

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



WPR23FA173

METEOROLOGY

Specialist's Factual Report

August 1, 2023

TABLE OF CONTENTS

A. ACCIDENT.....	3
B. METEOROLOGY SPECIALIST	3
C. SUMMARY	3
D. DETAILS OF THE INVESTIGATION	3
E. FACTUAL INFORMATION.....	4
1.0 SYNOPTIC CONDITIONS	4
1.1 Surface Analysis Chart.....	4
1.2 Upper Air Charts	5
2.0 SURFACE OBSERVATIONS	10
2.1 Big Bear City, California	10
2.2 San Bernardino, California.....	12
2.3 Victorville, California.....	13
2.4 Palm Springs, California.....	13
2.5 NWS Aviation Weather Center METAR Display.....	14
3.0 SOUNDING.....	15
4.0 SATELLITE IMAGERY	17
5.0 PILOT REPORTS	20
6.0 WEATHER RADAR IMAGERY	21
7.0 NWS FORECASTS AND ADVISORIES.....	21
7.1 Terminal Aerodrome Forecast.....	22
7.2 Area Forecast Discussion.....	22
7.3 Wind Advisory	24
7.4 Winds and Temperatures Aloft.....	25
7.5 Graphic Forecast for Aviation.....	25
7.6 Inflight Weather Advisories	27
8.0 WEATHER BRIEFING INFORMATION	29
9.0 ASTRONOMICAL CONDITIONS	30
10.0 MOUNTAIN WAVE REFERENCES.....	30
11.0 WEATHER RESEARCH AND FORECAST MODEL.....	35
F. ATTACHMENTS.....	41

A. ACCIDENT

Location: Big Bear City, California
Date: May 1, 2023
Time: 1402 Pacific daylight time (PDT)
2102 coordinated universal time (UTC)
Airplane: Beech A36; Registration: N2038Y

B. METEOROLOGY SPECIALIST

Donald Eick
Senior Meteorologist
National Transportation Safety Board
Office of Aviation Safety
Washington, DC

C. SUMMARY

On May 01, 2023, about 1402 Pacific daylight time (PDT), a Beech A36 Bonanza, N2038Y, was substantially damaged when it was involved in an accident near Big Bear City, California. The pilot and two passengers were fatally injured. The airplane was operated as a Title 14 Code of Federal Regulations (CFR) Part 91 personal flight.

The flight originated and departed from French Valley Airport (F70), Murietta/Temecula, California about 1122 PDT, landed at Corona Municipal Airport (KAJO), Corona, California about 1136 PDT. After picking up another passenger, the aircraft then departed KAJO at 1332 PDT for Big Bear City Airport (KL35).

D. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's Senior Meteorologist was not on scene for this investigation and conducted the meteorology phase of the investigation remotely, collecting data from official National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sources including the Weather Prediction Center (WPC) and the National Center for Environmental Information (NCEI). This report documents the general weather products and forecasts over the region during the period and the pertinent meteorological parameters related to the accident. All times are reported as PDT based upon the 24-hour clock, local time is -7 hours from UTC, and UTC=Z. NWS airport and weather station identifiers use the standard International Civil Aviation Organization 4-letter station identifiers versus the

International Air Transport Association 3-letter identifiers, which deletes the initial country code designator "K" for U.S. airports. Directions are referenced to true north and distances in nautical miles. Heights are in feet (ft) above mean sea level (msl) unless otherwise noted. Visibility is in statute miles and fractions of statute miles.

The accident site is based on the wreckage at the intersection of North Paradise Way and Maltby Boulevard at approximately latitude 34.266366°N and longitude 116.84013°W, located about 0.50 mile from the touchdown zone of runway 26 at KL35 at an elevation of about 6,740 ft.

E. FACTUAL INFORMATION

1.0 Synoptic Conditions

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 WPC located in College Park, Maryland. These are the base products used in describing weather features and in the creation of forecasts and warnings. Reference to these charts can be found in the Federal Aviation Administration (FAA) "Aviation Weather Handbook", FAA-H-8083-28¹.

1.1 Surface Analysis Chart

The southwest section of the NWS Surface Analysis Chart for 1400 PDT is included as figure 1 with the approximate accident site marked by a red star. The chart depicted a low-pressure system with a central pressure of 995-hectopascals (hPa)² over central California near the Nevada border to the north of the accident site along a frontal wave. A stationary front extending southeastward from the low across Nevada, then southward through southeastern California, southwestern Arizona and into Mexico. A trough³ also extended south and southwestward from the low into southern California to the northwest of the accident site.

The station model for Big Bear depicted a westerly wind at 10 knots, clear skies, a temperature of 55° F, and a dew point temperature of 9° F. While stations to the southwest through west depicted westerly winds of 10 to 15 knots, broken to overcast

¹ <https://www.faa.gov/regulationspolicies/handbooksmanuals/aviation/faq-h-8083-28-aviation-weather-handbook>

² Hectopascals (hPa) is the standard unit for pressure and is interchangeable with the former term millibar (mb) with the same units. The International Standard Atmosphere (ISA) is based on a sea-level pressure of 1013.25-hPa at 15° Celsius (C) or 59° Fahrenheit (F).

³ A trough is an elongated area of low-pressure and is typically associated with a wind shift, general convergence, and rising motion which enhances the likelihood of clouds and/or precipitation.

clouds, with temperatures in the low 60's °F, with temperature-dew point spreads of 4°F or less. To the northwest through northeast and south of Big Bear the station models depicted winds of 20 knots with clear skies.

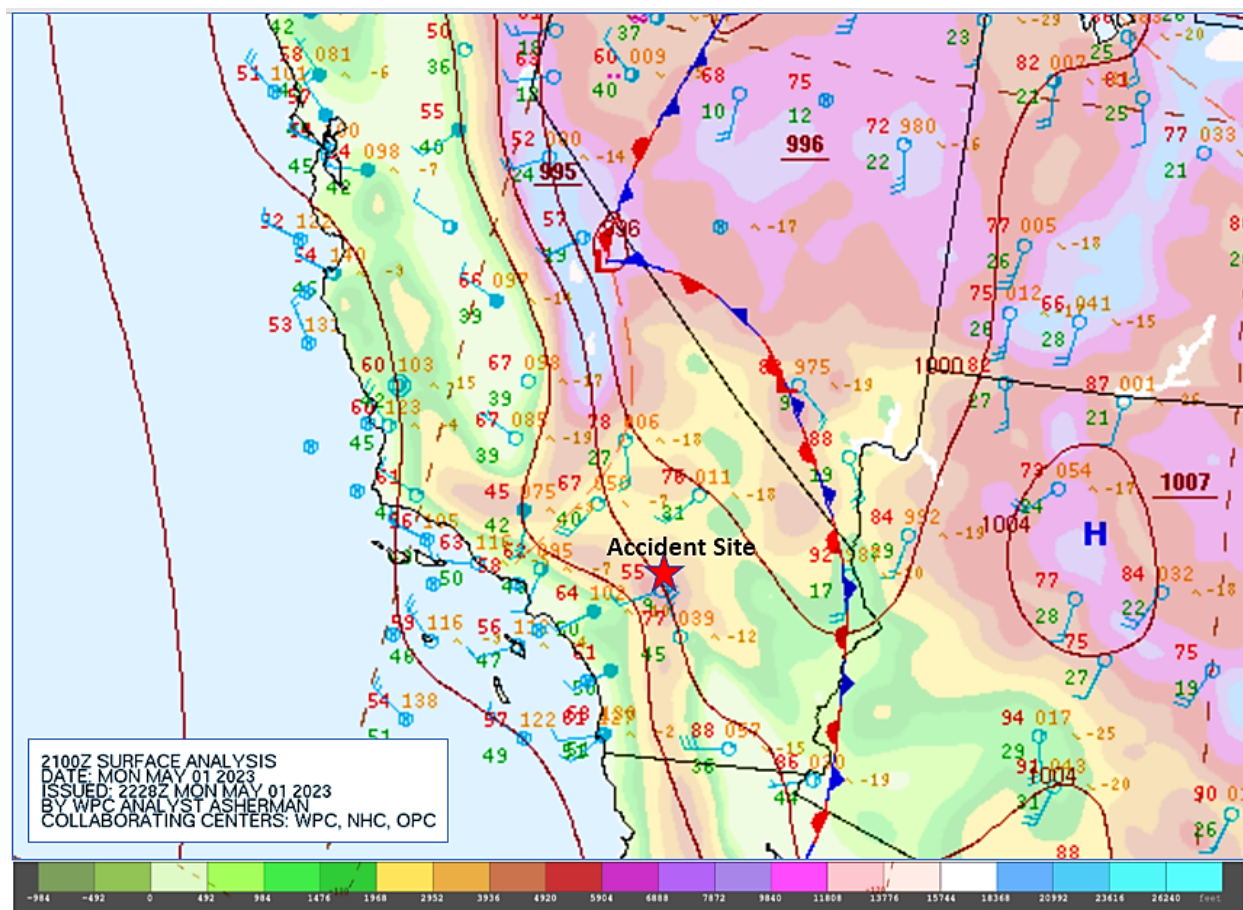


Figure 1 - Southwest section of the NWS Surface Analysis Chart for 1400 PDT with the accident site marked by the red star.

1.2 Upper Air Charts

The NWS Storm Prediction Center's upper air charts for 850-, 700-, 500-, and 300-hPa for 1700 PDT are included as figures 2 through 5. The charts depicted the contours of lines of equal height of the individual pressure surfaces, isotherms by the red dashed lines, temperature-dewpoint depressions less than 8° C in green dashed lines on the 850- and 700-hPa charts to show moist areas, and general wind flow and the station models from the individual rawinsonde sites. The 300-hPa chart also included shaded isotachs or wind speeds greater than 90 knots shaded in blue to depict the general jet stream location and areas of divergence⁴ in yellow. The charts

⁴ Divergence - is the expansion or spreading out of a vector field; usually said of horizontal winds. It is the opposite of convergence. Divergence at upper levels of the atmosphere enhances upward motion, and hence the potential for thunderstorm development (if other factors also are favorable).

depicted a closed upper-level low pressure system over Nevada at 850-hPa sloping northwestward to off the northwest California coast with height. A short-wave trough extending southward from the low through southern California and generally to the west of the accident site. The charts depicted general southerly winds at 25 knots at 850- and 700-hPa, and increased to 40 knots at 500-hPa, and to 70 knots at 300-hPa.

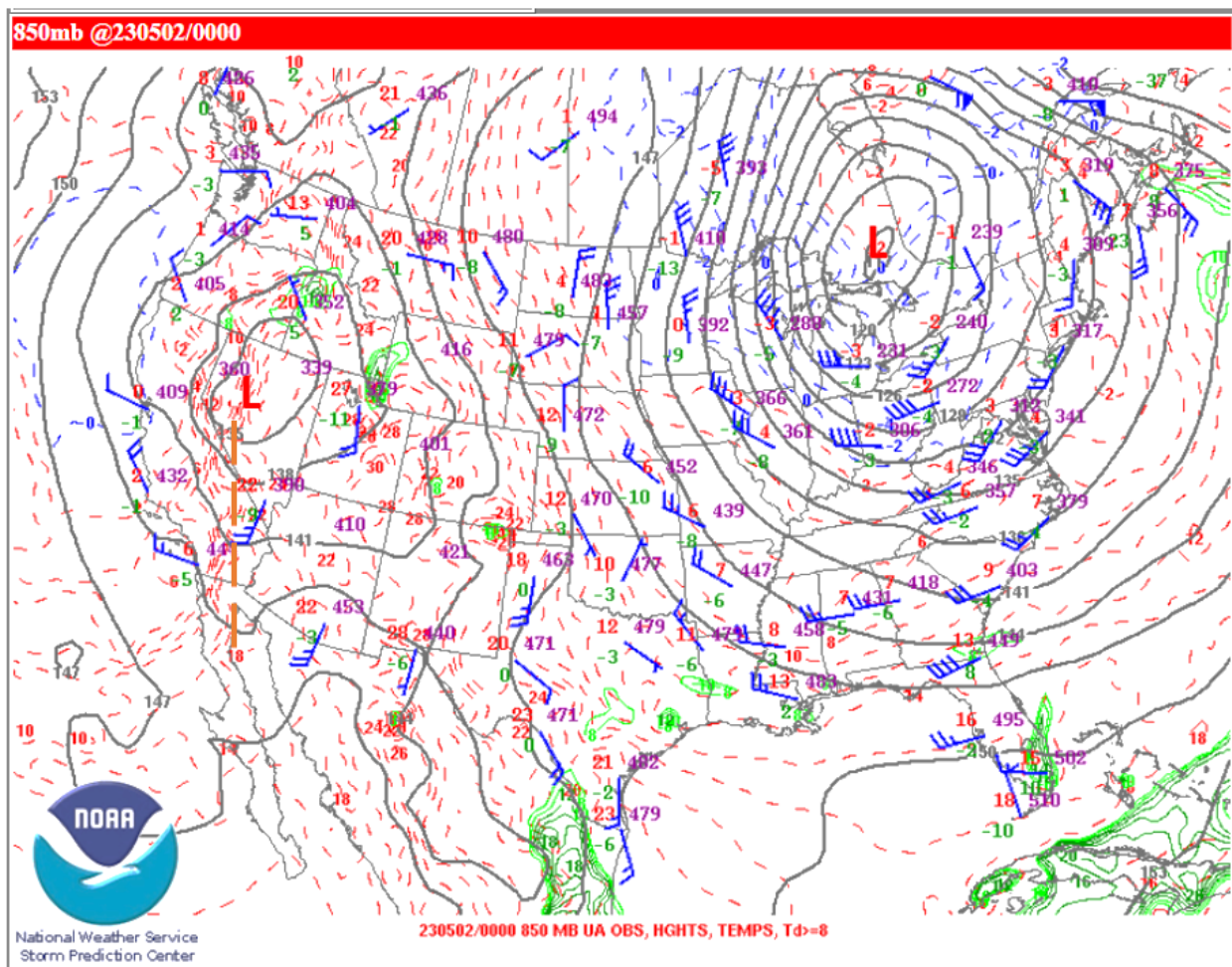


Figure 2 - NWS 850-hPa constant pressure chart for 1700 PDT, depicting the conditions at approximately 5,000 ft msl.

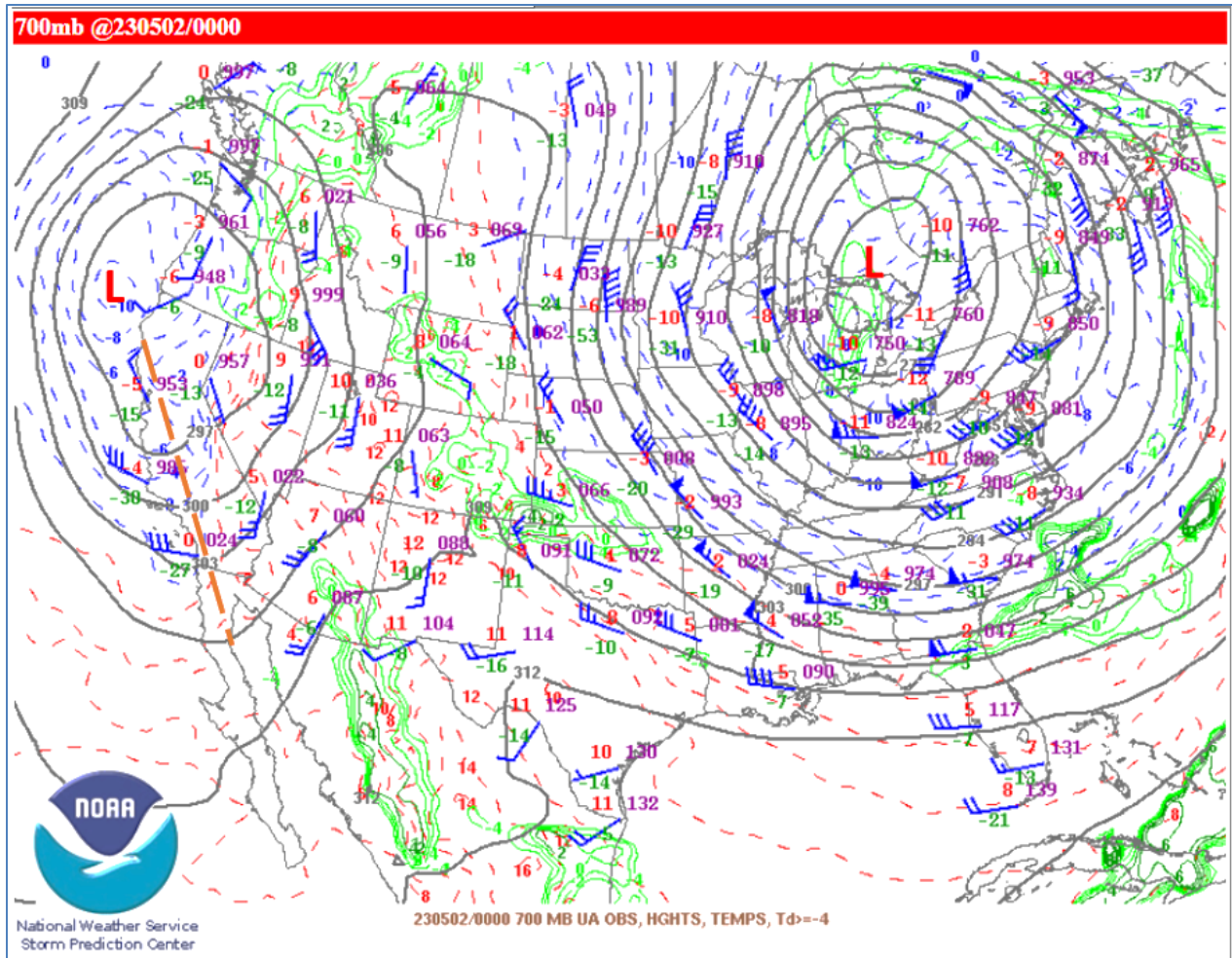


Figure 3 - NWS 700-hPa constant pressure chart for 1700 PDT, depicting the conditions at about 10,000 ft msl.

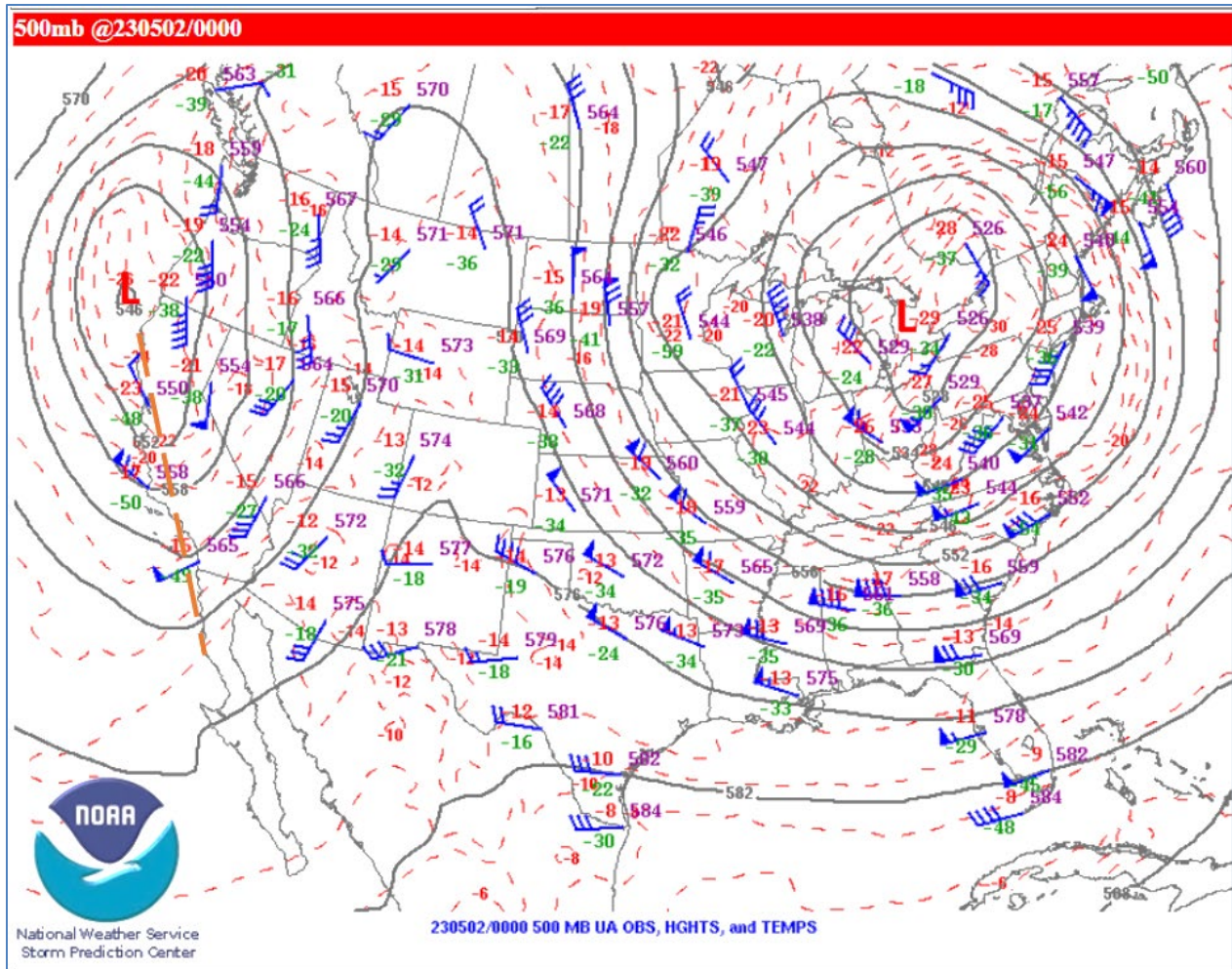


Figure 4 - NWS 500-hPa constant pressure chart for 1700 PDT, depicting the conditions at about 18,000 ft msl.

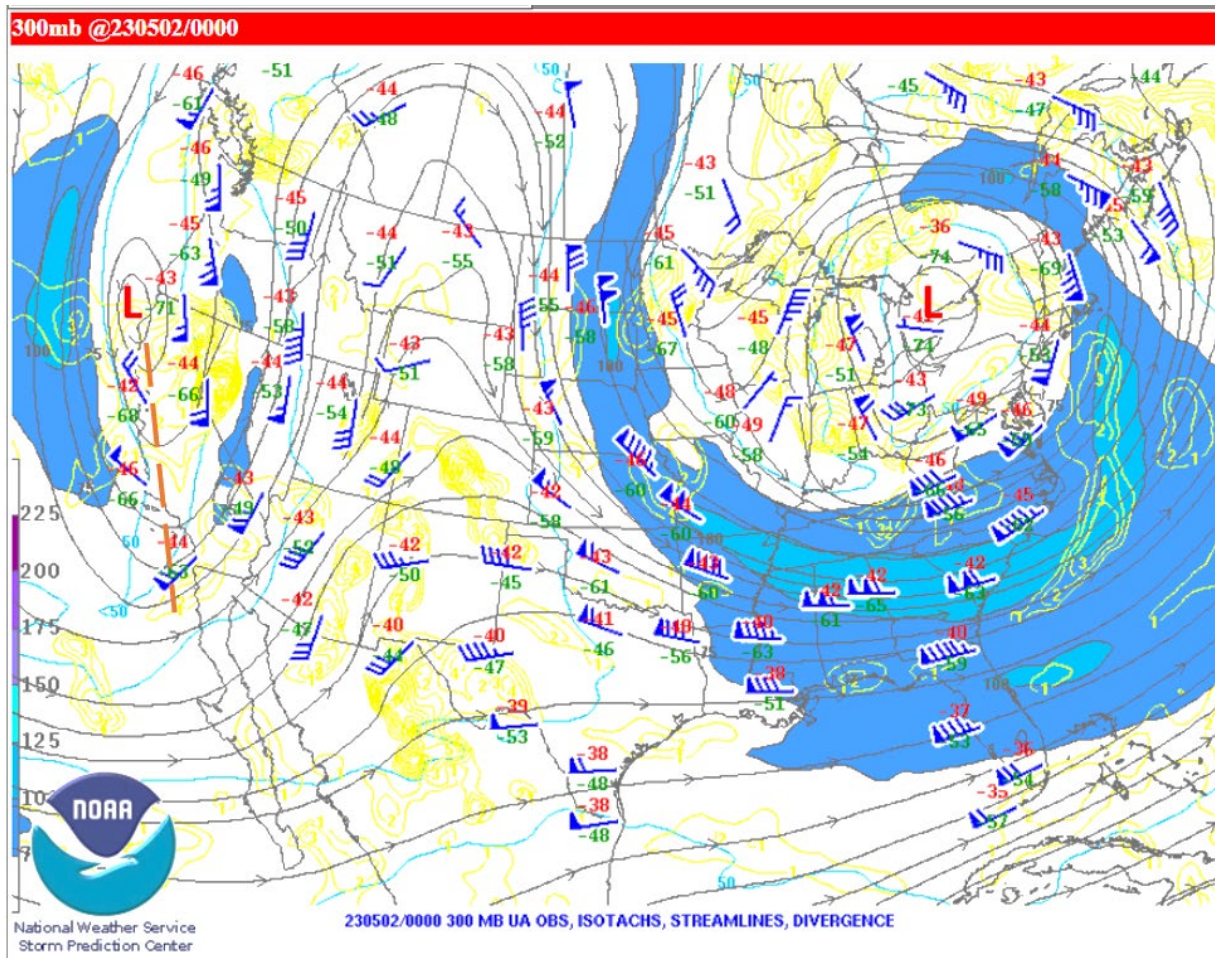


Figure 5 - NWS 300-hPa constant pressure chart for 1700 PDT, depicting the conditions at about 30,000 ft msl.

A North American Mesoscale (NAM) 500-hPa upper air chart for 1700 PDT with vorticity⁵ and the general wind field is included as figure 6. The chart depicted the general conditions at 18,000 ft and also depicted the closed low-pressure system off the northern California coast with a short-wave trough extending south-southeast over the southwestern California coast. The accident site was located east of the upper level trough and in an area favorable for upper level divergence and general rising motion, with strong positive vorticity advection over the area.

⁵ Vorticity is a measure of the rotation of air in a horizontal plane. Positive (counterclockwise or cyclonic) vorticity can be correlated with surface low development and upward vertical motion (in areas of positive vorticity advection).

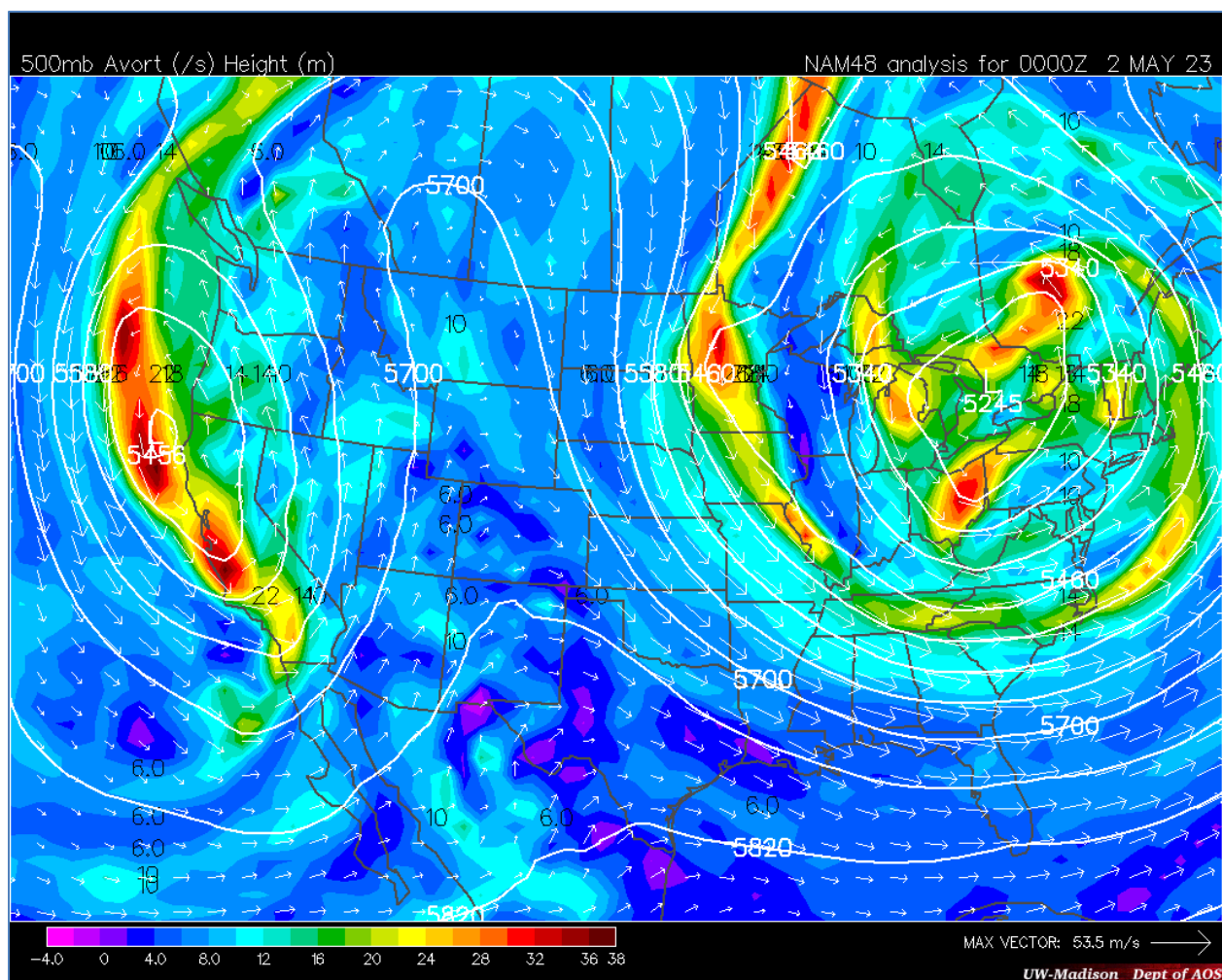


Figure 6 - NWS North American Mesoscale (NAM) model of the 500-hPa surface, vorticity, and wind field for 1700 PDT.

2.0 Surface Observations

The area surrounding the accident site was documented using official Aviation Routine Weather Reports (METAR)⁶ and Aviation Selected Special Weather Reports (SPECI). Cloud heights are reported above ground level (agl) in the following section, and the magnetic variation was estimated at 14.5° east based on the latest sectional chart for the area.

2.1 Big Bear City, California

The closest weather reporting facility to the accident site was from Big Bear City Airport (KL35), Big Bear City, California, located 0.5 mile west at an elevation of 6,752 ft. The airport and accident site were located east of Big Bear Lake and surrounded by

⁶ METAR is an abbreviation for Meteorological Aerodrome Report.

mountainous terrain in all quadrants, with Sugarloaf Mountain located 5 miles south of the accident site at 9,952 ft. The airport had an Automated Weather Observation System (AWOS), which was not augmented by any human observers and broadcasted locally on 135.925 Megahertz (MHz) and disseminated observations longline⁷ to users every 20-minutes. Surrounding the time of the accident the following conditions were being reported.

Weather observation for KL35 at 1355 PDT, automated, wind from 240° at 11 knots gusting to 18 knots, visibility 10 miles or more, sky clear below 12,000 ft agl, temperature 13° C, dew point temperature -13° C, and altimeter 29.84 inches of mercury (inHg).

Weather observation for KL35 at 1415 PDT, automated, wind from 220° at 6 knots gusting to 19 knots, visibility 10 miles or more, sky clear below 12,000 ft agl, temperature 13° C, dew point temperature -11° C, and altimeter 29.84 inHg.

The longline observations disseminated surrounding the period from 1100 through 1700 PDT were as follows. The observation transcribed above, and the time of the accident are in bold type below. Note, while the wind generally prevailed from the southwest during the period, there were numerous periods of 60° variations in wind direction reported during the period.

⁷ Longline - refers to the dissemination of the observation through the FAA and NWS using standard communication protocols in near real-time to users.

METAR KL35 011815Z AUTO 24010G16KT 194V274 10SM CLR 14/M08 A2989 RMK AO2=
 METAR KL35 011835Z AUTO 22007G15KT 194V274 10SM CLR 13/M15 A2988 RMK AO2=
 METAR KL35 011855Z AUTO 25009G15KT 214V274 10SM CLR 13/M17 A2988 RMK AO2=
 METAR KL35 011915Z AUTO 24008G15KT 10SM CLR 14/M14 A2987 RMK AO2=
 METAR KL35 011935Z AUTO 24009G14KT 10SM CLR 15/M12 A2986 RMK AO2=
 METAR KL35 011955Z AUTO 24010G15KT 214V274 10SM CLR 15/M12 A2986 RMK AO2=
 METAR KL35 012015Z AUTO 26012G15KT 224V284 10SM CLR 15/M11 A2986 RMK AO2=
 METAR KL35 012035Z AUTO 23011G17KT 10SM CLR 13/M11 A2985 RMK AO2=
METAR KL35 012055Z AUTO 24011G18KT 10SM CLR 13/M13 A2984 RMK AO2=
Accident 2102Z
METAR KL35 012115Z AUTO 22006G19KT 10SM CLR 13/M11 A2984 RMK AO2=
 METAR KL35 012135Z AUTO 22009G21KT 194V254 7SM CLR 13/M13 A2984 RMK AO2=
 METAR KL35 012155Z AUTO 23012G18KT 10SM CLR 13/M11 A2983 RMK AO2=
 METAR KL35 012215Z AUTO 20008G16KT 144V224 10SM CLR 13/M16 A2983 RMK AO2=
 METAR KL35 012235Z AUTO 20012G17KT 10SM CLR 13/M08 A2982 RMK AO2=
 METAR KL35 012255Z AUTO 22009G19KT 194V254 10SM CLR 07/00 A2984 RMK AO2=
 METAR KL35 012315Z AUTO 25005KT 10SM CLR 07/00 A2984 RMK AO2=
 METAR KL35 012335Z AUTO 24006G16KT 194V294 10SM CLR 07/M03 A2983 RMK AO2=
 METAR KL35 012355Z AUTO 28010G16KT 10SM CLR 07/M01 A2984 RMK AO2=

2.2 San Bernardino, California

The next closest weather reporting facility to the accident site was from San Bernardino International Airport (KSBD), San Bernardino, California, located 21 miles southwest of KL35 at an elevation of 1,159 ft. The airport had an AWOS which was augmented by tower personnel during normal operating hours. The following conditions were reported at the approximate time of the accident.

Weather observation for KSBD at 1354 PDT, wind calm, visibility 6 miles in haze, ceiling⁸ overcast at 5,000 ft agl, temperature 16° C, dew point temperature 8° C, and altimeter 29.85 inHg.

The raw observations reported from about 1100 through 1700 PDT are included below.

METAR KSBD 011651Z 27003KT 3SM DZ SCT007 BKN016 OVC020 13/10 A2987=
 METAR KSBD 011757Z 00000KT 7SM OVC018 13/10 A2987=
 METAR KSBD 011850Z 00000KT 7SM BKN026 OVC035 15/09 A2987=
METAR KSBD 012054Z 00000KT 6SM HZ OVC050 16/08 A2985=
Accident 2102Z
 METAR KSBD 012152Z 00000KT 10SM SCT030 OVC041 17/08 A2984=
 METAR KSBD 012255Z 21003KT 7SM BKN039 BKN050 19/07 A2980=
 METAR KSBD 020000Z 21004KT 10SM BKN048 18/07 A2980=

⁸ Ceiling is defined as the lowest layer of clouds reported as broken or overcast, or the vertical visibility into a surface based obscuration.

2.3 Victorville, California

The next closest weather facility to the northwest of the accident site was from Southern California Logistics Airport (KVCV), Victorville, California, located about 33 miles from the accident site, at an elevation of 2,885 ft. The airport had an AWOS and broadcasted locally on 135.475 MHz and disseminated observations longline every 20-minutes. At the time of the accident the following conditions were reported.

Weather observation for KVCV at 1355 PDT, automated, wind from 180° at 23 knots gusting to 29 knots, visibility 9 miles, sky clear below 12,000 ft agl, temperature 19° C, dew point temperature 4° C, and altimeter 29.77 inHg.

The raw observations report from 1035 through 1700 PDT were as follows.

METAR KVCV 011735Z 24004G10KT 10SM CLR 16/06 A2980 RMK AO2=
METAR KVCV 011755Z 20009G16KT 10SM CLR 17/05 A2980 RMK AO2=
METAR KVCV 011815Z AUTO 22008G15KT 160V260 3SM HZ CLR 18/05 A2980 RMK AO2=
METAR KVCV 011835Z 18014KT 10SM CLR 18/04 A2980 RMK AO2=
METAR KVCV 011855Z 17014G20KT 10SM CLR 18/04 A2980 RMK AO2=
METAR KVCV 011915Z AUTO 16014G23KT 10SM CLR 19/03 A2979 RMK AO2=
METAR KVCV 011935Z AUTO 17017KT 10SM CLR 18/04 A2978 RMK AO2=
METAR KVCV 011950Z AUTO 17018KT 9SM CLR 19/04 A2978 RMK AO2=
METAR KVCV 012015Z AUTO 17022G27KT 10SM CLR 19/04 A2978 RMK AO2=
METAR KVCV 012035Z AUTO 17024G31KT 10SM CLR 19/04 A2977 RMK AO2=
METAR KVCV 012055Z AUTO 18023G29KT 9SM CLR 19/04 A2977 RMK AO2=
Accident 2102Z
METAR KVCV 012115Z AUTO 17028KT 9SM CLR 18/04 A2976 RMK AO2=
METAR KVCV 012135Z AUTO 16028KT 9SM CLR 18/04 A2976 RMK AO2=
METAR KVCV 012155Z AUTO 17028G36KT 8SM CLR 18/03 A2976 RMK AO2=
METAR KVCV 012215Z AUTO 17028G34KT 9SM CLR 18/04 A2975 RMK AO2=
METAR KVCV 012235Z AUTO 17029G35KT 8SM CLR 18/03 A2975 RMK AO2=
METAR KVCV 012255Z AUTO 17027G32KT 9SM CLR 18/03 A2974 RMK AO2=
METAR KVCV 012315Z AUTO 17025G33KT 10SM CLR 17/02 A2974 RMK AO2=
METAR KVCV 012335Z AUTO 17023G30KT 10SM CLR 17/03 A2974 RMK AO2=
METAR KVCV 012355Z AUTO 19022G30KT 8SM UP CLR 18/02 A2974 RMK AO2=

A review of the observations from KVCV indicated southerly winds gusting over 25 knots from 1315 through 1800 PDT with clear skies. The highest reported gust was 36 knots and was reported at 1455 PDT or within the hour of the accident.

2.4 Palm Springs, California

Palm Springs International Airport (KPSP), Palm Springs, California, was located about 35 miles southwest of the accident site at an elevation of 476 ft. The airport had an Automated Surface Observation System (ASOS) and was augmented by contract weather observers. At the approximate time of the accident the following conditions were reported.

Weather observation for KPSP at 1353 PDT, wind from 330° at 24 knots gusting to 38 knots, visibility 10 miles or more, sky clear below 12,000 ft agl, temperature 25° C, dew point temperature 7° C, and altimeter 29.65 inHg. Remarks: automated station with a precipitation discriminator, peak wind from 320° at 38 knots occurred at 1348 PDT, sea-level pressure 1003.9-hPa, temperature 25.0° C, dew point 7.2° C, 3-hour pressure tendency fallen 1.2-Hpa.

The conditions reported from 1053 through 1753 PDT were as follows.

METAR KPSP 011753Z 33014G23KT 10SM CLR 26/06 A2969 RMK AO2 SLP050 T02610061 10261 20172 51003=

METAR KPSP 011853Z 32018G25KT 10SM CLR 27/07 A2969 RMK AO2 SLP049 T02670067=

METAR KPSP 011953Z 32018G27KT 10SM CLR 26/07 A2967 RMK AO2 PK WND 32029/1927 SLP044 T02560067=

METAR KPSP 012053Z 33024G38KT 10SM CLR 25/07 A2965 RMK AO2 PK WND 32038/2048 SLP039 T02500072 58012=

Accident 2102Z

METAR KPSP 012153Z 32021G30KT 10SM CLR 24/06 A2964 RMK AO2 PK WND 32033/2054 SLP036 T02440056=

METAR KPSP 012253Z 33014G29KT 10SM CLR 26/04 A2962 RMK AO2 PK WND 33032/2200 SLP029 T02610044=

METAR KPSP 012353Z 32012G20KT 10SM CLR 25/04 A2964 RMK AO2 PK WND 33028/2303 SLP033 T02500039 10267 20244 55006=

2.5 NWS Aviation Weather Center METAR Display

A display of the conditions for 1400 PDT from the NWS Aviation Weather Center's METAR display is included as figure 7 with a red circle around the accident site and KL35. Temperature and dew point temperatures are depicted in °F. The image depicted visual flight rule (VFR) conditions⁹ over KL35 with clear skies, while to the south through west most stations reported overcast clouds, and to the northwest and southeast several stations reported strong gusting winds to 30 to 40 knots. The station model for KL35 depicted southwest winds gusting to 20 knots, clear skies, a

⁹ Visual flight rule (VFR) conditions is defined as a ceiling above 3,000 ft agl and visibility greater than 3 statute miles.

temperature of 55° F, a dew point temperature of 9° F, and an altimeter setting of 29.84 inHg.

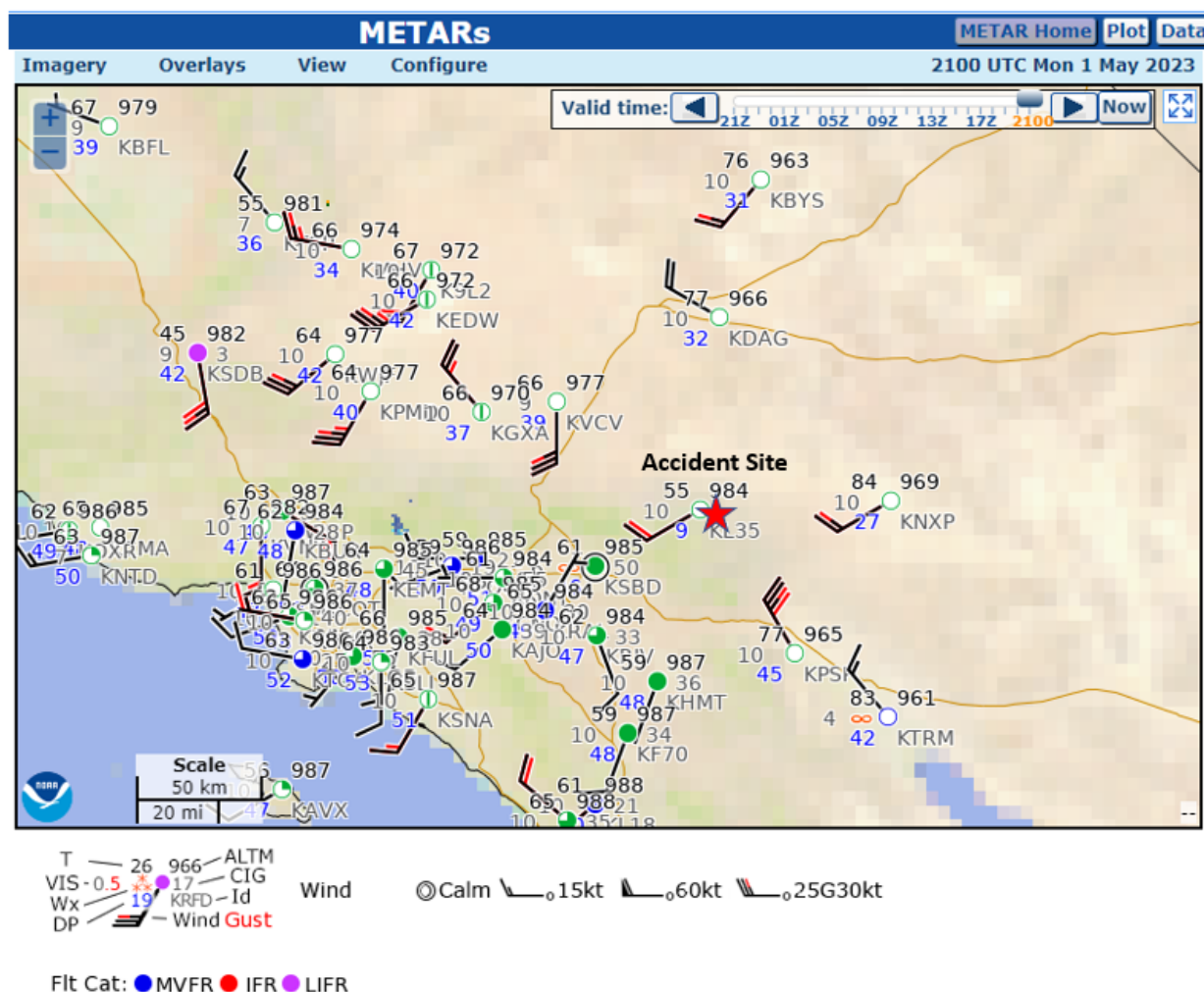


Figure 7 - NWS Aviation Weather Center's METAR display for 1400 PDT with the red star over the approximate accident site east of Big Bear City Airport.

3.0 Sounding

A High-Resolution Rapid Refresh (HRRR) numerical model¹⁰ sounding was obtained from the NOAA Air Resource laboratory for 1400 PDT for the nearest grid point¹¹ to the accident site. The HRRR data were then plotted on a standard Skew T log

¹⁰ 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.

¹¹ Grid point used was latitude 34.26° N, and longitude 116.86° W.

P diagram¹² using the RAOB Analysis software¹³ and is included as figure 8 from the surface through 450-hPa (about 21,000 ft).

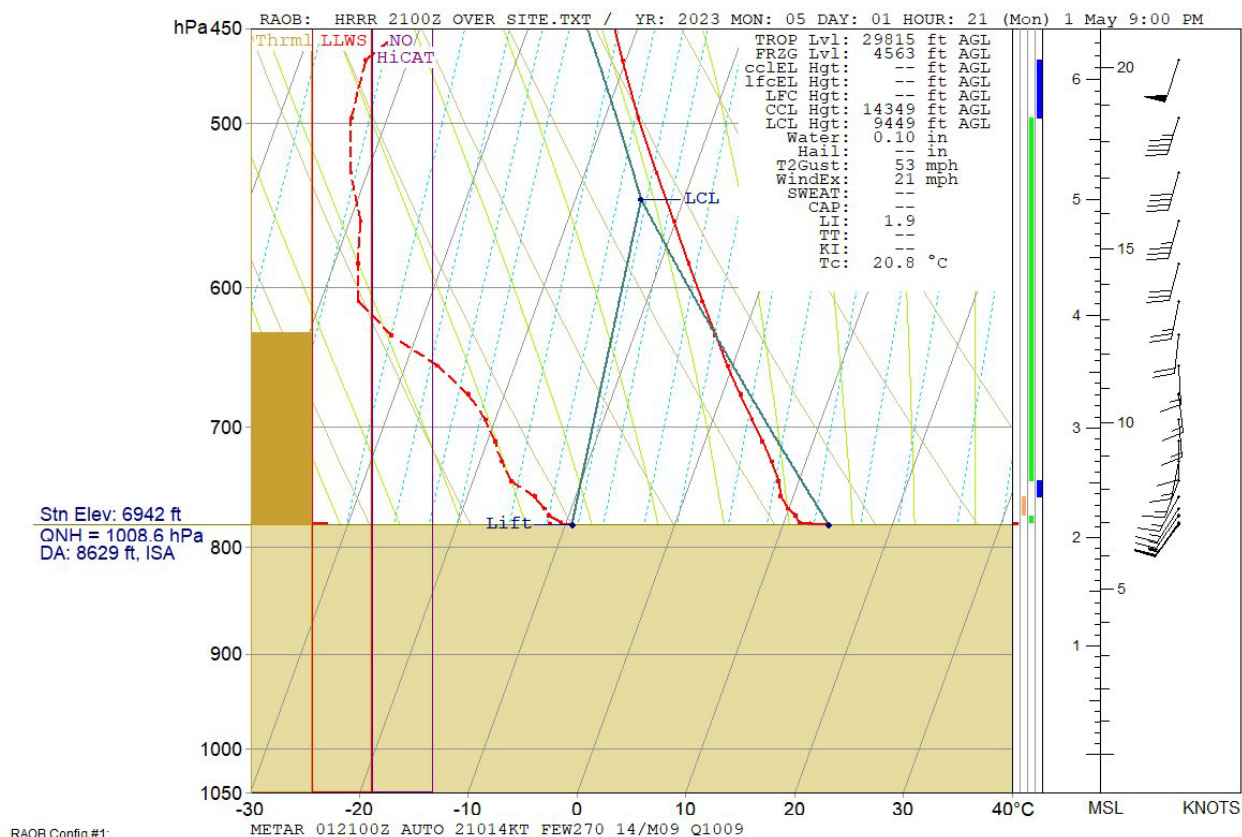


Figure 8 - High-Resolution Rapid Refresh (HRRR) numerical model sounding for 1400 PDT.

The HRRR 1400 PDT sounding depicted an elevation of 6,942 ft over the grid point¹⁴ with a near-surface temperature of 14° C (58° F), a dew point temperature of -9° C (15° F), a relative humidity of 19%, a sea-level pressure of 1008.6-hPa, and a density altitude of 8,629 ft. The lifted condensation level (LCL)¹⁵ was identified at 9,449 ft agl, with the convective condensation level (CCL)¹⁶ at 14,349 ft, with the precipitable water content of 0.10 inches. The RAOB analysis program did not support any clouds below

¹² Skew T log P diagram is a standard meteorological plot or thermodynamic diagram 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.

¹³ RAOB -The Universal RAWinsonde OBservation program is an interactive sounding analysis program developed by Eosonde Research Services (ERS) previously known as Environmental Research Services, The Villages, Florida.

¹⁴ Grid point closest to the accident coordinates was latitude 34.26° N, longitude 116.86°W.

¹⁵ Lifted Condensation Level (LCL) - the level at which a lifted parcel becomes saturated. The LCL height corresponds to cloud base height for forced ascent.

¹⁶ 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.

26,000 ft. The freezing level was identified at 11,500 ft with no icing conditions indicated. The atmosphere was characterized as unstable below 1,000 ft agl and conditionally unstable through 19,000 ft with a lifted index (LI)¹⁷ of 1.9 and supported thermals from the surface through 12,000 ft. The wind profile indicated a near surface wind from 210° at 14 knots with wind backing slightly with height through 8,000 ft with winds increasing in speeds above 12,000 ft. The mean 0 to 6 kilometer or 18,000 ft wind was from 200° at 39 knots, and the maximum wind was from 200° at 75 knots at about 34,000 ft.

A table of the HRRR sounding parameters of height, pressure, temperature (T), dew point temperature (Td), relative humidity (RH), wind, and derived clear air turbulence (CAT) and low-level wind shear (LLWS) potential is as follows. The RAOB Analysis program did not detect any icing or mountain wave activity below 12,000 ft. The wind directions have been rounding to the nearest 5°.

Height (ft-msl)	Pres (hPa)	T (°C)	Td (°C)	RH (%)	Wind (dir/kts)	CAT (FAA)	LLWS (FAA)
6942	780	14.2	-9.4	19	215/ 14		
6977	779	12.5	-11.5	18	215/ 14		LIGHT
7012	778	11.4	-10.5	20	215/ 16		
7224	772	10.8	-11.9	19	210/ 17		
7437	766	9.9	-12.5	19	210/ 17		
7794	756	8.8	-13.8	19	210/ 16		
8264	743	8.1	-16.5	16	200/ 14		
8851	727	6.8	-18.0	15	190/ 13		
9449	711	5.3	-19.3	15	180/ 12		
10095	694	3.6	-20.9	15	175/ 13		
10831	675	1.7	-23.3	14	175/ 14		
11663	654	-0.4	-27.1	11	180/ 16	LIGHT	
12557	632	-2.6	-32.4	8	185/ 19	LIGHT	

4.0 Satellite Imagery

The NOAA Geostationary Operational Environmental Satellite number 18 (GOES-18) infrared and visible imagery were obtained from an archive at the Space Science Engineering Center (SSEC) at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System (McIDAS) software. The infrared band 13 at a wavelength of 10.3 microns (μm)

¹⁷ Lifted Index (LI) - A common measure of atmospheric instability. Its value is obtained by computing the temperature that air near the ground would have if it were lifted to 500-hPa or approximately 18,000 feet and comparing that temperature to the actual temperature at that level. Negative values indicate instability - the more negative, the more unstable the air is, and the stronger the updrafts are likely to be with any developing thunderstorms.

provided a resolution of 2 kilometers (km) with radiative cloud top temperatures, with the visible band at 0.64 μm with a resolution of 0.5 km.

Figure 9 is the GOES-18 infrared image for 1401 PDT at 4X magnification with a standard MB temperature enhancement curve applied to highlight the higher and colder cloud tops associated with deep convection and/or cold cirriform type clouds. The accident site is marked by the red square and was located to the north of an area of low clouds which had a radiative cloud temperature near 275 Kelvin or 1.8° C, which corresponded to cloud tops near 5,000 ft, with clear skies over the accident site. Several bands of mid to high-level clouds were located north through east of the accident site which had distinct southern edges and streamed northward. Figure 10 is the GOES-18 visible image at 4X magnification for the same period of 1401 PDT. The image depicted clear skies over the accident site with the low clouds extending over and south of the mountainous terrain south of the accident site, with several band-like features.

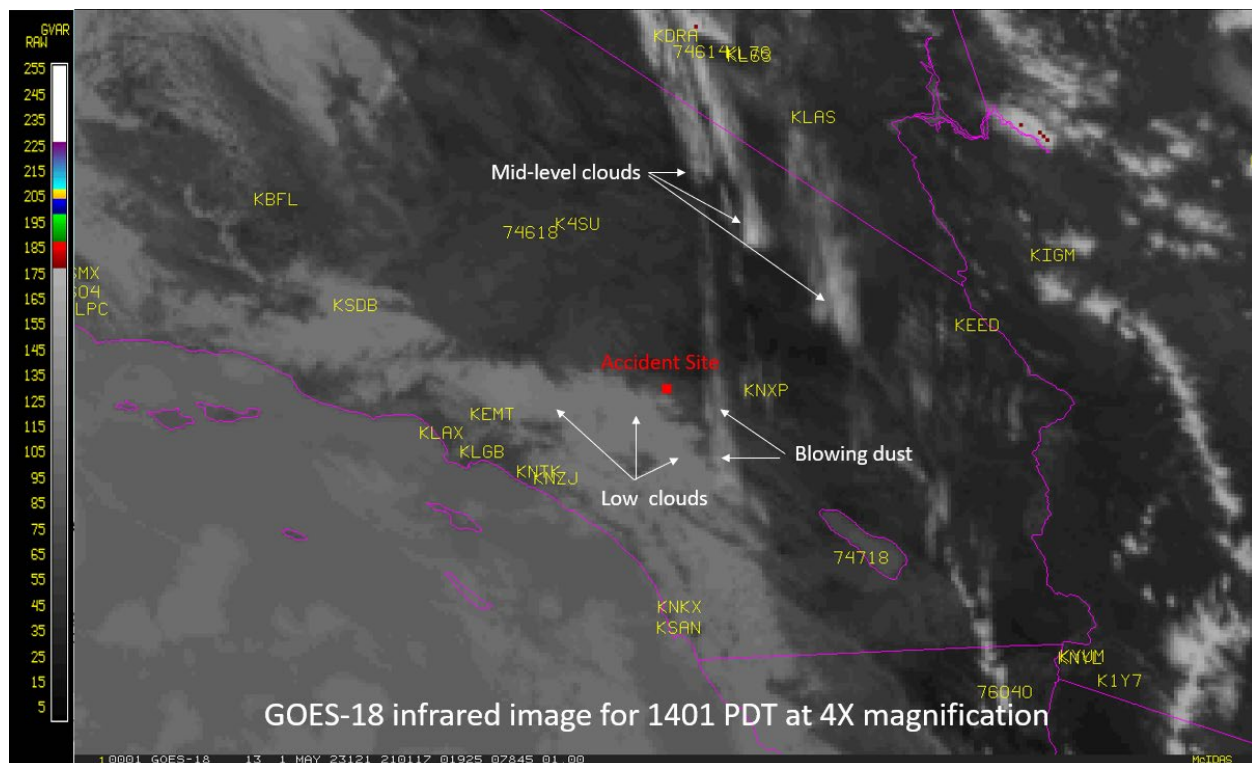


Figure 9 - GOES-18 infrared image for 1401 PDT at 4X magnification with a standard MB temperature enhancement curve applied and the accident site marked by a red square.

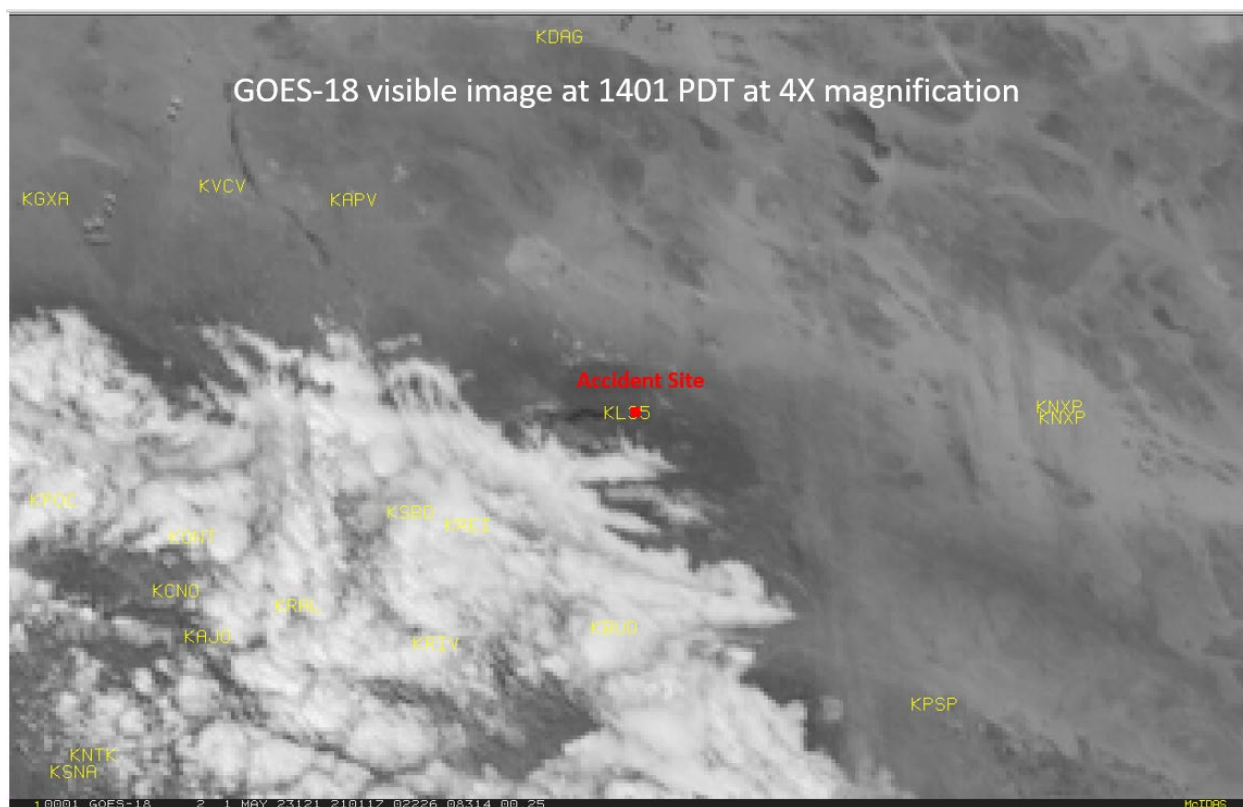


Figure 10 - GOES-18 visible image for 1401 PDT at 4X magnification with accident site marked by the red square immediately east of KL35.

The NOAA GOES-18 GeoColor imagery¹⁸ surrounding the time of the accident was downloaded. The GOES-18 GeoColor image for 1401 PDT is included as figure 11 with the approximate accident site marked by the red star. The image depicted clear conditions over the accident site with low clouds immediately south over the higher terrain with broken to overcast clouds extending over the coastal plan and into the Los Angeles basin to the coast. To the southeast, east, and northeast several bands of mid to high-level clouds can be seen streaming northward. An animation of the GOES-18 GeoColor imagery from 1306 through 1436 PDT (2006Z-2136Z) is included as Attachment 1.

¹⁸ The GeoColor was developed by the Cooperative Institute for Research in the Atmosphere (CIRA) and the Regional and Mesoscale Meteorology Branch (RAMMBA) of NOAA's Center for Satellite Applications and research (STAR).

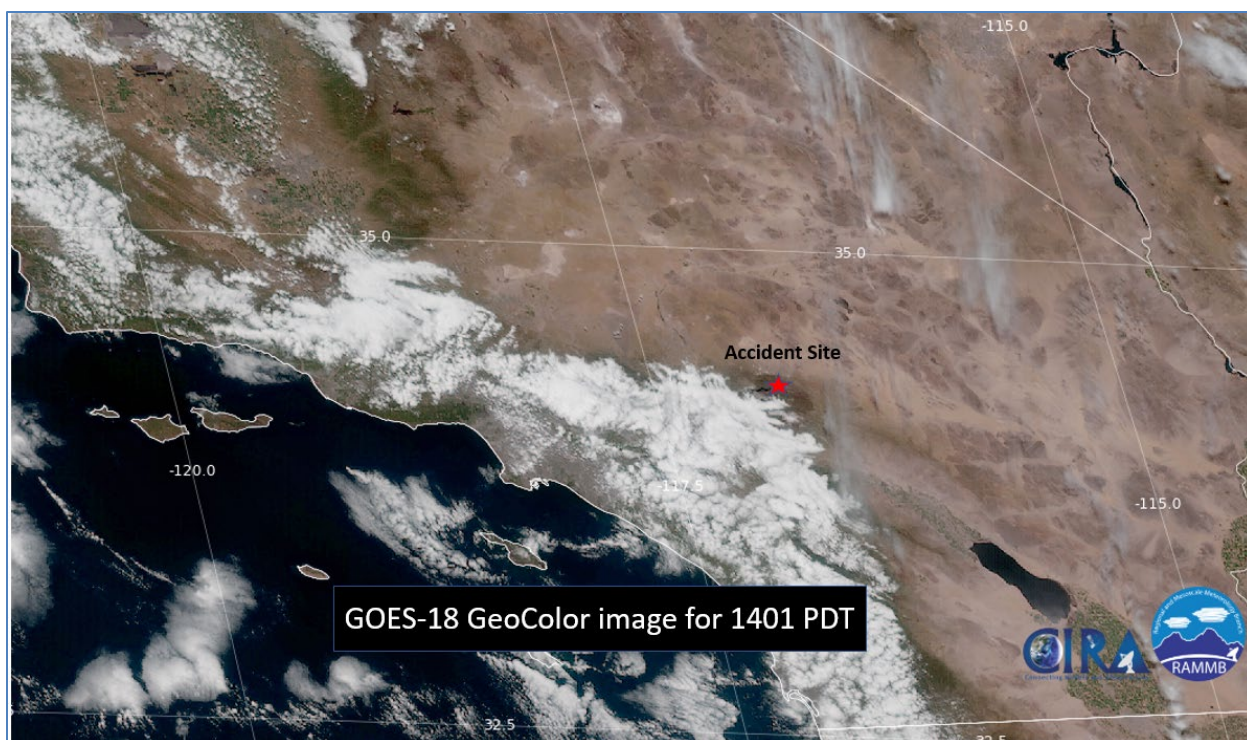


Figure 11 - NOAA GOES-18 GeoColor image for 1401 PDT with the accident site noted.

5.0 Pilot Reports

The following pilot weather reports or PIREPs were recorded¹⁹ between 1100 and 1600 PDT within 60 miles of the accident site.

RAL UA /OV 5 W RAL/TM 1803/FL025/TP PA44/SK OVC034-TOP050/RM DURC RY 9

ONT UA /OV ONT080005/TM 1832/FL019/TP B737/SK BKN019-TOP050/RM DURD

EMT UA /OV KEMT100030/TM 1837/FL017/TP HELO/SK BKN020

RAL UA /OV KEMT100030/TM 1837/FL017/TP HELO/SK BKN020/RM COR SA-ID. ZLA CWSU

ONT UA /OV 08006/TM 2028/FL029/TP A321/WX BASES-035 TOPS-UNKN

Accident 2102Z

PSP UA /OV PSP/TM 2150/FL012/TP B738/WV 31027G36/RM B738 REPORTED LOSS OF 25KTS ON DEP

TRM UA /OV PSP340015 /TM 2222 /FL120 /TP SR22 /TB MOD/RM AWC-WEB

¹⁹ Includes only the reports official recorded and disseminated as a PIREP and may not include "ride reports" broadcasted or other conditions solicited by air traffic controllers and not entered in the formal PIREP format coding. These reports are available to users in near real-time.

There were several reports generally south of the accident site reporting broken to overcast cloud cover with tops near 5,000 ft prior to the accident. At 1450 PDT a PIREP from a pilot of a B-737 departing KPSP reported the wind from 310° at 27 knots gusting to 36 knots with a loss of 25 knots of airspeed on departure. There was also a single report of moderate turbulence from a Cirrus SR22 at 12,000 ft about 20 miles to the southwest of the accident site.

6.0 Weather Radar Imagery

The NWS National Composite Radar Mosaic²⁰ for 1400 PDT with the approximate accident site marked by the red star is included as figure 12. The image depicted several small areas of echoes generally on the windward or southern side of the San Bernardino Mountains with no echoes over the accident site.

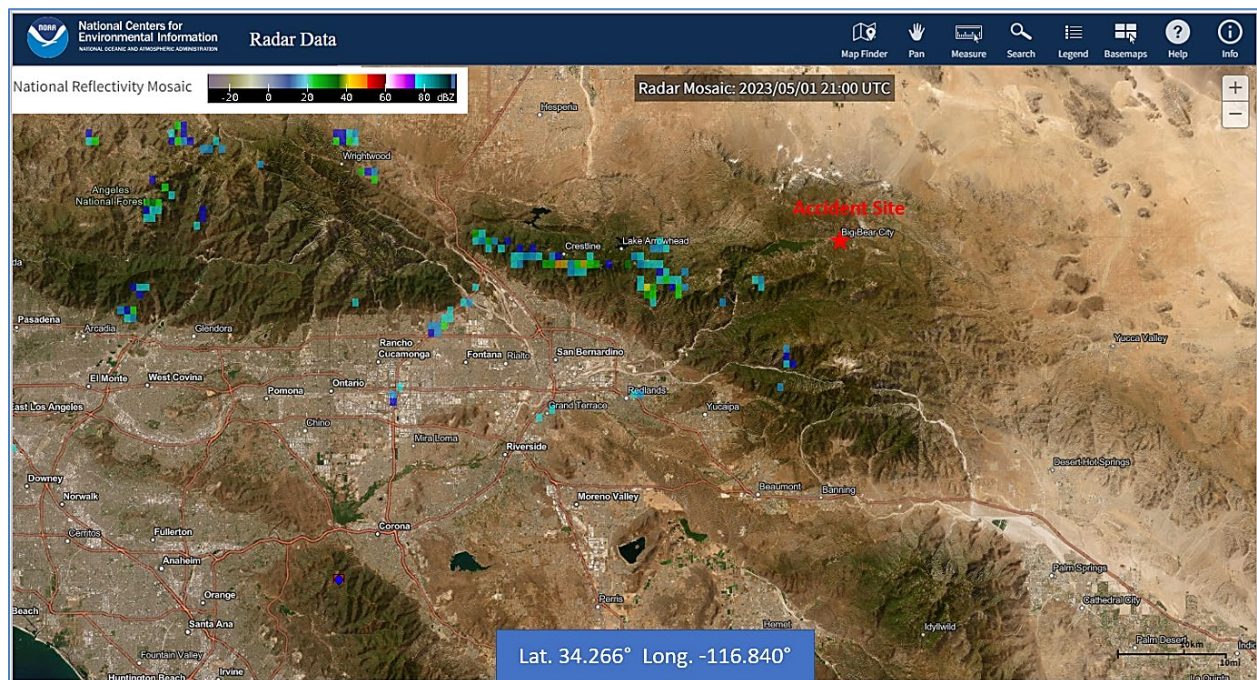


Figure 12 - NWS National Composite Reflectivity Mosaic image for 1400 PDT with the approximate accident site marked by the red star.

7.0 NWS Forecasts and Advisories

The local NWS San Diego (KSGX) Weather Forecast Office (WFO) were responsible for providing local forecasts and warnings to the public, while the NWS

²⁰ <https://www.ncei.noaa.gov/maps/radar/>

AWC located in Kansas City were responsible for the enroute and weather advisories for aviation. The general advisories and warnings issued surrounding the period applicable to the accident were documented.

7.1 Terminal Aerodrome Forecast

The closest Terminal Aerodrome Forecast (TAF)²¹ to KL35 was from San Bernardino International Airport (KSBD), San Bernardino, California, located about 21 miles southwest at an elevation of 1,159 ft. The airport was located on the southern side of the coastal range of the San Bernardino Mountains. TAFs are a concise statement of the expected meteorological conditions significant to aviation for a specific period typically 24-hours and are valid for 5 statute miles from the airport's runway complex (terminal). While not valid for KL35, the closest TAF is often used by various flight planning systems to provide pilots reference to the local conditions. The TAF issued for KSBD at 1045 PDT was as follows:

*TAF KSBD 011745Z 0118/0218 25005KT P6SM SCT006 OVC010
TEMPO 0118/0119 3SM -RA BKN007
FM012000 25011KT P6SM SCT012 BKN020
FM020500 25006KT P6SM VCSH OVC020=*

The forecast for KSBD from 1100 through 1300 PDT expected wind from 250° at 5 knots, visibility better than 6 miles, scattered clouds at 600 ft agl, ceiling overcast at 1,000 ft, with a temporary period²² between 1100 and 1200 PDT of visibility 3 miles in light rain with a ceiling broken at 700 ft. From 1300 through 2200 PDT expected a wind from 250° at 11 knots, visibility 6 miles or more, scattered clouds at 1,200 ft agl, ceiling broken at 2,000 ft.

7.2 Area Forecast Discussion

The NWS Area Forecast Discussions (AFD) are issued by each WFO to describe the short-term weather conditions within their region with an aviation section that includes the general conditions as they relate to the creation of the TAF. These are useful for additional aviation-related issues that cannot be encoded into the TAF and provide some reasoning behind the forecast. These are generated roughly every 6 hours and correspond to the release of the latest TAFs for that office. The NWS KSGX WFO issued the AFD at 1335 PDT and was as follows.

*FXUS66 KSGX 012035
AFDSGX*

²¹ www.nws.noaa.gov/directives/sym/pd01008013curr.pdf

²² Temporary group implies that a greater than 50% chance of occurrence, and is expected to last less than one hour, with the total duration of the temporary period is less than half of the forecast period.

Area Forecast Discussion
National Weather Service San Diego CA
135 PM PDT Mon May 1 2023
..SYNOPSIS...01/404 AM.

Low pressure near the West Coast will strengthen the onshore flow across southern California, bringing much cooler weather to inland areas with stronger and gusty west winds in the mountains and deserts into tonight. A coastal eddy has deepened the marine layer with areas of drizzle for some coastal and valley areas into Wednesday, mainly nights and mornings. A cold low pressure system from the northwest will bring showers and a slight chance of thunderstorms from the coast to the mountains for Wednesday night and Thursday. Then drier with slow warming into next weekend.

..DISCUSSION...FOR EXTREME SOUTHWESTERN CALIFORNIA INCLUDING ORANGE...SAN DIEGO...WESTERN RIVERSIDE AND SOUTHWESTERN SAN BERNARDINO COUNTIES...

Forecast Highlights:

- * Deep marine layer with clouds, spotty drizzle west of mountains**
- * Showers likely Wednesday evening through Thursday**
- * Temperatures well below normal this week, coldest on Thursday**

An upper level trough off the U.S. West Coast has brought strong southwest winds and a deeper marine layer to the region. The wind is strongest across the desert slopes and across parts of the deserts. Winds have been and will continue to be strongest on the desert side of through the San Geronio Pass, where wind gusts of 50-60 mph will continue.

Marine layer cloudiness is entrenched from the coast to the foothills and this pattern will continue this work week. Spotty drizzle will also occur each night and morning, especially along the slopes. Otherwise, it will continue to run cool with temps running well below normal - some 15-20 degrees below normal inland and 5-10 degrees below normal near the coast.

A closed low will drop southward along the California coast Tuesday through Wednesday, eventually moving across central and Southern California on Thursday. Showers will become likely as this system moves closer Wednesday evening and eventually takes a march eastward on Thursday. Wednesday night and Thursday morning looks to be the highest potential for rainfall area wide. It could rain over the deserts, but the most substantial rainfall will occur along and west of the mountains where 0.25-0.50 inches is most likely. Localized rainfall amounts could reach or near 1". The snow level will fall to around 5000 feet with 1-4" of snow possible above 6000 feet Wednesday night-Thursday.

The storm system will depart the region to the east Friday and over the upcoming weekend. This will lead to drying along with slowly moderating conditions. However, large scale upper troughing continues to look to be the dominant weather feature into the 2nd week of May, so below normal temperatures likely will continue along with a formidable marine layer, keeping May Gray going.

..AVIATION...

012000Z...Coast/Valleys/Mountains...Low clouds with bases 2000-3000 feet MSL will continue through today. Partial clearing in the valleys through the afternoon. Low clouds will spread further into the mountain foothills tonight into Tuesday, with bases 1500-2500 feet and tops to 5000 feet. Foothills obscured in clouds/fog. More -RA and DZ tonight into Tuesday morning.

Desert Slopes of Mountains/Deserts...Mostly clear with unrestricted vis today and tonight. Southwest winds 20-30 kts, gusting 40-50 kts over ridgetops and into adjacent deserts, strongest this afternoon and evening. Areas of strong up/downdrafts and pockets of LLWS in lee of mountains, including rotors near KPSP.

.SGX WATCHES/WARNINGS/ADVISORIES...

CA...Wind Advisory until 2 AM PDT Tuesday for Apple and Lucerne Valleys-Coachella Valley-Riverside County Mountains-San Bernardino County Mountains-San Diego County Deserts-San Diego County Mountains-San Gorgonio Pass Near Banning.

7.3 Wind Advisory

The NWS KSGX WFO issued the following advisory to the public at about 1300 PDT.

WWUS76 KSGX 012002
NPWSGX

URGENT - WEATHER MESSAGE
National Weather Service San Diego CA
102 PM PDT Mon May 1 2023

CAZ055-056-058-060>062-065-020445-
/O.EXT.KSGX.WI.Y.0031.000000T0000Z-230502T0900Z/
San Bernardino County Mountains-Riverside County Mountains-San Diego County Mountains-Apple and Lucerne Valleys-Coachella Valley-San Diego County Deserts-San Gorgonio Pass Near Banning-Including the cities of Crestline, Lake Arrowhead, **Big Bear City**, Big Bear Lake, Running Springs, Wrightwood, Idyllwild-Pine Cove, Julian, Pine Valley, Victorville, Hesperia, Apple Valley, Lucerne Valley, Indio, Palm Springs, Cathedral City, Palm Desert, Palm Desert Country, La Quinta, Coachella, and Borrego Springs
102 PM PDT Mon May 1 2023

...WIND ADVISORY NOW IN EFFECT UNTIL 2 AM PDT TUESDAY...

* WHAT...**Southwest winds 25 to 35 mph with gusts to 60 mph expected.**

* WHERE...**San Bernardino County Mountains**, Riverside County Mountains, San Diego County Mountains, Apple and Lucerne Valleys, Coachella Valley, San Diego County Deserts and San Gorgonio Pass Near Banning.

* WHEN...Until 2 AM PDT Tuesday.

* IMPACTS...Gusty winds could blow around unsecured objects. Tree limbs could be blown down.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

Use extra caution when driving, especially if operating a high profile vehicle. Secure outdoor objects. **Strong winds over desert areas could result in briefly lowered visibilities to well under a mile at times in blowing dust or blowing sand.** Use extra caution.

Gregoria

7.4 Winds and Temperatures Aloft

The NWS Winds and Temperature Aloft Forecast bulletin²³ for the four stations surrounding the accident area were documented. The stations were as follows:

- General William J. Fox Airport (WJF), Lancaster, California, located 75 miles WNW.
- Ontario International Airport (ONT), Ontario, California, located 40 miles W.
- Blyth Airport (BLH), Blyth, California, located 113 miles ESE.
- Harry Reid International Airport (LAS), Las Vegas, Nevada, located 137 miles NE.

The bulletin issued at 1300 PDT and valid for the period were as follows:

FBUS31 KWN0 012000

FD1US1

-DATA BASED ON 011800Z

VALID 020000Z FOR USE 2000-0300Z. TEMPS NEG ABV 24000

FT	3000	6000	9000	12000	18000	24000	30000	34000	39000
-BLH	2419	1817+13	1824+07	1924+01	2038-13	1949-27	205443	205451	215558
-WJF		2720+04	2519+02	2321-04	2325-17	2327-30	205045	205049	203649
-LAS		1827+17	1828+08	1928+00	1840-15	1853-28	195843	196152	205755
-ONT	2314	2411+04	2418+02	2219-03	2133-17	2049-29	196044	195550	214350

7.5 Graphic Forecast for Aviation

The NWS Graphic Forecast for Aviation (GFA) is a graphical depiction of surface wind, thunderstorms, precipitation, color-coded general flight categories, and cloud cover bases and tops reported in msl heights, from graphical output from the NWS National Digital Forecast Database (NDFD) with the Graphic-Airmen's Meteorological Information (G-AIRMET) for IFR conditions, mountain obscuration, icing conditions, and strong surface wind overlaid. The GFA provides a forecast for the enroute phase

²³ FBUS21 bulletins issued by the NWS National Center for Environmental Prediction.

of flight and for locations without a TAF. The GFA is available at the NWS AWC website and through other weather briefing services.

The 3-hour GFA surface and cloud forecasts, issued about 1200 PDT and valid for 1400 PDT, are included as figures 13 and 14, respectively. The GFA surface forecast (figure 13) depicted a surface wind from the south at 25 knots gusting to 40 knots immediately south of the accident, with continuous light rain over the Los Angeles basin to the southwest. Areas of widespread blowing dust or sand (\$) raised by the winds were depicted northeast through southeast. A G-AIRMET was depicted to the west through northwest of the accident site due to strong surface winds greater than 30 knots. The 3-hour GFA cloud forecast (figure 14) depicted clear skies over the accident site with broken clouds immediately south and southwest. A G-AIRMET for mountain obscuration conditions were depicted extending along the higher terrain to the south and west of the accident site and over the California coastal sections.

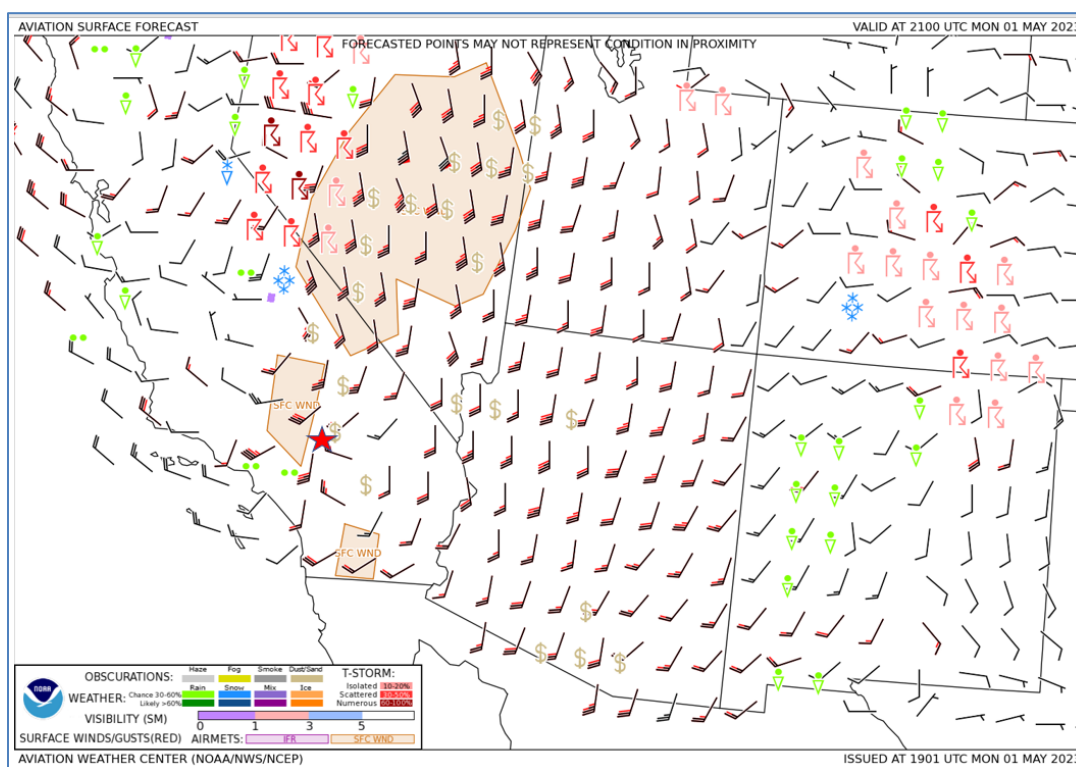


Figure 13 - Southwest section of the NWS 3-hour Graphic Forecast for Aviation (GFA) surface forecast valid for 1400 PDT with the approximate accident site marked as red star.

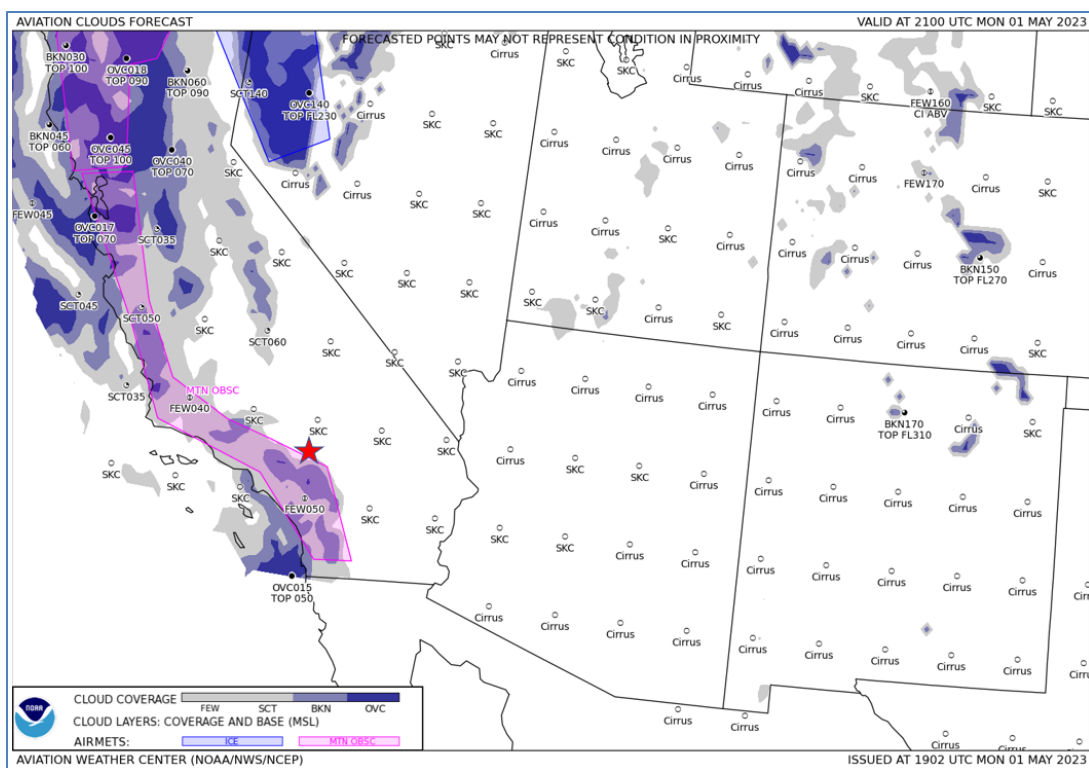


Figure 14 - Southwest section of the NWS 3-hour GFA cloud forecast valid for 1400 PDT with the approximate accident site marked as red star.

7.6 Inflight Weather Advisories

In-flight Aviation Weather Advisories are forecasts that advise en route aircraft of the development of potentially hazardous weather. Inflight aviation weather advisories in the conterminous U.S. are issued by the NWS AWC, as well as from the Center Weather Service Units (CWSU) at the various Air Route Traffic Control Centers (ARTCCs). There are four basic types of inflight aviation weather advisories: the Significant Meteorological Information (SIGMET), the Convective SIGMET, the G-AIRMET, and the Center Weather Advisory (CWA). Inflight advisories serve to notify en-route pilots of the possibility of encountering hazardous flying conditions that may not have been forecast at the time of the preflight briefing. Whether or not the condition described is potentially hazardous to a particular flight is for the pilot to evaluate based on experience and the operational limits of the aircraft. Once issued they are broadcast by FAA air traffic controllers upon issuance and available on inflight weather broadcasts.

Surrounding the period of the accident the NWS had no SIGMETs, Convective SIGMETs, or Center Weather Advisories current over southern California and the accident site. The NWS AWC did have several G-AIRMETs valid for 1400 PDT for occasional moderate turbulence below 16,000 ft over the area, and advisories for mountain obscuration and strong surface winds gusting over 30 knots immediately

bordering the Big Bear City area. Figure 15 is a depiction of these advisories followed by a text version of the AIRMETs.

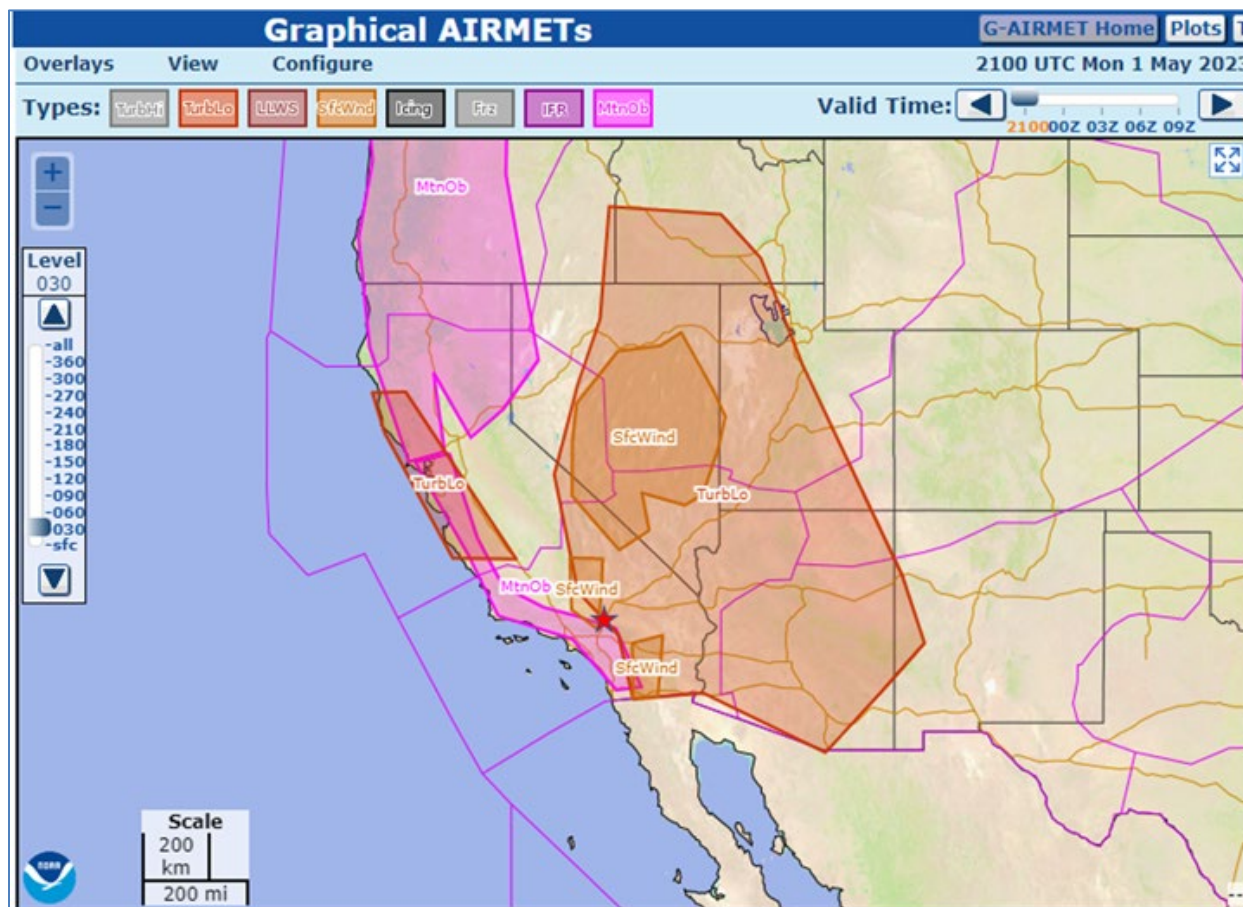


Figure 15 - NWS AWC depiction of the G-AIRMETs current at 1400 PDT with the accident site.

WAUS46 KPCI 012045

WA6S

SFOS WA 012045

AIRMET SIERRA UPDT 4 FOR IFR AND MTN OBSCN VALID UNTIL 020300

.

NO SGFNT IFR EXP OUTSIDE OF CNVT ACT.

.

AIRMET MTN OBSCN...CA

**FROM 20WSW SAC TO 40W EHF TO 20WSW HEC TO 60S TRM TO 20S MZB TO
LAX TO 40WSW RZS TO PYE TO 20WSW SAC
MTNS OBSC BY CLDS/BR/FG. CONDS CONTG BYD 03Z THRU 09Z.**

.

AIRMET MTN OBSCN...WA OR CA NV

FROM 20E HUH TO 50SE YDC TO 50WSW PDT TO 40SSE BKE TO 70NNE FMG
TO 50WSW BTY TO 60ESE EHF TO EHF TO RBL TO 20SW SAC TO PYE TO
FOT TO 20N ONP TO 20W TOU TO 20E HUH

MTNS OBSC BY CLDS/PCPN/BR. CONDS CONTG BYD 03Z THRU 09Z.

....

WAUS46 KPCI 012045

WA6T

SFOT WA 012045

AIRMET TANGO UPDT 3 FOR TURB AND STG SFC WNDZ VALID UNTIL 020300

AIRMET TURB...CA AND CSTL WTRS

FROM 40WSW RBL TO 30WNW EHF TO 50SSW SNS TO 30SW ENI TO 60S FOT
TO 40WSW RBL

MOD TURB BLW 100. CONDS ENDG 21-00Z.

**AIRMET TURB...WA OR CA ID MT WY NV UT AZ NM AND CSTL WTRS
FROM 30NNW PDT TO 50NNW LKT TO 30SE PIH TO 30N MTU TO 60WSW RSK
TO 80SSW RSK TO 60ESE SJN TO 60SE SSO TO 50S TUS TO BZA TO 20S
MZB TO 40N LAX TO 60ESE RBL TO 70S LKV TO 60ESE LKV TO 30NNW PDT
MOD TURB BLW 160. CONDS CONTG BYD 03Z THRU 09Z.**

AIRMET STG SFC WNDZ...CA NV UT

FROM 60WNW BVL TO 50E ELY TO 30NE ILC TO 60NNE LAS TO 40ESE BTY
TO 50S BTY TO 50NNE CZQ TO 70E FMG TO 20W BAM TO 60WNW BVL
SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG BYD 03Z
ENDG 03-06Z.

AIRMET STG SFC WNDZ...CA

FROM 20SSW BTY TO 40WSW LAS TO 40ENE HEC TO 20WSW HEC TO 50W TRM
TO 50SSE EHF TO 50NNE EHF TO 20SSW BTY
SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG BYD 03Z
ENDG 03-06Z.

AIRMET STG SFC WNDZ...CA

**FROM 50SE HEC TO 60SSE TRM TO 30SE MZB TO 40SSW HEC TO 50SE HEC
SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS ENDG BY 03Z.**

8.0 Weather Briefing Information

A search of the FAA contract Automated Flight Service Station provider Leidos indicated that neither they nor any third party vendors utilizing the LFS system had any contact with the flight for any weather briefing information on the day of the accident. A separate search of ForeFlight indicated that the pilot did not have an account with them and there were no weather briefings or flight plans filed for N2038Y on the day of the accident. It is unknown what weather information, if any, the accident pilot checked or received before or during the accident flight.

9.0 Astronomical Conditions

The United States Naval Observatory's website²⁴ provided the following astronomical conditions over Big Bear City, California on May 1, 2023.

<u>Sun</u>	<u>Time (PDT)</u>
Begin civil twilight	0531
Sunrise	0558
Upper transit	1244
<i>Accident</i>	<i>1402</i>
Sunset	1932
End civil twilight	1958

At the time of the accident the sun was 64° above the horizon at an azimuth of 227°.

10.0 Mountain Wave References

The FAA published Advisory Circular AC 00-57 "Hazardous Mountain Winds and Their Visual Indicators" in 1997 to assist pilots diagnose the potential for severe wind events in the vicinity of mountainous areas. The advisory circular provides information on preflight planning techniques and on in-flight evaluation strategies for avoiding destructive turbulence and loss of aircraft control. The advisory circular discussed the general formation and types of mountain wave conditions, which have been summarized below.

The illustrations are from the University Center for Atmospheric Research (UCAR) COMET web based training program "Mountain Waves and Downslope Winds" issued in July 2004.

Atmospheric Disturbances in Mountainous Areas

As strong winds move over mountains or high terrain and the atmosphere is stable, a wave will develop. The wave that forms vertical displacement of a stable air mass over a mountain or ridge can generate two forms: a vertically propagating mountain waves and trapped lee waves. The particular type of wave or combination of waves that forms depend on the nature of the mountain range and on the atmospheric properties upwind of the mountain. It is possible for both types of wave to exist at the same time, or a hybrid form where waves that are only partially trapped.

²⁴ <https://aa.usno.navy.mil/data/index>

Vertical Propagating Mountain Waves

Figure 16 is a schematic of a vertically propagating mountain wave. With this type of wave feature, air that is moving nearly perpendicular to the barrier is deflected upward and accelerated as it passes over the crests and down the lee slope of the terrain. A standing wave develops vertically above the mountain crest and that the resultant wave tilts upwind with height. Note the amplitude of the wave increases with height and results in significant updrafts above the ridge at altitude. With a wave of modest amplitude where the vertical displacement of air moving through the wave is relatively limited, an aircraft flying through this region would likely experience appreciable "wave action," with altitude and/or airspeed fluctuations, but with little turbulence. However, with sufficient amplitude, the wave breaks, and localized updrafts and downdrafts occur. The consequence for a pilot flying through this region include airspeed and altitude deviations and the possible sudden onset of severe or extreme turbulence.

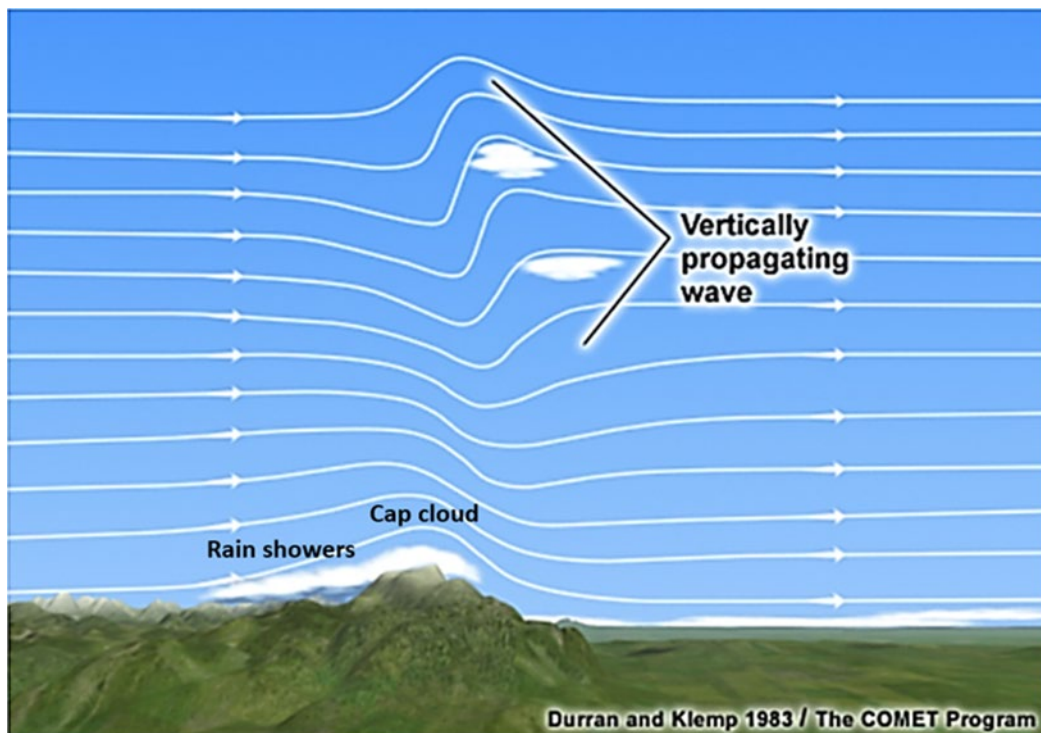


Figure 16 - AC 00-57 "Hazardous Mountain Winds and their Visual Identification" depiction of a vertical propagating mountain wave.

Often accompanying these high altitude effects is the occurrence of very strong surface winds in the form of downslope winds, that creates a low-level hazard to all aircraft. Further, these extreme low-level winds often terminate abruptly in a "jump" located some distance to the lee of the mountains themselves. These features are depicted schematically in figure 17. The jump region (or hydraulic jump²⁵) is frequently an area of sever-to-extreme turbulence extending to 10,000 ft or more above the surface. The jump region is sometimes

²⁵ Hydraulic Jump - A steady disturbance in the lee of a mountain, where the airflow passing over the mountain suddenly changes from a region of low depth and high velocity to a region of high depth and low velocity. Hydraulic jumps by their nature are a region of turbulence flow.

marked by a line of ragged rotor clouds exhibiting very turbulent motion, with turbulence typically decreases with distance away from the jump region.

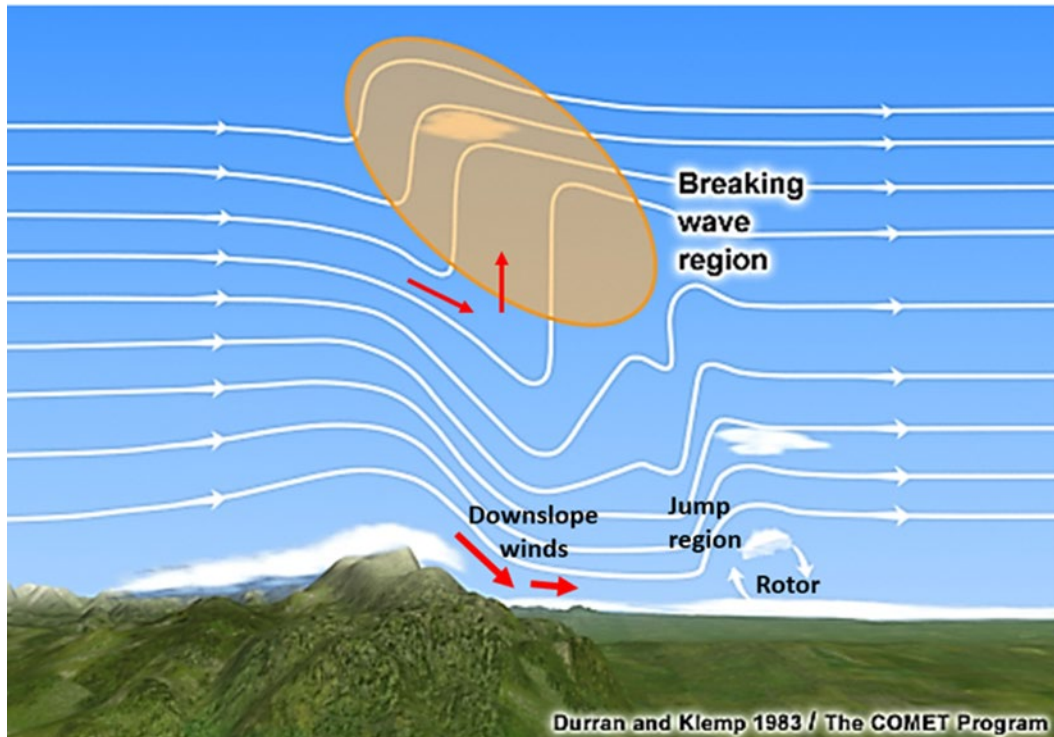


Figure 17 - AC 00-57 "Hazardous Mountain Winds and their Visual Identification" depiction of a breaking vertical propagating wave with downslope winds and pressure jump.

Summary Comments on Vertically Propagating Mountain Waves

- Large-scale winds at ridge level, blowing perpendicular (or nearly so) to the ridge-line, are normally required.
- Wind speeds at ridge level are normally 20 knots or greater.
- Relatively weak vertical wind shear is present. Typically, the ratio of the wind speed 6,000 ft above the ridge-top level to that at ridge-top level is less than 1.6 when this class of wave is of operational concern.
- The atmosphere is relatively stable. If there is a steep temperature lapse rate below 500-hPa (an unstable atmosphere), with evidence of convection present, this type of atmospheric wave is unlikely to form.
- Vertically propagating waves are most likely and most intense during the winter and early spring months, when the winds at ridge level are strongest.
- In the general prevailing westerly flow, these waves are most prevalent over mountain ranges that have a north-south orientation.
- Stronger ambient winds lead to a deeper wave.
- The greater the atmospheric stability, the shallower the wave (for a given wind speed).

Trapped Lee Waves

Trapped lee wave are often marked by a train of altocumulus standing lenticular (ACSL) clouds extending far downwind of the mountain. They are evident as relatively straight lines or bands of clouds with clear spaces between the bands and form parallel to and down range of the mountain range. The waves that produce these cloud features are often referred to as "trapped lee waves," because the wave energy is confined below a certain altitude. The mechanism confining this energy is strong wind shear above the ridge level. Trapped lee waves are most likely to occur when the wind crosses a narrow mountain range, with a layer close to the ridge level and upstream of the mountain that has a strongly increasing wind speed with height and high stability, capped by a layer of strong flow and low stability. Figure 18 is a depiction of a trapped lee waves. Notice that this wave type of wave extends downwind from the mountain, but does not develop to a very high altitude, and has no upstream tilt, in contrast to the vertically propagating wave.

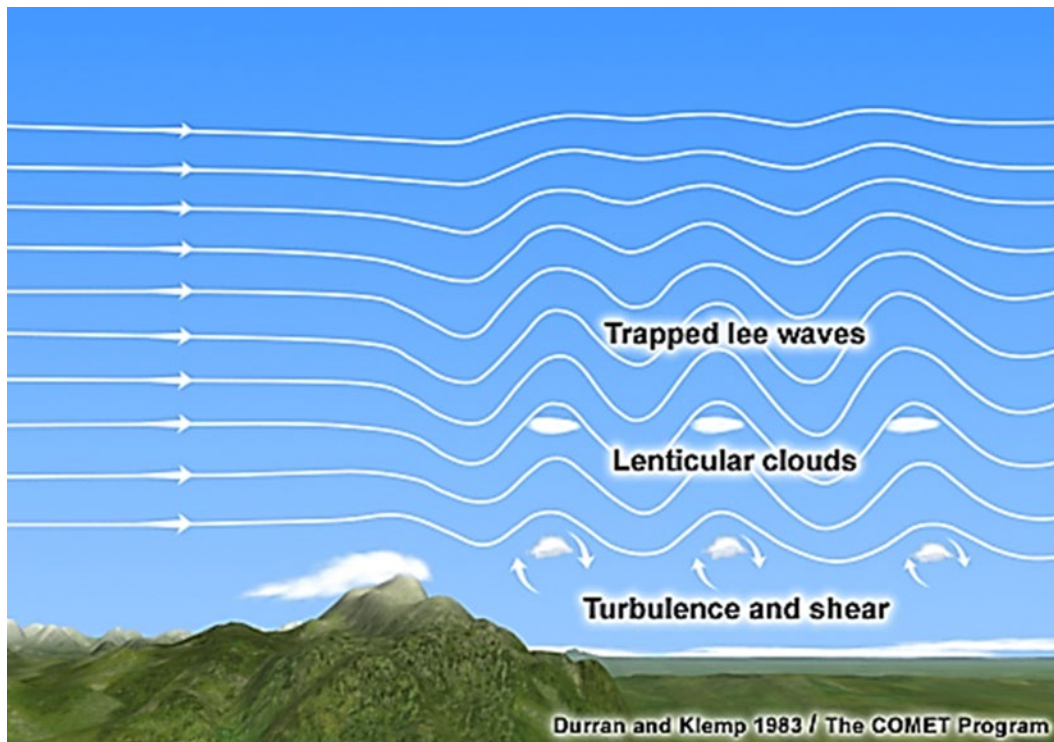


Figure 18 - AC 00-57 "Hazardous Mountain Winds and their Visual Identification" depiction of trapped lee waves and lenticular clouds.

This class of wave typically presents less turbulence hazard than do breaking vertically breaking waves, because the wave amplitude decreases with height within the "trapping layer," typically based within a few thousand feet of the ridge crest. As a result, these waves do not typically extend to as great altitude.

However, at lower altitude trapped lee waves can create strong turbulence encounters for aircraft. Cloud bases associated with trapped lee waves are typically one to several thousand feet above the ridge level, and pilot reports in the vicinity frequently indicate moderate-to-severe turbulence beneath the clouds, related to large horizontal and vertical wind shears below the cloud level.

In all cases, the forecast and/or measurement of ambient winds near the ridge level of 20 knots or more should cause pilots to presume that wave activity is present and take appropriate actions .

Summary Comments on Trapped Lee waves

- *Trapped lee waves do not propagate vertically because of the capping effects of strong wind shear or low stability above.*
- *Aircraft turbulence encounters related to trapped lee waves are generally restricted to lower altitudes, whereas vertically propagating waves can affect all altitudes.*
- *Strong turbulence can develop near the bases of accompanying lenticular clouds, although such clouds may not be present.*
- *Forecasts of winds 20 knots or greater at the ridge level should alert pilots to the likelihood of wave activity.*

Persistent Horizontal Roll Vortices (Rotors)

When mountain waves are present, it is quite common for a rotor zone to develop near or below the ridge level on the downwind side of the mountain, under a wave crest and associated lenticular clouds (if sufficient moisture is present). This is an area of potential severe-to-extreme wind shear and turbulence.

Figure 19, from Bedard²⁶, shows a schematic of the wind flow associated with this feature. As illustrated in this schematic, rotors typically mark the downwind terminus of a downslope windstorm. When this is the case, the rotor is really part of the “jump”. Although strong rotation is typically present within the rotor zone and associated cloud, a pilot in a moving aircraft may not be able to detect such motion visually until the aircraft is quite close to the vortex. In fact, from a distance a rotor cloud may look like a rather innocuous cumulus cloud; however, the downwind side of the rotor cloud will typically be rounded in the direction of rotation or the rotor, with cloud tags or streamers at the bottom of the cloud mass. The latter features appear to be rapidly forming and dissipating, thereby giving some sense of rotation with the cloud.

²⁶ Bedard, A. J., 1993: Atmospheric turbulence aloft: A review of possible methods for detecting, warning, and validation of predicted models. Washington, DC: American Institute of Aeronautics and Astronautics.

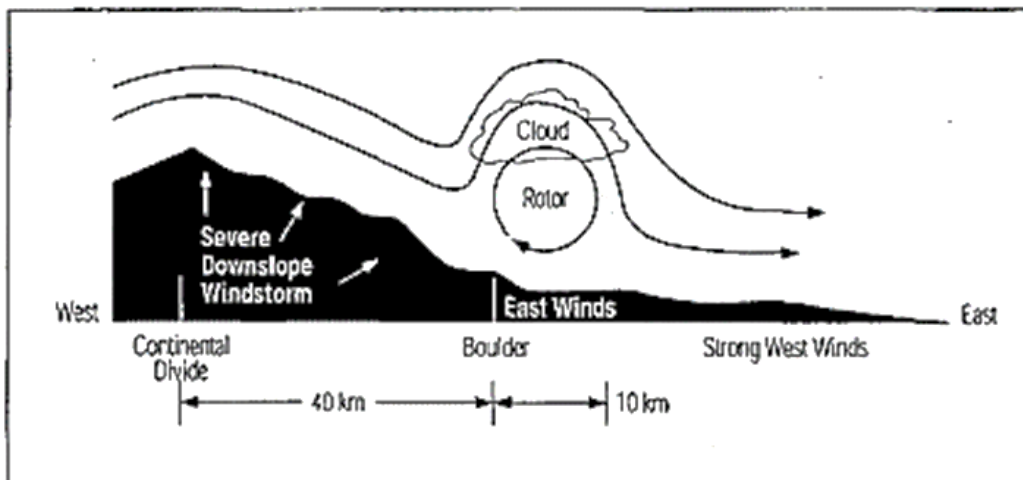


Figure 19 - AC 00-57 "Hazardous Mountain Winds and their Visual Identification" conceptual view of a mountain lee wave rotor zone (Bedard, 1993).

Because of their potential for causing turbulence and loss of aircraft control, rotor zones should be avoided. Doppler lidar measurements in rotor have documented rotational speeds greater than 20 knots. Rotor zones are of concern not only because of the likelihood of strong turbulence in their vicinity (particularly on the upwind side of the rotor), but also because of the potential for rolling moments that could exceed the roll authority of the aircraft or otherwise lead to loss of control.

Since rotor zones can be a product of either type of mountain wave, the previously discussed forecast and observed data and the associated rules can also be applied in forecasting the likelihood of rotor zones. When waves are present, one should assume that a rotor zone exists below the ridge level and within 20 nm of the ridge. Pilots should be particularly cautious when they know or suspect that breaking vertical propagating waves or a downslope windstorm are occurring. Under these conditions, the rotor or jump zone will very likely be a location of severe-to-extreme turbulence and, in addition to horizontal axis vortices, may also contain vertical axis vortices of great intensity.

11.0 Weather Research and Forecast Model

The NTSB ran a Weather Research and Forecasting (WRF) model simulation surrounding the time of the accident using initialization data from the North American Mesoscale model (NAM)²⁷. The terrain used in WRF are provided in figure 20 for

²⁷ NAM218 WRF ARW (Advanced Research WRF core) was run with 3 domains with horizontal grid spacing of 6 km, 1.2 km, and 320 m. Other WRF simulation parameters included: 60 vertical levels, the multi-scale 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, the Dudhia scheme used for short wave radiation, and the RRTM scheme for the long wave radiation. North American Mesoscale Forecast System, National Centers for Environmental Information (NCEI)

domain 2 (left) and for domain 3 (right) with height in ft, and the star depicting the approximate accident site.

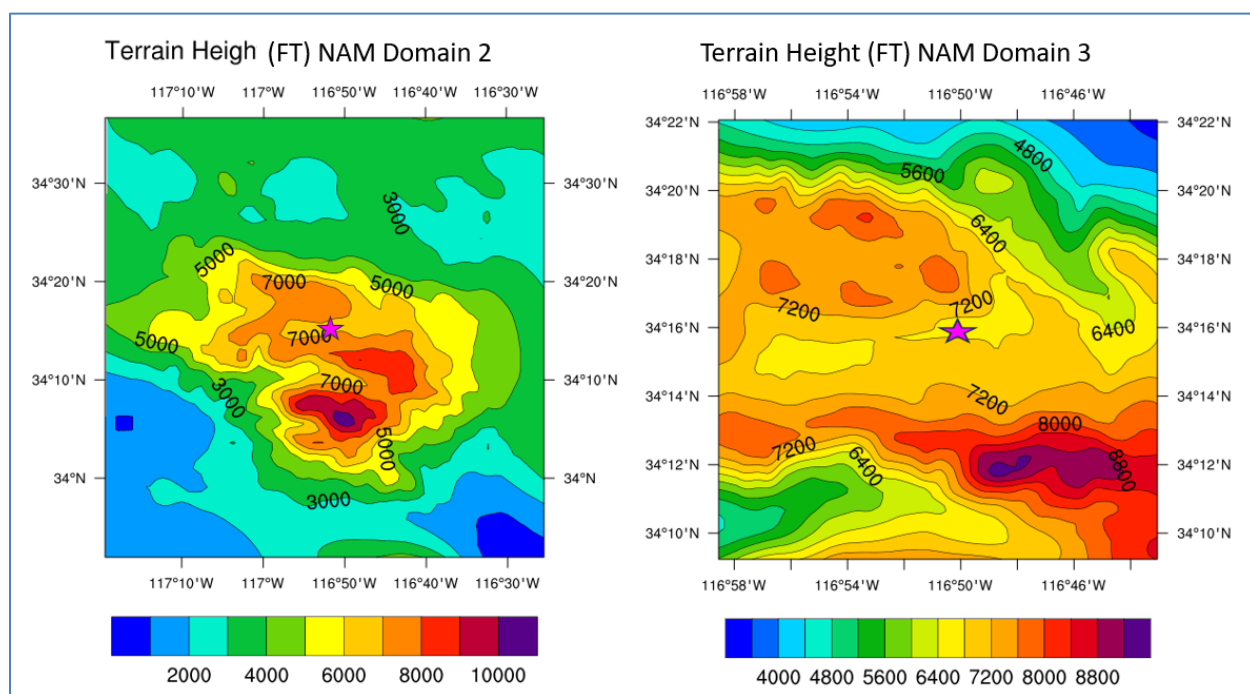


Figure 20 - WRF terrain for domain 2 (left) and domain 3 (right) with height in feet, with approximate accident site depicted by purple star.

Figures 21-23 are a depiction of the WRF domain 3 topography west-to-east cross section of the isentropes²⁸ or lines of potential temperature (in degrees Kelvin) and horizontal wind speeds at 1300, 1320, 1340, 1400, 1420, 1440, and 1500 PDT with the accident site located in the middle of the image near the grid point 40. Followed by figures 24-26 which depict the isentropes and vertical velocity in feet per minute (fpm) from 800- to 650-hPa for the same period. The images 21-23 depicted a band of winds from 14 to 22 knots descend to the surface and move eastward over the area with time, while the vertical velocity data showed a series of waves with downdrafts/updrafts also moving eastward with time. The maximum vertical velocities of 200 to 800 fpm moving over the area with strong winds at about 1300 PDT, like what is observed with a hydraulic jump.

(noaa.gov). Similar NAM 500-hPa charge depicted in figure 6.

²⁸ An isentropic process is an adiabatic process where there is parcel no heat exchange with its environment. For synoptic scale weather systems, air parcels generally move along constant potential temperatures or theta (isentropic) surfaces, and not constant pressure surfaces. Isentropic analysis allows the ability to attain quantitative estimates of vertical motion and coherently track air flow and the 3-dimensional transport of moisture in space and time.

Figures 27-29 are the WRF streamline²⁹ analysis for 770-hPa or approximately 7,000 ft from 1300 through 1440 PDT, depicted a convergence zone with winds from the south-southwest to the west of the accident site and from the northeasterly to the east of the boundary, with several eddies along the boundary. The convergence zone moves eastward through the accident area from 1240 through 1300 PDT. The change in wind direction is similar to what is shown associated with the rotor cloud in figure 19 above.

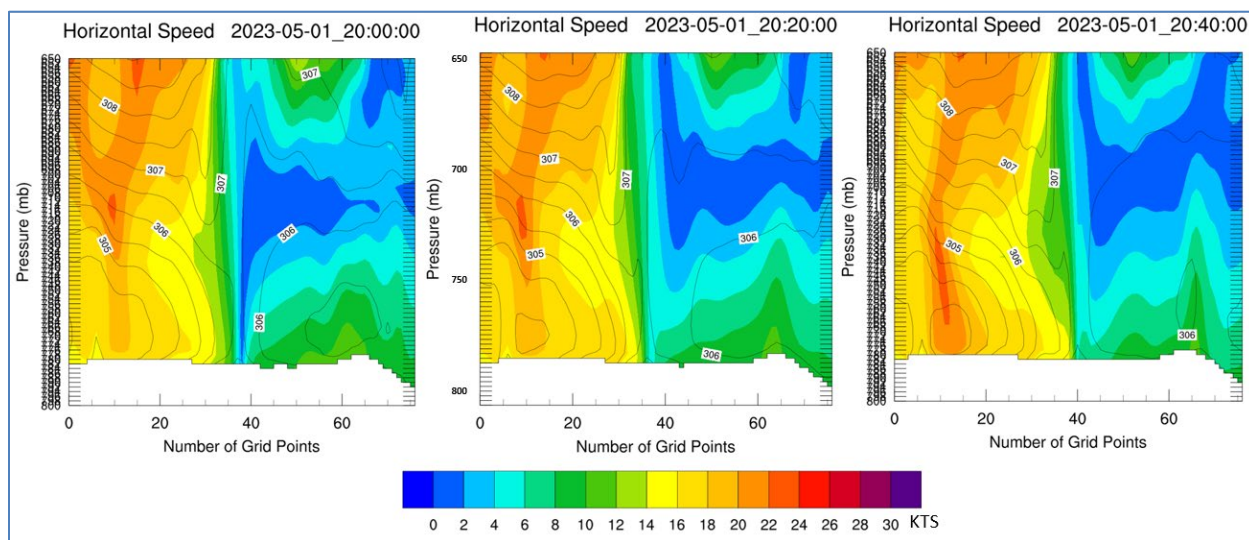


Figure 21 - WRP west-to-east cross section of isentropes and horizontal wind speeds and at 1300, 1320 and 1340 PDT, with the accident site is near center near grid 40.

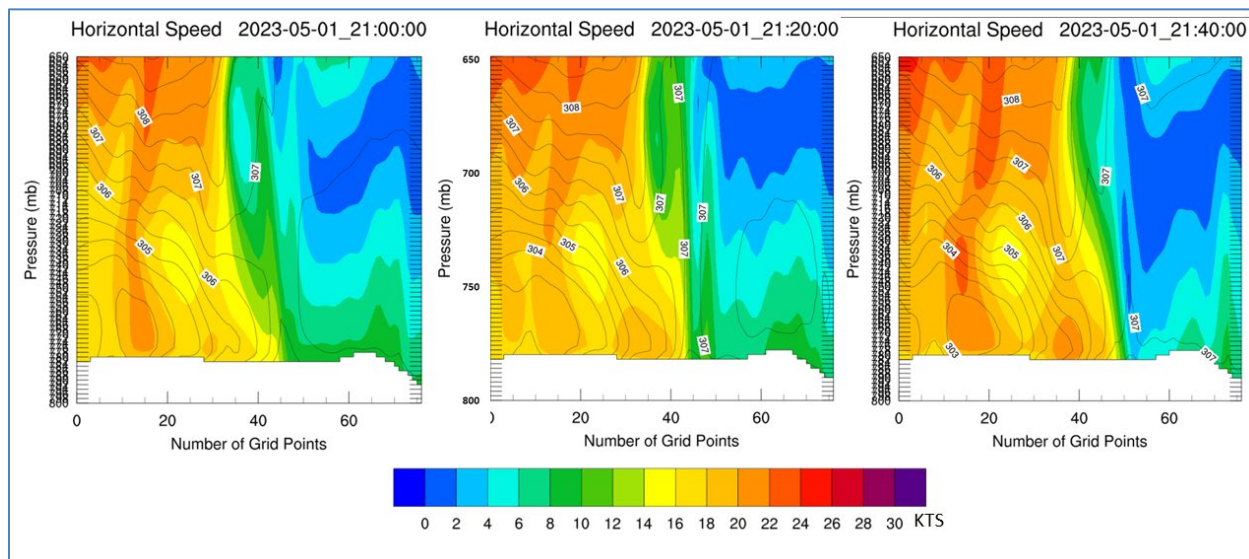


Figure 22 - WRP west-to-east cross section of isentropes and horizontal wind speeds and at 1400, 1420 and 1440 PDT, with the accident site is near center near grid 40.

²⁹ A streamline is a line with its tangent at any point in a fluid parallel to the instantaneous velocity of the fluid at that point. In meteorology it provides a depiction of the wind field.

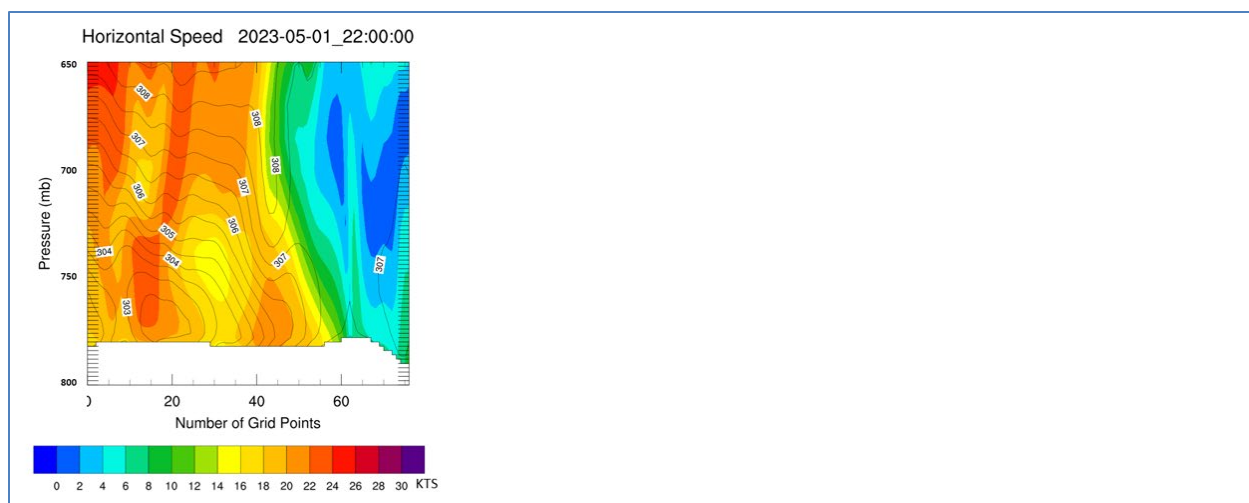


Figure 23 - WRP west-to-east cross section of isentropes and horizontal wind speeds and at 1500 PDT with the accident site near grid point 40.

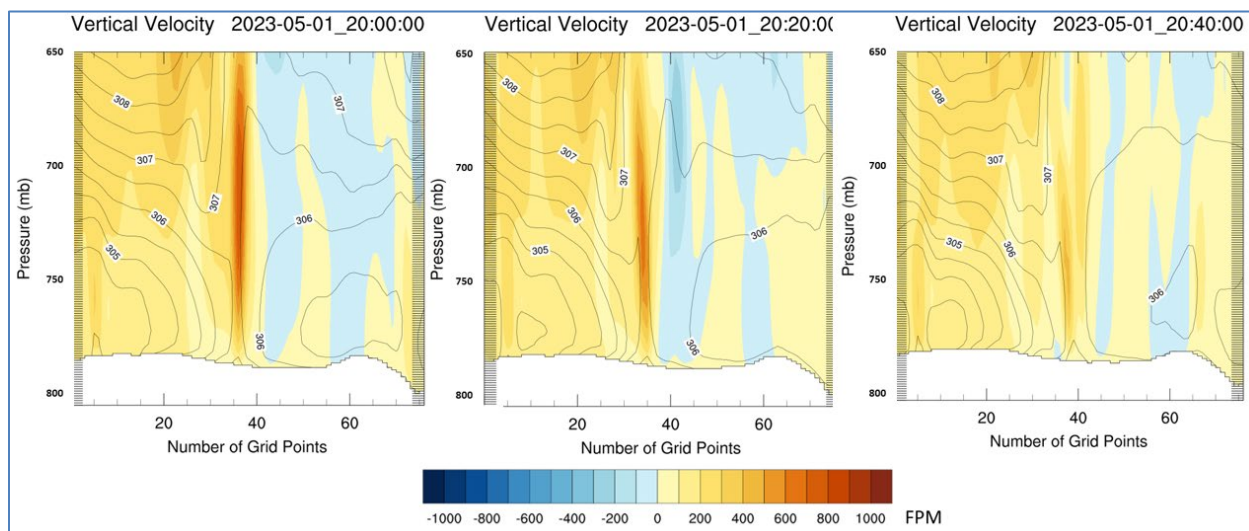


Figure 24 - WRP west-to-east cross section of isentropes and vertical velocity at 1300, 1320, and 1340 PDT with the accident site near grid point 40.

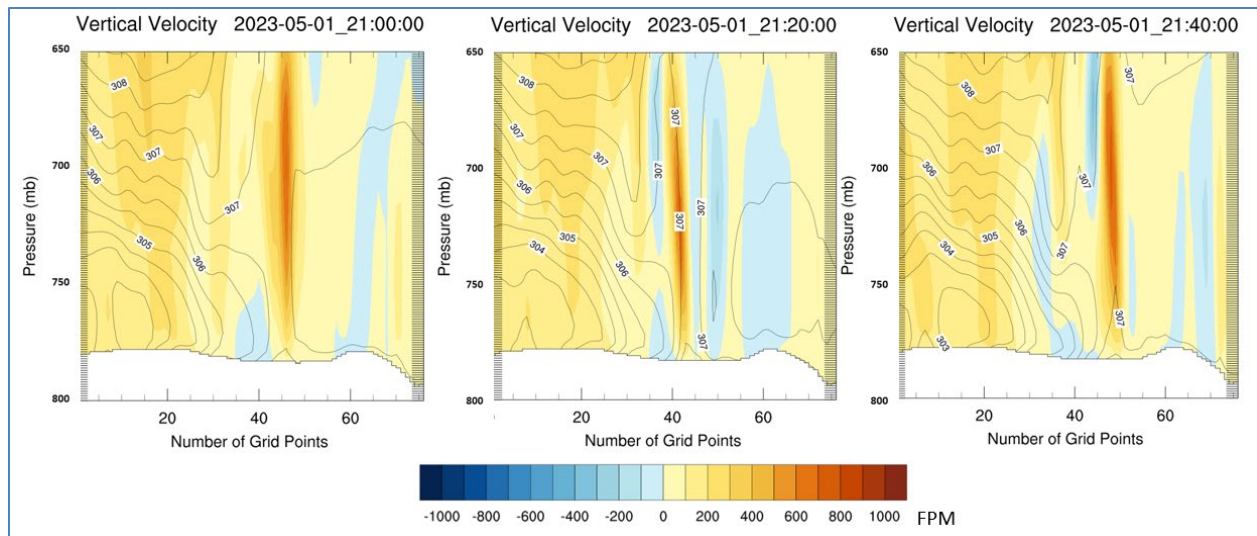


Figure 25 - WRP west-to-east cross section of isentropes and vertical velocity at 1400, 1420, and 1440 PDT with the accident site near grid 40.

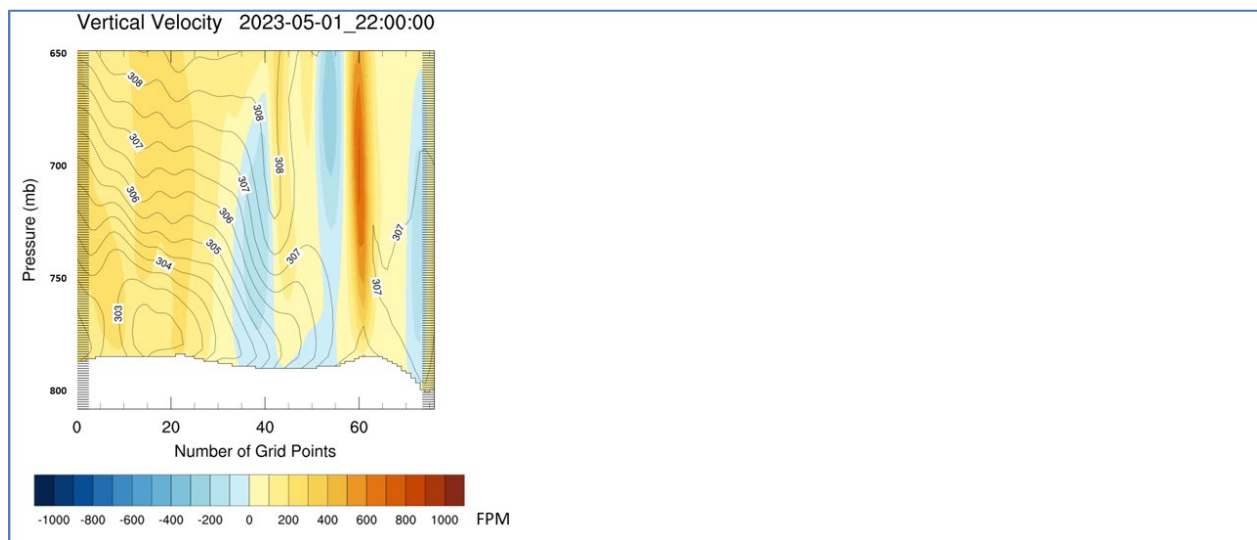


Figure 26 - WRP west-to-east cross section of isentropes and vertical velocity at 1500 PDT with the accident site near grid 40.

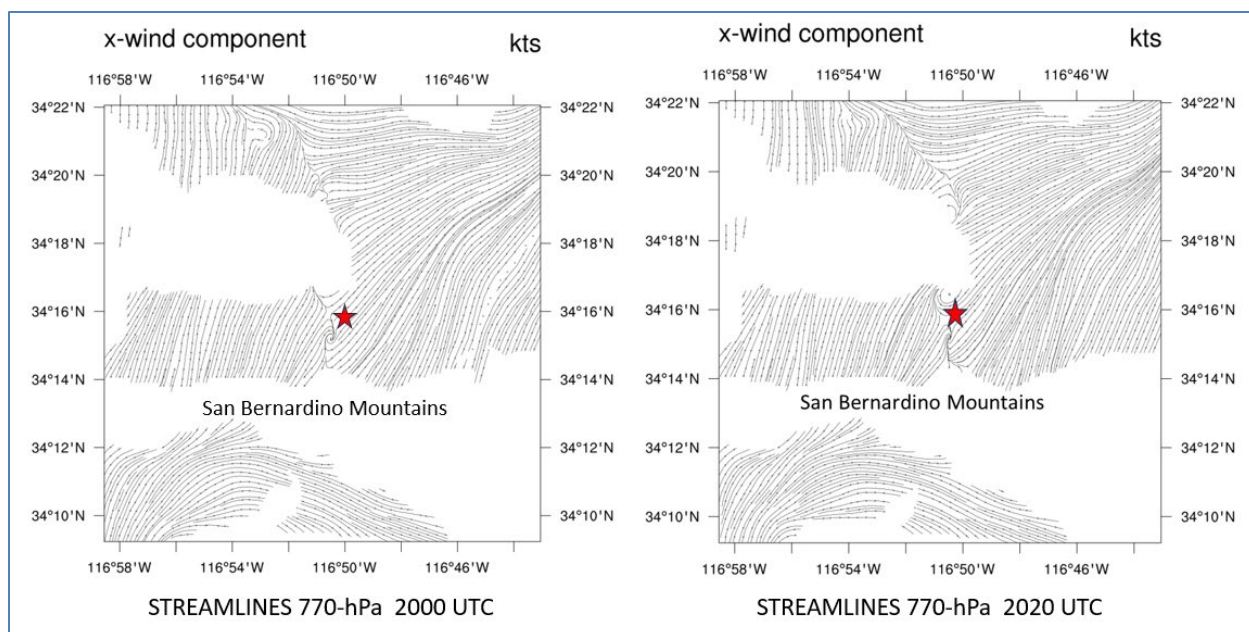


Figure 27 - WRF streamlines at 770-hPa at 1300 and 1320 PDT with approximate accident site marked by the red star.

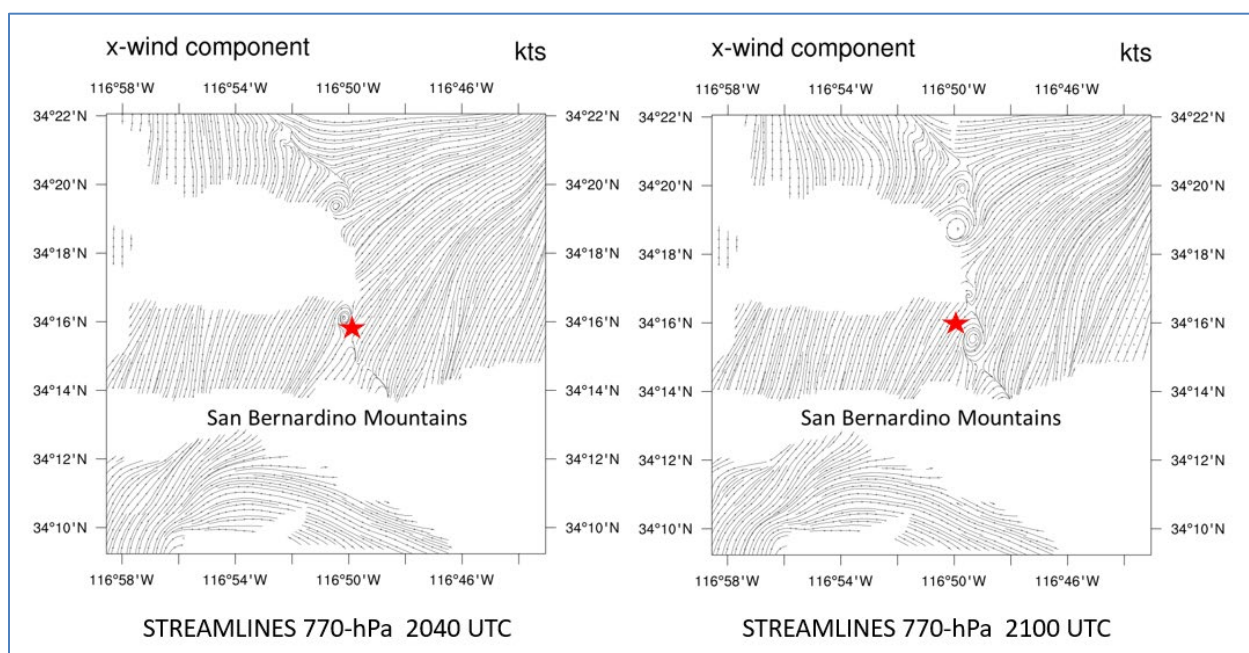


Figure 28 - WRF streamlines at 770-hPa at 1340 and 1400 PDT with approximate accident site marked by the red star.

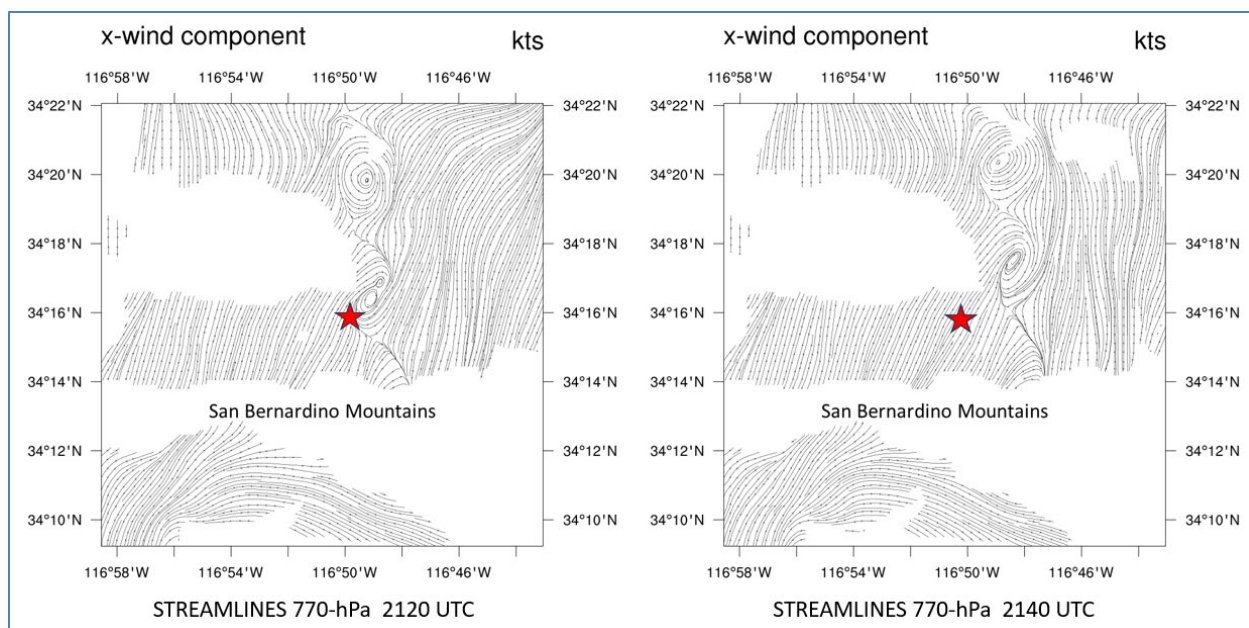


Figure 29 - WRF streamlines at 770-hPa at 1420 and 1440 PDT with approximate accident site marked by the red star.

F. ATTACHMENTS

Attachment 1 - GOES-18 GeoColor satellite animation surrounding the period of the accident.

Attachment 2 - WRF numerical model domain and raw imagery from 1300 through 1500 PDT in PowerPoint format.

Submitted by:

Donald Eick
NTSB Senior Meteorologist