J7.5

WIND AND TURBULENCE OBSERVATIONS IN JOINT URBAN 2003

Young Yee*, Manny Bustillos, Sam Chang, Ronald Cionco, Ed Creegan, Doyle Scott Elliott, Dennis Garvey, Giap Huynh, David Ligon, Edward Measure, David Quintis, Mario Torres, Gail Vaucher, Edward Vidal, Jr, Chatt Williamson, Jimmy Yarbrough

Army Research Laboratory
Battlefield Environment Division
Computational & Information Sciences Directorate
Adelphi, MD and White Sands Missile Range, NM

1. BACKGROUND

The, Joint Urban 2003 atmospheric dispersion study was successfully conducted in Oklahoma City, Oklahoma, during the summer of 2003 (Allwine, 2003). The study involved extensive meteorological measurements as well as gas sampling measurements to accurately track the movement of simulated contaminants in and around cities. The resulting data will be used to improve, refine and verify computer models that simulate the atmospheric transport and diffusion of contaminants in urban areas (Joint Urban 2003 Atmospheric Dispersion Study, Experiment Plan, 2003).

This study was sponsored by the U.S. Department of Energy's National Nuclear Security Administration (NNSA) - Chemical and Biological National Security Program and the U.S. Department of Defense's Defense Threat Reduction Agency (DTRA). The US Army Research Laboratory's Battlefield Environment Division (USARL, BED) actively participated in the meteorological support throughout the testing period.

2. INTRODUCTION

With the increased emphasis on military operations in urban domains, the Army is concerned with the city environment and its effects on systems, sensors, and personnel. These effects include the dispersion of obscurants and toxic agents, illumination and shadowing affecting target acquisition, and turbulence interactions on small systems and sensors such as those mounted on unmanned aerial or ground vehicles. The Joint Urban 2003 (JUT) project, a cooperative undertaking to study turbulent transport and dispersion in the atmospheric boundary layer conducted in Oklahoma City in the summer of 2003, afforded us the opportunity to leverage our measurement capabilities to increase our understanding of this environment. The Battlefield Environment Division (BED) of the Army Research Laboratory (ARL) deployed a number of measurement facilities, including a Doppler lidar system, a mobile radiosonde system (MMS), a temperature/moisture profiling microwave radiometer, and an array of 3D sonic anemometers mounted on five meteorological towers near and outside the central business district (CBD) in surrounding semi-rural and suburban areas.

The study consists of a series of experiments conducted during the period June 28 through July 31, 2003. To evaluate outdoor atmospheric meteorological and diffusion dispersion models, researchers need to learn how air flows through the urban area both day and night. The safe, inert tracer gas, sulfur hexafluoride (SF6), was released for a designated time (up to 6 hours) from several outdoor locations. Portable tracer samplers will collect outdoor air samples for up to several hours after SF6 is released to track its movement throughout Oklahoma City. More details on sensor placement and instrumentation for the Oklahoma City study can be found in the JU2003 Experimental Plan, 2003.

* Yee, Young, AMSRL-CI-EI, Army Research Laboratory, WSMR, NM 88002. Email: yyee@arl.army.mil

3. ARL TEST OBJECTIVES

The ARL objectives during the Joint Urban 2003 experiments were to actively participate in both the meteorological data collection and the data analysis in a full scale real urban environment, to perform basic research in boundary layer meteorology, to collect micrometeorological data for model evaluation, to utilize ARL expertise in support of the JU2003 experiments, and to investigate and perform inter-comparison between instrumentations. The meteorological and diffusion dispersion data sets collected during these trials will be used to support urban airflow and diffusion dispersion model development and validation. Within the scope of this field study, ARL's general scientific objectives are:

a. To understand boundary layer and surface layer flows within, around, and above the urban central business district (CBD) domain for model development, test and evaluation
b. To analyze and characterize mean and turbulent flow interactions for suburban and rural areas
c. To develop urban flow indices, coupling ratios, and profile behavior for the CBD and suburban regimes for generalized applications in our models
d. To understand dispersion behavior within, around, and above the urban domain for the development of urban diffusion coefficients and subsequent model test and evaluation

More specifically, these objectives can be recast in terms of field projects that define the design and deployment of meteorological systems and equipment. These ARL specific investigations will either complement or supplement the JU2003 Experimental Plan.

I. Develop data base to analyze flow characteristics, indices and coupling ratios for urban environments. (BED), (Cionco, 2003).
II. Develop data base to test and evaluate BED's urbanized microscale model/code called CCSL (BED).
III Dual Laser Doppler Wind Measurements (ARO, ASU, BED, CIRA*), (Bach, Ligon, Creegan, Newsom, 2003).
IV Stereo Satellite Derived Wind comparison with Lidar Measurements over OKC (CIRA*, ARL), (Campbell, 1998).

*Cooperative Institute for Research in the Atmosphere/Colorado State University

This research will yield data sets needed to develop urban characteristics, and flow indices, and coupling ratios so that BED models such as CCSL can be applicable to complex urbanized areas. These same data sets will be used for initialization, comparison, and evaluation of the urbanized CCSL code.

The data first must be analyzed to describe and establish urban characteristics such as a generalized urban canopy flow index CFI, a coupling ratio (Rc) of canopy airflow to ambient flow, velocity deficits and enhancements (delta U bar) as ambient flow traverses the rural-suburban-downtown zones of a urban domain, and the character of turbulence (such as intensity of turbulence, i) through the urban zones. The vertical structure of wind profiles also will be analyzed through these same urban zones. The characteristics, indices, and constants can then be introduced into the urbanized CCSL model/code for simulation purposes and applications. In regard to how the measured data base components will be used for initialization, comparison, and evaluation, Figure 1 depicts the flow of data in and out of the urbanized CCSL code and which variables are required for comparisons and evaluation versus the model input and output.

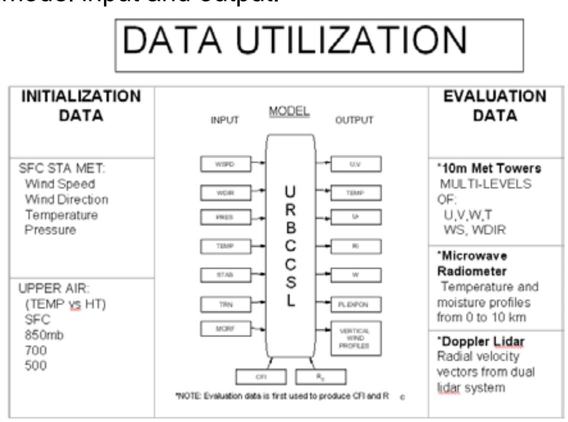

Figure 1. Data utilization and model input and output data sets (Cionco).

4. METEOROLOGICAL MEASUREMENT LAYOUT

DOE-NNSA and DTRA selected Oklahoma City as the experimental site because of its flat terrain, well-defined central city, moderate size, well-characterized climatology, and world-class supporting meteorological instrumentation already in use throughout the surrounding countryside.

An array of multiple-level, micrometeorological masts and towers were located in and about the Oklahoma City urban and rural areas for both horizontal and vertical spatial coverage to span the model's computational area of simulation. Ten-meter masts of sonic anemometers at two or three levels will be placed in three rural area locations to document incoming and out going flows. Two other 10m masts also with two or three levels of sonics will be placed in suburban, residential locations to document the interaction that low-level structures have upon the flow field (Figure 2). All masts and towers will operated 24 hours per day for up to end of the entire JU2003 test period.

In addition to these wind data, upper air soundings were also collected in a timely manner. Each upper air flight was to document the temperature-height-pressure profile up to balloon burst or the 400mb level. The upper air profiles and the surface-based meteorological data were required to supplement the JU2003 science objectives as well as to compute the atmospheric stability as required for input to the CCSL code. A nominal schedule of daily radiosonde flights was at 0600Z (100am CDT) and 1800Z (100pm CDT). In that NOAA maintained a schedule of 0000Z and 1200Z flights, our schedule foregoed those flights. Coordination with the DOE Teams allowed us to skip flight times when DOE intended to release radiosondes. Those times occurred during their ten Intensive Operational Periods (IOP).

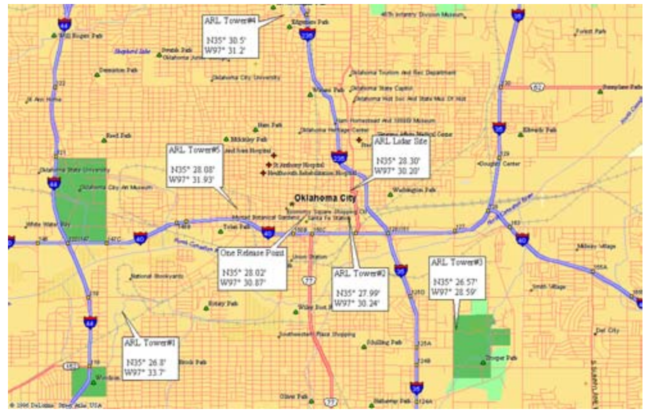

Figure 2 is a map of the selected ARL meteorological sites with their Latitude/Longitude coordinates given.

The list of USARL sites by street location, Lat/Lon and elevation is given as follows:

RURAL SITES:
Rural-N: NW 36th & No. Walker
N35° 30.49' W97° 31.16' @1147 Ft (est)
Rural-SE: SE 22nd & Eastern Ave.
N35° 26.57' W97° 28.59' @1238 Ft (est)
Rural-SW: SW 15th & So. Miller
N35° 26.87' W97° 33.67' @1010 Ft (est)

SUBURBAN/RESIDENTIAL SITES:
SURB-E: Sheridan St & Byers St
N35° 27.99' W97° 30.24' @1253 Ft (est)
SURB-W: Main St & Klein St
N35° 28.08' W97° 31.93' @1210 Ft (est)

ARL WIND TRACER LIDAR SITE:
4th Street & Lincoln Street
N35° 28.30' W97° 30.20' @1234 FT(est)

UPPER AIR SITE
NW 36th & No. Walker
N35° 30.49' W97° 31.16'@1147 Ft(est)

The lidar, a coherent technology Wind Tracer Lidar system was sited just east of the CBD and operated in conjunction with a nearly identical system operated by Arizona State University south to southeast of the CBD. The ARL LIDAR system was setup atop of a four story-parking garage at about 1 km east of the CBD of the city. On a regular basis, the systems would perform both vertical and horizontal scans to obtain wind velocity profiles. The dual lidars would also execute an appropriate elevation scan parallel to the mean wind, measuring the radial wind speed as a function of range, elevation, and time. Banta and Newsom show that these data can be transformed to Cartesian coordinates (distance and height) with estimates of mean speeds and reasonable estimates of wind speed variance. Such a configuration would permit analyses for the air coming toward and away from the lidars, within and peripheral to the city. These data – being three dimensional (r,z,t) - would be quite valuable in initialization of high resolution or computational fluid dynamic (CFD) models of the flows or in assessing the performance of the models as the air leaves the city. Questions about the urban drag could better be addressed since the vertical structure of turbulence and wind entering the city can be separated from the same structures downwind of the city.

In regard to investigation IV, CIRA/CSU and ARL have selected specific non-IOP days during the testing period to validate algorithms that derived winds from stereo satellite imagery of clouds over Oklahoma City. The wind tracer lidar provides accurate cloud height and cloud motion vectors for this study. The selected days require cloud structures that can be tracked by geostationary satellites.

5. SENSORS AND EQUIPMENT

Primary sensors and equipment included 3D sonic anemometers mounted on 10 meter towers, wind tracer lidar, microwave radiometer, and radiosondes.

5.1 3D Sonic Anemometers

All of the sonic anemometers measure or derive the three wind components (u,v,w), speed of sound, and ambient temperature, T. Each sonic anemometer will be sampled at a rate of 10Hz.

5.2 ARL Wind Tracer Lidar

The pulsed IR doppler lidar provides direct measurements of wind velocity vectors at multiple ranges. 150-200meter pulses are transmitted at 100-500 times per second. The width of the transmitting pencil beam is 10-30cm. Relative wind induces a Doppler frequency shift in the backscattered light from naturally occurring aerosols; this frequency shift is detected by the sensor. Figure 3 is a photograph of the wind tracer lidar and the microwave radiometer at the OKC measurement site.

Figure 3. Photograph of the ARL Microwave Radiometer (right) and the ARL Wind Tracer Lidar (left) measuring radial wind velocities over the Central Business District of Oklahoma City. (Photograph by Young Yee).

5.3 Microwave Radiometer

The Microwave Radiometer is a passive remote sensing device that measures the microwave emissions from oxygen and water molecules in the atmosphere. For the temperature profile measurements, the radiometer measures emissions near the 59-60GHz oxygen absorption line. The range is approximately near the surface up to 10 km height (Measure, et.al, 2001).

5.4 MMS Radiosonde

The LORAN radiosonde instrumentation from the Army's Meteorological Measuring Set (MMS) (Cogan, et.al.,1998) was setup north of the CBD to obtain upper air soundings. Standard measurements of temperature, pressure, wind speed and direction, and humidity were taken.

6. DATA COLLECTION

The recent emphasis on urban warfare will require high-resolution meteorological measurements in complex urban environments. Due to the number of sonic anemometers and the volume of data, data collection of the 3D sonic wind measurements presented special challenges. A methodology for the collection and management of a distributed array of 3 Dimensional sonic anemometers was developed and implemented for the JU2003 (Vidal and Yee, 2003). Issues that needed to be addressed were sensor interface, data basing, scalability of measurements (number of sonic instruments), distributed processing of loosely coupled systems, and performance of the data acquisition system(s). One of the major issues in the management and handling of enormous quantities of micro-met measurements is the time tagging of the data and location information of each instrument in a micro size grid. Scalability and integration of multiple sonic sensors are currently being investigated using the latest technologies such as loosely coupled Jini/Java Spaces.

Because of the complex nature of urban meteorological characterization, high-resolution wind measurements require special collection procedures in these areas. Using microchip technology to collect and process data at the sensor level, the data from individual sensors on a single met tower are networked together. Assembled data from each local network of sensors is transmitted wirelessly to a data collection node on a daily basis. Figures 4-5 (wind speed and wind direction, respectively) is an example of wind measurements at heights of 2.5m, 5.0m, and 10m from ARL Tower#3 (22nd St and Eastern Ave).

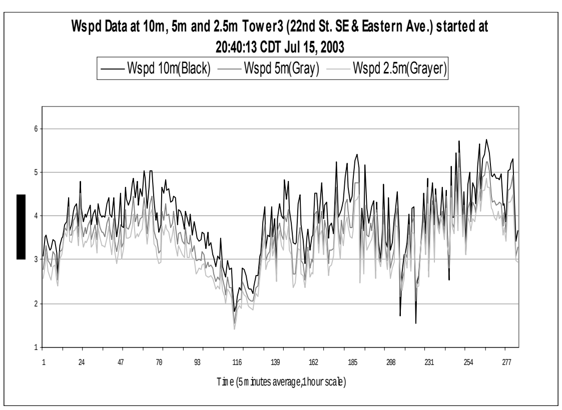

Figure 4. Wind Speed. Sample wind measurements from sonic anemometers mounted on 10 meter met tower (Huynh).

Automated lidar scans were scheduled for each IOP. The schedule included a variety of vertical and horizontal scans. Figure 6 is an example of azimuth polar velocity and aerosol backscatter measurements.

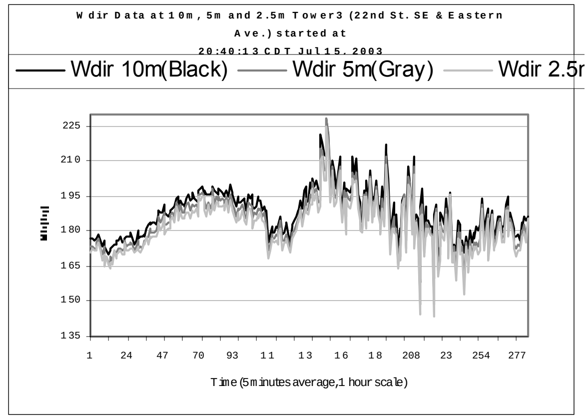

Figure 5. Wind Direction. Sample wind measurements from sonic anemometers mounted on 10 meter met tower (Huynh/Chang).

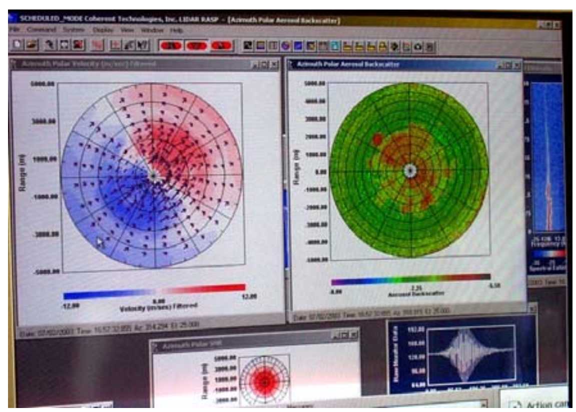

Figure 6. Lidar azimuth polar velocity and aerosol measurement (Ligon, Creegan).

7. SUMMARY AND CONCLUSIONS

Urban warfare is presenting the Army and other agencies with exceptional challenges in the areas of the dispersion of obscurants and toxic agents, illumination affecting target acquisition, and turbulent interactions on small systems such as those mounted on unmanned vehicles. The Joint Urban 2003 project afforded the Army the opportunity to address several ARL scientific objectives regarding this environment. A number of measurement facilities, including a Doppler lidar system, a mobile radiosonde system, a temperature/moisture profiling microwave radiometer, and an array of sonic anemometers mounted on five meteorological towers near and outside the CBD were deployed.

Meteorological wind measurements were successfully obtained from all the ARL 10meter met tower locations for the JU2003 experiment. The ARL Wind Tracer Lidar was ideally located 1km east of the CBD and operated in conjunction with an identical system operated by Arizona State University south-southeast of the CBD approximately 3-4 km. These simultaneous and orthogonal lidar measurements provide invaluable information concerning wind flows in and around the CBD. Preliminary results from these measurements show reasonable correlation (Newsom, 2003).

Quality control of the sonic anemometer data sets have begun and will be included in the JU2003 data archive. Further analyses of these data and the large set of meteorological and diffusion measurements obtained by other agencies and investigators should greatly increase our understanding of the urban boundary layer environment and our ability to predict effects within it.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Douglas Brown, Linda Duchow, Felipe Chavez, Gina Eaton, Nancy Fudge, Mike Mason, Rick Hanson, Felicia Chamberlain, Joseph Trammel, SGT Robert Brice, SGT Steve Morgan, Maj Raymond Pickering, SGT Alan Mariner, and other military personnel for their contributions and valuable support. Special thanks to the people of Oklahoma City especially Scott Smith, Brenda Mitchell, Vernon Banks, JR Caton, Allied Steel, Randolph Hume, and OKC parks & recreation for their tremendous cooperation throughout this endeavor.

8. REFERENCES

Allwine, K.J., et.al., 2003: Overview of Joint Urban 2003 – An Atmospheric Dispersion Study in Oklahoma City, *Planning, Nowcasting, and Forecasting in the Urban Zone Symposium,* 84th AMS, 11-15 January 2004, Seattle, Washington.

Bach, W. D. Ligon, E. Creegan, 2003: private communications, Dual Lidar proposal.

Campbell, G.G., 1998, Asynchronous Stereo Height and Motion Analysis: Applications, Fourth Winds Workshop, WMO.

Cionco, Ronald M, G.T. Vaucher, Y.P. Yee, M. Bustillos, R. Brice, D.S. Elliott, E. Creegan, J. Yarbrough, and E. Vidal, Measurements of AirFlow About a Building, Battlespace Atmospheric and Cloud Impacts on Military Operations, BACIMO 2003 conference, Monterey, CA, Sept 9-11, 2003.

Cogan, J., E. Measure, E. Vidal, E. Creegan, and G. Vaucher , 1998: The MMS-Profiler: Present and Future, Proceedings of the Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) Conference, 1-3 December 1998.

JOINT URBAN 2003 ATMOSPHERIC DISPERSION STUDY, Oklahoma City, July 2003, EXPERIMENTAL PLAN, US DOD Defense Threat Reduction Agency (DTRA), US DOE National Nuclear Safety Administration - Chemical and Biological National Security Program (CBNP).

Measure, E., Y. Yee, J. Cogan, M. Bleiweiss, “Neural Network Based Retrieval of Wind and Temperature Profiles from Combined Surface and Satellite Observations”, 17th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, Jan 14-18, 2001, Albuquerque, NM, Amer. Meteor. Soc., 287.

Newsom, R. and R. Banta, 2003: Sensitivity Analysis of Wind and Temperature Retrievals from Coherent Doppler Lidar Data, BACIMO 2003 conference proceedings, Monterey, CA, Sept 9-11, 2003.

USARL Research Proposal for Joint Urban 2003 Field Study, DTC Project No. 8-CO-160-000-052, DPG Document No. WDTC-TP-01-028.

Vidal, Jr, E. and Y. Yee, 2003: Data Collection Of High Resolution 3d Sonic Anemometers Measurements, 19th International Conference on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, Long Beach, CA.