J7.3 INTERACTIVE MODELING AND SENSING IN URBAN SETTINGS

J. Cogan *, R. Dumais, Y. Wang, and M. Torres

Computational and Information Sciences Directorate
Army Research Laboratory
White Sands Missile Range, NM 88002

1. INTRODUCTION

Response to man made or natural threats will require tools for analysis and prediction of the atmosphere that will need to operate effectively within urban settings and over complex terrain. These include sensing and modeling tools that will provide the necessary information at very high spatial and temporal resolutions, on the order of tens of meters and minutes. Furthermore, first response operations by local, state, and federal authorities will need the output in close to real time; delays of hours or even tens of minutes while models run or data are transferred may negate the value of the resultant information. By combining new environmental sensing capabilities, both remote and in-situ, with numerical models able to rapidly assimilate such data, implementation of fine scale interactive modeling and sensing strategies will become possible. This will allow for the tailoring of model runs and sensing strategies "on the fly" by post processing model output, as well as by the use of advanced atmospheric data assimilation strategies which may include the use of "targeted observations" for areas of high interest or more complex atmospheric events. This paper outlines a potential "system" combining models and sensors that will provide this capability, and the means for its development and evaluation. The technology already is in hand or currently under development. No breakthroughs are required. Furthermore the system is modular so that new or upgraded "modules" may replace older ones without significant impact to the rest of the system.

2. INTERACTIVE SYSTEM

2.1 *Models*

A potential mode of operations for weather in an emergency situation arising from a natural or man-induced event may include a "cloud scale" analysis of the current atmospheric situation based on local observations merged with output from the latest nowcast (short term forecast for $\leq$ 3 hours) at fine spatial (1 to 2 km) and temporal (30 to 60 min) resolutions. That type of analysis is under development at the Army Research Laboratory and is called the Weather Running Estimate (WRE). The accompanying nowcast can be produced on an hourly basis, such as from diabatic initialization (Shaw et al., 2004) of a numerical weather prediction (NWP) model initialized using the latest WRE analysis. An alternate and simpler (but non-physics based) method has been developed for the Army's Integrated Meteorological System (IMETS), based on extrapolation methods to produce the nowcast from the WRE (Henmi et al., 2005). The nowcast described here produces a frequently updated short range forecast at the same spatial resolution as the WRE analysis. It is steered by lateral boundary conditions extracted from an operational NWP model such as that run at the Air Force Weather Agency (AFWA) or the National Center for Environmental Prediction (NCEP). The complete system is called the Weather Running Estimate-Nowcast (WRE-N), since a nowcast component is included with the analysis.

Figure 1 presents a schematic of how the proposed Army-generated WRE-N as envisioned for a possible future scenario may fit into a larger forecast strategy. As a first step in the WRE production, a regional domain is populated with cloud scale resolution output from local nowcast runs of the Pennsylvania State University/NCAR Mesoscale Model 5 (MM5) (Warner and Seaman, 1990), or in the near future the Weather Research and Forecast (WRF) model (Skamarock et al., 2001). The NWP model used to produce the nowcast receives lateral boundary conditions from the operational mesoscale model run at AFWA or other center. These nowcast runs produced by the NWP model can occur every hour, and can

---

Corresponding author address: J. Cogan, Army Research Lab., CISD, White Sands Missile Range, NM 88002-5501, e-mail: jcogan@arl.army.mil.

initialize from the latest regional WRE fields (diabatic initialization method). Thus, the same regional domain (and spatial resolution) is used to produce a complete WRE-N gridded database that is updated hourly. Smaller WRE regions may be embedded or nested within the main WRE-N domain. These would update at a higher frequency than the WRE-N (e.g., every 20-30 min). These interior WRE runs would not couple directly to a NWP model. Figure 1 suggests the type of relationship between the different domains.

The larger-scale boundary conditions for the WRE-N will come from operational NWP forecasts from a meteorological center as noted above. It may not be MM5 or WRF. For example, Shaw Air Force Base typically uses the NCEP Global Forecast System (GFS) model for some non-North American areas. However, the modeling system proposed here will be designed to be modular and flexible so that any appropriate model may be used in place of MM5/WRF to provide lateral boundary conditions for the WRE-N, with minimal effort.

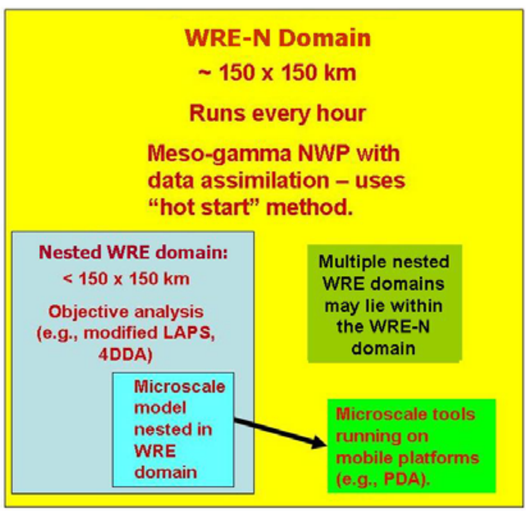

Figure 1. "High level" view of WRE domains within the larger WRE-N domain. In this figure, the NWP model (e.g., MM5) is executed using diabatic or "hot start" initialization from the WRE-N analysis. Smaller WRE regions can be embedded within the main WRE-N domain for even higher frequency analyses (without a nowcast component), to provide input to microscale analysis tools and models.

The WRE analysis as currently envisioned will likely be generated by an advanced atmospheric data analysis module, such as a modified version of the NOAA Forecast System Laboratory's Local Analysis and Prediction System (LAPS) (Shaw et al., 2004). This system will be capable of assimilating most conventional and non-conventional types of meteorological observations such as those from meteorological satellites. The modified LAPS tool may lead to development of better placement strategies for surface and upper air sensors.

Each WRE will provide updated corrections to the local atmospheric state, by combining the latest observations with the most recent WRE-N guidance for that region. In one potential plan the WRE-N would run once per hour at cloud scale, in a single nest mode, to provide both an analysis (WRE) and nowcast for a regional Area of Interest (AOI). In another variation, the WRE-N would be generated using a double nest approach, whereby the modified LAPS produces a WRE to drive a nowcast at 4 km grid spacing for a larger AOI, with the nested smaller and finer WRE-N at a 1 km resolution. For regions or nests within the main WRE-N domain, multiple WRE's could be produced at higher temporal frequencies (without a nowcast component).

The "sub-nested" WRE's could become input for localized higher resolution diagnostic (non-forecast) microscale models, in order to resolve additional microscale meteorological details over urban areas or complex and vegetated terrain. Spatial resolutions required for such urban or complex terrain areas may run from 100 m down to less than 10 m, and temporal resolutions may be as short as a few minutes. Figure 2 shows output from the Three-Dimensional Wind Field (3DWF) model, a diagnostic mass consistent model, for an area covering much of the central business district of Oklahoma City during July 2003 (Wang, et al, 2005). The 3DWF also can ingest local data and run in a stand alone mode, as in Figure 2 where combined lidar and tower measurements provided the initial sounding. A potential solution to the rapid update requirement imposed upon a very small scale model such as the 3DWF is the merging of lidar and other sensor data with the model's output field. This strategy could be used to create a detailed high resolution wind "nowcast" for the local area as defined by the model domain. While not a true wind nowcast, it will employ recent observations to modify the model output field in a manner similar to that used for the WRE-N. We plan to investigate another related possibility, whereby external 3D output from a mesoscale model (such as WRE-N) drives complex 1-D boundary layer models to produce high vertical resolution, very short range microscale nowcasts.

As its name implies, the 3DWF generates a microscale 3-D wind field over the domain of interest. That wind field can provide input data for a dispersion model that can in turn generate a realistic estimate of dispersion within an urban domain or over a small complex terrain region. Figure 3 displays output from an early version of a dispersion model "tool" known as the ARL Dispersion Analysis Tool (ARL DAT). The included dispersion model is the Second-order Closure Integrated Puff (SCIPUFF) module widely used by the Defense Threat Reduction Agency (DTRA) and others. In the version of Figure 4 a single set of values for a point on the surface, from either measurements or a model, provides the input data. Ongoing work will enable the ARL DAT to accept data from the 3DWF or equivalent model and use it to give a more accurate estimate of dispersion as the plume (or puffs or cloud of points in Lagrangian dispersion model) is carried by the spatially and temporally varying wind field. A good knowledge of the movement and dispersion of the plume will provide useful data for emergency response, and in a non-emergency mode for response planning and other applications.

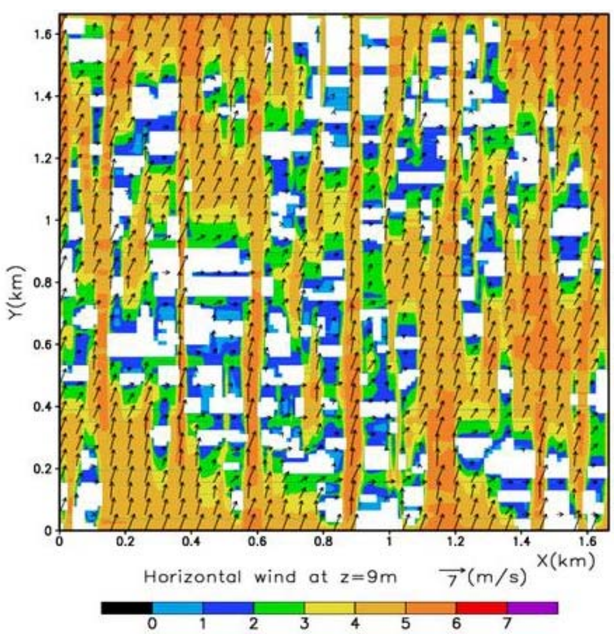

Figure 2. Flow over Oklahoma City on 9 July 2003 at 1530 UT. Horizontal and vertical grid spacing was 10.66 and 3 m respectively. Model run was initialized with wind profile from a lidar in VAD mode plus 10-m tower data. Only every fourth wind arrow is shown for clarity.

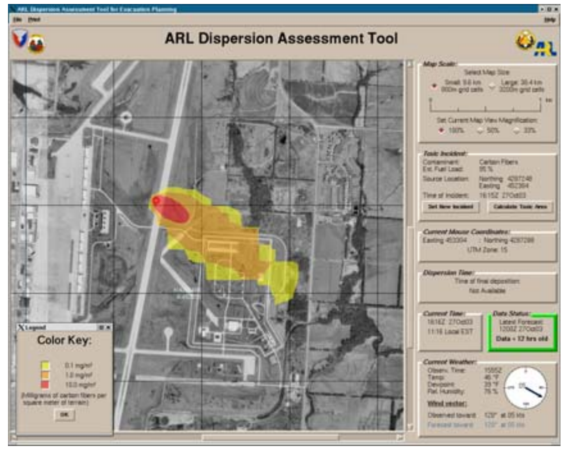

Figure 3. Display from the ARL DAT. The wind arrow on the lower right of the display points to the direction the wind blows towards vs. the usual convention of the direction where the wind is from.

2.2 *Sensors*

The exact configuration and distribution of meteorological sensors, both conventional and otherwise, during an actual operation will depend on the operational and environmental conditions, as well as on whatever local resources are readily available. Here we look at some potential in-situ and remote sensors and possible combinations of them that may be used in the context of homeland defense and appropriate meteorological experiments. For the hierarchal and interactive modeling system (cloud scale to microscale) of this paper, the selection of the number and mix of meteorological sensors will depend in large part upon the type and design of the experiments or activities supported. In general, for a fixed experimental site one would deploy a relatively large number of surface-based and tower mounted sensors for measurements in and around the test location, along with some remote sensing instrumentation whenever possible.

The sensors would measure the basic variables of pressure (P), temperature (T), humidity (H), and wind speed and direction, plus other parameters as needed. The wind instruments of choice for a particular location and application may include sonic anemometers or standard propeller and vane types. The sensed wind may have all three components (horizontal and vertical) or only horizontal components. The P, T, and H sensors (often grouped as PTH) may or may not be co-located with the wind sensors. Remote sensors such as lidar or wind radar may provide profiles of wind in the lower atmosphere, and a microwave radiometer may generate profiles of T and H. Doppler lidar can provide wind measurements over an area of several square kilometers, especially if two lidars can provide intersecting fields of view (that is, dual Doppler lidar). Figure 4 gives a view of a wind field derived from dual Doppler lidar for a single scan elevation. When operated in this manner, lidar can provide a rapid refresh, detailed, three dimensional view of the atmosphere. A single lidar also can provide a three-dimensional view. A lidar operating at an eye-safe wavelength (e.g., 1.54 µm) is recommended and often required.

The surface stations and met towers (5 and 10 m) can be left on site for extended periods. However, the cost and competing demands for certain remote sensors such as lidar, wind profiling radar, or microwave radiometer may limit their use to specific test periods. The sensor availability suggests an extended measurement period for the in-situ sensors and the use of pre-determined intensive operating periods for more costly remote sensors.

Technology already under development at ARL will permit remote query and collection of data from the sensors. An operator will have

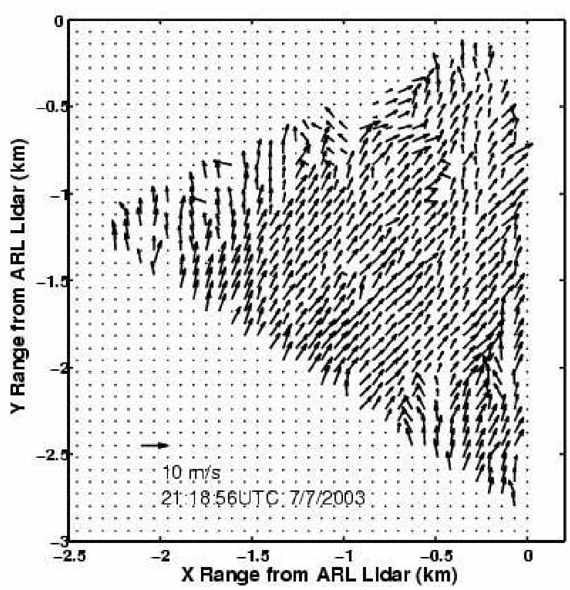

Figure 4. Overhead view of dual Doppler lidar winds from near Oklahoma City at the indicated day and time (UT). In this graphic the ARL and Arizona State University lidars were located near the upper right and lower right corners respectively.

the ability to change most user determined operating parameters of the instruments from a remote location. For example, researchers at White Sands Missile Range (WSMR), NM could alter the reporting times of sensors deployed at Playas, NM from their home location and not have to travel to the test site. The Playas, NM test site was formerly the small copper smelting town of Playas, and is now owned and operated by New Mexico Institute of Mining and Technology (also known as New Mexico Tech, NMT). It is located in southwest New Mexico far from population centers. Current uses include training of first responders to terrorist incidents or natural hazards.

A remote sensor such as a compact lidar or radar profiler may be mounted on an air or ground vehicle so that a few systems can obtain multiple soundings at different locations throughout the AOI. All sensors have their strong and weak characteristics such as a lidar not seeing through cloud, and radar profilers often not having as high a resolution as lidar and generally not providing a volumetric view. A good way to take advantage of the strong points and obtain the best observation set for a given atmospheric situation would be to have a suite of sensors on mobile platforms and at fixed sites that may be at distributed locations.

2.3 *Advanced data distribution*

The proposed Met-Spaces method for data distribution has Jini/Java Spaces as its basis and will provide a flexible yet robust method for distribution of data between the various sensors and between the sensors and data assimilation software (Torres and Vidal, 2003). Figure 5 provides an idea of the Met-Spaces concept as applied to connections between sensors and models. The model computers may be near to the test site or at a distant location as long as they are appropriately networked. The sensors and/or model computers may be mobile and may enter and leave the network in an ad-hoc manner. The use of Met-Spaces will allow them to deposit or query for data without adhering to a fixed schedule. The distributed nature of the concept will help reduce cost since researchers and sensors do not have to be co-located. This architecture combined with the capability to modify sensing parameters remotely will allow researchers at their home location to revise the operation of one or more sensors to fit data assimilation needs or to better support a new or revised test. Using figure 5 as an example, ARL's WSMR location may host computing environment A, the ARL Adelphi Laboratory Center, MD (ALC) could host computing environment B, and the sensors may be set up within any connected test site. This same method also may apply to transfer of data over a distributed field network where sensors and processors may be mobile or at a fixed site.

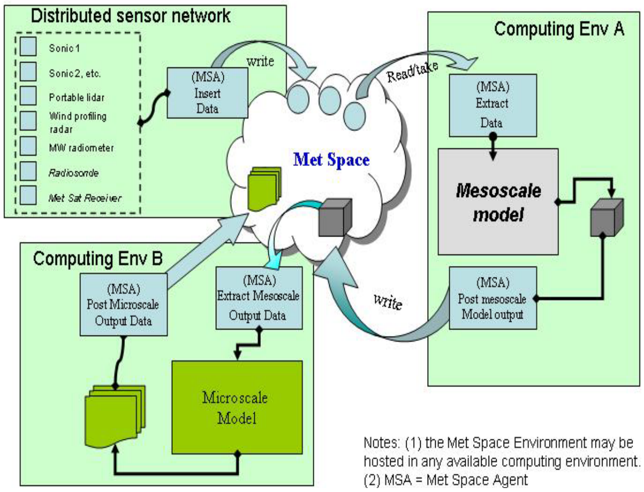

Figure 5. Data flow concept for a loosely coupled Met-Spaces network.

2.4 *Combined system*

The models mentioned above and the ready access to data from mobile and fixed platforms can lead to a combined system of models and measurements which are capable of producing computationally efficient rapid refresh "nowcasts" for planning and operations. Figure 6 shows how the various parts may interconnect in one variant of the concept. This system will have the ability to provide timely atmospheric information for update on the fly, that is, during operations. This "system" of models and observations will interact, via the Met Spaces or equivalent method, so that observations from, for example, aircraft will update model output. The updated output fields will feed decision tools or other application software that will in turn influence a planned or on-going experiment or operation. The aircraft will continue to send new data that will lead to a further update of model output via assimilation, for either a new model run or further post-processing. This mode of continual update will be maintained throughout a field test or an operation. If some sensors go off line during a particular operation the model-observation (WRE-N) system will continue running using data from other instruments and sensing systems, local or distant. "Distant" in this context refers to data from outside the local AOI including those from a weather center, such as NCEP or AFWA, or meteorological satellites. Another capability provided by a combined system of this type is the ability to "target" observations in terms of location, frequency, and data source. This targeting of observations will permit the spatial and temporal concentration of observations to maximize utility given the available set of remote and in-situ sensors.

A test and evaluation version of the proposed system consists of three main parts: (1) sensor selection, setup, and deployment; (2) advanced data distribution and handling that will allow remote operation; and (3) models developed for assimilation of data from mobile and fixed site remote and in-situ sensors in an interactive mode. One option is to take advantage of the new facility at Playas, NM in order to reduce operational costs, and it has the advantage of having structures that represent a small town or suburb. It or a similar isolated site will allow test and evaluation before possible application to a more heavily populated area. Also, it is small enough to cover with a relatively limited number of sensors. Other locations could be selected to increase geographical and climatological diversity. Figure 7 shows how the various functions in such an interactive system could fit together in one potential configuration.

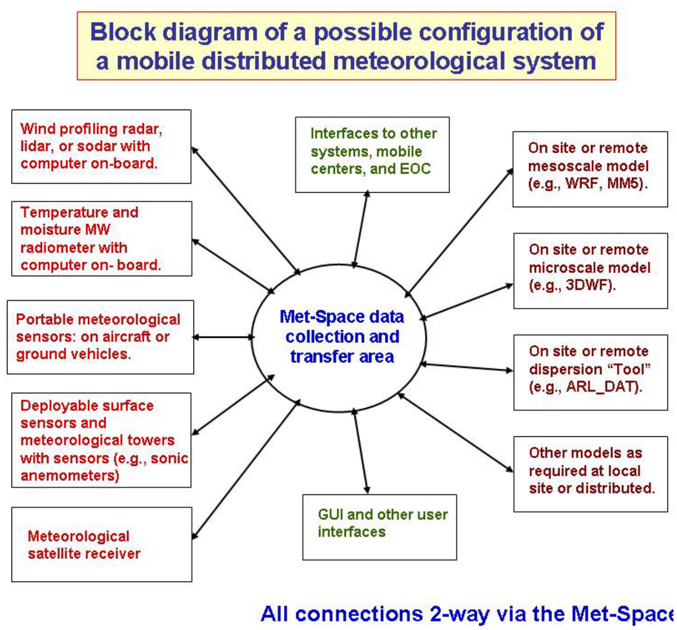

Figure 6. Block diagram of a possible configuration of a mobile distributed meteorological system.

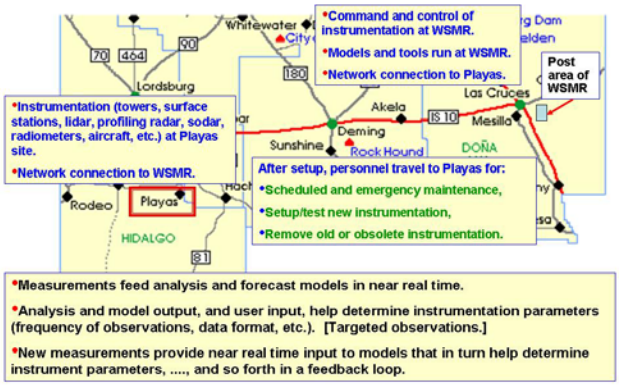

Figure 7. Interrelations of a potential configuration of a distributed interactive system.

3. CONCLUSION

The proposed interactive system will enable user organizations to evaluate a system of distributed sensors and models for operations and planning. Some key points are:

1. A combined multi-model and sensor system can provide essential information on the state of the atmosphere and short term predictions for operations, homeland defense, and natural or man-made emergencies.
2. The system can serve as a research and development test-bed, a means for rapid testing of sensor or model prototypes, or as a local meteorological center.
3. The technology for such a system exists today and will not require technological breakthroughs.
4. The modular design allows the flexibility to handle the addition, subtraction, or replacement/upgrade of sensors, models, or other software with minimal disruption.

4. REFERENCES

Henmi, T., R. Dumais, and R. Okrasinski, 2005: Development of a Weather Running Estimate-Nowcast Capability for the U.S. Army IMETS. U.S. Army Research Laboratory Technical Report ARL-TR-3647, 27 pp.

Shaw, B. L., S. Albers, D. Birkenheuer, J. Brown, J. McGinley, P. Schultz, J. Smart, and E. Szoke, 2004: Application of the Local Analysis and Prediction System (LAPS) diabatic initialization of mesoscale numerical weather prediction models for the IHOP-2002 field experiment. *20th Conf. on Weather Anal. and Forecast./16th Conf. on NWP*, Seattle, WA, Amer. Meteor. Soc., [P 3.7].

Skamarock, W.C., J.B. Klemp, and J. Dudhia, 2001: Prototypes for the WRF (Weather Research and Forecasting) model. *9th Conference on Mesoscale Processes*, Ft. Lauderdale, FL, Amer. Meteor. Soc., J11-J15.

Torres, M. and E. Vidal, 2003: Dissemination of Weather Intelligence Information and Met Sensor Data Acquisition Using Jini/JavaSpaces Technologies. *Battlespace Digitization and Network Centric Systems III, Proceedings of SPIE*, Vol. 5101.

Wang, Y., C. Williamson, D. Garvey, S. Chang, and J. Cogan, 2005: Application of a multigrid method to a mass consistent diagnostic wind model. *J. Appl. Meteor.*, **44**: 1078-1089.

Warner, T.T. and N.L. Seaman, 1990: A real-time mesoscale numerical weather prediction system used for research, teaching and public service at Penn State University. *Bull. Amer. Meteor. Soc.*, **71**, 792-805.