MAX-PLANCK-INSTITUT
FÜR METEOROLOGIE

Klimasensitivität und zukünftige Erwärmung

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Deutsche Physikalische Gesellschaft e.V. , Arbeitskreis Energie, Bad Honnef, 17. Oktober 2025

Der DMG/DPG Aufruf


KLIMAAUFRUF 2025

Ein Aufruf zu entschlossenem Handeln

DEN VOLLSTÄNDIGEN AUFRUF MIT ERLÄUTERUNGEN UND LITERATURHINWEISEN FINDEN SIE UNTER:

Ein gemeinsamer Aufruf der Deutschen Meteorologischen Gesellschaft und der Deutschen Physikalischen Gesellschaft

DMG Deutsche Meteorologische Gesellschaft

Deutsche Physikalische Gesellschaft DPG

3-GRAD-GRENZE KÖNNTE SCHON UM 2050 ÜBERSCHRITTEN WERDEN

Es ist nicht mehr zu leugnen: Der Klimawandel schreitet ungebremst voran und beschleunigt sich. In den Jahren 2023 und 2024 lagen die globalen Durchschnittstemperaturen erstmals 1,5 Grad über dem vorindustriellen Niveau. Es ist sogar möglich, dass die in Paris beschlossene 1,5-Grad-Grenze der globalen Erwärmung bereits dauerhaft überschritten sein könnte.

Inzwischen ist selbst die Verpflichtung, die globale Erwärmung deutlich unter 2 Grad zu halten, nur noch mit erheblich erhöhten Anstrengungen der internationalen Gemeinschaft erreichbar, und es besteht eine wachsende Gefahr, dass dieses Ziel verfehlt wird. Die globale Erwärmung ist in eine Phase der Beschleunigung eingetreten. Bereits um das Jahr 2050 könnte die Erwärmung sogar 3 Grad gegenüber der vorindustriellen Zeit erreichen, wobei der Temperaturanstieg in Deutschland deutlich höher als im globalen Mittel ausfällt. Ergebnisse von Klimamodellen deuten darauf hin, dass bis Ende des Jahrhunderts eine Erwärmung bis zu 5 Grad wahrscheinlich ist. Dies kann nur noch durch ein Umsteuern der Menschheit verhindert werden.

verfehlt wird. Die globale Erwärmung ist in eine Phase der Beschleunigung eingetreten. Bereits um das Jahr 2050 könnte die Erwärmung sogar 3 Grad gegenüber der vorindustriellen Zeit erreichen, wobei der Temperaturanstieg in Deutschland deutlich

Prognosen

Der Anstieg der atmosphärischen Konzentration von Treibhausgasen hat im Vergleich zum vorindustriellen Bezugszeitraum (1850–1900) zu einem Anstieg der mittleren bodennahen Temperatur auf der Erde um etwa 1,1 Grad (Mittelwert 2011–2020) und in den Jahren 2023 und 2024 von 1,5 Grad geführt. Aktuelle Klimamodellrechnungen prognostizieren mit hoher Wahrscheinlichkeit folgende Konsequenzen für die global gemittelte Temperatur an der Erdoberfläche:

- Bei einer Verdoppelung der CO_2-Konzentration im Vergleich zum vorindustriellen Wert steigt sie um etwa 2 bis 5 Grad [10], wobei derzeit vieles darauf hindeutet, dass der höhere Wert zutreffender ist.[11] Eine mögliche Ursache hierfür ist die weltweite Reduktion von Schwefelemissionen, die in der Vergangenheit zu einer erhöhten Rückstrahlung von einfallender Sonnenstrahlung beitrugen. Es könnte sich aber auch um eine signifikante Änderung der Bewölkung handeln, die durch die globale Erwärmung selbst ausgelöst wird.[17] Gleichzeitig wurde die verstärk-

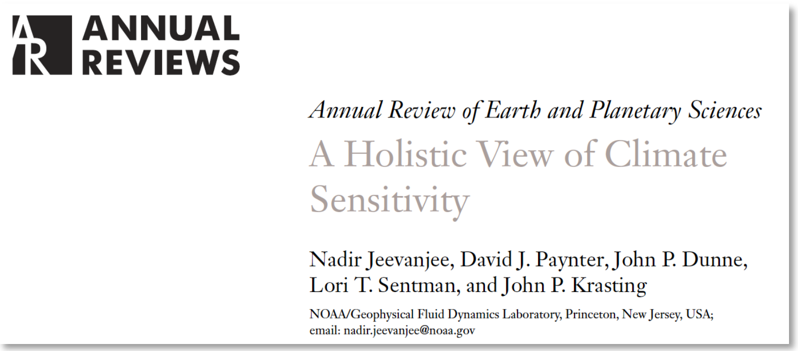
[10] siehe Abschnitt A4 in IPCC (2021), Assessment Report 6, Working Group 1, The Physical Science Basis, Summary for Policymakers, https://dx.doi.org/10.1017/9781009157896.001
Primärquelle: Sherwood et al. (2020). An Assessment of Earth's Climate Sensitivity Using Multiple Lines of Evidence. Reviews of Geophysics, 58(4), e2019RG000678. https://doi.org/10.1029/2019RG000678

[11] Hinweise für eine Unterschätzung der Klimasensitivität im letzten IPCC-Bericht:
a. Witkowski et al. (2024). Continuous sterane and phytane δ13C record reveals a substantial pCO_2 decline since the mid-Miocene. Nature Communications, 15(1), 5192. https://doi.org/10.1038/s41467-024-47676-9
b. Goessling et al. (2024). Recent global temperature surge intensified by record-low planetary albedo. Science. https://doi.org/10.1126/science.adq7280
c. Hansen et al. (2023). Global warming in the pipeline. Oxford Open Climate Change, 3(1), kgad008. https://doi.org/10.1093/oxfclm/kgad008

Inhalt

- Begrifflichkeiten: (Gleichgewichts-)Klimasensitivität, Transiente Klimaantwort, Strahlungsantrieb, Feedbacks / Strahlungsantwort auf Erwärmung, Zustandsabhängigkeit, Pattern Effect
- Klimasensitivität aus Klimamodellen
- Moderne Abschätzung der Klimasensitivität
- Der Unsicherheitsfaktor Wolken
- Die aktuelle Diskussion: Die Jahre 2023/24; gibt es eine beschleunigte Erwärmung?
- Die Rolle des Kohlenstoffkreislaufs

Equilibrium climate sensitivity (ECS) vs. transient climate response (TCR)

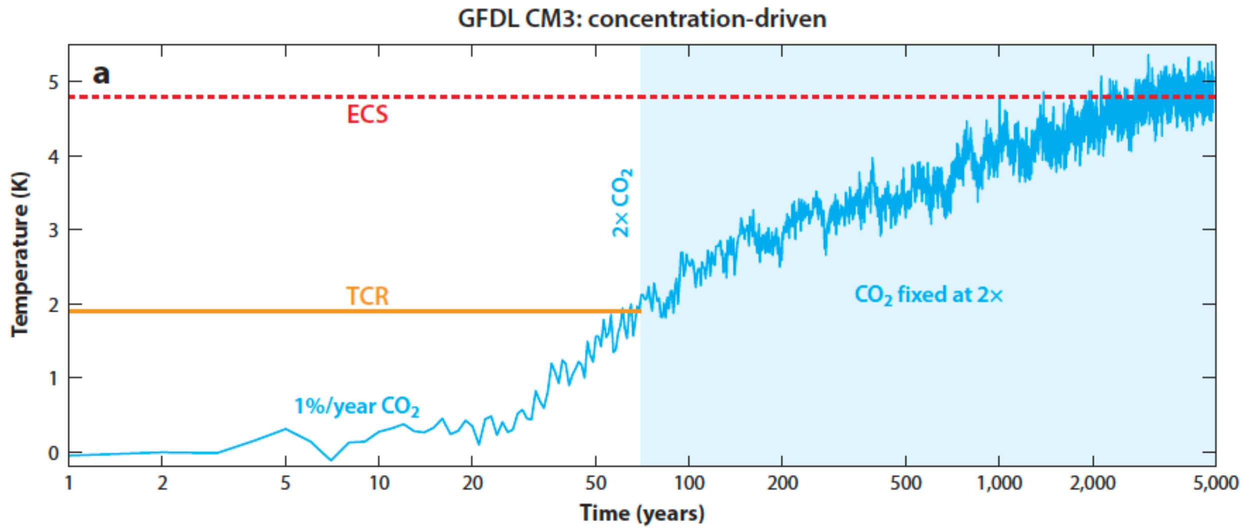

ANNUAL REVIEWS

Annual Review of Earth and Planetary Sciences

A Holistic View of Climate Sensitivity

Nadir Jeevanjee, David J. Paynter, John P. Dunne, Lori T. Sentman, and John P. Krasting

NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, USA; email: nadir.jeevanjee@noaa.gov



Der Begriff **Klimasensitivität** wird häufig synonym für die Gleichgewichtsklimasensitivität (**equilibrium climate sensitivity, ECS**) benutzt, d.h. die Änderung der oberflächennahen Lufttemperatur ausgelöst durch eine Verdopplung der atmosphärischen CO2-Konzentration nach dem Erreichen eines neuen Strahlungsgleichgewichts am Oberrand der Atmosphäre. (ohne Berücksichtigung sehr langsamer Rückkopplung wie z.B. von Eisschilden → **Erdsystemsensitivität**)

Es gibt andere relevante Klimasensitivitäten, z.B. die sogenannte **Transiente Klimaantwort** (**transient climate response; TCR**), d.h. die Temperaturänderung die im Erdsystem zum Zeitpunkt einer CO2-Verdopplung bei einer jährlichen Erhöhung von 1% erreicht wird.

(Jeevanjee et al., Ann. Rev., 2025)

The Forcing-Feedback Framework

The net power N entering a system characterized by state $\mathbf{X}$ and surface temperature T is zero in equilibrium:

$$N(T, \mathbf{X}) = 0. \tag{1}$$

Linearisation around an equilibrium state yields

$$0 = \frac{\partial N}{\partial T}\delta T + \frac{\partial N}{\partial \mathbf{X}}\delta \mathbf{X}. \tag{2}$$

The change of N by a change of the state (think, e.g., CO_2 concentration) can be considered as a forcing F,

$$F := \frac{\partial N}{\partial \mathbf{X}}\delta \mathbf{X}. \tag{3}$$

The response of N to a change in T is often named feedback parameter λ,

$$\lambda := \frac{\partial N}{\partial T}. \tag{4}$$

It follows that

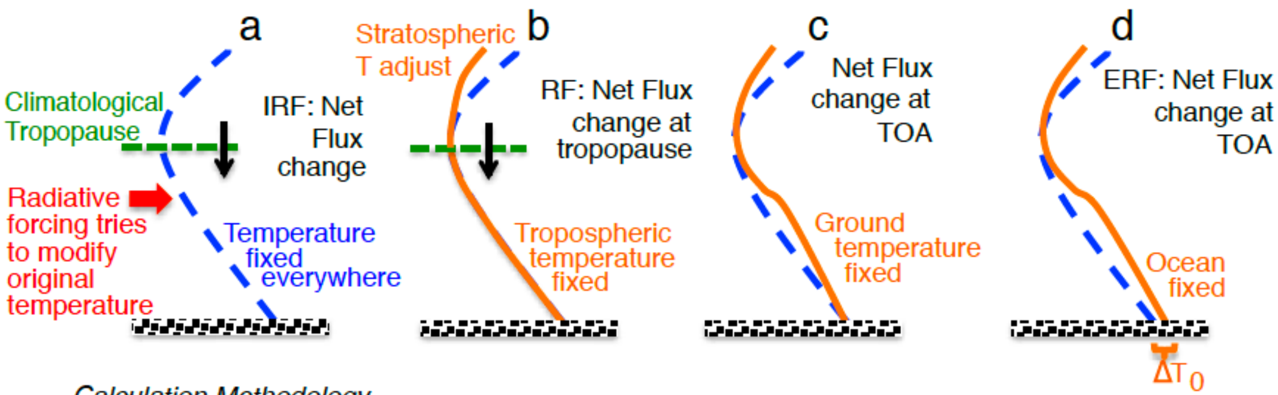
$$\delta T = \frac{-F}{\lambda},$$

and

$$N(\delta T) = F + \lambda \delta T. \tag{6}$$

If linearity holds, this is useful. Determining climate sensitivity can be broken down into determining forcing and feedback.

Instantaneous, adjusted, and effective radiative forcing



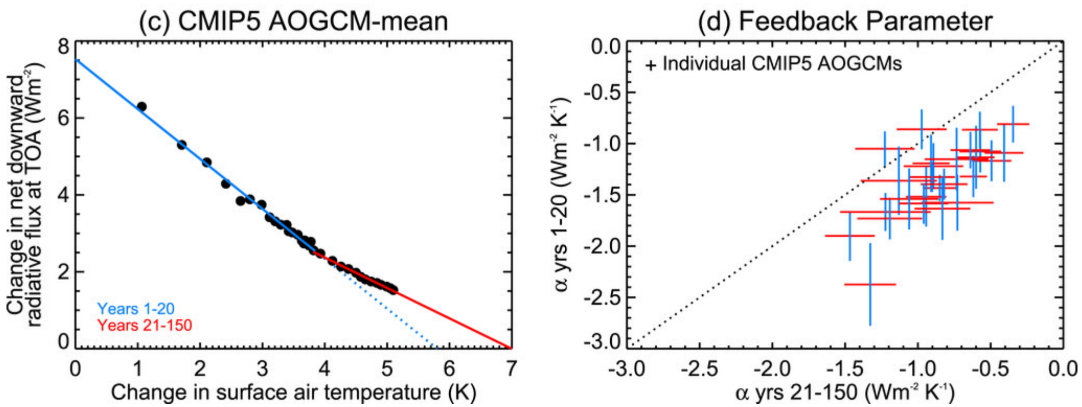
Calculation Methodology

Online or offline pair of radiative transfer calculations within one simulation	Difference between two offline radiative transfer calculations with prescribed surface and tropospheric conditions allowing stratospheric temperature to adjust	Difference between two full atmospheric model simulations with prescribed surface conditions everywhere or estimate based on regression of response in full coupled atmosphere-ocean simulation	Difference between two full atmospheric model simulations with prescribed ocean conditions (SSTs and sea ice)

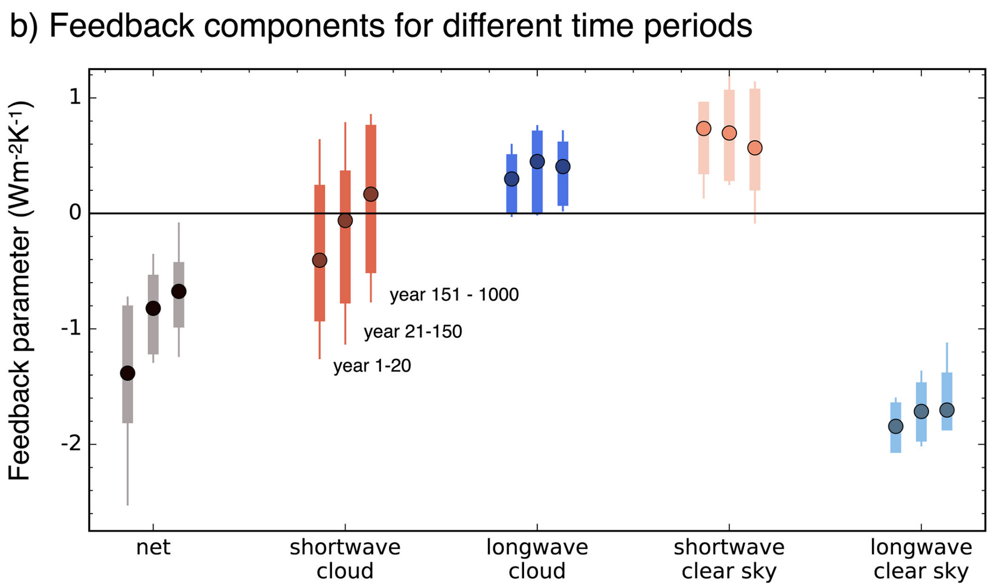
A modern, colorful (spectral) view on atmospheric radiant energy transfer allows surprisingly accurate analytic estimates of clear-sky radiative forcing and the radiative response to warming (feedback) (e.g. Stevens and Kluft, ACP, 2023; Jeevanjee et al., J. Clim., 2021).

(IPCC, AR5, WG1, Fig. 8.3, 2013)

The feedback can depend on time and state

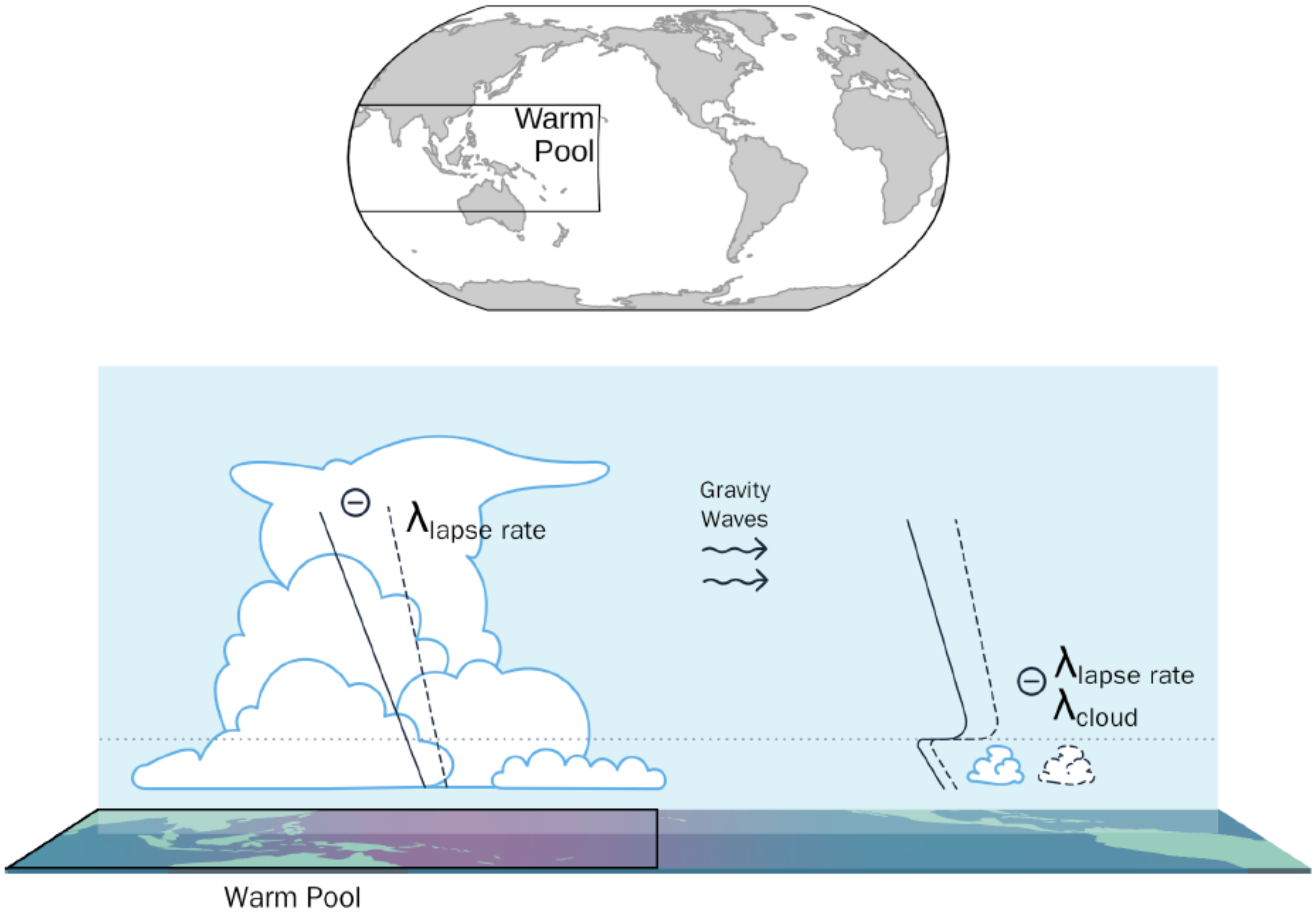


(Andrews et al., J. Climate, 2015)



(Rugenstein et al., J. Climate, 2019)

Pattern Effect

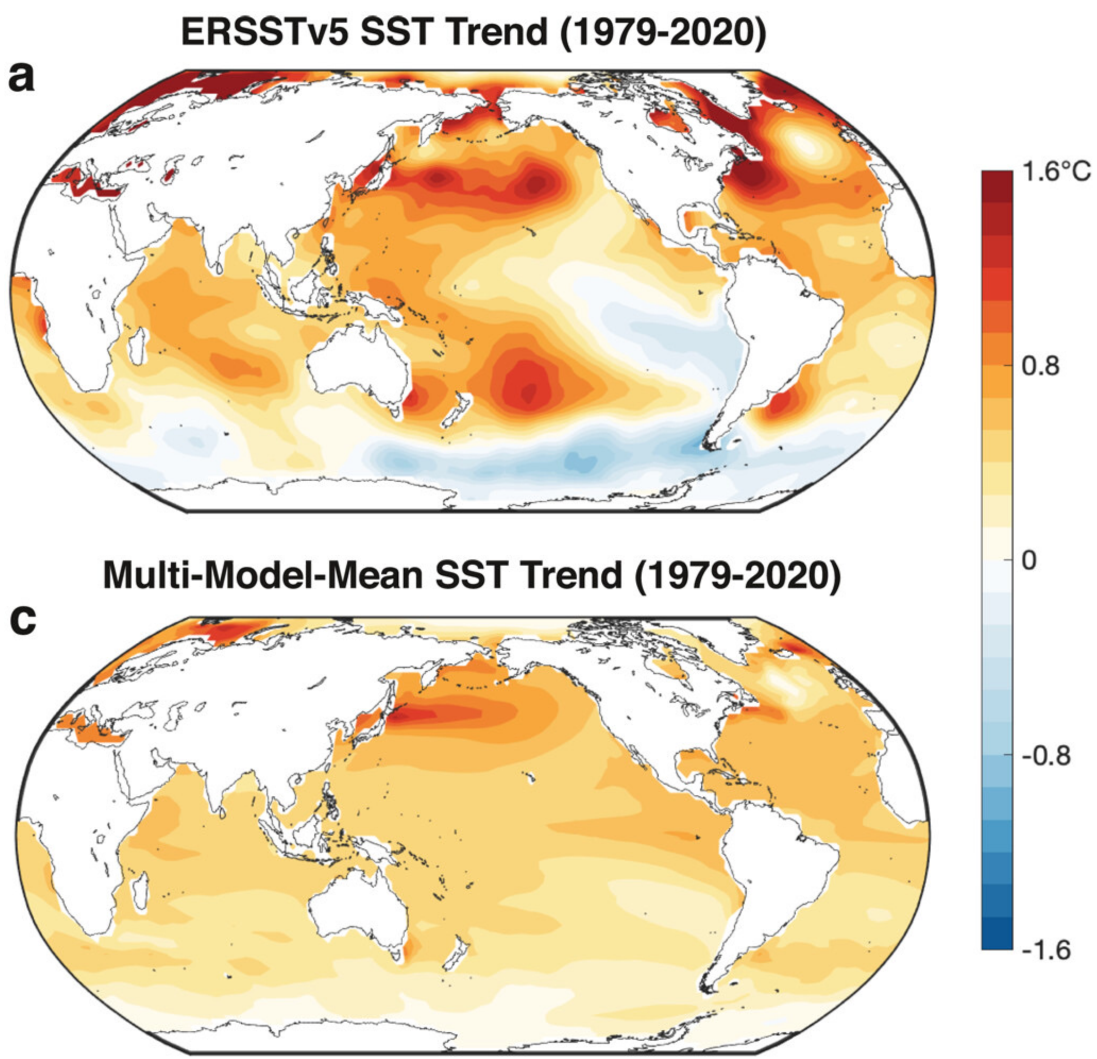


Unter dem Begriff “Pattern Effect” versteht man den Einfluss des geographischen Musters einer Temperaturänderung auf die Stärke des Feedbacks. Beispielsweis: Eine Erwärmung im sogenannten “Warm Pool” erhöht die Temperatur in der gesamten tropischen Troposphäre. Das verstärkt die Inversion im tropischen östlichen Pazifik, verstärkt dort die Bewölkung und erzeugt somit ein negatives Feedback. Eine Erwärmung im östlichen Pazifik schwächt die Inversion ab, verringert die Bewölkung und erzeugt ein negatives Feedback.

$$\lambda = \lambda(\delta T(x))$$

(Günther, Phd thesis, 2024; see also Stevens et al., 2016; Rugenstein et al., 2023)

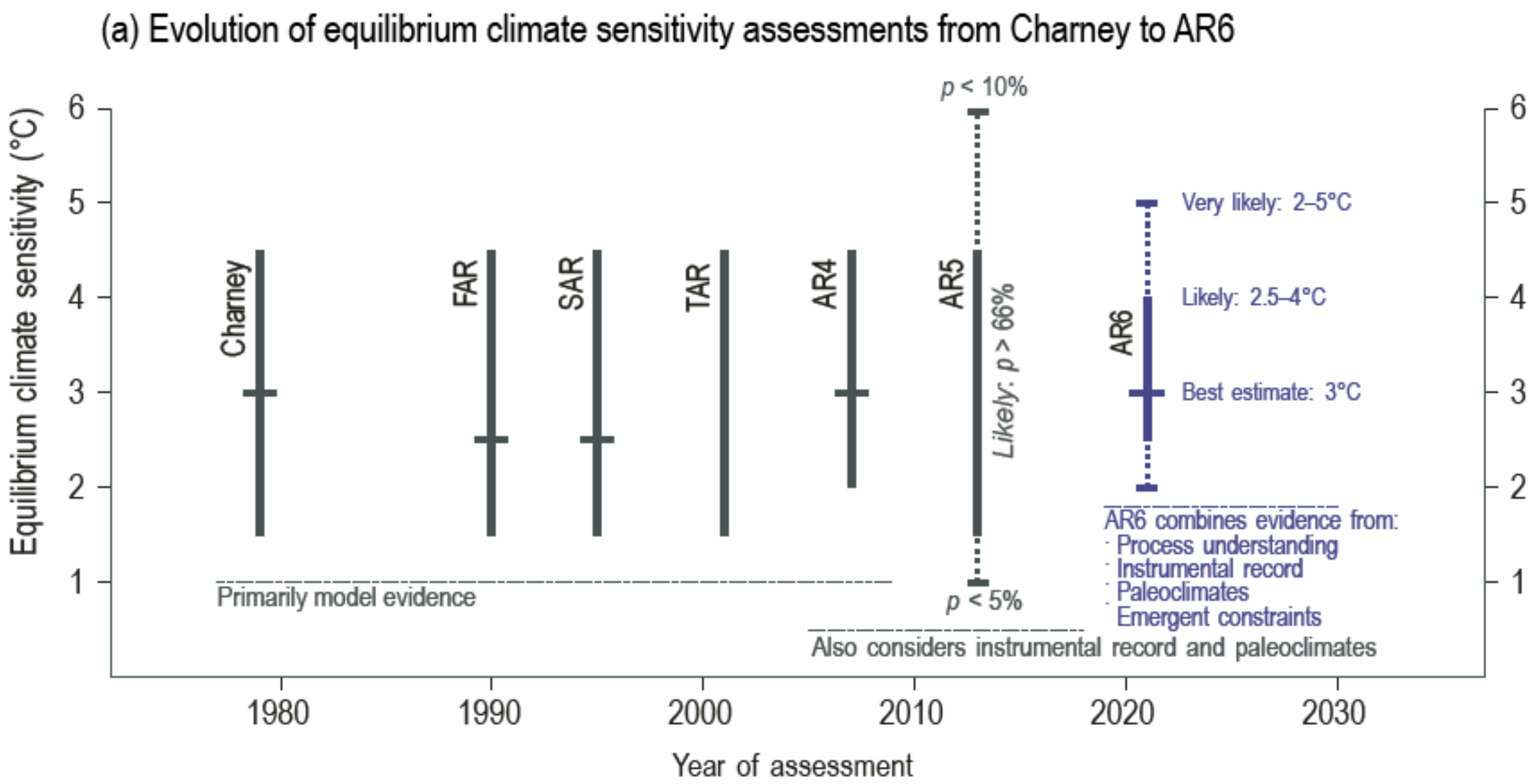
Models show a different warming pattern than observations



(Wills et al., GRL, 2022; see also Watanabe, nature, 2024)

Klimasensitivität aus Klimamodellen

Abschätzungen der Klimasensitivität in verschiedenen Berichten



(IPCC AR6, WG1, Fig.TS.16, 2021)

1896 – Svante Arrhenius

THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

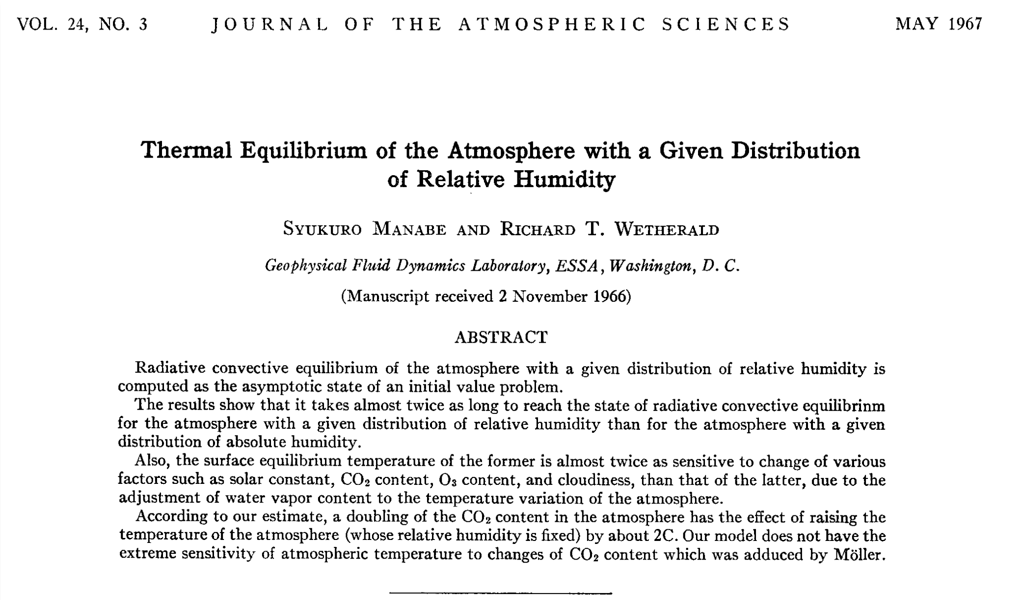
XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* *By* Prof. SVANTE ARRHENIUS *.

One may now ask, How much must the carbonic acid vary according to our figures, in order that the temperature should attain the same values as in the Tertiary and Ice ages respectively? A simple calculation shows that the temperature in the arctic regions would rise about 8° to 9° C., if the carbonic acid increased to 2·5 or 3 times its present value. In order to get the temperature of the ice age between the 40th and 50th parallels, the carbonic acid in the air should sink to 0·62–0·55 of its present value (lowering of temperature 4°–5° C.). The demands of the geologists, that at the genial

+ Umfangreiche Energiebilanzrechnungen mit Stift und Papier
+ Berücksichtigung von Wasserdampf- und Albedorückkopplungen
- Vernachlässigung des vertikalen Energietransports durch Konvektion

1967 – Syukuro Manabe

(source: Nobel Prize Outreach)



VOL. 24, NO. 3 JOURNAL OF THE ATMOSPHERIC SCIENCES MAY 1967

Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity

SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory, ESSA, Washington, D. C.

(Manuscript received 2 November 1966)

ABSTRACT

Radiative convective equilibrium of the atmosphere with a given distribution of relative humidity is computed as the asymptotic state of an initial value problem.

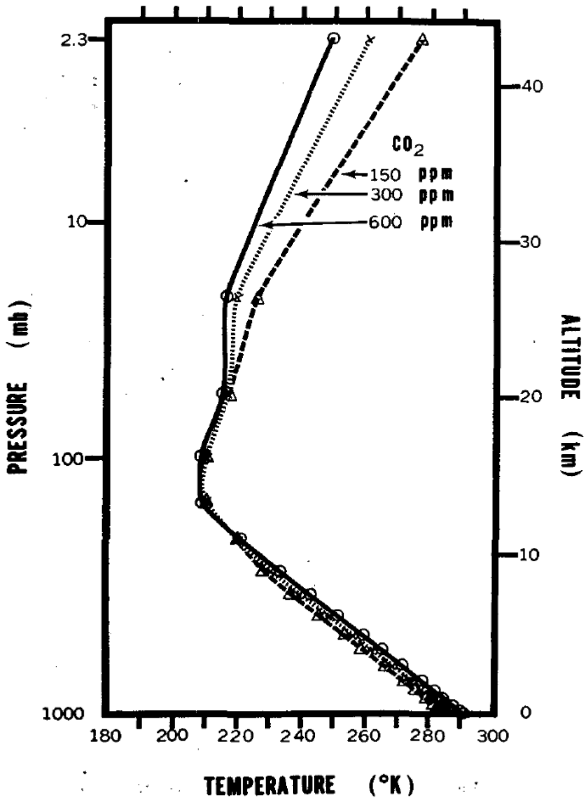
The results show that it takes almost twice as long to reach the state of radiative convective equilibrinm for the atmosphere with a given distribution of relative humidity than for the atmosphere with a given distribution of absolute humidity.

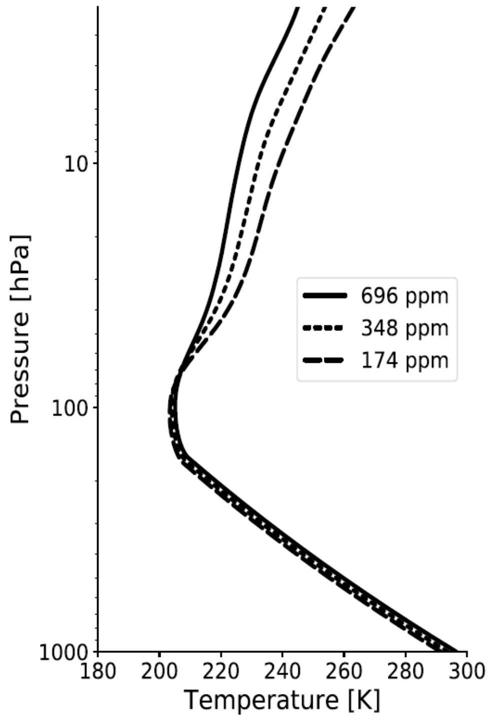
Also, the surface equilibrium temperature of the former is almost twice as sensitive to change of various factors such as solar constant, CO_2 content, O_3 content, and cloudiness, than that of the latter, due to the adjustment of water vapor content to the temperature variation of the atmosphere.

According to our estimate, a doubling of the CO_2 content in the atmosphere has the effect of raising the temperature of the atmosphere (whose relative humidity is fixed) by about 2C. Our model does not have the extreme sensitivity of atmospheric temperature to changes of CO_2 content which was adduced by Möller.

- Rechnungen mit einem 1D-RCE-Modell (RCE: Radiative-convective equilibrium)
- Berücksichtigung des vertikalen Energietransports durch Konvektion

1967 – Syukuro Manabe





Konrad ist frei verfügbar:

https://github.com/atmtools/konrad

Manabe & Wetherald (JAS, 1967) estimated a warming of 2.7 K for a doubling of the atmospheric CO_2 concentration. We (Kluft et al., J. Climate, 2019) repeated their calculations with „konrad“, arriving at 2.8 K.

Die Klimasensitivität von Modellen lässt sich tunen

JAMES Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2019MS002037

Special Section:
The Max Planck Institute for Meteorology Earth System Model version 1.2

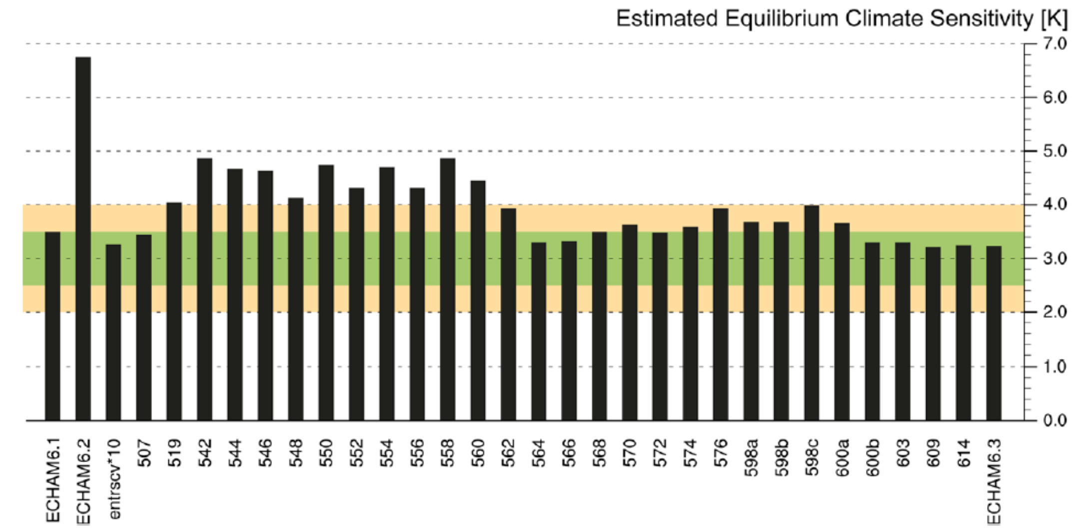
Key Points:
- We document how the MPI-ESM1.2 was tuned to the instrumental record warming

Tuning the MPI-ESM1.2 Global Climate Model to Improve the Match With Instrumental Record Warming by Lowering Its Climate Sensitivity

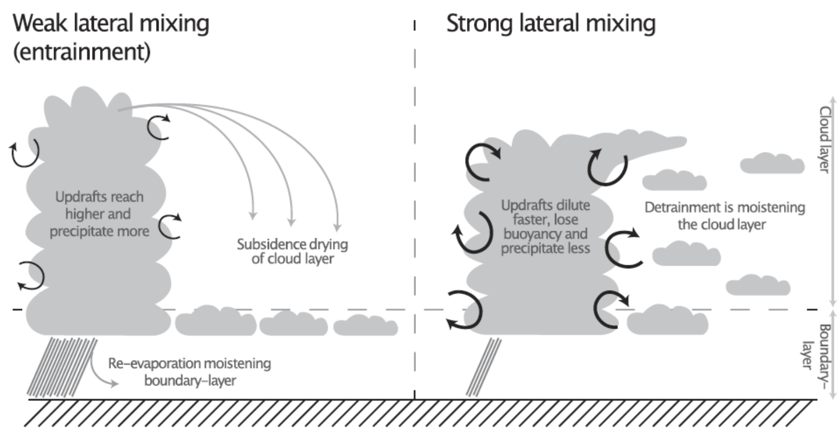
Thorsten Mauritsen[1] and Erich Roeckner[2]

[1]Department of Meteorology, Stockholm University, Stockholm, Sweden, [2]Max Planck Institute for Meteorology, Hamburg, Germany

Climate sensitivity estimated for a series of ECHAM models with different tunings



Cloud scenes for different entrainment parameter tunings



(Mauritsen & Roeckner, JAMES, 2020)

Moderne Abschätzungen der Klimasensitivität

Der Storyline Ansatz zur Abschätzung der Plausibilität extremer Klimasensitivitäten

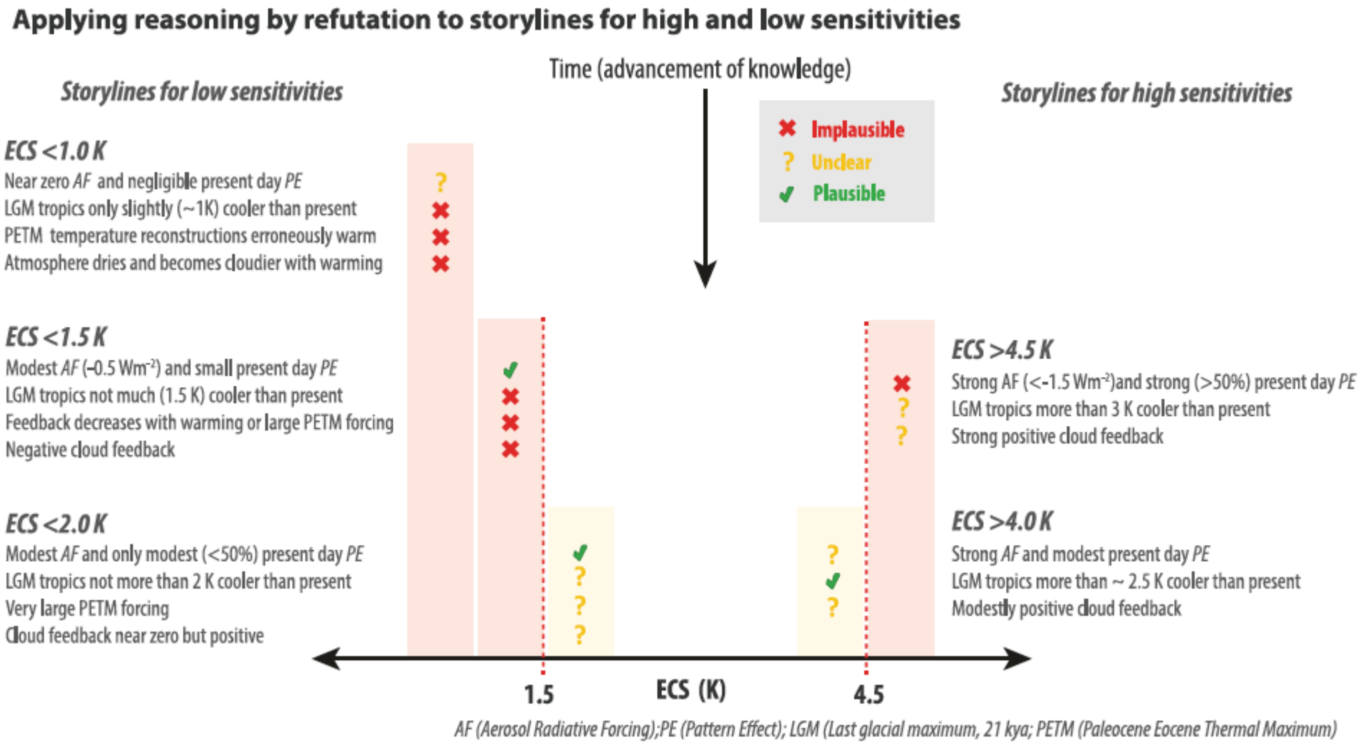
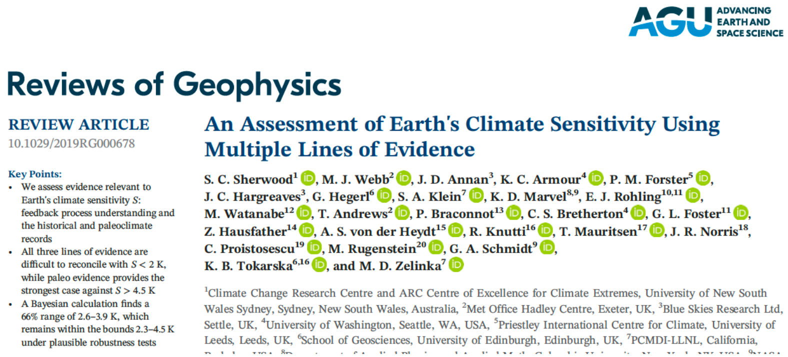


Figure 1. The application of refutational reasoning to storylines for successively more constraining bounds on ECS. For a particular bound on ECS to hold it must be consistent with all the lines of evidence, here formulated in terms of physical statements related to some interpretation of data or some specific process, for example, cloud response to warming. The hypotheses most fruitful to test progressively narrower bounds are those that are marked by a yellow question mark. This illustration is meant to encourage, rather than substitute, a more thorough assessment.

(Stevens et al., Earth's Future, 2016)

Klimamodelle sind nicht mehr die Hauptquelle für die Abschätzung der Klimasensitivität


AGU ADVANCING EARTH AND SPACE SCIENCE

Reviews of Geophysics

REVIEW ARTICLE
10.1029/2019RG000678

An Assessment of Earth's Climate Sensitivity Using Multiple Lines of Evidence

Key Points:
- We assess evidence relevant to Earth's climate sensitivity S: feedback process understanding and the historical and paleoclimate records
- All three lines of evidence are difficult to reconcile with $S < 2$ K, while paleo evidence provides the strongest case against $S > 4.5$ K
- A Bayesian calculation finds a 66% range of 2.6–3.9 K, which remains within the bounds 2.3–4.5 K under plausible robustness tests

S. C. Sherwood[1], M. J. Webb[2], J. D. Annan[3], K. C. Armour[4], P. M. Forster[5], J. C. Hargreaves[3], G. Hegerl[6], S. A. Klein[7], K. D. Marvel[8,9], E. J. Rohling[10,11], M. Watanabe[12], T. Andrews[2], P. Braconnot[13], C. S. Bretherton[4], G. L. Foster[11], Z. Hausfather[14], A. S. von der Heydt[15], R. Knutti[16], T. Mauritsen[17], J. R. Norris[18], C. Proistosescu[19], M. Rugenstein[20], G. A. Schmidt[9], K. B. Tokarska[6,16], and M. D. Zelinka[7]

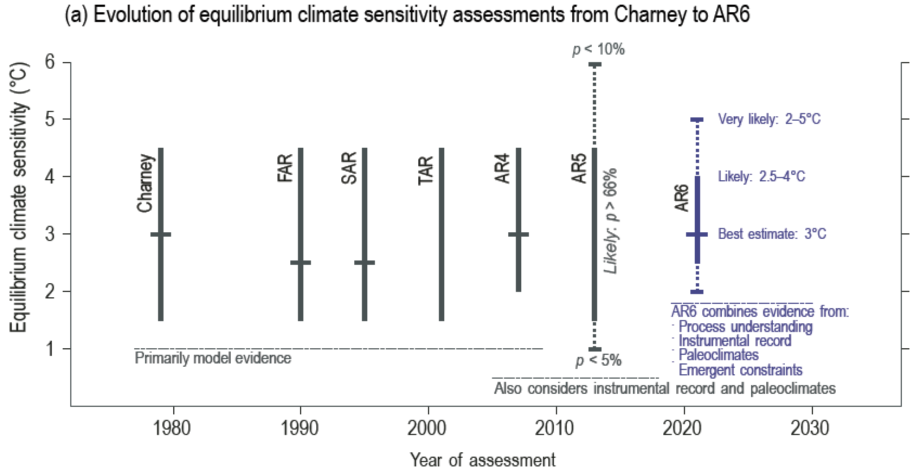
[1]Climate Change Research Centre and ARC Centre of Excellence for Climate Extremes, University of New South Wales Sydney, Sydney, New South Wales, Australia, [2]Met Office Hadley Centre, Exeter, UK, [3]Blue Skies Research Ltd, Settle, UK, [4]University of Washington, Seattle, WA, USA, [5]Priestley International Centre for Climate, University of Leeds, Leeds, UK, [6]School of Geosciences, University of Edinburgh, Edinburgh, UK, [7]PCMDI-LLNL, California,

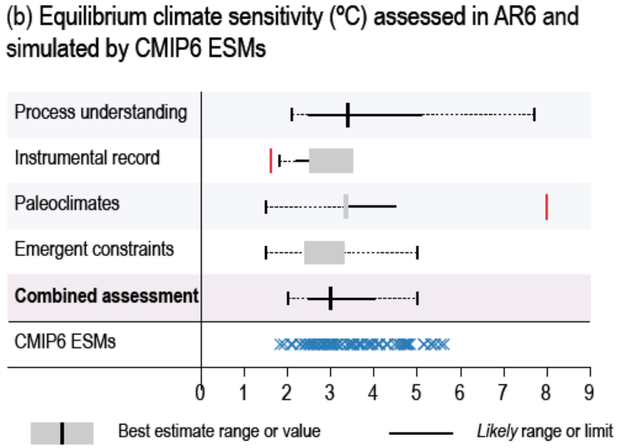
Sherwood et al. (2019) provide a comprehensive review of the current understanding of ECS. They follow the storytelling idea of Stevens et al. (2016) and base their estimates on three lines of evidence:

- Historical (instrumental) record
- Paleoclimates
- Process understanding

IPCC AR6 adds a fourth line of evidence:

- Emergent constraints

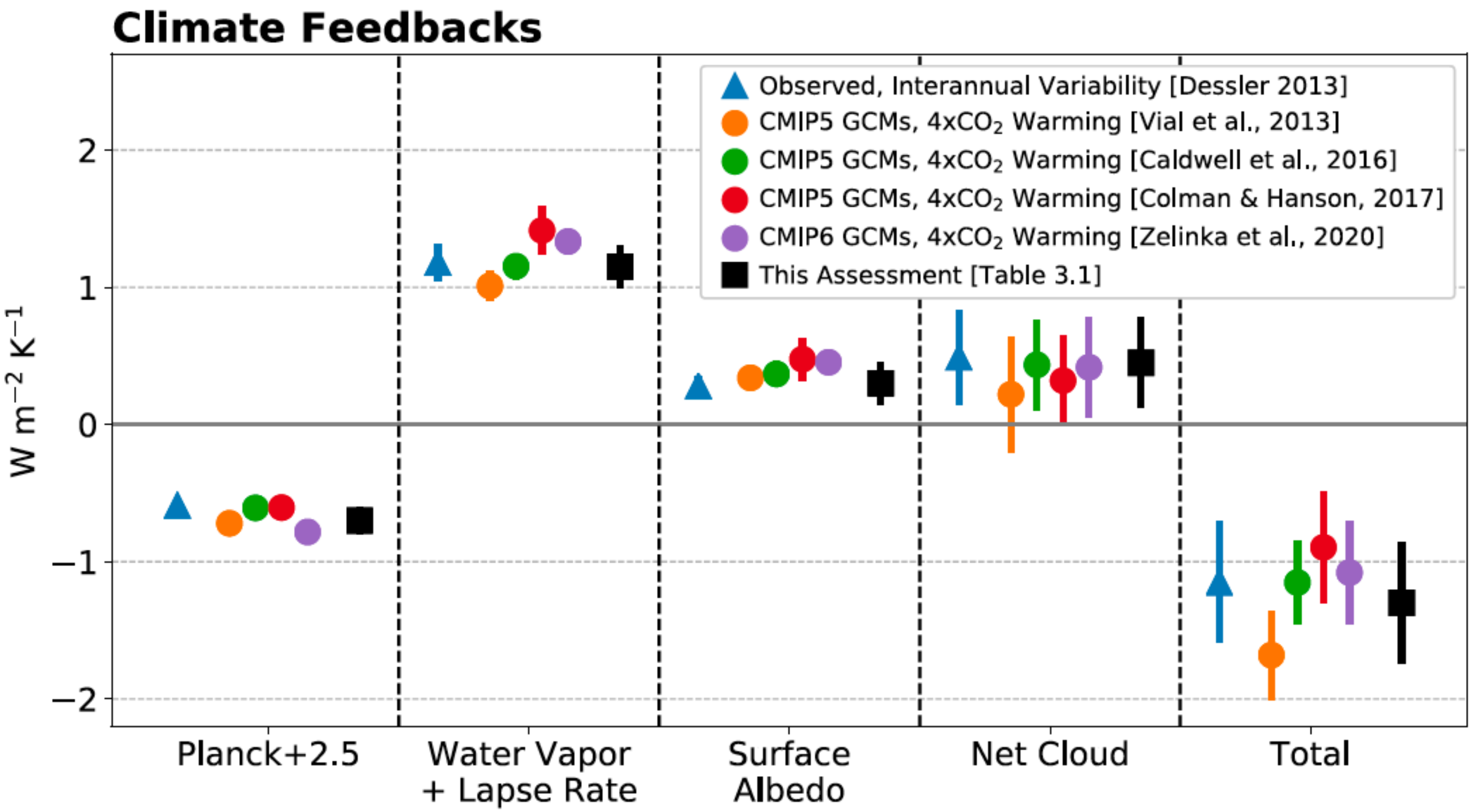




(IPCC AR6, WG1, Fig. TS.16, 2021)

Der Unsicherheitsfaktor Wolken

Wolken gelten als größter Unsicherheitsfaktor des Feedbacks



(Sherwood et al., Rev. Geophys., 2019)

Mögliche Feedbacks von Wolken

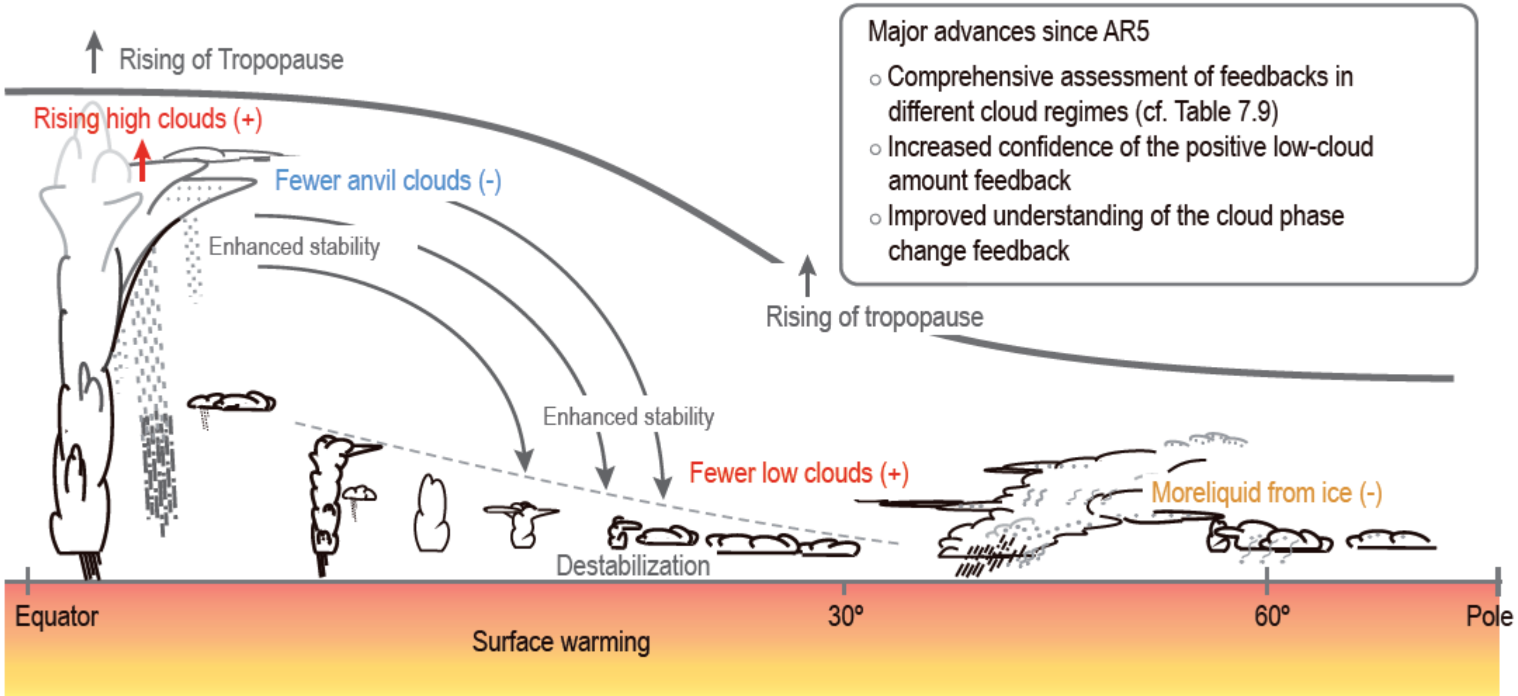


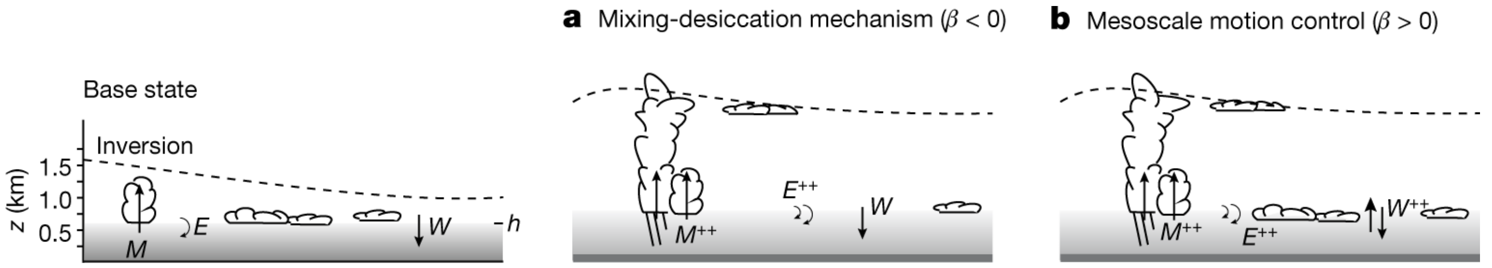
Figure 7.9 | Schematic cross section of diverse cloud responses to surface warming from the tropics to polar regions. Thick solid and dashed curves indicate the tropopause and the subtropical inversion layer in the current climate, respectively. Thin grey text and arrows represent robust responses in the thermodynamic structure to greenhouse warming, of relevance to cloud changes. Text and arrows in red, orange and green show the major cloud responses assessed with *high*, *medium* and *low confidence*, respectively, and the sign of their feedbacks to the surface warming is indicated in the parenthesis. Major advances since AR5 are listed in the box. Figure adapted from Boucher et al. (2013).

(IPCC AR6, WG1, Fig.7.9, 2021)

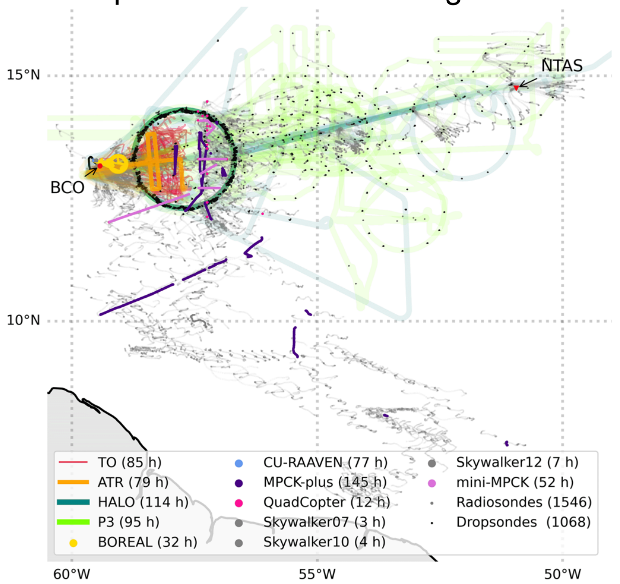
Trade wind cumulus

(https://mpimet.mpg.de)

Refuting the mixing-desiccation hypothesis using observations

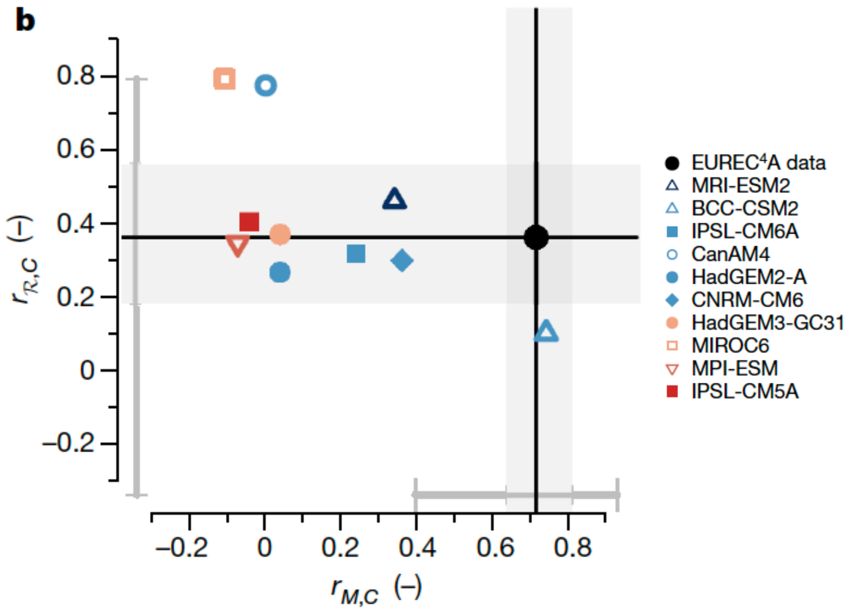


Heatmap of aircraft tracks during EUREC4A



(Stevens et al., ESSD, 2021)

A positive trade wind cloud feedback was hypothesized and is often represented in climate models. This would require cloud base mass flux M to correlate negatively or only weakly to cloud fraction. Aircraft observations during EUREC4A refute this hypothesis.

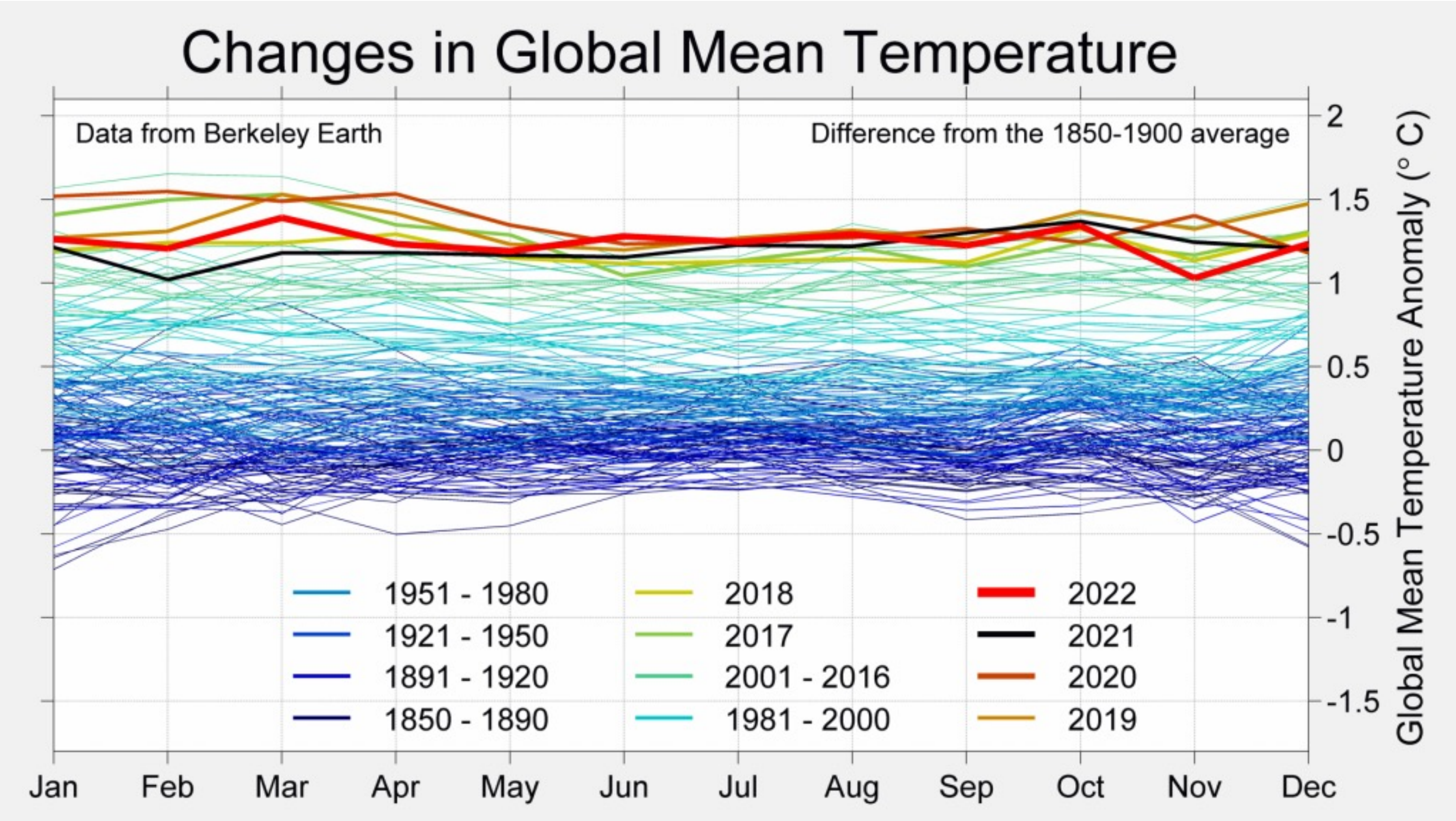


(Vogel et al., nature, 2022)

Die aktuelle Diskussion:

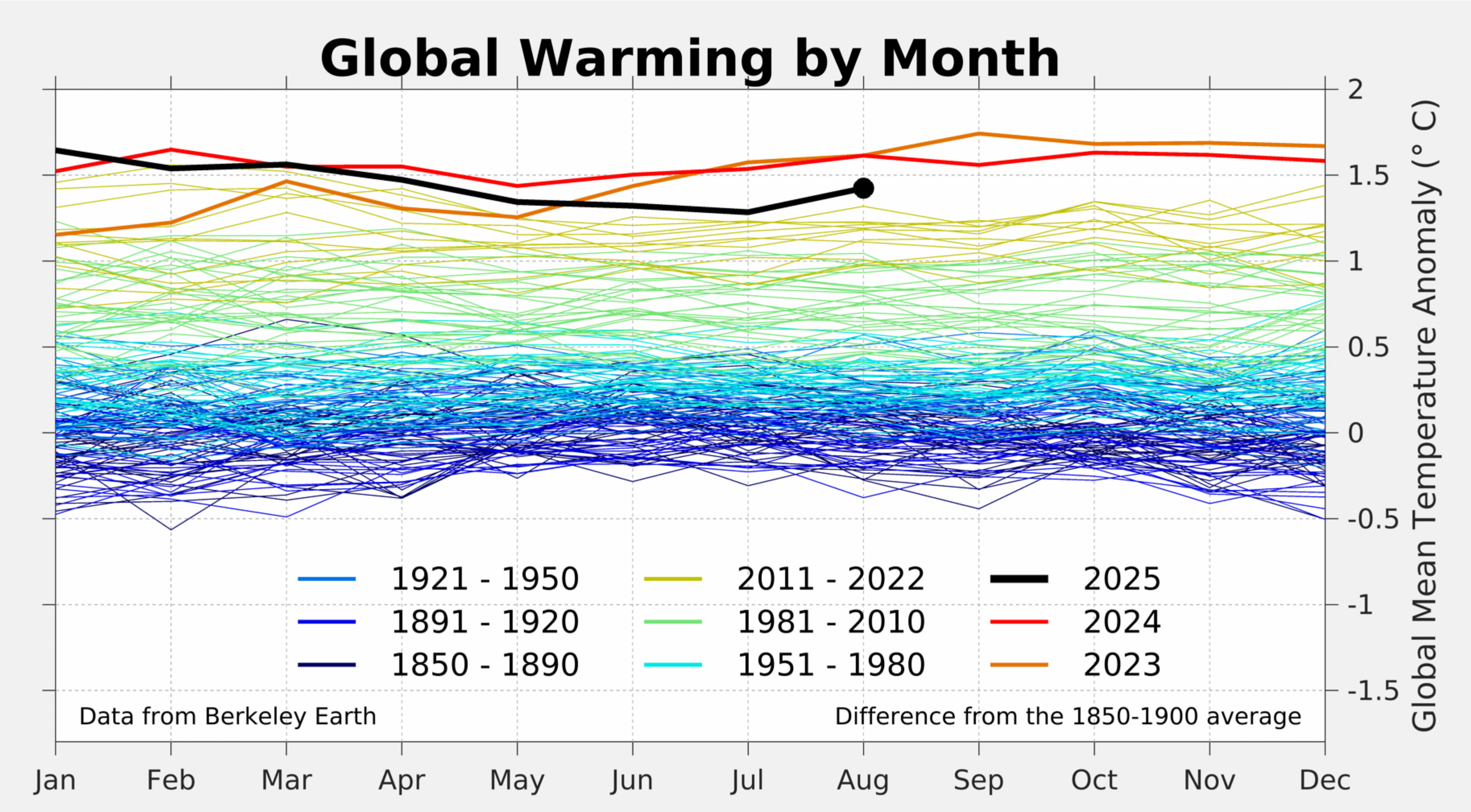
Die Jahre 2023/24; gibt es eine beschleunigte Erwärmung?

Monatliche globale Temperaturanomalien 1951-2022



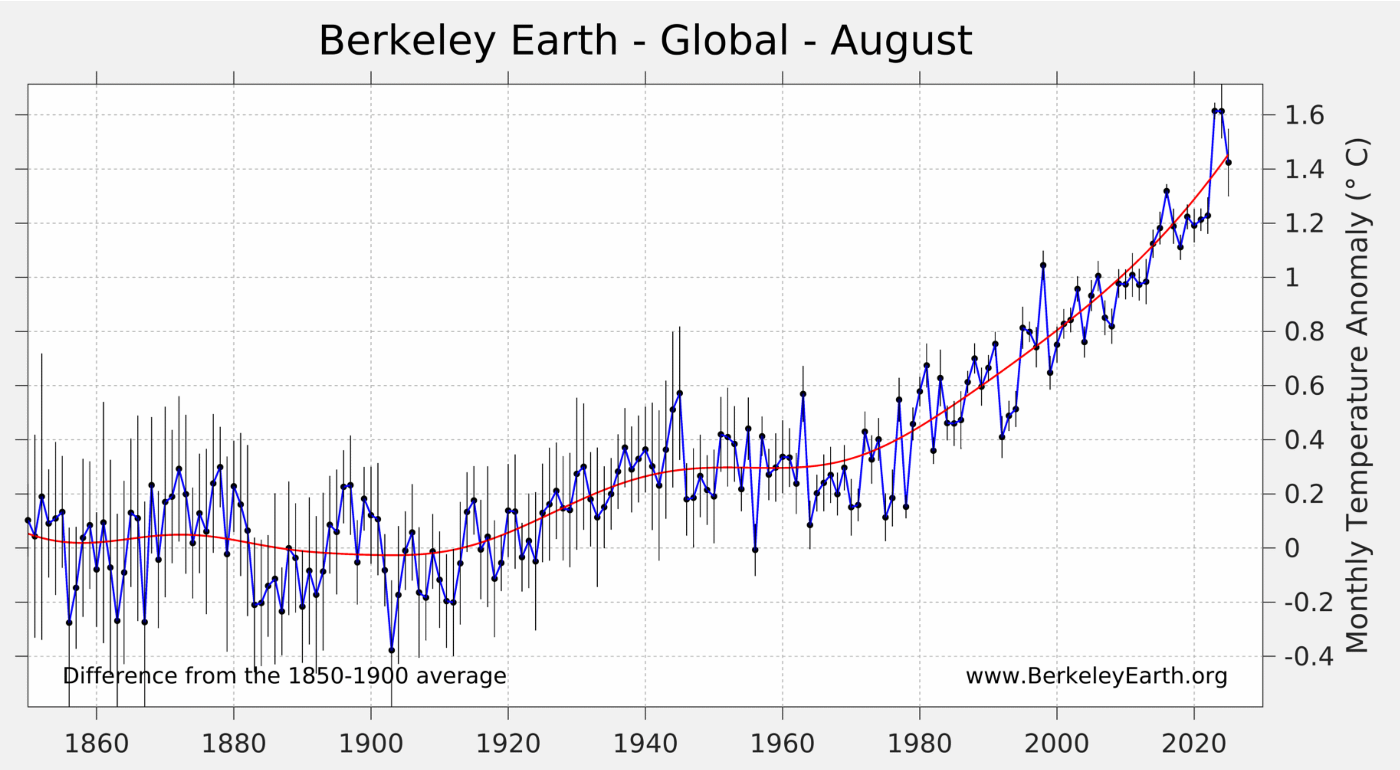
(https://berkeleyearth.org)

Monatliche globale Temperaturanomalien 1951- 08/2025



(https://berkeleyearth.org)

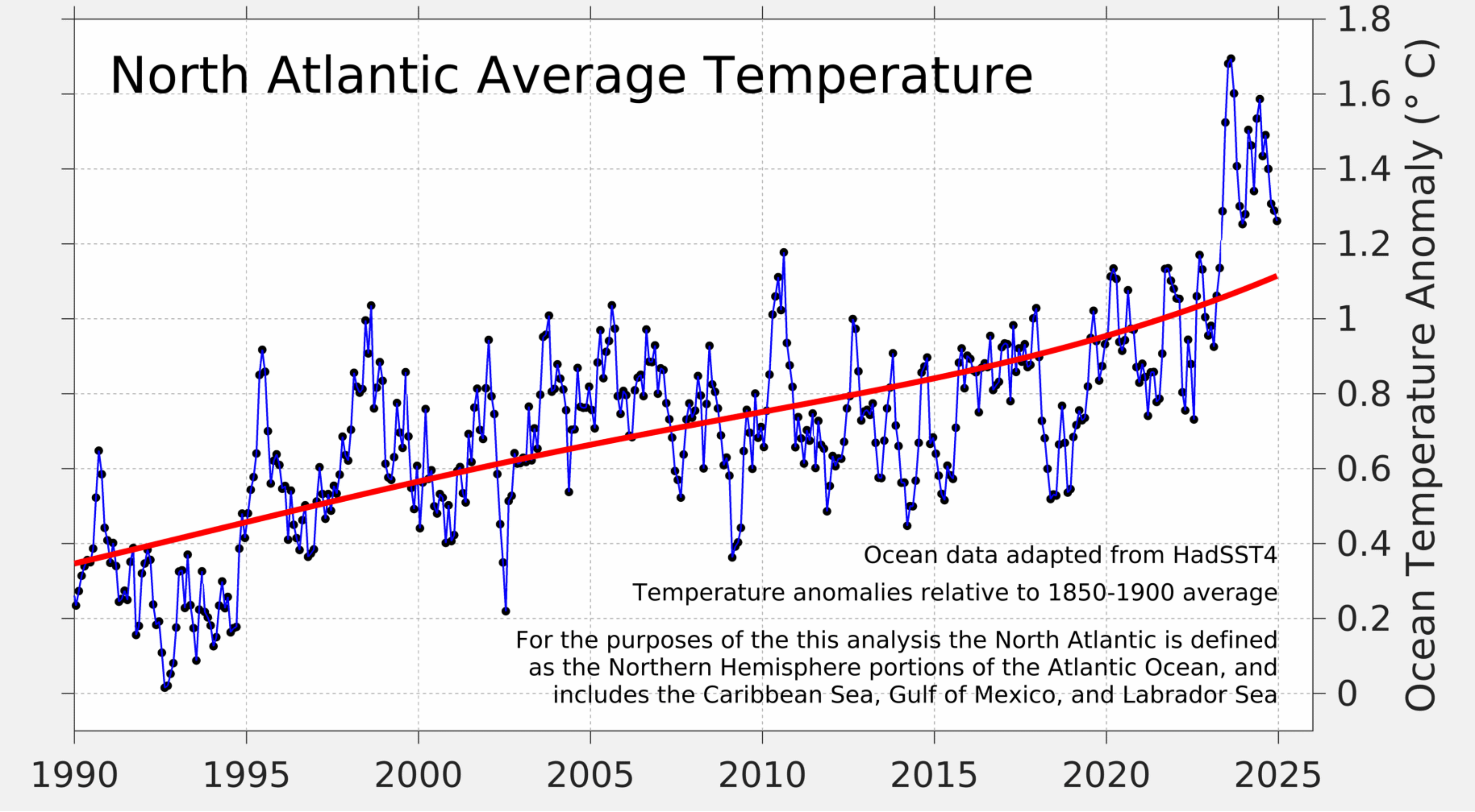
Globale jährliche Temperaturanomalien 1850 - 08/2025



From 1970 until 2020 global mean temperature increased by ca. 0.2℃ per decade. Hansen et al. (2023) expect "post-2010 […] global warming of at least 0.27℃ per decade. Even if we assume to be already at 1.5 ℃ above preindustrial in 2025, we would need 0.6℃/decade warming to reach 3℃ in 2050.

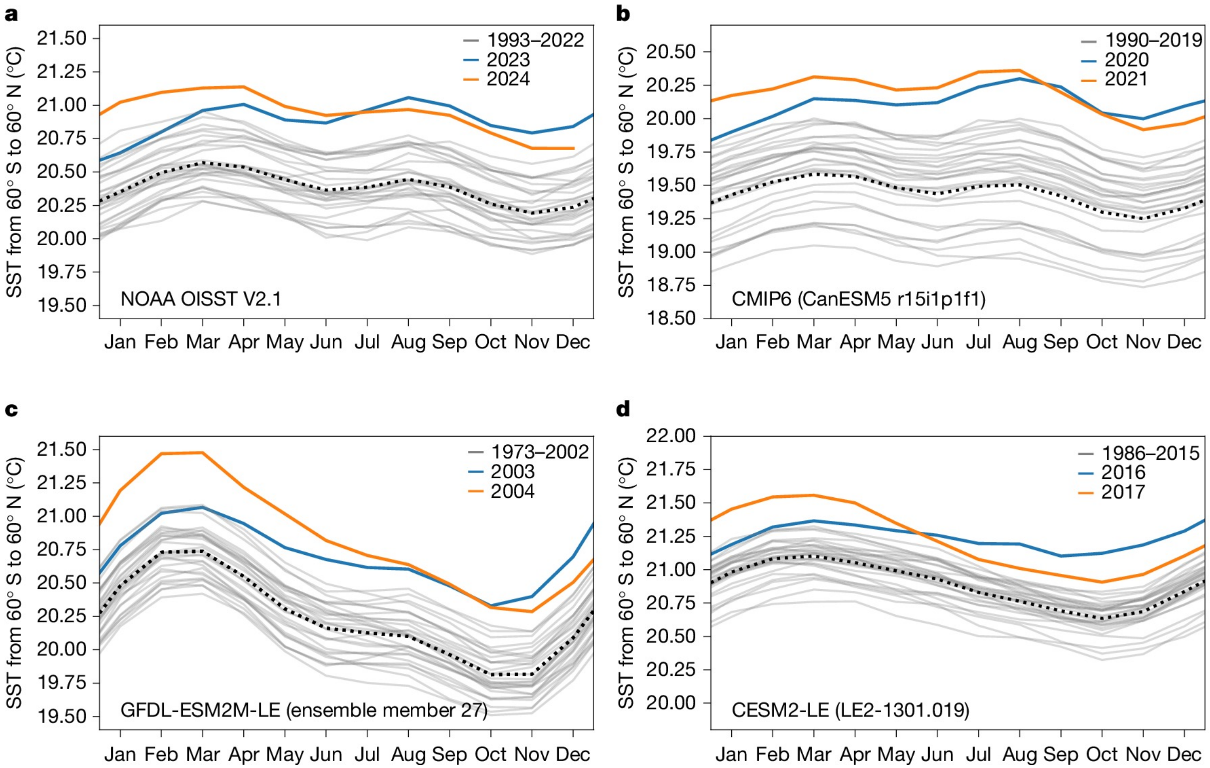
(https://berkeleyearth.org)

Nordatlantische Temperaturanomalien



(https://berkeleyearth.org)

Sind die Temperaturen in 2023/24 ein Anzeichen für eine beschleunigte Erwärmung?



Article

Record sea surface temperature jump in 2023–2024 unlikely but not unexpected

https://doi.org/10.1038/s41586-025-08674-z

Jens Terhaar[1,2], Friedrich A. Burger[1,2], Linus Vogt[3], Thomas L. Frölicher[1,2] & Thomas F. Stocker[1,2]

Received: 28 June 2024
Accepted: 17 January 2025
Published online: 12 March 2025
Open access
Check for updates

Global ocean surface temperatures were at record levels for more than a year from April 2023 onwards, exceeding the previous record in 2015–2016 by 0.25 °C on average between April 2023 and March 2024[1]. The nearly global extent and unprecedented intensity of this event prompted questions about how exceptional it was and whether climate models can represent such record-shattering jumps

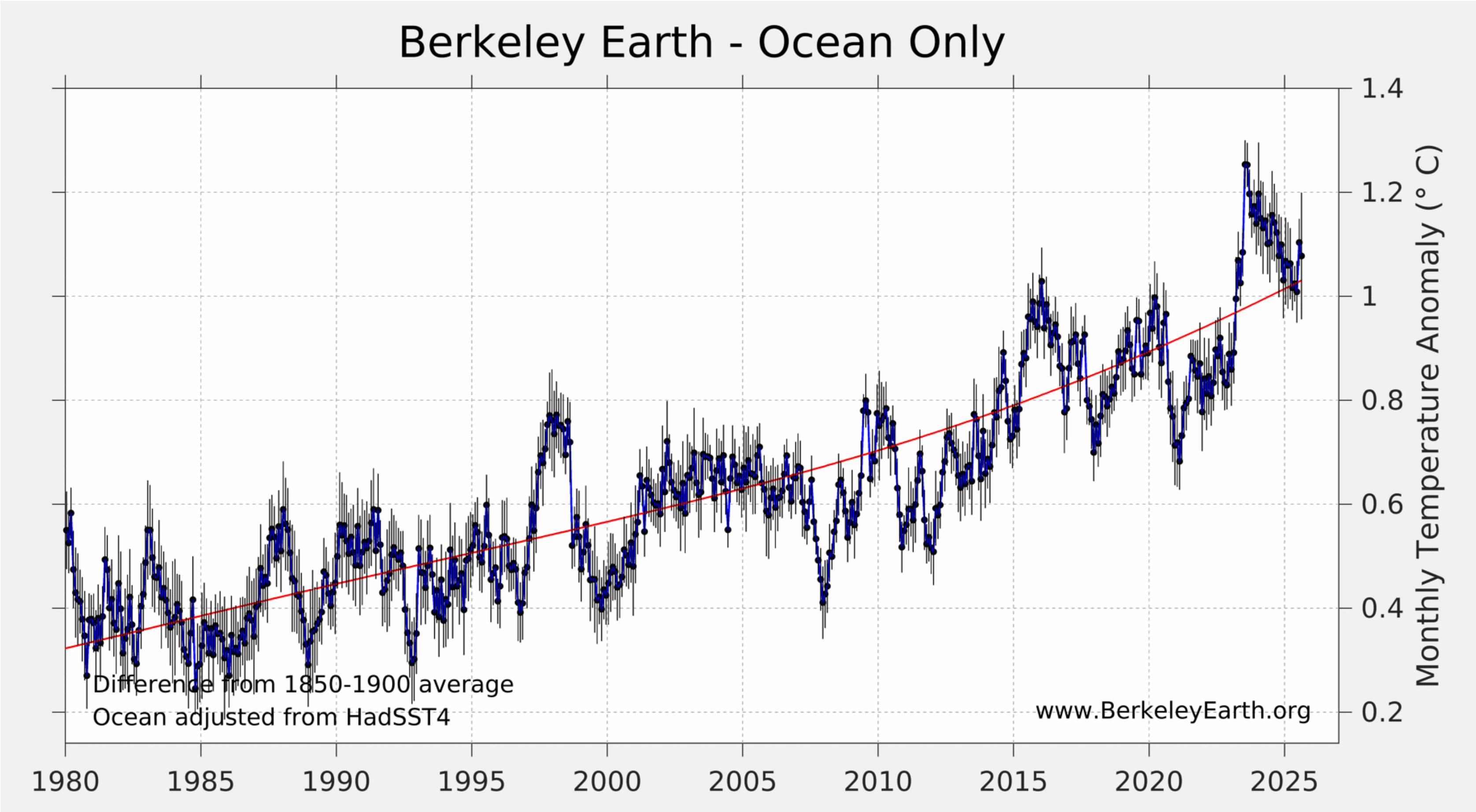
"… observation-based synthetic time series … show that a jump in global sea surface temperatures that breaks the previous record by at least 0.25 °C is a 1-in-512-year event under the current longterm warming trend"

"Using 270 simulations from a wide range of fully coupled climate models, we show that these models successfully simulate such record-shattering jumps in global ocean surface temperatures."

"… we conclude that it is likely that SSTs will return to pre-jump levels before September 2025"

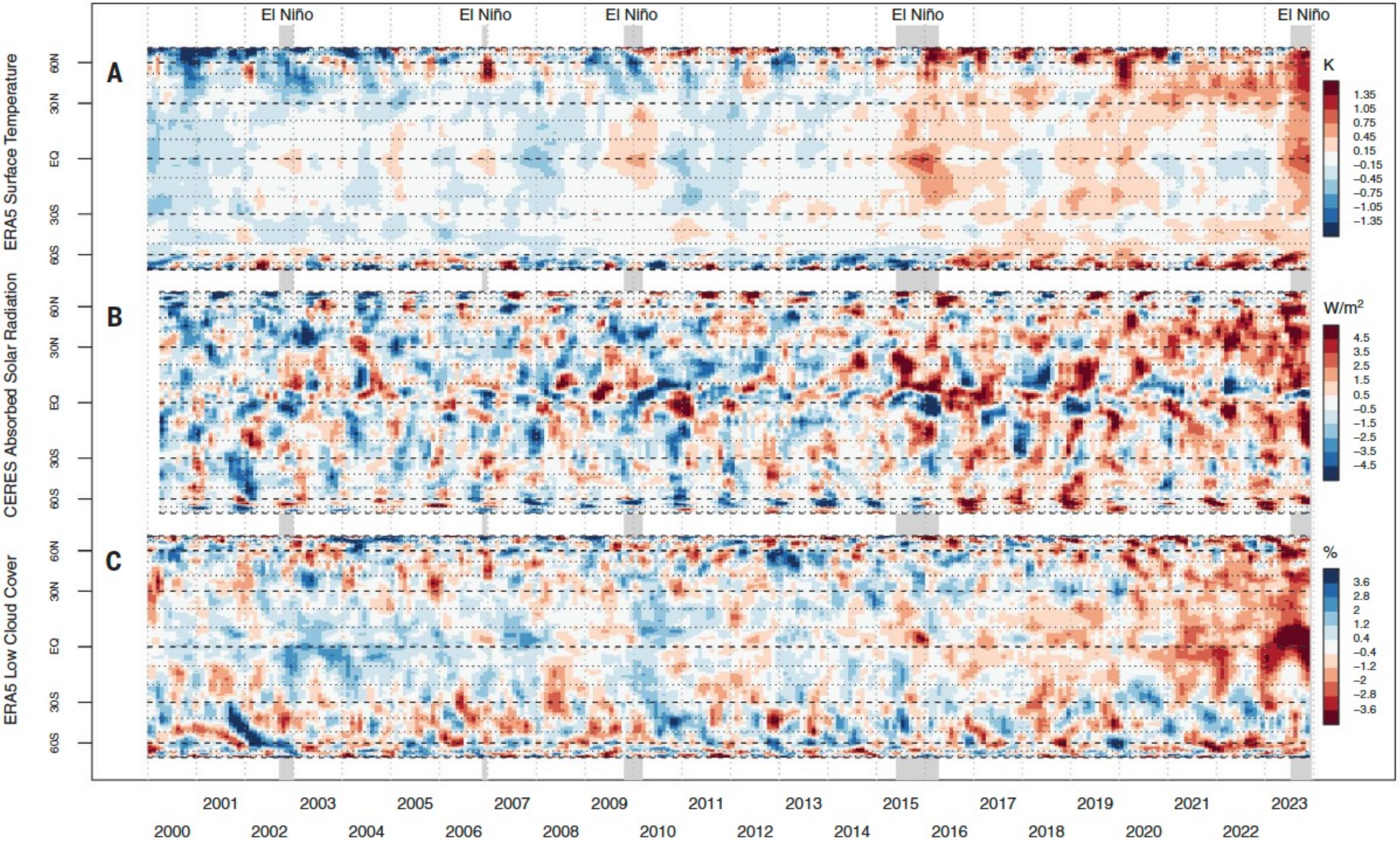
(Terhaar et al., nature, 2025)

Sind die Temperaturen in 2023/24 ein Anzeichen für eine beschleunigte Erwärmung?



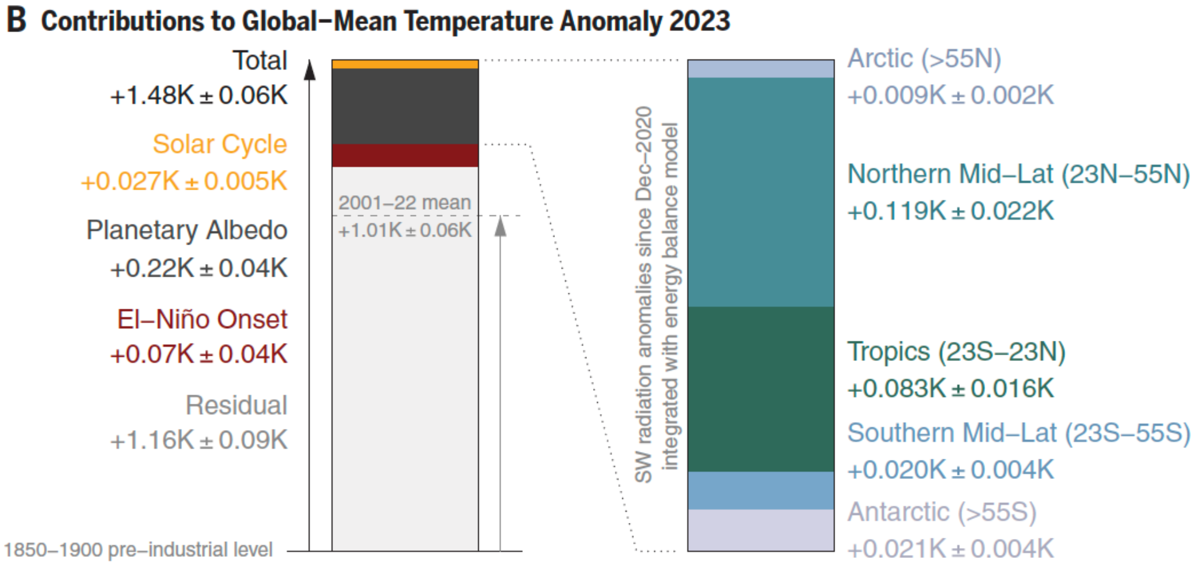
(https://berkeleyearth.org)

Die Temperaturanomalie von 2023



(Gössling et al., Science, 2025)

Die Temperaturanomalie von 2023



(Gössling et al., Science, 2025)

"Three fundamental mechanisms may have contributed to the record-low planetary albedo associated with reduced low-level clouds:

- *internal variability,*
- *an emerging low-cloud feedback, and*
- *aerosol effects."*

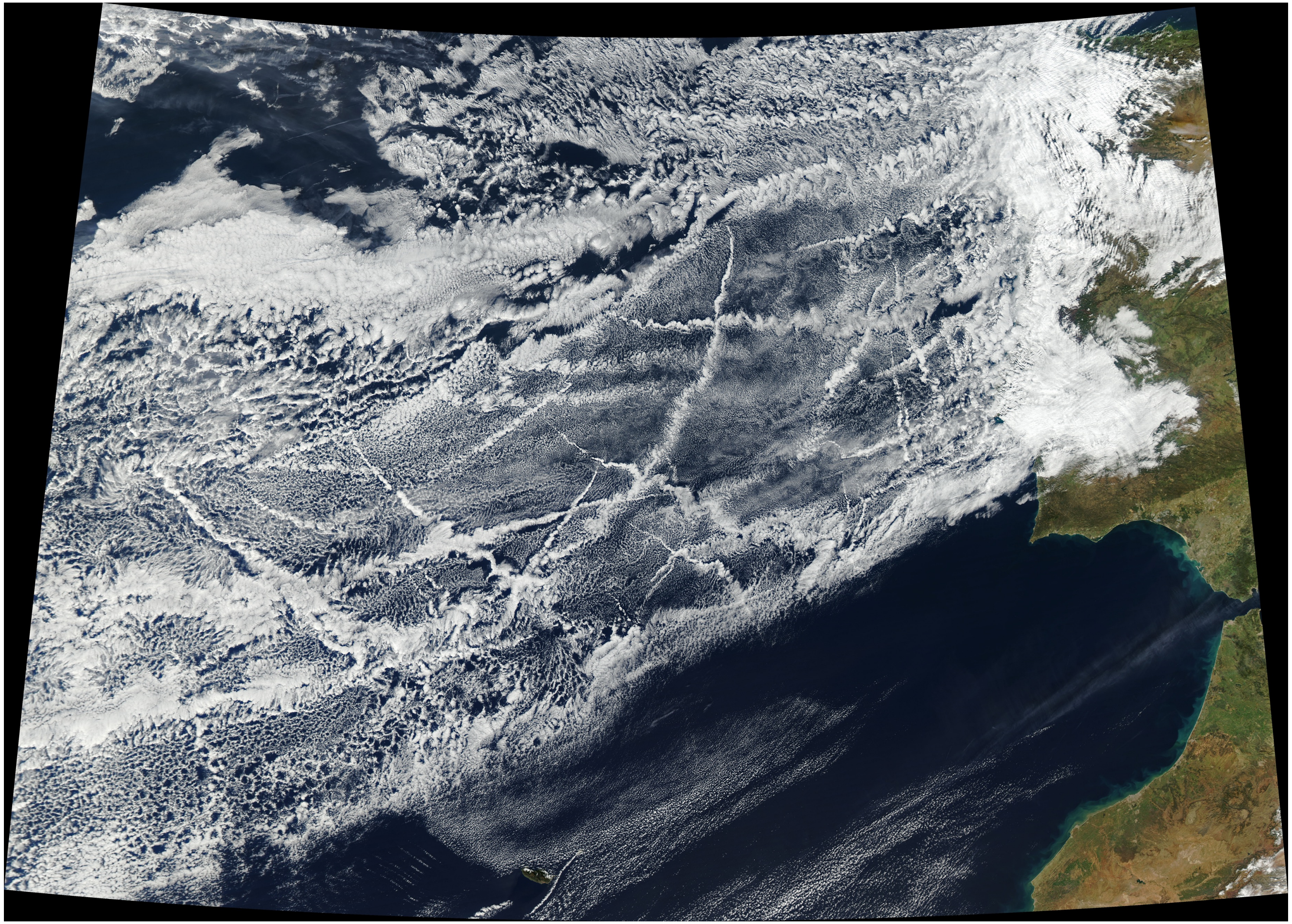
Causes suggested for the reduced North Atlantic SW reflection (only the first is mentioned in this paper)

- reduced sulfur in ship fuel

- anomalous low wind speed

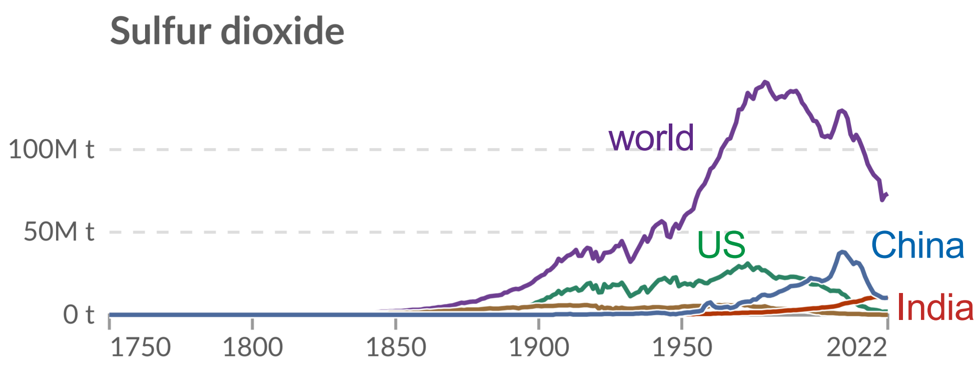
- reduced Saharan dust

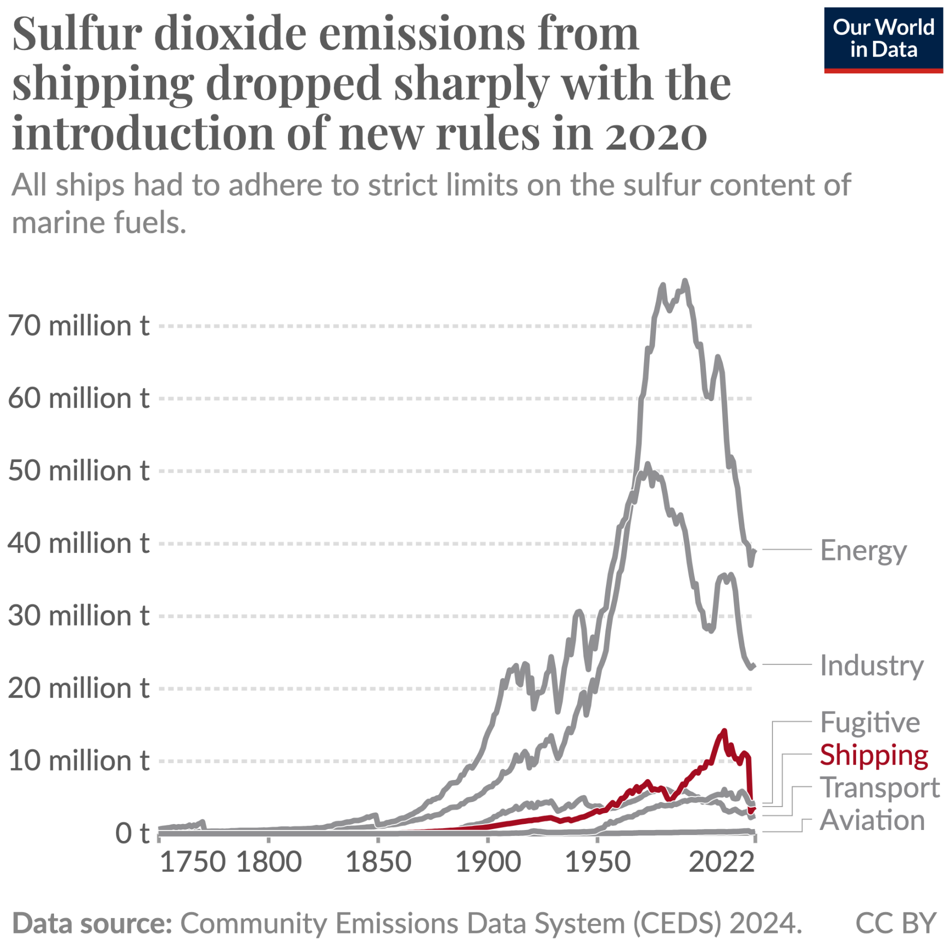
Ship tracks



(https://www.earthobservatory.nasa.gov)

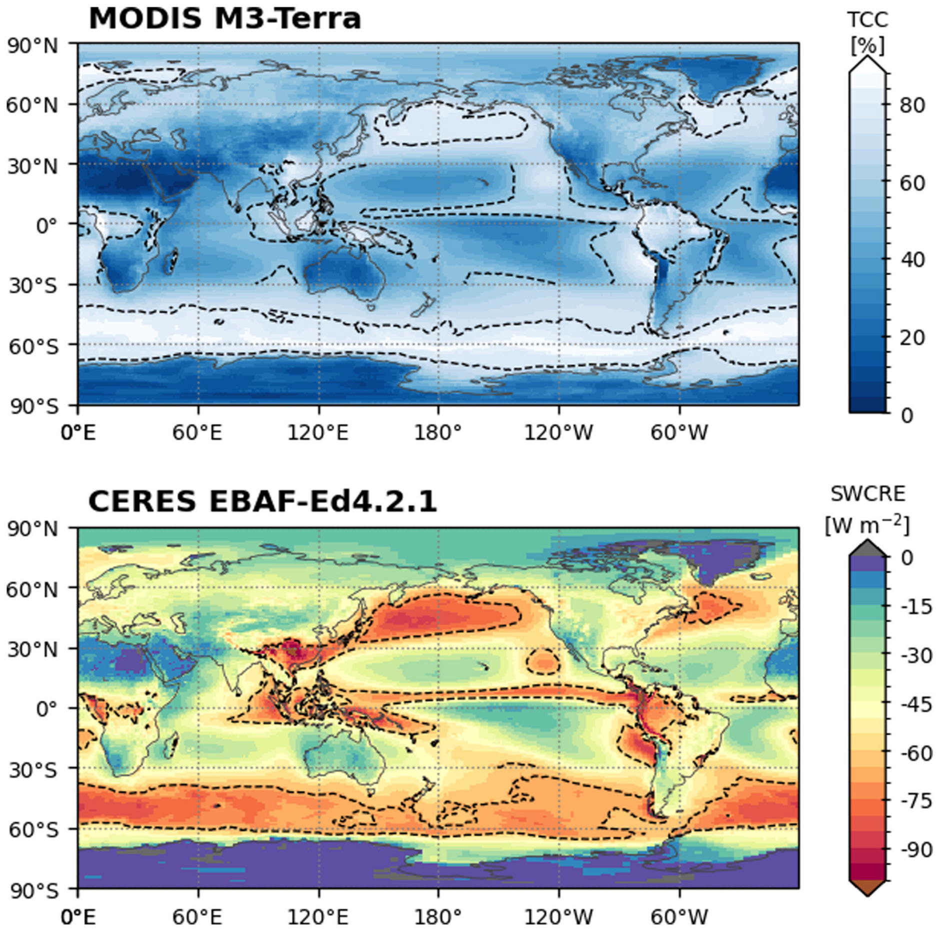
SO_2 Emissions

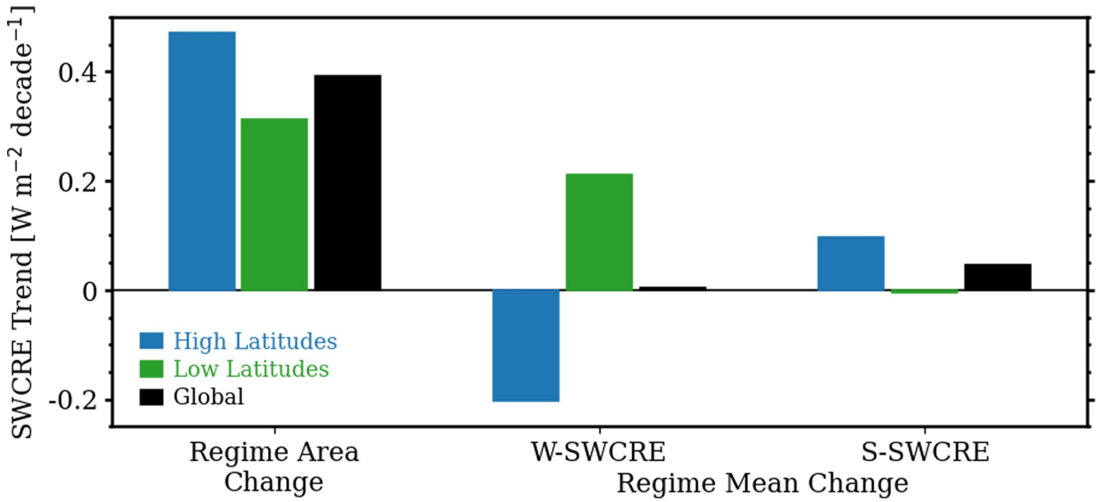




(https://ourworldindata.org; data from Hoesly et al., 2024)

Cloud radiative effects change dominated by regime shifts

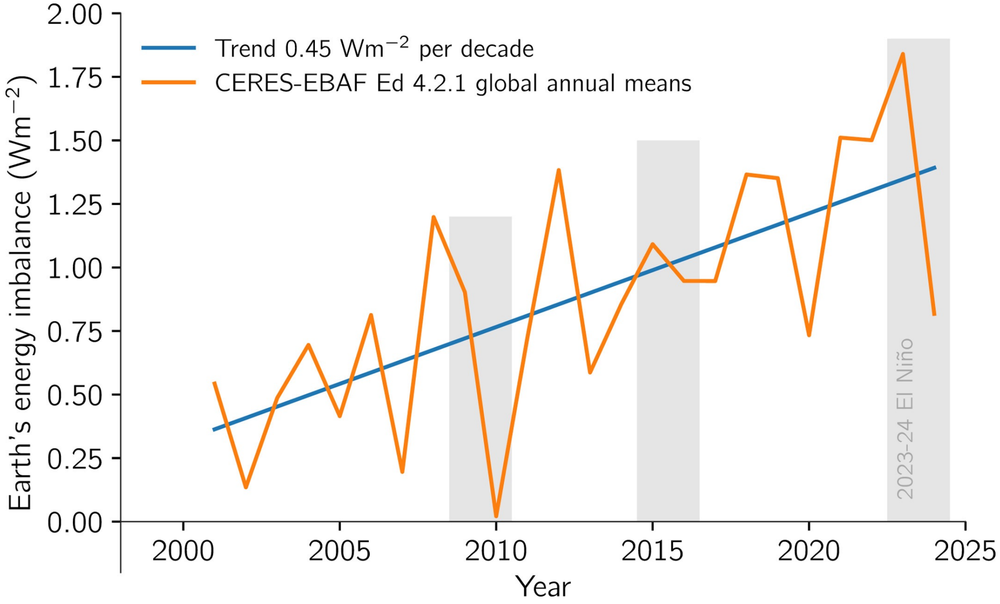




Satellite observations suggest that the positive trend in absorbed SW radiation is mainly due to regime shifts: contraction of both the ITCZ and storm tracks, less to changes within the regimes as possibly caused by decreased sulfur emissions from ships.

(Tselioudis et al., GRL, 2025)

Globale Energie-Imbalance

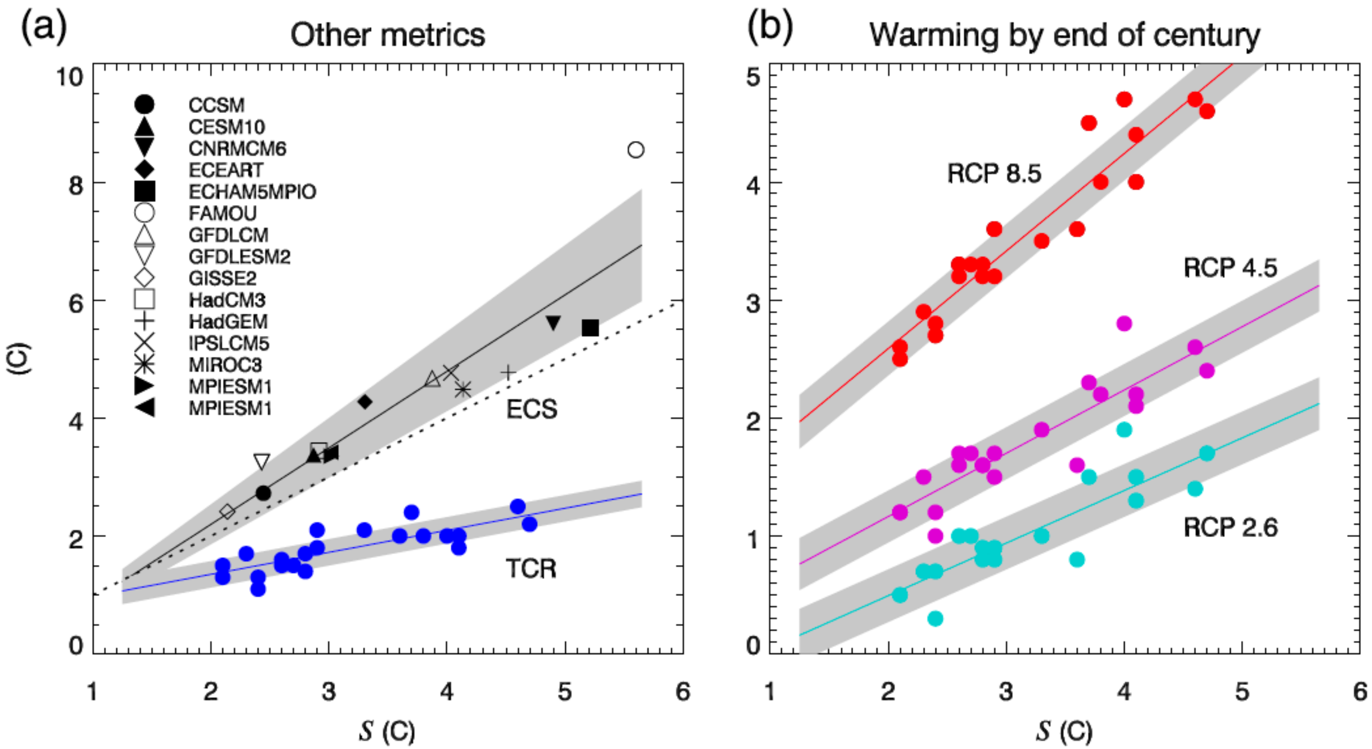


"Worryingly, the observed energy imbalance is rising much faster than expected, reaching 1.8 W/m² in 2023 - or twice that predicted by climate models - after having more than doubled within just two decades."

(Mauritsen et al., AGU Advances, 2025)

Die zukünftige Erwärmung

Simulated warming correlates well with ECS



S is a measure of the climate sensitivity estimated from abrupt 4xCO2 simulations running over 150 years. Here, ECS is instead taken from simulations that have run at least 1000 years.

(Sherwood et al., Rev. Geophys., 2019)

Hansen et al. (2023) global warming projections

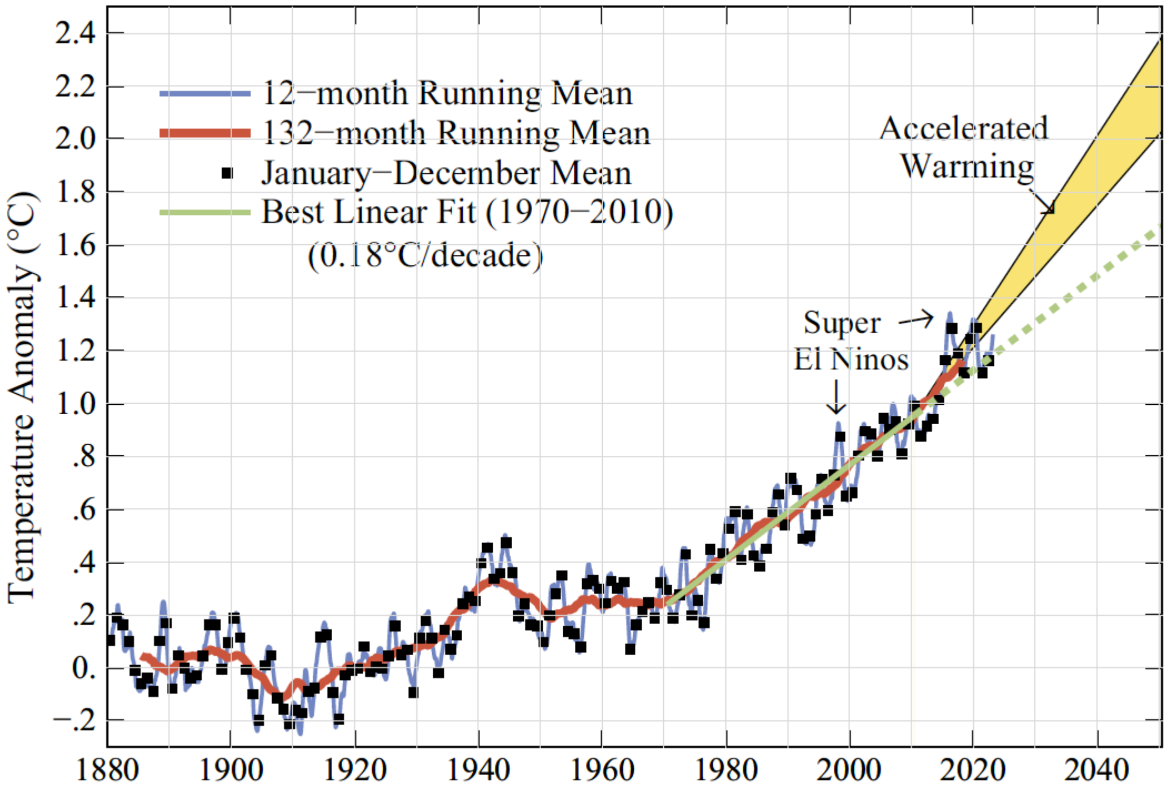


Figure 24. Global temperature relative to 1880–1920. Edges of the predicted post-2010 accelerated warming rate (see text) are 0.36 and 0.27°C per decade.

"Multiple lines of evidence show that aerosol forcing peaked early this century [174]. […] We estimate peak (negative) aerosol forcing as at least 1.5–2 W/m2, with turning point at 2010, […] GHG plus aerosol forcing grew 0.3 W/m2 per decade (GHGs: þ0.45, aerosols: –0.15) during 1970–2010, which produced warming of 0.18C per decade. With current policies, we expect climate forcing for a few decades post-2010 to increase [to] 0.5–0.6 W/m2 per decade and produce global warming of at least 0.27C per decade. In that case, global warming will reach 1.5C in the 2020s and 2C before 2050 (Fig. 24). "

(Hansen et al., OOCC, 2023)

Aerosol Forcing

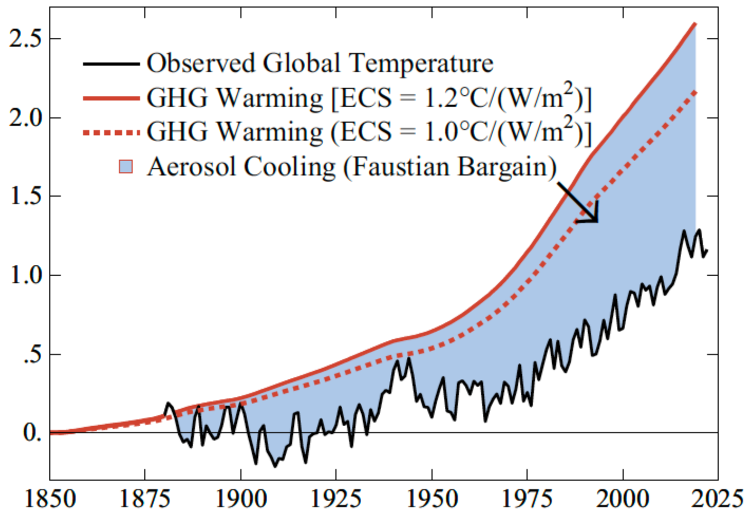
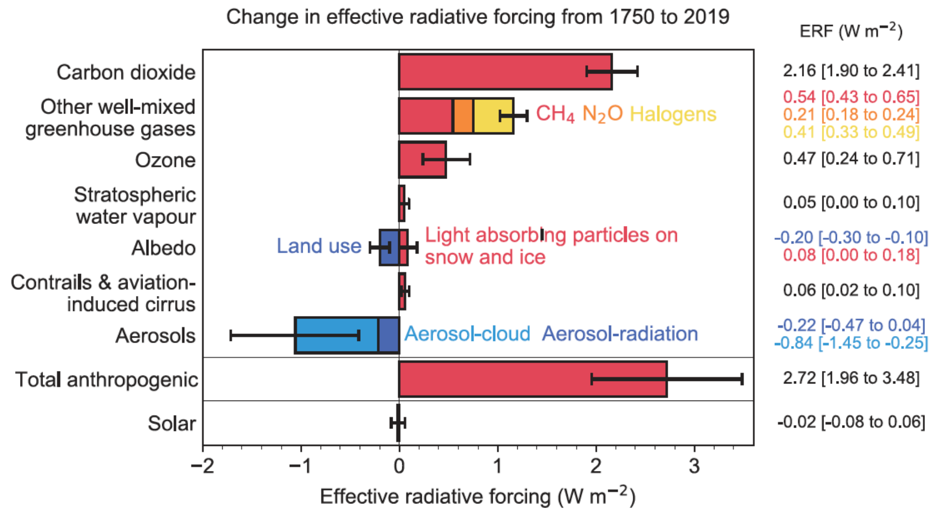
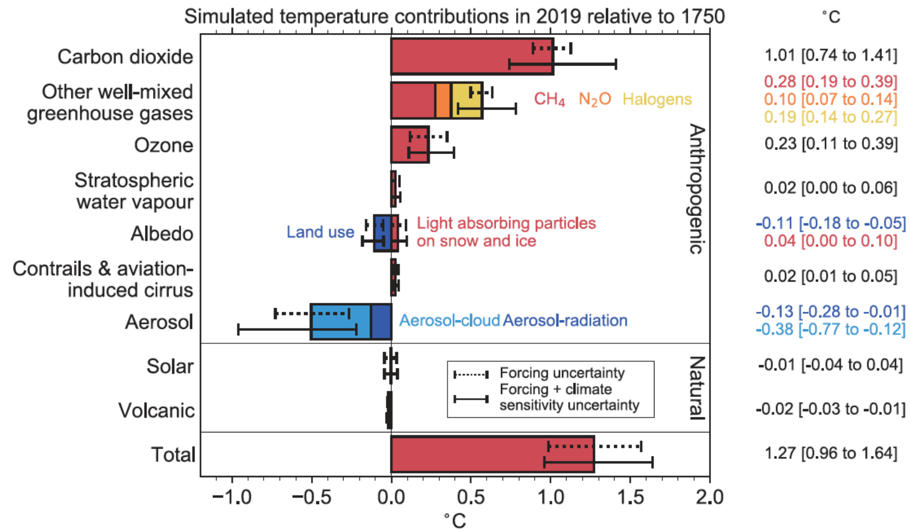


Figure 13. Observed global surface temperature (black line) and expected GHG warming with two choices for ECS. The blue area is the estimated aerosol cooling effect. The temperature peak in the World War II era is in part an artifact of inhomogeneous ocean data in that period [63].

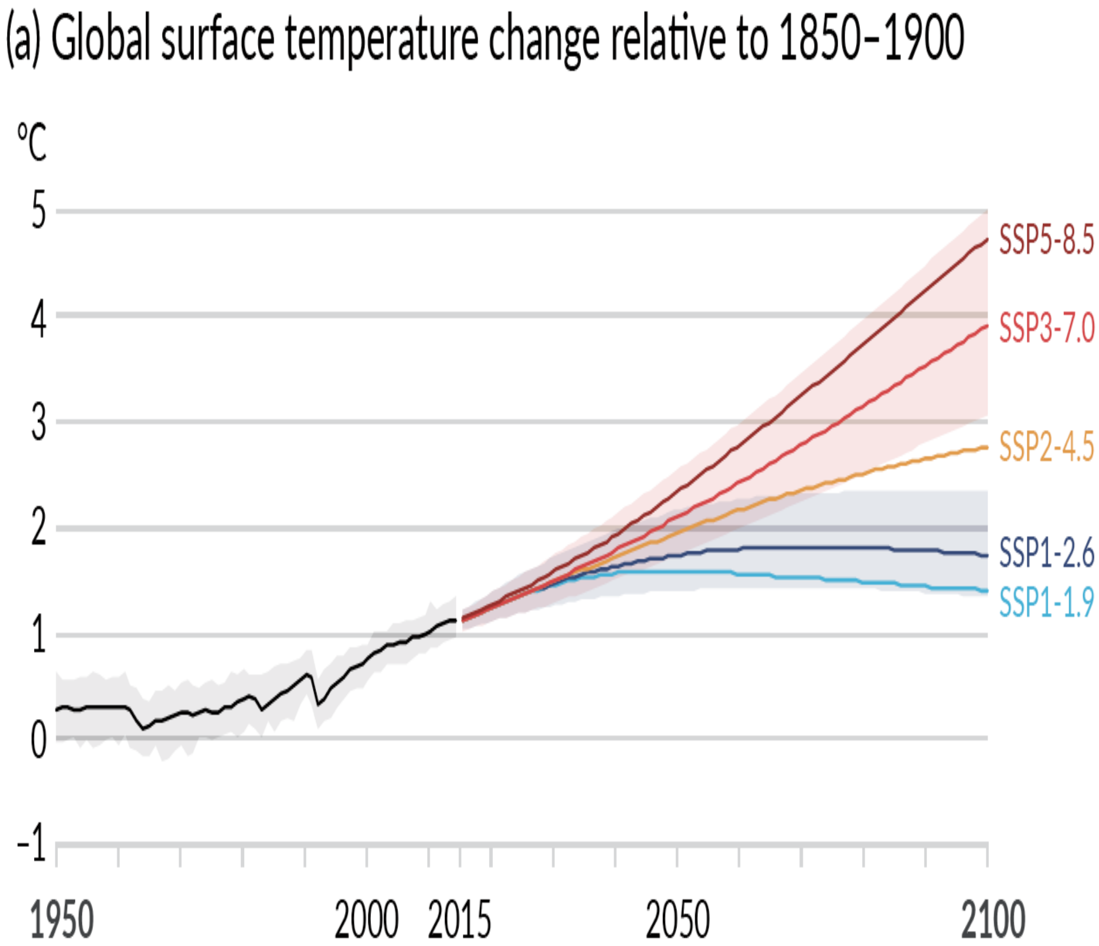




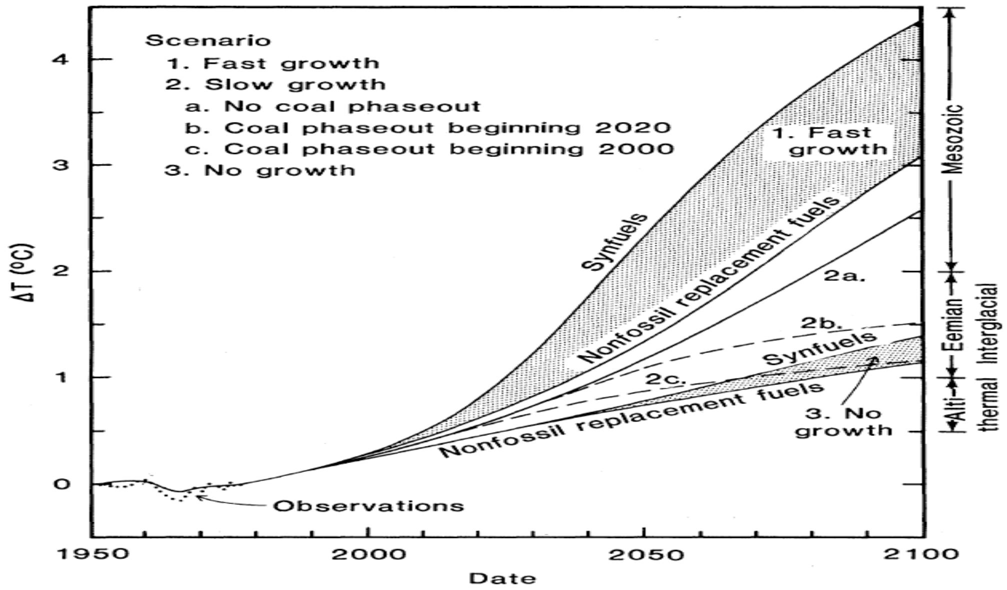
(Hansen et al., OOCC, 2023)

(IPCC AR6, WG1, Figs. 7.6 and 7.7)

IPCC AR6 vs. Hansen et al. (1981) global warming projections



(IPCC, AR6, WG1, Fig. SPM.8)



(Hansen et al., Science, 1981)

AR6 GSAT warming projections

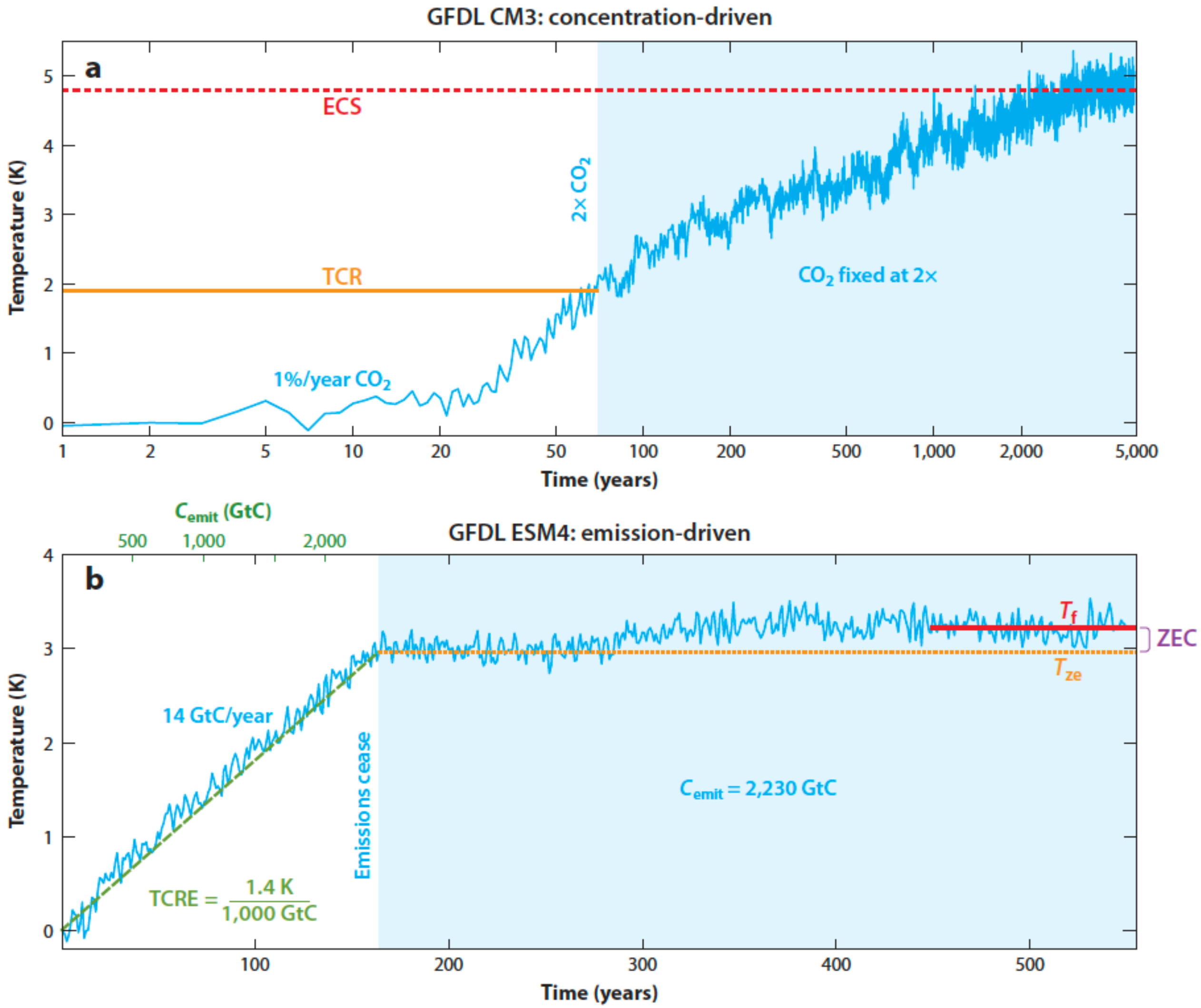
Table SPM.1 | Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative emissions scenarios considered. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C. This includes the revised assessment of observed historical warming for the AR5 reference period 1986–2005, which in AR6 is higher by 0.08 [–0.01 to +0.12] °C than in AR5 (see footnote 10). Changes relative to the recent reference period 1995–2014 may be calculated approximately by subtracting 0.85°C, the best estimate of the observed warming from 1850–1900 to 1995–2014.
{Cross-Chapter Box 2.3, 4.3, 4.4, Cross-Section Box TS.1}

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

(IPCC, AR6, WG1, Tab. SPM.1)

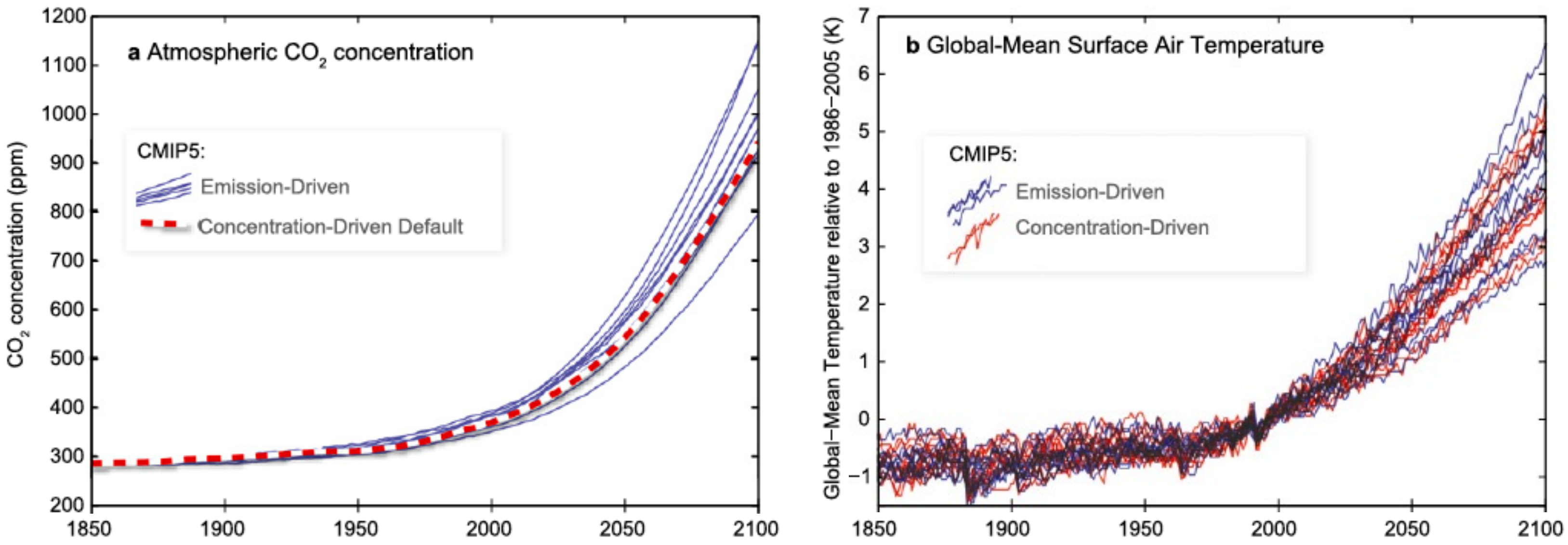
Die Rolle des Kohlenstoffkreislaufs

Simulationen mit und ohne Kohlenstoffkreislauf



(Jeevanjee et al., Ann. Rev., 2025)

Simulationen mit und ohne Kohlenstoffkreislauf



- Model complexity can enhance model spread.

(Friedlingstein et al., J. Climate, 2014)

Schlussbemerkungen

- Unter dem Begriff Klimasensitivität wird häufig die Erwärmung bis zum Erreichen eines Gleichgewichtszustands nach Verdopplung der atmosphärischen CO2-Konzentration verstanden, im Englischen mit ECS abgekürzt.
- ECS wird immer noch mit einem relative großen Unsicherheitsbereich abgeschätzt (IPCC AR6 “likely range”: 2.5-4℃). Wesentliche Unsicherheitsquellen:
  - Proxies für Palaeoklima
  - Aerosolforcing und interne Variabilität für die historische Periode
  - Fehlendes Prozessverständnis (Wolken)
- 2023/24 war ungewöhnlich warm. Noch ist unklar wie stark interne Variabilität oder andere Effekte (z.B. Reduktion von Schwefelaerosolen oder anthropogene Zirkulationsänderungen) beigetragen haben.
- Für eine Erwärmung um 3℃ bis 2050 müsste sich die seit 1970 beobachtete Erwärmungsrate mindestens verdreifachen.
- Die projizierten Erwärmungsraten aus AR6 erscheinen mir nach wie vor sehr plausibel. Das ist kein Grund zur Beruhigung.
- Die Frage nach der Klimasensitivität bleibt spannend, aber wir sollten nicht aus dem Blick verlieren, dass wir uns an den Klimawandel anpassen müssen. Dabei würden bessere Klimamodelle helfen.