Modeling Air Pollution from the Collapse of the World Trade Center and Assessing the Potential Impacts on Human Exposures

by Alan Huber, Panos Georgopoulos, Robert Gilliam, Gera Stenchikov, Sheng-wei Wang, Bob Kelly, and Henry Feingersh

INTRODUCTION

Prior to 9/11, the U.S. Environmental Protection Agency's (EPA) National Exposure Research Laboratory (NERL) and the Environmental and Occupational Health Sciences Institute (EOHSI) at UMDNJ–Robert Wood Johnson Medical School and Rutgers University had a University Partnership Agreement to develop improved methods for human exposure modeling. Subsequent to 9/11, part of this agreement has been directed toward assessment studies of potential human exposures following the collapse of the World Trade Center (WTC) in New York City and the fires that burned at the site. The scope of the modeling described in this article has three principal components: (1) meteorology and pollutant plume in the Metropolitan New York area and their impact on downwind locations, (2) impact of fine-scale pollution in the local area of lower Manhattan south of Canal St., and (3) assessment of human exposure to ambient pollution. In addition, a wind tunnel model study[1] was conducted to help understand the effects of pollution in and around the urban street canyons of lower Manhattan. The experience of the WTC site has increased the awareness that there are scientific shortcomings in performing exposure modeling of air pollution events in urban environments and in providing timely modeling support. The larger purpose of ongoing modeling developments and applications is to provide support for future homeland security concerns.

MODELING PROGRAM

EPA Region 2, which responded in the early days of the WTC disaster with its on-site Emergency Response Team, collected meteorological information from National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sites at airports around New York City and Central Park. In addition, Region 2 staff from the Air Programs Branch were on hand to provide advice based on the NWS weather data and additional local information as it became available after the U.S. Department of Interior installed wind sensors around the WTC site.

EPA had been developing applications using the CALMET–CALPUFF modeling system for application to urban-scale general plume modeling and immediately redirected this ongoing effort to the WTC site studies. Plume maps provided in the example below helped EPA Region 2 and EPA's National Center for Environmental Assessment (NCEA) in their initial assessments. EOHSI has since developed refined three-dimensional (3-D) plume simulations using the RAMS/HYPACT modeling system. These refined plume model results are now being used as part of a comprehensive human exposure modeling system to support ongoing exposure assessment studies. EPA had also been developing Computational Fluid Dynamics (CFD) simulations to better estimate fine-scale flow patterns and pollutant dispersion in midtown Manhattan. These efforts were also immediately redirected to the lower Manhattan area in support of WTC exposure studies. As described below, these developments are continuing and should enable federal agencies to reconstruct the potential pollutant plume from "Ground Zero" as it may have snaked through the streets of lower Manhattan. Also, the output from the CFD simulations may be integrated into the input of the plume model to best evaluate the potential urban-scale impact. A human exposure modeling system is being developed using existing data, and information from this system is being applied to reconstructing and modeling events.

METEOROLOGY AND POLLUTANT PLUME IN THE NEW YORK METROPOLITAN AREA

Actual emission rates of pollutants from Ground Zero are unknown and, therefore, models cannot be applied to estimate pollutant levels. Instead, a plume dilution factor of a large volume source emitted from Ground Zero is modeled. Differences in the values of the dilution factor represent differences in the effects of meteorology on plume transport and dispersion. The main purpose of the plume simulations was to provide general guidance on the likely pathway for pollutant emissions released

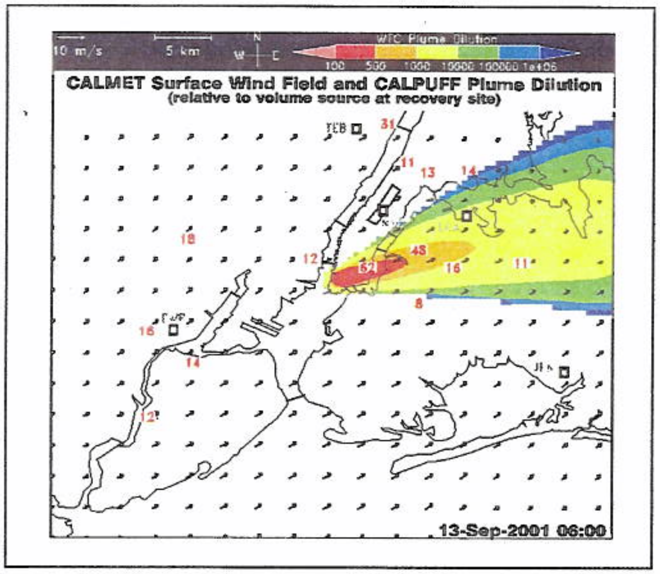

Figure 1a. Simulated CALPUFF dilution of a volume source located at the WTC. Numbers are hourly-averaged $PM_{2.5}$ concentrations.

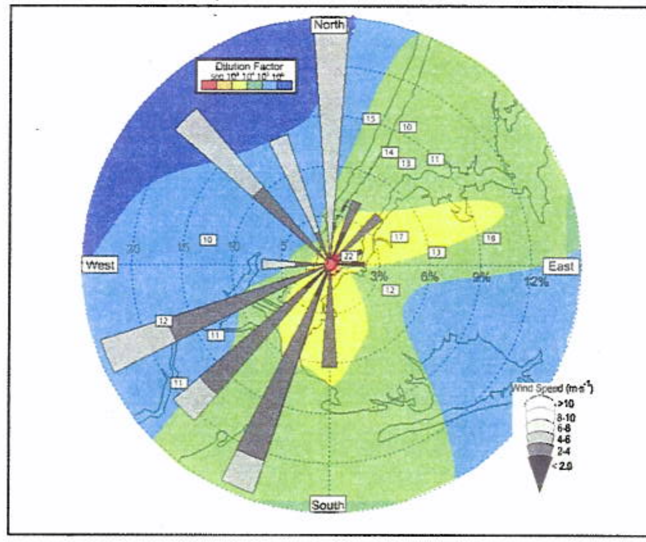

Figure 1b. Wind rose, dilution map, $PM_{2.5}$ concentrations averaged over the period September 11–13, 2001. Wind rose for the grid point closest to the WTC.

at the WTC site, both temporally and spatially. Local wind flow patterns caused by the sizable buildings in lower Manhattan are not considered here. Hence, these plume simulations can be considered appropriate for distances beyond 2 km downwind of the WTC site.

A CALMET–CALPUFF simple plume modeling system[2,3] was

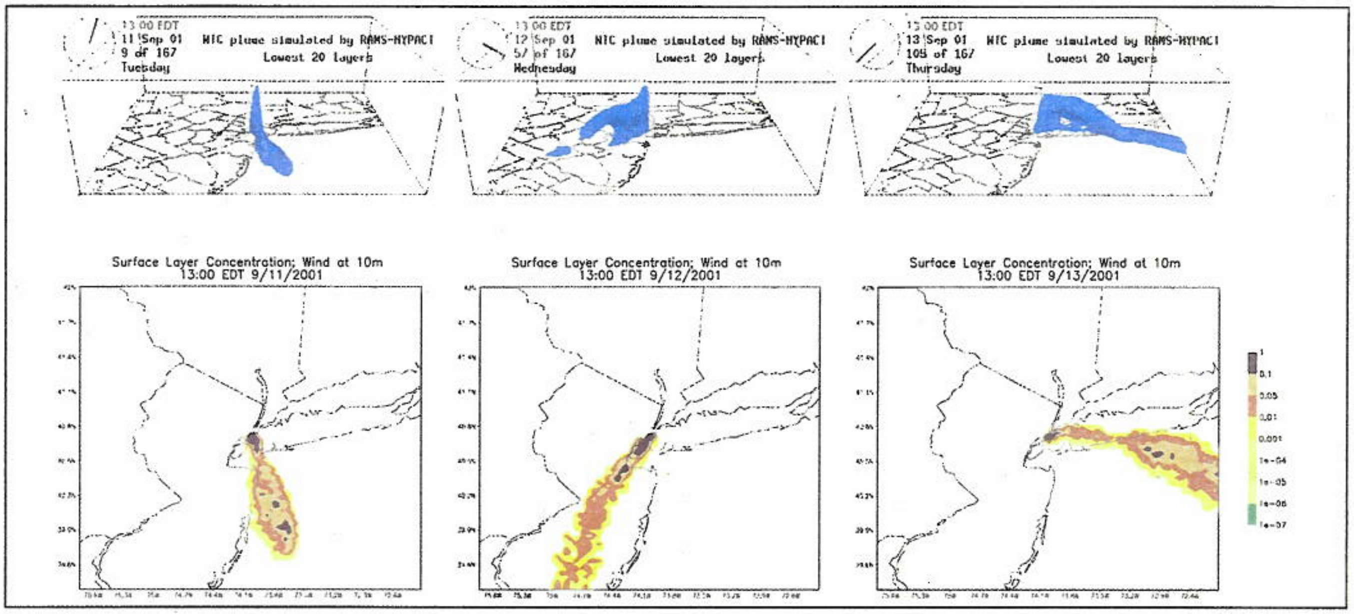

Figure 1c. Instantaneous views (top: 3-D; bottom: surface layer, wind fields, and normalized concentrations) of the WTC plume, location, and extent (with normalized distribution), simulated using the RAMS/HYPACT prognostic meteorological and particle dispersion models.

used to estimate the areas of potential impact of emissions from Ground Zero. Figure 1a displays an example plume mapping, which is representative of a single 1-hr plume. Figure 1b shows the time average of the 1-hr plumes and the wind rose for the period September 11–13, 2001. The plume color code represents the estimated dilution. Detailed papers have been prepared for the developments and applications of the CALMET–CALPUFF modeling system to support WTC studies.[4,5] A CALMET–CALPUFF type modeling system, which cannot provide as precise an estimate of pollution levels as fuller physics models might, is considered to be adequate for many applications. Even without the precise concentrations, knowing generally where the plume may have been can still help determine where to conduct more refined modeling of human exposures and where to study the population exposure in epidemiological studies. Having such results rapidly as a forecast or screening model could be very valuable to decision-makers. A fuller physics model has been applied for modeling the WTC plume location and dilution using the prognostic mesoscale Regional Atmospheric Modeling System (RAMS), in combination with the Hybrid Particle and Concentration Transport (HYPACT) dispersion model.[6] RAMS/HYPACT has been implemented with three 3-D nested grids with horizontal resolutions of 4 km (outer grid), 1 km (intermediate grid), and 250 m (inner grid extending over lower Manhattan and Brooklyn). Examples of the 3-D plume models are presented in Figure 1c.

Figure 2a. Information integration within a 3-D model of lower Manhattan.

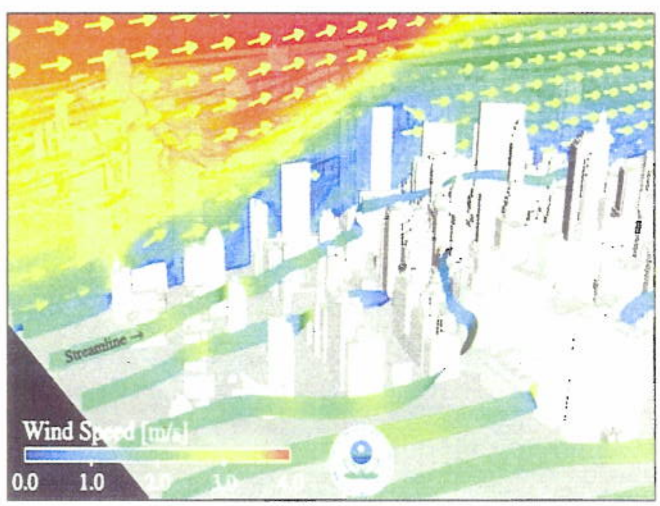

Figure 2b. CFD winds and streamlines through Manhattan street canyons.

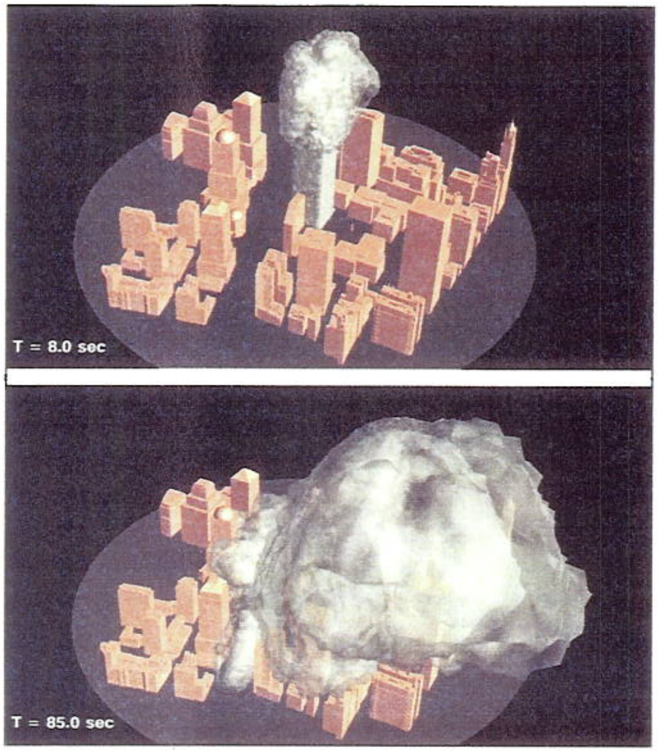

Figure 2c. CFD simulation of smoke and dust cloud following (top: Time=8 sec, bottom: Time=85 sec) the collapse of the North Tower.

FINE-SCALE POLLUTION IMPACT IN LOWER MANHATTAN

Based on a building geometry database developed by Vexcel Corporation, EPA has developed a 3-D digital model of lower Manhattan. Specific building geometry is critical to apply fine-scale models. A reconstruction of fine-scale numerical model of wind and pollution transport of potential pollutants from Ground Zero is being developed using Fluent Inc. Computational Fluid Dynamics (CFD) code. The setup of a fine-scale CFD model for lower Manhattan presents special challenges because of the complex and widely ranging scale of building geometry. Also, solutions for simulating fine-scale pollution transport for the 200-plus large buildings in lower Manhattan challenges computing resources.

The digital 3-D model developed for lower Manhattan is being used to display both modeled and measured meteorological conditions and air pollution concentrations. This visualization tool is valuable in identifying situations to model and in making comparisons. Figure 2a is an example of available measurements presented within the 3-D building model. Figure 2b is an example of a CFD simulation of the winds and potential pollution transport pathways (streamlines) for westerly winds. EPA's wind tunnel model study is providing data on the winds and pollution transport. Information from the wind tunnel model study will be used to develop and evaluate the numerical simulation models. Once these evaluation studies are completed, the numerical simulations can be extended to a wider range of situations and meteorological conditions.

In addition, a CFD model has been set up for simulation of the collapse of the North Tower of the WTC. The collapsing tower was modeled by "pancaking" the building floors under the force of gravity. The resulting simulated wind speeds exceeded 100 mph at the base of the collapsed tower where vortices are generated and radiated outward carrying smoke and dust, just as was observed. Figure 2c depicts the outline of the resulting smoke/dust plume. Ongoing developments include different mass (weight) particles to study particle transport and dispersion for comparison with available information of the deposition pattern around the WTC site.

HUMAN EXPOSURE ASSESSMENT

The Modeling Environment for Total Risk (MENTOR) system, under continuing development and application at the Computational Chemodynamics Laboratory (CCL) of EOHSI,[7] provides an integrated framework that links together a variety of databases (including both relational and geographic information system components) of environmental and microenvironmental attributes and contamination levels, demographic characteristics, human activities, exposure factors, physiological parameters; models of environmental, microenvironmental, and

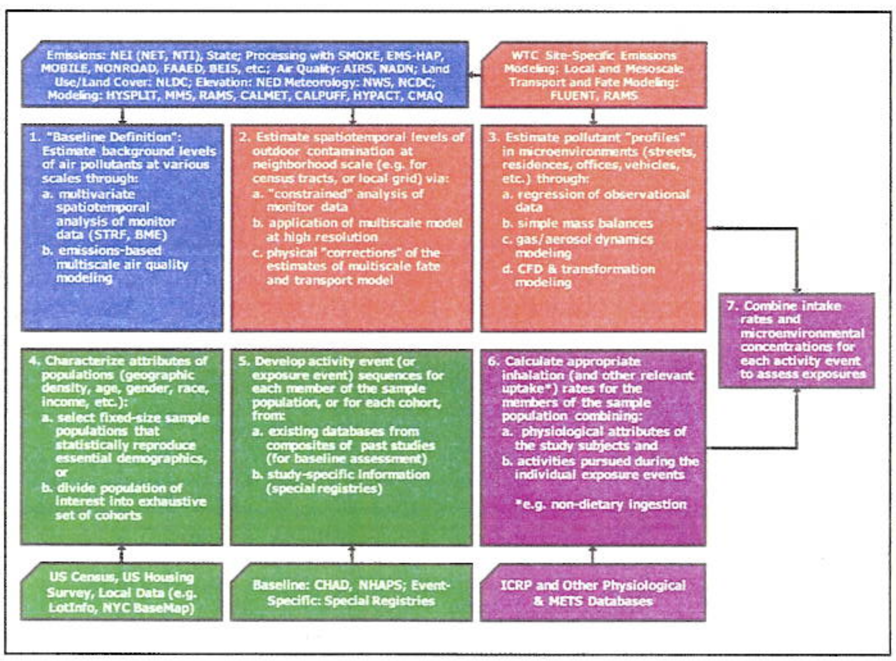

Figure 3a. Source-to-dose framework for reconstructing exposures to the WTC plume.

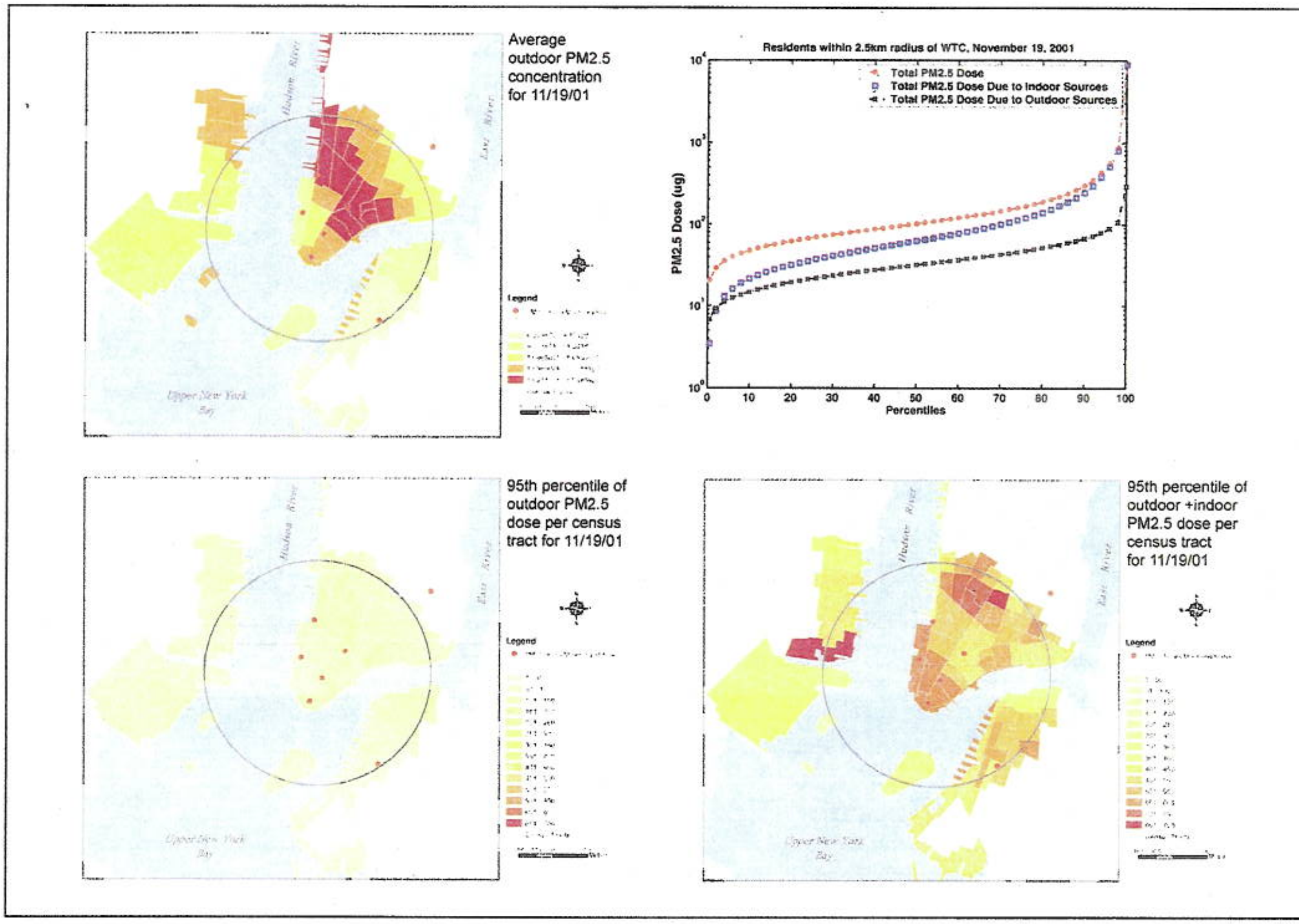

Figure 3b. MENTOR/SHEDS baseline for 11/19/2001.

biological processes; diagnostic computational tools for data mining, management, and analysis; and Bayesian methods for model/data fusion. This system is now being used for modeling the aftermath of 9/11 for New York City and the surrounding area. A WTC-specific geodatabase needed to support this system is being developed using multiple environmental, microenvironmental, and demographic components, compiled by various federal, state, city, and academic groups.

The initial application of the integrated MENTOR with the EPA's Statistical Human Exposure and Dose System (SHEDS) to calculate exposures and doses in the vicinity of the WTC site has focused on the establishment of baseline distributions (i.e., representative of "typical" conditions in New York City) after the elimination of major emissions from the collapse and fires of the WTC site. Model simulations have been combined with observational hourly data from the expanded $PM_{2.5}$ monitor network to provide ambient inputs for the MENTOR/SHEDS system (described schematically in Figure 3a) and obtain the above mentioned statistical baseline characterization of $PM_{2.5}$ exposures and doses for the population residing in census tracts within 2.5 km from the WTC site (see Figure 3b). The baseline characterization is currently being refined and also extended to the days immediately following the events of 9/11.

FUTURE DIRECTIONS

There are models available to facilitate general understanding of pollution transport on a metropolitan to regional scale. On these scales, modeling information combined with air monitoring information allows for the assessment of where and when potential emissions may affect people. Rapid responses using these models are possible if real-time meteorological measurements and demographics information are immediately available. Plans may be developed so that such information will be available to support future emergency situations. New models based on research and developments are needed to improve understanding of fine-scale pollution transport near the source and within the neighboring building environments. Further research and development is needed to adapt existing exposure models for emergency scenarios. For acute exposure assessments, models need to be developed based on investigated microenvironmental (e.g., outdoor and indoor) concentration fluctuations and exposure variability for different media (e.g., water, air, soil, dust, food, sediment). For chronic exposure, models need to be developed based on investigated microenvironmental average concentration and people's activities and locations relative to the source.

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