



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

May 10, 2021

Specialist's Factual Report

METEOROLOGY

WPR21LA111

Table Of Contents

A.	ACCIDENT	4
B.	METEOROLOGIST SPECIALIST.....	4
C.	SUMMARY.....	4
D.	DETAILS OF THE INVESTIGATION	4
E.	WEATHER INFORMATION.....	5
1.0	Synoptic Conditions.....	5
1.1	Surface Analysis chart	5
1.2	Upper Air Charts.....	6
2.0	Observations	9
2.1	Tehachapi, California.....	9
2.2	Mojave, California	10
2.3	Lancaster, California.....	11
2.4	Sandberg, California	12
2.5	Edwards, California	13
2.6	Aviation Weather Centers METAR Display	14
2.7	MesoWest Observations	15
3.0	Sounding Information	16
3.1	Numerical Model Sounding.....	16
3.2	Aircraft Soundings.....	18
3.2.1	Aircraft #11179 Sounding.....	19
3.2.2	Aircraft #11914 Sounding.....	20
4.0	Satellite Imagery	20
5.0	Weather Radar Imagery	22
6.0	Pilot Reports.....	23
7.0	NWS Forecasts.....	26
7.1	Terminal Aerodrome Forecasts.....	27
7.2	Area Forecast Discussion.....	27
7.3	Graphic Forecast for Aviation	28
7.4	Winds Aloft Forecast	30
7.5	Overview of Graphic Turbulence Guidance Display.....	31
7.5.1	Graphic Turbulence Guidance (GTG) Imagery	32
7.5.2	Graphic Turbulence Guidance Nowcast (GTG-N) Imagery	34
8.0	Inflight Weather Advisories.....	35

9.0	Weather Briefing Information.....	38
10.0	Astronomical Conditions	38
11.0	Mountain Wave References	38
12.0	Weather Research and Forecast Models	43
12.1	NTSB WRF Model	43
12.2	NCAR Numerical Models.....	47
F.	LIST OF ATTACHMENTS	50

A. ACCIDENT

Location: Tehachapi, California
Date: February 13, 2021
Time: 1627 Pacific standard time
0027 Coordinated Universal Time (UTC) February 14, 2021
Airplane: Piper PA-46-350T; Registration: N40TS

B. METEOROLOGIST SPECIALIST

Don Eick
Senior Meteorologist
Operational Factors Division (AS-30)
National Transportation Safety Board

C. SUMMARY

On February 13, 2021, about 1627 Pacific standard time, a Piper PA46R-350T airplane, N40TS, was destroyed when it was involved in an accident near Tehachapi, California. The pilot was fatally injured. The airplane was operated by the pilot as a Title 14 *Code of Federal Regulations* Part 91 personal flight.

D. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's (NTSB) Senior Meteorologist was not on scene for this investigation and conducted the meteorology phase of the investigation from the Washington D.C. office, collecting data from official National Weather Service (NWS) sources including the Weather Prediction Center (WPC) and the National Center for Environmental Information (NCEI). All times are Pacific standard time (PST) based upon the 24 hour clock, local time is +8 hours to UTC, and UTC=Z. 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.

This report provides a meteorological review on the weather conditions and NWS aviation weather products applicable to the region around the accident time. The accident site was based on the coordinates at latitude 35.0127° N and longitude 118.3873° W at an elevation of approximately 4,860 ft.

E. WEATHER 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) 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 and other weather products documented in this report can be found in the joint NWS and Federal Aviation Administration (FAA) Advisory Circular “Aviation Weather Services”, AC 00-45H change 2.

1.1 Surface Analysis chart

The southwest section of the NWS Surface Analysis Chart for 1600 PST with the approximate accident site marked by a red star is included as figure 1. The chart depicted a cold front extending west-southwest from a low pressure system over Utah at 995-hectopascals (hPa)¹ (located just off the regional view) across southern California and immediately south of the accident site. Another low pressure system was located to the east of the accident site over western Arizona at 996-hPa with a trough² of low pressure extending north and south of the low along the California and Arizona border. The accident site was located on the cold air side and immediately north of the front, with a strong pressure gradient³ of 16-hPa change in pressure between the low in western Arizona to the accident site about 220 miles west.

The station models surrounding the accident site depicted northwest to westerly winds of 20 knots with higher gusts, variable cloud cover from overcast clouds nearest the accident site to clear skies immediately east of the accident site, with a temperature near 44° Fahrenheit (F), with a dew point temperature near 37° F.

¹ Hectopascals (hPa) is the international standard for reporting sea-level pressure and is interchangeable with the term millibar (mb) with the same units. Standard sea-level pressure is 1013.25-hPa at a temperature of 59° Fahrenheit (F) or 15° Celsius (C).

² Trough, also abbreviated as TROF, is an elongated area of low pressure, and is similar to a front without a significant temperature discontinuity. Troughs are associated with a cyclonic shift in the wind, general convergence, and if sufficient moisture is present clouds and precipitation.

³ Pressure gradient is the rate of decrease in pressure in space at a fixed time, and denotes simply the magnitude of the gradient of the pressure field.

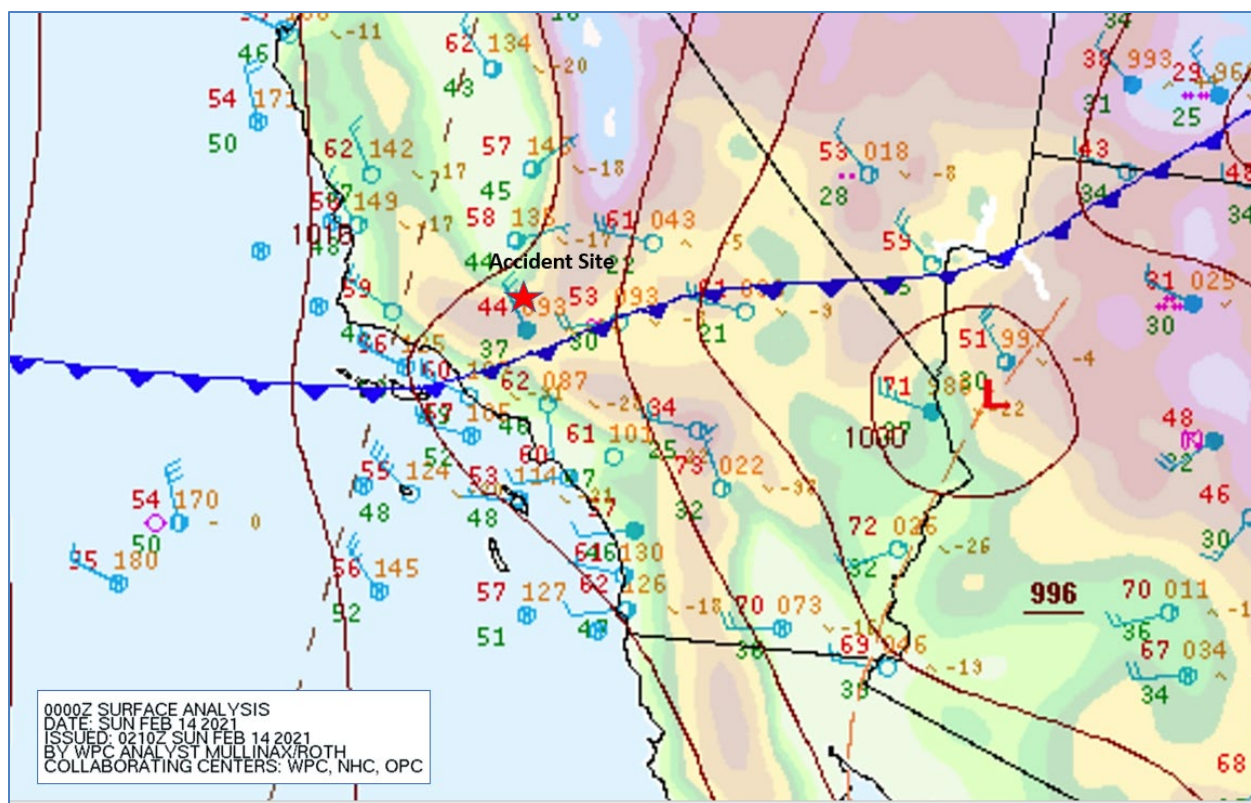


Figure 1 - Southwest section of the NWS Surface Analysis Chart for 1600 PST with the accident site marked by the red star.

1.2 Upper Air Charts

The NWS Constant Pressure Charts for 1600 PST (0000Z) for 850-, 700-, 500-, 300-, 250-hPa were obtained from the University of Wyoming archive site and are included as figures 2-6, with the approximate accident site marked by the red star. The charts depicted the observed pressure surface heights or contours, wind, temperature, and moisture fields aloft with the 300- and 250-hPa charts also including isotachs or lines of equal wind speed to highlight the location of the boundary of the jet stream with winds greater than 70 knots (light blue shade), and then at 20-knot intervals above that. The charts depicted a closed contour low-pressure system at 850-, 700-hPa over Utah, with a short wave trough extending westward and in the vicinity of the accident site. The low-pressure pressure system resulted in a north-northwesterly wind component over the accident site from 25 knots at 850-hPa or approximately 5,000 ft, and increased to 70 knots at 700-hPa or 10,000 ft, and to over 100 knots at 300-hPa or approximately 30,000 ft. A strong 165 knot jet streak was depicted over western Oregon into northern California, and western Nevada, north of the accident site digging⁴ southward over the west coast. The wind direction varied little over the accident site with wind speeds increasing with altitude.

⁴ Digging describes that the upper level jet stream and upper level trough is amplifying and slowing down and normally exists when the jet streak is strong on the left side of the trough than the right side.

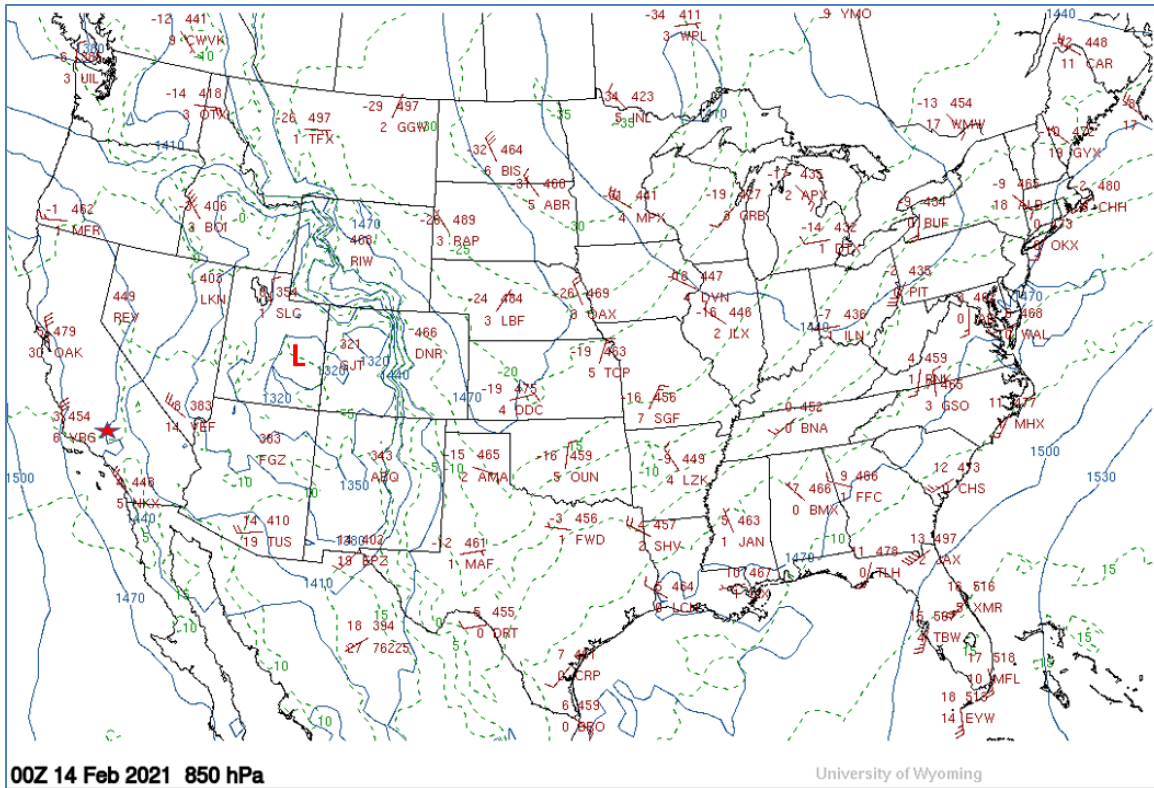


Figure 2 - 850-hPa Constant Pressure Chart for 1600 PST depicting the conditions at about 5,000 ft.

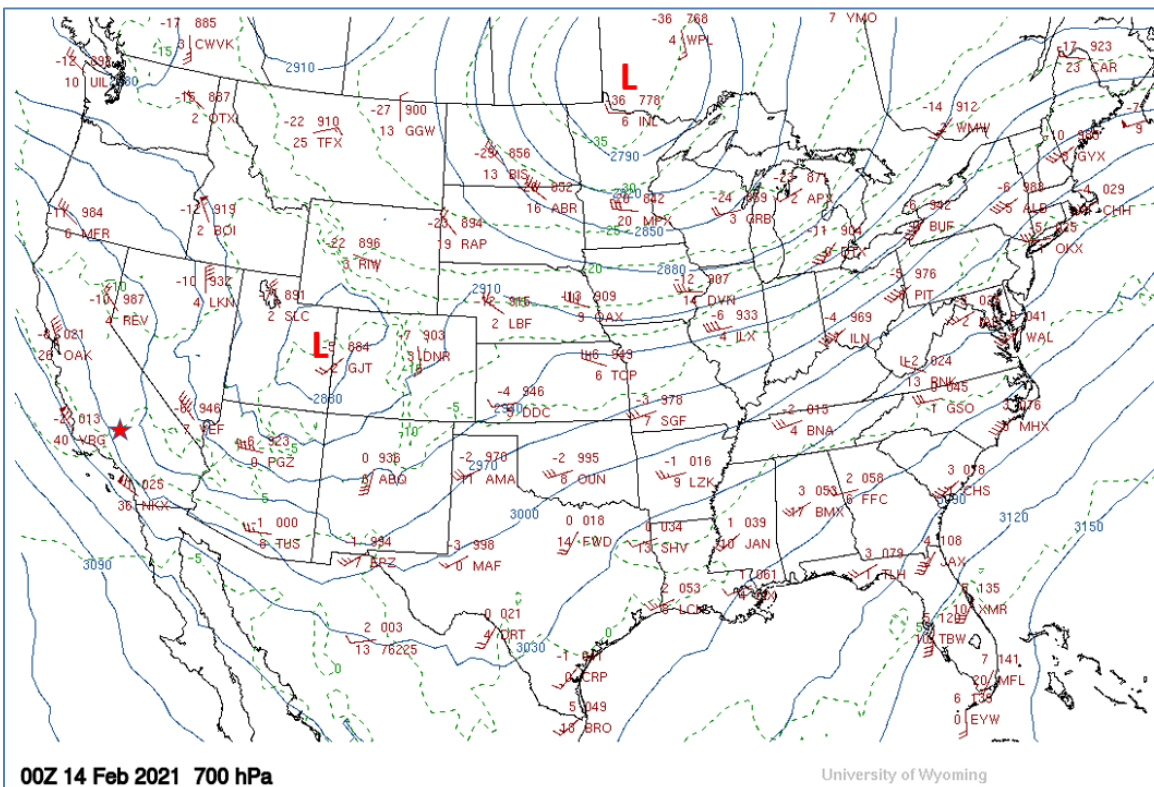


Figure 3 - 700-hPa Constant Pressure Chart for 1600 PST depicting the conditions at about 10,000 ft.

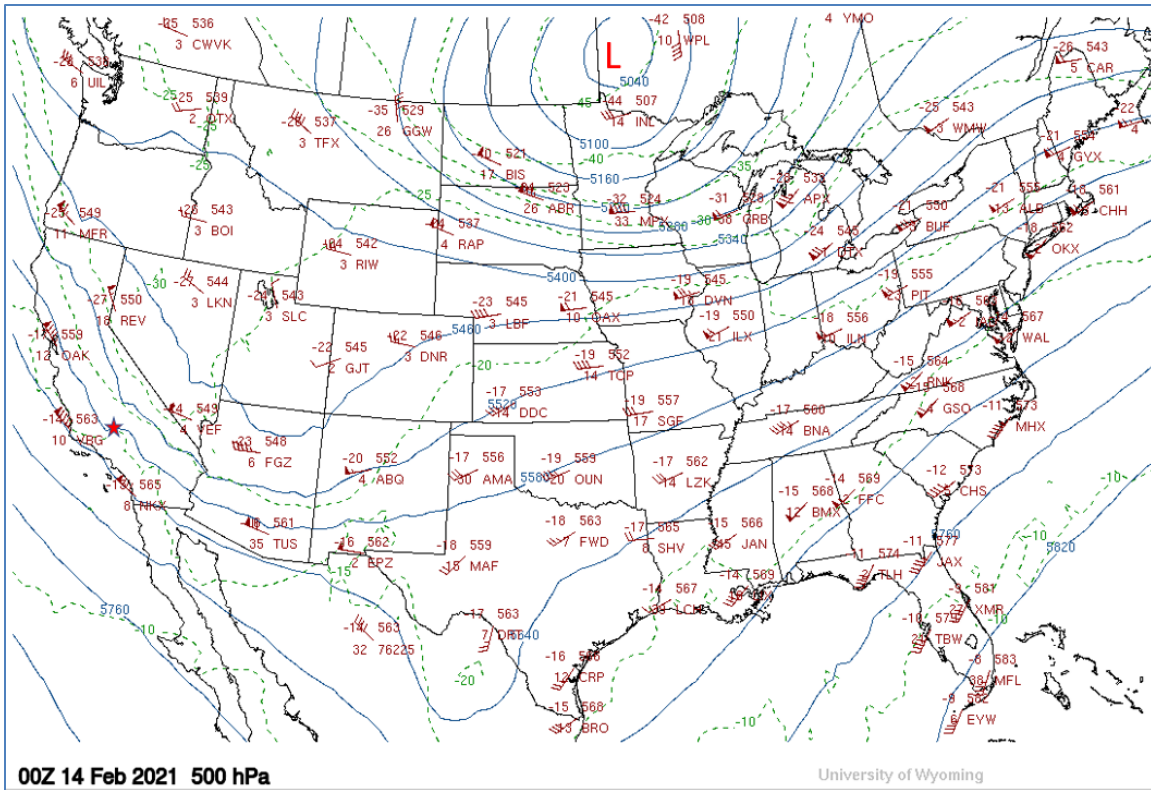


Figure 4 - 500-hPa Constant Pressure Chart for 1600 PST depicting the conditions at about 18,000 ft.

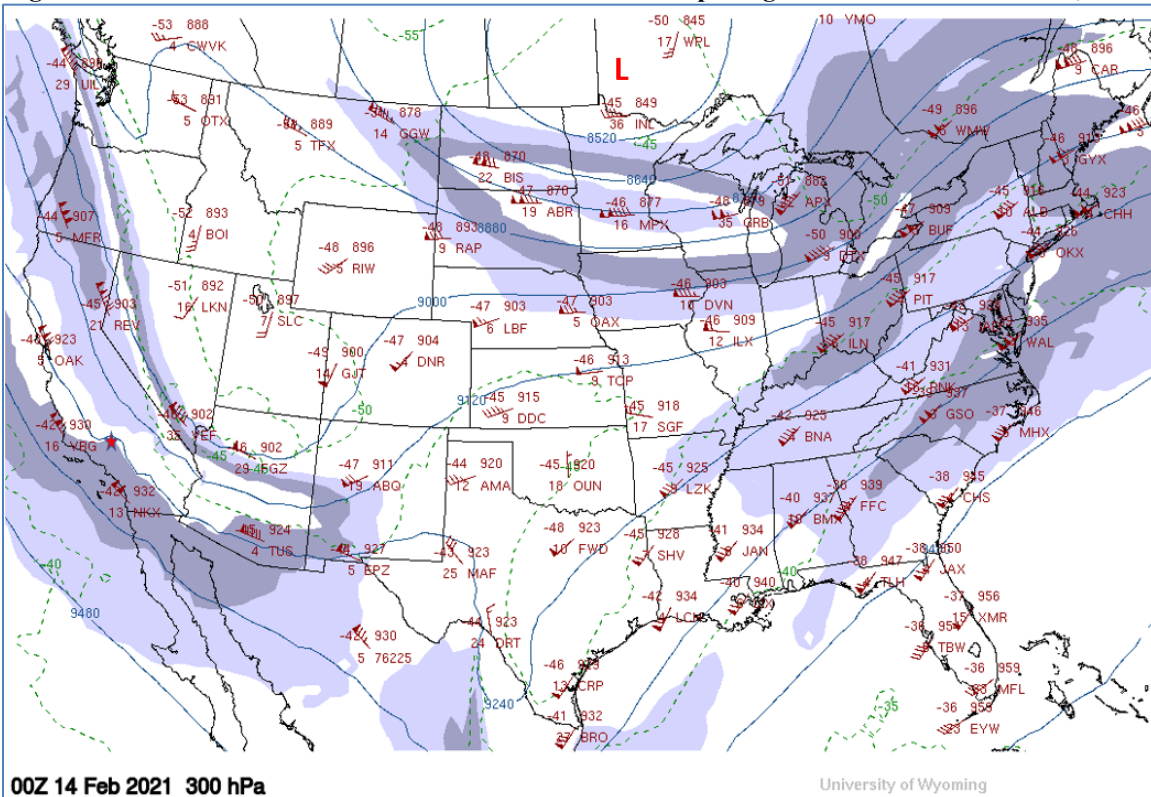


Figure 5 - 300-hPa Constant Pressure Chart for 1600 PST depicting the conditions at about 30,000 ft.

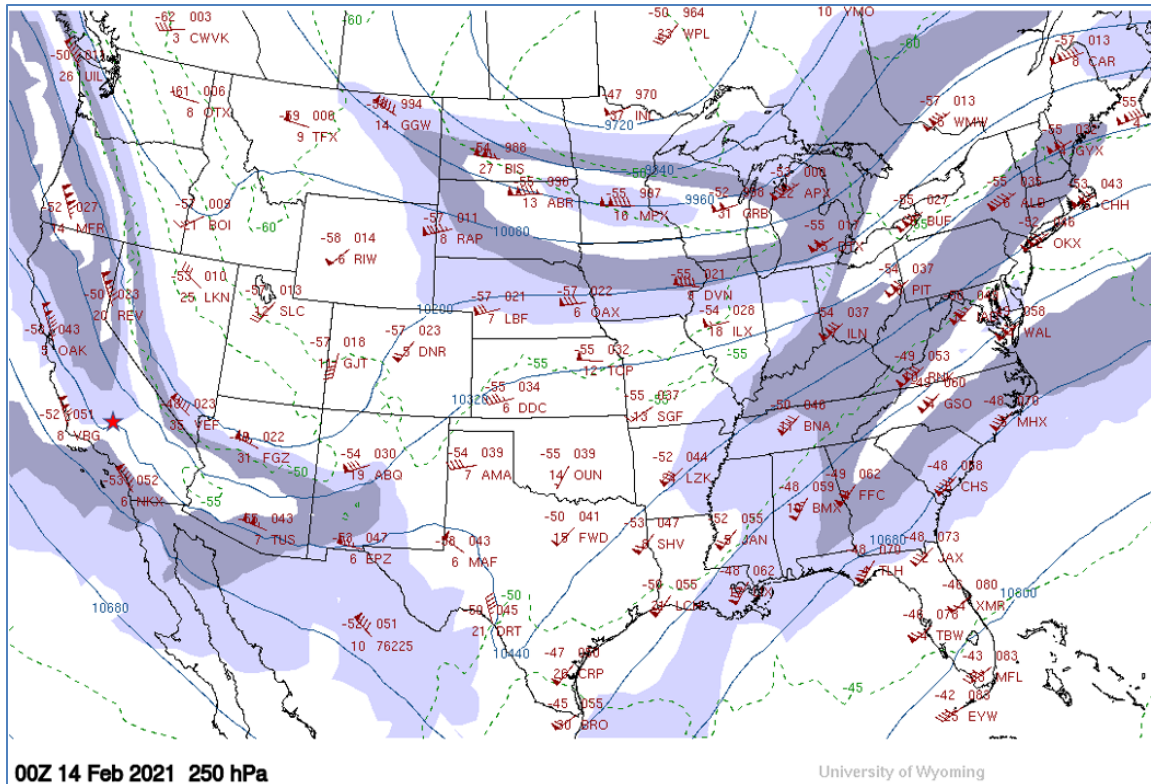


Figure 6 - 250-hPa Constant Pressure Chart for 1600 PST depicting the conditions at about 34,000 ft.

2.0 Surface Observations

The official NWS Meteorological Aerodrome Reports (METARs) and Special Reports (SPECIs) disseminated longline⁵ surrounding the period were documented for the area. The cloud heights are reported above ground level (agl) in the following section, and the magnetic variation over the region was estimated as 12° E based on the sectional chart for the area. A depiction of the closest reporting sites is included in figure 7 below.

2.1 Tehachapi, California

The closest weather reporting station to the accident site was from Tehachapi Municipal Airport (KTSP), Tehachapi, California, located approximately 7 ½ miles north of the accident site at an elevation 4,001 ft. The airport had an Automated Weather Observation System (AWOS) and issued observations every 20-minutes. The following conditions were reported at the approximate time of the accident.

KTSP weather observation at 1615 PST, automated, wind from 310° at 19 knots gusting to 26 knots, visibility 10 miles or more, ceiling⁶ broken at 1,200 ft agl, broken at 1,700 ft,

⁵ Longline refers to the dissemination of weather observations on national databases for accessibility to the NWS, FAA, weather vendors, and the general public. The observations are available typically every minute to pilot's on the station's Very High Frequency (VHR) broadcast to the local area for landing and takeoff operations.

⁶ A ceiling is defined as the lowest layer of clouds as reported as broken or overcast, or the vertical visibility into a surface based obscuration.

overcast at 2,500 ft, temperature 5° C, dew point 4° C, altimeter 29.92 inches of mercury (inHg).

The general flight categories⁷ and raw observations surrounding the period from 1035 through 1735 PST were as follows. The observation at the time of the accident decoded above is highlight in bold italic print and the peak wind gust noted.

IFR METAR KTSP 131835Z AUTO 31013G19KT 8SM BKN005 OVC010 03/03 A2999 RMK AO2
IFR METAR KTSP 131855Z AUTO 31014KT 8SM OVC005 04/04 A2998 RMK AO2
LIFR METAR KTSP 131915Z AUTO 30016KT 6SM BR OVC004 03/04 A2997 RMK AO2
LIFR METAR KTSP 131935Z AUTO 30014G22KT 7SM OVC004 04/04 A2996 RMK AO2
IFR METAR KTSP 131955Z AUTO 31014G21KT 9SM OVC005 04/04 A2995 RMK AO2
MVFR METAR KTSP 132035Z AUTO 29014G19KT 10SM SCT008 BKN013 OVC023 05/05 A2993 RMK AO2=
MVFR METAR KTSP 132055Z AUTO 27015G22KT 10SM FEW008 SCT012 BKN016 05/04 A2992 RMK AO2=
MVFR METAR KTSP 132115Z AUTO 27019G24KT 10SM BKN016 OVC022 05/03 A2992 RMK AO2=
MVFR METAR KTSP 132135Z AUTO 29017G27KT 4SM -RA BR OVC016 05/04 A2991 RMK AO2=
MVFR METAR KTSP 132155Z AUTO 29016G22KT 10SM BKN016 OVC021 05/04 A2990 RMK AO2=
MVFR METAR KTSP 132215Z AUTO 30018G25KT 7SM UP OVC019 06/04 A2990 RMK AO2=
MVFR METAR KTSP 132235Z AUTO 30029G36KT 10SM BKN018 OVC026 06/03 A2990 RMK AO2=
MVFR METAR KTSP 132255Z AUTO 30029**G40KT** 3SM -RA BR BKN019 BKN025 OVC034 05/03 A2990 RMK AO2=
UNKN METAR KTSP 132315Z AUTO RMK AO2 PNO PWINO FZFRANO TSNO=
UNKN METAR KTSP 132335Z AUTO 31018G28KT 10SM 05/04 A2991 RMK AO2=
MVFR METAR KTSP 132355Z AUTO 31022G29KT 10SM BKN012 OVC018 05/04 A2992 RMK AO2=
MVFR **METAR KTSP 140015Z AUTO 31019G26KT 10SM BKN012 BKN017 OVC025 05/04 A2992 RMK AO2**
Accident 0027Z
MVFR METAR KTSP 140035Z AUTO 31016G26KT 10SM FEW011 BKN016 OVC039 05/03 A2992 RMK AO2=
MVFR METAR KTSP 140055Z AUTO 31021G26KT 10SM SCT013 BKN026 OVC038 05/04 A2992 RMK AO2=
MVFR METAR KTSP 140115Z AUTO 30019KT 10SM SCT009 BKN013 OVC030 05/04 A2992 RMK AO2=

2.2 Mojave, California

The next closest weather reporting station was located approximately 12 miles east of the accident site at Mojave Air and Space Port (KMHV), Mojave, California, with an elevation of 2,801 ft. The airport also had an AWOS and issued observations every 20-minutes. The following conditions were reported at the approximate time of the accident.

KMHV weather observation at 1620 PST, automated, wind from 300° at 33 knots gusting to 47 knots, visibility 10 miles or more, sky clear below 12,000 ft agl, temperature 10° C,

⁷ As defined by the NWS and the FAA Aeronautical Information Manual (AIM) section 7-1-7, which defines the following general flight categories based on weather conditions reported:

- Low Instrument Flight Rules (LIFR*) – ceiling below 500 ft above ground level (agl) and/or visibility less than 1 statute mile.

- Instrument Flight Rules (IFR) – ceiling between 500 to below 1,000 feet agl and/or visibility 1 to less than 3 miles.

- Marginal Visual Flight Rules (MVFR**) – ceiling from 1,000 to 3,000 ft agl and/or visibility 3 to 5 miles.

- Visual Flight Rules (VFR) – ceiling greater 3,000 ft agl and visibility greater than 5 miles.

* By definition, IFR is a ceiling less than 1,000 ft agl and/or visibility less than 3 miles while LIFR is a sub-category of IFR.

**By definition, VFR is a ceiling greater than or equal to 3,000 ft agl and visibility greater than 5 miles while MVFR is a sub-category of VFR.

dew point temperature 0° C, altimeter 29.75 inHg. Remarks; automated station without a precipitation discriminator.

The general flight categories and raw observations reported from 1200 through 1720 PST were as follows. The observation at the time of the accident decoded above again is highlight in bold italic print and the peak wind gust noted.

VFR METAR KMHV 132000Z AUTO 29041G48KT 10SM CLR 11/02 A2980 RMK A01=
VFR METAR KMHV 132020Z AUTO 29038G50KT 10SM CLR 11/02 A2978 RMK A01=
VFR METAR KMHV 132040Z AUTO 29043G52KT 10SM CLR 12/02 A2977 RMK A01=
VFR METAR KMHV 132100Z AUTO 29043G56KT 10SM CLR 12/02 A2974 RMK A01=
VFR METAR KMHV 132120Z AUTO 29048G57KT 6SM HZ CLR 11/02 A2974 RMK A01=
VFR METAR KMHV 132140Z AUTO 29043G57KT 10SM CLR 12/02 A2974 RMK A01=
VFR METAR KMHV 132200Z AUTO 30043G54KT 10SM CLR 12/02 A2974 RMK A01=
VFR METAR KMHV 132220Z AUTO 29040**G62KT** 10SM CLR 12/02 A2975 RMK A01=
VFR METAR KMHV 132240Z AUTO 29044G57KT 9SM CLR 11/02 A2973 RMK A01=
VFR METAR KMHV 132300Z AUTO 29042G58KT 10SM CLR 11/02 A2972 RMK A01=
VFR METAR KMHV 132320Z AUTO 29037G55KT 9SM CLR 10/03 A2973 RMK A01=
VFR METAR KMHV 132340Z AUTO 30046G54KT 10SM CLR 11/00 A2973 RMK A01=
VFR METAR KMHV 140000Z AUTO 30038G52KT 10SM CLR 11/00 A2974 RMK A01=
VFR **METAR KMHV 140020Z AUTO 30033G47KT 10SM CLR 10/M00 A2975 RMK A01=**
Accident 0027Z
VFR METAR KMHV 140040Z AUTO 31033G41KT 10SM CLR 09/M00 A2978 RMK A01=
VFR METAR KMHV 140100Z AUTO 31027G48KT 10SM CLR 09/M00 A2979 RMK A01=
VFR METAR KMHV 140120Z AUTO 31035G49KT 10SM CLR 09/M01 A2979 RMK A01=

2.3 Lancaster, California

General William J. Fox Airfield (KWJF), Lancaster, California, was located approximately 18 miles south of the accident site in the Mojave Desert at an elevation of 2,351 ft. The airport had an Automated Surface Observation System (ASOS) which was augmented by air traffic control personnel during normal operating hours. The following conditions were reported at the approximate time of the accident.

KWJF weather observation at 1656 PST, automated, wind from 300° at 27 knots gusting to 34 knots, visibility 10 miles or more, sky clear below 12,000 ft agl, temperature 12° C, dew point temperature 0° C, altimeter 29.84 inHg. Remarks: automated station with a precipitation discriminator, peak wind from 330° at 35 knots occurred at 1621 PST, pressure falling rapidly⁸, sea-level pressure 1010.7-hPa, temperature 11.7° C, dew point temperature 0.0° C, maintenance indicator on.

The general flight categories and raw observations reported between 1256 and 2000 PST were as follows.

VFR METAR KWJF 132056Z 27024G34KT 10SM CLR 14/03 A2989 RMK AO2 PK WND 26036/2043 SLP119
T01390028 58020=
MVFR SPECI KWJF 132140Z 30027G39KT 4SM HZ FEW004 15/02 A2985 RMK AO2 PK WND 30039/2137

⁸ Pressure falling rapidly (PRESFR) is reported when pressure is falling at a rate of 0.06 inch per hour or more and the pressure change totals 0.02 inch or more at the time of the observation.

T01500022=
MVFR METAR KWJF 132156Z 30032G43KT 4SM HZ CLR 14/02 A2984 RMK AO2 PK WND 29043/2152 SLP101
T01440017=
VFR METAR KWJF 132256Z 30031G39KT 10SM CLR 14/02 A2983 RMK AO2 **PK WND 32044/2223** SLP100
T01390017=
UNK⁹ METAR KWJF 132356Z NIL
Accident 0027Z
VFR METAR KWJF 140056Z AUTO 30027G34KT 10SM CLR 12/00 A2984 RMK AO2 PK WND 33035/0021
PRESFR SLP107 T01170000 \$=
VFR SPECI KWJF 140145Z 31026G39KT 9SM FEW009 11/M02 A2981 RMK AO2 **PK WND 29044/0113**
T01111017 \$=
VFR METAR KWJF 140156Z 31016G27KT 10SM CLR 12/M02 A2983 RMK AO2 **PK WND 29044/0113**
PRESRR SLP103 T01171022 \$=
VFR METAR KWJF 140256Z 32014G21KT 10SM CLR 11/M03 A2985 RMK AO2 PK WND 30029/0157 SLP109
T01111028 \$=
VFR METAR KWJF 140356Z 31028G40KT 10SM CLR 11/M03 A2981 RMK AO2 PK WND 32040/0353 **PRESFR**
SLP092 T01061033 \$=

2.4 Sandberg, California

The Sandberg (KSDB) weather station was located 22 miles southwest of the accident site at an elevation of 4,521 ft, and not collocated at an airport. The KSDB ASOS was located near the top of Baldy Mountain and was not augmented by any observers. The station reported the following conditions as the accident aircraft flew near the station and immediately after the accident.

KSDB weather observation at 1553 PST, automated, wind from 320° at 26 knots gusting to 37 knots, visibility 10 miles or more, ceiling broken at 800 ft agl, broken at 1,200 ft, overcast at 1,900 ft, temperature 7° C, dew point temperature 3° C, altimeter 29.85 inHg. Remarks: automated station with a precipitation discriminator, peak wind from 320° at 40 knots occurred at 1533 PST, rain began at 1530 and ended at 1537 PST, ceiling variable from 600 ft to 1,000 ft, sea-level pressure 1009.3-hPa, hourly precipitation less than 0.01 inches, 6-hour precipitation less than 0.01 inches, temperature 6.7° C, dew point temperature 2.8° C, 6-hour maximum temperature 9.4° C, 6-hour minimum temperature 5.0° C, 3-hour pressure tendency fallen 2.4-hPa, maintenance indicator on .

KSDB weather observation at 1653 PST, automated, wind from 320° at 27 knots gusting to 39 knots, visibility 10 miles or more, ceiling broken at 800 ft agl, broken at 1,300 ft, temperature 6° C, dew point temperature 2° C, altimeter 29.82 inHg. Remarks: automated station with a precipitation discriminator, peak wind from 320° at 45 knots occurred at 1636 PST, sea-level pressure 1008.3-hPa, temperature 6.1° C, dew point temperature 2.2° C, maintenance indicator on¹⁰.

The general flight categories and raw observation surrounding the period from approximately 1200 through 1900 PST were as follows.

MVFR SPECI KSDB 132009Z AUTO 31009G24KT 10SM SCT014 BKN020 08/03 A2996 RMK AO2 PK WND 28030/1958 T00780028 \$=

⁹ UNK – abbreviation for unknown, report missing from normal polling or issuance.

¹⁰ Maintenance indicator sign (\$) is coded when an automated system detects that maintenance is needed on the system.

MVFR SPECI KSDB 132016Z AUTO 32012G20KT 290V360 10SM BKN012 BKN020 08/03 A2995 RMK AO2 PK WND 28030/1958 T00780028 \$=
VFR SPECI KSDB 132044Z AUTO 29020G34KT 10SM SCT011 SCT015 09/03 A2994 RMK AO2 PK WND 28034/2036 T00890028 \$=
VFR METAR KSDB 132053Z AUTO 30020G29KT 10SM FEW012 FEW018 09/02 A2994 RMK AO2 PK WND 28034/2036 SLP118 T00940022 58016 \$=
MVFR SPECI KSDB 132128Z AUTO 31027G37KT 10SM SCT018 BKN023 09/02 A2992 RMK AO2 PK WND 32040/2110 T00890022 \$=
MVFR METAR KSDB 132153Z AUTO 31023G37KT 10SM BKN015 08/03 A2991 RMK AO2 PK WND 32040/2110 SLP111 T00830028 \$=
MVFR SPECI KSDB 132207Z AUTO 32024G33KT 10SM BKN013 08/03 A2991 RMK AO2 PK WND 31035/2157 T00830028 \$=
VFR SPECI KSDB 132216Z AUTO 32022G31KT 10SM SCT013 08/03 A2991 RMK AO2 PK WND 31035/2157 T00780028 \$=
MVFR SPECI KSDB 132225Z AUTO 31017G30KT 10SM SCT010 BKN015 08/03 A2990 RMK AO2 PK WND 31035/2157 T00780028 \$=
MVFR SPECI KSDB 132231Z AUTO 32020G32KT 10SM BKN012 08/03 A2990 RMK AO2 PK WND 31035/2157 T00780028 \$=
MVFR METAR KSDB 132253Z AUTO 32028G35KT 10SM SCT010 BKN014 08/03 A2989 RMK AO2 PK WND 32035/2251 SLP106 T00780028 \$=
IFR SPECI KSDB 132342Z AUTO 33024G40KT 10SM BKN008 BKN016 07/03 A2986 RMK AO2 PK WND 32040/2333 RAB30E37 CIG 006V011 P0000 T00670028 \$=
IFR METAR KSDB 132353Z AUTO 32026G37KT 10SM BKN008 BKN012 OVC019 07/03 A2985 RMK AO2 PK WND 32040/2333 RAB30E37 CIG 006V010 SLP093 P0000 60000 T00670028 10094 20050 58024 \$=
Accident 0027Z
IFR METAR KSDB 140053Z AUTO 32027G39KT 10SM BKN008 BKN013 06/02 A2982 RMK AO2 PK WND 32045/0036 SLP083 T00610022 \$=
MVFR SPECI KSDB 140121Z AUTO 32035G45KT 10SM SCT008 BKN012 06/02 A2981 RMK AO2 PK WND 31045/0120 T00610022 \$=
IFR SPECI KSDB 140126Z AUTO 32038G48KT 10SM BKN007 BKN012 06/02 A2981 RMK AO2 PK WND 32048/0125 CIG 005V009 T00610022 \$=
MVFR SPECI KSDB 140135Z AUTO 33037G49KT 10SM SCT009 BKN016 06/02 A2981 RMK AO2 PK WND 33049/0127 T00560017 \$=
IFR SPECI KSDB 140139Z AUTO 33032G48KT 10SM BKN009 BKN016 06/02 A2981 RMK AO2 PK WND 33049/0127 CIG 005V012 T00560022 \$=
MVFR METAR KSDB 140153Z AUTO 33035G51KT 10SM FEW006 BKN010 BKN015 06/02 A2980 RMK AO2 PK WND 34051/0144 SLP076 T00560017 \$=
VFR SPECI KSDB 140159Z AUTO 33034G48KT 10SM FEW006 SCT010 05/02 A2980 RMK AO2 PK WND 33048/0159 T00500017 \$=
UNK METAR KSDB 140253Z AUTO 33032G43KT 10SM 05/02 A2981 RMK AO2 PK WND 33043/0244 SLP080 6//// T00500022 \$=

2.5 Edwards, California

Edwards Air Force Base (KEDW), Edwards, California, was located approximately 26 miles east of the accident site at elevation of 2,311 ft and had an ASOS and was augmented by observers and reported the following conditions at the approximate time of the accident.

KEDW weather observation at 1658 PST, wind from 280° at 28 knots gusting to 34 knots, visibility 60 miles or more, scattered clouds at 5,000 ft agl, scattered clouds at 15,000 ft, ceiling broken at 25,000 ft, temperature 11° C, dew point temperature -0° C, altimeter 29.79 inHg. Remarks: peak wind from 270° at 42 knots occurred at 1624 PST, sea-level pressure 1008.5-hPa, temperature 11.0° C, dew point temperature -0.5° C.

The general flight categories and raw observation surrounding the period from 1258 through 1858 PST were as follows.

VFR METAR KEDW 132058Z 30037G49KT 60SM FEW050 SCT150 BKN250 14/01 A2978 RMK AO2A
PRESFR SLP081 T01390012 58033=
VFR METAR KEDW 132158Z 29023**G35KT** 70SM FEW050 SCT150 BKN250 14/01 A2981 RMK AO2A PK
WND 28053/32 SLP091 T01380014=
VFR METAR KEDW 132258Z 30023G29KT 70SM FEW050 SCT150 BKN250 13/02 A2983 RMK AO2A PK
WND 25040/15 SLP097 T01270017=
VFR METAR KEDW 132358Z 28024G30KT 60SM SCT050 SCT150 BKN250 12/01 A2983 RMK AO2A PK
WND 28033/01 SLP098 T01160012 10145 20116 51015=
Accident 0027Z
VFR METAR KEDW 140058Z 28028G34KT 60SM SCT050 SCT150 BKN250 11/M00 A2979 RMK AO2A PK
WND 27042/24 SLP085 T01101005=
VFR METAR KEDW 140158Z 28022G32KT 50SM FEW050 SCT150 BKN250 10/M00 A2977 RMK AO2A PK
WND 29039/38 SLP079 T01041001=
VFR METAR KEDW 140258Z AUTO 26020G27KT 10SM CLR 10/M02 A2979 RMK AO2 PK WND 28037/0158
SLP088 T00981016 55012=

2.6 Aviation Weather Centers METAR Display

A display of the conditions from the NWS Aviation Weather Centers (AWC) METAR display from the Helicopter Emergency Medical Services (HEMS) Weather Tool¹¹ is included as figure 7, with the general topography of the area and the approximate accident site marked by a red star. The chart depicts the METARs current at the time of the chart, at 1630 PST with temperature and dew point temperatures displayed in° F. The dashed purple line represents the approximate flight track to the northeast, which passed immediately east of KSDB and west of KWJF across the Antelope Valley and immediately south of the Tehachapi Mountain Range.

The topographical features on the METAR display depicted the accident site immediately south of the Tehachapi Mountains which extended northeast to southwest and generally perpendicular to the surface winds.

¹¹ <https://aviationweather.gov/hemst>

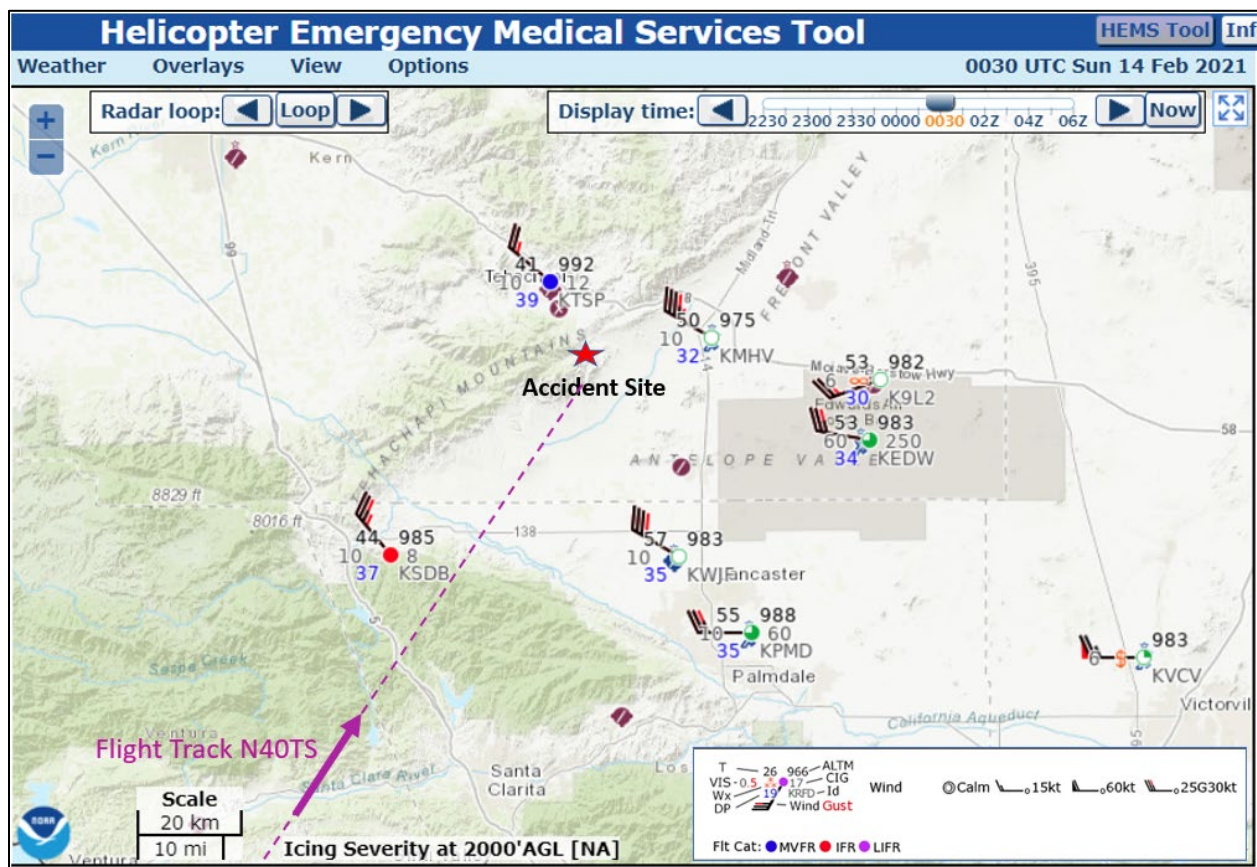


Figure 7 - METAR display at 1630 PST surrounding the accident site.

2.7 MesoWest Observations

A depiction of the official METAR observations and Remote Automated Weather Stations (RAWS) operated by the United States Forecast Service and Bureau of Land Management for 1630 PST obtained from the University of Utah's MesoWest website¹² is included as figure 8. The approximate accident site and flight track are also included. The image depicts the wind observation reports at 1630 PST with the peak wind gusts in the box to the left of the station with winds in miles per hour (mph).

¹² <https://mesowest.utah.edu/>

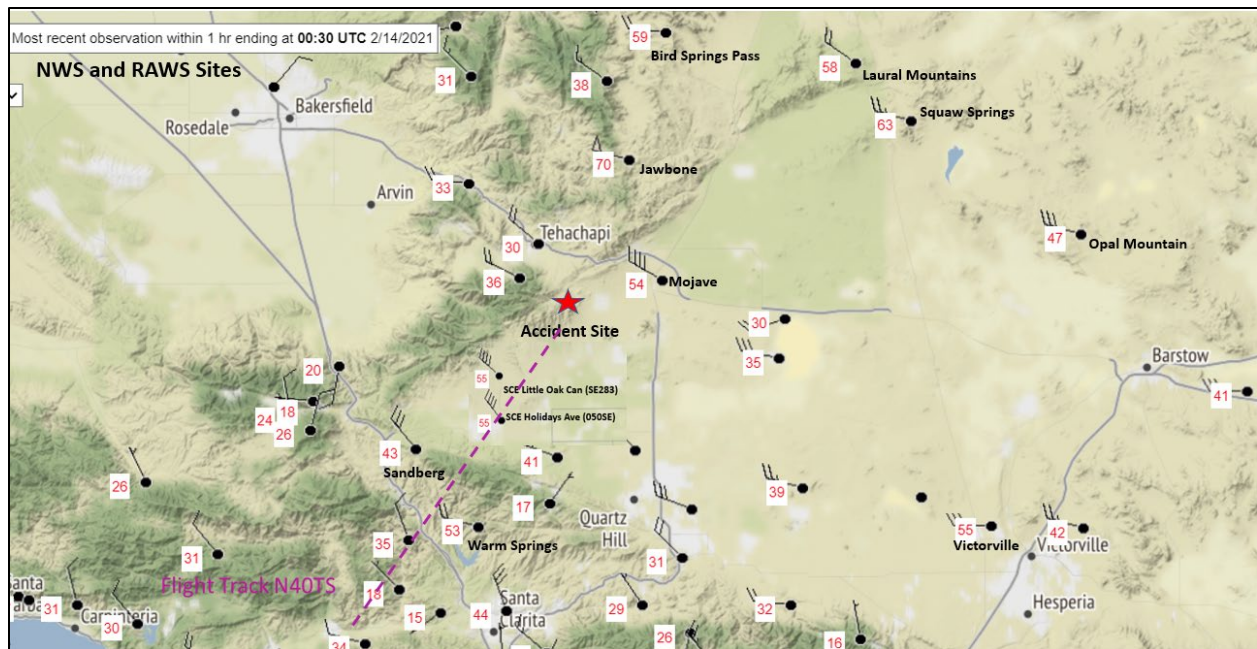


Figure 8 - MesoWest depiction of METAR and RAWS sites of wind and peak gusts for 1630 PST.

3.0 Sounding Information

To determine the vertical structure and state of the atmosphere over the area a combination of numerical model over the accident site and aircraft observations in the vicinity were reviewed and documented.

3.1 Numerical Model Sounding

A High-Resolution Rapid Refresh (HRRR)¹³ numerical model data were retrieved from the NOAA Air Resources Laboratory archive for the accident site coordinates. The HRRR numerical model was then plotted on a standard Skew T log P diagram¹⁴ using the Universal RAwinsonde OBservation (RAOB) program software¹⁵. Figure 9 is the HRRR sounding for 1600 PST plotted from the surface to 400-hPa or approximately 24,000 ft over the accident site coordinates.

¹³ The HRRR is a National Oceanic and Atmospheric Administration (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.

¹⁴ 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.

¹⁵ 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.

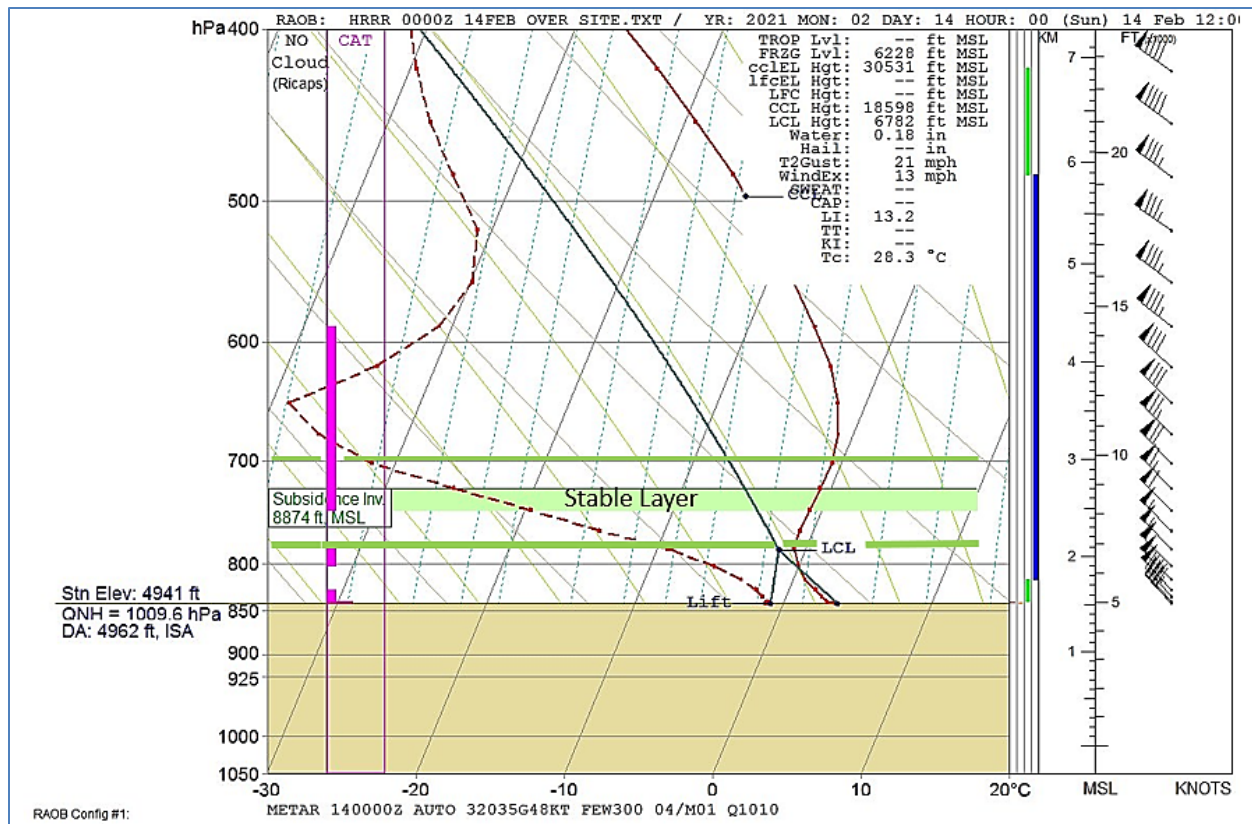


Figure 9 - HRRR numerical model over the accident site for 1600 PST

The 1600 PST HRRR sounding depicted an elevation of 4,941 ft for the accident site with a near surface wind from 320° at 35 knots with potential gusts to 48 knots, a temperature of 4° C, a dew point temperature of -1° C, with a 69% relative humidity. The freezing level was at 6,228 ft with no significant icing indicated. The sounding depicted an inversion or isothermal layer from the lifted condensation level (LCL)¹⁶ at 6,782 ft msl through approximately 10,000 ft (bracketed by the green lines). The convective condensation level (CCL)¹⁷ was at 18,598 ft. The sounding depicted low relative humidity's below 18,000 ft and thus did not depict any significant cloud layers, the precipitable water¹⁸ content of 0.18 inches. The atmosphere was classified as stable with a Lifted Index¹⁹ of 13.2. The HRRR wind profile indicated winds from the northwest with little variation in direction from the surface through 24,000 ft, with wind speeds above 50 knots immediately above the surface. The level of maximum wind was identified at 35,000 ft associated with the jet stream of 130 knots (depicted in figure 6). The wind at 10,000 ft or the accident airplanes last reported altitude was from approximately 320° at 65 knots, with a temperature of -1° C.

¹⁶ Lifted Condensation Level (LCL) - the level at which a lifted parcel becomes saturated. The LCL height corresponds to cloud base height for forced ascent.

¹⁷ 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.

¹⁸ Precipitable Water - The total amount of (condensed) water available within the lowest 400 mb of the sounding.

¹⁹ Lifted Index (LI) - is an index to assess low-level parcel (in)stability of the troposphere. the difference between the lifted parcel temperature at 500 hPa and the 500 hPa temperature in the sounding. Negative values denote parcels that are warmer than the background 500 hPa temperatures and are thus buoyant or "unstable".

The RAOB analysis of the HRRR model sounding did not directly indicate mountain wave conditions or any significant turbulence. However, the sounding did identify conditions in the thermal and wind profile consistent with conditions associated with the formation of mountain wave conditions. The sounding also indicated that the Scorer parameter (l^2)²⁰ decreased with height and was conducive to trapped lee waves.

3.2 Aircraft Soundings

The NOAA Earth System Research Laboratory's (ESRL) Global Systems Laboratory (GSL) archive data for the period provided multiple Aircraft Meteorological Data Relay (AMDAR) equipped aircraft in the vicinity of the accident site surrounding the period from 1600 through 1800 PST, as shown in figure 10. However, the instrumented aircraft immediately near the accident site were generally operating above 25,000 ft when they were within 20 miles of the accident site. Their descent soundings were documented for the general conditions over the area as they landed into Ontario International Airport (KONT), Ontario, California.

Two aircraft were identified passing near the accident site:

- Aircraft #11179 descent sounding from San Jose (KSJC)-KONT landing at 1636 PST
- Aircraft #11914 descent sounding from Sacramento (KSMF)-KONT landing at 1729 PST

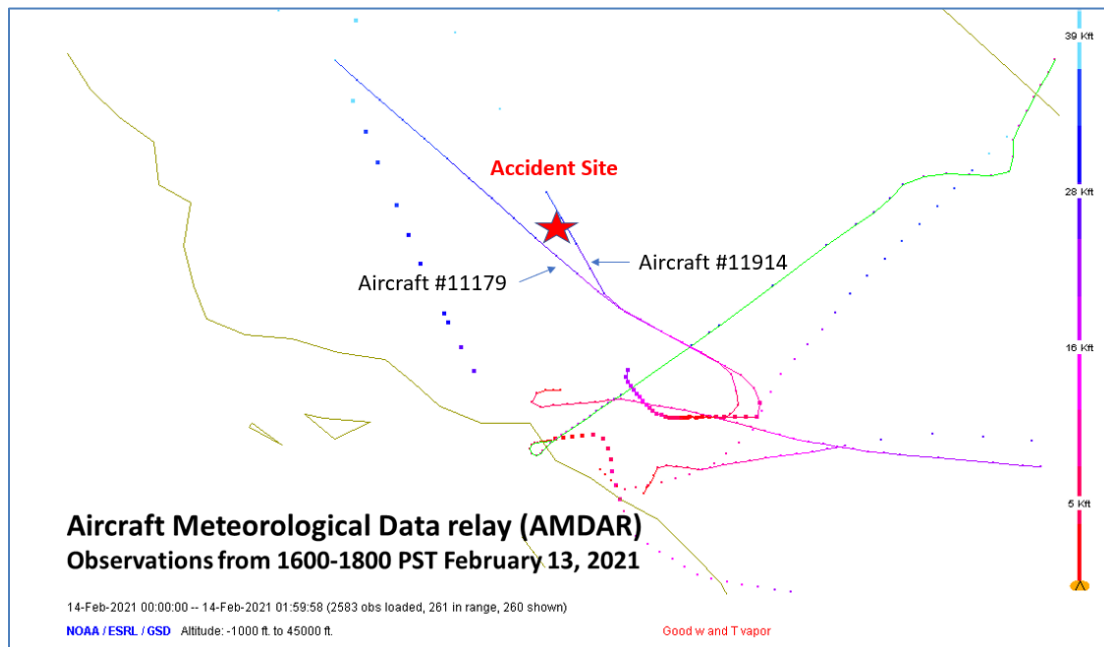


Figure 10 - Aircraft Meteorological Data Relay (AMDAR) reports between 1600 and 1800 PST

²⁰ The Scorer parameter l [m-1] is used to describe whether gravity waves will develop or not. It combines the Brunt-Väisälä frequency with characteristics of the vertical wind profile.

3.2.1 Aircraft #11179 Sounding

Aircraft identified as #11179 overflowed the accident site at approximately 1636 PST as it descended through 27,000 ft flying from SJC to ONT. The wind at that altitude was from 313° at 104 knots, with a temperature of -35.8° C. The descent sounding was plotted on a standard Skew T log P diagram is included as figure 11. The sounding depicted an elevation for KONT as 945 ft, with a temperature of 18° C, and a dew point temperature of 8° C. The LCL was identified at 3,026 ft msl (2,081 ft agl), and the CCL at 4,516 ft (3,571 ft agl) and RAOB supported multiple layers of clouds through 8,000 ft. An inversion was detected between 10,000 ft through 12,000 ft with RAOB indicating conditions favorable for a mountain wave at 12,000 ft with a wavelength of 8.12 miles, an amplitude of 1,626 ft, and maximum vertical velocity of 1,721 fpm. The low level wind profile indicated surface wind from the southwest at 10 knots with winds veering to the northwest through 7,000 ft and rapidly increasing in speeds above that level. The RAOB analysis program supported moderate and greater turbulence between 7,500 ft through 16,000 ft.

The KONT METAR current at the time the aircraft landed at 1653 PST was as follows.

Special weather observation for KONT at 1653 PST, wind from 240° at 11 knots, visibility 10 miles or more, a few clouds at 2,800 ft agl, ceiling broken at 5,000 ft, and broken at 25,000 ft, temperature 13° C, dew point temperature 8° C, altimeter 29.81 inHg. Remarks, automated station with a precipitation discriminator, sea-level pressure 1009.6-hPa, temperature 13.3° C, dew point temperature 8.3° C.

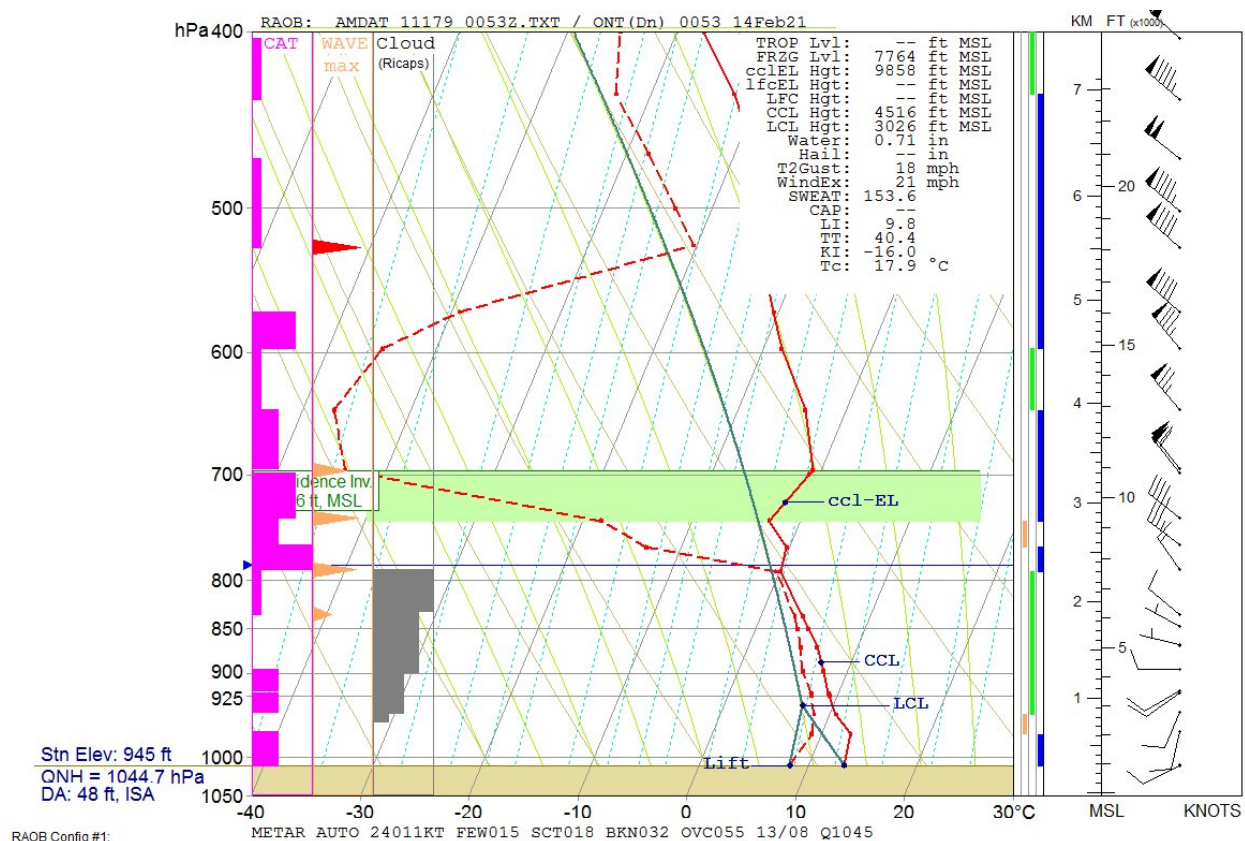
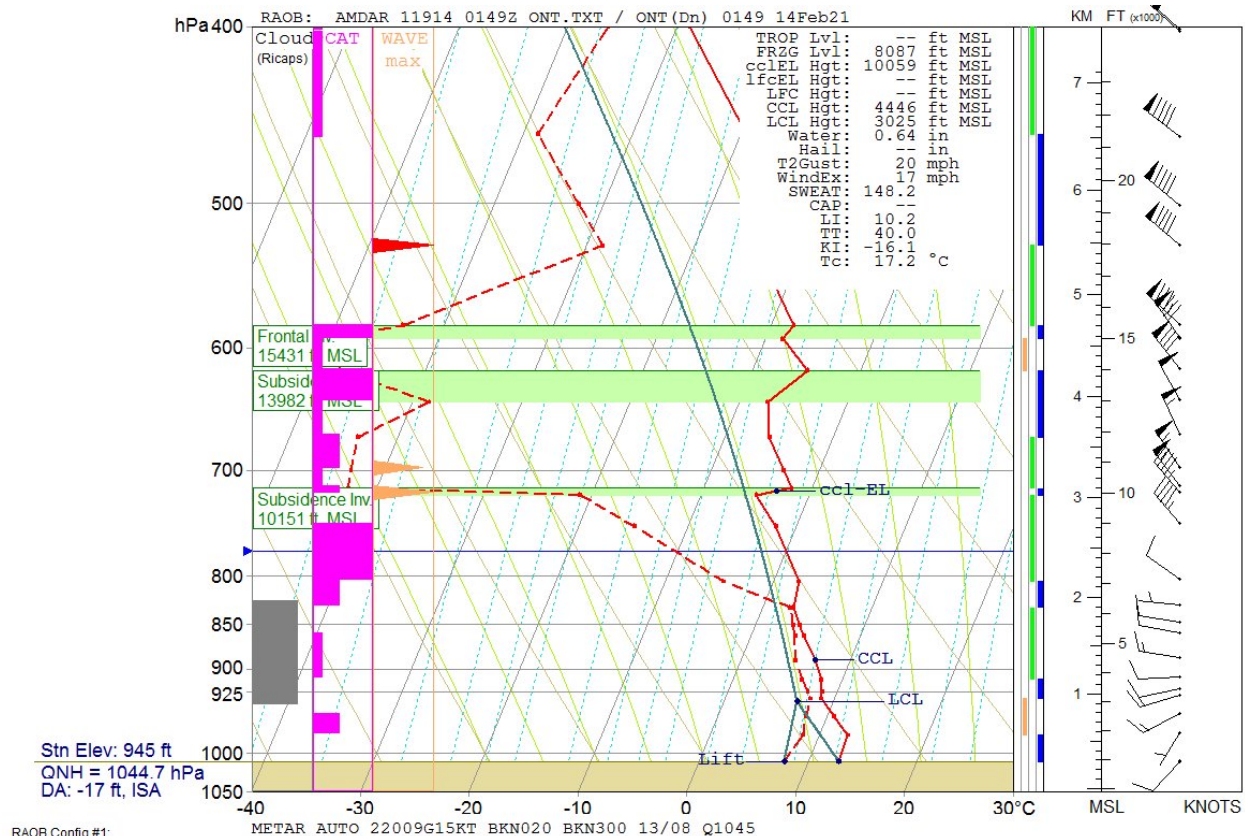


Figure 11 - AMDAR sounding from aircraft #11179 landing at 1653 PST

3.2.2 Aircraft #11914 Sounding

Another aircraft identified as #11914 overflow the accident site at 1729 PST as it descended through 29,460 ft and reported a wind from 317° at 92 knots with a temperature of -46.5° C. The aircraft landed at KONT at approximately 0749 PST. The descent sounding in figure 12 depicted a LCL at 3,025 ft and a CCL at 4,446 ft and supported multiple inversions between 11,000 ft through 16,500 ft. RAOB indicated the potential for moderate to severe turbulence in several layers between 7,000 ft through 15,500 ft, and supported a mountain wave near 11,000 ft.



4.0 Satellite Imagery

The Geostationary Operational Environmental Satellite number 17 (GOES-17) data 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 and visible imagery were reviewed surrounding the period, and the closest images to the accident time documented. The infrared long wave imagery (band 16) at a wavelength of 13.3 microns (μm) provided radiative cloud top temperatures with a nominal spatial resolution of 2 km. The visible (band 2) at a wavelength of 0.64 μm provided images at a resolution of 0.5 km.

Figure 13 is the GOES-17 visible image for 1631 PST at 4X magnification with the accident site marked by the red square. The image depicted the accident site on the eastern edge of a band of clouds which extended over KTSP, with clear conditions immediately east and southeast similar to a foehn gap²¹ with clouds reforming further southeast of the area. An animation of the visible satellite imagery is included as attachment 2 and depicted very little motion in the clouds over the general vicinity of the accident site given the strong environmental wind flow over the area, and identified the clouds as likely associated with orographic clouds²².

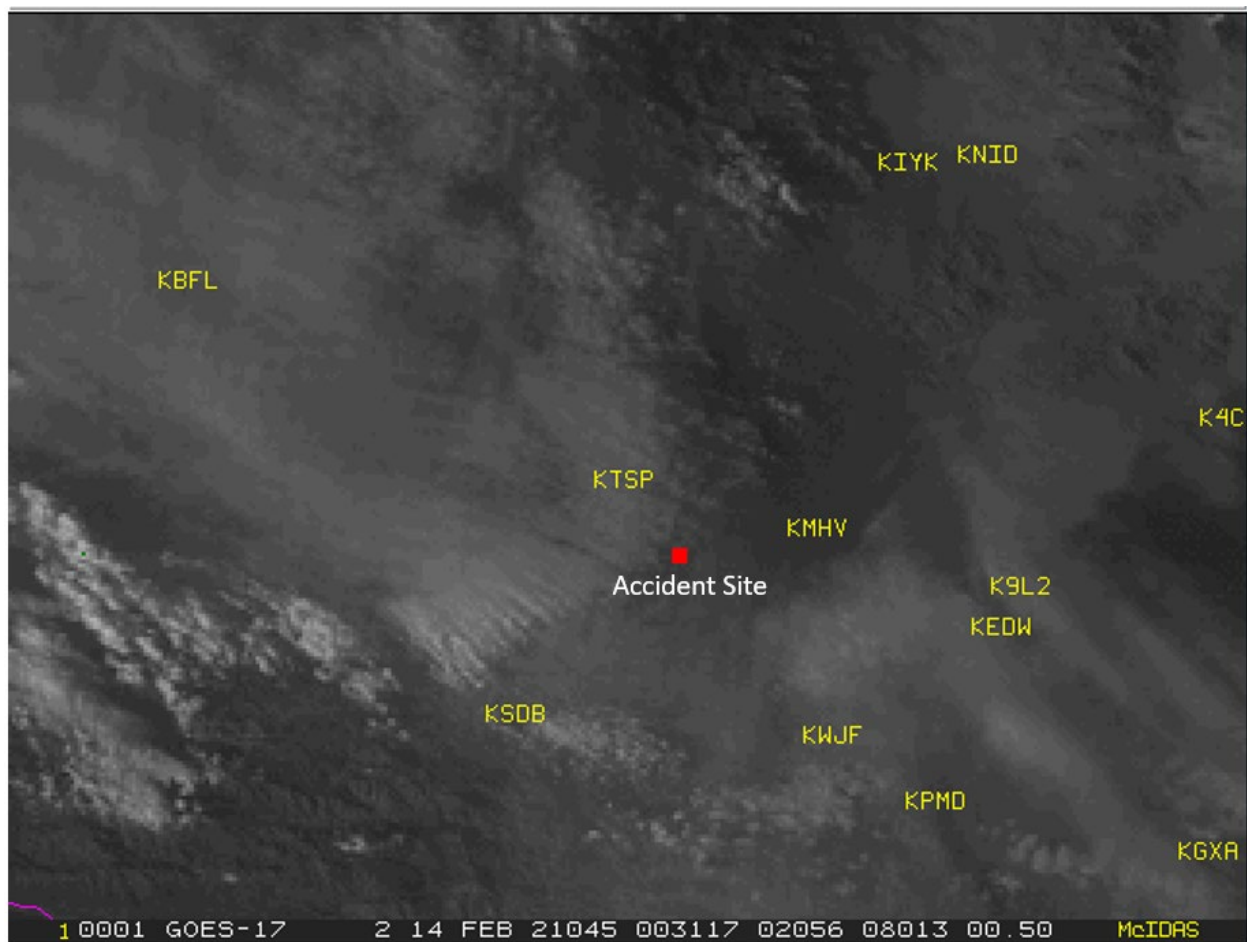


Figure 13 - GOES-17 visible image for 1631 PST at 4X magnification with the accident site

²¹ A foehn gap is a break in an extensive cloud deck or cloud shield, usually parallel to and downwind of the mountain ridge line. Especially visible in satellite imagery, this cloud-free zone results from the strong sinking motion on the lee side of a mountain barrier during a mountain wave activity or strong downslope winds or chinook.

²² Orographic clouds are clouds that develop in response to the forced lifting of air by topographical features on the earth's surface, like mountains.

5.0 Weather Radar Imagery

The closest Weather Surveillance Radar 1988 Doppler (WSR-88D)²³ was from Edwards Air Force Base with the radar antenna²⁴ located in Boren, California (KEYX) approximately 40 miles east of the accident site. During the period surrounding the accident the computer-controlled radar was operating in the clear air mode, volume coverage pattern 35 (VCP-35), where the radar makes 9 overlapping elevation scans every 7-minutes.

Figure 14 is the KEYX WSR-88D 1.27° base reflectivity image at 1632 PST with the flight path overlaid (in purple) and depicted the conditions extending over the airspace between 7,440 ft through 11,570 ft, with the center of the beam at 9,510 ft²⁵ assuming normal refraction of the WSR-88D radar beam. The image depicted very light intensity echoes of 15 dBZ or less over the last few minutes of the flight track and the highest reflectivity of 15 dBZ immediately bordering the accident site to the north with echoes near 10 dBZ over the accident site. At lower elevation scans the echo in the vicinity of the accident site reached a maximum of 30 dBZ.

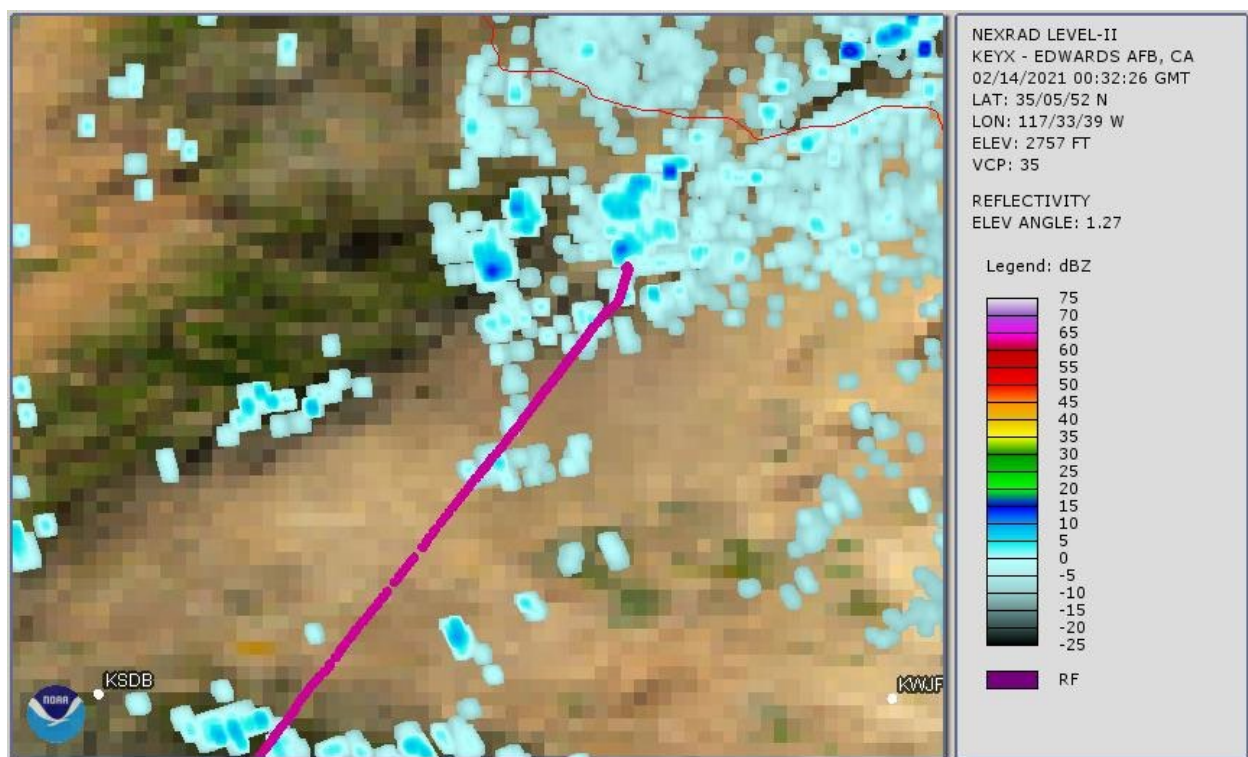


Figure 14 - KEYX WSR-88D 1.27° base reflectivity image at 1632 PST with the flight track overlaid

A review of the radar images in animation (attachment 2) showed a large section of the echoes along the Tehachapi Mountains Range were nearly stationary in time. The WSR-88D correlation

²³ The WSR-88D is a S-band 10-centimeter wavelength radar with a power output of 750,000 watts, with a 28-foot parabolic antenna concentrating the energy into a 0.95° beam width. The radar produces three basic types of products reflectivity, radial velocity, and spectral width.

²⁴ Radar Data Acquisition (RDA) associated with the antenna and hardware of the radar physically located in Boran, CA.

²⁵ Based on the KEYX antenna height of 2,873 ft at 41 nautical miles from the accident site to the antenna.

coefficient dual polarization product also indicated the some of the echoes in the sample showed a large variation in the sample volume over the region, with most of the hydrometeors the accident site having values of 0.75 or less.

A separate review of the Consolidated Storm Prediction for Aviation (CoSPA) data and the Geostationary Lightning Mapper (GLM) imagery indicated no lightning activity in the echoes in the vicinity during the hour prior to or at the time of the accident.

Figure 15 is the KEYX WSR-88D 1.27° spectrum width²⁶ image for 1632 PST, which showed strong shears in the echoes in the vicinity of the accident site, with shears between 18 and 24 knots.



Figure 15 - KEYX WSR-88D 1.27° spectrum width product for 1632 PST with the flight track

6.0 Pilot Reports

A search of pilot reports (or PIREPs) over the general route of flight between 1000 and 1900 PST provided the following reports over southern California. The reports are in raw format with abbreviations, with time referenced to UTC, followed by a plain language decode of the report with time converted to local. The time of the accident and PIREPs within 50 miles of the accident site are in **bold italic type** for reference.

²⁶ Spectrum width – measures velocity dispersion. In a radar bin, it provides a measure of the variability of the mean radial velocity estimates (movement) due to wind shear, turbulence, and/or the quality of the velocity samples. It is used to estimate turbulence associated with low-level boundaries, thunderstorms, and other mesocyclones in strong to severe thunderstorms.

VNY UA /OV FIM/TM 1809/FL9000/TP PC12/TB MODERATE

Van Nuys Airport (VNY) routine pilot report; Over – Fillmore VORTAC²⁷ (FIM); Time – 1009 PST; Altitude – 9,000 ft; Type aircraft – Pilatus PC-12; Turbulence – moderate.

LAX UA /OV SMO/TM 1810/FL080/TP CRJ2/TB CONT MOD

Los Angeles International Airport (LAX), Los Angeles, routine pilot report; Over – Santa Monica VORTAC (SMO); Altitude – 8,000 ft; Type aircraft – Bombardier CRJ200 regional jet; Turbulence – continuous moderate.

BUR UA /OV 15 MILES NORTH OF VNY /TM 1940/FL065/TP GLF4/TB MODERATE

Bob Hope Airport (BUR), Burbank, routine pilot report; Over – 15 miles north of Van Nuys VORTAC (VNY); Time – 1140 PST; Altitude – 6,500 ft; Type aircraft – Gulfstream IV; Turbulence – moderate.

SBA UA /OV SBA070020/TM 2029/FL070/TP C172/TB MOD

Santa Barbara Municipal Airport (SBA), Santa Barbara, routine pilot report; Over – 070° azimuth and 20 miles from SBA; Time – 1229 PST; Altitude – 7,000 ft; Type aircraft – Cessna 172 Skyhawk; Turbulence – moderate.

PMD UA /OV PMD240014/TM 2120/FL080/TP B738/TB MOD

Palmdale USAF Plant 42 Airport (PMD), Palmdale, routine pilot report; Over – 240° azimuth and 14 miles from Palmdale VORTAC (PMD); Time – 1320 PST; Altitude – 8,000 ft; Type aircraft – Boeing 737-800; Turbulence – moderate.

SBA UA /OV SBA 26NM E/TM2153/FL060/TP C182/TB MODERATE TURBULNECE 050 26NM E SBA

SBA routine pilot report; Over – 26 miles northeast of SBA; Time – 1353 PST; Altitude – 6,000 ft; Type aircraft – Cessna 182 Skylane; Turbulence – moderate turbulence between 50-26 miles east of SBA.

PSP UUA /OV TRM/TM 2145/FL075/TP DA40/TB SVR/RM RESENT AS UUA

Palm Springs International Airport (PSP) urgent pilot report (UUA); Over - Thermal VORTAC (TRM), Palm Springs; Time – 1345 PST; Altitude – 7,500 ft; Type aircraft – DA40 Diamond Star; Turbulence – severe; Remarks – resent as UUA.

PSP UUA /OV PSP090004/TM 2224/FL010/TP EC35/TB SEV010/RM LLWS -50KT

PSP urgent pilot report (UUA); Over – 090° azimuth and 4 miles from Palm Springs VORTAC (PSP), Palm Springs; Time – 1424 PST; Altitude – 1,000 ft; Type aircraft – Airbus Eurocopter EC-135 helicopter; Turbulence – severe at 1,000 ft; Remarks – low-level wind shear loss of 50 knots.

PSP UUA /OV PSP 25 NE/TM 2235/FL170/TB B738/TB MOD 070-170

PSP urgent pilot report (UUA); Over – 25 miles northeast of the PSP VORTAC; Time – 1435 PST; Altitude – 17,000 ft; Type aircraft – Boeing 737-800; Turbulence – moderate turbulence between 7,000 and 17,000 ft.

SDB UA /OC PMD0111026/TM 2243/FL430/TP E545 /RMK MTN WAVE

Sandberg (SDB) routine pilot report; Over – 111° azimuth and 26 miles from PMD VORTAC; Time – 1443 PST; Flight Level – 43,000 ft; Type aircraft – Embraer EMB-545 Legacy jet; Remarks – mountain wave.

²⁷ A VORTAC is a radio-based navigational aid for aircraft pilots consisting of a co-located VHF omnidirectional range (VOR) beacon and a tactical air navigation system (TACAN) beacon for distance information. Unless otherwise noted the name of the VORTAC is collocated with the city.

PSP UUA /OV PSP/TM 2250/FL005/TP B739/RM LLWS +20 KT 005 DURD

PSP urgent pilot report (UUA); Over – PSP; Time – 1450 PST; Altitude – 500 ft; Type aircraft – Boeing 737-900; Remarks – low-level wind shear gain of 20 knots of airspeed at 500 ft during descent.

PSP UUA /OV PSP 20S/TM 2253/FL090/TP SF50/TB SEV 090-070

PSP urgent pilot report (UUA); Over – PSP; Time – 1453 PST; Altitude – 9,000 ft; Type aircraft – SF50; Turbulence – severe turbulence between 9,000 ft and 7,000 ft.

SDB UA /OV PMD011026/TM 2255/FL430/TP E545/RM MTN WAVE

SDB routine pilot report; Over – 011° azimuth and 26 miles from PMD VORTAC; Time – 1455 PST; Flight Level – 430; Type aircraft – Embraer EMB-545 Legacy; Remarks – mountain wave.

PRB UA /OV AVE085020/TM 2255/FL400/TP C750/RM MTN WAVE +/-200FT AWC-WEB/

Paso Robles Municipal Airport (PRB), Paso Robles, routine pilot report; Over – 085° azimuth and 20 miles from the Avenal VORTAC (AVE); Time – 1455 PST; Flight Level – 400; Type aircraft – Cessna Citation 10; Remarks – mountain wave altitude deviations of +/- 200 ft of altitude; Remarks – entered thru AWC-website.

PRB UA /OV AVE075010/TM 2255/FL340/TP B737/TB LGT/RM AWC-WEB/

PRB routine pilot report; Over – 075° azimuth and 10 miles from AVE VORTAC; Flight Level – 340; Type aircraft – Boeing 737; Turbulence light; Remarks – entered thru AWC website.

Accident 0027Z

VNY UA /OV VNY360014/TM 0100/FL7000/TP CL35/SK BKN060/WX 10/WV 36016G21/TB SEV-MOD

VNY routine pilot report; Over – 360° azimuth and 14 miles from VNY VORTAC; Time – 1700 PST; Altitude – 7,000 ft; Type aircraft – Canadair Challenger 350 corporate jet; Sky cover – broken clouds with bases at 6,000 ft; Weather – flight visibility 10 miles; Wind – from 360° at 16 knots with gusts 21 knots; Turbulence – severe-to-moderate.

KLAX UA /OV SMO266015/TM 0111/FL100/TP CRJ2/TB MOD CHOP/RM 100-060 IN DESCENT

LAX routine pilot report; Over – 266° azimuth and 15 miles from the SMO VORTAC; Time – 1711 PST; Altitude – 10,000 ft; Type aircraft – Bombardier CRJ200 regional jet; Turbulence – moderate chop; Remarks – encountered between 10,000 ft and 6,000 ft in descent.

SDB UUA /OV FIM/TM 0127/FL090/TP GLF4/TB SEV 090-100/RM AWC-WEB/

Sandberg (SDB) urgent pilot report (UUA); Over – Fillmore VORTAC (FIM); Time – 1727 PST; Altitude – 9,000 ft; Type aircraft – Gulfstream IV; Turbulence – severe turbulence between 9,000 ft and 10,000 ft; Remarks – entered from AWC website.

SDB UA /OV PMD343008/TM 0127/FL380/TP FA7X/TB OCNL MOD CAT/RM AWC-WEB/

SDB routine pilot report; Over – 343° azimuth and 8 miles from the PMD VORTAC; Time – 1727 PST; Flight Level – 380; Type aircraft – Dassault Falcon 7X; Turbulence – occasional moderate CAT; Remarks – entered thru AWC website.

OXR UUA /OV FIM/TM 0128/FL090/TP GLF4/TB SEV 090-100

Oxnard Airport (OXR) urgent pilot report (UUA); Over – FIM VORTAC; Time – 1728 PST; Altitude – 9,000 ft; Type aircraft – Gulfstream IV; Turbulence – severe turbulence encountered between 9,000 ft and 10,000 ft.

**WJF UA/OV WJF300010/TM 0224/FL1200/TP SR22/RM DDFTS 1500FPM ON V197 NORTHWEST
BOUND**

General William J. Fox Airfield (WJF) routine pilot report; Over – 300° azimuth and 10 miles from WJF; Time – 1824 PST; Altitude – 12,000 ft; Type aircraft – Cirrus SR22; Remarks – downdrafts of 1,500 feet per minute (fpm) on victor airway V197 northwest bound.

BUR UA /OV FIM/TM 0235/FL100/TP B737/TB MOD TURBULENCE/RM MOD TURB 100-070

BUR routine pilot report; Over – FIM VORTAC; Time – 1835 PST; Altitude – 10,000 ft; Type aircraft – Boeing 737; Turbulence – moderate turbulence between 10,000 ft and 7,000 ft.

A depiction of the location of the PIREPs within 50 miles of the accident site is included as figure 16 over the GOES-17 visible image at the time of the accident.

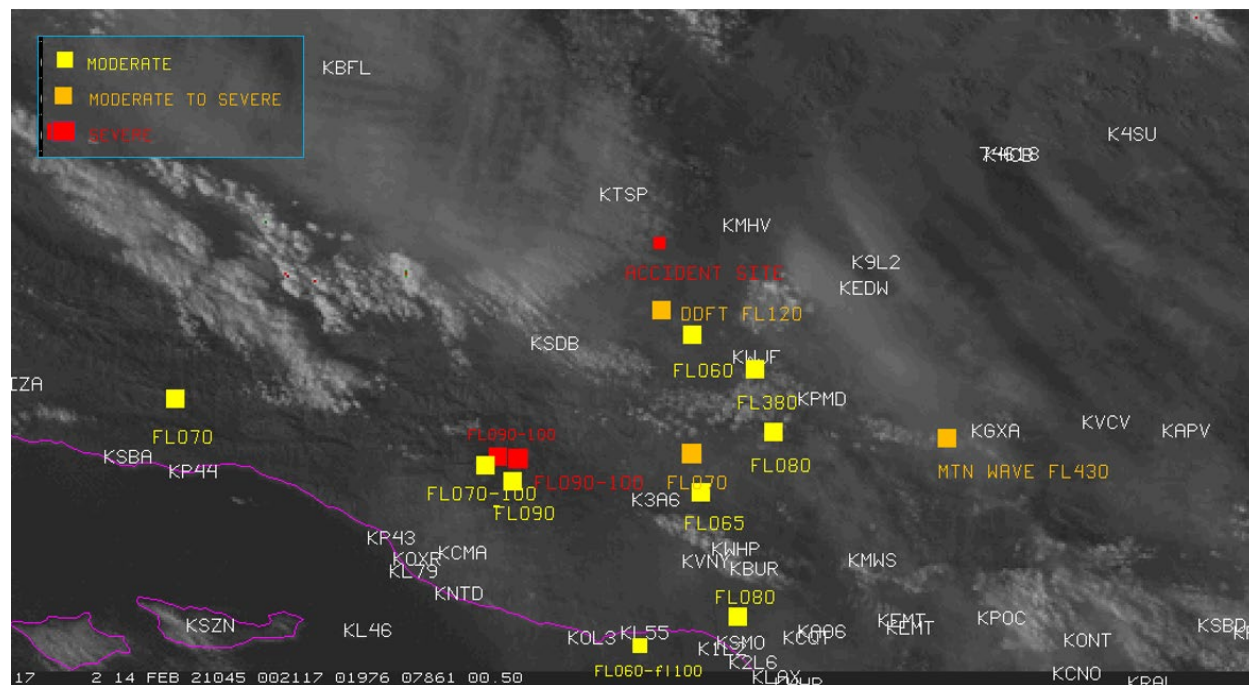


Figure 16 - Plot of the nearest PIREPs turbulence and altitude of encounter

7.0 NWS Forecasts

A review of the basic NWS aviation forecasts issued during the period and applicable for the flight were as follows. The accident site was located near the border of two NWS Weather Forecast Offices (WFOs) Los Angeles/Oxnard to the south along the general flight track and the accident site in Kern County and the Tehachapi area within the San Joaquin/Hanford area of responsibility.

7.1 Terminal Aerodrome Forecasts

A Terminal Aerodrome Forecast (TAF) is a concise statement of the expected meteorological conditions at an airport during a specified period, usually 24 hours. TAFs are valid for a 5 mile radius around an airport's center point. The closest airport issuing a TAF was from KWJF approximately 18 miles south of the accident site and was issued by the NWS Los Angeles/Oxnard Weather Forecast Office (WFO) at 1549 PST and was as follows.

TAF KWJF 132349Z 1400/1424 30030G40KT P6SM SCT200
FM140200 30035G45KT 2SM BLDU BKN002 BKN050
FM140400 30030G40KT P6SM SCT200
FM140800 30015G25KT P6SM SCT200
FM142300 29020G30KT P6SM SCT250=

The forecast for KWJF from 1600 through 1800 PST expected a surface wind from 300° at 34 knots with gusts to 40 knots, visibility 6 miles or more, with scattered clouds at 20,000 ft agl. The forecast after 1800 through 2000 PST expected IFR conditions with wind gusts to 45 knots with visibility 2 miles in blowing dust, with ceiling broken at 200 ft agl, and broken at 5,000 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. The discussion also gives some reasoning behind the forecast. These are generated roughly every 6 hours and corresponds to the release of the latest TAFs for that office. The NWS San Joaquin/Hanford (KHNX) WFO who were responsible for the Tehachapi area and Kern County issued the following AFD at 1558 PST was as follows.

FXUS66 KHNX 132358
AFDHXX

Area Forecast Discussion
National Weather Service Hanford CA
358 PM PST Sat Feb 13 2021

.UPDATE... Updated for the air quality section.

.SYNOPSIS...

Strong gusty winds will continue across the Kern County mountains and desert this evening then diminish overnight. Some light showers spreading southward will taper off this evening. Another system is forecast on Monday for light precipitation and increased wind. Dry weather and a warming trend is expected later next week.

.DISCUSSION...

A trough of low pressure diving southward along the CA/NV border is producing just light precipitation but strong gusty winds have developed over the mountains and desert in Kern County, as was expected. Showers have mainly been confined to the mountains with the highest amounts around a quarter to a third of an inch within the Mariposa and Madera County portions of the Sierra. Showers will mostly end this evening. But northwest flow will keep some low clouds banked up against the SJ Valley facing slopes

of Kern County tonight with some light showers possible. Snow level are currently around 6000 feet in Kern County but will drop to near 4000 feet towards morning and there could be a dusting of snow at the highway pass levels, such as the Grapevine along Interstate 5.

A High Wind Warning remains in effect for the Kern County desert and mountains until 1 AM tonight. A surface pressure gradient of nearly 17 MB from SFO-LAS along with a 140 knot 300 MB jet are combining to produce these very windy conditions. A peak gust of 83 mph was measured at the Bear Peak RAWS (8228') and 80 mph at Bird Springs Pass RAWS (6360') earlier today. The Mojave AWOS had a peak gust of 71 mph. Winds have likely peaked but will remain quite strong this evening before diminishing overnight.

Dry, cooler and breezy conditions will prevail on Sunday as high pressure over the eastern Pacific nudges inland a bit. Another disturbance drops down on Monday for light precipitation, mainly over the Sierra Nevada, similar to today's system. It will also kick up the winds again, but not to the extent of today. Looking more like a Wind Advisory scenario than High Wind Warning.

.AVIATION...

Areas of mountain obscuration in the Sierra through 06z. Wind gusts to 35 knots over the Tehachapi mountains and Mojave Desert until 09z. Mountain obscuration over the Tehachapi range through 12z Sunday. Otherwise, VFR conditions will prevail across the San Joaquin Valley.

.AIR QUALITY ISSUES...

None.

.CERTAINTY...

The level of certainty for days 1 and 2 is high.

The level of certainty for days 3 through 7 is medium.

Certainty levels include low...medium...and high. Please visit www.weather.gov/hnx/certainty.html for additional information an/or to provide feedback.

.HMX WATCHES/WARNINGS/ADVISORIES...

High Wind Warning until 1 AM PST Sunday for CAZ195>199.

The AFD indicated that a strong pressure gradient over the area was responsible for producing strong gusting winds over Kern County with peak winds of 83 mph (72 KT) reported at Bear Mountain RAWS, 80 mph (70 KT) at Bird Springs Pass RAWS, and 71 mph (62 KT) at KMHV. A high wind warning was issued for the general public and was current at the time of the accident.

7.3 Graphic Forecast for Aviation

The NWS Graphic Forecast for Aviation (GFA) product provides a graphical depiction of surface wind, visibility, weather, and cloud cover, with the Graphical Airmen's Meteorological Advisory (G-AIRMET) for IFR conditions, mountain obscuration, and icing conditions overlaid. The GFA is available at the NWS AWC website and through other weather briefing services.

Figures 17 and 18 are the GFA southwest region Surface and Cloud Forecasts issued at approximately 1400 PST and valid for 1600 PST with the approximate accident site marked by the red star. The GFA Surface Forecast depicted northwest to west-northwesterly winds of 20 to 45 knots in the vicinity of the accident site, with visibility unrestricted. A G-AIRMET for strong

surface winds over 40 knots extended over the area and enclosed the accident site. The GFA Cloud Forecast depicted a few clouds at 4,000 ft and scattered clouds at 7,000 ft with no cloud tops indicated. No G-AIRMETs for icing or mountain obscuration conditions extended over the accident site.

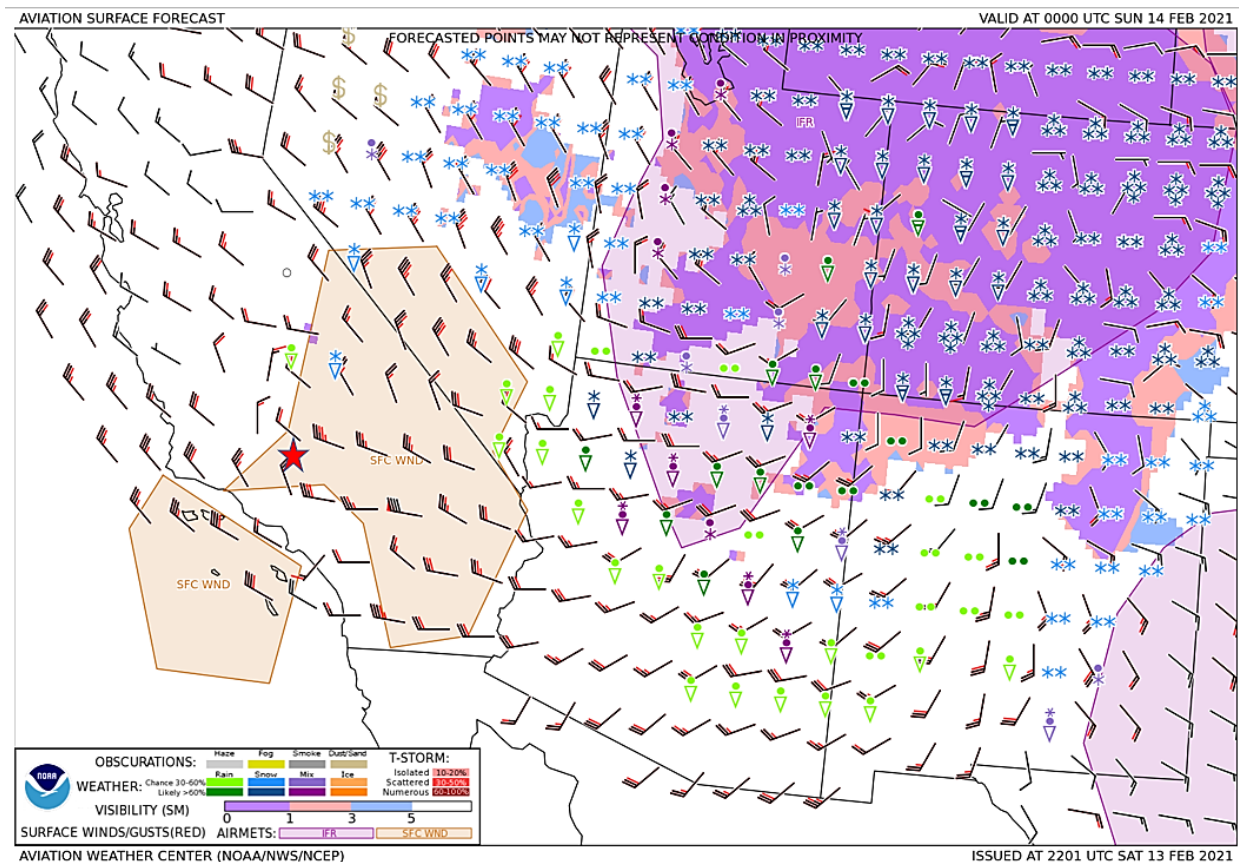


Figure 17 - Graphic Forecast for Aviation Surface Forecast valid for 1600 PST

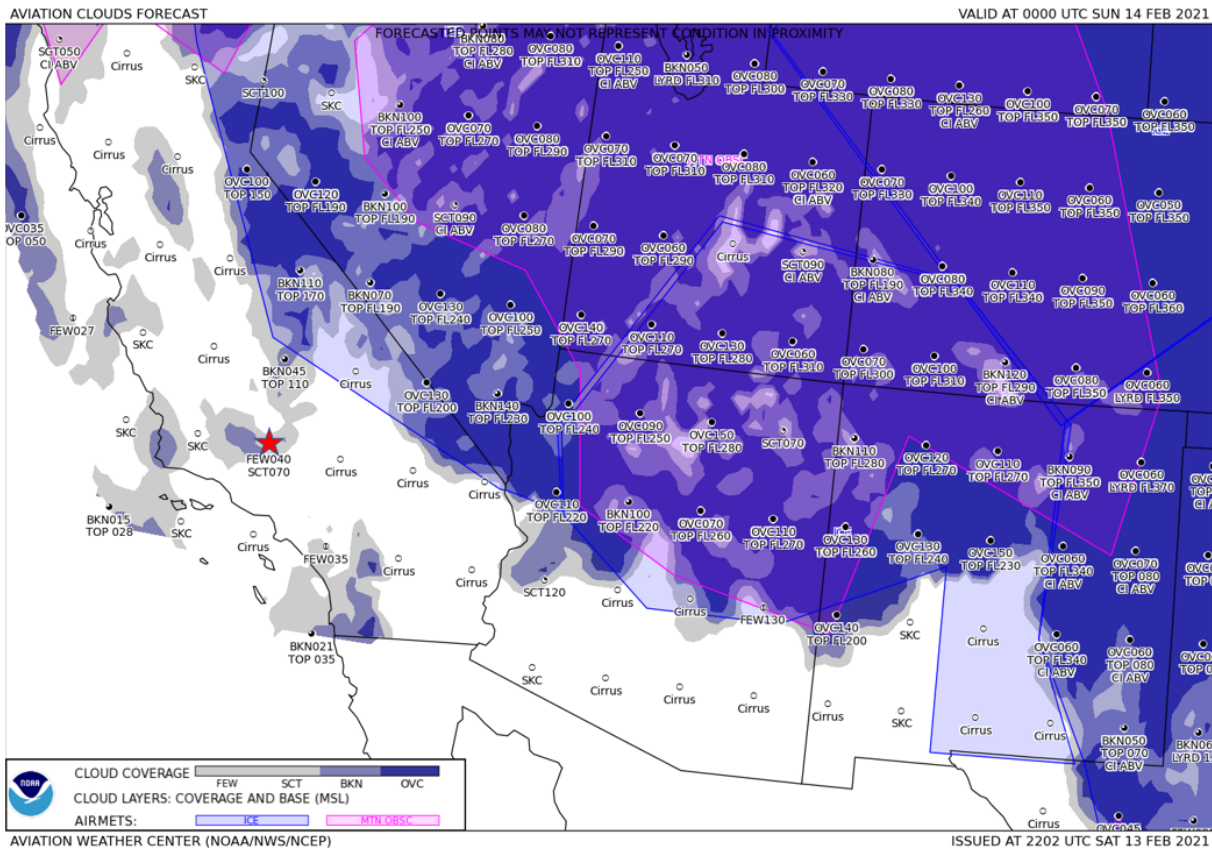


Figure 18 - Graphic Forecast for Aviation Cloud Forecast valid for 1600 PST

7.4 Winds Aloft Forecast

The NWS Winds and Temperature Aloft Forecast²⁸ for the general route of flight valid 1600 PST and for use between 1200 and 1900 PST was as follows.

WINDS ALOFT FORECASTS

DATA BASED ON 131800Z

VALID 140000Z FOR USE 2000-0300Z. TEMPS NEG ABV 24000

FT	3000	6000	9000	12000	18000	24000	30000	34000	39000
SBA	3320	3440+04	3259+00	3173-03	3182-15	8100-26	810742	831852	329861
WJF		3242+01	3255-01	3169-04	3186-15	3199-27	810843	831554	319661
ONT	2510	3227+03	3257+00	3170-04	3184-16	3199-27	810643	820554	810061

The forecast point for WJF immediately south of the accident site for 6,000 ft expected a wind from 320° at 42 knots with a temperature of 1° C, for 9,000 ft a wind from 320° at 55 knots with a temperature of -1° C, and for 12,000 ft a wind from 310° at 69 knots with a temperature of -4° C.

²⁸ NWS bulletin FBUS31 KWNO.

7.5 Overview of Graphic Turbulence Guidance Display

The Graphic Turbulence Guidance (GTG) was developed by the National Center for Atmospheric Research (NCAR) and is now run operationally at NOAA NCEP and is available to users on the AWC website from the surface to 45,000 ft. The current GTG version 3.0 model (GTG3) is generated from the NOAA Rapid Refresh numerical model with a horizontal spacing of 13.5 kilometers with 50 vertical levels, and provides a computer-generated four-dimensional forecast related to the expected intensity of atmospheric turbulence provided in eddy dissipation rate (EDR²⁹). Typical EDR varies from close to 0, “smooth”, to near 1, “extreme” for most aircraft types. NCAR defines the following EDR values to various aircraft weight classes and turbulence intensities and is included as figure 19. The accident airplane fits into the light aircraft weight category³⁰.

AC weight class	Estimated EDR Threshold * 100			
	Light	Moderate	Severe	Extreme
Light	13	16	36	64
Medium (Large)	15	20	44	79
Heavy	17	24	54	96

Figure 19 - EDR values versus turbulence intensity for various aircraft weight classes.

The GTG color coded legend for a light aircraft weight category EDR values and typical associated turbulence intensity is depicted in figure 20, with values of EDR from 16-36 typically associated with moderate turbulence, and values between 36-64 associated with severe turbulence, and EDR values greater than 64 associated with extreme intensity.

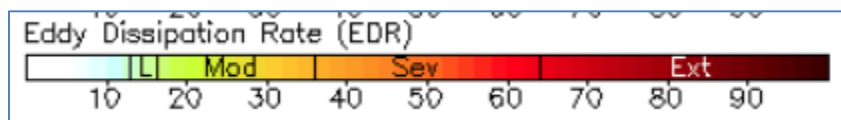


Figure 20 – Light aircraft weight category typical EDR values for the various intensities of turbulence.

The GTG product currently displayed for use on the NWS AWC website presently is not operationally archived by the NWS. As a result, the NTSB specialist contacted NCAR and requested that the current GTG and the newer GTG-N or Nowcast model which incorporates in situ EDR measurements, turbulence reports, radar reflectivity, NEXRAD Turbulence Detection Algorithm (NTDA), and the Rapid Refresh (RAP) model that is updated every 15-minutes, be run for this case. The newer GTG-N (version 4.0) is being run in an experimental mode and was not available to the pilot at the time of any preflight briefing. Both the present GTG and the experimental GTG-N model were documented below for this case. For more information on the GTG please see the reference on the NWS AWC website³¹ and the GTG-N product enhancements³². The NCAR GTG values are in decimal format versus the NWS display contours are multiplied by 100 for ease of interpretation.

²⁹ Eddy Dissipation Rate (EDR) is defined as $EDR = \epsilon^{1/3}$

³⁰ Light weight class is less than 15,500 pounds maximum takeoff weight.

³¹ <https://aviationweather.gov/turbulence/help>

³² New Capabilities of the Graphical Turbulence Guidance (GTG) Product, American Meteorological Society (AMS),

7.5.1 Graphic Turbulence Guidance (GTG) Imagery

The 2-hour GTG forecasts (version 3.0) valid for 1600 PST for 9,000 ft and for 10,000 ft with the accident airplanes flight track overlaid (black line) and accident site marked by a red star are included as figures 21-22. Figure 23 is the GTG 2-hour Cross Section from the surface to 20,000 ft. The figures show the combined GTG output (left), and the individual GTG forecast for Clear Air Turbulence (CAT) (center), and Mountain Wave Turbulence (MWT) (right) forecasts. A review of the 6-hour forecast valid for 1600 PST showed similar results and was not reproduced here.

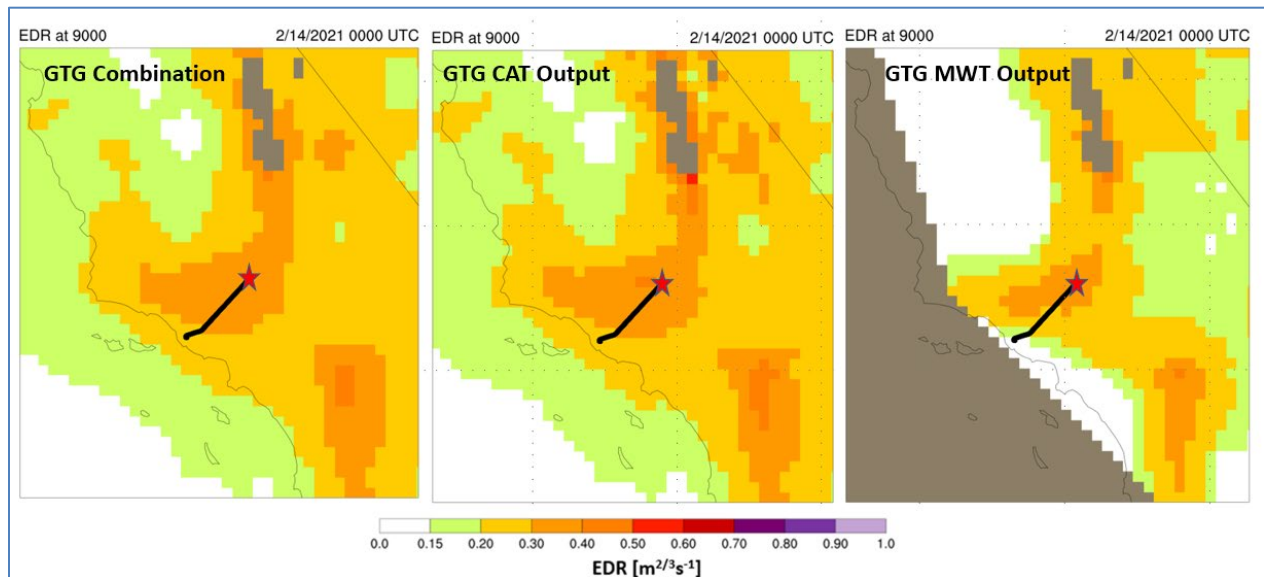


Figure 21 - GTG 2-hour forecast valid for 1600 PST of GTG Combined (left), CAT Output (center), and MWT Output (right) for 9,000 ft available at the time of departure with flight track and accident site.

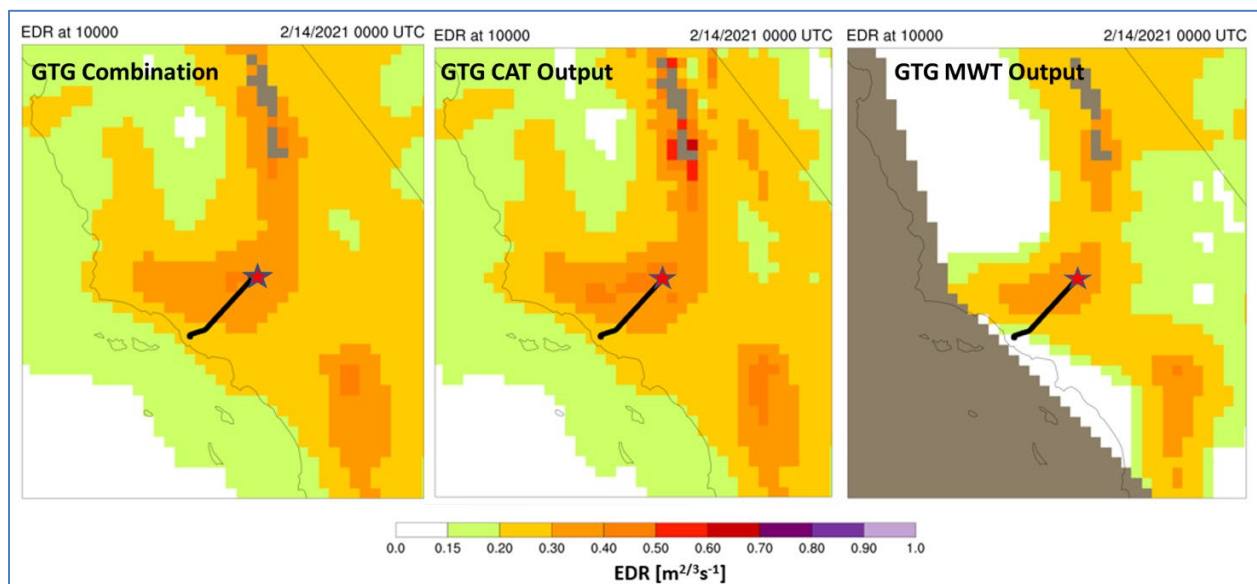


Figure 22 - GTG 2-hour forecast valid for 1600 PST of GTG Combined (left), CAT Output (center), and MWT Output (right) for 10,000 ft available at the time of departure with flight track and accident site.

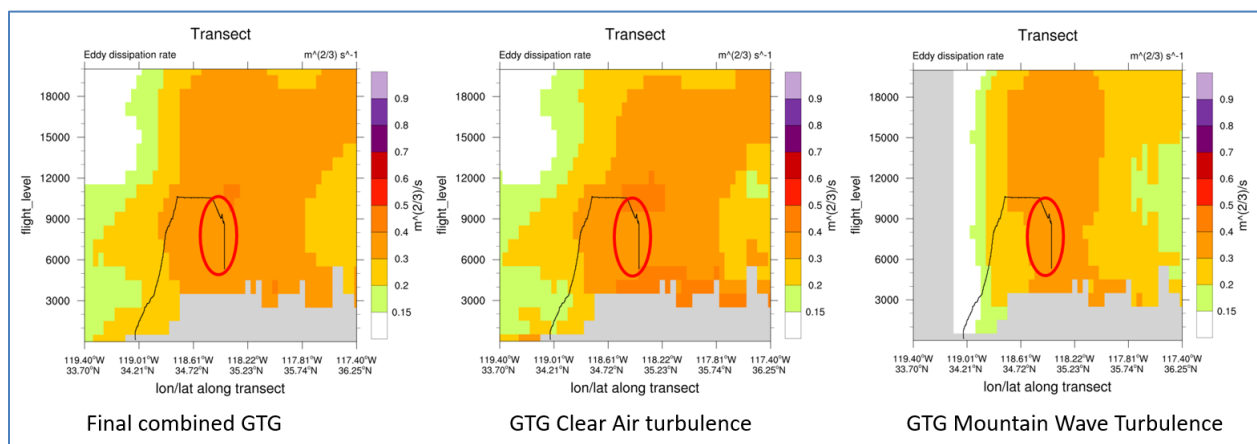


Figure 23 – GTG 2-hour Cross Section from surface to 20,000 ft valid for 1600 PST of the final combined GTG (left), CAT output (center), and MWT output (right).

The GTG combined model depicted EDR values between 0.3 to 0.4 $\text{m}^2/3 \text{ s}^{-1}$ EDR or moderate intensity range at 1600 PST at 9,000 ft with values between 0.3 to 0.5 at the 10,000 ft level over the flight track and the accident site. A maximum EDR values of 0.5 to 0.7 $\text{m}^2/3 \text{ s}^{-1}$ were depicted further north of the accident site downstream of the Sierra Nevada Mountain range. The adjacent altitudes at 8,000 ft and 11,000 ft (not shown) depicted lower EDR values between 0.2 to 0.3 $\text{m}^2/3 \text{ s}^{-1}$. The GTG cross section CAT forecast had the EDR values of 0.4 to 0.5 $\text{m}^2/3 \text{ s}^{-1}$ along the track, where control appears to be lost.

7.5.2 Graphic Turbulence Guidance Nowcast (GTG-N) Imagery

The NCAR also recreated the experimental GTG-N³³ product for the period, which is based on the WRF RAP based GTG3 with 13-km horizontal grid spacing. The GTGN is expected to replace the GTG version 3.0 as the operational forecast product and is currently based on the finer resolution HRRR with 3-km grid horizontal grid spacing. Figure 24 is the GTGN valid for 1615 EST for 9,000 ft and 10,000 ft with the flight track and accident site overlaid, which depicted EDR values of 0.3 to 0.4 $\text{m}^{2/3} \text{s}^{-1}$ over the accident site. Figure 25 is the GTG valid for 1615 PST for 9,000 ft with the red line depicting the general cross section, which is shown on the right side of the figure. Adjacent altitudes at 8,000 ft and 11,000 ft (not shown) depicted lower EDR values between 0.2 to 0.3 $\text{m}^{2/3} \text{s}^{-1}$.

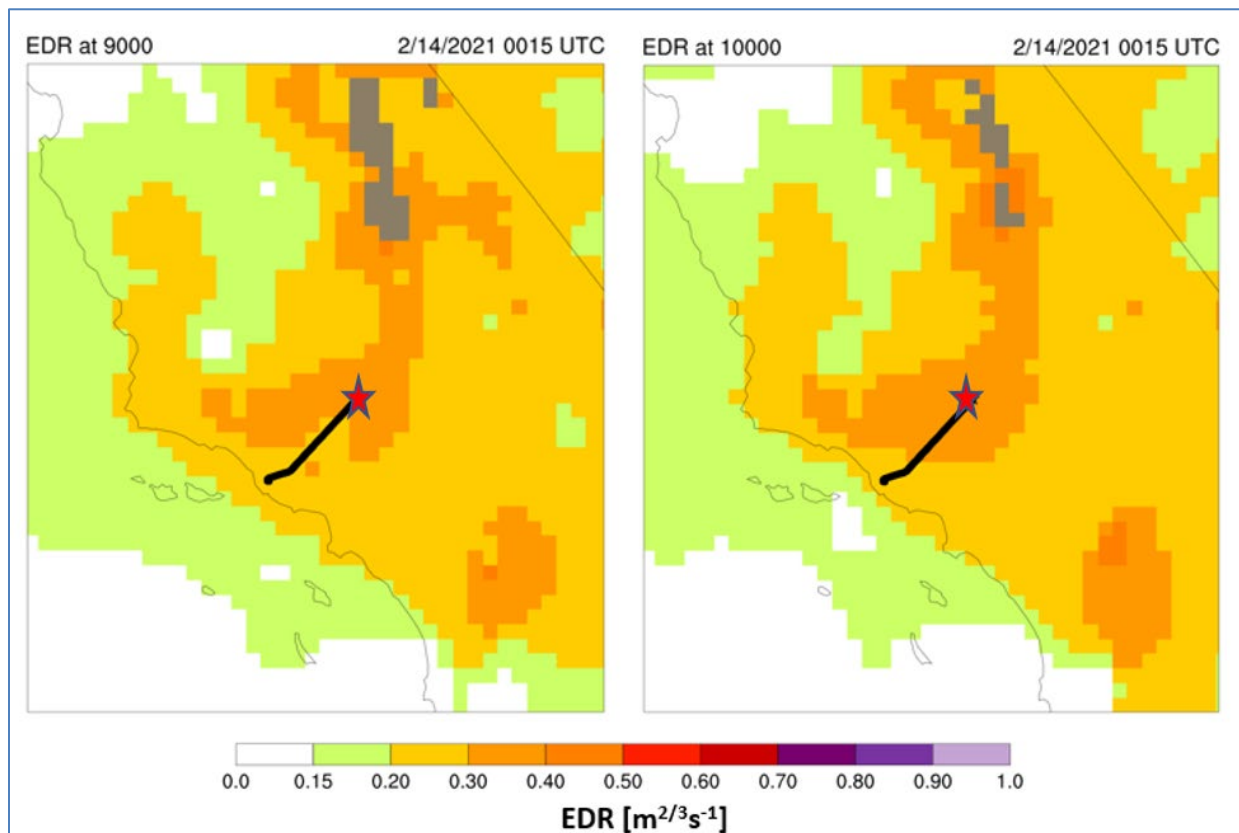


Figure 24 - GTGN for 9,000 ft and 10,000 ft valid for 1615 PST

³³ <https://ral.ucar.edu/projects/graphical-turbulence-guidance-nowcast-gtgn>

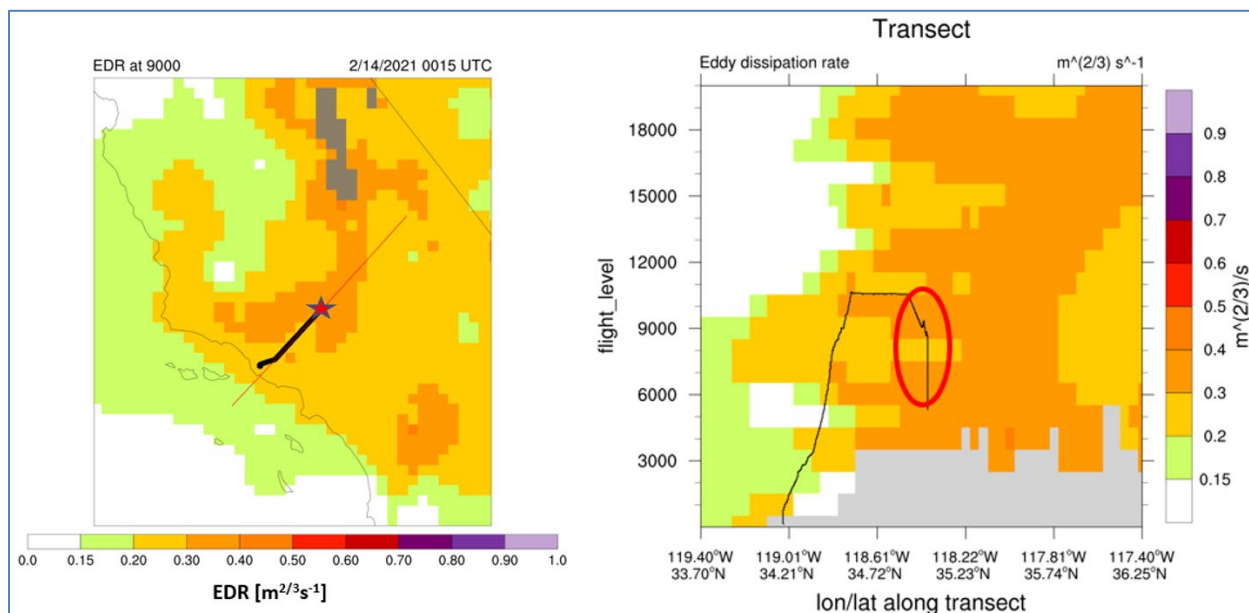


Figure 25 - GTGN valid for 1615 PST for 9,000 ft (left) and a cross section along flight track (right)

8.0 Inflight Weather Advisories

Inflight Aviation Weather Advisories are forecasts to 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 and from the Center Weather Service Units (CWSU) associated with FAA ARTCCs. There are four basic types of inflight aviation weather advisories: the Significant Meteorological Information (SIGMET), the Convective SIGMET, the AIRMET, and the Center Weather Advisory (CWA). Inflight advisories serve to notify en route pilots of the possibility of encountering hazardous flying conditions which 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 on the basis of experience and the operational limits of the aircraft.

At the time of the accident the NWS had a CWA and multiple G-AIRMETs current for turbulence conditions at the accident airplanes cruising altitude. Figure 26 is a depiction of the CWA with the accident site. The advisory warned of an area of occasional severe turbulence below 15,000 ft, low-level wind shear (LLWS), and strong surface wind gusts to 60 knots, and blowing dust in the desert region included in the advisory. The flight path crossed through this advisory and the accident site was located near the northern border of this advisory.

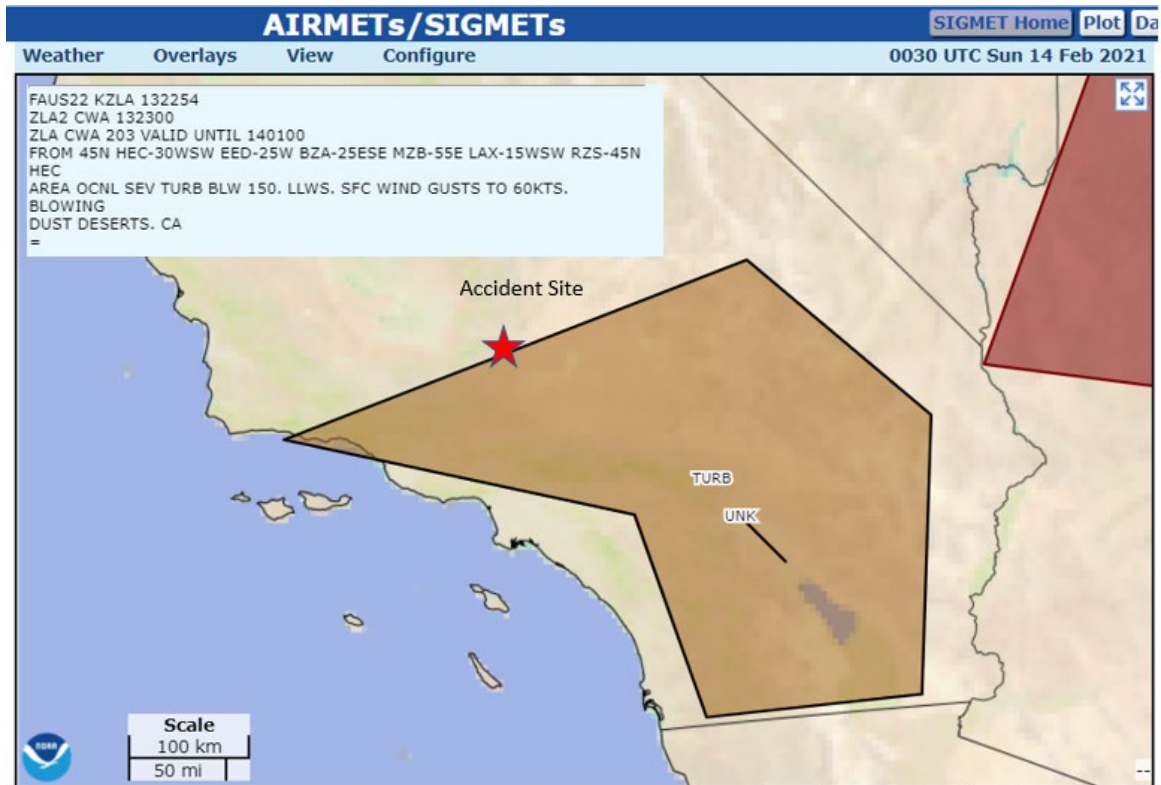


Figure 26 - CWA issued for an area of occasional severe turbulence below 15,000 ft, with LLWS, and surface wind gusts to 60 knots.

The NWS AWC also had a G-AIRMETS current for moderate turbulence below 16,000 ft over the region, LLWS with air speed loss or gain of 20 knots or more below 2,000 ft agl, and strong surface winds over 30 knots over the accident site, which are depicted in figure 27.

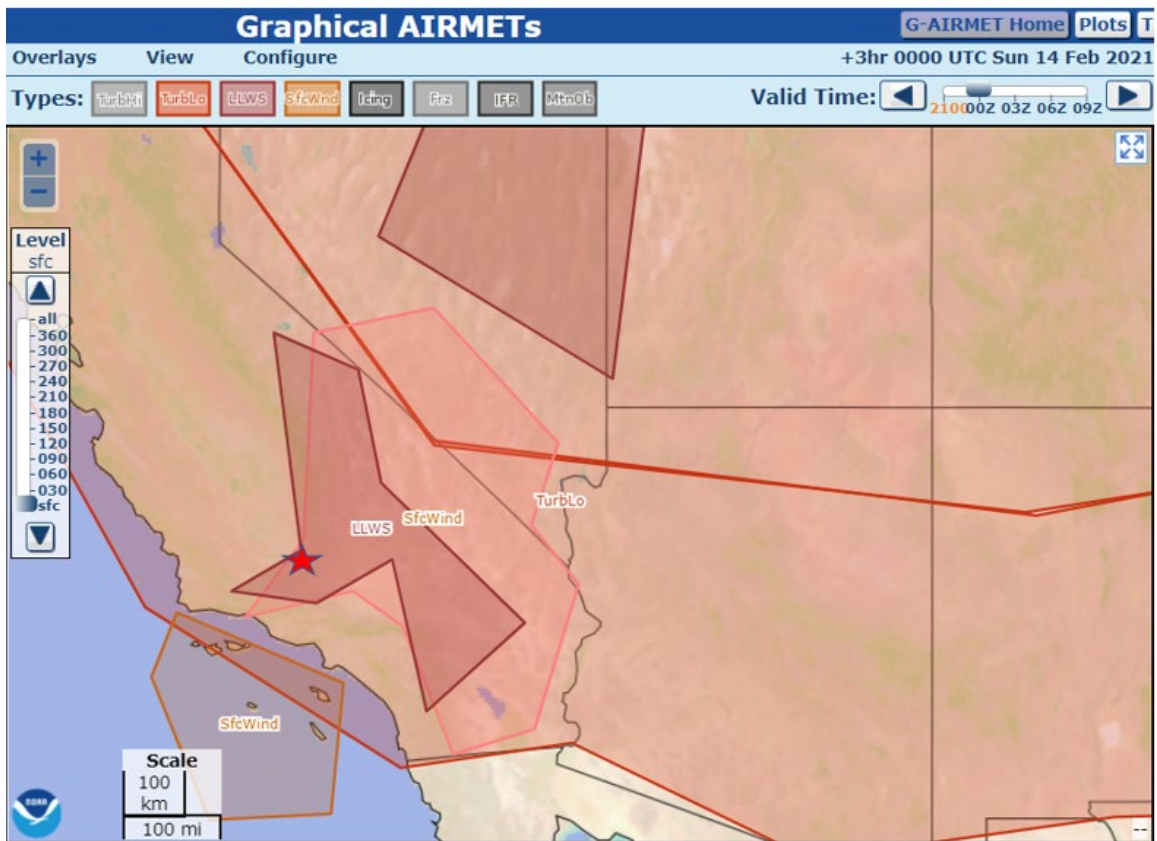


Figure 27 - G-AIRMET for moderate turbulence, LLWS, and strong gusting surface winds valid at the time of the accident.

The full text AIRMET Tango bulletin issued at 1535 PST and valid at the time of the accident is included below with the bold italic print applicable to the accident flight.

WAUS46 KPCI 132335 AAA

WA6T

-SFOT WA 132335 AMD

AIRMET TANGO UPDT 7 FOR TURB STG WNDZ AND LLWS VALID UNTIL 140300

AIRMET TURB...WA OR CA ID WY NV UT CO AZ NM AND CSTL WTRS
FROM YDC TO 40SW MLD TO 20S JNC TO BFF TO GLD TO 50W LBL TO
30ESE TBE TO INK TO ELP TO 50S TUS TO BZA TO 30S MZB TO 40SW RZS
TO 100SW PYE TO 140WSW FOT TO 110WNW ONP TO 140W TOU TO YDC
MOD TURB BTN FL180 AND FL400. CONDS CONTG BYD 03Z THRU 09Z.

AIRMET TURB...OR CA NV CO AZ NM AND CSTL WTRS
FROM 20SSW ONP TO 20NW OAL TO 50ENE LAS TO 60E TBC TO 40E RSK TO
30ESE TBE TO INK TO 50S TUS TO BZA TO 20S MZB TO 70W RZS TO 50SW
ENI TO 80W OED TO 20SSW ONP
MOD TURB BLW FL180. CONDS CONTG BYD 03Z THRU 09Z.

AIRMET TURB...WA OR CA ID WY NV UT CO AZ NM
FROM 70SE HUH TO 60SSE GEG TO 40ENE PIH TO 20NE DDY TO 30ESE TBE
TO 40E RSK TO 60E TBC TO 50ENE LAS TO 30NW OAL TO 20S ONP TO 20S
HQM TO 70SE HUH

MOD TURB BLW 160. CONDS CONTG BYD 03Z THRU 09Z.

AIRMET STG SFC WND...CA NV AZ

FROM 60NNE OAL TO 50NNE LAS TO EED TO 40S EED TO 30WNW BZA TO 40ESE MZB TO 60WSW HEC TO RZS TO 20ENE EHF TO 50ENE CZQ TO 60S FMG TO 60NNE OAL

SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG BYD 03Z ENDG 03-06Z.

AIRMET STG SFC WND...CA CSTL WTRS

FROM 50SSW SNS TO 50W RZS TO 40SE LAX TO 50SSW MZB TO 210SW MZB TO 120SW RZS TO 150WSW RZS TO 50SSW SNS

SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG BYD 03Z THRU 09Z.

LLWS POTENTIAL...CA

BOUNDED BY 40SSW FMG-EED-BZA-40ESE MZB-50W TRM-20WNW RZS-20SE EHF-40SSW FMG

LLWS EXP. CONDS CONTG BYD 03Z THRU 09Z.

9.0 Weather Briefing Information

A search of the FAA Automated Flight Service Station (AFSS) contract provider Leidos indicated that they had no contact with the pilot of N40TS for any weather briefing on the day of the accident and no third-party vendors utilized their system made any requests for weather data or to file any flight plans. It is therefore unknown what information the pilot may have familiarized himself with before departure or enroute regarding the weather conditions.

10.0 Astronomical Conditions

The astronomical conditions over the accident site obtained from the United States Naval Observatory software provided the following conditions for KTSP. The time of the accident has been added in bold italic print for reference.

<u>SUN</u>	<u>Time (PST)</u>
Begin of civil twilight	0615
Sunrise	0641
Cumulative	1207
<i>Accident</i>	<i>1627</i>
Sunset	1735
End civil twilight	1800

11.0 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.

Vertical Propagating Mountain Waves

Figure 28 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.

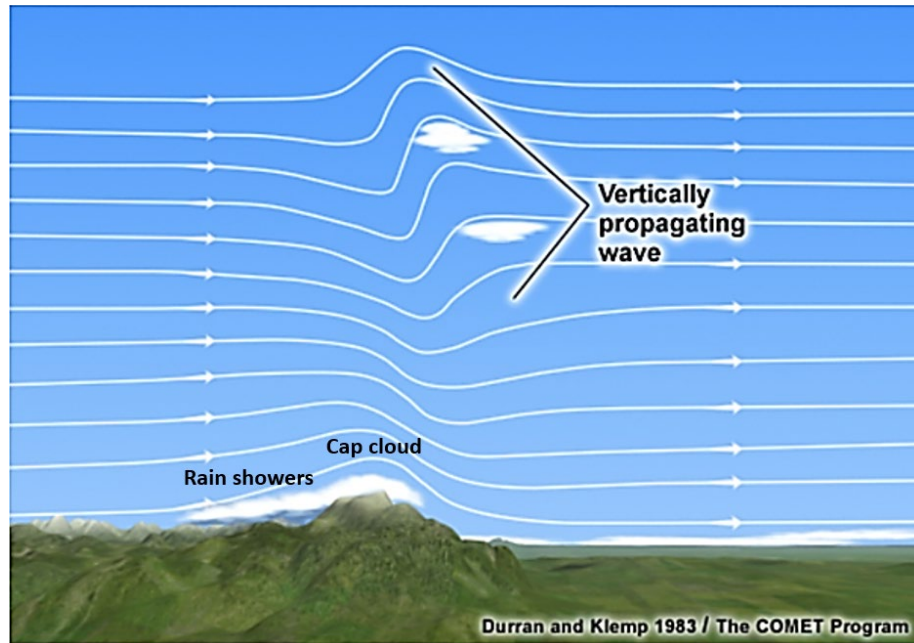


Figure 28 - Vertically propagating mountain wave

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 29. The jump region (or hydraulic jump³⁴) is frequently an area of sever-to-extreme turbulence extending to 10,000 ft or more above the surface. The jump region is sometimes marked by a line of ragged rotor clouds exhibiting very turbulent motion, with turbulence typically decreases with distance away from the jump region.

³⁴ 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.

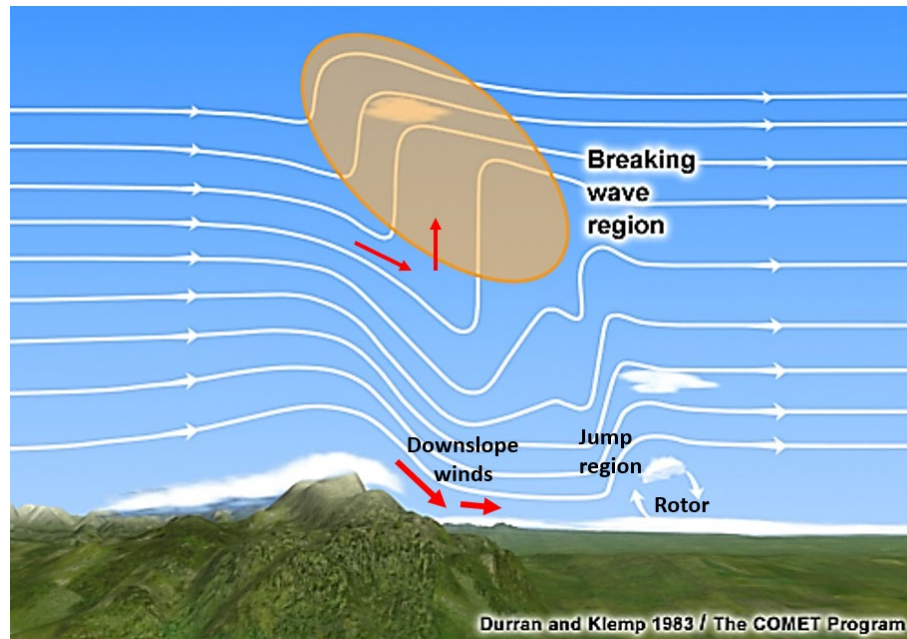


Figure 29 – Breaking vertical propagating wave with downslope winds and pressure jump area noted

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 30 is a depiction of a trapped lee wave. 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.

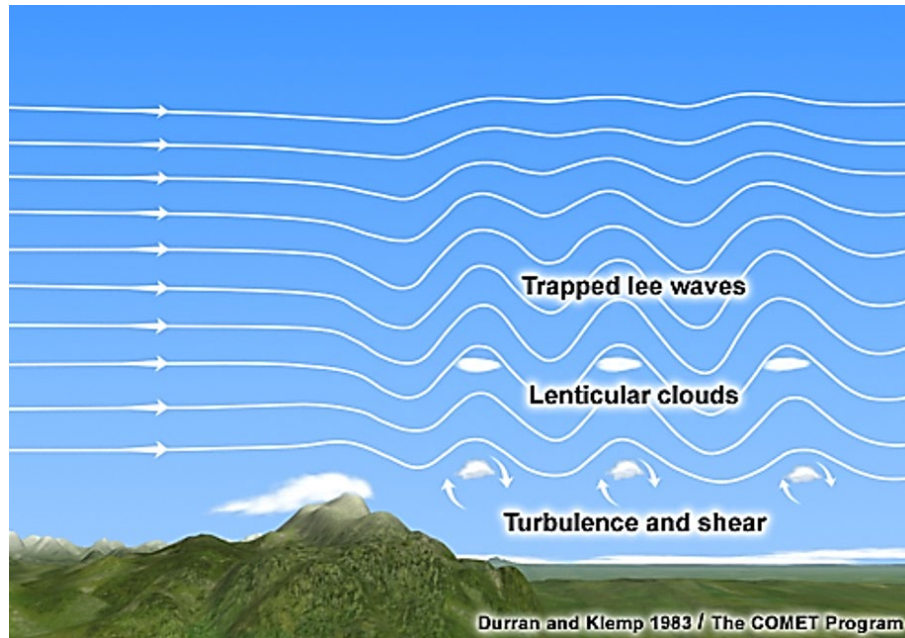


Figure 30 - Trapped lee wave and lenticular clouds

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 and 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 make 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.*

12.0 Weather Research and Forecast Models

Both the NTSB and the NCAR ran numerical models over the area to support the investigation.

12.1 NTSB WRF Model

The NTSB ran a Weather Research and Forecasting Model (WRF) simulation surrounding the time of the accident using initialization data from the Global Forecast System (GFS)³⁵. The terrain features are provided in figure 31 for domain 2 (left) and for domain 3 (right) with height in ft, and the center of the frame over the accident site. Figures 32 and 33 are the domain 2 and 3 images of the WRF horizontal winds at 700-hPa or approximately 10,000 ft centered over the accident site for 1600 PST (left), 1630 PST (middle), and 1700 PST (right). The image depicted a band of high winds near 80 knots extending along the higher terrain, with winds decreasing to the southeast, and increasing again in a wave like fashion.

³⁵ GFS4.[1] WRF ARW (Advanced Research WRF core) version 4.1.2 was run with 3 domains with horizontal grid spacing of 8 km, 1.6 km, and 320 m. Other WRF simulation parameters included: 50 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.

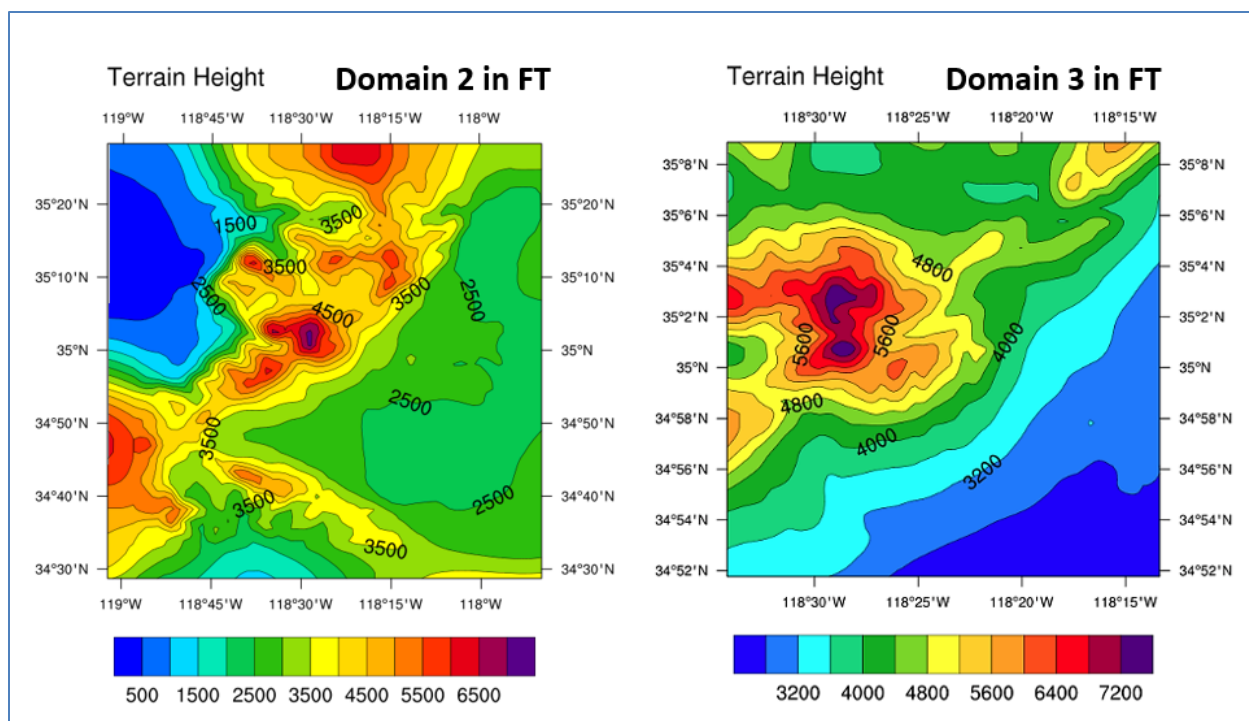


Figure 31 - Terrain features used in the WRF model for domain 2 (left) and domain 3 (right) with height in ft.

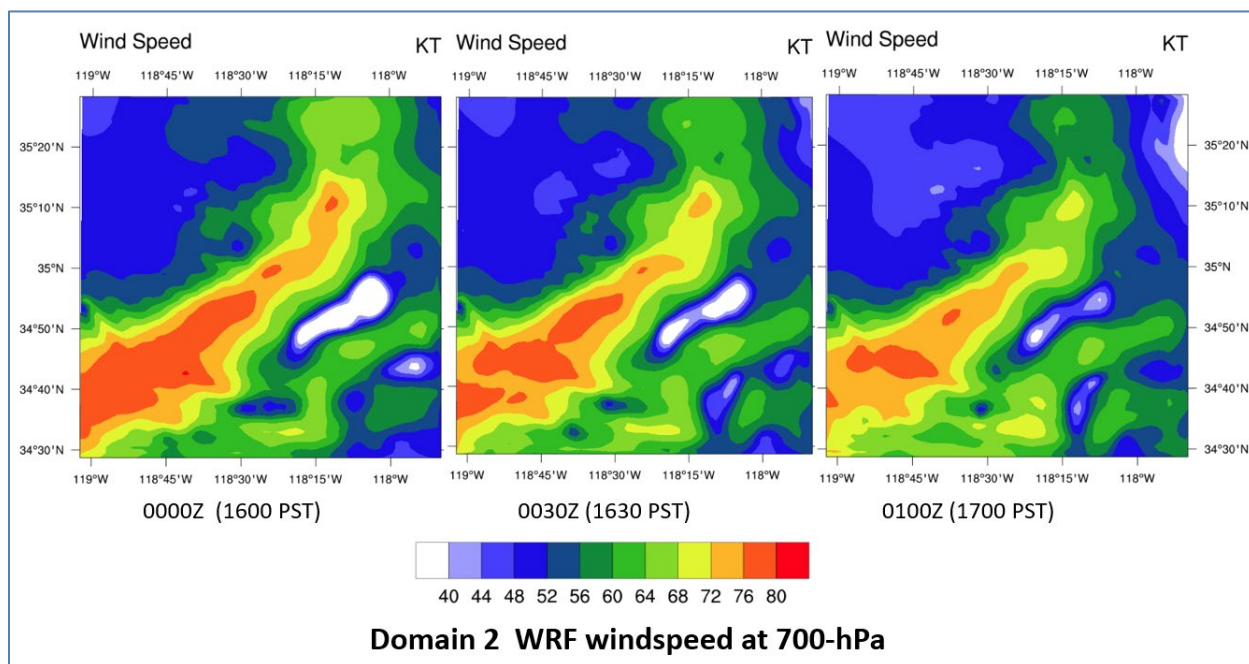


Figure 32 - WFR domain 2 depiction of the horizontal winds at 700-hPa for 1600 PST (left), 1630PST (middle), and 1700 PST (right) centered over the accident site.

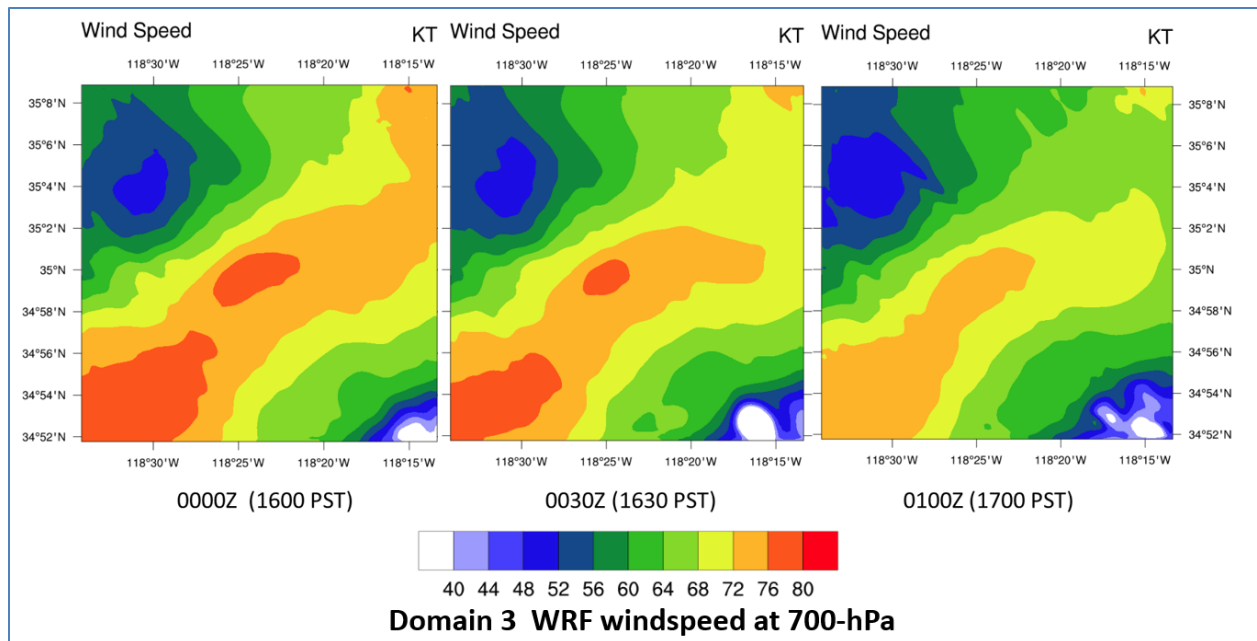


Figure 33 - WRF domain 3 model winds at 700-hPa for 1600 PST (left), 1630 PST (middle), and 1700 PST (right) centered over the accident site.

Figures 34 and 35 is a domain 3 topography of the west to east cross section with the accident site located in the middle of the image depicting the isentropes or lines of potential temperature (K) and wind speeds in knots and the vertical velocity in feet per minute (fpm) from 1600 through 1700 PST at 10-minute intervals.

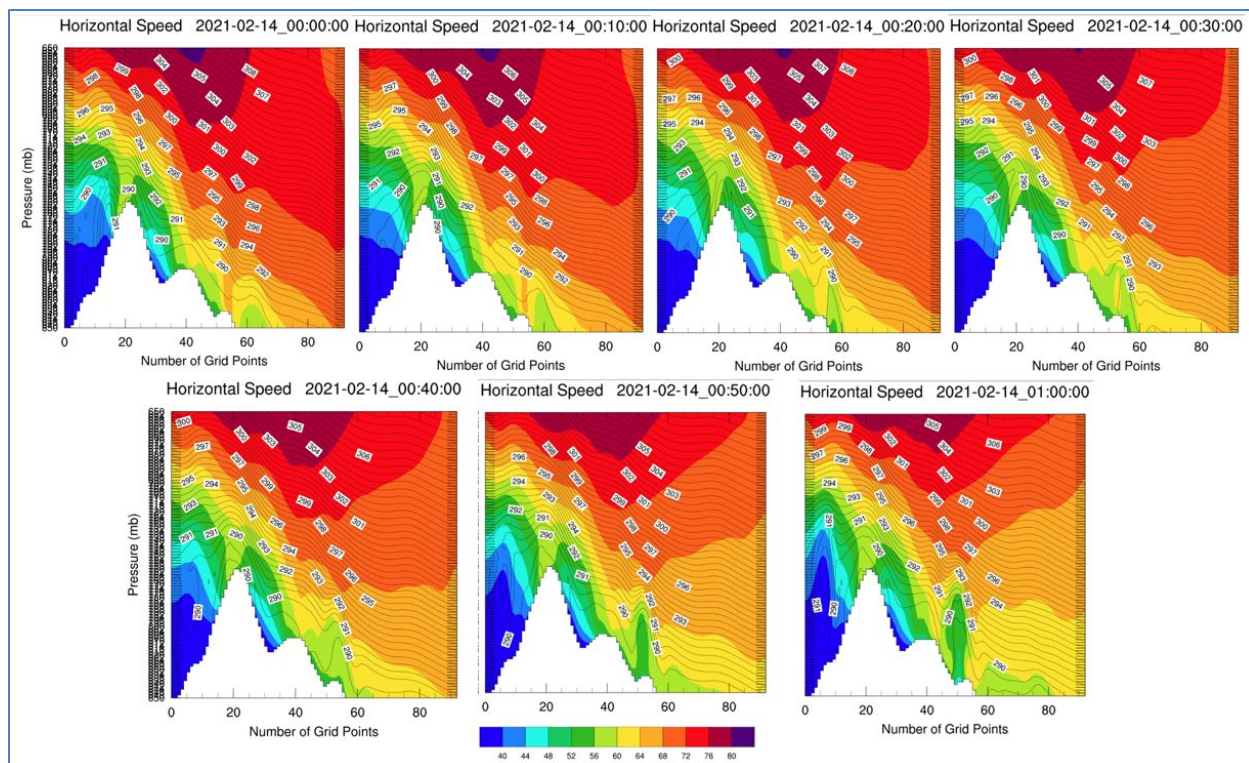


Figure 34 - WRF west to east cross section from 1600 through 1700 PST, at 10-minute intervals for domain 3.

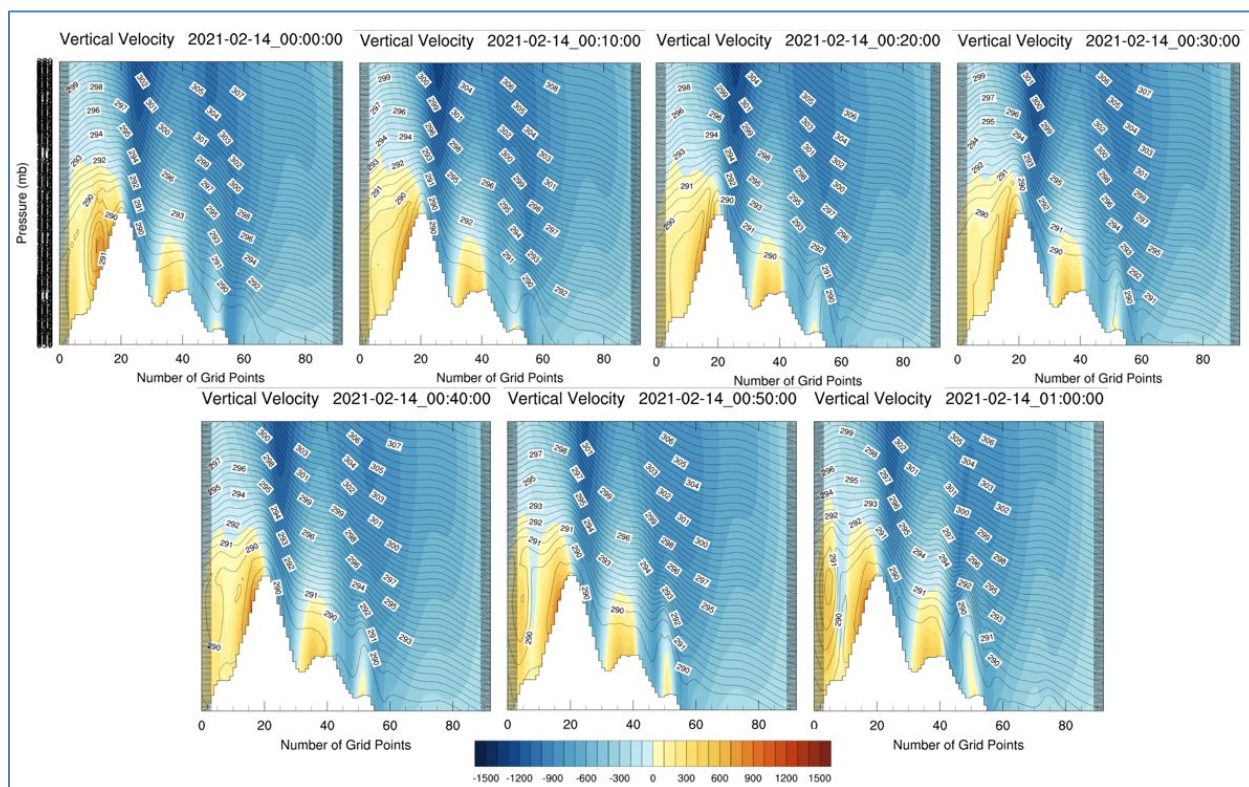


Figure 35 - WRF west to east cross section of vertical velocity from 1600 through 1700 PST at 10-minute intervals for domain 3 with speed in feet per minute (fpm).

12.2 NCAR Numerical Models

NCAR also ran several simulations evaluating the conditions. Figure 36 is the HRRR model derived soundings over the accident site of the horizontal (U), vertical wind component (V) in m/s, the virtual temperature (Tv)³⁶ (left) and the vertical profile of the Scorer parameter (P) (right). The sounding depicted a low-level temperature inversion with the wind predominately from the north at low levels. The scorer parameter decreases with height at low level and according to NCAR was conducive to wave trapping as identified in section 12.0.

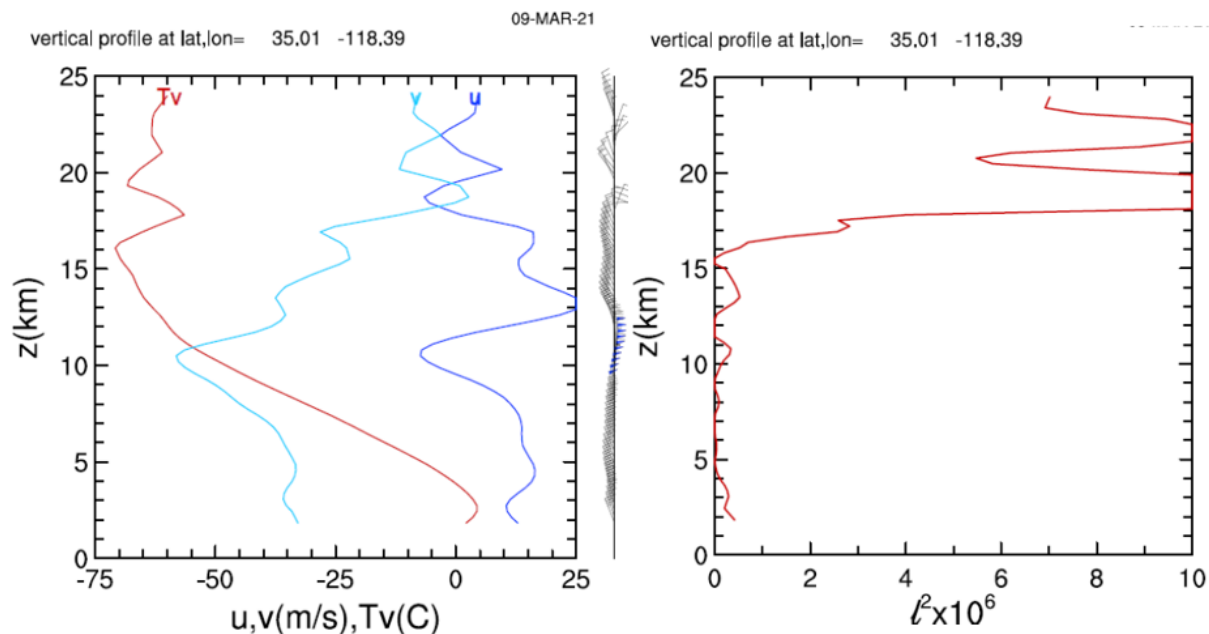
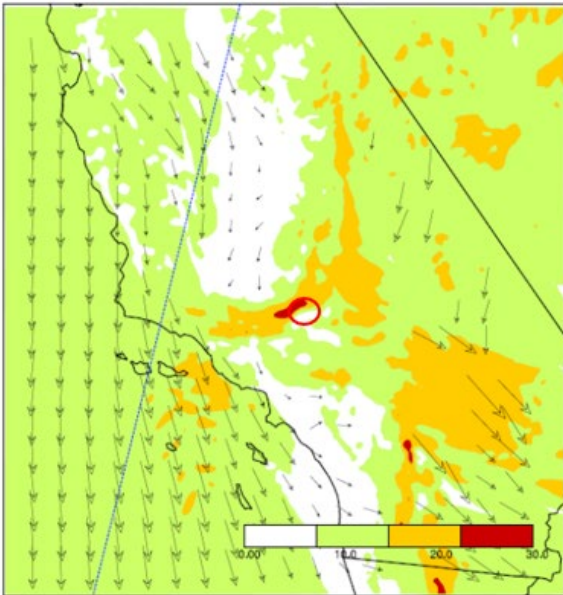


Figure 36 - NCAR numerical simulation soundings for 1700 PST over the accident site

Figure 37 is the NCAR HRRR 2-hour forecast of surface wind gusts (left) and turbulence kinetic energy (TKE) (right) at 9,000 ft valid at 1700 PST. The NCAR HRRR forecast valid for 1700 PST depicted an elevated surface wind gusts of 40 knots over the accident site and an area of 60 knots immediately south, and high values of TKE bordering the immediately north and south of the accident site.

³⁶ The virtual temperature (Tv) is the temperature at which dry air would have the same density as the moist air, at a given pressure. In other words, two air samples with the same virtual temperature have the same density, regardless of their actual temperature or relative humidity.

Elevated Surface Gusts in m^2s^{-3}
Valid for 0100Z 14 Feb 2021



Turbulence Kinetic Energy (TKE) in m^2s^{-3}
02-hr turbulence forecast at 9,000 ft valid 0100Z

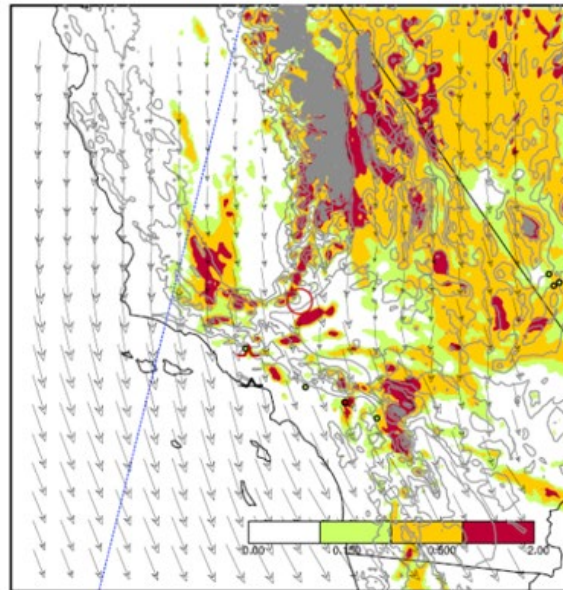
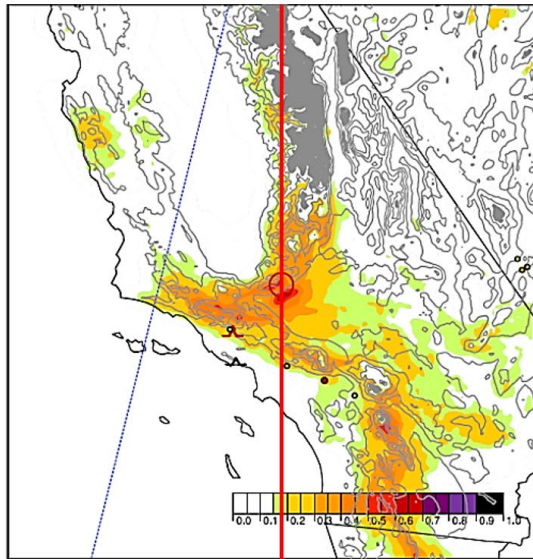


Figure 37 - NCAR numerical simulation of surface wind gusts and turbulent kinetic energy for 1700 PST.

The NCAR GTG version 4.0 Mountain Wave Turbulence (MWT) model using ensemble mean of 10 diagnostics is included as figure 38. The chart depicted the plan view (left) at 9,000 ft with the accident site located within the red circle, which was consistent with the HRRR gust and TKE (left) showing large values of EDR $>0.5 \text{ m}^{2/3} \text{ s}^{-1}$ south of the accident site. The south-to-north cross section along the red line running through the accident site is on the right and depicted the terrain (grey), the boundary layer height (thick blue line), and isentropes (light blue), wind speed (magenta), and various measures of the tropopause height.

GTG4 MWT using ensemble mean of 10 diagnostics

GTG MWT 02-hr turbulence forecast at 9,000 ft
Valid 0100Z 14 Feb 2021



mwt Indices= 472 473 474 475 477 481 482 483 484 485
gtg.config.HRRRv4-wmwt-clt_EqWts_trop-strat_5h2.dat

GTG MWT south-north cross section
Valid 0100Z 14 Feb 2021

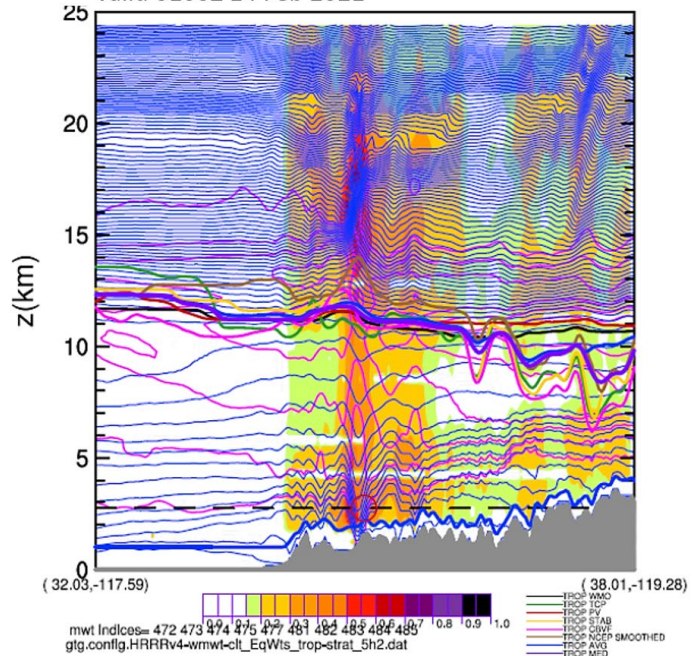


Figure 38 - NCAR numerical simulation of GTG version 4 Mountain Wave Turbulence forecast for 9,000 ft (left) and north to south cross section over the accident site for 1700 PST.

F. LIST OF ATTACHMENTS

Attachment 1 – Animation of GOES-17 visible imagery

Attachment 2 – KEYX WSR-88D 0.88° base reflectivity animation with flight track overlaid

Submitted by:

Don Eick
Senior Meteorologist