



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

January 6, 2022

Specialist's Factual Report

METEOROLOGY

ERA21FA354

A. ACCIDENT

Location: Provincetown, Massachusetts
Date: September 9, 2021
Time: about 1527 eastern daylight time (EDT)
1927 coordinated universal time (UTC)
Airplane: Cape Air flight 345, Cessna 402C; Registration: N88833

B. METEOROLOGY SPECIALIST

Donald Eick
Operational Factors Division (AS-30)
National Transportation Safety Board
Washington, DC

C. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's Senior Meteorologist was not on scene for this investigation and conducted the meteorology phase of the investigation remotely, collecting data from official National Weather Service (NWS) sources including the Weather Prediction Center (WPC) and the National Center for Environmental Information (NCEI). All times are reported as EDT based upon the 24-hour clock, local time is -4 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 main wreckage site was located at latitude 42.075993° N, longitude 70.211744°, at an elevation of approximately 8 ft.

D. FACTUAL INFORMATION

1.1 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 Weather Prediction Center (WPC) located in College Park, Maryland. These are the base products used in describing weather features and in the creation of forecasts and warnings. Reference to these charts can be found in the joint NWS and Federal Aviation Administration (FAA) Advisory Circular "Aviation Weather Services", AC 00-45H change 2.

1.2 Surface Analysis

The NWS WPC northeast Surface Analysis Chart for 1400 EDT is included as figure 1 with the approximate accident site marked by a red star. The chart depicted a low-pressure system with a central pressure of 1007-hectopascals (hPa)¹ off the Maryland and Delaware coast along a frontal wave, with a stationary front extending northward and turning into a cold front through Long Island, Connecticut, Massachusetts, New Hampshire, and Maine. This cold front was located west of the accident site and moving eastward. Another cold front was identified extending southward from Quebec, Canada, into central New York, then southwestward into western New York, Pennsylvania, and Ohio. Another east-to-west stationary front was over the Atlantic Ocean to the east-northeast off Nova Scotia, Canada.

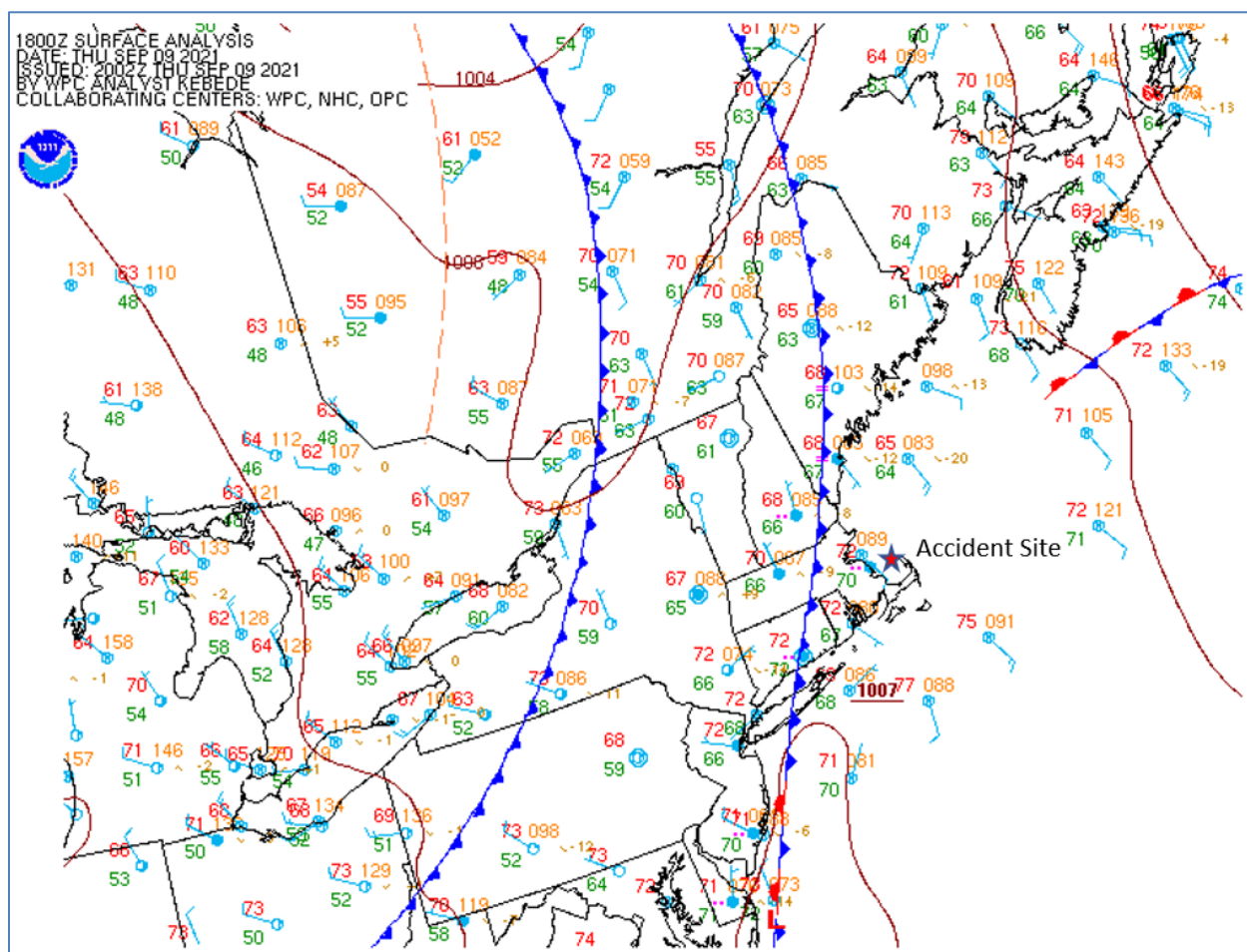


Figure 1 - NWS northeast section of the Surface Analysis Chart for 1400 EDT with the accident site.

The station models surrounding the accident site depicted southerly winds between 5 and 15 knots, overcast clouds, temperature near 72° Fahrenheit (F), and dew point temperature near 70° F, with several stations reporting rain.

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

1.3 National Forecast Chart

The NWS WPC 12-hour Surface Forecast depicting the expected conditions at 2000 EDT is included as figure 2. The chart depicted the expected movement of the pressure systems, fronts, and expected precipitation over the United States. The chart depicted the low-pressure system as having moved northward into eastern Massachusetts with the cold front extending south-southwestward off the coast over in the Atlantic Ocean and a stationary front stretching northward into Maine. An area of likely measurable rain (dark green) with a 60-70% probability of precipitation extended over the accident site and an area of thunderstorms was expected to the north and northeast of the low-pressure center over Maine and New Brunswick.

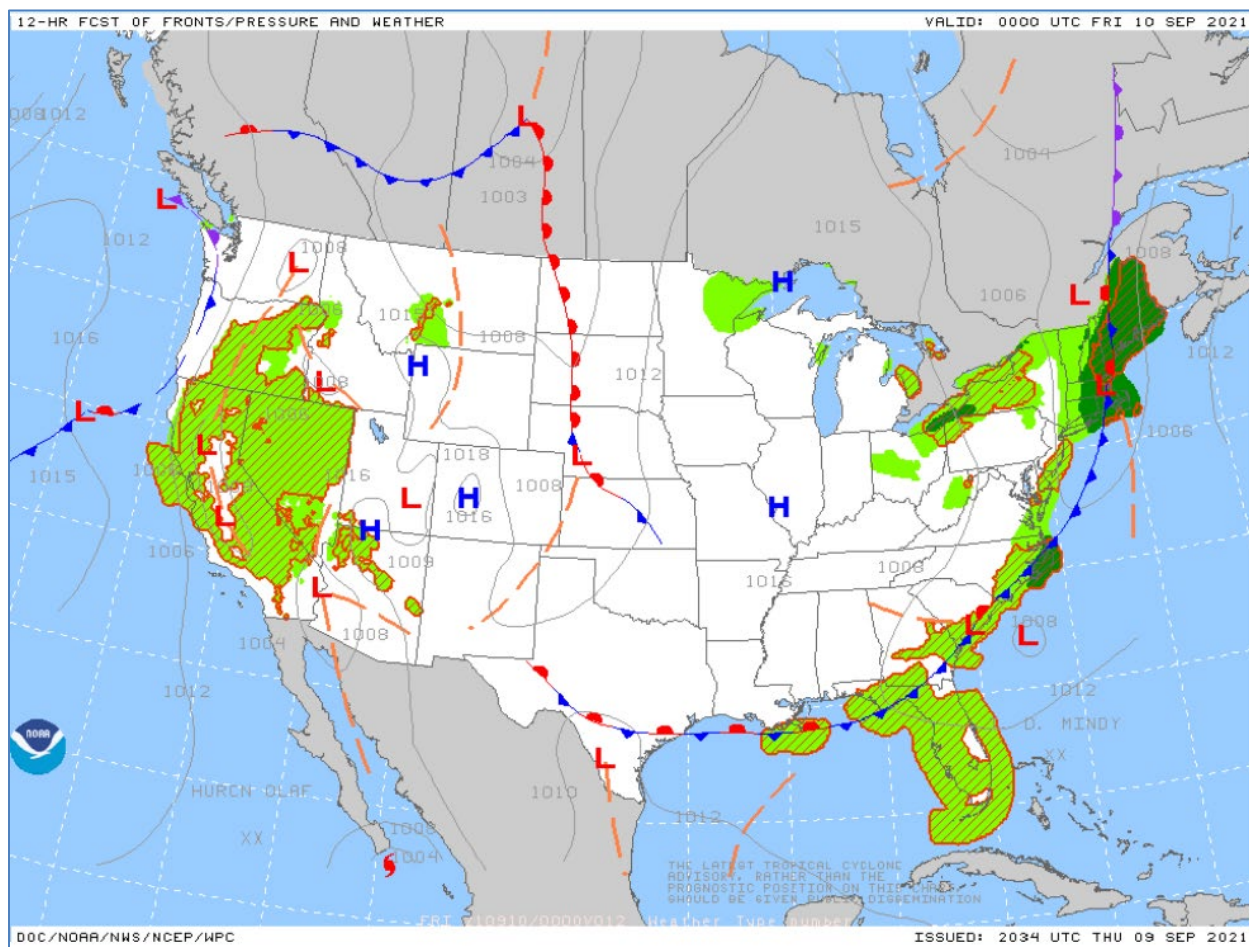


Figure 2 - 12-hour Surface Forecast valid for 2100 EDT.

1.4 Convective Outlook

The NWS Storm Prediction Center's (SPC) Day 1 Convective Outlook issued at 1130 EDT is included as figure 3. The outlook expected a general risk of airmass or ordinary thunderstorms over the eastern US coast, with no organized severe thunderstorms expected during the period.

Sep 9, 2021 1630 UTC Day 1 Convective Outlook

Updated: Thu Sep 9 16:11:37 UTC 2021 (📄 | 🗺️)
 Probabilistic to Categorical Outlook Conversion Table

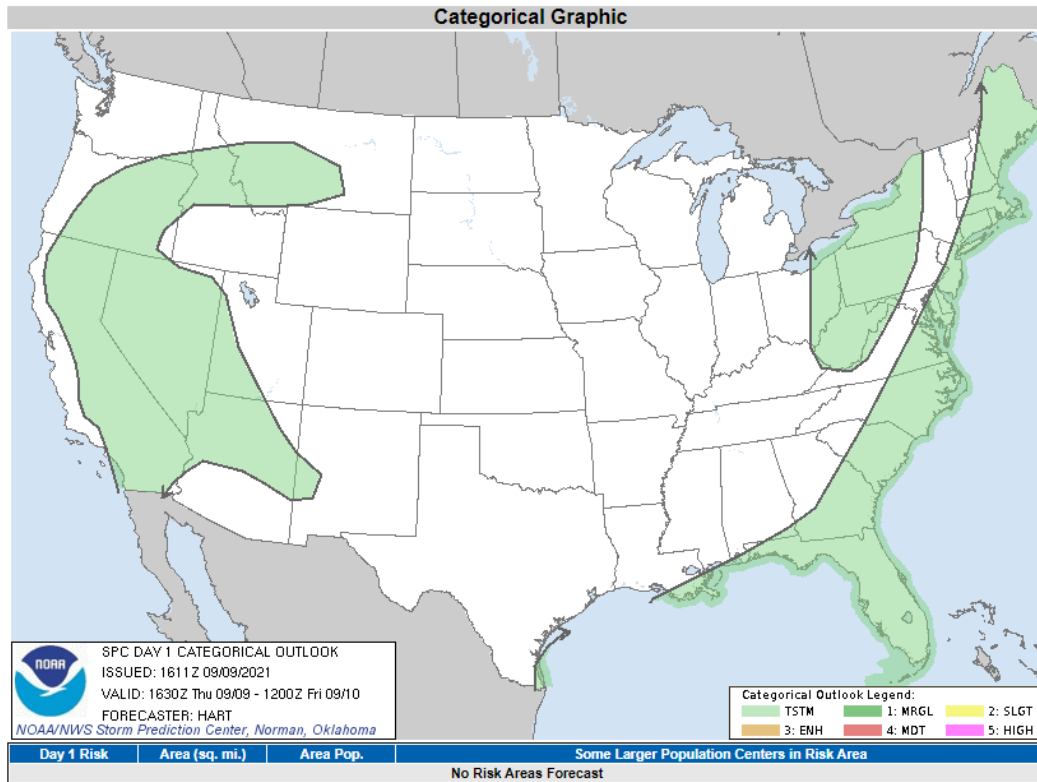


Figure 3 - NWS Storm Prediction Center's Convective Outlook issued at 1130 EDT.

The narrative to the NWS SPC Convective Outlook relevant for the area was as follows.

SPC AC 091611

Day 1 Convective Outlook

NWS Storm Prediction Center Norman OK

1111 AM CDT Thu Sep 09 2021

Valid 091630Z - 101200Z

...NO SEVERE THUNDERSTORM AREAS FORECAST...

...SUMMARY...

Severe thunderstorms are not expected across the U.S. today through tonight.

...Southeast MA...

Scattered afternoon and evening thunderstorms will affect much of the eastern United States and Upper Ohio Valley. The only area that could pose a low-end risk of a strong storm would be over Cape Cod. A series of thunderstorm clusters is currently noted along a warm front stretching from south of Long Island to just off the coast of southeast MA. The boundary is likely to stay offshore during this period, keeping the primary severe threat over the ocean. Nevertheless, a strong storm could affect areas around Nantucket or Cape Cod this afternoon, capable of gusty winds or a waterspout. Given the very small affected area and limited confidence, will not introduce a MRGL risk area.

..Hart.. 09/09/2021

2.0 Observations

The official observations issued surrounding the accident site were documented using Aviation Routine Weather Reports (METAR²) and Aviation Select Special Weather Reports (SPECI). Cloud heights are reported above ground level (agl) in the following section, and the magnetic variation was estimated at 15° west based on the latest sectional chart for the area.

2.1 Provincetown, Massachusetts

The accident occurred as the airplane was landing on runway 7 at Provincetown Municipal Airport (KPVC)³, Provincetown, Massachusetts, which lists an elevation of 8 ft. The airport had an Automated Weather Observation System (AWOS), which was not augmented by any human observers and issued observations longline⁴ hourly with specials as required. The following conditions were reported at the approximate time of the accident.

Weather observation for KPVC at 1456 EDT, automated, wind from 200° at 5 knots, visibility 4 miles in moderate rain and mist, ceiling broken at 200 ft agl, overcast at 600 ft agl, temperature 21° C, dew point temperature 21° C, altimeter 29.79 inches of mercury (inHg). Remarks: automated station with a precipitation discriminator, sea level pressure 1008.8-hPa, hourly precipitation 0.27 inches, temperature 21.1° C, dew point 21.1° C.

Accident 1527 EDT

Special weather observation for KPVC at 1537 EDT, automated, wind from 210° at 10 knots, visibility 3 miles in heavy rain and mist, a few clouds at 200 ft agl, ceiling broken at 3,400 ft agl, overcast at 5,000 ft agl, temperature 21° C, dew point temperature 21° C, altimeter 29.79 inHg. Remarks: automated station with a precipitation discriminator, hourly precipitation 0.02 inches.

The observations surrounding the time of the accident indicated low instrument flight rule conditions (LIFR) to marginal visual flight rule conditions (MVFR) due to the low broken ceiling at 200 ft agl, with visibility 3 to 4 miles in moderate to heavy rain and mist. The surface temperature and dew point were reported at 70° F (21.1° C), with 100% relative humidity, which resulted in a density altitude of 1,195 ft. Based on the 1456 EDT observation, the wind for runway 7 with a true heading of 059° resulted in a tailwind component of 4 knots with a right crosswind of 3 knots. The hourly precipitation total was 0.22 inches that was reported during the hour between 1457 and 1537 EDT, with a total of approximately 0.92 inches reported on September 9th at the time of the accident. The total rainfall at the end of the day was 1.38 inches.

² METAR is an abbreviation for meteorological aerodrome report.

³ KPVC has a single asphalt runway 7/25, at 3502 ft long by 100 ft wide, with an ILS precision approach procedure to runway 7, and nonprecision approach procedures for runway 25.

⁴ The AWOS issues METARs hourly with SPECIs as required for transmission on weather circuits to users. The system also provides the latest observation by VHF radio every minute for pilots in the local area, these observations are not archived.

The general flight categories⁵ and raw observations surrounding the period from 0655 through 2000 EDT were as follows:

VFR METAR KPVC 091056Z AUTO 16010KT 10SM SCT026 BKN060 22/20 A2983 RMK AO2 LTG DSNT W SLP099 T02220200=

MVFR METAR KPVC 091156Z AUTO 18010KT 5SM RA BR SCT021 BKN028 OVC055 21/21 A2984 RMK AO2 RAB07 SLP105 P0013 60013 70013 T02110206 10222 20211 53005=

MVFR SPECI KPVC 091243Z AUTO 18008KT 8SM BKN013 BKN075 22/21 A2984 RMK AO2 RAE17 P0001=

MVFR METAR KPVC 091256Z AUTO 17008KT 8SM BKN011 OVC080 22/21 A2984 RMK AO2 RAE17 SLP103 P0001 T02170211=

VFR SPECI KPVC 091353Z AUTO 19010KT 10SM FEW013 SCT029 22/21 A2985 RMK AO2 LTG DSNT E RAB15E46 P0000=

VFR METAR KPVC 091356Z AUTO 19010KT 10SM FEW013 SCT025 SCT031 22/21 A2985 RMK AO2 RAB15E46 SLP107 P0000 T02170211=

MVFR SPECI KPVC 091412Z AUTO 20012G18KT 10SM -RA SCT023 BKN029 22/21 A2985 RMK AO2 RAB1357 P0000=

VFR SPECI KPVC 091443Z AUTO 19009KT 10SM -RA FEW021 SCT050 22/22 A2985 RMK AO2 RAB1357 P0000=

VFR METAR KPVC 091456Z AUTO 18010G14KT 10SM -RA FEW049 22/22 A2985 RMK AO2 RAB1357 SLP106 P0000 60001 T02220217 50003=

VFR SPECI KPVC 091514Z AUTO 18008KT 10SM FEW008 22/22 A2984 RMK AO2 RAE11 P0000=

VFR METAR KPVC 091556Z AUTO 18009KT 10SM -RA FEW029 22/22 A2982 RMK AO2 SLP098 P0000 T02220217=

VFR METAR KPVC 091656Z AUTO 20007KT 10SM -RA SCT033 SCT060 BKN090 22/21 A2981 RMK AO2 SLP093 P0001 T02170211=

MVFR SPECI KPVC 091733Z AUTO 25008KT 3SM +RA BR FEW007 BKN040 OVC075 21/21 A2982 RMK AO2 P0012=

IFR METAR KPVC 091756Z AUTO 23006KT 2 1/2SM +RA BR FEW030 BKN050 OVC060 21/21 A2981 RMK AO2 SLP095 P0028 60030 T02110206 10222 20211 55010=

MVFR SPECI KPVC 091830Z AUTO 21007KT 3SM RA BR SCT006 BKN034 OVC046 21/21 A2981 RMK AO2 P0023=

⁵ 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.

LIFR METAR KPVC 091856Z AUTO 20005KT 4SM RA BR BKN002 OVC006 21/21 A2979 RMK AO2
SLP088 P0027 T02110211=

Accident 1927Z

MVFR SPECI KPVC 091937Z AUTO 21010KT 3SM +RA BR FEW002 BKN034 OVC050 21/21 A2979 RMK AO2
P0022=

VFR METAR KPVC 091956Z AUTO 21007KT 10SM -RA FEW026 SCT033 SCT041 21/21 A2977 RMK AO2
SLP081 P0024 T02110211=

VFR METAR KPVC 092056Z AUTO 15005KT 10SM -RA SCT060 BKN110 21/21 A2976 RMK AO2 RAE04B32
SLP076 P0000 60051 T02060206 56019=

VFR METAR KPVC 092156Z AUTO 14006KT 10SM FEW090 SCT120 21/20 A2974 RMK AO2 RAE37 SLP069
P0000 T02060200=

IFR METAR KPVC 092256Z AUTO 22007KT 2 1/2SM +RA BR FEW028 BKN041 OVC060 21/20 A2977 RMK
AO2 RAB2157 SLP079 P0019 T02060200=

VFR SPECI KPVC 092321Z AUTO 35003KT 8SM RA FEW026 OVC037 19/19 A2974 RMK AO2 P0021=

VFR SPECI KPVC 092350Z AUTO 00000KT 9SM -RA FEW007 BKN041 OVC055 19/19 A2976 RMK AO2
P0023=

VFR METAR KPVC 092356Z AUTO 00000KT 6SM -RA BR FEW007 BKN049 OVC055 19/19 A2975 RMK AO2
SLP074 P0025 60095 T01940194 10217 20194 50005

The observations indicated that MVFR to LIFR conditions prevailed in the period between 1330 through 1537 EDT surrounding the time of the accident.

According to a FAA Technical Operations Manager responsible for maintenance and service of the AWOS system, the KPVC AWOS completed a 4-month preventative maintenance on September 7, 2021, where no anomalies were found with the system. He indicated that a review of the data from KPVC indicated that the AWOS was in good condition and reporting normally and found within tolerance. A more detailed evaluation of the AWOS was scheduled and was completed on September 27, 2021, with no anomalies detected or adjustments required.

The FAA Technical Operations Manager was also able to retrieve some high-resolution data from the system immediately after the accident. Below is the AWOS 1-minute data between 1446 through 1537 PDT including the average 2-minute wind direction and wind speed, updated every minute, the present weather, the precipitation intensity⁶ estimation, and monthly precipitation or water summary for the month⁷ for September 9, 2021. The time of the accident is highlighted in bold red text. The 1-minute data indicated that heavy rain began at 1522 and continued through 1536 EDT

⁶ The precipitation intensity is not a 1-minute accumulation amount.

⁷ On September 2, 2021, KPVC reported over 2.07" of precipitation, which is included in the water summary below.

Time (EDT)	Wind Dir (°mag)	Wind Speed	Present WX	Precip Intensity	Water Sum
1456	191	3.3	R	0.09	2.38
1457	176	5.4	R	0.13	2.39
1458	196	4.9	R	0.10	2.39
1459	201	5.4	R-	0.05	2.40
1500	190	4.8	R-	0.06	2.40
1501	193	7.4	R	0.11	2.40
1502	186	6.0	R	0.08	2.40
1503	191	4.5	R-	0.05	2.40
1504	193	5.8	R-	0.07	2.40
1505	176	5.2	R-	0.03	2.40
1506	198	6.9	R-	0.02	2.40
1507	194	7.4	R-	0.03	2.40
1508	190	6.9	R-	0.02	2.40
1509	173	4.7	R-	0.03	2.40
1510	199	5.7	R-	0.04	2.40
1511	197	5.1	R	0.14	2.41
1512	190	5.4	R	0.16	2.41
1513	196	8.2	R	0.12	2.41
1514	192	5.9	R	0.10	2.41
1515	182	6.5	R	0.21	2.42
1516	175	6.3	R	0.25	2.42
1517	201	8.2	R	0.25	2.42
1518	189	6.8	R	0.27	2.43
1519	210	8.9	R	0.23	2.43
1520	212	6.4	R	0.23	2.44
1521	199	8.2	R	0.21	2.44
1522	193	8.4	R+	0.40	2.45
1523	203	8.9	R+	0.54	2.46
1524	194	11.2	R+	0.72	2.47
1525	212	8.5	R+	0.33	2.47
1526	199	11.0	R+	0.59	2.48
1527	213	12.4	R+	0.46	2.49
1528	215	9.9	R+	0.61	2.50
1529	219	10.7	R+	0.74	2.51
1530	217	8.3	R+	0.75	2.53
1531	222	12.5	R+	1.12	2.54
1532	218	9.7	R+	0.77	2.56
1533	213	12.4	R+	0.56	2.57
1534	212	8.1	R+	0.81	2.58
1535	200	8.7	R+	0.66	2.59
1536	204	8.4	R	0.24	2.60
1537	218	8.9	R	0.29	2.60

2.2 Boston, Massachusetts

The accident airplane departed from General Edward Lawrence Logan International Airport (KBOS), Boston, Massachusetts, around 1504 EDT. The airport had an Automated Surface

Observation System (ASOS) and was augmented by tower personnel during the period, and listed an elevation of 19 ft. At the time of departure, the following conditions were reported.

Weather observation for KBOS at 1454 EDT, wind from 170° at 7 knots, visibility 10 miles in light rain, scattered clouds at 2,500 ft agl, ceiling overcast at 12,000 ft, temperature 23° C, dew point temperature 21° C, altimeter 29.77 inHg. Remarks: automated station with a precipitation discriminator, sea level pressure 1008.0-hPa, hourly precipitation 0.01 inches, temperature 23.3° C, dew point 20.6° C.

The following general flight categories and weather conditions were reported between about 1200 through 2000 EDT.

MVFR SPECI KBOS 091607Z 19007KT 10SM BKN017 OVC120 24/21 A2980 RMK AO2 T02390211=

VFR METAR KBOS 091654Z 18008KT 10SM -RA FEW015 SCT022 OVC110 24/21 A2980 RMK AO2
RAB12E23B43 SLP089 P0000 T02390211=

MVFR SPECI KBOS 091732Z 18006KT 10SM -RA FEW017 BKN028 OVC049 23/21 A2979 RMK AO2 P0000
T02330211=

MVFR METAR KBOS 091754Z 19005KT 10SM -RA FEW018 BKN028 OVC110 23/21 A2979 RMK AO2 SLP089
P0001 60003 T02330211 10239 20233 56003=

VFR METAR KBOS 091854Z 17007KT 10SM -RA SCT025 OVC120 23/21 A2977 RMK AO2 SLP080 P0001
T02330206=

Departure 1904Z

VFR METAR KBOS 091954Z 18008KT 10SM -RA FEW022 SCT080 OVC110 23/21 A2975 RMK AO2 SLP073
P0001 T02330206=

VFR METAR KBOS 092054Z 19004KT 10SM -RA SCT013 SCT019 BKN120 OVC140 23/21 A2974 RMK AO2
SLP071 P0001 60003 T02330211 58009=

MVFR SPECI KBOS 092059Z 22005KT 10SM -RA BKN013 BKN021 BKN120 23/21 A2974 RMK AO2 P0000
T02330206=

VFR METAR KBOS 092154Z 22006KT 10SM RA SCT017 BKN110 OVC140 23/20 A2975 RMK AO2 SLP075
P0003 T02330200=

MVFR METAR KBOS 092254Z 23005KT 4SM RA FEW017 BKN065 OVC110 22/19 A2974 RMK AO2 SLP072
P0010 T02220194=

2.3 Aviation Weather Center's METAR Display

A display of the observations over the region at 1435 EDT from the NWS Aviation Weather Center's (AWC) website⁸ is included as figure 4 with the regional radar display overlaid. The station models depicted the general flight conditions and observed weather data with temperatures and dew point temperatures reported in °F.

⁸ <https://www.aviationweather.gov/metar?gis=on>

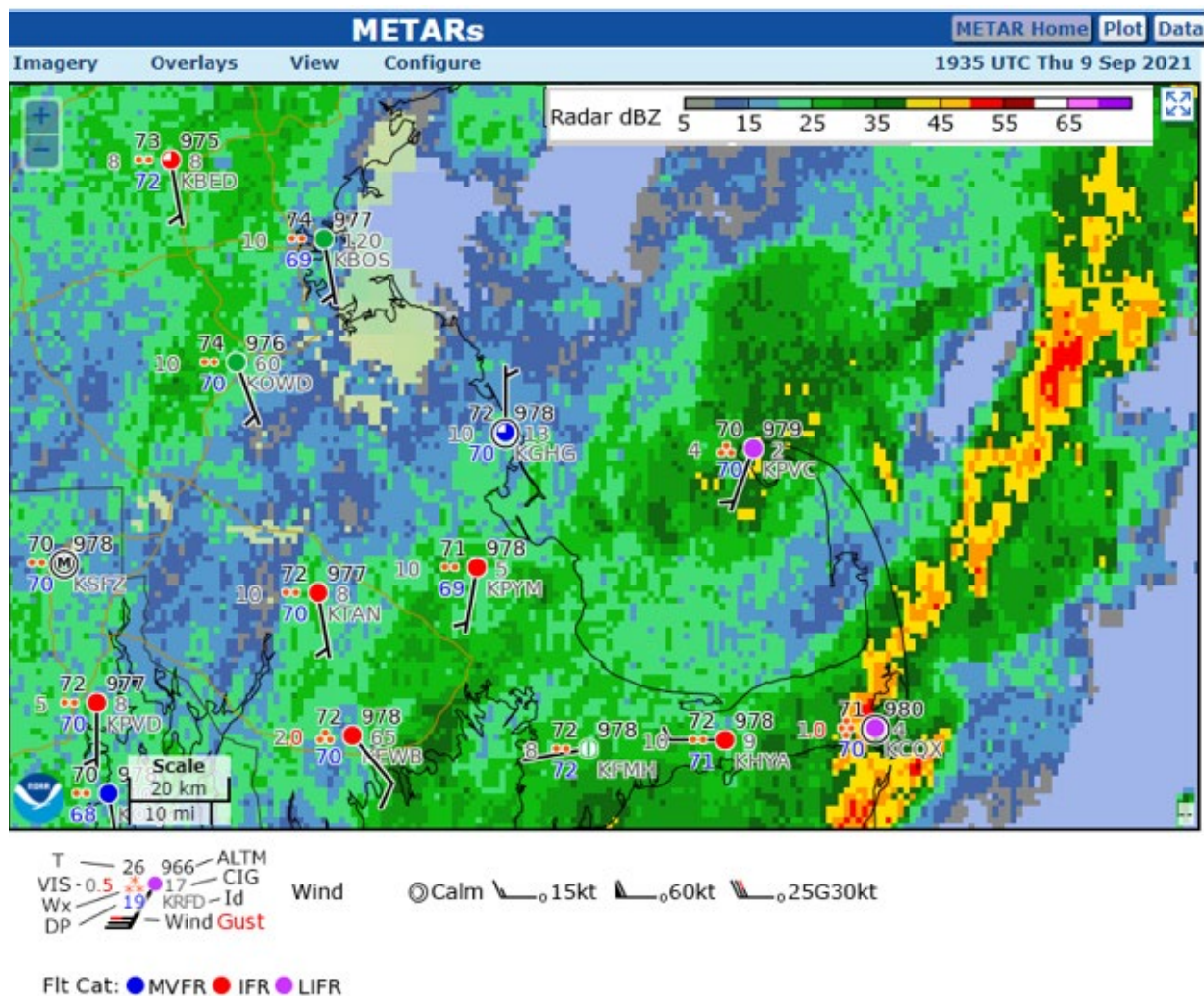


Figure 4 - NWS Aviation Weather Center's METAR display at 1435 EDT over the region.

The image depicted a northeast-to-southwest line of intense to extreme echoes east of KPVC with an area of moderate echoes over Cape Cod. LIFR conditions were depicted over KPVC and at Chatham Municipal Airport (KCQX) immediately southeast due to ceilings at 400 ft agl, with visibility restricted in moderate to heavy rain. Numerous other stations south through southwest of KPVC also reported IFR conditions due to low ceilings and visibility restricted in light to moderate rain. VFR conditions were reported over KBOS and Norwood Memorial Airport (KOWD), with MVFR conditions reported at Marshfield Municipal Airport (KGHG) to the southeast of Boston, and west of KPVC.

3.0 Sounding

To determine the vertical structure and state of the atmosphere over the accident site a High-Resolution Rapid Refresh (HRRR)⁹ numerical model data were retrieved from the NOAA Air

⁹ The HRRR is a National Oceanic and Atmospheric Administration (NOAA) real-time three-kilometer resolution,

Resources Laboratory using the coordinates 42.08° N, 70.21° W, which was the closest available data location to the accident site. The data were then plotted on a standard Skew T log P diagram¹⁰ using RAOB the complete Rawinsonde Observation Program software¹¹ from the surface to 450-hPa or approximately 20,000 ft for 1500 EDT and is included as figure 5.

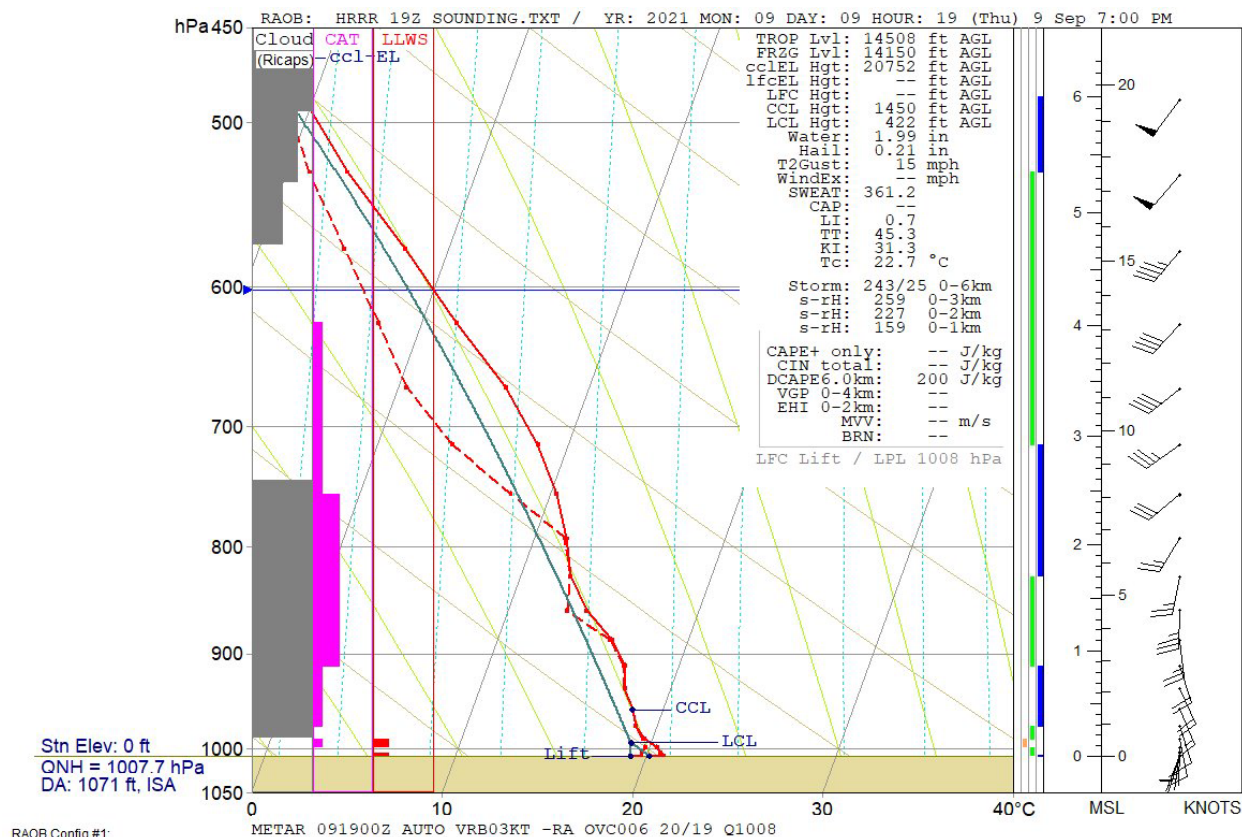


Figure 5 - HRRR numerical model sounding for 1500 EDT over the approximate accident site.

The HRRR 1500 EDT model sounding depicted the conditions at sea level over the area with a near surface temperature of 20.2° C (68.4° F), a dew point temperature of 19.2° C (66.6° F), a relative humidity of 94%, and a density altitude 1,071 ft. The lifted condensation level (LCL)¹² was at 422 ft agl, the convective condensation level (CCL)¹³ was at 1,450 ft agl, and the freezing level was at 14,150 ft agl. The precipitable water¹⁴ content was 1.99 inches. The RAOB analysis program used to review the sounding indicated a layer of nimbostratus type clouds from 600 ft agl

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.

¹⁰ Skew T log P diagram – is a standard meteorological plot or thermodynamic diagram using temperature and the logarithmic of pressure as coordinates, used to display winds, temperature, dew point, and various indices used to define the vertical structure of the atmosphere.

¹¹ RAOB – (The Universal RAWinsonde OBServation program) is an interactive sounding analysis program developed by Eosonde Research Services (ERS) previously known as Environmental Research Services, The Villages, Florida.

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

¹³ Convective Condensation Level - 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.

¹⁴ Precipitable Water - The total amount of (condensed) water available within the lowest 400 mb of the sounding.

with tops near 8,000 ft with another higher band of clouds between 16,000 ft and 24,000 ft. The atmosphere was characterized as conditionally unstable with a Lifted Index (LI)¹⁵ of 0.7, with the most unstable lifted index (MULI) of -1.5, with the atmosphere characterized as conditionally unstable. There were no positive areas of convective available potential energy (CAPE) values indicated.

The HRRR sounding wind profile indicated light surface winds with winds from the south-southeast immediately above the surface with a low-level jet near 4,600 ft with winds from 180° at 33 knots. The winds then veered to the southwest and began to increase with height above 8,000 ft. The RAOB analysis program indicated a light or low risk of low-level wind shear (LLWS) below 500 ft based on the vertical wind shear in the layer as wind speeds increased immediately above the surface. The mean 0 to 6 kilometer (18,000 ft) wind was from 210° at 33 knots, with the level of maximum winds at 37,000 ft from 230° at 80 knots. The tropopause was identified at 47,600 ft.

The HRRR parameters of height, pressure, temperature (T), dew point temperature (Td), relative humidity (RH), wind direction and speed, derived clear air turbulence (CAT) intensity, and low-level wind shear (LLWS) intensity from the surface through 6,000 ft were as follows.

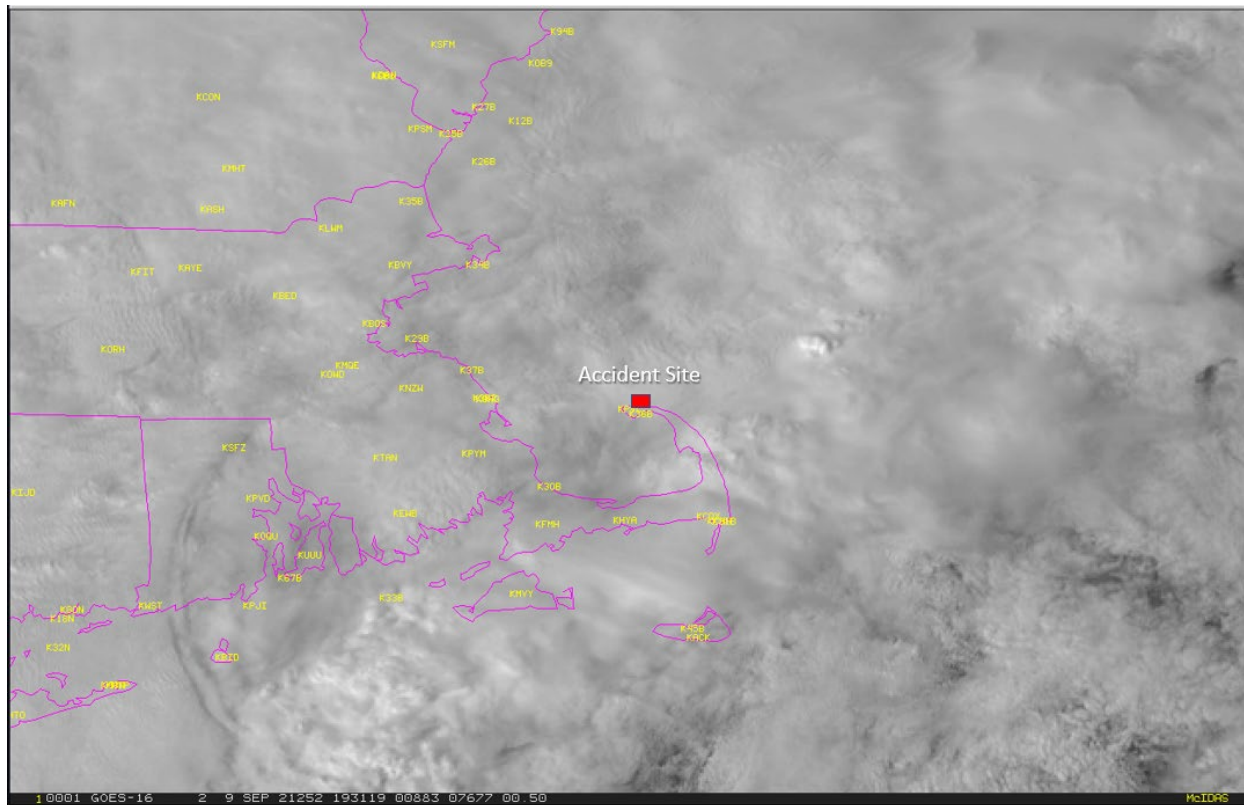
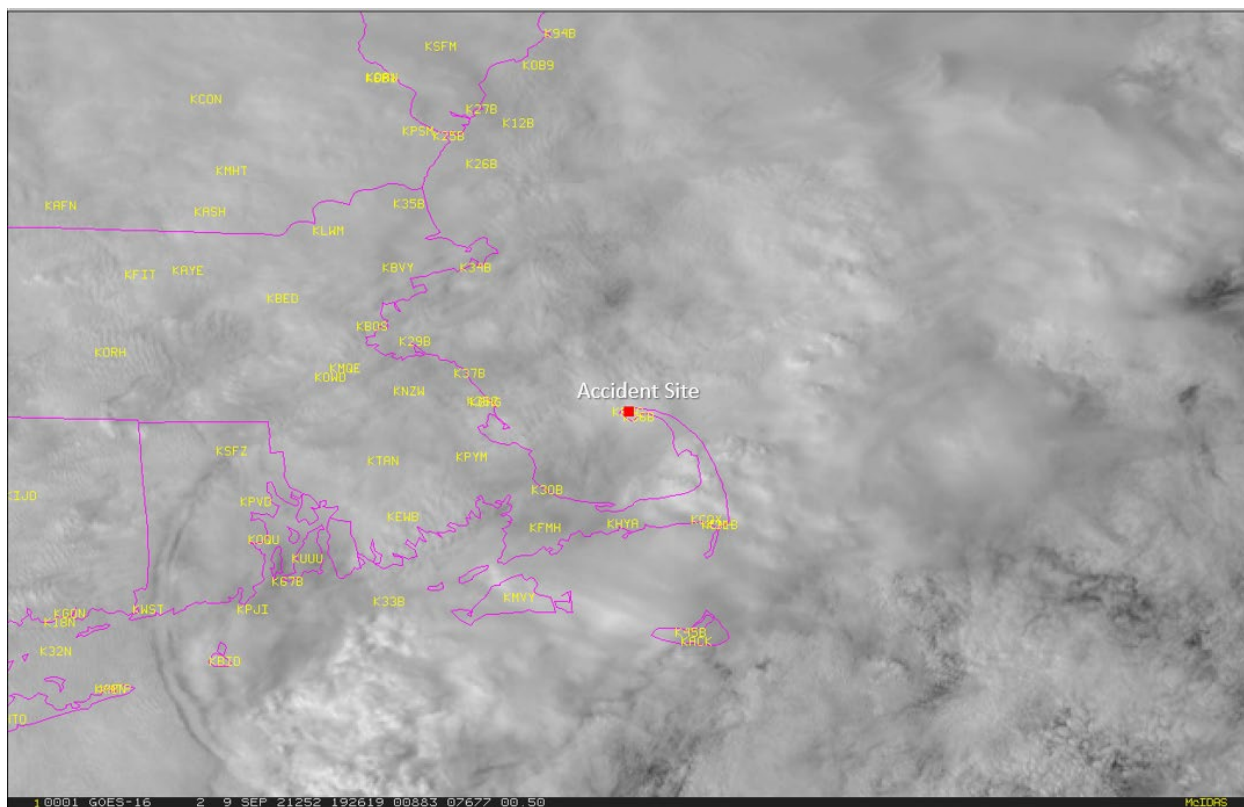
Height (ft msl)	Pres (hPa)	T (°C)	Td (°C)	RH(%) (%)	Wind (dir/kts) (dir/kts)	CAT (FAA)	LLWS
0	1008	20.2	19.2	94	197/ 3		
28	1007	20.9	20.2	96	199/ 3		LIGHT
113	1004	20.7	19.7	94	188/ 4		
284	998	20.4	19.8	96	182/ 5	LGT	LIGHT
541	989	19.6	19.5	99	170/ 8		
945	975	18.9	18.9	100	164/ 10	LGT	
1472	957	18.4	18.4	100	159/ 14	LGT	
2128	935	17.6	17.6	100	158/ 19	LGT	
2829	912	17.2	17.1	99	164/ 22	MDT	
3641	886	16.0	15.9	99	174/ 27	MDT	
4537	858	14.1	13.1	94	182/ 33	MDT	
5590	826	12.6	12.6	100	191/ 27	MDT	

4.0 Satellite Imagery

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

¹⁵ Lifted Index - the difference between the lifted parcel temperature at 500 mb and the 500 mb temperature in the sounding. Negative values denote parcels that are warmer than the background 500 mb temperatures and are thus buoyant or "unstable".

The GOES-16 visible image at 1526 and 1531 EDT at 2X magnification are included as figures 7 and 8 with the accident site noted by the red square. An extensive area of low to mid-level clouds extended over the region along and ahead of the cold front, with a band of cumulus congestus to cumulonimbus type clouds extending northeast, east, and south of KPVD over Cape Cod and into the Atlantic off Long Island.



5.0 Weather Surveillance Radar Information

The closest NWS Weather Surveillance Weather Radar 1988 Doppler (WSR-88D)¹⁶ was from Boston/Taunton (KBOX) located approximately 42 miles west of the accident site. The level II and III data were obtained from the NCEI archive and displayed using the NWS NEXRAD Interactive Viewer and Data Exporter software. During the period the KBOX WSR-88D was operating in the precipitation mode volume scanning 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 hydrometeors¹⁷, 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)¹⁸ and is a general measure of echo intensity. Figure 9 is a table of the NWS former 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 expected rainfall rates. Typically echoes over 15 dBZ are associated with precipitation reaching the surface.

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 9 - NWS VIP, WSR-88D levels, precipitation in dBZ, and rainfall rates.

¹⁶ The WSR-88D is a S-band 10-centimeter wavelength radar with a power output of 750,000 watts, with a 28-foot parabolic antenna concentrating the energy into a 0.95° beam width. The radar produces three basic types of products: reflectivity, radial velocity, and spectral width.

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

¹⁸ dBZ - 10 log Ze

The FAA has taken the NWS previous VIP levels 1 to 6 intensity levels and has redefined the intensity levels for pilots in Advisory Circular AC 00-24C - "Thunderstorm". That AC further defines echoes less than 30 dBZ as "light" in intensity, "moderate" echoes 30-40 dBZ, "heavy" with echoes of >40-50 dBZ, and "extreme" intensity with echoes above >50 dBZ. These are the standard radio phraseology terms used by air traffic controllers to describe weather conditions to pilots as shown in the figure 10. Figure 10 - Reflectivity in dBZ and echo intensity terminology.

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

Figure 10 - Reflectivity in dBZ and weather radar echo intensity

5.2 Composite Reflectivity Imagery

The NWS KBOX WSR-88D composite reflectivity images for 1511, 1518, and 1527 EDT are included as figures 11-13 with the accident aircraft's flight track overlaid in purple. The composite radar image depicts the highest reflectivity value from all the elevation scans for the period in dBZ, with a resolution at 1 x 1 km (0.54 x 0.54 nm) and provides a synopsis of the most important features in the entire vertical coverage area. The composite images depicted a line of extreme echoes moving across eastern Cape Cod and over the Atlantic Ocean, with a maximum echo of 59 dBZ at 1527 EDT with potential hail to 0.50" approximately 25 east-northeast of KPVD, with echoes between 25 to 40 dBZ over the flight path of N88833 into KPVC.

At 1511 EDT the KBOX WSR-88D detected a potential severe thunderstorm cell behind the main line of intense echoes about 10 miles south of KPVC moving northeastward, which resulted in the NWS issuing a Special Marine Warning at 1513 EDT. This area of intense to extreme intensity echoes had a tornadic vortex signature (TVS) indicated prior to the issuance of the advisory. The image at 1518 EDT depicts this area of echoes at 55.5 dBZ about 10 miles southeast of KPVC over Cape Cod, and at 1527 EDT moving into the Atlantic at 52.0 dBZ approximately 10 miles east of KPVC.

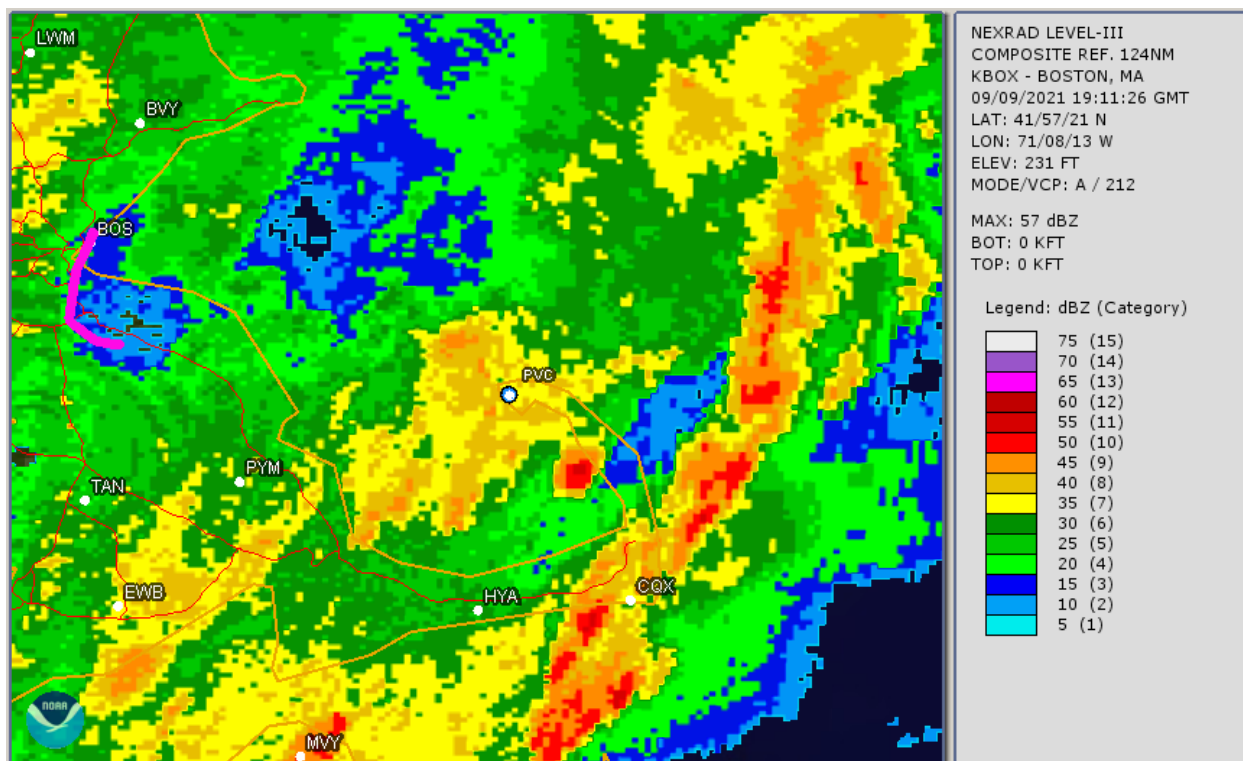


Figure 11 - KBOX WSR-88D composite reflectivity image at 1511 EDT with flight track.

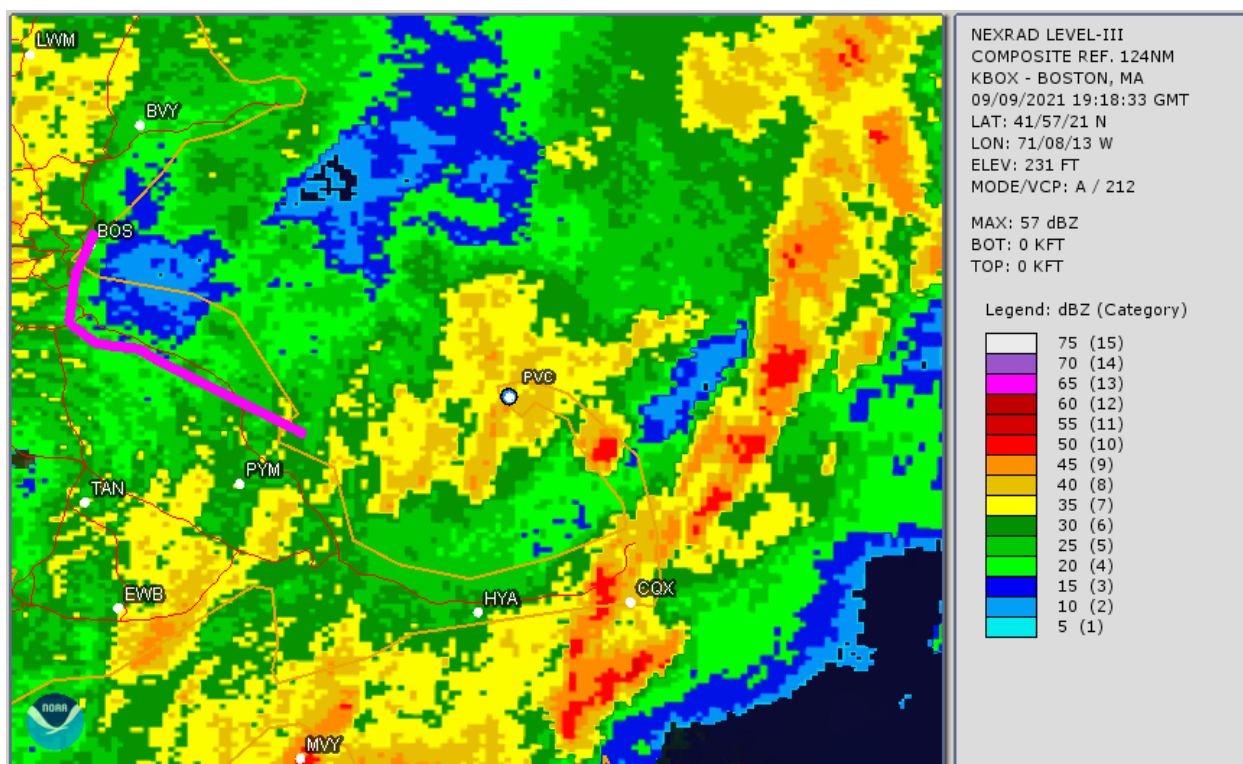


Figure 12 - KBOX WSR-88D composite reflectivity image at 1518 EDT with flight track.

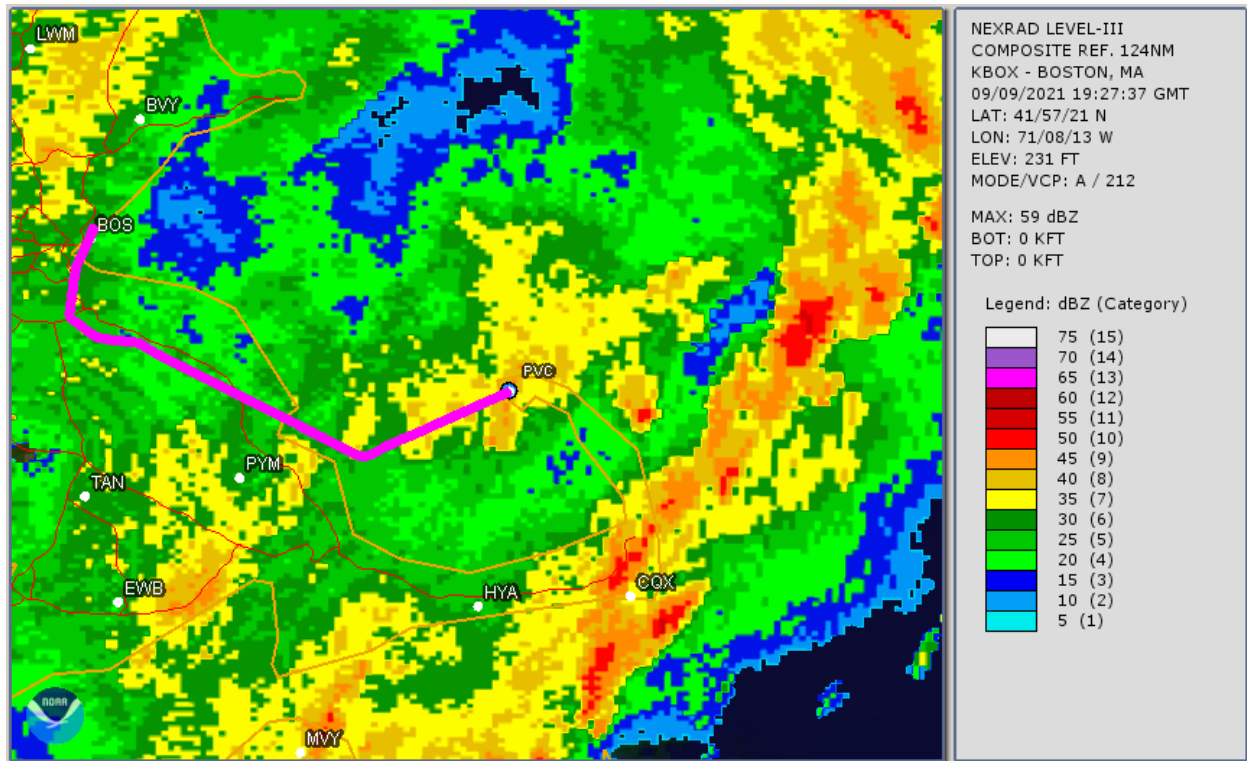


Figure 12 - KBOX WSR-88D composite reflectivity image at 1527 EDT with flight track.

5.3 Base Reflectivity Imagery

Figures 14 through 16 are the NWS KBOX WSR-88D 0.48° base reflectivity image at 1511, 1518, and 1527 EDT with the resolution of 0.5° x 0.25 km (0.13nm). Assuming a standard refraction of the WSR-88D radar beam with the KBOX antenna height of 232 ft, the 0.48° elevation scan saw altitudes from about 1,420 ft through 5,660 ft, with the center of the beam at 3,540 ft over the accident site. This low-level scan best reflected the conditions the accident airplane was operating in and when landing at KPVC. The images depicted echoes of 36 to 48 dBZ or moderate to heavy intensity over KPVC during the period. Figure 17 is a closeup of the flight track at 1527 EDT depicting the flight entering under echoes with maximum reflectivities between 39 to 47 dBZ or moderate to heavy intensity precipitation. Figure 18 is the NWS KBOX WSR-88D Enhanced Echo Tops product for 1527 EDT which showed echo tops¹⁹ between 18,400 ft and 17,100 ft over KPVC during the period.

¹⁹ Echo top is the highest sample volume point of the minimum reflectivity value of 18.5 dBZ. Echo top heights can differ significantly from visual cloud tops, which are much higher.

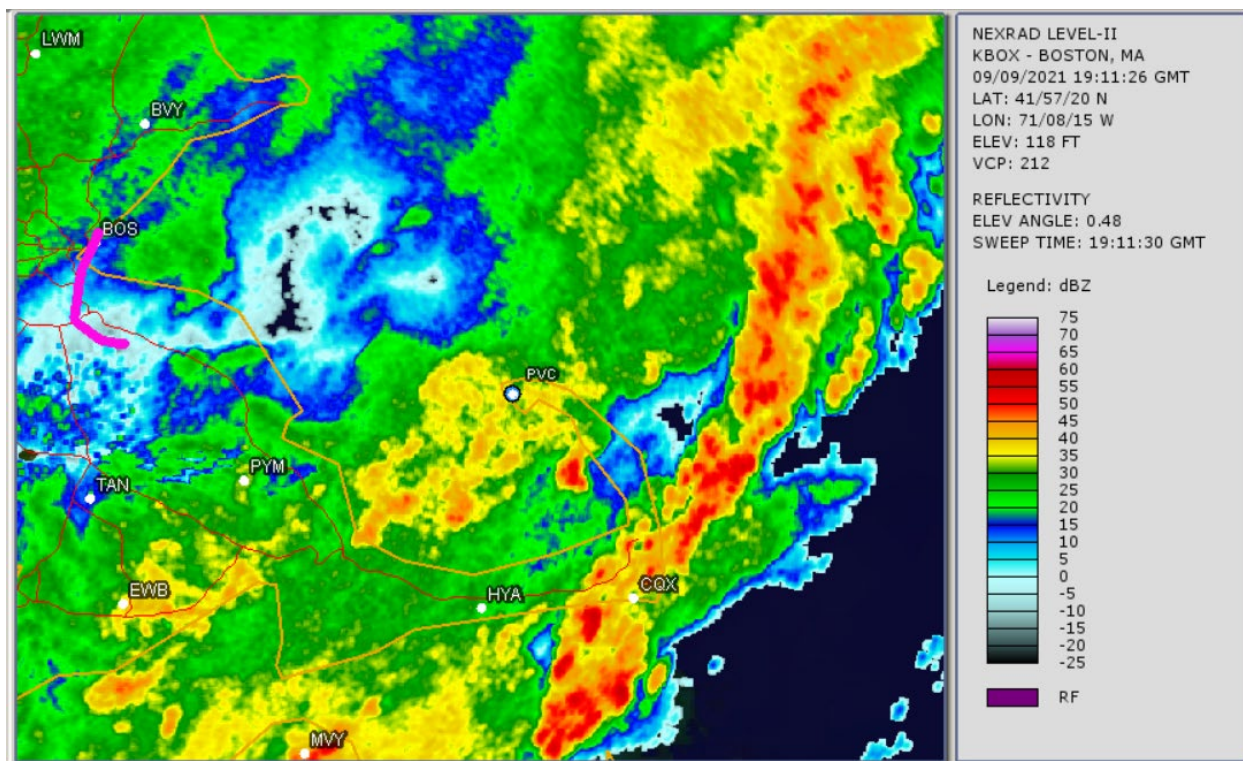


Figure 13 - NWS KBOX WSR-88D 0.48° base reflectivity image at 1511 EDT with flight track.

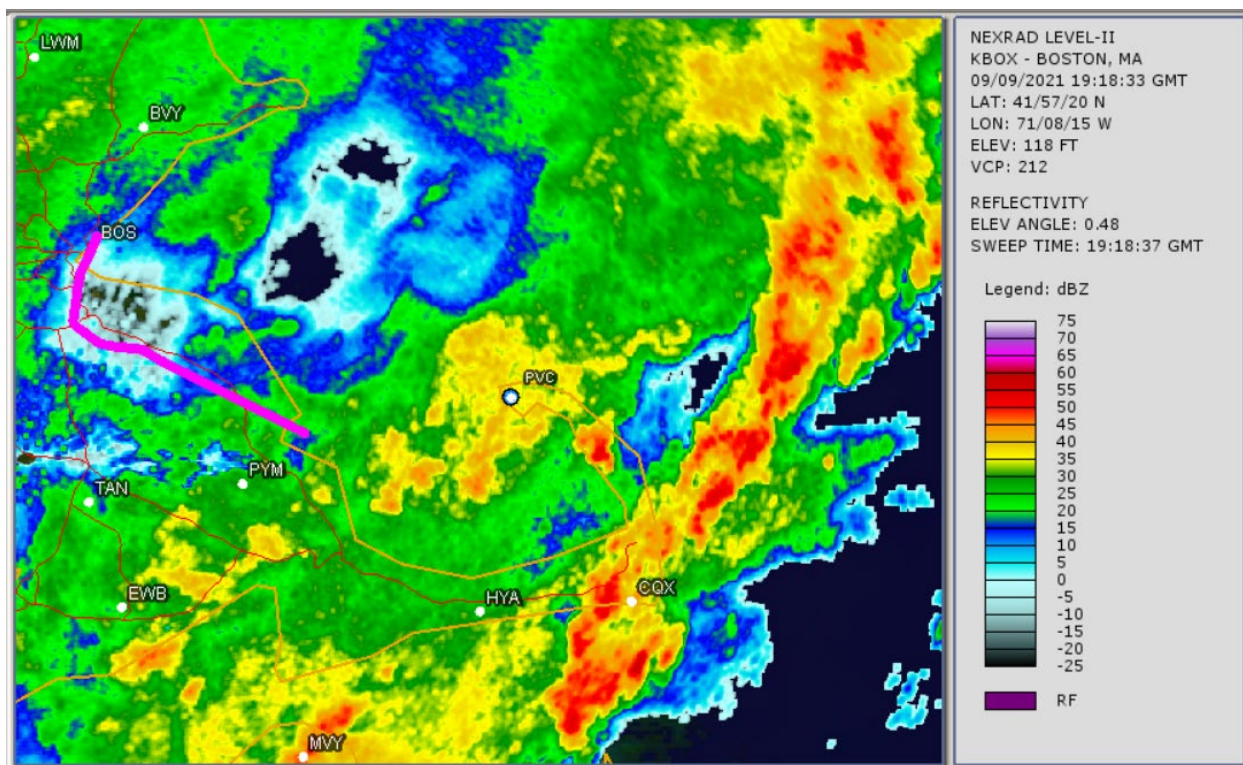


Figure 14 - NWS KBOX WSR-88D 0.48° base reflectivity image at 1518 EDT with flight track.

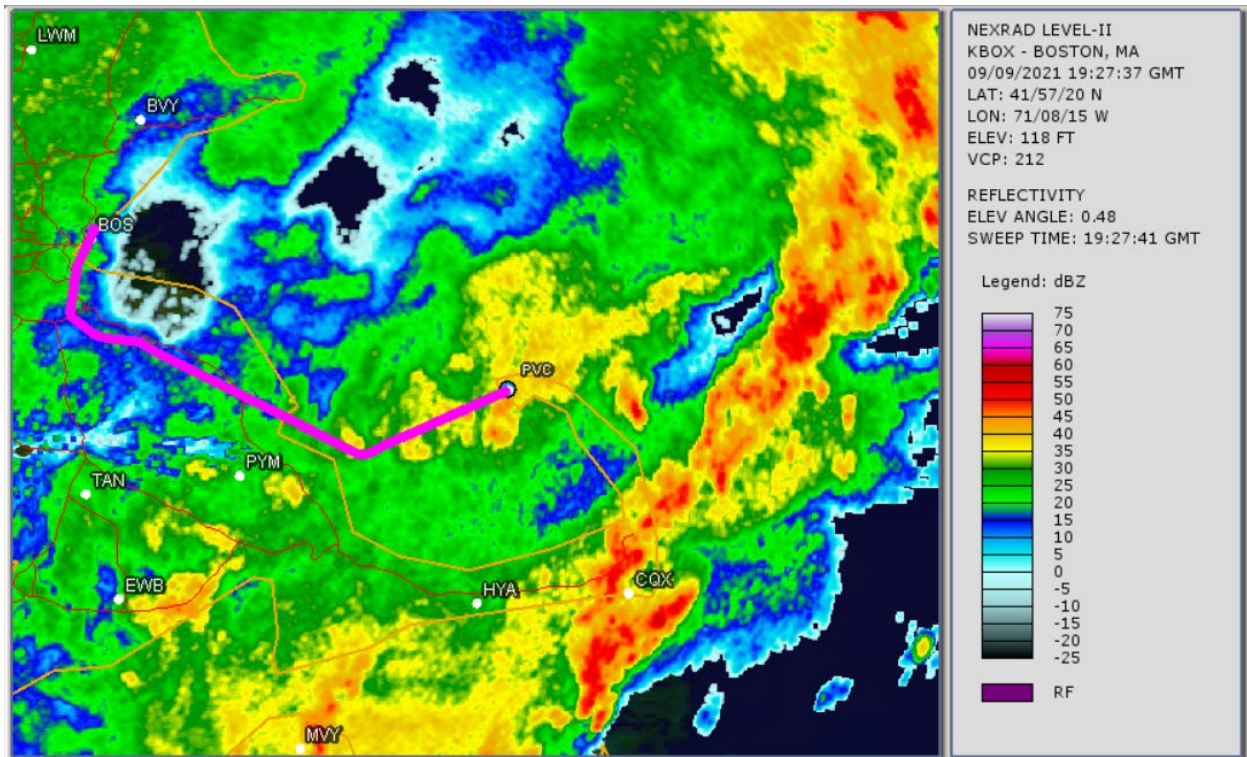


Figure 16- NWS KBOX WSR-88D 0.48° base reflectivity image at 1527 EDT with the flight track overlaid.

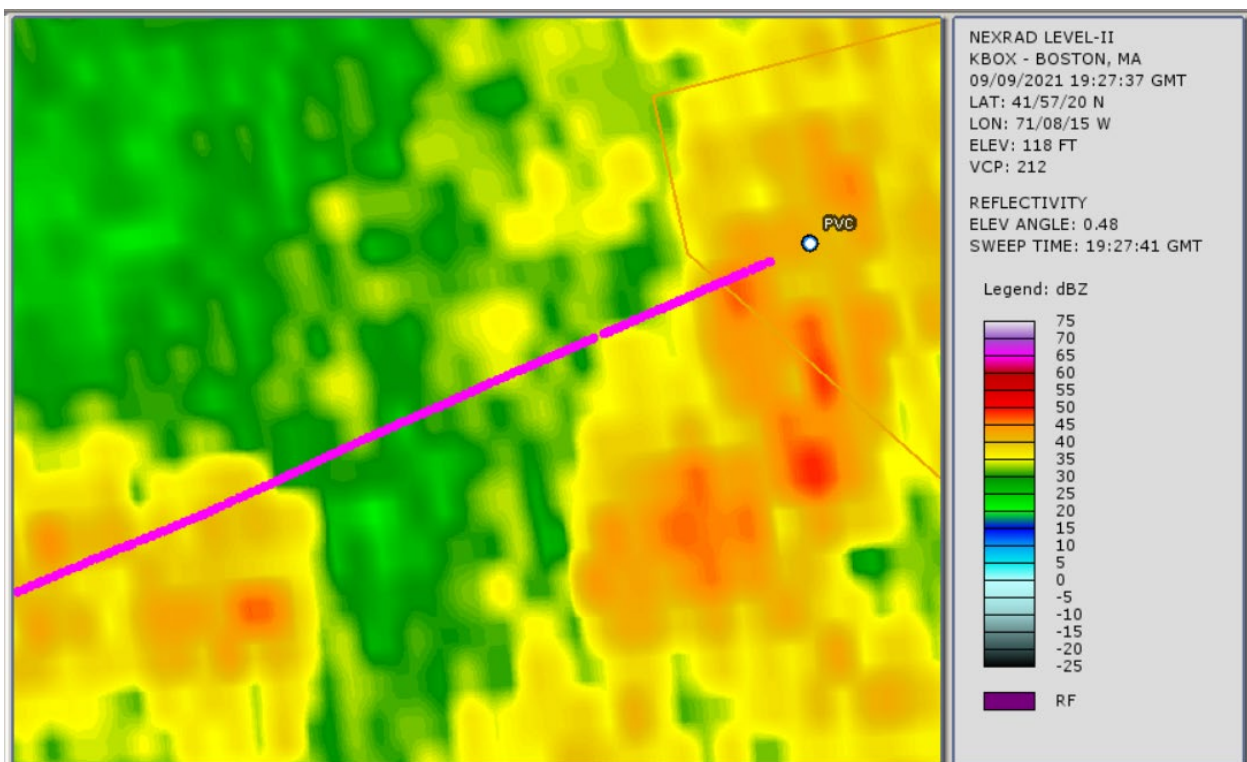


Figure 15 – NWS KBOX WSR-88D 0.48° base reflectivity image closeup at 1527 EDT

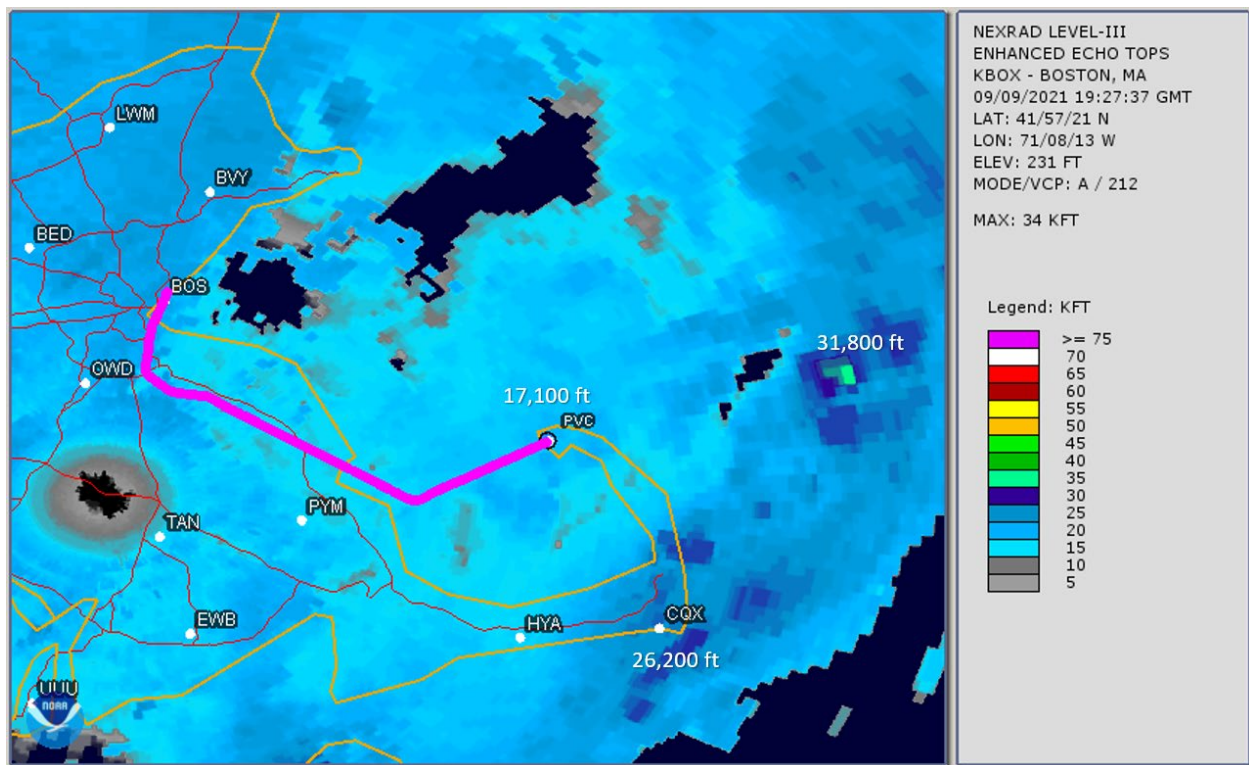


Figure 16 - MWS KBOX WSR-88D Enhanced Echo Tops product for 1527 EDT

A separate review of the KBOX WSR-88D radial velocity data depicted winds from the south at 10 to 14 knots over the KPVC area at the time of the accident and did not detect any divergence couplets associated with any microburst activity during the period. The one exception was the intense to extreme echo about 10 miles south and southeast of KPVC associated with the waterspout, which showed a small circulation feature.

Another view of the KBOX WSR-88D 0.48° base reflectivity image for 1427 EDT using the Gibson Ridge 2 Analysis (GR2Analyst) software program²⁰ is included as figure 19. The GR2Analyst image includes a display of the Special Marine Warning and location of the waterspout image, the radar indicated location of hail, and a line depicting the cross-section along the flight patch which is included as figure 20. The cross section display shows echoes to a maximum of 47.5 dBZ extending to near 8,000 ft over KPVC at 1527 EDT, with echo tops reaching near 19,000 ft.

²⁰ http://www.grlevelx.com/gr2analyst_2/

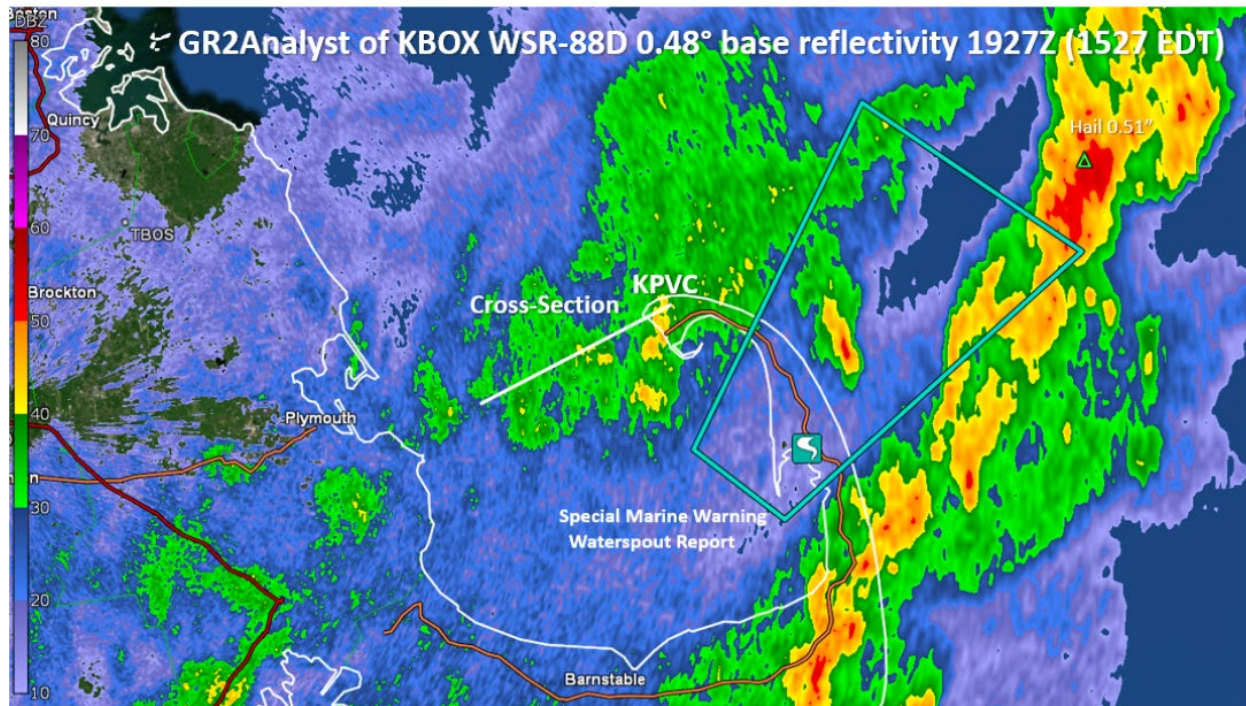


Figure 19 - GR2Analyst display of the KBOX WSR-88D 0.48 base reflectivity image for 1527 EDT.

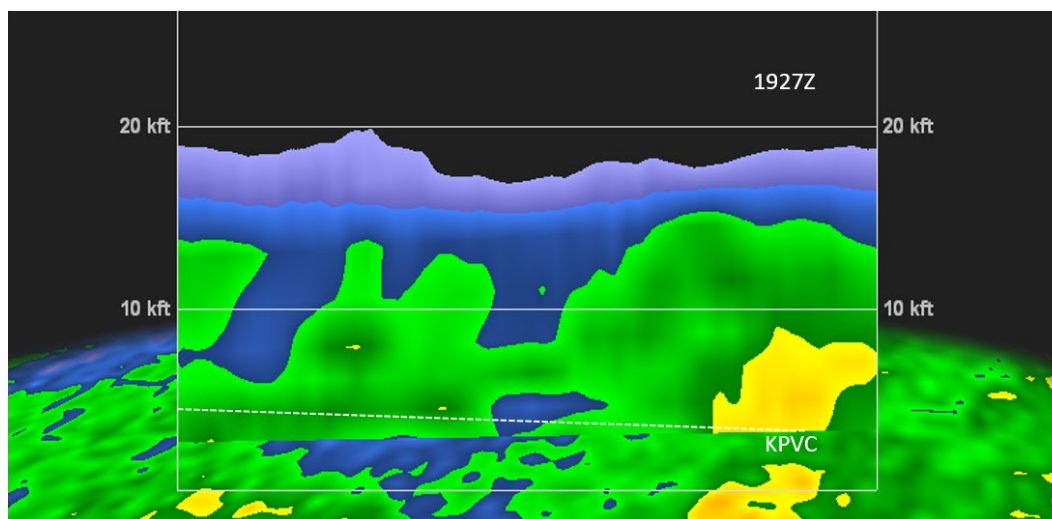


Figure 17 - GR2Analysis display of cross section along flight track at 1527 EDT.

5.4 CoSPA Imagery

The FAA Consolidated Storm Prediction for Aviation (CoSPA) weather display, which integrates several of the NWS and FAA weather systems into a single display, with lightning and convective initiation and growth combined into a single display surrounding the period were documented. These images were available to the Boston (KZBW) Air Route Traffic Control Center (ARTCC). The CoSPA display is of vertical integrated liquid (VIL) which is the vertical estimation of the mass of water, or liquid water content in a column of air versus reflectivity in

section 5.1 above. VIL uses the full volume scan of all the elevation scans and looks similar to reflectivity images. The VIL levels 1 through 6 correspond to the following table in figure 21.

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

Figure 18 - CoSPA VIL Levels

The CoSPA image at 1525 PDT is included as figure 22 and depicted VIL Level 3 over KPVC and the line of VIL Levels 5-6 extending east through Cape Cod. The cells were identified as moving to the northward at 35 knots, with echo tops near 30,000 ft east of the accident site. No lightning activity was identified with the echoes as they moved across the region.

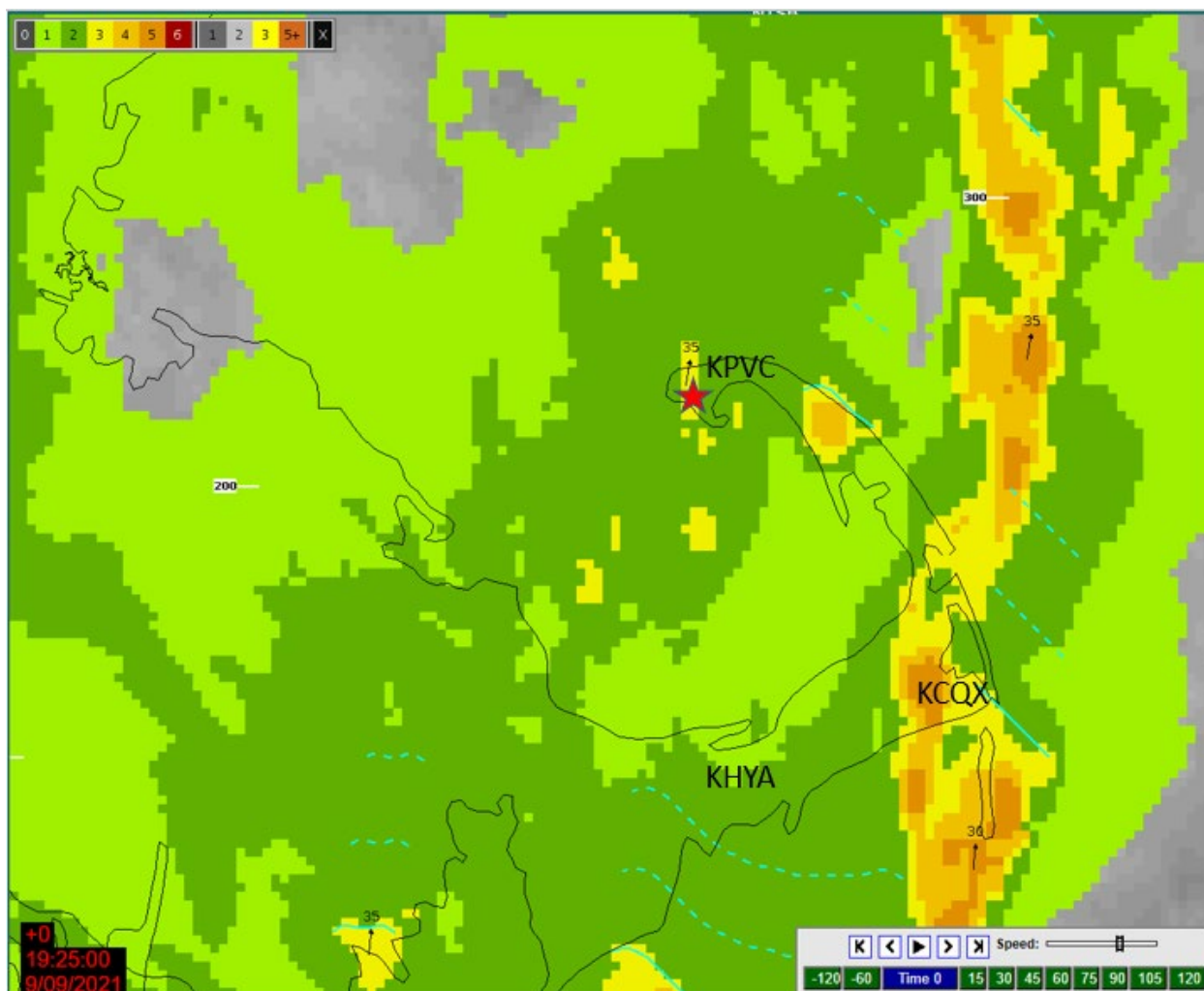


Figure 19 - FAA CoSPA image at 1525 PDT with KPVC and the accident site marked by the red star.

6.0 Pilot Reports

The following pilot reports (PIREPs)²¹ were distributed into the national airspace between 1000 and 1800 EDT within 100 miles of the accident site. The reports are provided in standard code and format as received.

BED UA /OV BED/TM 1405/FL013/TP P28A/SK OVC013

SFZ UA /OV PUT090020/TM 1409/FL170/TP BE9L/TA M03/IC LGT RIME

BOS UA /OV RY22L FINAL/TM 1409/FL015/TP C402/SK OVC

EWB UA /OV /OV EWB/TM 1418/FLDURD/TP C421/SK OVC007

MHT UA /OV MHT/TM 1427/FL240/TP B38M/TA M22/IC LGT RIME

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

ACK UA /OV ACK020020/TM 1445/FL050/TP C25B/WX RA/TB LGT-MOD
BOS UA /OV BOS190025/TM 1445/FL080/TP E170/WX -RA/TB - CHOP
BOS UA /OV BOS060035/TM 1552/FL220/TP B738/TA M12/IC MOD RIME
BED UA /OV BED/TM 1657/FL011/TP EVOT/SK SCT011
PVC UA /OV LFB050020/TM 1732/FL200/TP E55P/TA M01/IC LGT RIME
HYA UA /OV HYA050020/TM 1755/FL040/TP CL30/TA RA/TB LGT
BOS UA /OV BOS/TM 1817/FL040/TP A320/SK BKN
BED UA /OV BED/TM 1818/FL010/TP E55P/SK BKN010
HYA UA /OV HYA060010/TM 1830/FL020/TP C402/TB LGT OCNL MOD
OWD UA /OV OWD/TM 1839/FLDURGD/TP PRM1/SK SCT015 BKN029 OVC110/WX 10/TA 22/WV
18004/RM BASES REPORTED 009-010
MHT UA /OV MHT/TM 1920/FLDURGD/TP C25B/SK OVC003/RM BASES 50/ ABV MINS
BED UA /OV KBED/TM 2007/FL008/TP PC24/SK BKN008/RM FAP RY29 KBED
BOS UA /OV BOS/TM 2105/FL008/TP E75S/SK BKN
ASH UA /OV ASH315005/TM 2125/FL021/TP M20P/SK BKN021/WX 5SM FLT VIS/RM DURD LDG RY 14

Most of the reports (10) reported variable cloud cover indicating low ceilings across the region. There were 4 reports of light-to-moderate icing conditions between 17,000 ft through 24,000 ft by various aircraft, and 4 reports of light-to-moderate turbulence between 2,000 ft through 8,000 ft. One of the more relevant reports was from a Cessna 402 at 1430 EDT in the vicinity of Cape Cod Gateway Airport (HYA), Hyannis, Massachusetts, at 2,000 ft reporting light-to-moderate turbulence. At the time of the report KHYA was reporting visibility 4 miles in light rain with ceiling overcast at 900 ft agl.

7.0 NWS Forecasts

The NWS Boston/Norton (KBOX), Massachusetts, Weather Forecast Office (WFO) was responsible for the issuing forecast and weather advisories over the Cape Cod region. The NWS AWC located in Kansas City, Missouri, were responsible for the aviation weather products issued for the region also documented in this section.

7.1 Terminal Aerodrome Forecast

The NWS KBOX does not issue a Terminal Aerodrome Forecast (TAF) for KPVC. The closest TAF to the accident site was issued for Cape Cod Gateway Airport (KHYA), Hyannis, MA, located approximately 24 miles south at an elevation of 54 ft, and for the departure station of KBOS.

While a TAF is only valid for a 5 mile radius of the airport center, pilots will often refer to the closest forecast for a specific breakdown of winds, visibility, weather and clouds for the period. The forecast for KHYA and for KBOS current during the period were as follows:

TAF KHYA 091727Z 0918/1018 15004KT P6SM -SHRA FEW080 OVC100
FM092000 19009KT 3SM SHRA BR OVC030
FM092300 18007KT 2SM +SHRA BR OVC003
FM100500 31009KT 4SM -SHRA BR OVC015
FM100700 32010G18KT 5SM -SHRA BR OVC035
FM100900 32011KT P6SM OVC060

The forecast current KHYS for the period expected general VFR conditions to prevail through 1600 EDT, with a surface wind from 150° at 4 knots, visibility 6 miles or more with light rain showers, a few clouds at 8,000 ft agl, and a ceiling overcast at 10,000 ft. After 1600 through 1900 EDT MVFR conditions were expected with a wind was from 190° at 9 knots, visibility 3 miles in moderate rain showers and mist, with a ceiling overcast at 3,000 ft agl. Between 1900 and 0100 EDT LIFR conditions were expected with winds from 180° at 7 knots, visibility 2 miles in heavy rain and mist, with a ceiling overcast at 300 ft agl.

The TAF current for the departure station of KBOS was issued at 1327 EDT and was as follows.

TAF KBOS 091727Z 0918/1024 18008KT P6SM -SHRA FEW015 SCT022 OVC110
TEMPO 0918/0922 BKN015 OVC025
FM100100 26003KT 6SM -SHRA BR OVC025
FM100500 31008KT P6SM -SHRA OVC035
FM100800 30010KT P6SM OVC090=

The forecast current KBOS for the period expected general VFR to MVFR conditions to prevail through 2100 EDT, with a surface wind from 180° at 8 knots, visibility 6 miles or more with light rain showers, a few clouds at 1,500 ft agl, scattered clouds at 2,200 ft, with a ceiling overcast at 11,000 ft, with a temporary period between 1400 and 1800 EDT of ceiling broken at 1,500 ft, and overcast at 2,500 ft. After 2300 EDT a wind shift to the west from 260 at 3 knots, visibility 6 miles in light rain showers and mist, ceiling overcast at 2,500 ft agl.

7.2 Area Forecast Discussion

The NWS Area Forecast Discussions (AFD) are issued by each WFO to describe the short term weather conditions within their region with an aviation section that includes the general conditions as it relates to the creation of the TAF. These are useful for additional aviation-related issues that cannot be encoded into the TAF and provide some reasoning behind the forecast. These are generated roughly every 6 hours and corresponds to the release of the latest TAFs for that office. The KBOX WFO AFD issued at 1450 EDT was as follows with the long term and marine sections excluded.

FXUS61 KBOX 091850
AFDBOX

Area Forecast Discussion
National Weather Service Boston/Norton MA

250 PM EDT Thu Sep 9 2021

.SYNOPSIS...

Numerous showers and isolated thunderstorms with heavy rainfall may lead to some flooding into this evening, especially across southeast MA. Most areas will remain dry for much of Friday, but a few pop up showers are possible. High pressure builds in bringing dry and quiet weather for the weekend with an upward trend in temperatures. Next shot for precipitation is early to mid-next week.

.SHORT TERM /FRIDAY THROUGH FRIDAY NIGHT/...

High pressure over the Midwest and Great Lakes will gradually make its way east Friday into Friday night. Generally a dry stretch of weather for most of our region. That said, will still have to deal with a rather sharp mid level trough and shortwave. That should generate sufficient lift for at least some clouds. The bigger question is will there be enough moisture to generate some showers. Most of the CAMs are not very bullish on this prospect outside of eastern MA. While cannot completely rule out some showers there, opted to keep the forecast on the drier side.

.AVIATION /18Z THURSDAY THROUGH TUESDAY/...

Forecaster Confidence Levels.

Low - less than 30 percent.

Moderate - 30 to 60 percent.

High - greater than 60 percent.

Through 00Z...High confidence in trends. Moderate confidence in timing.

Mix of conditions early this afternoon. Most of the region was VFR, with areas of MVFR/IFR in showers towards the Cape and islands. Prospects for thunderstorms diminishing with time.

Tonight...Moderate confidence.

MVFR to LIFR with showers this evening with locally heavy rainfall focused across southern RI and southeastern MA. Improving conditions from west to east late this evening through the overnight as showers exit.

.BOX WATCHES/WARNINGS/ADVISORIES...

CT...None.

MA...High Surf Advisory until 7 PM EDT Friday for MAZ007-019-022>024.

RI...High Surf Advisory until 7 PM EDT Friday for RIZ006>008.

MARINE...Small Craft Advisory until 8 PM EDT Friday for ANZ235-237-250-251-254>256.

7.3 Special Weather Statement

The NWS KBOX WFO issued two Special Weather Statements for Cape Cod at 1357 and 1453 EDT for moderate to heavy rain, with wind gusts less than 25 knots, which was expected to produce minor flooding over the area. Another advisory was issued at 1513 EDT for a potential waterspout approximately 10 miles southeast of Provincetown. While these bulletins are not typically used by pilots, but they may be available for the airline station manager's and the general public's use. The advisories were as follows.

WWUS81 KBOX 091757

SPSBOX

Special Weather Statement

National Weather Service Boston/Norton MA

157 PM EDT Thu Sep 9 2021

MAZ018>023-RIZ007-091900-

Eastern Plymouth MA-Southern Bristol MA-Southern Plymouth MA-Western Plymouth MA-Dukes MA-Barnstable MA-Newport RI-

157 PM EDT Thu Sep 9 2021

...Moderate to Heavy Rain Could Cause Minor Flooding...

At 155 PM EDT, Doppler radar showed an area of moderate to heavy rain across southeast Massachusetts eastward over Cape Cod. This rain is expected to persist through mid-afternoon.

HAZARD...Moderate to locally heavy rain.

SOURCE...Radar indicated.

IMPACT...Minor flooding in urban, low lying and other locations prone to ponding of water during heavy rain

Locations impacted include...

New Bedford, Plymouth, Barnstable, Dartmouth, Falmouth, Marshfield, Marion, Oak Bluffs, Edgartown, Tisbury, Middleborough, Wareham, Sandwich, Bourne, Fairhaven, Westport, Duxbury, Mashpee, Kingston and Carver.

LAT...LON 4135 7075 4152 7068 4145 7082 4154 7065

4175 7063 4163 7087 4158 7082 4165 7092

4143 7089 4142 7086 4146 7118 4152 7105

4154 7105 4152 7107 4213 7069 4199 7070

4171 7031 4160 7047 4135 7051

TIME...MOT...LOC 1755Z 201DEG 29KT 4197 7058

MAX HAIL SIZE...0.00 IN

MAX WIND GUST...<30 MPH

WWUS81 KBOX 091853

SPSBOX

Special Weather Statement

National Weather Service Boston/Norton MA

253 PM EDT Thu Sep 9 2021

MAZ019-021>024-092015-

Nantucket MA-Eastern Plymouth MA-Southern Plymouth MA-Dukes MA-Barnstable MA-

253 PM EDT Thu Sep 9 2021

...Moderate to Heavy Rain Could Cause Minor Flooding Across the Cape and Islands...

At 248 PM EDT, Doppler radar showed an area of moderate to heavy rain across portions of Cape Cod and Martha's Vineyard. This area was slowly pushing east and will affect the remainder of the Cape and Nantucket through late afternoon.

HAZARD...Moderate to locally heavy rain.

SOURCE...Radar indicated.

IMPACT...Minor flooding in urban, low lying and other locations prone to ponding of water during heavy rain.

Locations impacted include...

Plymouth, Barnstable, Falmouth, Nantucket, Brewster, Oak Bluffs, Edgartown, Tisbury, Provincetown, Yarmouth, Wareham, Sandwich, Bourne, Dennis, Mashpee, Harwich, Chatham, Wellfleet, West Tisbury and Truro.

*LAT...LON 4126 6996 4125 6997 4127 7021 4164 7028
4164 7035 4128 7022 4155 7048 4142 7045
4141 7045 4155 7051 4135 7045 4142 7091
4143 7091 4190 7054 4179 7003 4206 7013
4207 7024 4208 7017 4205 7006
TIME...MOT...LOC 1848Z 208DEG 24KT 4129 7068*

*MAX HAIL SIZE...0.00 IN
MAX WIND GUST...<30 MPH*

*WWUS81 KBOX 091913
SPSBOX*

*Special Weather Statement
National Weather Service Boston/Norton MA
313 PM EDT Thu Sep 9 2021*

*MAZ022-092000-
Barnstable MA-
313 PM EDT Thu Sep 9 2021*

...A thunderstorm capable of producing a waterspout will impact portions of northeastern Barnstable County through 400 PM EDT...

At 312 PM EDT, Doppler radar was tracking a thunderstorm capable of producing a waterspout over Cape Cod Bay, near Wellfleet, or 10 miles southeast of Provincetown, moving northeast at 30 mph.

HAZARD...Waterspouts, winds in excess of 40 mph, and pea size hail.

SOURCE...Radar indicated.

IMPACT...Waterspouts can easily overturn boats and create locally hazardous waters. Gusty winds could knock down tree limbs and blow around unsecured objects. Minor damage to outdoor objects is possible.

Locations impacted include...Wellfleet and Truro.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

If outdoors, consider seeking shelter inside a building.

This storm may intensify, so be certain to monitor local radio stations and available television stations for additional information and possible warnings from the National Weather Service.

*LAT...LON 4193 7003 4193 7006 4192 7005 4190 7007
4191 7007 4201 7008 4204 7006 4200 7002 4196 6999
TIME...MOT...LOC 1912Z 219DEG 27KT 4191 7010*

*WATERSPOUT...POSSIBLE
MAX HAIL SIZE...0.25 IN
MAX WIND GUST...40 MPH*

7.4 Winds and Temperatures Aloft Forecast

The NWS Winds and Temperature Aloft Forecast current for the period was issued at 0958 EDT and was valid for 1400 EDT and for use between 1000 through 1700 EDT. The forecast was as follows.

FBUS31 KWNO 091358

FD1US1

-DATA BASED ON 091200Z

VALID 091800Z FOR USE 1400-2100Z. TEMPS NEG ABV 24000

<i>FT</i>	<i>3000</i>	<i>6000</i>	<i>9000</i>	<i>12000</i>	<i>18000</i>	<i>24000</i>	<i>30000</i>	<i>34000</i>	<i>39000</i>
<i>-BOS</i>	<i>2118</i>	<i>1919+12</i>	<i>2132+07</i>	<i>2237+02</i>	<i>2145-08</i>	<i>2150-19</i>	<i>228534</i>	<i>239243</i>	<i>249455</i>
<i>-ACK</i>	<i>2021</i>	<i>1926+14</i>	<i>2130+09</i>	<i>2136+04</i>	<i>2147-08</i>	<i>2256-17</i>	<i>236932</i>	<i>237043</i>	<i>247154</i>

The forecast for BOS at 3,000 ft was for wind from 210° at 18 knots, and at 6,000 ft from 190° at 19 knots with a temperature 12° C. The forecast for Nantucket (ACK) approximately 50 miles south of KPVC was for 3,000 ft wind from 200° at 21 knots, and at 6,000 ft from 190° at 26 knots with a temperature 14° C.

8.0 Inflight Weather Advisories

Inflight Aviation Weather Advisories are forecasts to advise en route aircraft of the development of potentially hazardous weather. Inflight aviation weather advisories in the conterminous U.S. are issued by the NWS AWC, as well as from the Center Weather Service Units (CWSU) associated with FAA air route traffic control centers (ARTCCs). There are four basic types of inflight aviation weather advisories: the Significant Meteorological Information (SIGMET), the Convective SIGMET, the Airmen's Meteorological Information (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 following advisories were current during the period.

During the period the NWS had a Convective SIGMET and G-AIRMET Sierra current for the area, which are depicted in figures 23 and 24 respectively. The Convective SIGMETs were issued at 1455 EDT and valid through 1655 EDT and are depicted in figure 23. Convective SIGMET 37E was issued at 1455 and valid through 1655 EDT and was issued for an area of thunderstorms moving from 210° at 30 knots, with tops to 34,000 ft. The Graphic-AIRMET Sierra was issued at 1045 EDT and valid through 1700 EDT for an area of IFR conditions with ceilings below 1,000 ft and visibility below 3 miles in precipitation and mist and also extended over the area. There were CWA or Meteorological Impact Statements (MIS) issued by the NWS Boston (KZBW) CWSU on September 9th.

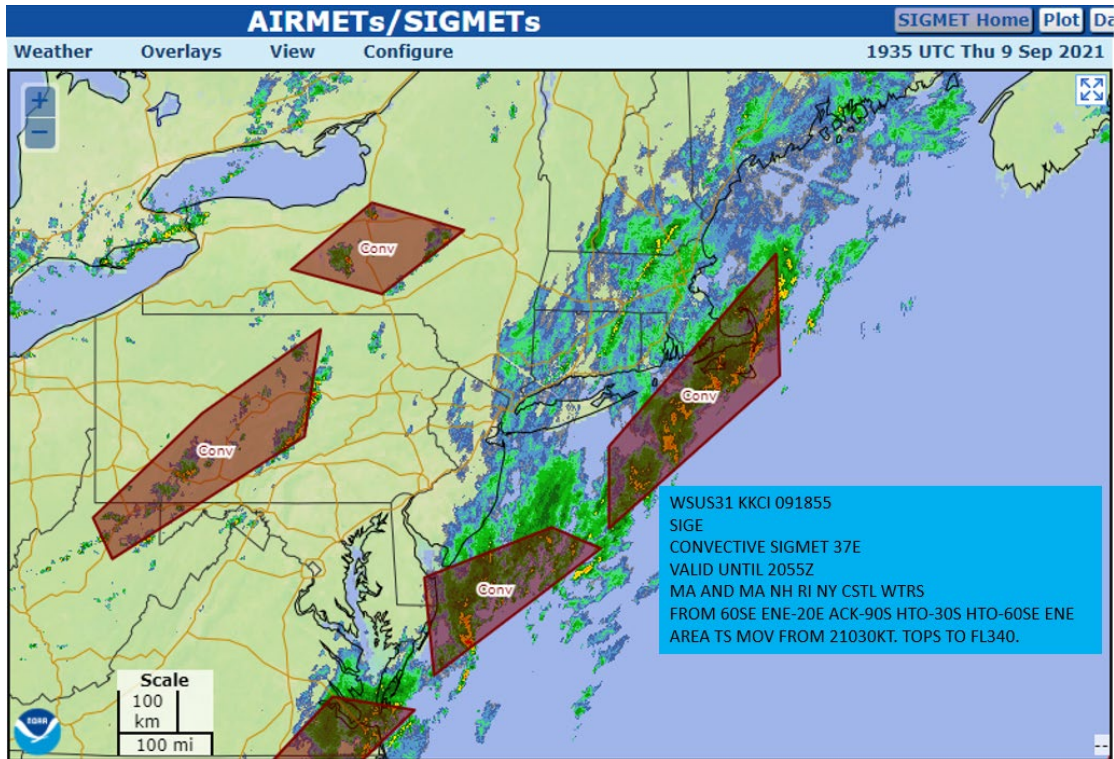


Figure 20 - Convective SIGMETs current at 1535 EDT with advisory 37E current for the route.

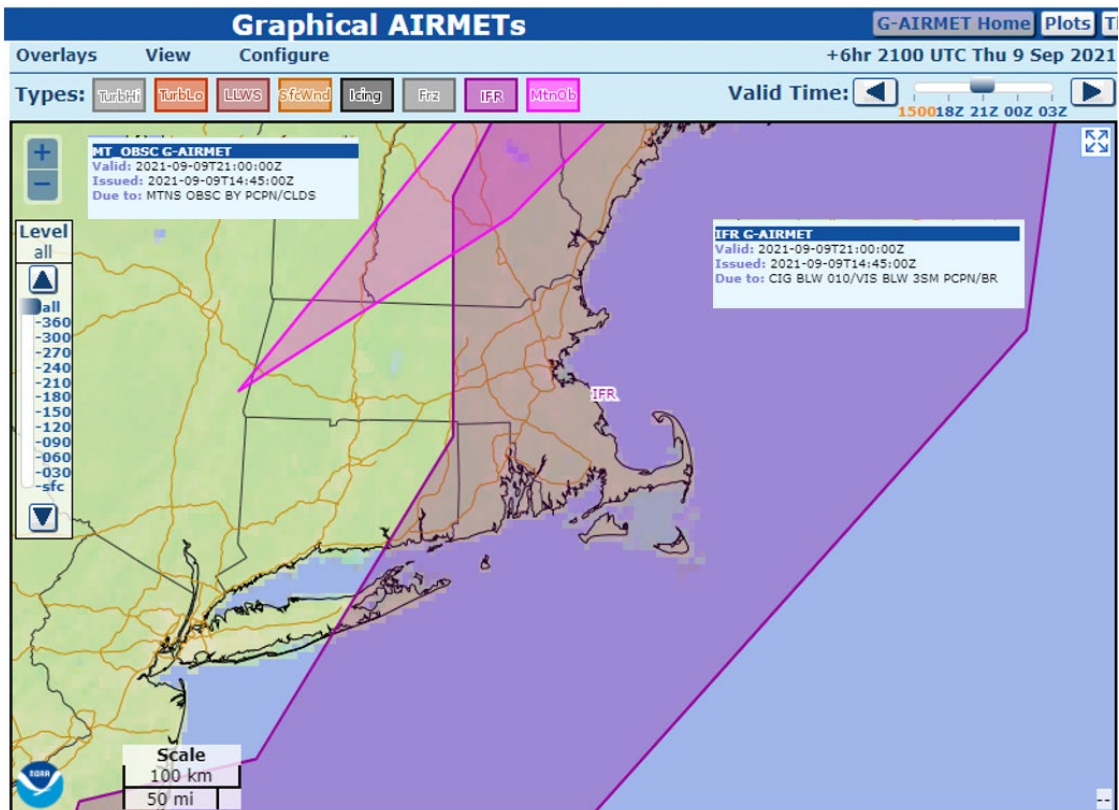


Figure 21 - NWS Graphic-AIRMET Sierra current for IFR conditions over the area.

The text version of the AIRMET Sierra was as follows.

WAUS41 KKCI 091445

WAIS

BOSS WA 091445

AIRMET SIERRA UPDT 2 FOR IFR AND MTN OBSCN VALID UNTIL 092100

***AIRMET IFR...VT MA CT NY NJ PA MD DE VA AND CSTL WTRS
FROM 40SSW MPV TO 130ESE SIE TO 90E ORF TO 20S ORF TO 60SSW RIC
TO 30NW RIC TO 40ESE EMI TO 30WSW ETX TO 40SSW MPV
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG BYD 21Z THRU 03Z.***

***AIRMET IFR...ME NH VT MA RI CT NY NJ AND CSTL WTRS
FROM 70NW PQI TO 60NE PQI TO 150ENE ACK TO 130ESE SIE TO 40SSW
MPV TO 50SW YSC TO 20NNE YSC TO 70NW PQI
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG BYD 21Z THRU 03Z.***

***AIRMET MTN OBSCN...ME NH VT MA NY
FROM 70NW PQI TO MLT TO CON TO 40S ALB TO 30NNW ALB TO 40SSE YSC TO 70NW PQI
MTNS OBSC BY CLDS/PCPN/BR. CONDS CONTG BYD 21Z THRU 03Z.***

OTLK VALID 2100-0300Z

***AREA 1...IFR ME NH MA RI CT NY NJ MD DE VA AND CSTL WTRS
BOUNDED BY 70NW PQI-60NE PQI-150ESE ACK-130ESE SIE-70E ECG-ORF-
20W CYN-30S JFK-30SSE BDL-20WNW CON-70NW PQI
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG THRU 03Z.***

***AREA 2...MTN OBSCN VT NY PA
BOUNDED BY MSS-50ESE MSS-HNK-40ESE EWC-20NNE EWC-JHW-SYR-MSS
MTNS OBSC BY CLDS. CONDS DVLPG 00-03Z. CONDS CONTG THRU 03Z.***

***AREA 3...MTN OBSCN ME NH VT MA NY
BOUNDED BY 50NW PQI-MLT-CON-40S ALB-40SW YSC-40E YSC-50NW PQI
MTNS OBSC BY CLDS/PCPN. CONDS CONTG THRU 03Z.***

9.0 Pilot Weather Briefing Documents

The accident pilot was interviewed by NTSB staff and indicated that he had checked the KPVC weather before departing KBOS, specifically the METARs, a radar image, and NOTAMs. As he approached KPVC he obtained the AWOS information through the VHF broadcast and performed a prelanding evaluation of the winds and landing distance calculations. Please see the docket for further details regarding the pilot's interview.

10.0 Witness Statements

A waterspout was photographed at approximately 1520 EDT off the coast of Cape Cod on September 9, 2021, near Duck Harbor in Wellfleet, MA (figure 25). According to the witness the waterspout occurred prior to heavy rain moving over the area and lasted several minutes before dissipating. The image below is the photograph looking southward.



Figure 22 - Waterspout photographed near Duck Harbor around 1520 EDT.

11.0 Astronomical Conditions

The astronomical conditions were calculated using the United States Naval Observatory's Multiyear Interactive Computer Alamac (MICA) software for Providence, MA. The time of the accident has been added for reference in italic bold type.

<u>Sun</u>	<u>Time (EDT)</u>
Civil twilight	0547
Sunrise	0615
Sun culmination	1238
<i>Accident</i>	<i>1527</i>
Sunset	1900
End civil twilight	1929

At the time of the accident the Sun was 37° above the horizon at an azimuth of 237°.

Submitted by:

Donald Eick
Senior Meteorologist