# Observations in support of radiative forcing and Earth's energy imbalance

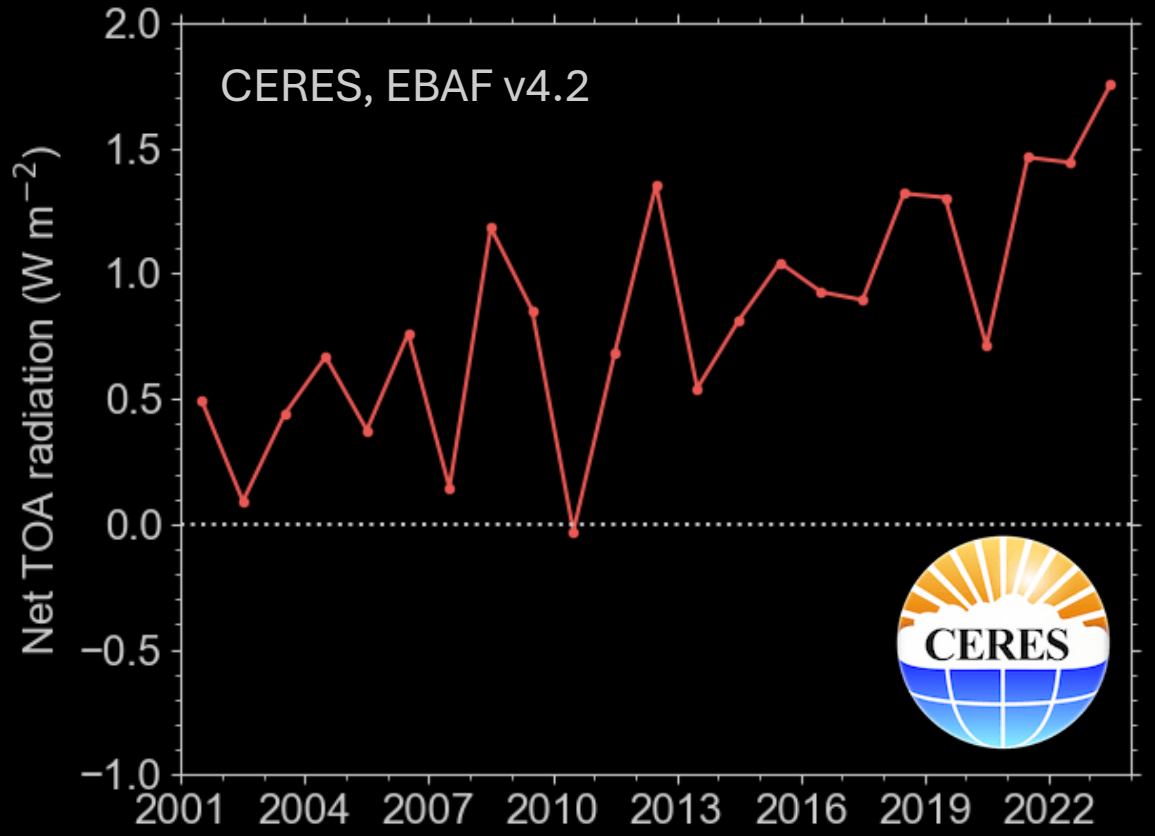
Chris Smith

with thanks to Ryan Kramer, Ben Sanderson, Gunnar Myhre and Robert Pincus

ESA TRUTHS for Climate Workshop, 28 June 2024

UNIVERSITY OF LEEDS

# Earth's energy imbalance is getting larger…



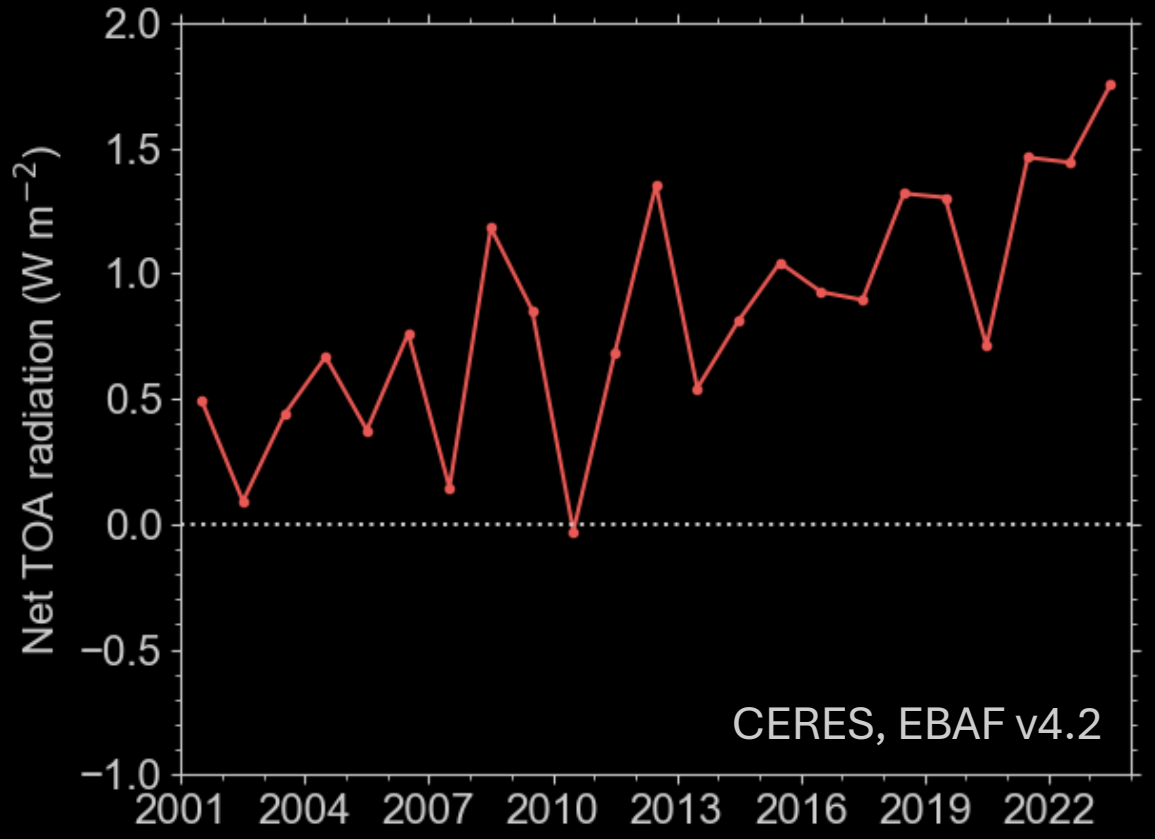

Total Radiative Imbalance | Radiative Forcing | Radiative Responses

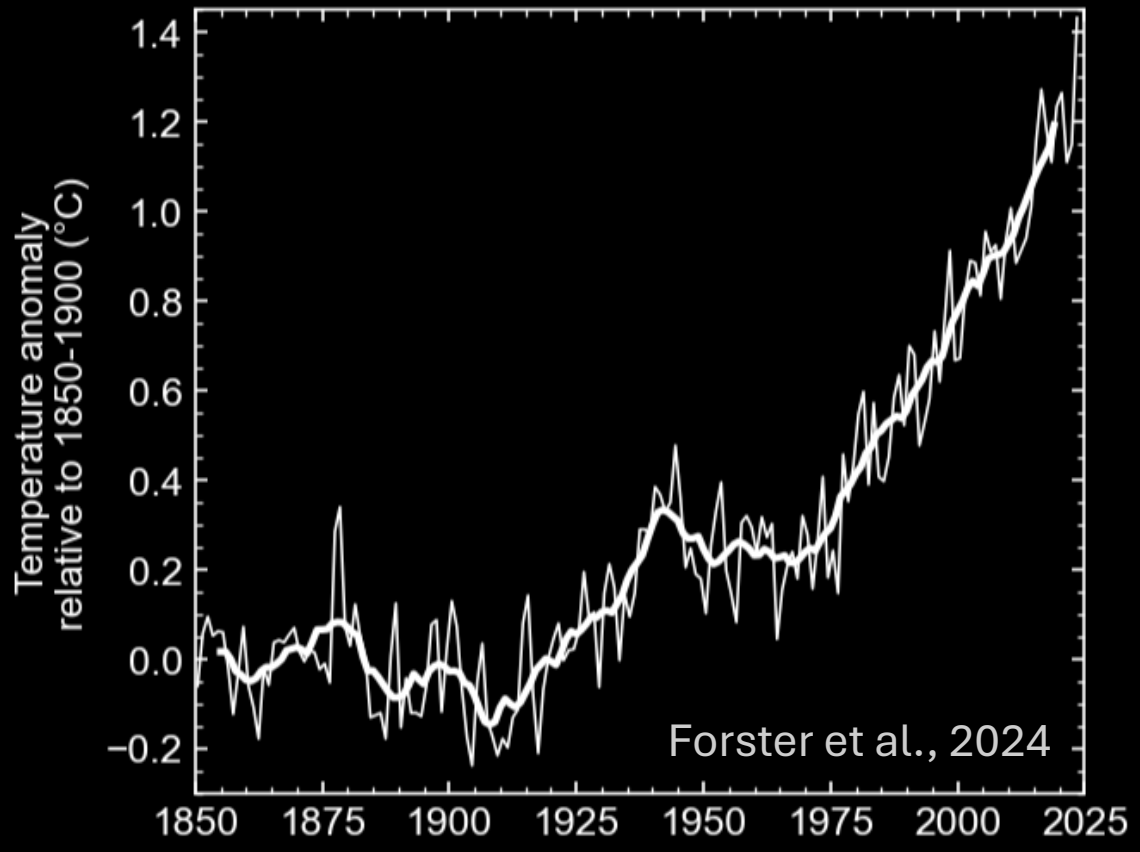
$$\Delta N = \Delta F + \lambda \Delta T$$

Observable | Not observable | Not observable | Observable

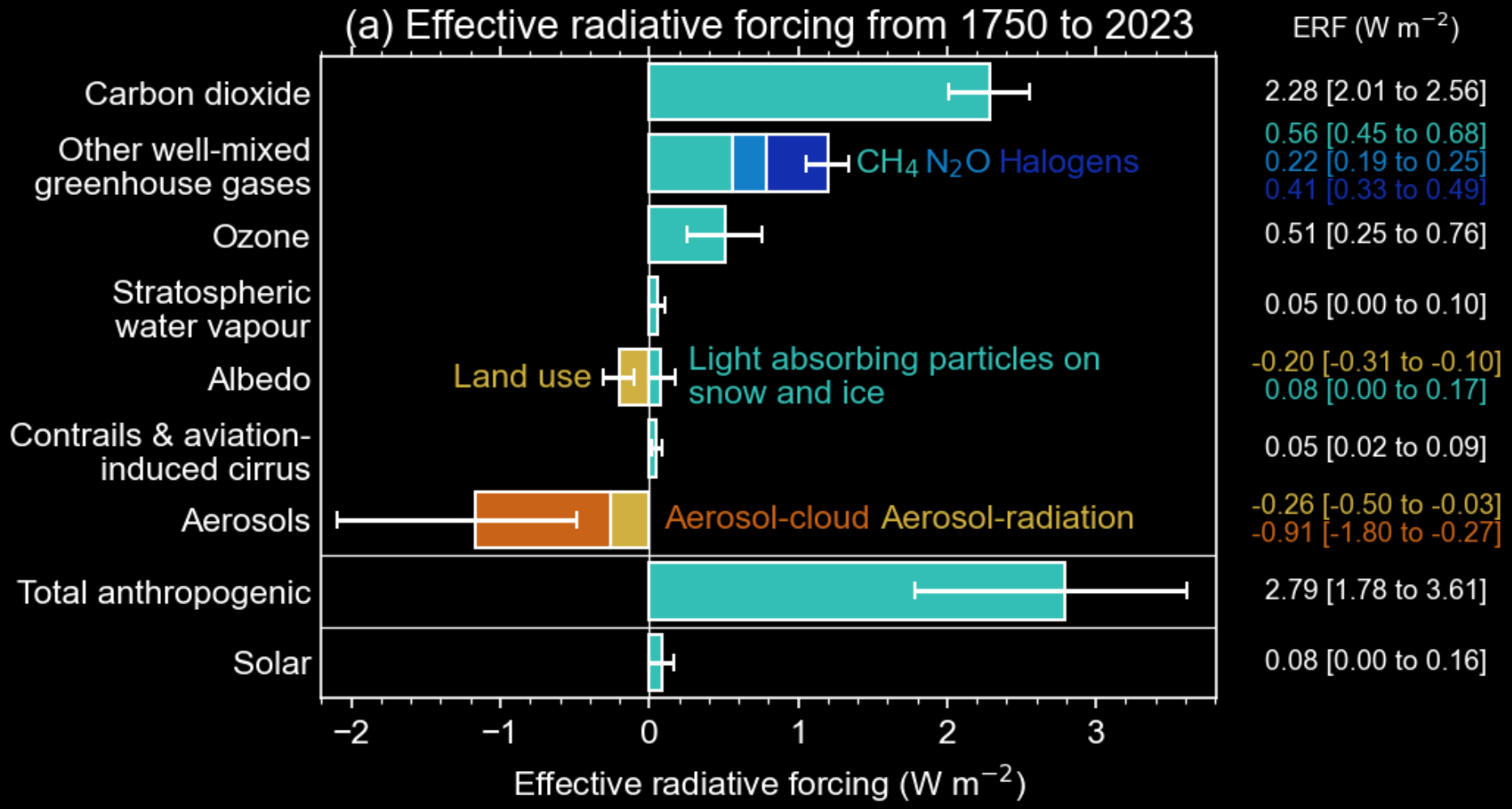
Schmidt et al. 2023
Loeb et al. 2021

# Earth's energy imbalance and surface temperature are observable…



# ...but radiative forcing is mostly from modelling studies, and quite uncertain




Forster et al., 2024 10.5194/essd-16-2625-2024

# Radiative forcing is…

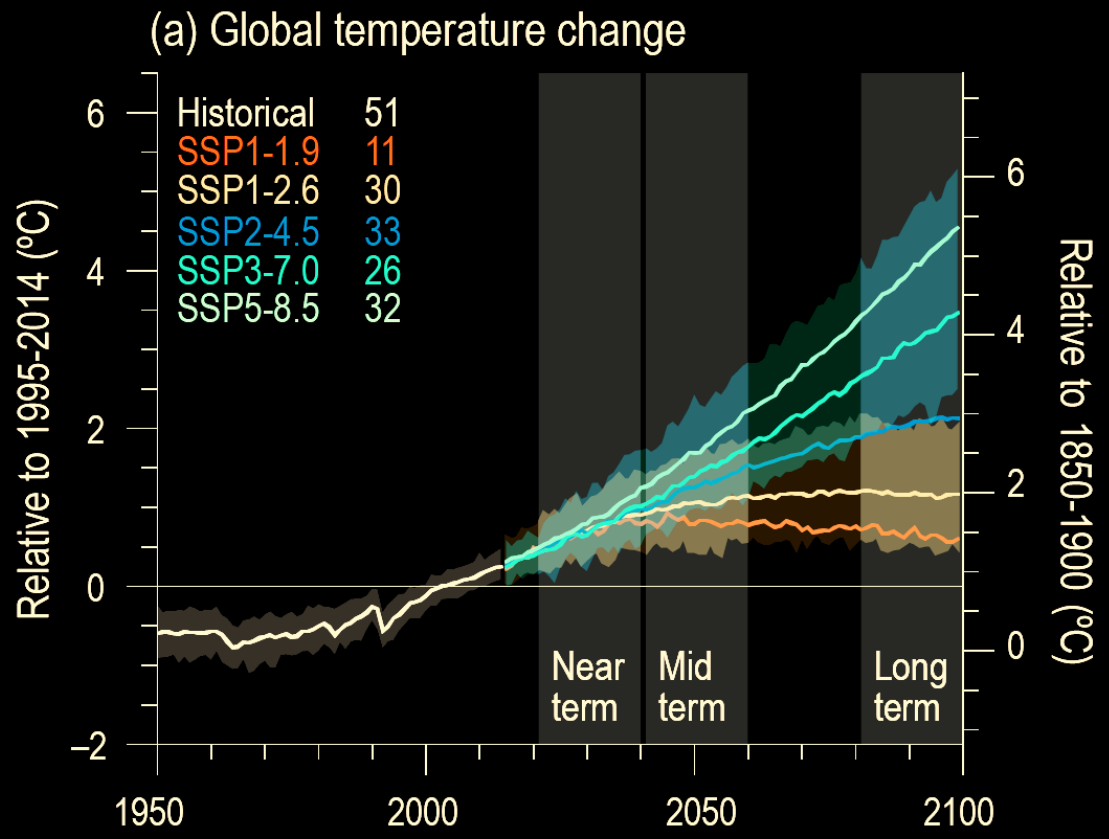
quite difficult to observe

often derived from climate or radiative transfer models rather than observations

uncertain (particularly aerosol forcing)

policy-relevant

the driver of climate change in the near-term and long term

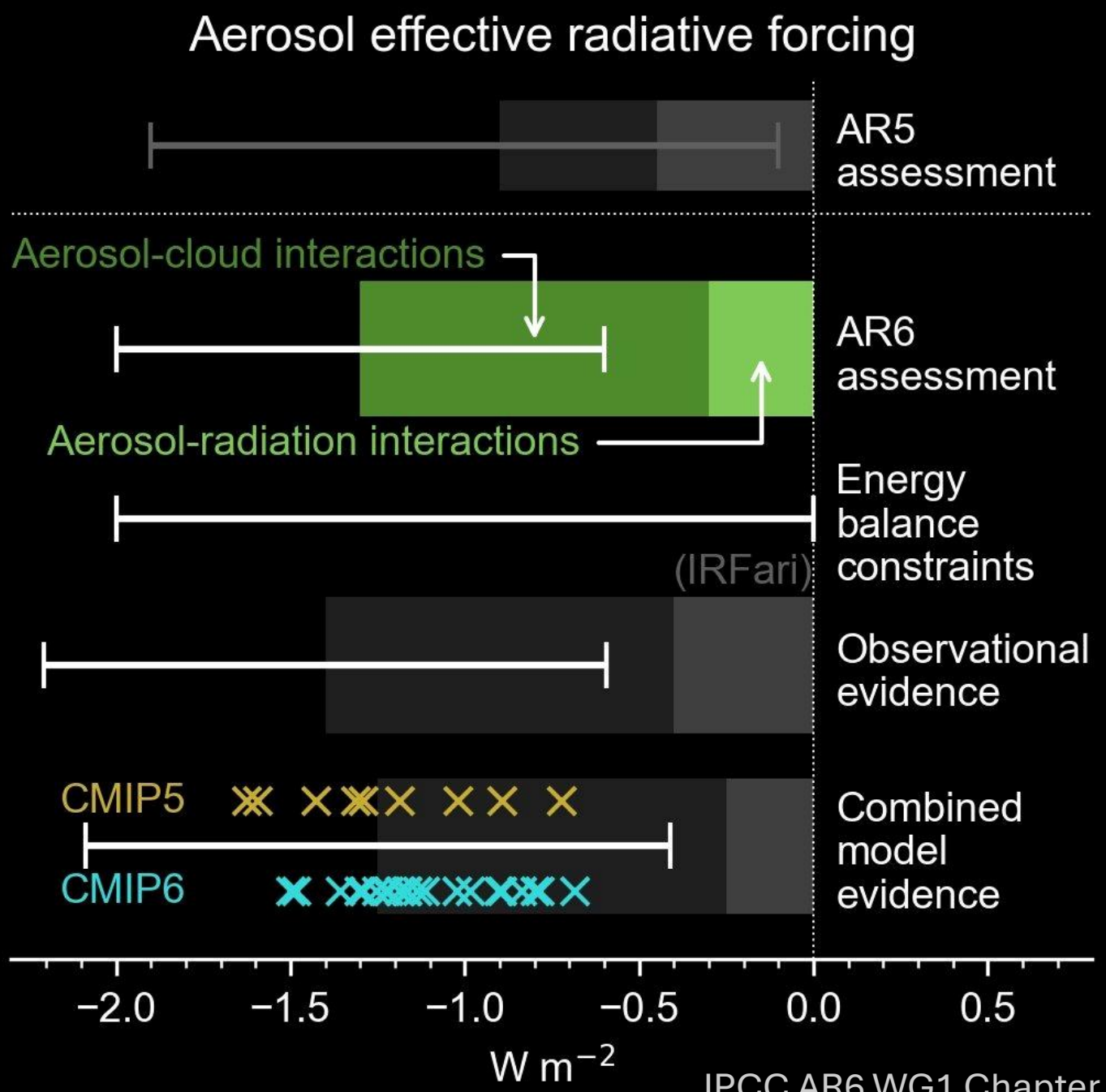



IPCC AR6 WG1 Chapter 4

# Aerosol forcing

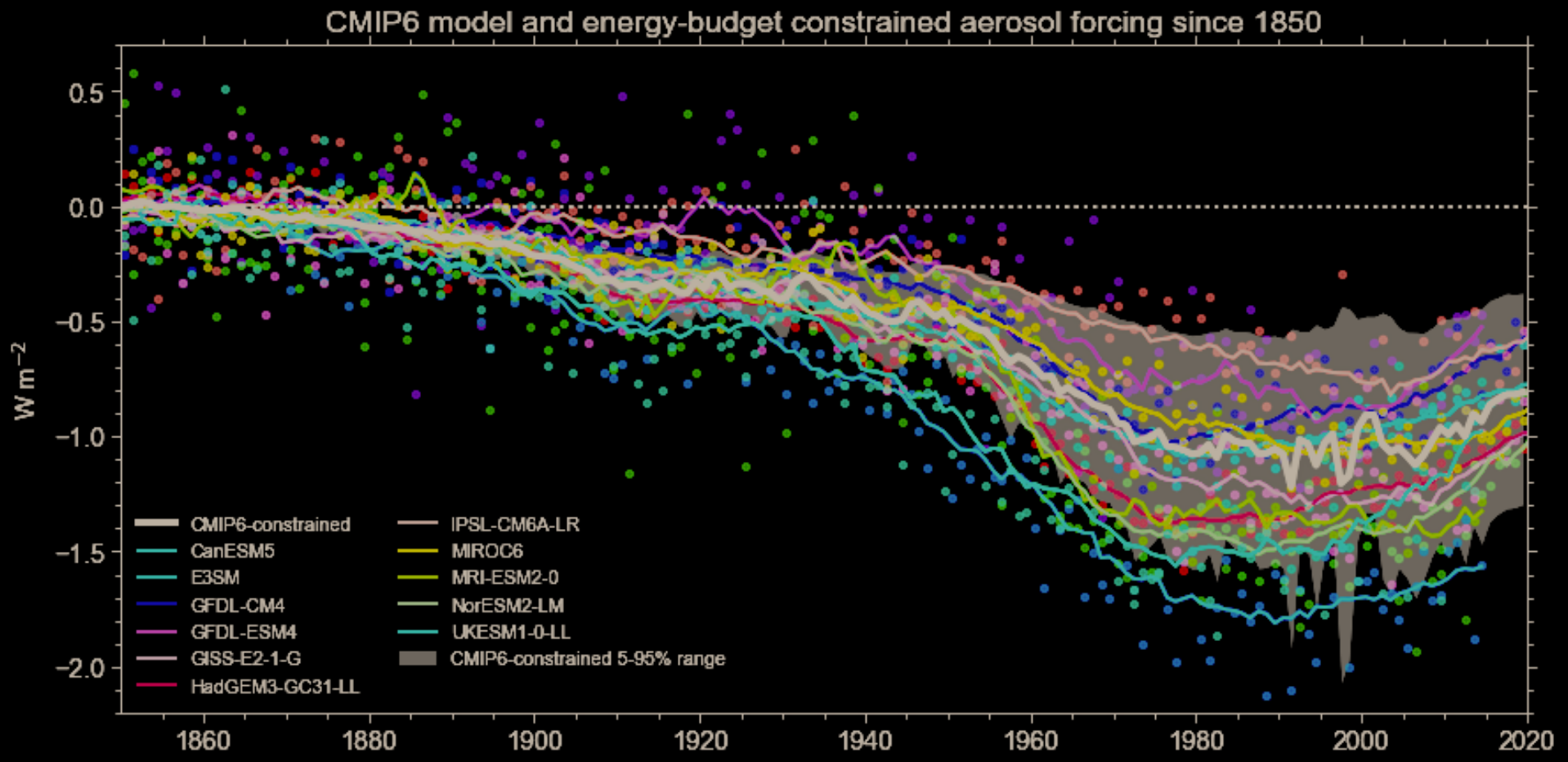
For the first time in the Sixth Assessment Report, IPCC were able to reconcile satellite-based estimates of aerosol forcing with model-based estimates

However, still a very large uncertainty in both



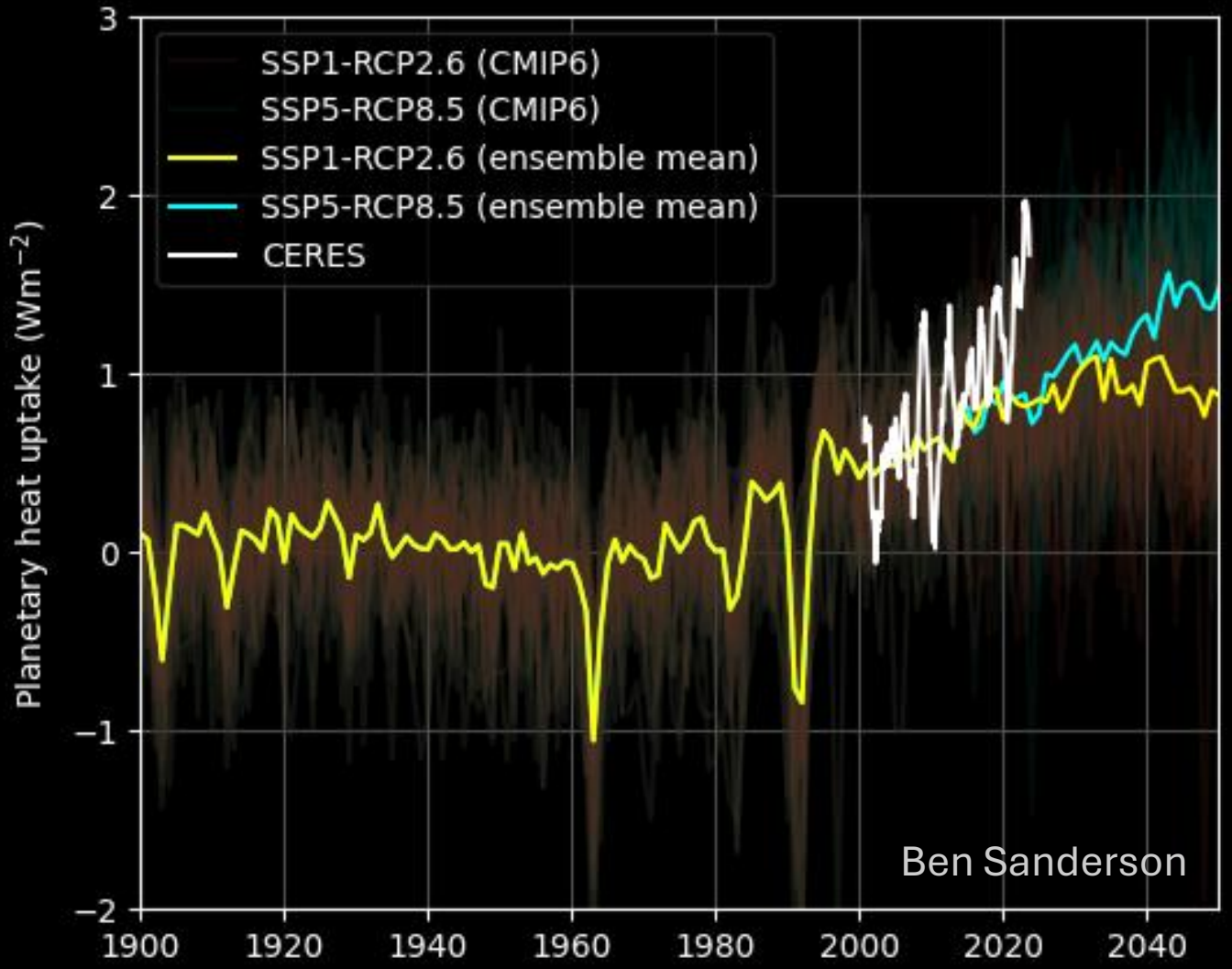

IPCC AR6 WG1 Chapter 7

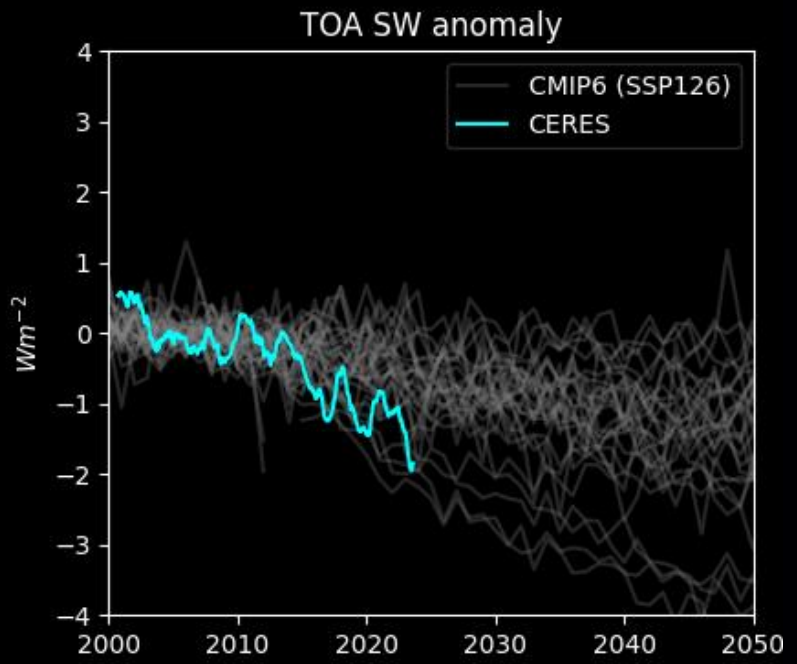
# Climate model divergence in historical aerosol forcing

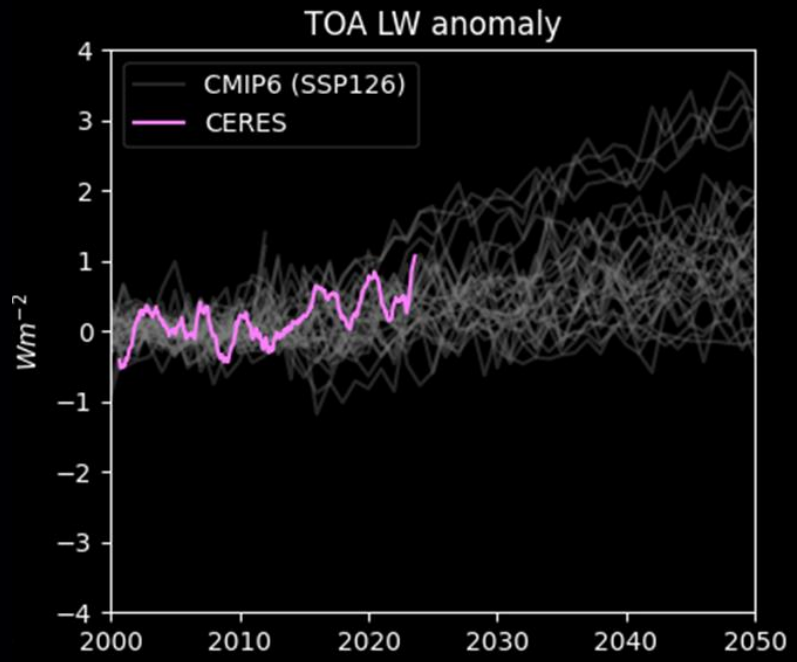



Smith et al. 2021 10.1029/2020JD033622

# CERES compared to CMIP6 models



# Importance of reducing forcing uncertainty and implications for climate sensitivity

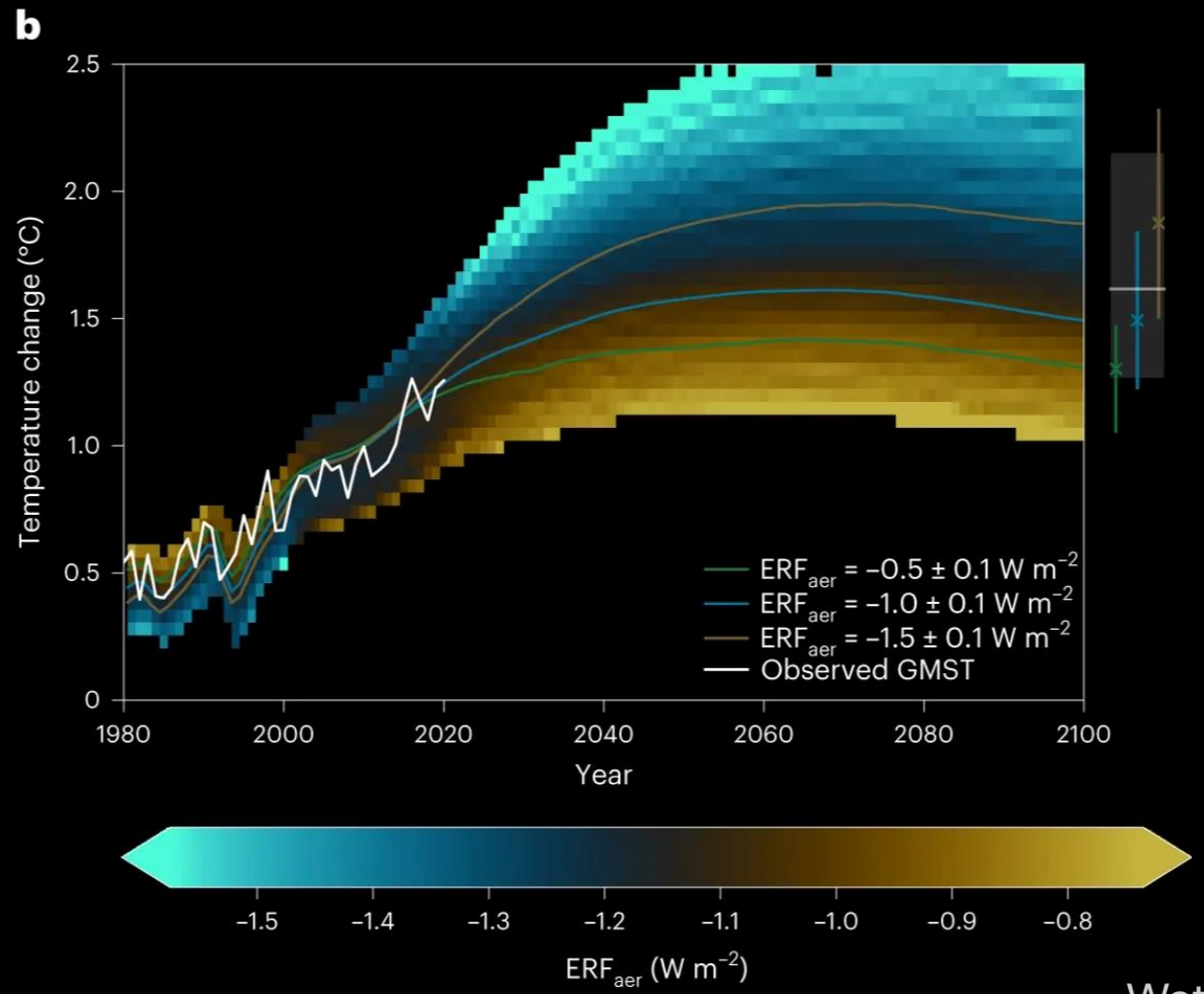
$$\Delta N = \Delta F + \lambda \Delta T$$

$\lambda$, the climate feedback parameter, tells us how sensitive the climate is: how much warming we expect for a unit forcing

Constraining $\lambda$ improves climate projections

The top of atmosphere imbalance is a combination of the forcing and the radiative response, so difficult to isolate $\Delta F$ and $\lambda$ from observations

# The uncertainty in forcing can be critical for Paris Agreement relevant warming thresholds




Same emissions scenario, varying uncertainty in aerosol forcing and consequent climate sensitivity

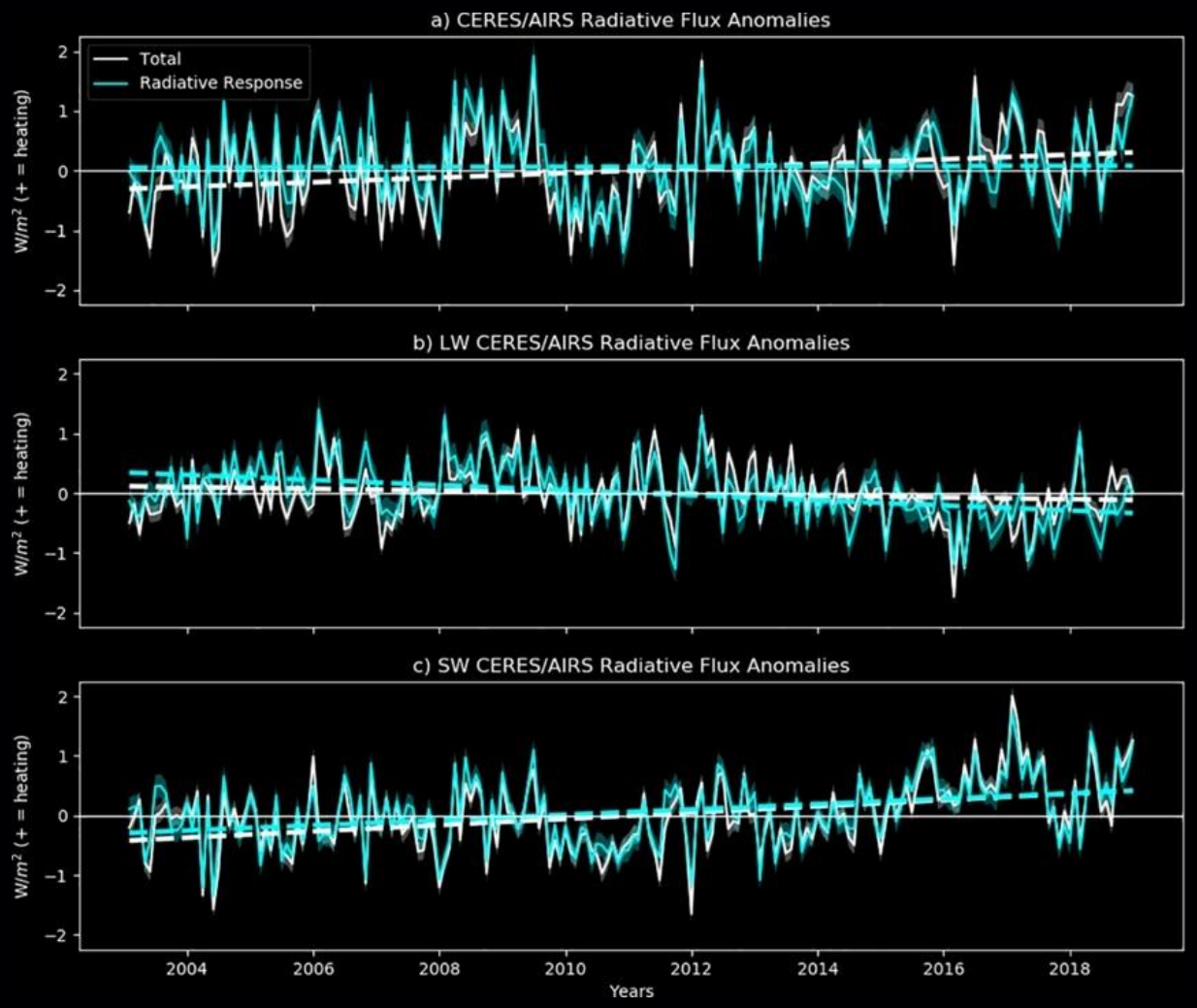
Watson-Parris and Smith 2022 10.1038/s41558-022-01516-0

# Attempting to separate forcing and radiative response

Kramer et al. 2021 estimated radiative response from forcing using CERES

LW outgoing radiation increasing: warming response (offset by increases in GHGs)

SW outgoing radiation decreasing: reductions in aerosol emissions




Kramer et al. 2021 10.1029/2020GL091585

# How spectral measurements help separate forcing from response

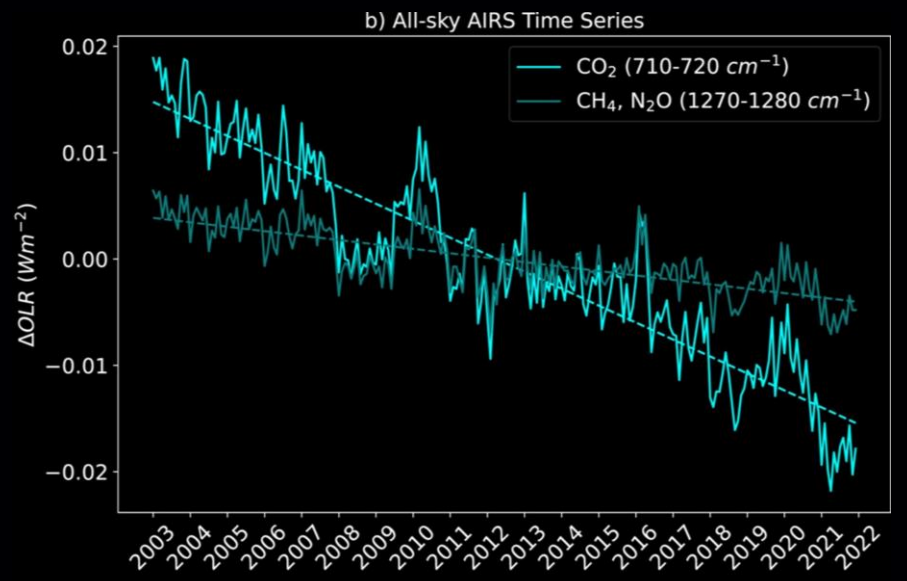
Detecting greenhouse gas radiative forcing from AIRS with spectral measurements (Raghuraman et al 2023; Rentsch 2019; Rentsch & Myhre 2023)

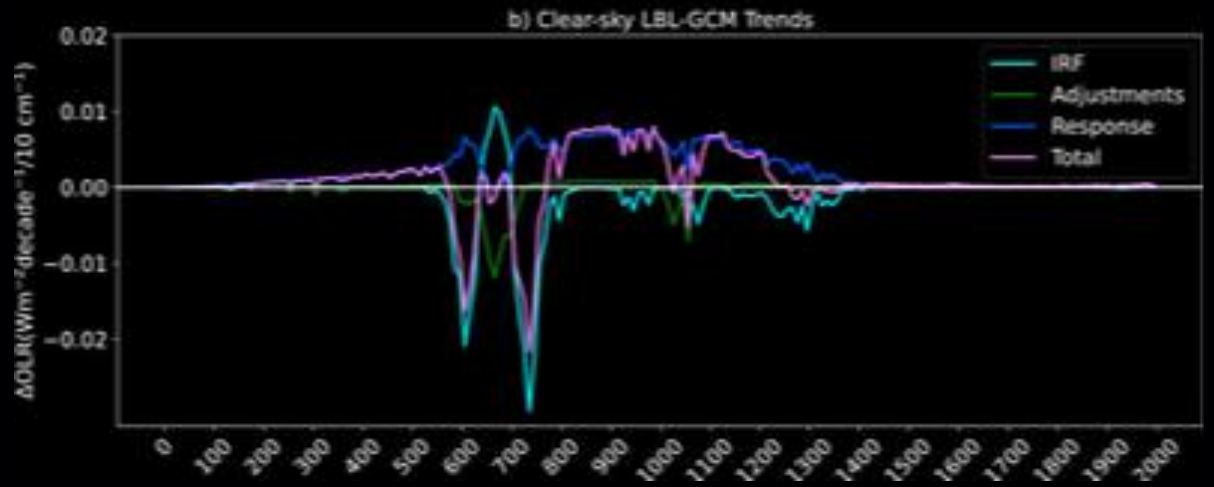
Decreases in OLR in $CO_2$, $CH_4$ and $N_2O$ bands

- Evidence of greenhouse gas radiative forcing

Increases in OLR in $H_2O$ and window bands

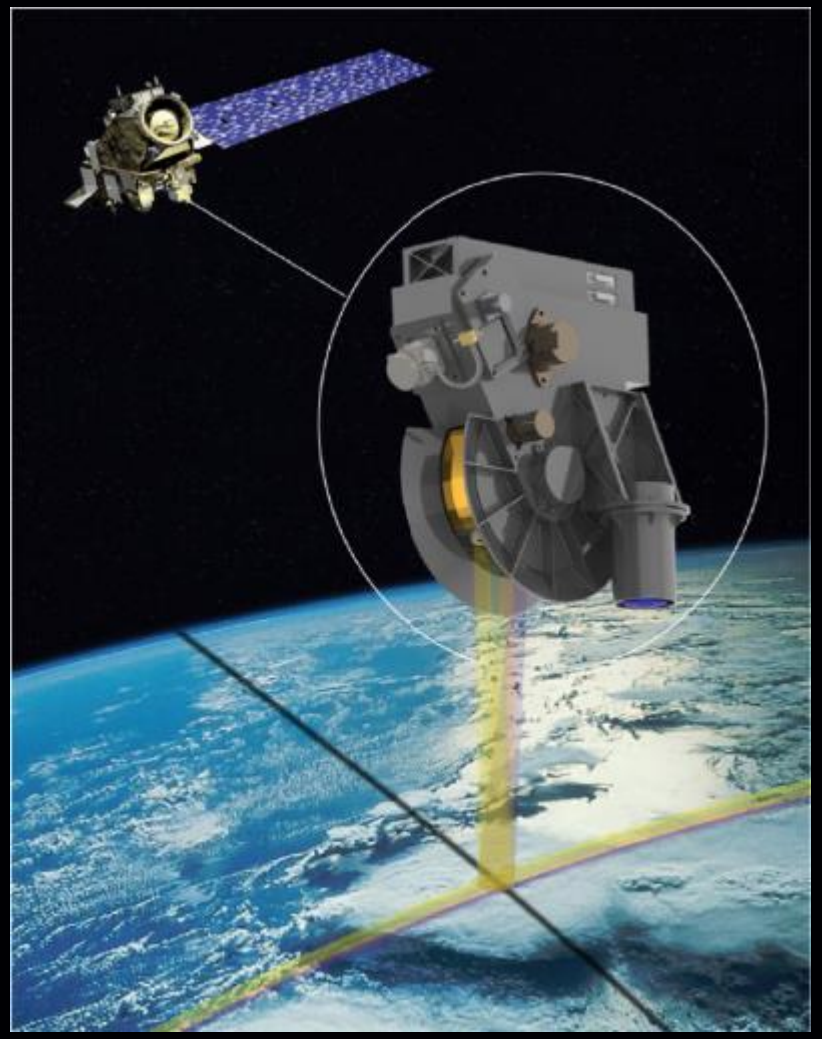
- Response from warming planet




Raghuraman et al. 2023, 10.1029/2023GL103947

Credit Maria Hakuba:
https://ceres.larc.nasa.gov/documents/STM/2021-05/14_mhakuba_CERES-L_talk_21.pdf



Libera

Understanding Earth's Energy Budget

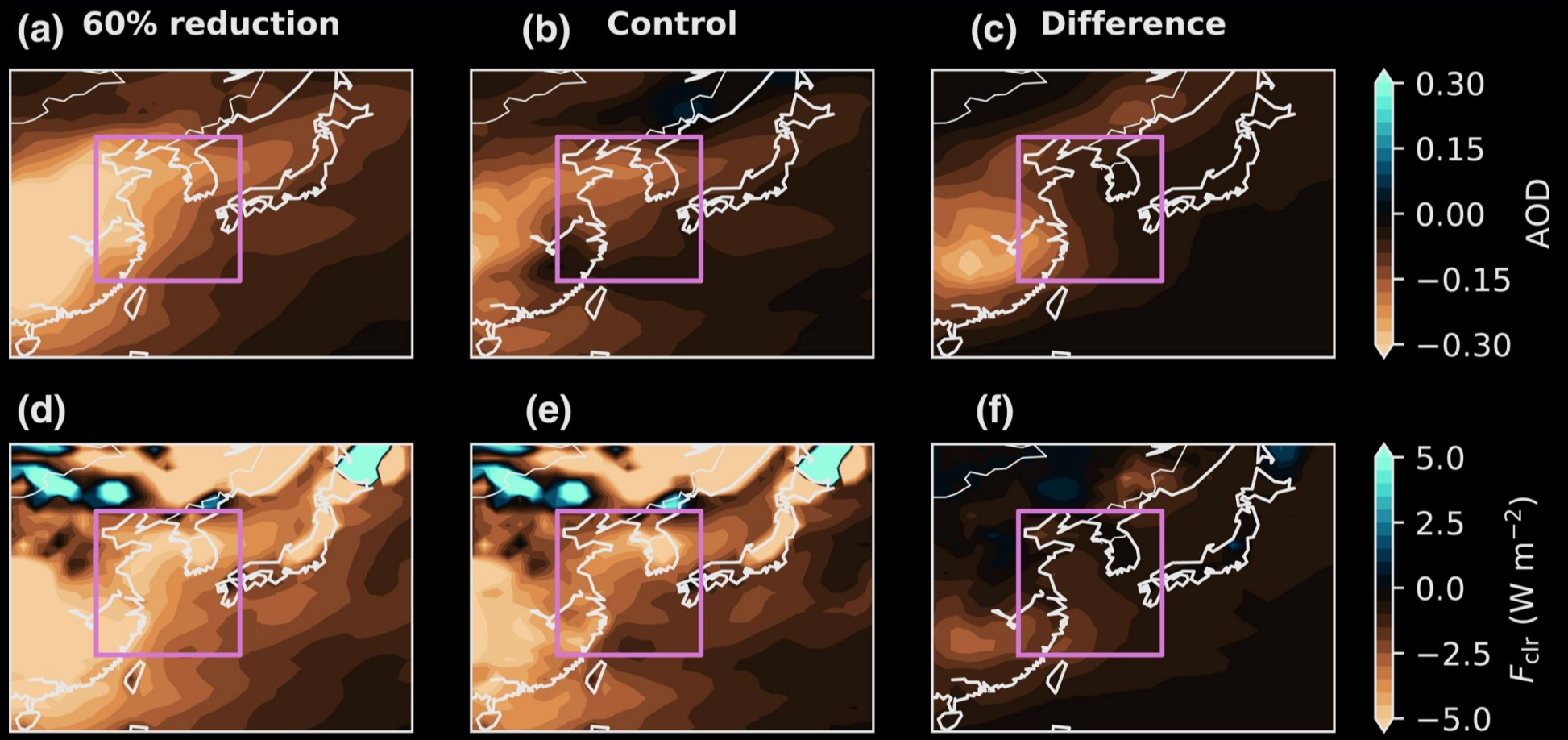
LASP • JPL • LBL • UA • CSU • UM • NIST • NOAA • Ball • SDL

Libera will be launched 2027 and continuity mission to CERES

Carries a fourth shortwave "split" channel (not a hyperspectral instrument)

Northern and Southern hemispheres have similar broadband SW albedo but different spectral signatures – a new tool for untangling forcing and response

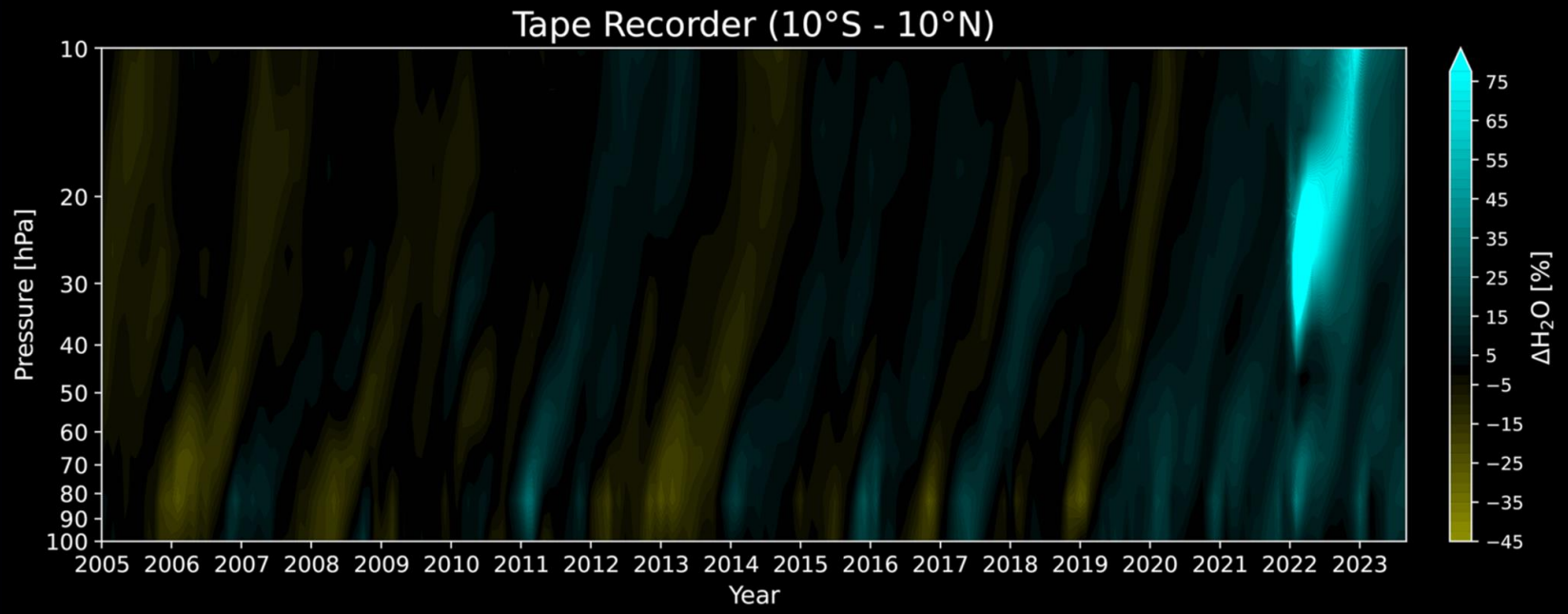
# Towards observational event attribution: COVID-19 aerosol reductions




Ming et al. 2021, 10.1029/2020GL091699

# Stratospheric water vapour from Hunga-Tonga volcano

- Microwave Limb Sounder (MLS) was critical to determine response to Hunga-Tonga eruption January 2022
- Radiative forcing estimate +0.14 W $m^{-2}$ in 2022, +0.18 W $m^{-2}$ in 2023
- MLS is running out of power…



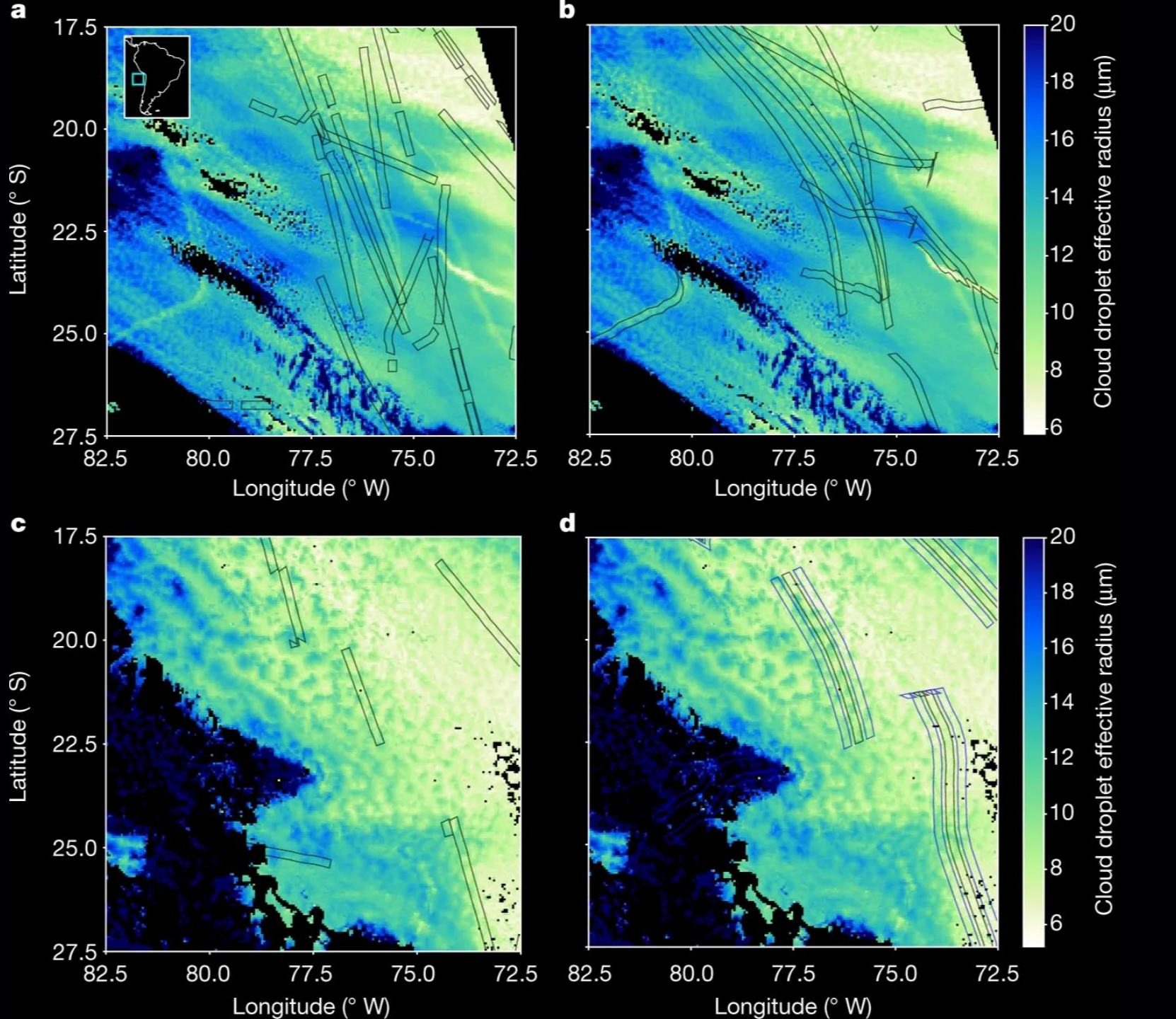


Chipperfield & Bekki 2024,
10.5194/acp-24-2783-2024
Millan et al. 2023,
10.1029/2022GL099381
Jenkins et al. 2023 ,
10.1038/s41558-022-01568-2

# Detection of ship tracks

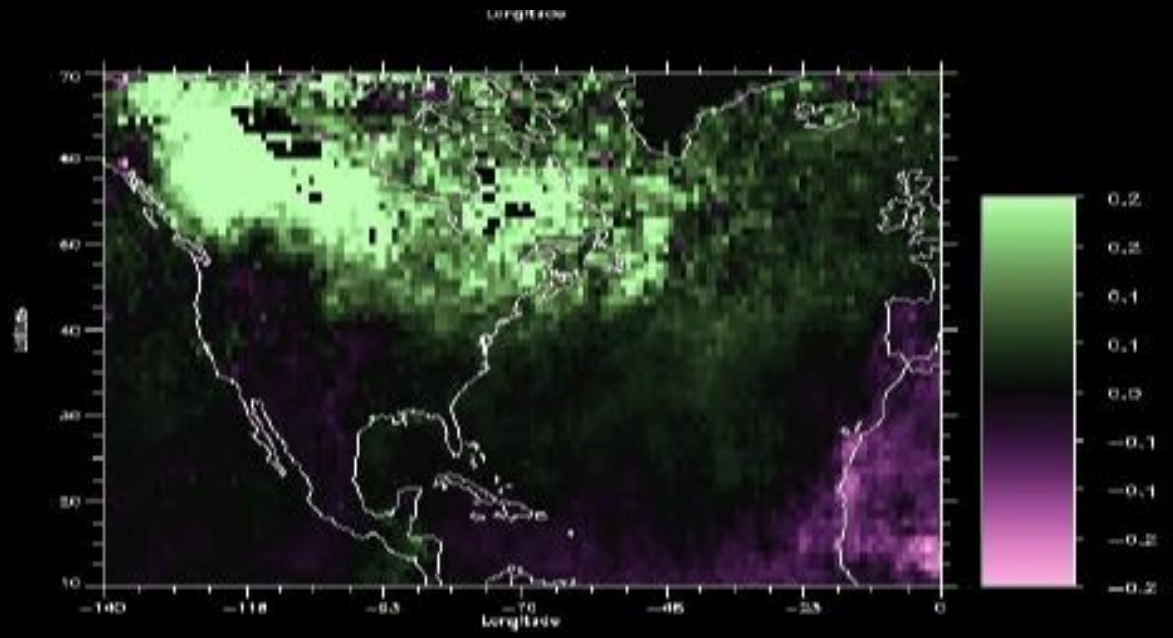
- Using machine learning to detect ship tracks from MODIS
- Estimate of radiative forcing due to shipping emissions legislation

Manshausen et al. (2022)
10.1038/s41586-022-05122-0



# 2023 biomass burning season

2023 minus 2022 AOD, MODIS TERRA



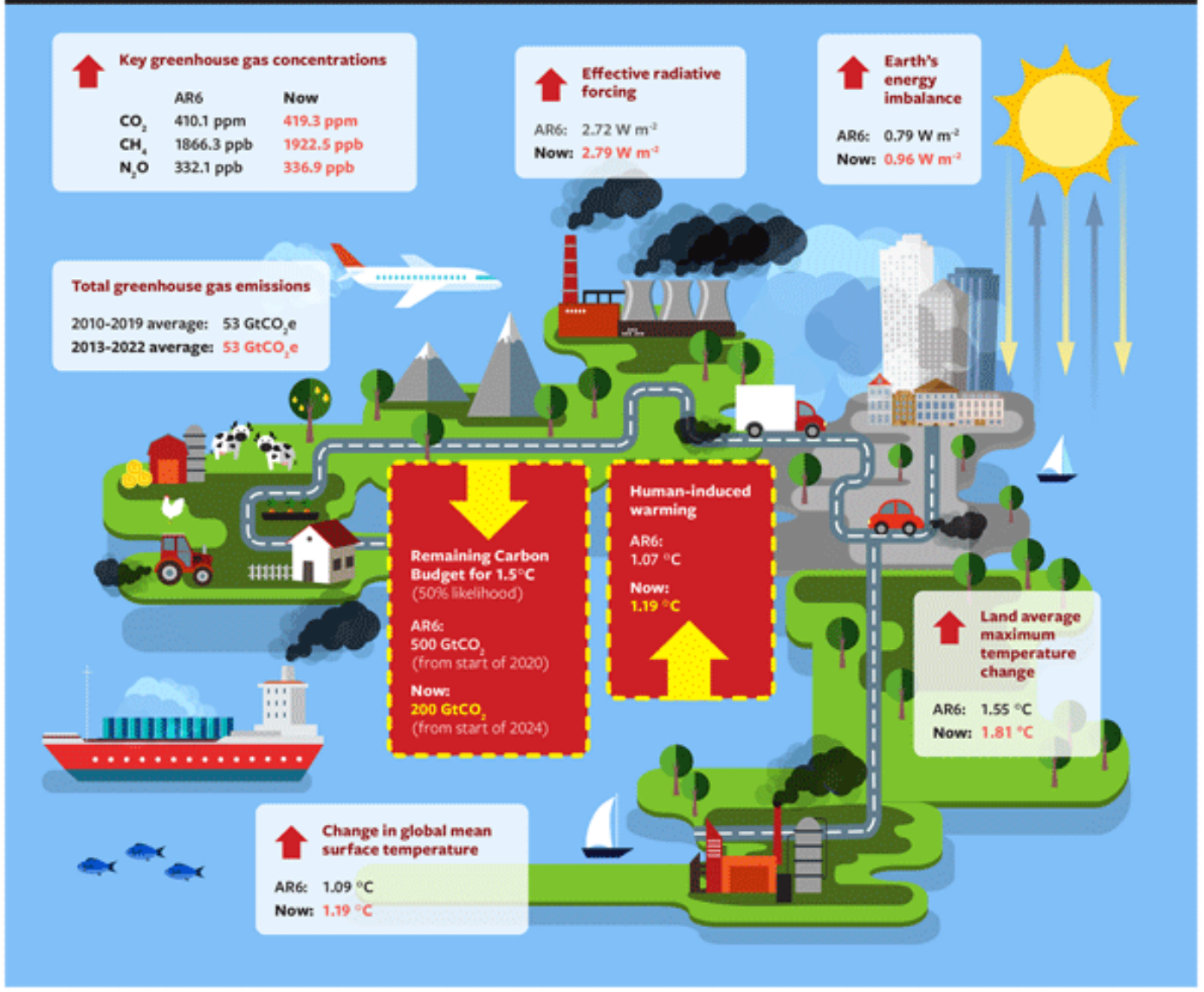

- Record biomass burning season in 2023 in North America
- Largest emission of organic carbon in satellite record
- Response to climate change? Or anthropogenic forcing?

Gunnar Myhre

Key indicators of global climate change 2023:

# What's changed since AR6?

Human-induced warming is increasing at the **unprecedented rate** of over 0.2°C per decade, the result of greenhouse gas emissions being at an all-time high over the last decade, as well as reductions in the strength of aerosol cooling.



# How observations support climate projections

- Reduce uncertainty in radiative forcing, particularly aerosols
- Reconcile the increasing trend in recent TOA radiation, particularly SW
- Continue to develop methods to separate forcing from climate response in observational records
- Provide annual updates on state of the climate system for policy support

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