NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

March 5, 2015

Group Chairman's Factual Report

METEOROLOGY

DCA15MA019

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A. ACCIDENT

Location: Near Koehn Dry Lake, California
Date: October 31, 2014
Time: 1007 Pacific daylight time (1707 UTC[1])
Vehicle: Scaled Composites SpaceShipTwo, registration: N339SS

B. METEOROLOGY GROUP

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C. SUMMARY

On October 31, 2014, about 1007 Pacific daylight time,[2] a Scaled Composites SpaceShipTwo (SS2) reusable suborbital rocket, N339SS, experienced an in-flight anomaly during a rocket-powered flight test, resulting in loss of control of the vehicle. SS2 broke up into multiple pieces and impacted terrain over a 5-mile area near Koehn Dry Lake, California. One test pilot (the copilot) was fatally injured, and the other test pilot was seriously injured. SS2 had launched from the WhiteKnightTwo (WK2) carrier aircraft, N348MS, about 12 seconds before the loss of control. SS2 was destroyed, and WK2 made an uneventful landing. Scaled Composites was operating SS2 under an experimental permit issued by the Federal Aviation Administration's (FAA) Office of Commercial Space Transportation under the provisions of 14 *Code of Federal Regulations* (CFR) Part 437.

[1] UTC – is an abbreviation for Coordinated Universal Time.
[2] Unless otherwise indicated, all times in this report are Pacific daylight time based on a 24-hour clock.

D. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's (NTSB) Meteorologist was not on scene and gathered the weather data for this investigation from the NTSB's Washington D.C. office and from official National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sources including the National Climatic Data Center (NCDC). All times are Pacific daylight time (PDT) on October 31, 2014, and are based upon the 24-hour clock, where local time is -7 hours from UTC, and UTC=Z (unless otherwise noted). Directions are referenced to true north and distances in nautical miles. Heights are above mean sea level (msl) unless otherwise noted. Visibility is in statute miles and fractions of statute miles.

The accident location was located at latitude 35.33° N, longitude 117.94° W, elevation: 2,046 feet.

E. FACTUAL INFORMATION

1.0 Synoptic Situation

The synoptic or large scale migratory weather systems influencing the area were documented using standard NWS charts issued by the National Center for Environmental Prediction (NCEP) and the Weather Prediction Center (WPC) located in College Park, Maryland. These are the base products used in describing synoptic weather features and in the creation of forecasts and warnings for the NWS. Reference to these charts can be found in the joint NWS and Federal Aviation Administration (FAA) Advisory Circular "Aviation Weather Services", AC-0045G CHG 1.

1.1 Surface Analysis Chart

The NWS Surface Analysis Chart for 1100 PDT[3] is provided as figure 1, with the approximate location of the accident site marked. The chart depicted a cold front stretching from the eastern Pacific Ocean northward into northern California. A trough[4] was stretched from central Nevada southward into western Arizona. A surface low pressure center with a pressure of 1009-hectopascals (hPa) was located in far southeastern California. Another surface low pressure center with a pressure of 1008-hPa was located in central Nevada. The station models around the accident site depicted air temperatures in the mid 60's to low 70's Fahrenheit (F), with temperature-dew point spreads of 19° F or more, a northwest to southwest surface wind between 5 and 15 knots, and mostly clear skies.

[3] NWS Surface Analysis Charts are made and archived every 3 hours and the 1100 PDT chart was the closest to the accident time.
[4] Trough – An elongated area of relatively low atmospheric pressure or heights.

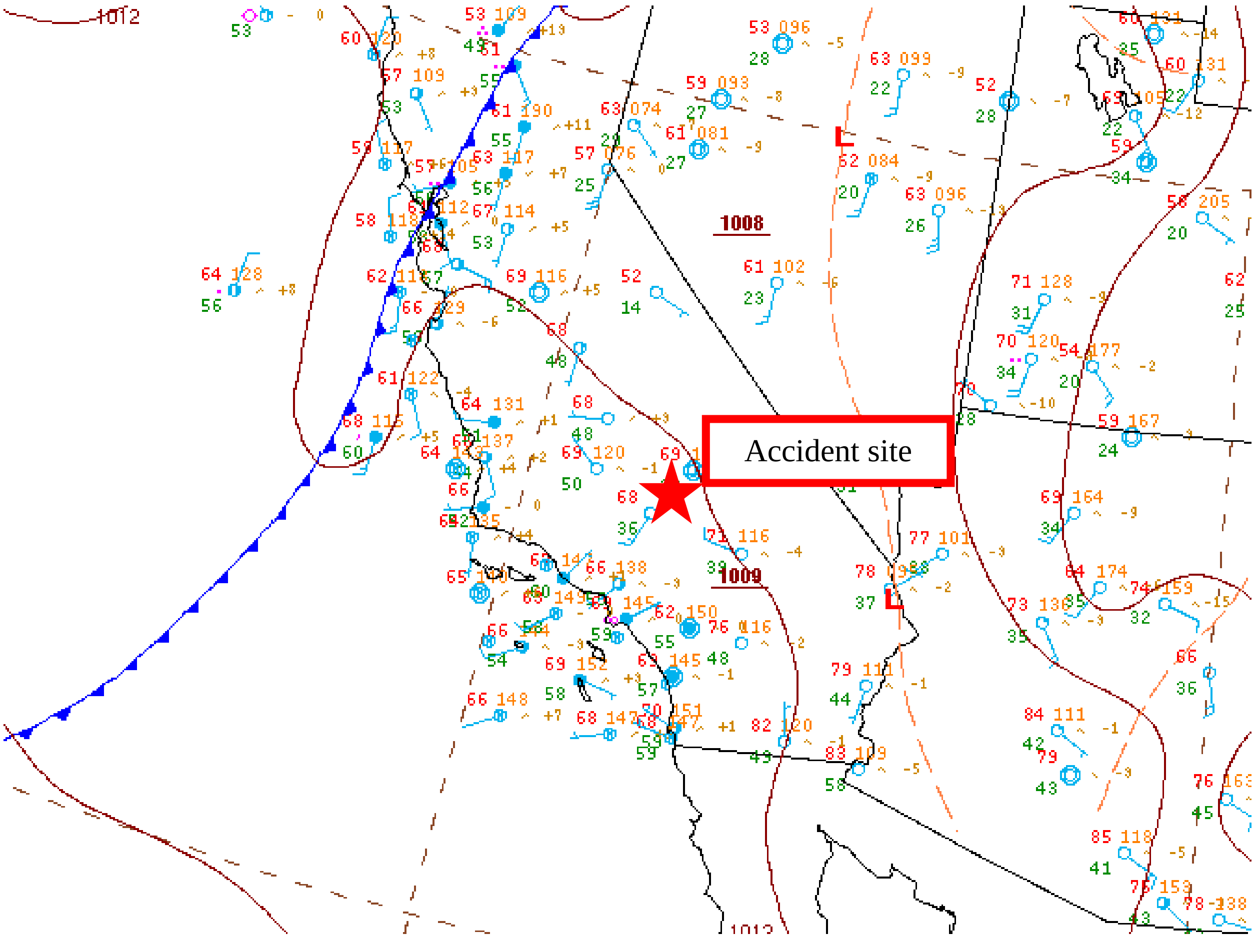

Figure 1 – NWS Surface Analysis Chart for 1100 PDT

1.2 Upper Air Charts

The NWS Storm Prediction Center (SPC) Constant Pressure Charts for 0500 PDT at 925-, 850-, 700-, 500-, and 300-hPa are presented in figures 2, 3, 4, 5, and 7, and the 1700 PDT charts for 500- and 300-hPa in figures 6 and 8. The 925-, 850-, and 700-hPa charts depicted low-level southwesterly winds over the accident site at 0500 PDT with winds as high as 15 knots at 700-hPa around the accident site (figures 2 through 4). A mid-level trough at 500-hPa (associated with the cold front, section 1.1) moved eastward towards western California from 0500 to 1700 PDT (figures 5 and 6). Enhanced lift, clouds, and precipitation can occur in areas near and ahead of troughs. At 300-hPa there was a large increase in wind speed between 0500 and 1700 PDT as an upper-level jet streak moved into northern California (figures 7 and 8). The west wind, near 40 knots at 0500 PDT, near the accident site (figure 7), increased to near 70 knots by 1700 PDT with the wind becoming southwesterly (figure 8).

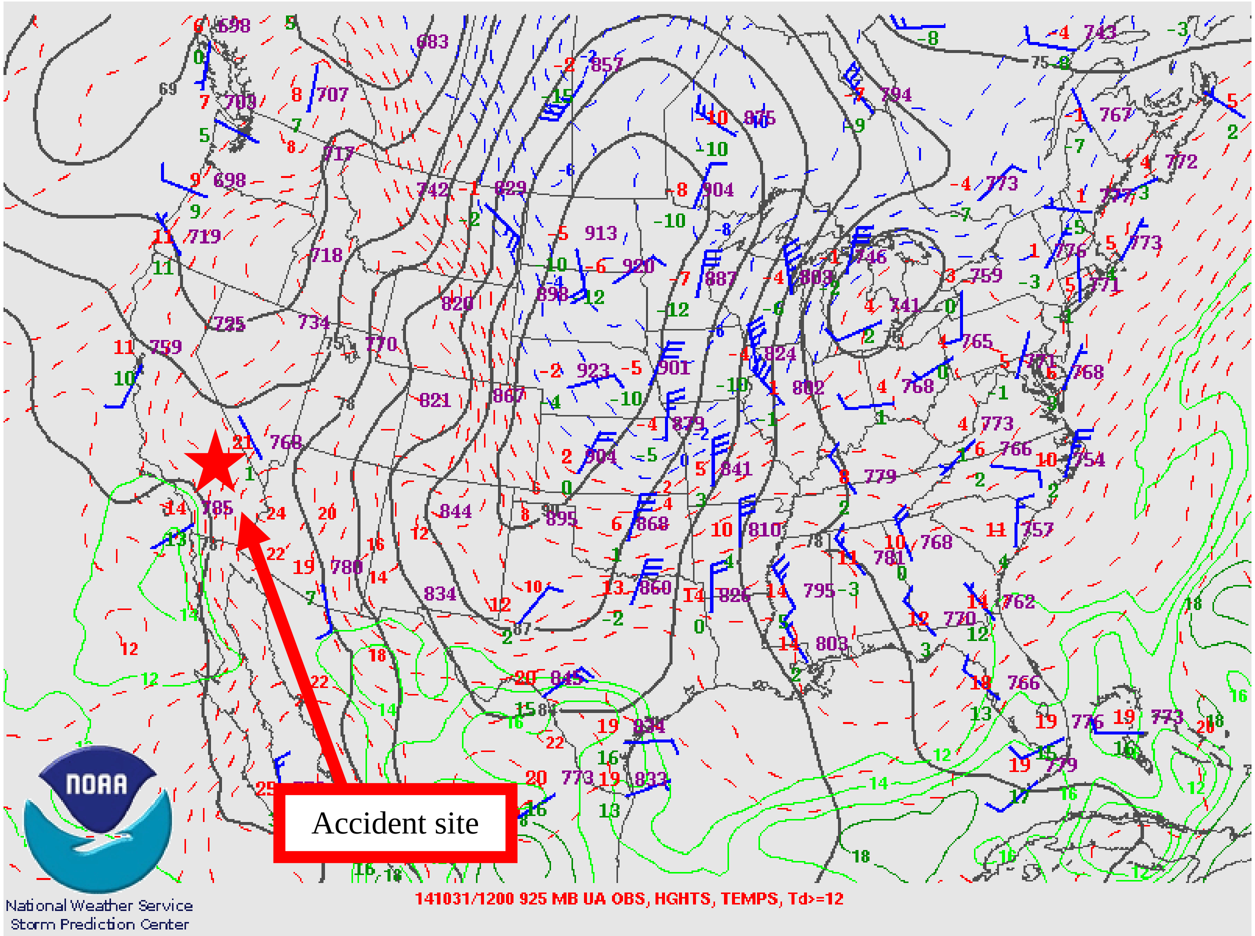

Figure 2 – 925-hPa Constant Pressure Chart for 0500 PDT

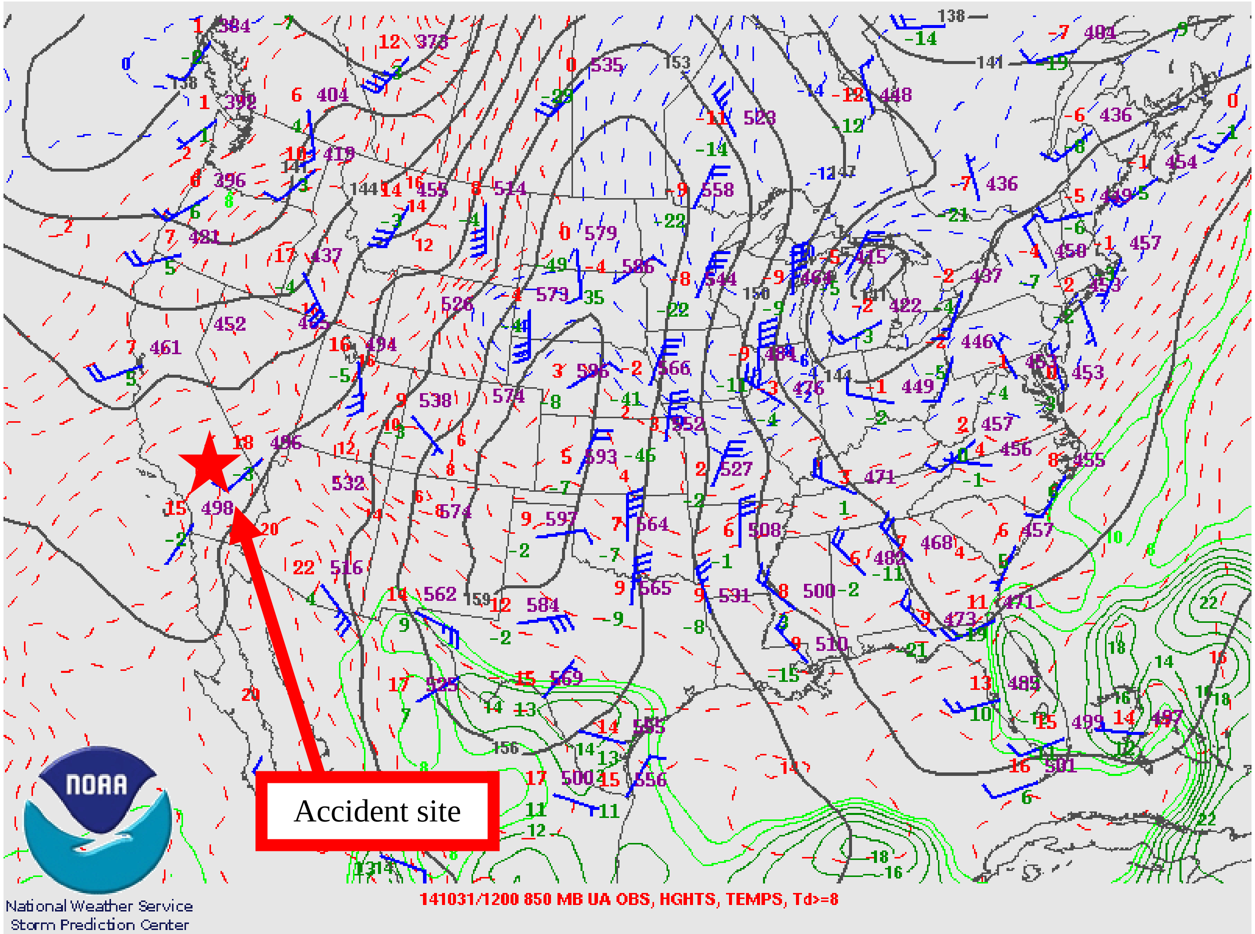

Figure 3 – 850-hPa Constant Pressure Chart for 0500 PDT

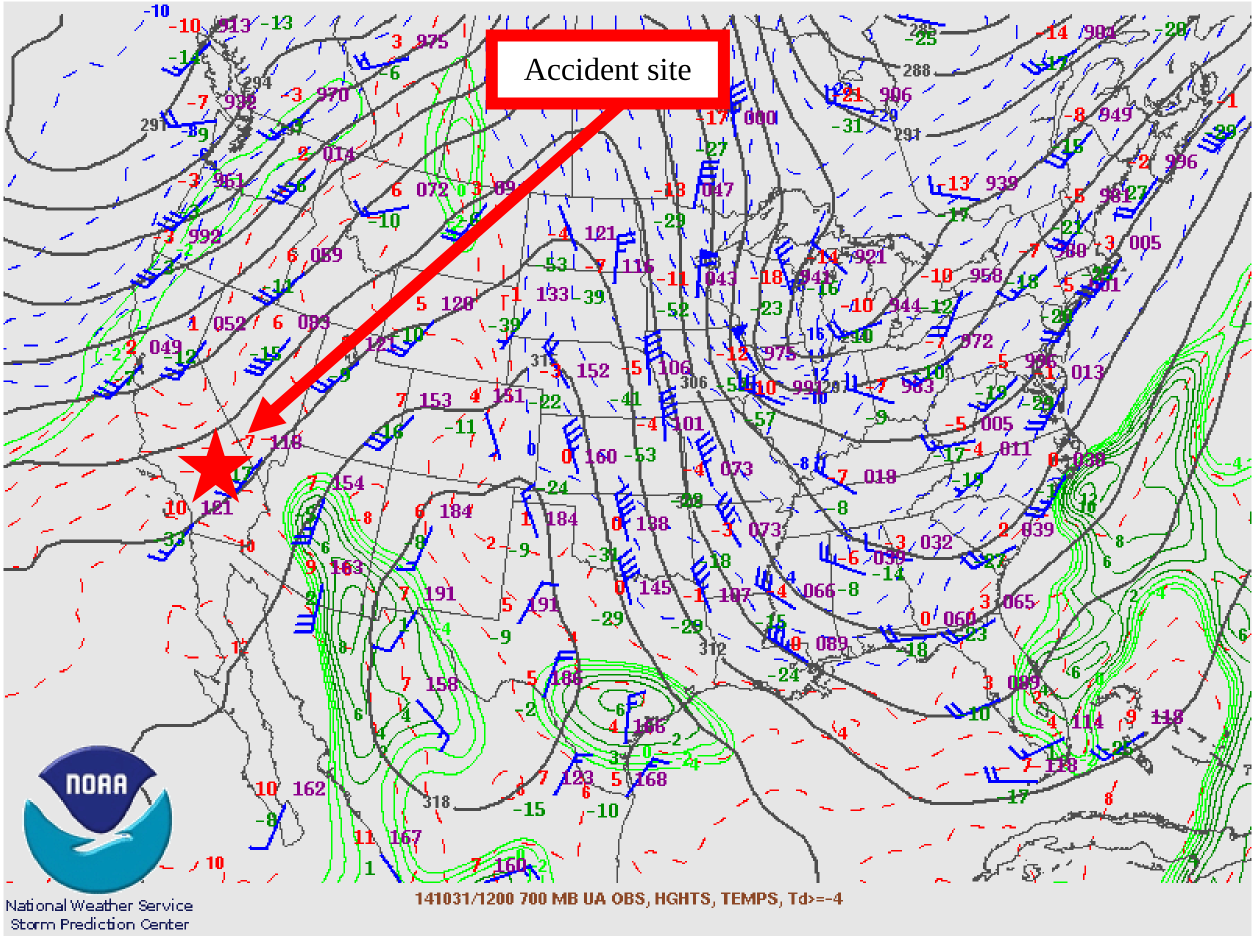

Figure 4 – 700-hPa Constant Pressure Chart for 0500 PDT

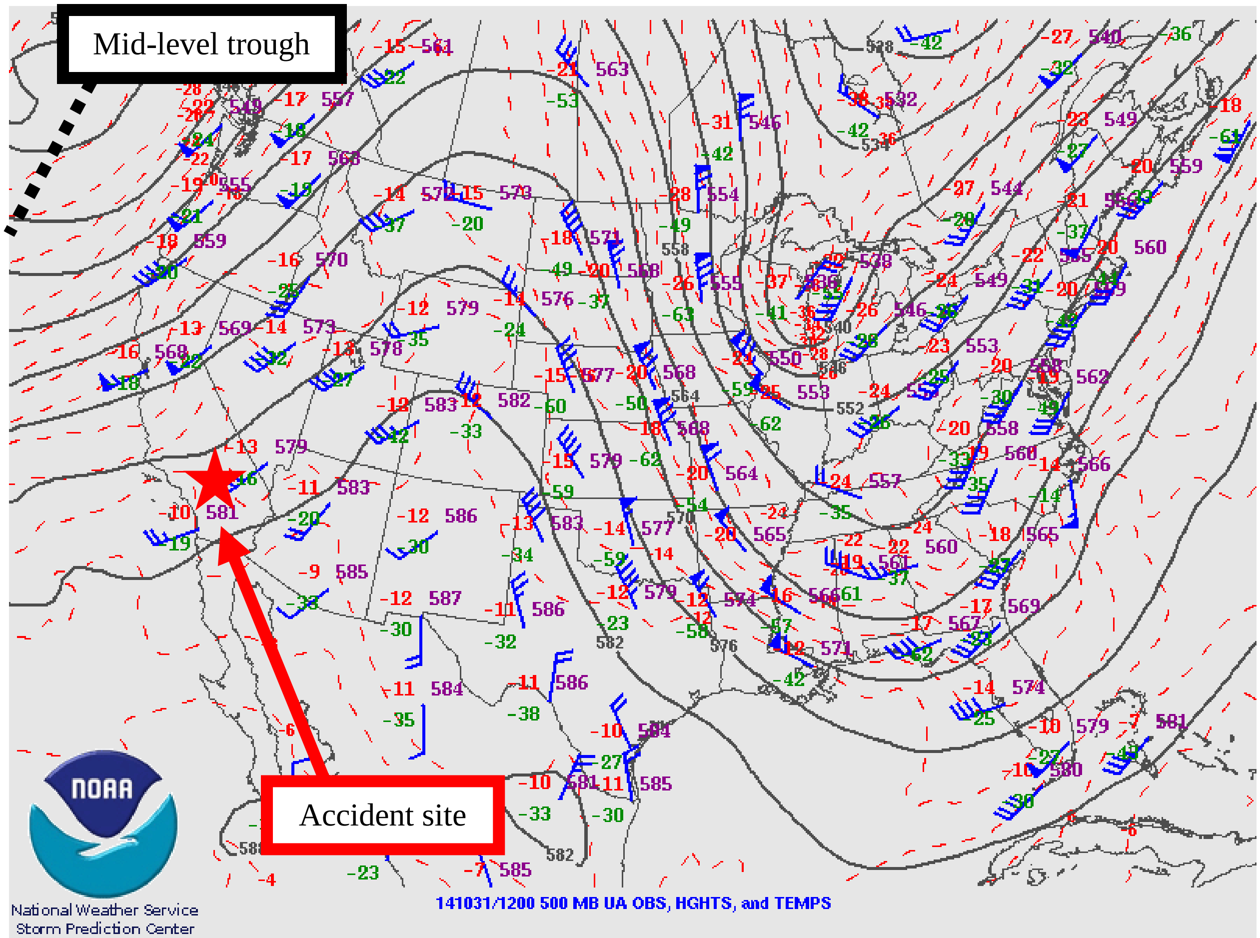

Figure 5 – 500-hPa Constant Pressure Chart for 0500 PDT

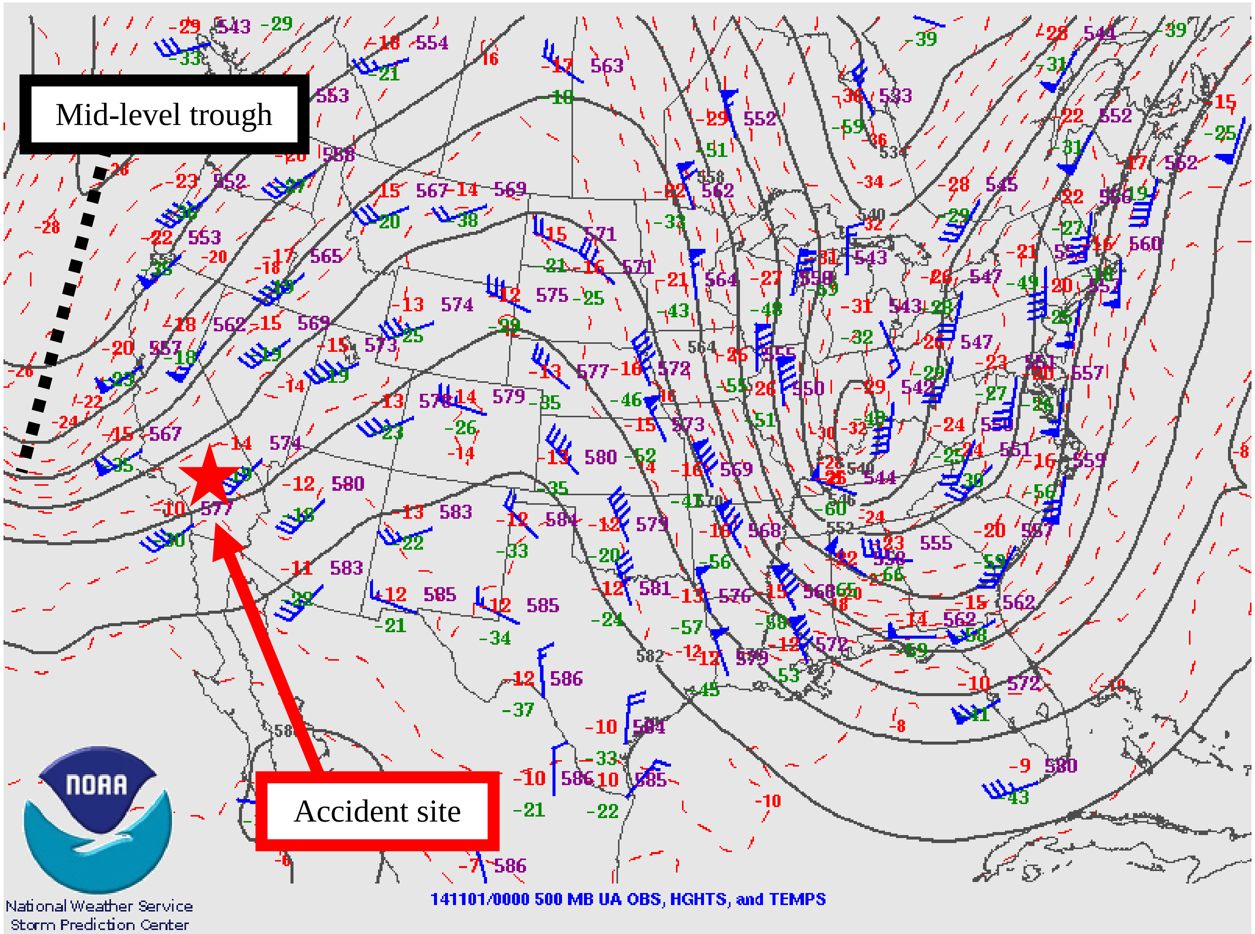

Figure 6 – 500-hPa Constant Pressure Chart for 1700 PDT

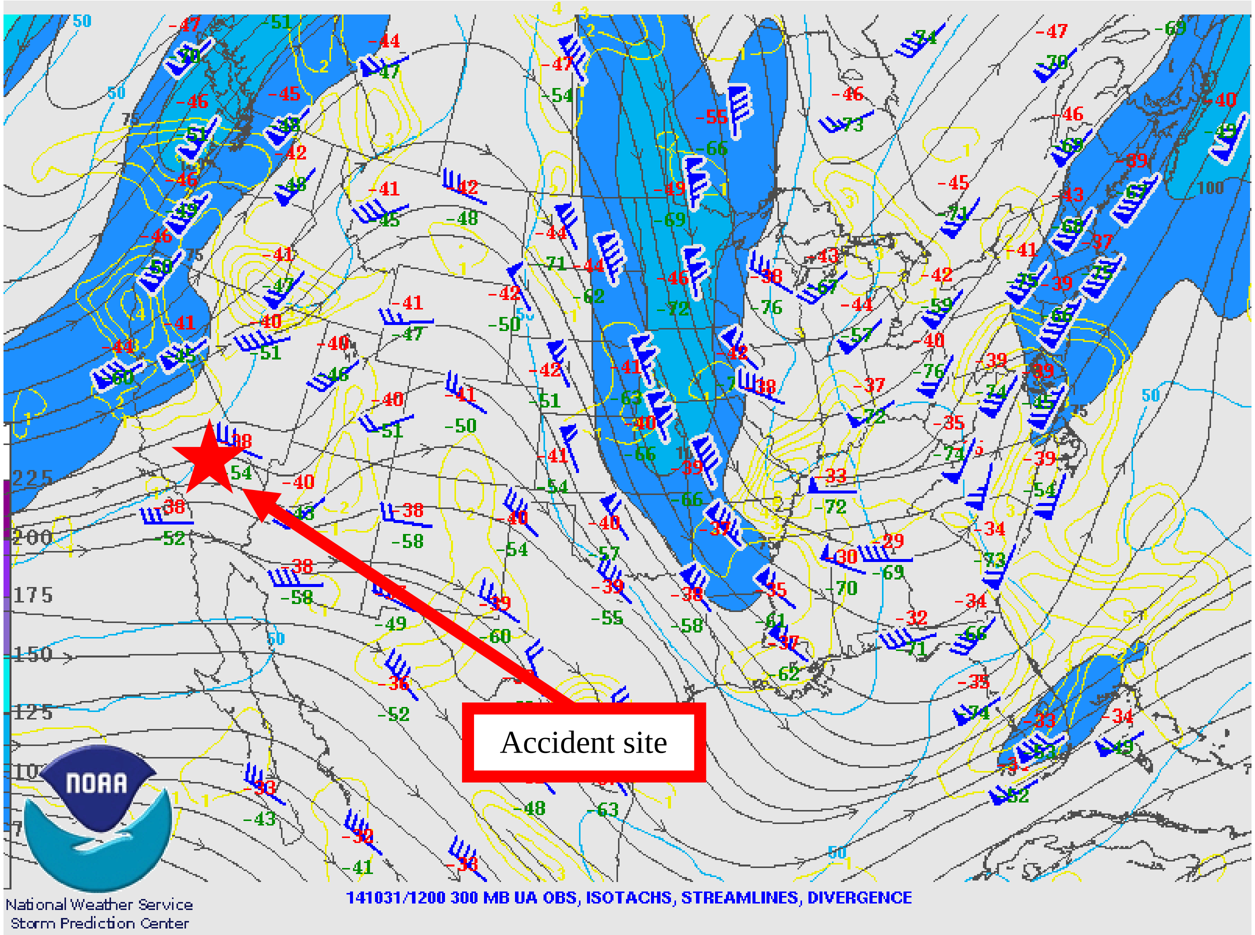

Figure 7 – 300-hPa Constant Pressure Chart for 0500 PDT

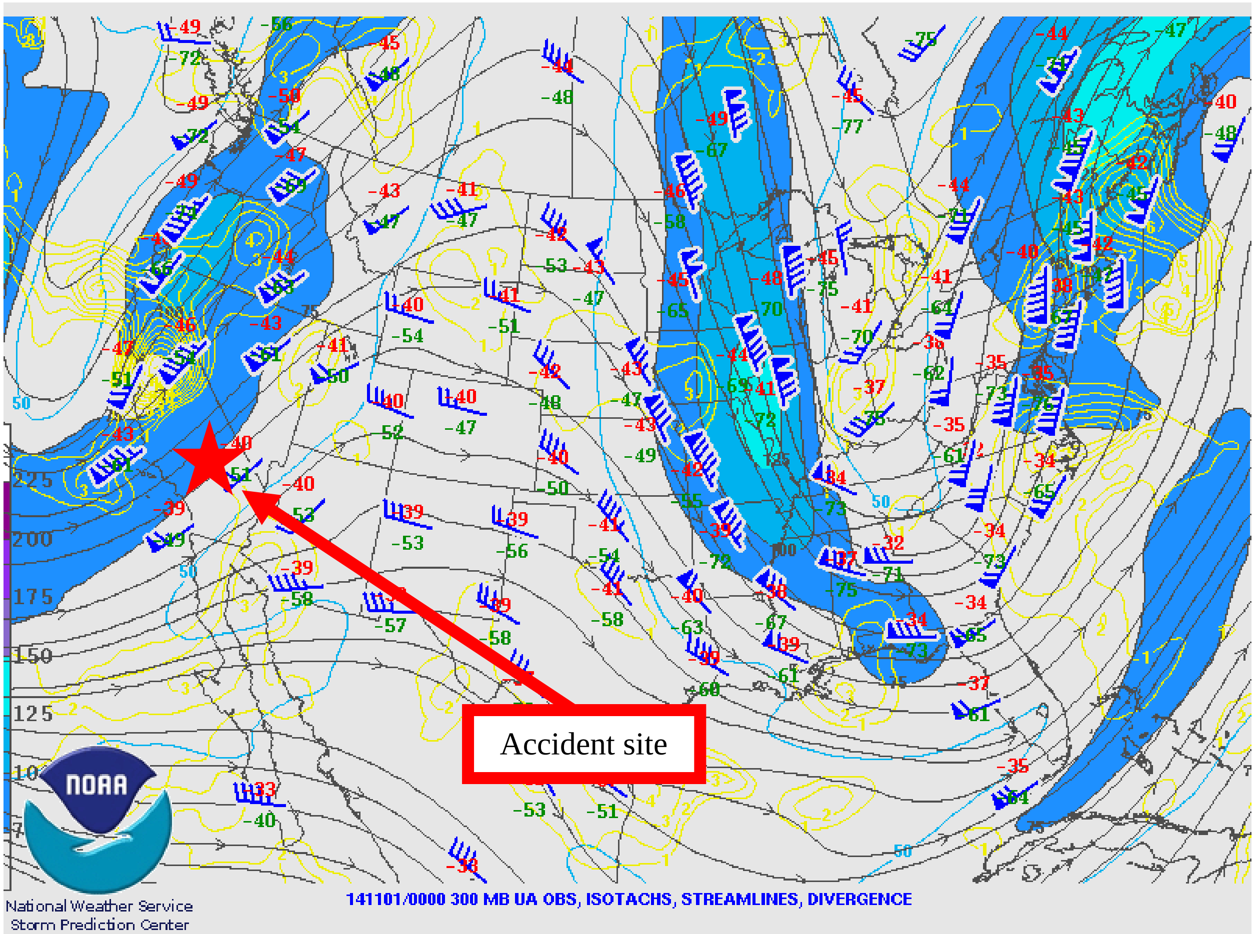

Figure 8 – 300-hPa Constant Pressure Chart for 1700 PDT

2.0 Storm Prediction Center Products

No convective activity was forecast by SPC in the Day 1 Convective Outlook valid for the accident site at the accident time.

3.0 Surface Observations

The area surrounding the accident site was documented utilizing official NWS Meteorological Aerodrome Reports (METARs) and Specials (SPECIs). The following observations were taken from standard code and are provided in plain language.

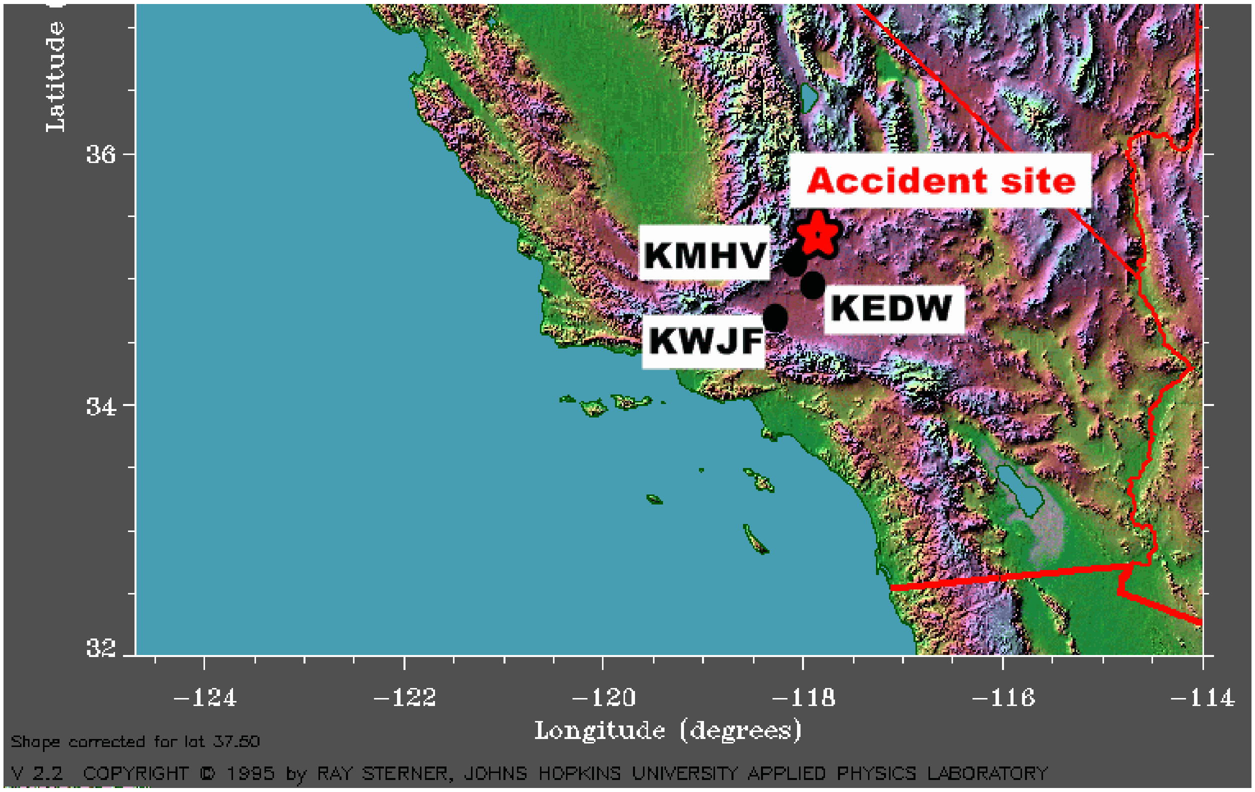

Figure 9 – Map of California with the location of the accident site, surface observation sites, and upper air sounding location

Mojave Airport (KMHV) was the closest official weather station to the accident site located 1 mile east of Mojave, California. KMHV had an Automated Weather Observing System (AWOS[5]) whose reports were not supplemented. KMHV was located 19 miles southwest of the accident site, at an elevation of 2,801 feet, and had a 14° easterly magnetic variation[6] (figure 9). The following observations were taken and disseminated during the times surrounding the accident[7]:

[0815 PDT] KMHV 311515Z AUTO 23006KT 10SM CLR 13/04 A2996 RMK AO1=

[0835 PDT] KMHV 311535Z AUTO 21005KT 10SM CLR 14/05 A2996 RMK AO1=

[0855 PDT] KMHV 311555Z AUTO 21006KT 10SM CLR 17/05 A2997 RMK AO1=

[0915 PDT] KMHV 311615Z AUTO 18004KT 10SM CLR 18/05 A2996 RMK AO1=

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[5] AWOS – Automated Weather Observing System is equipped with meteorological instruments to observe and report temperature, dewpoint, wind speed and direction, visibility, cloud coverage and ceiling up to twelve thousand feet, and altimeter setting.

[6] Magnetic variation – The angle (at a particular location) between magnetic north and true north.

[7] The bold sections in this NWS product and the rest of products in the weather factual report are to highlight the individual sections that directly reference the weather conditions that are or will affect the accident location around the accident time.

[0935 PDT] KMHV 311635Z AUTO 18005KT 10SM CLR 18/05 A2996 RMK AO1=

[0955 PDT] KMHV 311655Z AUTO 20009KT 10SM CLR 19/04 A2996 RMK AO1=

ACCIDENT TIME 1007 PDT

[1015 PDT] KMHV 311715Z AUTO 20011KT 10SM CLR 20/04 A2996 RMK AO1=

[1035 PDT] KMHV 311735Z AUTO 21011G19KT 10SM CLR 20/04 A2995 RMK AO1=

[1055 PDT] KMHV 311755Z AUTO 20014G21KT 10SM CLR 20/02 A2995 RMK AO1=

[1115 PDT] KMHV 311815Z AUTO 20013KT 10SM CLR 20/04 A2994 RMK AO1=

[1135 PDT] KMHV 311835Z AUTO 21014G20KT 10SM CLR 20/04 A2993 RMK AO1=

[1155 PDT] KMHV 311855Z AUTO 22019G24KT 10SM CLR 20/04 A2992 RMK AO1=

KMHV weather at 0935 PDT was reported as wind from 180° at 5 knots, 10 miles visibility, clear skies below 12,000 feet above ground level (agl), temperature of 18° Celsius (C), dew point temperature of 5° C, and an altimeter setting of 29.96 inches of mercury. Remarks: automated station without precipitation discriminator.

KMHV weather at 0955 PDT was reported as wind from 200° at 9 knots, 10 miles visibility, clear skies below 12,000 feet agl, temperature of 19° C, dew point temperature of 4° C, and an altimeter setting of 29.96 inches of mercury. Remarks: automated station without precipitation discriminator.

KMHV weather at 1015 PDT was reported as wind from 200° at 11 knots, 10 miles visibility, clear skies below 12,000 feet agl, temperature of 20° C, dew point temperature of 4° C, and an altimeter setting of 29.96 inches of mercury. Remarks: automated station without precipitation discriminator.

KMHV weather at 1035 PDT was reported as wind from 210° at 11 knots with gusts to 19 knots, 10 miles visibility, clear skies below 12,000 feet agl, temperature of 20° C, dew point temperature of 4° C, and an altimeter setting of 29.95 inches of mercury. Remarks: automated station without precipitation discriminator.

Edwards Air Force Base (KEDW) was located 6 miles southwest of Edwards, California, and also had automated surface observations around the accident time augmented by an official observer. KEDW was located 25 miles south of the accident site, at an elevation of 2,311 feet, and had a 15° easterly magnetic variation (figure 9). The following observations were taken and disseminated during the times surrounding the accident:

[0558 PDT] KEDW 311258Z 15004KT 50SM CLR 09/02 A2993 RMK AO2A
SLP124 T00920020=

[0658 PDT] KEDW 311358Z 18006KT 95SM CLR 09/02 A2993 RMK AO2A SLP124 T00910023=

[0758 PDT] KEDW 311458Z 17003KT 80SM FEW130 FEW250 10/02 A2994 RMK AO2A SLP128 T01020023 50004=

[0858 PDT] KEDW 311558Z 19005KT 80SM FEW130 SCT250 14/04 A2995 RMK AO2A SLP130 T01420039=

[0958 PDT] KEDW 311658Z 22011KT 50SM FEW030 SCT250 17/05 A2995 RMK AO2A SLP128 CONTRAILS T01690051=

ACCIDENT TIME 1007 PDT

[1058 PDT] KEDW 311758Z 23011KT 50SM FEW030 BKN250 19/07 A2994 RMK AO2A SLP125 CONTRAILS T01860068 10186 20077 58002=

[1158 PDT] KEDW 311858Z 21008KT 50SM FEW030 BKN250 20/06 A2990 RMK AO2A SLP113 CONTRAILS T02010062=

[1258 PDT] KEDW 311958Z 23010KT 50SM FEW030 BKN250 21/07 A2987 RMK AO2A SLP102 CONTRAILS T02070071=

[1330 PDT] KEDW 312030Z 24015G20KT 50SM FEW030 OVC250 22/08 A2985 RMK AO2A CONTRAILS=

[1358 PDT] KEDW 312058Z 24017G21KT 50SM FEW150 BKN250 21/08 A2983 RMK AO2A SLP092 CONTRAILS T02140078 57032=

KEDW weather at 0858 PDT was reported as wind from 190° at 5 knots, 80 miles visibility, few clouds at 13,000 feet agl, scattered clouds at 25,000 feet agl, temperature of 14° C, dew point temperature of 4° C, and an altimeter setting of 29.95 inches of mercury. Remarks: automated station with precipitation discriminator augmented by a human observer, sea level pressure 1013.0 hPa, temperature 14.2° C, dew point temperature 3.9° C.

KEDW weather at 0958 PDT was reported as wind from 220° at 11 knots, 50 miles visibility, few clouds at 3,000 feet agl, scattered clouds at 25,000 feet agl, temperature of 17° C, dew point temperature of 5° C, and an altimeter setting of 29.95 inches of mercury. Remarks: automated station with precipitation discriminator augmented by a human observer, sea level pressure 1012.8 hPa, contrails, temperature 16.9° C, dew point temperature 5.1° C.

KEDW weather at 1058 PDT was reported as wind from 230° at 11 knots, 50 miles visibility, few clouds at 3,000 feet agl, a broken ceiling at 25,000 feet agl, temperature of 19° C, dew point temperature of 7° C, and an altimeter setting of 29.94 inches of mercury. Remarks: automated station with precipitation discriminator augmented by a human observer, sea level pressure

1012.5 hPa, contrails, temperature 18.6° C, dew point temperature 6.8° C, 6-hourly maximum temperature of 18.6° C, 6-hourly minimum temperature of 7.7° C, 3-hourly pressure increase of 0.2 hPa.

KEDW weather at 1158 PDT was reported as wind from 210° at 8 knots, 50 miles visibility, few clouds at 3,000 feet agl, a broken ceiling at 25,000 feet agl, temperature of 20° C, dew point temperature of 6° C, and an altimeter setting of 29.90 inches of mercury. Remarks: automated station with precipitation discriminator augmented by a human observer, sea level pressure 1011.3 hPa, contrails, temperature 20.1° C, dew point temperature 6.2° C.

General William J Fox Airfield (KWJF) was located 4 miles northwest of Lancaster, California, and had an Automated Surface Observing System (ASOS[8]) whose reports were not supplemented by an official human observer. KWJF was located 38 miles southwest of the accident site, at an elevation of 2,351 feet, and had a 15° easterly magnetic variation[9] (figure 9). The following observations were taken and disseminated during the times surrounding the accident:

[0456 PDT] KWJF 311156Z 26009KT 10SM CLR 13/06 A2996 RMK AO2 SLP134 T01280061 10178 20117 57008=

[0556 PDT] KWJF 311256Z 25015KT 10SM CLR 13/06 A2995 RMK AO2 SLP133 T01280056=

[0656 PDT] KWJF 311356Z 24013KT 10SM CLR 13/06 A2995 RMK AO2 SLP134 T01330061=

[0756 PDT] KWJF 311456Z 24012KT 10SM CLR 14/06 A2996 RMK AO2 SLP139 T01390061 53002=

[0856 PDT] KWJF 311556Z 25020G25KT 10SM CLR 14/07 A2996 RMK AO2 SLP139 T01440072=

[0956 PDT] KWJF 311656Z 24020KT 10SM CLR 16/08 A2996 RMK AO2 PK WND 25028/1636 SLP139 T01560083=

ACCIDENT TIME 1007 PDT

[1056 PDT] KWJF 311756Z 25018KT 10SM CLR 17/08 A2996 RMK AO2 PK WND 24027/1705 SLP135 T01720083 10172 20122 58001=

[1156 PDT] KWJF 311856Z 25017KT 10SM CLR 18/08 A2994 RMK AO2 SLP132 T01830083=

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[8] ASOS – Automated Surface Observing System is equipped with meteorological instruments to observe and report wind, visibility, ceiling, temperature, dewpoint, altimeter, and barometric pressure.
[9] Magnetic variation – The angle (at a particular location) between magnetic north and true north.

[1256 PDT] KWJF 311956Z 25011G17KT 10SM CLR 18/08 A2992 RMK AO2 SLP123 T01830083=

[1356 PDT] KWJF 312056Z 23012KT 10SM CLR 18/08 A2988 RMK AO2 SLP110 T01830083 58024=

[1456 PDT] KWJF 312156Z 23017G29KT 10SM CLR 18/09 A2986 RMK AO2 PK WND 23029/2152 SLP104 T01830089=

KWJF weather at 0856 PDT was reported as wind from 250° at 20 knots with gusts to 25 knots, 10 miles visibility, clear skies below 12,000 feet agl, temperature of 14° C, dew point temperature of 7° C, and an altimeter setting of 29.96 inches of mercury. Remarks: automated station with a precipitation discriminator, sea-level pressure 1013.9 hPa, temperature 14.4° C, dew point temperature 7.2° C.

KWJF weather at 0956 PDT was reported as wind from 240° at 20 knots, 10 miles visibility, clear skies below 12,000 feet agl, temperature of 16° C, dew point temperature of 8° C, and an altimeter setting of 29.96 inches of mercury. Remarks: automated station with a precipitation discriminator, peak wind from 250° at 28 knots at 0936 PDT, sea-level pressure 1013.9 hPa, temperature 15.6° C, dew point temperature 8.3° C.

KWJF weather at 1056 PDT was reported as wind from 250° at 18 knots, 10 miles visibility, clear skies below 12,000 feet agl, temperature of 17° C, dew point temperature of 8° C, and an altimeter setting of 29.96 inches of mercury. Remarks: automated station with a precipitation discriminator, peak wind from 240° at 27 knots at 1005 PDT, sea-level pressure 1013.5 hPa, temperature 17.2° C, dew point temperature 8.3° C, 6-hourly maximum temperature of 17.2° C, 6-hourly minimum temperature of 12.2° C, 3-hourly pressure increase of 0.1 hPa.

KWJF weather at 1156 PDT was reported as wind from 250° at 17 knots, 10 miles visibility, clear skies below 12,000 feet agl, temperature of 18° C, dew point temperature of 8° C, and an altimeter setting of 29.94 inches of mercury. Remarks: automated station with a precipitation discriminator, sea-level pressure 1013.2 hPa, temperature 18.3° C, dew point temperature 8.3° C.

4.0 Upper Air Data

The closest official upper air sounding to the accident site was KEDW with a site number 72381, and the Edwards rawinsonde facility (B3520) was located about 1 mile north of the base weather station (B1202). The 0500 PDT sounding from KEDW was plotted on a standard Skew-T log P diagram[10] with the derived stability parameters included in figure 10 (with the chart plotted from the surface to 100-hPa, or 53,000 feet msl). The last data point from the 0500 PDT KEDW sounding was located at 48,577 feet msl. This data was analyzed utilizing the RAOB[11] software package. The sounding depicted the Lifted Condensation Level (LCL)[12] at 6,491 feet msl and a Convective Condensation Level (CCL)[13] of 14,495 feet. The freezing level was located at the 13,213 feet. The precipitable water value was 0.49 inches.

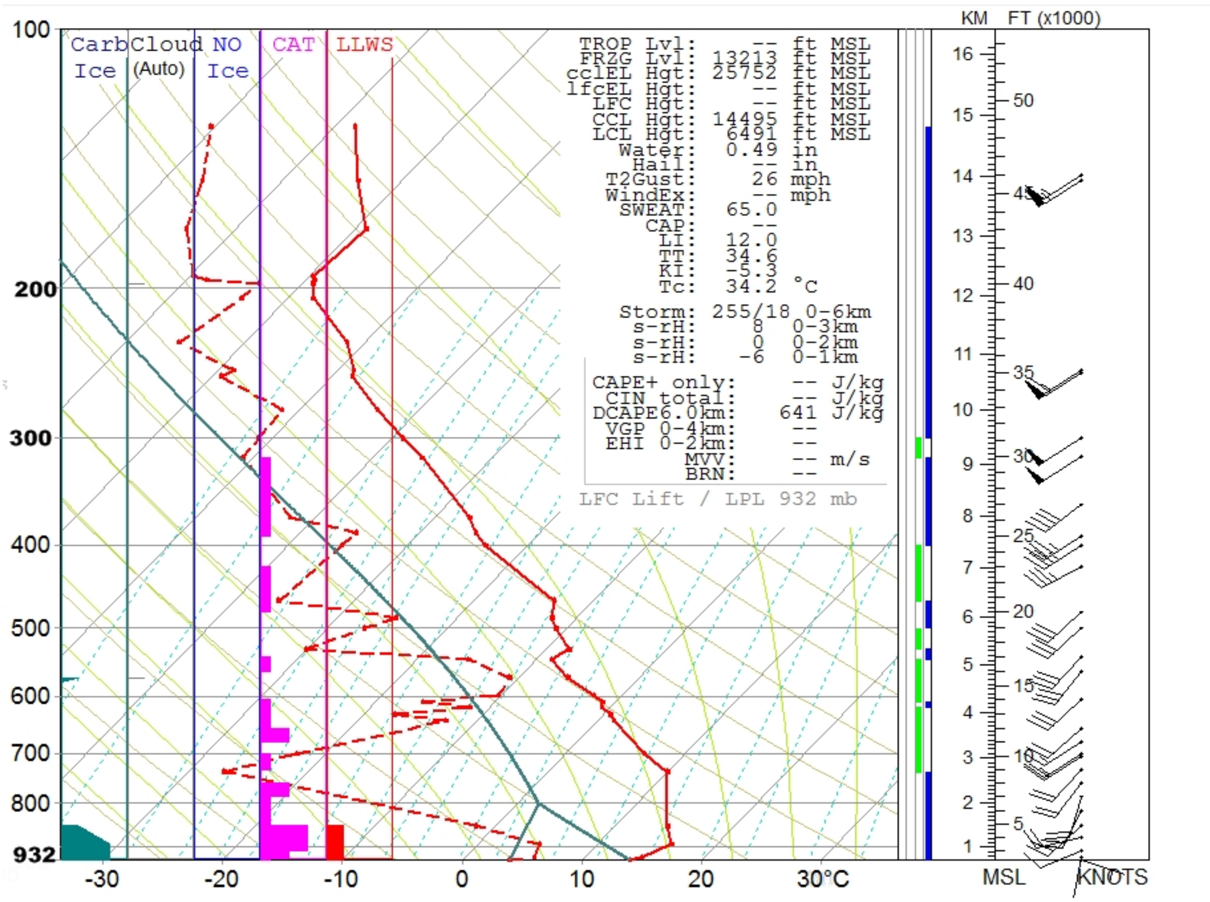

Figure 10 – 0500 PDT KEDW sounding

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[10] Skew T log P diagram – is a standard meteorological plot using temperature and the logarithmic of pressure as coordinates, used to display winds, temperature, dew point, and various indices used to define the vertical structure of the atmosphere.

[11] RAOB – (The complete Rawinsonde Observation program) is an interactive sounding analysis program developed by Environmental Research Services, Matamopras, Pennsylvania.

[12] Lifting Condensation Level (LCL) - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.

[13] Convective Condensation Level (CCL) – The level in the atmosphere to which an air parcel, if heated from below, will rise dry adiabatically, without becoming colder than its environment just before the parcel becomes saturated.

The 0500 PDT KEDW sounding indicated a relatively dry environment from the surface through 48,000 feet msl. There were several layers of both a conditionally unstable environment and a stable environment through 48,000 feet msl. RAOB did not indicate any layers of cloud formation. Icing conditions were not indicated by RAOB in the 0500 KEDW sounding.

The sounding wind profile indicated there was a surface wind from 110° at 4 knots and the wind became southwesterly by 3,000 feet msl and remained out of the southwest through 48,000 feet msl. The wind speed increased to 50 knots by 29,000 feet msl, with the wind from 235° at 54 knots at 46,000 feet msl. Low-level wind shear (LLWS) was indicated by RAOB below 4,000 feet msl. Several layers of possible clear-air turbulence were identified by RAOB from the surface through 30,000 feet.

5.0 Satellite Data

Visible and infrared data from the Geostationary Operational Environmental Satellite number 15 (GOES-15) data was obtained from the NCDC and processed with the NTSB's Man-computer Interactive Data Access System (McIDAS) workstation. Visible and infrared imagery (GOES-15 bands 1 and 4) at a wavelength of 0.65 microns (μm) and 10.7 μm retrieved brightness temperatures for the scene. Satellite imagery surrounding the time of the accident, from 0800 PDT through 1200 PDT at approximately 15-minute intervals, were reviewed and the closest images to the time of the accident are documented here.

Figures 11, 12, and 13 present the GOES-15 visible imagery from 0945, 1000, and 1015 PDT at 2X magnification with the accident site highlighted with a red square. Inspection of the visible imagery indicated cloud cover moving from west to east towards the accident site around the accident time. Figure 14 presents the GOES-15 infrared imagery from 1015 PDT at 6X magnification with the accident site highlighted with a red square. Inspection of the infrared imagery also indicated the cloud cover over the accident site around the accident time. Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 0500 PDT KEDW sounding, the approximate cloud-top heights over the accident site were 12,000 feet msl at 1015 PDT; with the bright yellow colors just north of the accident site indicating approximate cloud-top heights of 25,000 feet msl.

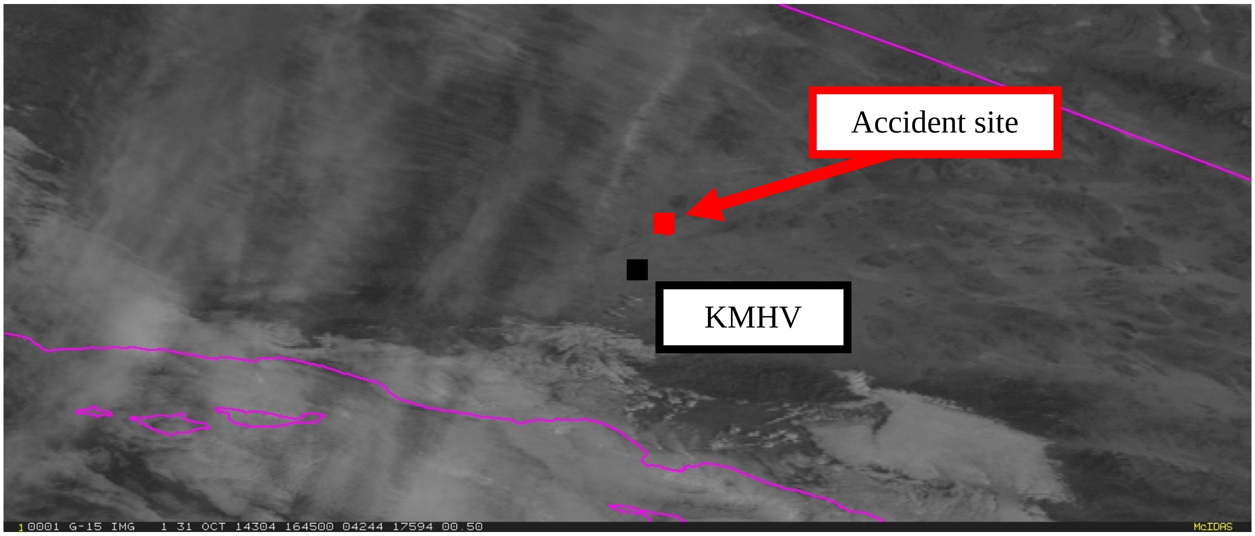


Figure 11 – GOES-15 visible image at 0945 PDT

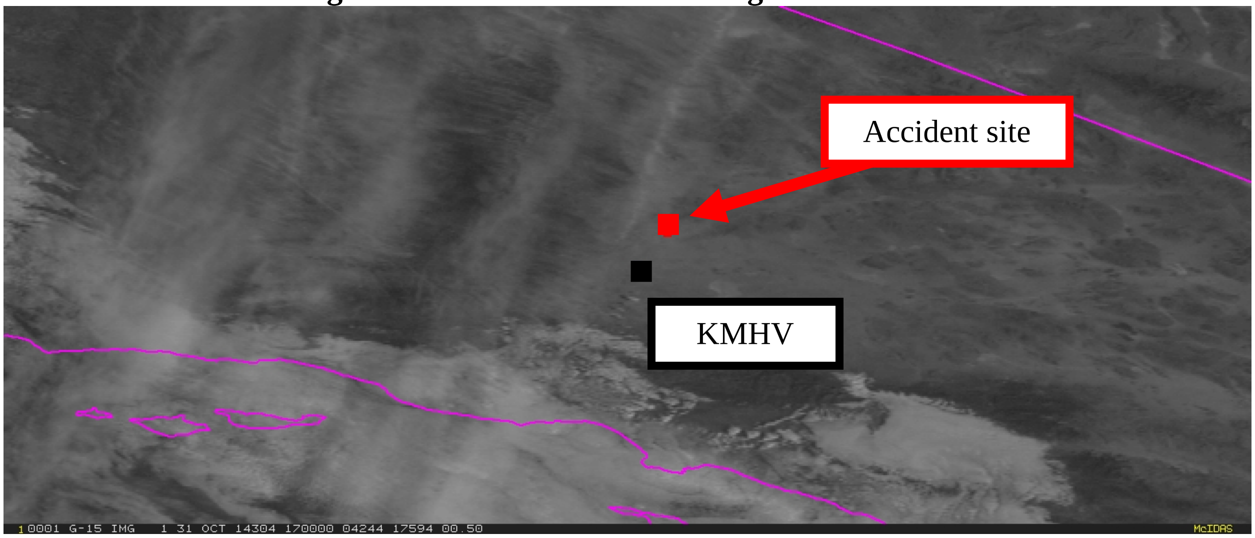


Figure 12 – GOES-15 visible image at 1000 PDT

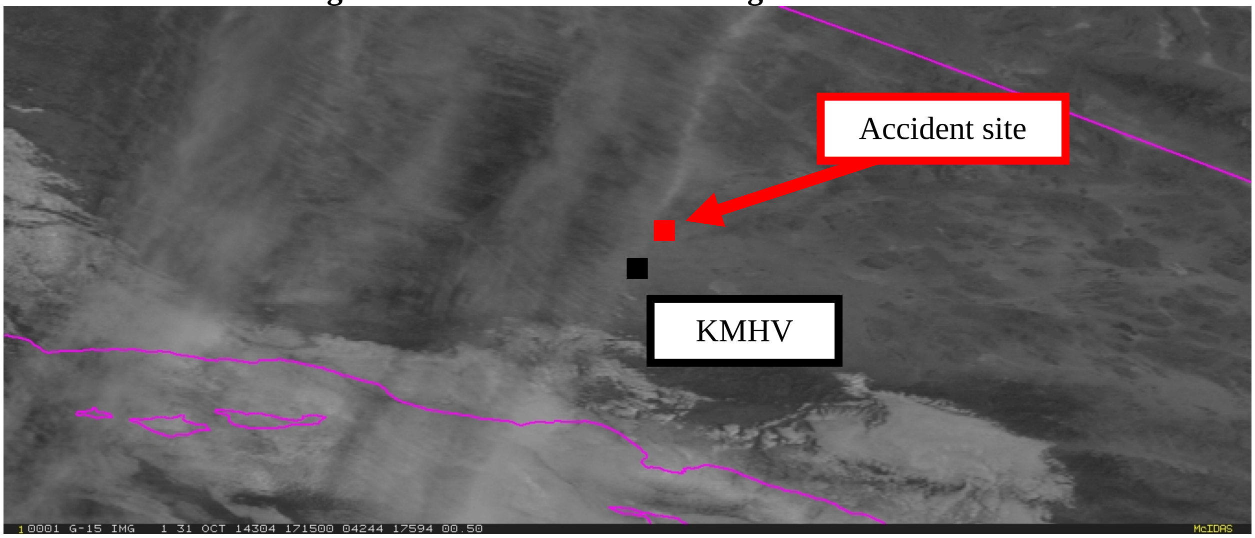


Figure 13 – GOES-15 visible image at 1015 PDT

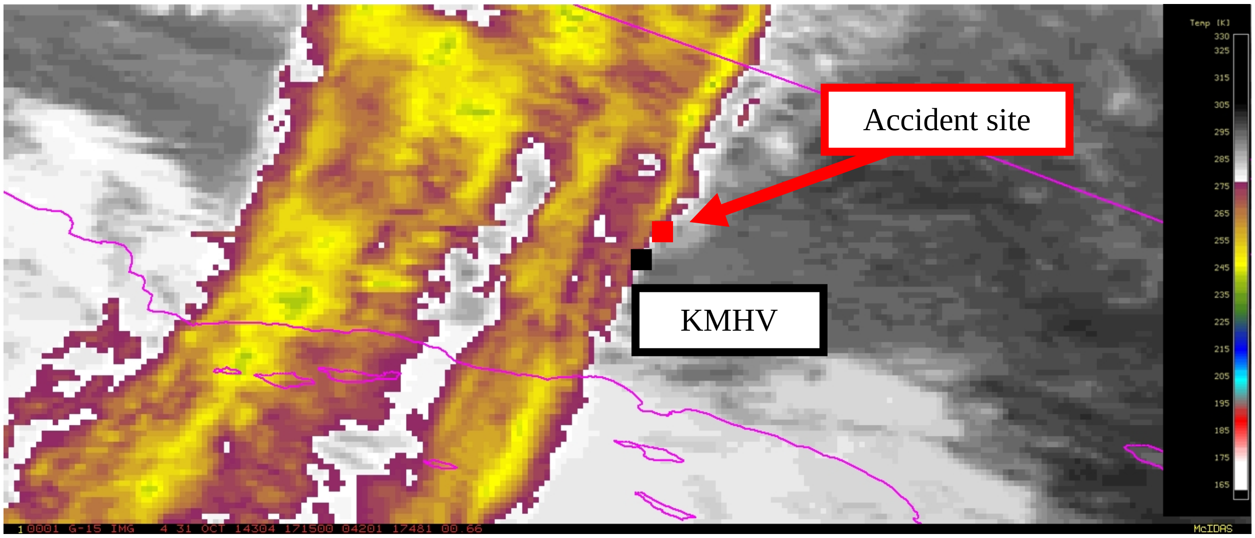


Figure 14 – GOES-15 infrared image at 1015 PDT

6.0 Radar Imagery Information

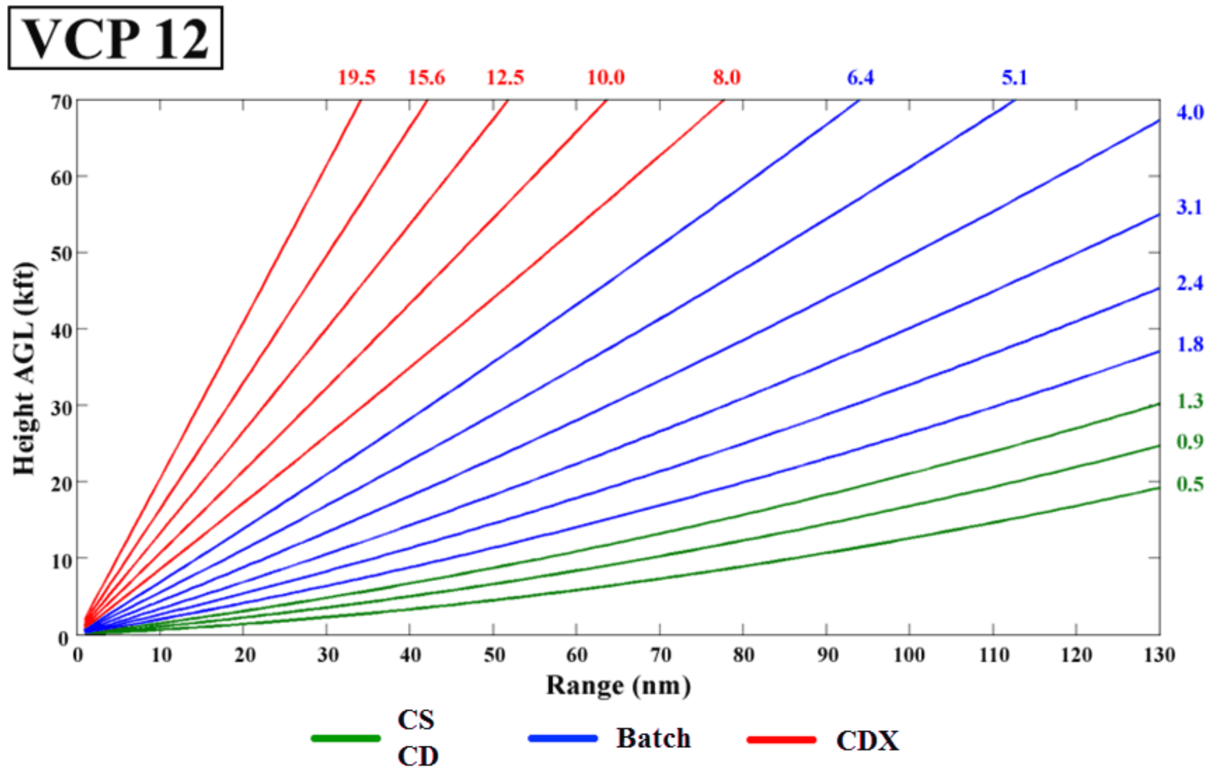
Both the NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)[14] radars at Edwards Air Force Base, California, (KEYX) and San Joaquin Valley, California, (KHNX) detected non-precipitation targets after the accident time just northeast of the accident site. The KEYX radar was located 23 miles southeast of the accident site at an elevation of 2,757 feet. The KHNX radar was located 101 miles northwest of the accident site at an elevation of 243 feet. Level II and III archive radar data was obtained from the NCDC utilizing the NEXRAD Data Inventory Search and displayed using the NOAA's Weather and Climate Toolkit software.

6.1 Volume Scan Strategy

The WSR-88D is a computer-controlled radar system, which automatically creates a complete series of specific scans in a specific sequence known as a volume scan. Individual elevation scans are immediately available on the WSR-88D's Principle Users Processor (PUP). Products that require data from multiple elevation scans are not available until the end of the five to ten minute volume scan.

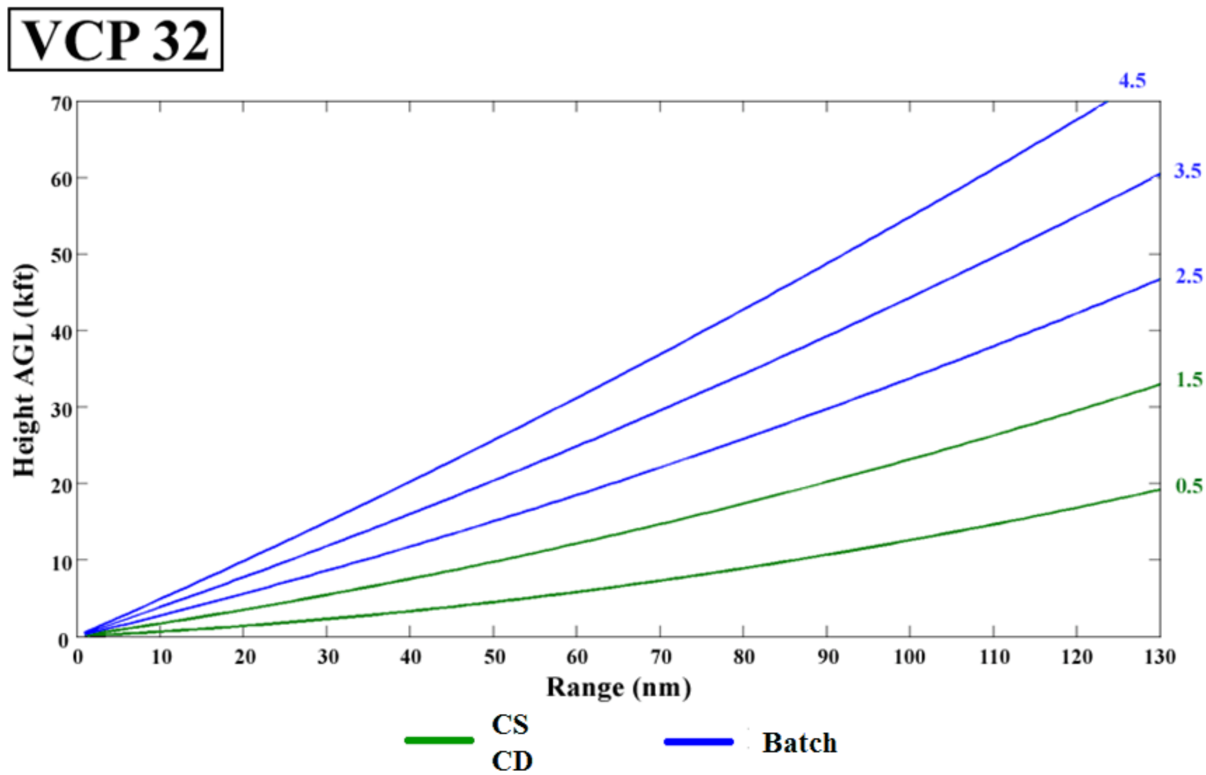
The WSR-88D operates in several different scanning modes, identified as Mode A and Mode B. Mode A is the precipitation scan and has two common scanning strategies. The most common is where the radar makes 14 elevation scans from 0.5° to 19.5° every four minutes. This particular scanning strategy is documented as volume coverage pattern 12 (VCP-12). Mode B is the clear-air mode, where the radar makes 5 elevation scans during a ten minute period. During the period surrounding the accident, the KHNX WSR-88D radar was operating in precipitation mode (Mode A, VCP-12). The following chart provides an indication of the different elevation angles in this VCP, and the approximate height and width of the radar beam with distance from the radar site.

[14] The WSR-88D is an S-band 10-centimeter wavelength radar with a power output of 750,000 watts, and with a 28-foot parabolic antenna that concentrates the energy between a 0.87° and 0.96° beam width. The radar produces three basic types of products: base reflectivity, base radial velocity, and base spectral width.



VCP-12 Precipitation Mode Scan Strategy

During the period surrounding the accident, the KEYX WSR-88D radar was operating in clear air mode (Mode B, VCP-32). The following chart provides an indication of the different elevation angles in this VCP, and the approximate height and width of the radar beam with distance from the radar site.



VCP-32 Precipitation Mode Scan Strategy

6.2 Beam Height Calculation

Assuming standard refraction[15] of the WSR-88D 0.95° wide radar beam, the following table shows the approximate beam height and width[16] information[17] of the radar display over the site of the accident. The heights have been rounded to the nearest 10 feet.

ANTENNA ELEVATION	BEAM CENTER	BEAM BASE	BEAM TOP	BEAM WIDTH
KEYX 2.5°	9,220 feet	8,080 feet	10,350 feet	2,270 feet
KEYX 3.5°	11,650 feet	10,510 feet	12,780 feet	2,270 feet
KHNX 0.9°	17,270 feet	12,290 feet	22,250 feet	9,960 feet
KHNX 1.3°	21,540 feet	16,560 feet	26,520 feet	9,960 feet

[15] Standard Refraction in the atmosphere is when the temperature and humidity distributions are approximately average, and values set at the standard atmosphere.

[16] Beamwidth – A measure of the angular width of a radar beam.

[17] Beamwidth values are shown for legacy resolution products. Super resolution products would an effective beamwidth that would be approximately half these values.

Based on the radar height calculations, the 2.5° and 3.5° elevation scans from KEYX depicted the conditions between 8,080 feet and 12,780 feet msl over the accident site. The 4.5° elevation scan showed additional targets, however, those targets were not as clear as the 2.5° and 3.5° data. Based on the radar height calculations, the 0.9° and 1.3° elevations scans from KHNX depicted the conditions between 12,290 feet and 26,520 feet msl over the accident site. In addition, KHNX depicted targets up to the 3.1° elevation scan, or as high as 45,710 feet msl, but those targets were not as clear as the 0.9° and 1.3° data.

6.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors[18] it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in decibels (dBZ[19]), and is a general measure of echo intensity. The chart below relates the NWS video integrator and processor (VIP) intensity levels versus the WSR-88D's display levels, precipitation mode reflectivity in decibels, and rainfall rates.

[18] Hydrometeors are any product of condensation or sublimation of atmospheric water vapor, whether formed in the free atmosphere or at the earth's surface; also, any water particles blown by the wind from the earth's surface. Hydrometeors are classified as; (a) Liquid or solid water particles suspended in the air: cloud, water droplets, mist or fog. (b) Liquid precipitation: drizzle and rain. (c) Freezing precipitation: freezing drizzle and freezing rain. (d) Solid (frozen) precipitation: ice pellets, hail, snow, snow pellets, and ice crystals. (e) Falling particles that evaporate before reaching the ground: virga. (f) Liquid or solid water particles lifted by the wind from the earth's surface: drifting snow, blowing snow, blowing spray. (g) Liquid or solid deposits on exposed objects: dew, frost, rime, and glazed ice.

[19] dBZ – A non-dimensional "unit" of radar reflectivity which represents a logarithmic power ratio (in decibels , or dB) with respect to radar reflectivity factor, Z.

NWS VIP/DBZ CONVERSION TABLE

NWS VIP	WSR-88D LEVEL	PREC MODE DBZ	RAINFALL
0	0 1 2	< 5 5 to 9 10 to 14	
1 Very Light	3 4 5	15 to 19 20 to 24 25 to 29	.01 in/hr .02 in/hr .04 in/hr
2 Light to Moderate	6 7	30 to 34 35 to 39	.09 in/hr .21 in/hr
3 Strong	8	40 to 44	.48 in/hr
4 Very Strong	9	45 to 49	1.10 in/hr
5 Intense	10	50 to 54	2.49 in/hr
6 Extreme	11 12 13 14 15	55 to 59 60 to 64 65 to 69 70 to 74 > 75	>5.67 in/hr

The Federal Aviation Administration (FAA) Advisory Circular AC 00-24B titled "Thunderstorms" dated January 2, 1983, also defines the echo intensity levels and potential weather phenomena associated with those levels. If the maximum VIP Level is 1 "weak" and 2 "moderate", then light to moderate turbulence is possible with lightning. VIP Level 3 is "strong" and severe turbulence is possible with lightning. VIP Level 4 is "very heavy" and severe turbulence is likely with lightning. VIP Level 5 is "intense" with severe turbulence, lightning, hail likely, and organized surface wind gusts. VIP Level 6 is "extreme" with severe turbulence, lightning, large hail, extensive surface wind gusts and turbulence.

6.4 Base Reflectivity and Lightning Data

Figures 15, 16, 17, 18, 21, and 22 present the KHNX WSR-88D base reflectivity images for the 0.9° and 1.3° elevation scans initiated at 1010, 1013, and 1016 PDT with a resolution of 0.5° X 250 m. Figures 19, 20, 23, 24, 25, and 26 present the KEYX WSR-88D base reflectivity images for the 2.5° and 3.5° elevation scans initiated at 1014, 1023, and 1033 PDT with a resolution of 0.5° X 250 m. Between 1010 and 1033 PDT, a cluster of non-precipitation echoes between 5 and 30 dBZ appeared just east-northeast of the accident site with continuing movement northeastward consistent with the environmental wind. These echoes are not consistent with precipitation targets (sections 6.6 and 6.7). There were no lightning strikes in the vicinity of the accident flight around the accident time.

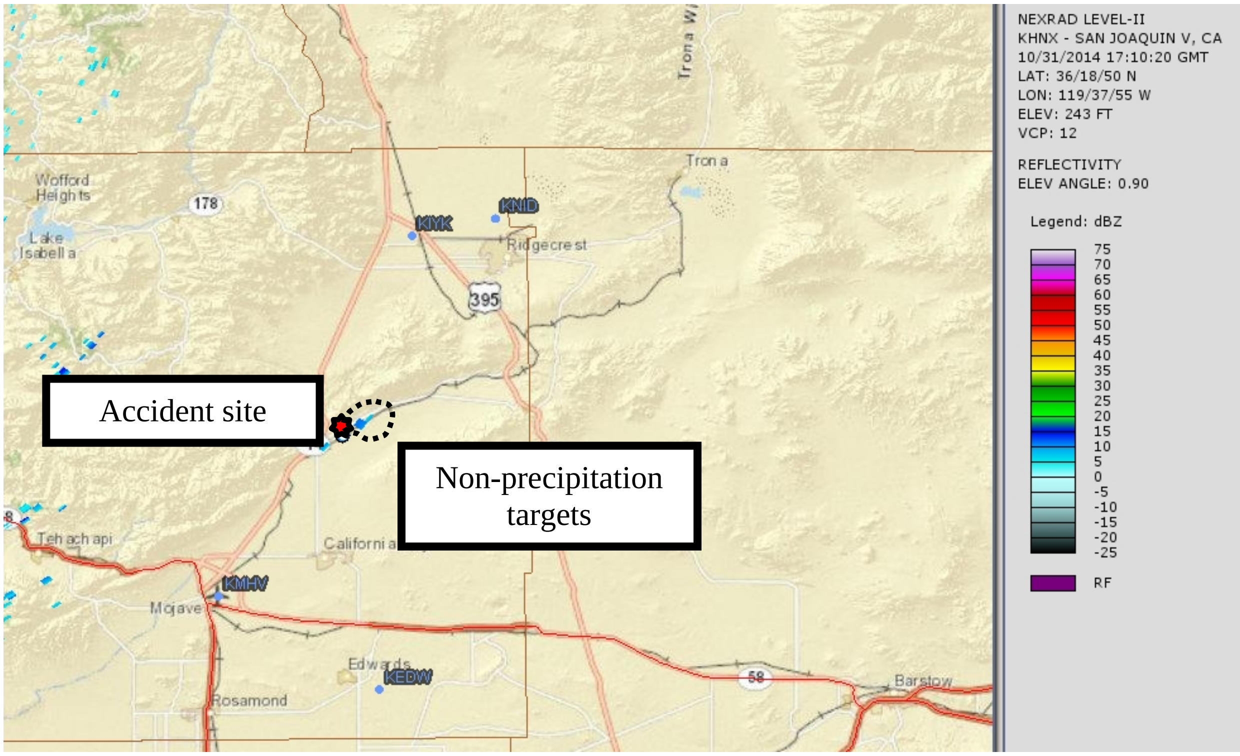


Figure 15 – KHNX WSR-88D reflectivity for the 0.9° elevation scan initiated at 1010 PDT

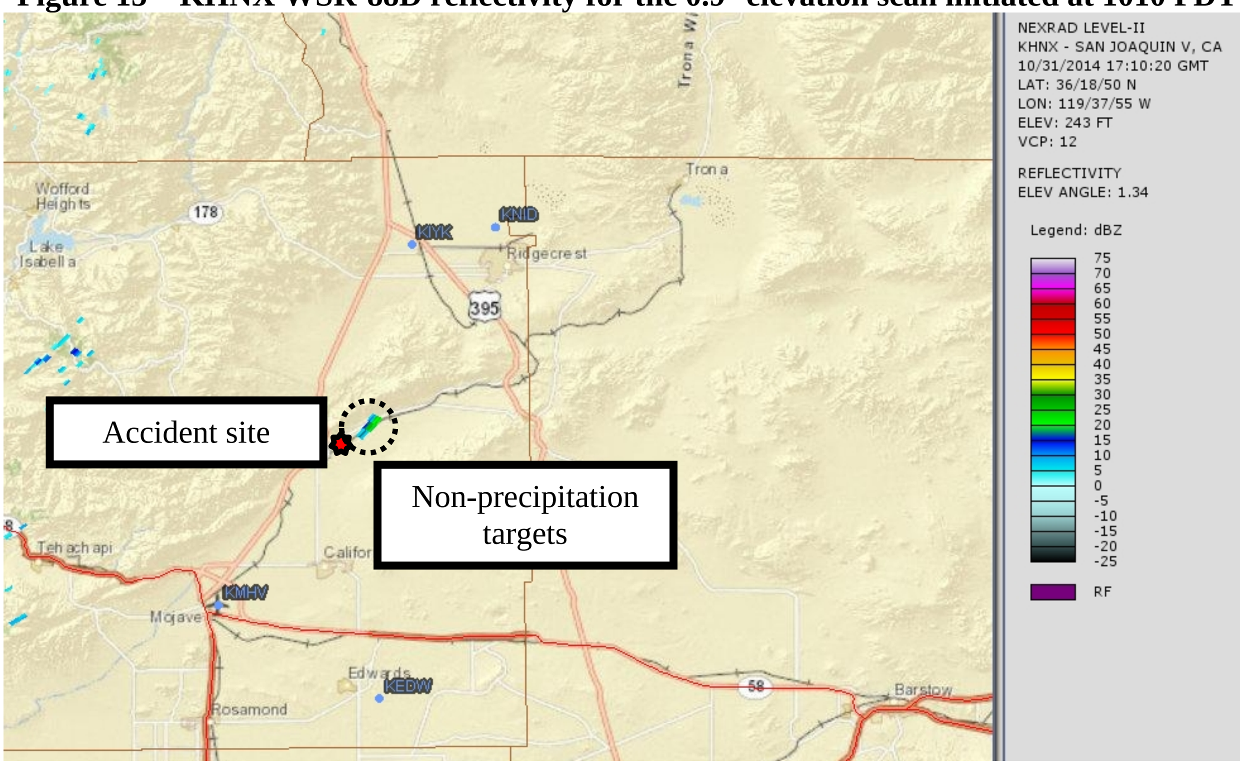


Figure 16 – KHNX WSR-88D reflectivity for the 1.3° elevation scan initiated at 1010 PDT

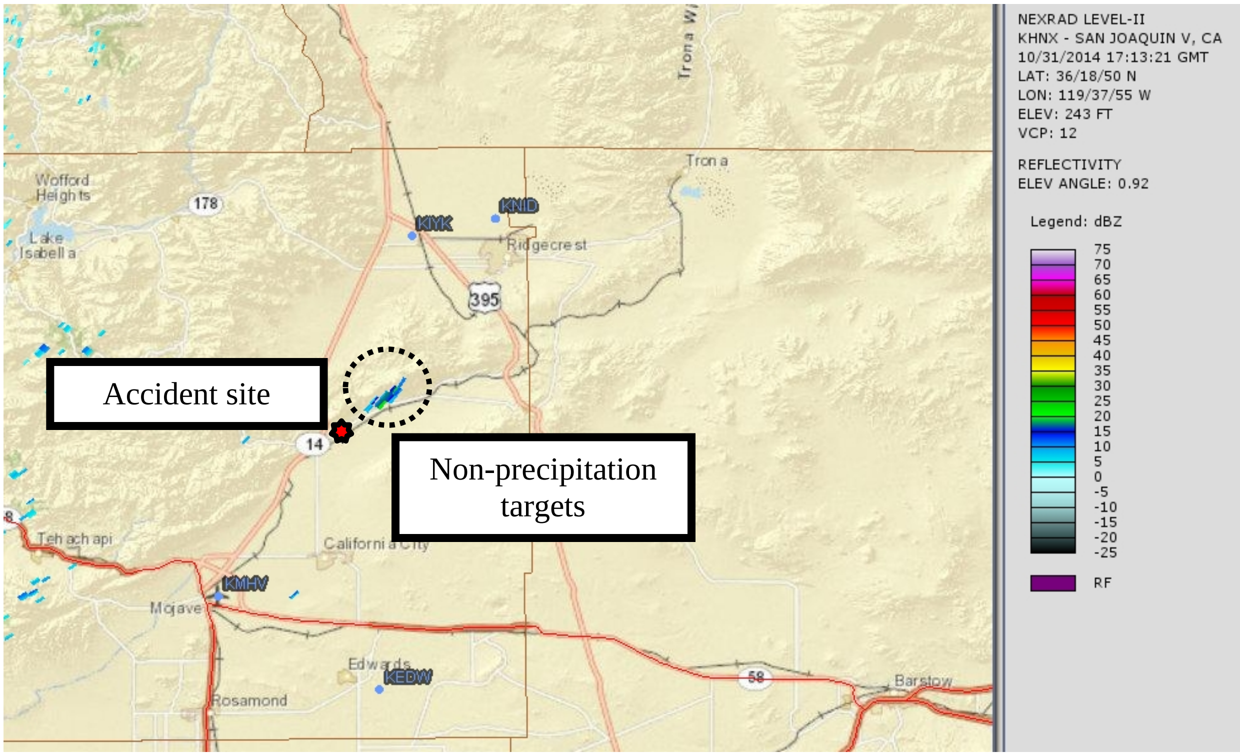


Figure 17 – KHNX WSR-88D reflectivity for the 0.9° elevation scan initiated at 1013 PDT

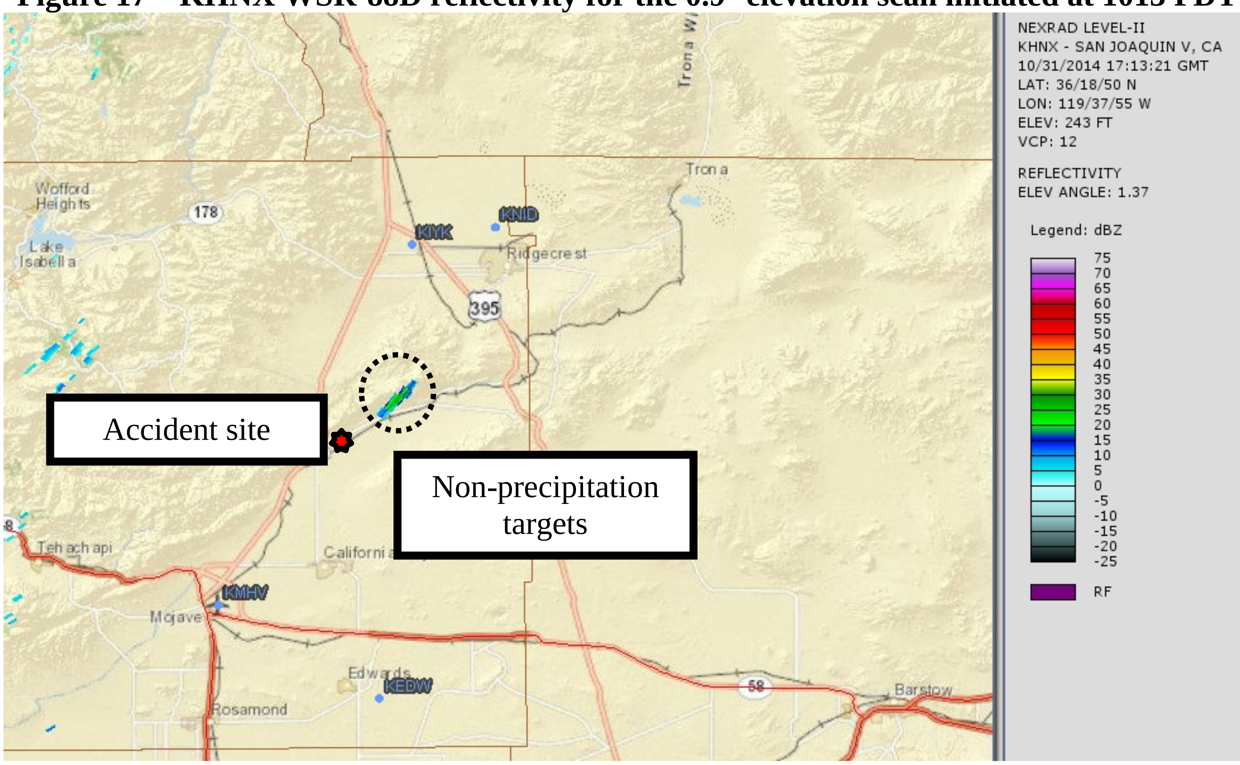


Figure 18 – KHNX WSR-88D reflectivity for the 1.3° elevation scan initiated at 1013 PDT

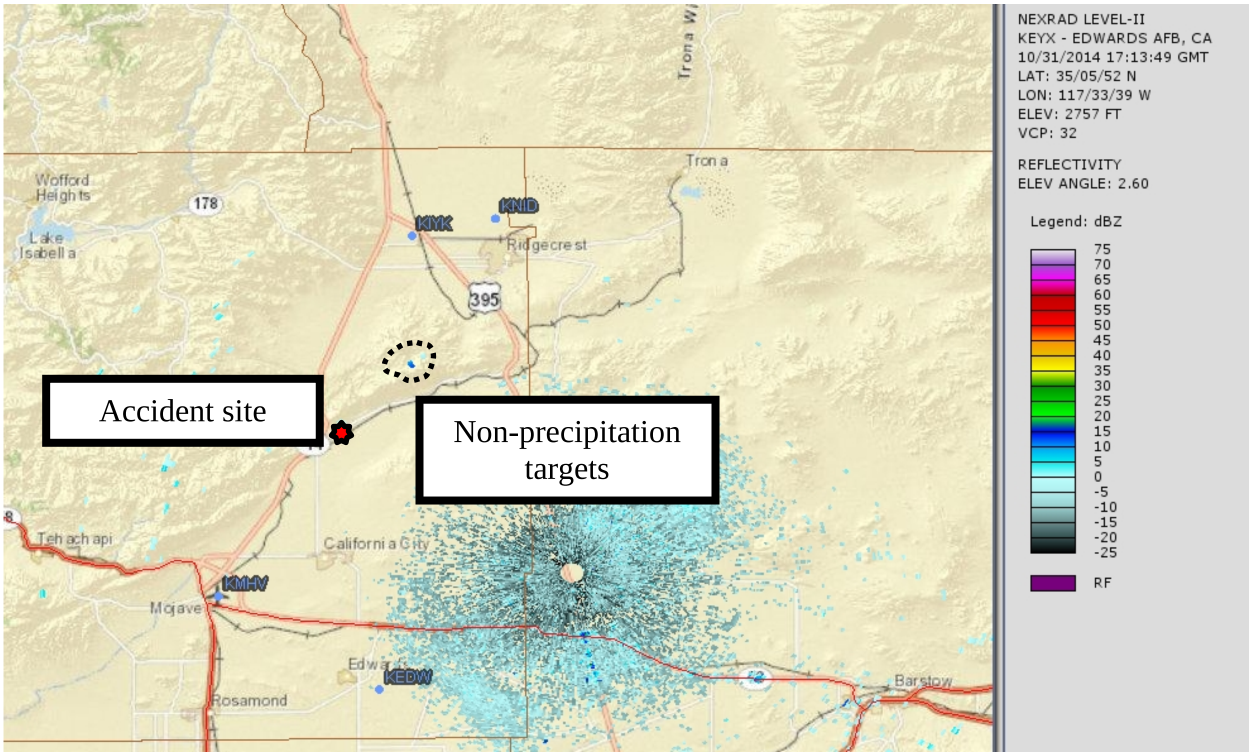


Figure 19 – KEYX WSR-88D reflectivity for the 2.5° elevation scan initiated at 1014 PDT

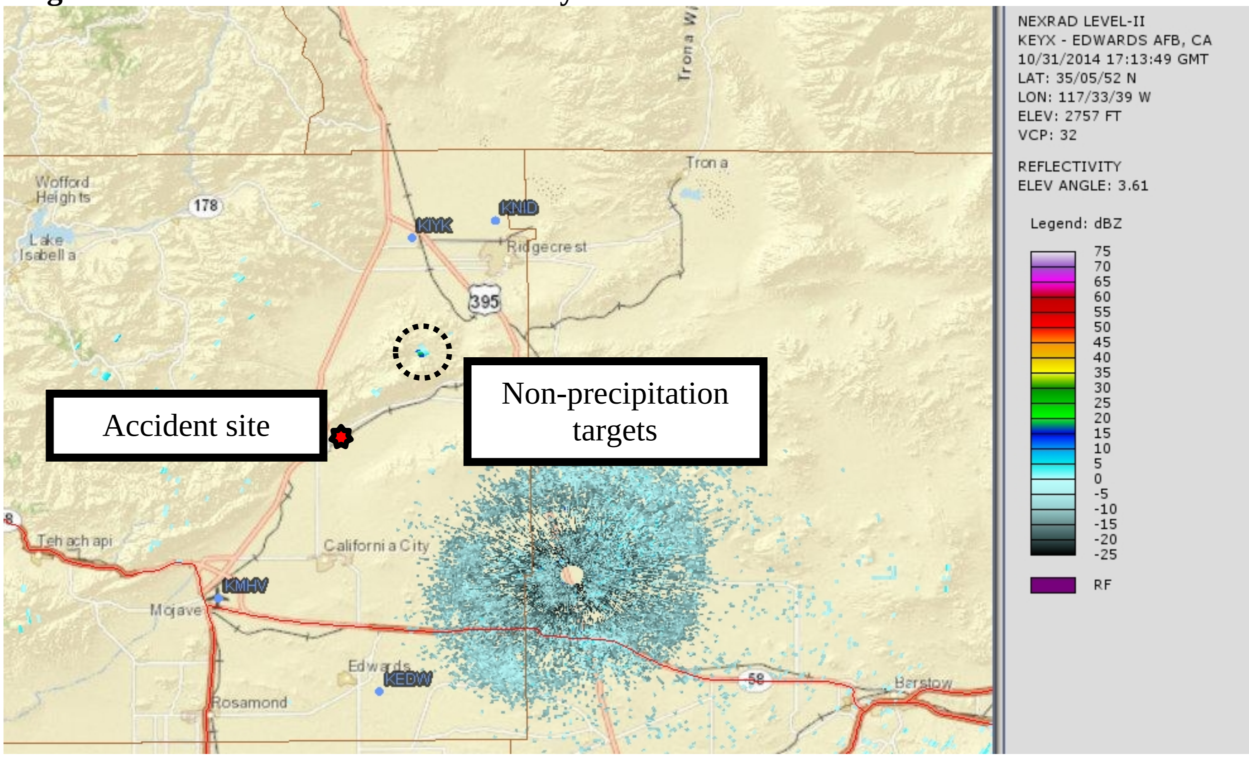


Figure 20 – KEYX WSR-88D reflectivity for the 3.5° elevation scan initiated at 1014 PDT

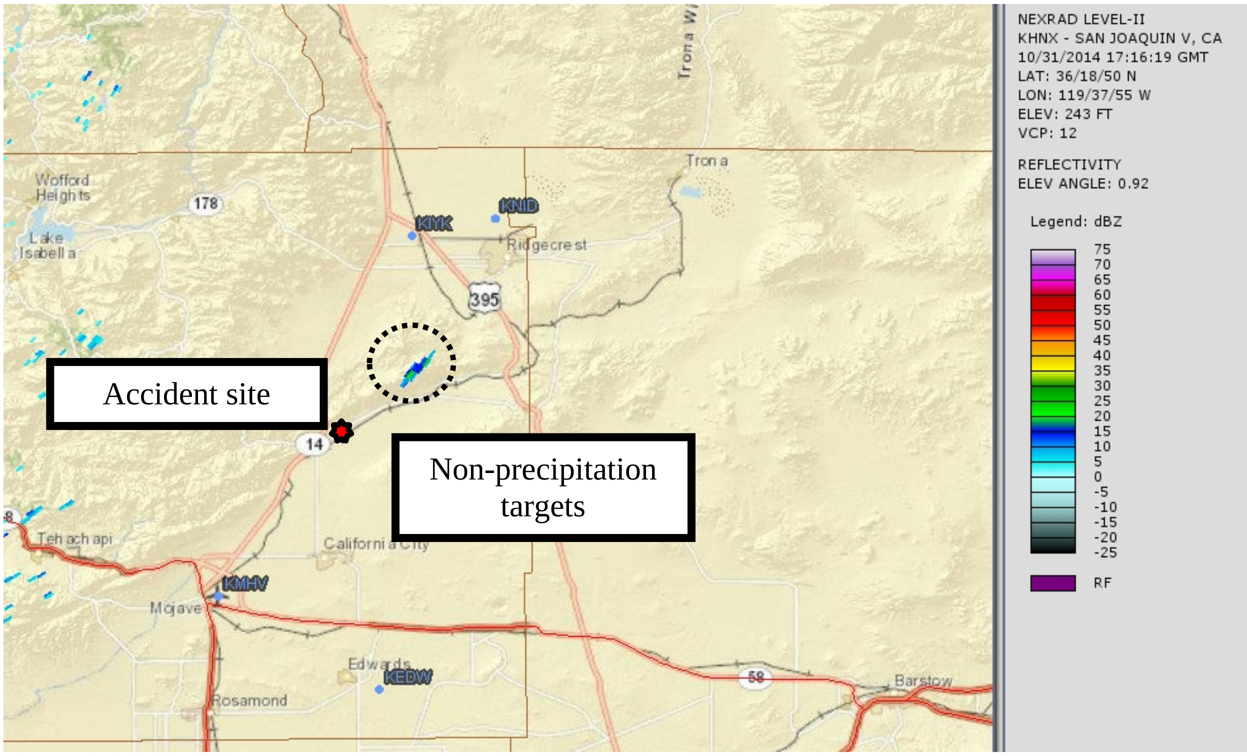


Figure 21 – KHNX WSR-88D reflectivity for the 0.9° elevation scan initiated at 1016 PDT

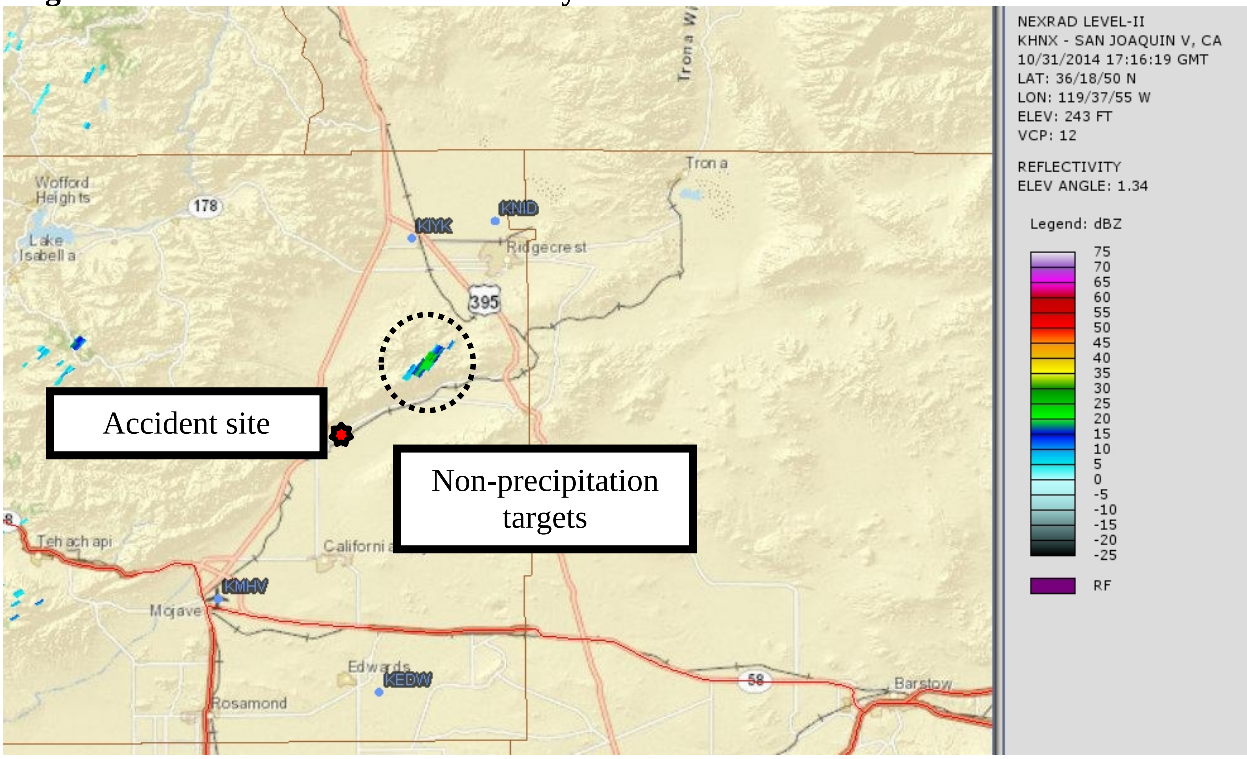


Figure 22 – KHNX WSR-88D reflectivity for the 1.3° elevation scan initiated at 1016 PDT

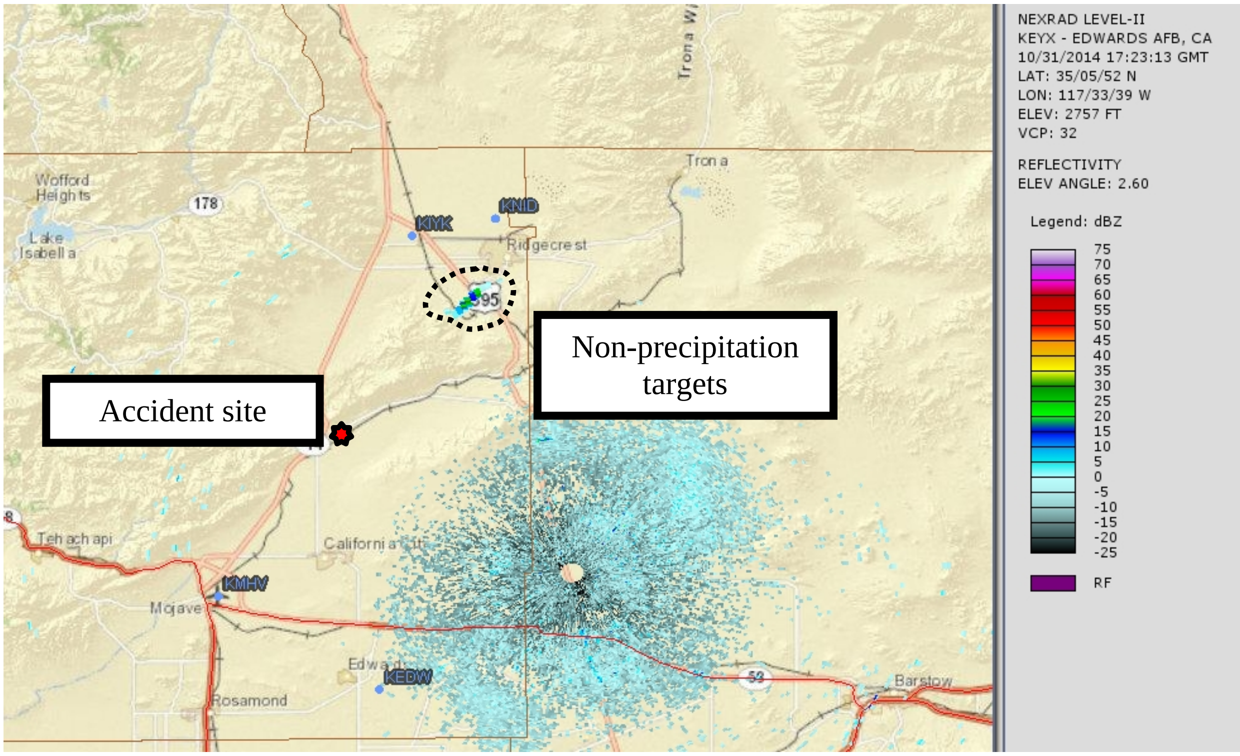


Figure 23 – KEYX WSR-88D reflectivity for the 2.5° elevation scan initiated at 1023 PDT

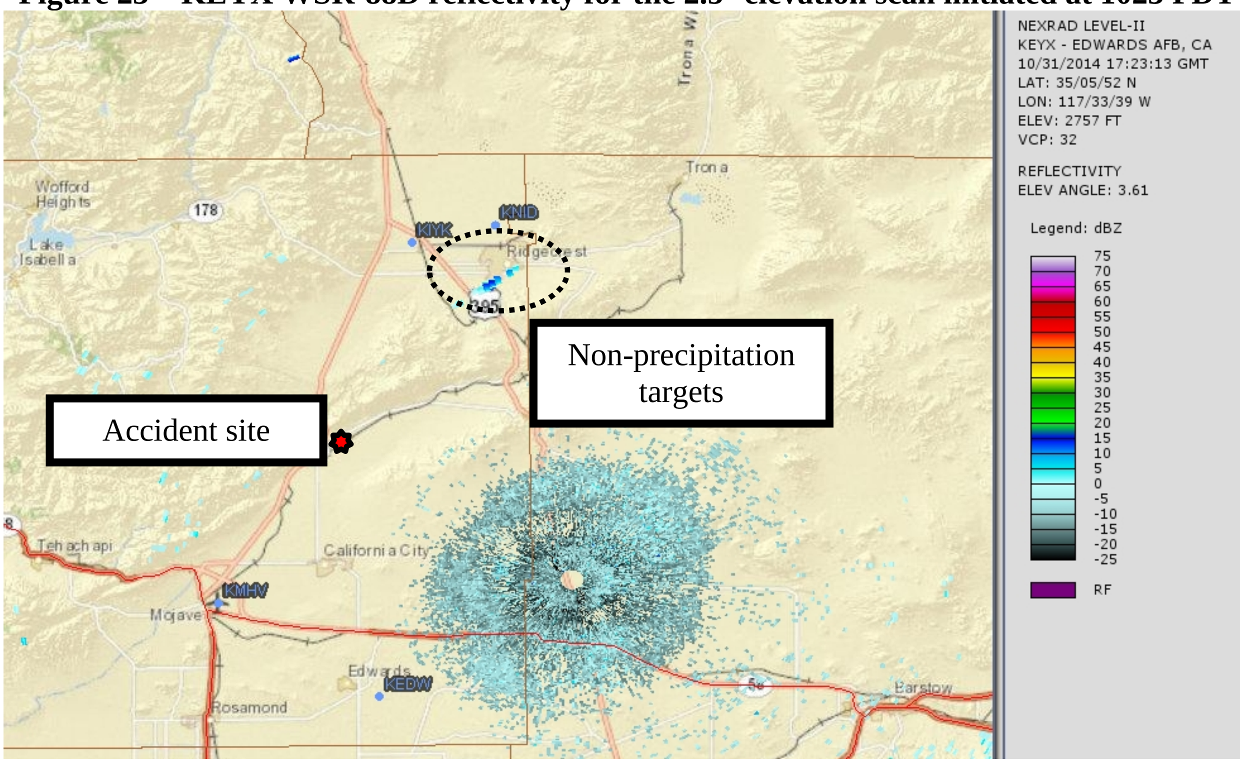


Figure 24 – KEYX WSR-88D reflectivity for the 3.5° elevation scan initiated at 1023 PDT

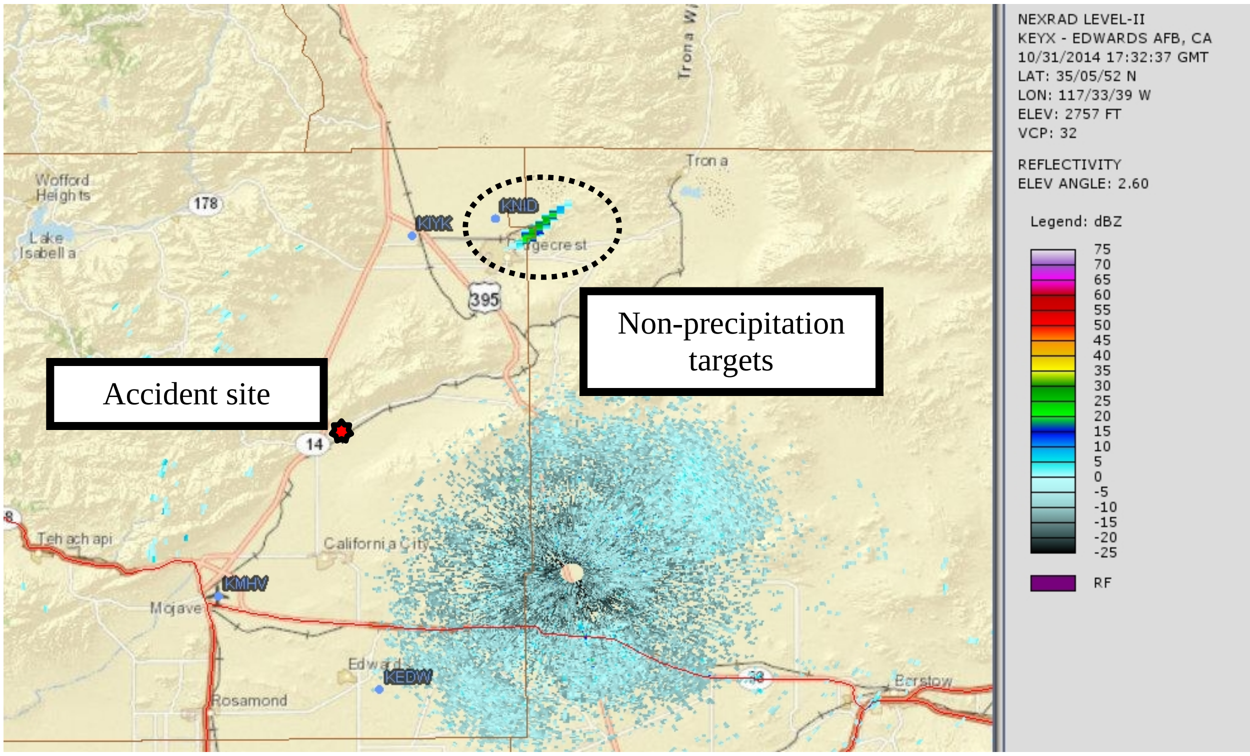


Figure 25 – KEYX WSR-88D reflectivity for the 2.5° elevation scan initiated at 1033 PDT

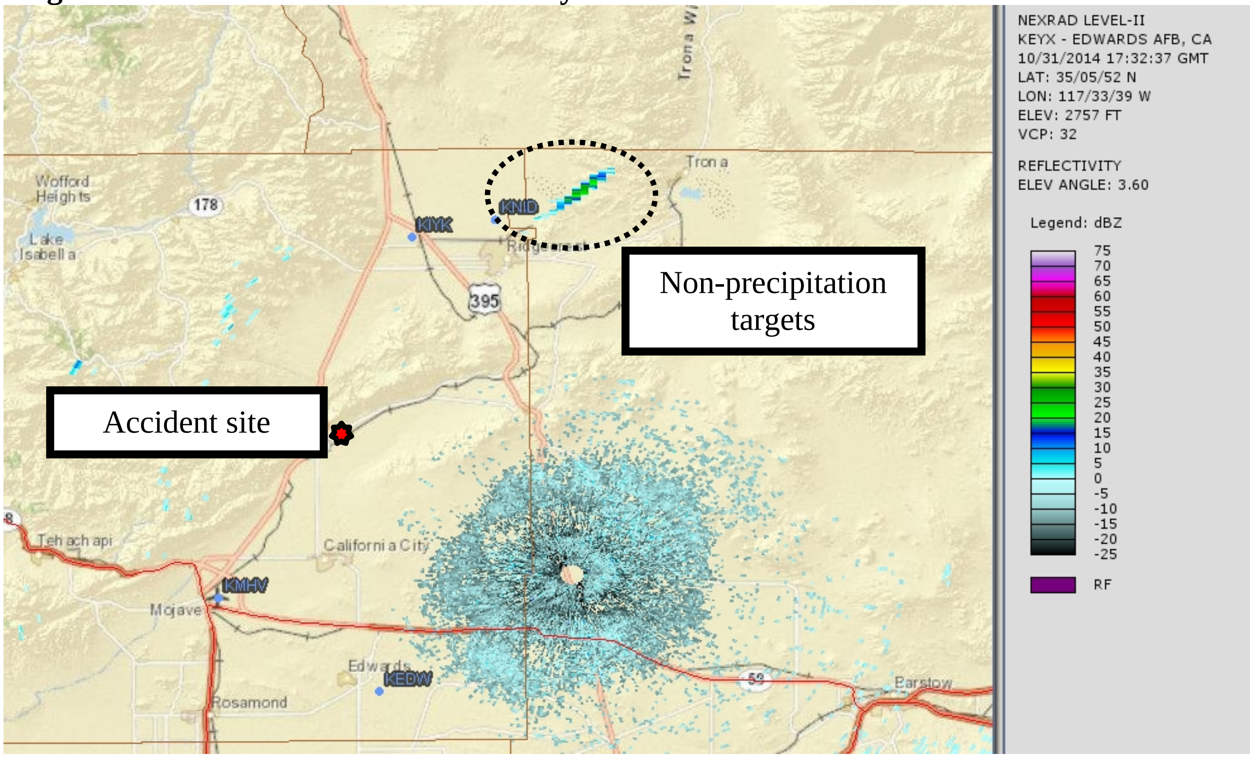


Figure 26 – KEYX WSR-88D reflectivity for the 3.5° elevation scan initiated at 1033 PDT

6.5 3-Dimensional Radar Reflectivity Data

Figures 27 through 30 present a 3-dimensional view of the KHNX WSR-88D base reflectivity for the elevation scans initiated at 1010, 1016, 1019, and 1029 PDT. The base reflectivity was plotted on the Google Earth image to give a more 3-dimensional view of the non-precipitation targets moving northeastward away from the accident site with time, with dBZ values greater than 10 plotted. The 3-dimensional plume of non-precipitation targets expanded in area and volume from 1010 through 1029 PDT, with the top portion of the targets further northeast than the bottom portion of the targets by 1029 PDT. This matched the base reflectivity data between 1010 and 1033 PDT as well (figures 27 to 30).

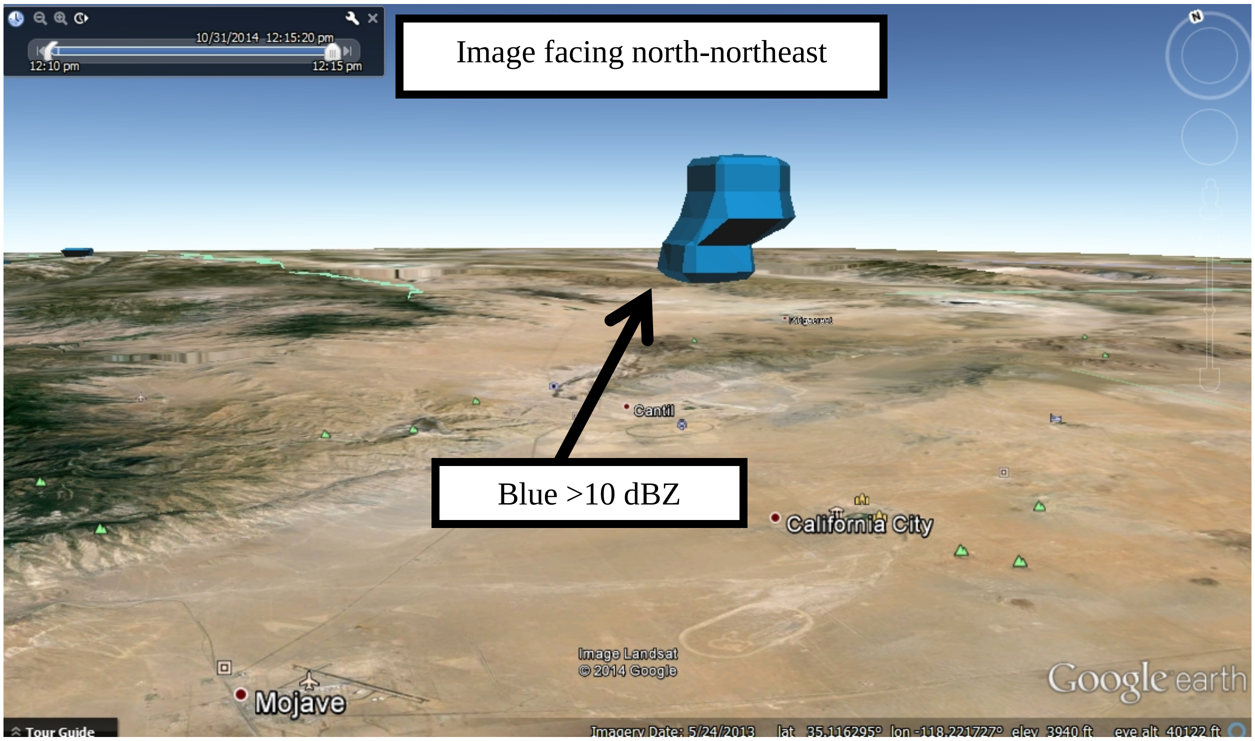


Figure 27 – 3-dimensional KHNX WSR-88D base reflectivity from the scan initiated at 1010 PDT

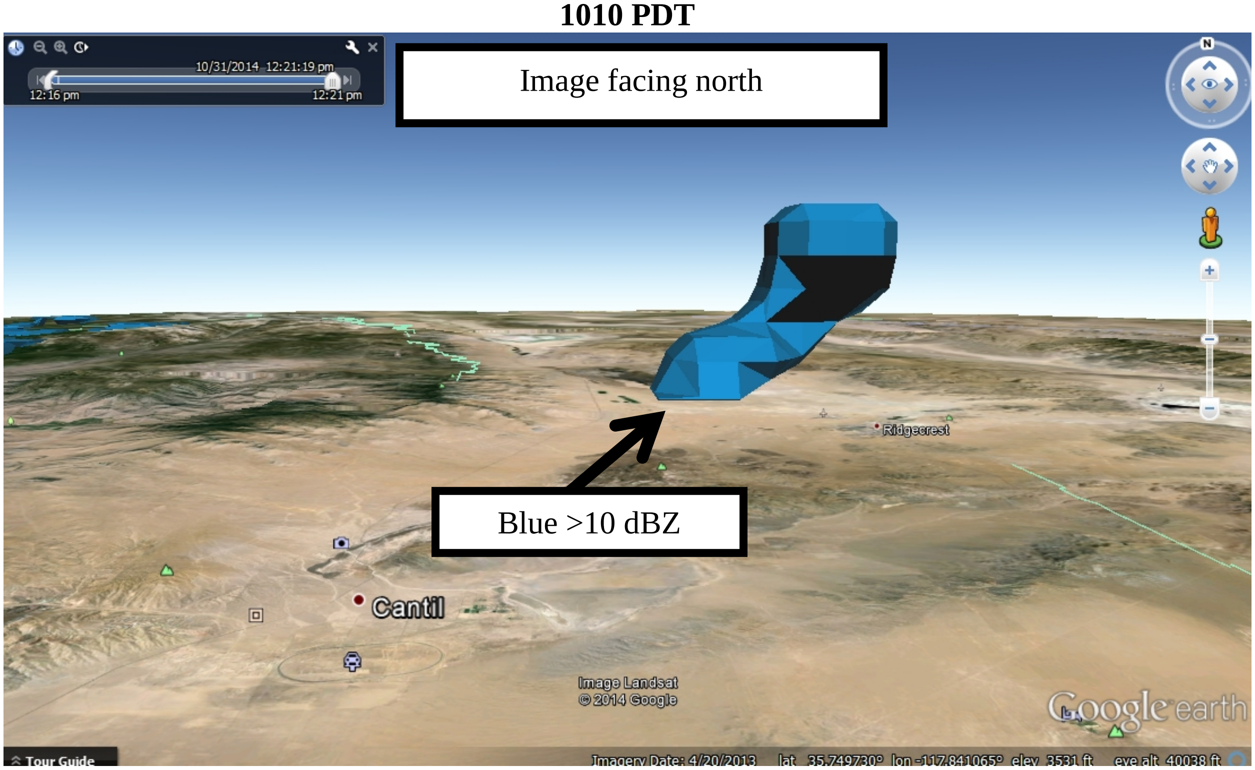


Figure 28 – 3-dimensional KHNX WSR-88D base reflectivity from the scan initiated at 1016 PDT

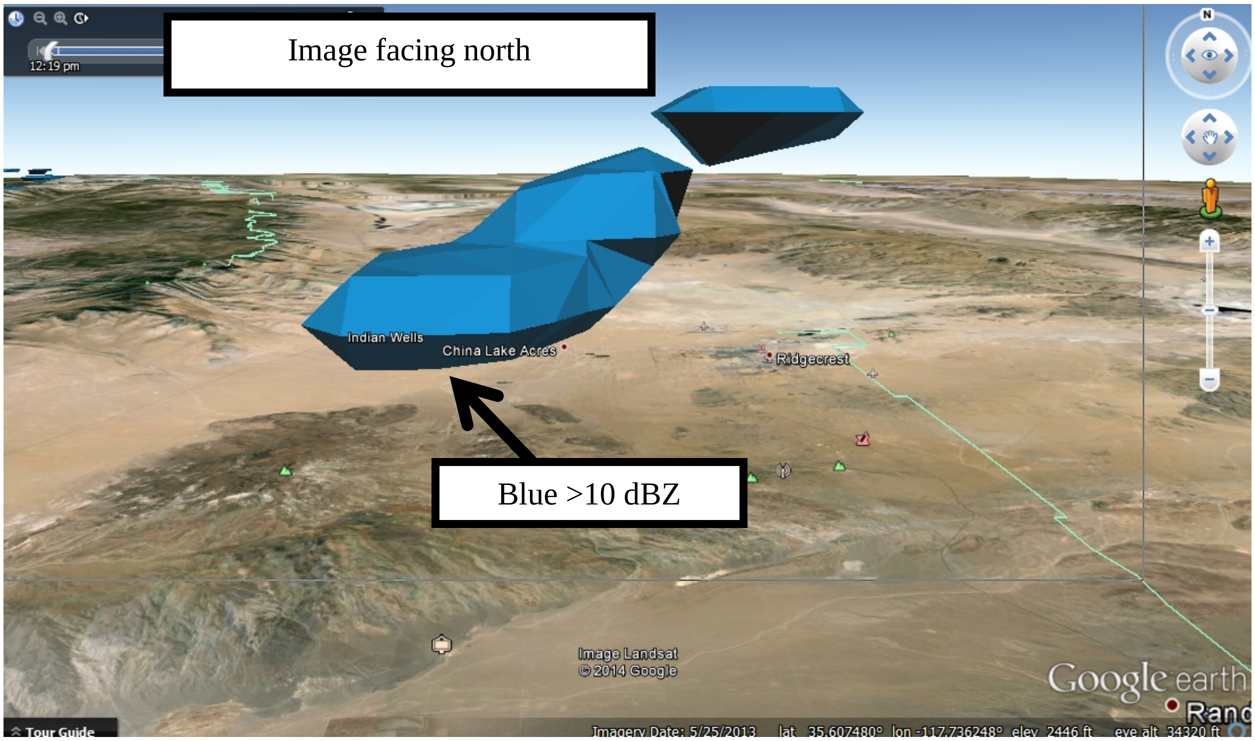


Figure 29 – 3-dimensional KHNX WSR-88D base reflectivity from the scan initiated at 1019 PDT

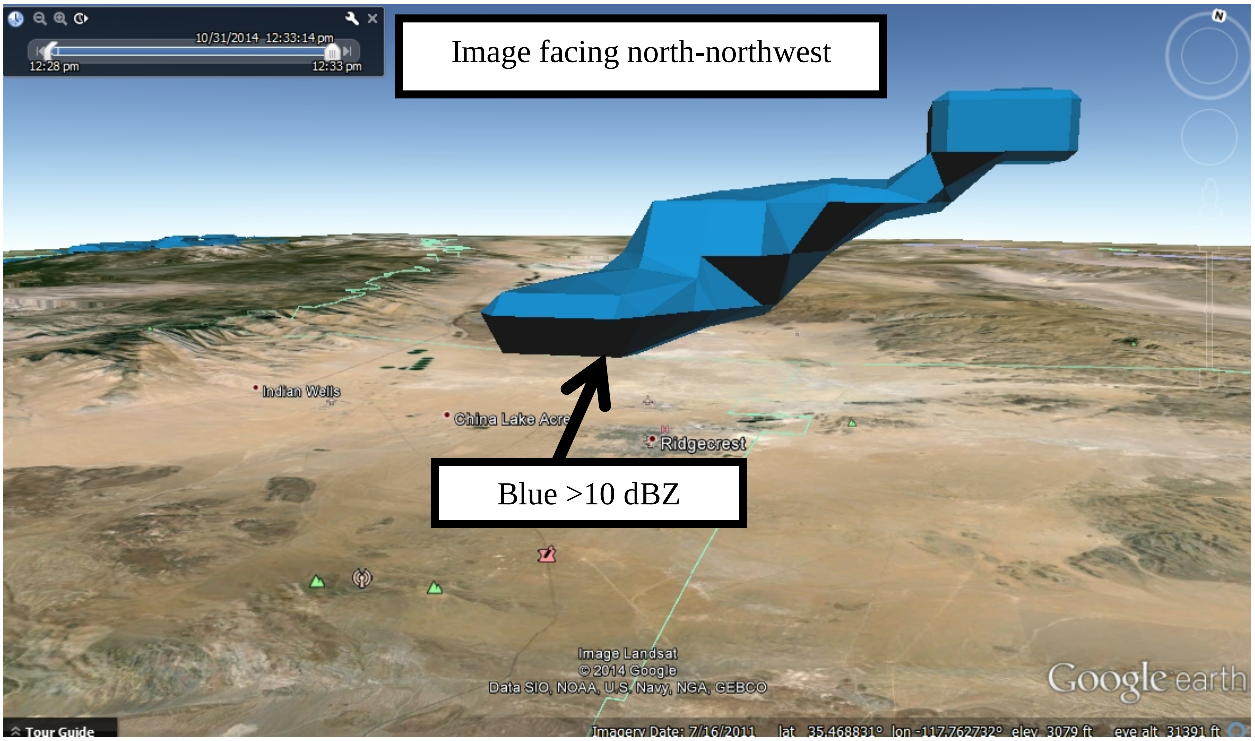


Figure 30 – 3-dimensional KHNX WSR-88D base reflectivity from the scan initiated at 1029 PDT

6.6 Zdr, CC, KDP, and HC[20]

Zdr is the logarithm ratio of the horizontal power return to the vertical power return. Positive values of Zdr indicate that there is more horizontal power return than vertical power return[21]. A negative value of Zdr indicates that there is more vertical power return than horizontal power return indicating that the dominant hydrometeors are larger in the vertical than in the horizontal[22]. Near zero values of Zdr indicate that both the horizontal and vertical power return from within the volume scanned are of similar values, meaning the dominant hydrometeors are similar in size in both the vertical and horizontal[23].

CC is a measure of how similar the horizontal and vertical returned pulse characteristics are among all pulses in the sampled WSR-88D volume. CC provides information about the diversity of hydrometeors within the volume and the values range from 0 to 1[24]. Meteorological echoes tend to have CC values greater than 0.80, with values greater than 0.96 indicating that the meteorological targets within the volume are all very similar in size, shape, type (liquid versus solid), and orientation. CC values between 0.96 and 0.80 indicate that the meteorological targets within the volume have a higher diversity of sizes, shapes, types, and orientations as the CC trends lower. If hail is located within the volume scanned the CC values are typically between 0.80 and 0.96. Non-meteorological echoes have CC values less than 0.80 and these non-meteorological echoes can include but are not limited to bugs, chaff, smoke, and birds.

KDP is a measure of the range derivative of the differential phase shift between the horizontal and vertical pulses phases. KDP has possible range values between -2 to 10 in degrees per kilometer. When a radar pulse is sent out and hits meteorological and non-meteorological targets alike, the radar pulse will have a phase shift between the horizontal and vertical pulses. Once we know the KDP value with meteorological targets, along with the other dual-pol parameters, one can tell areas of heavy rain, hail, and different characteristics in snow and ice crystals. KDP values that are large and positive often indicate areas of heavy rain. Areas with hail or snow often have KDP values much closer to 0. For non-meteorological targets, the KDP values are very noisy and difficult to interpret. In fact, for CC values less than 0.90 the KDP is not computed.

HC is a product produced by the hydrometeor classification algorithm and the HC attempts to discriminate between 10 classes of radar echoes at every 250 m range bin. HC ingests reflectivity, Zdr, CC, Kdp, and velocity, along with radially averaged and smoothed fields of reflectivity and differential phase. HC then uses the height of the melting layer along with the previous data and assigns a radar class to each bin with a weighted value. The HC then applies a set of hard thresholds to reduce the number of clearly wrong class designations, and given the weight and likelihood of each of the 10 classes at each bin, the HC assigns the radar classification with the highest likelihood value to that particular bin.

[20] Definitions for Zdr, CC, KDP, and HC adapted from training material from the NWS WDTB.
[21] A positive Zdr means that the dominant hydrometeors within the volume are larger in the horizontal than vertical (i.e. rain drops).
[22] A negative Zdr correlates to vertically oriented hydrometeors, i.e. vertically oriented crystals or conical graupel.
[23] A near zero Zdr is often an indication of hail or spherical rain drops.
[24] CC values greater than 1 indicate an untrustworthy signal due to low signal-to-noise ratio in areas of weak reflectivity.

6.7 Dual-Pol Imagery

Figure 31 presents the KEYX WSR-88D base reflectivity, Zdr, and CC values for the 2.5° elevation scans initiated at 1033 PDT with a resolution of 0.5° X 250 m. Figure 31 depicts light non-meteorological echoes to the northeast of the accident site located downstream as discussed and shown in time sequence in section 6.4 from both KHNX and KEYX radars. Within the non-meteorological echoes the dBZ values were observed between 10 and 30 dBZ, with Zdr values between -1.0 and 4.0 dB, and CC values at or below 0.3. These values in the dual-pol data were consistent from the beginning of the targets being visible in the weather radar data around 1010 PDT (section 6.4), and indicated a very non-homogeneous group of targets with greater varying characteristics and sizes, which correlated to non-meteorological targets (section 6.6).

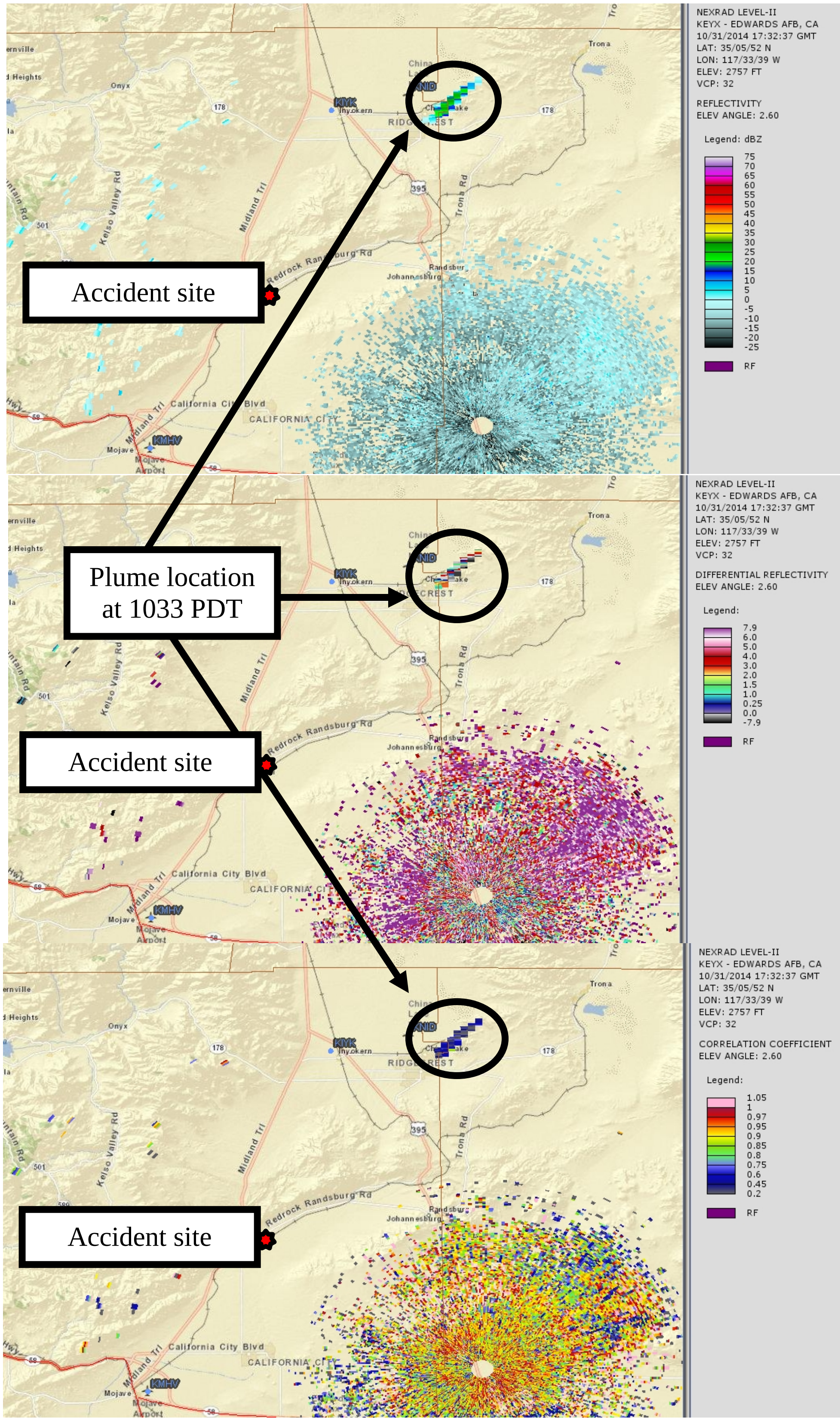


Figure 31 – KEYX WSR-88D 2.5° elevation scan for 1033 PDT (a) base reflectivity, (b) Zdr, and (c) CC

7.0 Pilot Reports

All pilot reports (PIREPs) were reviewed close to the accident site from around two hours prior to the accident time to around two hours after the accident time and the only PIREP close to the accident site is the PIREP below:

FAT UA /OV CZQ316018/TM 1739/FL330/TP B737/TB INTMT LGT CHOP 330/RM
MOSTLY SMOOTH AWC-WEB:SWA=

Routine pilot report (UA); 18 miles from Fresno, California, on the 316° radial; Time – 1039 PDT (1739Z); Altitude – FL330[25]; Type aircraft – Boeing 737; Turbulence – Intermittent light chop at FL330; Remarks – Mostly smooth.

8.0 SIGMET and CWSU Advisory

There were no SIGMETs valid for the accident site at the accident time.

No Center Weather Service Unit (CWSU) Advisory (CWA) was valid for the accident site at the accident time.

No Meteorological Impact Statements (MIS) were valid for the accident site at the accident time.

9.0 AIRMETs

There were no AIRMETs valid for the accident site above FL180 at the accident time.

10.0 Area Forecast

The Area Forecast issued at 0345 PDT, valid at the accident time, forecasted scattered cirrus clouds over the accident site at the accident time. At 1200 PDT scattered clouds at 15,000 feet msl with a broken cirrus ceiling above were forecast. The surface wind was forecast to be gusting to 25 knots out of the southwest after 1200 PDT as well:

FAUS46 KKCI 311045
FA6W
_SFOC FA 311045
SYNOPSIS AND VFR CLDS/WX
SYNOPSIS VALID UNTIL 010500
CLDS/WX VALID UNTIL 312300...OTLK VALID 312300-010500
WA OR CA AND CSTL WTRS
.

[25] Flight Level – A Flight Level (FL) is a standard nominal altitude of an aircraft, in hundreds of feet. This altitude is calculated from the International standard pressure datum of 1013.25 hPa (29.92 inHg), the average sea-level pressure, and therefore is not necessarily the same as the aircraft's true altitude either above mean sea level or above ground level.

SEE AIRMET SIERRA FOR IFR CONDS AND MTN OBSCN.
TS IMPLY SEV OR GTR TURB SEV ICE LLWS AND IFR CONDS.
NON MSL HGTS DENOTED BY AGL OR CIG.
.
SYNOPSIS...SEE SLC FA FOR SYNOPSIS. SFO SYNOPSIS UNAVBL DUE TO FA LENGTH LIMIT.
.
WA CASCDS WWD
CSTL SXNS...BKN030 OVC050 TOP FL280. VIS 3-5SM SCT/NMRS -SHRA.
19Z SCT030 BKN050. WDLY SCT -SHRA/ISOL -TSRA. CB TOP FL300.
OTLK...VFR SHRA.
PUGET SOUND-INTR VLY...BKN020 OVC040 TOP FL280. VIS 3-5SM -RA BR.
19Z SCT020 BKN040. SCT -SHRA. OTLK...VFR SHRA.
OLYMPICS-CASCDS...OVC060 TOP FL280. VIS 3-5SM -RA BR. 19Z OVC060.
SCT/NMRS -SHRA. OTLK...MVFR CIG SHRASN.
.
WA E OF CASCDS
CNTRL WA...OVC040 TOP FL280. VIS 3-5SM -RA BR. 18Z BKN040 OVC060.
SCT -SHRA. OTLK...VFR SHRA.
ERN WA...BKN040 OVC100 TOP FL280. VIS 3-5SM BR. ISOL -SHRA. 18Z
BKN040 OVC060. OCNL -RA. OTLK...MVFR CIG RA BR.
.
OR CASCDS WWD
CSTL SXNS...BKN020 OVC040 TOP FL280. VIS 3-5SM -RA BR. 18Z SCT030
BKN050. SCT -SHRA/ISOL -TSRA. CB TOP FL300. OTLK...VFR SHRA.
WILLAMETTE VLY...BKN025 OVC040 TOP FL280. VIS 3-5SM -RA BR. 18Z
BKN050 OVC080. SCT -SHRA. OTLK...VFR SHRA.
SWRN INTR...BKN040 OVC100 TOP FL280. OCNL VIS 3-5SM -RA BR. 13Z
OVC030. VIS 3-5SM -RA BR. 18Z BKN050 OVC070. SCT -SHRA.
OTLK...VFR SHRA.
CASCDS...OVC060 TOP FL280. VIS 3-5SM -RA BR. 19Z OVC060. SCT/NMRS
-SHRA. OTLK...MVFR CIG SHRASN.
.
OR E OF CASCDS
CNTRL...OVC060 TOP FL280. VIS 3-5SM -RA BR. 20Z BKN080. SCT
-SHRA. OTLK...VFR SHRA.
ERN 1/3 COLUMBIA BASIN...BKN100 TOP FL280. TIL 16Z VIS 3SM BR.
20Z OVC060. SCT -SHRA. OTLK...VFR SHRA.
RMNDR ERN...BKN120 TOP FL280. 21Z OVC100. ISOL -SHRA. OTLK...VFR
SHRA.
.
NRN CA...STS-SAC-TVL LN NWD
N 2/3 CSTL SXNS...OVC010 TOP FL280. VIS 3-5SM -RA BR. 16Z BKN020
OVC050. VIS 3-5SM SCT -SHRA. OTLK...MVFR CIG SHRA.
S 1/3 CSTL SXNS...OVC015 TOP FL280. VIS 3-5SM -RA BR. 20Z BKN020
OVC050. SCT -SHRA/ISOL -TSRA. CB TOP FL300. OTLK...MVFR CIG SHRA.
SAC VLY...OVC050 TOP FL280. ISOL -SHRA. 13Z OVC025. SCT -SHRA.
ISOL -TSRA DVLPG 18-20Z. CB TOP FL300. OTLK...VFR SHRA.
SHASTA-SISKIYOUS...OVC100 TOP FL280. VIS 3-5SM -RA BR. 15Z
OVC070. VIS 3-5SM SCT -SHRA. OTLK...MVFR CIG SHRA.
NERN CA-NRN SIERNEV...SCT-BKN150 TOP FL280. 15Z BKN100. ISOL
-SHRA. 20Z BKN080 OVC100. VIS 3-5SM -RA BR. OTLK...MVFR CIG RA
BR.
.
CNTRL CA
CSTL SXNS...

N 1/3...BKN020 OVC040 TOP FL280. 14Z VIS 3-5SM -RA BR. 19Z SCT020
BKN040. SCT -SHRA/ISOL -TSRA. CB TOP FL300. OTLK...VFR SHRA.
S 2/3...OVC020 TOP 040. 19Z BKN020 OVC040 TOP FL280. SCT
-SHRA/ISOL -TSRA. CB TOP FL300. OTLK...MVFR CIG SHRA.
SAN JOAQUIN VLY...
N 1/2...BKN CI. 13Z BKN120 TOP FL280. 21Z BKN060 OVC100. WDLY SCT
-SHRA/ISOL -TSRA. CB TOP FL300. OTLK...VFR SHRA.
S 1/2...SCT CI. 20Z SCT060 BKN100 TOP FL280. OTLK...VFR SHRA.
SRN SIERNEV...SCT CI. 18Z WND S 20G30KT. OTLK...VFR WND...02Z VFR
SHRA.
.
SRN CA..VBG-NID-60NNW BIH LN SWD
CSTL SXNS...
CSTLN...OVC010-015 TOP 040. 19Z BKN020 ST TOP 040. OVC100 TOP
FL250. OTLK...MVFR CIG.
INLAND...BKN020 TOP 040. 20Z BKN020 ST TOP 040. OVC100 TOP FL250.
OTLK...MVFR CIG.
**INTR MTNS-MOJAVE-SRN DESERTS...SCT CI. 19Z SCT150 WITH BKN CI
ABV. WND SW G25KT. OTLK...VFR WND.**
IMPERIAL-COACHELLA VLYS...SCT CI. OTLK...VFR.
.
CSTL WTRS
W OF 110W ONP-50W FOT-140WSW ENI LN...SCT030 BKN050 TOP FL180.
WDLY SCT -SHRA/ISOL -TSRA. CB TOP FL300. 19Z SCT -SHRA/ISOL
-TSRA. OTLK...VFR SHRA.
RMNDR N OF 120WSW SNS-30S OAK LN...BKN020 OVC040 TOP FL280. SCT
-SHRA/ISOL -TSRA. CB TOP FL300. 19Z SCT030 BKN050. SCT -SHRA/ISOL
-TSRA. OTLK...VFR SHRA.
S OF 60S SNS-150WSW RZS LN...OVC020 TOP 040. BECMG 1921 BKN020 ST
TOP 040. OVC100 TOP FL250. OTLK...MVFR CIG SHRA N 1/2...MVFR CIG
S 1/2.
RMNDR...SCT CI. 14Z BKN020 OVC040 TOP FL280. SCT -SHRA. 19Z SCT
-SHRA/ISOL -TSRA. CB TOP FL300. OTLK...MVFR CIG SHRA.
....

11.0 Terminal Aerodrome Forecast

KEDW was the closest non-official site with a Terminal Aerodrome Forecast (TAF). The TAF valid at the time of the accident was issued at 0313 PDT and was valid for a 30-hour period beginning at 0300 PDT. The TAF forecast for KEDW was as follows:

TAF KEDW 3110/0116 **VRB06KT 9999 FEW200 QNH2994INS**
BECMG 3118/3119 24012G18KT 9999 SCT250 QNH2985INS
BECMG 3121/3122 24015G25KT 9999 SCT250 520009 QNH2981INS
TEMPO 3122/0102 25020G30KT
BECMG 0103/0104 24012G18KT 9999 FEW250 QNH2977INS
TEMPO 0106/0112 VCSH BKN025 610901
TX26/3122Z TN07/3113Z=

The forecast expected a variable surface wind at 6 knots, greater than 6 miles visibility, few clouds at 20,000 feet agl, and an altimeter setting of 29.94 inHg, around the time of the accident.

KWJF was the closest site with a NWS TAF. The TAF valid at the time of the accident was issued at 0435 PDT and was valid for a 24-hour period beginning at 0500 PDT. The TAF forecast for KWJF was as follows:

TAF KWJF 311135Z 3112/0112 **24012KT P6SM SCT200**
FM311800 23016KT P6SM SCT150
FM312100 23018G28KT P6SM SCT060 BKN100
FM010400 25014KT P6SM SCT040 BKN080
FM010900 25012KT P6SM –SHRA SCT025 OVC040=

The forecast expected a wind from 240° at 12 knots, greater than 6 miles visibility, and scattered clouds at 20,000 feet agl around the time of the accident.

12.0 National Weather Service Area Forecast Discussion

The National Weather Service Office in Hanford, California, issued an Area Forecast Discussion (AFD) at 0242 PDT. The aviation section of the AFD indicated that VFR conditions would prevail across the central California interior until at least 1500 PDT:

FXUS66 KHNX 310942
AFDHNX
AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE SAN JOAQUIN VALLEY - HANFORD CA
242 AM PDT FRI OCT 31 2014
.SYNOPSIS...
THE FIRST SIGNIFICANT STORM OF THE WINTER SEASON WILL ARRIVE IN
CENTRAL CALIFORNIA THIS AFTERNOON. RAIN WILL SLIDE INTO THE VALLEY
FROM THE NORTHWEST BEGINNING LATE IN THE AFTERNOON AND COVER MOST
AREAS BY LATE IN THE EVENING. LIKEWISE SNOW WILL BEGIN FALLING IN
THE SIERRA FRIDAY AFTERNOON ABOVE 7500 FEET AT FIRST FALLING TO 5500
FEET BY SATURDAY MORNING. IN THE END MOST AREAS OF THE VALLEY SHOULD
SEE AT LEAST A QUARTER INCH OF RAIN...WITH OVER A FOOT OF SNOW
LIKELY ACROSS THE HIGH SIERRA. TEMPERATURES WILL BE MUCH COOLER THIS
WEEKEND AND SOME FOG WILL BE POSSIBLE SUNDAY AND MONDAY. QUIET AND
WARMER WEATHER WILL RETURN MONDAY AND CONTINUE THROUGH NEXT WEEK
&&
.DISCUSSION...AN UPPER TROUGH REMAINS JUST OFF THE CALIFORNIA
COAST THIS MORNING WITH AN ASSOCIATED COLD FRONT BEGINNING TO
NUDGE INTO NORTHERN CALIFORNIA. THE UPPER TROUGH WILL CONTINUE TO
MOVE EAST INTO CENTRAL CALIFORNIA TODAY INTO EARLY TOMORROW
MORNING. RAIN OVER COASTAL NORTHERN CALIFORNIA IS FORECAST TO
SPREAD SOUTH INTO THE REGION THIS AFTERNOON...IMPACTING THE ENTIRE
REGION BY MIDNIGHT.
THE HIGH RES ARW...THE HRRR...AND THE SREF ALL INDICATE THAT RAIN
WILL MOVE SOUTHEAST INTO FAR NORTHWEST MERCED COUNTY BY 2 PM
PDT...SPREADING SOUTH INTO FRESNO COUNTY BETWEEN 6 PM AND 8
PM...AND INTO KERN COUNTY BY 10 PM. FORECASTER CONFIDENCE IS HIGH
WITH TIMING AS THE SHORT RANGE HIGH RES MODELS ARE IN VERY GOOD
AGREEMENT.
IN ADDITION TO RAIN...THUNDERSTORMS WILL BE POSSIBLE AS THE STORM
SYSTEM MOVES INTO THE AREA...WITH THE SHORT RANGE MODELS
INDICATING DECENT SURFACE INSTABILITY. THE GREATEST THREAT FOR

THUNDERSTORMS WILL BE LATER THIS AFTERNOON INTO EARLY SATURDAY MORNING...WHERE SURFACE CAPE VALUES PEAK BETWEEN 600 AND 700 J/KG. SNOW LEVELS WILL ALSO DROP SIGNIFICANTLY AS COLD AIR FILTERS INTO THE AREA BEHIND THE COLD FRONT. SNOW LEVELS WILL DROP FROM 8500 FT ON FRIDAY AFTERNOON TO AROUND 5500 FEET BY SATURDAY MORNING. THE HIGH SIERRA COULD EASILY SEE OVER A FOOT OF SNOW BY SATURDAY MORNING.

AS FAR AS RAIN TOTALS GO...THE VALLEY COULD SEE BETWEEN A THIRD OF AN INCH TO NEARLY TWO-THIRDS OF AN INCH BY SATURDAY MORNING. THE DESERT LOCATIONS WILL SEE A BIT LESS...BETWEEN A FEW HUNDREDTHS TO AROUND TWO-TENTHS OF AN INCH.

THE UPPER TROUGH IS FORECAST TO SHIFT SLOWLY SOUTH INTO SOUTHERN CALIFORNIA SATURDAY EVENING INTO SUNDAY MORNING...BRINGING THE REGION SCATTERED SHOWERS INTO LATE SATURDAY NIGHT. THE SIERRA WILL LIKELY PICK UP ANOTHER FEW QUICK INCHES OF SNOW...HOWEVER TIMING AND LOCATION OF THESE SNOW SHOWERS WILL BE DIFFICULT TO NAIL DOWN. BY SUNDAY AFTERNOON...UPPER LEVEL NORTHERLY FLOW WILL DOMINATE THE AREA...KEEPING THE REGION DRY AND COOL. TEMPERATURES ON SUNDAY WILL BE SIMILAR TO THOSE ON SATURDAY...WITH VALLEY TEMPERATURES IN THE MID 60S.

HIGH PRESSURE WILL SLOWLY BEGIN TO BUILD OVER THE AREA MONDAY INTO THE FIRST HALF OF THE WEEK...RESULTING IN A WARMING AND DRYING TREND. BY THURSDAY...VALLEY TEMPERATURES WILL RANGE FROM THE MID 70S TO LOW 80S...NEARLY 10 DEGREES ABOVE NORMAL FOR THE BEGINNING OF NOVEMBER.

&&

.AVIATION...

AREAS OF MVFR AND LOCAL IFR CONDITIONS WILL DEVELOP AFTER 22Z FRIDAY AS PRECIPITATION MOVES OVER MERCED COUNTY. PRECIPITATION WILL SPREAD SOUTHEASTWARD ACROSS THE CENTRAL CALIFORNIA INTERIOR DURING THE EVENING. OTHERWISE...VFR CONDITIONS WILL PREVAIL ACROSS THE CENTRAL CALIFORNIA INTERIOR DURING THE NEXT 24 HOURS.

&&

.AIR QUALITY ISSUES...

NONE.

&&

.CERTAINTY...

THE LEVEL OF CERTAINTY FOR DAYS 1 AND 2 IS HIGH.

THE LEVEL OF CERTAINTY FOR DAYS 3 THROUGH 7 IS HIGH.

THIS INFORMATION IS PROVIDED AS PART OF A TRIAL PROJECT CONDUCTED BY THE NATIONAL WEATHER SERVICE SAN JOAQUIN VALLEY - HANFORD. CERTAINTY LEVELS INCLUDE LOW...MEDIUM...AND HIGH. PLEASE VISIT WWW.WEATHER.GOV/HNX/CERTAINTY.PHP /ALL LOWER CASE/ FOR ADDITIONAL INFORMATION AND/OR TO PROVIDE FEEDBACK.

&&

.CLIMATE...

RECORDS

SITE	DATE	HI_MAX:YEAR	LO_MAX:YEAR	HI_MIN:YEAR	LO_MIN:YEAR
KFAT	10-31	90:1949	57:1974	61:2008	32:1972
KFAT	11-01	88:1966	58:1935	61:2008	33:1971
KFAT	11-02	88:1949	53:1957	56:2012	34:1946
KBFL	10-31	92:1949	55:1923	65:2008	33:1935
KBFL	11-01	90:1966	58:2003	64:2008	30:1907
KBFL	11-02	89:1949	60:1947	58:1992	31:1935

&&

.HNX WATCHES/WARNINGS/ADVISORIES...

WINTER WEATHER ADVISORY FROM 8 PM THIS EVENING TO 11 AM PDT
SATURDAY ABOVE 7000 FEET FOR THE CAZ097.
WINTER STORM WARNING FROM 5 PM THIS AFTERNOON TO 11 AM PDT
SATURDAY ABOVE 6000 FEET FOR THE CAZ096.
&&
$$

13.0 National Weather Service Hazardous Weather Outlook

The National Weather Service Office in Hanford, California, issued a Hazardous Weather Outlook for the Kern County Mountains and desert locations including Mojave. The Hazardous Weather Outlook warned of gusty winds that would cause travel problems on north-south oriented roads. Weather spotters were encouraged to report any significant or unusual conditions:

CAZ095-098-099-010400-
KERN COUNTY MOUNTAINS-INDIAN WELLS VALLEY-
SOUTHEASTERN KERN COUNTY DESERT-
421 AM PDT FRI OCT 31 2014
THIS HAZARDOUS WEATHER OUTLOOK IS FOR THE KERN COUNTY MOUNTAINS
AND DESERT.
...GUSTY WINDS...
.DAY ONE...TODAY AND TONIGHT
* TIMING: THIS EVENING THROUGH LATE TONIGHT.
* LOCATIONS INCLUDE: CENTRAL AND EASTERN KERN COUNTY INCLUDING
TEHACHAPI...MOJAVE...RIDGECREST...AND ROSAMOND.

* IMPACTS: DIFFICULT TRAVEL CONDITIONS ESPECIALLY ON NORTH-SOUTH
ORIENTED ROADS.
.DAYS TWO THROUGH SEVEN...SATURDAY THROUGH THURSDAY
* TIMING: SATURDAY MORNING.
* LOCATIONS INCLUDE: CENTRAL AND EASTERN KERN COUNTY INCLUDING
TEHACHAPI...MOJAVE...RIDGECREST...AND ROSAMOND.

* IMPACTS: DIFFICULT TRAVEL CONDITIONS ESPECIALLY ON NORTH-SOUTH
ORIENTED ROADS.
* STAY TUNED TO NOAA WEATHER RADIO...OR YOUR FAVORITE NEWS
SOURCE...FOR FURTHER INFORMATION.

.SPOTTER INFORMATION STATEMENT...
SKYWARN SPOTTER ACTIVATION IS NOT ANTICIPATED.
WEATHER SPOTTERS ARE ENCOURAGED TO REPORT ANY SIGNIFICANT OR
UNUSUAL CONDITIONS TO THE NATIONAL WEATHER SERVICE.
$$

14.0 Pilot Weather Briefing[26]

The accident pilots were in the room for the day-before flight briefing, which contained the latest weather forecast information (section 15.0). The accident pilots were located in the room for the delta briefing on the morning of the accident flight and crosswind information was discussed during the delta briefing. Cellular telephone records indicated the co-pilot made a phone call to the Mojave Airport Automated Weather Observing System (AWOS) at 0416.[27] The accident pilots reviewed the flight test data card before the accident flight and the card contained wind information. There is no record of the accident pilots receiving any other additional weather information before the accident flight. Additional real-time monitoring and weather support for the accident flight was provided by a Jacobs Technology meteorologist (section 15.0).

15.0 Weather Forecaster Information

There was a Jacobs Technology meteorologist who provided weather forecasting information and flight test support for the accident flight. In the days leading up to the accident flight the meteorologist provided a weather outlook forecast around 1800 PDT on Wednesday, 2 days before the accident flight, and a weather forecast Thursday around 0700 and 1900 PDT, one day before the accident flight. The day of the accident the meteorologist provided an in-person weather briefing at 0500 PDT the morning of the accident flight, along with updating the mission managers twice in the control room once the schedule had slipped (attachment 1). The meteorologist monitored the weather conditions before and during the accident flight. The meteorologist's original forecast had the surface wind increasing at the landing site near or after 1000 PDT, therefore the meteorologist was routinely updating the flight test support information with the latest surface METAR, ASOS, and AWOS information to predict when the surface winds would increase at the landing site. In the meteorologist's experience the winds at mountain top and aloft were conducive for a weak mountain wave in the Owens Valley. The meteorologist stated that the wind direction was unfavorable for Tehachapi's and White's Mountain ranges to produce mountain waves during and around the accident time, as the wind speed would have needed to be higher during and around the accident time.

For more additional information please see attachment 2.

16.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on October 31, 2014, indicated the following:

[26] Please see the Operations Factual located in this docket.
[27] Please see the Human Performance Factual located in this docket.

SUN

Begin civil twilight	0646 PDT
Sunrise	0712 PDT
Sun transit	1235 PDT
Sunset	1758 PDT
End civil twilight	1824 PDT

17.0 Space Weather Information and Forecast

No significant space weather disturbances were forecast or observed around the accident site at the accident time. For additional information please see attachment 3.

18.0 Additional Weather Information from Edwards Air Force Base

Weather contractors at Edwards Air Force Base provided a weather package of information produced after the accident time and that is contained in attachments 3 through 6. One of those products is a R-2508 Mission Execution Forecasts (MEF) that is produced twice a day by the weather contractors at Edwards Air Force Base.[28] The 0454 PDT MEF forecasted few clouds at FL250 with that becoming a broken ceiling at FL250 after 1000 PDT. The MEF forecasted surface winds from 220° at 8 knots becoming 230° at 12 knots with gusts to 20 knots after 1200 PDT. No mountain wave activity was forecasted in the MEF with contrails between FL350 and FL595. For additional information on the MEF and other Edwards Air Force Base information please see attachments 4 and 5.

At 0200 PDT an upper air sounding was released at KEDW in support of the accident flight, along with the 0500 PDT upper air sounding (section 4.0). The 0200 PDT sounding transmitted data up to 97,000 feet. The 0500 PDT sounding transmitted data up to 55,000 feet. Between the 0200 and 0500 PDT soundings there was a 2 to 7 knot increase in wind speed and a 0.5° to 1° C temperature increase between 45,000 and 50,000 feet. The raw data from these soundings is provided in attachments 6 and 7.

[28] Please see wx email correspondence located in the docket of this accident.

19.0 Weather Research and Forecasting Model Simulation

A Weather Research and Forecasting Model (WRF) simulation was run to simulate the weather conditions surrounding the accident site at the accident time. WRF ARW (Advanced Research WRF core) version 3.2.1.5 was run with 3 domains with horizontal grid spacing of 8 km, 1.6 km, and 320 m over the accident site. Other WRF simulation parameters included: 60 vertical levels, the Kain-Fritsch cumulus parameterization scheme used on the outer domain, a Lin et al. microphysics scheme, a Yonsei University boundary layer scheme, Noah land surface physics, and the Dudhia scheme used for the long and short wave radiation. Figure 32 depicts the simulated terrain in feet used in the WRF run for domain 2, along with the location of the cross section from west to east displayed in figures 33 through 37. The horizontal wind speed decreased with height by 25 knots between 44,500 and 50,500 feet msl (Figures 33 and 34) at both 1010 and 1020 PDT, while the potential temperature lines were relatively flat at the same altitudes. On the same west to east cross section as figures 33 and 34, figures 35 and 36 depicted the potential temperature (solid lines) and Richardson Number values (color fill) around the accident site at 1000 and 1010 PDT. There was a steep drop in the Richardson number down to a value of 5 between 47,000 and 50,500 feet msl. Richardson Number values below 1.0 indicate locations where turbulence is favored, while Richardson Number values below 0.25 indicate areas were turbulence is likely[29]. Finally, on the same west to east cross section the vertical velocity was plotted (figure 37) for 1010 PDT with vertical velocity values indicative of downdrafts with a velocity between 100 and 50 feet per minute at and to the west of the accident site longitude between 44,500 and 50,500 feet. Outside of this location all the updrafts and downdrafts had velocities at or below 25 feet per minute (figure 37).

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[29] Lyons, R., H. A. Panofsky, and Sarah Wollaston, 1964: The Critical Richardson Number and Its Implications for Forecast Problems. Journal of Applied Meteorology, 3, 136-142.
Widseth, Christopher C. and Dean A. Morss, 1999: Airborne Verification of Atmospheric Turbulence using the Richardson Number. Weather Digest, 23, 38-44.
Lane, Todd P., Robert D. Sharman, Stanley B. Trier, Robert G. Fovell, and John K. Williams, 2012: Recent Advances in the Understanding of Near-Cloud Turbulence. Bulletin of the American Meteorological Society, 93, 499-515.

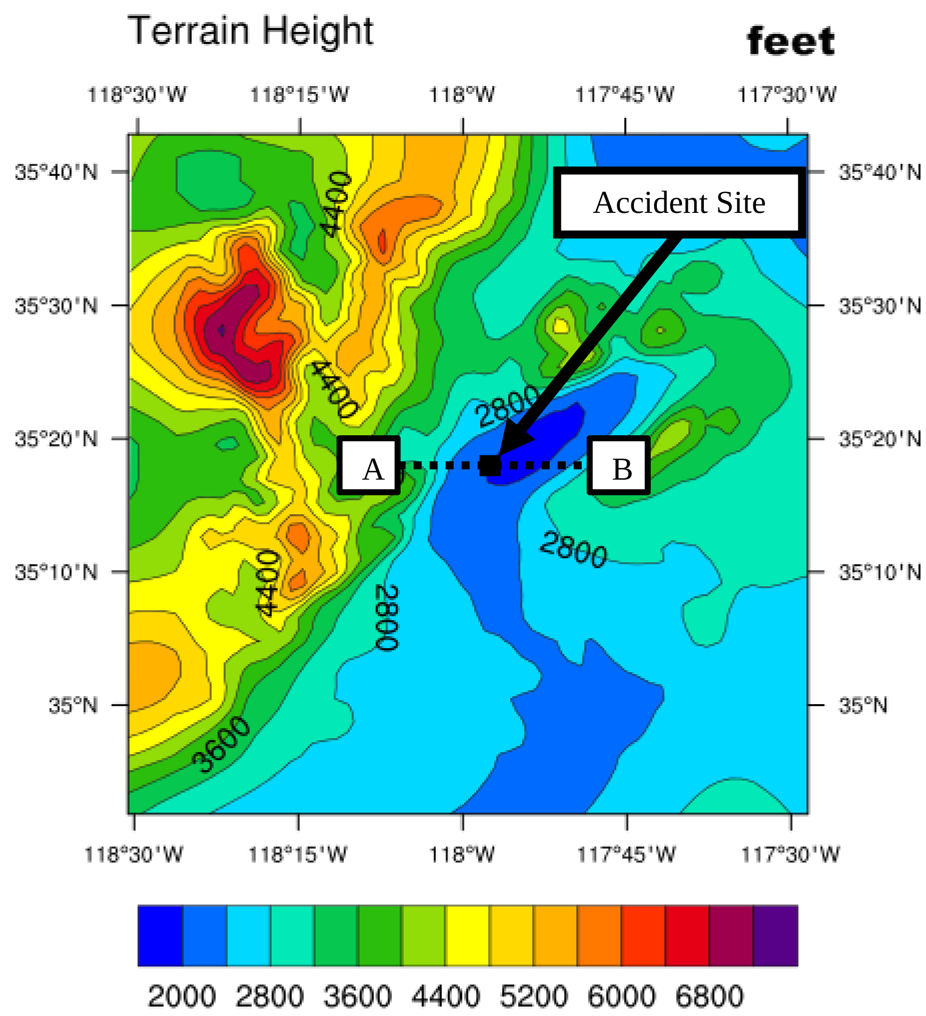

Figure 32 – WRF simulation terrain for domain 2 in feet with the approximate accident site marked and the location of the west to east cross section A-B

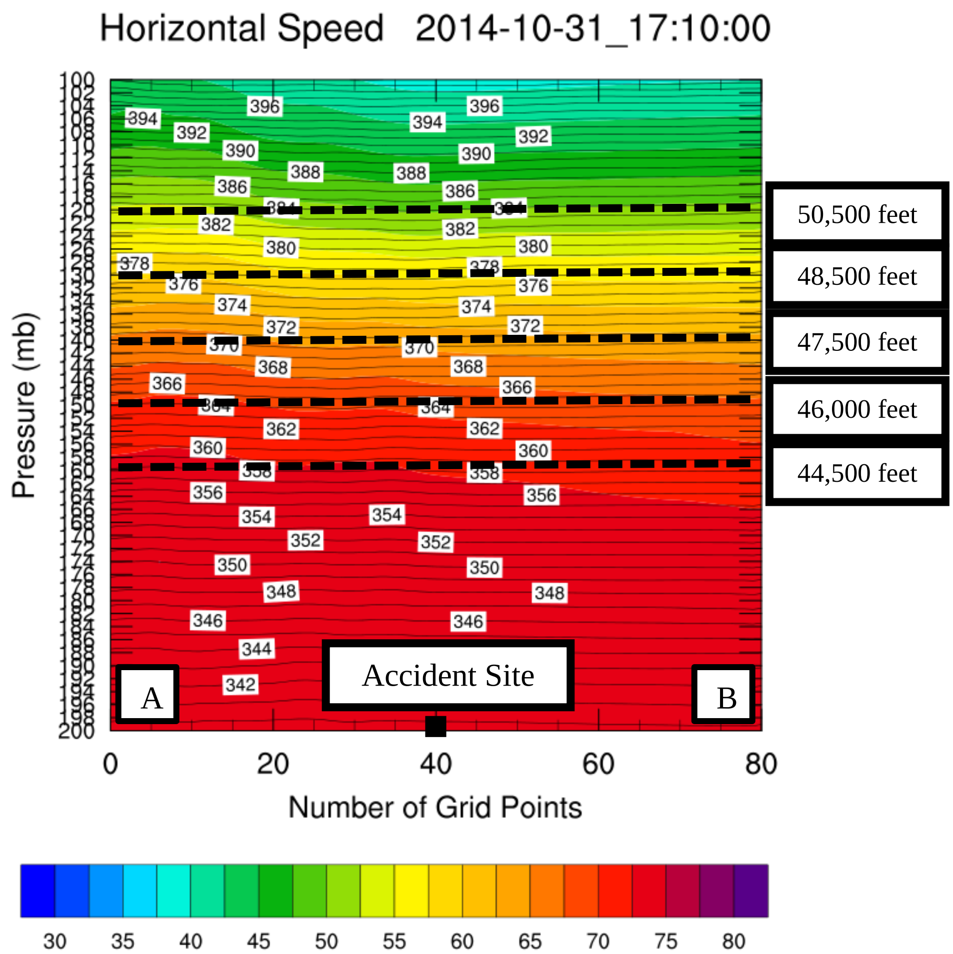

Figure 33 – WRF cross section from 1010 PDT of horizontal speed in knots (color fill) and potential temperature in kelvin (black lines) from west to east with the accident site marked

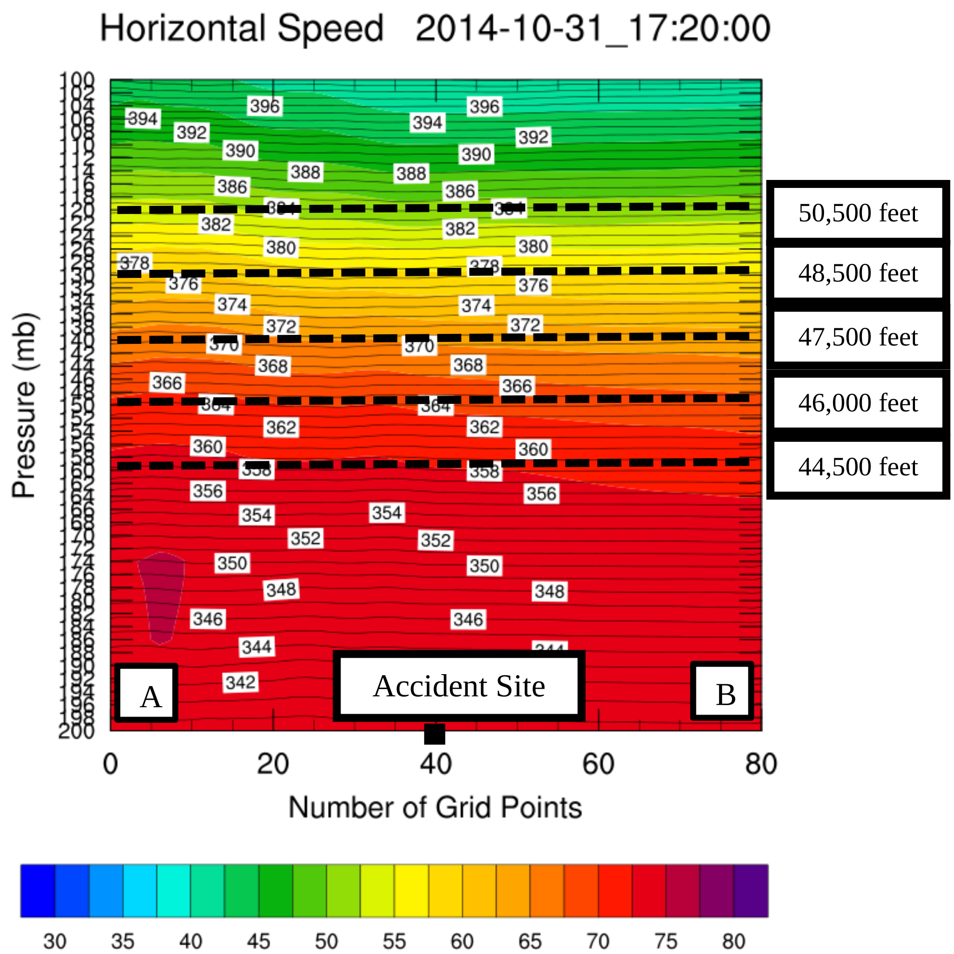

Figure 34 – WRF cross section from 1020 PDT of horizontal speed in knots (color fill) and potential temperature in kelvin (black lines) from west to east with the accident site marked

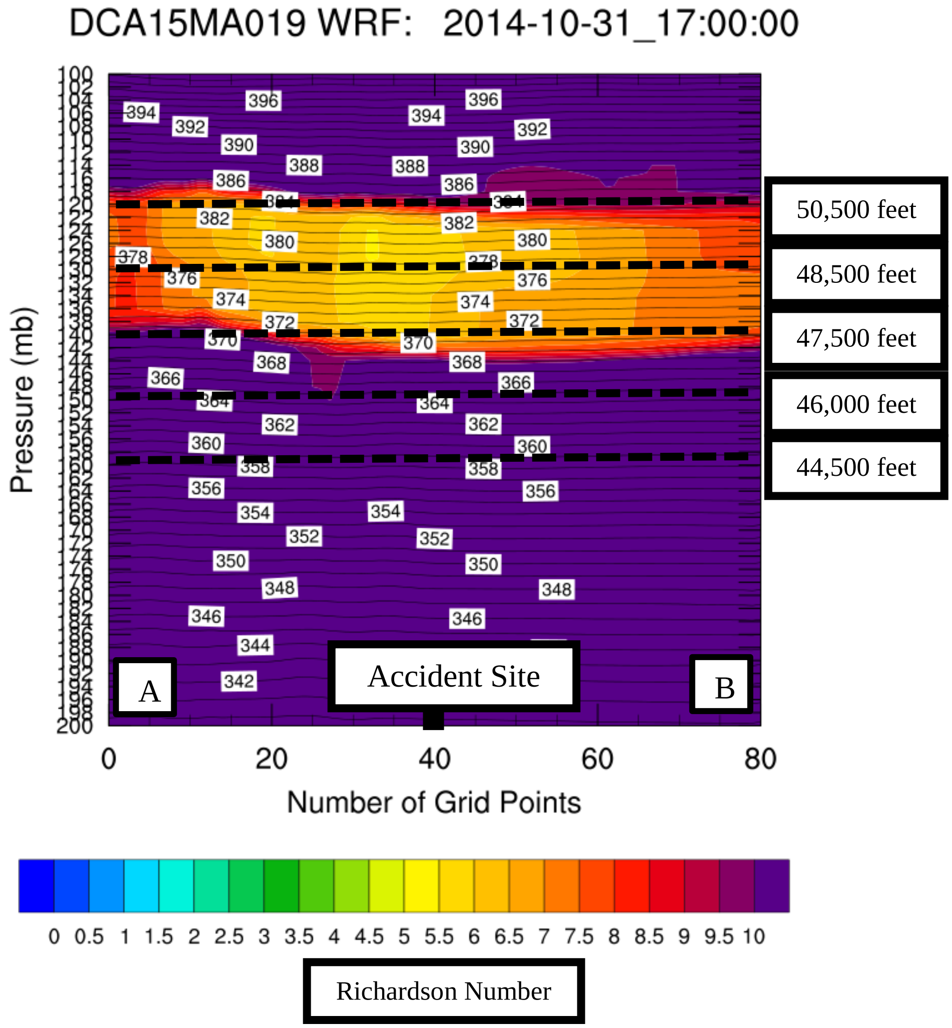

Figure 35 – WRF cross section from 1000 PDT of potential temperature (black lines) and Richardson Number (color fill) from west to east with the accident site marked

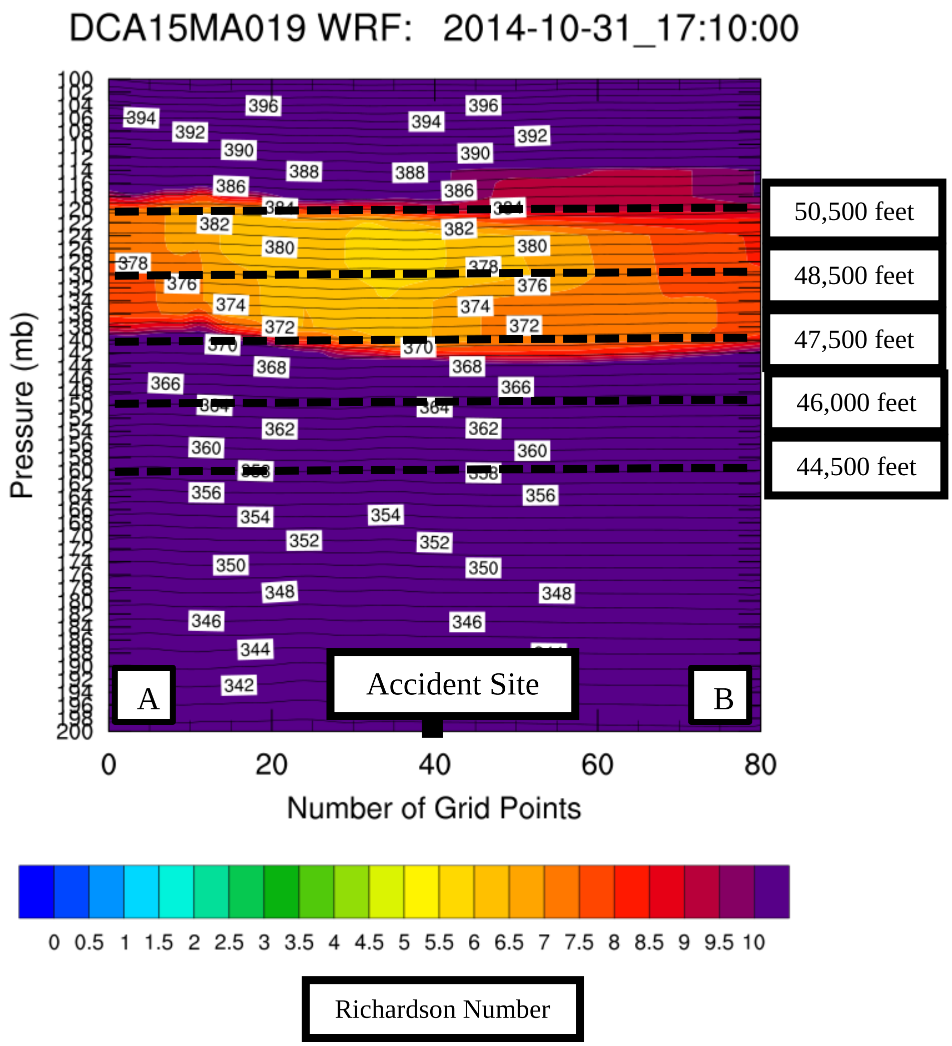

Figure 36 – WRF cross section from 1010 PDT of potential temperature (black lines) and Richardson Number (color fill) from west to east with the accident site marked

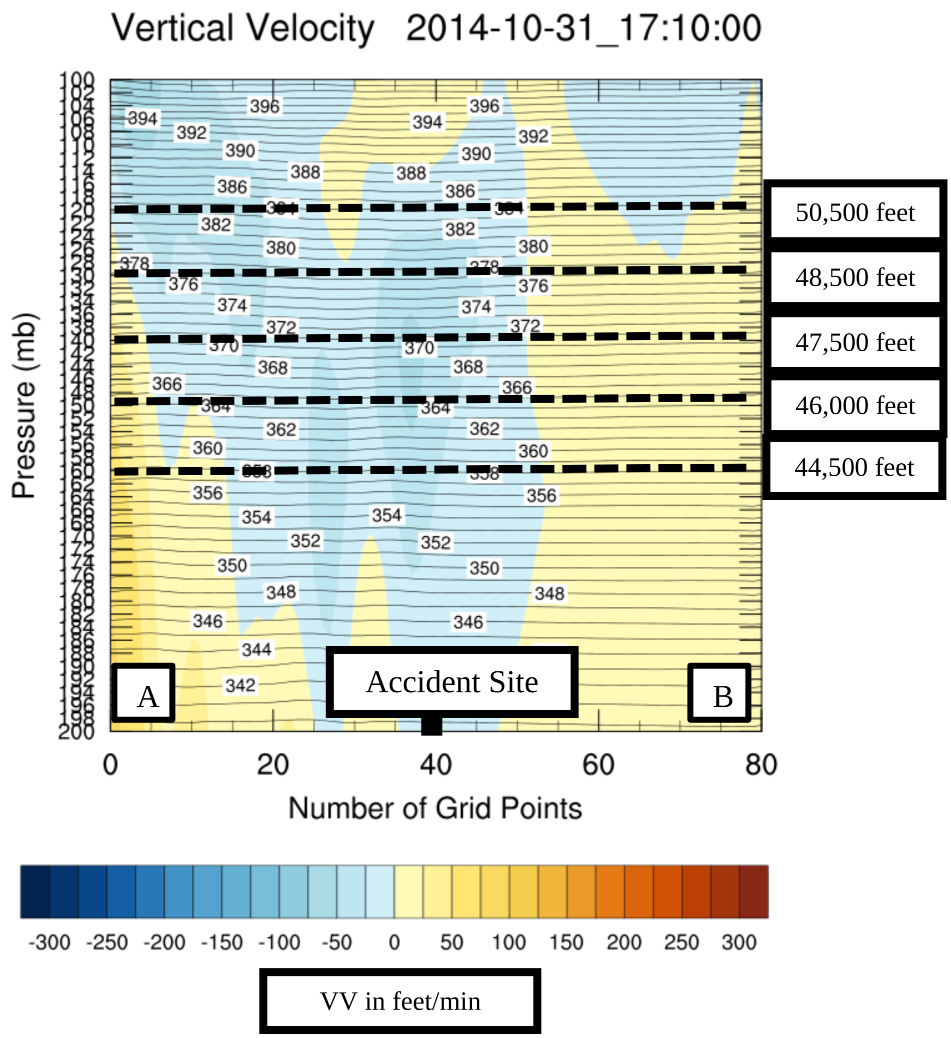

Figure 37 – WRF cross section from 1010 PDT of vertical velocity in feet per minute (color fill) and potential temperature (black lines) from west to east with the accident site marked

In addition to checking surface observations, satellite imagery, and other sources, the weather forecaster for the accident flight used a simple computer program, called the "RUC Tool", to retrieve weather computer model forecast data for specific points around the country. For the accident flight the specific point used was the Mojave location. The RUC Tool computer program is able to retrieve other weather computer model data from 4 specific sources and provide forecasted wind and temperature information with height for a specific latitude and longitude point. In addition to the forecasted wind and temperature information the RUC Tool is able to output such derived parameters as contrail formation and window fogging. The RUC Tool gets the initial atmosphere data from the latest run of the selected atmospheric weather computer model. Some of the weather computer model data used as a source in the RUC Tool computer program can be 1 to 12 hours old. The exact data used by the weather forecaster or accident flight team for the RUC Tool computer program is unknown, only that the program was used. For additional information regarding the RUC Tool please see attachment 8.

20.0 Vehicle Wind Data

Detailed wind information recorded by instruments aboard SpaceShipTwo (SS2) and WhiteKnightTwo (WK2) during the accident flight is contained in the factual reports submitted by the Flight Data Recorder and Aircraft Performance groups.

F. LIST OF ATTACHMENTS

Attachment 1 – SpaceShipTwo PF04 Flight Weather Forecast

Attachment 2 – Interview of weather forecaster for accident flight

Attachment 3 – Space weather forecast and analysis

Attachment 4 – Edwards AFB range complex Mission Execution Forecast (MEF)

Attachment 5 – Weather information gathered post-accident by Edwards AFB

Attachment 6 – 0200 PDT KEDW upper air sounding dataset

Attachment 7 – 0500 PDT KEDW upper air sounding dataset

Attachment 8 – RUC usage tool instruction manual

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NTSB, AS-30