Global warming - physicist's perspective

01 – an overview of the problem

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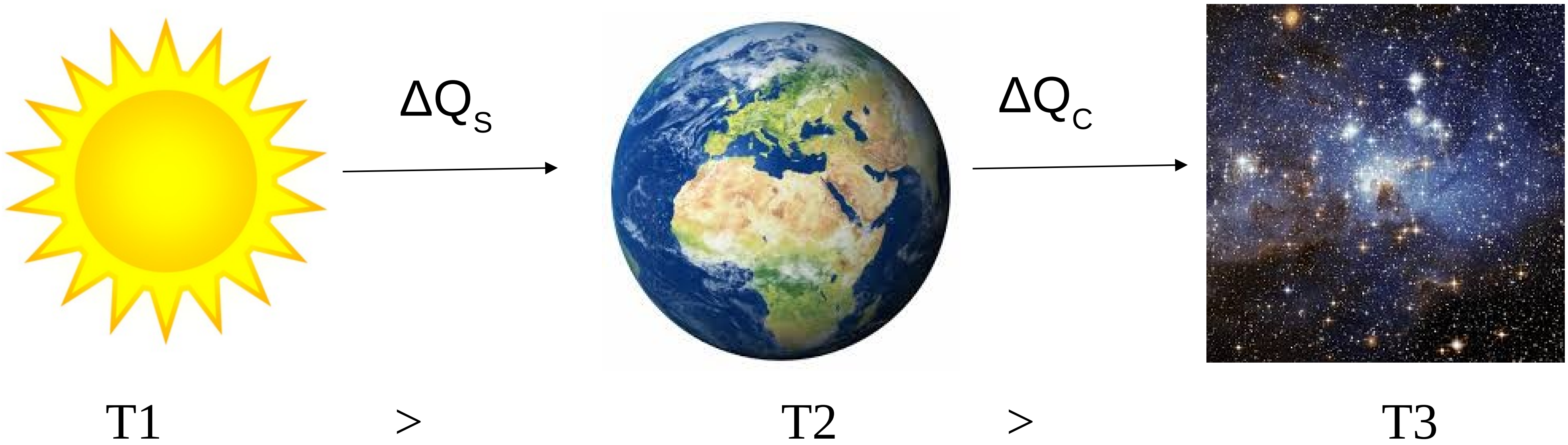


THE EARTH is illuminated by shortwave SOLAR radiation, which is partially absorbed (ΔQ_s) and partially reflected (not shown).

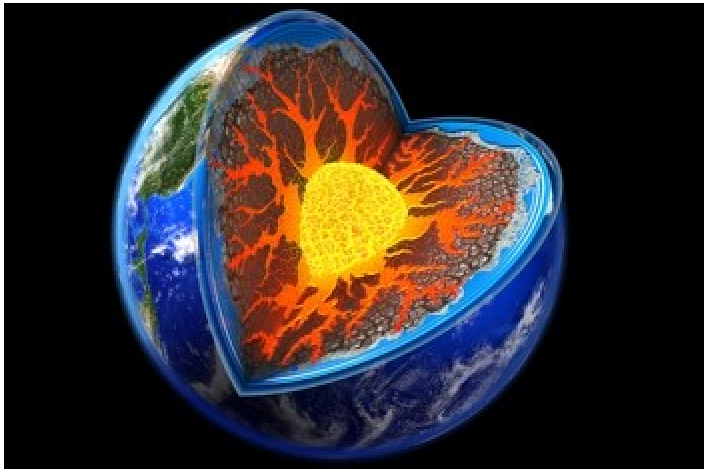
In (quasi) equilibrium energy of absorbed radiation ΔQ_s is balanced by emission of EARTH's radiation ΔQ_c in thermal infrared.

Heating $\Delta Q_s > \Delta Q_c$ → positive imbalance.

Cooling $\Delta Q_s < \Delta Q_c$ → negative imbalance.

Radiative forcing: change of radiation fluxes (from certain reference state)

~340 W/m^2 (160 W/m^2)



~0.1 W/m^2 << 160 W/m^2

~0.04 W/m^2 << 160 W/m^2

ENERGY IN CLIMATE SYSTEM

1. Solar energy flux = ¼ of Solar constant
   $1/4 * 1362 W/m^2 \approx 341 W/m^2$.

2. Earth's surface albedo, mean ≈0.3, highly variable, from 0.9 (fresh snow) to 0.07 (clean ocean).

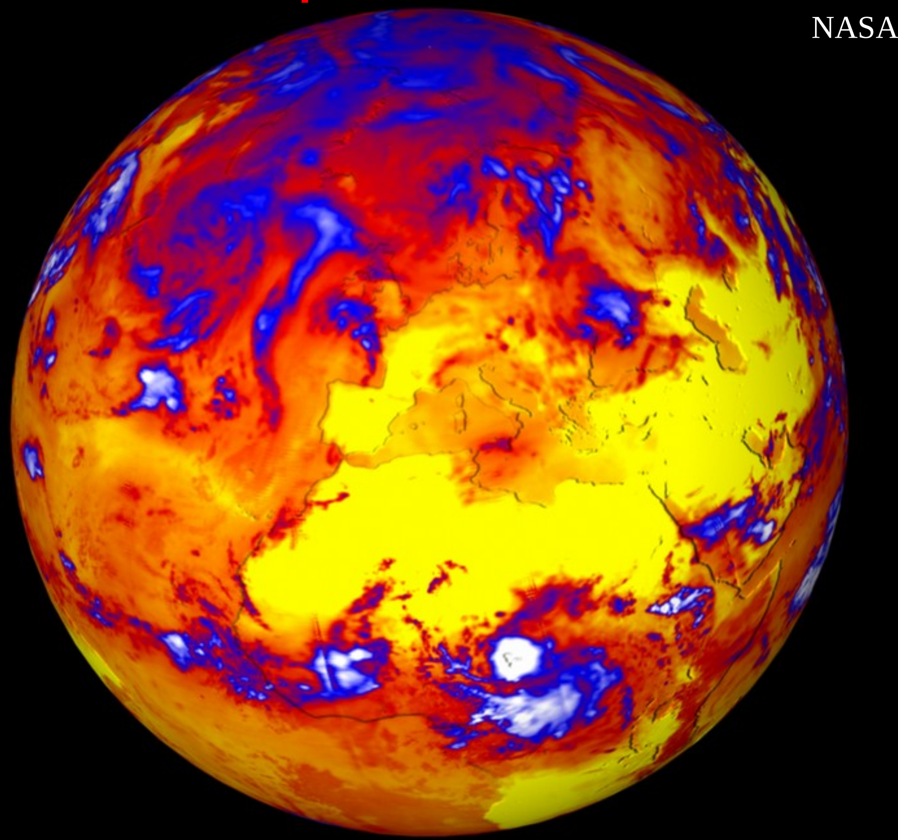
3. Geothermal energy flux $\approx 0.092 W/m^2$.

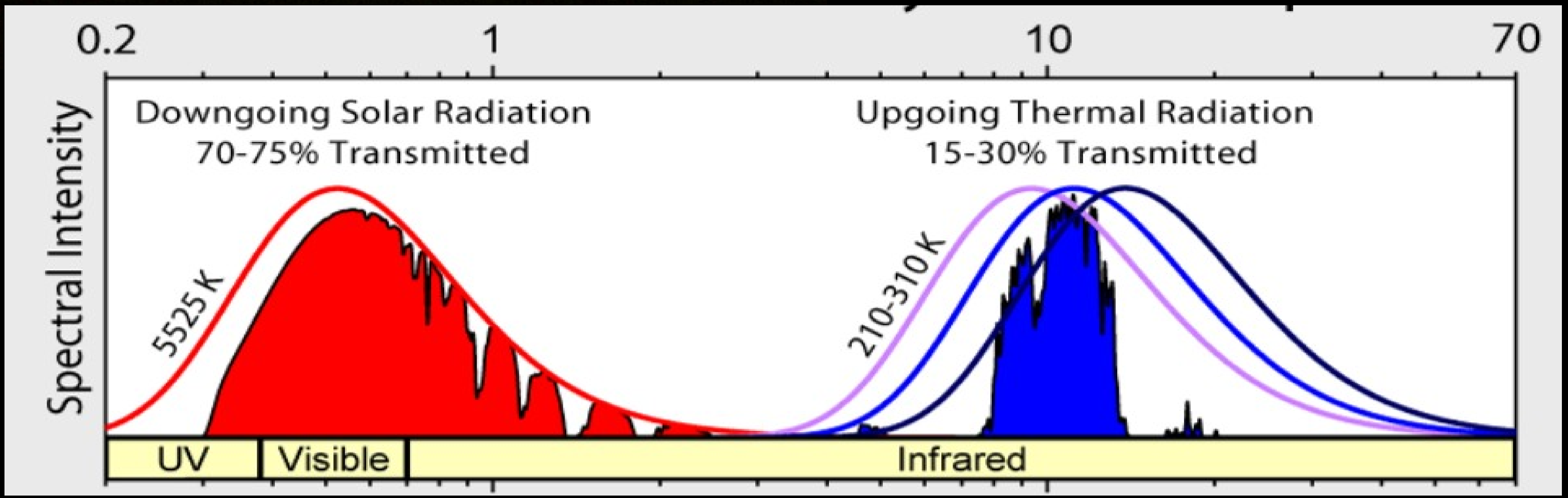
4. Heat flux from fossil fuel combustion $\approx 0.04 W/m^2$.

BASIC PROPERTIES OF THE CLIMATE SYSTEM

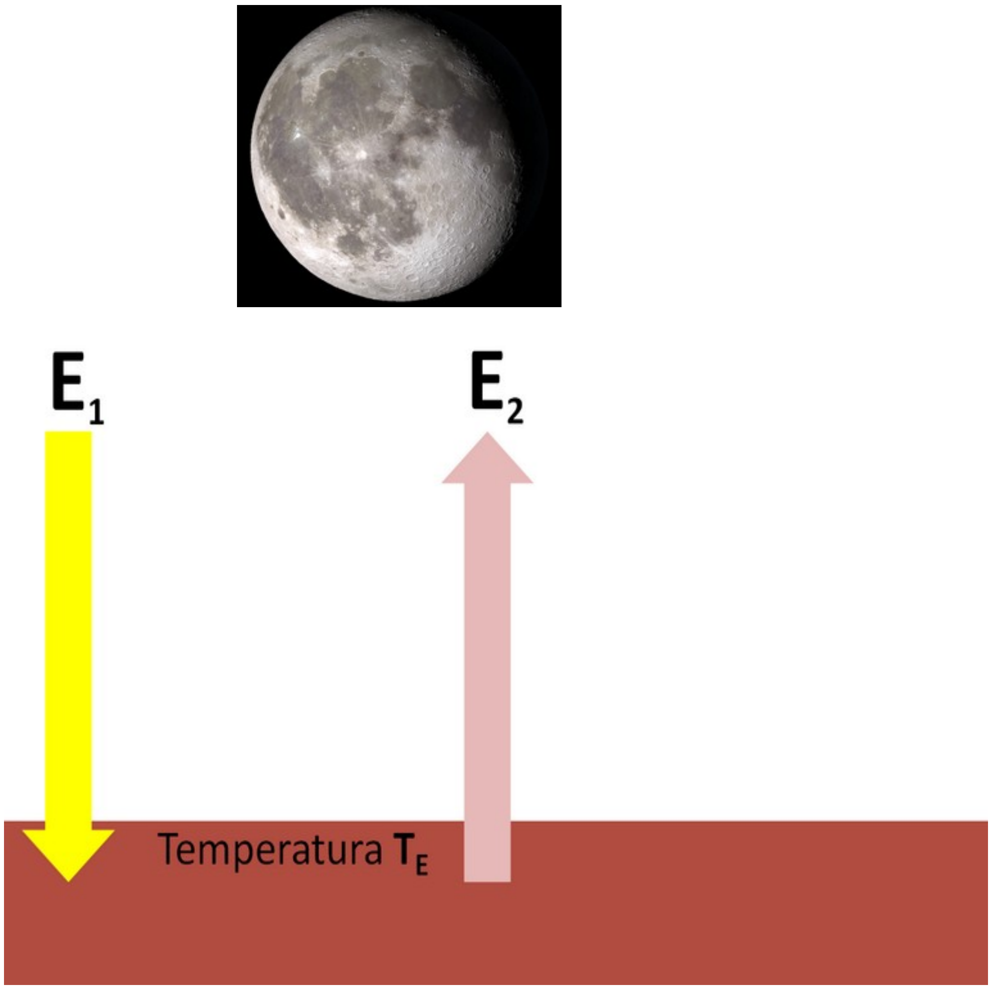
1. Air: surface pressure ≈1000hPa (10m of water), $c_p = 1004 J/kg*K$.
2. Water: global average depth ≈ 3000m, $c_w = 4192 J/kg*K$.
3. Ground – only a shallow layer responding to radiative fluxes.
4. Greenhouse gases: H_2O, CO_2, CH_4, O_3, many others.

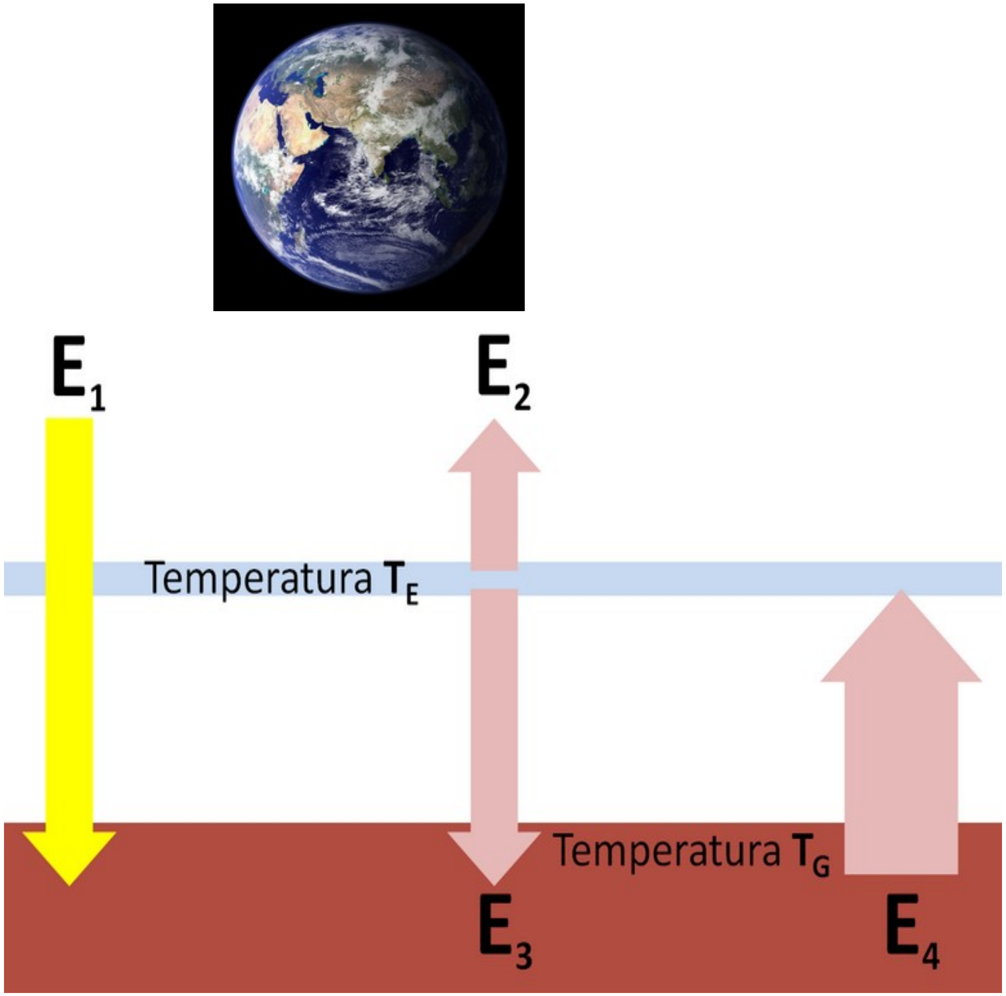
Transmission through the atmosphere





Greenhouse effect: a principle

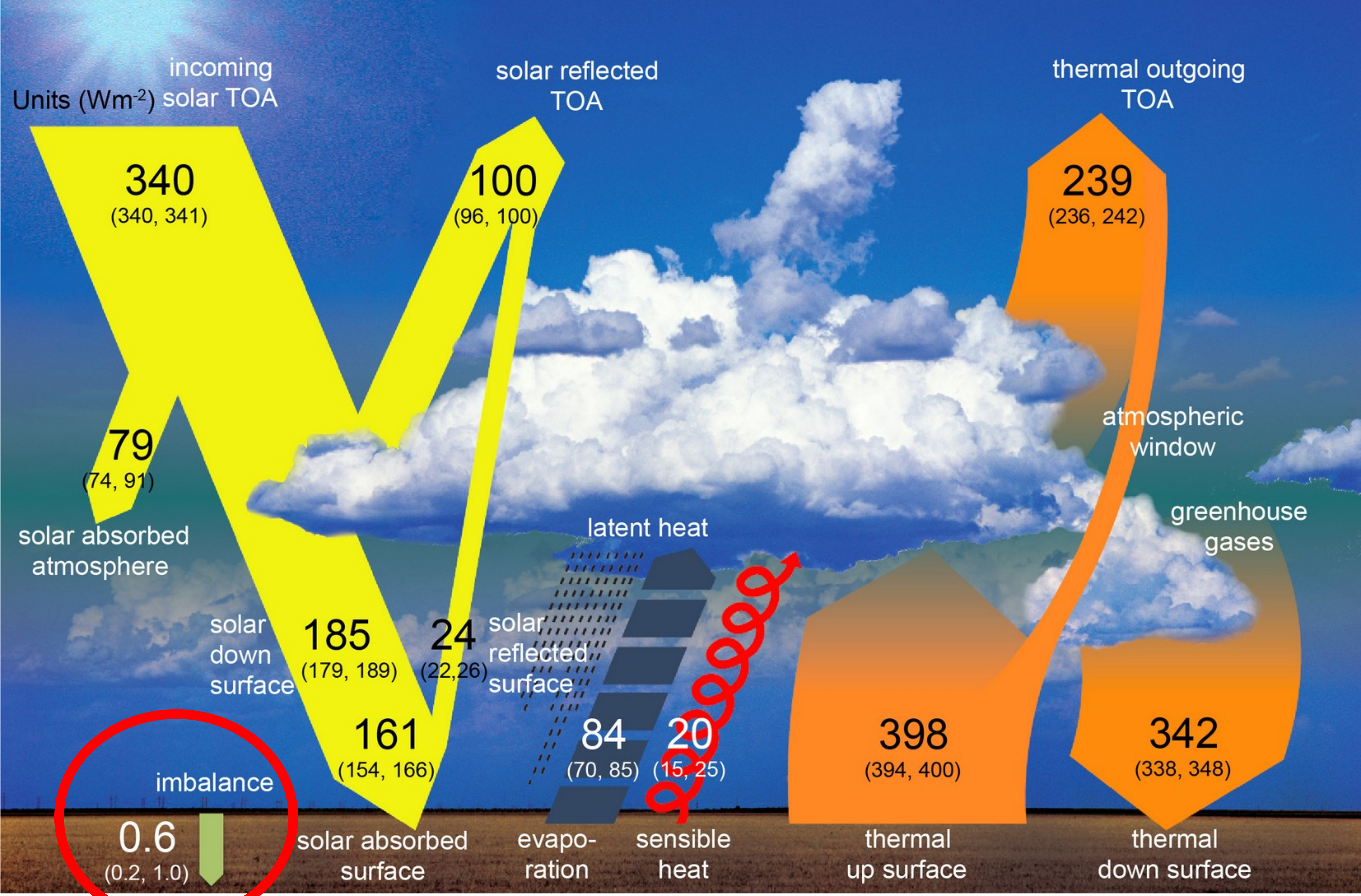




$E_1 = E_2$

$E_1 = E_2 = E_3$

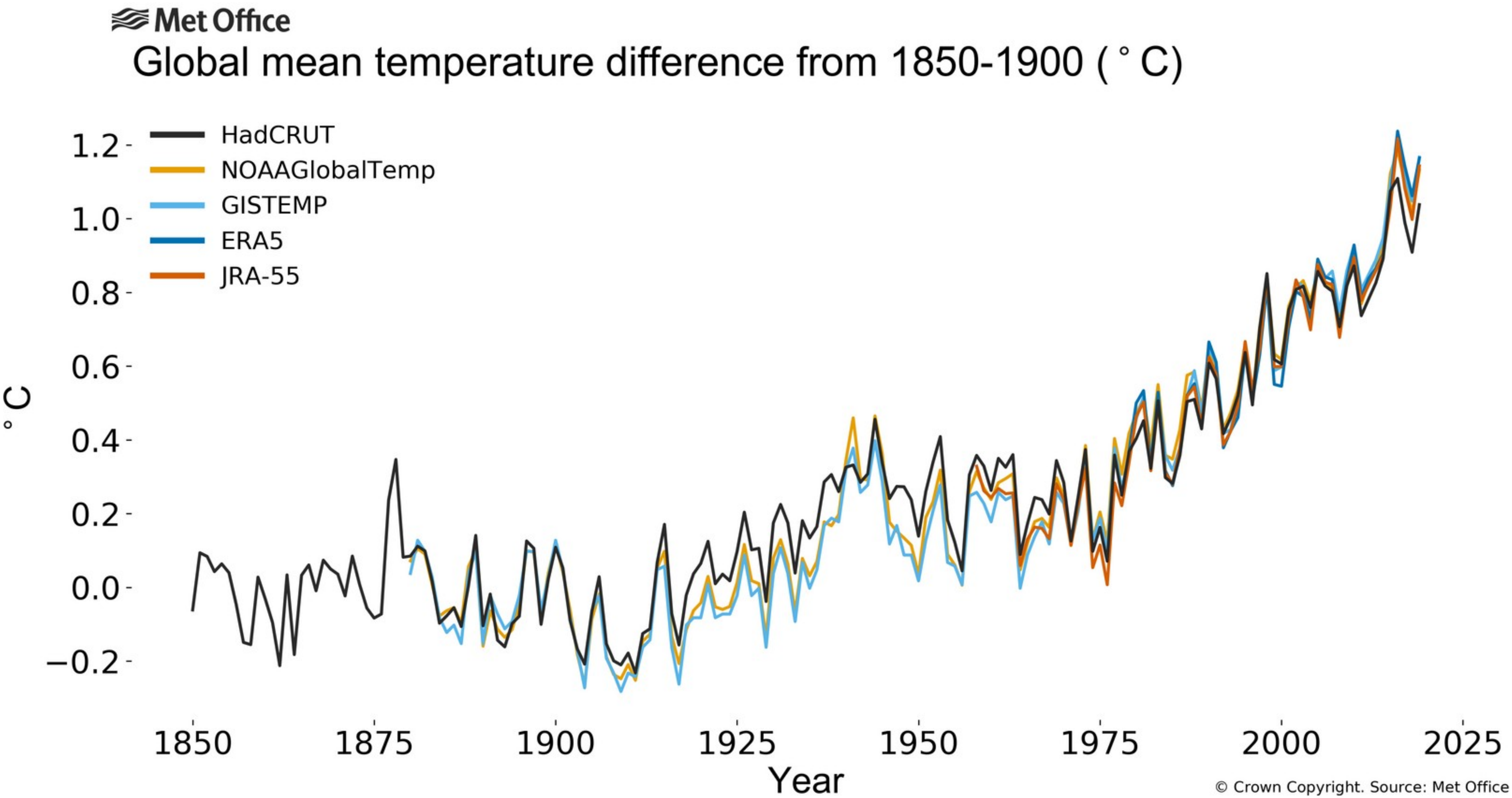
$E_4 = E_1 + E_3$

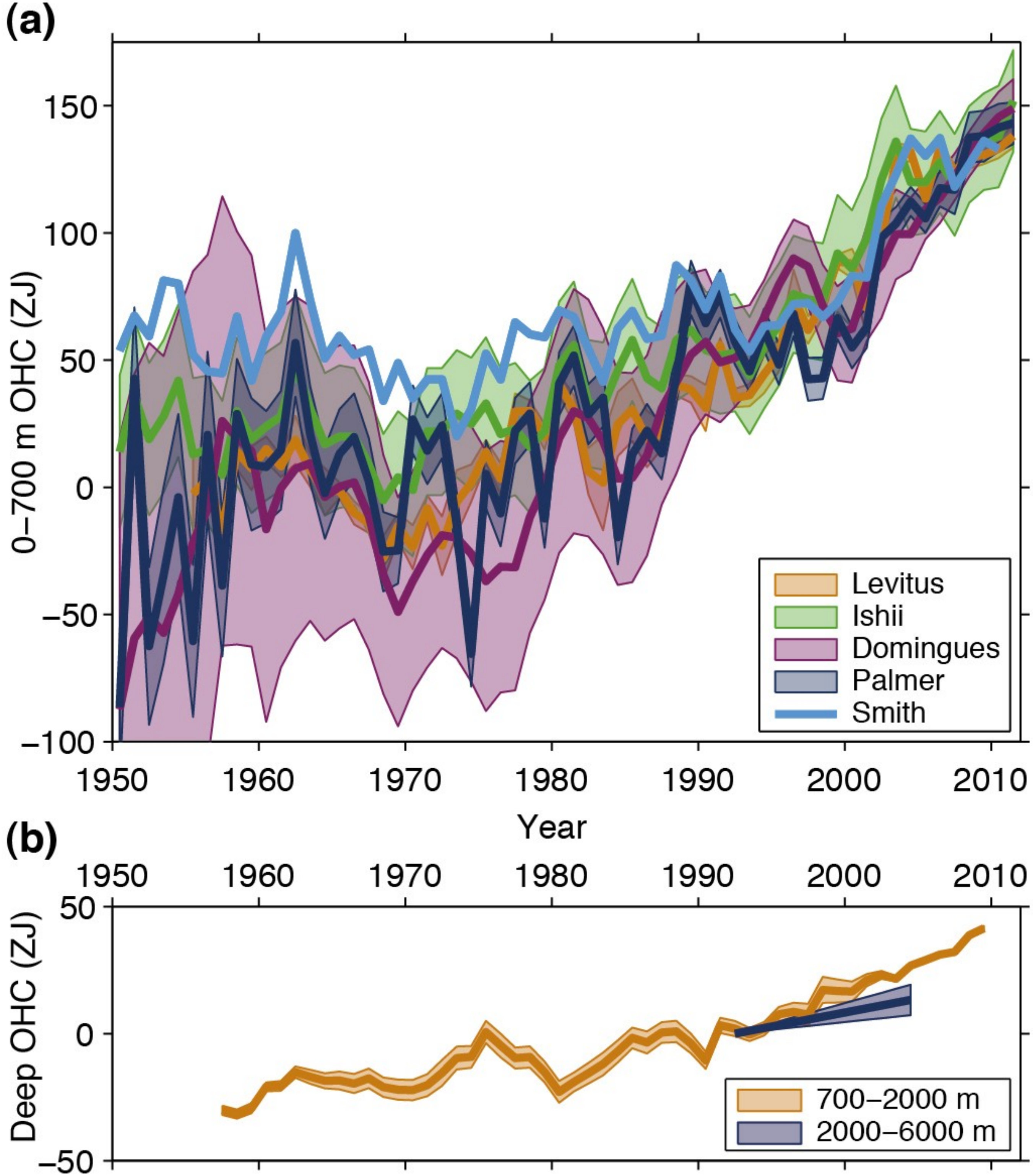


Energy balance of climate system. Units: W/m^2.

http://www.climatechange2013.org/report/

Positive energy balance – temperature of the air at the surface increases.





Ocean heat content

(a) Observation-based estimates of annual global mean upper (0 to 700m) ocean heat content in ZJ (1 ZJ = 1021 Joules). Uncertainties are shaded and plotted as published (at the one standard error level, except one standard deviation for Levitus, with no uncertainties provided for Smith). Estimates are shifted to align for 2006–2010, 5 years that are well measured by Argo, and then plotted relative to the resulting mean of all curves for 1971, the starting year for trend calculations.

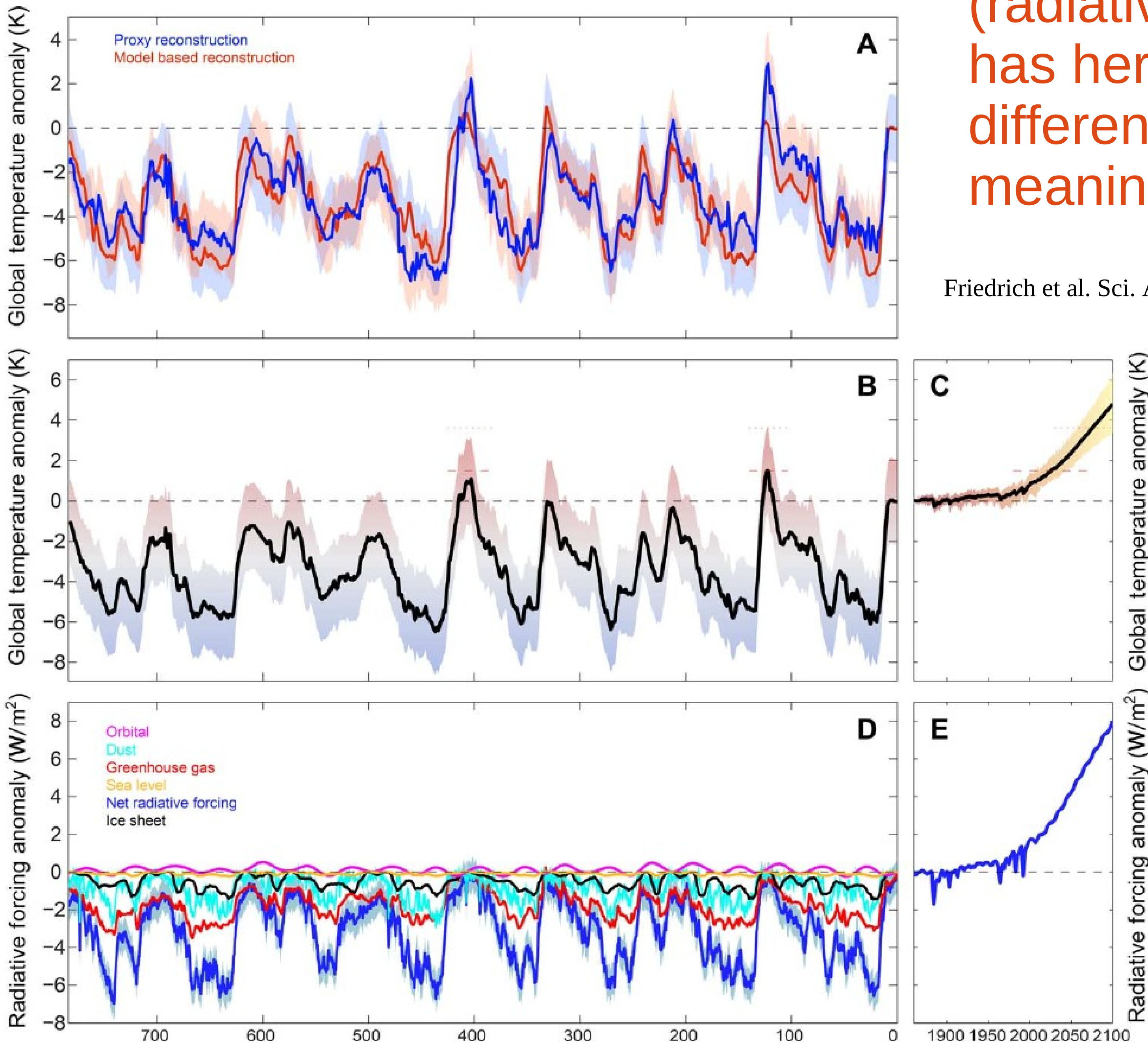
(b) Observation-based estimates of annual 5-year running mean global mean mid-depth (700 to 2000 m) ocean heat con-tent in ZJ, one standard error uncertainties shaded (see legend).

http://www.climatechange2013.org/report/

Orbital forcing and system **feedbacks in the course of ice ages** lead to remarkable radiative effects

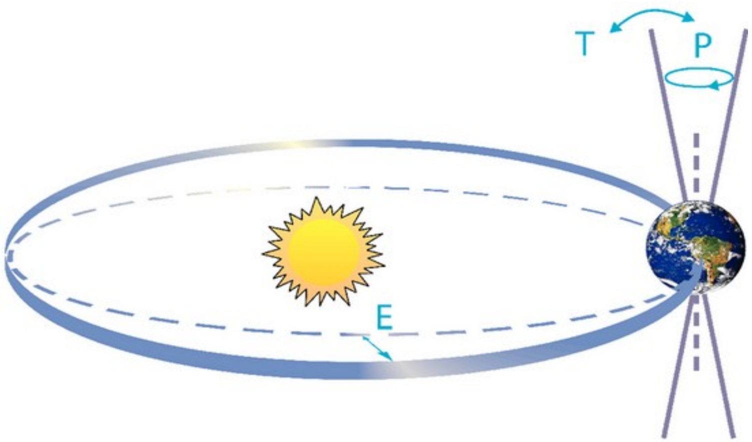
(radiative forcing has here a different meaning)

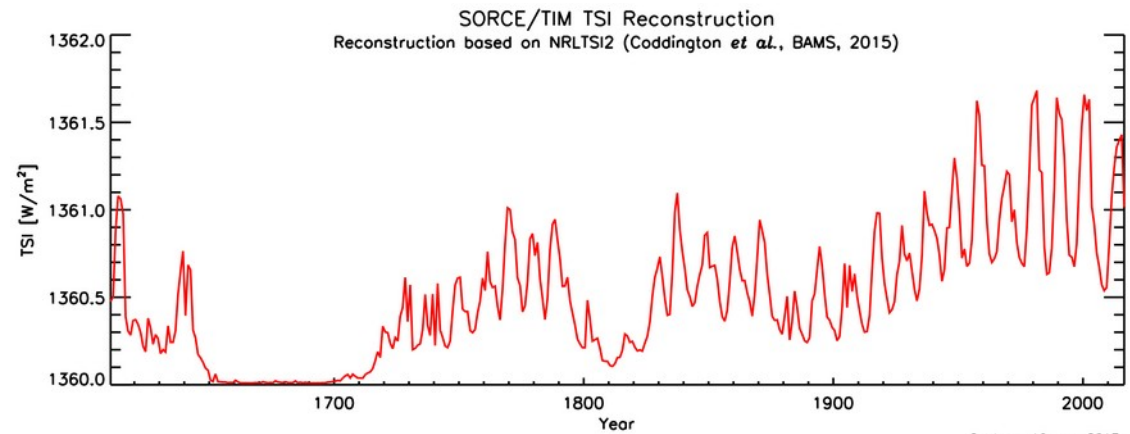
Friedrich et al. Sci. Adv. 2016; 2 : e1501923

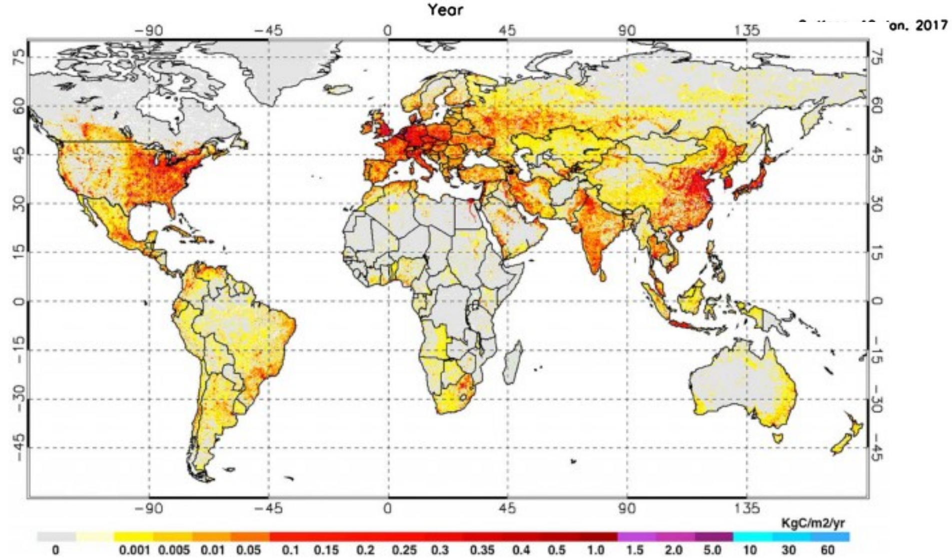


Forcings and **feedbacks** in climate system.

Climate **forcings** are the **initial drivers** of a climate shift.







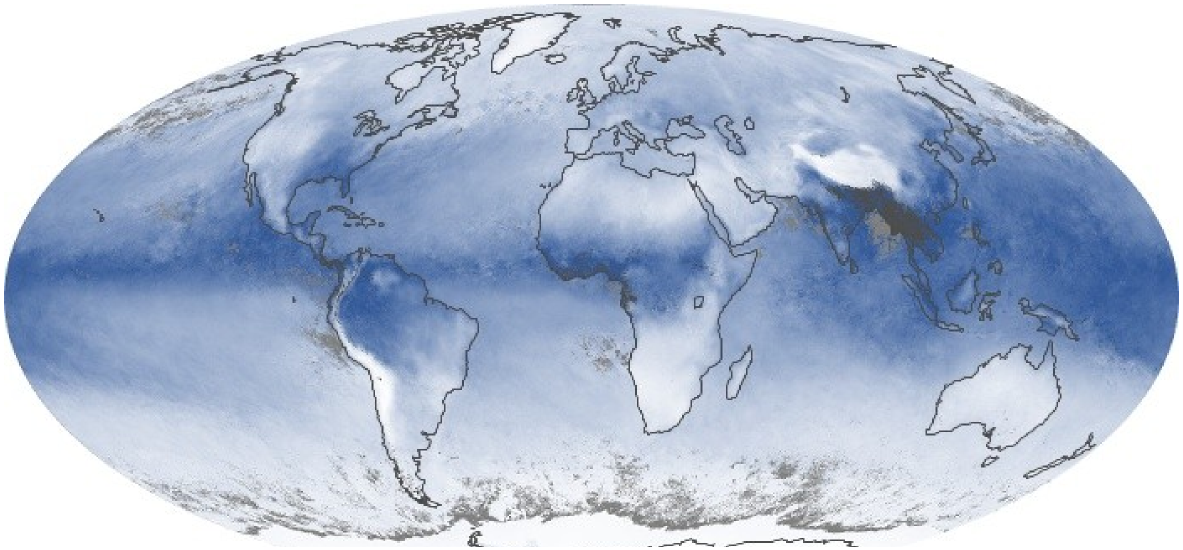
Examples: solar irradiance, changes in the planetary orbit, anthropogenic or volcanic emissions of greenhouse gases.

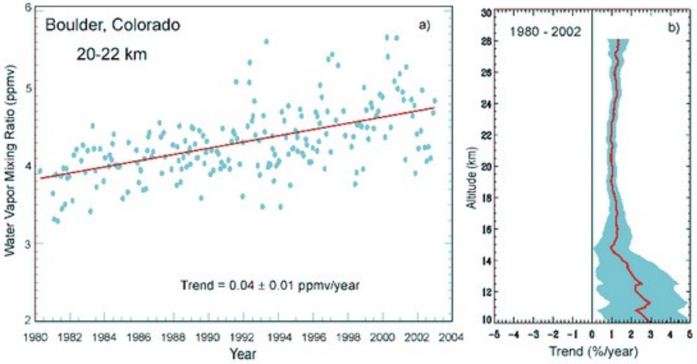
Forcings and **feedbacks** in climate system.

Climate **feedbacks** are processes that **change as a result of a change in forcing**, and **cause additional climate change**.

1979 SSMI Composite Data

2003 SSMI Composite Data

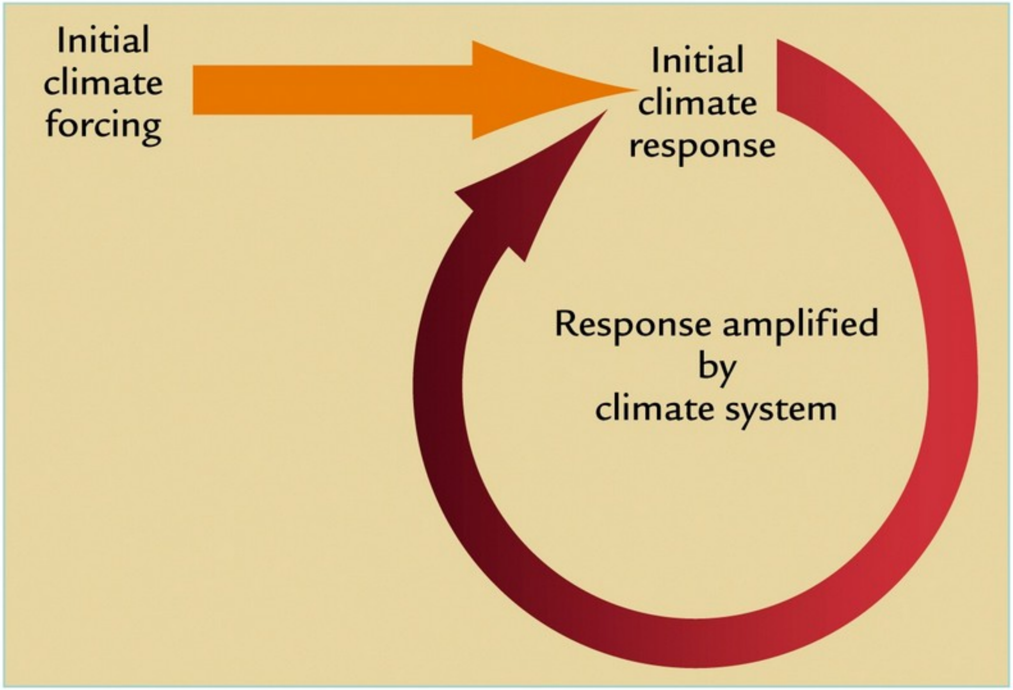




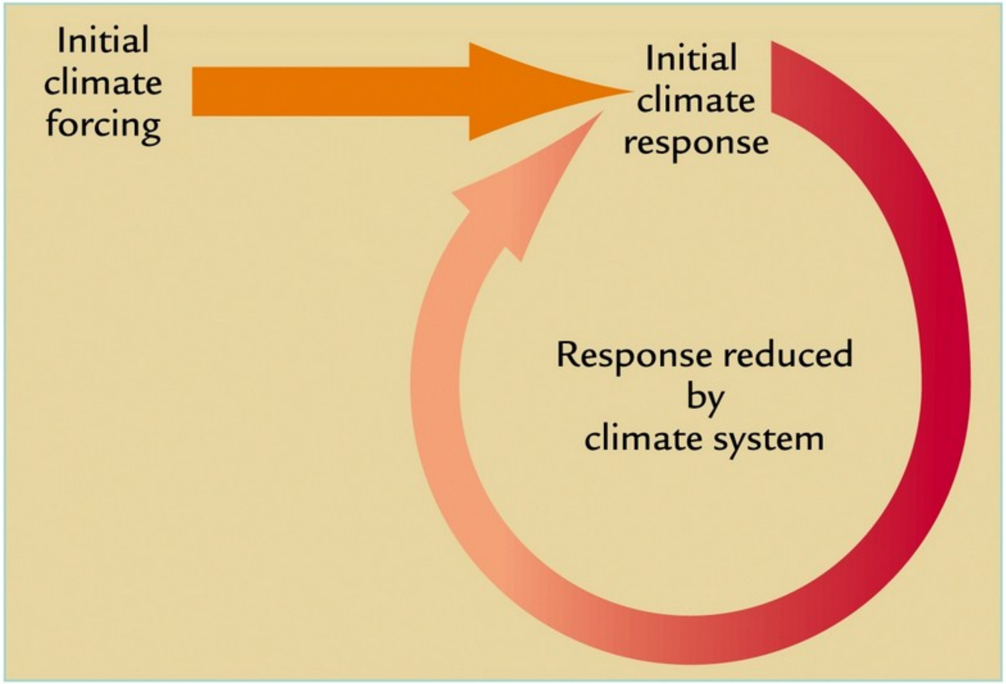
Examples : ice-albedo feedback, water vapor feedback.

Feedbacks can be positive or negative.

Positive feedbacks, when exceeding thresholds, may lead to rapid climate changes.

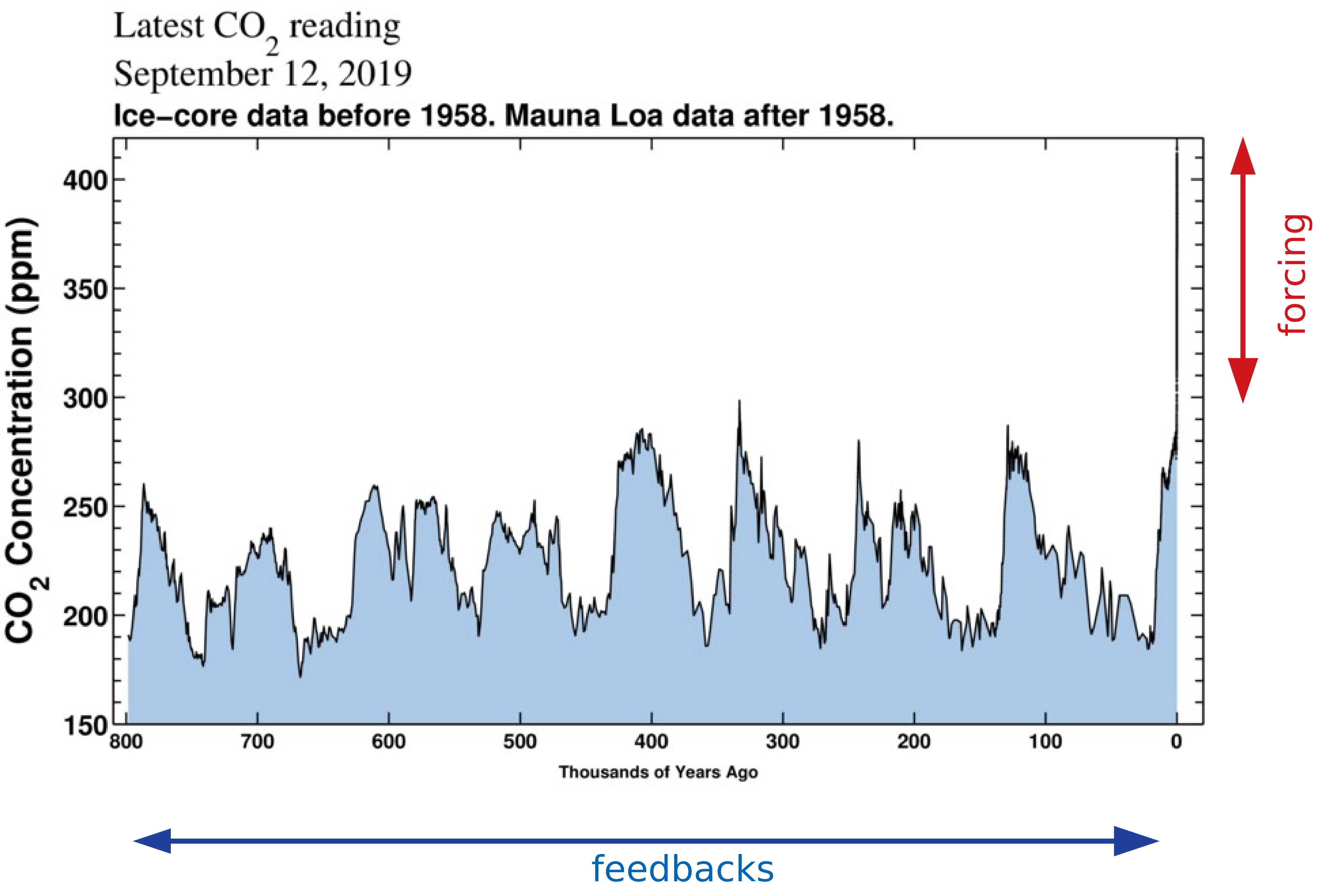


A Positive feedback

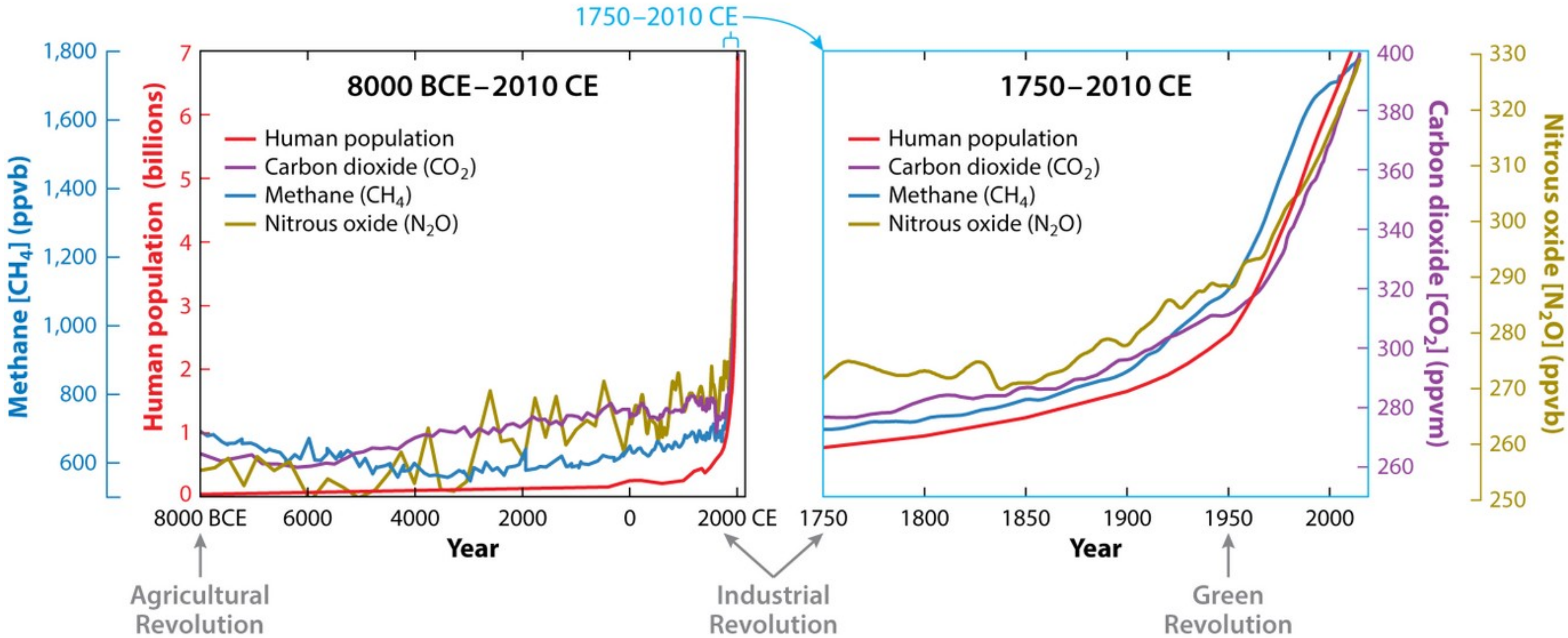


B Negative feedback

CO2: feedback and forcing.



Evolution of human population and greenhouse gases over the past 10,000 years

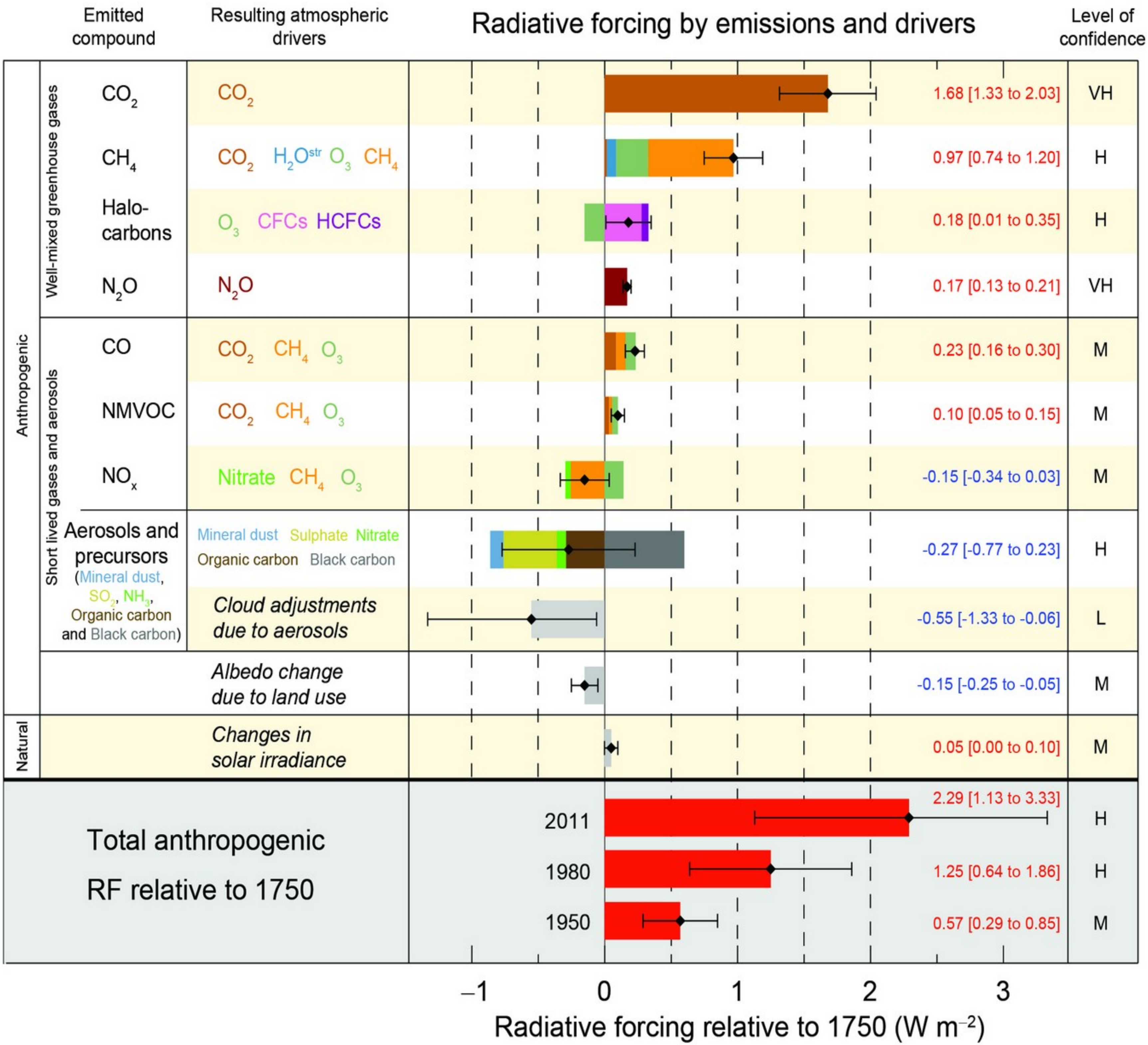


The abrupt and simultaneous upward trajectories of human population and greenhouse gases after the start of the Industrial Revolution (~1750), and the distinct acceleration after the start of the Green Revolution (~1950), show that the Human System has become the primary driver of these gases and the changes in the Earth System. Adapted from Fu & Li (2016), CC-BY, https://doi.org/10.1093/nsr/nww094.

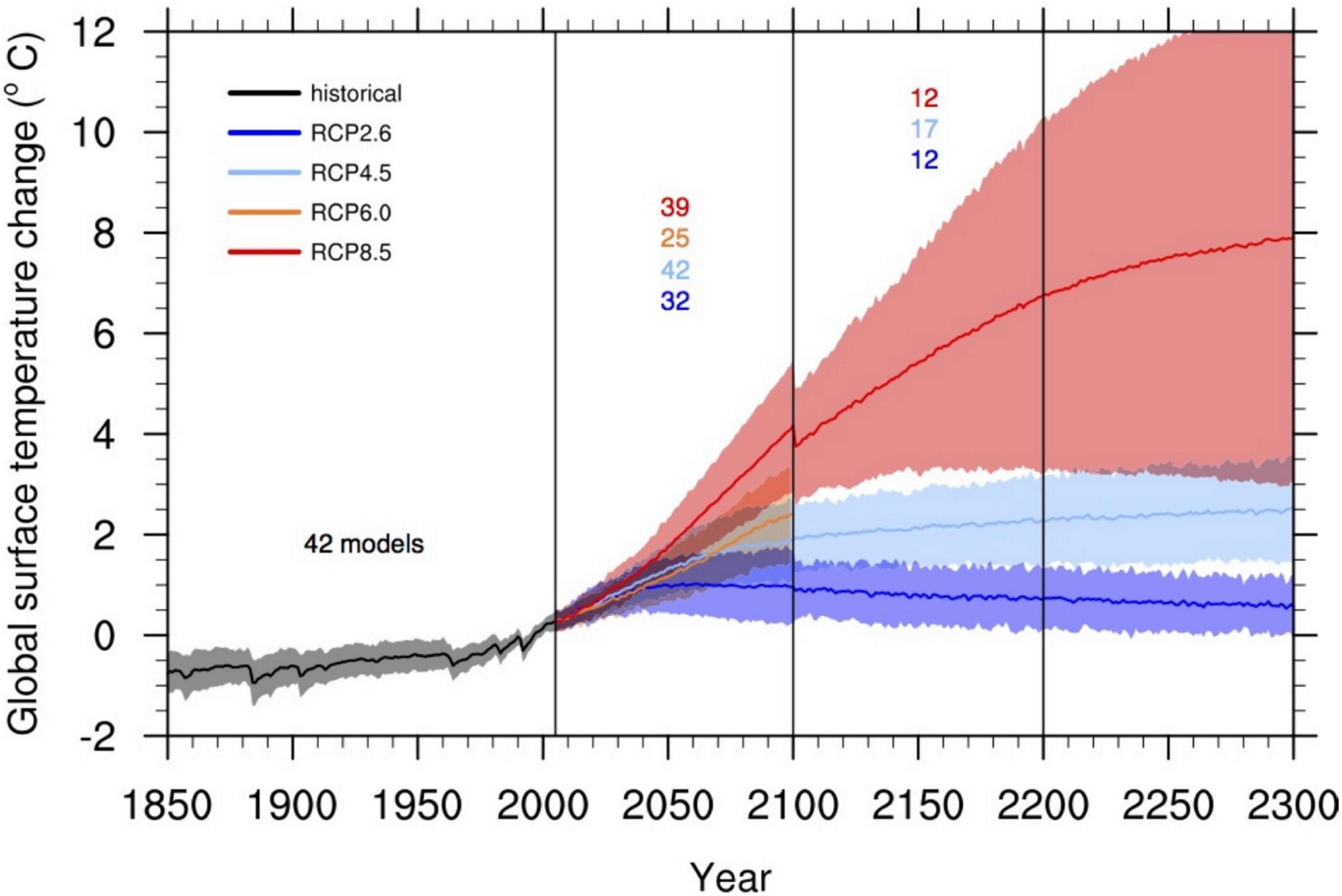
Mote S, et al. 2020.
Annu. Rev. Earth Planet. Sci. 48:657–83

“Radiative forcing” i.e. changes in radiative fluxes since 1750:

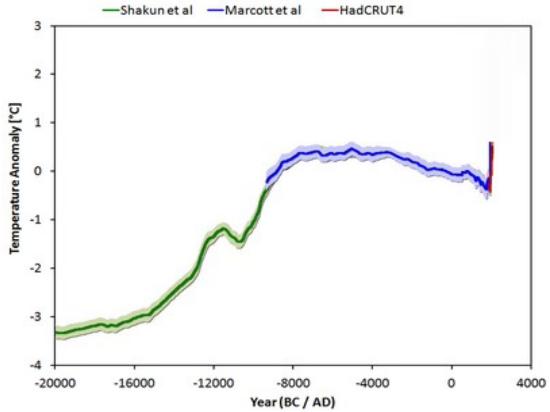
GHG
– positive,
aerosols
– negative
others
– minor.

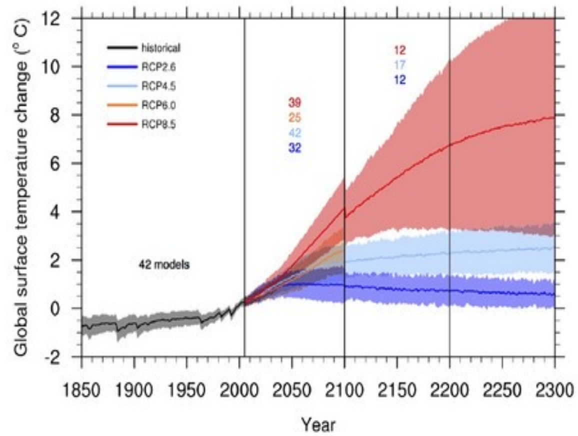


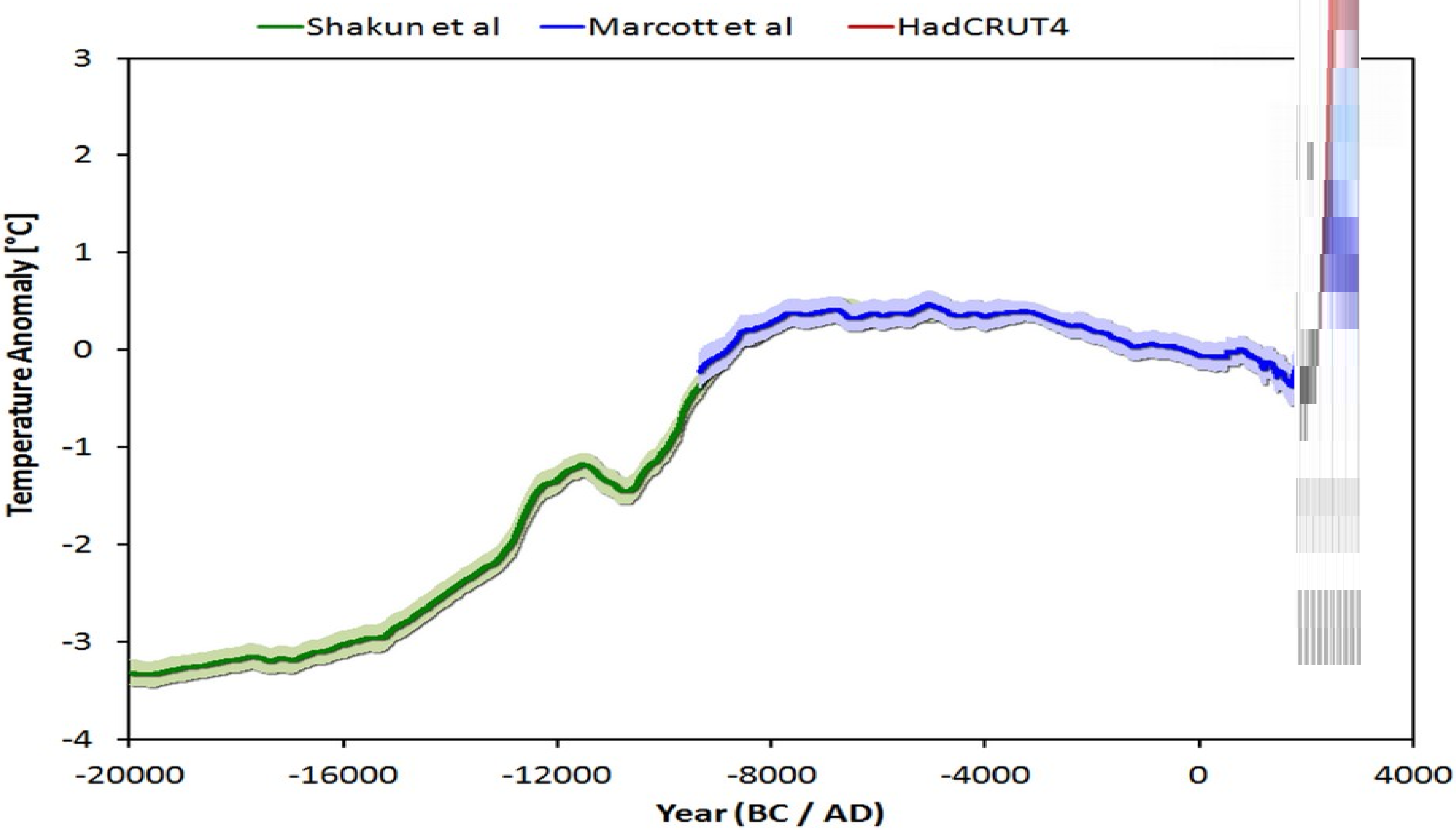
Global temperature anomalies up to 2300 for various emission scenarios (IPCC)



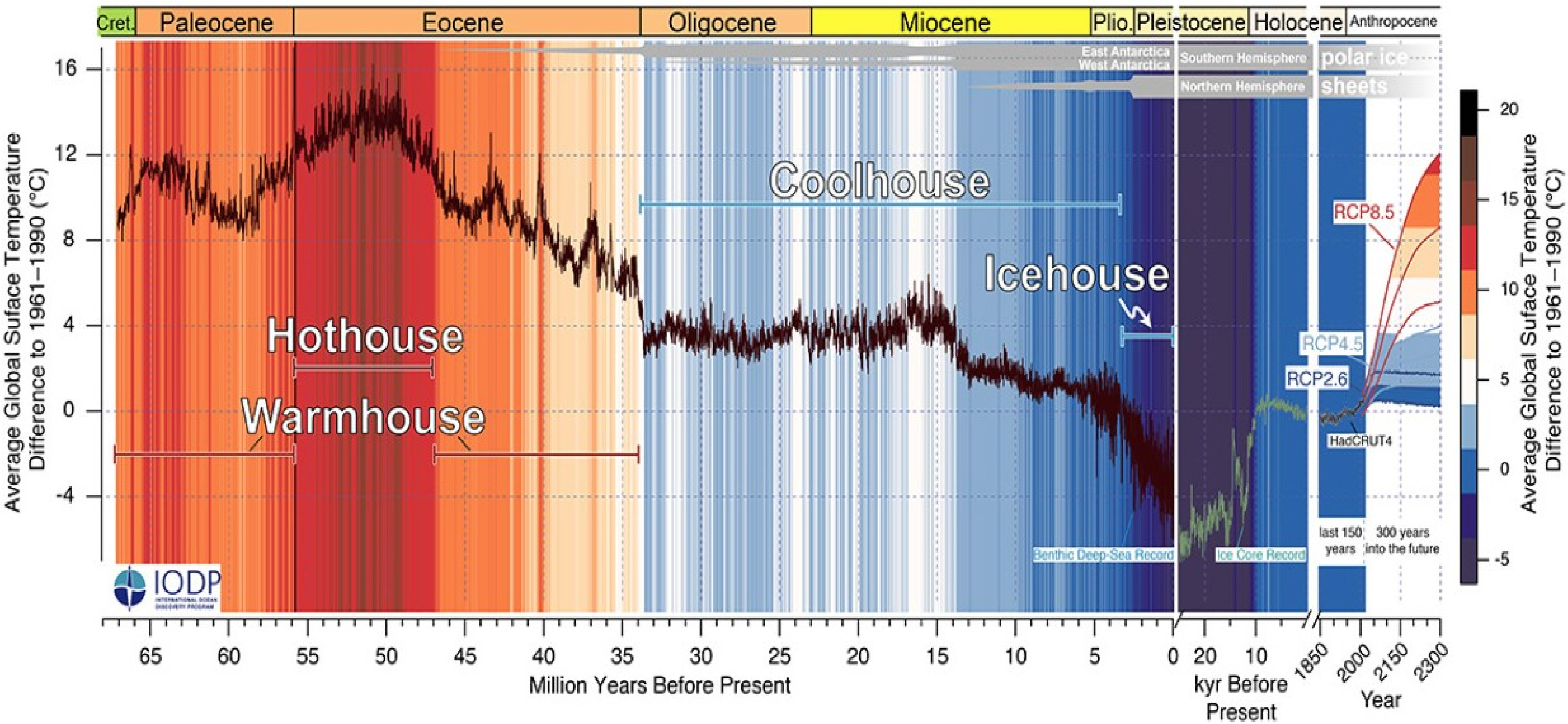
Holocene and Anthropocene



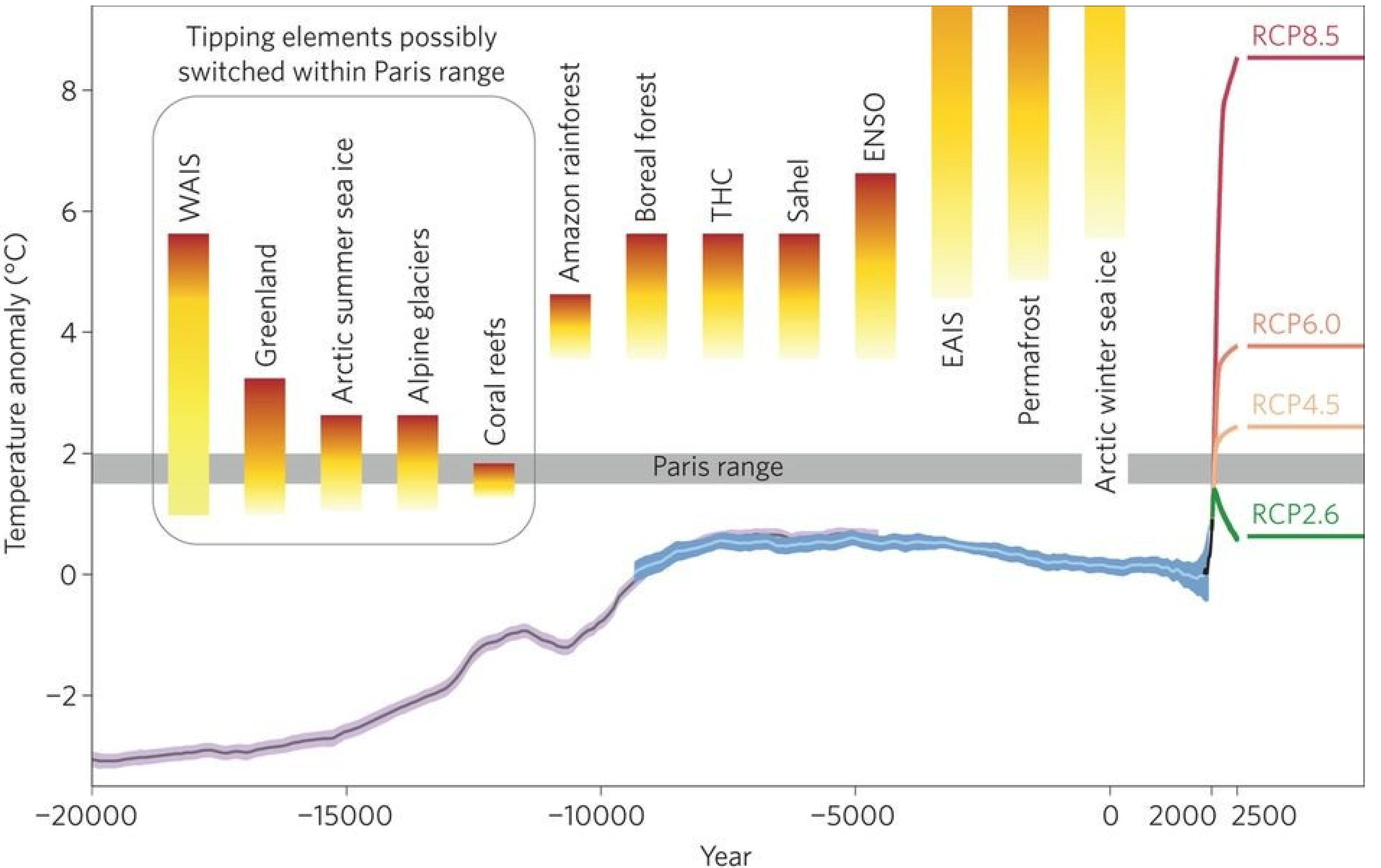




Very past and and near future climate



Near past and and near future climate

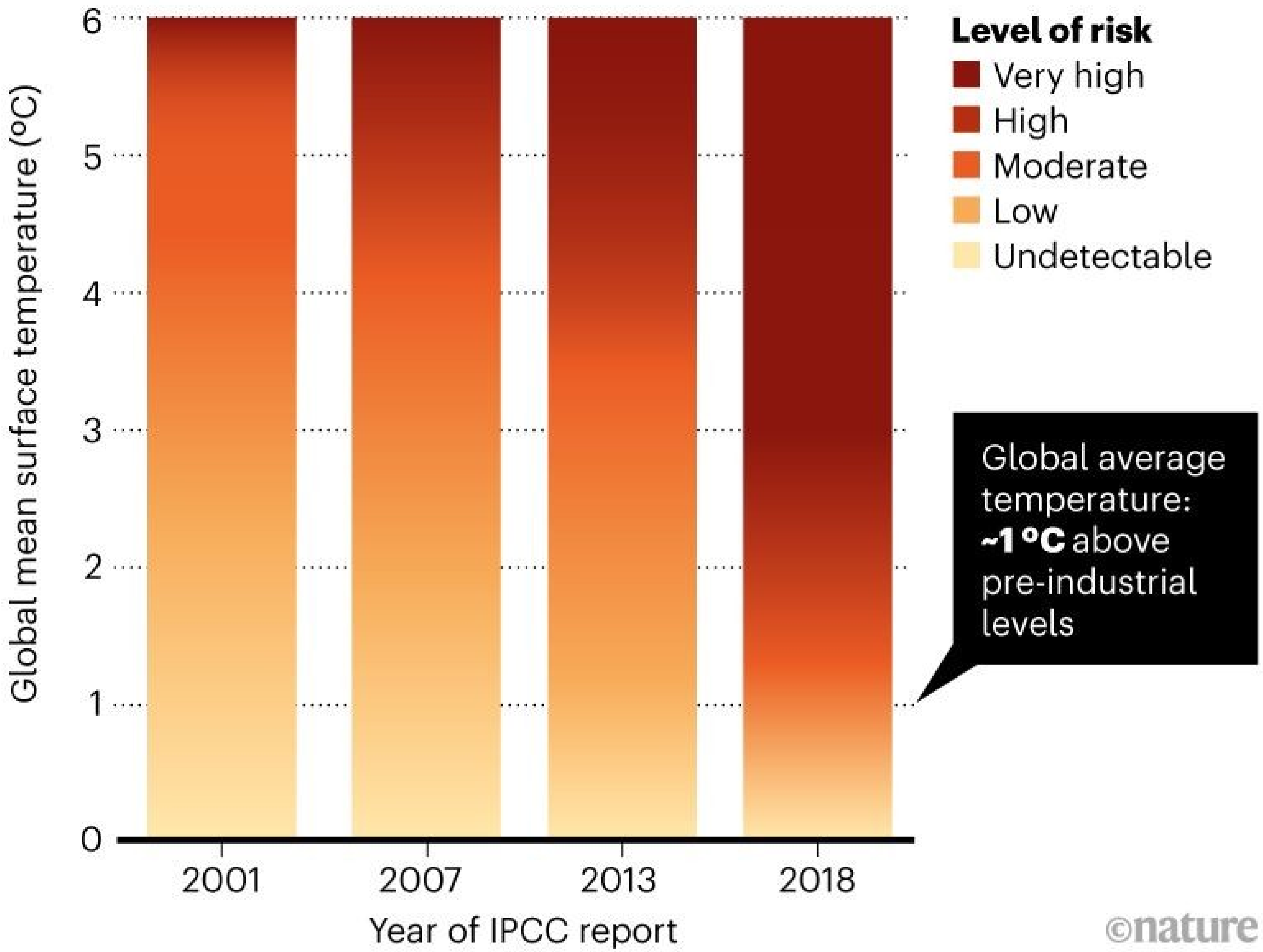


Estimated possibility of reaching tipping points: yellow – possible, red – certain.

Schellnhuber et al. Nature Climate Change volume 6, pages 649–653 (2016)

TOO CLOSE FOR COMFORT

Abrupt and irreversible changes in the climate system have become a higher risk at lower global average temperatures.



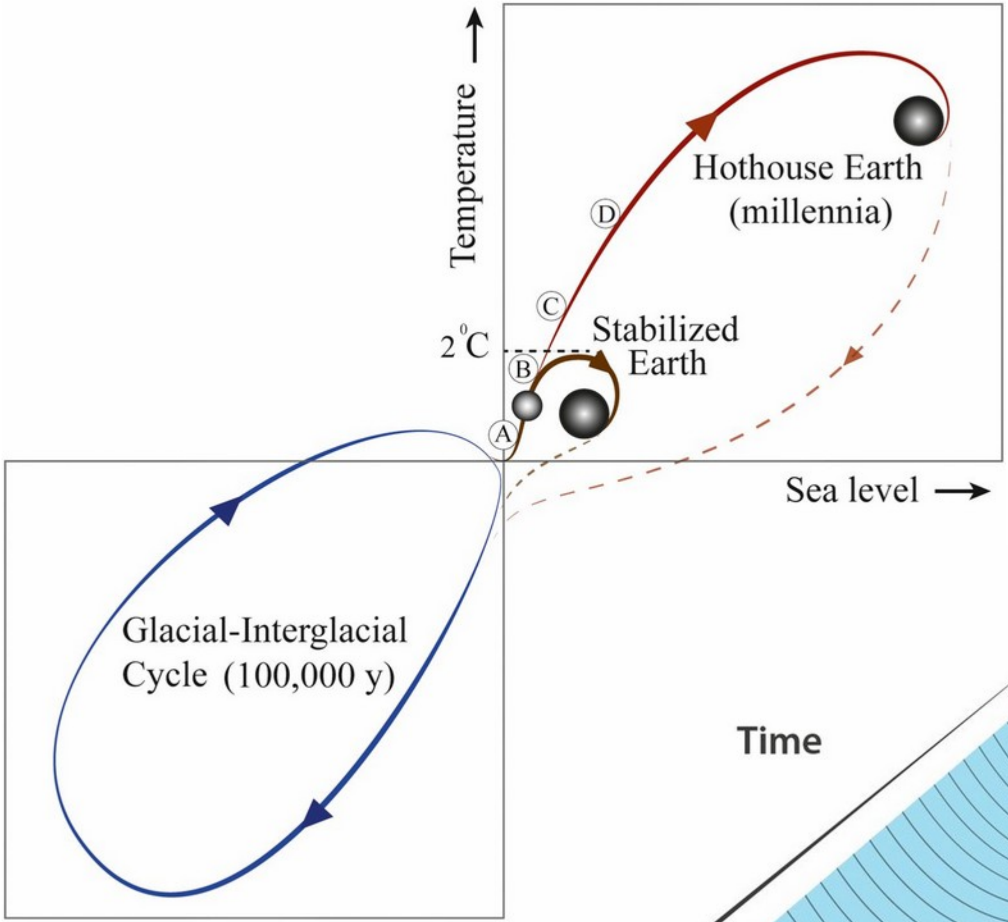
EMERGENCY: DO THE MATHS

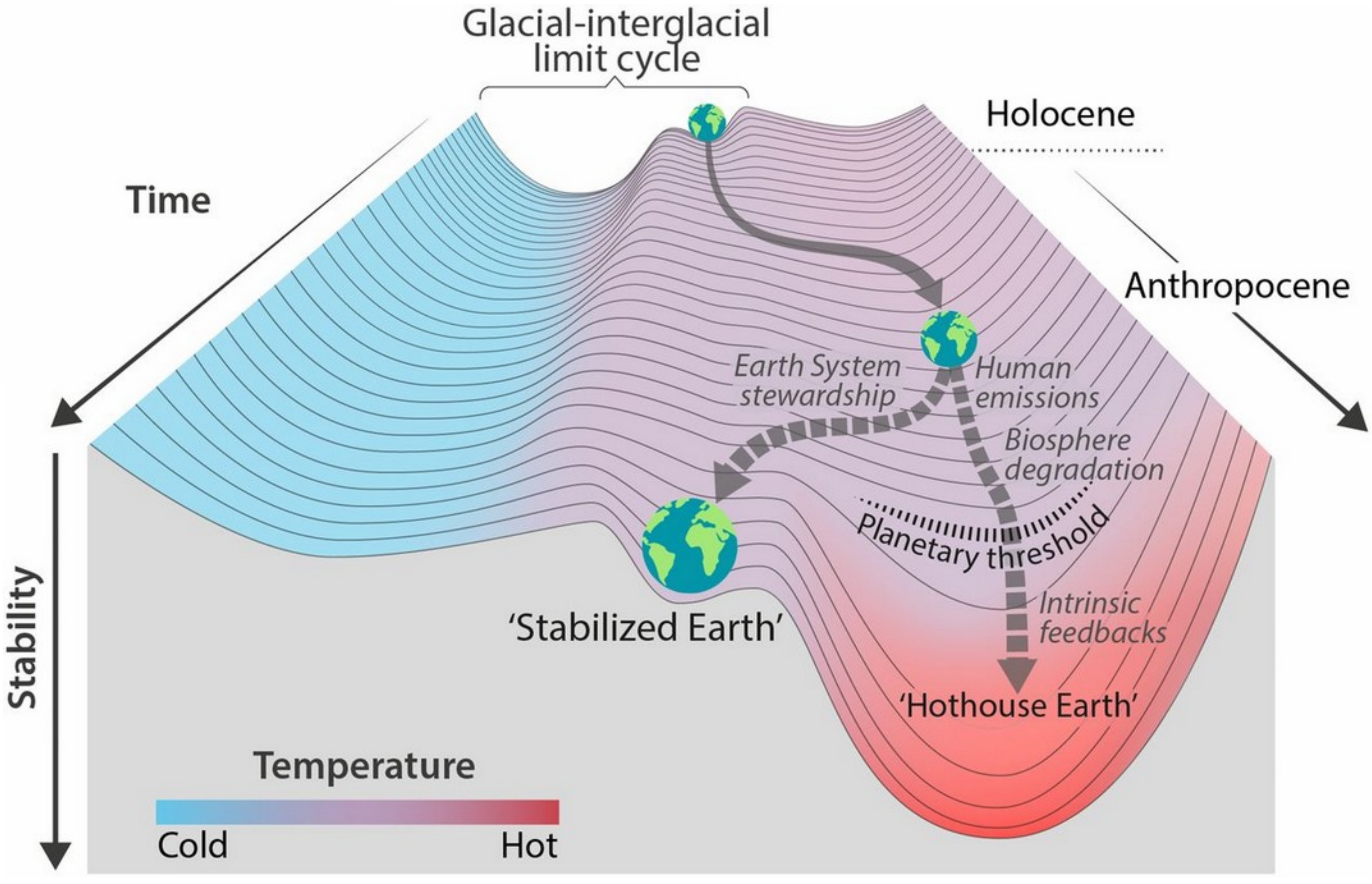
We define emergency (E) as the product of risk and urgency. Risk (R) is defined by insurers as probability (p) multiplied by damage (D). Urgency (U) is defined in emergency situations as reaction time to an alert (τ) divided by the intervention time left to avoid a bad outcome (T). Thus:

$$E = R \times U = p \times D \times \tau / T$$

The situation is an emergency if both risk and urgency are high. If reaction time is longer than the intervention time left ($\tau / T > 1$), we have lost control.

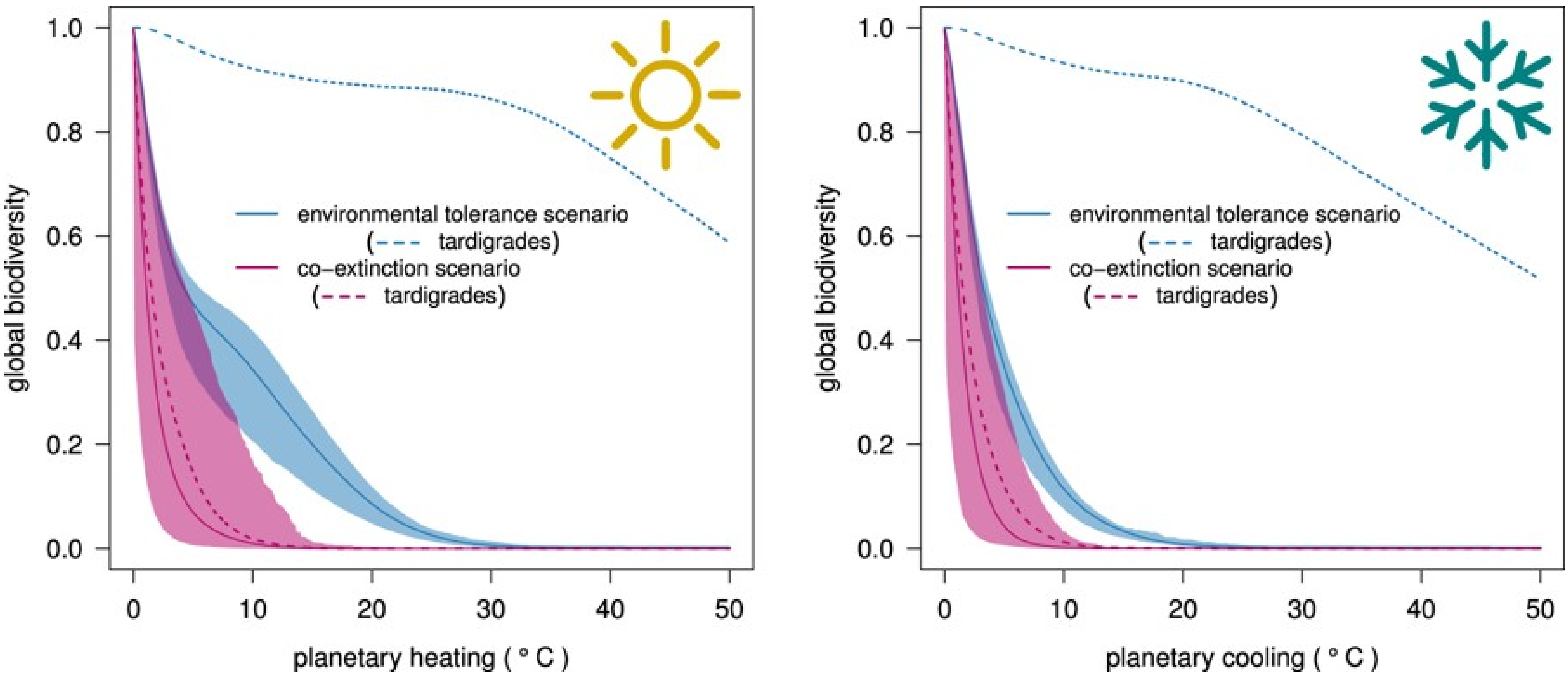
Stability of the Earth climate system endangered due to tipping points cascade crossings?





Steffen et al., PNAS August 14, 2018 115 (33) 8252-8259; https://doi.org/10.1073/pnas.1810141115

Climate and biodiversity: co-extinctions



Species either go extinct based only on their tolerance to environmental conditions ('environmental tolerance' scenarios = blue curves), or where species go extinct not only when unable to cope with changed environmental conditions, but also following the depletion of their essential resources ('co-extinction' scenarios = magenta curves)

Strona and Bradshaw, Scientific Reports, Vol, 8, Article number: 16724 (2018)

Roger R. Revelle and Hans E. Suess,
"Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO2 during the Past Decades,"
Tellus IX (1957), pp. 19-20.

"Thus human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future. Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in sedimentary rocks over hundreds of millions of years…."

SIXTY THREE YEARS AFTER
WE FACE THE FOLLOWING QUESTION:

Can we gain control on this experiment?

200 years of climate physics

- almost 200 years since term “greenhouse effect” was introduced and Earth's energy balance was considered a main driver of climate,

- almost 150 years from first measurements of properties of greenhouse gases,

- more than 100 years from the first calculations of temperature effect of CO_2 doubling,

- over 55 years from formulation of first modern radiative transfer / circulation models,

- over 25 years from successive applications of global climate models…

-we talk and deliver the message but it is not enough to avoid catastrophe.