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Forecasting the Impacts of Wildland Fires

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We utilize Hi-Res, a regional forecasting system which provides local air quality forecasts for the metro Atlanta area since 2006, to predict the air quality impacts from wildland fires. As extensions to the Hi-Res system, the Consume and FEPS models are used to estimate the fire emissions from potential fire events. Brute-force or DDM methods are used to calculate the air quality contributions from the fires. We have tested this tool to predict air quality impacts from Jasper County prescribed fires on February 28, 2007 and the Georgia-Florida wildfires which occurred during April-May, 2007.

1. INTRODUCTION

Wildland fires (wild and prescribed fires) burned about 9 million acres nationwide in the United States each year on average during the last three years. Burning of wildland vegetation increases the emissions of air pollutants such as fine particulate matter ($PM_{2.5}$), carbon monoxide (CO), volatile organic compounds (VOC) and nitrogen oxides (NO_X), which impact air quality, visibility and potentially public health. Especially, a severe wildland fire such as the prescribed fires on February 28, 2007 in Jasper County Georgia and later the Georgia-Florida wildfires lasting from April through May that hit Atlanta metro area with thick smoke clouds, could cause rapid increases of both ozone (O_3) and $PM_{2.5}$ to extremely high levels and cause exposure of urban population to unhealthy air for hours or even days sometimes.

Of interest is to what degree the air quality impacts from wildland fires can be forecast. For prescribed burning, the air quality forecast ahead of the actual igniting would help plan and conduct burns; for wildfires, the air quality forecast would warn people to avoid unhealthy air exposures.

Here we develop a fire-impacts forecasting system based on the Hi-Res air quality forecast framework which is serving the Atlanta metro area since 2006. We then apply this fire-impacts forecast tool to predict the February 28, 2007 prescribed fire event as well as another smoke event caused by the Georgia-Florida wildfires that hit Atlanta metro area on May 22, 2007. The forecast of the occurrence of wildfire is not intended here.

Fig. 1 Hi-Res modeling domains and Atlanta metro area.

2. THE FORECASTING SYSTEM

2.1 Hi-Res

We utilize the framework of Hi-Res to forecast fire-impacts on air quality. Hi-Res uses the Weather Research and Forecasting model (WRF, version 2.2) for forecasting meteorology (wrf-model.org), the Sparse Matrix Operator Kernel Emissions model (SMOKE, version 2.1) for emissions and the Community Multiscale Air Quality model (CMAQ, version 4.6) for chemistry and transport updated with strict mass conservation and equipped with the SAPRC-99 chemical mechanism. Hi-Res nests its 4-km forecasting grid in a 12-km mother grid covering Georgia and portions of neighboring states and uses a 36-km outer grid over the eastern U.S. to provide air quality boundary conditions (Figure 1). Hi-Res first simulates a 77-h (3 days plus 5 hours) period starting from 00Z on the 36-km grid. WRF is initialized and constrained at the boundaries using 00Z 84-h forecast products from the North American Mesoscale (NAM)

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model (nomads.ncdc.noaa.gov) and CMAQ is initialized from the previous forecasting cycle and uses "clean" boundary conditions. Then Hi-Res simulates the same 77-h period on the 12-km grid and nests down to the 4-km grid for the last 32 hours. This time WRF is initialized and constrained at the boundaries also using 00Z NAM forecasts, while CMAQ is initialized from the previous forecasting cycle and uses the 36-km forecasts for air quality boundary conditions. The simulations take about 12 hours on 6 dedicated CPUs. The Hi-Res forecast cycle (Fig. 2) allows sufficient time for extra efforts on fire-impacts forecast. "Background" fire emissions' impacts are included in Hi-Res' everyday forecasts by utilizing averaged historical fire events to represent typical fire emissions driving a forecasting day, in essence smoothing individual, more intense events both spatially and temporally. Like other air quality forecasting systems currently operational in the United States at either national or regional levels, Hi-Res has enjoyed reasonable forecasting accuracy.

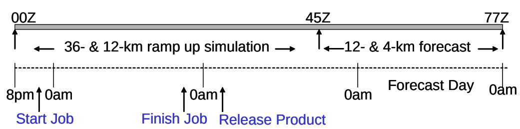

Fig. 2 The Hi-Res cycle.

2.2 Estimating Potential Fire Emissions and Calculating Air Quality Contribution

The extra efforts for fire-impacts forecast beyond the current Hi-Res framework are mainly first the emissions estimation of the potential fires and second the calculation of these emissions' contribution to the air quality.

For potential prescribed fires we estimate the emissions using information collected from the burning plans prepared in advance by the technical staff of wildland owner. Pre-burning information includes the acreage of the planned burning area, approximate locations, fuel load descriptions and operation schedules. We estimate the potential fuel consumption by using the Consume model version 3.0 (http://www.fs.fed.us/pnw/fera/research/smoke/consume/index.shtml). Since there is a lack of information for separating flaming and smoldering stages during the estimation of emissions, we use fuel consumption, emission factors and a temporal profile that merge the two stages together. We calculate emissions using the Fire Emission Production Simulator (FEPS) for each criteria pollutant and allocate them to the 12- and 4-km grid cells according to the approximate fire locations. Vertical distribution of fire emissions are based on the FEPS' typical plume rise calculated for a fair day in the season by using default fire temperature information. Gridded fire emissions are then added to other emissions for the Hi-Res standard forecast.

For existing/ongoing wildfire we forecast the potential impacts from continuing fires for the following days. We first determine the most likely fire locations on the following days according to the analysis of forecast meteorological conditions combined with the information on previous days' burning locations. We then estimate and collect other fire information including approximate acreage of burning area, fuel load and fire temperatures, and calculate the wildfire emissions through the same procedures as stated above for prescribed fires.

There are two ways to calculate the fire emission's contributions to the air quality. When there are only a couple of potential fires we choose the brute-force method, i.e., we first run Hi-Res at its standard configuration with "typical" emissions, then re-run Hi-Res' CMAQ only on the 12- and 4-km grids with the emissions from the potential wildland fires added in. The difference between simulated air quality fields from the above two Hi-Res runs is the contribution of the potential fire emissions. When there are multiple potential fires, as would be the case particularly in prescribed burning applications, a more efficient way to estimate contribution from each individual fire is by calculating emission sensitivities using Decoupled Direct Method (DDM) with the Hi-Res system. For this kind of application, the Hi-Res system is required to run only once with wildland fires' emissions added on top of the Hi-Res "typical" emissions.

We extend the function of this fire-impacts forecast system to estimate the total population of potential polluted air exposures, which is calculated by adding up the population (Census 2000, www.census.gov) living in the grid cell that has a predicted ambient $PM_{2.5}$ concentration higher than 35µg m^{-3}, the current 24-hr National Ambient Air Quality Standard (NAAQS), during the potential fire event when the fire emissions are added in.

3. APPLICATION AND RESULTS

3.1 The February 28, 2007 Prescribed Fire

On February 28 2007, thick smoke hit the Atlanta, Georgia metro area. Within a couple of hours, starting around 4 p.m., monitored hourly concentration of $PM_{2.5}$ soared up to almost 150 µg m^{-3} at several sites. Ultimately the monitored 24-hr concentration (midnight to midnight) of $PM_{2.5}$ in Atlanta, i.e. 37.8 µg m^{-3}, exceeded the NAAQS of 35 µg m^{-3}. At the same time, hourly O_3 concentrations jumped by up to 30 ppb. Two prescribed fires in adjacent wildlands about 80 km southeast, one in the Oconee National Forest (Oconee NF) and the other in the Piedmont National Wildlife Refuge (Piedmont NWR) (called Fire O and P hereafter, Figure 3), together totaling about 12 km^2, were blamed for “smoking out” metro Atlanta at the time “commuters headed home and ball teams took to the fields”. Asthma attacks, apparently triggered by the smoke or ozone, were reported by asthmatics that were able to self-medicate, as well as pediatric clinics that were receiving pulmonary patients the next day.

Fig.3 Smoke detected near the Atlanta metro area at 1:15 and 1:45 pm Eastern Standard Time (EST) on February 28th, 2007 by using the Geostationary Satellite (GOES) data (received from National Oceanic and Atmospheric Administration), which originated from the prescribed fires within the Oconee NF and Piedmont NWR.

To test our fire-impact forecast system we apply the system at its forecast mode to simulate the air quality impacts from Fires O and P together. Emissions are estimated (Table 1) using information collected from the prescribed fire plans prepared in advance by the technical staff on the Oconee NF and Piedmont NWR. We first run Hi-Res starting from February 26th 00Z through March 1st 05Z at Hi-Res standard configuration with “typical” emissions, then re-run Hi-Res’ CMAQ only for the last 32 hours on the 12- and 4-km grids with the emissions from Fires O and P added in. This second run takes an extra 2.5-h simulation time. To further assess the predictive capability of this system on specific fire-impacts and identify key weaknesses we also conducted a hindcast of this prescribed-fire-caused smoke event. At hindcast mode, reanalysis products from NAM are utilized to initialize WRF, constrain boundary conditions and nudge simulated fields at 6-h intervals. The Fires O and P emissions are re-estimated (Table 1) using actual and extra information collected and prepared after the burns, including the actual acreage burned each hour, fuel moisture information, fuel consumption information and hourly flaming/smoldering stage information, plus local meteorology and fire temperature information for estimating hourly plume rise. In addition, sensitivity tests found increased VOC emissions from trees due to exposure to fire and its elevated temperatures that is recommended to be included in the future forecasting of fire caused photochemical smoke events, as well as current inventories (Hu et.al 2007).

Table 1 Fires O and P estimated emissions (10^6g)

Pollutants		CO	VOC	NO_x	NH_3	SO_2	$PM_{2.5}$	PMC
Forecast Fire O		877	41.2	18.9	4.1	5.2	73.2	12.2
Forecast Fire P		708	37.6	17.2	3.7	4.8	66.8	11.1
Hindcast Fire O	Flaming	586	34.1*	30.2	1.4	0.3	48.0	8.6
	Smoldering	737	58.1*	5.8	2.6	0.5	57.5	10.4
Hindcast Fire P	Flaming	109	6.3*	5.6	0.3	0.1	8.9	1.6
	Smoldering	343	27.0*	2.7	1.2	0.2	26.8	4.8

* Biogenic emissions from pine needles induced by fire are not included in the totals. Sensitivity tests suggest the enhanced VOC emissions amount to about 368 and 133 × 10^6g for Fires O and P, respectively.

Our “forecast” simulated that Fires O and P scheduled on February 28, 2007 together significantly impacted air quality of Atlanta lasting from late afternoon through midnight. The fire impact reached its maximum between 10:00 and 11:00 p.m., when over 1 million Atlantans were estimated to have potential 1-hr exposures to 35 µg m^{-3} or higher $PM_{2.5}$ concentrations (the current 24-hr NAQQS). The maximum predicted increase was 94 µg m^{-3} in the Atlanta urban area (defined as having a population density higher than 5,000 per square mile [www.census.gov]), driving up ambient $PM_{2.5}$ concentrations to a peak of 121 µg m^{-3} between 8:00-9:00 p.m. (Fig. 4a). While the highest observed 1-h concentration was 152µg m^{-3}. Albeit large numbers of population with potentially unhealthy 1-h $PM_{2.5}$ exposures, our “forecast” simulated that only 380 thousand Atlantans were having potential 24-hr exposures to 35 µg m^{-3} or higher $PM_{2.5}$ concentrations on February 28th, 2007. The simulated maximum 24-hr $PM_{2.5}$ concentration in Atlanta urban area is 47.5 µg m^{-3} compared to the observed 37.8 µg m^{-3}.

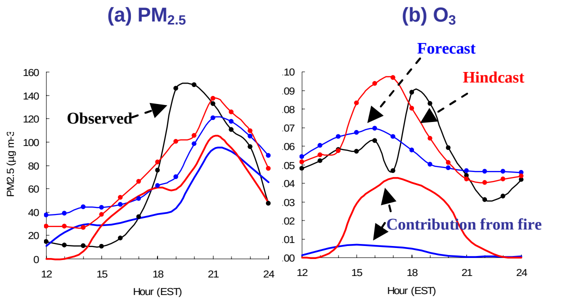

Fig.4 Predicted maximum ambient $PM_{2.5}$ (a) and O_3 (b) concentrations and maximum Fires O and P contributions within the Atlanta urban area versus observed maximum among the Atlanta urban sites.

With extra historic information and the enhanced biogenic emissions, our hindcast simulated more Atlantans would be potentially impacted by the fires. The fire impact reached its maximum between 7:00-8:00 p.m., when population of potential 1-hr exposure to $PM_{2.5}$ levels greater than 35 µg m^{-3} would increase to 1.8 million. This predicted peaking time (three hours earlier than the "forecast" prediction) is consistent with the peak $PM_{2.5}$ observations (Fig. 4a). The hourly burning information collected after the fire significantly improves timing. Note that the hindcast reproduces the "forecast" $PM_{2.5}$ peaking time, i.e. between 8:00-9:00 p.m. and 1-hr later than the measurements, but predicts the peak value at 137µg m^{-3}. In contrast to the "forecast" which doesn't include the enhanced VOC emissions, hindcast results capture the observed O_3 increases very well (Fig. 4b). The hindcast predicts a maximum jump in O_3 concentration of 40 ppb in the urban area due to the enhanced biogenic VOC emissions. The hindcast results also improve significantly in terms of Organic Matter (OM). The increased predicted OM drives the $PM_{2.5}$ prediction up to over 100 µg m^{-3} between 6:00-7:00 p.m., compared to around 70µg m^{-3} predicted by the forecast at that time (Fig. 4a). We also plot the spatial distribution of the "forecast" and the hindcast $PM_{2.5}$ plumes along with peak observations, which suggest a spatial extent for the observed plume (not shown). We calculated that there is about a 20 degree prediction error of the $PM_{2.5}$ plume direction in the "forecast" while a 10 degree error remains in the hindcast. This suggests that reanalysis data utilized with nudging technology improved simulated surface wind fields, though to a limited degree.

3.2 The Georgia-Florida Wildfire: First Attempt

The Georgia-Florida wildfires (G-F fires) started on April 16, 2007, burned about half million acres through the end of May, and continued to burn into the first week of June. The G-F fires have caused dozens of hazy days in Atlanta, GA, Miami, FL and Birmingham, AL. We apply the forecast system to simulate the May 18 -23, episode, during which the wildfire plume hit Atlanta, GA and surrounding areas with records high 24-hr $PM_{2.5}$ concentration of 76 µg m^{-3} and 1-hr $PM_{2.5}$ concentration of 365 µg m^{-3}.

A wildfire could burn much larger area of wild land, cause much higher increases of temperature and last for much longer time period, compared to a prescribed fire which is under control to burn the forest floor only. Because of these features that complicate the growth and movement of wildfire plume, there are large uncertainties in prediction of wildfire impacts. Our first attempt to simulate G-F fires totally missed the plume reaching Atlanta which according to satellite imagery occurred through long-range transport through Alabama under easterly winds on the previous day that turned to westerly on the day of the event (not shown). The possible reasons could be the missing of the surface thermal changes caused by the fire from the meteorological model, the coarse vertical resolution above 1-km from the ground in CMAQ.

4. CONCLUSIONS

We have developed and tested a modeling framework to forecast fire-impacts on air quality in Atlanta, Georgia. Application of the tool to the prescribed fires on February 28, 2007 was successful and indicates that the wildland fires could be reasonably well estimated using the system. The "forecast" predictions are in good agreement with $PM_{2.5}$ observations, though with extra historic information, the hindcast improves the predictions significantly on timing and location, and slightly on peak level. However, more efforts are needed to improve the capability of the system to simulate wildfires.

5. REFERENCES

Byun, D. W.; Ching, J. K. S., Science algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System, pp, Publisher, 1999.

CEP, Sparse Matrix Operator Kernel Emissions Modeling System (SMOKE) User Manual; Carolina Environmental Program - The University of North Carolina at Chapel Hill, Chapel Hill, NC, 2003.

Hu, Y. et. al., Simulation of Air Quality Impacts from Prescribed Fire on an Urban Area: Analysis of the February 28th, 2007 Episode, Submitted to Environmental Science & Technology 2007

Odman, M. T.; Hu, Y.; Chang, M. E.; Russell, A. G. Forecasting ozone and PM2.5 in southeastern U.S. In Developments in Environmental Science, Volume 6; Borrego, C., Renner, E., Eds.; Elsevier Ltd., 2007; pp 219-288.