ATS 421/521

Climate Modeling

Spring 2013

Lecture 4

- Climate Sensitivity (wrap-up)
- Stochastic Climate Models
- Meridional Energy Transport

April 10

Papers ?

Homework ?

Previous Lecture

Reading

- For Friday: Hargreaves et al. (2012)
- For Monday: Script chapter 2.5

Climate Sensitivity

Usual definition:
Global mean temperature increase due to a doubling of CO_2: ΔT_{2xC}.

Radiative forcing due to CO_2: $\Delta Q = 5.35\, W/m^2 \ln(C/C_0)$

For 2xCO_2: $\Delta Q_{2xC} = 3.7\ \mathrm{W/m^2}$

More general:

$$\alpha = \frac{\Delta T}{\Delta Q}$$

global mean temperature change

radiative forcing := change in energy balance at the tropopause with everything else (T, q, ...) constant

Our EBM in equilibrium:

$$(1-a)S = A + BT_0$$

$$(1-a)S + \Delta Q = A + B(T_0 + \Delta T)$$

$$\longrightarrow \quad \alpha = \frac{1}{B} = 0.3\,\mathrm{K}\left(\mathrm{Wm}^{-2}\right)^{-1}$$ Climate Sensitivity

or $\Delta T_{2xC} = 1$ K

GCMs have $\Delta T_{2xC} = 2\text{-}4.5$ K

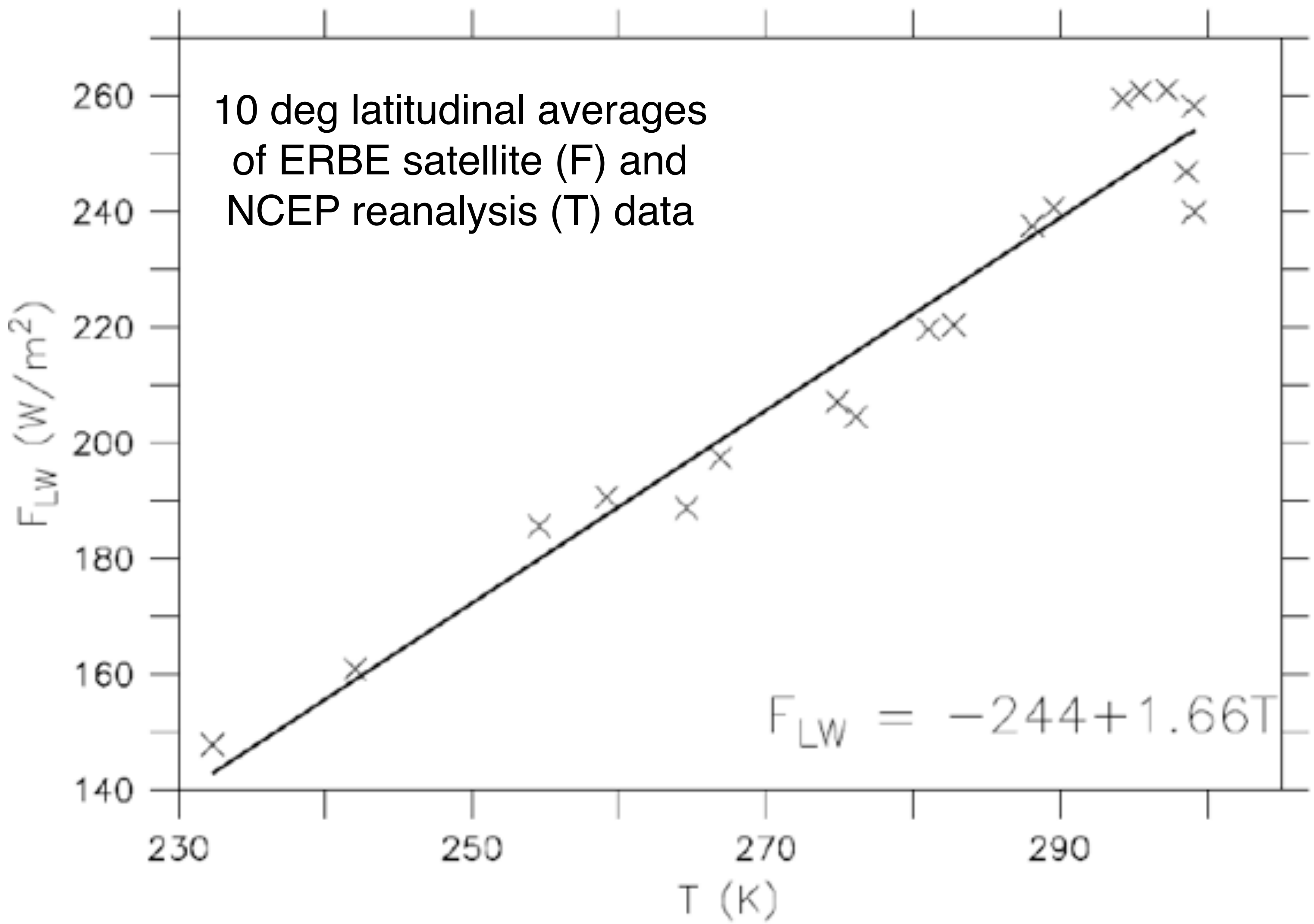
What's wrong?

$$B = 4g\sigma T_0^3 = \begin{cases} 3.4\,\mathrm{Wm^{-2}K^{-1}}, T_0 = 288\mathrm{K} \\ 1.7\,\mathrm{Wm^{-2}K^{-1}}, T_0 = 227\mathrm{K} \end{cases}$$

surface

tropopause

Determine B empirically from obs:



Implicitly includes feedbacks.

$$\frac{\partial T}{\partial t} = F(T, y_{1,} y_{2,..}.., y_n) \qquad F_0 = F(T_0, y_{10}, \ldots, y_{n0}) = 0$$

$$\frac{\partial(T_0 + \Delta T)}{\partial t} = F_0 + \frac{\partial F}{\partial T}\bigg|_{T_0, \vec{y_0}} \Delta T + \Sigma_n \left(\frac{\partial F}{\partial y_n}\frac{\partial y_n}{\partial T}\right)\bigg|_{T_0, \vec{y_0}} \Delta T + \Delta Q = 0$$

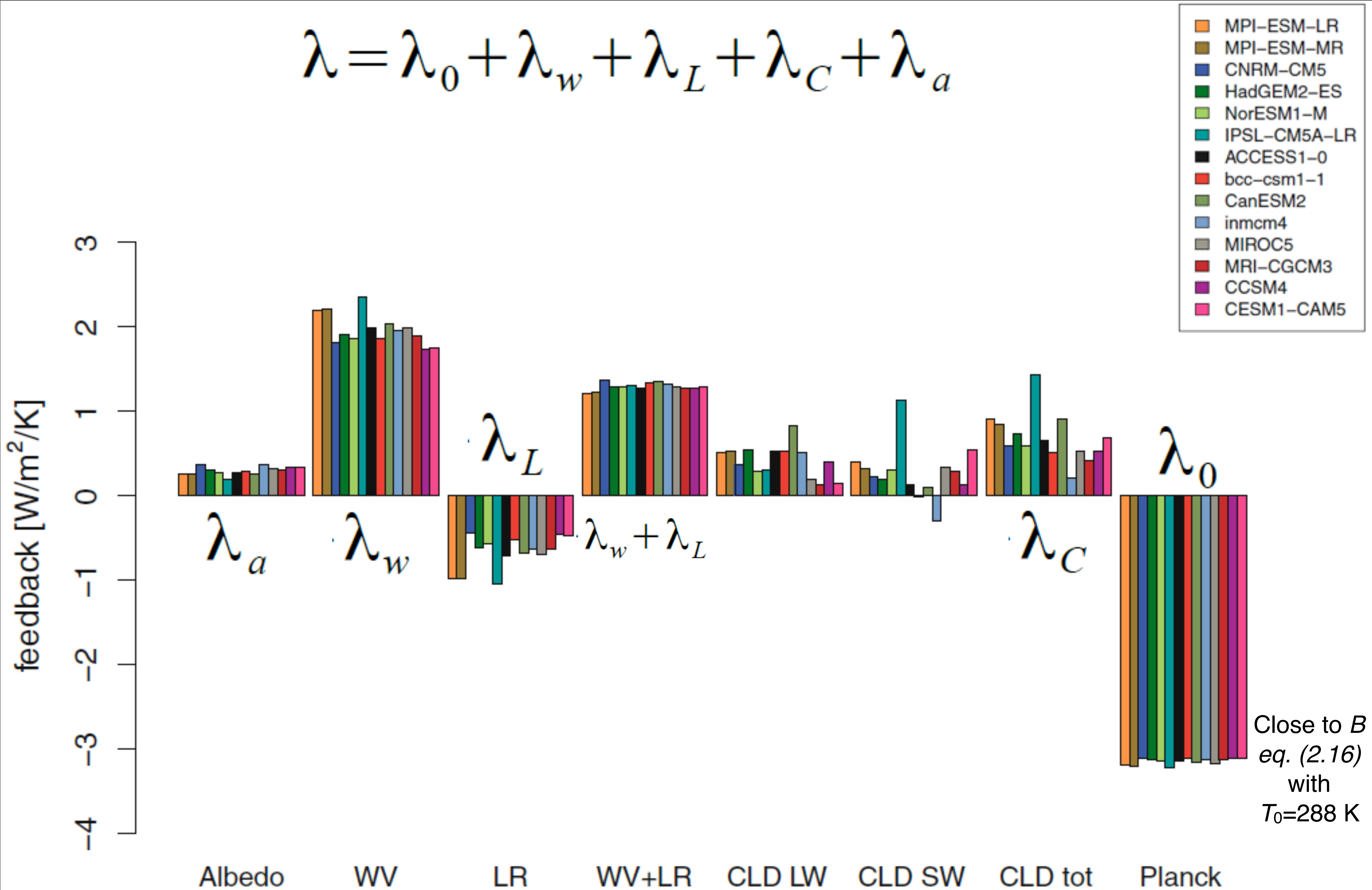
Feedback parameter

$$\lambda = \alpha^{-1} = \frac{\Delta Q}{\Delta T} = -\frac{\partial F}{\partial T} - \Sigma_n \left(\frac{\partial F}{\partial y_n}\frac{\partial y_n}{\partial T}\right) := \lambda_0 + \Sigma_n \lambda_n \qquad (2.17)$$

$$\lambda = \lambda_0 + \lambda_w + \lambda_L + \lambda_C + \lambda_a$$

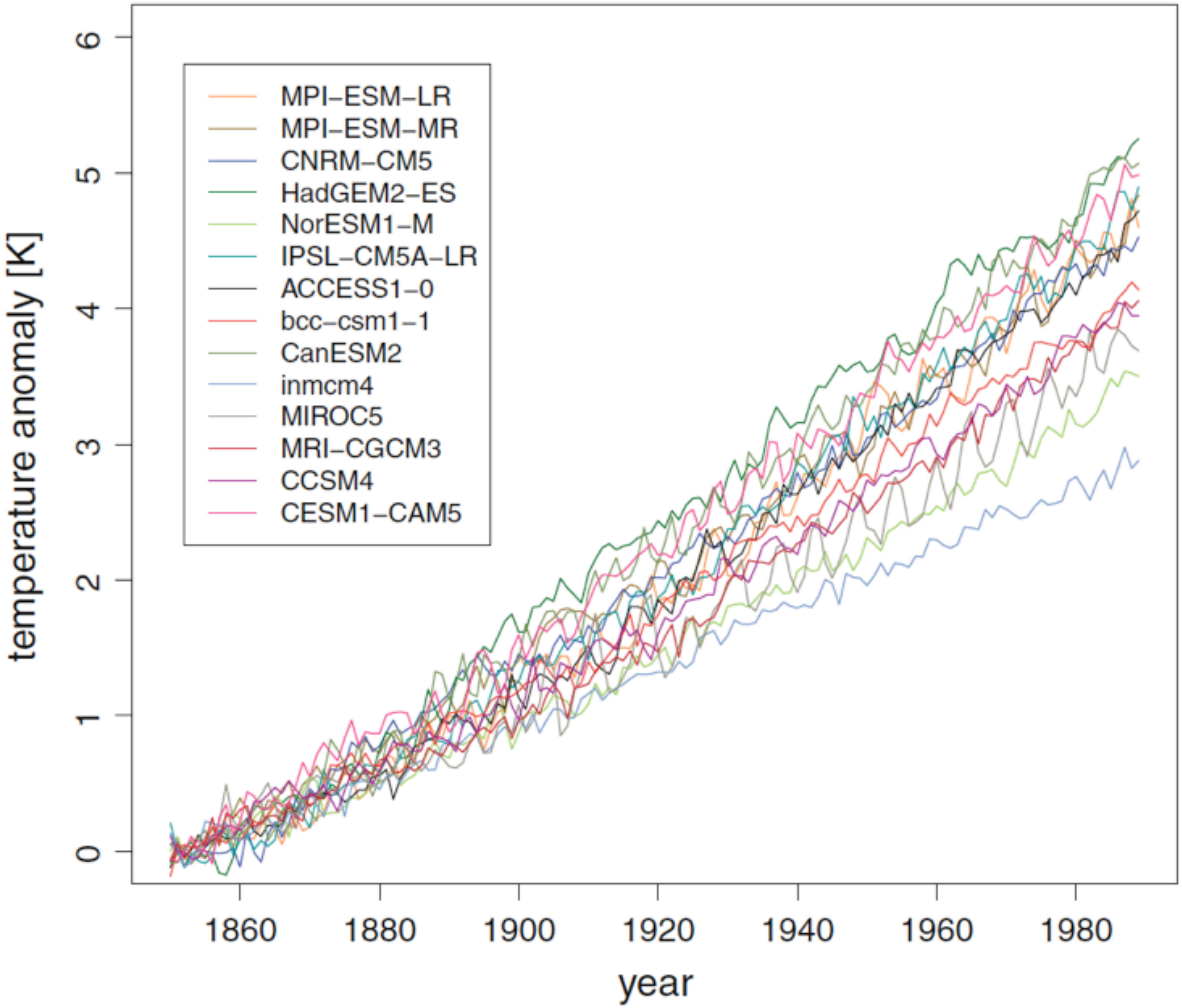
Planck	water vapor	lapse rate	cloud	sfc albedo

$$\lambda = \lambda_0 + \lambda_w + \lambda_L + \lambda_C + \lambda_a$$



Tomassini et al. (2013) Clim. Dyn.
Soden & Held (2006) J. Climate

Transient response of CMIP5 surface temperatures to exponential CO_2 increase at 1%/yr

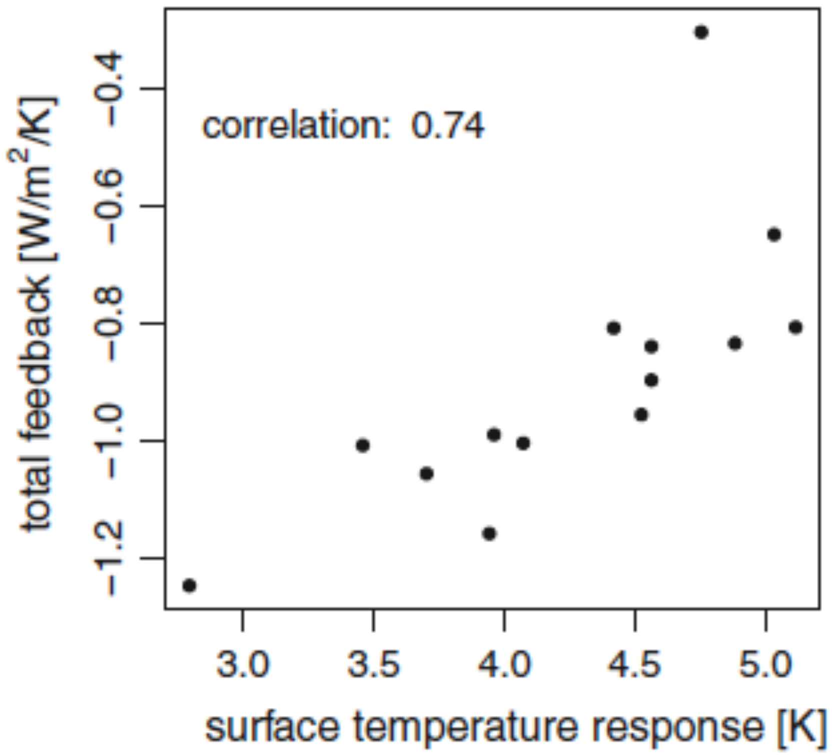


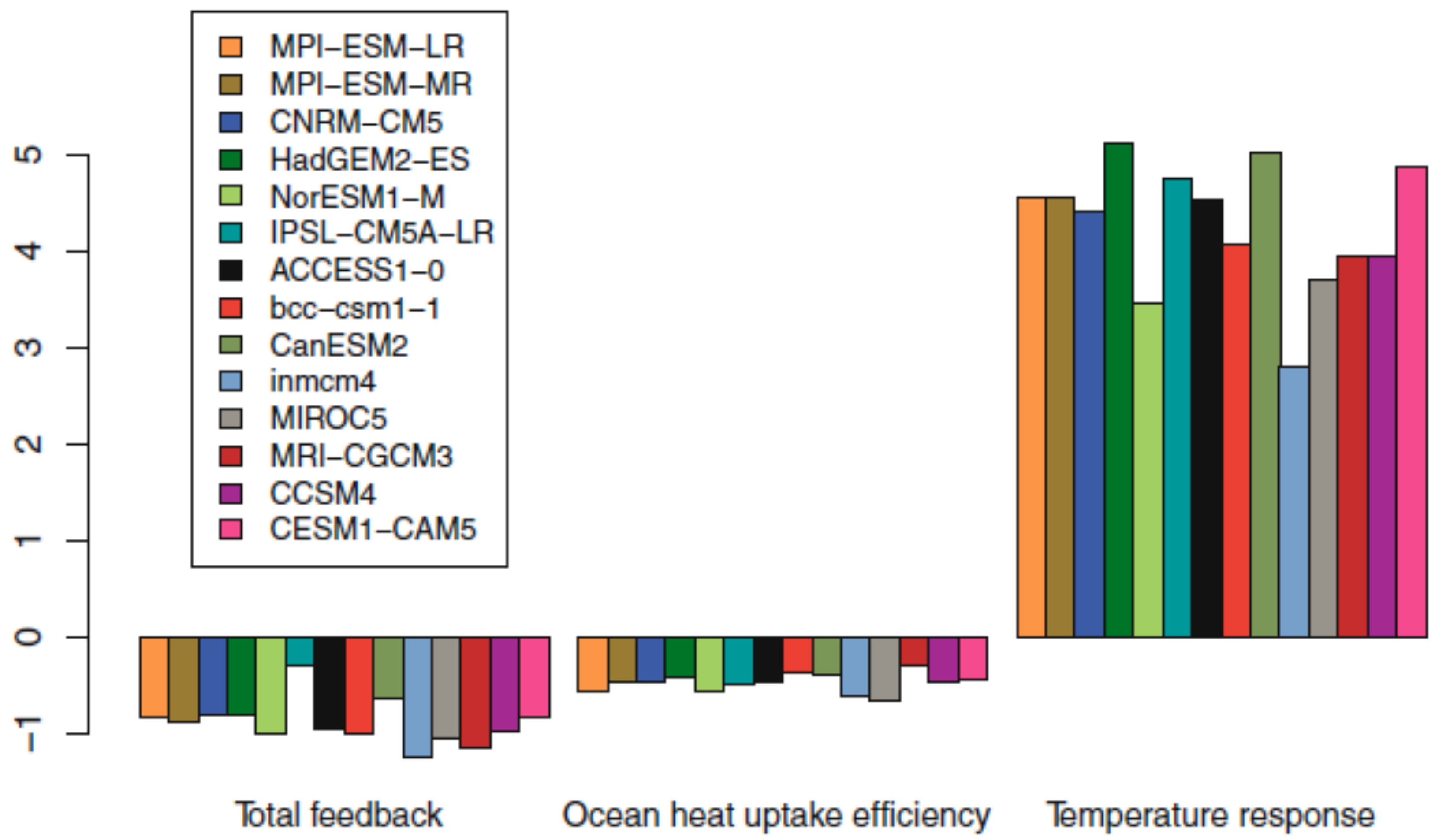
What's are the reasons for this spread?

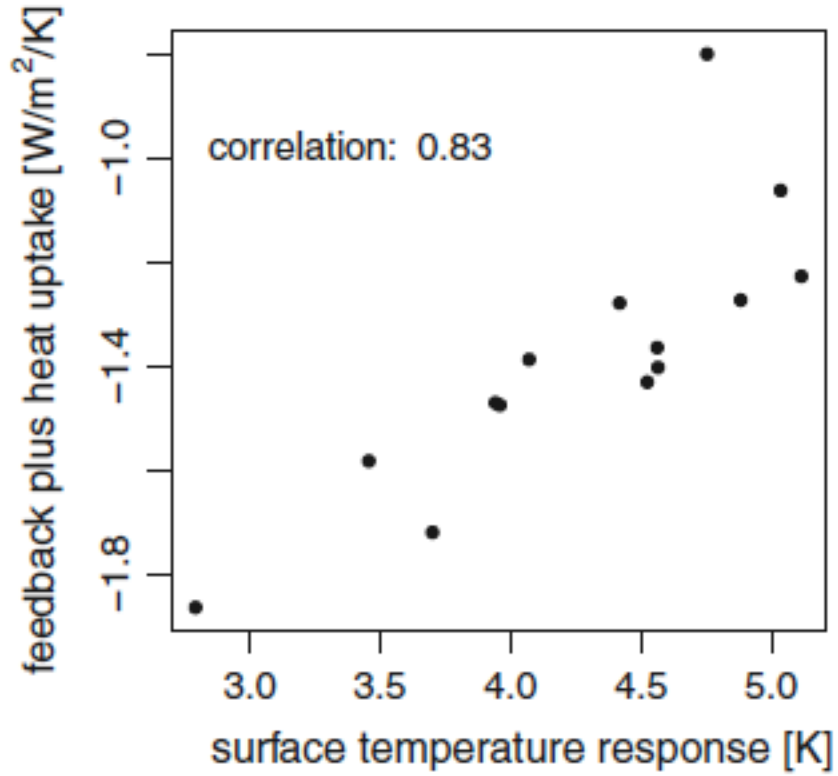
Tomassini et al. (2013) Clim. Dyn.

Two reasons have been identified:

1. climate sensitivity (feedbacks)
2. ocean heat uptake



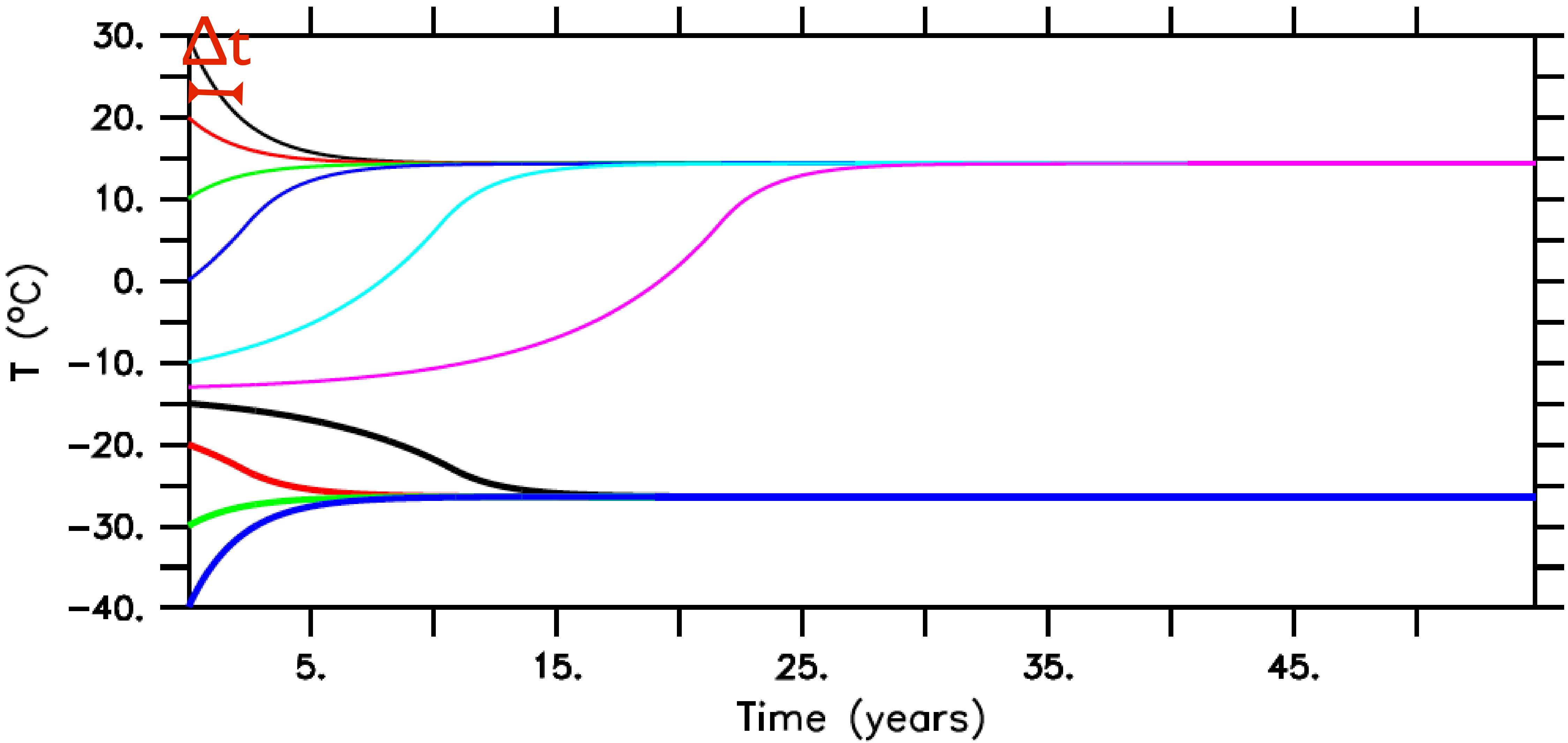




Stochastic Climate Models

0D-EBM Solutions

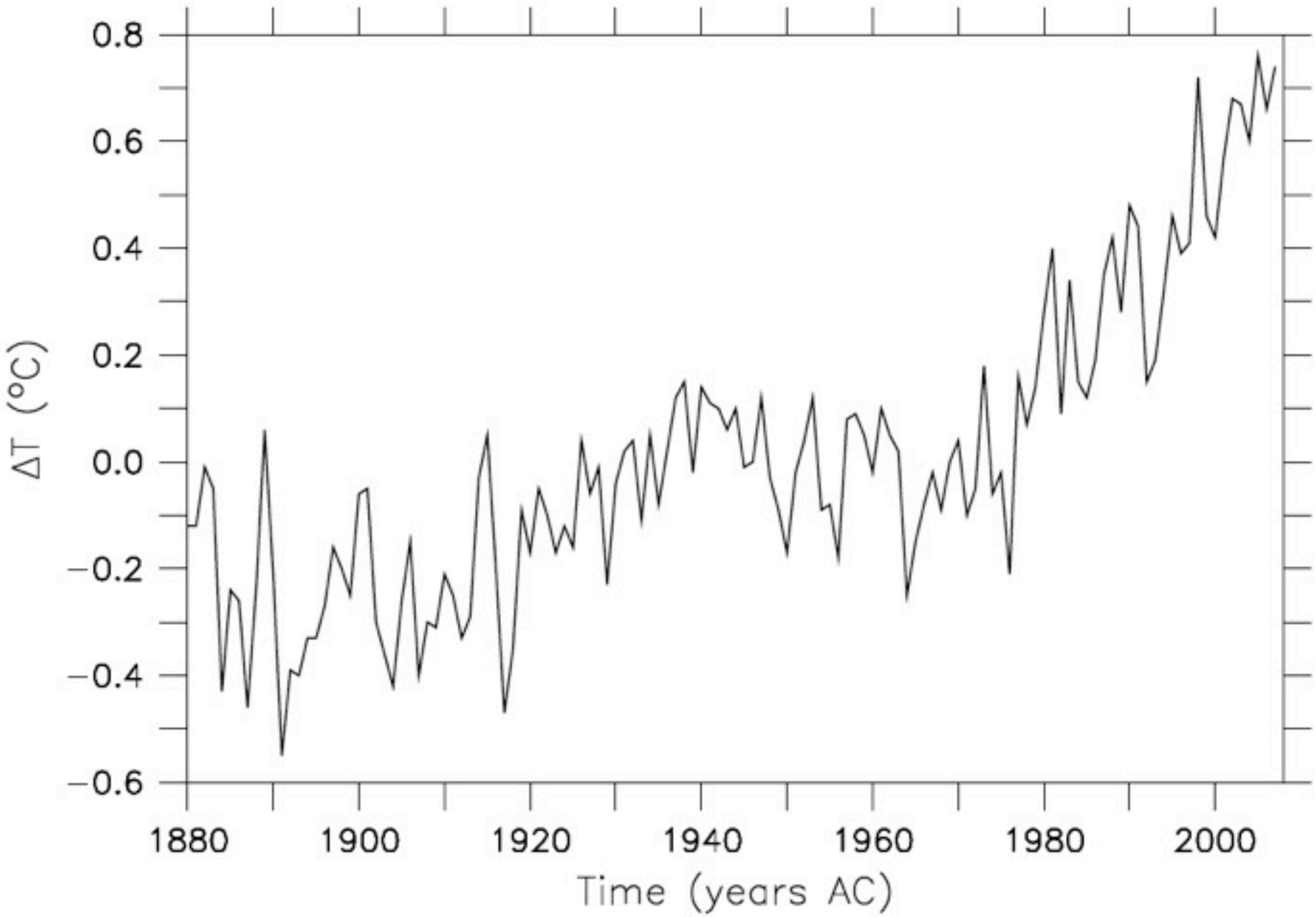
are smooth



Response timescale Δt = C/B = 2 years

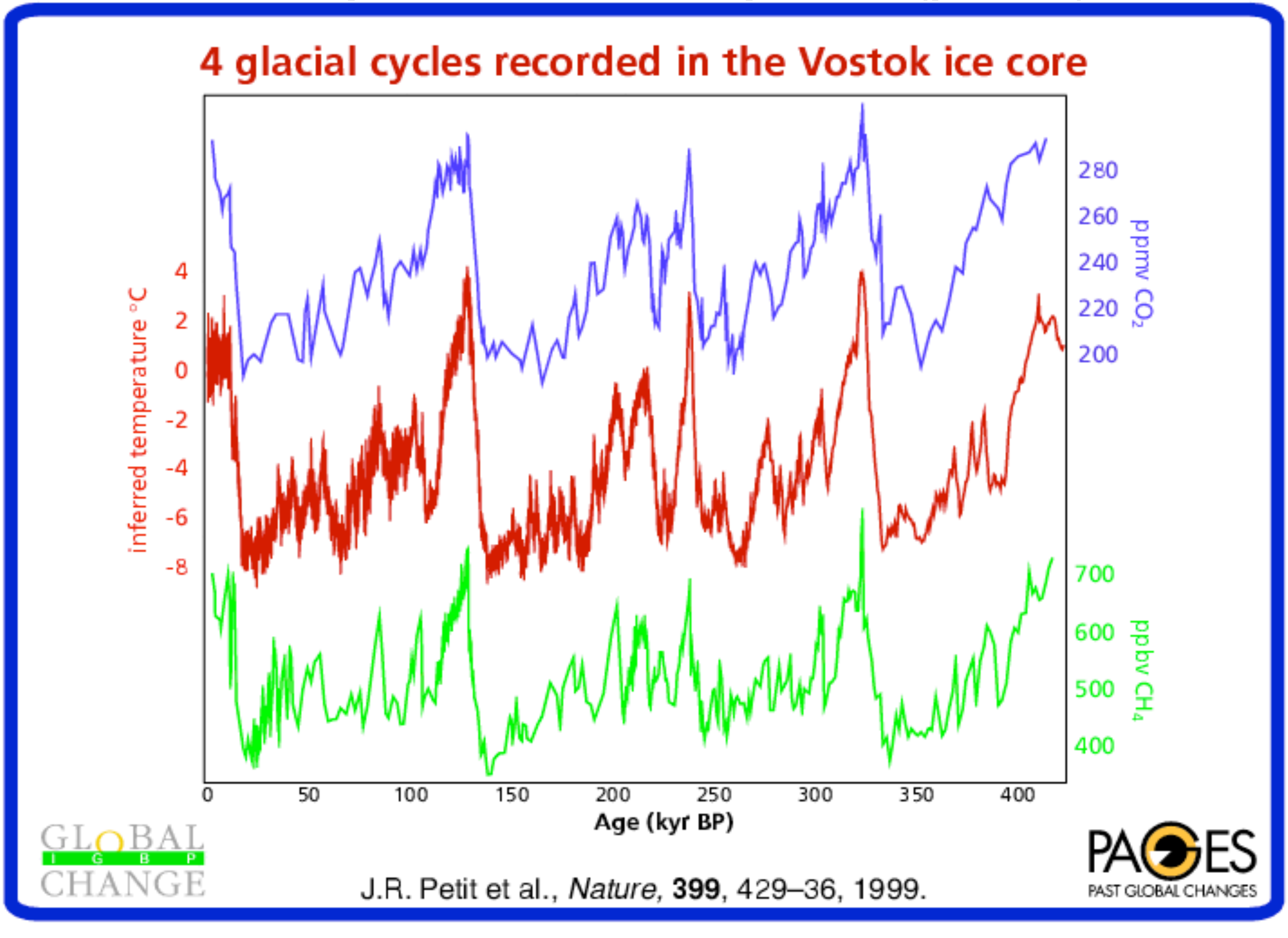
real world has variability

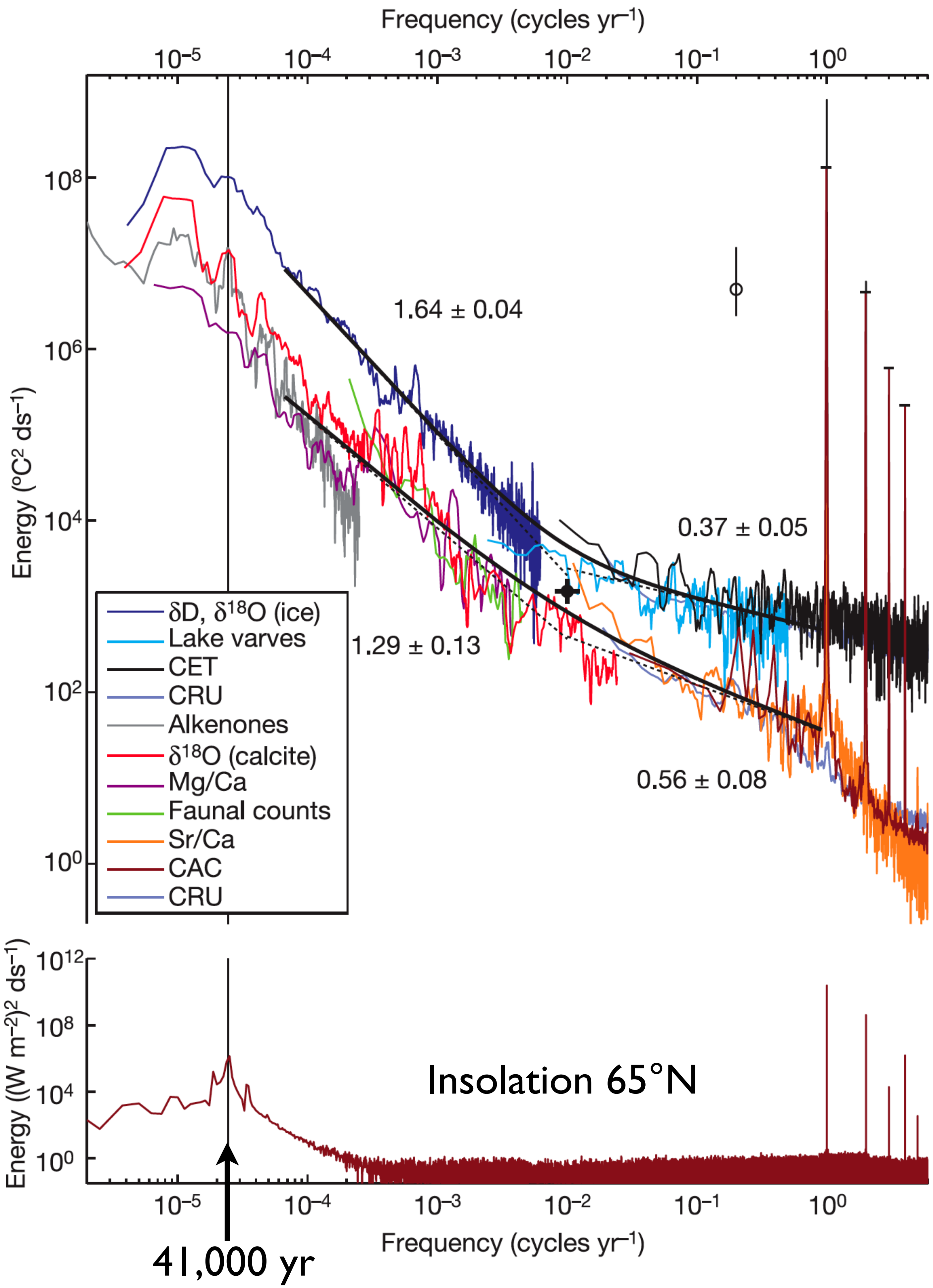
Variability last 150 years (instrumental period)



Global surface air temperature anomaly from NASA/GISS

Variability last 400,000 years (paleo)





Estimated spectrum of surface temperatures including paleoclimate proxies. From Huybers & Curry (2006, Nature 441, 329).

Auto-Regressive Process of Order One (AR1)

$$x_{n+1} = b x_n + w$$

auto-correlation coefficient

white noise

Hasselmann (1976) Tellus

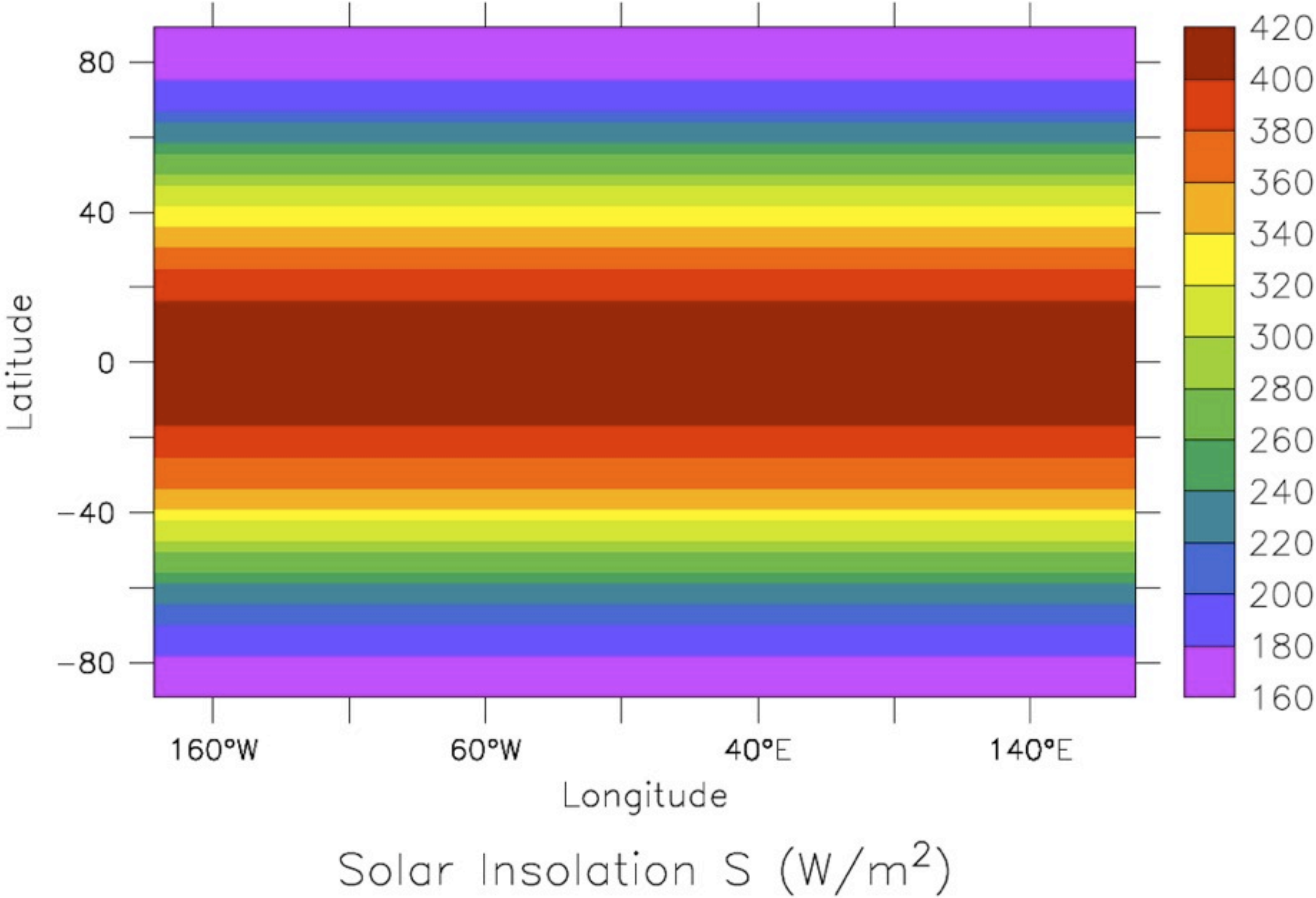
Periodogram

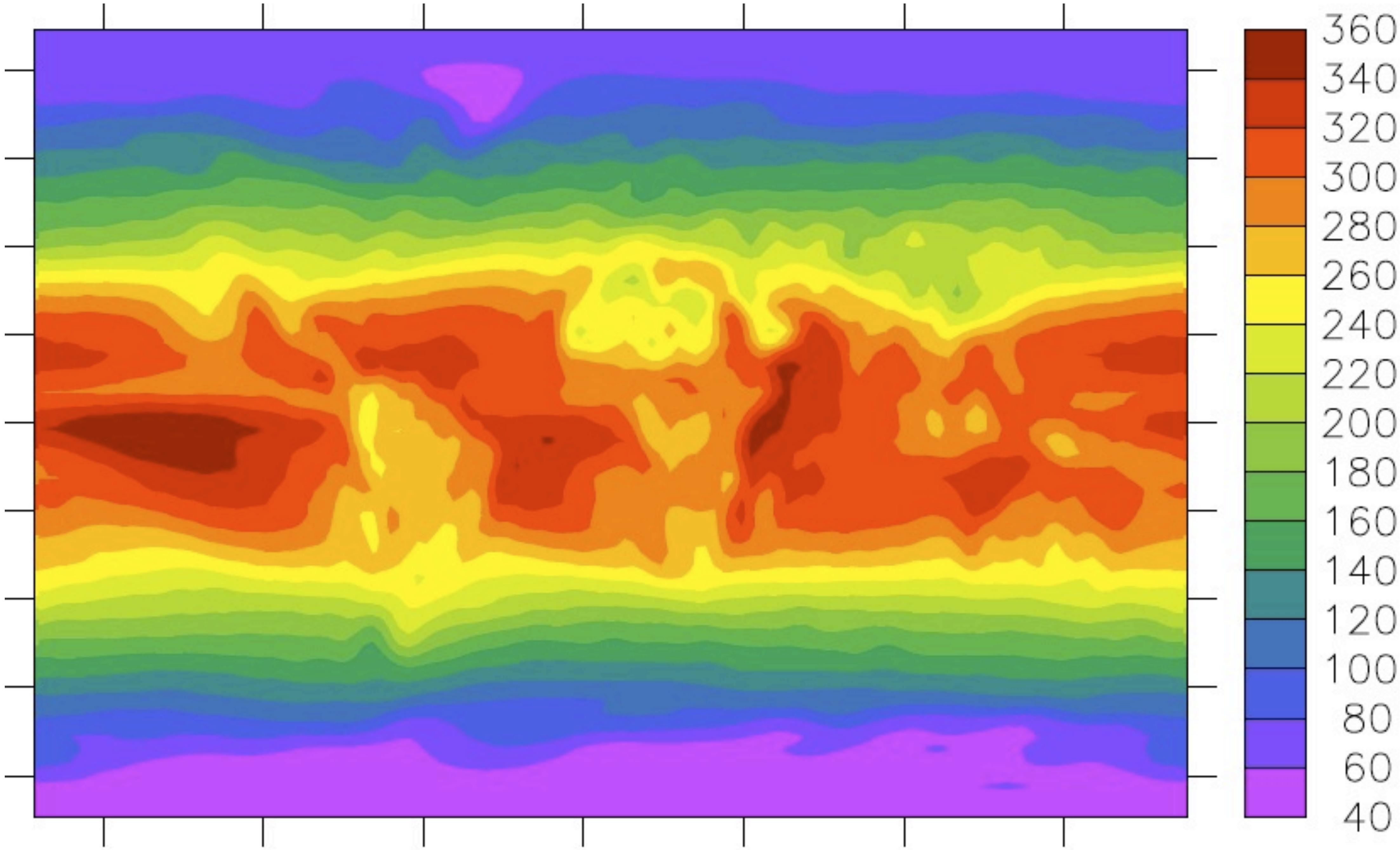
see chapter 12 of the book "Statistical Analysis in Climate Research" by von Storch and Zwiers (2001, Cambridge University Press)

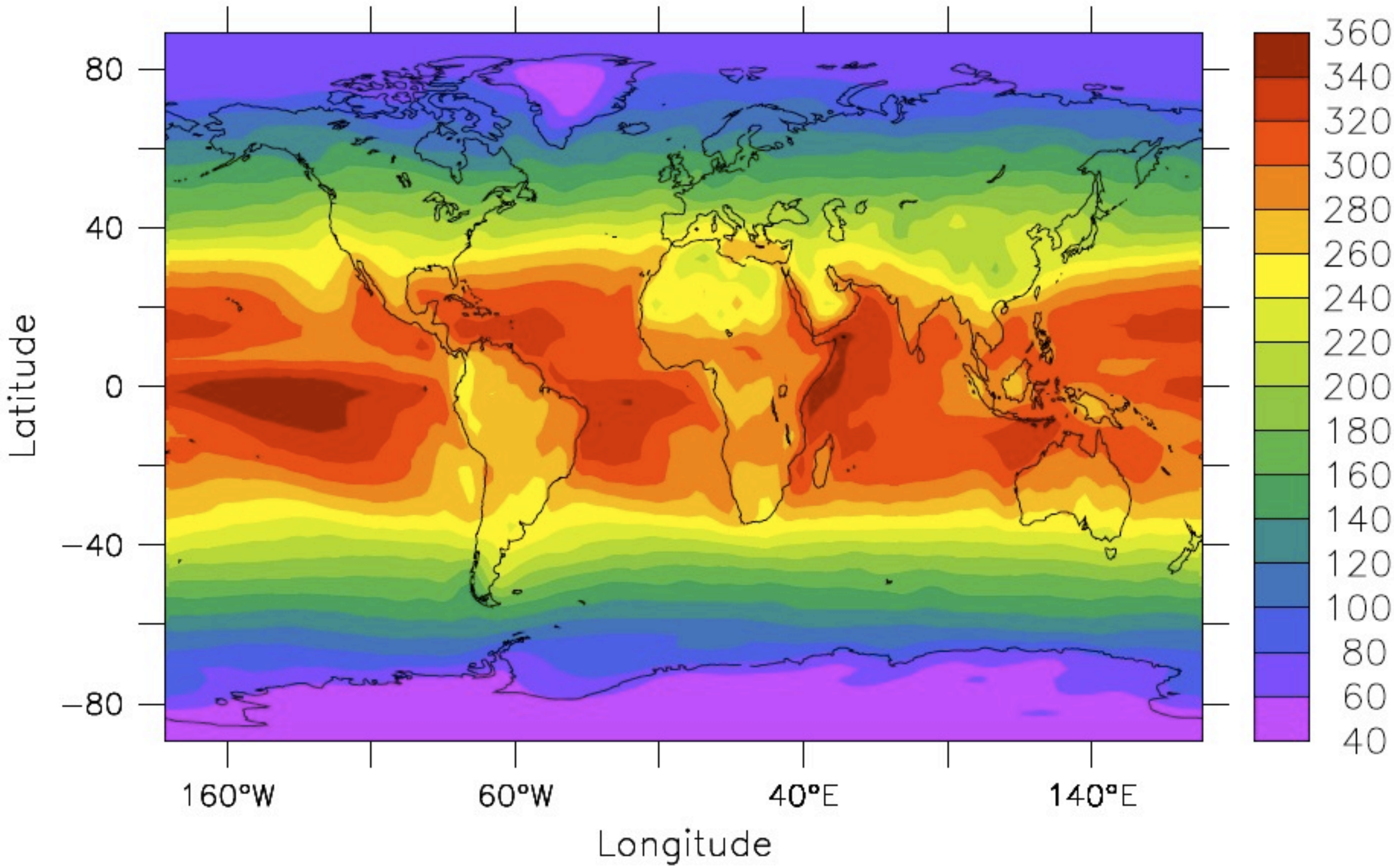
HW2: include variability in your 0D EBM !

Meridional Energy Transport

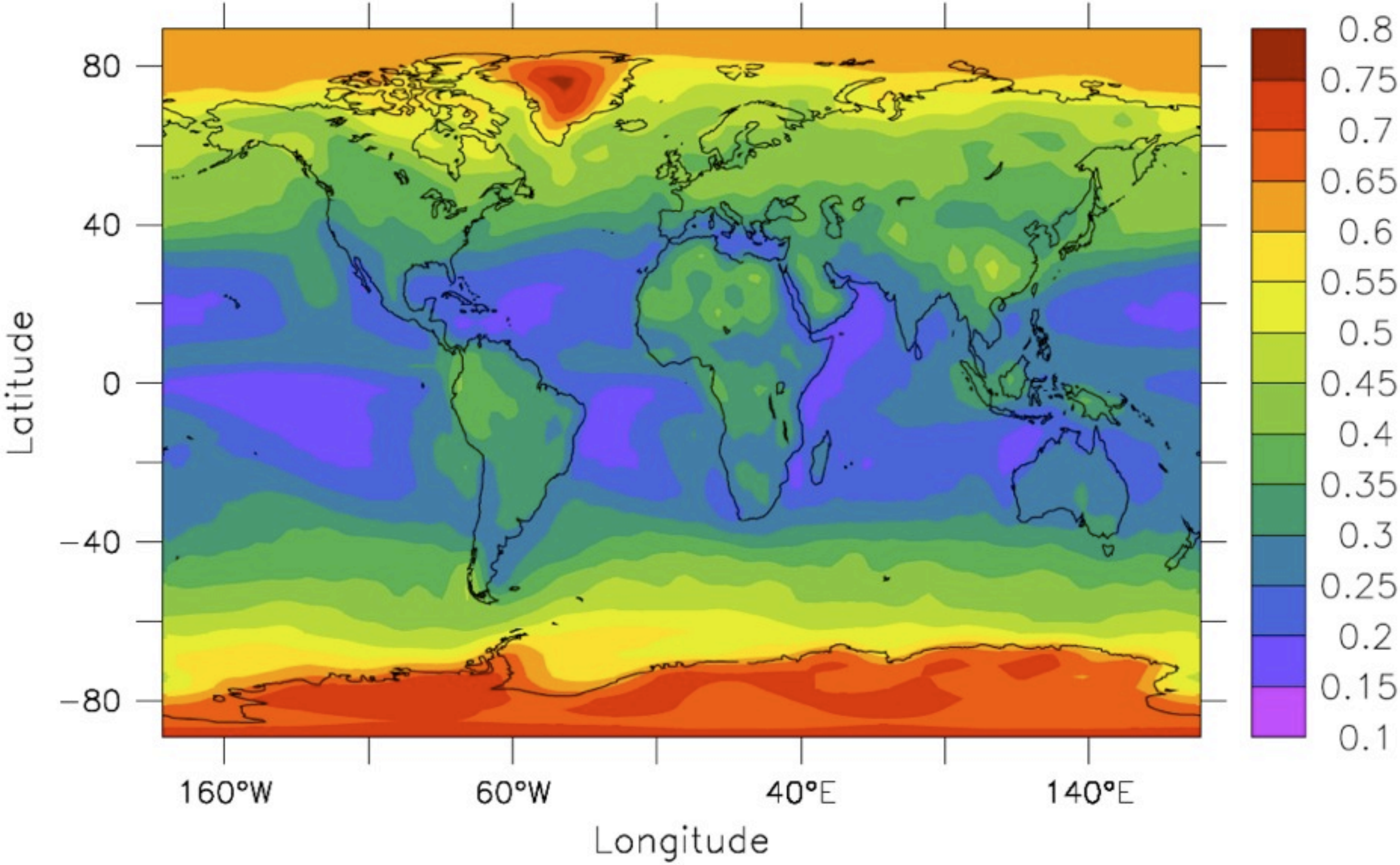
TOA Fluxes from Satellites
Earth Radiation Budget Experiment (ERBE)



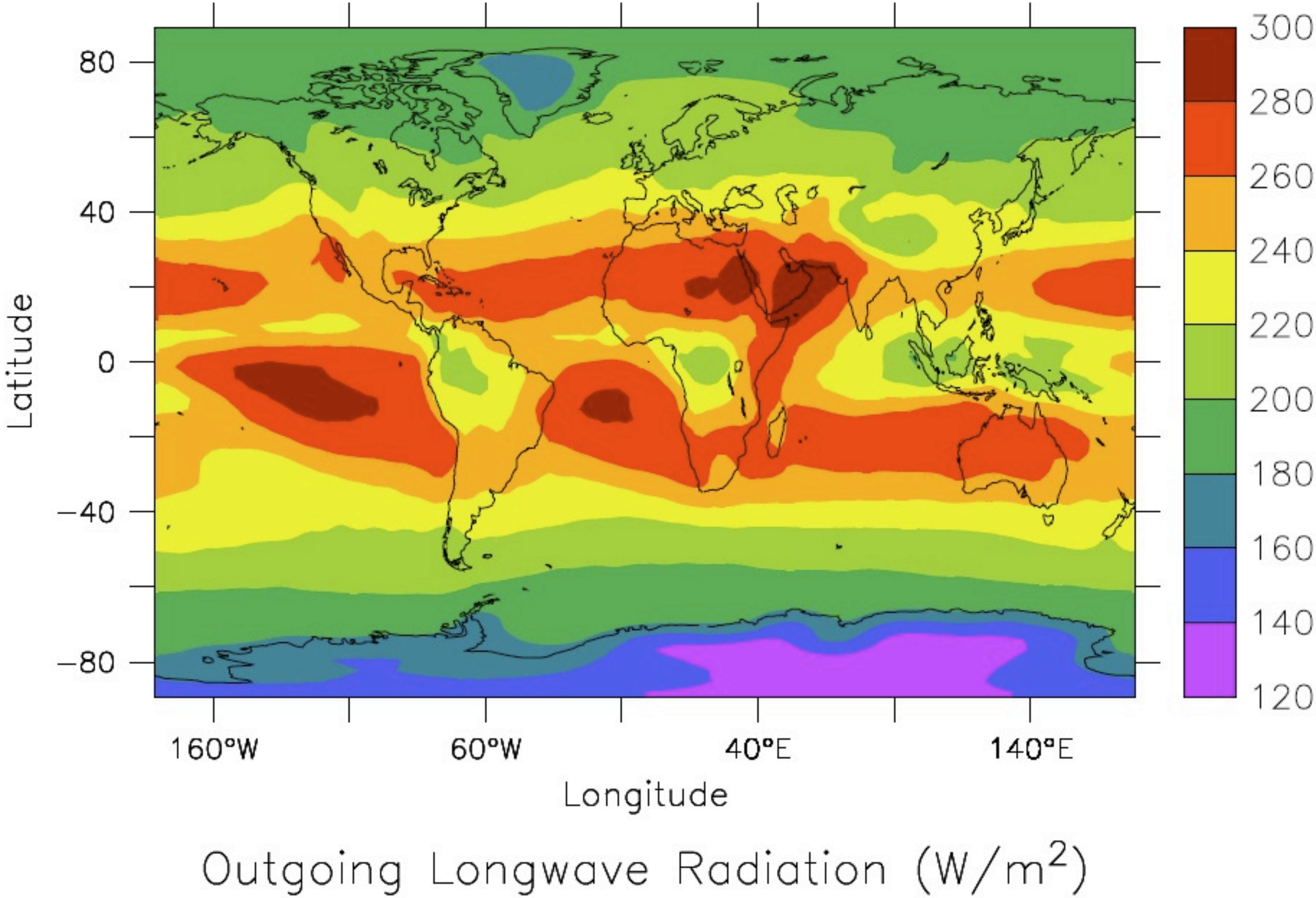

360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40

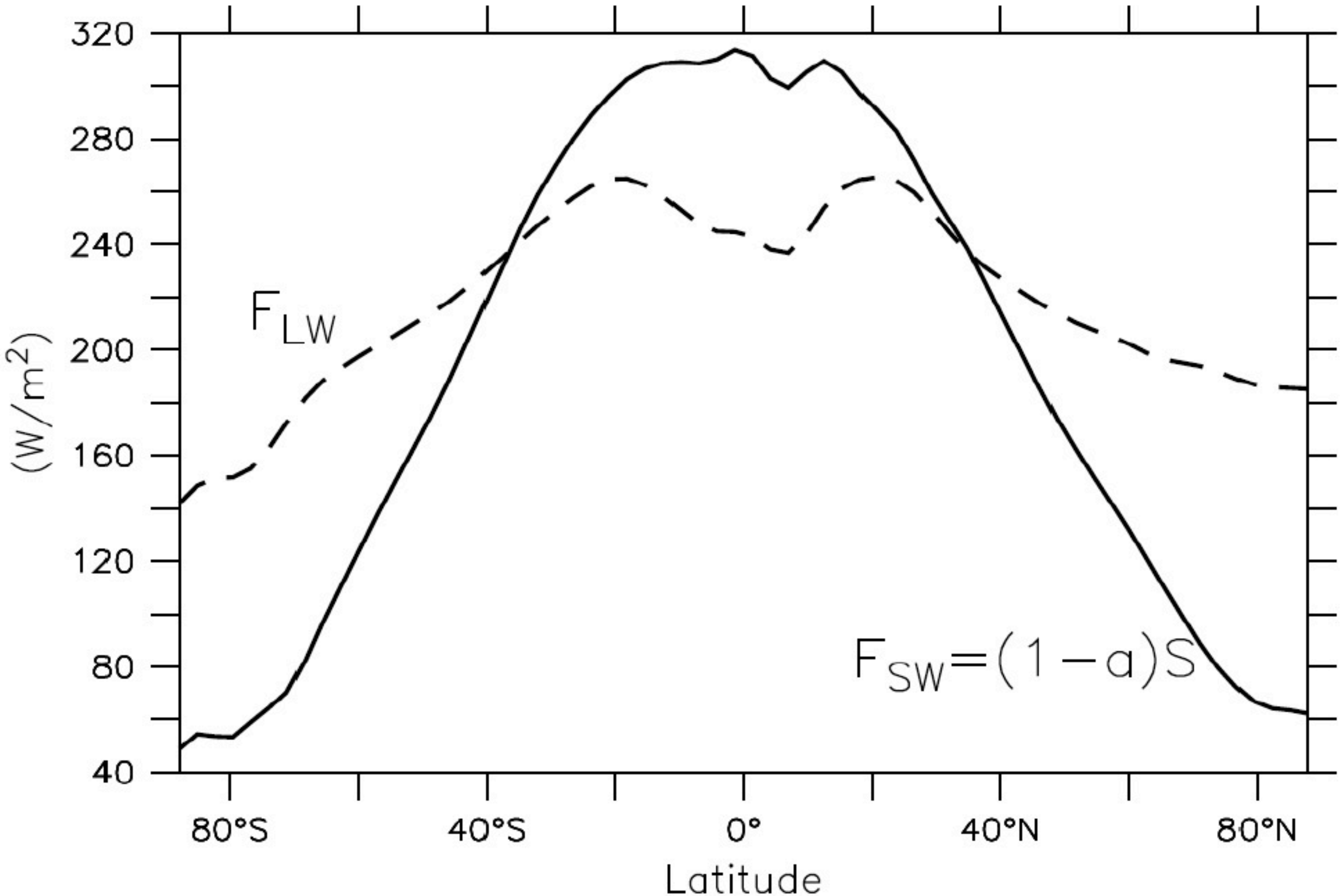


Absorbed Solar Radiation (W/m^2)

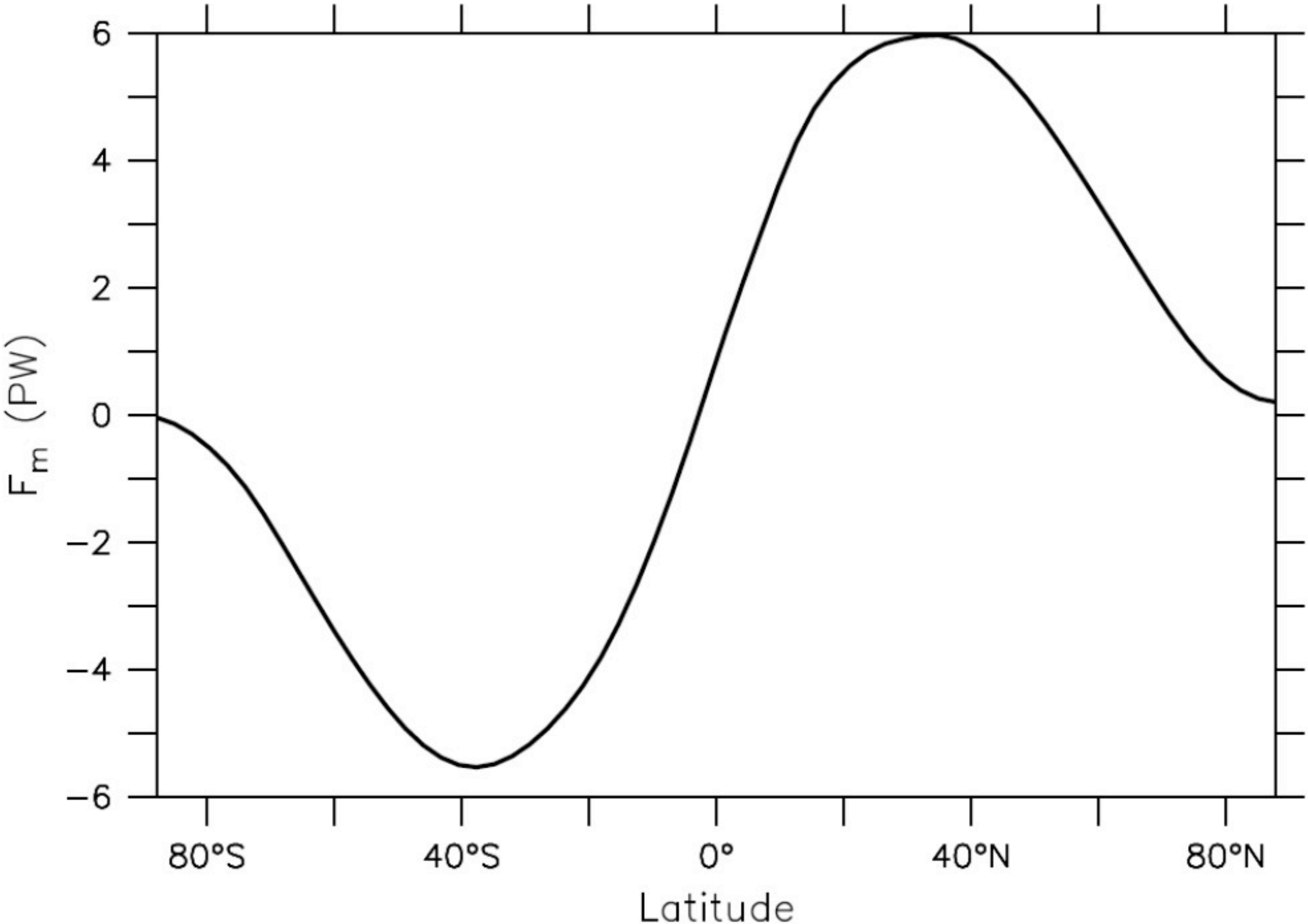

80
40
0
−40
−80
Latitude
160°W
60°W
40°E
140°E
Longitude
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1

Albedo

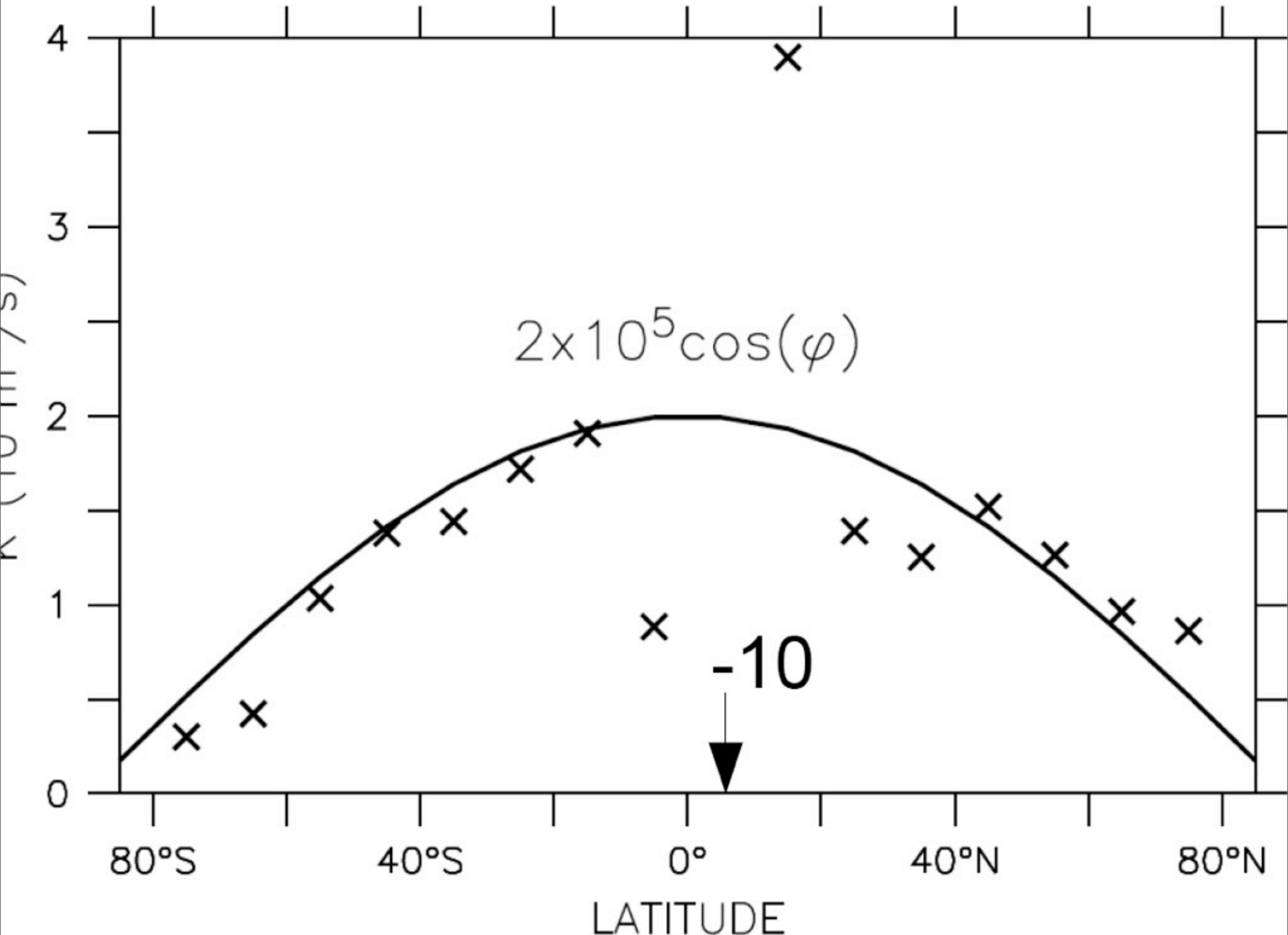

80
40
0
−40
−80
Latitude
160°W
60°W
40°E
140°E
Longitude
300
280
260
240
220
200
180
160
140
120
Outgoing Longwave Radiation (W/m2)



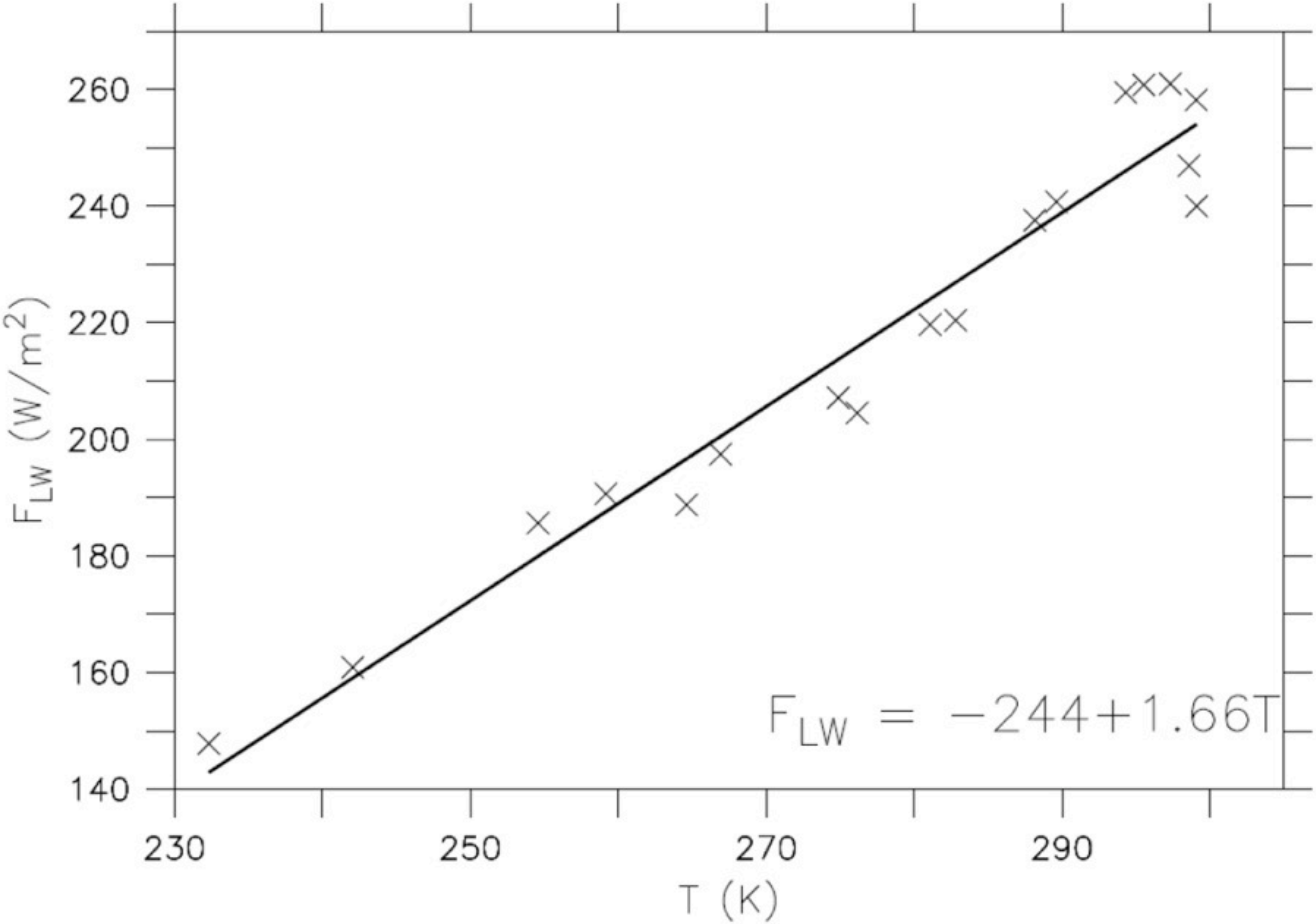
320
280
240
200
160
120
80
40
(W/m^2)
F_{LW}
$F_{SW}=(1-a)S$
80°S
40°S
0°
40°N
80°N
Latitude



6
4
2
0
−2
−4
−6
F_m (PW)
80°S
40°S
0°
40°N
80°N
Latitude



4
3
2
1
0
$2x10^5cos(\varphi)$
-10
80°S
40°S
0°
40°N
80°N
LATITUDE


260
240
220
200
180
160
140
F_{LW} (W/m^2)
230
250
270
290
T (K)
$F_{LW} = -244 + 1.66T$