



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

February 22, 2022

Specialist's Factual Report

METEOROLOGY

WPR22FA023

A. ACCIDENT

Location: North Bend, Washington
Date: October 28, 2021
Time: 0910 pacific daylight time (PDT)
1610 universal coordinated time (UTC)
Airplane: Mooney M20M; Registration: N40KA

B. METEOROLOGY SPECIALIST

Specialist Donald Eick
National Transportation Safety Board
Senior Meteorologist
Washington, D.C.

C. 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). 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 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.

This report documents the factual conditions associated with the weather conditions surrounding the flight. The accident site is based on the coordinates of latitude 47.5923° N and longitude 121.6330° W, at an elevation of approximately 2,886 ft.

D. 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 joint NWS and Federal Aviation Administration (FAA) Advisory Circular "Aviation Weather Services", AC 00-45H change 2¹.

1.1 Surface Analysis Chart

The northwest section of the NWS Surface Analysis Chart for 0800 PDT is included as figure 1 with the approximate accident site marked by the red star. The chart depicted a low-pressure system at 1011-hectopascals (hPa)² over the Washington coastline associated with a frontal wave, with a stationary front extending southwest into the Pacific and a warm front extending southeastward over Washington state and in the immediate vicinity of the accident site. A secondary trough of low-pressure extended southeastward from the warm front across Washington, northeast Oregon, and into western Idaho. A high-pressure system at 1030-hPa was located over central Idaho. The station models in the vicinity of the accident site depicted light winds, obscured skies in rain and fog, with temperatures in the 50's °F in the Seattle area and near 37° F immediately southeast of the accident site at Ellensburg, WA. Temperature-dew point spreads were less than 2° F over the area with light rain and fog over the area.

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

² Hectopascal is the standard term for reporting sea-level pressure and is interchangeable with the term millibar (mb) with the same units. The international standard atmosphere (ISA) is based on a sea-level pressure of 1013.25-hPa at 59° Fahrenheit (F) or 15° Celsius (C).

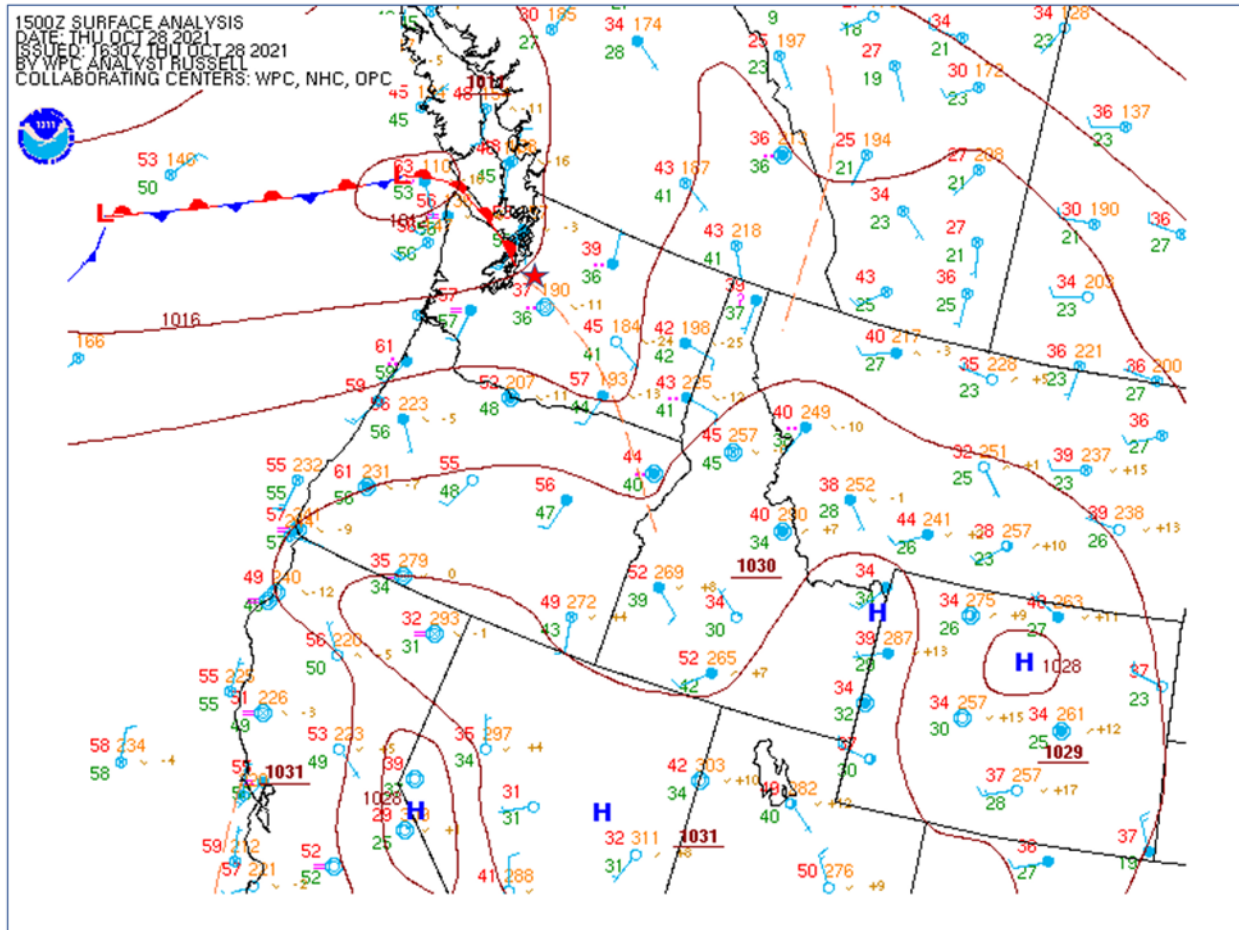


Figure 1 - Northwest section of the Surface Analysis Chart for 0800 PDT with accident site marked by the red star.

1.2 Regional Radar Mosaic

The northwest section of the NWS National Reflectivity Mosaic for 0910 PDT with the approximate accident site marked by the red star is included as figure 2. The departure airport from Arlington (KAWO), and the surrounding weather reporting stations documented in section 2.0 are identified. The radar image depicted several large areas of precipitation over Washington state with the accident site on the western edge of several echoes near 30 dBZ. While no significant meteorological echoes were noted over the general route of flight to the accident site, the closest weather surveillance radar will be further documented in section 5.0 of this report.

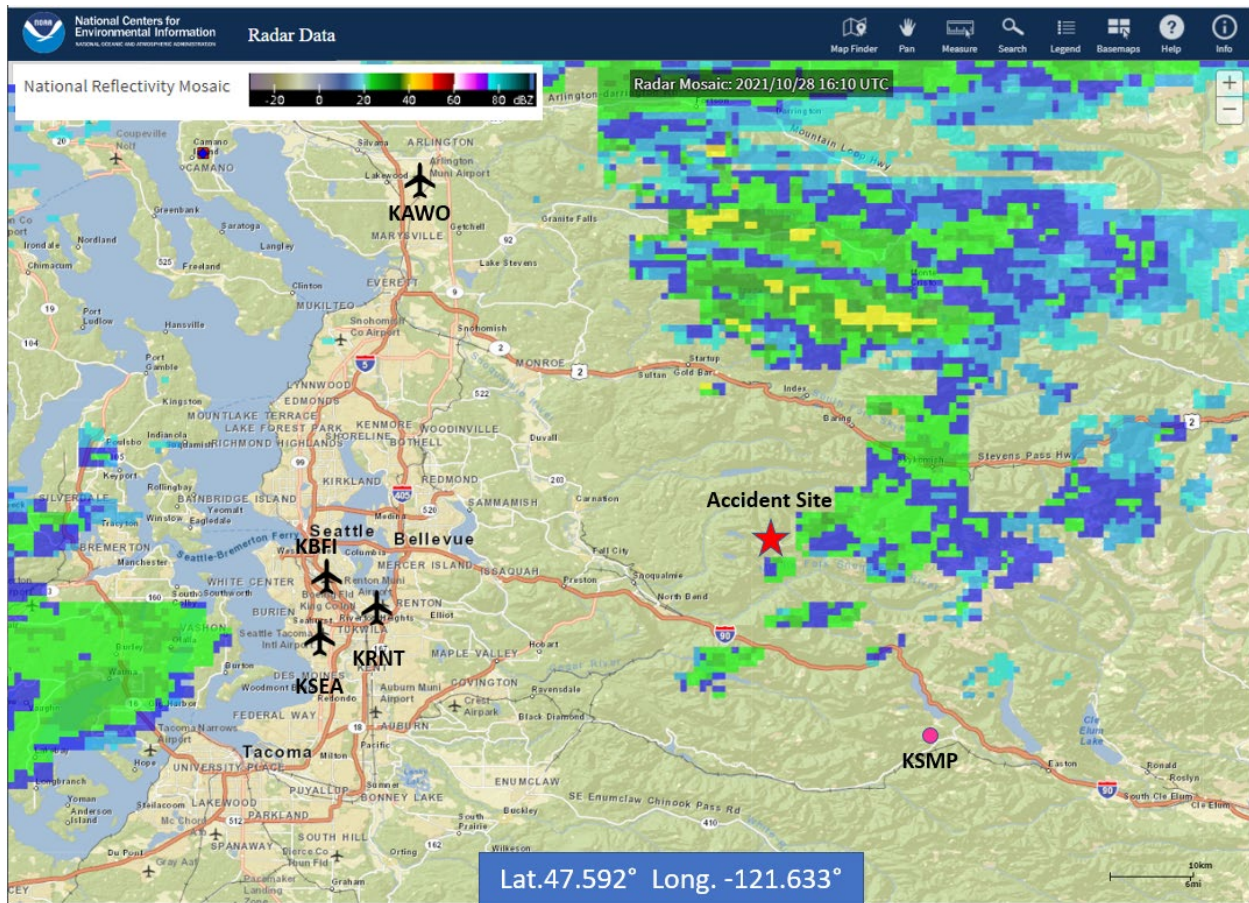


Figure 2 - Regional Radar Reflectivity Mosaic for 0910 PDT with the accident site marked by the red star.

1.3 Short Term Forecast Chart

The NWS WPC 6-hour Short Term Surface Forecast Chart valid for 1100 PDT is included as figure 3. The chart depicted the low-pressure system near 1010-hPa nearing the coast of Washington and Vancouver Island with the warm front extending southeast over the area. A large area of likely rain with a probability over 55% (dark green) was depicted over western and northern Washington, northwest Oregon, and northern Idaho and Montana, with a chance of rain (light green) over most of Washington with a probability less than 55%.

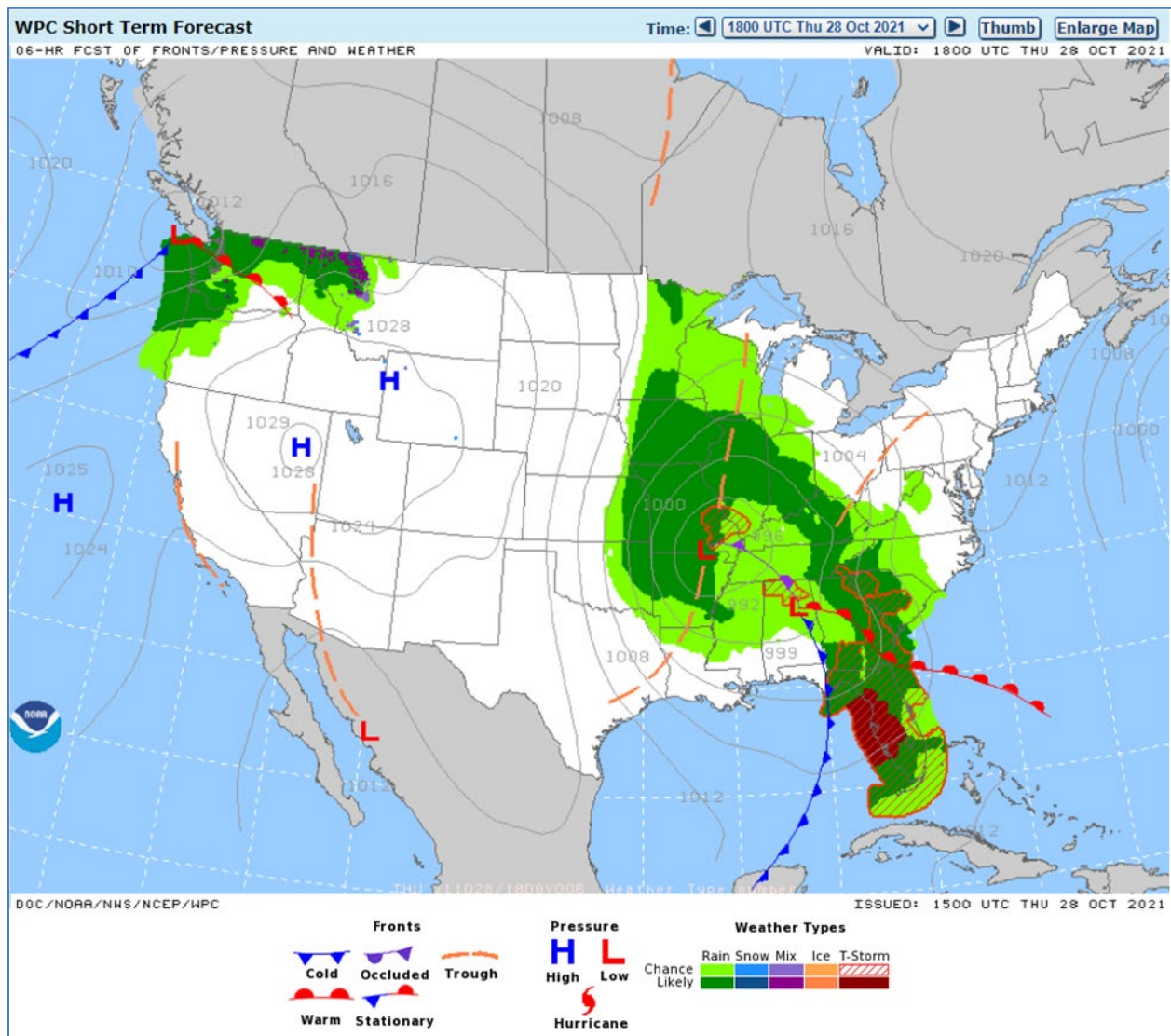


Figure 3 - NWS 6-hour Short Term Forecast Chart valid for 1100 PDT.

1.4 Low-Level Significant Weather Prognostic Chart

The 12-hour Low-Level Significant Weather Prognostic Chart provides a forecast of aviation weather hazards from the surface to 24,000 ft³, and depicts the general flight categories⁴, turbulence, and the freezing levels at 4,000 ft intervals. The chart for use

³ Flight Level 240 or FL240. Flight levels are referenced above 18,000 ft when aircraft fly constant pressure levels setting 29.92 inches of mercury into their altimeters for standard separation.

⁴ As defined by the NWS and the FAA Aeronautical Information Manual (AIM) section 7-1-7 defines the following general flight categories:

- Low Instrument Flight Rules (LIFR*) - ceiling or the lowest layer of clouds reported as broken or overcast, or the vertical visibility into a surface based obscuration below 500 ft above ground level (agl) and/or visibility less than 1 statute mile.

at the time of the accident was valid for 1700 PDT and is included as figure 4. The chart depicted an area of IFR conditions (enclosed by the red contour) over most of northern and western Washington, along the Oregon and northern California coast and the accident site. An area of MVFR conditions (depicted by the blue scalloped line) extended over northwest Montana, northern Idaho, most of Washington, western Oregon, and northwest California. A brown dashed line depicted an area of moderate turbulence from the surface to 16,000 ft over the Oregon, Washington, Idaho, and Montana and included the accident site. The freezing level (depicted by the dashed blue line) was forecast between 8,000 ft and 10,000 ft.

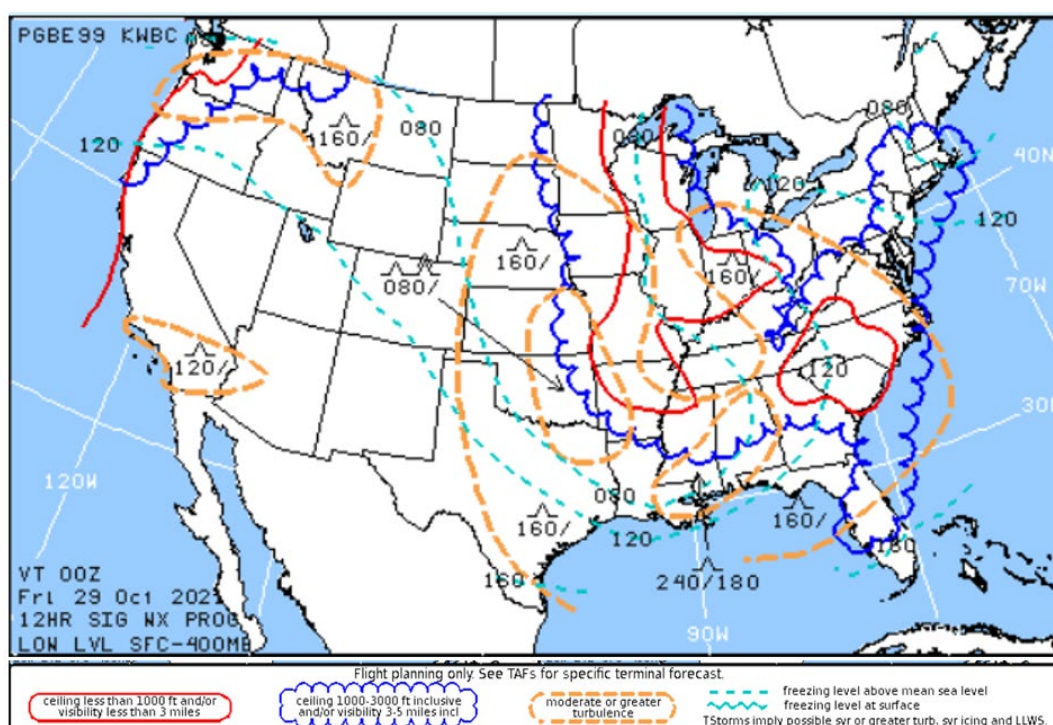


Figure 4 - NWS 12-hour Low-Level Significant Weather Prognostic Chart valid for 1700 PDT.

2.0 Surface Observations

The official observations issued surrounding the accident site were documented using Aviation Routine Weather Reports (METAR⁵) and Aviation Select Special Weather Reports (SPECI). Cloud heights are reported above ground level (agl) in the following section, and the magnetic variation was estimated at 15.5° east based on the latest

- 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.

⁵ METAR is an abbreviation for Meteorological Aerodrome Report.

sectional chart for the area. Figure 5 is the NWS Aviation Weather Center's METAR display⁶ for 0900 PDT with the approximate accident site marked by the red star. The station models are color coded for the general flight categories and are depicted in the legend below the chart, where purple is for LIFR conditions, red is for IFR conditions, blue is for MVFR conditions, and green is for VFR conditions. The METAR depiction indicated LIFR to MVFR conditions prevailing over the area.

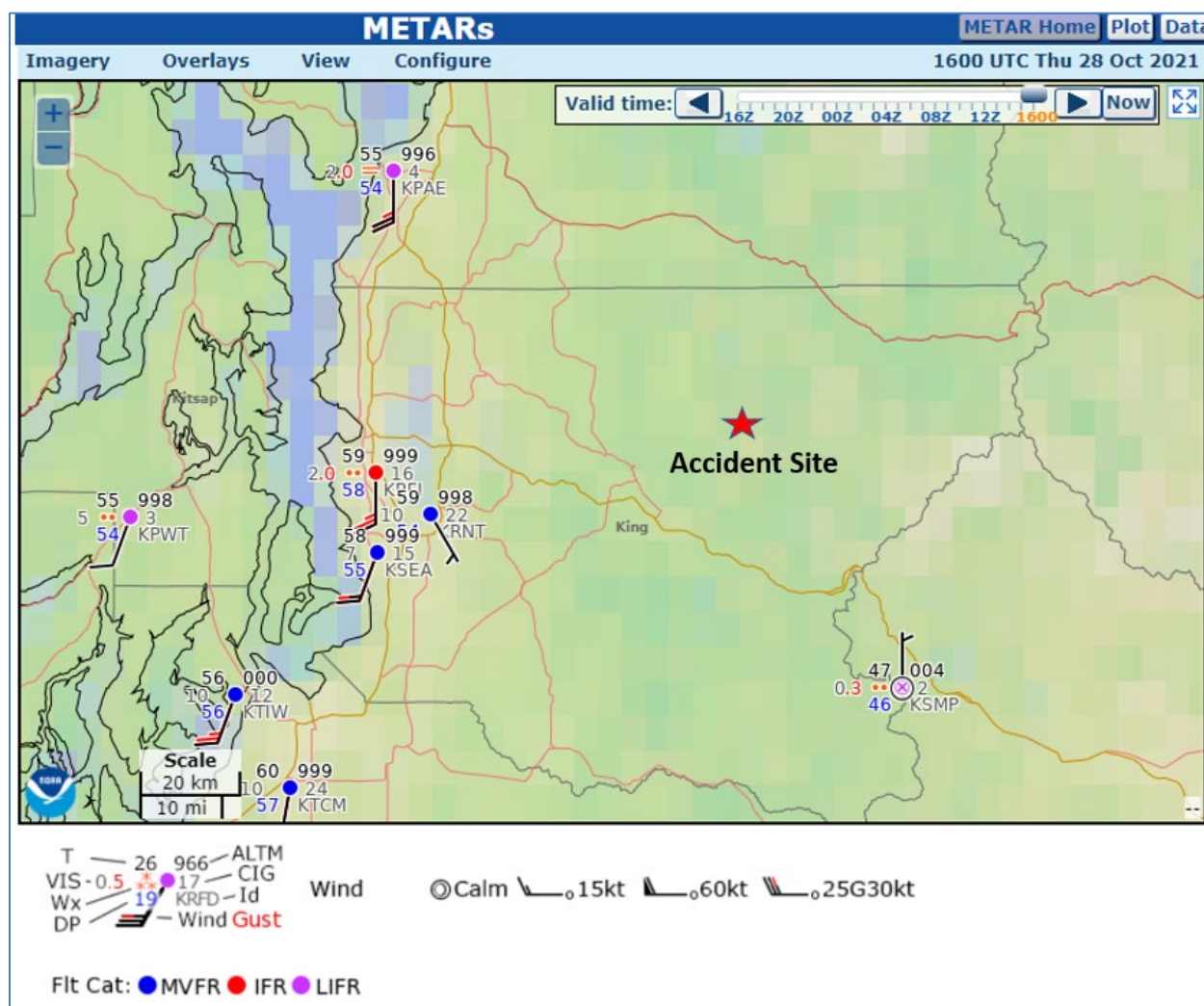


Figure 5 - NWS AWCs METAR display for 0900 PDT with the accident site marked by the star.

2.1 Stampede Pass, Kittitas, Washington

The closest weather reporting station to the accident site was from the NWS Stampede Pass (KSMP)⁷, Kittitas, Washington, Automated Surface Observation System

⁶ <https://www.aviationweather.gov/metar>

⁷ One of the NWS mountain pass weather stations located in the Cascades Mountain Range in

(ASOS), which was located approximately 22 miles southeast of the accident site at an elevation of 3,960 ft. The system reported the following conditions immediately surrounding the time of the accident.

Weather observation for KSMP at 0856 PDT, automated, wind variable at 5 knots, visibility 1/4 mile in light rain and fog, vertical visibility 200 ft agl, temperature 8° C, dew point temperature 8° C, altimeter setting 30.04 inches of mercury (inHg). Remarks: automated station with a precipitation discriminator, sea-level pressure 1018.2-hPa, hourly precipitation 0.17 inches, temperature 8.3° C, dew point 7.8° C.

Special weather observation for KSMP at 0915 PDT, automated, (wind not reported) visibility 1/2 mile in fog, vertical visibility 300 ft agl, temperature 9° C, dew point temperature 8° C, altimeter setting 30.03 inHg. Remarks: automated station with a precipitation discriminator, rain ended 0912 PDT, temperature 9.4° C, dew point 8.3° C.

The general flight categories (color coded) and raw observations surrounding the period from about 0600 through 1100 PDT were as follows. The observations decoded above, and the time of the accident are in bold italic print.

LIFR METAR KSMP 281256Z AUTO VRB03KT 3/4SM -RA BR BKN004 OVC009 03/02 A3005 RMK AO2 RAB10 SLP192 P0014 T00280017=

LIFR SPECI KSMP 281301Z AUTO 00000KT 3/4SM RA BR VV006 03/02 A3005 RMK AO2 P0001 T00280017=

LIFR SPECI KSMP 281323Z AUTO VRB04KT 1/2SM RA FG VV004 02/02 A3005 RMK AO2 P0012 T00220017=

LIFR METAR KSMP 281356Z AUTO VRB03KT 3/4SM RA BR VV005 03/02 A3005 RMK AO2 SLP191 P0026 T00280017=

LIFR SPECI KSMP 281437Z AUTO 00000KT 1/2SM -RA FG VV004 03/02 A3004 RMK AO2 P0014 T00280017=

LIFR METAR KSMP 281456Z AUTO 00000KT 3/4SM -RA BR VV004 03/02 A3004 RMK AO2 SLP190 P0018 60058 T00280022 56011=

LIFR SPECI KSMP 281503Z AUTO 00000KT 1SM -RA BR VV004 03/02 A3004 RMK AO2 P0002 T00330022=

LIFR SPECI KSMP 281508Z AUTO VRB03KT 1 3/4SM -RA BR OVC004 03/03 A3004 RMK AO2 P0004 T00330028=

LIFR SPECI KSMP 281514Z AUTO 00000KT 1SM RA BR VV004 03/02 A3004 RMK AO2 P0005 T00280022=

Washington.

LIFR SPECI KSMP 281517Z AUTO VRB03KT 1/2SM RA FG VV004 03/02 A3004 RMK AO2 P0007
T00280022=

LIFR SPECI KSMP 281525Z AUTO 00000KT 1/4SM -RA FG VV003 03/02 A3004 RMK AO2 P0010
T00280022=

LIFR **METAR KSMP 281556Z AUTO VRB05KT 1/4SM -RA FG VV002 08/08 A3004 RMK AO2
SLP182 P0017 T00830078=**

Accident 1610Z

LIFR **SPECI KSMP 281615Z AUTO 1/2SM FG VV003 09/08 A3003 RMK AO2 RAE12 P0002
T00940083=**

IFR SPECI KSMP 281622Z AUTO VRB06KT 1 1/2SM BR OVC005 09/09 A3003 RMK AO2 RAE12
P0002 T00940089=

IFR SPECI KSMP 281625Z AUTO 2 1/2SM BR BKN005 OVC012 09/09 A3002 RMK AO2 VIS 1 1/4V5
RAE12 P0002 T00940089=

IFR SPECI KSMP 281634Z AUTO 1 1/2SM BR OVC005 09/09 A3002 RMK AO2 RAE12 P0002
T00940089=

IFR SPECI KSMP 281637Z AUTO VRB04KT 1SM BR OVC005 09/09 A3002 RMK AO2 RAE12 P0002
T00940089=

LIFR SPECI KSMP 281648Z AUTO 1/2SM -RA FG OVC005 10/09 A3002 RMK AO2 RAE12B45 P0003
T01000089=

LIFR SPECI KSMP 281653Z AUTO 1/4SM FG VV004 10/09 A3002 RMK AO2 RAE12B45E51 P0003
T01000089=

LIFR METAR KSMP 281656Z AUTO VRB06KT 1/4SM FG VV004 10/09 A3002 RMK AO2 RAE12B45E51
SLP173 P0003 T01000089=

LIFR SPECI KSMP 281700Z AUTO VRB03KT 1/2SM FG VV004 10/09 A3002 RMK AO2 T01000089=

LIFR SPECI KSMP 281705Z AUTO 1/4SM FG VV003 10/09 A3002 RMK AO2 T01000089=

LIFR SPECI KSMP 281732Z AUTO 00000KT 1/2SM -RA FG VV003 10/09 A3002 RMK AO2 RAB09
P0002 T01000094=

LIFR SPECI KSMP 281738Z AUTO VRB03KT 1/4SM -RA FG VV003 10/09 A3002 RMK AO2 RAB09
P0003 T01000089=

LIFR METAR KSMP 281756Z AUTO 1/4SM FG VV003 10/09 A3002 RMK AO2 RAB09E48 SLP172
P0004 60082 T01000089 10100 20022 55006=

2.2 Renton, Washington

The next closest weather reporting station was at Renton Municipal Airport (KRNT), Renton, WA, located 24.5 miles west of the accident site at an elevation of 32 ft. The airport also had a federally installed and maintained ASOS, whose reports were augmented by air traffic control personnel during normal operating hours. At the approximate time of the accident the following conditions were reported.

Special weather observation for KRNT at 0908 PDT, wind from 170° at 6 knots, visibility 2 miles in light rain and mist, ceiling overcast at 2,100 ft agl, temperature 15° C, dew point temperature 13° C, altimeter 29.99 inHg. Remarks: automated station with a precipitation discriminator, rain began at 0859 PDT, hourly precipitation less than 0.01 inches (trace), temperature 15.0° C, dew point 12.8° C.

The general flight categories and raw observations surrounding the period from 0600 through 1100 PDT were as follows.

MVFR METAR KRNT 281253Z AUTO 16003KT 3SM BR SCT017 OVC021 10/09 A2999 RMK AO2
RAE01B06E43 SLP160 P0000 T01000089=

MVFR METAR KRNT 281353Z AUTO 00000KT 5SM BR OVC019 11/09 A2998 RMK AO2 RAB00E12
SLP155 P0000 T01060094=

MVFR METAR KRNT 281453Z 00000KT 8SM OVC020 12/11 A2998 RMK AO2 RAB30E46 SLP157 P0000
60000 T01170106 55007=

MVFR METAR KRNT 281553Z 15005KT 10SM OVC022 15/12 A2998 RMK AO2 SLP158 T01500122=

IFR **SPECI KRNT 281608Z 17006KT 2SM -RA BR OVC021 15/13 A2999 RMK AO2 RAB1559
P0000 T01500128=**

Accident 1610Z

IFR METAR KRNT 281653Z 18007KT 2SM -RA BR OVC022 16/13 A2998 RMK AO2 RAB1559 SLP156
P0002 T01560128=

IFR SPECI KRNT 281705Z 17008KT 1 3/4SM -RA BR OVC020 16/13 A2998 RMK AO2 P0000
T01560133=

IFR SPECI KRNT 281713Z 16007KT 2SM -RA BR OVC020 16/13 A2998 RMK AO2 P0000 T01560133=

IFR SPECI KRNT 281723Z 16007KT 1 3/4SM -RA BR BKN020 BKN025 OVC042 15/13 A2998 RMK
AO2 P0001 T01500133=

IFR SPECI KRNT 281734Z 14005KT 2 1/2SM -RA BR SCT017 BKN022 OVC041 15/13 A2998 RMK
AO2 P0001 T01500133=

IFR METAR KRNT 281753Z 15005KT 2SM -RA BR BKN015 BKN020 OVC031 15/14 A2998 RMK AO2

SLP156 P0002 60004 T01500139 10156 20094 58001=

2.3 Boeing Field, Seattle, Washington

Boeing Field/King County International Airport (KBFI), Seattle, Washington, was located 27.6 miles west of the accident site at an elevation of 22 ft. The airport had a federally installed and maintained ASOS which was augmented by air traffic control personnel during normal operating hours. At the time of the accident the following conditions were being reported.

Special weather observation for KBFI at 0857 PDT, wind from 180° at 11 knots gusting to 24 knots, visibility 2 miles in light rain and mist, ceiling overcast at 1,600 ft agl, temperature 15° C, dew point temperature 14° C, altimeter 29.99 inHg. Remarks: automated station with a precipitation discriminator, hourly precipitation less than 0.01 inches (trace), temperature 15.0° C, dew point 14.4° C.

The general flight categories and raw observations surrounding the period from 0600 through 1100 PDT were as follows.

IFR METAR KBFI 281253Z 17007KT 2SM -RA BR BKN005 OVC015 09/09 A2999 RMK AO2 SLP156 P0001 T00940094 \$=

IFR SPECI KBFI 281344Z 15007KT 3SM BR OVC005 10/10 A2998 RMK AO2 RAE33 P0000 T01000100=

IFR METAR KBFI 281353Z 15008KT 4SM BR OVC005 11/11 A2998 RMK AO2 RAE33 SLP150 P0000 T01060106=

IFR METAR KBFI 281453Z 17012KT 5SM BR BKN009 OVC016 13/13 A2998 RMK AO2 RAB1359E36 SLP150 P0000 60001 T01280128 56010=

MVFR METAR KBFI 281553Z 17013G19KT 4SM -RA BR OVC014 15/14 A2999 RMK AO2 RAB1454E02B51 SLP153 P0000 T01500144=

IFR **SPECI KBFI 281557Z 18011G24KT 2SM -RA BR OVC016 15/14 A2999 RMK AO2 P0000 T01500144=**

Accident 1610Z

IFR METAR KBFI 281653Z 18011G20KT 2SM -RA BR FEW018 OVC032 15/15 A2999 RMK AO2 SLP153 P0000 T01500150=

MVFR SPECI KBFI 281700Z 19009G20KT 5SM -RA BR SCT014 BKN018 OVC027 15/15 A2999 RMK AO2 P0000 T01500150=

MVFR SPECI KBFI 281743Z 18011G22KT 5SM -RA BR BKN012 BKN018 OVC041 16/14 A2998 RMK AO2 P0000 T01560144=

MVFR METAR KBF1 281753Z 17011G18KT 5SM -RA BR BKN013 OVC040 16/14 A2999 RMK AO2
SLP153 P0000 60001 T01560144 10156 20094 51003=

2.4 Seattle-Tacoma International, Seattle, Washington

The next closest weather reporting location was Seattle-Tacoma International Airport (KSEA), Seattle, Washington, located approximately 29 miles west-southwest of the accident site at an elevation of 432 ft. The airport had a federally installed and maintained ASOS which was augmented by contract weather observers.

Special weather observation for KSEA at 0902 PDT, wind from 190° at 13 knots, visibility 3 miles, runway 16L visual range 5,000 ft variable to better than 6,000 ft, light rain and mist, ceiling broken at 1,300 ft agl, overcast at 2,100 ft, temperature 14° C, dew point temperature 13° C, altimeter 29.99 inHg. Remarks: automated station with a precipitation discriminator, rain began at 0858 PDT, hourly precipitation 0.01 inches, temperature 14.4° C, dew point 12.8° C.

The general flight categories and raw observations surrounding the period from 0600 through 1100 PDT were as follows.

IFR METAR KSEA 281253Z 15005KT 3SM -RA BR OVC006 09/09 A2999 RMK AO2 SLP163 P0001
T00940089=

IFR METAR KSEA 281353Z 17007KT 5SM BR BKN005 OVC013 11/10 A2997 RMK AO2 RAE50
SLP157 P0001 T01060100=

MVFR SPECI KSEA 281415Z 20010KT 8SM SCT005 OVC013 12/12 A2997 RMK AO2 T01220117=

MVFR METAR KSEA 281453Z 20015G23KT 9SM BKN013 OVC025 14/13 A2998 RMK AO2 RAB24E41
SLP157 P0001 60003 T01390128 55008=

MVFR SPECI KSEA 281513Z 20012KT 10SM BKN015 OVC025 14/13 A2998 RMK AO2 T01440128=

MVFR METAR KSEA 281553Z 20014G22KT 7SM BKN015 OVC024 14/13 A2999 RMK AO2 SLP161
SHRA SW-W T01440128=

**MVFR SPECI KSEA 281602Z 19013KT 3SM R16L/5000VP6000FT -RA BR BKN013 OVC021 14/13
A2999 RMK AO2 RAB1558 P0001 T01440128=**

Accident 1610Z

MVFR SPECI KSEA 281637Z 21013KT 4SM -RA BR OVC015 14/13 A2998 RMK AO2 RAB1558 P0002
T01440128=

IFR SPECI KSEA 281649Z 20014G25KT 2 1/2SM R16L/5000VP6000FT -RA BR OVC015 14/13 A2998
RMK AO2 RAB1558 P0003=

*IFR METAR KSEA 281653Z 20016G25KT 2 1/2SM R16L/5000VP6000FT -RA BR OVC015 14/13
A2998 RMK AO2 RAB1558 SLP159 P0003 T01440133=*

*IFR SPECI KSEA 281745Z 20012KT 2SM -RA BR BKN006 OVC013 14/14 A2998 RMK AO2 P0006
T01440139=*

*IFR METAR KSEA 281753Z 20012KT 2SM R16L/6000VP6000FT -RA BR BKN006 OVC013 14/14
A2998 RMK AO2 SLP159 P0007 60013 T01440139 10144 20089 56002=*

3.0 Sounding

To determine the conditions over the accident site a High-Resolution Rapid Refresh (HRRR) numerical model⁸ was obtained from the NOAA Air Research Laboratory's archive for the nearest grid point⁹ to the accident site for 0900 PDT. The model sounding was then plotted on a standard skew T log P diagram¹⁰ using RAOB the complete RAwinsonde OBservation program¹¹ from the surface to 450-hPa or approximately 20,000 ft and is included as figure 6. The HRRR sounding depicted an elevation near 3,681 ft over the area, with a near surface temperature of 8.4° C (47.1° F), a dew point temperature of 8.1° C (46.6° F), a relative humidity of 98%, and a density altitude of 3,786 ft. The lifted condensation level (LCL)¹² was at 126 ft agl, the convective condensation level (CCL)¹³ at 1,664 ft agl, and cloud tops were estimated to be near 20,000 ft msl (gray bar on left axis). The freezing level was identified at 6,000 ft agl (9,682 ft msl) and is indicated by the blue horizontal line across the sounding. The precipitable water content was 0.86 inches. The atmosphere was characterized as stable (blue bar on right axis) with a Lifted Index (LI)¹⁴ of 3.4, except for a layer between 10,000 to 12,000 ft which was conditionally unstable (green bar on right axis). The RAOB analysis program indicated a high potential for light-to-moderate clear icing (blue) and rime ice (green) from the freezing level through 20,000 ft and is depicted on

⁸ 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.

⁹ HRRR coordinates used were 27.59° N and 121.63° W.

¹⁰ 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.

¹¹ 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.

¹² Lifted Condensation Level (LCL) - the level at which a lifted parcel becomes saturated. The LCL height corresponds to cloud base height for forced ascent.

¹³ Convective Condensation Level (CCL) - is the height at which a parcel of air, when heated sufficiently from below, rises and becomes saturated. It is where newly forming convective clouds should form bases.

¹⁴ 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.

the left vertical axis of the sounding. Saturated conditions were identified through 23,000 ft with some higher clouds with tops to 35,000 ft.

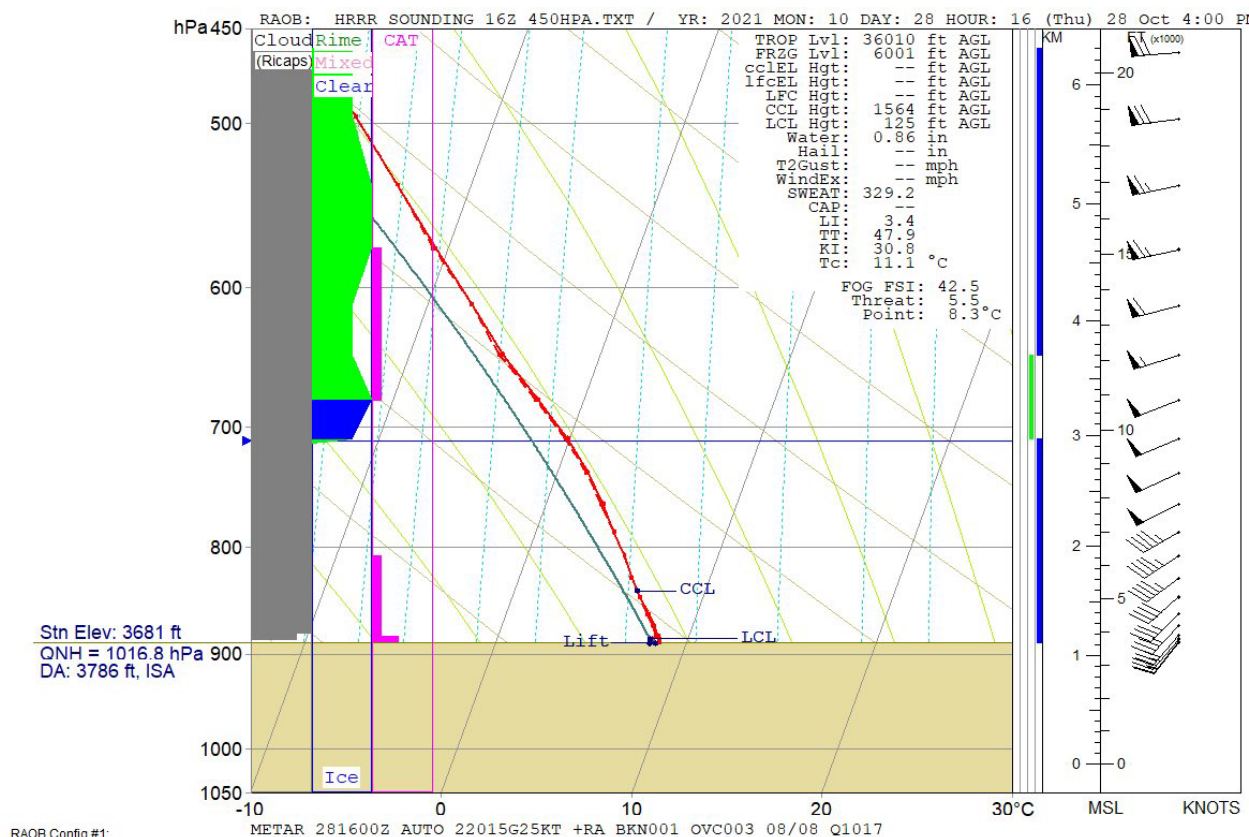


Figure 6 - HRRR model sounding for 0900 PDT over the approximate accident site coordinates.

The HRRR wind profile identified a surface wind from the southwest (220°) at 15 knots gusting to 25 knots, with winds slowly backing to the west with height. The wind at 16,500 ft (the accident airplanes highest obtained altitude¹⁵) was from 260° at 65 knots. The mean 0 to 6 kilometer (km) or 18,000 ft wind was from 255° at 57 knots.

The HRRR parameters of height, pressure, temperature (T), dew point temperature (Td), relative humidity (RH), wind (deg/kts), and expected clear air turbulence (CAT), low-level wind shear (LLWS), and icing intensity and type from the surface through 20,000 ft was as follows.

Height (ft-msl)	Pres (hPa)	T (C)	Td (C)	RH (%)	Wind (dir/kts)	CAT (FAA)	LLWS (FAA)	Icing (AFGWC)
3681	889	8.4	8.1	98	216/15		LIGHT	
3712	888	8.6	8.6	100	217/14	MDT	STRNG	

¹⁵ The accident airplane had been cleared to 19,000 ft, but only reached 16,525 ft before an upset occurred and a rapid loss of altitude (see Air Traffic Control Falcon replay).

3804	885	8.5	8.2	98	218/23	MDT	MODRT
3896	882	8.4	8.3	99	219/29	LGT	LIGHT
4206	872	8.0	7.9	99	221/34	LGT	
4550	861	7.5	7.4	99	223/37	LGT	
5057	845	6.7	6.7	100	226/40	LGT	
5638	827	5.9	5.9	100	231/43	LGT	
6296	807	5.1	5.1	100	235/46		
7003	786	4.1	4.1	100	238/47		
7831	762	3.0	2.9	99	241/48		
8753	736	1.6	1.5	99	243/49		
9740	709	-0.1	-0.2	99	246/50		LGT Rime
10873	679	-2.4	-2.5	99	247/51	LGT	MDT Clear
12166	646	-5.1	-5.3	98	251/53	LGT	LGT Rime
13597	611	-7.7	-7.7	100	255/59	LGT	LGT Rime
15185	574	-10.7	-10.8	99	256/64		MDT Rime
16952	535	-13.9	-13.9	100	258/67		MDT Rime
18827	496	-17.4	-17.4	100	261/70		LGT Rime
20561	462				264/70		
20668	460	-21.0	-21.0	100			LGT Rime

The RAOB analysis program indicated that at 16,500 ft the sounding indicated moderate rime type icing, with the liquid water content (LWC) of 0.004 g/m³, and a temperature of -12.0° C, with the relative humidity of 100%. Between 0904 and 0910 PDT the accident airplane went from approximately 16,500 ft down to 8,275 ft and was in favorable conditions for predominant light-to-moderate rime type icing conditions, with moderate clear icing indicated near the conditionally unstable layer near 10,000 ft.

4.0 Satellite Imagery

The Geostationary Operational Environmental Satellite number 17 (GOES-17) 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 and visible imagery were reviewed surrounding the period, and the closest images to the accident time documented. The infrared long wave imagery (band 13) at a wavelength of 10.3 microns (μ m) provided radiative cloud top temperatures with a nominal spatial resolution of 2 km, while the visible (band 2) at a wavelength of 0.64 μ m provided images at a resolution of 0.5 km. The following satellite imagery have not been corrected for parallax error.

The GOES-17 infrared longwave band 13 imagery for 0911 PDT at 4X magnification is included as figure 7 with the accident site marked by the white square and the fronts from 0800 PDT overlaid. The image depicted an extensive area of enhanced clouds associated with nimbostratus type clouds over northwest Washington state and extending over the accident site. The radiative cloud top temperature over the

accident site was 242 Kelvin or -31° C, which corresponded to cloud tops near 25,700 ft based on the HRRR sounding. The GOES-17 visible image at 2X magnification for 0911 PDT is included as figure 8 and depicted an extensive area of overcast low-to-mid-level nimbostratus type clouds associated with precipitation (rain and snow), with a higher band of cirriform type clouds above the accident site.

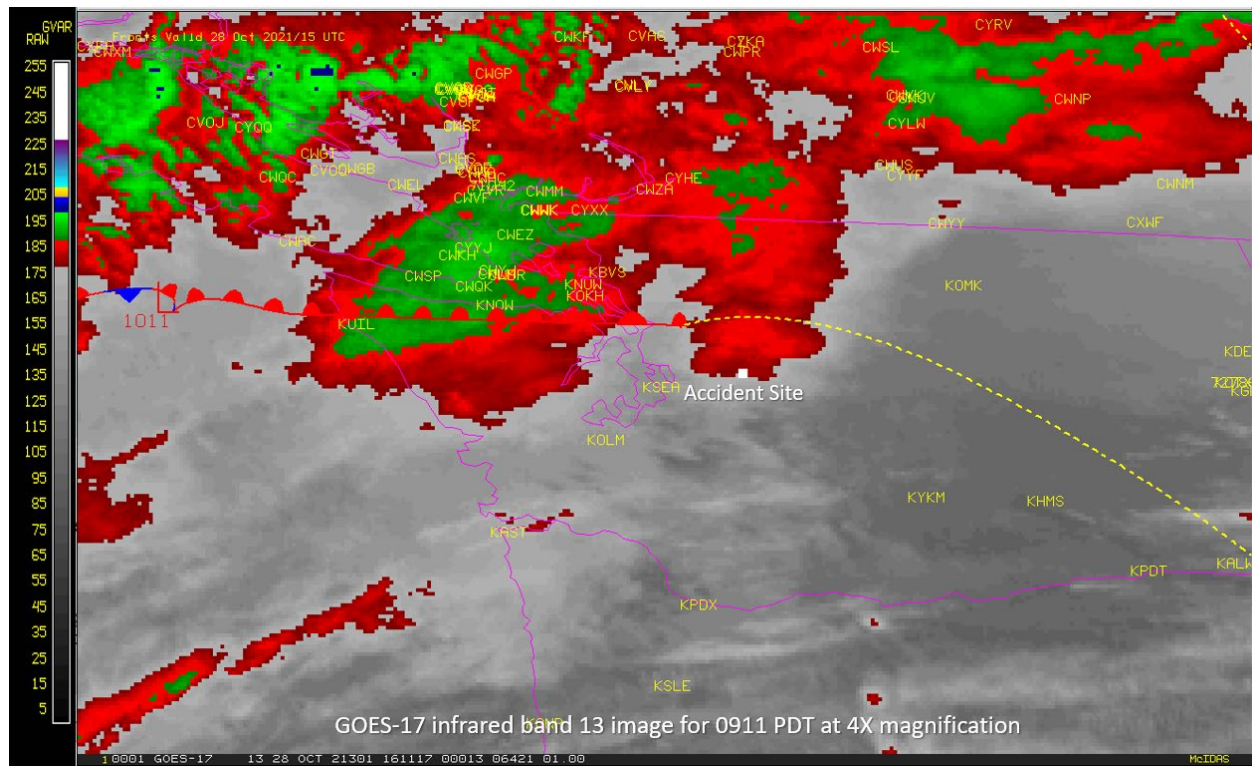


Figure 7 - GOES-16 infrared image for 0911 PDT at 4X magnification.

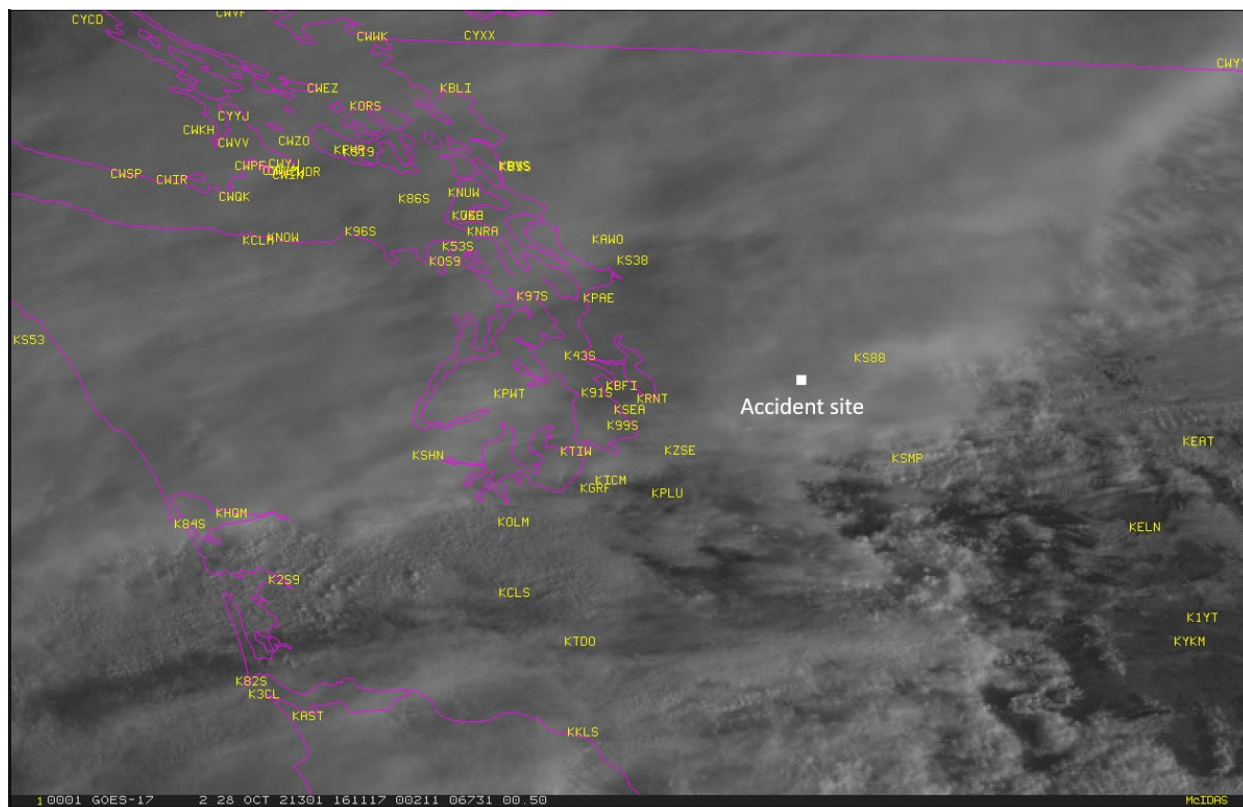


Figure 8 - GOES-17 visible image for 0911 PDT at 2X magnification.

5.0 Radar Imagery

The closest NWS Weather Surveillance Radar 1988 Doppler (WSR-88D)¹⁶ was from Seattle/Camano Island (KATX), Washington located approximately 50 miles northwest from the accident site. The level II archive data were obtained from the NCEI using the Hierarchical Data Storage System and displayed using the NWS NEXRAD Interactive Viewer and Data Exporter software. During the period the KATX WSR-88D was operating in the precipitation mode, volume scanning pattern 215 (VCP-215), which is currently the NWS standard precipitation mode scanning strategy where the radar makes 15 different elevation scans in 6 minutes.

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors¹⁷, it is a function of the drop size distribution, number

¹⁶ 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.

¹⁷ Hydrometeors are any product of condensation or sublimation of atmospheric water vapor, whether formed in the free atmosphere or at the earth's surface. Hydrometeors are classified as; (a) Liquid or solid water particles suspended in the air: cloud, water droplets, mist or fog. (b) Liquid precipitation: drizzle and rain. (c) Freezing precipitation: freezing drizzle and freezing rain. (d) Solid (frozen) precipitation: ice pellets, hail, snow, snow pellets, and ice crystals.

of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in decibels (dBZ)¹⁸ and is a general measure of echo intensity. The FAA defines the intensity levels for pilots in Advisory Circular AC 00-24C - "Thunderstorm". That AC further defines echoes less than 30 dBZ as "light" in intensity, "moderate" echoes 30-40 dBZ, "heavy" with echoes of >40-50 dBZ, and "extreme" intensity with echoes above >50 dBZ. These are the standard radio phraseology terms used by air traffic controllers to describe weather conditions to pilots as shown in the following table. Typically values above 20 dBZ are associated with precipitation reaching the surface.

Reflectivity (dBZ) Ranges	Weather Radar Echo Intensity Terminology
<30 dBZ	Light
30 to 40 BZ	Moderate
>40 to 50 dBZ	Heavy
>50 dBZ	Extreme

The KATX WSR-88D composite reflectivity image for 0906 PDT is included as figure 9 with the flight track of N40KA¹⁹ (in magenta) and the accident site overlaid. The composite radar image depicts the highest reflectivity value from all the elevation scans for the period in dBZ, with a resolution at 1 x 1 km (0.54 x 0.54 nm) and provides a synopsis of the most important features in the entire vertical coverage area. The image depicted echoes of 10 to 30 dBZ extending under most of the flight track, and echoes less than 30 dBZ over the accident site.

¹⁸ dBZ stands for decibels relative to Z and is mathematically defined as $10 \log Z_e$, which is the logarithmic dimensional unit.

¹⁹ Flight track of N40KA is included as Attachment 1.

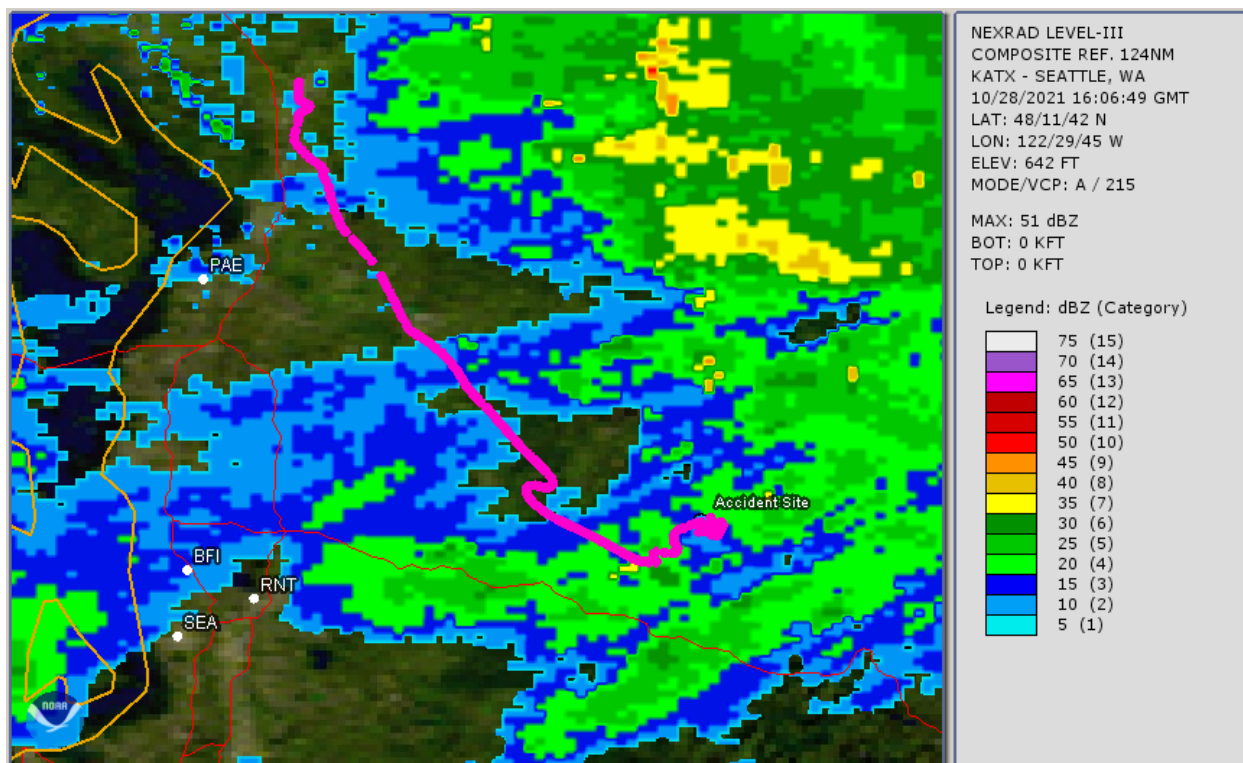


Figure 9 - NWS KATX WSR-88D composite reflectivity image for 0906 PDT with flight track.

The following table provides the height of the KATX WSR-88D five lowest elevation scans over the accident site at 50 miles and the antenna height of 642 ft, assuming standard refraction²⁰ of the beam. The heights have been rounded to the nearest 10 ft.

Elevation	Beam Center	Base of Beam	Top of Beam	Beam Width
0.53°	5,060 ft	2,540 ft	7,580 ft	5,040 ft
0.92°	7,180 ft	4,680 ft	9,610 ft	5,040 ft
1.36°	9,300 ft	6,780 ft	11,820 ft	5,040 ft
1.85°	11,840 ft	9,320 ft	14,360 ft	5,040 ft
2.42°	15,340 ft	12,820 ft	17,860 ft	5,040 ft

The KATX WSR-88D 0.53°, 1.36°, 1.85° and the 2.42° base reflectivity scans for 0906 PDT with the flight track overlaid are included as figures 10-13, respectively. The maximum altitude of 16,525 ft at 0904 PDT is marked, and the time of the image at 0906:42Z (1606:42Z) at an altitude of 12,625 ft, and the accident site. The 0.53° base reflectivity generally depicted echoes of 15 to 30 dBZ under the flight track, with the last location at 16,525 ft near an echo of 40 dBZ (figure 10). The KATX WSR-88D 1.36 base reflectivity image (figure 11) depicted echoes of 5 to 25 dBZ along the flight track.

²⁰ Standard refraction implies a standard atmosphere with no ducting of the radar beam.

The KATX WSR-88D 1.85° base reflectivity image (figure 12) depicted echoes of 0 to 15 dBZ over the flight track and best depicted the conditions at the accident airplane's altitude during the upset between 0904 and 0910 PDT. While the KATX WSR-88D 2.42° base reflectivity image (figure 13) showed only scattered light intensity echoes of 0 to 10 dBZ over the area and flight track.

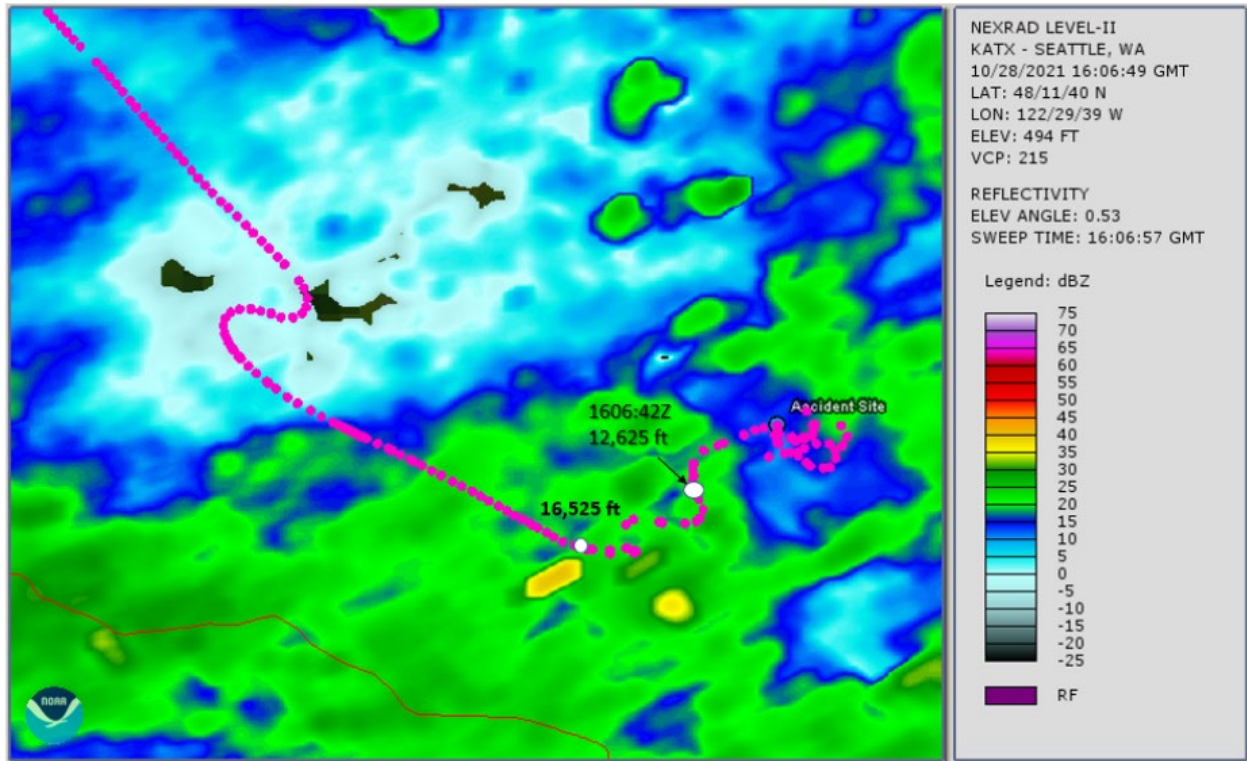


Figure 10 - NWS KATX WSR-88D 0.53° base reflectivity image for 0906 PDT with flight track.

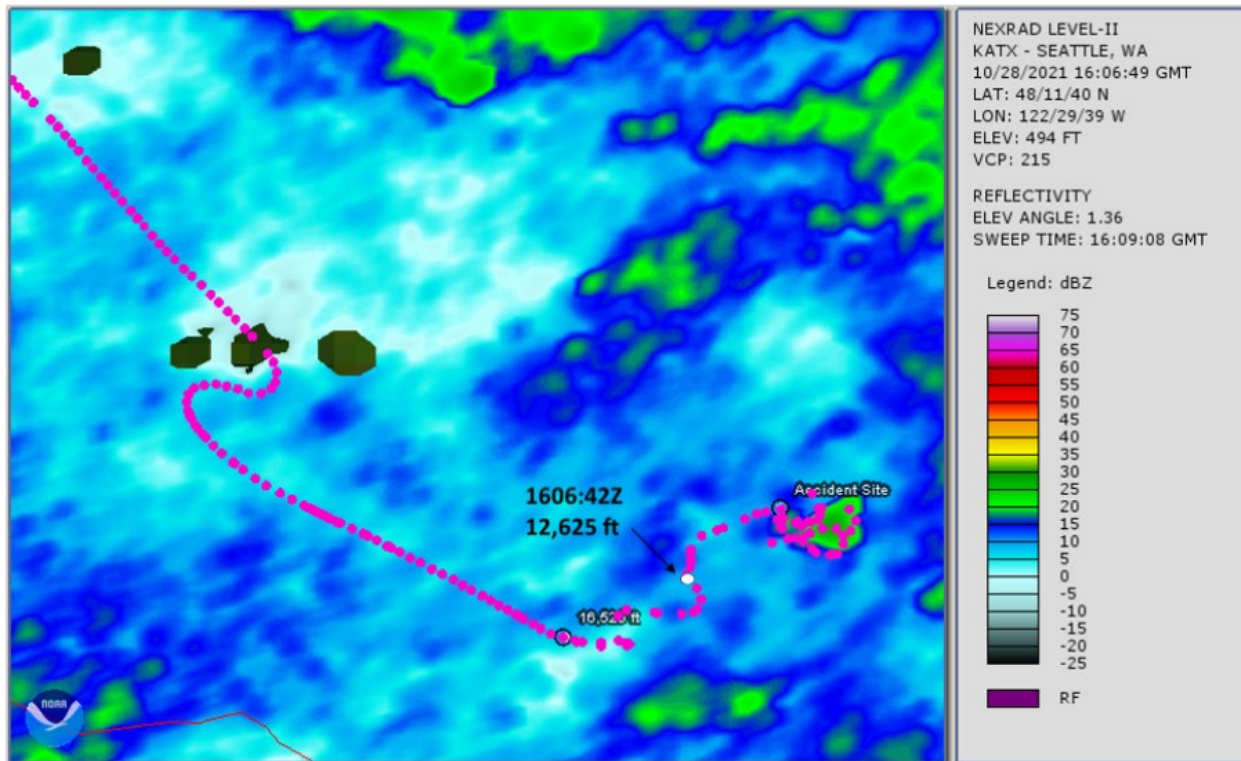


Figure 11 - NWS KATX WSR-88D 1.36° base reflectivity image for 0906 PDT with flight track.

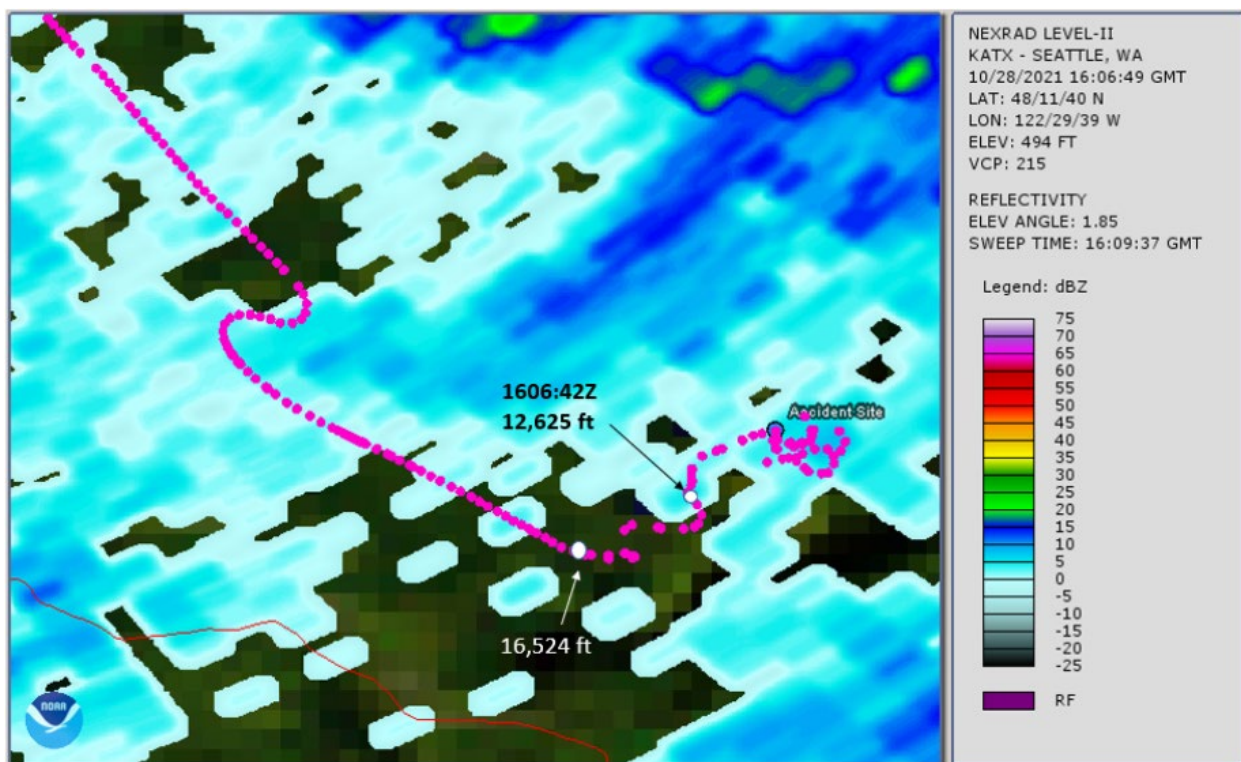


Figure 12 - NWS KATX WSR-88D 1.85° base reflectivity image for 0906 PDT with flight track.

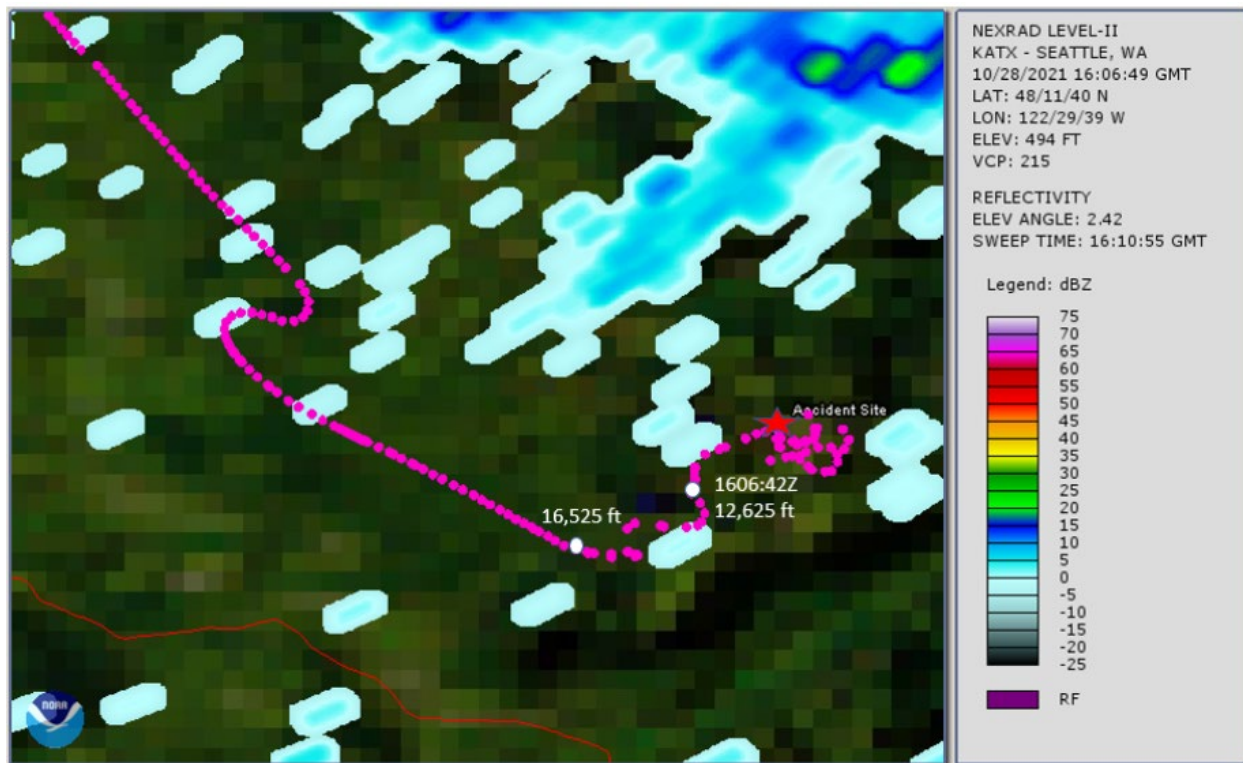


Figure 13 - NWS KATX WSR-88D 2.42° base reflectivity for 0906 PDT with flight track.

6.0 Pilot Reports

The following pilot reports or PIREPs²¹ were recorded within three hours prior to and after the accident (1300Z through 2000Z) and within approximately 100 miles of the accident site. The reports are provided in standard code and format as received, with time in UTC and altitude in ft msl. The time of the accident has been added in bold italic type for reference.

SEA UA /OV SEA020045/TM 1330/FL150/TP E75L/TA M8/IC MOD RIME/RM DURD 150-120
 SEA UA /OV SEA/TM 1342/FL009/TP B739/SK BKN009
 BFI UA /OV BFI 1NW/TM 1345/FL007/TP PC-12/SK OVC007
 SEA UA /OV SEA030045/TM 1353/FL130/TP B763/IC NEG
 PAE UA /OV PAE/TM 1408/FL014/TP E75L/SK OVC014
 SEA UA /OV SEA050040/TM 1449/FL170/TP B738/TA M14/IC LGT RIME/RM ..ZSE
 PAE UA /OV KPAE/TM 1505/FLUNKN/TP 56X/SK OVC010-TOPUNKN/RM DURC
 SEA UA /OV SEA043047/TM 1510/FL210/TP B738/TA M15/IC MOD RIME/RM DURD GLASR STAR 210-
 130
 SEA UUA /OV KSEA/TM 1525/FL025/TP B737/TB TB LGT 025/RM LLWS +/- 10KT
 SEA UUA /OV SEA340005/TM 1529/FL020/TP B737/RM LLWS +/- 10 KTS 020-SFC
 SEA UA /OV SEA072030/TM 1540/FL170/TP B737/TA 0/IC LGT RIME 170-200/RM ..ZSE
 SEA UA /OV SEA072030/TM 1546/FL150/TP B737/SK TOPS 180 /TB MOD CHOP 150-180/RM ..ZSE

²¹ Only includes PIREPs which were disseminated through normal weather circuits and do not include reports only broadcast to air traffic controllers via radio and not transcribed into the database.

PAE UA /OV PAE072040/TM 1548/FL180/TP B737/TB MOD CHOP/IC MOD RIME/RM GLASR1 180-120
 ..ZSE
 BFI UA /OV BFI 3NW/TM 1550/FL013/TP CL30/SK OVC013/WX 2 1/2SM
 BFI UA /OV BFI 1NW/TM 1600/FL008/TP CL35/SK OVC008
Accident 1610Z
 SEA UA /OV SEA146030/TM 1615/FL125/TP PA46/TA 0/IC LIGHT ICING /RM 115-125 DURC
 PAE UA /OV PAE/TM 1615/FL010/TP B38M/SK SCT010 BKN016
 SEA UA /OV SEA072025/TM 1619/FL120/TP B738/TA M17/IC LGT RIME/RM ..ZSE
 SEA UA /OV SEA060045/TM 1649/FL160/TP B738/TB MOD CHOP 160-210/RM ..ZSE
 SEA UUA /OV KSEA/TM 1655/FL005/TP B737/RM LLWS +/-10KT
 PAE UA /OV PAE/TM 1705/FL010/TP C56X/SK OVC010
 SEA UA /OV KSEA/TM 1720/FL005/TP A321/RM LLWS +/-05KT
 SEA UA /OV SEA165025/TM 1725/FL135/TP DH8D/TA M14/IC LGT MIC/RM DURC THRU 190 ..ZSE
 SEA UA /OV SEA038044/TM 1747/FL150/TP B739/IC LIGHT TRACE/RM AIRCRAFT REPORTED VERY
 LITTLE ICING
 SEA UA /OV SEA233007/TM 1751/FL8000/TP B38M/TB NEG/IC NEG/RM LIGHT PRECIP
 SEA UA /OV SEA040030/TM 1754/FL110/TP B738/TA M03/IC LGT RIME/RM 165-110
 SEA UA /OV SEA050060/TM 1755/FL140/TP GLF4/TB LGT-MOD CHOP/RM DURD GLASR1 ..ZSE
 SEA UA /OV SEA065040/TM 1801/FL185/TP B739/TA M19/IC LGT RIME/RM DURC ..ZSE
 PAE UA /OV PAE/TM 1802/FL010/TP P180/SK OVC010
 BFI UA /OV BFI 1SE/TM 1810/FL011/TP C25A/SK OVC011
 SEA UA /OV SEA065040/TM 1815/FL200/TP P180/TA M20/TB LGT-MOD CHOP/IC LGT RIME/RM DURC
 085-190 ..ZSE
 SEA UA /OV SEA 040030/TM 1822/FL130/TP A321/TA -3/IC LIGHT RIME/RM 130-115 DURD
 EAT UA /OV EAT250020/TM 1825/FL120/TP BE99/TA M01/IC LGT RIME/RM ..ZSE
 SEA UUA /OV SEA/TM 1825/FL010/TP B738/RM LLWS +/-10KTS SFC-010 DURD
 BFI UA /OV BFI 5NW/TM 1839/FL015/TP E55P/WV 19034KT
 OLM UA /OV OLM/TM 1900/FL008/TP PC12/SK BASES 008 MSL/RM DURD ILS RWY 17 APCH
 SEA UA /OV SEA100010/TM 1910/FL120/TP B739/TA M04/IC LGT RIME/RM 150-120 DURD
 OLM UA /OV OLM/TM 1925/FL007/TP H60/SK BASES 007/RM DURD VOR/DME RWY 35 APCH
 PAE UA /OV PAE/TM 1944/FL012/TP C68A/SK OVC012/TB LGT CHOP

Of the 39 reports issued during the period, there were 14 reports of light to moderate rime type icing between 8,500 ft through 20,000 ft, with 1 report of a trace of ice, and 2 negative reports over the area within 100 miles of the accident site. Most of the icing reports came from air carrier jet aircraft with superior anti-icing capability, while several other icing reports came from multiengine turboprop aircraft and other high performance turboprops. There were no severe icing reports during the period. There were 4 urgent PIREPs issued for LLWS with plus/minus 10 knots of airspeed, with a total of 6 reports of LLWS. There were 13 reports of low clouds and restricted visibility, and 5 reports of light-to-moderate chop.

Icing intensity is defined by the rate at which ice accumulates. The FAA Aeronautical Information Manual (AIM) section 7-1-20 defines icing rates as follows:

1. Trace. Ice becomes perceptible. Rate of accumulation slightly greater than sublimation. Deicing/anti-icing equipment is not utilized unless encountered for an extended period of time (over 1 hour).

2. Light. *The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.*

3. Moderate. *The rate of accumulation is such that even short encounters become potentially hazardous, and use of deicing/anti-icing equipment or flight diversion is necessary.*

4. Severe. *The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate flight diversion is necessary.*

The type of ice are defined as the following from the AIM.

Rime Ice is defined as a rough, milky, opaque ice formed by the rapid freezing of supercooled drops/droplets after they strike the aircraft. The rapid freezing results in air being trapped, giving the ice its opaque appearance and making it porous and brittle. Rime ice typically accretes along the stagnation line of an airfoil and is more regular in shape and conformal to the airfoil than glaze ice. It is the ice shape, rather than the clarity or color of the ice, which is most likely to be accurately assessed from the cockpit.

Mixed ice is defined as a simultaneous appearance or a combination of rime and glaze ice characteristics. Since the clarity, color, and shape of the ice will be a mixture of rime and glaze characteristics, accurate identification of mixed ice from the cockpit may be difficult.

Clear Ice or Glaze Ice is defined as ice, sometimes clear and smooth, but usually containing some air pockets, which results in a lumpy translucent appearance. Glaze ice results from supercooled drops/droplets striking a surface but not freezing rapidly on contact. Glaze ice is denser, harder, and sometimes more transparent than rime ice. Factors, which favor glaze formation, are those that favor slow dissipation of the heat of fusion (i.e., slight supercooling and rapid accretion). With larger accretions, the ice shape typically includes "horns" protruding from unprotected leading edge surfaces. It is the ice shape, rather than the clarity or color of the ice, which is most likely to be accurately assessed from the cockpit. The terms "clear" and "glaze" have been used for essentially the same type of ice accretion, although some reserve "clear" for thinner accretions which lack horns and conform to the airfoil.

7.0 NWS Forecasts

The NWS local and aviation weather forecast products over the region were documented and included below.

7.1 Terminal Aerodrome Forecast

The NWS Seattle/Tacoma (KSEW) Weather Forecast Office (WFO) responsible for the issuance of the Terminal Aerodrome Forecasts (TAFs) and weather warnings over the region. The forecasts issued for KBFI and KSEA that were current at the time are provided below. While a TAF is only valid for a 5-mile radius of the airport, it provides a breakdown of wind, visibility, precipitation, and sky cover for specific periods, and are typically used in briefings. The forecast period in bold italic print was the forecast valid at the time of the accident.

AMD TAF KBFI 281435Z 2815/2912 15008KT 4SM BR OVC005

TEMPO 2815/2816 17015KT 2SM -RA

FM281700 18012G25KT 4SM -RA OVC020

FM290300 18007KT 4SM RA BR OVC015

FM290700 25005KT 5SM -RA BR OVC015=

The KBFI TAF issued at 0735 PDT was an amended forecast and expected IFR conditions prevailing with winds from 150° at 8 knots, visibility 4 miles in mist, with a ceiling overcast at 500 ft agl, with a temporary²² period between 0800 and 0900 PDT of winds from 170° at 15 knots and visibility 2 miles in light rain.

AMD TAF KSEA 281434Z 2815/2918 20010KT 6SM BR SCT005 OVC015

TEMPO 2815/2816 6SM BR

FM281700 18012KT 5SM -RA BR SCT008 OVC015

FM281900 20015G22KT 5SM -RA BR OVC015

FM290300 29010KT 5SM RA BR SCT005 OVC015

FM291500 32005KT P6SM -RA OVC015=

The KSEA TAF was also an amended forecast issued at 0734 PDT and expected generally MVFR conditions to prevail during the period with wind from 200° at 10 knots, visibility 6 miles in mist, scattered clouds at 500 ft agl, ceiling overcast at 1,500 ft, with a temporary period between 0800 and 0900 PDT of visibility 6 miles in mist.

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 corresponds to the release of the latest TAFs for that office. The AFD synoptic, short term, and aviation sections issued by the KSEW WFO at 0940 PDT were as follows.

FXUS66 KSEW 281640

AFDSEW

Area Forecast Discussion

National Weather Service Seattle WA

940 AM PDT Thu Oct 28 2021

.SYNOPSIS...Rain will persist across the region through Friday with heavy accumulations across the Olympics and Northern and Central Cascades potentially yielding river flooding. Drier air arrives late Friday with dry and cooler conditions for the weekend. Active weather returns to Western Washington early next week.

²² TEMPO or temporary is used to identify a greater than 50% probability of occurrence, and that the conditions are expected to last less than one hour, with total duration of the temporary condition is less than half the forecast period.

.SHORT TERM /TODAY THROUGH SATURDAY/...Forecast remains generally on track this morning. The plume of deep moisture remains aimed across the northern portions of the area this morning and will gradually shift south through the day. Forecast was updated to lower QPF across the southern portions of the area for this morning, as it will be a few more hours before the steadier rain arrives. Otherwise no additional updates needed this morning and the previous short-term discussion follows below. Cullen

Snow levels will rise to 8000 to 9000 feet by later this morning with PWATs rising to 1" to 1.25". This will make conditions feel relatively warm and muggy out, with temperatures rising into the low 60s in some locations with dewpoints in the mid to upper 50s. This environment will set the stage for efficient rainfall through the day, with the heaviest rainfall accumulations occurring from the Southwest Olympics to the Northern and Central Cascades. Current NBM probabilities of rainfall accumulation exceedance in a 24 hour period for today are as follows:

- *Olympics - Probability of exceeding 1": 90%*
- *Olympics - Probability of exceeding 2": 40%*
- *Olympics - Probability of exceeding 3": 10%*
- *Olympics - Probability of exceeding 4": 5%*
- *Olympics - Probability of exceeding 5": >5%*
- *North & Central Cascades - Probability of exceeding 1": 90%*
- *North & Central Cascades - Probability of exceeding 2": 60%*
- *North & Central Cascades - Probability of exceeding 3": 20-25%*
- *North & Central Cascades - Probability of exceeding 4": 10%*
- *North & Central Cascades - Probability of exceeding 5": 5%*

In all, widespread rainfall totals in the aforementioned areas exceeding 3 inches can be expected through Friday morning. Confidence is increasing in a higher end totals in the North and Central Cascades, with some areas potentially seeing 4 to 6 inches of rain through tomorrow morning. Totals in the Olympics look to range between 3 and 4 inches, with isolated totals to 5 inches. Lowland areas can generally expect 1 to 2 inches, with the outer coast likely seeing 2 to 3 inches. As a result, expect widespread rises in rivers across the region, with the greatest threat for river flooding outside of the Skokomish basin likely in northern and central Cascade basins. Urban flooding will also be a concern, especially under any bands of high rainfall rates and in areas with poor drainage. Heavy rainfall rates could also pose a threat for an isolated landslide or two across the area as soils become more saturated over the next 12 to 18 hours. However, expecting this threat to remain conditional on heavy rainfall rates at this time. Refer to the hydrology section for specifics.

Breezy conditions are expected later this morning and early this afternoon, as some of those stronger low-level jet winds get mixed down to the surface. Note that stronger winds will be most likely south of the heaviest band of rain, including much of the Puget Sound region, extending southward toward the Chehalis Valley. Expect gusts in the 30 to 40 mph range at times. Expect impacts across these areas, including damage to trees and power disruptions.

Timing remains in sync across the current suite of model guidance in the timing of a cold front bringing drier air to the region through the day Friday. There likely will be a brief period of convergence behind the front that will keep low clouds and possibly light showers in the Central Puget Sound area through Friday afternoon before clearing. Nonetheless, this will end heavy precipitation and set the stage for drier weather and cooler overnight temperatures for the weekend.

.AVIATION...Westerly flow aloft through Friday evening. Rain across much of the area this morning, heaviest rain located across northern areas. MVFR/IFR cigs for most through the morning with areas of LIFR. MVFR/IFR cigs through much of today with rain for lowered vsbys at times in heaviest showers. Winds will increase through this morning with southerly wind gusts of 25 to 30 kts possible for areas through the day. Winds will taper off a bit tonight as a front moves through the area.

KSEA...MVFR cigs with IFR cigs possible at times today. There will be light to moderate rain through today, though a dry period is possible late this morning into the afternoon, with the heaviest rain tonight for lowered vsbys. Winds will increase this morning with southerly wind gusts of 25 to 30 kts possible late morning into the afternoon, tapering off as a front moves through. New guidance is suggestive of the switch to north winds potentially holding off until closer to mid morning tomorrow. Will put the rough estimate of the timing in the 18Z TAF for planning purposes.

JD/Kristell

7.3 Graphical 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, from graphical output from the NWS's National Digital Forecast Data (NDFD) with the Graphic-Airmen's Meteorological Information (G-AIRMET)²³ for IFR conditions, mountain obscuration, icing conditions, and strong surface wind overlaid. The GFA provides a forecast for the enroute phase 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 forecast charts issued at approximately 0600 PDT and valid at the time of the accident are included as figures 14 and 15, with the approximate accident site marked by the red star. The charts depicted visibilities 3 miles or less in rain, with overcast clouds at 1,100 ft msl with tops to 13,000 ft over the region. G-AIRMETs for IFR, mountain obscuration, and for icing conditions were depicted over the accident site.

²³ AIRman's METeorological Information (AIRMET) is a concise description of weather phenomena that are occurring or may occur (forecast) along an air route that may affect aircraft safety. Compared to SIGMETs, AIRMETs cover less severe weather: moderate turbulence and icing, sustained surface winds of 30 knots or more, low-level wind shear, or widespread restricted visibility.

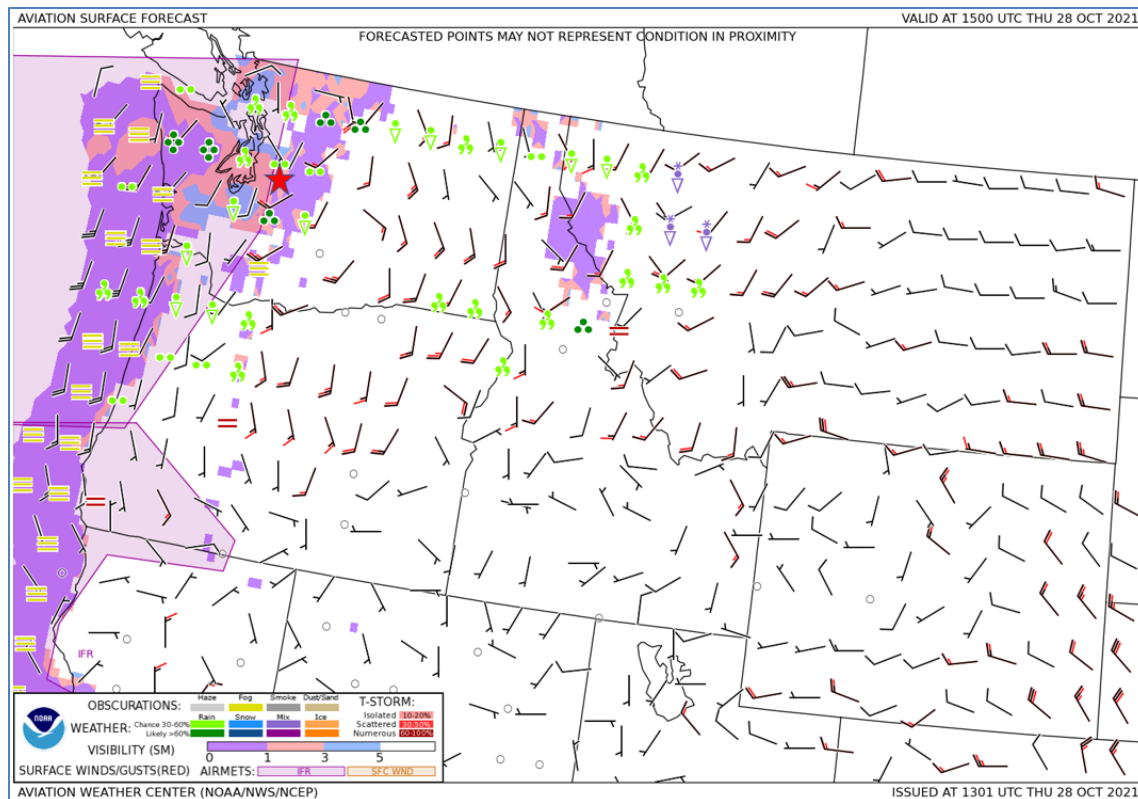


Figure 14 - GFA Surface Forecast valid for the period of the accident.

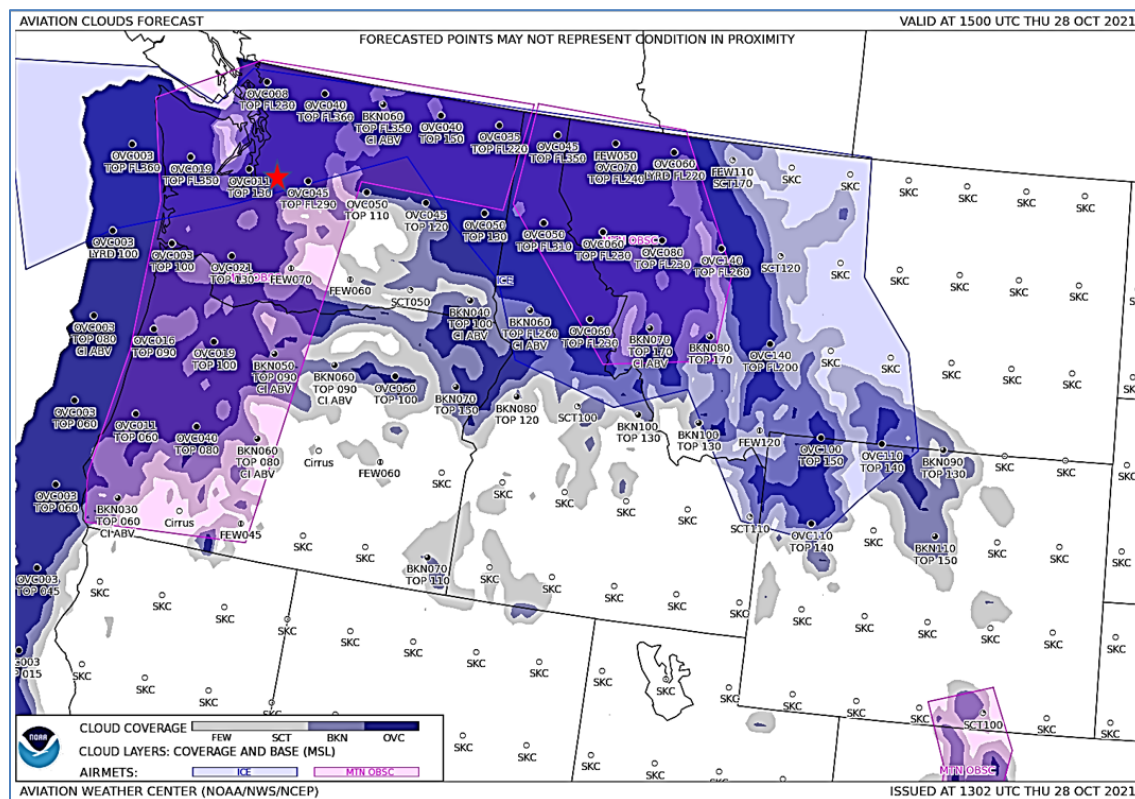


Figure 15 - GFA Cloud Forecast valid at the time of the accident.

7.4 Current Icing Products

The Current Icing Product (CIP) and the Forecast Icing Product (FIP) graphics are computer-generated three-dimensional analyses of information related to the likelihood of encountering icing conditions. The CIP/FIP graphics suite is automatically produced with no human modifications and available at the NWS AWC website²⁴. Information on the graphics is determined from observational data including WSR-88D radar, satellite, pilot weather reports, surface weather reports, lightning and computer model output. The CIP represents the latest analysis of potential icing regions. Besides the most-recent analyses, a forecast of anticipated icing conditions is available in the FIP product.

The National Center for Atmospheric Research (NCAR) who developed the CIP/FIP product was contacted and recreated the data from 0800 through 1000 PDT on October 28, 2021, from 10,000 through 16,000 ft, at 1,000 ft increments. CIP/FIP provide information on expected probability of icing conditions, the icing severity as five categories: none, trace, light, moderate, and heavy, and the potential for supercooled large droplets (SLD). The severity estimations are roughly based on the accretion rate of ice on an airplane, and the levels are determined by the time it would take for an airfoil to accrete 1/4-inch of ice: trace, 1-hour; light, 15-minutes to 1-hour; moderate, 5-15 minutes; and severe < 5 minutes. The rates are, in turn, estimated from the amount of supercooled liquid water expected with a nominal drop diameter of 15 microns (µm), and are further tuned by nearby pilot reports of encountered severity. These are relative values and the use of which should consider the airframe and the level of icing protection provided by the aircraft. Different aircraft and different flight configurations (airspeed, angle of attack, etc.) will experience variations in accretion rate. These rates have been simulated for a range of aircraft and are a "broad brush" approach to severity prediction.

The CIP Icing Probability (in percent) for 10000 ft, 12000 ft, 14000 ft, and 16000 ft for 0908 PDT with the accident site marked by the black circle are included in figure 16. The images depicted a 40-60% probability of icing at 10,000 ft with the probability increasing above 10,000 ft to 60-70% between 11,000 and 16,000 ft. An area of icing probabilities between 70-80% was indicated immediately south of the accident site between 12,000 through 13,000 ft. Figure 17 is a composite of the CIP icing severity categories from 10000 ft, 12000 ft, 14000 ft, and 16000 ft, which depicted a light to moderate icing conditions along the route of flight above 11,000 ft through 16,000 ft, with moderate icing over the accident site. Figure 18 is the CIP icing probability and icing severity composite or the maximum (i.e., worst case) conditions for 0908 PDT, which depicted a 60-70% risk of moderate icing over the flight path and over the accident site.

²⁴ <https://www.aviationweather.gov/icing>

The CIP supercooled large droplet (SLD)²⁵ potential product for 10000 ft, 12000 ft, 14000 ft, and 16000 ft is included as a composite image in figure 19. The SLD potential indicated unknown conditions over the accident site but did expect potential SLC conditions immediately south and east of the accident site.

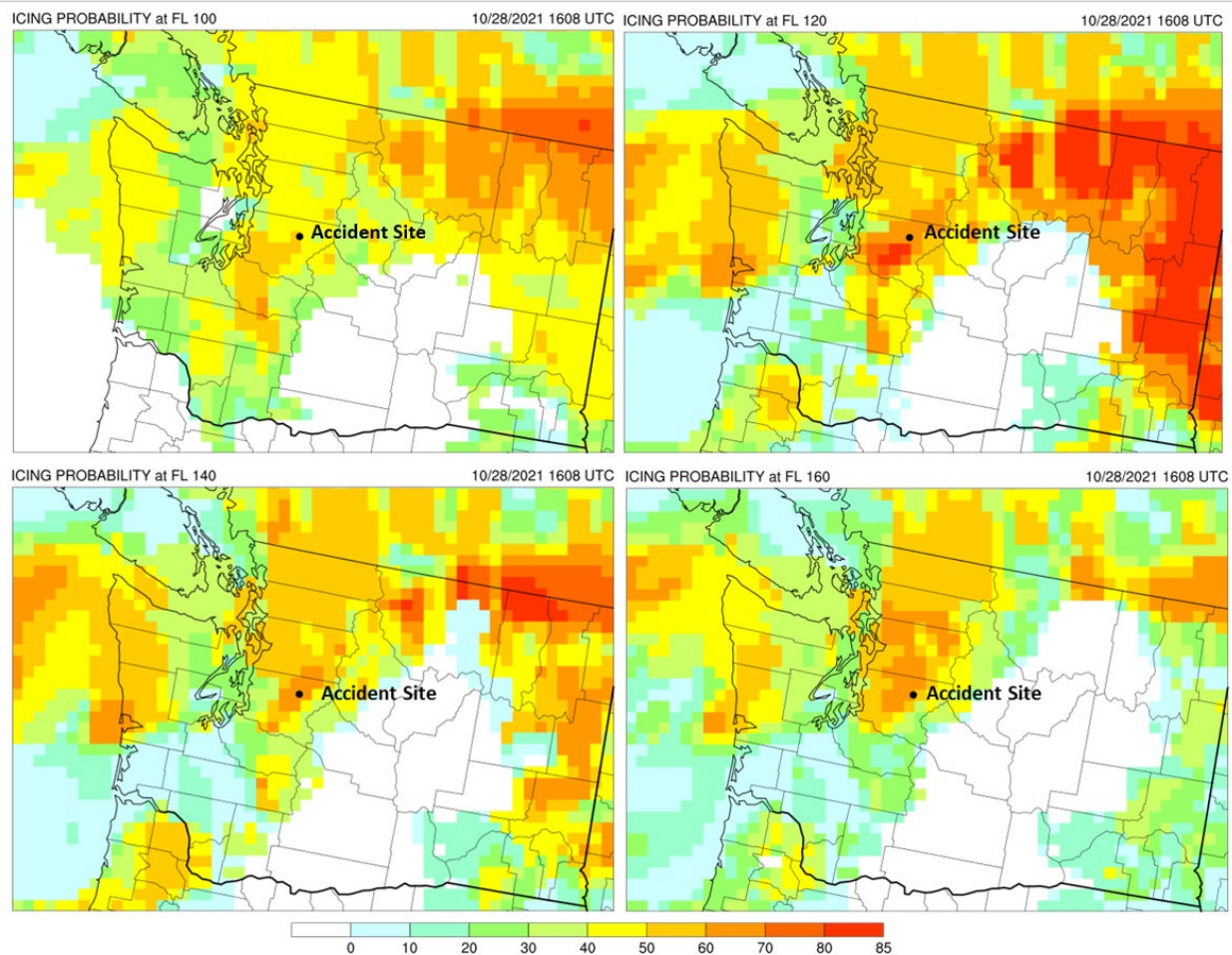


Figure 16 - CIP Icing Probability for 10000 ft, 12000 ft, 14000 ft, and 16000 ft for 0908 PDT.

²⁵ SLD conditions are defined as a liquid water droplet below 0° C with a droplet size or a medium volumetric diameter (MVD) greater than 50 µm. SLD conditions are often observed in freezing drizzle, freezing rain, and in thunderstorms conditions.

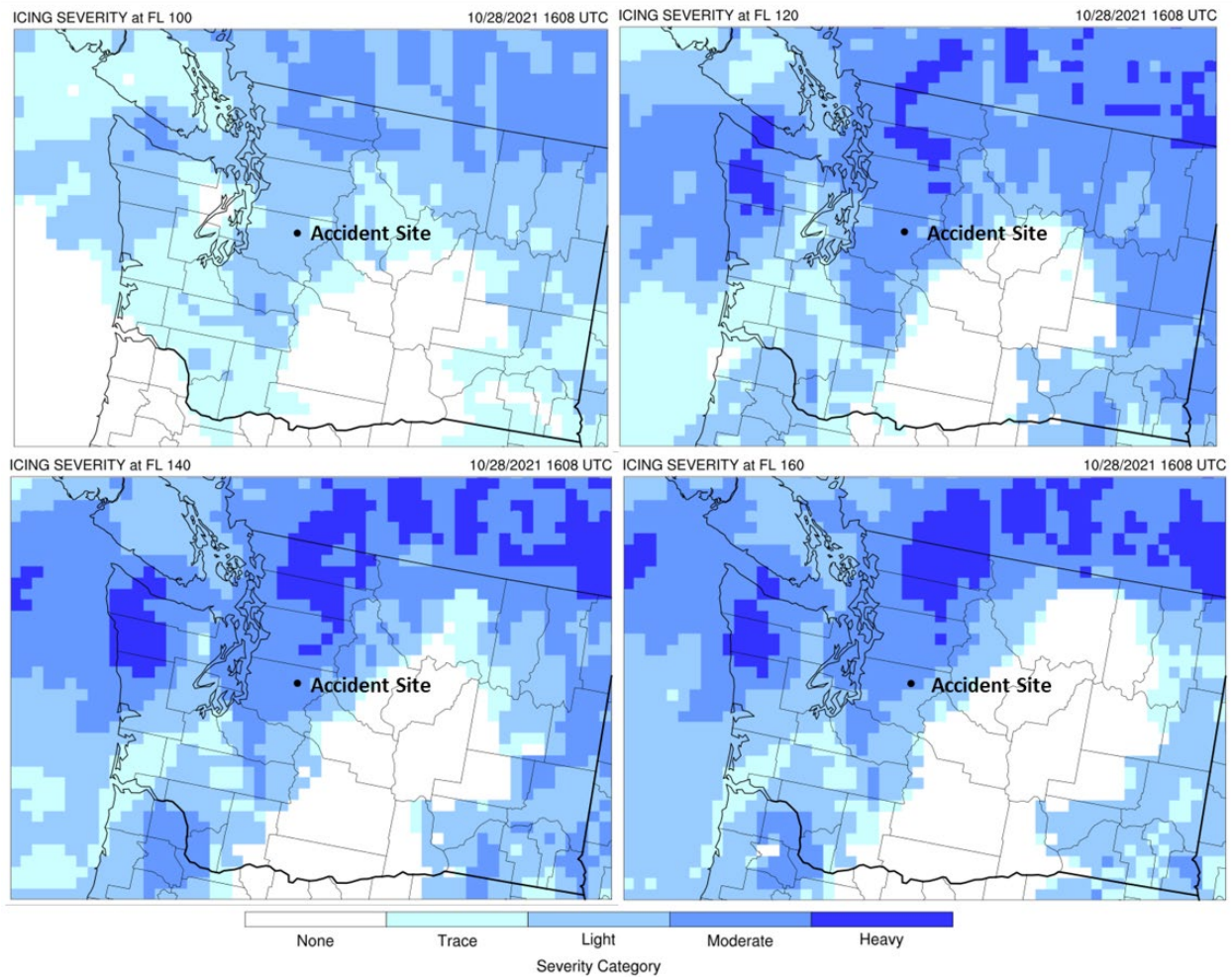


Figure 17 - CIP Icing Severity for 10000 ft, 12000ft, 14000 ft, and 16000 ft for 0908 PDT.

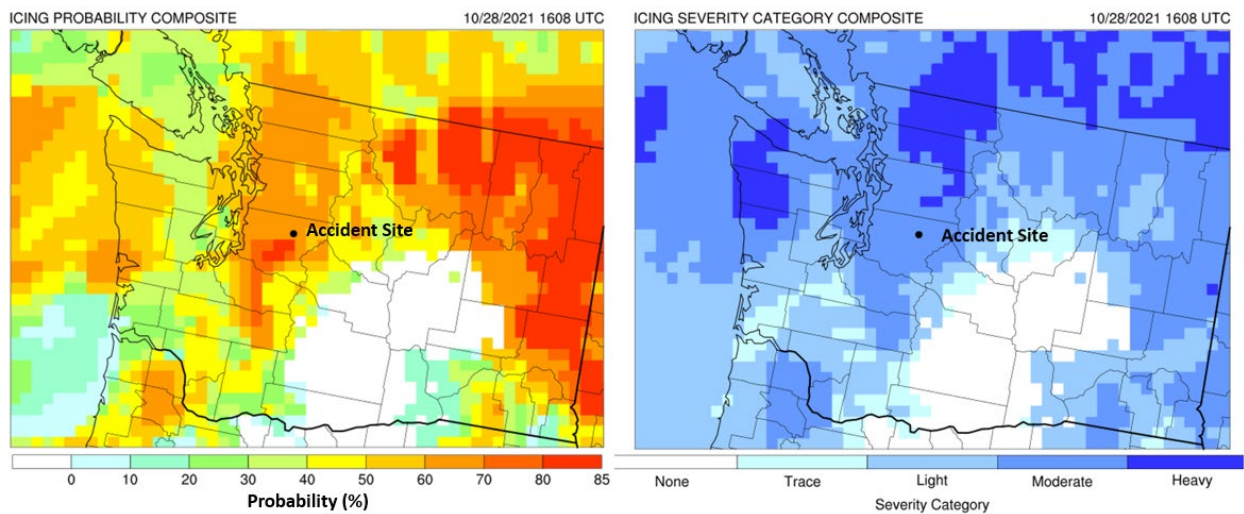


Figure 18 - CIP icing probability and severity composites for 0908 PDT.

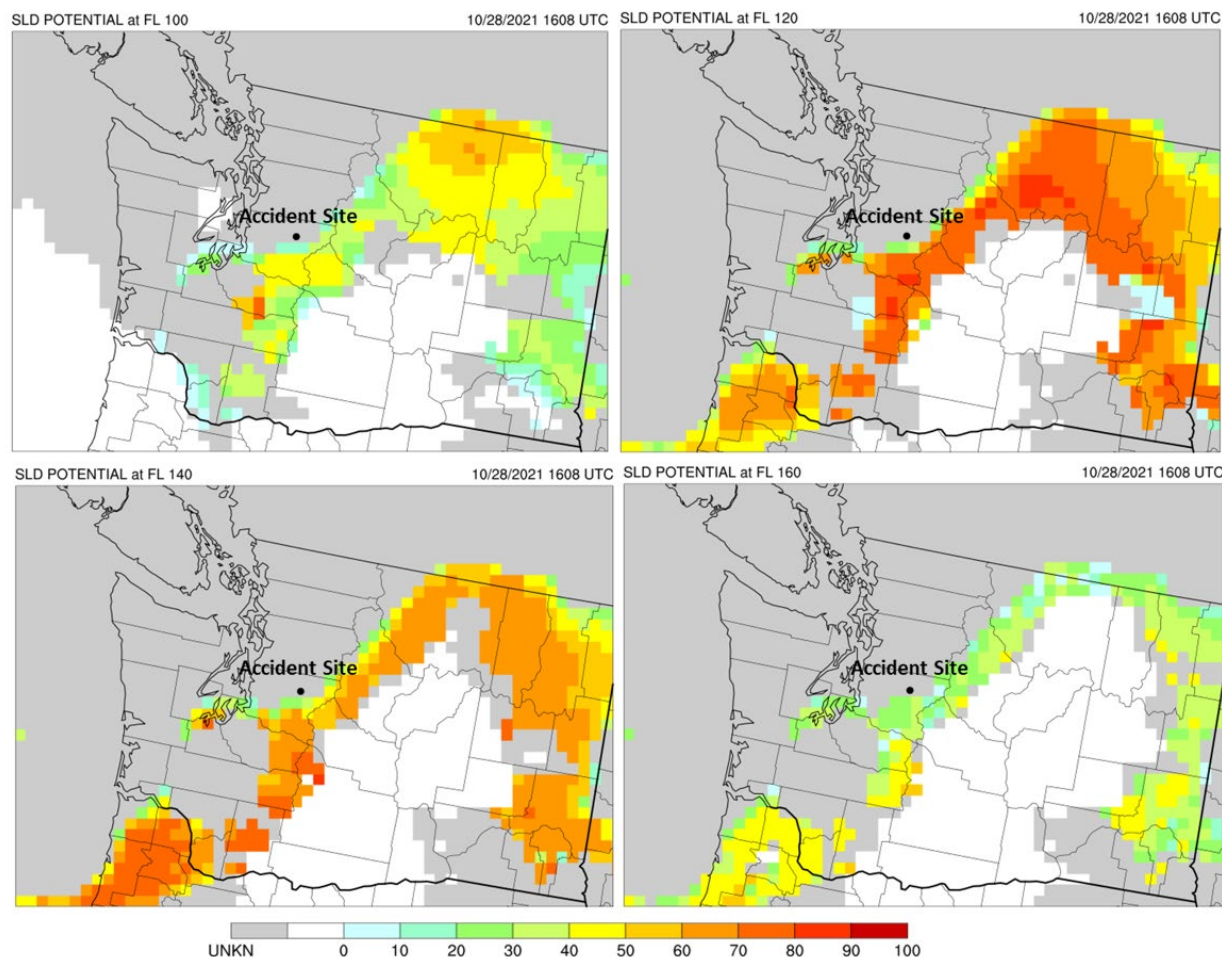


Figure 19 - CIP SLD potential for 10000 ft, 12000 ft, 14000 ft and 16000 ft for 0908 PDT.

7.5 Winds and Temperature Aloft Forecast

The NWS Winds and Temperature Aloft Forecast (FD)²⁶ derived from the NWS WPC forecast was issued at 0658 PDT and valid for 1100 PDT and for use between 0700 and 1400 PDT for the route of flight were as follows.

FBUS31 KWN0 281358

FD1US1

-DATA BASED ON 281200Z

VALID 281800Z FOR USE 1400-2100Z. TEMPS NEG ABV 24000

FT	3000	6000	9000	12000	18000	24000	30000	34000	39000
-SEA	2249	2346+06	2544+01	2554-03	2661-16	2669-27	269342	259750	750356
-YKM	2317	2650+08	2650+04	2648+00	2650-15	2663-26	269541	760350	269557
-LWS	2114	2642+08	2646+02	2644-03	2852-16	2766-26	279440	770249	279556
-BOI		2509+09	2715+02	2822-02	2934-13	2856-22	286939	276949	276956

²⁶ Based on the FBUS31 KWN0 bulletin.

The forecast for SEA was the closest to the accident site and expected the wind at 9,000 ft from 250° at 44 knots with a temperature of 1° C, at 12,000 ft from 250° at 54 knots with a temperature of -3° C, and for 18,000 ft from 260° at 61 knots with a temperature of -16° C.

7.6 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, as well as from the Center Weather Service Units (CWSU) associated with FAA 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 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 based on experience and the operational limits of the aircraft. The following advisories were current during the period.

The NWS AWC had a full series of G-AIRMETs that were issued at 0745 PDT and were current over the area for IFR conditions, mountain obscuration, low-level wind shear below 2,000 ft, turbulence from surface to 14,000 ft, and moderate icing conditions²⁷ from freezing level to 22,000 ft. No Convective SIGMETs, SIGMETs, or CWAs were current over the area at the time of the accident. Figures 20-22 are depictions of the G-AIRMET advisories for IFR conditions and mountain obscuration conditions, low-altitude turbulence, and icing conditions all valid until 1100 PDT (1800Z) with the approximate accident site marked by a red star.

²⁷ The accident airplane Mooney M20M, N40KA was equipped with limited anti-ice and deicing capability with a TKS weeping wing system (Tecalemit-Kilfrost-Sheepbridge Stokes). However, even with that icing protection the aircraft flight manual stated that flight into known icing conditions was prohibited.

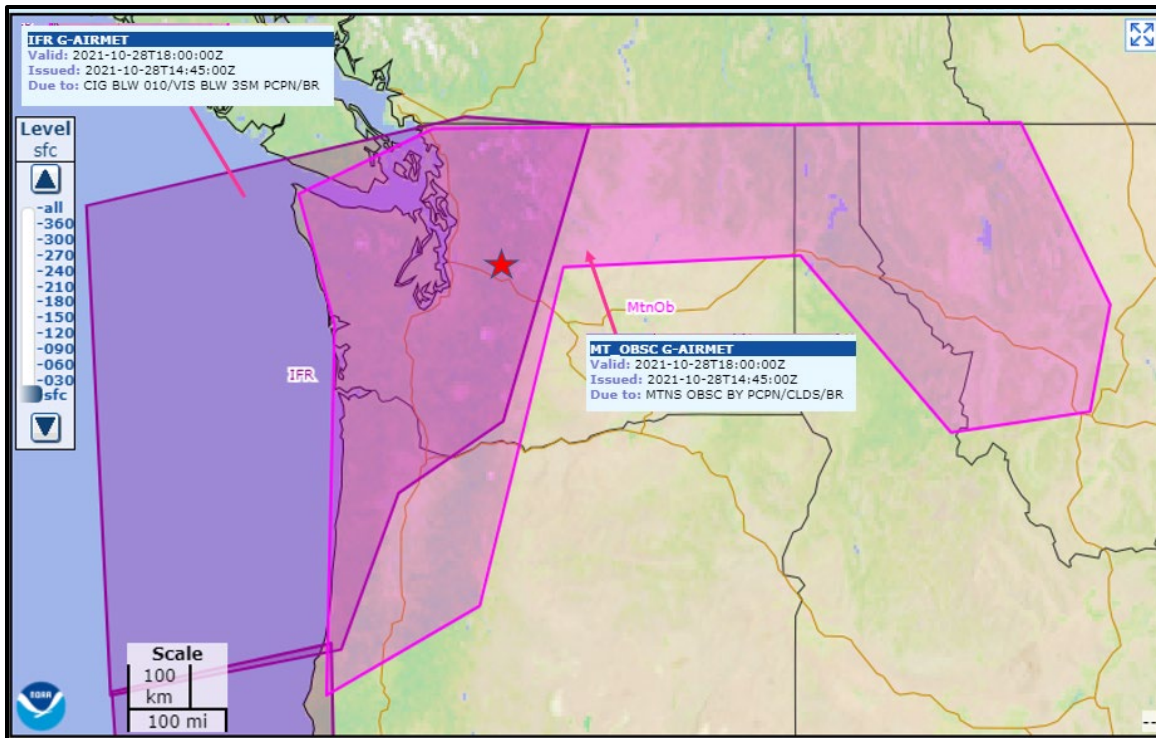


Figure 20 - G-AIRMET Sierra for IFR and mountain obscuration conditions.

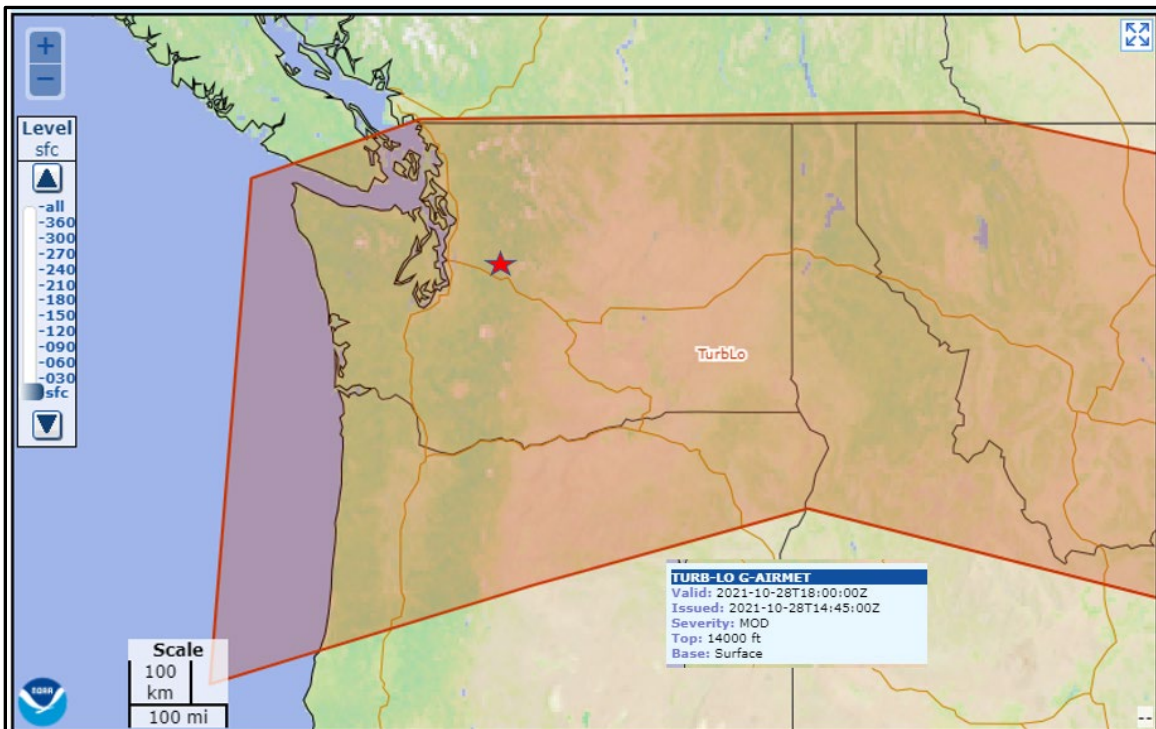


Figure 21 - G-AIRMET Tango for low-altitude turbulence from the surface to 14,000 ft.

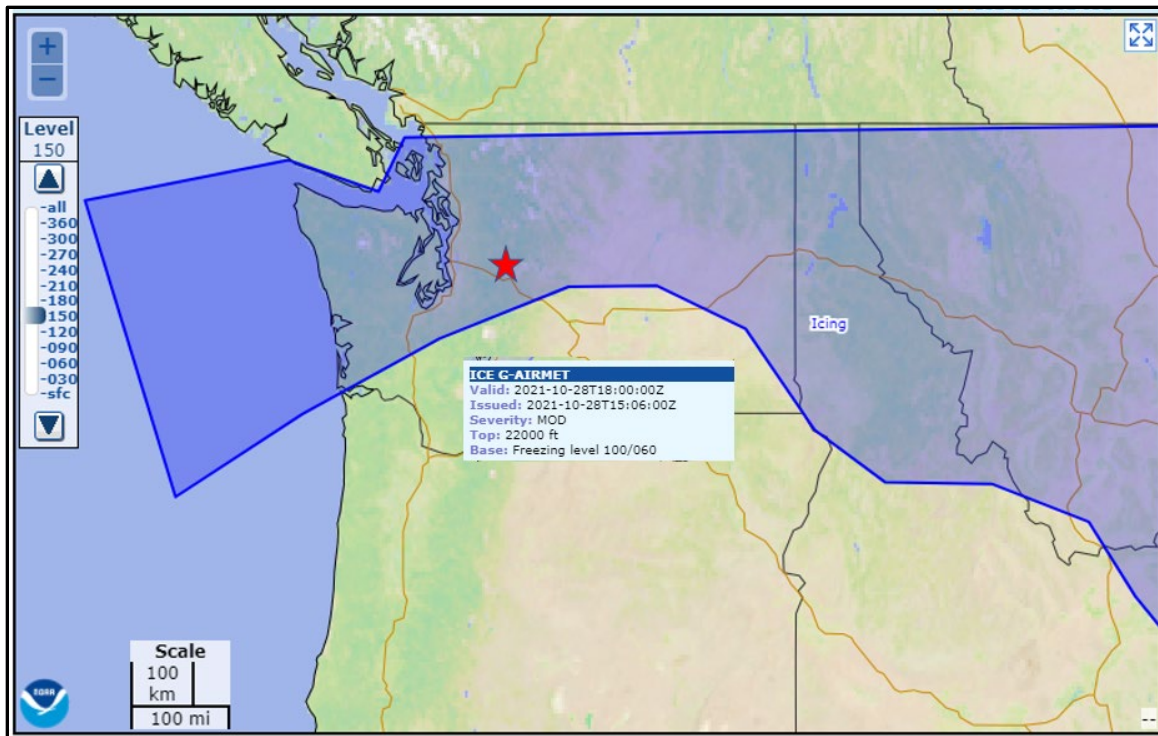


Figure 22 - G-AIRMET Zulu for icing conditions from freezing level to 22,000 ft.

8.0 Weather Briefing Information

A search of the FAA Contract Flight Service Station provider Leidos indicated that they had no contact from the pilot within 15 days of the accident flight for any weather briefing, flight plans, or any inflight contact. A further search from ForeFlight indicated that the accident pilot had filed an IFR flight plan through their system at 0807 PDT, with an estimated departure at 0830 PDT from KAWO to KTWF with a cruising level of 17,000 ft, and an estimated time enroute of 2:15. The filing of the flight plan generated a route briefing which is included as attachment 2. Prior to the filing of the flight plan no weather imagery was viewed using their app; however, the pilot pulled the airport pages for KAWO, KTWF, KLOW, KGRI, and KPAE which included the METARs and TAFs as well as general airport information.

9.0 Astronomical Conditions

The United States Naval Observatory's Multiyear Interactive Computer Almanac (MICA) software provided the astronomical conditions over the accident site provided the following conditions.

Sun	Time (PDT)
Dawn	0709
Sunrise	0740

<i>Accident</i>	0910
Culmination	1246
Sunset	1751
Dusk	1822

At the time of the accident the Sun was 12° above the horizon at an azimuth of 126°.

E. LIST OF ATTACHMENTS

Attachment 1 - Flight track of N40KA on October 28, 2021.

Attachment 2 - ForeFlight Route Briefing for 0807 PDT on October 28, 2021.

Submitted by:

Donald Eick
Senior Meteorologist