Warming in the pipeline
The effect of reducing sulphur emissions
without addressing greenhouse gases

Leon Simons
The Club of Rome Netherlands
Correspondence: leon.simons@clubofrome.nl
Global Temperature anomaly from 1850-1900 (C3S/ECMWF ERA 5)

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Global warming is mainly caused by greenhouse gases released from burning of fossil fuels. Fossil fuel burning also releases sulphur, which reduces global warming by reflecting sunlight and by making clouds more reflective, larger and longer lasting.

Adapted from IPCC AR6 WG1 Figure SPM.2

NASA, MERRA-2 Anthropogenic SO2
Total sulfate from all natural and human sources, and the percentage from global shipping

Warming in the pipeline, Figure 20. Total anthropogenic and natural; and shipping sulfate simulations from Jin et al.
Regulation of the International Maritime Organization (IMO) significantly reduced sulphur emissions over seas and oceans, both over Emissions Control Areas and globally.

Global and regional shipping regulations from the International Maritime Organization (IMO)
Changes in international sulfur dioxide emissions

Global sulfur dioxide emissions from international shipping. Sources: CEDS and Corbett et al.
Change in Absorbed Sunlight in ocean regions with and without large shipping emissions changes.
Global Net Flux

Earth's Energy Imbalance (EEI)
12-month running mean

©Leon simons - Data source: NASA CERES EBAF-TOA All-sky Ed4.2 Net flux, 2000/03-2023/09
Thank you

Leon Simons
The Club of Rome Netherlands
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Annexures

- IPCC Greenhouse gases and aerosols and preindustrial forcings
- Faustian bargain
- Regional effects of shipping emission changes
- Ocean area, heat uptake and desulphurisation
- Compliance to shipping emission control regulations
- Drivers of global warming
- Regional surface air temperature response IPCC AR6 WG1
- Drivers of the increase in Earth’s net heat uptake, Loeb et al. (2021)
- Aerosol termination shock
Increasing greenhouse gases warm the planet
Aerosols cause regional and global cooling (less warming)

Figure 17. (a) Estimated greenhouse gas and aerosol forcings relative to 1750 values. (b) Aerosol forcing as percent of GHG forcing. Forcings for dark blue area are relative to 1750. Light blue area adds 0.5 W/m^2 forcing estimated for human-caused aerosols from fires, biofuels and land use.

Warming in the pipeline, Figure 17
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].
Figure 22. Absorbed solar radiation for indicated regions relative to first 120 months of CERES data. Southern Hemisphere 20–60°S is 89% ocean. North Atlantic is (20–60°N, 0–60°W) and North Pacific is (20–60°N, 120–220°W). Data source: http://ceres.larc.nasa.gov/order_data.php.
The North Pacific and Atlantic Oceans show dense shipping traffic and are expected to show effects of sulfur reductions.
A large part of the planet is covered by oceans.
Most Earth Heat Gain warms oceans water
Sulphur emissions over oceans from shipping reduced with ~80% from 2020
Compliance to shipping emission control regulations

Inspections of compliance, low sulfur fuel sales and scrubber installations indicate strong compliance to sulphur fuel regulations.

IMO’s 2020 fuel sulfur limit

2020 sulfur limit: 0.5% maximum allowable sulfur content or alternative compliance technology

Scrubbers uptake in 2019 was four times higher than in the previous year
Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling.
Figure 6.13 | Multi-model mean surface air temperature response over the recent past (1995–2014) induced by aerosol changes since 1850. Calculation is based on the difference between CMIP6 ‘historical’ and AerChemMIP ‘hist-piAer’ experiments averaged over 1995–2014, where (a) is the spatial pattern of the annual mean surface air temperature response, and (b) is the mean zonally averaged response. Model means are derived from the years 1995–2014. Uncertainty is represented using the advanced approach: No overlay indicates regions with robust signal, where ≥66% of models show change greater than variability threshold and ≥80% of all models agree on sign of change; diagonal lines indicate regions with no change or no robust signal, where <66% of models show a change greater than the variability threshold; crossed lines indicate regions with conflicting signal, where ≥66% of models show change greater than variability threshold and <80% of all models agree on sign of change. For more
Increase in Earth net heat uptake

Loeb et al. 2021

Absorbed Solar Radiation

Emitted Thermal Radiation

Net Heat Uptake

(2002/09–2020/03)
Cause

- Powerfull sulfur mitigation policy
- Low sulphur fuel & scrubbers available
- Significant cooling of SOx aerosol source

Process

- Compliance with low sulfur fuel and scrubbers
- SOx reduction causing considerable net warming

Effect

- Termination shock!
Aerosol termination shock

The term termination shock is generally used to describe effects from sudden abruption of intentional Solar Radiation Management (SRM) such as stratospheric aerosol injections. Past and current anthropogenic SOx emissions could be classified as unintentional SRM and rapid abruption could cause a similar thermal shock. Research suggests a threshold at 0.2°C of warming per decade.

Parker et al. (2018) showed that for a termination shock to occur, ramp down of emissions need to be sudden, which would require the will and power to stop SRM globally. The rapid reduction of SOx emissions from global shipping could prove unintentional abrupt cessation of SRM. If the higher range ERF effects of IMO 2020 are a reality, this could be quantified as a termination shock, even more so when combined with other SOx reduction effects.