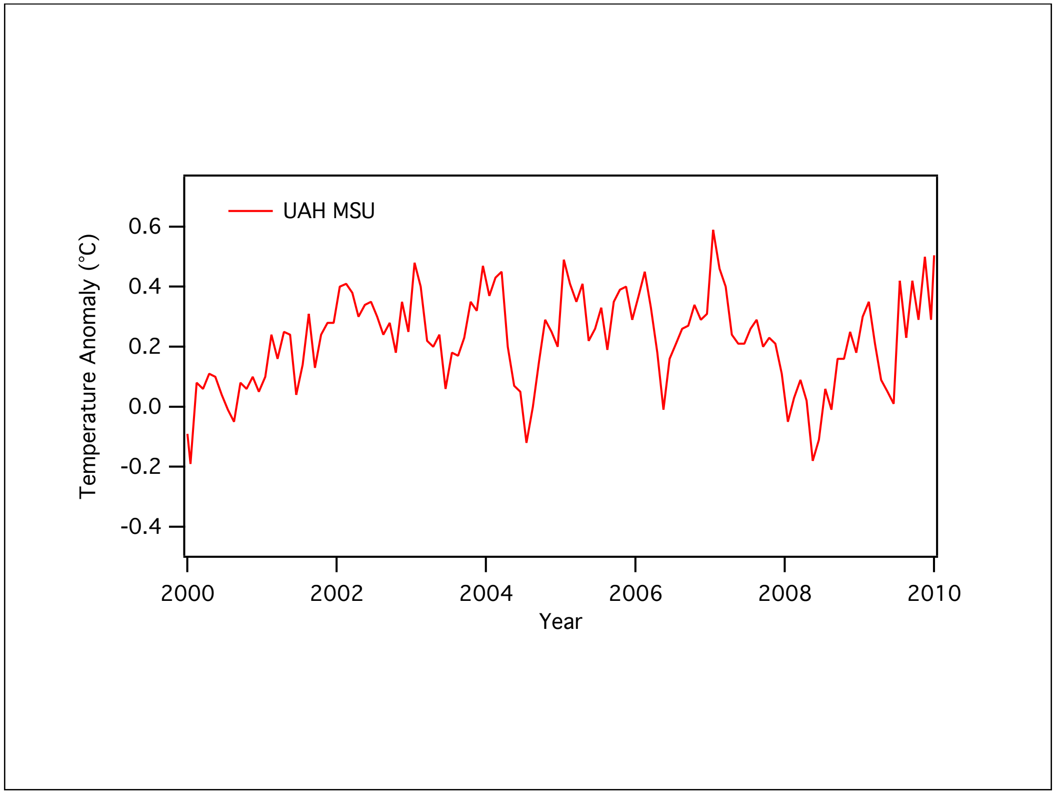
Measuring the cloud feedback in FlashFlux data, 2000-2009

A. E. Dessler
Department of Atmospheric Sciences
Texas A&M University

Clouds do two things, they warm the climate by absorbing upwelling IR and cool the planet by reflecting incoming solar. The net impact of clouds is the difference between these, the solar effect dominates and clouds cool by about 20 W/m2.

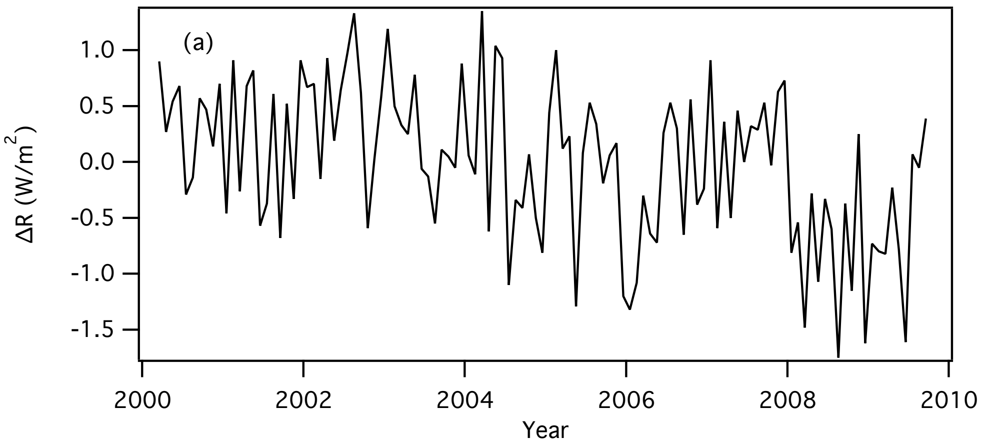
Cloud feedback

- Over the next century, models predict business-as-usual implies about 3°C of warming
- Of this warming, about 2/3rds come from feedbacks
- Water vapor is well understood
- The cloud feedback is the major remaining uncertainty
- few (no?) estimates from data on the size of the global feedback



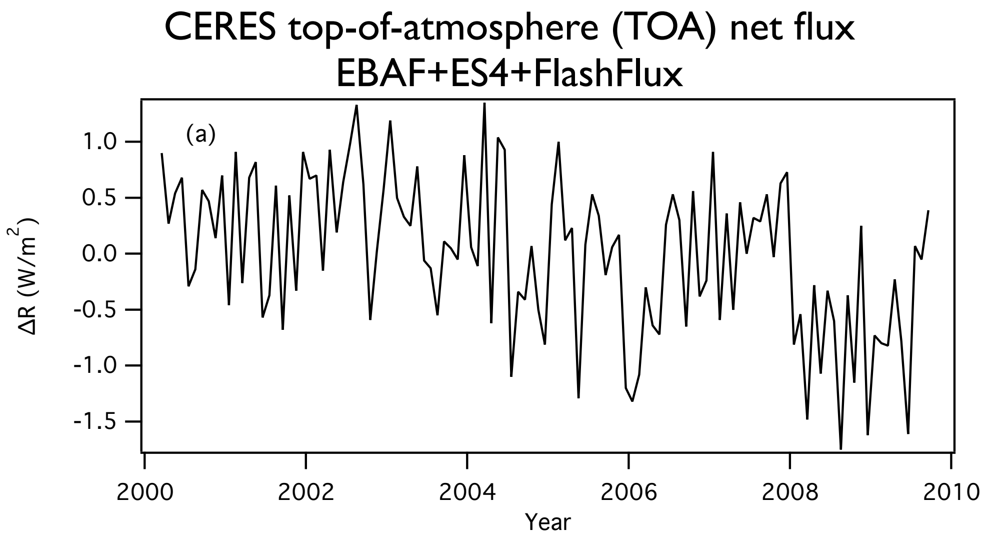
UAH MSU
Temperature Anomaly (°C)
0.6
0.4
0.2
0.0
-0.2
-0.4
2000
2002
2004
2006
2008
2010
Year

CERES top-of-atmosphere (TOA) net flux
EBAF+ES4+FlashFlux



Thanks to Paul Stackhouse, Tak Wong, Dave Kratz et al.

all fluxes in this analysis are upward positive



$$\Delta R = \Delta R_T + \Delta R_q + \Delta R_{alb} + \Delta R_{cloud} + \Delta F$$

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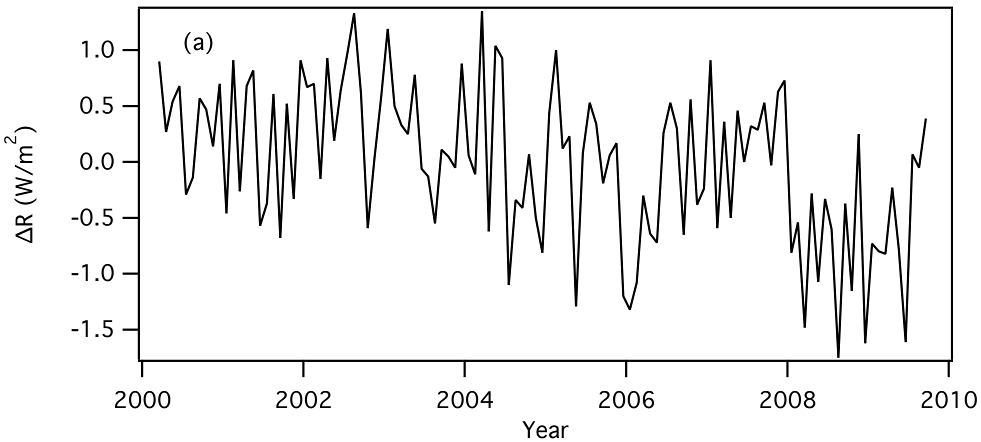

1. Extract the change that is due just to clouds, ΔR_{cloud}

2. Calculate $\lambda_{cloud} = \dfrac{\Delta R_{cloud}}{\Delta T_s}$

Partial Radiative Perturbation

$T_{s\text{-}a}$	$T_{s\text{-}b}$
q_a	q_b
$T_{atm\text{-}a}$	$T_{atm\text{-}b}$
ice_a	ice_b
...	...

Imagine that you have two climate states. They could be before and after a volcano, La Nina and El Nino, 1900 vs. 2100, etc. Each climate state is made up of a set of variables that define the climate: surface T, atmospheric q, atmospheric T, ice, and many others

ΔR = change in global average TOA flux due to Δq

ΔT_s = change in global avg. surface temperature change ($T_{s\text{-}b}$-$T_{s\text{-}a}$) associated with Δq

TOA net flux R_a

$T_{s\text{-}a}$

q_a

$T_{atm\text{-}a}$

ice_a

new TOA net flux R_b

$T_{s\text{-}b}$

q_b

$T_{atm\text{-}b}$

ice_b

Wetherald and Manabe, 1988?
Colman, 2003; Forster and Collins, 2004;
Soden and Held, 2006

dR is the contribution of q to the changing TOA net flux

- start with cloud radiative forcing (ΔCRF); CRF = -($\Delta R_{clear\text{-}sky}$ - $\Delta R_{all\text{-}sky}$)
- ΔCRF $\neq$ ΔR_{cloud}
- ΔCRF can also be affected by changes in T, q, albedo, radiative forcing
- Soden et al. [2008] describes how to adjust ΔCRF to get ΔR_{cloud}

$$\Delta R_{cloud} = dC_{RF} + (K^0{}_T - K_T)dT + (K^0{}_W - K_W)dW + (K^0{}_a - K_a)da + (G^0 - G).$$

$$\Delta R_{cloud} = -\left(\Delta R_{clear-sky} - \Delta R_{all-sky}\right) + (K^0{}_T - K_T)dT + (K^0{}_W - K_W)dW + (K^0{}_a - K_a)da + (G^0 - G).$$

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CERES

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CERES

ECMWF

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CERES

GISS

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$$+ \boxed{(K^0{}_a - K_a)}\boxed{da} + \boxed{(G^0 - G)}.$$

CERES

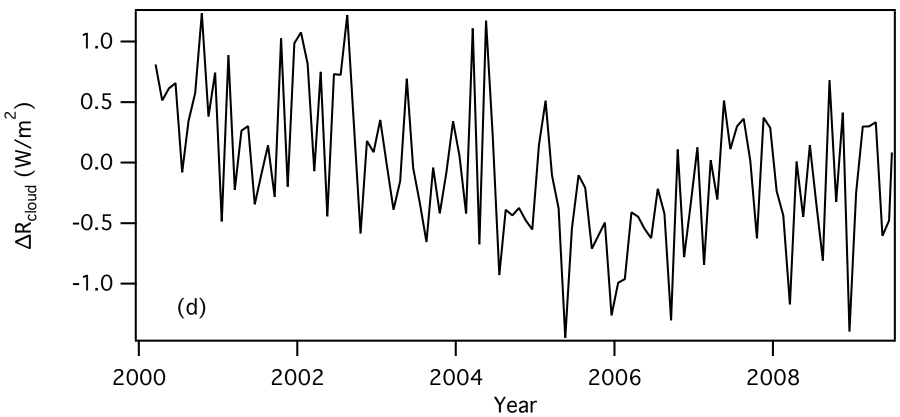
GISS

ECMWF

Soden et al.

Using MERRA has no effect on results

ΔR_{cloud}



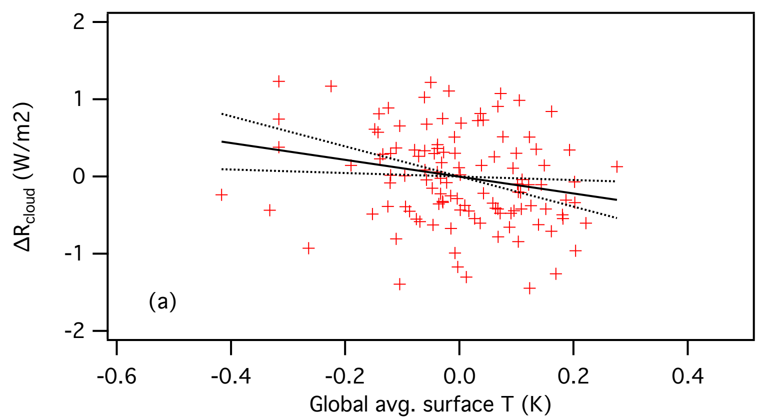
$$\lambda_{cloud} = \frac{\Delta R_{cloud}}{\Delta T_s}$$

λ_{cloud} = -1.09±0.86

negative slope = positive feedback

$$\lambda_{cloud} = \frac{\Delta R_{cloud}}{\Delta T_s}$$

Monthly average

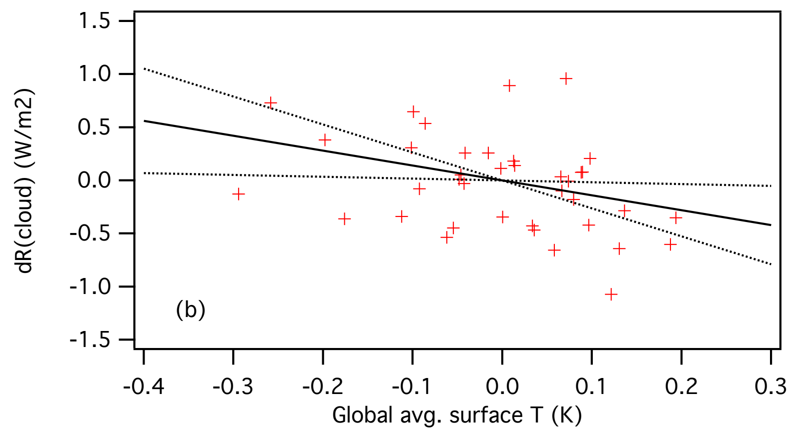


λ_{cloud} = -1.40±1.23

negative slope = positive feedback

$$\lambda_{cloud} = \frac{\Delta R_{cloud}}{\Delta T_s}$$

Seasonal average



- The cloud feedback in these data is positive in the CERES+ECWMF data
(also CERES+MERRA)
- Magnitude is somewhat uncertain:
-1 ± 1 W/m^2/K
- Due to non-Ts related scatter
- There is no evidence of a big negative cloud feedback (viz. Spencer or Lindzen)

Caveats

- feedbacks depend on the climate variation
  - e.g., water vapor feedback
    (e.g., Dessler and Wong, *J. Climate*, 2009)
- there is no single "cloud feedback"
- what we've measured here is the cloud feedback in response to short-term fluctuations
- if we want to test models, we need to calculate the short-term cloud feedback in models

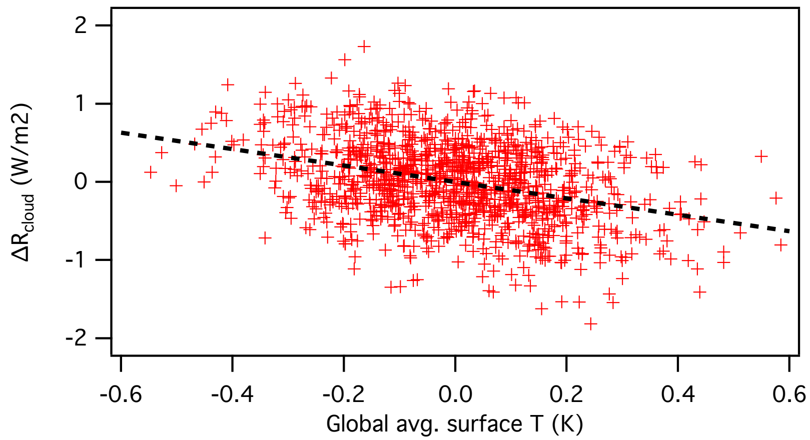
Estimate the short-term feedback in models

- Apply the same analysis to climate models
- Pre-industrial + present-day control runs
- Obtained from the PCMDI AR/4 archive

IPSL

traditional LS $\lambda_{cloud} = -1.05 \pm 0.16$

seasonal avg. $\lambda_{cloud} = -1.16 \pm 0.22$



monthly averaged data covering 100 years

IPSL

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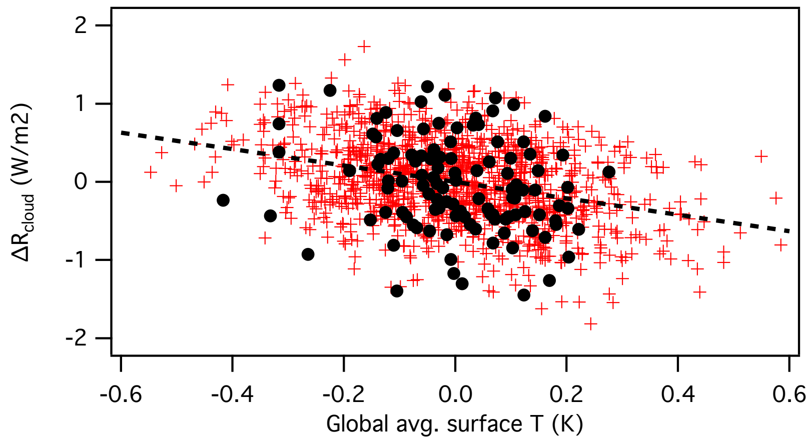
seasonal avg. λ_{cloud} = -1.16±0.22



model	**Total feedback**	**LW feedback**	**SW feedback**
pcm1	-1.11±0.20	-0.52±0.11	-0.60±0.21
ipsl	-1.05±0.16	-1.17±0.13	0.12±0.14
inmcm3	-0.98±0.18	-0.77±0.10	-0.21±0.19
ukmo	-0.88±0.31	-0.57±0.15	-0.31±0.35
ccsm	-0.52±0.53	-0.04±0.23	-0.48±0.51
mpi	-0.49±0.27	-1.07±0.12	0.58±0.27
ecmwf+ceres	-1.09±0.82	-0.86±0.42	-0.22±
merra+ceres	-1.08±0.89	-0.73±0.53	-0.35±

confidence intervals are 2σ

Agreement on statistically significant positive feedback

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confidence intervals are 2σ

No evidence the models *overestimate* the feedback

As a group the models do a good job

Additional info in the LW & SW feedbacks

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confidence intervals are 2σ

LW feedbacks are all positive, which makes sense

Overall, some models do better than others

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inmcm3	-0.98±0.18	-0.77±0.10	-0.21±0.19	0.35
ukmo	-0.88±0.31	-0.57±0.15	-0.31±0.35	1.08
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confidence intervals are 2σ

Cannot separate high-sensitivity models from low

Conclusions

- The cloud feedback in response to climate variations in the last 10 years has been robustly positive
- Magnitude is uncertain because of the scatter + relatively short time series
- Climate models have a similar cloud feedback for short-term fluctuations
  - no evidence that models *overestimate* the cloud feedback
- This is not a test of the long-term cloud feedback, this
  - But it should build confidence that climate models are doing a good job

Have we measured a feedback?

- It makes sense if one thinks of cause and effect
- This is how feedbacks are traditionally defined
- The comparison with models is apples-to-apples

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An analysis of the dependence of clear-sky top-of-atmosphere outgoing longwave radiation on atmospheric temperature and water vapor

A. E. Dessler,[1] P. Yang,[1] J. Lee,[1] J. Solbrig,[1] Z. Zhang,[1] and K. Minschwaner[2]

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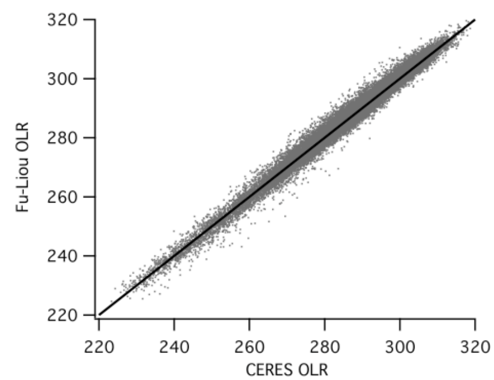

Figure 1. Scatterplot of 134,862 measured values of OLR against OLR calculated by the Fu-Liou model, both in units of W/m^2. The solid line is the one-to-one line.

$$\Delta T_{sensitivity} = \frac{\Delta RF}{\left(\lambda_T + \lambda_{wv} + \lambda_{ia} + \lambda_{cloud}\right)} = \frac{-4W/m^2}{\left(-1.8 + \lambda_{cloud}\right)}$$

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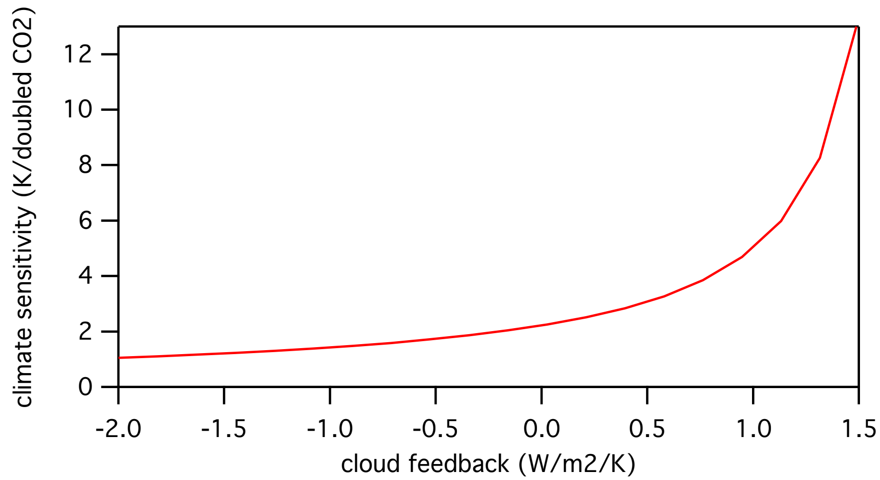

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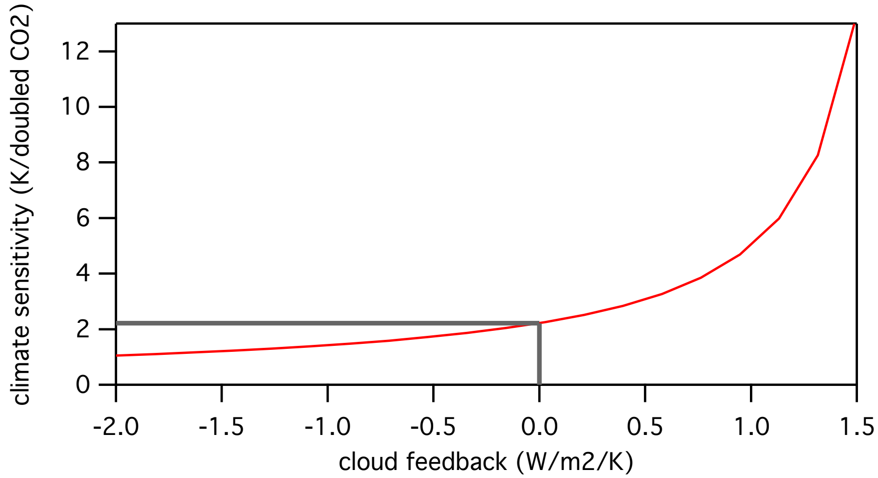

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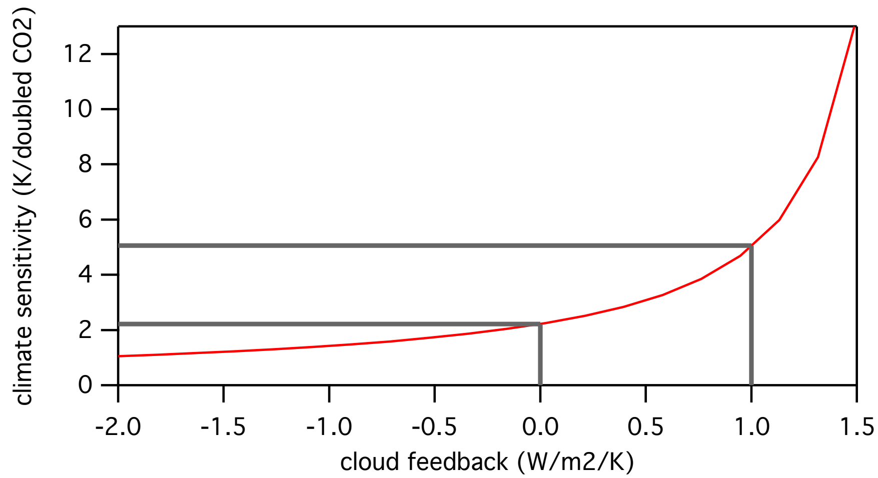
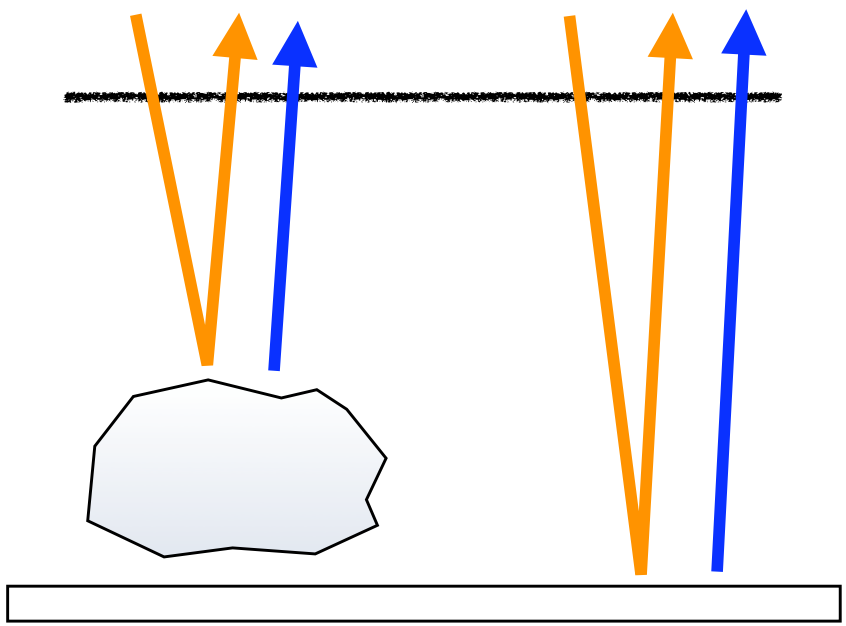


$$CRF = R_{all\text{-}sky} - R_{clear\text{-}sky}$$
$$CRF = 0$$



$$CRF = R_{all\text{-}sky} - R_{clear\text{-}sky}$$

$$CRF \neq 0$$