6.4 PRELIMINARY RESULTS FROM A SINGLE BUILDING AIR FLOW PATTERNS FIELD STUDY

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ABSTRACT

In March 2007, the U.S. Army Research Laboratory completed the last of a three-phase urban field study that detailed the sampling of airflow and stability around a single building in southeastern New Mexico. Unlike the earlier two Studies, this Study focused on the four-dimensional characterization of the following flow features: the cavity flow, reattachment zone, leeside eddies, canyon flow, velocity acceleration over the roof, and velocity deficit. The Study's field design was based on a Snyder and Lawson's 1994 wind tunnel study, as well as a three-dimensional diagnostic urban model. Measurements were acquired over a two-week period using 12 towers/tripods located along the north, east, south, and west building sides, the roof, and in strategic locations on the building's leeside. To minimize the heating/cooling bias, the equinox time period was selected for acquiring the data.

This paper gives a brief overview of the field study and provides a sample of the preliminary results. At the time of this writing, the in-progress data analysis had confirmed the presence of each feature, despite the atypical 2007 March NM "windy season." Available statistical and graphical results will be included when the paper is submitted.

1. INTRODUCTION

Airflow patterns around variously proportioned single building structures/simulations were published in 1994 by Snyder and Lawson (Snyder and Lawson, 1994). These EPA/NOAA Laboratory wind tunnel results were the foundation for a series of U.S. Army Research Laboratory (ARL) urban field study designs, which targeted the characterization of airflow and stability patterns around a single urban building structure. The initial urban field study was conducted in March 2003 at White Sands Missile Range (WSMR), NM, and also served to prepare ARL for participation in the JOINT URBAN2003. The 9-day March study, later labeled *WSMR 2003 Urban Study* (*W03US*), consisted of four 10 m towers, strategically placed on each side of the subject building and a 5 m tower on the near-flat roof of the subject building. With *W03US*, four wind tunnel airflow features (Fetch Flow, Velocity Acceleration, Velocity Deficit, and Cavity Flow) were verified from the mean data quantities acquired, and the characterizing of an urban diurnal stability pattern within the *W03US* small building complex was initiated (Vaucher et al., 2004).

In March 2005, the urban single building investigation enhanced the airflow characterization by including two additional flow features (leeside eddies and reattachment zone), as well as turbulent conditions. The urban stability research fine-tuned their characterization effort by focusing on the less frequent stable atmospheric conditions. This *WSMR 2005 Urban Study* (*W05US)* utilized the *W03US* field design, along with three supplemental tripods to capture the added airflow features, and a sensor selection more capable of capturing turbulent quantities. Documentation on *W03US* and *W05US* is available upon request.(Cionco et al., 2006)

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2. WSMR 2007 URBAN STUDY

In March 2007, the third urban field study of the series, the *WSMR 2007 Urban Study* (*W07US*), expanded the foundational resource of a physical model by also consulting a three-dimensional diagnostic urban computer model. The final field design consisted of 12 towers/tripods surrounding a single building (see figure 1). Specific tower/tripod placement was a follows: three 12 m towers were on the southwest, south, and northeast sides of the subject building; two 10 m towers were on the north and southeast sides; two partial 10 m towers captured the leeside eddy flows; three 6 m tripods sampled the east-reattachment zone, roof, and northwest canyon flows; and two 2 m tripods sampled the northeast and southeast reattachment zone flows. Dynamic data were acquired from all 12 towers/tripods. Thermodynamic data were acquired from the southwest, south, northeast, north, and roof towers/tripods.

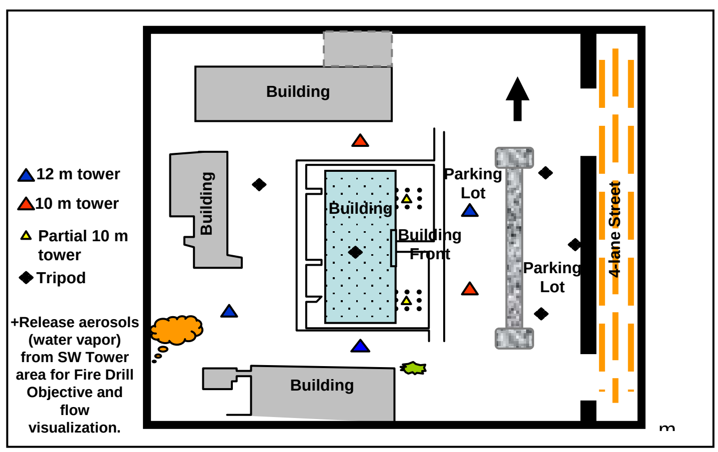

Figure 1. The *W07US* Field Site Configuration. The gray areas represent buildings, with the subject building as blue. Tower orientation with respect to the building was skewed to accommodate prevailing wind direction.

The thermodynamic measurements consisted of 1-min averaged data sampled by Campbell-T107 temperature sensors and Vaisala-HMP45AC temperature/humidity probes at 10 and 2 m above ground level (AGL), respectively. Mean pressure (Vaisala PTB-101B), solar and net radiation (Kipp/Zonen-CM3 pyranometer; Kipp/Zonen-NR-LITE-L) were sampled at approximately 2 m. Mean winds at 5 m AGL were captured by wind monitors (RM Young-05103).

The primary dynamic dataset consisted of u, v, and w (turbulence) measurements acquired at 20 Hz by RM Young Model 81000 ultrasonic anemometers (sonics) mounted at 10, 5, and 2.5 m AGL on most tower and tripod structures. The exceptions included the leeside-eddy partial towers, which acquired sonic data at three points for the south eddy (2 m east and west; 5 m west) and two 2 m points (east and west) at the north eddy location. The other exception was the roof tripod, which supported five sensors: at 6 m above roof level a sonic, a T107 temperature sensor and a wind monitor were mounted, at 2 and 1 m above roof level were mounted a net radiometer and a T107, respectively.

The subject building was concrete blocked. To the south was a similarly constructed single story building. To the west was a stair-cased, one- to two-story building. To the north was a matching two-story building. Nearly level gravel and dirt surfaces were between these buildings. East of the building were a grassy area, a sidewalk, and a paved 4-row parking lot. During the acquisition period, automobiles were not permitted to utilize the parking lots.

The 14-day period selected for data acquisition was based on both airflow and stability requirements. The ideal airflow was defined as sustained winds of greater than 10 m/s. Such winds, climatologically speaking, occur in March for southern New Mexico. March was also when the solar equinox occurred. The potential for an equal heating and cooling diurnal cycle was ideal for minimizing a systematic bias on the stability pattern characterization effort. During the actual data acquisition period, the weather pattern ranged from calm clear skies, to typical NM spring wind storms (winds greater than 10 m/s).

3. STABILITY CHARACTERIZATION RESULTS

A stereotype urban diurnal cycle would consist of neutral and unstable atmospheric conditions throughout a 24-h period. In all three WSMR urban studies, a small but significant percentage of stable conditions were reported on all four building sides. Dividing *W07US* into day intervals, an average of 74% of the field study days reported the presence of stable conditions around the building structure. This is 24% greater than the *W05US* value and supports an observation that the *W07US* occurred during a climatological anomaly.

While stable conditions are not considered characteristically "typical" for urban environments, understanding their pattern of occurrence is very useful in defining urban stability cycles. Table 1 presents a statistical summary of the *W07US* stable characteristics, using compass direction references to represent the various data acquisition sites with respect to the subject building. The first noteworthy anomaly is the order of locations for the most to least frequent stable conditions occurrences. Unlike the previous two studies where the east tower dominated the frequency of stable condition occurrence, in *W07US* the west tower showed the greatest occurrence of stable conditions with the roof reporting the second greatest. The least occurrence was present in the north tower in *W07US*.

To better view the stable conditions distribution, the periods of stable events were grouped into "cases.," where a case was defined as a condition whereby a stable profile was sustained over a period greater than or equal to 1 min in length. For *W07US,* the maximum number of cases per day increased from previous studies, as did the longest duration of a case. The only exception was in the east tower, where the longest duration was approximately the same as in *W05US*.

Stable Conditions	West	South	North	East	Roof
Percent of Days with…	84%	58%	63%	84%	79%
Total Stable Min in *W07US*	1724	1138	714	1344	1510
Avg min/day	91	60	38	71	80
Max cases per day	371	280	233	282	332
Longest case duration (min)	312	79	37	52	205
Avg case duration (min)	11	8	6	8	8

Table 1. *W07US* Stable Condition Statistical Summary. The compass directions refer to the tower location-data resource relative to the subject building.

The distribution of stable minutes over a 24-h diurnal cycle showed the period from 2100–0300 local time (LT) to hold the greatest occurrence of stable conditions. The second greatest was from 0300–0900 LT. These results were consistent with the earlier two studies. With sunrise and sunset occurring at approximately 0600 and 1800 LT, the suggested explanations for these time period preferences include seasonal and diurnal solar cycles, as well as anthropological influences. The night shift (2100-0300 LT) consisted of 6 h of darkness (no solar heating), while the sunrise shift (0300-0900 LT) contained 3 h of darkness and 3 h of daylight. Without the solar heating, the night shift would have the greatest potential for a stable environment, even with the radiative cooling from the buildings. The sunrise shift would continue this potential for stable conditions but has two counter influences:
the morning stability transition into the daytime unstable conditions (a systematic atmospheric diurnal cycle) and anthropological influences, such as the start of building heat systems. For additional discussion, see Vaucher (2007).

4. AIR FLOW CHARACTERIZATION RESULTS

One of the goals for our *W07US* data analysis is to parameterize various aspects of the urban airflow patterns. At the time of this publication, the data calibration analysis was drawing to a close, as was the initial data survey. While discussing the calibration methodology and results of the project exceeds the limits of this paper, the *W07US* airflow qualitative assessment will be summarized within the remainder of the text. The six airflow features flagged for the assessment were velocity acceleration (over the roof), velocity deficit (leeside of roof), cavity flows, reattachment zone flows, canyon flows, and leeside eddies.

Before the assessment could yield its most fruitful results, the 20 Hz sonic data were time-aligned into 1-min averages. The airflow assessment then began by defining equations capable of flagging those conditions when the ideal flow feature occurred. Ascertaining the feature's frequency and distribution of occurrence followed. Figures 2–8 graphically show the distribution of each flow feature along the 14-day timeline. Table 2 summarizes the feature distributions with the averaged percentage of a day each feature occurred. To help interpret the results, if a 100% occurrence was listed, this would indicate that all the minutes sampled during the field study days reported the given feature. A 10% occurrence means that, on average, 10% of each sampling day reported the occurrence of the given airflow feature.

4.1 Velocity Acceleration and Deficit Patterns

The velocity acceleration was defined with respect to the Southwest Tower (Fetch). Combining this feature with a velocity deficit in the northeast tower, on average the pattern was present for about 33% of a *W07US* sampling day. Combining the accelerated flow with the southeast tower, the pattern on average was present for 38% of a *W07US* sampling day (see figure 2). Even though Julian day number 81 showed a low percentage (system/power outage on the roof), all days do report the presence of these combined patterns.

4.2 Cavity Flows

Another term for cavity flow is "flow reversal." For this initial survey, the investigation considered only the northeast and southeast tower data. The meteorological sensor types and placements on these two towers were designed to capture this flow reversal feature as defined by wind tunnel and diagnostic wind flow computer models, using a prevailing wind from the west. On average, the northeast tower reported the idealized upper level westerly flow and lower level easterly flow in about 4% of the sampled day. The southeast tower reported this idealized flow an average of about 8% of the day sampled. Despite the low daily percentage in which this flow was evident, each day did report the feature's presence (see figure 3).

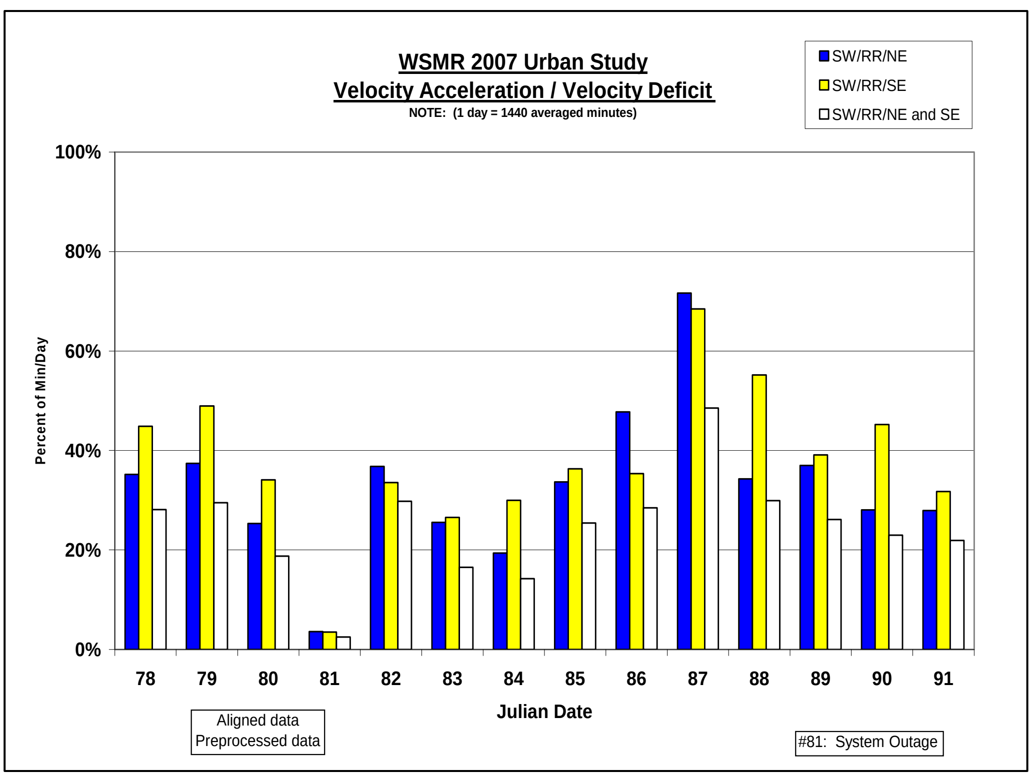

Figure 2. Percentage of the Day the Velocity Acceleration and Velocity Deficit Were Observed.

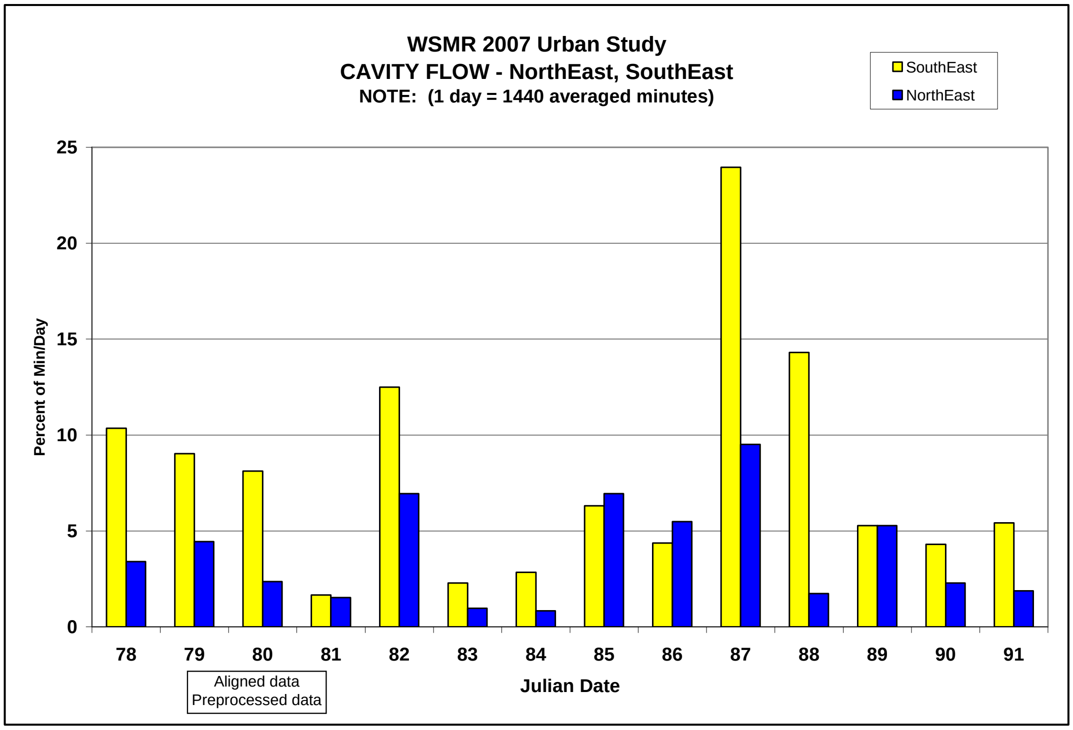

Figure 3. Percentage by Day in Which Cavity Flows Were Observed in the Northeast and Southeast Tower Data.

4.3 Reattachment Zones

The three tripods in the reattachment zone area were positioned to receive a continuation of the prevailing westerly flow. The north and south tripods each sported a single sonic at 2.5m AGL. The east tripod had sonics at the 5 and 2.5 m levels. For this preliminary review, our ideal considered the sonics individually, then reviewed each tripod as a unit. The purpose for this two phased approach was to assess the feature along a uniform horizontal plane first (at 2.5 m AGL), then to expand the observations with an added three-dimensional (vertical) perspective. The north tripod, on average, reported 39% of a sampled day as having westerly flow. The south tripod on average reported 26%. The east tripod's 2.5 m AGL sonic reported an average westerly flow for 13% of a sampled day. The 5 m AGL sonic averaged 23%. The east tripod's unified westerly flow (both levels) averaged about 11% of a sampled day. For all the days sampled, a westerly reattachment zone flow was reported (see figure 4).

4.4 Canyon Flows

The canyon flows were divided into latitudinal and longitudinal directions. The latitudinal canyons were to the north and south of the building (see figure 1). The ideal flow pattern through these canyons was from west to east. The westerly flows through the north and south canyons occurred on average 21% and 18% of a sample day, respectively. Figure 5 shows the daily occurrence of the west to east flow in the north and south canyons.

The longitudinal canyon was west of the subject building (see figure 1). With the prevailing wind source being from the west, the resulting ideal west-canyon airflow had to be either a northerly or southerly flow. Combining the results of both canyon flow directions, the average occurrence of the sampled day was 42%. The southerly flow occurred (on average) twice as frequently [28(+/-16) %] as the northerly flow [14(+/-8 %)]. During all days sampled, a canyon flow was reported from all three canyons. Figure 6 shows the daily occurrence of northerly and southerly flows through the west canyon.

4.5 Leeside Eddy Flows

The partial towers targeting the leeside eddy flows were positioned on the northeast and southeast corners of the subject building. The northeast partial tower had east and west 2.5 m AGL sonics. The southeast partial tower had three sonics: one sonic on the east and west sides of the partial tower at 2.5 m AGL, and one sonic on the west side of the tower at 5 m AGL. Fence posts with caution tape tied to their tops were installed around each partial tower. These posts allowed for a real-time visualization of the circular eddies expected in these areas. During the *W07US* smoke release event, the visualization was captured on video. Otherwise, the historical records were limited to the acquired data of the sonics.

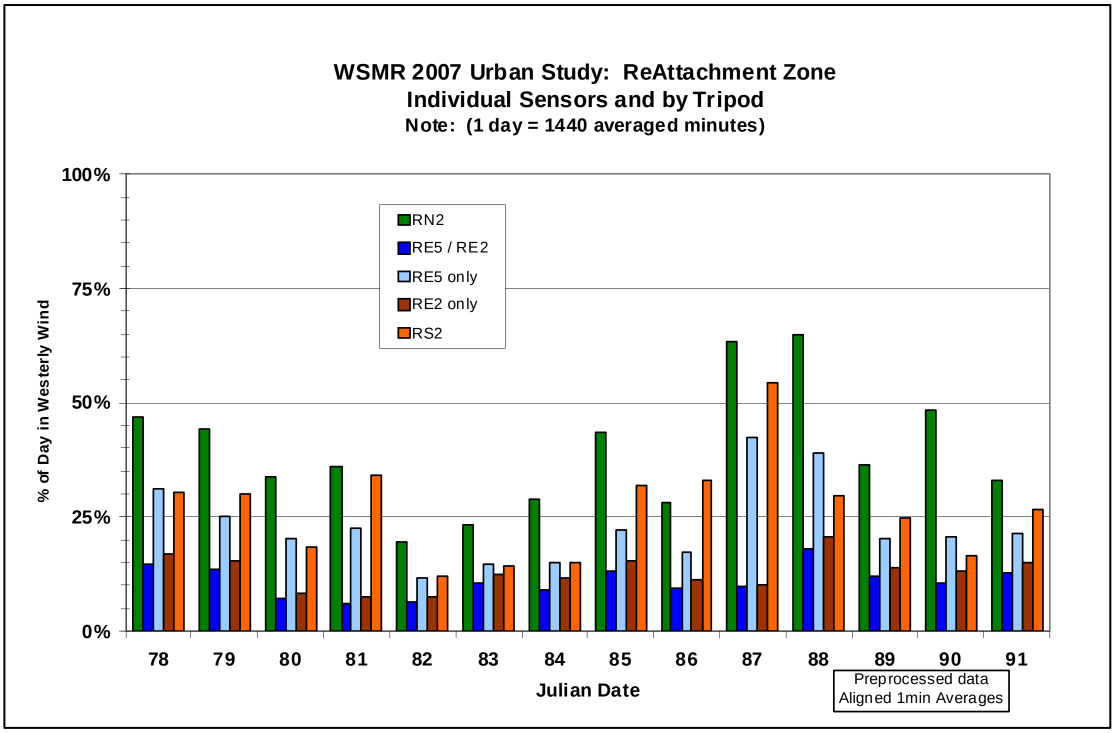

Figure 4. Percentage of the Day in Which the West to East Reattachment Zones Flow Was Observed.

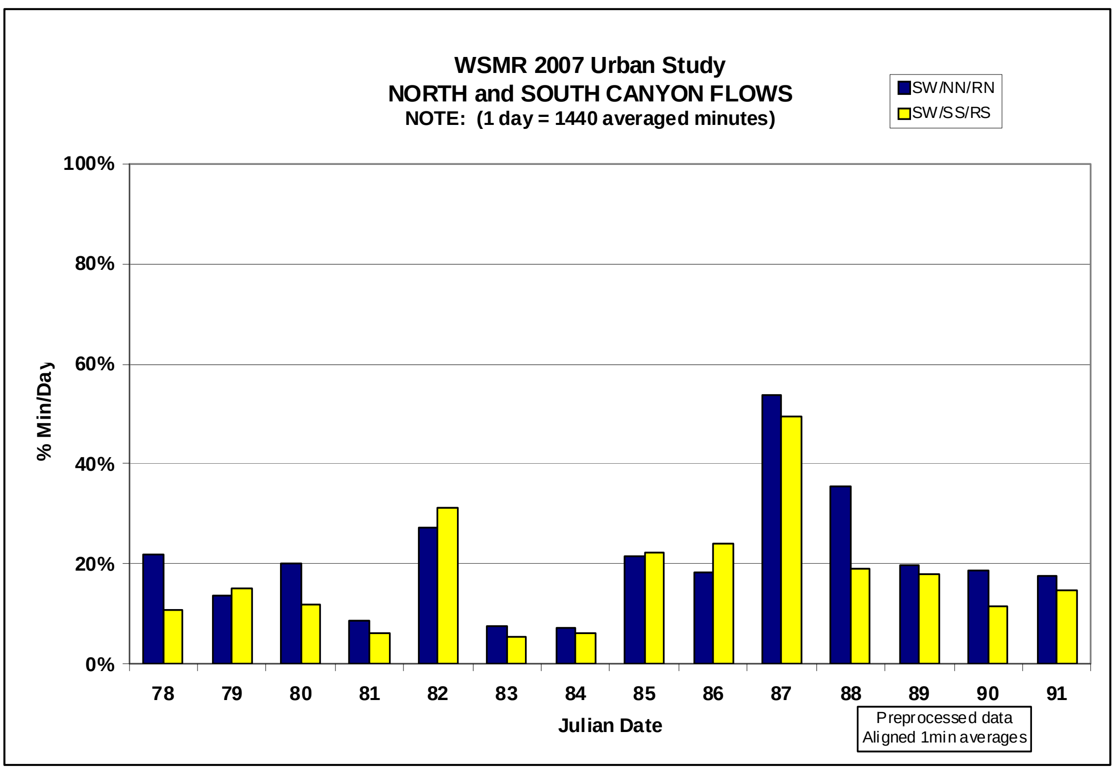

Figure 5. Percentage of the Day in Which Westerly Flow Through the North and South Canyon Flows Was Observed.

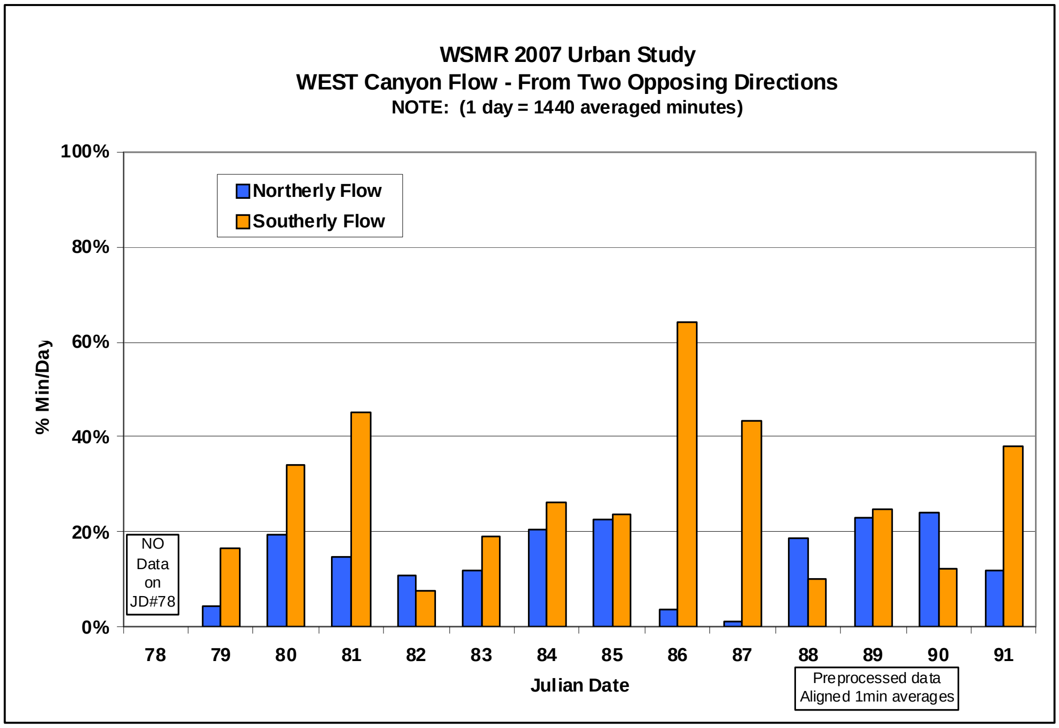

Figure 6. Percentage of the Day in Which the West Canyon Flow Observed a Southerly (Orange) or Northerly (Blue) Flow.

The idealized eddy flow for the northeast partial tower required a northerly flow over the eastern sonic and a southerly flow over the western sonic. This idealized condition occurred on average 3% of a sampled day (see figure 7). The southeast partial tower idealized eddy flow required a southerly flow over the eastern sonic and a northerly flow over the western sonics (both levels). These conditions occurred, on average, 3% of the sampled days (see figure 8).

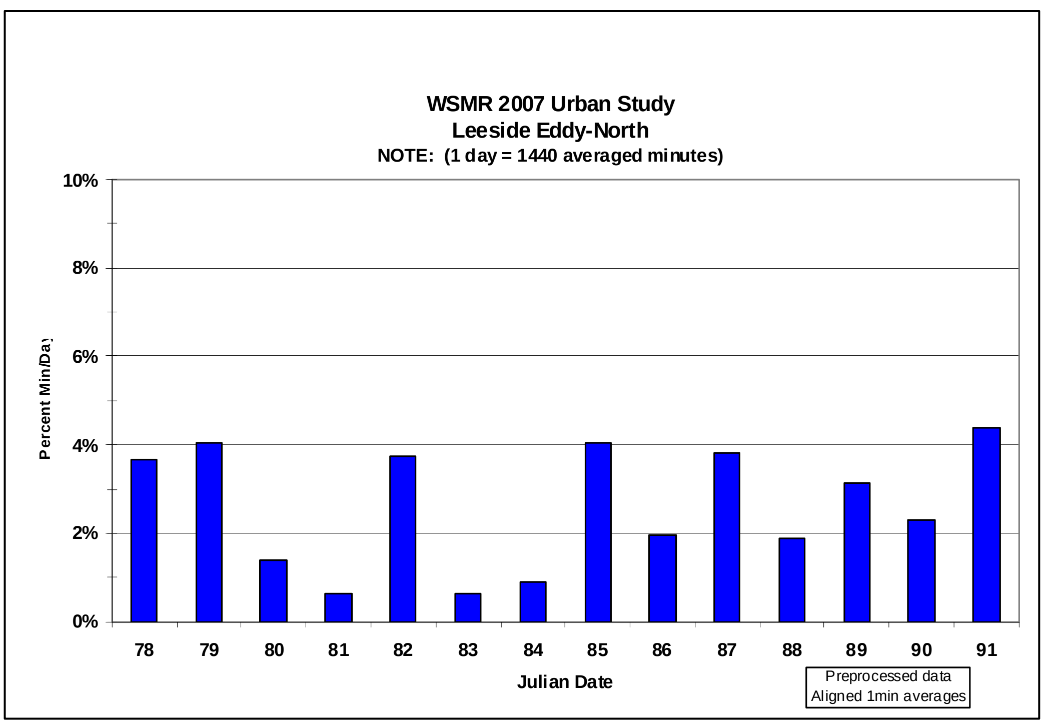

Figure 7. Percentage of the Day in Which the North Leeside Eddy Was Observed.

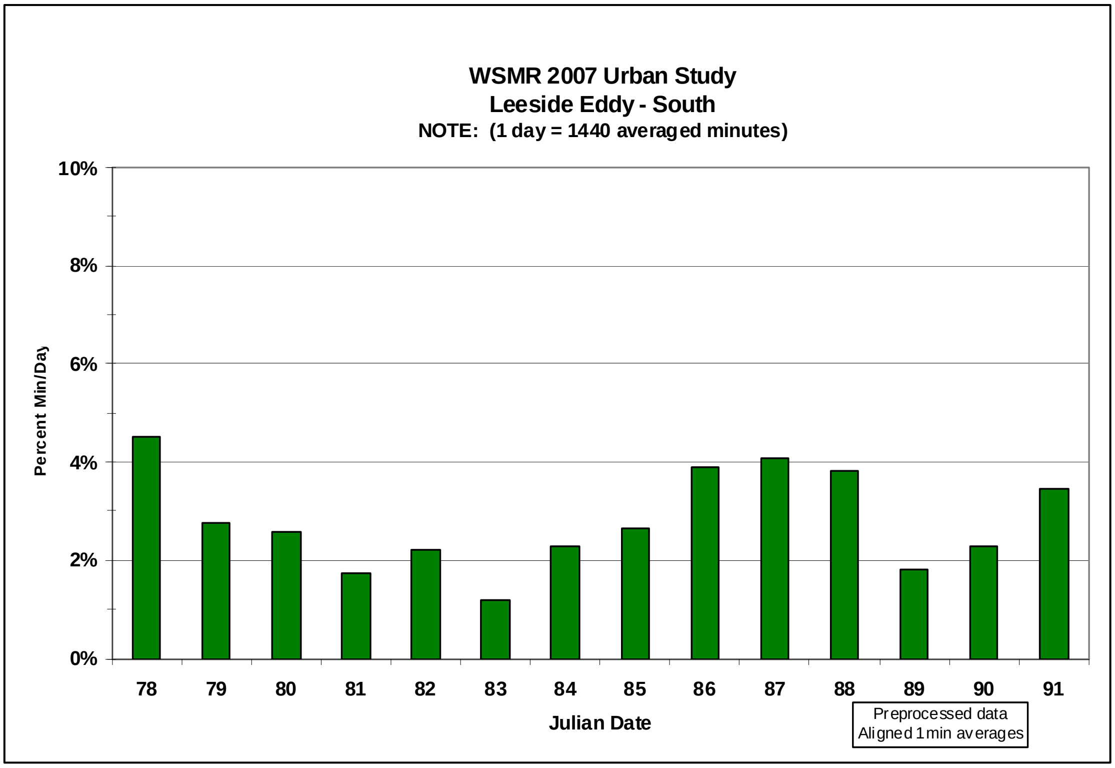

Figure 8. Percentage of the Day in Which the South Leeside Eddy Was Observed.

4.6 Airflow Features Discussion

Table 2 summarizes each airflow feature and their averaged daily occurrence. Some of the airflow features reported unusually low percentages of occurrences per day. These may be a function of the atypical climatological conditions observed. That is, unlike the earlier WSMR Urban Studies, the attributes of the 'windy season' as defined by the New Mexico climatology were not as pervasive during W07US. In addition to the climatological anomaly, the leeside eddy feature had another hurdle. When the field design was created, the subject building had two two-story evergreen-type trees on the northeast and southeast corners of the building. In previous studies, with the trees present, the eddy features were easily verified. The sudden, unexpected removal of these trees just prior to *W07US* cascaded into an intense, two-week reassessment of the leeside eddy features within the field design. Using the computer model (which had no morphology), as well

Airflow Features	Frequency of Occurrence/Day
1. Velocity Acceleration	NE: 33% SE: 38%
2. Velocity Deficit	NE: 33% SE: 38%
3. Cavity Flow – Northeast	NE: 4(+/-3) %
4. Cavity Flow – Southeast	SE: 8(+/-6)%
5a. Reattachment Zone – North	N: 39(+/-14)%
5b. Reattachment Zone – East	E: 11(+/-3)%
5c. Reattachment Zone – South	S: 26(+/-11)%
6. Canyon Flow – North	N: 21(+/-12)%
7. Canyon Flow – South	S: 18(+/-12)%
8. Canyon Flow – West	W: 42(+/-15)%
9. Leeside Eddy – Northeast	NE: 3(+/-1)%
10. Leeside Eddy – Southeast	SE: 3(+/-1)%
	All flow patterns were observed.

Table 2. *W07US* Airflow Feature Occurrence Summary. Each compass reference is with respect to the single subject building.

as numerous white-feather and parking lot dust releases to help trace the “new” eddy, the subsequent field design sketched the two leeside eddies with much larger diameters. To quantitatively capture the airflow pattern from this enlarged feature required additional unavailable equipment, along with investigating the safety requirements for crossing a public walkway. In short, the practical solution was to re-engineer the partial tower booms so that they’d extend to the very edge of the public walkway. While this wouldn’t necessarily reach the eddy’s perimeter flow, the inner edge of the eddy was expected to be traceable.

5. SUMMARY

ARL conducted the third of three urban studies in southern New Mexico entitled, *WSMR 2007 Urban Study* (*W07US). W07US* investigated the stability and airflow patterns around and above a single urban building. The field study was executed during the March New Mexico climatological “windy season” to optimize flow patterns over the subject building. The coincident March equinox enhanced the stability investigation by minimizing the heating/cooling biases over a 24-h cycle.

The weather conditions during the data acquisition period ranged from calm to windy (sustained winds greater than 10 m/s). The overall trend, however, was that there were more low wind days than in previous Studies. This scenario improved the stability research opportunities, with 74% of the days sampled reporting the less expected stable urban environment. Unique from the previous two studies, the building’s southwest side (Fetch) reported the most frequent occurrence of stable conditions. Consistent with the previous studies, the time period in which the majority of stable conditions reported was between 2100–0300 LT.

The airflow features targeted for verification of occurrence were: velocity acceleration (over the roof), velocity deficit (leeside of roof), cavity flows, reattachment zone flows, canyon flows, and leeside eddies. All features were verified and their averaged frequency of occurrence per day was assessed based on the field study design and an idealized scenario. Table 2 summarizes the averaged statistical representation for each feature. The low percentages of some airflow features may be a function of the atypical climatological conditions and/or a change in morphology. Of note is that all days sampled reported evidence of each targeted airflow feature.

The stability and airflow qualitative assessment was the first step in the larger goal to parameterize the various airflow and stability features. This assessment considered only the ideal scenarios for each feature. The next step is to investigate and quantify the many non-ideal scenarios in which these features occurred.

6. REFERENCES

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