NAUKA O KLIMACIE
DLA SCEPTYCZNYCH

# Global warming - physicist's perspective

# 01 – an overview of the problem

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$\Delta Q_S$

$\Delta Q_C$

T1 > T2 > T3

THE EARTH is illuminated by shortwave SOLAR radiation, which is partially absorbed ( $\Delta Q_s$) and partially reflected (not shown).

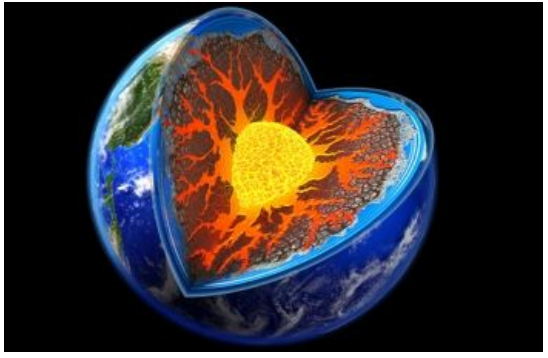
In (quasi) equilibrium energy of absorbed radiation $\Delta Q_s$ is balanced by emission of EARTH's radiation $\Delta Q_c$ in thermal infrared.

**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 a 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 THE CLIMATE SYSTEM

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

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

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

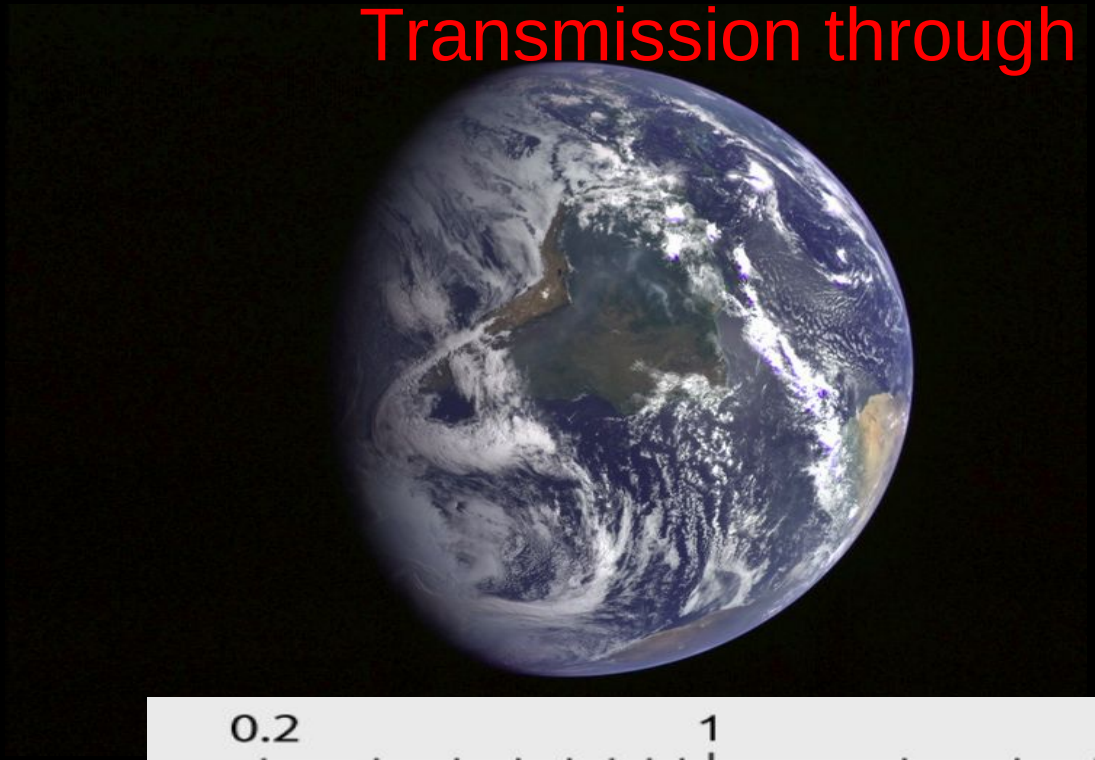
4. Heat flux from fossil fuel combustion ≈0.04W/$m^2$.

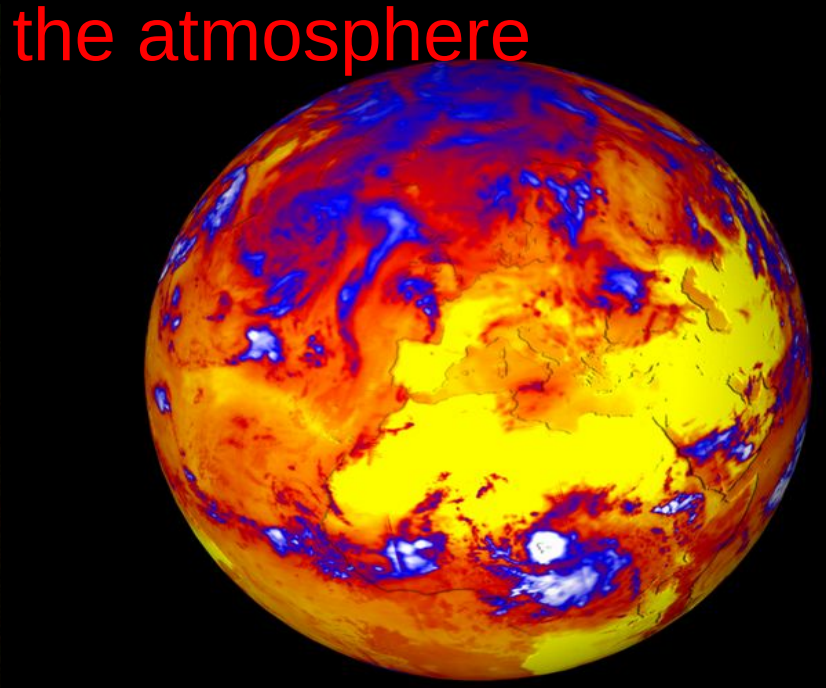
## BASIC PROPERTIES OF THE CLIMATE SYSTEM

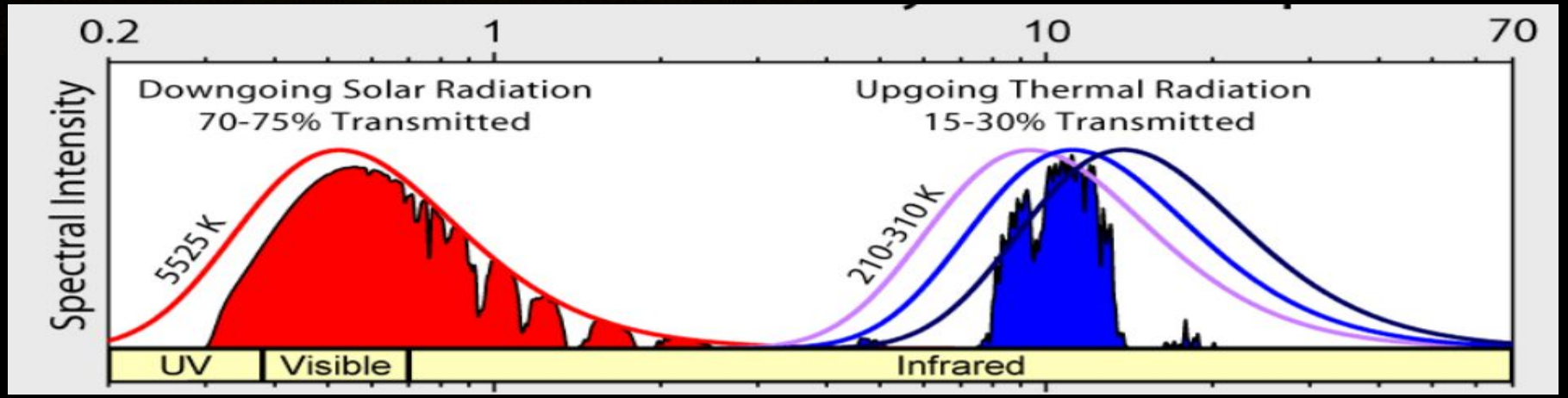
1. Air: surface pressure ≈1000hPa (10m of water),
$c_p$=1004J/kg*K.
2. Water: global average depth ≈ 3000m, $c_w$=4192J/kg*K.
3. Ground – only a shallow layer responding to radiative fluxes.
4. Greenhouse gases: $H_2O$, $CO_2$, $CH_4$, $O_3$, many others.

# Transmission through the atmosphere

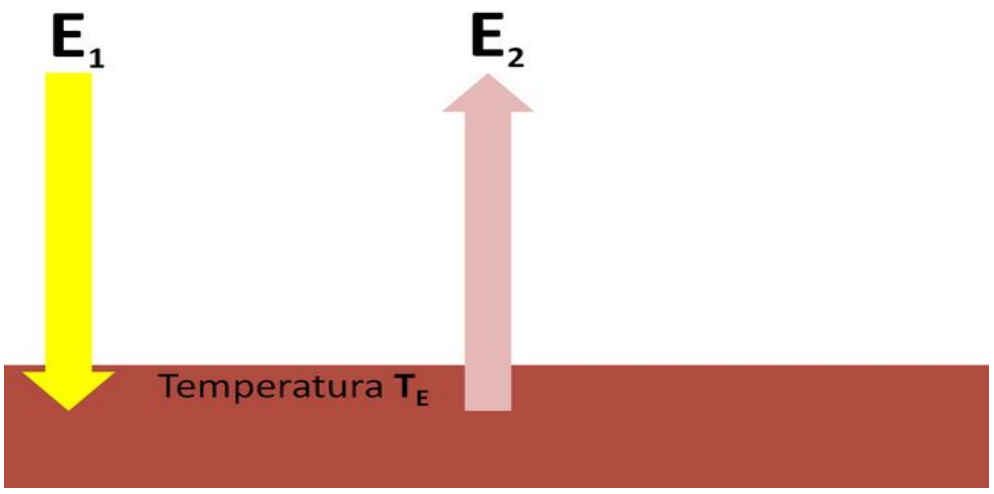
NASA

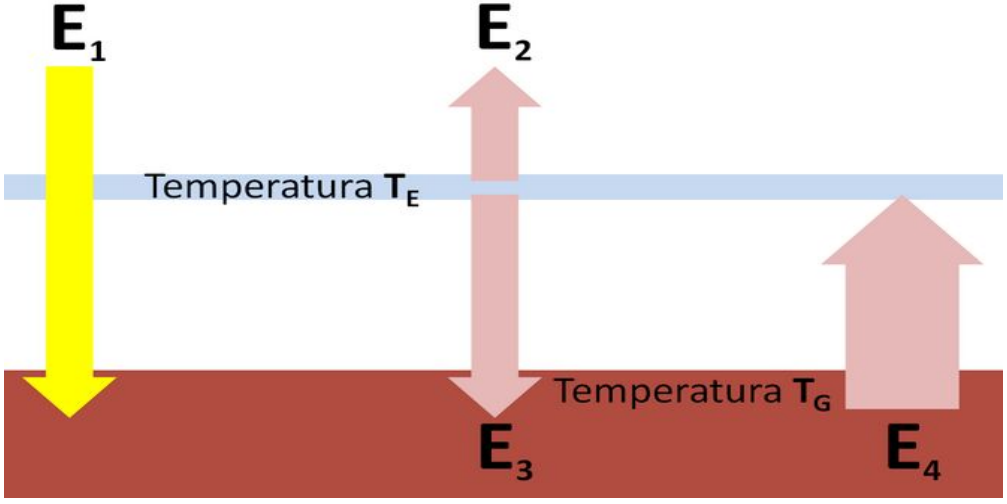






# Greenhouse effect: a principle

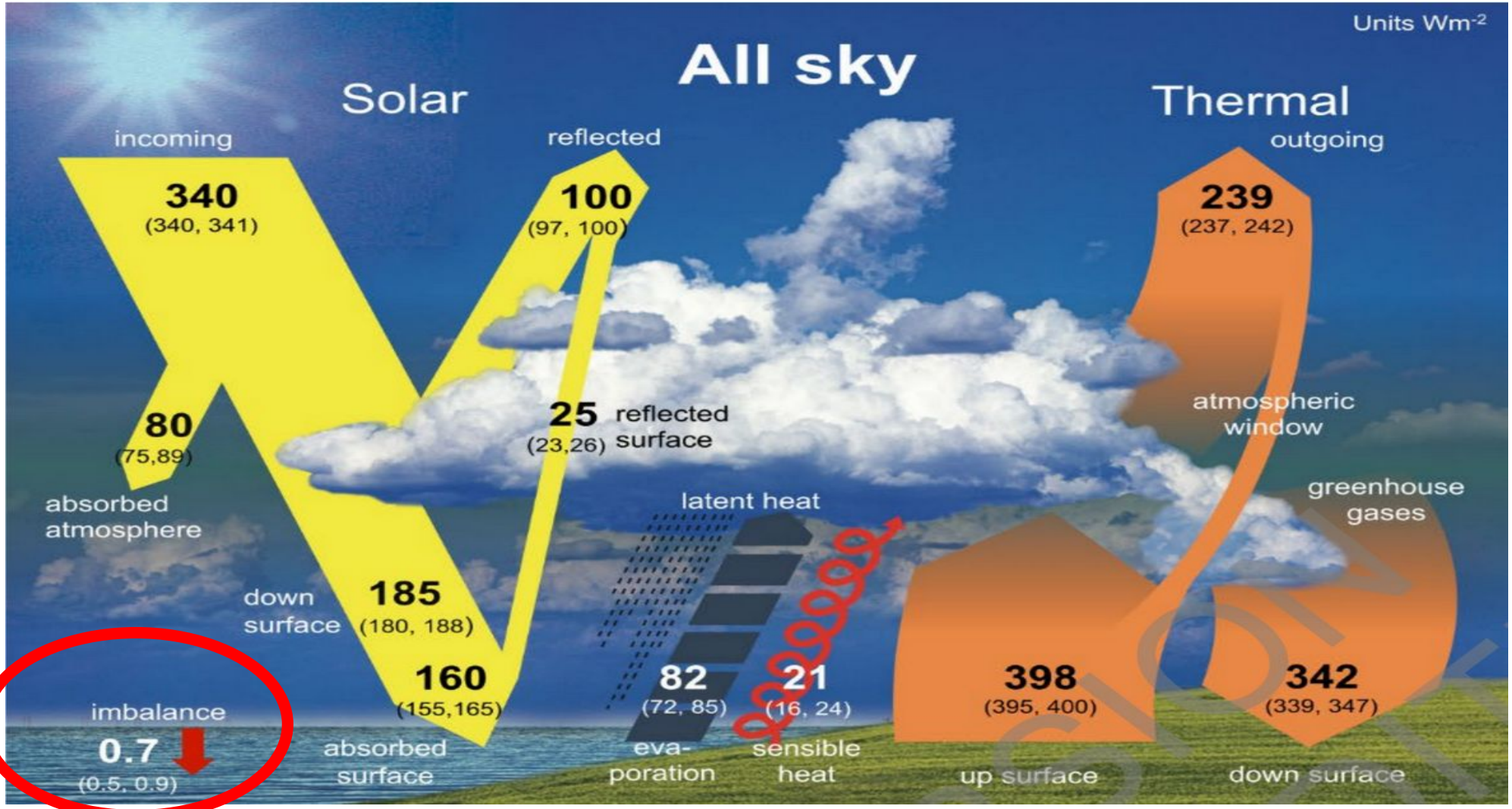



$E_1=E_2$

$E_1=E_2=E_3$

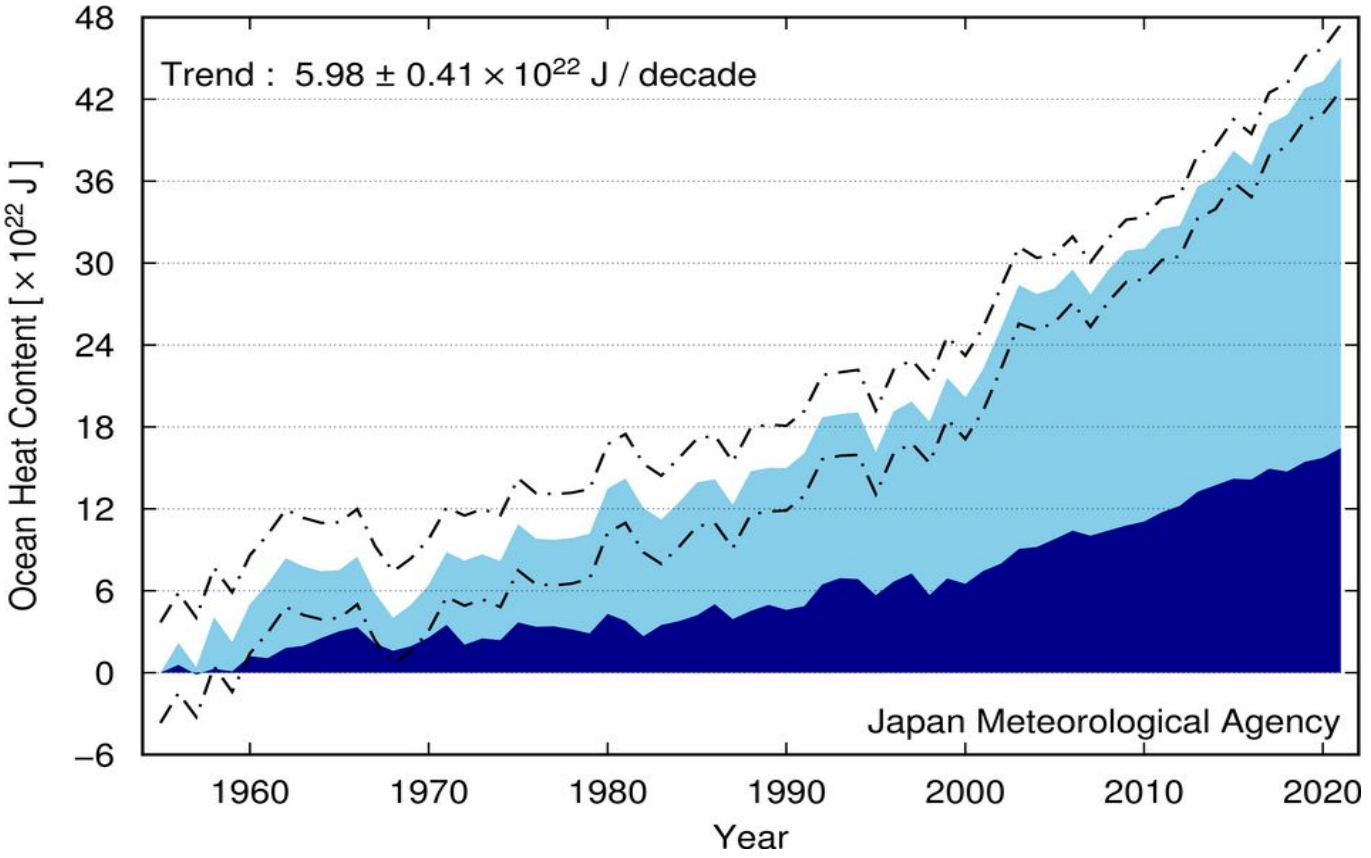
$E_4=E_1+E_3$



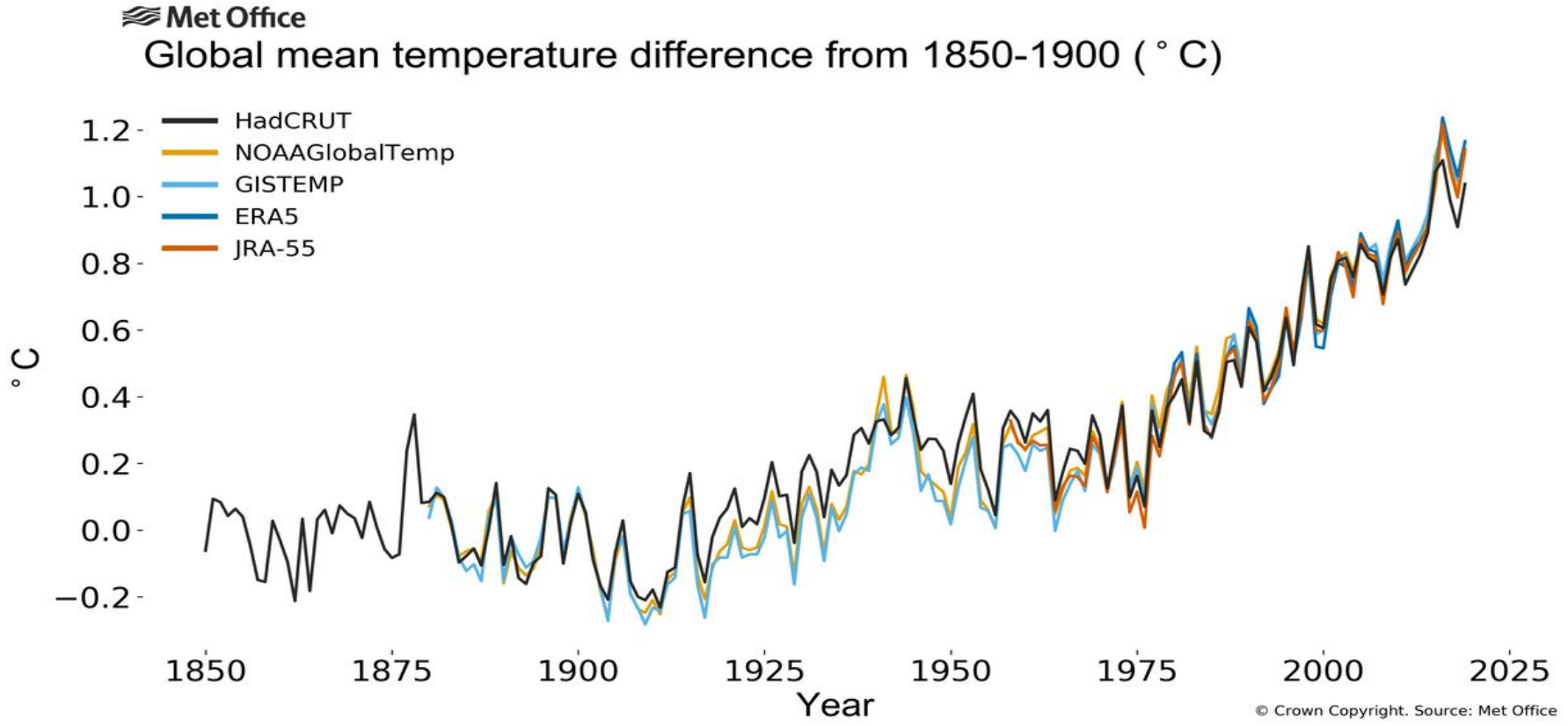

Energy balance of climate system. Units: W/m$^2$.

https://www.ipcc.ch/report/ar6/wg1/#FullReport

Ocean heat content increases. 96% of the energy imbalance ends in the ocean.

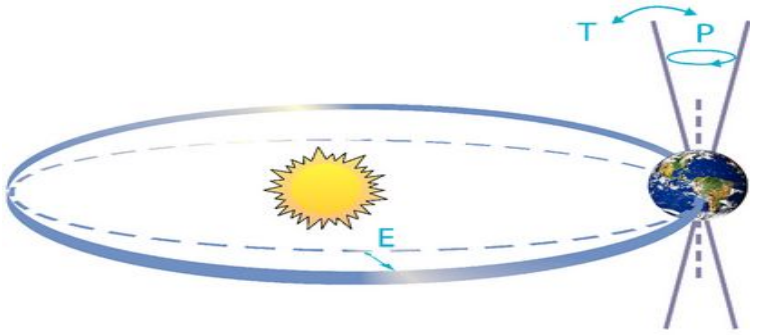


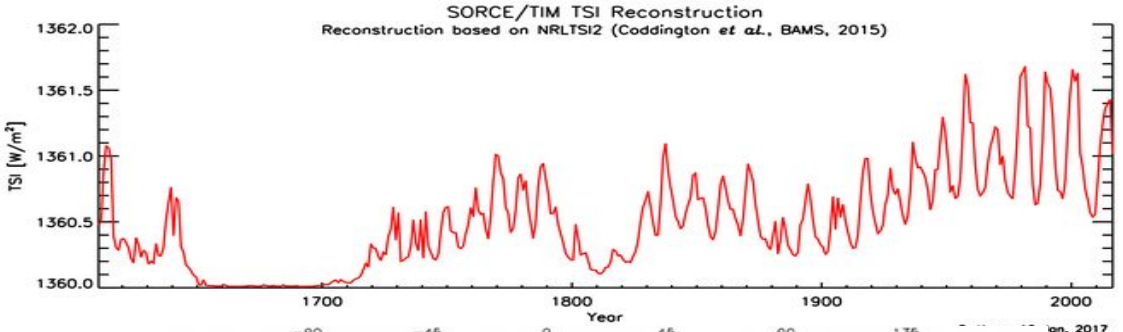
Positive energy balance – temperature of the air at the surface increases.

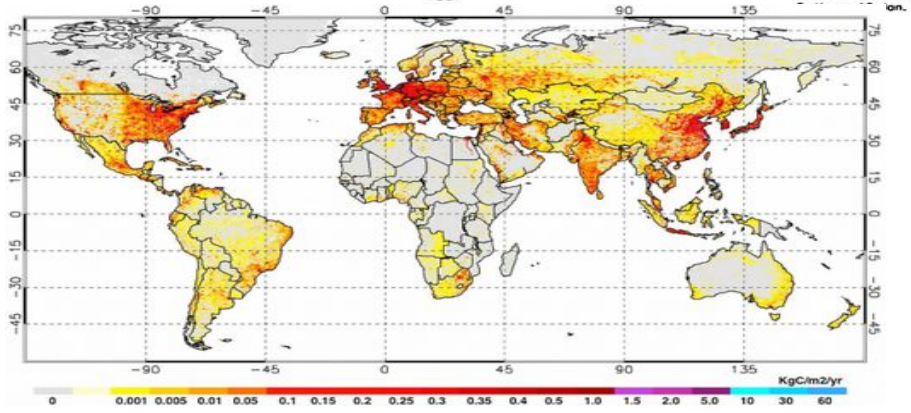


# **Forcings** and **feedbacks** in climate system.

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

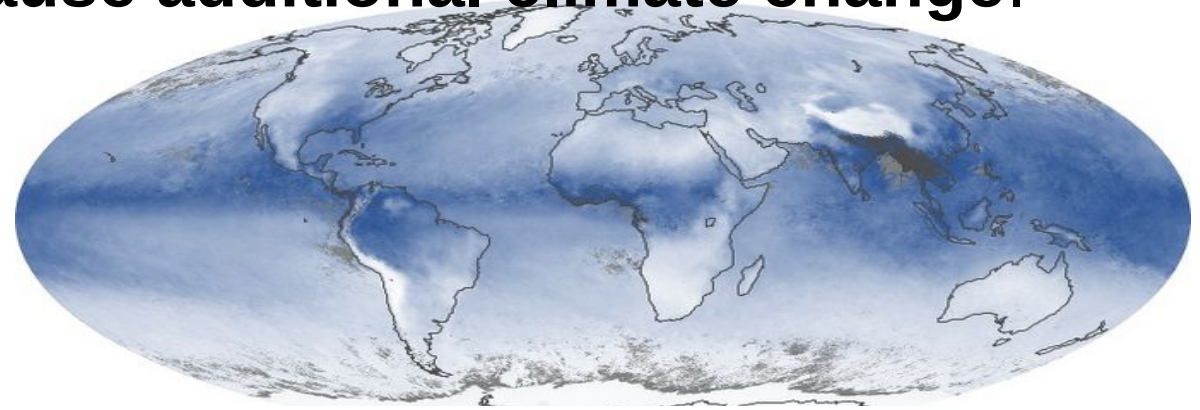


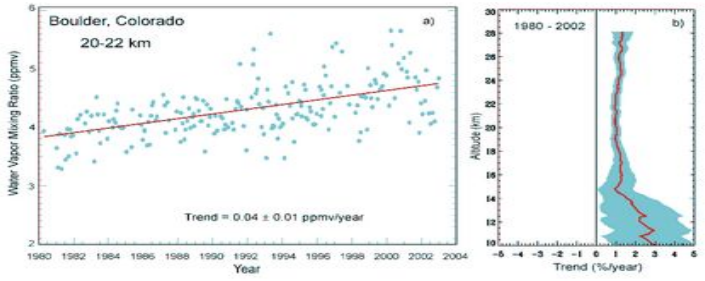



# **Forcings** and **feedbacks** in climate system.

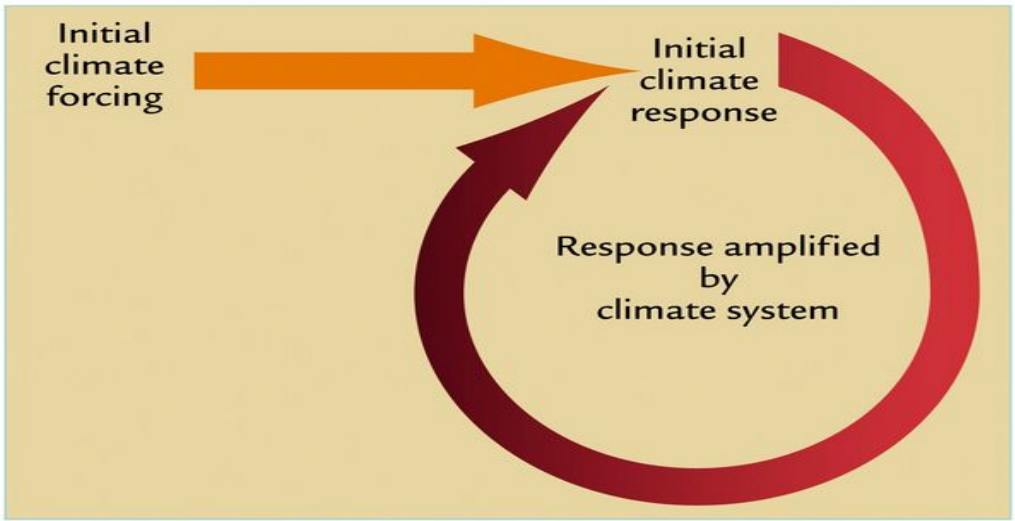
Climate **feedbacks** are processes that **change as a result of a change in forcing**, and **cause additional climate change**.

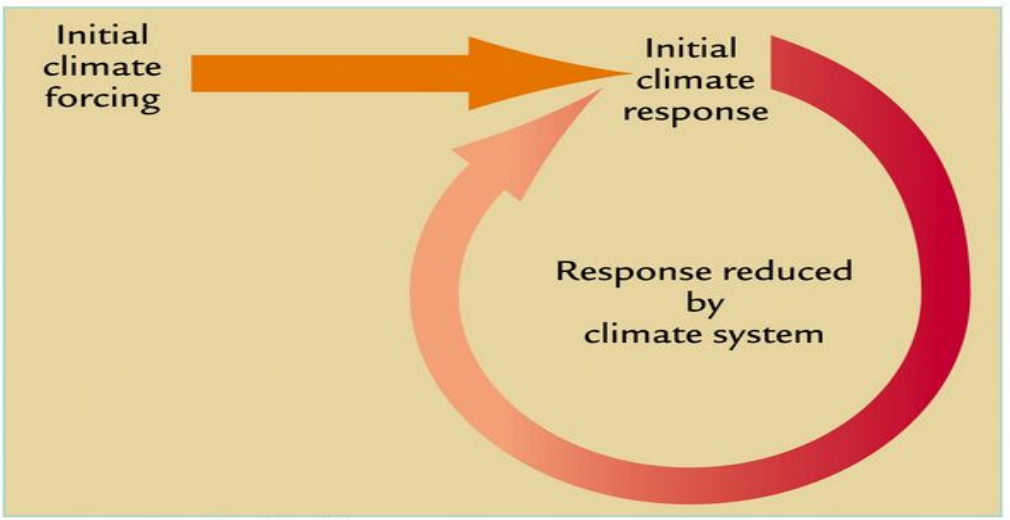


# **Feedbacks** can be positive or negative.

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

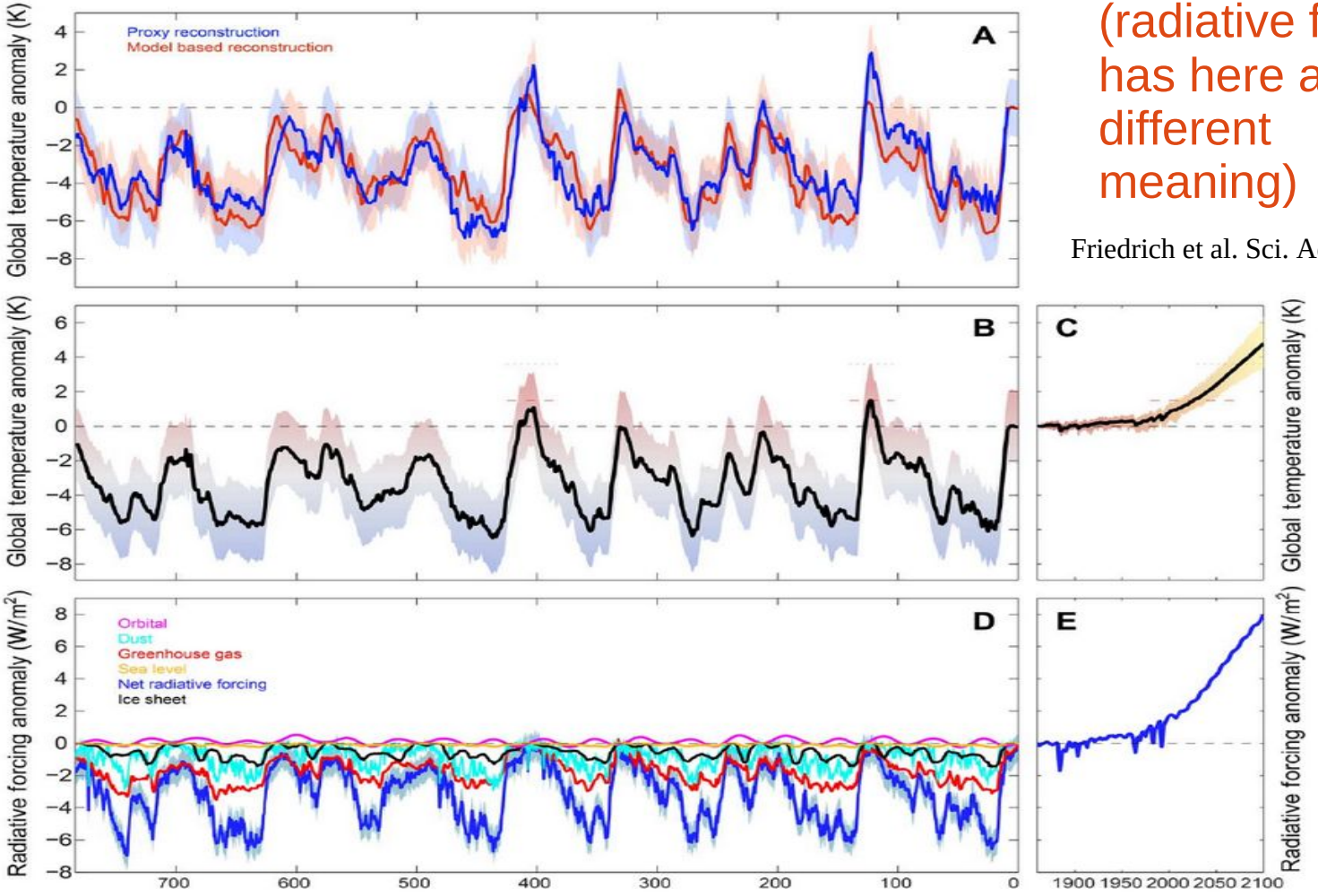



A Positive feedback




B Negative feedback

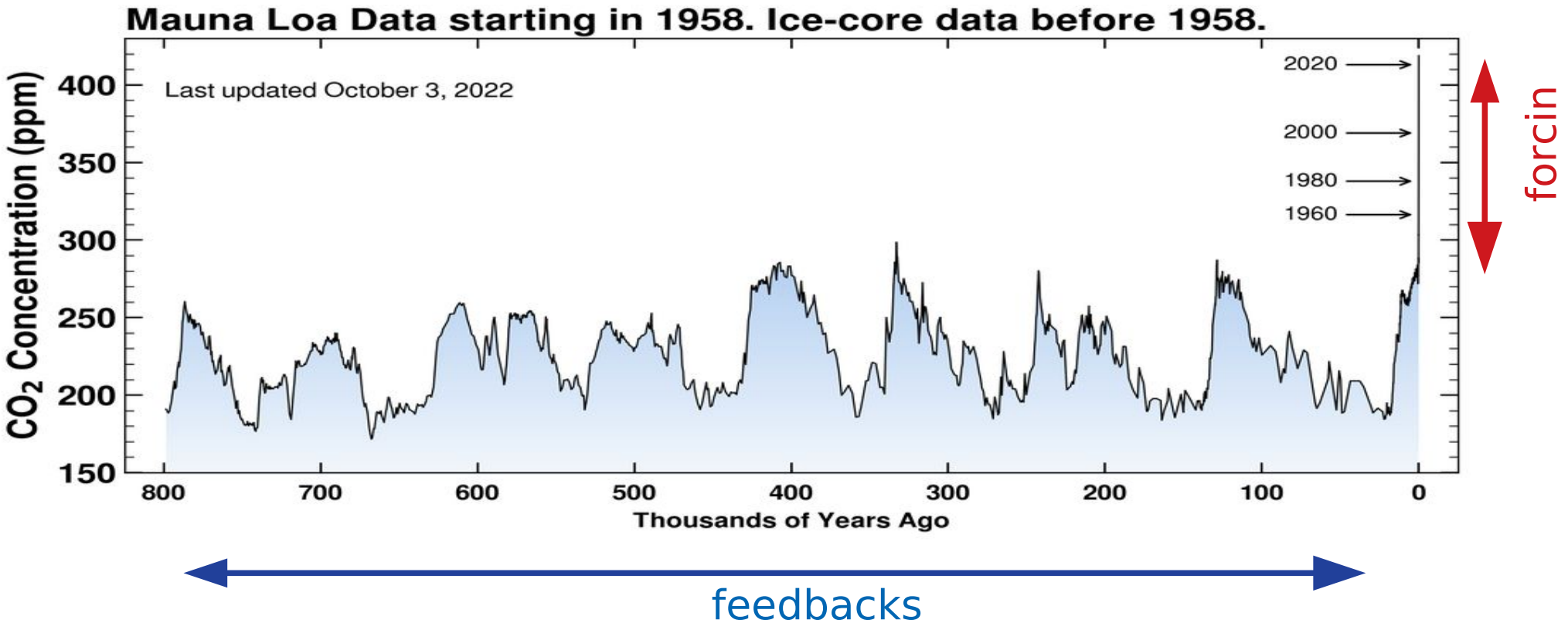
# **Orbital forcing** and system **feedbacks in the course of ice ages** lead to remarkable radiative effects

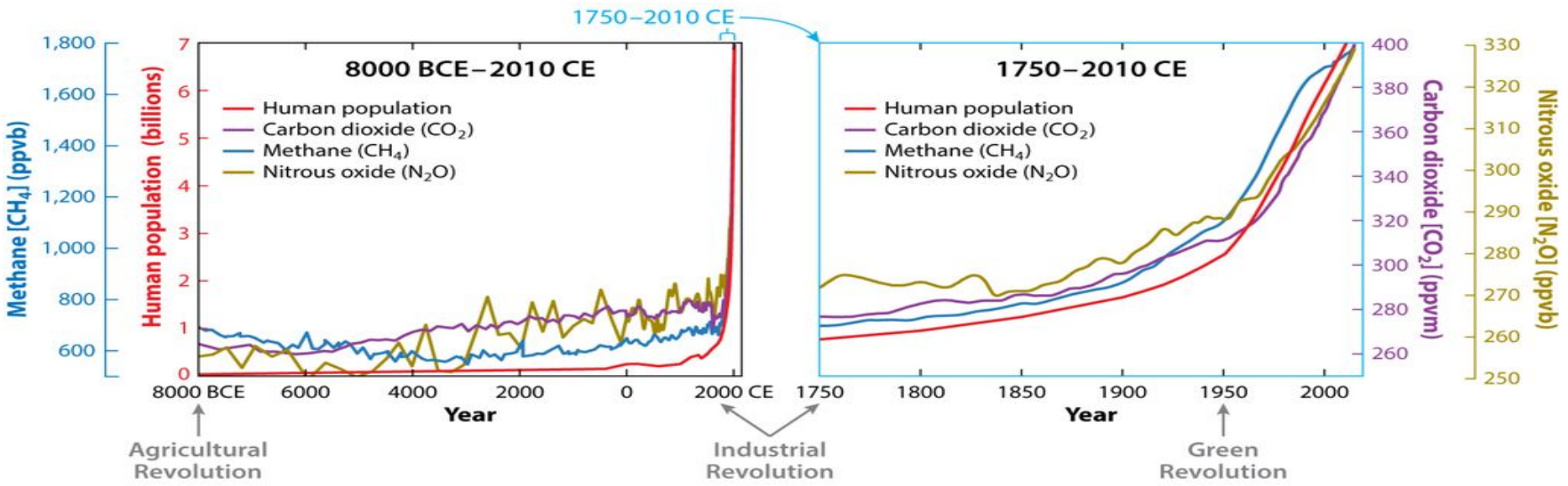



(radiative forcing has here a different meaning)

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

# CO2: feedback and forcing.

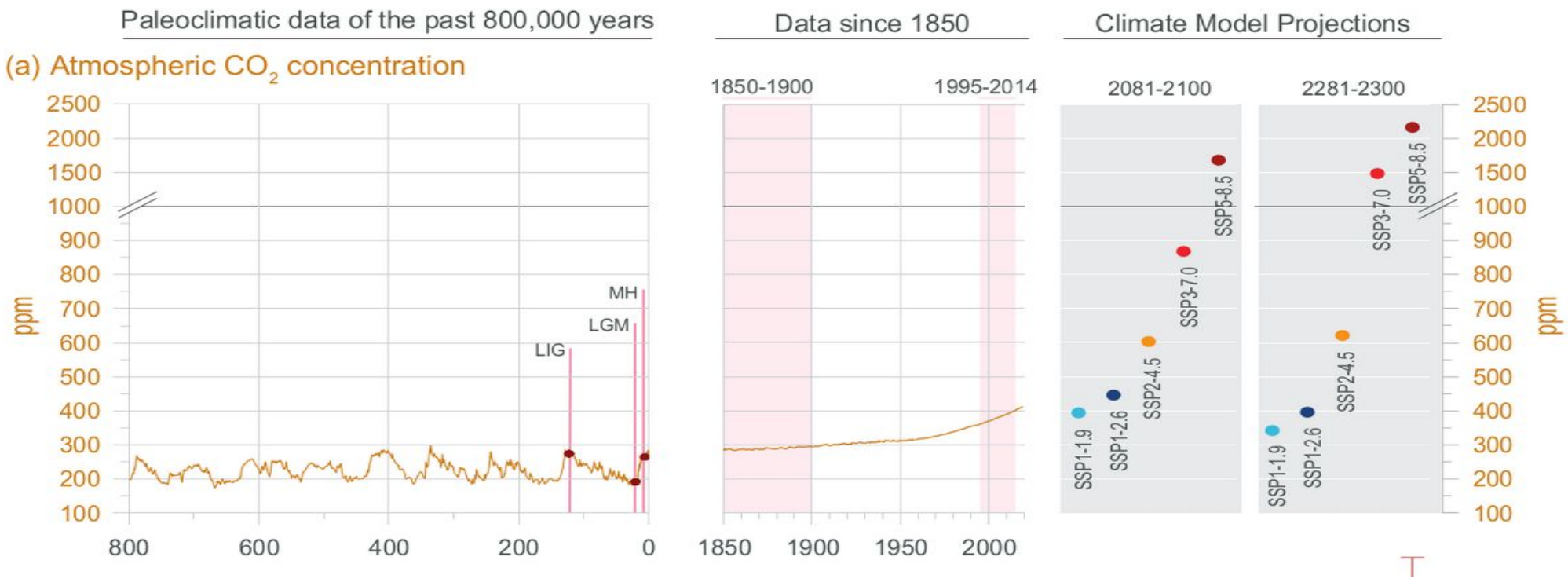




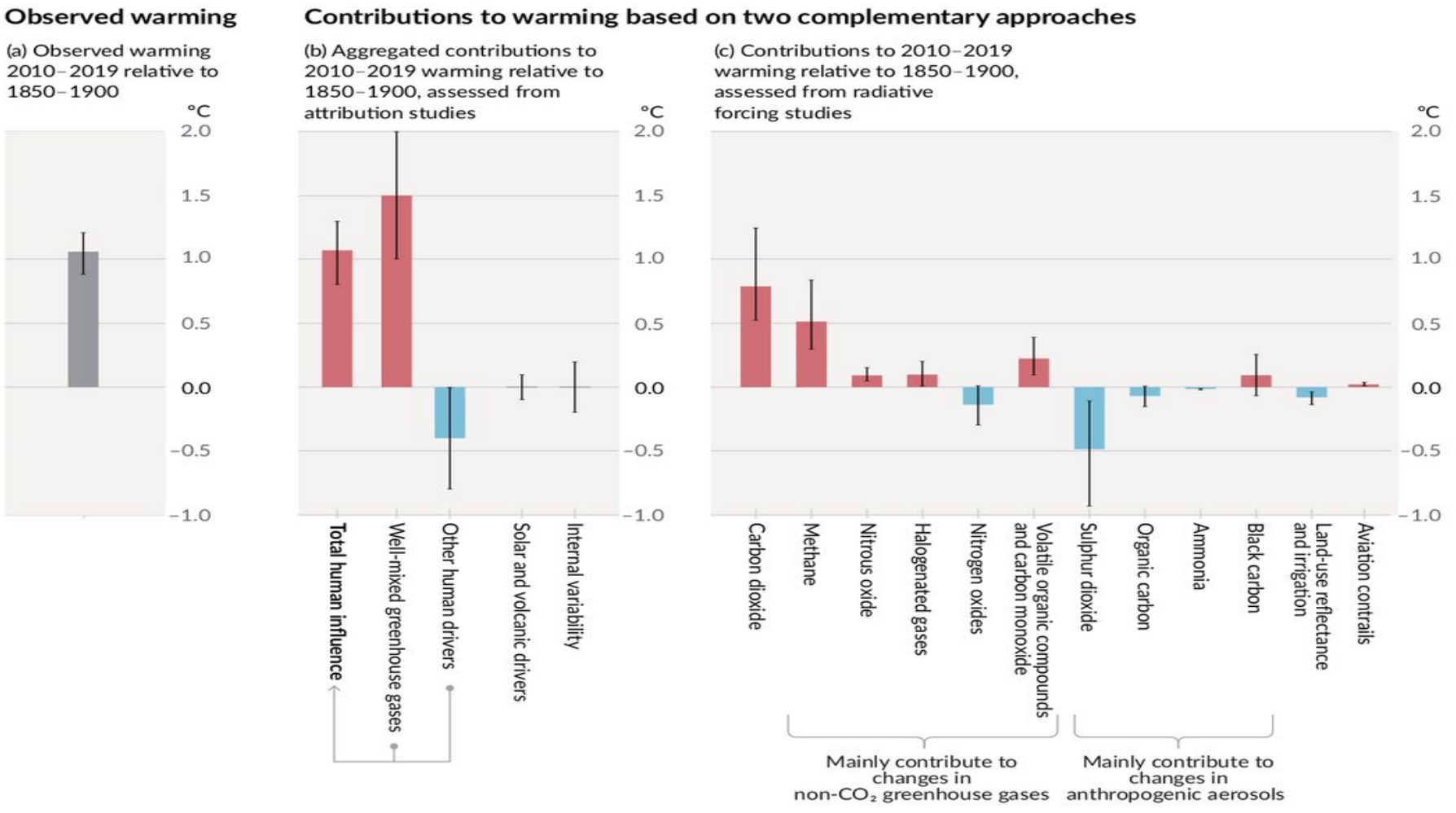

The abrupt and simultaneous upward trajectories of human population and greenhouse gases after the start of the Industrial Revolution (~1750), and the distinct acceleration after the start of the Green Revolution (~1950), show that the Human System has become the primary driver of these gases and the 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

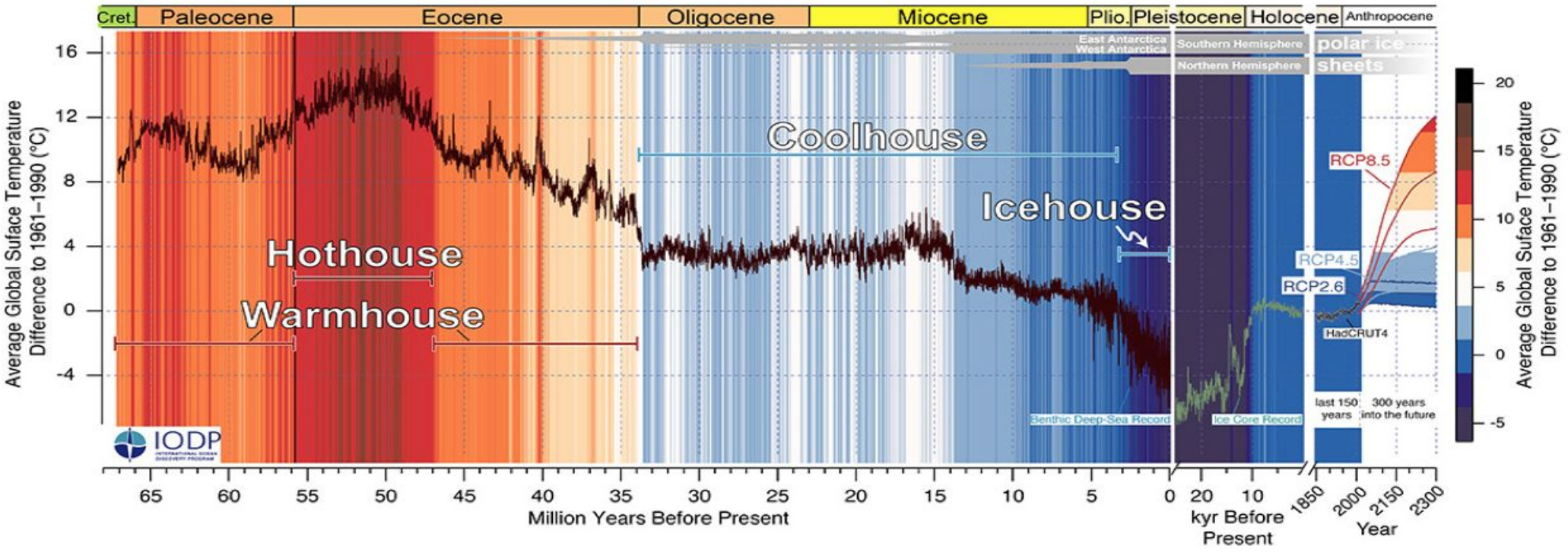
Annual Reviews


Paleoclimatic data of the past 800,000 years
Data since 1850
Climate Model Projections
(a) Atmospheric $CO_2$ concentration
ppm
2500
2000
1500
1000
900
800
700
600
500
400
300
200
100
800
600
400
200
0
MH
LGM
LIG
1850-1900
1995-2014
1850
1900
1950
2000
2081-2100
2281-2300
SSP1-1.9
SSP1-2.6
SSP2-4.5
SSP3-7.0
SSP5-8.5

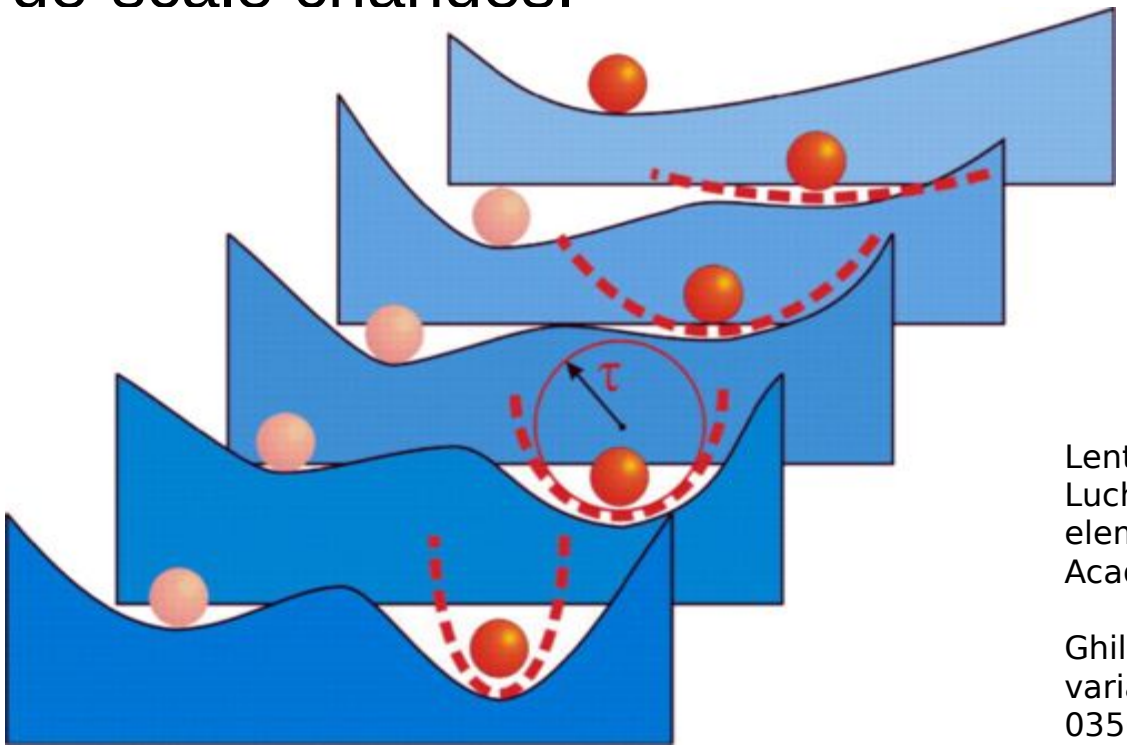
# Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling



# Very past and and near future climate



Tipping points.
Passing a tipping point leads to the change of the state of the system.
Crossing multiple tipping points could lead to irreversible large-scale changes.




Lenton, T. M., H. Held, E. Kriegler, J. W. Hall, W. Lucht, S. Rahmstorf, and H. J. Schellnhuber, Tipping elements in the Earth's climate system, Proc. Natl. Acad. Sci. U.S.A. 105, 1786–1793 (2008).

Ghil, M., V. Lucarini, The physics of climate variability and climate change, Rev. Mod. Phys. 92, 035002 (2020).

RESEARCH ARTICLE | CLIMATE CHANGE

# Exceeding 1.5°C global warming could trigger multiple climate tipping points

DAVID I. ARMSTRONG MCKAY, ARIE STAAL, JESSE F. ABRAMS, RICARDA WINKELMANN, BORIS SAKSCHEWSKI, SINA LORIANI, INGO FETZER, SARAH E. CORNELL, JOHAN ROCKSTRÖM, AND TIMOTHY M. LENTON

fewer Authors Info & Affiliations

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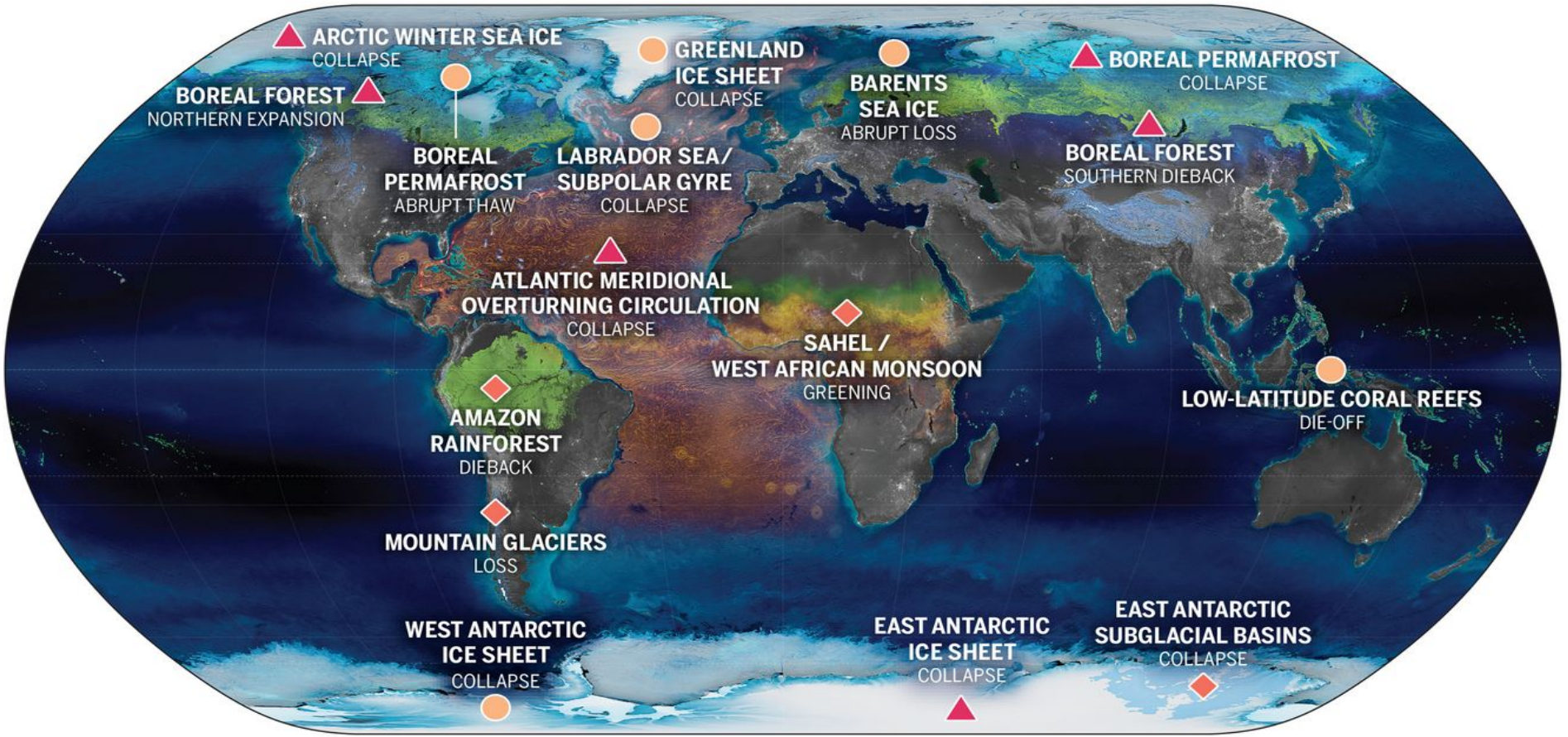
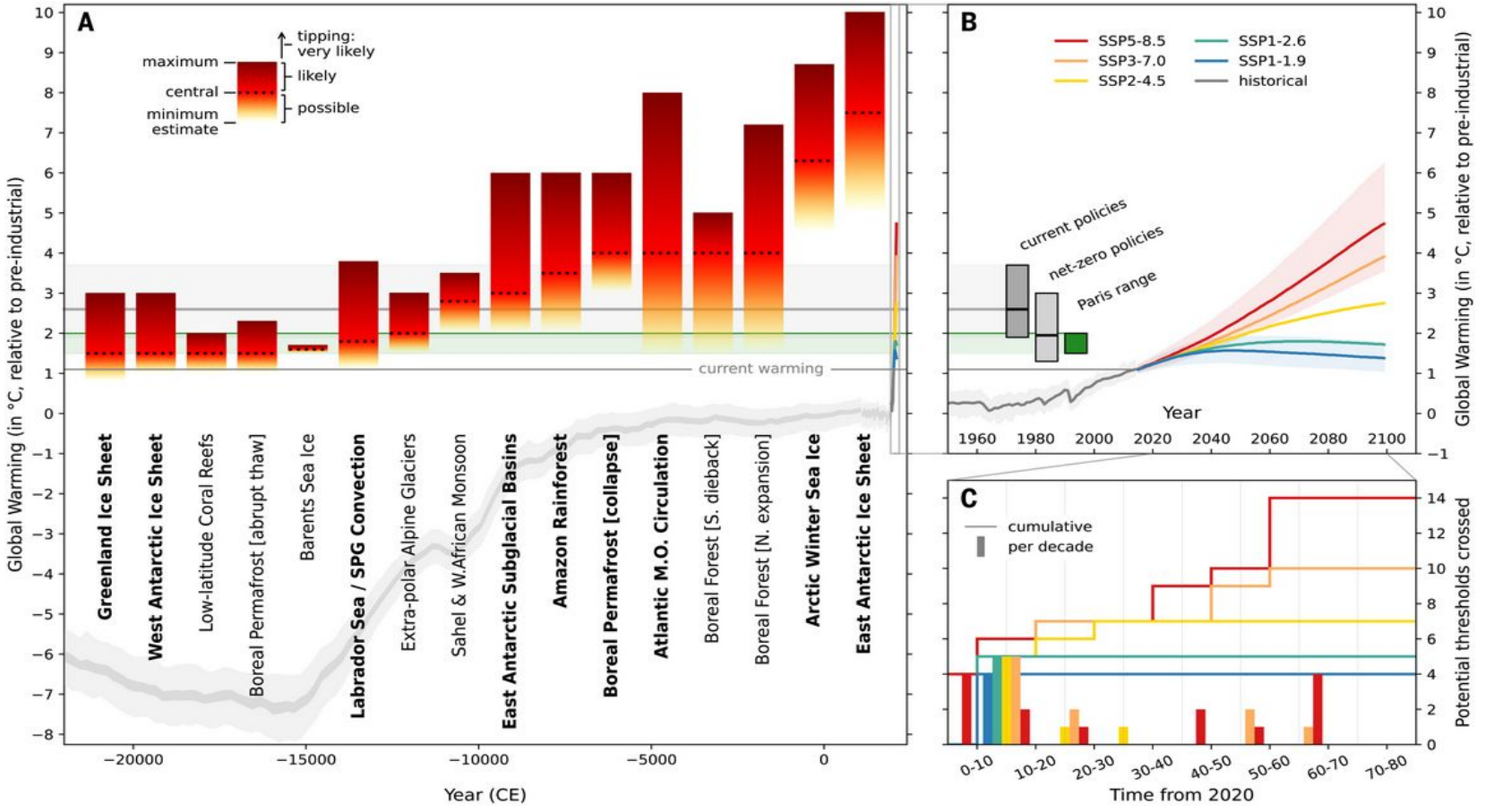
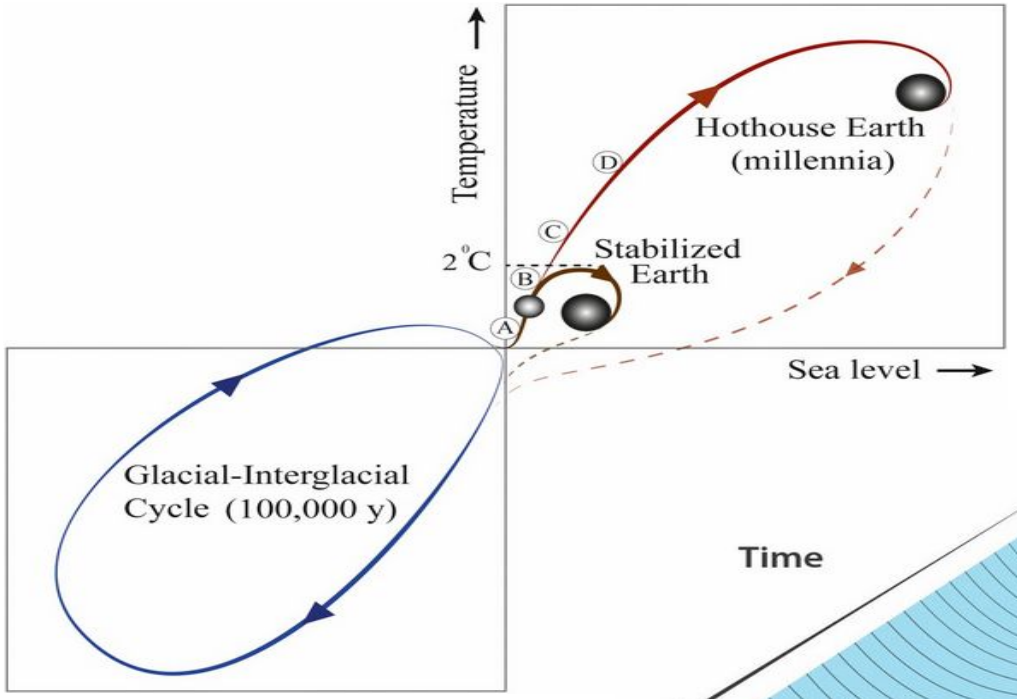
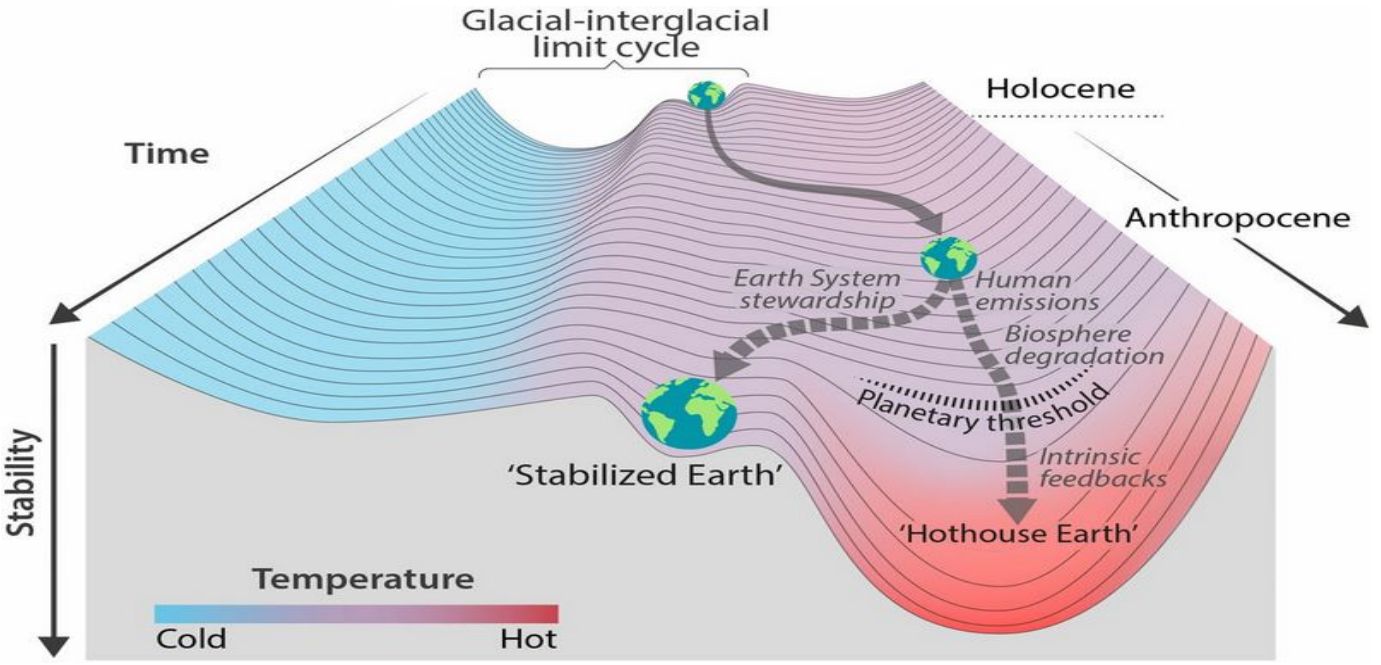





Global warming threshold estimates for global core and regional impact climate tipping elements.
Tipping elements (A) relative to IPCC SSP projections and likely future scenarios given current policies and targets (B) and how many thresholds may be crossed per Shared Socioeconomic Pathways (SSP) projection (C).

# 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

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.