ABSTRACT

This study investigates the competing and complementary aspects of anthropogenic sulfate and black carbon direct radiative forcing (DRF) in the context of a successful climate model — GFDL CM2.1. Results show that sulfate and black carbon global mean DRFs are almost offset one another (0.87 W/m² for black carbon; -0.96 W/m² at the top of atmosphere (TOA)), whereas surface direct radiative forcings are both negative and additive, exerting a combined forcing of -1.23 W/m².

We focus on factors governing the scattering-absorbing aerosol balance for the global-mean and geographically — clouds, relative humidity, surface albedo.

We describe how results show that without clouds, sulfate would dominate the aerosol TOA DRF balance, and without sulfate hygroscopic growth from high relative humidity, black carbon would dominate the balance.

INTRODUCTION

Aerosols directly perturb Earth’s radiative balance by scattering and absorbing shortwave and longwave radiation.

All aerosols decrease amount of radiation reaching surface, which can reduce the strength of the hydrological cycle.

Aerosols have competing warming/cooling characteristics at top-of-atmosphere, which can affect Earth temperature.

Scattering aerosols (e.g., black carbon) trap energy in climate.

Concentrations of aerosols have risen considerably since pre-industrial times.

RF is uncertain since aerosols are short-lived and vary spatially; therefore, offsetting characteristics may change rapidly.

MODEL DESCRIPTION

The GFDL CM2.1 model is used in conjunction with MOZART to simulate the global distribution and radiative forcing of black carbon and sulfate aerosols.

Horizontal resolution of MOZART is 2.8° by 2.8°, aerosols are remapped to the 2° by 2.5° resolution of CM2.1 with 24 vertical levels.

Emissions are taken from inventories compiled for IPCC AR4 (Horowitz, 2006).

CM2.1 radiation code used to calculate radiative forcings, with the shortwave radiation algorithm adapted from Feindelrich and Ramaswamy (1999) and the longwave radiation algorithm from Schwarzkopf and Ramaswamy (1999).

Aerosol optical depth, single scattering albedo and asymmetry parameter calculated as a function of hygroscopic growth and optical properties derived from Mie theory.

RESULTS

Control Case

- Cloud Impact
- Relative Humidity Impact
- Surface Albedo Impact

EXPERIMENTS

Control Case

1. Cloud Impact
2. Relative Humidity Impact
3. Surface Albedo Impact

MODEL SIMULATIONS

CONTROL CASE — Radiative forcing calculations derived using realistically simulated climate conditions, including typical geographical distributions of horizontal and vertical cloud cover and relative humidity, surface albedo, and insolation.

EXPERIMENTS — Sensitivity studies of governing factors

1. Cloud Impact — DRFs were calculated for clear-sky conditions (zero clouds) and subtracted from the control case to determine the impact from the presence of clouds.
2. Relative Humidity Impact — DRFs were calculated for dry sulfate conditions (30% relative humidity) and subtracted from the control case to determine the impact from hygroscopic sulfate.
3. High Albedo Impact — DRFs were calculated for constant low surface albedo conditions (0.1) and subtracted from the control case to determine the impact from presence of high surface albedos.

CONCLUSIONS

- Sulfate and black carbon top-of-atmosphere DRFs are offsetting.
- BC DRF (1.57 W/m²) is % of all GHG, % of CO2 RF
- Sulfate DRF (-1.96 W/m²)
- Sulfate and black carbon surface DRFs are additive and negative (BC -1.24 W/m²; SO2 -0.88 W/m²)
- May decrease strength of hydrological cycle.
- Sulfate DRF enhanced by relative humidity (63% globally) and reduced by clouds (~50% globally) and high albedo (8% globally).
- Black carbon DRF impacts different for top-of-atmosphere and surface — TOA affected more.
- TOA = BC DRF enhanced by clouds (78% globally) and high albedo (100% globally).
- SFC = BC DRF reduced by clouds (22% globally) and high albedo (5% globally).

FUTURE WORK

- Include internal mixtures, black carbon deposition in snow, and indirect effects on clouds.
- Perform sensitivity studies on the vertical distribution of clouds and aerosols in relation to one another.
- Implications for policy and climate will be explored.

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