Modeling Trends in Aerosol Direct Radiative Effects Over The Northern Hemisphere Using a Coupled Meteorology-Chemistry Model

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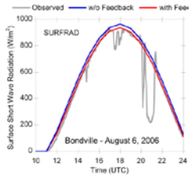
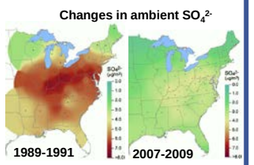
Problem Description

Though aerosol radiative effects have been recognized as some of the largest sources of uncertainty among the forcers of climate change, the verification of the spatial and temporal variability of the magnitude and directionality of aerosol radiative forcing has remained challenging. While global numerical atmospheric models have recently been used to estimate the anthropogenic aerosol radiative effects for future changing emission scenarios, little effort has been devoted to verifying the fidelity of the simulated radiative effects relative to available observations. Key questions in addressing these uncertainties include:

- How well do current models represent the regional and temporal variability of aerosol radiative forcing for current and past conditions?
- Is the signal detectable relative to the observations?
- Can models capture past trends in aerosol loading and associated radiative effects
  - SO_2 and NO_x reductions from EGUs as a result of Title IV of the Clean Air Act

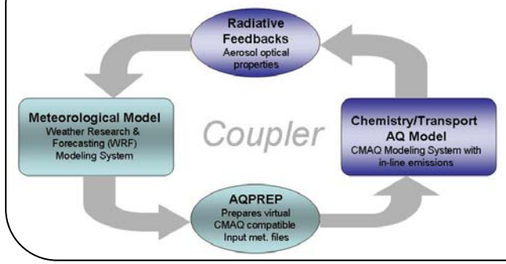




Time Period for Analysis:
- N. Hemisphere Domain: 1990-2010 (JJA)
- North American Domain: 1990, 1996, 2000, 2006 (JJA)

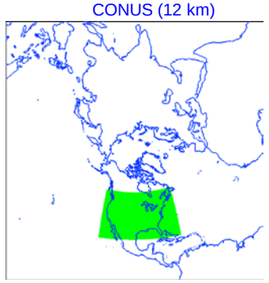
Modeling Approach

Coupled WRF-CMAQ Modeling System

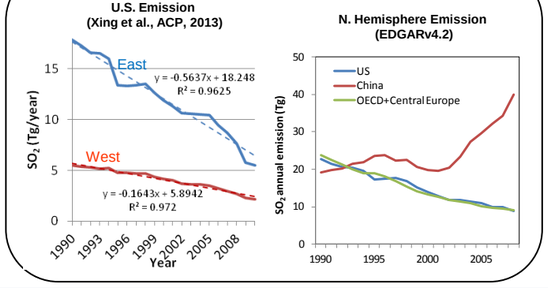


Simulated aerosol composition and size distributions are used to estimate optical properties of the aerosol which are then used in the radiation calculations in WRF. Thus, direct radiative effects of scattering and absorbing aerosols in the troposphere estimated from spatially and temporally varying simulated aerosol distributions are fed back to the WRF radiation calculations, resulting in "2-way" coupling of the atmospheric dynamics and chemical processes.

Domain: N. Hemisphere (108 km)
CONUS (12 km)

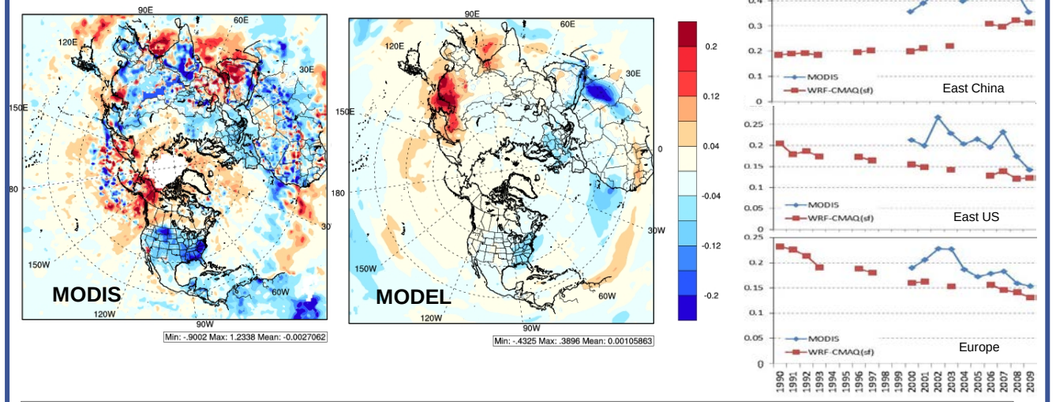


Trends in Emissions

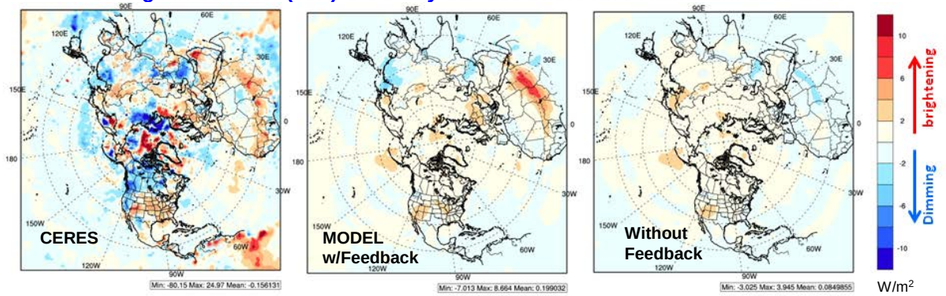


Simulated Trends: Northern Hemisphere

Change in Summer (JJA) Aerosol Optical Depth: 2009-2000



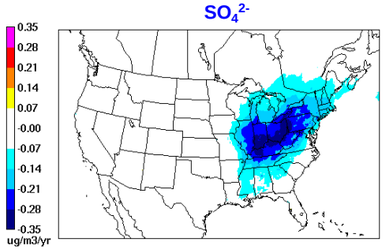
Change in Summer (JJA) Clear-sky Surface Shortwave Radiation: 2009-2000



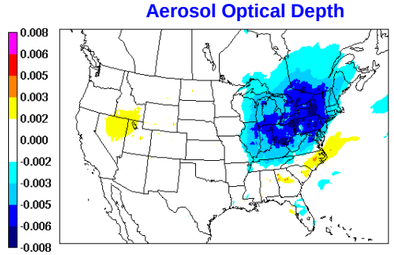
- Model with aerosol direct effects better captures:
  - Radiation dimming in China; brightening in Europe
  - Desert dust impacts in N. Africa
- Slight underestimation in magnitude of SW change

Simulated Trends (1990-2006): CONUS 12 km

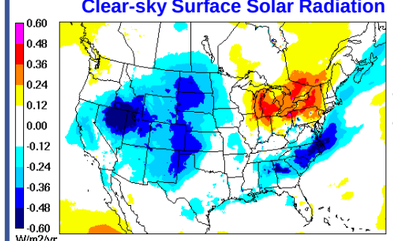
SO_4^{2-}



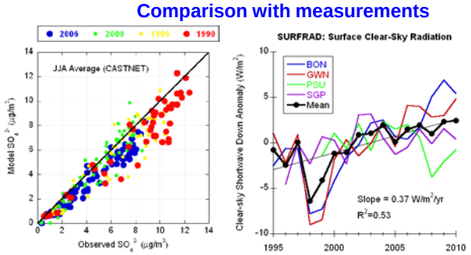
Aerosol Optical Depth



Clear-sky Surface Solar Radiation

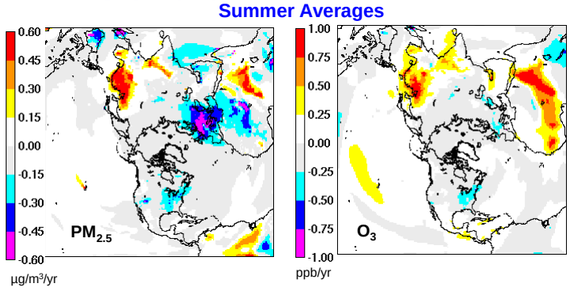


Comparison with measurements



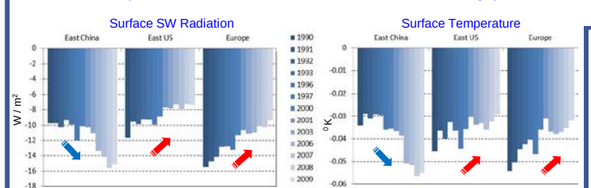
Reduction in tropospheric aerosol burden over NE US ➡ Radiation "brightening"
Increase in tropospheric aerosol burden over SE US ➡ Radiation "dimming"

Changing Tropospheric Composition: 1990-2010 Trend Summer Averages



Direct Aerosol Impacts

(with Feedback – without Feedback; JJA average)



Spatial heterogeneity in aerosol direct effects on SW radiation and cooling

Summary

- Significant changes have occurred in tropospheric aerosol loading across the northern hemisphere over the past two decades
- The model is able to capture:
  - The magnitude and trend in aerosol SO_4^{2-} and $PM_{2.5}$ over the US
  - The contrasting trends in aerosol loading over N. America/W. Europe vs. Asia
- Associated changes in aerosol optical depth and surface solar radiation during this period are also evident in both the model and measurements. Trends in modeled clear-sky SW radiation reflect the brightening and dimming in regions across the northern hemisphere