

# National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



DCA23LA096

## **METEOROLOGY**

Specialist's Factual Report

December 6, 2024

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## **A. ACCIDENT**

Location: Kahului, Hawaii  
Date: December 18, 2022  
Time: about 1007 Hawaii Standard Time (HST)  
2007 coordinated universal time (UTC) <sup>1</sup>  
Aircraft: Hawaiian Airlines flight 35, Airbus A330-243; Registration: N393HA

## **B. METEOROLOGY INVESTIGATOR**

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

## **C. SUMMARY**

On December 18, 2022, about 1007 Hawaii standard time, Hawaiian Airlines flight 35, an Airbus A330-200, N393HA, was operating at FL400 about 65 nautical miles north-northeast of Kahului, Hawaii, when the airplane encountered severe turbulence. Of the 2 flight crewmembers, 8 flight attendants, and 283 passengers (including 2 off-duty Hawaiian Airlines pilots in the cockpit jumpseats and 3 lap held children) aboard the airplane, 4 occupants (1 flight attendant and 3 passengers) sustained serious injuries, and 20 occupants (3 flight attendants and 17 passengers) sustained minor injuries. The airplane sustained minor damage. The regularly scheduled domestic passenger flight was operating under the provisions of Title 14 Code of Federal Regulations Part 121 from Phoenix Sky Harbor International Airport (PHX), Phoenix, Arizona, to Daniel K. Inouye International Airport (HNL), Honolulu, Hawaii.

## **D. DETAILS OF THE INVESTIGATION**

The National Transportation Safety Board's Senior Meteorologist was not on scene for this investigation and conducted the meteorology phase of the investigation remotely, collecting data from official National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sources including the Weather Prediction Center (WPC), and the National Center for Environmental Information (NCEI). This report documents the general weather products and forecasts

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<sup>1</sup> Based on preliminary information from the Flight Data Recorder (FDR) the time of turbulence encounter was recorded at 2007:43Z.

over the region during the period and documents the pertinent meteorological parameters to the accident. All times are reported as Hawaii standard time (HST) based upon the 24-hour clock, local time is -10 hours from UTC, and UTC=Z. Airport and NWS 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. continental airports., and "P" for most of the north Pacific region, or specifically "PH" for Hawaii airports. Directions are referenced to true north and distances in nautical miles. Heights are in feet (ft) above mean sea level (msl) unless otherwise noted. Visibility is in statute miles and fractions of statute miles.

The turbulence location was estimated at latitude 22.2754° North and longitude 154.8902° West, at an altitude of approximately 40,000 ft or FL400<sup>2</sup>.

## **E. FACTUAL 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) 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 and other products can be found in the Federal Aviation Administration (FAA) "Aviation Weather Handbook", FAA-H-8083-28<sup>3</sup>.

#### **1.1 Surface Analysis Chart**

The NWS Ocean Pacific Center's (OPC) Pacific Surface Analysis Chart for 0800 HST (1800Z) on December 18, 2022, is included as figure 1 with the approximate turbulence location marked by the red star. The chart depicted a low-pressure system at 986-hectopascals (hPa) associated with an occluded frontal system to the north-northwest of the Hawaiian Islands associated with storm force conditions<sup>4</sup> and was

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<sup>2</sup> In aviation meteorology, a Flight Level (FL) is an aircraft's altitude based on the standard air pressure, expressed in hundreds of feet. The air pressure is computed assuming an International Standard Atmosphere pressure of 1013.25-hectopascals (hPa) or 29.92 inches of mercury (inHg) at sea-level at 59° Fahrenheit (F) or 15° Celsius (C), and therefore is not necessarily the same as the aircraft's actual altitude, either above sea level (msl) or above ground level (agl). In the United States flight levels are reference above 18,000 ft.

<sup>3</sup> <https://www.faa.gov/regulationspolicies/handbooksmanuals/aviation/faa-h-8083-28-aviation-weather-handbook>

<sup>4</sup> Storm force conditions - A warning of sustained surface winds, or frequent gusts, in the range of 48 knots to 63 knots (55 to 73 mph) inclusive, either predicted or occurring, and not directly associated with

projected to move to the southeast and deepen<sup>5</sup> to 984-hPa during the next 24-hours. This storm system was being identified as a Kona Storm<sup>6</sup> and expected to affect the Hawaii Islands with strong westerly winds. Another dissipating frontal system was located east of this system with a trough<sup>7</sup> extending southward to the extreme western Hawaiian Islands and was associated with gale force conditions<sup>8</sup>. Another low-pressure system at 1005-hPa with an associated frontal system was located halfway between the U.S. mainland and the Hawaiian Islands near 32.5° N and 143° W with gale force conditions.

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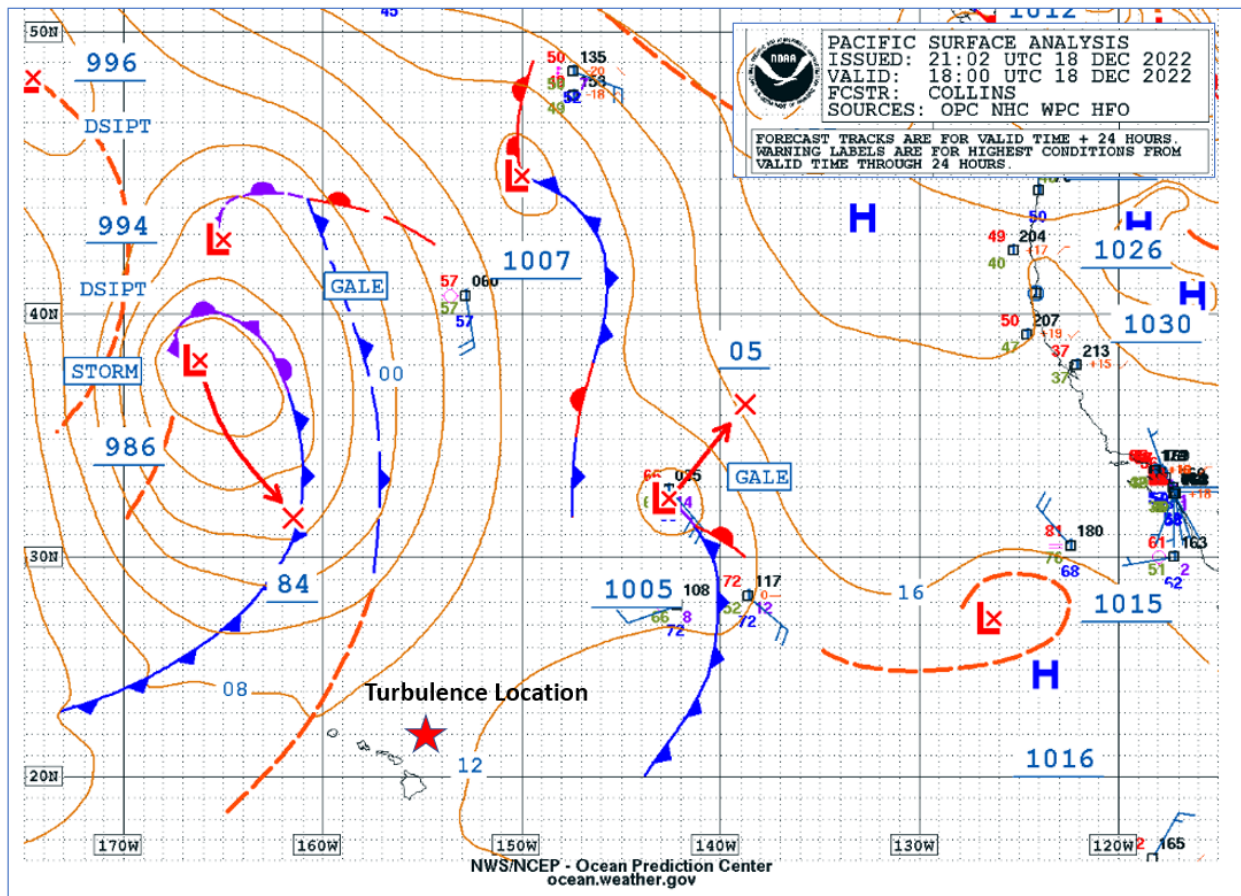
a tropical cyclone.

<sup>5</sup> Deepening - is a decrease in the central pressure of a surface low pressure system and is an indication the storm is intensifying.

<sup>6</sup> Kona (also called Kona Storms) are a stormy, rain-bringing wind from the southwest or south-southwest in Hawaii. It blows about five times a year on the southwest slopes that are in the lee of the prevailing northeast trade winds. Kona is the Polynesian word for "leeward." Kona storms are mainly cold core cyclones or extratropical storms that move slowly, and often bring heavy rain, thunderstorms, flash floods and associated landslides, high winds which result in large surf and swells, and waterspouts.

<sup>7</sup> Trough - is an elongated area of relatively low atmospheric pressure, usually not associated with a closed circulation, and thus used to distinguish from a closed low. The opposite of ridge. Troughs are typically associated with general convergence, rising air, and with sufficient moisture clouds and precipitation.

<sup>8</sup> Gale force conditions - A warning of sustained surface winds, or frequent gusts, in the range of 34 knots (39 mph) to 47 knots (54 mph) inclusive, either predicted or occurring, and not directly associated with a tropical cyclone.



**Figure 1 - NWS Ocean Prediction Center's Pacific Surface Analysis Chart for 0800 HST with the approximate turbulence location marked by the red star.**

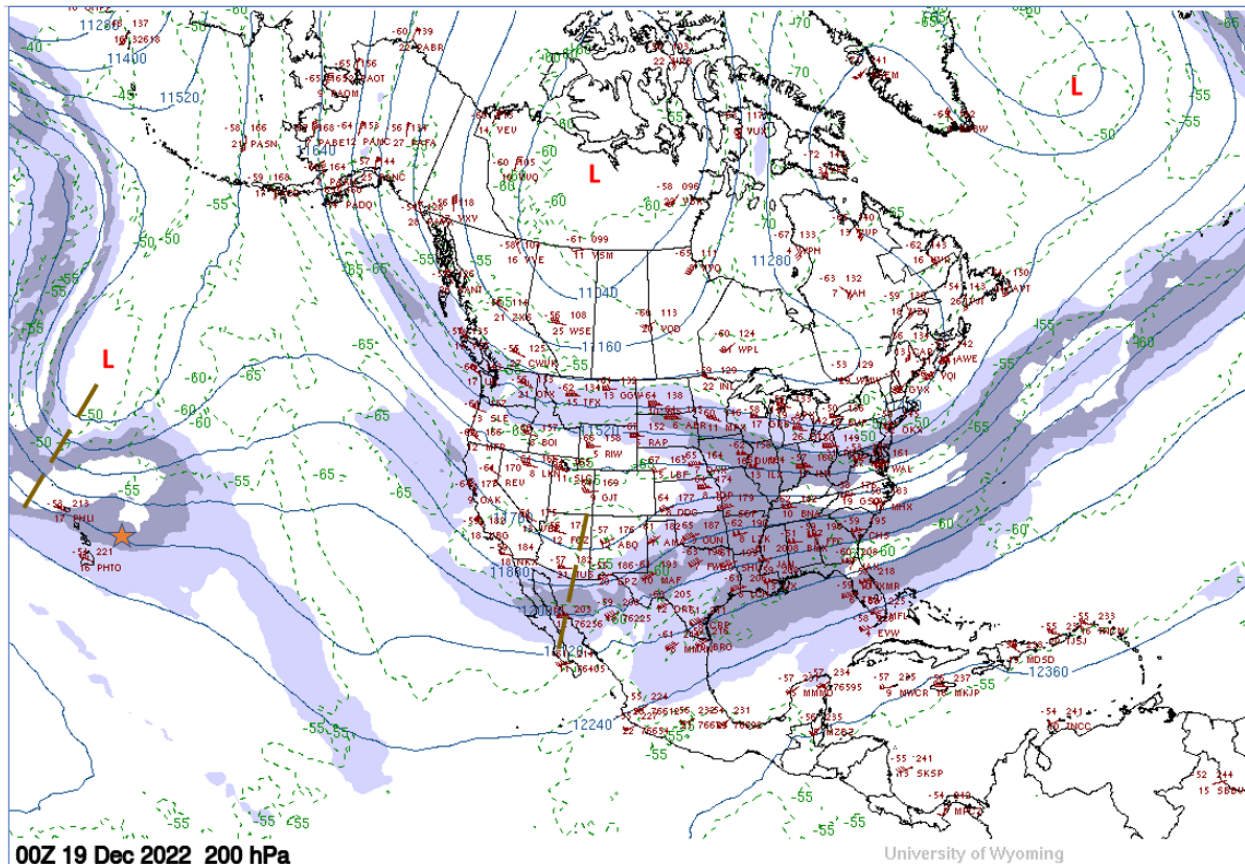
## 1.2 Constant Pressure Chart

The 200-hPa Constant Pressure Chart for 1200 HST (0000Z on December 19, 2022), for North America from the University of Wyoming archive website is included as figure 2 with the approximate turbulence location marked by the red star. The chart depicted the conditions at approximately FL390 and depicted the height contours (blue solid lines), isotherms (green dashed lines), isotachs (shaded areas) beginning at 70 knots, and the station models. The chart depicted a low-pressure system and longwave trough extending southward associated with the occluded front to the north-northwest of the Hawaiian Islands, with the accident site located ahead of the trough in a general area of diffluent flow<sup>9</sup> and in the front right exit region of a 110 knot jet stream with winds near 90 knots over the accident site. The maximum winds of 180 knots associated with the main jet stream core were located on the western side of the

<sup>9</sup> Diffluence - is a pattern of wind flow in which air moves outward (in a "fan-out" pattern) away from a central axis that is oriented parallel to the general direction of the flow. It is the opposite of confluence.

trough<sup>10</sup>, and indicated the trough was amplifying with an equatorward component of motion towards the Hawaiian Islands.

The upper air station model for Lihue (PHLI) at 200-hPa depicted a height of 12,130 meters (m), a temperature of -53° C, with a temperature-dew point spread of 17° C, with a westerly wind at 110 knots. While the station model for Hilo (PHTO) indicated the height of the 200-hPa level at 12,210 meters (40,059 ft), a temperature of -54° C, a temperature-dew point spread of 16° C, and wind from the west at 80 knots.



**Figure 2 - 200-hPa Constant pressure Chart for 1400 HST with the approximate turbulence location marked by a red star.**

### 1.3 High Level Significant Weather Prognostic chart

The NWS 24-hour Pacific High-Level Significant Weather Prognostic Charts valid for 0800 and 1400 HST with the approximate turbulence location are included as figures 3 and 4 respectively. The charts depicted a snapshot of expected conditions between FL240 and FL630, with the general position of upper-level lows and highs,

<sup>10</sup> Also known as a “Digging Upper-Level Trough” and implied positive vorticity advection and rising motion over ahead of the trough, which supported upward vertical motion and thunderstorm development over the Hawaiian Islands.

the jet streams, areas of expected clear air turbulence, and areas of organized convection activity. The chart valid for 0800 HST<sup>11</sup> (figure 3) depicted the upper-level low at FL260 immediately north-northwest of the Hawaiian Islands with a polar jet stream<sup>12</sup> with a maximum speed of 190 knots circulating around the low at FL320. The jet stream wind speeds decreased as it moved through the base of the trough and then turned northward at 90 knots east of the low at FL330. Another subtropical jet stream<sup>13</sup> was located to the right or generally south of the polar jet circulating around the low at FL390 with maximum winds of 160 knots on the west side of the trough, slowing into the trough and exiting east-northeastward north of the turbulence location at 120 knots at FL390. An area of moderate turbulence was indicated between the two jet streams from below FL240 to FL410 to the north of the accident location. Another area of moderate-to-severe turbulence was depicted on the western side of the upper-level low (yellow dash lines and symbols). An area of isolated embedded cumulonimbus clouds (CB's) was depicted over most of the Hawaiian Islands and bordered the accident site, with expected tops to FL390. The header warned that CB's implied moderate to severe turbulence and icing, and hail.

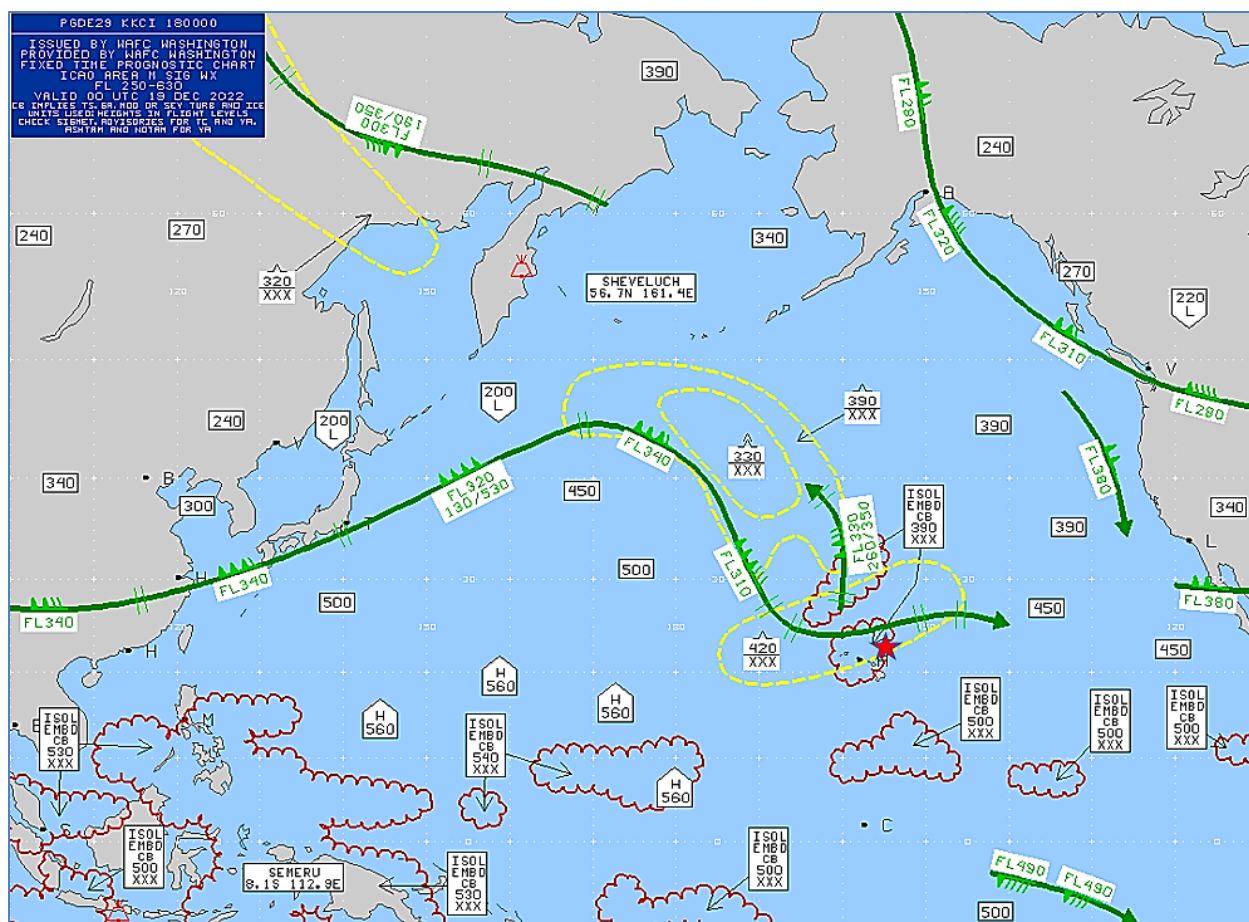
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<sup>11</sup> The chart valid for 1800Z was issued around 0200Z on the same day, based on earlier model data to provide the 24-hour forecast. While the 0000Z chart was issued around 0800Z the previous day.

<sup>12</sup> Polar Jet Stream - a jet stream marked by a concentration of isotherms and strong vertical shear, this jet is the boundary between the polar air and the subtropical air. It often divides into two branches, the north and the south, and marks the high speed core of the prevailing westerlies. It is associated with the location and motion of the high and low pressure areas of the middle latitudes, and therefore, is variable in position, elevation, and wind speed. Its position tends to migrate south in the Northern Hemispheric winter and north in the summer, and its core winds increase during the winter and become less strong in the summer.

<sup>13</sup> Subtropical jetstream - a band of relatively strong winds concentrated between 20° and 30° latitude in the middle and upper troposphere.





**Figure 4 - NWS High-Level Significant Weather Prognostic Chart for 1400 HST or 0000Z on December 19, 2022, with the approximate turbulence location marked by the red star.**

## 2.0 Observational Data

### 2.1 Surface Observations

The closest reporting station and destination airport was documented using official Aviation Routine Weather Reports (METAR<sup>14</sup>) and Aviation Selected Special Weather Reports (SPECI). Cloud heights are reported above ground level (agl) in the following section.

#### 2.1.1 Kahului, Hawaii

The closest NWS reporting station was from Kahului Airport (PHOG), Kahului, on the Island of Maui, Hawaii, located about 120 miles southwest of the accident site, at an elevation of 55 ft. The airport had a federally installed and maintained Automated

<sup>14</sup> Abbreviation for Meteorological Aerodrome Report.

Surface Observation System (ASOS) and was augmented by certified observers during normal operating hours. At the approximate time of the turbulence encounter the following conditions were reported.

*PHOG weather at 0954 HST (1945Z), wind variable at 3 knots, visibility 10 miles in light rain, a few clouds at 1,500 ft agl, ceiling broken at 2,500 ft, overcast at 6,000 ft, temperature 22° Celsius (C), dew point temperature 21° C, altimeter 29.83 inches of mercury. Remarks: automated station with a precipitation discriminator, rain began at 0903 HST, sea-level pressure 1010.6-hPa, hourly precipitation 0.02 inches, temperature 22.0° C, dew point temperature 20.6° C, maintenance indicator on.*

The general flight categories<sup>15</sup> and observations reported from about 0800 through 1300 HST (1800Z-2300Z) for KPOG were as follows:

VFR METAR PHOG 181754Z 23007KT 10SM -RA SCT025 SCT040 23/19 A2983 RMK AO2  
RAE02B23E32B50 SLP107 P0000 60005 T02280194 10233 20200 53010 \$=

VFR METAR PHOG 181854Z 22004KT 10SM FEW020 SCT040 23/21 A2983 RMK AO2 RAE34  
SLP108 P0000 T02330206 \$=

**MVFR METAR PHOG 181954Z VRB03KT 10SM -RA FEW015 BKN025 OVC060 22/21 A2983 RMK  
AO2 RAB03 SLP106 P0002 T02220206 \$=**

#### **Turbulence Encounter 2007Z**

MVFR SPECI PHOG 182038Z 05006KT 10SM -RA SCT009 BKN025 OVC060 23/21 A2983 RMK AO2  
P0005 T02280206\$

MVFR METAR PHOG 182054Z 03005KT 10SM -RA SCT009 BKN025 OVC060 23/21 A2982 RMK AO2  
SLP103 P0005 60007 T02280211 58004 \$=

IFR SPECI PHOG 182139Z 13009G17KT 3SM +RA BR BKN009 BKN030 OVC060 22/20 A2981  
RMK AO2 P0003 T02220200 \$=

LIFR METAR PHOG 182154Z 24004G14KT 1/2SM +RA FG BKN009 BKN030 OVC060 20/19 A2979  
RMK AO2 PRESFR SLP094 P0045 T02000189 \$=

IFR SPECI PHOG 182156Z 23004G14KT 2SM +TSRA BKN009 BKN030 OVC060 20/19 A2979

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<sup>15</sup> 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 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.

RMK AO2 TSB56 PRESFR TOWER VIS VARIABLE 1V3 P0014 T02000189 \$=

*IFR* SPECI PHOG 182222Z 05009KT 3SM TSRA BKN009 BKN030 OVC060 21/19 A2979 RMK AO2  
TSB2156 TOWER VIS 1V3SM TS OHD MOV NE P0058 T02110194 \$=

*MVFR* SPECI PHOG 182251Z 33007G15KT 5SM -RA BR BKN011 BKN020 OVC100 21/19 A2977  
RMK AO2 TSB2156E50 TS OHD MOV NE P0060=

*IFR* METAR PHOG 182254Z 34010KT 4SM RA BR BKN009 BKN020 OVC100 21/19 A2977 RMK  
AO2 TSB2156E50 SLP085 TS OHD MOV NE P0061 T02110194=

### 2.1.2 Honolulu, Hawaii

Daniel K. Inouye International Airport (PHNL), Honolulu, Hawaii, the planned destination was located about 178 miles west-southwest of the turbulence location. The airport had a federal installed and maintained ASOS and reported the following conditions surrounding the period from 0400 through 1200 HST (1400Z-2200Z).

*MVFR* SPECI PHNL 181409Z 20004KT 3SM +TSRA BR FEW024 BKN075CB BKN090 22/21 A2981 RMK  
AO2 TSB03 OCNL LTGICCCCA OHD TS MOV NE P0003 T02220211=

*MVFR* METAR PHNL 181409Z 20004KT 3SM +TSRA BR FEW024 BKN075CB BKN090 22/21 A2981=

*VFR* SPECI PHNL 181419Z 23004KT 10SM +RA FEW025 BKN050 OVC070 22/21 A2980 RMK AO2  
TSB03E11 CIG 021 RWY04R P0010 T02170211=

*VFR* METAR PHNL 181419Z 23004KT 10SM +RA FEW025 BKN050 OVC070 22/21 A2980=

*VFR* METAR PHNL 181453Z 32004KT 10SM FEW018 SCT050 BKN100 22/22 A2981 RMK AO2 RAE53  
TSB03E11 SLP093 P0018 60031 T02170217 56009=

*VFR* SPECI PHNL 181513Z 00000KT 10SM -RA FEW006 SCT020 BKN080 22/22 A2982 RMK AO2  
RAB09 P0001 T02170217=

*VFR* METAR PHNL 181513Z 00000KT 10SM -RA FEW006 SCT020 BKN080 22/22 A2982=

*MVFR* SPECI PHNL 181538Z 13009KT 7SM RA SCT009 BKN018 BKN049 21/21 A2983 RMK AO2 RAB09  
P0001 T02110211=

*MVFR* METAR PHNL 181538Z 13009KT 7SM RA SCT009 BKN018 BKN049 21/21 A2983=

*VFR* SPECI PHNL 181546Z 14007KT 7SM RA SCT013 SCT032 OVC080 21/20 A2983 RMK AO2 RAB09  
P0004 T02060200=

*VFR* METAR PHNL 181546Z 14007KT 7SM RA SCT013 SCT032 OVC080 21/20 A2983=

*VFR* METAR PHNL 181553Z 15006KT 6SM RA BR FEW016 SCT045 OVC110 21/20 A2983 RMK AO2  
RAB09 SLP101 P0005 T02060200=

*VFR* METAR PHNL 181653Z 08007KT 7SM -RA FEW020 OVC110 20/19 A2983 RMK AO2 SLP100

P0013 T02000194=

VFR METAR PHNL 181753Z 05007KT 7SM -RA SCT020 BKN050 OVC110 20/20 A2984 RMK AO2  
SLP104 P0015 60064 T02000200 10228 20200 51010=

MVFR SPECI PHNL 181806Z 06007KT 4SM +RA BR SCT011 BKN020 OVC033 20/19 A2984 RMK AO2  
CIG 014 RWY04R P0008 T02000194=

IFR SPECI PHNL 181820Z 07004KT 2SM +RA BR FEW016 BKN033 OVC045 20/20 A2985 RMK AO2  
P0013 T02000200=

IFR SPECI PHNL 181834Z 01004KT 2SM +RA BR FEW014 BKN023 OVC033 20/20 A2985 RMK AO2  
P0022 T02000200=

IFR SPECI PHNL 181838Z 36006KT 2SM +RA BR FEW009 OVC031 20/20 A2984 RMK AO2 P0025  
T02000200=

MVFR METAR PHNL 181853Z 09007KT 4SM -RA BR FEW012 BKN036 OVC060 20/20 A2984 RMK AO2  
SLP105 P0034 T02000200=

**VFR METAR PHNL 181953Z 12007KT 10SM -RA FEW015 BKN042 OVC100 20/20 A2984 RMK  
AO2 SLP106 P0004 T02000200=**

#### **Turbulence Encounter 2007Z**

MVFR SPECI PHNL 182046Z 12004KT 3SM +RA BR BKN021 BKN035 OVC065 21/21 A2984 RMK AO2  
P0003 T02060206=

MVFR METAR PHNL 182053Z 12004KT 3SM RA BR SCT021 BKN034 OVC085 21/21 A2984 RMK AO2  
SLP103 P0007 60045 T02060206 58000=

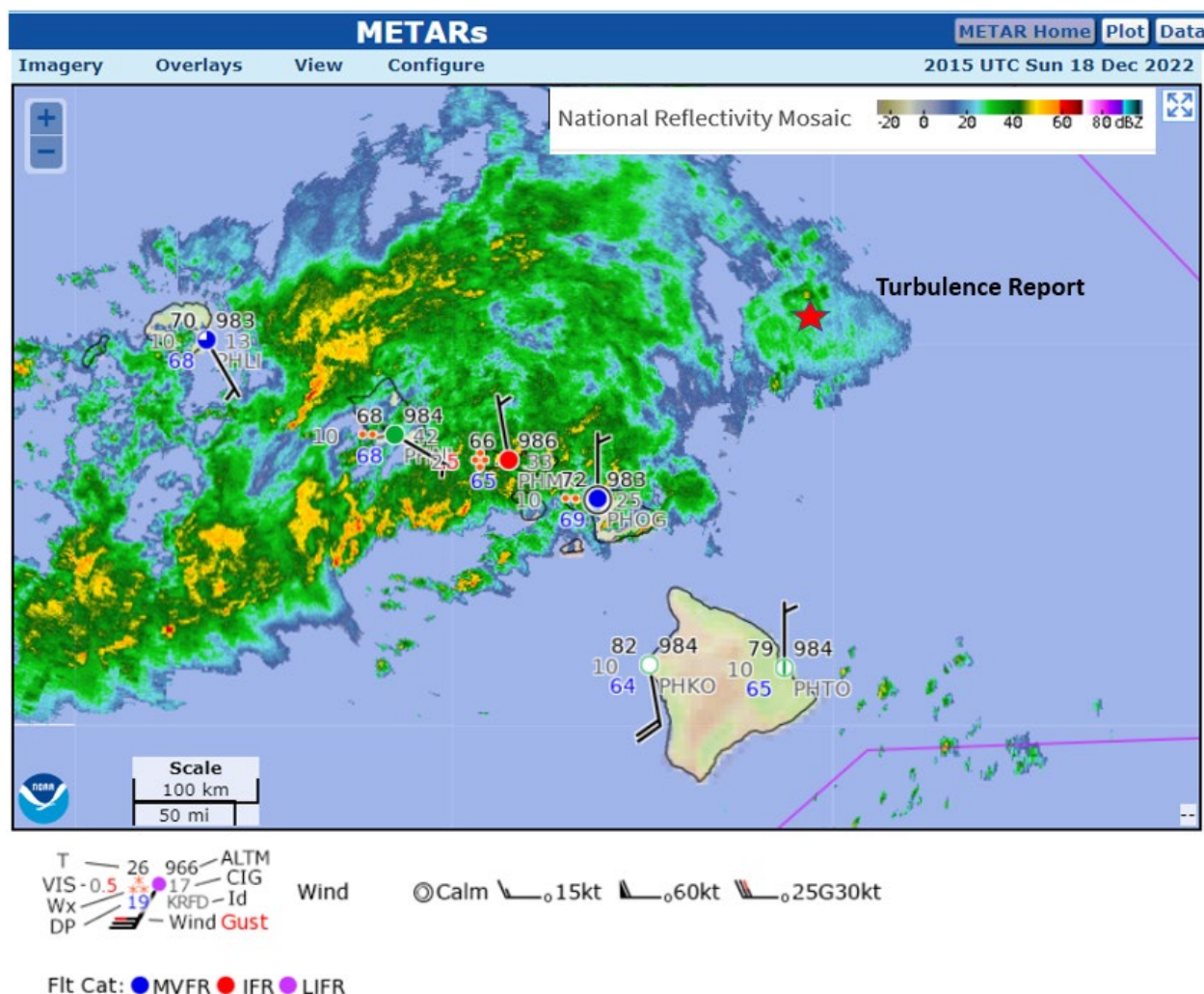
VFR METAR PHNL 182153Z 11003KT 10SM -RA SCT020 BKN070 OVC110 21/21 A2981 RMK AO2  
SLP093 P0007 T02110211=

### **2.1.3 METAR Display**

A depiction of the observations and the general flight conditions surrounding the approximate time of the accident from the NWS Aviation Weather Center's (AWC) METAR website<sup>16</sup> is included as figure 5 with the approximate turbulence location marked by a red star. The regional radar mosaic is also overlaid to provide an indication of precipitation over the area at the time of the event.

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<sup>16</sup> <https://www.aviationweather.gov/metar>



**Figure 5 - NWS Aviation Weather Center's METAR and radar display for 1015 HST with the approximate turbulence location marked by the red star.**

The accident site was located over a large area of echoes of reflectivity with a smaller embedded area of echoes with a maximum reflectivity near 50 dBZ or "heavy" intensity in the vicinity of the turbulence encounter. The observations for PHOG and PHNL indicated general MVFR to IFR conditions prevailing during the period with light to heavy rain, with broken to overcast cloud cover. While a review of the observations surrounding the period indicated that thunderstorms were reported at PHNL during the hour at approximately 0400 HST and at PHOG around 1200 HST.

## 2.2 Pilot Weather Reports

The following pilot weather reports (PIREPs) were reported<sup>17</sup> from 0800 through 1400 HST within 120 miles of the turbulence location. The reports are in standard code

<sup>17</sup> Includes PIREPs disseminated longline and may not include "ride reports" or other reports made on

and abbreviations as received. The PIREP thought to be associated with the Hawaiian Airlines flight 35 turbulence encounter entered by air traffic control is included in bold italic type.

*HNL UA /OV MKK/TM 1825/FL184/TP B712/TB SMOOTH*

*LNJ UA /OV LNJ/TM 1829/FL019/TP C208/SK OVC019/WX -RA/TB SMOOTH*

*UPP UA /OV UPP040030/TM 1841/FL250/TP B712/TB LGT CHOP*

*HNL UA /OV OGG350050/TM 1900/FL290/TP B737/TB LGT CHOP*

*OGG UA /OV OGG024007/TM 1936/FL022/TP B717/SK SCT020*

*OGG UA /OV OGG020005/TM 1945/FL015/TP B717/SK BKN015*

*OGG UA /OV OGG024004/TM 1946/FL015/TP B712/RM B712 BROKE OUT 1 500FT 4NM FINAL  
RWY20*

*HNL UA /OV OGG048107/TM 2001/FL300/TP A21N/TB MOD TURB*

***Turbulence encounter 2007Z***

***HNL UUA /OV OGG020065/TM 2016/FL360/TP A332/TB SEV***

*HNL UA /OV HNL060027/TM 2056/FL110/TP A21N/TB LGT DURD*

*OGG UA /OV OGG204001/TM 2114/FL003/TP B738/RM 20KT TAILWIND ON FINAL RWY2 UNTIL  
300FT THEN 330/07*

*OGG UA /OV OGG205008/TM 2126/FL025/TP C208/SK BASES 012/WX +RA/TB LGT*

*OGG UA /OV OGG204001/TM 2129/FL006/TP C208/RM 20KT TAILWIND 600FT FINAL RWY2  
CHANGES TO QUARTERING HEADWIND BY 300FT*

*LNJ UA /OV OJOVU/TM 2130/FL030/TP PC12/SK OVC028 BASES*

*OGG UA /OV OGG024001/TM 2206/FL005/TP B712/SK OVC005/WX 1SM +RA/RM BROKE OUT  
500FT FINAL RWY20*

*OGG UA /OV OGG024001/TM 2213/FL006/TP C208/RM BROKE OUT 650FT ON 1NM FINAL RWY20*

*OGG UUA /OV OGG024002/TM 2220/FL008/TP B38M/RM LLWS- DID NOT QUANTIFY GAINS OR  
LOSSES*

*OGG UUA /OV OGG204002/TM 2239/FL004/TP A21N/RM LLWS +15KTS 400'*

*OGG UA /OV PHOG /TM 2314 /FLUNKN /TP C208 /WX +RA*

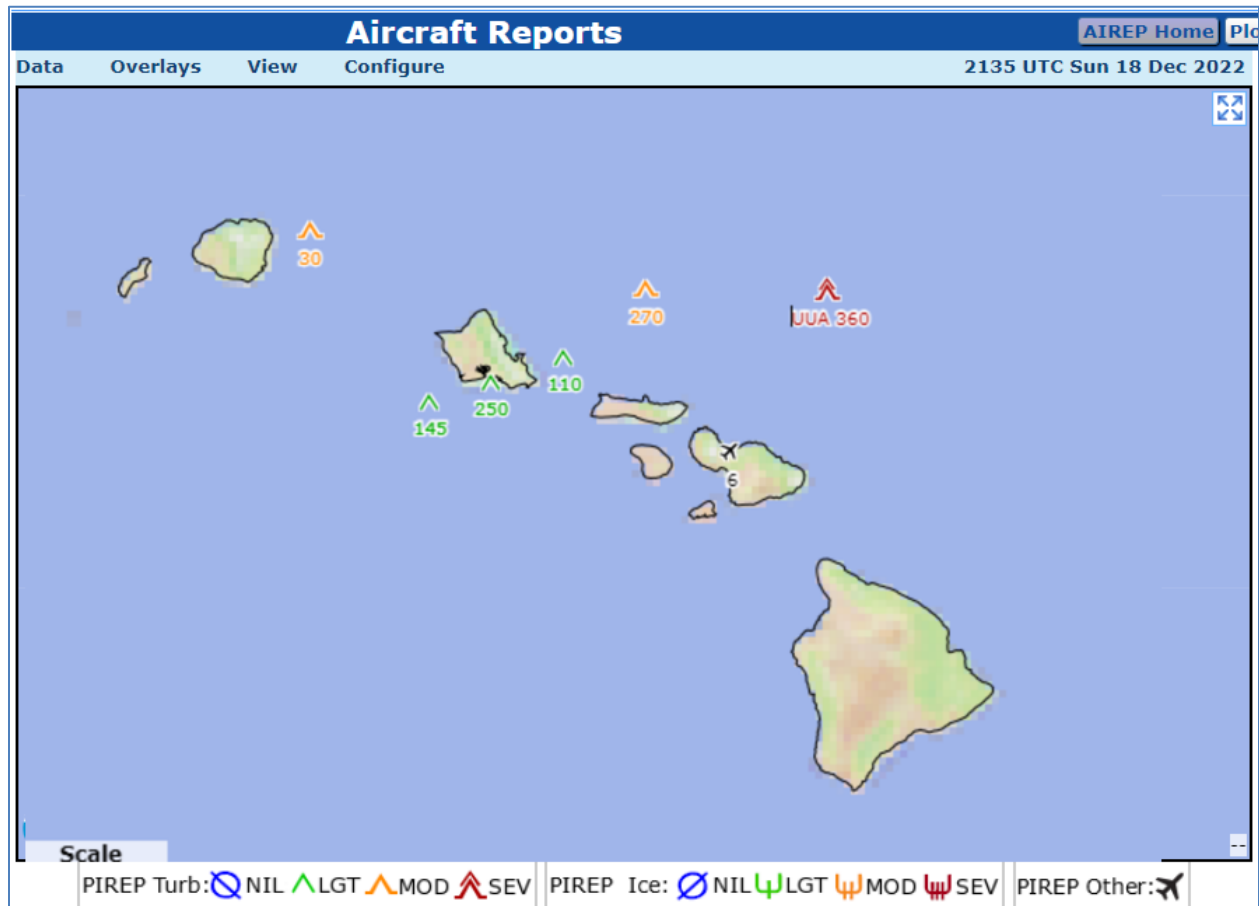
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radio frequency to air traffic control.

OGG UA /OV PHOG/TM 2328/FL000/TP B38M/RM LLWS GAINS AND LOSSES 20 KTS TIL SHORT FINAL

OGG UA /OV OGG204002/TM 2358/FL008/TP B772/SK BKN008/RM AP IN SIGHT 800' TAILWIND TIL 1800' THEN TURNS TO A CROSSWIND AT 1800'

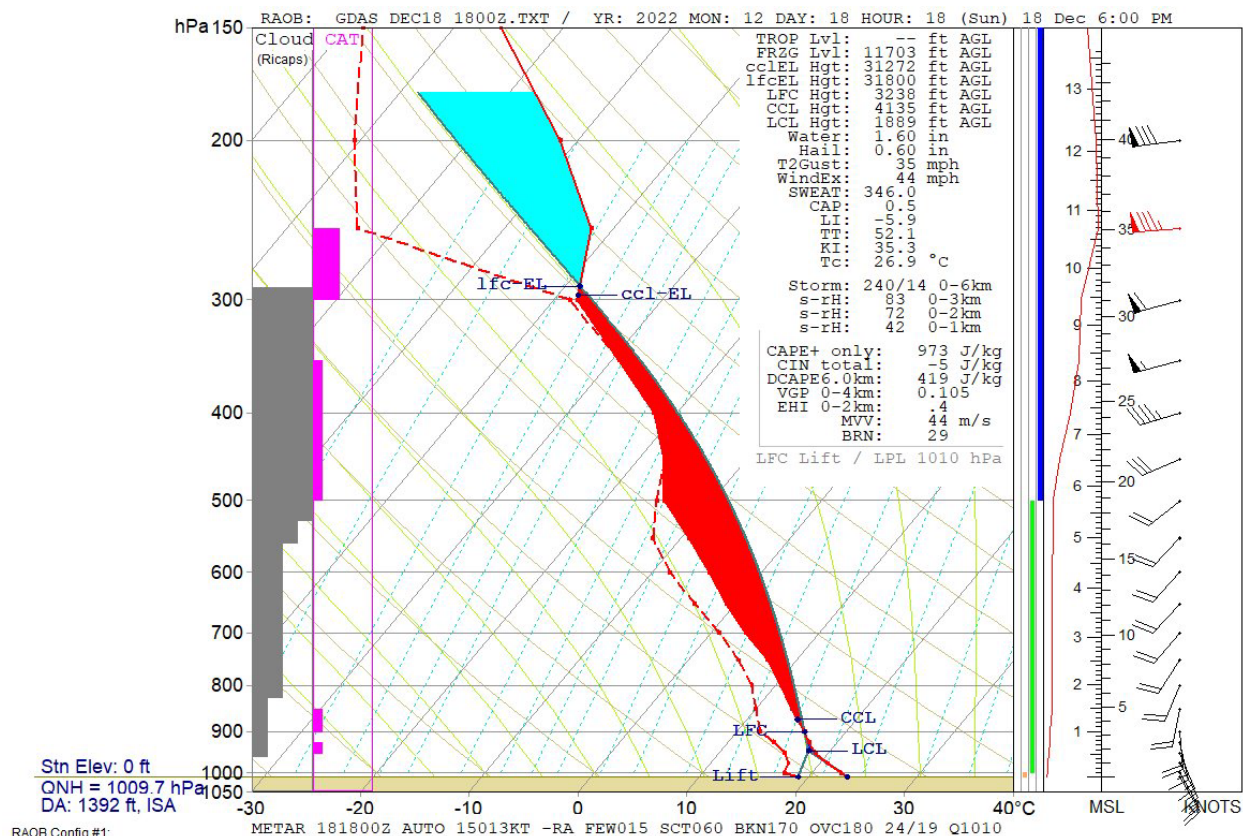
Of the 21 reports during the period, there were 7 reports of turbulence that ranged from light chop to moderate, with only the accident flight reporting severe turbulence over the region. There were also 3 reports of flights encountering heavy rain during this period. Figure 6 is a depiction of the NWS AWC website display of Aircraft Reports at 1135 HST over the Hawaiian Islands.



**Figure 6 - Depiction of the NWS AWC Aircraft Reports or PIREPs over the area at 1135 HST.**

## 2.3 Atmosphere Sounding

To help determine the conditions over the accident site a Global Data Assimilation System (GDAS) numerical model<sup>18</sup> data was obtained from the NOAA Air Resource Laboratory archive using the closest grid point to the accident site coordinates. The GDAS sounding was then plotted on a standard skew-T log P diagram<sup>19</sup> utilizing the RAOB Analysis software<sup>20</sup> from the surface to 150-hPa or approximately 45,000 ft and is included as figure 7.



**Figure 7 - NWS PHTO sounding for 1400 HST depicting the vertical structure of the atmosphere.**

The GDAS sounding for 0800 HST depicted a near-surface temperature of 23.6° C (75° F), a dew point temperature of 19.1° C (66° F), with a relative humidity of 76%. The sounding indicated a lifted condensation level (LCL)<sup>21</sup> at 1,889 ft agl, the level of

<sup>18</sup> GDAS model is a 1°, 3-hour, Global model run by the NCEP.

<sup>19</sup> 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.

<sup>20</sup> RAOB -The Universal RAOBsonde OBservation program is an interactive sounding analysis program developed by Eosonde Research Services (ERS) previously known as Environmental Research Services, The Villages, Florida.

<sup>21</sup> Lifted Condensation Level (LCL) - the level at which a lifted parcel becomes saturated. The LCL height corresponds to cloud base height for forced ascent.

free convection (LFC)<sup>22</sup> at 3,238 ft agl, and the convective condensation level (CCL)<sup>23</sup> at 4,135 ft agl. The sounding was characterized as unstable with a Lifted Index (LI)<sup>24</sup> of -5.9 and a Convective Available Potential Energy (CAPE)<sup>25</sup> of 973 Joules per kilogram (J/kg), with the downdraft CAPE of 419 J/kg. The sounding supported multiple layers of clouds with the expected cumulonimbus cloud tops (LFC-EL) to 31,800 ft. The precipitable water content was 1.60 inches. The RAOB Analysis program supported moderate to strong thunderstorms with potential wind gusts to 38 knots, and hail to 0.6 inches. The maximum vertical velocity (MVV) of the potential convective updrafts was indicated as 44 meters/second (m/s), or 8,661 ft/min.

The GDAS sounding wind profile indicated southerly surface winds at about 12 knots, that veered<sup>26</sup> to the southwest at low-levels and to the west above 15,000 ft with increasing wind speeds with height. The mean 0 to 6 kilometer (km) steering wind was from 210° at 20 knots, and the level of maximum wind was identified at about 35,100 ft from winds from 260° at 95 knots and was located below the accident aircraft's altitude and below the tropopause<sup>27</sup>, which was identified near 46,000 ft. At 40,000 ft or the altitude of the turbulence encounter, the sounding depicted a wind from 260° at 81 knots with a temperature of -52° C.

## 2.4 Satellite Imagery

NOAA Geostationary Operational Environmental Satellite number 17 (GOES-17) infrared and visible imagery were obtained from an archive at the Space Science Engineering Center (SSEC) at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System (McIDAS) software. The infrared band 13 at a wavelength of 10.3 microns (μm)

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<sup>22</sup> Level of Free Convection (LFC) - the level where a parcel becomes buoyant, or "warmer" than the environmental temperature at the same level. The LFC represents the bottom of the layer containing CAPE.

<sup>23</sup> 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.

<sup>24</sup> Lifted Index (LI) - A common measure of atmospheric instability. Its value is obtained by computing the temperature that air near the ground would have if it were lifted to 500-hPa or approximately 18,000 feet and comparing that temperature to the actual temperature at that level. Negative values indicate instability - the more negative, the more unstable the air is, and the stronger the updrafts are likely to be with any developing thunderstorms.

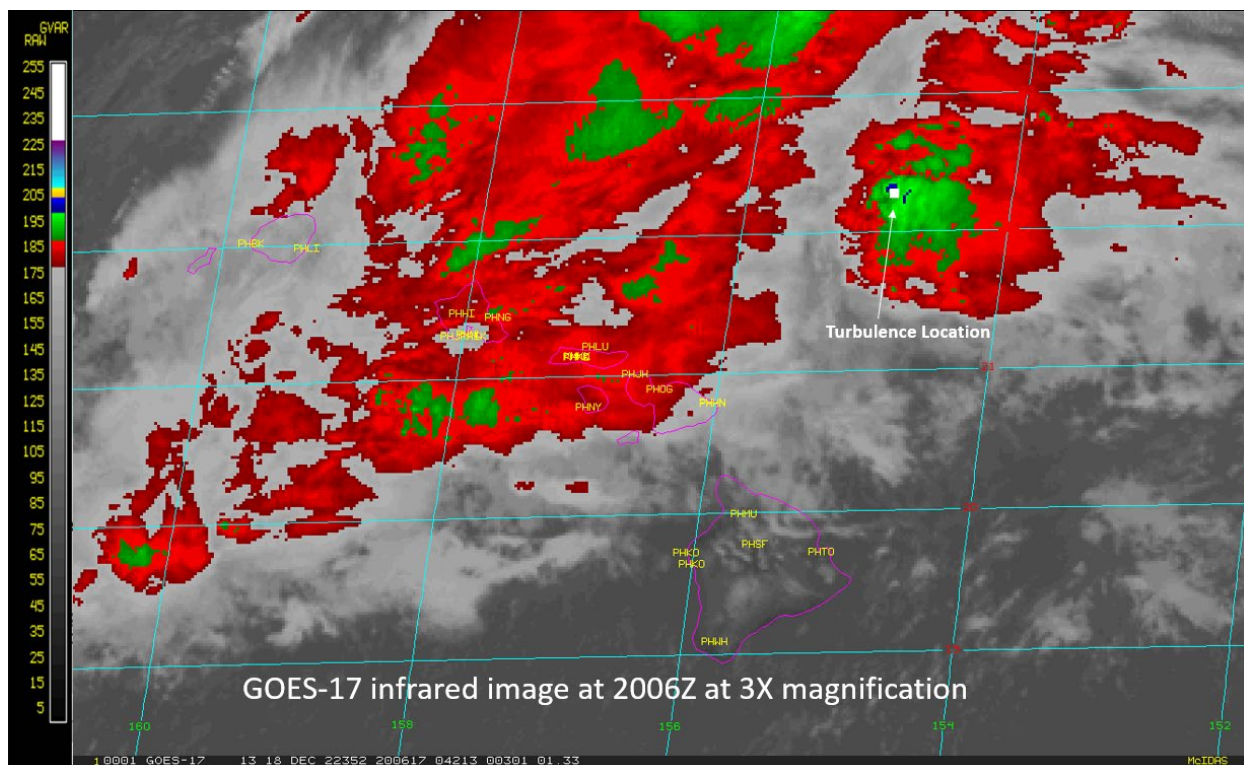
<sup>25</sup> Convective Available Potential Energy (CAPE) - is a measure of the amount of energy available for convection. CAPE is directly related to the maximum potential vertical speed within an updraft; thus, higher values indicate greater potential for severe weather.

<sup>26</sup> Veering - is a clockwise shift in wind direction.

<sup>27</sup> Tropopause - is the upper boundary of the troposphere, usually characterized by an abrupt change in lapse rate from positive (decreasing temperature with height) to neutral or negative (temperature constant or increasing with height). The tropopause separates the troposphere and the stratosphere.

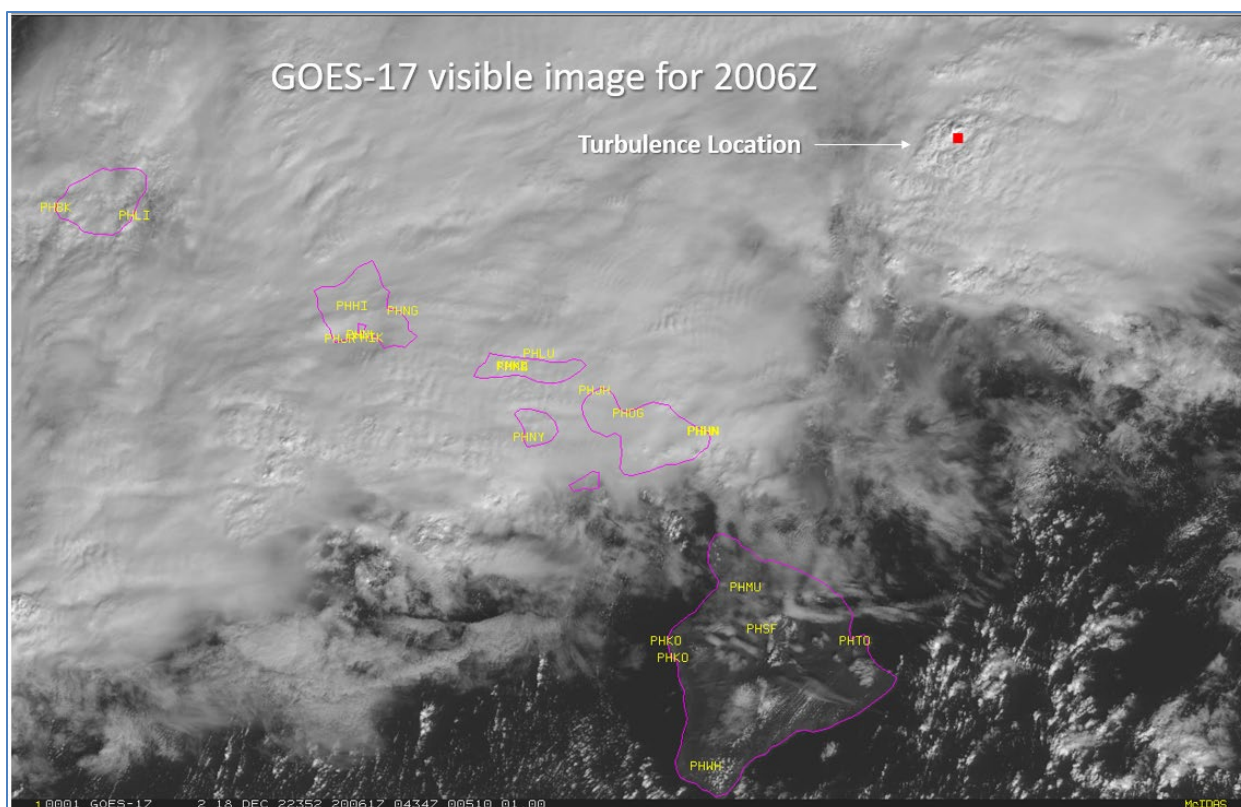
provided a resolution of 2 kilometers (km) with radiative cloud top temperatures, and the visible band 2 imagery at a wavelength of 0.64  $\mu\text{m}$  provided a resolution of 0.5 km.

Figure 8 is the GOES-17 infrared image for 1006 HST at 3X magnification with a standard MB temperature enhancement curve applied to highlight the higher and colder cloud tops associated with deep convection and with the accident site marked by the white square. A large area of enhanced clouds (green areas) was noted over the general route of flight with a radiative cloud top temperature of 229 Kelvin (K) or about  $-44^{\circ}\text{C}$ , which corresponded to cloud tops near 36,000 ft. While a small area of colder cloud tops (depicted in dark blue) was observed in the immediately vicinity of the aircraft's position with a radiative cloud temperature of 218 K or  $-55^{\circ}\text{C}$ , which corresponded to tops near 45,000 ft. Figure 9 is the GOES-17 visible image for 1006 HST with the turbulence location marked by the red square. The location was in the vicinity of overshooting tops<sup>28</sup> of embedded cumulonimbus clouds below.



**Figure 8 - GOES-17 infrared image for 1006 HST at 3X magnification with a standard MB temperature enhancement curve applied. The turbulence location noted by the white square.**

<sup>28</sup> Overshooting cloud tops is a dome-like protrusion shooting out of the tops of the anvil of a thunderstorm and into the lower stratosphere. When overshooting tops are present for 10 minutes or longer, it is often an indication that the storm is severe. It forms when a thunderstorm's updraft, due to momentum from rapid ascent and strength of lifting through the storm's equilibrium level. Thunderstorms with overshooting tops are often associated with strong horizontal and vertical wind shear and lightning in the strong updraft region, both of which represent potential significant turbulence.



**Figure 9 - GOES-17 visible image at 1006 HST at normal magnification, with the turbulence located noted by the red square.**

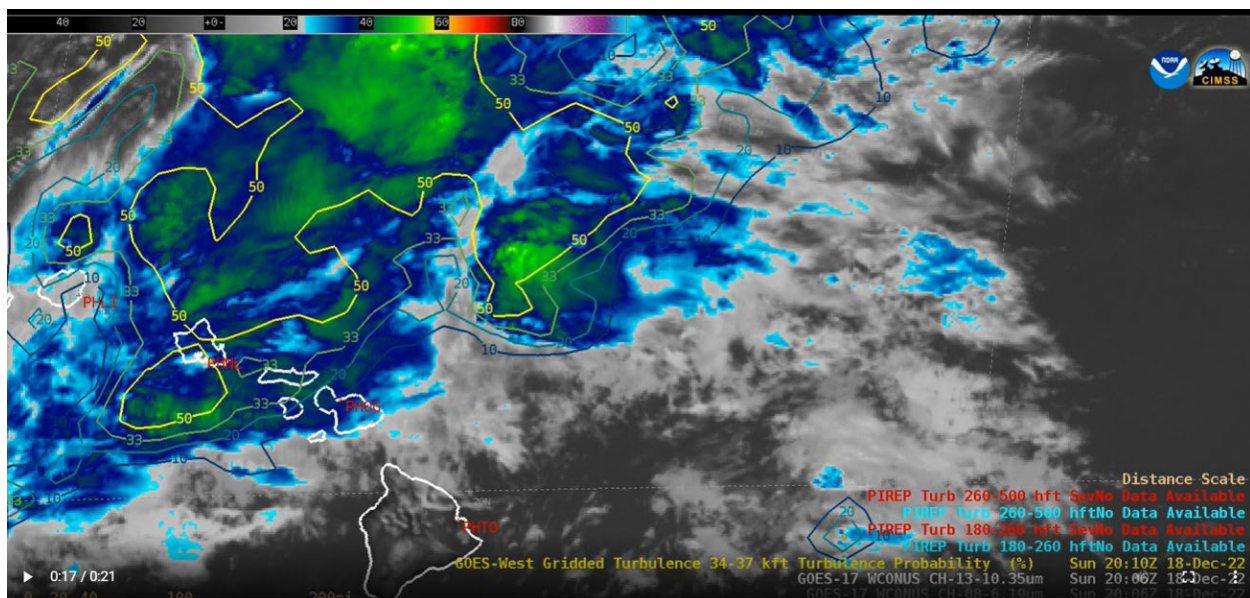
### 2.4.1 Satellite Turbulence Probability

Figures 10-12 are the GOES-17 infrared, mid-level water vapor images at 1010 HST, and the visible image for 1006 HST with the experimental Probability of Moderate or Greater (MOG) Turbulence algorithm<sup>29</sup> from the NOAA Cooperative Institute for Meteorological Satellite Studies (CIMSS)<sup>30</sup> at the University of Wisconsin-Madison SSEC. An animation of the GOES-17 infrared, water vapor and visible imagery and moderate or greater turbulence potential is included as Attachment 1.

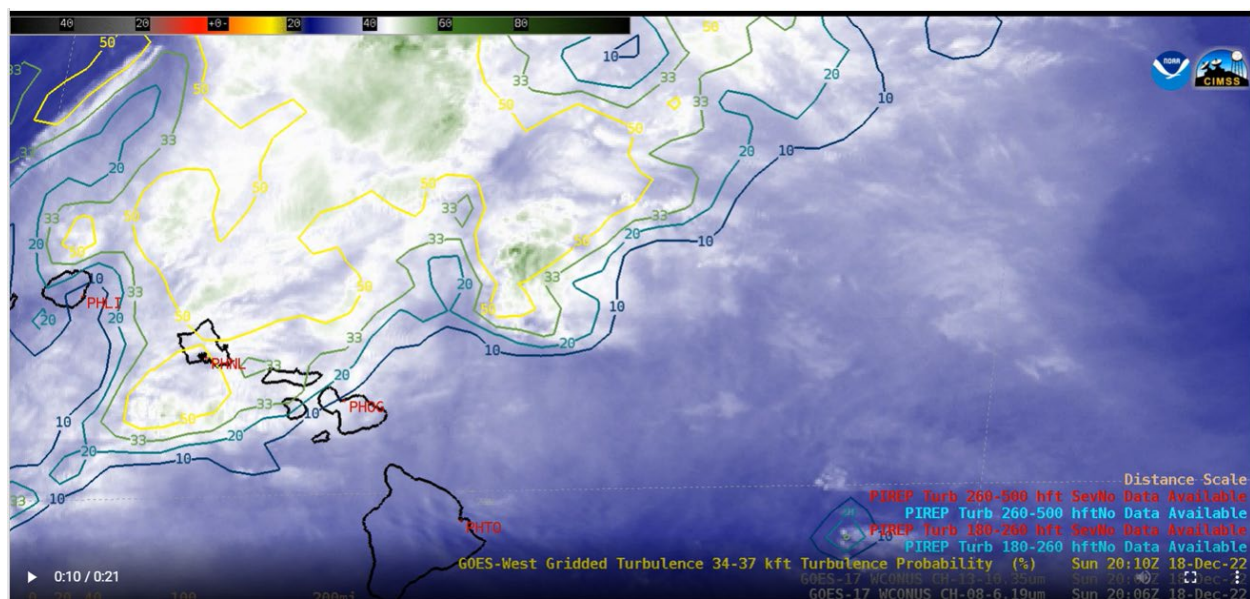
<sup>29</sup> The CIMSS Turbulence Product was developed by Dr. Tony Wimmers and uses deep machine learning to build a strong inference-based relationship between the GOES imagery, the Global Forecast System (GFS) model and an archive of automated Eddy Dissipation Rate (EDR) reports of turbulence. Based on over 4 years of EDR observations the system creates a probabilistic estimate of MOG turbulence based on the real-time satellite imagery and the GFS forecast fields to the nearest hour. When applying a threshold of 50% probability of MOG detection, the false alarm rate is 10%. All statistics are based around the likelihood of MOG over a 10-minute segment.

<sup>30</sup> <http://cimss.ssec.wisc.edu/turbulence/>

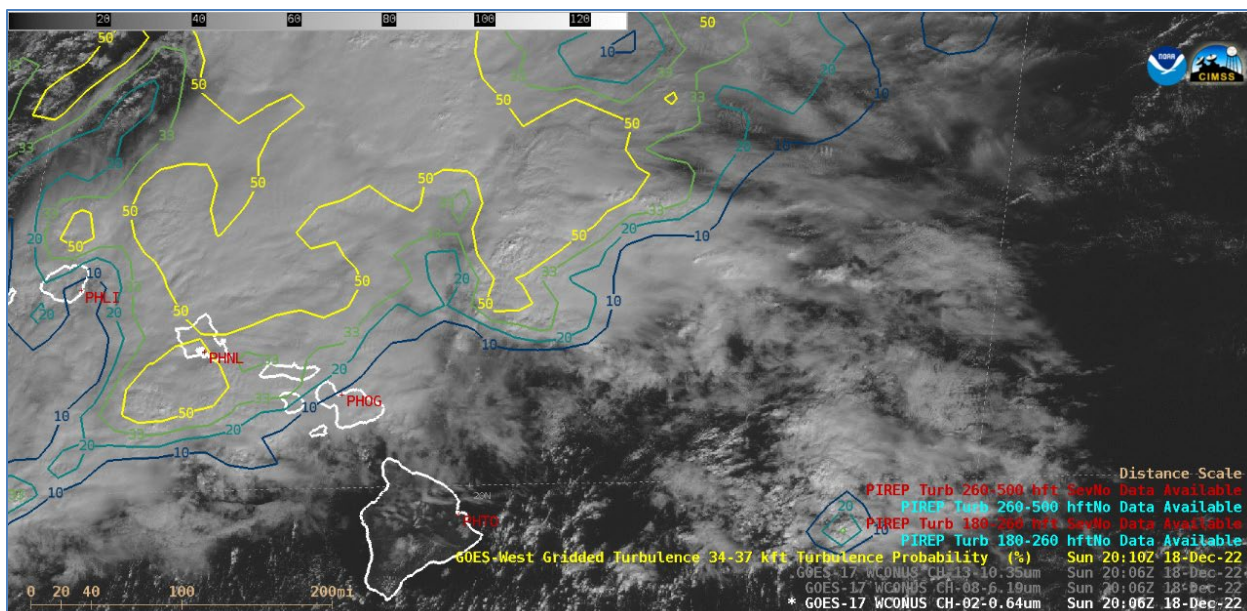
The case review and images surrounding the time of the turbulence encounter was produced by Scott Bachmeier and can be seen at the following satellite site <https://cimss.ssec.wisc.edu/satellite-blog/archives/49370>.



**Figure 10 - GOES-17 infrared image for 1010 HST with gridded turbulence probability for the period. The image depicted a greater than 50% probability of turbulence over the site.**



**Figure 11 - GOES-17 mid-level water vapor image for 1010 HST with gridded turbulence probability over the area.**

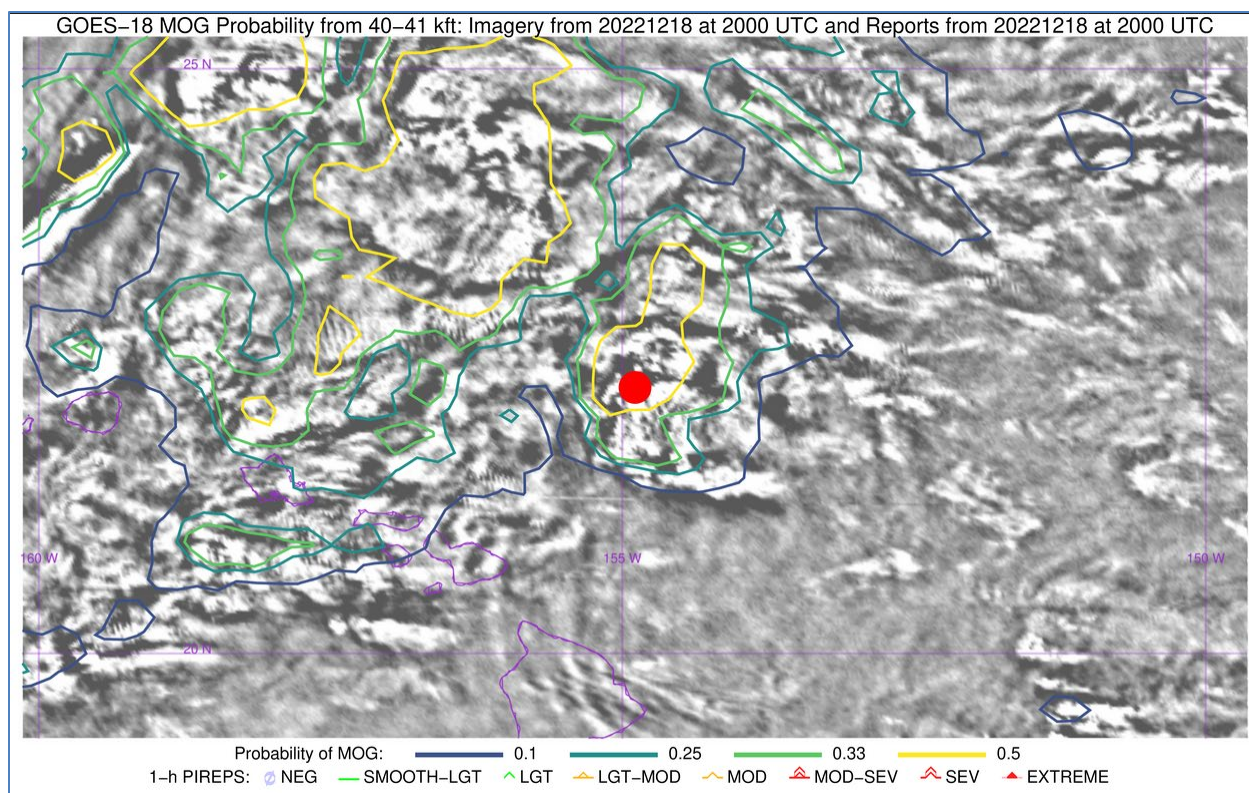


**Figure 12 - GOES-17 visible image for 1006 HST with gridded turbulence probability for the period. The image depicted a greater than 50% probability of turbulence over the site.**

Figure 13 is the GOES-18 visible image for 1000 HST at magnification between FL400-FL410 with the accident site marked by the red circle provided by CIMSS<sup>31</sup> for the higher altitude. The image depicted a greater than 50% probability of moderate or greater turbulence over the area. Dr. Wimmers, from CIMSS, indicated that in this particular event, the high MOG probabilities were likely triggered by both the cloud top textures that indicates thermal instability as well as the conditions within the Global Forecast System (GFS) model field, particularly the windspeed and vertical shear. Other features that contribute from the GFS model were the vertical temperature gradients and divergence<sup>32</sup> in the upper-level wind.

<sup>31</sup> Imagery provided by Sarah Griffin and Dr. Tony Wimmers at UW-CIMSS,

<sup>32</sup> Divergence - is the expansion or spreading out of a vector field; usually said of horizontal winds. It is the opposite of convergence. Divergence at upper levels of the atmosphere enhances upward motion, and hence the potential for thunderstorm development (if other factors also are favorable).

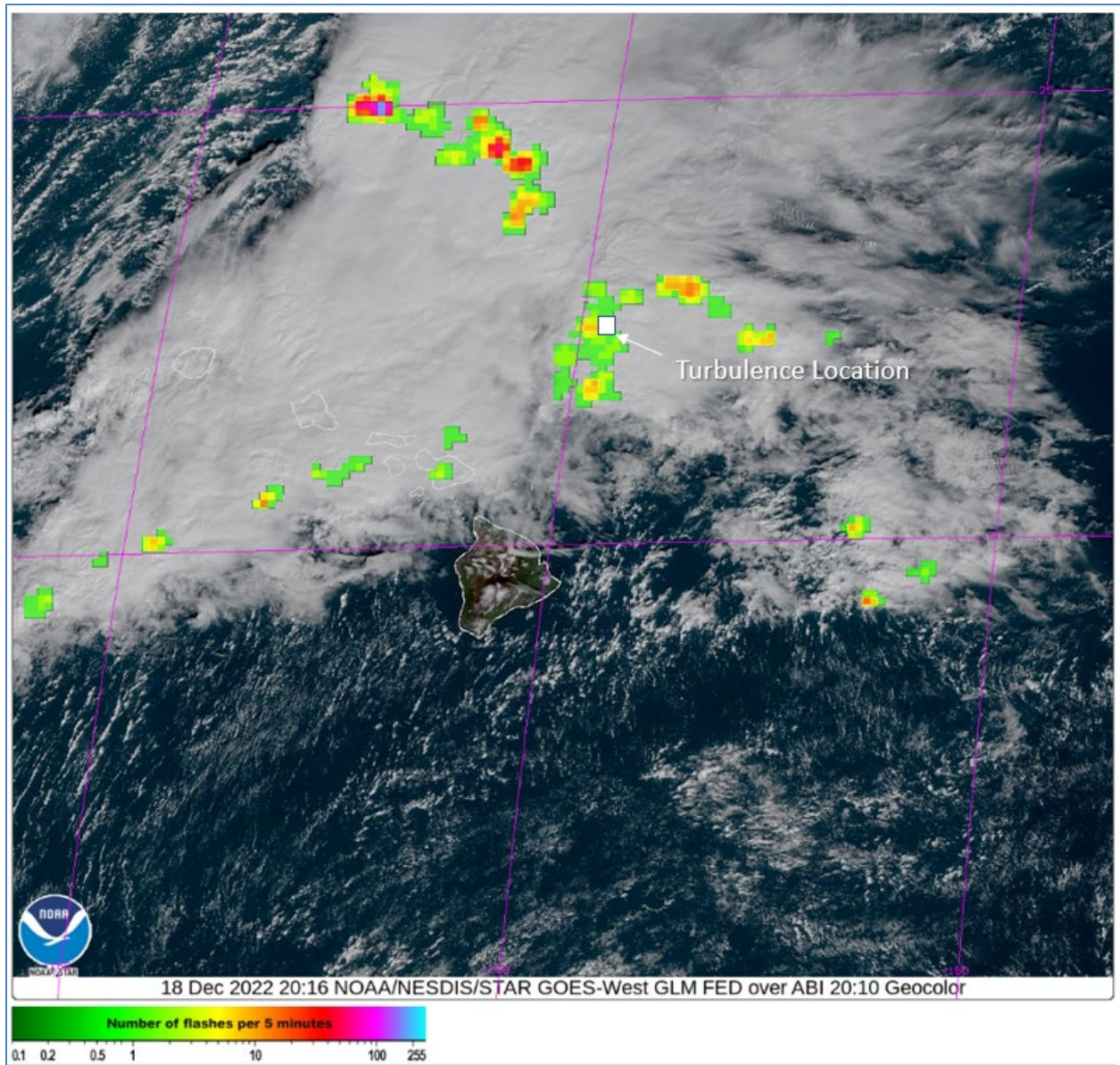


**Figure 13 - Experimental GOES-18 MOG Probability of Turbulence from FL400-FL410 and available pilot reports at 1000 HST, depicting a greater than 50% probability of turbulence over the accident site.**

## 2.4.2 Geostationary Lightning Mapper

Figure 14 is the GOES-17 GeoColor and Geostationary Lightning Mapper (GLM) image at 1016 HST with the approximate turbulence location noted. The GeoColor and GLM image provides as close as possible daylight true color image of the clouds and surface features with locations of lightning activity indicated. The clusters of lightning<sup>33</sup> detected are colored by the frequency of lightning flashes detected. The image detected a cluster of lightning in the vicinity of the turbulence with about 10 flashes per 5-minutes and cumulonimbus clouds under the flight.

<sup>33</sup> Lightning - is a visible electrical discharge produced by a thunderstorm or more specifically a cumulonimbus type cloud. The discharge may occur within or between clouds, between the cloud and air, between a cloud and the ground or between the ground and a cloud.



**Figure 14 - GOES-17 Geostationary Lightning Mapper (GLM) image for 1010 HST with the approximate turbulence location indicated with cluster of lightning.**

## 2.5 Weather Radar Imagery

The closest NWS Weather Surveillance Radar 1988 Doppler (WSR-88D)<sup>34</sup> was located at Kamuela/Kohala (PHKM) about 138 miles south-southwest of the turbulence location. The level II and III archive radar data were obtained from the NCEI using the Hierarchical Data Storage System and displayed using the NWS NEXRAD Interactive

<sup>34</sup> 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.

Viewer and Data Exporter software. During the period, the PHMO WSR-88D was operating in the precipitation mode identified as volume scanning pattern 215 (VCP-215), where the radar makes 15 different elevation scans during the 6 minute scan. This scan is typically used in general precipitation situations and provides the most vertical resolution of any other scanning strategies.

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors<sup>35</sup>, it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in decibels (dBZ) and is a general measure of echo intensity. The FAA Aviation Weather Handbook<sup>36</sup> 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 new standard radio phraseology terms used by air traffic controllers to describe weather conditions to pilots as shown in the following table. Light rain is typically reported at the surface when reflectivities reach 20 dBZ, while air traffic control will not display information of echoes less than 26 dBZ or light intensity echoes on their weather displays or disseminate alerts of any such echoes.

| Reflectivity<br>(dBZ) Ranges | Weather Radar Echo<br>Intensity Terminology |
|------------------------------|---------------------------------------------|
| < 30 dBZ                     | Light                                       |
| 30-40 dBZ                    | Moderate                                    |
| >40-50 dBZ                   | Heavy                                       |
| >50 dBZ                      | Extreme                                     |

The PHKM WSR-88D long range composite reflectivity image is included as figure 15 with the flight track of Hawaiian Airlines flight 35 overlaid. The image depicted several embedded convective echoes of greater than 50 dBZ<sup>37</sup> or extreme intensity echoes scattered over the region with one area under the flight track<sup>38</sup> and predominantly south of the flight track and south of PHNL. Figures 16-17 are closeups of the PHKM WSR-88D composite reflectivity images at 1005 and 1010 HST and depicted echoes of 40 to 45 dBZ under the flight track surrounding the period of the turbulence encounter.

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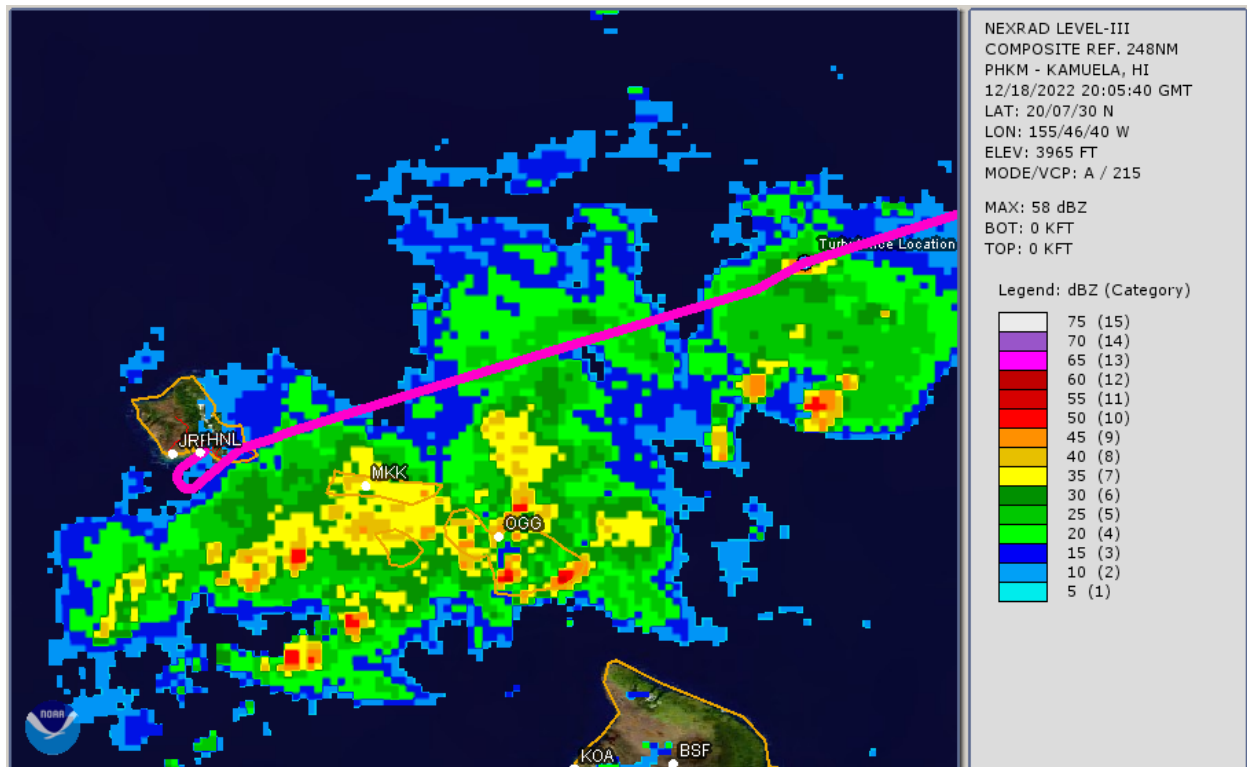
<sup>35</sup> Hydrometeors are any product of condensation or sublimation of atmospheric water vapor, whether formed in the free atmosphere or at the earth's surface. Hydrometeors are classified as; (a) Liquid or solid water particles suspended in the air: cloud, water droplets, mist or fog. (b) Liquid 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.

<sup>36</sup> FAA Aviation Weather Handbook - WSR-88D Radar Precipitation Intensity Terminology (Table 24-8).

<sup>37</sup> dBZ - Nondimensional "unit" of radar reflectivity which represents a logarithmic power ratio (in decibels, or dB) with respect to radar reflectivity factor, Z.

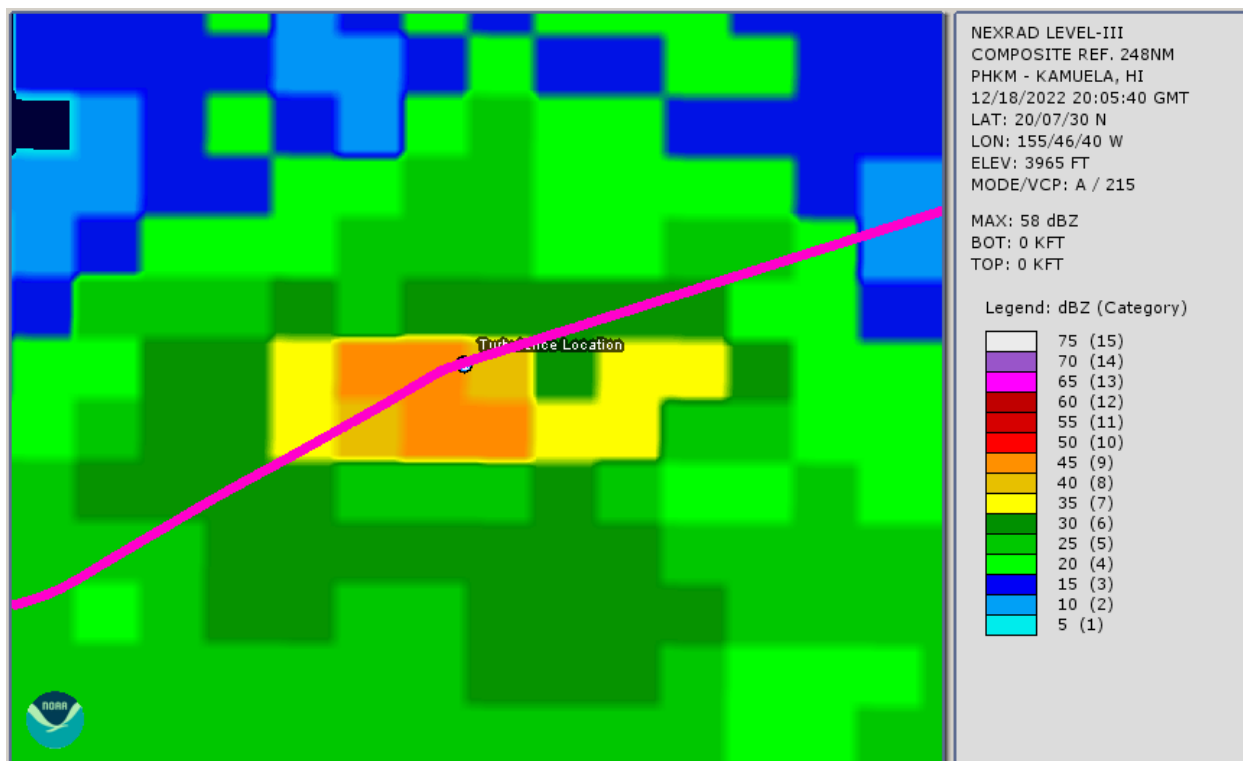
<sup>38</sup> Flight Track data obtained from Air Traffic Control specialist from ADS-B data from the FAA.

A closer review of the PHKM WSR-88 0.5° base reflectivity image<sup>39</sup> (not shown) also confirmed an area of echoes of 50.5 dBZ in the vicinity of the turbulence encounter at low-levels. The higher PHKM WSR-88D 1.76° elevation scan for 1005 HST depicted echoes of 27.5 dBZ to 38,500 ft, with echoes near 18.5 dBZ to 40,800 ft. By 1010 HST the PHKM WSR-88D 1.76° base reflectivity image showed the area decreasing in size and intensity and having moved eastward with echo intensity decreasing to 17.0 dBZ at 39,385 ft consistent with the composite reflectivity imagery (figure 17). See Attachment 2 for an animation of the radar imagery during the period.

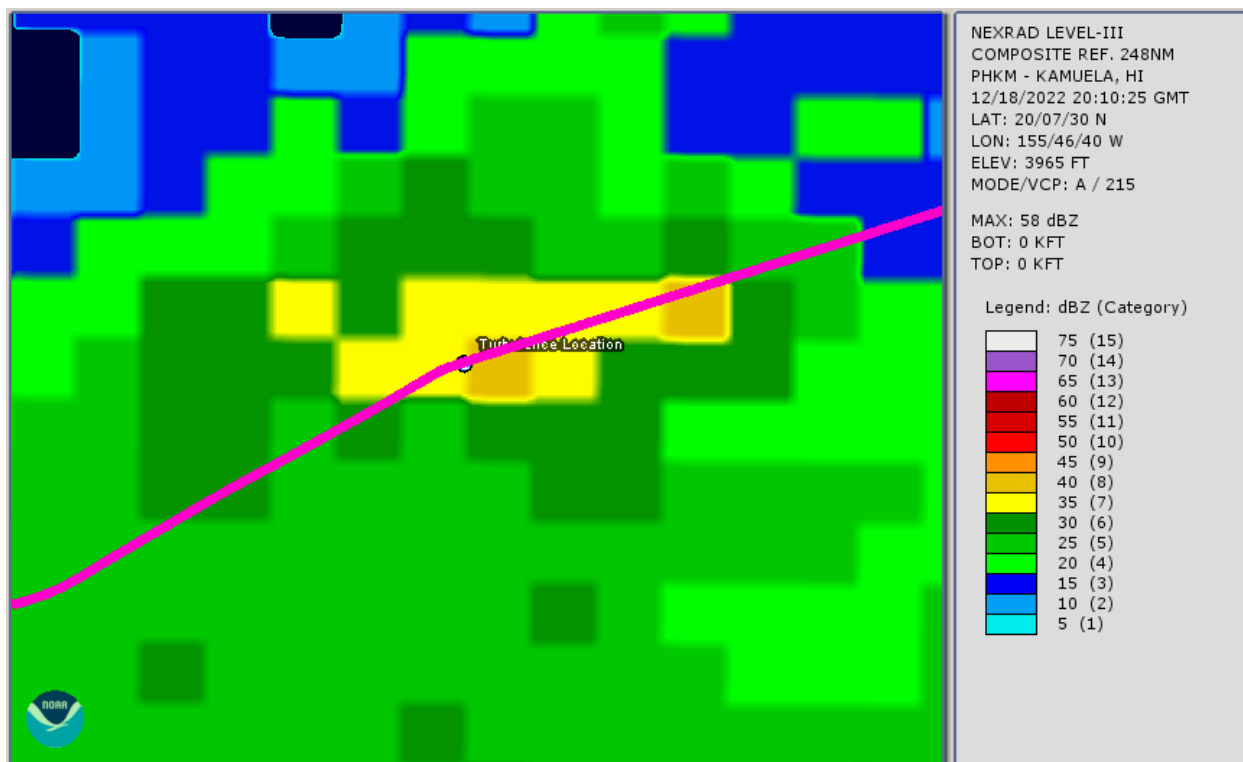


**Figure 15 - PHKM WSR-88D composite reflectivity image for 1005 HST with the flight track.**

<sup>39</sup> The PHKM WSR-88D 0.5° base reflectivity image at 137 miles the center of the beam was near 23,900 ft, and scanning the altitudes between 16,950 through 30,860 ft. While the 1.7° base reflectivity scan was centered near 42,620 ft and scanning the altitudes between 35,670 through 49,570 ft.



**Figure 16 - PHKM WSR-88D composite reflectivity image for 1005 HST with flight track overlaid.**



**Figure 17 - PHKM WSR-88D composite reflectivity image for 1010 HST with flight track overlaid.**

### 3.0 NWS Forecasts

The NWS Honolulu (PHFO) Weather Forecast Office (WFO) was responsible for the general weather forecast products over the Hawaiian Islands.

#### 3.1 Terminal Aerodrome Forecast

The Terminal Aerodrome Forecast (TAF) is a concise statement of the expected meteorological conditions significant to aviation for a specified time period and within 5 statute miles of the center of the airport's runway complex (terminal). The TAFs for Honolulu International Airport (PHNL) current at the time of the accident was as follows.

**AMD TAF PHNL 182005Z 1820/1924 12010KT 6SM SHRA SCT020 BKN035 OVC100**

*FM190000 23013G21KT 5SM -SHRA SCT020 BKN035*

*FM190800 23018G28KT P6SM VCSH SCT020 BKN035*

*FM191500 23018G28KT 3SM +SHRA BR BKN020 BKN035=*

The amended TAF for PHNL issued at 1005 HST (2005Z) and valid for the time of arrival expected VFR conditions to prevail with winds from 120° at 10 knots, visibility 6 miles in moderate rain showers, with scattered clouds at 2,000 ft agl, ceiling broken at 3,500 ft, and overcast at 10,000 ft.

#### 3.2 Area Forecast

The Area Forecast (FA) is an abbreviated plain language forecast concerning the occurrence or expected occurrence of specified en route weather phenomena. FAs cover an 18 to 24-hour period, and are issued four times daily for Hawaii, and are updated as needed. The FA current for the region was issued by the NWS PHFO WFO at 0644 HST and was as follows.

*FAHW31 PHFO 181644 AAA*

*FA0HI*

*HNLC FA 181642 AMD*

*SYNOPSIS AND VFR CLD/WX*

*SYNOPSIS VALID UNTIL 191000*

*CLD/WX VALID UNTIL 190400...OUTLOOK VALID 190400-191000*

**SEE AIRMET SIERRA FOR IFR CLD AND MTN OBSC.**

**TS IMPLY SEV OR GREATER TURB SEV ICE LOW LEVEL WS AND IFR COND.**

**NON MSL HGT INDICATED BY AGL OR CEILING.**

**SYNOPSIS...A STRONG COLD FRONT WILL MOVE RAPIDLY TOWARD THE REGION THROUGH THIS EVENING. A COMBINATION OF UNSTABLE ATMOSPHERIC CONDITIONS AND ABUNDANT MOISTURE IN THE VICINITY OF THE ISLANDS WILL RESULT IN WIDESPREAD CLOUDINESS AND SHOWERS...WITH ISOLATED**

**THUNDERSTORMS.** IN ADDITION...THE SW WINDS WILL STRENGTHEN THROUGH THIS EVENING.

**ENTIRE AREA.**

**SCT-BKN FL200-350. LOWER CLDS AND WX FOLLOW.**

BIG ISLAND LOWER SLOPES...COAST...AND ADJ WATERS  
FROM UPOLU POINT TO CAPE KUMUKAHI TO APUA POINT.

FEW025 FEW-SCT050 ISOL BKN020 TOPS 110 VIS 3-5SM SHRA BR. 23Z FEW-SCT025  
SCT-BKN040 TOPS 150 TEMPO BKN025 VIS 5SM SHRA BR ISOL BKN020 CB TOPS FL350  
VIS 3-5SM +SHRA/TSRA BR. OUTLOOK...MVFR CIG SHRA.

BIG ISLAND LOWER SLOPES...COAST...AND ADJ WATERS  
FROM APUA POINT TO SOUTH CAPE TO PHKO TO UPOLU POINT.

FEW030 FEW-SCT050 ISOL SCT-BKN030 TOPS 100 -SHRA. 22Z FEW-SCT025 SCT-  
BKN040 TOPS 120 TEMPO BKN025 VIS 5SM SHRA BR ISOL BKN020 CB TOPS FL350 VIS  
3-5SM +SHRA/TSRA BR. OUTLOOK...VFR.

**KAUAI OAHU MOLOKAI MAUI LANAI AND ADJ WATERS.**

**FEW-SCT025 SCT-BKN040 TOPS 120 TEMPO BKN025 VIS 5SM SHRA BR ISOL  
BKN020 CB TOPS FL350 VIS 3-5SM +SHRA/TSRA BR. OUTLOOK...MVFR CIG SHRA.**

The Area Forecast synoptic section warned that a strong frontal system was moving into the region with unstable atmospheric conditions and expected clouds and precipitation to the islands, with isolated thunderstorms.

### 3.3 Area Forecast Discussion

The NWS Area Forecast Discussions (AFD) are issued by each WFO to describe the short-term weather conditions within their region with an aviation section that includes the general conditions as they relate to the creation of the TAF. These are useful for additional aviation-related issues that cannot be encoded into the TAF and provide some reasoning behind the forecast. These are generated roughly every 6 hours and correspond to the release of the latest TAFs for that office. The PHFO WFO issued the AFD at 1000 HST immediately prior to the turbulence encounter and was as follows.

*FXHW60 PHFO 182000  
AFDHFO*

*Area Forecast Discussion  
National Weather Service Honolulu HI  
1000 AM HST Sun Dec 18 2022*

**.SYNOPSIS...**

**Numerous showers and thunderstorms will continue through Monday. Some storms may be severe tonight and Monday. Any severe storms will be capable of producing strong winds and hail.** Strong and damaging southwest, or kona, winds will develop tonight and continue through Monday. Periods of heavy rain throughout this time may

result in areas of flash flooding. Weather will gradually improve Tuesday with fair weather and much lighter winds expected by Wednesday.

#### **.DISCUSSION...**

**Satellite imagery shows an impressive mid-latitude cyclone deepening over the Central Pacific Basin as it digs southeastward toward the islands. Ahead of this cyclone, we have increasing southerly winds this morning which is pulling moisture from the tropics and producing widespread moderate rainfall with brief periods of heavy rainfall across the smaller islands.** The moisture axis remains centered over the western half of the state this morning, but as I write this discussion we are already seeing the moisture axis shift eastward towards Maui County. With the moisture shifting east and instability increasing throughout the day, Oahu, Maui County and the Kona side of the Big Island should see increasing rainfall today with pockets of heavy rain. A Flood Watch is in effect for all Hawaiian Islands through Monday night. Winds will also be increasing from the southwest at the surface and aloft this afternoon which will increase the storm motion. This should help decrease the flooding threat slightly, but with the widespread rainfall from this morning saturating the soils already, it would only take one intense thunderstorm sitting over a particular area briefly to cause flooding concerns.

The main weather concern looks to start from this evening and continue through Monday. As the mid-latitude cyclone continues to move closer to the state, kona winds will increase with sustained southwest surface winds of 20 to 30 mph with stronger gusts expected. In areas of local accelerations, such as the Windward zones and areas downwind of terrain will be highly susceptible to downsloping which will force damaging winds to the surface. Wind gusts of over 60 mph will be possible especially over Windward Oahu and downwind of Mt. Kaala, north and east Maui, and north and east Big Island. Convective instability will also be maximized during this time as 0-1km MLCAPE increases to at least 1500 j/kg. Any particularly vigorous showers will therefore have the potential to mix down severe winds up to 60 mph. For this reason, the High Wind Warning includes the entire area - not only favored downsloping areas.

Finally, a severe thunderstorm threat will exist tonight through the time of frontal passage on Monday. Lapse rates aloft are modeled to remain fairly impressive, in the neighborhood of 7 to 7.5 km/C in the prefrontal environment. Strong, deep unidirectional wind profiles in the presence of moderate convective instability will contribute to an enhanced threat for thunderstorms to evolve into northeast-moving bowing segments capable of producing damaging straight line winds. 0-6km bulk shear in excess of 40 kts and cold temperatures aloft will also support a marginal risk for hail up to 1 inch in diameter. The potential for a Severe Thunderstorm Watch will be evaluated today and this evening.

#### **.AVIATION...**

**A strong cold front and upper level trough associated with an impressive low pressure system far north of the main Hawaiian Islands will advance towards Kauai through tonight. Ahead of this feature, enhanced moisture has overspread the smaller islands from Kauai to Maui this morning, producing widespread MVFR ceilings and visibilities and occasional IFR conditions within heavier downpours. With ample instability in the area, thunderstorms have also been observed, especially across adjacent waters. Lightning, heavy rain, and moderate to severe turbulence have all been reported via PIREPs at various locations. As a result, SIGMET Victor has been issued for embedded thunderstorms over a large portion of the state. This SIGMET will likely remain in effect at least through the rest of the**

**morning, though the bulk of lightning is now greater than 40nm NNE of the island chain.**

*Expect clouds and showers with scattered thunderstorms to continue as the enhanced moisture eventually makes its way further south to the Big Island later this afternoon. Widespread MVFR ceilings and visibilities with occasional IFR conditions will persist for much of the day and into tonight across a large portion of the state. Additionally, as the front gets closer to the state, southwest wind speeds are expected to increase today and become strong through tonight.*

*AIRMET Sierra for mountain obscuration above 2500 feet remains in effect for Kauai, Oahu, Molokai, and Maui. This AIRMET will likely remain in effect through the afternoon and may need to be expanded to also include the Big Island later today.*

*In addition, as the gusty southwest winds increase later today, AIRMET Tango will likely be needed for TEMPO moderate mechanical turbulence northwest through southeast of the higher terrain on most islands. Once it is issued, this AIRMET will likely remain in effect into Monday. There is also potential for sustained surface wind speeds to reach 30kts or greater overnight for portions of the state, which would warrant an AIRMET for strong winds as well.*

***Finally, model data suggests that moderate to severe clear-air turbulence will be possible behind the main area of showers this afternoon into early evening.*** Should this materialize, an AIRMET for moderate upper level turbulence or possibly a SIGMET for severe turbulence from roughly Kauai to Oahu would be needed.

#### **4.0 NWS Inflight Weather Advisories**

The NWS PHFO issued the following advisories surrounding the period, Significant Meteorological Advisory (SIGMET) Victor series at 0356 HST, which was valid through 0745 HST, and updated by SIGMET Victor 2 which was current for the Hawaiian Airlines flight into PHNL and over the turbulence location. In addition, AIRMET Sierra 3 which was also current for temporary mountain obscuration conditions over the Hawaiian Islands. The advisories are included below. The AIRMET Tango indicated that no significant clear air turbulence outside of convective activity was expected through 1200 HST.

##### SIGMETs

WSPA09 PHFO 181744

SIGPAV

KZAK SIGMET VICTOR 2 VALID 181745/182145 PHFO-

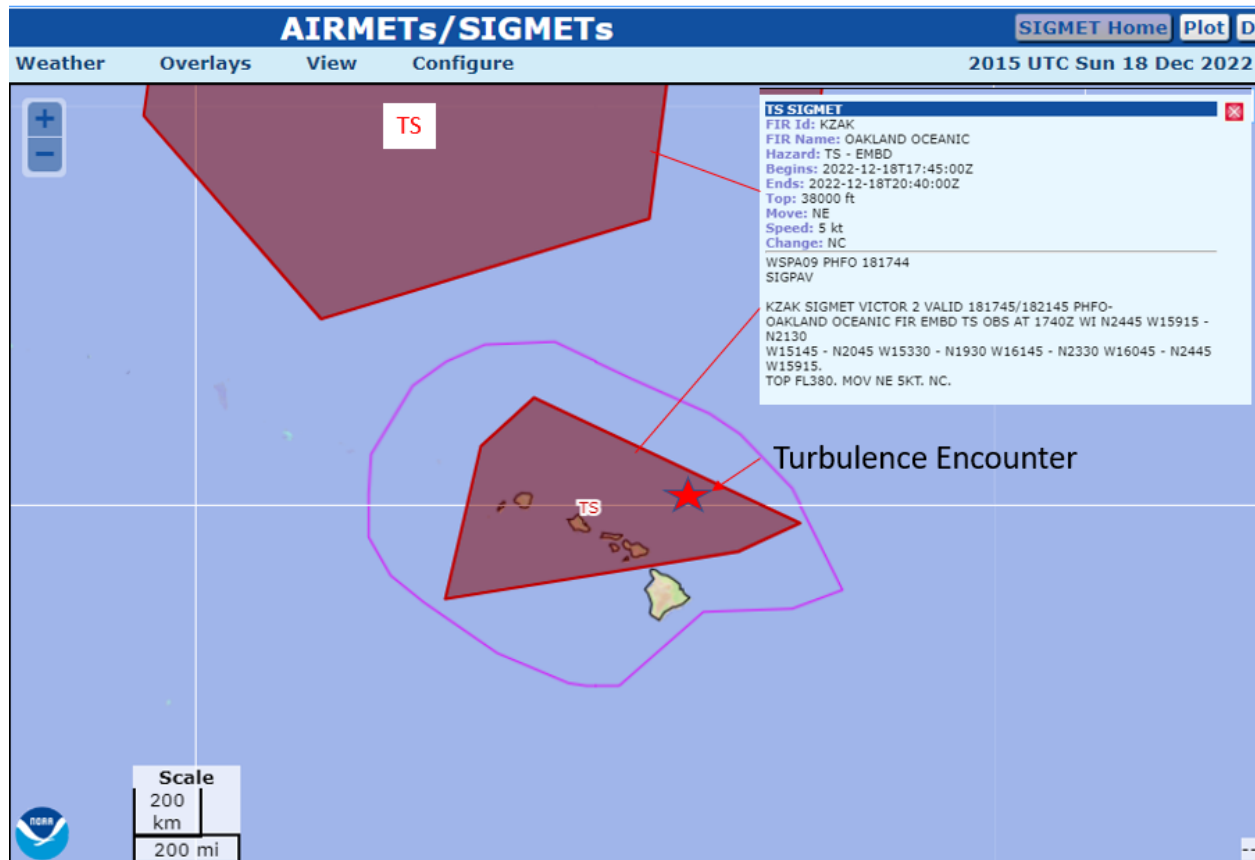
OAKLAND OCEANIC FIR EMBD TS OBS AT 1740Z WI N2445 W15915 - N2130

W15145 - N2045 W15330 - N1930 W16145 - N2330 W16045 - N2445 W15915.

TOP FL380. MOV NE 5KT. NC.

Figure 18 is a depiction of SIGMET Victor 2 which was issued at 0744 HST and current through 1145 HST for embedded thunderstorms with tops to FL380 and

moving northeastward at 5 knots over the Honolulu and Oakland Flight Information Regions (FIR). SIGMET Charlie 5 was also depicted north of the area for embedded thunderstorms which did not impact the route of flight.



**Figure 18 - Depiction of SIGMET Victor 2 valid for embedded thunderstorms with tops to FL380 over the Hawaiian Islands and the approximate turbulence location.**

## AIRMETS

WAHW31 PHFO 181530  
WA0HI

HNLS WA 181600  
AIRMET SIERRA UPDATE 3 FOR IFR VALID UNTIL 182200

.  
AIRMET MTN OBSC...KAUAI OAHU MOLOKAI AND MAUI ENTIRE AREA.  
MTN TEMPO OBSC ABV 025 EXP DUE TO CLD AND SHRA.  
COND CONT BEYOND 2200Z.

=HNLT WA 181600  
AIRMET TANGO UPDATE 2 FOR TURB VALID UNTIL 182200

.  
NO SIGNIFICANT TURB EXP.

=HNLZ WA 181600  
AIRMET ZULU UPDATE 2 FOR ICE AND FZLVL VALID UNTIL 182200  
.  
NO SIGNIFICANT ICE EXP.  
.  
FZLVL...125.

## 5.0 NCAR Oceanic Convective Products

The FAA Aviation Weather Research Program has supported the development of several turbulence products, the primary domestic product was developed by the National Center for Atmospheric Research (NCAR) is the Graphic Turbulence Guidance (GTG), which is available on the NWS AWC website<sup>40</sup>. The GTG provides a computer-generated four-dimensional forecast related to the expected intensity of atmospheric turbulence provided in eddy dissipation rate (EDR) to provide aircraft specific turbulence intensity values. NCAR has developed a newer version of the product, which includes convective turbulence and is referred to as the GTG-Nowcast (GTG-N) and is currently being run on the NWS AWC testbed and is slated for implementation at NCEP in the future. NCAR was asked if the GTG-N could be run over the domain of the accident site and were unable to reproduce the conditions; however, they were able to provide their Cloud Top Height (CTH)<sup>41</sup> and Convection Diagnosis Oceanic (CDO)<sup>42</sup> products.

The NCAR CTH and CDO products combines GOES infrared data and numerical weather prediction output to create a detailed diagnosis of the estimated heights of convective cloud tops over the open ocean. Initially intended to help international flights traversing the inter-tropical convergence zone (ITCZ)<sup>43</sup> where convection occurs frequently. The product was designed to provide pilots the convective cloud tops to help them make informed, strategic decisions to avoid hazardous convection ahead of the flight route, well beyond the range of airborne weather radar. The CTH product displays cloud top contours of opaque clouds as flight altitudes of FL320, FL340, FL380 and FL400 by converting the satellite IR brightness temperature to flight altitude using a numerical model sounding as reference. While the CDO displays hazards associated with the storm updraft, lightning and overshooting tops, using "interest values" between 0-6 to indicate increasing level of intensity, with a CDO value of 2 being the basic threshold where convective hazards may be present. Values of 3 and above typically indicate the presence of lightning and/or overshooting tops. Both the CTH and CDO are classified as supplemental products only and their use is for situational

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<sup>40</sup> <https://www.aviationweather.gov/turbulence>

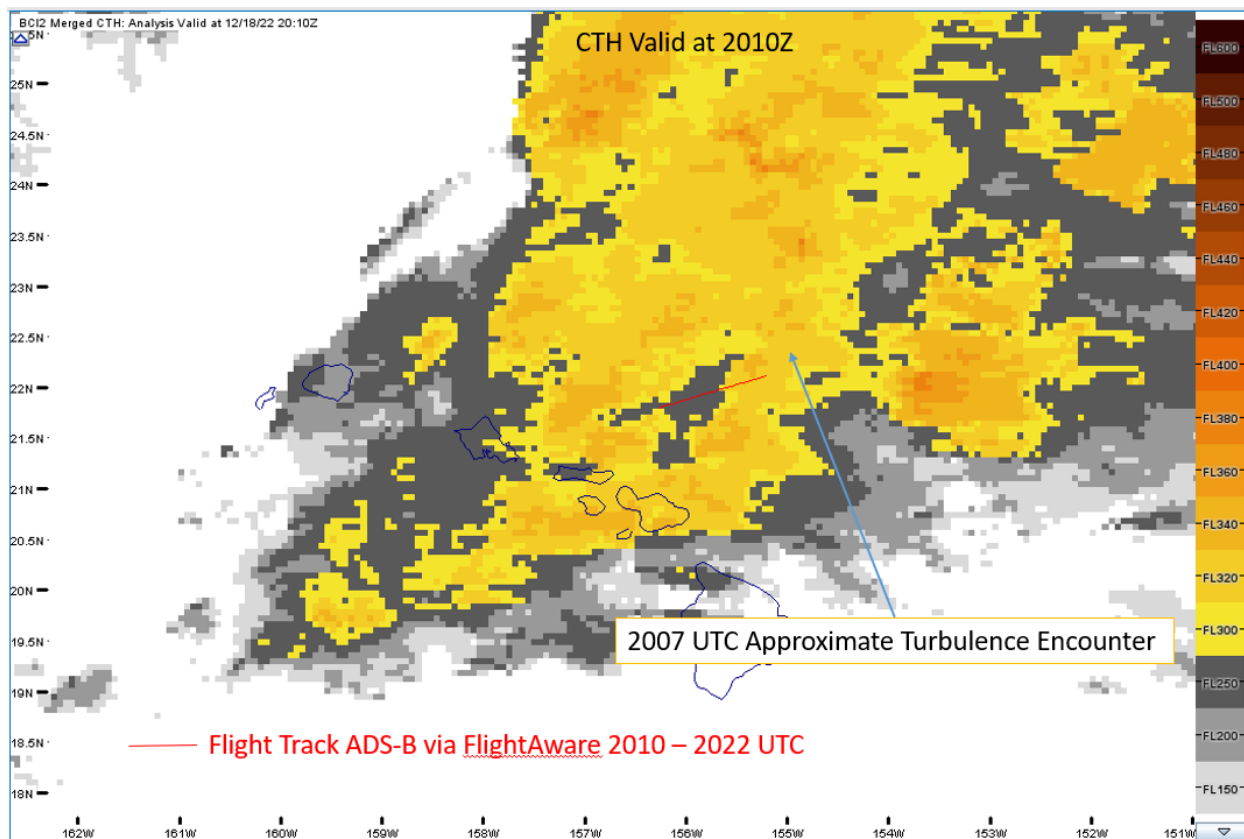
<sup>41</sup> Developed by Steve Miller, United States Naval Research laboratory and implemented at NCAR.

<sup>42</sup> Developed by Fred Mosher, NWS Aviation Weather Center and implemented at NCAR.

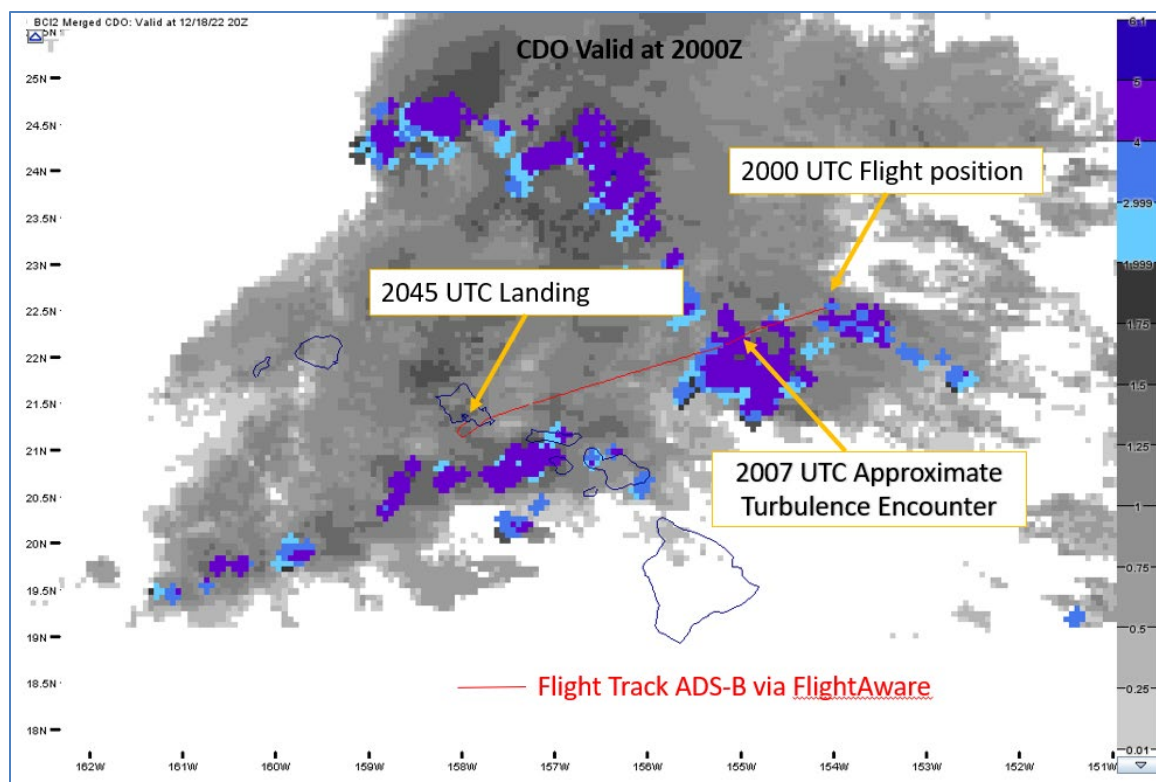
<sup>43</sup> This work was motivated by the Air France A330 accident on May 19, 2009, between Rio de Janeiro, Brazil to Paris, France, DCA09RA052, which encountered convective echoes near the ITCZ and resulted in the aircraft losing control and impacting the ocean, with a total of 228 fatalities.

awareness and for long range strategic planning and are available through a private vendor license agreement through NCAR.

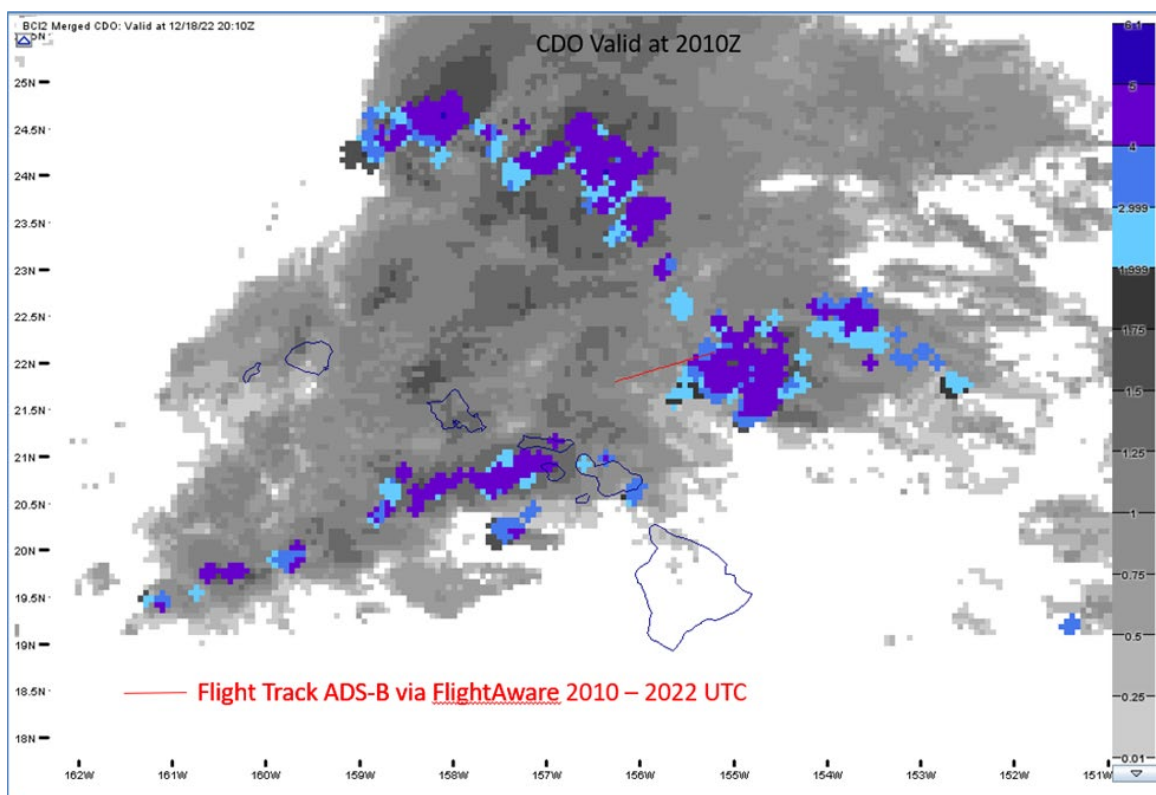
Figures 19 is the NCAR CTH image for 1010 HST (2010Z) and figures 20-22 are the CDO images at 1000,1010 and 1020 HST with the flight track overlaid. The images depicted cloud tops between FL320 to FL340 in the vicinity of the turbulence encounter, with maximum heights near FL360, with CDO value of 4 over the event location at 1010 HST, with values decreasing to 1 over the descent into PHNL.



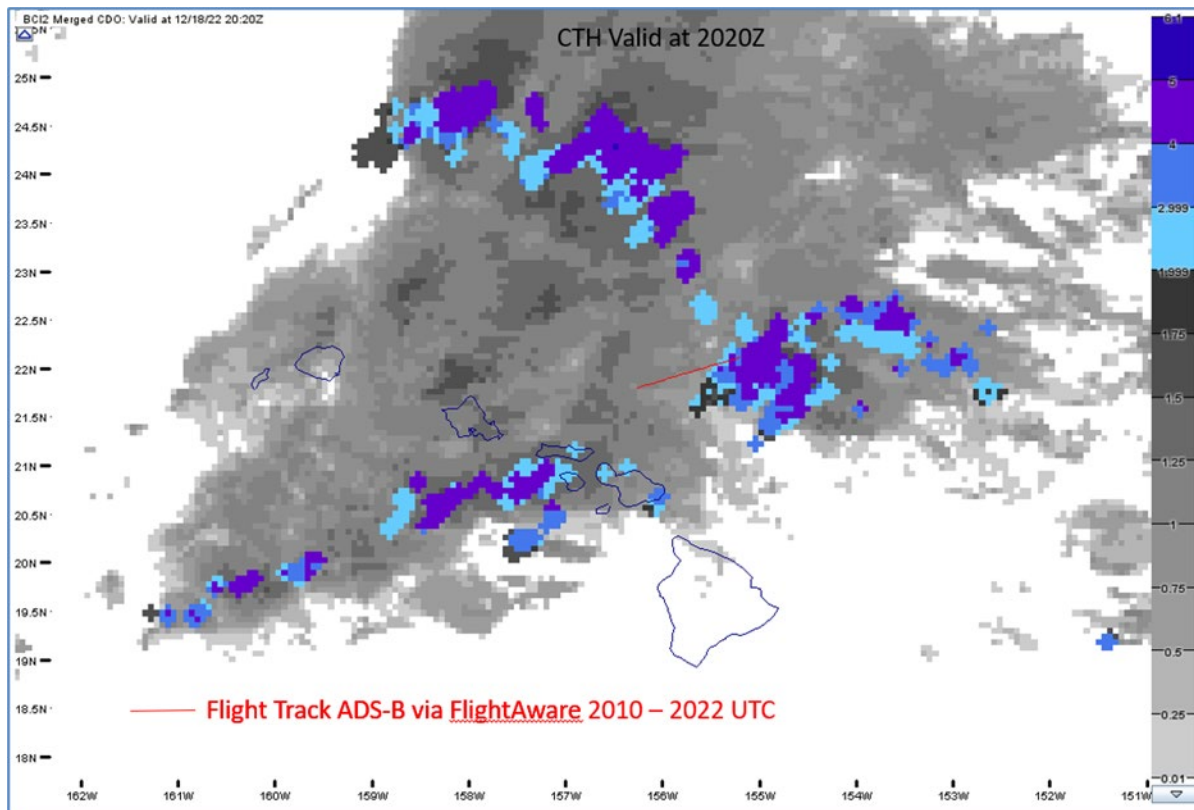
**Figure 19 - NCAR Cloud Top Height (CTH) image valid for 1010 HST with the flight track overlaid.**



**Figure 20 - NCAR Convection Diagnosis Oceanic (CDO) product for 1000 HST with flight track.**



**Figure 21 - NCAR CDO image for 1010 HST with flight track overlaid from 1010 to 1022 HST.**



**Figure 22 - NCAR CDO valid for 1020 HST with the flight track from 1010-1022 HST overlaid.**

## 6.0 Dispatch Release and Weather Document

The flight was released at 0141 HST on December 18, 2022, from KPHX to PHNL with an alternate airport of Ellison Onizuka Kona International Airport (KOA/PHKO), Kailua/Kona, HI. With a filed altitude of FL400. The weather document attached to the dispatch release included the departure, destination, and alternate airport METARs, TAFs, and NOTAMs, and other selected stations (KSFO). The document also included the inflight weather advisories of SIGMETs and AIRMETs that were current during the period.

Statements were requested from the releasing dispatch and the dispatcher on duty at the time of the accident. The releasing dispatchers statement indicated that the captain of flight 35 had contacted flight dispatch at 0233 HST and was briefed on the flight plan, and the expected forecast weather conditions. The dispatcher advised the flight of some potential turbulence near DUETS intersection associated with the jet stream and advised of the area of isolated embedded cumulonimbus clouds over the region and in the PHNL area. The dispatcher advised the captain of additional fuel added for possible holding and the weather expected in the PHNL area. Before the flight departed, the flight was provided updated weather information at 0311 HST regarding SIGMET Charlie 4 for thunderstorms, and the cancelation of SIGMET Alpha 3. At 0401 HST, the flight was issued SIGMET Victor 1 for embedded thunderstorms

over the area and a ride report from another Hawaiian flight over the area at FL400 which reported smooth conditions through ACARS. The flight was also alerted to the presence of thunderstorms at PHNL at 0414 HST. Later during the flight at 0745 HST the relieving flight dispatch officer provided the flight an update of SIGMET Victor 2 for embedded thunderstorms with tops to FL380, moving to the northeast with no change expected, which was acknowledged by the flight.

The flight dispatcher on duty at the time of the accident indicated that at 1010 HST the flight contacted them on SATCOM and advised of encountered turbulence just past the DENNS intersection at FL400, and that medical attention was requested on arrival. At 1014 HST, SATCOM from crew advised of additional injuries of 10 or more and the flight had declared an emergency with ATC.

## **7.0 Interviews**

The Flight Crew interviews can be found in the NTSB Operations Specialist Factual Report and related attachments in the docket. A brief review of the meteorological comments is reviewed in this section.

The captain, first officer, and jump seat riders commented that they were flying a few thousand feet over a layer of cirrostratus clouds below their cruising level estimated to be from 37,000 to 38,000 ft. While the captain and first officers indicated that they observed no radar returns on their airborne weather radar during the period, one of the deadheading pilot's in the jump seat noted some green returns on the first officers radar display in the developing clouds that were building up directly ahead of the flight. Within seconds of the encounter, they observed what they described as a "bump" or "plume" of clouds forming in the rising convective activity immediately ahead of the flight that shot up vertically without warning. With no time to deviate around the buildup, the captain advised the lead flight attendant of potential turbulence and within seconds flew over the buildup and encountered the turbulence. The pilot's indicated the autopilot disconnected, one wing dropped, and they went through at least 2 cycles of positive and negative forces in about 10-seconds.

## **8.0 Turbulence Reference Material**

The International Civil Aviation Organization (ICAO) Annex 3 - Meteorological Services for International Air Navigation, Appendix 4 on Technical Specifications Related to Aircraft Observations and Reports, section 2.6.2 defines EDR<sup>44</sup> and

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<sup>44</sup> The EDR is an aircraft-independent measure of turbulence. However, the relationship between the EDR value and the perception of turbulence is a function of aircraft type, and the mass, altitude, configuration and airspeed of the aircraft. The EDR values given above describe the severity levels for a medium-sized transport aircraft under typical en-route conditions (i.e. altitude, airspeed and weight).

turbulence intensity for a medium-size weight category transport aircraft under typical en-route conditions.

*Turbulence shall be considered:*

- a) severe when the peak value of the cube root of EDR exceeds 0.7;*
- b) moderate when the peak value of the cube root of EDR is above 0.4 and below or equal to 0.7;*
- c) light when the peak value of the cube root of EDR is above 0.1 and below or equal to 0.4; and*
- d) nil when the peak value of the cube root of EDR is below or equal to 0.1.*

The initial flight data recorder (FDR) indicated that the accident airplane experienced vertical accelerations more than 3 g's, specifically +2.1758 at 20:07:44.252Z followed by -0.9844 G's at 20:07:46.627Z. The World Meteorological Organization (WMO) in their Aviation Hazards training guide define the turbulence intensities, aircraft response, vertical acceleration, passenger experience, and EDR values for various turbulence intensities for a medium weight category aircraft as follows. Based on the chart the accident airplane experienced severe-to-extreme intensity turbulence.

| <b>Turbulence category</b> | <b>Aircraft response</b>                                                                                                                              | <b>Aircraft vertical acceleration magnitude (g)</b> | <b>Passenger experience</b>                                                                                                                   | <b>Approx <math>\epsilon^{1/3}</math> (<math>\text{m}^{2/3} \text{s}^{-1}</math>) for B737 and B757 aircraft</b> |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| <b>Light</b>               | Momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw)                                                             | 0.2–0.5                                             | A slight strain against seat belts; unsecured objects may be displaced slightly; food service may be conducted with little difficulty walking | 0.1–0.3                                                                                                          |
| <b>Moderate</b>            | Similar to light turbulence but greater intensity; changes in altitude, attitude, and/or airspeed occur; the aircraft remains in control at all times | 0.5–1.0                                             | Definite strain against seat belts; unsecured objects are dislodged; food service and walking are difficult                                   | 0.3–0.5                                                                                                          |
| <b>Severe</b>              | Large, abrupt changes in altitude, attitude, and/or airspeed; aircraft may be momentarily out of control                                              | 1.0–2.0                                             | Occupants are forced violently against seat belts; unsecured objects are tossed about; food service and walking are impossible                | 0.5–0.7                                                                                                          |
| <b>Extreme</b>             | The aircraft is violently tossed about and is practically impossible to control; it may cause structural damage                                       | > 2.0                                               | Truly frightening                                                                                                                             | > 0.7                                                                                                            |

**Figure 23 - WMO Turbulence Intensity Chart from light to extreme with aircraft and passenger response, aircraft vertical accelerations magnitude (g's), and eddy dissipation rate (EDR) for a medium weight category aircraft.**

**Light:** *Effects are less than those of moderate intensity.*

**Moderate:** *There may be moderate changes in aircraft attitude and/or height but the aircraft remains in control at all times. Air speed variations are usually small. Changes in accelerometer readings of 0.5--1.0g at the aircraft's center of gravity.*

*Occupants feel strain against seat belts. There is difficulty in walking. Loose objects move about.*

**Severe:** *Abrupt changes in aircraft attitude and/or height. The aircraft may be out of control for short periods. Air speed variations are usually large. Changes in accelerometer readings greater than 1.0 g at the aircraft's center of gravity as severe. Occupants are forced violently against seat belts. Loose objects are tossed about.*

**Extreme:** *Effects are more pronounced than for severe intensity.*

A search of FAA guidance material from Advisory Circular AC 00-24C "Thunderstorms" and incorporated in the FAA Weather Handbook mentions in section 22.8.2 general thunderstorm avoidance guidance that any thunderstorm with tops of 35,000 ft or higher are extremely hazardous and should be avoided. There is no other current guidance from the FAA for safe overflight of thunderstorms.

## 9.0 Astronomical Conditions

Data from the United States Naval Observatory's website provided the following astronomical conditions for PHNL at the time of the accident.

| <u>SUN</u>               | <u>TIME (HST)</u> | <u>TIME (UTC)</u>      |
|--------------------------|-------------------|------------------------|
| Beginning civil twilight | 0639              | 1639 December 18, 2022 |
| Sunrise                  | 0703              | 1703                   |
| <b>Accident</b>          | <b>1016</b>       | <b>2016</b>            |
| Upper Transit            | 1228              | 2228                   |
| Sunset                   | 1753              | 0353 December 19, 2022 |
| End civil twilight       | 1818              | 0418 December 19, 2022 |

## F. ATTACHMENTS

Attachment 1 - GOES-17 satellite imagery and moderate or greater turbulence

Attachment 2 - NWS PHKM WSR-88D radar animations.

Submitted by:

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