

PSI Center for Energy and
Environmental Sciences

Anthropogenic aerosol emissions at the nexus between air quality, climate and geoengineering

**An elaboration on the topic
from the perspective of my opinion**

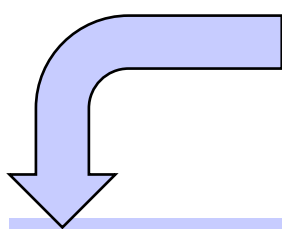
Martin Gysel-Beer

27th ETH-Nanoparticles Conference, Zurich, Switzerland, 11 June 2024

Online

NZZ Neue Zürcher Zeitung
8021 Zürich
044/ 258 11 11
<https://nzz.ch/>

Medienart: Internet
Medientyp: Tages- und Wochenpresse
UUpM: 3'081'000
Page Visits: 28'228'454



Klimaschutz in der Zwickmühle: Wird die Luft sauberer, beschleunigt sich die Erderwärmung – auch in der Schweiz

Höhere Luftqualität bringt ein Problem mit sich: Die Temperatur kann dadurch weltweit schneller ansteigen. Wie gross die Klimawirkung von Schwebepartikeln ist, untersuchen Forscher anhand von Messungen in den Alpen.

2024-02-15, Gwendolin Schönfeld

Climate protection in a dilemma: if the air gets cleaner, global warming accelerates - including in Switzerland

Higher air quality brings with it a problem: it can cause global temperatures to rise faster. ...

My opinion:

No, there's no dilemma!

Accepting air quality compromise in favour of climate is fighting against symptoms using poorly characterized medicine with known undesirable side effects.

Priorities must remain on eliminating both the causes for climate change and poor air quality:

Minimizing greenhouse gas emissions and minimizing aerosol emission

Ambient (outdoor) air pollution

19 December 2022

Key facts

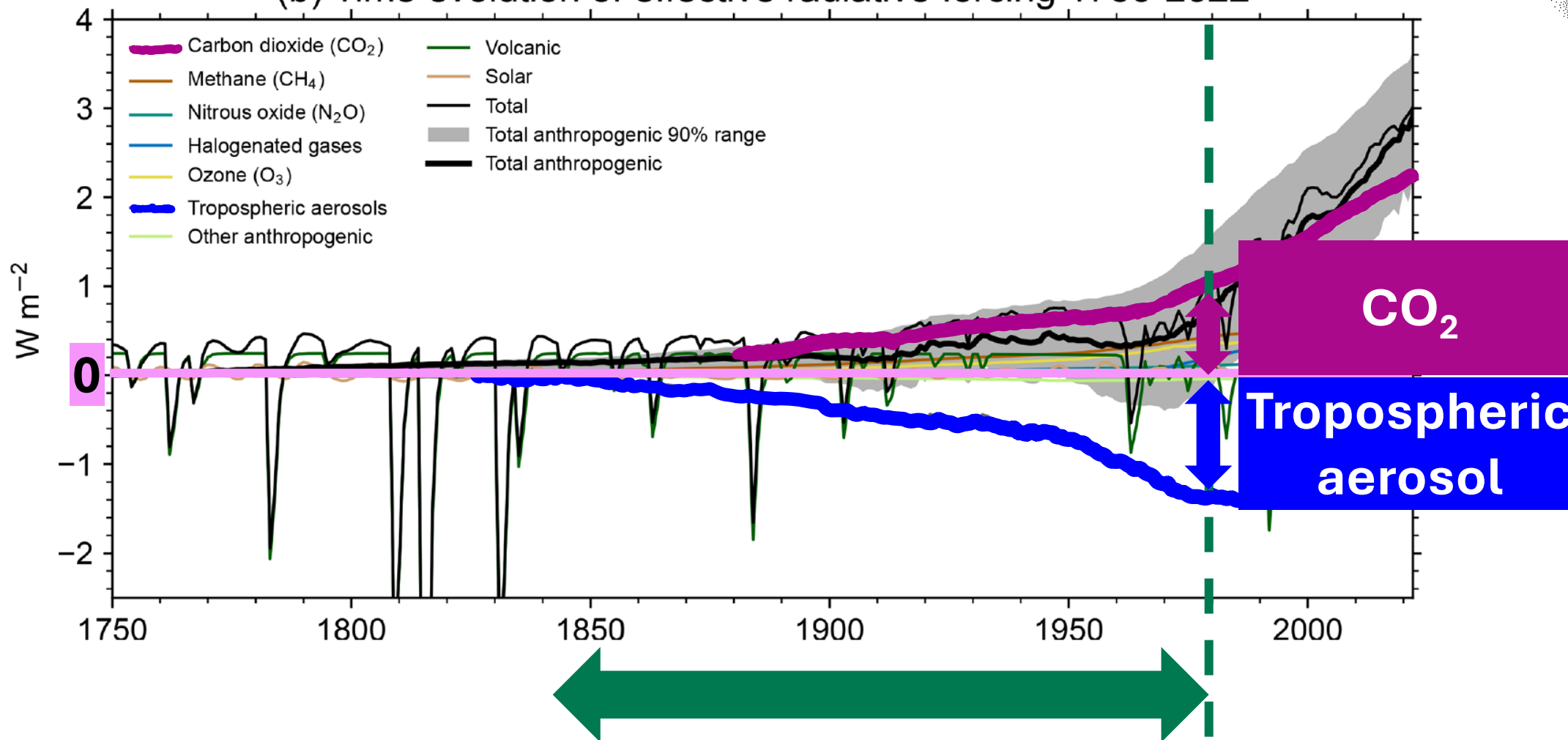
- Air pollution is one of the greatest environmental risk to health. By reducing air pollution levels, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma.
- In 2019, 99% of the world's population was living in places where the WHO air quality guidelines levels were not met.
- The combined effects of ambient air pollution and household air pollution are associated with 6.7 million premature deaths annually.
- Ambient (outdoor) air pollution is estimated to have caused 4.2 million premature deaths worldwide in 2019.
- Some 89% of those premature deaths occurred in low- and middle-income countries, and the greatest number in the WHO South-East Asia and Western Pacific Regions.

Its relevant

Impacts are *not* equally distributed

[https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health)

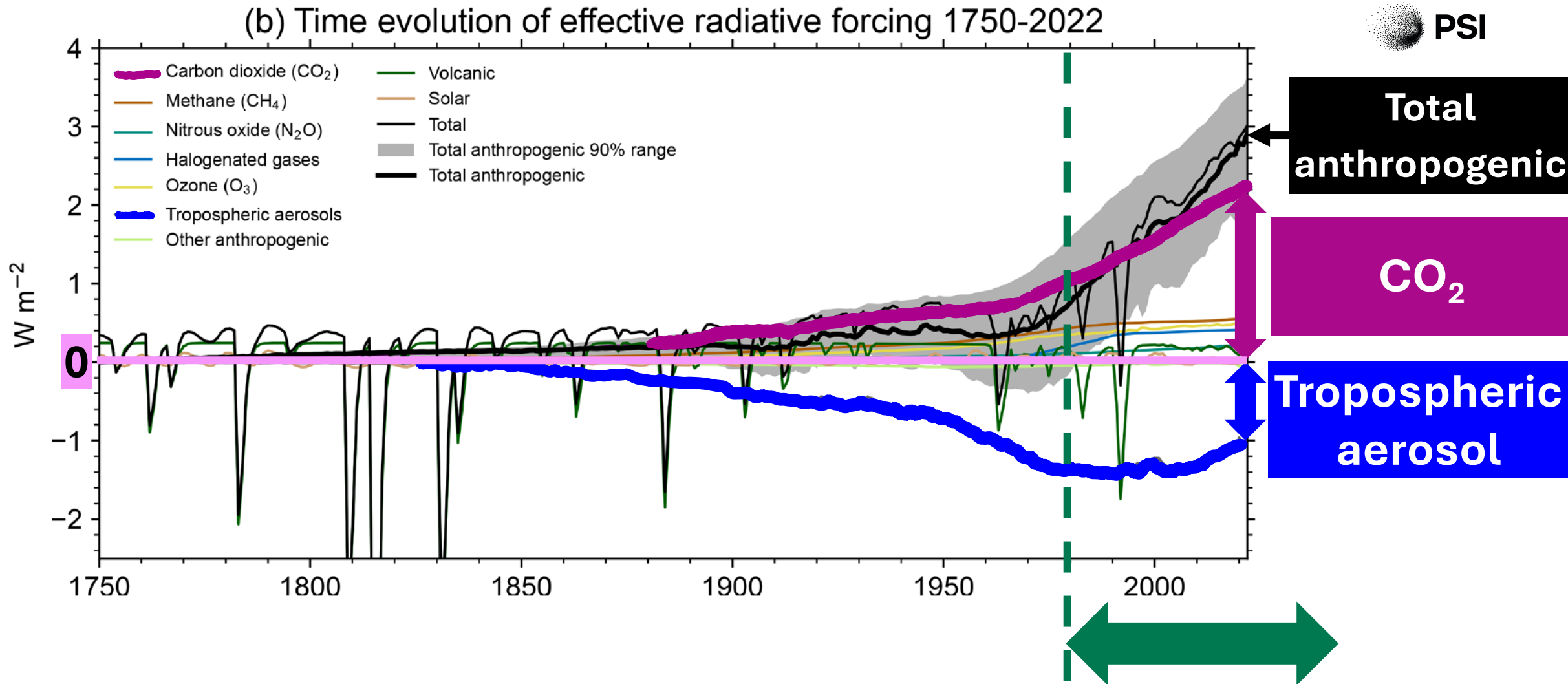
(b) Time evolution of effective radiative forcing 1750-2022



Aerosol driven cooling obscured fossil CO₂ driven warming (and vice versa)

Forster et al. (2023), Earth Syst. Sci. Data, 15, 2295–2327,
<https://doi.org/10.5194/essd-15-2295-2023>

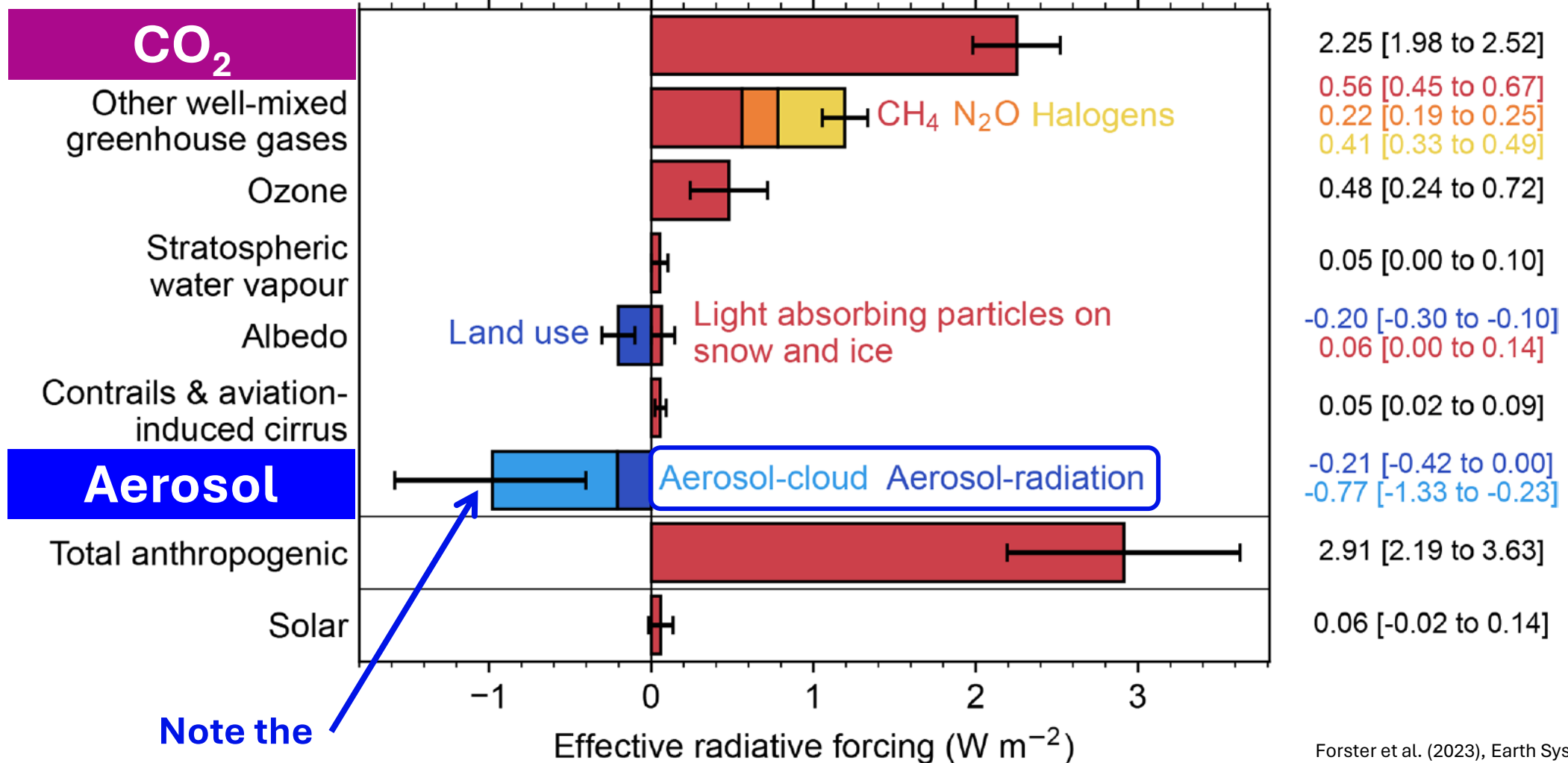
(b) Time evolution of effective radiative forcing 1750-2022



**Full warming power of fossil CO₂ revealed
after turn-over point of particulate air pollution**

Forster et al. (2023), Earth Syst. Sci. Data, 15, 2295–2327,
<https://doi.org/10.5194/essd-15-2295-2023>

(a) Effective radiative forcing from 1750 to 2022



Forster et al. (2023), Earth Syst. Sci. Data, 15, 2295–2327, <https://doi.org/10.5194/essd-15-2295-2023>

Contributions to warming

(b) Aggregated contributions to 2010–2019 warming relative to 1850–1900, assessed from attribution studies

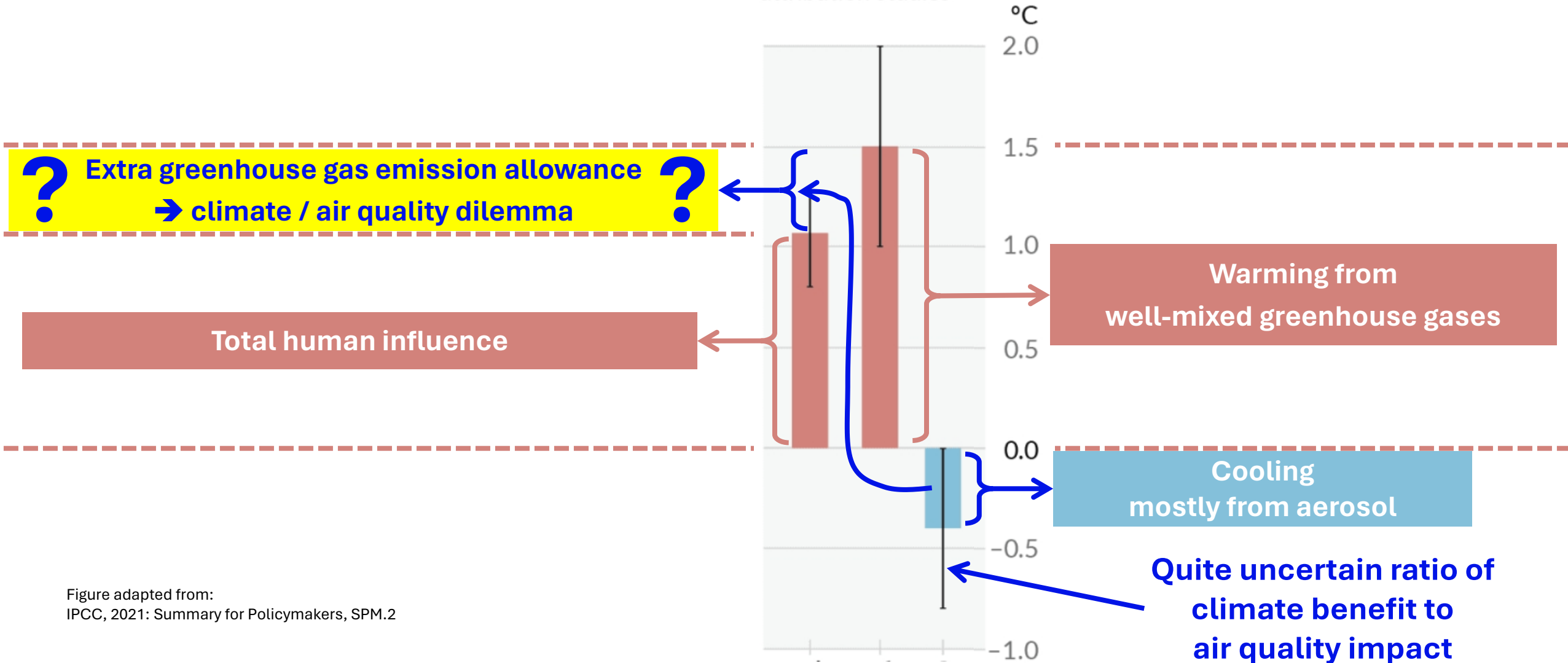


Figure adapted from:
IPCC, 2021: Summary for Policymakers, SPM.2

Contributions to warming

(b) Aggregated contributions to 2010–2019 warming relative to 1850–1900, assessed from attribution studies

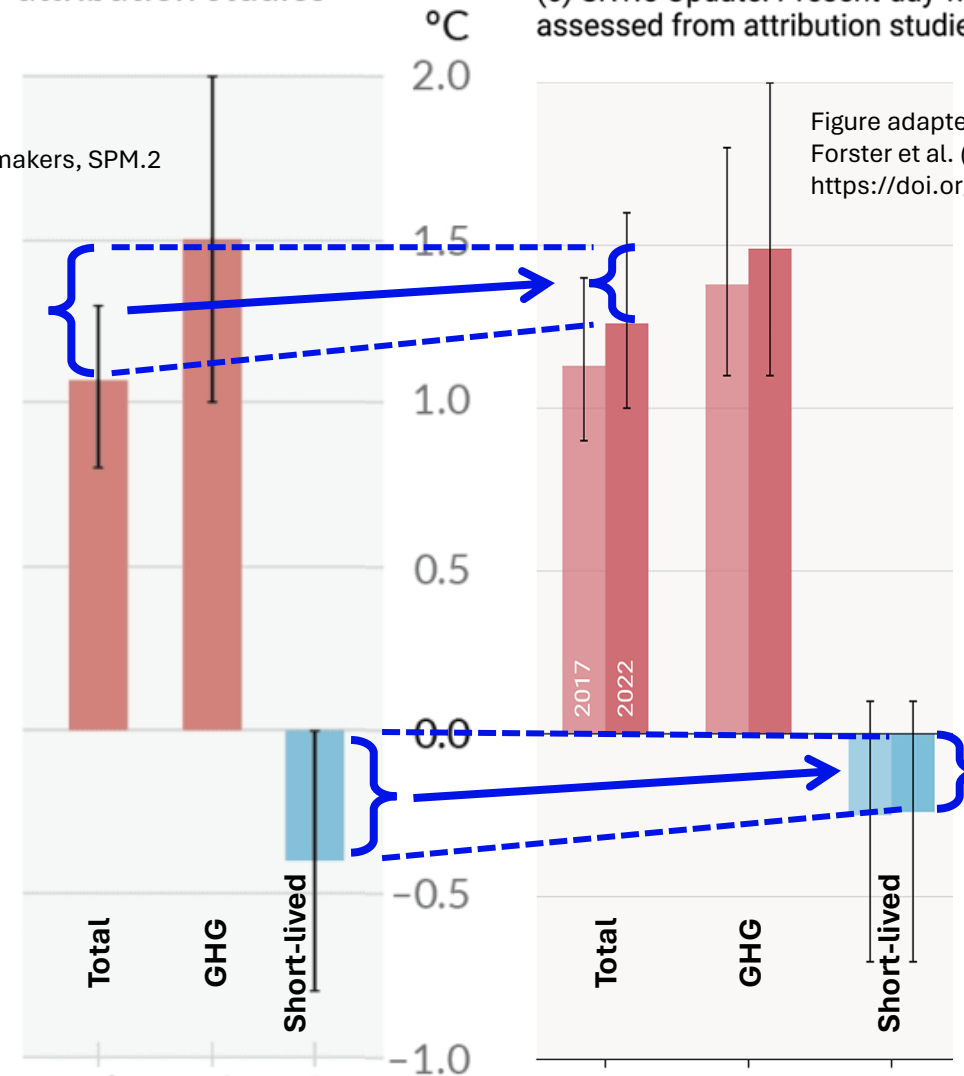
(c) SR1.5 Update: Present-day warming contributions assessed from attribution studies

Figure adapted from:
IPCC, 2021: Summary for Policymakers, SPM.2

Figure adapted from:
Forster et al. (2023), Earth Syst. Sci. Data
<https://doi.org/10.5194/essd-15-2295-2023>

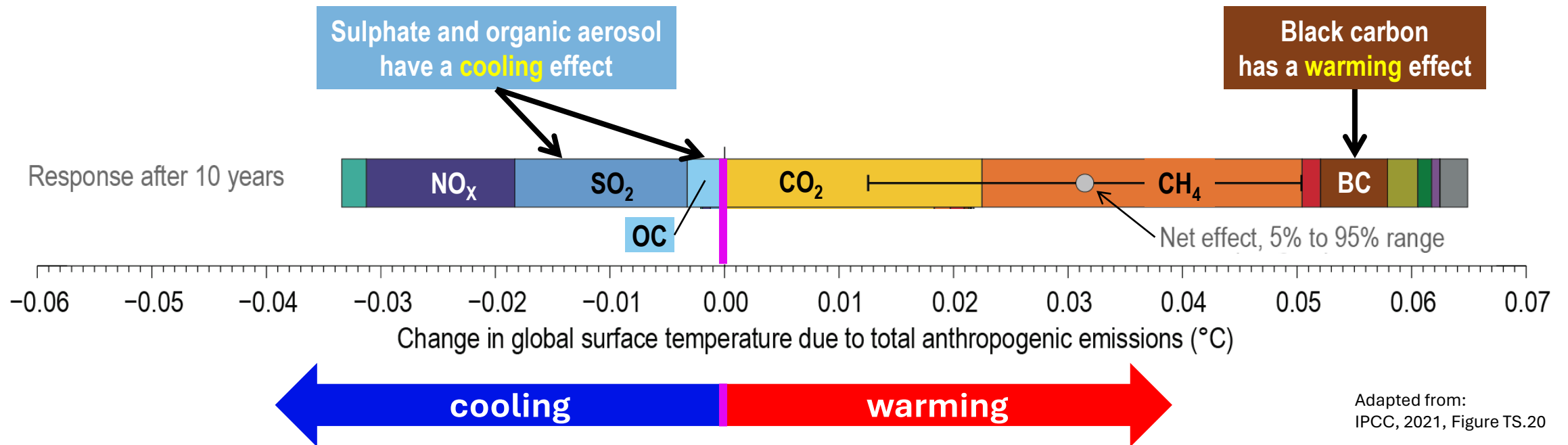
Latest results by Forster et al. (2023) suggest smaller effect of short-lived climate forcings

→ **Uncertainty speaks against** relaying on short-lived constituents which cause other detrimental impacts on the environment



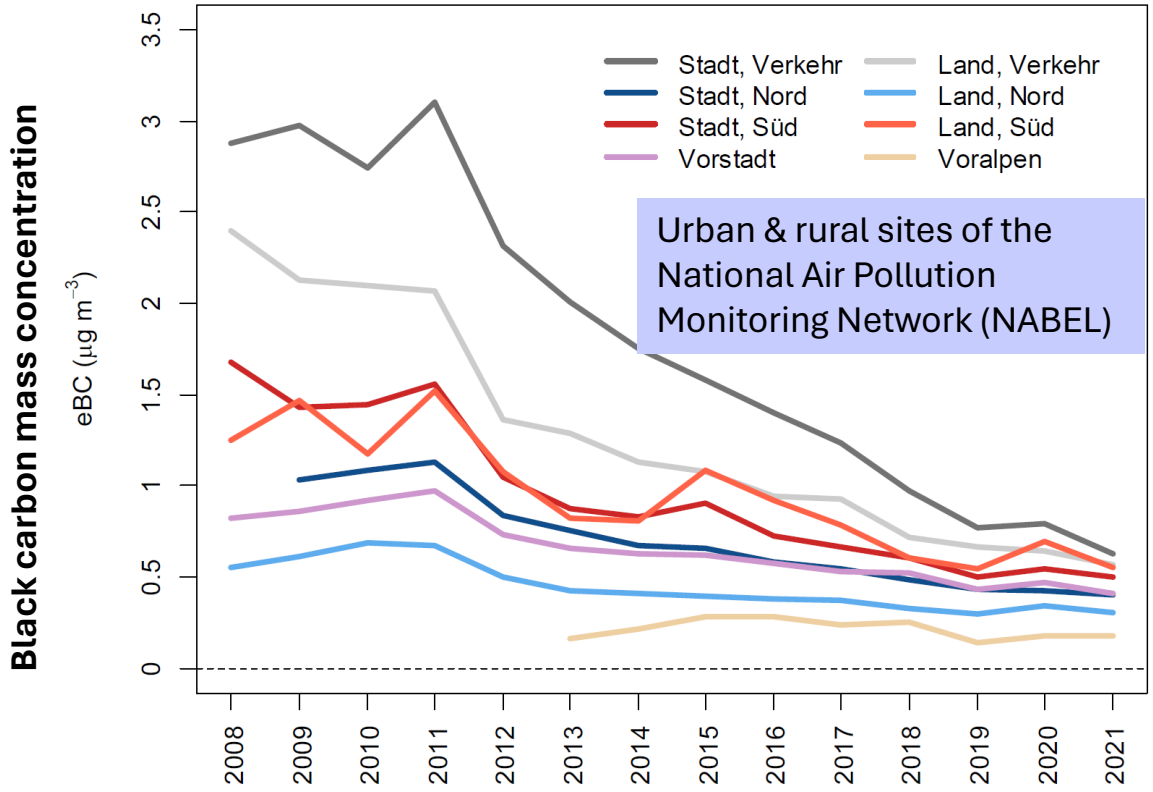
Sign and magnitude of aerosol effect depend on composition/source

Effect of a **one year pulse of present-day emissions** on global surface temperature

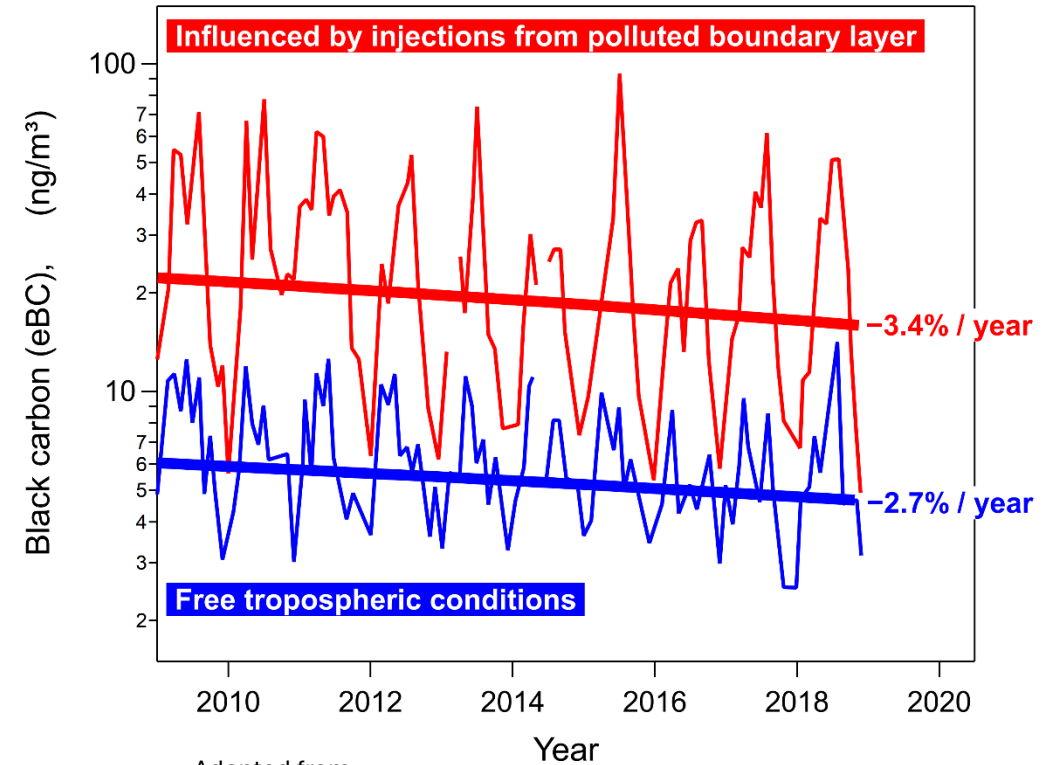


Adapted from:
IPCC, 2021, Figure TS.20

Success story of diesel particle filters



Hüglin & Fischer (2022)
Zeitliche Entwicklung der Russimmissionen an NABEL-Stationen



Adapted from:
Sun et al. (2021), <https://doi.org/10.1186/s12302-021-00488-w>

Distinct reduction of air pollution by particulate black carbon inside polluted boundary layer (left) as well as in the lower free troposphere (right)

Future potential of using particle filters for all internal combustion engines

Diesel particle filters are a key element of current success with reduction of particulate black carbon

Note:
Using renewable fuel does not automatically solve air quality problems

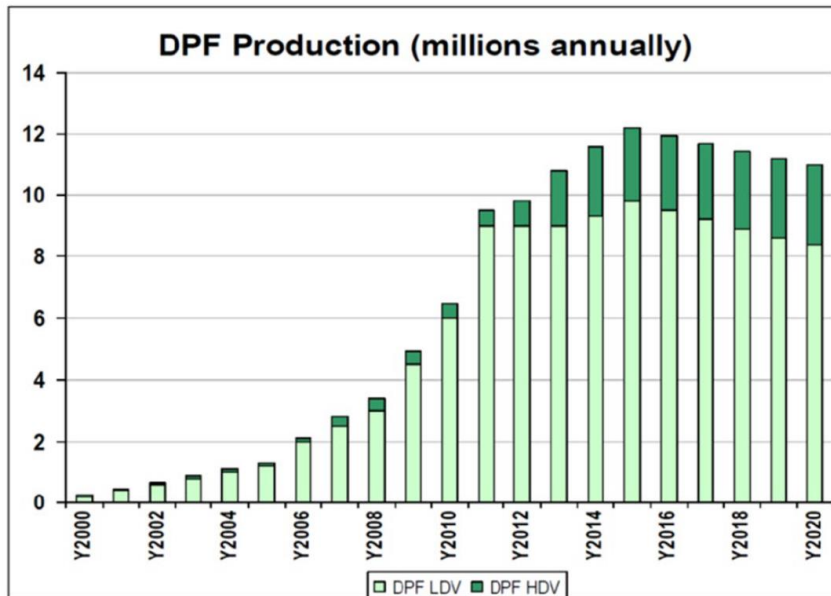


Fig.4 Particle Filter production of VERT member companies in EU and USA. Source VERT market research; see also [122]

Consequent integration of particle filters in new internal combustion engines and retrofitting of existing engines is desirable:

- Immediate effect given short life-time of atmospheric aerosol
- Air quality benefit
- Avoid additional global warming from particulate black carbon on top of GHG impacts

- Removal of co-emitted species can reduce cooling by these.
- Magnitude of climate benefit on global scale remains uncertain and limited

My opinion:

Yes, it is important to push particle filters and black carbon emission reductions forward.

The main argument to do so are air quality and adverse health impacts!



<https://doi.org/10.1038/s43247-024-01332-8>

Exacerbated summer European warming not captured by climate models neglecting long-term aerosol changes

Check for updates

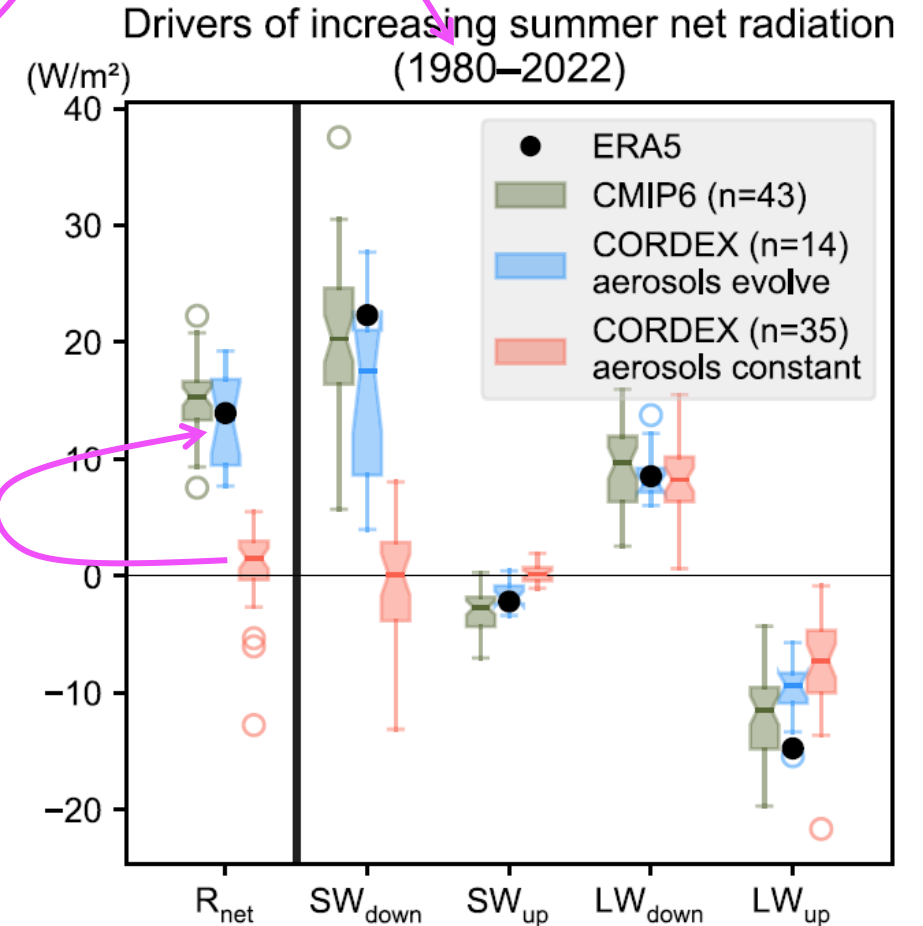
Dominik L. Schumacher , Jitendra Singh , Mathias Hauser , Erich M. Fischer , Martin Wild & Sonia I. Seneviratne

- Western-central Europe
- Summer
- From 1980 to 2022
- Brightening due to aerosol reductions estimated to cause ~0.5°C thermodynamic warming.

Reduced aerosol dimming

- Reduced aerosol burden *indeed reduced their cooling effect* on climate.
- Note: the year-round effect on global scale is smaller.

Reduced aerosol cooling in 2022 compared to 1980



Schumacher et al. (2024), *Commun. Earth Environ.*
<https://doi.org/10.1038/s43247-024-01332-8>

ICOS

Integrated
Carbon
Observation
System

ACTRIS
Exploring the Atmosphere

The Aerosol, Clouds and Trace Gases Research Infrastructure

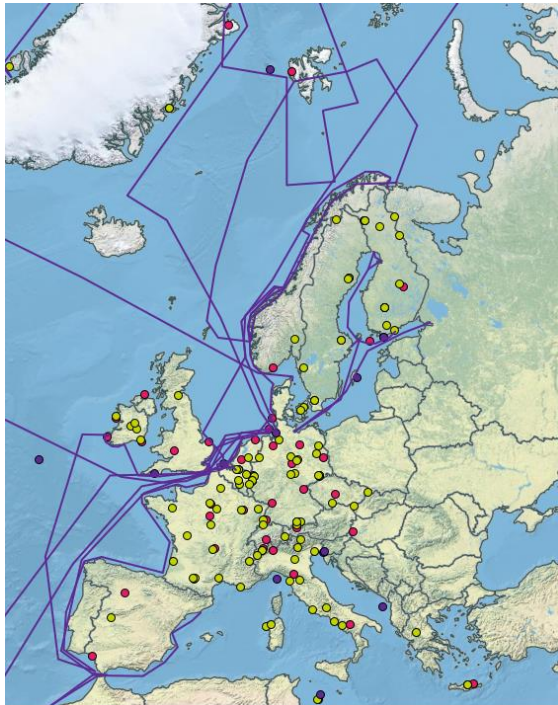
112 NATIONAL FACILITIES



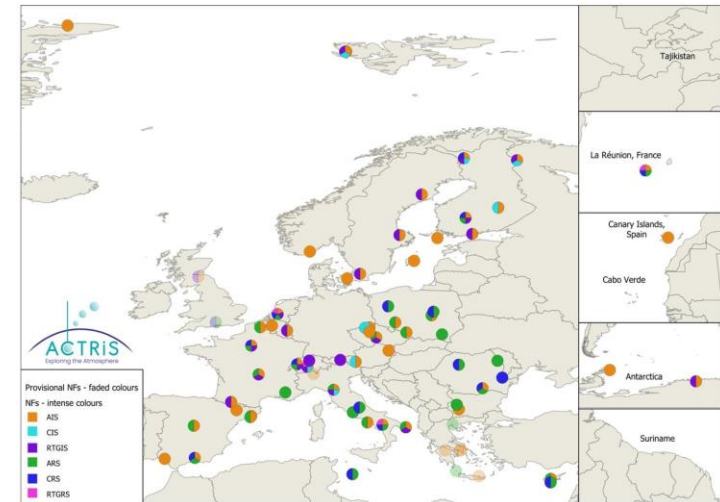
79 OBSERVATIONAL PLATFORMS



33 EXPLORATORY PLATFORMS



European observation networks
for long-lived greenhouse gases,
short-lived constituents,
and clouds



<https://www.icos-cp.eu/>

<https://www.icos-switzerland.ch/>

<https://www.actris.eu/>

<https://www.actris.ch/>

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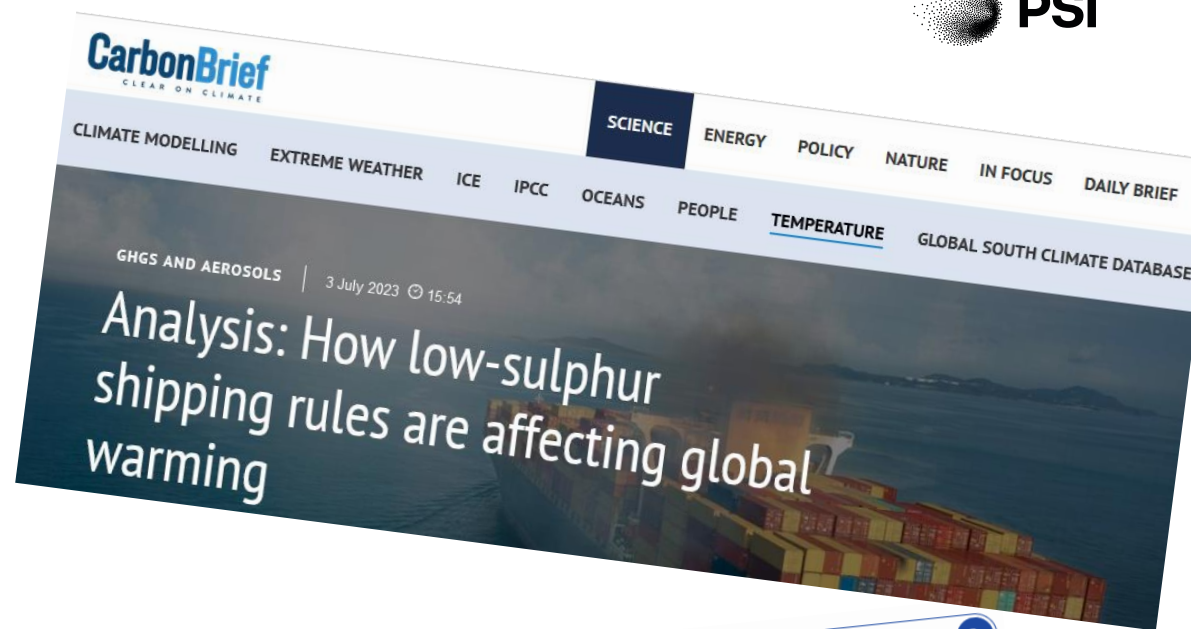


<https://doi.org/10.1038/s43247-024-01442-3>

Abrupt reduction in shipping emission as an inadvertent geoengineering termination shock produces substantial radiative warming

Check for updates

Tianle Yuan^{1,2}, Hua Song^{2,3}, Lazaros Oreopoulos², Robert Wood⁴, Huisheng Bian^{1,2}, Katherine Breen^{2,5}, Mian Chin², Hongbin Yu², Donifan Barahona², Kerry Meyer² & Steven Platnick²



Air quality – climate dilemma?
My wording: CO₂ driven warming becomes increasingly visible.

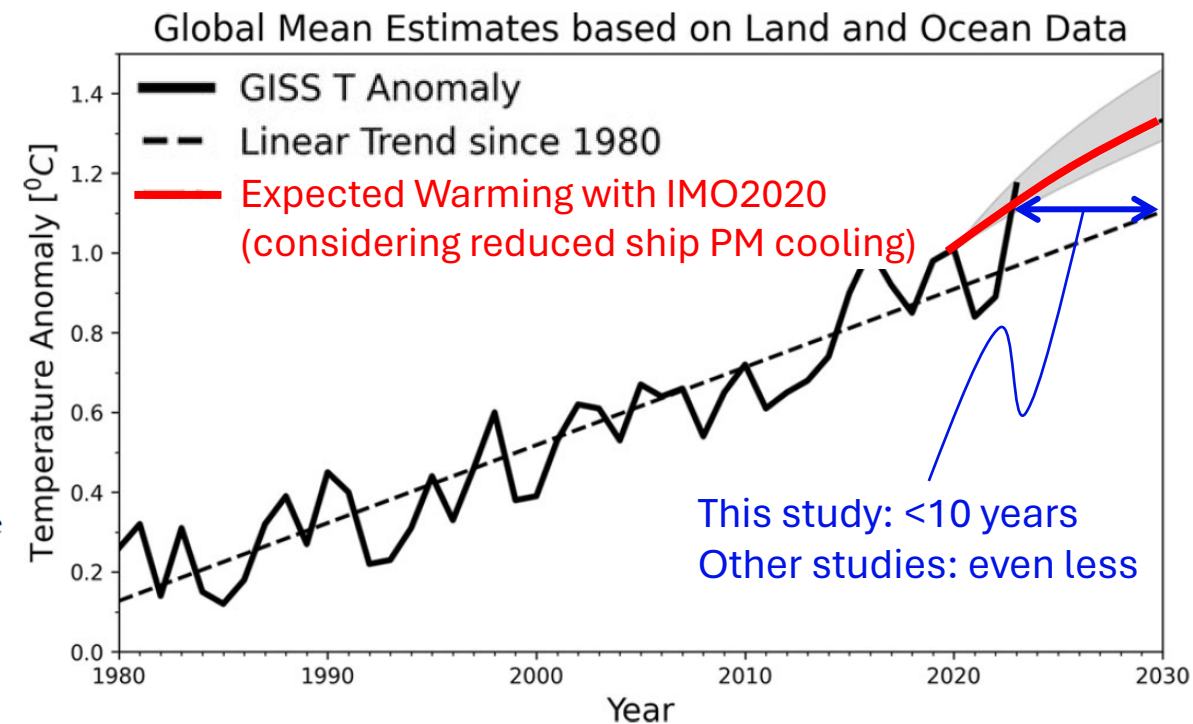
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Abrupt reduction in shipping emission as an inadvertent geoengineering termination shock produces substantial radiative warming

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Check for updates

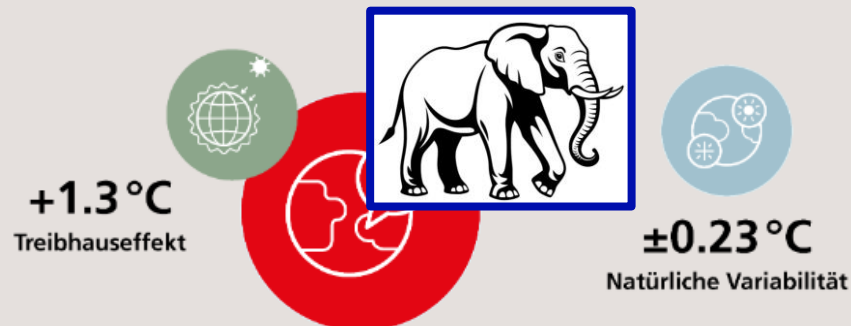
Fig. 3 | Time series of global temperature anomaly since 1980 (Lensen et al., 2019). The trend line is dashed. The expected warming trajectory from the combination of the linear trend and the calculated warming effect from IMO 2020 shock based on the energy balance model. The upper and lower bounds of the expected warming are shown in shades. The baseline period for temperature anomaly is between 1951 and 1980.



Hypothetically skipping sulphur reduction in marine fuels would hardly give additional time to reach net zero for CO₂ emissions.

Source: MeteoSwiss-Blog

Erwärmung seit vorindustrieller Zeit



Zusätzliche Erwärmung im Jahr 2023/2024 gegenüber Vorjahr*



Die Zahlen in der Grafik sind gemäss Literatur eine grobe Abschätzung (Stand: Juni 2024)

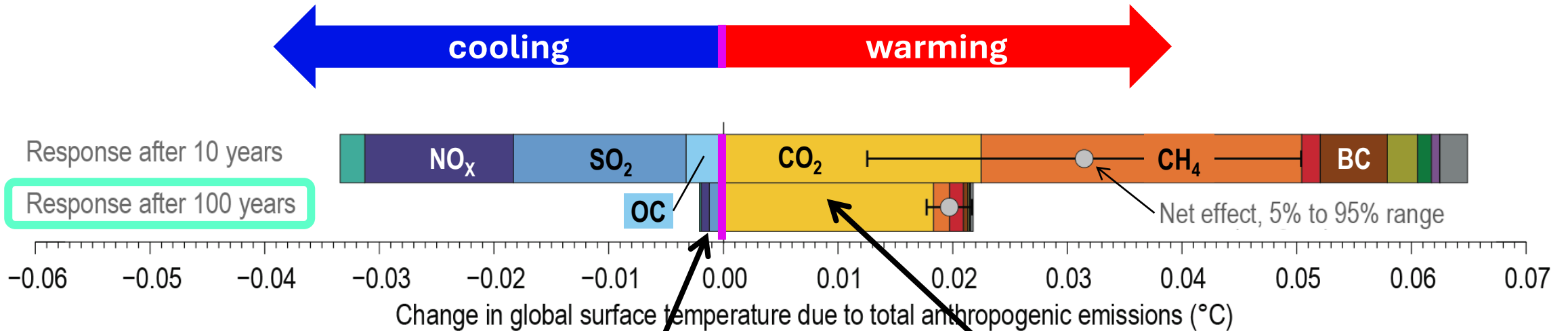
**My opinion:
SO₂ reduction in marine fuels
is a good idea to reduce
environmental impacts of sulfate
aerosol.**

**Cooling effects of SO₂ on climate
are not really an argument
against emission reductions.**

<https://www.meteoschweiz.admin.ch/ueber-uns/meteoschweiz-blog/de/2024/06/zwoelf-monate-infolge-wurden-die-globalentemperaturrekorde-gebrochen.html>

Importance of atmospheric lifetime

Effect of a **one year pulse of present-day emissions** on global surface temperature



Short lifetime of days to weeks of atmospheric aerosol makes their impact vanish on medium to long time scales (unless air pollution is kept at increasingly high level)

Persistent effect of fossil CO₂ due to lifetime of dozens to thousands of years

Adapted from:
IPCC, 2021, Figure TS.20

My opinion: excessively long lifetime of CO₂ makes it prohibitive to compromise air quality in favour of climate using aerosol with a cooling effect.

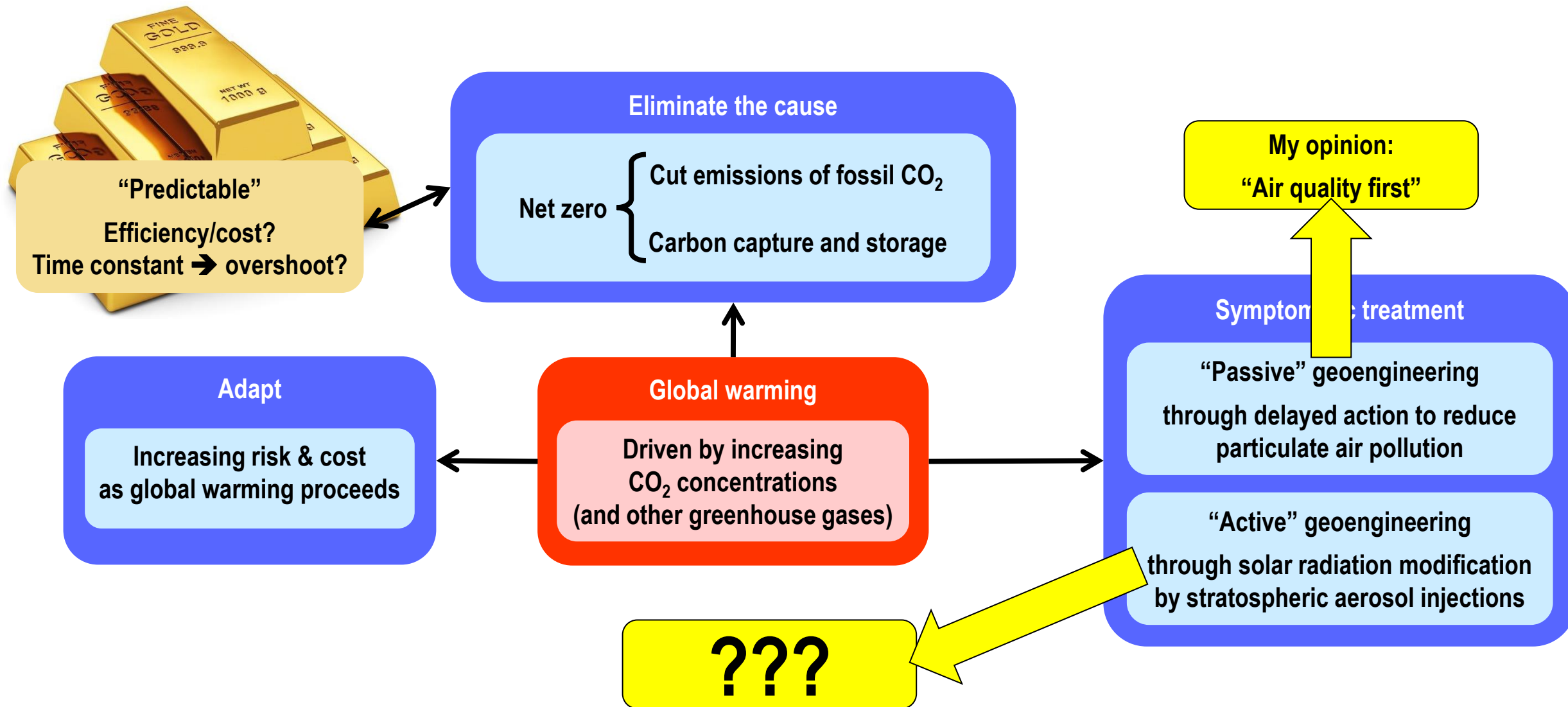
There's a "BUT" in small print: above statement could be weakened if true solutions to the problem have a ramp up time constant of ~10-20 years?

«Passive geoengineering» using tropospheric aerosol through delayed air quality mitigation

- It is symptomatic treatment of warmer temperatures
CO₂ mainly affects outgoing longwave radiation; aerosols and their cloud impacts alter in-coming solar radiation and to a lesser extent also outgoing longwave radiation.
➔ several side effects given the geosphere is a complex and highly coupled system.
- Does not address problem of ocean acidification due to increased CO₂ concentration
- “Advantage”: we are already using particulate air pollution to counteract global warming.
Effects are quite predictable.
- **Air quality penalty is unevenly distributed between incomes and regions.**
- Magnitude: only saves quite limited time & by no means a long-term solution
- Uncertainty of aerosol effects ➔ benefit might not be as high as relied upon.
- ...

**My opinion:
Air quality first! – There’s no dilemma at this end.**

Actions (possible and hypothetical) to mitigate global warming



The sixth session of the United Nations Environment Assembly (UNEA-6)

Press release of the Swiss Government:

[...]Switzerland will also advocate for the UNEP to **draw up a report on solar radiation modification technologies**. The **aim** is for countries **to be informed** about these technologies, in particular **about possible risks and cross-border effects**.[...]

<https://www.admin.ch/gov/de/start/dokumentation/medienmitteilungen.msg-id-100015.html>

My personal take home message:

At the very moment I mention “geoengineering” as a scientist, some will interpret it as possible solution to the global warming problem due to greenhouse gases.

→ Here’s a dilemma!



Solar Geoengineering

Schweiz scheitert mit Vorschlag die Sonne zu verdunkeln

Switzerland fails with proposal to darken the sun



Indem reflektierende Teilchen in die Stratosphäre entlassen werden, sollen die Wärme und das Licht im Idealfall zurück in den Weltraum reflektiert werden.

Quelle: Keystone/SDA

<https://www.bluewin.ch/de/news/international/uno-befasst-sich-nicht-mit-der-verdunkelung-der-sonne-2131078.html>

Solar radiation modification using stratospheric aerosol injections

Funding Opportunities

Solar Radiation Management

The Simons Foundation is launching an international collaborative research program designed to fill fundamental scientific knowledge gaps relevant to Solar Radiation Management.

Research needed on geoengineering?

Advantage (one of several?):

- **Can be stopped at any time** if unforeseen side effects

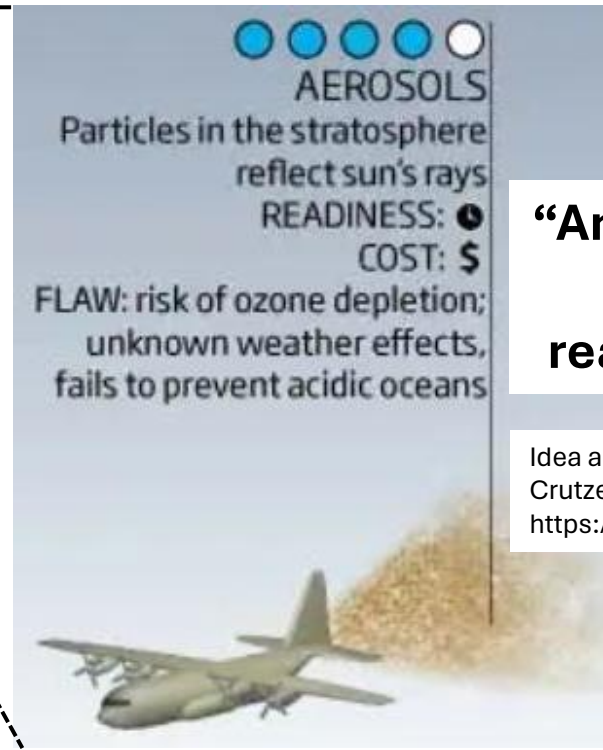
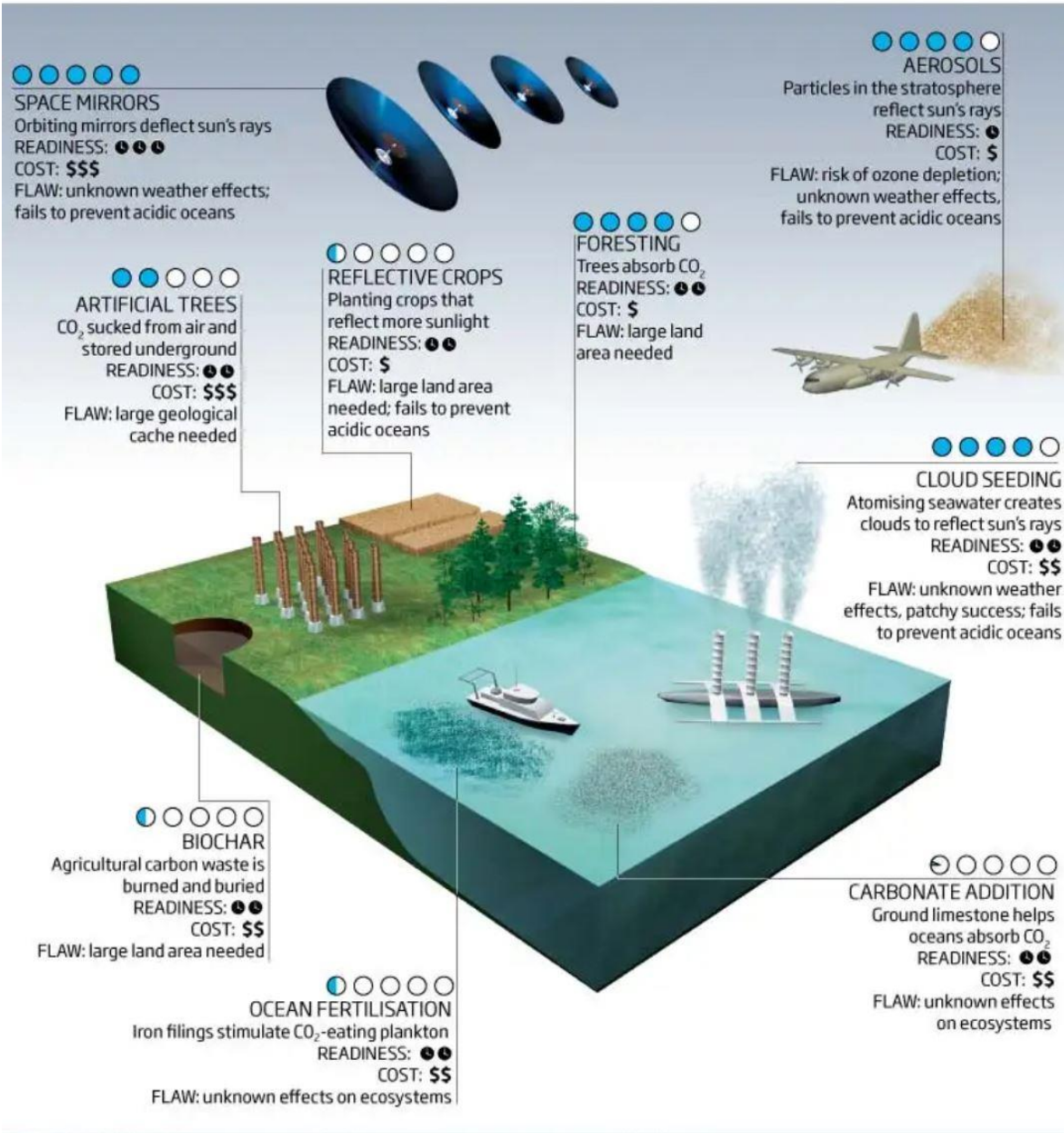
Doesn't really help too much

Disadvantage (one of many):

- **Can be stopped at any time** → termination shock if true solutions not ready

**Termination time constant:
~2 years residence time**

- **Considerably improved ratio of reduced warming per air quality penalty**
- **More cost-effective?**



“Among cheaper ideas but not really ready nor a solution”

Idea advocated in:
Crutzen (2006), Climatic Change
<https://doi.org/10.1007/s10584-006-9101-y>

Source:
Hacking the planet: The only climate solution left?
We may soon have no choice but to fiddle more directly with the climate

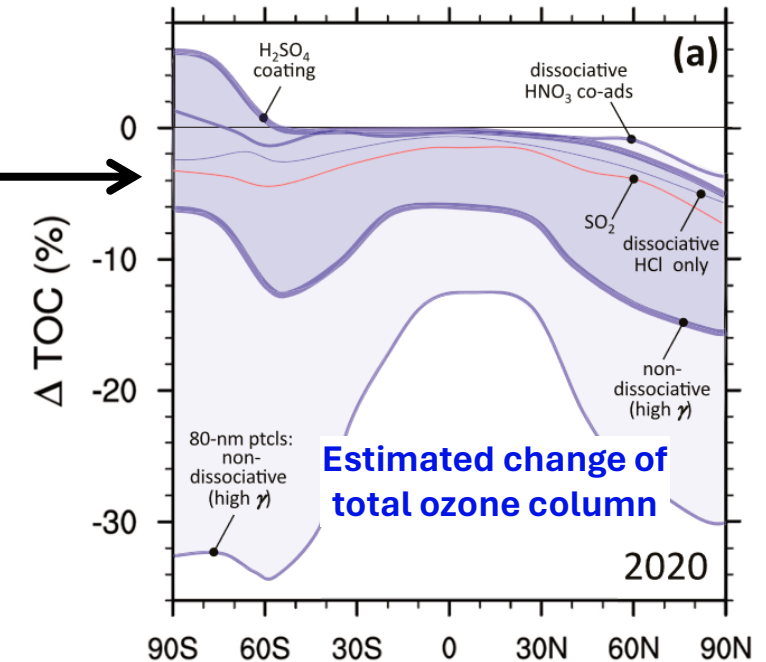
[Read More](#)

Publication Date: 28/02/2009
Author(s): Catherine Brahic
Source: New Scientist
Vol: 201 **Issue:** 2697 **pp:** 8

Cooling factor: potential to change Earth's energy budget	Readiness: ● - Within years ●● - Within decades ●●● - Within centuries	Cost: \$ - Cheap relative to cutting emissions \$\$ - Significant compared to cost of cutting emissions \$\$\$ - Cutting emissions might be cheaper
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Solar radiation modification is a symptomatic treatment with largely unknown side effects

- Additional aerosol heating in the lower stratospheric **can alter large scale air circulation patterns, water vapor transport, ...**
(Weisenstein et al., Atmos. Chem. Phys., 2022)
- Estimates of potential depletion of stratospheric ozone **are highly uncertain and may rely on single extrapolated measurement of reaction constants.** (e.g. Vattioni et al., Geophys. Res. Lett., 2023)
- **Does not address ocean acidification** due to enhanced CO₂ concentration
- Previous injections of volcanic ash and biomass burning aerosol offer **some training ground for model simulations.**
(e.g. Wells et al., Atmos. Chem. Phys., 2023)
- **Could fix temperature at least on global mean level.**
- **Unknown 1, unknown 2, etc.**



My opinion:

Solve the cause, don't even think about solar radiation modification

But maybe I'm not admitting to myself that I expect the pressure to do something to rise sharply. This could lead to someone starting half-baked experiments...

Take home messages



- Solid conclusion on my side: **there's no air quality climate dilemma**
- As for addressing global warming and climate change
 - *Ideal world:*
 - ➔ it's straight forward: **net zero!**
 - *Real world:*

It's not quite as straight forward, at least not if schedule to net zero gets delayed.

 - ➔ **Make up your own mind!**