Offsetting roles that black carbon and sulfate play in climate change

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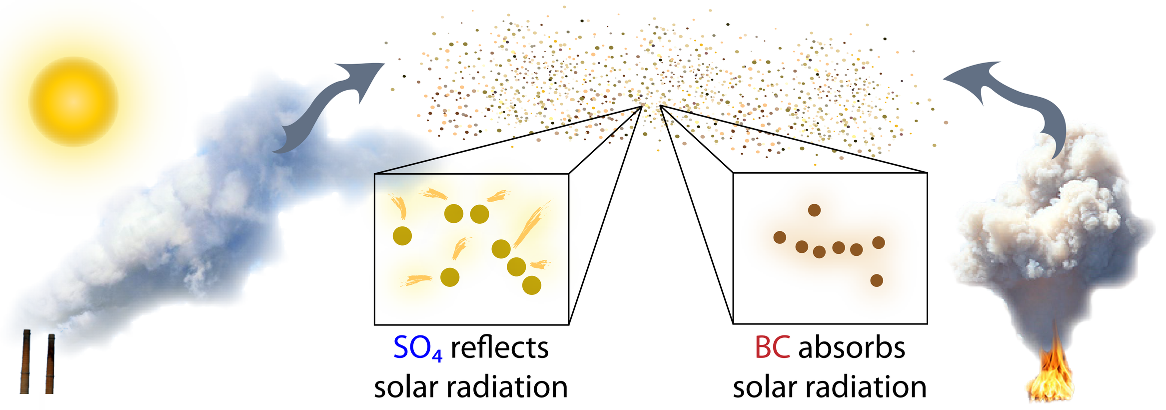
1. Background

- **Aerosols** as a whole are considered to offset the radiative effects of **greenhouse gases**
- However, there exists a robust offset amongst the main anthropogenic aerosol species themselves



- **Black carbon (BC)** and **sulfate (SO_4)** have comparable but offsetting top-of-atmosphere (TOA) direct radiative forcings (DRFs)
- Both species have negative surface forcing from reducing the solar radiation reaching the surface

RESEARCH QUESTION:

How have BC and SO_4 contributed to 20th century climate change?

2. Methods

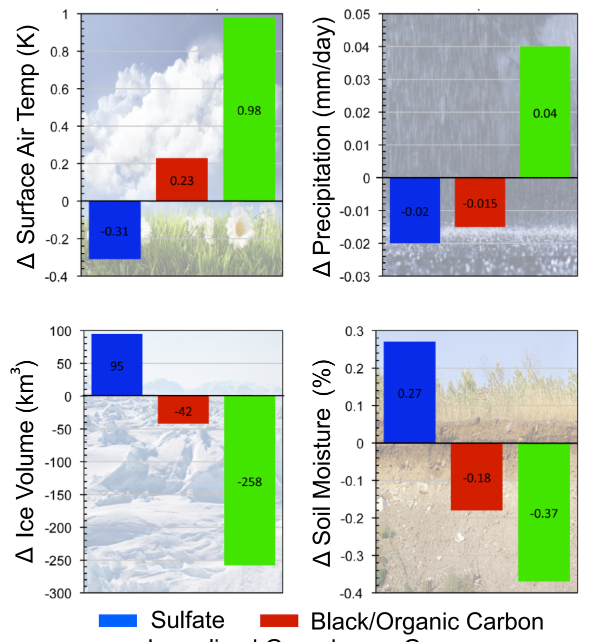
- NOAA GFDL coupled global climate model CM2. is used to assess changes in key climate variables from preindustrial (1860-1880) to present-day (1980-2000)
- Several forcing scenarios are run for 140 years for an ensemble of initial conditions
- Aerosol distributions are simulated by MOZART 2 [Horowitz et al., 2003] with IPCC AR4 emissions [Horowitz, 2006]
- Horizontal resolution of 2° (latitude) by 2.5° (longitude), with 24 vertical levels
- External mixtures of aerosols are used to calculate radiative forcings

3. Results

results represent climatic changes from pre-industrial to present-day

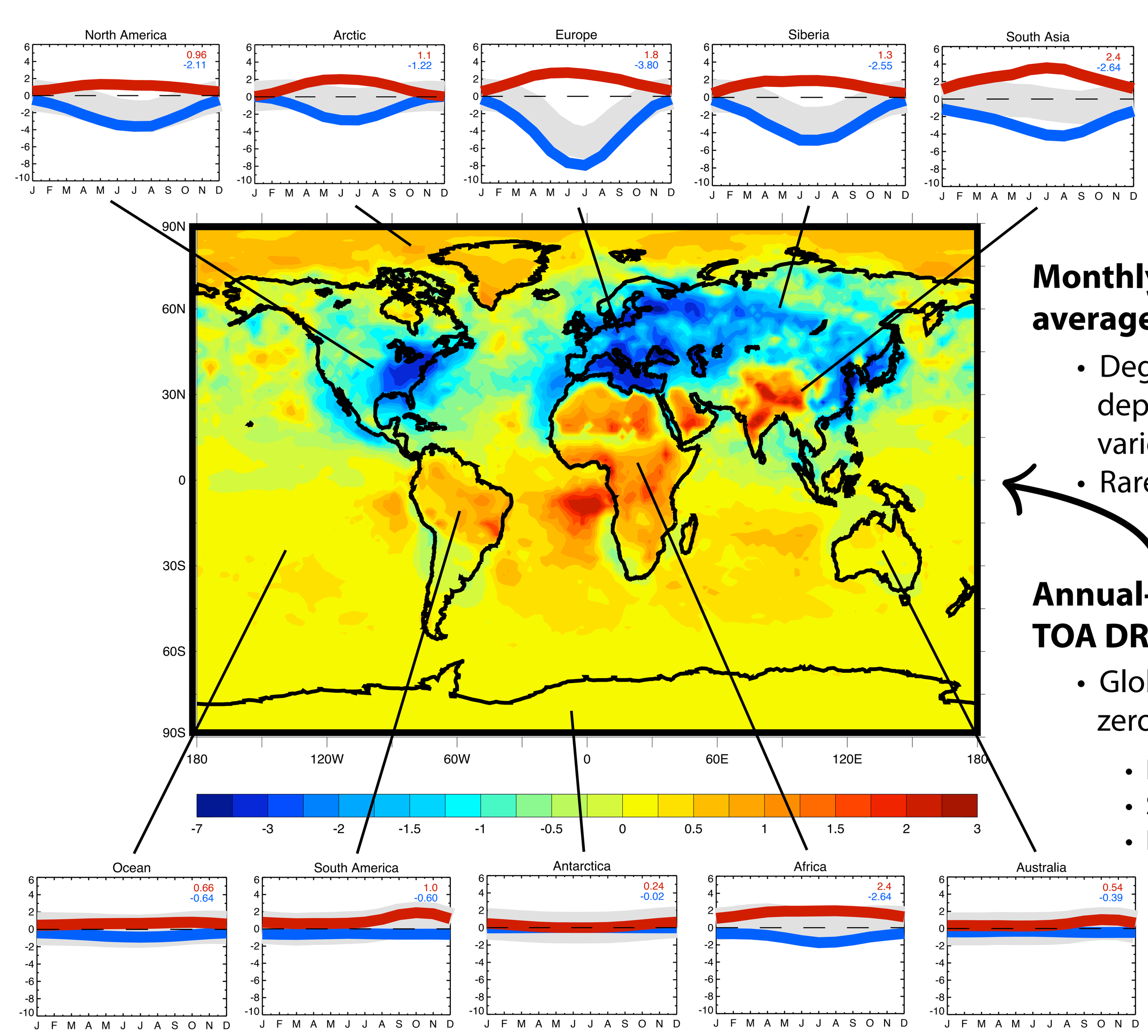
	Global-mean	Regionally
Radiative Forcing	TOA DRF offset of -0.09 Wm^{-2} consistent with IPCC AR4	Strongly depends on region and BC/SO_4 ratio (see map below)
Air Temperature	Offset proportional to that of forcing (-0.08 K)	Positive temperature responses in South Pole, overall negative in Arctic
Precipitation	Both responses negative and comparable, half of LLGHG's	Inverted zonal trends but SO_4's magnitude dominates
Soil Moisture	Reduced hydrological cycle for SO_4, less evaporation, wetter soil	Strong inverted trends do not match precip, peaks in NH mid-lats
Ice Volume	SO_4 increases ice volume more than BC reduces it	Both aerosols reduce ice in SH, but have opposing effects in NH

Global-mean climate responses



Offsetting radiative forcings

KEY:
- Black Carbon
- Sulfate
- Net

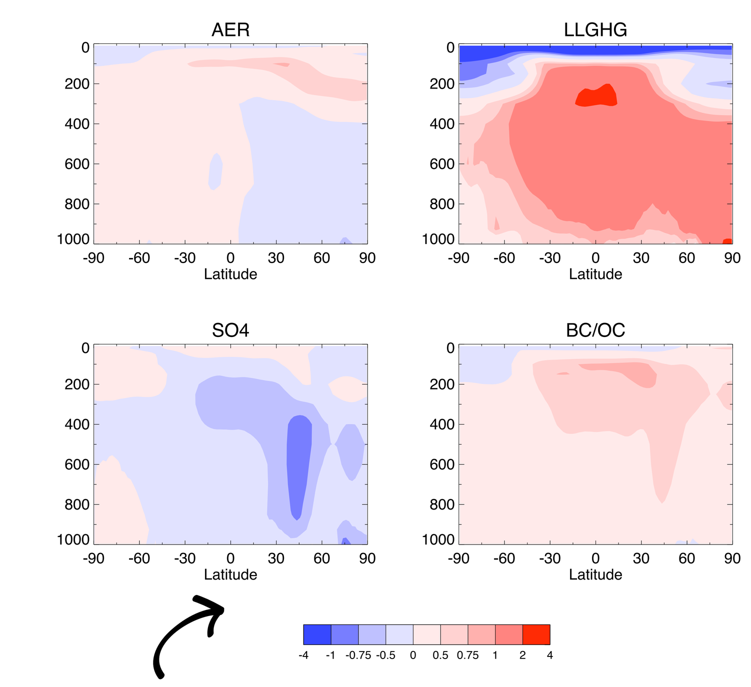


Monthly TOA DRFs (Wm^{-2}) averaged by region
- Degree of offset strongly depends on region and varies considerably
- Rarely zero

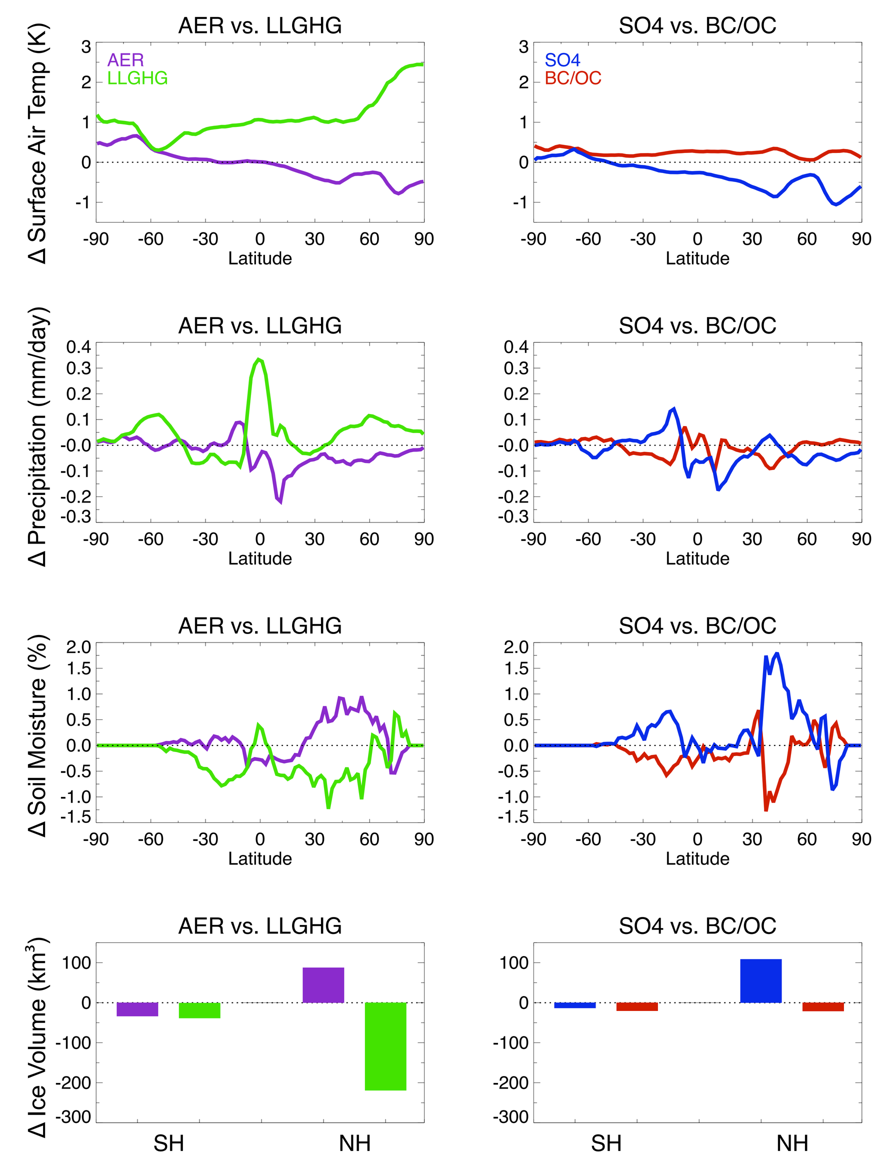
Annual-mean net TOA DRF (Wm^{-2})
- Global-mean net closer to zero than most regions
  - BC DRF: +0.87 Wm^{-2}
  - SO_4 DRF: -0.96 Wm^{-2}
  - Net: -0.09 Wm^{-2}

Offsetting climate responses

KEY:
- Aerosols (net)
- Long-lived Greenhouse Gases
- Black Carbon / Organic Carbon
- Sulfate



Zonal profile of changes in air temperature (K)
- Offsetting temperature feedbacks from BC and SO_4 lead to small temperature change compared to LLGHGs



Zonal changes in several climate parameters
- Zonal signatures are completely opposite for BC and SO_4 for every climate aspect

4. Conclusions

1. BC and SO_4 exhibit a radiative offset at the top-of-atmosphere, with a strong regional dependence and near-complete balance for the global-mean
2. BC and SO_4 DRFs cause opposing global-mean climate responses in air temperature, soil moisture, and ice volume, and similar responses in precipitation rates
3. Zonally, BC and SO_4 induce opposite results in all 4 climate variables, and zonal patterns are inverted
4. Overall, SO_4's climate responses slightly dominate that of BC's, and thus aerosols as a whole slightly offset climate changes due to long-lived greenhouse gases

Acknowledgements

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