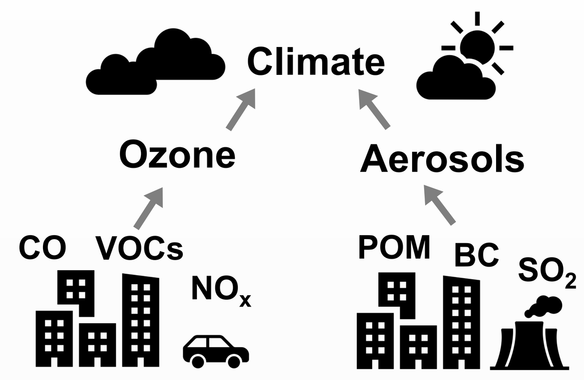
# Atmospheric Composition and Climate Responses to US Air Pollution Controls

Stephanie H. Elkins[1], Arlene M. Fiore[1], Gustavo P. Correa[2], Jean-François Lamarque[3], Steve J. Smith[4]

[1]Massachusetts Institute of Technology, [2]Lamont-Doherty Earth Observatory, [3]SilverLining , [4]Joint Global Change Research Institute, Pacific Northwest National Laboratory

## Key Question




How did avoided US emissions of aerosol and ozone precursors influence atmospheric composition and climate?

## Global Chemistry Climate Model Simulations

**CESM2–WACCM6:** fully coupled global chemistry-climate model

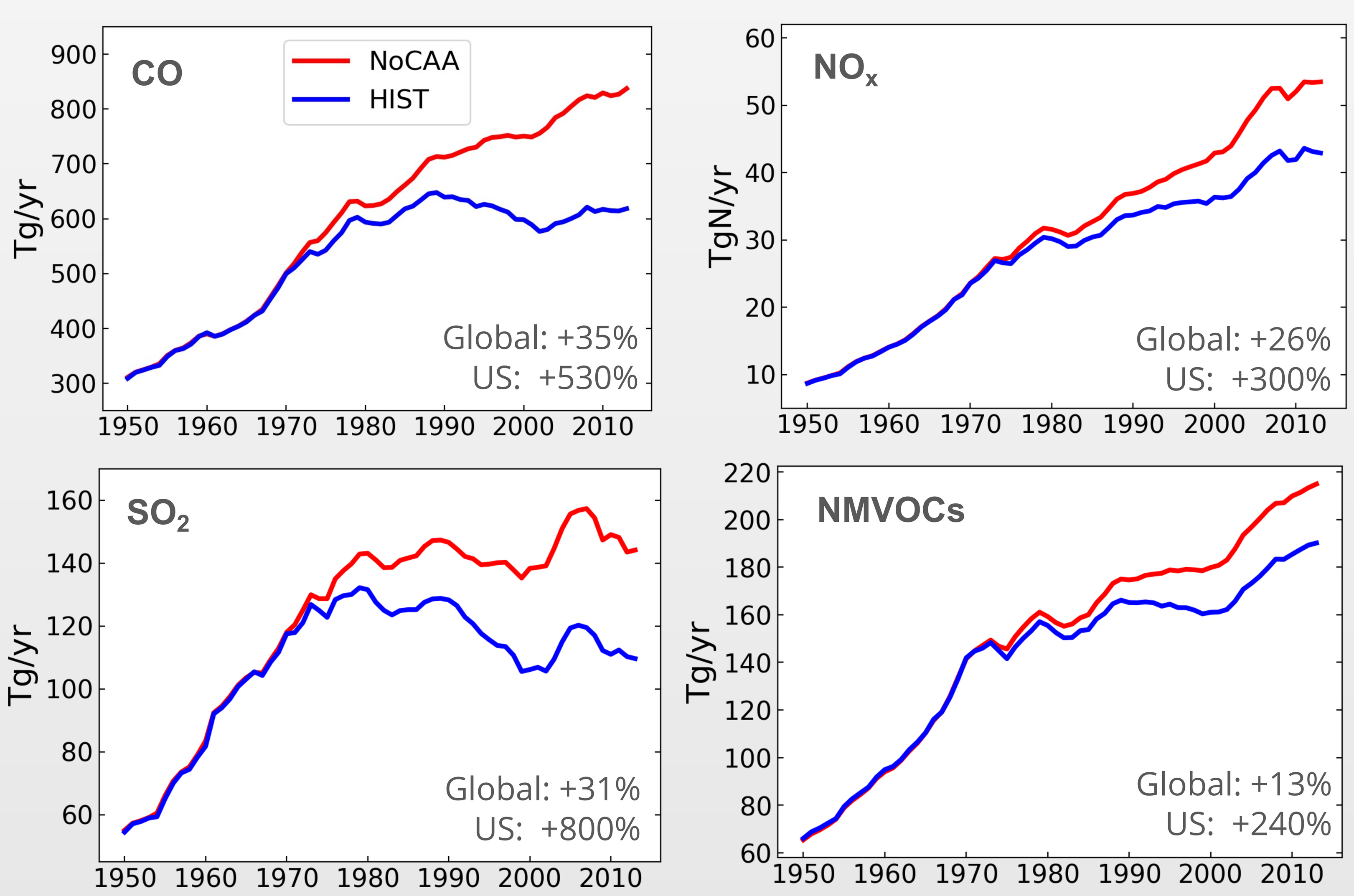
**Initial condition ensembles:**

- Individual ens. members = anthropogenic forcing + natural forcing + unique influence from internal climate variability
- Ensemble mean = average out noise from climate variability → isolate forced signal

## Emissions Scenarios

| Scenario | Description | Emissions | Ensemble Members | Years |
|---|---|---|---|---|
| **HIST** | Real-world historical | CMIP6 historical emissions (anthropogenic: CEDS) | 13 | 1970-2014 |
| **NoCAA** | "World avoided" by the CAA | CMIP6 historical emissions (anthropogenic: CEDS frozen US) | 13 | 1970-2014 |

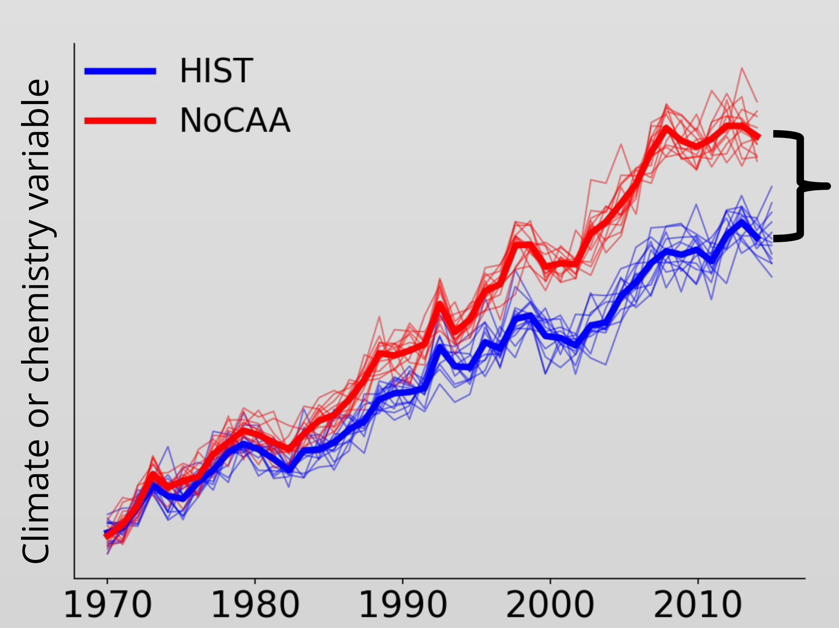
Global emissions trajectories:



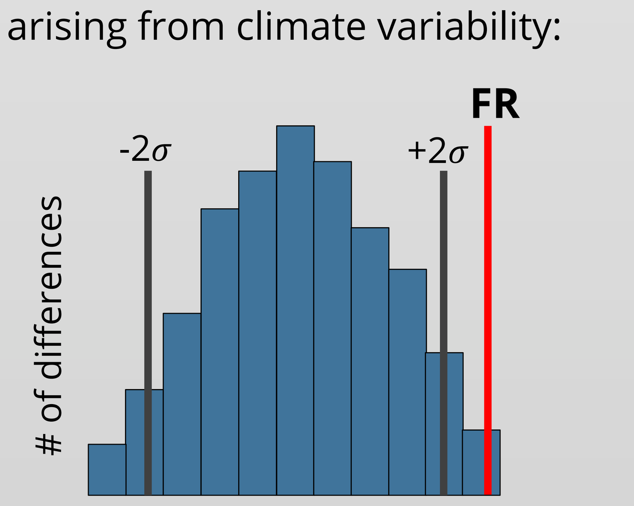

## Testing for Significance Against Climate Variability

A distribution representing the range of possible variation in an atmospheric constituent or climate parameter due to internal climate variability alone is developed by differencing each individual ensemble member from its respective ensemble mean for 10-year average time slices from 1970–2010.

The end-of-time-period ensemble mean difference between scenarios represents the **forced response (FR)** and is deemed significant if it exceeds the $\pm 2\sigma$ threshold of the distribution.




Decadal differences from ens. mean arising from climate variability:

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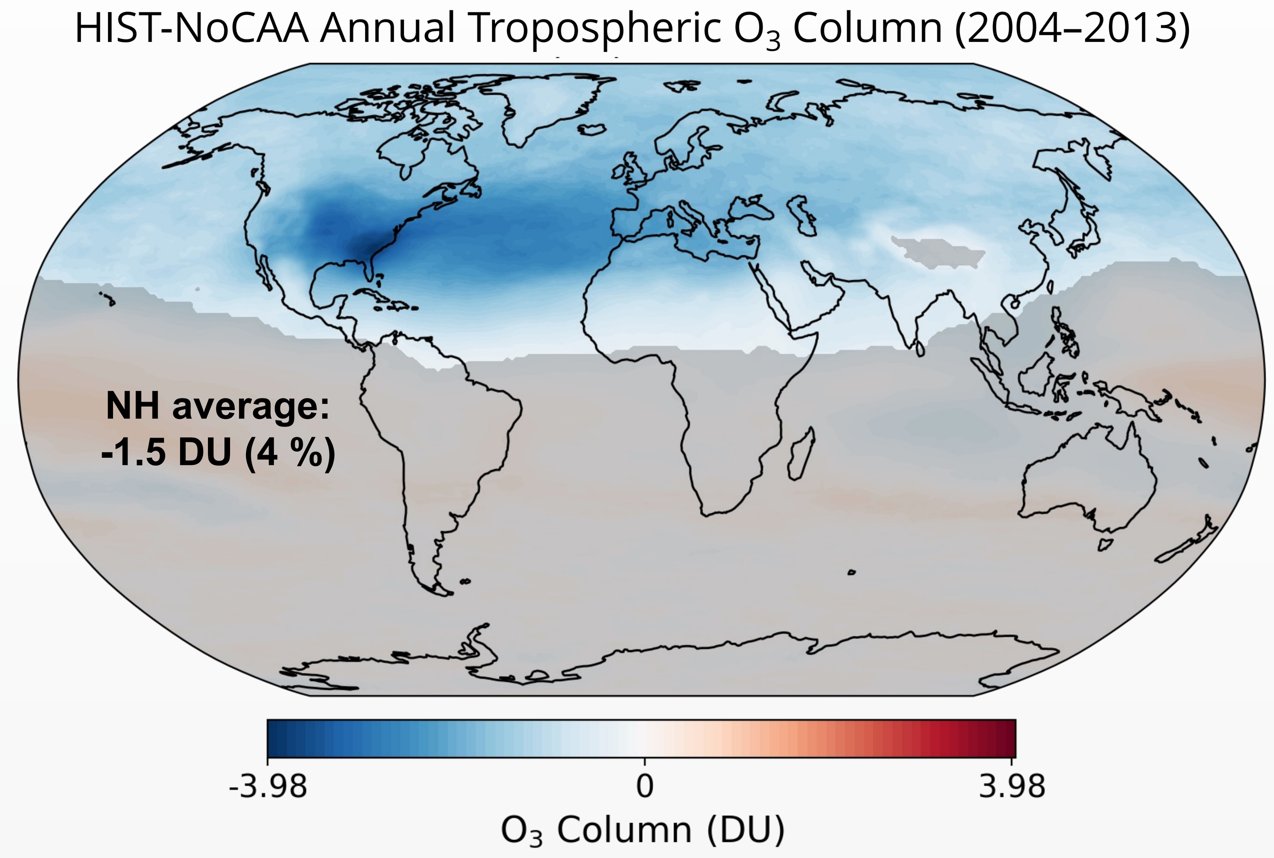
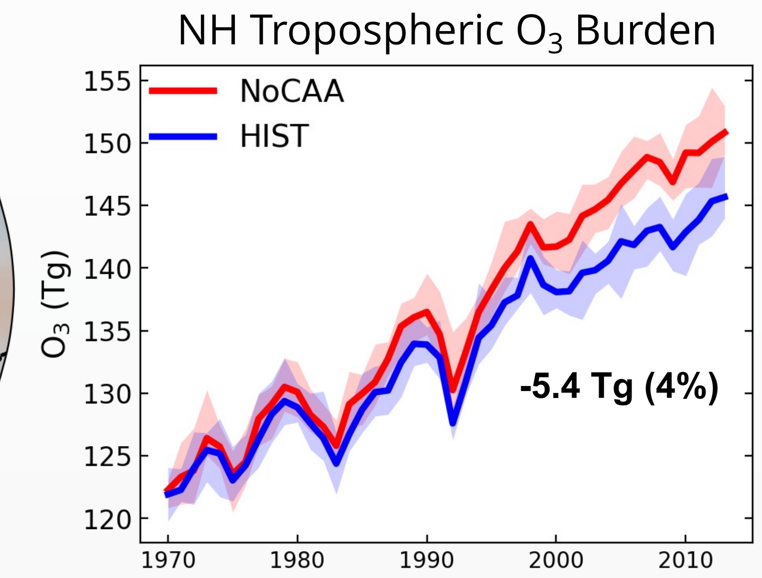
## Ozone and Aerosol Response to Avoided Emissions

**Tropospheric ozone column in the Northern Hemisphere decreases by 1.5 DU (4%)** on average in HIST compared to NoCAA due to avoided US emissions of precursor species $NO_x$, CO, and NMVOCs. Shading represents grid cells that are not significant at the $2\sigma$ level.

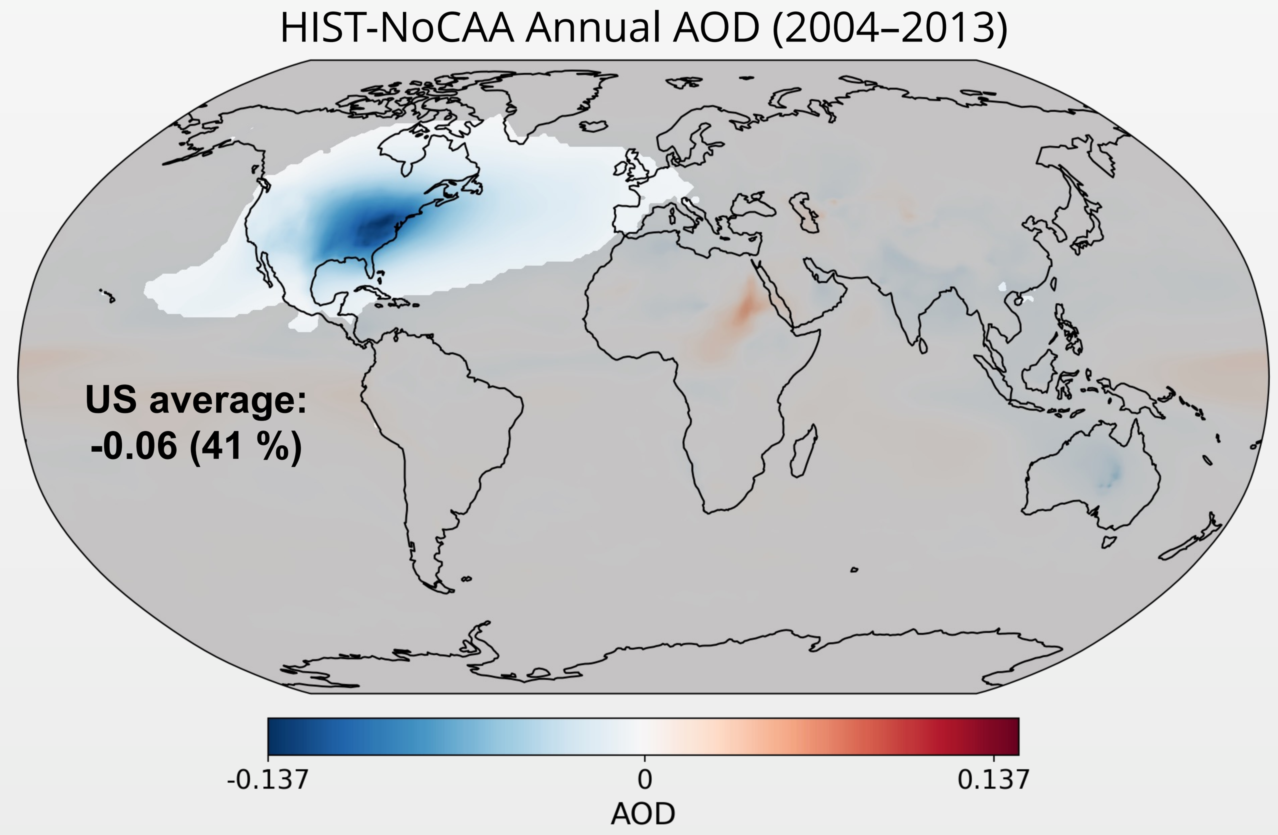
HIST-NoCAA Annual Tropospheric $O_3$ Column (2004–2013)

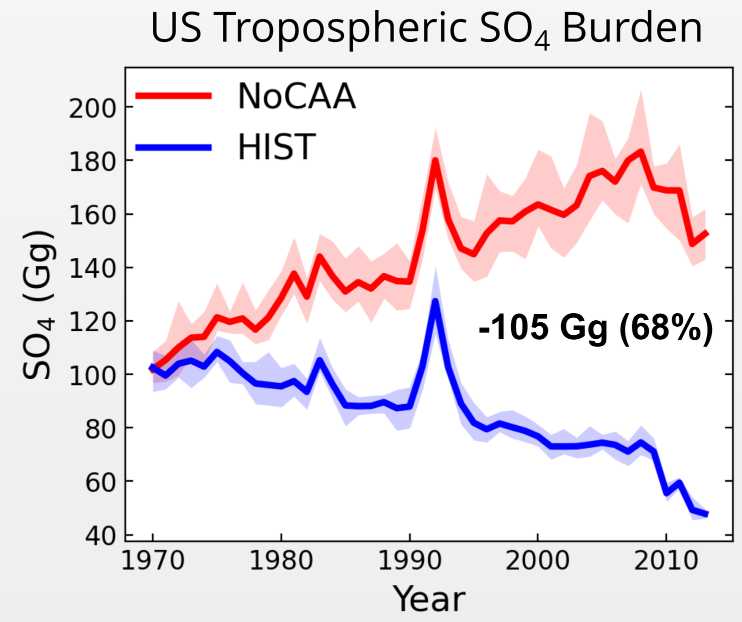



**US aerosol optical depth (AOD) decreases by 0.06 (41%)** in HIST compared to NoCAA due to avoided US emissions of both directly emitted aerosols (BC, POM, and $SO_4$) and aerosol precursor gases (NMVOCs and $SO_2$), which form SOA and $SO_4$.

HIST-NoCAA Annual AOD (2004–2013)




## Climate Response to Avoided Emissions

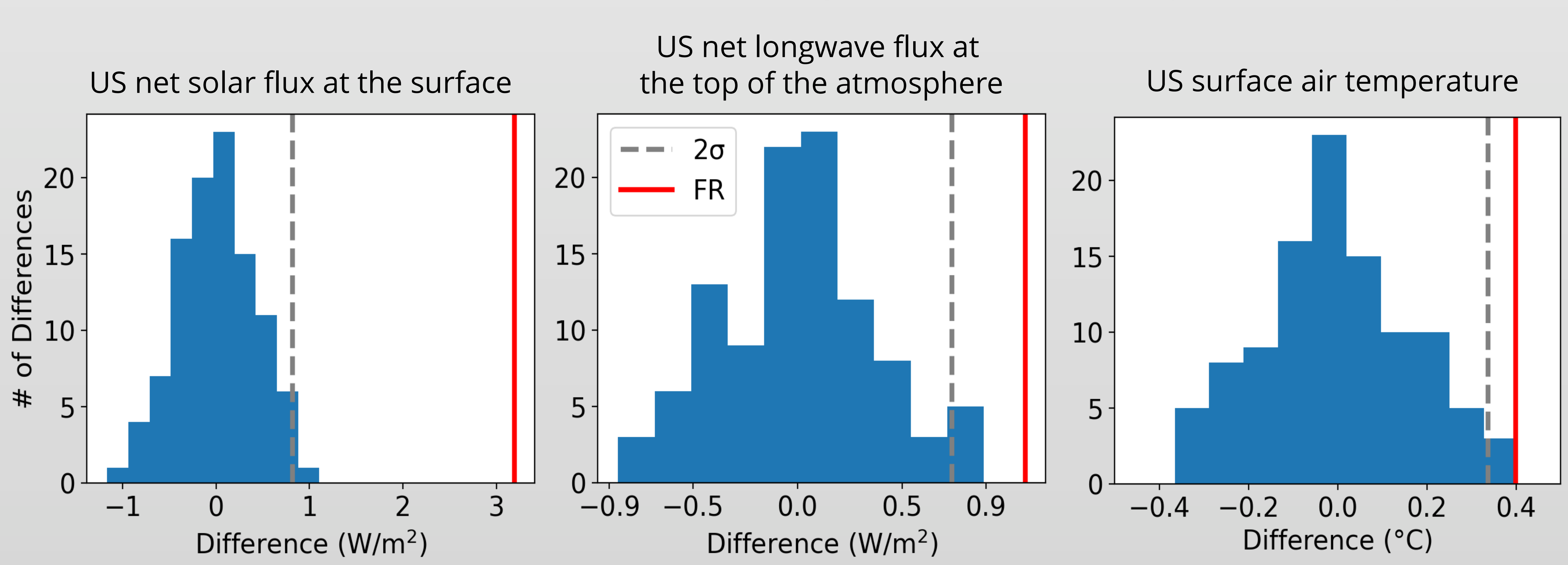
### Radiative response to avoided ozone

- Ozone absorbs outgoing longwave radiation in the troposphere → warms surface
- **Net longwave flux at the top of the atmosphere increases by 1 W/m² over the US.**

### Radiative response to avoided aerosols

- Aerosols reflect and absorb incoming solar radiation → cools surface
- **Annual net solar flux at the surface increases by 3.2 W/m² over the US.**

Decadal differences from ensemble mean arising from climate variability vs. forced response:




### Surface temperature response

Due to avoided US emissions from the CAA, **surface air temperature increases by 0.4°C over the US**, suggesting that the warming effect from avoided aerosols trumps the cooling effect from avoided ozone. This change is significant against climate variability at the $2\sigma$ level.

*Note: The NoCAA scenario does not account for possible reductions in emissions due to technology that may have occurred anyway without policy. Similarly, it does not account for changes in greenhouse gas emissions, for example, due to changes in fuel efficiency from the CAA.

Contact: shelkins@mit.edu