



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

July 3, 2019

Weather Study

METEOROLOGY

ERA19LA073

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A. ACCIDENT

Location: Kew West, Florida
Date: December 15, 2018
Time: 0933 eastern standard time
1433 Universal Coordinated Time (UTC)
Airplane: Learjet 35A; Registration: N55FN

B. METEOROLOGIST

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

C. SUMMARY

On December 15, 2018, about 0933 eastern standard time, a Learjet 35A, N55FN, was substantially damaged during landing at Key West International Airport (EYW), Key West, Florida. The captain, first officer, and two passengers were not injured. The flight was operated by Medway Air Ambulance as a positioning flight conducted under provisions of Title 14 *Code of Federal Regulations* Part 91. Instrument meteorological conditions prevailed, and an instrument flight rules flight plan was filed for the flight that departed Gwinnett County Airport (LZU), Lawrenceville, Georgia, about 0730.

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 from the Washington D.C. office, collecting data from official National Weather Service (NWS) sources including the Weather Prediction Center (WPC) and the National Center for Environmental Information (NCEI). All times are eastern standard time (EST) based upon the 24-hour clock, local time is -5 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.

The accident site was located at latitude 24.556111° N and longitude 81.753611° W at an elevation of about 21 ft.

E. WEATHER INFORMATION

1.0 Synoptic Conditions

The synoptic or large scale migratory weather systems influencing the area were documented using standard NWS charts issued by the National Center for Environmental Prediction (NCEP) located in College Park, Maryland. These are the base products used in describing weather features and in the creation of forecasts and warnings. Reference to these charts and all the other weather products documented in this report can be found in the joint NWS and Federal Aviation Administration (FAA) Advisory Circular “Aviation Weather Services”, AC 00-45H change 1.

1.1 Surface Analysis Chart

The NWS southeast section of the Surface Analysis Chart for 0700 EST on December 15, 2018 is included as figure 1 with the Key West area enclosed within the red circle. The chart depicted a low pressure system at 1011-hectopascals (hPa) over South Carolina at the triple point of an occluded front, with the occluded front extending northwestward, and a stationary front northeast. A cold front extended from the low southward into the Atlantic Ocean and into southern Florida and was located immediately west of Key West. A trough of low pressure was also depicted paralleling the cold front across Georgia and the Florida panhandle, and into the Gulf of Mexico. The station model for Key West indicated a southwesterly wind at 10 knots, broken cloud cover, with a temperature of 78° Fahrenheit (F), and a dew point temperature of 72° F.

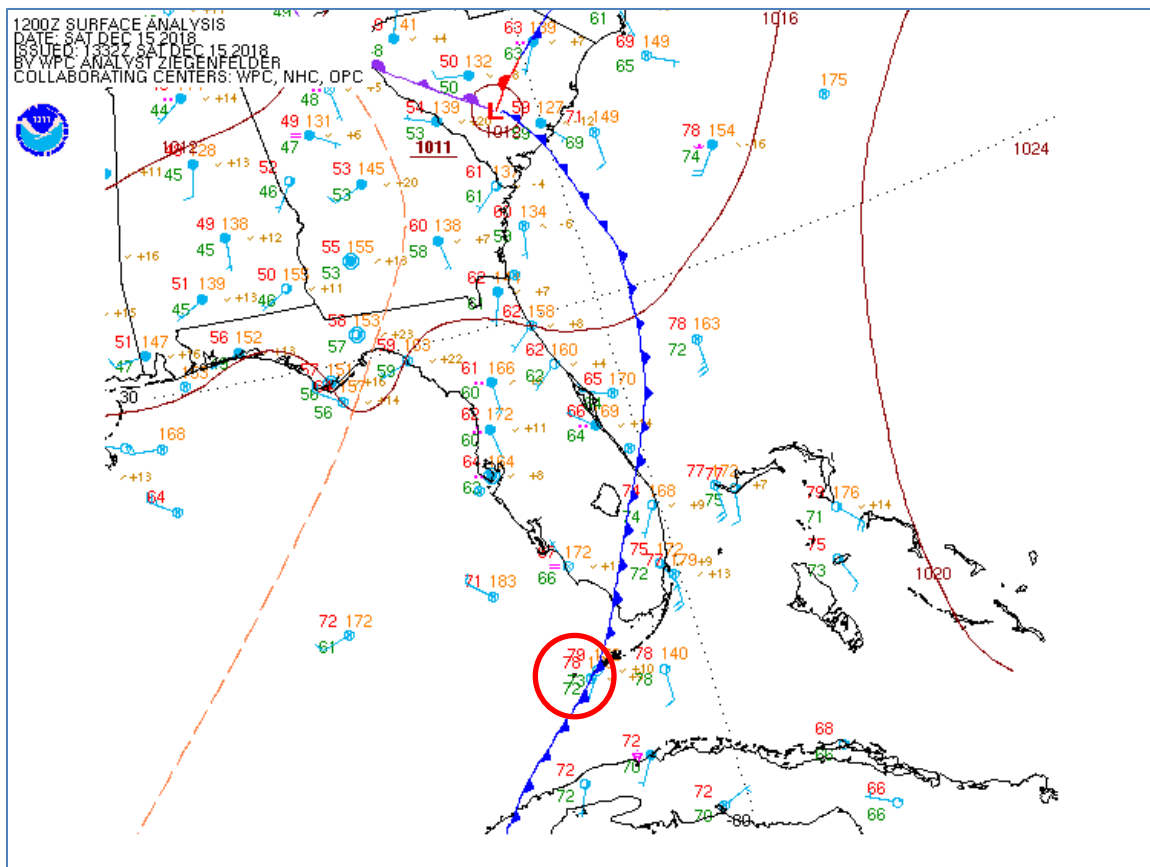


Figure 1 - Southeast section of the NWS Surface Analysis Chart for 0700 EST

The next NWS Surface Analysis Chart issued for 1000 EST immediately after the accident is included as figure 2. The chart depicted the cold front beginning to dissipate but was still defined over southern Florida and was located now east of Key West. A trough behind the primary front was now depicted as a developing cold front¹ and extended across northern Florida into the Gulf of Mexico. The accident site was now located behind the cold front in the cold air side of the front, and ahead of the new developing cold front over the Gulf of Mexico. The station model for Key West now depicted a wind from the north at 5 knots, overcast clouds, and a temperature of 74° F, and a dew point of 70° F.

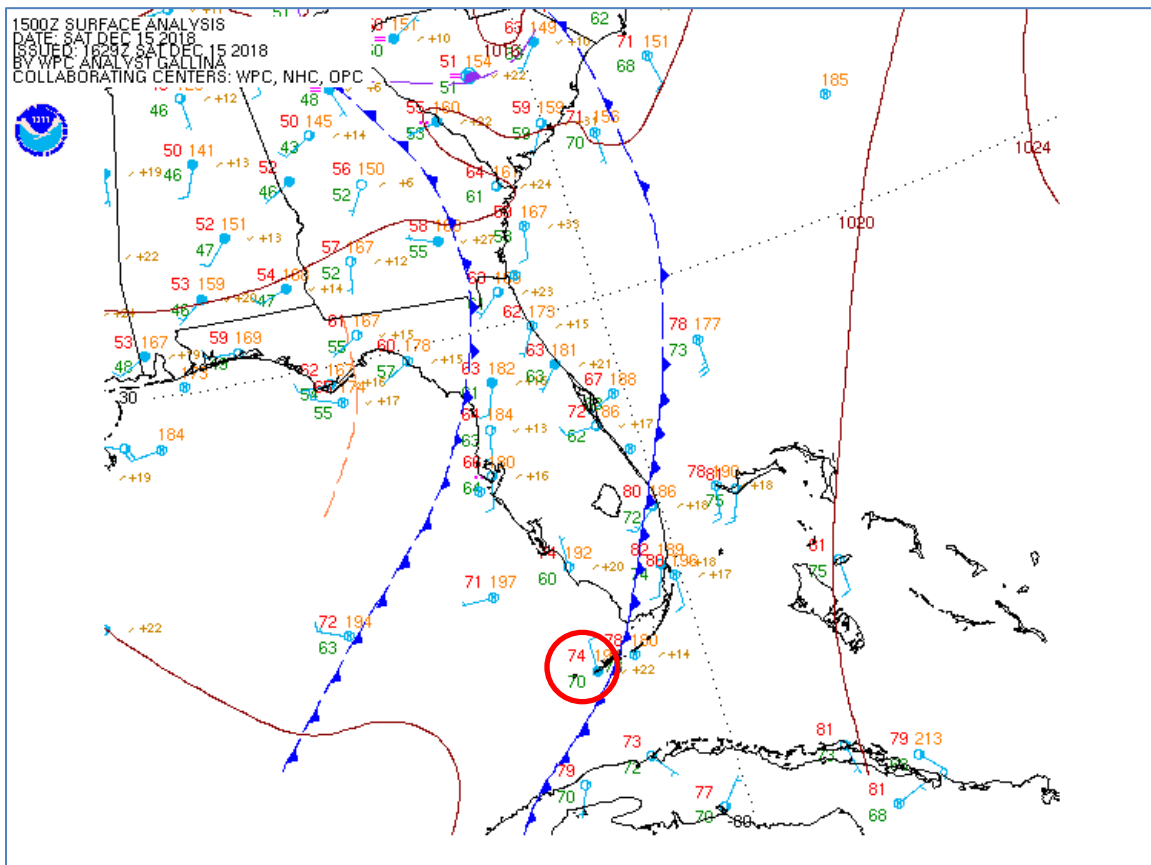


Figure 2 - Southeast section of the NWS Surface Analysis Chart for 1000 EST

Fronts are transition zones separating air masses of different temperature and hence of different densities and are areas of low pressure. The dynamics of frontal surfaces dictate that there is a discontinuity in the wind direction and speed across the surface, particularly in the lower levels of the atmosphere where there is a cyclonic shift in the wind; a frontal surface is therefore, by its very nature, a wind shear zone. Cold frontal wind shear typically occurs after the frontal passage and typically can last up to 30-minutes where strong shears can exist along the frontal zone at low altitudes that can impact aircraft landing or taking off.²

¹ Frontogenesis – the development of a frontal zone

² ICAO Manual on Low-Level Wind Shear, document 9817 AN/449, 2005.

1.2 National Composite Radar Mosaic

The NWS National Composite Radar Mosaic for 0935 EST centered over Key West, Florida, with the accident site marked by a red star in included as figure 3. The chart depicted an area of moderate to heavy echoes over the region and over Key West with echoes of 40 to 50 dBZ. Based on the existence of potentially strong echoes in the vicinity of the airport at the time of the accident, the closest NWS weather surveillance radar will be further documented in section 5.0 of this report.

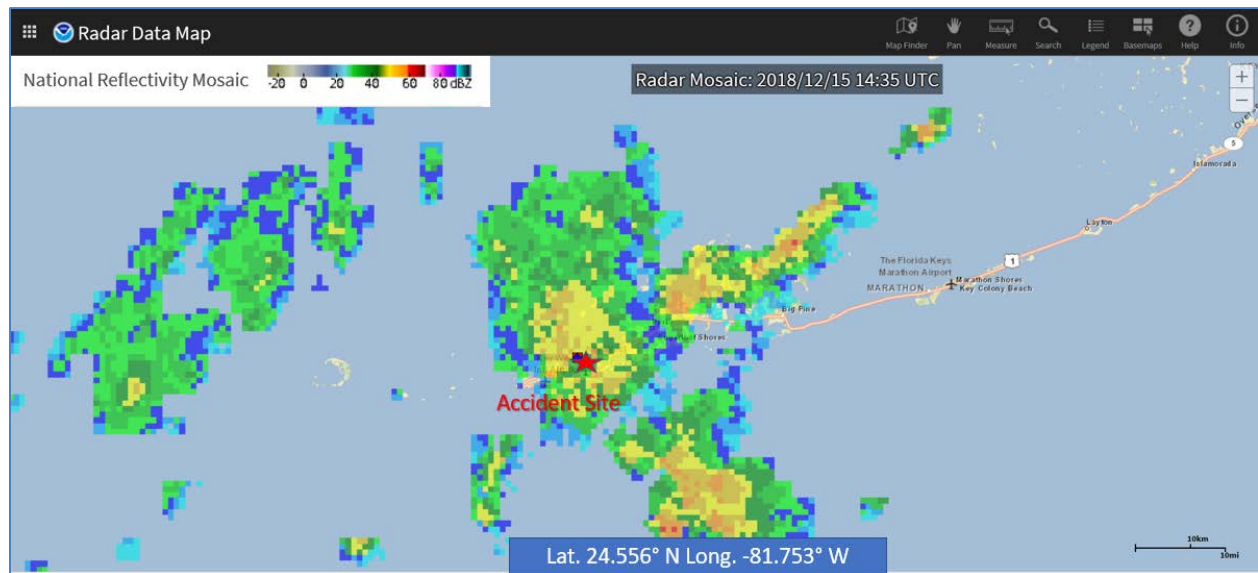


Figure 3 - National Composite Radar image for 0935 EST

1.3 Convective Outlook

The NWS Storm Prediction Centers (SPC) Day 1 Convective Outlook graphic issued for 0700 EST is included as figure 4 with the text bulletin (AC) current for the period below the graphic image. The Convective Outlook is designed to provide users a quick reference to where strong to severe organized convection or thunderstorms are expected within the next 24-hours, with the text bulletin providing a description of the meteorological conditions, the threat potential, and general timing in the forecast. The outlook expected a chance of general thunderstorms across central and southern Florida during the period. No severe or well organized severe thunderstorms were expected over Florida during the period.

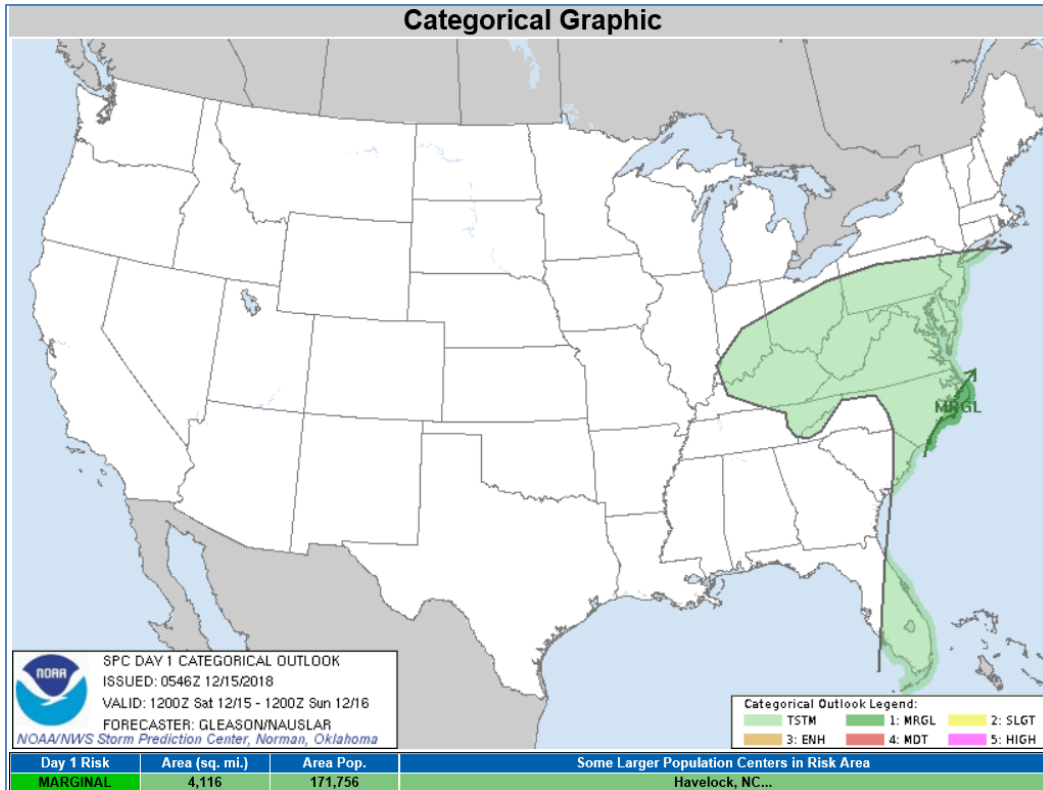


Figure 4 - Day 1 Convective Outlook issued for 0700 EST

SPC AC 150546
 Day 1 Convective Outlook
 NWS Storm Prediction Center Norman OK
 1146 PM CST Fri Dec 15 2018 (corrected time)

Valid 151200Z - 161200Z

...THERE IS A MARGINAL RISK OF SEVERE THUNDERSTORMS ACROSS PORTIONS OF EASTERN NORTH CAROLINA...

...SUMMARY...

Strong thunderstorms may impact coastal North Carolina mainly this morning, with gusty winds and perhaps a brief tornado possible.

...Synopsis...

An upper low over the Southeast and TN Valley will move northeastward to the Mid-Atlantic today. An occluded surface low will likewise develop northeastward across the TN Valley to the lower OH Valley through the period while slowly weakening. Secondary surface low over eastern NC should translate northeastward to the VA Tidewater by this evening.

...Eastern NC...

30-40 kt southwesterly winds associated with a low-level jet should persist over eastern NC through the morning, with a moist low-level airmass remaining in place across this region. Although relatively greater, but still weak, instability will likely remain offshore, very modest daytime heating coupled with mid 60s surface dewpoints may be sufficient to support near-surface-based thunderstorms. Strengthening and veering low-level winds will encourage updraft rotation with any cells that can move from the coastal waters onshore. Strong/gusty winds and perhaps a brief tornado cannot be completely ruled out along the immediate coast for the first few of hours of the period this morning

(around 12-16Z). The stronger low-level winds should shift offshore by early afternoon, and additional convective development across eastern NC appears unlikely after this occurs.

...Southern FL...

Isolated thunderstorms may develop by this afternoon along/ahead of a cold front across portions of the southern FL Peninsula. Even though there will be some modestly enhanced mid-level southwesterly flow over this region, poor mid-level lapse rates will likely limit updraft strength. With large-scale forcing for ascent associated with the upper low over the TN Valley and Mid-Atlantic remaining displaced well to the north, severe thunderstorms appear unlikely.

..Gleason/Nauslar.. 12/15/2018

2.0 Observations

The surrounding area was documented using official Meteorological Aerodrome Reports (METAR) and Specials (SPECI) reports. The area had a magnetic variation of 5° West based on the sectional chart for the area. Cloud heights are reported in height above ground level (agl) in the following section.

2.1 METARs for Key West, Florida

Key West International Airport (KEYW), Key West, Florida, at an elevation of 3.4 ft had a federally installed and maintained Automated Surface Observation System (ASOS) which was augmented by air traffic control tower personnel. The following conditions were reported surrounding the period of the accident.

KEYW special weather observation at 0918 EST, wind from 360° at 11 knots, visibility 7 miles in light rain, scattered clouds at 600 ft, ceiling broken at 1,900 ft, overcast 9,000 ft, temperature 23° Celsius (C), dew point temperature 22° C, altimeter 30.08 inches of mercury (Hg). Remarks: automated station with a precipitation discriminator, rain began at 0908 EST, hour precipitation a trace or less than 0.01 inches, temperature 23.3° C, dew point 21.7° C.

KEYW special weather observation at 0925EST, wind from 330° at 13 knots gusting to 19 knots, visibility 1 1/2 miles in moderate rain and mist, ceiling broken at 600 ft, broken at 1,900 ft, and overcast 5,000 ft, temperature 23° C, dew point temperature 22° C, altimeter 30.09 inches of Hg. Remarks: automated station with a precipitation discriminator, rain began at 0908 EST, hourly precipitation from 1354 EST 0.02 inches, temperature 23.3° C, dew point 21.7° C.

KEYW special weather observation at 0938EST, wind from 350° at 9 knots gusting to 19 knots, visibility 3/4 mile in heavy rain and mist, scattered clouds at 600 ft, ceiling broken at 1,400 ft, and overcast 5,000 ft, temperature 23° C, dew point temperature 22° C, altimeter 30.10 inches of Hg. Remarks: automated station with a precipitation discriminator, rain began at 0908 EST, hourly precipitation from 1354 EST 0.17 inches, temperature 22.8° C, dew point 21.7° C.

The general flight categories³ which are color coded and the raw observations in standard code, abbreviations, and time in UTC that were disseminated between 0753 and 1053 EST were as follows:

VFR METAR KEYW 151153Z 21005KT 10SM CLR 26/23 A3004 RMK AO2 SLP172 T02610228 10267 20261 53010

MVFR SPECI KEYW 151241Z 36007KT 8SM SCT014 BKN019 BKN120 24/22 A3006 RMK AO2 T02440217

MVFR METAR KEYW 151253Z 01008KT 8SM BKN014 BKN021 OVC038 24/22 A3007 RMK AO2 SLP180 T02390217

MVFR SPECI KEYW 151258Z 33006KT 8SM FEW005 BKN021 OVC038 24/22 A3007 RMK AO2

MVFR SPECI KEYW 151309Z 03005KT 9SM FEW006 BKN011 OVC018 24/22 A3007 RMK AO2

MVFR SPECI KEYW 151334Z 36007KT 10SM BKN015 OVC023 24/22 A3007 RMK AO2 T02390217

MVFR METAR KEYW 151353Z 01009KT 10SM FEW014 BKN019 OVC090 24/22 A3007 RMK AO2 SLP183

MVFR SPECI KEYW 151418Z 36011KT 7SM -RA SCT006 BKN019 OVC090 23/22 A3008 RMK AO2 RAB08 P0000 T02330217

IFR SPECI KEYW 151425Z 33013G19KT 1 1/2SM RA BR BKN006 BKN019 OVC050 23/22 A3009 RMK AO2 RAB08 P0002 T02330217

Accident 1433Z

IFR SPECI KEYW 151438Z 35009G19KT 3/4SM +RA BR SCT006 BKN014 OVC037 23/22 A3010 RMK AO2 RAB08 P0017 T02280217

IFR SPECI KEYW 151442Z 35011KT 1 1/4SM -RA BR SCT006 BKN010 OVC031 23/22 A3010 RMK AO2 RAB08 P0018 T02280217

MVFR SPECI KEYW 151445Z 34009KT 3SM -RA BR SCT006 BKN010 OVC031 23/22 A3010 RMK AO2 RAB08 P0018 T02330217

MVFR METAR KEYW 151453Z 36009KT 7SM SCT006 BKN010 OVC029 23/21 A3010 RMK AO2 RAB08E52 SLP194 P0018 60018 T02330211 53022

IFR SPECI KEYW 151503Z 34012KT 7SM BKN006 OVC029 23/21 A3011 RMK AO2 T02280211

³ 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.

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

VFR SPECI KEYW 151542Z 35010KT 10SM SCT006 SCT026 BKN075 23/21 A3011 RMK AO2 RAB05E28
P0001 T02330211

MVFR SPECI KEYW 151550Z 36008KT 10SM SCT006 BKN026 23/21 A3011 RMK AO2 RAB05E28 P0001

MVFR METAR KEYW 151553Z 35009KT 10SM SCT006 BKN026 OVC040 23/21 A3011 RMK AO2 RAB05E28
SLP194 P0001 T02330211

Prior to 0700 EST the observations reported VFR conditions with winds from the southwest at less than 10 knots, with winds slowly veering to the north and increasing cloud cover moving into the area after that period. Rain began at 0908 EST and increased in intensity with wind speeds increasing to 13 knots gusting to 19 knots at 0925 EST through the time of the accident with IFR conditions. The accident occurred during the period of heavy rain and with wind from 330° to 350° gusting to 19 knots.

2.2 ASOS 5-minute Observations

A search of the NWS 5-minute ASOS observations which were available locally by air traffic control and to users dialing into the system surrounding the period from 0900 to 1000 EST were as follows. The observations in bold print were disseminated as special observations or the hourly observation.

KEYW 151400Z AUTO 36010KT 10SM SCT016 BKN055 OVC090 24/22 A3007 RMK T02400220

KEYW 151405Z AUTO 35009KT 10SM SCT016 BKN019 OVC090 24/22 A3007 RMK T02400220

KEYW 151410Z AUTO 36008KT 10SM -RA SCT016 BKN019 OVC090 24/22 A3007 RMK T02400220

KEYW 151415Z AUTO 36009KT 7SM -RA SCT006 BKN019 OVC090 23/22 A3007 RMK T02300220

**SPECI KEYW 151418Z 36011KT 7SM -RA SCT006 BKN019 OVC090 23/22 A3008 RMK AO2 RAB08
P0000 T02330217**

KEYW 151420Z AUTO 34010G16KT 4SM -RA BR SCT006 BKN019 OVC090 23/22 A3009 RMK T02300220

**SPECI KEYW 151425Z AUTO 33013KT 1 1/2SM RA BR BKN006 BKN019 OVC050 23/22 A3009 RMK
P0001 T02300220**

KEYW 151430Z AUTO 33012KT 1 1/2SM +RA BR BKN006 BKN019 OVC050 23/22 A3010 RMK P0005
T02300220

Accident 1433Z

KEYW 151435Z AUTO 35010KT 1SM +RA BR SCT006 BKN014 OVC035 23/22 A3010 RMK P0014
T02300220

**SPECI KEYW 151438Z 35009G19KT 3/4SM +RA BR SCT006 BKN014 OVC037 23/22 A3010 RMK AO2
RAB08 P0017 T02280217**

KEYW 151440Z AUTO 35010KT 1SM -RA BR SCT006 BKN014 OVC037 23/22 A3010 RMK P0018
T02300220

**SPECI KEYW 151442Z 35011KT 1 1/4SM -RA BR SCT006 BKN010 OVC031 23/22 A3010 RMK AO2
RAB08 P0018 T02280217**

**SPECI KEYW 151445Z AUTO 34008KT 3SM -RA BR SCT006 BKN009 OVC031 23/22 A3010 RMK P0018
T02300220**

**KEYW 151450Z AUTO 35010KT 6SM -RA BR SCT006 BKN009 OVC029 23/22 A3010 RMK P0018
T02300220**

**METAR KEYW 151453Z 36009KT 7SM SCT006 BKN010 OVC029 23/21 A3010 RMK AO2 RAB08E52
SLP194 P0018 60018 T02330211 53022**

KEYW 151455Z AUTO 35008KT 8SM BKN006 BKN009 OVC029 23/22 A3011 RMK T02300220

KEYW 151500Z AUTO 35008KT 7SM BKN006 BKN009 OVC029 23/22 A3011 RMK T02300220

The observation recorded immediately prior to the accident and best represents the conditions at the time of the accident was as follows:

KEYW weather at 0930 EST, automated, wind from 330° at 12 knots, visibility 1 ½ miles in heavy rain and mist, ceiling broken at 600 ft agl, broken at 1,900 ft, overcast at 5,000 ft, temperature 23° C, dew point 22° C, altimeter 30.10 inches of Hg. Remarks: hourly precipitation since 0853 EST 0.05 inches, temperature 23.0° C, dew point 22.0° C.

2.3 ASOS 1-minute Data

The following table is the 1-minute ASOS data from KEYW surrounding the time of the accident. The 1-minute ASOS weather, precipitation, and wind direction and speed, and maximum wind data were obtained and are included below in table format. The current weather column (WX) abbreviation R is for rain, with the intensity provided as light (-), moderate (), and heavy (+), and with precipitation amount in hundreds of an inch. The 1-minute wind data represents the average 2-minute wind direction and speed, which is updated each minute by averaging the 5-second averages from the previous 2-minutes and recorded to the whole knot. The second value is maximum 5-second wind reported during the previous minute, which is used to report gust values and peak wind values as necessary.

Time (EST)	Weather Phenomena	Precip (inches)	2-minAvg Wind (Dir-KT)	Max Wind (Dir-KT)
0900		0.00	006° 10	005° 11
0901		0.00	001° 9	351° 11
0902		0.00	357° 8	348° 11
0903		0.00	357° 8	006° 10
0904		0.00	355° 9	345° 13
0905		0.00	354° 9	003° 11
0906		0.00	354° 8	353° 13
0907	P	0.00	355° 8	357° 10
0908	P	0.00	360° 8	009° 12
0909	P	0.00	002° 8	006° 10
0910		0.00	001° 8	005° 13

0911		0.00	001° 9	009° 12
0912		0.00	360° 10	355° 13
0913	P	0.00	359° 11	352° 15
0914	R-	0.00	359° 10	347° 12
0915	R-	0.00	358° 9	001° 12
0916	R-	0.00	357° 10	358° 14
0917	R-	0.00	359° 11	003° 14
0918	P	0.00	359° 11	001° 15
0919	P	0.00	353° 9	343° 10
0920	R	0.00	343° 10	337° 17
0921	R+	0.01	341° 13	343° 19
0922	R	0.00	340° 13	344° 16
0923	R	0.00	336° 13	352° 15
0924	R-	0.01	335° 12	325° 15
0925	R+	0.00	334° 13	324° 15
0926	R+	0.00	333° 13	327° 16
0927	R+	0.02	331° 12	324° 14
0928	R+	0.01	329° 12	319° 16
0929	R	0.01	327° 13	320° 19
0930	R	0.00	328° 13	340° 13
0931	R+	0.01	334° 9	327° 12
0932	R+	0.00	343° 7	357° 9
0933	R+	0.01	350° 7	344° 11
0934	R+	0.03	350° 9	345° 13
0935	R+	0.03	353° 10	005° 13
0936	R+	0.02	352° 11	351° 15
0937	R	0.01	346° 10	342° 15
0938	R-	0.00	347° 9	354° 14
0939	R-	0.00	349° 10	354° 14
0940	R-	0.00	349° 10	343° 13
0941	R-	0.00	351° 10	345° 14
0942	R	0.00	352° 11	353° 12
0943	P	0.00	348° 9	353° 11
0944	P	0.00	343° 9	346° 13
0945	P	0.00	343° 9	328° 9

The heaviest precipitation was reported between 0931 and 0936 EST, with the period from 0933 and 0936 reporting 0.03 inches/per minute of rain. Total rainfall recorded was 0.18 inches.

3.0 Upper Air Soundings

The NWS Key West upper air observation or sounding launched on December 15, 2018 for 0700 EST was obtained and plotted on a standard Skew T log P diagram⁴ from the surface to 450-hPa or approximately 21,000 ft using the complete Rawinsonde Observation RAOB program

⁴ 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.

software⁵, and is included as figure 5. The sounding depicted the conditions prior to the cold frontal passage through the area.

The KEYW 0700 EST sounding depicted a surface temperature of 25.4° C (77.7° F), with a dew point temperature of 22.7° C (72.9° F), which resulted in a relative humidity of 85%. An isothermal layer existed from the surface to approximately 500 ft where temperature remained near constant with height before decreasing. The convective temperature⁶ was (Tc) was 28.7° C (83.7° F). The significant levels identified on the sounding indicated a lifted condensation level (LCL) was at 1,144 ft agl, and the level of free convection (LFC) at 2,374 ft agl, and a convective condensation level (CCL) at 3,329 ft agl, and the expected top of any potential convective clouds estimated by the equilibrium level (LFC-EL) at about 44,700 ft with the tropopause at approximately 48,700 ft. The freezing level was identified at approximately 16,000 ft. The precipitable water content was 1.53 inches.

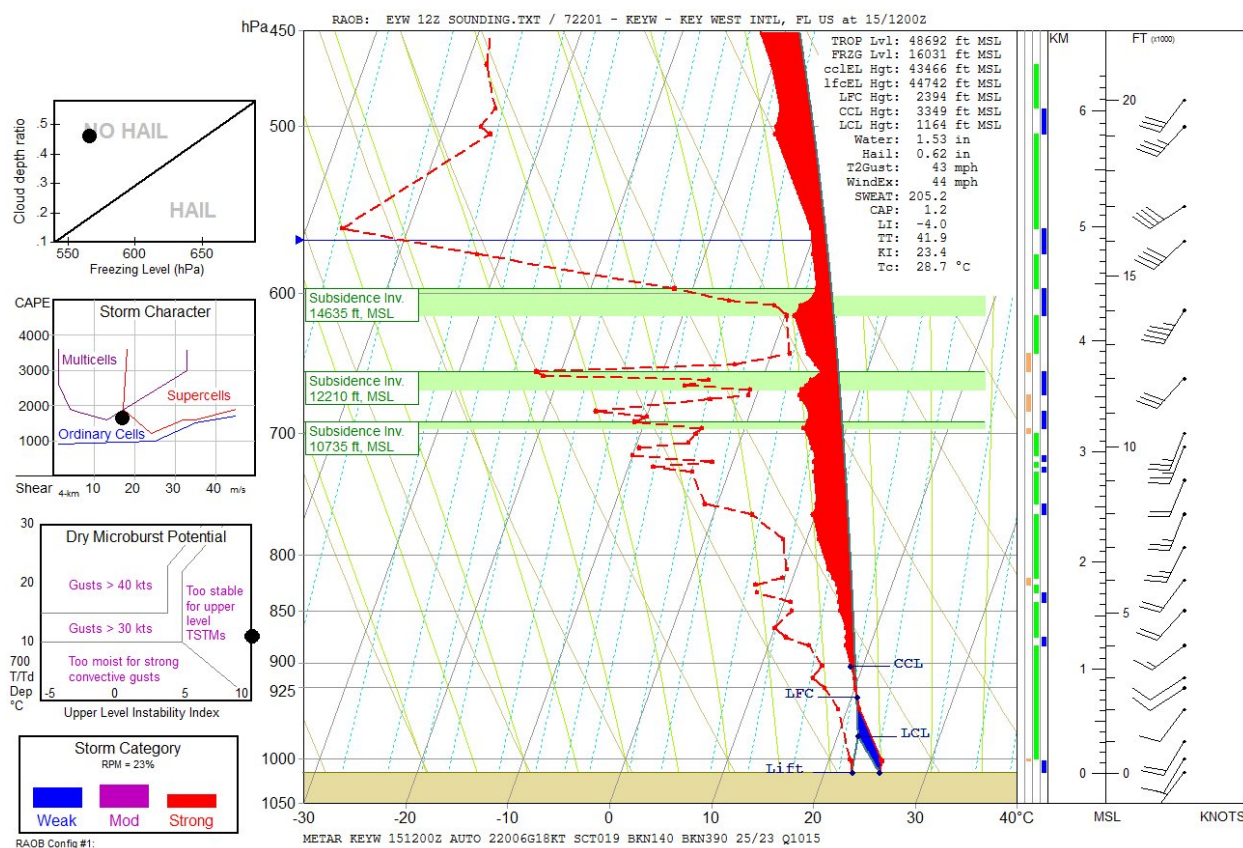


Figure 5 - KEYW 0700 EST sounding profile

The sounding wind profile on the right side of the diagram indicated a surface wind from the southwest or 220° at 6 knots with little directional variation with height and with wind speeds

⁵ RAOB software – The complete RAOB software is an interactive sounding analysis program developed by Environmental Research Services, Matamoras, Pennsylvania, for plotting and analyzing upper air data.

⁶ Convective Temperature - is the approximate temperature that the air near the ground must warm to in order for surface-based convection to develop in the absence of synoptic scale forcing mechanisms.

increasing with height. At 1,000 ft a low-level wind maximum was identified from 210° at 18 knots, which resulted in a slight risk or “light” low-level wind shear (LLWS) condition below this level and potential surface wind gusts. The mean 0 to 6 kilometer or 18,000 ft wind was from 220° at 26 knots, with the expected storm motion⁷ from 250° at 20 knots. The level of maximum wind was identified at 43,000 ft from 260° at 99 knots.

The KEYW sounding was characterized as being unstable based on the Lifted Index of -4, and a K-index of 23.4, which indicated an approximately 50% risk of air mass type thunderstorms. The convective available potential energy (CAPE) was 1,629 Joules/per kilogram (J/kg) and is indicated in the shaded red area of the sounding, and Downdraft CAPE (or DCAPE) at 1,122 J/kg in the blue shading. The maximum vertical motion (MVV) was determined to be 58 meters per second (mps) or approximately 116 knots, the maximum outflow winds were estimated by the WindEx index or microburst index which indicated potential wind outflows of 38 knots. The Wet Microburst Severity Index (WMSI) was 56 and indicated favorable conditions for microburst with similar outflow winds. The KEYW 0700 EST sounding indicated a moderate risk for ordinary or single cell thunderstorms.

Figure 6 is a table of the observed sounding data of height, pressure (Pres), temperature (T), dew point temperature (Td), relative humidity (RH%), wind direction and speed, and RAOB derived potential for clear air turbulence (CAT), LLWS, and icing from the surface to approximately 5,000 ft.

Height (ft-MSL)	Pres (hPa)	T (C)	Td (C)	RH (%)	DD / FF (deg / kts)	CAT (FAA)	LLWS	Icing - Type (AFGW/C method)
20	1015	25.4	22.7	85	215 / 6			
394	1002	25.2	22.2	83		MDT	LIGHT	
452	1000	25.0	22.0	83	210 / 12	MDT	LIGHT	
1000	981				210 / 18	MDT		
2017	947	21.2	19.1	88	215 / 12	LGT		
2686	925	20.0	17.0	83	235 / 12			
2994	915	19.6	15.5	77	235 / 12			
3368	903	18.8	16.0	84				
4000	883	17.6	14.0	79	230 / 13			
4256	875	17.4	11.4	68				
4546	866	17.0	10.0	63		MDT		
5068	850	15.8	11.1	74	220 / 19			

Figure 6 - KEYW observed sounding parameters and derived CAT, LLWS, and icing potential

A High-Resolution Rapid Refresh (HRRR)⁸ numerical model data was obtained from archive data from the NOAA Air Resource Laboratory (ARL) over KEYW for 1000 EST and is included as figure 7. The HRRR model sounding depicted surface wind from 320° at 4 knots showing the passage of the cold front, with a temperature of 25.1° C (77.2° F), and a dew point of 21.8° C (71.2° F). The LCL was identified at 1,395 ft agl, with the LFC and CCL at approximately 2,550 ft agl.

⁷ Storm Motion – assumes thunderstorms will move 30° right of the mean wind and 75% of the steering wind speed.

⁸ The HRRR is a National Oceanic and Atmospheric Administration (NOAA) real-time three-kilometer resolution, hourly-updated, cloud-resolving, convection-allowing atmospheric model, initialized by three-kilometer grids with three-kilometer radar assimilation. Radar data is assimilated in the HRRR every 15 minutes over a one-hour period.

RAOB: HRRR DATA 12Z FOR 15Z.TXT / YR: 2018 MON: 12 DAY: 15 HOUR: 15 (Sat) 15 Dec 3:0

Cloud (Ricaps)

NO HAIL
HAIL

Freezing Level (hPa)

CAPE

Storm Character

Multicells
Supercells
Ordinary Cells

Shear_{4-km} 10 20 30 40 m/s

Dry Microburst Potential

Gusts > 40 kts
Gusts > 30 kts
Too moist for strong convective gusts
Too stable for upper level TSTMs

Upper Level Instability Index

Storm Category
RPM = 15%

Weak Mod Strong

TROP Lvl: -- ft MSL
FRZG Lvl: 14782 ft MSL
CCL Lvl: -- ft MSL
LFC Lvl: -- ft MSL
LFC Hgt: 2536 ft MSL
CCL Hgt: 2552 ft MSL
LCL Hgt: 1395 ft MSL
Water: 1.80 in
Hail: 0.25 in
T2 Gust: 28 mph
Wind Ex: 35 mph
SWEAT: 212.0
CAP: 1.4
LI: -1.0
TT: 39.2
RI: 27.6
Tc: 27.1 °C

LFC CCL LCL
Lift

40°C MSL KNOTS

METAR 151500Z AUTO VRB04KT DZ SCT014 BKN022 BKN130 25/22 Q1018

The HRRR wind profile depicted northwesterly winds from the surface to approximately 500 ft with wind backing to the southwest above that level. As a result of this shear zone the HRRR sounding indicated an approximately a high probability of moderate turbulence between 400 and 1,000 ft. The mean 0 to 6 km wind was from 210° at 26 knots, with the expect storm motion from 240° at 19 knots. Figure 8 are the 1000 EST HRRR sounding parameters from the surface through 5,000 ft.

Height (ft-MSL)	Pres (hPa)	T (C)	Td (C)	RH (%)	DD / FF (deg / kts)	CAT (FAA)	LLWS	Icing - Type (AFGWC method)
0	1018	25.1	21.8	82	318 / 4			
28	1017	25.1	21.4	80	319 / 4			
113	1014	24.7	21.3	81	318 / 4			
284	1008	24.4	21.0	81	316 / 4	LGT	LIGHT	
543	999	24.0	20.7	82	262 / 3	MDT	LIGHT	
949	985	23.4	20.7	85	203 / 7	MDT	LIGHT	
1508	966	22.2	20.8	92	197 / 13	LGT		
2136	945	20.8	19.6	93	200 / 17			
2867	921	18.7	18.7	100	203 / 17	LGT		
3676	895	17.6	17.5	99	210 / 14	LGT		
4567	867	14.9	14.4	97	220 / 12			
5612	835	13.3	10.1	81	217 / 14	LGT		

Figure 8 - HRRR numerical model sounding parameters

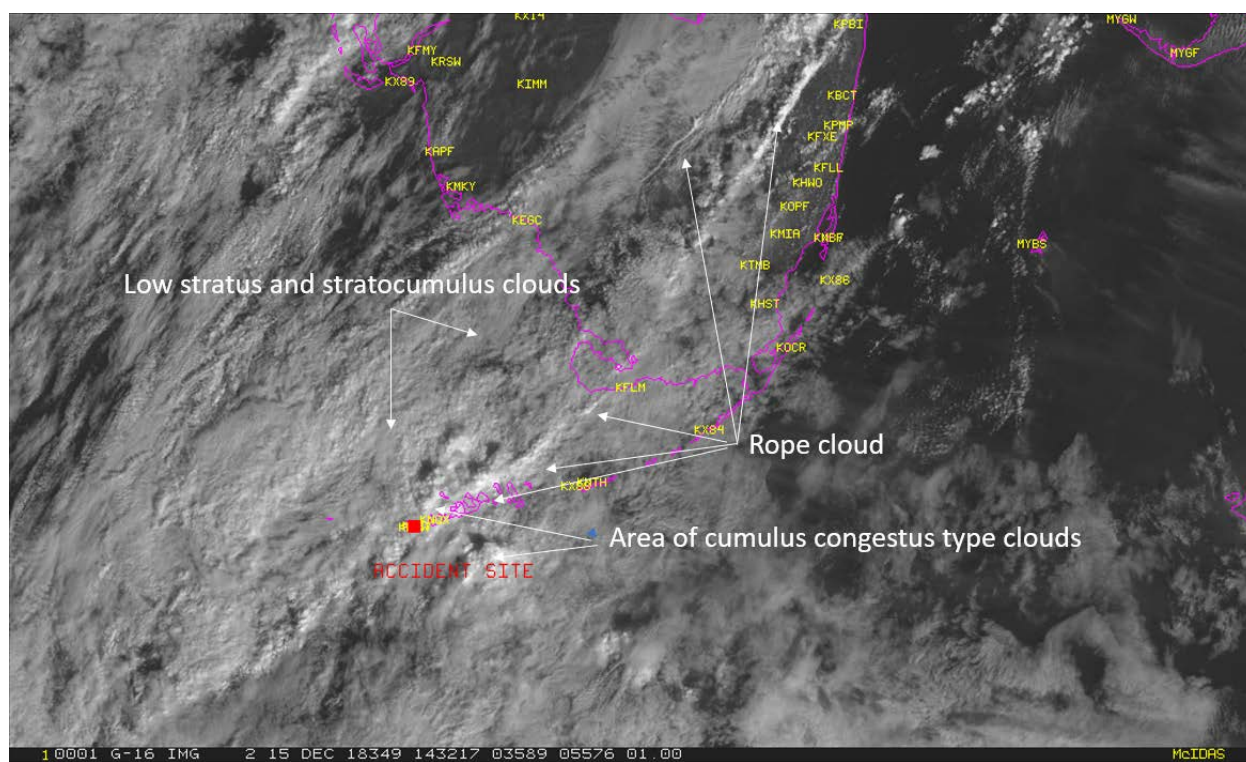
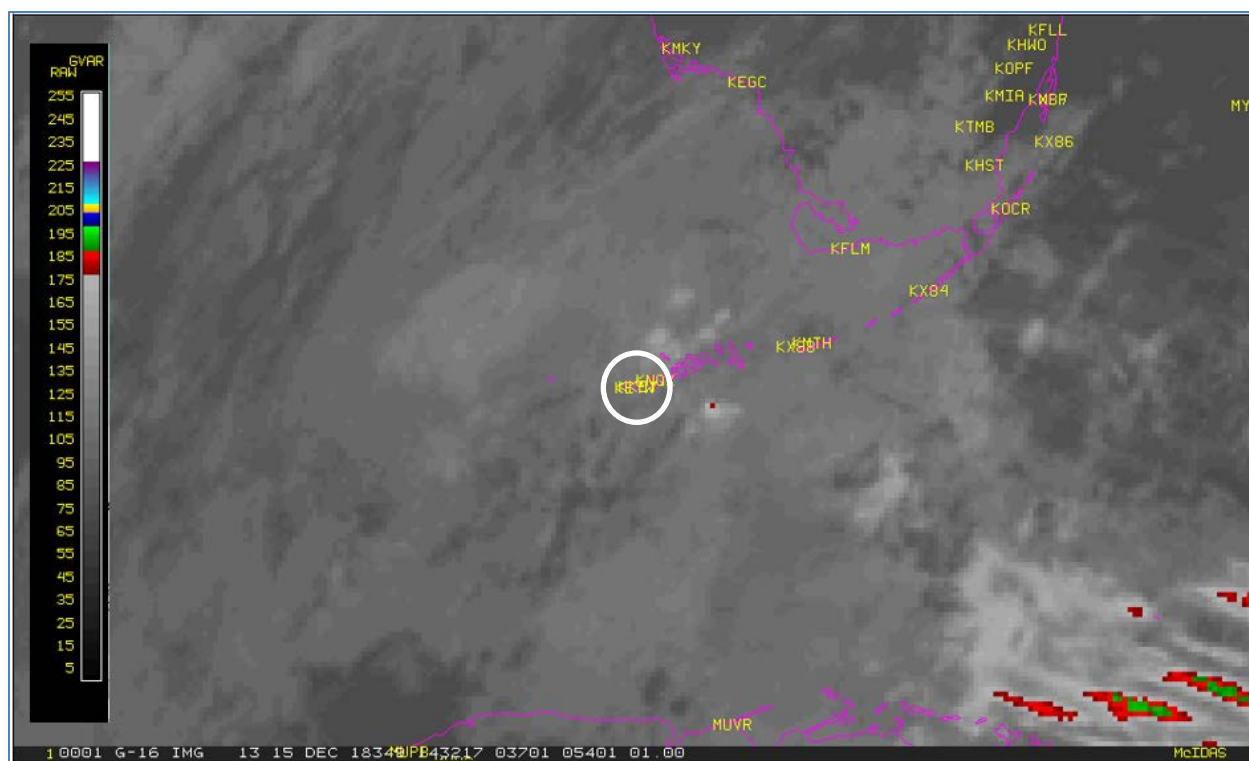
4.0 Satellite Imagery

The Geostationary Operational Environmental Satellite number 16 (GOES-16) data was obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System (McIDAS) software. The infrared long wave and visible imagery were obtained surrounding the time of the accident, with the images closest to the time of the accident documented below. The infrared long wave imagery (band 13) at a wavelength of 10.3 microns (μm) provided radiative cloud top temperatures with a nominal spatial resolution of 2 km. The visible (band 2) at a wavelength of 0.64 μm images at a resolution of 0.5 km.

The GOES-16 infrared band 13 image at 4X magnification with a standard MB temperature enhancement curve applied for 0932 EST is included as figure 9, with the accident site located within the white circle. The image depicted several layers of low, mid-level clouds over the southern Florida and the Keys, with several defined cumulus congestus type clouds, but no defined cumulonimbus type clouds with any extensive anvils. The radiative cloud top temperature over KEYW was 272° Kelvin or -1.16° C, which corresponded to cloud tops near 8,400 ft based on the KEYW sounding.

Figure 10 is the GOES-16 visible band 2 image for the same period at 0932 EST at normal magnification. The high resolution image depicted a line of cumulus congestus or towering cumulus type clouds identified as a “rope cloud” over the KEYW airport and were associated with the rain showers over the area during the period. No defined cumulonimbus anvils associated with defined thunderstorms were identified in the immediate vicinity of the accident site or near KEYW.

⁹ Rope cloud – is a very narrow, long, sometimes meandering, cumulus cloud formation that is frequently visible in satellite imagery. It is generally associated with a cold front or a land-sea breeze front.



5.0 Weather Radar Imagery

The NWS Key West (KBYX), Florida, Weather Surveillance Radar 1988 Doppler (WSR-88D) was located approximately 4 miles northeast of the accident site on Key West. The level II archive data was obtained from the NCEI using the Hierarchical Data Storage System and displayed using the NWS NEXRAD Interactive Viewer and Data Exporter software.

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.

During the period on December 15th the KBYX WSR-88D was operating in the severe storm precipitation mode volume scan pattern 212 (VCP-212), where the radar makes 14 different elevation scans in 4 ½ minutes.

5.1 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors, 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 (dBZ¹⁰) and is a general measure of echo intensity. The chart below (figure 11) relates the NWS video integrator and processor (VIP) intensity levels (1-6) versus the WSR-88D's display levels (0-15), precipitation mode reflectivity in decibels (DBZ), and rainfall rates.

NWS VIP/DBZ CONVERSION TABLE			
NWS VIP	WSR-88D LEVEL	PREC MODE DBZ	RAINFALL
0	0	< 5	
	1	5 to 9	
	2	10 to 14	
1 Very Light	3	15 to 19	.01 in/hr
	4	20 to 24	.02 in/hr
	5	25 to 29	.04 in/hr
2 Light to Moderate	6	30 to 34	.09 in/hr
	7	35 to 39	.21 in/hr
3 Strong	8	40 to 44	.48 in/hr
4 Very Strong	9	45 to 49	1.10 in/hr
5 Intense	10	50 to 54	2.49 in/hr
6 Extreme	11	55 to 59	>5.67 in/hr
	12	60 to 64	
	13	65 to 69	
	14	70 to 74	
	15	> 75	

Figure 11 -WSR-88D VIP reflectivity levels and rainfall rates

¹⁰ dBZ - 10 log Ze

The intensity levels are also referenced 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 new standard radio phraseology used by air traffic controllers to describe weather conditions to pilots as shown in figure 12.

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

Figure 12 - Reflectivity and weather echo intensity terminology chart

5.2 Base reflectivity Images

Figures 12 through 17 are the KBYX WSR-88D 0.5° base reflectivity images at 0918, 0923, 0928, 0932, and 0937 EST showing several cells of 30 to 50 dBZ moving across the KEYW airport associated with the rain showers.

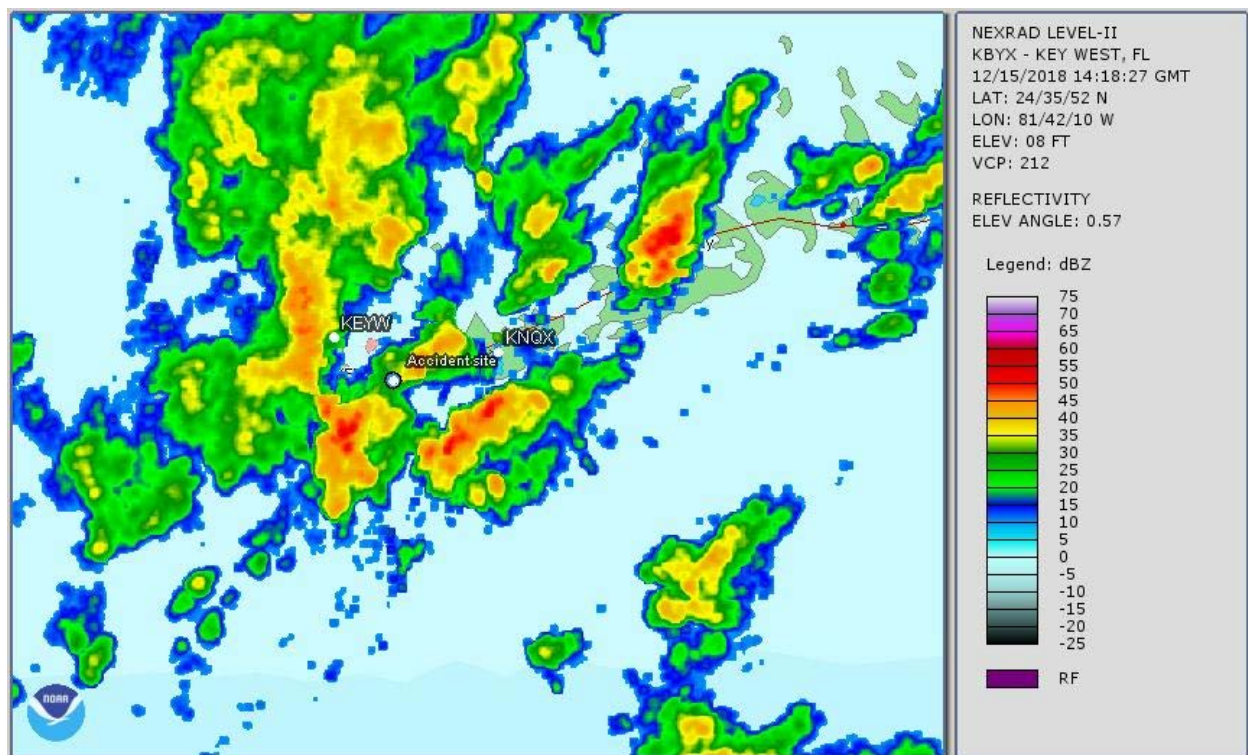


Figure 13 – KBYX WSR-88D 0.5° base reflectivity image for 0918 EST

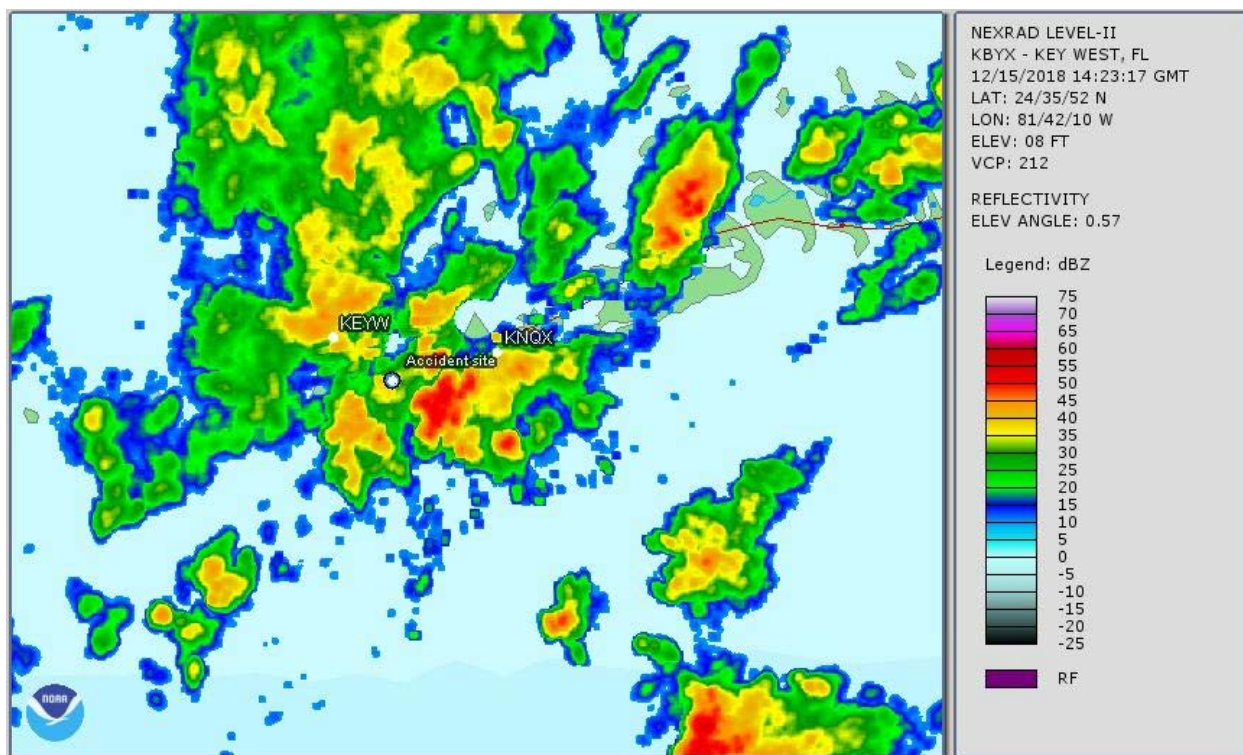


Figure 14 – KBYX WSR-88D 0.5° base reflectivity image for 0923 EST

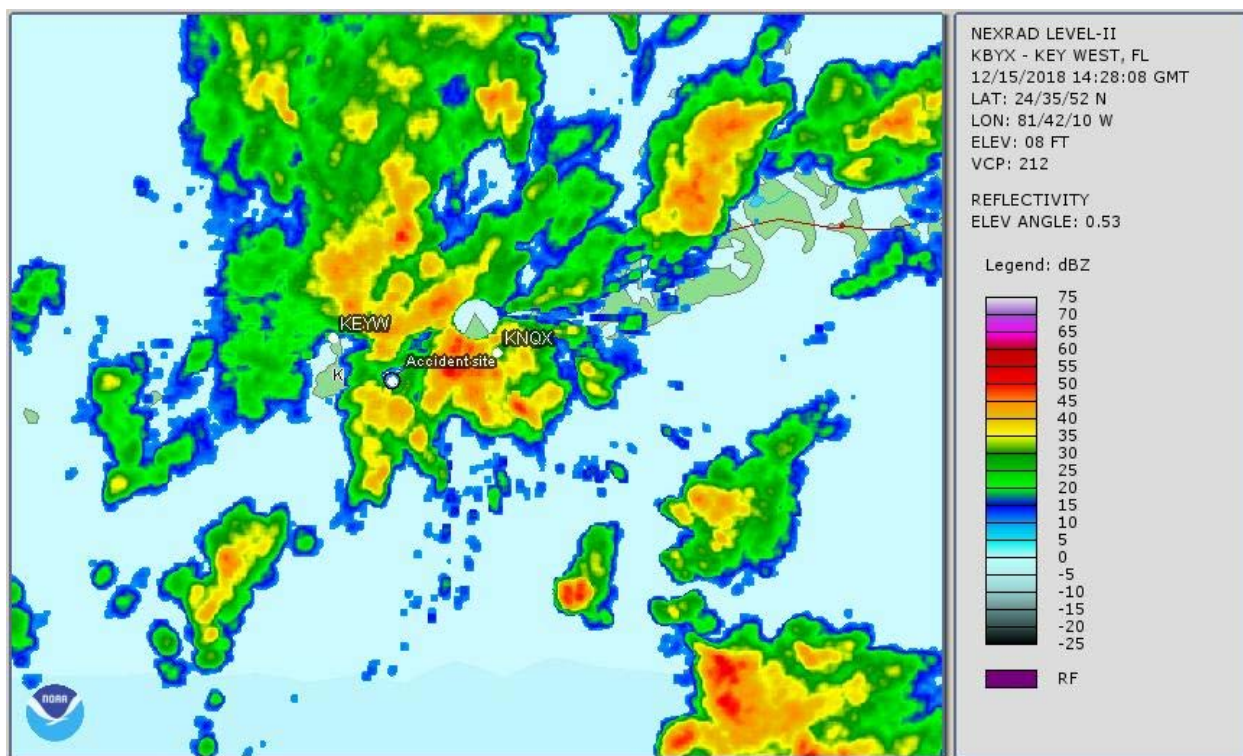


Figure 15 – KBYX WSR-88D 0.5° base reflectivity image for 0928 EST

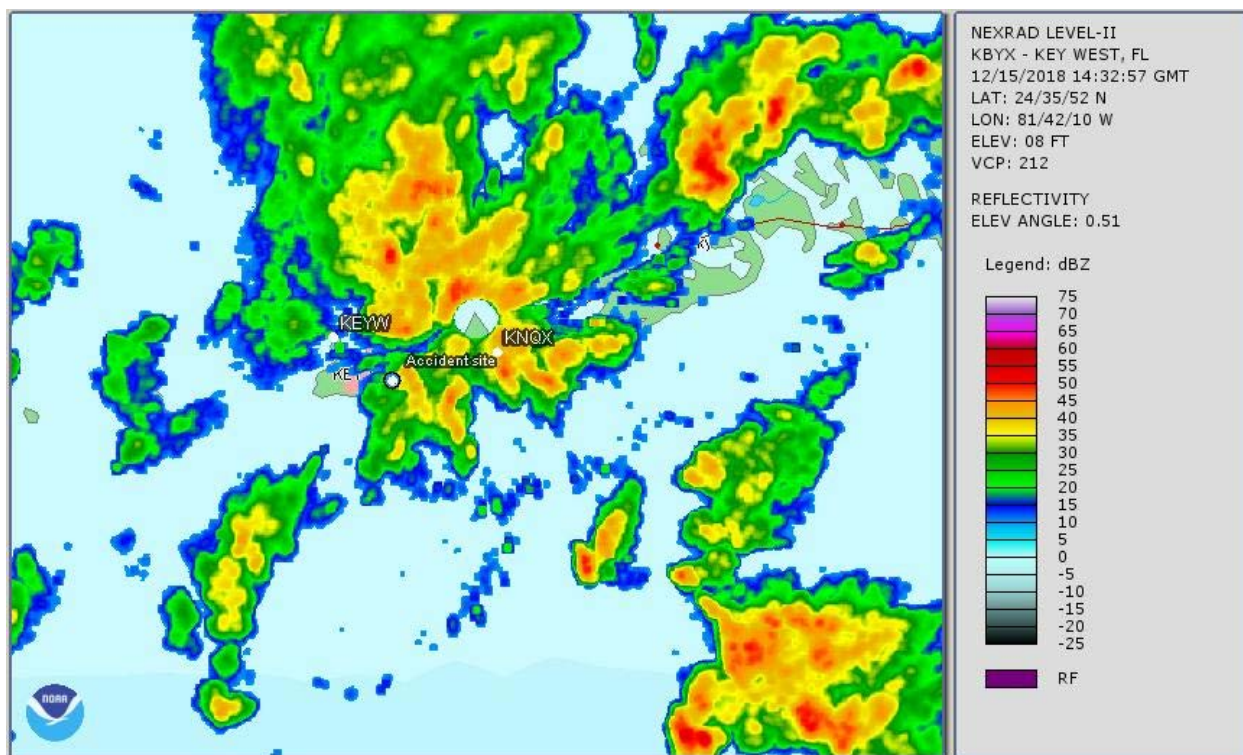


Figure 16 – KBYX WSR-88D 0.5° base reflectivity image for 0932 EST

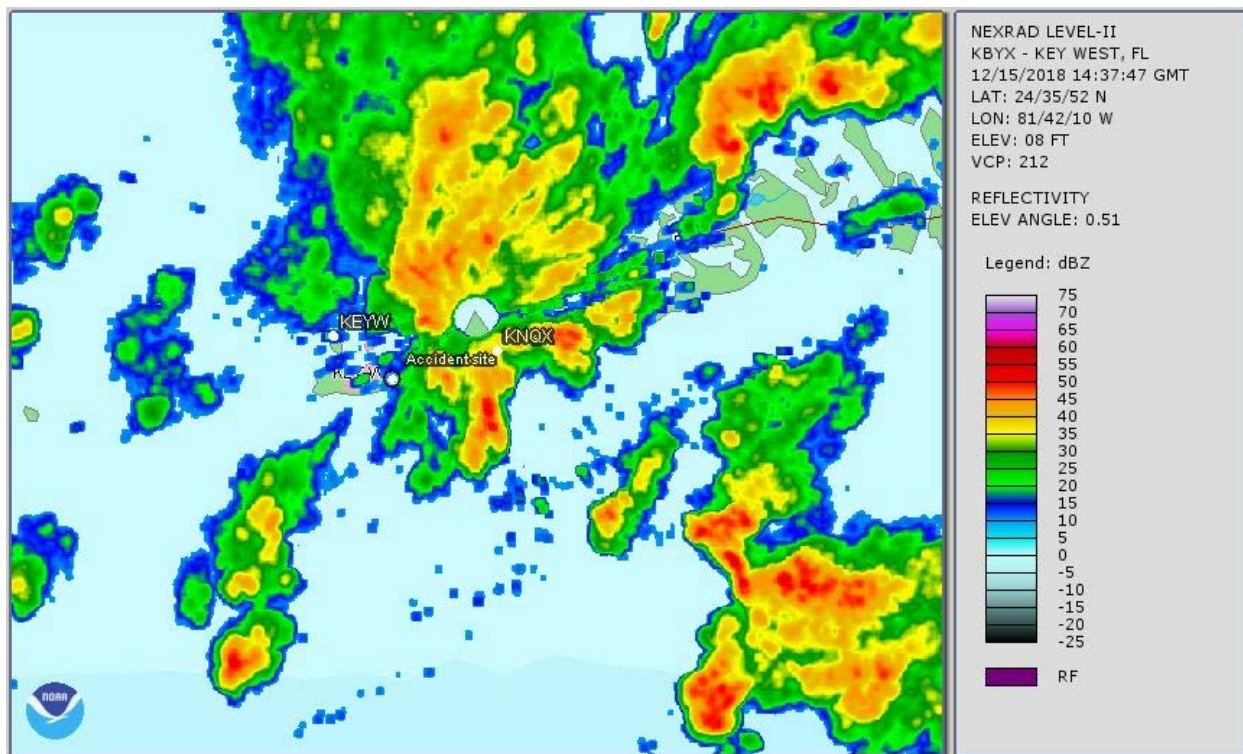


Figure 17 - KBYX WSR-88D 0.5° base reflectivity image for 0937 EST

A review of the KBTX WSR-88D echo tops product during the period indicated maximum height of echoes of 12.5 dBZ only reached between 10,500 and 13,500 ft over the area during the

period. A review of the radial velocity product also did not depict any divergent couplets or any strong outflow winds associated with microbursts or downburst in the vicinity during the period. There the echoes were associated moderate to heavy rain showers.

5.3 FAA CoSPA Radar Display

The FAA Consolidated Storm Prediction for Aviation (CoSPA) weather display was obtained from archives sources from the Massachusetts Institute of Technology (MIT) Lincoln laboratory website for the period surrounding the time of the accident. This weather display is used in the FAA Air Route Traffic Control Center (ARTCC) and Center Weather Service Units (CWSU). The CoSPA images depicts the intensity of the precipitation referenced to vertical integrated liquid (VIL) and is similar to reflectivity. Figure 18 is a chart compares the NWS (VIP) levels 1-6 to the equivalent VIL levels.

VIP or VIL Levels	VIL (digital VIL)	VIL (kg/m ²)	Past and Current VIL	Forecast VIL
1	16	0.15	Level 1	Level 1
2	74	0.76	Level 2	Level 2
3	133	3.47	Level 3	Level 3/4
4	160	6.92	Level 4	Level 3/4
5	181	12.0	Level 5	Level 5/6
6	219	31.6	Level 6	Level 5/6

Figure 18 - VIP/VIL levels

Figure 18 is the CoSPA image of VIL display for 0930 EST along with associated storm features such as lightning strikes, storm movement, echo tops, and 2-hour storm prediction out to 8-hours. The display shows VIP/VIL intensity 3 cells over KEYW moving to the north-northeast at 15 knots, with tops to 25,000 ft over the area with no cloud-to-ground lightning detected. The strongest echoes of level 4 were identified about 20 miles south-southeast of KEYW moving north at 20 knots with tops at 32,000 ft, with storm development to the northeast and continuing through 8 hours.

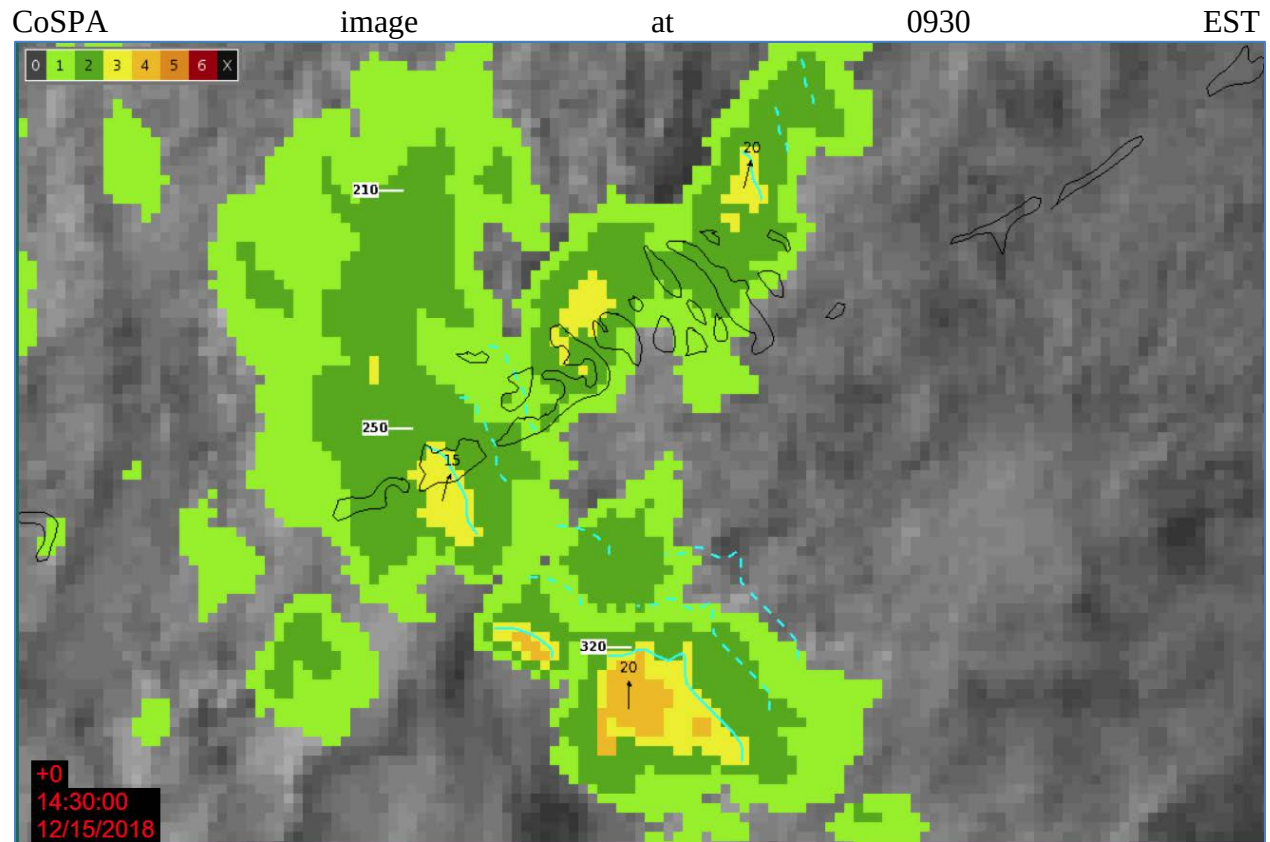


Figure 19 - CoSPA radar and lightning display at 0930 EST

6.0 Pilot Reports

A review of the pilot report summary for Florida for December 15, 2018 indicated no reports within 50 miles of Key West surrounding the period from 0600 through 1100 EST.

7.0 NWS Terminal Aerodrome Forecast

The NWS Key West (KKEY) Weather Forecast Office (WFO), located in downtown Key West was responsible for the issuance of the Terminal Aerodrome Forecast (TAF) for KEYW. A TAF is a concise statement of the expected meteorological conditions at an airport during a specified period (usually 24 hours). TAFs are valid for a 5 mile radius around an airport's center point. The TAF issued prior to the flight's departure was issued at 0629 EST and expected VFR conditions to prevail at the flight's estimated time of arrival, with rain showers in the vicinity of the airport with a southwest wind at 10 knots:

TAF KEYW 151129Z 1512/1612 21006KT P6SM SCT040
FM151300 21010KT P6SM VCSH SCT025 SCT060 BKN100
 FM151800 24009KT P6SM SCT020 BKN050
 FM152200 31012KT P6SM SCT020 BKN040
 FM160000 35009KT P6SM SCT020 BKN040=

Several amended forecasts were issued after the flight departed at 0725, 0821, 0853, and at 0933 EST and were as follows:

AMD TAF KEYW 151225Z 1512/1612 29006KT P6SM VCSH SCT020 SCT040 SCT100

TEMPO 1512/1513 35013G20KT BKN015 BKN040

FM151800 24009KT P6SM SCT020 BKN050

FM152200 31012KT P6SM SCT020 BKN040=

AMD TAF KEYW 151321Z 1513/1612 29006KT P6SM VCSH FEW005 SCT010 SCT020

TEMPO 1513/1514 02008KT BKN005 BKN010

FM151800 24009KT P6SM SCT020 BKN050

FM152200 31012KT P6SM SCT020 BKN040=

AMD TAF KEYW 151353Z 1514/1612 29006KT P6SM VCSH SCT015 SCT020

TEMPO 1514/1516 01008KT 3SM -SHRA BR FEW006 BKN015 BKN020

FM151800 27009KT P6SM SCT020 BKN050

FM152200 31012KT P6SM SCT020 BKN040=

AMD TAF KEYW 151433Z 1515/1612 35010KT P6SM VCSH SCT006 SCT015 SCT020

TEMPO 1515/1517 34012G20KT 1 1/2SM RA BR BKN006 BKN015

BKN020 FM151800 27009KT P6SM SCT020 BKN050 FM152200 31012KT

P6SM SCT020 BKN040=

8.0 Area Forecast Discussion

The NWS KKEY WFO issued the following Area Forecast Discussion providing additional background and details behind their TAF forecasts.

FXUS62 KKEY 150933

AFDKEY

Area Forecast Discussion

National Weather Service Key West FL

433 AM EST Sat Dec 15, 2018

.DISCUSSION...

*Dry and unseasonably warm weather prevails over the Florida Keys on this early Saturday morning. Temperatures have hovered in the mid 70s to near 80 degrees overnight, thanks to gentle southerly breezes coming off the warm waters of the Florida Straits. Skies are partly to mostly cloudy, but very little rainfall has been observed over the island chain during the night. **Radar shows a line of showers over the Gulf waters and western Straits, with a few showers also developing recently over the Gulf side waters north of the Lower Keys. No lightning has been detected over the marine area with this activity during the last few hours.***

***Regional satellite imagery depicts a large mid-latitude cyclone centered over AL/MS at this hour, with the trailing cold front located over southern Florida and into the southeastern Gulf of Mexico. A rope cloud associated with the line of showers mentioned above lies over our Gulf waters and the western Straits.** Model guidance is in good agreement with the large cyclone to our north moving to the mid Atlantic coast by Sunday morning, then offshore into the western Atlantic. The cold front is expected to pass through the Keys during the day, then clear through the Straits this evening. With the main forcing associated with the cyclone now lifting well to the north of our region, and a weakening front moving through our area, rain chances for today remain quite uncertain. Have gone with mid-range chance pops of 50 percent for today, along with a continued slight chance of thunderstorms.*

A drier airmass will gradually filter into the area tonight through Sunday night behind the front. There will be enough lingering moisture within southwest flow in the lower-mid levels above the shallow frontal inversion to keep slight rain chances in the forecast during this time.

Dry and modestly cooler weather will prevail for Monday through Tuesday, with gentle north breezes and temperatures dropping slightly below normal. Forecast uncertainty increases considerably by midweek and beyond, when model guidance develops a rather strong low pressure area over the Southeastern states in response to a digging mid/upper trough. This would bring our flow back around to the south, with increasing rain chances and warmer temperatures for the later part of the week, and possibly another frontal passage by the end of the week.

.AVIATION...

VFR conditions expected to prevail at both terminals, with increasing clouds and VCSH ahead of a cold front. Winds will gradually veer from south to southwest as the front slowly approaches, reaching the terminals around 15/18Z. VCSH after 09/12Z. Expect northwest to north winds with gusts up to 16 knots behind the front. Ceilings will be between FL040 and FL050 and persist for the next day or two.

The aviation discussion described the wind direction, shift with the passage of the front with increased gusts behind the front, but missed the timing of the passage of the front through KEYW, which occurred prior to the accident.

9.0 Inflight Weather Advisories

Inflight Aviation Weather Advisories are forecasts to advise en route aircraft of 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 ARTCCs. There are four basic types of inflight aviation weather advisories: the Significant Meteorological Information (SIGMET), the Convective SIGMET, the AIRMET, and the Center Weather Advisory (CWA). Inflight advisories serve to notify en route pilots of the possibility of encountering hazardous flying conditions which may not have been forecast at the time of the preflight briefing. Whether or not the condition described is potentially hazardous to a particular flight is for the pilot to evaluate on the basis of experience and the operational limits of the aircraft.

The NWS AWC issued several Convective SIGMETs for activity off the northeast Florida coast during the period but no advisories for south Florida that extended over the Keys or the accident site. And no SIGMETs, AIRMETs, or CWAs issued for the area that were valid at the time of the accident.

10.0 Center Weather Service Unit Products

As mentioned in section 9.0 the Miami CWSU did not issue any CWAs for any hazardous weather conditions during the period prior to 1200 EST, they also did not issue any Meteorological Impact Statements (MIS) for any other hazard weather conditions for air traffic control planning. The KZMA CWSU also collaborates in the development of convective forecasts impacting the National airspace system in the Traffic Flow Management (TFM) Convective Forecast. The convective forecast current at the time of the accident is included as figure 20 and depicted the

possibility of scattered convective activity off the Florida east coast, but no activity across the Florida Keys.

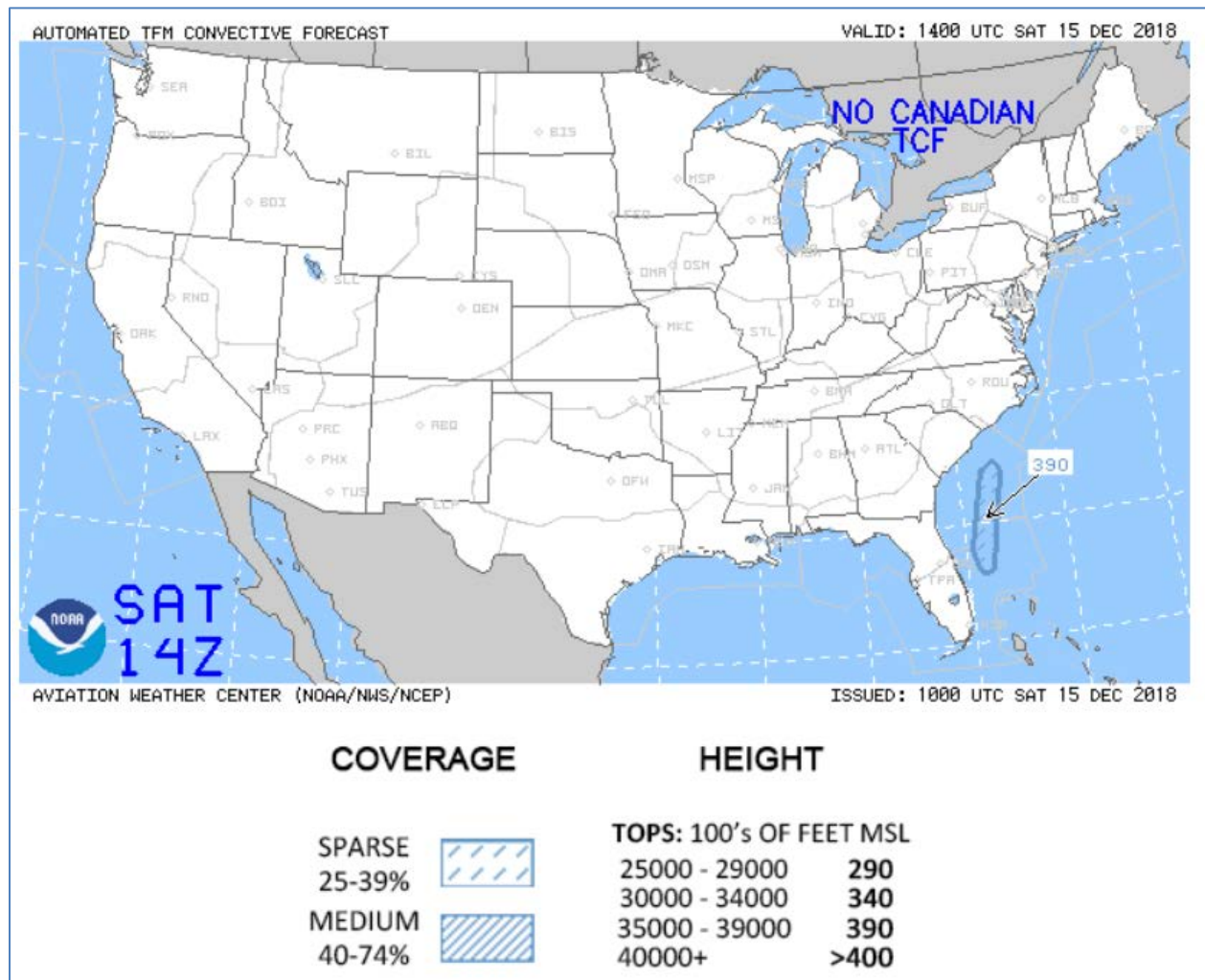


Figure 20 - TFM Convective Forecast issued at 0500 EST for 0900 EST

Submitted by:

Don Eick
Senior Meteorologist