What we can learn about ECS from short-term climate variations

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$$\Delta R_{total} - \Delta F = + \lambda_{total} \Delta T$$

climate sensitivity

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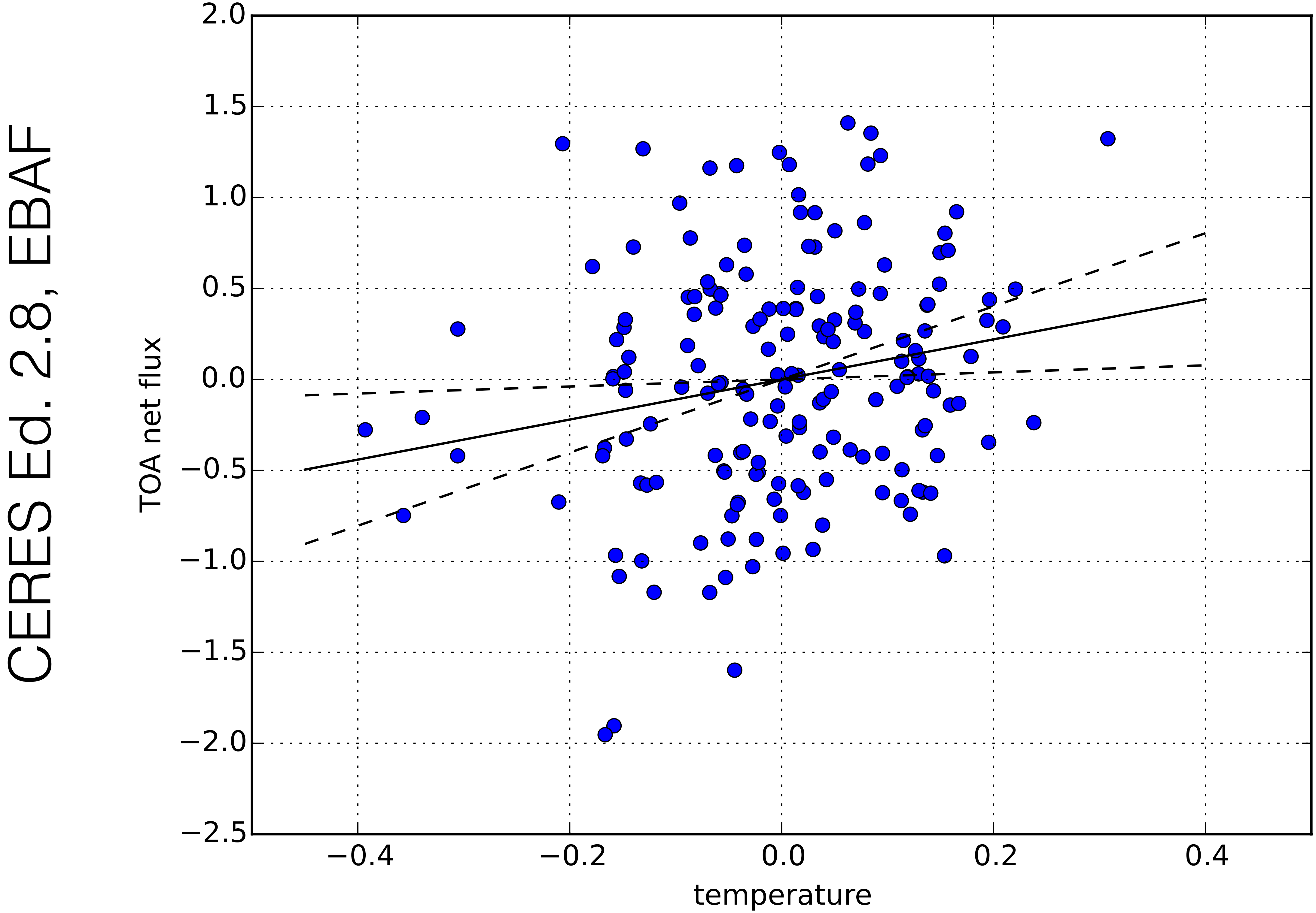
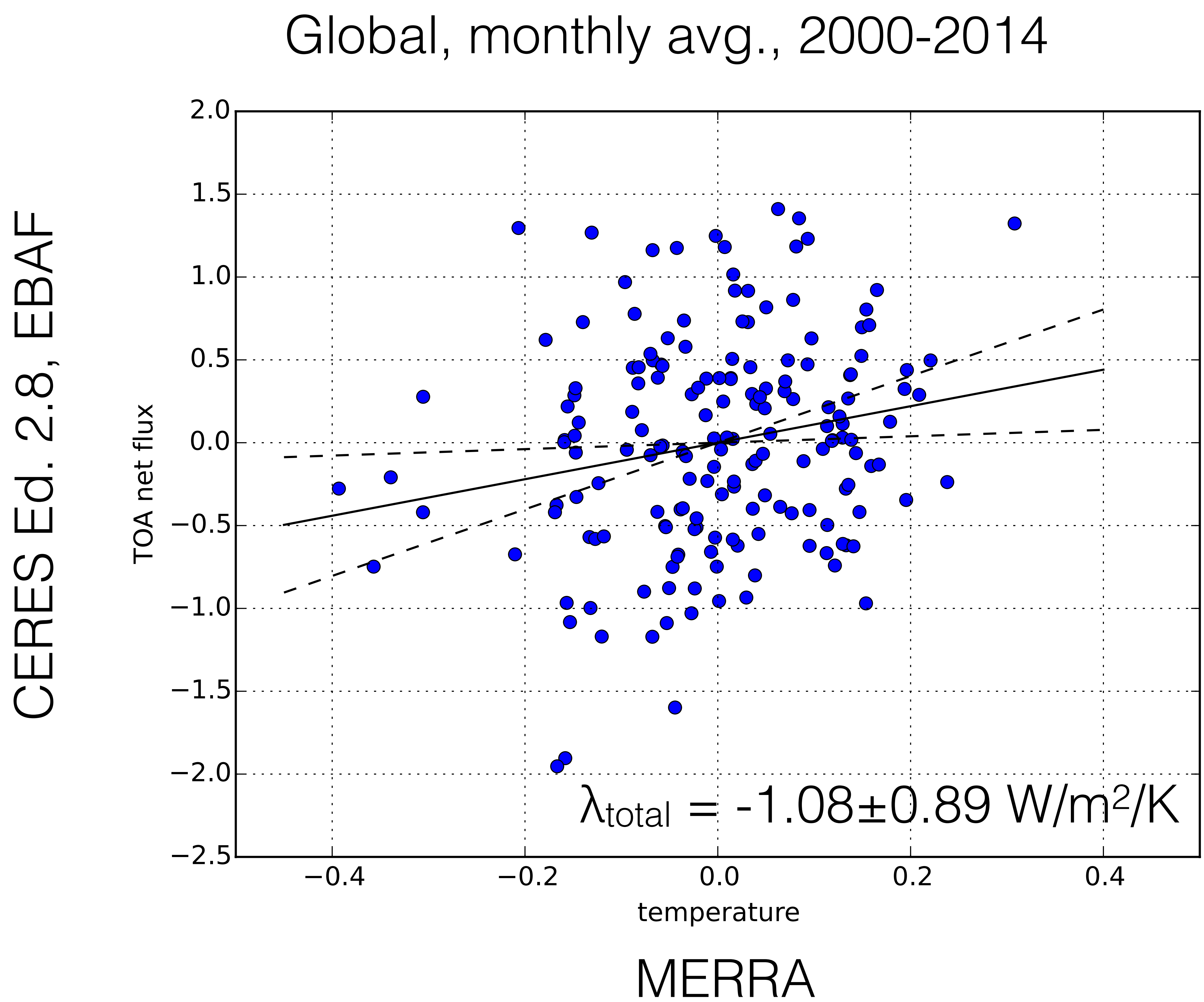
CERES **MERRA**

Global, monthly avg., 2000-2014



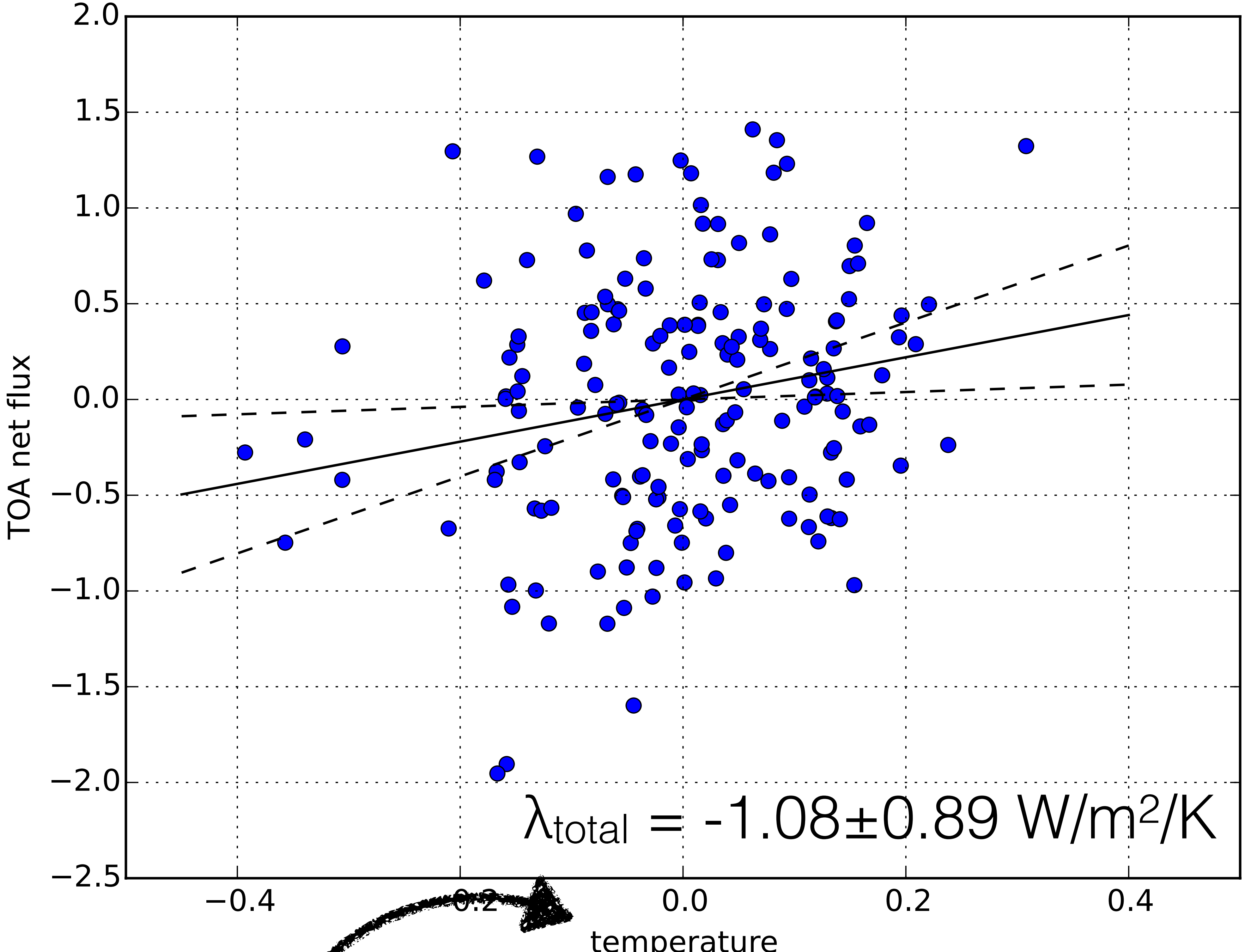
MERRA



Global, monthly avg., 2000-2014
CERES Ed. 2.8, EBAF
TOA net flux
temperature
MERRA
λtotal = -1.08±0.89 W/m2/K
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−0.4
−0.2
0.0
0.2
0.4

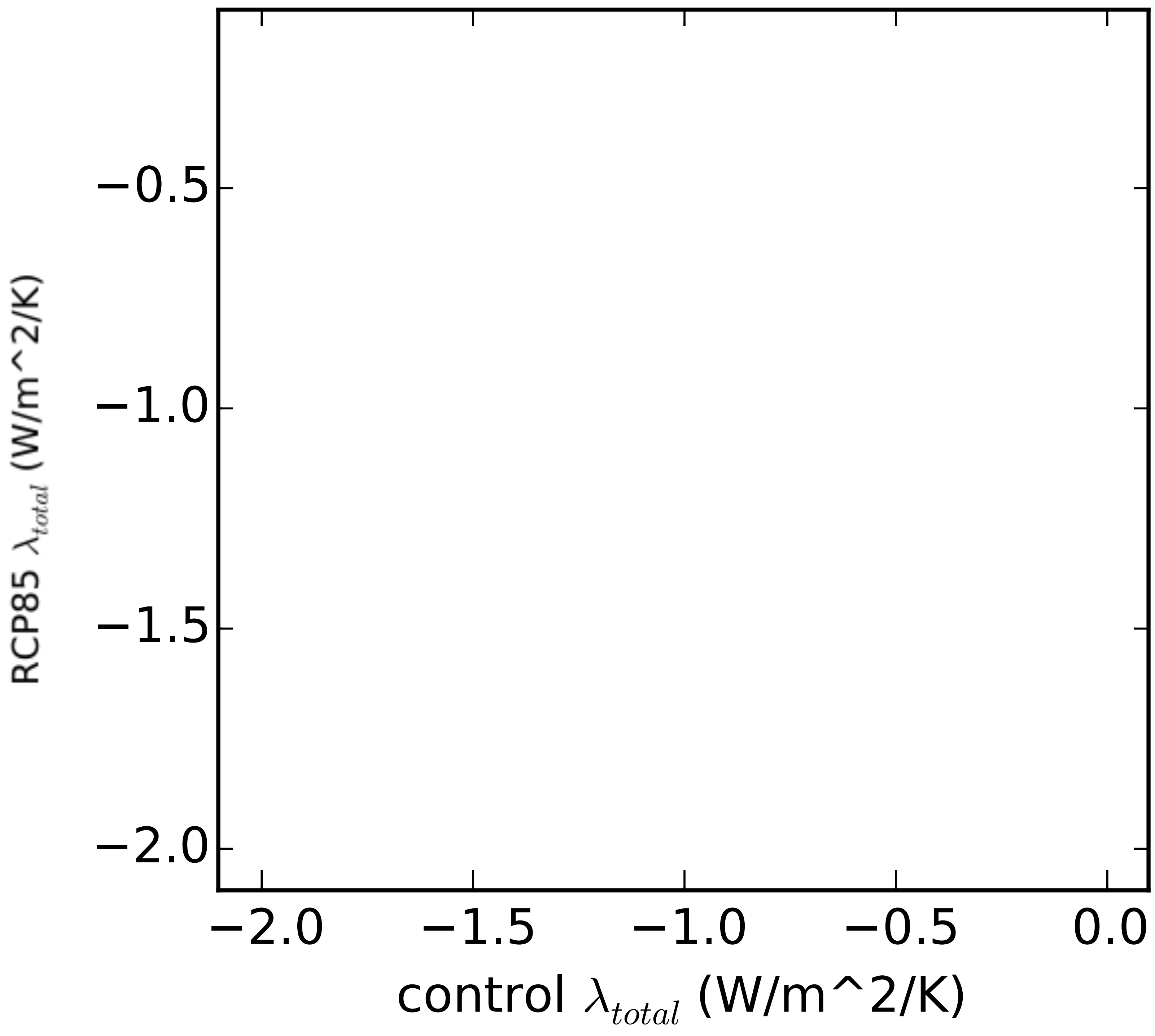
Global, monthly avg., 2000-2014

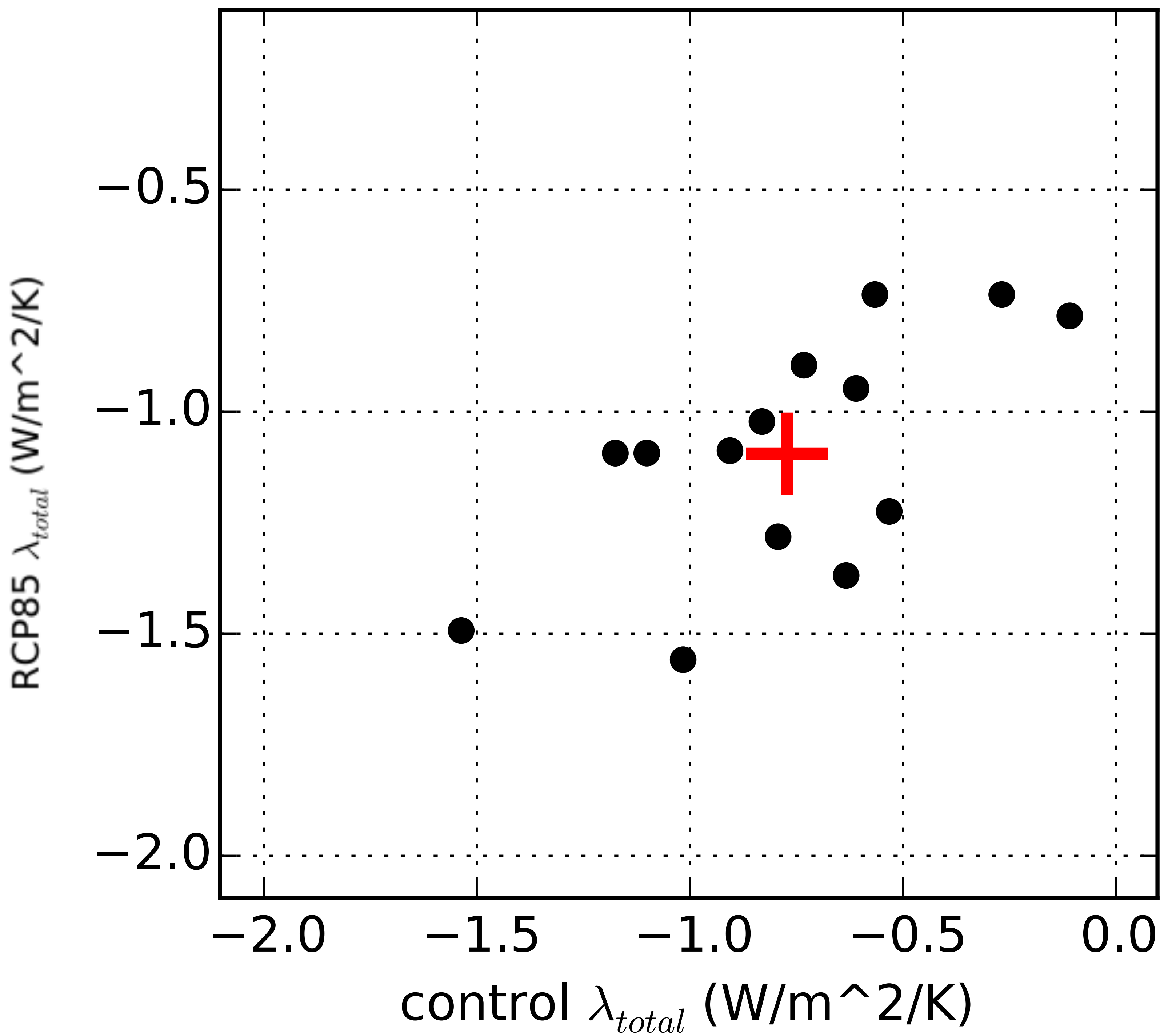
CERES Ed. 2.8, EBAF



RA

due to short-term variations


−0.5
−1.0
−1.5
−2.0
RCP85 λ_{total} (W/m^2/K)
−2.0
−1.5
−1.0
−0.5
0.0
control λ_{total} (W/m^2/K)


−0.5
−1.0
−1.5
−2.0
−2.0
−1.5
−1.0
−0.5
0.0
RCP85 λ_{total} (W/m^2/K)
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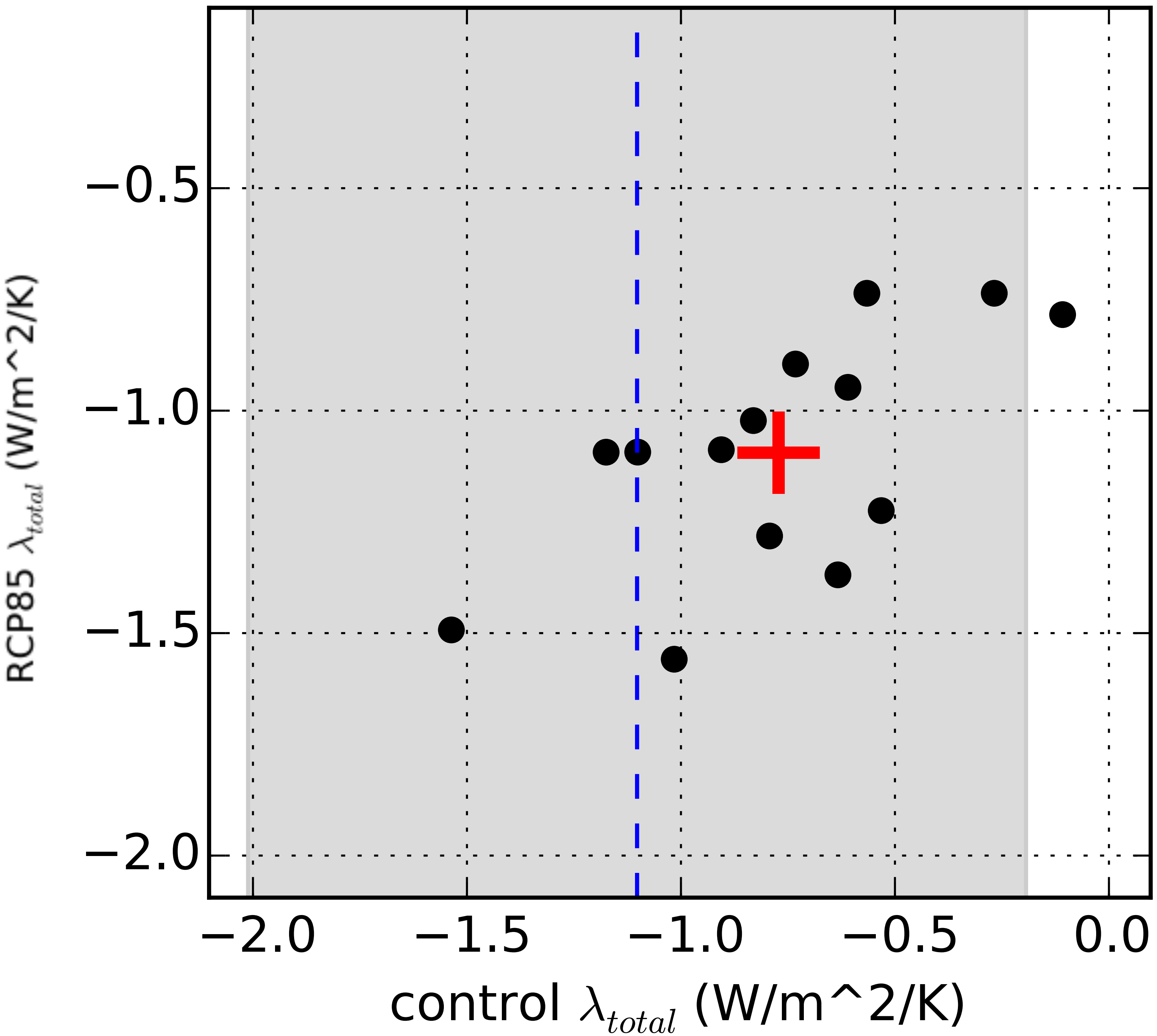

−0.5
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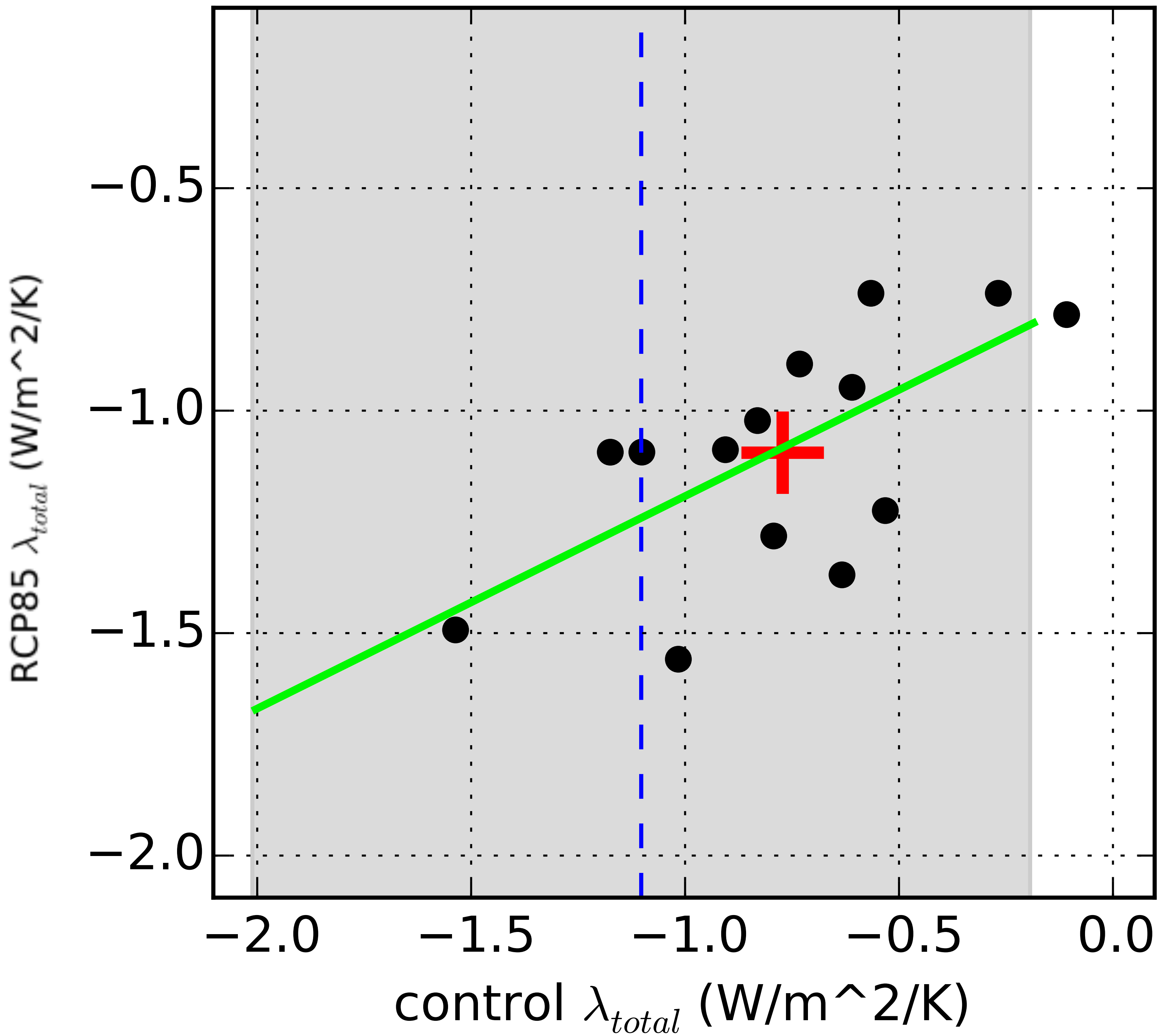

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−2.0
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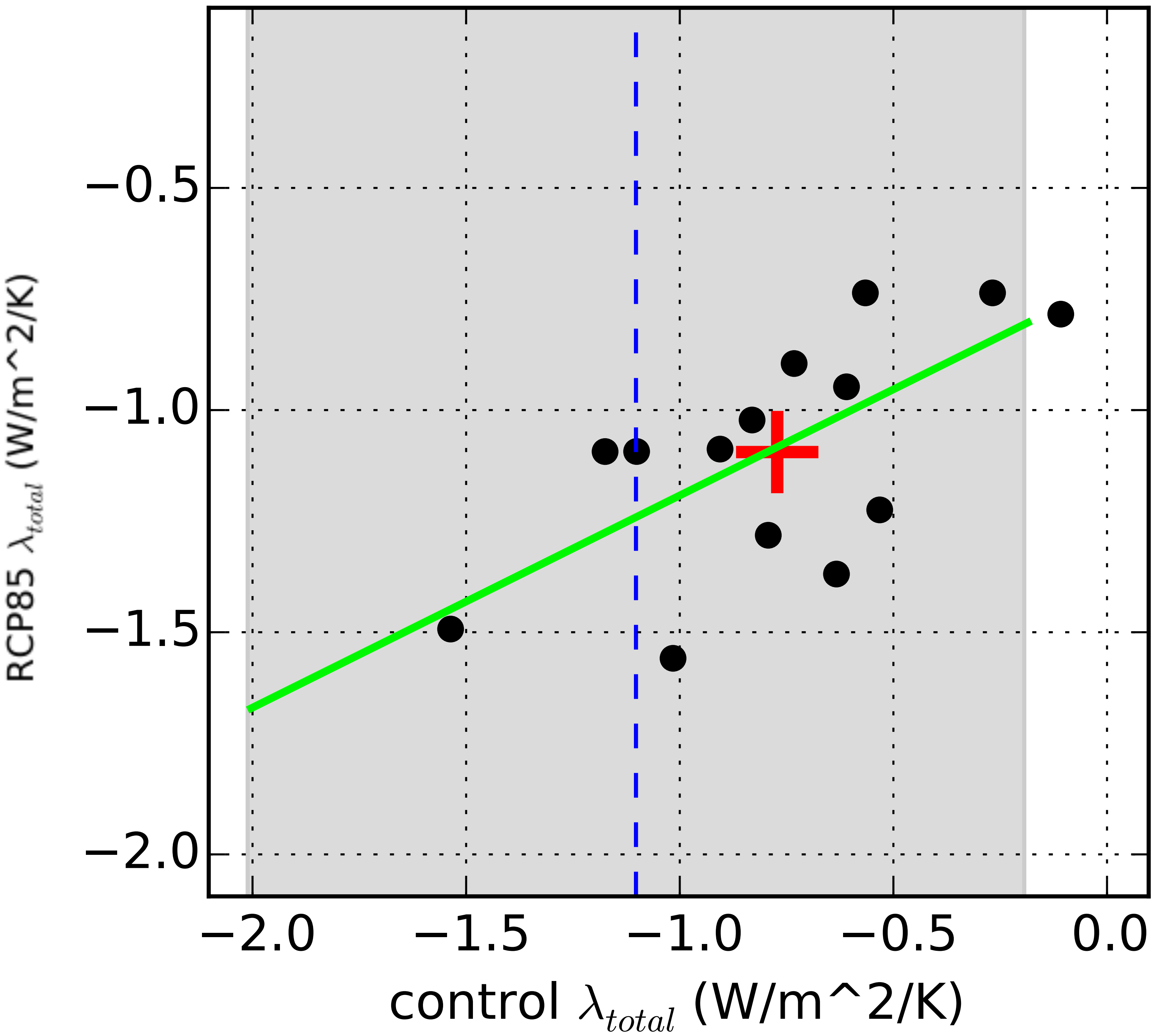
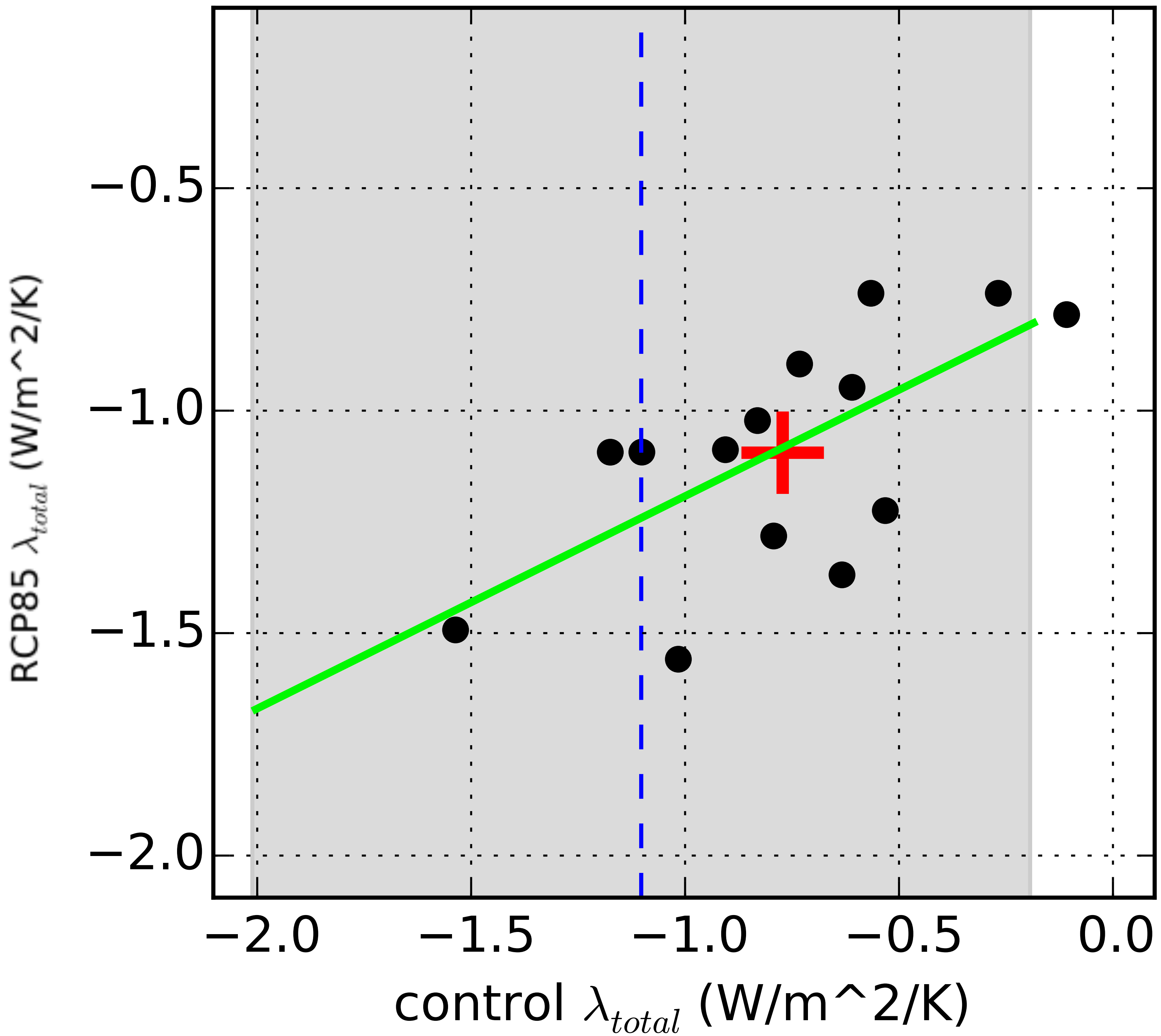
−1.0
−0.5
0.0
control λ_{total} (W/m^2/K)

λ_{total} = -1.23±0.60 W/m²/K



λ_{total} = -1.23±0.60 W/m²/K ECS = 3.0±1.4 K



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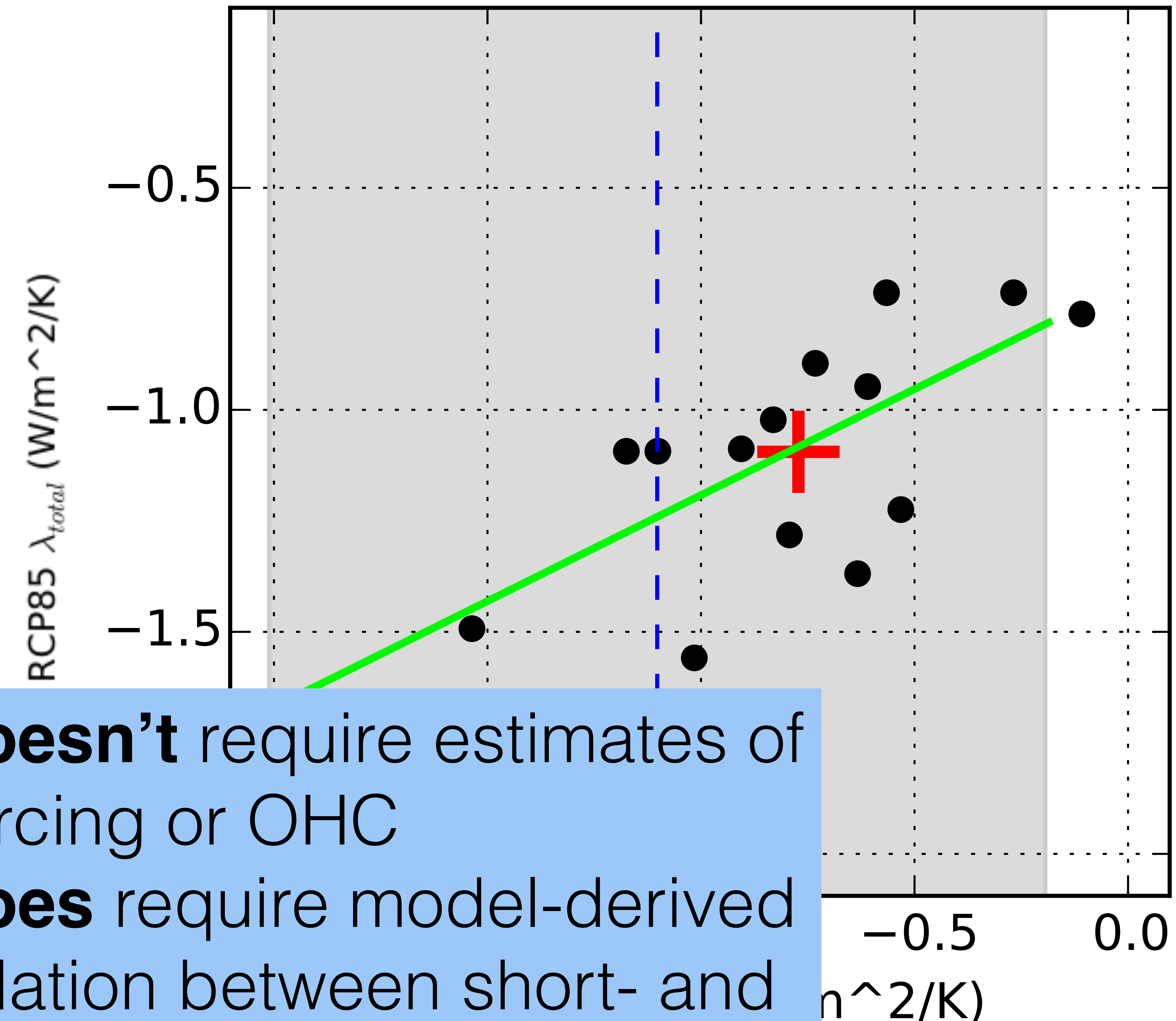

- **doesn't** require estimates of forcing or OHC
- **does** require model-derived relation between short- and long-term λ_{total}

$$\Delta R_{total} = \Delta F + \lambda_{total} \, \Delta T$$

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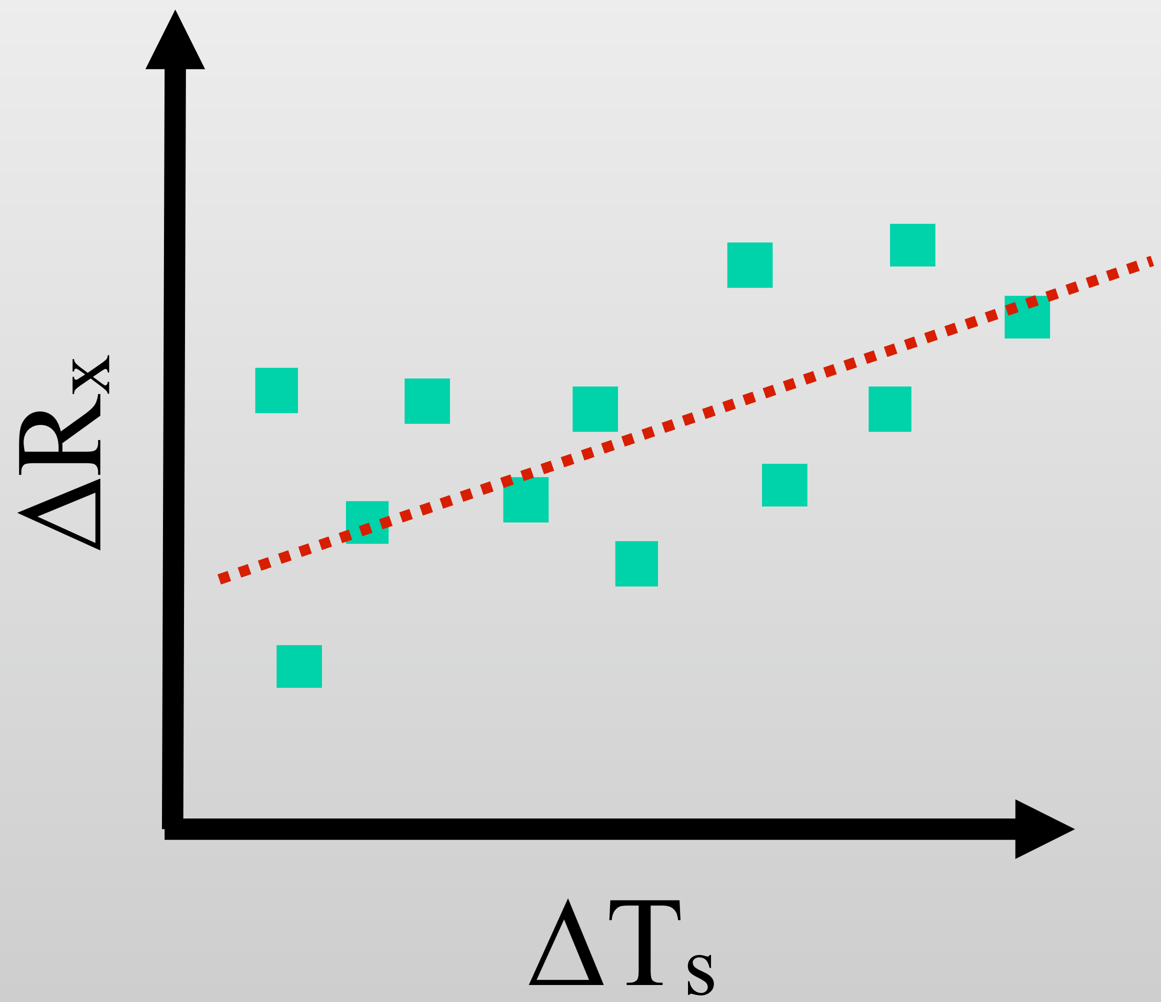
$$\Delta R_{temp} + \Delta R_{wv} + \Delta R_{clouds} + \ldots$$

Estimate ΔR_x using radiative kernels

Regress ΔR_x vs. ΔT_s

x = Planck, lapse rate, cloud, etc.



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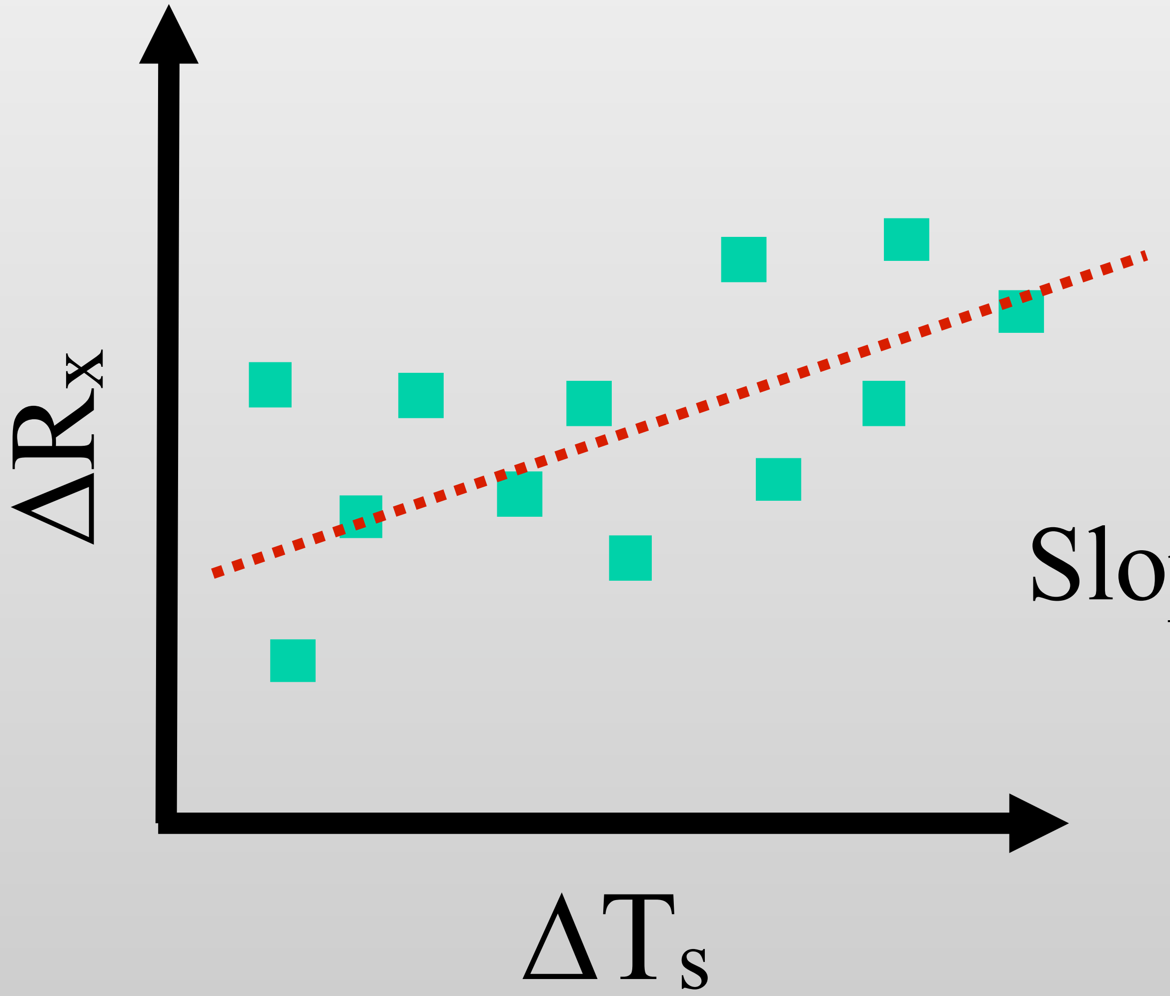

Slope = feedback λ_x
(W/m^2/K)

$$\Delta R_{total} = \Delta F + \lambda_{total}\,\Delta T$$

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Estimate ΔR_x using radiative kernels

$$\lambda_{total} = \lambda_{temp} + \lambda_{wv} + \lambda_{clouds} + \ldots$$

examine λ_{total} budget for in control and RCP8.5 models & obs.

Feedbacks

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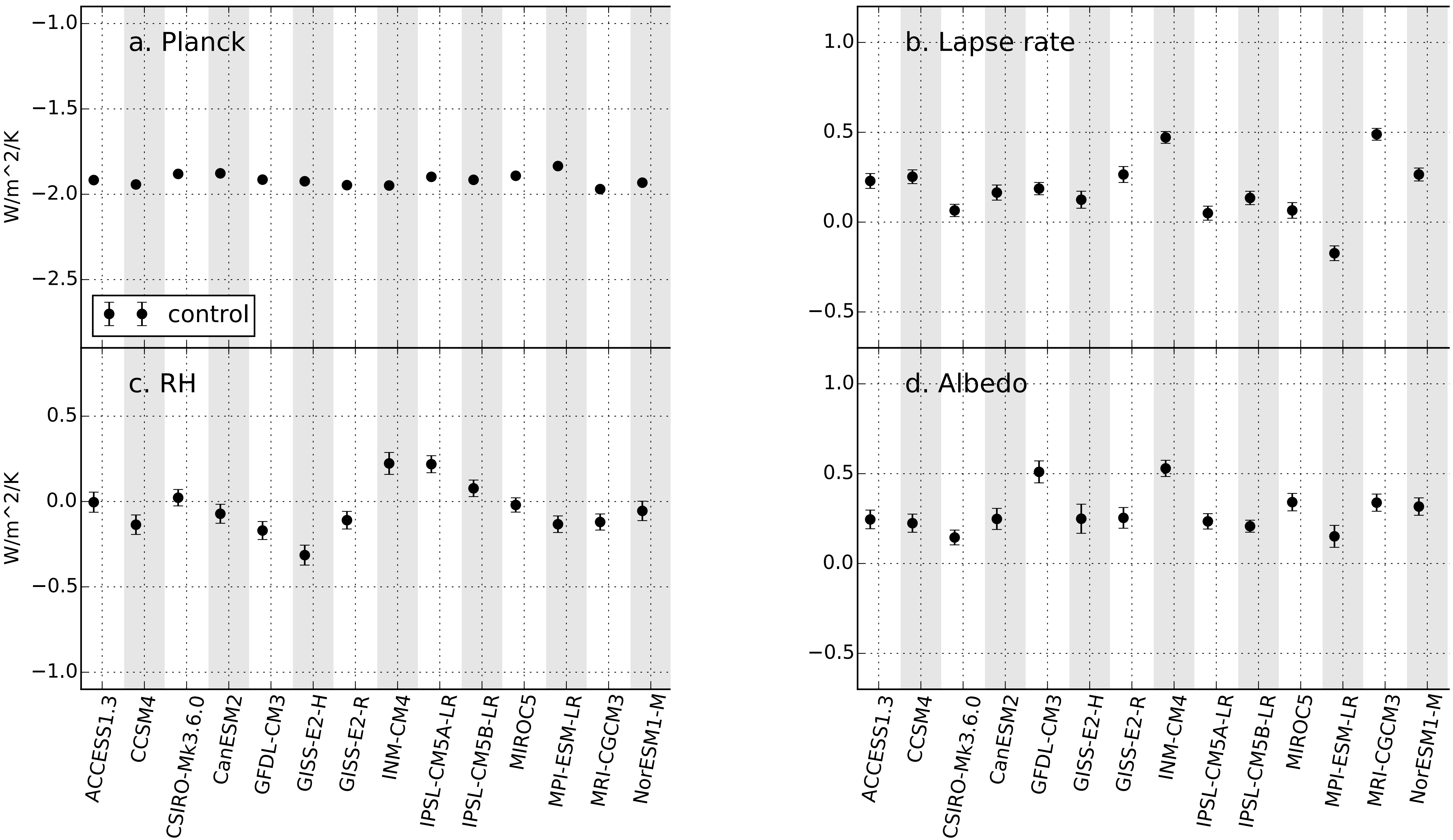
  - Lapse-rate: differential warming of the surface and atmosphere, <u>constant RH</u>
  - ΔRH: change in RH
  - albedo & clouds: change due to changing surface albedo and clouds

(non-cloud) feedbacks from control runs



error bars on models are 95% confidence intervals

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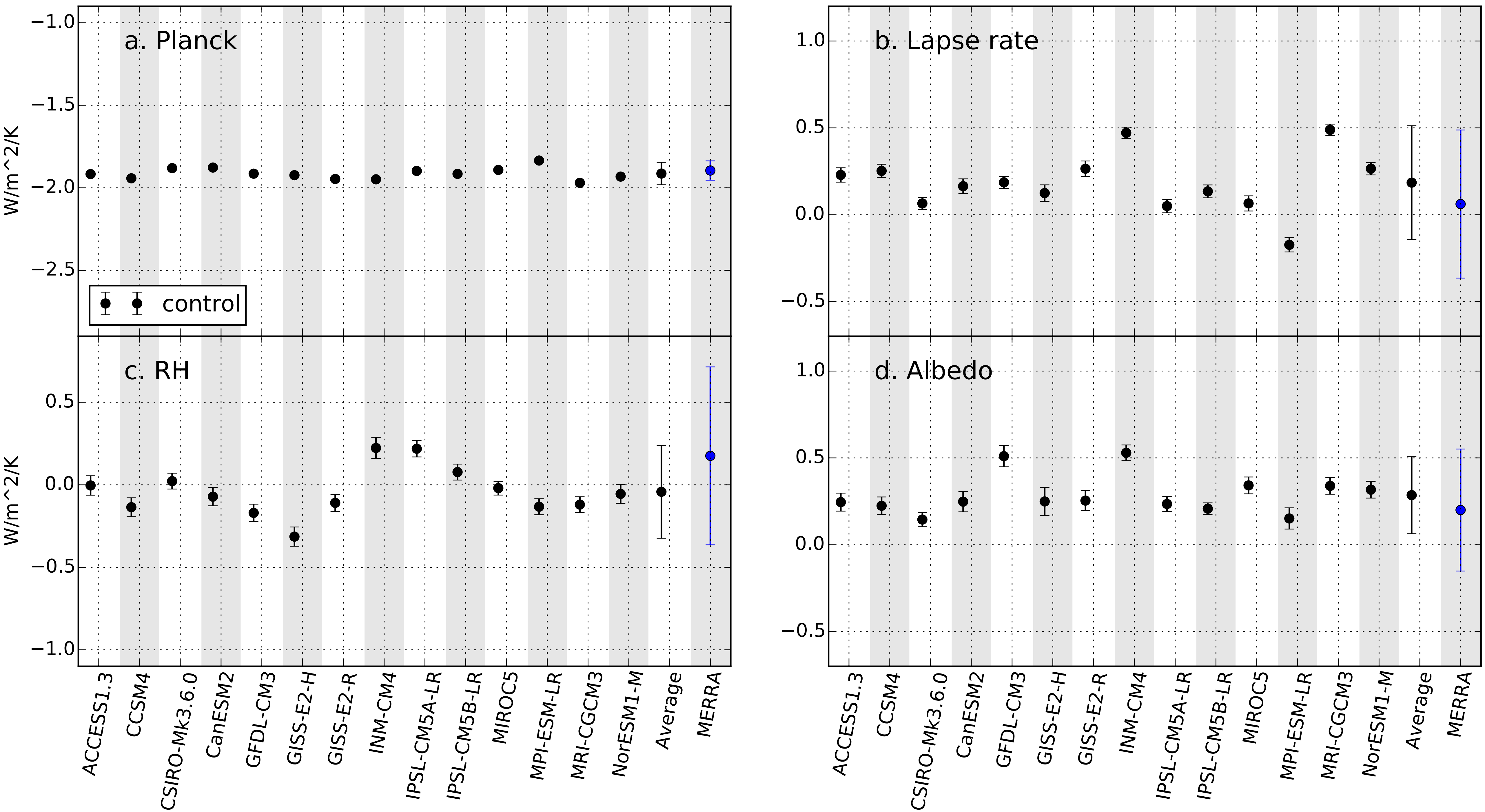

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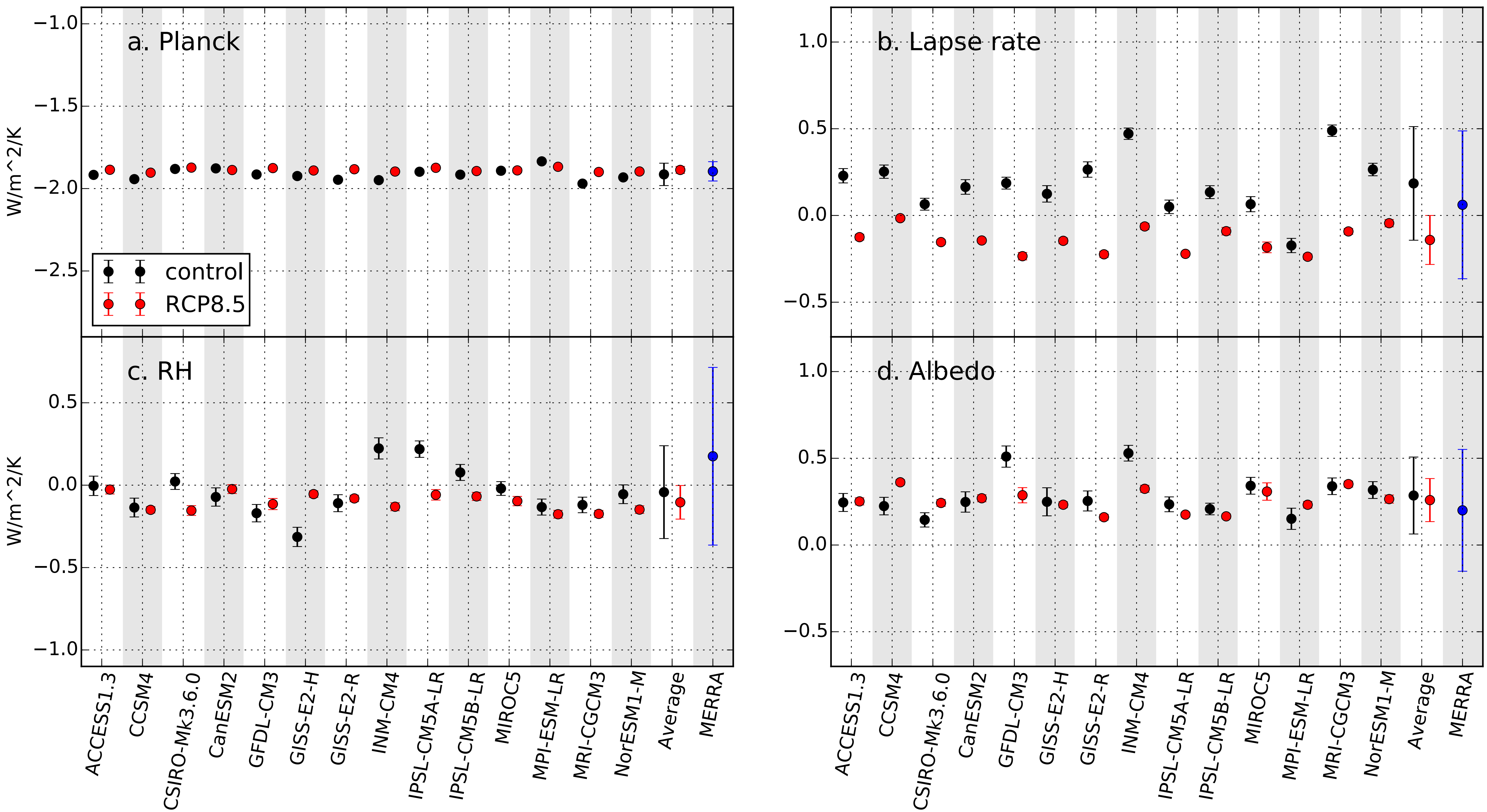
error bars on ensemble avg. are 2 std. dev.



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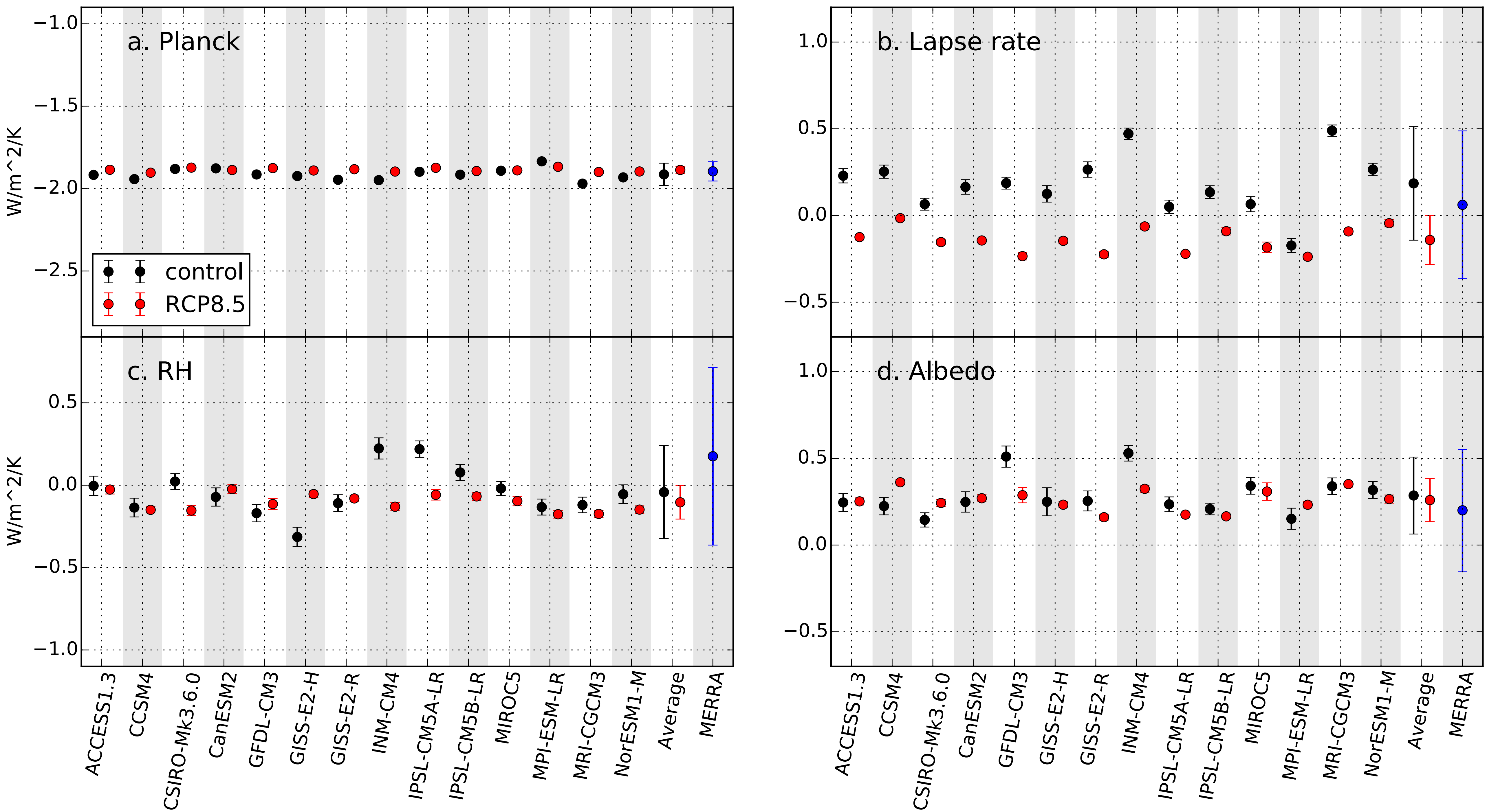
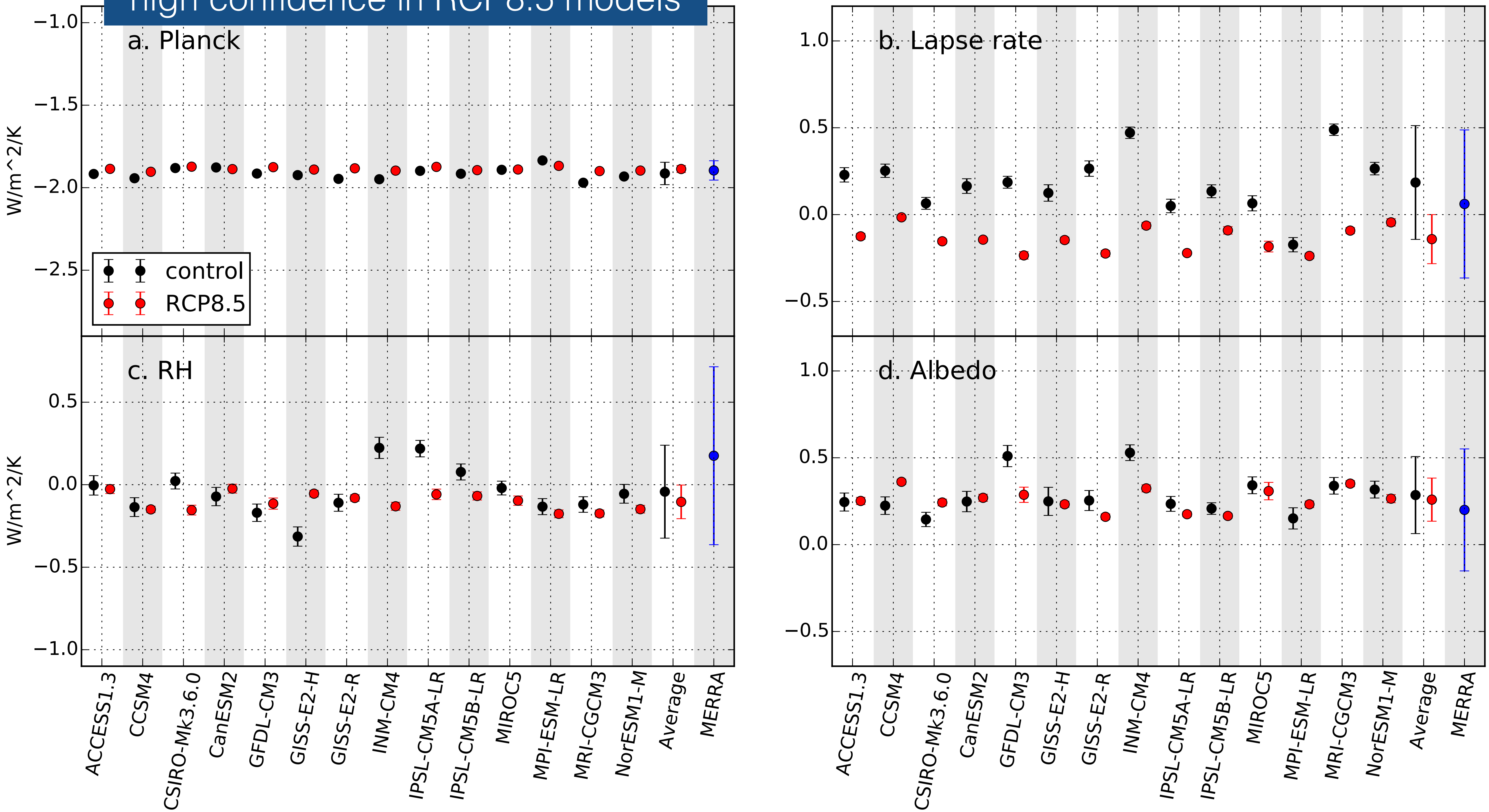


er rvals

er

1. Agreement between control runs and MERRA obs. gives us confidence

2. Planck feedback is set by pattern of surface warming; we should have high confidence in RCP8.5 models



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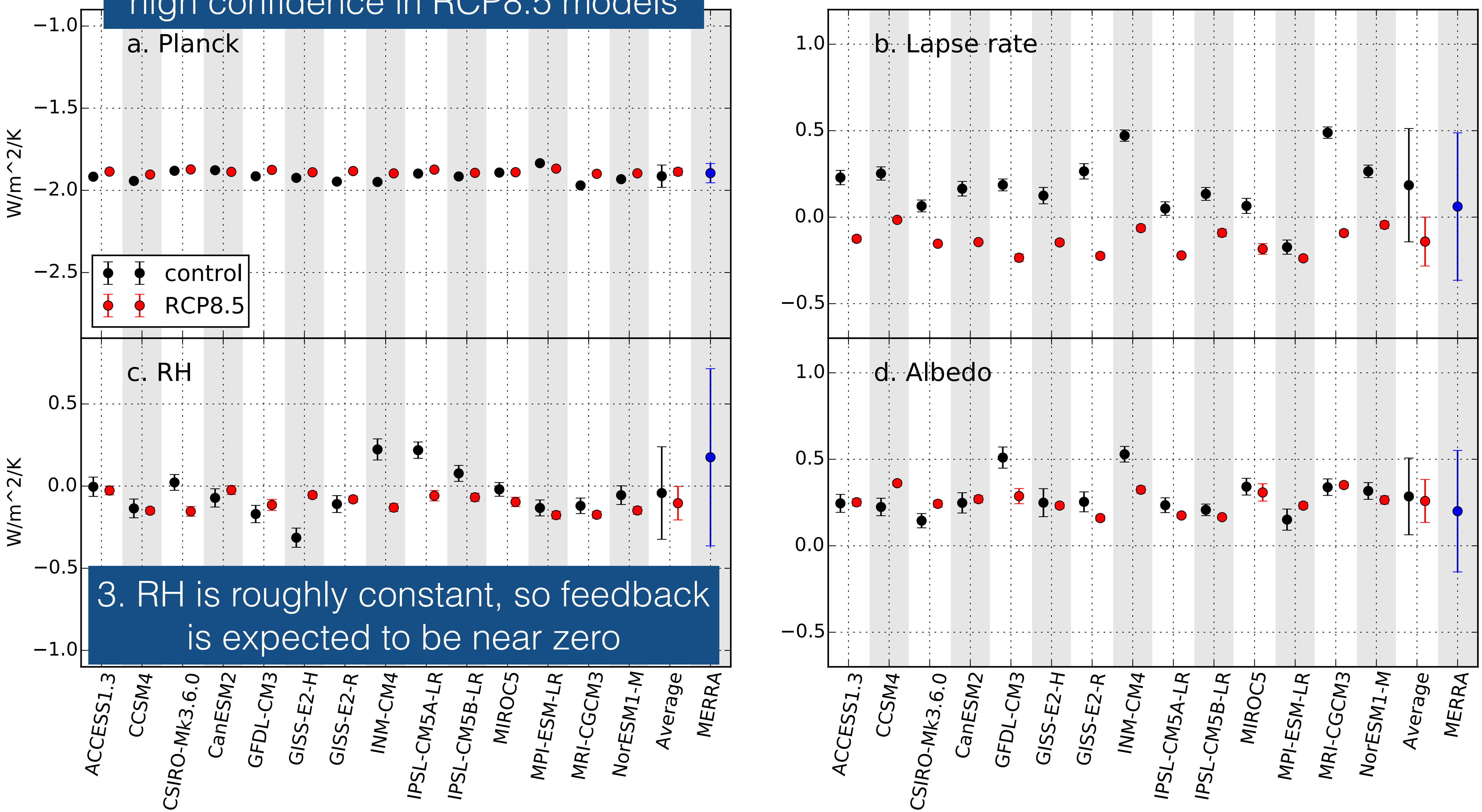

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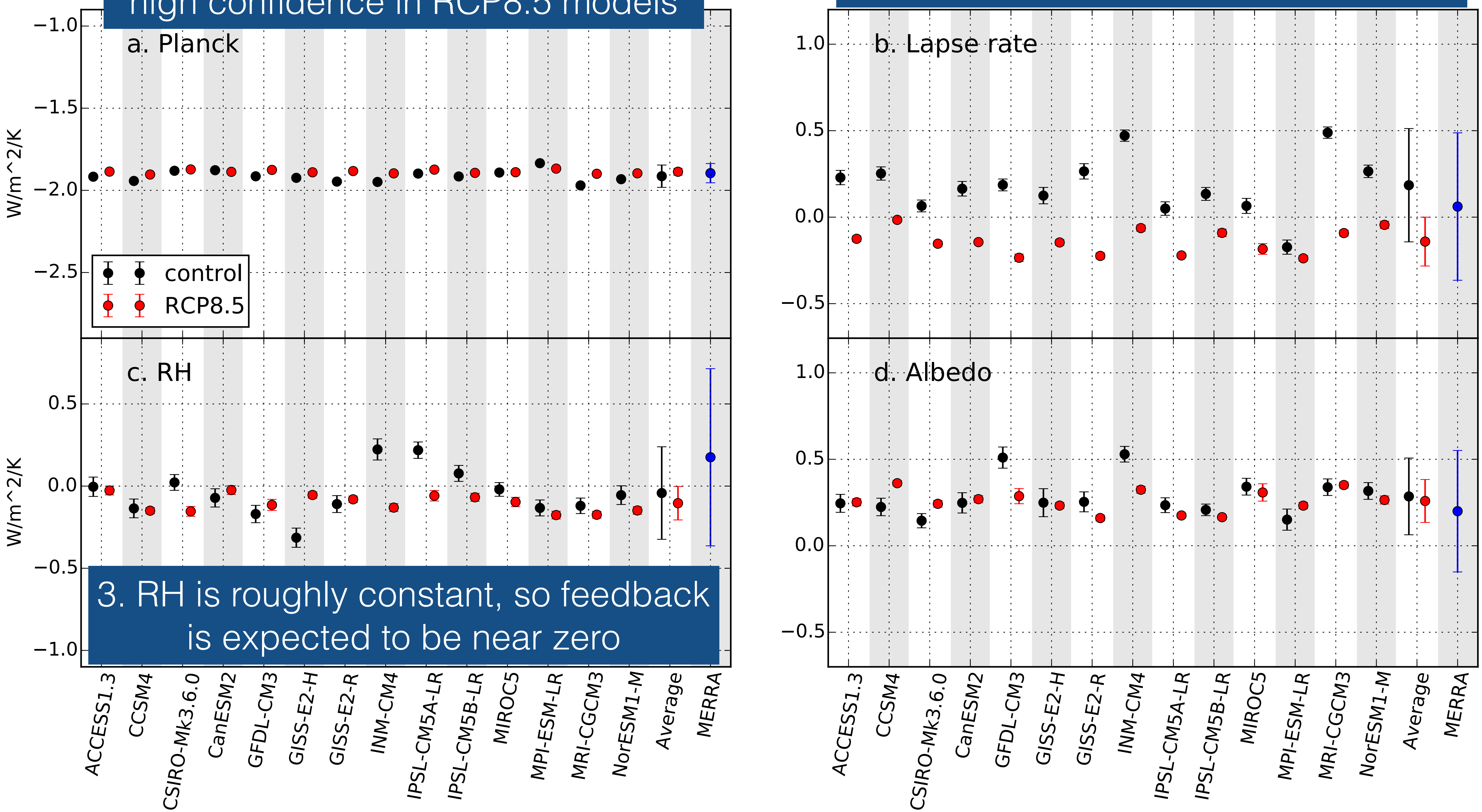
4. Temperature and WV effects cancel; this leads to a small feedback



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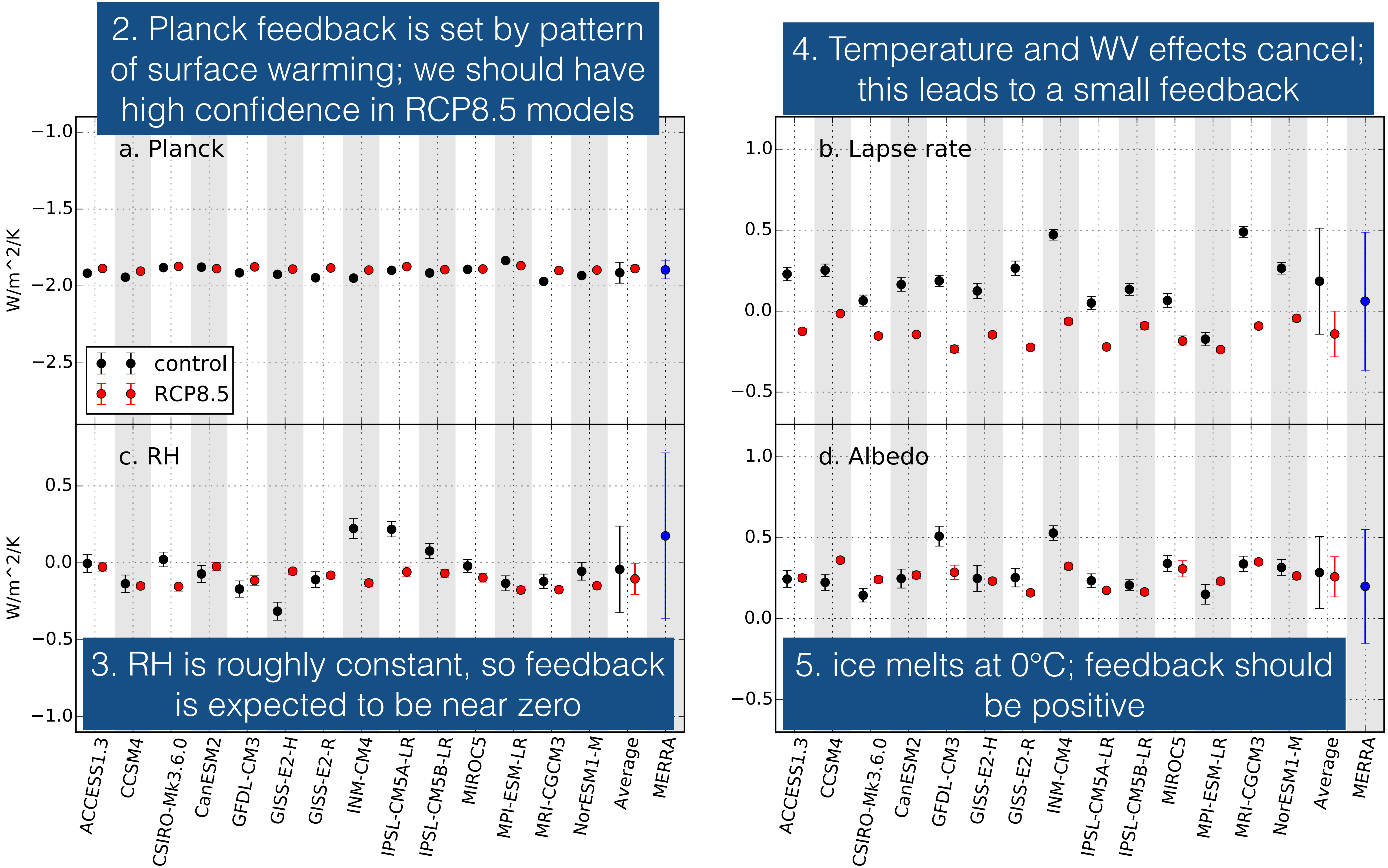

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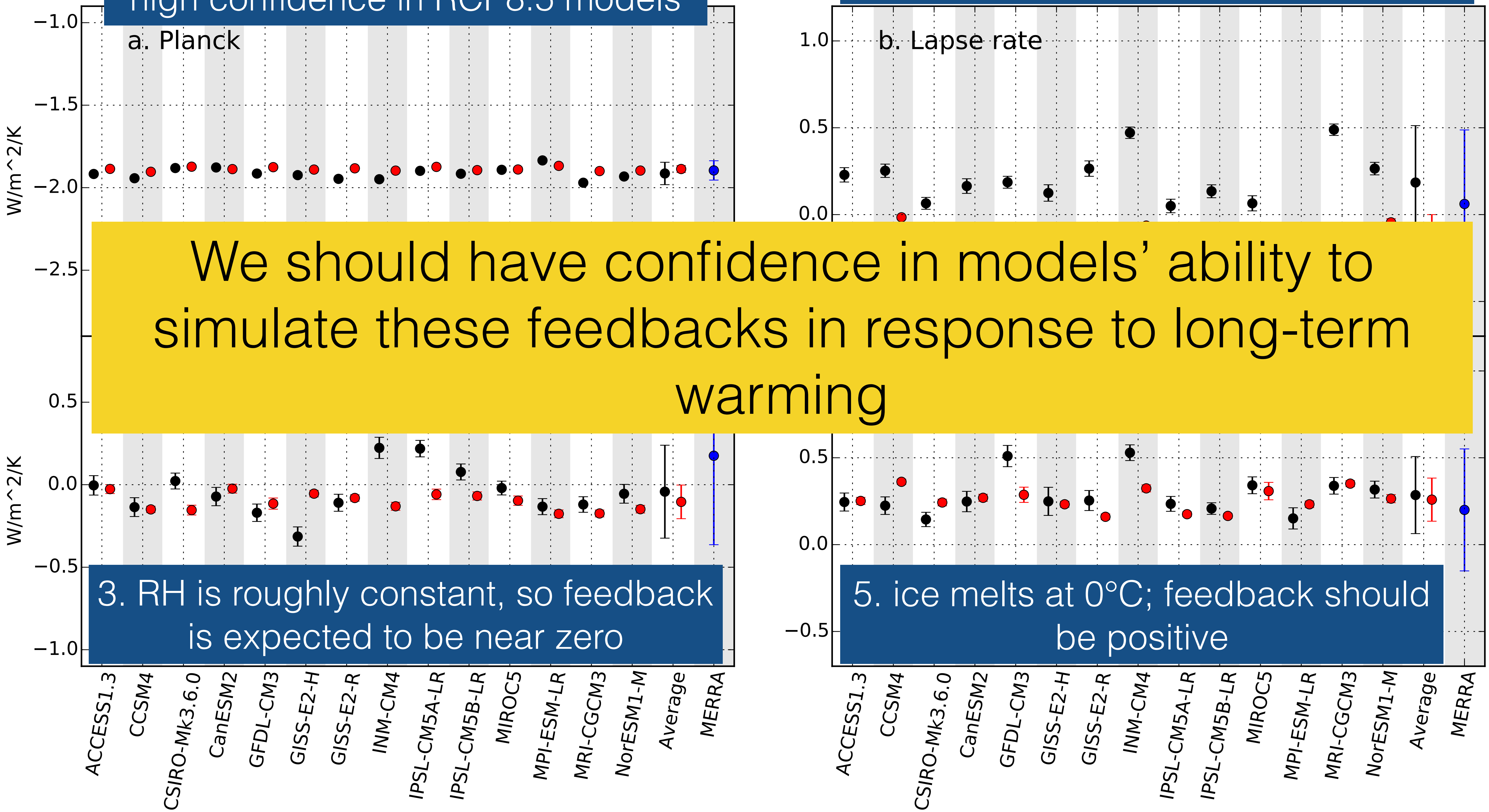
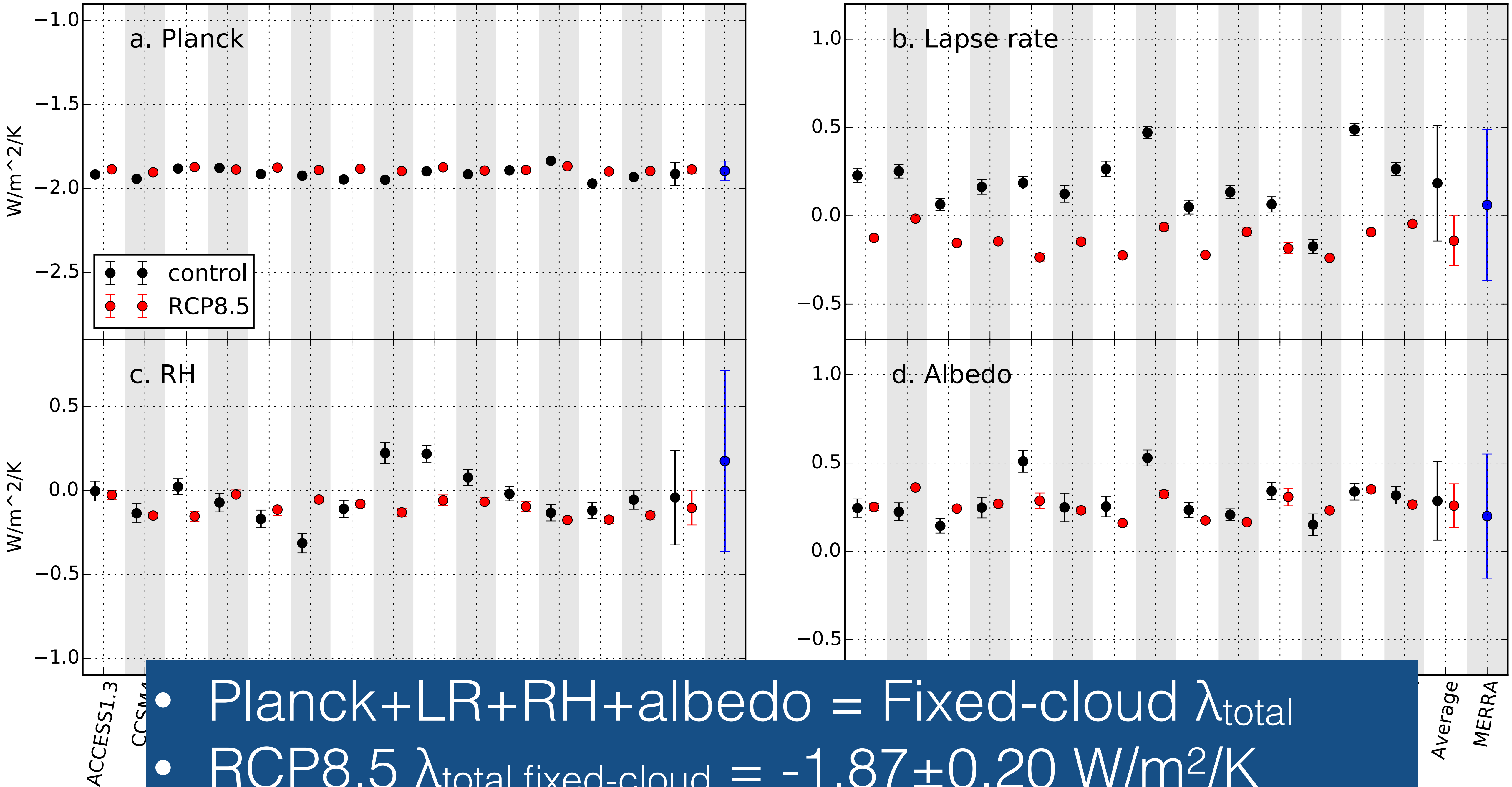


We should have confidence in models' ability to simulate these feedbacks in response to long-term warming

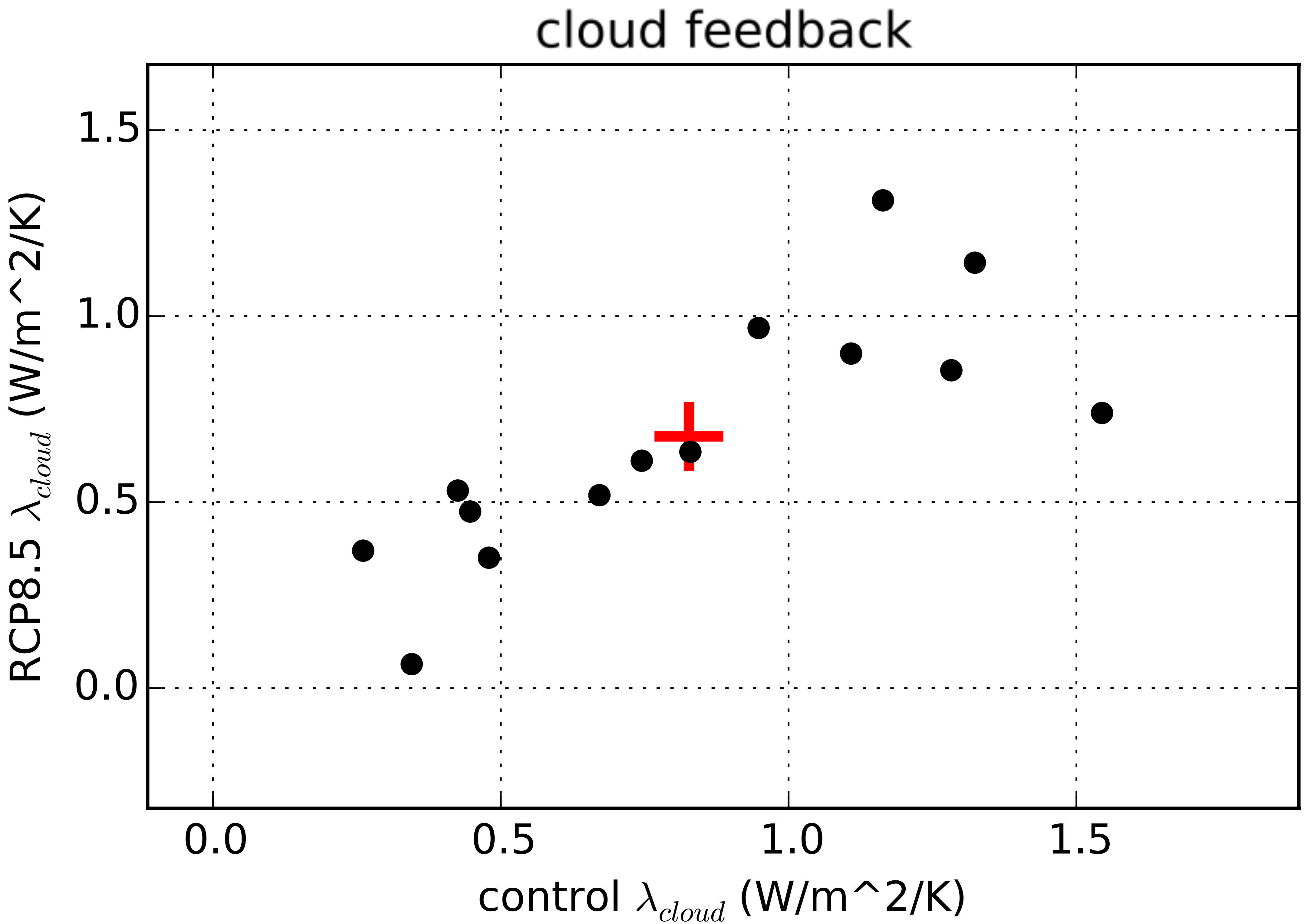
3. RH is roughly constant, so feedback is expected to be near zero

5. ice melts at 0°C; feedback should be positive

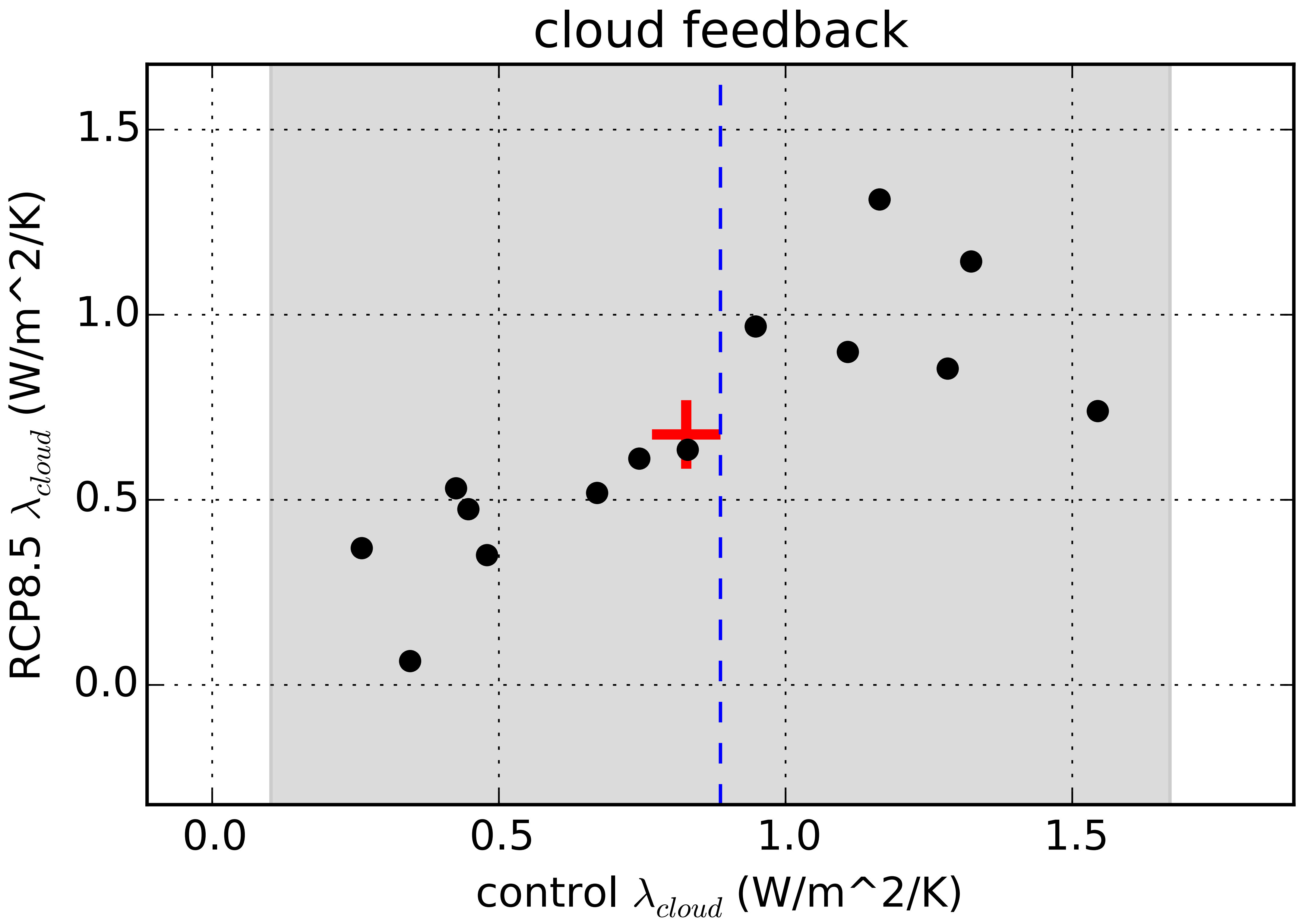
1. Agreement between control runs and MERRA obs. gives us confidence



- Planck+LR+RH+albedo = Fixed-cloud λ_{total}
- RCP8.5 $\lambda_{total,fixed\text{-}cloud}$ = -1.87±0.20 W/m^2/K
- translates to ECS of 1.8-2.2°C ≈ 2°C
- clouds add on to this …

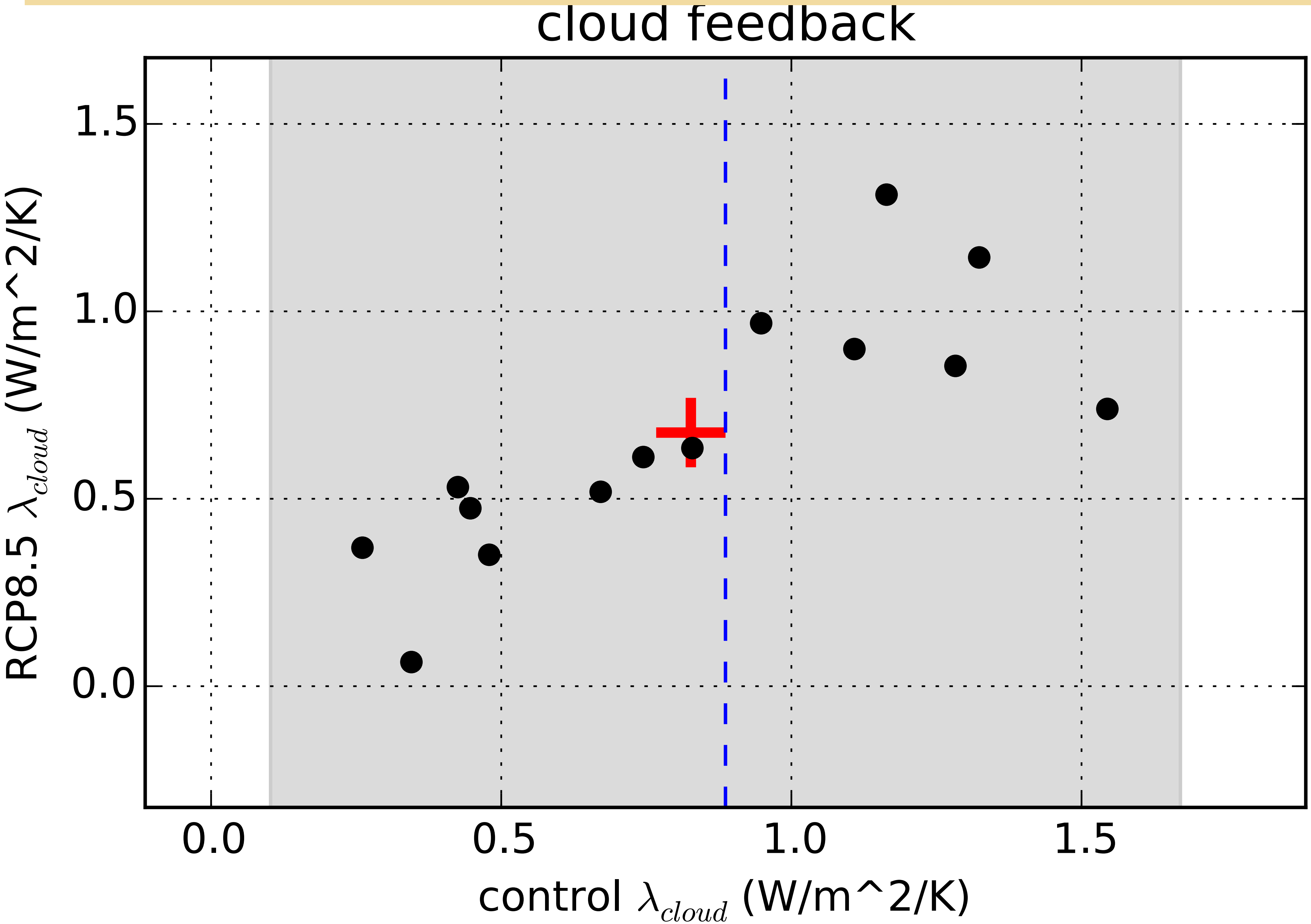


Chen Zhou et al., in prep.

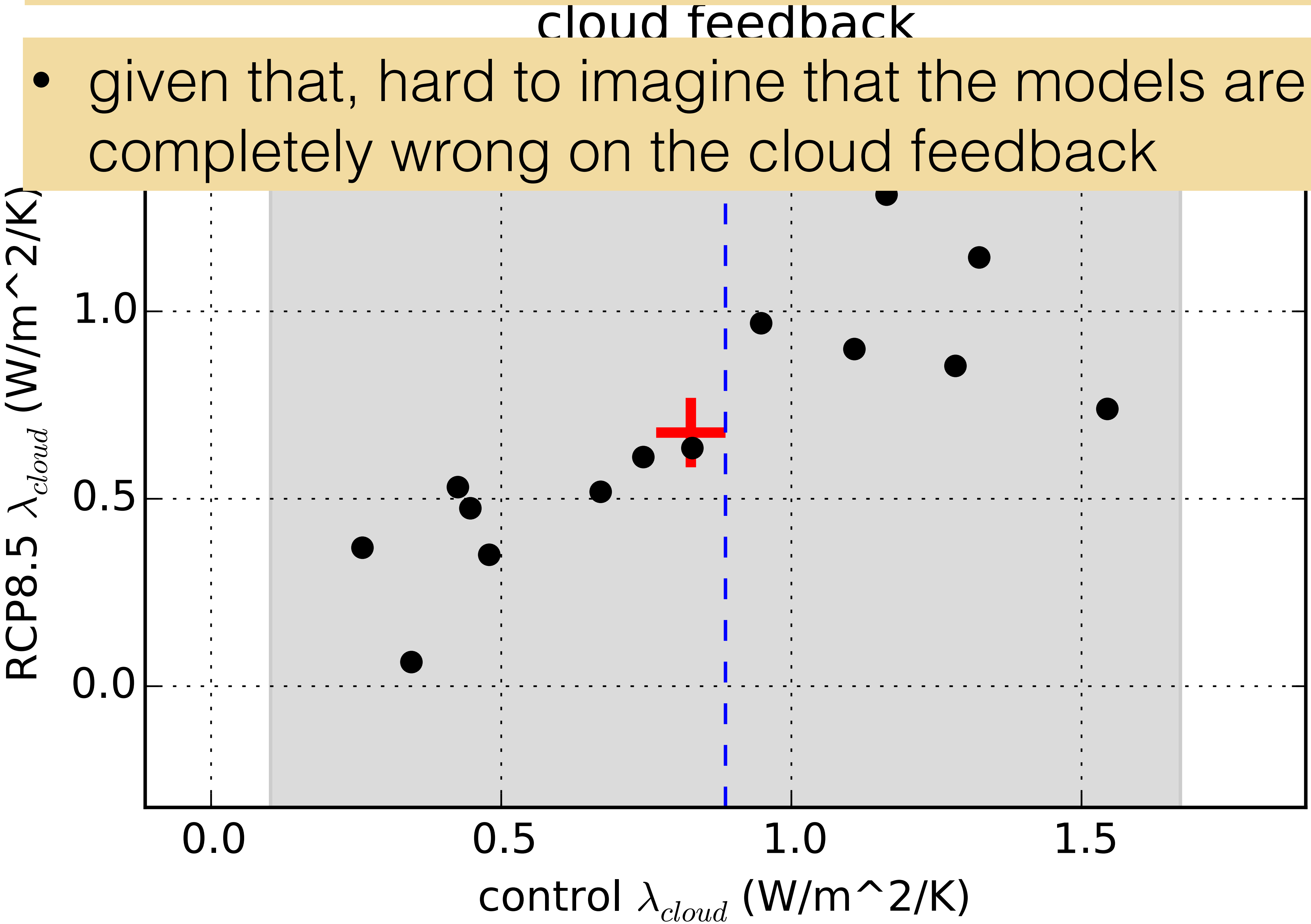


cloud feedback
1.5
1.0
0.5
0.0
RCP8.5 λ_{cloud} (W/m^2/K)
0.0
0.5
1.0
1.5
control λ_{cloud} (W/m^2/K)

- good agreement between ensemble avg. of control models and observations of λ_{cloud}



- good agreement between ensemble avg. of control models and observations of λ_{cloud}
- given that, hard to imagine that the models are completely wrong on the cloud feedback



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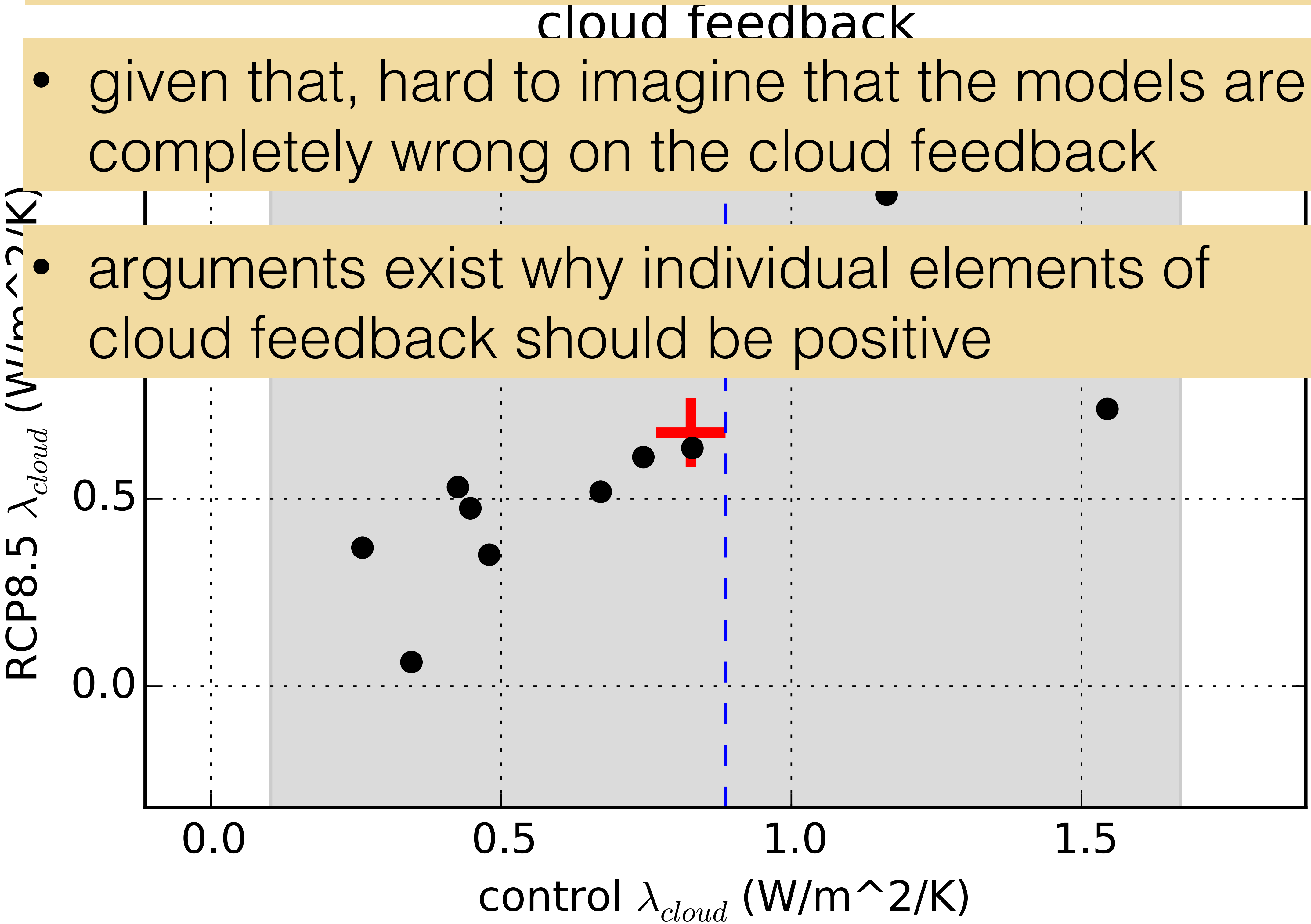
- arguments exist why individual elements of cloud feedback should be positive



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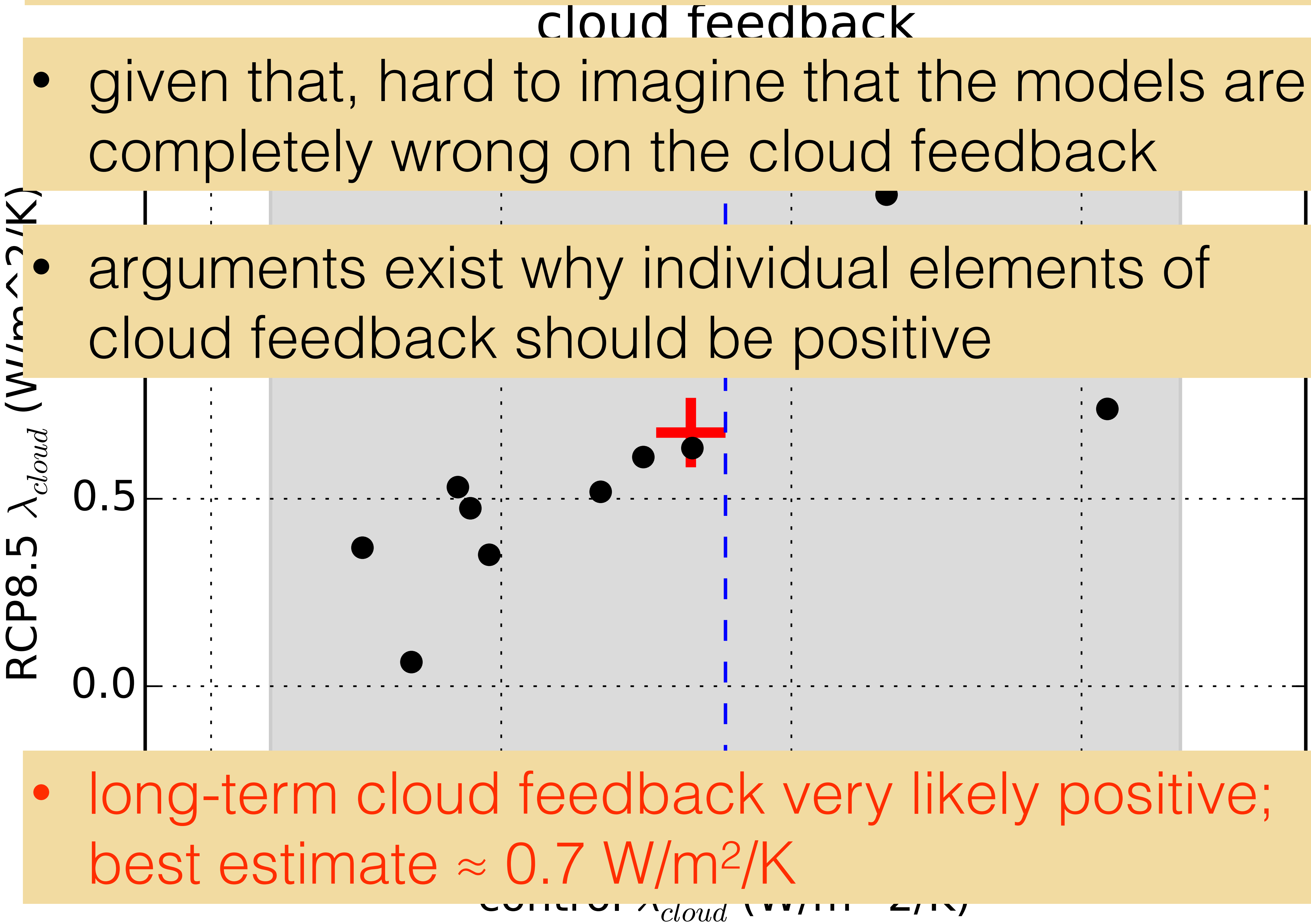

- long-term cloud feedback very likely positive; best estimate ≈ 0.7 W/m^2/K

Back of envelope calculation

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- $\lambda_{total,fixed\text{-}cloud} = -1.87 \pm 0.20\ W/m^2/K$
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- $\lambda_{total} = \lambda_{total,fixed\ cloud} + \lambda_{cloud}$

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- translates to ECS of 1.8-2.2°C
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- if $\lambda_{cloud} = +0.7$ W/m^2/K, then ECS ≈ 3.5±1.6°C

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- if $\lambda_{cloud} = +0.7$ W/m^2/K, then ECS $\approx 3.5 \pm 1.6$°C
- if $\lambda_{cloud} > 0$ W/m^2/K, then ECS > 2°C

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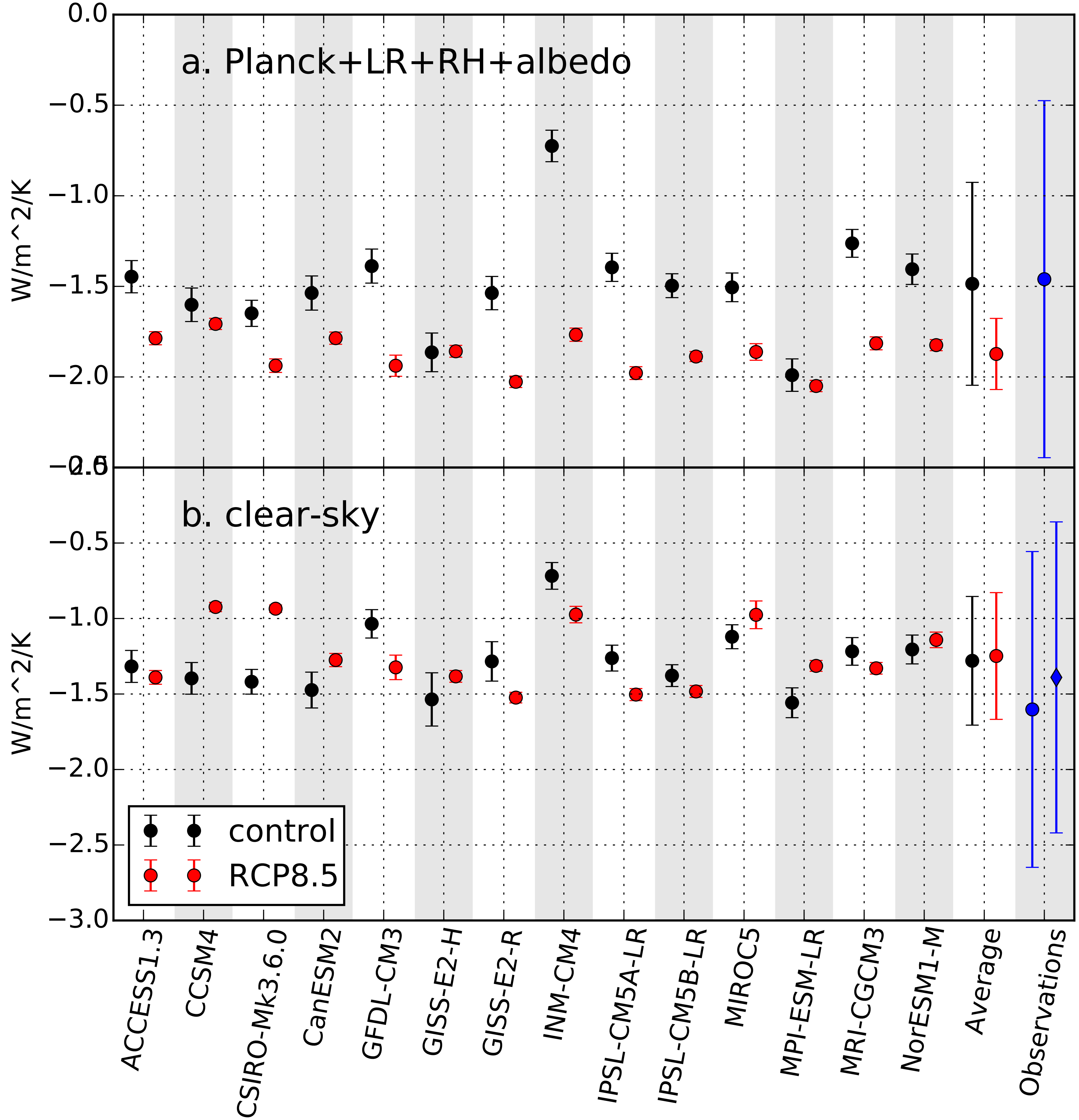
- if $\boxed{\lambda_{cloud} > 0\ \mathrm{W/m^2/K}}$ then ECS > 2°C

This is at least "likely" and perhaps "very likely"

Conclusions

- analysis of CERES TOA flux & models implies ECS of 3.0±1.4°C (very likely range)
- With fixed clouds, we can have high confidence in ECS of 1.8-2.2°C
- Evidence of positive cloud feedback is at least *likely*, suggesting in turn that ECS > 2°C is also at least *likely*



a. Planck+LR+RH+albedo
b. clear-sky
W/m^2/K
W/m^2/K
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
control
RCP8.5
ACCESS1.3
CCSM4
CSIRO-Mk3.6.0
CanESM2
GFDL-CM3
GISS-E2-H
GISS-E2-R
INM-CM4
IPSL-CM5A-LR
IPSL-CM5B-LR
MIROC5
MPI-ESM-LR
MRI-CGCM3
NorESM1-M
Average
Observations

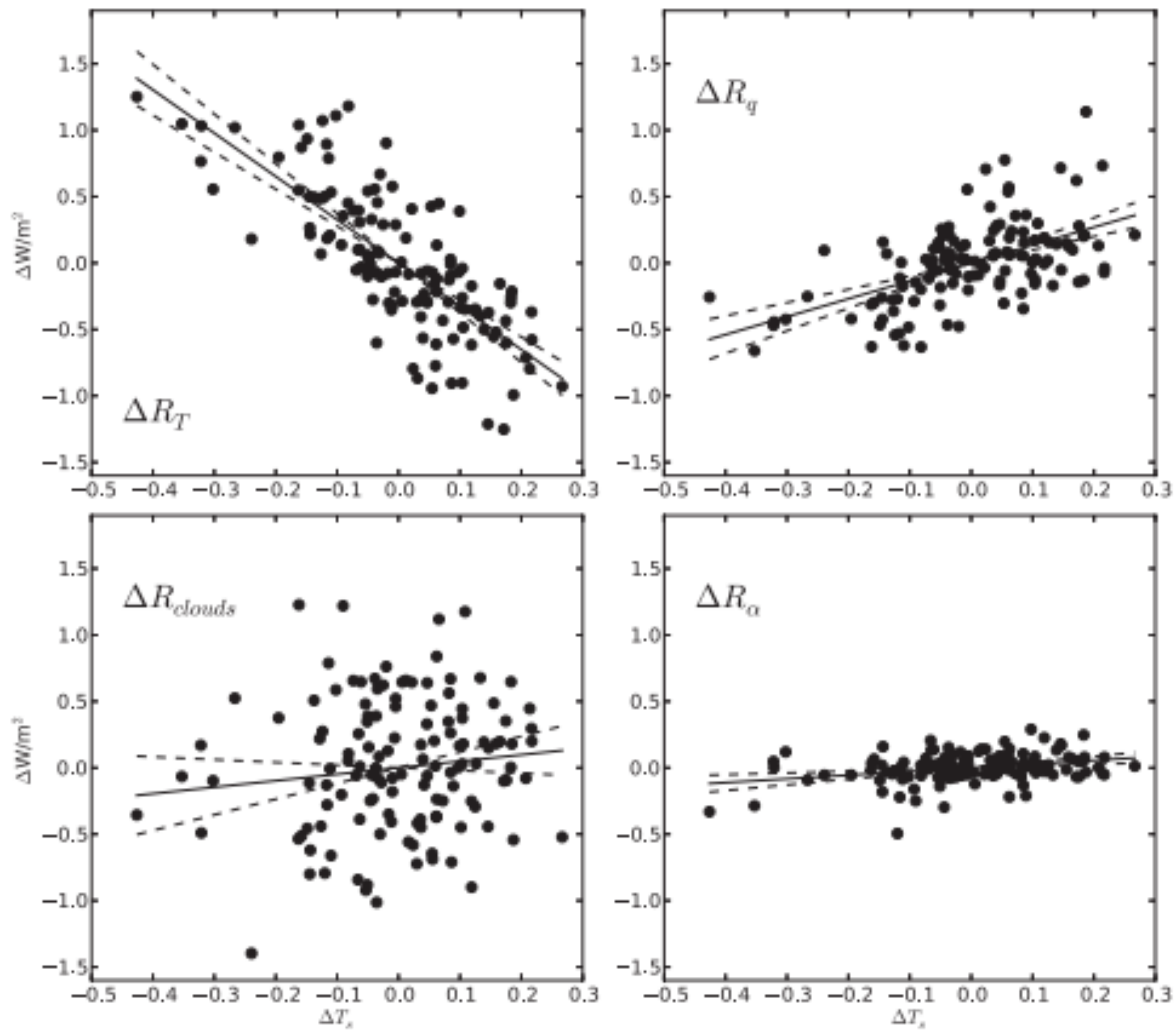


FIG. 1. Scatterplot of the temperature (ΔR_T), water vapor (ΔR_q), albedo (ΔR_α), and cloud ($\Delta R_{\mathrm{cloud}}$) flux anomalies vs surface temperature anomaly in the observations (using the ERA-Interim reanalysis). Also shown are a linear fit to the data and the 95% confidence intervals.

Dessler, J. Climate, 2013

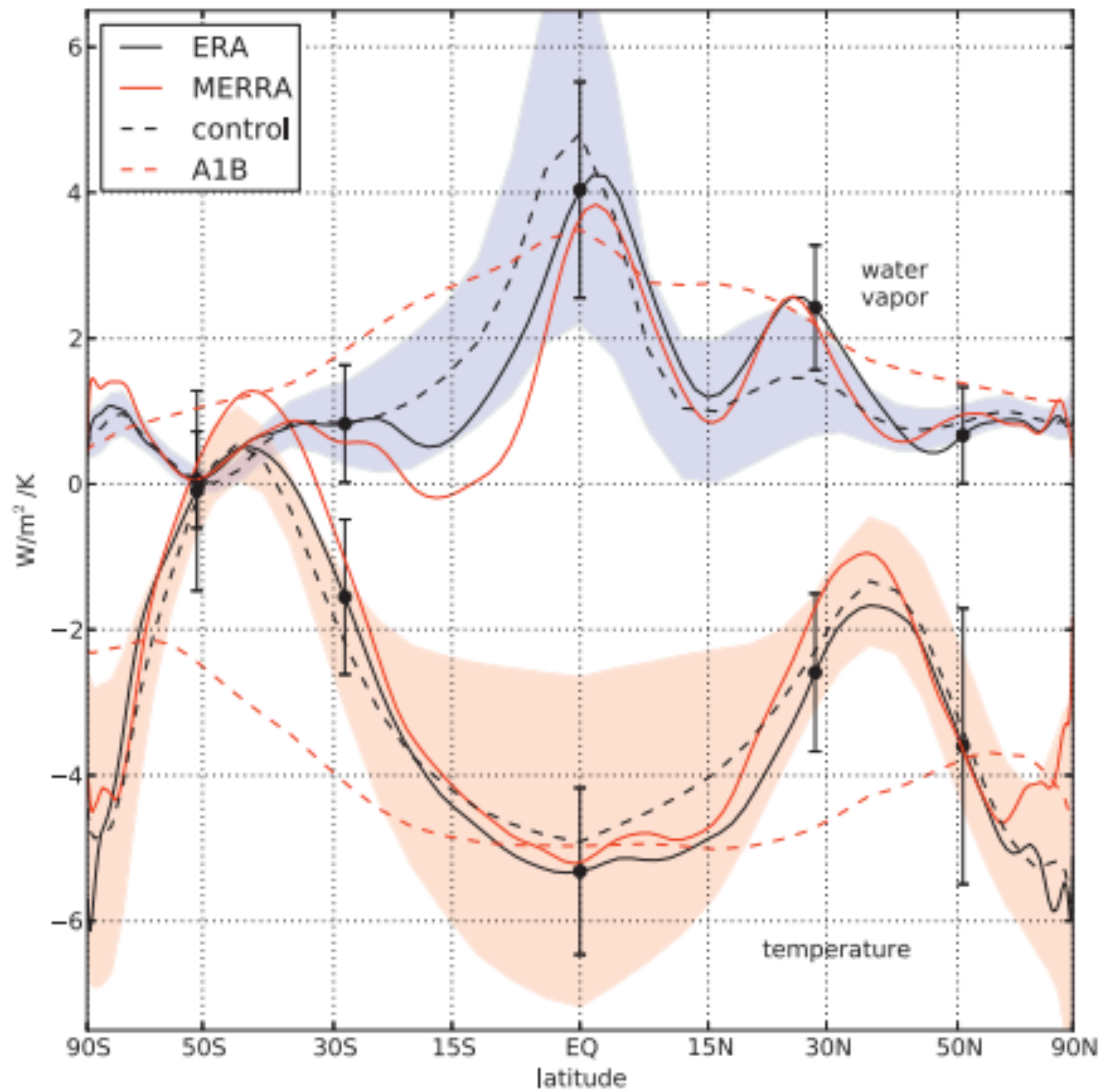


FIG. 3. The zonal average temperature (bottom curves) and water vapor feedbacks (top curves). Observations are the solid lines (black is ERA-Interim and red is MERRA) and the models are dashed (black dashed is the control ensemble and red dashed is the A1B ensemble). The shading indicates one standard deviation about the average of the control ensemble. Error bars indicate the 2σ uncertainty of the fit for the ERA-Interim calculation at selected latitudes.

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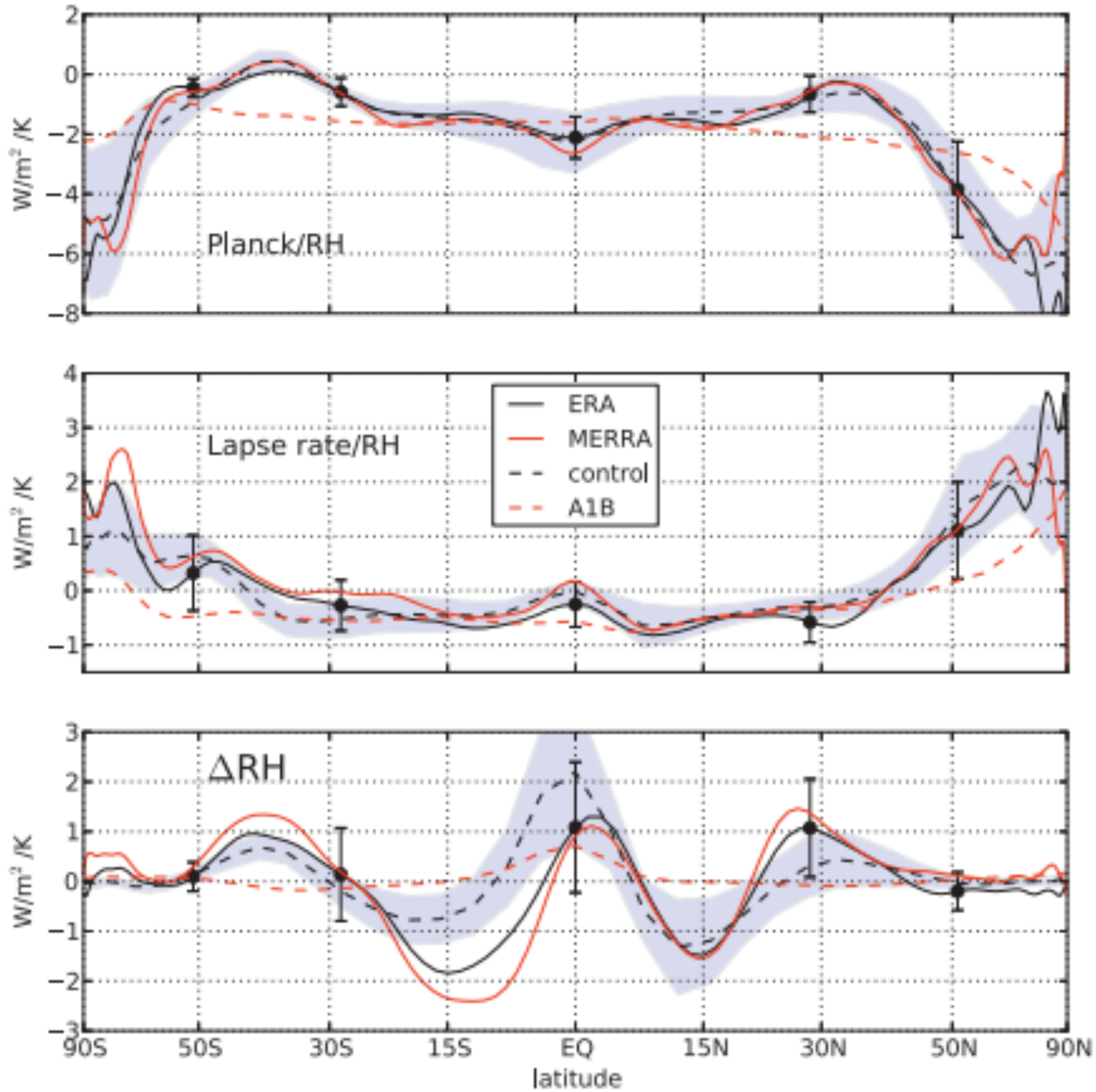

FIG. 4. The zonal average Planck–RH, lapse-rate–RH, and ΔRH feedbacks (these are from an alternative decomposition of the feedbacks in which the Planck and lapse-rate feedbacks also include changes in water vapor needed to maintain constant RH). Observations are the solid lines (black is ERA-Interim and red is MERRA) and the models are dashed (black dashed is the control ensemble and red dashed is the A1B ensemble). The shading indicates one standard deviation about the average of the control ensemble. Error bars indicate the 2σ uncertainty of the fit for the ERA-Interim calculation at selected latitudes.

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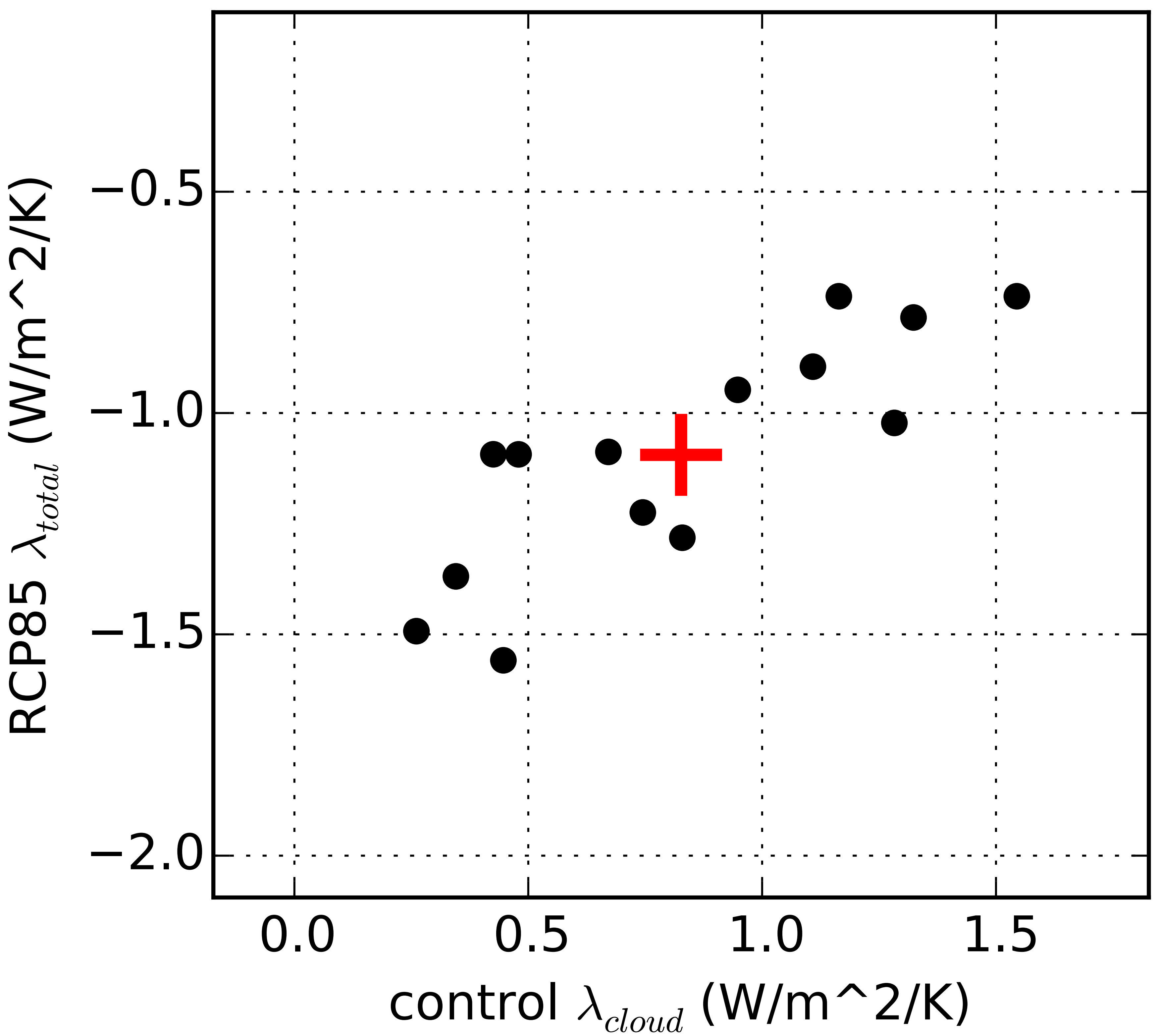
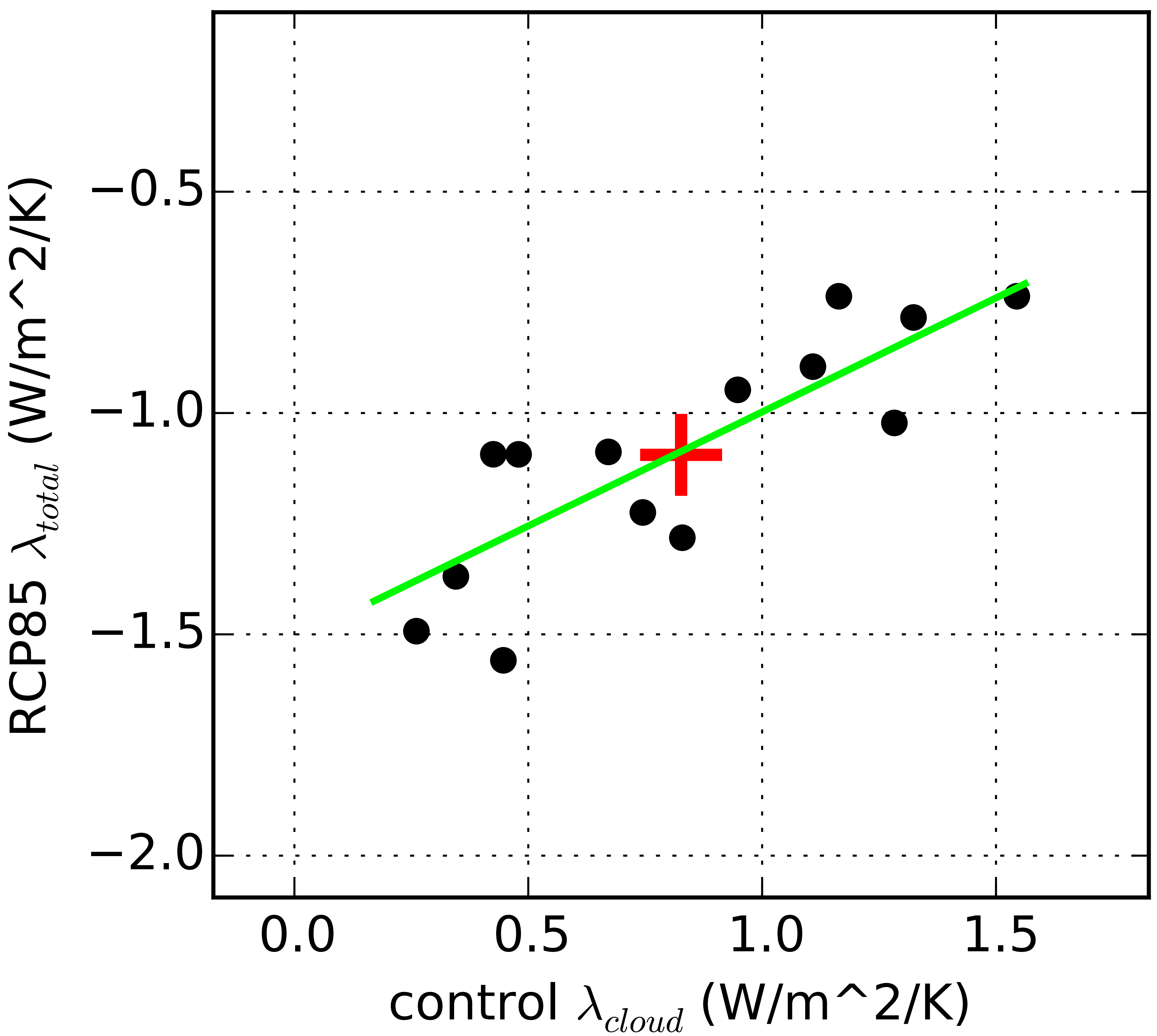

−0.5
−1.0
−1.5
−2.0
0.0
0.5
1.0
1.5
RCP85 λ_{total} (W/m^2/K)
control λ_{cloud} (W/m^2/K)



−0.5
−1.0
−1.5
−2.0
RCP85 λ_{total} (W/m^2/K)
0.0
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1.0
1.5
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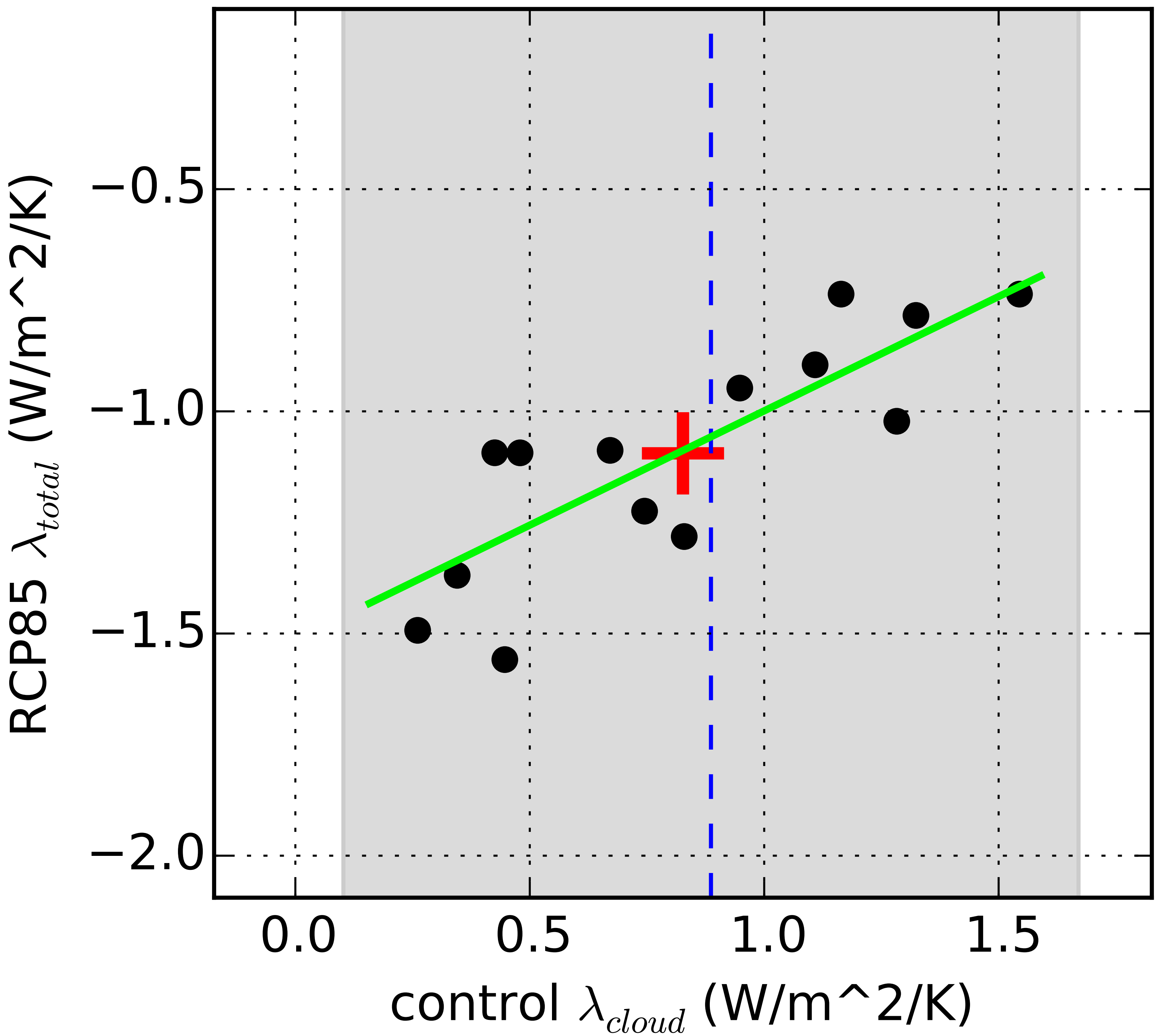

−0.5
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1.0
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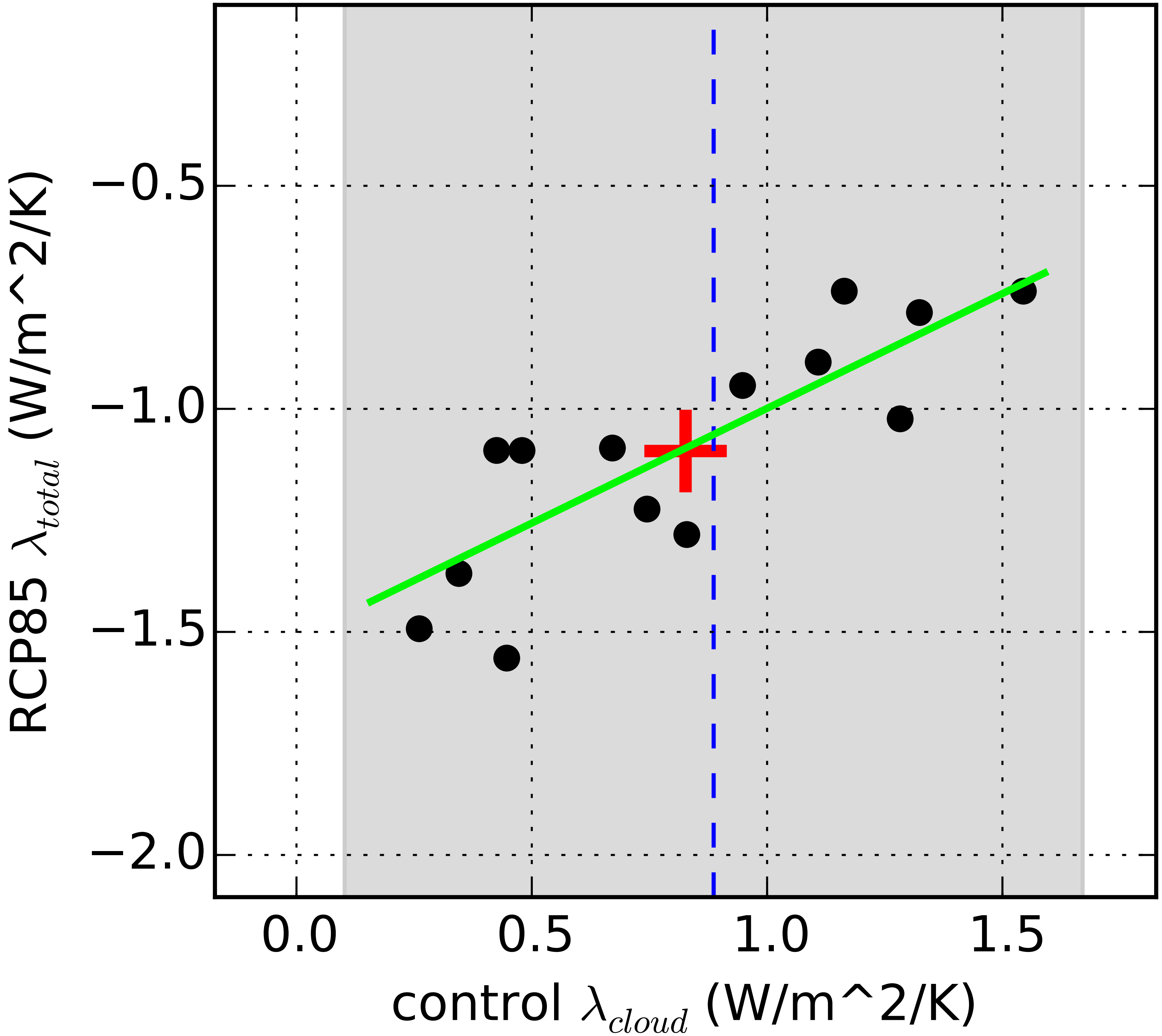
λ_{total} = -1.06±0.49 W/m^2/K



λ_{total} = -1.06±0.49 W/m²/K ECS = 3.5±1.6 K