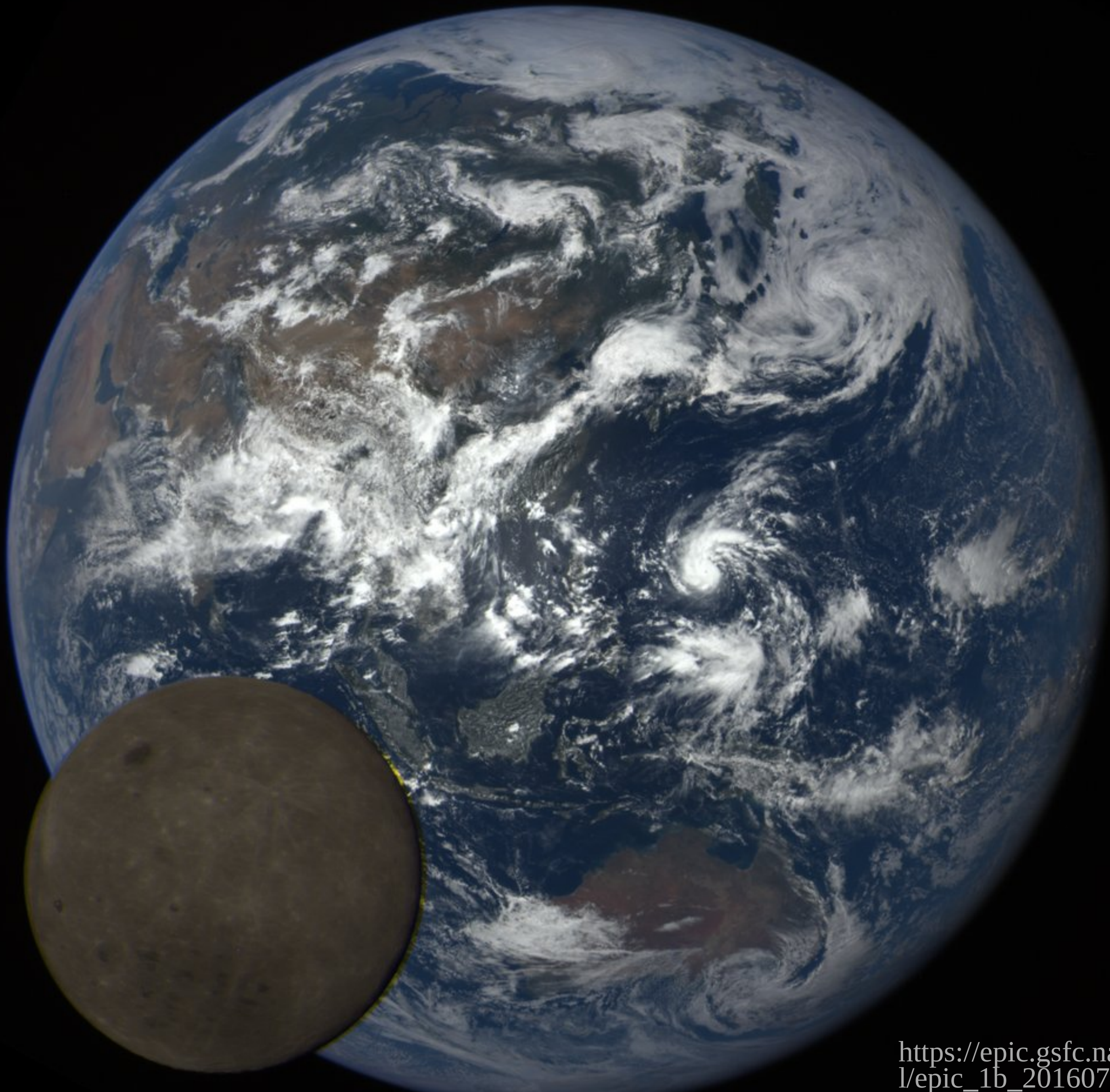
Not only greenhouse gases.

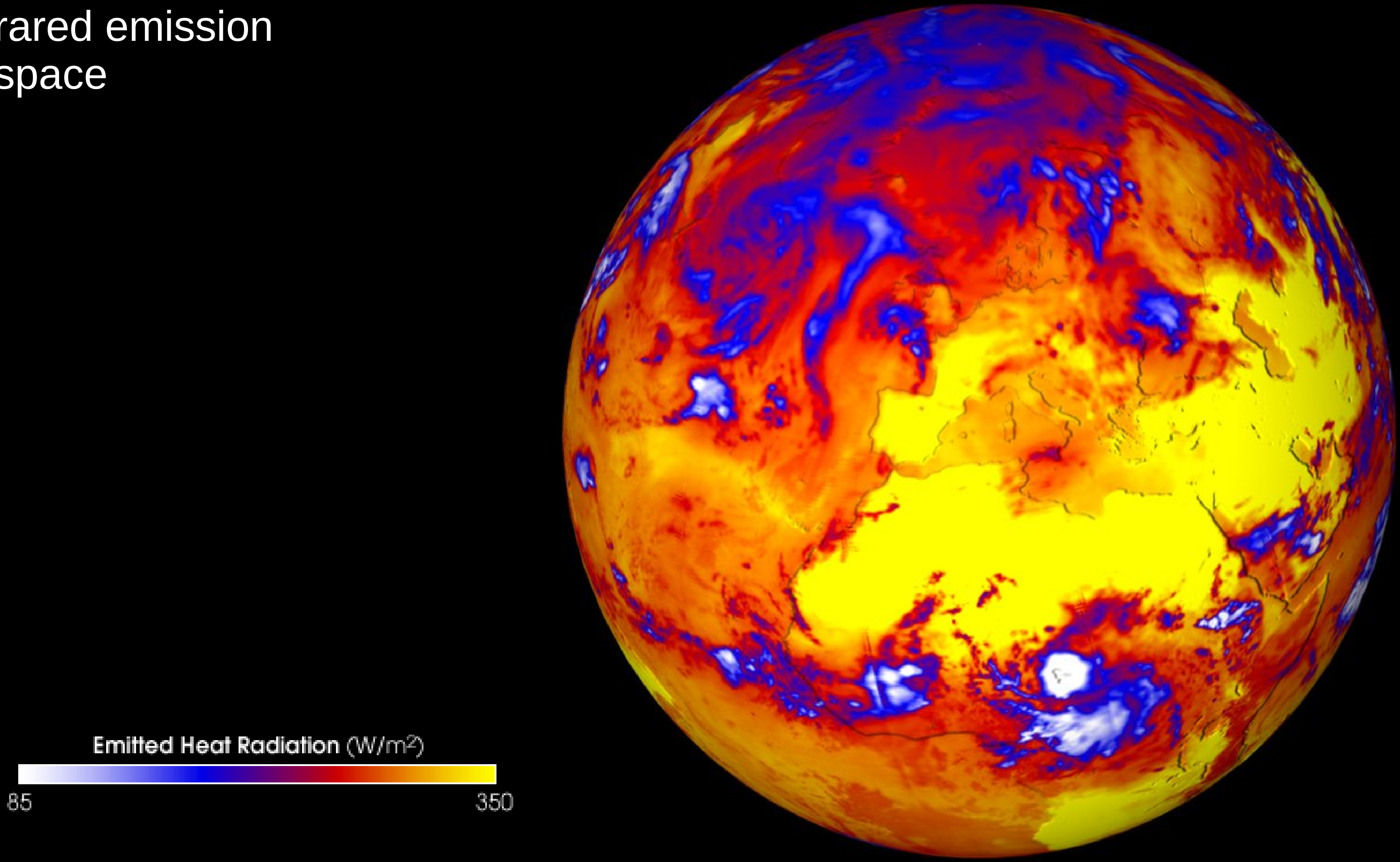
Why the Earth is already 1.5 C warmer than at the end of XIX century?

Szymon Malinowski
University of Warsaw, Faculty of Physics



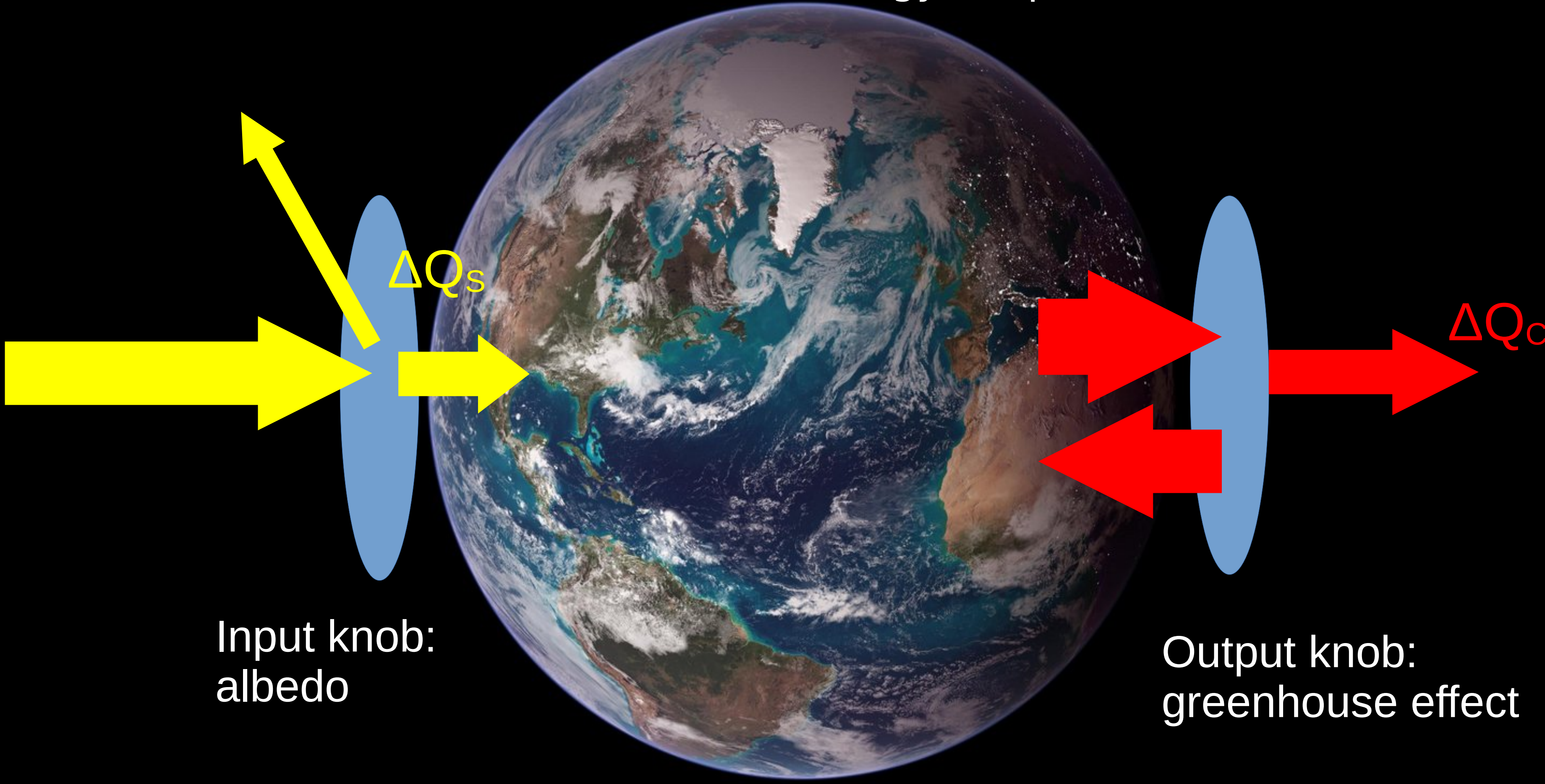
https://epic.gsfc.nasa.gov/epic-galleries/2016/lunar_transit/full/epic_1b_20160705044720_01.png

Infrared emission to space

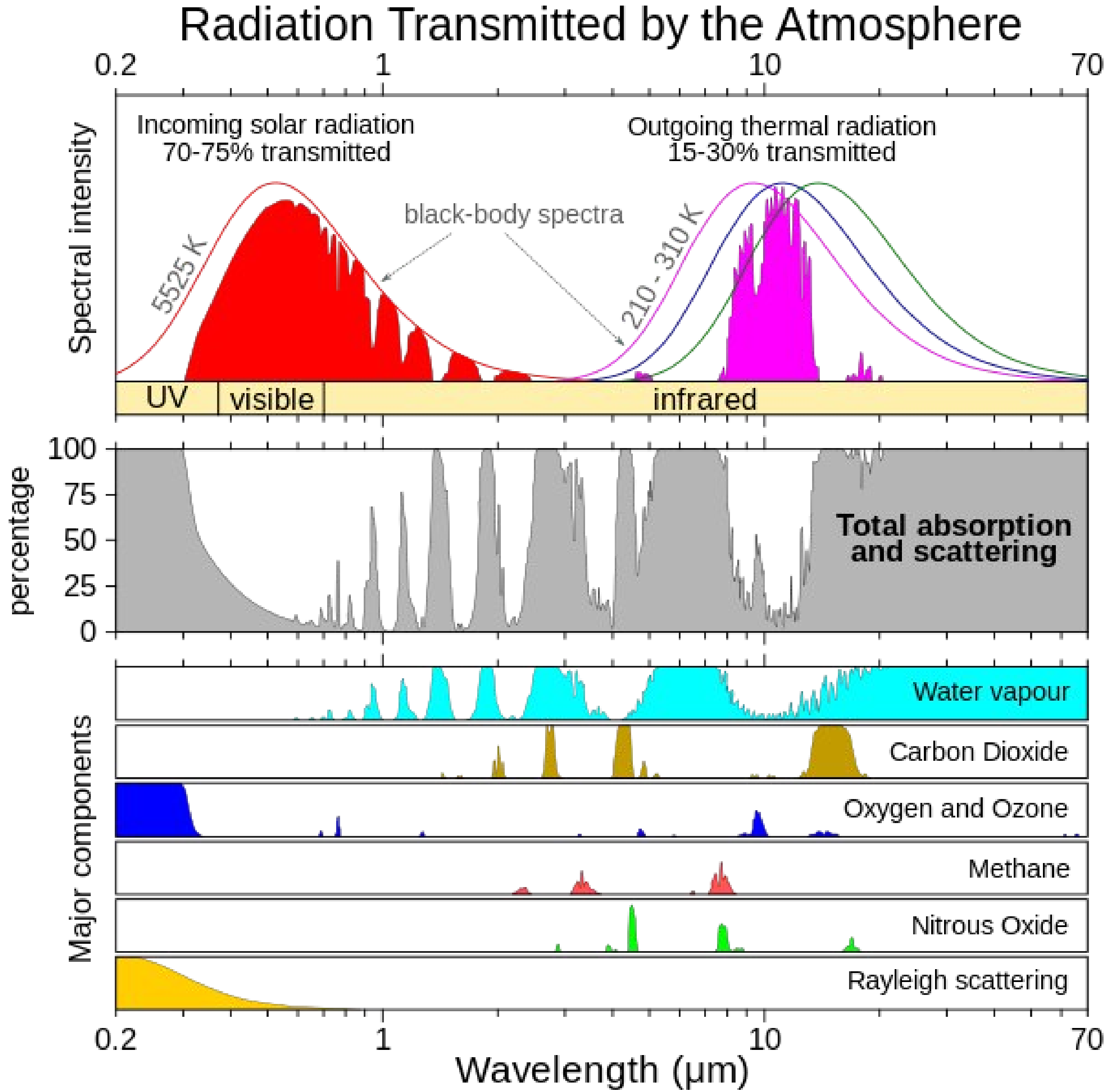


NASA

Earth's temperature depends on energy balance: absorption of Solar energy ΔQ_S and emission of energy to space ΔQ_C

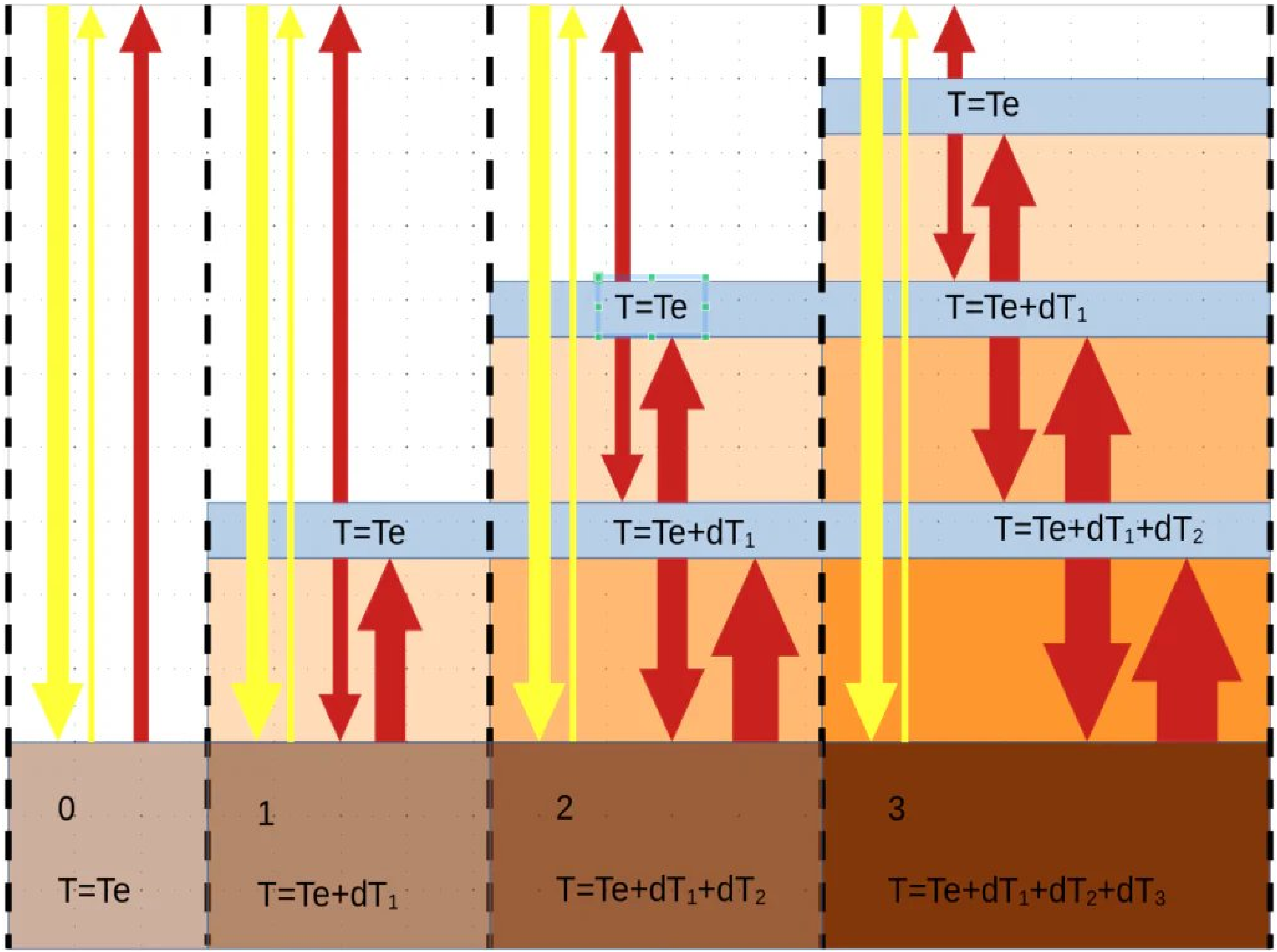


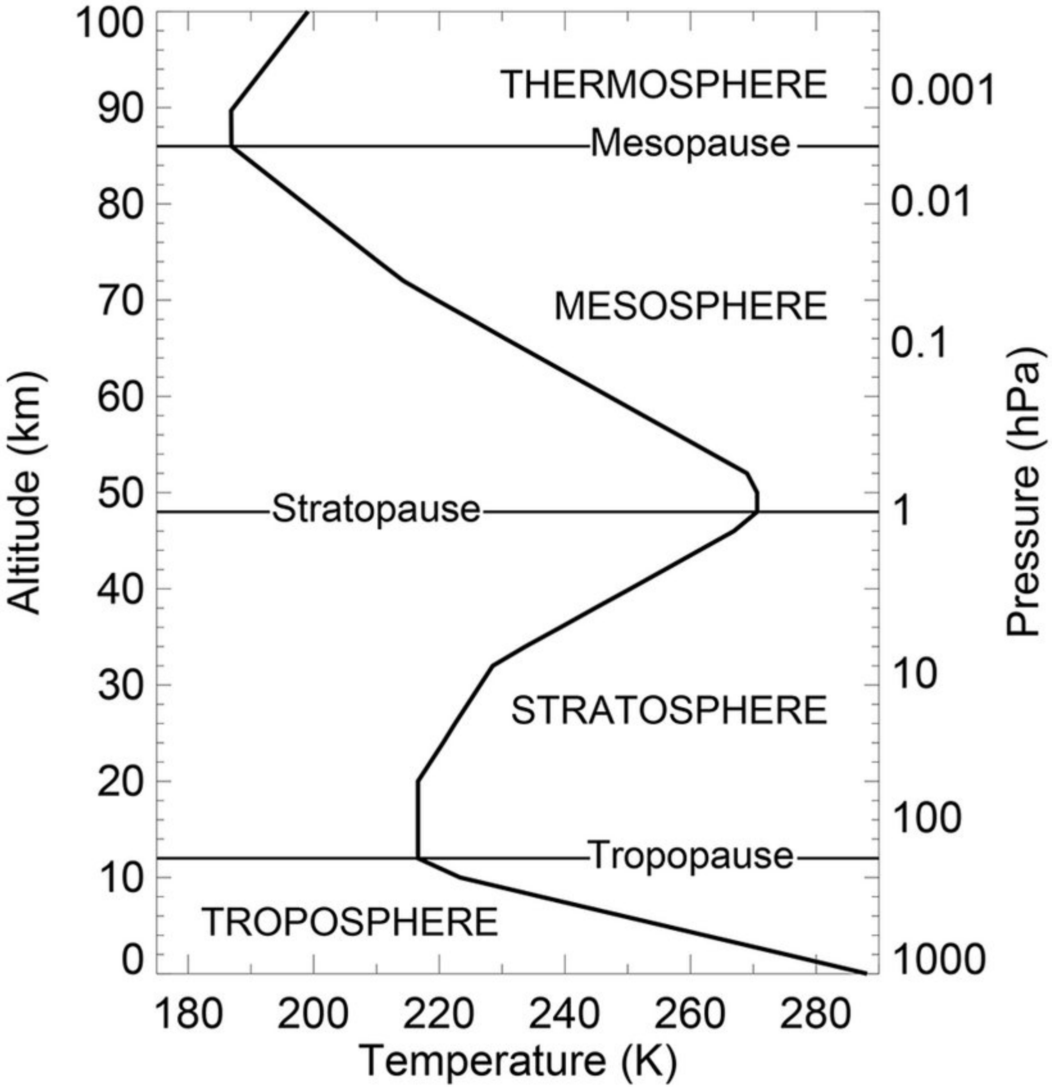
Planetary temperature increases when $\Delta Q_S > \Delta Q_C$
Planetary temperature decreases when $\Delta Q_S < \Delta Q_C$

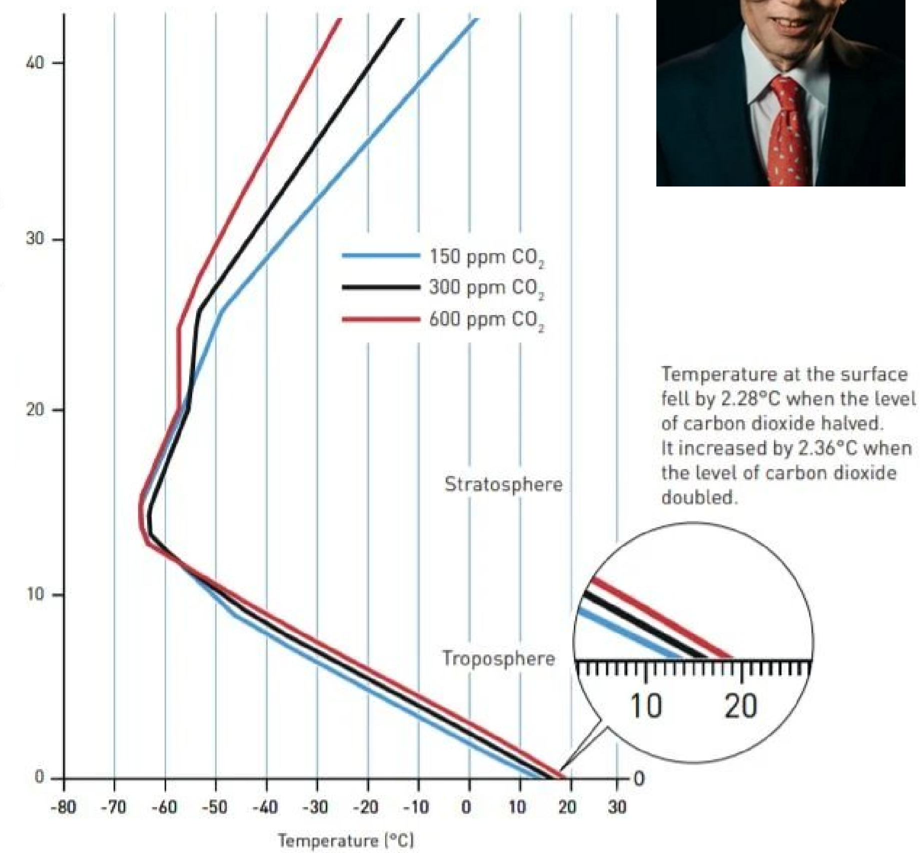


Electromagnetic radiation (shortwave – solar and logwave – far infrared) in the atmosphere. Transmission and scattering by various factors,.

Greenhouse effect – a principle

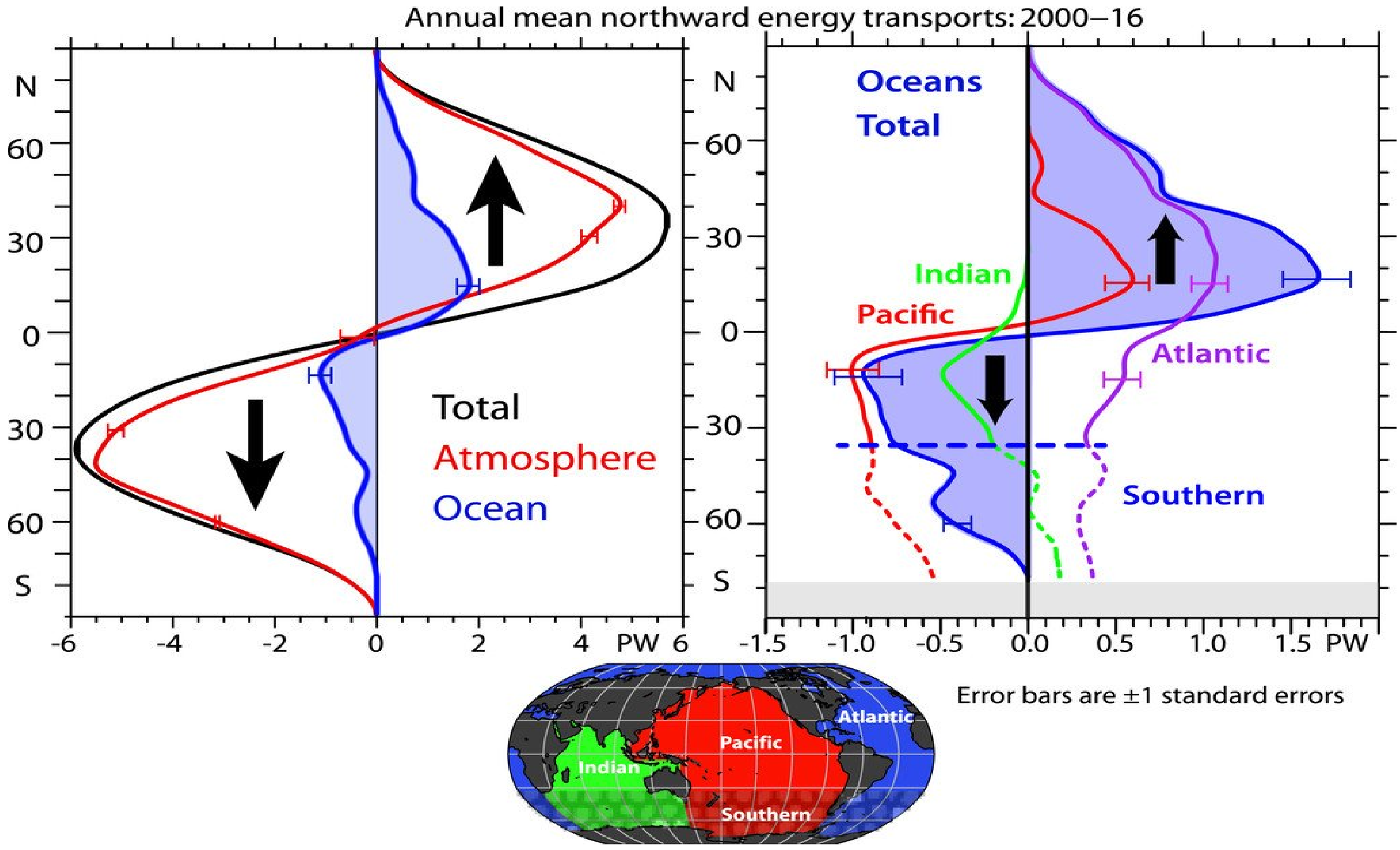






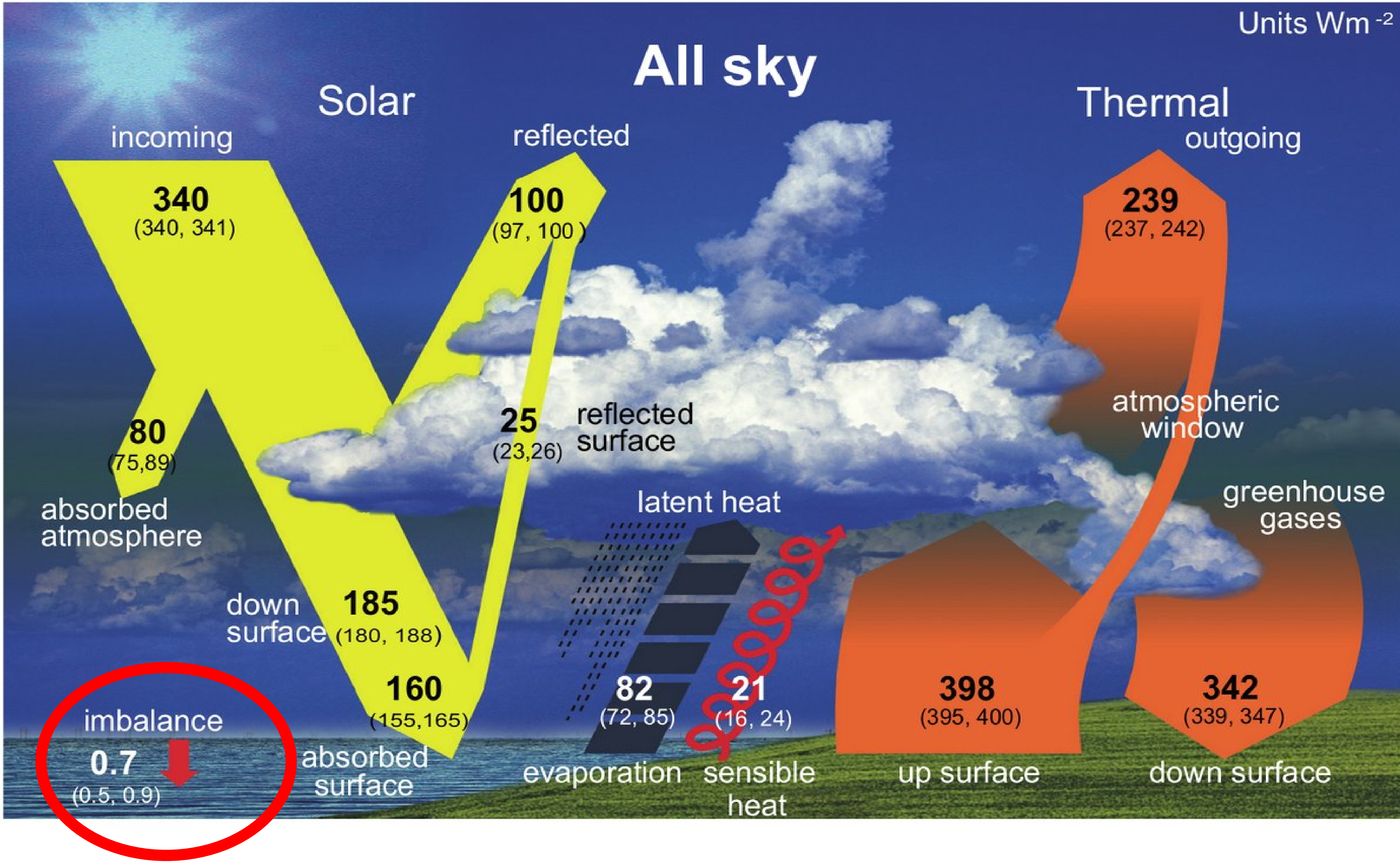
Manabe and Wetherald (1967) Thermal equilibrium of the atmosphere with a given distribution of relative humidity, Journal of the atmospheric sciences, Vol. 24, Nr 3, May.

Fig. 3.



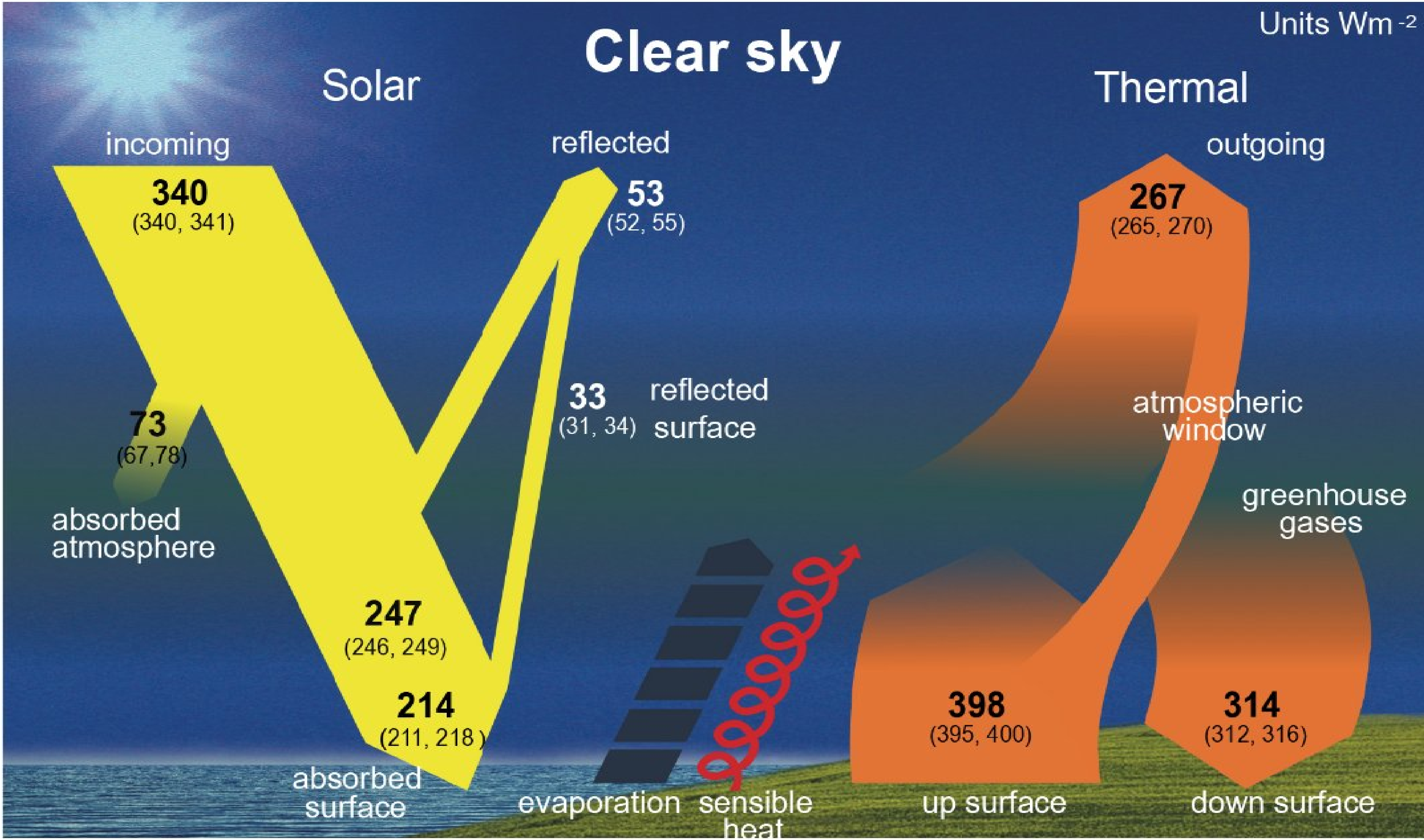
Zonal-mean annual long-term average meridional transports in PW for 2000–16. (left) Those inferred from TOA radiation (black), within the atmosphere from ERA-I (red), and the residual for the oceans (blue). (right) The breakdown for the oceans for the Atlantic (purple), Pacific (red), and Indian (green) and combined for the Southern Ocean south of 35°S (blue) in PW. (bottom) The domains used and the standard errors are 1σ. The ITF transport is not included here.

https://doi.org/10.1175/JCLI-D-18-0872.1



Averaged energy budget of the climate system in W/m².

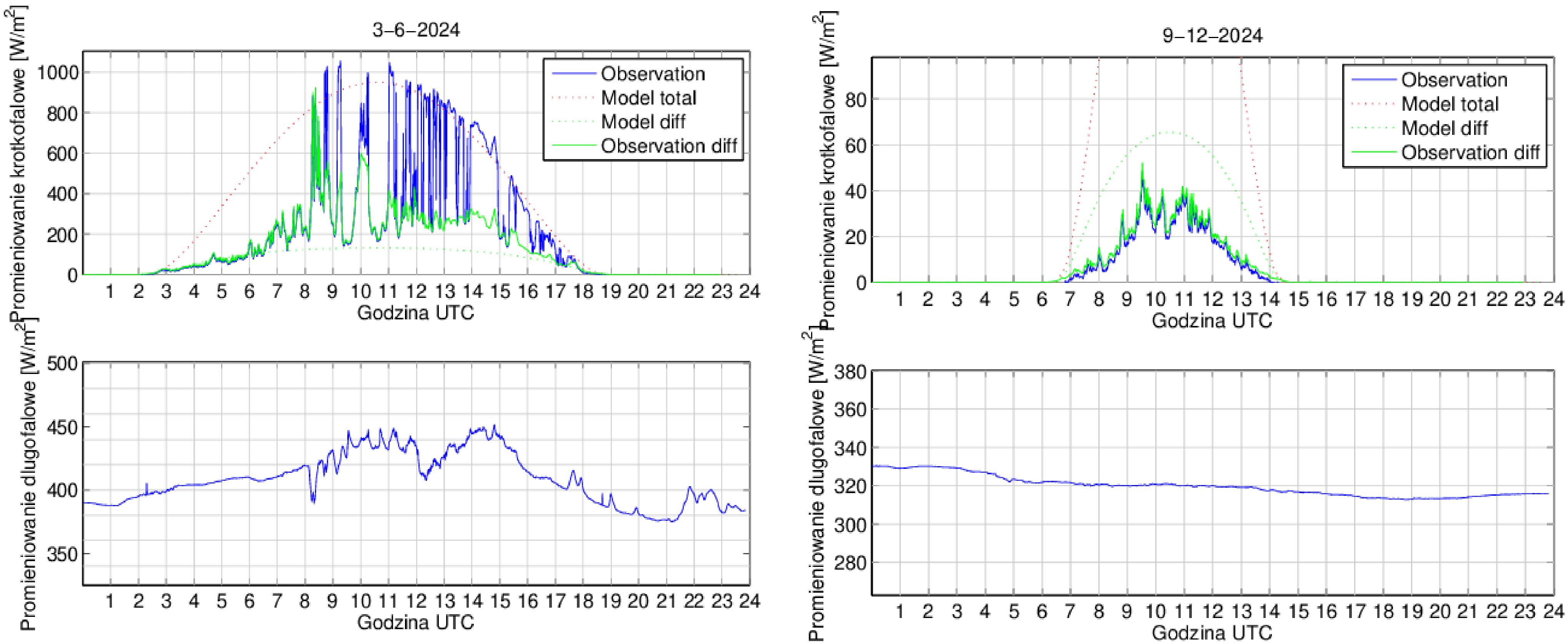
https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-2/



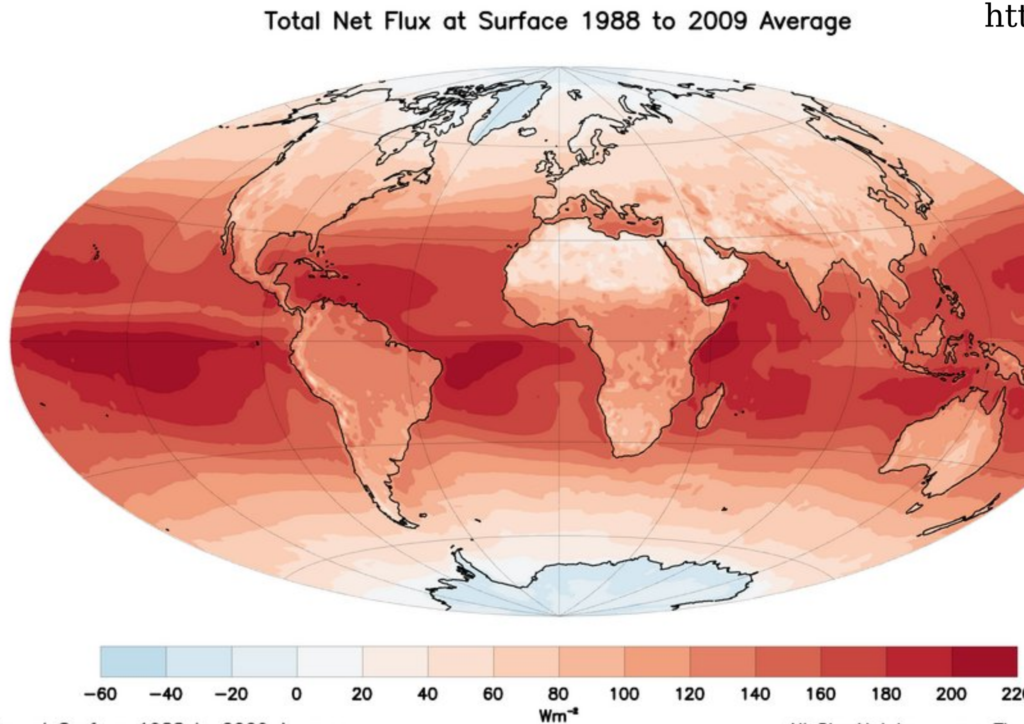
Hypothetic average mean energy budget of the Earth without considerations of cloud effects.

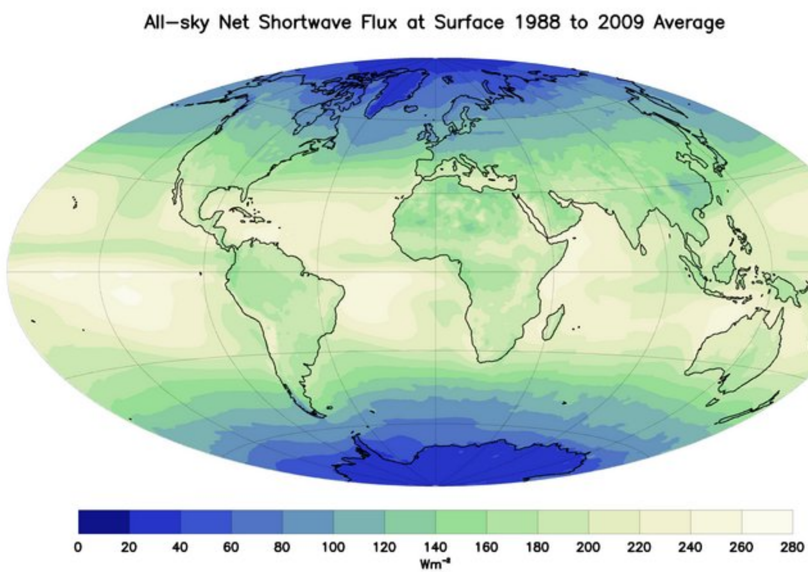
https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-2/

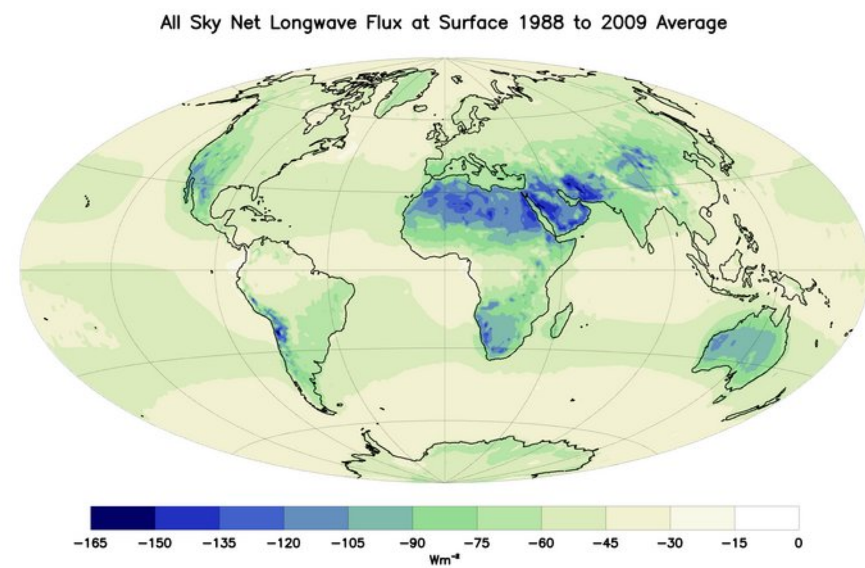
Energy fluxes in Warsaw - examples



https://science.larc.nasa.gov/gewex-srb/

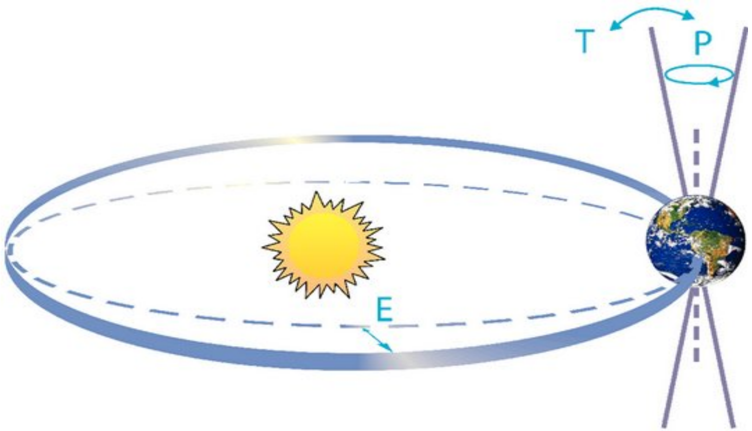


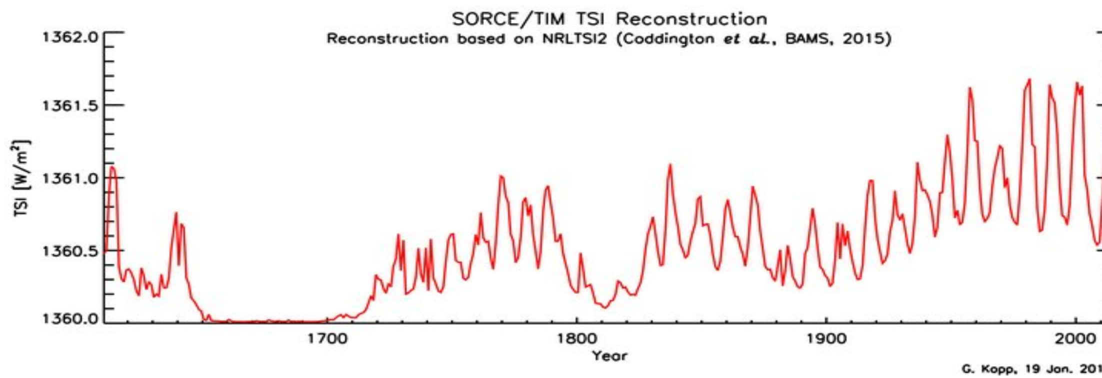


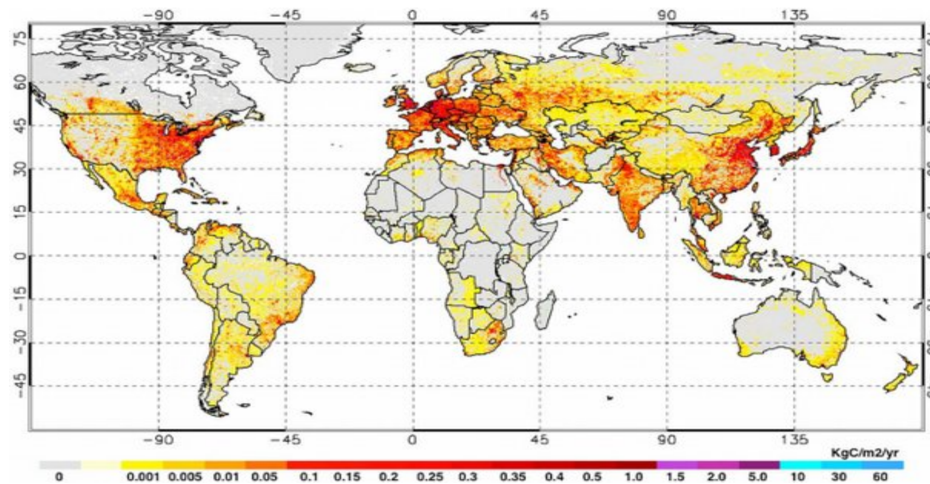


Forcings and **feedbacks** in climate system.

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





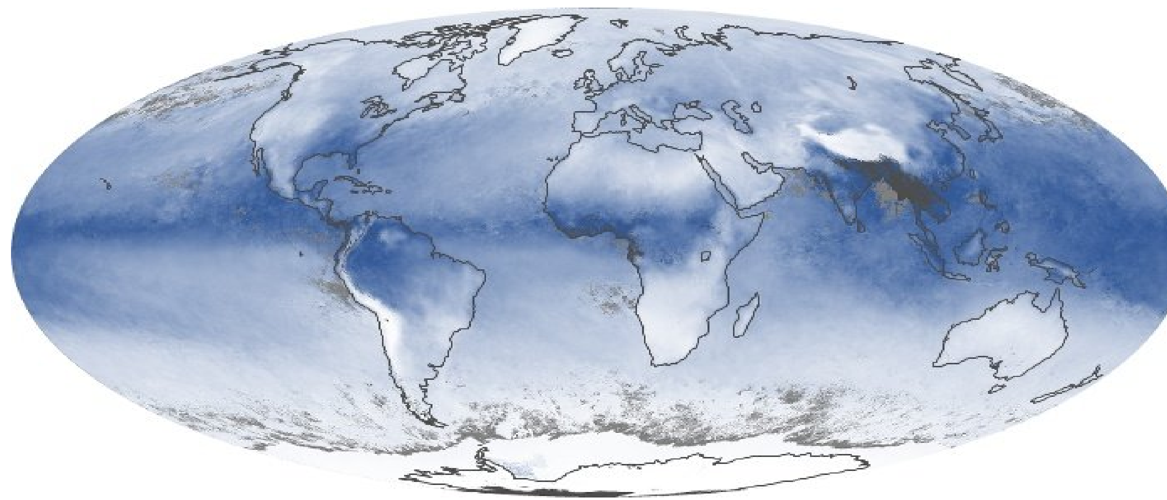


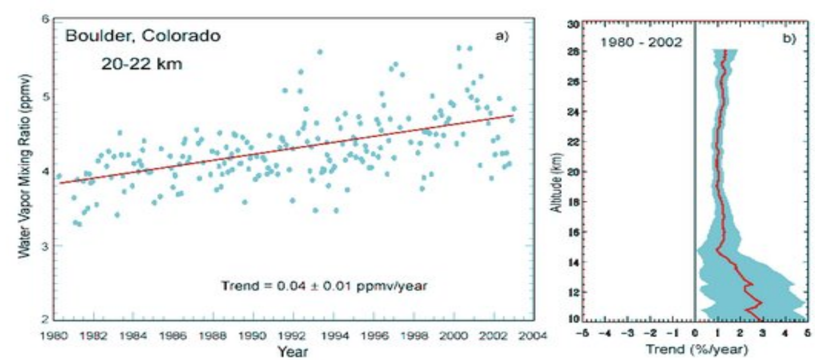
Forcings and **feedbacks** in climate system.

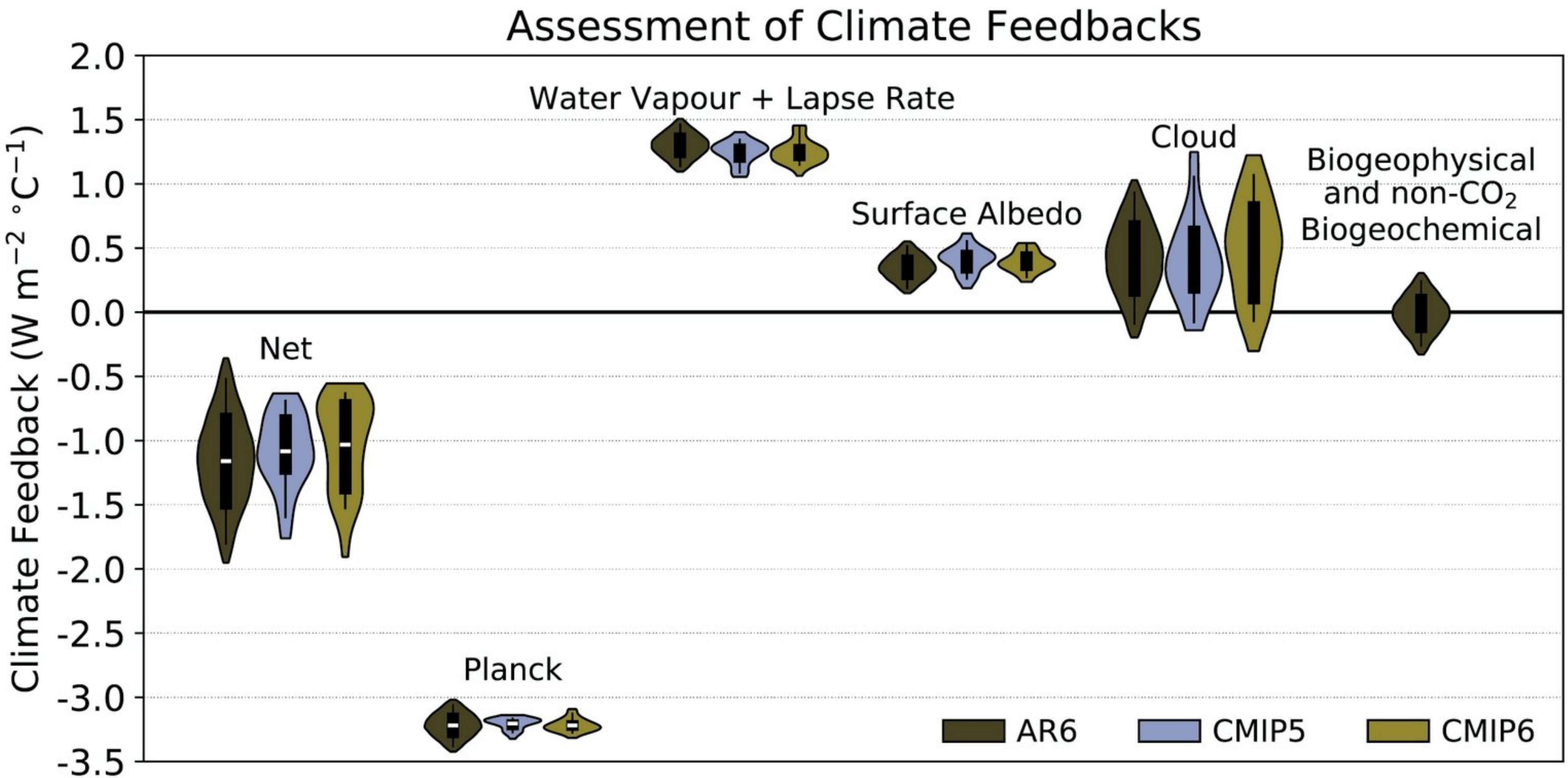
Climate **feedbacks** are processes that **result from forcings**, and cause additional climate change.


1979 SSMI Composite Data


2003 SSMI Composite Data

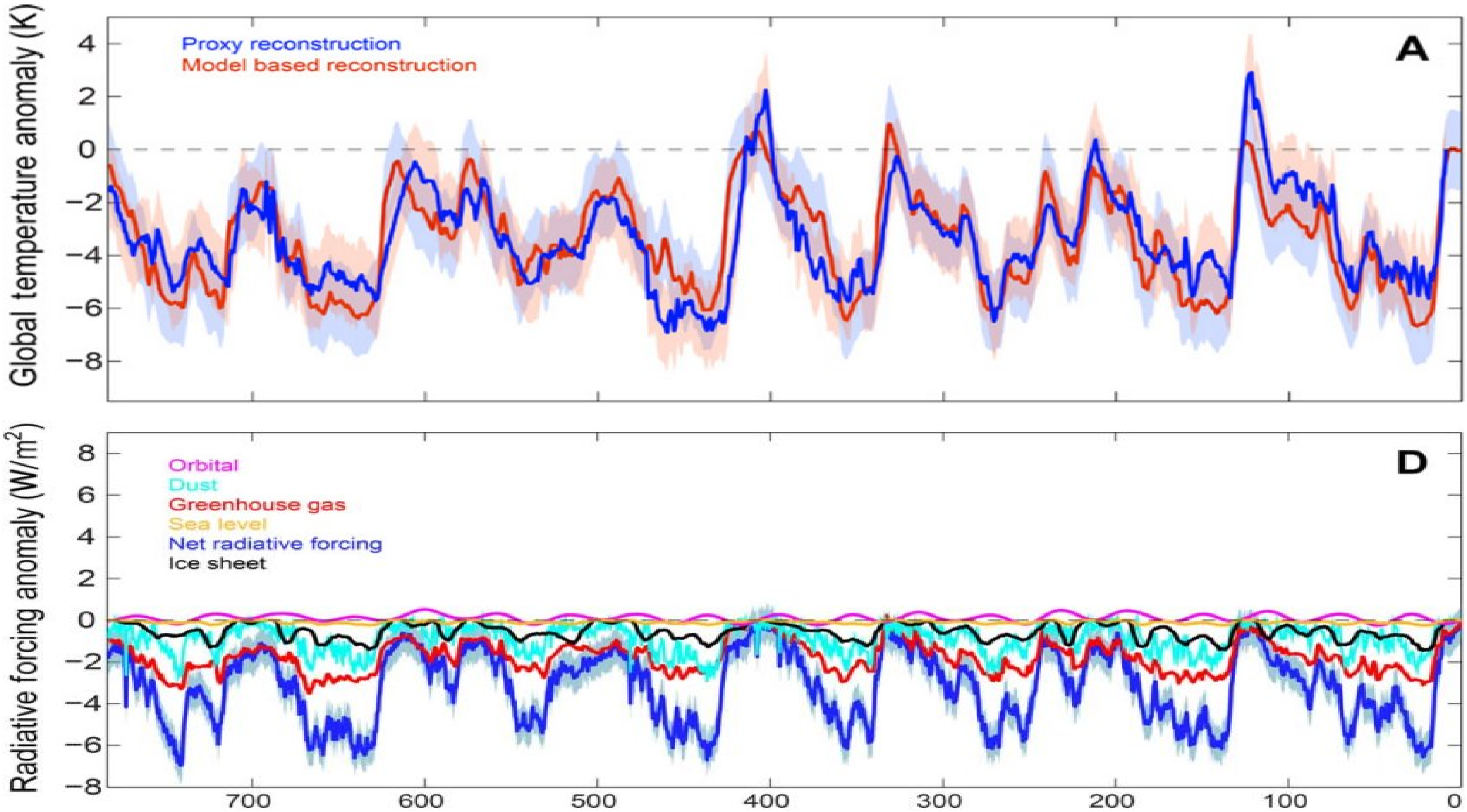






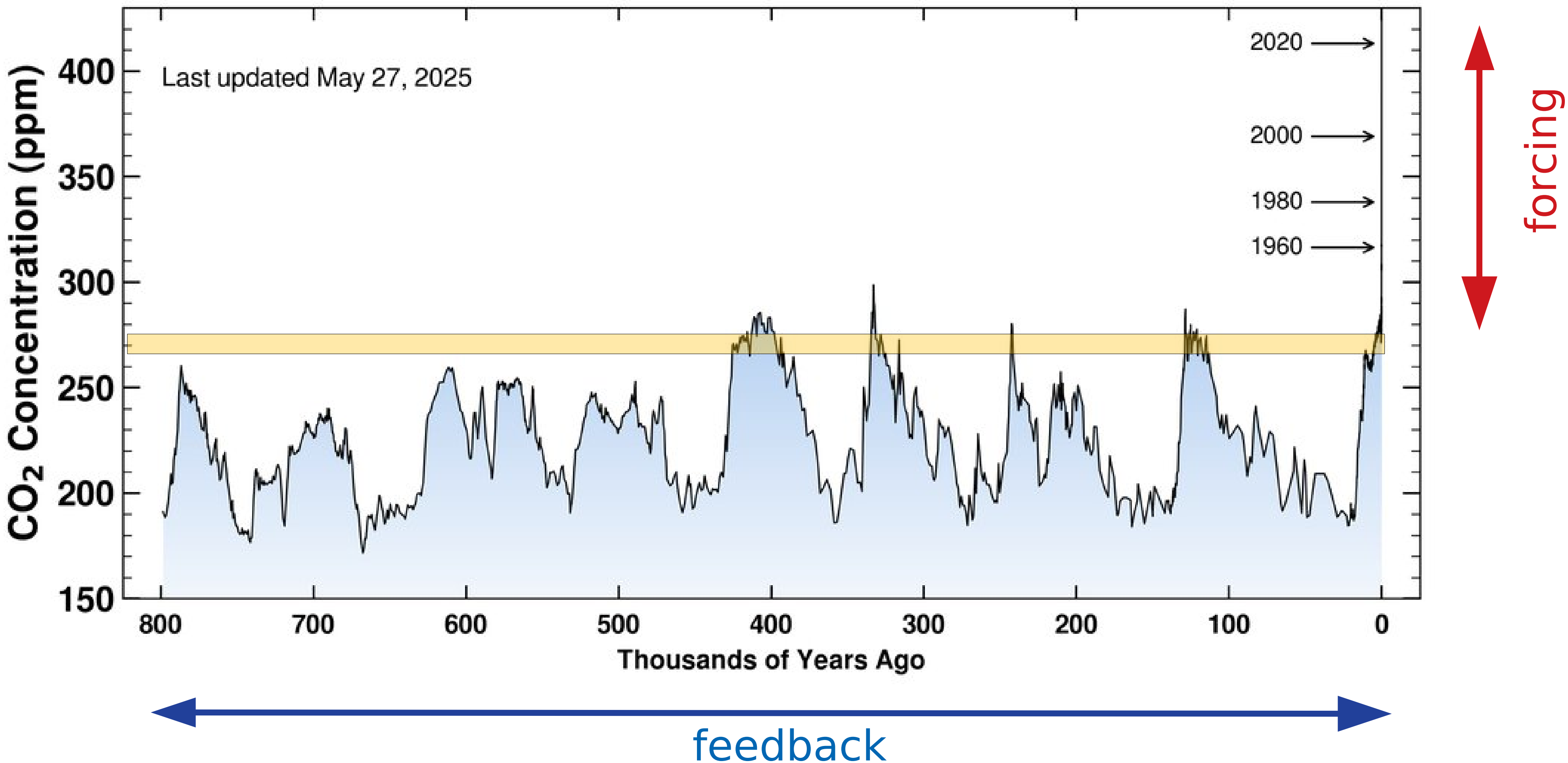
https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-10/

Orbital forcing (A) and **system feedbacks** (A) lead to remarkable **radiative forcings** (D) and consecutive **temperature variations** (A) which explains mechanism of ice ages.

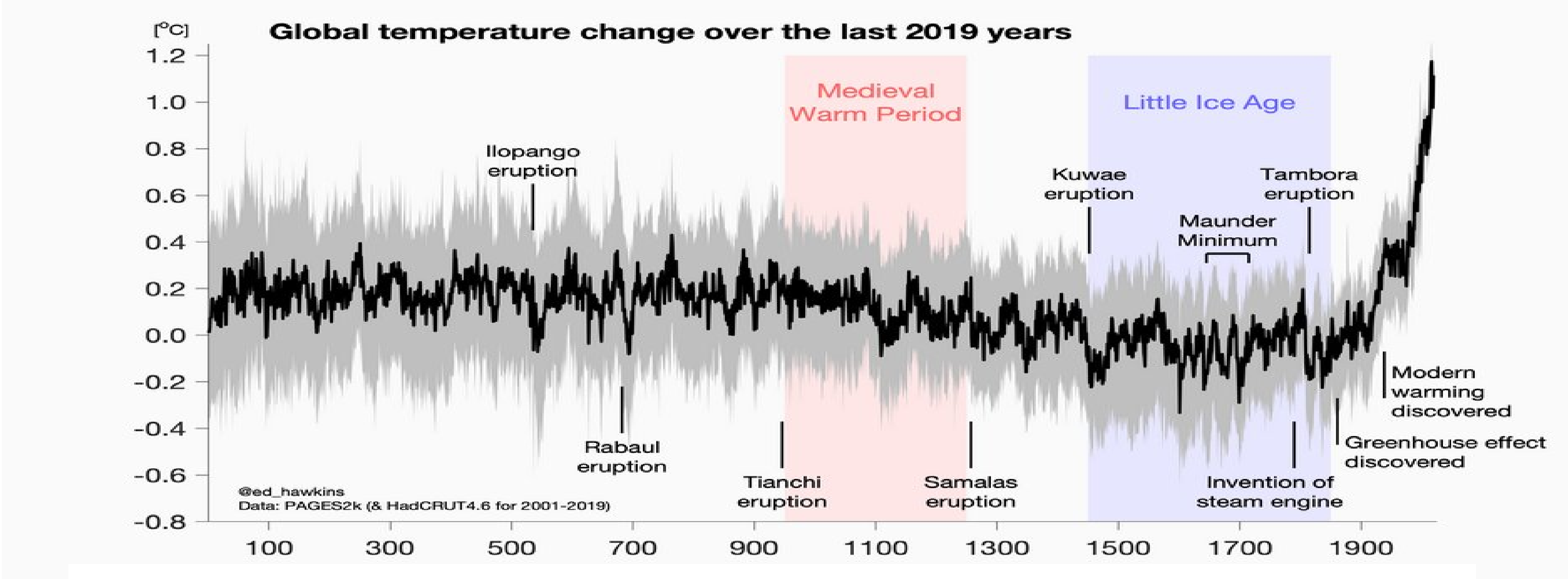


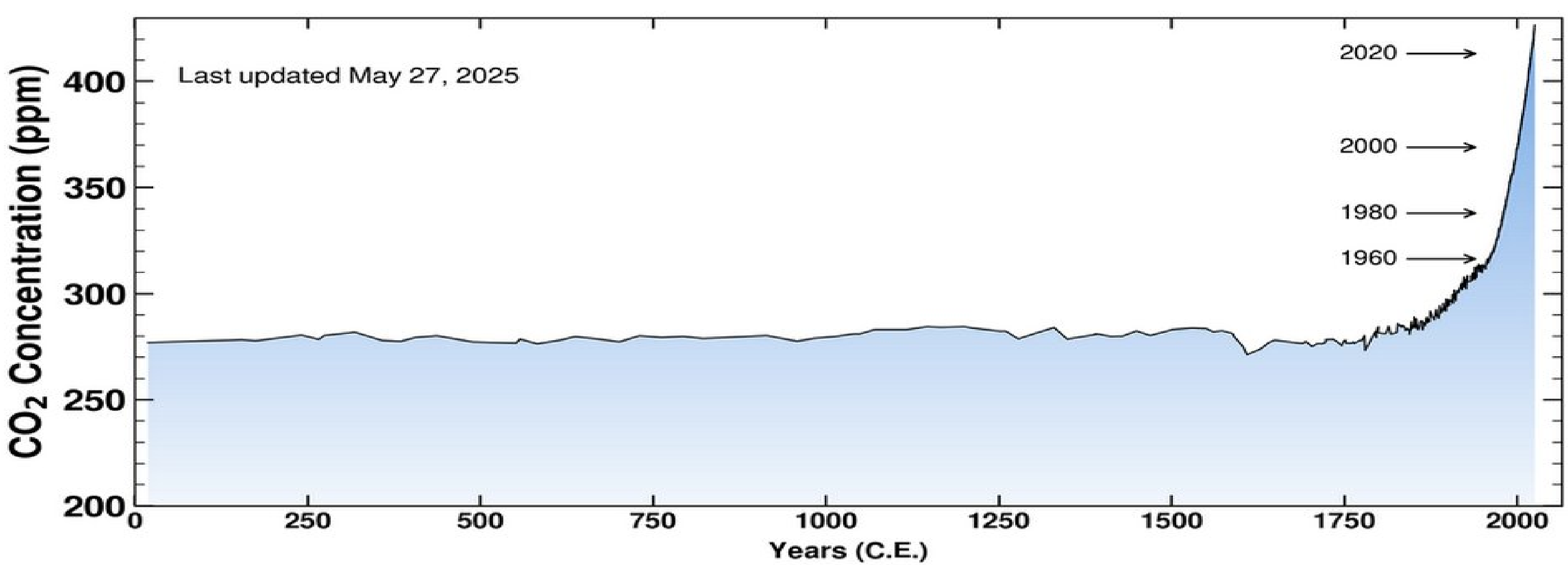
Friedrich et al., Science Advances 09 Nov 2016: Vol. 2, no. 11, e1501923 DOI: 10.1126/sciadv.1501923

CO_2 concentration: once feedback, today forcing



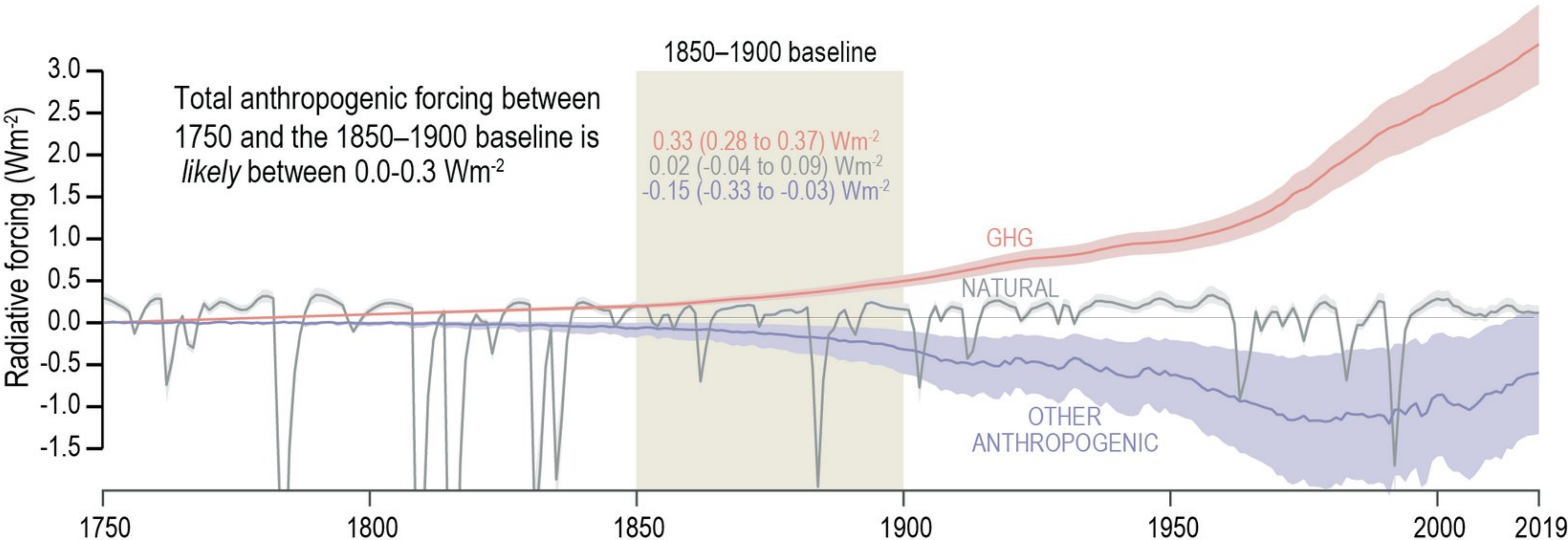
https://keelingcurve.ucsd.edu/



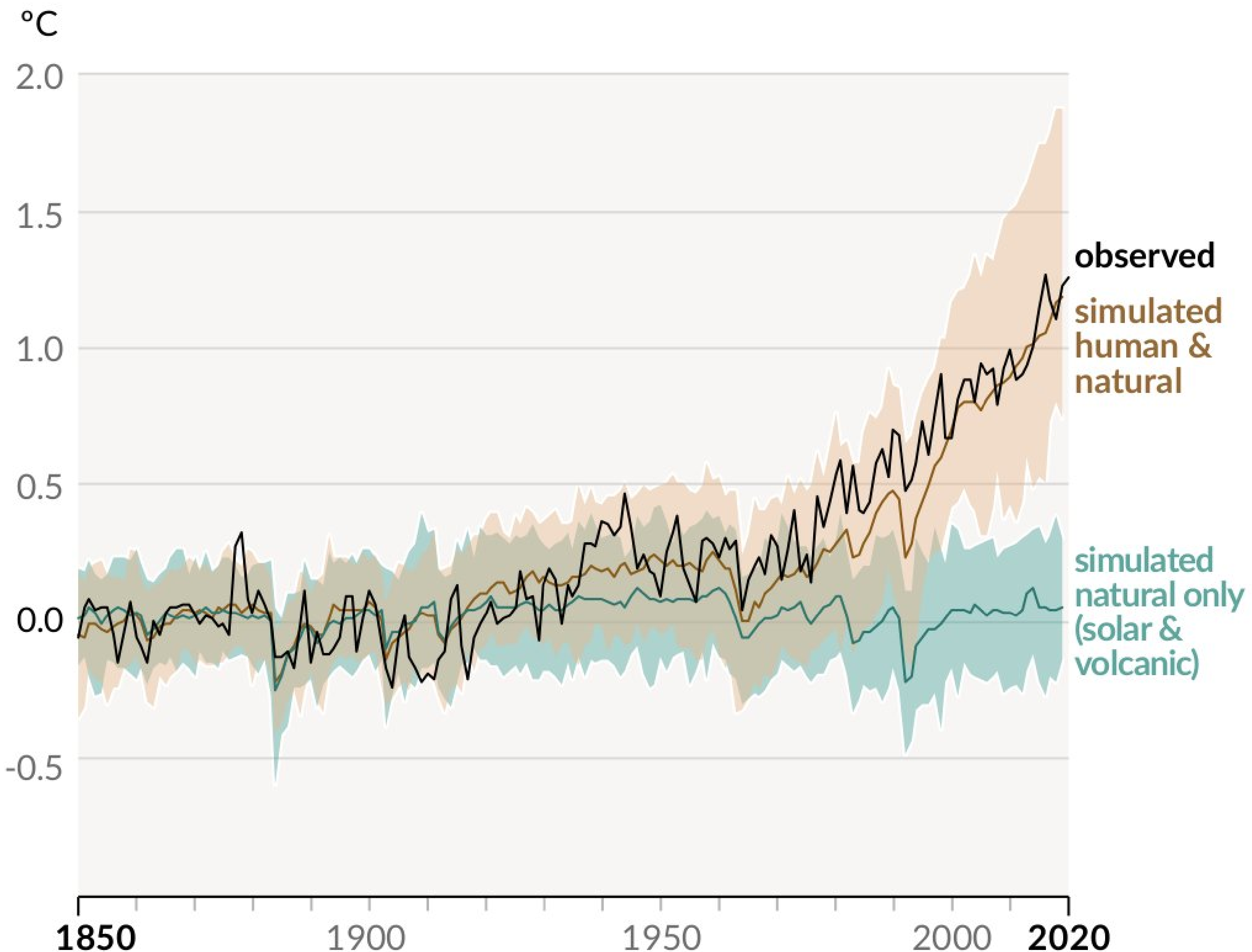


https://keelingcurve.ucsd.edu/

Another anthropogenic forcing: aerosols

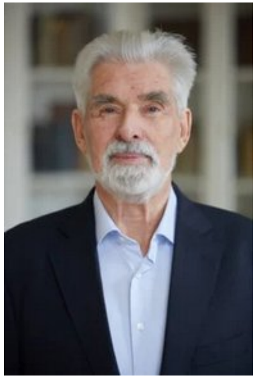


https://www.ipcc.ch/report/ar6/wg1/figures/chapter-1

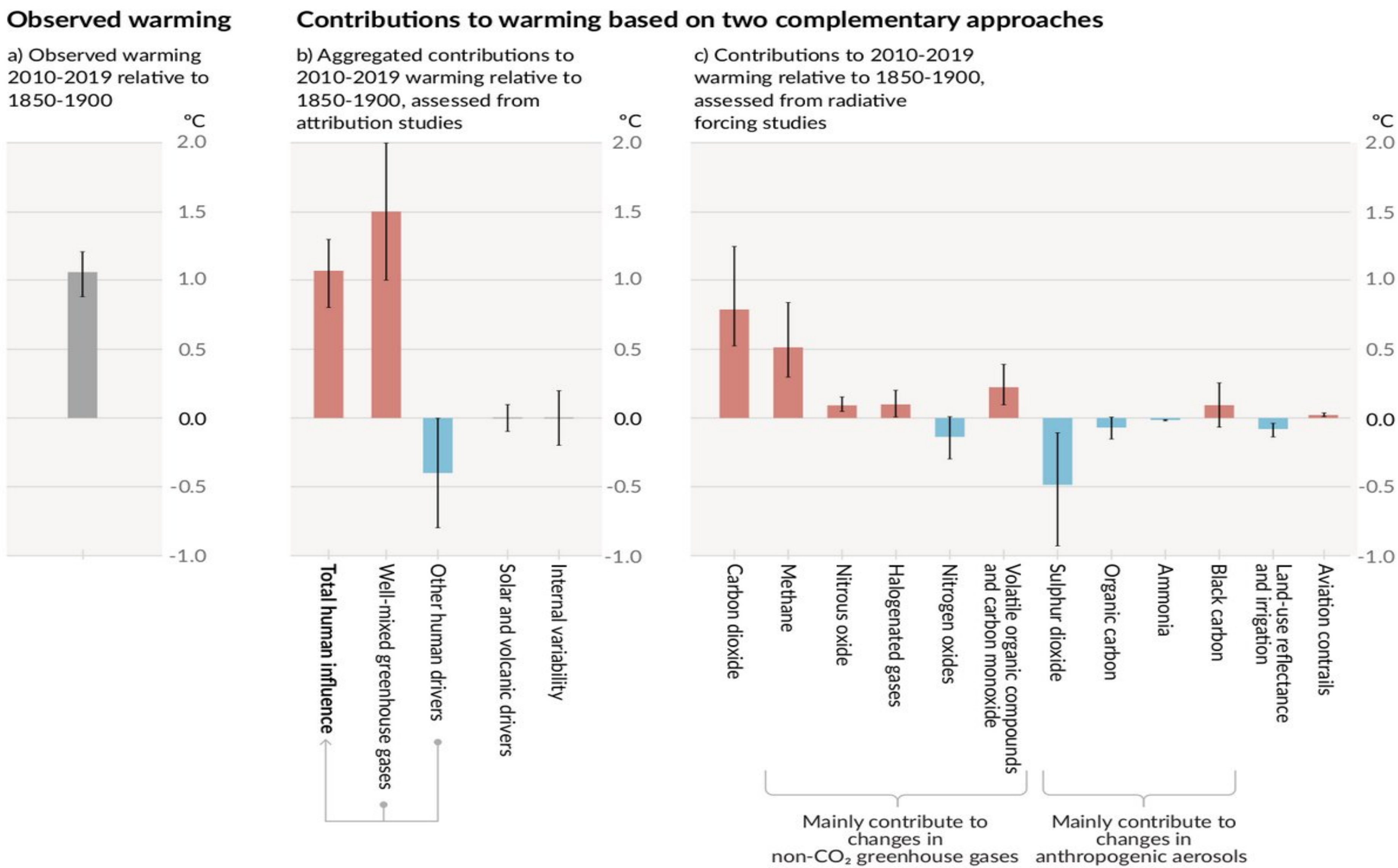


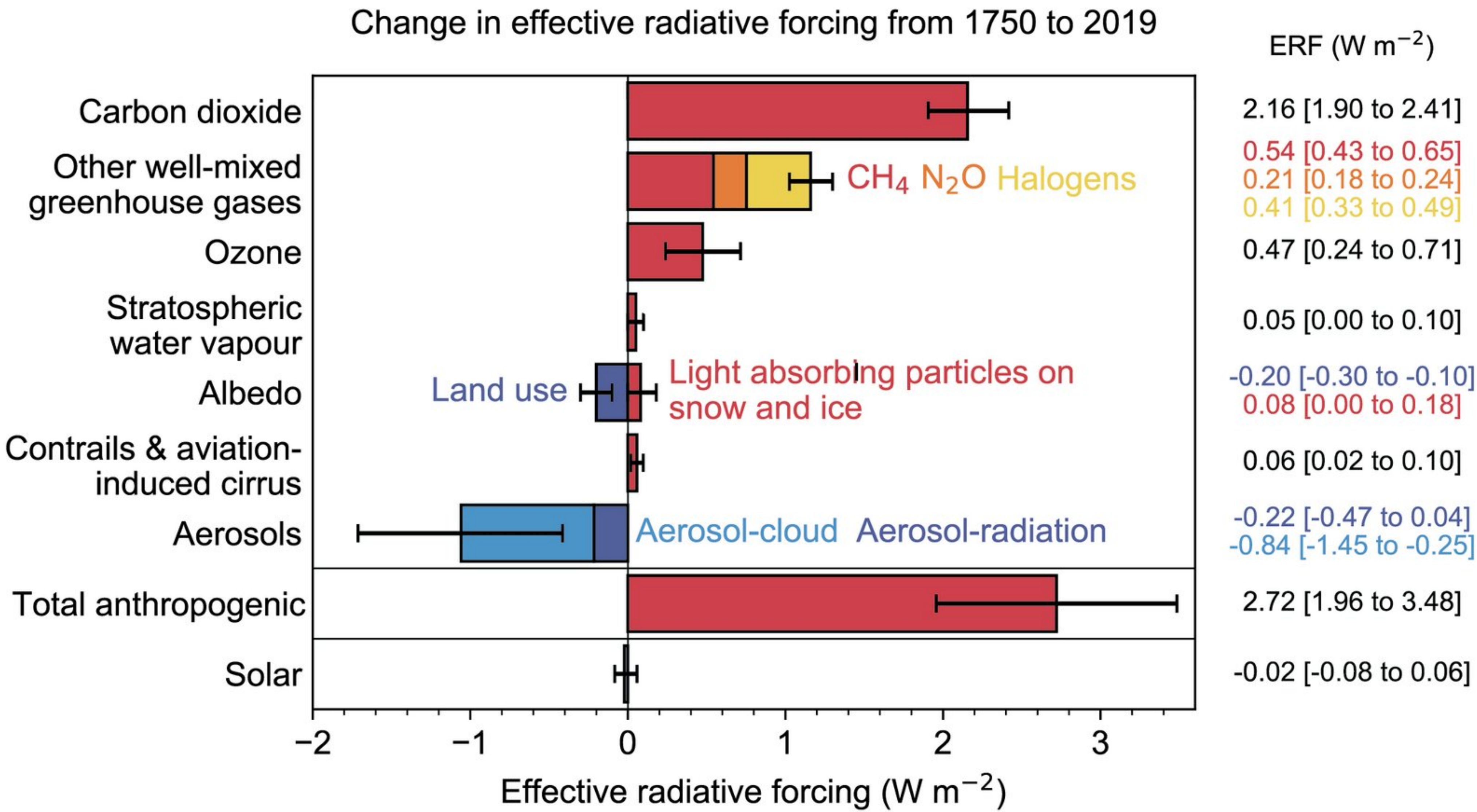
Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850-2020)

IPCC 2021



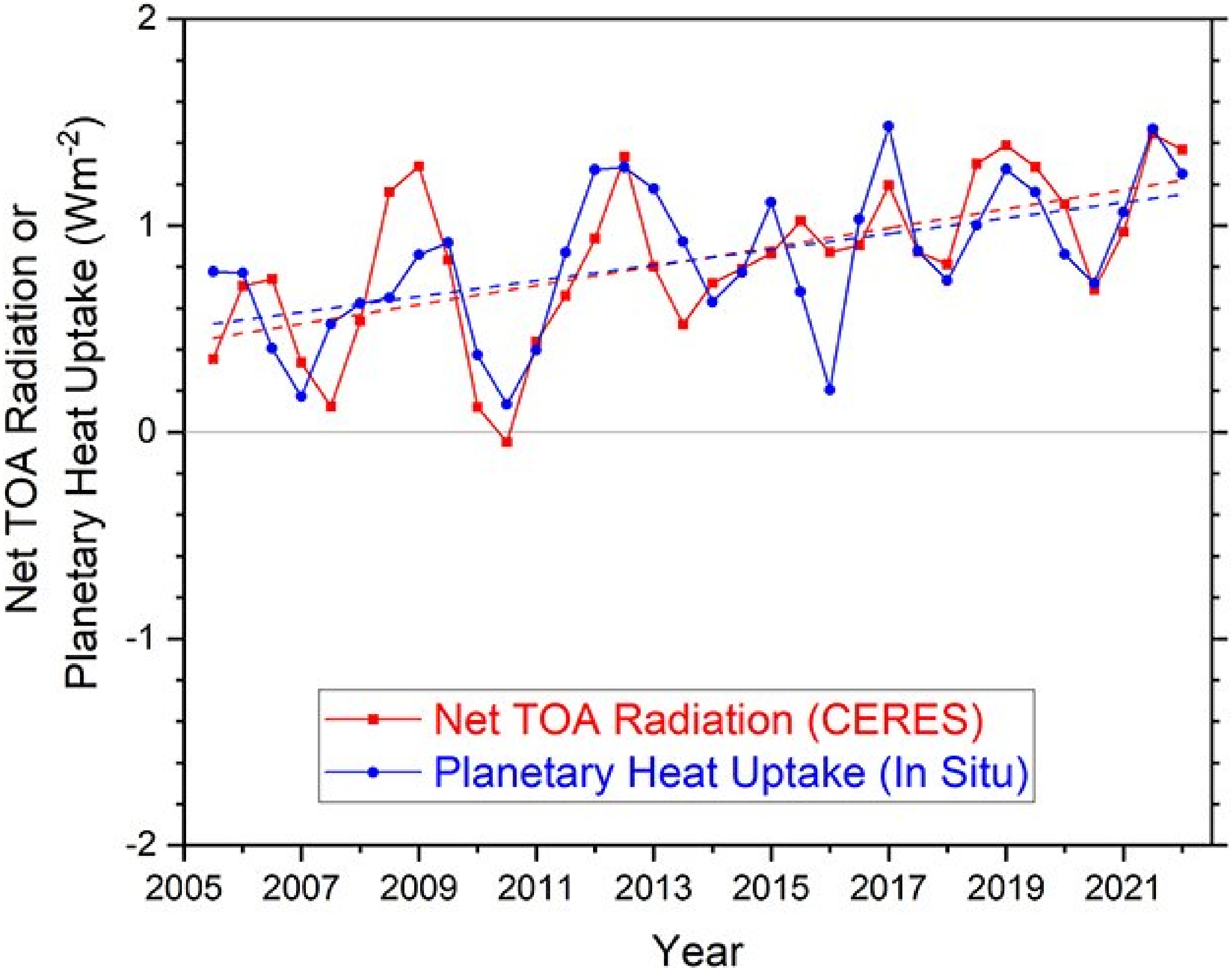
Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling





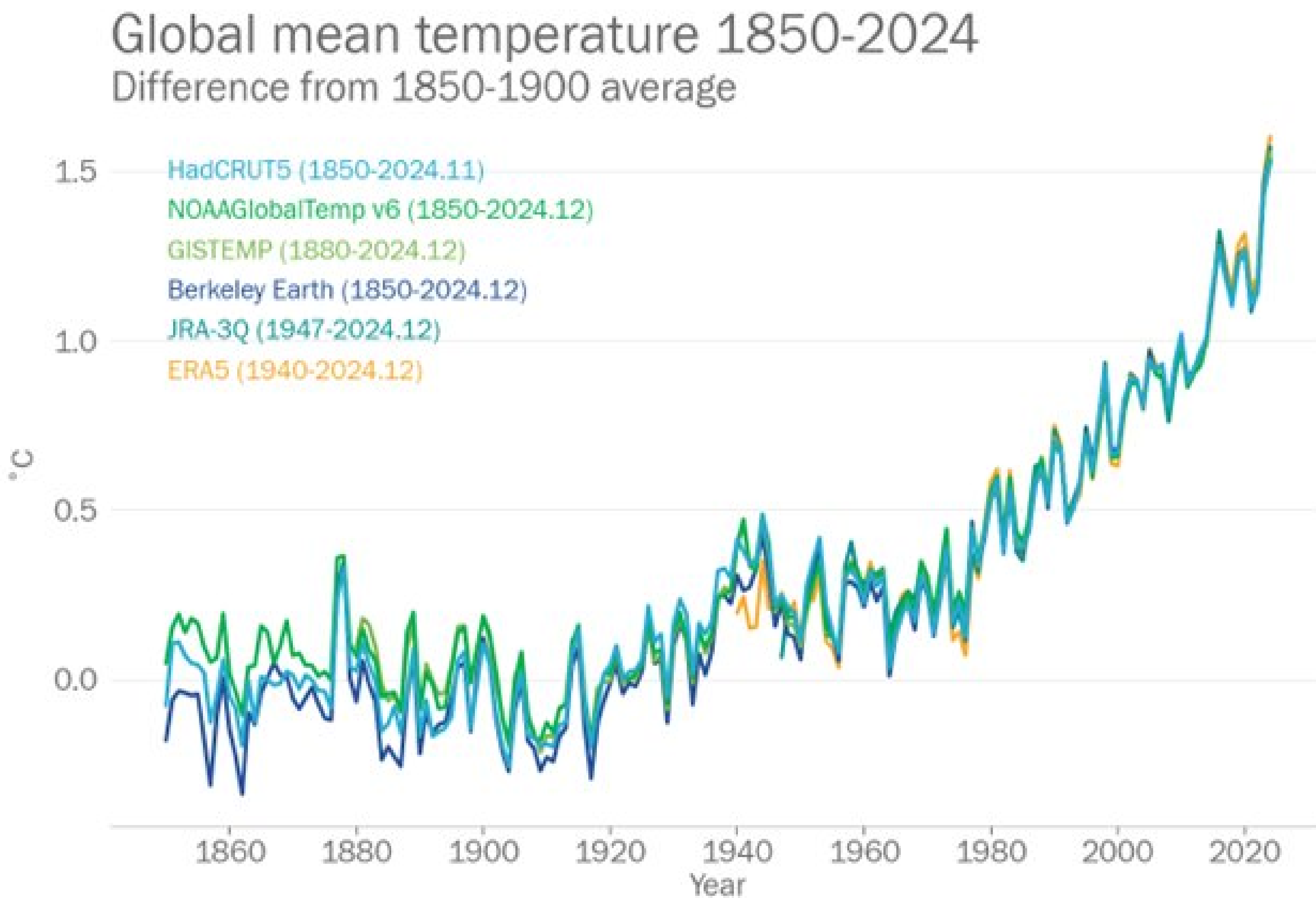
https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-6/

Energy imbalance increases ...



Schmidt GA, et al., 2023, CERESMIP: a climate modeling protocol to investigate recent trends in the Earth's Energy Imbalance. *Front. Clim.* 5:1202161. https://doi.org/10.3389/fclim.2023.1202161

... and surface temperature increases.



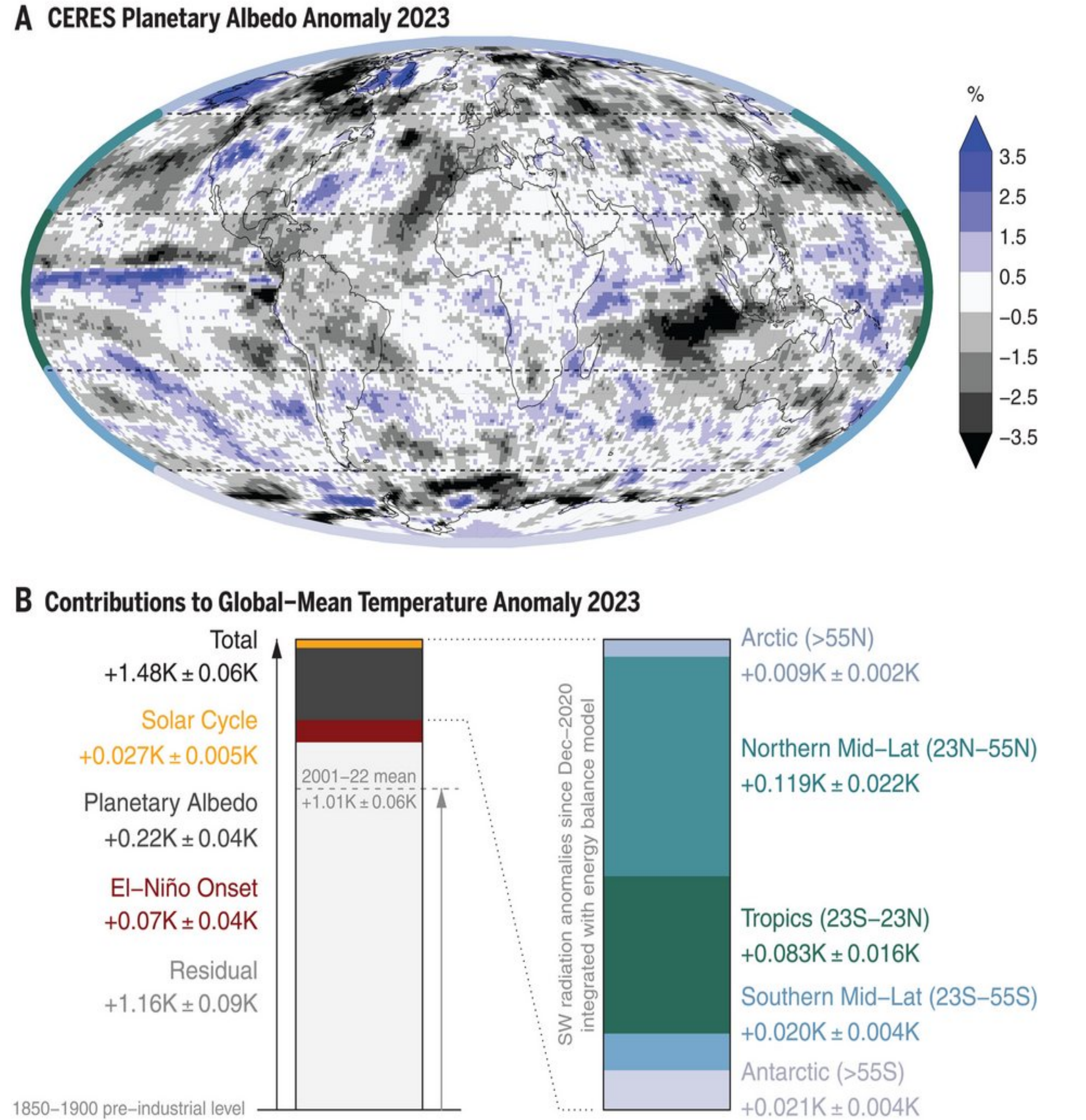
https://wmo.int/news/media-centre/wmo-confirms-2024-warmest-year-record-about-155degc-above-pre-industrial-level

RESEARCH ARTICLE | GLOBAL WARMING

Recent global temperature surge intensified by record-low planetary albedo

HELGE F. GOESSLING, THOMAS RACKOW, AND THOMAS JUNG Authors Info & Affiliations

SCIENCE • 5 Dec 2024 • Vol 387, Issue 6729 • pp. 68-73 • DOI: 10.1126/science.adq7280



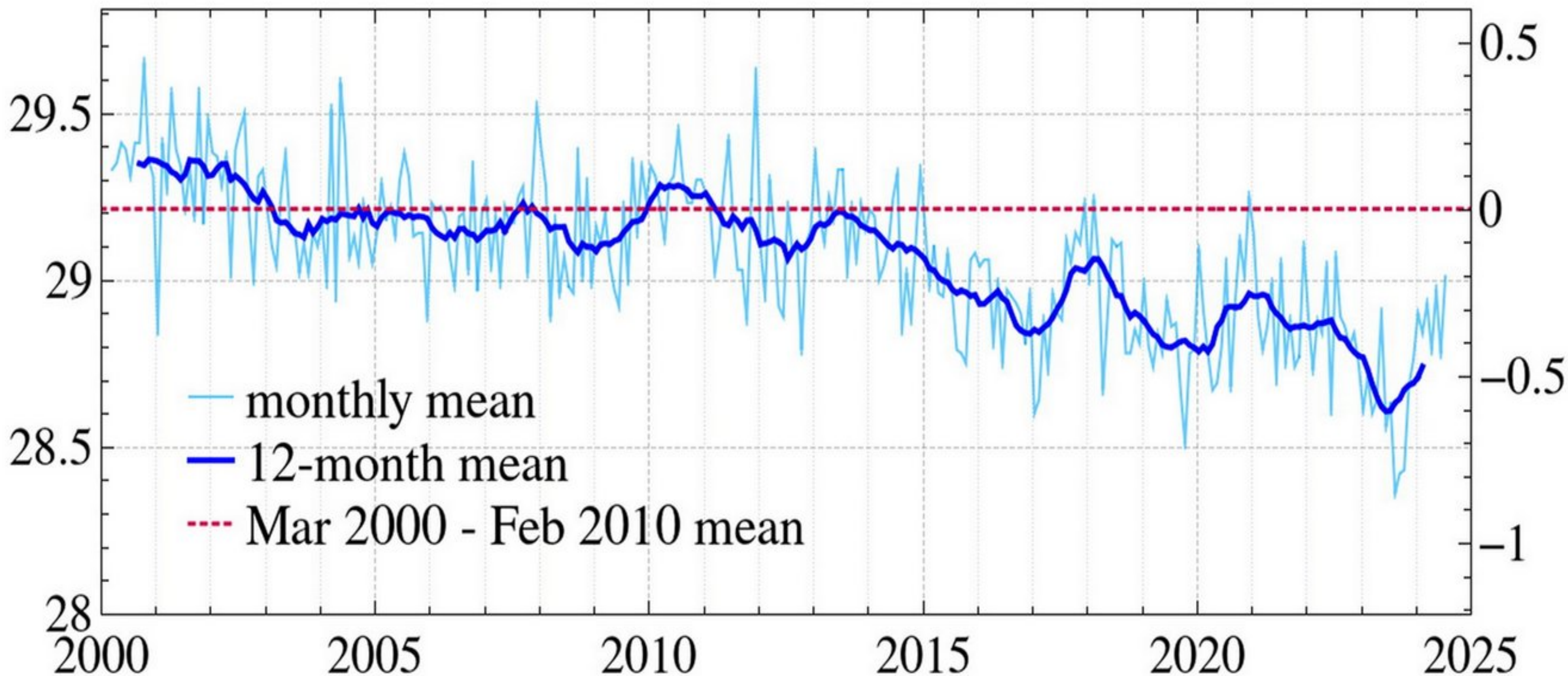
Global Warming Has Accelerated: Are the United Nations and the Public Well-Informed?

James E. Hansen, Pushker Kharecha, Makiko Sato, George Tselioudis, Joseph Kelly, Susanne E. Bauer, Reto Ruedy, Eunbi Jeong, Qinjian Jin, Eric Rignot, Isabella Velicogna, Mark R. Schoeberl, Karina von Schuckmann, Joshua Amponsem, Junji Cao, Anton Keskinen, Jing Li & Anni Pokela

https://doi.org/10.1080/00139157.2025.2434494

PUBLISHED ONLINE:
03 February 2025

Figure 6. Earth's albedo (reflectivity, in percent), seasonality removed.**



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https://doi.org/10.1080/00139157.2025.2434494

PUBLISHED ONLINE:
03 February 2025

Figure 10 of 39

Figure S5. Sulfate aerosols and sulfur limit on emissions, p.p.t.v. = parts per trillion by volume.

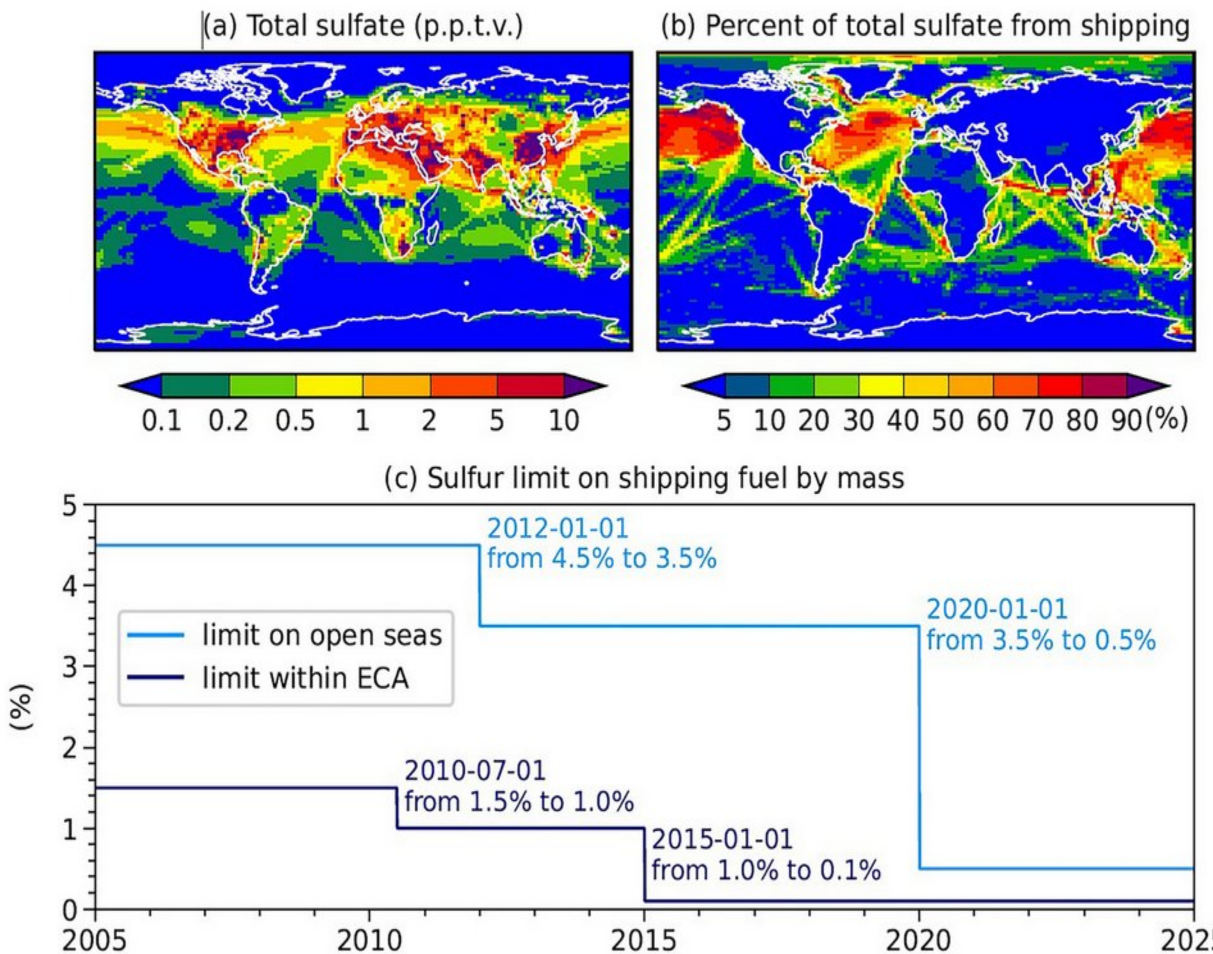

Figure 11. Global and 30-60°N Sea Surface Temperature anomalies.**

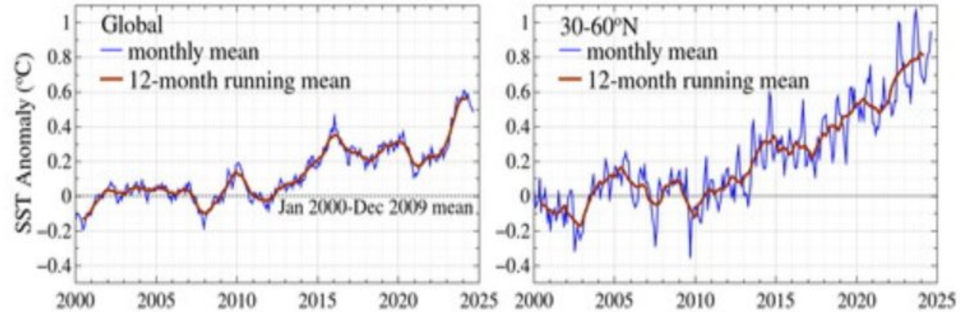

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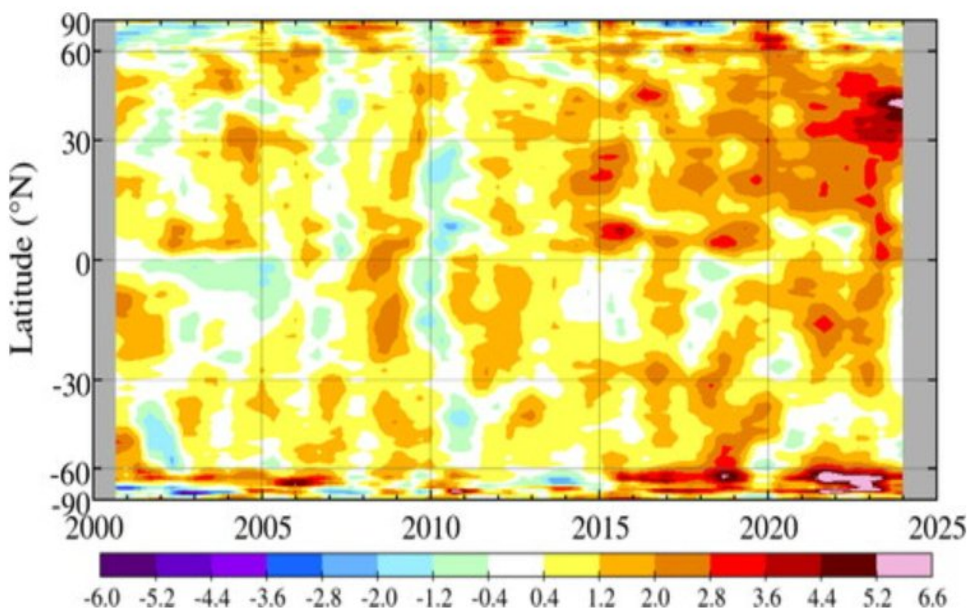
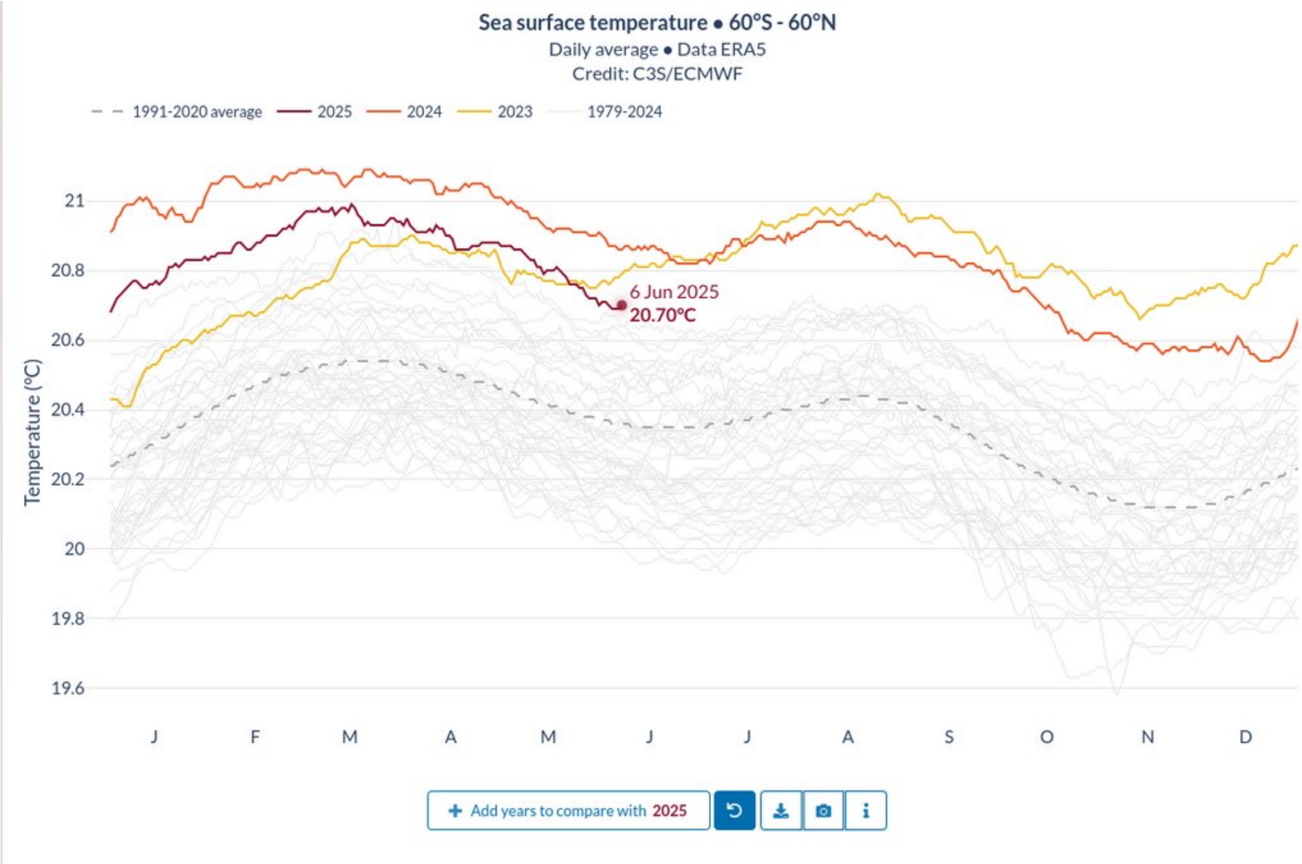
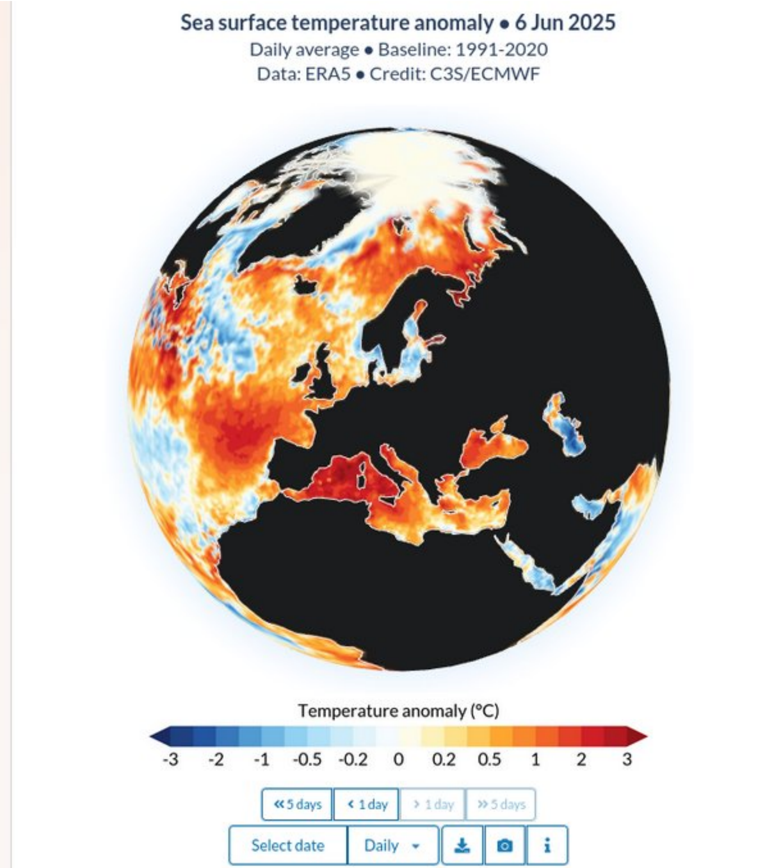
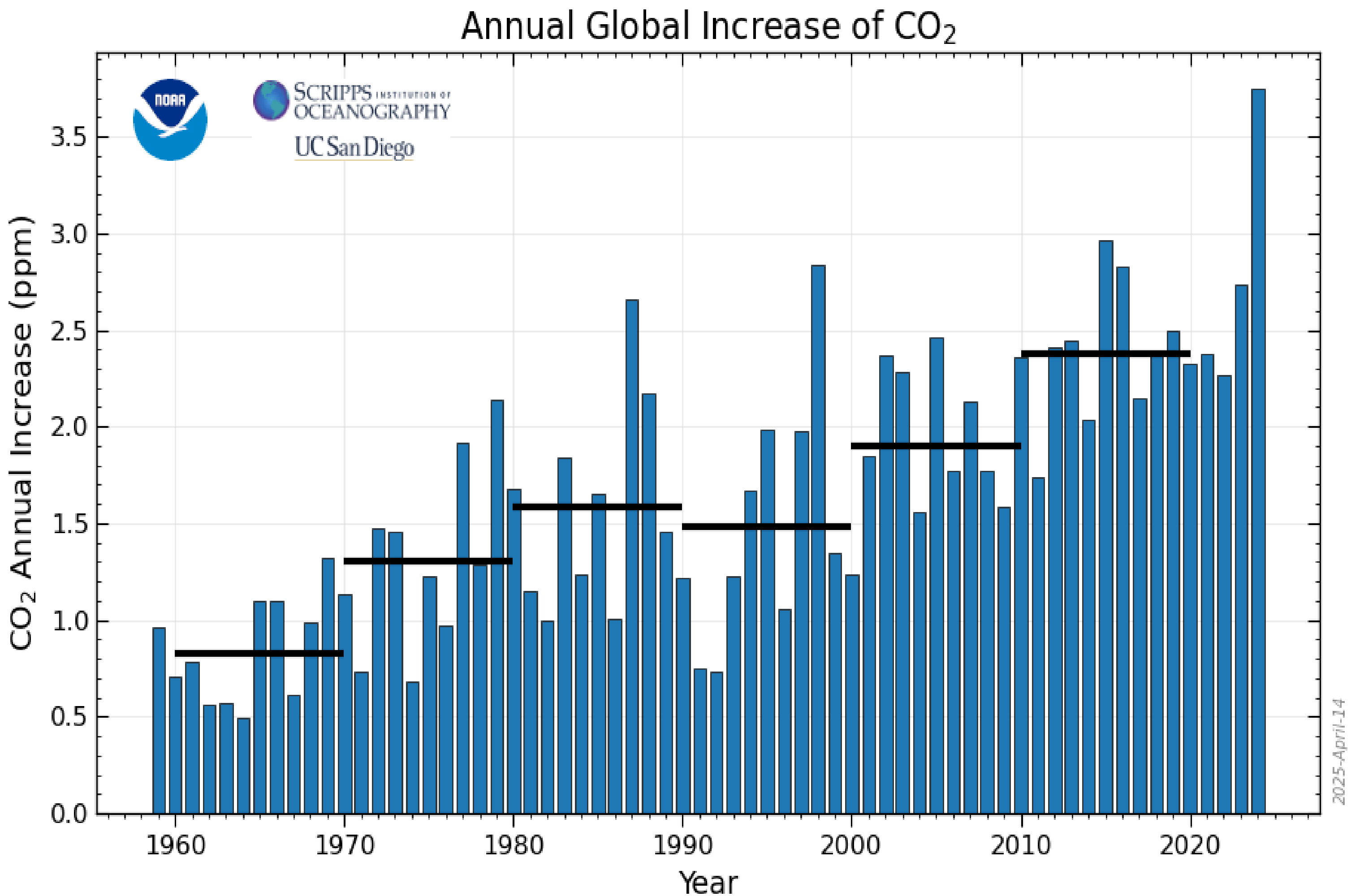
Figure 12. Zonal-mean Earth energy balance over ocean (W/m^2).**



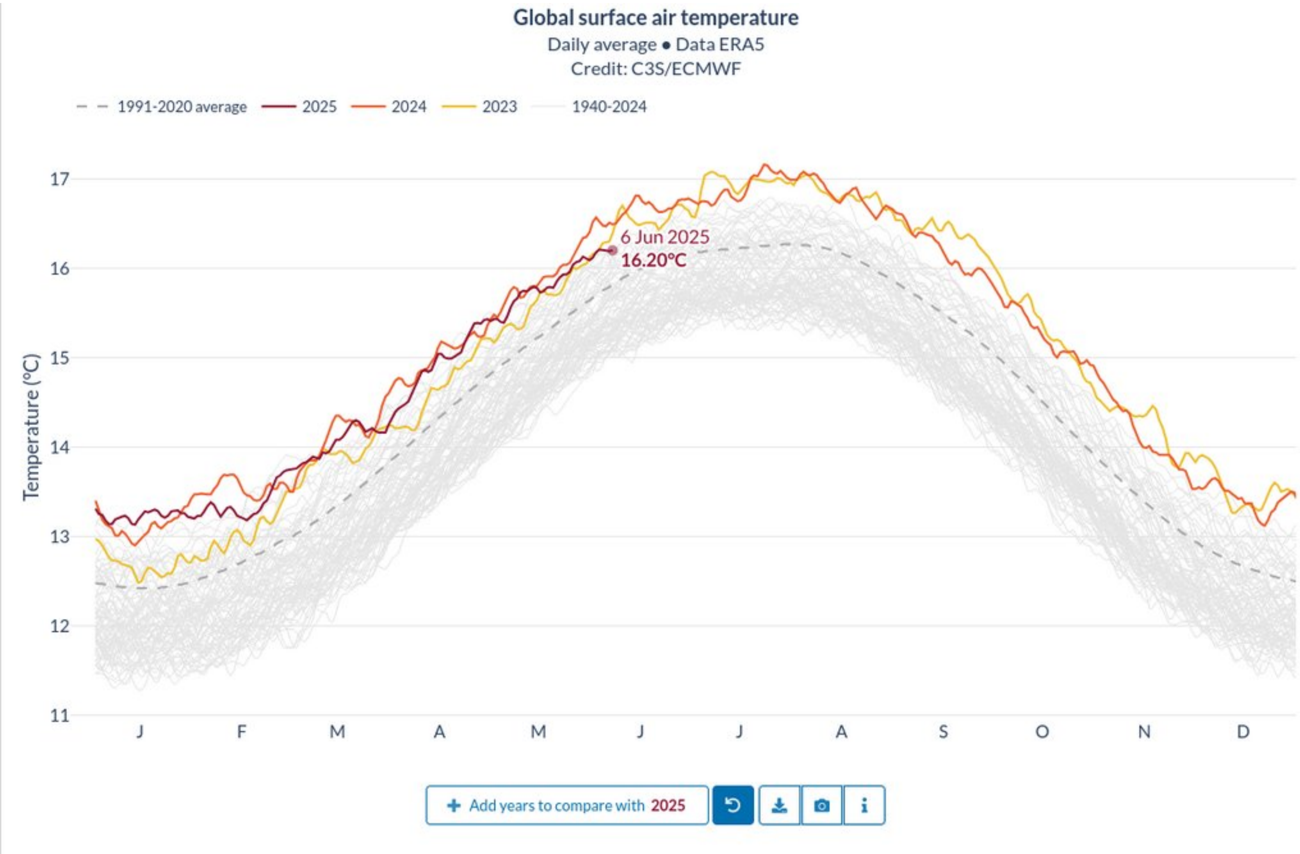


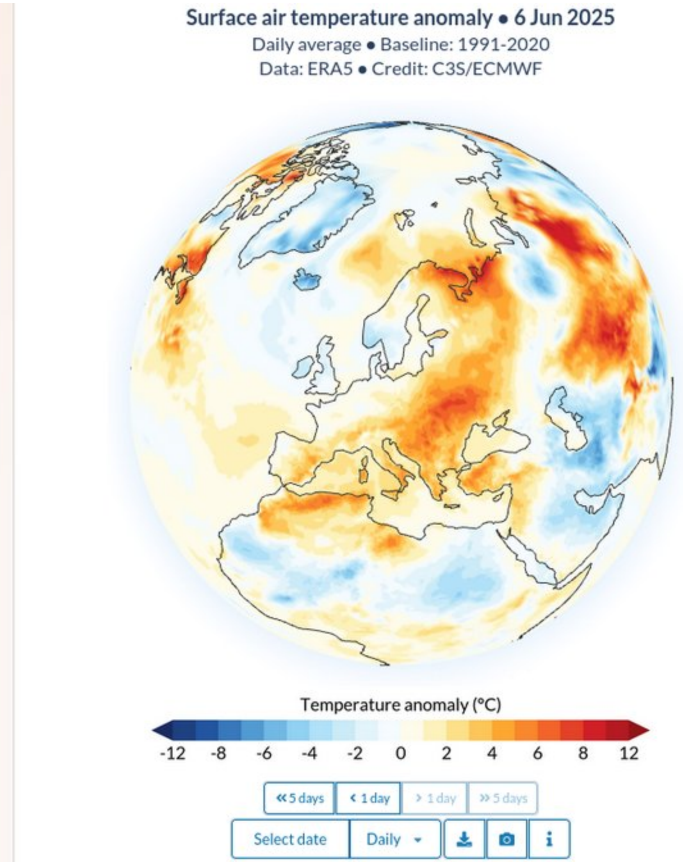


https://pulse.climate.copernicus.eu/

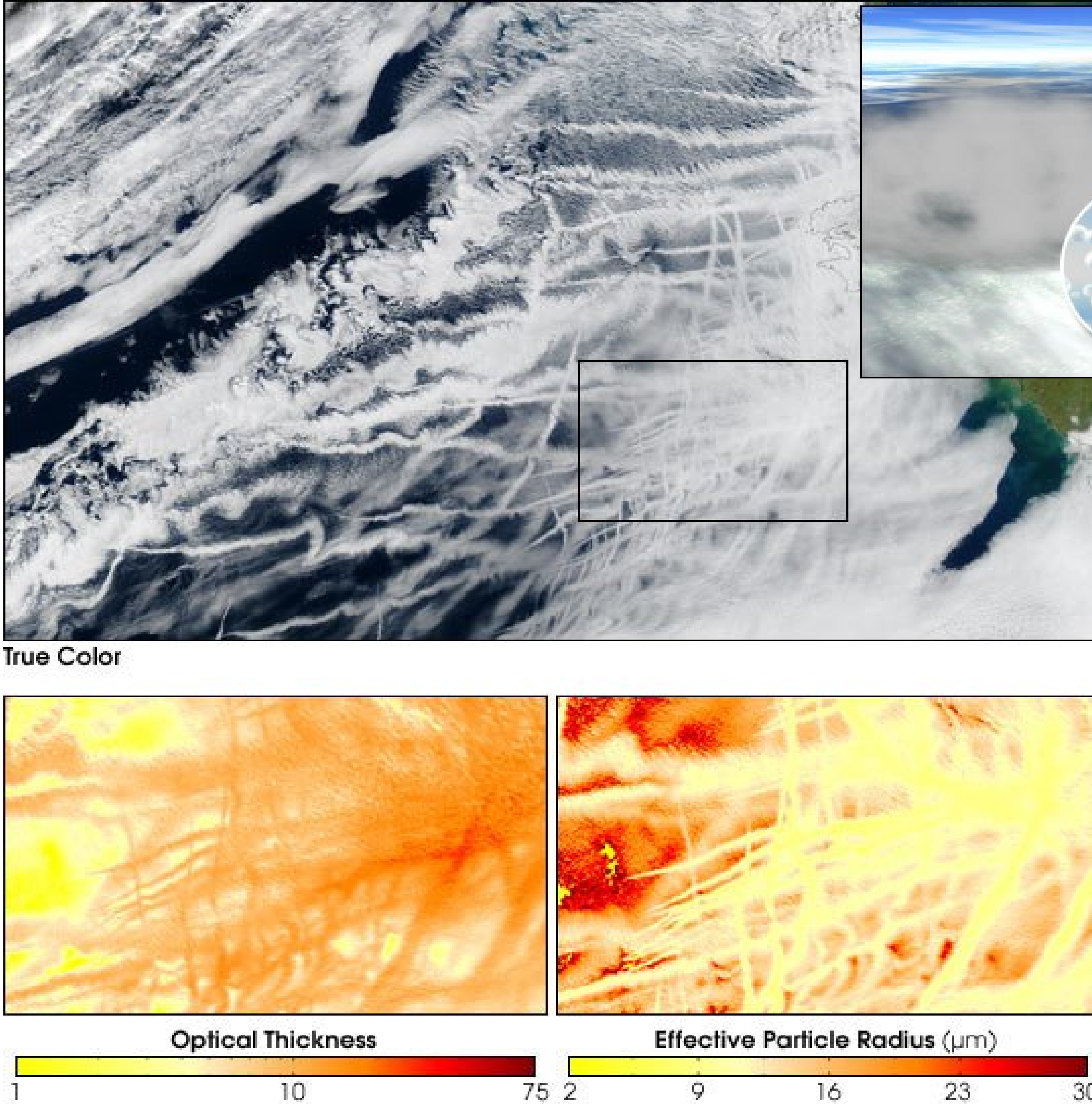


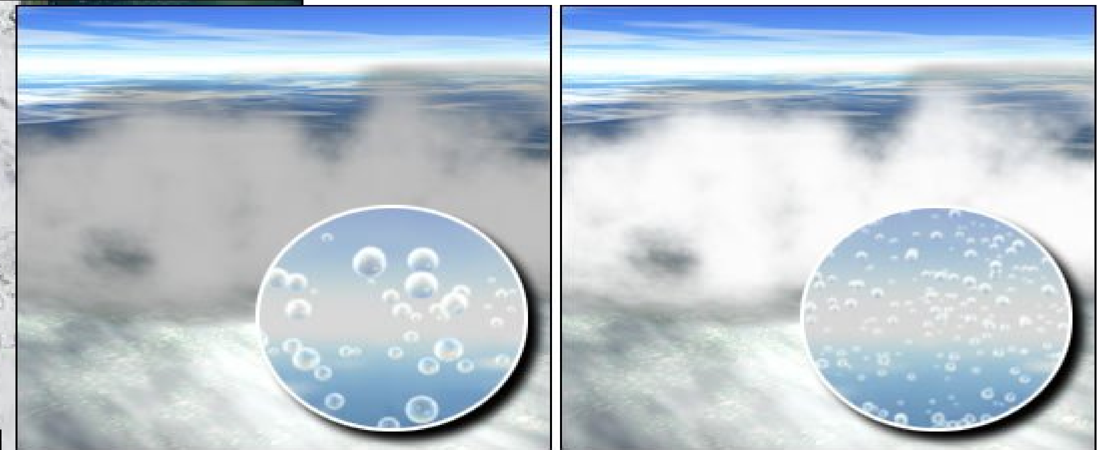
Annual Global Increase of CO_2
SCRIPPS INSTITUTION OF OCEANOGRAPHY
UC San Diego
CO_2 Annual Increase (ppm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
1960
1970
1980
1990
2000
2010
2020
Year
2025-April-14





https://pulse.climate.copernicus.eu/





Number of aerosol particles which act as cloud condensation nuclei in given thermodynamic and dynamic conditions influences droplet sizes and droplet number concentration.

Two effects:
- albedo
- lifetime.

Editorial Type: Article

Article Type: Research Article

Radiative Properties of Boundary Layer Clouds: Droplet Effective Radius versus Number Concentration

Jean-Louis Brenguier, Hanna Pawlowska, Lothar Schüller, Rene Preusker, Jürgen Fischer, and Yves Fouquart

Print Publication: 01 Mar 2000

DOI: https://doi.org/10.1175/1520-0469(2000)057<0803:RPOBLC>2.0.CO;2

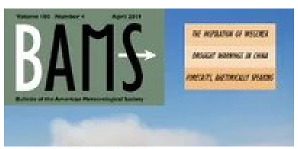
JOURNAL OF GEOPHYSICAL RESEARCH
Atmospheres
AN AGU JOURNAL

Aerosols and Clouds | Free Access

Cloud microphysical and radiative properties for parameterization and satellite monitoring of the indirect effect of aerosol on climate

Jean-Louis Brenguier, Hanna Pawlowska, Lothar Schüller

First published: 07 August 2003 | https://doi.org/10.1029/2002JD002682 | Citations: 102



Editorial Type: Article

Article Type: Research Article

Modeling of Cloud Microphysics: Can We Do Better?

Wojciech W. Grabowski, Hugh Morrison, Shin-Ichiro Shima, Gustavo C. Abade, Piotr Dziekan, and Hanna Pawlowska

Print Publication: 01 Apr 2019

DOI: https://doi.org/10.1175/BAMS-D-18-0005.1

Page(s): 655–672

PERSPECTIVE | ATMOSPHERIC SCIENCE
Science

Can We Understand Clouds Without Turbulence?

Advances at the interface between atmospheric and turbulence research are helping to elucidate fundamental properties of clouds.

E. BODENSCHATZ, S. P. MALINOWSKI, R. A. SHAW, AND F. STRATMANN Authors Info & Affiliations

SCIENCE • 19 Feb 2010 • Vol 327, Issue 5968 • pp. 970-971 • DOI: 10.1126/science.1185138

Editorial Type: Article

Article Type: Research Article

Dynamics and Chemistry of Marine Stratocumulus—DYCOMS-II

Bjorn Stevens, Donald H. Lenschow, Gabor Vali, Hermann Gerber, A. Bandy, B. Blomquist, J. -L. Brenguier, C. S. Bretherton, F. Burnet, T. Campos, S. Chai, I. Faloona, D. Friesen, S. Haimov, K. Laursen, D. K. Lilly, S. M. Loehrer, Szymon P. Malinowski, B. Morley, M. D. Petters, D. C. Rogers, L. Russell, V. Savic-Jovcic, J. R. Snider, D. Straub, Marcin J. Szumowski, H. Takagi, D. C. Thornton, M. Tschudi, C. Twohy, M. Wetzel, and M. C. van Zanten

Online Publication: 01 May 2003

Print Publication: 01 May 2003

DOI: https://doi.org/10.1175/BAMS-84-5-579

Page(s): 579–594

Atmospheric Chemistry and Physics
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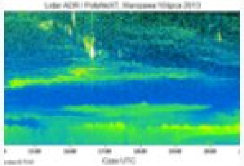
Physics of Stratocumulus Top (POST): turbulent mixing across capping inversion

S. P. Malinowski[1,2], H. Gerber[3], I. Jen-La Plante[1], M. K. Kopec[1], W. Kumala[1], K. Nurowska[1], P. Y. Chuang[4], D. Khelif[5], and K. E. Haman[1]

[1]Institute of Geophysics, Faculty of Physics, University of Warsaw, Warsaw, Poland
[2]Interdisciplinary Centre for Mathematical and Computational Modelling, University of Warsaw, Warsaw, Poland
[3]Gerber Scientific Inc., Reston, VA, USA
[4]Earth and Planetary Sciences, University of California, Santa Cruz, CA, USA
[5]Department of Mechanical and Aerospace Engineering, University of California, Irvine, CA, USA



Laboratorium Pomiarów Zdalnych
dr hab. Iwona S. Stachlewska

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ZFA

Laboratorium Transferu Radiacyjnego
prof. dr hab. Krzysztof Markowicz

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The unprecedented 2017–2018 stratospheric smoke event: decay phase and aerosol properties observed with the EARLINET

Holger Baars[1], Albert Ansmann[1], Kevin Ohneiser[1], Moritz Haarig[1], Ronny Engelmann[1], Dietrich Althausen[1], Ingrid Hanssen[2], Michael Gausa[2], Aleksander P
Jens Reichardt[5], Annett Skupin[1], Ina Mattis[6], T
Alexander Haefele[8], Karen Acheson[9], Albert A.
Thierry Podvin[11], Philippe Goloub[11], Igor Vesel
Michaël Sicard[15,16], Adolfo Comerón[15], Alfonso
Carmen Córdoba-Jabonero[18], Juan Luis Guerre
Maria João Costa[20,21], Davide Dionisi[22], Gian L
Nikolaos Papagiannopoulos[25], Antonella Boselli
Maria Rita Perrone[26], Livio Belegante[27], Doina
Ourania Soupiona[30], Alexandros Papayannis[30], Rodanthi-Elisaveth Mamouri, Argyro Nisantzi, Birgit Heese[1], Julian Hofer[1], Yoav Y. Schechner[32], Ulla Wandinger[1], and Gelsomina Pappalardo[25]

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ROLA AEROZOLU W PROCESACH KLIMATYCZNYCH

ACTRIS National facility Labelling   Facilities   Log in

Warsaw

Type
Observational platform

Country
Poland

Hosting institute
University of Warsaw (UW)

Website
https://www.igf.fuw.edu.pl/pl/laboratories/laboratorium-pomiarow-zdalnych/

Contacts
Iwona Stachlewska
Facility PI (since 1 Mar 2008)

Dominika Szczepanik (ARS component)
PI deputy (since 11 Jan 2022)

Lucja Janicka (CRS component)
PI deputy (since 11 Jan 2022)

Description
Ground-based fixed (urban, central Poland)

Location

52.211°N 20.983°E 112 m a.s.l.

ELSEVIER

Journal of Aerosol Science
Volume 101, November 2016, Pages 156-173

Review

Study of aerosol optical properties during long-range transport of biomass burning from Canada to Central Europe in July 2013

K.M. Markowicz[a], M.T. Chilinski[a], J. Lisok[a], O. Zawadzka[a], I.S. Stachlewska[a], L. Janicka[a], A. Rozwadowska[b], P. Makuch[b], P. Pakszys[b], T. Zielinski[b], T. Petelski[b], M. Posyniak[c], A. Pietruczuk[c], A. Szkop[c], D.L. Westphal[d]

International Journal of Climatology   RMetS

RESEARCH ARTICLE | Open Access

A large reduction of direct aerosol cooling over Poland in the last decades

Krzysztof M. Markowicz, Olga Zawadzka-Manko, Michal Posyniak

First published: 03 December 2021 | https://doi.org/10.1002/joc.7488 | Citations: 3

BAMS
Article

Observations of Aerosol, Cloud, Turbulence, and Radiation Properties at the Top of the Marine Boundary Layer over the Eastern North Atlantic Ocean

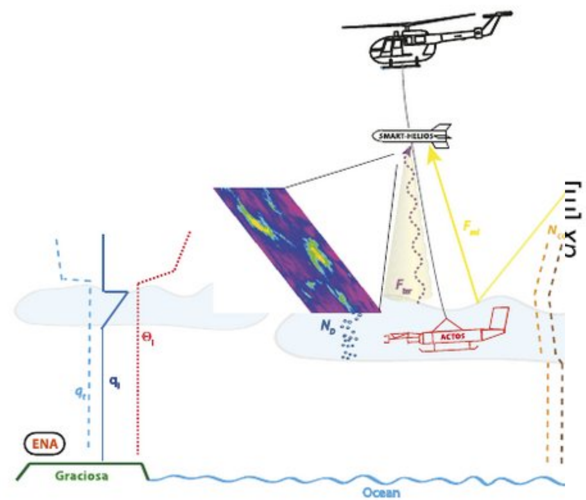
The ACORES Campaign

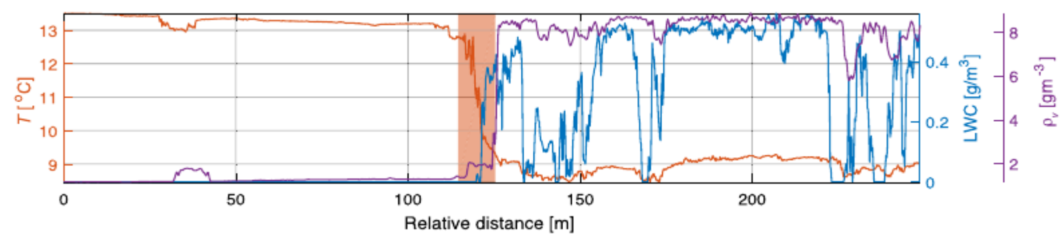
Holger Siebert, Kai-Erik Szodry, Ulrike Egerer, Birgit Wehner, Silvia Henning, Karine Chevalier, Janine Lückerath, Oliver Welz, Kay Weinhold, Felix Lauermann, Matthias Gottschalk, André Ehrlich, Manfred Wendisch, Paulo Fialho, Greg Roberts, Nithin Allwayin, Simeon Schum, Raymond A. Shaw, Claudio Mazzoleni, Lynn Mazzoleni, Jakub L. Nowak, Szymon P. Malinowski, Katarzyna Karpinska, Wojciech Kumala, Dominika Czyzewska, Edward P. Luke, Pavlos Kollias, Robert Wood, and Juan Pedro Mellado

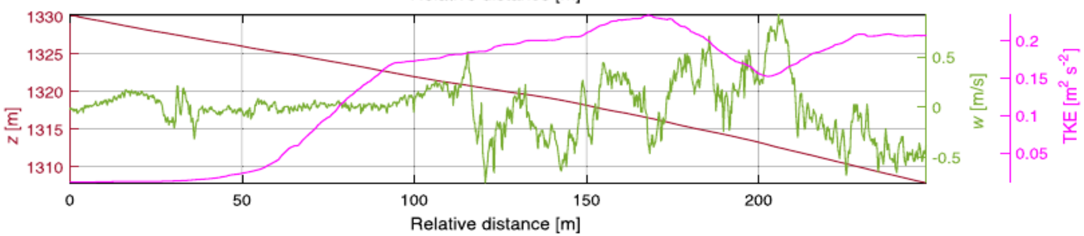
https://doi.org/10.1175/BAMS-D-19-0191.1

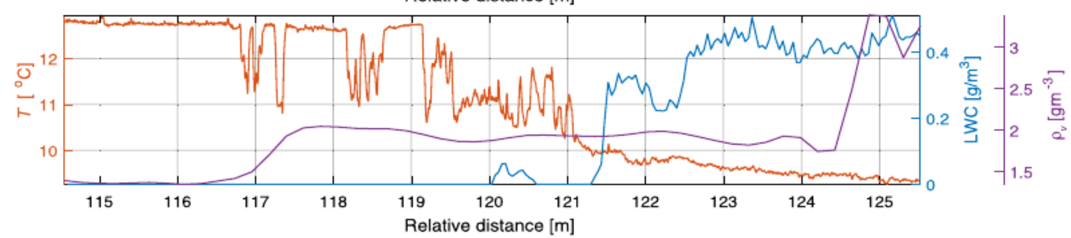
Corresponding author: Holger Siebert, siebert@tropos.de

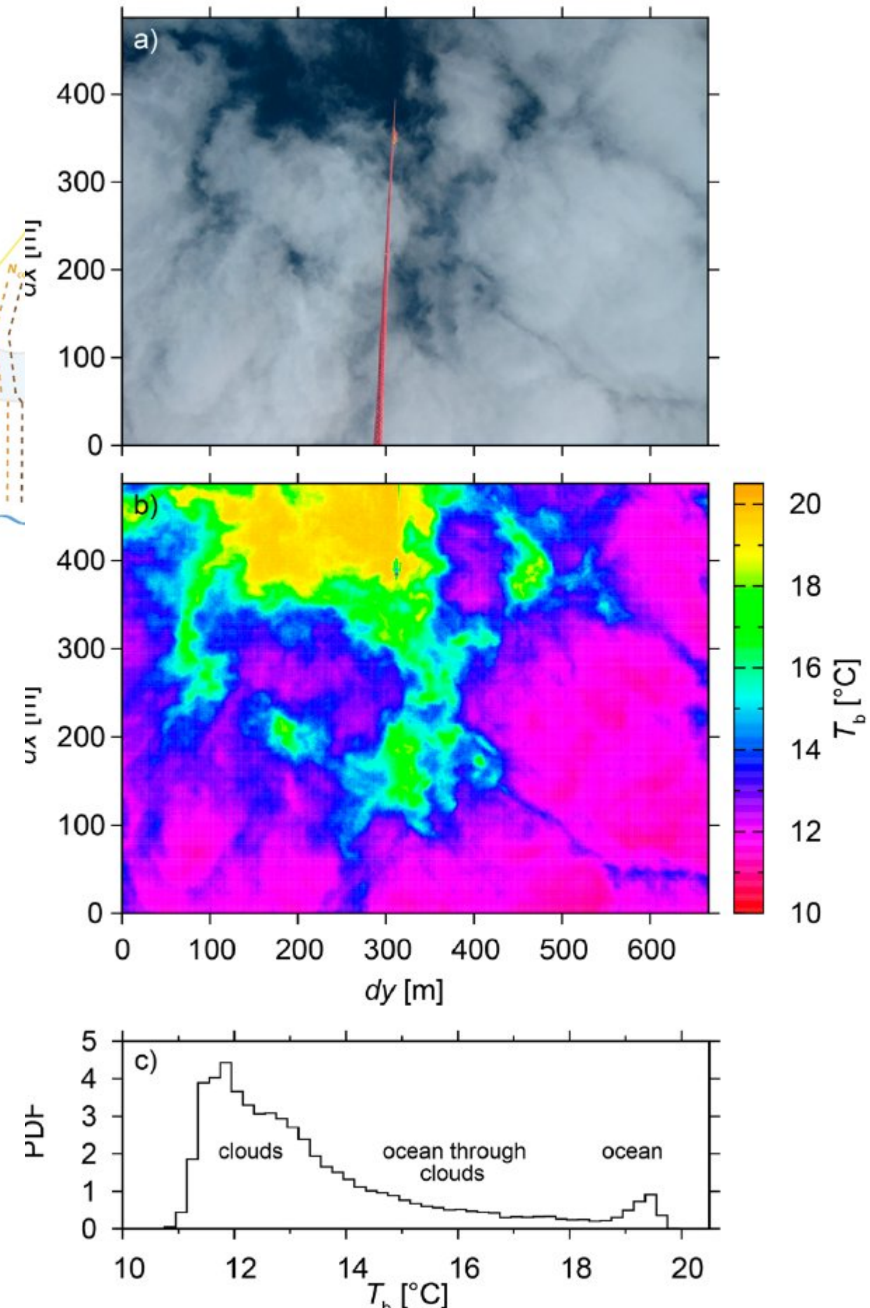
In final form 8 June 2020

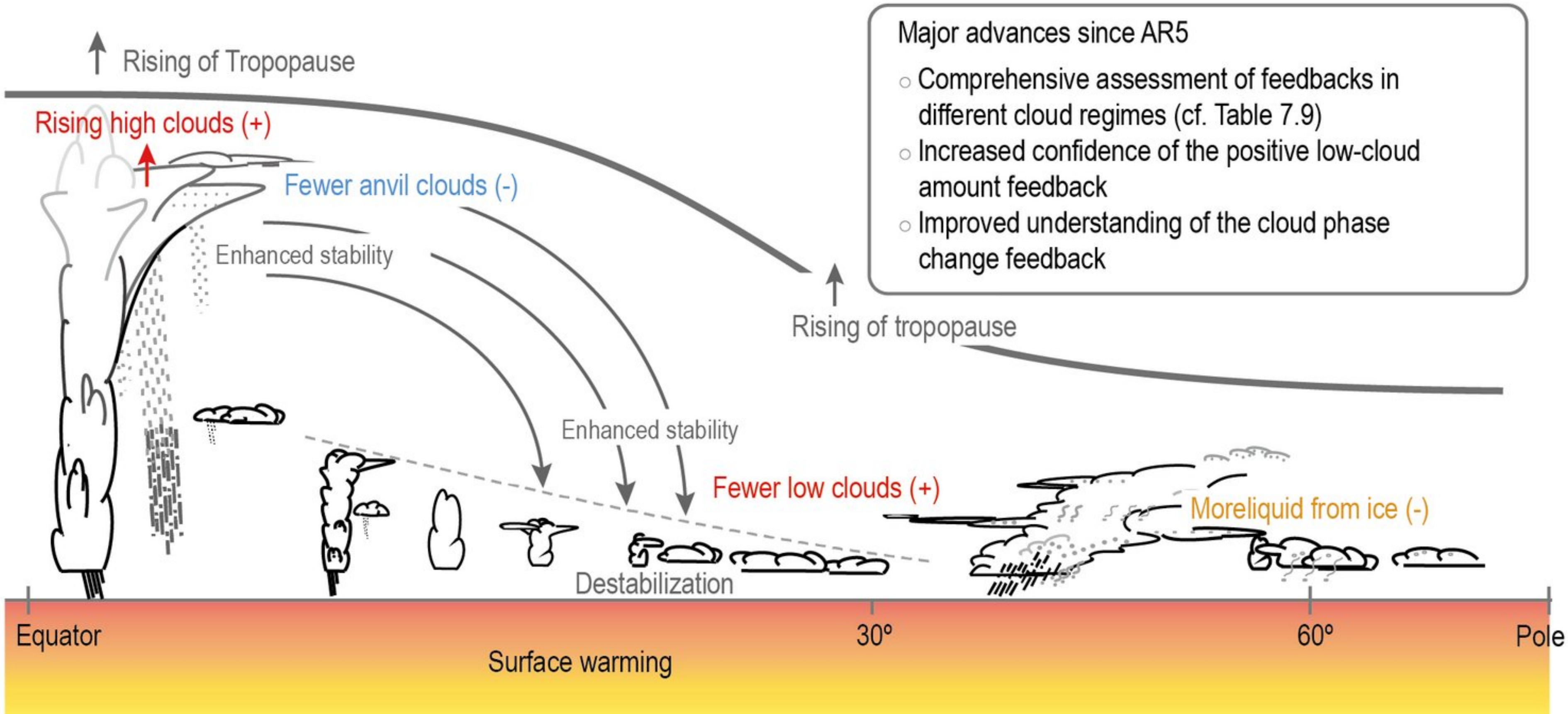












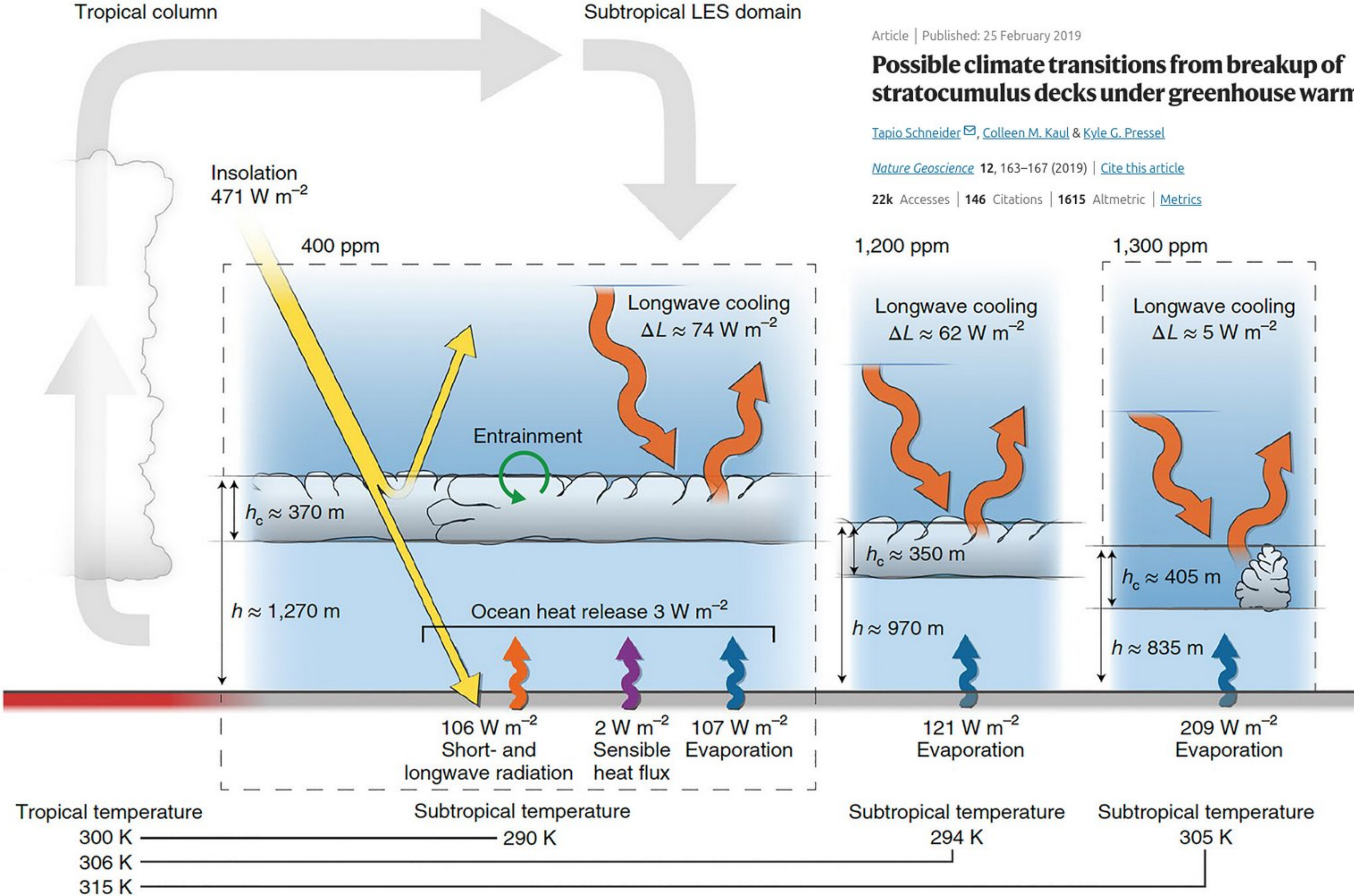
https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-9/

Article | Published: 25 February 2019

Possible climate transitions from breakup of stratocumulus decks under greenhouse warming

Tapio Schneider, Colleen M. Kaul & Kyle G. Pressel

Nature Geoscience 12, 163–167 (2019) | Cite this article

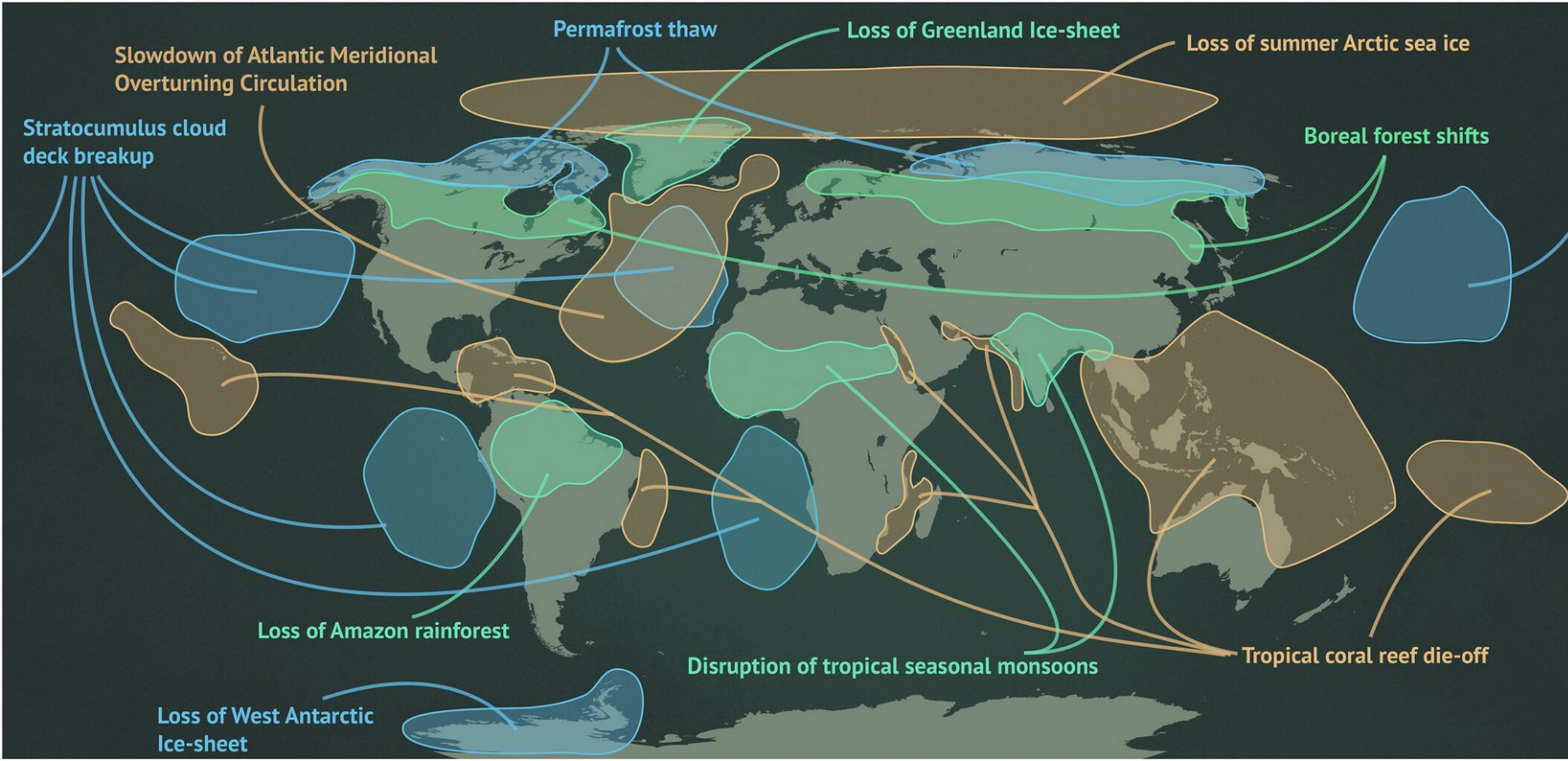


Reviews of Geophysics

Review Article | Open Access

Mechanisms and Impacts of Earth System Tipping Elements

Seaver Wang, Adrianna Foster, Elizabeth A. Lenz, John D. Kessler, Julienne C. Stroeve, Liana O. Anderson, Merritt Turetsky, Richard Betts, Sijia Zou, Wei Liu, William R. Boos, Zeke Hausfather

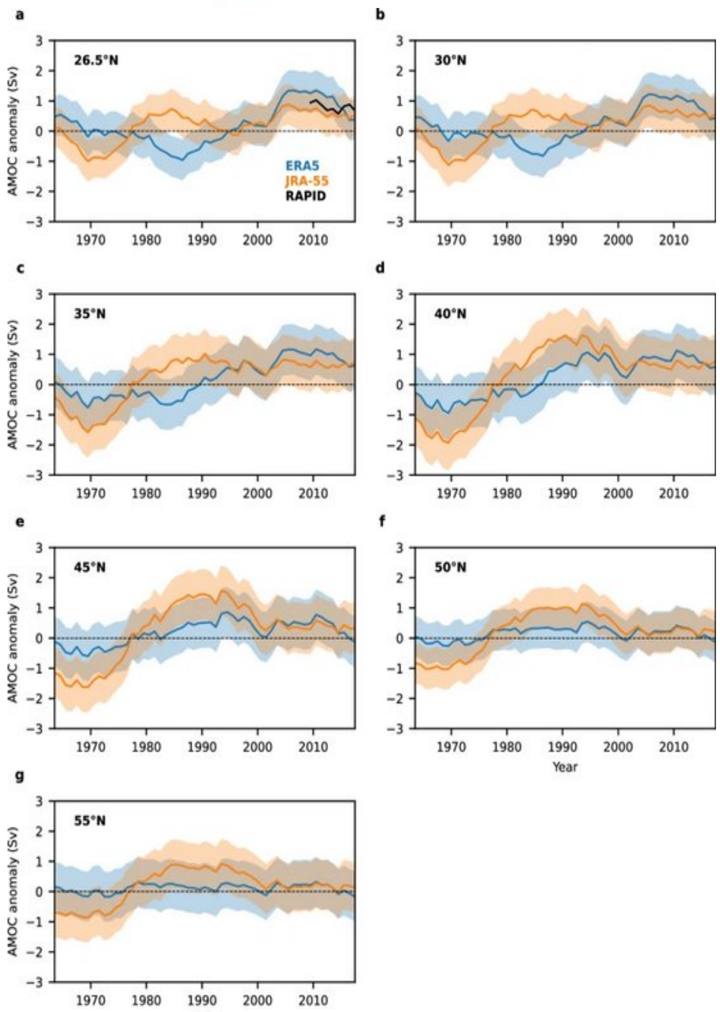


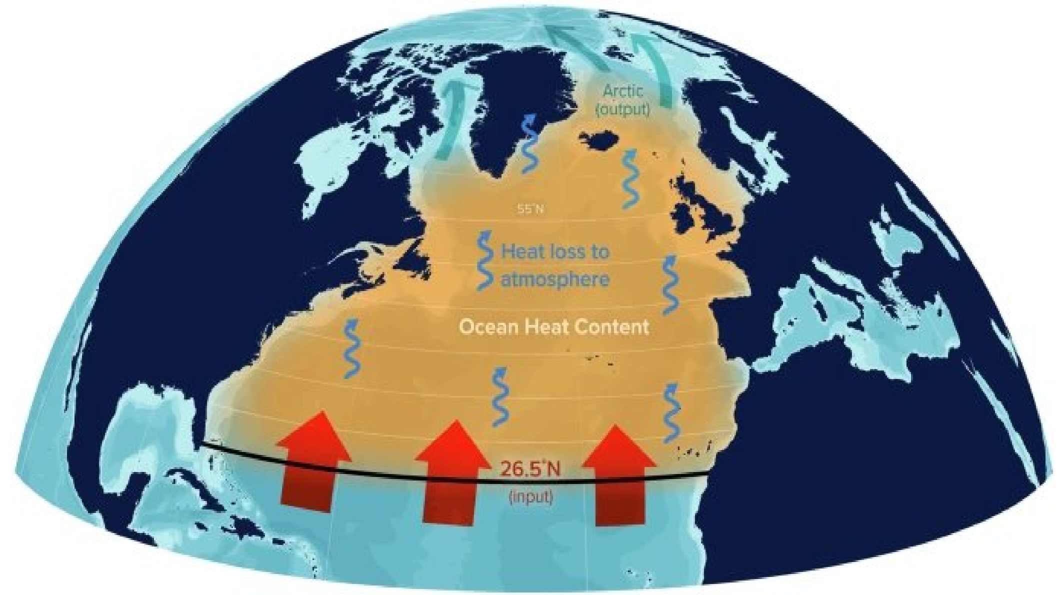
Article | Open access | Published: 15 January 2025

Atlantic overturning inferred from air-sea heat fluxes indicates no decline since the 1960s

Jens Terhaar, Linus Vogt & Nicholas P. Foukal

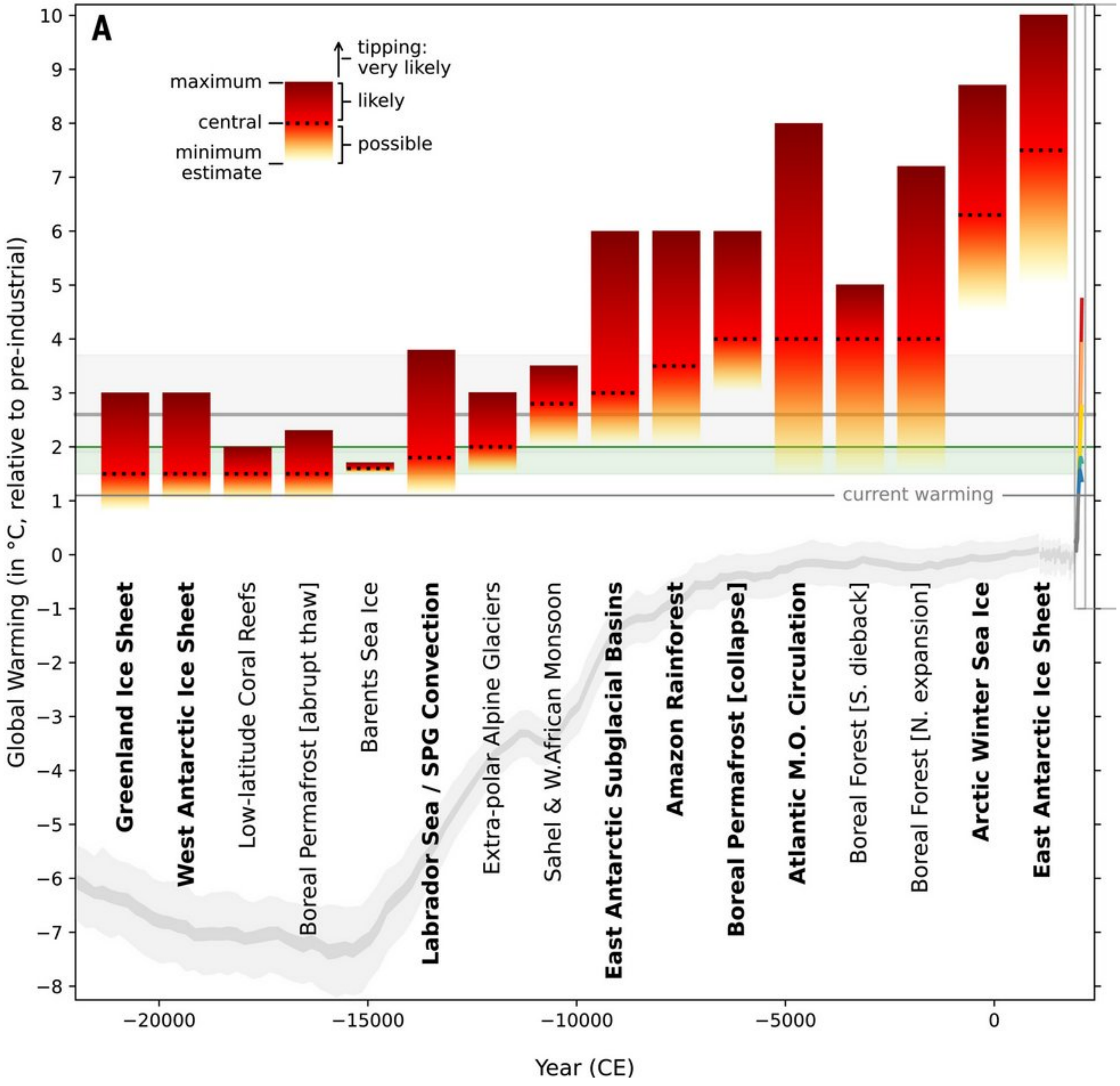
Nature Communications 16, Article number: 222 (2025) | Cite this article





Here, we use 24 Earth System Models from the Coupled Model Intercomparison Project Phase 6 (CMIP6) to demonstrate that these temperature anomalies cannot robustly reconstruct the AMOC. Instead, we find that air-sea heat flux anomalies north of any given latitude in the North Atlantic between 26.5°N and 50°N are tightly linked to the AMOC anomaly at that latitude on decadal and centennial timescales. On these timescales, air-sea heat flux anomalies are strongly linked to AMOC-driven northward heat flux anomalies through the conservation of energy. On annual timescales, however, air-sea heat flux anomalies are mostly altered by atmospheric variability and less by AMOC anomalies.

Based on the here identified relationship and observation-based estimates of the past air-sea heat flux in the North Atlantic from reanalysis products, the decadal averaged AMOC at 26.5°N has not weakened from 1963 to 2017 although substantial variability exists at all latitudes.



RESEARCH ARTICLE | CLIMATE CHANGE

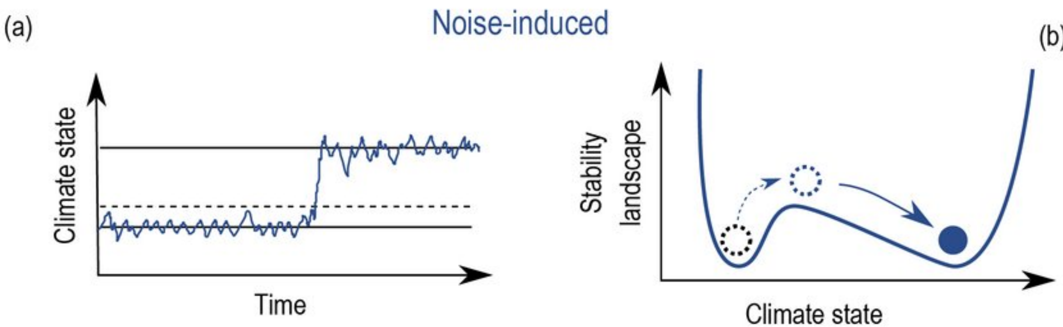
Exceeding 1.5°C global warming could trigger multiple climate tipping points

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

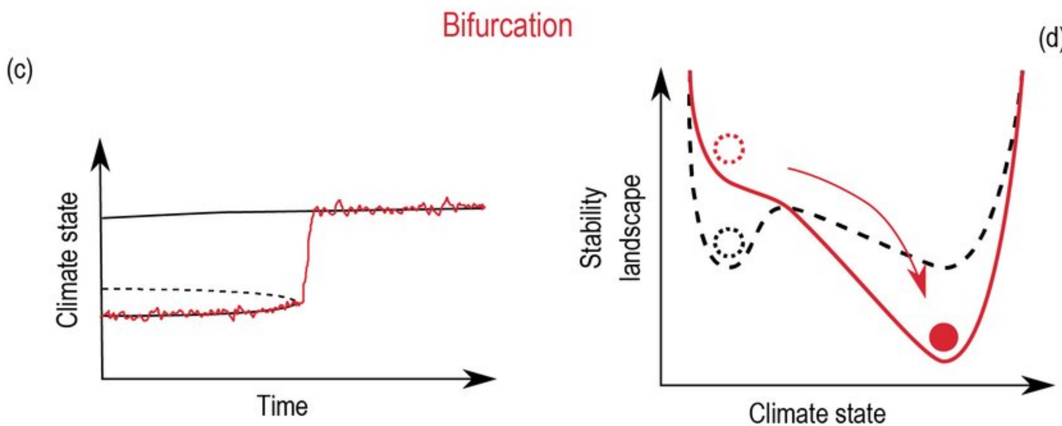
SCIENCE • 9 Sep 2022 • Vol 377, Issue 6611 • DOI: 10.1126/science.abn7950

Global warming threshold estimates for global core and regional impact climate tipping elements.

Changes resulting from forcings and feedbacks, if pass tipping points, may lead to new feedbacks and cascade effects.



e.g. glacial-interglacial



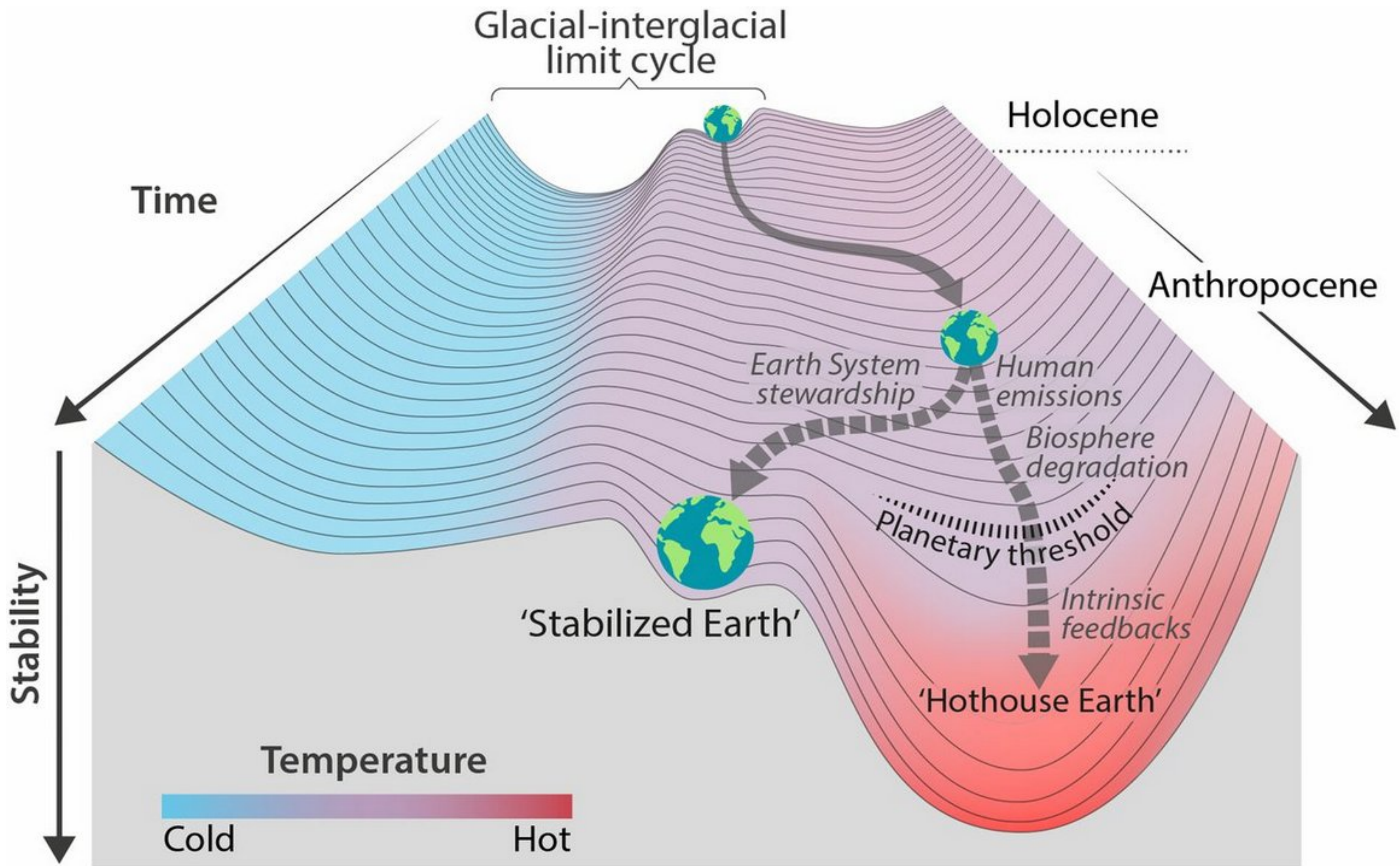
e.g. planetary threshold

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).

IPCC 2021 WG1

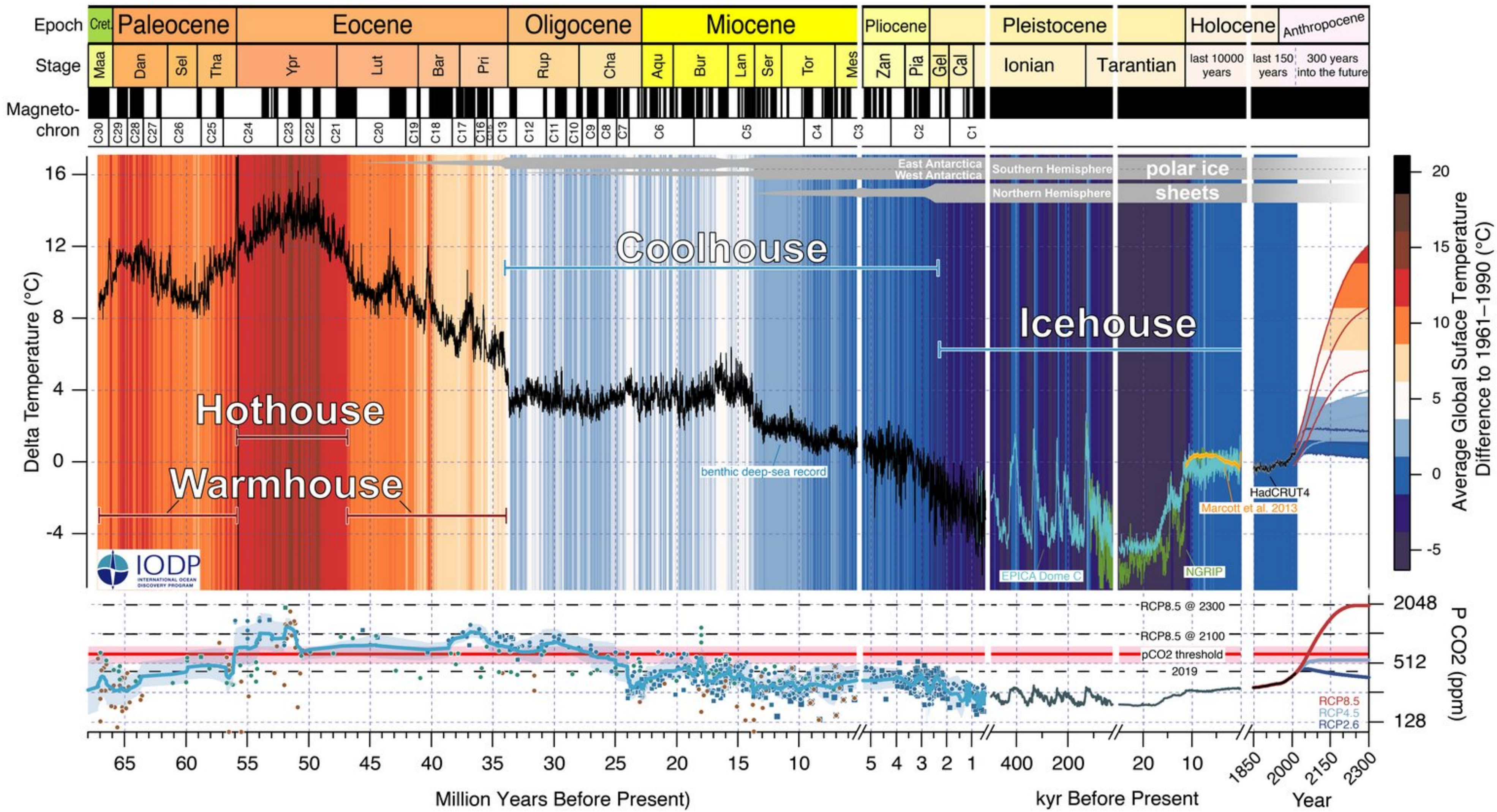
Stability landscape showing the pathway of the Earth System out of the Holocene and thus, out of the glacial–interglacial limit cycle to its present position in the hotter Anthropocene.



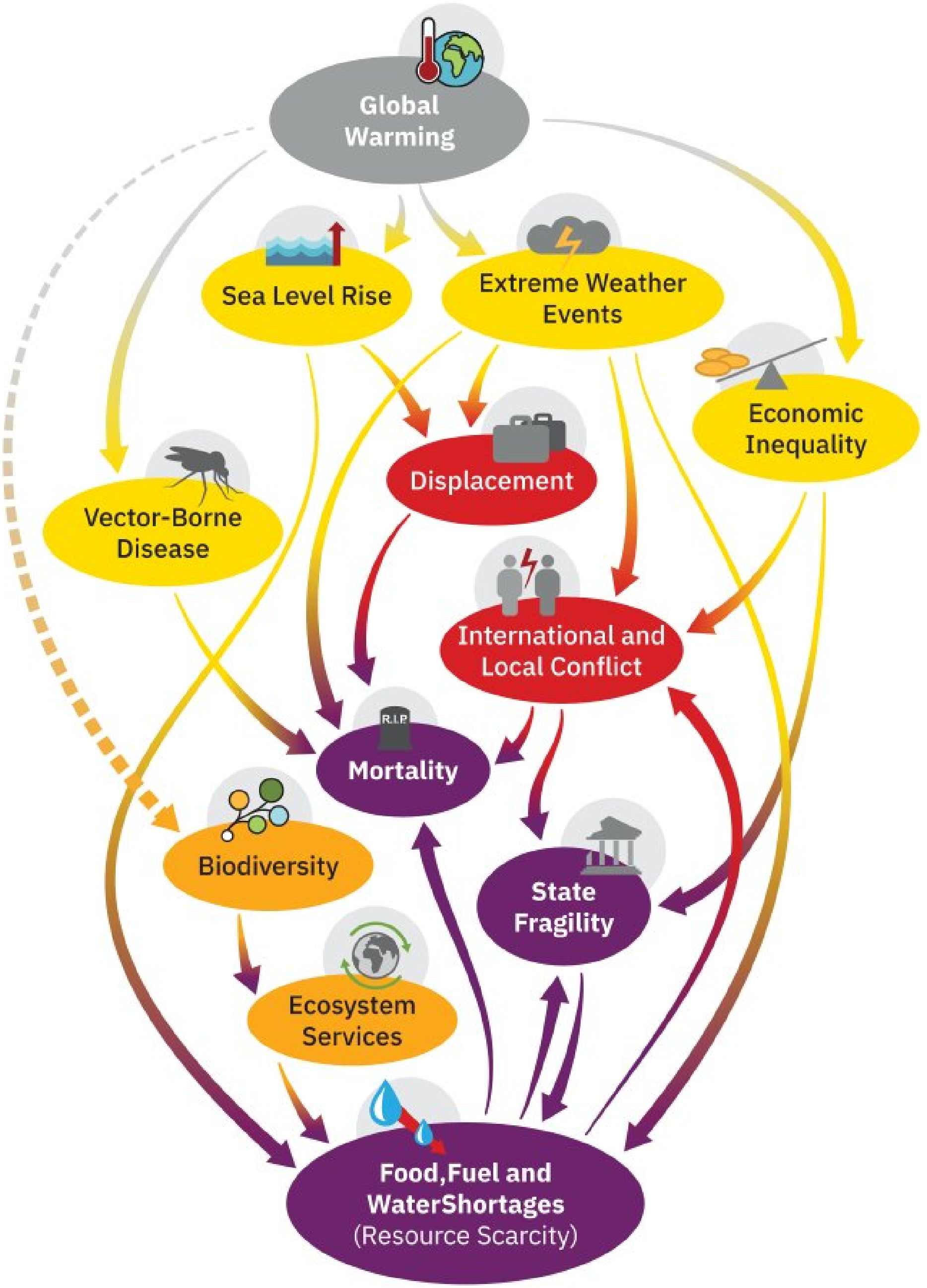
Will Steffen et al. PNAS 2018;115:33:8252-8259

PNAS

Global mean temperatures in Cenozoic era and climate projections.



https://websites.pmc.ucsc.edu/~jzachos/images/CENOGRID_Cartoon_withProjection_alternate.png



PERSPECTIVE | SUSTAINABILITY SCIENCE

Climate Endgame: Exploring catastrophic climate change scenarios

Luke Kemp, Chi Xu, Joanna Depledge, +7, and Timothy M. Lenton Authors Info & Affiliations

Edited by Kerry Emanuel, Massachusetts Institute of Technology, Cambridge, MA; received May 20, 2021; accepted March 25, 2022

August 1, 2022 | 119 (34) e2108146119 | https://doi.org/10.1073/pnas.2108146119

Cascading global climate failure.

This is a causal loop diagram, in which a complete line represents a positive polarity (e.g., amplifying feed-back; not necessarily positive in a normative sense)
and a dotted line denotes a negative polarity (meaning a dampening feedback).

Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO_2 during the Past Decades

By ROGER REVELLE and HANS E. SUESS, Scripps Institution of Oceanography, University of California, La Jolla, California

(Manuscript received September 4, 1956)

Tellus IX (1957), 1

"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…."

Can we control this experiment any more?

Toward a Cenozoic history of atmospheric CO_2

THE CENOZOIC CO_2 PROXY INTEGRATION PROJECT (CENCO$_2$PIP) CONSORTIUM Authors Info & Affiliations

SCIENCE • 8 Dec 2023 • Vol 382, Issue 6675 • DOI: 10.1126/science.adi5177