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Analysis of the 18 July 2005 Microburst Wind Event at Phoenix Sky Harbor Airport: A Comparison of the WSR-88D and TDWR Radars

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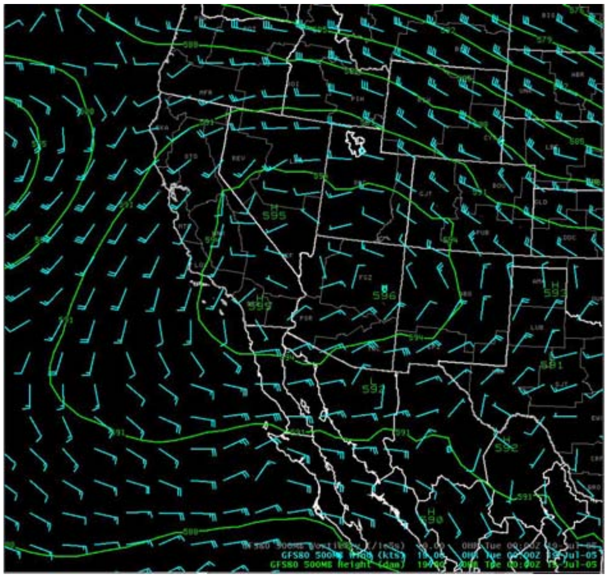
Introduction:

On the evening of 18 July 2005, several clusters of rather innocuous looking thunderstorms developed over the Phoenix metropolitan area. At 11:18 MST (0618 UTC 19 July), an isolated convective cell produced a peak wind gust of 67 knots (77 mph) as measured by the Phoenix Sky Harbor ASOS. Several storage buildings and airport hangers at Sky Harbor Airport suffered significant damage from this microburst.

Although the KIWA WSR-88D radar indicated several storm features indicative of microburst occurrence, including a weak divergent “footprint” in the low-level base velocity data, it failed to properly resolve the magnitude of the wind. This was not surprising given the temporal and spatial character of the event, the distance the event occurred in relation to the KIWA RDA site (25 nm), and the sampling strategy employed by the KIWA WSR-88D. The Phoenix FAA Terminal Doppler Weather Radar (TDWR) located only 6 nm west of Sky Harbor Airport was able to more accurately resolve the magnitude and duration of the microburst. This paper will examine the synoptic situation, the radar evolution of the event from both the WSR-88D (KIWA) and TDWR (TPHX) perspectives, and will conclude by summarizing the advantages of utilizing the TDWR in future warning operations.

Synoptic Background:

The upper air analysis during the evening of 18 July 2005 (valid at 0000 UTC 19 July 2005) consisted of a strong upper level high at 500hPa, centered over far northern Arizona (Figure 1) with a corresponding 300hPa anticyclone centered further west near Los Angeles, California (KLAX) (Figure 2).



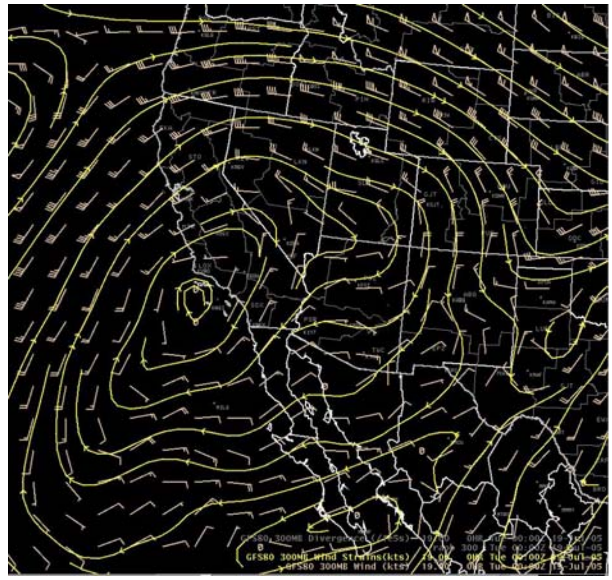


Figure 1. GFS initial analysis of 500hPa heights and winds valid 0000 UTC 19 July 2005.

Figure 2. GFS initial analysis of 300hPa winds and streamlines valid 0000 UTC 19 July 2005.

This juxtaposition of the high pressure centers produced a generally weak east to northeast flow in the 700-300hPa layer over south-central Arizona. The 300hPa streamline analysis indicated an area of weak diffluence near the Arizona/New Mexico border at 0000 UTC, which the GFS model indicated would spread west over south-central Arizona by 0600 UTC. This type of quiescent upper level pattern with minimal baroclincity or quasi-geostrophic forcing is very typical over south-central Arizona during the summer convective season (July through early September). At lower levels, the boundary layer moisture was on the lower end of what is typically observed during the summer convective season as the 850hPa dew point temperatures at KPSR and KTUS were both 9 C, where 8 C is typically referred to as the lower bound of the monsoonal moisture boundary (Vasquez, personal communication) (Figure 3). The Phoenix Sky Harbor surface dew point valid at 0000 UTC was 50 F, also below the climatological normal of 55 F for mid-July.

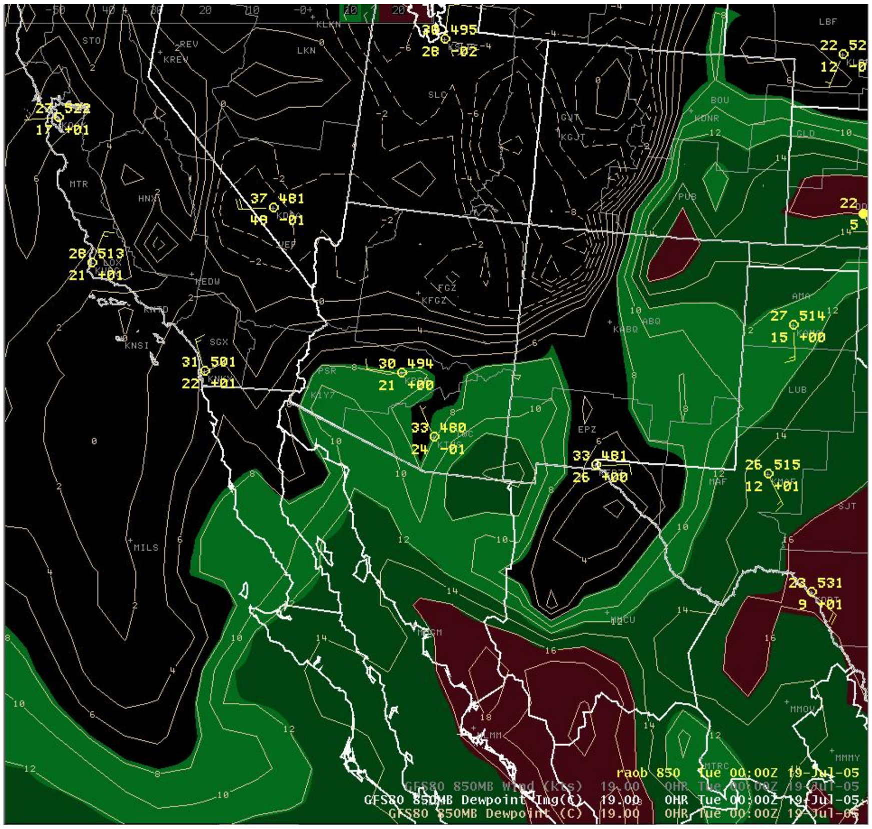
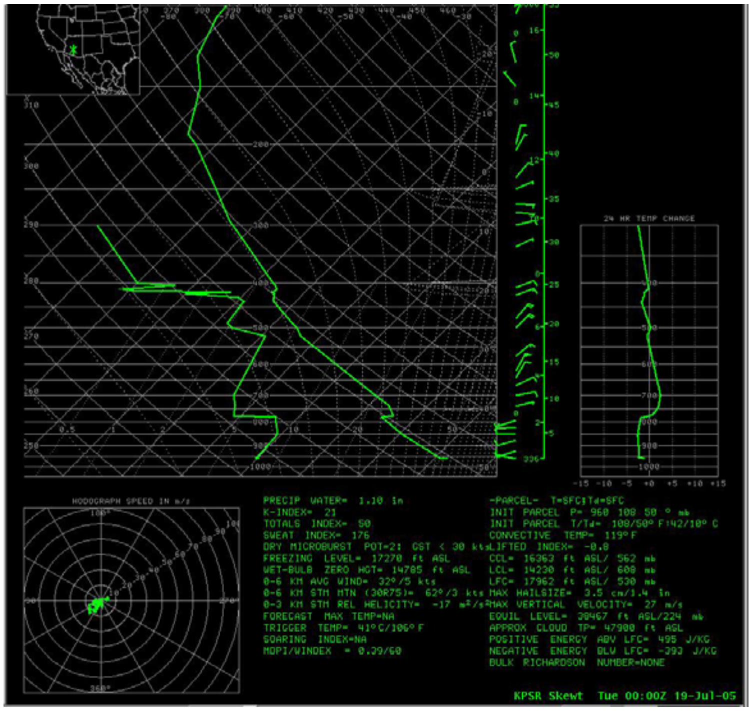


Figure 3. 850hPa RAOB plot data and GFS initial 850hPa dew point analysis valid at 0000 UTC 19 July 2005. Dew point above 8 C is shaded.

Thermodynamically, the KPSR sounding valid at 0000 UTC on 19 July 2005 indicated only marginal instability (Figure 4). The lifted index (LI) was computed to be -0.8 C, with a mixed layer convective available potential energy (MLCAPE) value of ~500 Jkg^{-1} (using a mean mixing ratio of 8 g/kg in the lowest 100hPa). In addition, a low level inversion present at about 780hPa indicated the atmosphere would be capped (CIN ~ 390 Jkg^{-1}) at least during the early evening. Thus, in order for widespread storm initiation to occur, deep outflow boundaries would be required to lift parcels to the level of free convection (LFC). Visually, the sounding did exhibit a typical "inverted-V" type structure, with a deep, nearly dry adiabatic mixed layer to 500hPa, a large temperature-dew point spread at the surface, and a high LFC height of nearly 18,000 feet MSL.



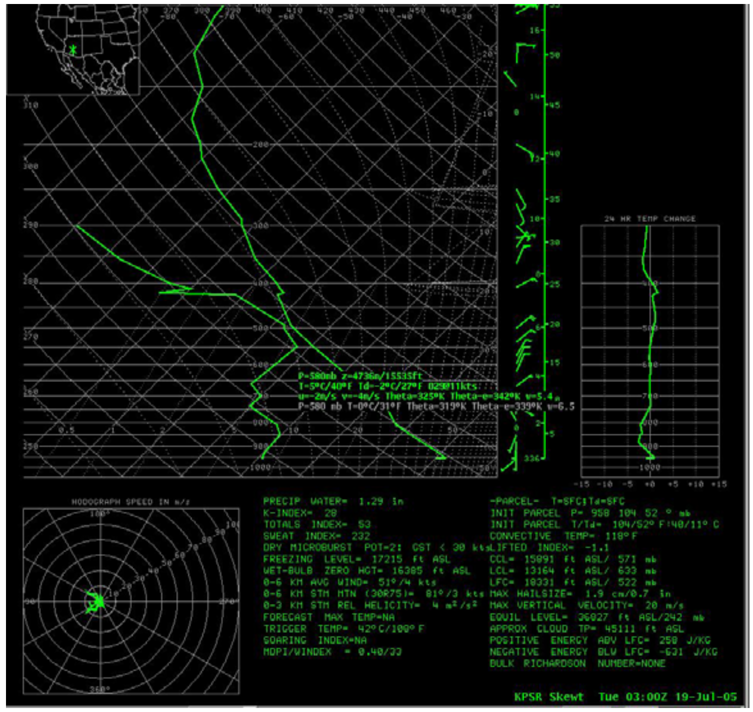


Figure 4. KPSR sounding valid at 0000 UTC 19 July 2005.

Figure 5. KPSR sounding valid at 0300 UTC 19 July 2005.

A special KPSR sounding valid at 0300 UTC indicated some subtle, but important changes had taken place between 0000 UTC and 0300 UTC (Figure 5). Thermodynamically, the environment had become slightly more unstable due to some modest warming in the surface to 800 hPa layer. This warming eroded the cap somewhat above 800hPa (CIN ~ 300 Jkg^{-1}) and also resulted in a slightly more unstable LI of -1.1 C. In addition, some further moistening occurred in the 550-450 hPa layer, which brought it almost to saturation. Temperatures above the LFC ranged from 0 C to -10 C; thus any precipitation forming above that layer would likely contain at least some ice crystals, thus enhancing the threat for stronger downburst winds via sublimation.

From a situational awareness (SA) perspective, this synoptic regime is fairly representative of a typical monsoonal-type flow pattern observed during the summer convective season over the south-central Arizona deserts. An east to northeast steering flow in the 700-300 hPa layer supported the potential for storms to discretely propagate toward Phoenix from the higher terrain. The combination of marginal instability, weak vertical wind shear, and limited upper level forcing suggested only limited storm organization with ordinary pulse storms the preferred convective mode. The inverted-V sounding profile indicated that strong downburst winds were possible with any storms that developed.

Thunderstorm Initiation and WSR-88D/KIWA Analysis:

Thunderstorms initiated over the higher terrain well north and east of Phoenix around 2000 UTC on 18 July 2005, and propagated very slowly to the west-southwest towards Phoenix during the late afternoon and early evening. Around 0300 UTC 19 July, new storms formed along a strong gust front originating from an intense cluster of cells centered approximately 80 nm northeast of Phoenix (Figure 6). As the gust front pushed west-southwest during the next 1.5 hours, new isolated convective storms developed along the leading edge, which produced additional storm scale outflow, providing further enhancement of the convective line.

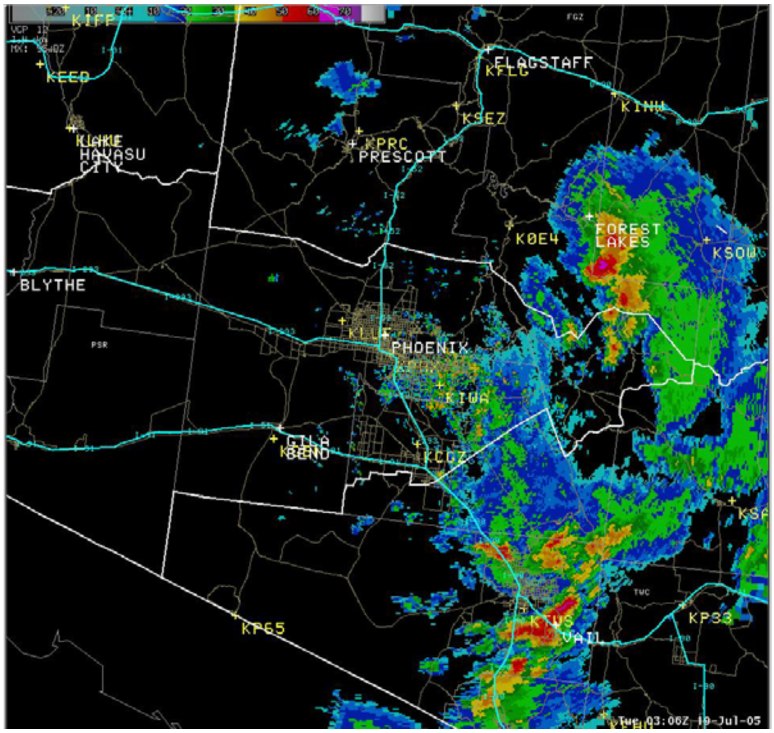


Figure 6. KIWA composite reflectivity valid at 0306 UTC 19 July 2005.

At approximately 0507 UTC, the leading edge of this gust front reached Phoenix Sky Harbor Airport (KPHX), and a wind gust of 43 knots (50 mph) was reported at the Phoenix ASOS. Base velocity data from KIWA resolved the peak wind speeds in this leading gust front quite well. An examination of the 0.5 degree velocity cut at 0507 UTC indicated the maximum outbound velocity sampled over KPHX was approximately 40 knots (46 mph) (Figure 7).

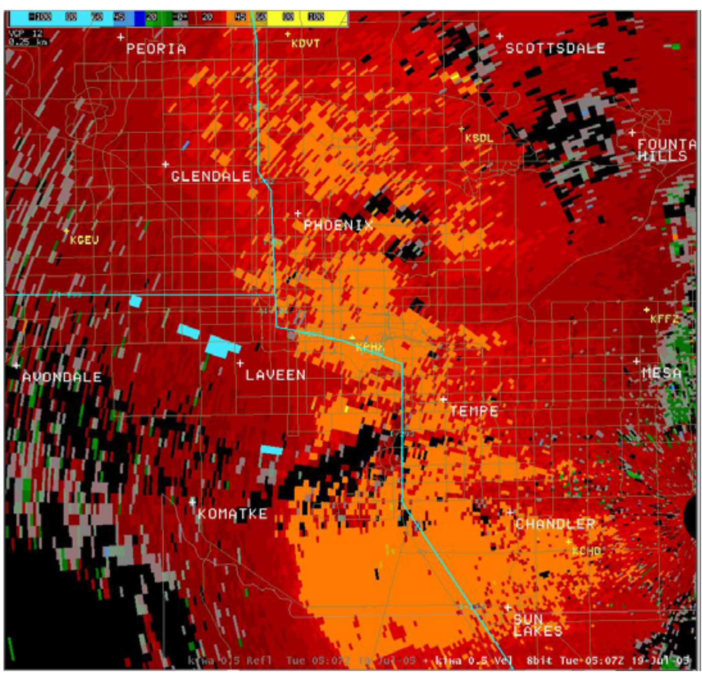


Figure 7. 0.5º KIWA base velocity valid at 0507 UTC 19 July 2005.

As the gust front pushed west through the Phoenix metro area, additional “pulse” thunderstorms continued to develop primarily along the leading edge. At approximately 0530 UTC, a slightly more intense line of cells (not shown) formed about 30 nm northeast of KPHX, well behind the leading gust front. Around 0545 UTC, this cluster of cells began to propagate toward the south-southwest, deviating from the predominant westerly movement of the convective line. One particular convective cell in this cluster moved directly over Sky Harbor Airport between 0615 and 0620 UTC (Figures 8 and 9). At 0618 UTC, a peak wind gust of 67 knots (77 mph) was recorded at the Phoenix ASOS.

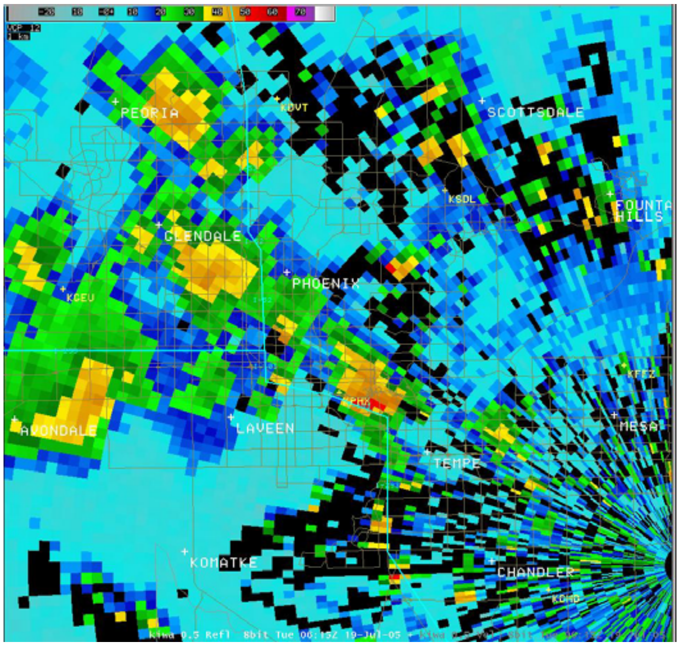


Figure 8. 0.5º KIWA reflectivity valid at 0615 UTC 19 July 2005 centered just north of Phoenix Sky Harbor Airport (KPHX).

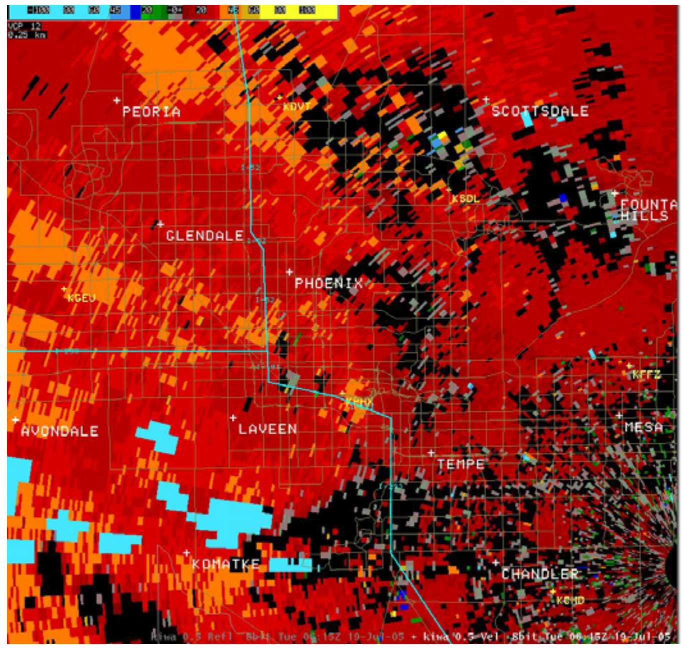


Figure 9. 0.5º KIWA velocity valid at 0615 UTC 19 July 2005 centered just north of Phoenix Sky Harbor Airport (KPHX).

Examination of KIWA-derived products revealed that the storm cell briefly intensified just prior to reaching Phoenix Sky Harbor Airport. Table 1 below summarizes the cell trends of maximum reflectivity (max dBZ), legacy vertically integrated liquid (VIL), and Echo Tops (ET) during the period 0603 UTC through 0628 UTC. The intensification was not deemed sufficient to warrant the issuance of a severe thunderstorm warning, as several other storms with similar, or even slightly stronger, reflectivity characteristics had not produced severe weather earlier that evening.

Table 1: Cell Trends of the Microburst Producing Storm

Time	Max dBZ	VIL (kg/m^2)	ET (thousand feet)
0603 UTC	50-55	20-25	30-35
0607 UTC	55-60	30-35	30-35
0611 UTC	55-60	35-40	35-40
0615 UTC	60-65	20-25	40-45
0620 UTC	50-55	10-15	30-35
0624 UTC	50-55	5-10	30-35
0628 UTC	45-50	5-10	20-25

KIWA base velocity data gives some indication that localized strong outflow occurred over and near Sky Harbor Airport; however, its exact magnitude was not well resolved. The 0.5 degree base velocity data from 0620 UTC indicates an inbound-outbound velocity couplet indicative of a downburst “footprint” (East of KPHX in Figure 10); however, the max outbound velocity at any gate was approximately 41 knots, with a max inbound velocity of approximately 9 knots. It should be noted that microburst winds did not appear to be maximized perpendicular to the radials, such that some loss in peak magnitude was likely. One other important note is that the KIWA WSR-88D is located approximately 23 nm east-southeast of Sky Harbor Airport. Therefore, the lowest elevation the radar is able to sample above Sky Harbor is approximately 1540 feet AGL.

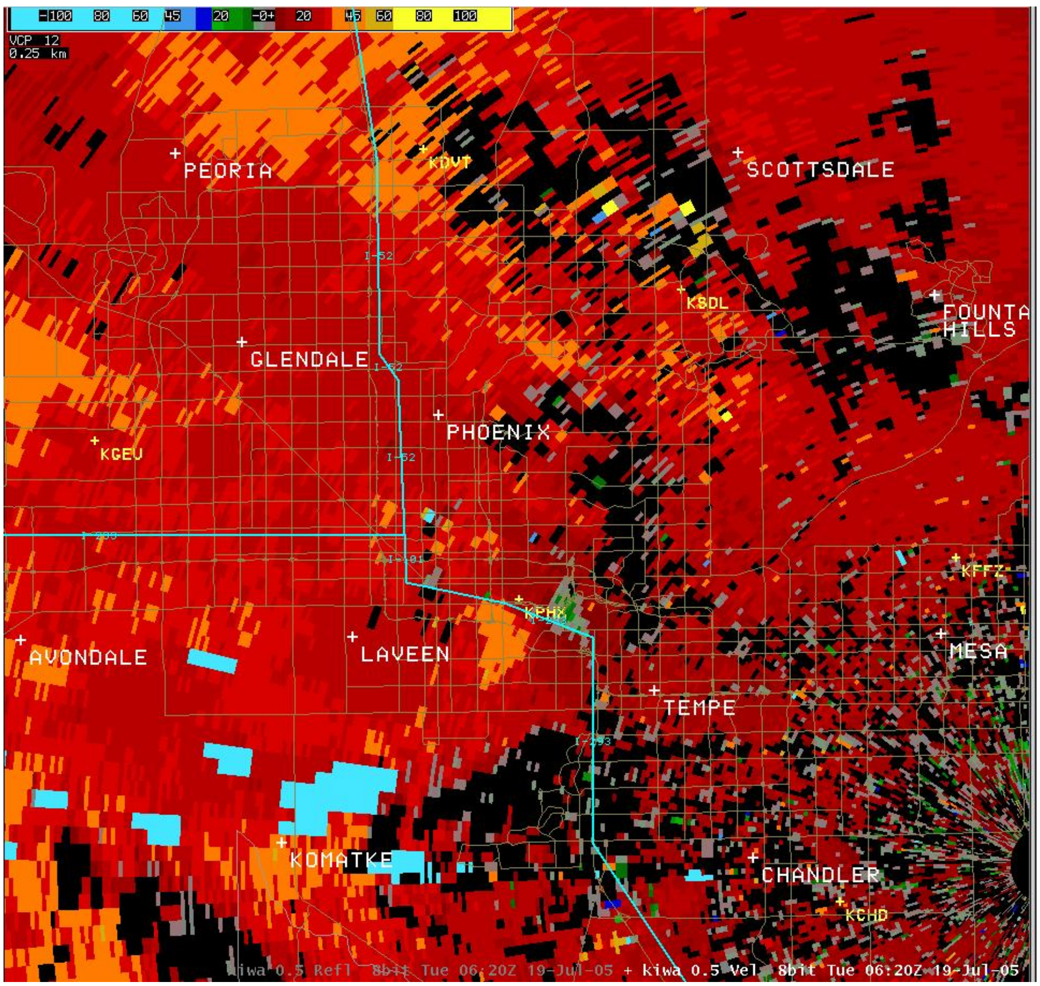


Figure 10. 0.5º KIWA base velocity valid at 0620 UTC 19 July 2005.

Terminal Doppler Weather Radar (TDWR) Background Information:

The TDWR was designed to provide high temporal and spatial radar data over and near major airports. The Phoenix FAA Terminal Doppler Weather Radar (TPHX) is located only 6 nm west of Sky Harbor Airport. Thus, WFO Phoenix warning forecasters have noted several advantages of TDWR data during warning operations: 1) during TDWR "hazardous" operation mode, the 0.6 degree base velocity products are updated approximately once per minute, while the WSR-88D provides an updated 0.5 degree base velocity product only once every four minutes in VCP-12; 2) TDWR base velocity (reflectivity) data resolution is currently 150 meters (300 meters) within 90 kilometer (48 nm) of the radar site; whereas WSR-88D 8-bit velocity (reflectivity) data is 250 meters (1000 meters) within 124 nm of the radar site; 3) the TDWR provides excellent low level coverage over a majority of the Phoenix metropolitan area (with a significant improvement over the western metro area); 4) since the TDWR is located west of Sky Harbor while the KIWA WSR-88D is located east of Sky Harbor, the TDWR provides the user a different viewing angle for storms over metro Phoenix. Figure 11 depicts locations of the TDWR radar (TPHX), the WSR-88D radar (KIWA), and Phoenix Sky Harbor Airport (KPHX).

However, the TDWR is not without it weaknesses. Because the TDWR is a C-band radar, while the WSR-88D is an S-band radar, range folding and velocity aliasing occur more frequently with the TDWR (examples will be shown later). Thus, the TDWR velocity dealiasing and range unfolding algorithms typically have a higher failure rates. Due to its proximity to the metropolitan Phoenix area, TDWR low elevation scans are subject to beam blockage and ground clutter contamination (especially south of the radar). Finally, during summer 2005, display capabilities of TDWR data were limited to a separate PC-based system which did not possess high-quality background maps and was not as "user-friendly" as AWIPS. (Note: Since December 2005, TDWR data has been ingested and displayed in AWIPS.) In this study, one-minute base velocity data and six-minute TDWR reflectivity data will be highlighted to illustrate the strengths and weaknesses of the TDWR in NWS warning operations.

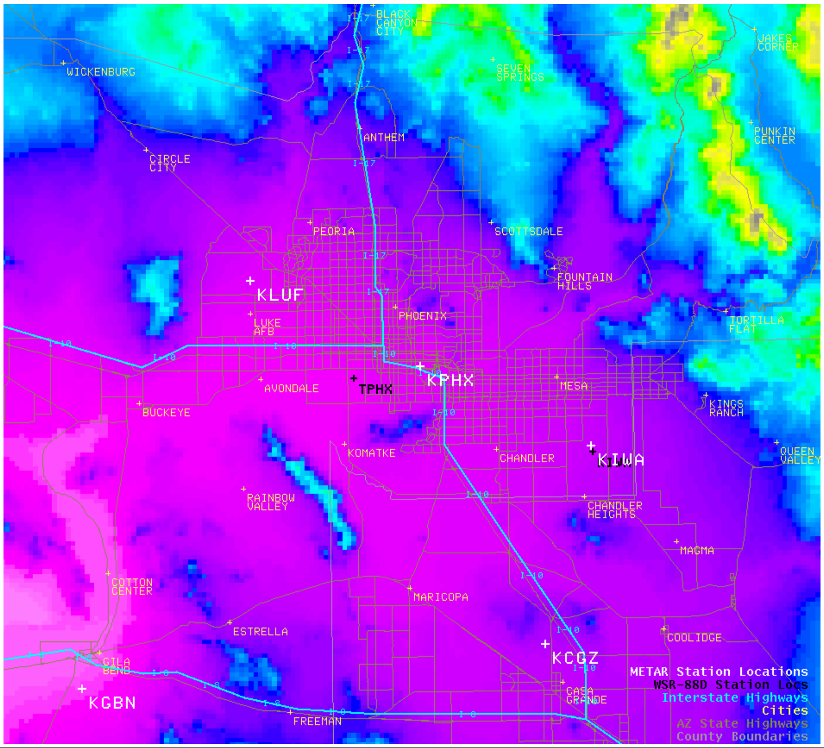


Figure 11. AWIPS high resolution topographic display of the Phoenix Metropolitan area including the locations of Phoenix Sky Harbor Airport (KPHX), the Phoenix WSR-88D (KIWA), the Phoenix Sky Harbor Terminal Doppler Radar (TPHX), major interstates, roadways, and selected cities/towns in the Phoenix metropolitan area (approximate dimension of this display is 90 x 90 miles).

TDWR/TPHX Analysis of the Microburst:

The base velocity and reflectivity data from the TDWR will be examined more closely in this section. Figures 12 through 14 show a series of one-minute base velocity (0.6 degree) images from TPHX during the timeframe 0617 – 0619 UTC. Of particular interest is the area of enhanced inbound velocity occurring almost due east of TPHX. At 0617 UTC, TPHX indicated inbound velocity values in the -34 to -50 knot range (light blue shading) with a few pixels of -50 to -64 knots (lightest blue) (Figure 12). At 0618 UTC, the color within the enhanced velocity core changes abruptly from a light blue shade (-34 to -50 knots) to one of a red shade, representing outbound velocity values of +20 to +26 knots (Figure 13). Then at 0619 UTC, the red shading (outbound velocity) disappears, and only strong inbound velocities (blue shading) are displayed (Figure 14).

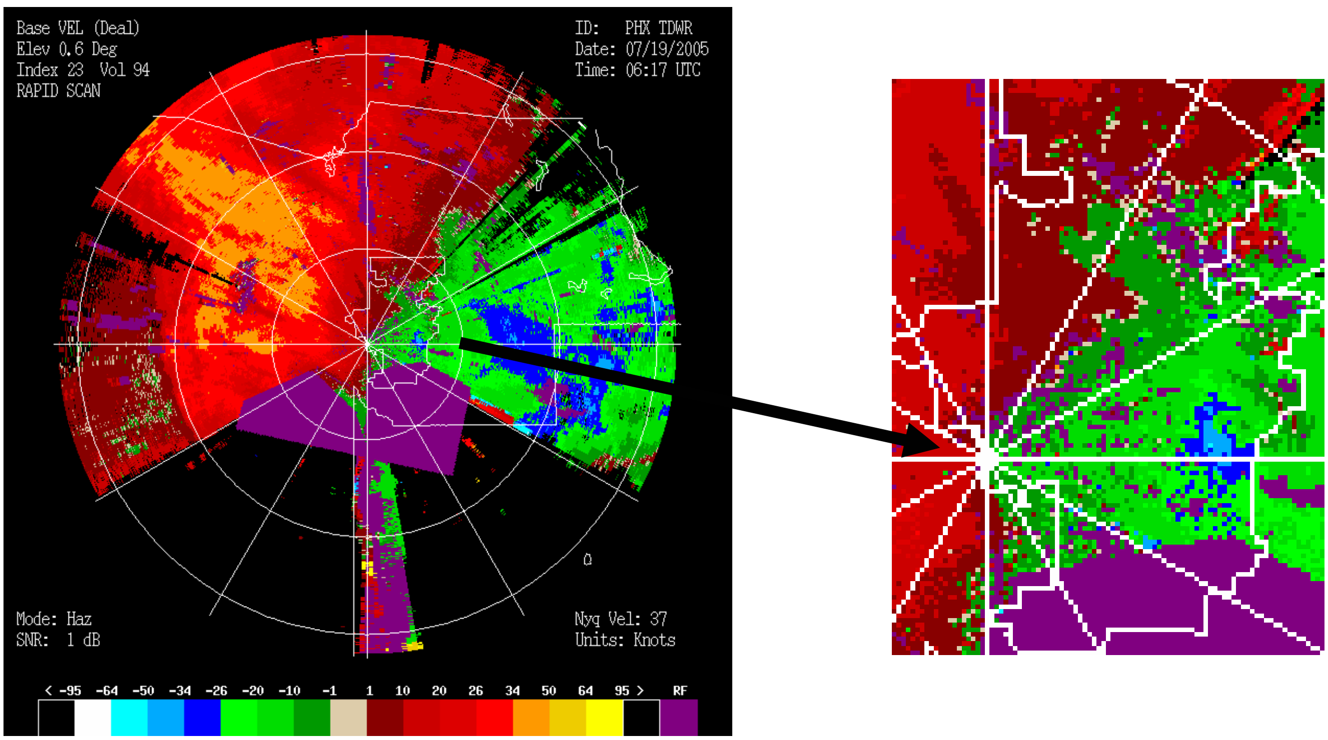


Figure 12. 0.6 degree base velocity from TPHX at 0617 UTC. Of particular interest is the area of strong inbound velocity values (-34 to -50 knots as depicted by the light blue shading) occurring almost due east of TPHX. Zooming in on this area reveals a few pixels in the -50 to -64 knot range (very light blue shading) near the leading edge of velocity gradient.

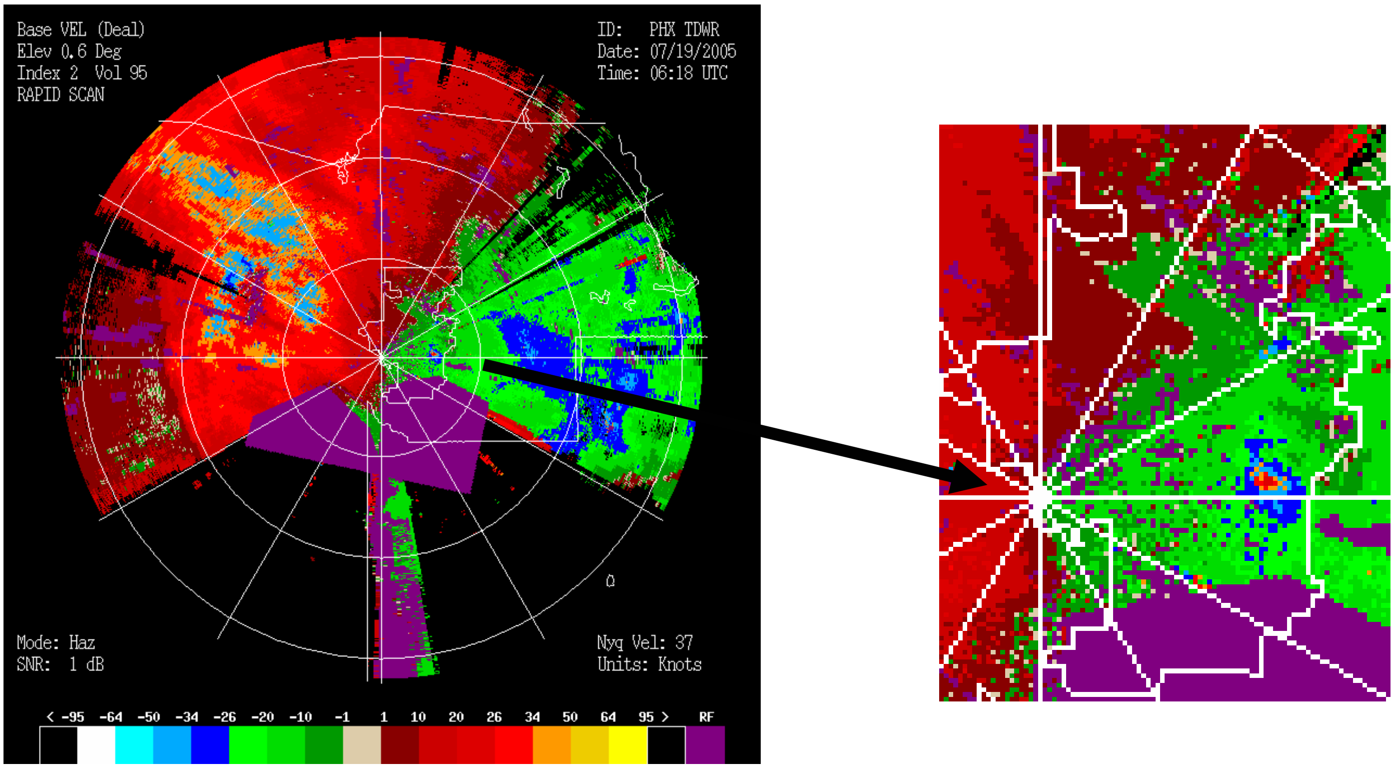


Figure 13. 0.6 degree base velocity from TPHX at 0618 UTC. Note that the center of the strong velocity core changes abruptly from light blue (inbound) to red (outbound). This is an example of improper velocity dealiasing.

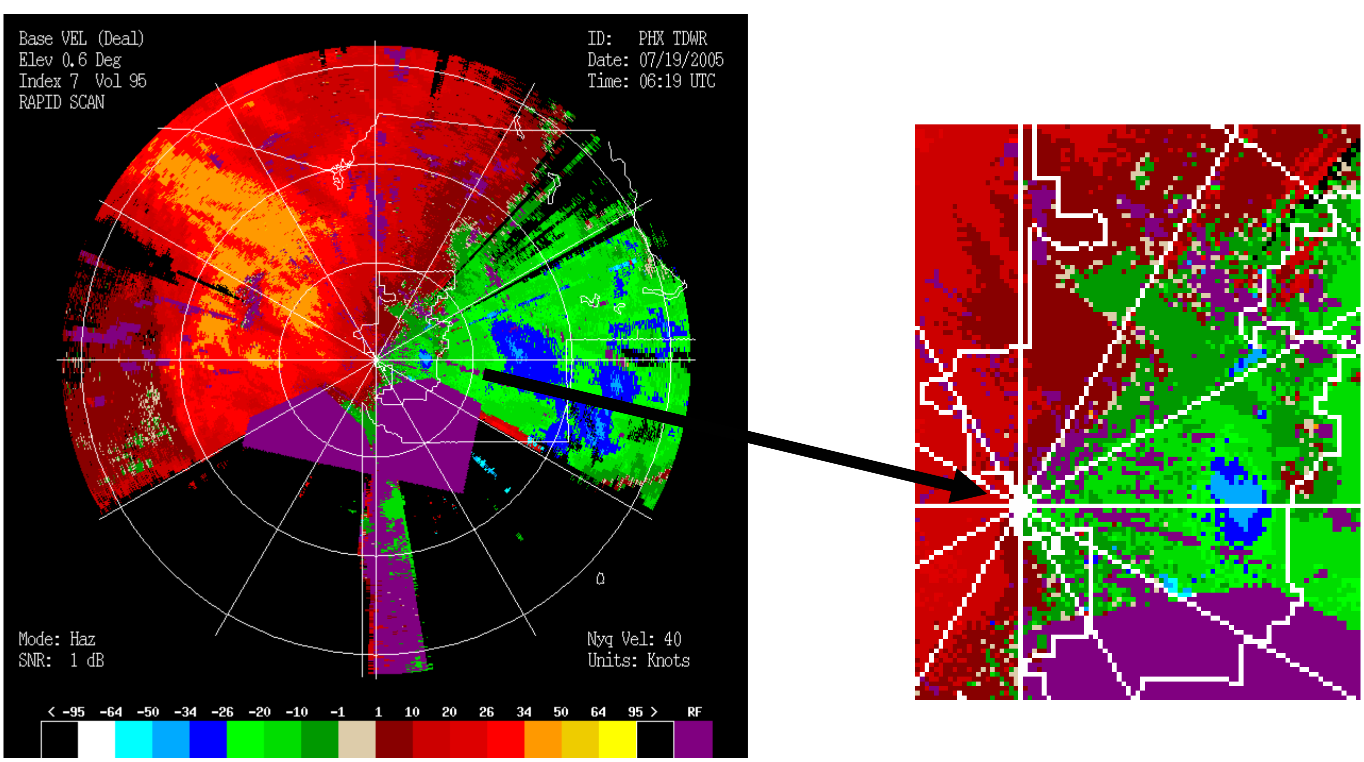


Figure 14. 0.6 degree base velocity from TPHX at 0619 UTC. Note that the outbound velocity values (red shade) have disappeared, with only inbound velocities (light blue shade) depicted once again.

At 0618 UTC, base velocity values near the center of the apparent microburst appear to have incorrectly "folded over" into the outbound velocity spectrum (velocity dealisaing problem). Discrete sampling of individual pixels was not possible on the PC display; however, the best estimate of the velocity values in the improperly dealiased area fall in the +20 to +26 knot outbound range (by visual estimation). The following equation can be used to determine possible velocity values:

$$V_p = V_{fg} + n(2\ V_{max})$$

where V_p is a possible velocity, V_{fg} is the first guess velocity (~20 knots), V_{max} is the maximum unambiguous velocity (37 knots) and n = (0, ±1, ±2…). Since radial velocity in the area of interest appears to be toward the radar (inbound), a negative velocity is desired. Thus, the most likely estimate of V_p occurs when n = -1:

V_p = *20 knots + (-1) (2 * 37 knots) = -54 knots (inbound)*
if n = -2, V_p = -128 knots, probably too strong!

Thus, the TDWR appears to be indicating a small, but significant area of severe winds (i.e. winds > 50 knots (58 mph)) near Phoenix Sky Harbor Airport at approximately 0618 UTC which was confirmed when the KPHX ASOS reported a peak wind of 67 knots (77 mph). As was mentioned above, velocity dealiasing can make proper interpretation of TDWR velocity data problematic. However, if velocity dealiasing errors occur, very strong winds are often the primary cause.

Resolution Comparison of the TDWR versus the WSR-88D

Another interesting aspect of this case is the difference in resolution between the TDWR and the WSR-88D as seen near the time of microburst occurrence. Figure 15 provides a comparison of the base low level reflectivity images from the two local Doppler radars. The improved range and azimuthal resolution provided by the TDWR allows the warning forecaster to view details of the cell not observable via the WSR-88D; including how the storm near Sky Harbor evolved into a small bow-shaped echo, indicative of a very strong outflow. Due to siting differences, base data from TPHX produces a viewing height of approximately 445 feet AGL above KPHX versus 1540 feet AGL in KIWA. This difference of nearly 1000 feet can make a significant impact in detecting low level features (i.e. downburst signatures).

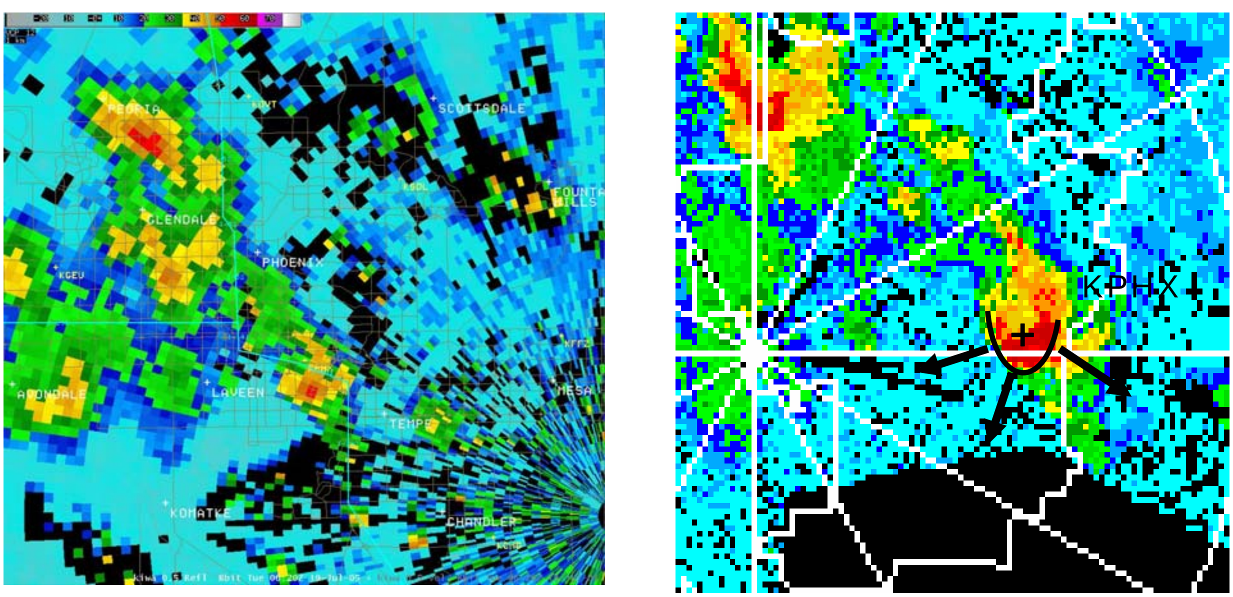


Figure 15. Base reflectivity images valid near the time of the microburst. (a) KIWA WSR-88D 0.5 degree base reflectivity valid at 0620 UTC. (b) TPHX 0.6 degree base reflectivity valid at 0618 UTC, including approximate location of KPHX (plus sign).

Similarly, Figure 16 provides a comparison between the low level base velocity data from the TDWR and WSR-88D. Again, the higher resolution of the TDWR coupled with the fact that it was much closer to the storm than KIWA allows it to better resolve small scale velocity features. Even with velocity dealiasing, it is able to depict the magnitude of the winds speeds, as well as the overall structure of the microburst, including subtle features in the velocity field not seen in the coarser resolution of the WSR-88D data.

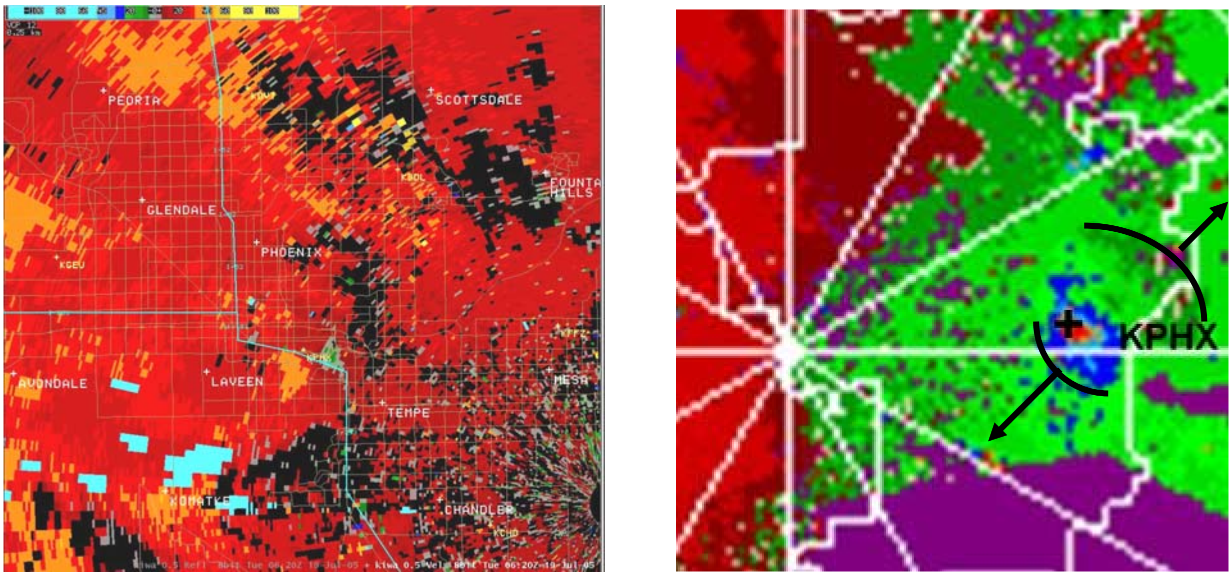


Figure 16. Base velocity images valid near the time of the microburst. (a) KIWA WSR-88D 0.5 degree base velocity valid at 0620 UTC. (b) TPHX 0.6 degree base velocity valid at 0618 UTC including the approximate location of KPHX.

Event Discussion:

The size, strength, and time span of this event fit Fujita's classic definition of a microburst: "A small downburst with its outburst, damaging winds extending only 4 km (2.5 miles) or less," as well as "a short life of less than 10 minutes." Reports received at the Phoenix WFO confirmed the areal extent of the damage was confined to a relatively small region in and around Phoenix Sky Harbor Airport. In addition, the high winds generated from the storm cell persisted for less than 10 minutes.

A severe thunderstorm warning was NOT issued for the storm that produced the strong and damaging winds over and near Phoenix Sky Harbor Airport on the evening of 18 July 2005; however, several short-term forecasts (NOWs) were issued prior to the event highlighting the potential for strong winds. Numerous "pulse" type storms occurred over the Phoenix metropolitan area that evening, some of which appeared stronger from a reflectivity standpoint than the cell that produced the microburst (i.e. greater max reflectivity, higher VIL, longer lifetimes, etc.). However, the only report of damaging winds that night occurred with the storm examined in this paper.

Damaging winds occurred directly over a major airport hub and were actually measured by the Phoenix ASOS, which is quite rare considering the small spatial scale of the event. Even though microburst events occur rather frequently over and near the greater Phoenix area during the summer convective season, the 77 mph peak wind gust was the third strongest wind gust ever recorded at the official NWS observation site at Sky Harbor Airport during the period 1946-2005 (strongest gust: 86 mph on 7/7/1976; second strongest gust: 78 mph on 8/6/1978).

The environment in which the microburst-producing storm occurred ("inverted-V" sounding, with small CAPE and large DCAPE, coupled with a weak steering flow and weak vertical wind shear) is commonly observed over the Phoenix County Warning Area (CWA) during the summer thunderstorm season. Forecasters at WFO Phoenix expected storms over and near the Phoenix metro area to produce strong, gusty winds, with the possibility that one or more pulse cells would produce damaging winds. However, the evolution of this particular microburst-producing storm is still somewhat puzzling. Surface observations at KPHX revealed that the temperature fell from 105 to 98 F after gust front passage, while the dew point remained nearly steady (lowered 1 degree, from 56 to 55 F). Warning forecasters noticed this trend and assumed the environment behind the gust front would be more stable with somewhat lower cloud bases, thus reducing the threat for damaging winds from any storms that developed in this area. The area of greatest concern for wind damage was expected to remain near the leading edge of the gust front, where storms continued to actively "pulse up." However, no other reports of damaging winds were documented that evening.

Conclusions:

This event exemplifies some of the challenges faced by WFO Phoenix warning forecasters during the summer convective season. The low instability-weak vertical wind shear environment typically observed does not permit organized storm development, with poorly organized, short-lived "pulse" convective storms the favored mode. The limited spatial and temporal scales of microburst-producing storms often prove to be one of the most difficult scenarios in the warning decision-making process. Even after a thorough "post-mortem" examination of this event, information that would have allowed a warning forecaster to issue an effective severe thunderstorm warning with a minimum lead time of 5-10 minutes, while not issuing multiple "false alarm" severe thunderstorm warnings for other potent-looking cells, was not readily apparent. Improved interrogation tools and more rapid update cycles may be required before warning forecasters can warn for events while maintaining a high probability of detection (POD) coupled with a low false alarm rate (FAR).

The usefulness of interrogating TDWR data into the warning decision-making process, especially for storms near the greater Phoenix metropolitan area is readily apparent from this study. The benefits of the TDWR include higher base data resolution, faster base velocity update times, a different viewing angle, and proximity to a large population center and major airport hub. When used in conjunction with a good understanding of the mesoscale environment, the TDWR data can be a valuable tool for warning decision-makers. Now that the TDWR data stream is ingested into AWIPS software, forecasters will have a better opportunity to properly assess the potential for an individual storm to produce damaging winds over the Greater Phoenix metropolitan area.

Reference:

Fujita, T.T., 1985: "The Downburst." The University of Chicago, SMRP Research Paper No. 210, 122pp.