WESTERN REGION TECHNICAL ATTACHMENT
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THE SOUTHERN ARIZONA SEVERE WEATHER OUTBREAK OF 14 AUGUST 1996: AN INITIAL ASSESSMENT

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Introduction

The southern Arizona severe weather outbreak of 14 August 1996 was one of the most significant storms in Arizona weather history. A severe multicell thunderstorm complex struck northwest Phoenix during the early evening hours, then propagated to the southwest and affected many communities between Phoenix and Yuma (Fig. 1) before exiting the state late that night. Intense outflow winds caused most of the estimated $100,000,000 in damage in the Phoenix metropolitan area, and led to over 70,000 storm-related insurance claims. The total damage area in Phoenix was conservatively estimated at 180 mi^2 (Fig. 2). Over 250,000 people lost power during the storm, and some people still did not have power restored one week later.

The storm generated wind speeds of 100 kt (115 mph) at Deer Valley Airport in far north Phoenix, which established a record for the highest measured wind gust in Arizona. Several other observation sites in northwest and west-central Phoenix reported "severe" wind gusts ($\geq$50 kts). Although southern Arizona typically experiences a large number of severe convective windstorms, especially during the summer, this storm was unusually long-lived and intense.

This Technical Attachment is not an exhaustive and detailed meteorological case study; rather, it is meant to be an informative summary of the storm environment, the post-storm damage assessment, and the real-time response to the storm by the Phoenix NWSFO.

Synoptic Overview

Boundary layer evolution was critically important with respect to determining the potential for deep moist convection over southern Arizona. Between 1200 UTC 11 August and 1200 UTC 12 August, a strong 500 mb height maximum strengthened and remained stationary over central Utah. Surface dew points over southern Arizona fell dramatically during the day of 12 August as dry, hot air generated by subsidence associated with the strengthening ridge affected the area. A record high temperature for the date, 46.5°C (116°F), was established at Yuma. A Phoenix sounding taken at 0000 UTC 13 August (not

shown) revealed that a nearly dry adiabatic lapse rate extended from the surface to 500 mb and a mean mixing ratio in the surface-700 mb layer of only 7 g kg^{-1}.

However, the boundary layer over southern Arizona would undergo significant changes during the next two days. Convective activity over the southern Gulf of California created a surface pressure gradient over southern Arizona after 0000 UTC 13 August, and low-level southerly winds over the Gulf led to an increase in low-level moisture over far southwest Arizona, where Yuma's dew point reached 23°C (73°F) overnight.

During the ensuing 36-hour period, the 500 mb height maximum (5980 m) drifted slowly to the southeast, while low-level moisture increased over all of southern and central Arizona. This increase appeared as two distinct "surges": the surface dew point at Phoenix increased from 8°C (46°F) at 1300 UTC 13 August to 14°C (57°F) by 1900 UTC (+6°C/+11°F in six hours), showed little change for a 10-hour period, then increased to 20°C (68°F) during the 3-hour period ending at 0900 UTC 14 August (an increase of +6°C/+11°F) (Table 1). These dew points are at least 5°C (9°F) above the climatological mean for mid-August. Upswings in thunderstorm activity over Arizona frequently accompany these moisture "surges" (Hales 1974, Carleton 1986); however, the somewhat cooler moist air initially results in a boundary layer less conducive to supporting convective storms over the desert. No moist convective storms were observed over the south-central desert on August 13.

By the morning of 14 August, the atmosphere over southern and central Arizona was quite unstable, and the potential existed for strong convective updrafts and downdrafts. Special late morning soundings taken at Tucson and Phoenix on 14 August (Fig. 4) indicated that CAPEs exceeded 1500 J kg^{-1}, and, with expected surface heating, CAPEs would exceed 2000 J kg^{-1} by mid-afternoon. These values are more than twice as much than what is typically observed over southern Arizona in mid-August (Bradley and Smith 1994), and resulted from a steep temperature lapse rate in the 750-500 mb layer and the high supply of low-level moisture (surface-700 mb mean mixing ratio at Phoenix near 10 g kg^{-1}). Intense downdrafts were also likely; in addition to CAPE, melting, precipitation loading, and vertical pressure gradient effects were expected to contribute to strong outflows (Roberts and Wilson 1989).

A strong 500 mb height maximum was situated over the Four Corners area (Fig. 3a). Easterly mid-level flow supported westward propagation of storms from higher terrain east and north of Phoenix to the lower deserts. The strength of the anticyclone (5970 meters) led to somewhat stronger than normal mid-level winds. The large-scale pattern at 500 mb was similar to a Type I central Arizona severe thunderstorm pattern as defined by Maddox et al. (1995). Baroclinicity existed since the ridge position varied with height (Fig. 3b-d), so the environment was ripe for perturbations in the wind flow to affect Arizona. The degree of vertical wind shear indicated that organized multicell storm development was likely. High-level ($\geq$ 10 km) west winds were expected to advect storm anvils to the east,

permitting more surface heating on the preferred propagation flank of any storm that developed.

Although moisture and instability considerations supported the potential for strong thunderstorms over south-central Arizona, potentially mitigating factors would have to be overcome before intense convection affected the south-central desert. The 1600 UTC Phoenix sounding (Fig. 4b) possessed a large capping layer, which indicated that a very strong, deep outflow would be required in order for parcels to acquire enough lift to reach their LFC. Although thunderstorms form over the high terrain north and east of Phoenix on a majority of days during the summer convective season, the depth, strength, and location of storm outflow is not easily forecasted. The apparent lack of identifiable upper divergence or the presence of a well-defined upper level disturbance/jet streak upwind from south-central Arizona was another concern: the development of organized severe convective weather over southern Arizona is strongly correlated to upper level kinematics (Vasquez 1993).

The severe weather outlook (Fig. 5) issued by the Phoenix NWSFO mesoscale/radar shift forecaster at 2015 UTC (1315 MST) 14 August indicated that a moderate risk of severe thunderstorms was expected over southeast Arizona during the afternoon and evening of 14 August. A slight risk of severe thunderstorms with damaging winds was forecast for the south-central deserts, including Phoenix and Gila Bend, during the evening. The slight risk forecast for the south-central desert reflected the degree of uncertainty due to the mitigating factors previously mentioned.

Satellite and WSR-88D Products Summary

Phoenix forecasters have noted that outflow intersection locations are highly correlated with new thunderstorm development, especially over the south-central desert. The severe storm that affected Phoenix was initiated by intersecting outflows from intense storms to the north and east of the Phoenix metropolitan area (Fig. 6). The most intense outflow was generated by an intense thunderstorm over southeast Yavapai County (OB2), and was moving to the south; weaker outflow was spreading west from thunderstorms over eastern Maricopa and Pinal Counties (OB1). The initial intersection of these two boundaries occurred northeast of Phoenix, and outflow intersection continued toward the southwest. An intense storm-scale updraft developed and propagated toward the southwest in conjunction with the intersecting outflows. As the updraft intensified, radial convergence in the lower portion of the cloud (approximately 4.5 km AGL) increased dramatically, exceeded 40 m s^{-1} at 0114 UTC, and remained in excess of 40 m s^{-1} through 0126 UTC (Fig. 7). Pronounced radial convergence in the lower portion of a convective cloud is typically observed prior to intense thunderstorm outflow (Roberts and Wilson 1989). Indeed, significant wind and damage reports began to stream into the Phoenix NWSFO shortly after 0130 UTC (Fig. 7).

WSR-88D Composite Reflectivity images (Figs. 8 and 9) depict the thunderstorms occurring over the greater Phoenix area. At 0027 UTC (Fig. 8), thunderstorms were already developing along the outflow boundaries. One hour later (Fig. 9), one large, intense multicell thunderstorm existed over north Phoenix. Vertically Integrated Liquid water (VIL) values were quite high for storms on this day (Fig. 10): VIL values were in excess of 65 kg m^{-2} prior to the high wind reports, and peaked in the 70-80 kg m^{-2} range. Echo Tops with the intense thunderstorm (not shown) were in excess of 60 kft (20 km).

An inspection of 1 km infrared satellite imagery revealed that the coldest storm cloud tops, -80°C, occurred at 0130 UTC August 15 when the storm was over north Phoenix (Fig. 11a). At that time, other strong thunderstorms were occurring west of Tucson (Figs. 9 and 11a). Storm intensification in the Gila Bend area occurred around 0330 UTC August 15 as outflow from the Phoenix storm apparently collided with outflow from the storms west of Tucson (not shown). The 0400 UTC infrared satellite image (Figure 11b) depicted cloud top temperatures around -80°C just west of Gila Bend.

Damage Survey Overview

A damage survey was conducted by four NWSFO Phoenix staff members on 15 August 1996. The survey consisted of a visual inspection of the area, along with eyewitness interviews. The damage area was quite extensive, with more than 180 mi^2 (465 km^2) of the northwest Phoenix metropolitan area receiving significant damage. Analysis of damage vectors revealed a broad, divergent pattern, and was consistent with macroburst/imbedded microburst damage (Bunting and Smith 1993). Based on observed damage, maximum macroburst wind gusts were 60 to 85 kts (70 to 100 mph), with peak microburst wind gusts between 85 and 100 knots (100 to 120 mph).

Typical damage observed in the area included: numerous uprooted mature trees; extensive damage to roofs and shingles, including clay tiles which are more resistant to wind damage than asphalt shingles; block walls and fences blown down; several hundred downed power poles and lines; damage to cacti and other native plants; damage to trailers that were not tied down; damage or destruction of air conditioning and/or evaporative cooling units located on rooftops; and damage to boats on lakes. Two railroad cars were flipped, and two 720-ton pillars erected to support a highway overpass/bridge were blown over.

Some witnesses believed a tornado was responsible for the damage, even though few residents observed anything resembling a tornado. While it is likely that several gustnadoes were generated along the leading edge of the macrobursts or microbursts, no evidence of tornadic damage could be found during the damage survey.

A follow-up aerial survey, conducted in a helicopter provided by the Salt River Project, was conducted by an NWS/NSSL team on 16 August 1996. This survey, which took 1.5 hours to complete, confirmed the findings of the ground survey.

Warning and Services Overview

NWSFO Phoenix meteorologists and HMTs issued 12 Severe Thunderstorm Warnings, 10 of which verified, and 24 NOWs and SPSs during the event (Table 2). Warning lead times for this event were 20-35 minutes. NWSOs Tucson and Flagstaff also issued timely severe thunderstorm warnings and follow-up information for events in their county warning areas.

NWSFO Phoenix maintained close coordination with the Storm Prediction Center (SPC), which provided excellent severe weather forecasting support throughout the episode. A Severe Thunderstorm Watch was issued at 2112 UTC 14 August, for parts of southeast Arizona, which included extreme eastern Maricopa County (just east of metro Phoenix). A subsequent Severe Thunderstorm Watch was issued at 2355 UTC, which included all of Maricopa County (including Phoenix and Gila Bend).

Mass News Media (MNM) response to the NWS storm effort was quite favorable, with no criticism of NWS warning services noted. The potential for severe thunderstorms over southern Arizona was well-advertised during the afternoon, which heightened MNM awareness. A few local radio and TV stations discontinued regular programming and/or preempted the Republican National Convention throughout the evening to provide live, nearly real-time coverage of NWS warnings, NOWs and SPSs.

Aftermath Overview

The extensive damage prompted Arizona Governor J. Fife Symington to declare northwest Phoenix a disaster area. This declaration enabled residents and businesses to apply for interest-free loans to aid in property restoration and recovery. Fortunately, only one fatality occurred during the storm: a person drove through an intersection where traffic lights were out due to the high winds, and collided with another vehicle. Multiple injuries occurred when individuals intercepted flying debris, but most of these injuries were minor.

More that 250,000 customers lost power and telephone service. Power and telephone outages in some of the harder-hit areas continued for a week after the event. Five NWSFO Phoenix employees reported that their homes were damaged by the storm.

Conclusions

Violent, damaging thunderstorms are not uncommon across southern Arizona during July and August, the months when the "Mexican monsoon" exerts its greatest influence on the state (Douglas et.al. 1993). However, the areal extent of wind damage (180 mi^2) and peak wind gusts (115 mph) **were** unusual. The severe weather outlook issued by the Phoenix NWSFO and the severe thunderstorm watches issued by the SPC provided the MNM and

the general public with increased awareness regarding the potential for damaging thunderstorms over the south-central desert. Many time-proven warning techniques used during the summer convective season (i.e., warning issuance for locations near intersecting outflow boundaries) allowed forecasters to provide impressive warning lead times.

A more detailed meteorological interrogation of this meteorological event will be pursued by several Phoenix NWSFO staff members.

Acknowledgments: Many people within the Phoenix NWSFO contributed to this paper. Special thanks to WCM Mike Franjevic and forecasters Dan Koch and Jeff Davis for their substantial input and technical support.

References

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Vasquez, H., 1993: Weak upper-level divergence and its role in organizing mesoscale convective storms along the Arizona monsoon moisture boundary. Western Region Technical Attachment No. 93-26.

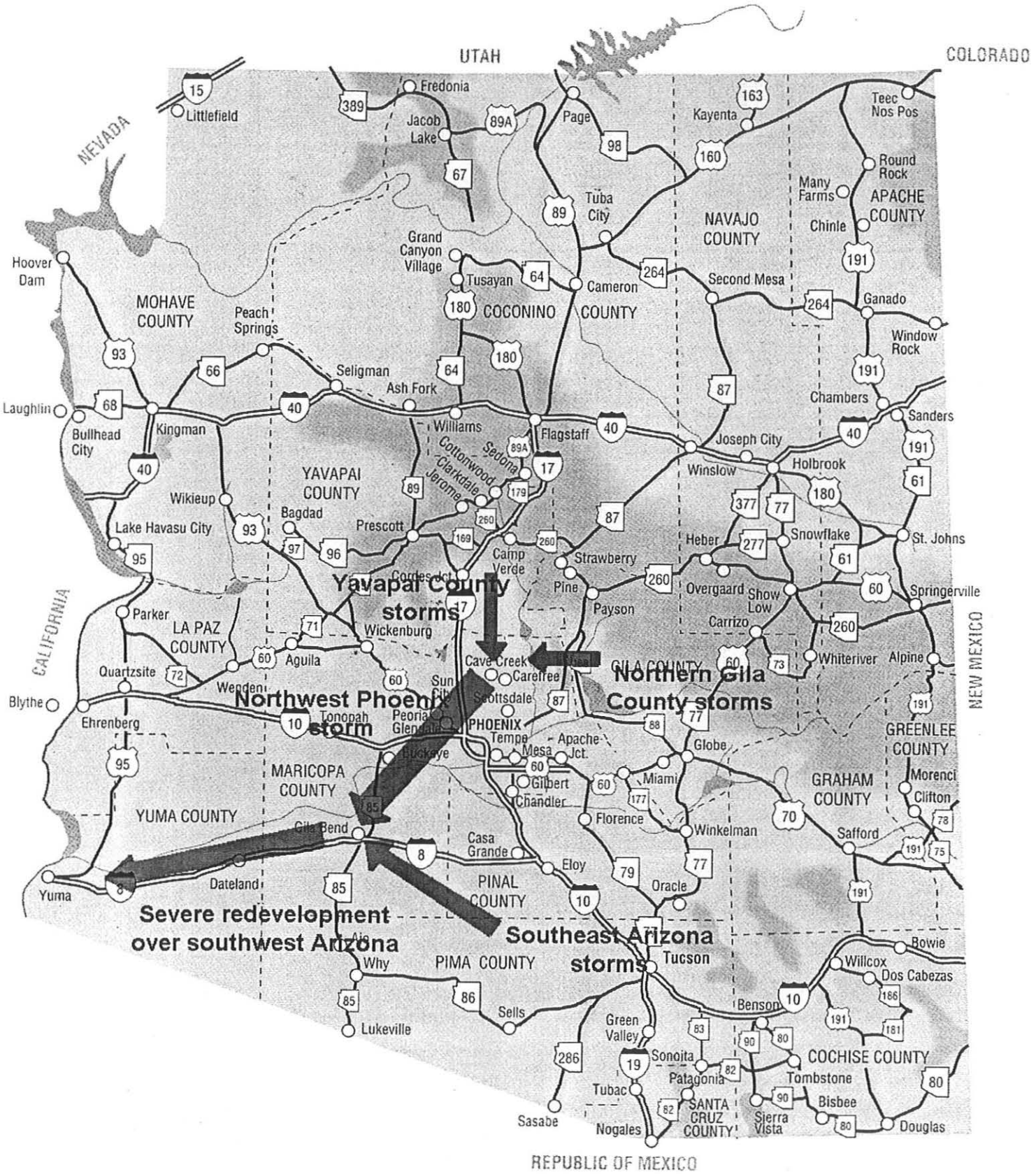

Fig. 1 State of Arizona map depicting storm movement, propagation and development on the afternoon and evening of 14 August 1996.

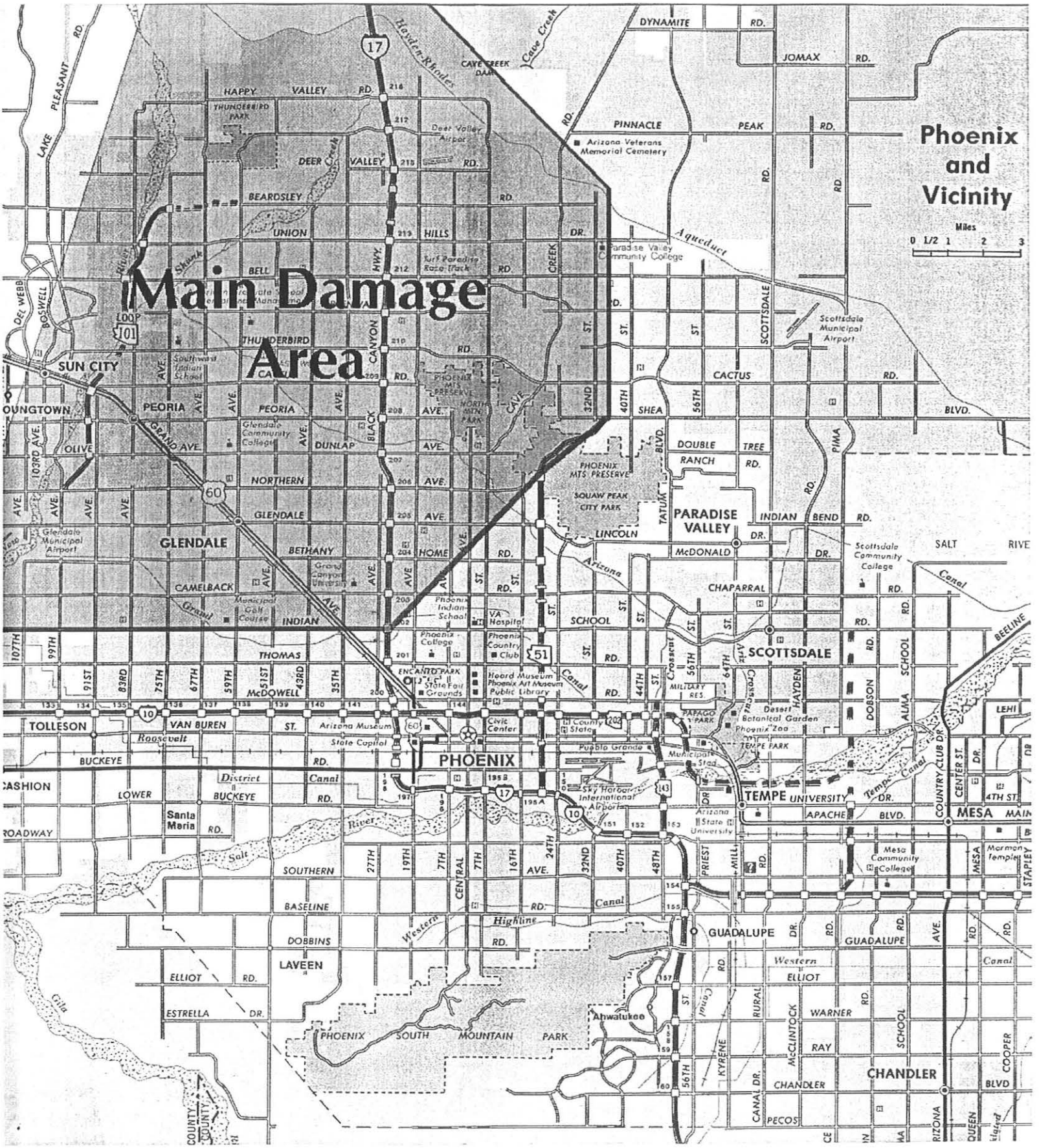

Fig. 2 City of Phoenix map depicting the main area of damage caused by the severe thunderstorm of 14 August 1996.

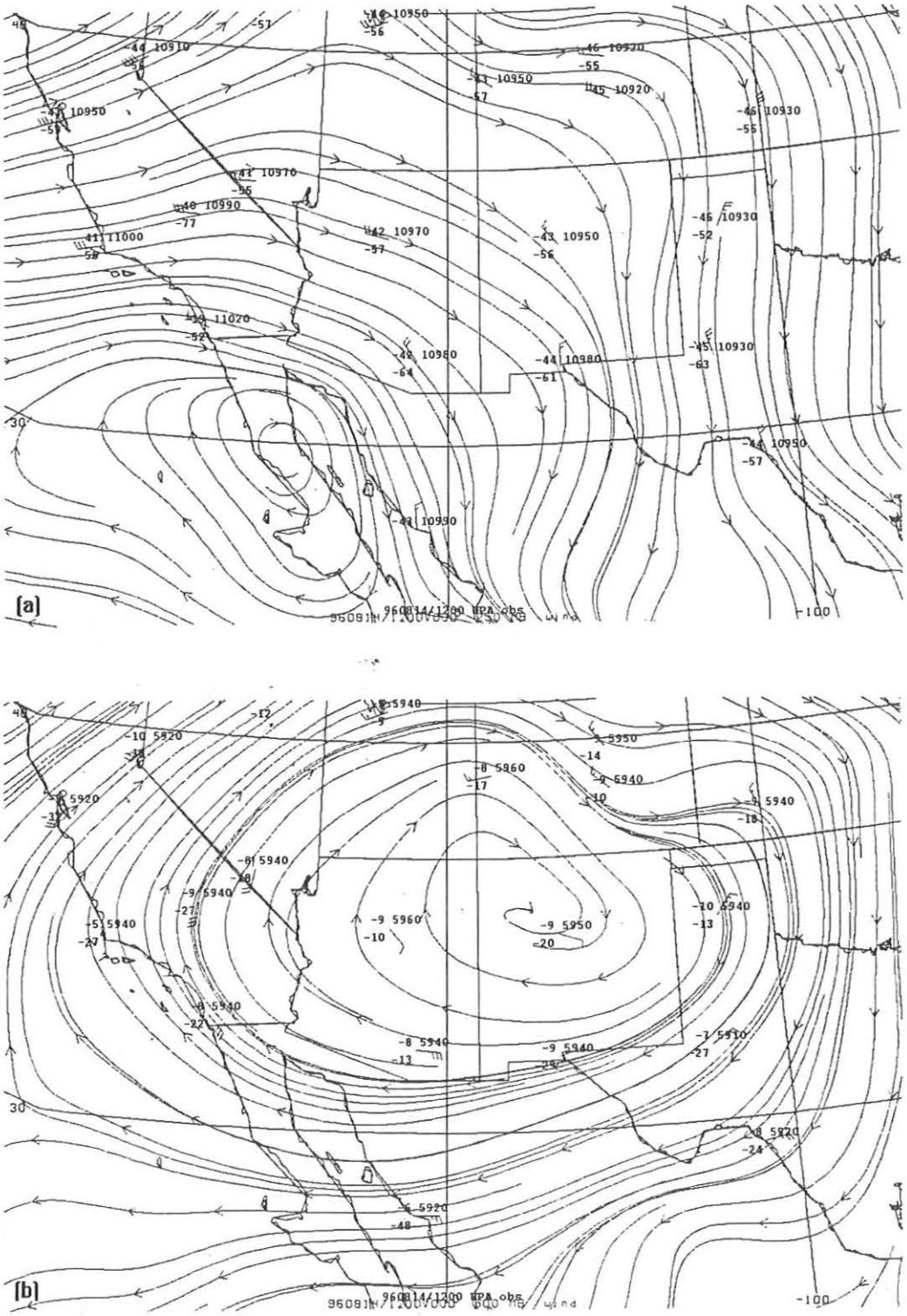

Fig. 3 Upper air observations (number to the lower left of station is dew point in °C) overlaid with ETA model initial analyses of wind field streamlines valid at 1200 UTC 14 August 1996 at a) 250 mb and b) 500 mb.

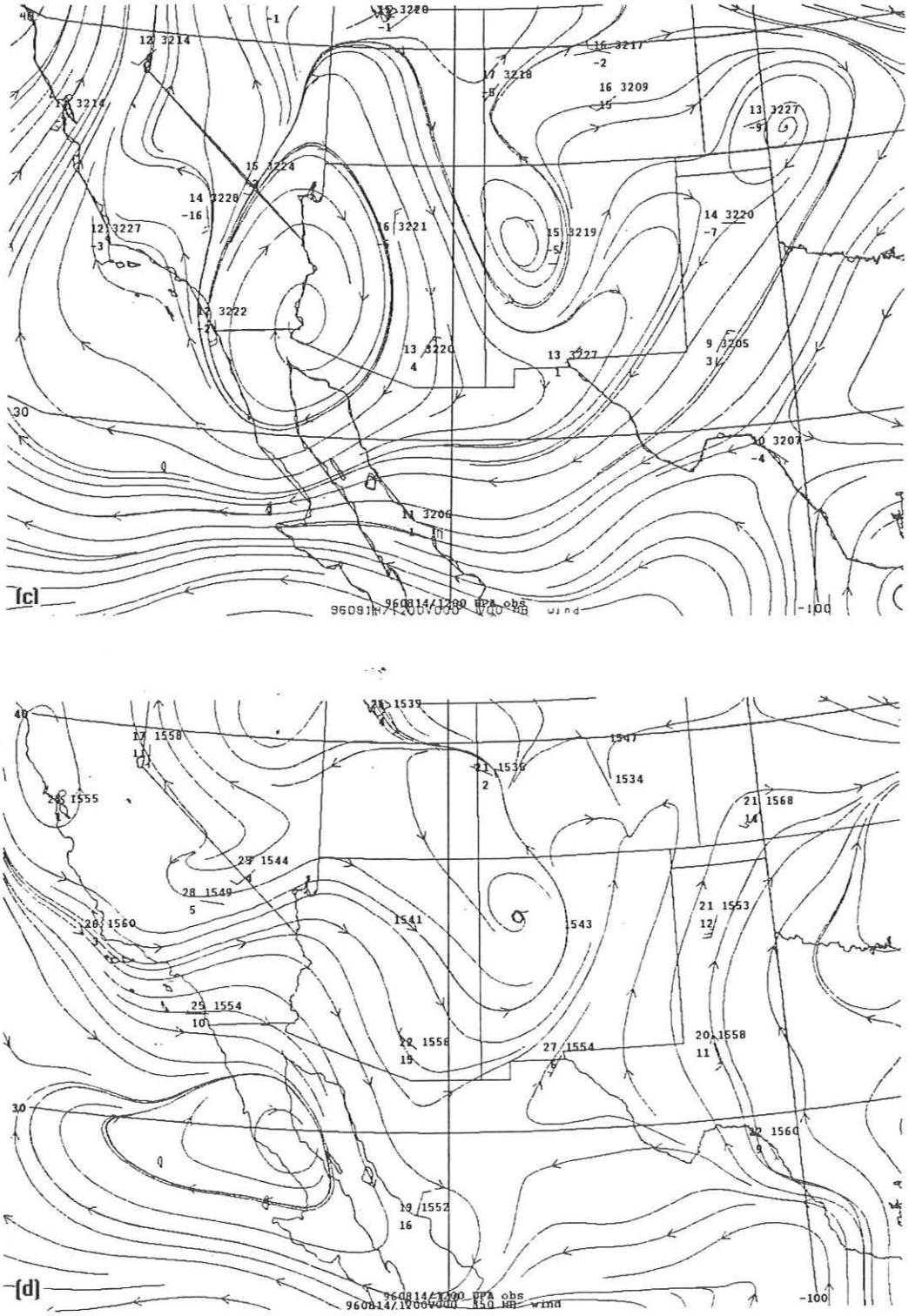

Fig. 3 (cont.) Upper air observations (number to the lower left of station is dew point in °C) overlaid with ETA model initial analyses of wind field streamlines valid at 1200 UTC 14 August 1996 at c) 700 mb and d) 850 mb.

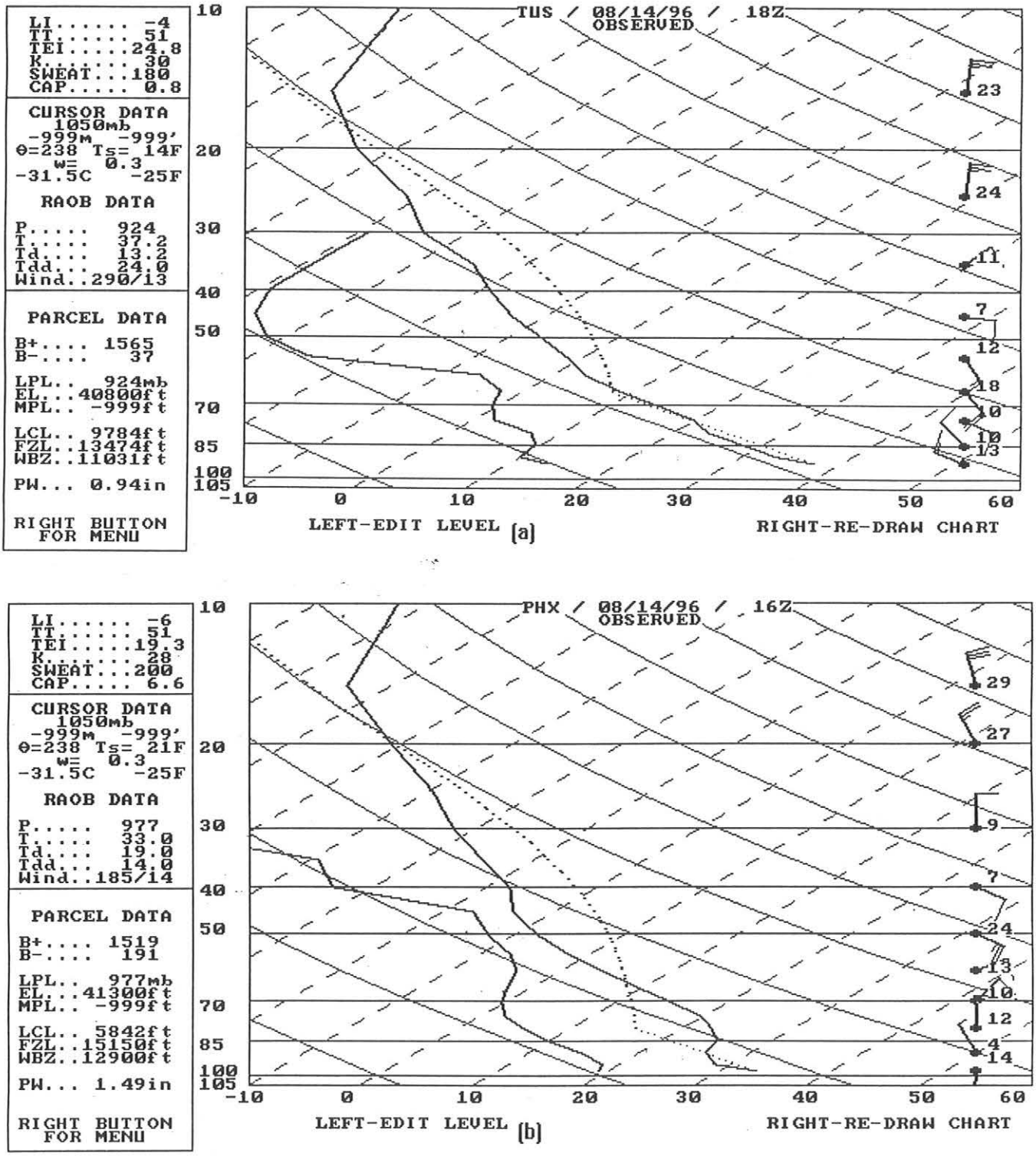

Fig. 4 (a) Tucson (TUS) sounding valid at 1800 UTC 14 August 1996 and (b) Phoenix (PHX) sounding valid at 1600 UTC 14 August 1996.

ZCZC PHXSPSPHX
TTAA00 KPHX 142016
AZZ015>026-151200-

SEVERE WEATHER OUTLOOK FOR THE SOUTHERN HALF OF ARIZONA
NATIONAL WEATHER SERVICE PHOENIX AZ
115 PM MST WED AUG 14 1996

...MODERATE RISK FOR SEVERE THUNDERSTORMS OVER SOUTHEAST ARIZONA THIS AFTERNOON AND TONIGHT...
...SLIGHT RISK FOR SEVERE THUNDERSTORMS OVER SOUTH-CENTRAL ARIZONA TONIGHT...

THERE IS A MODERATE RISK FOR SEVERE THUNDERSTORMS OVER SOUTHEAST ARIZONA THIS AFTERNOON AND EVENING. THE MODERATE RISK AREA INCLUDES THE FOLLOWING COUNTIES...SOUTHERN GILA...GRAHAM...COCHISE... SANTA CRUZ...EASTERN PIMA...AND SOUTHEASTERN PINAL.

THERE IS A SLIGHT RISK FOR SEVERE THUNDERSTORMS OVER SOUTH-CENTRAL ARIZONA TONIGHT. THE SLIGHT RISK AREA INCLUDES THE FOLLOWING COUNTIES...MARICOPA...NORTHWESTERN PINAL...AND WESTERN PIMA.
THE MAIN THREAT FROM THESE STORMS WILL BE DAMAGING STRAIGHT-LINE WINDS AND INTENSE LIGHTNING. STRONGEST STORMS WILL ALSO PRODUCE LOCALLY HEAVY RAINFALL AND HAIL.

LOW-LEVEL MOISTURE HAS INCREASED SIGNIFICANTLY OVER THE SOUTHERN HALF OF ARIZONA SINCE TUESDAY EVENING. SURFACE DEW POINTS ARE IN THE MIDDLE 60S...WHICH IS WELL ABOVE THE CLIMATOLOGICAL NORM. THE ATMOSPHERE IS VERY UNSTABLE OVER SOUTHEAST ARIZONA...AND SURFACE HEATING WILL LEAD TO FURTHER DESTABILIZATION THIS AFTERNOON.

SCATTERED THUNDERSTORMS ARE EXPECTED TO DEVELOP OVER HIGHER TERRAIN LOCATIONS BY MID-AFTERNOON AND AFFECT LOWER TERRAIN SITES... INCLUDING THE TUCSON...NOGALES...SIERRA VISTA...DOUGLAS...AND SAFFORD AREAS...BY LATE AFTERNOON OR EARLY EVENING. STRONGER-THAN-NORMAL UPPER LEVEL EASTERLY WINDS WILL STEER STORMS TO THE WEST AND INCREASE THE POTENTIAL FOR DAMAGING STRAIGHT LINE WINDS AND BLOWING DUST OVER SOUTH-CENTRAL ARIZONA...INCLUDING THE GREATER PHOENIX METRO AREA...GILA BEND...AND CASA GRANDE...BY EARLY TONIGHT.

GREEN

Fig. 5 Severe Weather Outlook issued for the southern half of Arizona on the afternoon of 14 August 1996.

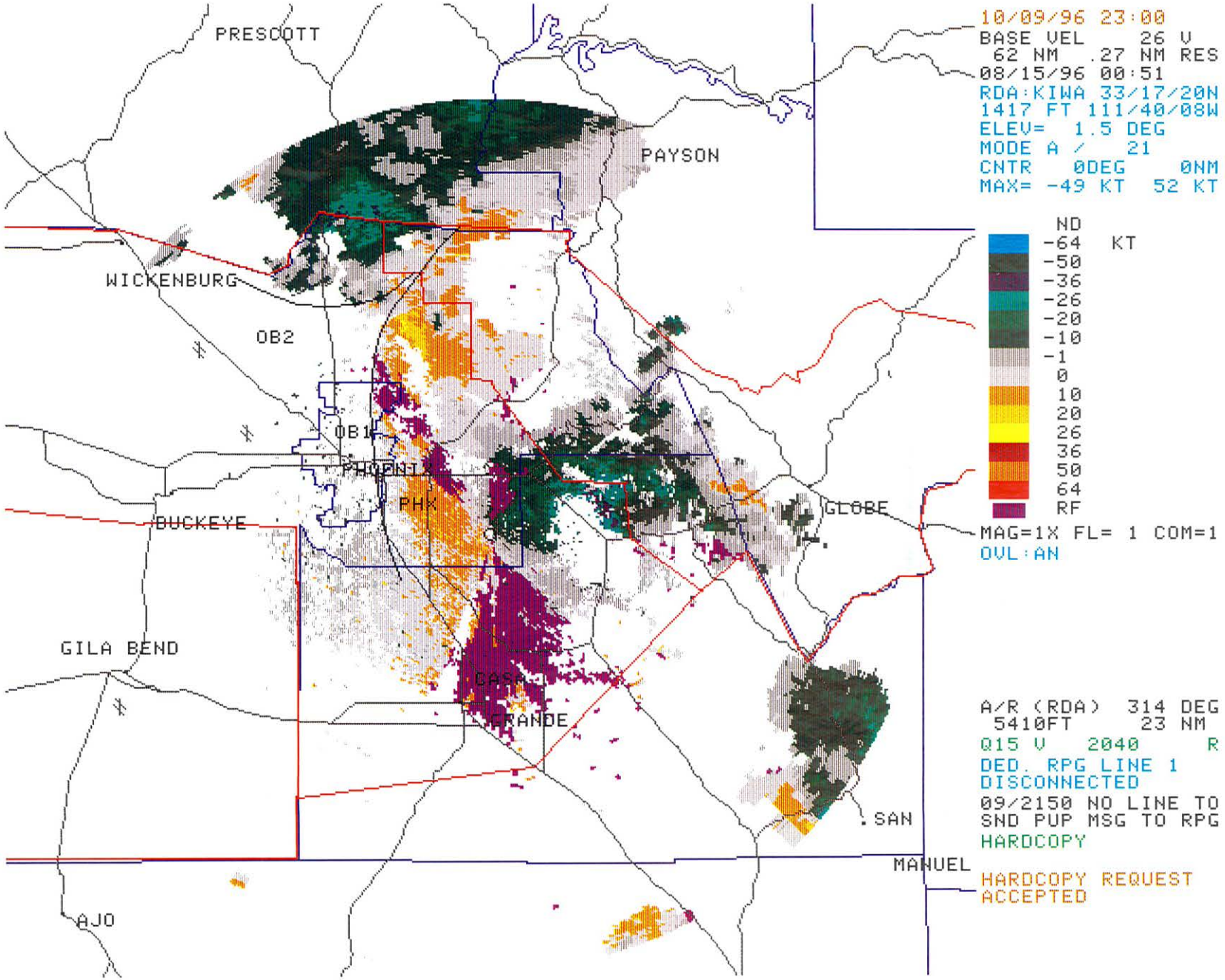

Fig. 6 Phoenix (KIWA) WSR-88D Base Velocity product at 0051 UTC 15 August 1996.

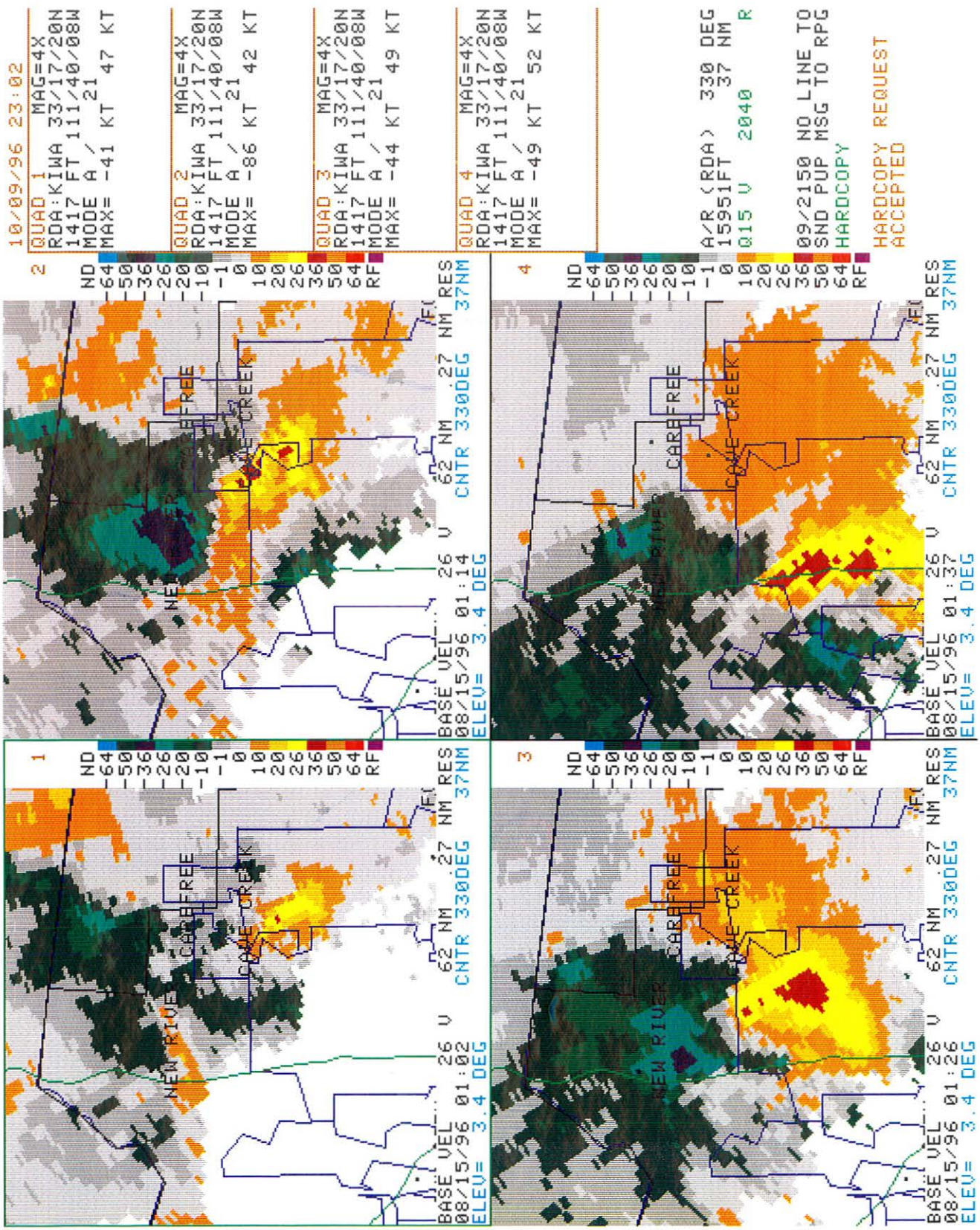

Fig. 7 Phoenix (KIWA) WSR-88D 4-panel Base Velocity product valid at 0102, 0114, 0126, and 0137 UTC 15 August 1996.

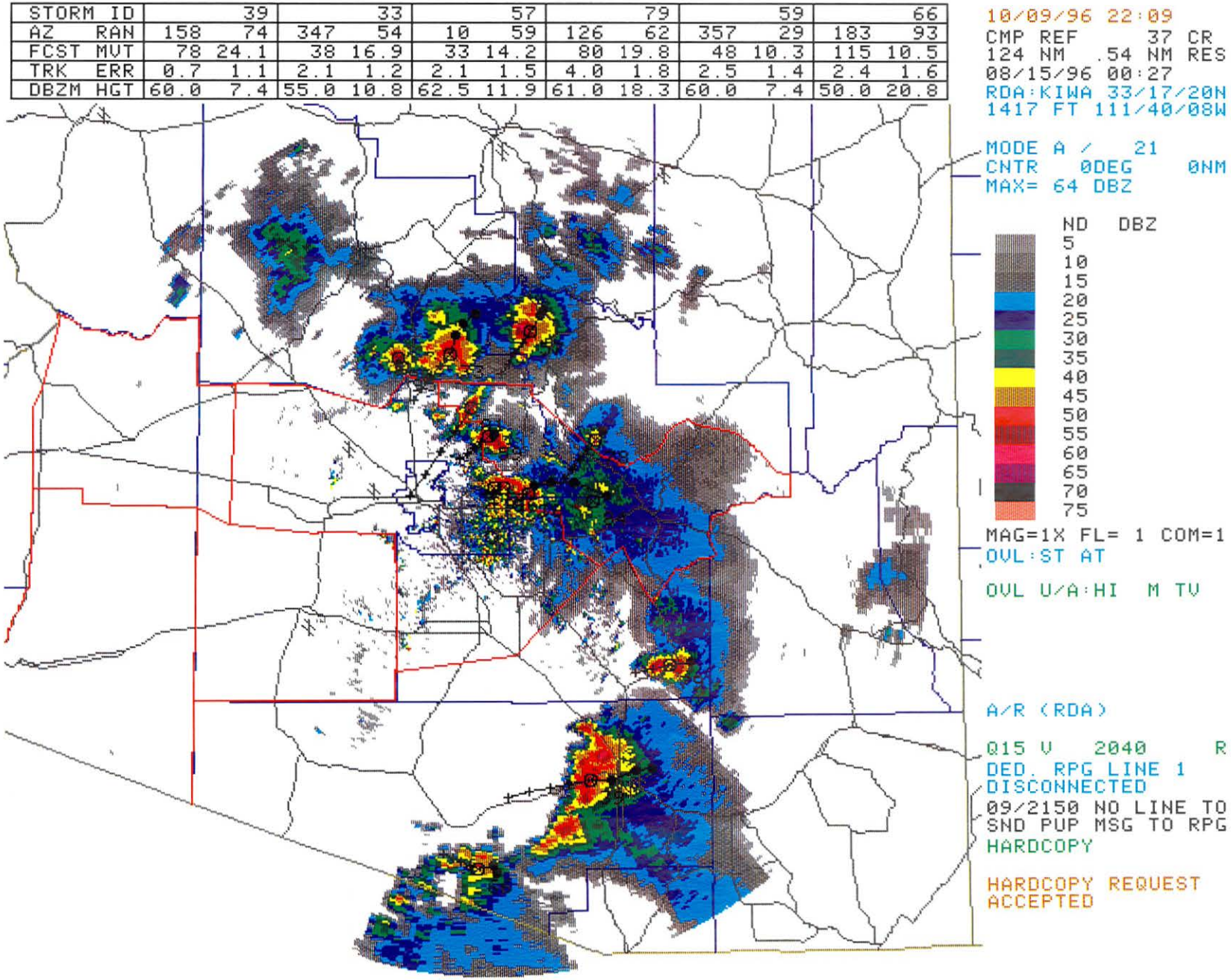

Fig. 8 Phoenix (KIWA) WSR-88D Composite Reflectivity product valid at 0027 UTC 15 August 1996.

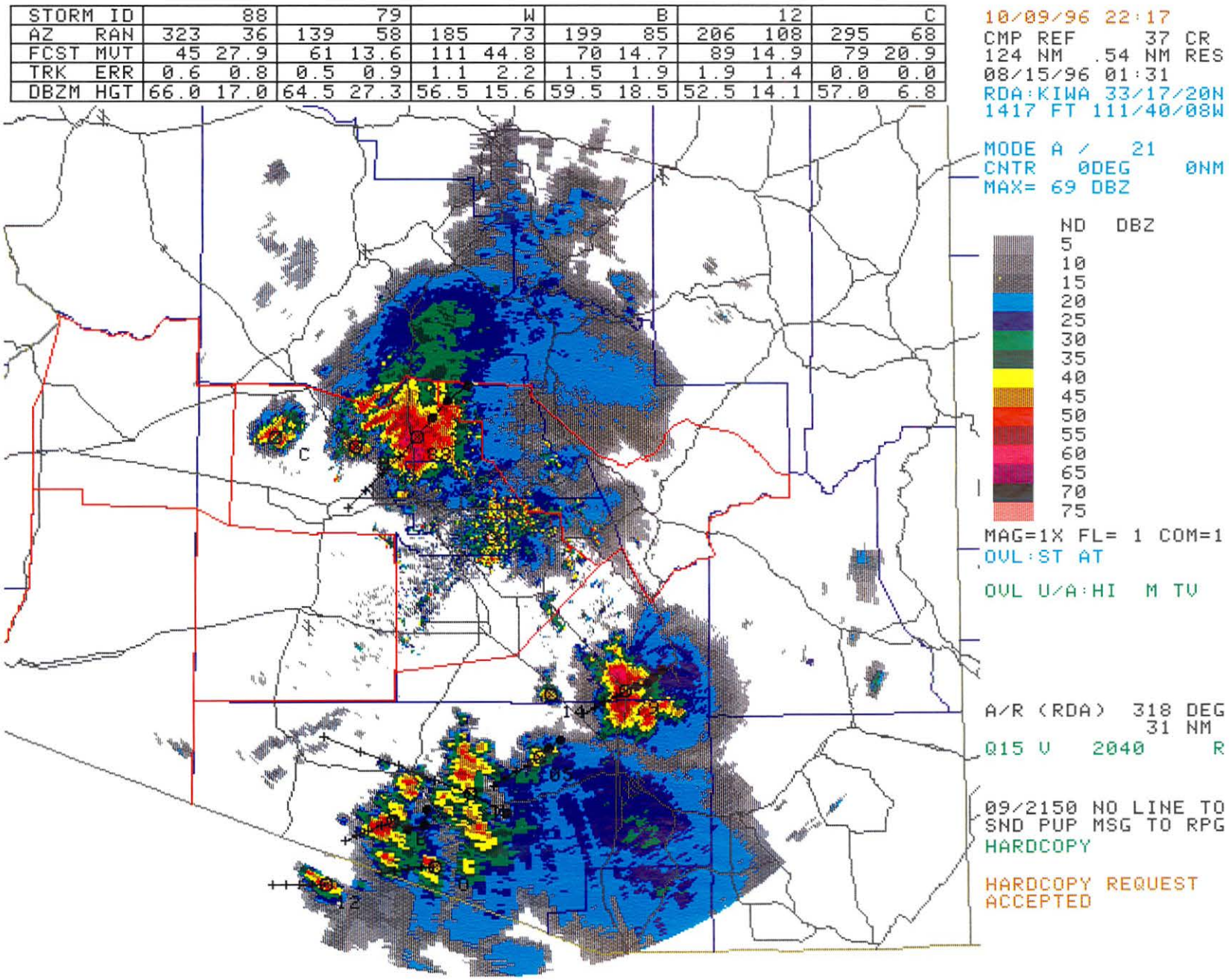

Fig. 9 Phoenix (KIWA) WSR-88D Composite Reflectivity product valid at 0131 UTC 15 August 1996.

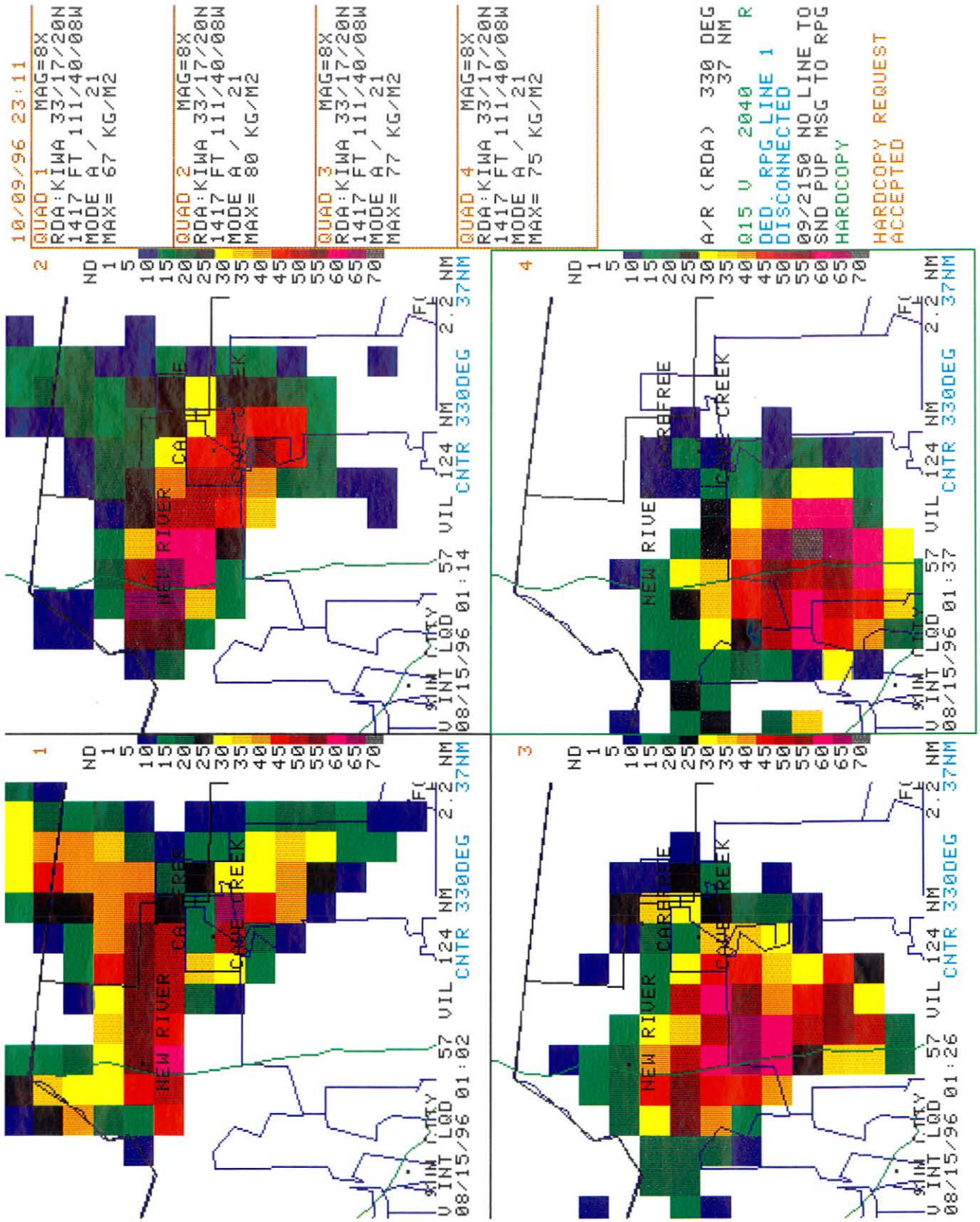

Fig. 10 Phoenix (KIWA) WSR-88D Vertically Integrated Liquid (VIL) 4-panel product valid at 0102, 0114, 0126, and 0137 UTC 15 August 1996.

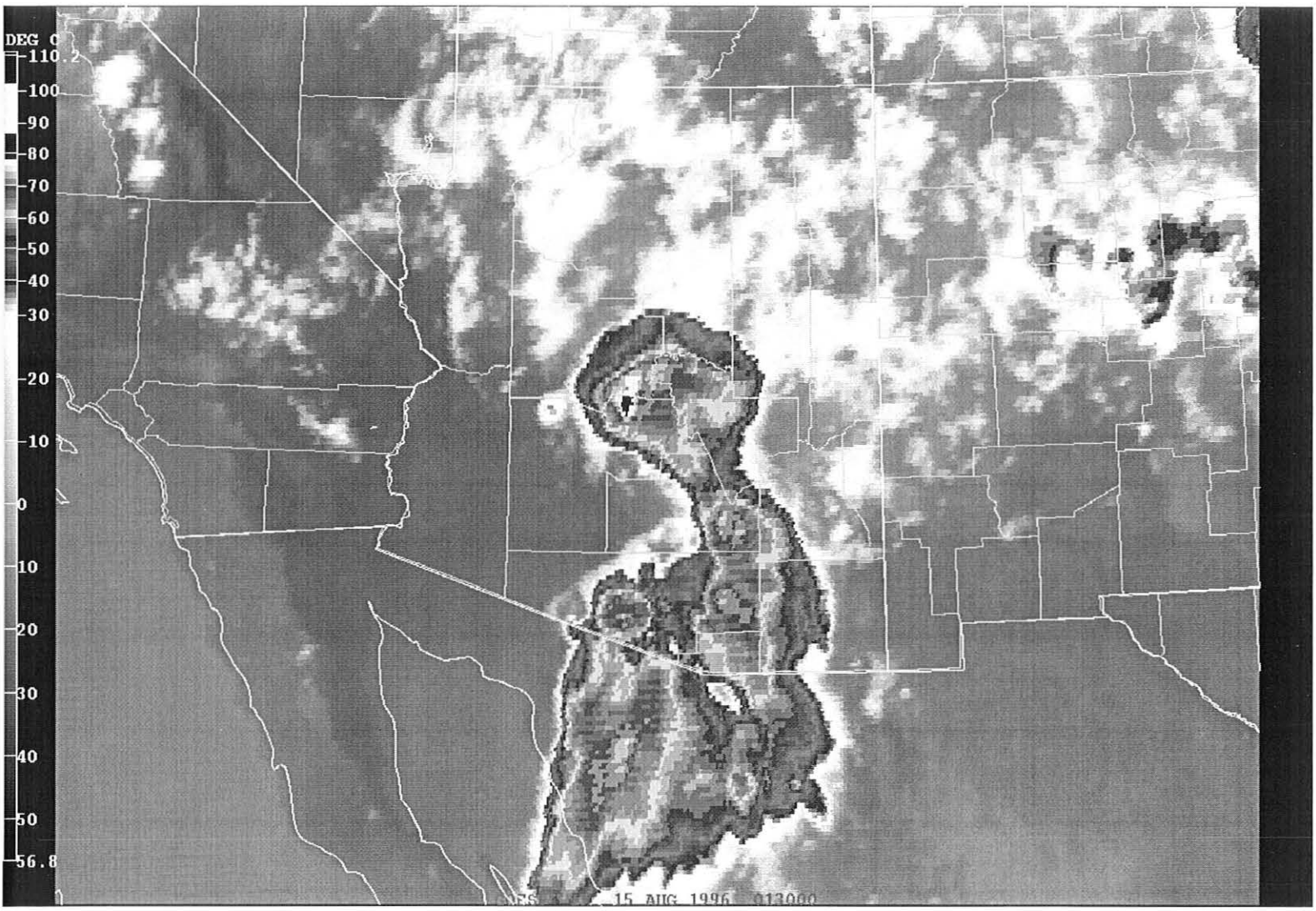

Fig. 11a GOES-9 1km resolution IR satellite imagery valid at 0130 UTC 15 August 1996

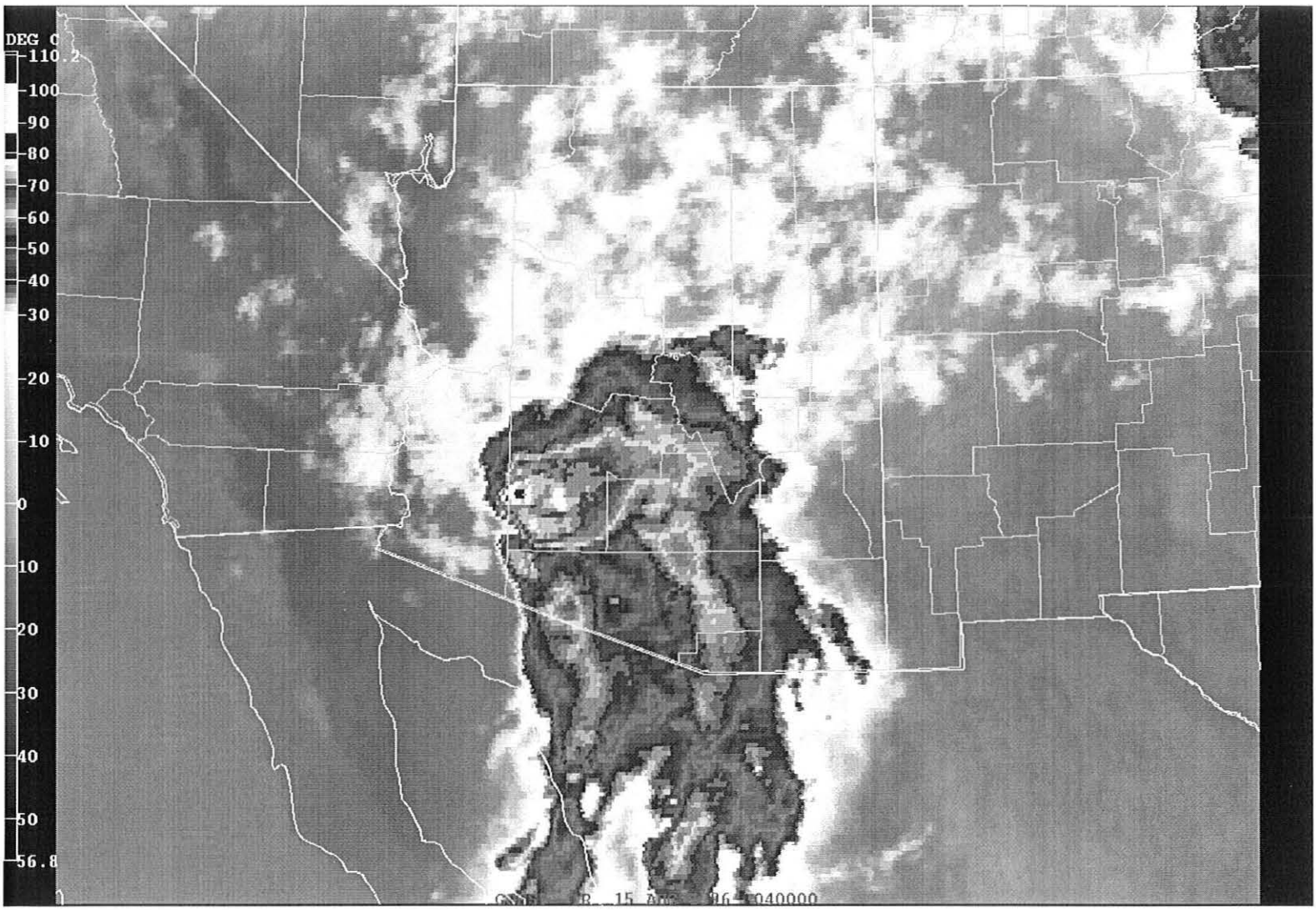

Fig. 11b GOES-9 1km resolution IR satellite imagery valid at 0400 UTC 15 August 1996

Table 1 METAR observations for KPHX for the period 1256 UTC 13 August 1996 to 0856 UTC 14 August 1996

METAR KPHX 140856Z 28014G18KT 10SM BKN130 34/20 A2992 RMK A02 PRESFR SLP107 T03390200 50013 $
METAR KPHX 140756Z 26013KT 10SM SCT090CB BKN130 35/20 A2994 RMK A02 PRESFR SLP114 CB FRQ LTGICCC DSNT NW-N MVG NW T03500200 $
METAR KPHX 140656Z VRB05KT 10SM FEW090CB SCT120 37/19 A2993 RMK A02 SLP112 CB FRQ LTGICCC DSNT N T03670189 404280306 $
METAR KPHX 140556Z 24009KT 10SM CLR 38/15 A2990 RMK A02 SLP101 T0383150 10428 20372 53014 $
METAR KPHX 140456Z 00000KT 10SM CLR 38/14 A2988 RMK A02 SLP095 T03780139 $
METAR KPHX 140356Z 23007KT 10SM CLR 40/12 A2986 RMK A02 SLP089 T04000122 $
METAR KPHX 140256Z 27006KT 10SM CLR 41/11 A2985 RMK A02 SLP086 T04060111 53001 $
METAR KPHX 140156Z 32005KT 10SM CLR 42/12 A2984 RMK A02 SLP083 T04170122 $
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METAR KPHX 131856Z 30005KT 10SM CLR 39/14 A2997 RMK A02 SLP124 T03890139
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METAR KPHX 131656Z VRB04KT 10SM CLR 36/13 A3000 RMK A02 SLP134 T03610133
METAR KPHX 131556Z 11005KT 10SM CLR 34/13 A3000 RMK A02 SLP137 T03390133
METAR KPHX 131456Z 11005KT 10SM CLR 33/09 A2999 RMK A02 SLP132 T03280094 53021
METAR KPHX 131356Z 10004KT 10SM CLR 32/09 A2997 RMK A02 SLP125 T03170094
METAR KPHX 131256Z 10006KT 10SM CLR 31/08 A2994 RMK A02 SLP115 T03060083 $

Table 2 Summary of statements and reports issued and/or received by the Phoenix NWSFO during the afternoon and evening hours of 14 August 1996.

Legend:
FFS...FLASH FLOOD STATEMENT
NOW...SHORT TERM FORECAST
RPT...SEVERE STORM REPORT
SEL...SEVERE LOCAL STORM WATCH
SLS...SEVERE LOCAL STORM WATCH AREAL OUTLINE
SPS...SPECIAL WEATHER STATEMENT
SVR...SEVERE THUNDERSTORM WARNING
SVS...SEVERE WEATHER STATEMENT

1:15 PM MST	SPS	Arizona Severe Weather Outlook
2:12 PM MST	SEL	Severe Thunderstorm Watch #952 Southeast Arizona including extreme eastern Maricopa County
2:25 PM MST	SLS	Watch #952 Areal Outline
2:50 PM MST	SPS	Definition of Watch - #952
3:47 PM MST	NOW	Thunderstorms approaching North and East Valley
4:20 PM MST	SVR	Northwest Pinal County including State Route 60.
4:55 PM MST	SEL	Severe Thunderstorm Watch #954 Southern Arizona including Maricopa, and Western Pinal Counties
5:17 PM MST	SVR	Eastern Maricopa including the Eastern Phoenix Metro area
5:17 PM MST	SLS	Watch #954 Areal Outline
5:35 PM MST	NOW	Severe Thunderstorms will affect much of Phoenix Metro by 7:00 PM MST.
5:55 PM MST	SVR	Northeast Maricopa County including far north valley, Cave Creek and Carefree.
6:20 PM MST	NOW	Severe thunderstorms affecting North Valley from Scottsdale to Sun City for next two hours.
6:33 PM MST	RPT	Wind gust estimated in excess of 100 MPH northern Glendale between Pinnacle Peak Rd and Happy Valley Rd. Considerable damage. 1" diameter hail.

Table 2 (cont.)

6:34 PM MST	RPT	Roof off 63rd Avenue and Bell Road.
6:38 PM MST	RPT	115 MPH wind gust at Deer Valley Airport Tower.
6:36 PM MST	SVS	Various damage reports
6:45 PM MST	SVR	Severe Thunderstorm Warning Northern and Western Phoenix Metro.
6:50 PM MST	RPT	85 MPH wind gust 5 miles west of Luke Air Force Base.
7:07 PM MST	SVR	Central and Western Metro.
7:15 PM MST	RPT	69 MPH wind gust at Goodyear Airport Tower.
7:17 PM MST	FFS	Urban and Small Stream Flood Advisory Central and Western Metro.
7:41 PM MST	SVR	Western Maricopa County.
8:05 PM MST	SVR	Southwest Maricopa County including Gila Bend.
8:15 PM MST	SVS	Metro Area Warnings have expired.
8:30 PM MST	NOW	Thunderstorm continue over Maricopa County.
8:35 PM MST	RPT	Damaging winds reported at Gila Bend AFB Auxiliary Airport.
8:37 PM MST	SVS	Western Maricopa County warning expires.
8:55 PM MST	SVR	Eastern Yuma County
9:08 PM MST	SVR	Southwest Maricopa County between Gila Bend and Ajo.
9:41 PM MST	SVR	Central and Eastern Yuma county including Dateland and Tacna.
9:50 PM MST	NOW	Thunderstorms mainly over western Maricopa county.
10:10 PM MST	SVS	Warning for Southwest Maricopa County has expired.
10:15 PM MST	SVR	Western Yuma county including city of Yuma.
10:15 PM MST	RPT	Power Poles down at Tacna. (Yuma Co.)

Table 2 (cont.)

10:35 PM MST	RPT	48 MPH wind gust at Yuma Marine Corps Air Station. Visibility zero in blowing dust.
10:40 PM MST	SVS	Warning for Eastern and Central Yuma county has expired.
10:45 PM MST	RPT	Power Lines down in Yuma.
10:48 PM MST	FFS	Urban and Small Stream Flood Advisory for southwest Yuma County until 2:00 AM MST.
10:55 PM MST	NOW	Yuma area Severe Thunderstorms
11:08 PM MST	FFS	Urban and Small Stream Flood Advisory for Central and Western Maricopa County has expired.
11:37 PM MST	SVS	Warning for western Yuma county has expired.