The Sun's effect on Climate and its implications to the understanding of climate change

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Hebrew University of Jerusalem

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Take Away Points

The Sun has a large effect on climate

Part of the 20th century warming is solar (about $^1/_2$ to $^2/_3$)

Effect is through cosmic ray modulation of cloud cover

(Svensmark next talk)

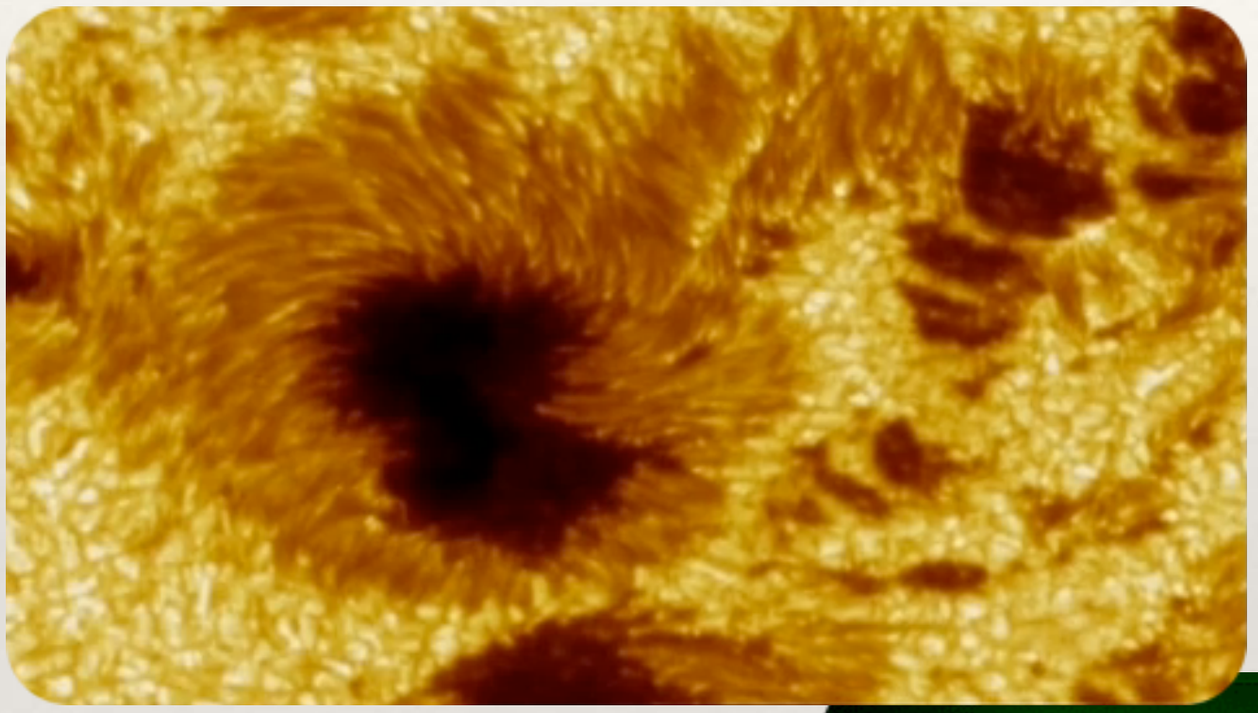
Climate Sensitivity is low (ΔT_{x2} ~ 1-2°C)

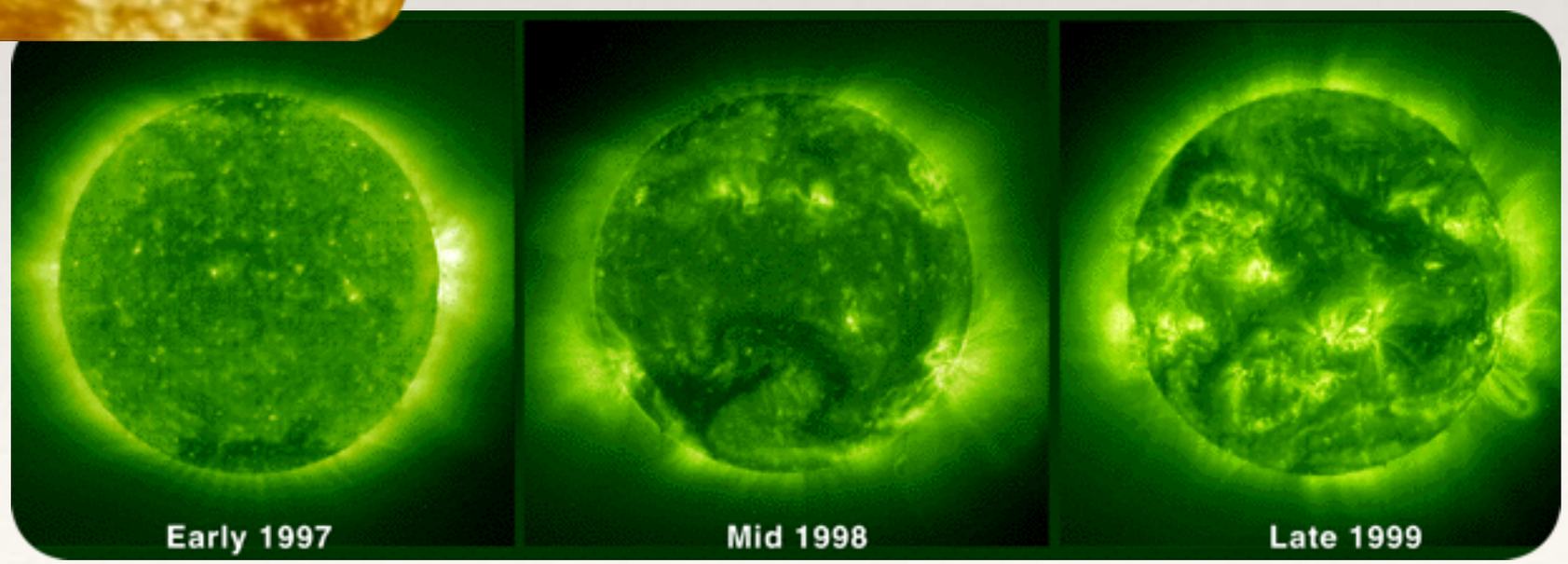
Future warming will be benign (0.15±0.2°C/decade)

Solar effect on climate (is large)

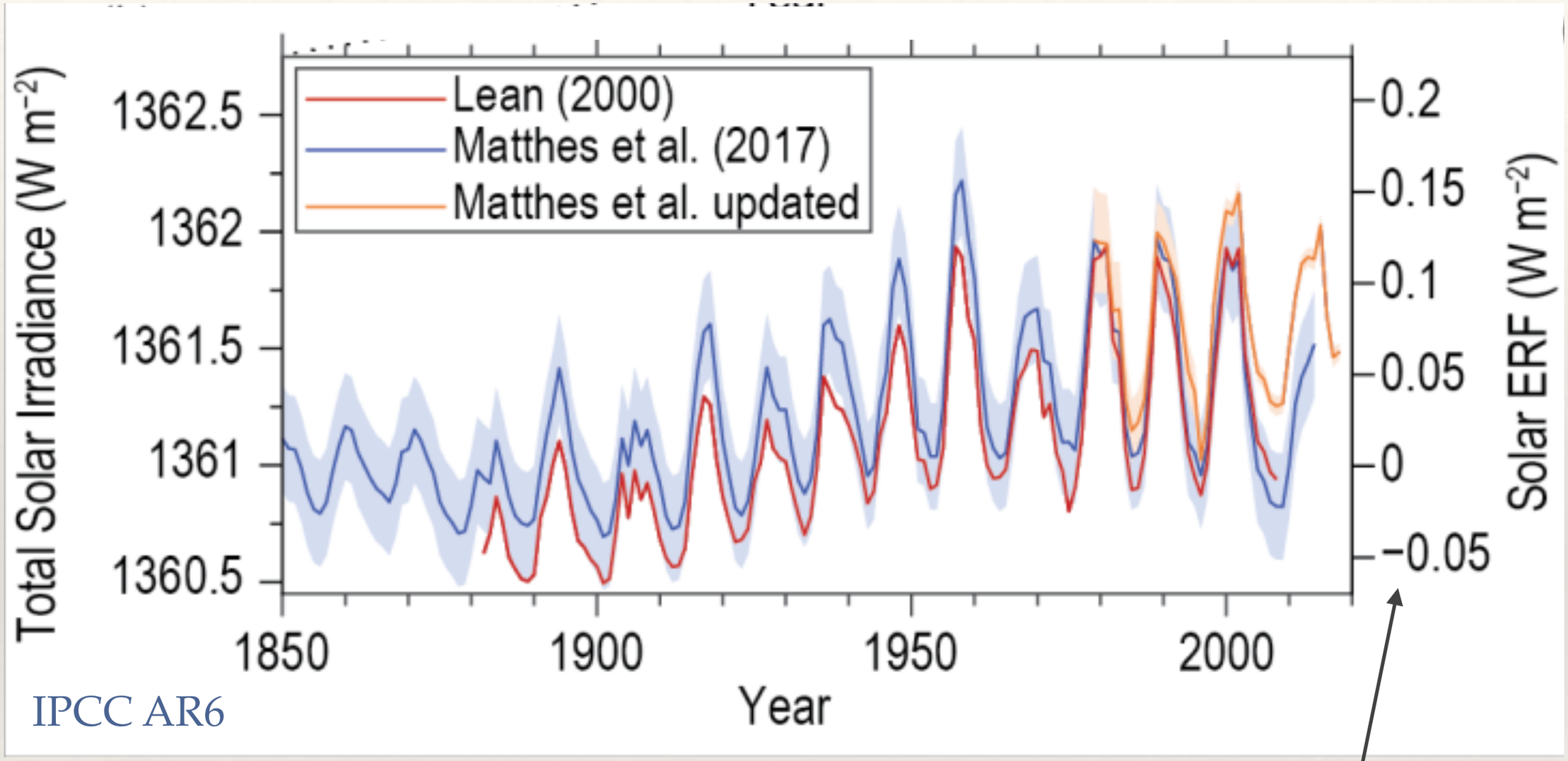
Solar Activity & Climate

- *Solar activity varies in time. This manifests itself in small changes in the irradiance, but large changes in UV, solar wind, magnetic field, sunspots, and indirectly,* ***cosmic rays****.*



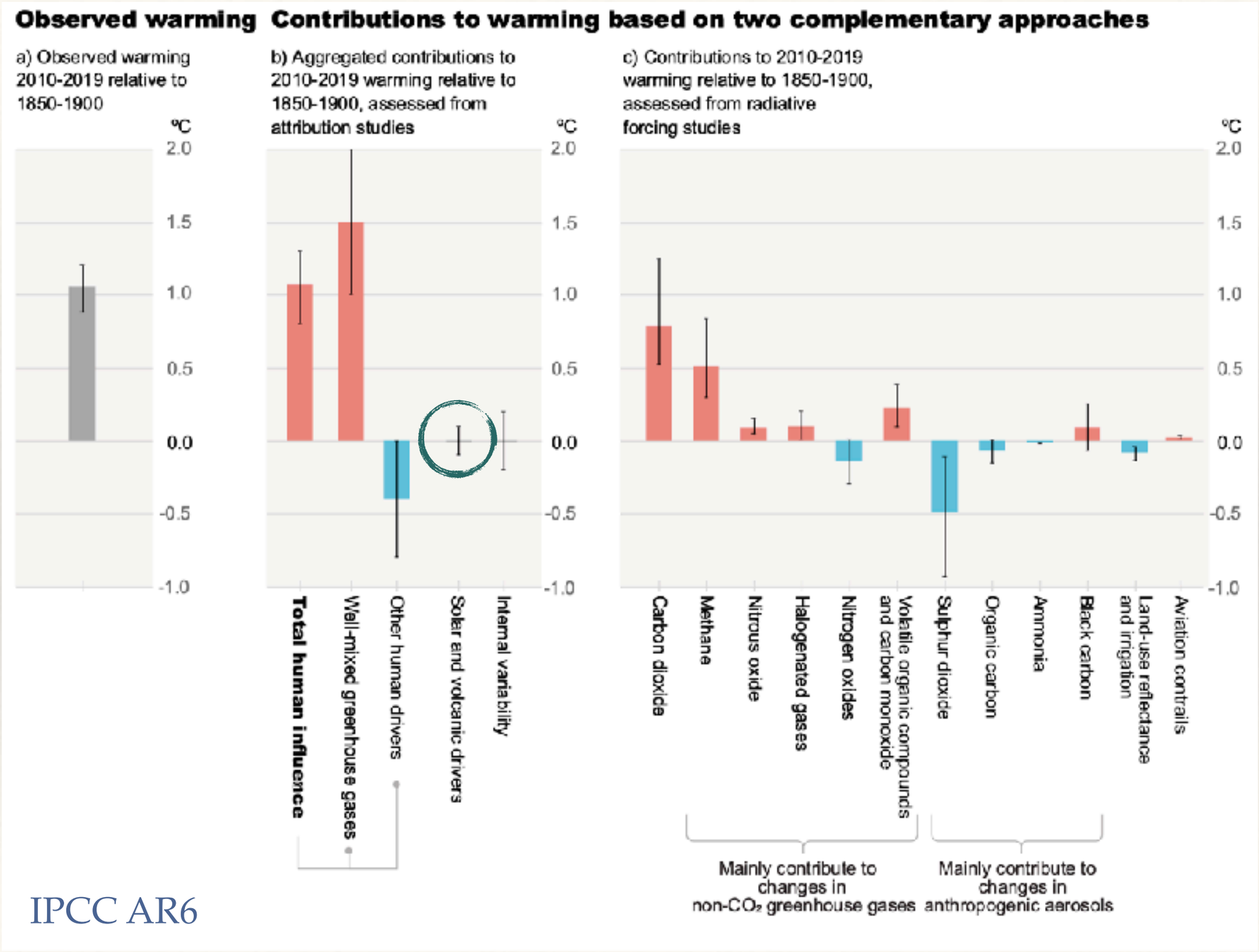


Solar forcing according to IPCC



Note that typical variations are very small, of order 0.1 W/m²
Compared to 1-2 Wm² of Greenhouse Gases

Solar forcing according to IPCC



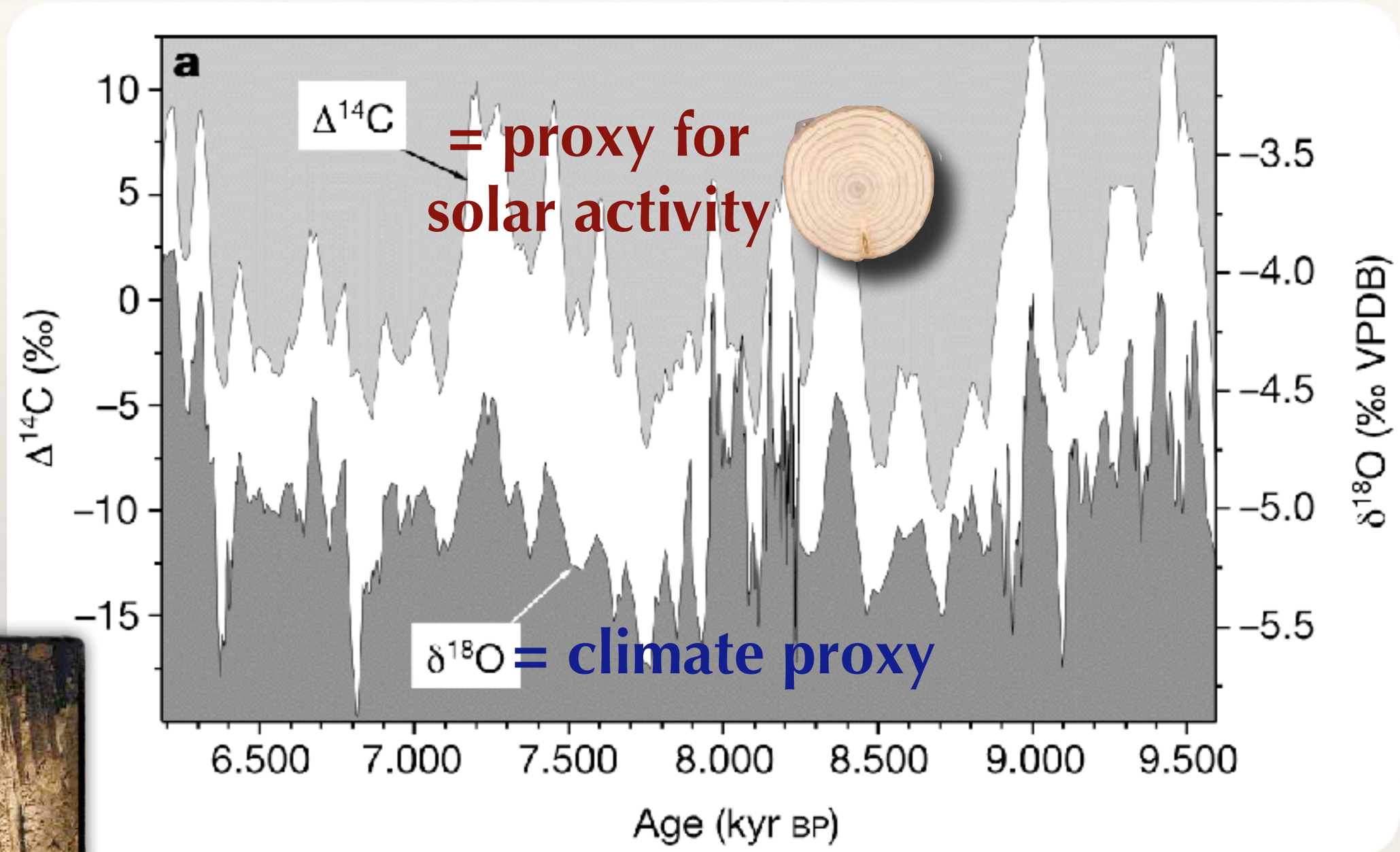
IPCC AR6

Solar forcing according to IPCC

		Emitted compound	Resulting atmospheric drivers	Radiative forcing by emissions and drivers	Level of confidence
Anthropogenic	Well-mixed greenhouse gases	CO_2	CO_2	1.68 [1.33 to 2.03]	VH
		CH_4	CO_2 H_2O^{str} O_3 CH_4	0.97 [0.74 to 1.20]	H
		Halo-carbons	O_3 CFCs HCFCs	0.18 [0.01 to 0.35]	H
		N_2O	N_2O	0.17 [0.13 to 0.21]	VH
	Short lived gases and aerosols	CO	CO_2 CH_4 O_3	0.23 [0.16 to 0.30]	M
		NMVOC	CO_2 CH_4 O_3	0.10 [0.05 to 0.15]	M
		NO_x	Nitrate CH_4 O_3	-0.15 [-0.34 to 0.03]	M
		Aerosols and precursors (Mineral dust, SO_2, NH_3, Organic carbon and Black carbon)	Mineral dust Sulphate Nitrate Organic carbon Black carbon	-0.27 [-0.77 to 0.23]	H
			Cloud adjustments due to aerosols	-0.55 [-1.33 to -0.06]	L
			Albedo change due to land use	-0.15 [-0.25 to -0.05]	M
Natural			*Changes in solar irradiance*	0.05 [0.00 to 0.10]	M

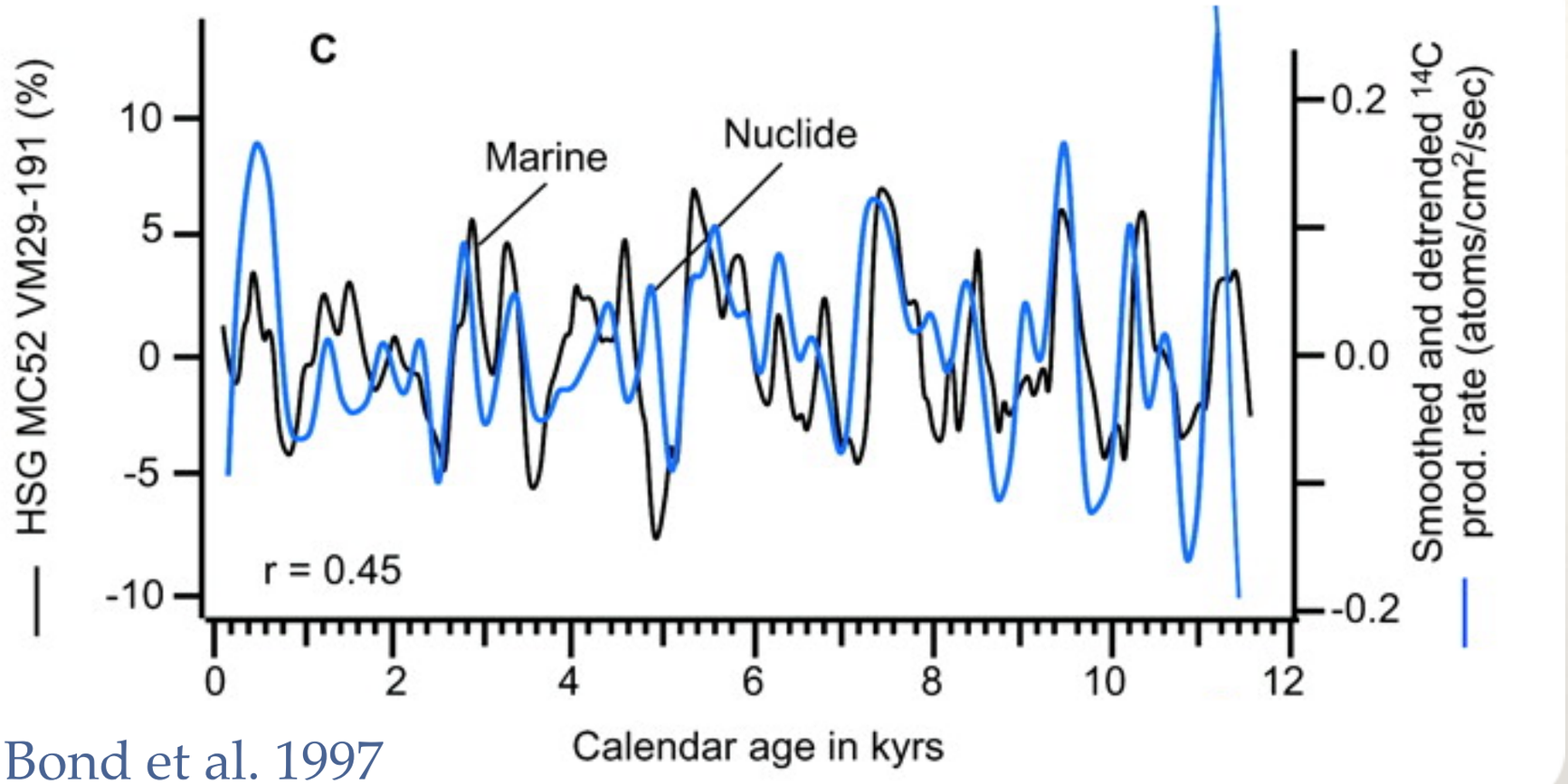
IPCC AR5

The link over several millennia

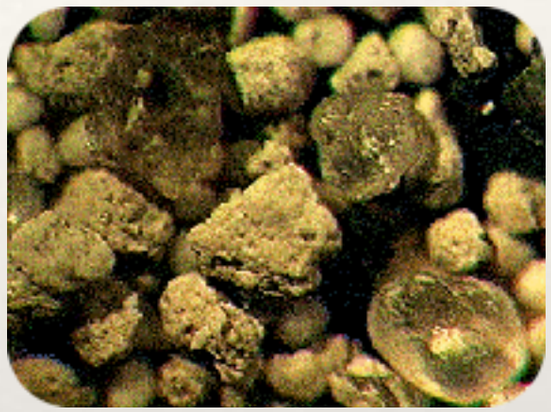


Neff et al., 2001

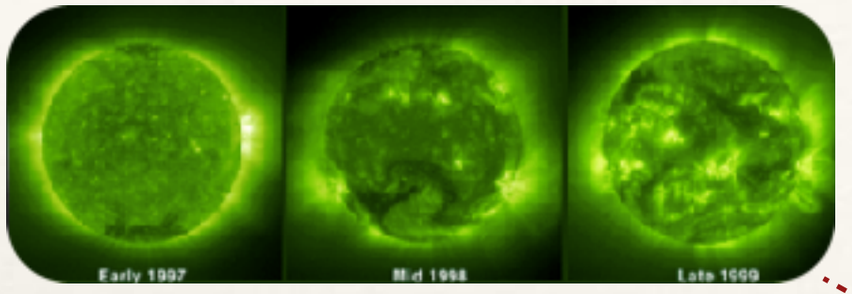
The link over several millennia



Bond et al. 1997

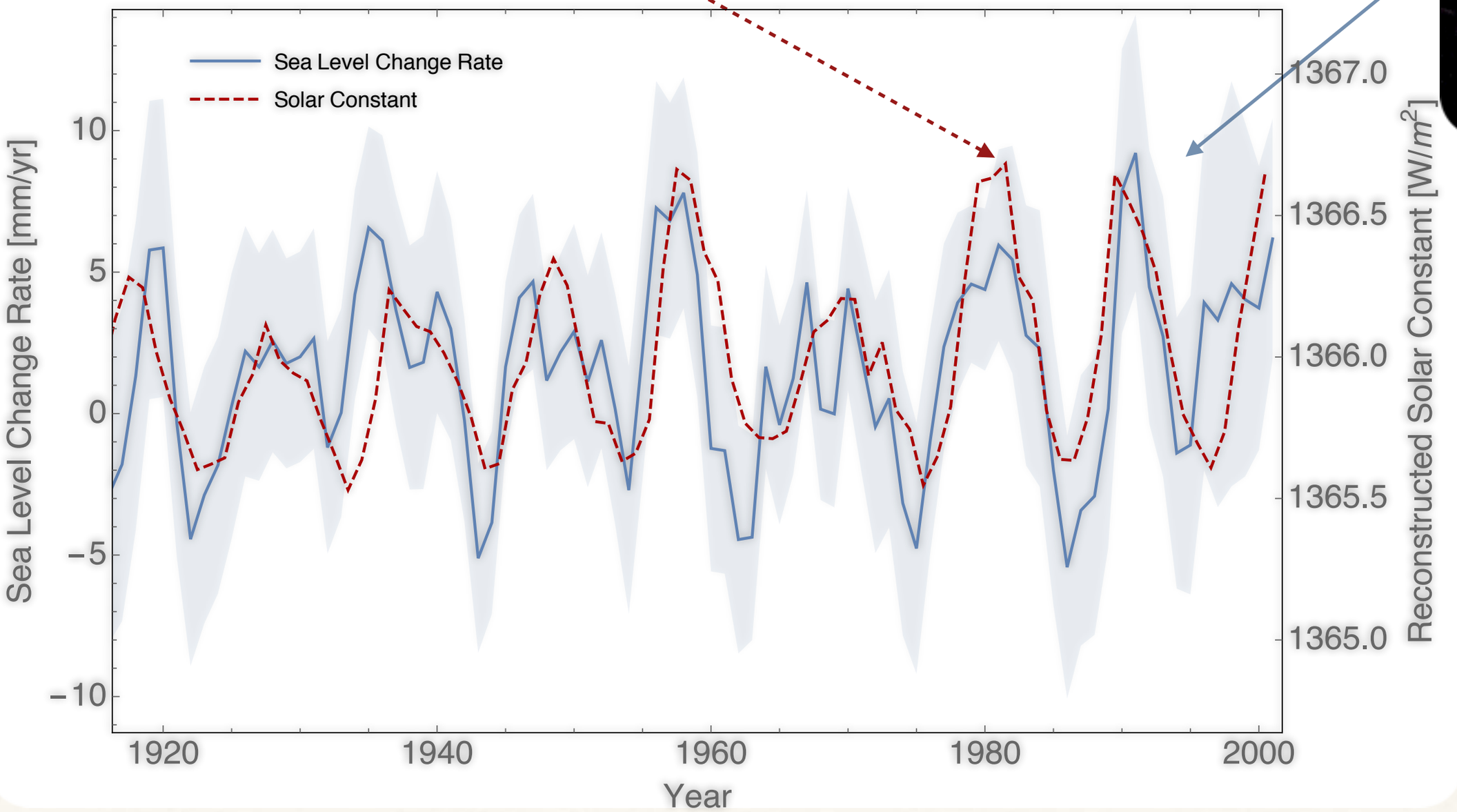


Link over the 11-year Cycle



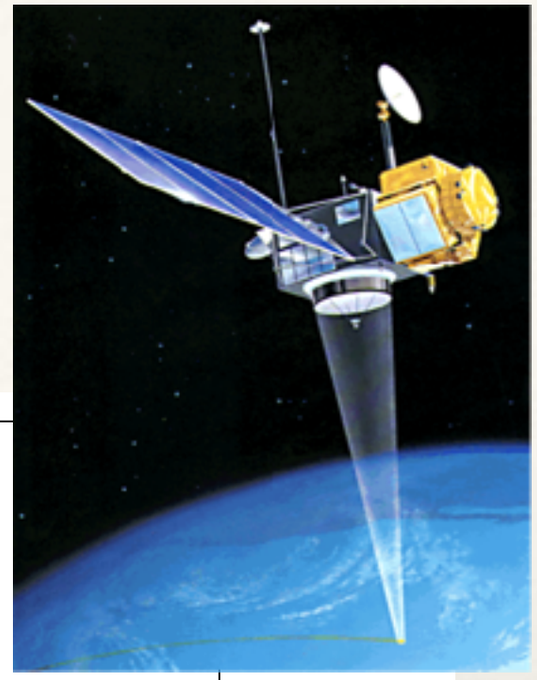
Solar Activity

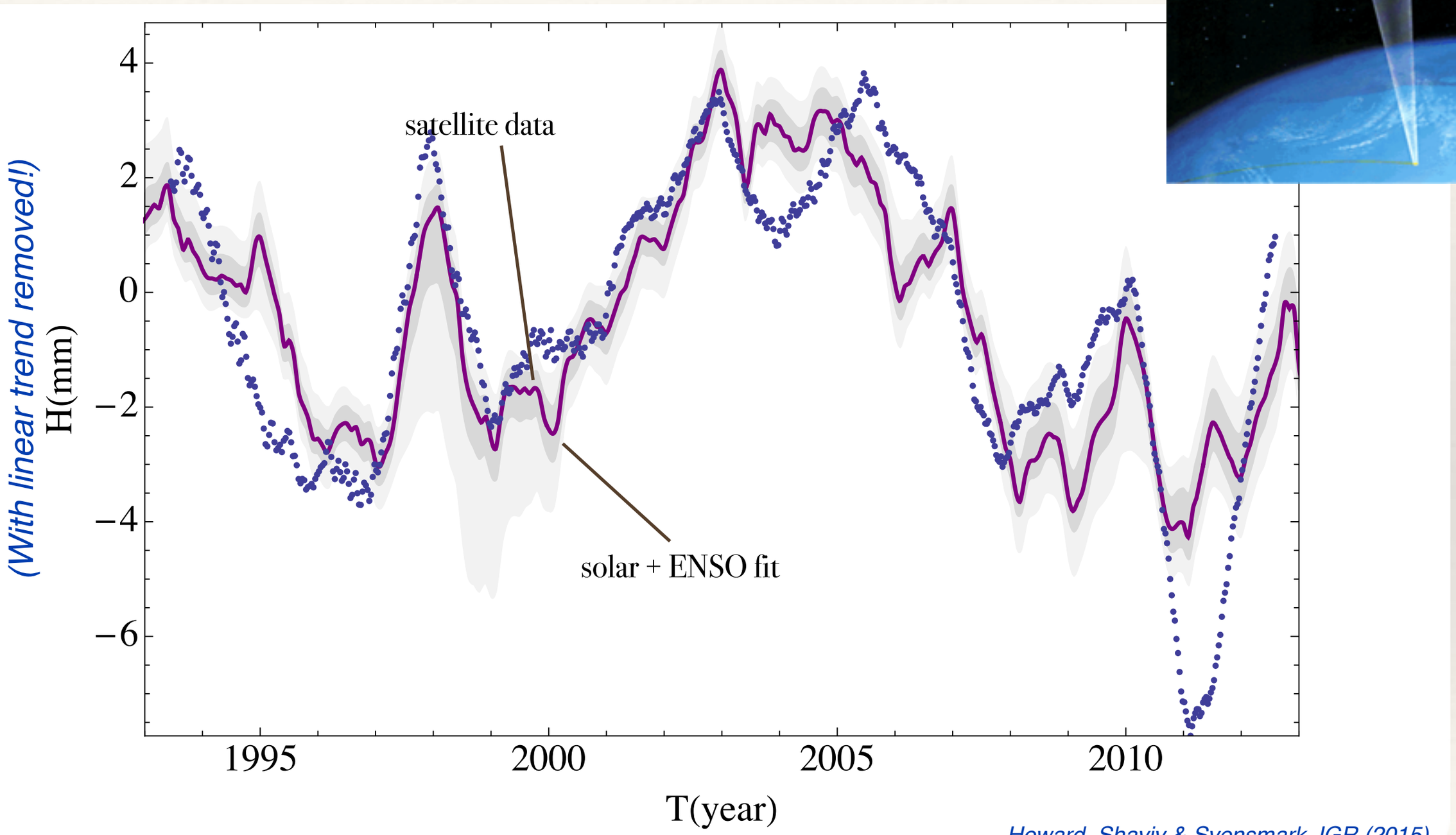
Sea Level Change Rate



Shaviv, 2008

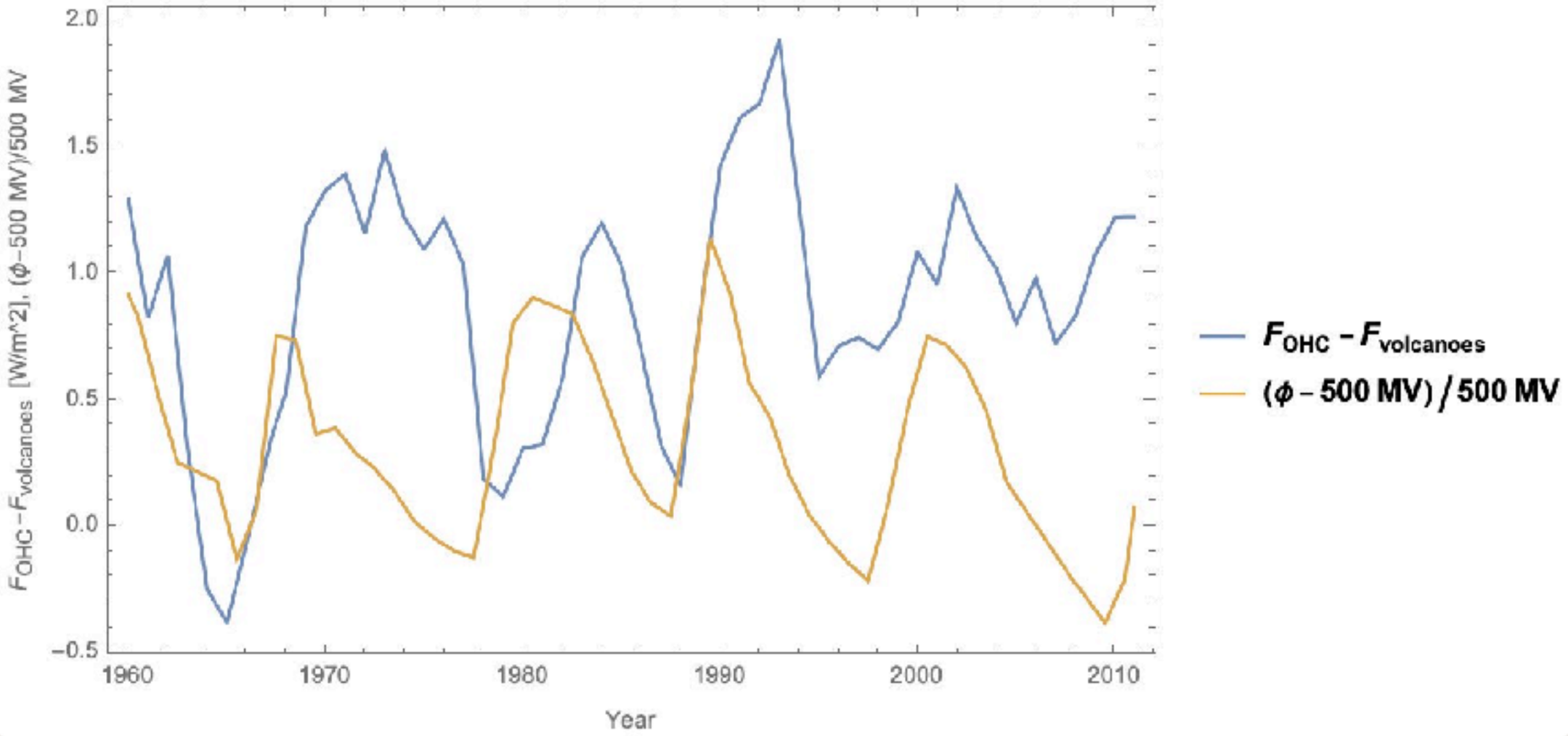
Satellite Altimetry





Howard, Shaviv & Svensmark JGR (2015)

Ocean Heat Flux

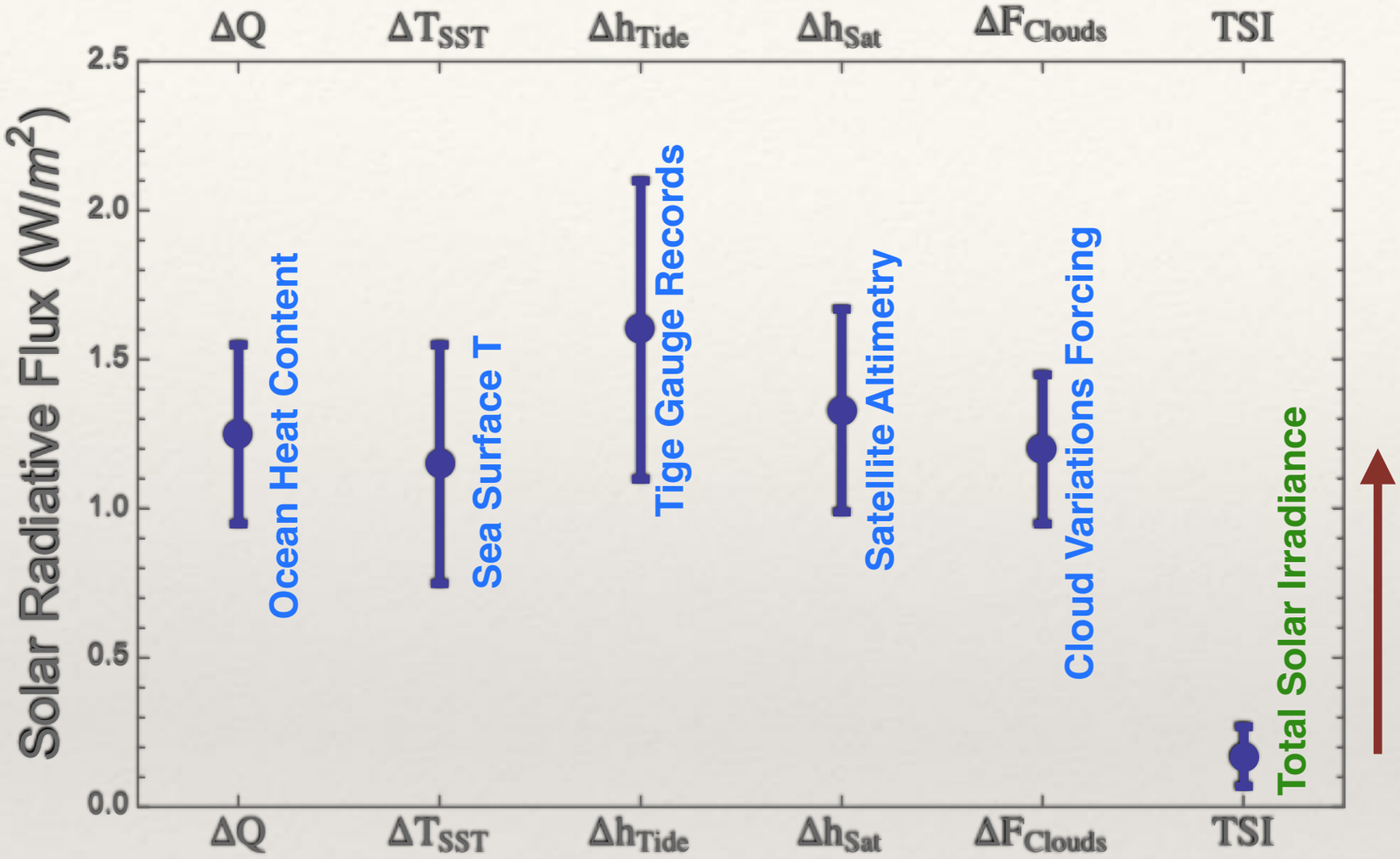


OHC - World Ocean Atlas (NOAA) https://www.ncei.noaa.gov/access/global-ocean-heat-content/basin_heat_data.html

Volcanic Forcing - NASA GISS https://data.giss.nasa.gov/modelforce/Fe_H11_1880-2011.txt

Solar Modulation - Matthes et al. 2017 doi: 10.1093/mnras/stx190

Link over the 11-year Cycle



Requires an amplification mechanism

Shaviv 2008, Howard et al. 2015

20th century increase of solar activity

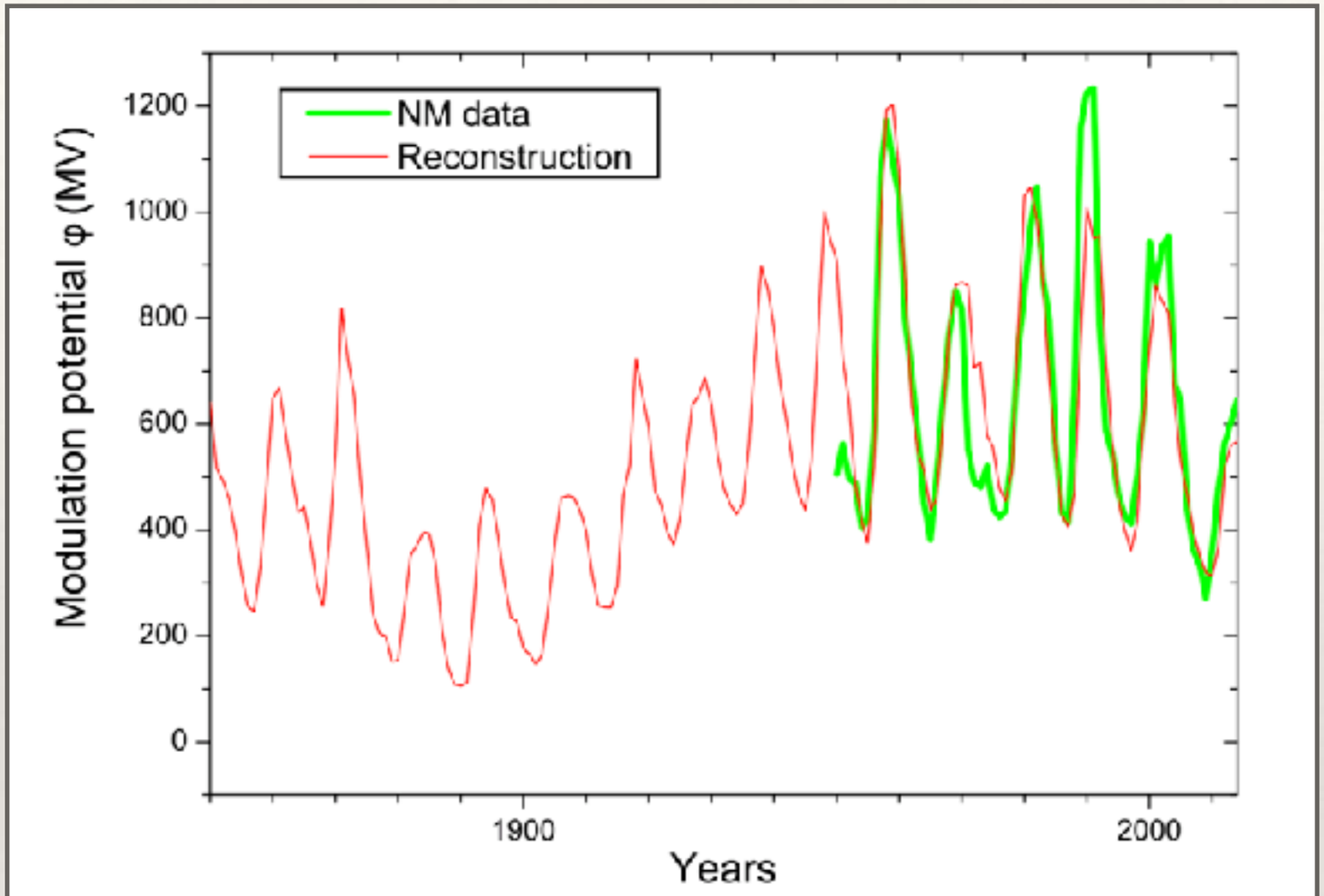
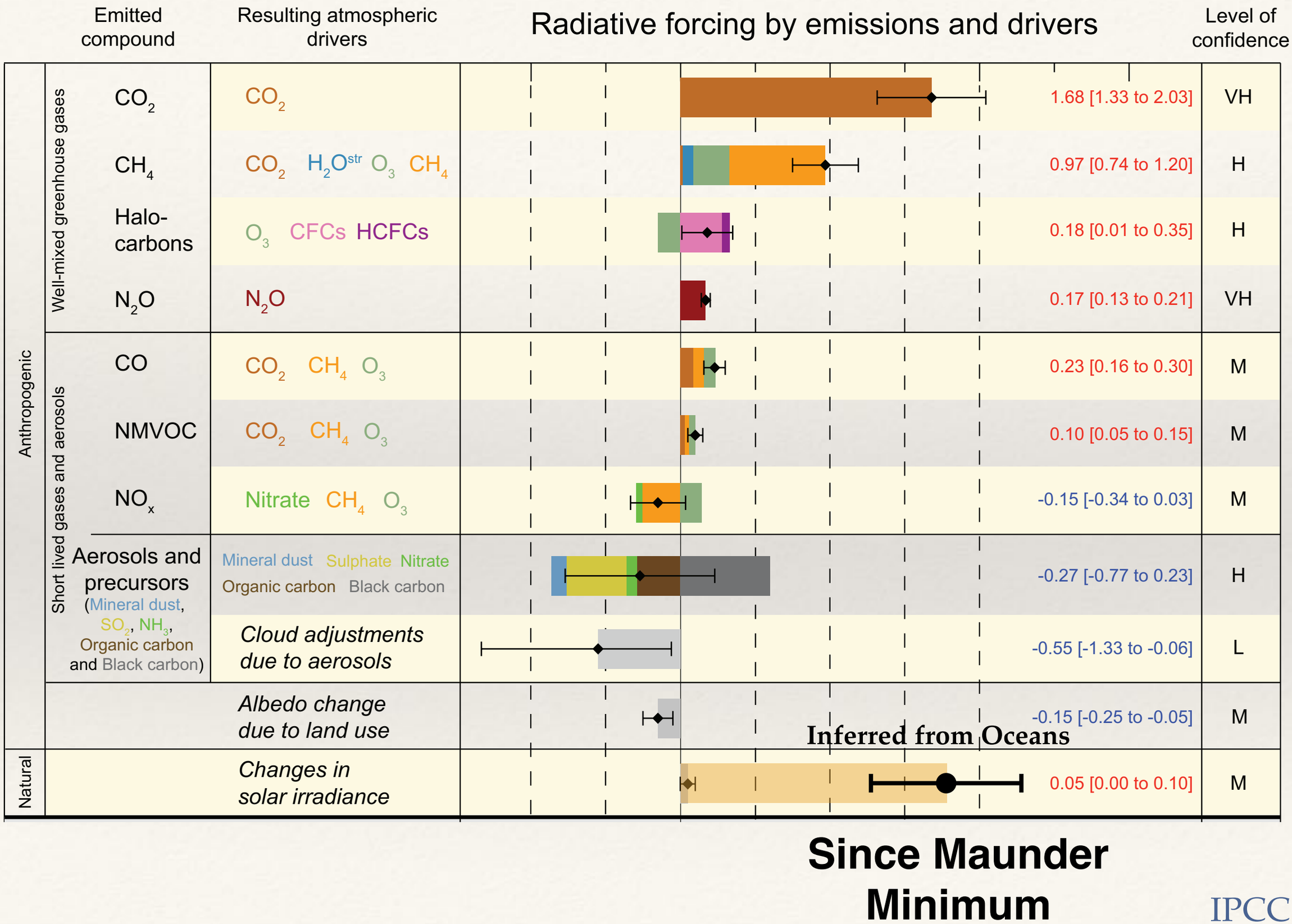


Figure 19. Time series of the reconstructed heliospheric modulation potential ϕ including solar-cycle variations. The thick green line is the modulation potential reconstructed for the period 1951–2014 using data from the worldwide neutron monitor (NM) network (Usoskin et al., 2011).

Matthes et al. 2017

Solar forcing according to IPCC



IPCC AR5

The Sun has a large effect on climate

Part of the 20th century warming is solar (~ 1/2 to 2/3)

Effect is through cosmic ray modulation of cloud cover

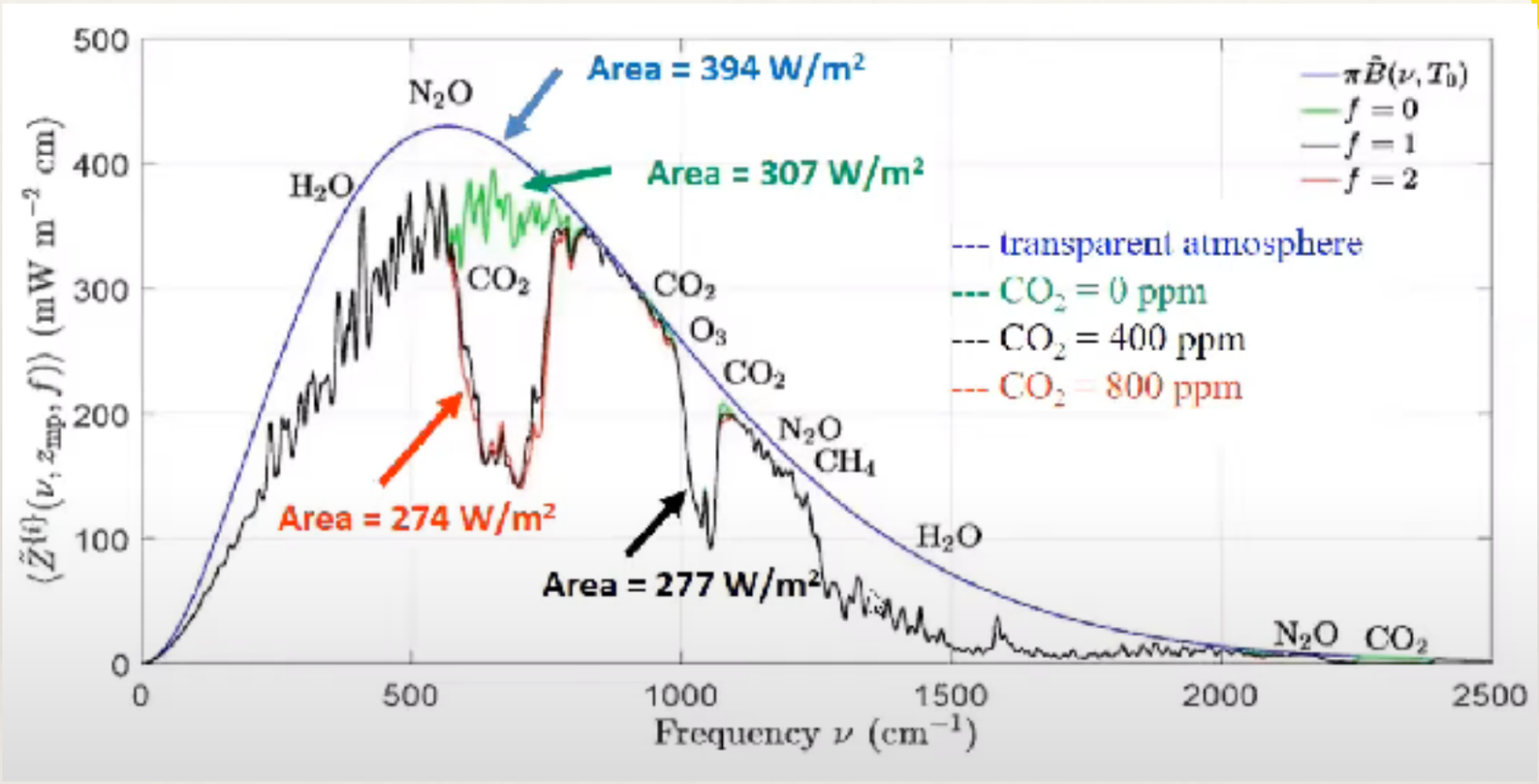
(Svensmark next talk)

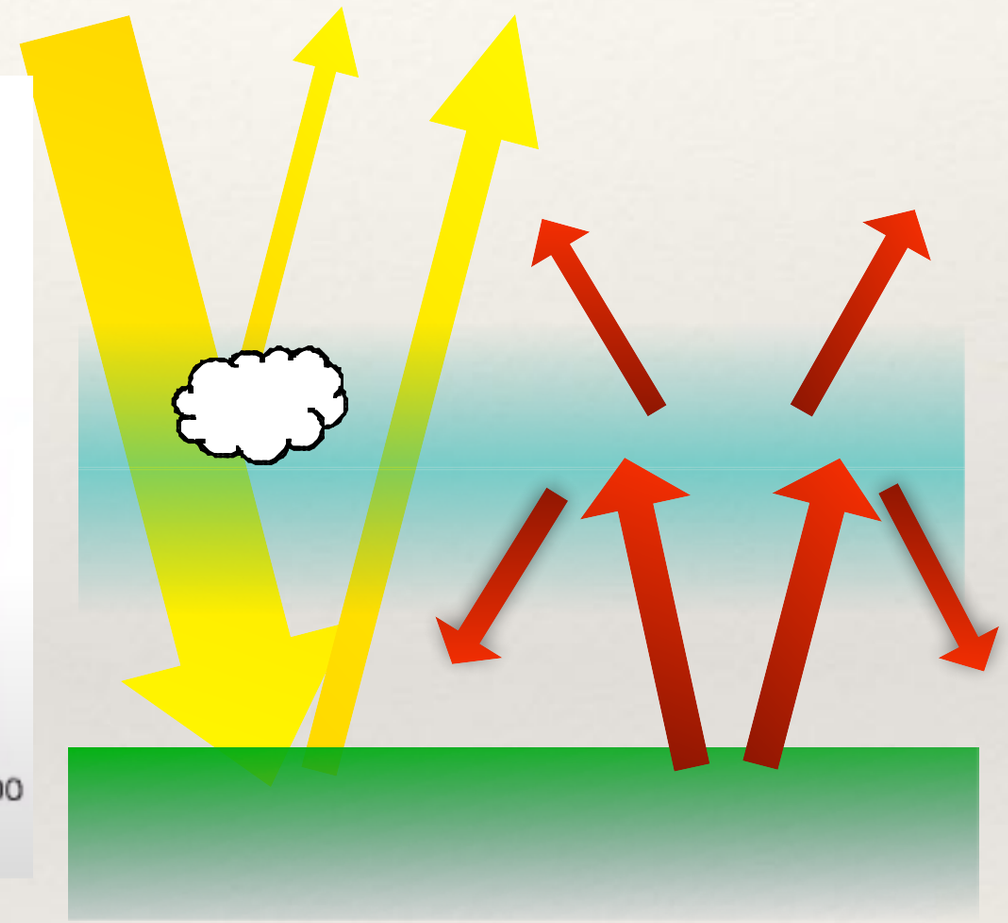
Climate Sensitivity is low

Future warming will be benign

What is climate sensitivity?

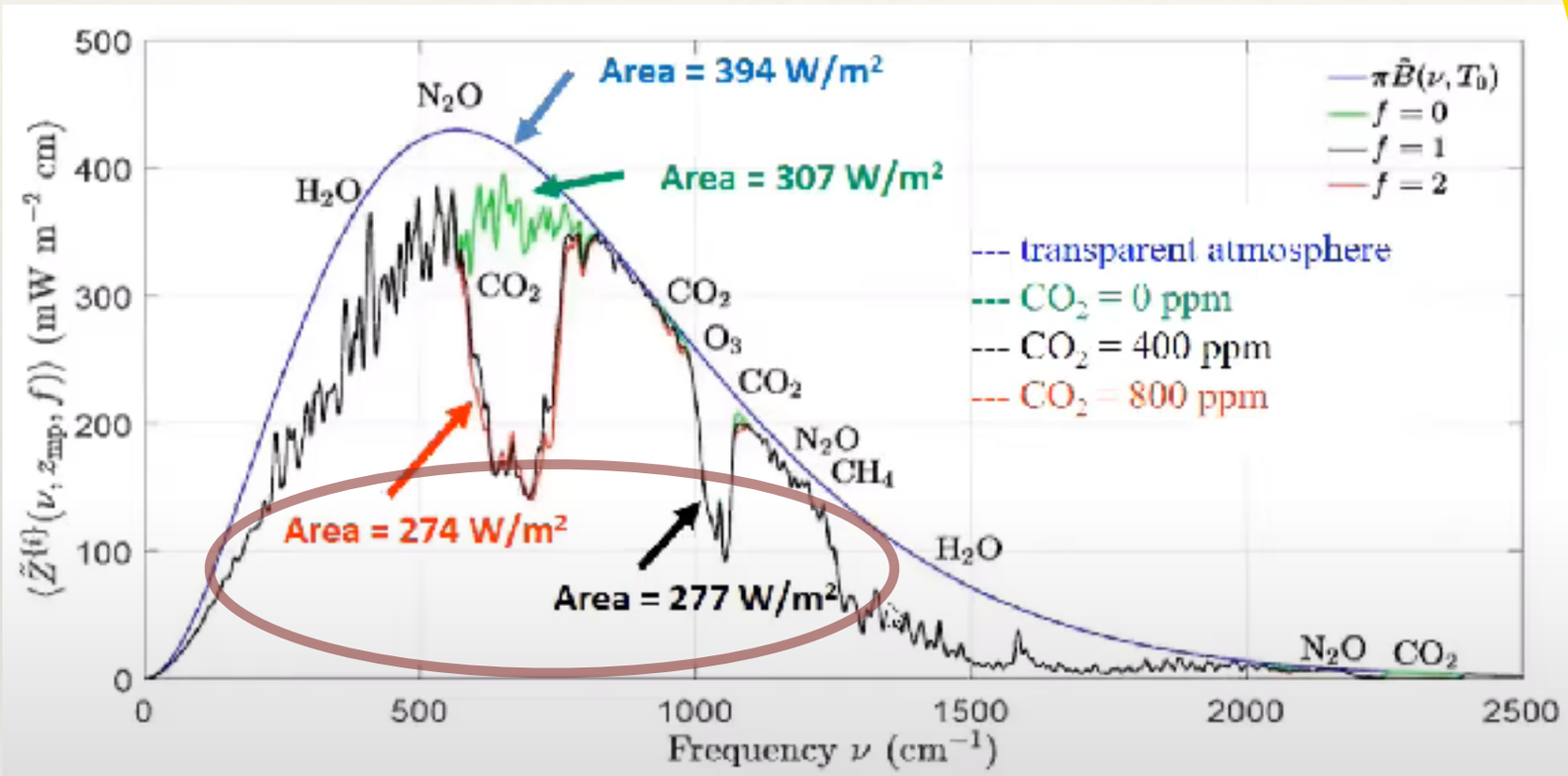
The Greenhouse Effect

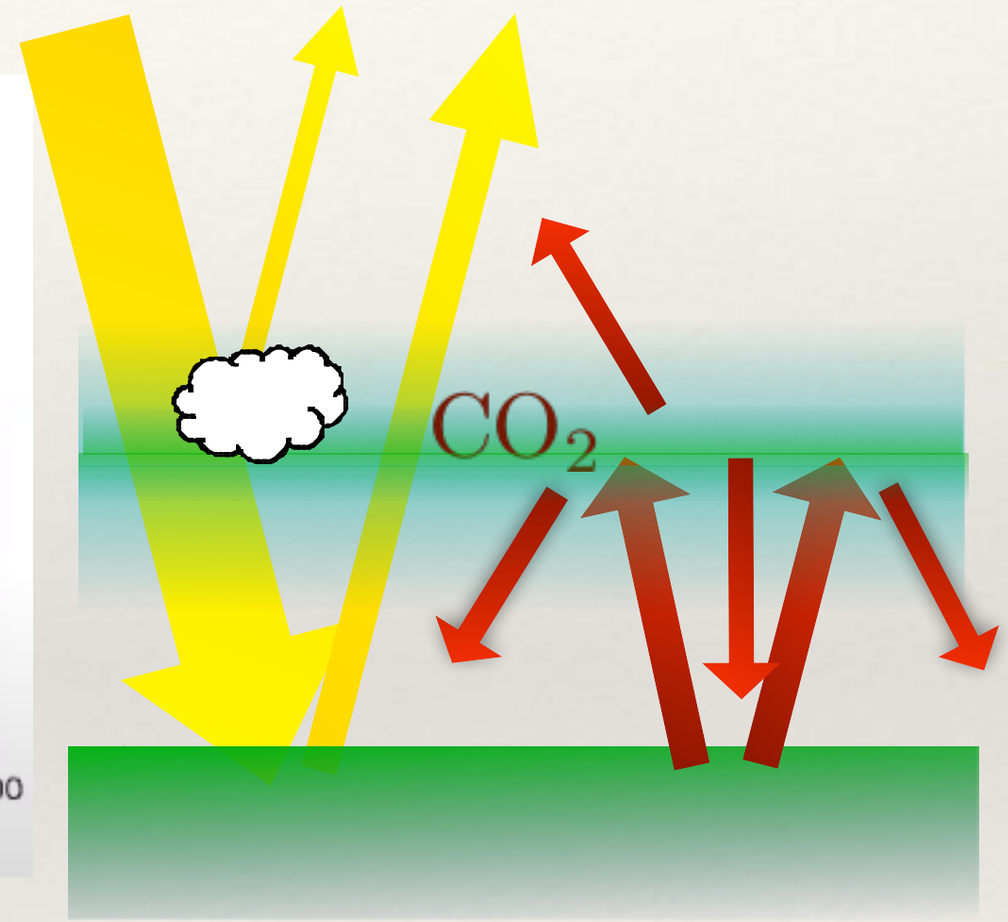




- All atoms/molecules in the atmosphere except N_2, O_2 & Nobel Gases absorb IR radiation. The radiation going to space is smaller than leaving the surface.

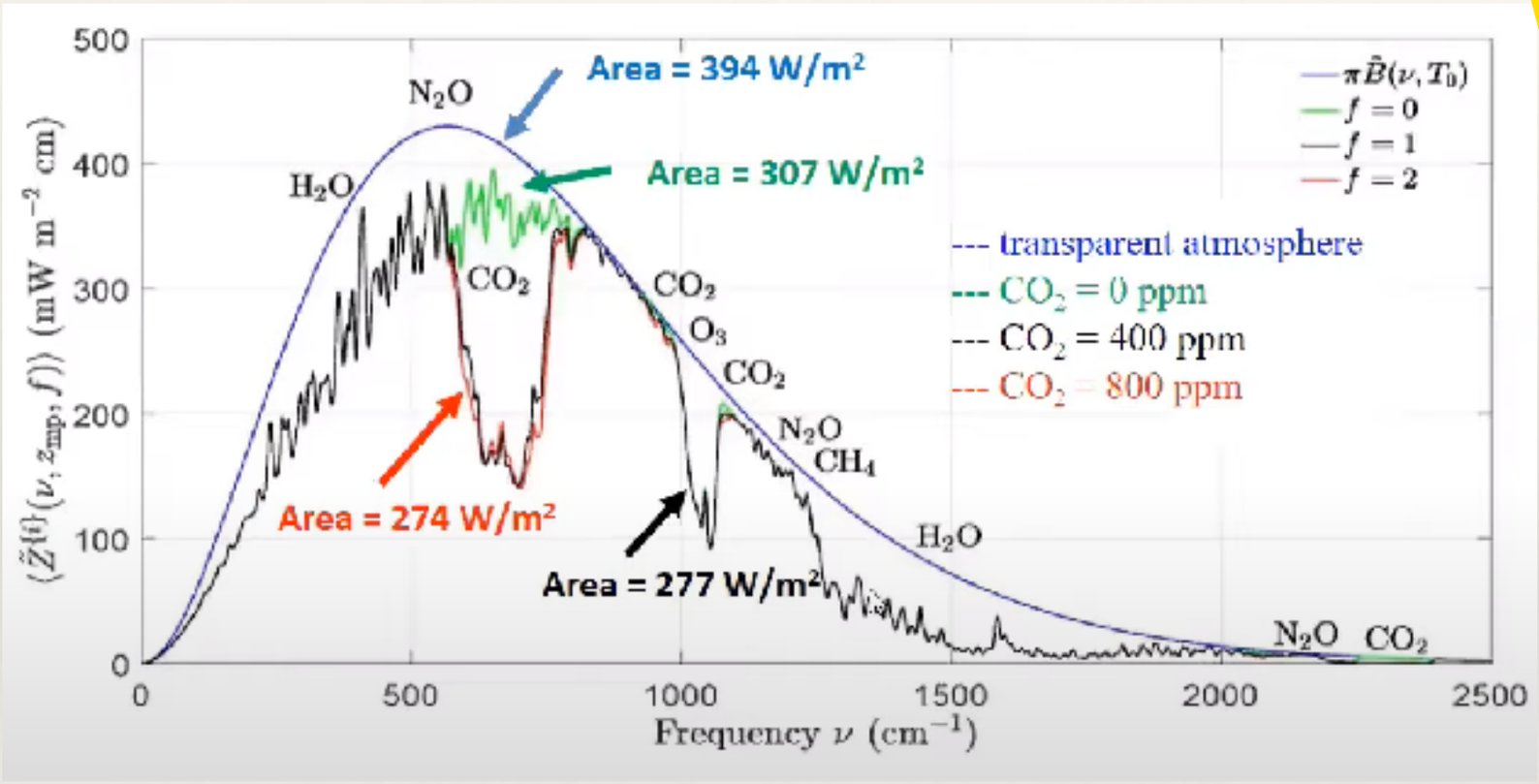
The Greenhouse Effect

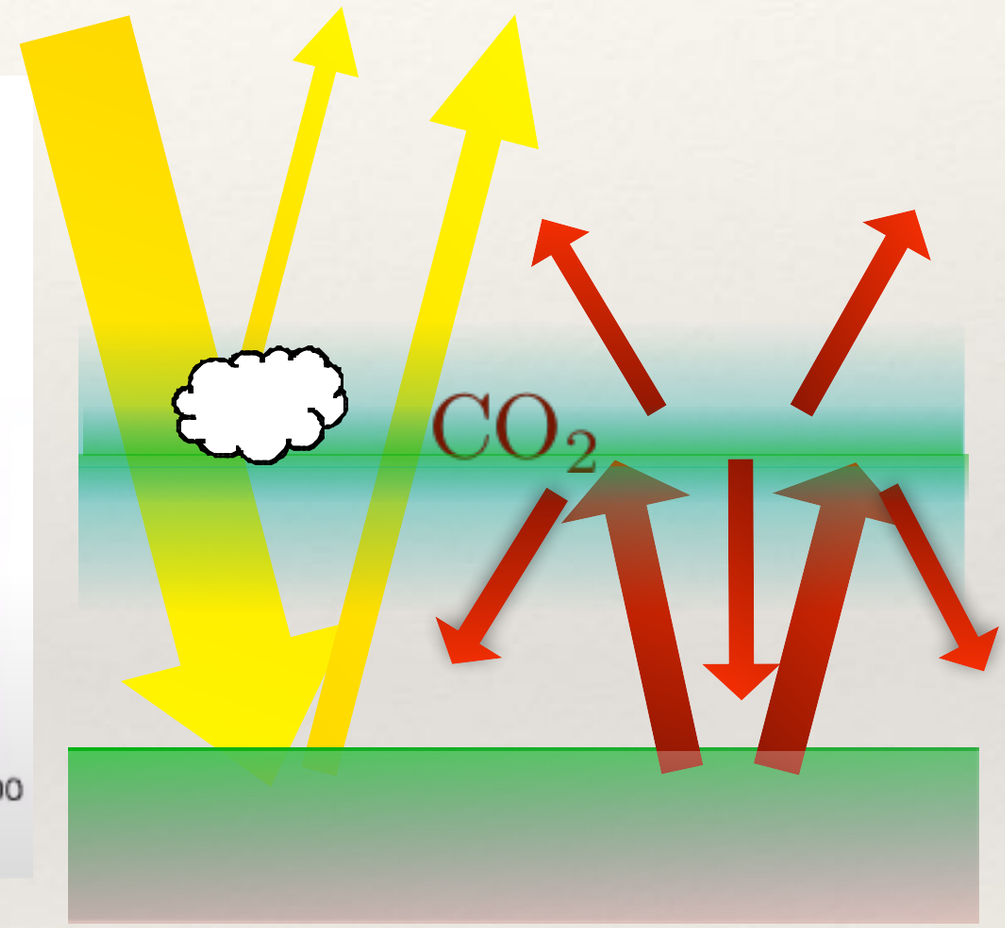




- Adding more greenhouse gases reduces radiation going to space by 3-4 W/m² (compared with 240 W/m² that reaches the surface)

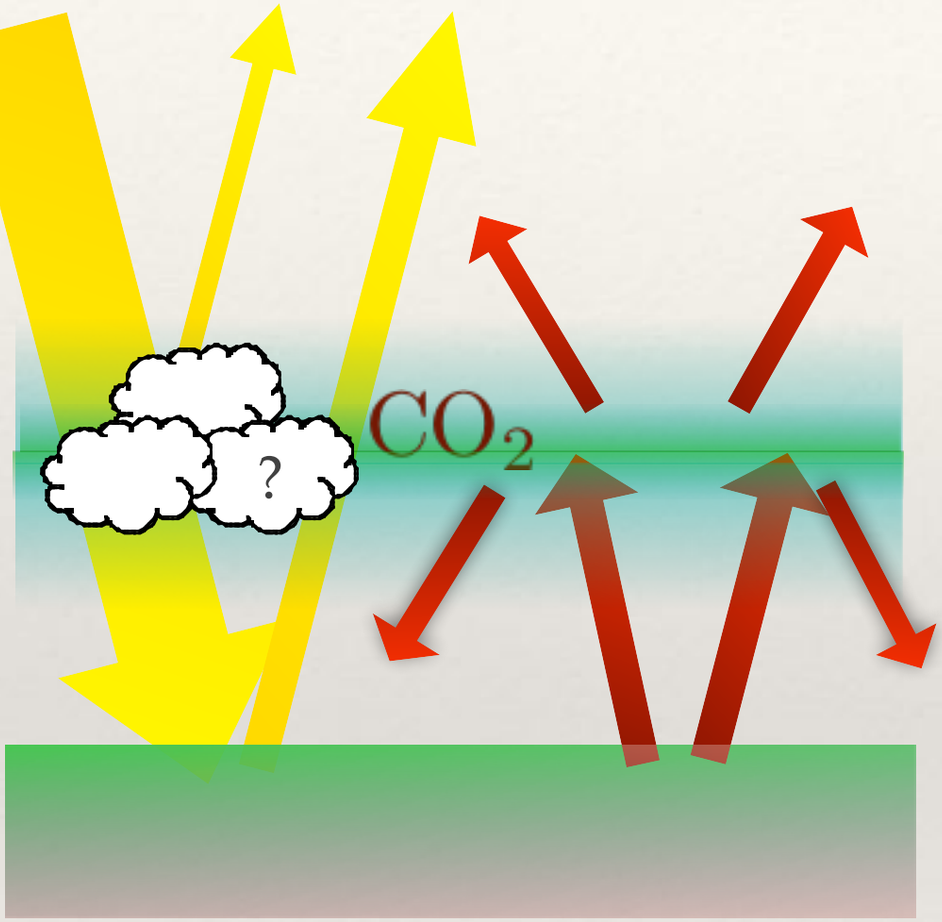
The Greenhouse Effect



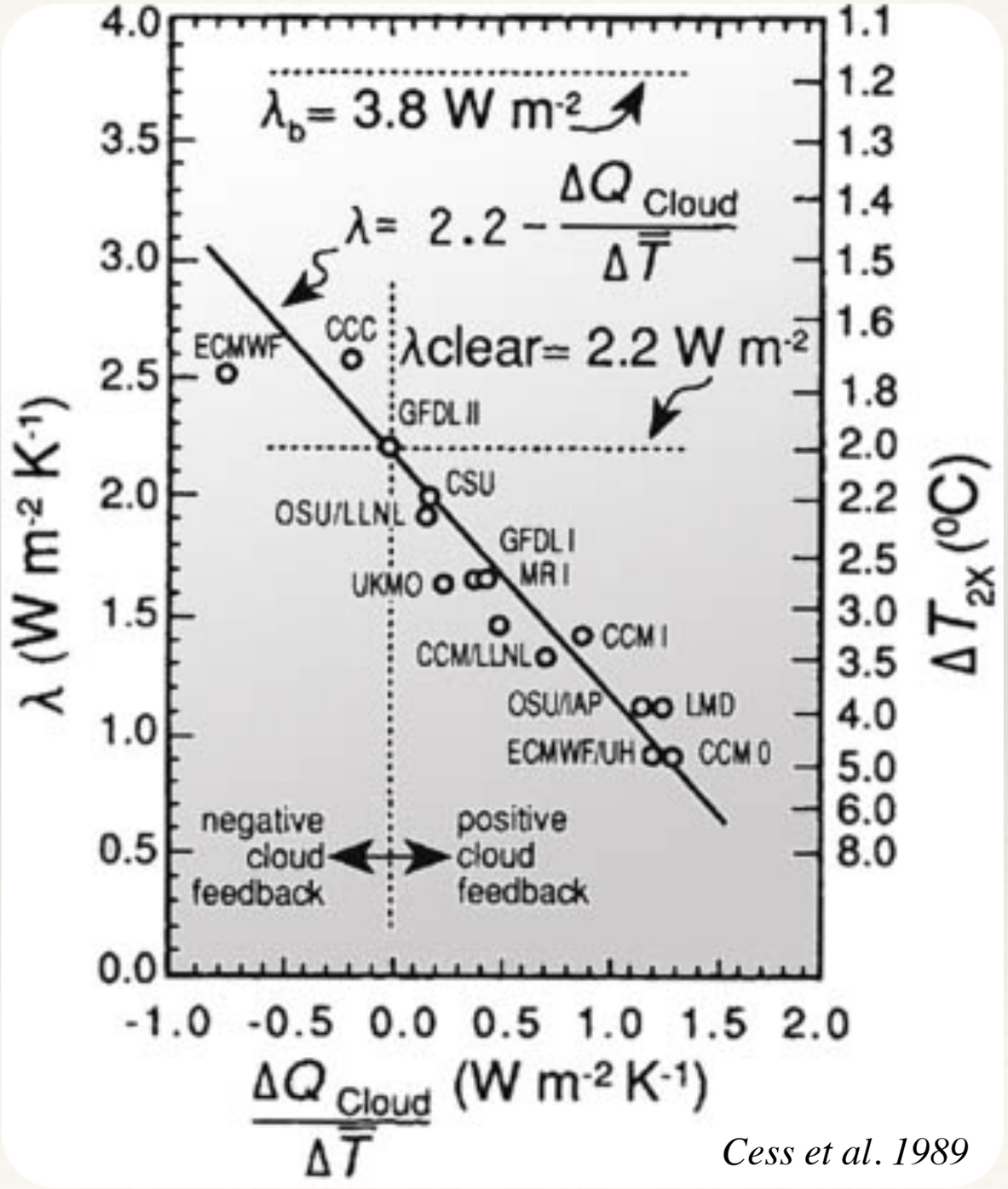


- To compensate for the reduced radiation to space, the surface temperature has to increase. If everything stays the same, $\Delta T = 1.0\text{-}1.2°C$ per CO_2 doubling.

Cloud Feedback is a large uncertainty

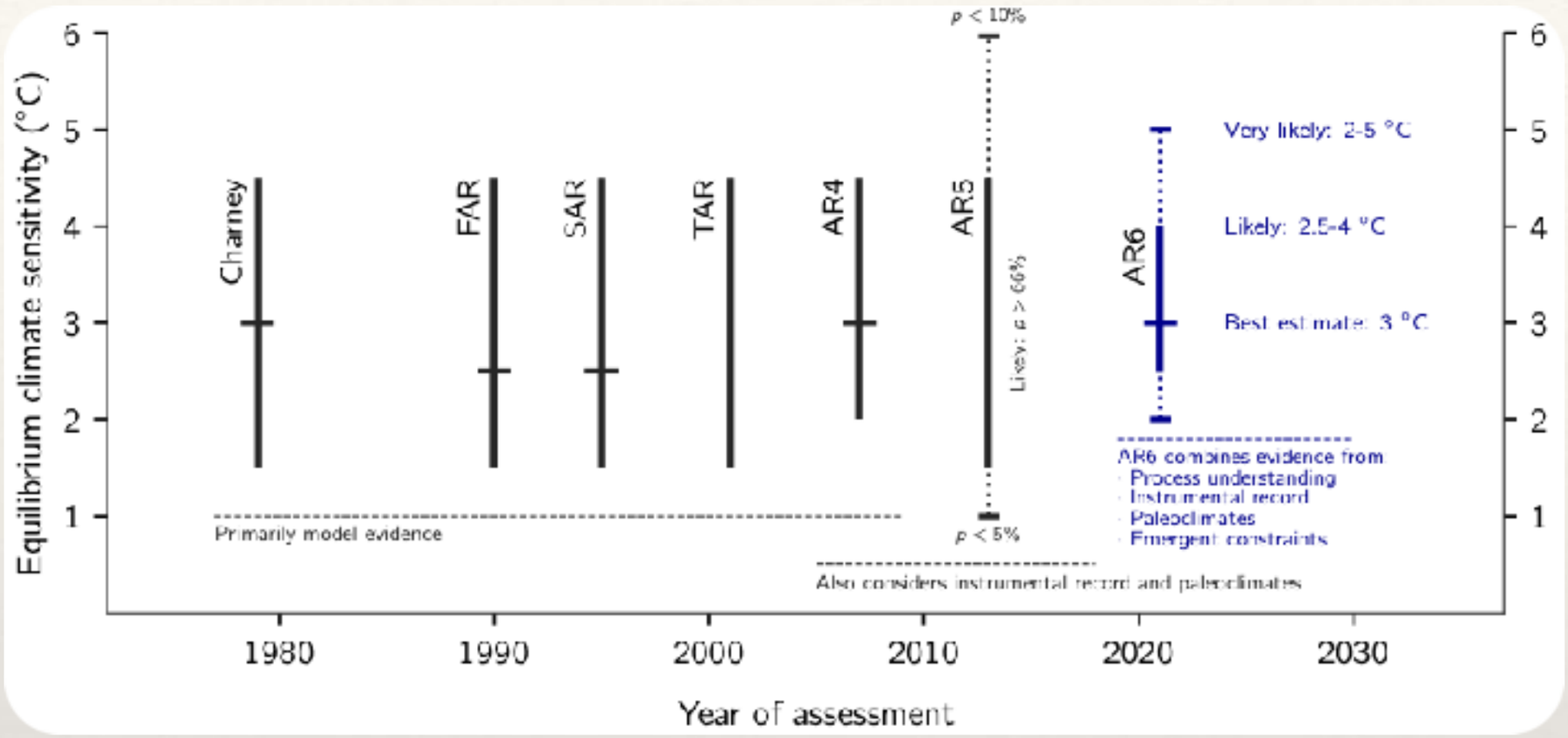


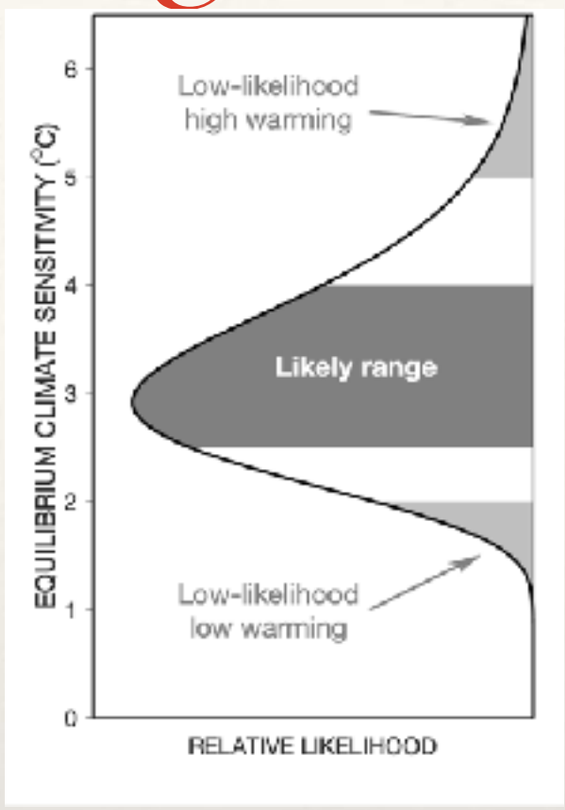
- The feedback through clouds "used to be" the largest uncertainty governing the numerical climate models. According to the AR6, we understand it much better.

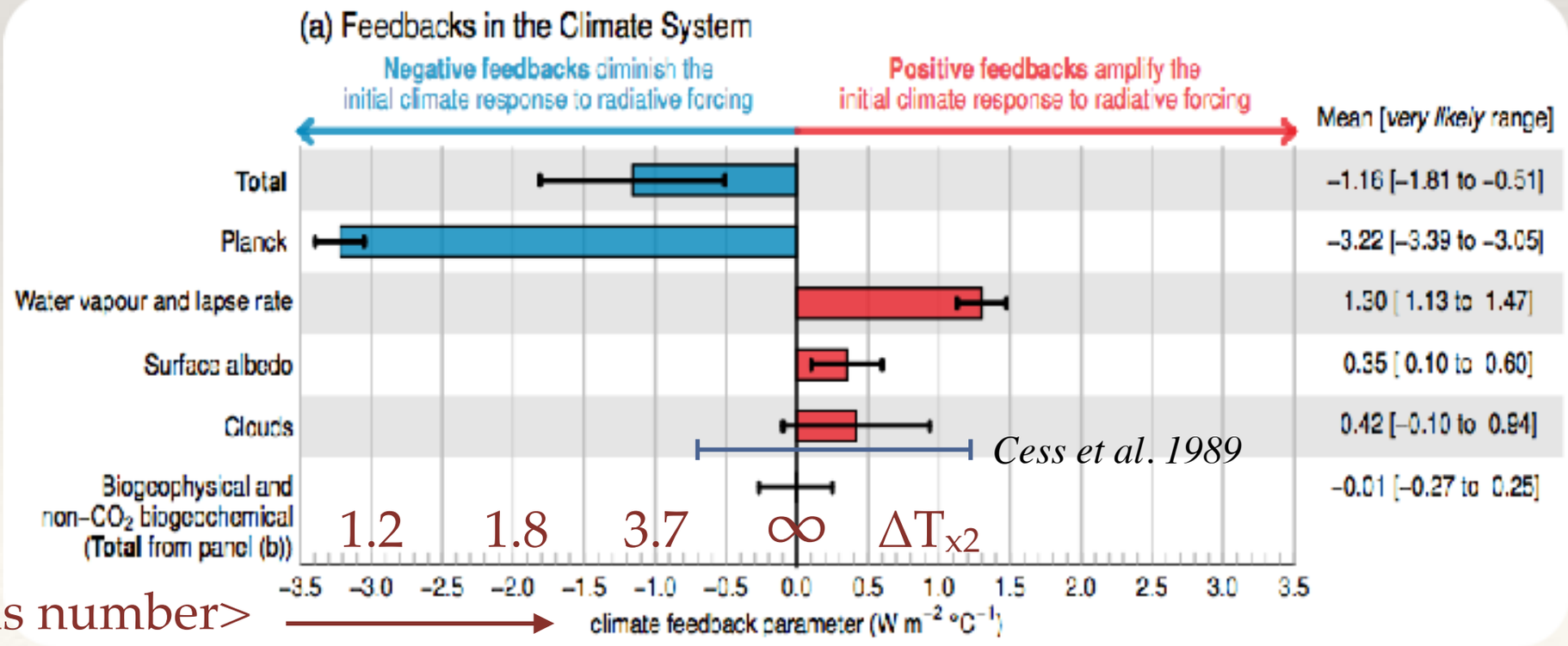


Cess et al. 1989

Feedback uncertainty according to AR6





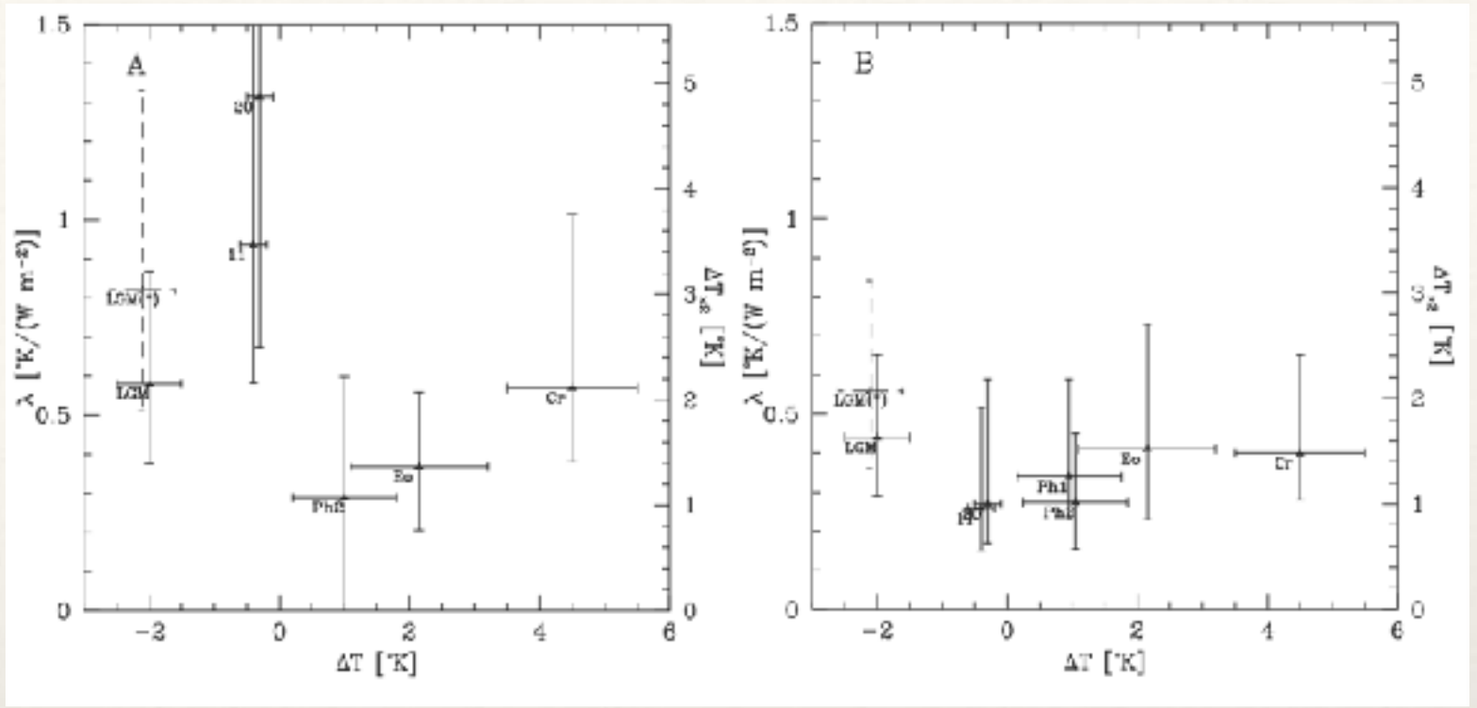


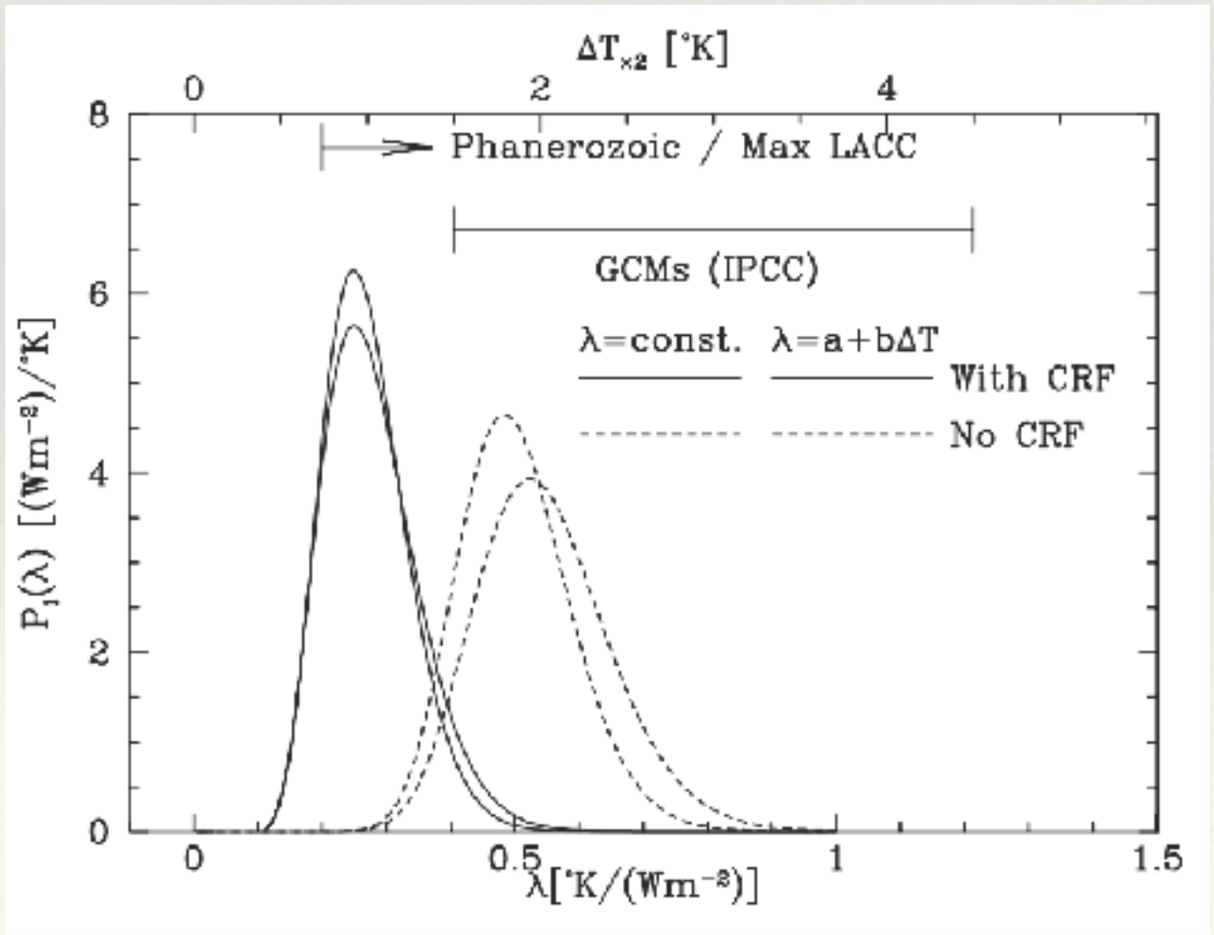
$\Delta T_{x2} \sim 3.7\ W/m^2$ / <this number>

What is the climate sensitivity?

Empirical over different time scales

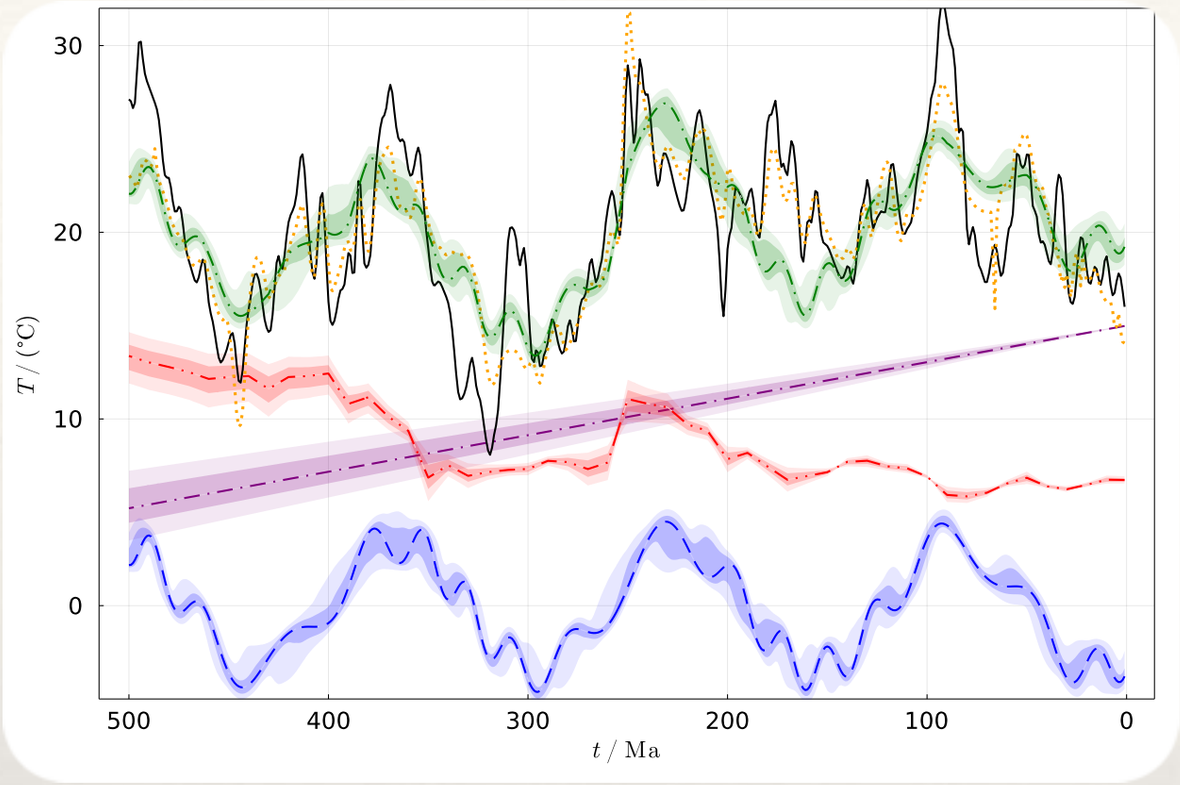
$$\Delta T_{\times 2} = \frac{\Delta T_{\text{interval}}}{\Delta F_{\text{interval}}} \Delta F_{\times 2}$$





Shaviv 2005

Variations over the Phanerozoic

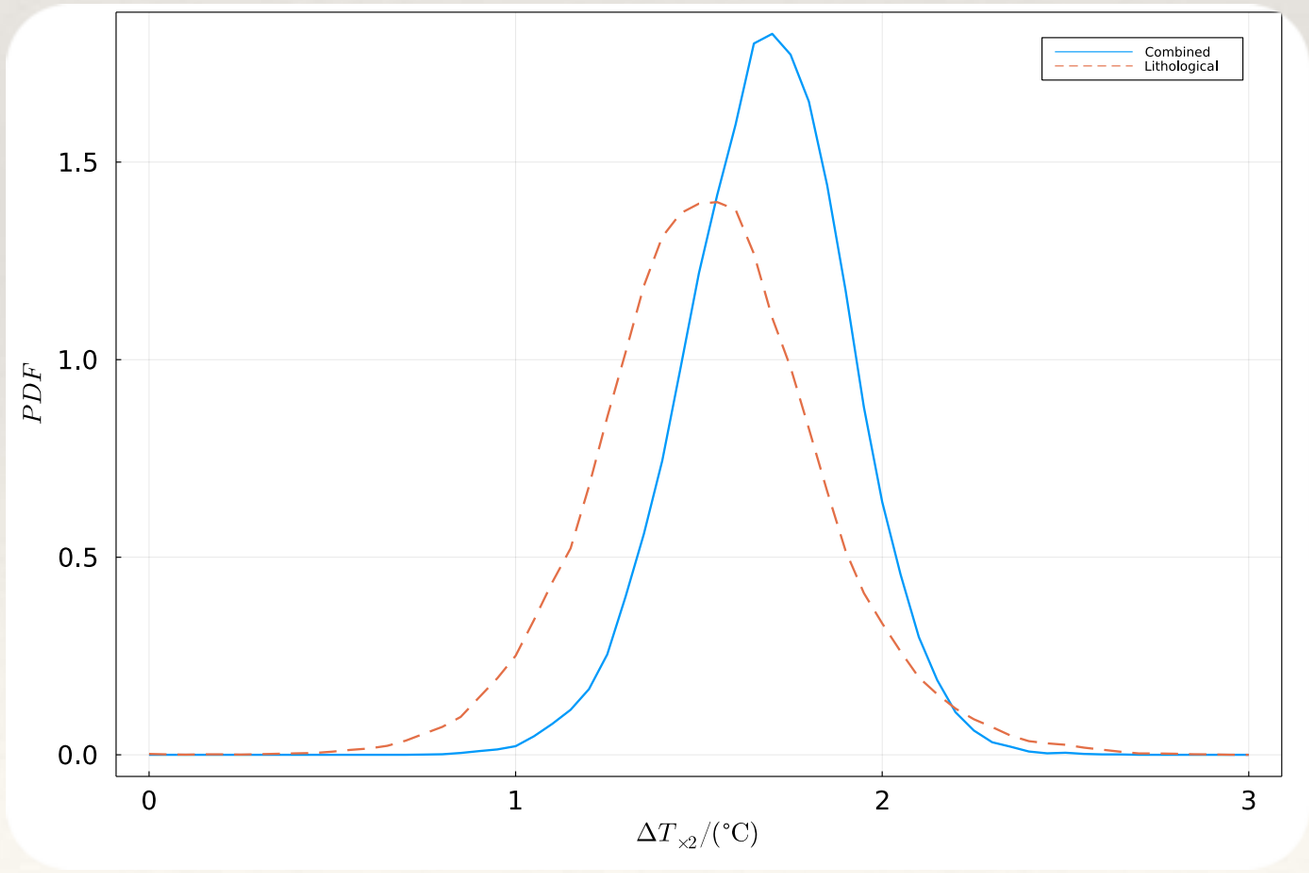


Reconstruction (black) + Model Fit (Green)

Solar Constant increase

CO_2 contribution

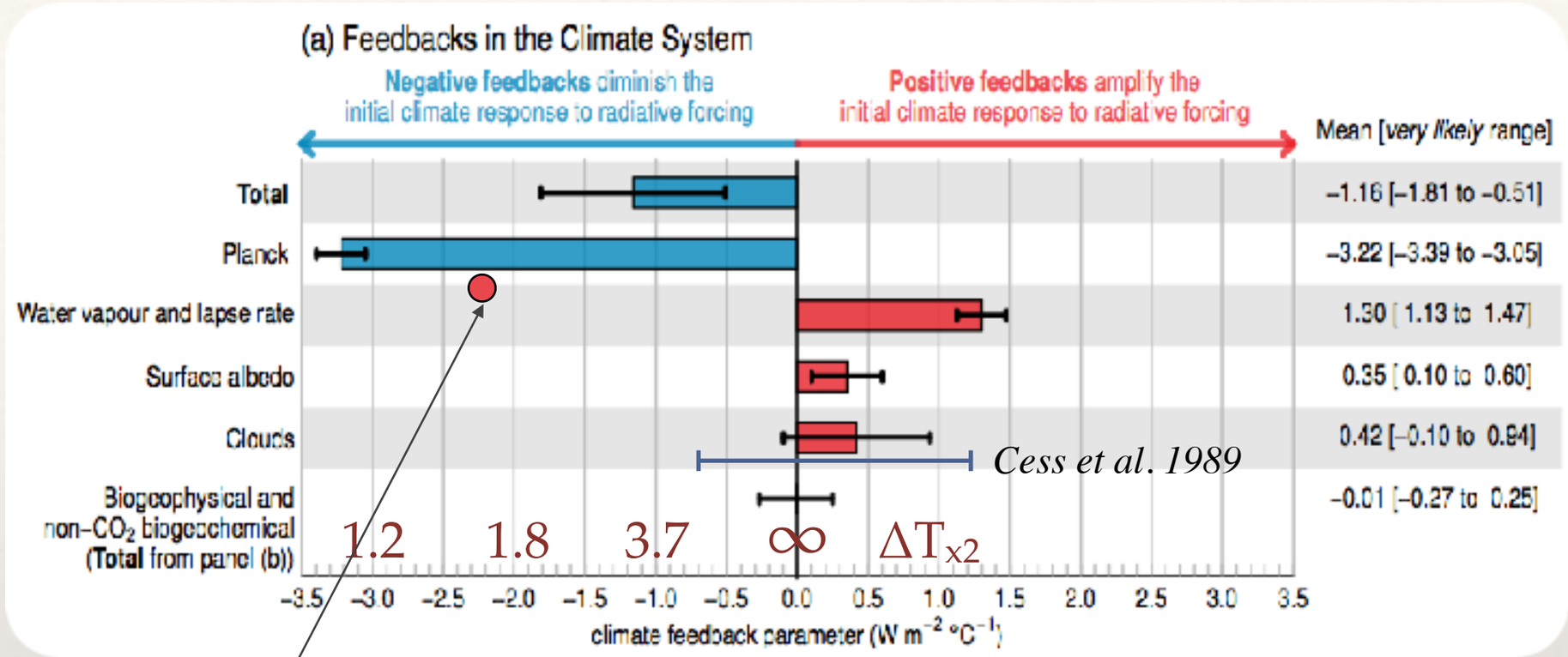
Galactic cosmic rays

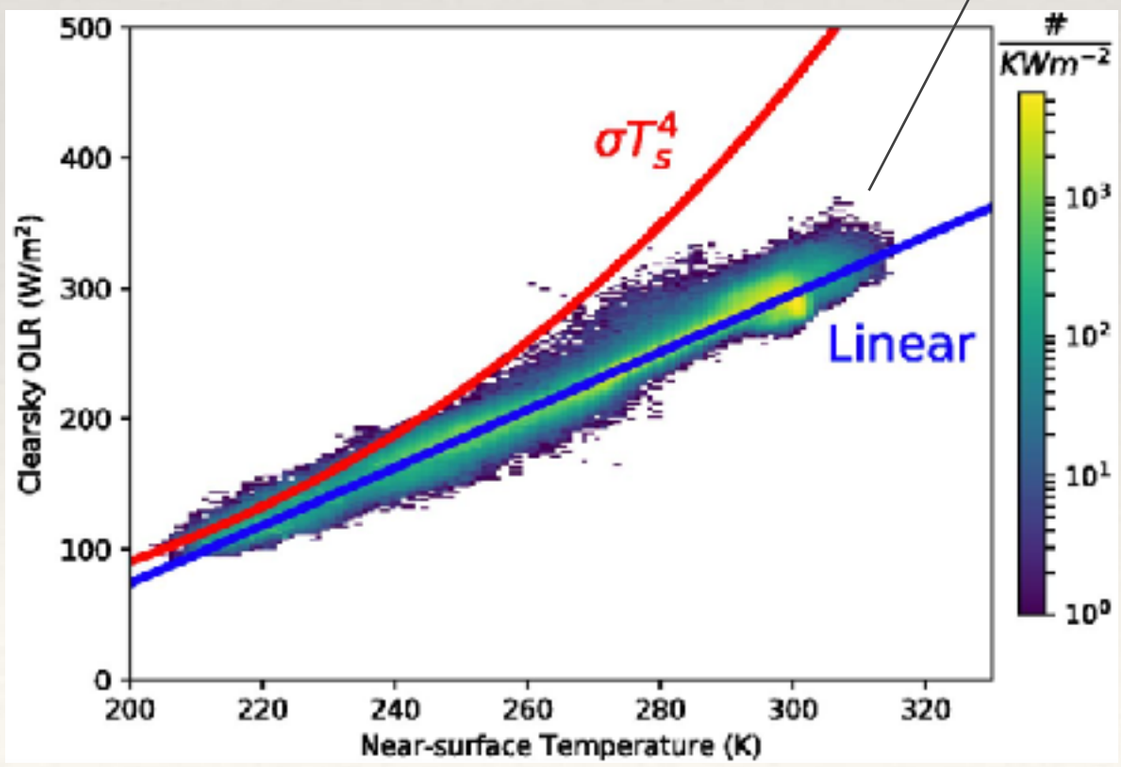


Shaviv Svensmark Veizer 2021

Clear sky feedback & sensitivity

Fast clear sky feedbacks { ?



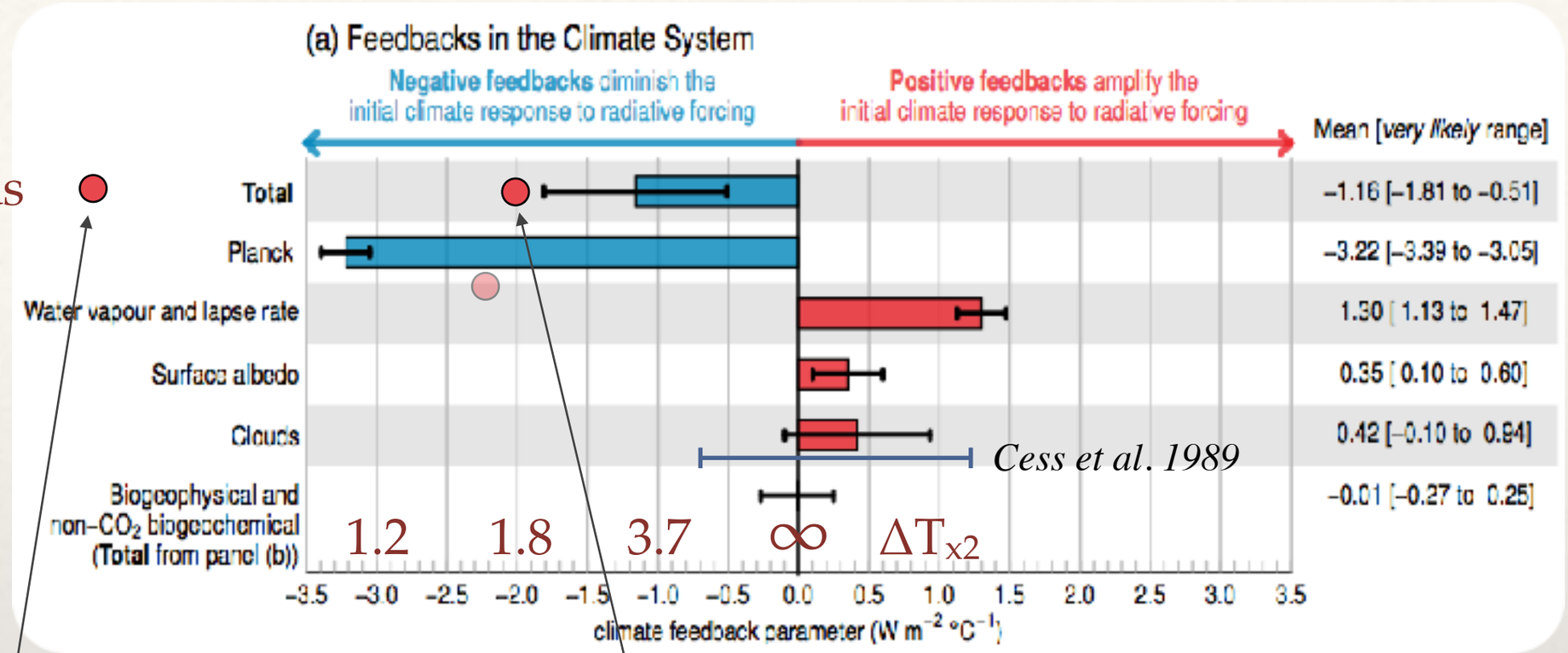


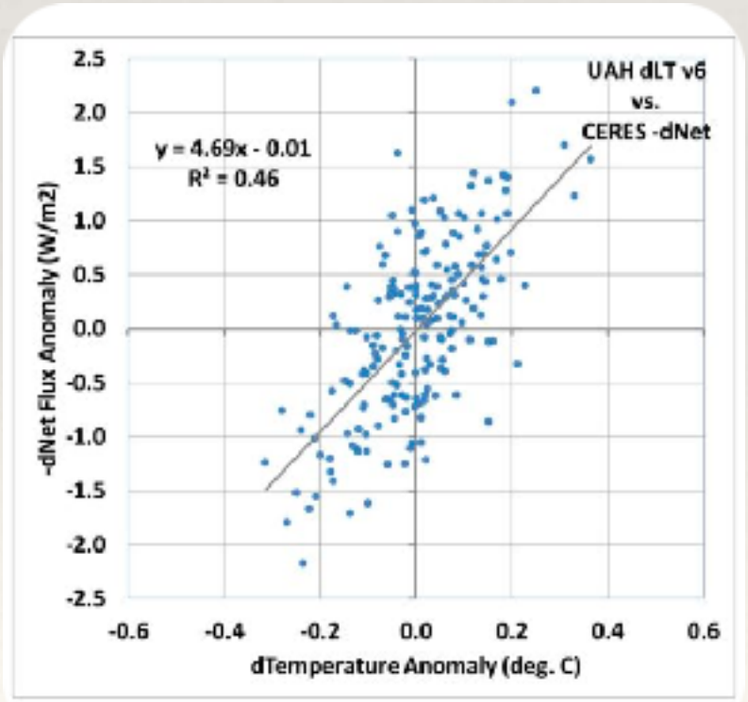
Koll & Cronin PNAS 2019

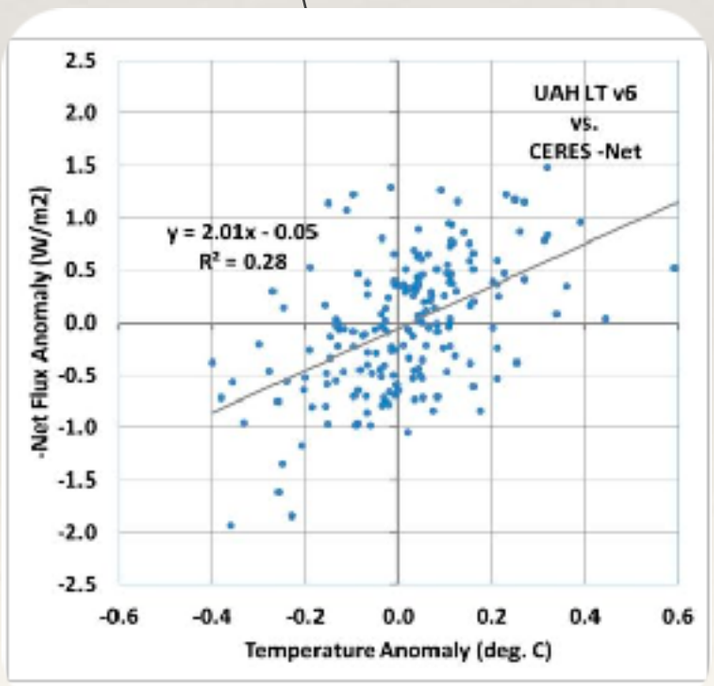
Measuring total (fast) feedback?

without slow feedbacks

All fast feedbacks





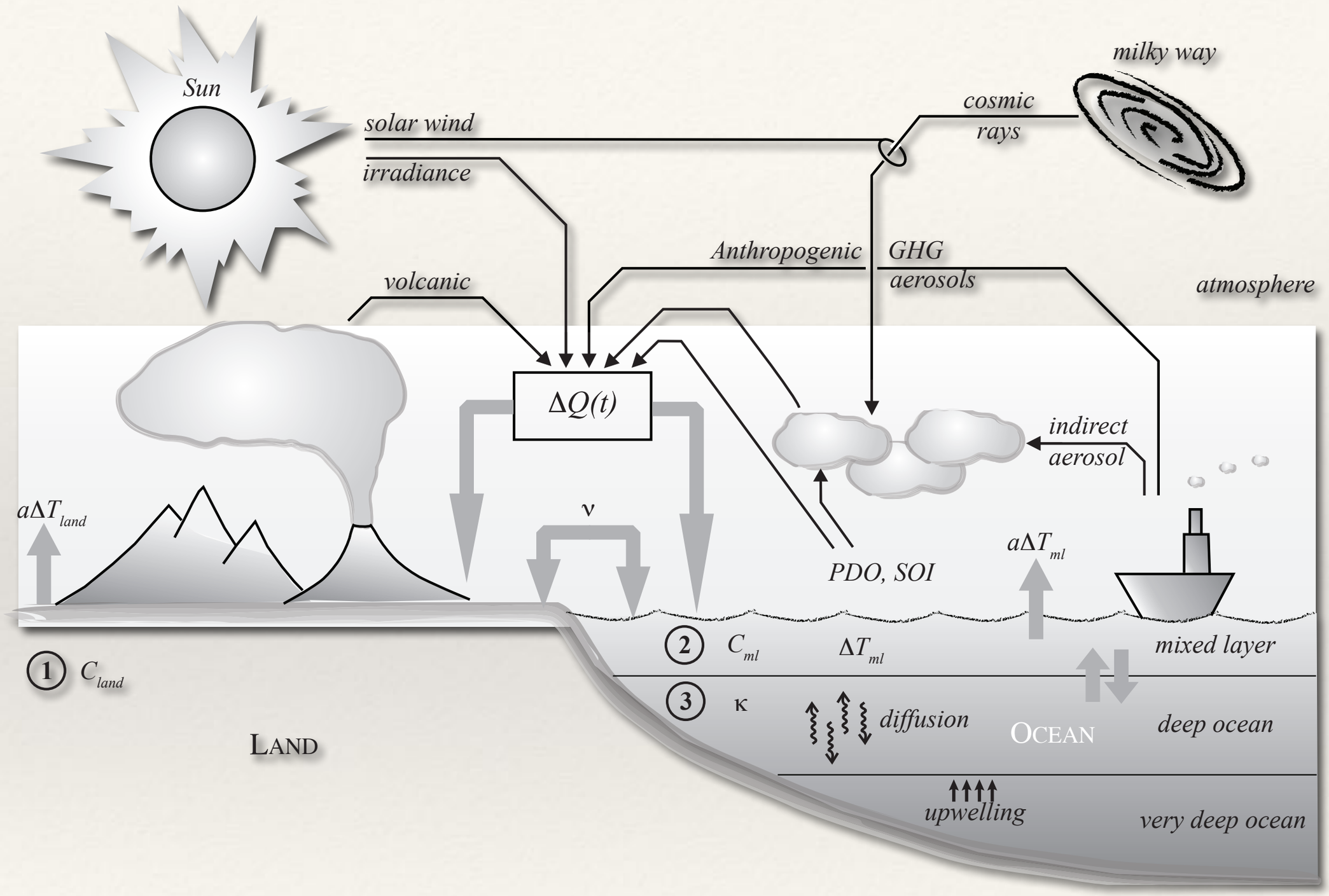


$(\Delta F_{m+1} - \Delta F_m)$ vs. $(\Delta T_{m+1} - \Delta T_m)$

(ΔF_m) vs. (ΔT_m)

R. Spencer's website (2016)

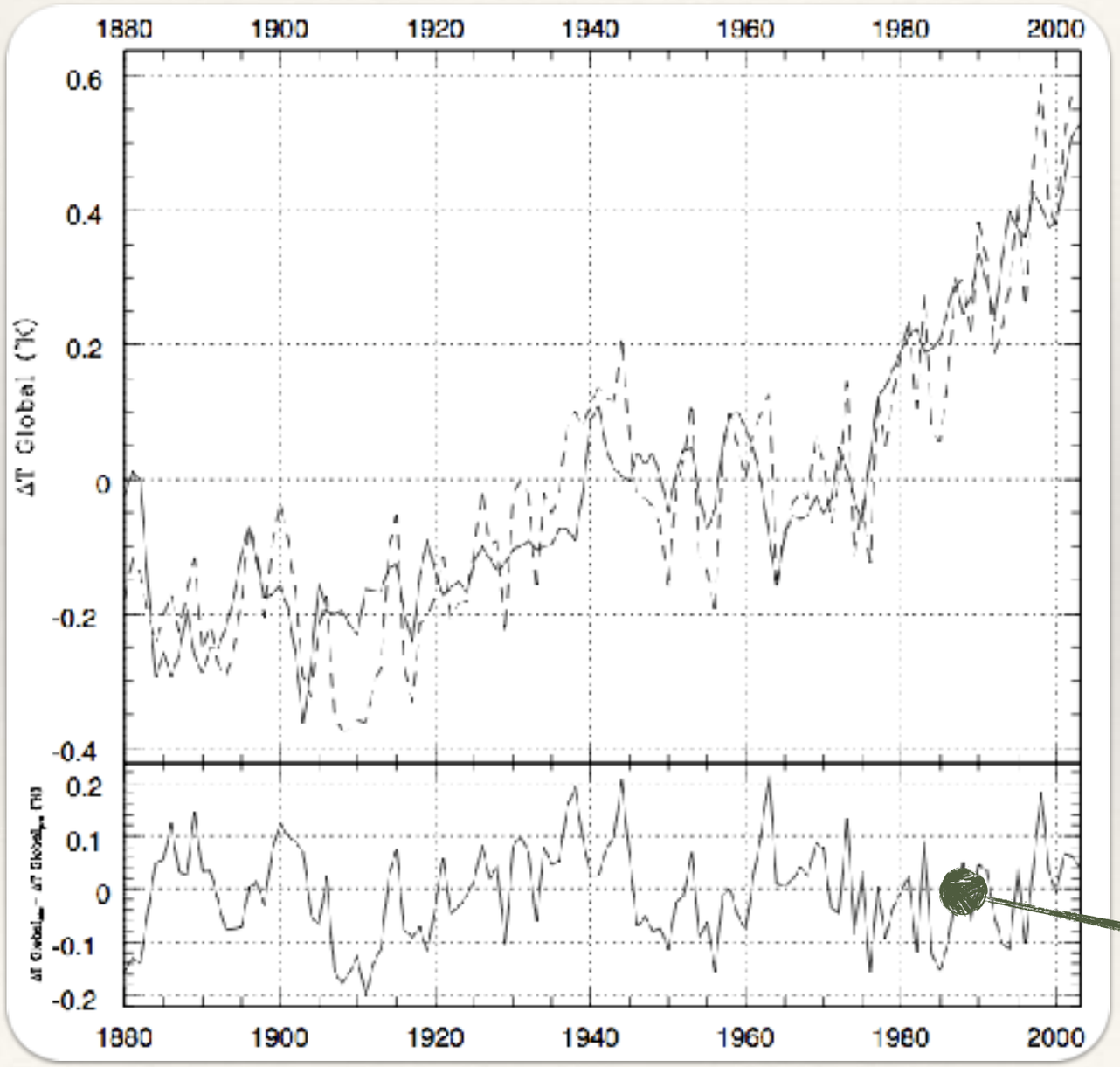
Basic Climate Model



Ziskin & Shaviv, 2012
(elboration of Lindzen & Giannitsis,1998)

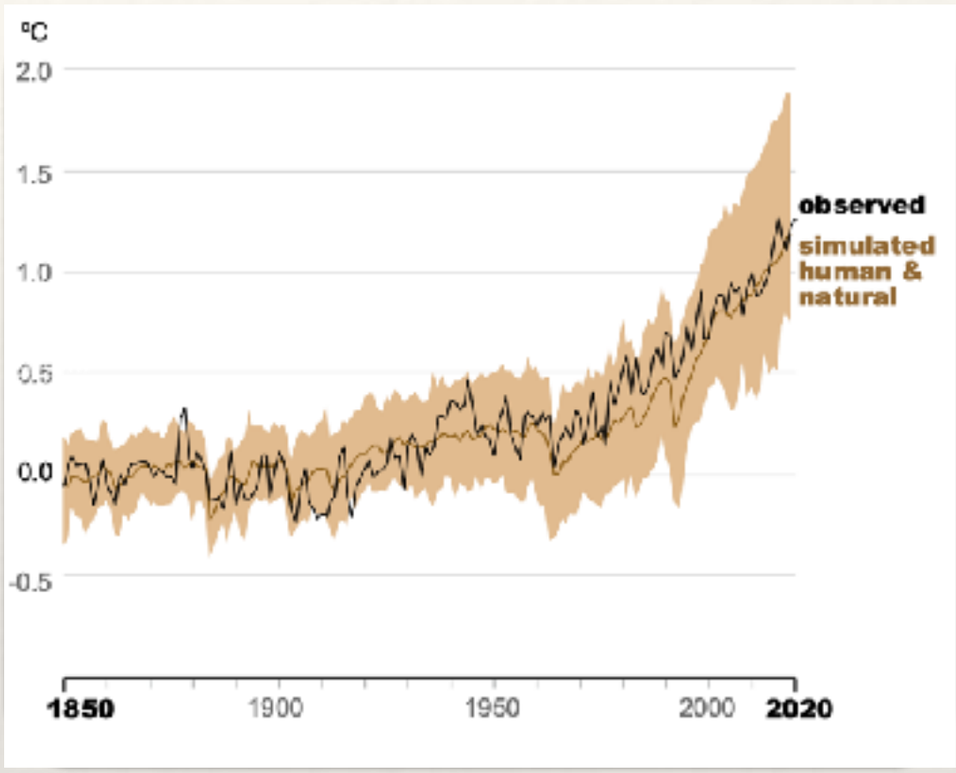
20th century warming

- *Best fit (i.e., after parameter optimization)*



Ziskin & Shaviv, 2012

Comparison: IPCC-AR6



Residual more than twice smaller than with GCMs (without solar amplification)

Standard Explanation to 20th century warming

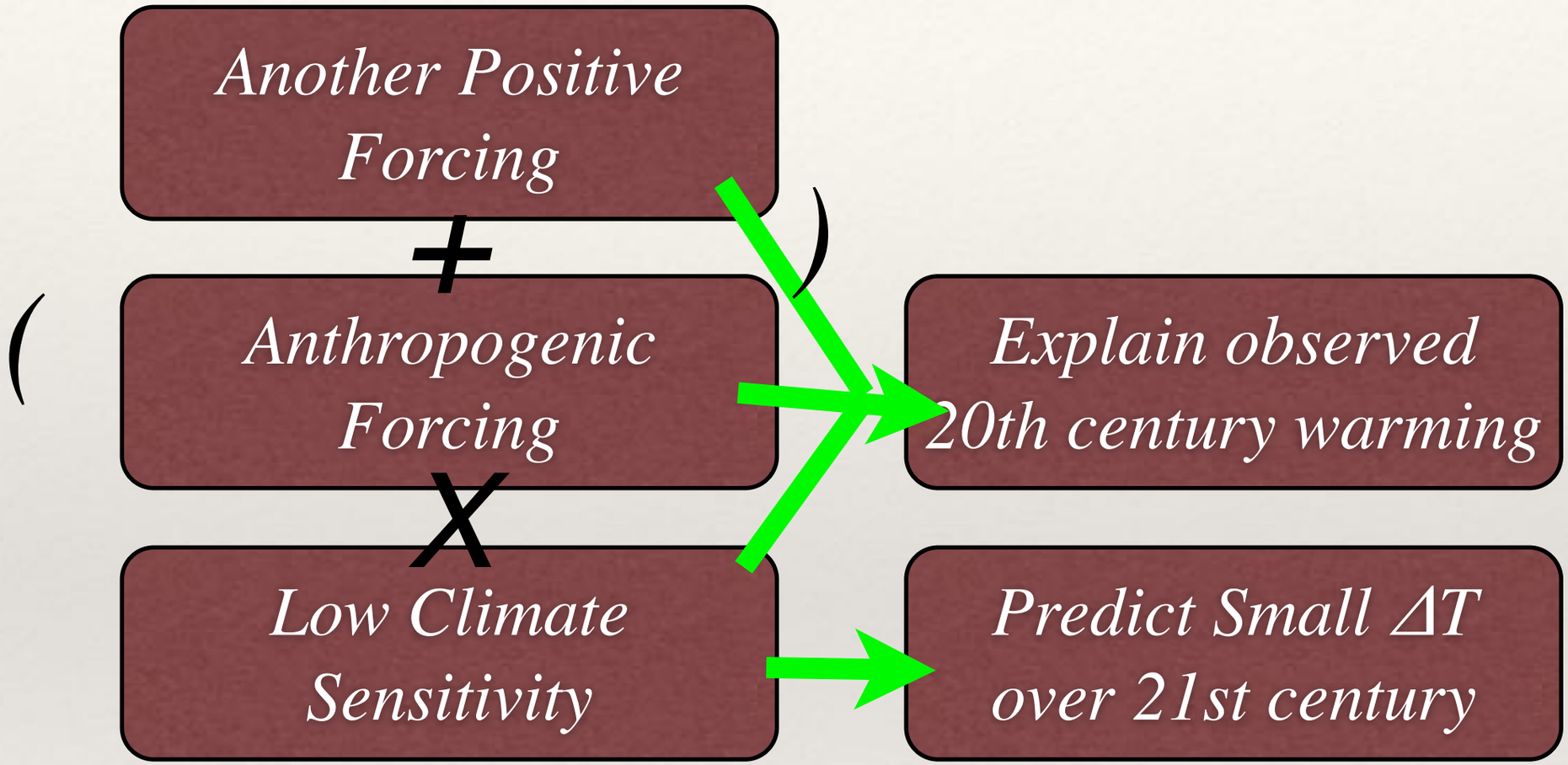
Anthropogenic Forcing Only

Explain observed 20th century warming

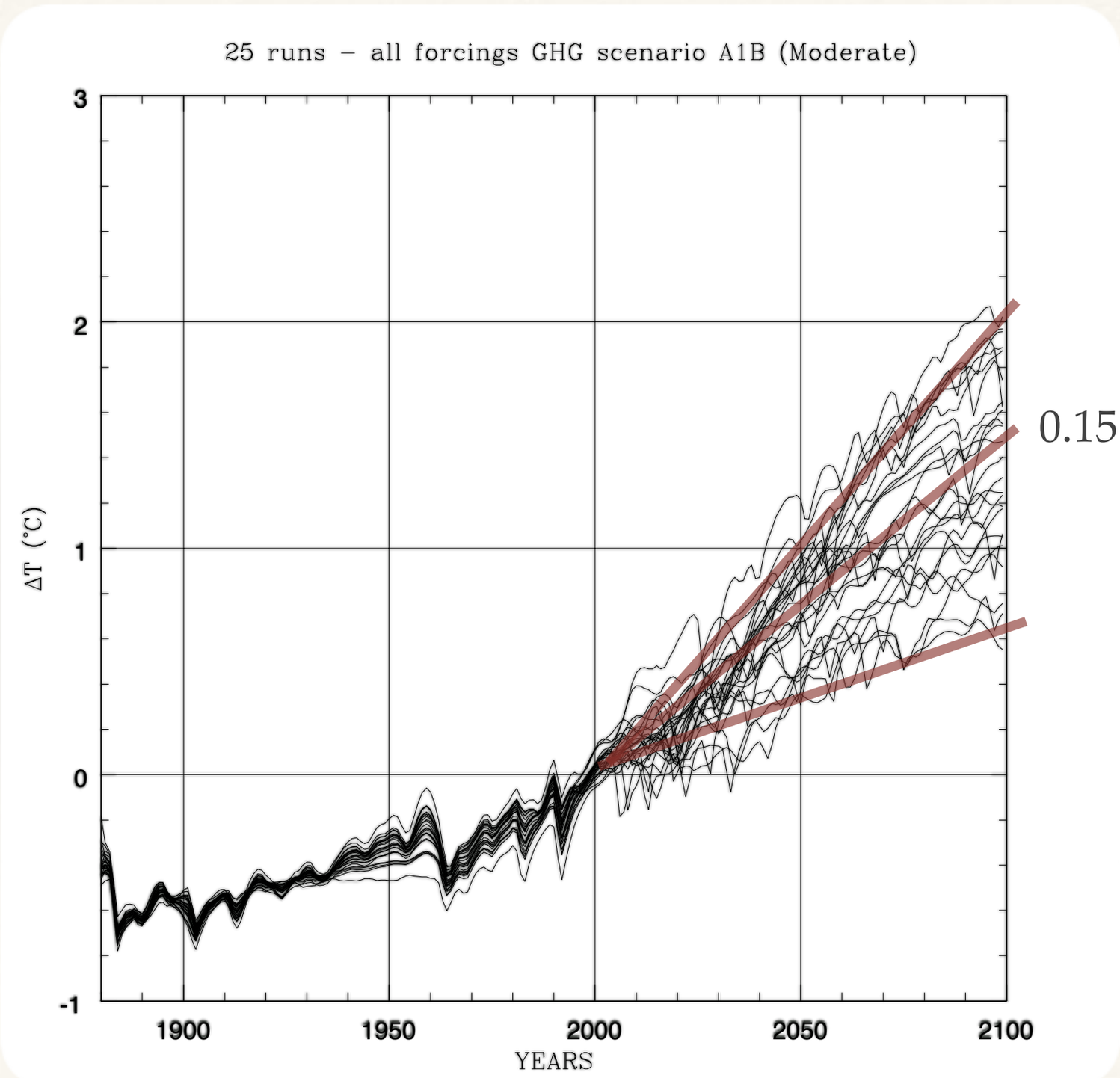
High Climate Sensitivity

Predict Large ΔT over 21st century

Modified interpretation

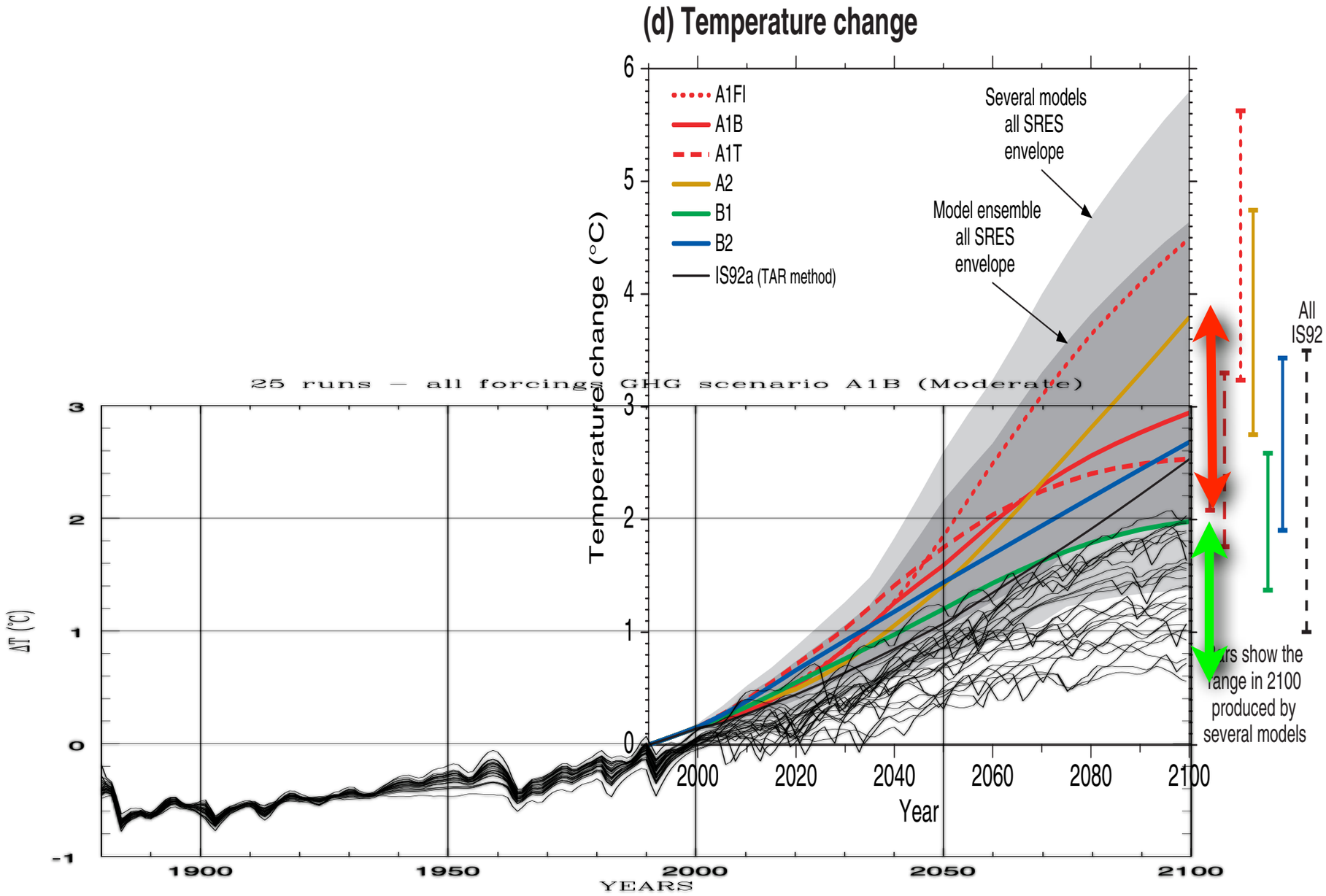


21st century temperature increase

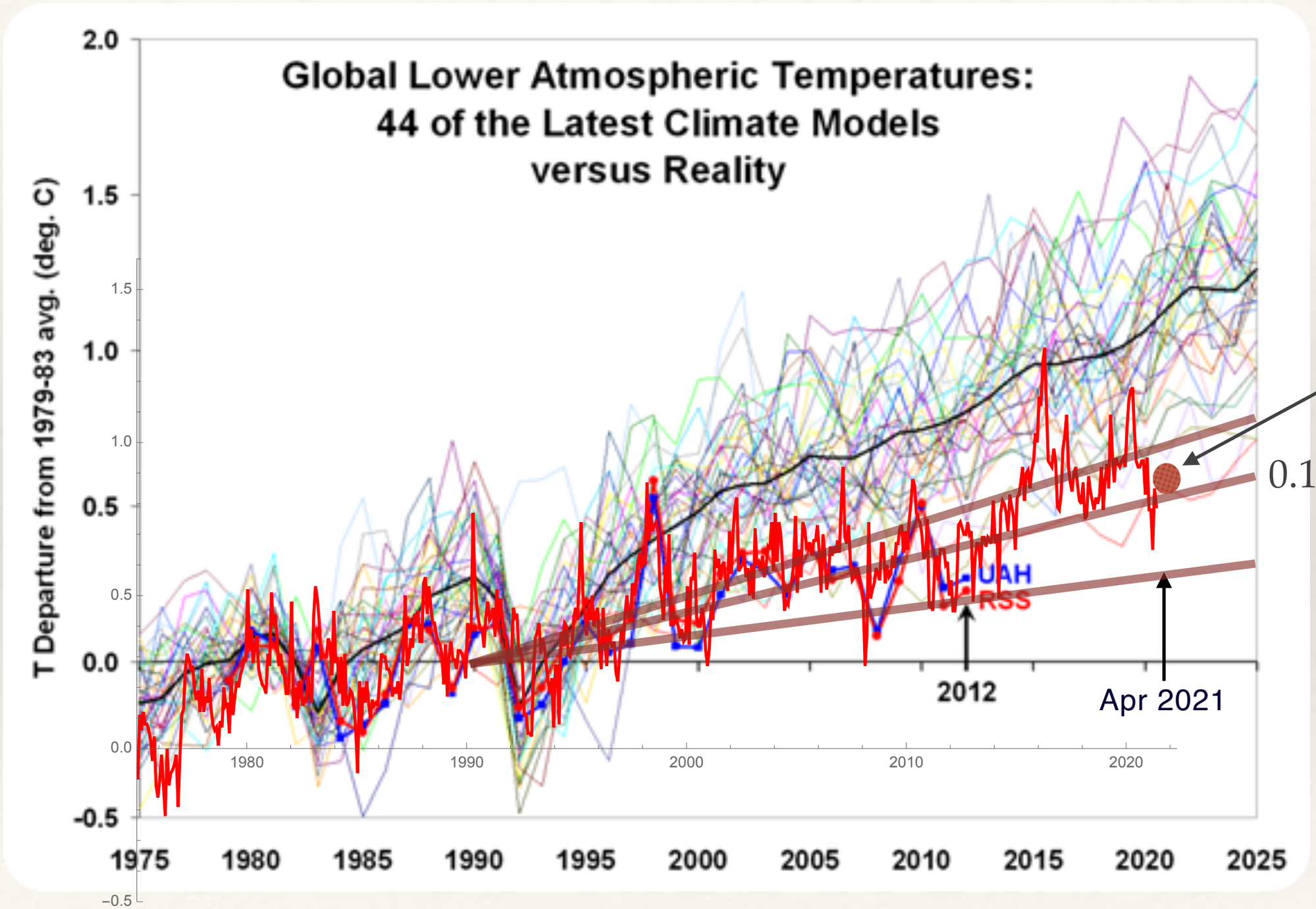


0.15° per decade

21st century temperature increase



Warming smaller than predicted by GCMs



Take Away Points

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Part of the 20th century warming is solar (about $^1/_2$ to $^2/_3$)

Effect is through cosmic ray modulation of cloud cover

(Svensmark next talk)

Climate Sensitivity is low (ΔT_{x2} ~ 1-2°C)

Future warming will be benign (0.15±0.2°C/decade)

What is the moral?