NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE JOAQUIN

(AL112015)

28 September – 7 October 2015

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NOAA GOES-EAST VISIBLE SATELLITE IMAGE (TRUE-COLOR BACKGROUND) OF HURRICANE JOAQUIN AT 1900 UTC 1 OCTOBER WHILE IT WAS CENTERED NEAR THE CENTRAL AND SOUTHEASTERN BAHAMAS

Joaquin was a category 4 hurricane (on the Saffir-Simpson Hurricane Wind Scale) whose strong winds and storm surge devastated Crooked Island, Acklins, Long Island, Rum Cay, and San Salvador in the central and southeastern Bahamas. Joaquin took the lives of 34 people—all at sea—including the 33 crewmembers of the cargo ship *El Faro*, which sunk during the storm northeast of Crooked Island. Joaquin is the strongest October hurricane known to have affected the Bahamas since 1866 and the strongest Atlantic hurricane of non-tropical origin in the satellite era.

Hurricane Joaquin

28 SEPTEMBER – 7 OCTOBER 2015

SYNOPTIC HISTORY

Joaquin's formation is notable in that the cyclone did not have tropical origins, which is rare for a major hurricane. The incipient disturbance can be traced back to 8 September when a weak mid- to upper-tropospheric low developed over the eastern Atlantic Ocean west-southwest of the Canary Islands. A piece of this system moved westward across the Atlantic for over a week, and amplified into a more significant mid- to upper-level low over the central Atlantic northeast of the Leeward Islands on 19 September. This feature continued to move westward for several more days and gradually acquired more vertical depth, with a stronger perturbation forming in the lower troposphere late on 25 September. Satellite images indicated that a small but well-defined surface low developed by 1800 UTC 26 September about 355 n mi east-northeast of San Salvador Island in the central Bahamas. The low was displaced to the northwest of a small area of disorganized showers and thunderstorms for another day or so, but deep convection developed close enough to the center for the low to be designated as a tropical depression at 0000 UTC 28 September, while centered about 360 n mi northeast of San Salvador. The "best track" chart of the tropical cyclone's path is given in Fig. 1, with the wind and pressure histories shown in Figs. 2 and 3, respectively. The best track positions and intensities are listed in Table 1[1].

Moderate north-northwesterly shear prevented the depression from strengthening for about a day, but the cyclone became a tropical storm at 0000 UTC 29 September while centered about 295 n mi northeast of San Salvador. A blocking ridge of high pressure located over the western Atlantic forced Joaquin to move slowly southwestward, and while the shear increased a bit and turned out of the north, Joaquin moved over very warm waters of about 30°C near the Bahamas. A 60-h period of rapid intensification began at 0600 UTC 29 September, and Joaquin became a hurricane at 0600 UTC 30 September about 170 n mi east-northeast of San Salvador, and then a major hurricane at 0000 UTC 1 October about 90 n mi east of San Salvador. Sea surface temperatures in the area where Joaquin formed and rapidly intensified (Fig. 4) were about 1.1°C higher than normal and were the warmest on record for the period between 18 and 27 September.

Meanwhile, a mid- to upper-level trough over the eastern United States deepened on 1 and 2 October, causing Joaquin to slow down and make a clockwise hairpin turn over the southeastern and central Bahamas. Joaquin continued to strengthen, reaching a relative peak in intensity as a 120-kt category 4 hurricane between 0000 and 0600 UTC 2 October. About 15 kt of north-northeasterly shear was still affecting Joaquin at this time, and despite the very cold cloud

[1] A digital record of the complete best track, including wind radii, can be found on line at ftp://ftp.nhc.noaa.gov/atcf. Data for the current year's storms are located in the *btk* directory, while previous years' data are located in the *archive* directory.

tops seen in infrared satellite imagery, Joaquin did not have a clear eye typical of category 4 hurricanes (Fig. 5). Joaquin made landfall as a major hurricane on several islands of the Bahamas on 1 and 2 October, first on Samana Cay at 1200 UTC 1 October, then on Rum Cay at 1600 UTC 2 October and San Salvador at 2100 UTC 2 October. In addition, Joaquin's eyewall moved over Crooked Island, Long Cay, and Long Island. Even though it weakened slightly on 2 October, Joaquin was a major hurricane the entire time that it moved through the southeastern and central Bahamas, and it was the strongest October hurricane known to have affected the Bahamas since 1866 (although the records for the Bahamas may be incomplete before the aircraft reconnaissance era began in the 1940s).

By 3 October, the deep-layer low over the eastern United States and a second mid- to upper-level low northeast of Joaquin had completely dissolved the western Atlantic ridge, causing the hurricane to accelerate northeastward away from the Bahamas. At the same time, Joaquin re-intensified, with data from an Air Force Reserve Hurricane Hunter aircraft indicating that the hurricane reached a peak intensity around 135 kt, just shy of category 5 strength, at 1200 UTC that day (Figs. 6a and 6b). However, soon thereafter increasing northwesterly shear eroded the western eyewall (Fig. 6c), and Joaquin lost its status as a major hurricane by 1200 UTC 4 October.

The flow around the deep-layer low located over the southeastern United States caused Joaquin to move north-northeastward over the western Atlantic late on 4 and 5 October. Weakening continued, but Joaquin's intensity stabilized near 75 kt for about a day. Joaquin made its closest approach to Bermuda, about 60 n mi west-northwest of the island, around 0000 UTC 5 October. The hurricane turned northeastward and east-northeastward on 6 and 7 October as it became embedded in the mid-latitude westerlies, and increasing shear and colder sea surface temperatures caused the cyclone to weaken to a tropical storm by 1200 UTC 7 October while centered about 420 n mi southeast of Cape Race, Newfoundland. With strong west-southwesterly shear displacing the remaining deep convection well away from Joaquin's less-defined center, the cyclone became post-tropical by 0000 UTC 8 October about 385 n mi west-northwest of the northwestern Azores. Although Joaquin had begun to merge with a frontal boundary as early as 6 October, the cyclone did not complete extratropical transition until 0000 UTC 9 October after it was fully embedded in the frontal zone over the north Atlantic (Figs. 7a and 7b).

The extratropical low moved eastward and southeastward over the northeastern Atlantic from 9 October until 12 October, with its center moving inland just north of Lisbon, Portugal, around 1200 UTC 12 October. The low then turned southward, weakened below gale force, and moved back over the Atlantic waters off the coast of Portugal on 13 October. The low ultimately dissipated after 0000 UTC 15 October between Portugal and Morocco over the Gulf of Cádiz.

METEOROLOGICAL STATISTICS

Observations in Joaquin (Figs. 2 and 3) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), and objective Advanced Dvorak Technique (ADT) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. Data and imagery from NOAA polar-orbiting satellites including the Advanced Microwave Sounding Unit (AMSU), the NASA Global Precipitation Mission (GPM), the European Space Agency's Advanced Scatterometer (ASCAT), and Defense Meteorological Satellite Program

(DMSP) satellites, among others, were also useful in constructing the best track of Joaquin. Aircraft observations include flight-level, stepped frequency microwave radiometer (SFMR), and dropwindsonde observations from 12 flights of the 53rd Weather Reconnaissance Squadron of the U. S. Air Force Reserve Command. The NOAA Aircraft Operations Center (AOC) G-IV aircraft flew four synoptic surveillance flights around Joaquin. In addition, a NASA WB-57 aircraft flew several flights into Joaquin and deployed dropwindsondes in support of the Office of Naval Research's Tropical Cyclone Intensity (TCI) Experiment. Ship reports of winds of tropical storm force associated with Joaquin are given in Table 2, and selected surface observations from land stations and data buoys are given in Table 3.

Flooding rains and coastal flooding affected portions of the United States East Coast during the first several days of October while Joaquin was near the Bahamas, but the hurricane only indirectly contributed to these hazardous conditions. A cut-off low aloft that developed over the southeastern U.S. on 1 October drew a steady plume of upper-level moisture from Joaquin northwestward into South Carolina; this moisture contributed to a multi-day rainfall event that caused historic flooding in that state's two largest cities of Charleston and Columbia. Contributing to the coastal flooding was a strong pressure gradient off the New England coast behind a frontal boundary that produced a long fetch of northeasterly gales directed at the mid-Atlantic coast at the start of the month, while tides were already running higher than normal. Although the gales were not part of Joaquin's circulation, the pressure gradient increased when the hurricane moved northward from the Bahamas, and swell from Joaquin also emanated northwestward toward the U.S. East Coast. All of these factors contributed to coastal flooding along portions of the U.S. East Coast even while Joaquin remained well offshore. Selected wind, rainfall, and storm surge observations along the East Coast of the United States associated with the indirect effects of Joaquin are given in Table 4.

Winds and Pressure

Joaquin reached tropical storm status at 0000 UTC 29 September, as evidenced by Dvorak satellite intensity estimates of T2.5/35 kt from TAFB and SAB, as well as two ASCAT passes at 0120 UTC and 0215 UTC that showed 35-kt winds. The storm is estimated to have become a hurricane at 0600 UTC 30 September based on a Dvorak estimate of T4.0/65 kt from TAFB, and an interpolation between SFMR surface winds of 59 kt measured at 1818 UTC 29 September and 70 kt measured at 1231 UTC 30 September. Joaquin became a major hurricane at 0000 UTC 1 October—an analysis supported by a peak 700-mb flight-level wind of 113 kt at 2352 UTC 30 September and an SFMR wind of 102 kt at 2351 UTC 30 September.

Joaquin reached its first of two relative peaks in intensity at 0000 UTC 2 October, with estimated maximum sustained winds of 120 kt when its eye was located between Crooked Island and Long Island in the southeastern and central Bahamas (Fig. 5). There were several SFMR observations between 115 kt and 120 kt from Air Force Reserve reconnaissance flights on 1 and 2 October, and it is estimated that Joaquin's intensity reached 120 kt at 0000 UTC 2 October, coincident with a peak in objective and subjective satellite intensity estimates.

The hurricane's minimum central pressure occurred coincidently with the first relative peak in intensity, with the analyzed minimum based on data from a dropsonde released into the eye at 2312 UTC 1 October. The sonde measured a surface pressure of 932 mb with 12 kt of wind, yielding an estimated minimum central pressure of 931 mb.

Joaquin's absolute peak in intensity occurred around 1200 UTC 3 October while the hurricane was moving away from the Bahamas. A reconnaissance flight during the morning measured a peak 700-mb flight-level wind of 144 kt and a peak SFMR surface wind of 138 kt at 1446 UTC. Although the SFMR observation suggests that Joaquin could have attained category 5 intensity, the flight-level winds suggest a lower intensity, near 130 kt. The best track peak intensity of 135 kt blends the surface and flight-level data, in consideration of the inherent uncertainties of the various observations. With this intensity, Joaquin is by far the strongest Atlantic hurricane of non-tropical origin to form during the satellite era. The previous strongest hurricanes of non-tropical origin in the satellite era were Diana (1984) and Claudette (1991), each of which had peak intensities of 115 kt.

Microwave data showed that Joaquin's eyewall moved over several islands in the southeastern and central Bahamas. It is likely that sustained category 3 winds, and possibly sustained category 4 winds, affected portions of Samana Cay, Crooked Island, Long Island, Rum Cay, and San Salvador Island. An Automatic Observing Weather Station (AWOS) in Cockburn Town on San Salvador measured a maximum sustained wind of 59 kt, but this measurement appears too low since the eyewall of the hurricane passed directly over the island. In fact, Joaquin's eye moved over San Salvador, and a weather station on the island reported a minimum pressure of 944.0 mb at 2100 UTC 2 October. A personal weather station from the Weather Underground network in the Church Grove area on Crooked Island reported a sustained wind of 99 kt and a gust to 129 kt before it stopped transmitting. Elsewhere, sustained hurricane-force winds also likely affected Acklins and southern portions of the Exumas and Cat Island. Sustained tropical-storm-force winds affected the remainder of the Exumas and Cat Island, Eleuthera Island in the northwestern Bahamas, and Mayaguana and the Inagua Islands in the southeastern Bahamas. Surface observations (Table 3) also suggest that sustained tropical-storm-force winds likely affected the Turks and Caicos Islands and portions of eastern Cuba.

Sustained tropical-storm-force winds and gusts to hurricane force affected Bermuda late on 4 October and early on 5 October. An offshore sensor located at the Crescent on the North Channel measured a 1-min sustained wind of 55 kt with a gust to 69 kt, while the airport reported a 10-min sustained wind of 49 kt and a gust to 63 kt. At an elevation of 290 ft, RCC Bermuda Radio measured a 1-min sustained wind of 80 kt and a gust to 100 kt.

Storm Surge[2]

According to the Bahamas Department of Meteorology, Joaquin produced storm surges of 12 to 15 ft on Rum Cay, Crooked Island, and Acklins. Staff from the department visited Rum Cay, San Salvador, Crooked Island, and Acklins after the hurricane and measured water marks as high as 15 ft in some areas.

[2] Several terms are used to describe water levels due to a storm. **Storm surge** is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tide, and is expressed in terms of height above normal tide levels. Because storm surge represents the deviation from normal water levels, it is not referenced to a vertical datum. **Storm tide** is defined as the water level due to the combination of storm surge and the astronomical tide, and is expressed in terms of height above a vertical datum, i.e. the North American Vertical Datum of 1988 (NAVD88) or Mean Lower Low Water (MLLW). **Inundation** is the total water level that occurs on normally dry ground as a result of the storm tide, and is expressed in terms of height above ground level. At the coast, normally dry land is roughly defined as areas higher than the normal high tide line, or Mean Higher High Water (MHHW).

Some coastal flooding due to Joaquin occurred in the Turks and Caicos Islands, Haiti, and Cuba, but no water level observations are available from those areas.

Higher-than-normal tides, onshore gale-force winds behind a frontal boundary, and swells propagating away from Joaquin all contributed to storm surge flooding along the U.S. East Coast, with the worst flooding occurring in South Carolina, North Carolina, and Virginia. The highest storm surges reported by NOS gauges were 4.19 ft above normal tide levels at Oyster Landing, South Carolina, and 4.11 ft at Money Point, Virginia. The storm surge resulted in inundation of 2-3 ft above ground level along portions of the coasts of North and South Carolina, and as much as 3-4 ft above ground level around portions of Hampton Roads, Virginia. A maximum storm tide of 3.8 ft above Mean Higher High Water (MHHW) was reported at Money Point, Virginia. Farther north, inundation of 1-3 ft above ground level occurred along the coast from Maryland to New York. The storm surge flooding in the United States is not considered directly attributable to Joaquin.

Rainfall and Flooding

No official rainfall observations are available from the Bahamas, but the Bahamas Department of Meteorology estimated that Joaquin produced 5 to 10 inches of rainfall in portions of the central and southeastern Bahamas.

Moisture advected away from Joaquin contributed to an historic rainfall and flooding event in South Carolina and parts of southern North Carolina. Rainfall amounts exceeding 15 inches occurred in a swath extending from the South Carolina Lowcountry northwestward through the Midlands, as well as along the coast near the North Carolina/South Carolina border. In the Lowcountry, rainfall amounts greater than 20 inches occurred in Charleston and Berkeley Counties, with a maximum rainfall amount of 26.88 inches measured near Mt. Pleasant. One-, two-, three-, and four-day rainfall records were set at the Charleston International Airport according to reports from the National Weather Service Weather Forecast Office (WFO) in Charleston. The airport measured a one-day rainfall amount of 11.50 inches on 3 October and a four-day total of 17.29 inches between 1-4 October. The flooding in Downtown Charleston and surrounding areas was exacerbated by higher-than-normal tides, which kept rainwater from draining into Charleston Harbor. In the Midlands, rainfall amounts greater than 20 inches occurred in Richland, Sumter, and Orangeburg Counties. WFO Columbia reported that one-, two-, and three-day rainfall records were also set at the Columbia Metro Airport, with 6.71 inches measured on 4 October and 11.44 inches for the whole event. In North Carolina, a maximum rainfall amount of 18.79 inches was reported near Sunset Beach in Brunswick County.

CASUALTY AND DAMAGE STATISTICS

Joaquin is directly responsible for 34 deaths[3] in the waters off the Bahamas and Haiti. Almost all of the deaths occurred when the U.S.-flagged cargo ship *El Faro* was lost at sea near the Bahamas while Joaquin was moving through the area. The *El Faro* left Jacksonville, Florida, on the evening of 29 September, bound for San Juan, Puerto Rico. The ship sailed east of the Bahamas and got caught in the hazardous winds and seas associated with Joaquin, and on the morning of 1 October the shipmaster reported that the vessel had lost propulsion and was listing 15 degrees. The National Transportation Safety Board reports that the *El Faro* sent a distress signal to the U.S. Coast Guard at 1115 UTC 1 October while located 36 n mi northeast of Acklins and Crooked Island. Hurricane conditions in the area initially hampered the Coast Guard's search for the ship, but a damaged lifeboat, two damaged life rafts, and a deceased crewmember wearing an immersion suit were found on 4 October. A debris field and oil slick were spotted the next day, and the Coast Guard declared that the *El Faro* was lost. The unsuccessful search for survivors was suspended at sunset on 7 October. The 33 crewmembers (28 Americans and 5 Polish nationals) of the *El Faro* are presumed to have perished when the ship sank near the Bahamas. A U.S. Navy search team located the wreckage of the *El Faro* in 15,000 ft of water on 31 October, but investigators ended their search for the vessel's voyage data recorder on 16 November.

The Caribbean Disaster Emergency Management Agency (CDEMA) reported that a fisherman in his 30s drowned when his and another fisherman's boat capsized in rough seas off the coast of Haiti between Petit-Trou-de-Nippes and Grand Boucan.

Bahamas

The prime minister of the Bahamas and the Bahamas Department of Meteorology estimate that the damage caused by Joaquin is well over $60 million USD[4]. Figure 8 provides some examples of damage on Long and Crooked Islands.

Crooked Island and Long Cay: 70% of Crooked Island was flooded with at least 5 ft of water. The entire island lost power, and there was significant damage to buildings and homes. All houses on the eastern side of the island had severe roof damage. Water was heavily contaminated with fecal matter due to seepage from septic tanks, and water from wells was not suitable for drinking.

Acklins: Significant flooding was reported on the island, with an estimated 20 homes destroyed. The main bridge was completely destroyed, and 90% of the homes in Lovely Bay, Chester, and Snug Corner were severely damaged or completely destroyed.

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[3] Deaths occurring as a direct result of the forces of the tropical cyclone are referred to as "direct" deaths. These would include those persons who drowned in storm surge, rough seas, rip currents, and freshwater floods. Direct deaths also include casualties resulting from lightning and wind-related events (e.g., collapsing structures). Deaths occurring from such factors as heart attacks, house fires, electrocutions from downed power lines, vehicle accidents on wet roads, etc., are considered "indirect" deaths.

[4] Virgil, K. (15 October 2015). $60m+ to Rebuild: Pm Reveals Cost of Hurricane Joaquin Repairs. *Tribune242*. http://www.tribune242.com/news/2015/oct/15/60m-rebuild-pm-reveals-cost-hurricane-joaquin-repa/

Long Island: Power lines were downed, private fresh water wells were flooded, and structural damage occurred to homes. Over two-thirds of the island remained inundated with 4-6 ft of water by 7 October. The marina was severely damaged, and coastal roads were impassable due to flooding and debris. Severe damage occurred to vegetation, even a considerable distance inland. The main cause of damage to buildings was high wind, but several houses were damaged due to storm surge in low-lying areas. The local fishing fleet in Clarence Town was destroyed.

Rum Cay: Severe flooding, downed trees, impassable roads, and downed power lines and poles were reported across the island. The airport was flooded, and the government dock was destroyed.

San Salvador: Flooding, downed power lines and poles, and significant damage to homes were reported throughout the island. Many roads were impassable, and the airport building was completely destroyed.

Mayaguana: Minor damage to homes was reported.

Exuma: Extreme flooding and downed power lines were reported.

Turks and Caicos Islands

Flooding was reported in downtown Providenciales, and two boats reportedly sank at the ferry terminal. Storm surge and rain caused some roads to be partially or fully impassable. Road damage accounted for 90% of all damage on the islands.

Haiti

In the northwestern part of Haiti, a tree fell onto two homes, resulting in minor injuries to two people. More than 100 homes flooded in coastal towns, especially in Gonaives and Anse-Rouge due to storm surge, large waves, and higher-than-normal tides. River flooding and landslides were also reported.

Cuba

Coastal flooding affected more than 100 homes along the southern coast of Cuba in the municipalities of Niquero and Manzanillo in the province of Granma. Some coastal flooding also occurred along the northern coast in the state of Ciego de Avila.

Bermuda

The Bermuda Weather Service reported that damage on Bermuda was considerably less than that caused by Hurricanes Fay and Gonzalo in 2014. There was some relatively minor damage to vegetation, and some structural damage occurred to the Bermuda Maritime Museum in Dockyard, which was still undergoing renovations from the previous year’s hurricanes.

FORECAST AND WARNING CRITIQUE

The genesis of Joaquin was poorly forecast. The precursor disturbance was introduced in the Tropical Weather Outlook (TWO) and given a low (< 40%) chance of genesis during the ensuing 48- and 120-h periods only 48 h before genesis occurred. The system was given a medium (40 – 60%) chance of formation during both forecast periods 24 h before genesis, and the probability was only raised to a high (> 60%) chance at the time of genesis. Table 5 provides the number of hours in advance of formation associated with the first NHC Tropical Weather Outlook forecast in each likelihood category. The numerical models showed little to no deepening of the mid- to upper-level low over the western Atlantic in the days leading up to genesis, and forecasters were unable to recognize that tropical cyclone formation was even a possibility until 48 h before genesis occurred.

A verification of NHC official track forecasts for Joaquin is given in Table 6a. 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. A homogeneous comparison of the official track errors with selected guidance models is given in Table 6b. The European Centre for Medium-Range Weather Forecasting model (EMXI) had the lowest errors out of all the dynamical models, and it beat the NHC official forecast at all forecast times. The various model consensus aids also had lower errors than the official forecasts, led by GFEX, an average of the EMXI and the National Weather Service's Global Forecast System (GFSI). The Florida State Superensemble (FSSE) also had lower errors than the official forecasts at all forecast times.

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. Figure 9 shows forecast track plots from the NHC official forecasts and several of the dynamical models and model consensus aids for forecasts beginning within this time period. 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 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. Figure 10 shows that the ECMWF predicted a deeper cyclone compared to the GFS model, but it also showed a different orientation of the western Atlantic ridge, which pushed Joaquin southwestward toward the Bahamas. To a large degree, the ECMWF model's overall low errors are a result of the model's ability to accurately depict a track closer to the Bahamas at the beginning of Joaquin's life.

The spread among the track models yielded greater-than-normal uncertainty regarding if and how Joaquin would affect the eastern United States. A majority of the track models showed Joaquin taking a track close to or inland over the eastern United States, and the GFS and HWRF models in particular depicted landfall along the East Coast for several model cycles (Figs. 9b and 9d, respectively). On the other hand, the ECMWF consistently depicted a much sharper turn toward the northeast with a close approach to Bermuda (Fig. 9c). The large spread among the typically most reliable track models led to low confidence in the track forecast and presented NHC with a unique communications challenge (see below).

A verification of NHC official intensity forecasts for Joaquin is given in Table 7a. Official forecast intensity errors were greater than the mean official errors for the previous 5-yr period at all forecast times. However, as with the track forecasts, OCD5 errors were also larger than their respective 5-yr means, indicating that Joaquin's intensity was more difficult to forecast than for a typical tropical cyclone. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 7b. The official intensity forecasts were generally very competitive with the various intensity models and generally had lower average errors than the models at 96 and 120 h. Overall, the HWRF and the FSSE had the lowest intensity errors, but only between 12 and 72 h.

Figure 11 shows composites of the individual NHC official intensity forecasts and the model intensity forecasts from the HWRF, FSSE, and the IVCN consensus. The figure shows that the first few official forecasts and model forecasts indicated that there would be little to no strengthening of Joaquin. After about a day, the models began indicating that Joaquin would strengthen during the next few days, but only the HWRF (Fig. 11b) showed intensification rates similar to what was observed with the hurricane. Interestingly, the SHIPS Rapid Intensification (RI) Index was never very high for Joaquin, and it only showed an 8% chance of a 30-kt increase in intensity over the next 24 h when RI began at 0600 UTC 29 September. The RI Index reached a peak value of 36% for a 30-kt increase in winds over 24 h only after Joaquin had already become a major hurricane. Despite the HWRF's success in showing strengthening, the model weakened Joaquin too quickly after the hurricane reached its first relative peak intensity, and no model anticipated Joaquin's re-intensification to its peak intensity of 135 kt.

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.

Watches and warnings associated with Joaquin are given in Table 8.

ACKNOWLEDGMENTS

Data in Tables 3 and 4 were derived from storm reports issued by National Weather Service Forecast Offices (WFOs) in Charleston and Columbia, South Carolina; the Weather Prediction Center; National Data Buoy Center; and the National Ocean Service Center for Operational Oceanographic Products and Services. The Bahamas Department of Meteorology and the Bermuda Weather Service provided data and damage reports from their respective countries, and the Caribbean Disaster Emergency Management Agency also provided reports on the post-storm aftermath in the central and southeastern Bahamas. The NOAA Hurricane Research Division quality controlled SFMR data around the time of Joaquin's peak intensity.

Table 1. Best track for Hurricane Joaquin, 28 September – 7 October 2015.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
26 / 1800	26.8	68.7	1011	20	low
27 / 0000	26.9	68.6	1011	20	"
27 / 0600	27.0	68.5	1010	20	"
27 / 1200	27.1	68.6	1009	25	"
27 / 1800	27.2	68.8	1007	30	"
28 / 0000	27.4	69.0	1007	30	tropical depression
28 / 0600	27.6	69.3	1007	30	"
28 / 1200	27.7	69.7	1006	30	"
28 / 1800	27.4	70.0	1003	30	"
29 / 0000	26.9	70.1	1002	35	tropical storm
29 / 0600	26.5	70.3	1002	35	"
29 / 1200	26.2	70.5	999	45	"
29 / 1800	26.0	70.8	992	55	"
30 / 0000	25.8	71.3	985	60	"
30 / 0600	25.4	71.8	978	65	hurricane
30 / 1200	24.9	72.2	971	70	"
30 / 1800	24.4	72.5	961	80	"
01 / 0000	23.9	72.9	951	100	"
01 / 0600	23.5	73.3	947	110	"
01 / 1200	23.1	73.7	942	115	"
01 / 1800	23.0	74.2	936	115	"
02 / 0000	22.9	74.4	931	120	"
02 / 0600	23.0	74.7	935	120	"
02 / 1200	23.4	74.8	937	115	"
02 / 1600	23.6	74.8	940	110	"
02 / 1800	23.8	74.7	941	110	"
02 / 2100	24.1	74.5	942	110	"
03 / 0000	24.3	74.3	943	115	"
03 / 0600	24.8	73.6	945	120	"
03 / 1200	25.4	72.6	934	135	"

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
03 / 1800	26.3	71.0	934	130	"
04 / 0000	27.4	69.5	941	115	"
04 / 0600	28.9	68.3	949	105	"
04 / 1200	30.4	67.2	956	95	"
04 / 1800	31.6	66.5	958	85	"
05 / 0000	32.6	66.0	961	75	"
05 / 0600	33.6	65.6	964	75	"
05 / 1200	34.4	65.2	964	75	"
05 / 1800	35.3	64.5	964	75	"
06 / 0000	36.2	63.6	967	75	"
06 / 0600	37.0	62.3	970	75	"
06 / 1200	37.9	60.4	974	70	"
06 / 1800	38.8	58.0	974	70	"
07 / 0000	39.6	54.9	974	70	"
07 / 0600	40.3	51.5	977	65	"
07 / 1200	41.0	47.5	977	60	tropical storm
07 / 1800	41.5	43.3	977	60	"
08 / 0000	41.9	39.1	977	55	low
08 / 0600	42.4	35.0	977	50	"
08 / 1200	43.0	31.0	980	45	"
08 / 1800	43.5	27.3	984	45	"
09 / 0000	43.9	24.1	987	45	extratropical
09 / 0600	44.1	21.9	988	45	"
09 / 1200	44.2	19.9	988	45	"
09 / 1800	44.1	18.2	989	40	"
10 / 0000	43.8	16.4	992	35	"
10 / 0600	43.4	15.0	993	35	"
10 / 1200	43.1	13.9	996	35	"
10 / 1800	42.8	12.9	998	30	"
11 / 0000	42.5	12.0	999	30	"
11 / 0600	42.2	11.3	1000	30	"

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
11 / 1200	41.8	10.8	1001	35	"
11 / 1800	41.2	10.5	1001	35	"
12 / 0000	40.4	10.2	1002	35	"
12 / 0600	39.8	9.7	1002	35	"
12 / 1200	39.5	9.1	1003	35	"
12 / 1800	39.1	8.8	1005	30	"
13 / 0000	38.6	8.9	1007	25	"
13 / 0600	38.0	9.1	1009	20	"
13 / 1200	37.3	9.2	1010	20	"
13 / 1800	36.6	9.1	1010	20	"
14 / 0000	36.0	9.0	1011	20	"
14 / 0600	35.5	8.7	1011	20	"
14 / 1200	35.1	8.4	1011	20	"
14 / 1800	35.0	8.0	1012	15	"
15 / 0000	35.2	7.7	1012	15	"
15 / 0600					dissipated
02 / 0000	22.9	74.4	931	120	minimum pressure
03 / 1200	25.4	72.6	934	135	maximum winds
01 / 1200	23.1	73.7	942	115	landfall on Samana Cay
02 / 1600	23.6	74.8	940	110	landfall on Rum Cay
02 / 2100	24.1	74.5	942	110	landfall on San Salvador Island

Table 2. Selected ship reports with winds of at least 34 kt for Hurricane Joaquin, 28 September – 7 October 2015.

Date/Time (UTC)	Ship call sign	Latitude (°N)	Longitude (°W)	Wind dir/speed (kt)	Pressure (mb)
29 / 2100	9HA348	25.0	71.2	270 / 40	998.0
30 / 0000	9HA348	24.9	70.4	180 / 45	1001.0
30 / 0300	9HA348	25.2	68.7	160 / 36	1005.0
30 / 0600	J8PE4	26.1	78.1	*** / 53	1009.0
01 / 0700	H3VU	21.7	74.8	250 / 57	998.0
01 / 2000	H3VR	20.5	73.2	180 / 50	999.0
01 / 2300	H3VR	20.5	73.9	180 / 46	998.0
02 / 0500	C6ZL6	21.1	75.0	210 / 55	993.0
02 / 0600	H3VR	21.3	75.8	230 / 45	995.0
02 / 0900	H3VR	21.7	76.7	260 / 50	995.0
03 / 0300	ZCEI3	20.5	74.2	210 / 40	1001.8
03 / 0600	ZCEI3	20.3	73.1	240 / 40	1004.8
03 / 0600	DGHJ	21.2	75.0	250 / 35	1001.0
03 / 1100	H3GR	25.4	77.4	290 / 40	998.0
04 / 1200	3FCD9	37.8	67.8	040 / 42	1014.0
04 / 1800	3FCD9	38.5	65.3	050 / 45	1015.0
05 / 0600	3FCD9	39.8	61.0	090 / 39	1017.0
05 / 1800	PHDL	39.2	69.3	040 / 35	1010.9
06 / 0600	PHDL	40.2	67.0	010 / 35	1007.9
06 / 1200	A8MB5	35.1	60.5	240 / 42	1004.5

Table 3. Selected surface observations for Hurricane Joaquin, 28 September – 7 October 2015.

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed		
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)
Bahamas					
Cockburn Town, San Salvador (MYSM) (24.06N 74.52W)			2/1500	59	
Church Grove, Crooked Island				99[u]	129[u]
San Salvador (M089) (24.07N 74.50W)	2/2100	944.0			
Turks and Caicos Islands					
Providenciales (MBPV) (21.77N 72.27W)			1/1400	32	46
Cuba					
Guantanamo Bay NAS (MUGM) (19.90N 75.13W)	2/0756	1000.8	2/1138	34	48
Santiago de Cuba (MUCU) (19.97N 75.84W)	2/0752	1001.0	1/2123	27	38
Punta Lucrecia (78365) (21.07N 75.62W)	2/0900	997.6			
Bermuda					
L. F. Wade International Airport (TXKF) (32.36N 64.68W) (40 ft.)	5/0055	990.7	5/0105	49 (10 min)	63
RCC Bermuda Radio (32.38N 64.48W) (290 ft.)	4/2300	990.0	5/0100	80 (1 min)	100
The Crescent – North Channel Marker (20 ft.)	4/2300	990.0	5/0154	55 (1 min)	69
Buoys					
NOAA					
East of Bahamas (41046) (23.89N 68.36W)	3/1847	1002.4	3/1446	29	34
NE of Bahamas (41047) (27.52N 71.48W)	3/2048	985.8	3/1845	43	49
W of Bermuda (41048) (31.87N 69.57W)	4/0837	999.3	4/0948	31	36

[a] Date/time is for sustained wind when both sustained and gust are listed.
[b] Except as noted, sustained wind averaging periods for buoys are 8 min.
[u] Unofficial observations

Table 4. Selected surface observations along the East Coast of the United States due to the indirect effects of with Hurricane Joaquin.

Location	Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)[f]
	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Florida							
Mayport (Bar Pilots Dock)	2/0400	22	26	2.25	3.94	2.0	
Fernandina Beach	5/1648	18	21	2.98	4.88	2.2	
Georgia							
Fort Pulaski	3/1830	24	34	2.74	5.89	2.4	
South Carolina							
Charleston	4/0030	30	37	2.79	5.15	2.5	
Oyster Landing (N Inlet Estuary)				4.19	5.07	2.7	
Springmaid Pier	3/1554	33	40	3.25	5.14	2.7	
Mount Pleasant 6 NE							26.88
Kingstree							24.75
Boone Hall Plantation 3 NNE							24.23
Shadowmoss 3 SSW							24.10
Longs							23.74
Charleston 5 SSE							23.61
Limerick 1 NNW							22.02
Folly Beach 3 SW							21.45
Huger 5 NNW							21.04
Georgetown 4 SSW							20.75
Gills Creek							20.28
Summerville 3 NW							19.47
Shaw AFB							19.32
Wateree							18.90
Kiawah Island 4 NNW							18.25
Effingham 2 W							17.95
Myrtle Beach 8 WNW							17.40
Charleston (KCHS)							17.29

Location	Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)[f]
	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
James Island County Park 1 NNE							17.00
Little River 1 N							16.00
Garris Landing 2 NNW							15.81
Santee							14.84
Huger 3 NNE							14.68
Sangaree 2 NE							14.51
Florence 5 W							14.34
Charleston NWS							13.88
Darlington 7 SSW							13.00
Goose Creek 5 E							11.26
Columbia Metro Airport							10.77
Wando 1 SSW							8.76
North Carolina							
Wrightsville Beach	4/1854	40	54	3.40	4.90	3.1	
Wilmington				2.85		2.2	
Beaufort	5/1542	26	36	2.65		2.4	
USCG Station Hatteras	5/1548	25	34	2.28		2.6	
Oregon Inlet Marina	4/1854	27	37	1.98	2.25	1.8	
Duck	4/1700	37	42	3.19	4.65	3.2	
Smith Reynolds Airport			37				
Sunset Beach 2 WNW							18.79
Longwood 1 NNW							17.83
Longwood 1 NW							13.63
Southport 1 NE							13.42
Bayshore 1 ENE							12.74
Wilmington 4 SE							12.30
Tabor City 4 NE							12.29
Bolivia 8 SSW							11.48
Topsail Beach 1 E							10.17
Wilmington (KILM)							8.79
Lake Waccamaw 3 S							8.63

Location	Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)[f]
	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Elizabethtown 4 NNE							8.01
Oakboro 1 WNW							7.76
Pope AFB							7.33
Fort Bragg							7.00
Benson 1 SSW							6.87
Cameron 8 E							6.71
Wilson 2 NNW							6.52
Anson County Airport							6.32
Pinetops							5.79
Raleigh-Durham International Airport							3.76
Virginia							
Money Point	4/1518	19	32	4.11		3.8	
Chesapeake Bay Bridge Tunnel	2/1700	36	42	3.89		3.6	
Sewells Point				4.02	4.89	3.7	
Yorktown USCG Training Center	4/0524	31	39	3.42		3.4	
Windmill Point				2.79		3.0	
Lewisetta	3/2212	32	41	2.81	2.99	2.3	
Kiptopeke	2/1742	23	37	3.20	3.97	2.9	
Wachapreague	2/2300	38	48	3.90		3.5	
District of Columbia							
Washington	1/0024	13	20	2.77	4.01	2.2	
Maryland							
Solomons Island	3/1806	24	32	2.51	2.04	1.4	
Annapolis				2.30	2.66	2.0	
Baltimore	4/0406	18	25	2.11	2.58	1.8	
Chesapeake City	3/2018	19	31	2.09		1.2	
Tolchester Beach	1/0218	22	26	1.80		1.6	
Cambridge	3/0006	26	36	2.19	2.73	1.8	

Location	Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)[f]
	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Bishops Head	4/0054	28	38	2.19	2.68	1.9	
Ocean City Inlet	3/0430	26	43	2.65	3.08	2.3	
Oxford 2 NNW			35				
Delaware							
Lewes	3/0248	42	54	4.00	4.94	2.9	
Brandywine Shoal Light	2/2212	44	54	3.45		2.6	
Reedy Point				2.81	4.43	1.6	
Delaware City	2/2218	28	35	2.82		2.0	
Big Stone Beach 18 SE			50				
Lewes Beach			39				
Rehoboth Beach			36				
Pennsylvania							
Newbold	2/2212	17	34	2.30		1.2	
Philadelphia				2.30	5.20	1.6	
Landenberg			46				
New Jersey							
Burlington, Delaware River	2/2230	22	32	2.09		1.4	
Ship John Shoal	2/2242	32	42	3.39		2.1	
Cape May	3/1912	24	42	3.21	5.05	2.6	
Atlantic City				2.08	4.14	2.2	
Sandy Hook	3/2354	23	34	2.52	4.60	2.2	
Cape May			54				
Seaside Heights			49				
Tuckerton			48				
Little Sheepshead Creek			47				
Long Beach Island			41				
Ocean City			41				
Port Norris 19 ESE			39				
South Seaside Park			39				

Location	Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)[f]
	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
New York							
Bergen Point West Reach				2.53		2.1	
The Battery				2.32	4.43	2.2	
Kings Point	1/0048	23	32	2.72		2.2	
Montauk				1.45	2.43	1.5	
Rhode Island							
Charlestown			40				
Massachusetts							
Nantucket			41				
Oak Bluffs			39				

[a] Date/time is for sustained wind when both sustained and gust are listed.
[b] Except as noted, sustained wind averaging periods for C-MAN and land-based reports are 2 min; buoy averaging periods are 8 min.
[c] Storm surge is water height above normal astronomical tide level.
[d] Storm tide is water height above the North American Vertical Datum of 1988 (NAVD88).
[e] Estimated inundation is the maximum height of water above ground. For NOS tide gauges, the height of the water above Mean Higher High Water (MHHW) is used as a proxy for inundation.
f Rainfall amounts in North and South Carolina are storm total amounts from 8 AM EDT 1 October through 10 PM EDT 5 October.

Table 5. Number of hours in advance of formation associated with the first NHC Tropical Weather Outlook forecast in the indicated likelihood category. Note that the timings for the "Low" category do not include forecasts of a 0% chance of genesis.

	Hours Before Genesis	
	48-Hour Outlook	**120-Hour Outlook**
Low (<40%)	48	48
Medium (40%-60%)	24	24
High (>60%)	0	0

Table 6a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Joaquin, 28 September – 7 October. Mean errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	**26.3**	50.6	79.7	121.0	231.7	360.9	450.4
OCD5	52.5	127.0	203.7	276.6	413.9	586.0	682.7
Forecasts	38	36	34	32	28	23	17
OFCL (2010-14)	28.4	45.0	60.4	77.1	113.1	157.8	210.0
OCD5 (2010-14)	48.3	101.5	161.5	222.6	329.8	412.6	483.9

Table 6b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Joaquin, 28 September – 7 October. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 6a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	24.6	44.2	69.3	106.4	203.7	287.2	421.1
OCD5	52.8	130.9	207.8	278.0	398.2	586.4	814.1
GFSI	27.7	47.6	72.1	**102.1**	**195.7**	291.4	431.4
EMXI	**23.0**	**36.8**	**49.8**	**62.0**	**106.3**	**150.0**	**177.6**
EGRI	28.5	50.9	72.1	**95.1**	**189.4**	291.9	553.5
NGVI	40.0	78.3	123.7	186.0	405.5	616.1	783.6
CMCI	35.7	68.9	110.1	170.8	361.1	518.3	619.8
GHMI	28.0	55.5	84.6	124.7	278.2	480.4	567.8
HWFI	29.1	54.8	80.2	114.6	226.7	384.8	590.7
GFNI	32.1	65.0	104.5	162.4	370.9	648.4	778.9
TCON	**23.7**	**43.4**	**64.1**	**90.1**	**197.5**	324.3	476.8
TVCA	**22.5**	**39.4**	**58.0**	**81.7**	**171.2**	**277.2**	**399.2**
TVCX	**22.6**	**37.5**	**53.9**	**75.2**	**154.3**	**247.6**	**349.9**
GFEX	**22.5**	**38.1**	**53.9**	**72.3**	**124.7**	**179.4**	**259.0**
FSSE	**24.0**	**40.1**	**60.4**	**85.5**	**190.1**	**276.0**	**371.1**
AEMI	28.5	52.6	79.0	114.3	220.7	307.4	**420.0**
BAMS	80.3	169.8	255.4	335.4	511.9	755.5	1143.5
BAMM	43.3	92.4	145.5	205.6	349.0	556.7	870.7
BAMD	36.7	76.1	129.0	184.6	312.7	457.0	681.8
Forecasts	31	31	29	27	23	17	12

Table 7a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Joaquin, 28 September – 7 October 2015. Mean errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	7.2	11.0	15.0	17.3	24.8	25.9	21.5
OCD5	8.5	12.4	16.5	20.3	27.5	27.3	25.8
Forecasts	38	36	34	32	28	23	17
OFCL (2010-14)	6.2	9.4	11.5	13.3	14.6	14.6	15.8
OCD5 (2010-14)	7.3	10.8	13.3	15.3	17.7	17.8	17.6

Table 7b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Joaquin. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 7a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	8.4	10.5	13.4	13.9	17.0	15.8	12.7
OCD5	9.4	11.9	15.9	18.7	21.9	18.9	20.2
DSHP	9.3	11.6	13.5	15.3	**16.8**	**15.4**	20.8
LGEM	8.9	11.8	14.2	15.9	**15.7**	16.2	22.5
GHMI	10.0	14.0	16.6	16.7	19.6	28.1	28.2
HWFI	**7.8**	**9.6**	13.8	**13.5**	**14.2**	25.3	31.6
GFNI	11.3	16.4	21.2	23.9	26.3	39.7	32.7
ICON	8.5	11.2	**13.1**	14.0	**15.2**	18.8	24.2
IVCN	8.5	11.2	**13.1**	14.0	**15.2**	18.8	24.2
FSSE	**7.8**	**10.3**	**12.4**	**13.7**	**16.3**	16.6	13.9
GFSI	10.2	15.4	21.6	25.6	37.1	36.0	28.4
EMXI	11.4	15.8	21.8	27.7	36.8	38.1	27.1
Forecasts	31	31	29	27	23	18	13

Table 8. Watch and warning summary for Hurricane Joaquin, 28 September – 7 October 2015.

Date/Time (UTC)	Action	Location
30 / 0300	Hurricane Watch issued	Central Bahamas
30 / 0900	Hurricane Watch changed to Hurricane Warning	Central Bahamas
30 / 0900	Hurricane Watch issued	Northwestern Bahamas excluding Andros Island
30 / 2100	Hurricane Watch changed to Hurricane Warning	Northwestern Bahamas excluding Andros Island and Bimini
30 / 2100	Tropical Storm Warning issued	Southeastern Bahamas
1 / 0300	Tropical Storm Warning and Hurricane Watch issued	Andros Island
1 / 0935	Tropical Storm Warning changed to Hurricane Warning	Acklins, Crooked Island, and Mayaguana in the southeastern Bahamas
1 / 1500	Tropical Storm Warning issued	Turks and Caicos Islands
2 / 0000	Tropical Storm Warning issued	Cuban provinces of Camaguey, Las Tunas, Holguin, and Guantanamo
2 / 2100	Tropical Storm Watch issued	Bermuda
2 / 2100	Tropical Storm Warning discontinued	Cuban provinces of Camaguey, Las Tunas, Holguin, and Guantanamo
3 / 0300	Tropical Storm Watch changed to Tropical Storm Warning	Bermuda
3 / 0300	Hurricane Watch issued	Bermuda
3 / 0300	Hurricane Warning discontinued	Northwestern Bahamas
3 / 0300	Tropical Storm Warning discontinued	Andros Island
3 / 0300	Hurricane Watch discontinued	Bimini and Andros Island
3 / 1200	Hurricane Warning discontinued	All
3 / 1200	Tropical Storm Warning discontinued	Remainder of southeastern Bahamas and Turks and Caicos Islands
4 / 0300	Tropical Storm Warning and Hurricane Watch changed to Hurricane Warning	Bermuda
5 / 0600	Hurricane Warning changed to Tropical Storm Warning	Bermuda
5 / 1800	Tropical Storm Warning discontinued	All

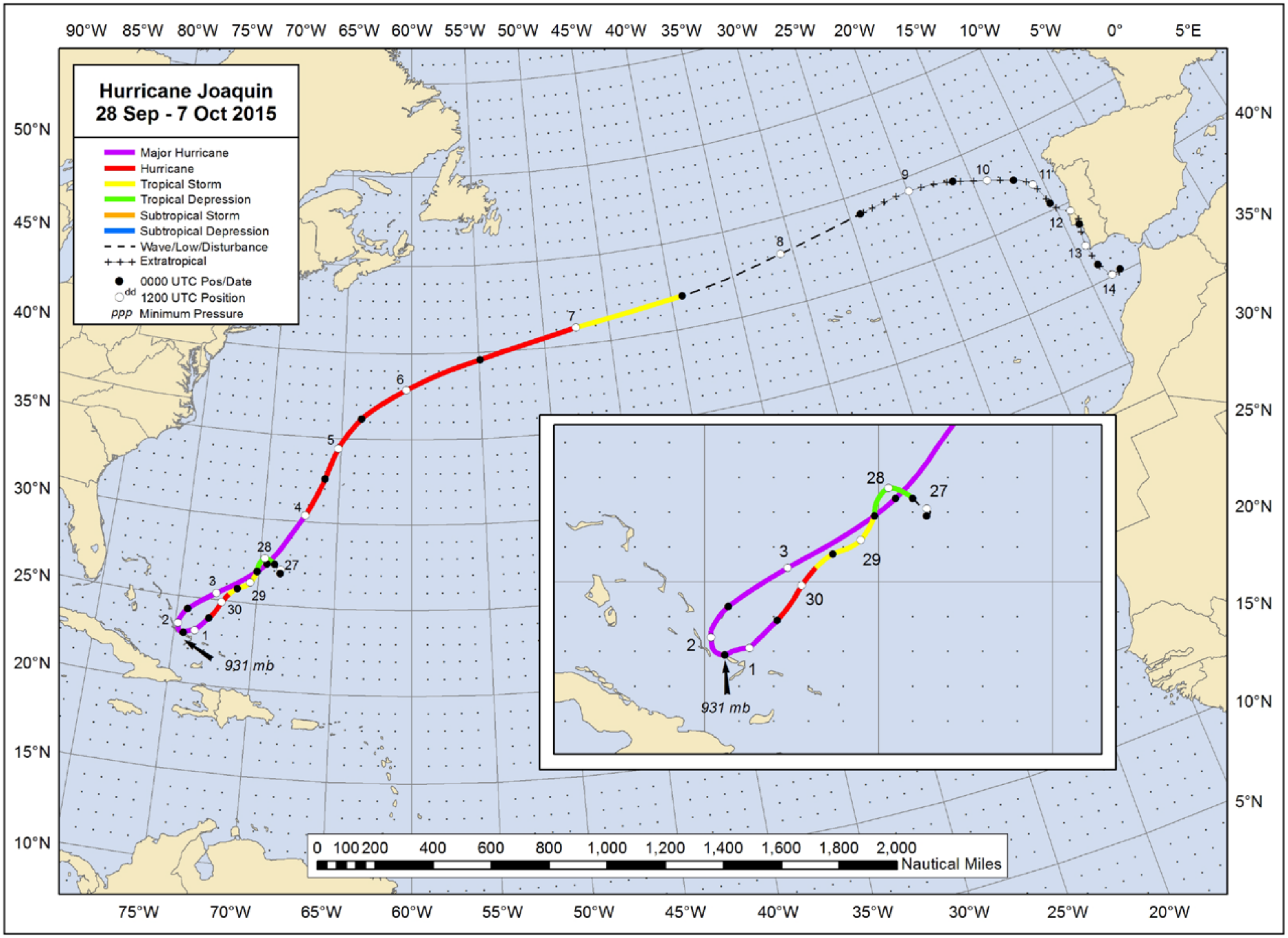

Figure 1. Best track positions for Hurricane Joaquin, 28 September – 7 October 2015. The track during the post-tropical stage is partially based on analyses from the NOAA Ocean Prediction Center.

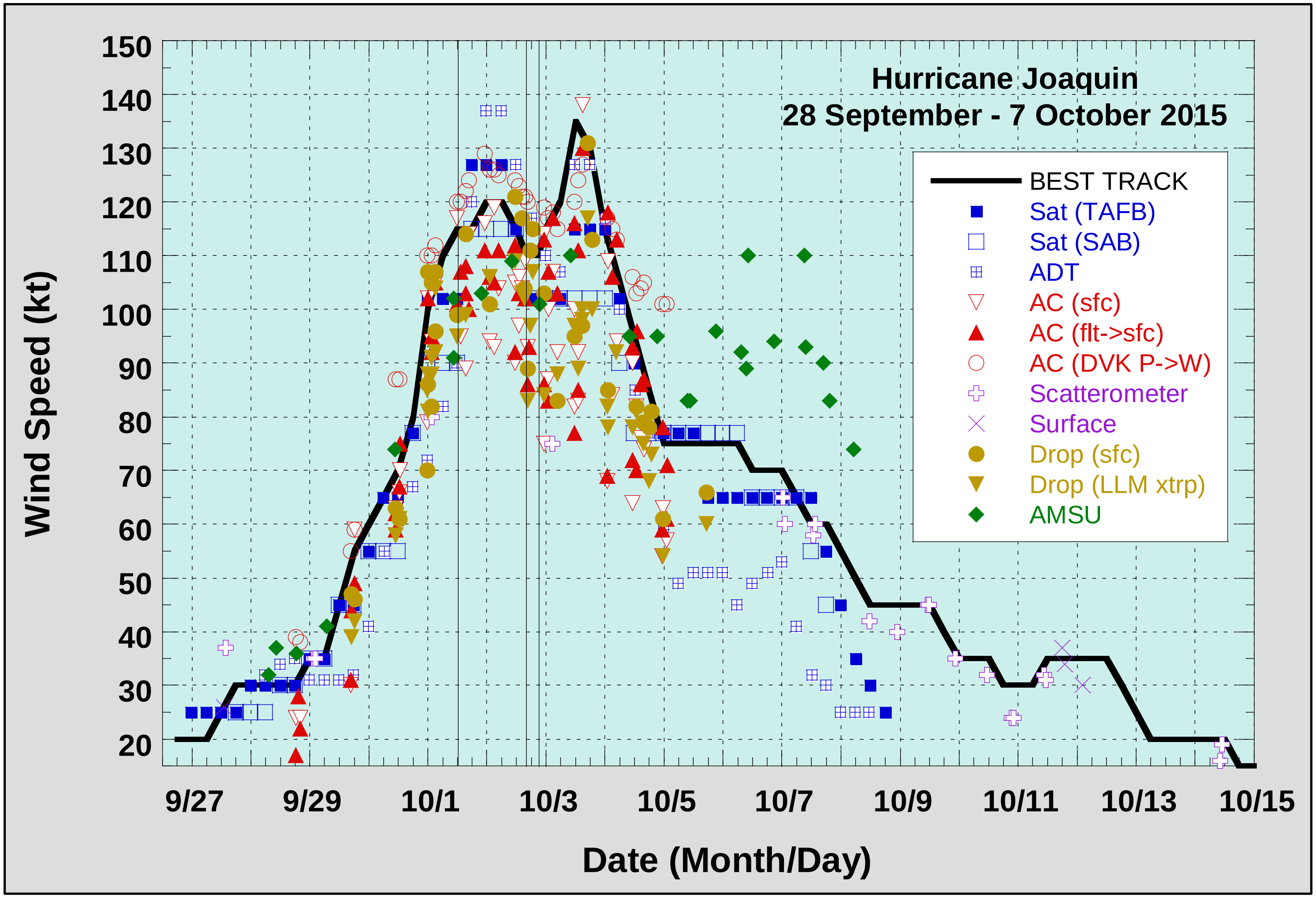

Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Joaquin, 28 September – 7 October 2015. Aircraft observations have been adjusted for elevation using 90%, 80%, and 80% adjustment factors for observations from 700 mb, 850 mb, and 1500 ft, respectively. Dropwindsonde observations include actual 10 m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM). Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. AMSU intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies technique. Dashed vertical lines correspond to 0000 UTC, and solid vertical lines correspond to landfalls.

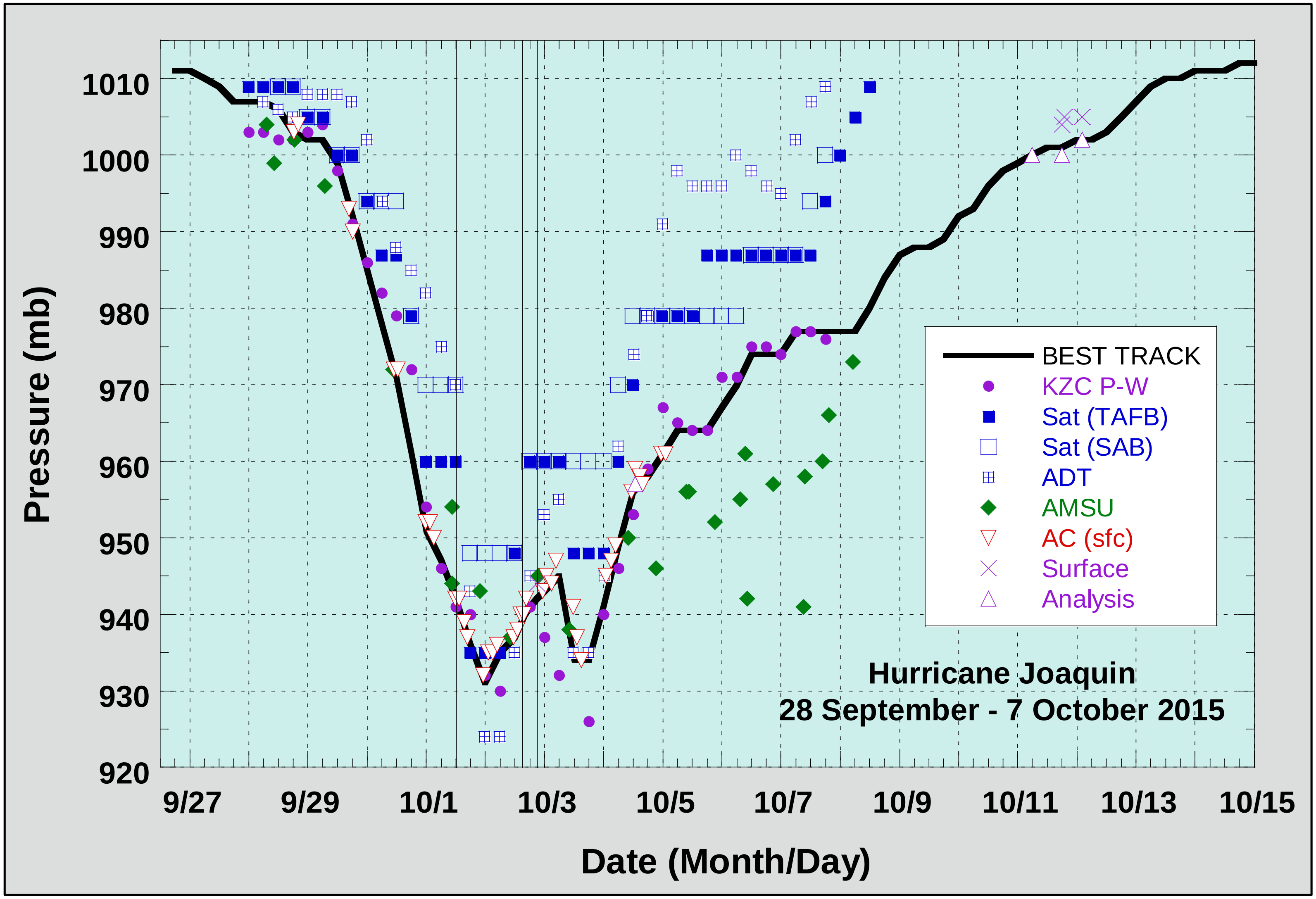

Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Joaquin, 28 September – 7 October 2015. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. AMSU intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies technique. KZC P-W refers to pressure estimates derived using the Knaff-Zehr-Courtney pressure-wind relationship. Dashed vertical lines correspond to 0000 UTC, and solid vertical lines correspond to landfalls.

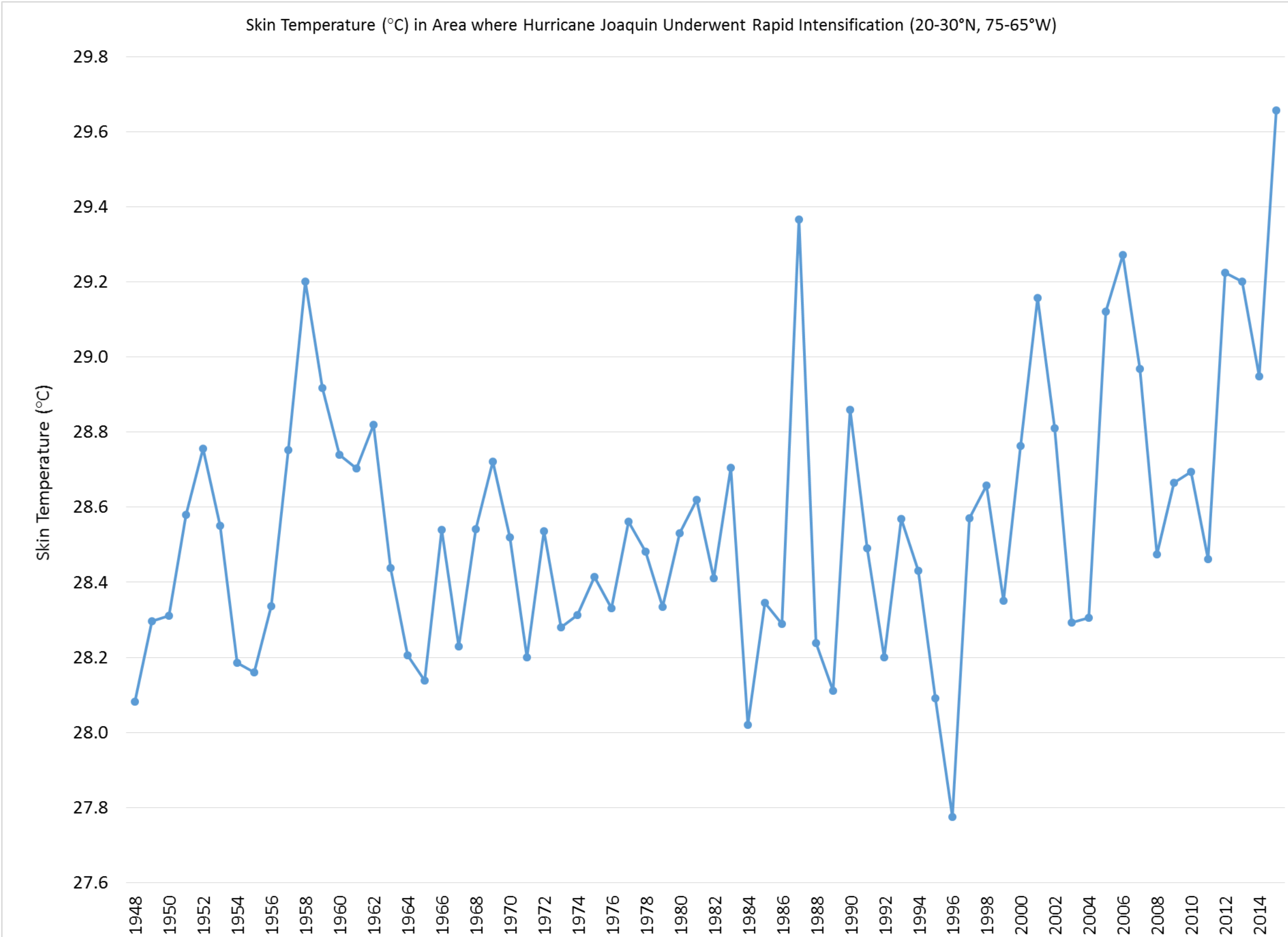

Figure 4. NCEP/NCAR reanalysis of yearly sea surface skin temperatures (°C) from 1948 to 2015 averaged over the 10-day period from 18 to 27 September in an area over the western Atlantic Ocean from 20° to 30°N between 65° and 75°W.

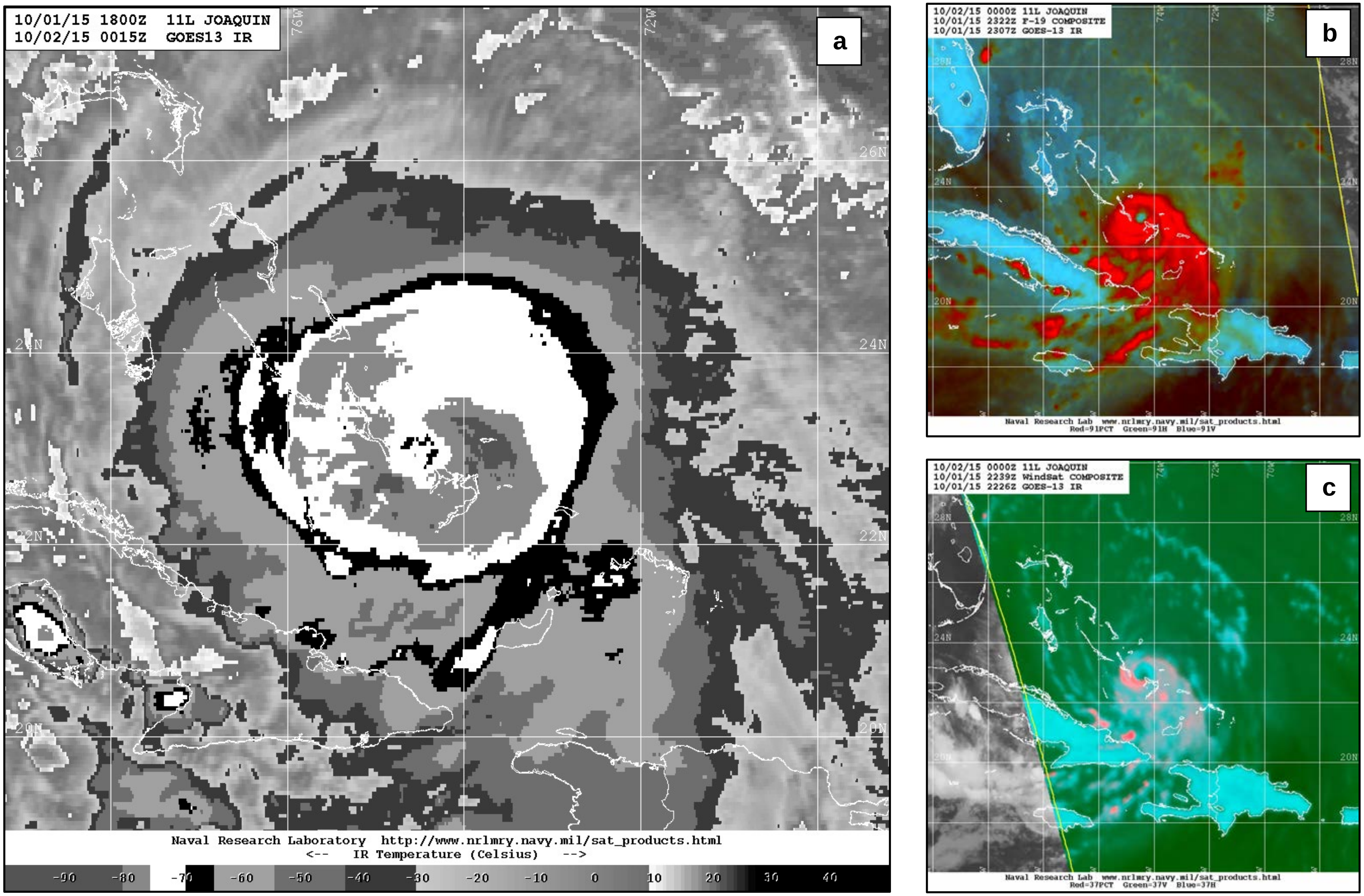

Figure 5. (a) GOES-13 infrared satellite image (using the Dvorak BD enhancement curve) of Hurricane Joaquin at 0015 UTC 2 October 2015 at the time of its first relative peak in intensity as a 120-kt category 4 hurricane. (b) 91-GHz color composite SSMI/S image of Joaquin at 2322 UTC 1 October and (c) 37-GHz color composite WindSat image at 2239 UTC 1 October. Images courtesy of the Naval Research Laboratory.

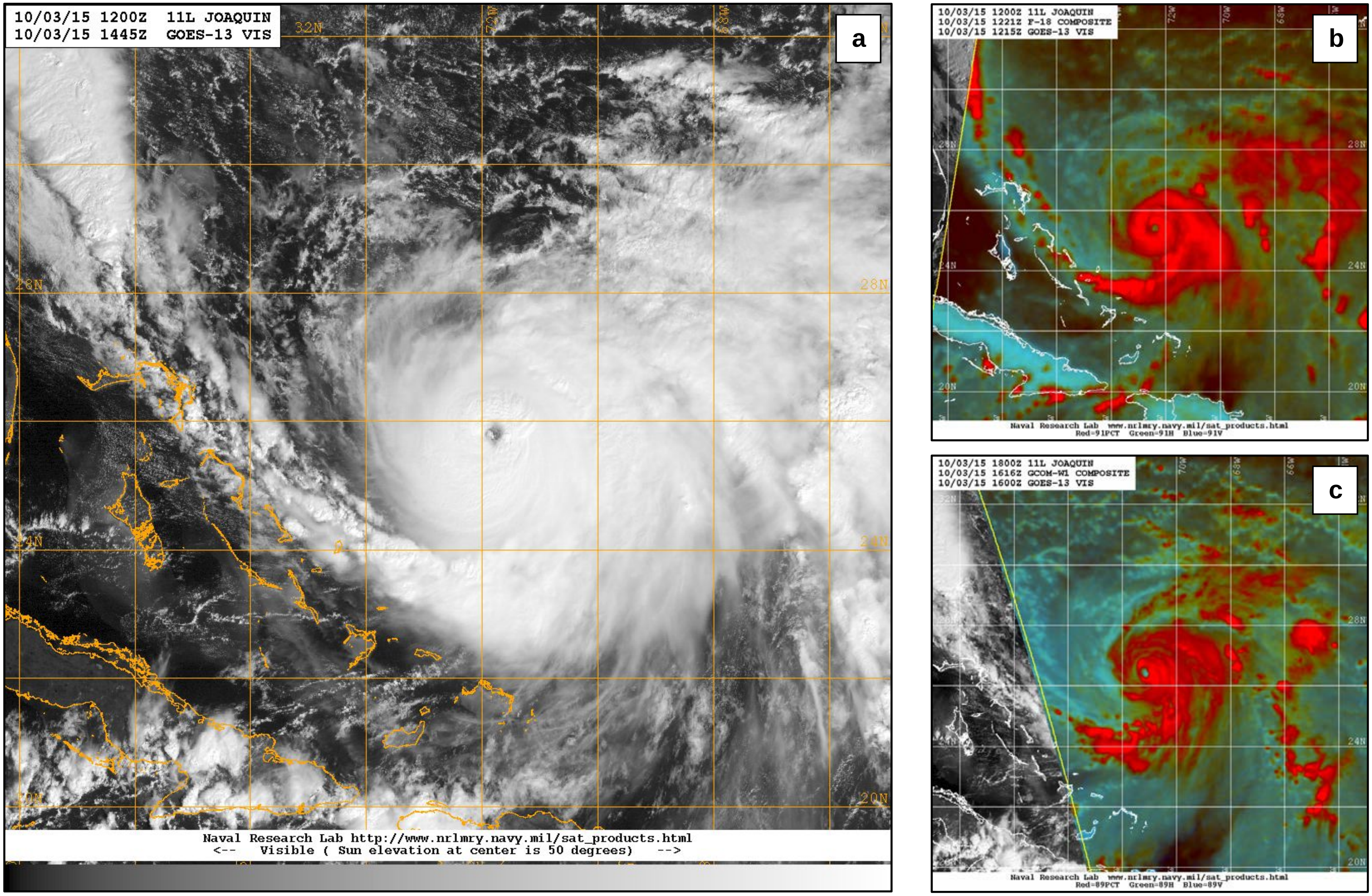

Figure 6. (a) GOES-13 visible satellite image of Hurricane Joaquin at 1445 UTC 3 October 2015, near the time that an Air Force Reserve reconnaissance mission measured winds supporting an absolute peak intensity of 135 kt. (b) 91-GHz color composite SSMI/S image of Joaquin at 1221 UTC 1 October and (c) 91-GHz color composite GCOM image at 1616 UTC 1 October showing the quick erosion of the western eyewall. Images courtesy of the Naval Research Laboratory.

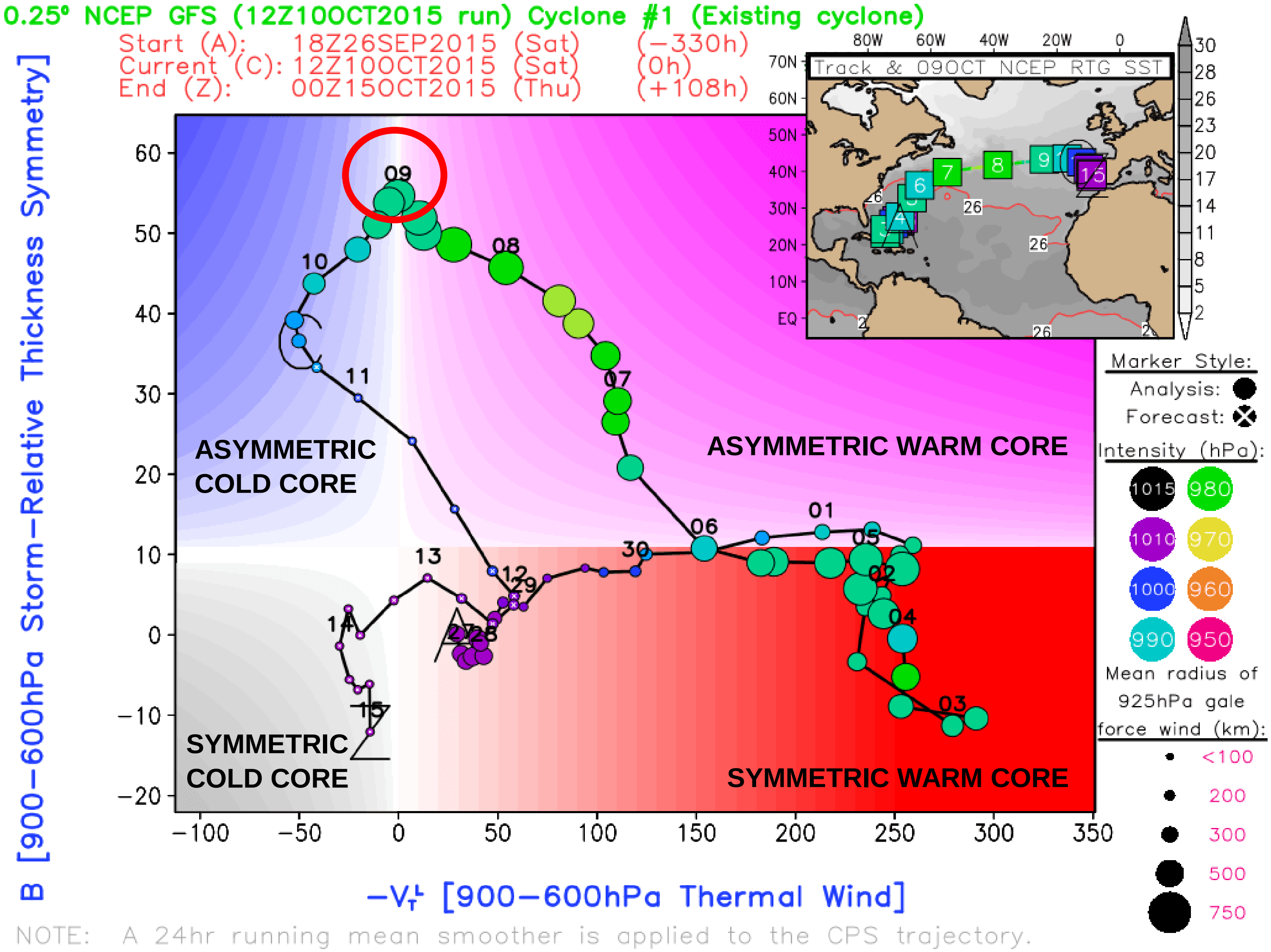

Figure 7a. Cyclone phase-space diagram of Hurricane Joaquin based on analyses and forecasts from the GFS model. Along with Fig. 7b (see below), the analysis shows that Joaquin completed extratropical transition by 0000 UTC 9 October, when it went from being asymmetric shallow warm core to asymmetric deep cold core (indicated by the red circle). Image courtesy of Dr. Robert Hart at Florida State University.

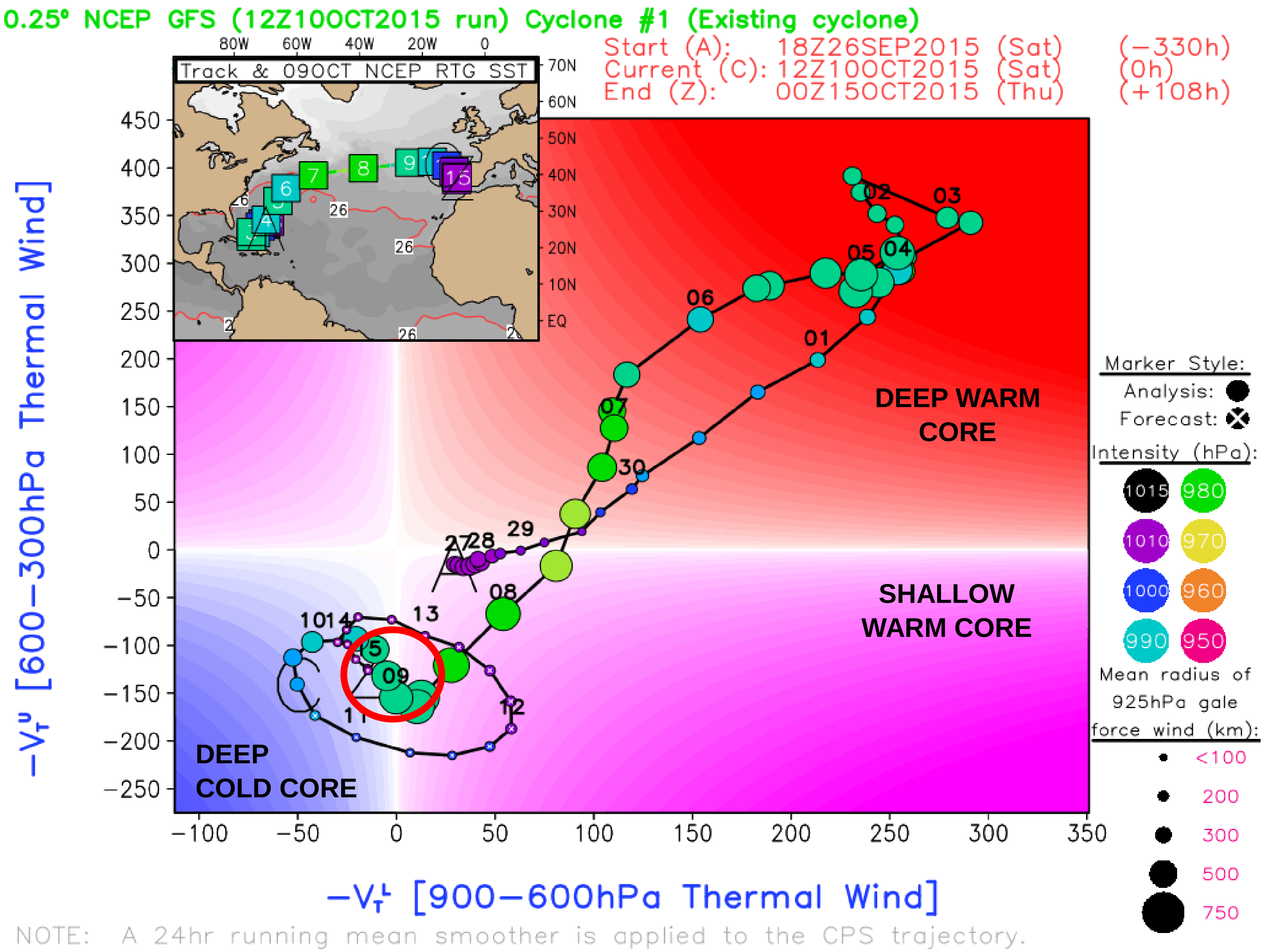

Figure 7b. Cyclone phase-space diagram of Hurricane Joaquin based on analyses and forecasts from the GFS model. Along with Fig. 7a (see above), the analysis shows that Joaquin completed extratropical transition by 0000 UTC 9 October, when it went from being asymmetric shallow warm core to asymmetric deep cold core (indicated by the red circle). Image courtesy of Dr. Robert Hart at Florida State University.

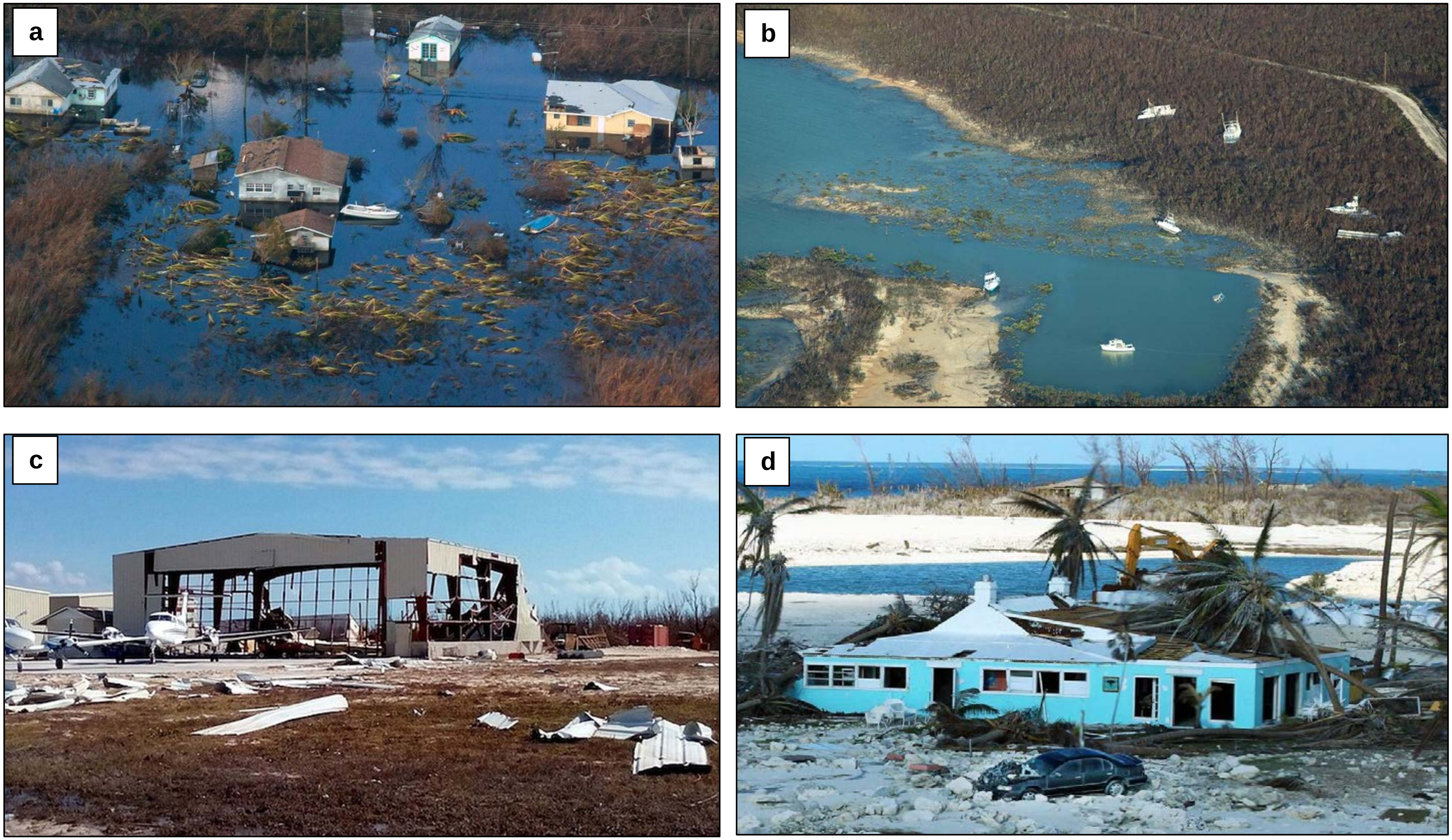

Figure 8. Damage photos from the Bahamas after Hurricane Joaquin. (a) South Long Island (AP/Tim Auyen) (b) South Long Island (AP/Tim Auyen) (c) Crooked Island airport (*Tribune 242*) (d) Pittstown on Crooked Island (*El Nuevo Herald*/Pedro Portal)

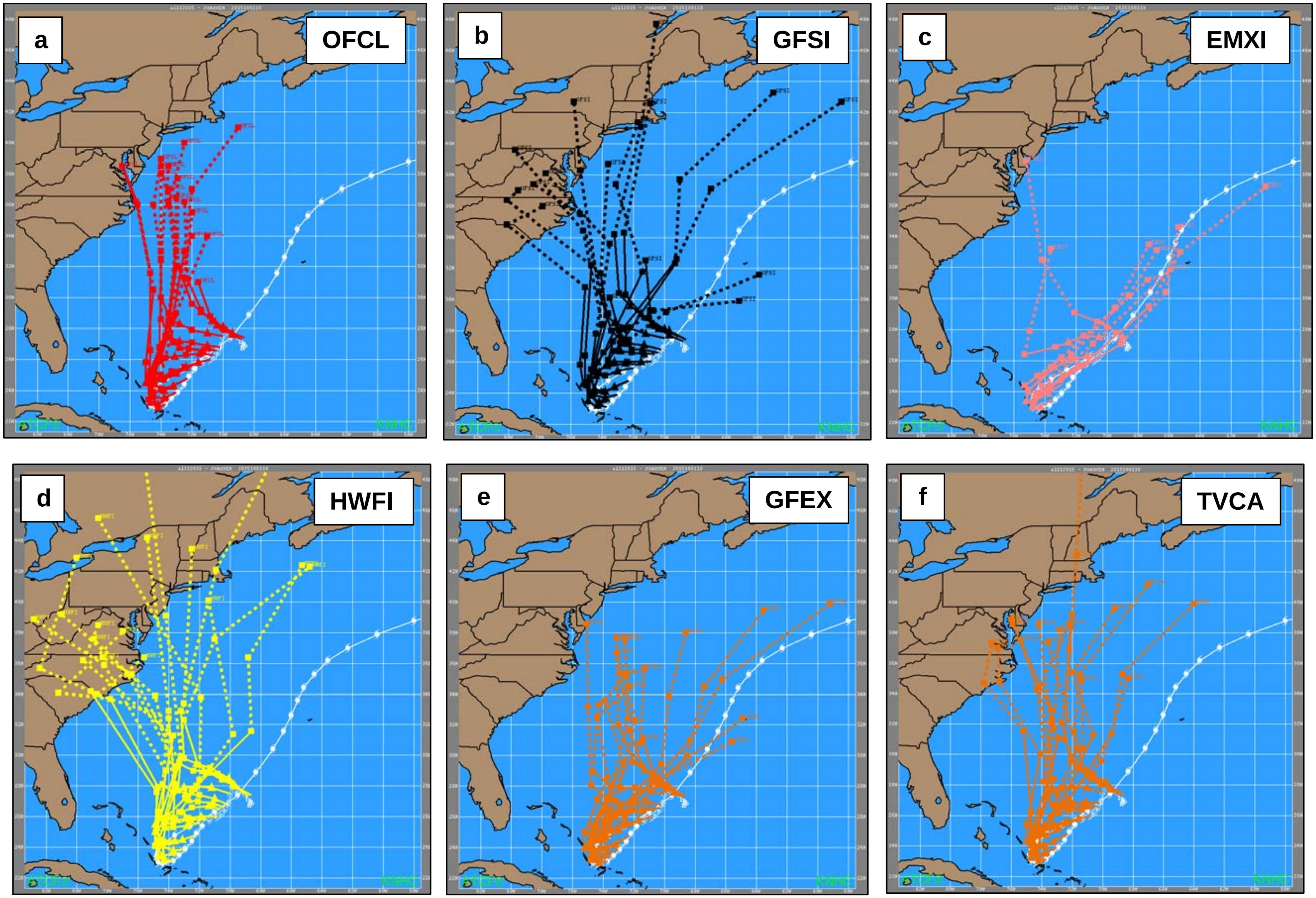

Figure 9. Five-day forecast track plots of the (a) NHC official forecasts (OFCL), (b) GFSI, (c) EMXI, (d) HWFI, (e) GFEX, and (f) TVCA for the forecast cycles between 0000 UTC 28 September and 1800 UTC 1 October 2015 for Hurricane Joaquin. The best track of Joaquin is indicated by the white lines with six-hourly tropical cyclone positions.

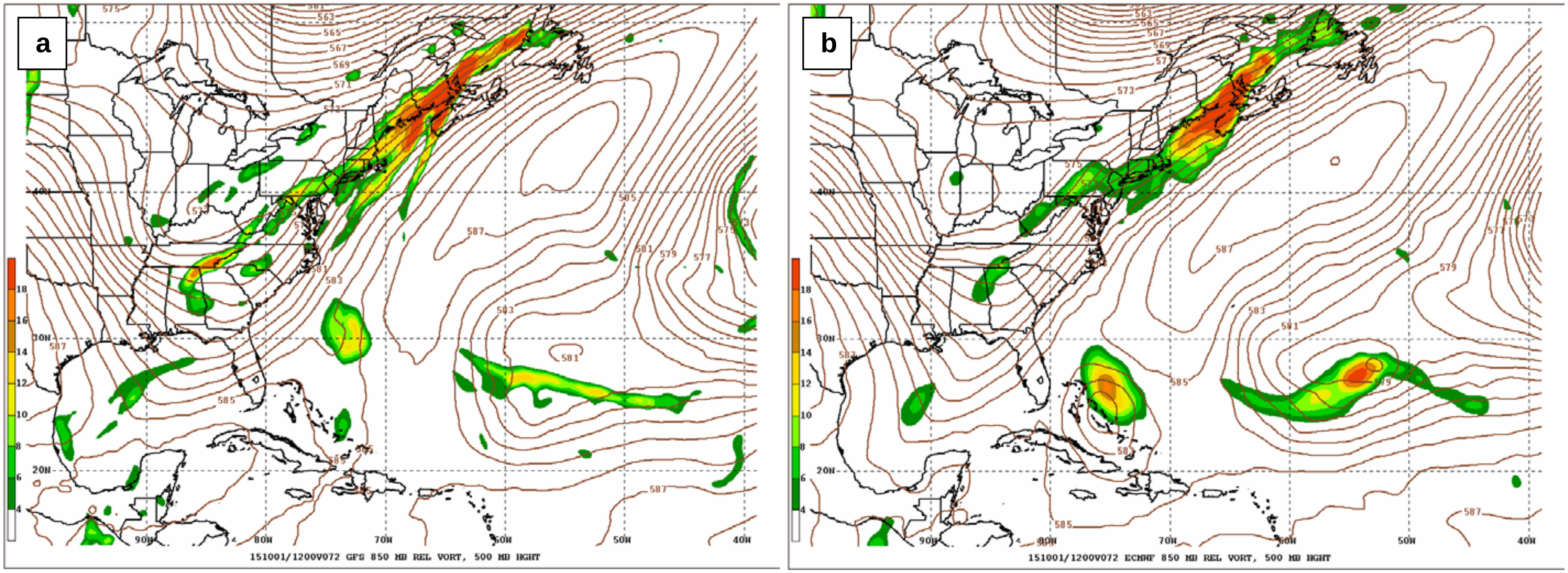

Figure 10. 72-h model forecast fields of 850-mb relative vorticity (× 10^{-5} s^{-1}, colored shading) and 500-mb geopotential height (× 10 m, solid brown lines) valid at 1200 UTC 1 October 2015 from the (a) GFS and (b) ECMWF models. The fields reveal that the GFS showed a weaker vortex for Joaquin being picked up by the eastern U.S. trough while the ECMWF showed a stronger Joaquin being blocked and pushed southwestward by a western Atlantic mid-level ridge.

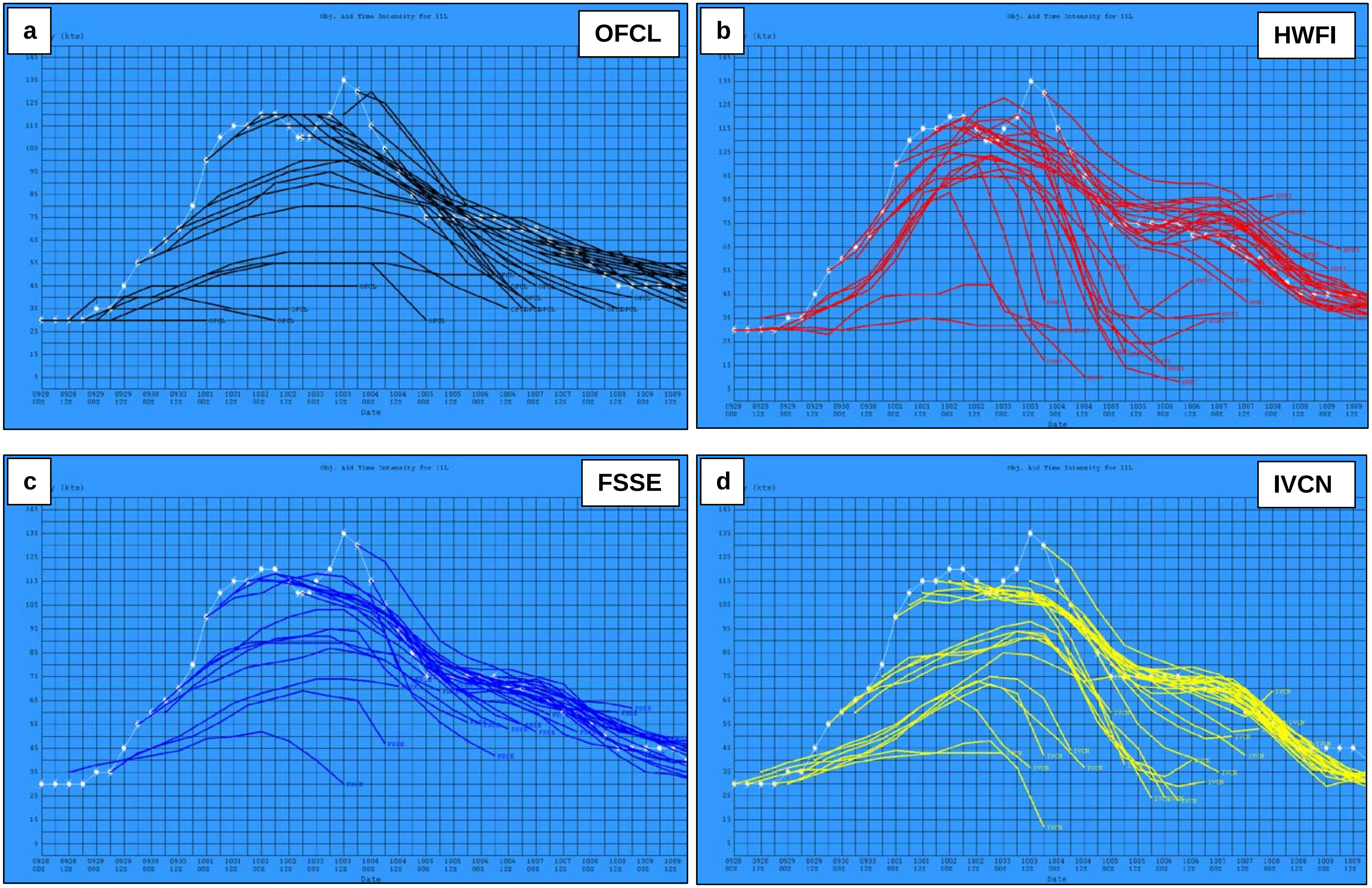

Figure 11. Intensity plots of the (a) NHC official forecasts (OFCL), (b) HWFI, (c) FSSE, and (d) IVCN for the forecast cycles between 0000 UTC 28 September and 0000 UTC 8 October 2015 for Hurricane Joaquin. The best track intensity of Joaquin is indicated by the white lines on each figure.