Biomass Smoke Emission Estimation over the Eastern US Using Satellite and Surface Data along with a Diagnostic Monte Carlo Model

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Background. Biomass smoke impact from forest fires produces the highest measured regional scale PM2.5 concentrations over the Eastern US. Yet, it is the least understood component of the Eastern US aerosol system. Compliance with the National Air Quality Standard (NAAQS) for PM2.5 and the implementation of the Regional Haze Rule depend heavily on quantifying the magnitude and frequency of smoke impacts. For instance, if a state can identify specific “exceptional events” caused by smoke, those high concentration days can be removed from the yearly averaging for NAAQS.

Challenges and Opportunities: The main challenges on smoke-related air quality are threefold: (1) Smoke emissions arise from natural or partially controlled sporadic unpredictable events; (2) a priory estimation of smoke emission rate is difficult and highly uncertain; (3) the physical and chemical properties of the emitted smoke vary considerably from event-to-event. On the other hand, since the 1990s, new opportunities arise from smoke detection, monitoring and information technologies. There is an on-going revolution in remote sensing and surface monitoring of particulates. High-resolution satellite sensors can now routinely detect and monitor fire locations and reveal the spatial pattern of smoke under cloud-free conditions at the time of satellite detection. Real-time surface monitoring of PM25 mass and scattering is now routinely performed at hundreds of sites over the Eastern US. Furthermore, new information systems, powered by the Internet, allow the rapid dissemination of these monitoring data (e.g. MODIS Rapid Response System, EPA’s AIRNOW and the NOAA-NWS surface weather observations as well as value-adding after products such as VIEWS, FASTNET and IDEA.

Smoke Characterization: Smoke is a complex mixture of particulate and gaseous matter. Smoke characterization of smoke requires at least seven dimensions: a(X,Y,Z,T,D,C,M,F,M). The physical coordinates of smoke, X, Y, X and T are common to all environmental parameters. The unique ‘aerosol dimensions’ are size D, composition C, shape F, and mixing M which determine the impact on health and welfare. The smoke characterization requires the complete system description in all the dimensions. The existing measurement techniques (Figure 1) cover only a small fraction of the above data space. Some instruments provide sparse point data in space/time (surface monitors). Conversely, satellite sensors integrate over height and chemical composition.

Data-Model Integration Framework: The challenges of unpredictable smoke emission modeling and the opportunities arising from rich real-time fire location and smoke data suggests an observation-based smoke emission monitoring strategy. This report outlines a possible framework for smoke emission estimation.

The approach depicted schematically in Figure 2, uses a smoke dispersion model to simulate emissions. The model is driven by the best available observed fire locations, land and fuel conditions and transport winds. However, the pattern of smoke emission rates is derived from the observed smoke data assimilated into the smoke model. This is an inverse modeling approach to emission estimation. The smoke observations include satellite data from MODIS, GOES, AVHRR, TOMS and other emerging sensors. The surface observations include continuous PM25 (EPA AIRNOW), surface visibility (NWS ASOS), chemical measurements from IMPROVE and STN networks and miscellaneous sensors such as sun photometers (AERONET), lidar (e.g. MPLNet) etc. Each dataset is contributed by different agency. A key aspect of the framework is the information system that brings together, homogenizes and fuses the numerous observational and model data on various aspects of smoke.

Satellite Smoke Detection: Satellites offer a unique opportunity for spatial (X,Y) characterization of smoke through high spatial resolution snap shots. The satellite-derived aerosol optical thickness at 1 km resolution provides unprecedented spatial detail, routinely sensed by the contemporary sensors. However, the satellite data also indicate that some of the forest fire smoke is bluish in color, while other smoke plumes are yellow. This clearly indicates that size and chemical composition of these two smoke types is different. There is also considerable evidence that multiple scattering in a thick smoke plume is prevalent. Thus, the retrieval of the true vertical optical thickness for such plumes is problematic.

Examples are given below to provide a realistic expectation on what satellite and surface smoke sensing can contribute to smoke quantification.

Dimension	Abbr.	Data Sources
Spatial dimensions	X, Y	Satellites, dense networks
Height	Z	Lidar, soundings
Time	T	Continuous monitoring
Particle size	D	Size-segregated sampling
Particle Composition	C	Speciated analysis
Particle Shape/Form	F	Microscopy
Ext/Internal Mixture	M	Microscopy

Figure 1.Dimensions of the aerosol data system.

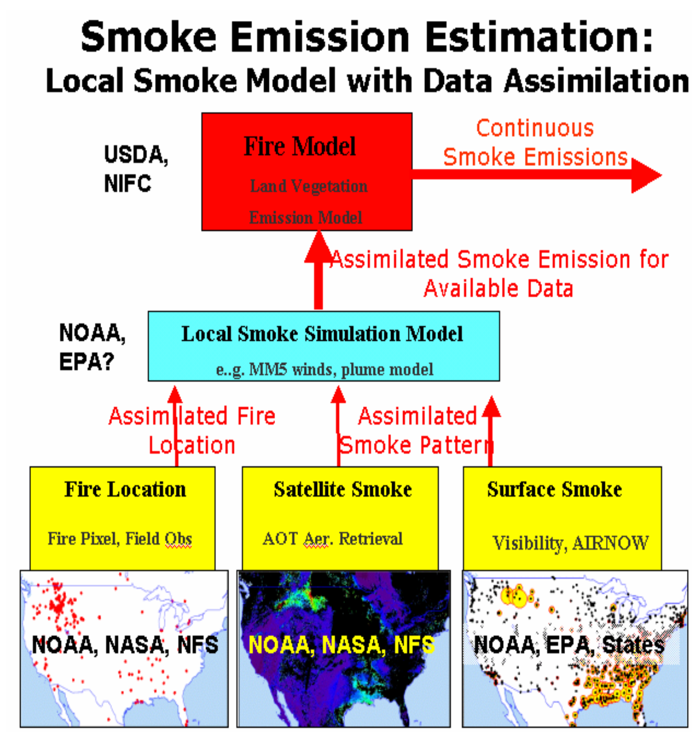

Figure 2. Smoke emission estimation framework

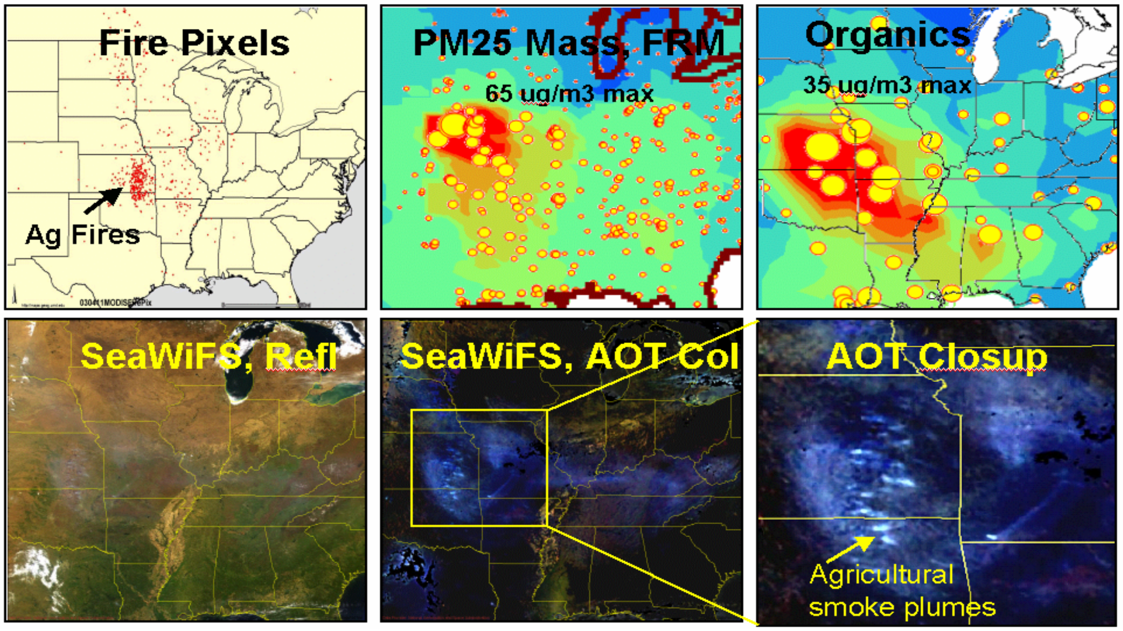

Figure 3. Surface and remote sensing data for agricultural smoke in Kansas, April 12, 2003

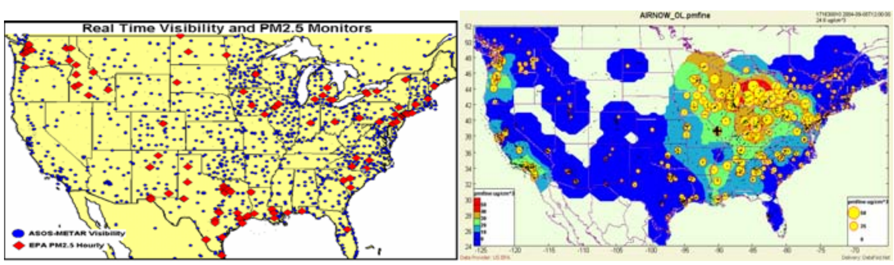

Figure 4. Real-time monitoring networks for aerosol light scattering by the National Weather Service (ASOS, left) and PM25 (EPA AIRNow)

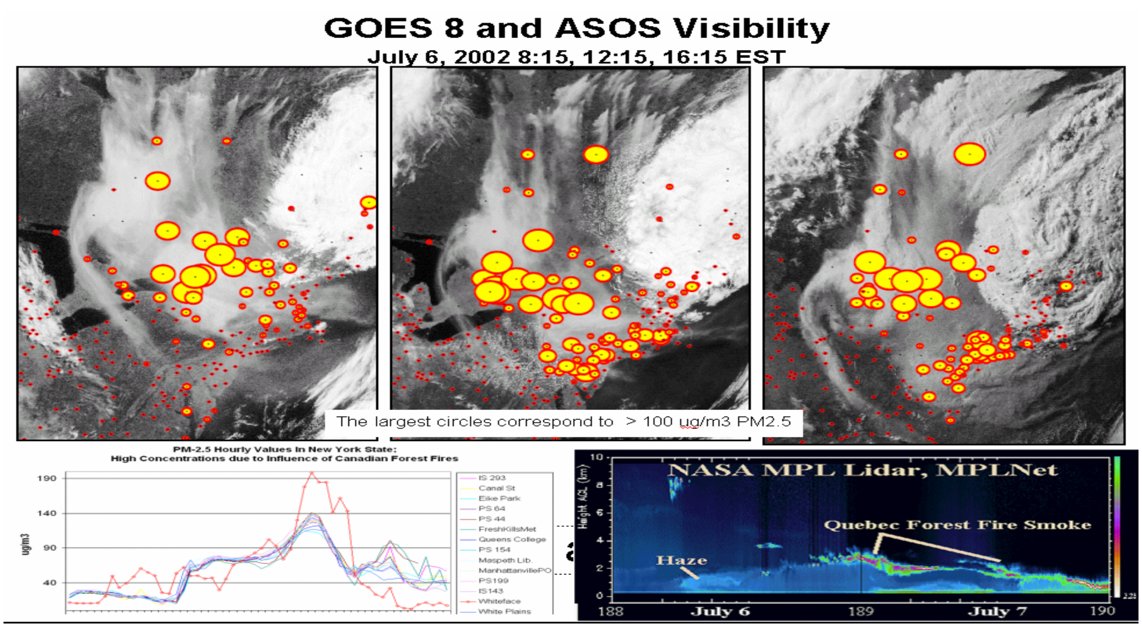

Figure 5. Dynamic pattern of smoke emission, concentration and vertical distribution during the July 2002 Quebec Smoke event.

Figure 3 illustrates the application of surface monitoring data (PM2.5 mass and organic composition) during an agricultural smoke event, April 12, 2003. Figure 4a,b shows the two main real-time surface networks (1200-station ASOS and 350-station AIRNow). The1 km SeaWiFS-derived AOT clearly shows the individual smoke plumes emanating from the fires. The ASOS light scattering network data further reveal that the smoke is at the surface at night but elevated during the daytime. Early Monte Carlo plume simulations indicate that through a fitting procedure one can construct a smoke emission field that yields the observed smoke pattern after dispersion. The chemical composition data confirm that the elevated PM2.5 is due to smoke organics.

Figure 5 shows the pattern of the Quebec smoke on July 6, 2002 as observed through the GOES satellite (30 minute intervals, 1 km resolution); ASOS light scattering (circles on satellite images), AIRNow PM2.5 time series and the MPLNet lidar at NASA Goddard. The multi-sensory integration documents the magnitude of the smoke emission pattern (highly diurnal), the smoke impact on surface PM concentration and light scattering as well as some aspects of the smoke vertical distribution

Facilitation through ESIP Federation: The above-described smoke monitoring, modeling and emission estimation framework has been shown to be feasible with the currently available data and technologies. However, the proper execution of the complex smoke emission estimation is well beyond the capabilities of any single group. For this reason it is here proposed as a case study for multi-agency, multi-disciplinary collaboration facilitated by the Earth Science Information Partners (ESIP) federation. The information flow infrastructure can be well handled by the DataFed data sharing system. The analysis can be distributed and the results shared among the participating analysts. Finally, the products of these analyses can benefit all the participating organization interested in smoke for air quality management, hazard identification/forecasting, sensor algorithm development, etc. Thus, it is hoped that the smoke emission and characterization effort can be conducted as a broad community endeavor.

Biography: Rudolf Husar is Professor of Mechanical Engineering and Director of Center for Air Pollution Impact and Trend Analysis (CAPITA) at Washington University in St. Louis. Over the past thirty years Husar has divided his research activities between the study of atmospheric aerosols and environmental informatics, i.e. the application of information science, engineering and technology to environmental problems. Husar pursues the development of software tools to access, process, manipulate and display air quality information. His recent software work focuses on web services-based integration of data access, data processing and rendering. This latter activity is directly applicable to the support synergistic collaborative work on fire emissions, particularly through the Earth Science Information Partners Federation, where he is co-chair of the Air Quality Cluster.