NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

May 17, 2018

Group Chairman's Factual Report

METEOROLOGY

ANC18FA028

Table Of Contents

A. ACCIDENT

Location: Petaluma, California
Date: April 6, 2018
Time: 1715 Pacific daylight time
0015 Coordinated Universal Time (UTC) on April 7
Aircraft: Mooney M20P, Registration: N9133Z

B. METEOROLOGIST

Paul Suffern
Senior Meteorologist
Operational Factors Division (AS-30)
National Transportation Safety Board

C. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's (NTSB) Meteorologist did not travel for this investigation and gathered the weather data for this investigation from official National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sources including the National Centers for Environmental Information (NCEI). All times are Pacific daylight time (PDT) on April 6, 2018, 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 was located at approximate latitude 38.2689° N, longitude 122.5764° W, at an elevation of 310 feet (ft).

D. 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 and the Weather Prediction Center, 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 00-45H.[1]

[1] https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1030235

1.1 Surface Analysis Chart

The western United States section of the NWS Surface Analysis Chart for 1700 PDT is provided as figure 1 with the approximate location of the accident site marked within the red circle. The chart indicated a frontal boundary and low-pressure system west of California in the eastern North Pacific Ocean. Another stationary frontal boundary was located from eastern California through southern Utah. There was a low-pressure system at 1001-hectopascals (hPa) located in southern Nevada. A high-pressure system at 1012-hPa was located in northern Nevada.

The station models around the accident site depicted air temperatures in the low to mid 60's degrees Fahrenheit (°F), dew point temperatures near 60 °F with temperature-dew point spreads of 2° F or less, a south wind of 5 to 10 knots, moderate rain, and overcast skies.

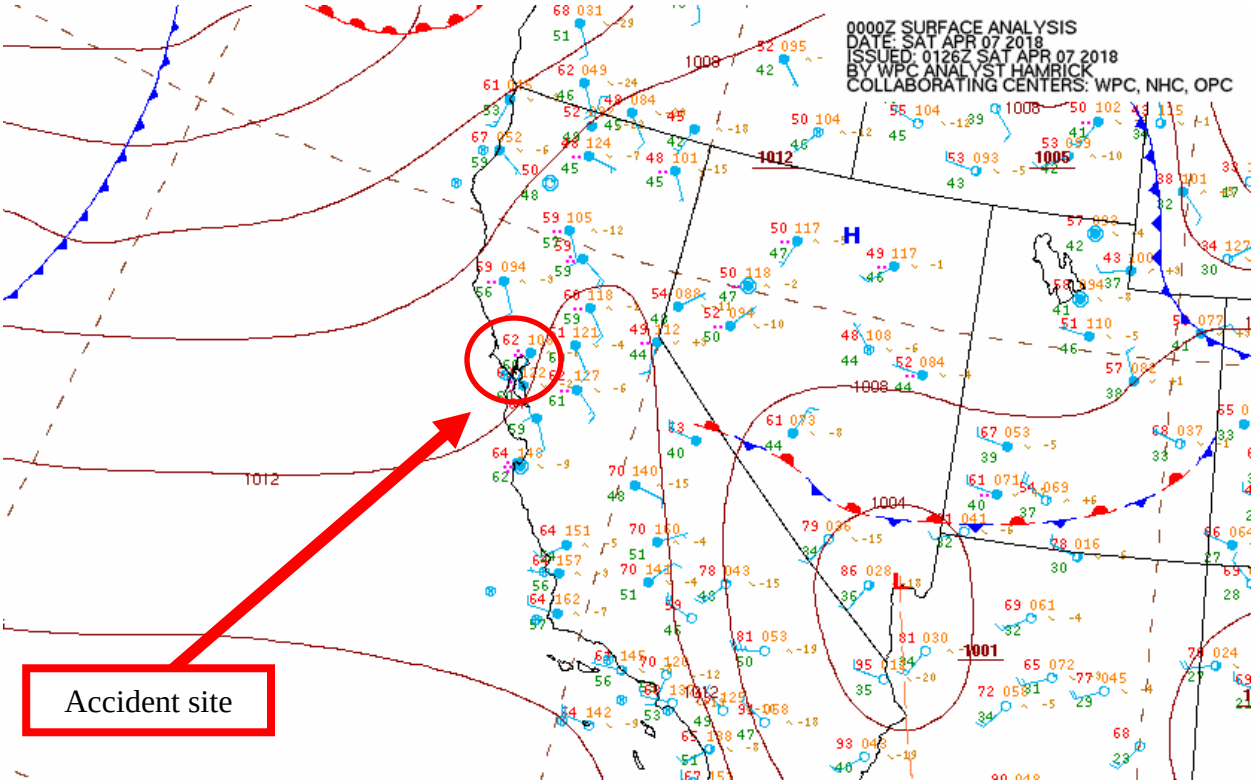


Figure 1 – NWS Surface Analysis Chart for 1700 PDT

1.2 Upper Air Charts

The NWS Storm Prediction Center (SPC) Constant Pressure Charts for 1700 PDT at 925-, 850-, 700-, 500-, and 300-hPa are presented in figures 2 through 6. There was a low-level trough[2] located northeast of the accident site over northern California at 1700 PDT (figures 2 and 3) at 925- and 850-hPa. Troughs can act as lifting mechanisms to help produce clouds and precipitation if sufficient moisture is present. There was a southwest wind at 20 knots at 925-hPa that became a westerly 50 knot wind by 700-hPa (figure 4). By 300-hPa, the wind remained from the west and had increased in magnitude to 70 knots (figure 6).

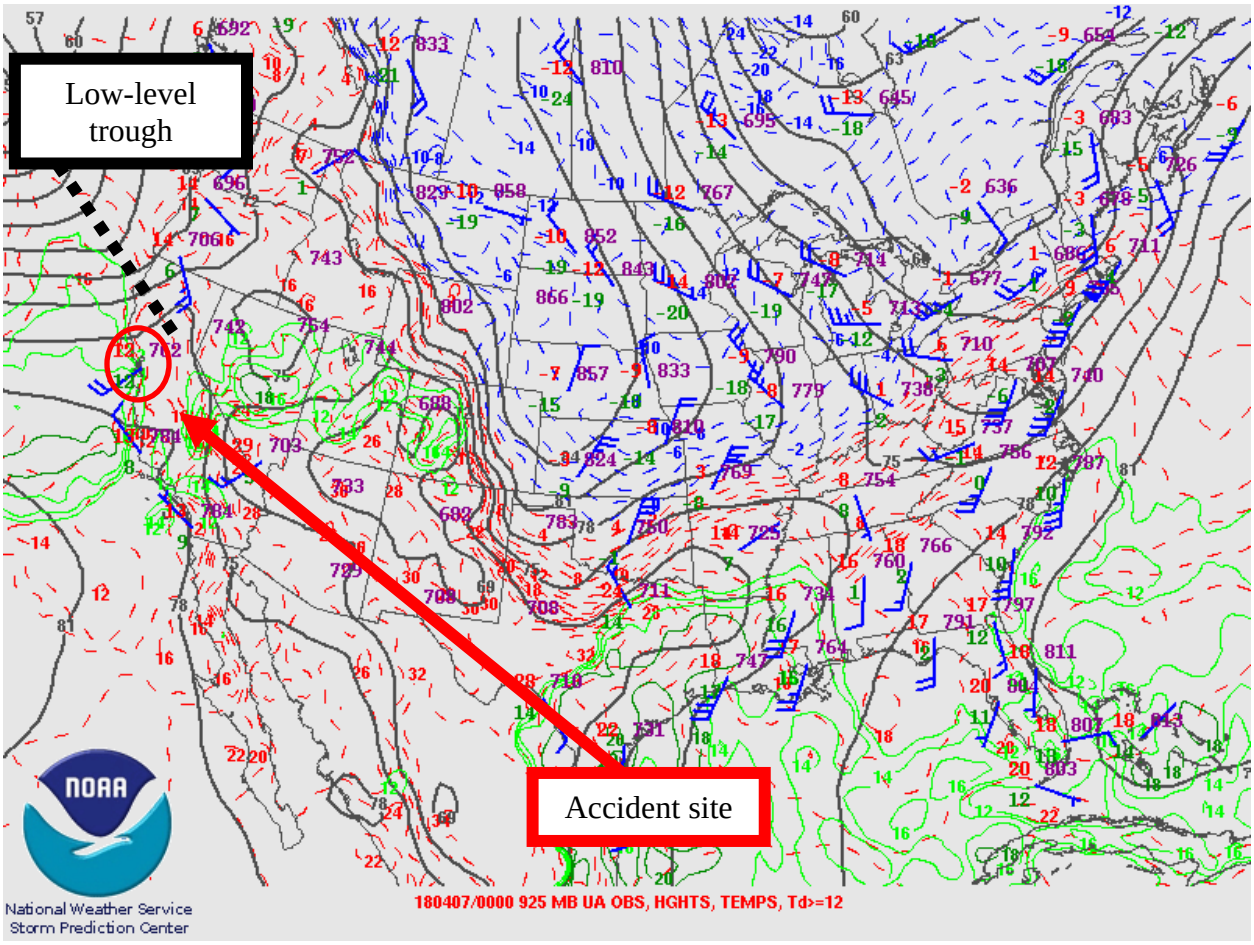


Figure 2 – 925-hPa Constant Pressure Chart for 1700 PDT

[2] Trough – An elongated area of relatively low atmospheric pressure or heights.

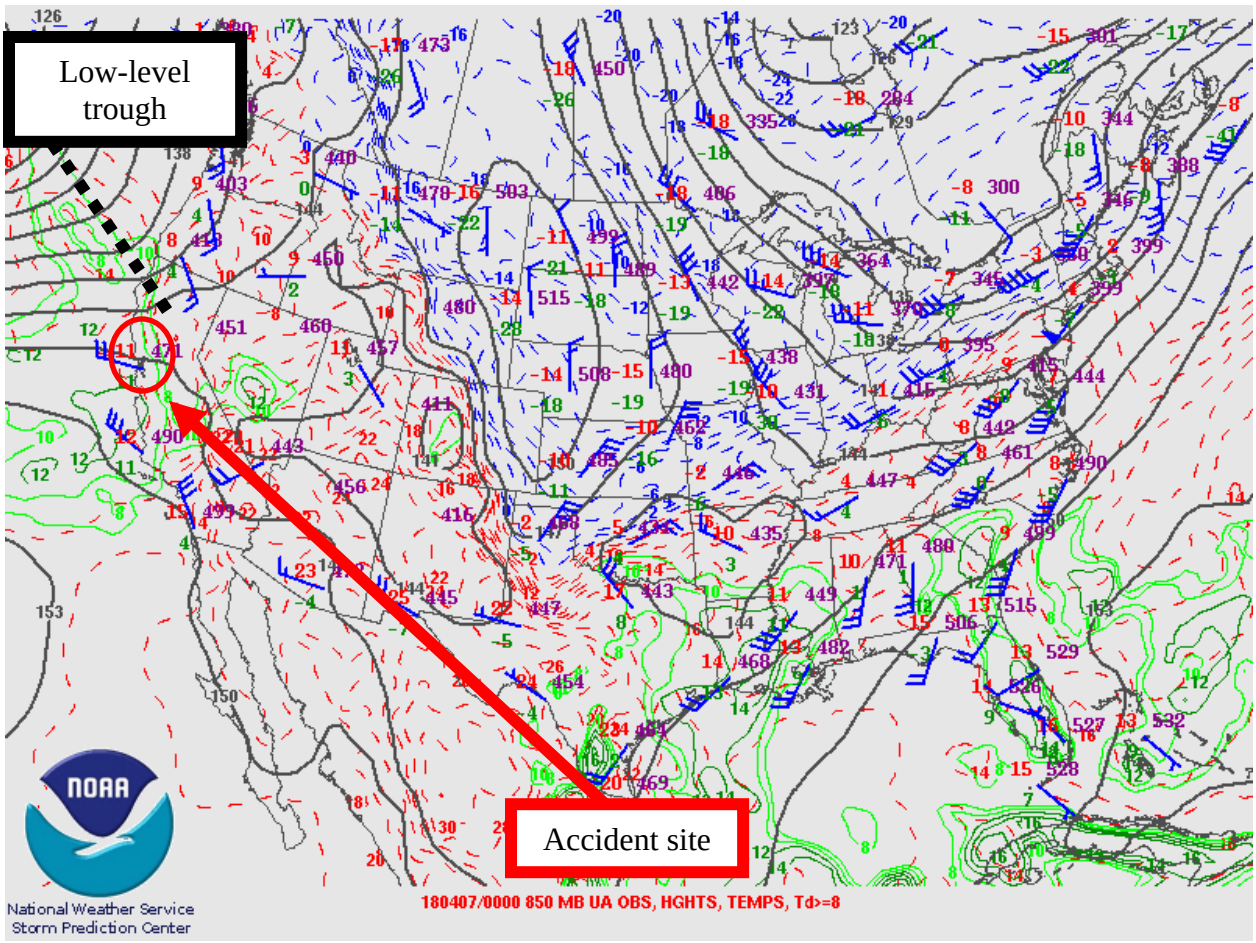


Figure 3 – 850-hPa Constant Pressure Chart for 1700 PDT

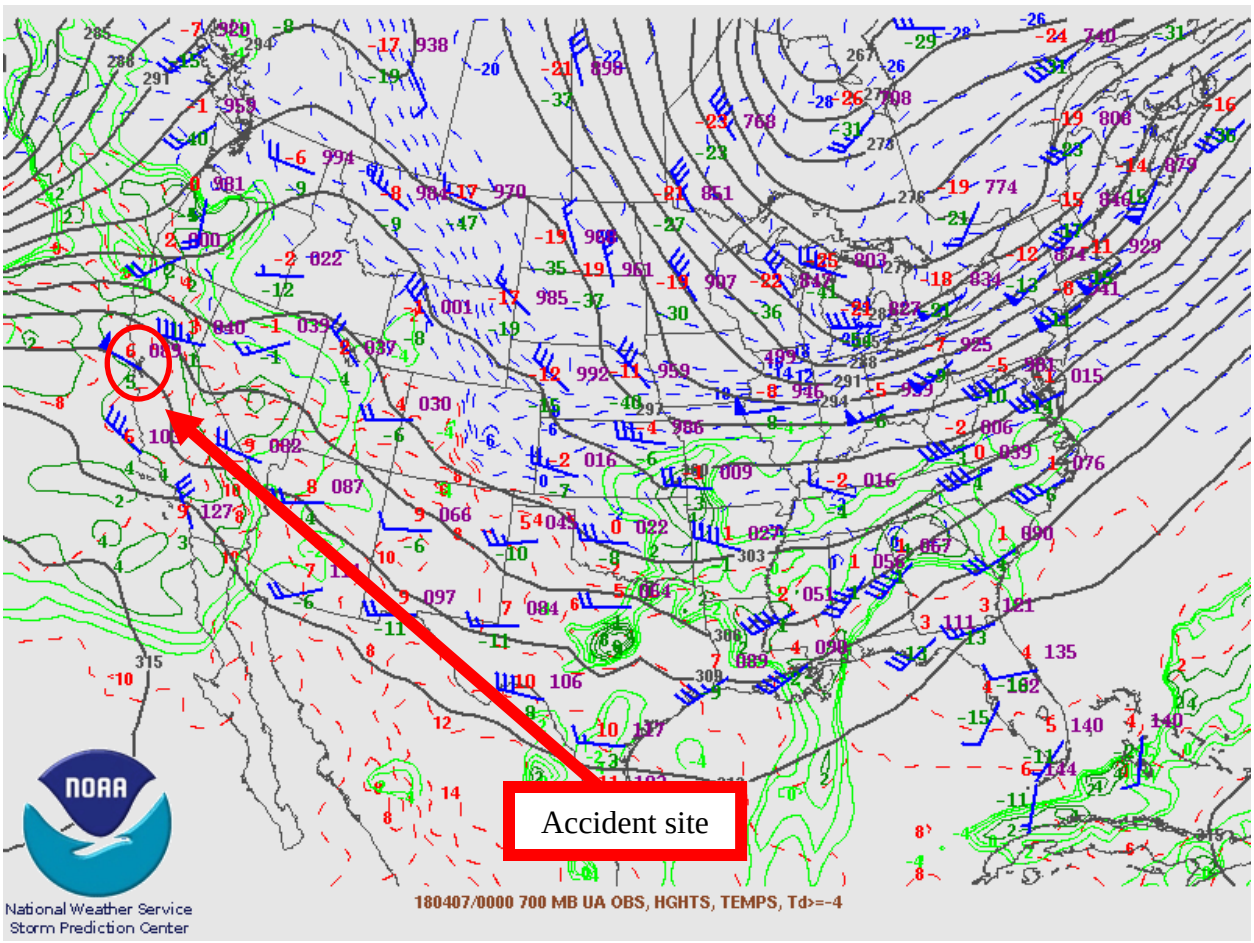


Figure 4 – 700-hPa Constant Pressure Chart for 1700 PDT

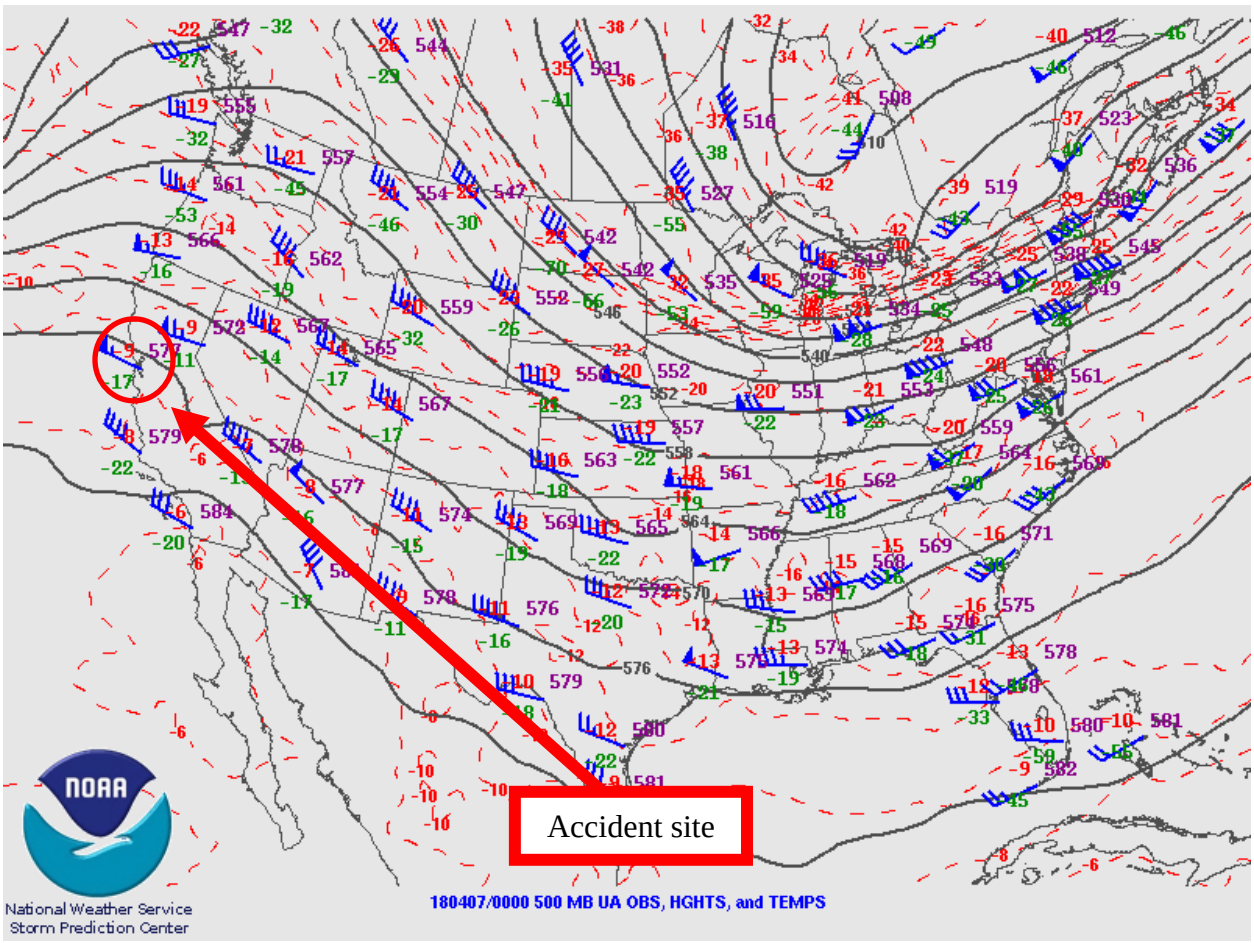


Figure 5 – 500-hPa Constant Pressure Chart for 1700 PDT

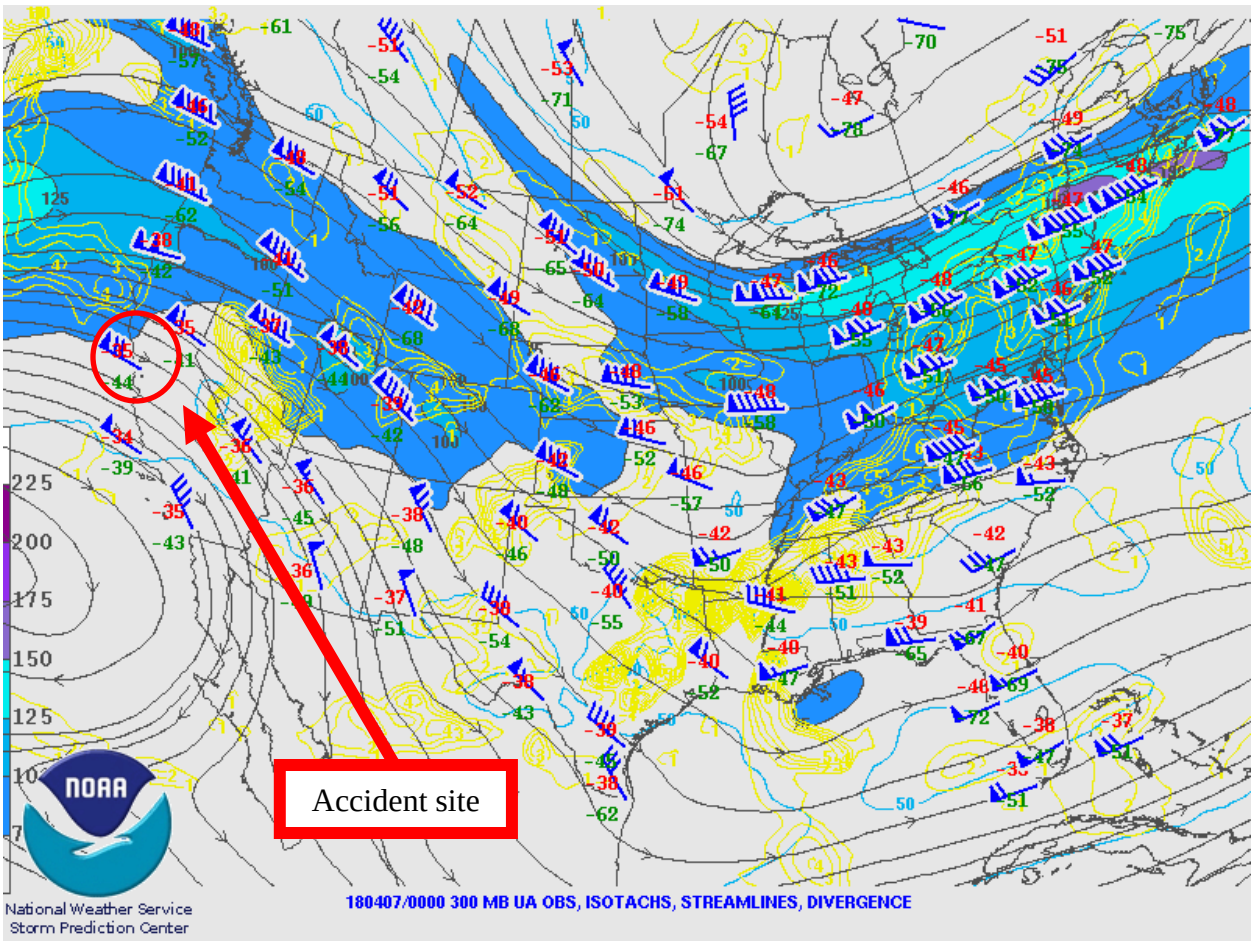


Figure 6 – 300-hPa Constant Pressure Chart for 1700 PDT

2.0 SPC Products

The SPC issued the following Day 1 Convective Outlook at 1250 PDT (figure 7) with areas of general thunderstorms forecast for the accident site. The SPC defines the "TSTM" area as an area that encloses where a 10 percent or higher probability of thunderstorms is forecast during the valid period:

SPC AC 061950

Day 1 Convective Outlook
NWS Storm Prediction Center Norman OK
0250 PM CDT Fri Apr 06 2018

Valid 062000Z - 071200Z

...THERE IS AN ENHANCED RISK OF SEVERE THUNDERSTORMS THIS AFTERNOON THROUGH EARLY TONIGHT FROM NORTHEAST TX TO WEST CENTRAL MS...

...THERE IS A SLIGHT RISK OF SEVERE THUNDERSTORMS CENTRAL AND NORTH TX TO THE LOWER MS VALLEY...

...THERE IS A MARGINAL RISK OF SEVERE THUNDERSTORMS SURROUNDING THE

SLIGHT RISK AREA...

...SUMMARY...
Severe thunderstorms with damaging winds, occasional hail, and a few tornadoes, are expected this afternoon through tonight from north and central Texas eastward to the lower Mississippi Valley.

...20Z Update...
Overall, the forecast outlined in the previous discussion (appended below) is still anticipated and only very minor changes were needed to the outlook based on frontal position and recent guidance.

...Central and northern LA into central and southwest MS...
Warm advection showers and thunderstorms have increased across the area over the past hour or so. Current character of these storms suggests they are elevated but continued destabilization downstream could eventually result in more surface-based development. Given the favorable kinematic profiles, a supercell capable of all severe hazards, including a tornado or two, is possible. More short-term details regarding this area are available in MCD 222.

...Elsewhere across the southern Plains and lower MS Valley...
Current surface analysis placed a low just west of ADM with a cold front extending west-southwestward into the TX South Plains and a warm front extending southeastward through northeast LA. A dryline also extends southwestward from the low into the TX Big Bend. The airmass ahead of the dryline and south of the warm front continues to destabilize as modest diurnal heating and moisture advection persists. Recent surface observations reveal mid 60s dewpoints as far north as the Red River with MLCAPE estimated over 2000 J/kg across much of TX. 18Z SHV sounding confirmed the presence of an EML with mid-level lapse rates greater than 8 degree C per km.

Given this destabilization and southward/southeastward surging cold front, the development of a strong convective line is still anticipated. Primary severe threat within this line will be damaging wind gusts although embedded tornadoes are also possible. Some hail is also possible, particularly with initial development along the cold front. More favorable thermodynamic environment for very large hail is expected across north-central and central TX this evening.

..Mosier.. 04/06/2018

.PREV DISCUSSION... /ISSUED 1123 AM CDT Fri Apr 06 2018/

...Southern Plains to the lower MS Valley through tonight...
A remnant lee cyclone now near Wichita Falls will move east-southeastward toward northeast TX and northwest LA by this evening, in advance of a series of low-amplitude mid-upper speed maxima. The moist warm sector, characterized by boundary-layer dewpoints of 65-70 F, will continue to spread northward to a baroclinic zone from the Red River valley of TX/OK across southern AR/northern LA through the afternoon. This southern baroclinic zone will be overtaken from northwest to southeast by a surge of arctic air now moving into the I-44 corridor, and this consolidated cold front will continue southeastward to south central/southeast TX and

the lower MS Valley by the end of the period.

Regional 12z soundings revealed an elevated mixed layer atop the moistening boundary layer across TX. Daytime heating will boost MLCAPE to in excess of 3000 J/kg across TX, and closer to 1000-1500 J/kg as far as west central MS by mid afternoon as the moisture spreads northward. A few surface-based storms may form by this evening near the dryline-cold front triple point in TX, as well as southward along the dryline into central TX. Here, the storm environment will favor supercells capable of producing isolated very large hail, especially with any storms that can remain discrete. Otherwise, the main convective evolution is expected to be a gradual transition of the ongoing elevated convection across eastern OK/AR into surface-based convection along the consolidating cold front by mid afternoon. These frontal storms will grow upscale fairly quickly into a squall line that will then surge southeastward this afternoon through tonight with the cold front. The cap will be weaker with eastward extent from northeast TX across LA, and some convection could develop in the warm sector this afternoon. Low-level shear/hodograph curvature will favor supercells with some conditional tornado threat, though there is uncertainty regarding the duration of any semi-discrete storms. The more probable scenario will be for a couple of tornadoes with embedded supercells and/or QLCS mesovortices, along with damaging winds and isolated large hail this afternoon through early tonight.

Buoyancy will slowly weaken overnight, and the convection should likewise weaken. However, there will still be some threat for at least isolated damaging winds as far south as the I-10 corridor from southeast TX eastward to southern MS through early Saturday morning.

CLICK TO GET WUUS01 PTSDY1 PRODUCT

NOTE: THE NEXT DAY 1 OUTLOOK IS SCHEDULED BY 0100Z

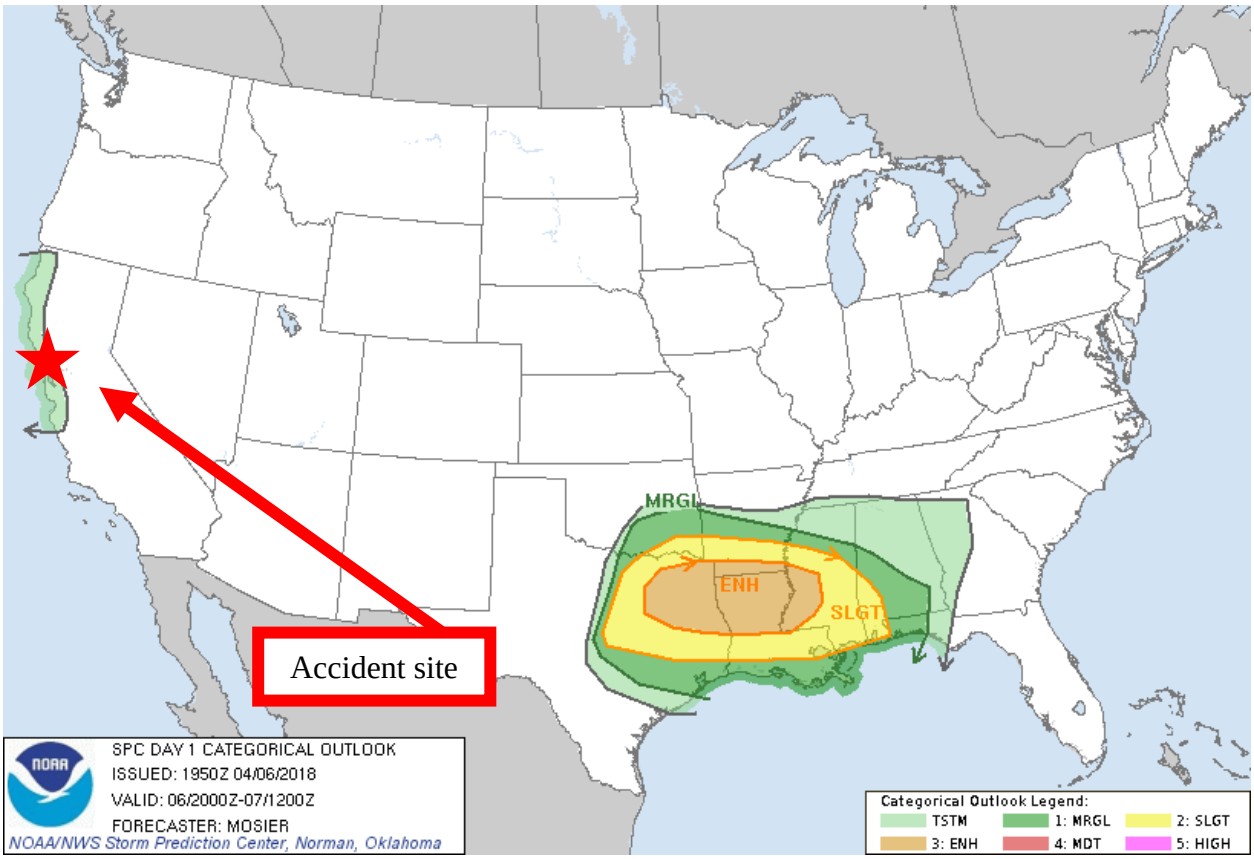


Figure 7 – SPC day 1 Convective Outlook valid at the time of the accident

3.0 Surface Observations

The area surrounding the accident site was documented using official Meteorological Aerodrome Reports (METARs) and Specials (SPECIs). Figure 8 is a sectional chart with the accident site and the closest weather reporting locations to the accident site marked.

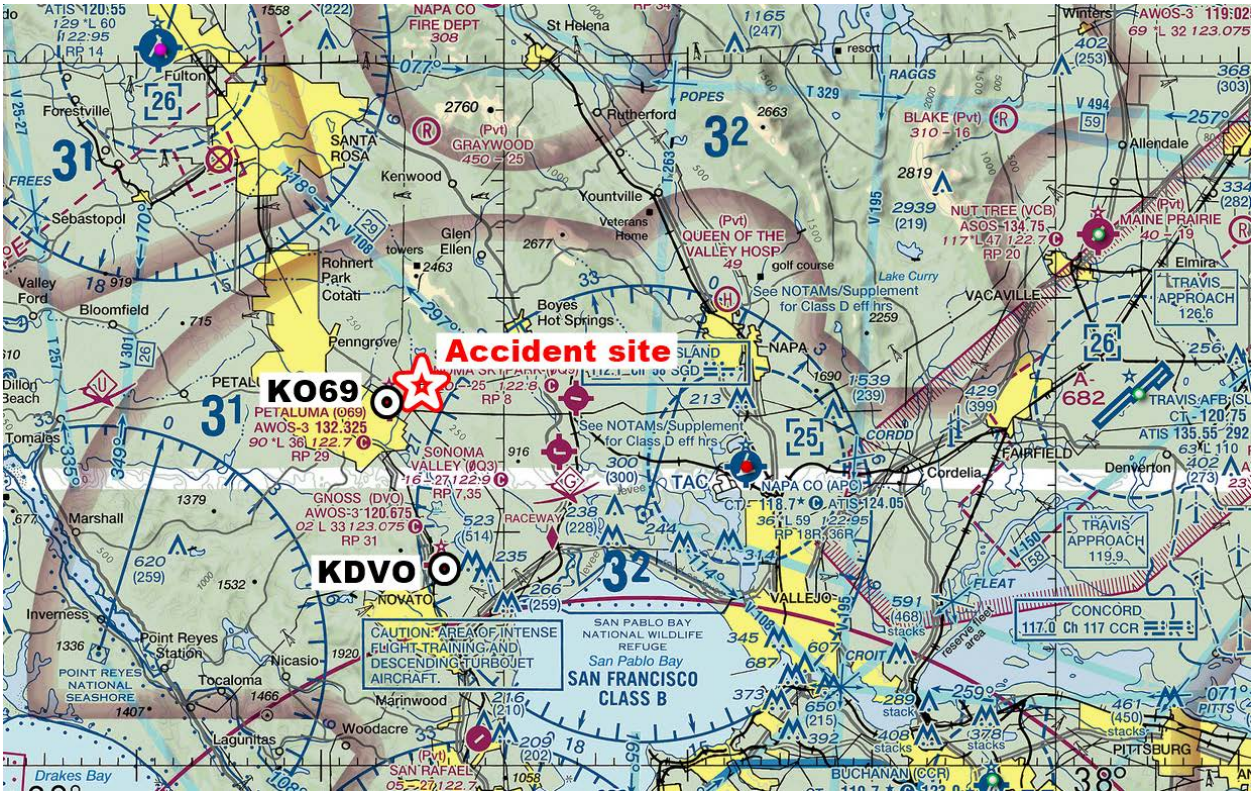


Figure 8 – Sectional chart of accident area with the location of the accident site and the closest surface observation sites

Petaluma Municipal Airport (KO69) had the closest official weather observation to the accident site, and was located 1-mile northeast of Petaluma, California. KO69 had an Automated Weather Observing System (AWOS[3]) whose reports were not supplemented. KO69 was located 2 miles southwest of the accident site, at an elevation of 90 ft, and had a 16° easterly magnetic variation[4] (figure 8). The following observations were taken and disseminated during the times surrounding the accident:[5]

[1555 PDT] METAR KO69 062255Z AUTO 00000KT 1SM BR BKN005 OVC015 15/15

[1615 PDT] METAR KO69 062315Z AUTO VRB03KT 3/4SM BR BKN005 OVC014 15/15 A2987 RMK A01=

[1635 PDT] METAR KO69 062335Z AUTO 12003KT 1SM BR BKN005 BKN012 OVC020 16/16 A2987 RMK A01=

[3] 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.

[4] Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from http://airnav.com/airport/O69

[5] Bolded sections in this report highlight information that directly reference the weather conditions that affected the accident location around the accident time.

[1655 PDT] METAR KO69 062355Z AUTO 00000KT 3/4SM BR OVC006 15/15 A2987 RMK A01=

[1715 PDT] METAR KO69 070015Z AUTO 10004KT 3/4SM BR OVC005 16/16 A2987 RMK A01=

ACCIDENT TIME 1715 PDT

[1735 PDT] METAR KO69 070035Z AUTO VRB03KT 3/4SM BR OVC005 16/16 A2988 RMK A01=

[1755 PDT] METAR KO69 070055Z AUTO 00000KT 1SM BR OVC006 15/15 A2988 RMK A01=

[1815 PDT] METAR KO69 070115Z AUTO VRB04KT 1SM BR BKN004 BKN007 OVC017 15/15 A2988 RMK A01=

[1835 PDT] METAR KO69 070135Z AUTO VRB03KT 1 1/4SM BR OVC005 15/15 A2988 RMK A01=

KO69 weather at 1655 PDT, wind calm, three quarters of a mile visibility, mist, an overcast ceiling at 600 ft above ground level (agl), temperature of 15° Celsius (C), dew point temperature of 15° C, and an altimeter setting of 29.87 inches of mercury. Remarks, station without a precipitation discriminator.

KO69 weather at 1715 PDT, wind from 100° at 4 knots, three quarters of a mile visibility, mist, an overcast ceiling at 500 ft agl, temperature of 16° C, dew point temperature of 16° C, and an altimeter setting of 29.87 inches of mercury. Remarks, station without a precipitation discriminator.

KO69 weather at 1735 PDT, wind variable at 3 knots, three quarters of a mile visibility, mist, an overcast ceiling at 500 ft agl, temperature of 16° C, dew point temperature of 16° C, and an altimeter setting of 29.88 inches of mercury. Remarks, station without a precipitation discriminator.

KO69 weather at 1755 PDT, wind calm, one mile visibility, mist, an overcast ceiling at 600 ft agl, temperature of 15° C, dew point temperature of 15° C, and an altimeter setting of 29.88 inches of mercury. Remarks, station without a precipitation discriminator.

Gnoss Field Airport (KDVO) was the next closest airport to the accident site with official weather information. KDVO had an AWOS whose reports were not supplemented. KDVO was located 8 miles south of the accident site, at an elevation of 2 ft, and had a 16° easterly magnetic variation[6] (figure 8). The following observations were taken and disseminated during the times surrounding the accident:

[6] Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from http://airnav.com/airport/KDVO

[1515 PDT] METAR KDVO 062215Z AUTO 18007KT 1 1/2SM -DZ BKN020 BKN025 16/15 A2987 RMK AO2=

[1535 PDT] METAR KDVO 062235Z AUTO 18005KT 2SM -RA SCT017 16/15 A2988 RMK AO2=

[1555 PDT] METAR KDVO 062255Z AUTO 18005KT 1 3/4SM -RA FEW003 BKN018 16/16 A2987 RMK AO2=

[1615 PDT] METAR KDVO 062315Z AUTO 14004KT 4SM BR SCT019 BKN025 16/15 A2987 RMK AO2=

[1635 PDT] METAR KDVO 062335Z AUTO 18006KT 2 1/2SM BR SCT018 SCT024 16/15 A2987 RMK AO2=

[1655 PDT] METAR KDVO 062355Z AUTO 18007KT 2 1/2SM BR SCT017 SCT022 16/15 A2986 RMK AO2=

[1715 PDT] METAR KDVO 070015Z AUTO 16006KT 4SM -DZ SCT018 BKN023 16/15 A2987 RMK AO2=

ACCIDENT TIME 1715 PDT

[1735 PDT] METAR KDVO 070035Z AUTO 19009KT 2 1/2SM BR SCT018 SCT023 16/15 A2987 RMK AO2=

[1755 PDT] METAR KDVO 070055Z AUTO 16007KT 3SM BR FEW019 SCT026 16/15 A2987 RMK AO2=

[1815 PDT] METAR KDVO 070115Z AUTO 16005KT 2 1/2SM BR FEW021 SCT028 16/15 A2987 RMK AO2=

[1835 PDT] METAR KDVO 070135Z AUTO 15006KT 1SM -RA FEW016 SCT021 SCT028 16/15 A2989 RMK AO2=

KDVO weather at 1655 PDT, automated, wind from 180° at 7 knots, 2 and one half miles visibility, mist, scattered clouds at 1,700 ft agl, scattered clouds at 2,200 ft agl, temperature of 16° C, dew point temperature of 15° C, and an altimeter setting of 29.86 inches of mercury. Remarks: automated station with a precipitation discriminator.

KDVO weather at 1715 PDT, automated, wind from 160° at 6 knots, 4 miles visibility, light drizzle, scattered clouds at 1,800 ft agl, a broken ceiling at 2,300 ft agl, temperature of 16° C, dew point temperature of 15° C, and an altimeter setting of 29.87 inches of mercury. Remarks: automated station with a precipitation discriminator.

KDVO weather at 1735 PDT, automated, wind from 190° at 9 knots, 2 and one half miles visibility, mist, scattered clouds at 1,800 ft agl, scattered clouds at 2,300 ft agl, temperature of 16° C, dew point temperature of 15° C, and an altimeter setting of 29.87 inches of mercury. Remarks: automated station with a precipitation discriminator.

KDVO weather at 1755 PDT, automated, wind from 160° at 7 knots, 3 miles visibility, mist, few clouds at 1,900 ft agl, scattered clouds at 2,600 ft agl, temperature of 16° C, dew point temperature of 15° C, and an altimeter setting of 29.87 inches of mercury. Remarks: automated station with a precipitation discriminator.

The observations from KO69 and KDVO surrounding the accident time indicated mainly IFR[7] and LIFR[8] conditions. Mist, drizzle, and light rain were observed at KDVO at and surrounding the accident time.

4.0 Upper Air Data

A High-Resolution Rapid Refresh (HRRR)[9] model sounding was created for the accident site for 1700 PDT with a station elevation of 558 ft. The 1700 PDT HRRR sounding was plotted on a standard Skew-T Log P diagram[10] with the derived stability parameters included in figure 9 (with data from the surface to 600-hPa, or approximately 14,000 ft msl). This data was analyzed using the RAOB[11] software package. The sounding depicted the lifted condensation level (LCL)[12] at 95 ft agl, the level of free convection (LFC)[13] at 174 ft agl, and the convective condensation level (CCL)[14] at 1,316 ft agl. The sounding had a greater than 80 percent relative humidity from the surface through 14,000 ft. The freezing level was at 13,417 ft msl. The precipitable water value was 1.55 inches.

[7] Instrument Flight Rules (IFR) – Refers to the general weather conditions pilots can expect at the surface. IFR criteria means a ceiling below 1,000 ft agl and/or less than 3 miles visibility.
[8] Low Instrument Flight Rules (LIFR) – Refers to the general weather conditions pilots can expect at the surface. LIFR criteria means a ceiling below 500 ft agl and/or less than one mile visibility.
[9] The HRRR is a NOAA real-time three-kilometer resolution, hourly-updated, cloud-resolving, convection-allowing atmospheric model, initialized by three kilometer grids with three kilometer radar assimilation. Radar data is assimilated in the HRRR every 15 minutes over a one hour period.
[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, Matamoras, Pennsylvania.
[12] LCL - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.
[13] LFC – The level at which a parcel of saturated air becomes warmer than the surrounding air and begins to rise freely. This occurs most readily in a conditionally unstable atmosphere.
[14] 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.

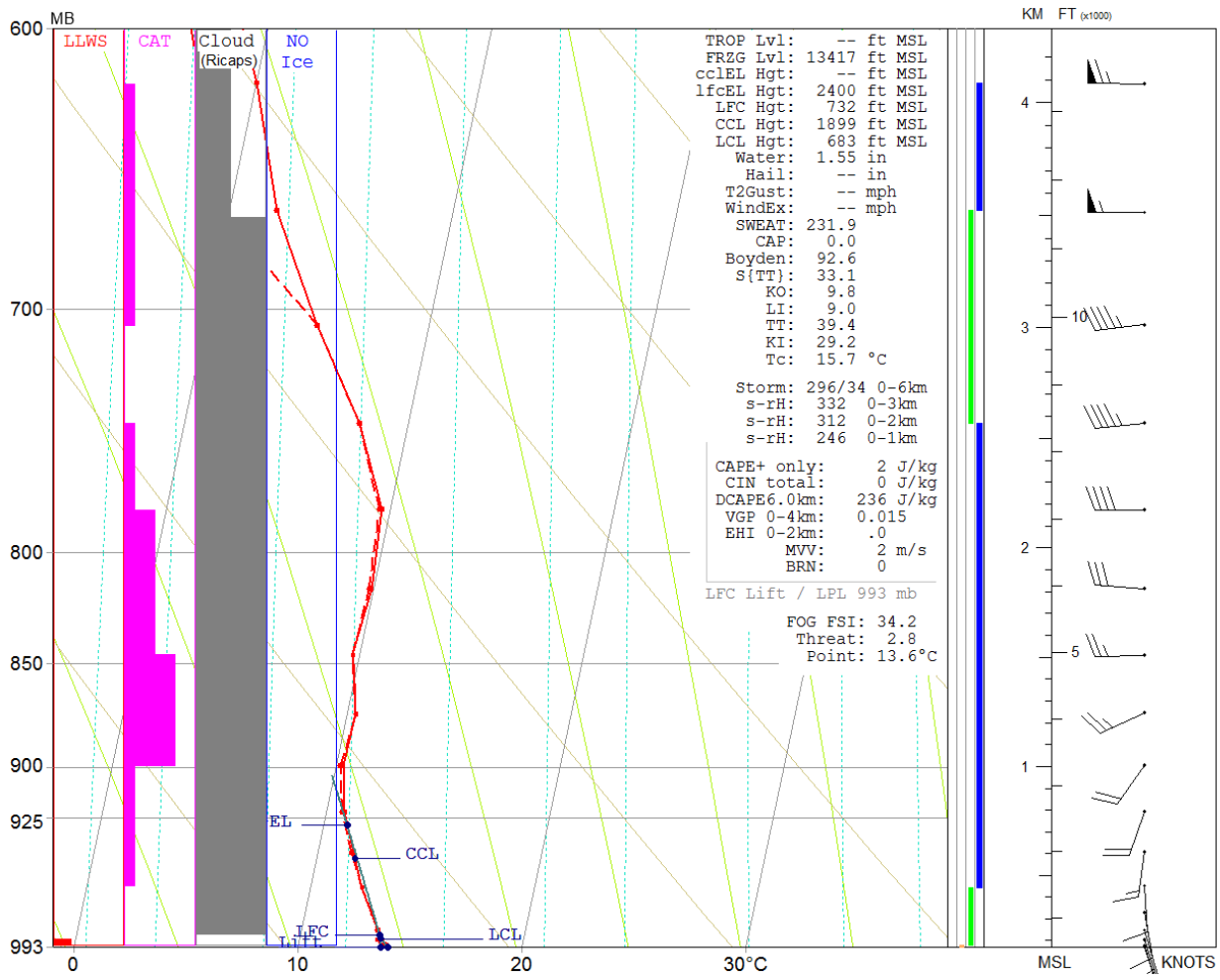


Figure 9 – 1700 PDT HRRR sounding

The 1700 PDT HRRR sounding indicated an alternating conditionally unstable and stable environment from the surface through 14,000 ft. RAOB identified the possibility of clouds between 95 ft agl through 14,000 ft. No areas of icing were indicated by RAOB below 14,000 ft.

The 1700 PDT HRRR sounding wind profile indicated a surface wind from 163° at 5 knots with the wind becoming westerly through 5,000 ft. By 5,000 ft the wind speed had increased to 25 knots and the wind continued to remain westerly while increasing in speed to 65 knots by 14,000 ft. RAOB indicated the possibility of light low-level wind shear (LLWS) between the surface and 100 ft agl. RAOB indicated the possibility of light to moderate clear-air turbulence in several layers between 2,000 ft and 14,000 ft.

5.0 Satellite Data

Visible and infrared data from the Geostationary Operational Environmental Satellite number 15 (GOES-15) data was obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System software. Visible and infrared imagery (GOES-15 bands 1 and 4) at wavelengths of 0.65 microns (μm) and 10.7 μm, respectively, were retrieved for the period. Satellite imagery surrounding the time of the accident, from 1500 PDT through 2000 PDT at approximately 15-minute intervals, were reviewed, and the closest images to the time of the accident are documented here.

Figures 10 and 11 present the GOES-15 visible imagery from 1700 and 1730 PDT at 3X magnification with the accident site highlighted with a red square. Inspection of the visible imagery indicated abundant cloud cover above the accident site at the accident time with the cloud cover moving from west to east. Figure 12 present the GOES-15 infrared imagery from 1730 PDT 6X magnification with the accident site highlighted with a red square. Inspection of the infrared imagery indicated cloud cover over the accident site. The lower brightness temperatures (green and blue colors; higher cloud tops) were located northwest of the accident site and east of the accident site. Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 1700 PDT HRRR sounding, the approximate cloud-top heights over the accident site were 23,000 ft at 1730 PDT. It should be noted these figures have not been corrected for any parallax error.

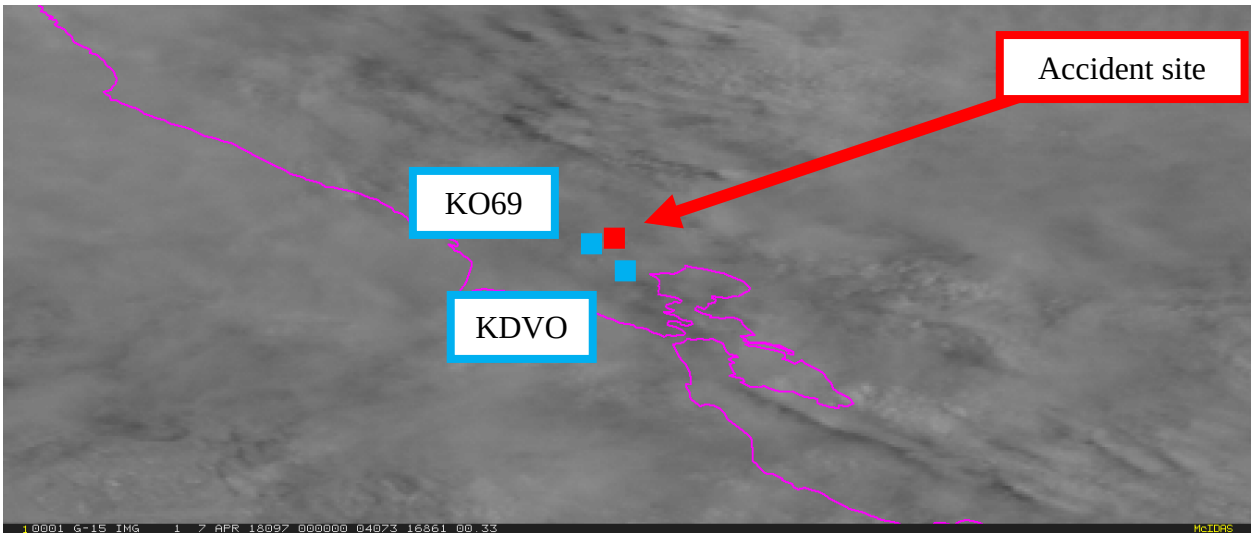


Figure 10 – GOES-15 visible image at 1700 PDT

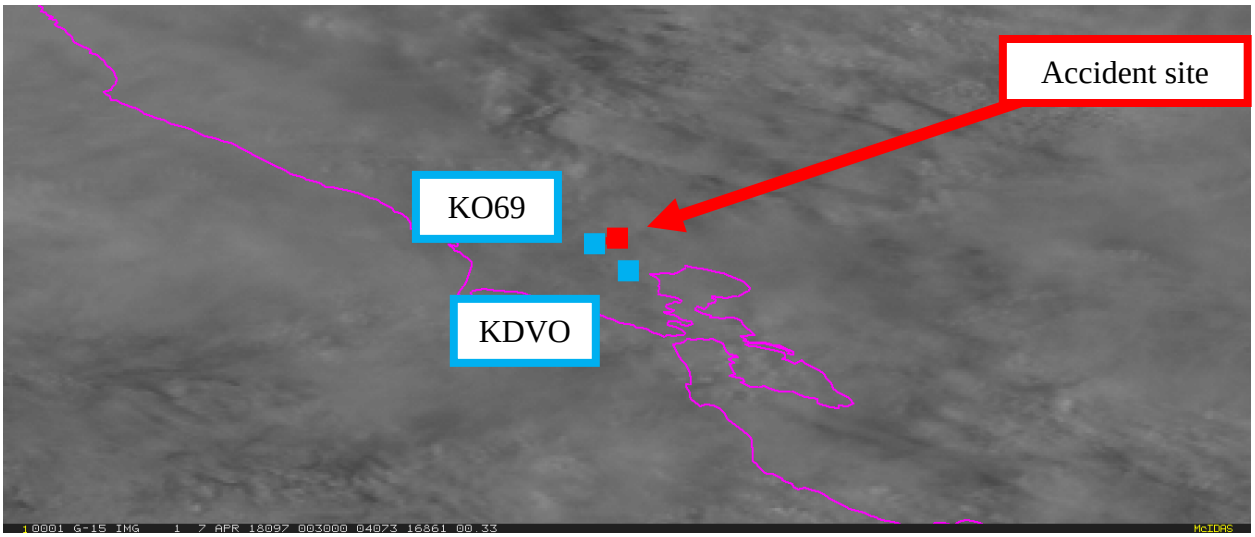


Figure 11 – GOES-15 visible image at 1730 PDT

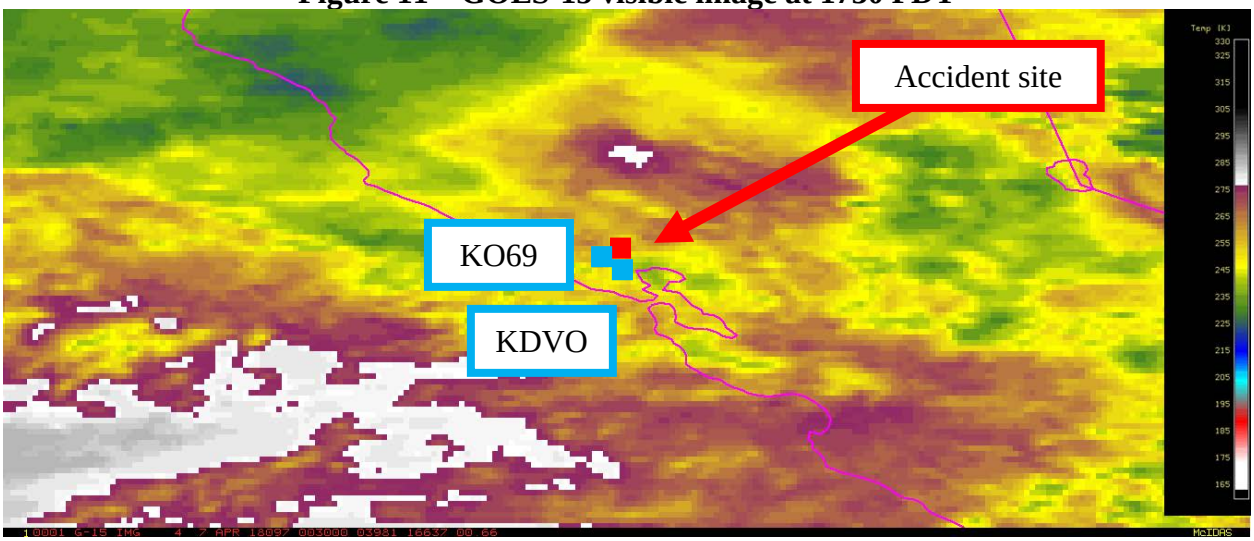


Figure 12 – GOES-15 infrared image at 1730 PDT

6.0 Radar Imagery Information

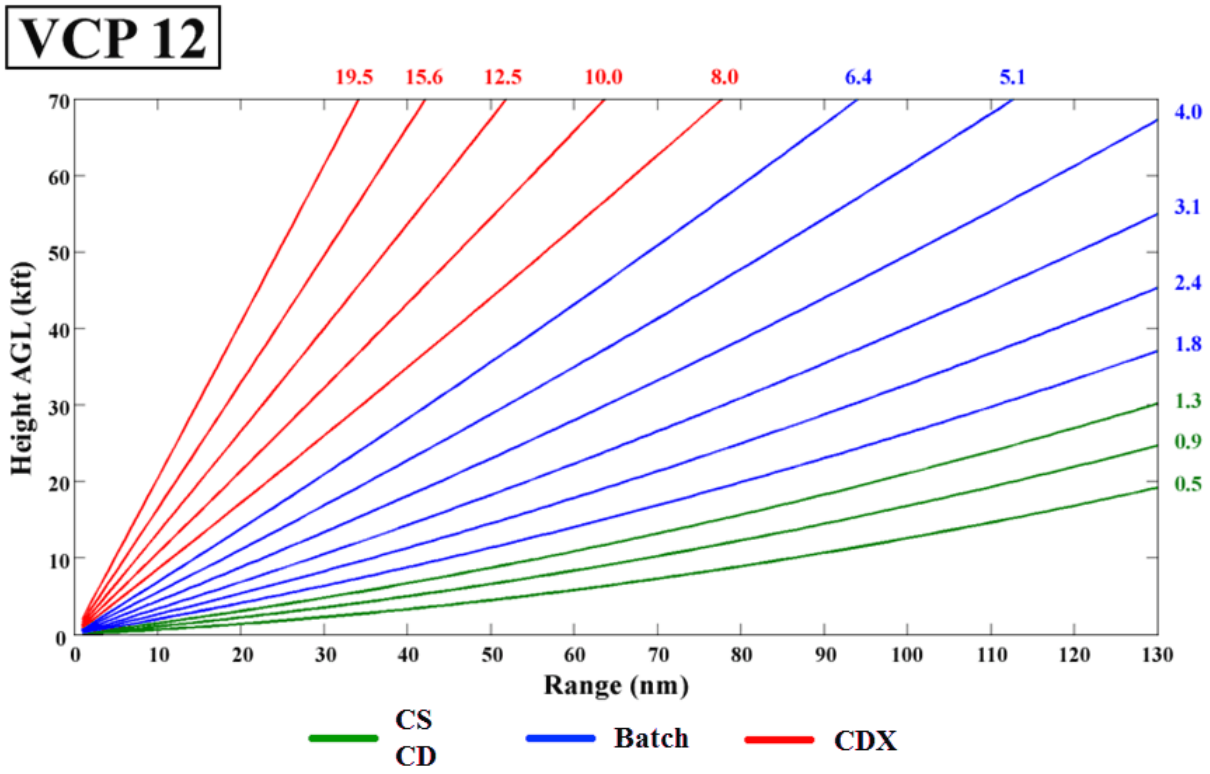
The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)[15] to the accident site was the Sacramento, California, radar (KDAX), which was located 44 miles east-northeast of the accident site at an elevation of 30 feet. Level II archive radar data was obtained from the NCEI utilizing the NEXRAD Data Inventory Search and displayed using the NOAA's Weather and Climate Toolkit software.

[15] 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.

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. 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 three common scanning strategies. The most common is where the radar makes 14 elevation scans from 0.5° to 19.5° every four and a half 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 KDAX WSR-88D radar was operating in the 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.



VCP-12 Precipitation Mode Scan Strategy[16]

[16] Contiguous Surveillance (CS)--The low Pulse Repetition Frequency (PRF) scan of the split cut. Gives a high R_{max} value to determine proper target location and intensity, but a low V_{max} value limits the velocities that can be measured. Contiguous Doppler (CD)--The high PRF scan of the split cut. Gives a low R_{max} value causing more range folded (multiple trip) echoes, but a high V_{max} value to get higher, more accurate velocity values.
Batch Mode – Uses alternating low and high PRFs on each radial for one full rotation at each elevation angle. The two resulting data sets (low PRF and high PRF) are combined to resolve range ambiguity. Used in the middle elevation angles.
W – With range unfolding (W)

6.2 Beam Height Calculation

Assuming standard refraction[17] of the WSR-88D radar beam, and considering a beamwidth[18] of 0.95°, the following table shows the approximate heights for the radar beam center, top and base for several antenna elevations over the accident site. These heights have been rounded to the nearest 10 feet.

ANTENNA ELEVATION	BEAM CENTER	BEAM BASE	BEAM TOP
0.5°	3,760 feet	1,590 feet	5,930 feet
0.9°	5,620 feet	3,450 feet	7,790 feet

Based on the radar beam height calculations, the 0.5° and 0.9° elevation scans depicted the conditions between 1,590 feet and 7,790 feet msl over the accident site.

6.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors[19] 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[20]), and is a general measure of echo intensity. FAA Advisory Circular AC 00-24C[21], "Thunderstorms," dated February 19, 2013, also defines the echo intensity levels and weather radar echo intensity terminology associated with those levels. For dBZ values less than 30 the weather radar echo intensity terminology should be "light." For dBZ values between 30 and 40, the terminology should be "moderate." "Heavy" terminology is used for dBZ values greater than 40 dBZ but less than 50 dBZ, inclusive. Finally, any dBZ values above 50 dBZ shall be described as "extreme." From the NWS, precipitation conditions at the surface can be inferred from VIP Levels described in the chart below:

WO – Without range unfolding (WO)

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

[18] Beamwidth - the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum value.

[19] 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.

[20] 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.

[21] https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1020774

- VIP 1 (Level 1, 18-30 dBZ) - Light precipitation
- VIP 2 (Level 2, 30-38 dBZ) - Light to moderate rain.
- VIP 3 (Level 3, 38-44 dBZ) - Moderate to heavy rain.
- VIP 4 (Level 4, 44-50 dBZ) - Heavy rain
- VIP 5 (Level 5, 50-57 dBZ) - Very heavy rain; hail possible.
- VIP 6 (Level 6, >57 dBZ) - Very heavy rain and hail; large hail possible.

6.4 Base Reflectivity and Lightning Data

Figures 13 and 15 present the KDAX WSR-88D base reflectivity images for the 0.5° elevation scans initiated at 1712 and 1715 PDT, respectively. Figures 14 and 16 present the KDAX WSR-88D base reflectivity images for the 0.9° elevation scans initiated at 1713 and 1716 PDT, respectively. These radar images have a resolution of 0.5° X 250 m. There were no reflectivity targets above the accident site between 1712 and 1716 PDT. There were reflectivity values between -5 and 20 dBZ above the accident site between 1648 and 1705 PDT (attachments 1 and 2). The light precipitation values (section 6.3) were travelling from west to east; moving from the Pacific Ocean and west coast of California onshore and across into the central valley of California between 1648 and 1721 PDT (attachments 1 and 2). There were no lightning strikes around the accident site at the accident time.[22]

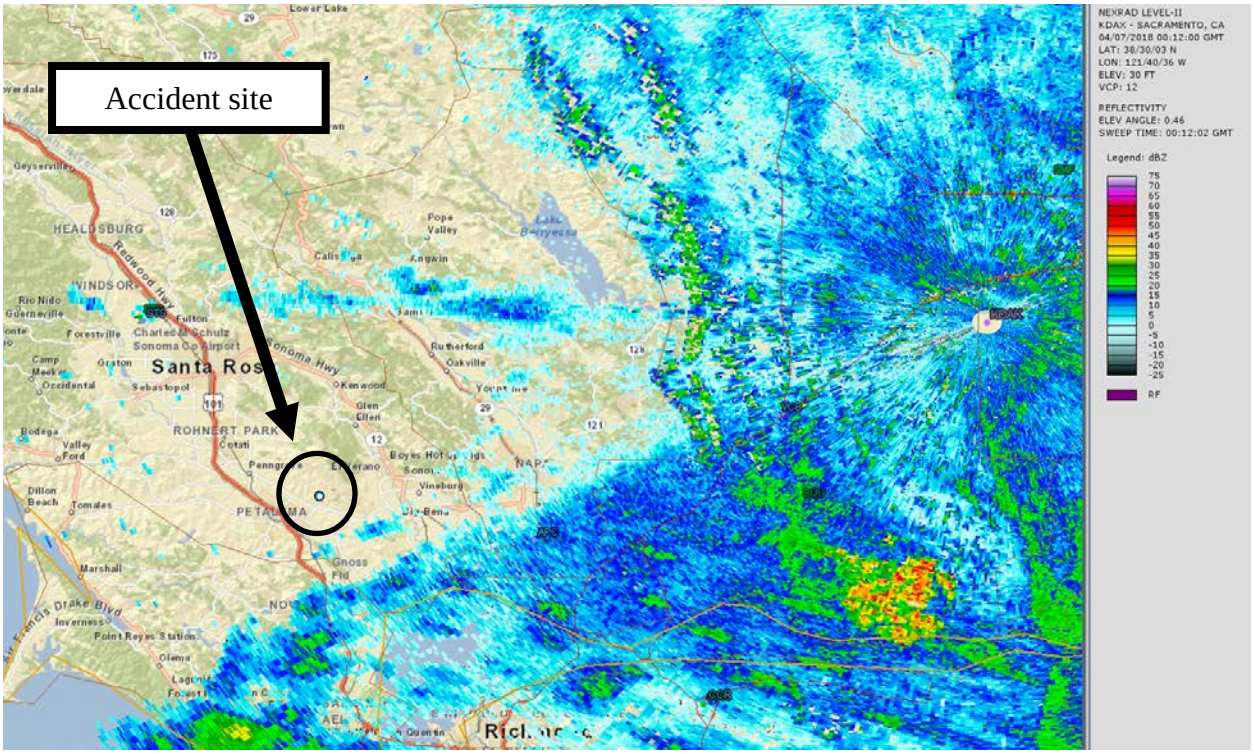


Figure 13 – KDAX WSR-88D reflectivity for the 0.5° elevation scan initiated at 1712 PDT with the accident site marked with black circle

[22] A review of data from the Earth Networks Total Lightning network was done.

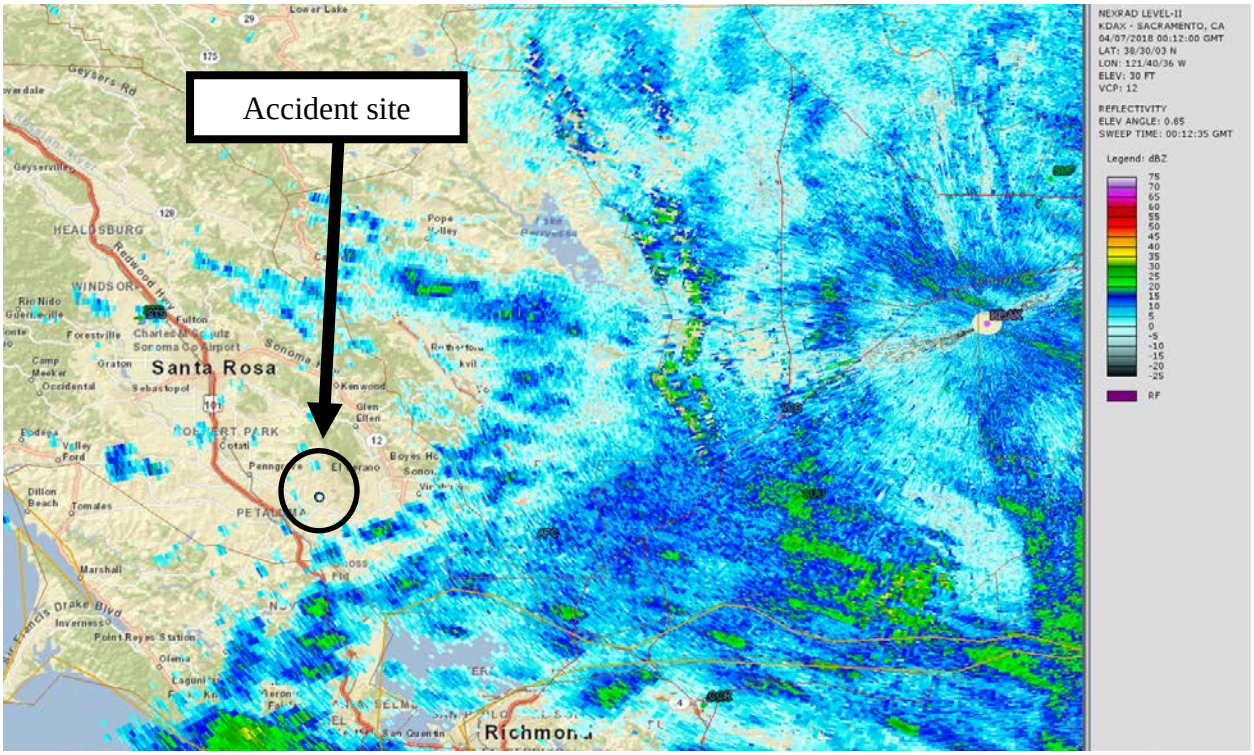


Figure 14 – KDAX WSR-88D reflectivity for the 0.9° elevation scan initiated at 1713 PDT with the accident site marked with black circle

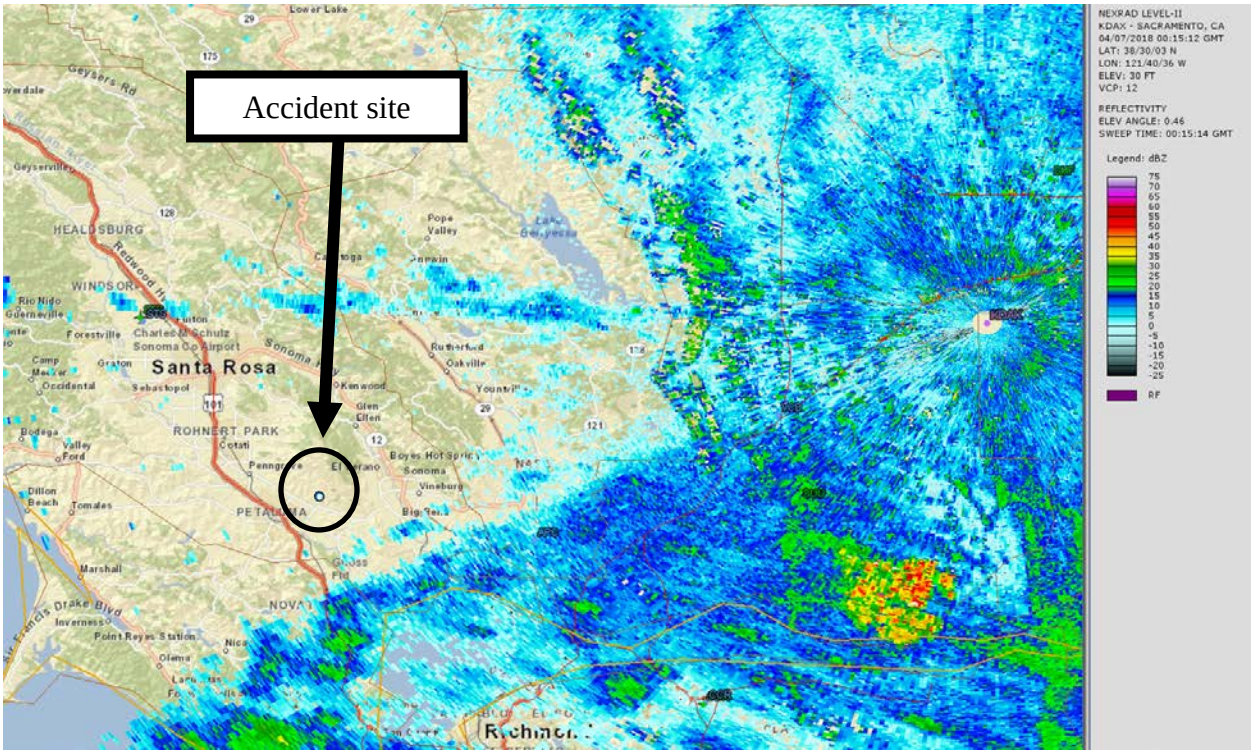


Figure 15 – KDAX WSR-88D reflectivity for the 0.5° elevation scan initiated at 1715 PDT with the accident site marked with black circle

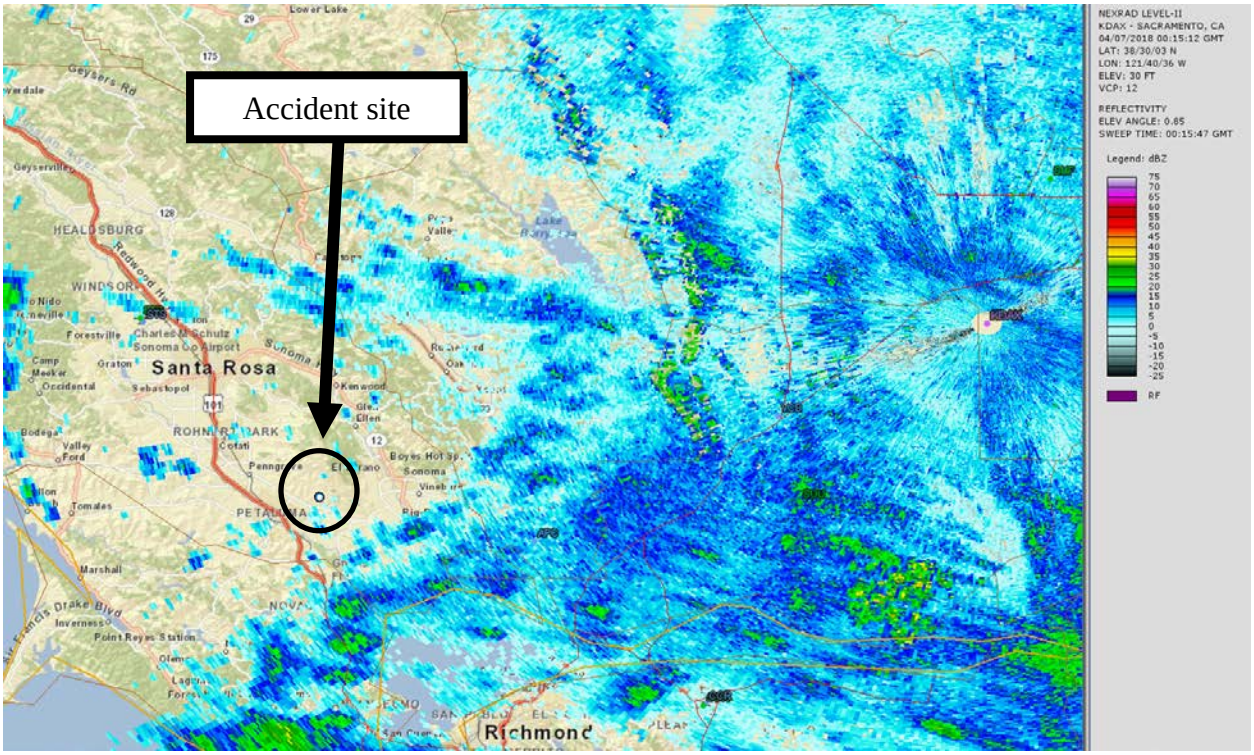


Figure 16 – KDAX WSR-88D reflectivity for the 0.9° elevation scan initiated at 1716 PDT with the accident site marked with black circle

7.0 Pilot Reports[23]

All PIREPs within 100 miles of the accident site from about two hours prior to the accident time to about two hours after the accident time were reviewed. Only PIREPs for below FL180[24] are provided here:

SFO UA /OV SFO/TM 2242/FLUNKN/TP UNKN/SK OVC020/RM 6NM FINAL SFO/ZOA CWSU AWC-WEB/

APC UA /OV 4SM S/TM 2304/FL005/TP BE9L/SK OVC004

HWD UA /OV 4 SE/TM 2308/FL022/TP BE20

KSUU UA /OV KSUU210001/TM 2314/FLUNKN/TP E6/SK OVC007-TOPUNKN/RM DURD

ARP UAL58 3820N 12123W 2315 F110 TB MOD RM B773 OV MOGEE MDT TURB ON CLIMB BELOW FL110

SFO UUA /OV SFO010002/TM 2338/FL019/TP A320/RM LLWS +/-15KTS ON FINAL DURD RY19 SFO

HWD UA /OV KHWD/TM 0125/FL009/TP GALX/SK OVC009/RM BASES 009

[23] Only pilot reports with the World Meteorological Organization header UBCA** identifier were considered.
[24] Flight Level – A Flight Level (FL) is a standard nominal altitude of an aircraft, in hundreds of ft. 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.

Routine pilot report (UA), San Francisco International Airport, California (SFO); Over – SFO; Time – 1542 PDT (2242Z); Altitude – Unknown; Type aircraft – Unknown; Sky – Overcast skies at 2,000 ft; Remarks – 6 miles final into SFO.

Routine pilot report (UA), Napa County Airport, California (APC); Over – 4 miles south; Time – 1604 PDT (2304Z); Altitude – 500 ft; Type aircraft – Beech 90 King Air; Sky – Overcast skies at 400 ft.

Routine pilot report (UA), Hayward Executive Airport, California (HWD); Over – 4 miles southeast; Time – 1608 PDT (2304Z); Altitude – 2,200 ft; Type aircraft – Beech 200 Super King Air.

Routine pilot report (UA), Travis Air Force Base, California (SUU); Over – 1 mile from SUU on the 210° radial; Time – 1614 PDT (2314Z); Altitude – Unknown; Type aircraft – Boeing E-6; Sky – Overcast skies at 700 ft with unknown tops; Remarks – During descent.

Routine pilot report (UA) from United Flight 58 over 38.20° N, 121.23° W; Time – 1615 PDT (2315Z); Altitude – 11,000 ft; Type aircraft – Boeing 777-300; Turbulence – Moderate; Remarks – Moderate turbulence on climb below 11,000 ft.

Urgent pilot report (UUA), SFO; Over – 2 miles from SFO on the 010° radial; Time – 1638 PDT (2338Z); Altitude – 1,900 ft; Type aircraft – Airbus A320; Remarks – LLWS +/- 15 knots on final during descent into runway 19 at SFO.

Routine pilot report (UA), HWD; Over – HWD; Time – 1825 PDT (0125Z); Altitude – 900 ft; Type aircraft – Gulfstream G200; Sky – Overcast skies at 900 ft; Remarks – Bases at 900 ft.

8.0 SIGMET and CWSU Advisories

There were no convective or non-convective Significant Meteorological Information (SIGMET) advisories valid for the accident site at the accident time.

There was no Center Weather Service Unit (CWSU) Center Weather Advisories (CWA) or Meteorological Impact Statements (MIS) valid at the accident site at the accident time.

A CWA was issued by the Oakland Air Route Traffic Control Center (ZOA) CWSU at 1551 through 1751 PDT with the CWA valid for an area 10 miles south of the accident site. The CWA warned of an area of occasional moderate and isolated severe turbulence between the surface and 5,000 ft with LLWS possible:

```
FAUS21 KZOA 062251

ZOA1 CWA 062251

ZOA CWA 104 VALID UNTIL 070051

FROM 25NE OAK-30WSW MOD-35SSE OAK-15SSE PYE-25NE OAK

AREA OCNL MOD ISOL SEV TURB. SFC-050. LLWS POSS. ZOA CWSU

=
```

9.0 AIRMETs

There were Airmen's Meteorological Information (AIRMET) Sierra and Tango advisories that were valid for the accident site at the accident time. The AIRMETs were issued at 1345 PDT and warned of IFR conditions due to precipitation and mist, mountain obscuration conditions due to clouds, precipitation, and mist, and moderate turbulence conditions below 10,000 ft. The advisories were as follows:

WAUS46 KKCI 062045
WA6S
-SFOS WA 062045
AIRMET SIERRA UPDT 5 FOR IFR AND MTN OBSCN VALID UNTIL 070300
.
AIRMET IFR...WA OR AND CSTL WTRS
FROM 70ESE YDC TO 50ESE YKM TO 60S YKM TO 40SW BTG TO 20S HQM TO
20NNW TOU TO 70ESE YDC
CIG BLW 010/VIS BLW 3SM BR. CONDS ENDG 00-03Z.
.
AIRMET IFR...OR CA AND CSTL WTRS
FROM 90SW EUG TO 30NNE LKV TO 40SE LKV TO 40SSW FMG TO 60NNE CZQ
TO 50SSE SNS TO 60W SNS TO 60SSW FOT TO 90SW EUG
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG BYD 03Z THRU 09Z.
.
AIRMET IFR...CA AND CSTL WTRS
FROM 40SSE SNS TO 30W RZS TO 40SSW LAX TO 50SSW MZB TO 150SW MZB
TO 140SSW SNS TO 40SSE SNS
CIG BLW 010/VIS BLW 3SM BR. CONDS DVLPG 00-03Z. CONDS CONTG BYD
03Z THRU 09Z.
.
AIRMET MTN OBSCN...WA OR
FROM YDC TO DSD TO 20SSW ONP TO TOU TO YDC
MTNS OBSC BY CLDS. CONDS ENDG 00-03Z.
.
AIRMET MTN OBSCN...WA OR ID MT WY UT
FROM 90E YDC TO 30SSW YQL TO 70SSW LWT TO BOY TO 40N MTU TO SLC
TO 30NNE BOI TO BKE TO 90E YDC
MTNS OBSC BY CLDS. CONDS CONTG BYD 03Z THRU 09Z.
.
AIRMET MTN OBSCN...OR CA ID NV
FROM 20SSW ONP TO DSD TO 20S BOI TO 30SE TWF TO 20ESE ELY TO
60NW RZS TO 20WSW SNS TO ENI TO FOT TO 70WNW OED TO 20SSW ONP
MTNS OBSC BY CLDS/PCPN/BR. CONDS CONTG BYD 03Z THRU 09Z.
.

OTLK VALID 0300-0900Z
AREA 1...MTN OBSCN WA OR CA ID NV UT
BOUNDED BY HQM-20SSE PDT-80S LKT-20ESE PIH-20SSE SLC-20NNW ILC-50WNW RZS-30S OAK-ENI-FOT-HQM
MTNS OBSC BY CLDS/PCPN/BR. CONDS CONTG THRU 09Z.
.
AREA 2...MTN OBSCN CA
BOUNDED BY RZS-30SW HEC-60SSE TRM-20S MZB-20WNW LAX-RZS
MTNS OBSC BY CLDS. CONDS DVLPG 03-06Z. CONDS CONTG THRU 09Z.
....

WAUS46 KKCI 062045
WA6T
-SFOT WA 062045
AIRMET TANGO UPDT 3 FOR TURB AND LLWS VALID UNTIL 070300
.
AIRMET TURB...OR CA AND CSTL WTRS
FROM 40SE LKV TO 40SSW FMG TO EED TO 20ESE BZA TO 50NE LAX TO 110WSW FOT TO 130WNW FOT TO 40SE LKV
MOD TURB BTN FL270 AND FL430. CONDS CONTG BYD 03Z THRU 09Z.
.
AIRMET TURB...OR CA NV
FROM 60SE EUG TO 40E LKV TO 70WSW ELY TO 70W ILC TO 40NE HEC TO 60SW BTY TO 20NE EHF TO 30NNW SAC TO 60SE EUG
MOD TURB BLW FL180. CONDS CONTG BYD 03Z THRU 09Z.
.
AIRMET TURB...OR CA AND CSTL WTRS
FROM 50W ONP TO 60SE EUG TO 20NNW SAC TO 20NE EHF TO 60SW BTY TO 40NE HEC TO 20W EED TO BZA TO 40SSW MZB TO 50WNW RZS TO 130SW PYE TO 140WSW FOT TO 130W ONP TO 50W ONP
MOD TURB BLW 100. CONDS CONTG BYD 03Z THRU 09Z.
.
AIRMET TURB...WA OR CA ID MT WY NV UT CO NM AND CSTL WTRS
FROM 30NW HVR TO 70NNW RAP TO 70SW RAP TO BFF TO GLD TO 50W LBL TO 30ESE TBE TO 70ESE REO TO 130WNW FOT TO 160WSW ONP TO 140W TOU TO 30NW HVR
MOD TURB BTN FL200 AND FL410. CONDS CONTG BYD 03Z THRU 09Z.
.
LLWS POTENTIAL...CA NV
BOUNDED BY 20NNW FMG-20ENE OAL-30E EHF-30E SAC-60ESE RBL-20NNW FMG
LLWS EXP. CONDS CONTG BYD 03Z THRU 09Z.
.
LLWS POTENTIAL...OR CA AND CSTL WTRS
BOUNDED BY 60SSW ONP-40SE EUG-40NW LKV-30SSW LKV-20W ENI-20WSW FOT-60SSW ONP
LLWS EXP. CONDS CONTG BYD 03Z THRU 09Z.
.
OTLK VALID 0300-0900Z
AREA 1...TURB OR CA ID WY NV UT CO AZ NM AND CSTL WTRS
BOUNDED BY 50NE LKV-GLD-50W LBL-30ESE TBE-INK-ELP-50SSE SSO-20SW PHX-50NE LAX-140WNW FOT-50NE LKV
MOD TURB BTN FL270 AND FL430. CONDS CONTG THRU 09Z.
.
AREA 2...TURB OR CA NV
BOUNDED BY 40SE BTG-80SW BKE-60WSW ELY-30ESE HEC-30NNE LAX-20WSW

SAC-40SSE EUG-40SE BTG
MOD TURB BLW FL180. CONDS CONTG THRU 09Z.
.
AREA 3...TURB WA OR CA AND CSTL WTRS
BOUNDED BY 20ENE TOU-40SE BTG-40SSE EUG-20WSW SAC-30NNE LAX-30ESE HEC-20WSW BZA-20SE MZB-120WSW PYE-140WSW FOT-140W TOU-20ENE TOU
MOD TURB BLW 100. CONDS CONTG THRU 09Z.
....

10.0 Graphical Forecasts for Aviation

The Graphical Forecasts for Aviation (GFA) products made available before the accident time and before the accident flight departed, indicated likely (greater than 60 percent chance) moderate to heavy rain and rain showers along the west coast of California including the accident site after 1400 PDT (attachment 3). The GFA products also indicated likely visibilities of less than 3 statute miles and an AIRMET Sierra for IFR conditions for the accident site. The GFA cloud forecast indicated overcast ceilings at 1,500 ft with clouds tops at 13,000 ft and an AIRMET Sierra for mountain obscuration (attachment 3).

11.0 Terminal Aerodrome Forecast

Charles M Schulz - Sonoma County Airport (KSTS) located 18 miles northwest of the accident site at an elevation of 129 ft, was the closest site with a NWS Terminal Aerodrome Forecast (TAF). The KSTS TAF valid at the accident time was issued at 1639 PDT and was valid for a 24-hour period beginning at 1700 PDT. The 1639 PDT TAF for KSTS was as follows:

TAF KSTS 062339Z 0700/0724 **18008KT 2SM RA BR BKN005 OVC012**
FM070300 17005KT 4SM RA BR BKN004 OVC010
TEMPO 0708/0711 18018G28KT 3/4SM +RA BR OVC008
FM071100 24011KT 2SM -SHRA BR OVC014
FM071700 26016G24KT P6SM VCSH SCT008 BKN035=

Between 1700 and 2000 PDT the TAF expected a wind from 180° at 8 knots, 2 miles visibility, moderate rain, mist, a broken ceiling at 500 ft agl, and overcast skies at 1,200 ft agl.

12.0 NWS Area Forecast Discussion

The NWS Office responsible for the San Francisco Bay Area, California, issued the following Area Forecast Discussion (AFD) at 1334 PDT (closest AFD to the accident time with an aviation section). The aviation section of the AFD discussed light to moderate rain throughout the day with the visibilities and ceilings dropping during the rainy periods and widespread IFR conditions:

391
FXUS66 KMTR 062034
AFDMTR

Area Forecast Discussion
National Weather Service San Francisco Bay Area

134 PM PDT Fri Apr 6 2018

.SYNOPSIS...A classic atmospheric river will impact the Bay Area today into Saturday bringing periods of heavy rainfall and locally gusty winds. Drying condition will develop Sunday and Monday. Rain chances return Tuesday.

&&

.DISCUSSION...as of 1:34 PM PDT Friday...Radar and surface observations this early afternoon show widespread light to moderate rain from the San Francisco Bay Area and points north as the well- advertised atmospheric river continues to impact the area. Satellite-derived Total Precipitable Water imagery shows the long, narrow plume of moisture extending southwestward to the Hawaiian Islands; truly a "Pineapple Express" atmospheric river. The latest 12Z GFS indicates the core of the AR having an integrated vapor transport max of over 1000 kg/m/s, with the maximum forecast value over the San Francisco Bay Area in the 800-900 kg/m/s during the peak of the event, expected later tonight. Rain totals through midday have exceeded 1.5 to 2 inches in portions of the North Bay Valleys, with some of the southwest-facing slopes of Sonoma County already passing 3 inches. There have been a few reports of urban/small stream flooding in associated with some of the more moderate to heavy rain rates observed earlier around noon. Consequently, a Flood Advisory has been posted for parts of Sonoma County through 2 pm PDT.

Through the rest of the day expect periods of rain/no rain as we remain in the warm sector of the system, ahead of the cold front. It's important to emphasize that even though it may have stopped raining this afternoon at some locations, there is plenty of moisture yet to come. Heavier rain is expected to arrive later in the afternoon and evening, beginning first in the North Bay, as the cold front begins to approach the area. The renewed opportunity of moderate to heavy rain will then push south and eastward through the night as the cold front passes through the San Francisco Bay Area. It is along this boundary when we would expect the heaviest rain rates to fall. With the continued moderate to heavy rain rates expected overnight, a Flood Watch remains in effect for the North Bay Mountains, North Bay Valleys, as well as the Santa Cruz Mountains until 11 am PDT Saturday.

Storm total rain amounts will vary from location to location. The highest totals are expected to be in the North Bay Mountains, particularly for the south- and west-facing slopes, where rain accumulations are expected to exceed 4 to 6 inches. As mentioned in previous discussions, it's quite conceivable isolated locations in the North Bay Mountains could surpass 8 inches. Most urban areas in the North Bay along the US Hwy 101 corridor can expect around 3 to 4 inches storm total rain. Rain amounts will decrease south of the Golden Gate, but regardless, impressive rain totals for any event in April. In fact, the entire month of April normally receives 1.46 inches of rain at the Downtown San Francisco station. This single atmospheric river is expected to give San Francisco above normal rainfall for the month.

By Saturday night into Sunday, the core of the heavy rain should have exited the region to the east and southeast. Expect a drying trend Sunday and Monday followed by some passing showers or light rain midweek as system clip the area from the north.

Overall, abundant rain is expected over the next 24 hours for the Bay Area and especially North Bay. Debris flows may become a concern as the higher rain rates move over the burn scars. Isolated rock falls and small areas of mudslides are likely in steeper terrain. These issues are typical during any periods of heavy rain. Wind is not expected to be an issue, but with buds and leafs on trees there may be more surface area for the wind to grab. Thus some localized power outages are possible due to downed branches or isolated trees. An unsettled pattern remains in place through next week.

&&

.AVIATION...As of 10:40 AM PDT Friday...For 18z Tafs. Very moist air mass being advected across region by strong late season storm system. Expect light to moderate rain through most of the day, with brief periods of heavy rain. Visby and cigs will drop with the deeper moisture surges through the day. Mixed bag of flight rules, with mixed VFR/MVFR this morning as main band of moisture remains farther north. MVFR will become more widespread with periods of IFR posbl as main moisture band transitions southward through the next 24 hours. Southerly winds will occasionally increase to around 20 kt sust with gusts up to 30 kt, but these winds will not prevail for long durations.

Vicinity of KSFO...MVFR conditions will dominate the TAF. Light to moderate, occasionally heavy, rain will bring wet runways. Visby and cig will drop with the deepest moisture surges, which are anticipated later today and tonight. Winds will slowly veer from southeast to southwest through the TAF, increasing and becoming gusty later tonight.

SFO Bridge Approach...Similar to SFO.

Monterey Bay Terminals...VFR this morning as bulk of moisture and energy remains farther northward. Deteriorating cigs/visbys as main moisture plume shifts southward later today and tonight. Light to moderate, occasionally heavy rain, tonight into early Saturday will bring wet runways.

&&

.MARINE...as of 10:35 AM PDT Friday...A strong late season storm system will bring moderate to locally strong south to southwest winds and steady rain to the coastal waters through the day. Winds will veer west to northwest through the day tomorrow in the wake of a cold front passing through the waters. West swells will increase and create hazardous seas through the next couple of days.

&&

.MTR WATCHES/WARNINGS/ADVISORIES...
.Tngt...Flood Watch...CAZ505>507-512
SCA...SF Bay
SCA...Pt Reyes to Pigeon Pt 0-10 nm
SCA...Pigeon Pt to Pt Pinos 0-10 nm
SCA...Pt Pinos to Pt Piedras Blancas 0-10 nm
SCA...Pt Arena to Pigeon Pt 10-60 nm
SCA...Pigeon Pt to Pt Piedras Blancas 10-60 nm
SCA...Pt Arena to Pt Reyes 0-10 nm until 3 AM

&&

$$

13.0 Winds and Temperature Aloft Forecast

The NWS 1304 PDT Winds and Temperature Aloft forecast valid for the closest point to the accident site is included below:

```
FBUS31 KWNO 062004
FD1US1
DATA BASED ON 061800Z
VALID 070000Z   FOR USE 2000-0300Z. TEMPS NEG ABV 24000

FT  3000    6000    9000   12000   18000   24000  30000  34000  39000

SFO 2539 2743+12 2740+07 2849+03 2756-09 2756-20 277235 277845 277357
```

The accident site was closest to the San Francisco, California, (SFO) forecast point. The 1304 PDT SFO forecast for use between 1300 and 2000 PDT indicated a wind at 3,000 ft from 250° at 39 knots, a wind at 6,000 ft from 270° at 43 knots with a temperature of 12° C, and a wind at 9,000 ft from 270° at 40 knots with a temperature of 7° C.

14.0 Pilot Weather Briefing

A search of official weather briefing sources such as contract Automated Flight Service Station (AFSS) provider Leidos weather briefings and the Direct User Access Terminal Service (DUATS) was done and the accident pilot did not request a weather briefing through Leidos. However, the accident pilot received weather briefing information from DUATS at 1900 PDT on April 5 and at 1040 PDT on April 6. The 1040 PDT April 6 DUATS weather briefing contained all the standard weather information including current METARs, SPC day 1 outlook, TAFs along the route, AIRMETs Sierra and Tango valid along the route and adverse conditions forecast, winds aloft forecast, and PIREPs (attachment 4). In addition, the accident pilot did contact Leidos at 1657 PDT to request an IFR clearance from O69 to Fallbrook, California, (L18, the intended destination). For more information please see attachments 5, 6, and 7.

A search of archived data from ForeFlight was done and the accident pilot did not request a weather briefing or weather information via ForeFlight. It is unknown if the accident pilot checked or received any additional weather information before or during the accident flight.

15.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on April 6, 2018, indicated the following:

SUN	
Begin civil twilight	0621 PDT
Sunrise	0647 PDT
Sun transit	1312 PDT
Accident	***1715 PDT***
Sunset	1938 PDT
End civil twilight	2005 PDT

E. LIST OF ATTACHMENTS

Attachment 1 – Animation of KDAX WSR-88D reflectivity for the 0.5° elevation scan initiated between 1648 and 1721 PDT

Attachment 2 – Animation of KDAX WSR-88D reflectivity for the 0.9° elevation scan initiated between 1648 and 1721 PDT

Attachment 3 – GFA products available before the accident flight for around the accident time

Attachment 4 – DUATS weather briefing from 1238 PDT

Attachment 5 – DUATS Flight Plan for N9133Z from April 5 and 6

Attachment 6 – Timeline summary of discussions between accident pilot and Leidos

Attachment 7 – Audio of discussions between accident pilot and Leidos

Submitted by:

_____

Paul Suffern
Senior Meteorologist

THIS PAGE INTENTIONALLY BLANK