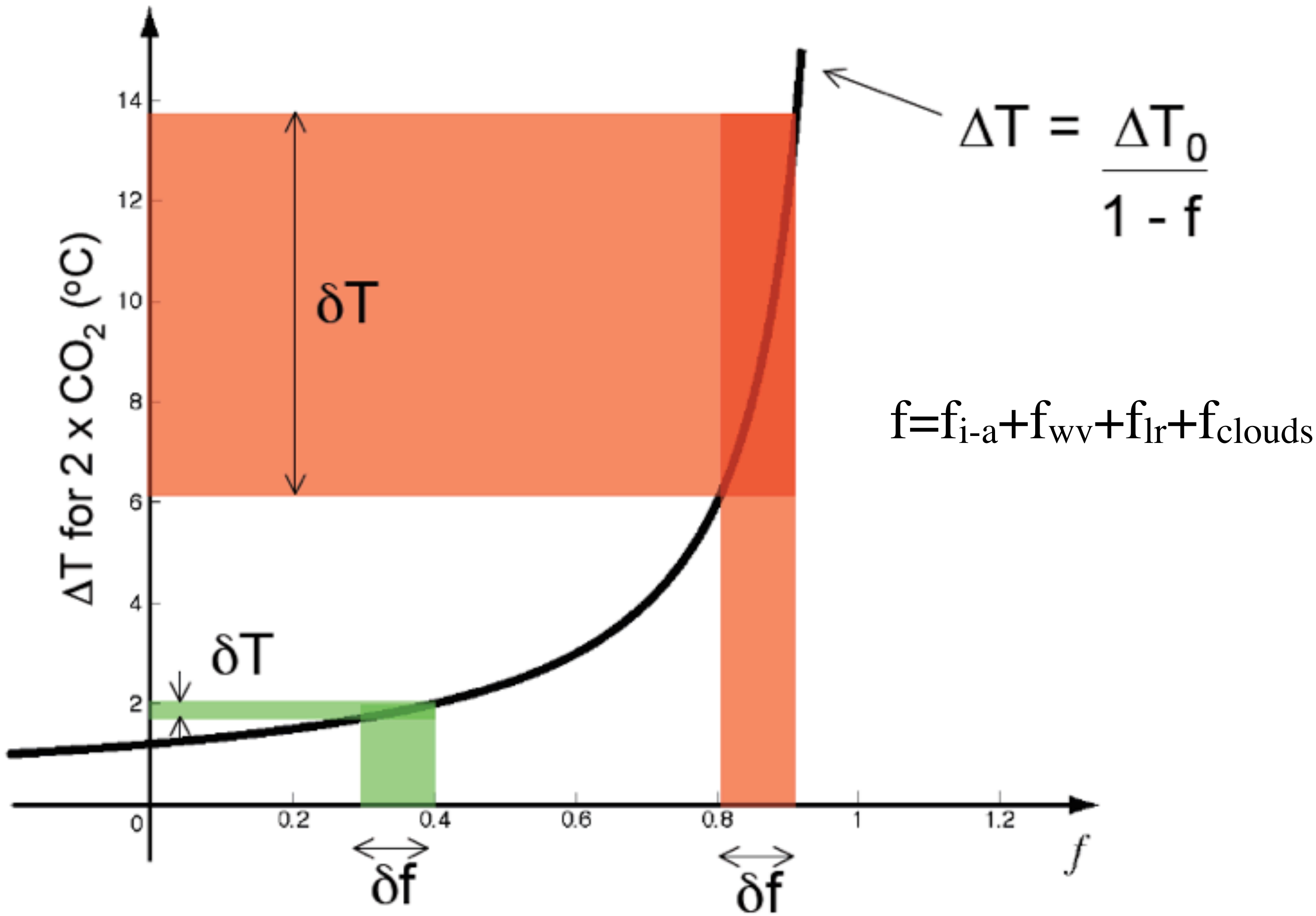


FIG. 1

Cloud: 0.14-1.18



From Baker and Roe, CERES STM presentation



$f = f_{i\text{-}a} + f_{wv} + f_{lr} + f_{clouds}$

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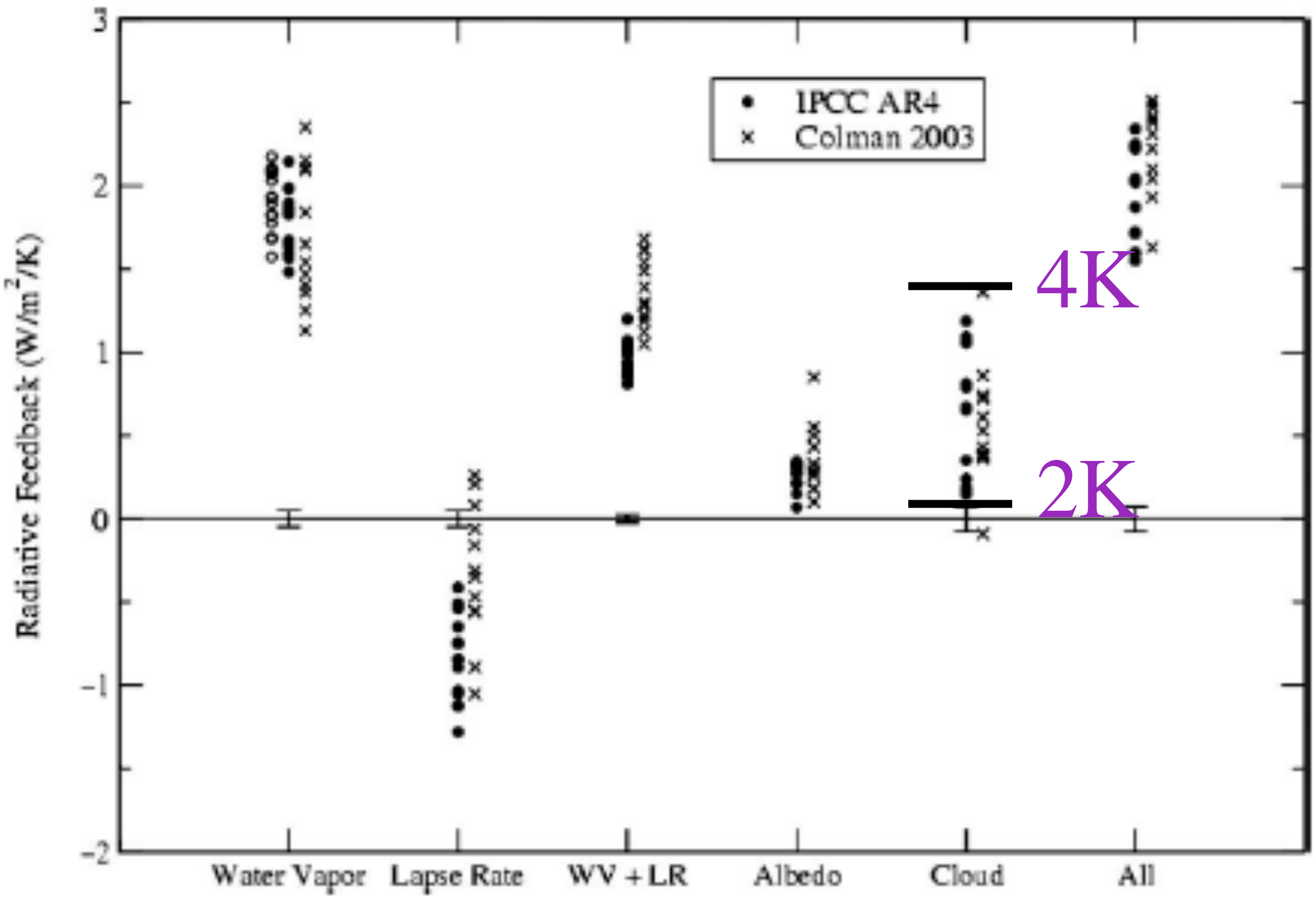


FIG. 1

Cloud: 0.14-1.18

DUFRESNE AND BONY, J.Clim. 2008

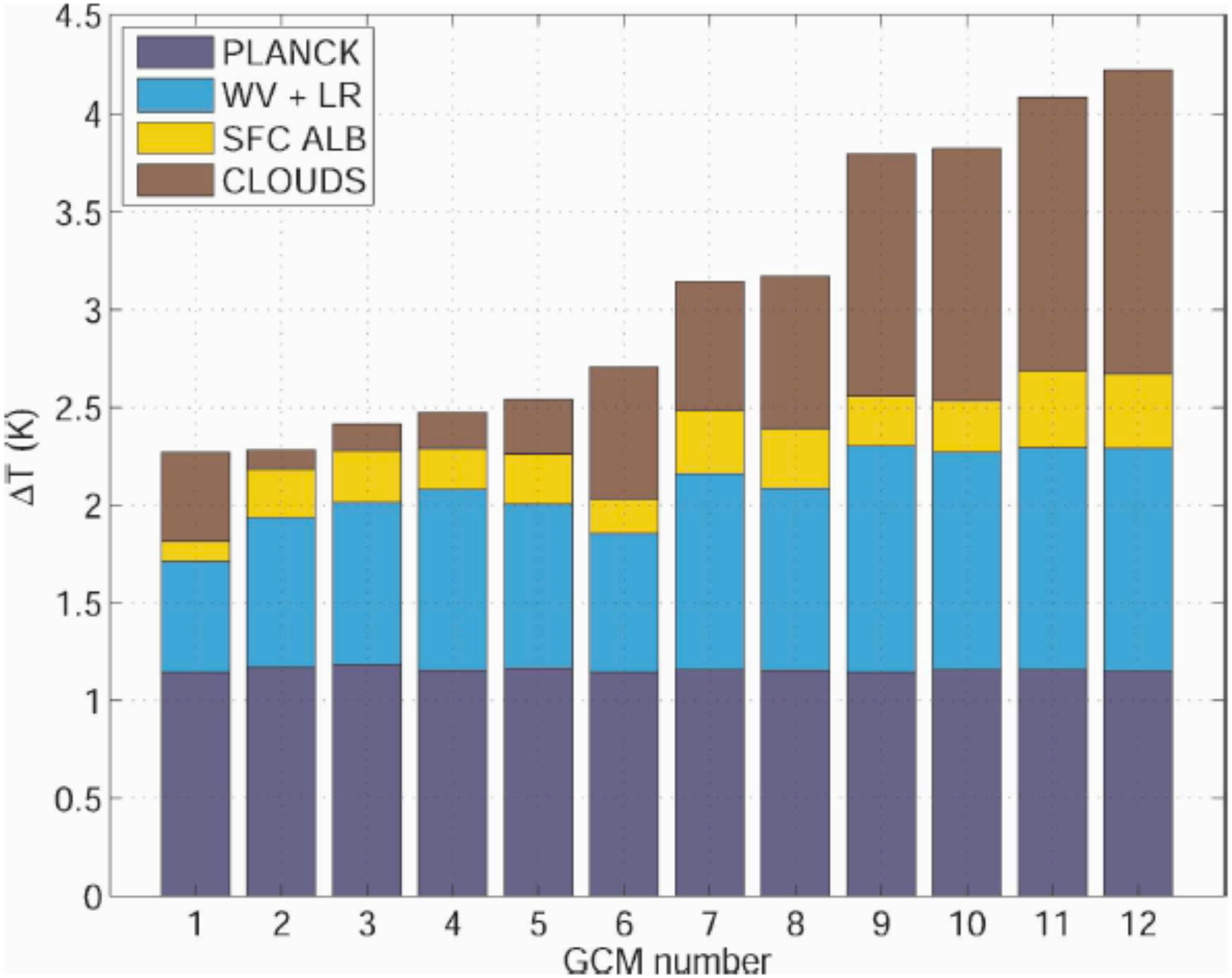
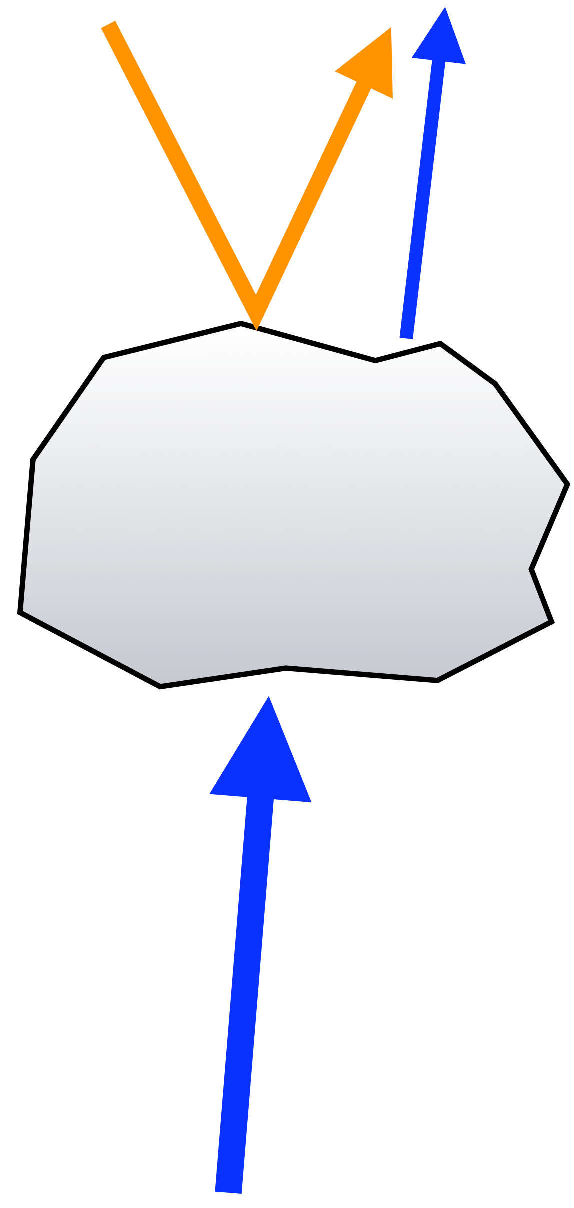
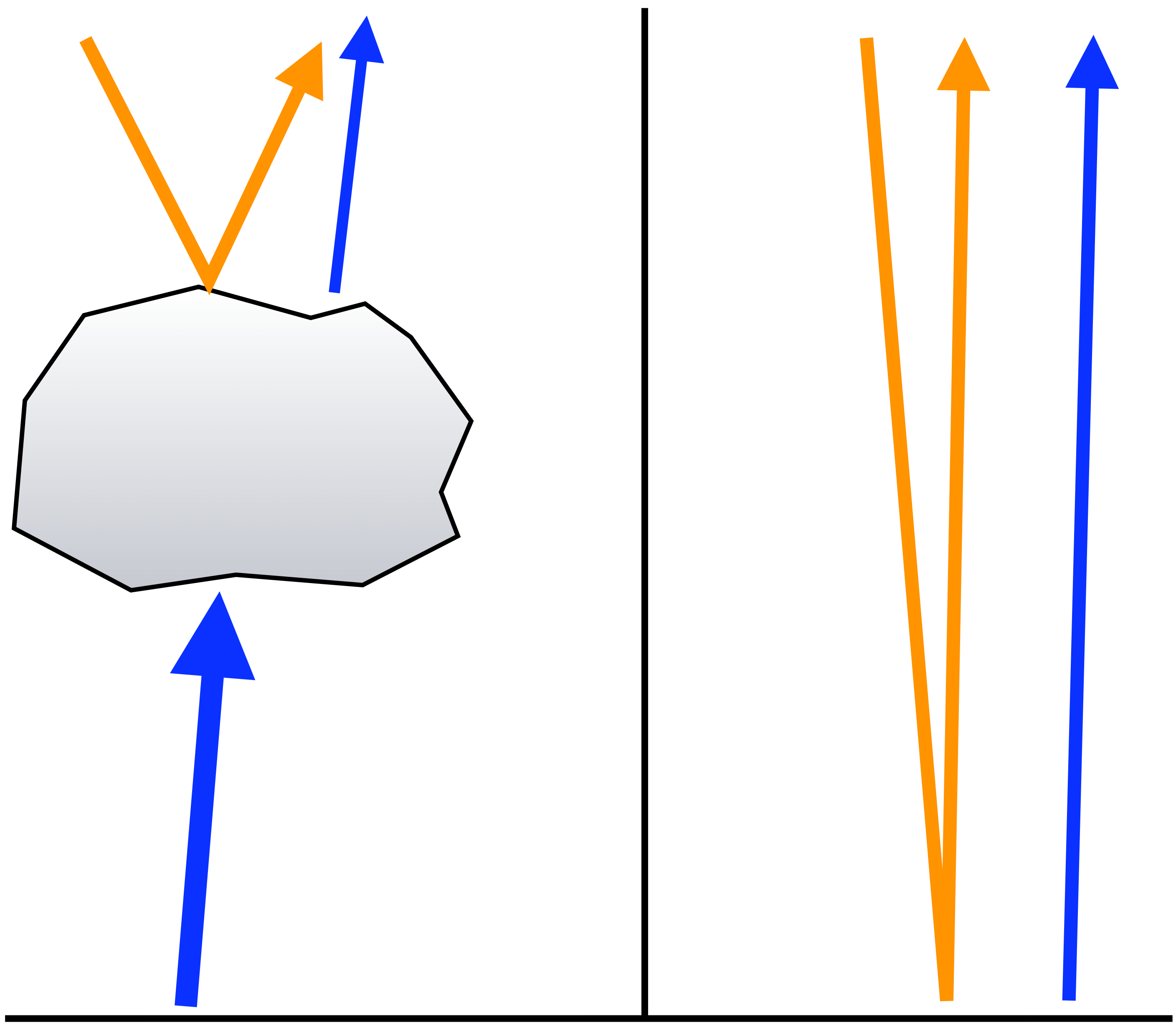


FIG. 2. Equilibrium temperature change associated with the Planck response and the various feedbacks, computed for 12 CMIP3/AR4 AOGCMs for a $2 \times CO_2$ forcing of reference ($3.71\ W\ m^{-2}$). The GCMs are sorted according to ΔT_s^e.



Cloud radiative forcing



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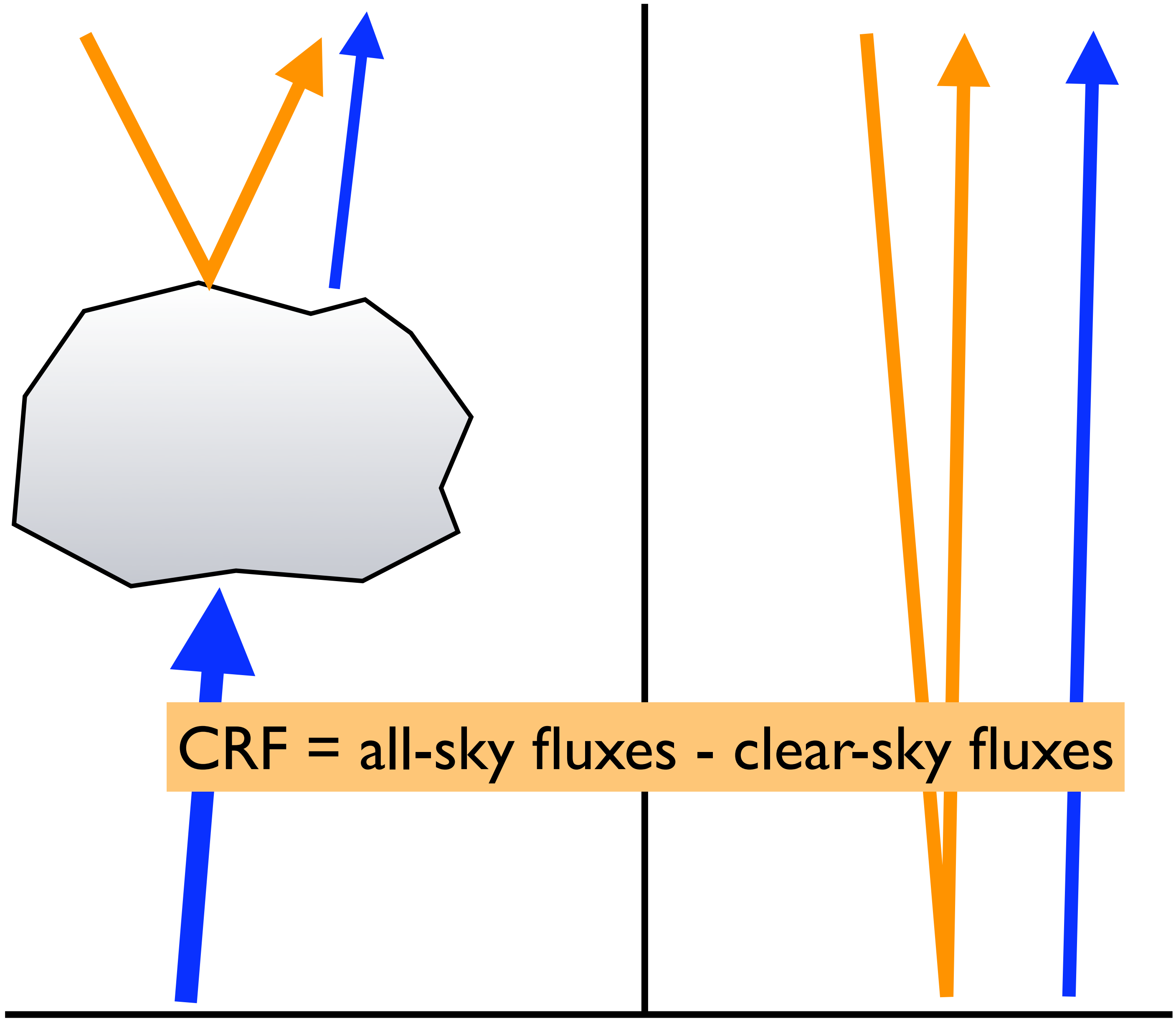

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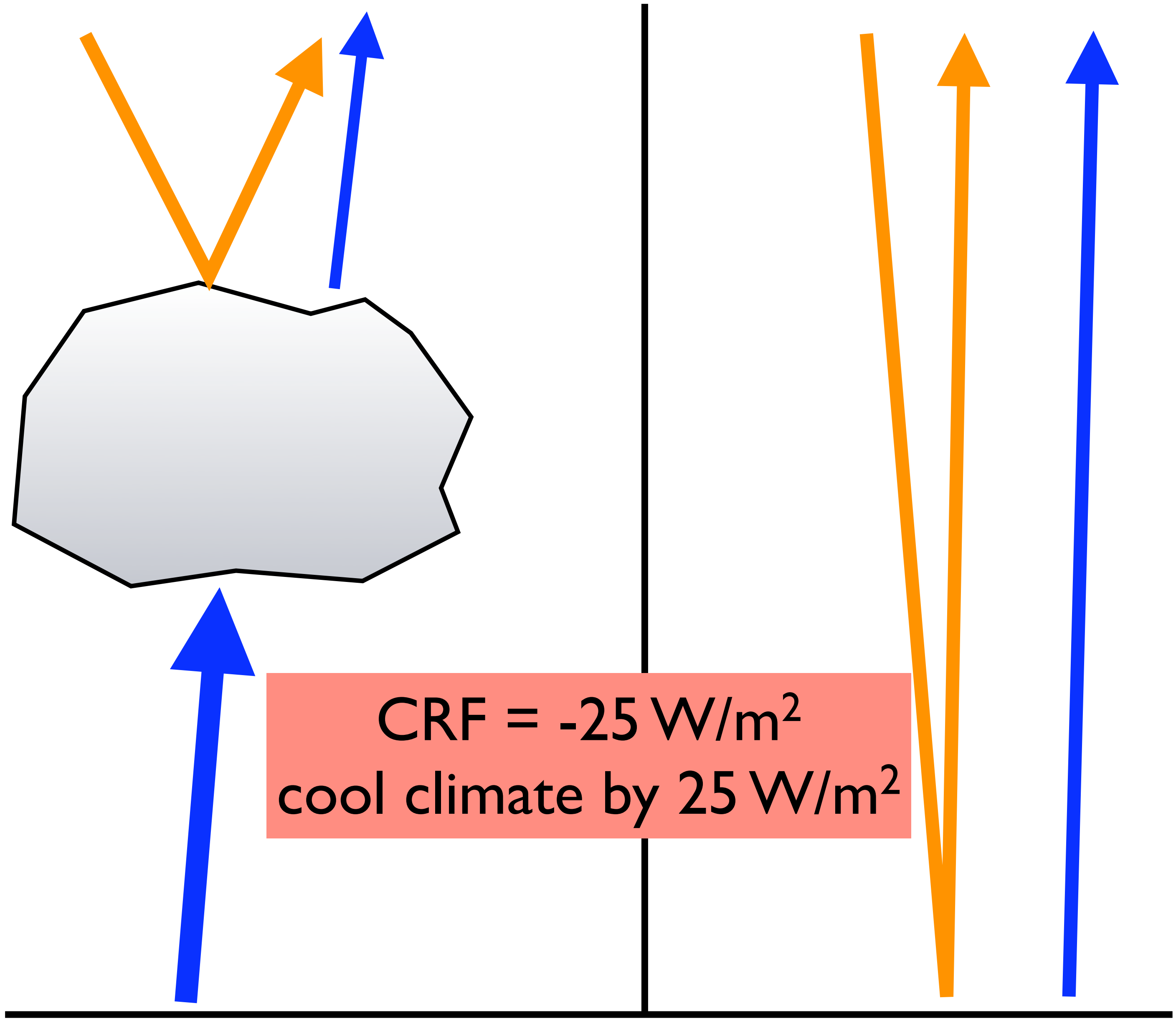
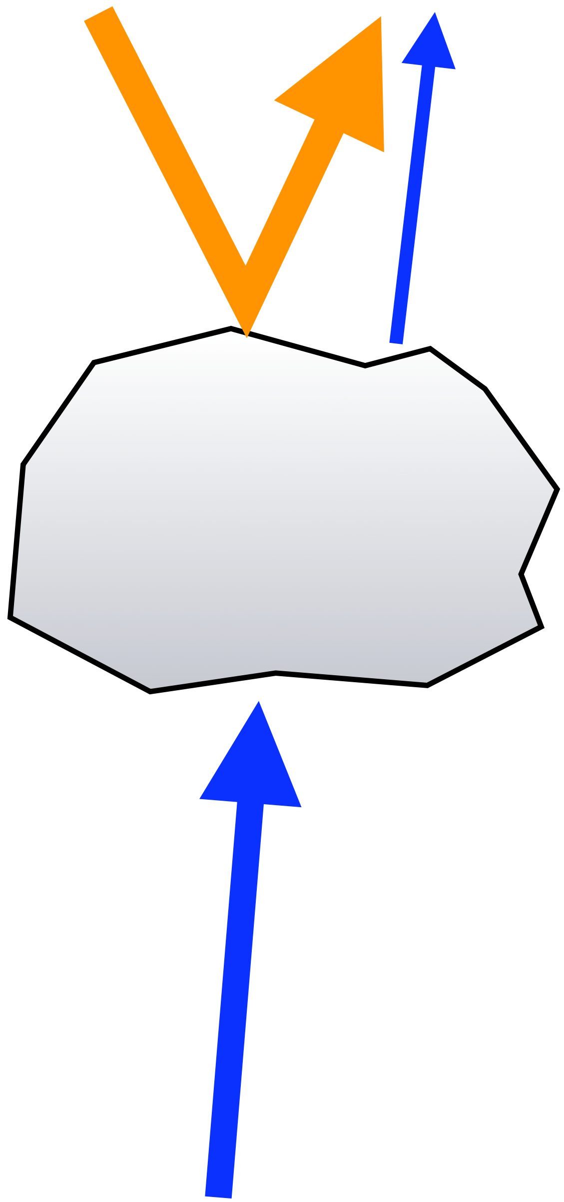
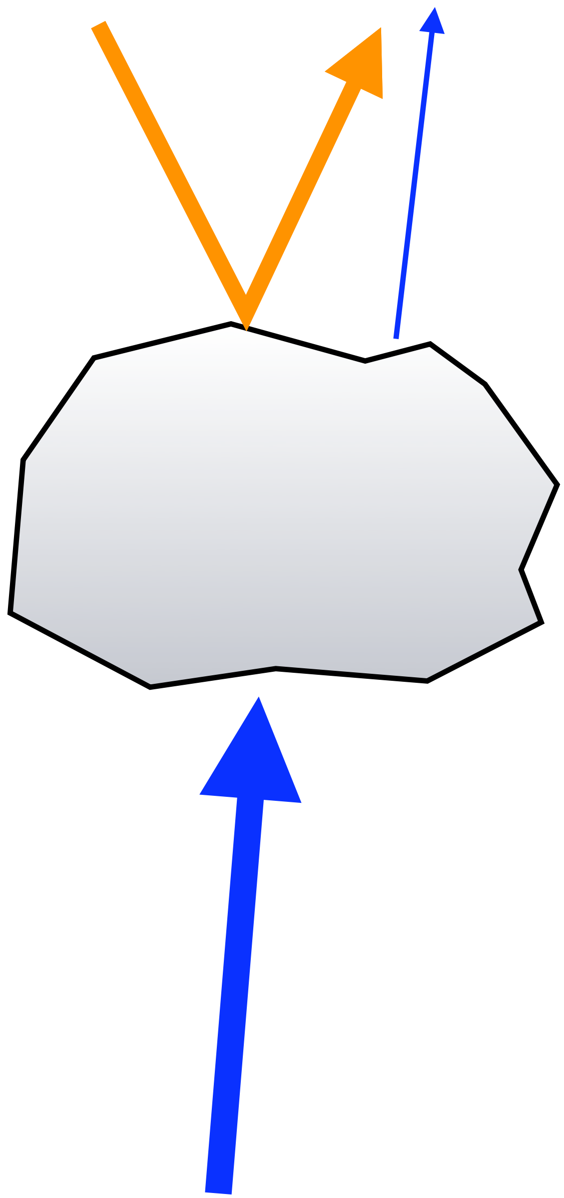




clouds cool more



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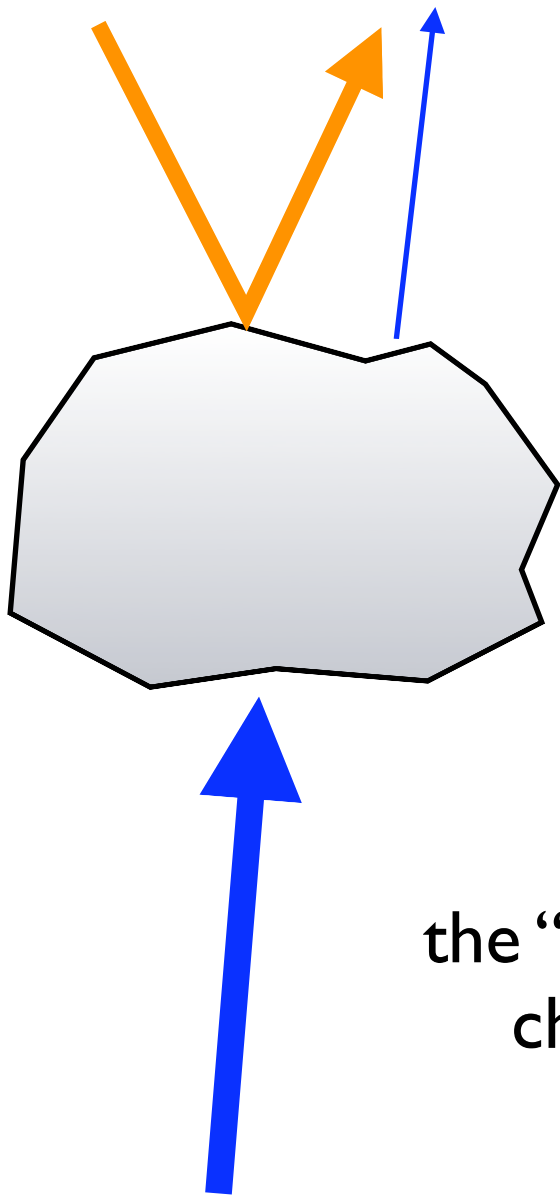


the “cloud feedback” is the
change in CRF as the
climate varies

Does the Earth Have an Adaptive Infrared Iris?

Richard S. Lindzen,* Ming-Dah Chou,+ and Arthur Y. Hou+

ABSTRACT

Observations and analyses of water vapor and clouds in the Tropics over the past decade show that the boundary between regions of high and low free-tropospheric relative humidity is sharp, and that upper-level cirrus and high free-tropospheric relative humidity tend to coincide. Most current studies of atmospheric climate feedbacks have focused on such quantities as clear sky humidity, average humidity, or differences between regions of high and low humidity, but the data suggest that another possible feedback might consist of changes in the relative areas of high and low humidity

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L15707, doi:10.1029/2007GL0296

Cloud and radiation budget changes associated with tropical intraseasonal oscillations

Roy W. Spencer,[1] William D. Braswell,[1] John R. Christy,[1] and Justin Hnilo[2]

Received 15 February 2007; revised 30 March 2007; accepted 16 July 2007; published 9 August 2007.

[1] We explore the daily evolution of tropical intraseasonal oscillations in satellite-observed tropospheric temperature, precipitation, radiative fluxes, and cloud properties. The warm/rainy phase of a composited average of fifteen oscillations is accompanied by a net reduction in radiative input into the ocean-atmosphere system, with longwave heating anomalies transitioning to longwave cooling during the rainy phase. The increase in longwave cooling is traced to decreasing coverage by ice clouds, potentially supporting Lindzen's "infrared iris" hypothesis of climate stabilization. These observations should be considered in the testing of cloud parameterizations in climate models, which remain sources of substantial uncertainty in global warming prediction. **Citation:** Spencer, R. W., W. D. Braswell, J. R. Christy, and J. Hnilo (2007), Cloud and radiation budget changes associated with tropical intraseasonal oscillations, *Geophys. Res. Lett.*, *34*, L15707, doi:10.1029/2007GL029698.

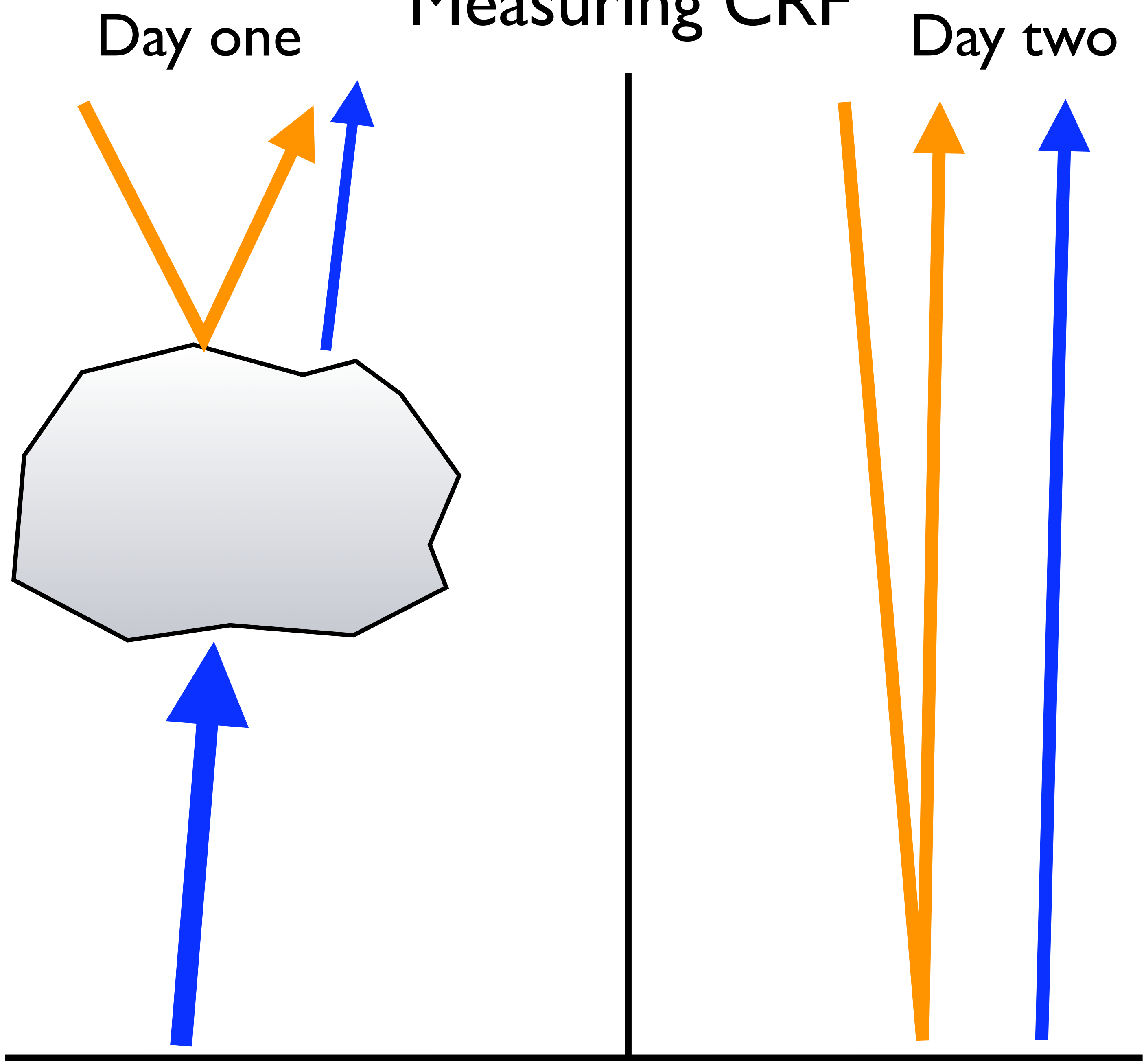
perature, etc., which can then b
metrics diagnosed from GCMs.

[5] Here we address the obser
ommendation by analyzing the d
composite of fifteen tropical i
(ISOs) in a variety of satellite-m
most investigations of these even
expression over the tropical west
al., 2004], we will instead anal
oceanic averages in an attempt
ascending and descending branc
vective circulations and hopefully
effect on the tropical atmosphere.

2. Data and Analysis Meth

[6] Tropical (20°N to 20°S la
covering the period 1 March 20

Measuring CRF



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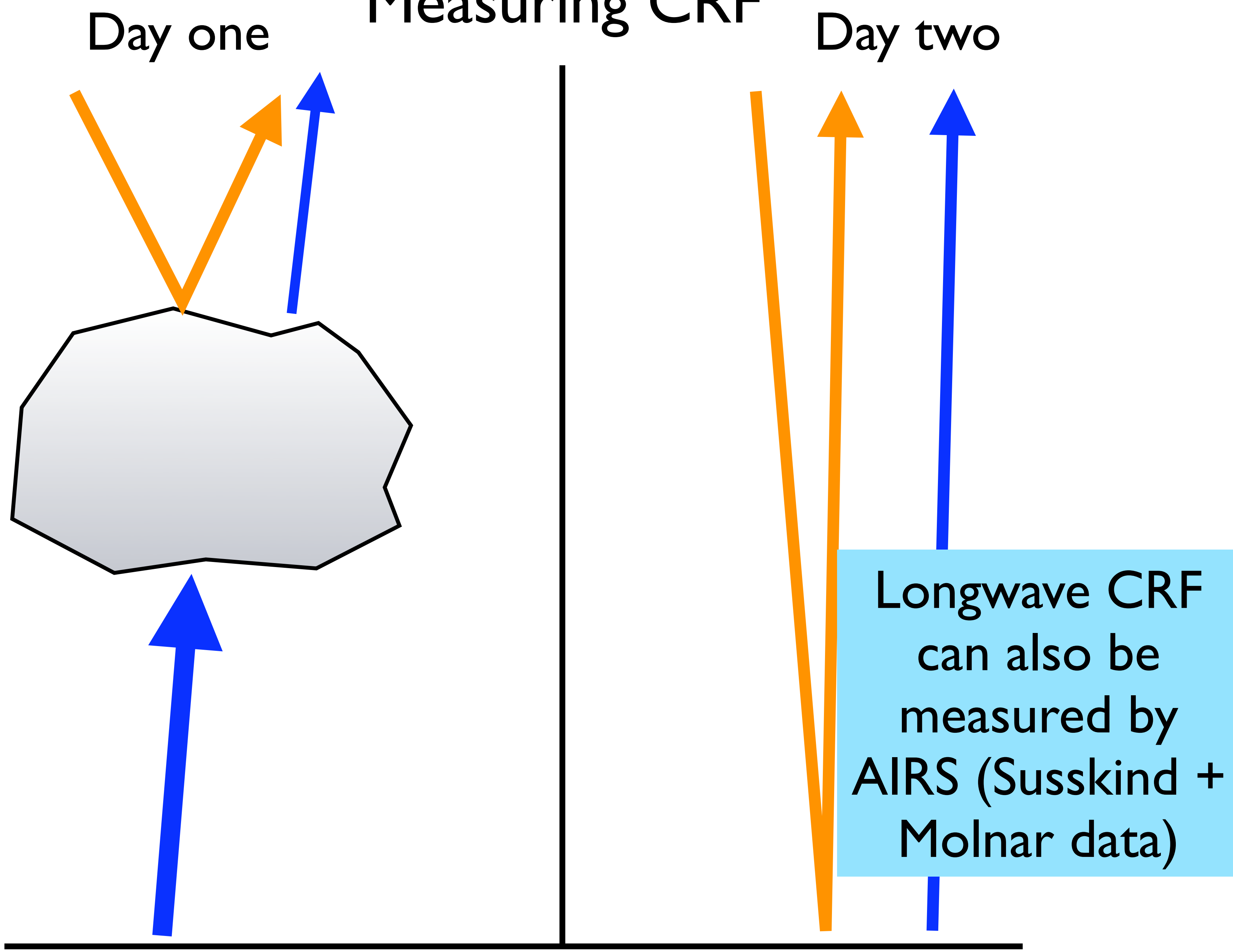


How to measure cloud feedback

- Select your climate variation
- Measure variation in cloud radiative forcing
  - e.g., CRF(El Nino)-CRF(La Nina)
  - $(CRF_{LW}+CRF_{SW})_1-(CRF_{LW}+CRF_{SW})_2 \approx 1\ W/m^2$
  - other terms $\approx \pm 100\ W/m^2$
- Regress vs. surface T variations

20°N-20°S

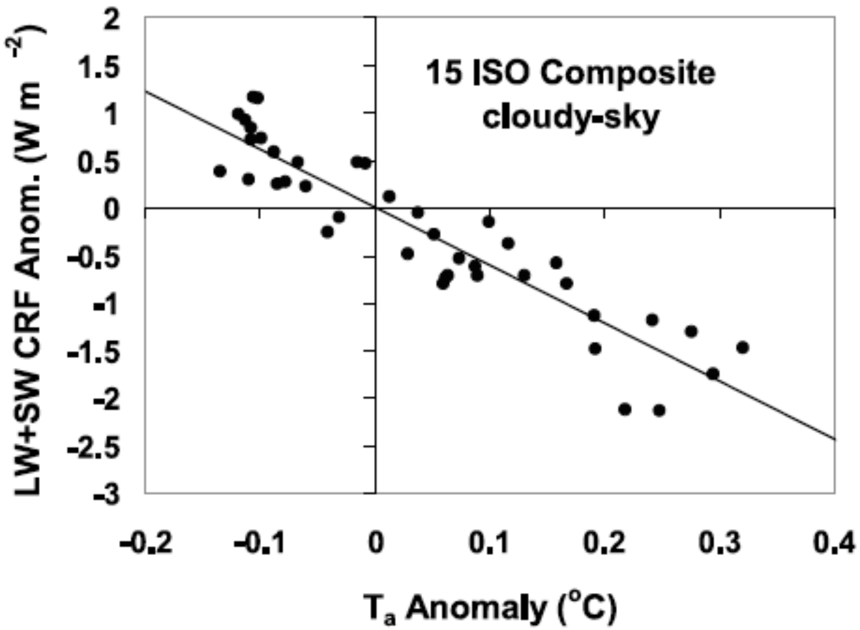
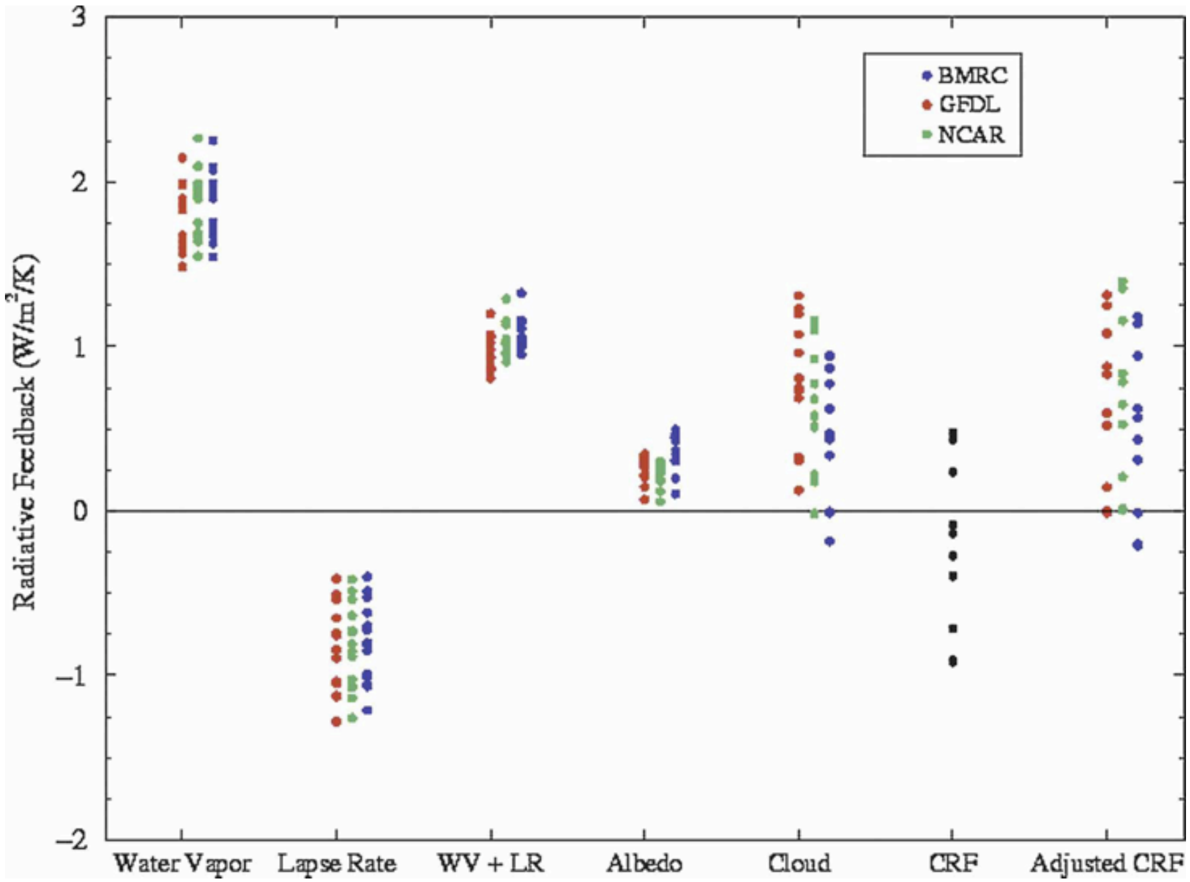


Figure 4. The sum of SW and LW cloud radiative forcings (CRF) versus tropospheric temperature for the 15-ISO composite, which represents about 30% of the six-year data record.

Spencer et al., 2008

How to measure cloud feedback

- Select your climate variation
- Measure variation in cloud radiative forcing over the climate variation
- Regress vs. Ts
- Adjust for changes in q, T (Soden et al., 2004)



Soden et al., 2008

How to measure cloud feedback

- Select your climate variation
- Measure variation in cloud radiative forcing over the climate variation
- Regress vs. Ts
- Adjust for changes in q, T (Soden et al., 2004)
- For a global average, this is quite hard

Summarize cloud feedback

- Main source of uncertainty in climate predictions
- If the mainstream view of climate change is wrong, this is where it will go wrong
- Lots of analysis of models, but little analysis of observations
- Observational analysis of cloud feedback in response to short-term climate fluctuations

Summarize water vapor feedback

- Overall, this feedback is strongly positive for all climate variations
- As the climate warms, tropical UT detrainment temperature increases
- No credible theory for negative feedback
- WV+LR feedback is better constrained
- to do: Better theoretical and (to the extent possible) observational work on how the feedback varies for different variations
- to do : More analysis on how UT humidity is regulated

Feedback

$$\lambda = \sum_{x,y,z} \frac{\partial R}{\partial q(x,y,z)} \frac{\Delta q(x,y,z)}{\Delta T_s}$$

Use pre-computed kernels from Soden et al., 2008

Measured change between climate states