# 2.5 EVOLUTION OF AN INTENSE MCS OVER SOUTH-CENTRAL ARIZONA ON 16-17 AUGUST 2001

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## 1. INTRODUCTION

Severe thunderstorms are frequently observed over the lower desert of south-central Arizona during July, August and early September. Storm environment is typically characterized by weak 850-500 hPa vertical wind shear, a deep, well-mixed boundary layer (at or above 650 hPa), and large surface-to-LFC dew point depression; therefore, storms are typically poorly organized, short-lived, and capable of producing strong wind. Well-organized, long-lived mesoscale convective systems (MCSs) may occur when favorable gust front interaction occurs in an environment characterized by moderate vertical shear and instability (typically, both are well above the climatological norm).

An intense, long-lived MCS developed over south-central Arizona during the early morning of 17 August 2001. The MCS reached its peak intensity around 0930 UTC (230 am MST) just north of Gila Bend, Arizona (40 nm [75 km] southwest of Phoenix), where straight line winds estimated at 70 to 85 kt (81 to 98 mph) downed in excess of 130 power poles near an electric substation, leaving a number of communities in southwest Maricopa County, eastern Yuma County, and western Pima County without electricity for several days. In response to the widespread power outage, the Governor of Arizona, Jane Dee Hull, declared a “state of emergency” for the affected area.

This MCS was the most intense organized convective event of the 2001 summer convective season, and caused at least $1.2 million in damage to Arizona Public Service (APS) equipment, making it the most costly windstorm to affect south-central Arizona since the $30 million east Mesa microburst of 19 September 1999 (Green, 2000). Noteworthy was the fact that this MCS developed after midnight local time, after a rather quiet convective day and early evening over the higher terrain north and east of Phoenix.

This paper will provide a brief climatology of convective storms over south-central Arizona during its active summer thunderstorm season, review the meteorological conditions preceding this MCS development, briefly describe thunderstorm and MCS evolution as observed primarily by NWS Doppler radar, and list “lessons reinforced” .

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## 2. SUMMER THUNDERSTORM CLIMATOLOGY

The vast majority of severe thunderstorms over south-central Arizona occur during July, August and early September. Many of these storms are observed in conjunction with 700-400 hPa mean flow from the northeast, east, southeast, or south (wet monsoonal). Typically, this flow develops when the mid-tropospheric reflection of the subtropical ridge drifts north and east of south-central Arizona. The approach of an easterly wave or inverted trough can be the catalyst for more organized, long-lived thunderstorm development. The degree of atmospheric instability can vary widely from day to day and even over nearby locations over the south-central desert; as expected, low level moisture variability is a key factor.

MCS development over south-central Arizona during the summer convective season typically occurs as follows: 1) during the early to mid-afternoon, scattered thunderstorms develop over or near the Mogollon Rim, White Mountains, and the higher terrain of southeast Arizona; 2) outflows from these storms propagate downslope toward the lower desert during the late afternoon/early evening, while continuing to trigger new thunderstorm cells over the hilly terrain situated between the lower desert and mountains, as well as the lower desert; 3) storm outflows from the north, east, and/or south collide over or near Phoenix (often between 0200 and 0600 UTC), triggering moist convection; 4) potential for a longer-lived convective complex exists if outflow intersection and resultant storm propagation correlates with low-mid level vertical shear vector orientation; if vertical shear interacts favorably with the strengthening, deepening cold pool, a MCS may develop.

## 3. RECENT RESEARCH

Maddox et al (1995) identified three large-scale patterns associated with severe summertime thunderstorms over Central Arizona, based on data collected during July-August for the period 1978-1990. Wallace et al (1999) examined all “monsoon days” (days where the average Phoenix dew point is 55 F (13 C) or greater) for the period July-August 1990-1995, then subdivided the days according to frequently observed mean 700-400 hPa wind directions (northeast, southeast, south, light and variable, and west) and computed the percent of time storms affected the greater Phoenix area for each classification. For northeast flow situations, storms affected the greater Phoenix area in 13 of 29 cases (45%).

Green and Runk (1998) examined MCS evolution over Arizona on two successive days, 7 and 8 August 1997

The atmosphere over south-central and southwest Arizona was unusually unstable (CAPE > 2000 j/kg), and 700-400 hPa vertical wind shear was moderate to strong (30 kt [~15 m/s]), so severe weather and MCS development were anticipated. Interestingly, widely varying convective evolution occurred on those two days, with storms affecting the Phoenix area only one day. Degree of instability and resultant location of early/mid-afternoon convective development over the Mogollon Rim and adjacent higher terrain was shown to be a critical factor with regard to MCS development over the lower desert of south-central Arizona.

## 4. SYNOPTIC SITUATION, OBSERVED WEATHER, AND FORECASTS: 1200- 2300 UTC 16 AUGUST

The large-scale flow pattern over south-central Arizona at 1200 UTC 16 August 2001 did not conform to a particular severe weather pattern identified by Maddox et. al. (1995), though it possessed characteristics supportive of severe convective storm development. A mid-tropospheric ridge extended from south-central California east across northern Arizona. To the south, water vapor imagery revealed the presence of an easterly wave moving slowly toward the west across northwest Mexico. To the north, a weak upper disturbance was moving east across central Utah, with the "tail" of the disturbance passing across the northern quarter of Arizona. Mostly clear skies existed over northern and central Arizona; mid-level clouds and a few showers were occurring over southeast Arizona.

The most prominent feature in the 300-250 hPa layer was a deformation zone/stretching axis which bisected Arizona from NNE to SSW and passed directly over the greater Phoenix area. The deformation zone had moved only slightly northwest during the previous 12-hour period, indicating the easterly wave's increasing influence over far southeast Arizona. Morning eta and AVN model forecasts indicated this deformation zone would persist over or near the 1200 UTC position through the upcoming 36 hours.

At 500 hPa, a ridge axis arched anticyclonically from south-central Nevada to southwest New Mexico, placing most of Arizona under 15 knot northeast to east flow. Plot and trajectory data revealed cooler, more moist air had advected over the northern half of Arizona from Utah and southwest Colorado, where active convective storms occurred during the previous 24 hours. Temperatures cooled by 2-3 C in 24 hours, and a thermal trough bisected Arizona from northeast to southwest (aligned with the upper level deformation axis). Dew point depressions decreased by 20-25C in 24 hours; T-Td = 5 C at Flagstaff and 2 C at Phoenix.

Conversely, 850-700 hPa temperatures had warmed 1-2 deg C in 24 hours, resulting in a steepening of the 850-500 hPa lapse rate by 3-5 C. At 700 hPa, the dew point had lowered to 0 C at Flagstaff, a 6 C decrease; however, a 2 C rise in dew point was observed at Phoenix in the 850-700 hPa layer, with an 850 hPa dewpoint of 11 C. A north-south moisture gradient existed, with highest mixing ratios near the Arizona-Mexico border. Winds were light, and had backed from east to north-northeast at Tucson in response to the approach of the easterly wave.

Surface dew points were above average over southern Arizona, mainly in the upper 60s to lower 70s F (20-23 C). Maximum temperatures at Phoenix and Yuma had risen 1 C on the 14$^{th}$ and again on the 15$^{th}$, and with a warmer airmass at and below 700 hPa, a similar increase was expected on the 16$^{th}$, with daytime highs forecast to be 1-2 C above normal. Soundings confirmed the presence of above-average theta-e air in the surface-700 hPa layer, while a near-dry adiabatic lapse rate extended to the 500 hPa level.

Thermodynamic parameters indicated a high conditional probability of severe weather with any storms over the lower desert floor, while kinematic parameters indicated organized multicell storms were possible. SPC's mid-morning convective outlook, issued by forecaster Jonathan Racy at 1626 UTC and valid from 1630 UTC 16 August through 1200 UTC 17 August, stated "Deformation axis appears to have shifted into southeastern/south-central Arizona this morning. Weak diffluence aloft, in combination with residual moisture, will aid in additional thunderstorm formation today along the higher terrain. *Potential exists for upscale organization onto the south-central/southeastern Arizona desert floors* (author italics) later this afternoon given 15-20 knot northeasterly mid-tropospheric flow and weak inhibition. Isolated wind damage will be possible with these thunderstorms."

Morning area forecast discussions (AFDs) from WFO forecasters at Flagstaff, Phoenix, and Tucson indicated storms were expected to develop primarily near and just east of the 300-250 hPa deformation zone, mainly over the higher terrain of central, eastern, and southeastern Arizona during the afternoon, with a few evening storms developing over the lower desert of southern Arizona.

Typically the higher terrain of north, central and southeast Arizona becomes convectively active by early to mid-afternoon during August. On 16 August 2001, afternoon moist convective development was well below average over the higher terrain of northern, central and southeast Arizona, with only isolated non-severe storm development observed; the degree of moist convection was less than forecasters had anticipated. Low-level drying and associated reduction of CAPE were thought to be key factors responsible for the relatively inactive convective day upstream from south-central Arizona; insolation reduction by mid-level clouds appeared to be responsible for inhibiting storms over southeast Arizona.

The afternoon AFD issued by the Flagstaff WFO noted 1) the occurrence of a drying trend in the mid and upper troposphere, with more modest drying in the low levels, 2) a steepening lapse rate through a deeper layer, indicating the presence of instability; and 3) the development of a few showers with light to moderate rainfall over the higher terrain. The AFD issued by WFO Phoenix highlighted: 1) existence of a persistent 300-250 hPa deformation zone over south-central Arizona; 2) impressive 850-500 hPa lapse rates (nearly dry-adiabatic); 3) 15-25 kt northeast steering flow in the 700-400 hPa layer over south-central Arizona, with somewhat weaker flow to the west; 4) isolated storm development over the higher terrain by 2200 UTC (well north and east of the lower desert); 5) high potential for any lower desert storms to be severe, given the degree of instability and strength of 700-400 hPa flow (mid-afternoon surface dew points remained relatively high, in the low to mid 60s F (17-19 C) over the lower desert, while daytime highs were 1-2 C (2-4 F) above average). The WFO Tucson AFD indicated that storm activity was anticipated to increase by late afternoon and early evening, noting that weakness in the flow on the south side of the (300-250 hPa) deformation axis between the ridge building in across northern Arizona and the wave over northwest Mexico would help focus storm development (sustained convection occurred over far southeast Arizona the previous evening when the deformation axis was just northwest of that area).

Given the notable lack of upstream convective development, the 2245 UTC 16 August zone forecast product (ZFP) issued by WFO Phoenix employed uncertainty terms, calling for a 20% chance for evening thunderstorms, with strong gusty winds, for southwest and south-central Arizona, including Phoenix, Gila Bend, and Yuma (climatology for August 16 indicates a 11% chance for measurable rain at Sky Harbor Airport in Phoenix, with < 5% chance for measurable rain in Yuma). A hazardous weather outlook issued by WFO Phoenix at 2300 UTC highlighted the risk for isolated severe thunderstorms over south-central and southwest Arizona the night of 16 August.

## 5. SYNOPTIC SITUATION, OBSERVED WEATHER, AND FORECASTS: 2300 UTC 16 AUGUST TO 1100 UTC 17 AUGUST

The 0000 UTC 300-250 hPa plot data revealed that the easterly wave/upper low had moved west across northwest Mexico, while the weak upper trough had moved east to western Colorado, with the trailing edge extending southwestward into north-central Arizona. The deformation axis/zone bisected Arizona from northeast to southwest, with speed divergence noted primarily over eastern Arizona. At 500 hPa, the center of high geopotential heights (5980 m) had strengthened by 20 m/24 hrs and had drifted slightly south to south-central California. Northeasterly winds 10-20 knots were observed over Arizona, with a thermal trough over northern and central Arizona (-9 C at Flagstaff). At 700 hPa, the center of high heights was also over south central California, and heights had risen 10-15 m over Arizona during the previous 24 hours. 700 hPa wind was east at 10 kt at Tucson, but northwest at 5 kt at Flagstaff. North wind to 15 kt was observed via the KIWA VWP (the KIWA 88D is about 30 km east-southeast of downtown Phoenix). Dew points were generally 2-3 C. At 850 hPa, light northwest wind existed, and dew points had lowered 1-2 C since the previous evening; however, the north-south moisture gradient was still impressive. The SPC convective outlook issued at 0103 UTC 17 August, noted the drying trend, but indicated that steep lapse rates and large temperature/dew point spreads continued to support a threat for isolated storms, with microbursts possibly accompanying stronger storms for the next few hours.

During the period 2300 UTC 16 August to 0330 UTC 17 August, no convective storms were noted over north-central and central Arizona (including all of the Phoenix CWA); however, isolated storms continued over southeast Arizona. Between 0330 and 0400 UTC, a small area of thunderstorms developed over the higher terrain of south-central Arizona 75 km east-southeast of Phoenix, while isolated weak storms developed over a small portion of north-central Arizona about 120 km north of Phoenix. The evening AFD from Flagstaff noted the presence of isolated, rather weak storms over Yavapai County (the county north of Phoenix),and the fact that storms were “slow to end”. The Phoenix AFD observed that “only 1 thunderstorm was noted in the CWA at 0345 UTC”, noted that yesterday’s numerical guidance had forecast the upper level deformation zone to be further northwest, and ended with “updates to first period will be to continue a slight chance for storms through midnight” over Phoenix. At 0430 UTC, the Phoenix zone forecast for “tonight” was updated to ”partly cloudy with a 10 percent chance for a thunderstorm until midnight”; the forecast for the area southwest of Phoenix was updated to “mostly clear”.

Between 0400 and 0500 UTC, a multicell storm system evolved and moved southwest from extreme southern Gila County into south-central Pinal County, 55 km southeast of Phoenix. A second multicell thunderstorm system quickly developed over the higher terrain about 55 km east-northeast of Phoenix in south-central Gila County, then propagated west-southwestward into far eastern Maricopa County. Weakening shower activity continued to move slowly south across east-central Yavapai County, 85 km north of Phoenix. Shower and thunderstorm activity had weakened over southeast Arizona. though thunderstorms continued near Tucson.

Between 0530 and 0600 UTC, the multicell system originally over eastern Maricopa County intensified noticeably and moved west toward the far eastern portion of the Greater Phoenix area. A microburst signature was detected by the NSSL WDSS, and the Phoenix WFO issued a severe thunderstorm warning for this area of thunderstorms at 0602 UTC [29 power poles were blown down in the far east portion of the Phoenix metropolitan area east of Apache Junction] . This multicell storm complex generated a strong cold pool that expanded and moved west across the greater Phoenix area between 0600 and 0645 UTC. During that time, weaker outflow/cold pool from isolated weak storms north of Phoenix moved south toward northwest Maricopa County, becoming visible via the KIWA radar by about 0630 UTC. As the outflows collided, *explosive* convective development occurred over north-central and northwest Maricopa County between 0645 and 0715 UTC. At 0650 UTC, the zone forecasts for Maricopa County, including Phoenix and Gila Bend, were updated to: “scattered showers and thunderstorms. Strong wind...brief heavy rain...and blowing dust possible. Chance for measurable rain 30 percent”. Interestingly, between 0400 and 0700 UTC, 700-400 hPa winds increased to 20-35 kt, while vertical shear in the 850-500 hPa layer increased to 25-30 kt.

Between 0730 and 0945 UTC, an organized MCS, with intense, frequent cloud-to-ground lightning, locally heavy rain, and strong to damaging straight line wind, developed and propagated south-southwest, eventually producing significant wind damage, with over 130 power poles (41-230 KV poles; 76-69 KV poles; 15-12 KV poles) downed just north and west of Gila Bend, near an electrical substation operated by Arizona Public Service (APS). Peak gusts near the substation were estimated at 90 to 100 mph (78 to 87 kt) by an APS engineer. A wind sensor south of Gila Bend recorded a peak gust of 66 kt (76 mph) at 0945 UTC, but radar indicated strongest winds occurred ~10 km northwest of that location. As this MCS propagated toward the southwest, wind damage, power outages, and near zero visibility due to blowing dust occurred over much of Yuma County, including Yuma, where TV and radio stations were off the air for a time. Strong winds and dense blowing dust reached far southeast California by 1200 UTC 17 August.

## 6. SUMMARY AND “ LESSONS REINFORCED”

A long-lived MCS developed over northwest and west Maricopa County, Arizona, after 0700 UTC (midnight MST) on 17 August 2001, then propagated toward the south and southwest during the following 5 hours. Damaging winds, intense CG lightning, dense blowing dust, and locally heavy rain (> 2.5 cm [1 inch] in less than 1 hour in several rain gauges over western Maricopa County) occurred from near Phoenix southwest to far southeast California.

The synoptic pattern, as well as thermodynamic and kinematic considerations, favored convective storm development over the lower desert. The 2300 UTC hazardous weather outlook issued by WFO Phoenix highlighted the risk for isolated severe thunderstorms over southwest and south-central Arizona the night of 16-17 August. However, zone forecasts failed to convey the potential for what actually transpired [2245 UTC: “a 20 percent chance for an evening thunderstorm”; 0430 UTC: “mostly clear” southwest of Phoenix; 0650 UTC: “scattered showers and thunderstorms” over western and southern Maricopa County, “mostly clear” for Yuma County.] Why? The lack of typical thunderstorm development over the higher terrain of central and east-central Arizona during the afternoon and early evening of 16 August indicated that nighttime storms over southwest and south-central Arizona were unlikely. Had storms developed an hour or two earlier over the higher terrain, forecasters would’ve provided excellent short-term zone forecast guidance regarding potential for storms over southwest and south-central Arizona during the night of 16-17 August. As shown by Wallace et al (1999), a rather strong correlation exists between a) degree of afternoon/ early evening thunderstorm/lightning activity over higher terrain upstream from and near Phoenix, and b) potential for nighttime thunderstorms over Phoenix.

Key lessons reinforced by this event were: 1) no matter how minimal upstream convective development may be over the afternoon and early evening, forecasters should never remove the chance for convective storms over the lower desert floor when the atmosphere is extremely unstable, a favorable 300-250 hPa flow pattern is observed and/or expected, and vertical shear is greater than normal; 2) an increasing temperature lapse rate during the preceding 1-2 days, accompanied by sufficient low-mid level moisture to produce CAPE, is a strong signal that convective storm development is imminent; 3) increasing low-middle level vertical shear during the evening and nighttime hours, especially when the shear vector has a downslope component, as would be the case as an easterly wave approaches, favors nighttime moist convection even with minimal daytime moist convection (Maddox, workshop presentation, 2002); 4) moderate shear, coupled with weak and/or decreasing CAPE, typically suppresses widespread convective development over the higher terrain during the afternoon and early evening; 5) low-mid level vertical shear in excess of 25 kt favors MCS development (Maddox, workshop presentation, 2002); 6) long-lived MCS development becomes likely when strong, deep outflows intersect such that their intersection axis parallels the orientation of the low-mid level shear vector, especially when surface wind is parallel to, but in the opposite direction of, the shear vector.

## 7. REFERENCES


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