National Transportation Safety Board

Office of Marine Safety

Washington, D.C. 20594

Group Chairman's Factual Report

Meteorology Group

El Faro

DCA16MM001

December 13, 2016

Mike Richards

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1. ACCIDENT INFORMATION

Vessel:	SS *El Faro*
Accident Number:	DCA16MM001
Date:	October 1, 2015
Time:	0739 eastern daylight time (EDT) 1139 coordinated universal time (UTC)
Location:	23˚23′ 33″ N, 73˚54′ 10″ W 23.3925° N, 73.9029° W
Accident type:	Sinking
Complement:	27 crew, 6 supernumeraries

2. METEOROLOGY GROUP

Chairman	Mike Richards Senior Meteorologist National Transportation Safety Board Office of Aviation Safety Operational Factors Division, AS-30 Washington, DC 20594
Member – U.S. Coast Guard[1]	Michael Comerford, LT Staff Chemical Engineer United States Coast Guard Marine Safety Center Vessel and Cargo Branch Washington, DC 20593
Member – National Weather Service[2]	James Franklin Branch Chief, Hurricane Specialist Unit National Hurricane Center National Oceanic and Atmospheric Administration/ National Weather Service Miami, Florida 33165

[1] Joined Meteorology Group in December 2015.
[2] Joined Meteorology Group in October 2016.

3. SUMMARY

On Thursday, October 1, 2015, about 0715 EDT, the US Coast Guard received distress alerts from the 790-foot roll-on/roll-off container ship *El Faro*. The US-flagged ship, owned by TOTE Maritime Puerto Rico (formerly Sea Star Line, LLC[3]) and operated by TOTE Services (TOTE), was 40 nautical miles northeast of Acklins and Crooked Islands, Bahamas, and close to the eye of Hurricane Joaquin. The ship was en route from Jacksonville, Florida, to San Juan, Puerto Rico, with a cargo of containers and vehicles. Just minutes before the distress alerts were received, the *El Faro* master had called TOTE's designated person ashore and reported that a scuttle had popped open on deck two and there was free communication of water into the No. 3 hold. He said the crew had controlled the ingress of water but that the ship was listing 15° and had lost propulsion. The Coast Guard and TOTE were unable to reestablish communication with the ship. Twenty-eight US crewmembers, including an off-duty engineering officer sailing as a supernumerary, and five Polish workers were on board. The vessel sank in 15,300 feet of water.

The Coast Guard, US Navy, and US Air Force dispatched multiple assets to the ship's last known position, but the search was hampered by hurricane-force conditions on scene. On Sunday, October 4, a damaged lifeboat and two damaged liferafts were located. The same day the Coast Guard found a deceased crewmember wearing an immersion suit. A Coast Guard rescue swimmer tagged the body in the immersion suit and left to investigate reported signs of life elsewhere, but then could not relocate the tagged suit. No signs of life were found, and on Monday, October 5, a debris field and oil slick were discovered. The Coast Guard determined that *El Faro* was lost and declared the accident a major marine casualty. The Coast Guard suspended the unsuccessful search for survivors at sundown on Wednesday, October 7.

4. DETAILS OF INVESTIGATION

The National Transportation Safety Board (NTSB) learned of the accident from the Coast Guard on the afternoon of October 1, 2015. A team of five investigators, a board member, and support staff launched from NTSB headquarters on October 6, and arrived on scene in Jacksonville later the same day. The investigation was led by the NTSB. Parties to the investigation were the Coast Guard, TOTE, the American Bureau of Shipping, and the National Weather Service. The on-scene part of the investigation was completed on October 15. On October 31, a Navy ship fitted with underwater detection equipment located the wreckage of *El Faro* at a depth of about 15,000 feet.

In April 2016, a research vessel from the National Science Foundation and Woods Hole Oceanographic Institution located *El Faro*'s voyage data recorder (VDR) but could not retrieve it. In August 2016, the Navy ship revisited the site of the sinking and on August 8, recovered the VDR capsule, which yielded 26 hours of data.

[3] On September 17, 2015, the parent company, TOTE, Inc., announced that Sea Star Line had been renamed TOTE Maritime Puerto Rico.

5. FACTUAL INFORMATION

Unless otherwise noted, directions are in reference to true north, and distances are in nautical miles (i.e., "miles" refers to nautical rather than statute miles). **All plotted positions of *El Faro* found in this report's images are approximations based on data from the NTSB Electronic Data Factual Report for the accident.**[4] Readers are referred to that report for the authoritative track of the accident vessel. Attachment 1 lists dates, times, and coordinates used to create the approximate vessel track employed in this report, except where noted.

5.1. Overview – Hurricane Joaquin

On January 12, 2016, the National Hurricane Center (NHC) released a Tropical Cyclone Report (TCR) on Hurricane Joaquin (see Attachment 2). The TCR gives a general history of the storm and an overview of the meteorological environment before Hurricane Joaquin formed and during its lifetime, based on a post-storm analysis of all available data.

According to the TCR, the weather system that was to become Hurricane Joaquin became a tropical depression at 2000 EDT on September 27, 2015, while centered about 360 miles northeast of San Salvador Island, Bahamas. At 2000 EDT the next evening, the system became Tropical Storm Joaquin, and, during a period of rapid intensification, Joaquin became a hurricane at 0200 EDT on September 30, 2015, when centered 170 miles east-northeast of San Salvador Island. The TCR gives the NHC's "best track"[5] coordinates for Joaquin's position and intensity; the TCR's figure illustrating Hurricane Joaquin's best track positions is reproduced here as figure 1. During the event, the NHC did not publicly identify the storm as a hurricane until 0739 EDT on September 30, 2015 (see section 5.2.1.1), although Joaquin had been forecast to become a hurricane before that time.

[4] Graphics in section 5.2.2.5 contain preliminary position information that, as discussed there, is not based on authoritative NTSB information. The positions are not found in the NTSB Electronic Data Factual Report.

[5] *Best track* is a post-storm, subjectively smoothed representation of a tropical cyclone's location and intensity over its lifetime, in which short-term variations in position or intensity that cannot be resolved in a 6-hourly time series are deliberately removed. The location of a strong hurricane with a well-defined eye might be known with great accuracy in real time, but the best track may indicate a location at a distance of 5 to 10 miles away or more if the precise location of the cyclone at a particular time was unrepresentative. Real-time analyses tend to follow the observed position of the storm more closely than best track analyses, since it is more difficult to determine unrepresentative behavior in real time. The best track contains the cyclone's latitude, longitude, maximum sustained surface winds, and minimum sea-level pressure at 6-hour intervals. Best track positions and intensities, which are based on a post-storm assessment of all available data, may differ from the values in storm advisories. They also will generally not reflect the erratic motion implied by connecting individual center fix positions.

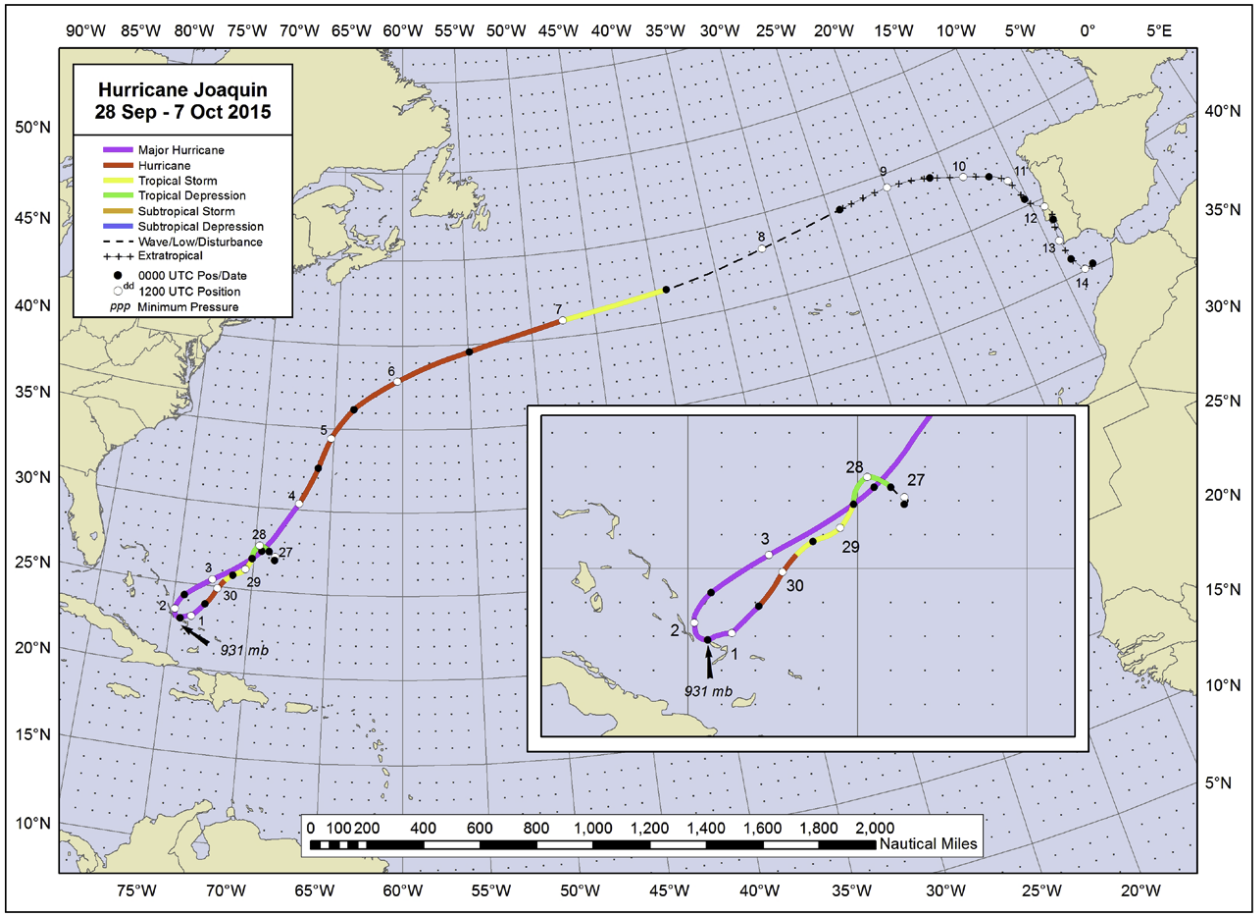

Figure 1 *– Figure 1 from TCR, captioned: "Best track positions for Hurricane Joaquin, 28 September – 7 October 2015. The track during the post-tropical stage is partially based on analyses from the National Oceanic and Atmospheric Administration's (NOAA) Ocean Prediction Center (OPC)."*

According to correspondence with the NHC, the NHC's best post-storm estimate of eye diameter for Hurricane Joaquin between 0500 and 0900 EDT on October 1, 2015, was 25 to 30 miles. The NHC issued estimates of eye diameter in its Tropical Cyclone Forecast/Advisory products[6] (see Attachment 3) issued at 1100 EDT on September 30, 2015 (diameter of 50 miles), at 1700 EDT on September 30, 2015 (diameter of 45 miles), and at 1100 EDT on October 1, 2015 (diameter of 30 miles). According to the NHC, the 30-mile estimate was based on data retrieved from a reconnaissance aircraft around 0800 EDT on October 1, 2015 (see section 5.6.4). However, its post-storm review of satellite images from around that time suggested a slightly smaller diameter of 25 miles.

During the lifecycle of Joaquin leading to the accident time, the following tropical cyclone watches or warnings were issued for the region (all by the government of the Bahamas). See Attachment 3 for the NHC text products that delivered the information. Graphical depictions of the watches and warnings are found in Attachment 4.

[6] This report considers only advisories issued through about 1100 EDT on October 1, 2015.

2300 EDT, September 29, 2015	A Hurricane Watch was issued for the central Bahamas.
0500 EDT, September 30, 2015	The Hurricane Watch in effect for the central Bahamas was changed to a Hurricane Warning. A Hurricane Watch was issued for the northwestern Bahamas excluding Andros Island.
1700 EDT, September 30, 2015	The Hurricane Watch in effect for the northwestern Bahamas excluding Andros Island was changed to a Hurricane Warning for the northwestern Bahamas excluding Andros Island and Bimini. A Tropical Storm Warning was issued for the southeastern Bahamas excluding the Turks and Caicos Islands.
2300 EDT, September 30, 2015	A Tropical Storm Warning and Hurricane Watch were issued for Andros Island
0535 EDT, October 1, 2015	The Tropical Storm Warning issued for the southeastern Bahamas was changed to a Hurricane Warning for Acklins, Crooked Island, and Mayaguana in the southeastern Bahamas

At 0800 EDT on October 1, 2015, the following watches/warnings were in effect in the accident region:

A Hurricane Warning was in effect for...

- Central Bahamas
- Northwestern Bahamas including the Abacos, Berry Islands, Eleuthera, Grand Bahama Island, and New Providence
- Acklins, Crooked Island, and Mayaguana in the southeastern Bahamas

A Hurricane Watch was in effect for...

- Bimini
- Andros Island

A Tropical Storm Warning was in effect for...

- Remainder of the southeastern Bahamas excluding the Turks and Caicos Islands
- Andros Island

Figure 2 shows NHC official 5-day forecast tracks (black lines) for Joaquin issued between 2300 EDT on September 27, 2015, and 0500 EDT on October 1, 2015, as publicly distributed through the Tropical Cyclone Forecast/Advisory text product (see Attachment 3). The figure does not reproduce forecast track uncertainty “cones” or danger areas dictated by the “Mariner’s 1-2-3

rule" for forecast errors (see section 5.2.2.3). NHC products issued with these graphics are presented in section 5.2.2. Included in figure 2 is the best track (blue line) for Joaquin between 0200 EDT on September 28, 2015, and 0800 EDT on October 1, 2015.

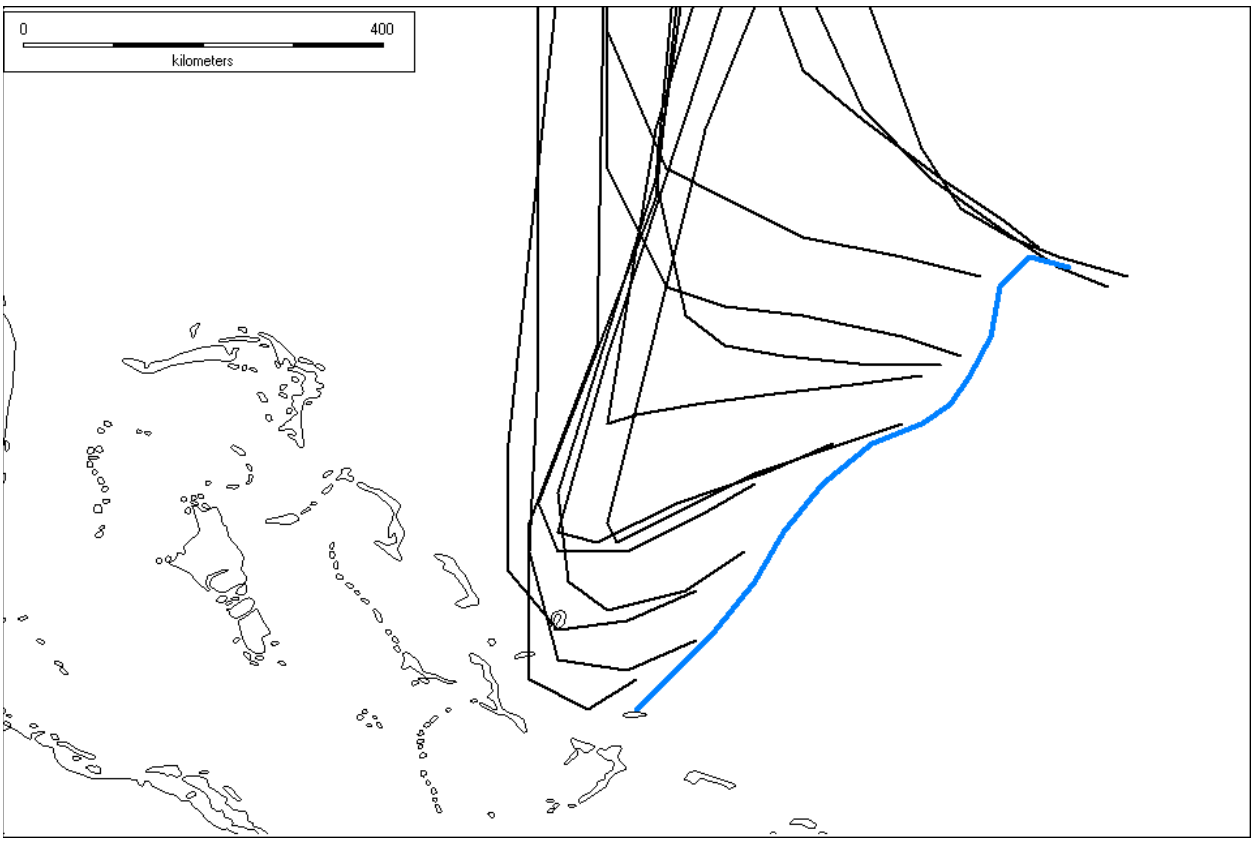

Figure 2 *– NHC official 5-day forecast tracks (black lines) and best track (blue line) for Joaquin through morning of October 1, 2015.*

Figure 3 is taken from TCR figure 11 and presents a plot of the NHC official intensity (maximum sustained wind magnitude) for forecast cycles initiated for Joaquin between 2000 EDT on September 27, 2015, and 2000 EDT on October 7, 2015. The best track intensity of Joaquin is indicated by the white line.

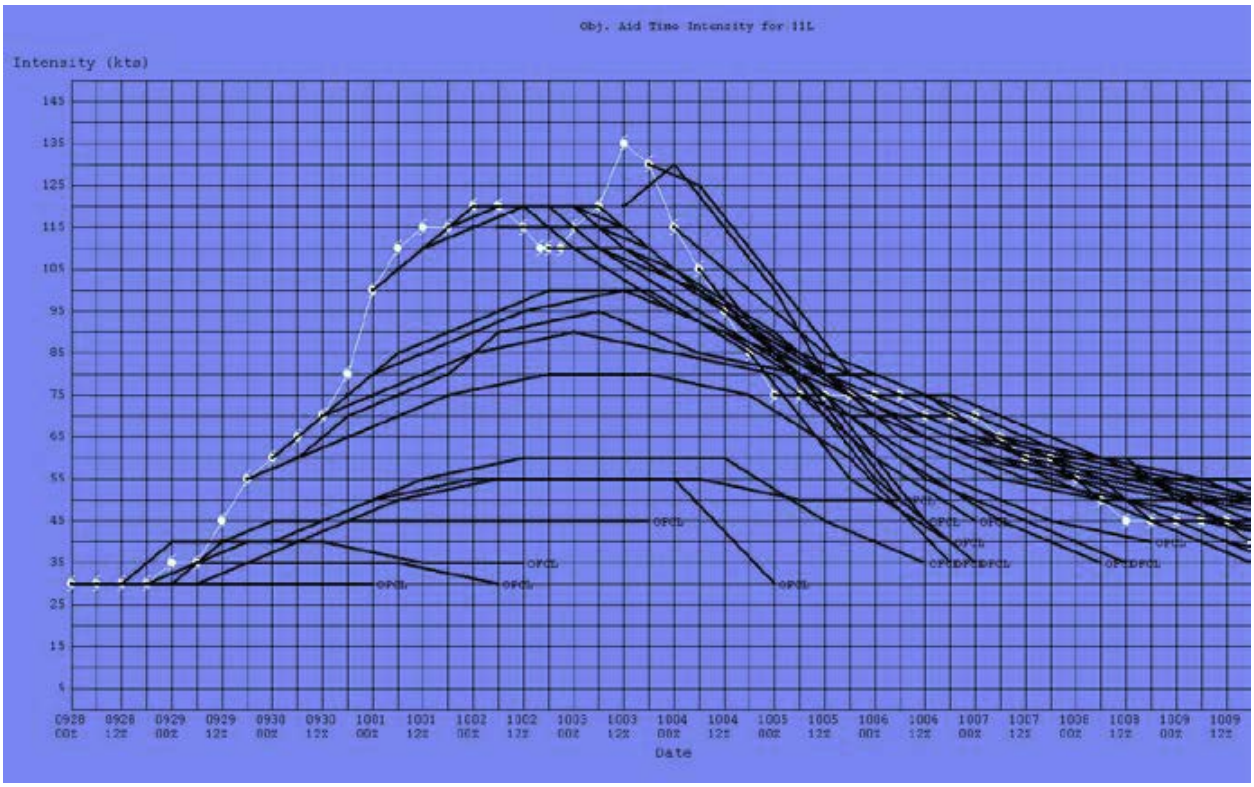

Figure 3 *– NHC official intensity forecasts (black lines) and best track intensity (white line) for Joaquin through evening of October 7, 2015.*

The TCR critiques NHC forecasting for Joaquin. With regard to track, it states: "Official forecast track errors were lower than the mean official errors for the previous 5-yr period at 12 h but were higher between 24 and 120 h. In fact, official forecast track errors between 72 and 120 h were more than double the mean official errors for the previous 5-yr period. However, Joaquin was not a particularly well-behaved storm in terms of its track, and climatology and persistence model (OCD5) errors were larger than their respective mean errors during the previous 5-yr period." The TCR further states: "Much of the error in the forecast track resulted from Joaquin's atypical southwestward motion toward the Bahamas from 0000 UTC 28 September through 1800 UTC 1 October. . . . Most of the models, as well as the official forecast, indicated that Joaquin would move northwestward or westward once it became a tropical cyclone, and they were late in showing the southwestward motion that persisted for several days. The ECMWF [European Centre for Medium-Range Weather Forecasting] model did, however, accurately depict a definitive southwestward motion, with only its first two post-genesis runs showing an immediate westward or northwestward turn. The ECMWF's success may be partly due to its deepening of the cyclone more than the other models, with a deeper-layer flow subsequently pushing Joaquin southwestward." See section 5.10.3 for plots of some ECMWF track forecasts.

With regard to intensity, the TCR states: "Official forecast intensity errors were greater than the mean official errors for the previous 5-yr period at all forecast times."

Further analysis of model performance of the forecasting of Joaquin is found in Appendix I of the NOAA Service Assessment "The Historic South Carolina Floods of October 1-5, 2015."[7] This appendix is included as Attachment 5 and focuses mainly on Joaquin track forecasts valid after the accident time. However, its summary states (in part): "The ECMWF runs consistently and accurately captured the initial movement of Joaquin to the south-southwest, while the GFS [Global Forecast System] had a very difficult time capturing the initial track. This resulted in less warning given to the Bahamas, where significant storm impacts occurred."

Calculations of forecast track and intensity errors for individual forecasts valid near the accident time may be found in section 5.2.1.2.

The TCR further states: "Given the substantial forecast uncertainties associated with Joaquin, and the expectation of inclement weather over parts of the eastern United States irrespective of Joaquin's evolution, NHC took special care in highlighting the most important forecast and preparedness themes associated with the storm. Between the morning of 30 September and the evening of 2 October, NHC provided a set of 'key messages' via its Tropical Cyclone Discussions for Joaquin and its various social media accounts. The key messages detailed NHC's lack of confidence in its track and intensity forecasts for Joaquin and focused attention on the direct—and indirect—effects of the hurricane on the Bahamas and the eastern United States despite the forecast uncertainties."

NTSB discussions with the NHC after the TCR's release revealed that Joaquin was one of the most challenging storms for forecasting track. In particular, the computer models had difficulty defining the cyclone's vertical structure (system depth). According to the NHC, the early stages of Joaquin existed in a northerly shear environment, and early model guidance solutions for Joaquin agreed that wind shear was too strong and that Joaquin would remain a relatively weak system and move to the northwest. However, Joaquin strengthened, became a deep system, and moved southwest.

Readers can refer to the TCR (Attachment 2) for formal analysis of the NHC forecasting of Joaquin, comparisons of model guidance performance, remote sensing images, and in situ datasets. The TCR, as well as the NOAA Service Assessment, also contains information about Joaquin after October 1, 2015.

The NHC's entire internal deck of forecasting aids (in ATCF[8] format) for models initialized through (or interpolated to) 0200 EDT on October 1, 2015, are found in Attachment 6.[9] Section 5.10.3 plots forecast tracks from some of those aids.

[7] The Service Assessment can be found at: http://www.nws.noaa.gov/os/assessments/pdfs/SCFlooding_072216_Signed_Final.pdf

[8] ATCF = Automated Tropical Cyclone Forecast system.

[9] The data were provided by the NHC, with permission to use the ECMWF forecast data given to the NTSB by the Director of Forecasts (acting) at the ECMWF.

5.2. National Hurricane Center Products

The NHC produces both text and graphical products, both of which are discussed in this report.

5.2.1. Text Products

This section describes eleven text products (and one special package) produced by the NHC: the Tropical Cyclone Public Advisory, the Tropical Cyclone Forecast/Advisory, the Aviation Tropical Cyclone Advisory, the Tropical Cyclone Discussion, the Tropical Cyclone Update, the Tropical Weather Discussion, Special Advisory Packages, the High Seas Forecast (both NHC and OPC issuances), the Offshore Waters Forecast, the Marine Weather Discussion, and the VOBRA and NAVTEX text products. The Wind Speed Probabilities text products[10] are not included here. The Tropical Weather Outlook is discussed in section 5.9.6. Attachment 3 contains the complete set, including corrections and amendments and in order of public dissemination, of the above products (except for the Tropical Weather Outlook, VOBRA, and NAVTEX products) issued (nominally[11]) between 2300 EDT on September 27, 2015, and 1100 EDT on October 1, 2015. A presentation, also in order of public dissemination, of the NAVTEX text products and the geographically applicable zones of the VOBRA text products disseminated between 2243 EDT on September 27, 2015, and 0821 EDT on October 1, 2015, is found in Attachment 7.

Marine tropical cyclone warnings (as found in the High Seas Forecast text product) are based on information in the Tropical Cyclone Forecast/Advisory product. The issuance criteria for the marine tropical cyclone warnings are more objective (based on the forecast 34-knot wind radii[12]) than coastal warnings which, in the United States, require coordination between the NHC and the National Weather Service (NWS) Weather Forecast Offices (WFO) and involve coastal "breakpoints." Coastal tropical cyclone warnings for other countries are issued by the meteorological services of those countries or others designated to do so by the World Meteorological Organization (WMO). The NHC issues international land warnings only for Haiti.

The NHC and its international government meteorological service partners coordinate by telephone, as necessary. According to the NHC, the NHC will often call a foreign meteorological service to advise it that the NHC's forthcoming forecast implies a risk to the foreign service area that could qualify for a hurricane or tropical storm watch or warning. If the foreign meteorological service decides (sometimes in consultation with its own government officials) to issue a watch or warning, the NHC will include that watch/warning in its advisory. If and how the foreign meteorological service decides it will communicate that watch or warning and any other information for a storm to users is at its discretion. The forms of such communication are not generally known to or monitored by the NHC.

[10] An example of a current Wind Speed Probabilities text product can be found at http://www.srh.noaa.gov/data/NHC/PWSAT1

[11] "Nominal" time for products or data is the time when they are scheduled to be issued or published; or (e.g., for satellite images), it can mean the overall time stamp for a dataset. Nominal time may be different from actual issuance or retrieval time.

[12] Wind radii represent the maximum possible extent of a given wind speed in particular areas (quadrants) around a tropical cyclone.

The NHC indicated that it was not familiar with, or aware of, any publicly disseminated text or graphical products issued by the government of the Bahamas for Joaquin.

With regard to the first four products detailed below, the NHC will normally issue[13] the Tropical Cyclone Forecast/Advisory first, followed by the Tropical Cyclone Public Advisory and the Aviation Tropical Cyclone Advisory. The three products are usually disseminated within a minute or two of each other. The Tropical Cyclone Discussion might not be completed and disseminated for several minutes after the other products.

Note that the header/initial description of each text product issued by NWS facilities such as the NHC lists two time groups, the nominal issuance time and the actual public dissemination time. In the example below, the nominal issuance time of the product is shown in green highlight,[14] and the actual public dissemination time is shown in blue highlight. The format of the actual public dissemination time is DDHHMM, where DD is the day of month and HHMM is the time of day (UTC) in the 24-hour-clock format. In this example, the Tropical Cyclone Public Advisory for 2300 Atlantic standard time (AST)[15] on September 27, 2015 (Advisory Number 1), was publicly disseminated at 0237 UTC on September 28 (2237 EDT/AST on September 27).[16]

In addition, each text product contains what we define here as WMO and Advanced Weather Interactive Processing System (AWIPS)[17] "headers."[18] The WMO header is identified in gray highlight, and the AWIPS header is identified in yellow highlight.

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WTNT31 KNHC 280237
TCPAT1

BULLETIN
TROPICAL DEPRESSION ELEVEN ADVISORY NUMBER   1
NWS NATIONAL HURRICANE CENTER MIAMI FL       AL112015
1100 PM AST SUN SEP 27 2015
```

[13] NWS text products that contain the statement "ISSUED BY THE NWS WEATHER PREDICTION CENTER COLLEGE PARK MD" are prepared at the Weather Prediction Center (WPC). The WPC is the designated backup office to NHC for Atlantic basin tropical cyclone advisory products. During Joaquin, an NHC forecaster was stationed at the WPC and working with its forecasters to train WPC staff.

[14] Some products print the actual dissemination time in this field.

[15] AST represents the same time as EDT (-0400 from UTC).

[16] Although actual public dissemination time does not explicitly identify month and year, it is assumed that the month and year correspond to those indicated in the nominal time of the text product.

[17] AWIPS is an information processing, display, and telecommunications system used by the NWS.

[18] These headers are part of the product's "AWIPS product identifier."

5.2.1.1. Tropical Cyclone Public Advisory

The Tropical Cyclone Public Advisory for the Atlantic (WMO header WTNT3[1-5][19] KNHC, AWIPS header TCPAT[1-5][20]) lists all current watches and warnings on a tropical or subtropical cyclone. It also gives the cyclone position in latitude and longitude and distance from a selected land point or island, as well as current motion. The advisory includes the maximum sustained winds in miles per hour (mph)[21] and the estimated or measured minimum central pressure in millibars (mb) and inches of mercury. The advisory may also include information on potential storm tides, rainfall, or tornadoes associated with the cyclone, as well as pertinent weather observations.

The Tropical Cyclone Public Advisory is issued for all Atlantic tropical or subtropical cyclones every 6 hours at the nominal times of 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT. Tropical Cyclone Public Advisories are also issued at the 3-hour interval between the regularly scheduled advisories[22] when coastal watches or warnings are in effect, even if the watches or warnings were issued by another country's government (e.g., the Bahamas). In addition, Special Public Advisories may be issued at any time to report on unexpected significant changes with the cyclone, or to issue US watches or warnings.

Below is a partial chronology of the Tropical Cyclone Public Advisory products issued for Joaquin during the time leading to the accident. The chronology is not intended to completely summarize the information in the advisories. Attachment 3 contains all Tropical Cyclone Public Advisory products issued for Joaquin through the accident time.

- At 2237 EDT on September 27, 2015 (nominal advisory time of 2300 EDT on September 27, 2015), Tropical Depression Eleven Public Advisory Number 1 was issued, reporting the formation of a depression at 27.5°N 68.7°W.

- At 2236 EDT on September 28, 2015 (nominal advisory time of 2300 EDT on September 28, 2015), Tropical Storm Joaquin Public Advisory Number 5 was issued indicating that the tropical depression had strengthened to a tropical storm. The advisory indicated that tropical-storm-force winds extended southeastward up to 105 miles (165 kilometers [km]) from the center.

- At 1651 EDT on September 29, 2015 (nominal advisory time of 1700 EDT on September 29, 2015), Tropical Storm Joaquin Public Advisory Number 8 was issued, indicating that additional strengthening was forecast during the next 48 hours, and that Joaquin could become a hurricane the following day.

[19] The numbers 1-5 in the WMO header are assigned on a rotating basis by cyclone number, i.e., advisories on the first, sixth, or eleventh cyclones of the Atlantic season would be sent under the WMO header WTNT31 KNHC; advisories on the second, seventh, or twelfth cyclones of the Atlantic season would be sent under the WMO header WTNT32 KNHC, and so on.

[20] The numbers 1-5 in the AWIPS header are assigned on a rotating basis by cyclone number, i.e., advisories on the first, sixth, or eleventh cyclones of the Atlantic season would be sent under the AWIPS header TCPAT1; advisories on the second, seventh, or twelfth cyclones of the Atlantic season would be sent under the AWIPS header TCPAT2, and so on.

[21] Maximum sustained wind is the standard measure of a tropical cyclone's intensity. When the term is applied to a particular weather system by NHC, it refers to the highest 1-minute average wind (at an elevation of 10 meters with an unobstructed exposure) associated with that weather system at a particular point in time.

[22] These "Intermediate Public Advisories" are issued at nominal times of 0200 EDT, 0800 EDT, 1400 EDT, and 2000 EDT.

- At 2254 EDT on September 29, 2015 (nominal advisory time of 2300 EDT on September 29, 2015), Tropical Storm Joaquin Public Advisory Number 9 was issued indicating that Joaquin was expected to become a hurricane later that night or the next day, and that the government of the Bahamas had issued a hurricane watch for the Central Bahamas (meaning that hurricane conditions were possible in the watch area within the next 36 to 48 hours).

- At 0443 EDT on September 30, 2015 (nominal advisory time of 0500 EDT on September 30, 2015), Tropical Storm Joaquin Public Advisory Number 10 indicated that the government of the Bahamas had issued a hurricane warning for the central Bahamas, including Cat Island, the Exumas, Long Island, Rum Cay, and San Salvador. A hurricane warning is a statement advising that hurricane conditions are expected somewhere in the warning area, with the warning typically issued 36 hours before the anticipated first occurrence of tropical-storm-force winds. The advisory also indicated that the government of the Bahamas had issued a hurricane watch for the northwestern Bahamas excluding Andros Island. The watch area included the Abacos, Berry Islands, Bimini, Eleuthera, Grand Bahama Island, and New Providence.

- At 0739 EDT on September 30, 2015 (nominal advisory time of 0800 EDT on September 30, 2015), Hurricane Joaquin Intermediate Public Advisory Number 10A was issued indicating that Joaquin had become a hurricane.

- At 2249 EDT on September 30, 2015 (nominal advisory time of 2300 EDT on September 30, 2015), Hurricane Joaquin Public Advisory Number 13 was issued, indicating that Joaquin had become a Category 3 hurricane.

The NHC defines a tropical storm as a tropical cyclone in which the maximum sustained wind magnitude ranges from 39 mph (34 knots or 63 kilometers per hour [km/hr]) to 73 mph (63 knots or 118 km/hr). C*yclone* is the general term for an atmospheric closed circulation that rotates around a center of low atmospheric pressure. A *tropical cyclone* is defined by the NHC to be a warm-core, nonfrontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined center. A tropical cyclone with maximum sustained winds of at least 74 mph is a hurricane. The Saffir-Simpson Hurricane Wind Scale classifies hurricanes as follows:

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74-95 mph 64-82 knots 119-153 km/hr	**Very dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 83-95 knots 154-177 km/hr	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (major)	111-129 mph 96-112 knots 178-208 km/hr	**Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph 113-136 knots 209-251 km/hr	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher 137 knots or higher 252 km/hr or higher	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

5.2.1.2. Tropical Cyclone Forecast/Advisory

The Tropical Cyclone Forecast/Advisory text product (WMO header WTNT2[1-5] KNHC, AWIPS header TCMAT[1-5] for Atlantic products) contains a list of all current watches and warnings for a tropical or subtropical cyclone, as well as its current latitude and longitude, intensity, system motion, and size of the wind field. The advisory contains forecast values of the cyclone positions, intensities, and wind fields for 12, 24, 36, 48, and 72 hours from the forecast initialization time. Forecast positions and intensities are also given for 96 and 120 hours from the forecast initialization time. Wind magnitudes are given in knots.

The Tropical Cyclone Forecast/Advisory text product is issued for all Atlantic tropical and subtropical cyclones every 6 hours at the nominal times of 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT (i.e., 3 hours after each forecast initialization time). Special Tropical Cyclone

Forecast/Advisory products may be issued at any time to report on unexpected significant changes with the cyclone, or to issue US watches or warnings.

Reproduced below are current and forecast storm positions, intensities, and wind radii from the noncorrected[23] Tropical Cyclone Forecast/Advisory text products issued between (nominally) 2300 EDT on September 27, 2015, and 0500 EDT on October 1, 2015. Forecasts valid after 2000 EDT on October 1, 2015, are not included. Attachment 3 contains all Tropical Cyclone Forecast/Advisory text products issued for Joaquin through the accident time. See section 5.9.3 for graphical depictions of the current and forecast storm center positions and the 34-knot, 50-knot, and 64-knot wind field radii.

- TROPICAL DEPRESSION ELEVEN FORECAST/ADVISORY NUMBER 1
  NWS NATIONAL HURRICANE CENTER MIAMI FL AL112015
  0300 UTC MON SEP 28 2015

  TROPICAL DEPRESSION CENTER LOCATED NEAR 27.5N 68.7W AT 28/0300Z
  POSITION ACCURATE WITHIN 30 NM

  PRESENT MOVEMENT TOWARD THE NORTHWEST OR 315 DEGREES AT 2 KT

  ESTIMATED MINIMUM CENTRAL PRESSURE 1007 MB
  MAX SUSTAINED WINDS 30 KT WITH GUSTS TO 40 KT.

  FORECAST VALID 28/1200Z 27.7N 69.4W
  MAX WIND 30 KT...GUSTS 40 KT.

  FORECAST VALID 29/0000Z 27.9N 69.9W
  MAX WIND 30 KT...GUSTS 40 KT.

  FORECAST VALID 29/1200Z 28.2N 70.4W
  MAX WIND 30 KT...GUSTS 40 KT.

  FORECAST VALID 30/0000Z 28.8N 70.8W
  MAX WIND 30 KT...GUSTS 40 KT.

  FORECAST VALID 01/0000Z 31.0N 71.6W
  MAX WIND 30 KT...GUSTS 40 KT.

- TROPICAL DEPRESSION ELEVEN FORECAST/ADVISORY NUMBER 2
  NWS NATIONAL HURRICANE CENTER MIAMI FL AL112015
  0900 UTC MON SEP 28 2015

  TROPICAL DEPRESSION CENTER LOCATED NEAR 27.3N 68.9W AT 28/0900Z
  POSITION ACCURATE WITHIN 30 NM

  PRESENT MOVEMENT TOWARD THE WEST OR 275 DEGREES AT 2 KT

  ESTIMATED MINIMUM CENTRAL PRESSURE 1007 MB
  MAX SUSTAINED WINDS 30 KT WITH GUSTS TO 40 KT.

  FORECAST VALID 28/1800Z 27.6N 69.4W

[23] The Tropical Cyclone Forecast/Advisory nominally issued at 0500 EDT on September 30, 2015 (Advisory Number 10), was corrected and reissued at 0534 EDT on September 30, 2015, to "show [the] hurricane watch for the northwestern Bahamas excluding Andros Island." The original version of the product had incorrectly indicated a hurricane warning had been issued for the northwestern Bahamas. Both versions can be seen in Attachment 3.

MAX WIND 30 KT...GUSTS 40 KT.

FORECAST VALID 29/0600Z 28.0N 70.0W
MAX WIND 35 KT...GUSTS 45 KT.
34 KT... 40NE 40SE   0SW 20NW.

FORECAST VALID 29/1800Z 28.5N 70.7W
MAX WIND 35 KT...GUSTS 45 KT.
34 KT... 40NE 40SE   0SW 20NW.

FORECAST VALID 30/0600Z 29.2N 71.4W
MAX WIND 35 KT...GUSTS 45 KT.
34 KT... 40NE 40SE   0SW 20NW.

FORECAST VALID 01/0600Z 31.2N 72.3W
MAX WIND 35 KT...GUSTS 45 KT.
34 KT... 40NE 40SE   0SW 20NW.

- TROPICAL DEPRESSION ELEVEN FORECAST/ADVISORY NUMBER 3
NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
1500 UTC MON SEP 28 2015

TROPICAL DEPRESSION CENTER LOCATED NEAR 27.8N 69.6W AT 28/1500Z
POSITION ACCURATE WITHIN 20 NM

PRESENT MOVEMENT TOWARD THE WEST-NORTHWEST OR 295 DEGREES AT 4 KT

ESTIMATED MINIMUM CENTRAL PRESSURE 1006 MB
MAX SUSTAINED WINDS 30 KT WITH GUSTS TO 40 KT.

FORECAST VALID 29/0000Z 28.1N 70.0W
MAX WIND 40 KT...GUSTS 50 KT.
34 KT... 60NE 40SE   0SW   0NW.

FORECAST VALID 29/1200Z 28.5N 70.6W
MAX WIND 40 KT...GUSTS 50 KT.
34 KT... 70NE 40SE   0SW   0NW.

FORECAST VALID 30/0000Z 29.1N 71.4W
MAX WIND 40 KT...GUSTS 50 KT.
34 KT... 70NE 60SE 20SW 30NW.

FORECAST VALID 30/1200Z 29.6N 72.0W
MAX WIND 40 KT...GUSTS 50 KT.
34 KT... 70NE 60SE 30SW 40NW.

FORECAST VALID 01/1200Z 32.0N 72.9W
MAX WIND 35 KT...GUSTS 45 KT.
34 KT... 60NE 70SE   0SW 50NW.

- TROPICAL DEPRESSION ELEVEN FORECAST/ADVISORY NUMBER 4
NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
2100 UTC MON SEP 28 2015

TROPICAL DEPRESSION CENTER LOCATED NEAR 27.5N 70.2W AT 28/2100Z
POSITION ACCURATE WITHIN 20 NM

PRESENT MOVEMENT TOWARD THE WEST OR 270 DEGREES AT 5 KT

ESTIMATED MINIMUM CENTRAL PRESSURE 1003 MB
MAX SUSTAINED WINDS 30 KT WITH GUSTS TO 40 KT.

FORECAST VALID 29/0600Z 27.7N 71.0W
MAX WIND 30 KT...GUSTS 40 KT.

FORECAST VALID 29/1800Z 27.9N 72.0W
MAX WIND 35 KT...GUSTS 45 KT.
34 KT... 50NE 40SE 20SW   0NW.

FORECAST VALID 30/0600Z 28.3N 72.8W
MAX WIND 40 KT...GUSTS 50 KT.
34 KT... 50NE 40SE 20SW   0NW.

FORECAST VALID 30/1800Z 28.6N 73.4W
MAX WIND 45 KT...GUSTS 55 KT.
34 KT... 70NE 70SE 50SW 40NW.

FORECAST VALID 01/1800Z 30.0N 74.0W
MAX WIND 45 KT...GUSTS 55 KT.
34 KT... 70NE 70SE 50SW 40NW.

- TROPICAL STORM JOAQUIN FORECAST/ADVISORY NUMBER 5
NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
0300 UTC TUE SEP 29 2015

TROPICAL STORM CENTER LOCATED NEAR 26.7N 70.4W AT 29/0300Z
POSITION ACCURATE WITHIN 25 NM

PRESENT MOVEMENT TOWARD THE SOUTHWEST OR 230 DEGREES AT 4 KT

ESTIMATED MINIMUM CENTRAL PRESSURE 1002 MB
MAX SUSTAINED WINDS 35 KT WITH GUSTS TO 45 KT.
34 KT....... 0NE 90SE   0SW   0NW.

FORECAST VALID 29/1200Z 26.9N 71.0W
MAX WIND 40 KT...GUSTS 50 KT.
34 KT... 50NE 70SE 40SW 50NW.

FORECAST VALID 30/0000Z 27.1N 72.0W
MAX WIND 40 KT...GUSTS 50 KT.
34 KT... 60NE 60SE 40SW 50NW.

FORECAST VALID 30/1200Z 27.2N 72.8W
MAX WIND 45 KT...GUSTS 55 KT.
34 KT... 70NE 60SE 50SW 70NW.

FORECAST VALID 01/0000Z 27.4N 73.4W
MAX WIND 50 KT...GUSTS 60 KT.
50 KT... 40NE   0SE   0SW   0NW.
34 KT... 80NE 70SE 60SW 70NW.

FORECAST VALID 02/0000Z 28.6N 74.0W
MAX WIND 55 KT...GUSTS 65 KT.
50 KT... 40NE 40SE   0SW   0NW.
34 KT... 90NE 80SE 70SW 70NW.

- TROPICAL STORM JOAQUIN FORECAST/ADVISORY NUMBER 6
  NWS NATIONAL HURRICANE CENTER MIAMI FL AL112015
  0900 UTC TUE SEP 29 2015

  TROPICAL STORM CENTER LOCATED NEAR 26.6N 70.6W AT 29/0900Z
  POSITION ACCURATE WITHIN 30 NM

  PRESENT MOVEMENT TOWARD THE WEST OR 270 DEGREES AT 4 KT

  ESTIMATED MINIMUM CENTRAL PRESSURE 1002 MB
  MAX SUSTAINED WINDS 35 KT WITH GUSTS TO 45 KT.
  34 KT..... 0NE 60SE 0SW 0NW.
  12 FT SEAS.. 0NE 90SE 0SW 0NW.

  FORECAST VALID 29/1800Z 26.6N 71.3W
  MAX WIND 40 KT...GUSTS 50 KT.
  34 KT... 30NE 60SE 20SW 20NW.

  FORECAST VALID 30/0600Z 26.7N 72.2W
  MAX WIND 40 KT...GUSTS 50 KT.
  34 KT... 30NE 60SE 30SW 30NW.

  FORECAST VALID 30/1800Z 26.8N 72.8W
  MAX WIND 45 KT...GUSTS 55 KT.
  34 KT... 50NE 70SE 50SW 50NW.

  FORECAST VALID 01/0600Z 27.1N 73.2W
  MAX WIND 50 KT...GUSTS 60 KT.
  50 KT... 30NE 30SE 20SW 30NW.
  34 KT... 70NE 70SE 70SW 70NW.

- TROPICAL STORM JOAQUIN FORECAST/ADVISORY NUMBER 7
  NWS NATIONAL HURRICANE CENTER MIAMI FL AL112015
  1500 UTC TUE SEP 29 2015

  TROPICAL STORM CENTER LOCATED NEAR 26.5N 70.8W AT 29/1500Z
  POSITION ACCURATE WITHIN 30 NM

  PRESENT MOVEMENT TOWARD THE WEST OR 260 DEGREES AT 4 KT

  ESTIMATED MINIMUM CENTRAL PRESSURE 1001 MB
  MAX SUSTAINED WINDS 40 KT WITH GUSTS TO 50 KT.
  34 KT..... 0NE 60SE 0SW 0NW.
  12 FT SEAS.. 90NE 90SE 60SW 90NW.

  FORECAST VALID 30/0000Z 26.4N 71.5W
  MAX WIND 45 KT...GUSTS 55 KT.
  34 KT... 30NE 60SE 20SW 20NW.

  FORECAST VALID 30/1200Z 26.3N 72.4W
  MAX WIND 45 KT...GUSTS 55 KT.
  34 KT... 30NE 60SE 30SW 30NW.

  FORECAST VALID 01/0000Z 26.2N 73.1W
  MAX WIND 50 KT...GUSTS 60 KT.
  50 KT... 30NE 20SE 20SW 30NW.

34 KT... 50NE 70SE 50SW 50NW.

FORECAST VALID 01/1200Z 26.1N 73.7W
MAX WIND 55 KT...GUSTS 65 KT.
50 KT... 30NE 30SE 20SW 30NW.
34 KT... 70NE 70SE 70SW 70NW.

- TROPICAL STORM JOAQUIN FORECAST/ADVISORY NUMBER 8
NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
2100 UTC TUE SEP 29 2015

TROPICAL STORM CENTER LOCATED NEAR 26.0N 71.0W AT 29/2100Z
POSITION ACCURATE WITHIN 30 NM

PRESENT MOVEMENT TOWARD THE WEST-SOUTHWEST OR 240 DEGREES AT 4 KT

ESTIMATED MINIMUM CENTRAL PRESSURE 990 MB
MAX SUSTAINED WINDS 55 KT WITH GUSTS TO 65 KT.
50 KT..... 30NE 50SE   0SW   0NW.
34 KT..... 60NE 80SE   0SW   0NW.
12 FT SEAS..120NE 90SE 60SW 90NW.

FORECAST VALID 30/0600Z 25.8N 71.6W
MAX WIND 60 KT...GUSTS 75 KT.
50 KT... 30NE 50SE   0SW   0NW.
34 KT... 60NE 80SE 40SW   0NW.

FORECAST VALID 30/1800Z 25.5N 72.5W
MAX WIND 65 KT...GUSTS 80 KT.
64 KT... 20NE 20SE   0SW   0NW.
50 KT... 30NE 50SE   0SW   0NW.
34 KT... 60NE 80SE 40SW 30NW.

FORECAST VALID 01/0600Z 25.1N 73.3W
MAX WIND 70 KT...GUSTS 85 KT.
64 KT... 20NE 20SE   0SW   0NW.
50 KT... 30NE 50SE   0SW   0NW.
34 KT... 60NE 80SE 40SW 30NW.

FORECAST VALID 01/1800Z 24.8N 73.9W
MAX WIND 75 KT...GUSTS 90 KT.
50 KT... 30NE 50SE   0SW   0NW.
34 KT... 60NE 80SE 60SW 60NW.

- TROPICAL STORM JOAQUIN FORECAST/ADVISORY NUMBER 9
NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
0300 UTC WED SEP 30 2015

TROPICAL STORM CENTER LOCATED NEAR 25.8N 71.7W AT 30/0300Z
POSITION ACCURATE WITHIN 25 NM

PRESENT MOVEMENT TOWARD THE WEST-SOUTHWEST OR 240 DEGREES AT 4 KT

ESTIMATED MINIMUM CENTRAL PRESSURE 988 MB

MAX SUSTAINED WINDS 60 KT WITH GUSTS TO 75 KT.
50 KT....... 40NE 50SE   0SW   0NW.
34 KT....... 80NE 110SE 30SW 30NW.
12 FT SEAS..120NE 90SE 60SW 90NW.

FORECAST VALID 30/1200Z 25.5N 72.4W
MAX WIND 70 KT...GUSTS 85 KT.
64 KT... 20NE 20SE   0SW   0NW.
50 KT... 40NE 50SE   0SW 20NW.
34 KT... 80NE 100SE 40SW 40NW.

FORECAST VALID 01/0000Z 25.2N 73.3W
MAX WIND 75 KT...GUSTS 90 KT.
64 KT... 20NE 20SE   0SW 20NW.
50 KT... 40NE 50SE 20SW 30NW.
34 KT... 80NE 100SE 50SW 50NW.

FORECAST VALID 01/1200Z 24.8N 74.1W
MAX WIND 80 KT...GUSTS 100 KT.
64 KT... 20NE 20SE   0SW 20NW.
50 KT... 40NE 50SE 20SW 30NW.
34 KT... 80NE 100SE 50SW 50NW.

FORECAST VALID 02/0000Z 24.9N 74.5W
MAX WIND 85 KT...GUSTS 105 KT.
50 KT... 40NE 50SE 20SW 30NW.
34 KT... 80NE 100SE 50SW 60NW.

- TROPICAL STORM JOAQUIN FORECAST/ADVISORY NUMBER 10
  NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
  0900 UTC WED SEP 30 2015

  TROPICAL STORM CENTER LOCATED NEAR 25.4N 72.5W AT 30/0900Z
  POSITION ACCURATE WITHIN 25 NM

  PRESENT MOVEMENT TOWARD THE WEST-SOUTHWEST OR 245 DEGREES AT 5 KT

  ESTIMATED MINIMUM CENTRAL PRESSURE 988 MB
  MAX SUSTAINED WINDS 60 KT WITH GUSTS TO 75 KT.
  50 KT....... 40NE 50SE   0SW   0NW.
  34 KT.......100NE 110SE 40SW 60NW.
  12 FT SEAS..150NE 90SE 60SW 120NW.

  FORECAST VALID 30/1800Z 25.1N 73.0W
  MAX WIND 70 KT...GUSTS 85 KT.
  64 KT... 20NE 20SE   0SW   0NW.
  50 KT... 50NE 50SE   0SW 20NW.
  34 KT...100NE 110SE 50SW 70NW.

  FORECAST VALID 01/0600Z 24.7N 73.8W
  MAX WIND 75 KT...GUSTS 90 KT.
  64 KT... 30NE 30SE   0SW 20NW.
  50 KT... 50NE 50SE 30SW 30NW.
  34 KT...110NE 110SE 60SW 70NW.

FORECAST VALID 01/1800Z 24.7N 74.5W
MAX WIND 80 KT...GUSTS 100 KT.
64 KT... 30NE 30SE   0SW 20NW.
50 KT... 60NE 60SE 30SW 40NW.
34 KT...110NE 110SE 60SW 70NW.

- HURRICANE JOAQUIN FORECAST/ADVISORY NUMBER 11
  NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
  1500 UTC WED SEP 30 2015

  HURRICANE CENTER LOCATED NEAR 24.7N 72.6W AT 30/1500Z
  POSITION ACCURATE WITHIN 25 NM

  PRESENT MOVEMENT TOWARD THE SOUTHWEST OR 230 DEGREES AT 5 KT

  ESTIMATED MINIMUM CENTRAL PRESSURE 971 MB
  MAX SUSTAINED WINDS 70 KT WITH GUSTS TO 85 KT.
  64 KT....... 30NE 30SE 20SW 20NW.
  50 KT....... 40NE 50SE 30SW 30NW.
  34 KT.......100NE 110SE 60SW 60NW.
  12 FT SEAS..160NE 100SE 90SW 130NW.

  FORECAST VALID 01/0000Z 24.3N 73.2W
  MAX WIND 80 KT...GUSTS 100 KT.
  64 KT... 30NE 30SE 20SW 20NW.
  50 KT... 50NE 50SE 30SW 30NW.
  34 KT...100NE 110SE 60SW 70NW.

  FORECAST VALID 01/1200Z 24.1N 74.0W
  MAX WIND 85 KT...GUSTS 105 KT.
  64 KT... 40NE 40SE 30SW 30NW.
  50 KT... 60NE 60SE 40SW 50NW.
  34 KT...120NE 120SE 70SW 80NW.

  FORECAST VALID 02/0000Z 24.4N 74.4W
  MAX WIND 90 KT...GUSTS 110 KT.
  64 KT... 40NE 40SE 30SW 30NW.
  50 KT... 70NE 70SE 40SW 50NW.
  34 KT...130NE 130SE 80SW 100NW.

- HURRICANE JOAQUIN FORECAST/ADVISORY NUMBER 12
  NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
  2100 UTC WED SEP 30 2015

  HURRICANE CENTER LOCATED NEAR 24.3N 73.1W AT 30/2100Z
  POSITION ACCURATE WITHIN 20 NM

  PRESENT MOVEMENT TOWARD THE SOUTHWEST OR 225 DEGREES AT 7 KT

  ESTIMATED MINIMUM CENTRAL PRESSURE 967 MB
  MAX SUSTAINED WINDS 75 KT WITH GUSTS TO 90 KT.
  64 KT....... 30NE 30SE 20SW 20NW.
  50 KT....... 40NE 50SE 30SW 30NW.
  34 KT.......100NE 110SE 80SW 80NW.
  12 FT SEAS..160NE 100SE 90SW 130NW.

FORECAST VALID 01/0600Z 24.0N 73.8W
MAX WIND 85 KT...GUSTS 105 KT.
64 KT... 30NE 30SE 20SW 20NW.
50 KT... 60NE 60SE 40SW 60NW.
34 KT...120NE 120SE 80SW 80NW.

FORECAST VALID 01/1800Z 23.9N 74.5W
MAX WIND 90 KT...GUSTS 110 KT.
64 KT... 40NE 40SE 30SW 30NW.
50 KT... 70NE 70SE 40SW 50NW.
34 KT...130NE 130SE 80SW 100NW.

- HURRICANE JOAQUIN FORECAST/ADVISORY NUMBER 13
NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
0300 UTC THU OCT 01 2015

HURRICANE CENTER LOCATED NEAR 23.8N 73.1W AT 01/0300Z
POSITION ACCURATE WITHIN 15 NM

PRESENT MOVEMENT TOWARD THE SOUTHWEST OR 220 DEGREES AT 5 KT

ESTIMATED MINIMUM CENTRAL PRESSURE 951 MB
MAX SUSTAINED WINDS 100 KT WITH GUSTS TO 120 KT.
64 KT....... 25NE 30SE 20SW 20NW.
50 KT....... 40NE 60SE 30SW 40NW.
34 KT.......100NE 120SE 80SW 80NW.
12 FT SEAS..210NE 160SE 120SW 180NW.

FORECAST VALID 01/1200Z 23.5N 73.8W
MAX WIND 110 KT...GUSTS 135 KT.
64 KT... 30NE 30SE 20SW 20NW.
50 KT... 60NE 60SE 40SW 60NW.
34 KT...120NE 120SE 80SW 80NW.

FORECAST VALID 02/0000Z 23.6N 74.5W
MAX WIND 120 KT...GUSTS 145 KT.
64 KT... 40NE 40SE 30SW 30NW.
50 KT... 70NE 70SE 40SW 50NW.
34 KT...130NE 130SE 80SW 100NW.

- HURRICANE JOAQUIN FORECAST/ADVISORY NUMBER 14
NWS NATIONAL HURRICANE CENTER MIAMI FL   AL112015
0900 UTC THU OCT 01 2015

HURRICANE CENTER LOCATED NEAR 23.4N 73.7W AT 01/0900Z
POSITION ACCURATE WITHIN 25 NM

PRESENT MOVEMENT TOWARD THE WEST-SOUTHWEST OR 240 DEGREES AT 4 KT

ESTIMATED MINIMUM CENTRAL PRESSURE 948 MB
MAX SUSTAINED WINDS 105 KT WITH GUSTS TO 130 KT.
64 KT....... 25NE 30SE 20SW 20NW.
50 KT....... 40NE 60SE 30SW 40NW.
34 KT.......100NE 120SE 100SW 80NW.

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12 FT SEAS..220NE 180SE 100SW 180NW.

FORECAST VALID 01/1800Z 23.1N  74.2W
MAX WIND 115 KT...GUSTS 140 KT.
64 KT... 35NE  40SE  20SW  20NW.
50 KT... 60NE  70SE  40SW  60NW.
34 KT...120NE 130SE 100SW  90NW.
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The NTSB calculated track and intensity forecast errors[24] for Joaquin in the forecasts provided through the Tropical Cyclone Forecast/Advisory products issued during the 48 hours leading to the accident. Errors were calculated by comparing Joaquin's forecast center position and intensity valid for 0800 EDT on October 1, 2015, with the best track center position and intensity valid for 0800 EDT on October 1, 2015 (23.1°N, 73.7°W - 115 knots).

The following table presents these calculated errors (rounded to nearest whole number) along with the pertinent forecast period (the time interval for which a forecast is made[25]) from each Tropical Cyclone Forecast/Advisory product. Because the Tropical Cyclone Forecast/Advisory is not released (nominally) until 3 hours after the beginning of each forecast cycle, the time difference between the nominal product issuance time and the valid time will always be 3 hours less than the applicable forecast period.

Nominal Product Dissemination Time	Forecast Center Position and Intensity^	Forecast Period	Errors
1100 EDT September 29, 2015 (Advisory Number 7)	26.1°N 73.7°W - 55 knots	48 hours	180 miles 60 knots
2300 EDT September 29, 2015 (Advisory Number 9)	24.8°N 74.1°W - 80 knots	36 hours	104 miles 35 knots
1100 EDT September 30, 2015 (Advisory Number 11)	24.1°N 74.0°W - 85 knots	24 hours	62 miles 30 knots
2300 EDT September 30, 2015 (Advisory Number 13)	23.5°N 73.8°W - 110 knots	12 hours	25 miles 5 knots

^ Forecast valid for 0800 EDT on October 1, 2015, contained in the Tropical Cyclone Forecast/Advisory.

Tables 6a and 7a in the TCR present mean 5-year forecast track and forecast intensity errors for the NHC's official forecasts[26], respectively. Mean 5-year errors (between 2010 and 2014) for track and intensity for the 12-hour, 24-hour, 36-hour, and 48-hour forecast periods were 28.4 miles/6.2 knots, 45.0 miles/9.4 knots, 60.4 miles/11.5 knots, and 77.1 miles/13.3 knots, respectively.

[24] Forecast track error is defined as the great-circle distance between a cyclone's forecast position and the best track position at the forecast verification time. Forecast intensity error is defined as the absolute value of the difference between the forecast and best track intensity at the forecast verifying time.

[25] A forecast initiated at 0000 EDT that is valid for 1200 EDT would have a forecast period of 12 hours.

[26] As relayed through the Tropical Cyclone Forecast/Advisory products.

5.2.1.3. Aviation Tropical Cyclone Advisory

The Aviation Tropical Cyclone Advisory (WMO header FKNT2[1-5] KNHC, AWIPS header TCANT[1-5] for Atlantic products) provides short-term tropical cyclone forecasts for international aviation safety and routing purposes. The product lists the current tropical cyclone position, motion, and intensity, and includes forecast positions and intensities for 6, 12, 18, and 24 hours from product issuance times. Position and intensity information for 6, 12, 18, and 24 hours from the product issuance time is interpolated from information in the Tropical Cyclone Forecast/Advisory. Intensity is rounded to the nearest 5 knots. Though the product is called "aviation," it can be used by anyone and is unique among NHC products in providing interpolated forecasts of intensity and position.

The Aviation Tropical Cyclone Advisory is issued every 6 hours at the regular advisory issuance times of (nominally) 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT. Aviation Tropical Cyclone Advisory products for special advisories are issued for the same circumstances that apply to the Tropical Cyclone Public Advisory. Attachment 3 contains all Aviation Tropical Cyclone Advisory products issued for Joaquin through the accident time.

5.2.1.4. Tropical Cyclone Discussion

The Tropical Cyclone Discussion (WMO header WTNT4[1-5] KNHC, AWIPS header TCDAT[1-5] for Atlantic products) explains the reasoning for the analysis and forecast of a tropical or subtropical cyclone. It includes a table of the forecast track and intensity. Tropical Cyclone Discussions are issued for all Atlantic tropical and subtropical cyclones every 6 hours at nominal times of 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT. Special Discussions may be issued at any time to report on unexpected significant changes with the cyclone, or to issue US watches or warnings. Attachment 3 contains all Tropical Cyclone Discussions issued for Joaquin through the accident time.

5.2.1.5. Tropical Cyclone Update

The Tropical Cyclone Update (WMO header WTNT6[1-5] KNHC, AWIPS header TCUAT[1-5] for Atlantic products) is a brief alphanumeric text product containing either block paragraph text, a formatted storm summary, or both. Tropical Cyclone Updates are issued to inform users of significant changes in a tropical cyclone between regularly scheduled Tropical Cyclone Public Advisories. Its uses include, but are not limited to, the following:

- Providing timely information of an unusual nature, such as the time and location of landfall, or to announce an expected change in intensity that results in an upgrade or downgrade of status (e.g., from a tropical storm to a hurricane).
- Providing a continuous flow of information about the center location of a tropical cyclone when watches or warnings are in effect and the center can be easily tracked with land-based radar.

- Providing advance notice that significant changes to storm information will be conveyed shortly, through either a Tropical Cyclone Update or a special advisory.
- Announcing changes to international watches or warnings made by other countries, or to cancel US watches or warnings.
- Issuing a US watch or warning, but only if the Tropical Cyclone Update both precedes a special advisory with the same watch or warning information and indicates that the special advisory will be issued shortly.

Only one Tropical Cyclone Update was issued for Joaquin before 1100 EDT on October 1, 2015. The following was issued at 0535 EDT on October 1, 2015:

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WTNT61 KNHC 010935
TCUAT1

HURRICANE JOAQUIN TROPICAL CYCLONE UPDATE
NWS NATIONAL HURRICANE CENTER MIAMI FL       AL112015
535 AM EDT THU OCT 1 2015

At 535 AM EDT (0935 UTC) the Government of the Bahamas has
issued a Hurricane Warning for the Acklins, Crooked Island, and
Mayaguana in the southeastern Bahamas.

$$
Forecaster Brennan
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5.2.1.6. Tropical Weather Discussion

The Tropical Weather Discussion (WMO header AXNT20 KNHC, AWIPS header TWDAT for Atlantic products) describes major synoptic weather features and significant areas of disturbed weather in the tropics. The product is intended to provide current weather information for those who need to know the current state of the atmosphere and expected trends for decision-making purposes. The product gives significant weather features, areas of disturbed weather, expected trends, the meteorological reasoning behind the forecast, model performance, and in some cases a degree of confidence. As events dictate, the product will include descriptions of hurricanes, tropical storms, tropical depressions, subtropical cyclones, and any other feature of significance that may develop into a tropical or subtropical cyclone. For active tropical cyclones, this section includes the latest advisory data on the system.

The NHC issues two Tropical Weather Discussions, one of which covers the Atlantic region from the equator to 32°N west of the prime meridian, including the Caribbean Sea, Gulf of Mexico, and adjacent land areas (southeast United States, Mexico, Central America, northern South America and western Africa).

Tropical Weather Discussions for the Atlantic are issued every 6 hours at nominal times of 0205 EDT, 0805 EDT, 1405 EDT, and 2005 EDT. Attachment 3 contains all Tropical Weather Discussions issued for Joaquin through the accident time.

5.2.1.7. Special Advisory Packages

Special advisory packages are issued on an unscheduled basis as needed. Special advisories are issued whenever an unexpected significant change occurs or when US watches or warnings are to be issued between regularly scheduled advisories. When a special advisory is required, the entire advisory package is issued, including the Tropical Cyclone Public Advisory, the Tropical Cyclone Forecast/Advisory, the Tropical Cyclone Discussion, the Aviation Tropical Cyclone Advisory, and the suite of graphics. When the special advisory is issued for a new watch or warning, it contains the track and intensity forecast from the previous regularly scheduled advisory, with only the initial position and intensity updated. When the special advisory is issued for an unexpected change, the previous track and intensity forecast is updated accordingly.

No special advisories were issued for Joaquin between 2300 EDT on September 27, 2015, and 1100 EDT on October 1, 2015. The only special advisory for Joaquin was issued at 1200 EDT on October 3, 2015. The text of the Tropical Cyclone Discussion in the package (Discussion Number 24) included the following:

> This special advisory is to adjust the initial and forecast intensity through 36 hours. An Air Force Hurricane Hunter plane just penetrated the eye of Joaquin and measured 144 kt at 700 mb and SFMR winds of around 135 kt. No change in the forecast track is necessary.

5.2.1.8. High Seas Forecast

The NHC issues High Seas Forecasts for the Atlantic Ocean (from 7°N to 31°N west of 35°W, including the Caribbean Sea and the Gulf of Mexico). The High Seas Forecast is updated every 6 hours at nominal times of 0030 EDT, 0630 EDT, 1230 EDT, and 1830 EDT, and includes a description of winds and waves for the current time and 24- and 48-hour forecasts of wind and waves, using a 20-knot threshold for the wind and an 8-foot threshold for the seas. Positions and intensities are also given for tropical cyclones out to 120 hours. Intermediate forecast times are given for rapidly changing weather events. The High Seas Forecasts also include updated descriptions of convection, particularly along the ITCZ.[27] The products include marine warnings for gale-, storm- and hurricane-force winds and tropical cyclone-related conditions, and can include information on reduced visibility and other marine hazards.

[27] The Intertropical Convergence Zone (ITCZ), known as the “doldrums,” is the area encircling the earth near the equator where the northeast and southeast trade winds meet.

The NHC-issued High Seas Forecast applicable to the accident region carries WMO header FZNT02 KNHC and AWIPS header HSFAT2. That specific product is included in the OPC-issued High Seas Forecast with WMO header FZNT01 KWBC and AWIPS header HSFAT1. The OPC-issued High Seas Forecast is issued after the OPC receives the NHC-issued product and also provides current and forecast information for a separate Atlantic region.

Note that the NHC-issued High Seas Forecast may be completed well before its nominal issuance time and are publicly disseminated before the OPC-issued High Seas Forecast. The following table lists the public dissemination times of the NHC-issued High Seas Forecast and the OPC-issued High Seas Forecast (which carries and redistributes the NHC-issued High Seas Forecast) between about 0000 EDT on September 28, 2015, and 0600 EDT on October 1, 2015.

Dissemination Time of NHC-issued High Seas Forecast FZNT02 KNHC/HSFAT2	**Dissemination Time of OPC-issued High Seas Forecast FZNT01 KWBC/HSFAT1**	**Time Difference (minutes)**
2357 EDT September 27, 2015	2358 EDT September 27, 2015	1
0616 EDT September 28, 2015*	0620 EDT September 28, 2015	4
1154 EDT September 28, 2015	1155 EDT September 28, 2015	1
1816 EDT September 28, 2015	1817 EDT September 28, 2015	1
2311 EDT September 28, 2015	2348 EDT September 28, 2015	37
0539 EDT September 29, 2015	0553 EDT September 29, 2015	14
1201 EDT September 29, 2015	1205 EDT September 29, 2015	4
1735 EDT September 29, 2015	1803 EDT September 29, 2015	28
2304 EDT September 29, 2015	0002 EDT September 30, 2015	58
0504 EDT September 30, 2015	0547 EDT September 30, 2015	43
1206 EDT September 30, 2015	1211 EDT September 30, 2015	5
1805 EDT September 30, 2015	1808 EDT September 30, 2015	3
2255 EDT September 30, 2015	0017 EDT October 1, 2015	82
0501 EDT October 1, 2015	0600 EDT October 1, 2015	59

* Corrected version.

Presented below are synopses and forecasts of surface wind and sea state, as well as marine warnings, carried in both NHC and OPC High Seas Forecast products issued between (nominal times) of 0030 EDT on September 28, 2015, and 0630 EDT on October 1, 2015. Forecasts valid after 2000 EDT on October 1, 2015, are not included. Attachment 3 contains all High Seas Forecast products issued by both the NHC and the OPC through the accident time.

Each High Seas Forecast contained current position and forecast track and intensity information for Joaquin originally disseminated in the previously issued (nominally, 90 minutes earlier) Tropical Cyclone Forecast/Advisory.[28]

The NHC's High Seas Forecast issued at 0609 EDT (nominal time 0630 EDT) on September 28, 2015, delivered the first marine tropical storm warning for Joaquin.[29] The NHC's High Seas Forecast issued at 1735 EDT (nominal time 1830 EDT) on September 29, 2015, contained the first marine hurricane warning for Joaquin.[30]

- HIGH SEAS FORECAST
  0430 UTC MON SEP 28 2015

  SYNOPSIS VALID 0000 UTC MON SEP 28.
  24 HOUR FORECAST VALID 0000 UTC TUE SEP 29.
  48 HOUR FORECAST VALID 0000 UTC WED SEP 30.

  .TROPICAL DEPRESSION ELEVEN NEAR 27.5N 68.7W 1007 MB AT 0300 UTC SEP 28 MOVING NW OR 315 DEG AT 2 KT. MAXIMUM SUSTAINED WINDS 30 KT GUSTS 40 KT. WITHIN 210 NM NE SEMICIRCLE WINDS 20 TO 30 KT. SEAS TO 10 FT IN NE SWELL.
  .24 HOUR FORECAST TROPICAL DEPRESSION ELEVEN NEAR 27.9N 69.9W. MAXIMUM SUSTAINED WINDS 30 KT GUSTS 40 KT. WITHIN 240 NM NE SEMICIRCLE WINDS 20 TO 30 KT. SEAS TO 11 FT IN NE SWELL.
  .48 HOUR FORECAST TROPICAL DEPRESSION ELEVEN NEAR 28.8N 70.8W. MAXIMUM SUSTAINED WINDS 30 KT GUSTS 40 KT. OVER FORECAST WATERS WITHIN 240 NM NE SEMICIRCLE WINDS 20 TO 30 KT. SEAS TO 11 FT IN NE TO E SWELL.
  .72 HOUR FORECAST TROPICAL DEPRESSION ELEVEN NEAR 31.0N 71.6W. MAXIMUM SUSTAINED WINDS 30 KT GUSTS 40 KT.

- HIGH SEAS FORECAST...CORRECTED
  1030 UTC MON SEP 28 2015

  SYNOPSIS VALID 0600 UTC MON SEP 28.
  24 HOUR FORECAST VALID 0600 UTC TUE SEP 29.
  48 HOUR FORECAST VALID 0600 UTC WED SEP 30.

  ...TROPICAL STORM WARNING...
  .TROPICAL DEPRESSION ELEVEN NEAR 27.4N 68.9W 1007 MB AT 0900 UTC SEP 28 MOVING W OR 275 DEG AT 2 KT. MAXIMUM SUSTAINED WINDS 30 KT GUSTS 40 KT. WITHIN 60 NM NE AND AND 45 SW SEMICIRCLE WINDS 20 TO 30 KT. SEAS 8 TO 10 FT. ELSEWHERE N OF 27N BETWEEN 65W AND 75W WINDS 20 KT OR LESS. SEAS 8 TO 12 FT PRIMARILY IN NE SWELL.
  .24 HOUR FORECAST TROPICAL STORM ELEVEN NEAR 28.0N 70.0W. MAXIMUM SUSTAINED WINDS 35 KT GUSTS 45 KT. TROPICAL STORM FORCE

[28] The High Seas Forecasts (both the NHC uncorrected/corrected issuances and the OPC issuance) issued (nominally) at 0630 EDT on September 28, 2015, stated that Tropical Depression Eleven was "near 27.4N 68.9W." The Tropical Cyclone Forecast/Advisory issued (nominally) at 0500 EDT on September 28, 2015 (Advisory Number 2), identified the tropical depression center as "near 27.3N 68.9W."

[29] A corrected product was issued at 0616 EDT on September 28, 2015, to correct a formatting error.

[30] The Offshore Waters Forecast issued at 1718 EDT (nominal time 1730 EDT) on September 29, 2015, was the first product to carry a marine hurricane warning for Joaquin.

WINDS WITHIN 40 NM E SEMICIRCLE...0 NM SW QUADRANT AND 20 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 45 NM NE SEMICIRCLE WITH SEAS TO 13 FT. ELSEWHERE WITHIN 75 NM NE AND 45 SW SEMICIRCLE WINDS 20 TO 33 KT. SEAS 8 TO 12 FT. REMAINDER OF AREA N OF 27N BETWEEN 65W AND 73W WINDS 20 KT OR LESS. SEAS 8 TO 10 FT PRIMARILY IN NE SWELL.
.48 HOUR FORECAST TROPICAL STORM ELEVEN NEAR 29.2N 71.4W. MAXIMUM SUSTAINED WINDS 35 KT GUSTS 45 KT. LITTLE CHANGE IN RADIUS OF TROPICAL STORM FORCE WINDS AND SEAS 12 FT OR GREATER. ELSEWHERE N OF 28N BETWEEN 65W AND 71W SE WINDS 20 TO 25 KT. SEAS 8 FT.
.72 HOUR FORECAST TROPICAL STORM ELEVEN NEAR 31.2N 72.3W. MAXIMUM SUSTAINED WINDS 35 KT GUSTS 45 KT. EXTENDED OUTLOOK...USE FOR GUIDANCE ONLY...ERRORS MAY BE LARGE.

- HIGH SEAS FORECAST
  1630 UTC MON SEP 28 2015

  SYNOPSIS VALID 1200 UTC MON SEP 28.
  24 HOUR FORECAST VALID 1200 UTC TUE SEP 29.
  48 HOUR FORECAST VALID 1200 UTC WED SEP 30.

  ...TROPICAL STORM WARNING...
  .TROPICAL DEPRESSION ELEVEN NEAR 27.8N 69.6W 1006 MB AT 1500 UTC SEP 28 MOVING WNW OR 295 DEG AT 4 KT. MAXIMUM SUSTAINED WINDS 30 KT GUSTS 40 KT. WITHIN 60 NM NE AND AND 45 SW SEMICIRCLE WINDS 20 TO 30 KT. SEAS 8 TO 10 FT. ELSEWHERE N OF 27N BETWEEN 65W AND 75W WINDS 20 KT OR LESS. SEAS 8 TO 12 FT PRIMARILY IN NE SWELL.
  .24 HOUR FORECAST TROPICAL STORM ELEVEN NEAR 28.5N 70.6W. MAXIMUM SUSTAINED WINDS 40 KT GUSTS 50 KT. TROPICAL STORM FORCE WINDS WITHIN 0 NM W SEMICIRCLE...70 NM NE QUADRANT AND 40 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 60 NM N SEMICIRCLE WITH SEAS TO 13 FT. ELSEWHERE WITHIN 75 NM NE AND 45 SW SEMICIRCLE WINDS 20 TO 33 KT. SEAS 8 TO 12 FT. REMAINDER OF AREA N OF 26N BETWEEN 65W AND 73W WINDS 20 KT OR LESS. SEAS 8 TO 10 FT PRIMARILY IN NE SWELL.
  .48 HOUR FORECAST TROPICAL STORM ELEVEN NEAR 29.6N 72.0W. MAXIMUM SUSTAINED WINDS 40 KT GUSTS 50 KT. TROPICAL STORM FORCE WINDS WITHIN 70 NM NE QUADRANT...60 NM SE QUADRANT...30 NM SW QUADRANT...AND 40 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 60 NM N SEMICIRCLE WITH SEAS TO 13 FT. ELSEWHERE WITHIN 90 NM NE AND 45 SW SEMICIRCLE WINDS 25 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA 27N BETWEEN 67W AND 73W WINDS 20 TO 25 KT. SEAS 8 TO 10 FT IN MIXED SWELL.
  .72 HOUR FORECAST TROPICAL STORM ELEVEN NEAR 32.0N 72.9W.MAXIMUM SUSTAINED WINDS 35 KT GUSTS 45 KT. EXTENDED OUTLOOK...USE FOR GUIDANCE ONLY...ERRORS MAY BE LARGE.

- HIGH SEAS FORECAST
  2230 UTC MON SEP 28 2015

  SYNOPSIS VALID 1800 UTC MON SEP 28.

24 HOUR FORECAST VALID 1800 UTC TUE SEP 29.
48 HOUR FORECAST VALID 1800 UTC WED SEP 30.

...TROPICAL STORM WARNING...
.TROPICAL DEPRESSION ELEVEN NEAR 27.5N 70.2W 1003 MB AT 2100 UTC SEP 28 MOVING W OR 270 DEG AT 5 KT. MAXIMUM SUSTAINED WINDS 30 KT GUSTS 40 KT. WITHIN 120 NM E SEMICIRCLE WINDS 20 TO 30 KT. SEAS TO 10 FT.
.24 HOUR FORECAST TROPICAL STORM ELEVEN NEAR 27.9N 72.0W. MAXIMUM SUSTAINED WINDS 35 KT GUSTS 45 KT. TROPICAL STORM FORCE WINDS WITHIN 50 NM NE QUADRANT...40 NM SE QUADRANT...20 NM SW QUADRANT...AND 0 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 180 NM NE SEMICIRCLE WITH SEAS TO 13 FT. ELSEWHERE WITHIN 120 NM NE AND 45 SW SEMICIRCLE WINDS 20 TO 33 KT. SEAS 8 TO 10 FT.
.48 HOUR FORECAST TROPICAL STORM ELEVEN NEAR 28.6N 73.4W. MAXIMUM SUSTAINED WINDS 45 KT GUSTS 55 KT. TROPICAL STORM FORCE WINDS WITHIN 70 NM E SEMICIRCLE...50 NM SW QUADRANT AND 40 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 90 NM N SEMICIRCLE WITH SEAS TO 13 FT. ELSEWHERE WITHIN 120 NM NE AND 45 SW SEMICIRCLE WINDS 25 TO 33 KT. SEAS 8 TO 10 FT.
.72 HOUR FORECAST TROPICAL STORM ELEVEN NEAR 30.0N 74.0W. MAXIMUM SUSTAINED WINDS 45 KT GUSTS 55 KT. EXTENDED OUTLOOK...USE FOR GUIDANCE ONLY...ERRORS MAY BE LARGE.

- HIGH SEAS FORECAST
0430 UTC TUE SEP 29 2015

SYNOPSIS VALID 0000 UTC TUE SEP 29.
24 HOUR FORECAST VALID 0000 UTC WED SEP 30.
48 HOUR FORECAST VALID 0000 UTC THU OCT 01.

...ATLANTIC TROPICAL STORM WARNING...
.TROPICAL STORM JOAQUIN NEAR 26.7N 70.4W 1002 MB AT 0300 UTC SEP 29 MOVING SW OR 230 DEG AT 4 KT. MAXIMUM SUSTAINED WINDS 35 KT GUSTS 45 KT. TROPICAL STORM FORCE WINDS WITHIN 0 NM OF CENTER EXCEPT 90 NM SE QUADRANT. SEAS 8 TO 11 FT WITHIN 90 NM NE SEMICIRCLE. ELSEWHERE WITHIN 120 NM E SEMICIRCLE WINDS 20 TO 30 KT. SEAS TO 12 FT.
.24 HOUR FORECAST TROPICAL STORM JOAQUIN NEAR 27.1N 72.0W. MAXIMUM SUSTAINED WINDS 40 KT GUSTS 50 KT. TROPICAL STORM FORCE WINDS WITHIN 60 NM E SEMICIRCLE...40 NM SW QUADRANT AND 50 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 180 NM NE SEMICIRCLE WITH SEAS TO 13 FT. ELSEWHERE WITHIN 120 NM NE AND 45 SW SEMICIRCLE WINDS 20 TO 33 KT. SEAS 8 TO 10 FT.
.48 HOUR FORECAST TROPICAL STORM JOAQUIN NEAR 27.4N 73.4W. MAXIMUM SUSTAINED WINDS 50 KT GUSTS 60 KT. TROPICAL STORM FORCE WINDS WITHIN 70 NM NW AND SE QUADRANTS...80 NM NE QUADRANT AND 60 NM SW QUADRANT. SEAS 12 FT OR GREATER WITHIN 90 NM N SEMICIRCLE WITH SEAS TO 13 FT. ELSEWHERE WITHIN 120 NM NE AND 45 SW SEMICIRCLE WINDS 25 TO 33 KT. SEAS 8 TO 10 FT.
.72 HOUR FORECAST TROPICAL STORM JOAQUIN NEAR 28.6N 74.0W. MAXIMUM SUSTAINED WINDS 55 KT GUSTS 65 KT. EXTENDED OUTLOOK...USE FOR GUIDANCE ONLY...ERRORS MAY BE LARGE.

- HIGH SEAS FORECAST
  1030 UTC TUE SEP 29 2015

  SYNOPSIS VALID 0600 UTC TUE SEP 29.
  24 HOUR FORECAST VALID 0600 UTC WED SEP 30.
  48 HOUR FORECAST VALID 0600 UTC THU OCT 01.

  ...ATLC TROPICAL STORM WARNING...
  .TROPICAL STORM JOAQUIN NEAR 26.6N 70.6W 1002 MB AT 0900 UTC SEP 29 MOVING W OR 270 DEG AT 4 KT. MAXIMUM SUSTAINED WINDS 35 KT GUSTS 45 KT. TROPICAL STORM FORCE WINDS WITHIN 60 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 90 NM SE QUADRANT WITH SEAS TO 13 FT. ELSEWHERE WITHIN 120 NM E SEMICIRCLE WINDS 20 TO 30 KT. SEAS TO 12 FT.
  .24 HOUR FORECAST TROPICAL STORM JOAQUIN NEAR 26.7N 72.2W. MAXIMUM SUSTAINED WINDS 40 KT GUSTS 50 KT. TROPICAL STORM FORCE WINDS WITHIN 30 NM OF CENTER EXCEPT 60 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 120 NM SE AND 60 NM NW SEMICIRCLES WITH SEAS TO 15 FT. ELSEWHERE WITHIN 120 NM NE AND 45 SW SEMICIRCLE WINDS 20 TO 33 KT. SEAS 8 TO 10 FT.
  .48 HOUR FORECAST TROPICAL STORM JOAQUIN NEAR 27.1N 73.2W. MAXIMUM SUSTAINED WINDS 50 KT GUSTS 60 KT. TROPICAL STORM FORCE WINDS WITHIN 70 NM OF CENTER. SEAS 12 FT OR GREATER WITHIN 120 NM OF CENTER WITH SEAS TO 18 FT. ELSEWHERE WITHIN 120 NM NE AND 45 SW SEMICIRCLE WINDS 25 TO 33 KT. SEAS 8 TO 10 FT.

- HIGH SEAS FORECAST
  1630 UTC TUE SEP 29 2015

  SYNOPSIS VALID 1200 UTC TUE SEP 29.
  24 HOUR FORECAST VALID 1200 UTC WED SEP 30.
  48 HOUR FORECAST VALID 1200 UTC THU OCT 01.

  ...ATLC TROPICAL STORM WARNING...
  .TROPICAL STORM JOAQUIN NEAR 26.5N 70.8W 1001 MB AT 1500 UTC SEP 29 MOVING W OR 260 DEG AT 4 KT. MAXIMUM SUSTAINED WINDS 40 KT GUSTS 50 KT. TROPICAL STORM FORCE WINDS WITHIN 0 NM OF CENTER EXCEPT 60 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 90 NM OF CENTER EXCEPT 60 NM SW QUADRANT WITH SEAS TO 14 FT. ELSEWHERE WITHIN 120 NM E SEMICIRCLE WINDS 20 TO 30 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 25N BETWEEN 65W AND 75W WINDS 20 KT OR LESS. SEAS 8 TO 10 FT PRIMARILY IN NE SWELL.
  .24 HOUR FORECAST TROPICAL STORM JOAQUIN NEAR 26.3N 72.4W. MAXIMUM SUSTAINED WINDS 45 KT GUSTS 55 KT. TROPICAL STORM FORCE WINDS WITHIN 30 NM OF CENTER EXCEPT 60 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 120 NM SE AND 60 NM NW SEMICIRCLES WITH SEAS TO 16 FT. ELSEWHERE WITHIN 150 NM NE AND 60 SW SEMICIRCLE WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 24N BETWEEN 65W AND 75W WINDS 20 KT OR LESS. SEAS 8 TO 10 FT IN MIXED SWELL.
  .48 HOUR FORECAST TROPICAL STORM JOAQUIN NEAR 26.1N 73.7W. MAXIMUM SUSTAINED WINDS 55 KT GUSTS 65 KT. TROPICAL STORM FORCE

WINDS WITHIN 70 NM OF CENTER. SEAS 12 FT OR GREATER WITHIN 120 NM OF CENTER WITH SEAS TO 20 FT. ELSEWHERE WITHIN 180 NM NE AND 75 SW SEMICIRCLE WINDS 25 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 25N BETWEEN 65W AND 78W OUTSIDE THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 10 FT IN MIXED SWELL.

- HIGH SEAS FORECAST
  2230 UTC TUE SEP 29 2015

  SYNOPSIS VALID 1800 UTC TUE SEP 29.
  24 HOUR FORECAST VALID 1800 UTC WED SEP 30.
  48 HOUR FORECAST VALID 1800 UTC THU OCT 01.

  ...HURRICANE WARNING...
  .TROPICAL STORM JOAQUIN NEAR 26.0N 71.0W 990 MB AT 2100 UTC SEP 29 MOVING WSW OR 240 DEG AT 4 KT. MAXIMUM SUSTAINED WINDS 55 KT GUSTS 65 KT. TROPICAL STORM FORCE WINDS WITHIN 60 NM NE QUADRANT AND 80 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 90 NM NW AND SE QUADRANTS...120 NM NE QUADRANT AND 60 NM SW QUADRANT WITH SEAS TO 21 FT. ELSEWHERE WITHIN 180 NM NE AND 90 NM SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 25N BETWEEN 65W AND 75W WINDS 20 KT OR LESS. SEAS 8 TO 10 FT PRIMARILY IN NE SWELL.
  .24 HOUR FORECAST HURRICANE JOAQUIN NEAR 25.5N 72.5W. MAXIMUM SUSTAINED WINDS 65 KT GUSTS 80 KT. TROPICAL STORM FORCE WINDS WITHIN 60 NM NE QUADRANT...80 NM SE QUADRANT...40 NM SW QUADRANT...AND 30 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 120 NM NE AND 60 NM SW SEMICIRCLES WITH SEAS TO 24 FT. ELSEWHERE WITHIN 210 NM NE AND 120 SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 24N BETWEEN 65W AND 77W AND OUTSIDE THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 10 FT IN MIXED SWELL.
  .48 HOUR FORECAST HURRICANE JOAQUIN NEAR 24.8N 73.9W. MAXIMUM SUSTAINED WINDS 75 KT GUSTS 90 KT. TROPICAL STORM FORCE WINDS WITHIN 60 NM OF CENTER EXCEPT 80 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 120 NM OF CENTER WITH SEAS TO 28 FT. ELSEWHERE WITHIN 240 NM NE AND 150 SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 22N BETWEEN 65W AND 77W OUTSIDE THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 10 FT IN MIXED SWELL.

- HIGH SEAS FORECAST
  0430 UTC WED SEP 30 2015

  SYNOPSIS VALID 0000 UTC WED SEP 30.
  24 HOUR FORECAST VALID 0000 UTC THU OCT 01.
  48 HOUR FORECAST VALID 0000 UTC FRI OCT 02.

  ...HURRICANE WARNING...
  .TROPICAL STORM JOAQUIN NEAR 25.8N 71.7W 988 MB AT 0300 UTC SEP 30 MOVING WSW OR 240 DEG AT 4 KT. MAXIMUM SUSTAINED WINDS 60 KT GUSTS 75 KT. TROPICAL STORM FORCE WINDS WITHIN 30 NM W SEMICIRCLE...80 NM NE QUADRANT AND 110 NM SE QUADRANT. SEAS 12

FT OR GREATER WITHIN 90 NM NW AND SE QUADRANTS...120 NM NE QUADRANT AND 60 NM SW QUADRANT WITH SEAS TO 24 FT. ELSEWHERE WITHIN 180 NM NE AND 120 NM SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 25N BETWEEN 65W AND 75W WINDS 20 KT OR LESS. SEAS 8 TO 10 FT PRIMARILY IN NE SWELL.
.24 HOUR FORECAST HURRICANE JOAQUIN NEAR 25.2N 73.3W. MAXIMUM SUSTAINED WINDS 75 KT GUSTS 90 KT. TROPICAL STORM FORCE WINDS WITHIN 50 NM W SEMICIRCLE...80 NM NE QUADRANT AND 100 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 120 NM NE AND 60 NM SW SEMICIRCLES WITH SEAS TO 26 FT. ELSEWHERE WITHIN 210 NM NE AND 150 SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 23N BETWEEN 65W AND 77W AND OUTSIDE THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 10 FT IN MIXED SWELL.
.48 HOUR FORECAST HURRICANE JOAQUIN NEAR 24.9N 74.5W. MAXIMUM SUSTAINED WINDS 85 KT GUSTS 105 KT. TROPICAL STORM FORCE WINDS WITHIN 80 NM NE QUADRANT...100 NM SE QUADRANT...50 NM SW QUADRANT...AND 60 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 150 NM NE AND 90 NM SW SEMICIRCLES WITH SEAS TO 28 FT. ELSEWHERE WITHIN 210 NM NE AND 150 SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 22N BETWEEN 65W AND 78W OUTSIDE THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 10 FT IN MIXED SWELL.

- HIGH SEAS FORECAST
  1030 UTC WED SEP 30 2015

  SYNOPSIS VALID 0600 UTC WED SEP 30.
  24 HOUR FORECAST VALID 0600 UTC THU OCT 01.

  ...HURRICANE WARNING...
  .TROPICAL STORM JOAQUIN NEAR 25.4N 72.5W 988 MB AT 0900 UTC SEP 30 MOVING WSW OR 245 DEG AT 5 KT. MAXIMUM SUSTAINED WINDS 60 KT GUSTS 75 KT. TROPICAL STORM FORCE WINDS WITHIN 100 NM NE QUADRANT...110 NM SE QUADRANT...40 NM SW QUADRANT...AND 60 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 150 NM NE QUADRANT...90 NM SE QUADRANT...60 NM SW QUADRANT...AND 120 NM NW QUADRANT WITH SEAS TO 22 FT. ELSEWHERE WITHIN 210 NM NE AND 120 NM SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 9 TO 12 FT. REMAINDER OF AREA N OF 24N BETWEEN 66W AND 75W WINDS 20 KT OR LESS. SEAS 8 TO 10 FT PRIMARILY IN NE SWELL.
  .24 HOUR FORECAST HURRICANE JOAQUIN NEAR 24.7N 73.8W. MAXIMUM SUSTAINED WINDS 75 KT GUSTS 90 KT. TROPICAL STORM FORCE WINDS WITHIN 110 NM E SEMICIRCLE...60 NM SW QUADRANT AND 70 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 210 NM N AND 90 NM S SEMICIRCLES WITH SEAS TO 27 FT. ELSEWHERE WITHIN 240 NM NE AND 120 SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 23N BETWEEN 68W AND 77W AND OUTSIDE THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 11 FT IN MIXED SWELL.

- HIGH SEAS FORECAST
  1630 UTC WED SEP 30 2015

SYNOPSIS VALID 1200 UTC WED SEP 30.
24 HOUR FORECAST VALID 1200 UTC THU OCT 01.

...ATLC HURRICANE WARNING...
.HURRICANE JOAQUIN NEAR 24.7N 72.6W 971 MB AT 1500 UTC SEP 30 MOVING SW OR 230 DEG AT 5 KT. MAXIMUM SUSTAINED WINDS 70 KT GUSTS 85 KT. TROPICAL STORM FORCE WINDS WITHIN 60 NM W SEMICIRCLE...100 NM NE QUADRANT AND 110 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 160 NM NE QUADRANT...100 NM SE QUADRANT... ...90 NM SW QUADRANT...AND 130 NM NW QUADRANT WITH SEAS TO 25 FT. ELSEWHERE WITHIN 210 NM NE AND 120 NM SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 9 TO 12 FT. REMAINDER OF AREA N OF 24N BETWEEN 66W AND 79W WINDS 20 KT OR LESS. SEAS 8 TO 10 FT PRIMARILY IN NE SWELL.
.24 HOUR FORECAST HURRICANE JOAQUIN NEAR 24.1N 74.0W. MAXIMUM SUSTAINED WINDS 85 KT GUSTS 105 KT. TROPICAL STORM FORCE WINDS WITHIN 120 NM E SEMICIRCLE...70 NM SW QUADRANT AND 80 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 240 NM N AND 90 NM S SEMICIRCLES WITH SEAS TO 28 FT. ELSEWHERE WITHIN 300 NM NE AND 120 SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 22N BETWEEN 68W AND 79W AND OUTSIDE THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 11 FT IN MIXED SWELL.

- HIGH SEAS FORECAST
2230 UTC WED SEP 30 2015

SYNOPSIS VALID 1800 UTC WED SEP 30.
24 HOUR FORECAST VALID 1800 UTC THU OCT 01.

...ATLC HURRICANE WARNING...
.HURRICANE JOAQUIN NEAR 24.3N 73.1W 967 MB AT 2100 UTC SEP 30 MOVING SW OR 225 DEG AT 7 KT. MAXIMUM SUSTAINED WINDS 75 KT GUSTS 90 KT. TROPICAL STORM FORCE WINDS WITHIN 80 NM W SEMICIRCLE...100 NM NE QUADRANT AND 110 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 160 NM NE...100 NM SE...90 NM SW AND 130 NM NW QUADRANTS WITH SEAS TO 27 FT. ELSEWHERE WITHIN 210 NM NE AND 120 NM SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 9 TO 12 FT. REMAINDER OF AREA N OF 23N BETWEEN 66W AND 78W WINDS 20 KT OR LESS. SEAS 8 TO 10 FT PRIMARILY IN NE SWELL.
.24 HOUR FORECAST HURRICANE JOAQUIN NEAR 23.9N 74.5W. MAXIMUM SUSTAINED WINDS 90 KT GUSTS 110 KT. TROPICAL STORM FORCE WINDS WITHIN 130 NM E SEMICIRCLE...80 NM SW QUADRANT AND 100 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 240 NM N AND 120 NM S SEMICIRCLES WITH SEAS TO 30 FT. ELSEWHERE WITHIN 300 NM NE AND 120 SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 10 TO 12 FT. REMAINDER OF AREA N OF 22N BETWEEN 68W AND 79W NE OF THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 11 FT IN MIXED SWELL.

- HIGH SEAS FORECAST
0430 UTC THU OCT 1 2015

SYNOPSIS VALID 0000 UTC THU OCT 01.
24 HOUR FORECAST VALID 0000 UTC FRI OCT 02.

...ATLC HURRICANE WARNING...
.HURRICANE JOAQUIN NEAR 23.8N 73.1W 951 MB AT 0300 UTC OCT 01 MOVING SW OR 220 DEG AT 5 KT. MAXIMUM SUSTAINED WINDS 100 KT GUSTS 120 KT. TROPICAL STORM FORCE WINDS WITHIN 80 NM W SEMICIRCLE...100 NM NE QUADRANT AND 120 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 210 NM NE...160 NM SE...120 NM SW AND 180 NM NW QUADRANTS WITH SEAS TO 30 FT. ELSEWHERE WITHIN 270 NM NE AND 180 NM SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 8 TO 12 FT E OF BAHAMAS. REMAINDER OF AREA N OF 22N BETWEEN 67W AND 78W WINDS 20 KT OR LESS. SEAS 8 TO 11 FT PRIMARILY IN NE SWELL.
.24 HOUR FORECAST HURRICANE JOAQUIN NEAR 23.6N 74.5W. MAXIMUM SUSTAINED WINDS 120 KT GUSTS 145 KT. TROPICAL STORM FORCE WINDS WITHIN 130 NM E SEMICIRCLE...80 NM SW QUADRANT AND 100 NM NW QUADRANT. SEAS 12 FT OR GREATER WITHIN 270 NM NE AND 120 NM SE SEMICIRCLES WITH SEAS TO 36 FT. ELSEWHERE WITHIN 330 NM NE AND 180 SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 8 TO 12 FT E OF BAHAMAS. REMAINDER OF AREA N OF 22N BETWEEN 67W AND 79W NE OF THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 11 FT IN MIXED SWELL.

- HIGH SEAS FORECAST
  1030 UTC THU OCT 01 2015

  SYNOPSIS VALID 0600 UTC THU OCT 01.

  ...HURRICANE WARNING...
  .HURRICANE JOAQUIN NEAR 23.4N 73.7W 948 MB AT 0900 UTC OCT 01 MOVING WSW OR 240 DEG AT 4 KT. MAXIMUM SUSTAINED WINDS 105 KT GUSTS 130 KT. TROPICAL STORM FORCE WINDS WITHIN 100 NM NE AND SW QUADRANTS...80 NM NW QUADRANT AND 120 NM SE QUADRANT. SEAS 12 FT OR GREATER WITHIN 180 NM NW AND SE QUADRANTS...220 NM NE QUADRANT AND 100 NM SW QUADRANT WITH SEAS TO 36 FT. ELSEWHERE WITHIN 270 NM NE AND 180 NM SW SEMICIRCLES WINDS 20 TO 33 KT. SEAS 8 TO 12 FT E OF BAHAMAS. REMAINDER OF AREA N OF 21.5N BETWEEN 67W AND 78W AND OUTSIDE OF THE BAHAMAS WINDS 20 KT OR LESS. SEAS 8 TO 11 FT IN MIXED SWELL.

5.2.1.9. Offshore Waters Forecast

The Offshore Waters Forecasts provide forecast and warning information to mariners who travel on the oceanic waters next to the United States and its territorial coastal waters in the Gulf of Mexico, Caribbean Sea, and parts of the tropical and subtropical North Atlantic Ocean. The area covered by the Offshore Waters Forecasts is divided into 32 zones (see figure 4). The NHC issues two Offshore Waters Forecast products, one for the Caribbean Sea and one for parts of the Atlantic Ocean south of 31°N and west of 55°W. The products are issued every 6 hours at nominal times of 0530 EDT, 1130 EDT, 1730 EDT, and 2330 EDT. The Offshore Waters Forecast covering the accident region carries WMO header FZNT23 KNHC and AWIPS header OFFNT3.

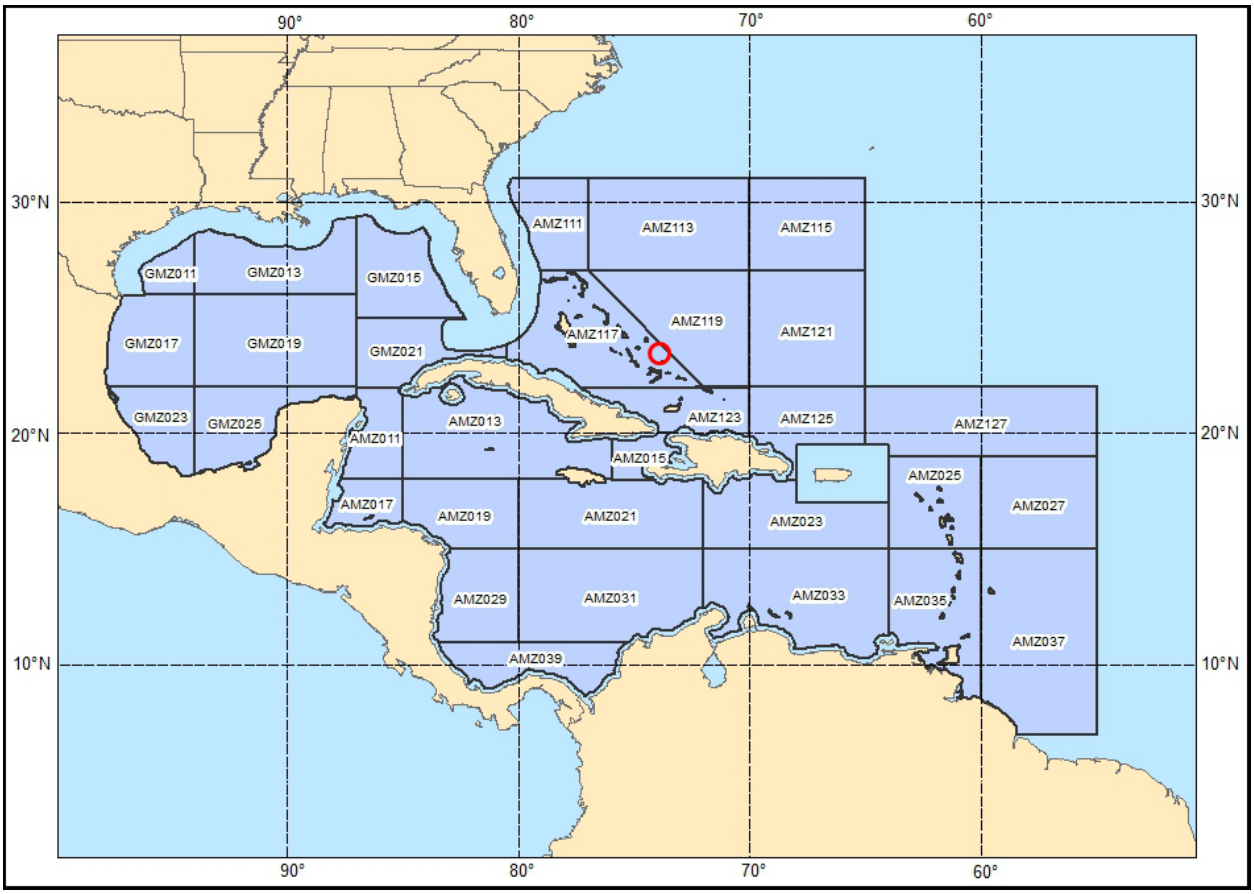

Figure 4 *– Offshore Waters Forecast zones. Red circle shows accident location.*

Offshore Waters Forecasts give mariners an overview of large-scale environmental marine conditions out to 5 days, including expected winds, seas, and major weather effects. Marine warnings are headlined for each affected zone through the first 36 hours of the forecast period. Brief, plain-language synopses are included in forecasts for the Gulf of Mexico, Caribbean Sea and Tropical Atlantic, and Southwest North Atlantic. Wind information reflects predominant conditions at 10 meters above the sea surface. Wind direction is described by the eight compass points. Sea state is described as significant wave height.[31] Seas are typically expressed as a range of values, consistent with forecast uncertainty and the size of the marine zones. Dominant swell and direction are described as needed.

This report focuses on the two Offshore Waters Forecast zones in the accident region (see figure 4): AMZ117 (Bahamas north of 22°N including the Cay Sal Bank) and AMZ119 (Atlantic from 22°N to 27°N east of the Bahamas to 70°W). Attachment 3 contains all Offshore Waters Forecast products issued for Joaquin for regions AMZ117 and AMZ119 through the accident time.

[31] Significant wave height is the mean or average height of the highest one-third of all waves in a swell train (a series of waves moving from the same source) or in a wave-generating region. It approximates the value an experienced observer would report if visually estimating sea height.

5.2.1.10. Marine Weather Discussion

The Marine Weather Discussion (WMO header AGXX40 KNHC, AWIPS header MIMATS for Atlantic products) is a semitechnical product primarily used to explain the scientific rationale behind the Offshore Waters Forecast and to summarize the warnings in effect. The Marine Weather Discussion conveys forecast and warning information to federal agencies, weather-sensitive officials, and the media.

The NHC issues one Marine Weather Discussion to convey forecast reasoning covering both its offshore forecast product areas. The areas include the Gulf of Mexico, the Caribbean Sea, the Tropical North Atlantic, and the Southwest North Atlantic Ocean south of 31°N and west of 55°W. The area between 55°W and 65°W is not specifically covered by the Offshore Waters Forecast products, but conditions in the area are discussed because they can affect offshore waters in the future. The Marine Weather Discussion is issued twice a day (at nominal times of 0330 EDT and 1530 EDT), shortly before the scheduled Offshore Waters Forecasts.

The Marine Weather Discussion describes synoptic and mesoscale features expected to affect areas in and next to offshore waters of the Gulf of Mexico, Caribbean Sea, and Southwest and Tropical North Atlantic Ocean. The narrative describes weather, wind magnitude, and seas, focusing on the next 48 hours. The product emphasizes timing and issuance of warnings, includes future trends of wind and sea conditions, discusses the effects of currents such as the Gulf Stream on winds and seas, and addresses how the latest model guidance handles features significant to mariners. The product may also indicate a forecaster's level of confidence in the forecast. According to the NHC, no objective criteria exist for establishing a confidence level, and assignment of confidence levels is entirely subjective.

Reproduced below are the discussion sections of the Marine Weather Discussion applicable to Joaquin issued between (nominal times) of 0330 EDT on September 28, 2015, and 0330 EDT on October 1, 2015. Attachment 3 contains all Marine Weather Discussion products issued for Joaquin through the accident time.

- MARINE WEATHER DISCUSSION
  307 AM EDT MON SEP 28 2015

  ...SW N ATLANTIC INCLUDING THE BAHAMAS...

  MODEL PREFERENCE: LATEST GFS BLENDED WITH PREVIOUS FORECAST.
  LATEST TAFB NWPS FOR WAVE PARAMETERS.

  T.D. ELEVEN...A 1006 MB LOW PRES IS ANALYZED NEAR 27N69W.
  CONVECTION CONTINUES WITHIN THE SOUTHEAST QUADRANT AND CONTINUES
  TO BECOME A LITTLE BETTER ORGANIZED DURING THE LAST 12-24 HOURS.
  THE FORECAST FOR T.D. ELEVEN IS TO MAINTAIN TROPICAL DEPRESSION
  STATUS WHILE DRIFTING SLOWLY NW AND WILL LIKELY DISSIPATE BY THE
  END OF THE WEEK DUE TO UNFAVORABLE WINDS ALOFT. MEANWHILE A
  FRONTAL BOUNDARY WILL SAG SOUTHWARD TO THE EAST OF THE AREA WITH
  STRONG HIGH PRES TO THE NORTH. THIS WILL PROMOTE STRONG TO NEAR

GALE EASTERLY WINDS BEHIND THE FRONT THAT WILL IN TURN GENERATE SWELL IN 8 TO 12 FT MOVING INTO THE WATERS N OF 29N E OF 76W THROUGH TUESDAY NIGHT. GENTLE TO MODERATE WINDS AND SEAS OF 4 TO 6 FT IN SWELL WILL PREVAIL ELSEWHERE OUTSIDE OF THE BAHAMAS THROUGH THE FORECAST PERIOD.

- MARINE WEATHER DISCUSSION
  137 PM EDT MON SEP 28 2015

  ...SW N ATLANTIC INCLUDING THE BAHAMAS...

  MODEL PREFERENCE: GLOBAL MODEL CONSENSUS. LATEST TAFB NWPS FOR WAVE PARAMETERS. MEDIUM CONFIDENCE.

  THE MAIN FORECAST ISSUE CONCERNS THE DEVELOPMENT...TRACK AND INTENSITY OF T.D. ELEVEN CENTERED NEAR 27N69W. T.D. ELEVEN HAS MAX WINDS TO 30 KT WITH GUSTS TO 40 KT...AND IS FORECAST TO INTENSIFY TO TROPICAL STORM STRENGTH WITH 40 KT BY THIS EVENING AS IT MOVES SLOWLY NNW. A BROAD SWATH OF CONVECTION COVERS THE AREA EAST OF 70W. ELSEWHERE TO THE WEST AND SOUTHWEST OF T.D. ELEVEN...GENERALLY GENTLE TO MODERATE WINDS PREVAIL. BUOY OBSERVATIONS INDICATE NE SWELL GENERATED FROM A LARGE SWATH OF STRONG E WINDS OVER THE SUBTROPICAL ATLC WATERS HAS REACHED FARTHER WEST THAN PREVIOUSLY ANTICIPATED...AND INITIAL FORECAST GRIDS HAVE BEEN ADJUSTED ACCORDINGLY. WAVE GUIDANCE INDICATES THE SWELL WILL NOT PUSH MUCH MORE TO THE WEST AND SOUTH AND WILL START TO DECAY BACK TO THE EAST THROUGH MID WEEK...WITH THE EXCEPTION OF WAVES GENERATED BY THE DEVELOPING TROPICAL STORM WITHIN A COUPLE OF HUNDRED MILES OF ITS CENTER. THE TROPICAL STORM WILL SHIFT N OF THE AREA BY EARLY THU...LEAVING LIGHT TO GENTLE BREEZES AND SEAS 4 TO 6 FT NE OF THE BAHAMAS INTO FRI. A COLD FRONT WILL MOVE INTO THE WATERS OFF NE FLORIDA FRI INTO SAT FOLLOWED BY MODERATE TO FRESH NORTHERLY FLOW AND SEAS TO 7 FT. SOME UNCERTAINTY PERSISTS IN MODEL OUTPUT ON THE INTENSITY AND SPEED OF MOVEMENT OF THE TROPICAL CYCLONE. THE OFFICIAL FORECAST IS A GENERAL BLEND OF GFS AND ECMWF GUIDANCE.

- MARINE WEATHER DISCUSSION

  309 AM EDT TUE SEP 29 2015

  ...SW N ATLANTIC INCLUDING THE BAHAMAS...

  MODEL PREFERENCE: GLOBAL MODEL CONSENSUS AND TCM WINDS. LATEST TAFB NWPS FOR WAVE PARAMETERS. MEDIUM CONFIDENCE.

  THE MAIN FORECAST ISSUE CONCERNS THE MOVEMENT AND INTENSITY OF WHAT IS NOW TROPICAL STORM JOAQUIN. JOAQUIN IS FORECAST TO MOVE SLOWLY WESTWARD FOR THE NEXT 48 HOURS OR SO BEFORE ACCELERATING NORTHWARD OVER THE WESTERN ATLC. CURRENTLY MAXIMUM SUSTAINED WINDS ARE 35 KT WITH GUSTS TO 45 KT. BUOY OBSERVATIONS CONTINUE TO INDICATE NE SWELL GENERATED FROM A LARGE FETCH AREA OF STRONG EASTERLY WINDS OVER THE SUBTROPICAL ATLC WATERS HAS REACHED THE ENTIRE AREA N OF THE BAHAMAS. WAVE GUIDANCE INDICATES THE SWELL

WILL REMAIN ACROSS THE NORTHERN PART OF THE AREA MIXING IN WITH WIND GENERATED SEAS AND SWELLS GENERATED BY JOAQUIN. AS JOAQUIN SHIFTS N OF THE AREA LATE THU AND FRI...LIGHT TO GENTLE BREEZES AND SEAS 4 TO 6 FT WILL PREVAIL NE OF THE BAHAMAS INTO FRI. A COLD FRONT WILL MOVE INTO THE WATERS OFF NE FLORIDA FRI INTO SAT FOLLOWED BY MODERATE TO FRESH NORTHERLY FLOW AND SEAS TO 7 FT. THE OFFICIAL FORECAST FOR THE PERIPHERAL WINDS AROUND JOAQUIN IS A GENERAL BLEND OF GFS AND ECMWF GUIDANCE.

- MARINE WEATHER DISCUSSION
  247 PM EDT TUE SEP 29 2015

  ...SW N ATLANTIC INCLUDING THE BAHAMAS...

  MODEL PREFERENCE: GLOBAL MODEL CONSENSUS AND OFFICAL NHC FORECAST FOR JOAQUIN. WINDS. LATEST TAFB NWPS FOR WAVE PARAMETERS. LOW CONFIDENCE.

  THE FORECAST FOR THE SW ATLC IS DEPENDENT UPON THE DEVELOPMENT AND MOVEMENT OF T.S. JOAQUIN...NOW CENTERED ABOUT 250 NM NE OF THE CENTRAL BAHAMAS. THE STORM IS FORECAST TO CONTINUE SLOWLY WEST THROUGH THE NEXT 24 HOURS THEN TURN NORTH. LONG PERIOD NE TO E SWELL IS ALSO IN PLACE OVER MUCH OF THE REGION N OF 25N...THE RESULT OF A LONG FETCH OF EASTERLY WINDS ALONG A FRONTAL BOUNDARY OVER THE CENTRAL ATLC. THERE IS CONSIDERABLE UNCERTAINTY AMONG MAJOR MODELS WITH THE DETAILS OF TRACK...INTENSITY AND TIMING NOT ONLY OF JOAQUIN BUT ALSO THE SURROUNDING ENVIRONMENT. WITH THE CURRENT MOVEMENTS MARINE INTERESTS ALONG THE ATLC EXPOSURES OF THE CENTRAL AND NORTHERN BAHAMAS SHOULD BE AWARE OF HIGHER SEAS ON THE PERIPHERY OF JOAQUIN THROUGH THE NEXT 3-4 DAYS BEFORE THE STORMS MOVES SUFFICIENTLY NORTH OF THE AREA. AS THE STORM AND ITS EFFECTS SHIFT NORTH OF THE AREA THIS WEEKEND...EXPECT GENTLE TO MODERATE SW TO W WINDS ACROSS THE REGION.

- MARINE WEATHER DISCUSSION
  317 AM EDT WED SEP 30 2015

  ...SW N ATLANTIC INCLUDING THE BAHAMAS...

  MODEL PREFERENCE: GLOBAL MODEL CONSENSUS AND OFFICIAL NHC FORECAST FOR JOAQUIN WINDS. LATEST TAFB NWPS FOR WAVE PARAMETERS. MEDIUM CONFIDENCE.

  THE FORECAST FOR THE SW ATLC IS DEPENDENT UPON THE DEVELOPMENT AND MOVEMENT OF T.S. JOAQUIN...NOW CENTERED ABOUT 300 NM EAST OF THE NORTHWESTERN BAHAMAS. JOAQUIN IS FORECAST TO CONTINUE SLOWLY WEST-SOUTHWEST THROUGH THE NEXT 48 HOURS THEN TURN NORTH AND ACCELERATE. LONG PERIOD NE TO E SWELL REMAINS IN PLACE OVER MUCH OF THE REGION N OF 25N AND THE BAHAMAS...THE RESULT OF A LONG FETCH OF EASTERLY WINDS ALONG A FRONTAL BOUNDARY OVER THE CENTRAL ATLC. THERE IS CONSIDERABLE UNCERTAINTY AMONG MAJOR MODELS WITH THE DETAILS OF TRACK...INTENSITY AND TIMING NOT ONLY OF JOAQUIN BUT ALSO THE SURROUNDING ENVIRONMENT. WITH THE

CURRENT MOVEMENTS MARINE INTERESTS ALONG THE ATLC EXPOSURES OF THE CENTRAL AND NORTHERN BAHAMAS SHOULD BE AWARE OF HIGHER SEAS ON THE PERIPHERY OF JOAQUIN THROUGH THE NEXT THREE DAYS BEFORE THE STORM MOVES SUFFICIENTLY NORTH OF THE AREA. AS THE STORM AND ITS EFFECTS SHIFT NORTH OF THE AREA BY SUN...EXPECT GENTLE TO MODERATE SW TO W WINDS ACROSS THE REGION...EXCEPT RESIDUAL STRONG SW WINDS N OF 25N AND W OF 73W. SEAS HERE WILL BE SLOW TO SUBSIDE.

- MARINE WEATHER DISCUSSION
  239 PM EDT WED SEP 30 2015

  ...SW N ATLANTIC INCLUDING THE BAHAMAS...

  MODEL PREFERENCE: GLOBAL MODEL CONSENSUS AND OFFICIAL NHC FORECAST FOR JOAQUIN WINDS. USED LATEST TAFB NWPS WAVE PARAMETERS FOR WAVEHEIGHTS. MEDIUM CONFIDENCE.

  THE FORECAST FOR THE SW ATLC IS DEPENDENT UPON THE DEVELOPMENT AND MOVEMENT OF NOW STRENGTHENING HURRICANE JOAQUIN...CENTERED ABOUT 165 NM E OF THE CENTRAL BAHAMAS OR NEAR 24.4N 72.9W AS OF 2 PM THIS AFTERNOON. JOAQUIN IS FORECAST TO CONTINUE SLOWLY WSW THROUGH TONIGHT BEFORE IT TURNS TO THE NW AND DECREASES ITS FORWARD SPEED THU AND THU NIGHT. LONG PERIOD NE TO E SWELL REMAINS IN PLACE OVER MUCH OF THE REGION N OF 25N AND THE BAHAMAS...THE RESULT OF A LONG FETCH OF EASTERLY WINDS ALONG A FRONTAL BOUNDARY OVER THE CENTRAL ATLC. TAFB WAVEHEIGHT GRIDS WERE ADJUSTED UPWARD ABOUT 2-3 FT FAR WESTERN WATERS TO ACCOUNT FOR THE HIGH SEAS RESULTING IN THE NE-E SWELL AS REPORTED BY BUOY 41010 AND EARLIER ALTIMETER PASS NEAR THAT AREA. THE 1504 UTC ASCAT PASS NICELY DEPICTED PERIPHERAL 20-30 KT WINDS OVER THE W SEMICIRCLE OF JOAQUIN.

  WITH THE STRENGTHENING OF JOAQUIN OVER THE NEXT FEW DAYS...EXPECT LARGE SEAS IN SWELL TO CONTINUE TO RADIATE OUTWARD FROM JOAQUIN AFFECTING THE VAST MAJORITY OF THE BASIN. THE LATEST NHC ADVISORY VALID 15 UTC HAS JOAQUIN CONTINUING TO STRENGTHEN AS IT NEARS NEARS 25.3N 74.5W EARLY FRI MORNING AND TO NEAR 28.5N 73.5W EARLY SAT WITH MAXIMUM SUSTAINED WINDS 100 KT GUSTS 120 KT. FORECAST CONDITIONS AND TRACK IS SUBJECT TO CHANGE. STAY TUNED TO THE LATEST ADVISORY. AS THE STORM WARNING AND ITS EFFECTS SHIFT N OF THE AREA BY SUN...EXPECT GENTLE TO MODERATE SW TO W WINDS ACROSS THE REGION...EXCEPT RESIDUAL STRONG SW WINDS N OF 25N AND W OF 73W...SHIFTING TO N OF 27N W OF 73W MON WITH SEAS IN THE 6-8 FT RANGE.

- MARINE WEATHER DISCUSSION
  225 AM EDT THU OCT 1 2015

  ...SW N ATLANTIC INCLUDING THE BAHAMAS...

MODEL PREFERENCE: GLOBAL MODEL CONSENSUS AND OFFICIAL NHC FORECAST FOR JOAQUIN WINDS. USED LATEST TAFB NWPS WAVE PARAMETERS FOR WAVE HEIGHTS. MEDIUM CONFIDENCE.

HURRICANE JOAQUIN WAS CENTERED NEAR NEAR 23.8N 73.1W AT 01/0300Z WITH WINDS OF 100 KT WITH GUSTS TO 120 KT. WIND FLOW OVER THE AREA IS DOMINATED BY HURRICANE JOAQUIN WITH MODERATE TO FRESH CYCLONIC WINDS ACROSS THE AREA OUTSIDE OF THE SYSTEM. HURRICANE JOAQUIN IS FORECAST TO CONTINUE TO INTENSIFY THROUGH EARLY FRIDAY BEFORE STARTING TO WEAKEN. WITH THE STRENGTHENING OF JOAQUIN OVER THE NEXT FEW DAYS... EXPECT LARGE SEAS TO EXPAND OUTWARD FROM JOAQUIN AFFECTING THE VAST MAJORITY OF THE BASIN. FORECAST CONDITIONS AND TRACK IS SUBJECT TO CHANGE...AND REFER TO THE MOST RECENT ADVISORY FOR THE MOST UP TO DATE INFORMATION. JOAQUIN IS CURRENTLY FORECAST TO SHIFT N OF THE AREA SAT NIGHT. AS THE SYSTEM MOVES FURTHER FROM THE AREA...EXPECT CONDITIONS TO START TO IMPROVE SUN INTO EARLY NEXT WEEK.

5.2.1.11. NHC VOBRA Text Product

High frequency (HF) voice broadcasts (also known as VOBRA) of NWS weather information are provided by the Coast Guard for vessels operating beyond the range of coastal NOAA Weather Radio stations. The information is prepared cooperatively by the OPC, NHC, and the NWS WFO in Honolulu, Hawaii. The NHC issues two VOBRA text forecasts that give an overview of large-scale environmental marine conditions out to 5 days, including expected winds, seas, and major weather effects. Marine warnings are headlined for each affected zone through the first 36 hours of the forecast period. Brief, plain-language synopses are included in forecasts for the Gulf of Mexico, Caribbean Sea and Tropical Atlantic, and Southwest North Atlantic. Winds reflect predominant conditions at 10 meters above the sea surface. Wind direction is described by the eight compass points.

Sea state is described as significant wave height. Seas are typically expressed as a range (e.g., 2 to 4 feet). The range represents uncertainty in the forecast, especially considering the large expanse of each marine zone. Unlike the Offshore Waters Forecasts, VOBRA forecasts do not include swell information, because broadcast times are limited. VOBRA forecasts include weather effects whenever they are expected to pose a danger to navigation, such as widespread areas of fog, smoke, or volcanic ash that limit visibility, or clusters of moderate to strong thunderstorms.

The VOBRA text product applicable to the accident region carries WMO header FZNT31 KNHC and AWIPS header OFFN20. The two VOBRA zones (figure 5) applicable to the accident region are “Bahamas N of 22N” and “Atlantic waters from 22N to 27N between 65W and the Bahamas.” Attachment 7 contains all NHC VOBRA text product zones applicable to the accident region issued through the accident time.

For the dissemination schedule, see section 5.9.6.

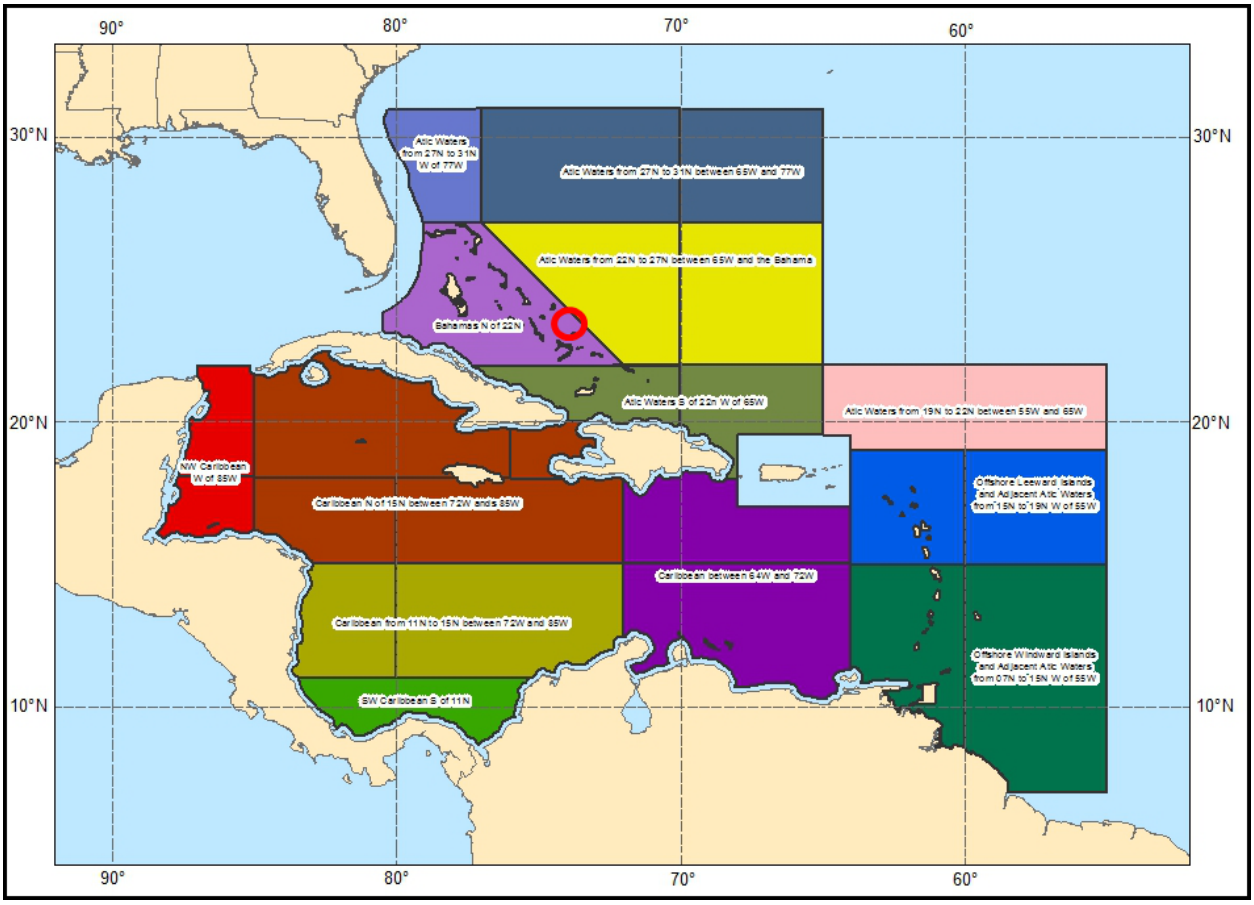

Figure 5 *– NHC VOBRA zones for Atlantic Ocean and Caribbean Sea. Red circle shows accident location.*

5.2.1.12. NHC NAVTEX Product

Navigational TELEX (NAVTEX) is an international automated medium-frequency (MF; 518 kilohertz [kHz]) direct-printing service for delivery of navigational and meteorological warnings and forecasts and urgent marine safety information to ships. A major element of the Global Marine and Distress Safety System (GMDSS), it provides a low-cost, simple, and automated means of receiving information aboard ships at sea within about 200 miles of shore.[32] NAVTEX stations in the United States are operated by the Coast Guard.

The NHC produces three NAVTEX marine forecast messages, transmitted from New Orleans, Louisiana; Miami, Florida; and San Juan. The broadcast includes a synopsis describing surface weather features that may cause significant winds and seas over the forecast area during the forecast period. The synopsis identifies major weather systems and the strength, trend, and movement of each. Detail is focused in the first 48 hours of the forecast. The synopsis includes tropical cyclone forecast positions out to 120 hours. NAVTEX also forecasts wind and seas over the affected area for roughly the next 5 days and includes significant weather that would pose a

[32] Actual transmission range can vary.

hazard to navigation, such as precipitation or restrictions to visibility. Warnings are issued when conditions are expected to meet the respective warning criteria during the 36 hours of the forecast.

NAVTEX forecasts are similar to the Offshore Waters Forecasts but differ in important respects. Since the NAVTEX zones (figure 6) were designed to accommodate the listening area of their transmitters, they are configured differently from the more comprehensive Offshore Waters Forecast zones. Both forecasts relate to the same weather elements and cover similar areas over the same times. However, the NAVTEX forecast zones include coastal areas within 60 nautical miles of shore, while the Offshore Waters Forecasts do not. The NAVTEX forecast text is required to be less than 89 lines, sometimes limiting its detail. While Offshore Waters Forecasts are concise, there is no similar limitation on text length. Thus, NAVTEX forecasts include less information than the Offshore Waters Forecasts. That can produce slight differences in wording between the two products. Warning information is exactly the same for each forecast, however.

Daily issuance (nominal) times for each product are 0545 EDT, 1145 EDT, 1745 EDT, and 2345 EDT. The NAVTEX product applicable to the first part of the accident voyage carries WMO header FZNT25 KNHC and AWIPS header OFFN04. According to the Coast Guard, actual broadcast times for this product from Miami are 0000 EDT, 0800 EDT, 1200 EDT, and 2000 EDT.

NAVTEX broadcasts applicable to *El Faro*'s traveled route were broadcast from Miami and were applicable to the area depicted in figure 6 (referencing the "OFFN04 Atlantic" product range east of Florida), with the predicted broadcast range[33] (red lines) shown in the inset to figure 6. Attachment 7 contains all applicable NAVTEX products issued through the accident time.

Each NAVTEX product contained current position and forecast track and intensity information for Joaquin originally disseminated in the previously-issued (nominally 45 minutes prior) Tropical Cyclone Forecast/Advisory.[34]

[33] As of February 18, 1998.

[34] The NAVTEX product issued (nominally) at 0545 EDT on September 28, 2015, identified that Tropical Depression Eleven was "near 27.4N 68.9W" and that it "will move to 27.6N 68.9W." The Tropical Cyclone Forecast/Advisory issued (nominally) at 0500 EDT on September 28, 2015 (Advisory Number 2), identified the tropical depression center as "near 27.3N 68.9W" and that its next forecast position was "27.6N 69.4W" at 1400 EDT on September 28, 2015.

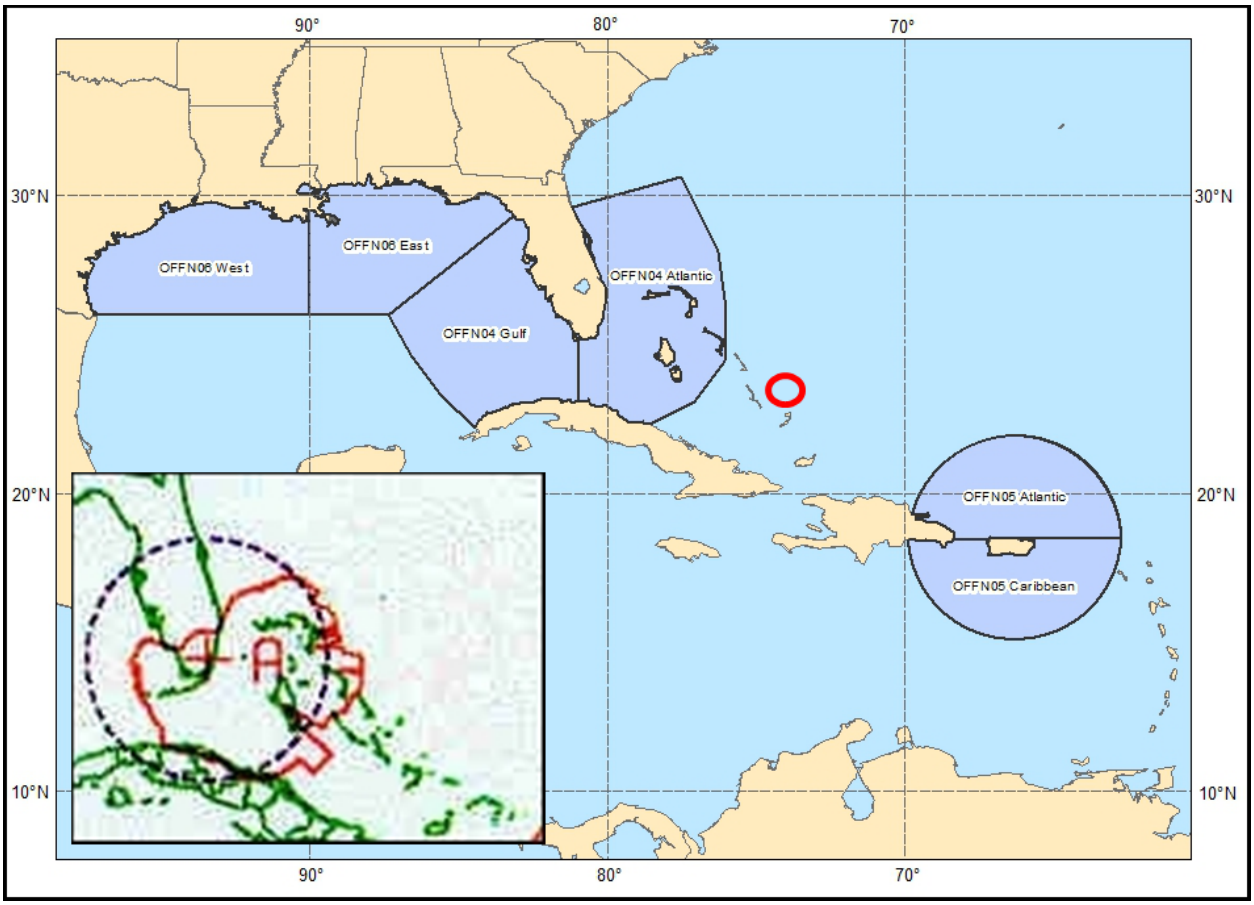

Figure 6 *– NHC NAVTEX zones. Red circle shows accident location. Inset depicts broadcast range of the Miami NAVTEX (red lines).*

According to data received from the Coast Guard (see section 5.9.6 for a description of these data), NAVTEX forecasts (OFFN04) were broadcast from Miami between 2000 EDT on September 29, 2015, through the accident time, at the following times: at 2012:51 EDT on September 29, 2015, at 0011:41 EDT, 0811:11 EDT, 1211:11 EDT, and 2012:02 EDT on September 30, 2015, and at 0013:59 EDT and 0813:52 EDT on October 1, 2015.

5.2.2. Graphical Products

This section describes six graphical products for Joaquin issued by the NHC: the Tropical Cyclone Track Forecast Cone and Watches/Warnings, the Tropical Cyclone Surface Wind Field, the Tropical Cyclone Surface Wind Speed Probabilities (34 knots, 50 knots, and 64 knots), and the Tropical Cyclone Danger graphic. A complete set, in chronological order, of graphical products issued between 2300 EDT on September 27, 2015, and 1100 EDT on October 1, 2015, is found in Attachment 4.

The NHC prepares and issues the Tropical Cyclone Track Forecast Cone and Watches/Warnings and the Tropical Cyclone Surface Wind Field graphical products after it issues the associated text products. The time varies for preparing and issuing the graphics, but they often trail the last of the text products by 5 to 10 minutes. The graphics for Tropical Cyclone Surface Wind Speed Probabilities follow a different timeline and have two versions, preliminary and final.[35] The final versions are normally disseminated 10 to 15 minutes after the nominal advisory release time (e.g., between 1110 and 1115 EDT for the 1100 EDT advisory).

This section concludes with graphical post-storm analyses developed by the NHC.

5.2.2.1. Tropical Cyclone Track Forecast Cone and Watches/Warnings

This graphic shows a tropical cyclone's current position, forecast track and intensity, forecast track uncertainty, and an approximate representation of coastal areas under a hurricane warning (red), hurricane watch (pink), tropical storm warning (blue), or tropical storm watch (yellow). The plotted positions of the current location and forecast track are based on the current applicable advisories (Tropical Cyclone Forecast/Advisory and Tropical Cyclone Public Advisory). Interpolated data in the Aviation Tropical Cyclone Advisory are not used to prepare the NHC's plotted forecast graphics.

The orange circle indicates the current position of a tropical cyclone's center. The black line and small circles show the NHC's forecast track for the center at the indicated times. The letter inside the circle at a forecast point represents the NHC's forecast intensity for that time: D = sustained winds less than 39 mph [~34 knots], S = sustained winds between 39 mph and 73 mph [~63 knots], H = sustained winds between 74 mph [~64 knots] and 110 mph [~96 knots], M = sustained winds greater than 110 mph).

Forecast uncertainty is conveyed by the track forecast "cone," the solid white and stippled white areas in the graphic. The solid white area depicts the track forecast uncertainty for days 1 through 3 of the forecast, while the stippled area depicts the uncertainty on days 4 through 5. Historical data indicate that the entire 5-day path of the center of a tropical cyclone will remain inside the cone 60 to 70 percent of the time. To form the cone, a set of imaginary circles is placed along the forecast track at the 12-, 24-, 36-, 48-, 72-, 96-, and 120-hour positions. Each circle is sized to enclose 67 percent of the previous 5 years of official forecast errors. The cone is then formed by smoothly connecting the area swept out by the set of circles.

The Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic is issued in conjunction with each regular Tropical Cyclone Public Advisory, at the nominal times of 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT. The graphic is also issued with each Intermediate Public Advisory and with each Special Advisory.

[35] The preliminary version includes only the likelihood associated with a specific storm, while the final version includes the risk associated with all ongoing storms.

All Tropical Cyclone Track Forecast Cone and Watches/Warnings graphics for Joaquin issued through 1100 EDT on October 1, 2015, are found in Attachment 4. The graphic issued at 2300 EDT on September 29, 2015, is shown in figure 7.

El Faro's accident location was first enclosed in Joaquin's track forecast cone with the graphic issued at 1700 EDT on September 29, 2015. After this track forecast cone was issued, the accident location was not enclosed in subsequent track forecast cones until 1100 EDT on September 30, 2015. After then, the accident location was enclosed in Joaquin's track forecast cones through the accident time.

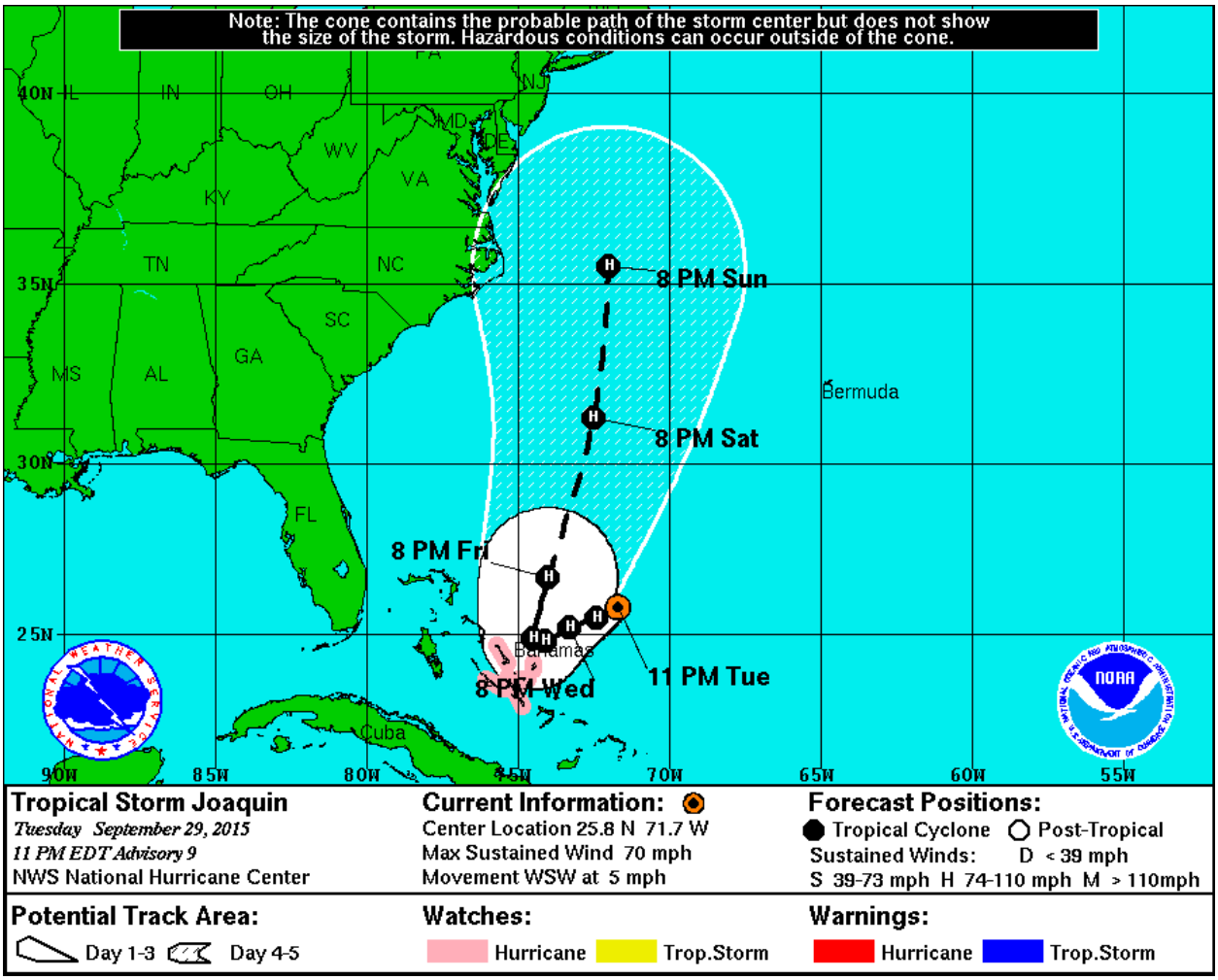

Figure 7 *– NHC Tropical Cyclone Track Forecast Cone and Watches/Warnings graphic for Joaquin issued at 2300 EDT on September 29, 2015.*

5.2.2.2. Tropical Cyclone Surface Wind Speed Probabilities – 34 knots, 50 knots and 64 knots

These graphics illustrate the probabilities of a sustained surface wind magnitude of at least 34 knots, 50 knots, and 64 knots at a specific location in the next 5 days (120 hours). The graphics are issued in conjunction with each regular Tropical Cyclone Public Advisory, at the nominal times of 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT. The graphic is also issued with each Special Advisory.

All Tropical Cyclone Surface Wind Speed Probabilities graphics for Joaquin issued through 1100 EDT on October 1, 2015, are found in Attachment 4. The graphics issued at 2300 EDT on September 29, 2015, are shown in figures 8, 9, and 10.

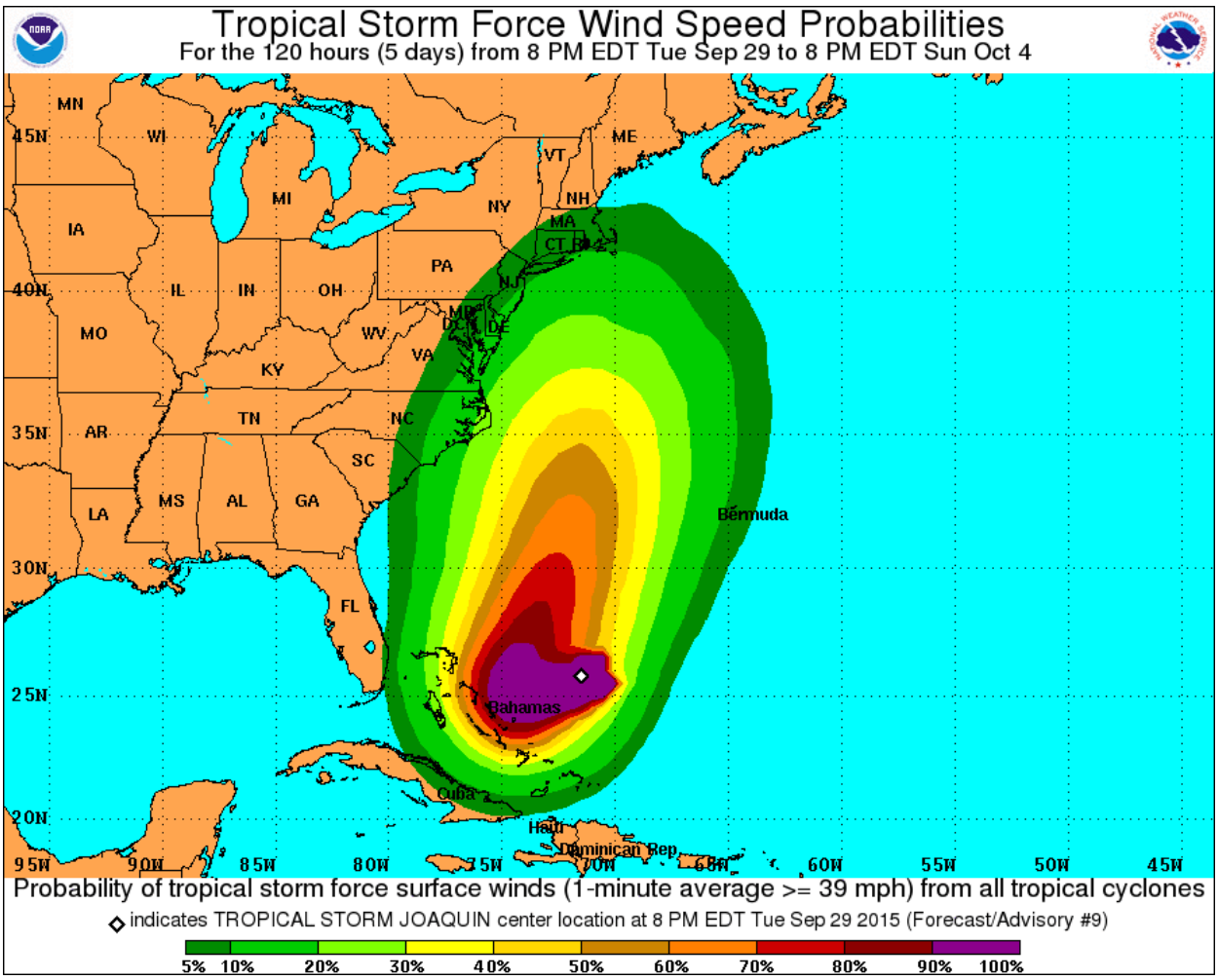

Figure 8 *– NHC 5-day, 34-knot Wind Speed Probability graphic for Joaquin issued at 2300 EDT on September 29, 2015.*

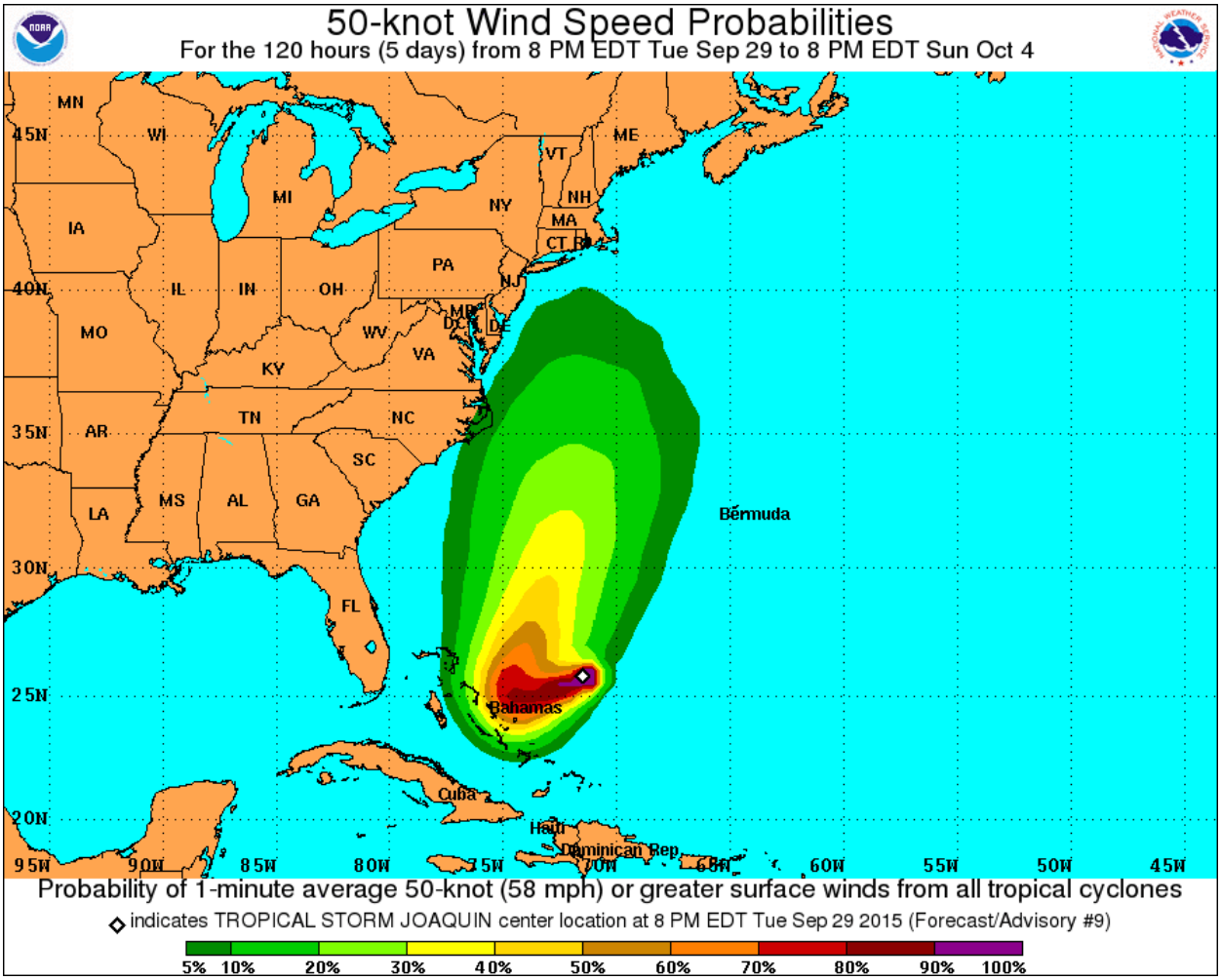

Figure 9 *– NHC 5-day, 50-knot Wind Speed Probability graphic for Joaquin issued at 2300 EDT on September 29, 2015.*

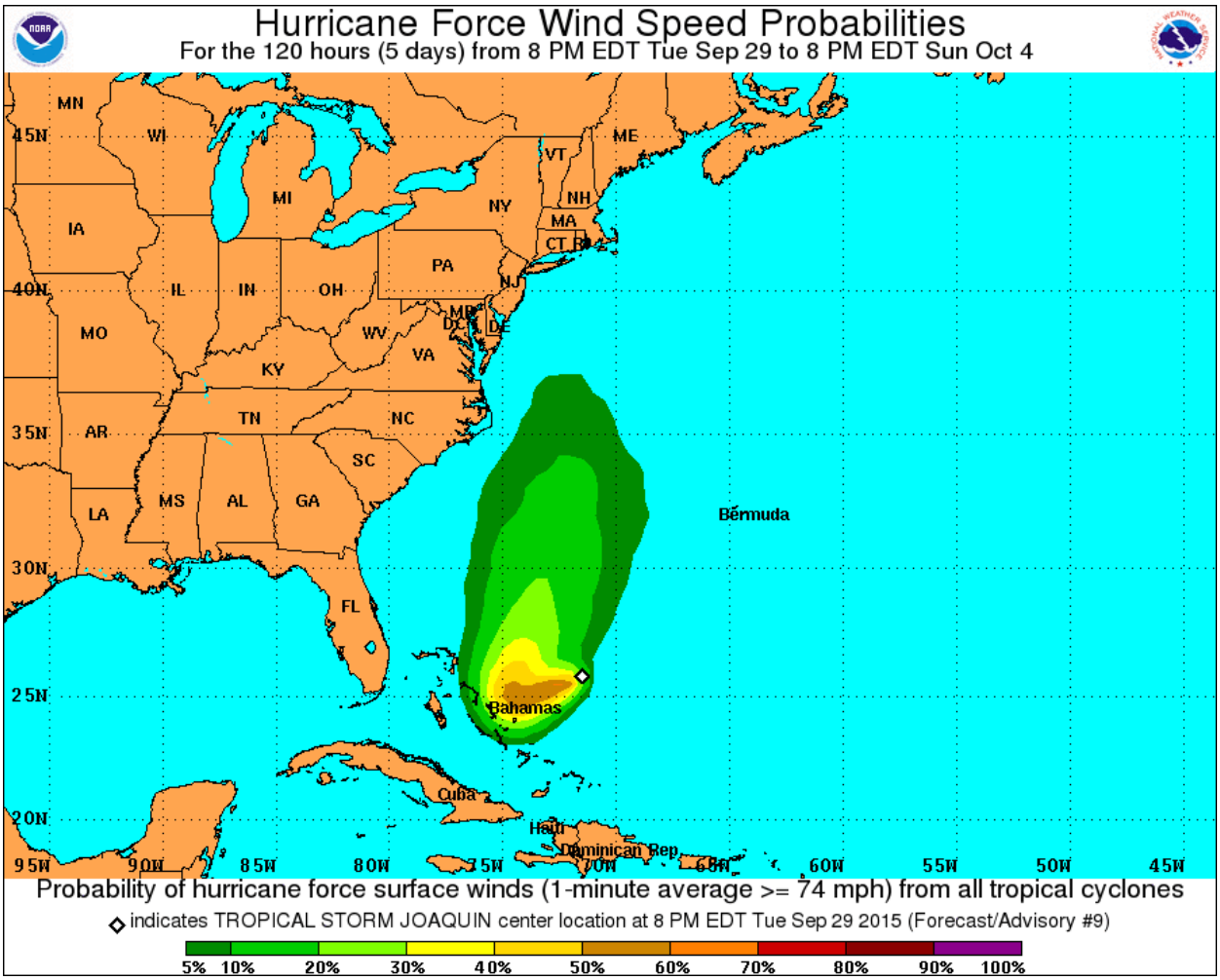

Figure 10 *– NHC 5-day, 64-knot Wind Speed Probability graphic for Joaquin issued at 2300 EDT on September 29, 2015.*

5.2.2.3. Tropical Cyclone Danger

The Tropical Cyclone Danger graphic is a product intended to help mariners avoid tropical cyclones. The version of the product operational at the time of the accident depicted avoidance areas based on the "Mariners' 1-2-3 rule,"[36] so named because it made use of approximate tropical cyclone forecast errors of 100, 200, and 300 miles at 24, 48, and 72 hours, respectively. The shaded "danger" area in the graphic was determined by taking the forecast area of tropical-storm-force winds and extending that area outward from the forecast 24-, 48- and 72-hour points by 100, 200, and 300 miles, respectively. Note that a different methodology, based on Wind Speed Probabilities (section 5.2.2.2), replaced the Mariners' 1-2-3 rule in August 2016.

The graphics are normally issued every 6 hours at the nominal times of 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT.

[36] The Mariners' 1-2-3 rule is a guideline for mariners to help keep them out of a tropical storm or hurricane's path.

All Tropical Cyclone Danger graphics valid between 2300 EDT on September 27, 2015, and 1100 EDT on October 1, 2015, are found in Attachment 4. The graphic valid for 2300 EDT on September 29, 2015, is shown in figure 11. The different (e.g., red) colors seen in some danger areas in figure 11 and in the figures in Attachment 4 are merely artifacts of the reproduction process used for images the NHC provided to the NTSB and have no intended meaning for users.

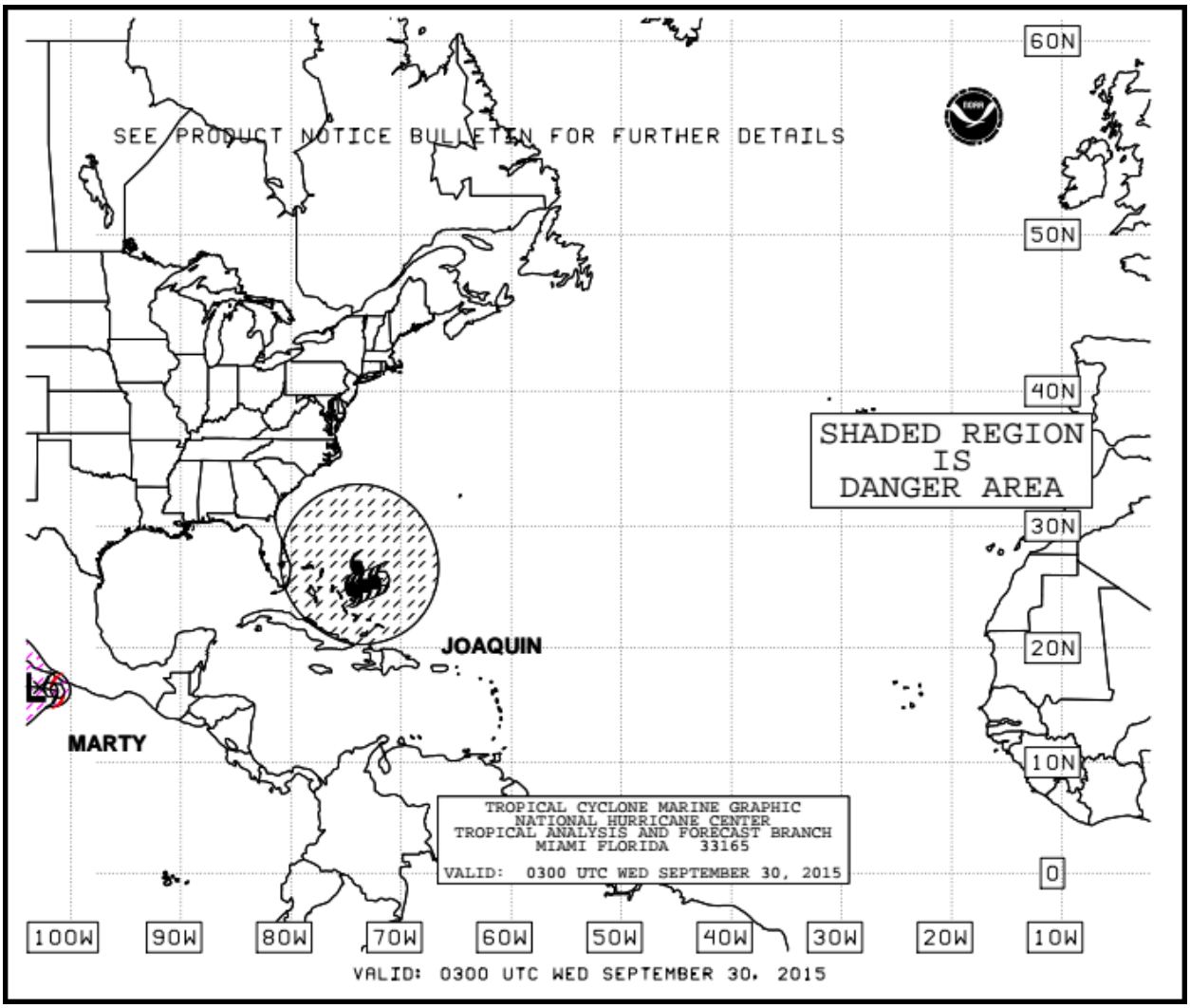

Figure 11 *– NHC Tropical Cyclone Danger graphic for Joaquin valid for 2300 EDT on September 29, 2015.*

5.2.2.4. Tropical Cyclone Surface Wind Field

This graphic (example in figure 12) identifies areas potentially affected by sustained winds of tropical-storm (orange) and hurricane (red) force. The display is based on the wind radii published in the latest Tropical Cyclone Forecast/Advisory (see top of figure 12). Because the

Tropical Cyclone Forecast/Advisory wind radii represent the maximum possible extent of a given sustained wind in particular quadrants around a tropical cyclone, not all locations falling inside the orange- or red-shaded areas will experience sustained tropical-storm or hurricane-force winds. The white dot indicates the current position of the center of the tropical cyclone. The dashed line shows the previous path of the cyclone's center.

The graphic is issued in conjunction with each regular Tropical Cyclone Public Advisory, at the nominal times of 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT. The graphic is also issued with each Special Advisory.

All Tropical Cyclone Surface Wind Field graphics for Joaquin issued through 1100 EDT on October 1, 2015, are found in Attachment 4. The graphic issued at 1100 EDT on October 1, 2015, is shown in figure 12.

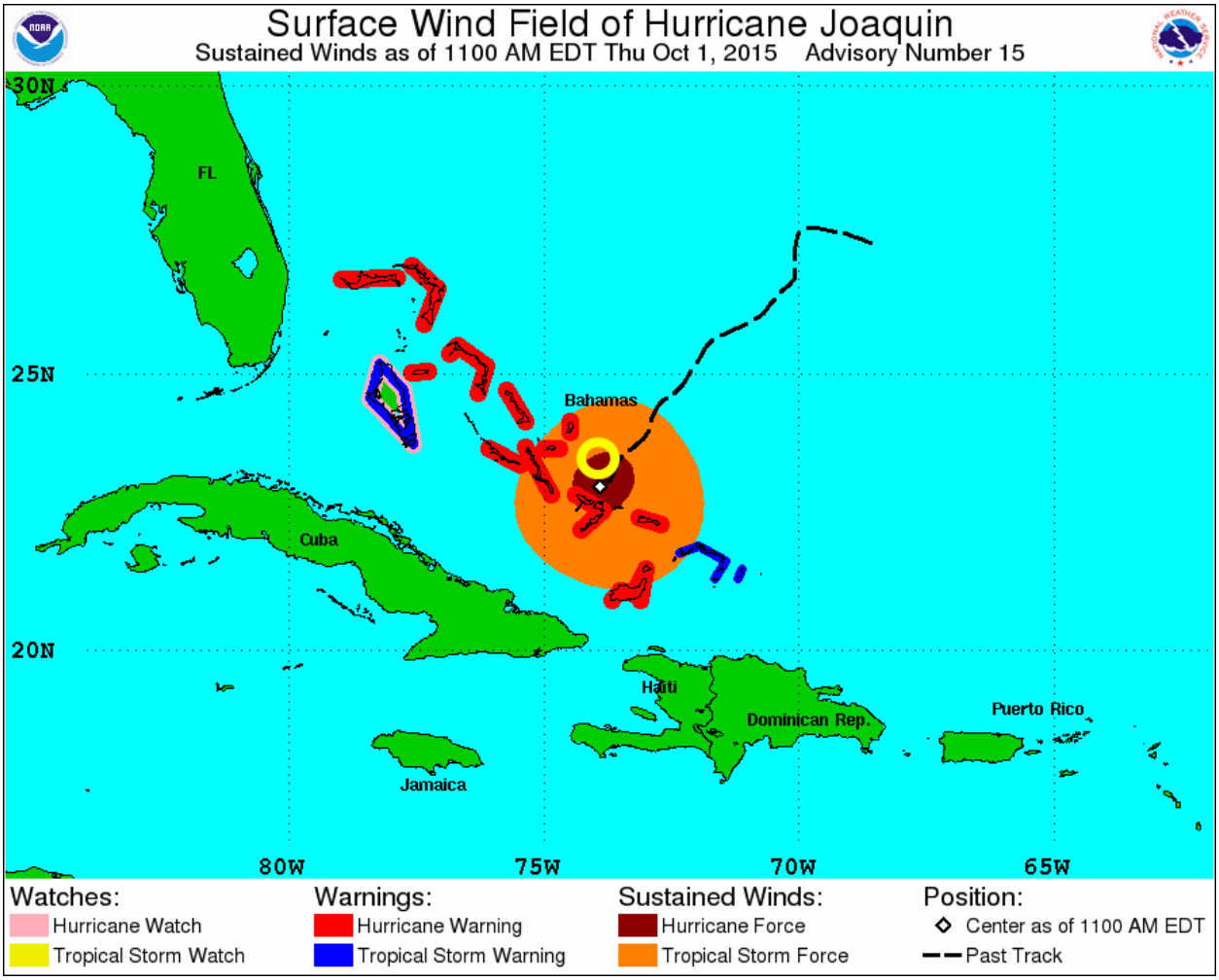

Figure 12 *– NHC Tropical Cyclone Surface Wind Field graphic for Joaquin issued at 1100 EDT on October 1, 2015. Yellow circle shows accident location.*

5.2.2.5. Post-Storm Graphics

Presented here are images the NHC provided to the NTSB on May 18, 2016 (figures 13 through 21).

Note that in these images, the locations of *El Faro* and the time of "last communication" should be considered estimates. The images were constructed before that information was publicly available and released by the NTSB; the positions used to construct the images were obtained from unofficial and in some cases unknown sources. For verified vessel locations and related times of communication, refer to the NTSB's Electronic Data Factual report for the *El Faro* accident.

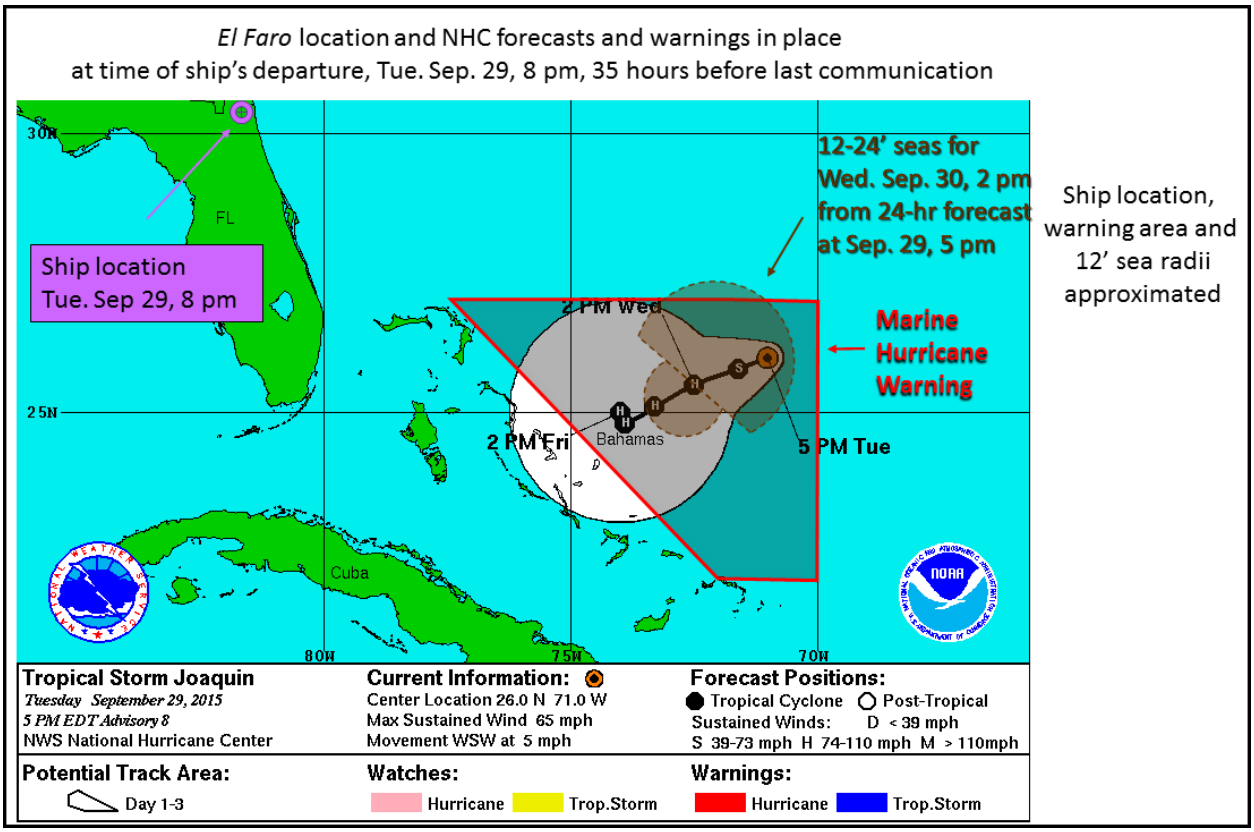

Figure 13 *– NHC post-storm analysis image 1. See text for disclaimer on vessel location and "last communication" timing.*

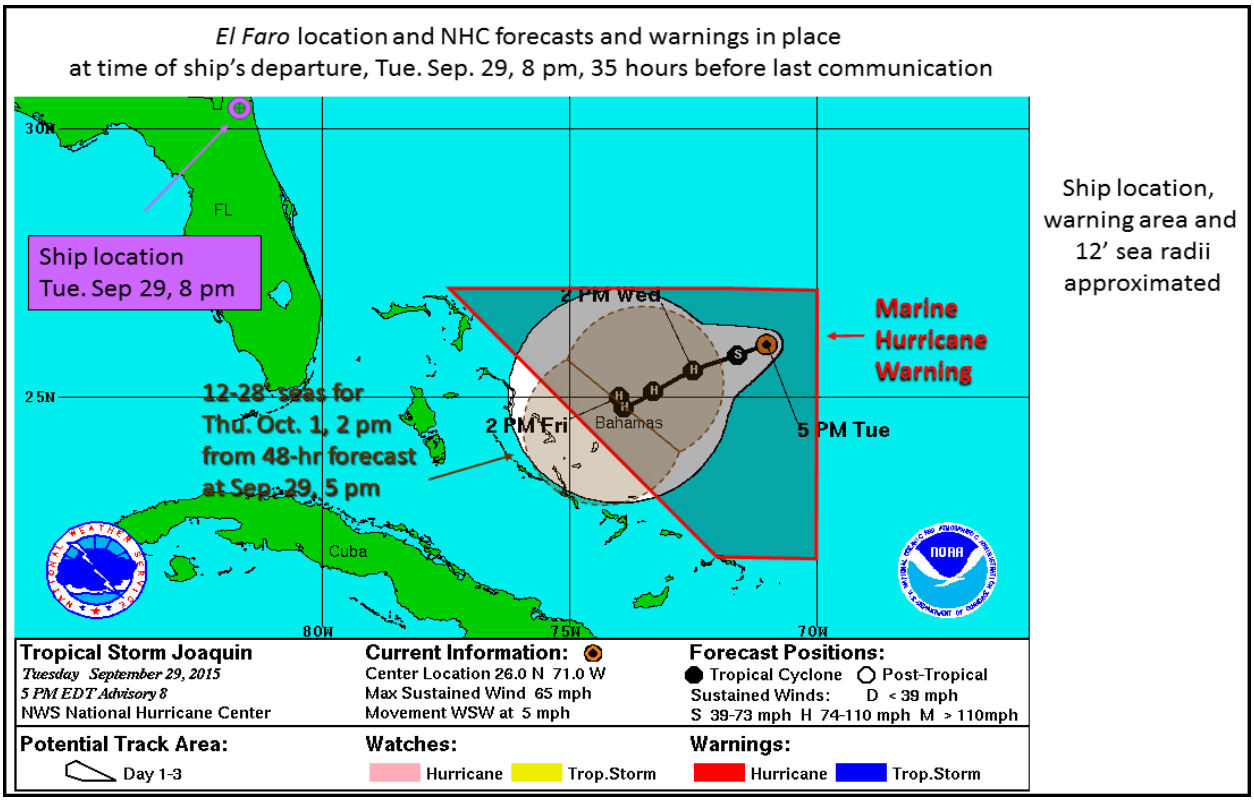

Figure 14 *– NHC post-storm analysis image 2. See text for disclaimer on vessel location and "last communication" timing.*

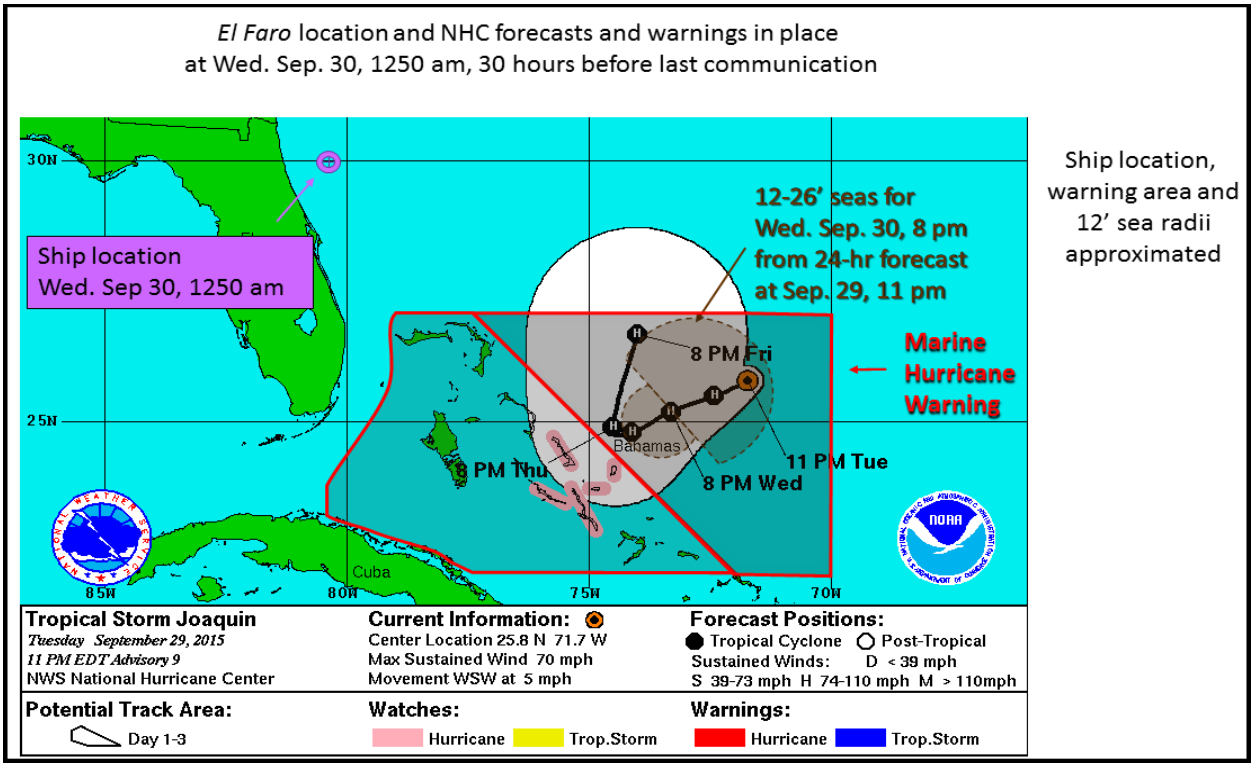

Figure 15 *– NHC post-storm analysis image 3. See text for disclaimer on vessel location and "last communication" timing.*

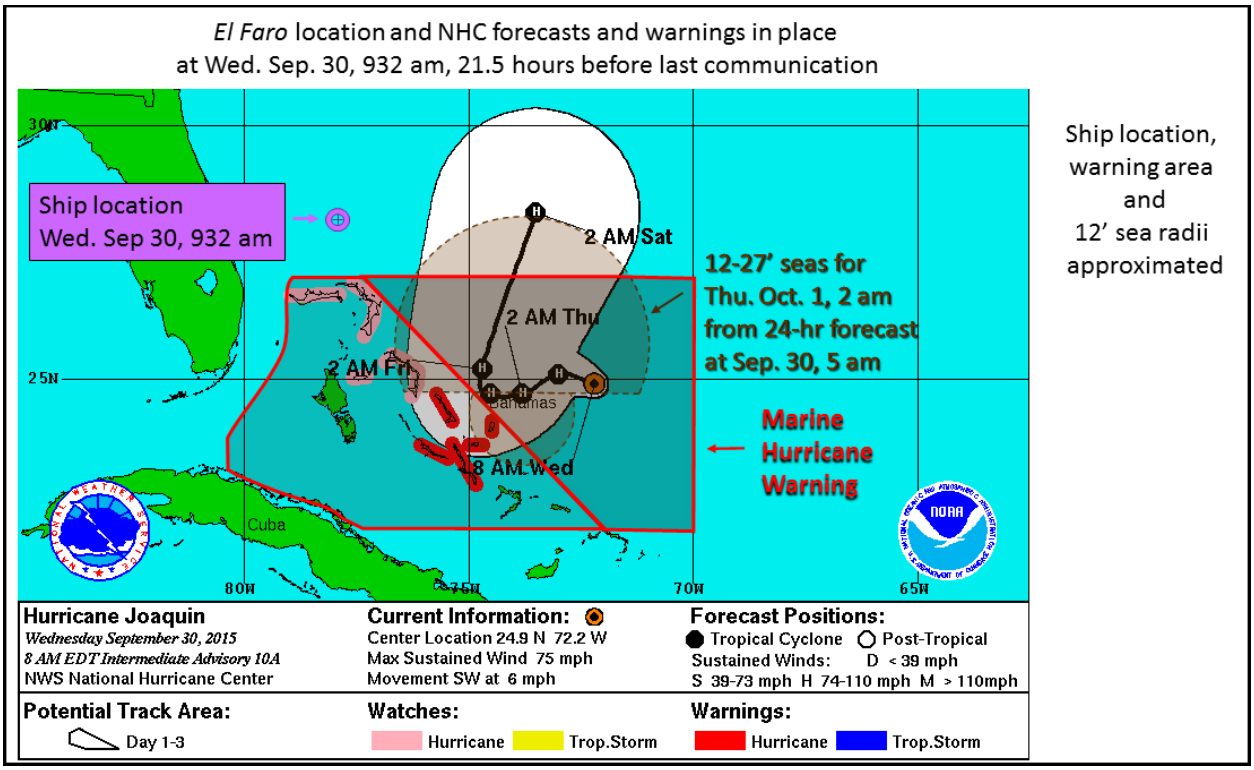

Figure 16 *– NHC post-storm analysis image 4. See text for disclaimer on vessel location and "last communication" timing.*

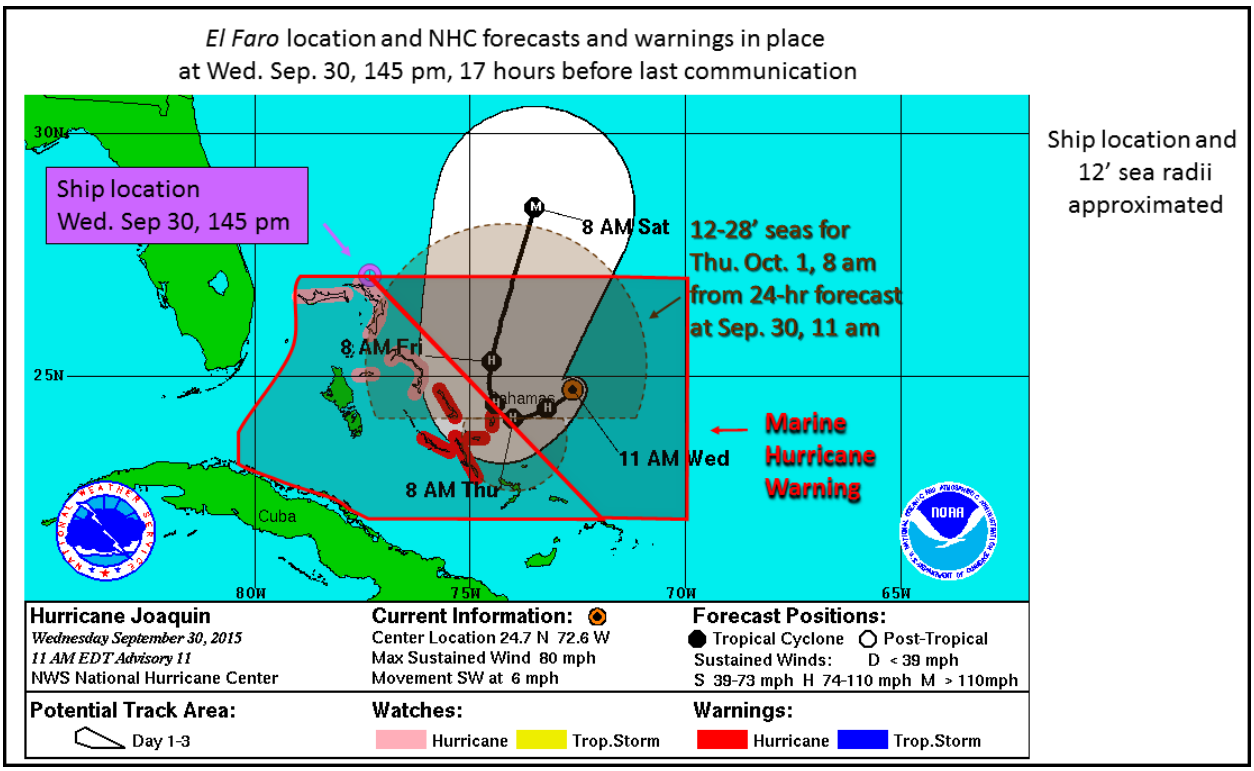

Figure 17 *– NHC post-storm analysis image 5. See text for disclaimer on vessel location and "last communication" timing.*

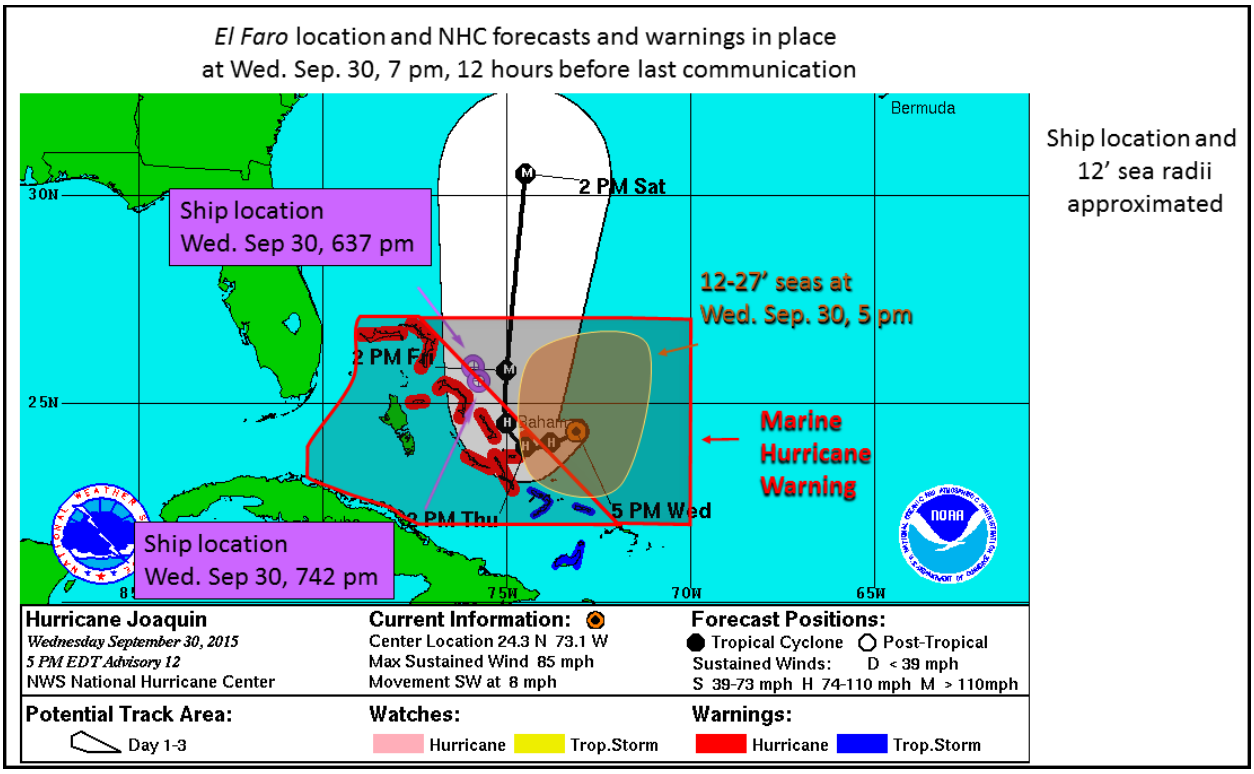

Figure 18 *– NHC post-storm analysis image 6. See text for disclaimer on vessel location and "last communication" timing.*

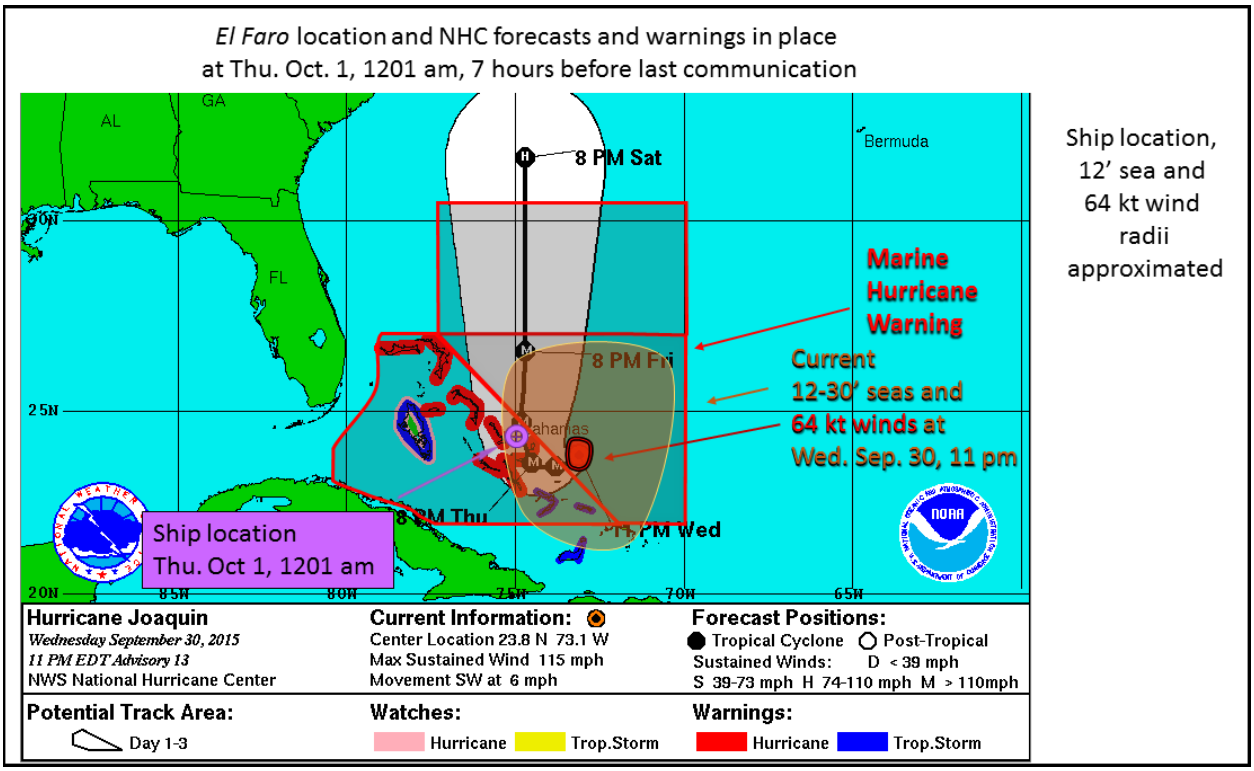

Figure 19 *– NHC post-storm analysis image 7. See text for disclaimer on vessel location and "last communication" timing.*

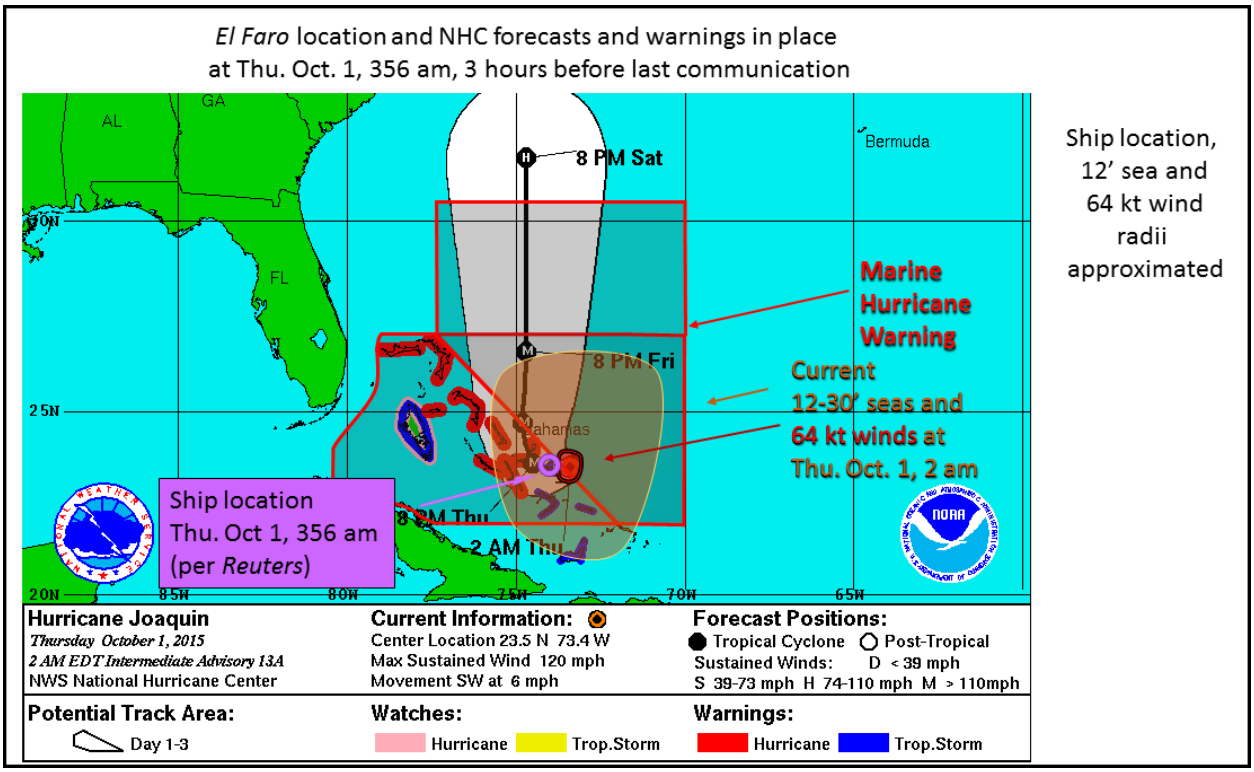

Figure 20 *– NHC post-storm analysis image 8. See text for disclaimer on vessel location and "last communication" timing.*

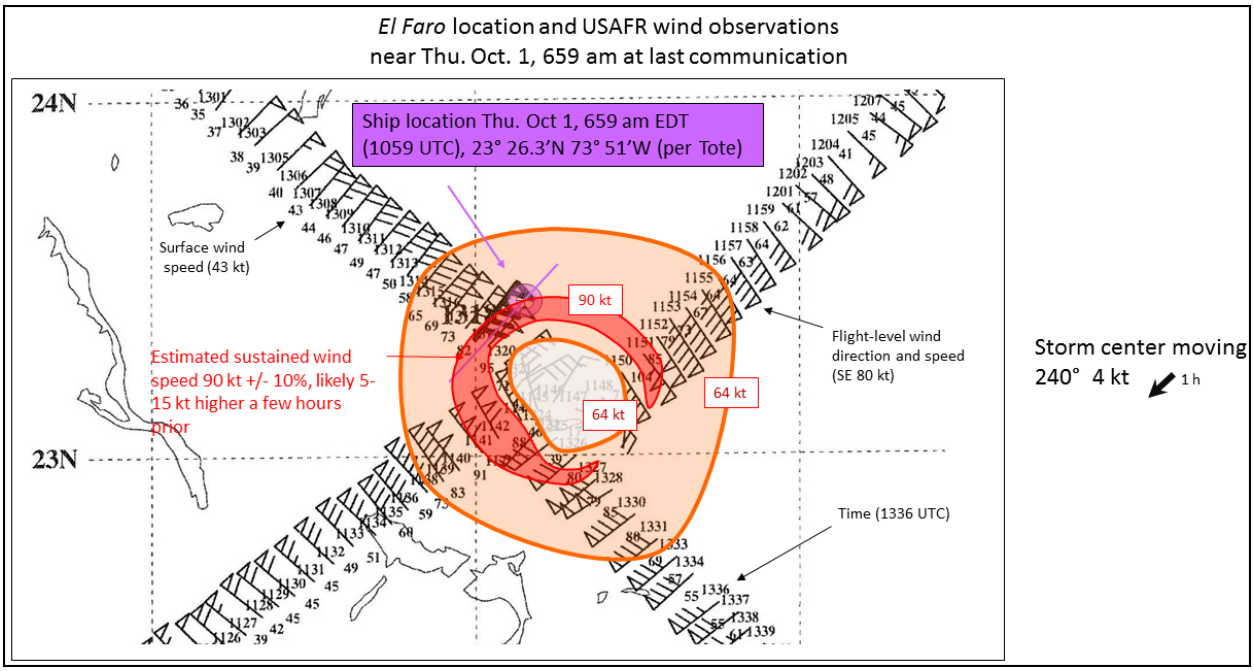

Figure 21 *– NHC post-storm analysis image 9. See text for disclaimer on vessel location and "last communication" timing.*

5.3. Additional Analysis and Forecast Graphical Products

Both the NHC and the OPC produce additional graphical products not specific to tropical cyclones. The descriptions of these products below are based on information from the NHC and OPC websites.

5.3.1. Graphical Analysis Products

A number of graphical analysis products describing current atmospheric or oceanic conditions issued by the NHC and the OPC cover the accident region. Attachment 8 contains, in chronological order, all such analysis products valid between 2000 EDT on September 28, 2015, and 0800 EDT on October 1, 2015.

Gridded forecasts of significant wave heights are available in the National Digital Forecast Database (NDFD).[37] Archived data valid for the accident time are not available.

5.3.1.1. NHC Significant Wave Height Analysis

The NHC's Significant Wave Height Analysis ("Sea State Analysis") is created every 12 hours, at the nominal times of 0800 EDT and 2000 EDT. The analysis depicts the current significant wave height and primary swell direction over tropical and subtropical Atlantic and East Pacific waters. The significant wave height is contoured at intervals of 3 feet, with additional contours added in areas of little spatial variation. Maximum and minimum significant wave height values are indicated as necessary. Arrows indicate the primary swell direction.

Figure 22 is the NHC's Significant Wave Height Analysis for 0800 EDT on October 1, 2015. Maximum significant wave heights identified in the accident region are 36 feet.

[37] http://digital.weather.gov/

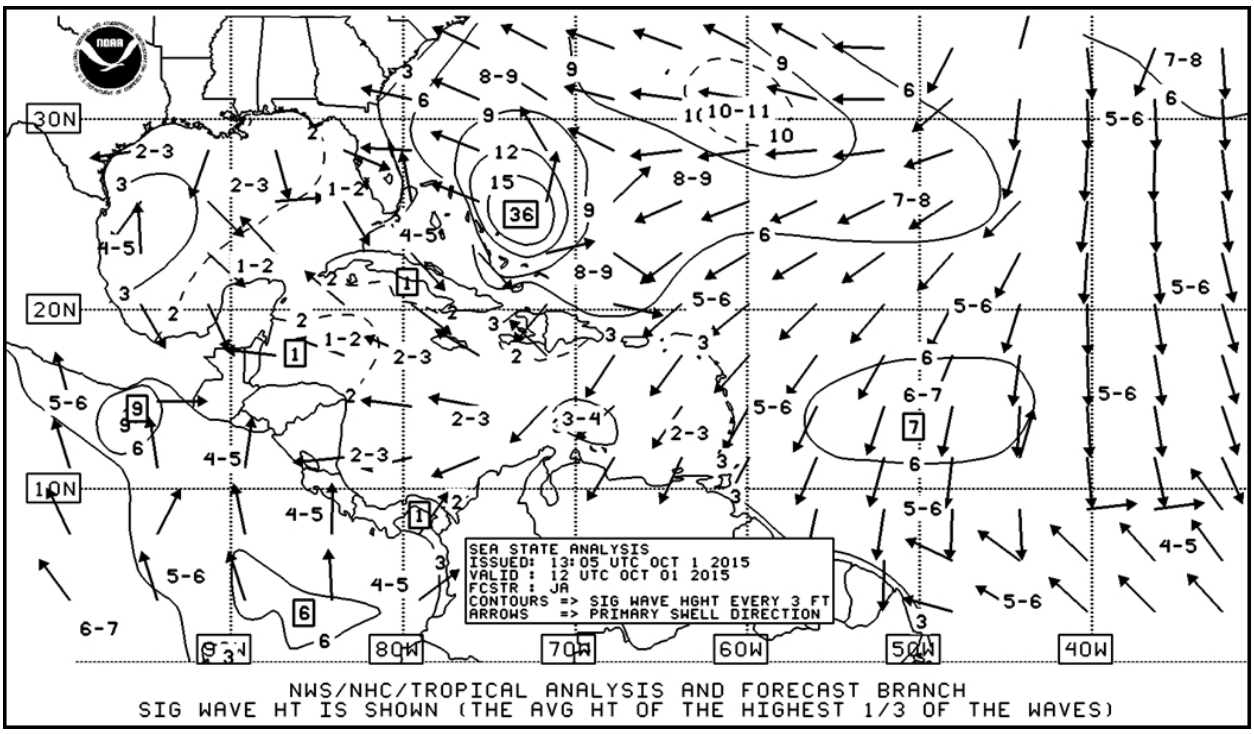

Figure 22 *– NHC's Significant Wave Height Analysis for 0800 EDT on October 1, 2015.*

5.3.1.2. OPC Northwest Atlantic Sea State Analysis

The OPC's Northwest Atlantic Sea State Analysis is issued every 3 hours, with analyses of ship reports and automated weather stations for sea state (in feet) and observed wind magnitude (in knots). The analyses highlight areas of significant combined sea states and are issued at the nominal times of 0200 EDT, 0500 EDT, 0800 EDT, 1100 EDT, 1400 EDT, 1700 EDT, 2000 EDT, and 2300 EDT.

The sea state analysis is contoured in 3-foot intervals. Where appropriate, relative maxima and minima of combined wave height values (approximately one-third the height of the wind wave added to the height of the swell wave) are depicted inside a small box. The analysis is based on available observations but is supplemented by forecast models in areas of sparse data.

Figure 23 is the OPC's Northwest Atlantic Sea State Analysis for 0800 EDT on October 1, 2015. Maximum significant wave heights identified in the accident region are 36 feet.

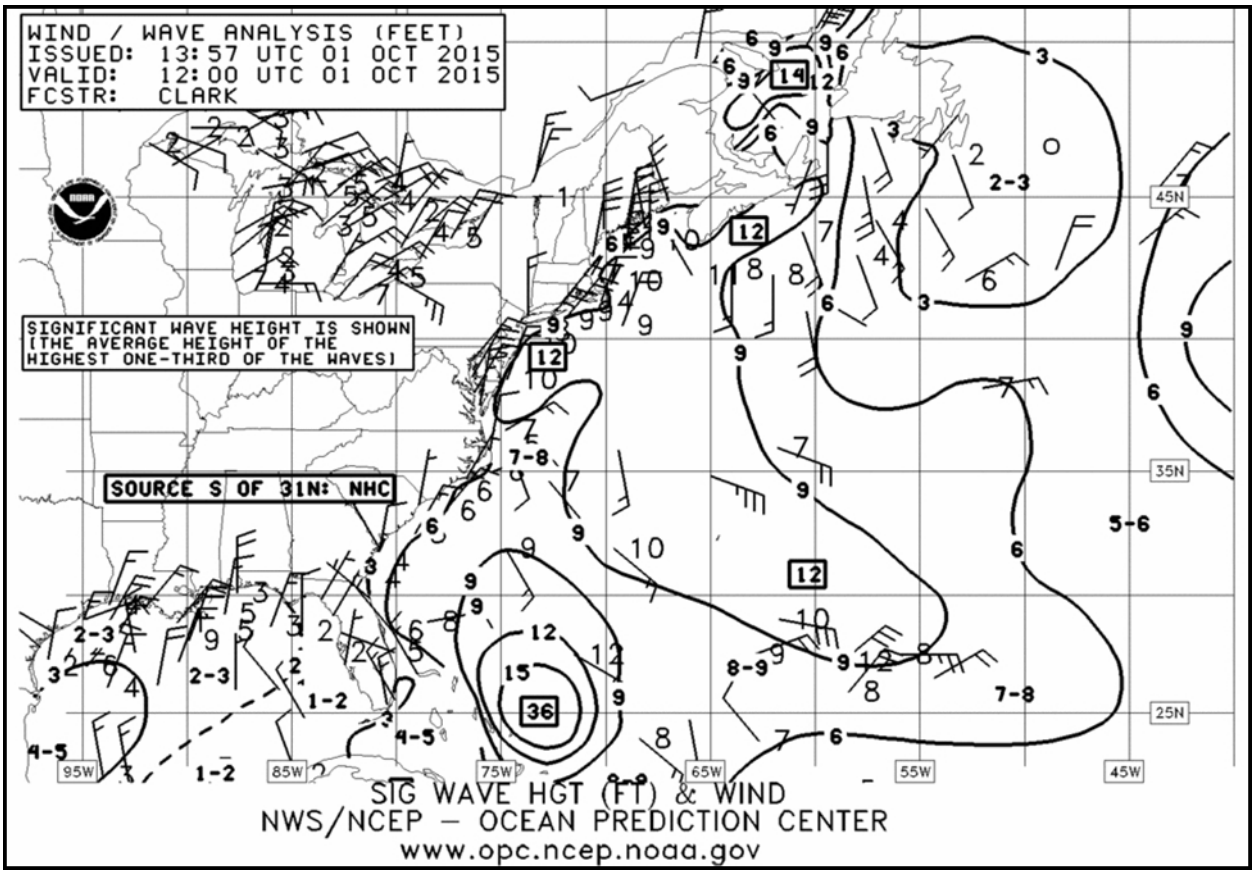

Figure 23 *– OPC's Northwest Atlantic Sea State Analysis for 0800 EDT on October 1, 2015.*

5.3.1.3. OPC North Atlantic Sea State Analysis

The OPC's North Atlantic Sea State Analysis is issued once a day at 0800 EDT (the time of day when most observations are made) and highlights areas of significant combined sea states. The product includes sea state data from ship reports and automated weather stations (in meters), with sea state contours in 1-meter intervals. Where appropriate, relative maxima and minima of combined wave height values are depicted inside a small box. The analysis is based on available observations but is supplemented by forecast models in areas of sparse data. Arrows indicate dominant wave direction.

Figure 24 is the OPC's North Atlantic Sea State Analysis for 0800 EDT on October 1, 2015. Maximum significant wave heights identified in the accident region are 11 meters.

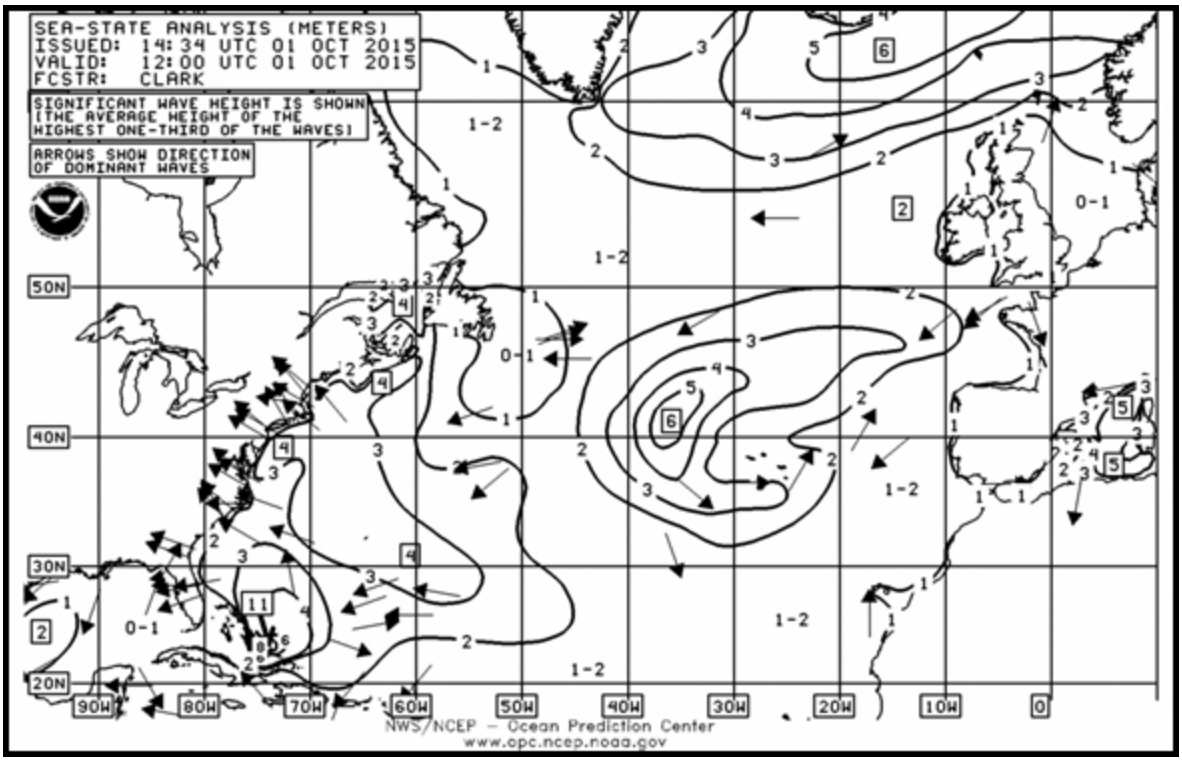

Figure 24 *– OPC's North Atlantic Sea State Analysis for 0800 EDT on October 1, 2015.*

5.3.1.4. OPC Northwest Atlantic Surface Analysis

The OPC's Northwest Atlantic Surface Analysis is generated four times a day, at the nominal times of 0200 EDT, 0800 EDT, 1400 EDT, and 2000 EDT. The analysis consists of isobaric pressure analyses at 4-mb contour intervals. Central pressure values of low- and high-pressure systems are underlined and placed beside or under the boldface letters H or L. The analysis includes abbreviated automated ship plots of wind direction (eight points on the compass rose), wind magnitude (in knots) and current reported weather (using standard symbols). The graphic displays 24-hour forecast locations of low- or high-pressure systems by extending an arrow to the 24-hour forecast position, identified as an X for lows and a circled-X for highs. Forecast central pressures (in mb, with the hundreds and thousands digits omitted) are indicated by an underlined two-digit number under or beside the 24-hour position label. Significant weather systems are labeled if they are associated with gale-, storm-, or hurricane-force conditions. The labels "developing gale," "developing storm," or "developing hurricane force" are appended, as appropriate, to the 24-hour forecast positions of the various weather systems.

If the current or forecast central pressure of a weather system cannot be estimated, the pressure value is replaced by Xs.

Figure 25 is the OPC's Northwest Atlantic Surface Analysis for 0800 EDT on October 1, 2015.

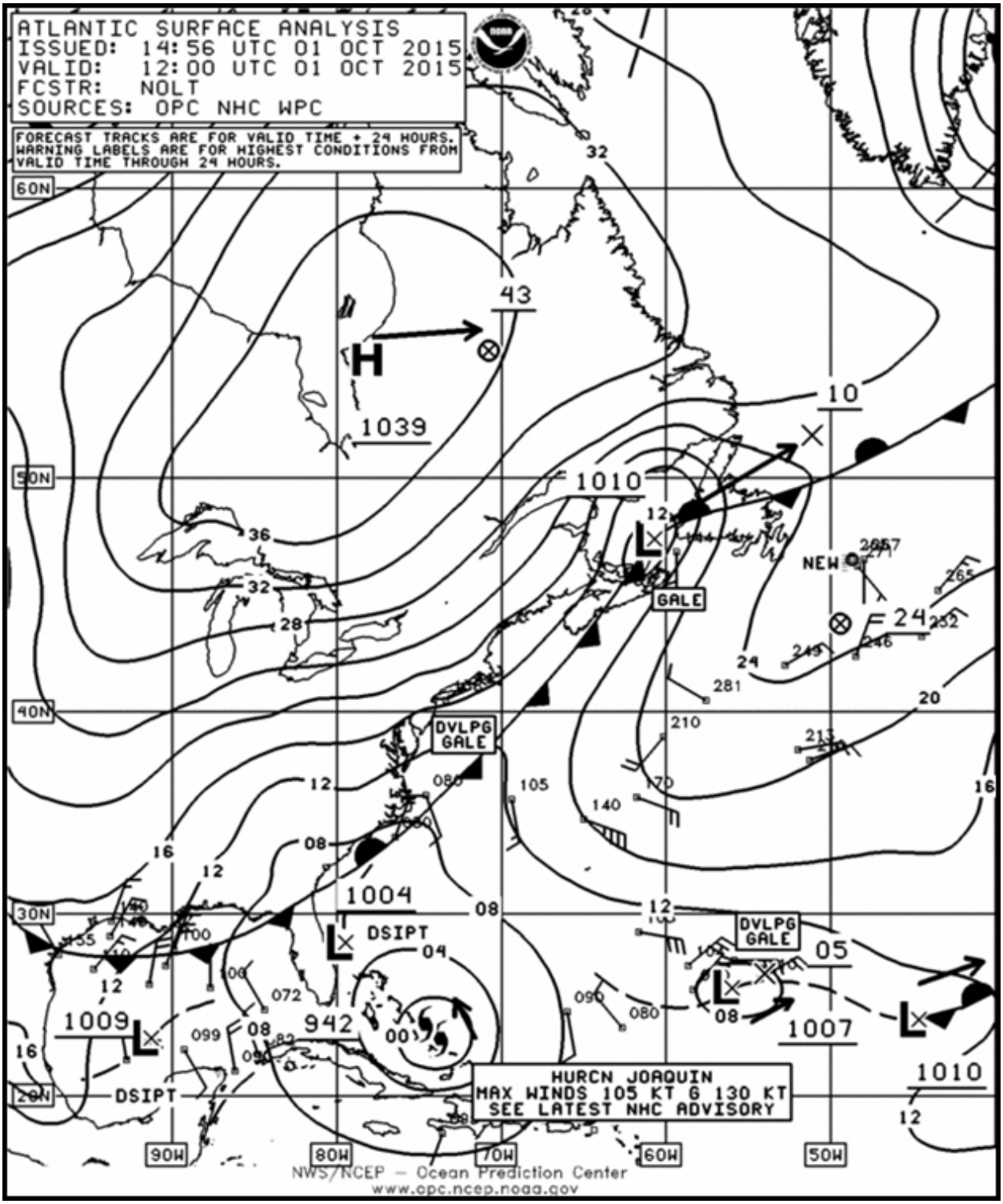

Figure 25 *– OPC's Northwest Atlantic Surface Analysis for 0800 EDT on October 1, 2015.*

5.3.2. Graphical Forecast Products

This section describes graphical forecast products issued by the NHC and the OPC that covered the accident area. Attachment 9 contains a complete set, in chronological order, of the graphical forecast products valid between 2000 EDT on September 28, 2015, and 2000 EDT on October 1, 2015.

Gridded forecasts of significant wave heights are available in the NDFD. Archived data valid for the accident time are not available.

5.3.2.1. NHC Atlantic Wind/Wave Forecasts

The NHC's Wind/Wave Forecasts show 24-, 48-, and 72-hour forecasts of surface features, surface wind magnitude and direction, and significant wave heights over the tropical and subtropical Atlantic from the equator to 31°N between 35°W and 100°W, including the Pacific Ocean east of 100°W. The Atlantic Wind/Wave Forecast includes relevant surface features, areas of high and low pressure, frontal systems, troughs, ridges, tropical waves, and tropical cyclones. Wind barbs indicate the forecast wind magnitude and direction at specific points. Solid triangles indicate 50 knots, long barbs indicate 10 knots, and short barbs indicate 5 knots. The significant wave height is contoured at 3-foot intervals, although contours may be added in areas of little spatial variation. Maximum and minimum significant wave height values are indicated as necessary.

Figures 26, 27, and 28 show respectively the 24-, 48-, and 72-hour NHC Atlantic Wind/Wave Forecasts valid for 0800 EDT on October 1, 2015.

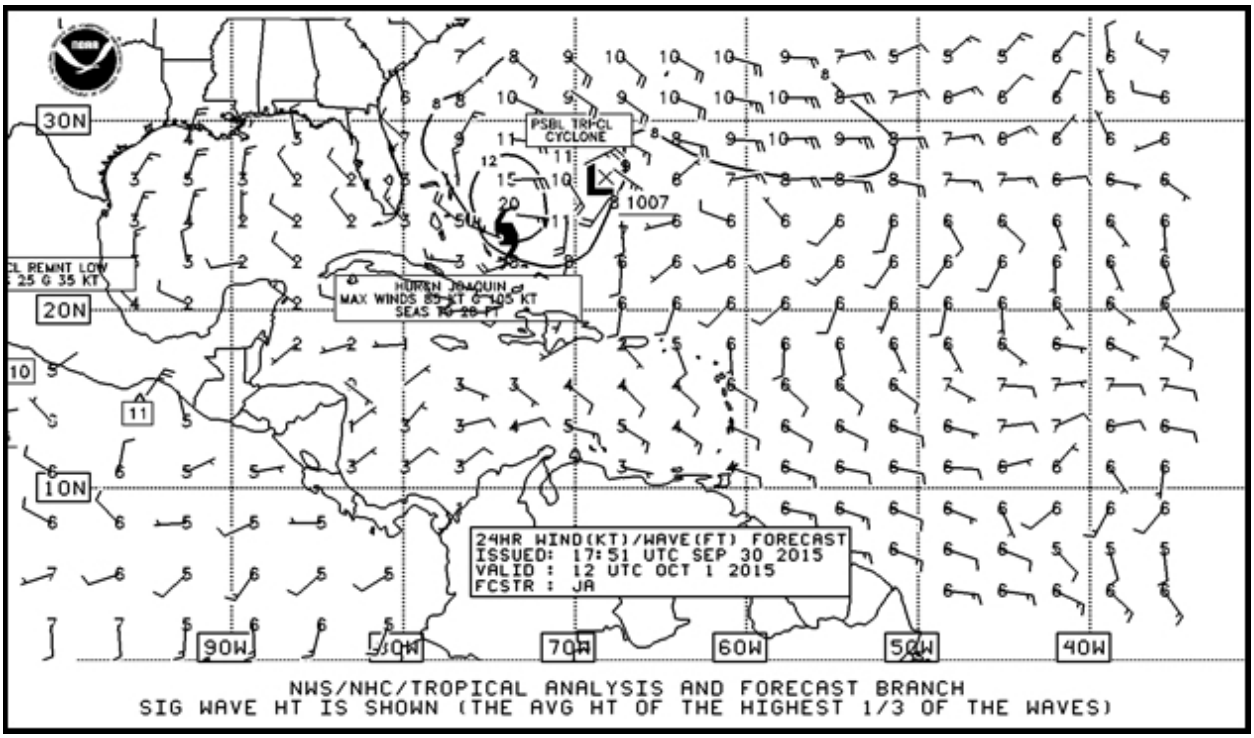

Figure 26 *– 24-hour NHC Atlantic Wind/Wave Forecasts valid for 0800 EDT on October 1, 2015.*

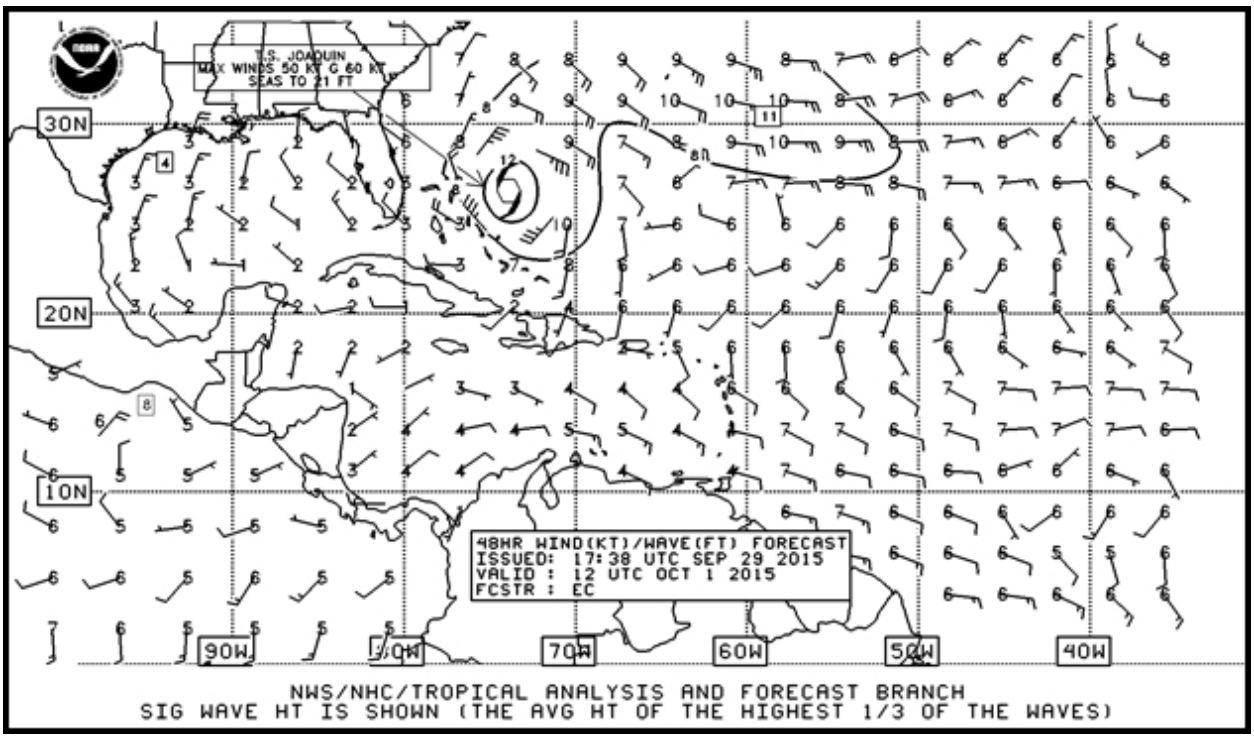

Figure 27 *– 48-hour NHC Atlantic Wind/Wave Forecasts valid for 0800 EDT on October 1, 2015.*

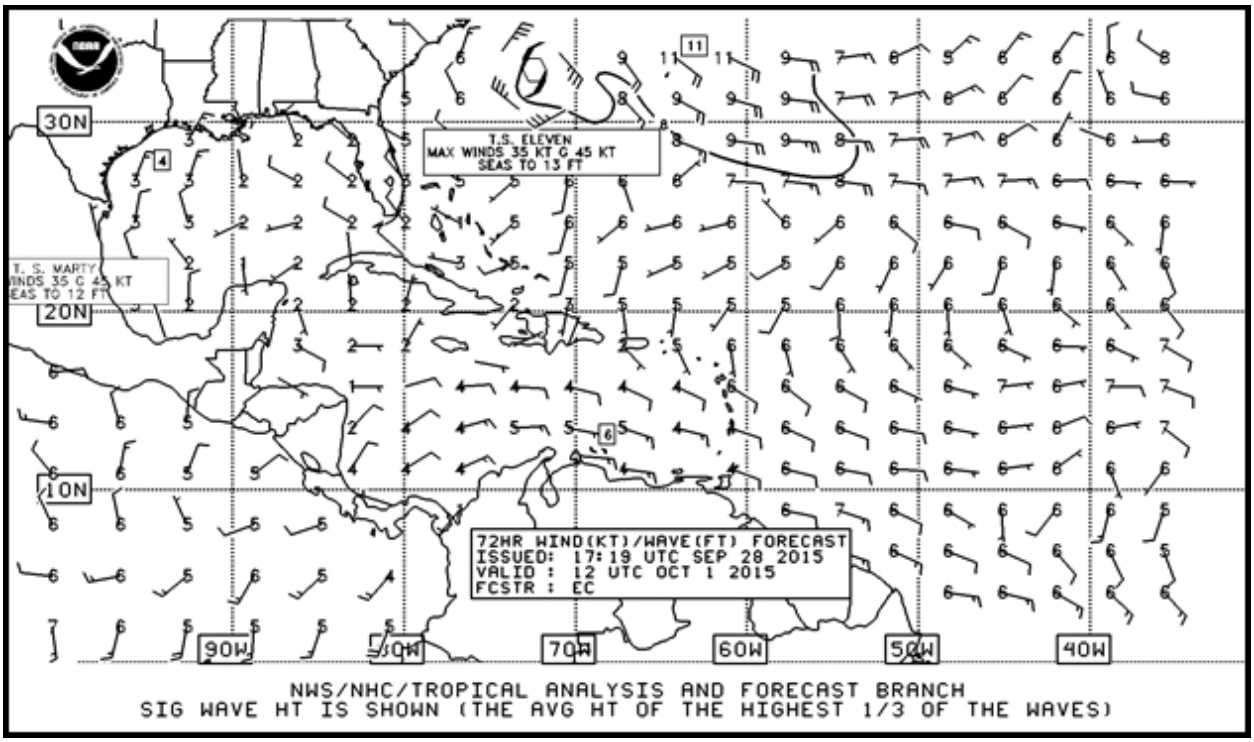

Figure 28 *– 72-hour NHC Atlantic Wind/Wave Forecasts valid for 0800 EDT on October 1, 2015.*

5.3.2.2. OPC Northwest Atlantic 24-hour Wind/Wave Forecast

The OPC's two Northwest Atlantic 24-hour Wind/Wave Forecast products depict 24-hour forecasts of wind magnitude (in 5-knot increments) and direction, as well as significant wave heights (isopleths of combined sea and swell in 3-foot intervals). During severe weather, substantially higher wind/wave height values are highlighted. Arrows point to a superimposed hatched area of the Gulf Stream. During especially significant northeast winds, the statement "Winds and Waves may be significantly higher than indicated in the Gulf Stream" may appear. "Swell fronts" originating from tropical storms may also be highlighted; they can be hazardous to marine operations and to people in coastal areas. A scalloped line depicts the front and is labeled, for example, "SWELL FRONT FROM HURRICANE DEBBY." Arrows point from the text to the leading edge of the swell front. Guidance for preparing the forecast comes from wave height and wave period models of the National Centers for Environmental Prediction (NCEP). Wave height values are depicted by solid contours. Superstructure icing is displayed by a half moon with one or two lines crossing the center, depending on whether the forecast is for light or heavy accumulation.

Figure 29 is the OPC's Northwest Atlantic 24-hour Wind/Wave Forecast for the southwest Atlantic Ocean valid for 0800 EDT on October 1, 2015.

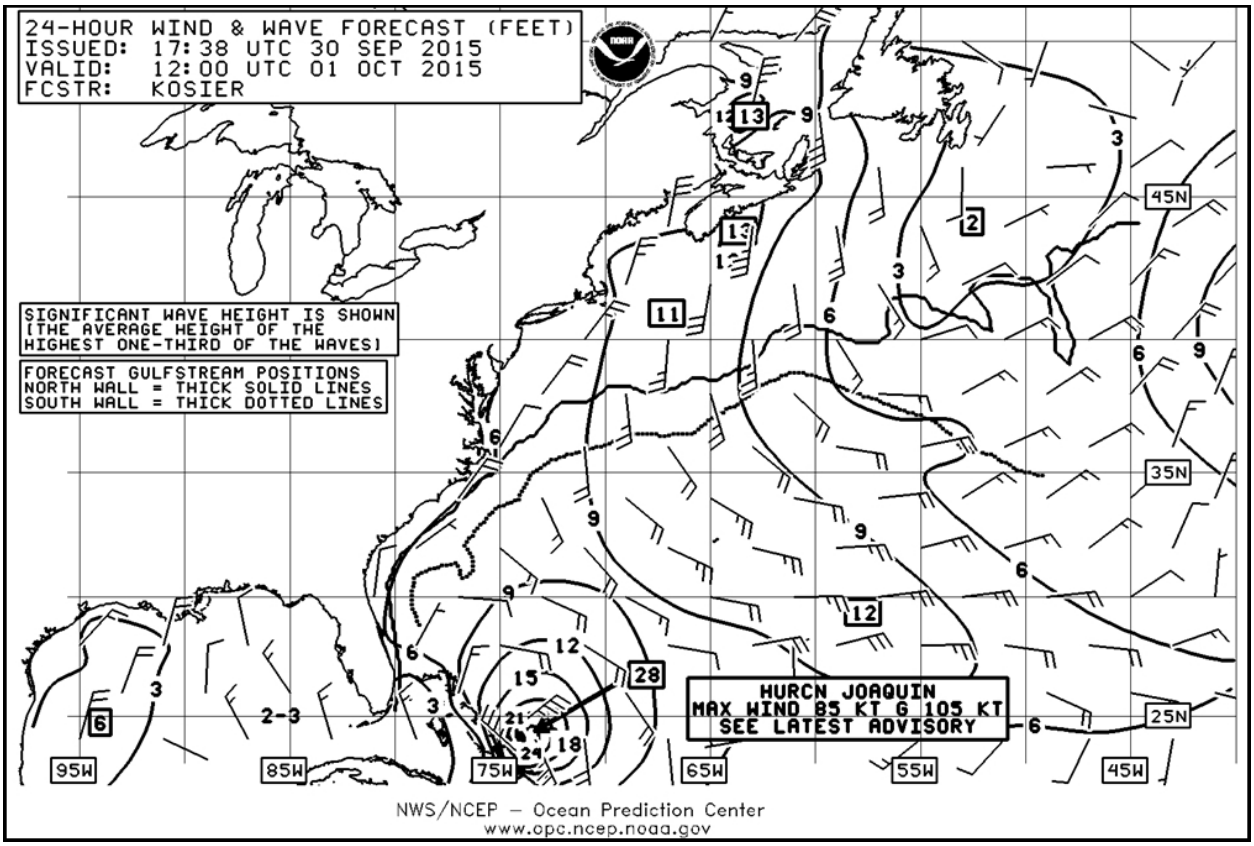

Figure 29 *– OPC's Northwest Atlantic 24-hour Wind/Wave Forecast for southwest Atlantic Ocean valid for 0800 EDT on October 1, 2015.*

5.3.2.3. NHC Atlantic Surface Forecast

The NHC produces 24-, 48-, and 72-hour forecasts of sea level pressure and surface features over the tropical and subtropical Atlantic. The products include the forecast sea-level pressure field, shown as isobars contoured every 4 mb. Intermediate 2-mb isobars are sometimes included where pressure gradients are light. Relevant surface features are shown, including areas of high and low pressure, frontal systems, troughs, ridges, drylines, tropical waves, and tropical cyclones. The 72-hour forecast chart also shows the 96-hour forecast positions of highs, lows, and tropical cyclones.

Figures 30, 31, and 32 show respectively the 24-, 48- and 72-Hour NHC Surface Forecasts for the Atlantic valid for 0800 EDT on October 1, 2015.

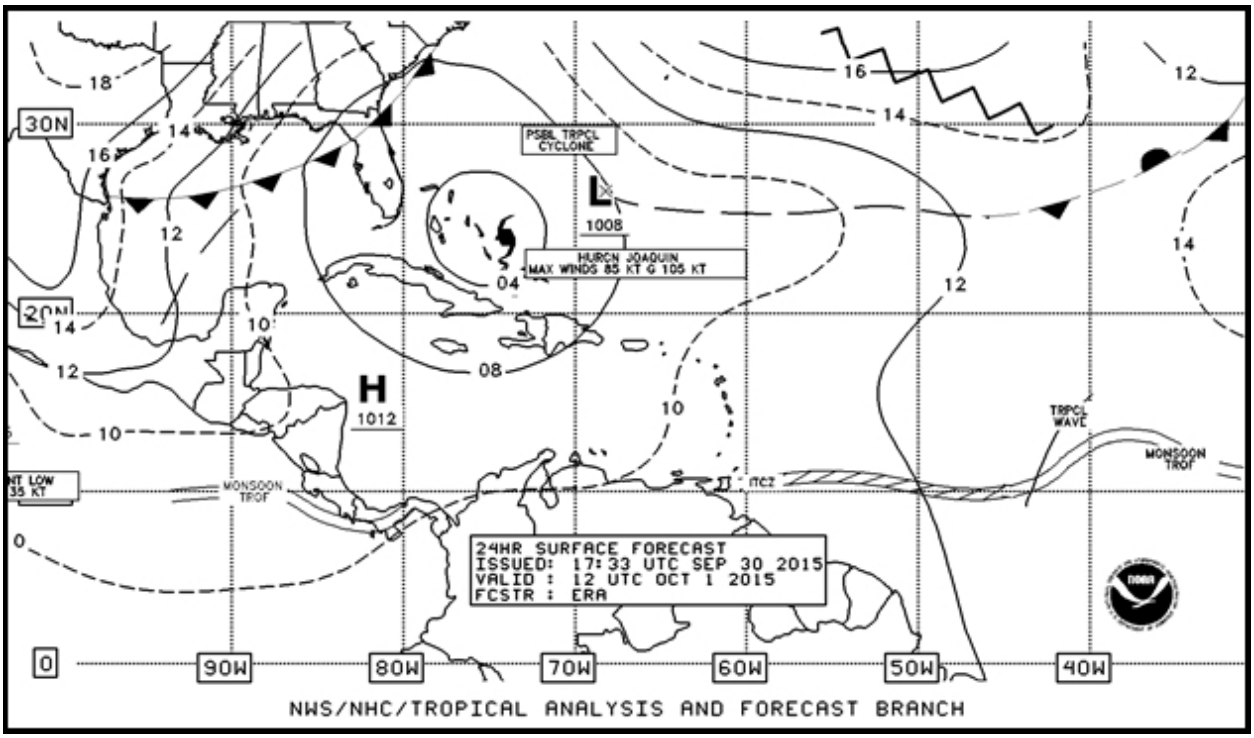

Figure 30 *– 24-hour NHC Surface Forecasts for the Atlantic valid 0800 EDT on October 1, 2015.*

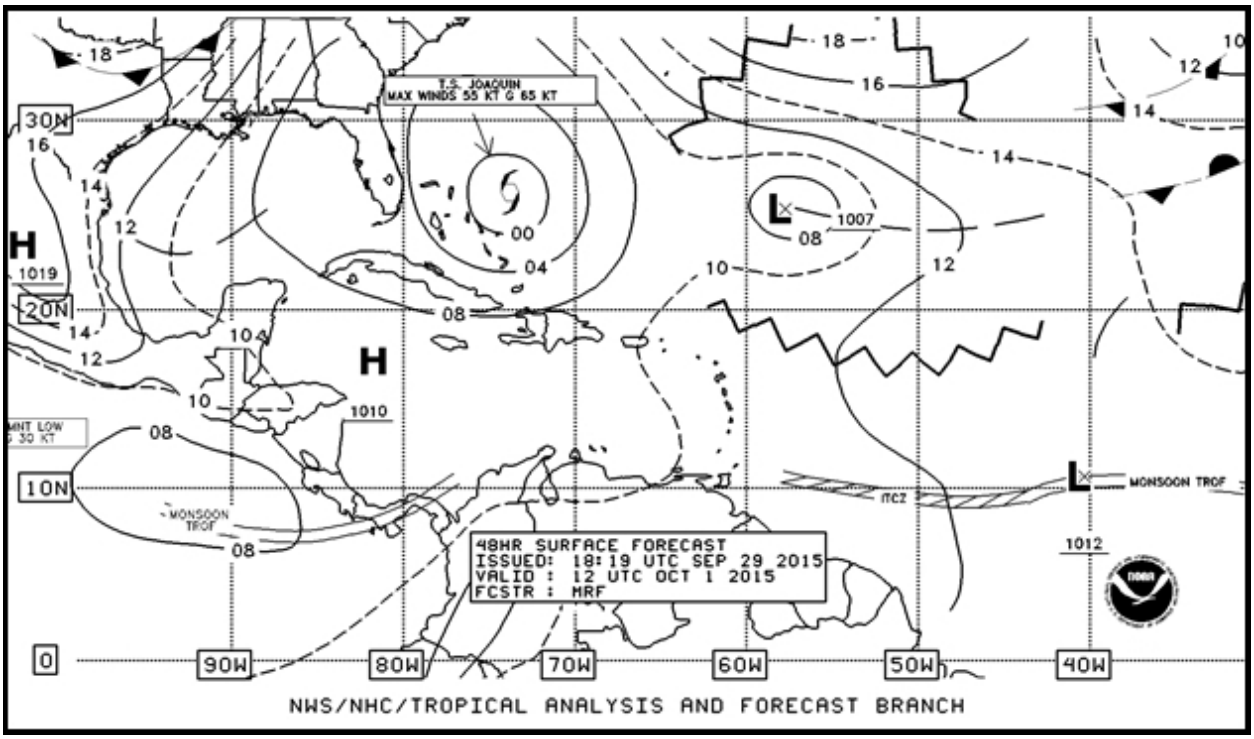

Figure 31 *– 48-hour NHC Surface Forecasts for the Atlantic valid 0800 EDT on October 1, 2015.*

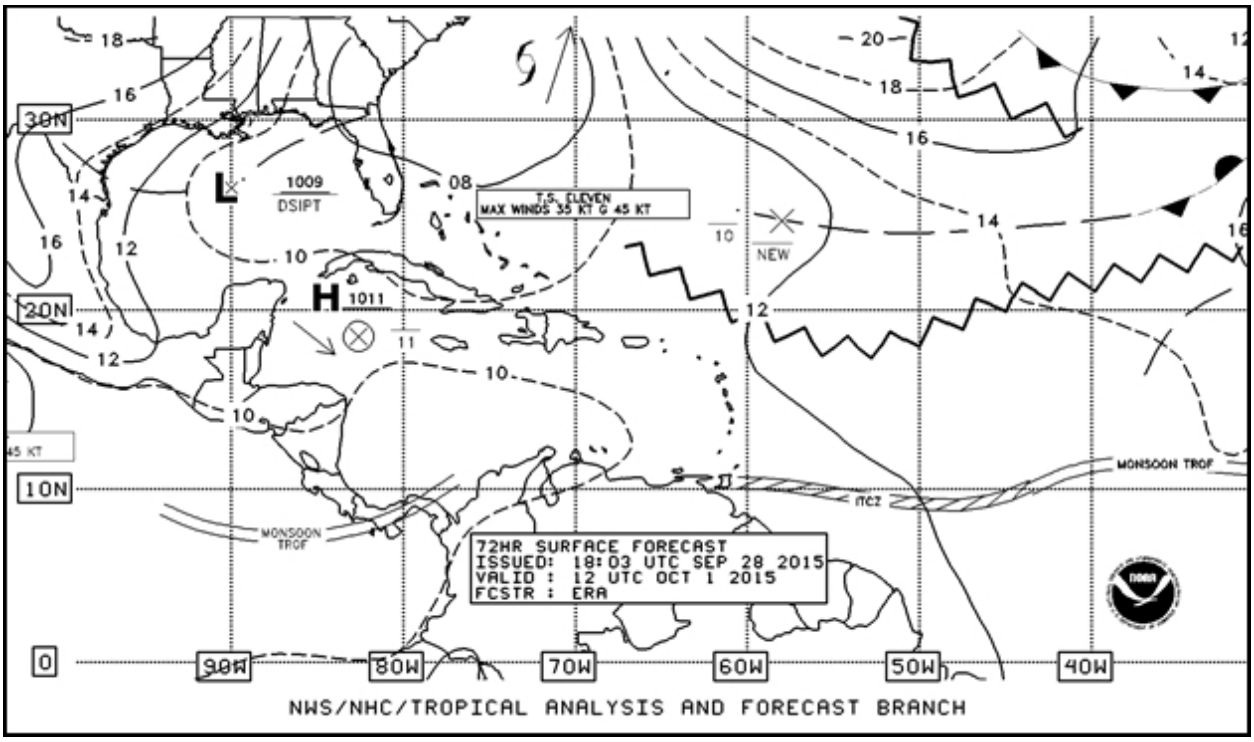

Figure 32 *– 72-hour NHC Surface Forecasts for the Atlantic valid 0800 EDT on October 1, 2015.*

5.3.2.4. OPC Northwest Atlantic 24-Hour Surface Forecast

The OPC's Northwest Atlantic 24-Hour Surface Forecast features low- and high-pressure center positions with underlined three- or four-digit central pressure values placed under or beside a boldface L or H. The 00-hour (FROM: time) position and future 48-hour forecast position of lows and highs have vector arrows, with an X for low centers and a circled X for high centers placed near the arrow's head. An underlined two-digit central pressure value (mb) is placed under or beside the recent analyzed pressure of lows and highs and for the 48-hour position label, following the convention described in section 5.3.1.4.

The 24-hour surface forecast also depicts wind magnitudes in knots (wind barbs in increments of 5 or 10 knots) for areas where winds exceed 33 knots. Significant systems are labeled if the system is expected to produce gale-, storm- or hurricane-force conditions. If the 24-hour forecast indicates that such conditions are expected, the system is labeled appropriately. If the conditions are expected within 48 hours, the appropriate area is labeled "developing gale," "developing storm," or "hurricane force."

Also displayed are frontal systems and associated areas of fog that could potentially restrict visibility. The frontal systems themselves imply visibility-impairing precipitation, which for clarity and brevity are not shown. Isobars are generally depicted with 4-mb contours, although for deep systems, 8-mb contours are used. If a tropical cyclone is expected, the 24-hour position is indicated by the appropriate tropical cyclone symbol, with the pressure shown as XXX for unknown. The 48-hour position corresponds to the latest official NHC forecast.

Figure 33 is the OPC's Northwest Atlantic 24-Hour Surface Forecast valid for 0800 EDT on October 1, 2015.

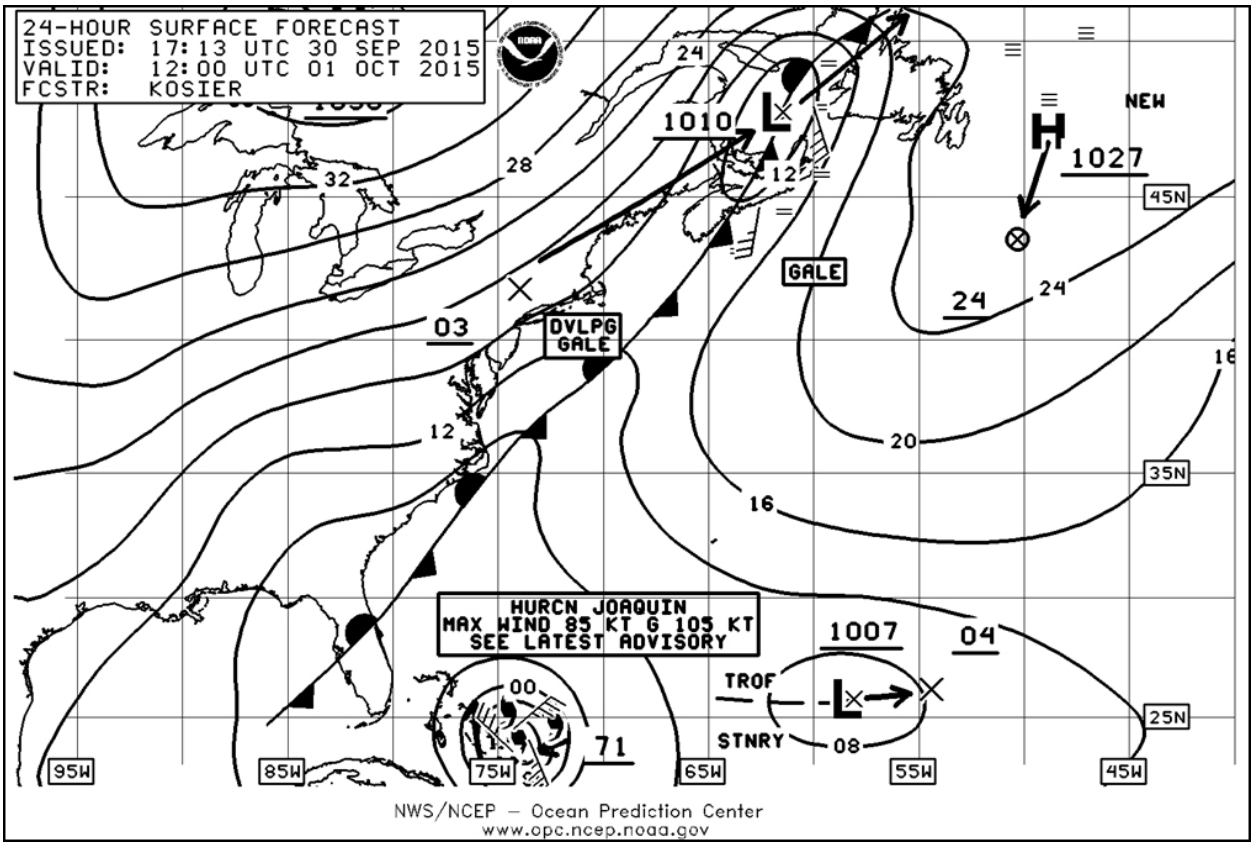

Figure 33 *– OPC's Northwest Atlantic 24-Hour Surface Forecast valid 0800 EDT on October 1, 2015.*

5.3.2.5. OPC North Atlantic 48-Hour Surface Forecast

The OPC produces a North Atlantic 48-Hour Surface Forecast twice a day. It shows surface isobars every 4 mb, with two-digit labels in increments of 8 mb. The three- or four-digit central pressure values of synoptic-scale lows and highs are underlined and placed beside or under a boldface L or H. The 24- and 72-hour forecast positions of lows and highs are shown by vector arrows, with an X for low centers and a circled X for high centers placed by the arrow's head. An underlined two-digit central pressure value (mb) is placed under or beside the 24- and 72-hour position labels, following the convention described in section 5.3.1.4. The 48-hour surface forecast depicts wind magnitudes in knots (wind barbs in increments of 5 or 10 knots) for areas where winds exceed 33 knots, and frontal systems. Significant systems are labeled if they are expected to produce gale-, storm-, or hurricane-force conditions. If the 72-hour forecast indicates that such conditions are expected, the affected area is labeled "developing gale," "developing storm," or "developing hurricane force." If a tropical cyclone typhoon is expected, the 48-hour position is indicated by the appropriate tropical cyclone symbol, with the pressure

shown as XXX for unknown. The 24-hour and 72-hour positions correspond to the latest official NHC forecast.

Figure 34 is the OPC's North Atlantic 48-Hour Surface Forecast valid for 0800 EDT on October 1, 2015.

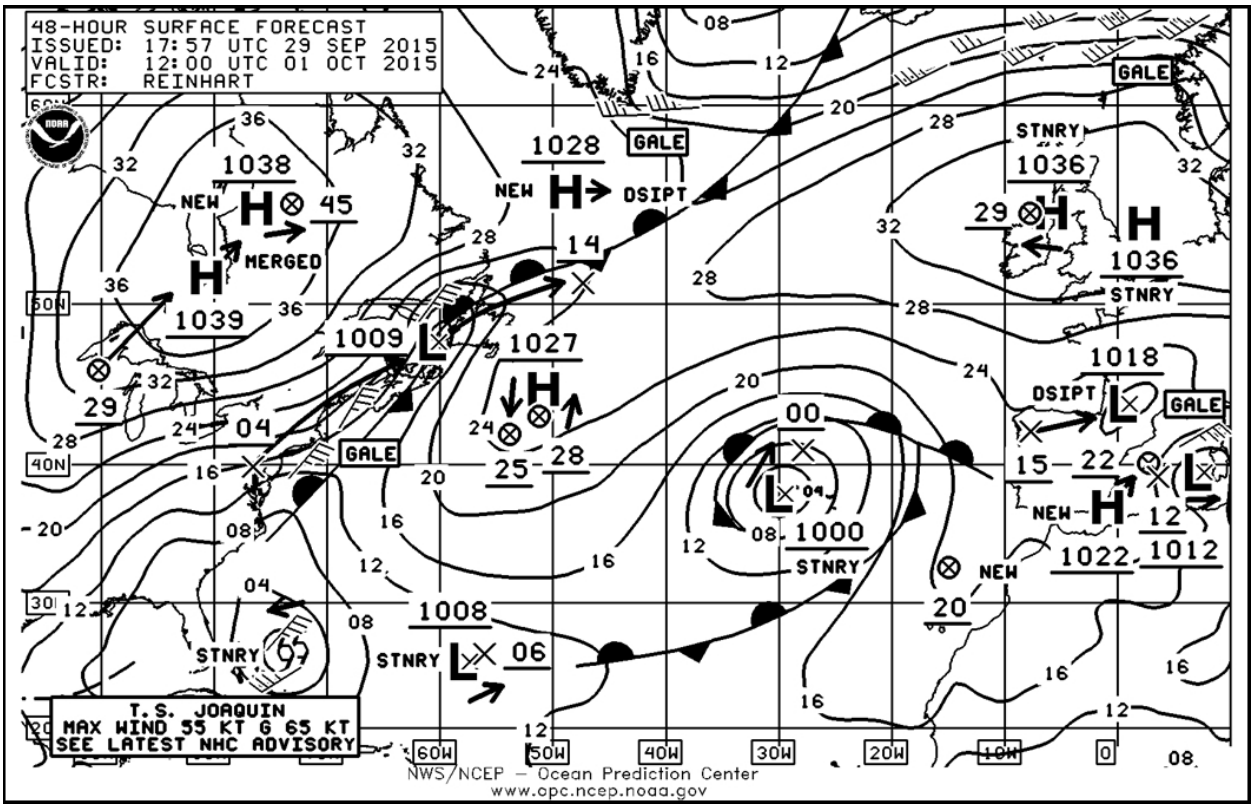

Figure 34 *– OPC's North Atlantic 48-Hour Surface Forecast valid 0800 EDT on October 1, 2015.*

5.4. Satellite Products

Weather satellite images from the accident day are shown in figures 35 through 39. No image was corrected for parallax error.

Figure 35 presents infrared (11.0 micron [µm]) brightness data from 0300 EDT on October 1, 2015, from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on board the National Aeronautics and Space Administration AQUA polar-orbiting platform.

Figure 36 presents infrared (10.8 µm) brightness data from 0639 EDT on October 1, 2015, from the Advanced Very High Resolution Radiometer (AVHRR) instrument on board the NOAA-15 polar-orbiting platform.

Figure 37 presents visible (~0.7 µm) data for near 0800 EDT on October 1, 2015, from the Operational Linescan System (OLS) instrument on board the Defense Meteorological Satellite Program (DMSP) F-19 polar-orbiting platform.

Figure 38 is a Red-Green-Blue (RGB) composite of the Polar Corrected Temperature (PCT) composite[38] product (red), the 91-gigahertz (GHz) horizontal component (green), and the 91-GHz vertical component (blue) from a scan taken near 0800 EDT on October 1, 2015, by the Special Sensor Microwave Imager/Sounder (SSMIS) instrument on board the DMSP F-19 platform. The RGB composite image gives a high-resolution view of the structure of a tropical cyclone. Deep convection appears in red; low-level clouds, water vapor, and warm precipitation appear as blue/green; and relatively cloud-free and dry parts of the atmosphere over the ocean outside the storm environment appear as gray or black.

Figure 39 presents rainfall rate estimates from a scan taken near 0800 EDT on October 1, 2015, by the SSMIS instrument on board the DMSP F-19 platform.

Further information on SSMIS and additional microwave and wind vector data applicable to Joaquin can be found through the Naval Research Laboratory.[39]

Visible and infrared images from the NOAA Geostationary Operational Environmental Satellite (GOES)-13 geostationary platform are found in section 5.9.3.

[38] The PCT composite combines the two polarizations of the 91-GHz channels.

[39] http://www.nrlmry.navy.mil/TC.html

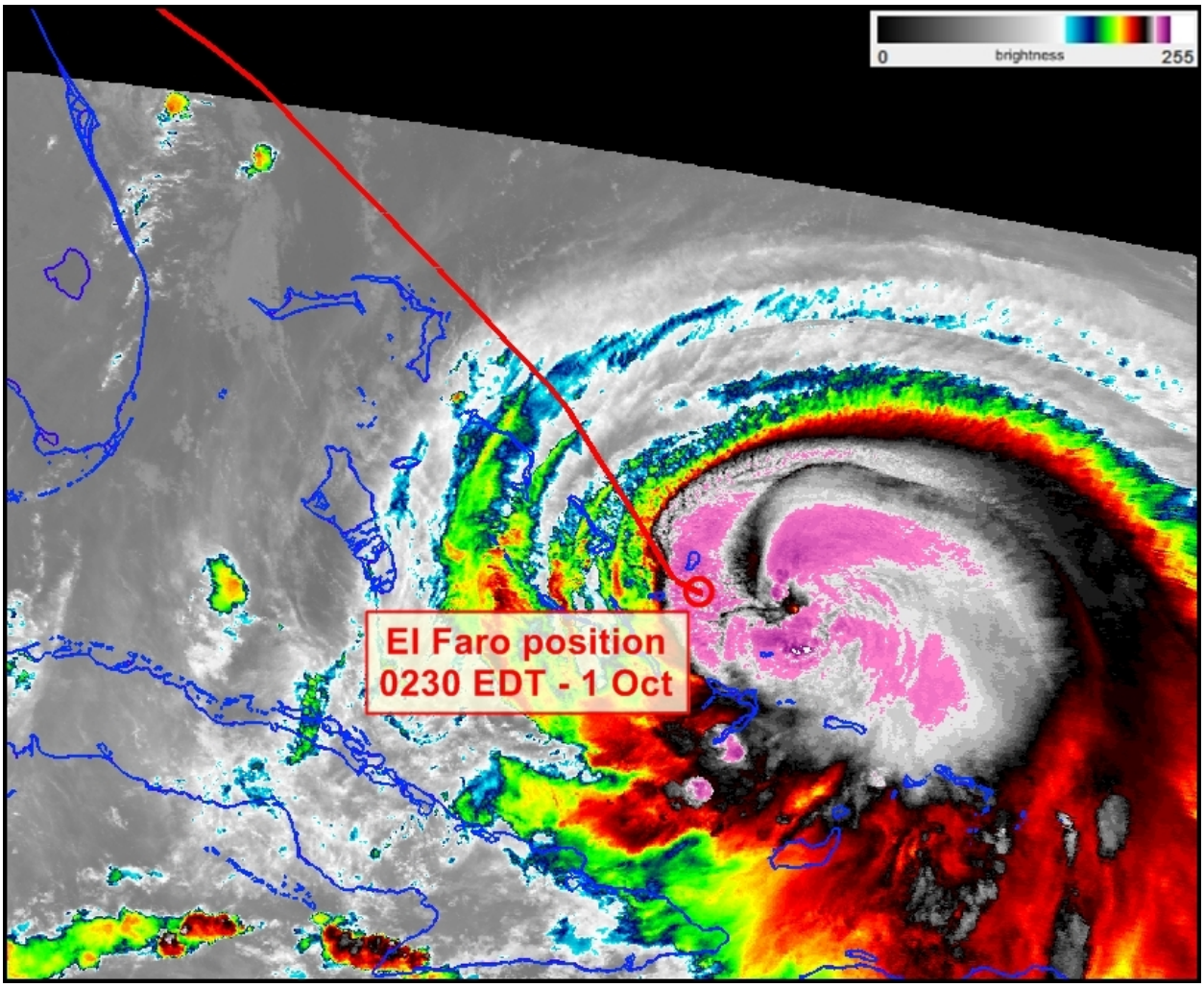

Figure 35 *– MODIS color-enhanced infrared brightness image from 0300 EDT on October 1, 2015. Red line marks* El Faro *track through 0230 EDT on October 1, 2015.*

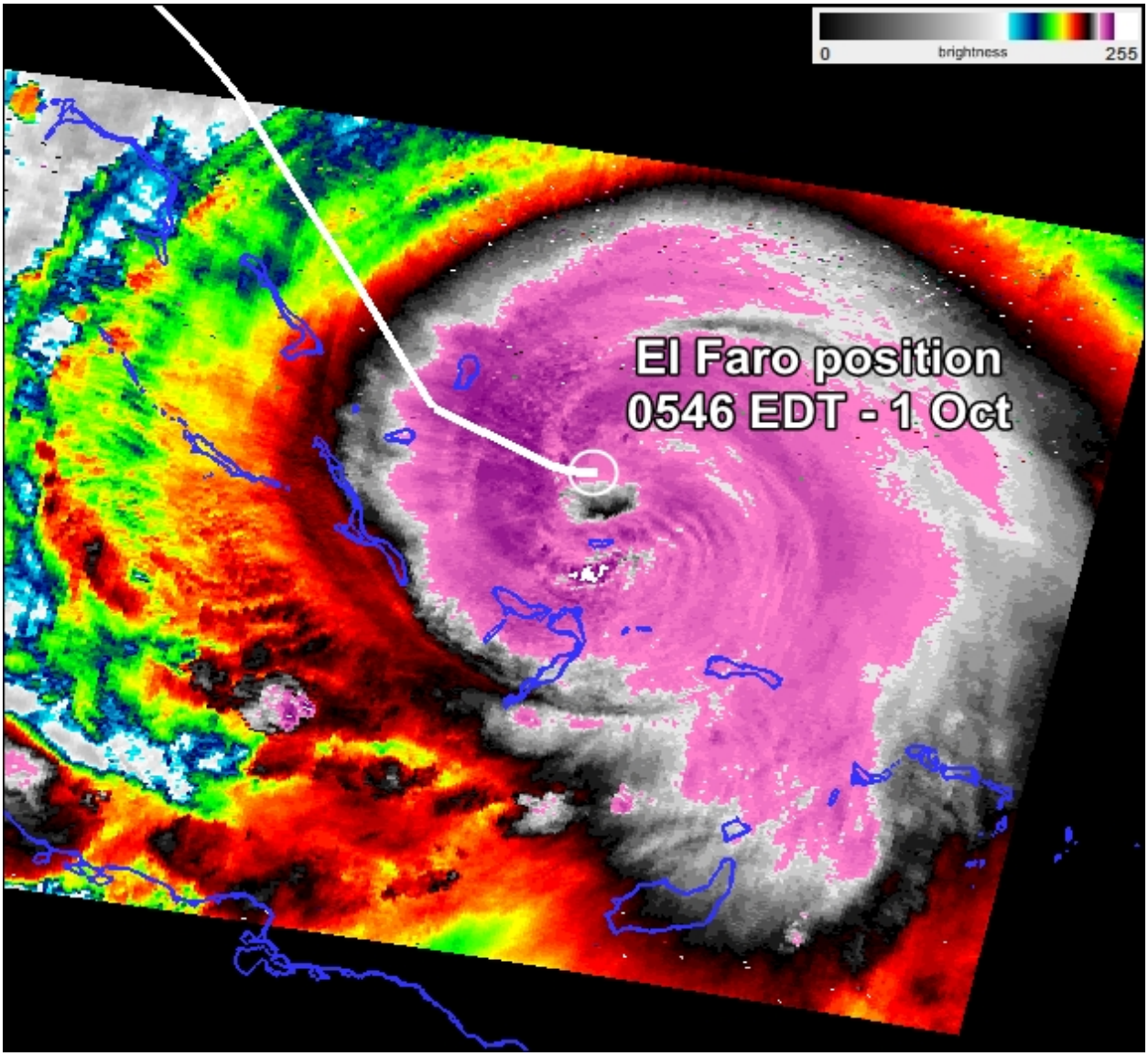

Figure 36 *– AVHRR color-enhanced infrared brightness image from 0639 EDT on October 1, 2015. White line marks* El Faro *track through 0546 EDT on October 1, 2015.*

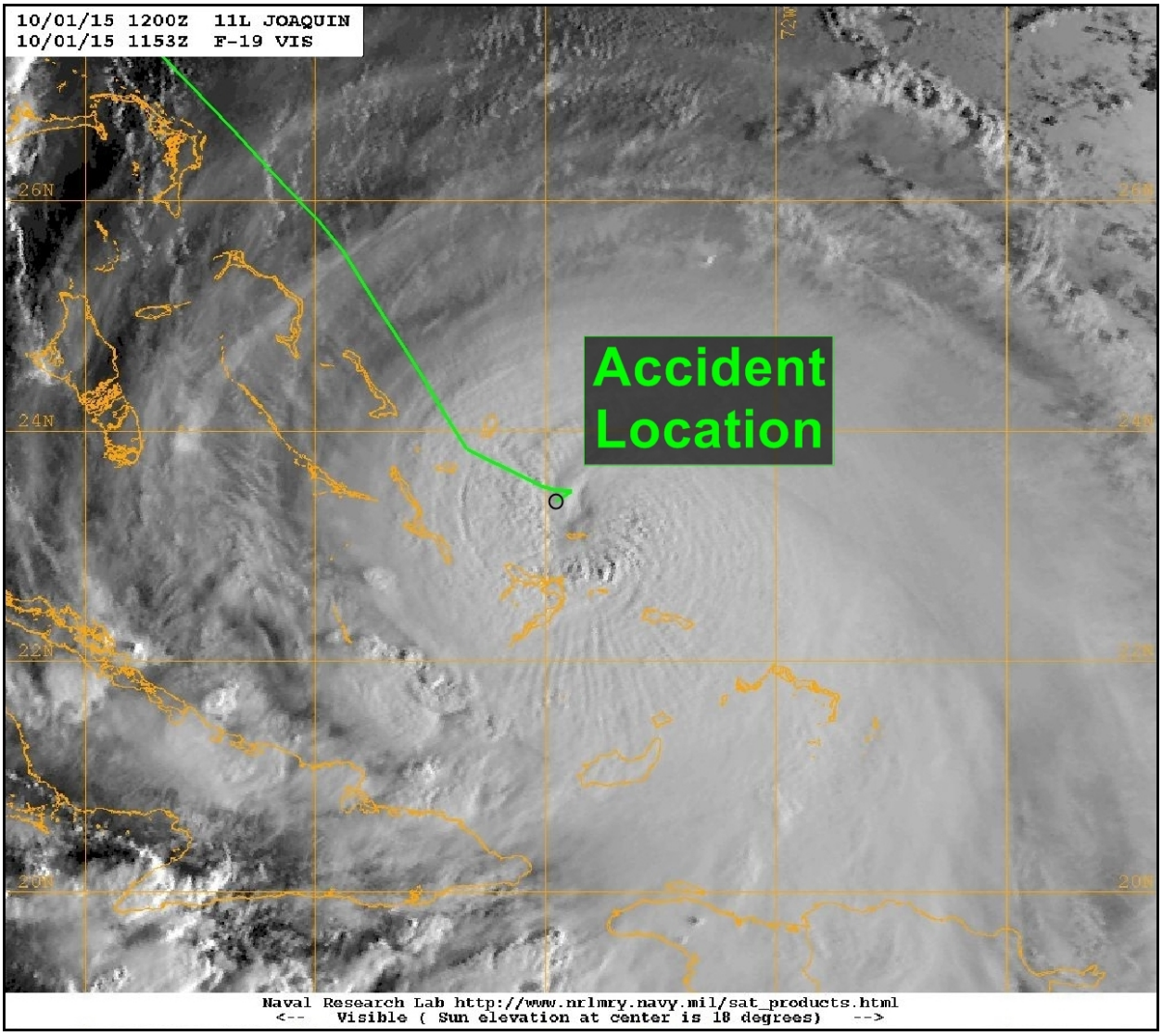

Figure 37 *– DMSP OLS visible image near 0800 EDT on October 1, 2015. Green line marks* El Faro *track through accident time.*

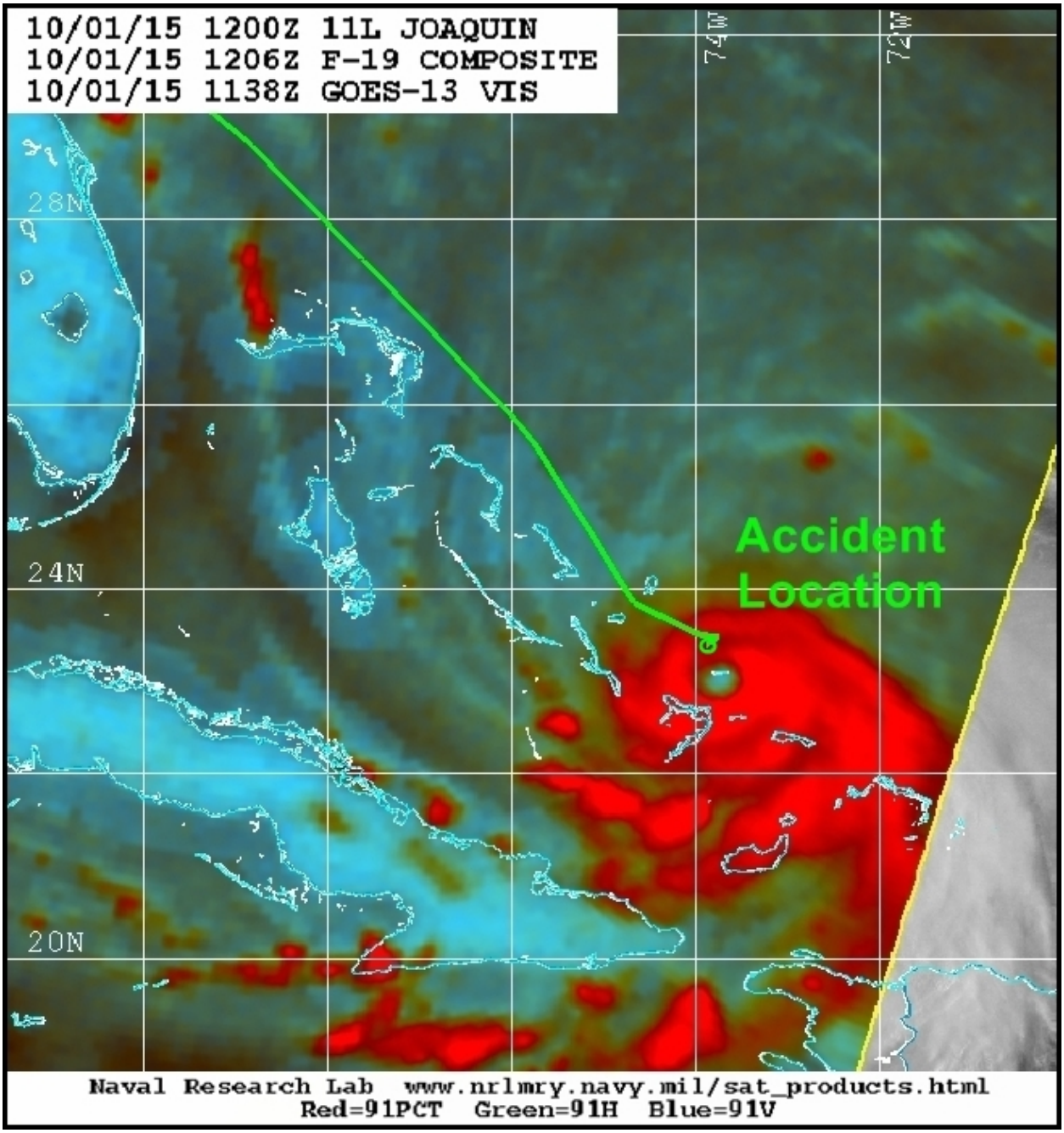

Figure 38 *– DMSP SSMIS RGB composite image near 0800 EDT on October 1, 2015. Green line marks* El Faro *track through accident time.*

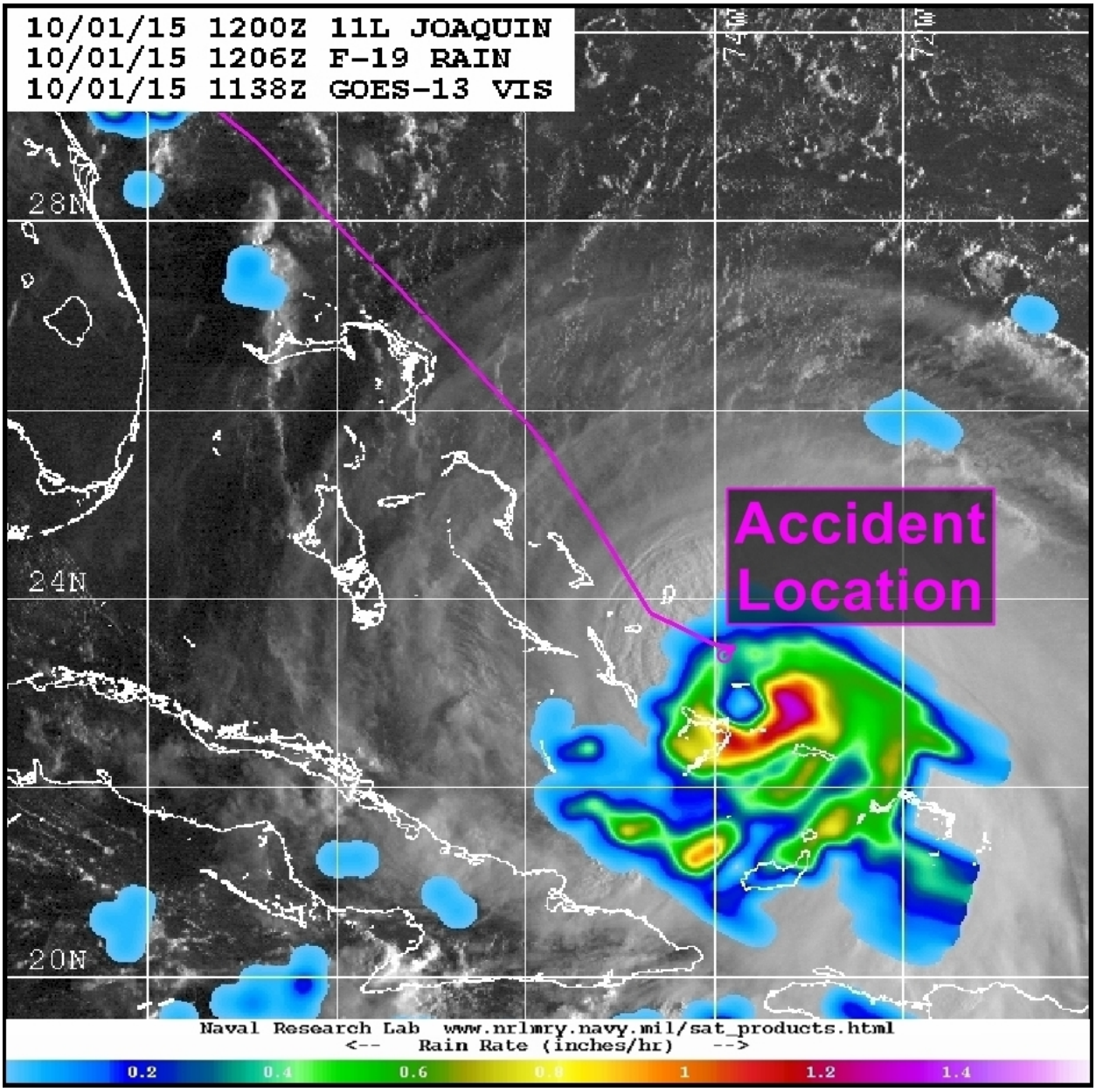

Figure 39 *– DMSP SSMIS rain-rate estimate image near 0800 EDT on October 1, 2015. Purple line marks* El Faro *track through accident time.*

5.5. Weather Radar

Weather radar data were not available from the Bahamas. The closest known ground-based weather radar site was in Cuba.

Composite[40] weather radar images were obtained from the Instituto de Meteorología de Cuba for an S-band radar located near Camagüey, Cuba, at an elevation of about 459 feet. The lowest radar tilt considered in the composite was 0.5°, with a beam width[41] of 1.5°. Reflectivity[42] is only presented for distances up to 460 km (about 243 miles) from the radar site. The accident occurred very near this distance from the radar, but most likely slightly farther away.[43] At a distance of 243 miles, the center of the beam for the 0.5° tilt would have "seen" an altitude of approximately 52,500 feet above mean sea level (msl), with the lower beam boundary[44] seeing about 33,150 feet above msl.

Attachment 10 presents composite reflectivity images from the Camagüey, Cuba, radar between 0615 EDT and 0900 EDT on October 1, 2015. Reflectivity is not depicted in the immediate area of the accident site during that period.

5.6. Additional Observations

5.6.1. *El Faro* Anemometer

El Faro's VDR recorded wind observations from an anemometer located onboard the vessel. Recorded parameters included ship-relative wind speed and ship-relative wind direction, which were recorded with a frequency of about 15 samples-per-second during the 26 hours of retrieved VDR data. The anemometer data are available in the NTSB Electronic Data Factual Report for the accident. Representativeness to actual wind conditions of *El Faro's* recorded anemometer reporting in the VDR data is unknown.

5.6.2. Buoys

No known buoys within 250 miles of the accident site at the accident time had data available from the NHC or the National Data Buoy Center (NDBC) website.[45]

[40] Composite reflectivity is the maximum reflectivity from any of the available radar tilts for that volume scan above a specific point (i.e., it shows the maximum reflectivity value in a column above a single point).

[41] Beam width is the angular separation between the half-power points on the antenna radiation pattern, where the gain is one-half the maximum value.

[42] Reflectivity is the sum of all backscattering cross sections (e.g., precipitation particles) in a pulse resolution volume divided by that volume. For radar to calculate reflectivity, it sends out a small burst of energy that strikes the particles in the volume. To simplify, assume that the particles are evenly spread throughout the volume. The more particles in the volume, the greater the energy returned to the radar. Reflectivity returns are greater from heavy rain than from light rain.

[43] Exact coordinates for the Camagüey radar are unknown.

[44] Beam boundary is defined as the point of the beam where half-power is realized.

[45] http://www.ndbc.noaa.gov/

5.6.3. Ship Reports

The NHC provided ship reports (figure 40) from vessels that observed winds of 34 knots or greater within 400 miles of Joaquin between 2000 EDT on September 28, 2015, and 1400 EDT on October 1, 2015.

Date/Time (EDT)	Ship Call Sign	Latitude (°N)	Longitude (°W)	Wind dir/mag (kt)	Pressure (mb)
29 / 1700	9HA348	25.0	71.2	270 / 40	998.0
29 / 2000	9HA348	24.9	70.4	180 / 45	1001.0
29 / 2300	9HA348	25.2	68.7	160 / 36	1005.0
30 / 0200	J8PE4	26.1	78.1	*** / 53	1009.0
01 / 0300	H3VU	21.7	74.8	250 / 57	998.0

Figure 40 *– Selected ship reports provided by NHC. Dates are September 29, 2015, through October 1, 2015. Wind dir = wind direction. Wind mag = wind magnitude.*

The NTSB retrieved the following raw[46] ship reports, which coincide with the NHC's table. However, decoding of the wind report from vessel J8PE4 in the raw data appears to conflict with the NHC's decoding (if the two reports are the same[47]). Attempts to resolve the issue with the NHC's data and to confirm translation were unsuccessful.

```
BBXX 9HA3488 29214 99250 70712 41397 82740 10290 20242 49980 57040
75822 886// 22233 295 21210 304// 41006 80255=

BBXX 9HA3488 30004 99249 70704 41/96 /1845 10255 20220 40010 53030
713// 8//// 22233 292 2//// 80230=

BBXX 9HA3488 30034 99252 70687 41/96 /1636 10270 20243 40050 53035
764// 8//// 22213 289 2//// 80250=

BBXX J8PE4 30064 99261 70781 41497 53520 10295 20255 40090 50010
70122 83238 22264 300 20404 3//// 40402 5//// 6//// 80265 ICE
/////=

BBXX H3VU 01074 99217 70748 41497 82557 10260 20231 49980 57050
76566 87718 22264 300 20406 326// 40406 80240=
```

The captain of *El Yunque* emailed the captain of *El Faro* at 1121 EDT on September 30, 2015: "As we passed to the west of (Joaquin) we recorded a 100 knot relative wind gust." The NTSB was unable to identify any ship report that delivered a wind observation of that magnitude. The

[46] Weather observation messages are formatted in accordance with NWS Observing Handbook No. 1: http://www.vos.noaa.gov/ObsHB-508/ObservingHandbook1_2010_508_compliant.pdf

[47] The NHC referenced the following raw report for the J8PE4 observation:

```
201509300600 J8PE4 26.1 -78.1 -99 53 1009.0 W 20 4 2 -9 4 1 30
```

time and location of the *El Yunque*'s encounter with this 100-knot relative wind gust are unknown.

According to the NWS, *El Faro* sent a ship report on September 30, 2015, for conditions at 1000 EDT. That was the only ship report the NWS received from *El Faro* during the accident voyage. The raw text of the ship report is as follows:

```
BBXX WFJK 30143 99210 70771 41598 73408 10306 20290 40072 70288
86498 22234 00278 20402 310// 40804 80294
```

Attachment 11 presents a summary of this report from the Coast Guard.

5.6.4. Reconnaissance Aircraft

Aircraft operated by the Air Force Reserve 53rd Weather Reconnaissance Squadron and NOAA's Aircraft Operations Center conducted data-collection missions for Joaquin that included flight-level observations, surface wind magnitude retrievals from the Stepped-Frequency Microwave Radiometer (SFMR [48]), and dropsonde observations. The Wide Swath Radar Altimeter (WSRA), which can retrieve information on ocean direction wave spectra and significant wave height, and other instruments on NOAA's two P3 aircraft were unavailable because both aircraft were grounded for maintenance during Joaquin.[49]

Raw reports from dropsonde observations and VORTEX data messages between 2000 EDT on September 30, 2015, and 1000 EDT on October 1, 2015, are found in Attachment 12. The VORTEX messages identify, among other parameters, the observed center of the cyclone (location of minimum flight-level wind), as well as the observed peak flight-level and surface winds, and the locations of those peak winds relative to the center.

High-Density Observations (HDOB) report flight-level parameters such as wind, temperature, moisture, and surface wind magnitude from the SFMR, as often as every 30 seconds. Raw HDOB observations between 2000 EDT on September 30, 2015, and 1000 EDT on October 1, 2015, are found in Attachment 12. SFMR-retrieved wind magnitudes are the peak 10-second average surface wind magnitude within the 30-second reporting interval. The observation time defines the midpoint of the 30-second interval.

Figure 41 illustrates potential distances from the storm that 50-kt winds, as well as the storm's peak winds, might have occurred near the time of the accident. The distances are based on the SFMR observations from the reconnaissance aircraft, as well as the NHC's post-storm best track analysis, which is based on all observations available to NHC analysts. The orange- and brown-shaded areas depict the NHC best track estimates of the farthest extent that 50- and 64-

[48] The SFMR measures microwave radiation that is primarily determined by the amount of foam on the ocean surface and the intensity of the rain between the aircraft and the surface. Algorithms on the aircraft separate the contributions from rain and wind and compute estimated surface wind speeds and rain rates. NHC advises that the instrument is subject to errors from a number of sources and that expert interpretation is advised.

[49] The WSRA may not have been available for Joaquin regardless of NOAA P3 availability, since aircraft and instruments are scheduled for particular times of the season or for particular missions.

kt winds, respectively, were occurring in each quadrant around the storm, valid at 0800 EDT on October 1, 2015. In the storm's northwest quadrant, the NHC best track analysis was that 50-kt winds extended outward as far as 50 miles from the center.

Figure 41 also shows selected SFMR-retrieved surface winds observed during a reconnaissance flight close to the accident time. During the aircraft's inbound leg from the southwest, the first SFMR wind of at least 50 kt was observed at 0734:30 EDT about 38 miles from the center. A few minutes later, at 0742:30 EDT, the peak SFMR wind in the quadrant was observed, about 14 miles from the center.[50] On the aircraft's outbound pass from the center in the northeast quadrant, a peak SFMR wind of 104 kt was observed at 0751:30 EDT. The winds remained above 50 kt until 0803:30 EDT.

The aircraft began its inbound leg in the northwest quadrant about 0850 EDT. The first SFMR wind of 50 kt on this pass was encountered at 0912:00 EDT, about 39 miles from the center. At 0919:00 EDT, the peak SFMR wind in the quadrant, 95 kt, was observed about 17 miles from the center. Note that the accident location is about as far from the center as the storm's radius of maximum wind, as depicted by the SFMR data.

[50] Although the HDOB data show a maximum wind of 129 kt at 1142:00 EDT, the aircraft crew deemed this report unreliable, and instead reported the 1142:30 observation of 117 kt as the maximum inbound wind in a VORTEX message transmitted at 0816 EDT. NHC also disregarded the 129-kt observation in its post-storm analysis of Joaquin.

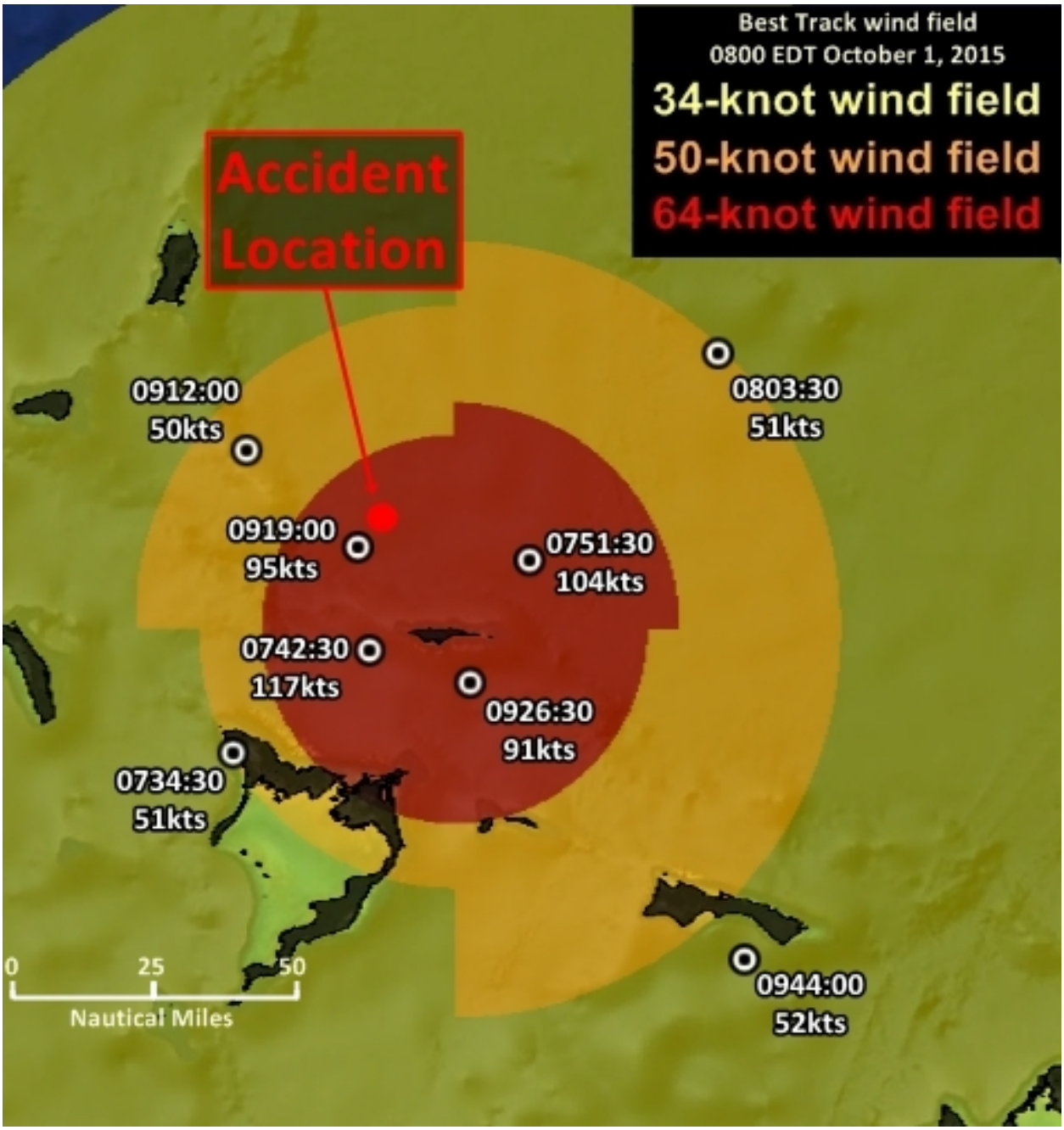

***Figure** 41 - 50-knot and maximum surface wind retrievals from SFMR-retrieved peak 10-second average surface wind observations found in Attachment 12 to this report, overlaid on best track wind fields from 0800 EDT on October 1, 2015 (Advisory 14). Pertinent SFMR observations are labeled with time of midpoint of each 30-second reporting interval (HHMM:SS format in EDT) and average wind magnitude.*

5.6.5. Bahamas Surface Observations

Archived land-based surface weather observations in the accident region are severely limited. Table 3 in Attachment 2 lists some surface observations from the area.

5.7. Simulations

At the NTSB's request, wind and sea-state conditions for Joaquin during the accident timeframe were simulated.

5.7.1. Georgia Tech/INSEAN

At the request of the NTSB, scientists from the College of Engineering at the Georgia Institute of Technology (Georgia Tech) and the Italian Ship Model Basin (INSEAN) conducted a study[51] to determine the potential for a "rogue wave" event for the time surrounding the *El Faro* sinking. The full study is found in Attachment 13, and includes recommendations for future work that would further the predictability of wave extremes and enhance early warnings of areas at risk of rogue waves.

5.7.2. EMC/NCEP

The Environmental Modelling Center (EMC) at NCEP estimated wind and sea states using state-of-the-art computer models[52] (see Attachment 14). GRIB2 and point spectra files for the accident region from the EMC may be found in the NTSB's public docket for the accident.

The EMC also provided plots of msl pressure for the region surrounding Joaquin for the times surrounding the accident.[53] The plots (figures 42 and 43) are based on analysis from the Hurricane Weather Research and Forecasting (HWRF) model.[54] In these figures, we have adjusted[55] the center of model circulation relative to *El Faro's* track to correlate circulation center with the NHC best track center position for Joaquin valid at these times. Because of these adjustments, the unlabeled latitude/longitude grid *should be ignored* relative to *El Faro's* track in these figures. Note that while storm position is adjusted in these figures (relative to *El Faro's* track) to correlate with the NHC best track, minimum msl pressure in the HWRF plots remains different from the NHC best track minimum msl pressure. That is, at 0200 EDT on October 1, 2015, the HWRF minimum msl pressure is about 944 mb (or slightly less) and the NHC best track minimum msl pressure is 947mb. At 0800 EDT on October 1, 2015, the HWRF

[51] The study was led by Dr. Francesco Fedele, Associate Professor, School of Civil & Environmental Engineering, School of Electrical & Computer Engineering, Georgia Institute of Technology.

[52] The study was conducted by Dr. Arun Chawla, Waves Team Lead, Marine Modelling & Analysis Branch at the Environmental Modelling Center.

[53] These data were provided by Dr. Avichal Mehra, Acting Hurricane Team Lead/Ocean Modelling Lead, Environmental Modelling Center

[54] The plots are generated from archived results from the HWRF model running operationally at NCEP for Joaquin in 2015.

[55] The adjustments are quantified in the figure captions.

minimum msl pressure is about 936mb (or slightly less) and the NHC best track minimum msl pressure is 942mb.

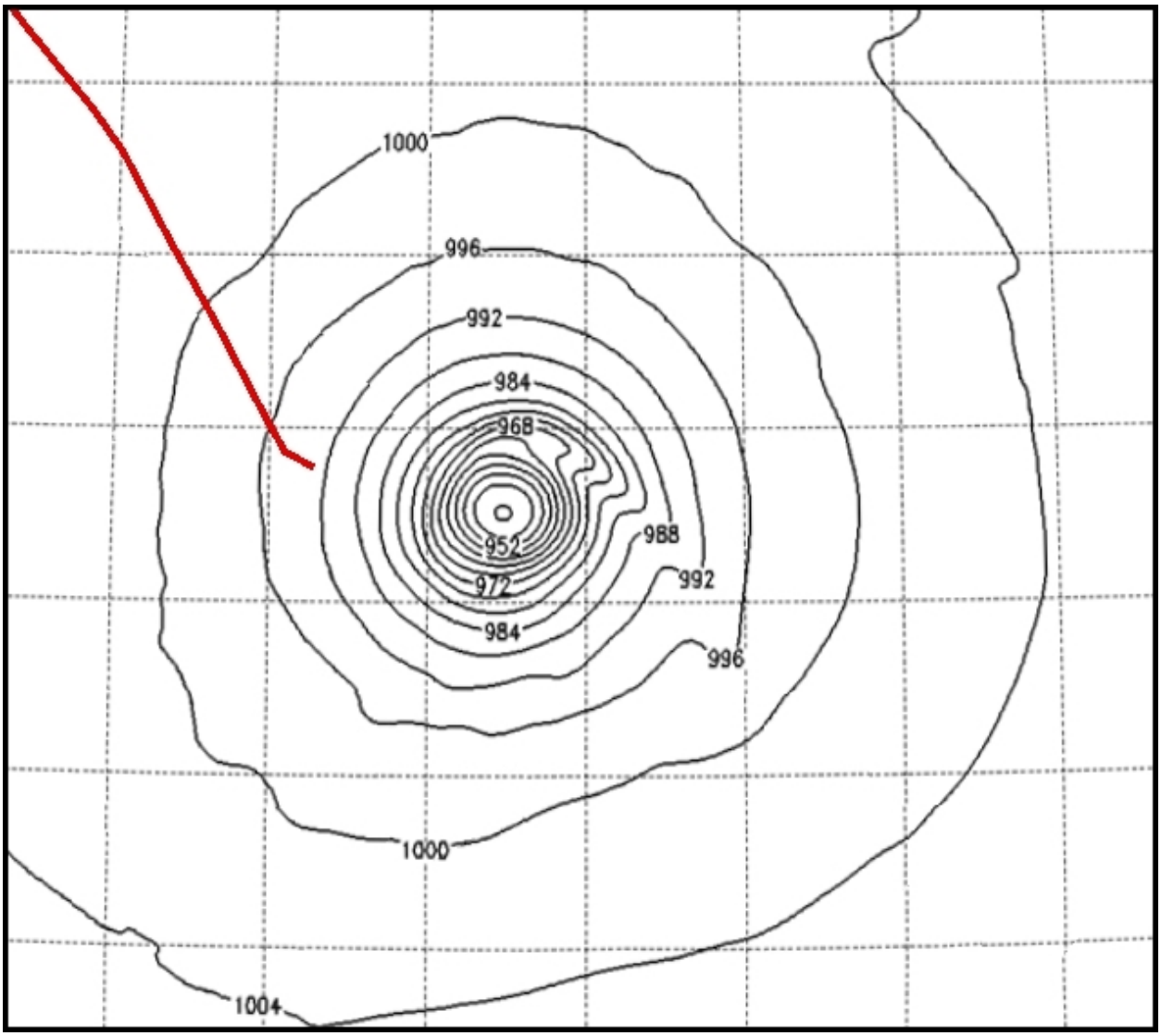

Figure 42 *– HWRF msl pressure plot valid for 0200 EDT on October 1, 2015. Red line shows* El Faro *track through 0207 EDT on October 1, 2015. Center of model circulation has been adjusted relative to* El Faro *track (about 12 miles east) to correlate circulation center with NHC best track center position for Joaquin valid at this time. Unlabeled latitude/longitude grid should be ignored relative to* El Faro *track.*

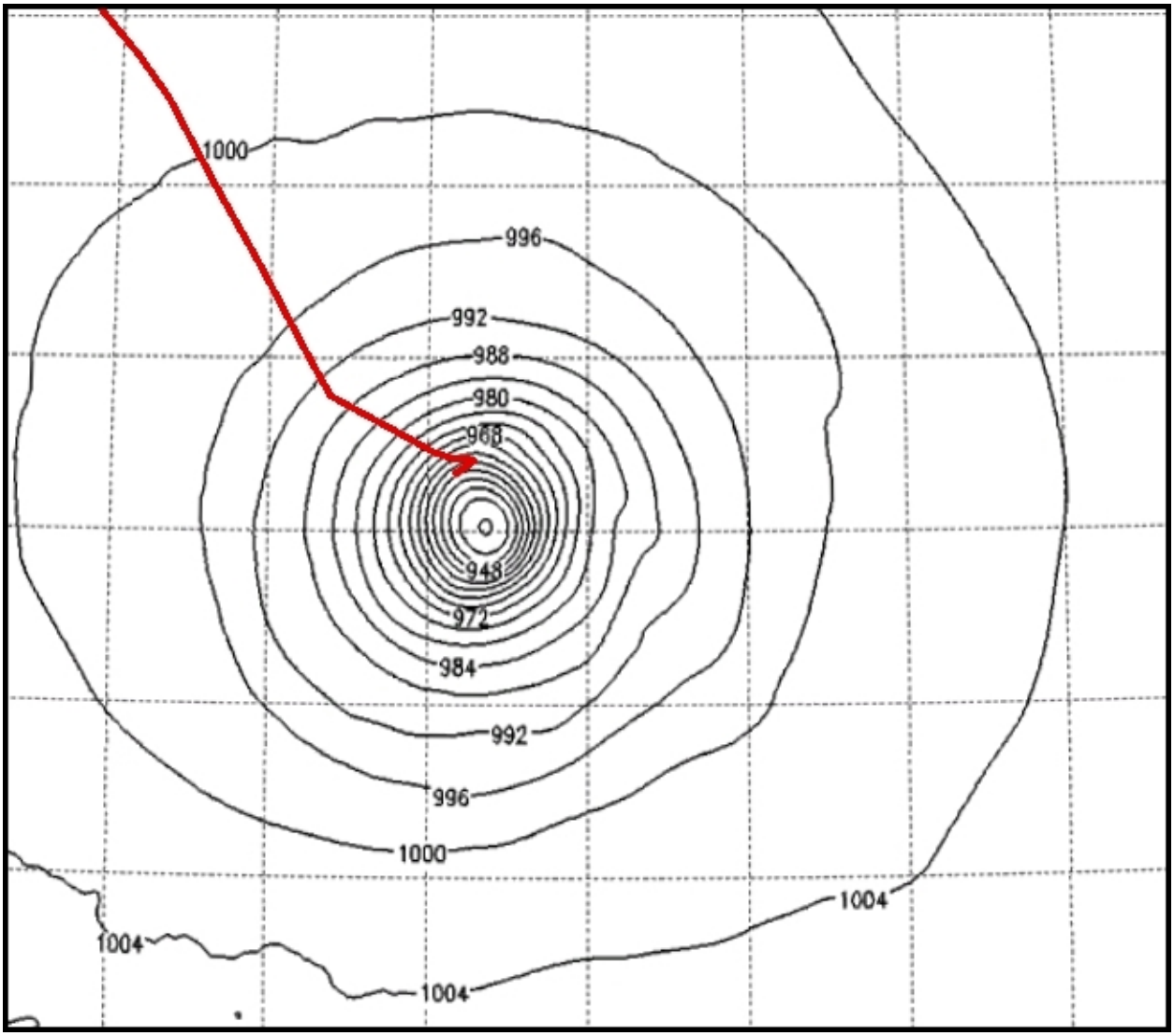

Figure 43 *– HWRF msl pressure plot valid for 0800 EDT on October 1, 2015. Red line shows* El Faro *track through the accident time. Center of model circulation has been adjusted relative to* El Faro *track (about 6 miles northwest) to correlate circulation center with NHC best track center position for Joaquin valid at this time. The unlabeled latitude/longitude grid should be ignored relative to El Faro's track.*

5.8. Astronomical Data

Astronomical data from the United States Naval Observatory for latitude 27°26'N (27.43°N) and longitude 77°30'W (77.5°W) for September 30, 2015, show beginning of civil twilight at 0639 EDT, sunrise at 0702 EDT, moonset at 0940 EDT,[56] sunset at 1858 EDT, end of civil twilight at 1921 EDT, and moonrise at 2113 EDT.

Astronomical data from the United States Naval Observatory for latitude 23°23'N (23.38°N) and longitude 73°54'W (73.9°W) for October 1, 2015, show beginning of civil twilight at 0625 EDT, sunrise at 0647 EDT, moonset at 1023 EDT, sunset at 1843 EDT, end of civil twilight at 1906 EDT, and moonrise at 2103 EDT.

5.9. Onboard Weather Receipt Options

This section describes means by which the accident vessel could have received text and graphical weather information during the accident voyage. Dissemination vehicles that are limited to delivery along the US coast (e.g., NOAA Weather Radio) are not included.

According to Inmarsat, per contract (see Attachment 15), computers on *El Faro* connected to Inmarsat's Fleet Broadband service could not access the internet for web browsing.[57]

Further, the Coast Guard[58] provided the following information regarding requirements for ships at sea to monitor weather. With regard to potential requirements established in Title 47 Code of Federal Regulations (CFR) 80.1123 for monitoring weather information via HF/MF broadcasts, the Coast Guard stated:

"Section 80.1123 applies only to 'compulsory vessels,'[59] i.e., vessels subject to the Global Maritime Distress and Safety System (GMDSS), part II of title III of the Communications Act of 1934 or the SOLAS Convention, not to all vessels. It mandates that vessels maintain a watch on, i.e., listen to, specified channels, which may be used to transmit weather information. In particular, Section 80.1123(b) requires that GMDSS vessels maintain a radio watch for broadcasts of maritime safety information, which includes weather information. In addition, Section 80.1123(a) requires GMDSS vessels to maintain watches on safety and distress frequencies. Among the 'safety communications' that vessels may transmit on those channels are 'important meteorological warnings.' So although Section 80.1123 by its terms does not mandate that GMDSS vessels monitor weather information, it operates to do so by requiring such vessels to monitor channels on which weather information is broadcast."

[56] Moonrise occurred at 2025 EDT the previous day.

[57] The NWS publishes a disclaimer with regard to its weather.gov server, which reads (in part): "This server is available 24 hours a day, seven days a week. Timely delivery of data and products from this server through the Internet is not guaranteed."

[58] The Federal Communications Commission (FCC) provided a significant amount of input to the Coast Guard's information.

[59] The Coast Guard indicated that on the accident voyage, *El Faro* would have been considered a "compulsory vessel." According to the Coast Guard, "U.S. Commercial vessels of 300 gross tons and upward [are] required to participate in the GMDSS by installing required equipment and carrying certified GMDSS radio operators. GMDSS applies to vessels on international voyages and on domestic voyages offshore but not to vessels on voyages limited to inland waters and the Great Lakes."

With regard to potential requirements established in Title 47 CFR 80.1123 for monitoring weather information via an "INMARSAT ship earth station," the Coast Guard stated: "[Vessels] are required to monitor the INMARSAT ship earth station for shore-to-ship distress alerts without limitation, including but not limited to weather-related alerts. Only GMDSS vessels that travel in Sea Area A3, more than 100 nautical miles from shore, are required to carry an INMARSAT ship earth station."

With regard to Title 47 CFR 80.1123 section (b), the Coast Guard stated: "Section 80.1123(b) requires GMDSS vessels to listen to maritime safety information broadcasts. A watch simply refers to listening to communications on a radio frequency. Radios in the context of this section are receive-only. Maritime safety information [MSI] is broadcast by NOAA and other government agencies and consists of navigational and weather warnings. Radio watches are generally continuous, but that adjective is not used in Section 80.1123(b). That is probably because MSI broadcasts generally are scheduled and the watch for MSI information can be automated."

With regard to whether send/receive email capabilities are required for US vessels while at sea, the Coast Guard stated: "The FCC's maritime radio rules do not specifically refer to email. They do require send/receive communications capability for compulsory vessels."

5.9.1. Inmarsat-C SafetyNET

Inmarsat-C SafetyNET [60, 61] is an internationally adopted, automated satellite system that promulgates weather forecasts and warnings, marine navigational warnings, and other safety-related information to all types of vessels. It is part of GMDSS, and no user fees are required to receive its broadcasts. SafetyNET is used by, but not limited to, NAVAREA[62] coordinators for NAVAREA warnings and other urgent safety-related information, national coordinators for coastal warnings and other urgent safety-related information, METAREA[63] issuing services for meteorological warnings and forecasts, and Maritime Rescue Coordination Centers for shore-to-ship distress alerts, search-and-rescue information, and other urgent safety-related information. Figure 44 maps METAREAs and the countries responsible for providing weather products for each. *El Faro* was equipped to receive weather information via Inmarsat-C SafetyNET.

[60] SafetyNET is a service for broadcasting and automatic reception of Maritime Safety Information via the Enhanced Group Call (EGC) system. Its receiving ability is part of the mandatory equipment for certain SOLAS-compliant ships. SOLAS = International Convention for the Safety of Life at Sea, an international maritime treaty.

[61] Inmarsat-C SafetyNET is one of several names used for this service, commonly called Sat-C.

[62] NAVAREAs are the geographic areas where various governments are responsible for navigation hazards. The regions are identical to METAREAs.

[63] METAREAs are geographical sea regions established to coordinate transmission of meteorological information to mariners on international voyages through international and territorial waters.

Figure 44 *– METAREAs and countries responsible for providing weather products for each.*

SafetyNET messages can be directed to all ships in an entire ocean satellite region, to fixed NAVAREAs/METAREAs, to recipient-defined circular or rectangular addressed areas, and to coastal areas with "safety," "urgency," or "distress" priority. Reception of messages with urgency and distress priority will set off audible and visible alarms on an onboard terminal. These messages will automatically print out on SOLAS-compliant terminals. All ships navigating inside a particular addressed area will receive information automatically. Weather information applicable to *El Faro*'s location and receiver settings were broadcast via Inmarsat's Atlantic Ocean Region-West (AOR-W)[64] space-based platform.

NWS delivers weather information via Inmarsat-C SafetyNET (as of March 2016) under contract with Satcom Direct Government, Inc. (formerly known as Airbus DS Satcom Government, Inc.), using Inmarsat geostationary satellites. NWS makes particular weather bulletins available to Satcom Direct Government, Inc., which then sends the information to Inmarsat via the Satcom Direct Government, Inc., land earth station (LES) in Eik, Norway, for satellite broadcast.

The NWS products broadcast over Inmarsat-C SafetyNET via AOR-W, and which apply geographically to *El Faro's* accident voyage (METAREA IV), are the OPC-issued High Seas

[64] AOR-W is in geosynchronous orbit above longitude 54°W.

Forecast (WMO header FZNT01 KWBC, AWIPS header HSFAT1), the NHC Tropical Cyclone Forecast/Advisory for Atlantic basin tropical cyclones (WMO header WTNT2[1-5] KNHC, AWIPS header TCMAT[1-5]), and several tsunami bulletins.[65] According to the NWS, no tsunami bulletins were issued for the Atlantic before or during the accident. A full list of NWS products broadcast on Inmarsat-C SafetyNET over the entire globe is available from the NWS.

Nominal NWS issuance times for the OPC-issued High Seas Forecast are 0030 EDT, 0630 EDT, 1230 EDT, and 1830 EDT. According to the NWS, if an OPC-issued High Seas Forecast is disseminated 16 to 60 minutes before its nominal issuance time, it is not made available to Satcom Direct Government, Inc., until 15 minutes before its nominal issuance time.[66] If an OPC-issued High Seas Forecast is disseminated from 15 minutes before to 5 hours after its nominal issuance time, it is made available immediately. NHC Tropical Cyclone Forecast/Advisory products are made available whenever issued.

Transmission times for NWS products from the Eik, Norway, LES to Inmarsat for broadcast by AOR-W between 2000 EDT on September 27, 2015, and 1000 EDT on October 1, 2015, were provided by Airbus DS Satcom Government, Inc. (see Attachment 16). Although individual products are not identified in this listing, it can be inferred from the transmission durations that some NWS products are broadcast a second time, 6 minutes after the initial broadcast.[67] According to the International Maritime Organization (IMO) SafetyNET Manual (Attachment 17), information providers (e.g., NWS/NOAA) may designate certain messages for repetition. If the first message is received at an onboard terminal error-free, receipt of the second message may be suppressed locally.

Inmarsat could not provide exact times, message titles, or contents for weather products disseminated by satellite. Inmarsat indicated, however, that its systems experienced no outages affecting the accident region during the period leading to the accident. Considering the actual issuance times of the applicable OPC-issued High Seas Forecasts and NHC Tropical Cyclone Forecast/Advisory products during these days, the NTSB infers[68] that Airbus DS Satcom Government, Inc., distributed the products to Inmarsat at the following times:

NWS Weather Product and Actual Product Dissemination Time from NWS	**Dissemination Time from Eik LES to Inmarsat**
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 1) 2237 EDT September 27, 2015	22:38:30 EDT September 27, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 1) 2237 EDT September 27, 2015 *	22:44:31 EDT September 27, 2015
OPC-issued High Seas Forecast 2358 EDT September 27, 2015	00:15:54 EDT September 28, 2015

[65] http://www.nws.noaa.gov/om/marine/inmarsat.htm.

[66] According to the NWS, maritime customers want to receive these products close to the scheduled times.

[67] The NTSB infers that this occurs for NWS products made available to Satcom Direct Government, Inc., with an urgency priority.

[68] NWS products were matched with known message dissemination times to Inmarsat based on best available information, but were not confirmed. The NWS could not confirm the exact times individual products were made available to Satcom Direct Government, Inc., because receipts had been scrubbed from the NWS database by the time the NTSB requested the information.

NHC Tropical Cyclone Forecast/Advisory (Advisory Number 2) 0450 EDT September 28, 2015	04:51:20 EDT September 28, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 2) 0450 EDT September 28, 2015 *	04:57:19 EDT September 28, 2015
OPC-issued High Seas Forecast 0620 EDT September 28, 2015	06:20:54 EDT September 28, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 3) 1050 EDT September 28, 2015	10:50:52 EDT September 28, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 3) 1050 EDT September 28, 2015 *	10:56:50 EDT September 28, 2015
OPC-issued High Seas Forecast 1155 EDT September 28, 2015	12:16:24 EDT September 28, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 4) 1643 EDT September 28, 2015	16:44:13 EDT September 28, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 4) 1643 EDT September 28, 2015 *	16:50:14 EDT September 28, 2015
OPC-issued High Seas Forecast 1817 EDT September 28, 2015	18:17:39 EDT September 28, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 5) 2236 EDT September 28, 2015	22:36:56 EDT September 28, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 5) 2236 EDT September 28, 2015 *	22:42:59 EDT September 28, 2015
OPC-issued High Seas Forecast 2348 EDT September 28, 2015	00:16:02 EDT September 29, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 6) 0432 EDT September 29, 2015	04:33:09 EDT September 29, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 6) 0432 EDT September 29, 2015 *	04:39:12 EDT September 29, 2015
OPC-issued High Seas Forecast 0553 EDT September 29, 2015	06:15:55 EDT September 29, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 7) 1035 EDT September 29, 2015	10:35:52 EDT September 29, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 7) 1035 EDT September 29, 2015 *	10:41:52 EDT September 29, 2015
OPC-issued High Seas Forecast 1205 EDT September 29, 2015	12:16:00 EDT September 29, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 8) 1651 EDT September 29, 2015	16:52:27 EDT September 29, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 8) 1651 EDT September 29, 2015 *	16:58:26 EDT September 29, 2015
OPC-issued High Seas Forecast 1803 EDT September 29, 2015	18:16:17 EDT September 29, 2015
OPC-issued High Seas Forecast 1803 EDT September 29, 2015 *	18:22:14 EDT September 29, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 9) 2253 EDT September 29, 2015	22:54:16 EDT September 29, 2015

NHC Tropical Cyclone Forecast/Advisory (Advisory Number 9) 2253 EDT September 29, 2015 *	23:00:16 EDT September 29, 2015
OPC-issued High Seas Forecast 0002 EDT September 30, 2015	00:16:20 EDT September 30, 2015
OPC-issued High Seas Forecast 0002 EDT September 30, 2015 *	00:22:19 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 10) 0437 EDT September 30, 2015	04:38:25 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 10) 0437 EDT September 30, 2015 *	04:44:19 EDT September 30, 2015
OPC-issued High Seas Forecast 0547 EDT September 30, 2015	06:18:25 EDT September 30, 2015
OPC-issued High Seas Forecast 0547 EDT September 30, 2015 *	06:21:57 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 10)^ 0634 EDT September 30, 2015	06:34:52 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 10)^ 0634 EDT September 30, 2015 *	06:40:52 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 11) 1053 EDT September 30, 2015	10:53:30 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 11) 1053 EDT September 30, 2015 *	10:59:31 EDT September 30, 2015
OPC-issued High Seas Forecast 1211 EDT September 30, 2015	12:16:18 EDT September 30, 2015
OPC-issued High Seas Forecast 1211 EDT September 30, 2015 *	12:22:16 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 12) 1649 EDT September 30, 2015	16:50:19 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 12) 1649 EDT September 30, 2015 *	16:56:20 EDT September 30, 2015
OPC-issued High Seas Forecast 1808 EDT September 30, 2015	18:16:13 EDT September 30, 2015
OPC-issued High Seas Forecast 1808 EDT September 30, 2015 *	18:22:18 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 13) 2249 EDT September 30, 2015	22:49:53 EDT September 30, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 13) 2249 EDT September 30, 2015 *	22:55:53 EDT September 30, 2015
OPC-issued High Seas Forecast 0017 EDT October 1, 2015	00:18:36 EDT October 1, 2015
OPC-issued High Seas Forecast 0017 EDT October 1, 2015 *	00:24:35 EDT October 1, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 14) 0443 EDT October 1, 2015	04:43:35 EDT October 1, 2015
NHC Tropical Cyclone Forecast/Advisory (Advisory Number 14) 0443 EDT October 1, 2015 *	04:49:39 EDT October 1, 2015

OPC-issued High Seas Forecast 0600 EDT October 1, 2015	06:16:01 EDT October 1, 2015
OPC-issued High Seas Forecast 0600 EDT October 1, 2015 *	06:21:59 EDT October 1, 2015

* Repeated message.
^ Corrected version.

According to the IMO Maritime Safety Committee's revised group standards for EGC equipment (see Attachment 18), receiving an urgency or distress priority message should prompt audible and visible alarms at onboard terminals. The alarms should not be susceptible to being disabled, although they can be manually reset at the terminal. Messages are printed automatically, with exceptions. The IMO SafetyNET Manual describes how messages should be formatted by their generator (e.g., NWS/NOAA) to establish message priority (safety, urgency, distress).[69] A header containing "C-codes" is used to establish message priority.

OPC-issued High Seas Forecasts contain a line of C-code.[70] In the following examples, the green-highlighted 1 indicates a safety message and the highlighted 2 indicates an urgency message.

```
CCODE/1:31:04:01:00/AOW/NWS/CCODE
CCODE/2:31:04:11:00/AOW+AOE/NWS/CCODE
```

All High Seas Forecasts applicable to the accident region that the OPC issued from 1803 EDT on September 29, 2015, through the accident time carried an urgency priority (see Attachment 3).

NHC Tropical Cyclone Forecast/Advisory products do not contain a C-code. According to the former NWS Marine Dissemination Manager's best recollection, NHC Tropical Cyclone Forecast/Advisory products are always "hard-coded" with an urgency priority at some point in the product relay process.[71] Receiving an NHC Tropical Cyclone Forecast/Advisory should thus prompt audible and visible alarms at an onboard terminal.

To confirm the content of NHC Tropical Cyclone Forecast/Advisory and OPC-issued High Seas Forecast products available to users of Inmarsat-C SafetyNET, the NTSB requested TOTE provide copies of the NHC Tropical Cyclone Forecast/Advisory and OPC-issued High Seas Forecast products received onboard one of their vessels operating in the Atlantic during the life cycle of Hurricane Nicole (October 2016). Attachment 19 contains images of Inmarsat-C SafetyNET printouts from October 16, 2016, as provided by TOTE, as well as the same text products as released by the NWS.

[69] Also see National Weather Service Instruction (NWSI) 10-311: http://www.nws.noaa.gov/directives/sym/pd01003011curr.pdf

[70] NHC-issued High Seas Forecasts do not contain a C-code.

[71] The NTSB could not confirm this urgency priority coding with current NWS employees, though it is consistent with the Tropical Cyclone Forecast/Advisory products being broadcast twice (as assumed for urgent priority OPC-issued High Seas Forecasts).

5.9.2. Globe Weather

Sea Star Line, LLC, had a contract with Inmarsat for Fleet Broadband services for *El Faro*, giving the vessel access to 3-day weather forecast synopsis files from GlobeWeather.[72] According to Inmarsat, GlobeWeather[73] provides "key weather data including: surface pressure, wind speed & direction, fronts, sea surface temperature, currents, wave height, swell conditions, tropical storms and other weather information." When a user requests a weather synopsis, a GlobeWeather file is emailed. According to Inmarsat, *El Faro* did not request the GlobeWeather data available to it between September 28, 2015, and October 1, 2015. According to TOTE, these data were not requested because they were on "automatic download."

Inmarsat sent the NTSB samples of tropical, pressure, and wind data from GlobeWeather applicable to a time not associated with the accident and to regions not necessarily applicable to the accident location (figures 45, 46, 47, and 48). Valid or forecast times for the samples are unknown. According to Inmarsat, customers who receive the 3-day GlobeWeather package can access tropical, pressure, and wind data, but other features are available only through premium services such as 5-day and 10-day package subscriptions.

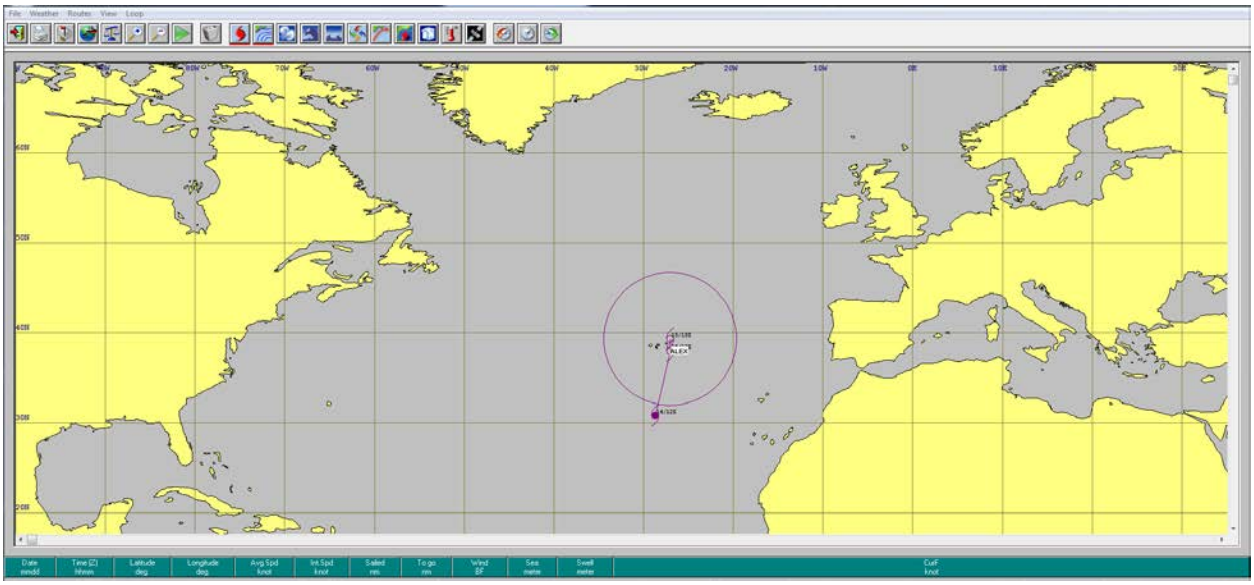

***Figure 45** – Sample of GlobeWeather "tropical" data accessible in 3-day package available from Inmarsat (for a time not associated with accident).*

[72] Included in the subscription was free access to 32 downloads of GlobeWeather per month, with charges applicable to additional downloads.

[73] http://www.globewireless.com/_solutions/appscontent.php#globeweather

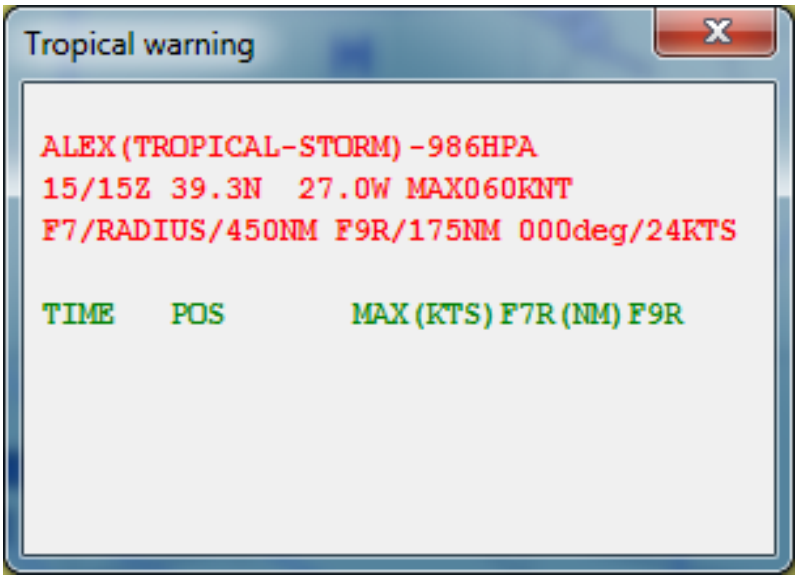

Figure 46 *– Dialogue box that results from clicking on storm name in figure 45.*

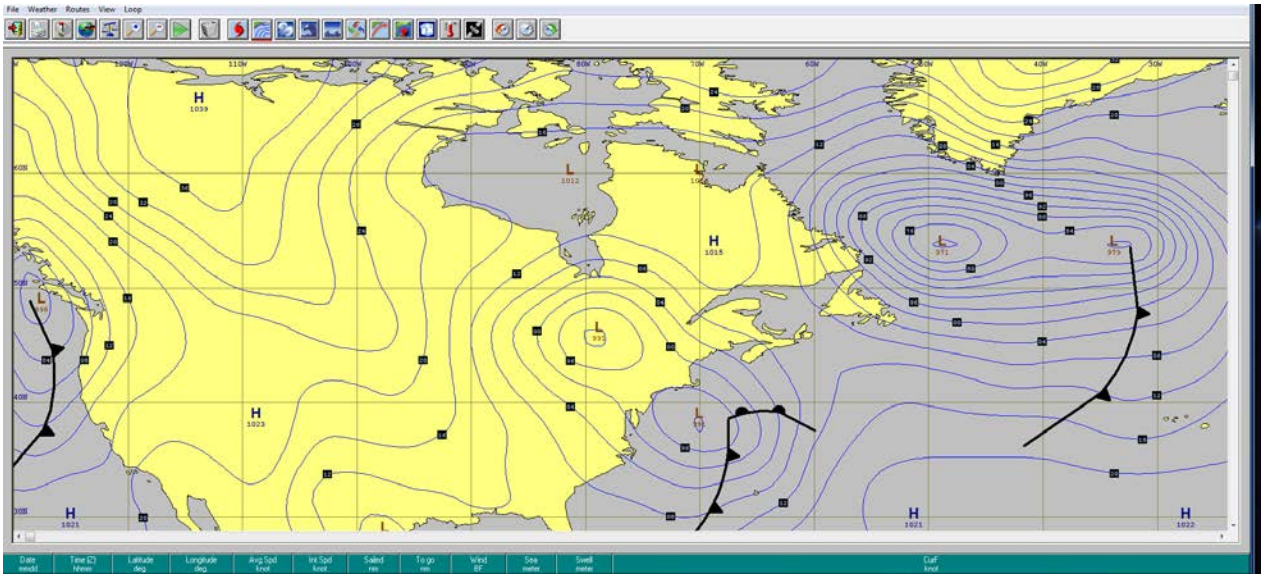

Figure 47 *– Sample of GlobeWeather "pressure" data accessible in 3-day package available from Inmarsat (for a time not associated with accident).*

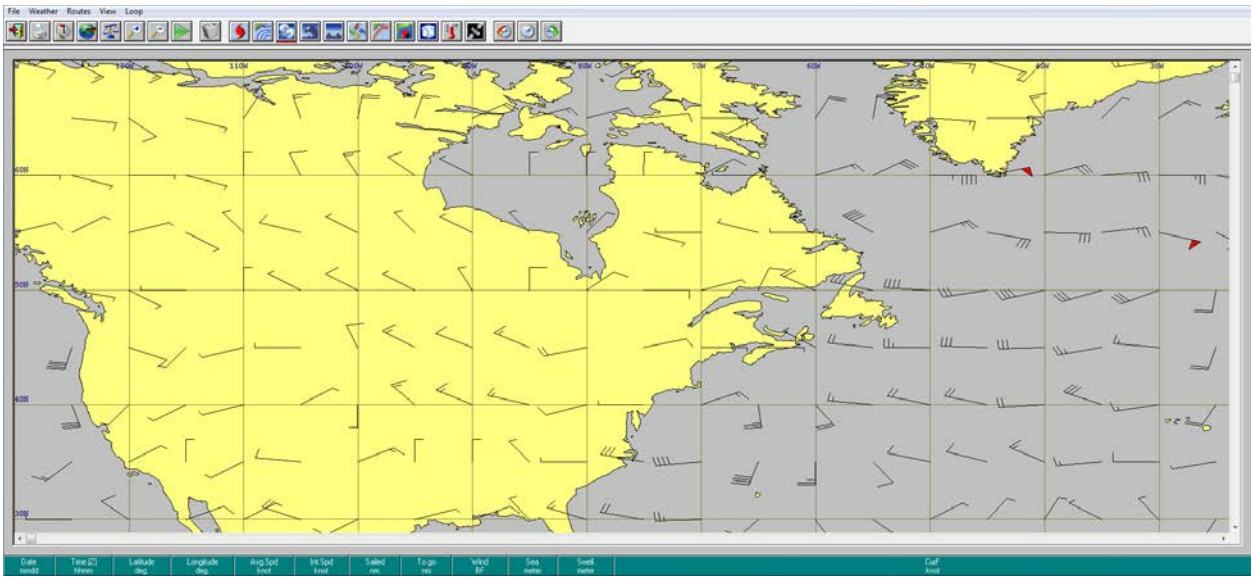

Figure 48 *– Sample of GlobeWeather "wind" data accessible in 3-day package available from Inmarsat (for a time not associated with accident).*

5.9.3. Bon Voyage System

The Bon Voyage System (BVS) from Applied Weather Technology, Inc. (AWT), was available to *El Faro* during the accident voyage. BVS is a desktop application that can be installed on ship or shore computers. According to AWT's brochure for BVS version 7 (see Attachment 20), BVS "is a graphical marine voyage optimization system that provides on-board and around-the-clock weather-routing information…Using [an] on-board computer, BVS 7 provides the most recent weather and ocean data to the ship by broadband or email communications in a highly compressed format…This data is then used to generate color-enhanced maps and graphics that allow the ship's captain to easily view and interpret potential problem areas in advance."

This section describes BVS version 7. The capabilities of earlier BVS versions are unknown.

According to AWT, a company can subscribe to BVS for any or all of its ships, and the subscription is not tied to a specific individual (e.g., a ship's captain). AWT's only record establishing BVS (the service current at the time of the accident) for *El Faro* is an email from Sea Star Line, LLC, to AWT on December 3, 2013 (see Attachment 21).

BVS is believed to have been installed on at least two computers onboard *El Faro*. Emails (see Attachment 22) sent to AWT requesting updates of hardware keys for instances of BVS on *El Faro* originated from two email accounts [redacted]*@nltote.rydex.com* and [redacted]*@globeemail.com*. AWT assumes from those emails that BVS was installed on computers in the *El Faro* captain's office and on the vessel's bridge (though AWT does not know for certain how many instances of BVS were installed on *El Faro* or where the applicable computers were located). In separate correspondence, TOTE confirmed that the captain's computer and the bridge computer had the BVS program installed. The emails in Attachment 22 suggest that BVS version 7.0.0.78 was installed on the captain's computer as of March 14,

2014, and on a bridge computer as of June 12, 2015. AWT did not find any update emails from *El Faro* regarding hardware keys for earlier BVS versions.

The BVS brochure outlines two methods of receiving weather files from AWT to be opened in BVS. Users can request BVS weather files via email (*El Faro*'s delivery method) as scheduled (automatically recurring) deliveries, or as a "one-time email delivery." The AWT system does not have default settings for data delivery when a customer establishes service. Instructions for establishing email receipt of BVS weather files are given in the BVS version 7 User Manual (Attachment 23), section 3.3.1:

> *To receive updated weather data, you will need to:*
>
> *1. Set up request. Either perform a 'one time email delivery request' or set up a scheduled request. The procedure for one-time requests is given in Section 25.1. Instructions for scheduled request setup are given in Section 0.*
>
> *2. Select the forecast region and user-defined weather parameters, etc.*
>
> *3. Update BVS with the incoming email file. The data update arrives as an ".RKW" file in an email message from bvs@awtworldwide.com. The RKW file can either be opened directly from the email message or it can be stored in the \weather\import folder for automatic processing. BVS will thereafter display the data corresponding to this RKW file and the forecast base time associated with this file will be displayed in the upper right menu bar area of the BVS window.*

AWT indicated that once a BVS weather file is emailed to a user, AWT cannot determine whether or how the file is used.

Users can also receive BVS weather files by broadband. The BVS version 7 User Manual, section 1.1, states: "When connected to a Broadband service, BVS has immediate access to AWT's frequently updated data and handles larger data files than email generally supports. Using Broadband, BVS systems automatically download data and thereafter provide it for instant display on the chart. With BVS and Broadband, there is no manual intervention required in normal operation. Once data are received, BVS automatically updates its files and makes the data available. When appropriate, weather data is automatically interpolated between the model data intervals." According to the BVS version 7 User Manual, section 3.3.1, "Upon startup, if Broadband is enabled, BVS will immediately begin checking for new weather and chart data automatically." Broadband-delivered weather files contain some higher spatial-resolution graphical data compared with emailed BVS weather files (see BVS version 7 User Manual, section 26.3). Cyclone depictions and marine bulletin text weather products are the same.

According to the BVS version 7 User Manual, section 1.3.1, BVS weather files provide displayable meteorological and oceanographic data including tropical storms, hurricanes, and other severe weather, marine bulletin text products, weather satellite images, and forecasts of wind, currents, significant wave heights, swells, and rogue waves. AWT's Vice President for Route Advisory Services stated: "The NOAA GFS model is the basis of the weather forecast and AWT provides information on tropical cyclone activity based on the National Hurricane

Center." Other AWT employees indicated in correspondence that the NCEP *Wavewatch III* model output is used for significant wave height. The computer models that produce some of the forecast data for the BVS weather files are started every 6 hours (four times a day) and require hours to complete. BVS weather files containing output from a model run are emailed to users about 9 hours after the model initialization time. All weather forecast products are available via the BVS weather files (as configured by users). Nominal times for AWT's earliest email dissemination of the BVS weather files are as follows:

- 0000 UTC (2000 EDT) forecast model run is available to users at 0900 UTC (0500 EDT)
- 0600 UTC (0200 EDT) forecast model run is available to users at 1500 UTC (1100 EDT)
- 1200 UTC (0800 EDT) forecast model run is available to users at 2100 UTC (1700 EDT)
- 1800 UTC (1400 EDT) forecast model run is available to users at 0300 UTC (2300 EDT)

In the days leading to the accident, AWT emailed BVS weather files to *El Faro* 2 minutes after the nominal earliest availability times listed above. Discussion on when the emailed BVS weather files might have been received or available onboard *El Faro* may be found in the NTSB Electronic Data Factual Report for the accident.

On May 26, 2016, AWT sent information to the Coast Guard to clarify its testimony on May 18, 2016, during the Coast Guard's second Marine Board of Inquiry hearing. The information is found in Attachment 24.[74] According to this document and follow-up discussion with AWT, AWT retrieves certain parameters, such as msl pressure and 10-meter wind, from the GFS model. These data are generally available to AWT 5 hours after the model initialization time (e.g., a 0200 EDT model run is available by 0700 EDT). After acquiring the GFS parameters, AWT will take the central storm pressure and storm wind fields from the (then) most recent (e.g., 0500 EDT) Tropical Cyclone Forecast/Advisory product (with WMO header WTNT21 KNHC) from the NHC and use those data to modify the GFS pressure and wind fields for presentation to the user. [75] The modified fields are then used as input to the AWT run of the *Wavewatch III* model to produce sea conditions. According to AWT, *Wavewatch III* version 2.22 was used to generate wave conditions for the data sent to *El Faro*. Thus, the emailed BVS wind and wave fields received by the user would be based on a GFS model run initialized 9 hours before the earliest possible receipt of the data, and on an NHC Tropical Cyclone Forecast/Advisory (nominally) issued 6 hours before the earliest possible receipt of the data. See Attachment 24 for graphical illustration and further description of these processes.

AWT includes recent NHC tropical cyclone information for graphic display in the BVS weather files it emails, as well as marine weather bulletins and other forecast weather data (as previously discussed). According to AWT, graphical depiction of Joaquin in the BVS weather files used only NHC tropical cyclone information carried in the NHC's Tropical Cyclone Forecast/Advisory. According to the advisories collected in Attachment 3, the nominal and

[74] As stated, once a BVS weather file is emailed to a user, AWT cannot determine whether or how the file is used. The NTSB believes that references to BVS weather file "delivery" and "download" times in Attachment 24 are intended to identify the nominal times for AWT to email the BVS weather files to *El Faro*.

[75] During times of no applicable storm activity, no Tropical Cyclone Forecast/Advisory products would be available, in which case no modification of the GFS fields would take place.

actual public dissemination times of the NHC's Tropical Cyclone Forecast/Advisory products for Joaquin through the accident time were as follows:

Advisory Number	Nominal Issuance Time for NHC's Tropical Cyclone Forecast/Advisory	Public Issuance Time for NHC's Tropical Cyclone Forecast/Advisory
4	1700 EDT - September 28, 2015	1643 EDT - September 28, 2015
5	2300 EDT - September 28, 2015	2236 EDT - September 28, 2015
6	0500 EDT - September 29, 2015	0432 EDT - September 29, 2015
7	1100 EDT - September 29, 2015	1035 EDT - September 29, 2015
8	1700 EDT - September 29, 2015	1651 EDT - September 29, 2015
9	2300 EDT - September 29, 2015	2253 EDT - September 29, 2015
10	0500 EDT - September 30, 2015	0437 EDT - September 30, 2015
10 *	0500 EDT - September 30, 2015	0634 EDT - September 30, 2015
11	1100 EDT - September 30, 2015	1053 EDT - September 30, 2015
12	1700 EDT - September 30, 2015	1649 EDT - September 30, 2015
13	2300 EDT - September 30, 2015	2249 EDT - September 30, 2015
14	0500 EDT - October 1, 2015	0443 EDT - October 1, 2015

* Corrected version.

According to AWT, weather data available until 20 or 25 minutes before the nominal email time of a BVS weather file to a user are included in that file. For example, a BVS weather file scheduled for email at 0500 EDT will include NHC tropical cyclone information and marine bulletins available until 0435 to 0440 EDT. NHC information that becomes available after that time will not be included in the 0500 EDT email. Rather, the emailed BVS file will contain the next-most-current bulletin (i.e., bulletins issued before 0435 to 0440 EDT).

To provide the most current NHC tropical cyclone information to recipients of emailed BVS weather files sent at nominal times of 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT (referred to here as the *main* BVS weather files), AWT offers separate tropical updates that are automatically emailed to users after a new Tropical Cyclone Forecast/Advisory is published by the NHC. Opening this emailed tropical update BVS weather file will update BVS's graphical depiction of tropical cyclone position and forecast information, and also the text position and forecast data via the interactive "View Tropical Report" option (see BVS version 7 User Manual, section 23.2.3). The emailed tropical update BVS weather files do *not*, however, update the entire suite of marine bulletin text products available through the emailed main BVS weather files—which include the same Tropical Cyclone Forecast/Advisory product and are readily accessed with a separate clickable option in BVS (see BVS version 7 User Manual, section

23.2.6). The emailed tropical update BVS weather files also do *not* update the wind, wave, pressure, and other graphical weather parameter depictions (aside from the storm-specific wind radii) available through the most recent main BVS weather file.

To receive the emailed tropical update BVS weather files, a user must specifically request them. Figure 49 shows the BVS dialogue box that allows a user to schedule or update the email times of main BVS weather files and request emails of the tropical update BVS weather files. Instructions in the BVS version 7 User Manual, section 32.3.1 ("Delivery Schedule"), for the "Special Updates/Tropicals" part of the dialogue box state: "This option allows you to receive by email the most recent tropical storm forecasts. The files sent to you would be quite small, about two to three Kilobytes [KBs] in size, but would ensure that you have the most recent information regarding storm intensity and movement."

According to AWT, *El Faro* did not request, and therefore did not receive, the separately emailed tropical update BVS weather files. Had *El Faro* requested those files, AWT would have sent emails containing them exactly 30 minutes after it emailed the main BVS weather files in the days preceding the accident and on the accident day.

Another option for receiving the most current NHC tropical cyclone information via email is for users to delay emailing (from the earliest available time) of the main BVS weather files. For example, though a main BVS weather file may be available for emailing at the earliest (nominal) time of 0500 EDT, requesting emailing of the file at 0600 EDT would allow it to include more current NHC tropical cyclone information if issued by the NHC. The BVS version 7 User Manual, section 22.1 ("How do I change weather parameters?") states: "To receive the most current data, request a delivery time shortly after one of the four availability times above" (see figure 49).

A further option for receiving the most current NHC tropical cyclone information via email is to make a "one-time email delivery request" after the main BVS weather file is emailed (allowing enough time for the new NHC data to be incorporated into AWT's system). Instructions for making such a request are found in the BVS version 7 User Manual, section 25.1: "A one-time email delivery request is a single email message which results in an immediate & one-time email delivery from the BVS Data Server with up-to-date weather information." AWT says that the size of the file emailed via this method would be in the "100's of KB."

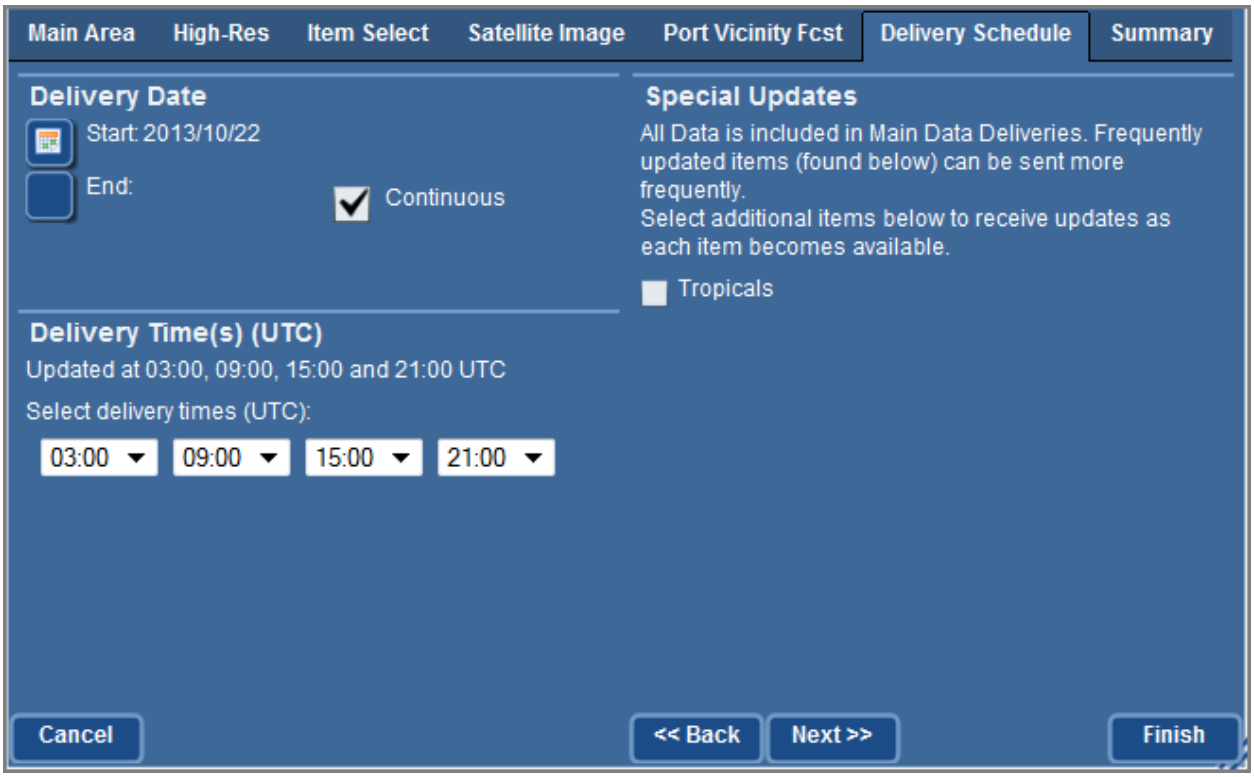

Figure 49 *– BVS dialogue box that allows users to schedule/update emailing times of main BVS weather files and request emailing of Tropical Update files.*

Despite the manual's instructions, described above, regarding the actions that nonbroadband users must take to stay current with tropical cyclone information via BVS, section 22.1 of the BVS version 7 User Manual ("When are Weather Data forecasts available?") states: "The most up-to-date tropical data will be sent together with your main forecast delivery. If additional tropical emails are requested, they will be sent to you immediately after becoming available on our BVS Server." Section 32.3.1 of the manual indicates that the "Delivery Schedule" tab (refer to figure 49) of the "Weather Data Delivery Configuration" dialogue can be configured to email the most up-to-date information by selecting the times shown on the tab: "Recommended times, when data is most up-to-date is shown above the drop-down delivery hour fields (03z, 09z, 15z & 21z)." The times are shown on the tab (figure 49) as UTC, which is equivalent to Z (Zulu) time.

In addition, according to the manual, tropical data are available as follows:[76]

00:00Z forecast at 04:00Z
06:00Z forecast at 10:00Z
12:00Z forecast at 16:00Z
18:00Z forecast at 22:00Z

Note that a BVS broadband connection allows automatic updating of NHC tropical cyclone information, with no user action required.

According to correspondence with AWT, main BVS weather files were emailed to only one address on *El Faro*: [redacted]*@globeemail.com*. According to AWT, when only one person receives emailed main BVS weather files, the recipient usually distributes the files internally (e.g., to other onboard users) via email. Witnesses at the Coast Guard's first Marine Board of Inquiry hearing testified that incoming emails containing BVS weather files were received and forwarded to the bridge by the captain.

To change BVS weather file email settings for *El Faro*, emails requesting modifications would have been accepted by AWT from four email addresses: [redacted]*@globeemail.com,* [redacted]*@nltote.rydex.com*, [redacted]*@seawave.net* and [redacted]*@globeemail.com*.[77] AWT stated that if a phone call came from the vessel requesting changes to its configuration, the BVS support team would make those changes for the vessel, then place a note in the trouble ticket system. When the NTSB asked whether someone from *El Faro*'s company, such as corporate management, could have adjusted *El Faro*'s email schedule for main or tropical update BVS weather files, AWT said that as long as it could verify that the call originated with the vessel or its management, AWT personnel could have modified the email schedule and would have followed up with an email to the requestor, copying the vessel.

A screenshot provided by AWT shows changes requested on the *El Faro* account (figure 50). The most recent configuration change was on November 4, 2014. The email (identified as Source E—request sent by email from valid user) requesting the change is found in Attachment 25. The last entry in AWT's log for the *El Faro* subscription shows that on June 12, 2015, AWT was requested to add new "hardware KEYS" to the database (this did not modify the weather data delivered or the data email schedule).

[76] The NTSB believes that the forecast times indicate the model initialization times for the models that support production of the NHC's Tropical Cyclone Forecast/Advisory nominally issued 3 hours later, and the availability times are nominal times that AWT identifies these data being available to recipients of emailed tropical update BVS weather files (and/or the earliest times that a user may schedule email delivery of the main BVS weather files, per figure 49). According to AWT (see Attachment 24), "Hurricane forecasts from the [NHC] take approximately 3 hours in processing time before they are made available to the public. From there AWT does some internal processing and disseminates the forecast one hour after receipt from the NHC." However, as indicated in this section, AWT would have emailed tropical update BVS weather files exactly 30 minutes after it emailed the main BVS weather files in the days preceding the accident and on the accident day, which was 28 minutes earlier than AWT's nominal dissemination time.

[77] In a previous email, AWT stated: "The following email was the only authorized address which could modify the forecast (by sending a Weather Data Delivery Configuration email msg): [redacted]@globeemail.com."

Schedules / Service Dates

Schedules: Past — Add New

Schedule			Fcst.	Region				Created
Source	Start	End	Days	ULat	LLat	LLon	RLon	On
E	2014/11/04	2015/10/05	10	60.00	-20.00	-120.00	15.00	2014/11/04
E	2014/08/22	2014/11/03	10	60.00	-20.00	-120.00	15.00	2014/08/22
E	2014/05/17	2014/08/21	10	50.00	-20.00	-120.00	10.00	2014/05/17
E	2014/05/13	2014/05/16	10	55.00	-10.00	-125.00	15.00	2014/05/14
E	2013/12/20	2014/05/12	10	50.00	-20.00	-100.00	15.00	2013/12/20

Figure 50 *– Recent BVS data schedule/service changes requested for* El Faro*.*

Figures 51 through 55 show the main BVS weather file data configuration and email settings for the five “Start” dates in figure 50. They identify the weather parameters requested for the main BVS weather files emailed to the ship, the geographic region of interest, and the requested email times. The “Pressure” and “Tropical” options are grayed out because, according to AWT, their delivery is forced, no matter what else a user requests. The “Tropical Update” option shows a setting “With Weather,” meaning that tropical cyclone information will be automatically sent only with the main BVS weather files. The alternative selection would be to also receive tropical cyclone information in separate emails (i.e., to request tropical update BVS weather files).

Edit Schedule And Weather

Weather: Save / Close

Wind	Wave	Pressure	Height 500mb	Tropical	SST	Swell	Ice
Bulletin	Gulfstream	Kuroshio	Ports	Front	Image	Movement	Visibility
Highs/Lows	Wx.Type	Vsl.Icing	Ice Density	Temperature	Clouds	HYCOM	4 days
Piracy	30 days	Humidity	Rogue Waves	Seas	Port Fcst		

Edit Nested Grid

Options: Interval: 6 Hours — Forecast: 10 days — Tropical Update: With Weather

Region: U.Lat: 60.00 N N/S* — L.Lat: 20.00 S N/S* — L.Lon: 120.00 W E/W* — R.Lon: 15.00 E E/W*

Schedule: Start Date: 2014/11/04 — End Date: 2015/10/05

Time 1: None — Time 2: None — Time 3: None — Time 4: None

Figure 51 *–* El Faro*’s BVS weather file data configuration and email settings for November 4, 2014.*

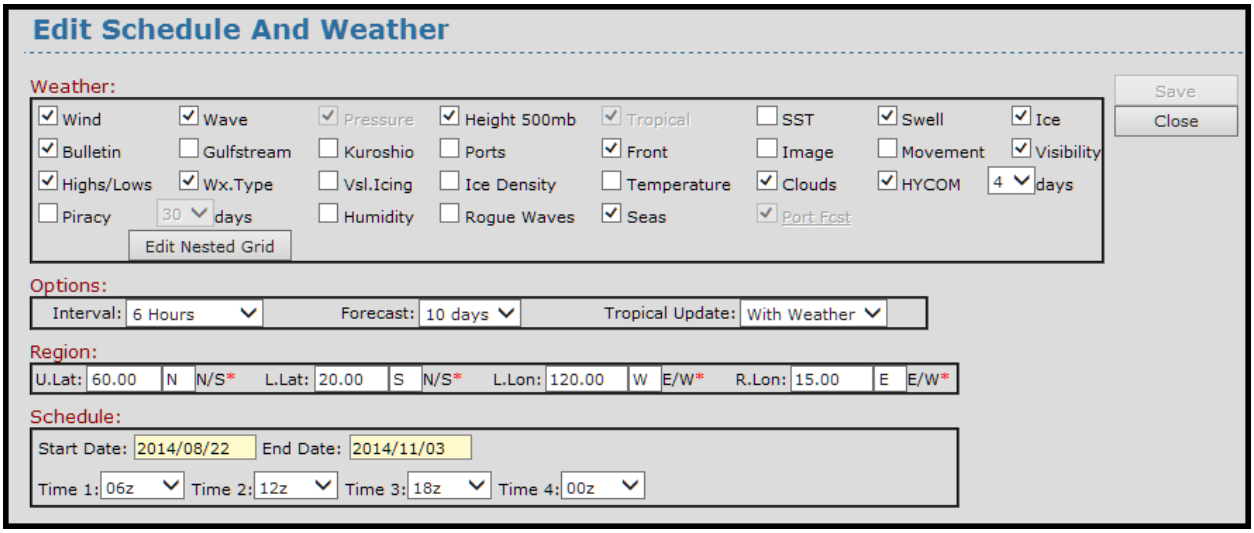

Figure 52 – El Faro*'s BVS weather file data configuration and email settings for August 22, 2014.*

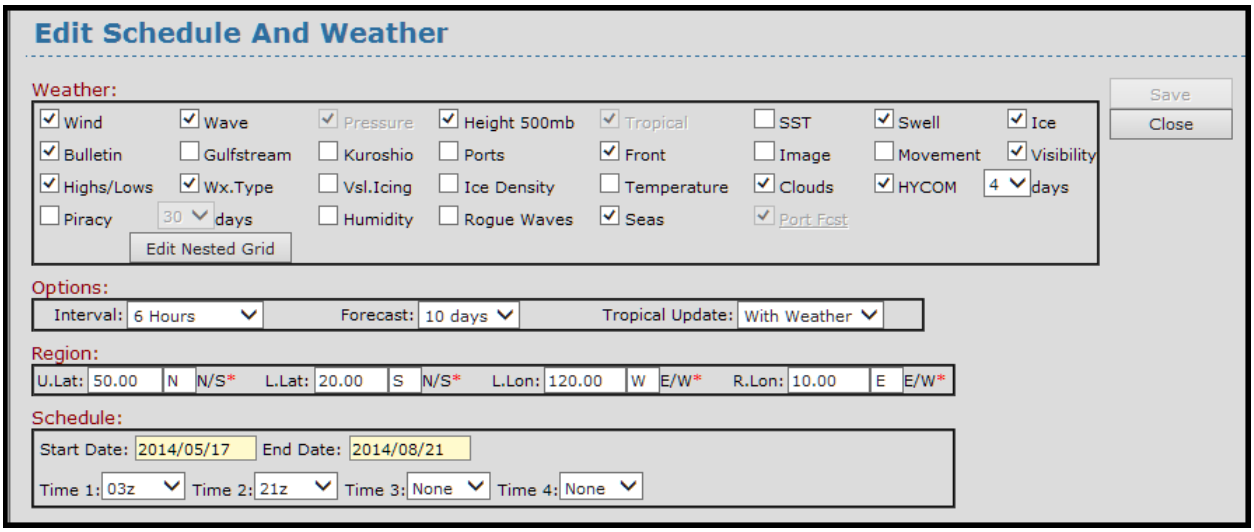

Figure 53 – El Faro*'s BVS weather file data configuration and email settings for May 17, 2014.*

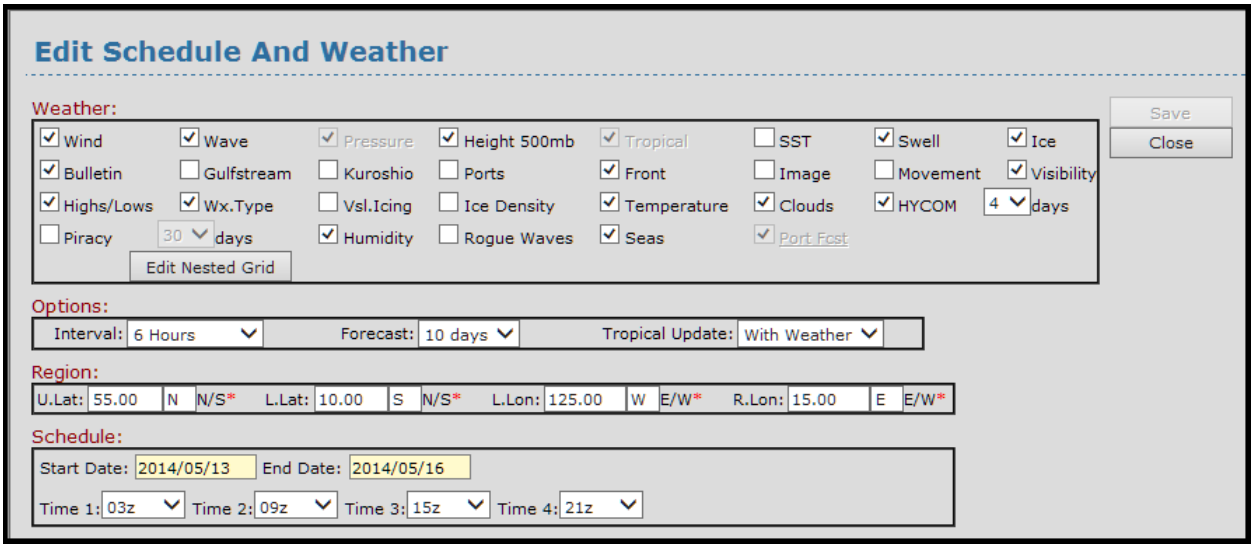

Figure 54 – El Faro*'s BVS weather file data configuration and email settings for May 13, 2014.*

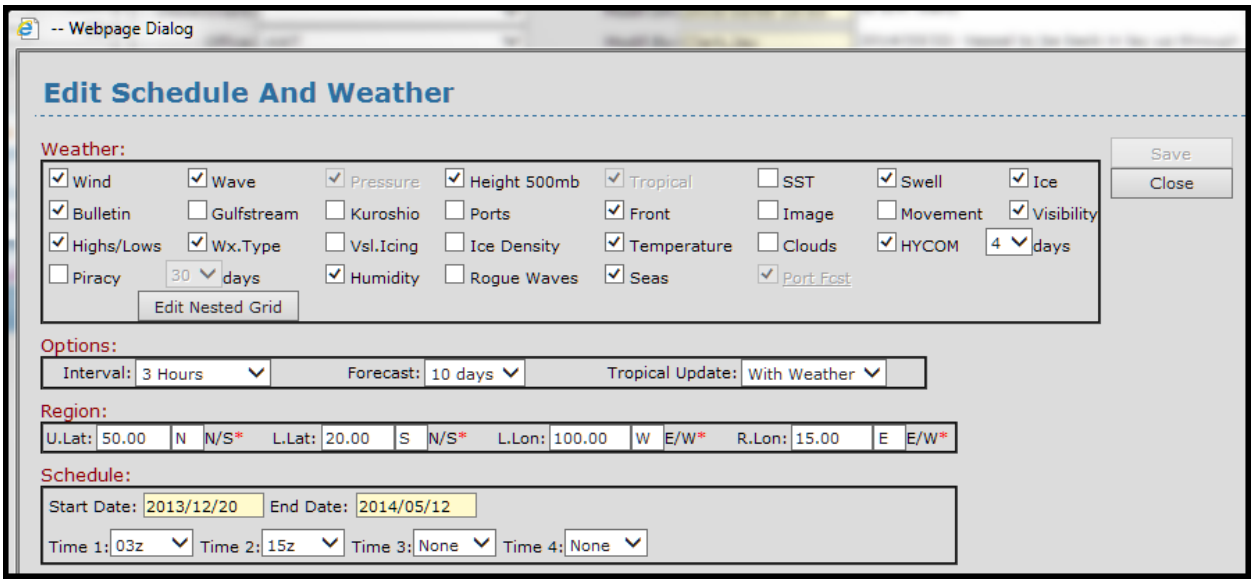

Figure 55 – El Faro*'s BVS weather file data configuration and email settings for December 20, 2013.*

The body of the email in which AWT delivered the October 1, 2015, 0500 EDT (nominal time) main BVS weather file as an attachment listed weather items to be delivered to the user in the requested geographic region (see Attachment 26). The email lists "Tropical" as a delivery item, but according to AWT, that does not imply the emailing of tropical update BVS weather files.

In the emailed main BVS weather files, AWT delivered six marine bulletin text products to *El Faro* that applied to the accident region: the NHC Tropical Cyclone Forecast/Advisory, the Tropical Cyclone Discussion, the Tropical Weather Discussion, the Offshore Waters Forecast, the Marine Weather Discussion, and the OPC-issued High Seas Forecast. As stated, text products are not updated with the emailed tropical update BVS weather files. The following table details the actual public dissemination time for each text product delivered in the emailed main BVS weather files:

Main BVS Weather File Nominal Email Time	**Actual Text Product Public Dissemination Time**
1700 EDT September 29, 2015	Tropical Cyclone Forecast/Advisory - 1035 EDT September 29, 2015 * Tropical Cyclone Discussion - 1250 EDT September 29, 2015 * Tropical Weather Discussion - 1403 EDT September 29, 2015 Offshore Waters Forecast - 1147 EDT September 29, 2015 Marine Weather Discussion - 0311 EDT September 29, 2015 OPC-issued High Seas Forecast - 1205 EDT September 29, 2015
2300 EDT September 29, 2015	Tropical Cyclone Forecast/Advisory - 1651 EDT September 29, 2015 ^ Tropical Cyclone Discussion - 1652 EDT September 29, 2015 ^ Tropical Weather Discussion - 1951 EDT September 29, 2015 Offshore Waters Forecast - 1718 EDT September 29, 2015 Marine Weather Discussion - 1447 EDT September 29, 2015 OPC-issued High Seas Forecast - 1803 EDT September 29, 2015
0500 EDT September 30, 2015	Tropical Cyclone Forecast/Advisory - 2253 EDT September 29, 2015 † Tropical Cyclone Discussion - 2254 EDT September 29, 2015 † Tropical Weather Discussion - 0203 EDT September 30, 2015 Offshore Waters Forecast - 2312 EDT September 29, 2015 Marine Weather Discussion - 1447 EDT September 29, 2015 OPC-issued High Seas Forecast - 0002 EDT September 30, 2015
1100 EDT September 30, 2015	Tropical Cyclone Forecast/Advisory - 0634 EDT September 30, 2015 @ Tropical Cyclone Discussion - 0449 EDT September 30, 2015 $ Tropical Weather Discussion - 0812 EDT September 30, 2015 Offshore Waters Forecast - 0514 EDT September 30, 2015 Marine Weather Discussion - 0317 EDT September 30, 2015 OPC-issued High Seas Forecast - 0547 EDT September 30, 2015
1700 EDT September 30, 2015	Tropical Cyclone Forecast/Advisory - 1053 EDT September 30, 2015 % Tropical Cyclone Discussion - 1058 EDT September 30, 2015 % Tropical Weather Discussion - 1327 EDT September 30, 2015 Offshore Waters Forecast - 1155 EDT September 30, 2015 Marine Weather Discussion - 1439 EDT September 30, 2015 OPC-issued High Seas Forecast - 1211 EDT September 30, 2015
2300 EDT September 30, 2015	Tropical Cyclone Forecast/Advisory - 1649 EDT September 30, 2015 # Tropical Cyclone Discussion - 1655 EDT September 30, 2015 # Tropical Weather Discussion - 1953 EDT September 30, 2015 Offshore Waters Forecast - 1730 EDT September 30, 2015 Marine Weather Discussion - 1501 EDT September 30, 2015 OPC-issued High Seas Forecast - 1808 EDT September 30, 2015

0500 EDT October 1, 2015	Tropical Cyclone Forecast/Advisory - 2249 EDT September 30, 2015 [+] Tropical Cyclone Discussion - 2250 EDT September 30, 2015 [+] Tropical Weather Discussion - 0154 EDT October 1, 2015 Offshore Waters Forecast - 2314 EDT September 30, 2015 Marine Weather Discussion - 0225 EDT October 1, 2015 OPC-issued High Seas Forecast - 0017 EDT October 1, 2015

* Advisory/Discussion Number 7
[^] Advisory/Discussion Number 8
† Advisory/Discussion Number 9
[@] Advisory Number 10 (corrected)
[$] Discussion Number 10.
[%] Advisory/Discussion Number 11.
[#] Advisory/Discussion Number 12.
[+] Advisory/Discussion Number 13.

According to AWT, up to the time of the accident, Sea Star Line did not have an "office" BVS account (an account not tied to a particular vessel). Sea Star Line and TOTE[78] company personnel did not log into AWT's "Global View" and "FleetDSS" services, which allow access to data from AWT's www.weatherrouting.com. Sea Star Line did not directly log into www.weatherrouting.com, but AWT indicated that TOTE did (the specific information accessed is unavailable).

AWT said that Sea Star Line had signed up for North Atlantic tropical system alerts (see example in figure 56), and that they were sent daily to two email addresses: [redacted]*@seastarline.com* and [redacted]*@seastarline.com*. According to TOTE, these reports were not sent daily, but were sent only if AWT issued a formal alert.

[78] According to AWT, both TOTE and Sea Star Line had service and were billed as two different entities.

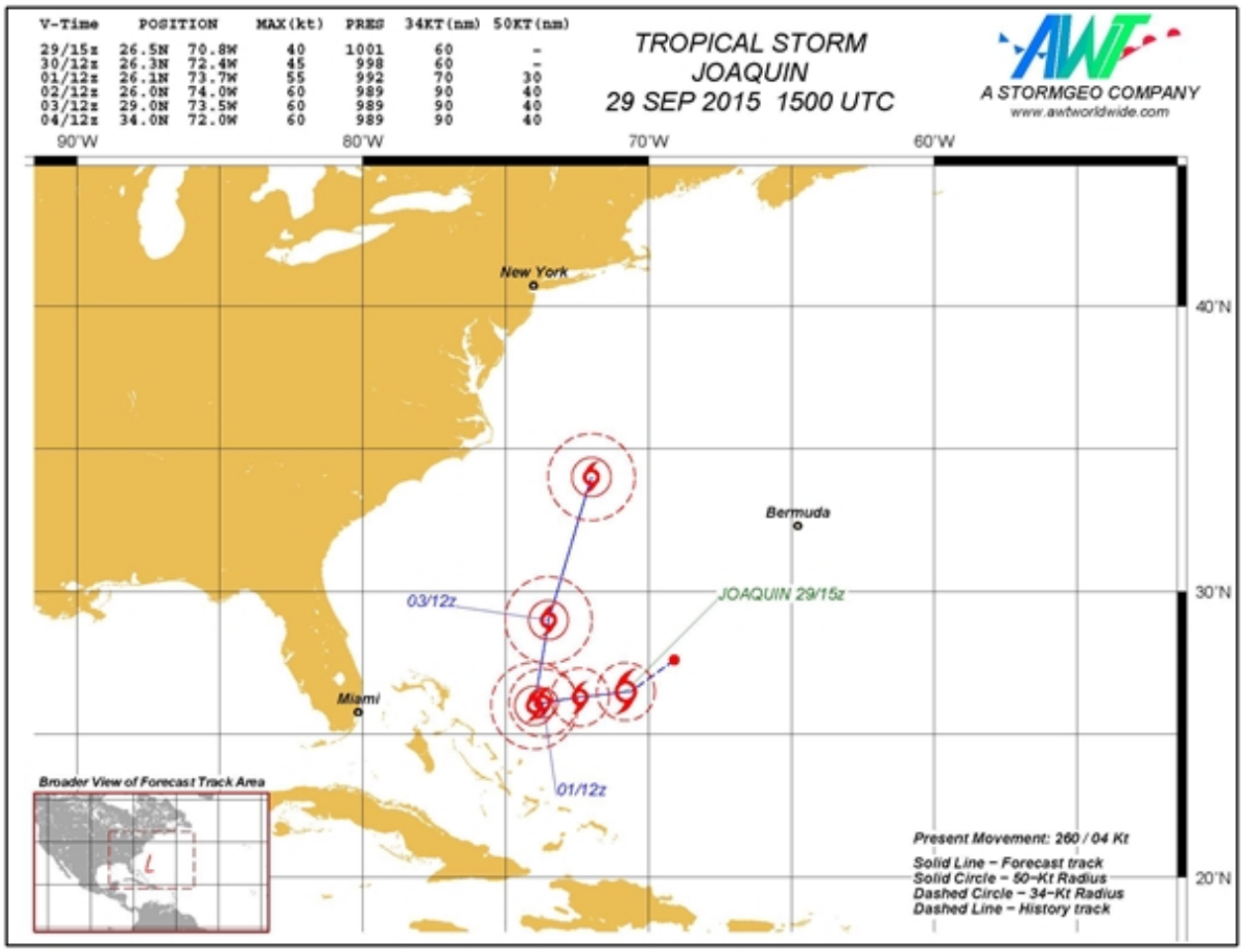

Figure 56 *– Example of daily North Atlantic tropical system alerts sent to Sea Star Line from AWT (alert is from September 29, 2015).*

Figures 57 through 68 illustrate NHC storm location and forecast position information for Joaquin that would have been available to *El Faro*, from the emailed main BVS weather files[79] and Inmarsat-C SafetyNET[80], at various times before and during the accident voyage. In these figures, the available NHC data for Joaquin are plotted and superimposed on GOES-13 satellite images of the storm. Also superimposed on the images is the most current position of the storm from the NHC's Intermediate Public Advisories (where applicable) and the positions of Joaquin taken from the post-storm NHC best track. Recall that plots and text coordinates for the NHC data were available on BVS, but that only text coordinates from the Tropical Cyclone Forecast/Advisory are carried on Inmarsat-C SafetyNET (and would therefore have to have been manually plotted for visualization). Also, the Intermediate Public Advisory (or any Tropical Cyclone Public Advisory) was not available through any onboard weather receipt options

[79] Figures 57 through 68 ignore the ~2 minute latency in emailing the main BVS weather files, considering a file emailed at 0502 EDT to have been emailed at the nominal email time of 0500 EDT.

[80] As discussed in section 5.9.1, the NTSB was unable to determine from INMARSAT at what times specific products were broadcast from AOR-W. Figures 57 through 68 assume that the Tropical Cyclone Forecast/Advisory products were broadcast by AOR-W at about the products' nominal issuance time by the NHC.

considered in this report except FTPmail (see section 5.9.8). The purpose of these diagrams is to illustrate the storm position and forecast information emailed to *El Faro* in the main BVS weather files, along with storm information available to *El Faro* through several other onboard weather receipt options, at fixed times during the accident voyage. [81]

As an example of this series of figures, figure 63 shows the storm locations and forecast tracks that would have been available to *El Faro* from the emailed main BVS weather files and Inmarsat-C SafetyNET about 1400 EDT on September 30, 2015, along with the ship's approximate location near that time. The blue cyclone symbol and line show the location and forecast track for Joaquin from the most recently emailed main BVS weather file (in this case, from about 1100 EDT). The red cyclone symbol and line represent the location and forecast track drawn from the coordinates in the Tropical Cyclone Forecast/Advisory text delivered by Inmarsat-C SafetyNET about that time. The purple cyclone symbol is the current NHC storm center position from the Intermediate Public Advisory from about 1400 EDT (a purple cyclone symbol does not appear in all figures in this series, since the Intermediate Public Advisory is only issued between the Tropical Cyclone Forecast/Advisory products). The NHC post-storm best track location for Joaquin at 1400 EDT is shown by the black cyclone symbol.[82] In each figure, panel B zooms in on part of panel A and shows the date and time for each forecast position.

With some exceptions, as noted below, each BVS storm location and forecast track for Joaquin was consistent with[83] the NHC storm location and forecast track issued publicly about 6 hours earlier. That is, the storm location and forecast track for Joaquin delivered in the emailed main BVS weather files were not identical to the storm location and forecast track available at about that time from either the NHC (see Attachment 3) or through Inmarsat-C SafetyNET. The storm location and forecast track in the tropical update BVS weather files emailed 30 minutes after the main BVS weather files were emailed (which *El Faro* did not elect to receive) were, however, consistent with the information provided by the NHC's Tropical Cyclone Forecast/Advisory (delivered to *El Faro* via Inmarsat-C SafetyNET and available through other onboard weather receipt options) that was current at that time.

One exception was that Joaquin's location and forecast track delivered in the main BVS weather file emailed at 0500 EDT on September 30, 2015 (figure 60), were identical to the storm position and forecast track delivered in the main BVS weather file emailed 6 hours earlier, at 2300 EDT on September 29, 2015 (figure 58). According to AWT, "Upon further investigation, we have found that our data update system for all AWT services/products (BVS 6, BVS 7, FleetDSS, Portal, AWT Internal wx display) did have updated 'tropical storm track file' for all products except BVS 7 in the specific timeframe…" Another exception was that this issue also affected the tropical update BVS weather file available for emailing about 2330 EDT on September 29, 2015, in which Joaquin's location and forecast track were identical to those in the main BVS weather file emailed 30 minutes earlier. Joaquin's location and forecast track provided in the

[81] Best track information was determined after the accident and was not available to *El Faro*.

[82] Note that for figures in this series that do not fall on an NHC best track analysis time, a linearly interpolated position is used.

[83] AWT provides interpolated forecast cyclone center position and intensity information between NHC-issued forecast times.

tropical update BVS weather file available for emailing at about 0530 EDT on September 30, 2015, were consistent with the NHC's current information.

Similarly, information on Joaquin's current and forecast intensity (i.e., maximum sustained wind, wind gust magnitude) in the emailed main BVS weather files (see "Tropical Report" screenshots in Attachment 27) reflected intensities issued from the NHC's Tropical Cyclone Forecast/Advisory products and delivered via Inmarsat-C SafetyNET about 6 hours earlier.[84] The emailed tropical update BVS weather files, had that option been selected, would have provided intensities consistent with the Tropical Cyclone Forecast/Advisory current at that time.

[84] Intensities in the main BVS weather file emailed about 0500 EDT on September 30, 2015, would have been consistent with the NHC's Tropical Cyclone Forecast/Advisory that was delivered via Inmarsat-C SafetyNET about 12 hours earlier (Advisory Number 8).

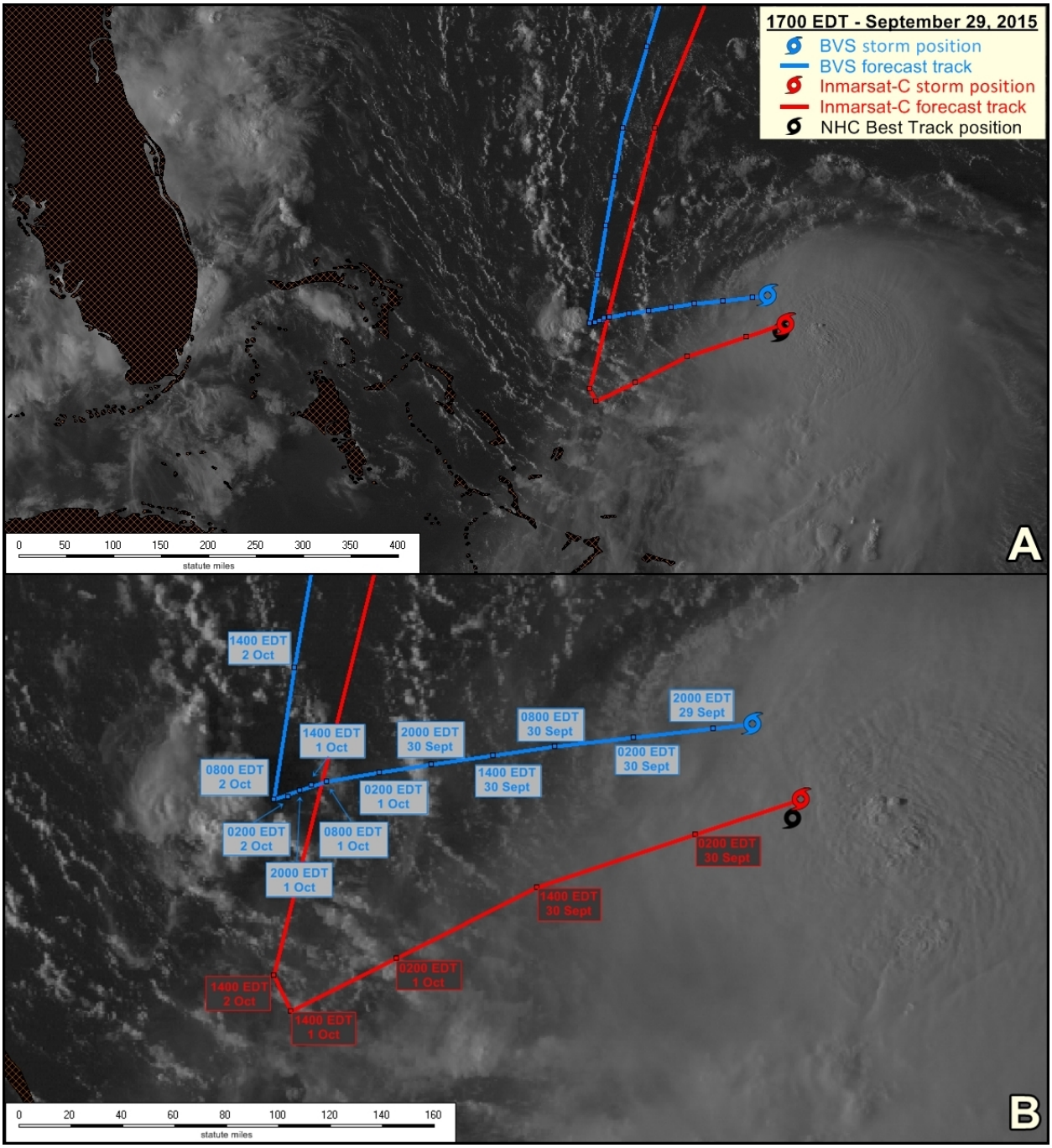

Figure 57 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 1700 EDT on September 29, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, and best track data. Depictions are overlaid on GOES-13 visible image from 1715 EDT on September 29, 2015. Image is not corrected for parallax error.*

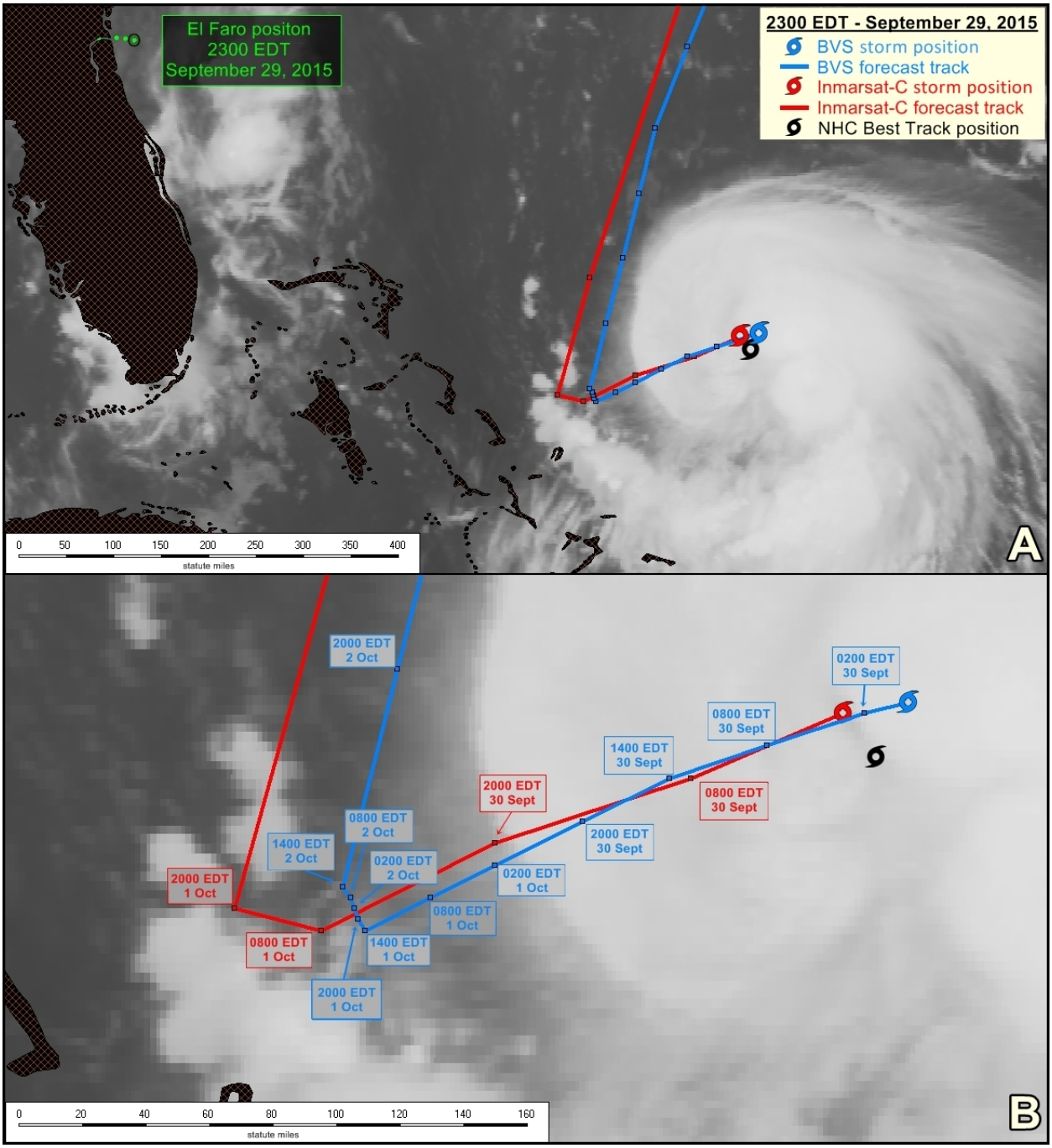

Figure 58 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 2300 EDT on September 29, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, and best track data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 infrared image from 2315 EDT on September 29, 2015. Image is not corrected for parallax error.*

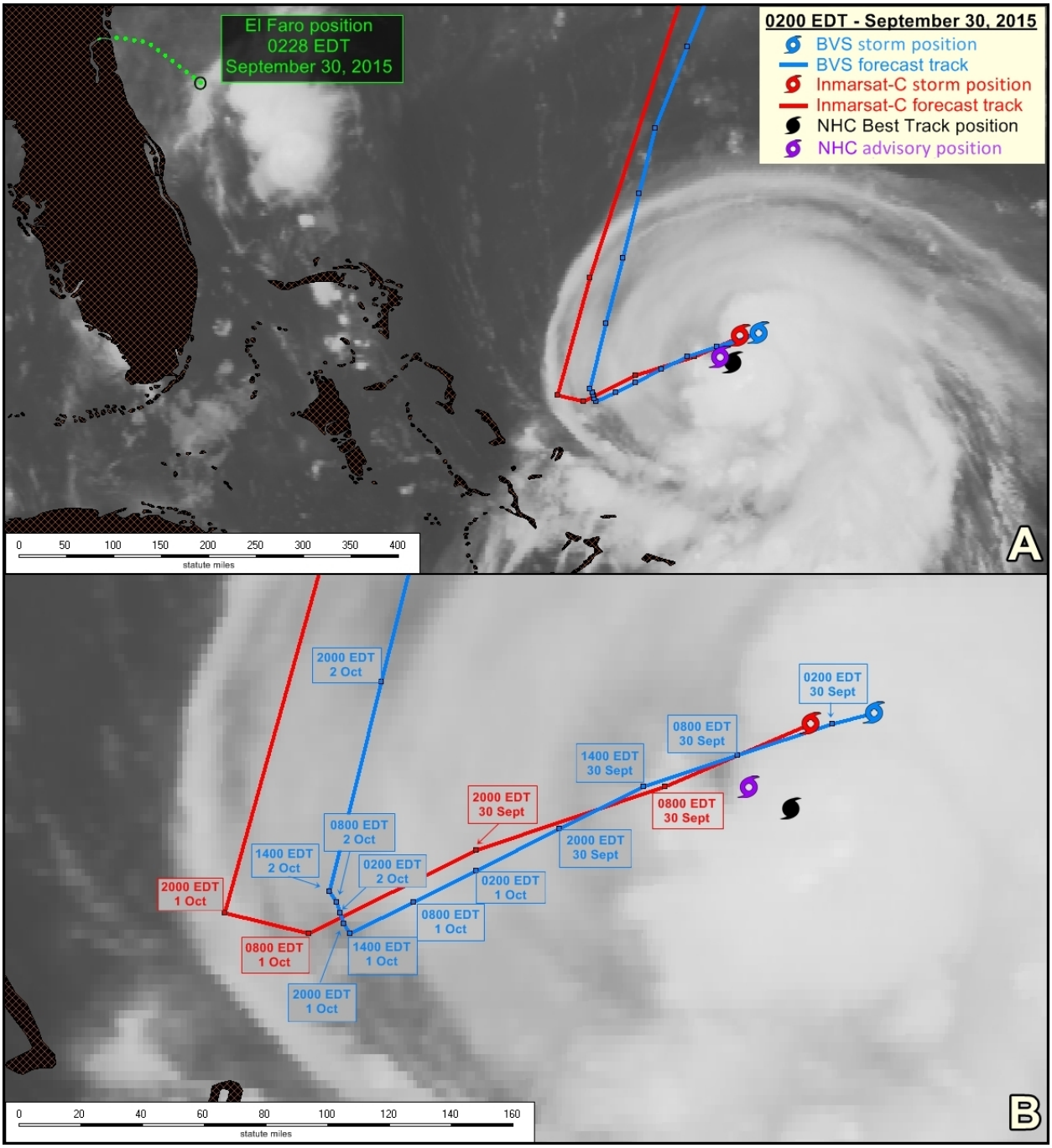

Figure 59 *– Comparison of Joaquin's location and forecast track delivered via BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 0200 EDT on September 30, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, best track, and NHC Intermediate Public Advisory data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 infrared image from 0215 EDT on September 30, 2015. Image is not corrected for parallax error.*

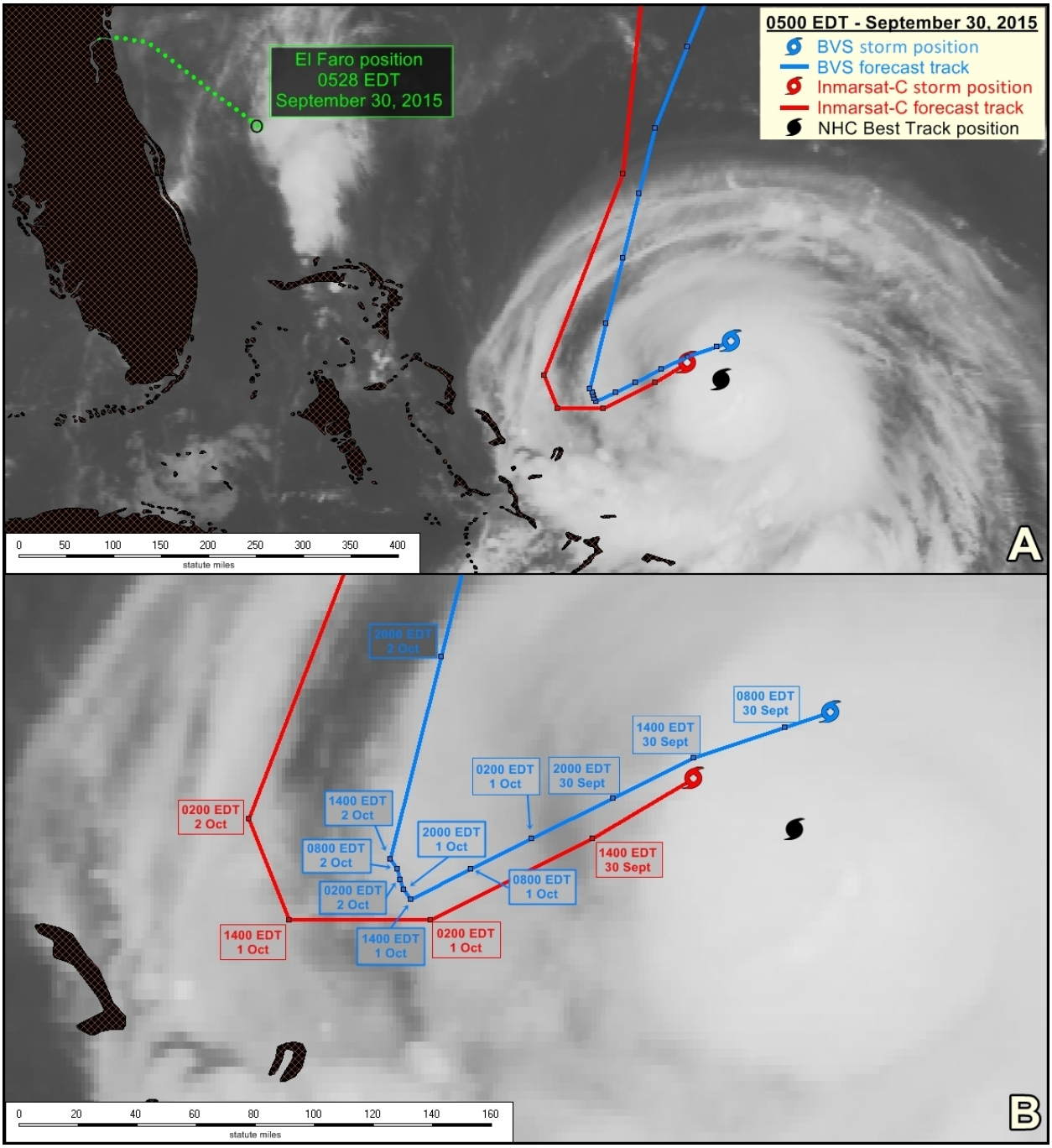

Figure 60 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 0500 EDT on September 30, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, and best track data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 infrared image from 0915 EDT on September 30, 2015. Image is not corrected for parallax error.*

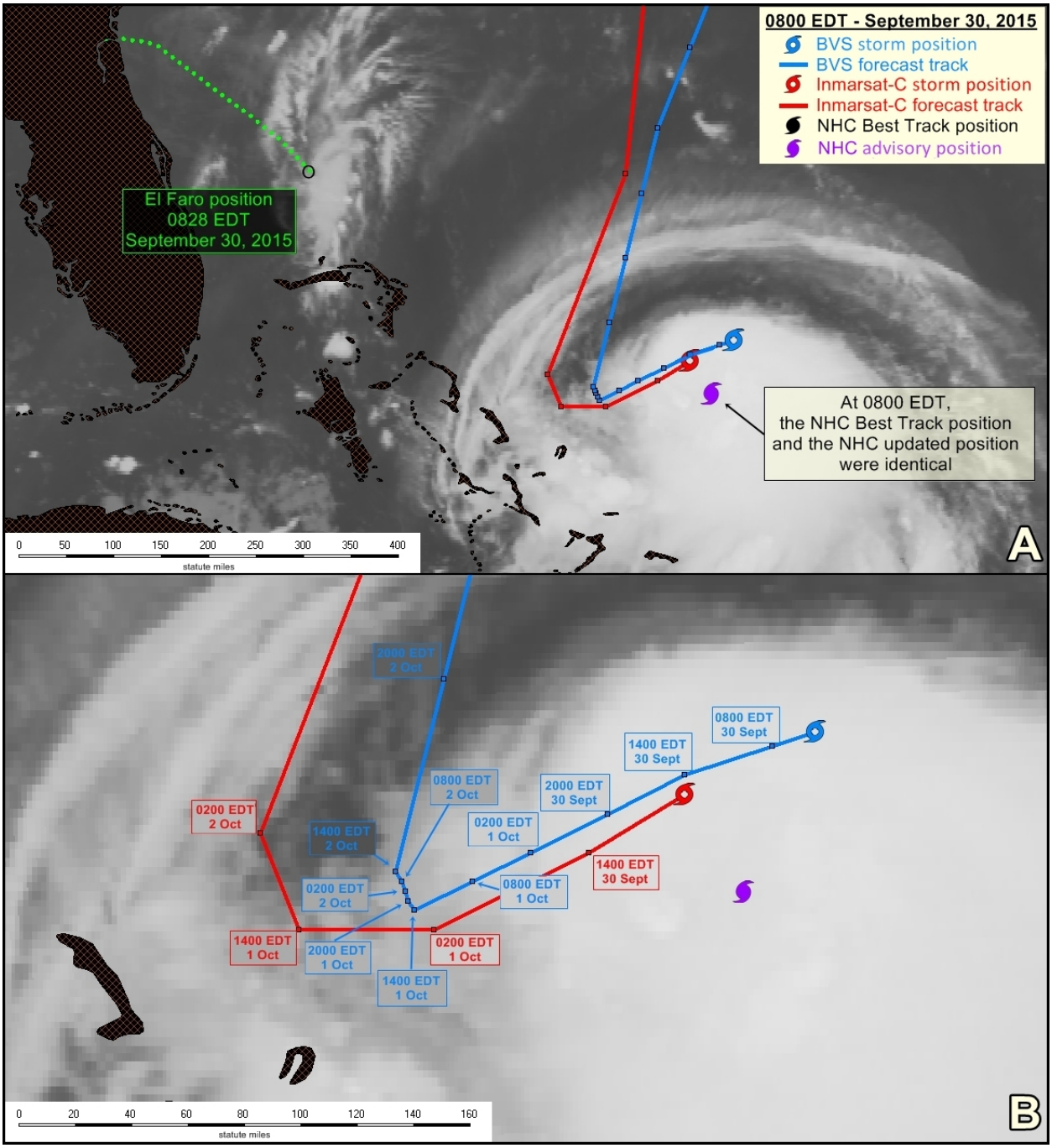

Figure 61 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 0800 EDT on September 30, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, best track, and NHC Intermediate Public Advisory data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 infrared image from 1215 EDT on September 30, 2015. Image is not corrected for parallax error.*

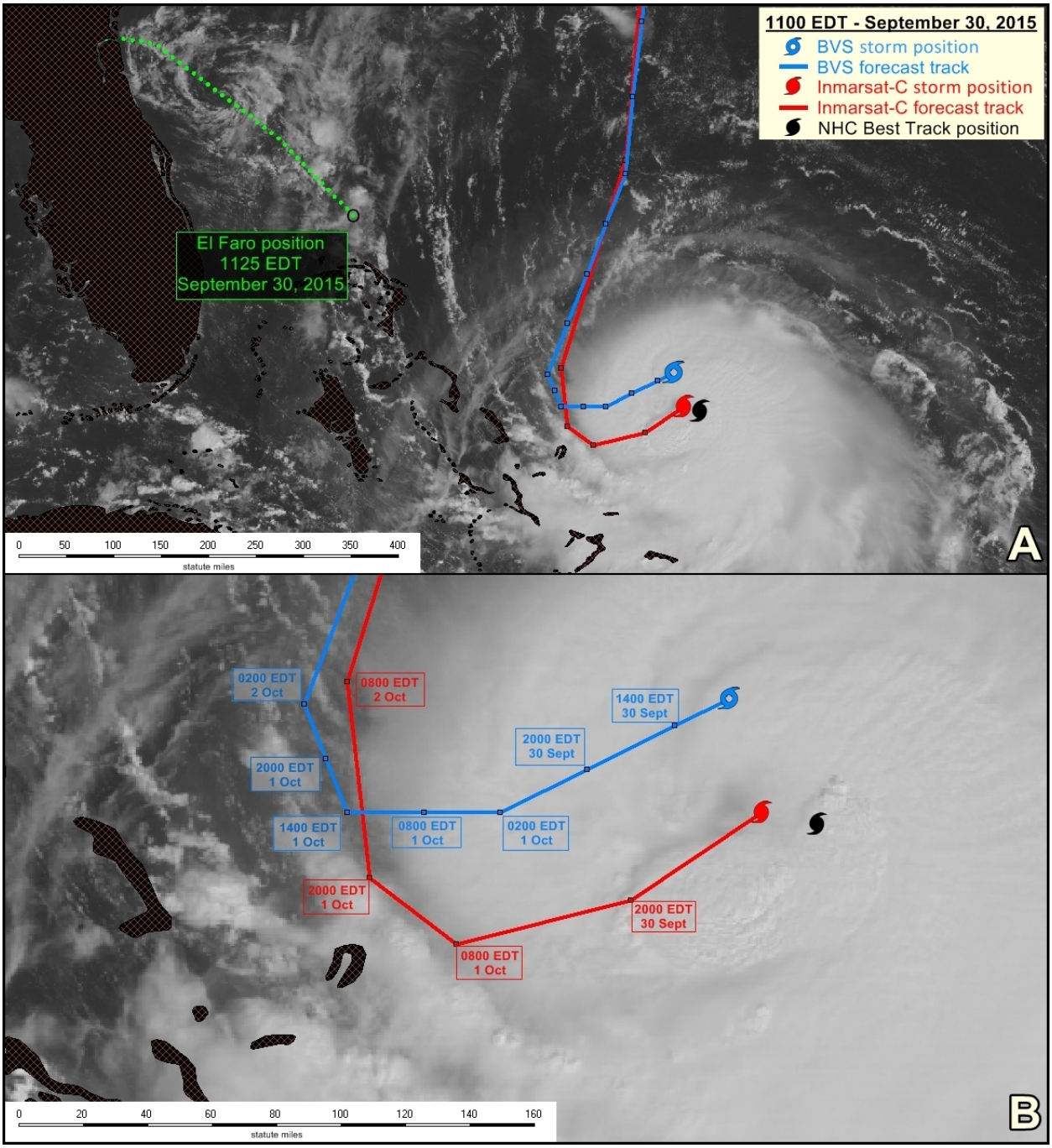

Figure 62 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 1100 EDT on September 30, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, and best track data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 visible image from 1115 EDT on September 30, 2015. Image is not corrected for parallax error.*

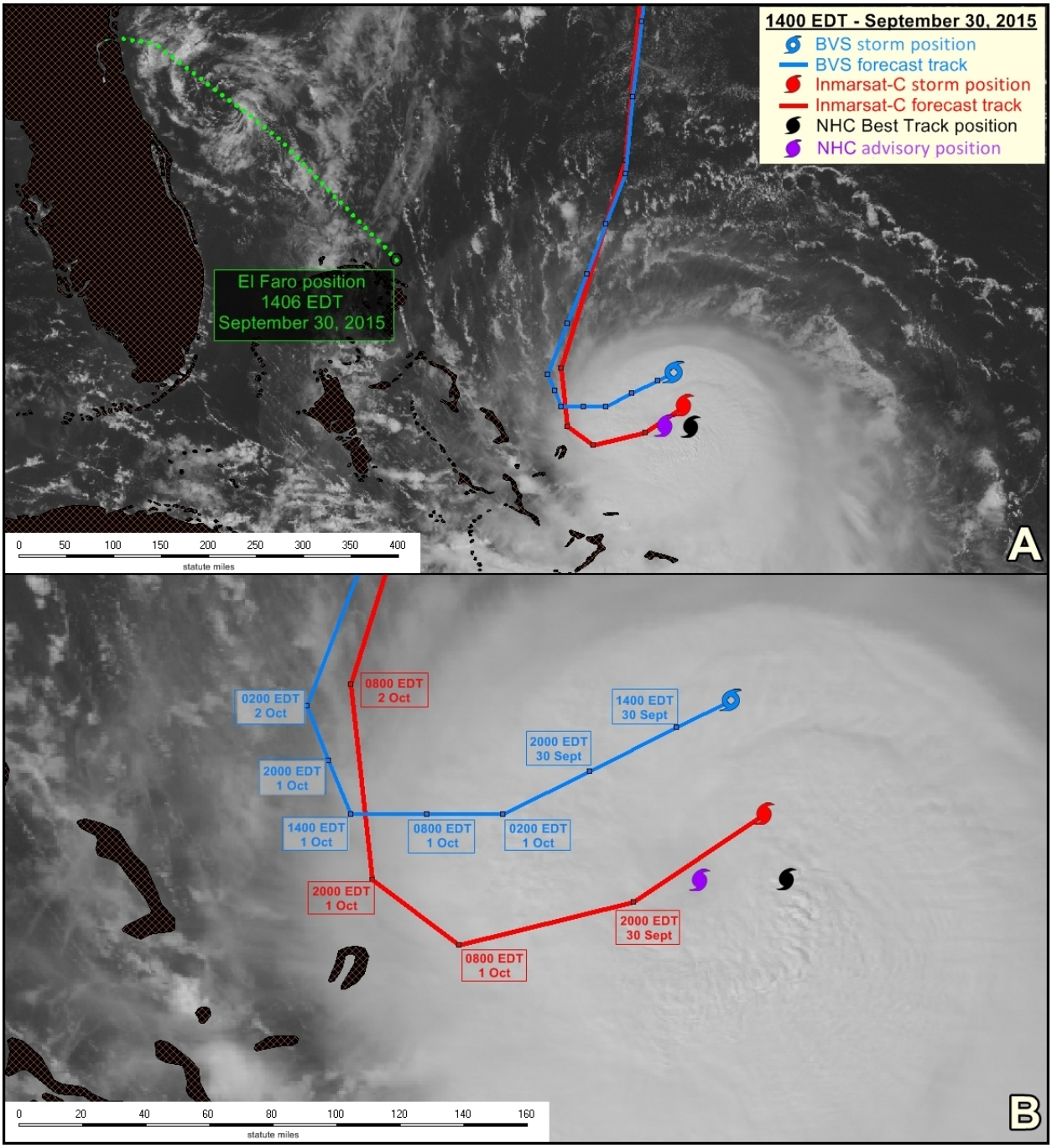

Figure 63 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 1400 EDT on September 30, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, best track, and NHC Intermediate Public Advisory data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 visible image from 1415 EDT on September 30, 2015. Image is not corrected for parallax error.*

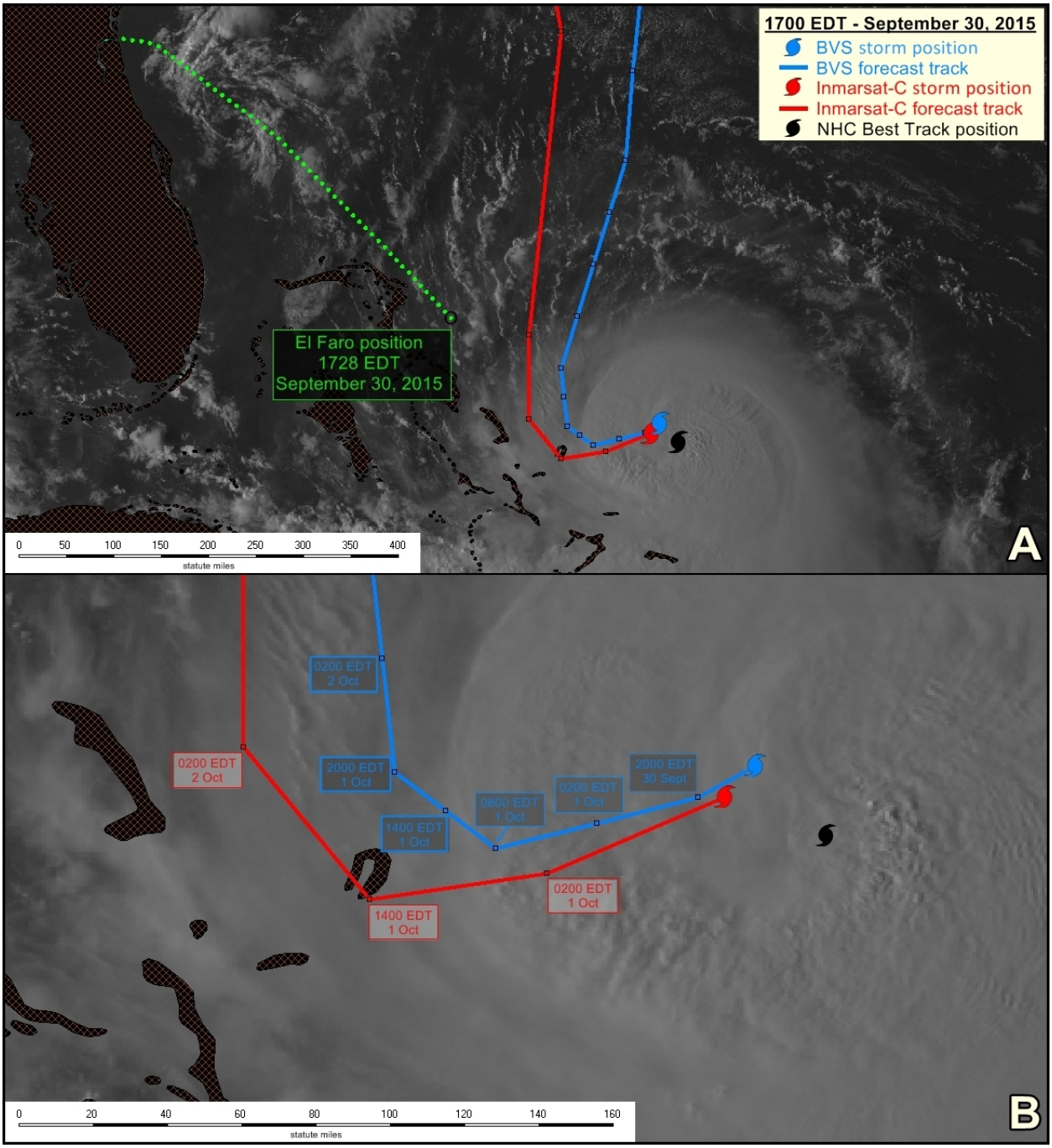

Figure 64 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 1700 EDT on September 30, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, and best track data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 visible image from 1715 EDT on September 30, 2015. Image is not corrected for parallax error.*

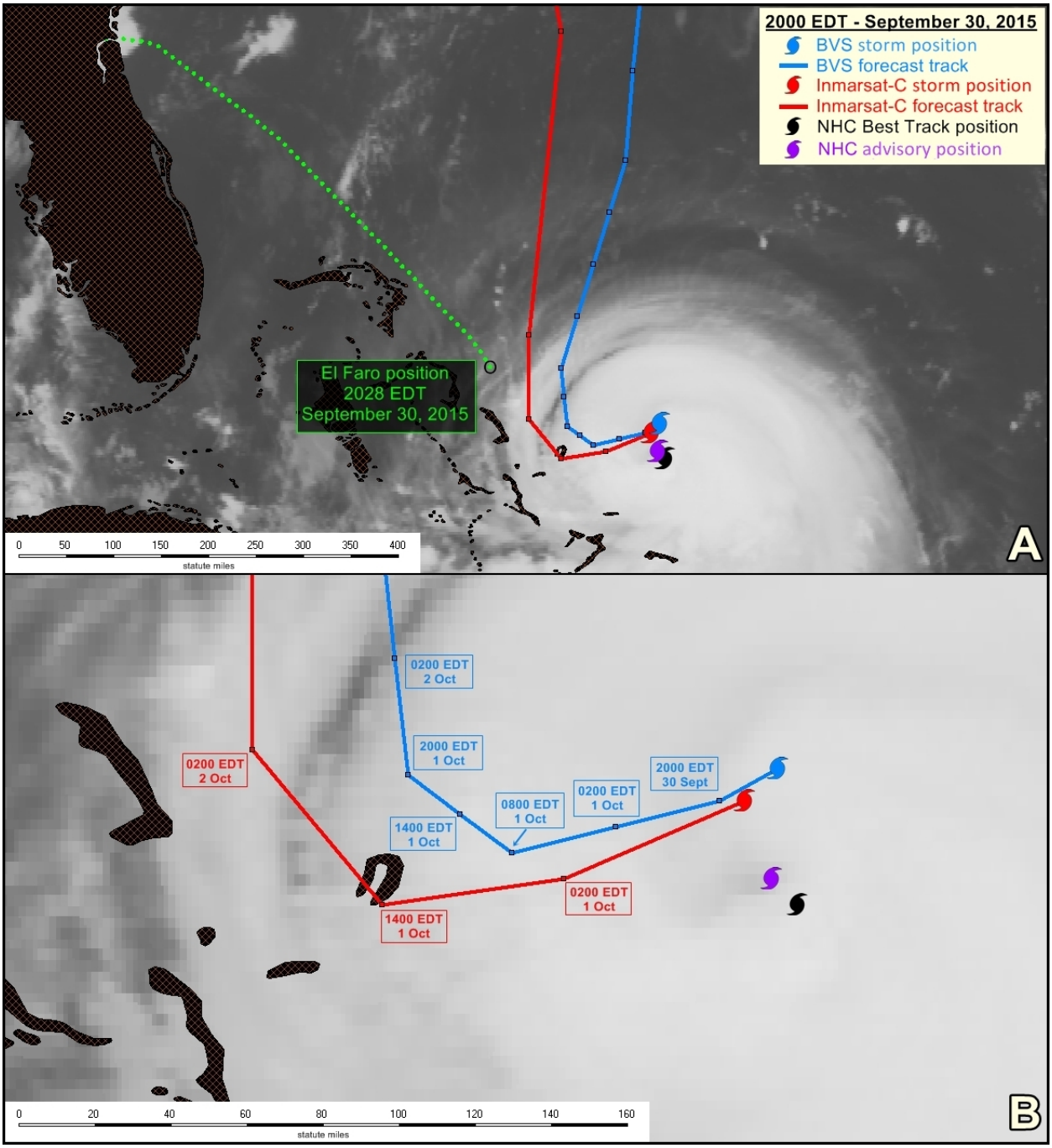

Figure 65 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 2000 EDT on September 30, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, best track, and NHC Intermediate Public Advisory data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 infrared image from 2015 EDT on September 30, 2015. Image is not corrected for parallax error.*

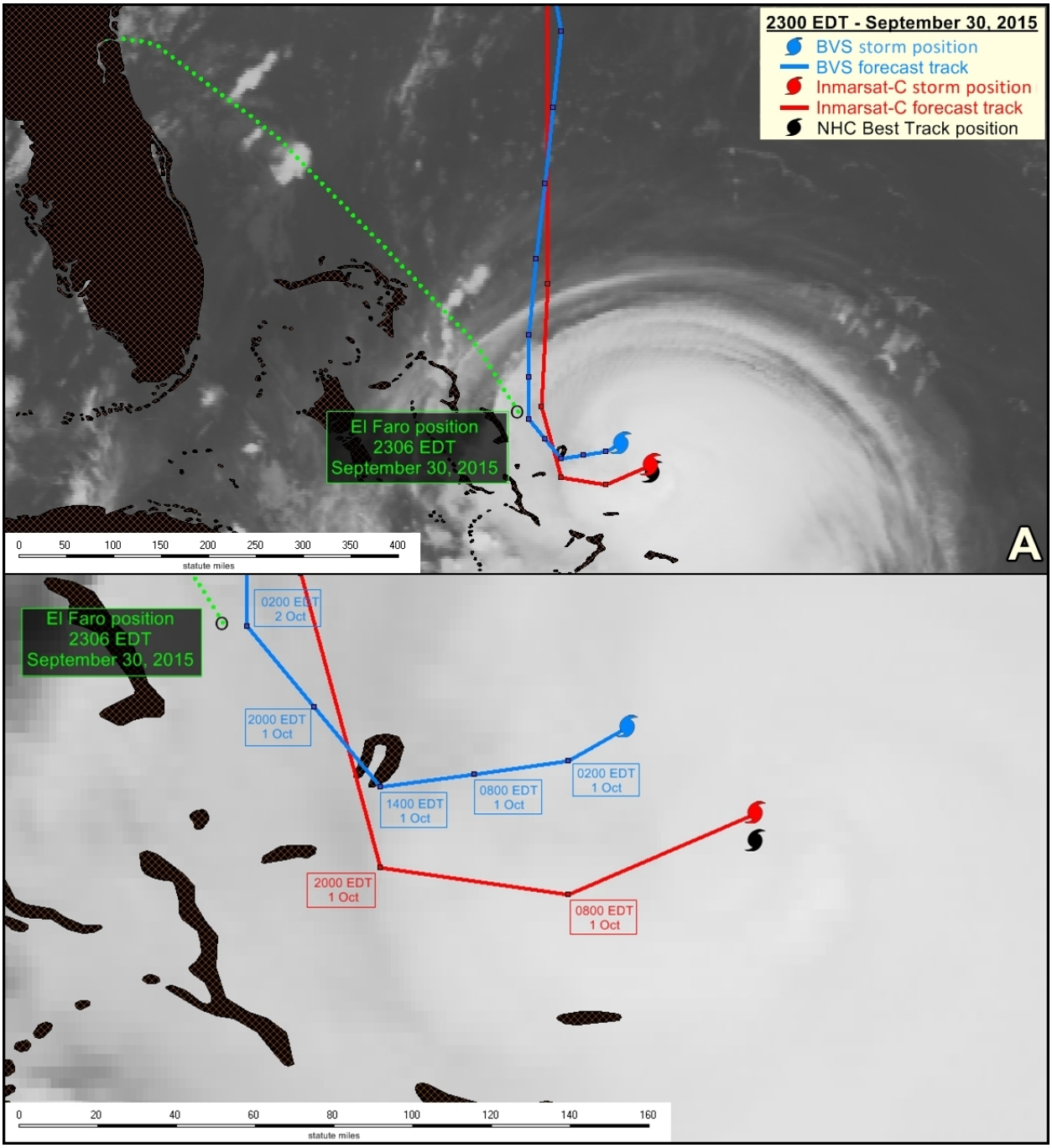

Figure 66 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 2300 EDT on September 30, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, and best track data. Green dotted line shows El Faro position. Depictions are overlaid on GOES-13 infrared image from 2315 EDT on September 30, 2015. Image is not corrected for parallax error.*

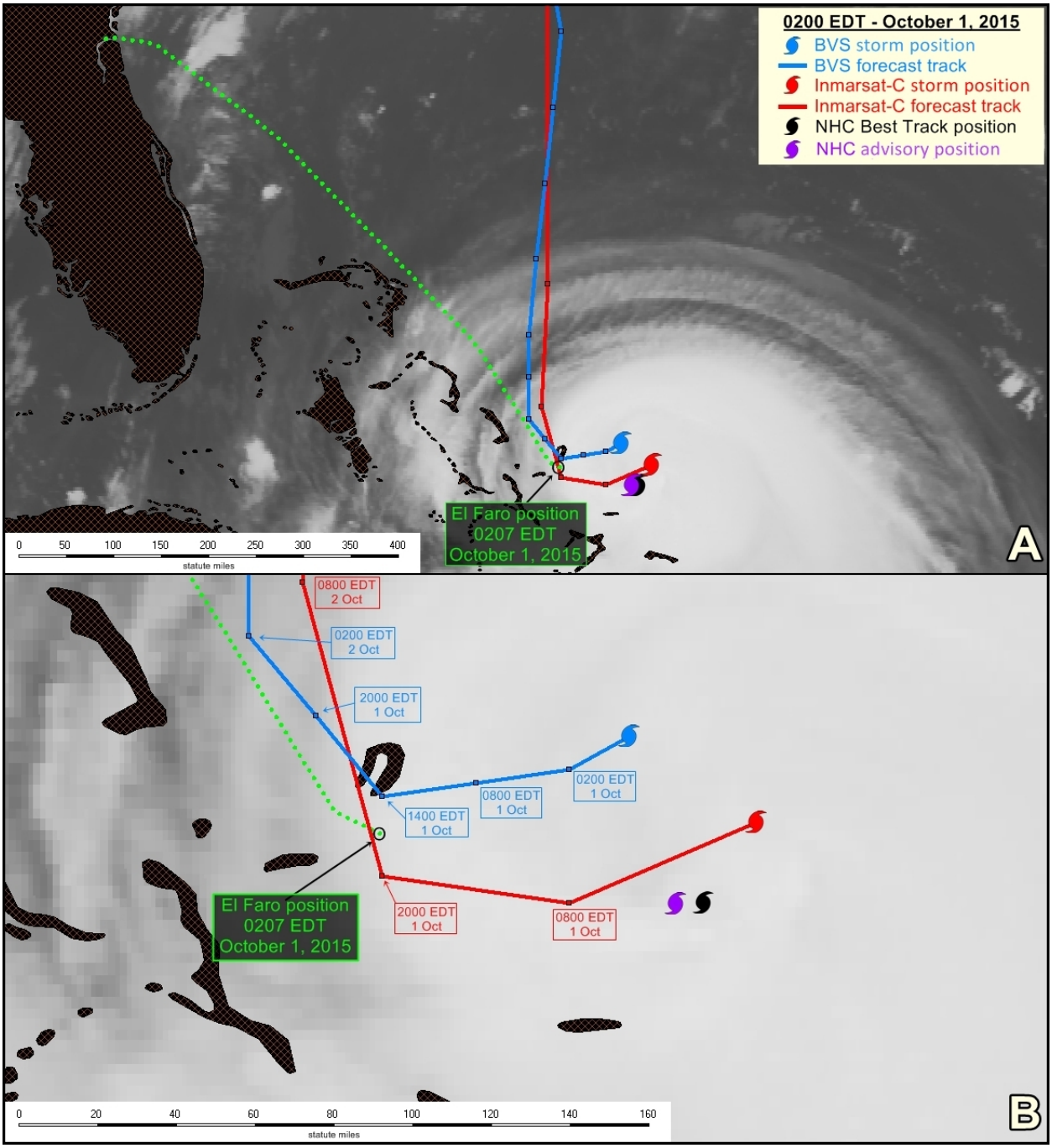

Figure 67 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 0200 EDT on October 1, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, best track, and NHC Intermediate Public Advisory data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 infrared image from 0215 EDT on October 1, 2015. Image is not corrected for parallax error.*

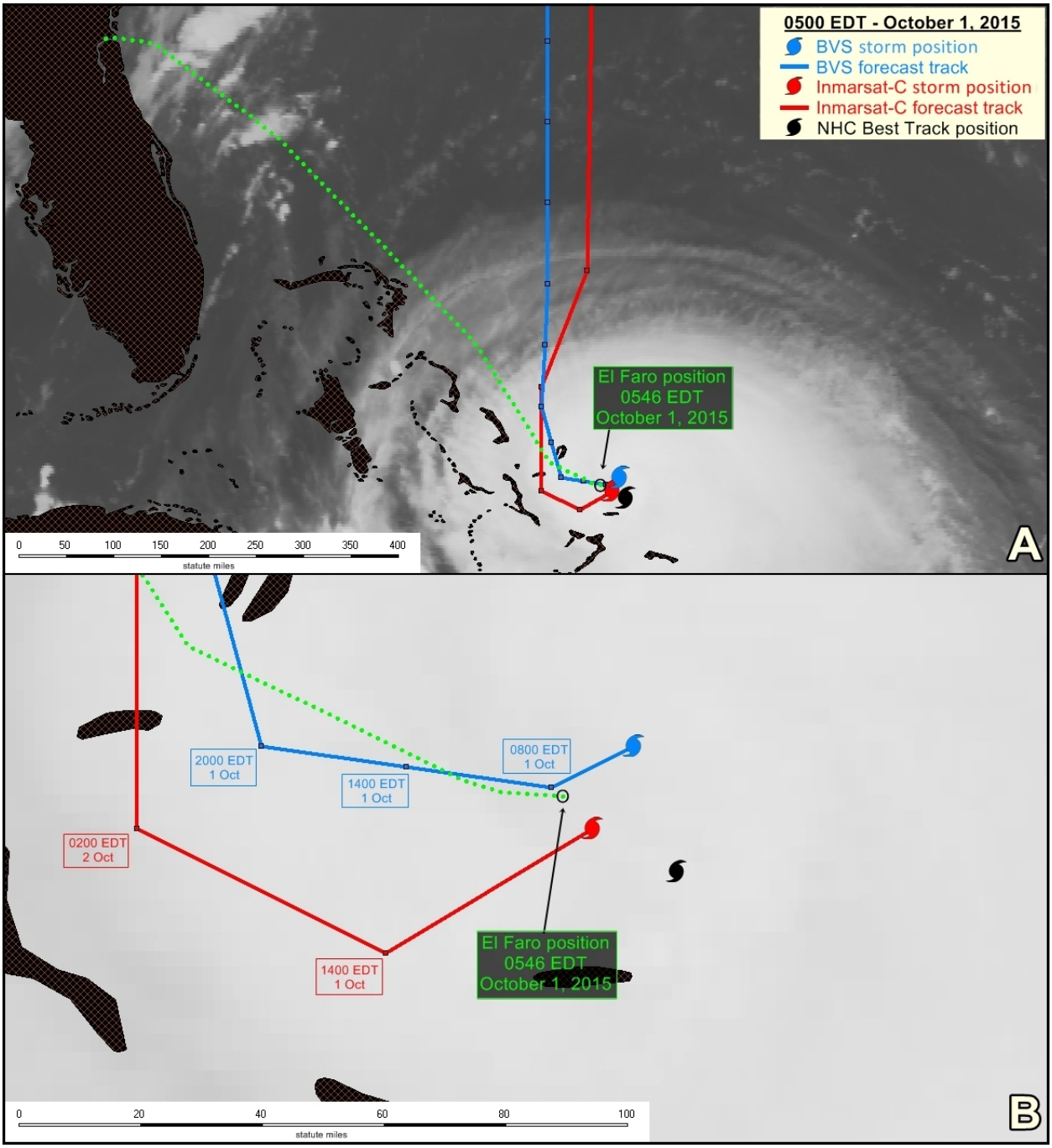

Figure 68 *– Comparison of Joaquin's location and forecast track delivered by BVS main weather files and Inmarsat-C SafetyNET and available to* El Faro *about 0500 EDT on October 1, 2015. Different-colored cyclone symbols show Joaquin's location from BVS, Inmarsat-C SafetyNET, and best track data. Green dotted line shows* El Faro *position. Depictions are overlaid on GOES-13 infrared image from 0515 EDT on October 1, 2015. Image is not corrected for parallax error.*

Figures 69 through 77 present two types of information: (1) Screenshots of graphics in the main BVS weather files emailed to *El Faro* between about 2300 EDT on September 29, 2015, and about 0500 EDT on October 1, 2015, as users would have seen them.[85, 86] (2) Displays developed by NTSB investigators of the NHC forecast wind fields around Joaquin valid for 0800 EDT on October 1, 2015, from Tropical Cyclone Forecast/Advisory Numbers 9, 11, and 13, issued during the same period. The maximum forecast extent of the 34-knot (tropical-storm-force), 50-knot, and 64-knot (hurricane-force) wind fields are shown for each quadrant (northwest, northeast, southeast, southwest) around Joaquin's center.

The BVS screenshots show Joaquin's forecast center position and wind fields valid for 0800 EDT on October 1, 2015. The images were part of the main BVS weather files emailed to *El Faro* between September 29, 2015, and October 1, 2015. The screenshots include the forecast sea-level pressure (red contour lines), surface wind (barbs),[87] and significant wave heights (colored contours) for the forecast time. A "low" or "high" likelihood of rogue waves would have been indicated by a red polygon (see BVS version 7 User Manual, section 23.1.1).

Users could project forecasts into the future at 3-hour intervals when viewing data from any one emailed main BVS weather file. Attachment 27 reproduces similar screenshots of all "step-able" forecast times in BVS (every 3 hours) leading to and including 0800 EDT on October 1, 2015. The images were sent in the main BVS weather files emailed to *El Faro* over the stated period. Attachment 27 also includes screenshots of the "Tropical Report" text box in each emailed main BVS weather file that gives storm center coordinates, tabular information on wind fields, and other meteorological parameters.

[85] Users can adjust which parameters to view, but cyclone position and forecast track are forced.

[86] Figures 69, 71, 72, 74, 75, and 77 ignore the ~2 minute latency in emailing the main BVS weather files, considering a file emailed at 0502 EDT to have been emailed at the nominal email time of 0500 EDT.

[87] Adjusting the zoom of the BVS display would change the number of wind barbs on the screen. That is, zooming in would improve the spatial resolution of the depicted surface wind information.

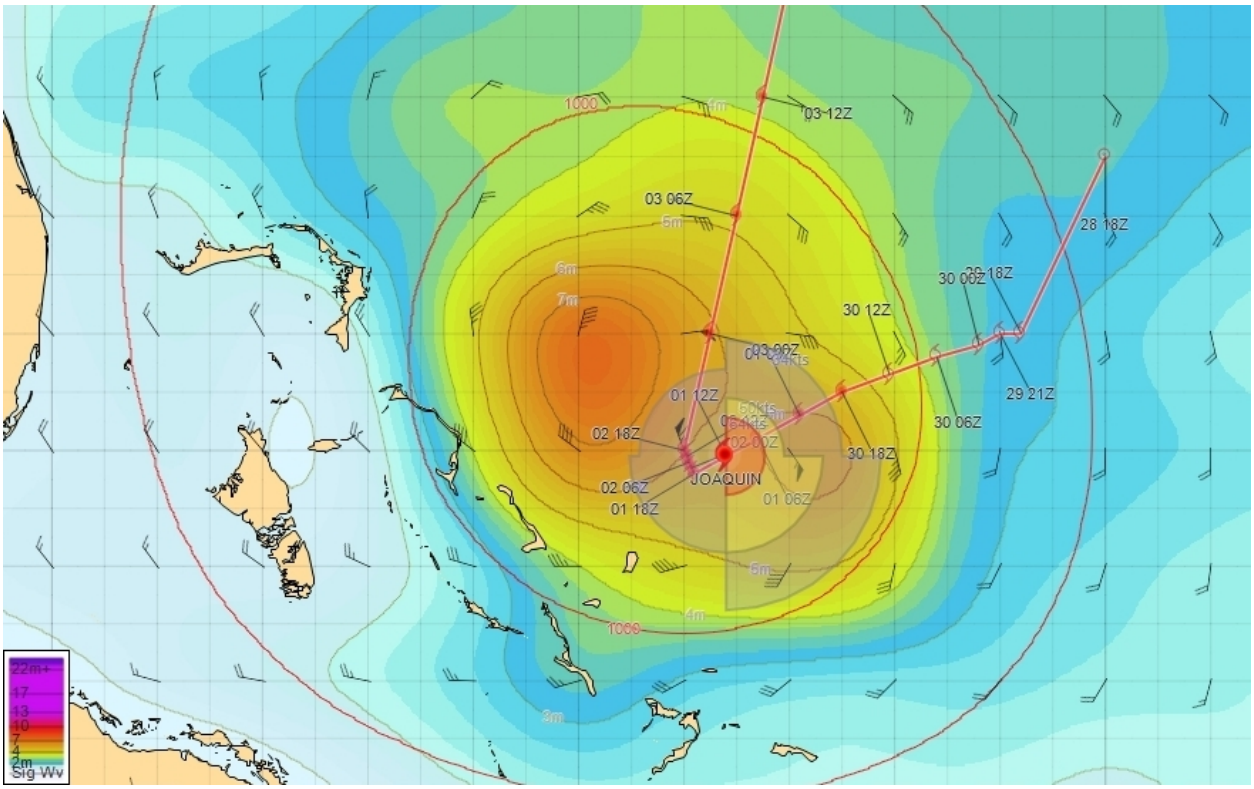

Figure 69 *– BVS screenshot showing Joaquin forecast center position, storm wind fields, sea-level pressure, surface wind, and significant wave height valid for 0800 EDT on October 1, 2015—part of the main BVS weather file emailed to* El Faro *about 2300 EDT on September 29, 2015.*

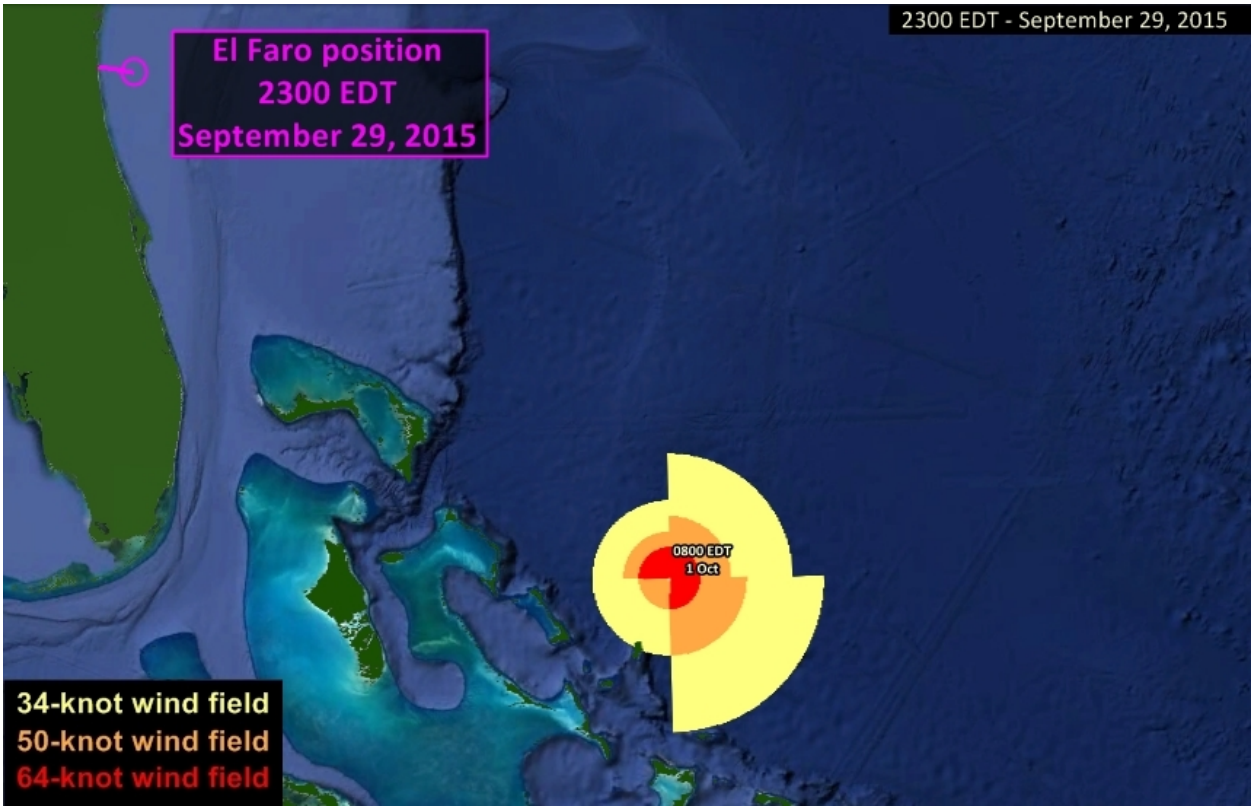

Figure 70 *– Forecast 34-knot, 50-knot, and 64-knot wind fields valid for 0800 EDT on October 1, 2015, from NHC's Tropical Cyclone Forecast/Advisory text product issued (nominally) at 2300 EDT on September 29, 2015 (Advisory Number 9). Nominal public issuance time shown in upper right-hand corner.* El Faro *position shown as pink line.*

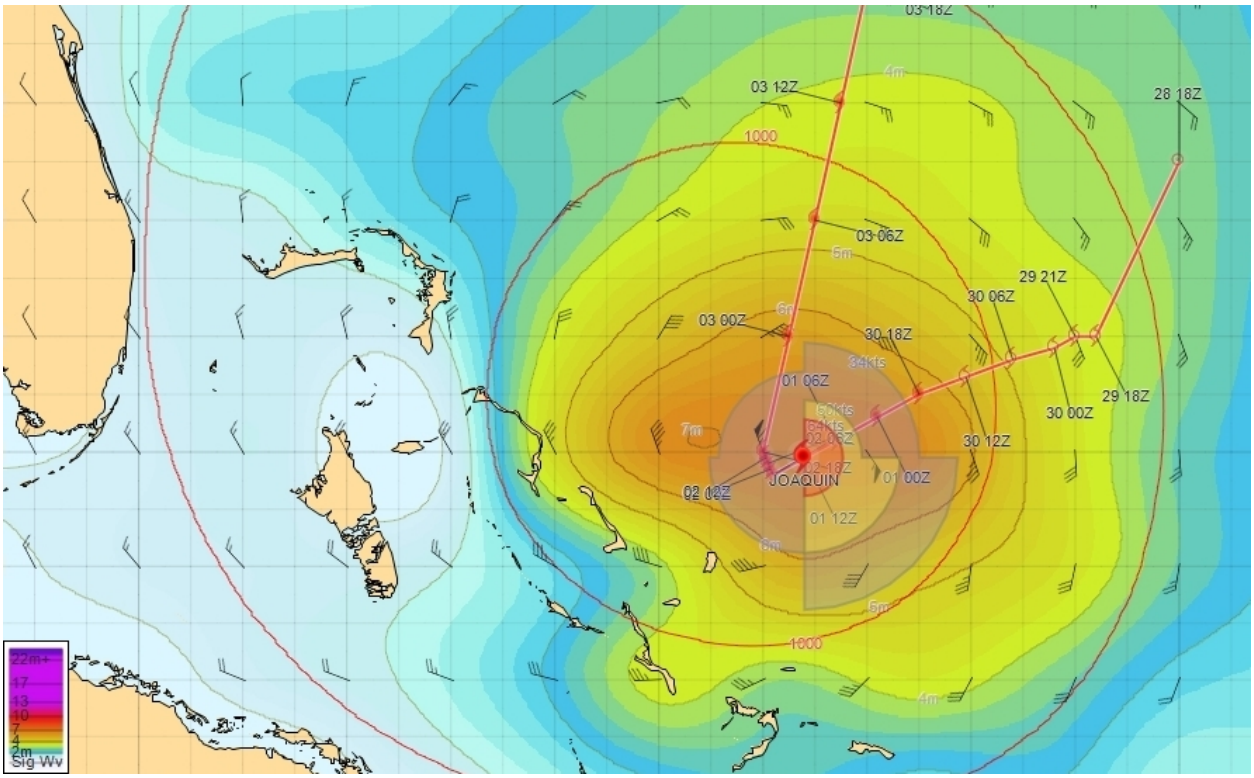

Figure 71 *– BVS screenshot showing Joaquin forecast center position, storm wind fields, sea-level pressure, surface wind, and significant wave height valid for 0800 EDT on October 1, 2015—part of the main BVS weather file emailed to* El Faro *about 0500 EDT on September 30, 2015.*

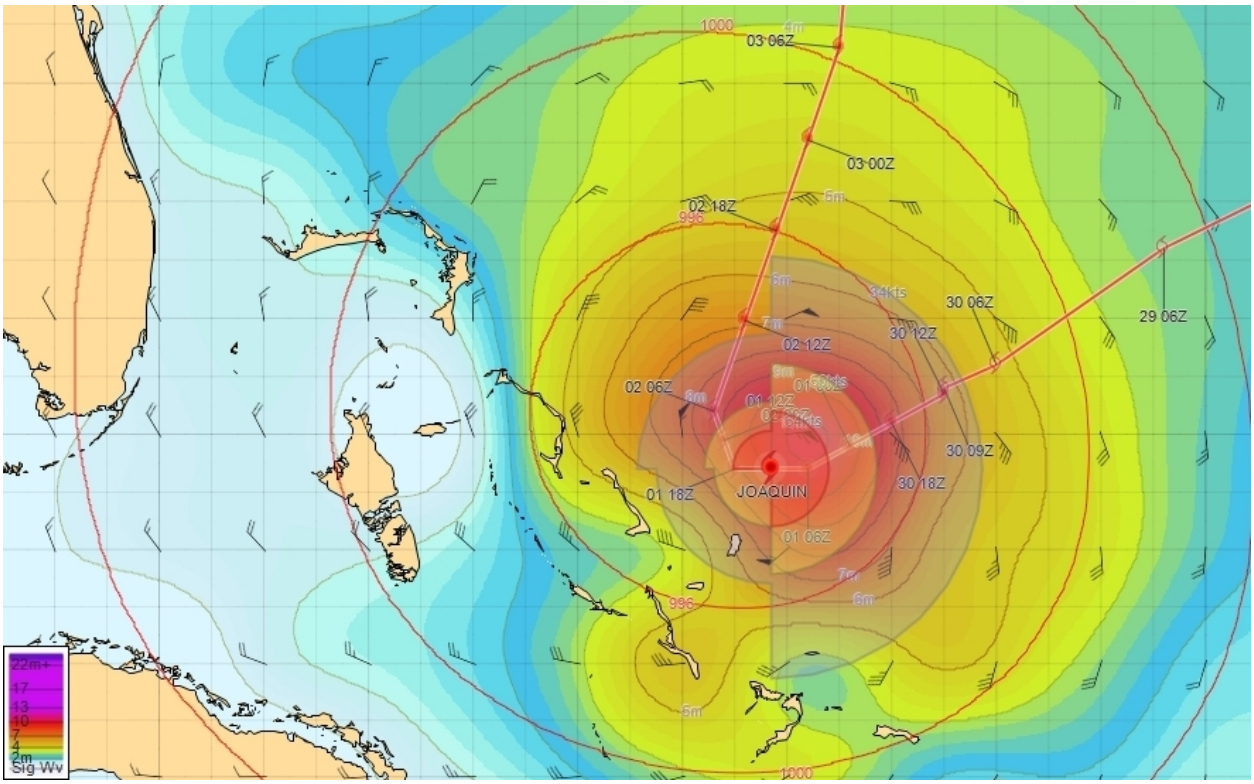

Figure 72 *– BVS screenshot showing Joaquin forecast center position, storm wind fields, sea-level pressure, surface wind, and significant wave height valid for 0800 EDT on October 1, 2015—part of the main BVS weather file emailed to* El Faro *about 1100 EDT on September 30, 2015.*

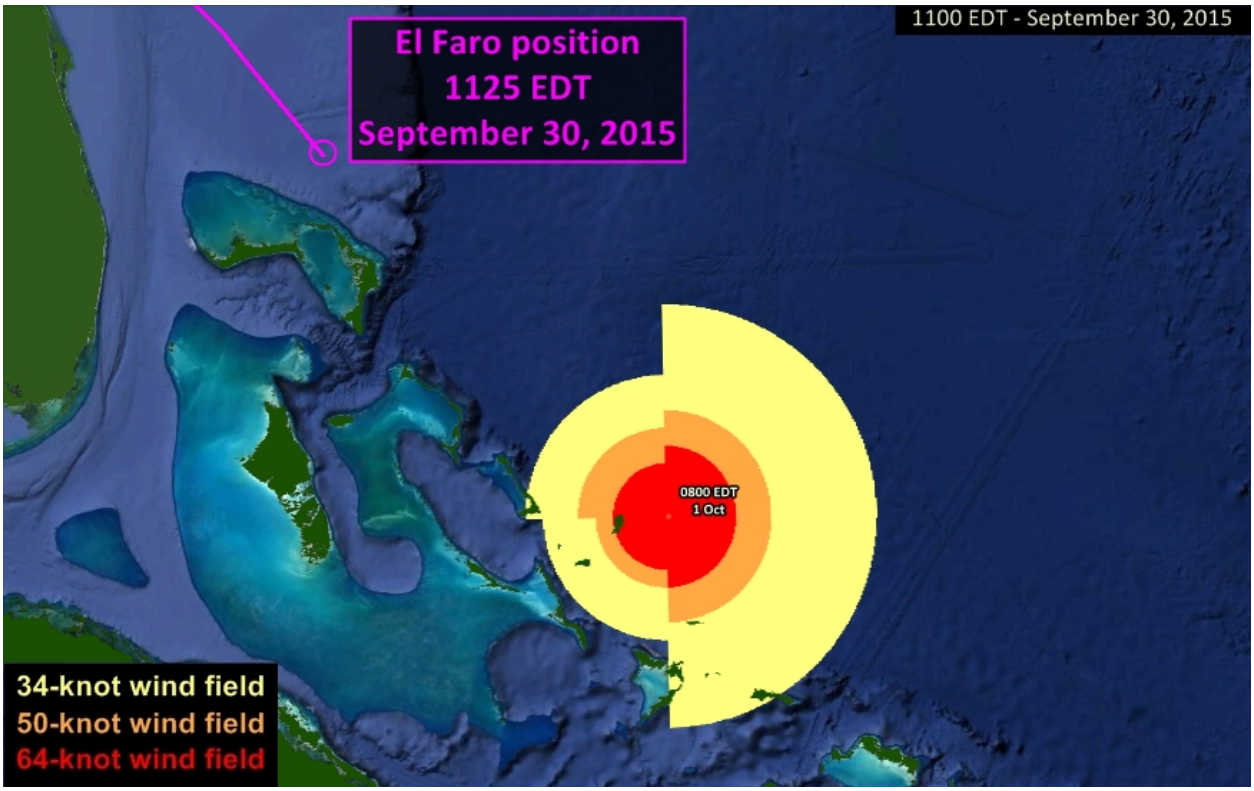

Figure 73 *– Forecast 34-knot, 50-knot, and 64-knot wind fields valid for 0800 EDT on October 1, 2015, from NHC's Tropical Cyclone Forecast/Advisory text product issued (nominally) at 1100 EDT on September 30, 2015 (Advisory Number 11). Nominal public issuance time shown in upper right-hand corner.* El Faro *position shown as pink line.*

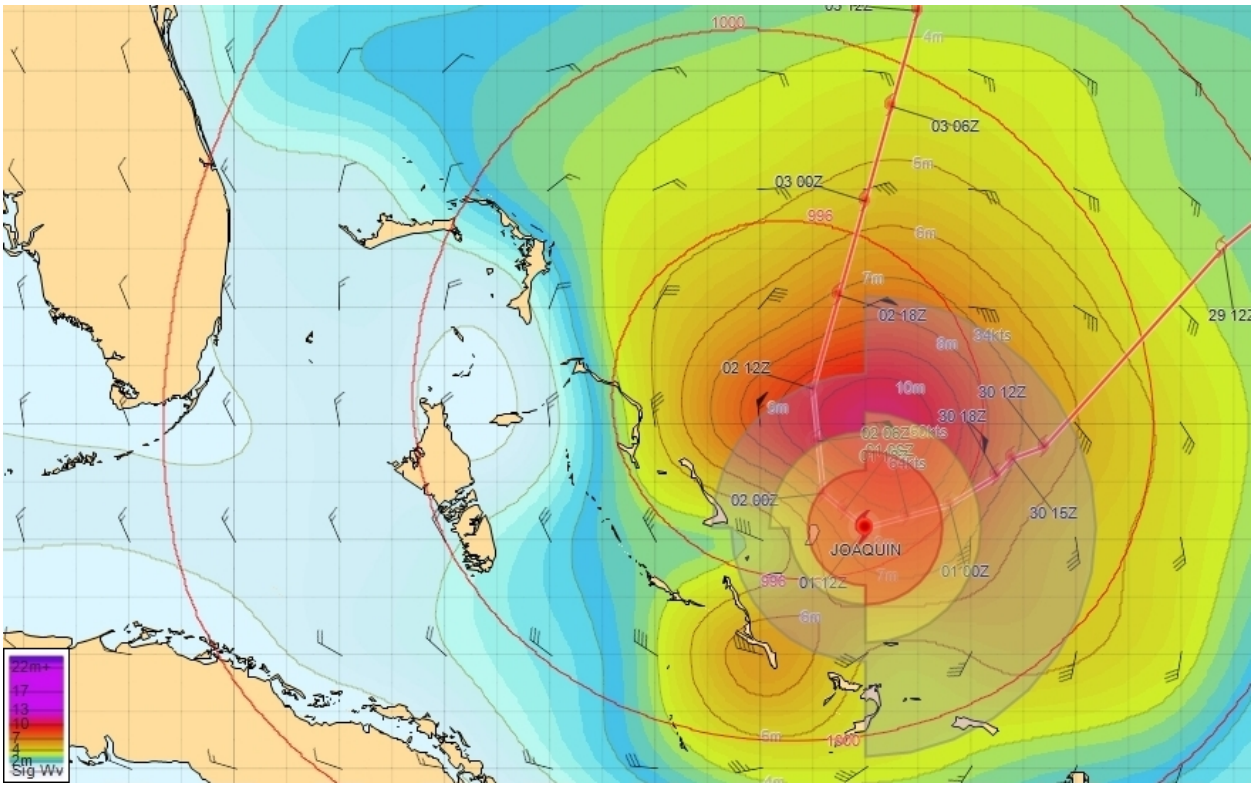

Figure 74 *– BVS screenshot showing Joaquin forecast center position, storm wind fields, sea-level pressure, surface wind, and significant wave height valid for 0800 EDT on October 1, 2015—part of the main BVS weather file emailed to* El Faro *about 1700 EDT on September 30, 2015.*

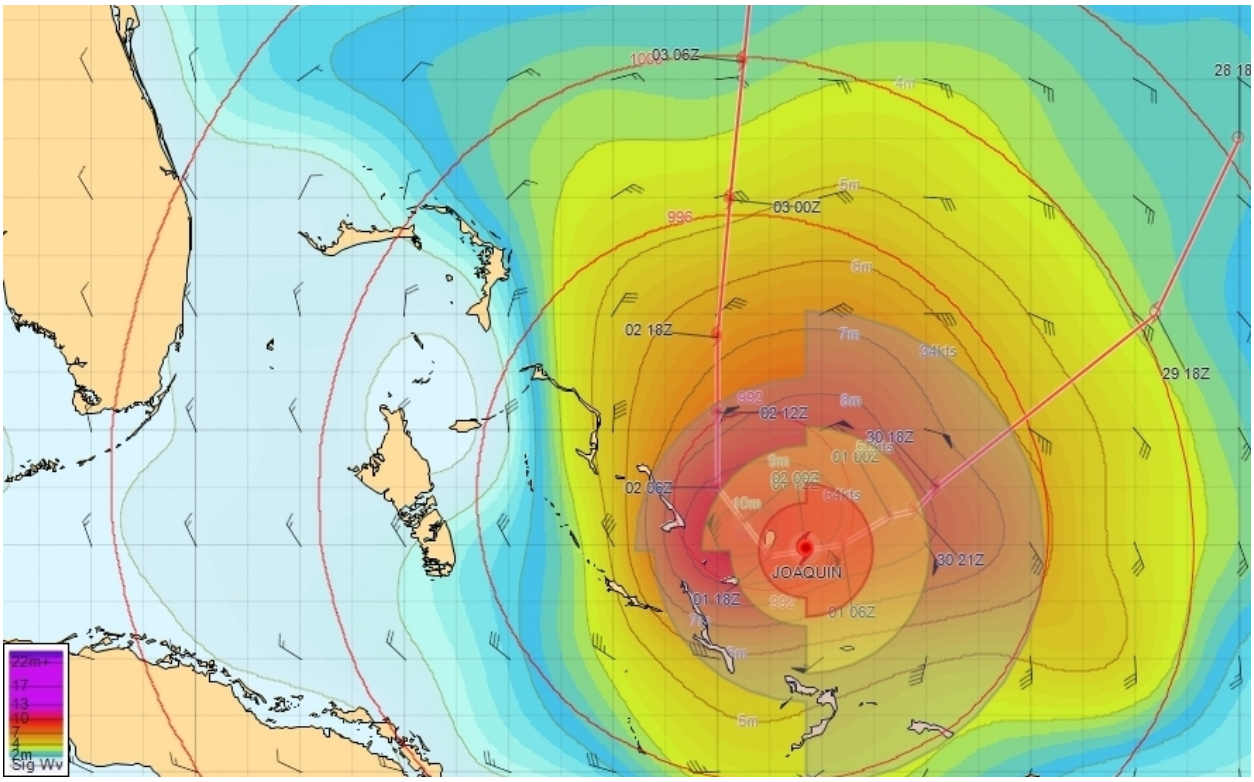

Figure 75 *– BVS screenshot showing Joaquin forecast center position, storm wind fields, sea-level pressure, surface wind, and significant wave height valid for 0800 EDT on October 1, 2015—part of the main BVS weather file emailed to* El Faro *about 2300 EDT on September 30, 2015.*

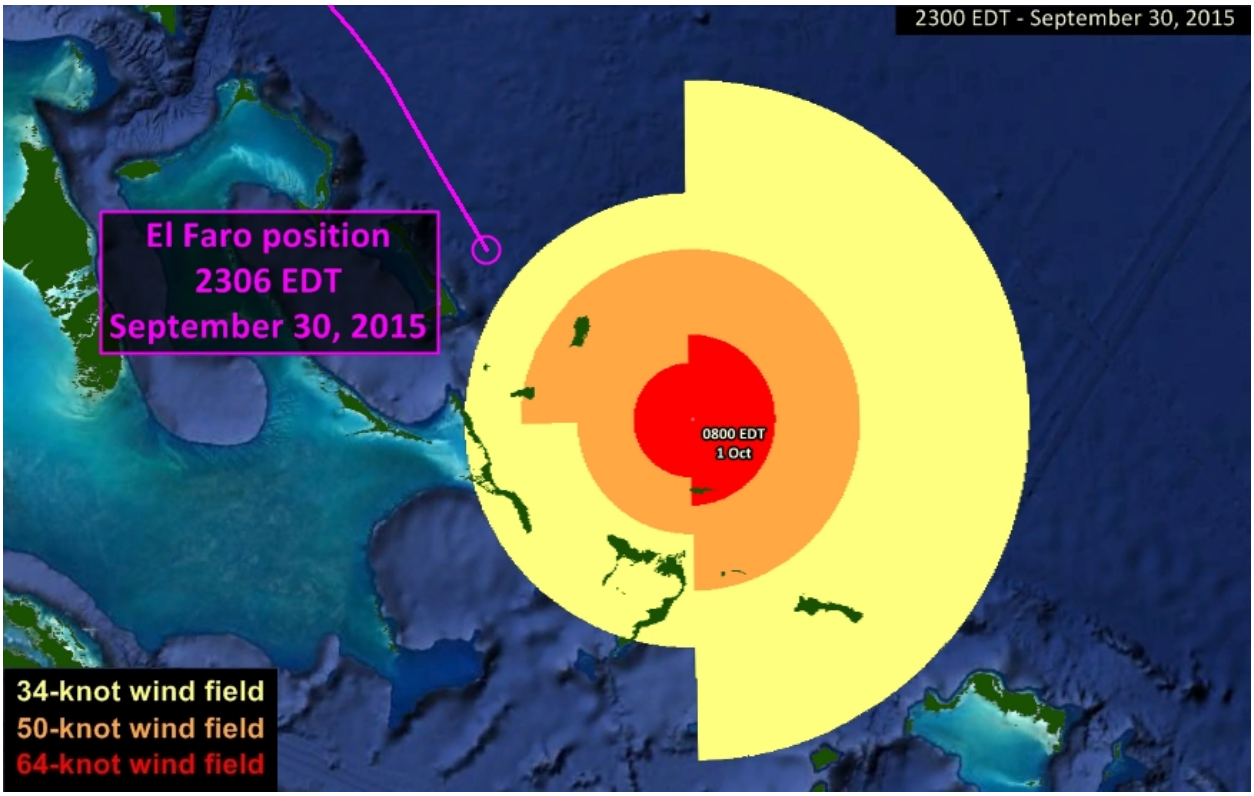

Figure 76 *– Forecast 34-knot, 50-knot, and 64-knot wind fields valid for 0800 EDT on October 1, 2015, from NHC's Tropical Cyclone Forecast/Advisory text product issued (nominally) at 2300 EDT on September 30, 2015 (Advisory Number 13). Nominal public issuance time shown in upper right-hand corner.* El Faro *position shown as pink line.*

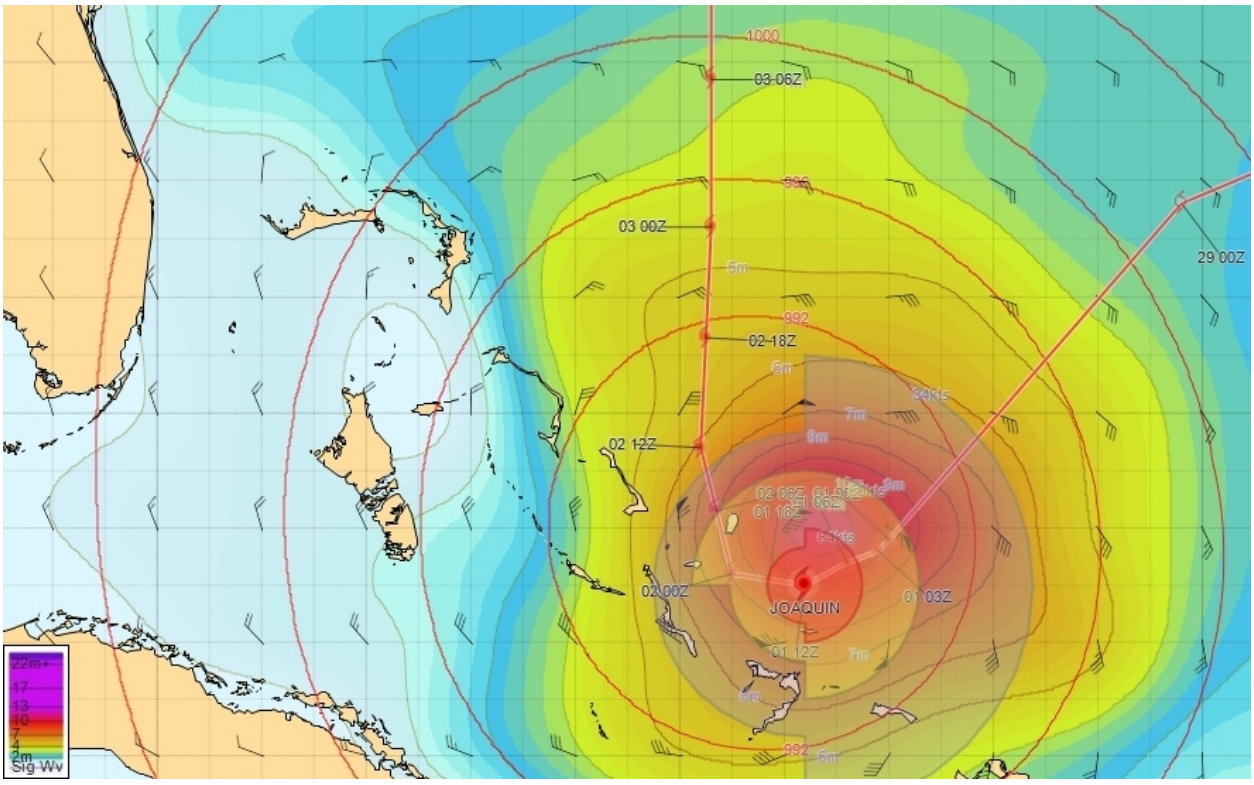

Figure 77 *– BVS screenshot showing Joaquin forecast center position, storm wind fields, sea-level pressure, surface wind, and significant wave height valid for 0800 EDT on October 1, 2015—part of the main BVS weather file emailed to* El Faro *about 0500 EDT on October 1, 2015.*

Section 5.2.1.2 presented calculations of forecast track and intensity errors from the NHC Tropical Cyclone Forecast/Advisory products for a sequential set of NHC forecasts all verifying at 0800 EDT on October 1, 2015. Because the emailed main BVS weather files contained Joaquin forecast track and intensity information taken from Tropical Cyclone Forecast/Advisory products that were not current at the time they were sent, forecasts contained in those emailed main BVS weather files would have had different forecast errors than those from the NHC forecasts available from Inmarsat-C SafetyNET about the same times.

The following table presents track and intensity errors for the forecasts contained in the emailed main BVS weather files, again for the set of forecasts all verifying at 0800 EDT on October 1, 2015. Errors were calculated by comparing Joaquin's forecast center position and intensity valid for 0800 EDT on October 1, 2015, from each of the emailed main BVS weather files with the best track center position and intensity valid for 0800 EDT on October 1, 2015. Note that because NHC forecast positions are not given at 6-hourly resolution, some of the forecast positions were interpolated to be valid at 0800 EDT October 1.

It should be noted that the following table lists the time difference between the time of email transmission and the forecast's verifying time (e.g., roughly 33 hours for the main BVS weather

file emailed at 2302 EDT on September 29, 2015). This is not directly comparable to the "forecast period" presented in the error table in section 5.2.1.2. The actual forecast period (the difference between the forecast initialization time and the verifying time) is shown in the table below for ease of comparison with the data in section 5.2.1.2. The table below is intended to highlight the forecast track and intensity errors sent to *El Faro* via the emailed main BVS weather files at the earliest time of their receipt.

Main BVS Weather File Nominal Email Time from AWT to *El Faro*	Forecast Center Position and Intensity^	Time Difference[a]	Actual Forecast Period	Errors
2300 EDT September 29, 2015	24.95°N 73.6°W 70 knots	33h	42h	111 miles 45 knots
0500 EDT September 30, 2015	24.95°N 73.6°W 70 knots	27h	42h	111 miles 45 knots
1100 EDT September 30, 2015	24.7°N 74.15°W 75 knots	21h	30h	99 miles 40 knots
1700 EDT September 30, 2015	24.1°N 74.0°W 85 knots	15h	24h	62 miles 30 knots
2300 EDT September 30, 2015	23.95°N 74.15°W 85 knots	9h	18h	57 miles 30 knots
0500 EDT October 1, 2015	23.5°N 73.8°W 110 knots	3h	12h	25 miles 5 knots

^ Forecast valid for 0800 EDT on October 1, 2015, contained in the Tropical Cyclone Forecast/Advisory.
[a] Time difference between main BVS weather file email time from AWT to *El Faro* and forecast verifying time of 0800 EDT on October 1, 2015.

BVS can be used for route optimization. According to the BVS Version 7 User Manual (section 28), "an optimization track is a route created by BVS to optimize the voyage in regard to your current sailing intentions. It takes into account weather conditions, user defined goals and constraints, and calculated vessel performance within the program." Users define constraints and thresholds through the "Tools" tab in the sidebar on the BVS display, using the "Threshold/Constraints" and "Fuel Cost Thresholds" buttons (see BVS version 7 User Manual, section 12). For optimization, the vessel must input performance parameters in the vessel setup window (see BVS version 7 User Manual, section 32.1). Optimization can be made for "Least Time," "Least Fuel," and "Least Fuel with a Fixed Arrival Time" (see BVS version 7 User Manual, sections 28.3.3, 28.3.4 and 28.3.5).

BVS can also be used to monitor routes by means of the sidebar's "Snap Shot" tab (figure 78), which displays resonance alert thresholds for high waves, broaching, parametric roll, and

synchronous rolls[88] (see BVS version 7 User Manual, section 29.3). The tab is used to input thresholds such as wave height (in meters) for high waves, broaching, parametric rolling, and synchronous rolling. The polar display graphically depicts seas, swell, significant wave height, and wind at any dead-reckoned position. Detailed information is listed under “Seas” and “Swell” below the polar display.

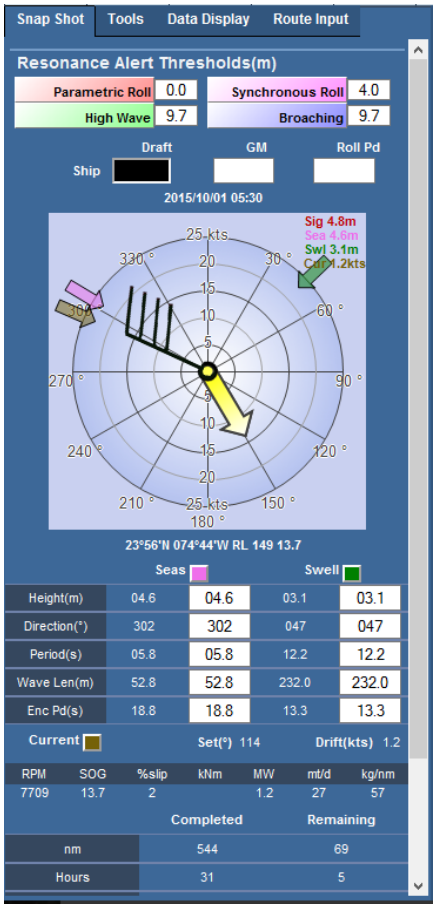

Figure 78 *– BVS Snap Shot tab.*

5.9.4. NAVTEX

See also section 5.2.1.12.

[88] These four parameters are expressed in terms of height (meters).

5.9.5. Facsimile

Radiofax, also known as “HF FAX,” radiofacsimile, or weatherfax, broadcasts weather charts and other data via HF radio. HF radiofax is also known as WEFAX, although that term generally refers to the reception of weather charts and images via satellite. Charts are received by a dedicated radiofax receiver or a single sideband shortwave receiver connected to an external facsimile recorder or to a personal computer equipped with a radiofax interface and application software.

Shown below is the nominal schedule on which the Coast Guard delivered weather graphics and text via facsimile from New Orleans. Links to examples of graphics sent at specific times can be found at http://www.nws.noaa.gov/om/marine/hfgulf_links.htm. Many of those graphics are reproduced in section 5.3.

NEW ORLEANS, LOUISIANA, U.S.A.

CALL SIGN	FREQUENCIES	TIMES (UTC)	EMISSION	POWER
NMG	4317.9 kHz	ALL BROADCAST TIMES	F3C	4 KW
	8503.9 kHz	ALL BROADCAST TIMES	F3C	4 KW
	12789.9 kHz	ALL BROADCAST TIMES	F3C	4 KW
	17146.4 kHz	1200-2045	F3C	4 KW

TRANS TIME	CONTENTS OF TRANSMISSION	RPM/IOC	VALID TIME	MAP AREA
0000/1200	TEST PATTERN	120/576		
0005/1205	U.S./TROPICAL SURFACE ANALYSIS (W HALF)	120/576	18/06	1
0020/1220	TROPICAL SURFACE ANALYSIS (E HALF)	120/576	18/06	2
0035/1235	REBROADCAST OF 1925/0725 (24 HR WIND/WAVE)	120/576	12/00	3
0045/1245	REBROADCAST OF 1950/0750 (48 HR WIND/WAVE)	120/576	12/00	3
0055/1255	REBROADCAST OF 2015/0815 (72 HR WIND/WAVE)	120/576	12/00	3
0105/1305	REBROADCAST OF 1855/0655 (24 HR SURFACE)	120/576	12/00	3
0115/1315	REBROADCAST OF 1905/0705 (48 HR SURFACE)	120/576	12/00	3
0125/1325	REBROADCAST OF 1915/0715 (72 HR SURFACE)	120/576	12/00	3
0135/1335	CYCLONE DANGER AREA* or HIGH WIND/WAVES	120/576	21/09	6
0150/----	REBROADCAST OF 0825 (72 HR WAVE PD/SWELL)	120/576	0000	3
----/1350	36 HR WIND/WAVE FORECAST	120/576	1200	3
0200/1400	GOES IR TROPICAL SATELLITE IMAGE	120/576	00/12	4
0215/1415	SEA STATE ANALYSIS	120/576	00/12	3
0225/1425	REQUEST FOR COMMENTS/PRODUCT NOTICE	120/576		
0245/1445	HIGH SEAS FORECAST (IN ENGLISH)	120/576	22/10	5
0600/1800	TEST PATTERN	120/576		
0605/1805	U.S./TROPICAL SURFACE ANALYSIS (W HALF)	120/576	00/12	1
0620/1820	TROPICAL SURFACE ANALYSIS (E HALF)	120/576	00/12	2
0635/1835	48 HR WAVE PERIOD/SWELL DIRECTION	120/576	00/12	3
0645/1845	REBROADCAST OF 0215/1415 (SEA STATE ANAL')	120/576	00/12	3
0655/1855	24 HR SURFACE FORECAST	120/576	00/12	3
0705/1905	48 HR SURFACE FORECAST	120/576	00/12	3
0715/1915	72 HR SURFACE FORECAST	120/576	00/12	3
0725/1925	24 HR WIND/WAVE FORECAST	120/576	00/12	3
0735/1935	CYCLONE DANGER AREA* or HIGH WIND/WAVES	120/576	03/15	6
0750/1950	48 HR WIND/WAVE FORECAST	120/576	00/12	3
0800/2000	GOES IR TROPICAL SATELLITE IMAGE	120/576	07/18	4
0815/2015	72 HR WIND/WAVE FORECAST	120/576	00/12	3

```
0825/----   72 HR WAVE PERIOD/SWELL DIRECTION          120/576  0000      3
0835/----   REBROADCAST OF 0215  (SEA STATE ANALYSIS)  120/576  0000      3
----/2025   BROADCAST SCHEDULE                         120/576
0845/2045   HIGH SEAS FORECAST (IN ENGLISH)           120/576  04/16     5

* Tropical Cyclone Danger Area chart replaced by 48HR High Wind/Wave Warning
chart Dec 01 - May 14 Valid times 00z,06z,12z and 18z, Map area 05N-40N,
35W-100W

MAP AREAS:      1.   5S - 50N, 55W - 125W
                2.   5S - 50N,  0W -  70W
                3.   0N - 31N, 35W - 100W
                4.  12S - 44N, 28W - 112W
                5.   7N - 31N, 35W -  98W (AREA COVERED BY TEXT FORECAST)
                6.  05N - 60N,  0W - 100W
```

5.9.6. VOBRA

The Coast Guard's VOBRA broadcasts of weather information applicable to the Bahamas region were disseminated from New Orleans and from Chesapeake, Virginia. Included in these broadcasts were the applicable NHC VOBRA text product, the applicable OPC-issued High Seas Forecast, the NHC Tropical Cyclone Forecast/Advisory text products, and the Tropical Weather Outlooks for the Atlantic.[89] A complete set, in chronological order, of Tropical Weather Outlooks for the Atlantic valid between 2000 EDT on September 28, 2015, and 0800 EDT on October 1, 2015, is found in Attachment 28.

According to Coast Guard Communications Command (COMMCOM), the nominal transmission range for HF is 400 miles, but it can vary up to 1,500 miles and depends on time of day, atmospheric conditions, and the height of the disseminating and receiving antennas.

According to the Coast Guard, VOBRA broadcast times from New Orleans and Chesapeake are as follows:

0115 EDT	OPC-issued High Seas Forecast, Tropical Cyclone Forecast/Advisory, Tropical Weather Outlook
0530 EDT	Various NHC VOBRA text products, Tropical Cyclone Forecast/Advisory, Tropical Weather Outlook
0715 EDT	OPC-issued High Seas Forecast, Tropical Cyclone Forecast/Advisory, Tropical Weather Outlook
1130 EDT	Various NHC VOBRA text products, Tropical Cyclone Forecast/Advisory, Tropical Weather Outlook

[89] The Tropical Weather Outlook (WMO header ABNT20 KNHC and AWIPS header TWOAT for the Atlantic) discusses significant areas of disturbed weather and their potential for development during the next 5 days, including quantitative probabilistic forecasts of the likelihood of tropical cyclone formation during the first 48 hours and during the entire 5-day forecast period. The Outlook for the Atlantic is issued between June 1 and November 30 at 0200 EDT, 0800 EDT, 1400 EDT, and 2000 EDT when daylight saving time is active. When eastern standard time [EST] is active, the Outlooks are issued one hour earlier (e.g., 0100 EST, 0700 EST, 1300 EST, and 1900 EST).

1315 EDT	OPC-issued High Seas Forecast, Tropical Cyclone Forecast/Advisory, Tropical Weather Outlook
1730 EDT	Various NHC VOBRA text products, Tropical Cyclone Forecast/Advisory, Tropical Weather Outlook
1915 EDT	OPC-issued High Seas Forecast, Tropical Cyclone Forecast/Advisory, Tropical Weather Outlook
2330 EDT	Various NHC VOBRA text products, Tropical Cyclone Forecast/Advisory, Tropical Weather Outlook

COMMCOM provided server logs of Chesapeake VOBRA broadcast activity (Attachment 29) for September 30, 2105, and October 1, 2015 (in UTC time). The logs also included NAVTEX, HF SImplex Teletype Over Radio (SITOR), and facsimile broadcast activity from Chesapeake and other Coast Guard broadcasting sites, as well as VOBRA broadcast activity from Point Reyes, California, and Honolulu. VOBRA broadcast activity from New Orleans was not included in the server logs provided by COMMCOM. However, according to additional information from the Coast Guard, transmission from New Orleans of a scheduled, weather-related VOBRA product is implied when that same product is logged as having been transmitted from Chesapeake. Additional server logs were not available because that information was requested after the 30-day log retention period had expired. The server logs provided by COMMCOM were retained by the Coast Guard without request from the NTSB.

According to the Coast Guard and the Navy, NOAA/NWS weather products intended for broadcast are provided to the Coast Guard by the Navy's Fleet Weather Center. According to the Coast Guard "The CG [Coast Guard] transitioned from CGMS (Coast Guard Message System) to C2OIX (Command and Control Official Information Exchange) on 03 AUG 2015. Since NOAA/NWS was unable to directly transmit messages via C2OIX, we coordinated w/Navy FLEWEACEN [Fleet Weather Center] to retransmit NOAA/NWS weather messages to the CG from their NOAAPort stream. The text of the messages is never changed, just the header indicating it was forwarded by FLEWEACEN."

The following table details the actual times of broadcast for weather products (previously identified as applicable to the accident region [90]) being disseminated via VOBRA from Chesapeake according to the server logs provided by COMMCOM (advisory numbers, where applicable, are not included). Records for broadcast times after the accident are included. Note that the records for the Chesapeake VOBRA broadcast of the OPC-issued High Seas Forecast expected soon after the regularly scheduled daily nominal dissemination time of 1915 EDT on both September 30, 2015, and October 1, 2015, indicated (in part) "MSG MISSED BCST." According to the Coast Guard, this means that the OPC-issued High Seas Forecast was not broadcast for that nominal time on those days; however, the NTSB is unable to confirm this. Further, the server logs do not provide records that indicate the Chesapeake VOBRA broadcasts of (1) the Tropical Cyclone Forecast/Advisory associated with the regularly scheduled daily nominal dissemination times of 2330 EDT on September 29, 2015, 0530 EDT,

[90] We neglect VOBRA text products not applicable to the accident region.

1130 EDT, 1730 EDT, and 2330 EDT on September 30, 2015, and 0530 EDT, 1130 EDT, and 1730 EDT on October 1, 2015; and (2) the NHC VOBRA text product (AWIPS header OFFN20) associated with the regularly scheduled daily nominal dissemination time of 1130 EDT on September 30, 2015.

0014:38 EDT September 30, 2015	NHC VOBRA text product (AWIPS header OFFN20)
0025:23 EDT September 30, 2015	Tropical Weather Outlook
0122:35 EDT September 30, 2015	Tropical Cyclone Forecast/Advisory
0137:13 EDT September 30, 2015	OPC-issued High Seas Forecast
0139:38 EDT September 30, 2015	Tropical Weather Outlook
0614:15 EDT September 30, 2015	NHC VOBRA text product (AWIPS header OFFN20)
0624:27 EDT September 30, 2015	Tropical Weather Outlook
0723:41 EDT September 30, 2015	Tropical Cyclone Forecast/Advisory
0739:39 EDT September 30, 2015	OPC-issued High Seas Forecast
0742:04 EDT September 30, 2015	Tropical Weather Outlook
1222:50 EDT September 30, 2015	Tropical Weather Outlook
1323:05 EDT September 30, 2015	Tropical Cyclone Forecast/Advisory
1341:42 EDT September 30, 2015	OPC-issued High Seas Forecast
1344:12 EDT September 30, 2015	Tropical Weather Outlook
1815:29 EDT September 30, 2015	NHC VOBRA text product (AWIPS header OFFN20)
1825:30 EDT September 30, 2015	Tropical Weather Outlook
1924:21 EDT September 30, 2015	Tropical Cyclone Forecast/Advisory
1924:21 EDT September 30, 2015	(MISSED) OPC-issued High Seas Forecast
1926:53 EDT September 30, 2015	Tropical Weather Outlook
0016:57 EDT October 1, 2015	NHC VOBRA text product (AWIPS header OFFN20)
0027:04 EDT October 1, 2015	Tropical Weather Outlook
0123:46 EDT October 1, 2015	Tropical Cyclone Forecast/Advisory
0141:05 EDT October 1, 2015	OPC-issued High Seas Forecast
0143:34 EDT October 1, 2015	Tropical Weather Outlook
0616:22 EDT October 1, 2015	NHC VOBRA text product (AWIPS header OFFN20)
0625:50 EDT October 1, 2015	Tropical Weather Outlook
0723:26 EDT October 1, 2015	Tropical Cyclone Forecast/Advisory
0740:13 EDT October 1, 2015	OPC-issued High Seas Forecast
0742:41 EDT October 1, 2015	Tropical Weather Outlook
1215:06 EDT October 1, 2015	NHC VOBRA text product (AWIPS header OFFN20)
1224:35 EDT October 1, 2015	Tropical Weather Outlook
1323:38 EDT October 1, 2015	Tropical Cyclone Forecast/Advisory
1341:57 EDT October 1, 2015	OPC-issued High Seas Forecast
1344:27 EDT October 1, 2015	Tropical Weather Outlook

1819:32 EDT October 1, 2015	NHC VOBRA text product (AWIPS header OFFN20)
1829:48 EDT October 1, 2015	Tropical Weather Outlook
1923:33 EDT October 1, 2015	Tropical Cyclone Forecast/Advisory
1923:33 EDT October 1, 2015	(MISSED) OPC-issued High Seas Forecast
1926:07 EDT October 1, 2015	Tropical Weather Outlook

5.9.7. HF SITOR

The Coast Guard broadcasts NWS text weather information from four high seas communication stations in the SITOR mode. The broadcasts are prepared cooperatively by the OPC, the NHC, and the NWS WFO in Honolulu. The Coast Guard broadcasts weather information for the Bahamas region out of Boston, Massachusetts. Included are the OPC-issued High Seas Forecast and an OPC-issued VOBRA text product applicable for the Atlantic waters of the northeastern coast of the United States (WMO header FZNT33 KWBC and AWIPS header OFFN31).

According to COMMCOM, the nominal transmission range for HF is 400 miles, but it can vary up to 1,500 miles and depends on time of day, atmospheric conditions, and height of disseminating and receiving antennas. Published broadcast times from Boston for these products are 1230 EDT and 2140 EDT.

According to the server logs provided by COMMCOM discussed in section 5.9.6, between 2000 EDT on September 29, 2015, and the accident time, the OPC-issued High Seas Forecasts were broadcast via HF SITOR from Boston at 2157:25 EDT on September 29, 2015, and at 1258:07 EDT and 2200:59 EDT on September 30, 2015.

5.9.8. NWS FTPmail

The NWS FTPmail system, which has been available since 1997, allows users to access NWS real-time[91] text and graphics by standard email. Mariners who have email connectivity (e.g., via satellite) but no open internet activity (capability to web-browse) are identified as the ideal users of the FTPmail system. Weather information is accessed via FTPmail when the user sends an email to *ftpmail@ftpmail.nws.noaa.gov*, with a series of specific commands in the email body. Once the request is received, the NWS server runs the commands and returns the results (requested weather data as an attachment or text) in an automated email back to the requestor's email account. One product is usually sent per reply email. It is not possible to schedule recurring data delivery via FTPmail; an individual request must be made each time

[91] The NWS includes a disclaimer that reads (in part): *Check time and date of forecasts. "Downloaded data may not represent the latest forecast. The Internet is not part of the National Weather Service's operational data stream and should never be relied upon as a means to obtain the latest forecast and warning data. Become familiar with and use other means, such as NOAA Weather Radio, to obtain the latest forecasts and warnings."* According to the NWS, after products are generated, it typically takes 1 to 5 minutes before they appear on the server used for FTPmail. Availability is product-specific, and urgent products, such as warnings, have a higher priority than routine products and are available on the server sooner than routine products.

weather information is desired. FTPmail typically receives requests from between 1,000 and 2,000 individual users a month.

The syntax for sending user commands to the NWS is strict. The complete user help file for FTPmail (see Attachment 30) contains instruction for generating email requests and ensuring that requested data are received correctly. According to the help file, "99% of errors using FTPmail are simple typing errors, incorrect capitalization, failure to send in plain text format, leading or trailing spaces, or failure to set up any spam filters properly" and "correct capitalization for commands, directory and file names is critical." Proper construction of user-emailed commands is essential, and knowledge of WMO or AWIPS text and graphical product headers is necessary (some headers can be obtained by following instructions in the help file). For products such as the Tropical Cyclone Forecast/Advisory that have WMO headers in which the sixth digit is assigned according to cyclone number, prior knowledge of the number is required to request products for the desired cyclone. (Alternatively, individual requests can be sent for each of the five WMO/AWIPS header options to cover any active storm numbers.) A thorough documentation of FTPmail options is found in the NWS publication "Worldwide Marine Radiofascimile Broadcast Schedules."[92] According to the former NOAA Marine Dissemination Manager, in the past NWS Port Meteorological Officers (PMOs) sent the document directly to vessels, but funding for this service ended "several years ago."

As an example, if a user wants to receive via FTPmail the most recent Tropical Cyclone Public Advisory for the Atlantic for cyclone number 1 (WMO header WTNT31 KNHC, AWIPS header TCPAT1), the following email message should be sent:

```
open
cd data
cd raw
cd wt
get wtnt31.knhc.tcp.at1.txt
quit
```

According to the NWS, email response time is "generally less than one hour; however, performance may vary widely and the NWS cannot guarantee receipt." The NTSB generally received email responses from the NWS FTPmail system in less than 5 minutes.

The NWS text product types discussed in this report are available through FTPmail (the returned products are current at the time of request, rather than archived data). FTPmail can also send .gif or .tif files of certain analysis and forecast charts and weather satellite images.[93] Not currently available (though they were in the past) are the following graphics: NHC Tropical Cyclone Surface Wind Field; 5-day forecasts of 34-knot, 50-knot, and 64-knot Wind Speed Probability; and Tropical Cyclone Track Forecast Cone and Watches/Warnings.

A review of emails sent to and from *El Faro* between September 1, 2015, and the accident time did not discover any email traffic between the vessel and FTPmail.

[92] http://www.nws.noaa.gov/om/marine/rfax.pdf

[93] A full list of available charts may be found at: ftp://tgftp.nws.noaa.gov/fax

5.9.9. Coast Guard Airplane

The Coast Guard launched an aircraft on September 30, 2015, and October 1, 2015, to broadcast weather information to mariners in the Bahamas region. The Coast Guard is not required to issue prestorm advisories or callouts from aircraft and does so as a "best practice" to minimize the number of mariners placed in harm's way. The decision to launch a broadcast flight or to broadcast during an already airborne flight is made at the local level, usually by the SAR Mission Coordinator (SMC). Factors that could influence a decision to provide the service include the availability of missions of opportunity (meaning that an aircraft is already tasked for another mission in an area and could make weather callouts at the same time), the storm's forecast strength, how long the storm has been tracked, and how well the storm has adhered to its forecast track. According to the Coast Guard, in the case of Hurricane Joaquin, the SMC considered the storm's unusual point of origin; the short time mariners had to assess the storm, the storm's continued and unexpected strengthening, and the availability of fixed-wing aircraft to support the flights. The SMC decided to launch Coast Guard aircraft to broadcast prestorm weather advisories. Air Force and NOAA reconnaissance aircraft also made specific callouts to *El Faro* after the vessel was determined to be in distress. They were not engaged ahead of time to convey weather advisories, however, because other government aircraft are typically not used on behalf of the Coast Guard for such purposes.

At 1121 EDT on September 30, 2015, the Coast Guard launched an HC-144 Ocean Sentry aircraft (tail number CG2310) from Miami. Written statements were obtained from the six-member crew (see Attachment 31). The crew stated that they were tasked with broadcasting hurricane warnings over maritime channel 16 and were directed to cover the Straits of Florida and as much of the Bahamian islands as possible, depending on inflight weather. The broadcast script was read every 15 minutes [94] and contained information from NOAA and www.weather.com. It identified specific islands for which storm warnings had been issued, described the storm's severity, and gave its predicted strength and location over the next several days. According to the Aircraft Commander, it was suggested to all underway vessels in the areas[95] that they seek shelter. CG2310 received responses from unidentified vessels that included thank-yous, requests for additional information pertaining to a particular island, and requests to repeat information. [96] According to one crewmember, "Occasionally, mariners couldn't quite hear us due to the traffic on 16, so we directed them to working frequency Ch. 22 and repeated the message to them." According to the Aircraft Commander, Coast Guard Sector Key West could hear CG2310's broadcast when the aircraft was about 250 miles away. At some point, CG2310 diverted to respond to a Mayday call. The aircraft then completed its mission and returned to base at 1530 EDT on September 30, 2015.

[94] However, the Aircraft Commander approximated a larger broadcast interval of 15 to 30 minutes.

[95] The specific areas are unknown. No archived copy of the broadcast script was available.

[96] Separately, the Coast Guard indicated that *El Faro* did not query CG2310.

Figure 79 shows an approximate flight path for CG2310 on September 30, 2015, provided by the Aircraft Commander. The aircraft flew south on departing Miami. The following text is from the official flight record for CG2310:

> *Call outs conducted on Maritime CH16 from 8000' MSL throughout the FL Straits, East to 23-10N 76-29W (43 SW of Great Exuma Island), North to 25-17N 76-17W (Governors Harbour). Call outs confirmed to reach at least 280NM radius via Sector KW watchstander. Call out was a 30 second script created from information on NOAA's website about hurricane watch and hurricane warning areas, all mariners were told to contact the Coast Guard on CH 16 with concerns, 05 vessels responded asking for amplifying informaiton* [sic] *about the hurricane. 01 SAR response for Mayday call 20 NM SE of Nassau in response to call out. MISLE: 996087. UCN: 398-15. 08 lives assisted. Continuted* [sic] *call outs from 6000' MSL once north bound from assisting vessel.*

The Coast Guard flight of October 1, 2015, began after the accident.

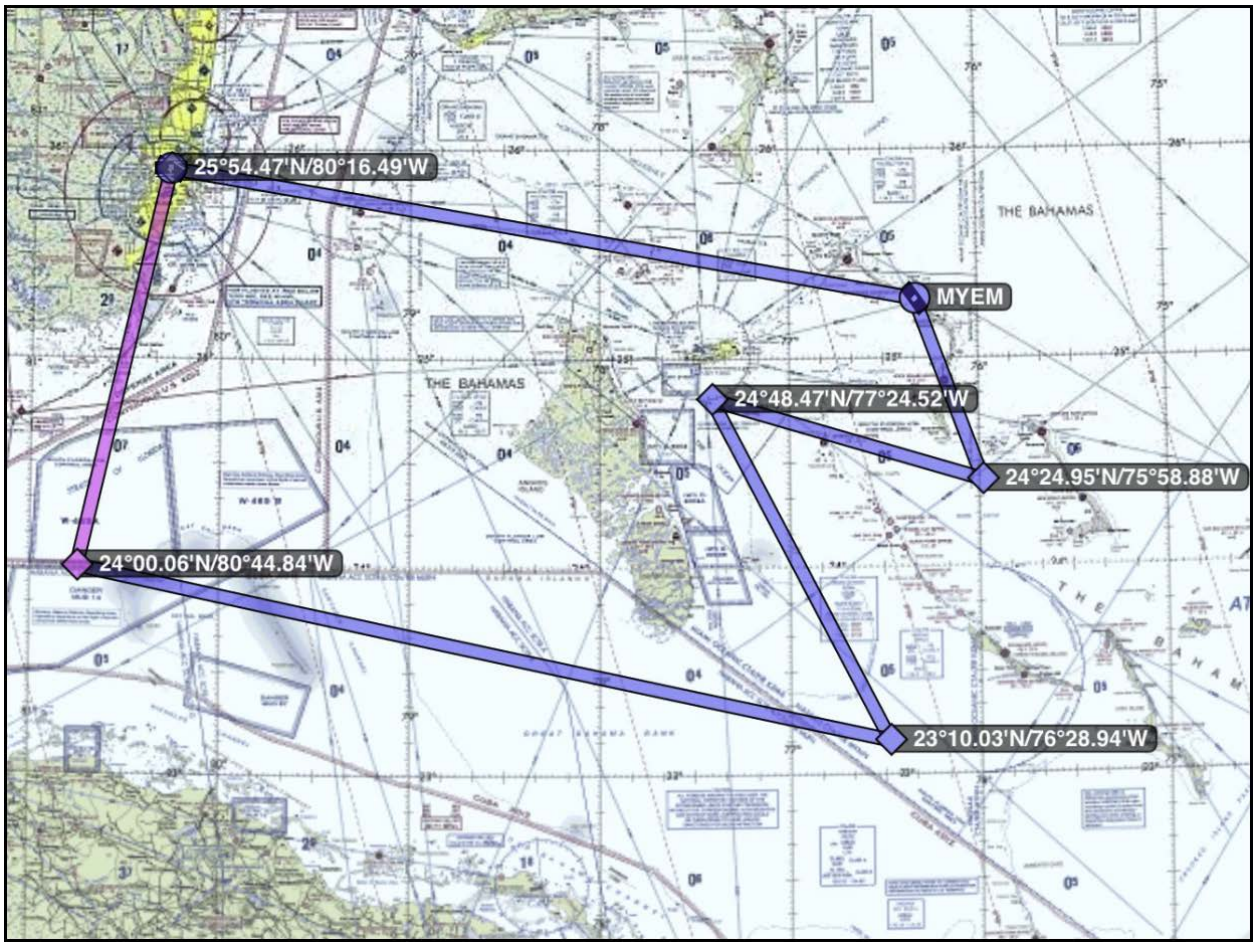

Figure 79 *– Approximate flight path of CG2310 on September 30, 2015. The aircraft flew south on departing Miami.*

5.9.10. Radio Transmissions from the Bahamas

Every morning, the Bahamas Air Sea Rescue Association (BASRA) broadcasts weather information that includes the southeast Florida 5-day forecast and the Bahamas 3-day forecast. Forecasts are read over very-high-frequency (VHF) channel 72 at 0715 local time (LT) and over upper sideband 4003 kHz at 0720 LT. BASRA also identified a Waterway Radio ham net that operates at 0745 LT over lower sideband 7268 kHz. According to BASRA, the VHF broadcast is available only in the Nassau area, but the single-sideband broadcasts can be heard throughout the Bahamas. BASRA stated that on September 30, 2015, and October 1, 2015, its broadcasts would have included details about Hurricane Joaquin as it knew them. It was not possible to verify the content of the BASRA broadcasts.

BASRA further indicated that it is not aware of any other entity transmitting weather information over VHF in the Bahamas.

5.9.11. WWV HF Voice (Time Tick)

The National Institute of Standards and Technology broadcasts a time and frequency service from Colorado (station WWV)[97] over 2.5, 5, 10, 15, 20, and 25 megahertz. Mariners call it the "time tick" and use it to aid celestial navigation. Hourly voice recordings of current high seas storm warnings for the Atlantic region are broadcast at 8 and 9 minutes past the hour. The service is intended to supplement the more-complete primary marine weather broadcasts found in this report. Broadcasts from WWV can also be heard over the telephone.

The recordings, which are generated by the OPC, are short, typically lasting 40 seconds or less. According to the OPC, “The WWV Boulder Broadcast is a recorded telephone version of the Atlantic High Seas Text Forecast synoptic features west of 35W. The recording is made four times per day after each Atlantic High Seas Text Forecast is disseminated. The recording consists of two portions; Warning Forecasts and Other Forecasts. The recorded forecasts are a very condensed version of the High Seas Forecast and contain initial conditions with an accompanying 24 hour forecast. The Atlantic forecast is recorded under Messages 2 AND 3, and is limited to 43 seconds in length each…. The broadcasts are usually completed by 1630 UTC, 2230 UTC, 0430 UTC, and 1030 UTC.” OPC continues: “the broadcast(s) should provide the lat/lon of the location of the center of a tropical cyclone if it was west of 35W.”

[97] A second broadcast is also made from Kauai, Hawaii (station WWVH).

5.10. Additional Information

5.10.1. NWS Metadata on *El Faro*

The NWS provided metadata for *El Faro (*Attachment 32), which it describes as "a dynamic document. In other words, as ships change equipment, upgrade, etc., the PMO responsible for the ship should be updating this metadata as needed in those regards to reflect its current status indicating what they are using for producing marine weather observations…The last onboard visit [to *El Faro*] from the PMO was logged April 28 2015… In the [screenshot] below [figure 80] it shows the visits to this ship and that the PMO was very engaged with the ship and crew. It can be assumed that metadata is updated each onboard visit, so that would make April 28 2015 when it was [last] updated." According to the NWS, with the exception of the aneroid barometer (which is calibrated in a laboratory), "all instrument calibrations are conducted by the ship's company. The PMOs are not trained or tasked, nor do we support the cost or effort to calibrate the ships equipment."

The metadata are intended to record data and history for any weather-measuring instruments held on a ship: instrument ownership, type, model number, and other pertinent information. With regard to *El Faro*'s anemometer, according to the NWS the calibration date "was the date that the ship's owner recorded that they themselves had calibrated their anemometer. [The NWS] no longer calibrate[s] any instruments on ships. We only record the dates that the ship's crew/owner/captain can provide to us. In some cases, that information is not available to us, because that paperwork/information cannot be found by the crew. . . . The fact that the anemometer was recorded in [our system] indicates that there was a working anemometer on the ship [as of the last input date] and the metadata gives you the type/model and where it was located. . . . it is indicated by the PMO that the general wind observing practice was to use the true wind computed by the anemometer." According to TOTE, the anemometer provided relative wind magnitude and direction, and true wind was computed by the crew. A common practice employed on *El Faro* was to input relative wind magnitude and direction into a program (WayPoint for Windows) to get true wind magnitude and direction.

According to the NWS, "The *El Faro*…held an analog style aneroid barometer[98] in addition to a digital type barograph,[99] a DBX1 which would give the user a digital output of the current pressure as well as a graph which would display a one day graph screen of the tendency. It has the capability of displaying up to 5 days of information (tendency, high/low pressure recorded, the 6 and 12 hour pressure change). None of this information is printed or recorded for purposes to be archived…This DBX1 was installed by the PMO on 10/7/2014 at the request of the ship's crew. The old marine barograph, the style which would have the paper trace…was

[98] According to the NWS, on March 24, 2015, the PMO made an adjustment to this instrument of 0.50 hPa (hectopascals) to reflect mean sea level pressure. The instrument was not calibrated at that time, and the NWS has no record of when this piece of equipment was calibrated in a calibration lab. The NWS estimates that it would have been calibrated when it was installed on the vessel on April 8, 2011 (see Attachment 32).

[99] According to the NWS, the digital barograph was installed and adjusted (0.50 hPa) by the PMO on October 7, 2014. The NWS stated that according to internal records, the digital barograph was calibrated on purchase and receipt on January 1, 2014.

removed. VOS[100] has been phasing them out due to the high cost of trying to maintain obsolete instrumentation such as the Belfort Marine Barograph. You cannot even purchase paper for these anymore, and the barograph mechanisms are no longer available for purchase or repairable."

Ship information

Ship Name: EL FARO
Call Sign: WFJK
IMO Number: 7395351
Ship Status: De-recruited from VOS program

List of visits

Add a new visit

Visit Date	PMO	Visit Loca
2015-04-28	Jacksonville	Jacksonville FL
2015-03-24	Jacksonville	Jacksonville FL
2014-12-31	Jacksonville	Jacksonville FL
2014-12-16	Jacksonville	Jacksonville FL
2014-12-04	Jacksonville	Jacksonville FL
2014-11-25	Jacksonville	Jacksonville FL
2014-10-07	Jacksonville	Jacksonville FL
2014-09-23	Jacksonville	Jacksonville FL
2014-09-16	Jacksonville	Jacksonville FL
2014-08-19	Jacksonville	Jacksonville FL
2014-05-27	Jacksonville	Jacksonville FL
2014-05-20	Jacksonville	Jacksonville FL
2014-03-17	Jacksonville	Jacksonville FL
2014-02-26	Jacksonville	Jacksonville FL
2013-11-26	Jacksonville	Jacksonville FL
2012-01-31	Jacksonville	Jacksonville FL
2011-04-28	Jacksonville	Jacksonville FL
2011-04-08	Jacksonville	Jacksonville FL

Figure 80 *– NWS screenshot identifying PMO visits to* El Faro*.*

[100] Voluntary Observing Ship Program. Further information can be found at: http://www.vos.noaa.gov/

5.10.2. VOS Anemometer Information

The NWS provided metadata on anemometer installations and wind reporting practices for all ships (active and inactive) in the US VOS Program database (current as of October 12, 2016). These data[101] are presented in Attachment 33. With regard to wind observing practice, approximately 99 percent of the vessels in the database (who did not have a "NULL" indicator for wind observing practice) were identified as using anemometers rather than visual estimation techniques for assessing the wind information they provide in ship reports.

5.10.3. Panasonic Weather Solutions

Panasonic Avionics Corporation[102] provided the NTSB with initial position and forecast track output for Joaquin from Panasonic Weather Solutions' global weather forecasting platform, Panasonic Global 4D Weather. The platform runs four forecast cycles a day (0200 EDT, 0800 EDT, 1400 EDT, and 2000 EDT), has 13-km horizontal resolution with 64 vertical levels, assimilates Panasonic's TAMDAR[103] data, and advertises an enhanced tropical cyclone relocation algorithm.

Figures 81 through 90 show the Panasonic Global 4D Weather initial position and forecast track for Joaquin for forecast cycles initiated between 2000 EDT on September 28, 2015, and 0200 EDT on October 1, 2015. Forecast tracks are truncated for graphical purposes and do not show forecast positions beyond 0200 EDT on October 1, 2015 (for model runs initiated at 0800 EDT and 2000 EDT), or 1400 EDT on October 1, 2015 (for model runs initiated at 0200 EDT and 1400 EDT).

Figures 81 through 90 also show initial position and forecast track output for Joaquin from the GFS model [ATCF ID: AVNO], the Geophysical Fluid Dynamics Laboratory (GFDL) model [ATCF ID: GFDL], the ECMWF model [ATCF ID: EMX], the United Kingdom Met Office (UKMET) model [ATCF ID: EGRR], and the HWRF model [ATCF ID: HWRF], based on the data listed in Attachment 6. Output from those typically high-performing track models provide input to some of the primary consensus models used at the NHC. The figures include forecast cycles initiated between 2000 EDT on September 28, 2015, and 0200 EDT on October 1, 2015. The tracks are truncated for graphic purposes and do not show forecast positions beyond 0200 EDT on October 1, 2015. ECMWF and UKMET are initialized only at 0800 EDT and 2000 EDT.

Figures 81 through 90 also show the NHC's best track for Joaquin between 2000 EDT on September 28, 2015, and 0800 EDT on October 1, 2015.

[101] Some information that would allow specific vessels to be identified has been removed at the request of the NWS.

[102] Courtesy of Dr. Neil Jacobs, Chief Atmospheric Scientist, Panasonic Avionics Corporation.

[103] Panasonic's Tropospheric Airborne Meteorological Data Reporting (TAMDAR) instrument suite collects atmospheric information from participating commercial aircraft.

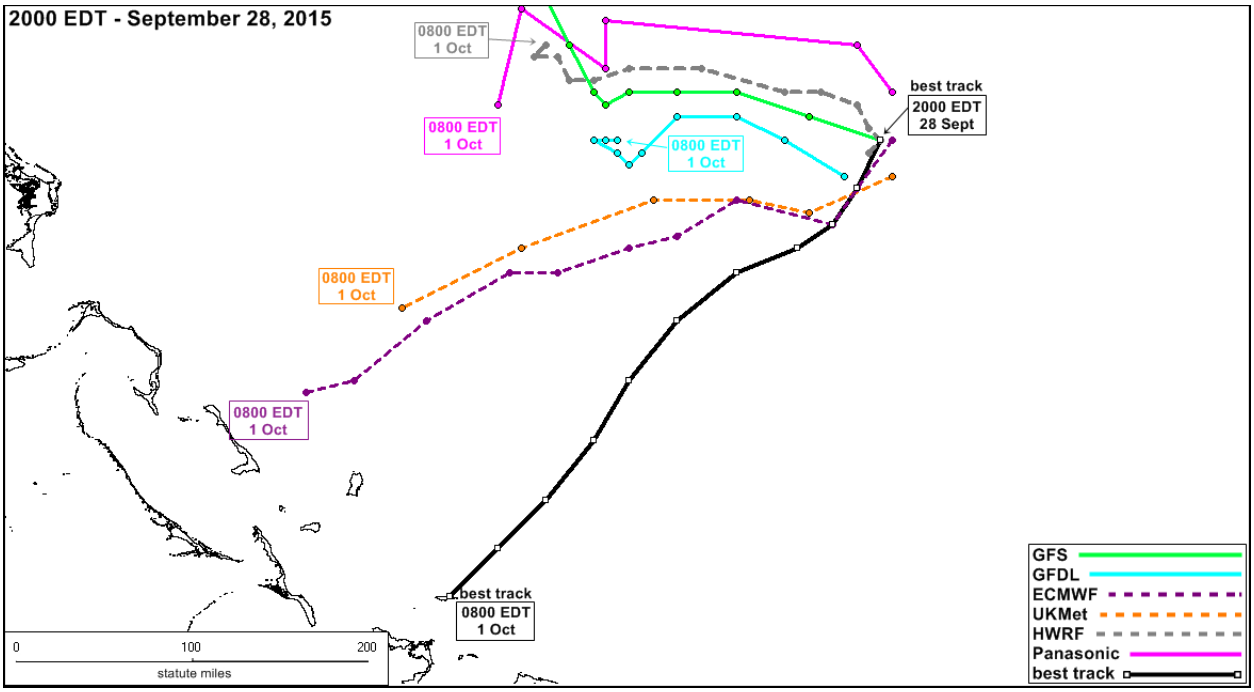

Figure 81 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 2000 EDT on September 28, 2015. Best track and forecast model output are truncated.*

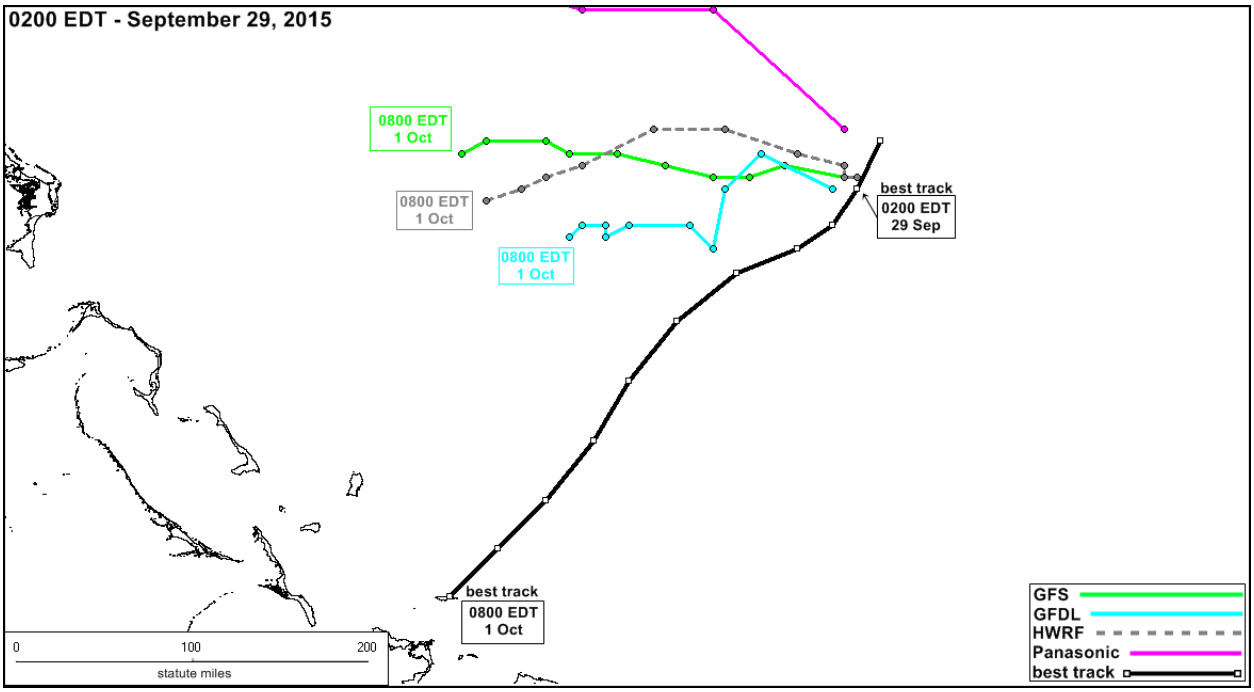

Figure 82 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 0200 EDT on September 29, 2015. Best track and forecast model output are truncated.*

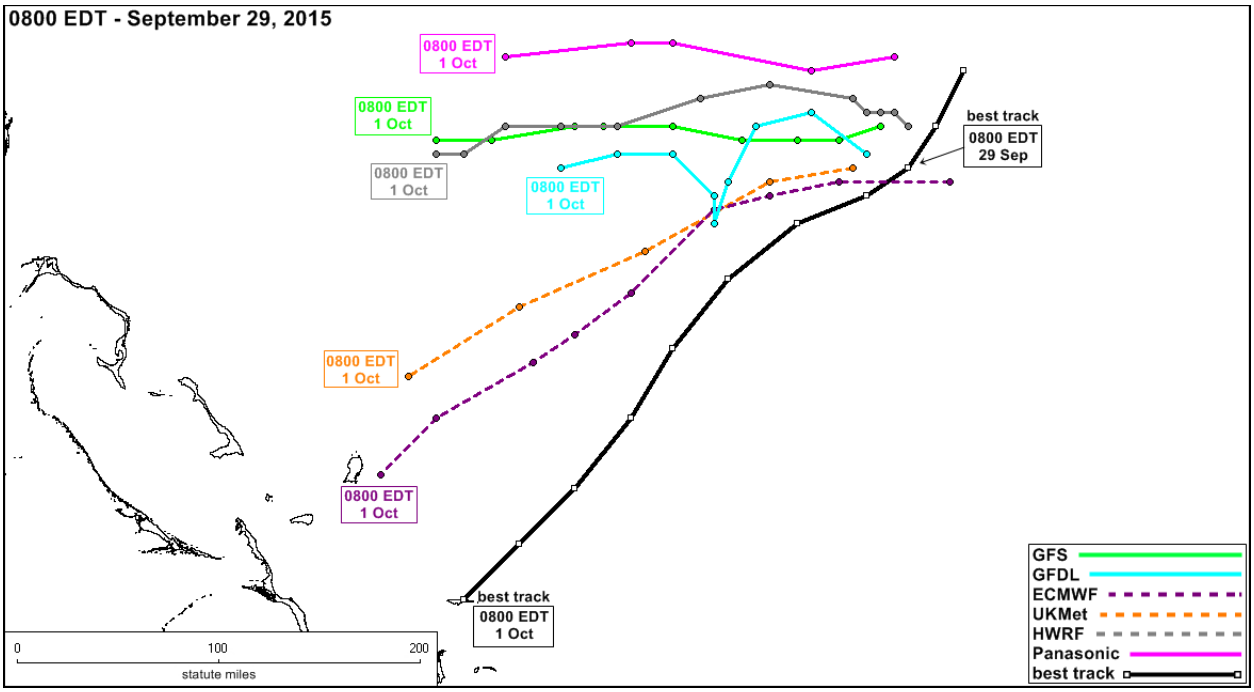

Figure 83 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 0800 EDT on September 29, 2015. Best track and forecast model output are truncated.*

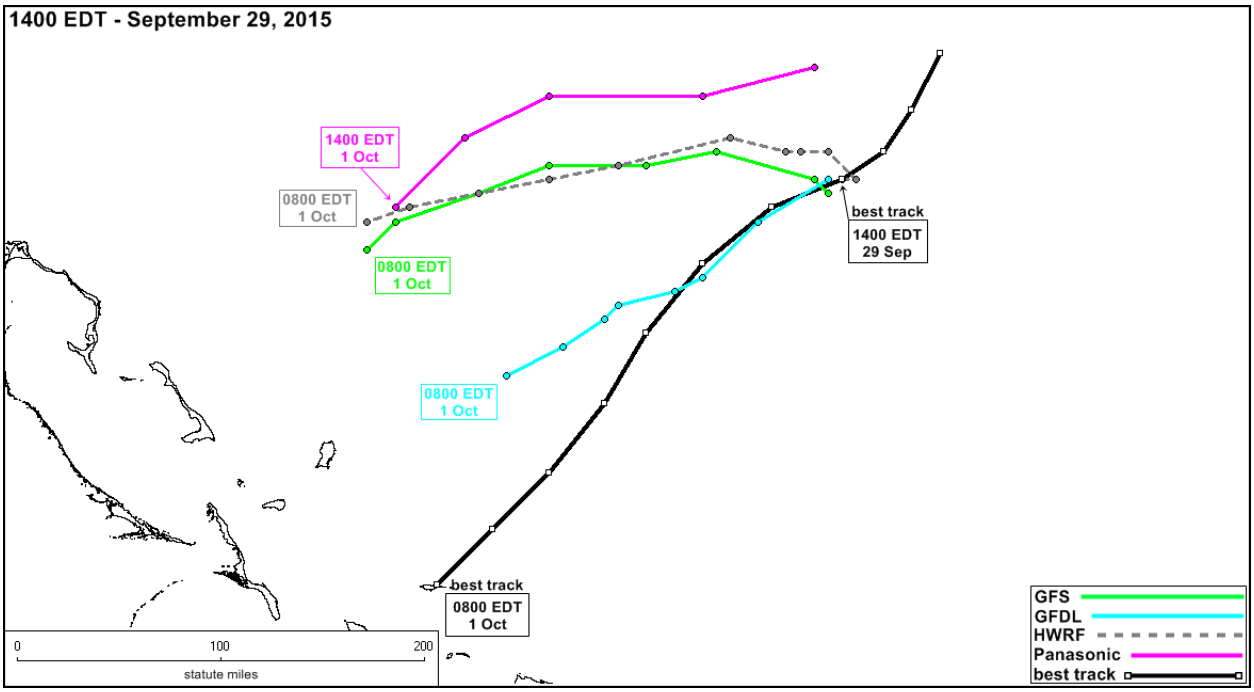

Figure 84 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 1400 EDT on September 29, 2015. Best track and forecast model output are truncated.*

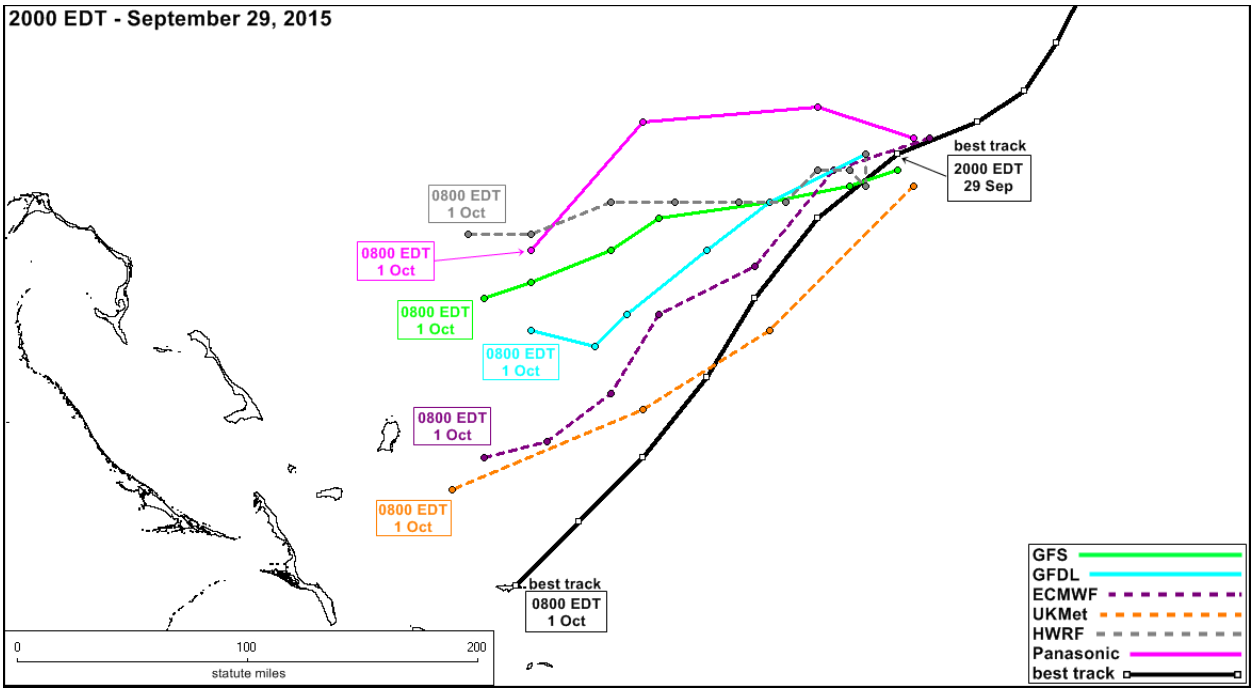

Figure 85 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 2000 EDT on September 29, 2015. Best track and forecast model output are truncated.*

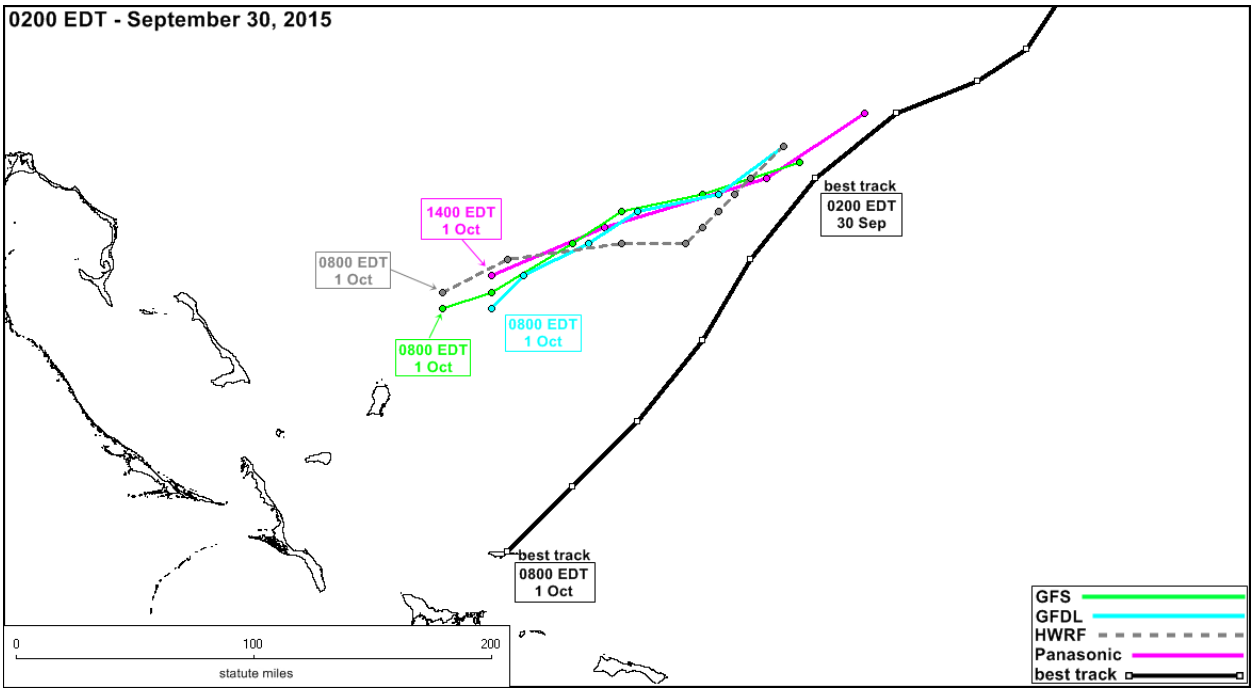

Figure 86 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 0200 EDT on September 30, 2015. Best track and forecast model output are truncated.*

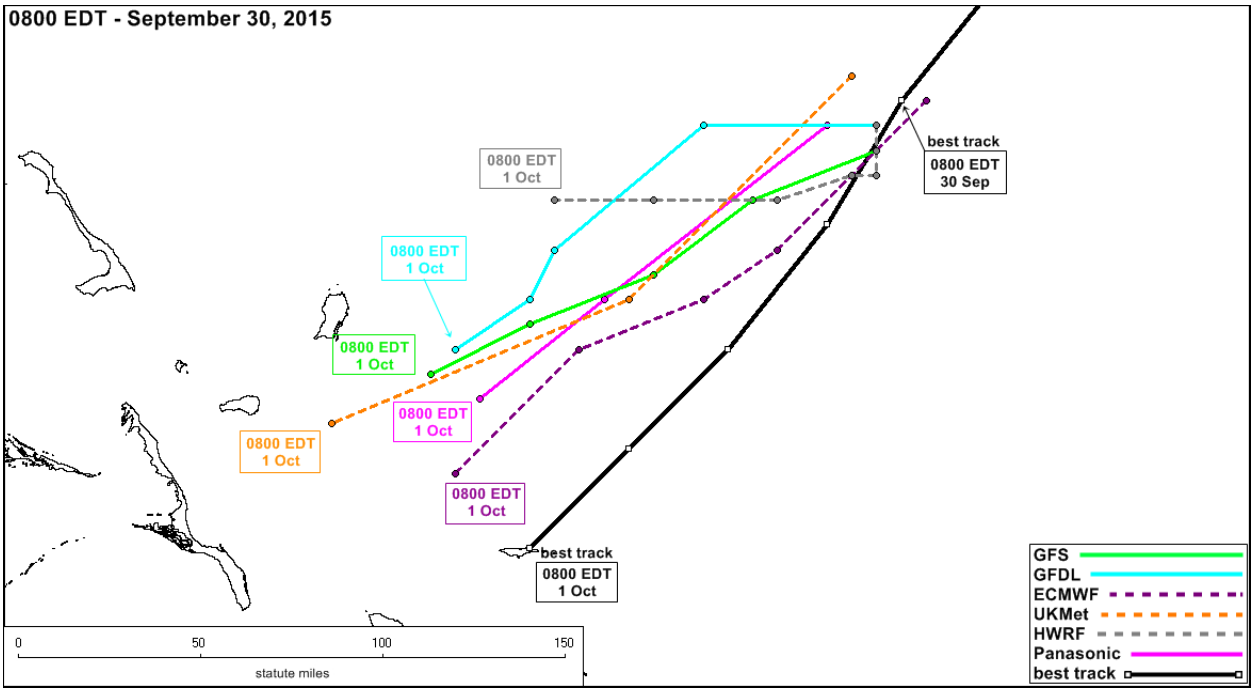

Figure 87 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 0800 EDT on September 30, 2015. Best track and forecast model output are truncated.*

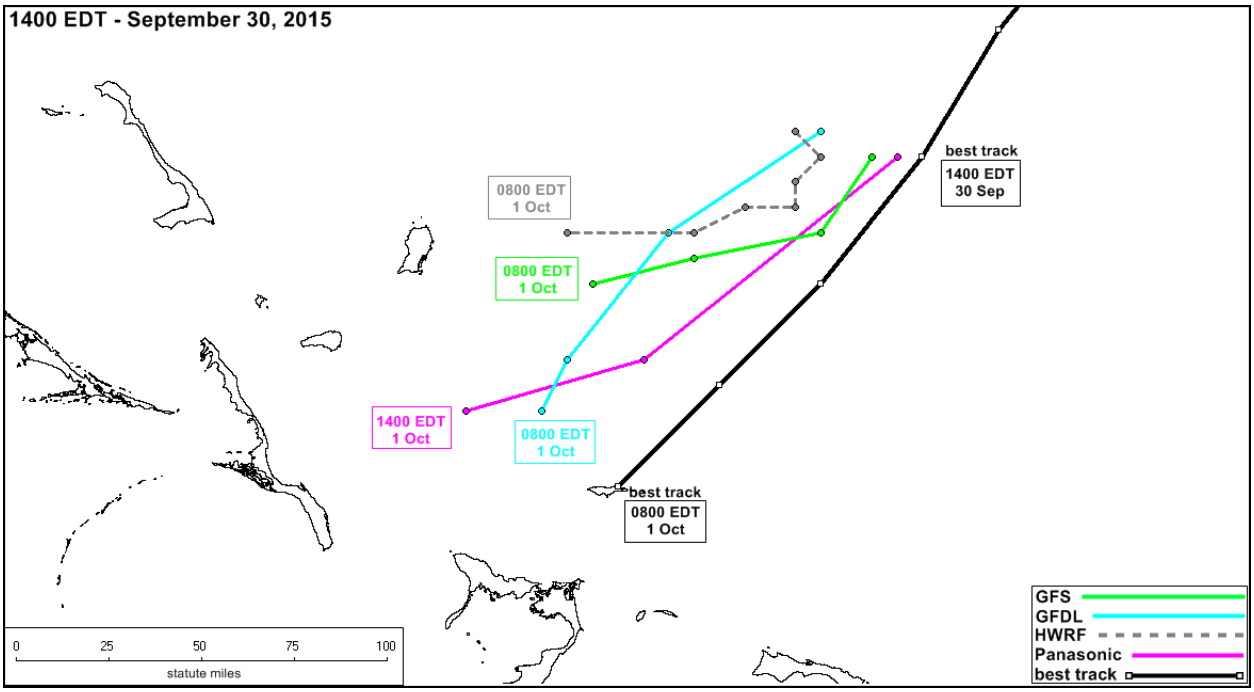

Figure 88 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 1400 EDT on September 30, 2015. Best track and forecast model output are truncated.*

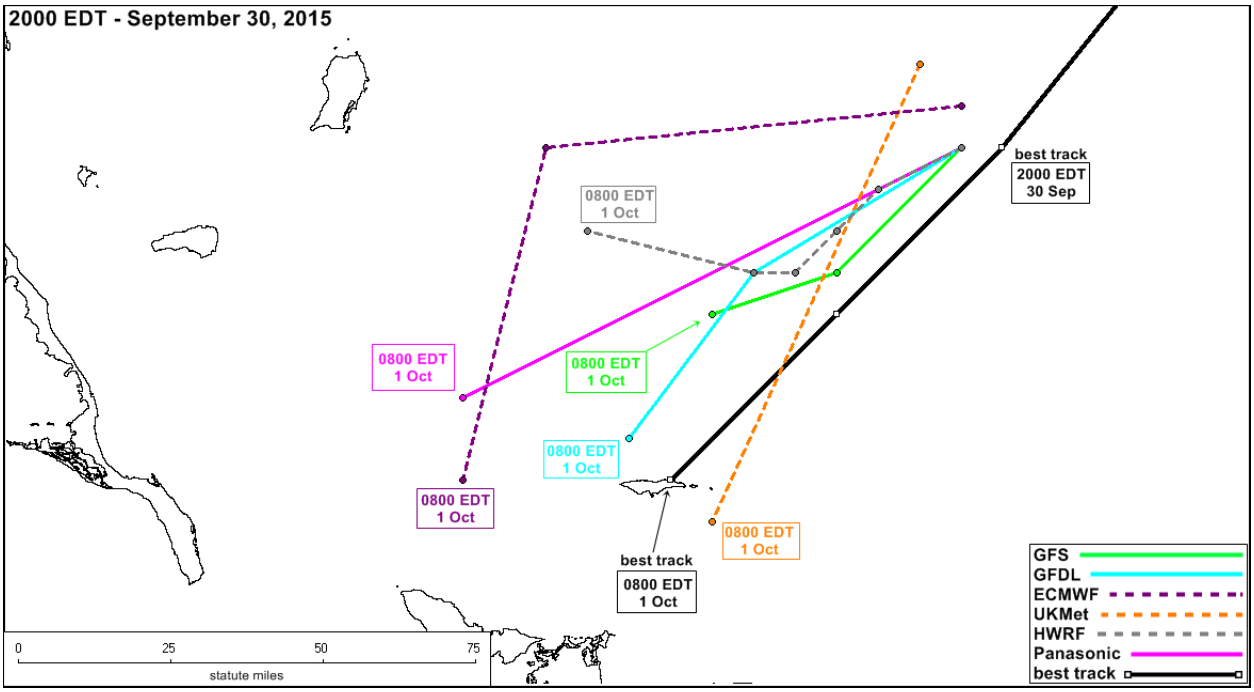

Figure 89 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 2000 EDT on September 30, 2015. Best track and forecast model output are truncated.*

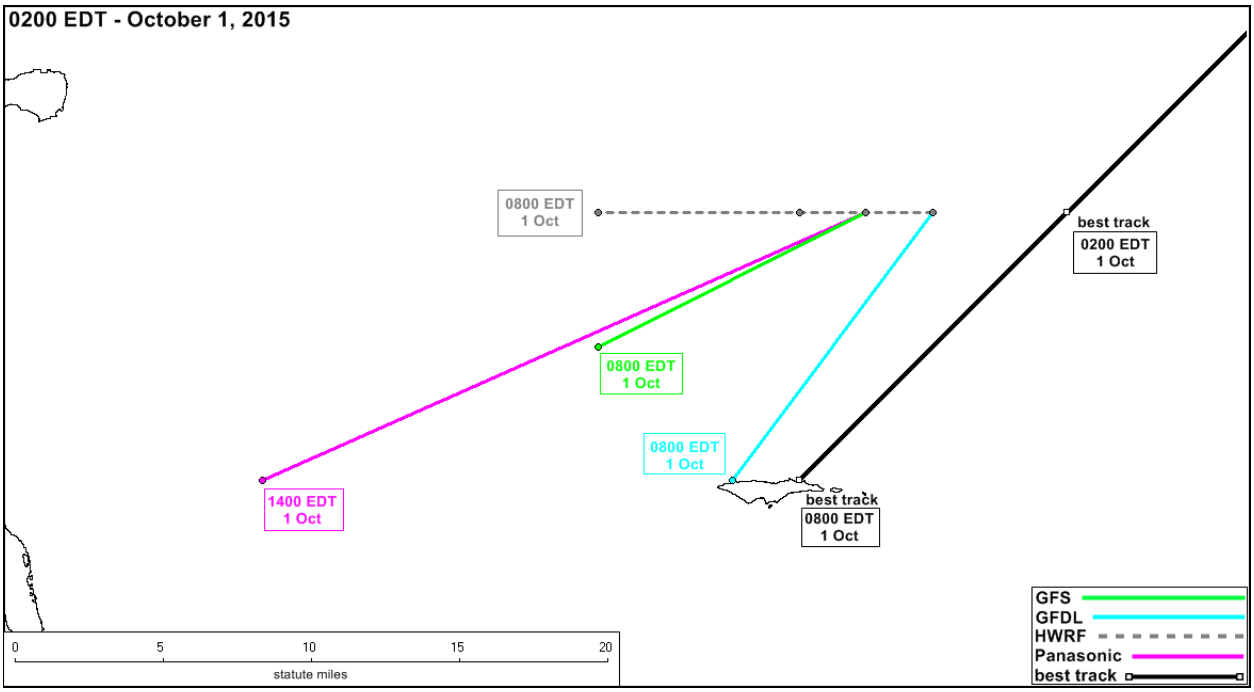

Figure 90 *– NHC best track and selected weather model output for Joaquin's current position and forecast track for model runs initiated at 0200 EDT on October 1, 2015. Best track and forecast model output are truncated.*

5.10.4. NHC Policy

The NTSB asked the NHC about its policy for issuing text products to the public to update cyclone information between the regularly scheduled Tropical Cyclone Forecast/Advisory products (nominally 0500 EDT, 1100 EDT, 1700 EDT, and 2300 EDT). The NHC responded on April 12, 2016, as follows:

A. *TCP [Tropical Cyclone Public Advisory] issued three hours after 6-hourly full product suite (includes the Tropical Cyclone Forecast/Advisory) when coastal tropical cyclone watch/warning in effect anywhere.*

B. *TCU [Tropical Cyclone Update] issued after first, second, fourth and fifth hours following the 6-hourly product suite (includes the Tropical Cyclone Forecast/Advisory) when coastal tropical cyclone watch/warning in effect anywhere, and cyclone center can be easily tracked by land-based radar. As a practical matter, that is usually limited to U.S. radars as other radars do not provide the navigation information requisite to quantifying the location of the storm center.*

C. *Special Advisories (full product suite, which include Tropical Cyclone Forecast/Advisory products) issued as necessary.*

D. *TCUs [Tropical Cyclone Updates] issued as necessary beyond their use described above.*

The NHC stated that much of this information is covered by NWSI 10-601.[104] However, some information in the NWSI regarding intermediate advisories and Tropical Cyclone Updates is outdated (as of April 12, 2016). The NHC referred to a Service Change Notice[105] that gives current policy on the use of Tropical Cyclone Updates and intermediate advisories that is not yet reflected in NWSI 10-601 (last updated on May 27, 2014).

This policy information is current as of April 12, 2016.

[104] http://www.nws.noaa.gov/directives/sym/pd01006001curr.pdf

[105] http://www.nws.noaa.gov/om/notification/scn15-24tcp.htm

5.10.5. The Weather Channel

Weather Group Television, LLC, provided archive footage of The Weather Channel's television broadcast for the time periods 0500–1000 EDT on September 30, 2015, and 0500–0800 EDT on October 1, 2015.[106] The footage (edited[107]) may be found in the NTSB's public docket for this accident. The broadcast footage for the morning of September 30, 2015, contained extensive discussion[108] about Joaquin, including track forecast and its uncertainty, applicable watches and warnings for the Bahamas (figure 91), and forecast conditions (including wave-height forecasts). During this time period, the footage revealed timely broadcast of updated Joaquin information publicly disseminated by the NHC (figures 92 and 93), including information contained in the Tropical Cyclone Public Advisory issued by the NHC (nominally) at 0800 EDT on September 30, 2015 (Advisory Number 10A; figure 93). In addition, the broadcast footage showed that The Weather Channel routinely advised viewers when to expect the next NHC Joaquin update (figures 94-96).

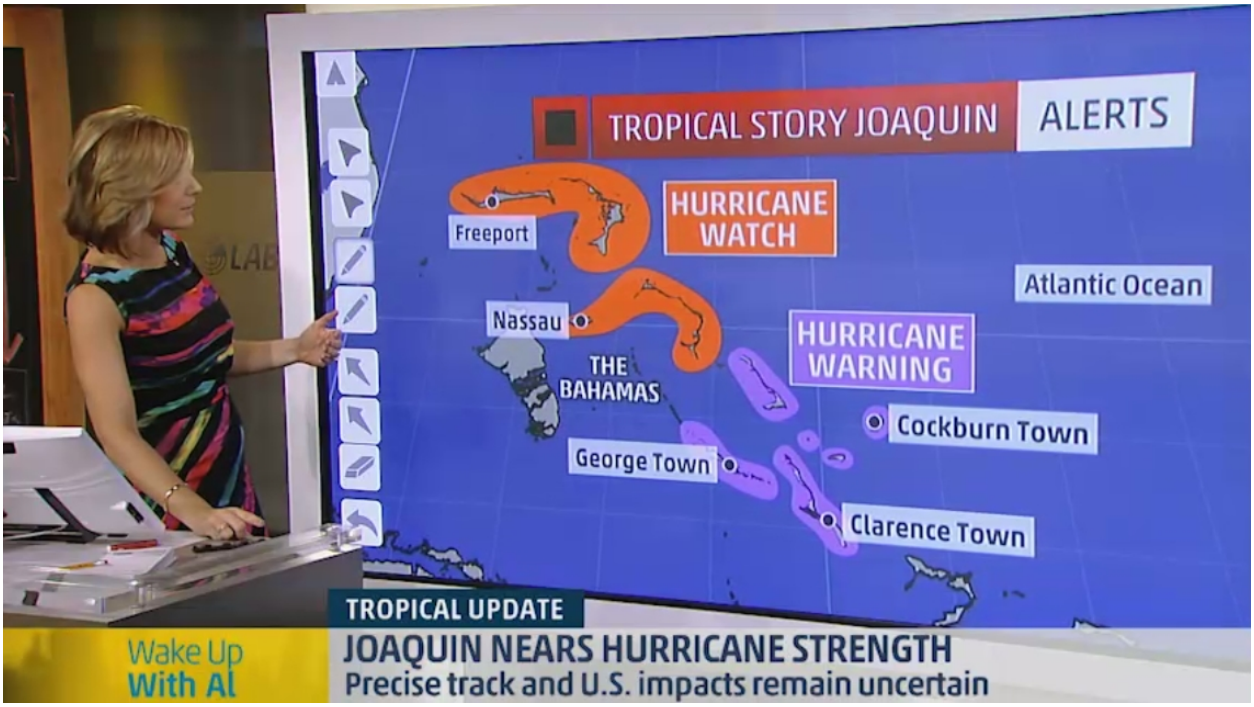

***Figure 91** – Screenshot of The Weather Channel television broadcast from about 0525 EDT on September 30, 2015, that shows graphical depictions of current watches and warnings associated with Tropical Storm Joaquin.*

[106] The NTSB had requested archive broadcast footage for the timeframe 1700 EDT on September 29, 2015, through 0800 EDT on October 1, 2015. However Weather Group Television, LLC, stated that the provided broadcast time periods were "…the only footage that we retained from the relevant time period, but not all the footage that aired."

[107] The footage contained recordings from the television studio not intended to be seen by viewers; those portions have been removed.

[108] Discussion of Tropical Storm/Hurricane Joaquin often centered around potential impacts to the east coast of the continental United States.

Figure 92 *– Screenshot of The Weather Channel television broadcast from about 0500 EDT on September 30, 2015, that provides viewers with recently released information from the NHC on Tropical Storm Joaquin.*

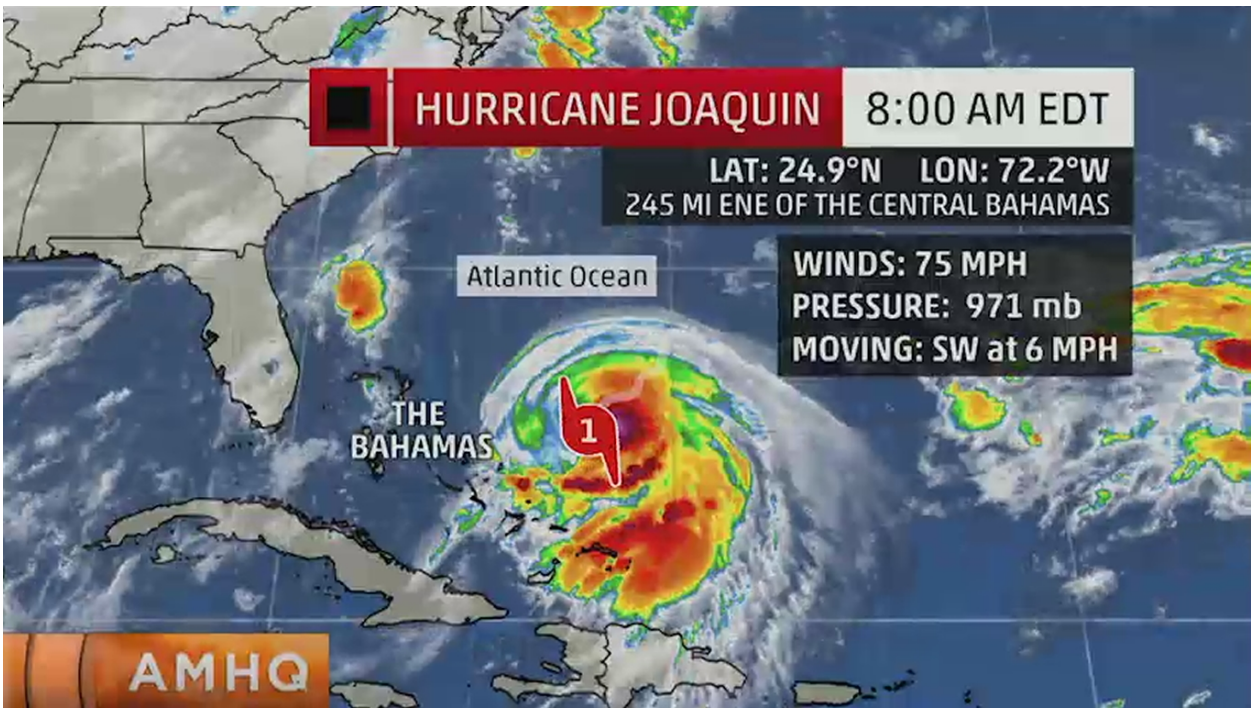

Figure 93 *– Screenshot of The Weather Channel television broadcast from about 0800 EDT on September 30, 2015, that provides viewers with recently released information from the NHC's Tropical Cyclone Public Advisory on Hurricane Joaquin (Advisory Number 10A).*

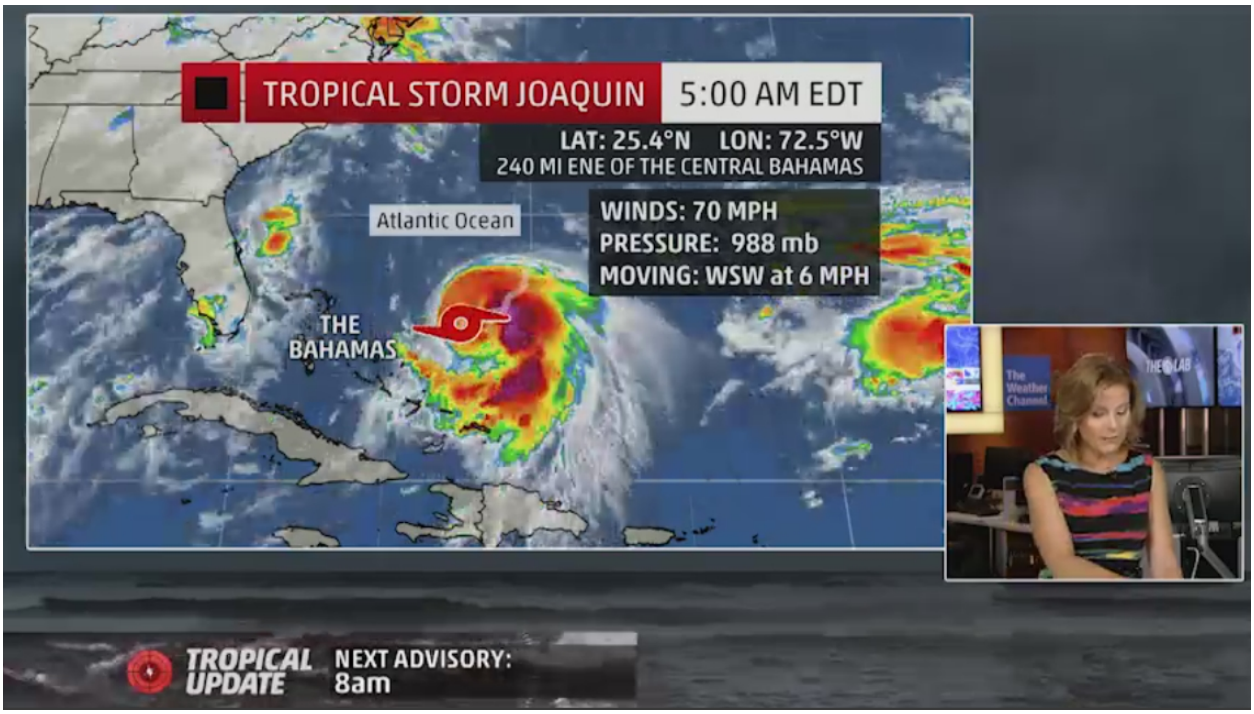

Figure 94 *– Screenshot of The Weather Channel television broadcast from the morning of September 30, 2015, that advises viewers when to expect the next NHC Joaquin advisory*

Figure 95 *– Screenshot of The Weather Channel television broadcast from the morning of September 30, 2015, that advises viewers when to expect the next NHC Joaquin advisory.*

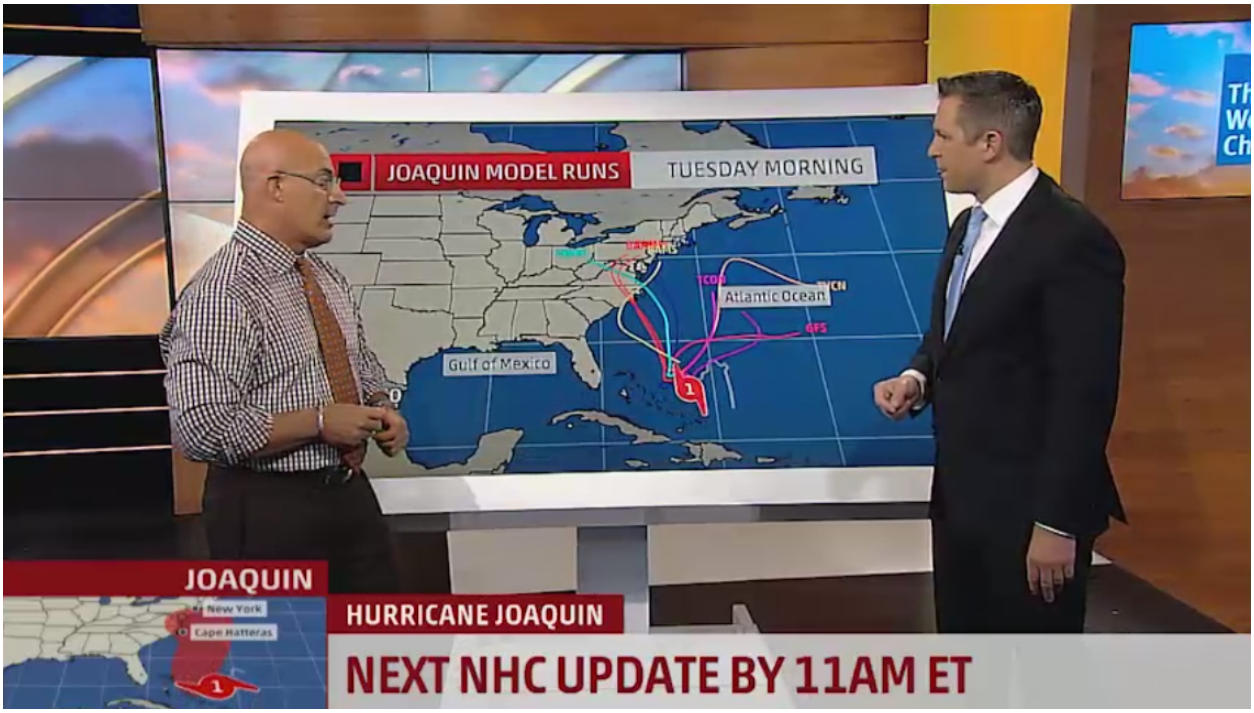

Figure 96 *– Screenshot of The Weather Channel television broadcast from the morning of September 30, 2015, that advises viewers when to expect the next NHC Joaquin advisory.*

Weather Group Television, LLC, provided a schedule of The Weather Channel's programming for the week of September 28, 2015, and indicated that the schedule and content is consistent across all distributors (e.g., DirecTV).[109] Further, The Weather Channel indicated that it had "national cut-ins" between 2000 EDT on September 30, 2015, and 0000 EDT on October 1, 2015. With regard to general programming policy related to tropical cyclones, Weather Group Television, LLC, stated: "…it would be very rare for us not to be preempting if there [were] active tropical cyclone warnings in the US…we would crawl all local warnings during long-form programming so if you are under a tropical cyclone warning of some kind, you would still receive all official watch/warning messages. We would also do cut-ins airing the tropical update product at the tops of every hour, which provides the viewer with the latest advisory information including current storm location and strength along with the 5 day forecast." Below is The Weather Channel's programming schedule capturing the time between 1700 EDT on September 29, 2015, and 0800 EDT on October 1, 2015.

[109] According to The Weather Channel, the only difference in content would be the insertion of local weather during "Local On The 8s" and the "L-bar."

Broadcast Time Period (EDT)	Program
1500 - 1800 September 29, 2015	Weather Center Live
1800 - 2100 September 29, 2015	Weather Underground
2100 September 29, 2015 – 0000 September 30, 2015	A Special: "Eastern Flood Danger"
0000 - 0100 September 30, 2015	Prospectors UnEarthed - Poppin' Rocks
0100 - 0200 September 30, 2015	Strangest Weather on Earth - Big Bangs
0200 - 0300 September 30, 2015	Strangest Weather on Earth – Worldwide Weather Wipeouts
0300 - 0400 September 30, 2015	Strangest Weather on Earth – Freak Weather
0400 - 0700 September 30, 2015	Wake Up With Al
0700 - 1000 September 30, 2015	AMHQ with Sam Champion
1000 - 1800 September 30, 2015	Weather Channel Live
1800 - 2000 September 30, 2015	Weather Underground
2000 - 2100 September 30, 2015	Special: Top Ten Worst Hurricanes
2100 - 2200 September 30, 2015	Special: Irene's Fury
2200 - 2300 September 30, 2015	Special: KATRINA 2065
2300 September 30, 2015 – 0000 October 1, 2015	Special: Coast Guard - HMS Bounty Rescue
0000 - 0100 October 1, 2015	Building Invincible - Hurricane Proof Ballpark
0100 - 0130 October 1, 2015	Storm Stories - Red River Rescue
0130 - 0200 October 1, 2015	Storm Stories - Iniki Wedding
0200 - 0230 October 1, 2015	Storm Stories - Murfreesboro Tornado
0230 - 0300 October 1, 2015	Storm Stories – Hurricane Camille: Pass Christian

0300 - 0330 October 1, 2015	Storm Stories - Katrina Cats
0330 - 0400 October 1, 2015	Storm Stories - Blizzard Transplants
0400 - 0430 October 1, 2015	Weather that Changed the World – Lost Legions of Rome
0430 - 0500 October 1, 2015	Breaking Ice - Call Me Ishmael
0500 - 0700 October 1, 2015	Wake Up With Al
0700 - 1000 October 1, 2015	AMHQ with Sam Champion

5.10.6. Tropical Storm Erika

Tropical Storm Erika occurred in August 2015, roughly a month before the *El Faro* accident. In February 2016, the NHC published a TCR for Tropical Storm Erika, which is reproduced in Attachment 34.

5.10.7. Hurricane Danny

Hurricane Danny occurred in August 2015, roughly six weeks before the *El Faro* accident. In January 2016, the NHC published a TCR for Hurricane Danny, which is reproduced in Attachment 35.

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