Regional and Global Climate Effects of Combustion PM Sources in the United States

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Regulations of short-lived species that improve air quality and warm the planet (BC) present a “win-win” situation, while regulations of short-lived species that reduce cooling and improve air quality (SO$_4$, SO$_2$) present a “win-lose” situation.
US emissions increased with the country’s growth. Air quality, acid deposition, and visibility concerns have caused steep emission reductions.

Further emission reductions are expected as the National Ambient Air Quality Standards become more strict.
Do aerosols and ozone, which are not well-mixed in the atmosphere, have climate effects that match their spatial distribution or more global in scale?

Previous studies say no. These studies have changed all aerosol sources at once, but what effects do individual regions have?
Modeling Framework: From Emissions to Climate

Past, Present, Future Emissions

GEOS-Chem
chemical transport model

BC, OC, Sulfate, Nitrate

GISS GCM 3 climate model

Sensitivity simulations with GEOS-Chem and the GISS GCM allow us to quantify the impact of U.S. emissions on regional and global climate
From Emissions to 3-D Concentrations: GEOS-Chem

Chemical Transport Model:
• GEOS-Chem v8-01-01
• 2° x 2.5° resolution
• GEOS-4 meteorology for 2001 – precludes climate’s influence on aerosols
• Two year simulations were conducted for each decade (1950, 1960...2050), the first being used as spin-up.

Control - Reconstructed Emissions and A1B
0 U.S. SO$_2$, NO$_x$, BC and POA Emissions
Past, Present, and Future Emissions

Emissions from biomass burning, NH₃, CO, and other trace gases held constant at present day levels.
The model compares favorably with observed concentrations of sulfate, nitrate, and ammonium, capturing the spatial gradients. Sulfate and ammonium match the magnitude of the observations very well, while nitrate is underestimated in the Midwest.
Model Evaluation: Black Carbon and Organic Carbon

The model generally has a low bias of BC compared to IMPROVE observations. The bias is likely due to the lower emissions of BC we use from Bond et al. [2007]. The model captures the magnitude and spatial gradient of much of the OC observations.
From 3-D Concentrations to Climate Changes: GISS GCM 3

Global Climate Model:
• GISS GCM 3 [Rind et al., 2007]
• 4° x 5° resolution, 23 vertical levels
• 1950-2050 transient climate simulations
• Ensembles of four control and four sensitivity simulations
• All results shown have 95% significance.

1950 2010 2050

Control - Reconstructed Emissions and A1B

0 U.S. SO₂, NOₓ, BC and POA Emissions
Internal mixing increases the ability of BC to absorb solar radiation, reducing the TOA radiative forcing.
Direct Radiative Forcing from U.S. Sources

Similar to the sulfate burden, radiative forcing over the eastern US maximizes in the 1980-90s and begins a steep decrease.
U.S.-sourced aerosol sources have cooled the annual mean surface temperature of the eastern U.S. by 0.5-0.75°C
Direct Radiative Forcing from U.S. Sources by Component

All-sky radiative forcing over the eastern US (east of 90°W) from US aerosol sources.

Compensating changes from black carbon and sulfate make the surface forcing roughly constant between 1950-2000.
Temperature changes over the eastern US (east of 90°W) do not follow the TOA forcing (and thus changes in sulfate).

Increasing trend between 2000 and 2050 acts in addition to warming from greenhouse gases.

What’s plotted: Effect of US Aerosol Sources
Conclusions

- US aerosol sources have cooled the eastern US by about 0.5°C.

- As aerosol sources are reduced, this cooling disappears causing faster warming trends across the eastern US.

- When considering only the aerosol direct effect, US sources mainly affect the US.