7.3 FORECASTING STABILITY TRANSITIONS AND AIR FLOW AROUND AN URBAN BUILDING – PHASE I

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ABSTRACT

In March of 2003, the Army Research Laboratory conducted a 1-week Urban Experiment to challenge the current understanding of the surface layer stability transition and airflow around a two-story rectangular building. This Experiment was, in part, an extension of the ongoing Surface Layer Stability Transition Forecasting effort. The Experiment design was based on published wind tunnel measurements simulating airflow around a variety of model building sizes. Using wind tunnel results as a forecast of airflow features, the wind tunnel parameters were enlarged for the given building and the orientation was proportionately skewed for prevailing winds. Finally, four 10m meteorological towers were installed in specific locations along the building's North, Northeast, South, and Southwest sides. These ground layer towers reported standard meteorological parameters at the 2m and 10m levels. An additional 5m tower sampled the atmosphere above the roof.

Preliminary results confirmed, visually and quantitatively, the presence of the forecasted cavity flow, a bi-level accelerated flow between buildings, and the anticipated prevailing wind direction. The stability transitions were greatly influenced by the inhabited building. Unlike the forecasted stability transitions for an open desert, these urban environment transitions were not always evident. In fact, there were times when the daytime unstable surface layer persisted well into the traditional stable nighttime periods. Lessons learned and recommendations for improving future urban measurements / forecasting methods conclude this paper.

1. Introduction.

In March 2003, the Army Research Laboratory executed an urban field test, *PreTest#1*, in preparation for the joint URBAN2003 experiment in Oklahoma City. Two of the four mission objectives for *PreTest#1* were (1) to characterize surface layer stability transition patterns in an urban environment and (2) to characterize airflow behavior around and above a single building. Four 10m Meteorological Towers were placed on each side of a two-story office building at White Sands Missile Range [WSMR], NM. A 5m tower was mounted on the building's flat roof. The exact placement of each tower was determined from the Snyder and Lawson wind tunnel experiments published in 1994 (1994, Snyder and Lawson). Campbell sensors were mounted at 2m and 10m levels of the surface towers and at the 4m level of the roof tower. Variables sampled included: Pressure, Temperature, Wind Speed/Direction and Solar Radiation at 2m; and Temperature, Wind Speed/Direction at 10m. These were reported at a 1-minute average sampling rates. Thirty-two Hz wireless sonic data were sampled on the south tower at 3m, 5m, 8m AGL. Since this data acquisition system was still in the process of being proven, it was not included in this data analysis.

The selected concrete-block building had single story buildings on the south and west sides. To the north was a matching two-story building. Nearly level gravel and dirt were between these buildings. East of the building was a grassy area, a sidewalk and a paved 4-row parking lot. See Figure 1. During the acquisition period, automobiles were confined to the farthest two parking lot rows and no vehicle traffic was permitted near the towers.

The weather pattern during acquisition ranged from calm clear skies to a typical dusty spring windstorm.

1.1 Stability Transition Characterization.

The foundational stability transition [ST] characterization study for this project began as an effort to forecast optimal 'seeing' conditions for a high-energy laser along a horizontal path. 'Seeing' is primarily a function of atmospheric density variations and is quantified by the statistical index of refraction structure function, C_n^2. Scintillometers sample C_n^2 but were unavailable during this Urban test. Therefore, an alternate method, calculating the vertical temperature difference (Delta-T), was employed. Cloud cover and building shadowing were quantified by the solar radiation measurements.

1.2 Desert Model and Forecasting Effort.

A normal diurnal desert stability cycle includes four basic elements: (1) a nighttime stable atmosphere, (2) a morning transition to (3) the daytime unstable atmosphere and (4) an evening transition back to the nighttime stable atmosphere. Since the atmosphere is neither stable nor unstable during the transition, this time period is often referred to as a "Neutral Event". Under ideal atmospheric conditions, namely clear skies - low winds - low ground moisture, the stability transitions will have duration of 2 minutes or less. In the mid-1990s, a seasonal cycle in the stability transition timing was discovered (1995, Vaucher &

Endlich). This discovery greatly improved the success of the Stability Transition Forecasting Model.

1.3 2001 Stability Transition Forecast Model Validation.

In 2001, the Stability Transition Forecasting Model was brought to a new desert field site at WSMR, NM. Three field tests (2001 March, June, September) were conducted based on the forecasted statistical maximum and minimum time from local sunrise to the stability transition. The Test results validated the Stability Transition Forecasting Model under Ideal atmospheric conditions, documented quantitatively a Neutral Event longer than 25 minutes occurring at night and opened the door for an improved understanding of the local moisture and sun occultation effects on the transition timing. For specifics see Technical Reports: 2003, Vaucher et al, ARL-TR-2798; ARL-TR-2823; and ARL-TR-2827.

With growing interest in urban seeing conditions, the Stability Transition Forecasting Model was brought to an urban environment. Two 2003 Mar acquisition periods were selected. The first was during a single tower sampling test; the second was the actual 5-tower, 7-day full test. The results are in Section 2.

1.4 Sensor Layout for Wind Tunnel Validation.

Snyder and Lawson ran several wind tunnel experiments that mapped streamlines and flow patterns around simulated single building structures. (1994, Snyder and Lawson) While they had 300 samplers from which to define the flow pattern, the *PreTest#1* had only 9 sensor sets on the 5 meteorological towers. Therefore, the tower placement was selected to maximize the recognition of the following flow features documented by the Snyder and Lawson study: separation streamlines, reattachment streamlines and a 'cavity'. The primary feature *PreTest#1* aimed to capture was the cavity flow.

Observed prevailing winds for the building were determined to be Southwesterly. Taking the equivalent rectangular wind tunnel case and skewing the fetch to the prevailing winds, the west and east towers were placed such that the southwest tower would have a least obstructed upstream airflow. The northeast tower was positioned to report the anticipated cavity's Westerly-top flow and Easterly-return flow. The north and south towers were also placed such that if a cavity were present, they would quantify this attribute. Since these later towers were between aligned buildings, an accelerated flow was expected (verses a cavity flow).

2. Stability Transition Characterization Results

12 MAR CASE: This trial run employed just the South tower sensors. The observed ST was earlier than forecasted. Less than 10 minutes before sunrise, an abrupt wind shift from westerly to easterly was coupled with a near uniform 7 deg temperature drop at both the 2 and 10m levels. Soon after this radical air mass change, the night-to-day ST was observed. This was the only time during the test that the data documented such a pattern.

25-31 MAR CASE: Results from these 7 mornings of ST showed the forecasted ST to be a gross threshold for initiating the daytime unstable temperature profile around the building. The temperature differences (T_{10m} minus T_{2m}) occurring between sunrise and the forecasted ST were characterized by near zero magnitudes. There were several examples where the expected stable nighttime profiles were not observed. On 28 Mar, the AFTER-sundown unstable lapse rate persisted through midnight at ALL ground towers around the building. Perhaps the Urban Heat Island effect is as much an attribute of one building's atmosphere as it is of a city of buildings.

3. Air Flow around an Urban Building Results

EAST Tower (Lee side): The most striking result was the real-time visual confirmation that the cavity flow noted in the wind tunnel experiment was a predictable effect around a full-sized building. See Figure 2. Time series data further verified these 'wind bird' orientation observations.

SOUTHWEST Tower (Fetch side): Prior to the field test, the SW tower was considered the building's fetch side. This attribute was confirmed by the near-coincident wind direction magnitudes reported at 10m and 2m levels. On Day 86, the 10m wind exceeded 18m/s and the 10m boom realigned from its west-east orientation to that of the prevailing wind. While signaling a design flaw, this realignment also validated the fetch characteristic of the building airflow. Appropriate wind corrections were applied to the processed SW tower data.

NORTH/SOUTH Towers: North and South towers showed a slightly faster peak wind velocity (~2m/s quicker) with respect to the SW and E towers. Since these towers were sandwiched between buildings, such results confirmed the anticipated Bernoulli effect. Also observed was a weaker cavity effect in the South tower, when winds were northerly.

ROOF Tower: Unlike the ground towers, the roof tower consisted of only one sensor level. Clear day temperatures spanned between 8 and 16^{o}C. The greatest *PreTest#1* wind speed (19.4 m/s) was reported from the Roof tower at 0848 MST during the Day 86 windstorm.

4. Lessons Learned and Recommendations for Future Urban measurements

The two-story building being characterized was uniquely placed in that, an open desert was within 3 km of the east side, and similar-sized/type buildings were situated to the north, west and south. To better understand the mini-Urban Heat Island thermal effects, additional eastern towers could be aligned from the building cavity flow out to the open desert environment. Another suggestion is to locate a similar configuration of buildings, with a paved parking lot preceding the desert.

For future urban airflow measurements, doubling the tower number would improve the quantitative description of the flow pattern around a building. For example, adding towers closer to the building on the upwind side will help locate the upstream stagnation point. Towers placed further away on the lee side will better capture the shape of the cavity flow.

The 10m-tower height did capture the building's primary airflow characteristics around the building. However, having a 10m Roof Tower with at least two levels (preferably 3) of meteorological sensors would help enhance the above building airflow and thermodynamic characterization. This would further validate the stable atmosphere reported in the MUST study (2002, Pardyjak et al).

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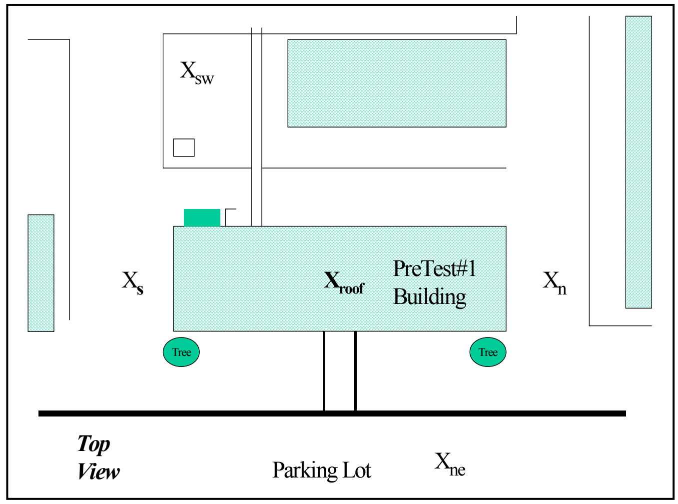

Figure 1. PreTest#1 tower configuration. Cross-hatched areas represent buildings. Filled circles are trees.

Figure 2. The eastern tower displays the cavity flow with westerly flow (10m AGL) over the top of the building and an easterly return flow at 2m AGL.