

# A revision of the Earth's energy balance framework

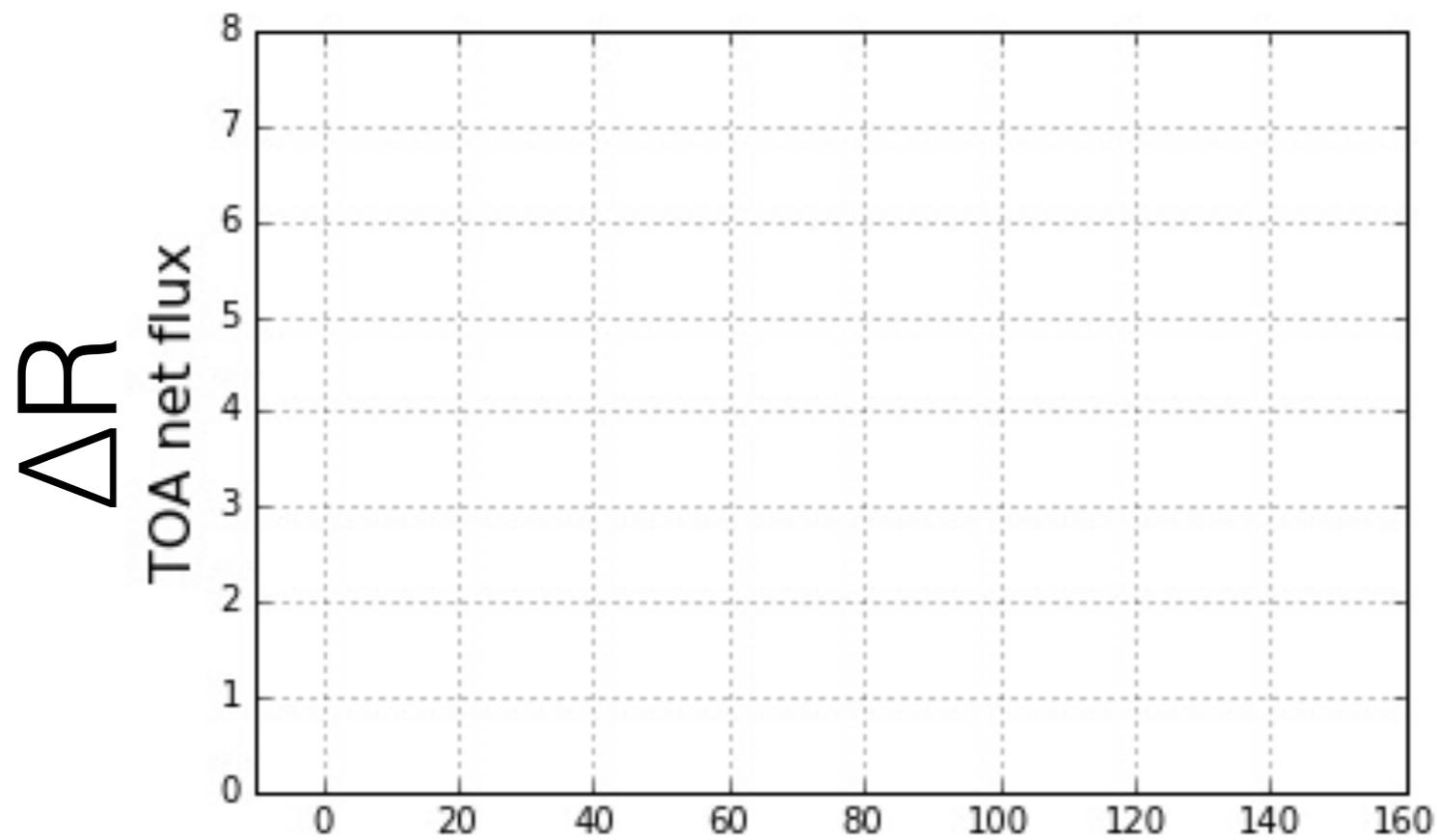
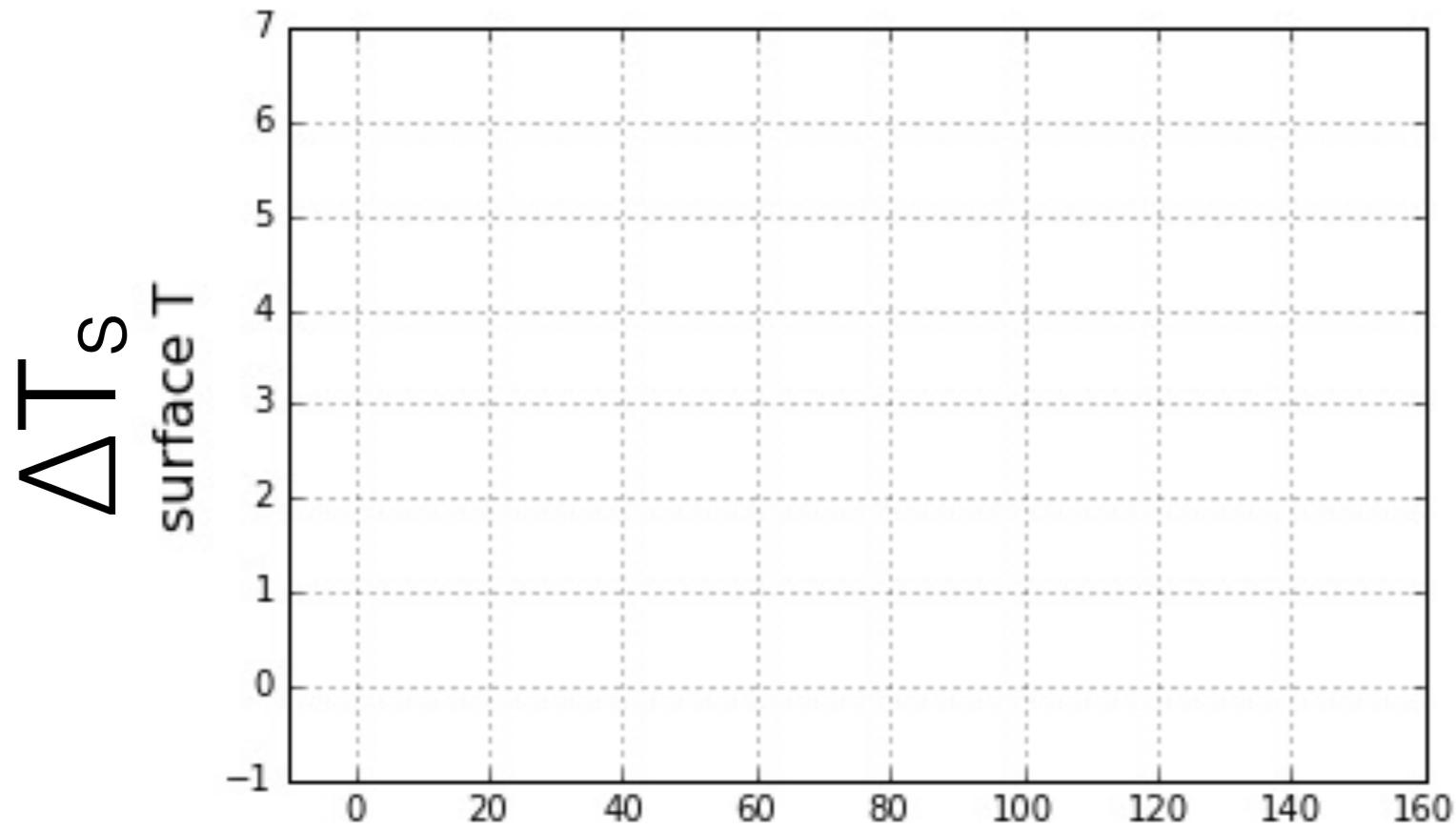
**A. E. Dessler**

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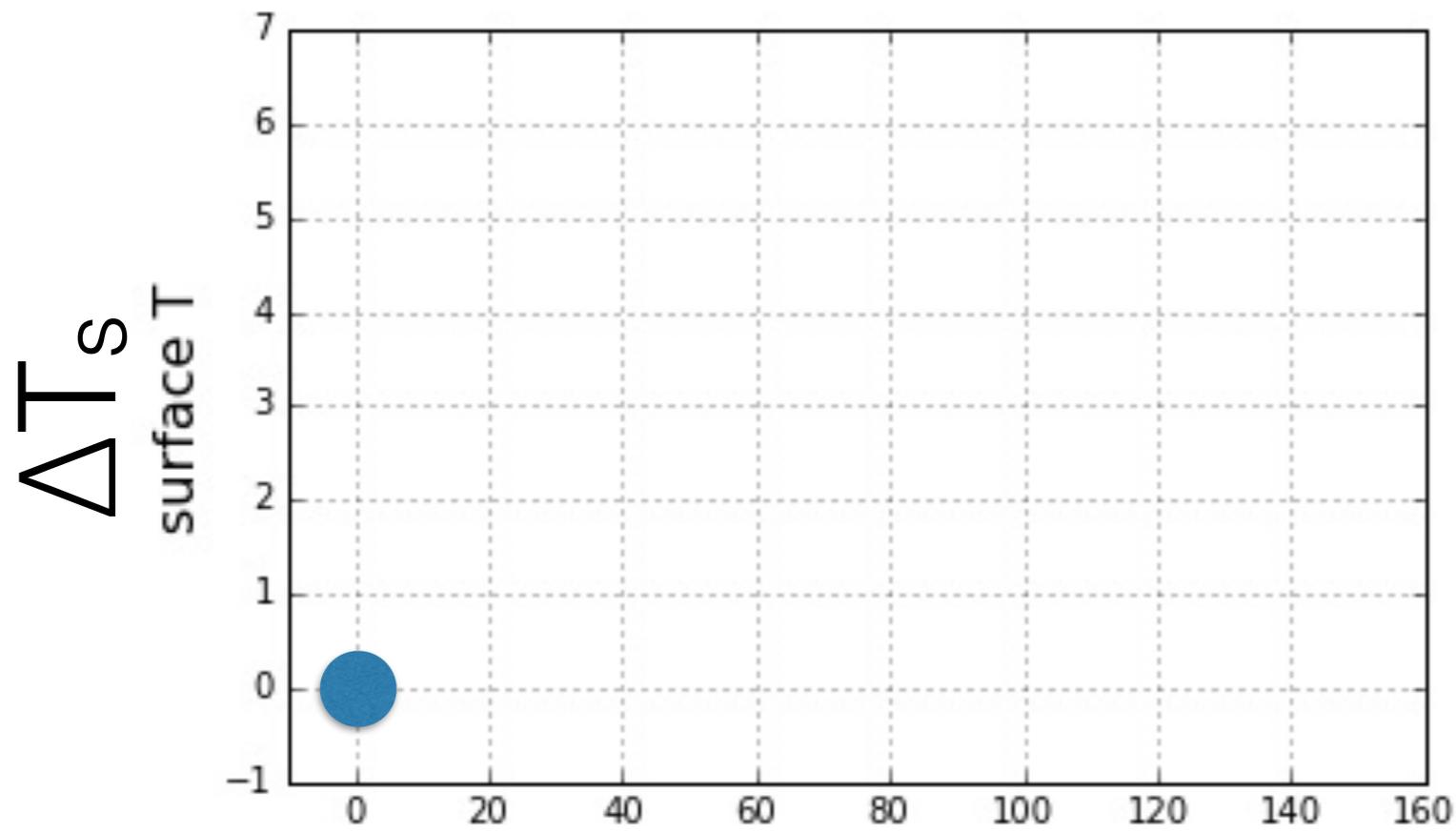
Max Planck Institute for Meteorology



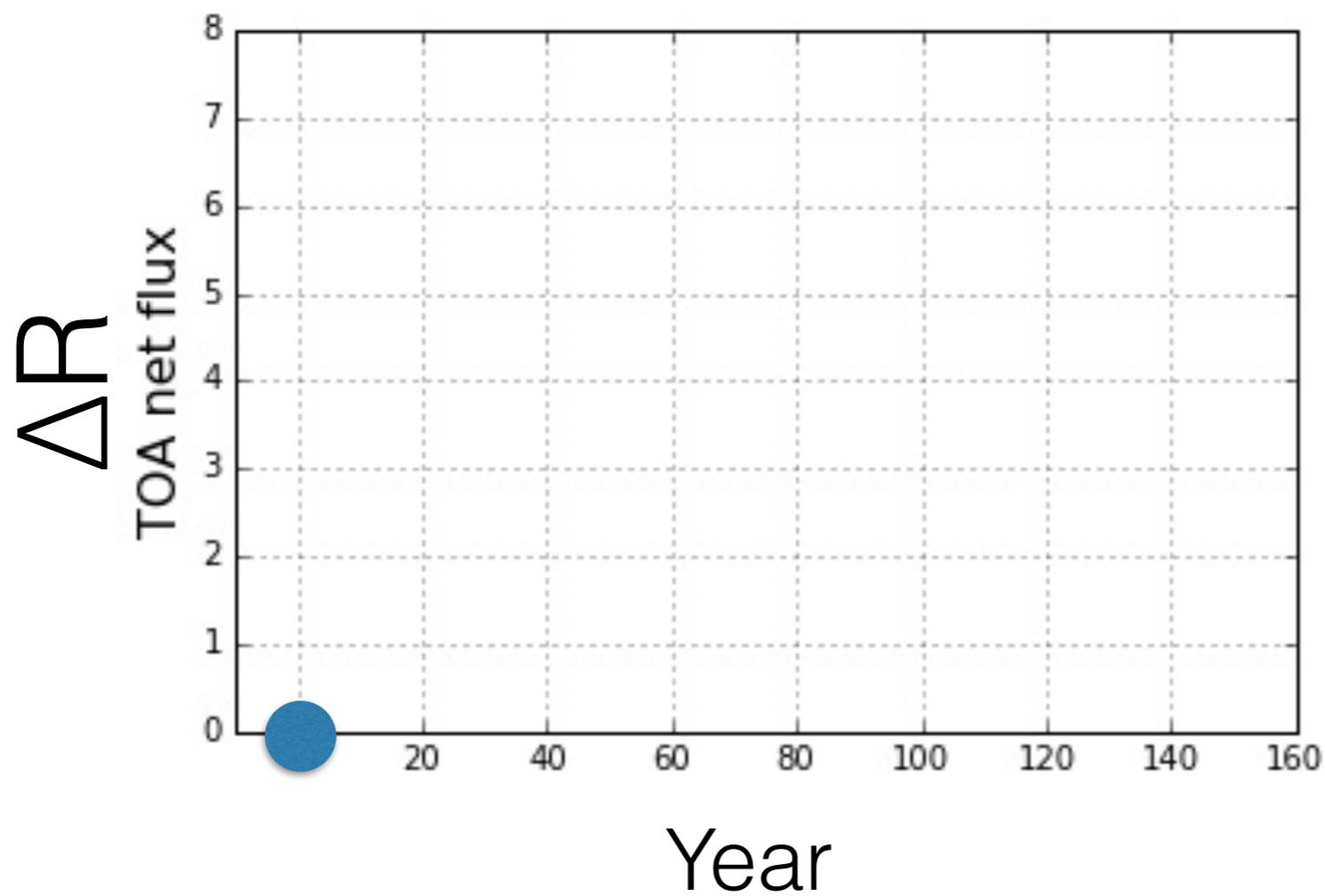


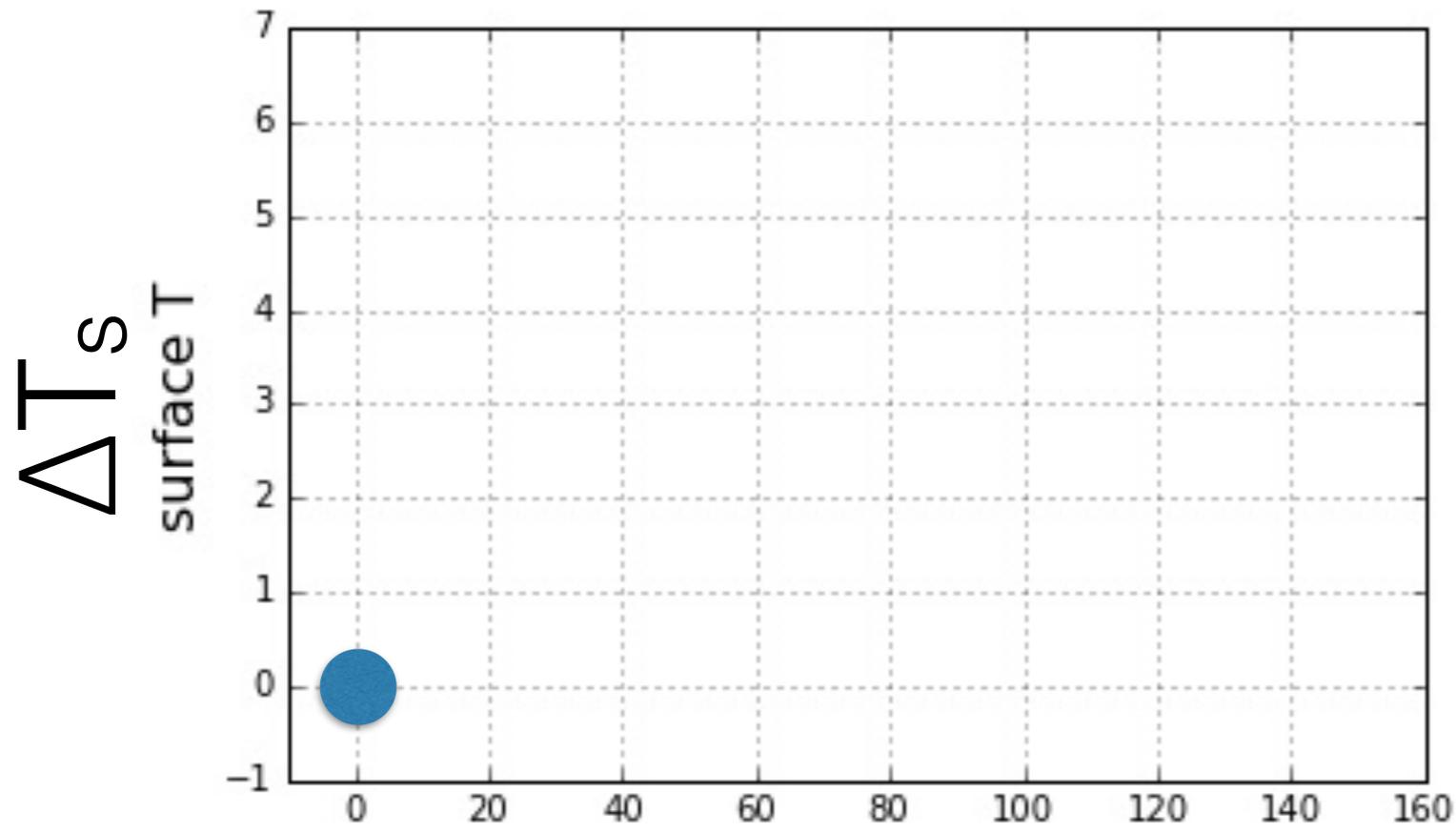
abrupt 4xCO2  
GFDL-CM3

Year

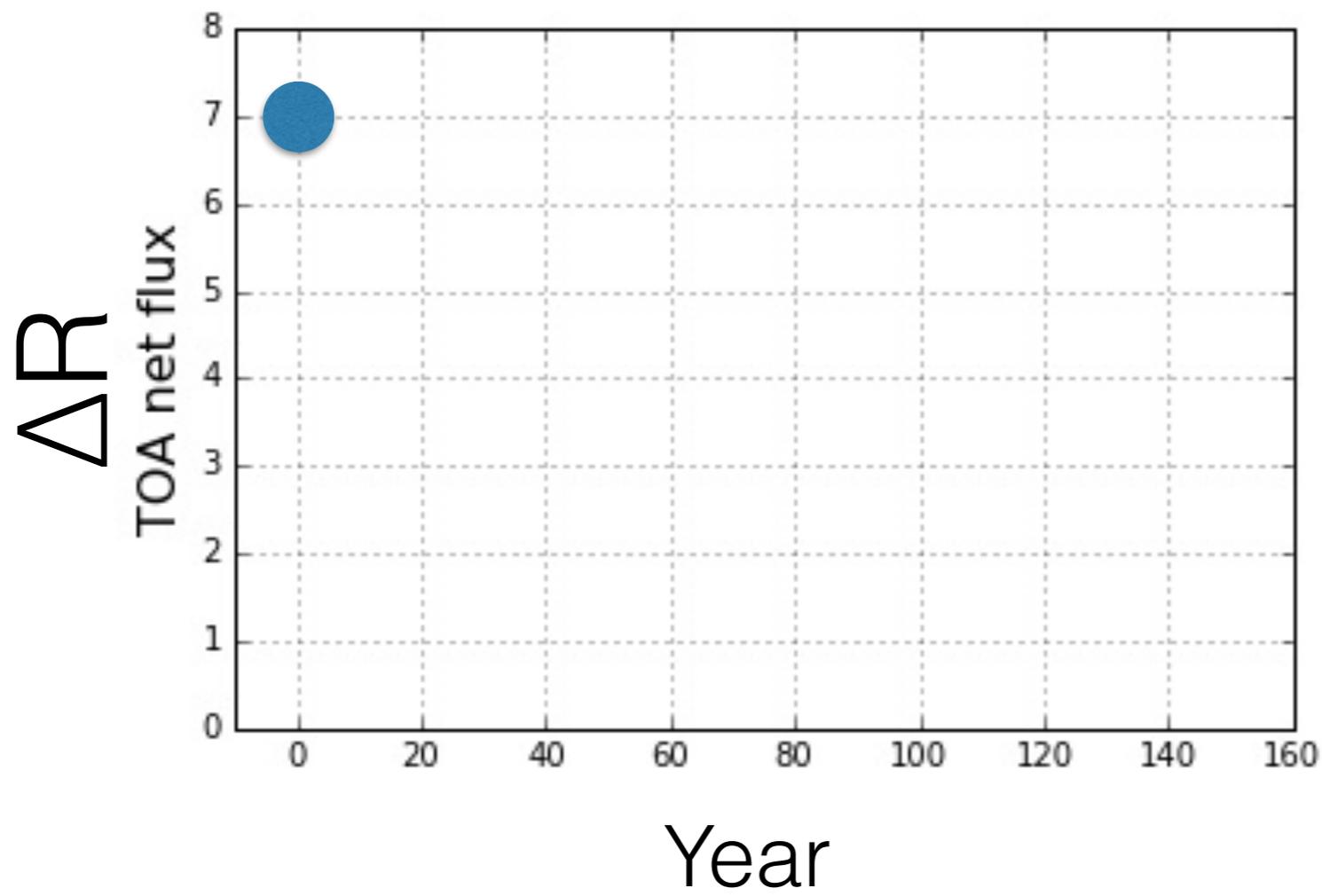


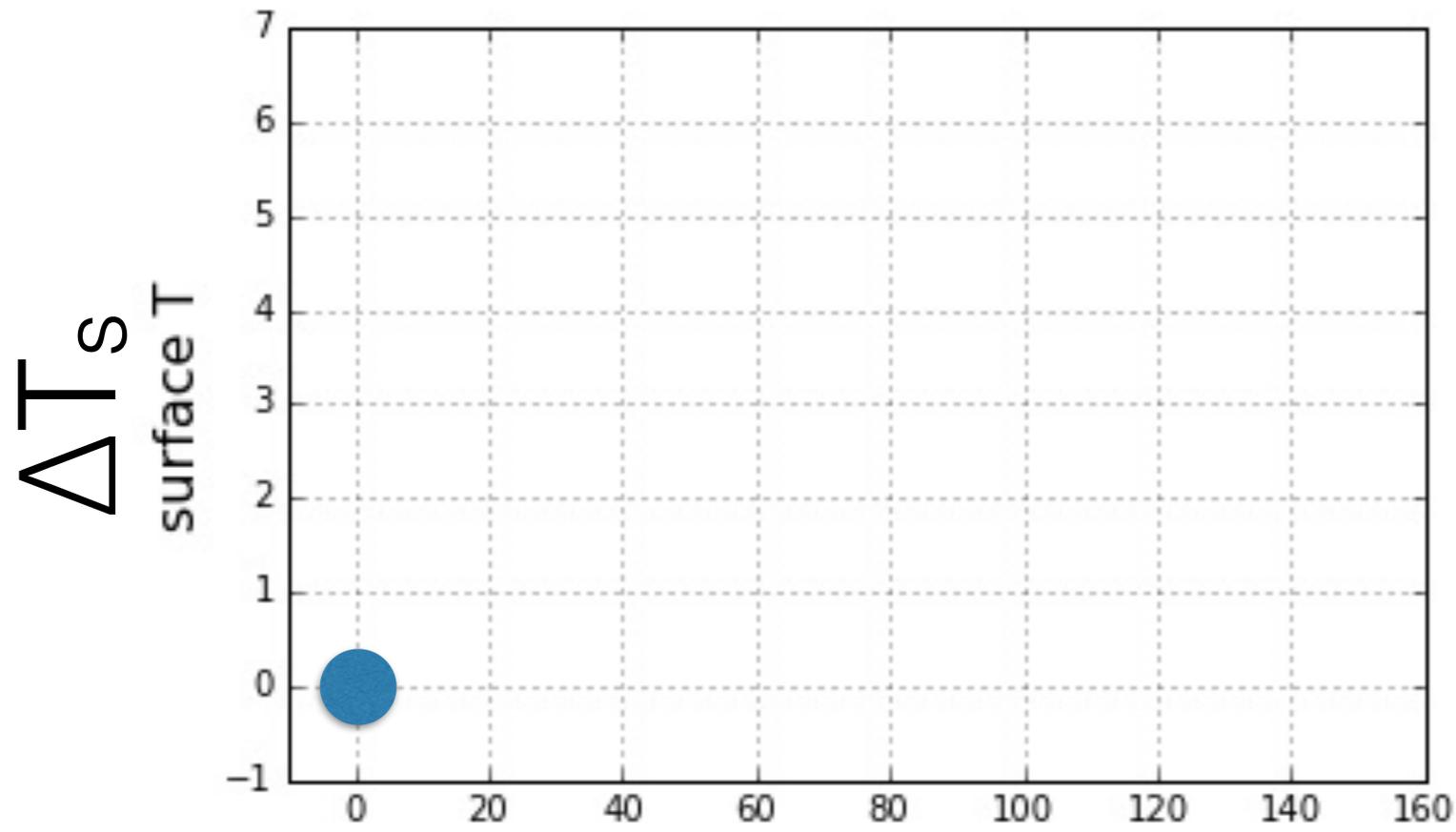
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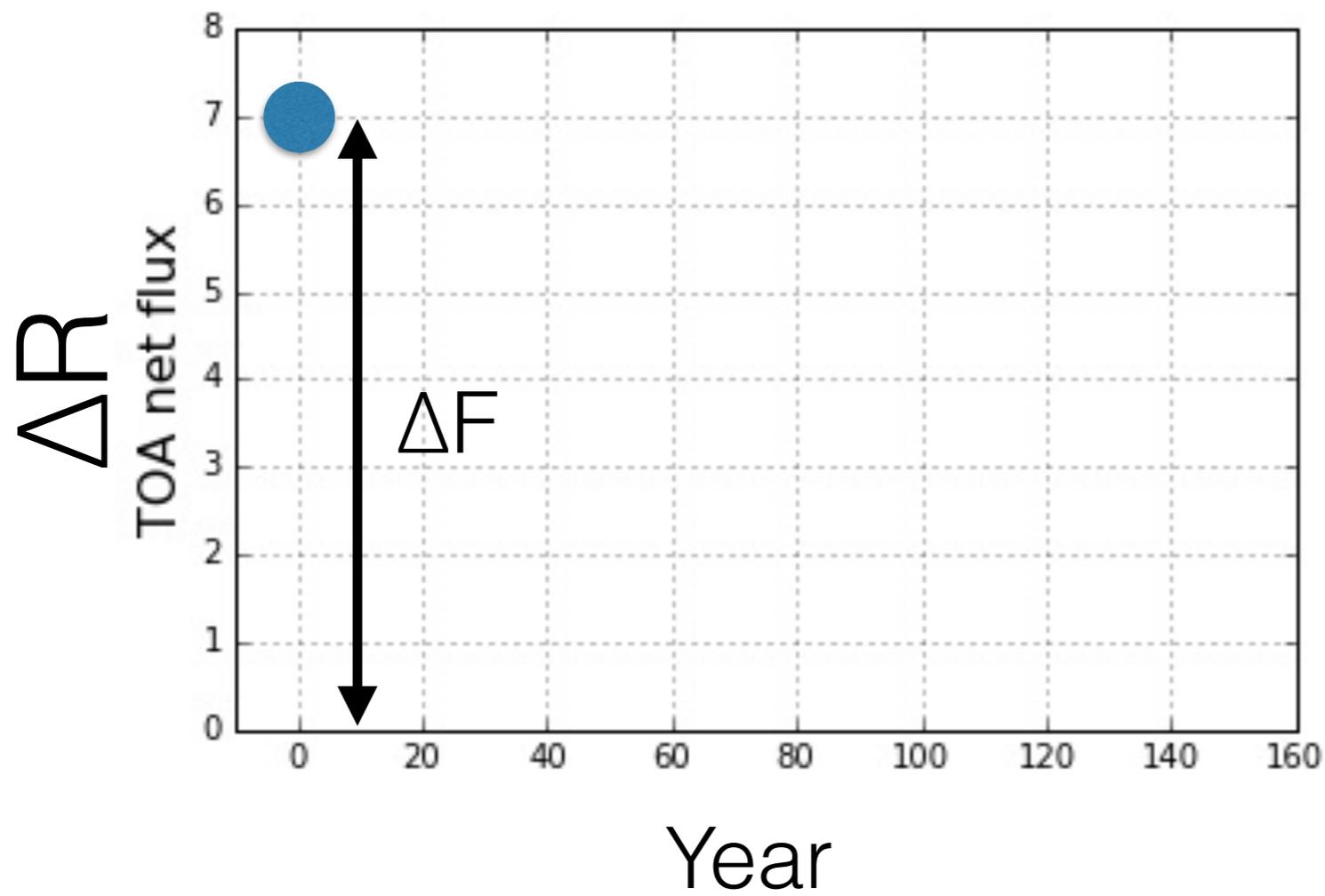


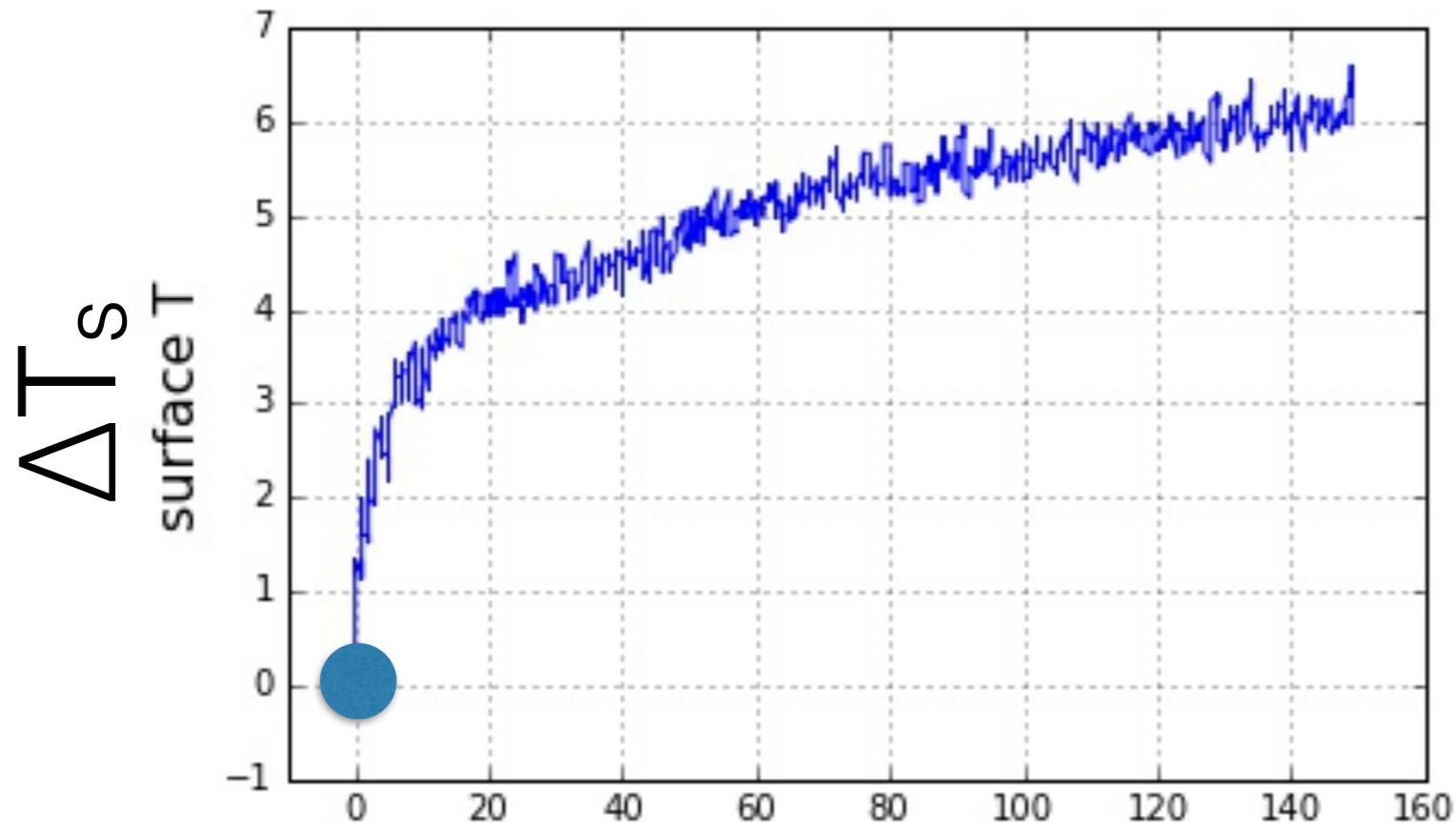
abrupt 4xCO<sub>2</sub>  
GFDL-CM3



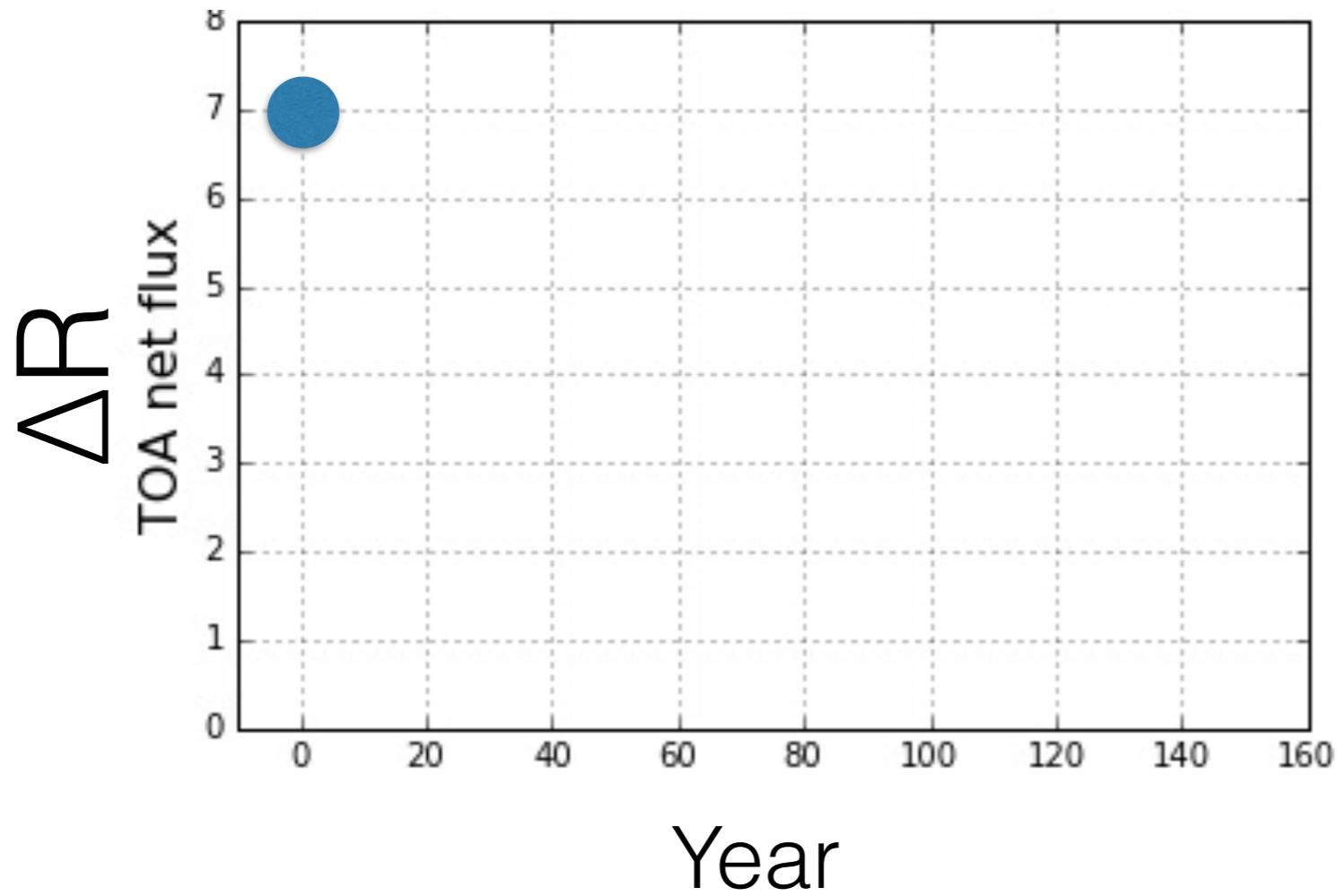


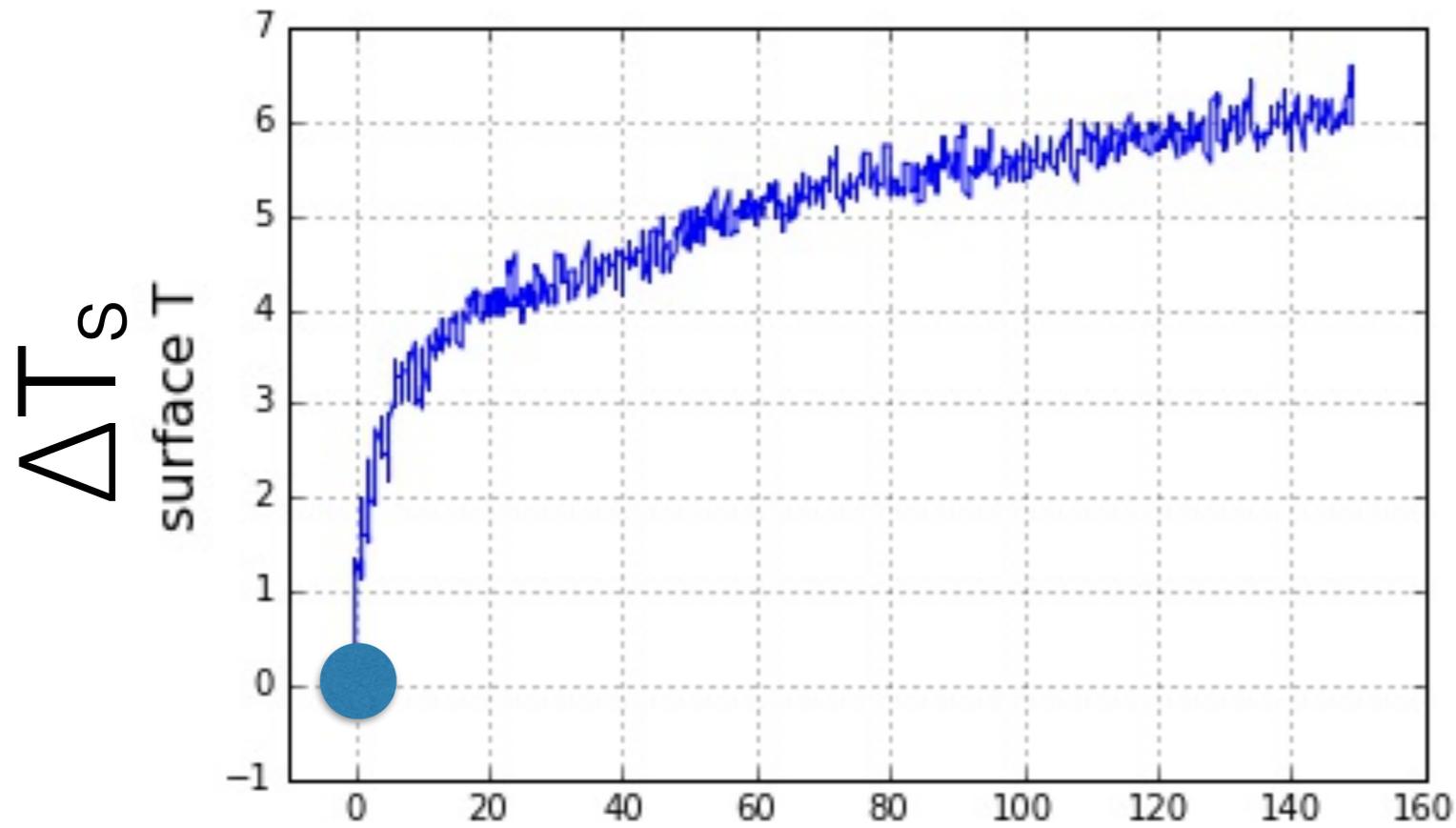
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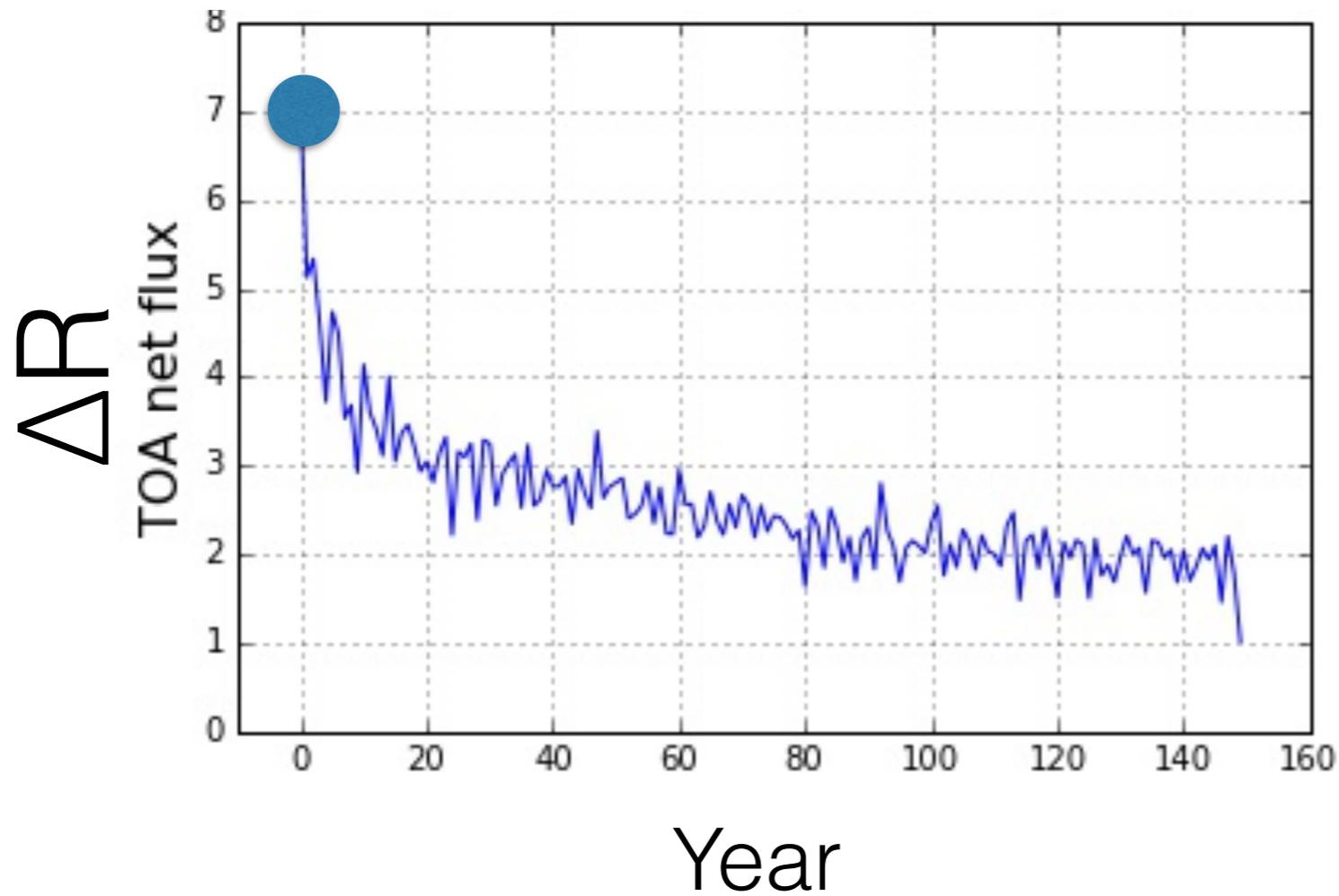


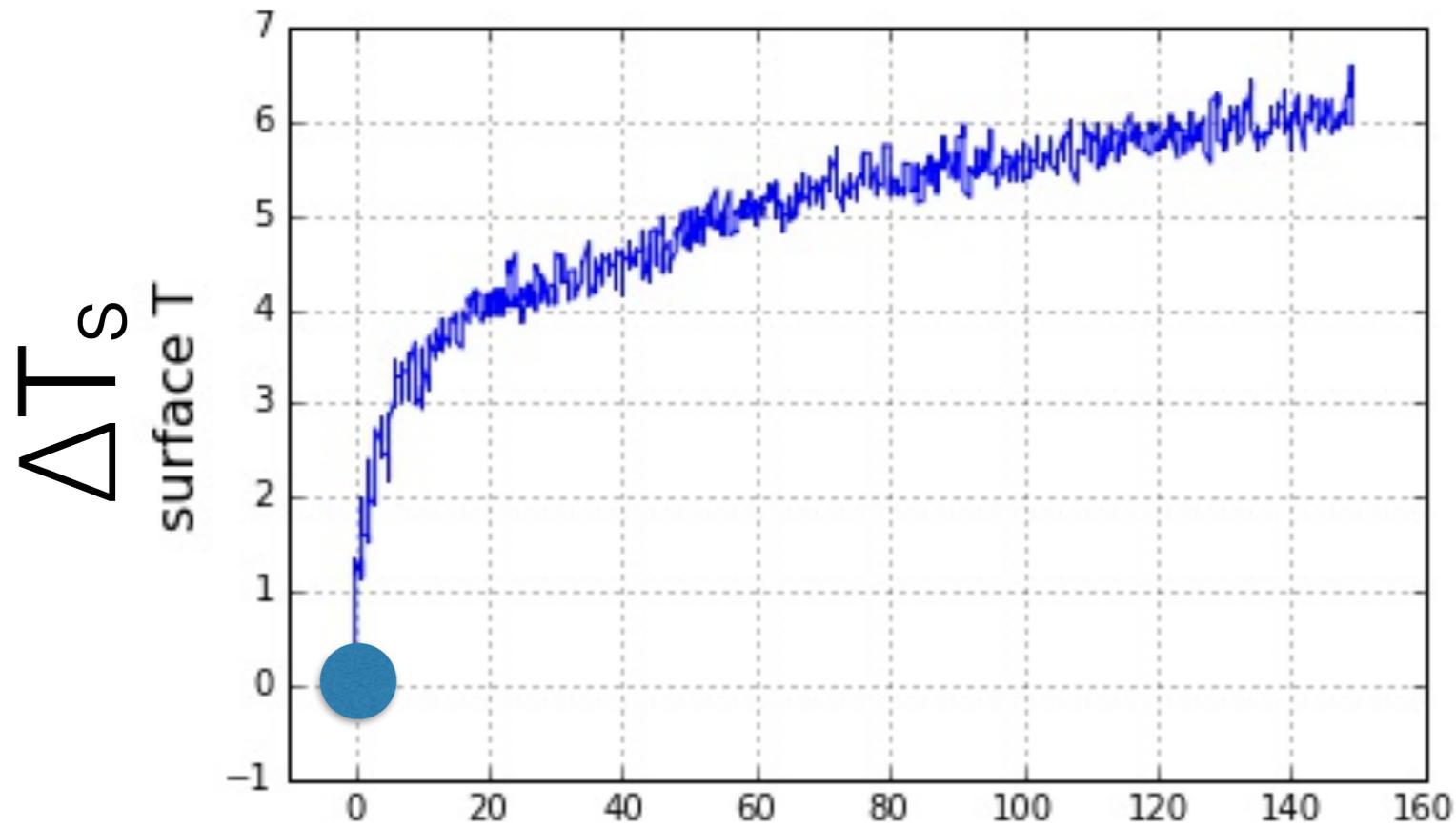
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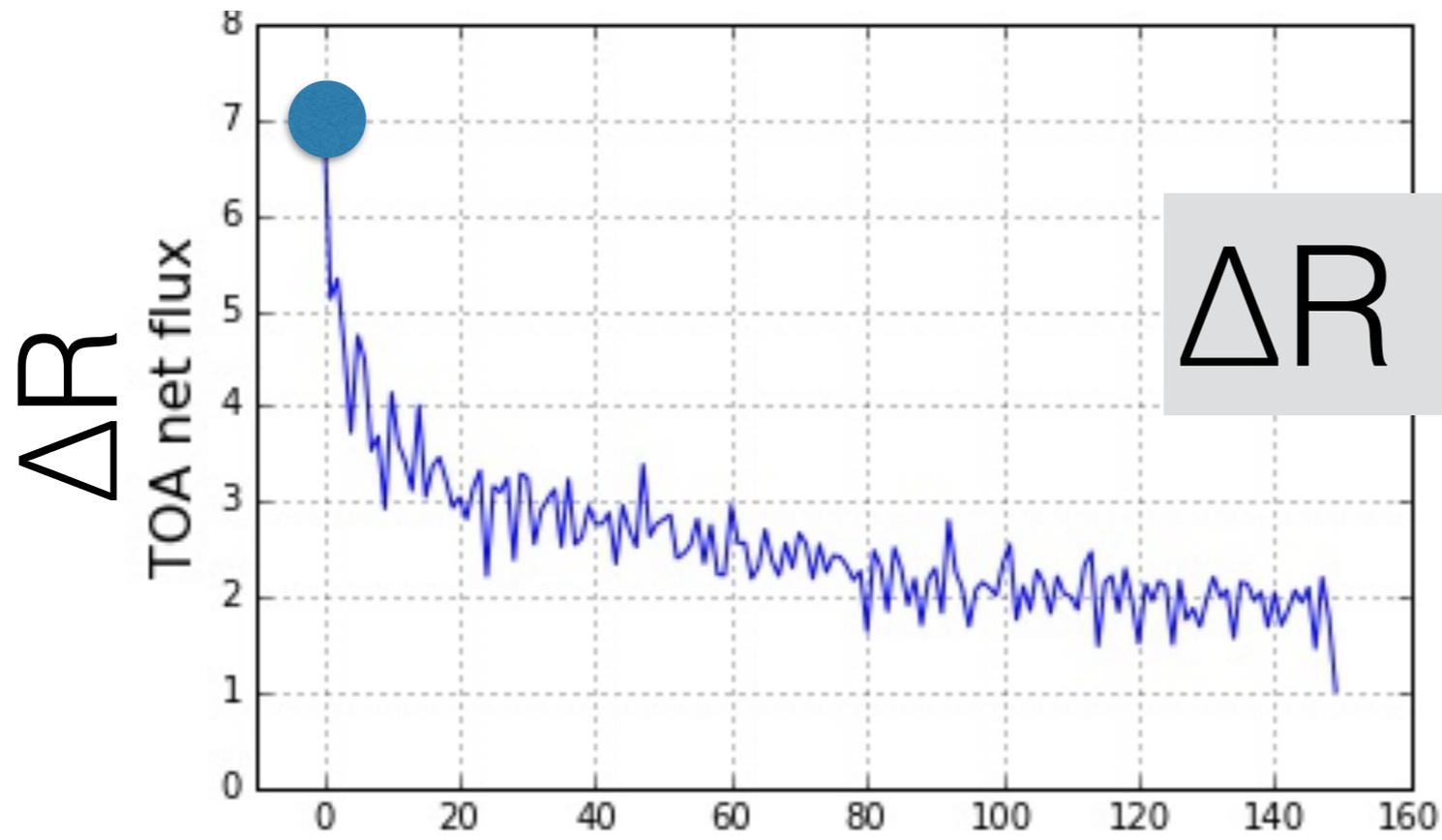


abrupt 4xCO2  
GFDL-CM3





abrupt 4xCO2  
GFDL-CM3



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

Year

At equilibrium:

$$\Delta R = \Delta F + \lambda \Delta T_s = 0$$

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$$\Delta T_s = -\Delta F/\lambda$$

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$$\Delta T_s = -\Delta F / \lambda$$

$$\Delta T_{2\times\text{CO}_2} = -\Delta F_{2\times\text{CO}_2} / \lambda = \text{ECS}$$

At equilibrium:

$$\Delta R = \Delta F + \lambda \Delta T_s = 0$$

Q: is this the right way to describe our planet's energy balance?

$$\Delta T_{2\times\text{CO}_2} = -\Delta F_{2\times\text{CO}_2}/\lambda = \text{ECS}$$

At equilibrium:

$$\Delta R = \Delta F + \lambda \Delta T_s = 0$$

Q: is this the right way to describe our planet's energy balance?

$$\Delta T_{\text{TOA}} = -\Delta F_{\text{TOA}} / \lambda = \text{ECS}$$

Q: is the response of the TOA flux linear in global avg. surface temperature?

# satellite obs. record (2000-2016)



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

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$$\Delta R_{\text{CERES}} = \Delta F + \lambda \Delta T_s$$

satellite obs. record (2000-2016)

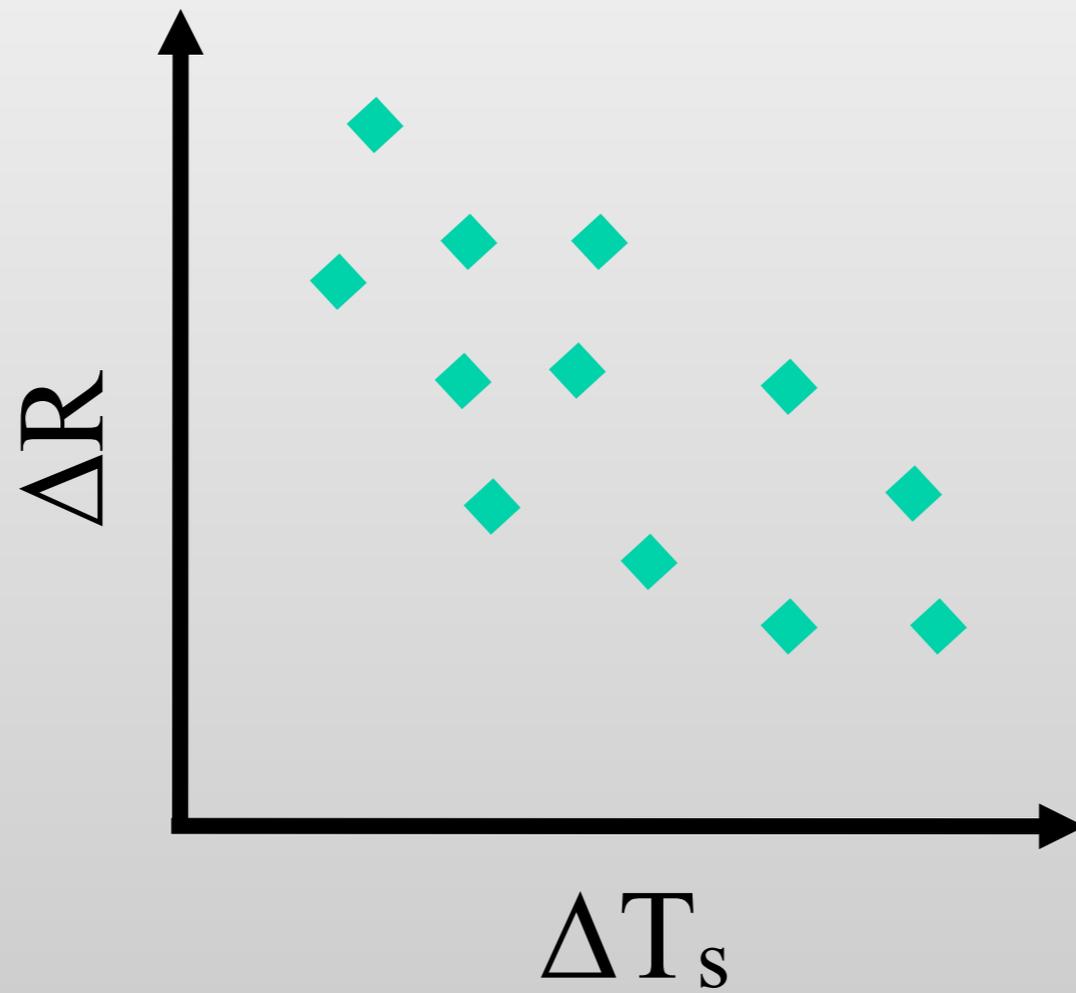
$$\Delta R_{\text{CERES}} = \Delta F + \lambda \Delta T_{\text{obs}}$$



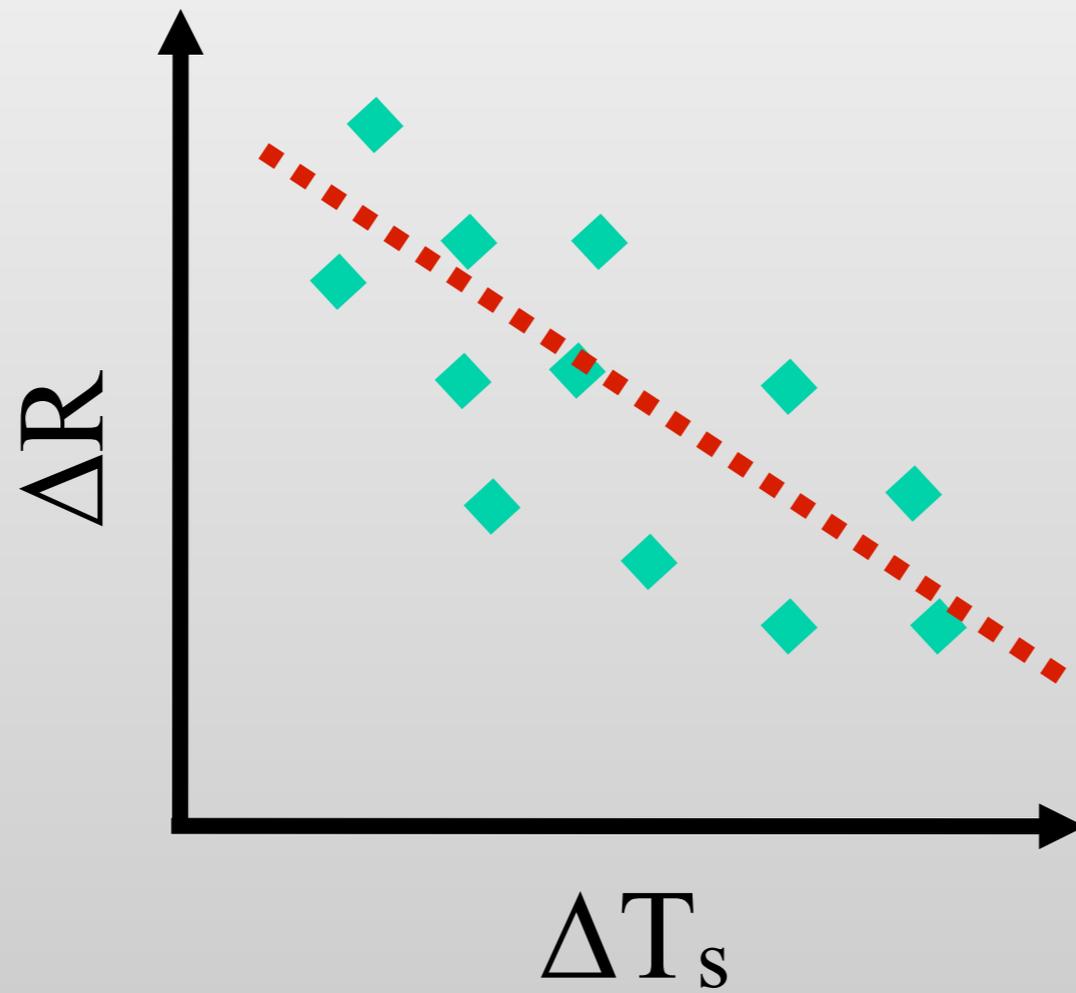
satellite obs. record (2000-2016)

$$\Delta R_{\text{CERES}} = \overset{\text{small}}{\Delta F} + \lambda \Delta T_{\text{obs.}}$$

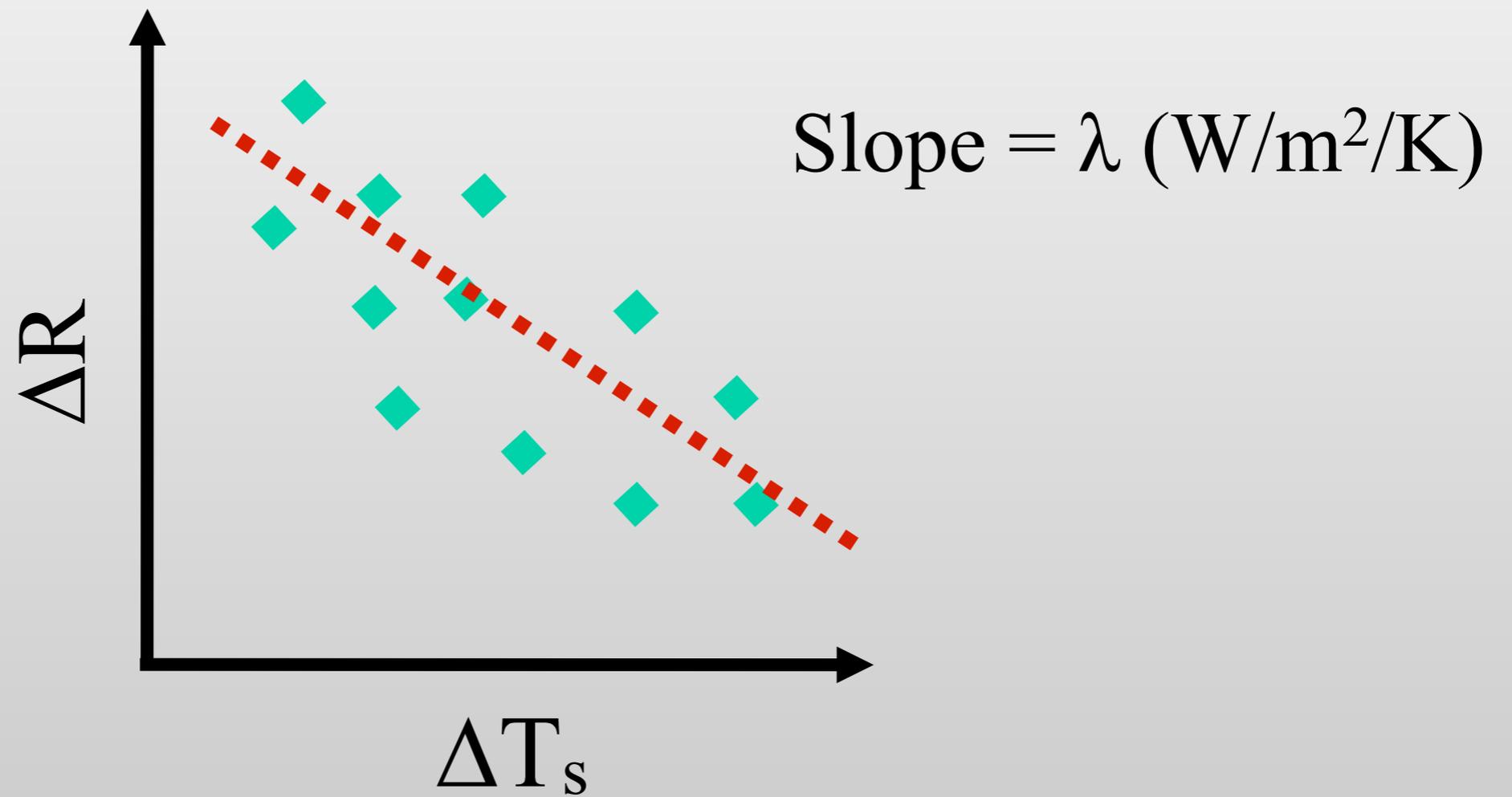
$$\Delta R = \cancel{\Delta F} + \lambda \Delta T_s$$



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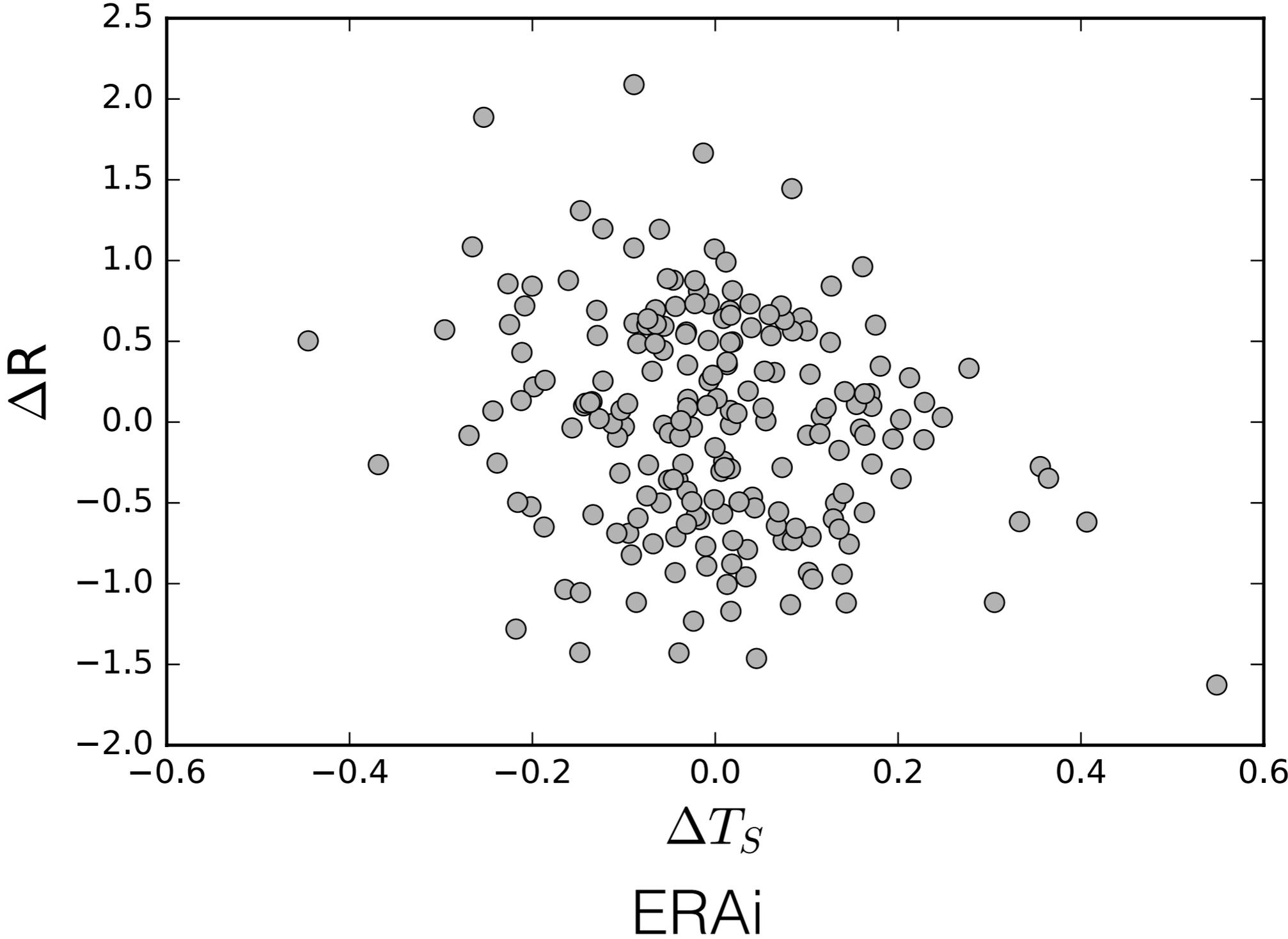


$$\Delta R = \cancel{\Delta F} + \lambda \Delta T_s$$



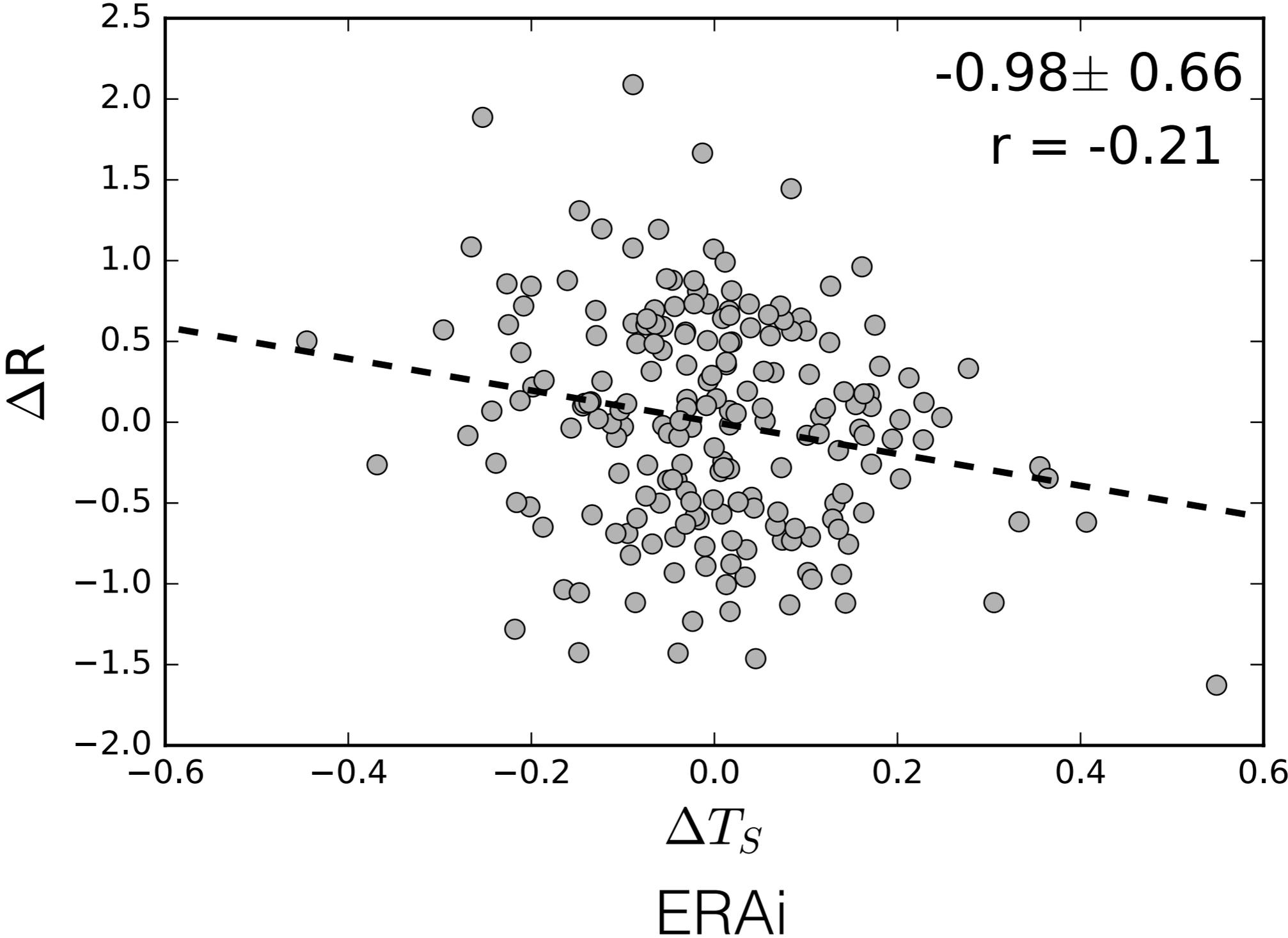
Global, monthly avg., detrended, 3/2000-9/2016

CERES Ed. 4, EBAF



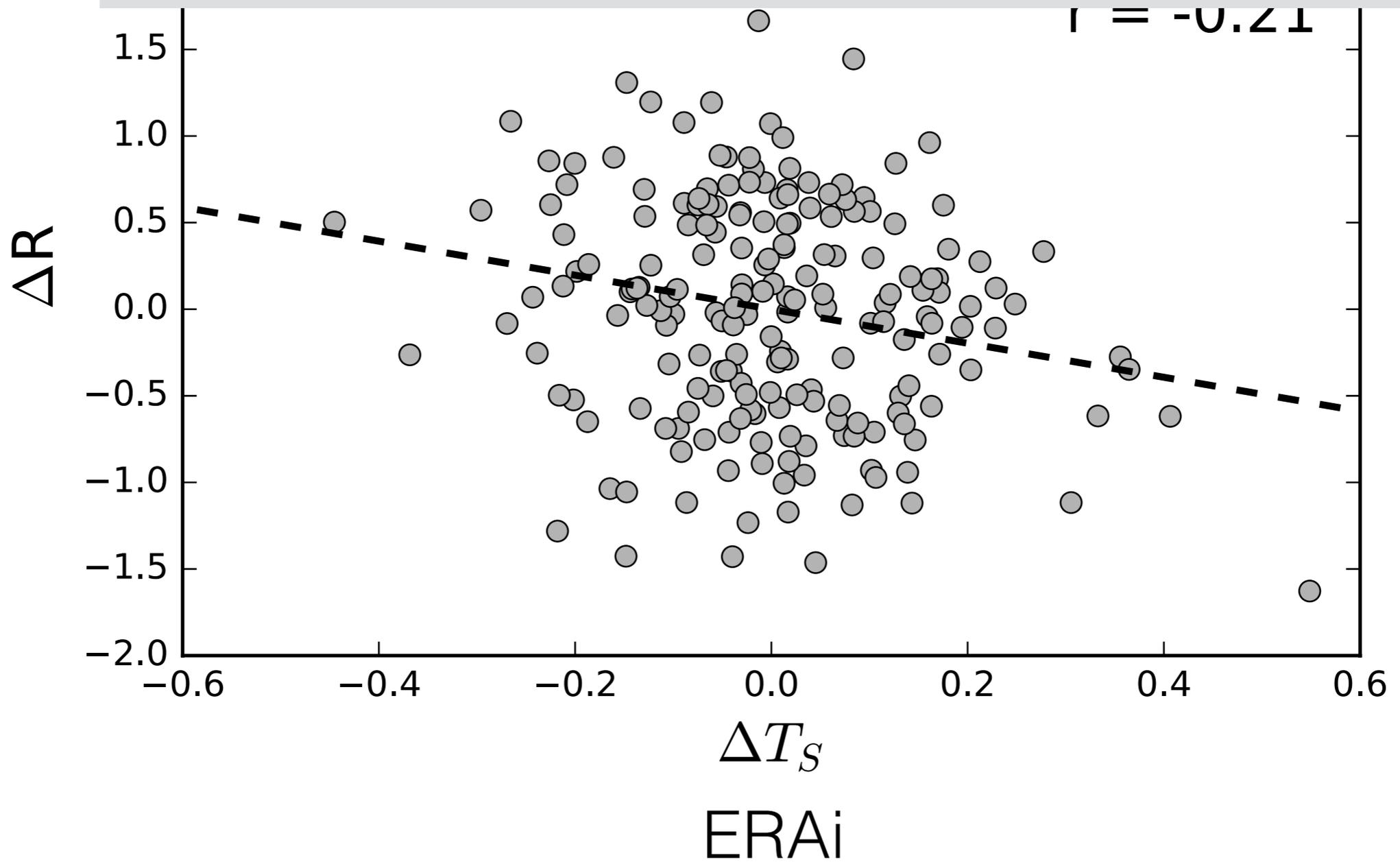
Global, monthly avg., detrended, 3/2000-9/2016

CERES Ed. 4, EBAF

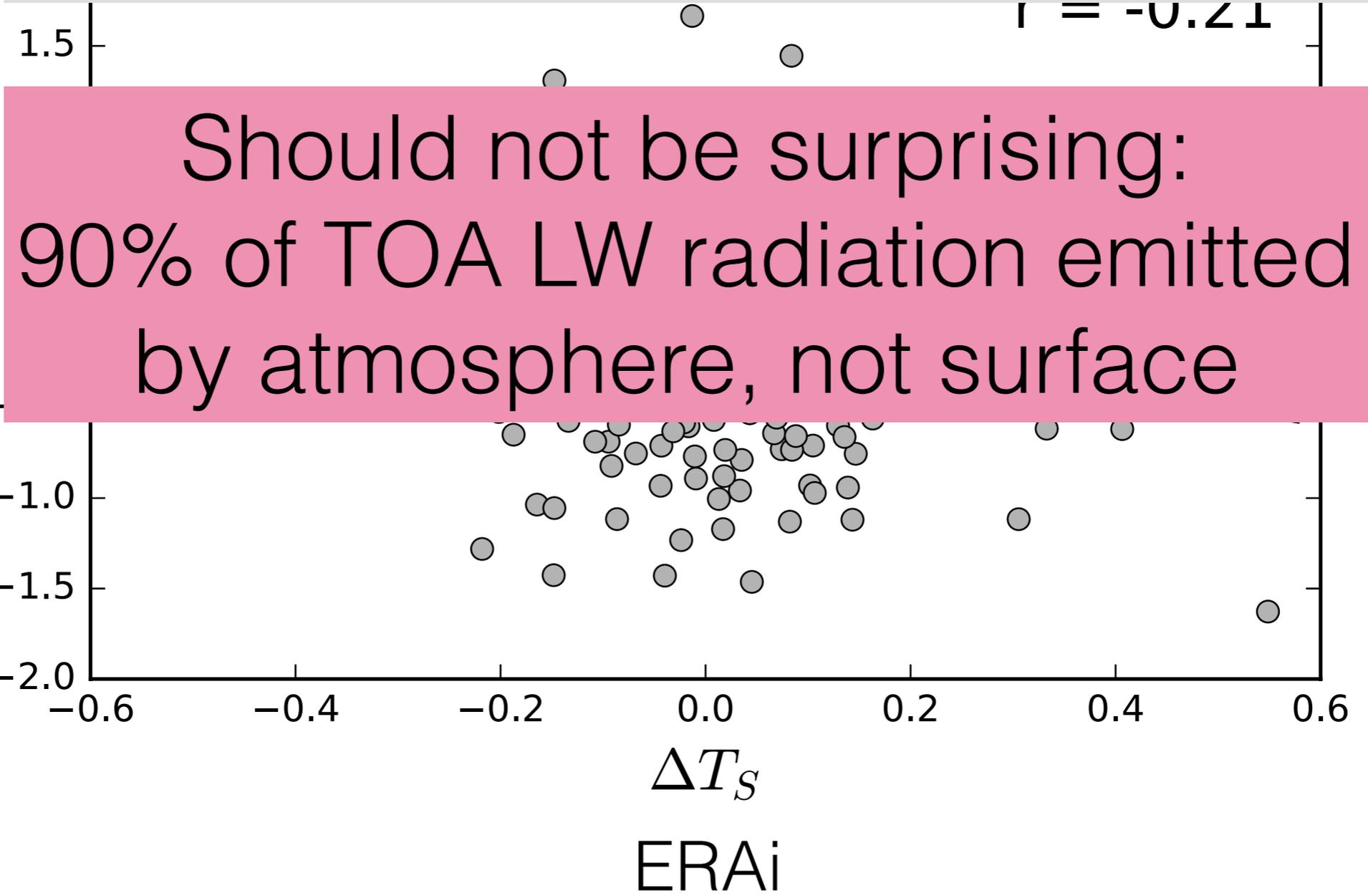


Lesson:  $\lambda\Delta T$  is not a very good parameterization for  $\Delta R$  (for interannual variability)

CERES Ed. 4, EBAF



Lesson:  $\lambda\Delta T$  is not a very good parameterization for  $\Delta R$  (for interannual variability)



Derive ECS &  $\lambda$  from 20th century record

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



Derive ECS &  $\lambda$  from 20th century record

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

**obs.**

Derive ECS &  $\lambda$  from 20th century record

$$\Delta R = \overset{\text{climate model}}{\Delta F} + \lambda \underset{\text{obs.}}{\Delta T_s}$$

Derive ECS &  $\lambda$  from 20th century record

$$\Delta R_{\text{OHC}} = \Delta F_{\text{climate model}} + \lambda \Delta T_{\text{obs}}$$

# Derive $\lambda$ from 20th century record

$$\Delta R_{\text{OHC}} = \Delta F_{\text{climate model}} + \lambda \Delta T_s_{\text{obs.}}$$

$$\lambda \approx -2 \text{ W/m}^2/\text{K}$$

$$\text{ECS} \approx 1.5\text{-}2.0 \text{ K}$$

# Derive $\lambda$ from 20th century record

$$\Delta R_{\text{OHC}} = \Delta F_{\text{climate model}} + \lambda \Delta T_s_{\text{obs.}}$$

$$\lambda \approx -2 \text{ W/m}^2/\text{K}$$

$$\text{ECS} \approx 1.5\text{-}2.0 \text{ K}$$

This anchors the low end of the IPCC's  
ECS range to 1.5 K

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

obs.

models

$\Delta F$

$\Delta R$

$\Delta T_s$

$$\lambda \approx -2 \text{ W/m}^2$$

$$\text{ECS} < 2 \text{ K}$$

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

obs.

$\Delta F$

$\Delta R$

$\Delta T_s$

$\lambda \approx -2 \text{ W/m}^2$

ECS < 2 K

models

same

same

same

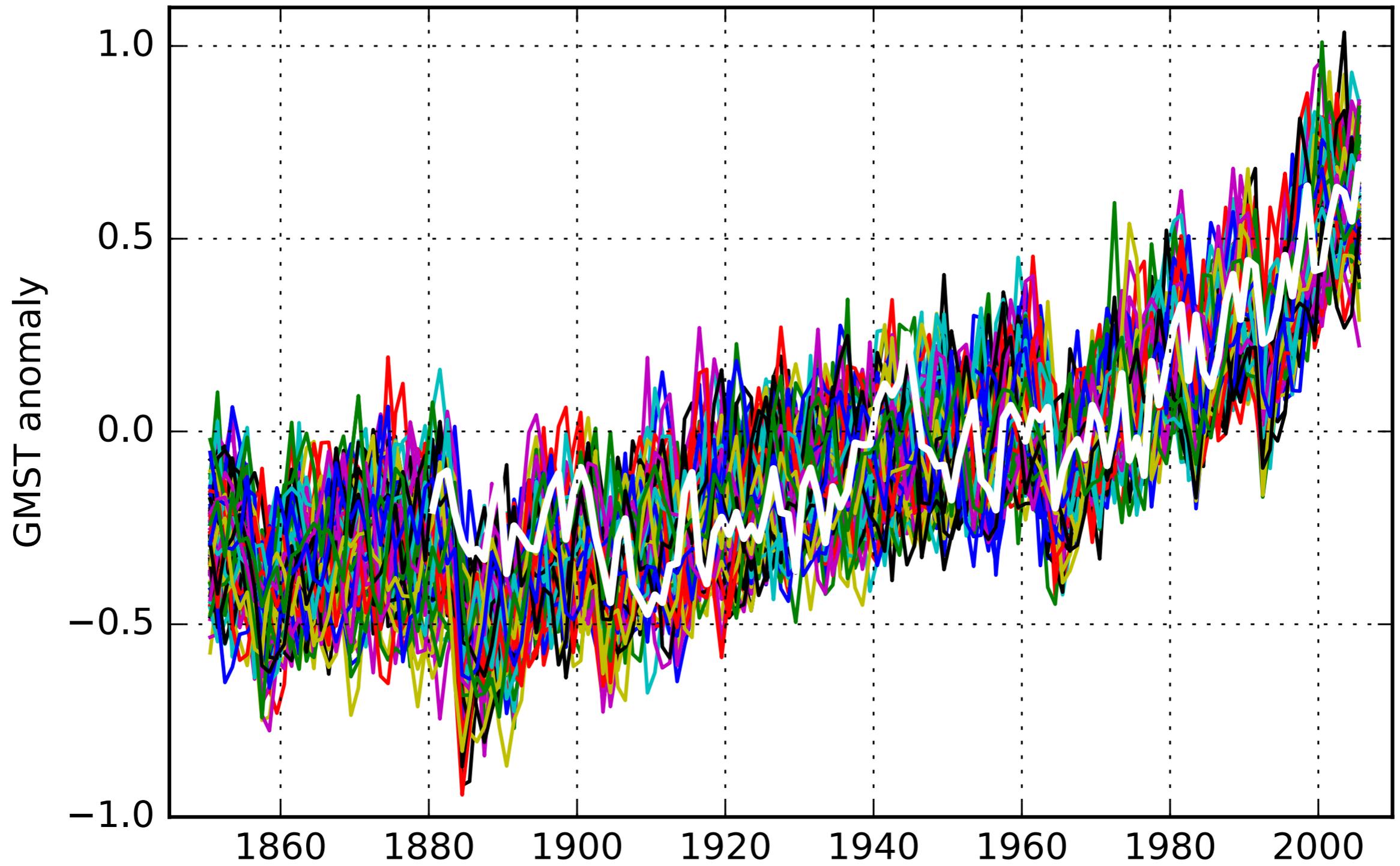
$\lambda \approx -1.3$

ECS 2-4.5 K

# Perfect model experiment

- 100-member MPI-ESM1.1 ensemble
  - model producing output for CMIP6
- 1850-2005; identical historical forcing
- only difference is the initial conditions





For each ensemble member ...

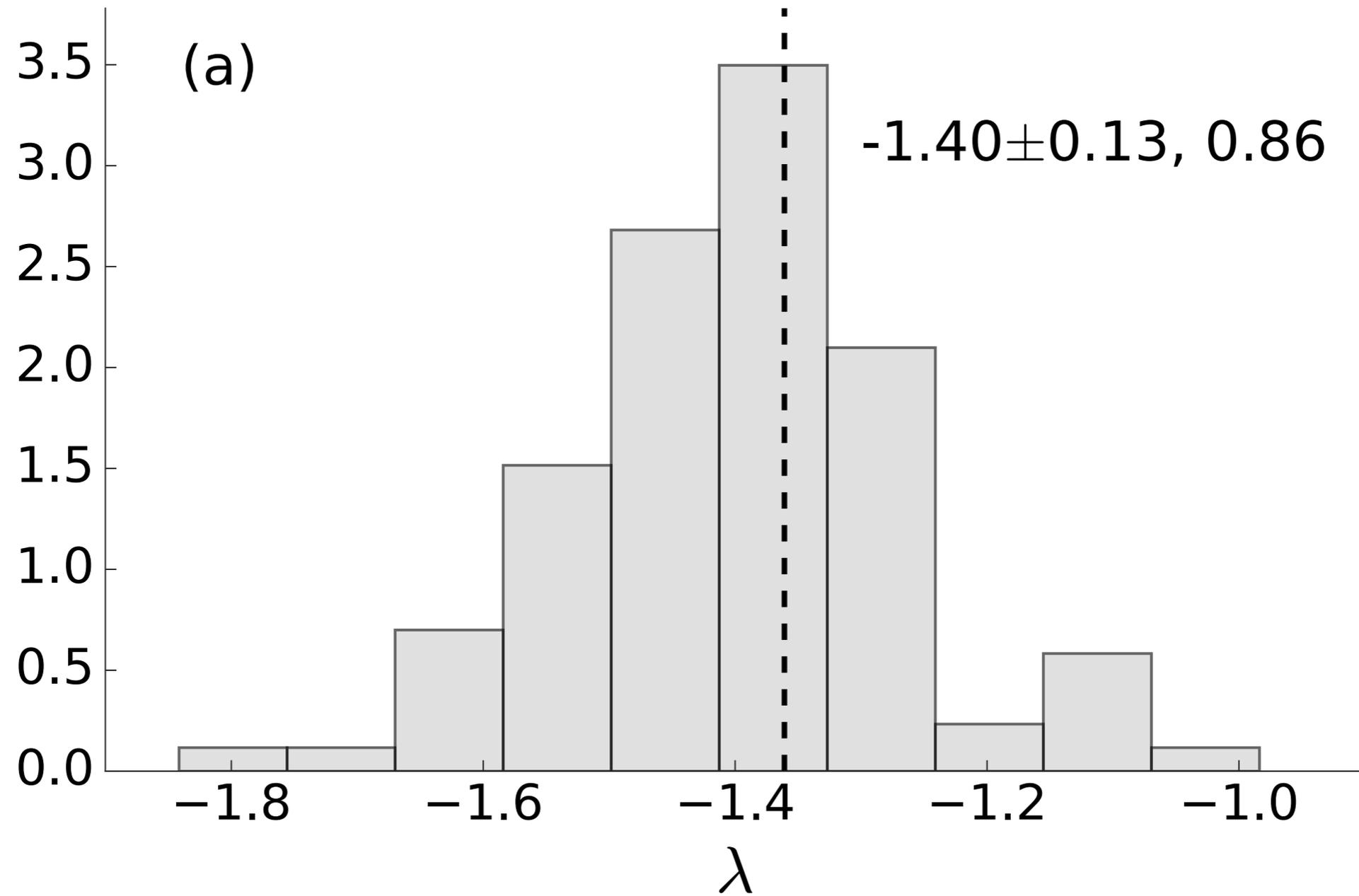
$$\Delta R = \Delta F + \lambda \Delta T$$

For each ensemble member ...

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



solve for this

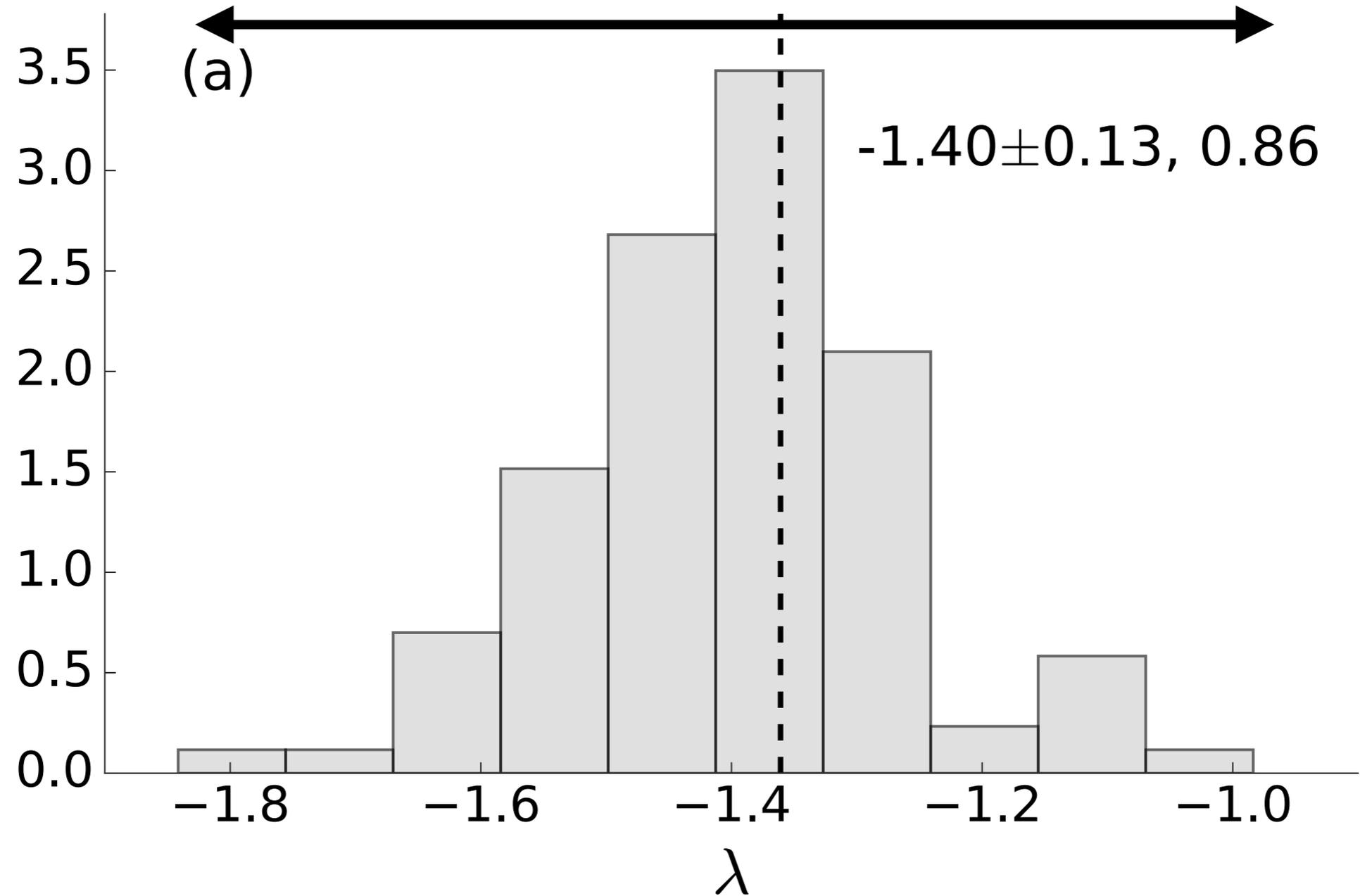


$$\lambda = \Delta(R-F)/\Delta T_s$$

W/m<sup>2</sup>/K

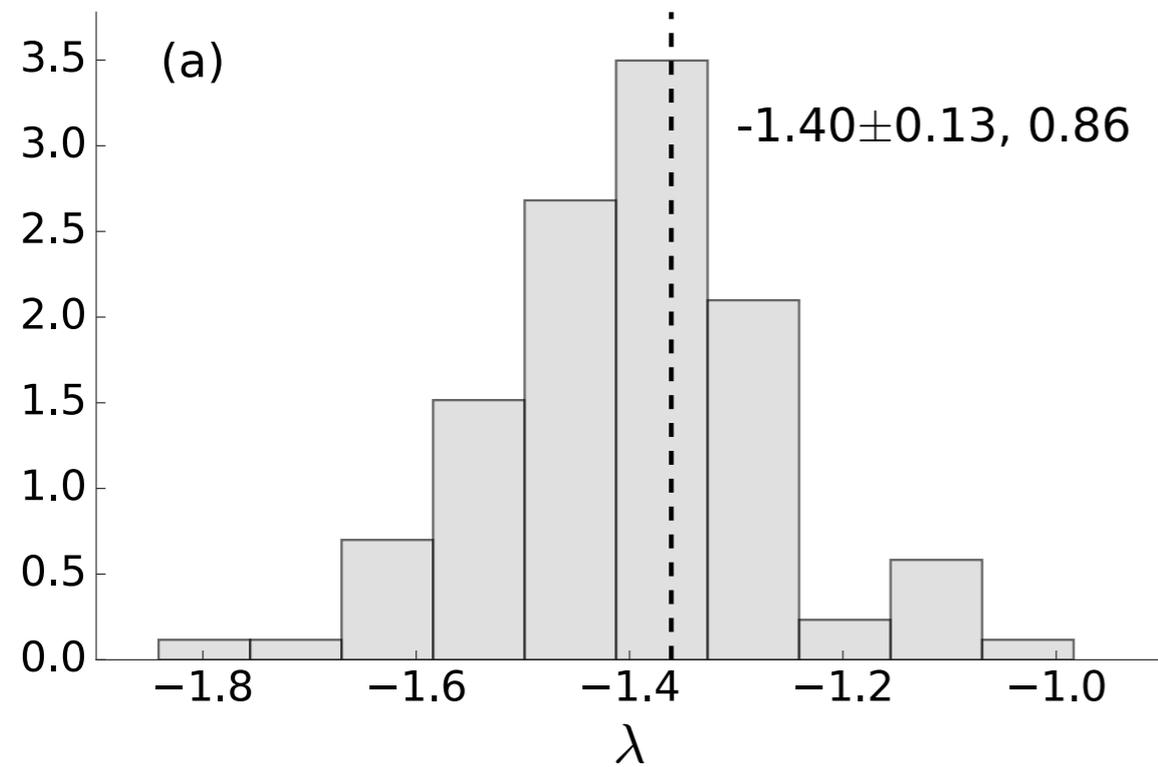


internal variability



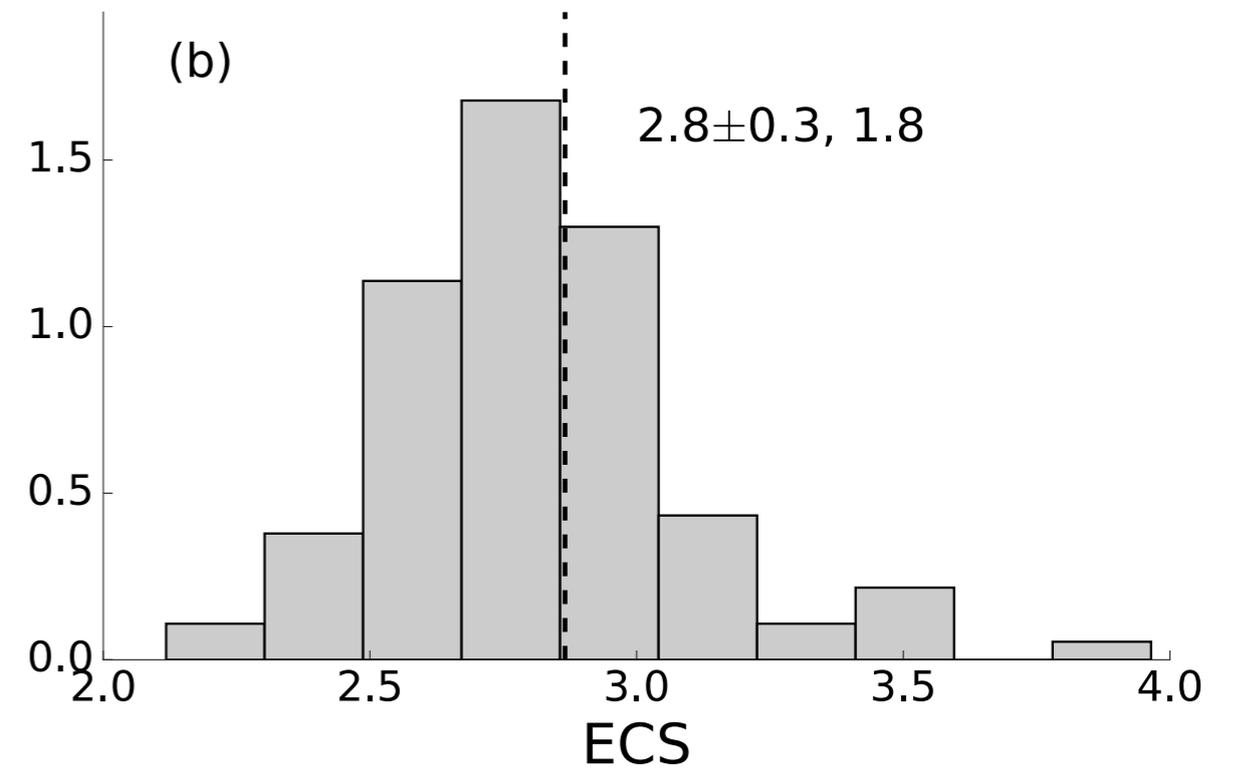
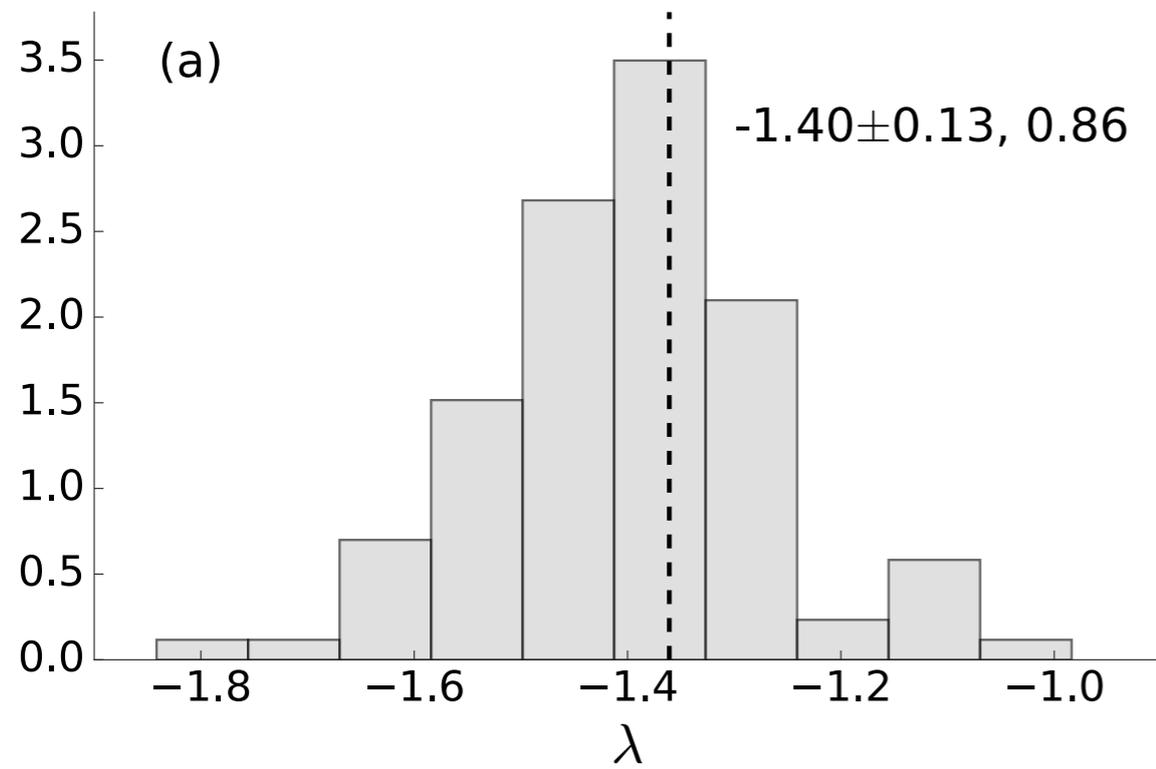
$$\lambda = \Delta(R-F)/\Delta T_s$$

W/m<sup>2</sup>/K



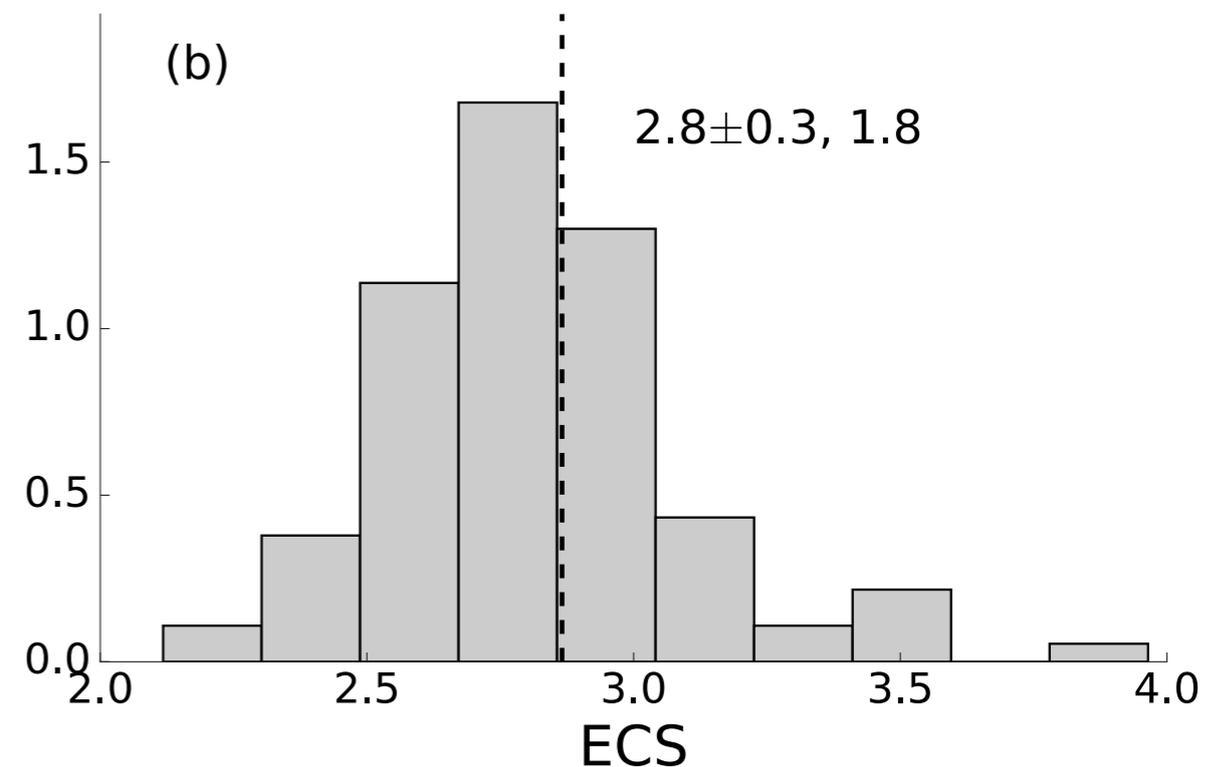
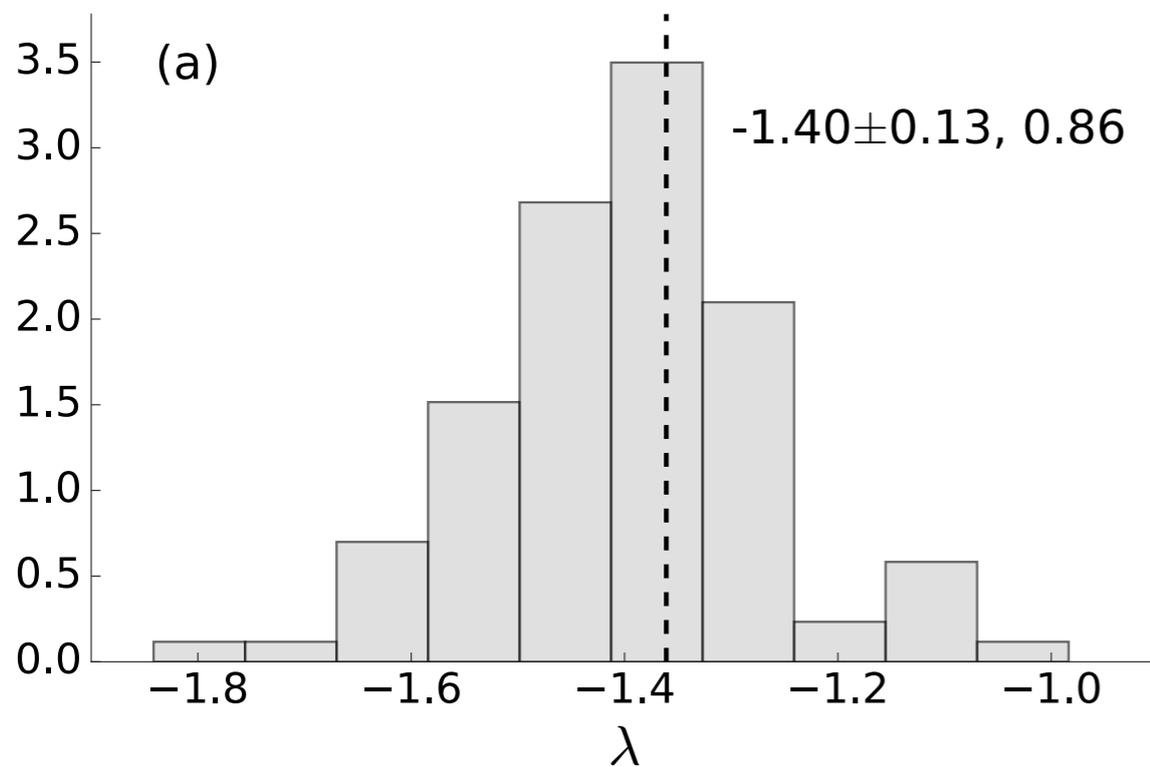
$$\lambda = \Delta(R-F)/\Delta T_s$$

$$ECS = -\Delta F_{2\times CO_2}/\lambda$$



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$$\lambda = \Delta(R-F)/\Delta T_s$$

$$ECS = -\Delta F_{2xCO_2}/\lambda$$

We only have one realization of the 20th century, so there's no guarantee that  $\lambda$  and ECS based on these calculations are good estimates

revised framework

$$\Delta R = \Delta F + \Theta \Delta T_A$$



revised framework

$$\Delta R = \Delta F + \Theta \Delta T_A$$

500-hPa tropical  
temperatures



revised framework

$$\Delta R = \Delta F + \Theta \Delta T_A$$

500-hPa tropical  
temperatures



following Trenberth, Murphy, Spencer

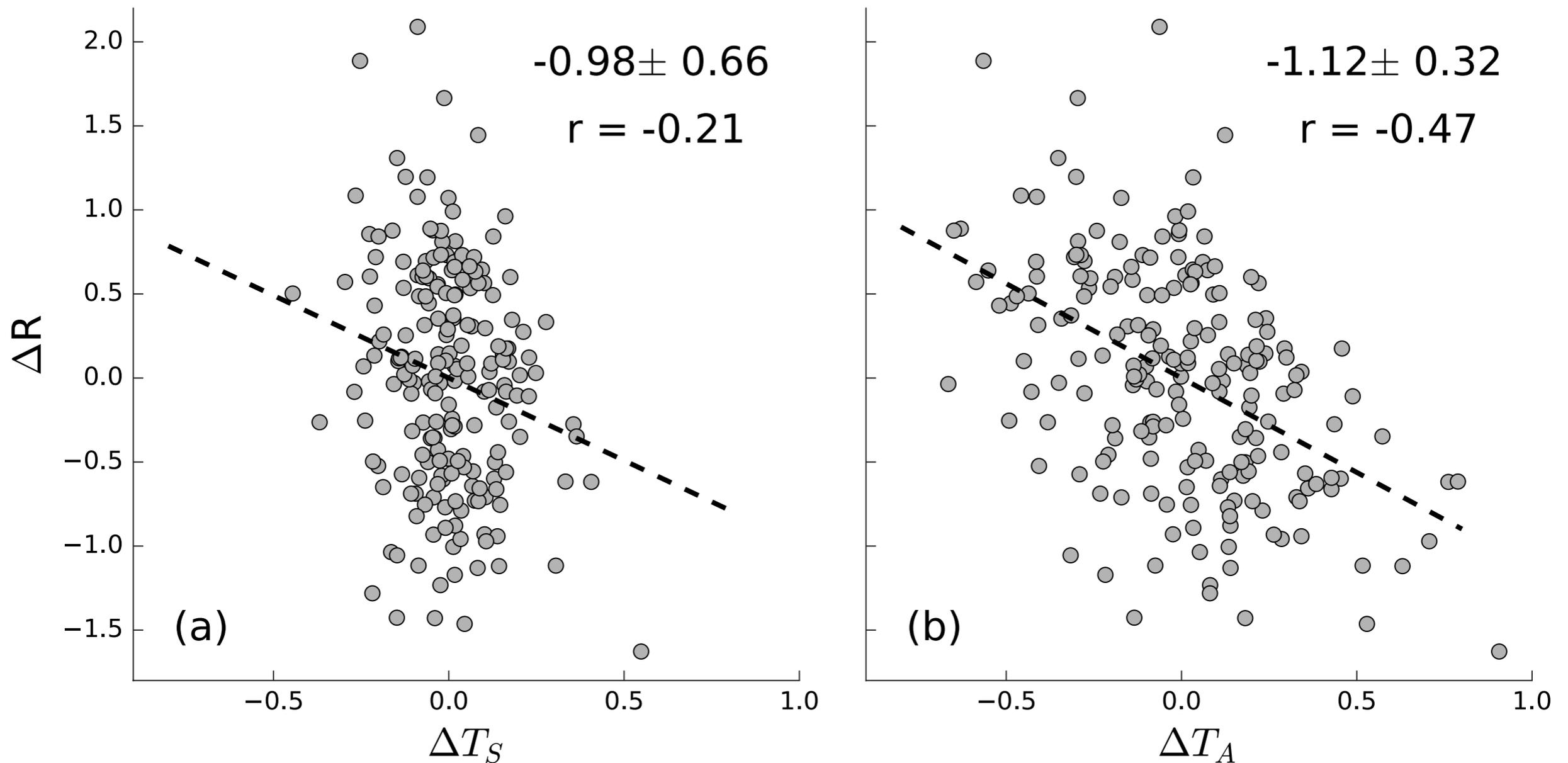
# revised framework

$$\Delta R = \Delta F + \Theta \Delta T_A$$

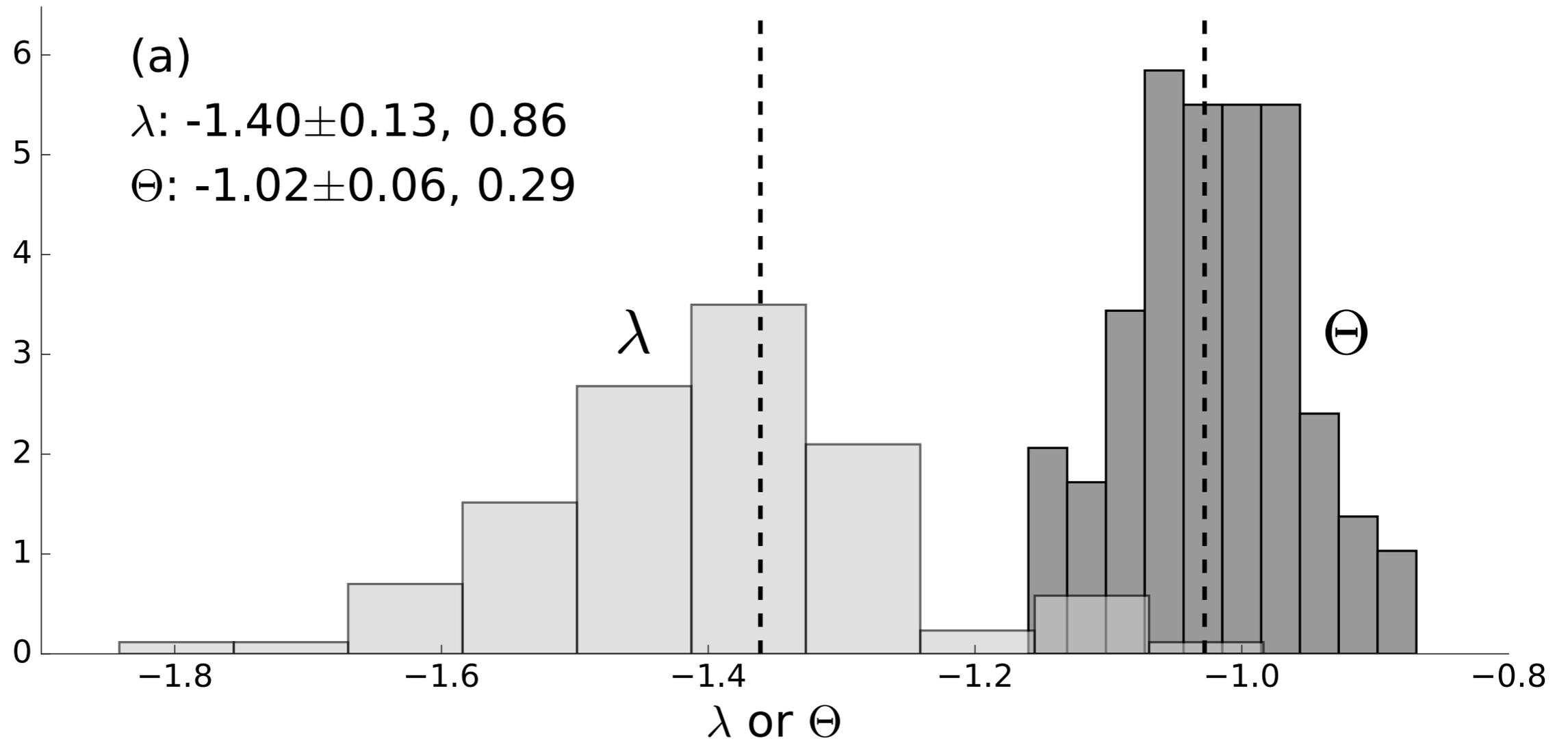
Converts change  
in  $T_A$  to flux;  
replaces  $\lambda$

500-hPa tropical  
temperatures

following Trenberth, Murphy, Spencer



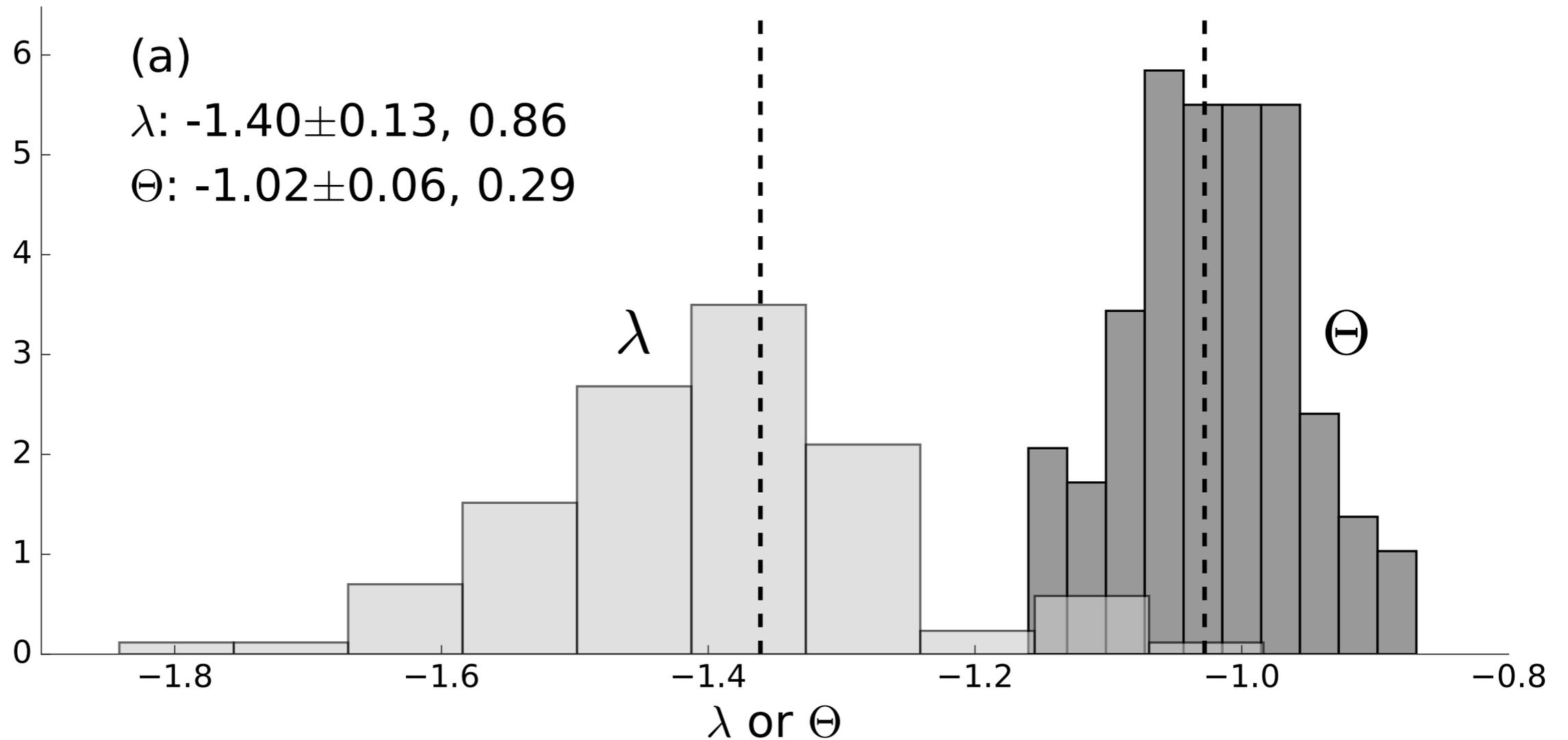
CERES Ed. 4 TOA fluxes & ERA-interim temperatures  
monthly avg. detrended anomalies  
 $T_s$  = global avg. surface temperature  
 $T_A$  = tropical avg. 500-hPa temperature



$$\lambda = \Delta(R-F)/\Delta T_S$$

$$\Theta = \Delta(R-F)/\Delta T_A$$

confirmed in CMIP5 control runs



$$\lambda = \Delta(R-F)/\Delta T_S$$

$$\Theta = \Delta(R-F)/\Delta T_A$$

$$\Delta R = \Delta F + \Theta \Delta T_A$$

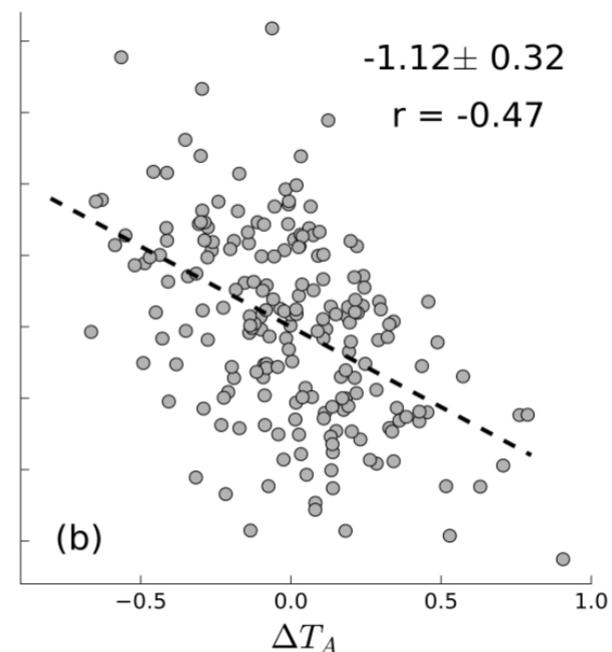


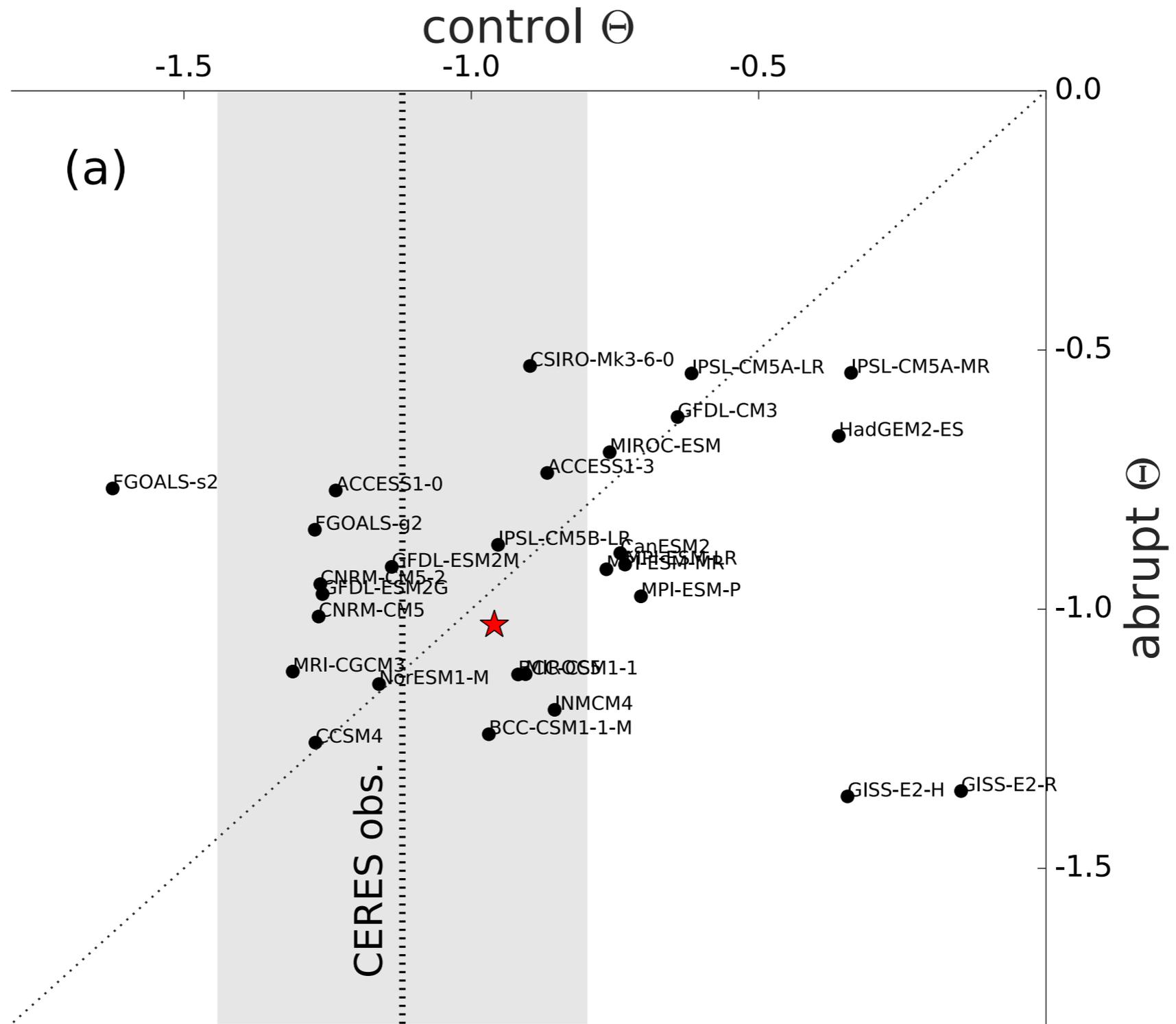
$$\Delta R = \Delta F + \Theta \Delta T_A$$

- Can we use our new framework to better predict ECS?

$$\Delta R = \Delta F + \Theta \Delta T_A$$

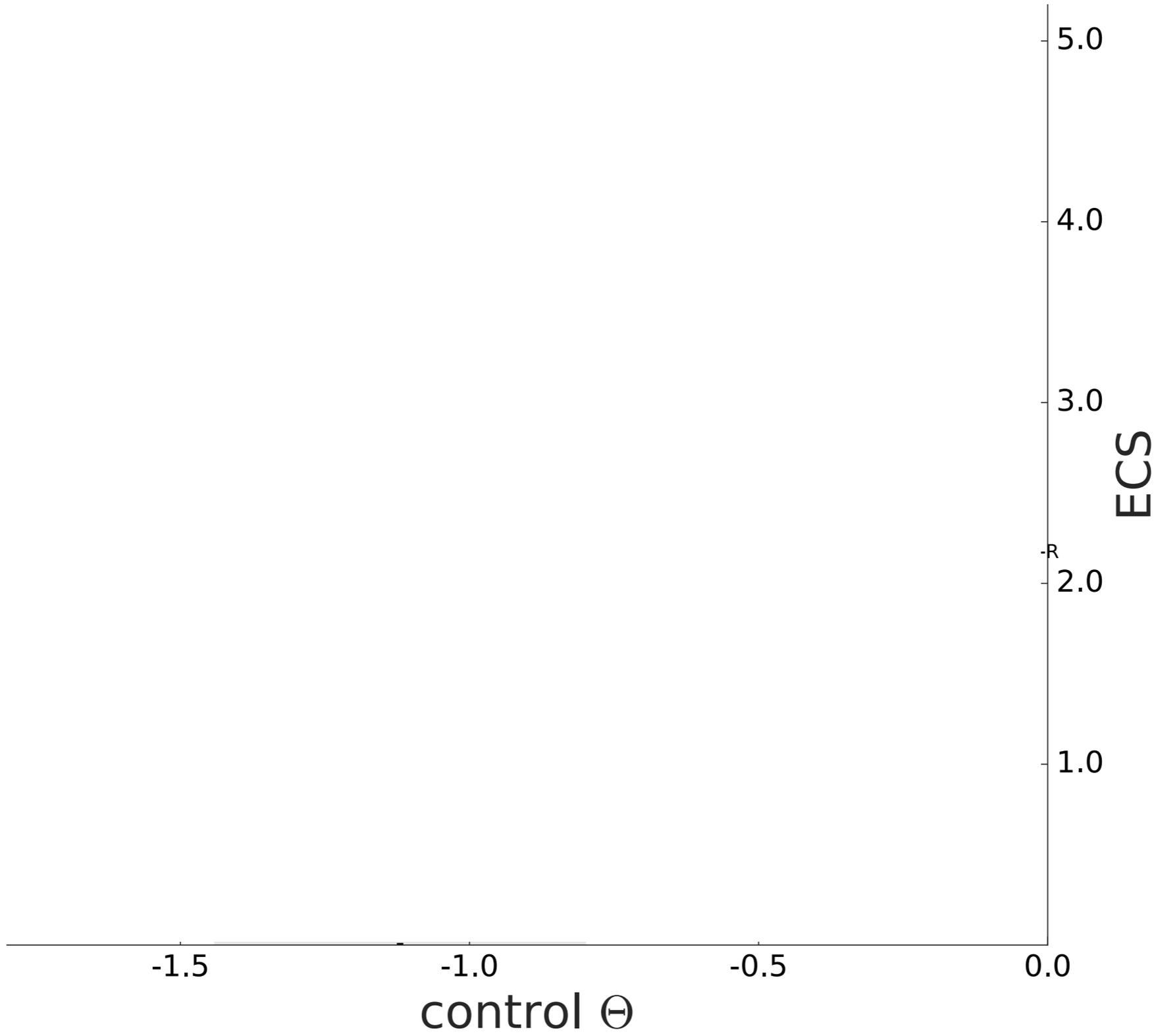
- Can we use our new framework to better predict ECS?
- Use measurement of  $\Theta_{\text{control}}$  from CERES to constrain ECS



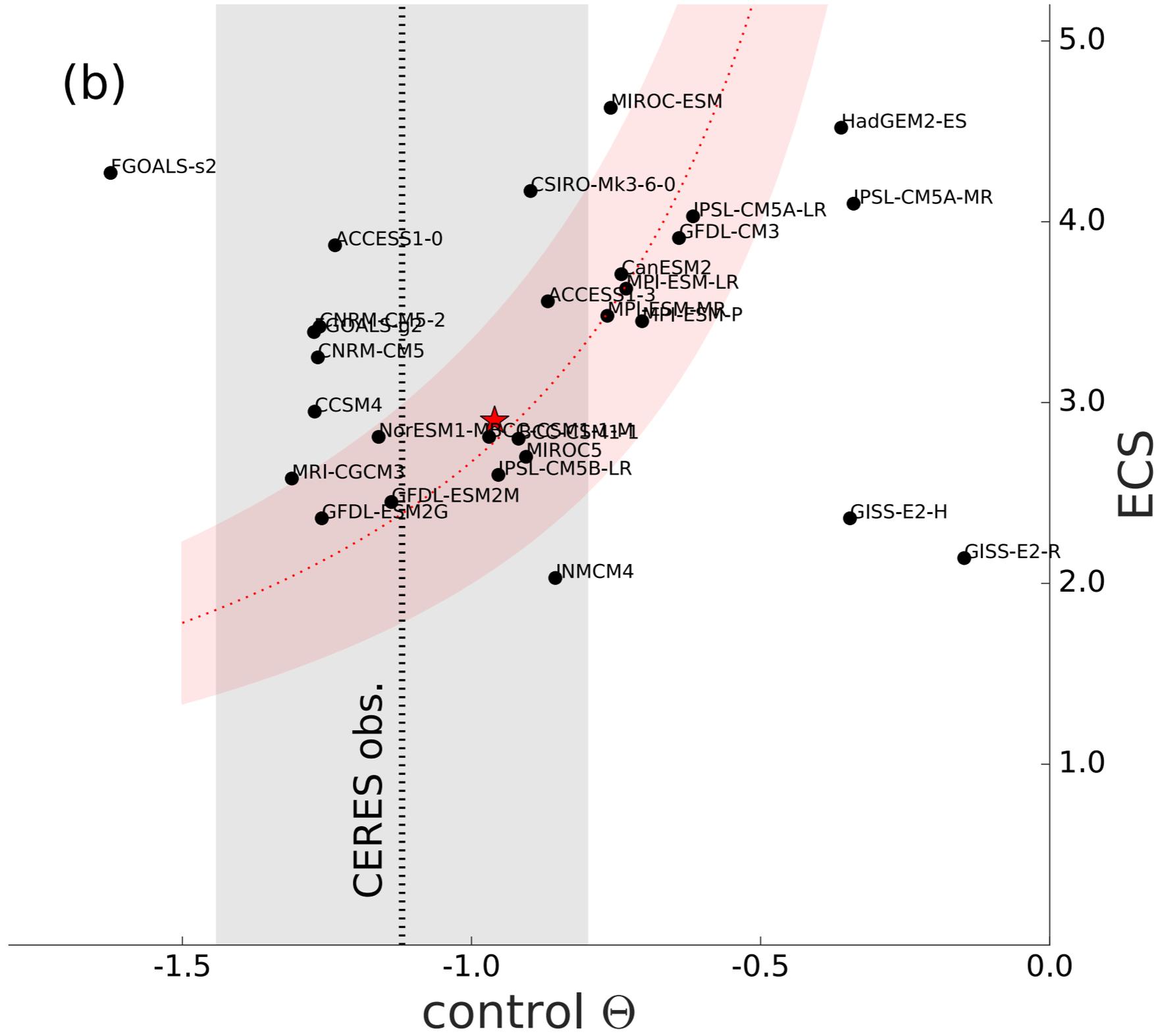


$$\Delta R = \Delta F + \Theta \Delta T_A$$

- Can we use our new framework to better predict ECS?
- Use measurement of  $\Theta_{\text{control}}$  from CERES to constrain ECS
- In CMIP5 ensemble,  $\Theta_{\text{control}} \approx \Theta_{\text{abrupt4xCO2}}$

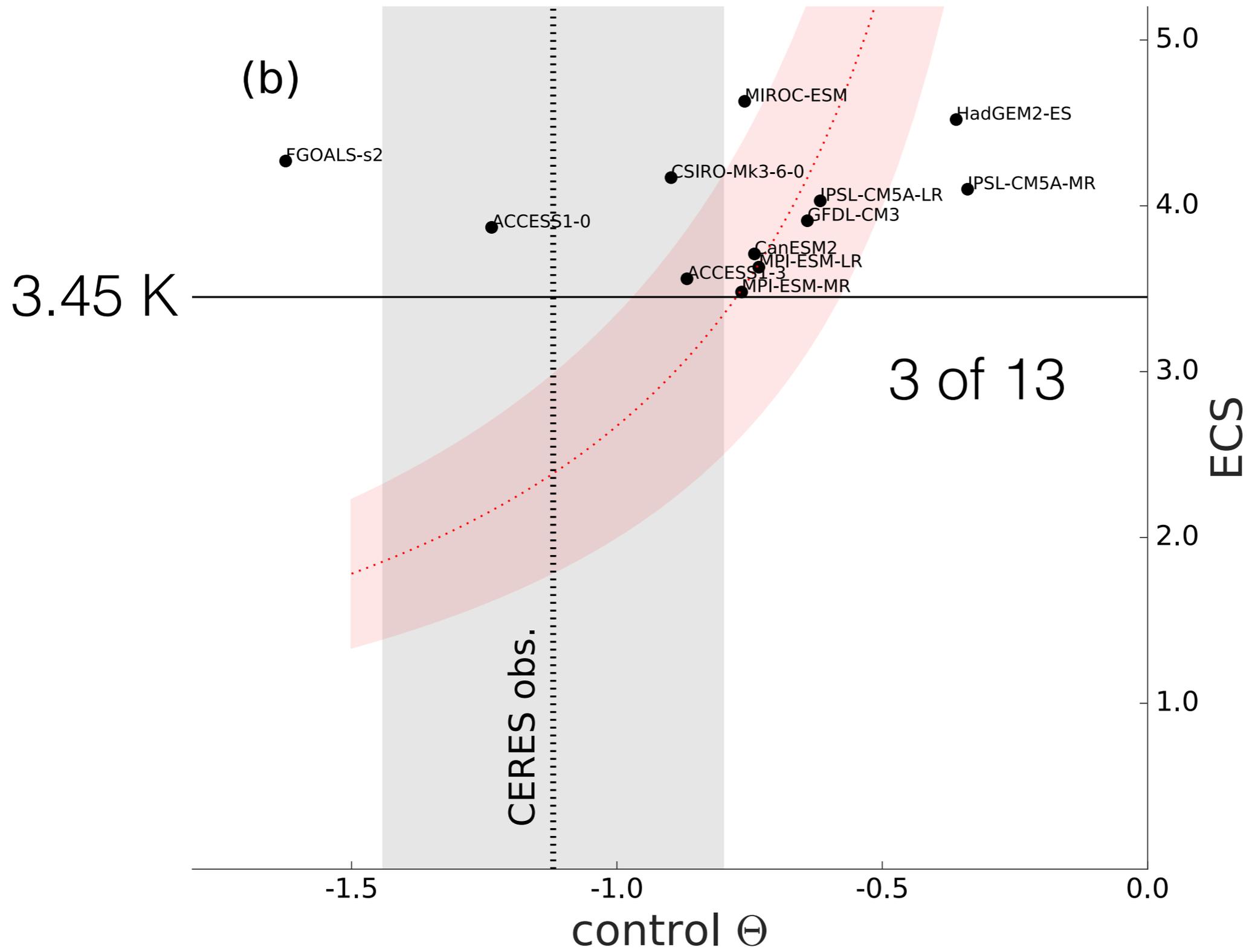


(b)













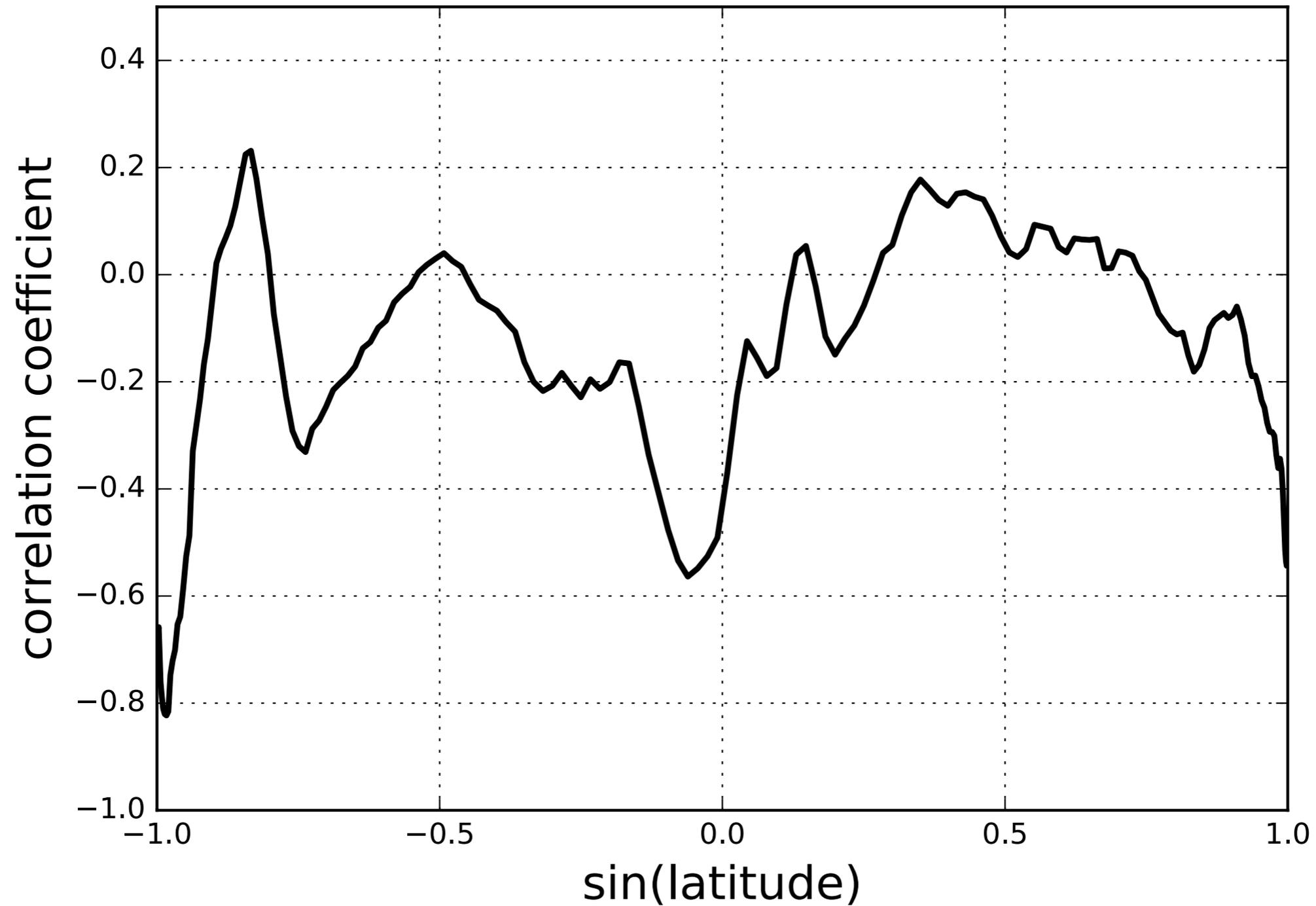
# Conclusions

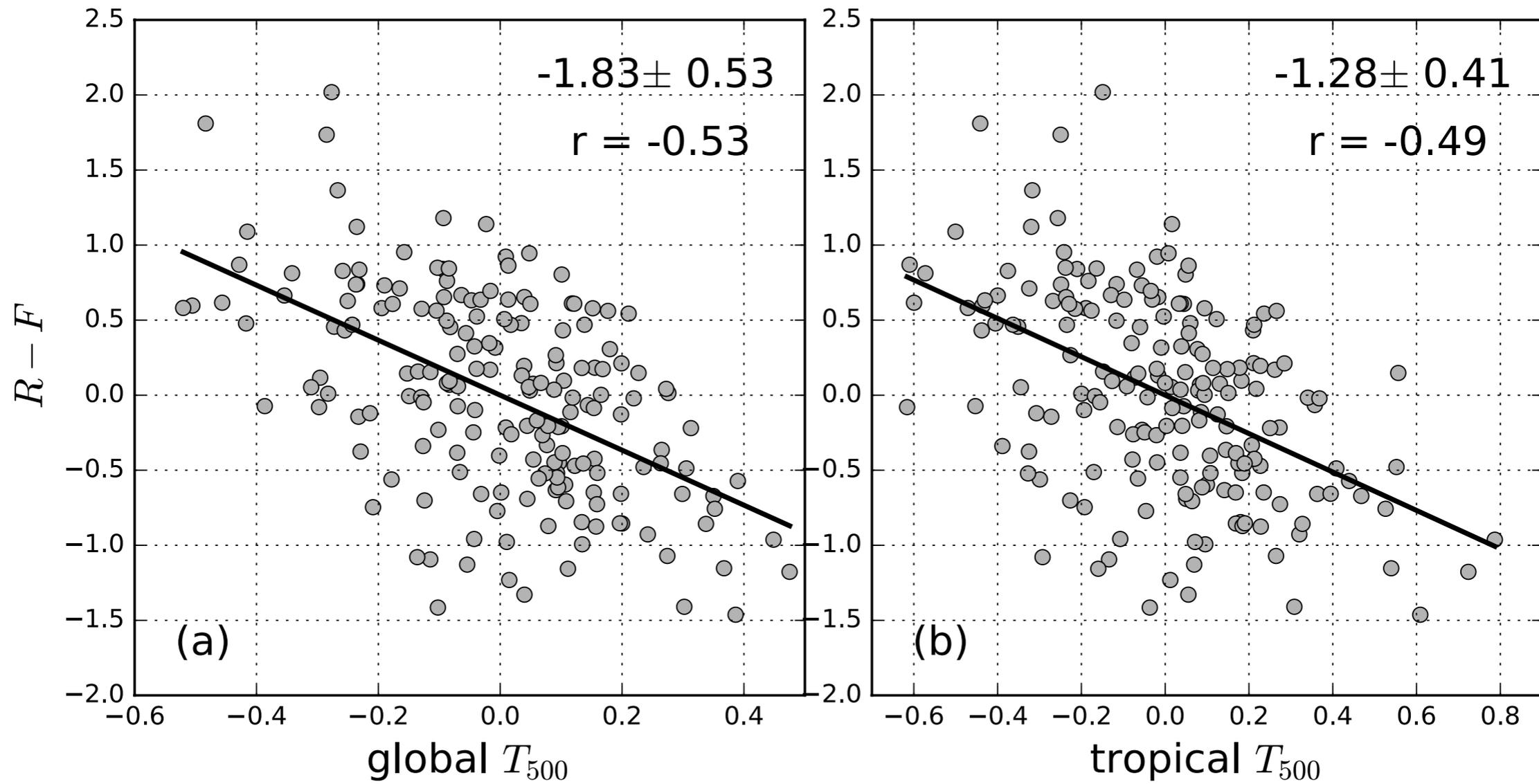
- the conventional energy balance framework has problems — TOA flux is not strongly related to surface temperature
- creates problems inferring ECS from historical data
- new framework using atmospheric temperature:  $ECS < 3.5 \text{ K}$

backup slides



CERES  $\Delta R$  at each latitude vs.  $\Delta T$ s at that same latitude  
detrended monthly avg. anomalies





global vs. tropical  $T_{500}$

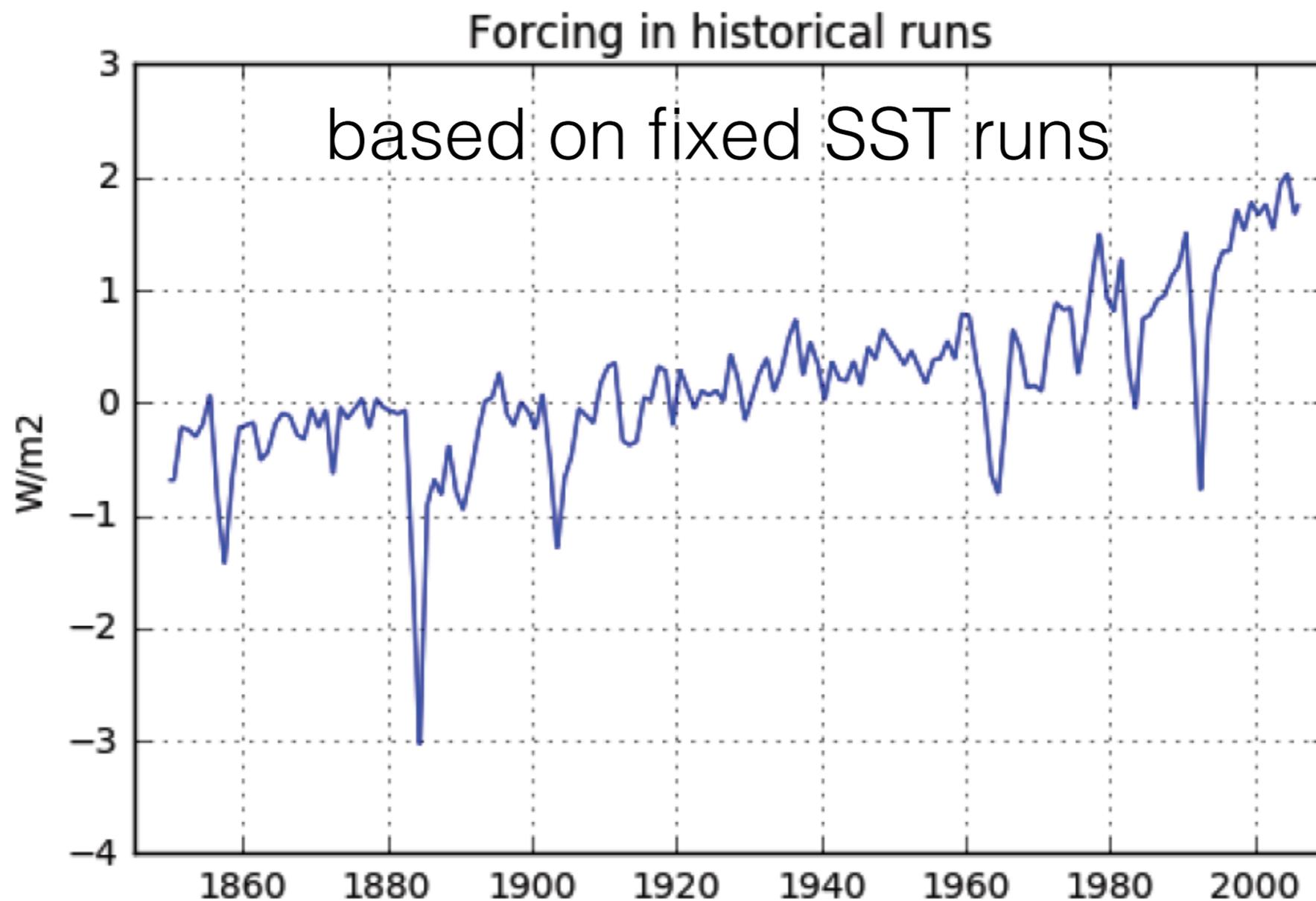
20th century obs. record

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



# 20th century obs. record

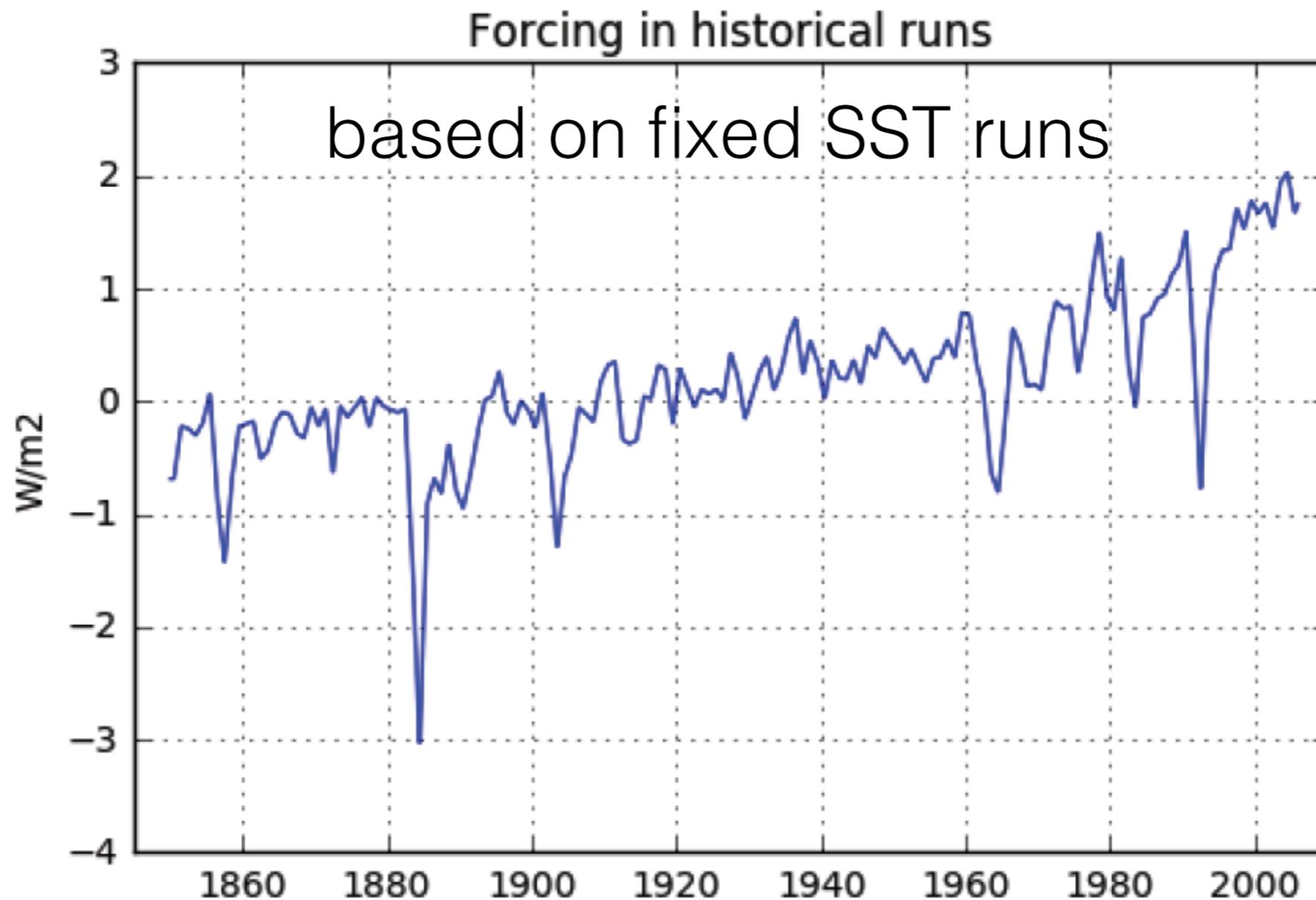
$$\Delta R = \Delta F + \lambda \Delta T$$



# 20th century obs. record

ensemble

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

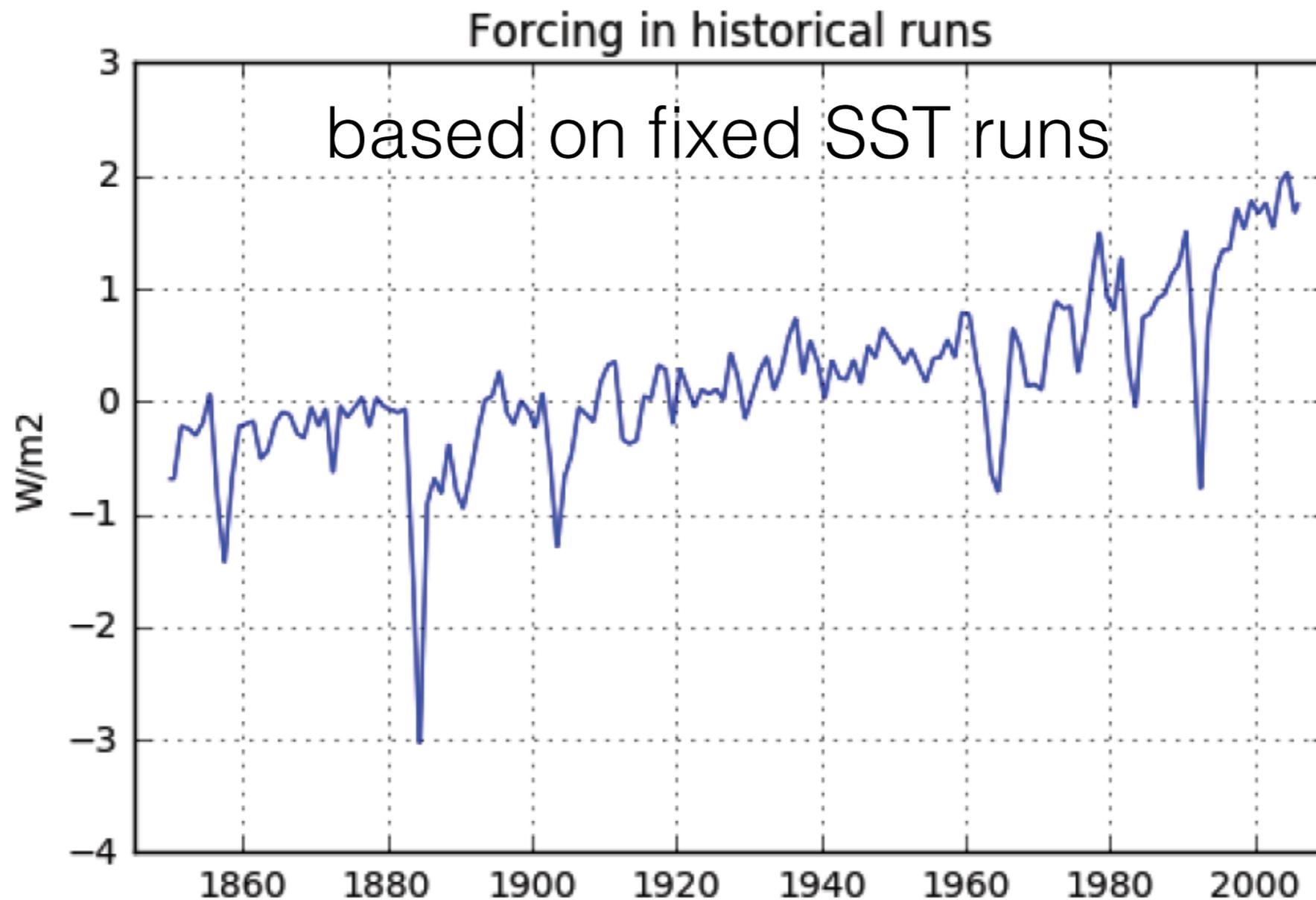


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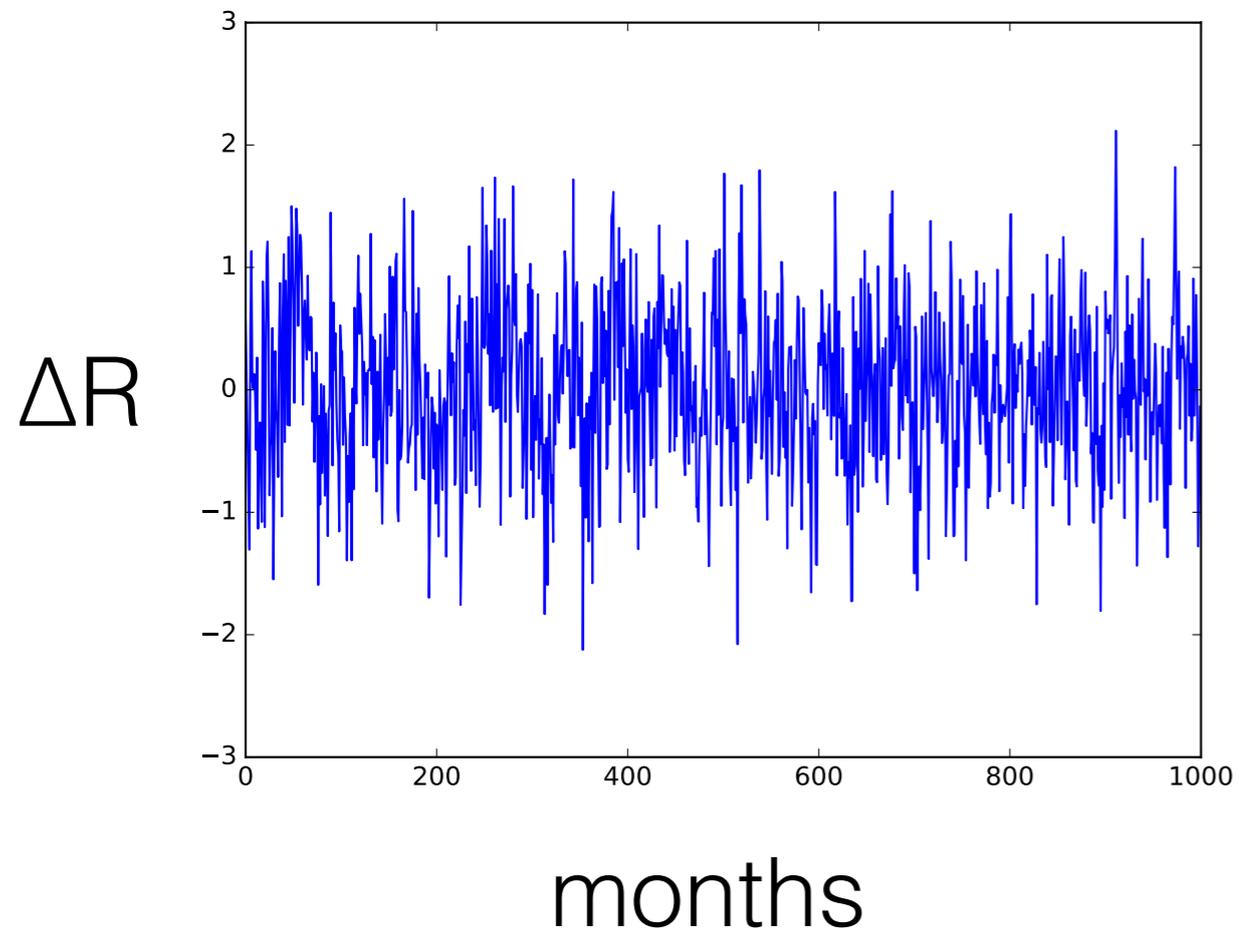
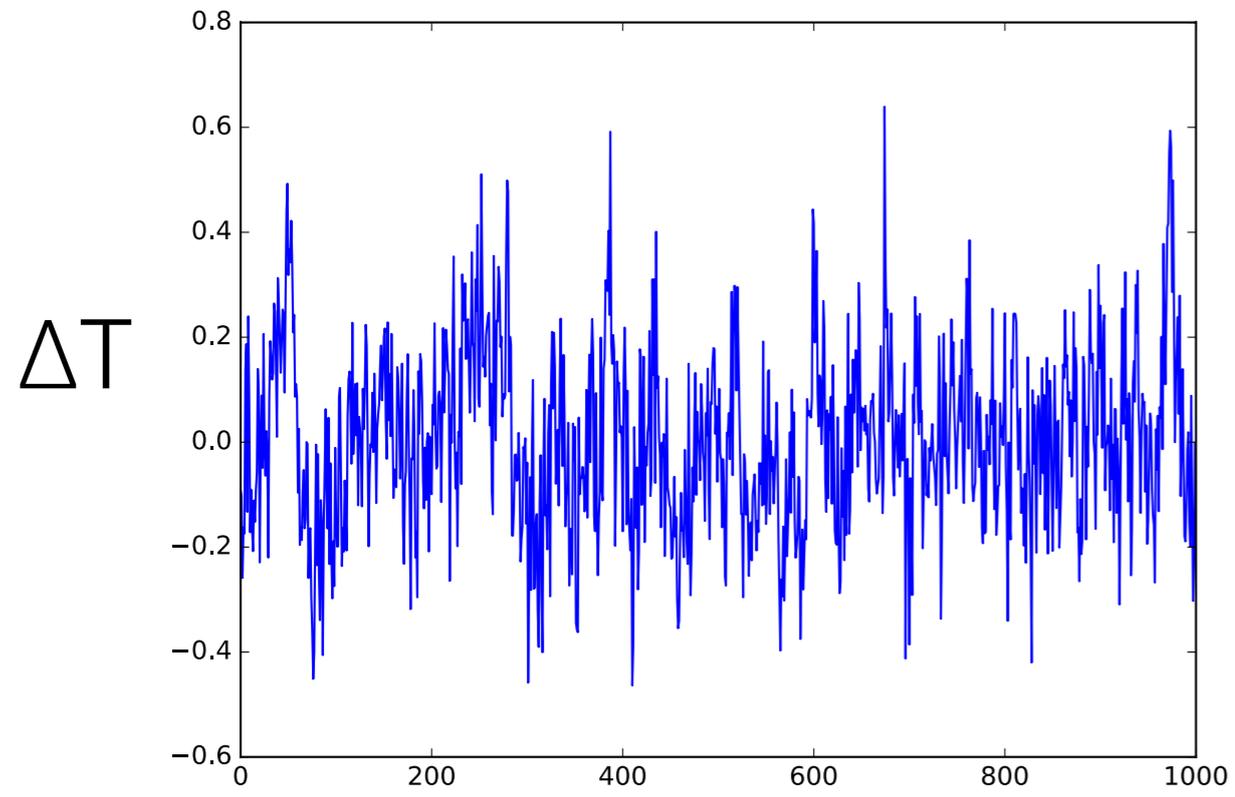
ensemble

ensemble

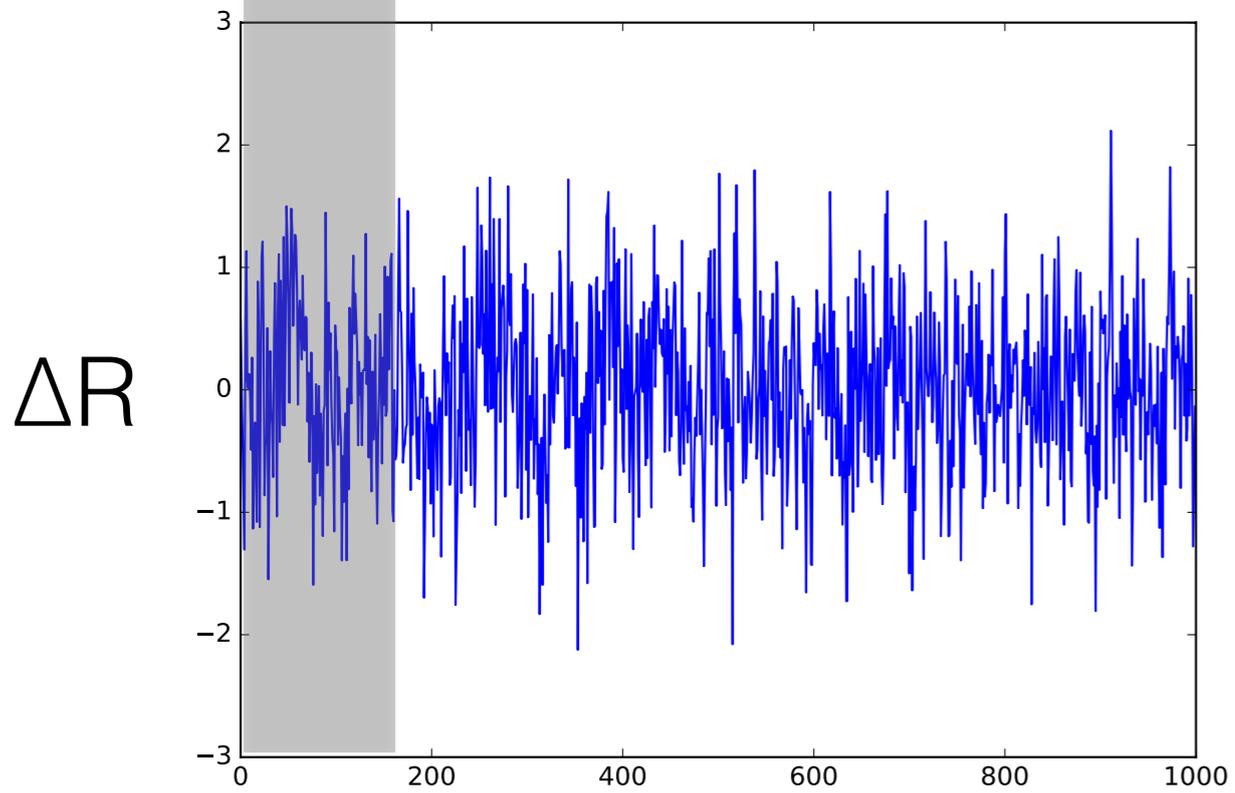
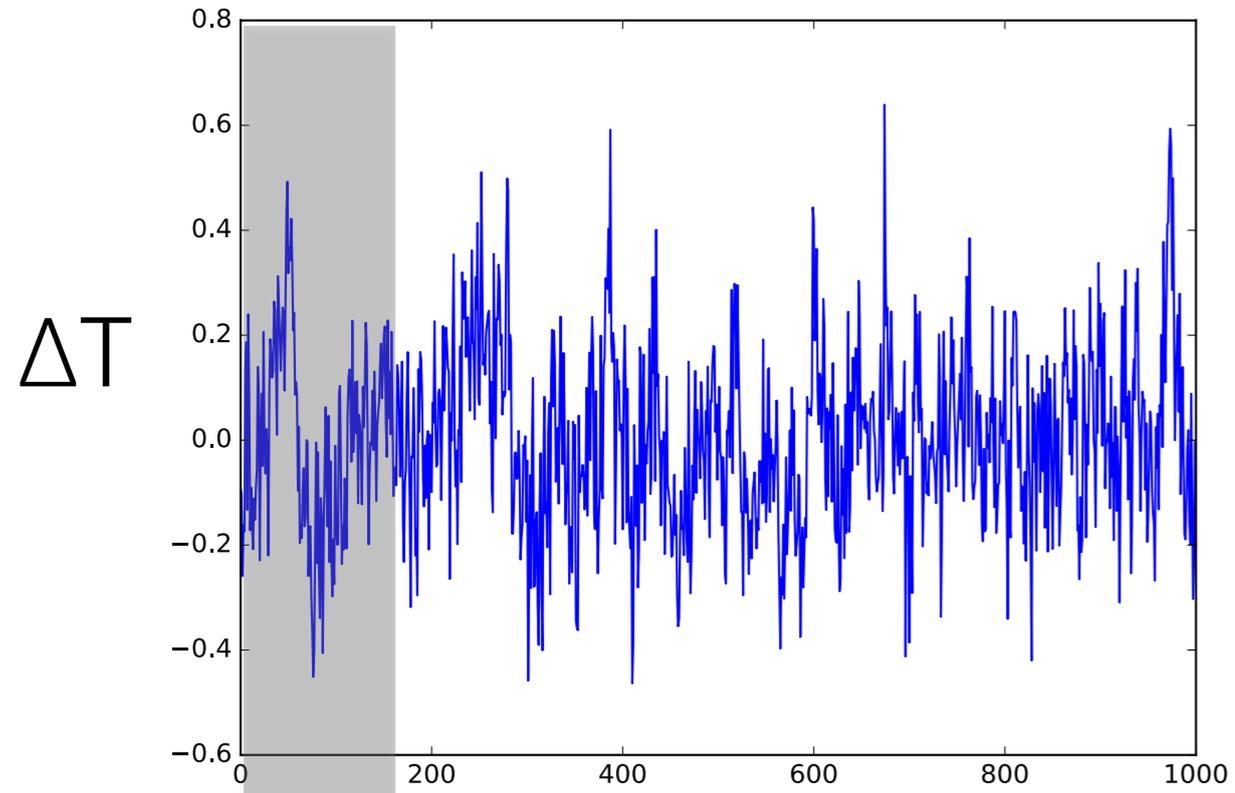
$$\Delta R = \Delta F + \lambda \Delta T$$



# CMIP5 control runs (NorESM1-M)

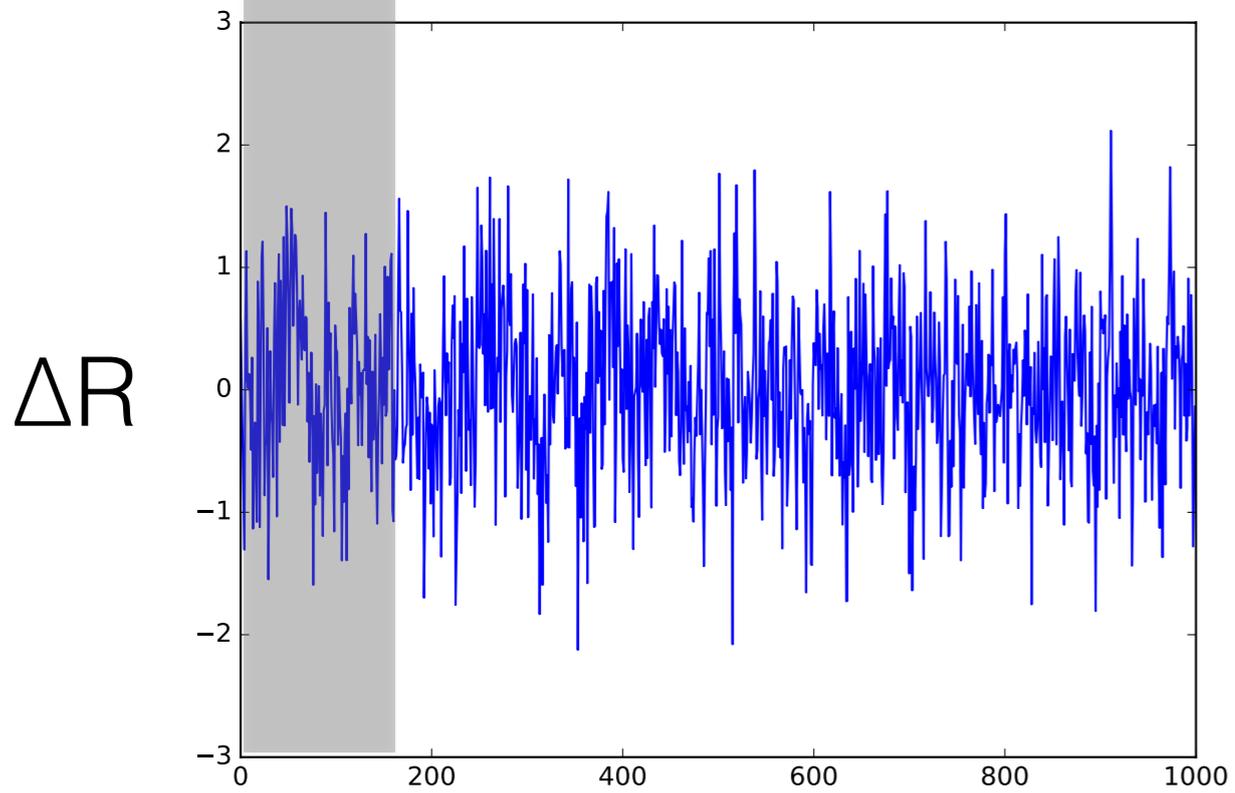
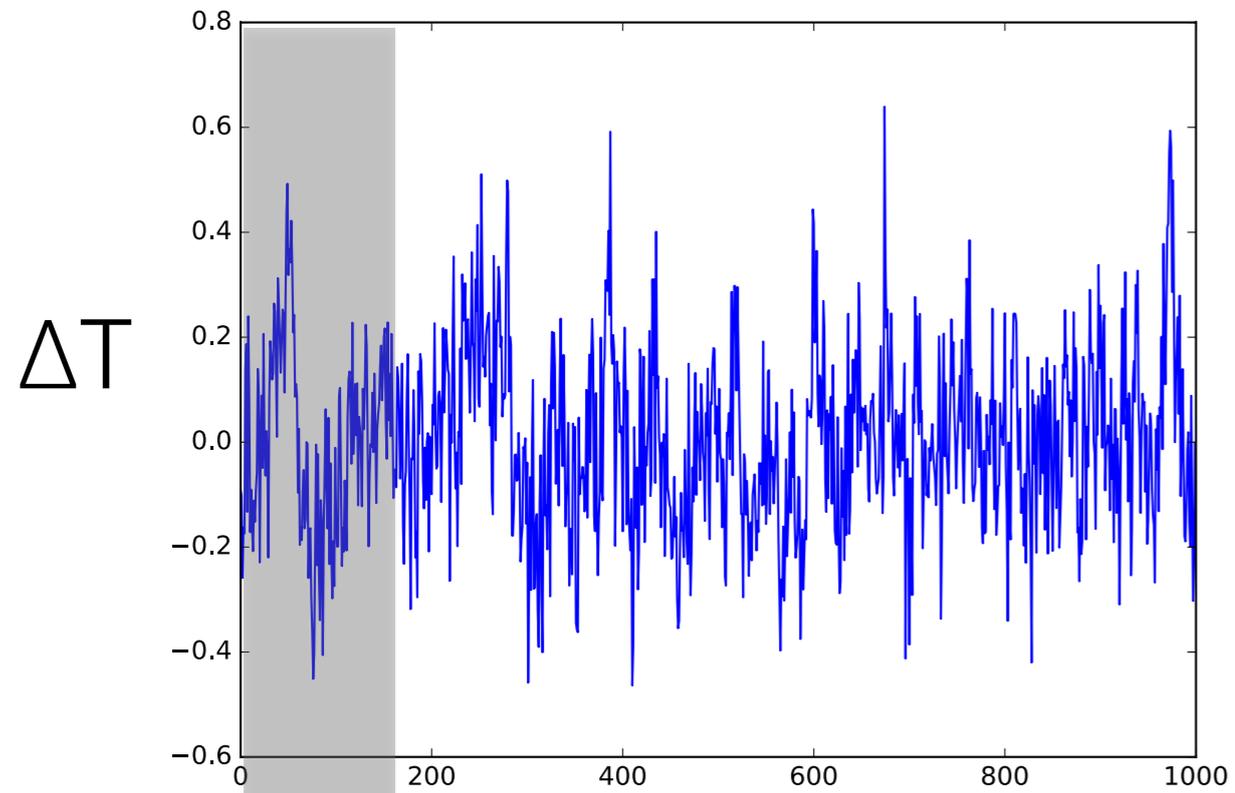


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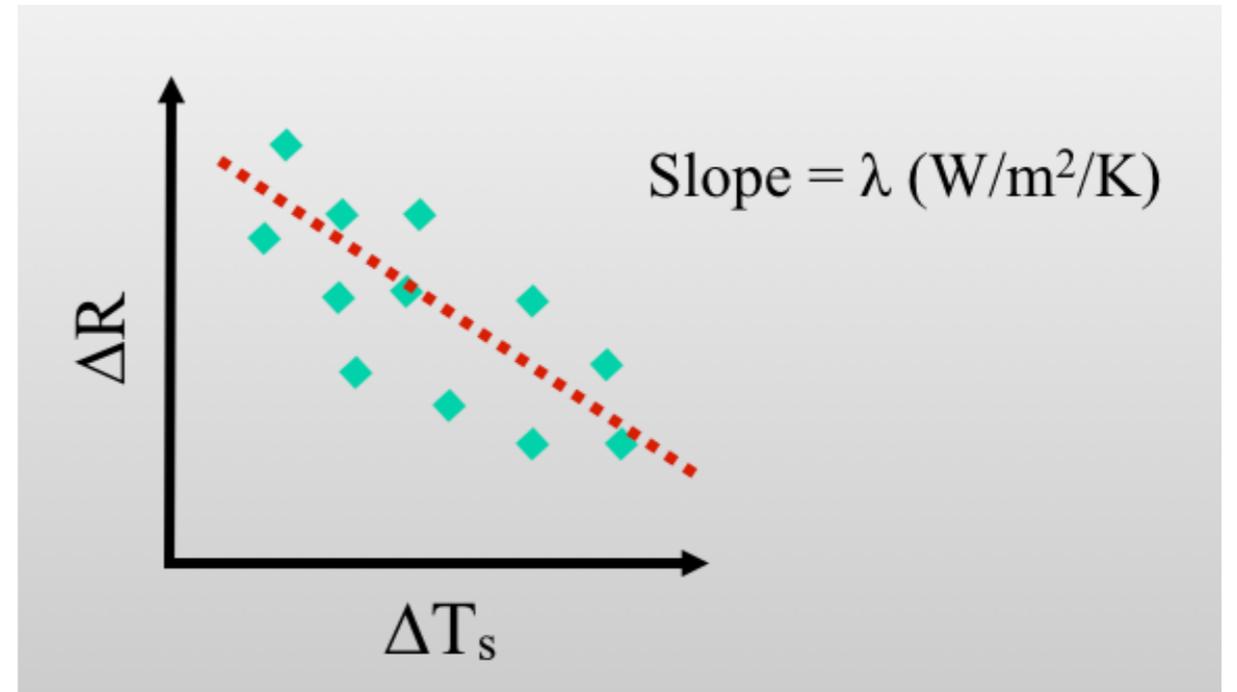


months

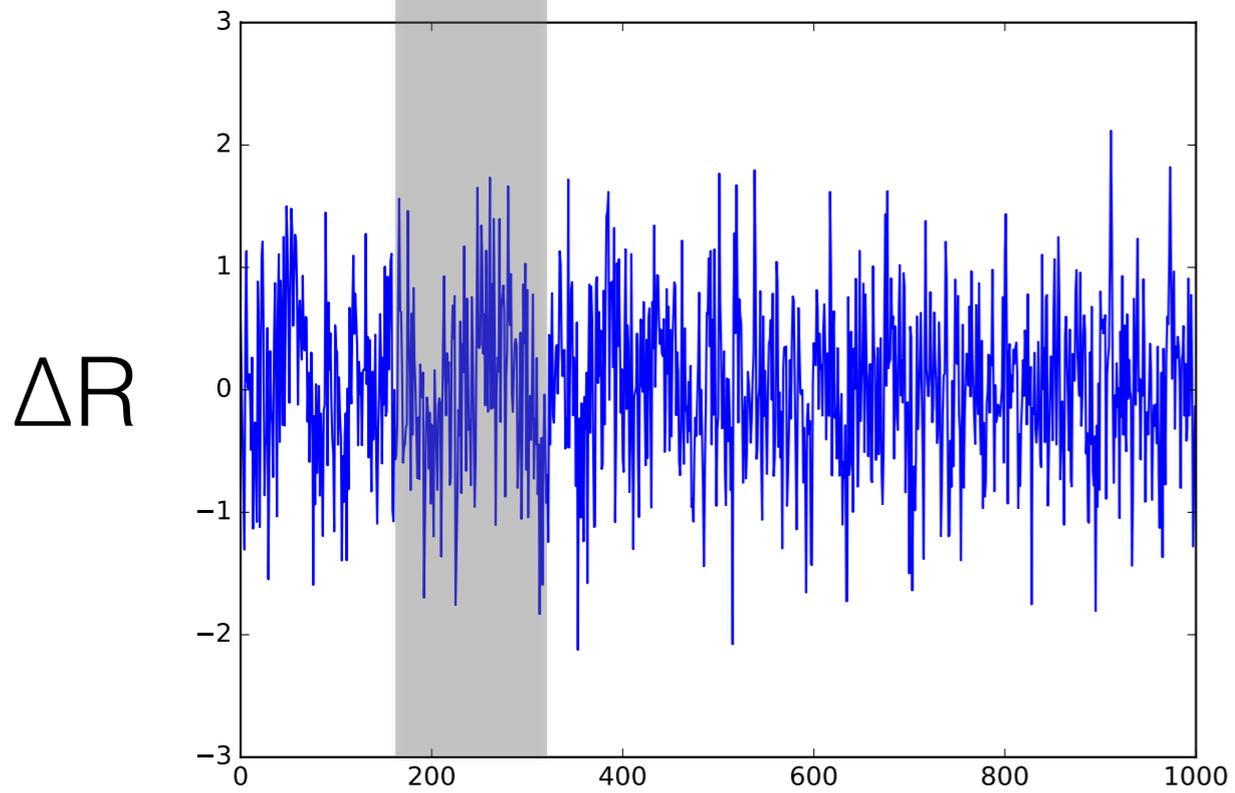
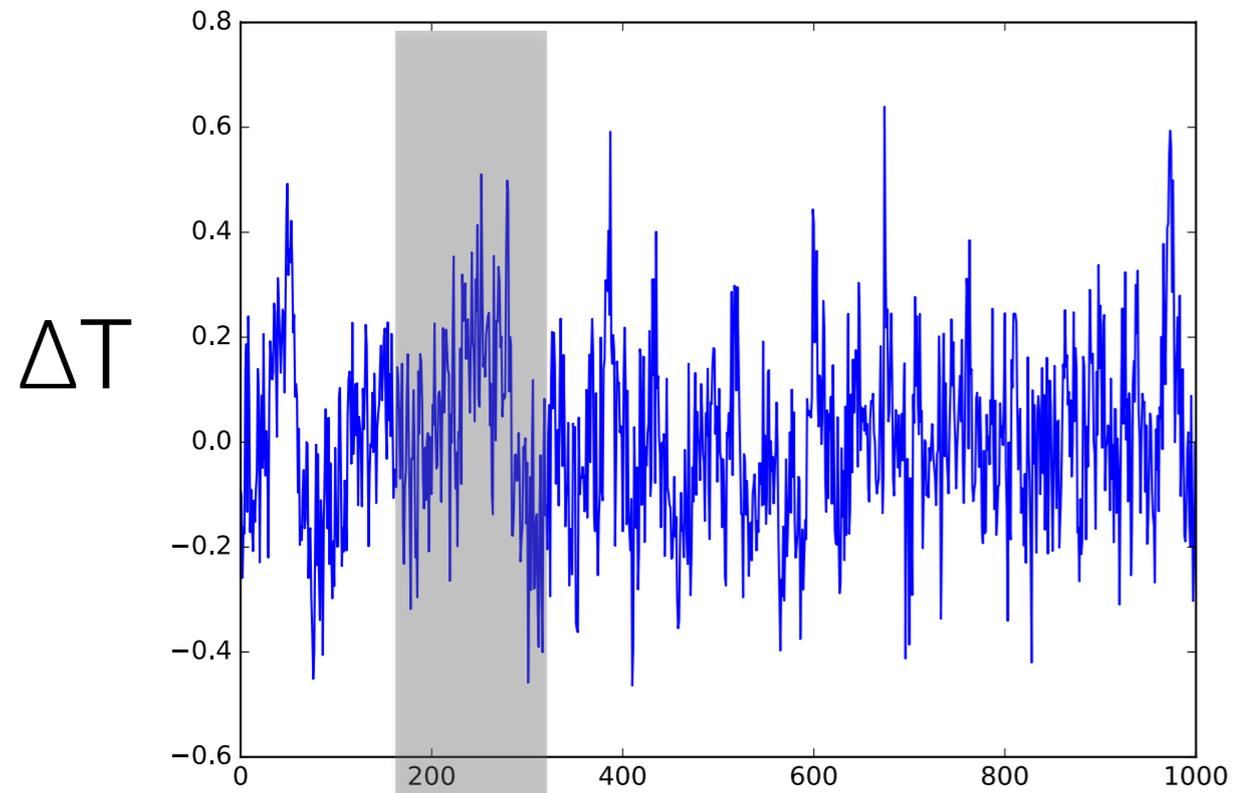
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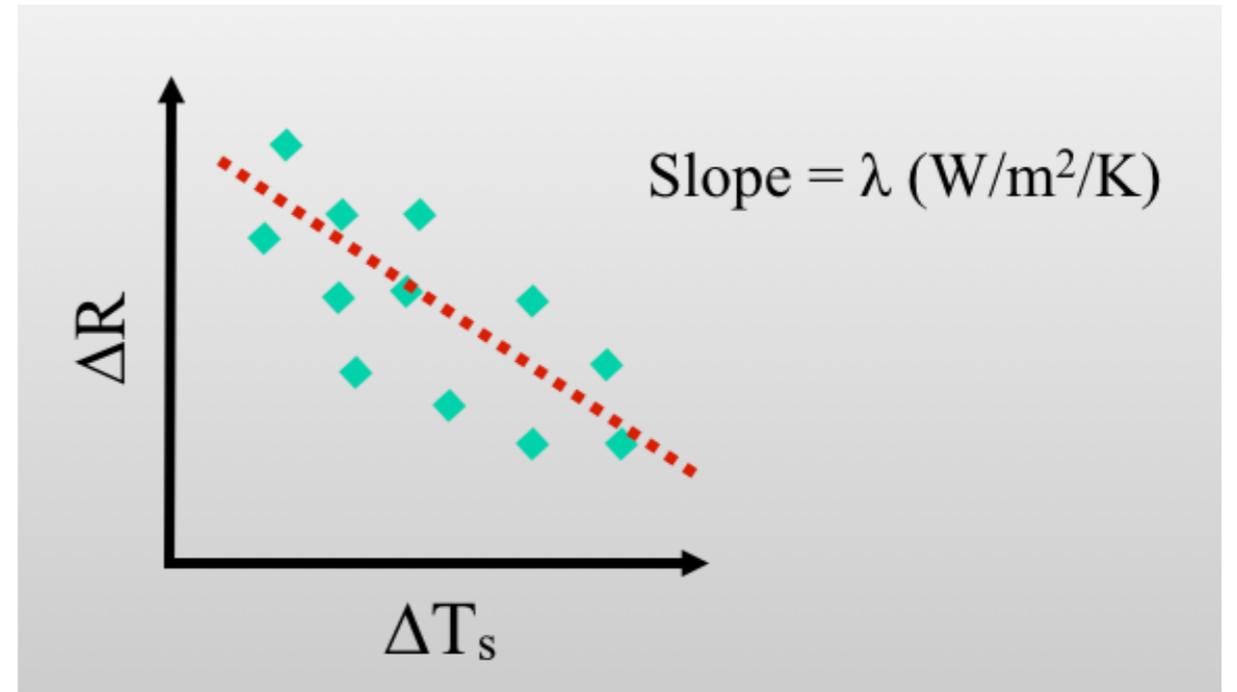
months



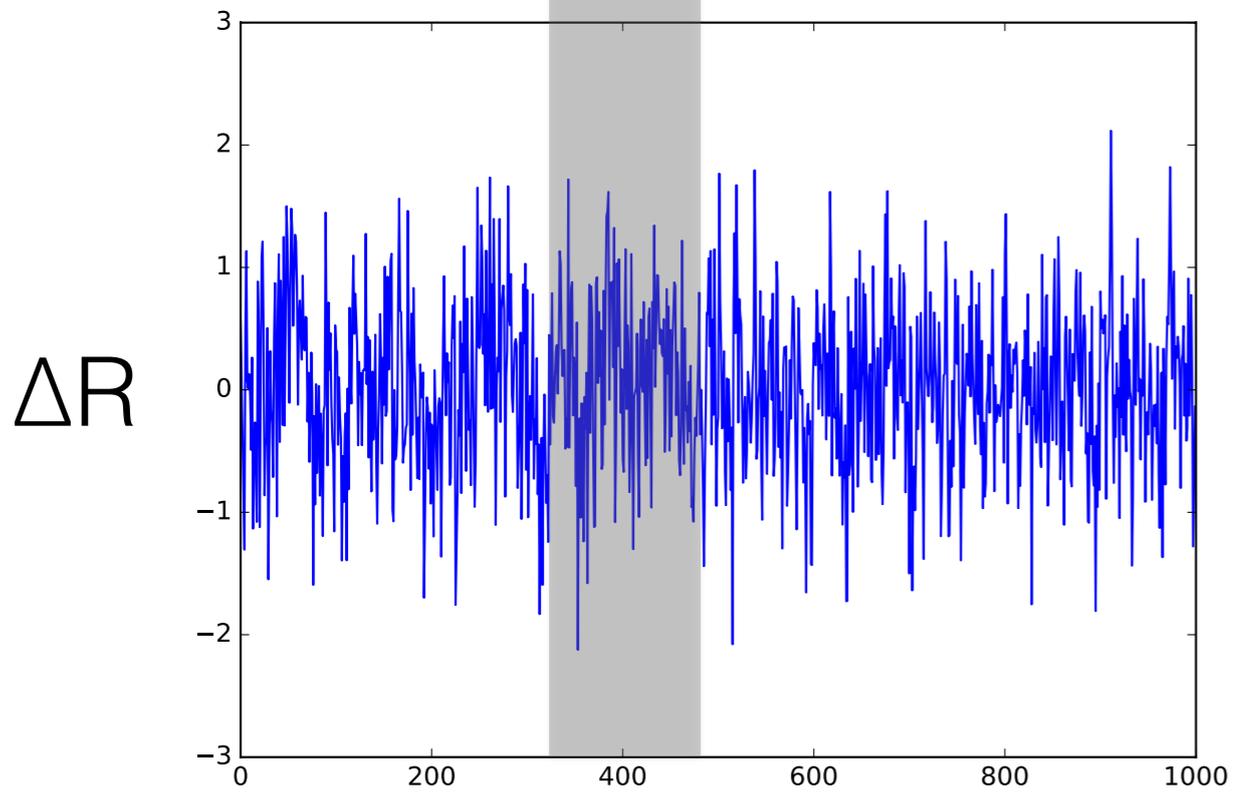
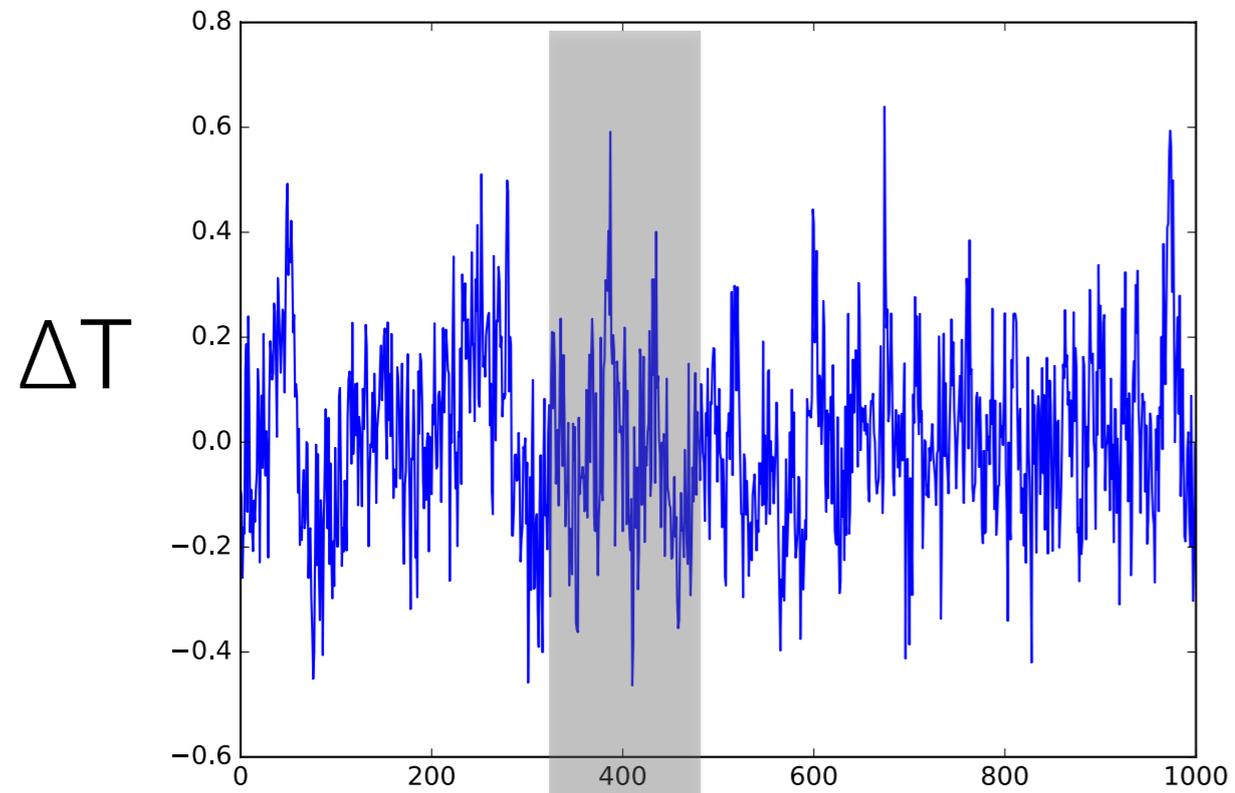
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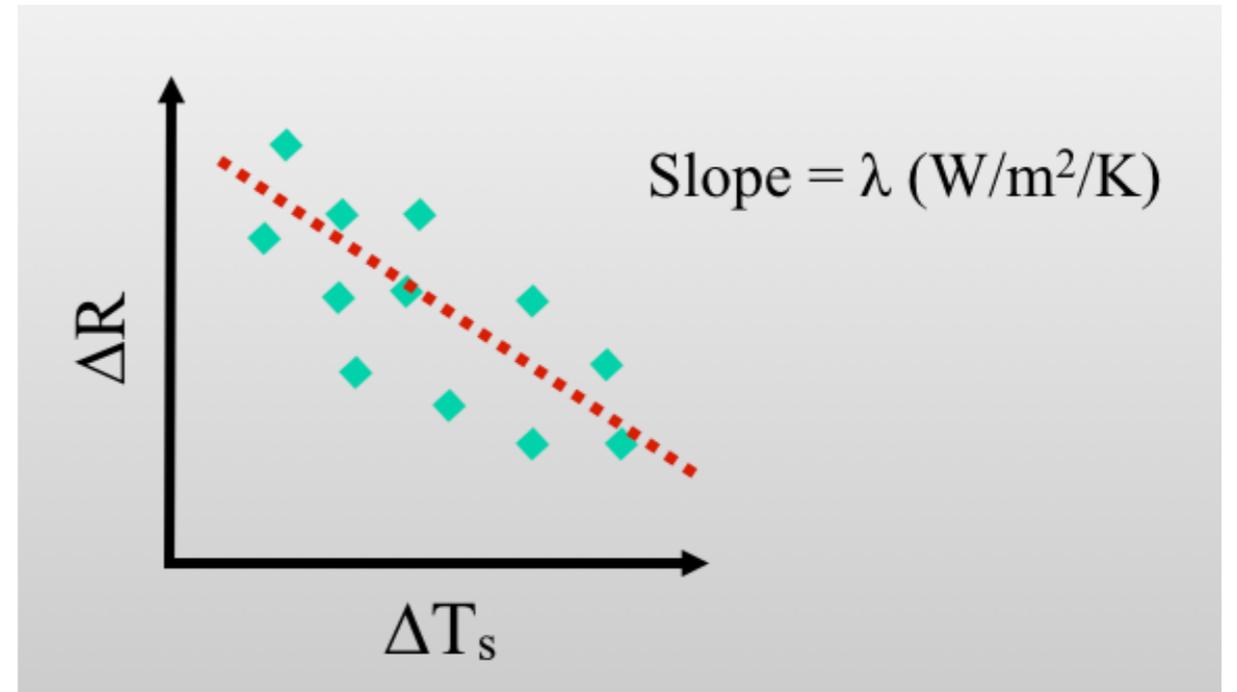
months



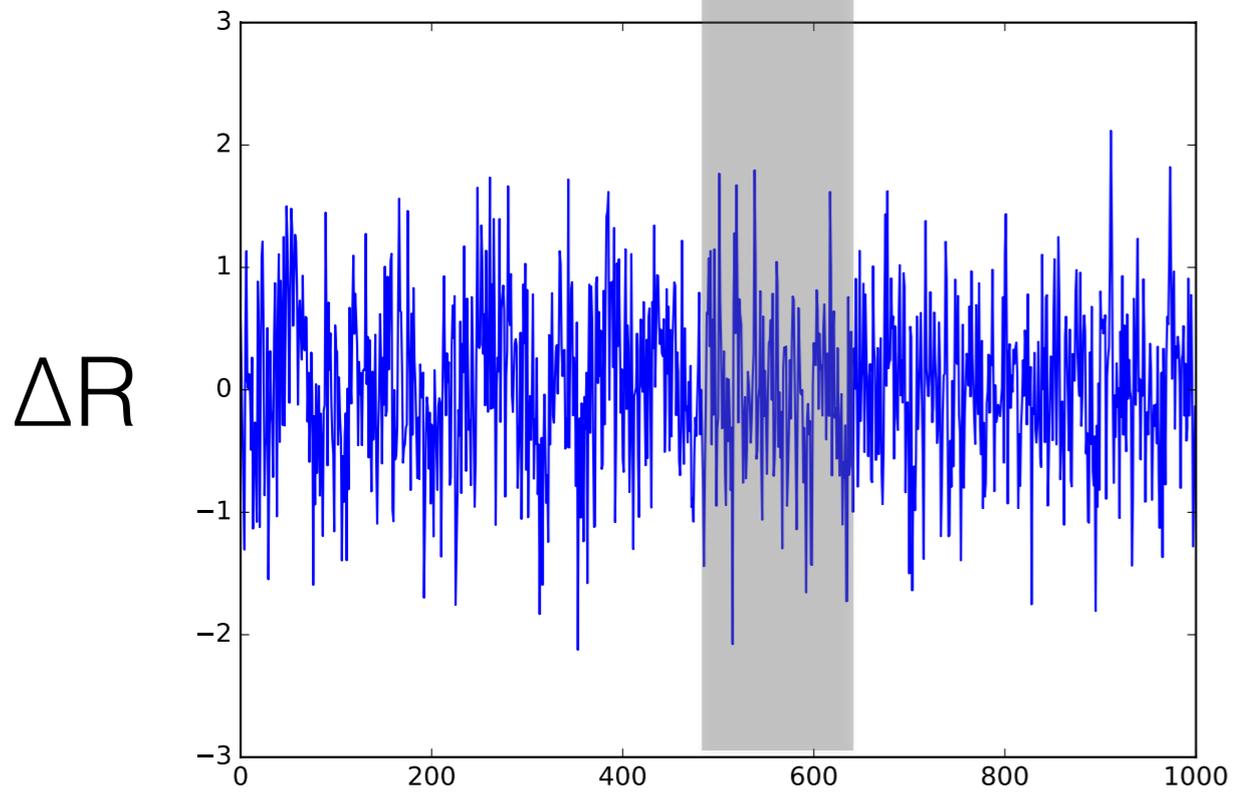
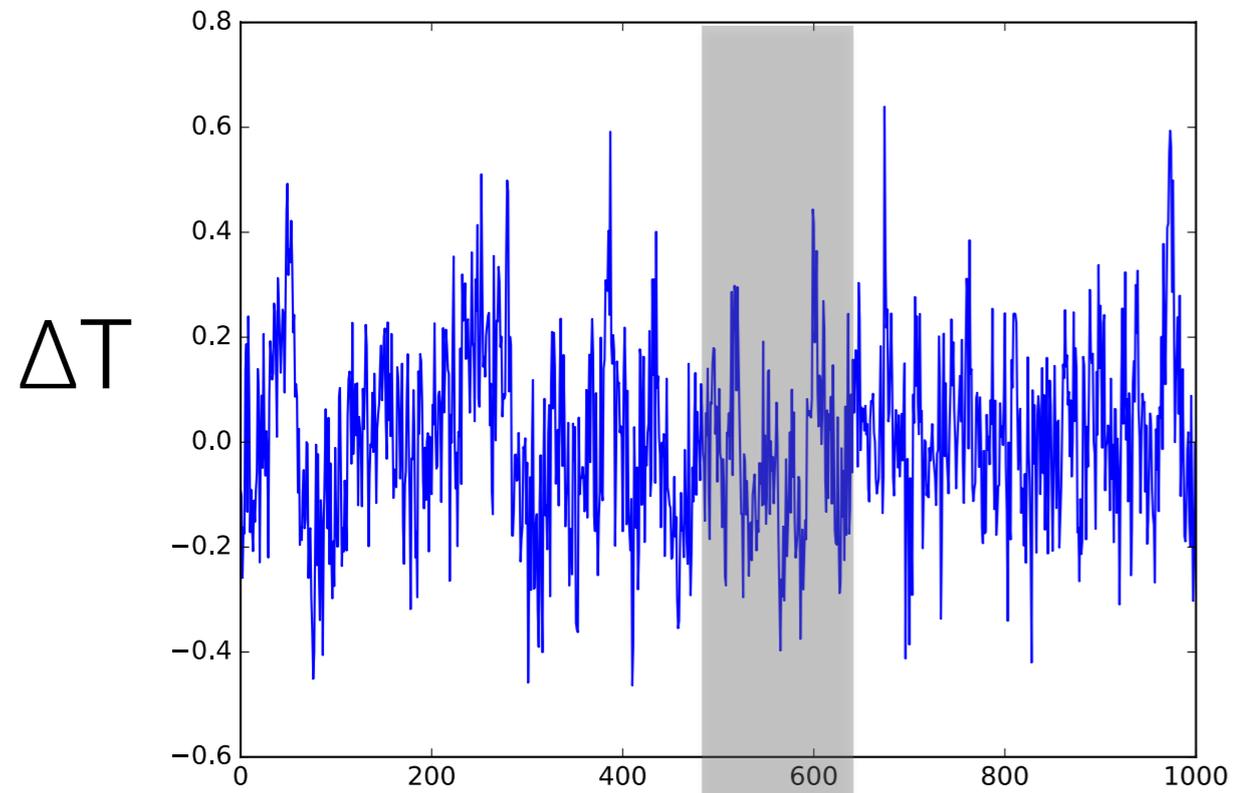
# CMIP5 control runs (NorESM1-M)



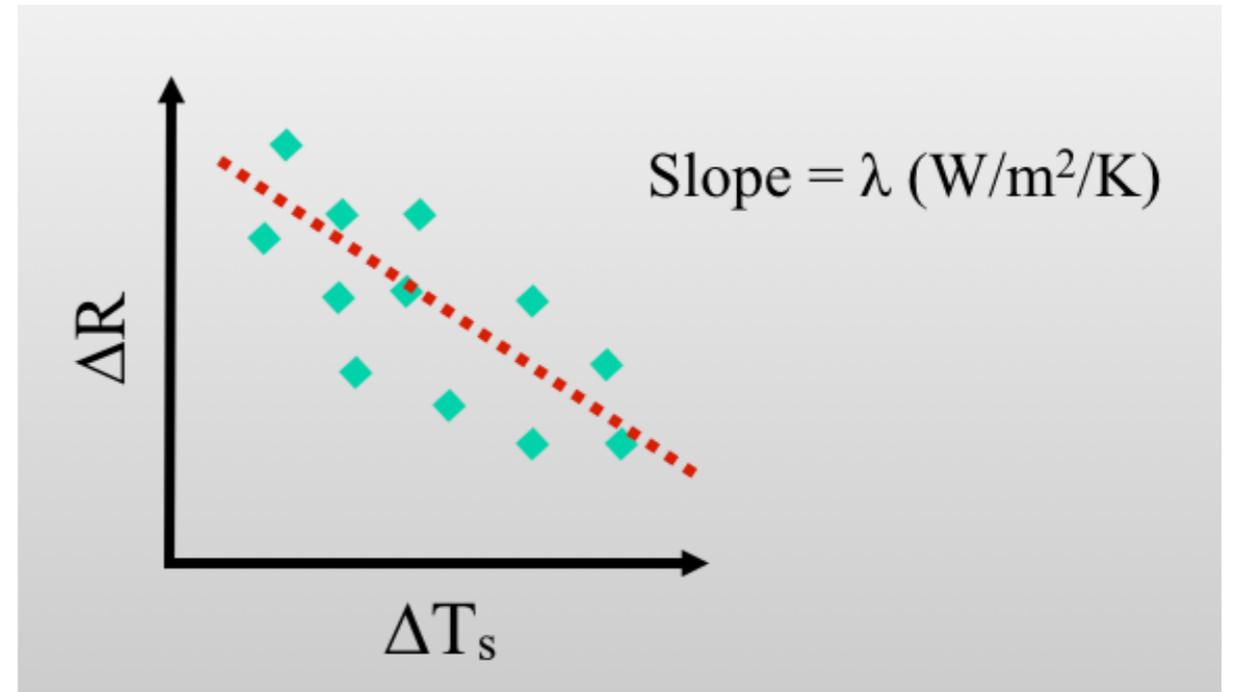
months



# CMIP5 control runs (NorESM1-M)

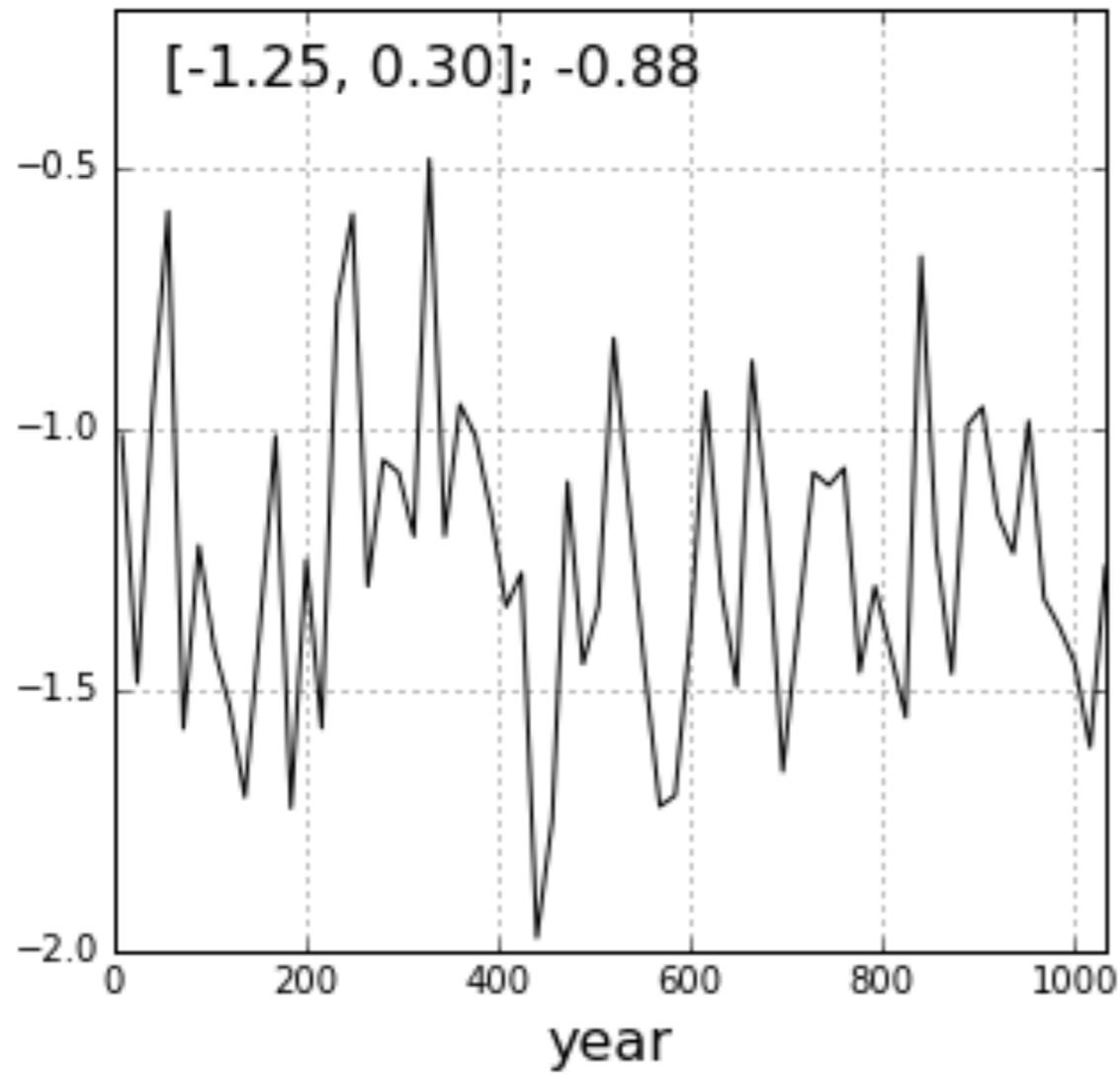


months

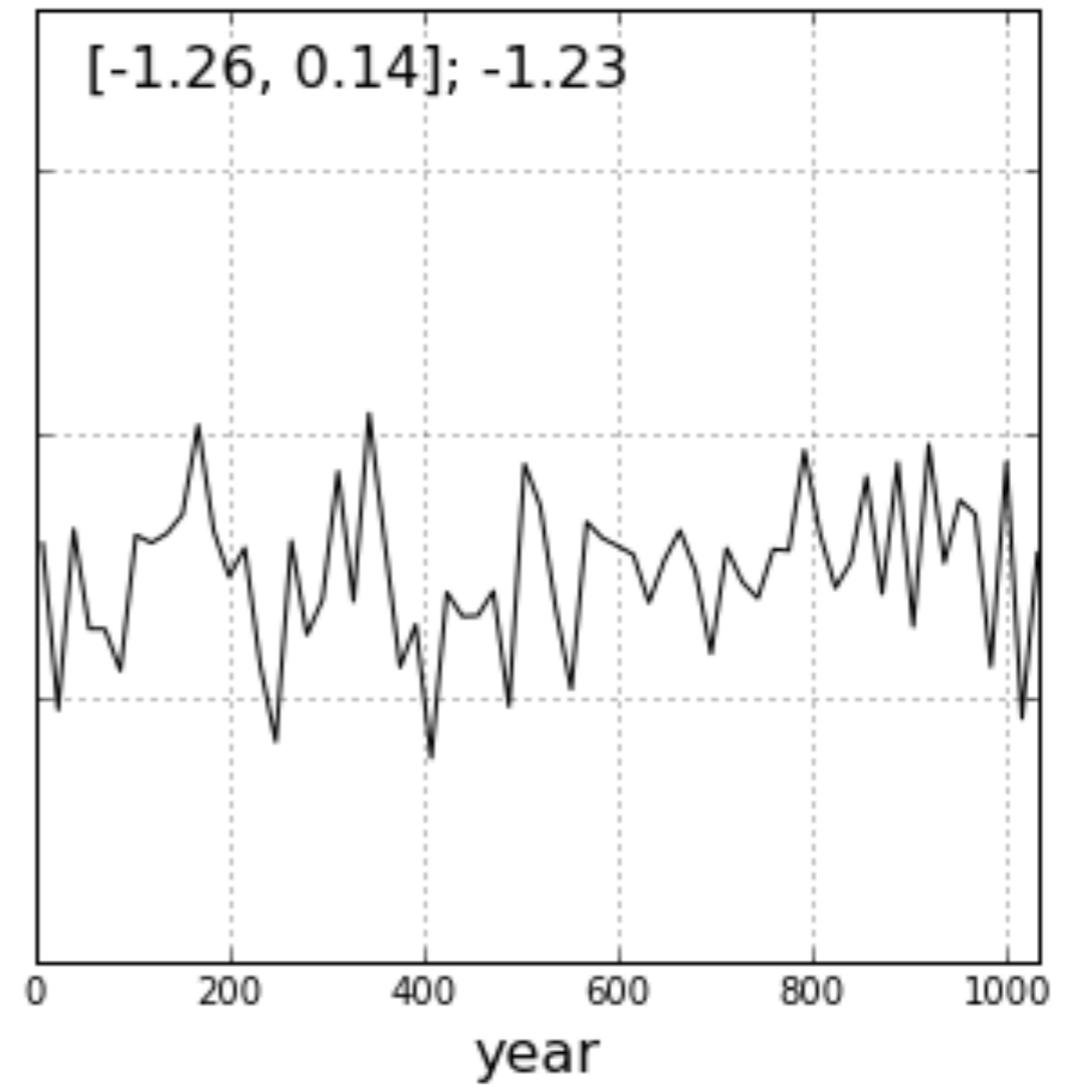


# CCSM4

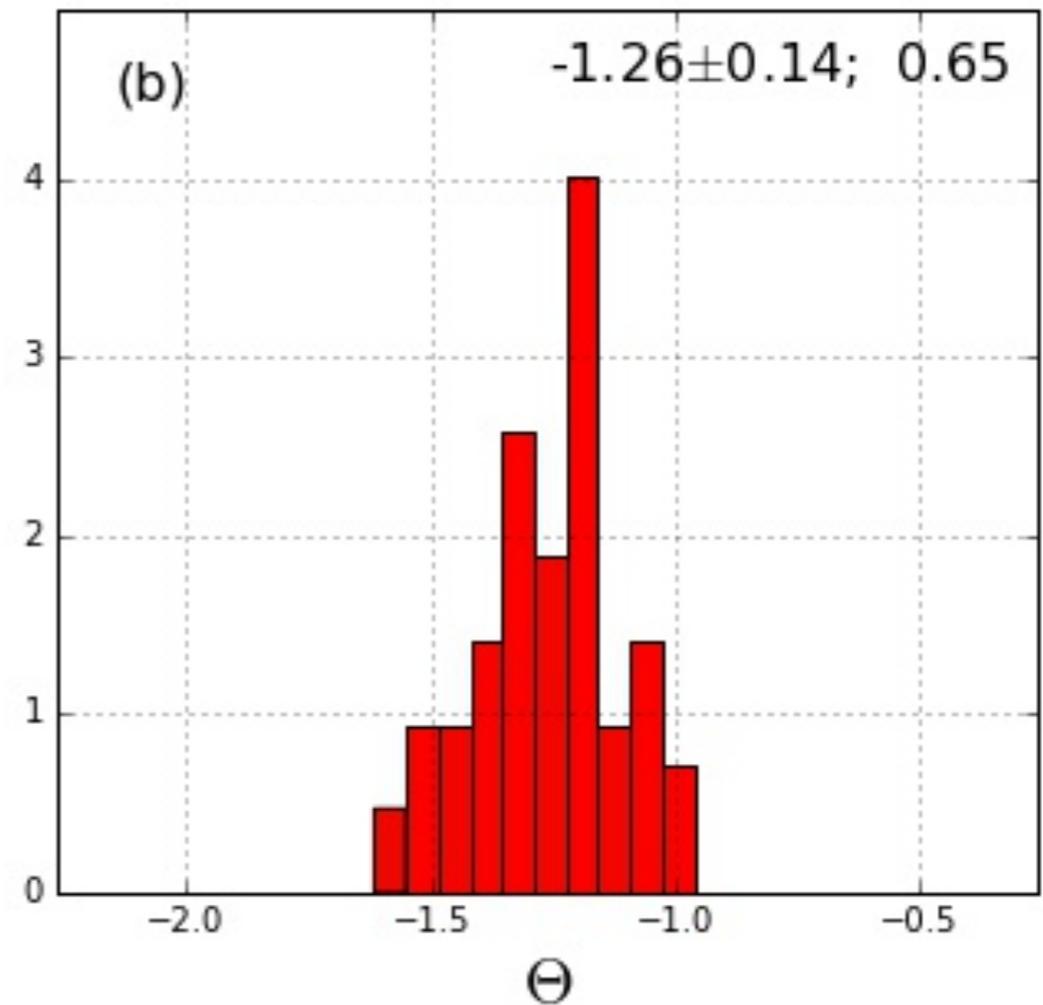
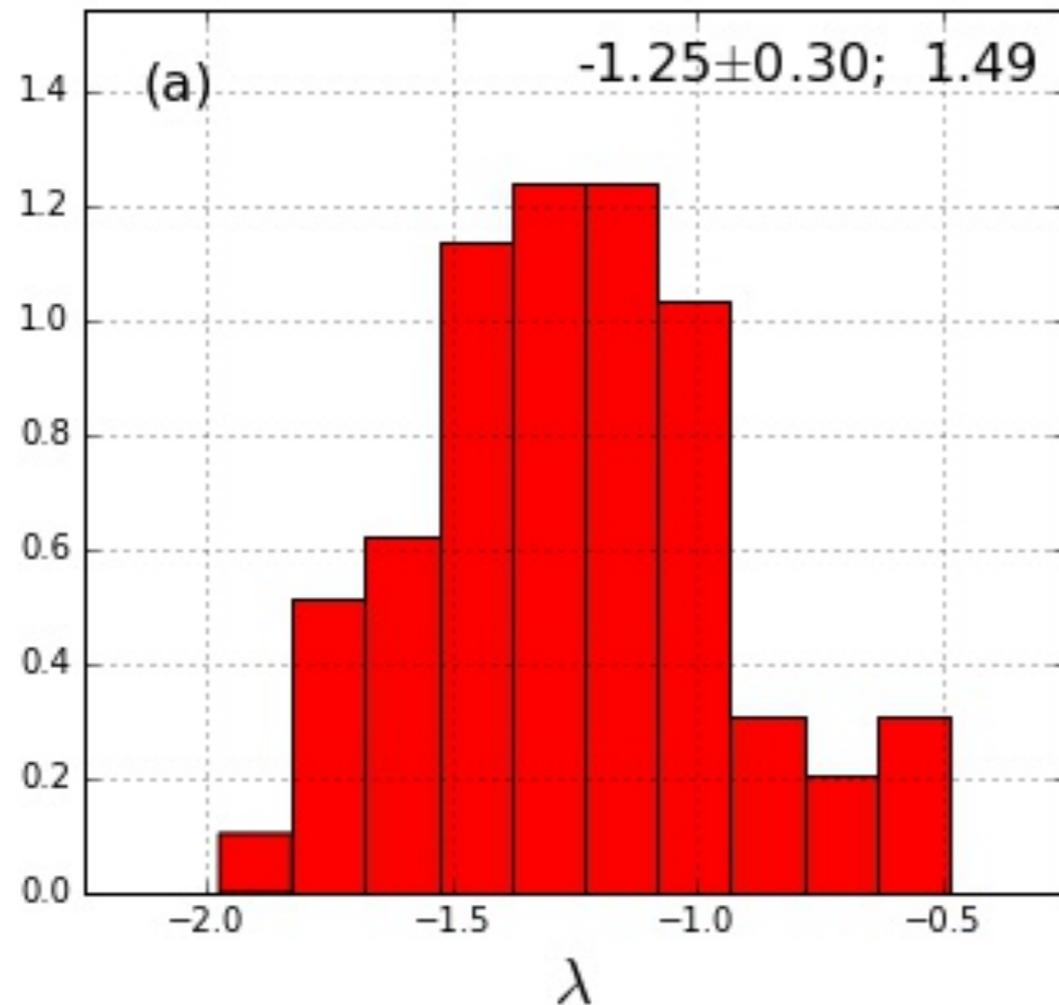
a.  $\lambda$



b.  $\Theta$



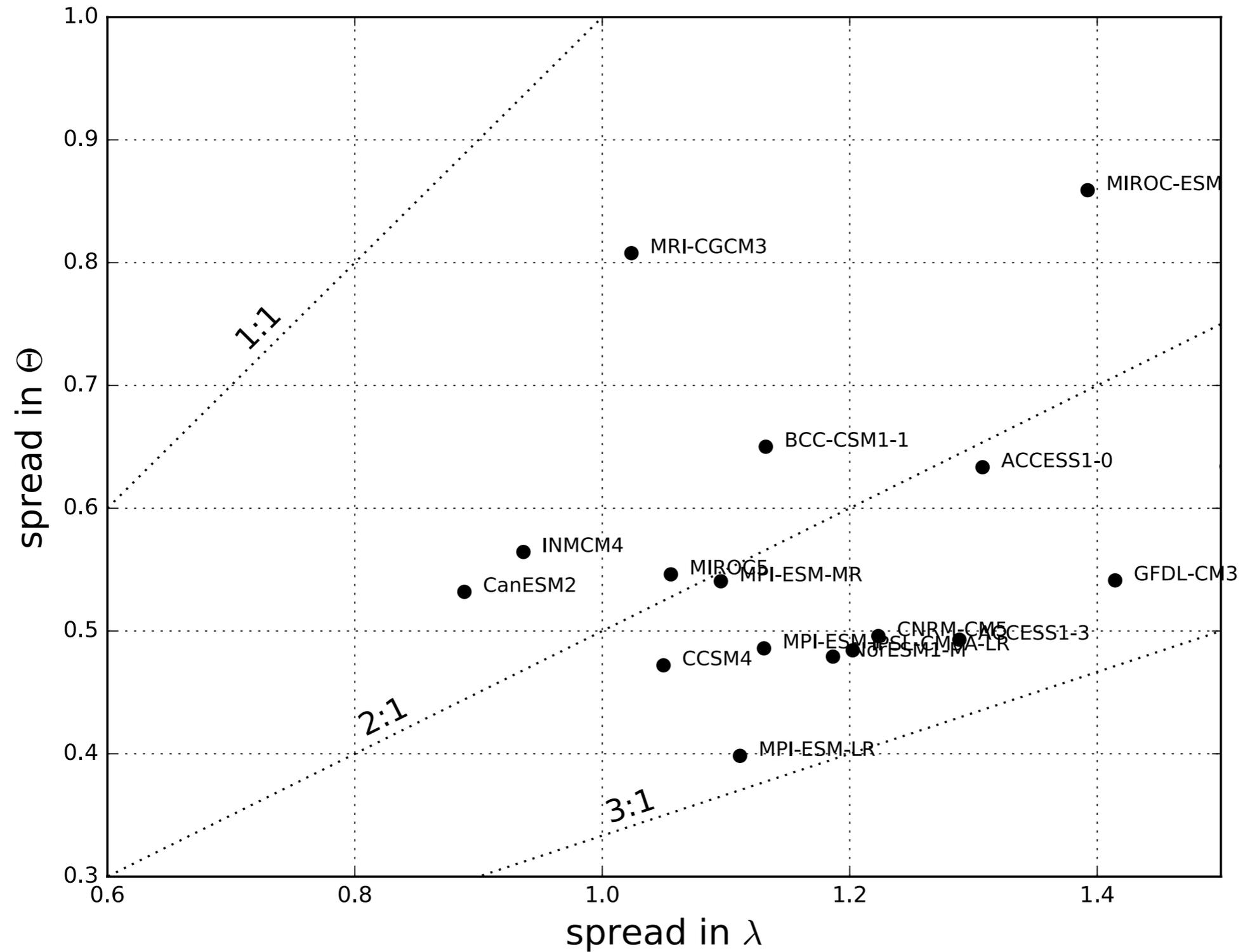
# CCSM4 CMIP5 control run



$$\lambda = \Delta(R-F)/\Delta T_s$$

$$\Theta = \Delta(R-F)/\Delta T_{500t}$$

# CMIP5 control runs



5-95% percentile range



