1.3 AN OVERVIEW OF THE PENTAGON SHIELD 2004 FIELD CAMPAIGN

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1. INTRODUCTION

A better understanding of the microscale properties of the atmospheric boundary layer over urban and suburban areas could lead to better defenses against airborne hazards from terrorism and environmental mishaps. Accordingly, the Special Projects Office of the Defense Advanced Research Projects Agency (DARPA) recently funded a highly focused meteorological field campaign at the Pentagon in Arlington, VA. In-situ and remote-sensing meteorological instruments were deployed to observe the boundary layer and monitor the transport and diffusion of the passive tracer sulfur hexafluoride, SF_6, released during the campaign's intensive observing periods (IOPs). The knowledge gained will aid the development and installation of a system for detecting airborne hazards and predicting their transport and concentration near the Pentagon and other strategically important locations.

2. SCIENTIFIC OBJECTIVES

The scientific objectives of Pentagon Shield 2004 were 1) to characterize the perturbed wind, including turbulence, around the Pentagon and adjacent structures; 2) to measure the urban boundary layer's depth, and its thermodynamical and kinematical profiles, during day and night under various stability regimes; and 3) to trace the transport and diffusion of gases around the Pentagon and within its complex architecture. The data from the field campaign will be used to compare the performances of the instruments used; to evaluate predictions from transport-and-diffusion models and from computational fluid dynamics models; to test techniques for data assimilation; to compare against results from wind-tunnel experiments; and to investigate general topics in urban micrometeorology.

3. PARTICIPATING ORGANIZATIONS

The Research Applications Program of the National Center for Atmospheric Research (NCAR) provided overall scientific planning and direction of the campaign. All primary participating organizations are listed in Table 1.

4. OPERATIONS

4.1 Meteorological instruments

Many of the meteorological instruments deployed during Pentagon Shield 2004 required little or no attention once they were operational (Fig. 1). These instruments provided virtually continuous feeds of data, whether or not an IOP was in progress, barring problems with mechanics or communications (labeled *continuous* in Table 2). Other instruments required more involvement from operators or had limited operating windows. These instruments were used mostly or entirely during IOPs (labeled *periodic* in Table 2).

Conditions near the ground and near the Pentagon roof were measured by 15 Portable Weather Information Display Systems (PWIDS) and 10 Super-PWIDS, which were deployed and maintained by Dugway Proving Ground (DPG). The systems measure wind speed and direction, temperature, and relative humidity. The PWIDS anemometers are mechanical, whereas those on the Super-PWIDS are sonic. The sonic anemometers measure all three spatial components of wind at 10 Hz, yielding turbulence statistics and fluxes of heat and momentum. Systems were mounted on tripods, light poles, and other structures (Fig. 1). Four Super-PWIDS were mounted at different altitudes on a 32-m (105-ft) tower, which also included matched probes that measured temperature and relative humidity at fives altitudes. Data from PWIDS were collected every second and averaged over 10 s before being sent via a radio network to a laptop for recording. Data from Super-PWIDS were collected locally on disc at each instrument.

Other than from the instrumented tower, in-situ soundings were available from balloon-borne sondes and from a tethered blimp outfitted with instruments. During IOPs, the sondes were released hourly from the southern end of

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Table 1: Primary organizations that participated in Pentagon Shield 2004.

Aerospace Corporation
Army Research Laboratory
Coherent Technologies, Incorporated
Cooperative Institute for Research in the Environmental Sciences, University of Colorado at Boulder
Defense Advanced Research Projects Agency
Dugway Proving Ground, United States Army
National Center for Atmospheric Research
National Oceanic and Atmospheric Administration Air Resources Laboratory, Field Research Division
Northrop Grumman
Pentagon Force Protection Agency

Arlington National Cemetery (just west of the Pentagon) by DPG personnel. The 21-m^3 blimp, part of a Tethered Lifting System (TLS; Balsley et al. 1998, 2003), was operated by personnel from the Cooperative Institute for Research in the Environmental Sciences (CIRES) at the University of Colorado at Boulder. Suspended beneath the blimp were a hot–/cold–wire turbulence payload and a meteorological payload. Measurements from the former include temperature and wind velocity sampled at 200 Hz. The blimp and its payloads were raised and lowered from a winch placed in the southern parking lot of the Pentagon (Fig. 1). Because of the low-flying aircraft at the Pentagon and at nearby Reagan National Airport, authorities restricted the blimp to flights below 76 m (250 ft) AGL, except from 0200–0500 EDT, when the ceiling was set at 1 km (3281 ft) AGL.

Shallow, remotely sensed soundings of wind were made by an AeroVironment Model 4000 mini-sodar (a Doppler acoustic sounder) operated by DPG. Every second, the sodar emitted a 4500-Hz pulse, then used a phased array antenna to direct the pulse and to measure its backscatter and Doppler shift off discontinuities in air density (Aerovironment, Inc. 2001; Barthelmie et al. 2003). In this way, the sodar provided columnar observations of three-dimensional wind and turbulence every 5 m between roughly 10 m and 200 m AGL.

A net radiometer measured solar and terrestrial radiation. The unit comprised a boom at 1.5 m AGL, on which were mounted a pair of pyranometers, which measure hemispheric incoming or outgoing radiation of wavelengths 0.3–4.0 μm, and a pair of pyrgeometers, which measure hemispheric incoming or outgoing radiation of wavelengths 4.0–50.0 μm. One sensor of each pair faced skyward, the other faced groundward. Power was supplied by solar-charged batteries. Data were stored locally on Campbell storage modules.

A coherent Doppler lidar called the WindTracer (CLR Photonics, Inc. 2002), built by CLR Photonics, Inc., was installed on the roof of one wing of the Navy Annex, which is on a small hill roughly 850 m west-southwest of the Pentagon (Fig. 1). The location was ideal for providing an unobstructed, slightly downward view to the Pentagon and the surrounding reservation. The WindTracer's pulsed laser is eye-safe at a wavelength of 2 μm. During the field campaign, the lidar was generally programmed to scan 90° in azimuth, centered on the Pentagon, and 22° in elevation. Volume scans took approximately 4 min. On many days, the lidar beam's effective range was at least 7 km. Through the application of velocity-azimuth display (VAD) algorithms, volume scans from the WindTracer provided horizontally averaged wind profiles to about 3 km AGL. WindTracer data were also assimilated into NCAR's variational lidar assimilation system (VLAS), which will be part of an overall system of sensors, models, and algorithms that will assess and predict airborne hazards at the Pentagon.

A second WindTracer was located at Bolling Air Force Base and operated by the Army Research Laboratory. However, data from that lidar are still being analyzed and are not included in this paper, so henceforth *WindTracer* refers only to the lidar on the roof of the Navy Annex.

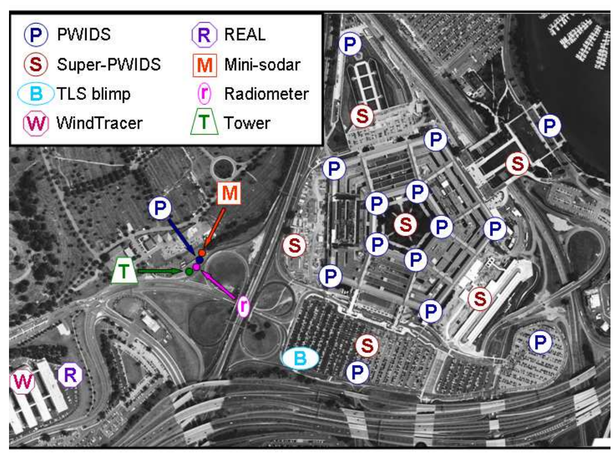

Figure 1: Approximate locations of meteorological instruments. North is toward the top of the figure. The second of the two WindTracers, which was located at Bolling Air Force Base, is not shown.

Pentagon Shield also served as the first field test of the 1.54-μm Raman-shifted Eye-safe Aerosol Lidar (REAL), newly developed at NCAR (Mayor and Spuler 2004). The REAL was located at the eastern edge of the Navy Annex parking lot, stacked atop a large shipping container so that the lidar beam cleared some intervening obstacles such as a fence and trees (Fig. 1).

Table 2: Meteorological instruments, periods of data collection, and mode of data collection. Acronyms are explained in the text.

Instrument	**First data**	**Last data**	**Data collection**
PWIDS	14 April	15 May	continuous
SPWIDS	14 April	16 May	continuous
radiosondes	15 April	13 May	periodic
TLS	22 April	11 May	periodic
WindTracer	19 April	ongoing	continuous
REAL	3 May	9 May	continuous
mini-sodar	9 April	15 May	continuous
net radiometer	13 April	16 May	continuous
tower	24 April	16 May	continuous

4.2 Chemical instruments

Three types of instruments were used to detect the SF_6. Six to eight Tracer Gas Analyzers (TGAs, model TGA-4000 manufactured by Scientech, Incorporated) deployed and operated by the Field Research Division of the National Oceanic and Atmospheric Administration's Air Resources Laboratory (NOAA/ARL/FRD), provided fast-response, real-time, in-situ observations of concentration. Field scientists used the observations to plan and adjust release strategies during the IOPs. TGA data were stored on a laptop at 2 Hz. Remotely sensed, real-time observations were available from three Fourier Transform Infrared (FTIR) Spectrometers, one operated by Aerospace Corporation and the other two by Northrop Grumman. The latter FTIRs were part of Northrop Grumman's Mobile Chemical Agent Detectors (MCADs). Finally, during each of the IOPs, roughly 100 Programmable Integrating Gas Samplers (PIGS) were deployed by NOAA/ARL/FRD outside and inside the Pentagon. Each PIGS was programmed to collect 12 air samples, each one in a Tedlar bag, during a specific hour of an IOP. After each IOP, the bags were collected for later analysis by a gas chromatograph called an Automated Tracer Gas Analysis System (ATGAS).

4.3 Intensive observation periods (IOPs)

Collection and storage of meteorological data began on 9 April and ended on 16 May, although various instruments were operational for only part of that time, as summarized in Table 2. The transport-and-diffusion element of the campaign was organized around five IOPs: 4–5 May (IOP1), 6–7 May (IOP2), 8–9 May (IOP3), 10–11 May (IOP4), and 12–13 May (IOP5). Each IOP involved multiple releases of SF_6 at different locations near the Pentagon in a variety of temporal and spatial patterns. The tracer was invaluable for revealing some of the microscale patterns of airflow around and into the building.

Operations during each IOP began in the late afternoon and ended very early the following morning. This schedule was dictated by two main factors. First, it was simplest to operate instruments—especially those inside the Pentagon—after business hours. Moreover, it was completely impractical to adjust the building's HVAC (heating, ventilation, and air conditioning) until most employees had left for the day. Second, Air Traffic Controls at the Pentagon and nearby Reagan National Airport did not permit the TLS blimp to be flown to useful altitudes during the business day, as mentioned earlier.

4.4 Direction of operations

Operations were directed from a hotel room on the sixteenth floor of the Marriott Residence Inn immediately south of the Pentagon, within line of site of almost all instruments. In the room were four to five laptop computers with high-speed Internet connections. These computers provided real-time displays of data from many of the instruments, including the PWIDS, mini-sodar, and WindTracer. The computers also served as data repositories and were used by campaign forecasters to display observations and output from numerical models. The operations center was the site of daily planning meetings, during which forecasters briefed participants on short-term and long-term predictions. Then participants reviewed the status of instruments and permissions, and determined the details of upcoming operations.

5. EXAMPLES OF DATA

Quality-control and analysis of the data are on-going, but a few preliminary figures give early indications of the campaign's success. *(All data in the figures should be considered subject to change.)*

As already mentioned, one goal of the campaign was the comparison of various instruments. Figure 2 shows how data from the TLS blimp, WindTracer, and mini-sodar compare with one another for one series of observations. All three instruments observed wind to veer with altitude and to increase in speed with altitude beneath the nocturnal inversion, subjectively defined for our purposes by a gradual, then sharper increase in temperature with altitude (arrow in Fig. 2). Through the statically neutral layer, energy dissipation diagnosed from WindTracer VADs and from the TLS were quite similar, then the estimates diverged above the boundary layer. The high vertical gradients (wiggliness) in the profiles from

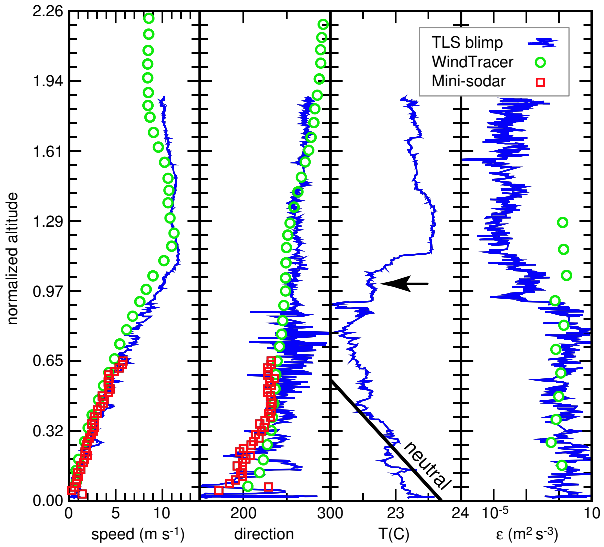

Figure 2: Comparison of profiles from the TLS blimp (thin blue line), from the WindTracer lidar (open green circles), and from the mini-sodar (open red squares). Panels show a) wind speed, b) wind direction, c) temperature, and d) energy dissipation rate, ϵ. Altitude is normalized by the approximate level of the base of the temperature inversion atop the boundary layer, marked by the arrow. The thick black line marks a neutral lapse rate. *Data are preliminary and subject to change.*

the TLS (blue lines in Fig. 2) are a product of the fast response (200 Hz) of the TLS instrument payload, the

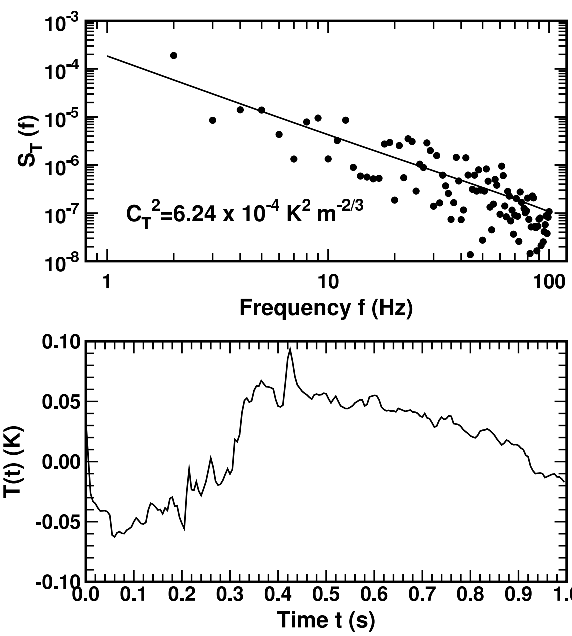

Figure 3: Calculations of temperature spectrum (top panel) from observations by the TLS during a 1-s period (bottom panel). A best-fit line in the top panel marks the temperature structure constant, C_t^2. *Data are preliminary and subject to change.*

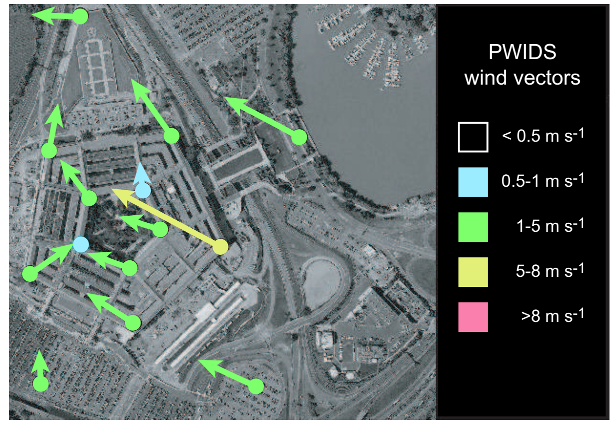

Figure 4: Ten-second averages of wind speed and direction from the PWIDS. *Data are preliminary and subject to change.*

blimp's ascent rate, and the lower troposphere's inherent fine variability. Figure 3 demonstrates that with such high temporal resolution, even data over a 1-s period are sufficient for a spectral decomposition and the calculation of a temperature structure constant, C_t^2 (the best-fit line in the top panel of the figure).

Data from the PWIDS and Super-PWIDS show just how spatially variable the wind around the Pentagon was on short time scales (Fig. 4). Amid the overall south-easterlies in the example figure are numerous small areas of positive and negative divergence and shear vorticity.

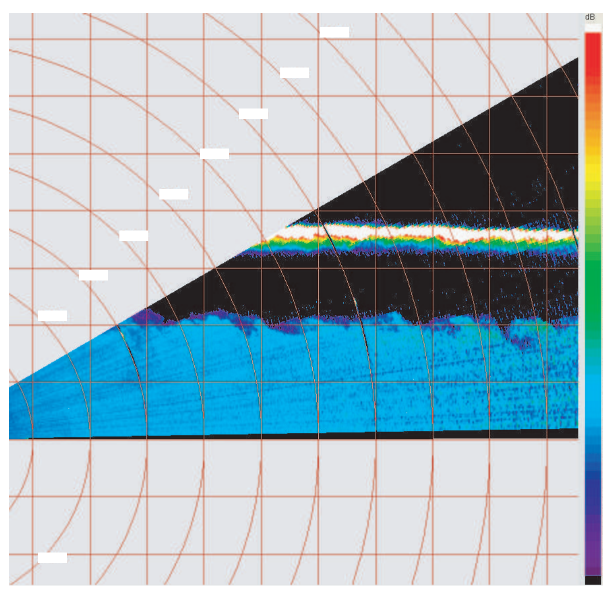

Figure 5: Vertical cross section from an RHI (range-height indicator) scan by the REAL operating at 10 Hz. The scan was directed into the wind. Aerosol concentrations increase from blue to red. Ranges and values of the color shading are intentionally omitted from the figure. *Data are preliminary and subject to change.*

Such perturbations to the mean flow must be studied in detail if we are to develop a better understanding of transport and diffusion near the Pentagon and other buildings.

The REAL performed extremely well. When the lower troposphere was thick with scatterers, the REAL was able to observe flow features and structures in the boundary layer over 10 km away. RHI (range-height indicator) scans such as those in Figure 5 clearly reveal the boundary layer, and what appears to be an elevated layer above it, where aerosols were concentrated. Even small features at the boundary layer's top were apparent, such as the Kelvin-Helmholtz waves in Figure 5.

6. SUMMARY

A meteorological field campaign was conducted at the Pentagon in Arlington, VA from mid April to mid May 2004. In-situ and remote-sensing meteorological instruments were deployed to observe the boundary layer and monitor the transport and diffusion of an inert tracer, SF_6, released during the campaign's intensive observing periods (IOPs). Preliminary analyses of some of the data point to the campaign's success.

Acknowledgments. The National Center for Atmospheric Research is sponsored by the National Science Foundation. Primary funding for the field campaign came from the Defense Advanced Research Projects Agency (DARPA).

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