P1.2 SEVERE WEATHER OUTBREAK OVER PHOENIX ARIZONA ON 14 JULY 2002

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1. INTRODUCTION

Severe convective storms, dust storms, and localized flash floods are frequently observed over the lower desert of south-central and southeast Arizona during the summer convective season (late June-mid September). However, the first widespread severe thunderstorm outbreak of summer 2002, which occurred on 14 July, was particularly intense, especially over and near Phoenix, Arizona. Several modes of severe weather were observed in the Phoenix area: 1) widespread dust storm with near zero visibility and 17-26 m/s (40-60 mph) sustained wind; 2) damaging microbursts, with peak wind estimated near 45 m/s, caused extensive damage over Sky Harbor International Airport; and 3) unusually high rainfall rates (> 15 cm/hr) and associated flash flooding occurred over portions of central and south Phoenix. The Arizona Insurance Information Association reported that $45 million in property damage occurred as a consequence of the microbursts at Sky Harbor (Frederikson, personal communication, 2003), making this the second-costliest storm in the State of Arizona since 1971.

Severe weather was expected over Arizona during the afternoon and evening of 14 July; however, the brunt of the severe weather was expected to occur over southeast Arizona, to the south and east of Phoenix. This paper provides a brief review of the meteorological events which culminated in the severe weather outbreak, describes the outbreak over southeast and south central Arizona, including the Phoenix and Tucson WFO County Warning Forecast Areas (CWFAs), highlights the importance of situational awareness, and points out how difficult it is to provide meaningful severe weather outlooks, especially for the lower desert of south-central Arizona, during the summer convective season.

2. SYNOPTIC SITUATION

All-time record high temperatures were recorded across much of the western United States during the period 10-14 July 2002 as an anomalously strong area of mid-upper tropospheric high pressure affected the area. A peak 500 hPa height of 6020 gpm occurred over northern Nevada and southern Oregon on 11 July. The area of high pressure slowly weakened and drifted southeast during the period 12-14 July. By 1200 UTC 14 July, the upper level high was centered over southern Utah with a maximum height of 5940 gpm.

Stronger-than-normal east to northeast wind occurred throughout the mid-troposphere over much of Arizona during the period 12-14 July, which resulted in above-average vertical shear in the low-mid troposphere. The Storm Prediction Center (SPC), noting that vertical shear favored development of longer-lived multicellular storms/MCSs, issued a severe thunderstorm watch for a portion of northwest Arizona on 12 July, and a portion of central and south-central Arizona, including the Greater Phoenix area, on 13 July, when a rather strong upper level disturbance moved across northern and central Arizona. Indeed, MCS development and severe weather occurred in and near the watch areas on 12 and 13 July; however, severe thunderstorms did not occur over the Greater Phoenix area the evening of 13 July.

Low-level moist advection, in the form of a "gulf surge", occurred over the lower Colorado River valley and far southeast California the night of 13-14 July as Tropical Storm Cristina tracked west-northwest over the eastern Pacific Ocean. If other meteorological conditions are favorable for severe convective storms, the increase in low level moisture associated with a "surge" event can be great enough allow severe storms to develop over the lower desert of southern Arizona. However, the surge extended upward only to around 1200 m (4000 feet) AGL, according to the KYUX WSR-88D, and surface dew points over south central Arizona, including the Greater Phoenix metropolitan area, only rose to 13-14 C (mid 50s F) as a consequence of this surge event. Surface dew points of this magnitude are considered marginal, at best, for supporting deep convective storms over the lower desert of south-central Arizona during the summer convective season.

Kinematic and thermodynamic factors derived from the 14 July 1200 UTC Tucson sounding which supported the potential for severe thunderstorm development over southeast Arizona later in the day included: 1) unusually large convective available potential energy (CAPE) values, with MLCAPE near 2500 J/kg, 2) 700-500 hPa

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mean layer vertical wind shear of 30 knots, 3) inverted-V thermodynamic profile, 4) a weak capping inversion near the 750 hPa level, and 5) favorable NE-to-SW steering flow from higher terrain toward the lower desert. The 1200 UTC Phoenix research sounding, funded by SRP, revealed: 1) MLCAPE (sfc-750 hPa) of 1950 J/kg, and 2) a 700-500 hPa mean layer vertical wind shear of 20 knots. So, conditions were more unstable and vertical wind shear was greater over and near Tucson, situated 160 km (100 miles) south-southeast of Phoenix. Although the local environment was quite unstable, no well-defined synoptic-scale trigger was evident via water vapor satellite images, upper air plot data, or numerical model initial condition analyses. No short wave trough was approaching Arizona underneath the strong mid-level high center. Morning area forecast discussions from Tucson and Phoenix focused on the degree of instability and favorable steering flow. Storms were expected to become strong to severe over the higher terrain, then propagate west over portions of the lower desert during the evening. Based on the morning Tucson sounding, the Tucson WFO increased the chance for storms and included enhanced wording in its zone forecasts for the upcoming afternoon and evening.

3. SEVERE WEATHER EVOLUTION OVER SOUTHEAST ARIZONA

Skies were clear over southeast Arizona until 1900 UTC on 14 July, when convective temperatures were reached in the highest mountains of southeast Arizona and west-central New Mexico. In just one hour, thunderstorms were approaching severe limits over the Chiricahua, White, Huachuca and Whetstone Mountains, with the 2000 UTC visible GOES-10 image (not shown) depicting overshooting tops at these locations. The first Severe Thunderstorm Warning was issued on a cluster of storms over the Huachucas and Whetstones of far eastern Santa Cruz county, in extreme southern Arizona, at 2008 UTC. Meanwhile, thunderstorm outflows pushing southwest off the White and Gila Mountains in east-central Arizona produced dust storms with wind gusts of 17-22 m/s (40-50 mph) near Safford (KSAD).

A visible satellite image at 2100 UTC 14 July 2002 highlights the active convection over southeast Arizona, as well as several areas of storms along or near the Mogollon Rim in north-central and east-central Arizona (Figure 1).

At 2200 UTC 14 July, the NWS Storm Prediction Center (SPC), citing the degree of instability and vertical shear, as well as the character of the early afternoon convection, issued a severe thunderstorm watch for southeast Arizona, valid until 0400 UTC 15 July, which included nearly all of WFO Tucson's CWFA. However, the watch did not include any portion of WFO Phoenix's CWFA. Phoenix opted out of the watch for several reasons: 1) it appeared to all participants that the focus of the severe weather would be over WFO Tucson's CWFA, 2) the previous day's watch was a "bust" for the Phoenix CWFA, even though a well-defined upper level disturbance moved over northern and central Arizona, and 3) the Phoenix lead forecaster, though agreeing that severe weather was a good bet over the eastern portion of the Phoenix CWFA, mentioned that the overnight "gulf surge" had failed to bring a noticeable increase in low-level moisture to south-central Arizona, and observed that, as of 2145 UTC, less-than-optimal thunderstorm coverage existed upstream from his CWFA (this was attributed to the fact the atmosphere had dried somewhat in that area). Lack of confidence regarding the potential for severe weather led to the decision not to issue a hazardous weather outlook (HWO) for the Phoenix CWFA during the day shift on 14 July. Nevertheless, the zone forecast for the Phoenix area and for the area immediately south and east of Phoenix, issued at 2245 UTC (345 pm MST) 14 July, called for a 30 percent chance for evening thunderstorms, with blowing dust likely. Since POP (probability of measurable precipitation) climatology for the Phoenix area is only 10-15 percent during mid-July, an above-average chance for storms was forecast.

By 2200 UTC, outflows from the initial thunderstorm clusters started to trigger valley-based convection which rapidly became severe. By 2345 UTC, the KEMX WSR-88D southeast of Tucson detected numerous strong and severe thunderstorms to the east, south, and southwest of the Tucson metropolitan area. By 0024 UTC 15 July, a strong line of thunderstorms had swept into the Tucson area. At 0100 UTC, the infrared satellite image highlighted the ferocity of the maturing MCS over southeast Arizona, with several overshooting tops cooling below -70 C (Figure 2).

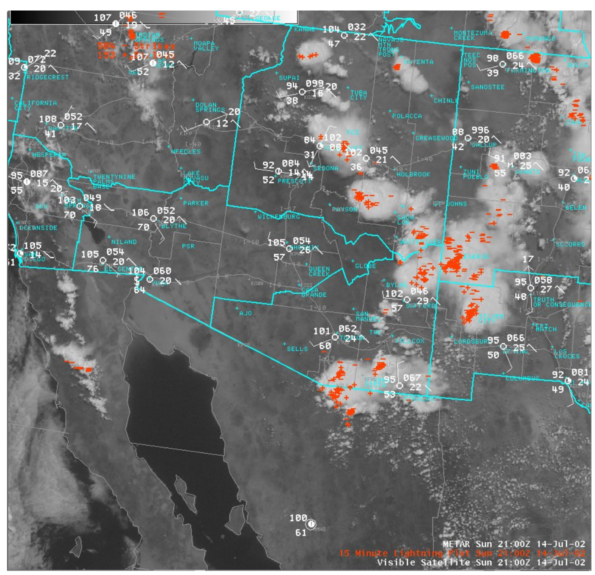


Figure 1. Visible satellite image valid at 2100 UTC (2 pm MST) 14 July 2002. 15-minute cloud-to-ground lightning and metar reports are also displayed. Phoenix is near the center of the image.

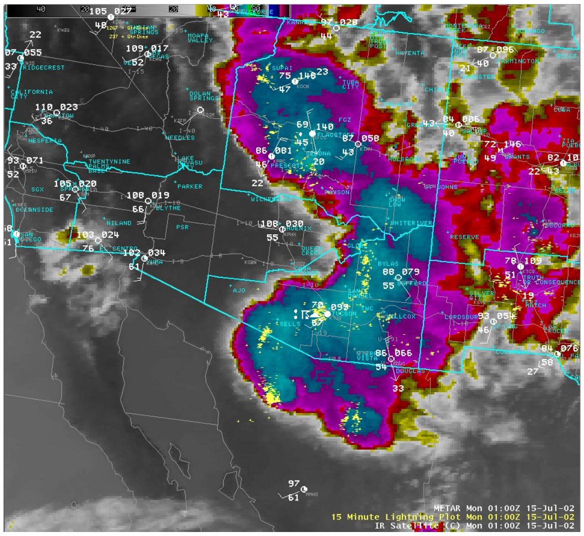


Figure 2. Infrared satellite image valid at 0100 UTC (6 pm MST) 15 July 2002. Severe thunderstorms had already affected the Tucson area. Strong to severe thunderstorms were occurring north, east-southeast, and south of Phoenix.

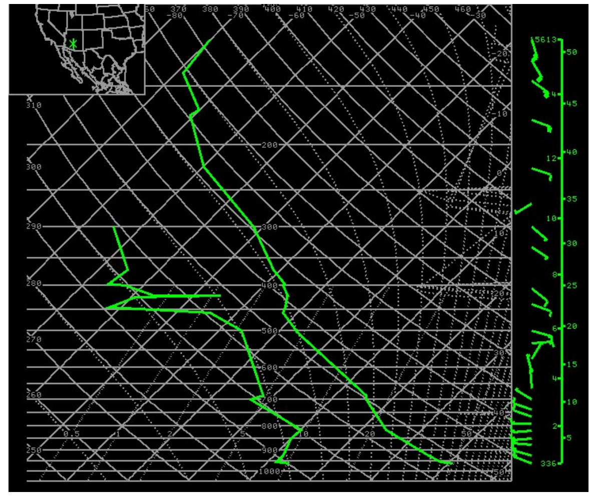


Figure 3. Phoenix sounding: 0000 UTC 15 July 2002

The loosely-organized MCS over southeast Arizona then pushed outflow boundaries to the west and north. These outflows, accompanied by wind gusts near 26 m/s (60 mph), generated a large dust storm, and triggered more severe thunderstorms. This new development, aided by typical afternoon flow upslope from the Phoenix metro area toward Tucson effectively turned the propagation of the MCS to the west-northwest and toward the Phoenix metropolitan area.

4. SEVERE WEATHER EVOLUTION OVER THE GREATER PHOENIX AREA

A special rawinsonde release over Phoenix at 0000 UTC 15 July indicated that the local atmosphere possessed modest low-level moisture, with a mixing ratio of 9 g/kg in the 950-800 hPa layer (Figure 3). Precipitable water had lowered to 3 cm (1.17 inch), primarily from drying above 800 hPa; 1200 UTC value: 3.3 cm (1.34 inch). Computed MLCAPE was 640 j/kg, with the LFC at 560 hPa; CIN was 180 j/kg, with the LCL at 635 hPa. Although CAPE existed, widespread convective activity over Phoenix was far from certain; as is usually the case, the approach of a strong and deep outflow (cold pool), or the intersection of 2 strong, deep outflows, would be required to release the potential instability over Phoenix.

As mentioned in the previous section, strong to severe thunderstorms occurred over southeast Arizona during the late afternoon of 14 July, which had been expected (a severe thunderstorm watch was in effect for the portion of Arizona south and east of the Phoenix CWFA). As of 0000 UTC 15 July, the most intense storms were southeast of the Greater Phoenix area, while storms near the Mogollon Rim in north-central Arizona north and east of Phoenix were decreasing in intensity.

At 0009 UTC 15 July, WFO Phoenix issued a hazardous weather outlook (HWO) for south-central Arizona, including the Greater Phoenix area, highlighting the threat for damaging straight line winds and dense blowing dust during the upcoming evening. The HWO was issued based on storm evolution over and near the Tucson area, and was predicated on the idea that strong outflow would move northwestward from Tucson toward Phoenix and trigger new storms as it approached Phoenix.

Between 0000 and 0100 UTC 15 July, outflow intersection to the north of Phoenix led to the development of an intense area of thunderstorms. At 0100, the strongest storms were about 100 km north of Phoenix. This thunderstorm complex propagated slowly south over higher terrain, and storms associated with this propagation reached the far northeast portion of the Phoenix area shortly after 0200 UTC 15 July (Figure 4).

A severe thunderstorm warning was issued at 0215 UTC, valid until 0315 UTC, for north-central and northeast Maricopa County, including the north and east portion of the Greater Phoenix area; between 0215 UTC and 0315 UTC, storms propagated toward the south-southwest in a narrow NE-SW band, over progressively lower terrain, and reached central Phoenix by 0315 UTC. Evolution and persistence of the narrow band of storms over and northeast of Phoenix was a key factor in setting the stage for the severe weather outbreak over Phoenix.

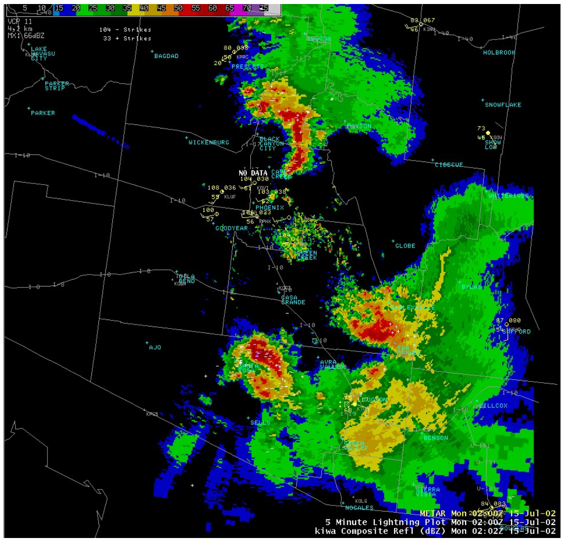


Figure 4. Composite Reflectivity image from the KIWA WSR-88D valid at 0200 UTC 15 July.

4.1 *Intense Dust Storm with High Winds*

Meanwhile, an unusually strong, deep cold pool, generated by strong to severe thunderstorms over and near Tucson, moved northwest across the south-central desert southeast of Phoenix between 0130 UTC and 0230 UTC, reached the southeast portion of the Phoenix metropolitan area by 0245 UTC (745 pm MST), then overspread nearly all the Phoenix metropolitan area by 0400 UTC (9 pm MST). The Phoenix WFO issued a dust storm warning for the southeast portion of the Greater Phoenix area at 0227 UTC (727 pm).

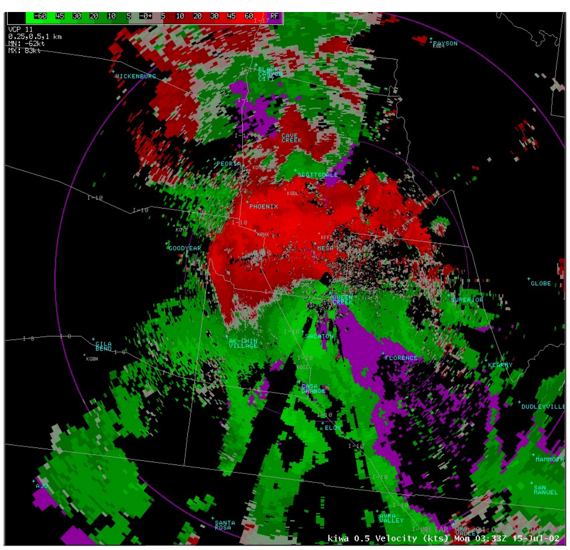


Figure 5. 0.5 degree Base Velocity image from the KIWA WSR-88D valid at 0333 UTC 15 July 2002.

As this outflow moved toward Phoenix, new thunderstorms were triggered to the south and east of Phoenix; these storms strengthened the outflow as it reached the southeast portion of the Phoenix metropolitan area; winds of 17-26 m/s (40-60 mph) along with near-zero visibility were observed at a number of observation sites. This strong outflow boundary was destined to intersect the narrow band of convective storms associated with the thunderstorm complex that had propagated toward Phoenix from the north, as well as an outflow boundary generated by an area of storms north of Phoenix (outflows can be seen on Figure 5).

4.2 *Destructive Sky Harbor Airport Microburst*

An infrared satellite image taken at 0300 UTC 15 July vividly shows the two areas of organized convection, converging on Phoenix from the north and south (Figure 6). The combination of 1) observed strong to severe straight line winds, and 2) the fact that strong outflow from the southeast would intersect the quasi-stationary convergent band of storms, led to the issuance of a severe thunderstorm warning for east-central Maricopa County, including the Greater Phoenix area, at 0315 UTC (815 pm MST), valid until 0415 UTC (915 pm MST).

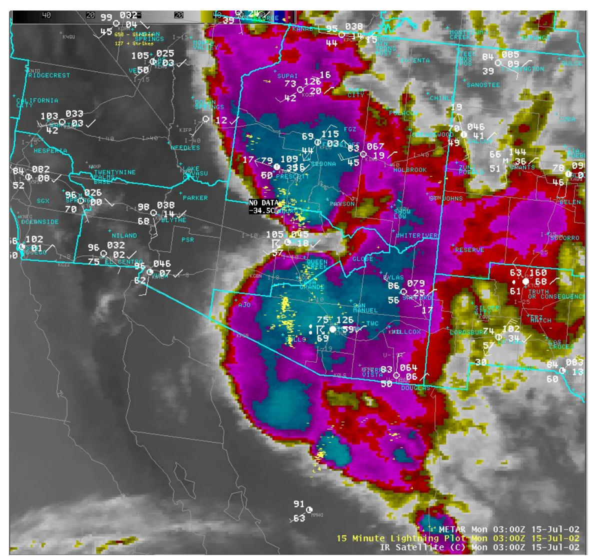
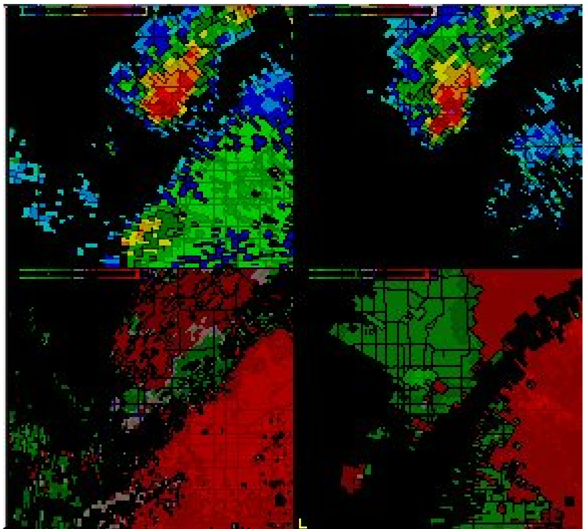


Figure 6. Infrared satellite image valid at 0300 UTC 15 July 2002. The Phoenix Sky Harbor ASOS site is situated between the two areas of coldest cloud tops

The strong outflow boundary intersected the southern end of the narrow band of storms between 0315 UTC and 0320 UTC; rapid intensification of a convective storm was observed between 0320 UTC and 0330 UTC (Figures 7 and 8), and an intense microburst occurred over Sky Harbor Airport around 0330 UTC.

0.5 degree reflectivity 4.5 degree reflectivity



0.5 degree base velocity 4.5 degree storm relative velocity (SRM)

Figure 7. Four-panel radar display of the microburst-producing storm at 0318 UTC 15 July, 12 minutes prior to microburst onset. Rapid and intense development was observed on the south flank of the storm 4 km north of Sky Harbor Airport, situated at center of panel.

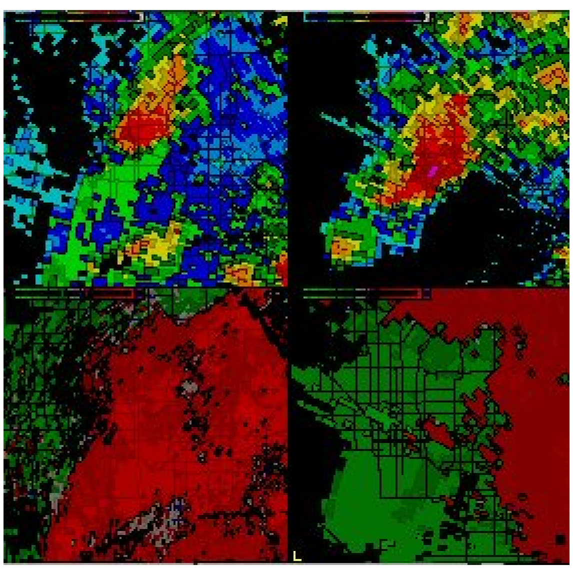


Figure 8. Same as Figure 7, except at 0328 UTC 15 July. Rapid echo development directly above Sky Harbor (WER present), with peak reflectivity > 65 dBz at 4.5 deg elevation.

No well-defined low-level divergent signature was observed, which is rather unusual since the storm was only 35 km west of the KIWA WSR-88D. However, mid-level gate-to-gate radial convergence increased to 50 knots approximately 15 minutes prior to microburst occurrence, associated with a noticeable increase in mid-upper level reflectivity (Figure 6). Near-surface reflectivity values were in excess of 70 dBz over Sky Harbor at the height of the microburst, and the height of the maximum reflectivity decreased dramatically over a period of several minutes in conjunction with microburst occurrence (Figure 7).

The Sky Harbor ASOS site is located on the east end of the airport; microburst damage occurred 1-2 km to the west. At the ASOS site, southeast winds with peak gusts to 17 m/s (38 mph) were observed at 0334 UTC; 3 minutes later, in response to the microburst, winds were northwest with peak gusts to 19 m/s (43 mph). By 0344 UTC, southeast wind, with peak gusts to 18 m/s (41 mph), was observed.

4.3 *Unusually High Rainfall Rates and Flash Flooding*

Cold pool outflow from the southeast collided with another area of thunderstorm outflow over north-central Maricopa County shortly after 0330 UTC; outflow collision occurred very close to the position of the pre-existing convergent zone over central Phoenix. Lightning activity increased dramatically shortly after the boundary collision, with peak cloud-to-ground lightning strike frequency occurring over central and north-central Phoenix between 0330 UTC and 0400 UTC (Figure 9).

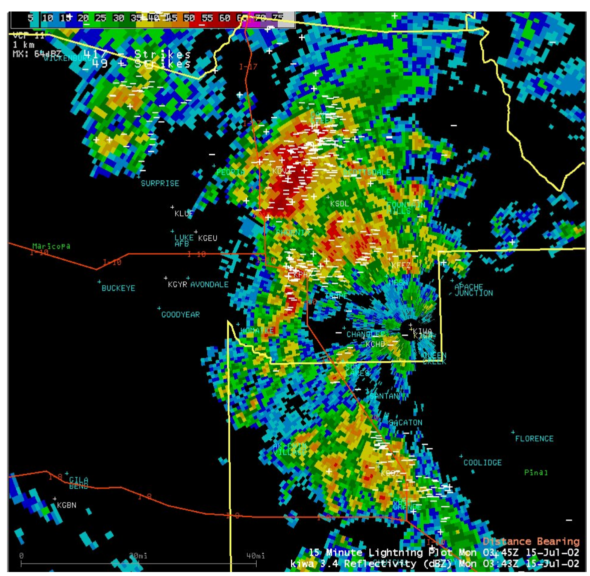


Figure 9. 3.4 degree base reflectivity valid at 0343 UTC, overlain by 15-minute cloud-to-ground lightning.

Torrential rainfall, at least by Arizona standards, was observed after cloud-to-ground lightning increased. Rainfall rates at several Flood Control District of Maricopa County ALERT rain gauges peaked at slightly above 15 cm/hour (6"/hr) between 0350 UTC and 0415 UTC (850 and 915 pm MST), with two gauges recording in excess of 1.25 cm (0.5") of rain in 5 minutes. Ten rain gauges in central Phoenix recorded greater than 1.9 cm (0.75") of rain in 15 minutes, while 2 gauges received over 2.5 cm (1") of rain in 15 minutes (peak 15-minute rainfall was 1.18"; see Figure 10). Observed rain gauge rainfalls were only slightly below the rainfall estimates provided by the KIWA WSR-88D (Figure 11). An urban and small stream flood advisory was in effect for the area; however, the outflow mergers with the convergent band of storms served to enhance rainfall rates to the degree that flash flooding became likely, and a flash flood warning was issued for central and north-central Phoenix at 0410 UTC (910 pm MST). Numerous reports of flash flooding were received; fortunately, no injuries or significant damage was reported.

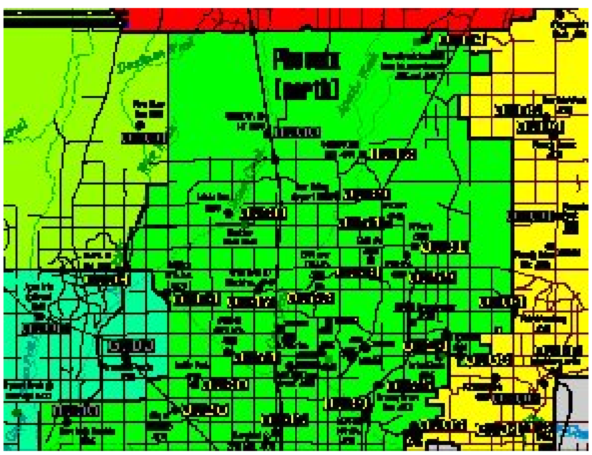


Figure 10. 15-minute precipitation between 0400 and 0415 UTC 15 July 2002, as measured by ALERT rain gauges from the Maricopa County Flood Control District.

4.4 *Weather Event Simulator Training*

The following items from the 14 July 2002 severe weather events over and near Phoenix were highlighted during Weather Event Simulator (WES) training at WFO Phoenix: 1) evolution of the cold pool from the time it developed near Tucson to the time it overspread the Greater Phoenix area, 2) southward propagation of the southeast Yavapai County storms, and evolution of a narrow band of storms over a portion of the Greater Phoenix area, 3) cold pool interaction with the pre-existing band of storms, 4) rapid evolution and other characteristics of the microburst-producing storm over Sky Harbor, and 5) the noticeable increase in C-G lightning frequency, followed by the dramatic increase in rainfall rate, over central and north-central Phoenix.

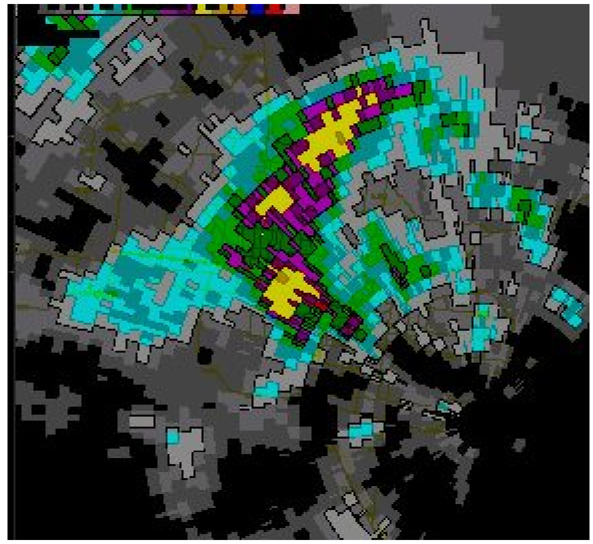


Figure 11. KIWA One Hour Precipitation (OHP) ending at 0428 UTC 15 July 2002. Yellow areas indicate rainfall in excess of 7 cm.

5. REVIEW OF EVENTS OVER THE TUCSON CWFA

During the southeast Arizona portion of the outbreak extending from 2000 UTC on the 14th until around 0100 UTC on the 15th, the following products were issued: 11 Severe Thunderstorm Warnings (10 verified), 3 Dust Storm Warnings (all verified), 2 Urban and Small Stream Flood Advisories (both verified), and 1 Flash Flood Warning (did not verify). The highest wind gust, 34.5 m/s (79 mph), was measured by a retired NWS employee on the southwest side of Tucson, while a gust of 29.5 m/s (67 mph) was measured at the University of Arizona. Numerous reports of wind damage were received by WFO Tucson, and dust storm conditions, with visibilities briefly falling as low as 1/8th of a mile, were observed.

As is typical for relatively early summer thunderstorm events, blowing dust was a significant problem over the lower desert. Dust storms were exacerbated by extreme drought conditions prior to this event; Tucson's longest dry spell on record (100 days) ended just a week earlier, and no widespread heavy rains had fallen across the CWA prior to 14 July. As is also typical for the first round of summer thunderstorms, rainfall was not particularly heavy, with spotty 2.5 cm (1 inch) totals around central Tucson.

Situational awareness by the forecasters, despite the lack of a triggering synoptic-scale feature, was key in providing excellent lead times and forecast accuracy. The possibility of a significant moisture increase was recognized the day before the outbreak, when the PoP was raised to 40-50 percent. Upon receiving the 1200 UTC 14 July upper air data from the Tucson sounding, Tucson forecasters added heightened wording for damaging winds and brief heavy rain to the public forecasts, while the SPC outlook called for a "slight risk" of severe thunderstorms over southern Arizona. Severe Thunderstorm Watch Number 510 was issued by SPC at 300 pm MST, valid until 900 pm MST, which prompted forecasters to raise PoPs into the 60-80 percent range. The watch redefining statement for southeast Arizona mentioned the greatest threat would be from "wind gusts well over 60 mph along with blowing dust." Warning lead times were also unusually high, with a 45 minute lead time for a severe thunderstorm warning for the Tucson metropolitan area.

6. REVIEW OF EVENTS OVER THE PHOENIX CWFA

During the south-central Arizona portion of the severe weather outbreak, the following products were issued: 5 Severe Thunderstorm Warnings (4 verified); 2 Dust Storm Warnings (both verified); 1 Flash Flood Warning (verified), 3 Urban and Small Stream Flood Advisories (all verified), and 1 Airport Weather Warning (verified). Nearly all of these products (exception: 2 severe thunderstorm warnings) were issued for a portion of the Greater Phoenix area between 0215 and 0415 UTC. The peak measured wind gust of 33.5 m/s (76 mph) was measured at Deer Valley Airport in north Phoenix at 0347 UTC 15 July. Two automated rain gauges in central Phoenix recorded in excess of 5 cm (2 inches) of rain in 1 hour. The average yearly rainfall for these sites is less than 25 cm (10 inches)). Radar estimated that several areas in the Greater Phoenix area may have received in excess of 6.25 cm (2.5 inches) of rain in one hour. Several trained weather observers in the southeast portion of the Greater Phoenix area reported the worst dust storm they had ever experienced, with near zero visibility and wind gusts to 60 mph. Airport officials reported that the powerful microburst over Sky Harbor airport produced the most significant wind damage ever observed at that site. Fortunately, landings and takeoffs had been halted due to the approaching dust storm.

Dust storms, damaging straight line winds, and excessive localized rainfalls are frequent occurrences over the south-central Arizona desert during the summer convective season; however, the occurrence of extreme versions of all three phenomena in the Phoenix area over a short period of time (< 2 hours) was noteworthy. In this instance, forecasters at WFO Phoenix expected some severe weather to occur over their CWA the evening of 14 July; however, the magnitude and multi-faceted nature of what actually transpired far exceeded the day shift forecasters' expectations. The potential for an unusually severe event over or near Phoenix was noted by evening shift forecasters, but the HWO issued at 0009 UTC provided less than 3 hours' lead time. In this case, situational awareness, as it pertained to the potential for a major severe weather outbreak over a large metropolitan area, was less than optimal, and resulted in a forecast that called for only a slightly higher chance for thunderstorms (30%) than what climatology would indicate.

The task, however daunting, to provide summer convective forecasts with noticeable departures from, and improvements over, climatology, especially with regard to identifying unusually dangerous weather situations, has becoming increasingly important as the population of Arizona, including the Greater Phoenix area, continues to increase at a rapid rate.

The WES has allowed forecasters at WFO Phoenix to review many facets of this event; hopefully, review of this case, as well as other interesting and challenging convective events, will help improve situational awareness, thereby providing more useful hazardous weather outlooks and forecasts to local emergency managers, media outlets, and the general public.

7. REFERENCES

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