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SHIELD – A SYSTEM FOR URBAN EMERGENCY RESPONSE MODELING

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Abstract: Shield is an operational emergency response system used to predict the transport and dispersion of hazardous materials in the event of an atmospheric release of hazardous materials within metropolitan areas. A realistic wind field is a key component to any successful transport and dispersion model simulation. In the urban environment observing the wind field accurately is complicated by the presence of the building structures themselves. An important consequence is that in situ measurements are only representative over a limited area near the point of observation due to the influence of nearby buildings. Remotely sensed winds, via radar or lidar, on the other hand have good spatial resolution but are limited to making measurements above rooftop. In order to provide building aware wind fields over urban areas that are typically on the order of 100 square kilometers for transport and dispersion modeling we have implemented an integrated approach of using remotely sensed wind observations to drive a very high resolution, ~10 meters, diagnostic wind model.
In brief, the Shield system uses 3-D wind analyses from Doppler radar and/or lidar as input to the Los Alamos National Laboratory QUIC-Urb Röckle formulation wind model. Hazardous release incidents can be initiated either by a human operator or via sensor detects in real-time. The building aware wind fields from QUIC-Urb are then used to launch events with QUIC-Plume, an urban Lagrangian particle transport and dispersion model. Key issues that are faced on an operational basis include; blending winds from a variety of sources and scales, maintaining real-time quality control of wind inputs, and determining a wind confidence level in real-time.

Key words: *Transport, Dispersion, Emergency Response, Urban.*

INTRODUCTION

American cities contain a wide variety chemical storage and transportation facilities in order to meet the needs of industry and manufacturing. The potential for an accidental release of hazardous chemicals is a real and unfortunately common threat. Cities also represent likely targets for terrorist attacks using chemical, biological, or radiological material released into the atmosphere. Motivated by these threats, an urban emergency response system, called Urban Shield, has been developed and deployed to address operational needs of tracking and predicting the atmospheric transport and dispersion of hazardous materials.

Urban Shield was initially deployed in metropolitan Washington DC in late 2005 (Warner *et al.*, 2007). The current domain covers a 144 square kilometer region including many facilities of national significance. The objective of the system is to predict the transport of hazardous materials that are released into the atmosphere in urban areas, and to provide results to decision support systems and personnel that protect urban citizens and facilities. This is achieved by accurately characterizing the flow in urban areas from the metropolitan scale down to individual buildings, detecting hazardous releases, and then modeling the transport and dispersion of the hazardous materials.

Urban Shield is an integrated system consisting of four main components:

1. A variety of data-assimilation, wind analysis, and forecast models, which resolve processes from the mesoscale to city scale to building scale, and assimilate meteorological observations that are measured by remote and *in situ* sensors.
2. A building-aware transport and dispersion (T&D) model that is used to provide a forecast of the concentration and dosage of a released agent, and to provide situational awareness products for high-value infrastructure facilities within the Urban Shield domain.
3. A user interface and display that allows an operator to initiate release events and view a wide variety of display products from the wind and T&D models.
4. Integration with other decision support systems that serve the needs of the emergency response community.

An overview of the first two components will be covered in this paper.

THE URBAN SHIELD SYSTEM

Figure 1 illustrates the main data flow interactions between the wind and T&D modeling components. A variety of wind models are used in order to provide complete spatial coverage and data redundancy. The blended wind field uses a mass-consistent diagnostic wind model that is based upon MINERVE (Perdriel *et al.*, 1995) to combine data from the three non-building-aware wind models, along with remotely sensed and *in situ* observations (not shown). The blended wind field provides a common operational picture for the building-aware models. The building-aware flow models use the blended wind field to compute the urban effects of building structures on the wind field. All of the wind models are run on an operational basis whenever new data arrives. A plume prediction is launched either by an operator at the control GUI display, or by sensor detection of an airborne threat.

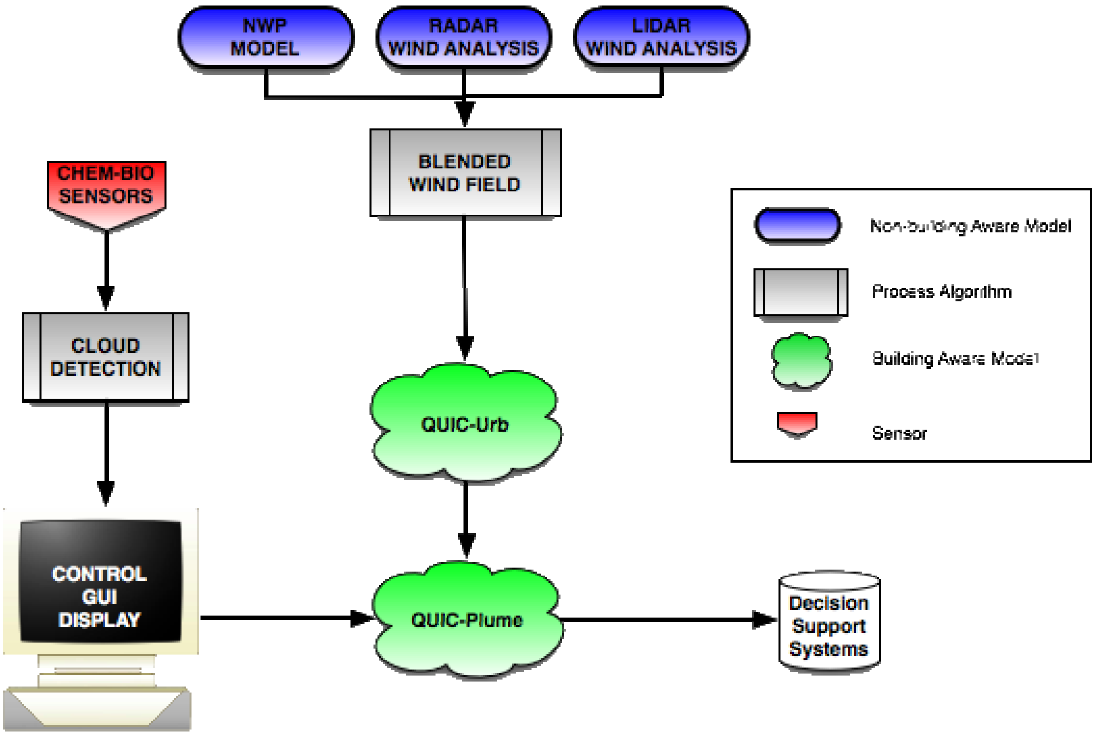

Figure 1. Data flow between the components of the Urban Shield system.

NWP Model
The NWP model used in the Urban Shield system is the RT-FDDA (Real Time Four-Dimensional Data Assimilation System) developed by NCAR (National Center for Atmospheric Research) (Liu *et al.*, 2008a, 2008b). RT-FDDA is an atmospheric numerical weather prediction system originally built around the Penn State/NCAR Fifth Generation Mesoscale Model (MM5), but recently it has been changed to make use of the Weather Research and Forecasting (WRF) model. RTFDDA incorporates a data assimilation system that employs continuous Newtonian nudging of observational data. RT-FDDA is run on a parent grid that covers the eastern United States, within which are two telescopically nested domains. The finest domain focuses on the area surrounding metropolitan Washington DC and encompasses the Urban Shield domain. Forecasts from NCEP (National Centers for Environmental Prediction) are used to derive lateral boundary conditions during RT-FDDA assimilation cycling and to provide initial conditions at cold-starts, which occur once a week. The 4-D continuous data assimilation scheme of RT-FDDA is capable of weighting each observation according to its observation time and location, and thus it is able to incorporate data that can be very irregular in time and space.

RT-FDDA incorporates various observations including:

- Standard WMO/GTS radiosondes (World Meteorological Organization/Global Temperature System)
- METARs (Meteorological Terminal Air Report)
- Ship and buoy observations
- Wind profilers
- TAMDAR/ARINC ACARS (Tropospheric Airborne Meterological Data Report/Aeronautical Radio, Inc. Aviation Communication, Addressing, and Reporting System)
- Satellite derived winds
- Various mesonets
- RADAR VAD (Velocity Azimuth Display) winds

RT-FDDA is the only predictive source for winds within the system; all other wind models used provide an instantaneous wind analysis. The model is run every hour to provide a wind analysis and 12-hour forecast, with a finest resolution of 1.5 kilometers.

RADAR Wind Analysis
Doppler-RADAR provides a good source of remotely sensed winds over many urban environments. The Urban Shield system uses VDRAS (Variational Doppler-Radar Assimilation System) developed at NCAR (Crook and Sun, 2001; Sun and Crook, 2002). VDRAS is a software system that analyses the 3D wind field from the radial velocity data provided by one or more Doppler radars. The current system makes use of the National Weather Service NEXRAD instrument located in

Sterling, Virginia in addition to the Federal Aviation Administration Terminal Doppler Weather Radars located at Andrews AFB and Dulles, BWI, and Reagan National airports.

A high-resolution (500 m) wind model and its adjoint are used in an iterative process to determine the 3D wind field structure that best represents the input radial velocity field. The quality of the resulting 3D wind field is directly related to the quality of the Doppler-radar radial velocities. Periods without precipitation during the winter may have insufficient clear-air targets (*e.g.* bugs) for the radar signal and may reduce the wind field analysis quality.

Model details include:

- Output Frequency: Once per radar data volume, roughly every 5 minutes.
- Domain Size: 20km wide by 20km wide by 5000m deep
- Horizontal Resolution: 500 meters
- Vertical Resolution: 375 meters
- Lowest Vertical Level: 190 meters

LIDAR Wind Analysis

Doppler-RADARs provide a good sense of wind conditions aloft but, due to the scan strategies used, they do not typically provide information within the lowest few hundred meters of the atmosphere. In order to address this crucial shortcoming we make use of a Doppler-LIDAR located near Reagan National airport. The VLAS (Variational Lidar Assimilation System) developed at NCAR (Lim *et al.*, 2010a, 2010b) is used to analyze the three-dimensional wind field from the Doppler-LIDAR signal. VLAS is similar VDRAS, but has been optimized for LIDAR data and its typical scales. A high-resolution (150 m) wind model and its adjoint are used in an iterative process to determine the 3D wind field structure that best represents the input radial velocity field. The quality of the resulting 3D wind field is directly related to the quality of the Doppler-LIDAR radial velocities. Periods of heavy fog and/or rainfall will severely block the LIDAR signal and may reduce the wind field analysis quality. Periods of extremely clean air following heavy precipitation may have insufficient clear-air targets for the LIDAR signal and may also reduce the wind field analysis quality.

Model details include:

- Output Frequency: Once per LIDAR data volume, roughly every 5 minutes.
- Domain Size: 6km wide by 6km wide by 1500m deep
- Horizontal Resolution: 150 meters
- Vertical Resolution: 50 meters
- Lowest Vertical Level: 25 meters

QUIC-Urb

QUIC-Urb is a fast-running model for computing mean flow fields around buildings developed by the Los Alamos National Laboratory (Nelson *et al.*, 2008). It uses empirical algorithms and mass conservation to quickly compute 3D flow fields around building complexes. The underlying code is based on the work of Röckle (1990). Empirical flow parameterizations are applied for the downwind cavity and wake, upwind cavity, rooftop recirculation zone, street canyon vortex, and intersections based on the prevailing wind direction and the height, width, length, and spacing of the buildings. Mass conservation is then imposed and a 3D wind field is produced. Some of the original Röckle schemes have been modified to better agree with experimental data and new schemes have also been introduced. QUIC-Urb has been modified to account for dense urban areas, complex building shapes, and forest-induced drag. The model can assimilate wind measurements from just a single sensor to whole high-resolution grids from the blended wind field. For small problems covering an area of a few square kilometers the code runs in minutes on a standard single processor. For larger problems with several million grid cells encompassing over a hundred square kilometers in a downtown built-up area, such as Urban Shield, the domain is broken up into several independent tiles which are run in parallel. The tile results are then merged into a single building-aware wind field for use by the transport and dispersion model.

QUIC-Urb details include:

- Output Frequency: Once per blended wind field output, roughly every 5 minutes.
- Runtime: 4 minutes
- Domain Size: 12km wide by 12km wide by 200m deep
- Horizontal Resolution: 20 meters
- Vertical Resolution: 4 meters
- Total Number of Tiles: 4 (6km by 6km each)

QUIC-Plume

QUIC-Plume is a Lagrangian random-walk dispersion model for computing concentration fields around buildings developed by the Los Alamos National Laboratory (Williams *et al.*, 2002). It has been adapted to work in the inhomogeneous environment of cities. It includes more terms than the normal random-walk model in order to account for the 3D gradients in turbulent and mean flow fields. It includes reflection terms for building and street surfaces. The dispersion of aerosols and gases can be simulated, including deposition and gravitational settling processes. Point, moving point, line, area, and volume sources can be simulated. An explosive buoyant rise and multi-particle size capability has been added for dealing with radiological dispersal devices. A dense-gas cloud model has been incorporated in order to evaluate the effects of heavier-than-air chemical industrial gas dispersion. Source terms can be selected manually by a modeler at the user interface workstation or automatically generated via sensor detections. The QUIC-Plume domain is a limited nest within the whole QUIC-Urb domain. The QUIC-Plume domain is located relative to the release location to maximize the downwind area available. Plume predictions are typically for thirty minutes and execute in one to two minutes on a single processor.

QUIC-Plume details include:

- Runtime: Typically 90 seconds, varies with type of source and location of source relative to domain boundaries.
- Domain Size: 6km wide by 6km wide by 200m deep
- Horizontal Resolution: 20 meters
- Vertical Resolution: 4 meters
- Total Number of Particles: 10000

SUMMARY

The Urban Shield system uses various wind models and analysis systems operationally to define a building-aware wind field in an urban environment. These building-aware wind fields are used to drive a Lagrangian particle dispersion model that predicts the atmospheric transport and dispersion of hazardous material releases.

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