

Geographic Sensitivity of PM_{2.5} Mass to Large Point Source Emissions

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Summary

An air quality model called URM-1ATM was used to investigate regional tendencies in fine particle (PM_{2.5}) species in response to changes in regional SO₂ and NO_x emissions. This model was developed for the Southern Appalachian Mountains Initiative (SAMI) at the Georgia Institute of Technology. The model employs the direct decoupled method (DDM) to estimate sensitivities without the need for multiple model runs for different emissions. This time-saving technique can, with one model run, discriminate sensitivities associated with emission changes in user-defined geographic regions within the modeling domain.

Method – The URM-1ATM model was used by SAMI to investigate air quality over the southern Appalachian Mountains. SAMI examined air quality during nine meteorological episodes. This study focuses on four of these episodes, three in summer and one in spring. Five geographic areas were defined in the eastern U.S. that served as both source and receptor regions for the sensitivity analysis: Midwest (MW), Mid-Atlantic coast (MA), Southeast (SE) and New England (NE). Another region, denoted “W” (first tier of states west of the Mississippi River), was used as a source region only. Emissions projected to 2010 were modeled.

The DDM approach determined the average daily change in ground-level aerosol concentrations across all model grid cells that fell within a region in response to changes in emissions from each region. For most species, concentration changes were normalized by the aerosol concentration to derive relative changes.

Sensitivity modeling as implemented in URM-1ATM is subject to several significant limitations. Interpreting the results requires a familiarity with the sensitivity technique. It is best to regard the sensitivities as providing qualitative guidance to policymakers on pollutant responses to emissions changes. Users of this information are cautioned against over interpretation of results.

Another qualification on the results is that they are only reported here for grid cells of 96 km and smaller. The model grid included a series of nested grids that started with a parent grid composed of 192-km cells. The finest nested grid, aligned with the southern Appalachians, had cells of 12 km. Parent grids expanded outward from the mountains. However, only the 192-km grid covered all the eastern U.S. The analysis had to use results from the 96-km grid in order to report impacts for New England and most of the Midwest. Thus, results for these two regions are subject to more uncertainty than are results for the other regions because more of MW and NE were covered by the lowest resolution grid cells.

Results – Sensitivities reported here are for fine (<2.5 μm) sulfate, fine organic carbon (OC), fine nitrate and PM_{2.5}. Impacts are only reported for regions east of the Mississippi River because of the model’s low spatial resolution west of the river. All sensitivities, defined as the change in 24-h average concentration, were computed for a ten percent reduction in emissions. Regional impacts were measured in several ways:

- **Average relative sensitivity (ARS)** – the average, for each region, of the sensitivity in a grid cell normalized by the aerosol concentration in the grid cell
- **Maximum relative sensitivity (MRS)** – the highest relative sensitivity in any cell within a region
- **Threshold relative sensitivity (TRS)** – the average relative sensitivity for those grid cells with aerosol concentrations exceeding a given threshold value.

Individual grid cell sulfate sensitivities, expressed as MRS, ranged from zero to -9% in response to a 10% SO₂ emission reduction. ARS values were 0-3%. The largest ARS values occurred in response to emissions from regions MW and SE, and the smallest were from source region NE. OC sensitivities to SO₂ reductions were much smaller, with -3%<MRS<+2%.

Most source regions produced very small ARS and MRS values for OC. However, during some episodes in some regions negative OC MRS values were computed to be as low as -6% for SO₂ emission reductions. Modest positive OC MRS values were computed in one case. The reason for this variable response is unknown. PM_{2.5} sensitivities (0 to -5%) were in line with those for sulfate because it is a major component of PM_{2.5}. However, PM_{2.5} sensitivities were smaller in magnitude.

ARS and MRS nitrate sensitivities were not computed because the very small nitrate concentrations lead to very large (in some cases, >1000%) relative sensitivity values. Instead, actual concentration changes were determined to identify trends. During the August episode, nitrate changes in response to SO₂ and NO_x emission changes were very small, no more than ±0.4 µg m⁻³. In most cases, nitrate concentrations were computed to be <1 µg m⁻³ (isolated locations with levels as high as 3 µg m⁻³ were computed for April and June episodes). As expected, nitrate tends to increase as SO₂ (and sulfate) decreases, but decrease as NO_x (and nitric acid) decreases. Aerosol responses to changes in point source and low-level NO_x emissions were consistently smaller than those for SO₂ emission reductions.

Regional ARS and MRS values computed for each of the four episodes were very similar although spatial patterns and actual pollutant concentrations varied because of meteorological differences. This implies that the various aerosol species respond similarly in a relative sense to emission changes despite seasonal and weather-related differences.

The modeled regional average response of 24-h average PM_{2.5} concentrations to SO₂ emission reductions (all source regions) increased as conditions became more favorable for sulfate formation. The lowest average responses were computed for the spring episode and the largest responses occurred for a dry summer episode with above-normal temperatures.

Conclusions – Sensitivity model simulations reveal that sulfate is the species that changes the most in response to SO₂ and NO_x emission reductions. Sulfate decreases are expected from decreases in both emission species, although it is most responsive to SO₂ reductions. OC shows a varied response to emission changes, increasing in some cases while decreasing in others. Nitrate changes are expected to be small in response to the relatively small emission changes modeled, but large increases cannot be ruled out for large reductions in SO₂. As a rule, modeled PM_{2.5} relative sensitivities are similar to those for sulfate but smaller in magnitude. Aerosol changes are projected to be smaller for NO_x emission reductions at large point sources than for similar reductions in low-level sources.