The Sun's role in Climate

15th International EIKE Climate and Energy Conference

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Hebrew University of Jerusalem

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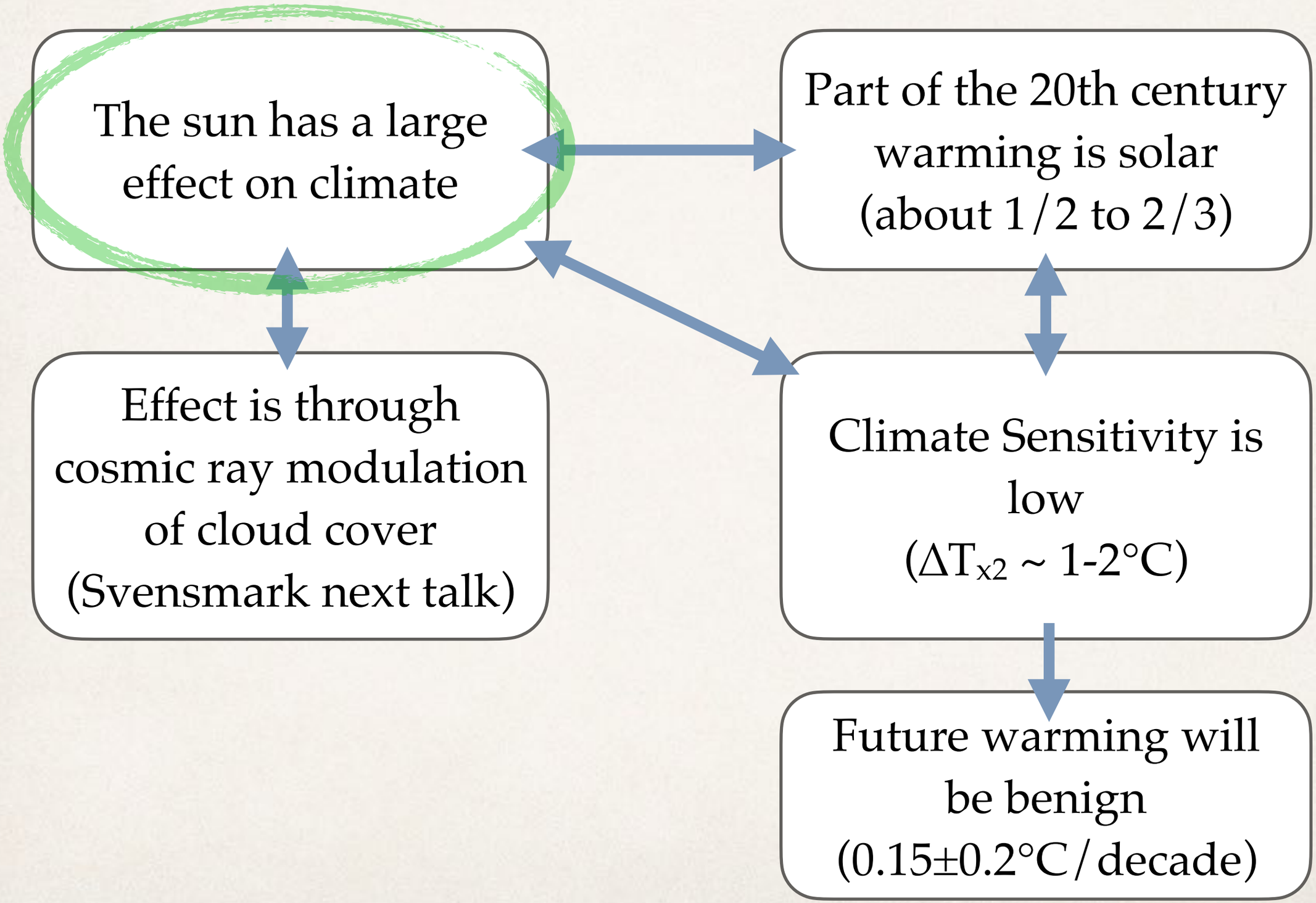
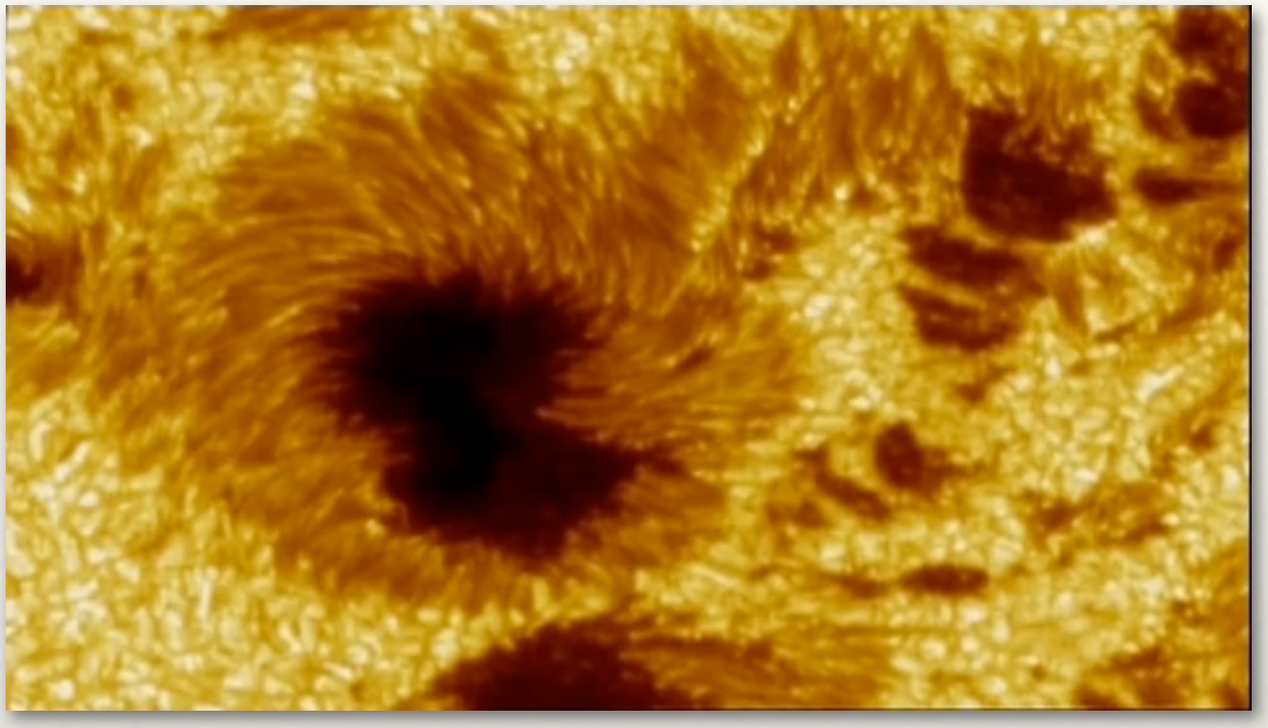
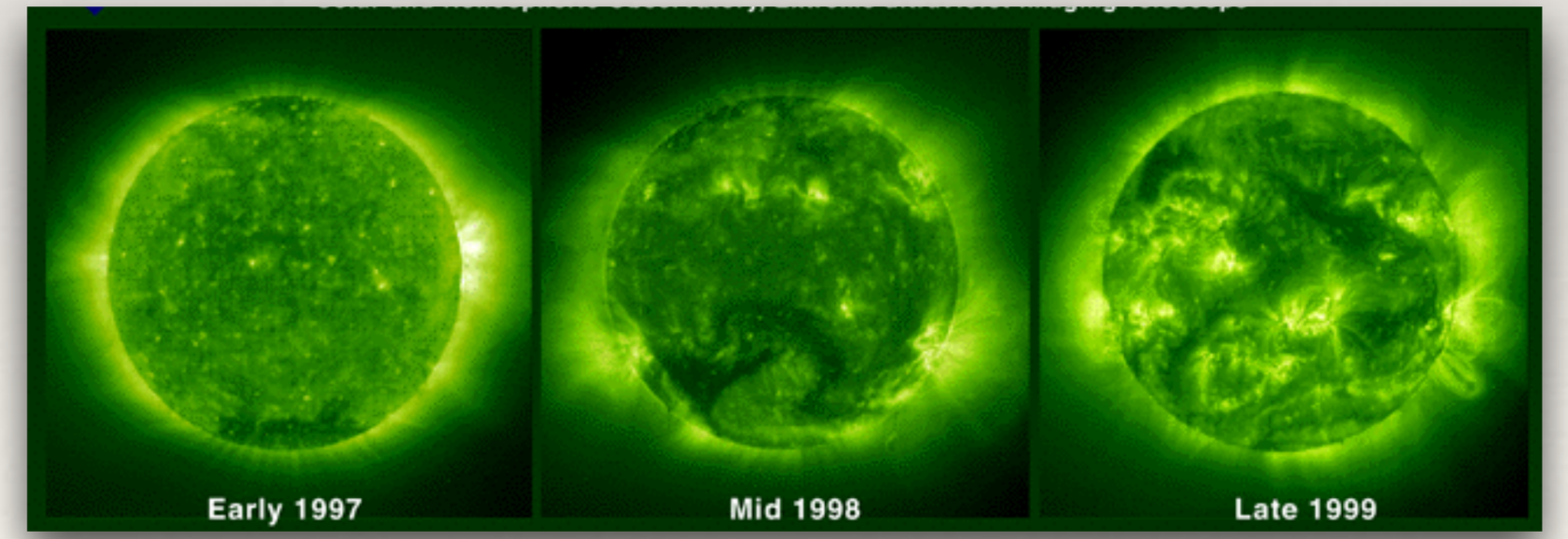
Take Away Points



The Solar - Climate Link

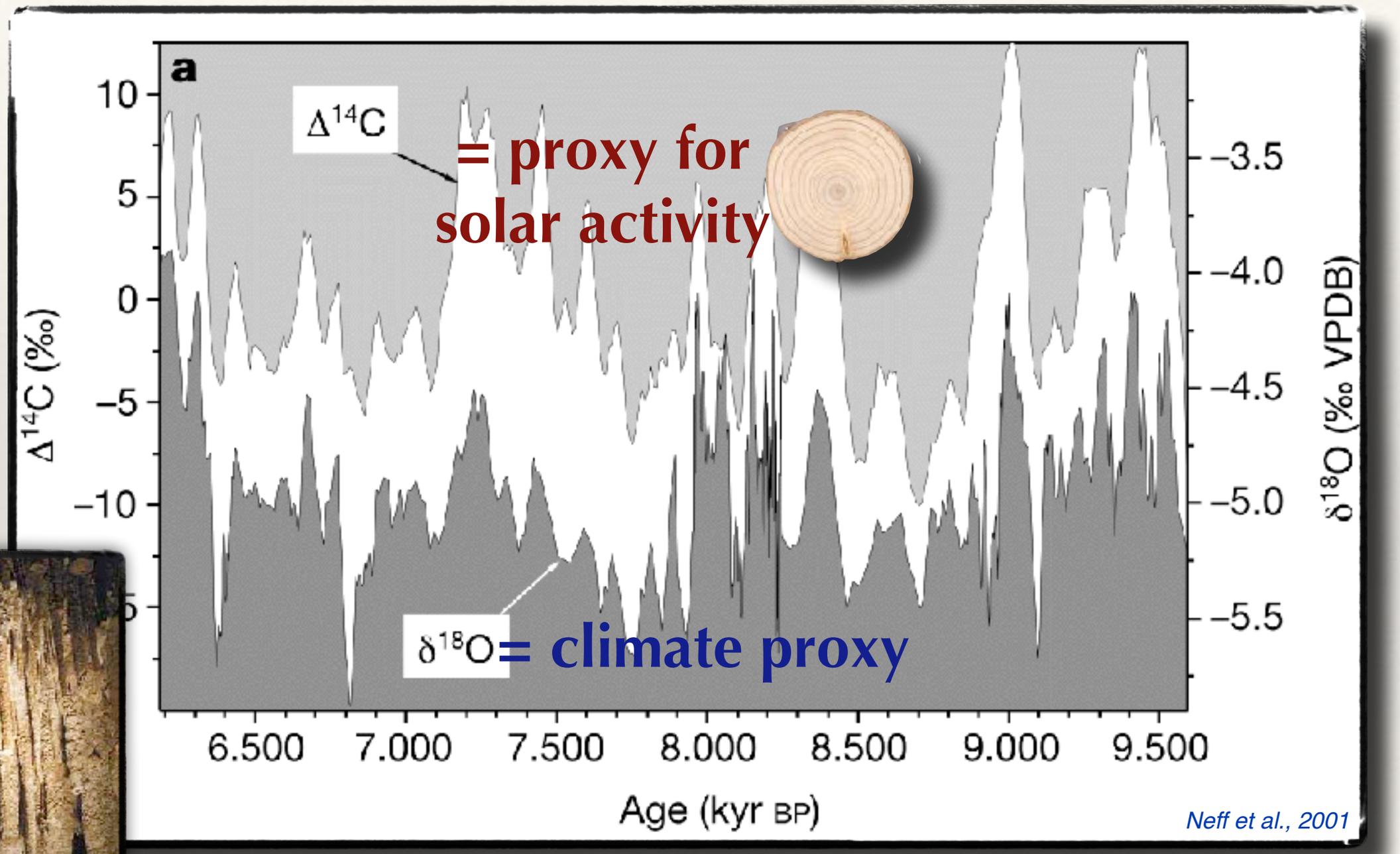
The Sun is a variable star!



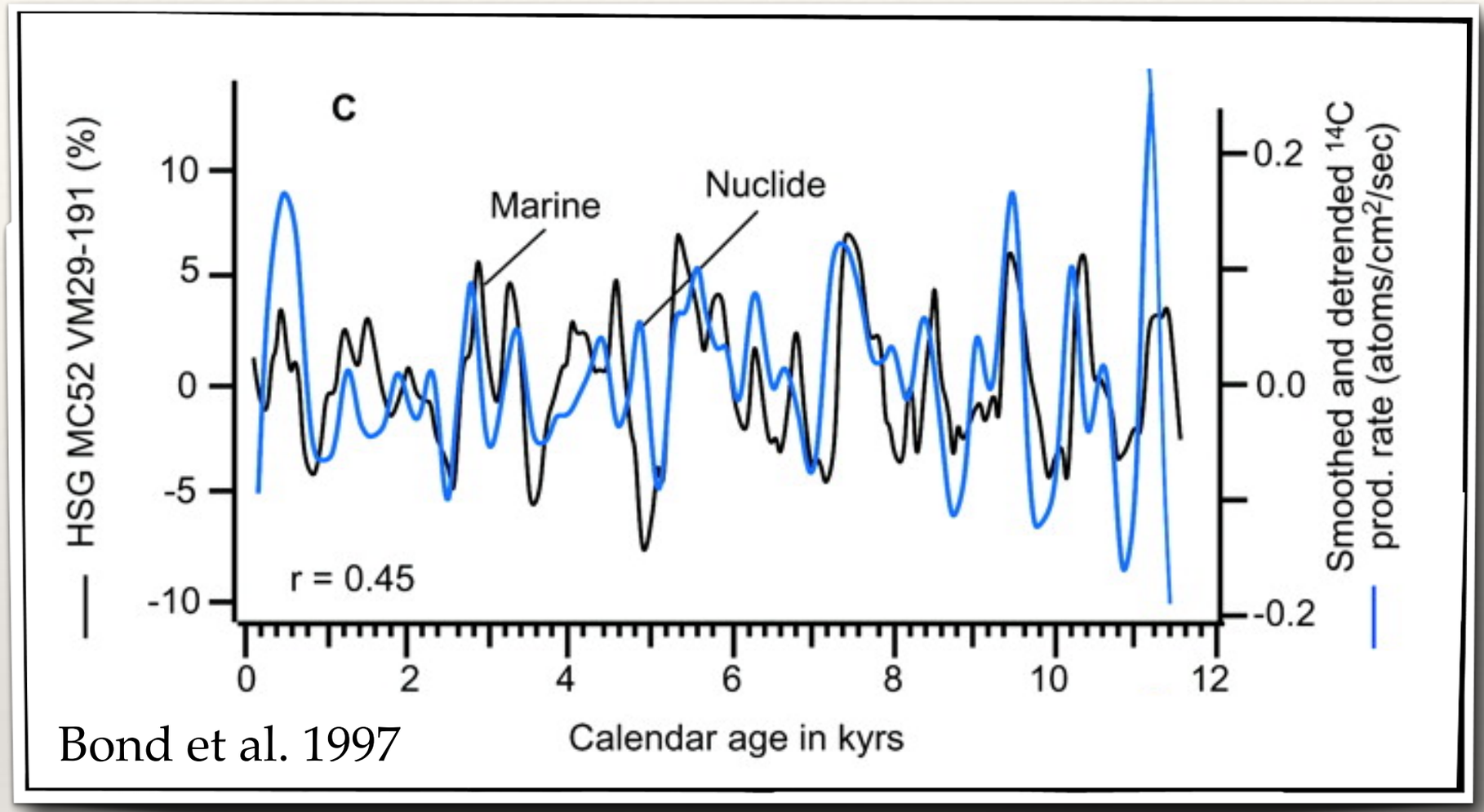


Soho images at 19.5nm (UV from Iron at 10^6K)

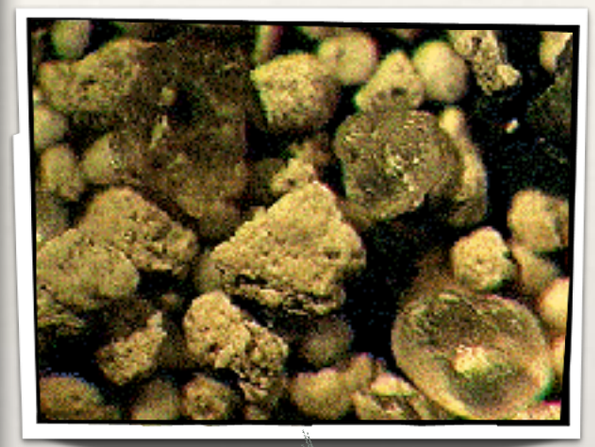
The link over several millennia



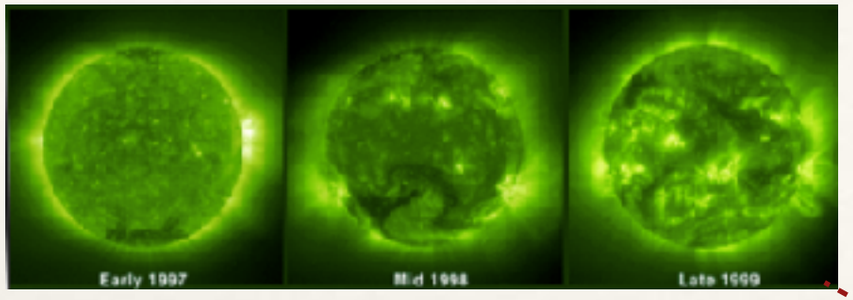
The link over several millennia



Bond et al. 1997

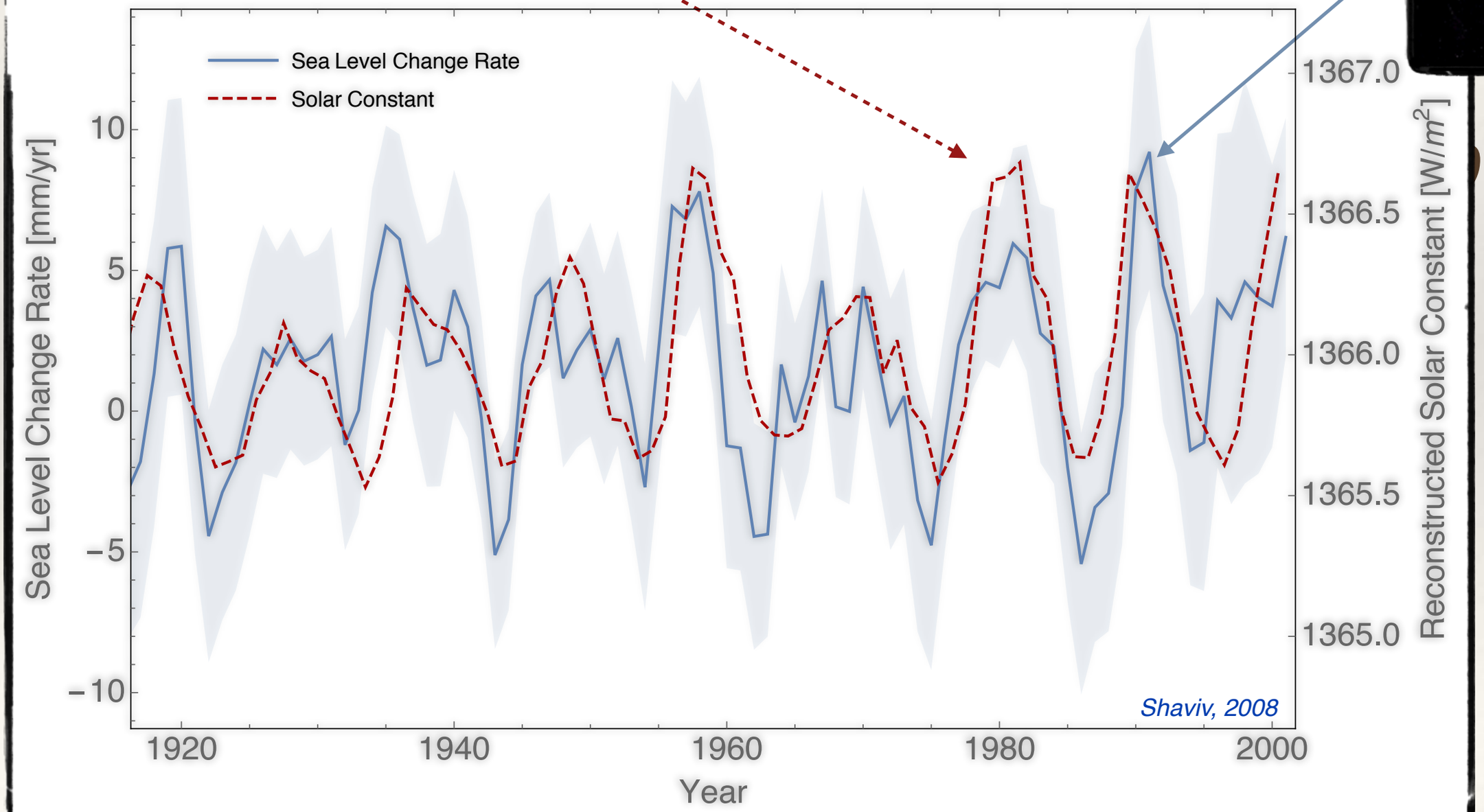


Link over the 11-year cycle

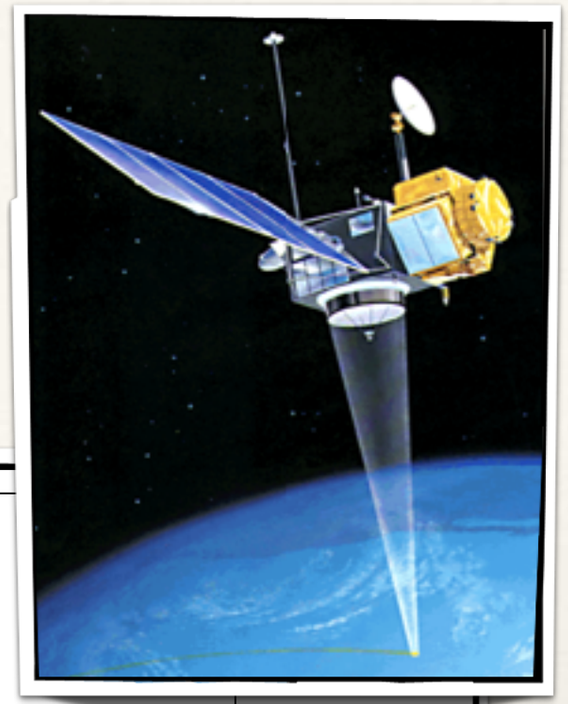


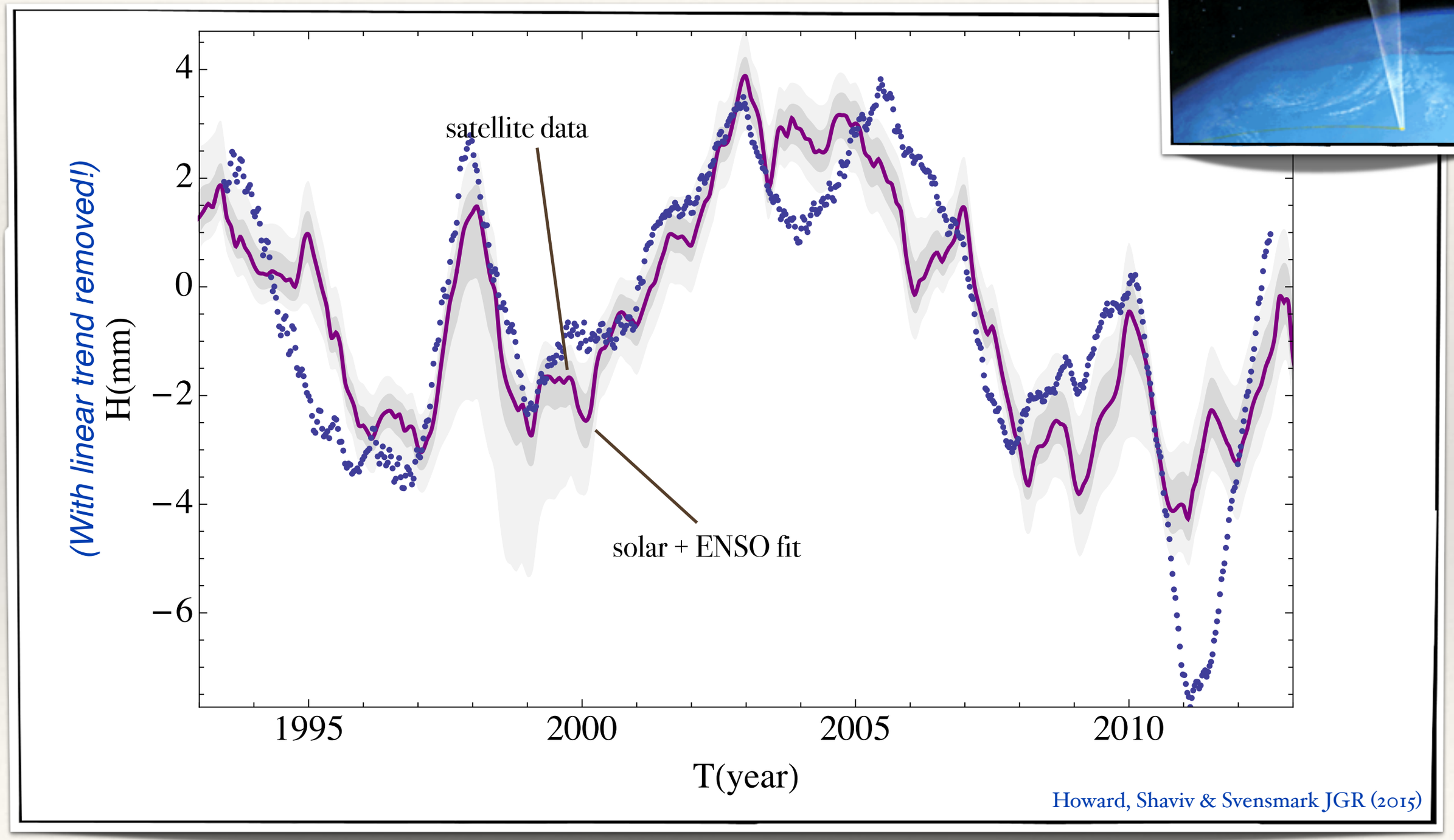
Solar Activity

Sea Level Change Rate



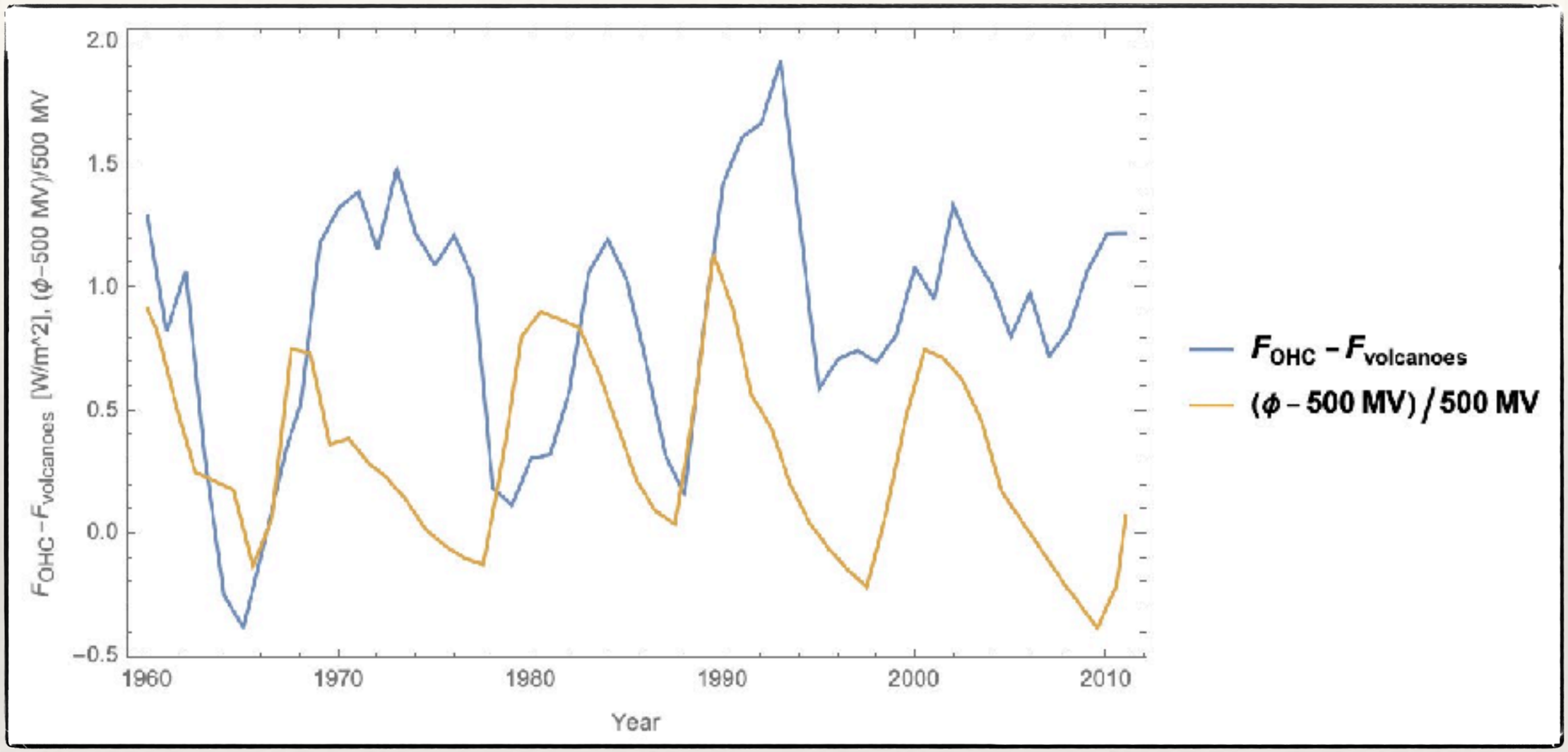
Link over the 11-year cycle





Howard, Shaviv & Svensmark JGR (2015)

Ocean Heat Flux

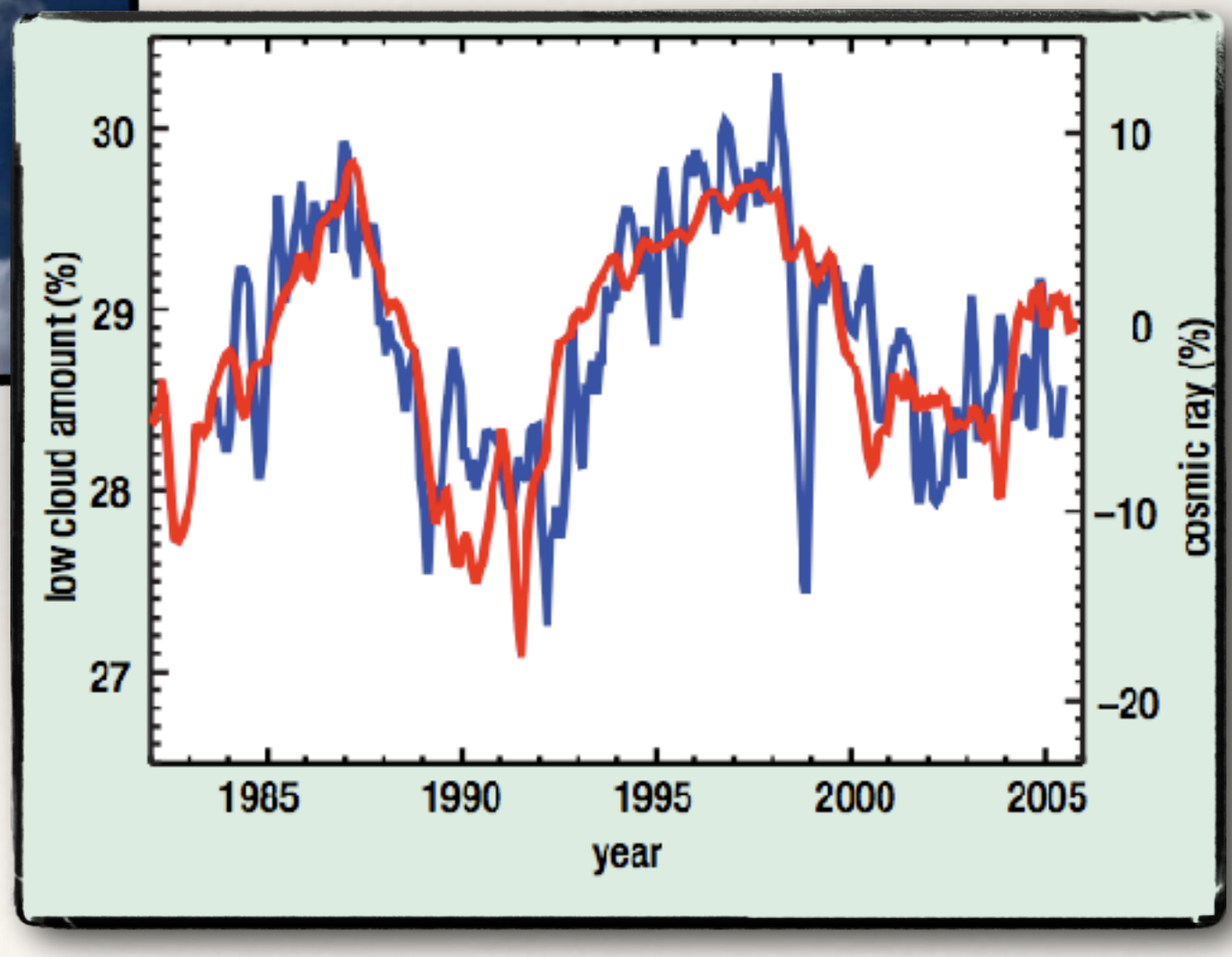


OHC - World Ocean Atlas (NOAA) https://www.ncei.noaa.gov/access/global-ocean-heat-content/basin_heat_data.html

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

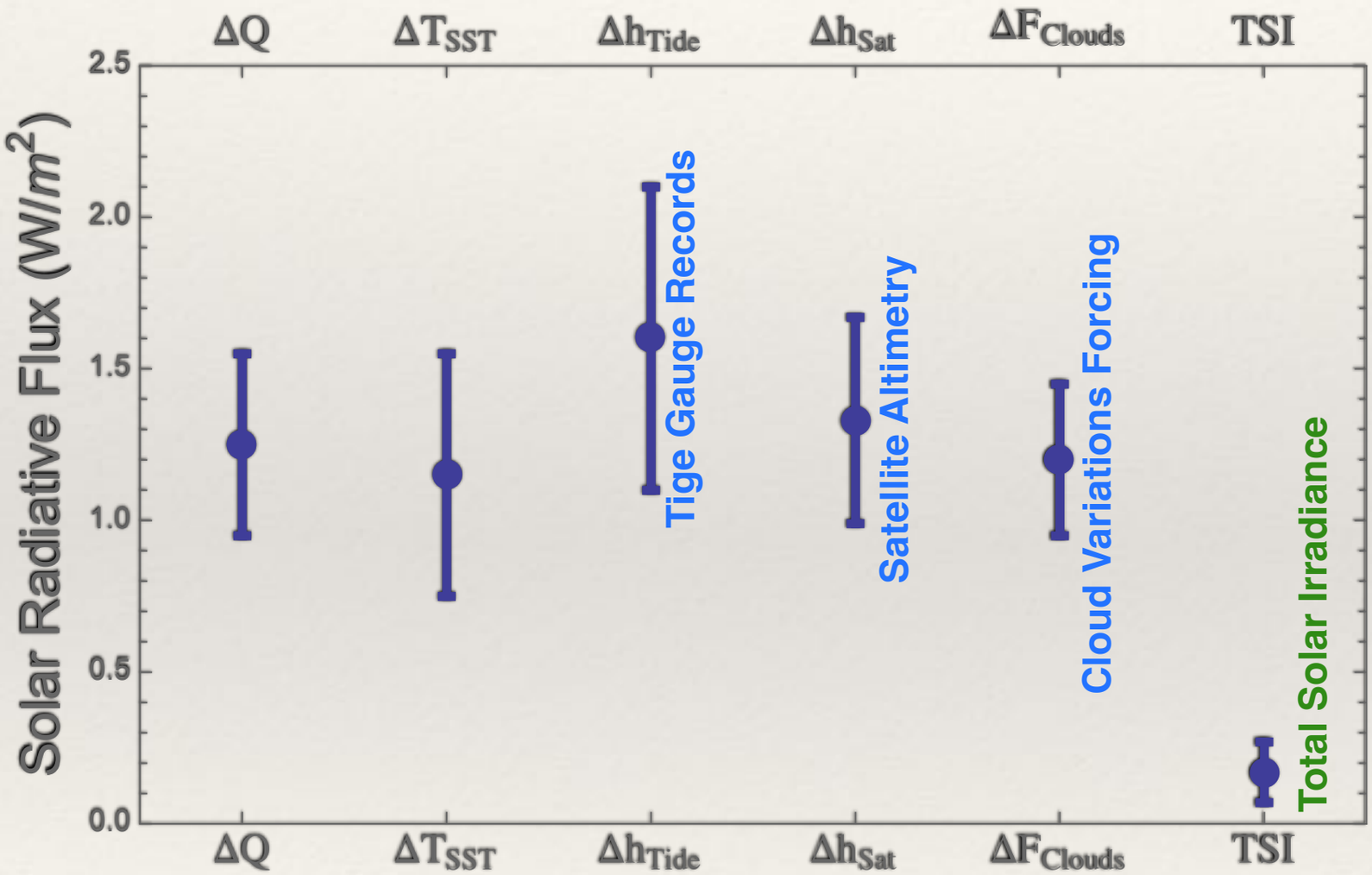
Solar Modulation - Matthes et al. 2017 doi: 10.1093/mnras/stx190

Link over the 11-year cycle



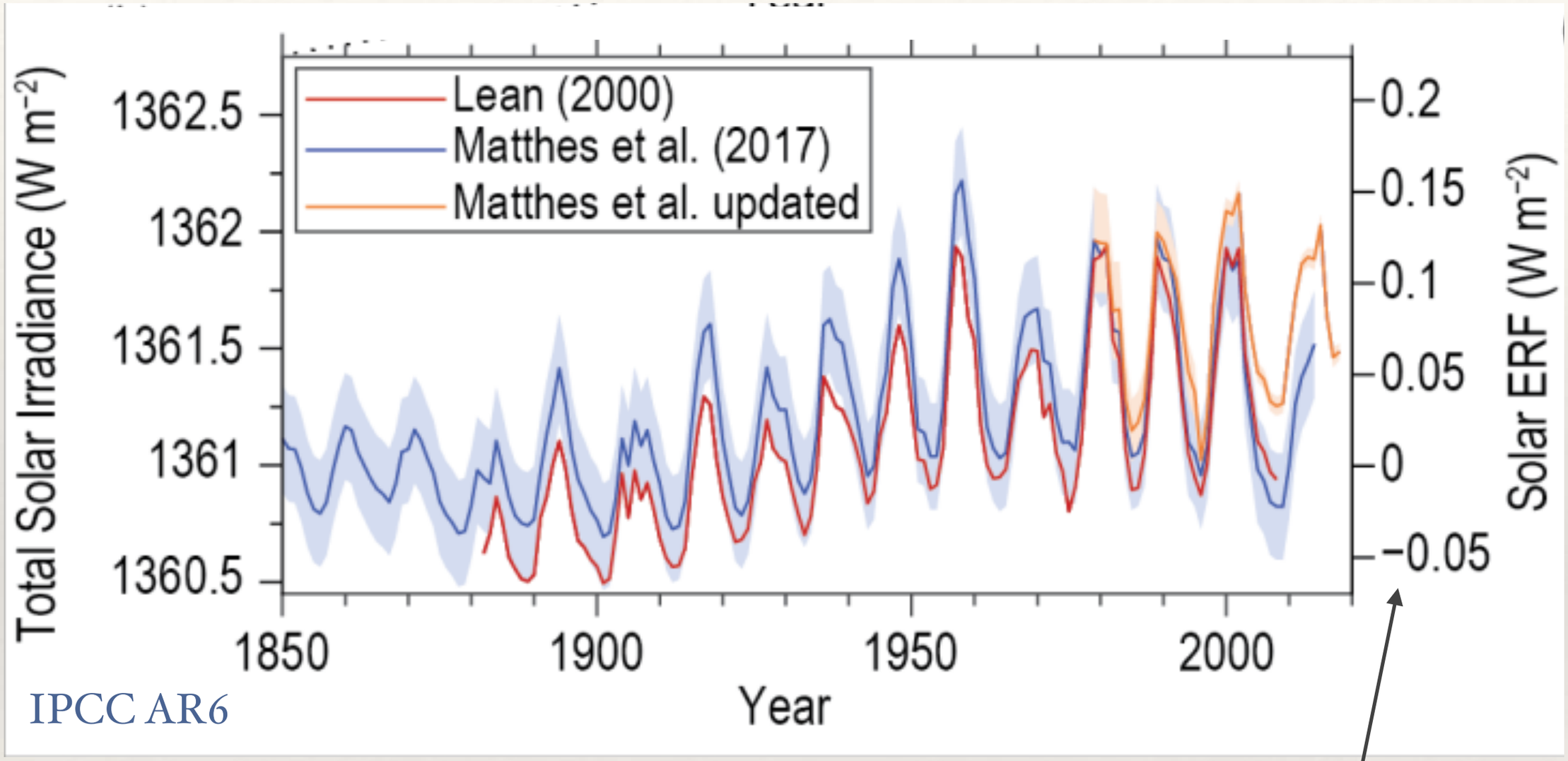
Svensmark 1998, Marsh & Svensmark 2000

Link over the 11-year cycle



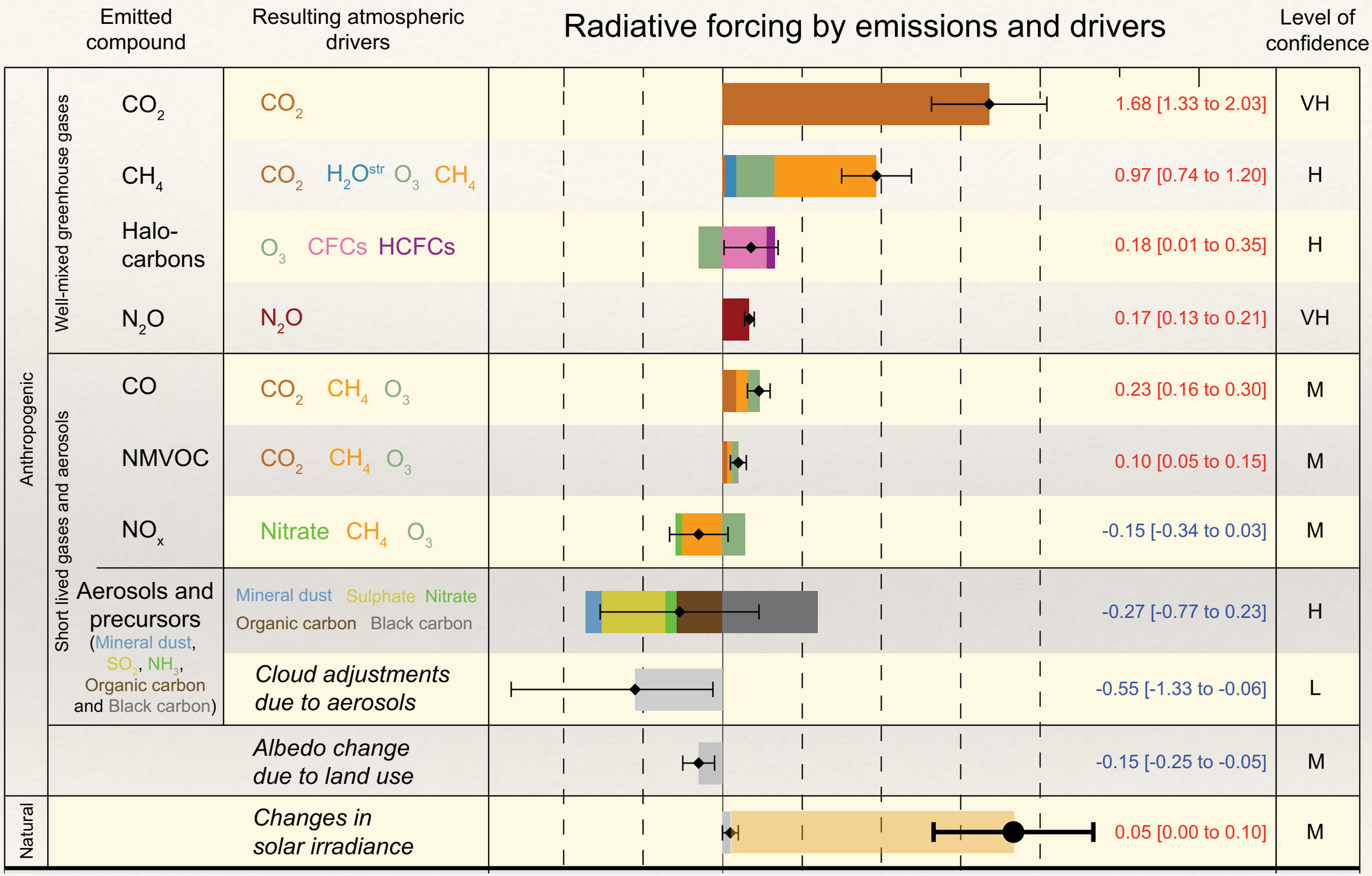
Requires
an amplification
mechanism

Solar forcing according to the IPCC



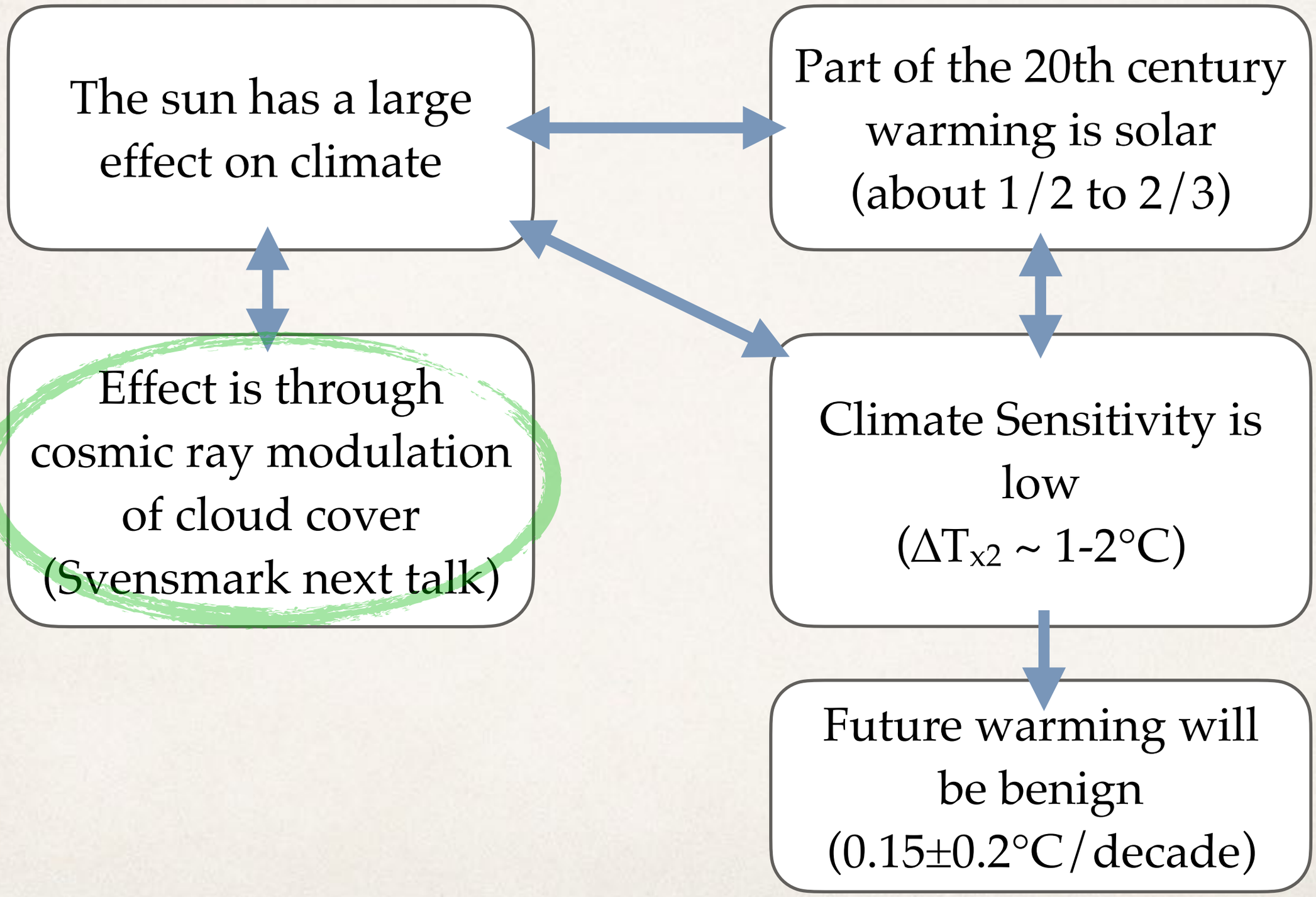
Note that typical variations are very small, of order 0.1 W/m²
Compared to 1-2 Wm² of Greenhouse Gases

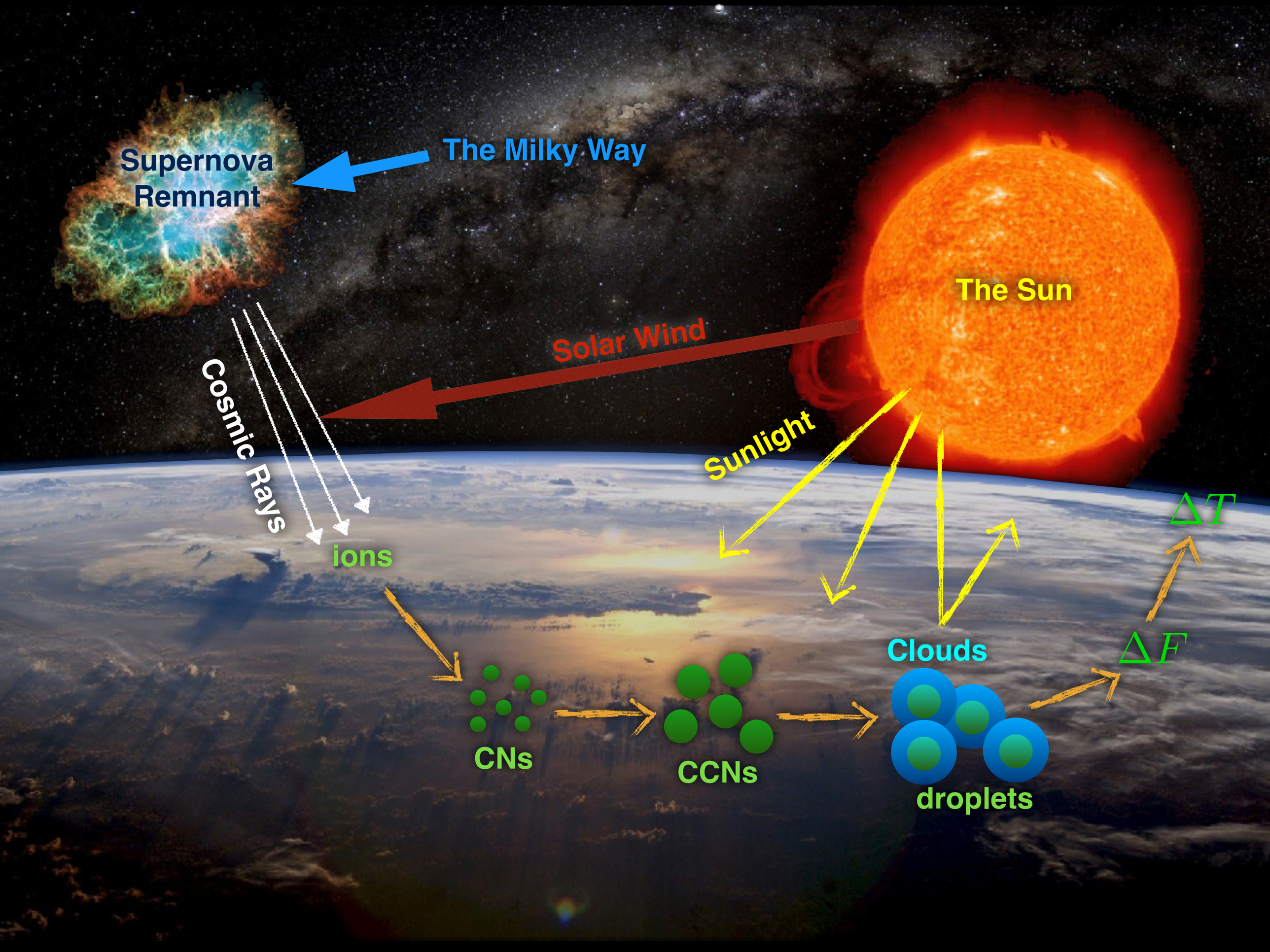
IPCC 5AR forcing graph



The Cosmic Ray - Climate Link

Take Away Points




Supernova Remnant
The Milky Way
The Sun
Solar Wind
Cosmic Rays
Sunlight
ions
CNs
CCNs
Clouds
droplets
ΔT
ΔF

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)

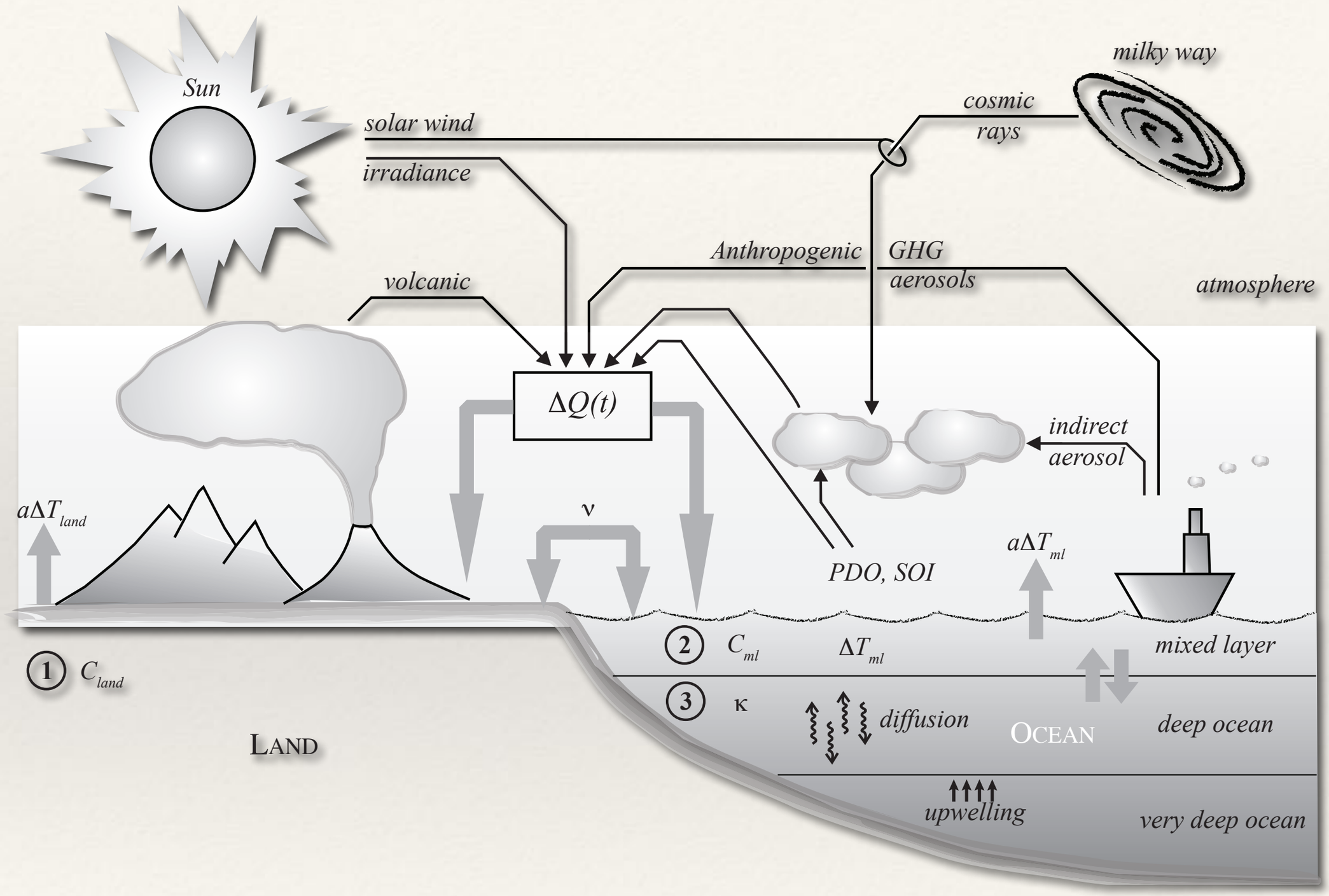
Effect is through cosmic ray modulation of cloud cover (Svensmark next talk)

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

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

Modeling the 20th century

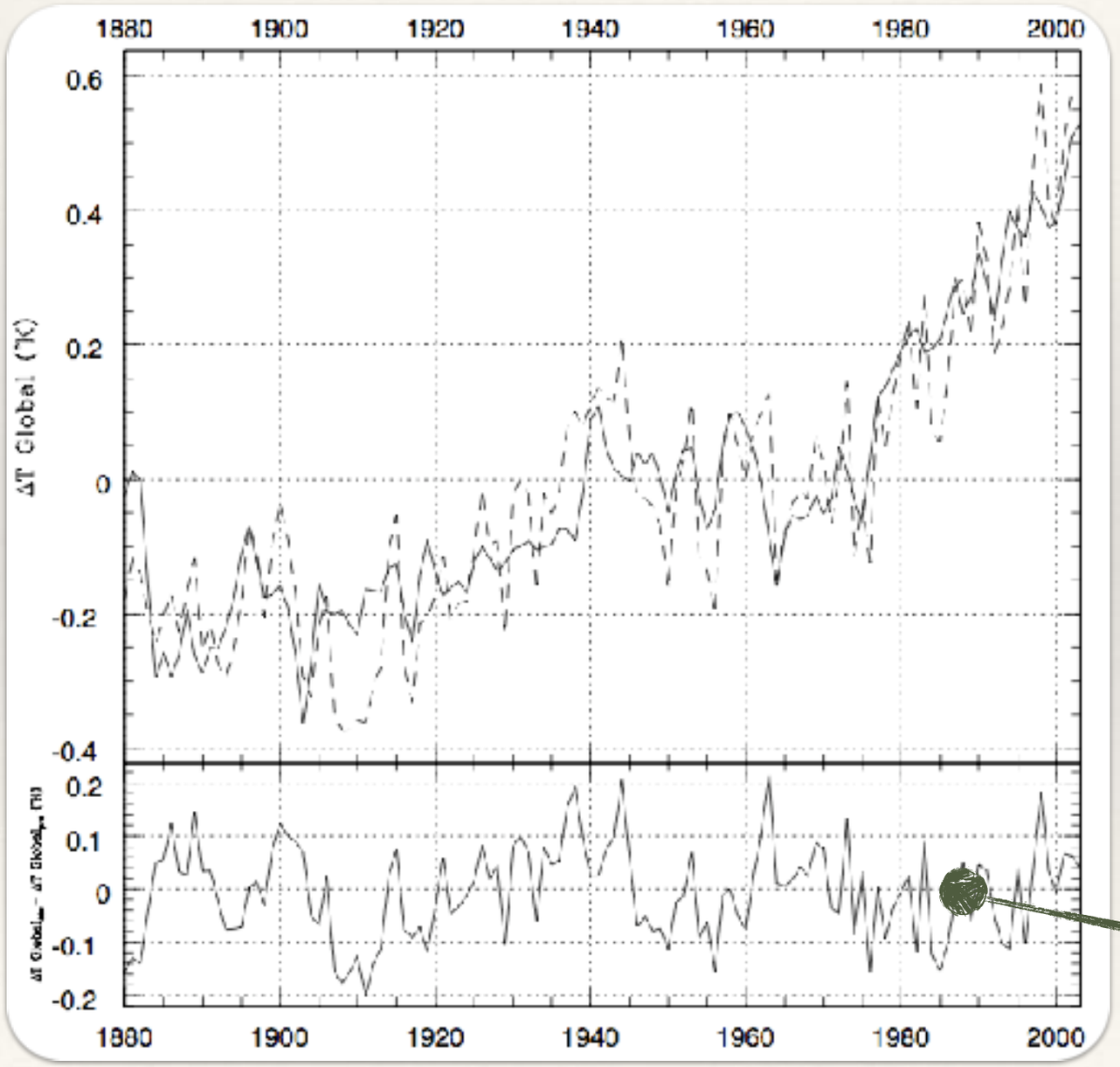
Basic Climate Model



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

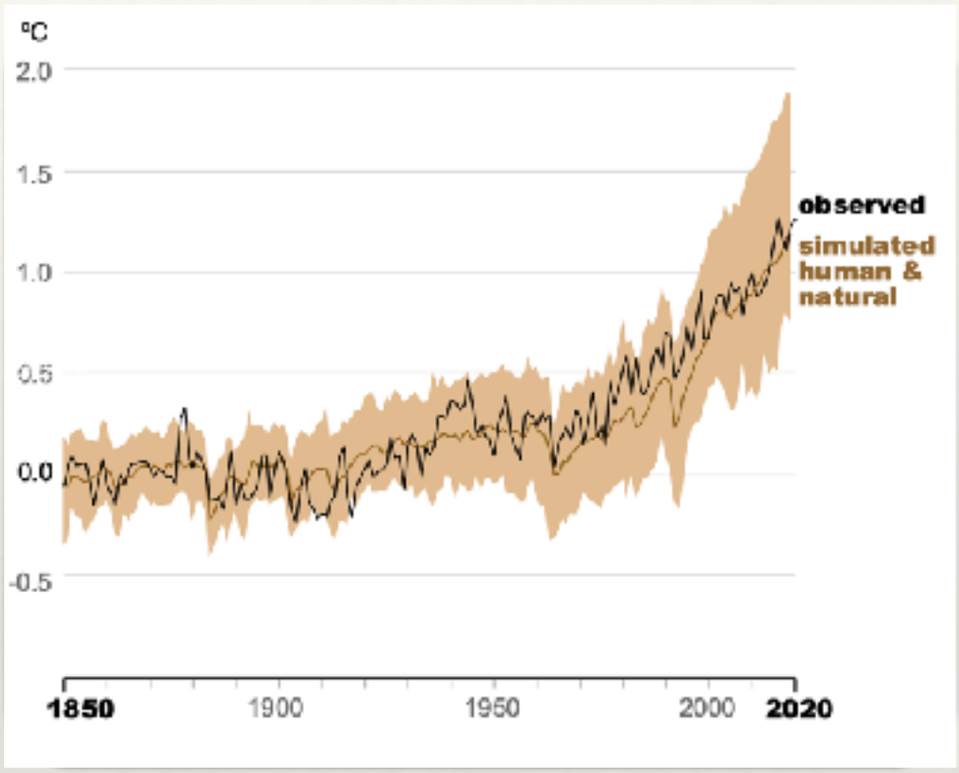
20th century warming

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



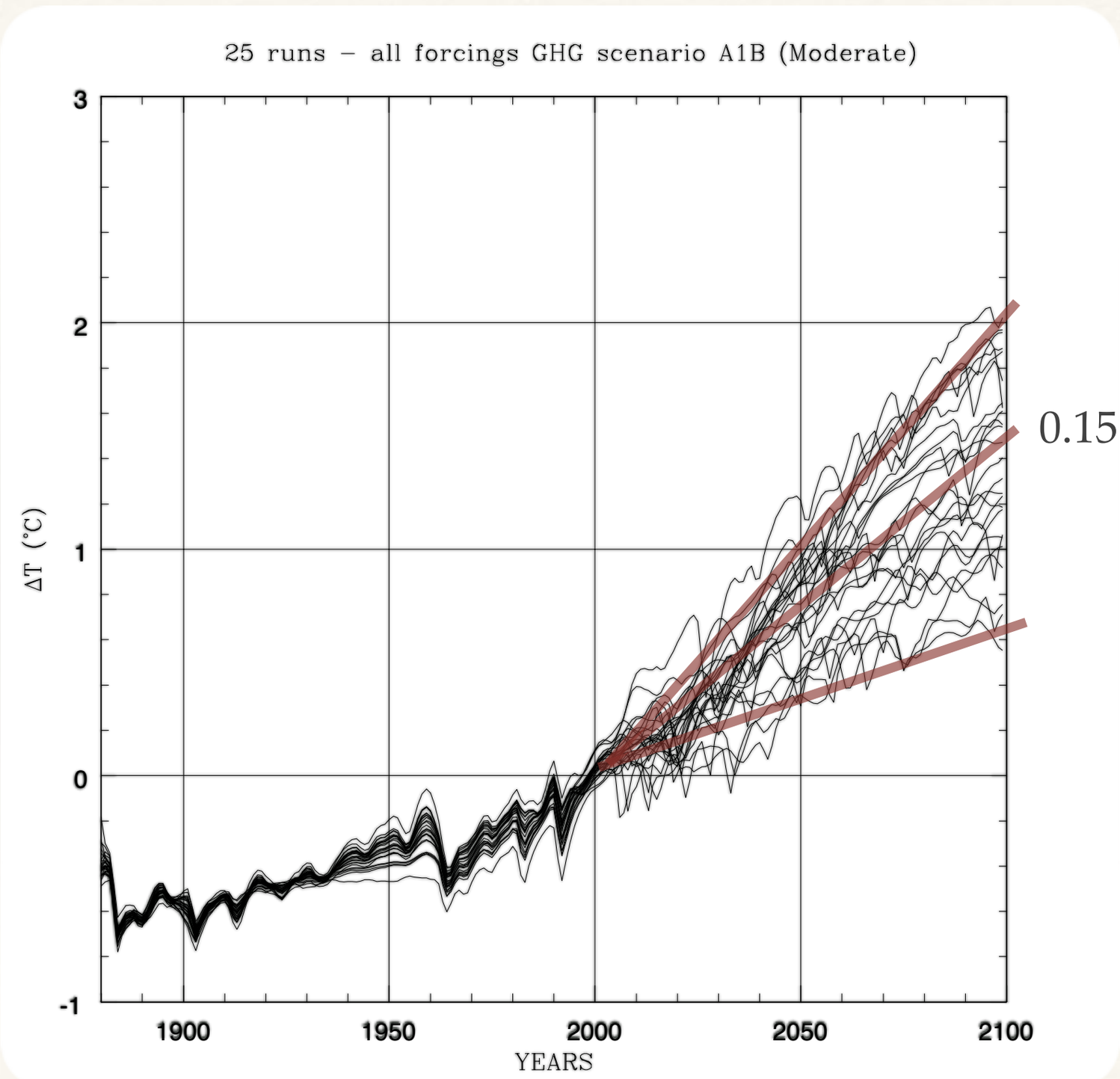
Ziskin & Shaviv, 2012

Comparison: IPCC-AR6



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

21st century temperature increase



0.15° per decade

Take Away Points

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

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Earth's climate sensitivity

Climate Sensitivity

- To predict the temperature increase, we need to know how sensitive is the climate:

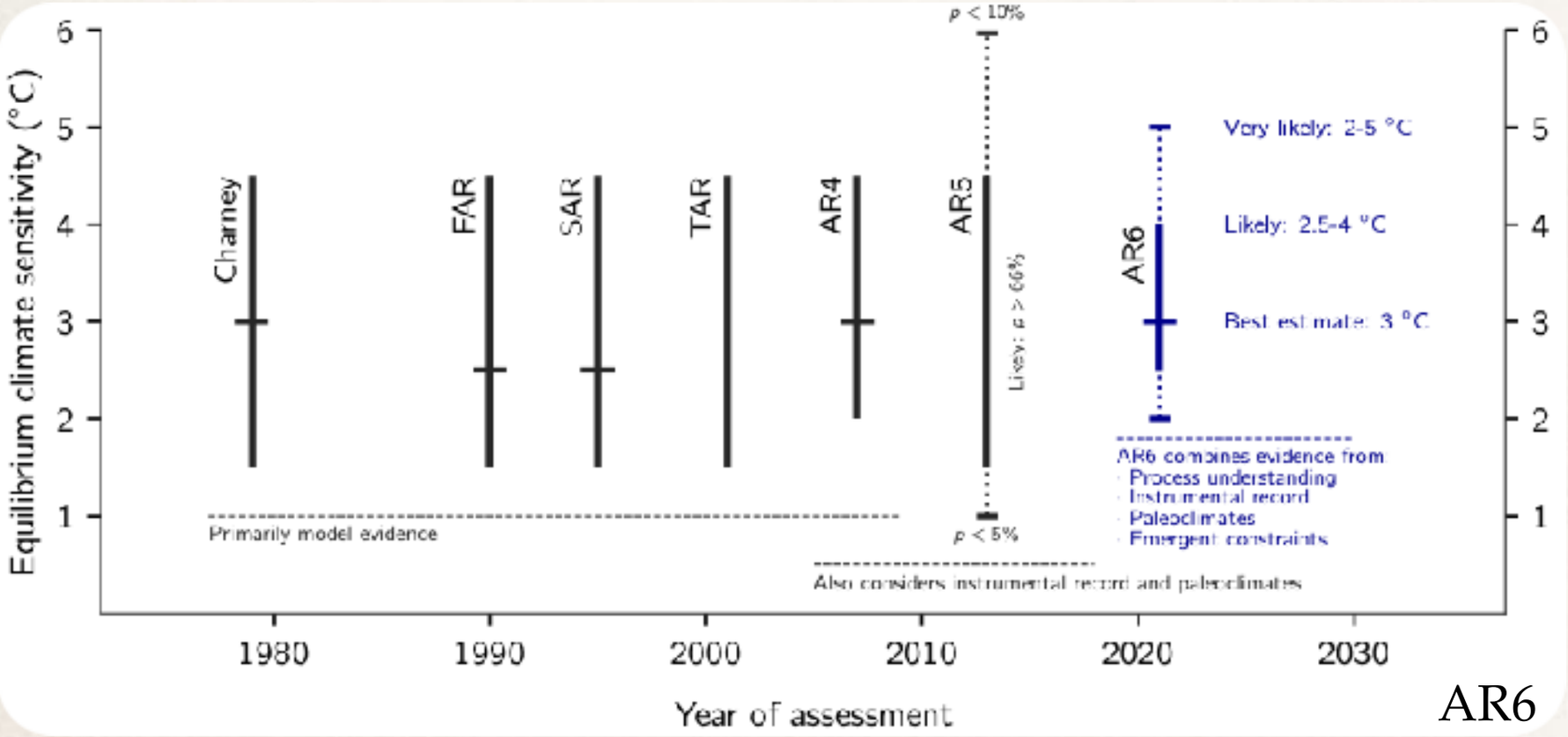
$$\text{Climate sensitivity} = \frac{\text{Amount of warming (°C)}}{\text{Energy budget change (W/m}^2\text{)}} = \frac{\Delta T_{x2}}{3.7\ \text{W/m}^2)}$$

$$\text{Climate feedback} = \frac{\text{Energy budget change (W/m}^2\text{)}}{\text{Amount of warming (°C)}}$$

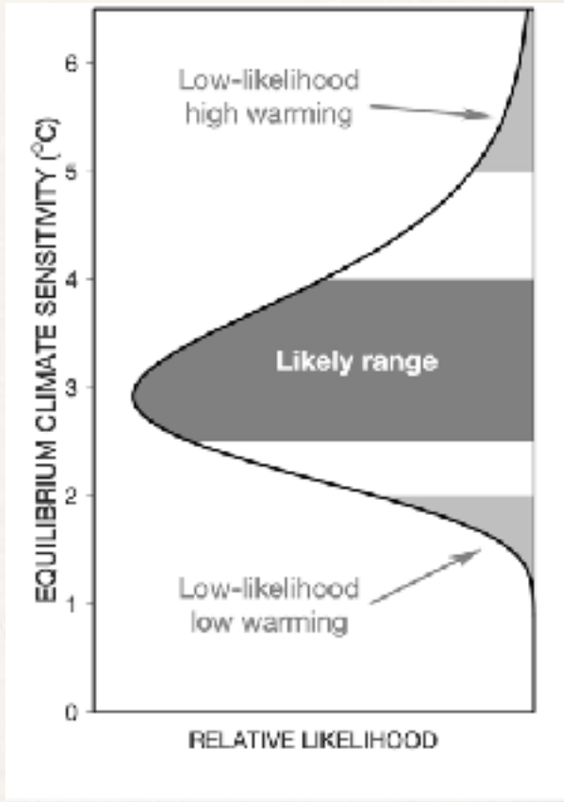
- Caveats: Not all drivers are the same (is 1 W/m^2 of CO_2 the same as 1W/m^2 of solar forcing?), you have to wait long enough, do you allow ice and vegetation to change?

Climate Sensitivity - IPCC range

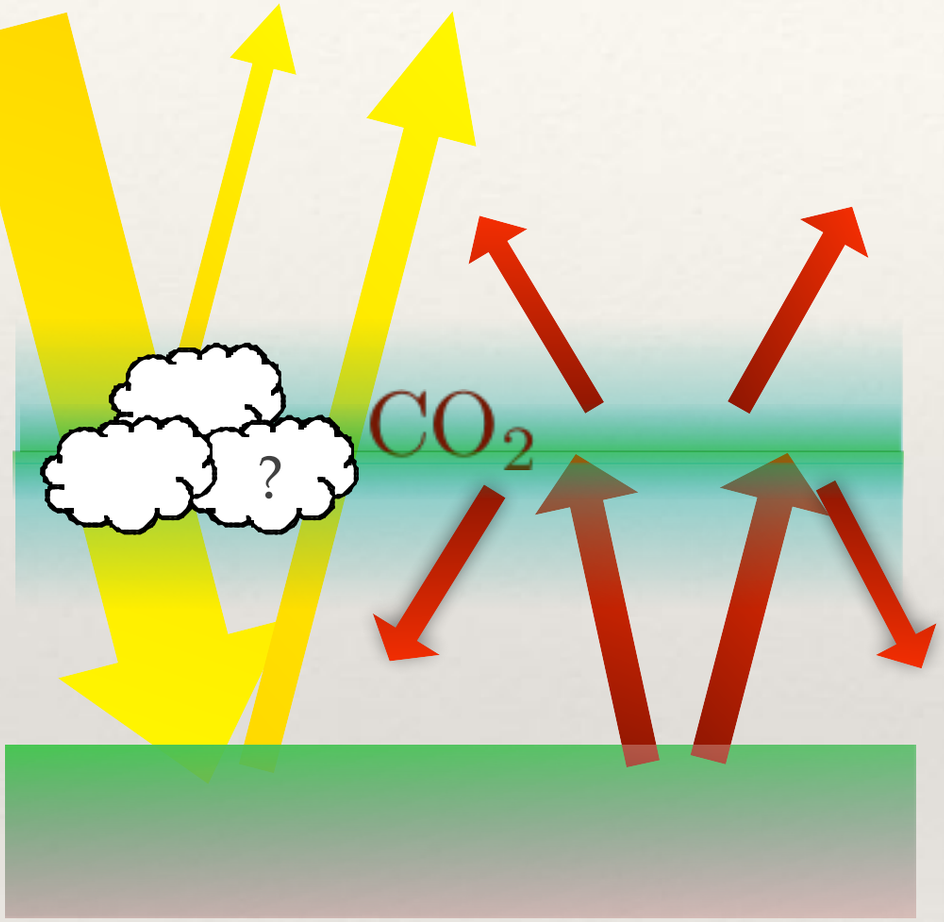
- Canonical Range set by a federal committee in 1979.



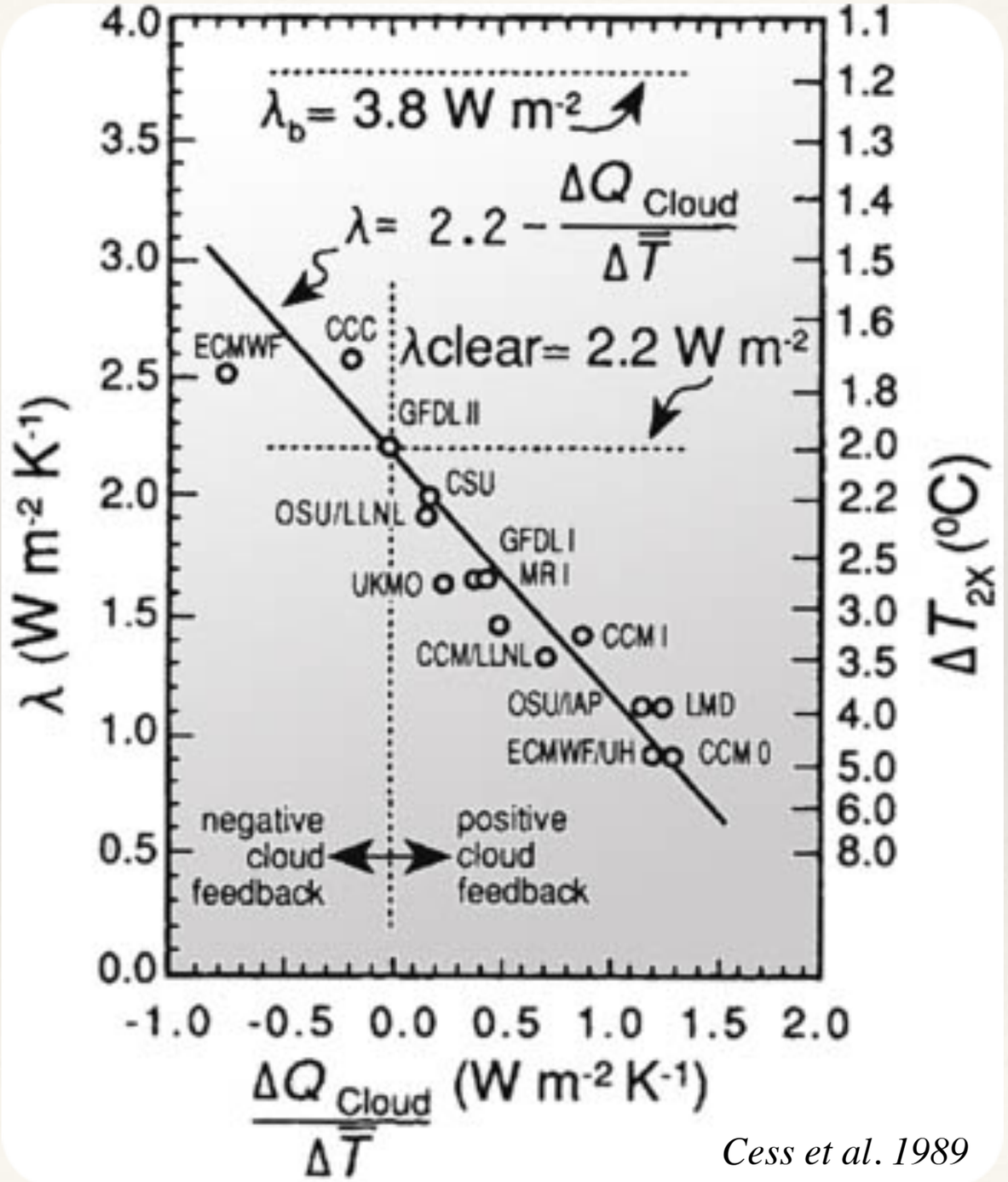
AR6



Cloud Feedback is a large uncertainty

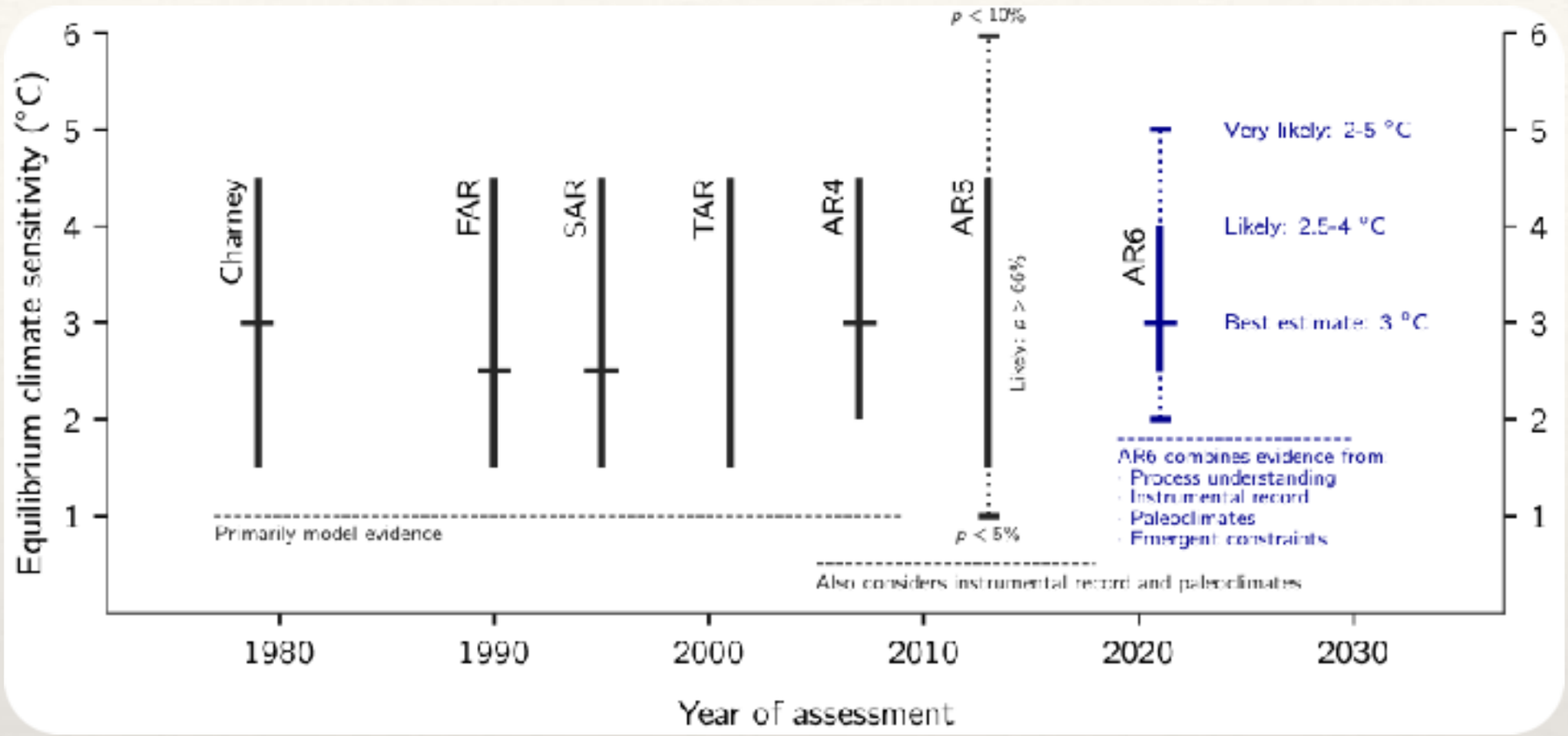


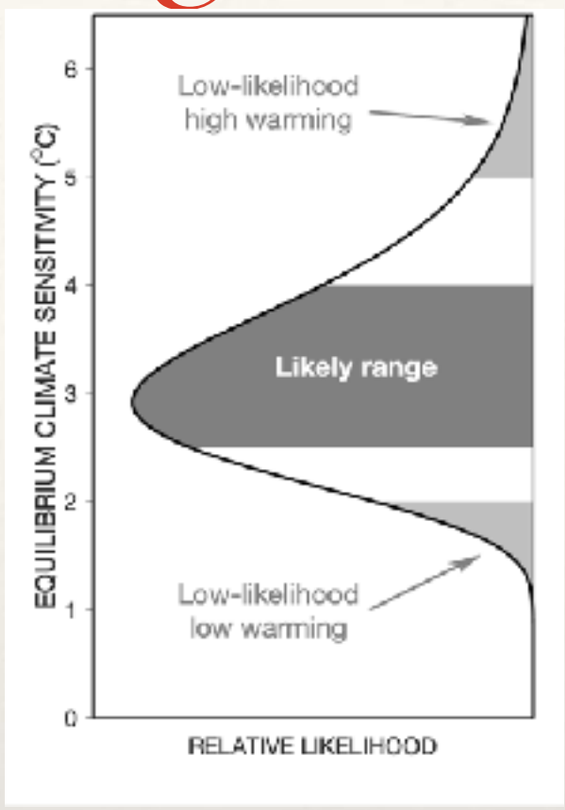
- The feedback through clouds is the largest uncertainty governing the numerical climate models.

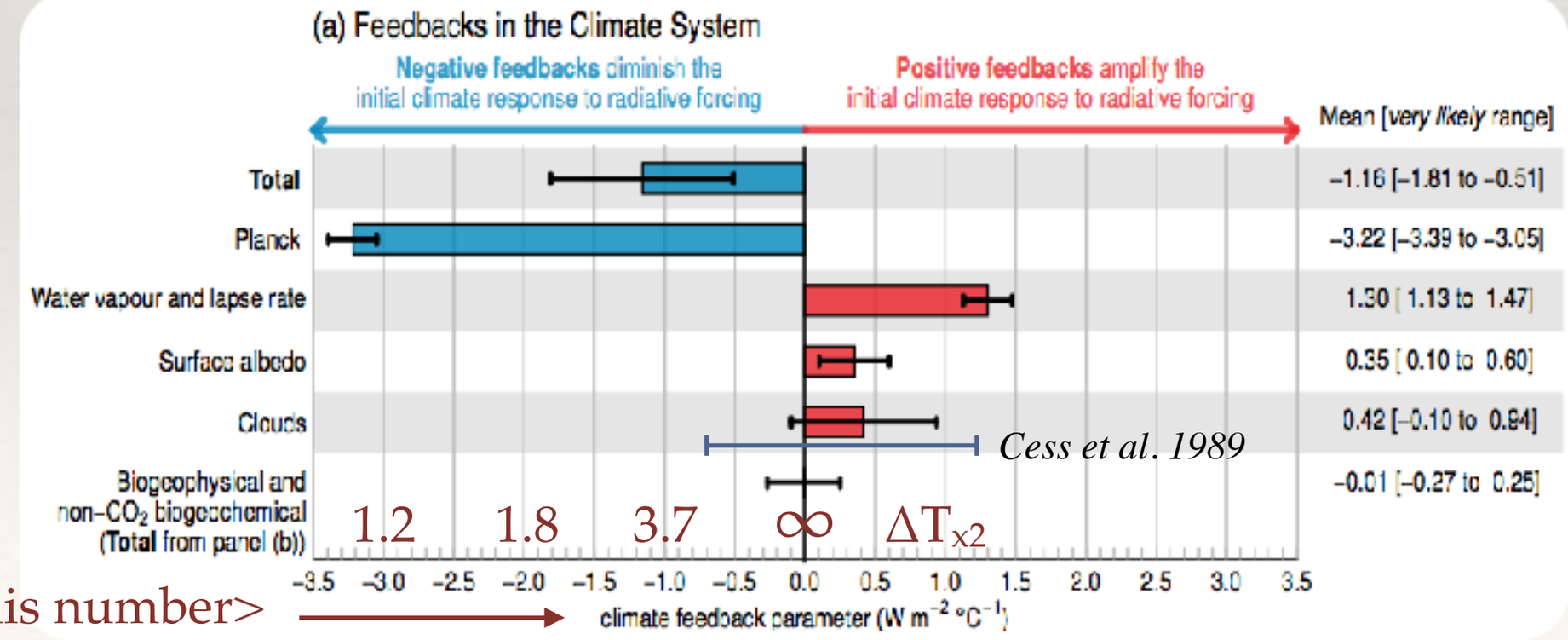


Cess et al. 1989

Feedback uncertainty according to AR6

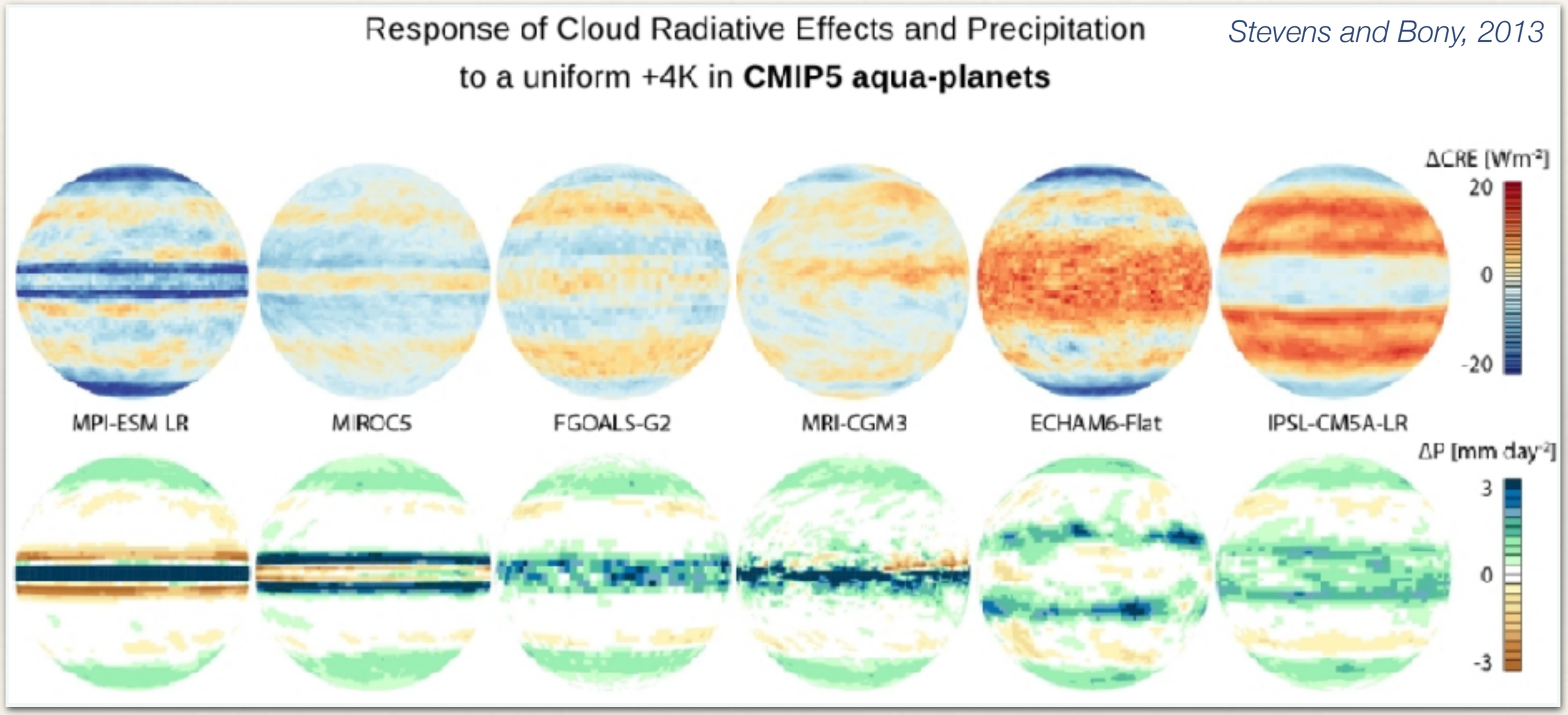






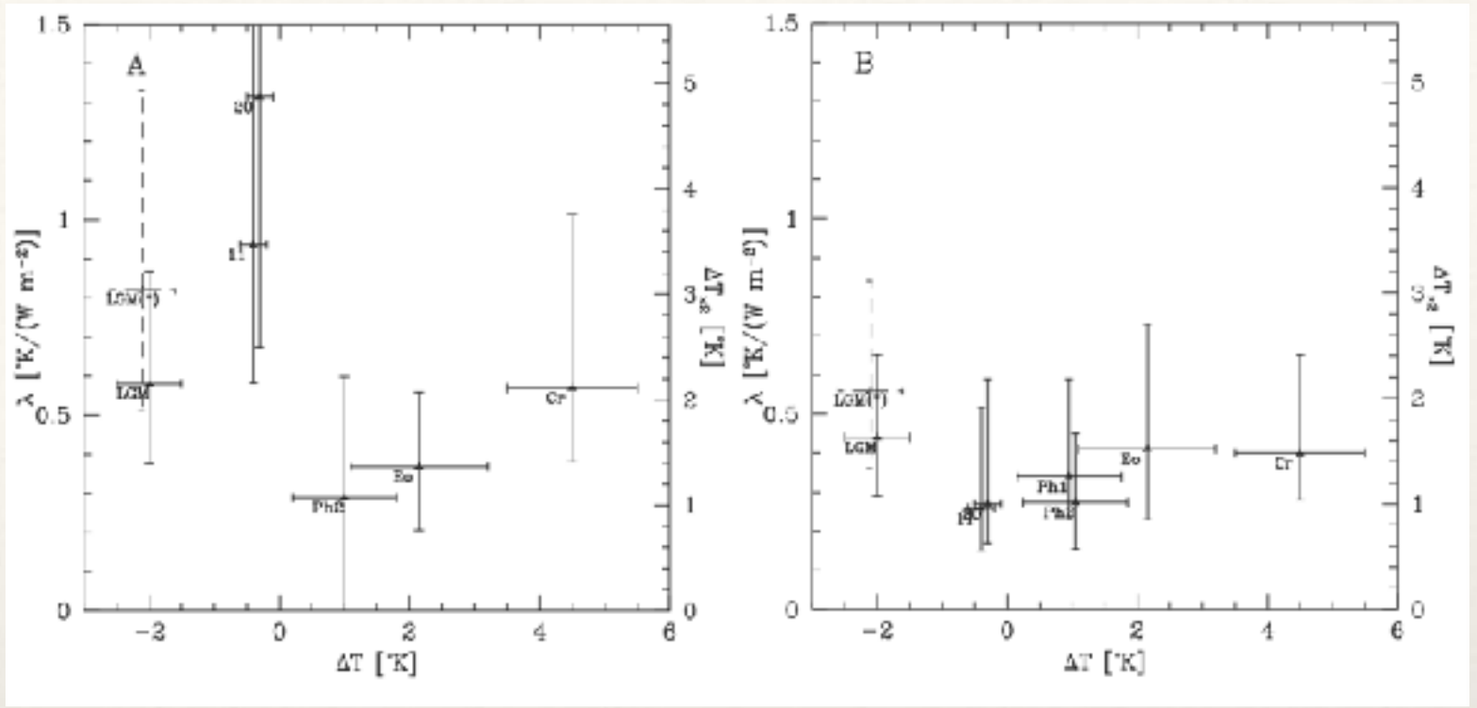
$\Delta T_{x2} \sim 3.7\ W/m^2$ / <this number>

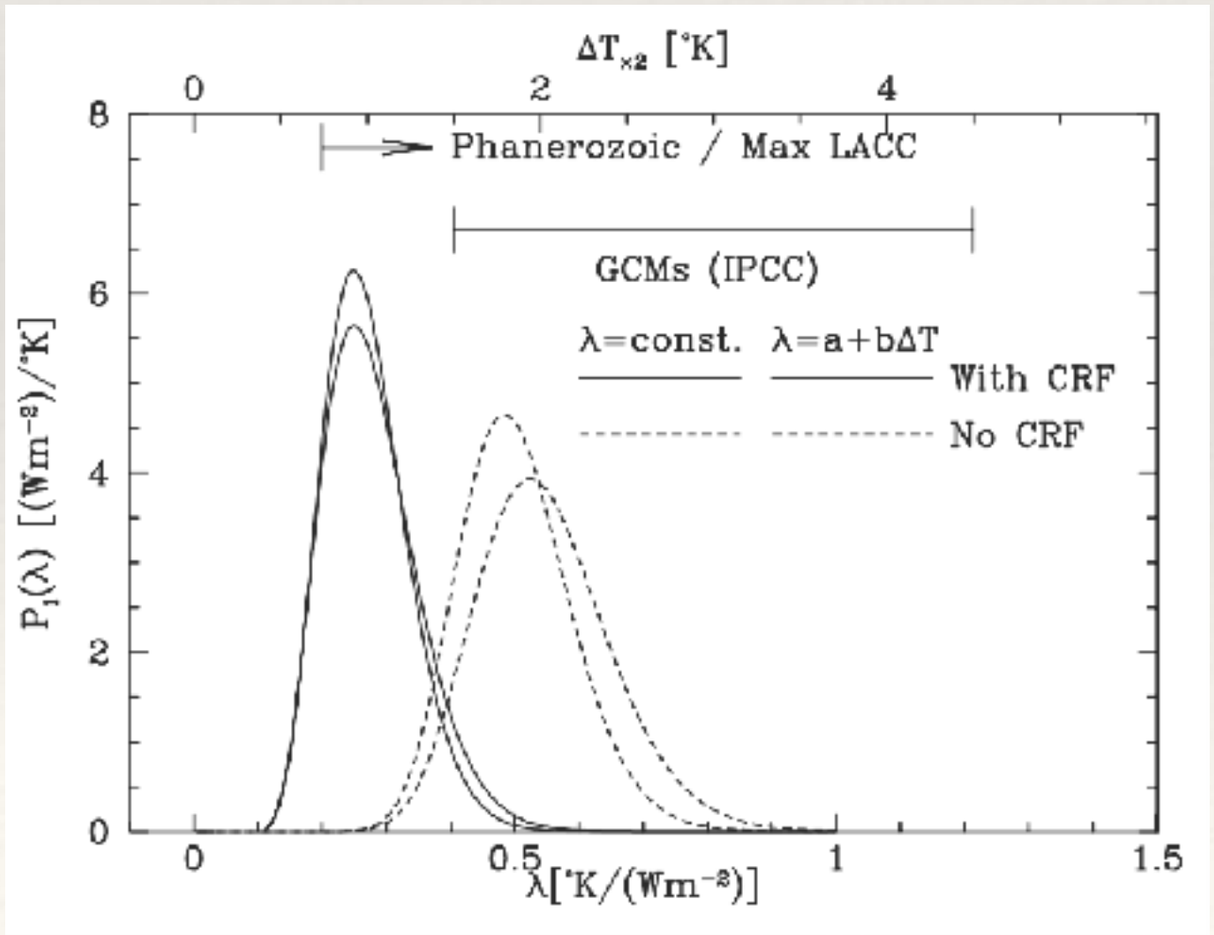
Cloud Feedback is a large uncertainty



Empirical over different time scales

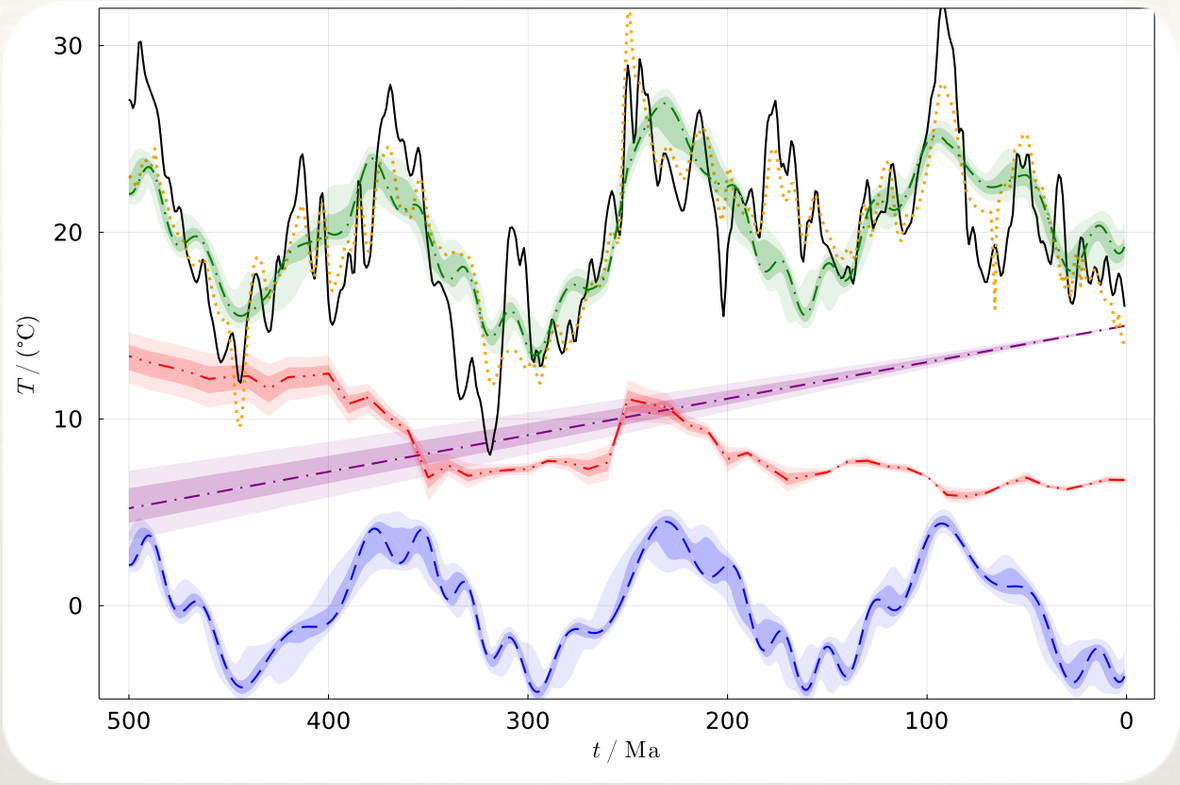
$$\Delta T_{\times 2} = \frac{\Delta T_{\text{interval}}}{\Delta F_{\text{interval}}} \Delta F_{\times 2}$$





Shaviv 2005

Variations over the Phanerozoic

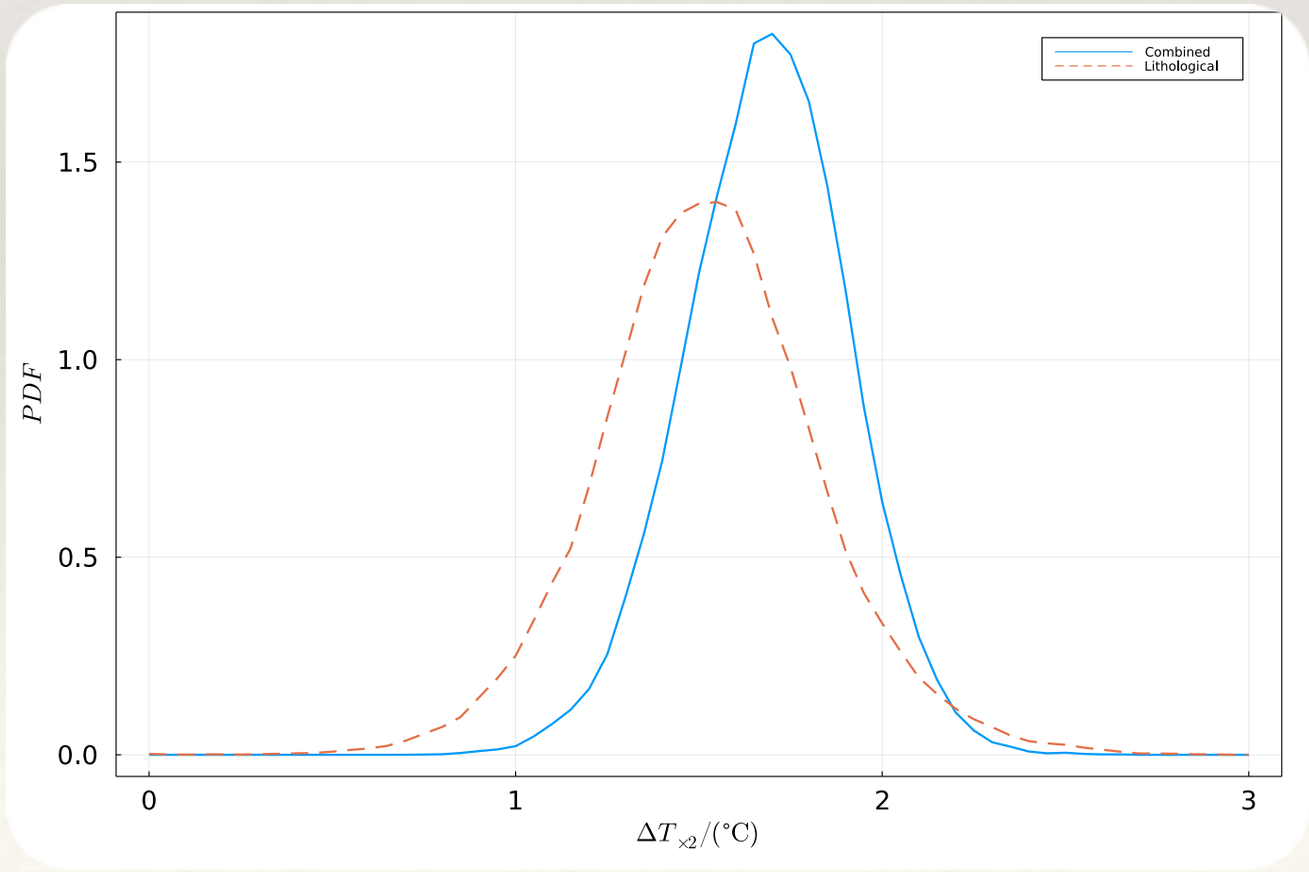


Reconstruction (black) + Model Fit (Green)

Solar Constant increase

CO_2 contribution

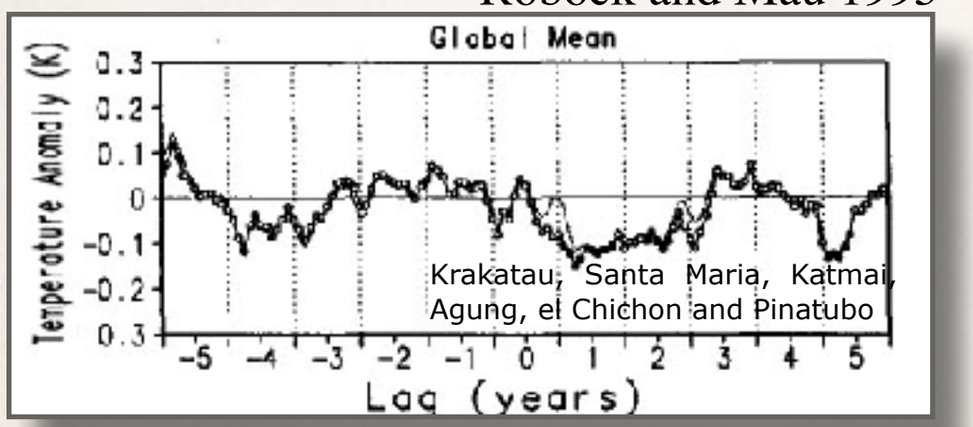
Galactic cosmic rays

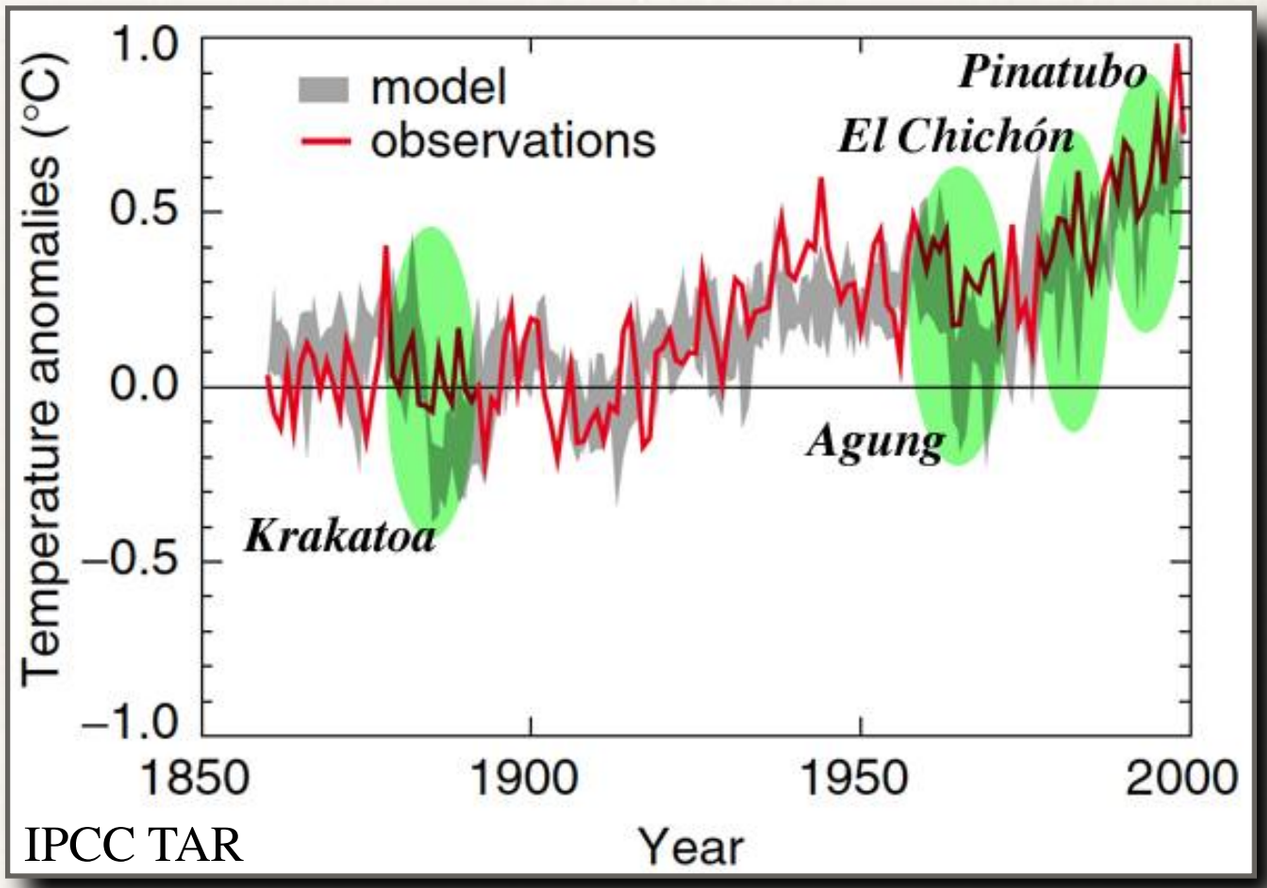


Shaviv Svensmark Veizer 2021

Response to volcanic eruptions is small

Robock and Mau 1995





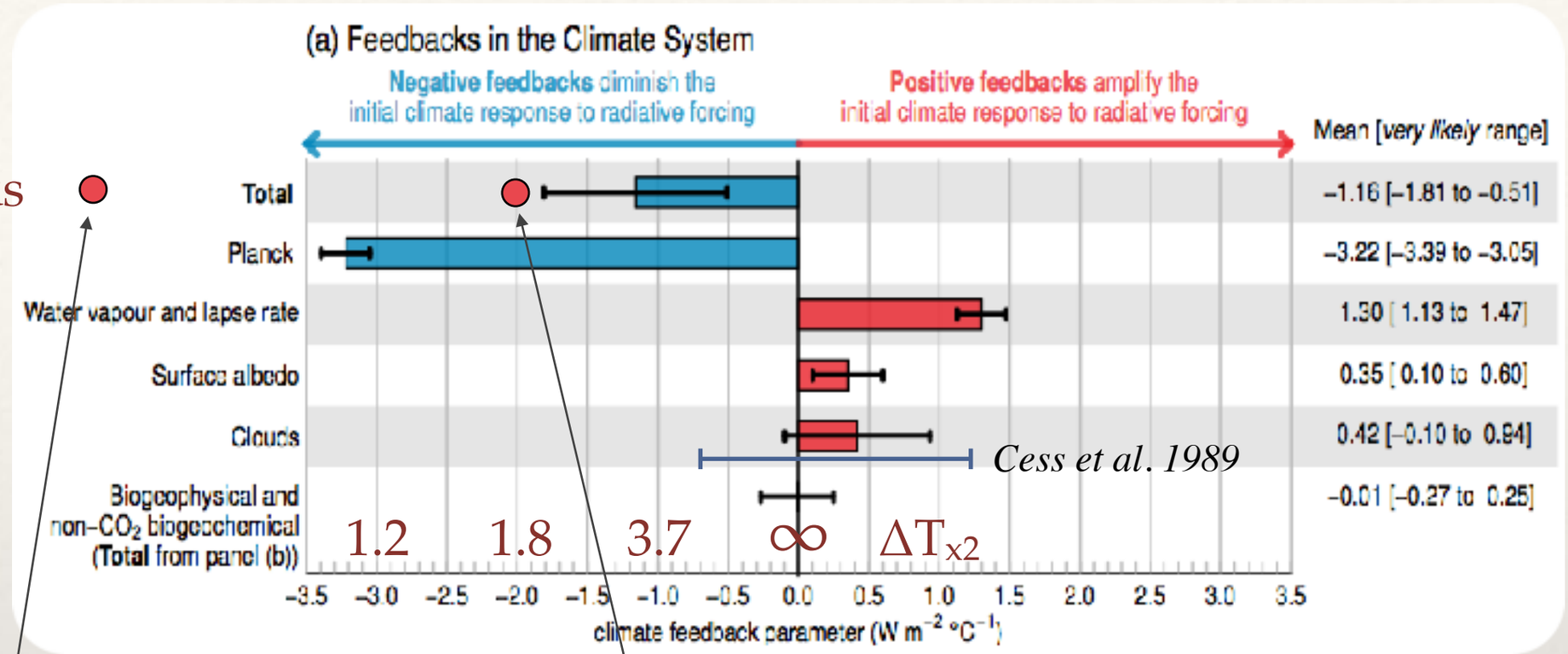
IPCC TAR

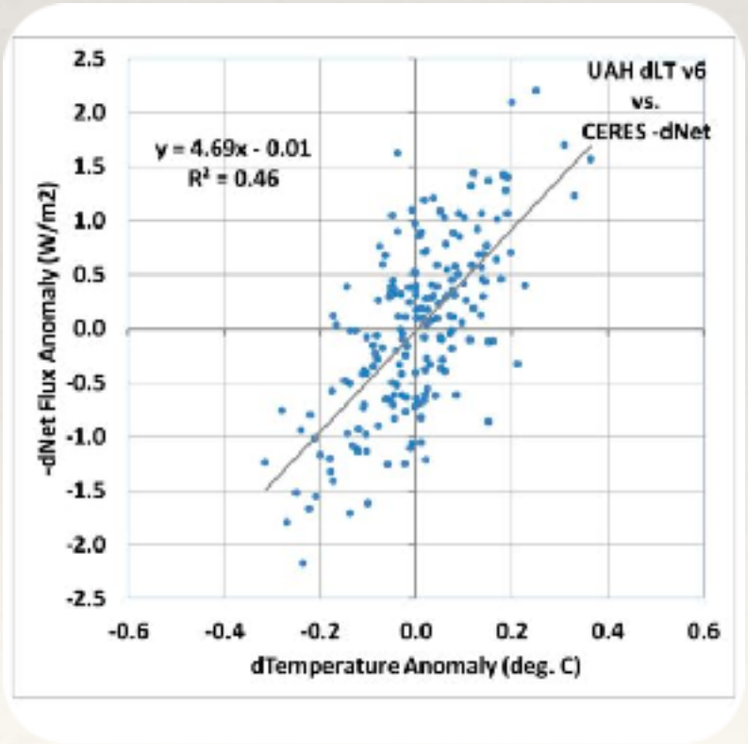
Model predictions: Decrease of 0.3-0.5°C.
Reality: Decrease of 0.1°C on average

Measuring total (fast) feedback?

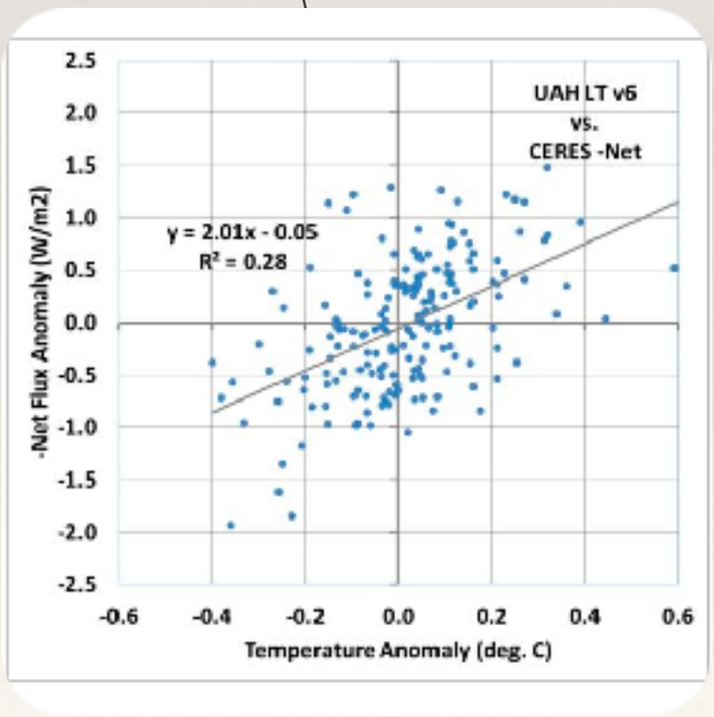
without slow feedbacks

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)

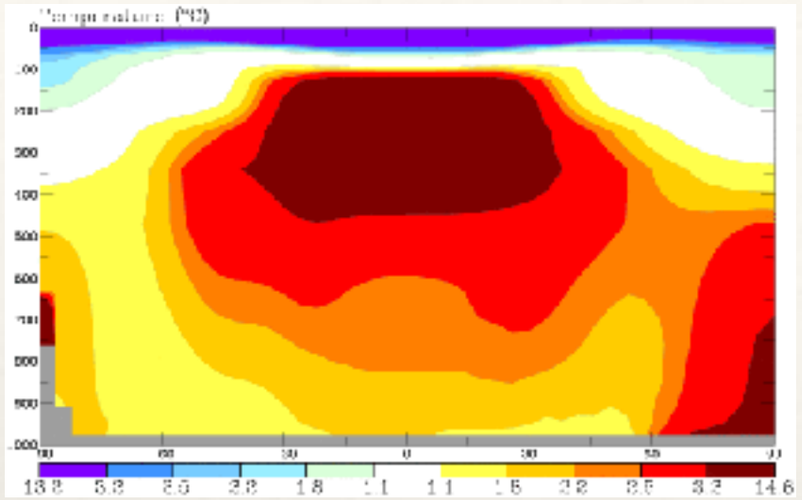
Lack of tropospheric “hot spot”

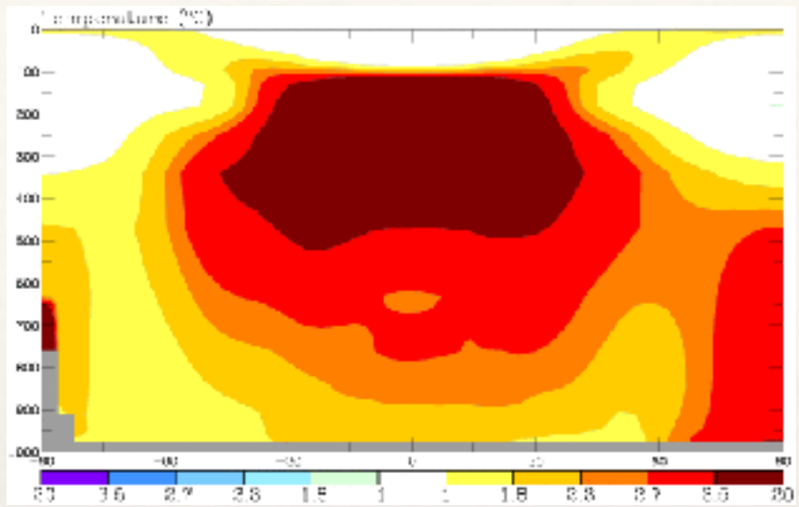
Doubled CO2

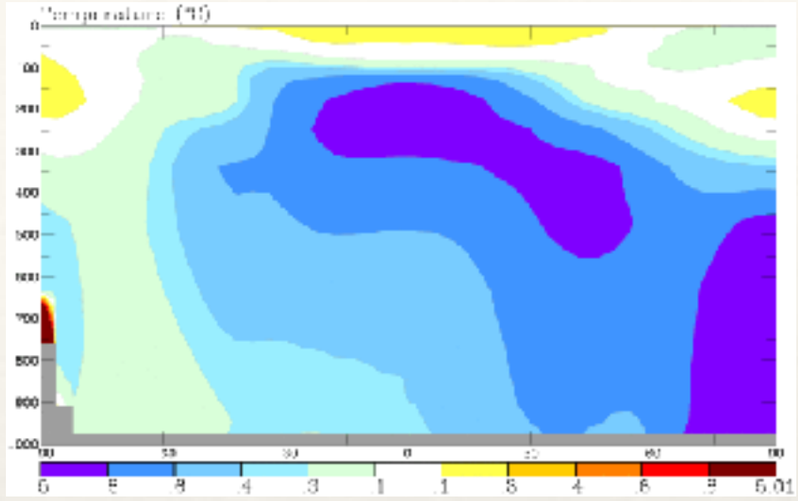
Increased solar irradiance

Indirect Aerosol Effect

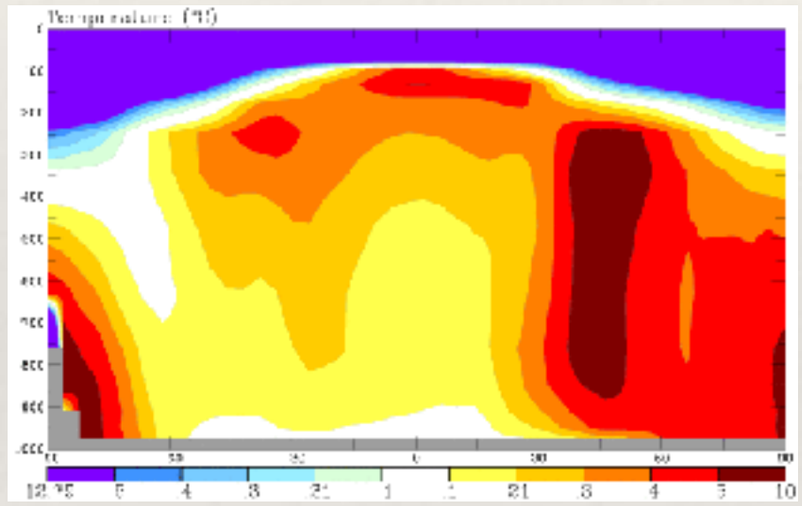
Full Model

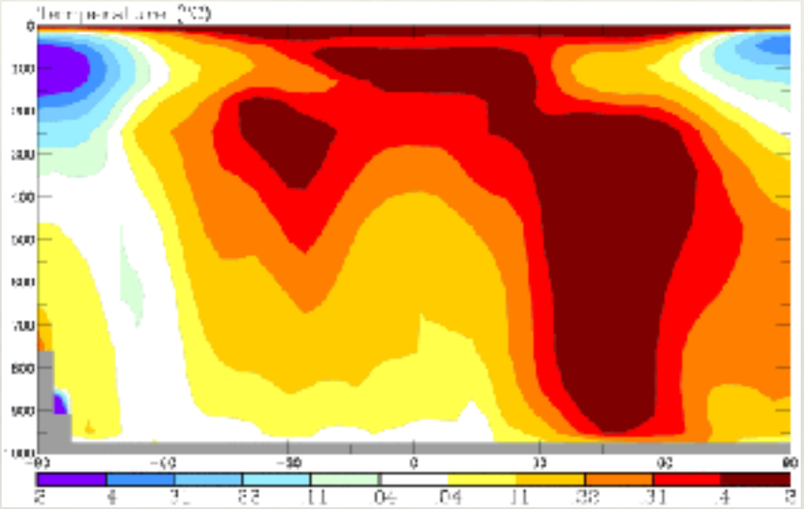


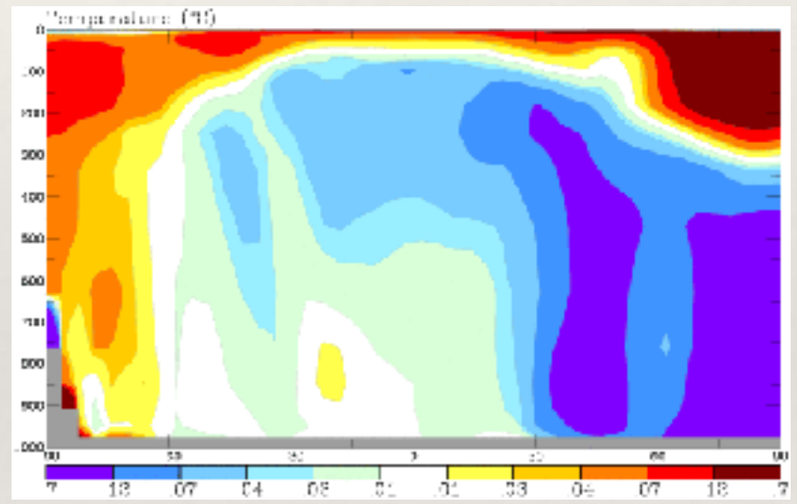




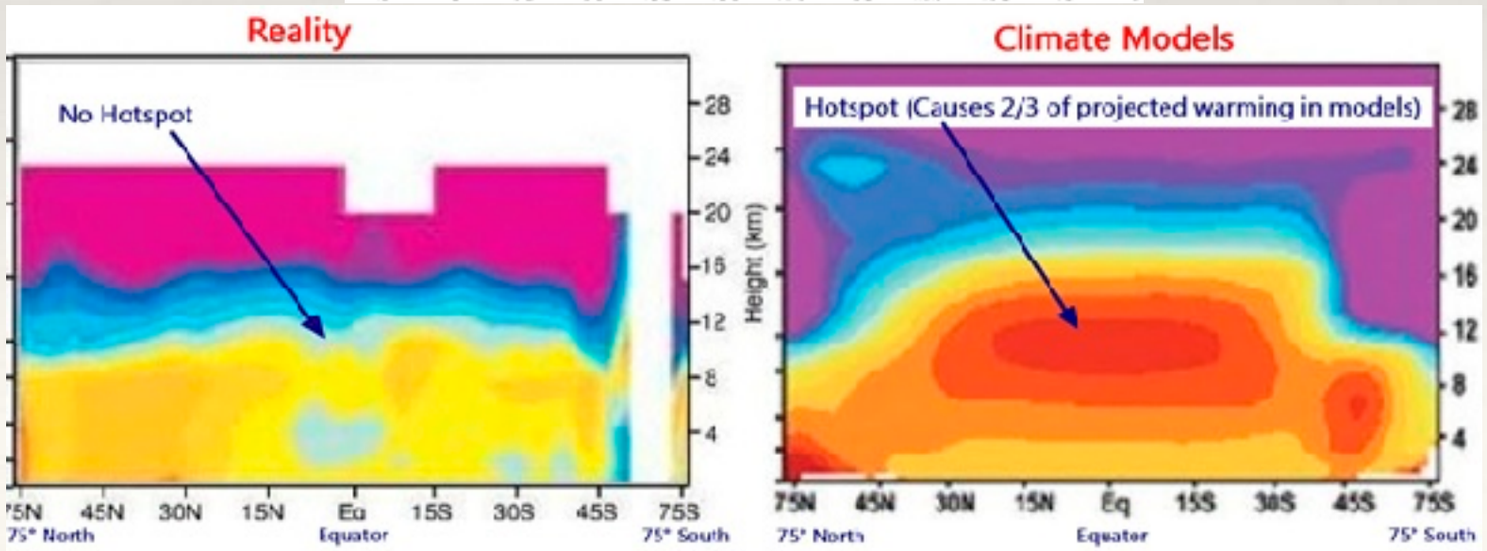
Sea Surface T fixed



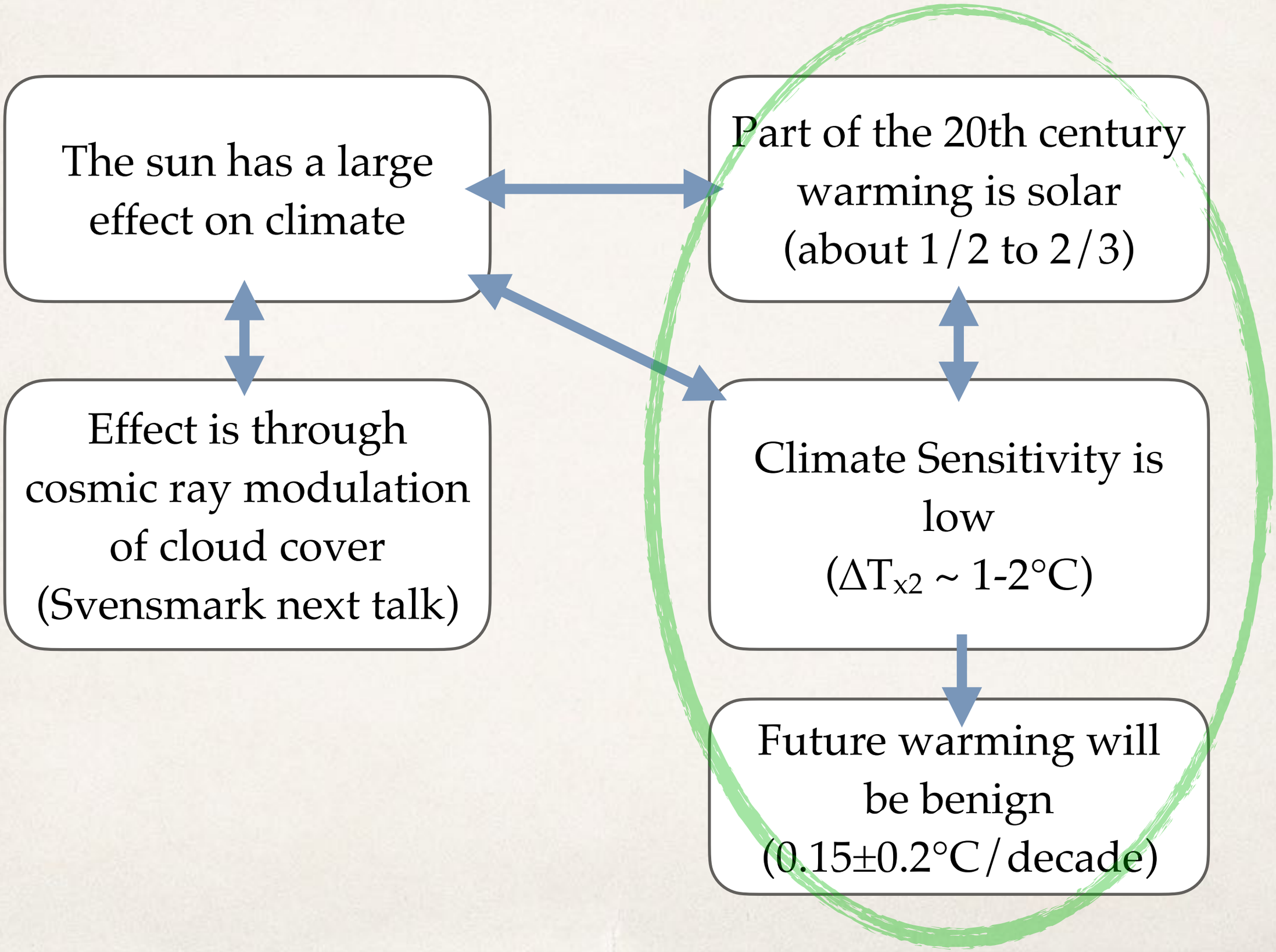




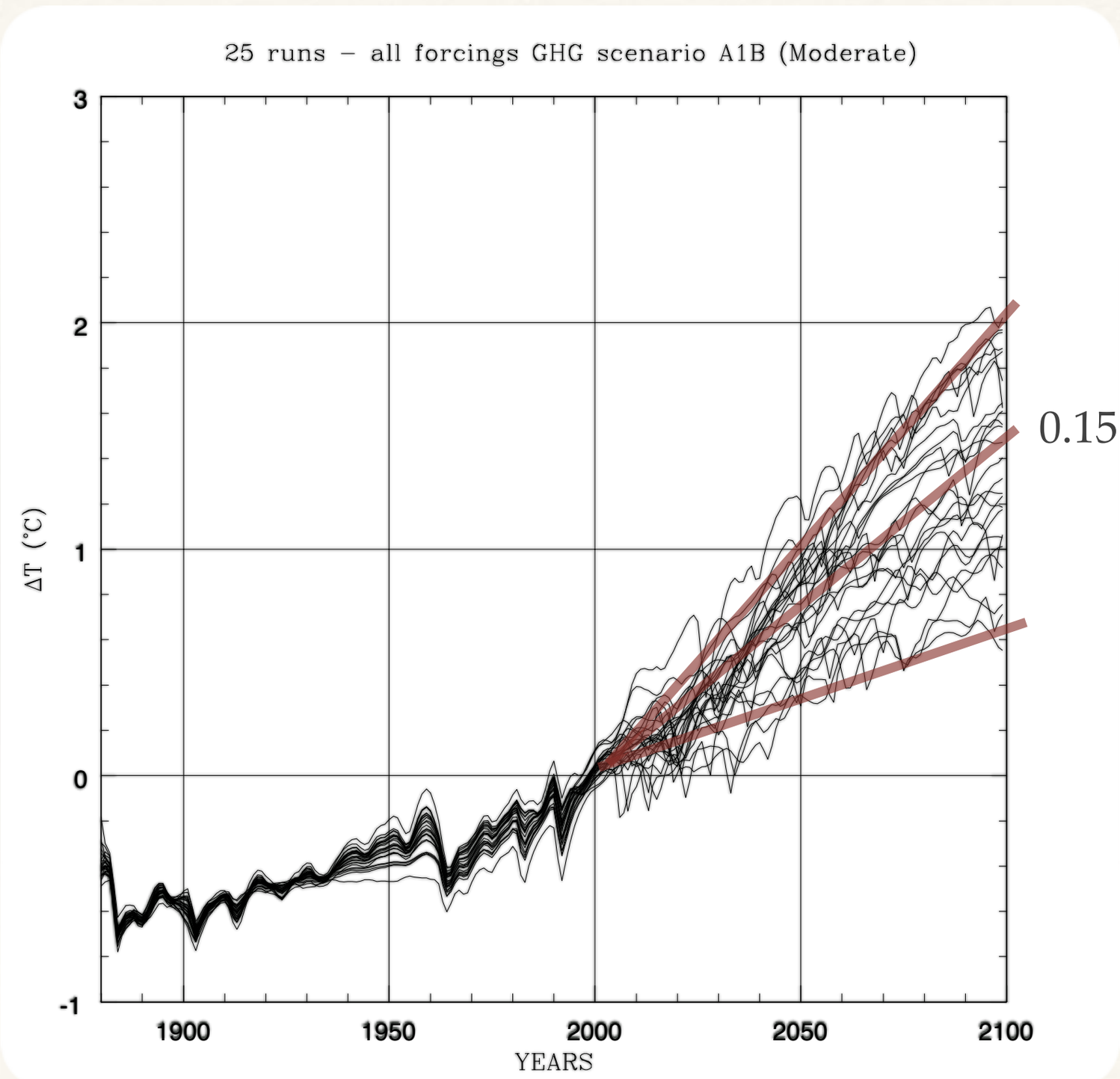
This is evidence that water feedback is much smaller than models predict



Take Away Points

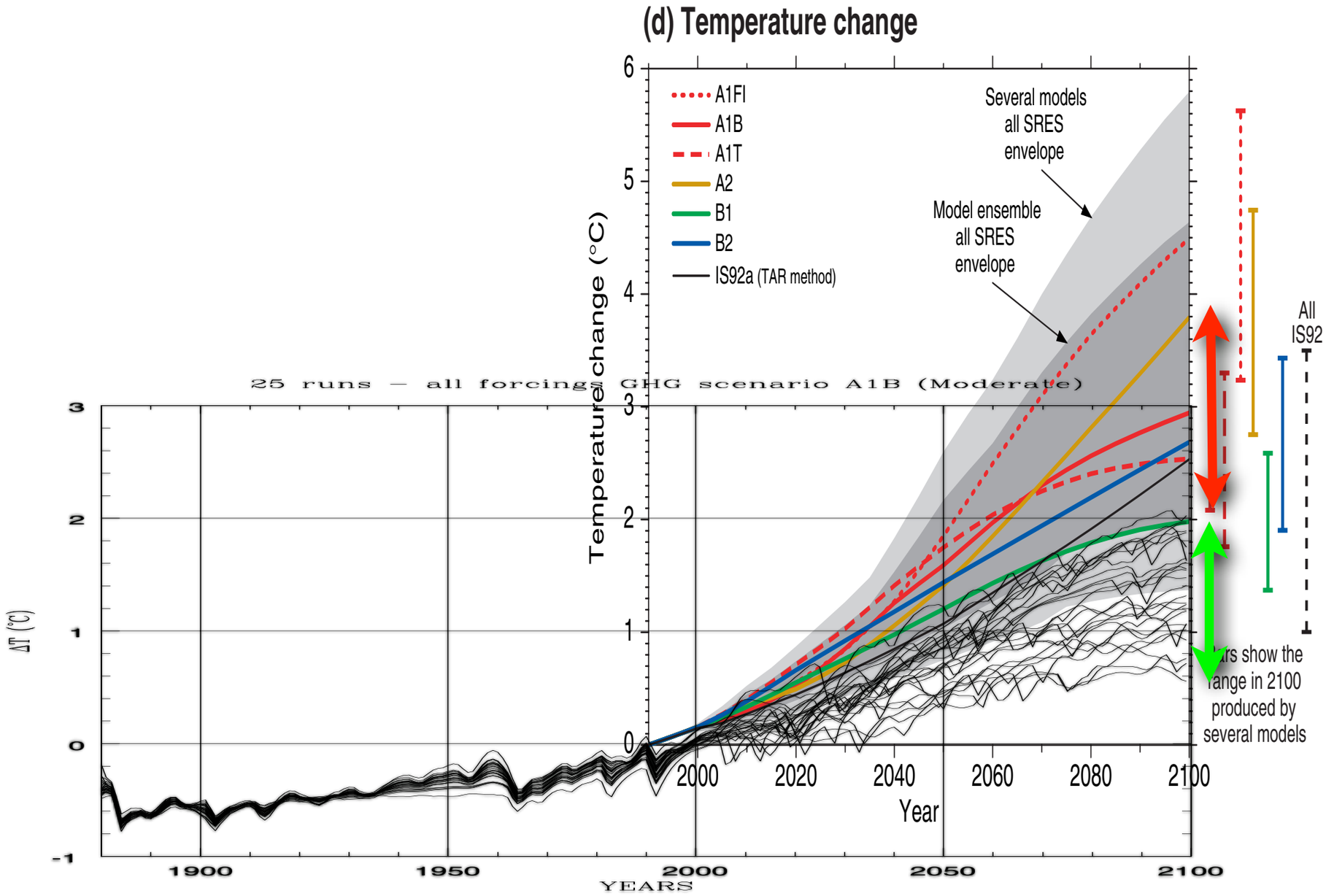


21st century temperature increase

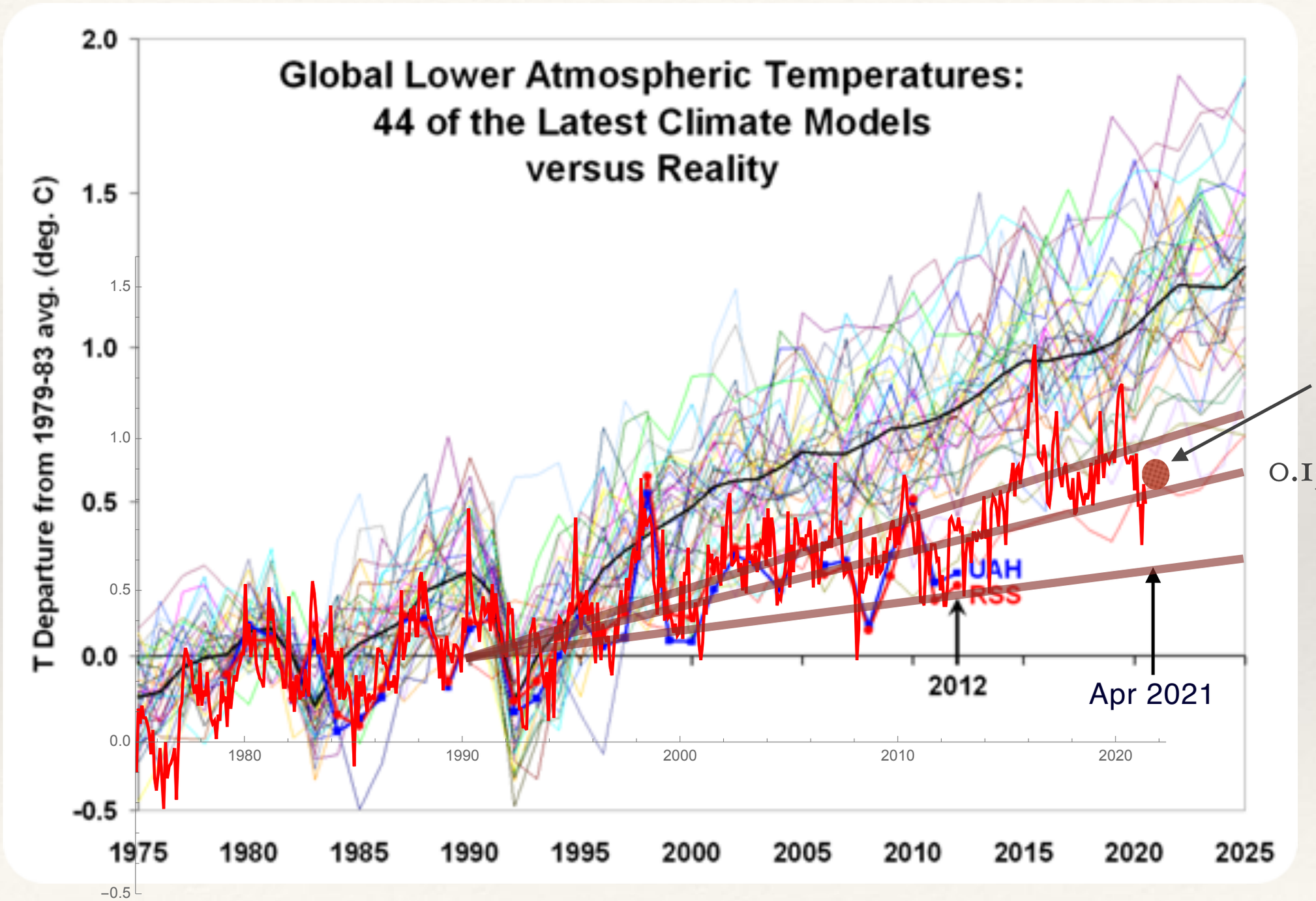


0.15° per decade

21st century temperature increase



Warming smaller than predicted by GCMs



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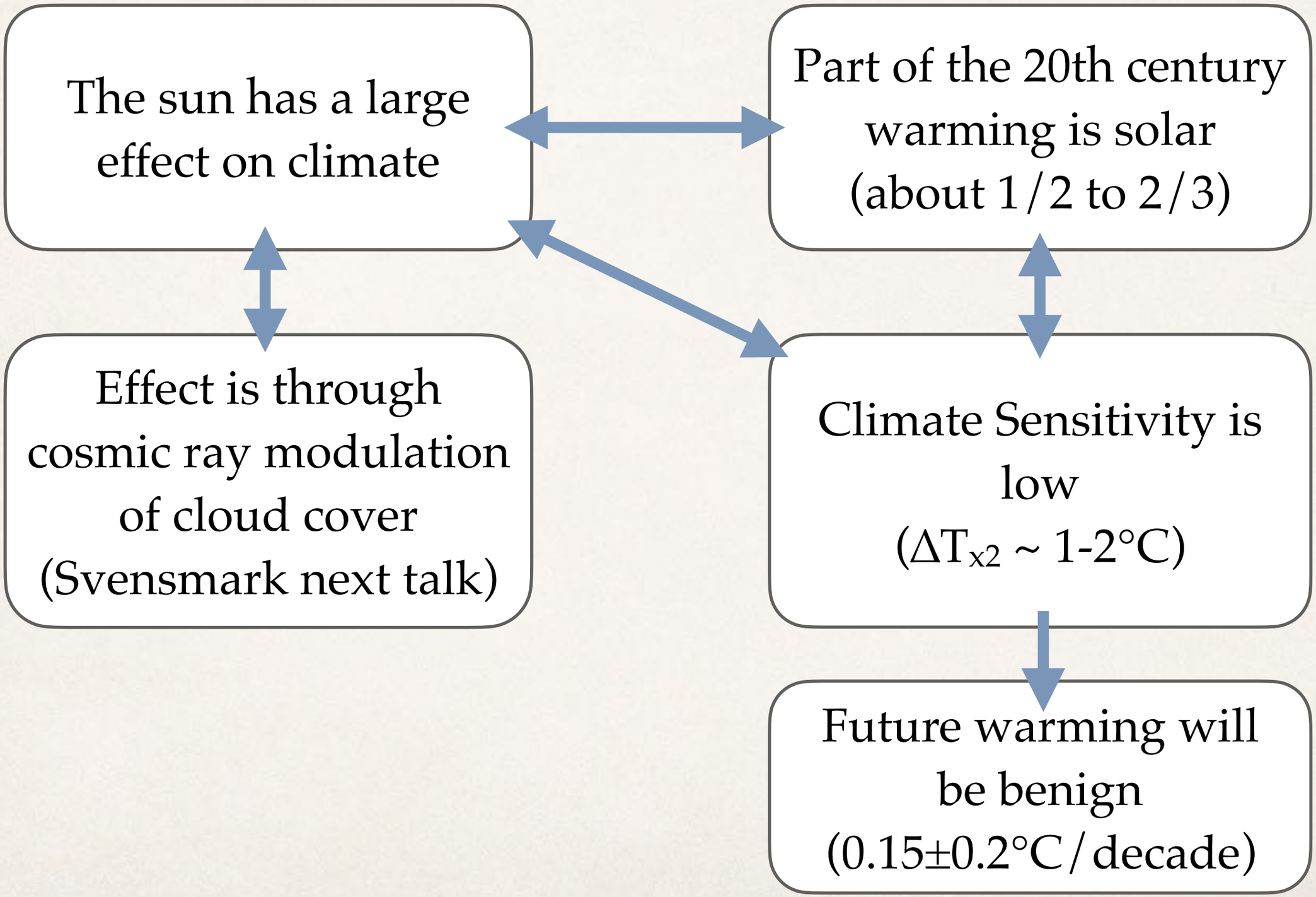

What is the moral?