JFSP 6 Month Project Progress Report

Title: Sensitivity Analysis of Air Quality to Meteorological Data in Fire Simulations

Project ID: 12-3-01-6

Principal Investigator: M. Talat Odman - Georgia Institute of Technology

Student Investigator: Fernando Garcia Menendez - Georgia Institute of Technology

Smoke Episode Simulations:

An objective of this project is to simulate fire-related smoke transport affecting air quality at urban areas downwind of wildfires or prescribed burns. We have completed the simulation of a smoke episode in Atlanta, GA on Feb. 28th, 2007 believed to be caused by two prescribed burns 80 km southeast and which lead to an increase in $PM_{2.5}$ levels recorded at monitoring sites throughout metro Atlanta of up to nearly 150 µg m^{-3}. The Community Multiscale Air Quality Modeling system (CMAQ version 4.5) was used to numerically simulate the transport and transformation pollutant emissions at 4, 12 and 36 km horizontal resolutions. Emissions inputs from non-fire sources were processed with the Sparse Matrix Operator Kernel Emission processor (SMOKE version 2.1). Emission rates for wildland fires featured in the simulated urban smoke episode were prepared through the Fire Emissions Production Simulator (FEPS). Plume rise was estimated with the Daysmoke model. Figure 1 shows observed and CMAQ-predicted $PM_{2.5}$ concentrations at the several monitoring sites within metro Atlanta. Consistent with previously reported simulations, CMAQ significantly underestimates $PM_{2.5}$ concentrations observed.

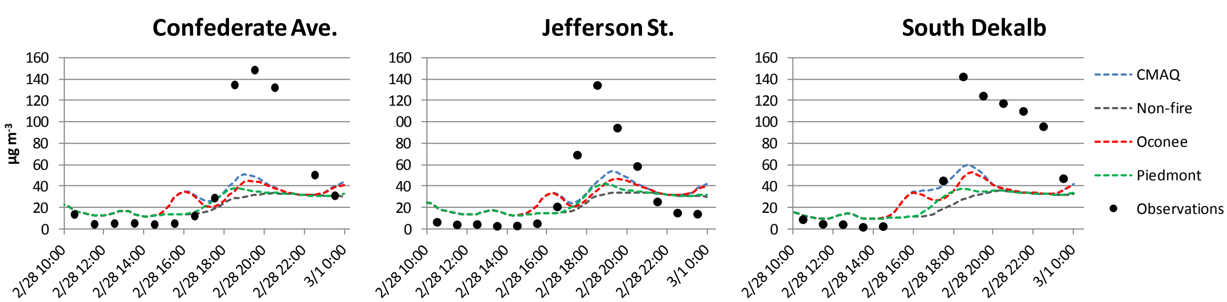

Figure 1. CMAQ-predicted PM2.5 concentrations for 28 February 2007 (LT) Atlanta smoke episode and simulations with no fire emissions (Non-fire), Oconee fire emissions (Oconee), and Piedmont fire emissions (Piedmont) on (LT). Observed 1-hour average concentrations at monitoring sites are also shown.

Sensitivity Analyses:

A series of model runs repeating the Atlanta 2007 smoke episode smoke simulation under perturbed wind fields were carried out to observe the responsiveness of CMAQ-predicted $PM_{2.5}$ concentrations at specific downwind receptors to variations in winds. Wind fields were modified within the Meteorology-Chemistry Interface Processor (MCIP, version 3.4.1) used to convert WRF output fields into CMAQ-compatible inputs. Wind directions were uniformly perturbed by ± 5°, ± 15°, and ± 30° across the entire domain. Figure 2a shows $PM_{2.5}$ concentrations simulated by CMAQ at the Jefferson St. monitoring site in downtown Atlanta under altered fields. The sensitivity of predicted $PM_{2.5}$ concentrations to wind direction is extremely high at Jefferson St., and at all other receptors considered. Modified wind fields were also produced by uniformly perturbing wind speeds by ± 10%, ± 20%, and ± 30% across meteorological inputs. Figure 2b shows simulated $PM_{2.5}$ concentrations at the Jefferson St. monitoring site for each wind speed perturbation. An extremely strong response to variations in wind speed is evident.

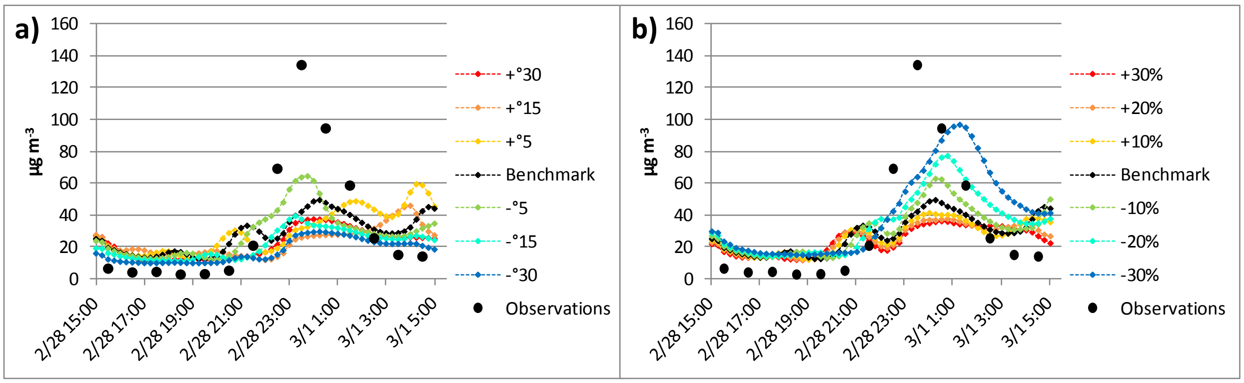

Figure 2. CMAQ-predicted $PM_{2.5}$ concentrations for 28 February 2007 (UTC) Atlanta smoke episode at the Jefferson St. monitoring site under (a) wind direction perturbations and (b) wind speed perturbations. Base case simulation results are also included.

Meteorological Uncertainty Assessment:

Wind values produced with WRF for the 2007 Atlanta smoke episode were evaluated against surface-layer hourly observations from weather stations located within the modeling domain. Observations and predictions from 33 stations were spatially and temporally paired to calculate episode-mean performance metrics for key meteorological variables. Figure 3 compares mean predicted and observed temperature, humidity, wind direction, and wind speed. WRF performance for this simulation appears adequate. However, a significant positive bias in ground-level wind speed predictions was identified. The mean bias and error in wind direction predictions with respect to observations were +5.8° and 6.9° respectively. The maximum hourly wind direction error was nearly 15°. During the episode, the mean bias and error in simulated wind speeds were +1.1 m s^{-1} and 1.2 m s^{-1} respectively. Wind speed predictions closely agree with observations during the first half of the episode and exhibit a positive bias of approximately +2 m s^{-1} thereafter. The uncertainties in WRF-generated surface-layer winds, and wind speeds are especially relevant to air quality involving smoke plume transport given the large sensitivities of pollutant level predictions to small variations in winds detected.

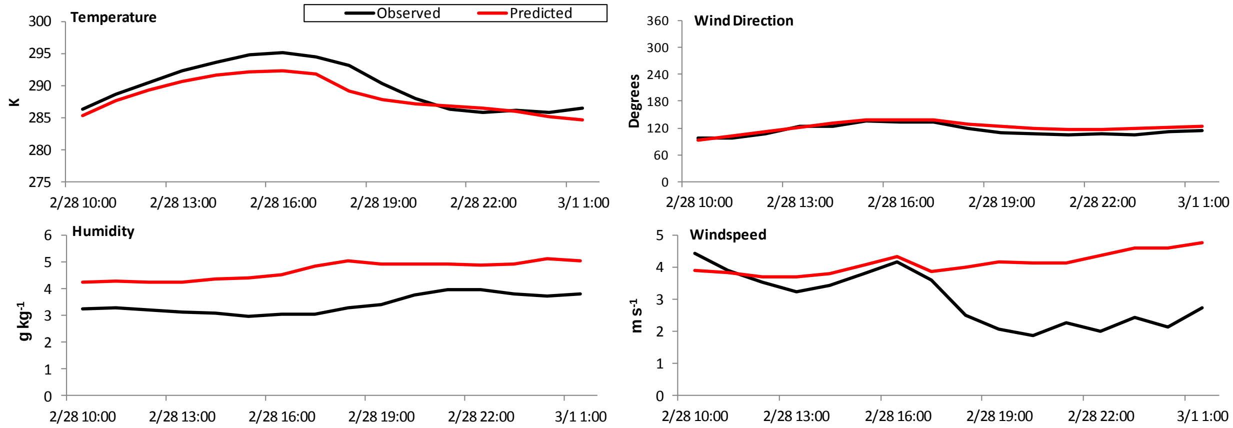

Figure 3. Mean observed and WRF-predicted ground-level temperature, humidity, wind direction, and wind speed over northern Georgia for 28 February 2007 Atlanta smoke episode.

Ongoing and future work:

The methodology used to evaluate modeled air quality simulations' sensitivity to uncertainty in meteorological inputs will be applied to additional smoke episodes, including both prescribed burns and wildfires, covering different spatial and temporal scales, and involving different numbers of fires. Additionally, we are currently exploring the interactions between meteorology-related sensitivities and grid resolution and planetary boundary layer height. Further uncertainty evaluations of wind fields generated with meteorological models will be conducted using upper air data from atmospheric soundings. An estimate of wind-associated error in $PM_{2.5}$ predictions will be quantified through the following process: (1) determining the output variables most relevant to the modeling application, (2) identifying the input variables that significantly influence the values of the outputs of interest, (3) assessing the range of uncertainty in these model inputs, and (4) quantifying the sensitivity of output variables to input variable perturbations within their uncertainty range. In this study the focus will be on $PM_{2.5}$, the atmospheric pollutant most commonly associated with fire-related air quality impacts, and wind inputs, clearly among the meteorological variables dominating predicted $PM_{2.5}$ concentration. The analysis will provide a better understanding of the uncertainty in fire-related air quality forecasts produced with atmospheric chemical transport models and the degree to which they may be constrained by errors in meteorological inputs.