# NATIONAL HURRICANE CENTER ANNUAL SUMMARY

## 2015 ATLANTIC HURRICANE SEASON

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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

## ABSTRACT

Tropical cyclone activity in the Atlantic basin during the 2015 season was somewhat below average. Of the 11 tropical storms that formed, 4 became hurricanes, and 2 reached major hurricane strength (category 3 or higher on the Saffir-Simpson Hurricane Wind Scale). In comparison, the 1981-2010 averages are 12 tropical storms, 6 hurricanes, and 3 major hurricanes. The Accumulated Cyclone Energy (ACE) index was 68% of the long-term median value. Most of the season's tropical cyclones occurred well east of the United States east coast, although Tropical Storm Ana made landfall in South Carolina — the earliest U.S.-landfalling tropical cyclone on record — and Tropical Storm Bill made landfall along the central Texas coast. In addition, Hurricane Joaquin battered the southeastern and central Bahamas as a category 4 hurricane, and was the strongest October hurricane known to have affected the Bahamas since 1866. Seventy-six direct deaths were caused by the season's tropical cyclone activity.

# OVERVIEW

Tropical cyclone activity was somewhat below average in the Atlantic basin during 2015. Eleven tropical storms formed, of which four became hurricanes, and two became major hurricanes. In comparison, the long-term (1981-2010) averages are 12 named storms, 6 hurricanes, and 3 major hurricanes. The NOAA Accumulated Cyclone Energy (ACE) index, a measure that takes into account both the strength and duration of the season's tropical storms and hurricanes, in 2015 was 68% of the long-term median. Despite the below-average activity of the season overall, five tropical cylones made landfall. There was also a tropical depression that did not intensify into a tropical storm.

Table 1 lists the tropical cyclones of the 2015 season, and the tracks of the season's (sub)tropical storms and hurricanes are shown in Figure 1. There was a distinct lack of activity in the Caribbean Sea due to El Nino-enhanced westerly vertical wind shear. However, the remainder of the deep Tropics was unusually active for a season that was influenced by a strong El Nino event in the central and eastern Pacific Ocean. Five tropical cyclones formed south of 20°N, including one hurricane (Fred) and one major hurricane (Danny). The lack of activity in the Caribbean region can be at least partially explained by some anomalous large-scale atmospheric features. Figure 2 depicts the 200-850 mb anomalous vertical wind shear during August through October 2015. Above-normal shear, which was hostile for tropical cyclone formation and intensification, prevailed over all of the Caribbean sub-basin and into the western portion of the tropical Atlantic Main Development Region (MDR). Similar to conditions in 2014, there was weaker shear north of 20°N near the Bahamas and Hispaniola, which was the area where Hurricane Joaquin formed. Another unfavorable environmental factor during the 2015 Atlantic hurricane season was the anomalous 200-mb velocity potential for August-October (Fig. 3), which featured a distinct pattern of upper-tropospheric convergence that dominated nearly the entire MDR. This pattern resulted in atypical sinking motion and drier air at lower latitudes (Fig.4), especially west of 40$^{O}$W longitude, which likely suppressed tropical cyclone development and maintenance.

The following section summarizes the most significant tropical cyclones of 2015: Ana, Bill, Erika, Fred, and Joaquin. More detailed information on the tropical cyclones of 2015 can be found at http://www.nhc.noaa.gov/2015atlan.shtml .

# SELECTED STORM SUMMARIES

## Tropical Storm Ana

Ana originated from the interaction of an old frontal system and a sharp mid- to upper-level trough on 3-5 May. Surface pressures slowly decreased, and a non-tropical low pressure system with a well-defined center of circulation formed early on 6 May just offshore of the southeastern coast of Florida. The low moved slowly northward over the next two days and developed an associated area of gales. On 8 May, the low acquired sufficient organized deep convection for the system to be designated a subtropical storm when it was located about 150 n mi south-southeast of Myrtle Beach, South Carolina – the subtropical designation being based on the cyclone's association with an upper trough and a large (~100 n mi) radius of maximum wind.

Ana moved slowly north-northwestward over the warmer waters of the Gulf Stream on 8-9 May. Deep convection, which steadily developed closer to the surface center and was accompanied by the formation of upper-level anticyclonic outflow, marked Ana's transition to a tropical storm early on 9 May when the cyclone was located about 115 n mi southeast of Myrtle Beach. Ana's intensity remained steady near 50 kt while the cyclone was over the warm waters of the Gulf Stream. However, by late that day, the tropical storm began a weakening trend as it moved westward away from the Gulf Stream and over the cooler coastal shelf waters, where sea-surface temperatures were as low as $20^{O}$ C. Moderate to strong vertical wind shear enhanced the weakening process, and Ana made landfall around 1000 UTC 10 May just southwest of North Myrtle Beach, South Carolina, with an intensity of 40 kt. The 10 May landfall makes Ana the earliest U.S.-landfalling tropical cyclone on record.

Shortly after making landfall, Ana slowed and turned northward, and weakened to a tropical depression. On 11 May the cyclone turned northeastward and moved across eastern North Carolina, degenerating into a remnant low pressure area before emerging off of the United States mid-Atlantic coast near the Delmarva Peninsula by 12 May. The low became embedded in the flow ahead of a mid-latitude trough and accelerated northeastward off of the New England coast, and merged with a frontal system near Nova Scotia on 13 May.

Ana produced minor storm surge flooding along portions of the coasts of South Carolina and North Carolina. The highest storm surge values were approximately 2.5 ft above normal tide levels at Oyster Landing, South Carolina, and Springmaid Pier, South Carolina, respectively.

Ana generally produced storm-total rainfall of 3 to 6 inches across portions of eastern North Carolina, with much lesser amounts over South Carolina. The highest rainfall reports were 6.89 inches and 6.87 inches near Kinston, North Carolina. Locally heavy rainfall caused some inland freshwater flooding in Lenoir County, North Carolina, near the border with Jones County.

There was one direct death associated with Ana. Media reports indicate that a 25-year old Ohio man was pulled under water for more than ten minutes in strong rip currents off of the coast of Oak Island, North Carolina, on 11 May. The man died the next day due to anoxic brain injury.

Well before Ana made landfall, large swells moved into Charleston Harbor and drove a sailboat aground on 7 May. The vessel's pierced hull filled with water, forcing a Coast Guard mission to rescue the two sailors onboard. No one was injured. Abnormally high tides in combination with Ana's storm surge resulted in minor beach erosion along the coasts of northeastern South Carolina and southeastern North Carolina. Roads were washed out in North Myrtle Beach, South Carolina, and a long-term beach erosion condition along Cherry Grove

Beach was exacerbated. Farther north in Surf City, North Carolina, portions of the sunken schooner *William H. Sumner*, which was wrecked in 1919, became visible along the beach front. Although Tropical Storm Ana caused some property damage in the United States, insured losses did not meet the Property Claim Services' $25 million minimum reporting threshold.

## Tropical Storm Bill

Tropical Storm Bill formed from the complex interaction of an upper-level trough over the Gulf of Mexico, a broad area of low pressure near the Yucatan Peninsula, and a trough associated with eastern North Pacific Hurricane Carlos. The combination of these three features resulted in an elongated area of low pressure forming over northern Belize and the Yucatan Peninsula on 13 June. The broad disturbance moved northwestward into the western Gulf of Mexico on 14-15 June, and finally developed a well-defined center of circulation by 0000 UTC 16 June about 175 n mi east-southeast of Corpus Christi, Texas. At that point the system became a tropical storm since it was already producing sustained winds over 34 kt. Bill continued northwestward during most of 16 June, but slowed down and turned west-northwestward as it approached the Texas coast.

Bill made landfall on Matagorda Island at 1645 UTC 16 June with maximum winds of 50 kt, and was then nearly stationary along the coast for a couple of hours. Later that evening, the center turned northward and accelerated inland over eastern Texas, and Bill weakened to a tropical depression by 0600 UTC 17 June when it was centered about 30 n mi east of Austin, Texas. The depression continued northward for the next two days, and became a remnant low on 18 June while centered about 65 n mi south-southeast of Tulsa, Oklahoma. Bill's remnant low moved east-northeastward for the next few days, producing heavy rain, flooding, and tornadoes across southern Missouri, northern Arkansas, and portions of the Ohio River Valley. The low dissipated on 21 June over the mountainous terrain of central West Virginia.

Bill produced moderate storm surge flooding along portions of the Texas coast north of where it made landfall. Combined with the normal tide, Bill's surge produced inundation of 1 to 3 ft above ground level for parts of the Texas and southwestern Louisiana coasts. The highest measured storm surge was 3.50 ft at Port Lavaca, Texas. A storm surge of 3.42 ft was measured at the Galveston Bay entrance, 3.22 ft at Eagle Point, and 3.04 ft at Freeport. A storm surge occurred as far north as southwestern Louisiana, where 2.79 ft was measured at the Freshwater Canal Locks.

Heavy rains fell from the central Texas coast northward across eastern Texas, western Louisiana, and southern and eastern Oklahoma. Many locations reported storm-total amounts in excess of 10 inches. The highest rainfall report available from the storm was 13.78 inches in Ganado, Texas, located north of Port Lavaca in Jackson County. A report of 13.50 inches was also received near El Campo, Texas, not too far to the northeast of Ganado. In Oklahoma, the highest rainfall report received was 9.72 inches in Lone Grove in the southern part of the state just west of Ardmore. The maximum reported rainfall in western Louisiana was 7.88 inches at Bayou Toro.

The heavy rainfall from Bill caused flash floods and flooding of major rivers across portions of Texas and Oklahoma. In many areas, the flooding was exacerbated by already-saturated grounds resulting from heavy rainfall and flooding which had occurred in May. The Red River at Interstate 35 along the Texas/Oklahoma border reached a record crest of 42.05 ft, which was 17 ft above flood stage and about 2 ft above the previous record crest set in 1987. West Mustang Creek near Ganado, Texas, reached a record crest of 27.45 ft, which was over 7 ft above flood stage. The Lavaca River near Edna, Texas, reached 29.72 ft, its fourth-highest crest and more than 8 ft above flood stage. Farther north, the Washita River near Dickson, Oklahoma, reached a record crest of 48.70 ft, which was more than 21 ft above flood stage. Flash flooding was also reported in the Austin and San Antonio metro areas.

Moisture associated with Bill's precursor disturbance and Hurricane Carlos over the eastern North Pacific Ocean produced heavy rains, flooding, and landslides over portions of Central America and the Yucatan Peninsula of Mexico. In Honduras, two people died in floodwaters near Tegucigalpa, while two other people were reported missing. More than 500 people were affected by floods and landslides in Honduras. Two people died in a landslide in Guatemala, where 516,000 people were affected by flooding and landslides.

Bill caused two direct deaths as a result of heavy rain and flooding in Oklahoma during its tropical depression stage. An 80-year-old woman died near Macomb in Pottawatomie County after she reportedly ignored barricades and drove through a flooded roadway. A 2-year-old boy drowned in Ardmore, Oklahoma, after he was swept from his father's arms while the two were trying to escape floodwaters. Although Tropical Storm Bill caused some property damage in the United States, insured losses did not meet the Property Claim Services' $25 million minimum reporting threshold.

## Tropical Storm Erika

Erika had its origins in a tropical wave that moved off of the coast of Africa on 21 August, and quickly moved westward across the tropical Atlantic for the next three days, producing gale-force winds by 23 August. The fast-moving wave passed over NOAA data buoy 41041 late on 24 August, and observations from that platform indicated that the circulation had finally become well defined, with maximum winds near 40 kt, and the system became a tropical storm while centered more than 850 n mi east of the Lesser Antilles.

The cyclone continued westward at a brisk pace, being steered by strong flow to the south of a subtropical ridge. By late on 25 August, the low-level center became partially exposed and Erika had weakened slightly to 35 kt. The tropical cyclone maintained a generally westward heading, and passed near the northern tip of Guadeloupe by early 27 August, strengthening a little to 45 kt. West-northwesterly shear prevented additional intensification while Erika moved over the northeastern Caribbean Sea early on 28 August, passing south of the U.S. Virgin Islands and Puerto Rico. Later that day, Hurricane Hunter aircraft observations revealed that Erika no longer had a well-defined center of circulation, and the tropical cyclone dissipated just south of the eastern tip of Hispaniola. The remnant low pressure area moved across Haiti on 29 August, between the Bahamas and Cuba on 30 August, and turned northward and moved slowly over the eastern Gulf of Mexico on 31 August and 1 September. The disturbance moved over northern Florida on 2 September and then drifted into southeastern Georgia, losing its identity on 3 September.

The largest rainfall amounts associated with Erika were observed on Dominica, where totals reached 12.62 inches. Practically all of this precipitation occurred during a 12-h period on 27 August. These torrential rains produced catastrophic flooding and mudslides over the island. There was also localized flooding in Guadeloupe, and the rains were described as beneficial in Puerto Rico, due to the drought conditions that prevailed over portions of that island.

Erika was responsible for 30 direct deaths, all in Dominica. Also, 574 persons on that island were made homeless by the storm. In Haiti, one person died due to a mudslide after Erika had dissipated as a tropical cyclone.

In Dominica, 271 houses were reportedly damaged or destroyed. There was also major damage to roads, bridges and other infrastructure on the island. Total damage estimates for Dominica were highly variable, but ranged up to US$500 million.

Most of the damage from Erika in Puerto Rico occurred in the agricultural sector and it was estimated to be about $17.4 million, mainly due to losses of plantains, bananas, and coffee. Some trees and power lines were downed in Puerto Rico with 250,000 people without power. In St. Croix, Erika's winds downed trees, limbs, light poles and power lines causing power outages to 11,000 customers.

## Hurricane Fred

Fred developed from a tropical wave that emerged from the west coast of Africa on 29 August. Unlike most tropical waves, Fred's precursor began to develop almost immediately upon reaching the Atlantic, and a low pressure area formed just west of the coast of Guinea later that day. The center of the low re-formed northward by late that day, and it is estimated that a tropical depression developed early on 30 August about 260 n mi west-northwest of Conakry, Guinea.

The depression moved quickly on an atypical northwestward track toward the Cape Verde Islands (Cabo Verde). The combination of above-average sea-surface temperatures and light vertical wind shear enabled rapid strengthening to occur, which was also not normal for this area. The cyclone reached tropical storm strength 6 h after genesis, and it became a hurricane by 31 August about 145 n mi south-southeast of Sal, Cabo Verde. Fred moved through the islands later that day as it reached an estimated peak intensity of 75 kt. After that, a combination of decreasing sea-surface temperatures and increasing southwesterly vertical wind shear caused weakening, and Fred dropped below hurricane strength early on 1 September as it moved away from Cabo Verde. Fred was the first hurricane to move through Cabo Verde since 1892.

Fred turned west-northwestward later that day and this general motion would continue for the next two days. During this time, thunderstorms occurred in episodic sheared bursts, with the result that Fred gradually weakened. The cyclone moved westward on 4 September and weakened to a tropical depression. Later that day, however, a new burst of convection caused the cyclone to strengthen back to a tropical storm for about 12 h as it turned back toward the west-northwest. A deep-layer trough forced Fred to turn northward on 6 September. The cyclone remained in a strongly sheared environment, which caused it to degenerate to a trough later that day more than 1000 n mi southwest of the Azores. Shortly thereafter, the remnants of Fred were absorbed by a front.

Media reports indicate that storm surge, accompanied by high surf, occurred on several islands of Cabo Verde. In addition, swells generated by the hurricane caused above normal tides on the western coast of Africa from Guinea-Bissau northward to Senegal.

No detailed rainfall observations are available from Cabo Verde, but media reports suggest that 6-8 inches of rain occurred on several of the islands. These rains caused some flooding, but also filled reservoirs that were low due to drought conditions.

Media reports indicate there were 9 deaths directly associated with Fred. The Greek-registered fishing boat *Dimitrios* sank off the coast of Guinea-Bissau due to the high waves generated by Fred, and 7 members of its crew of 19 were not found. In addition, two fishermen from Cabo Verde were reported missing and presumed dead when their fishing boat failed to return to the island of Boa Vista.

Media reports also indicate that Fred caused damage on several islands of Cabo Verde, with Boa Vista being the hardest hit. These reports suggest that about US$1 million of damage occurred on the islands. Additional damage from surf and above normal tides occurred along the coast of Africa, with damage to crops reported in Guinea-Bissau due to salt water inundation.

## Hurricane Joaquin

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-level 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 small but well-defined surface low developing on 26 September about 350 n mi east-northeast of San Salvador Island in the central Bahamas. A tropical depression formed two days later on 28 September.

Moderate north-northwesterly shear prevented the depression from strengthening for about a day, but the cyclone became a tropical storm early on 29 September while centered about 300 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 on 29 September, and Joaquin became a hurricane on 30 September about 170 n mi east-northeast of San Salvador, and then a major hurricane on 1 October about 85 n mi east of San Salvador. Sea-surface temperatures in the area where Joaquin formed and rapidly intensified were more than 1°C higher than normal and were the warmest on record for the period 18-27 September.

Meanwhile, a mid- to upper-level trough over the eastern United States deepened on 1-2 October, causing the hurricane to slow down and make a tight clockwise turn over the southeastern and central Bahamas. Joaquin continued to strengthen, reaching a relative peak in intensity as a 120-kt category 4 hurricane early on 2 October. The powerful cyclone made landfall as a major hurricane on several islands of the Bahamas on 1-2 October, first on Samana Cay in the morning of 1 October, then on Rum Cay and San Salvador during the afternoon of 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 early 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, and data from an Air Force Reserve Hurricane Hunter aircraft indicated that the hurricane had reached a peak intensity near 135 kt, just shy of category 5 strength. However, soon thereafter increasing northwesterly shear eroded the western eyewall, and Joaquin lost its status as a major hurricane by early 4 October.

Joaquin moved north-northeastward over the western Atlantic on 4-5 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 early on 5 October. The hurricane turned northeastward and east-northeastward on 6-7 October as it became embedded in the mid-latitude westerlies. Increasing shear and colder sea-surface temperatures caused the cyclone to weaken to a tropical storm early on 7 October while centered about 420 mi southeast of Cape Race, Newfoundland. With strong west-southwesterly shear displacing the remaining thunderstorm activity well away from Joaquin's ill-defined center, the cyclone became post-tropical by 8 October about 380 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 9 October after it was fully embedded in the frontal zone over the north Atlantic.

The extratropical low moved eastward and southeastward over the northeastern Atlantic on 9-12 October, with its center moving inland just north of Lisbon, Portugal, early on 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 by 15 October between Portugal and Morocco over the Gulf of Cádiz.

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

Joaquin's effects were far-reaching. 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 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. However, the storm surge flooding in the United States is not considered directly attributable to Joaquin.

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 transported 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. The airport measured a one-day rainfall amount of 11.50 inches on October 3 and a four-day total of 17.29 inches during 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. 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 entire event. In North Carolina, a maximum rainfall amount of 18.79 inches was reported near Sunset Beach in Brunswick County.

Joaquin is directly responsible for 34 deaths 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 (NTSB) reports that the “El Faro” sent a distress signal to the U.S. Coast Guard early on 1 October while located 35 miles 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 NTSB 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.

The prime minister of the Bahamas and the Bahamas Department of Meteorology estimate that the damage caused by Joaquin is well over US$60 million. Seventy percent 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. On Acklins, significant flooding was reported, 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.

Power lines were downed, private fresh water wells were flooded, and structural damage occurred to homes on Long Island. 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.

On 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. Flooding, downed power lines and poles, and significant damage to homes were reported throughout the island of San Salvador. Many roads were impassable, and the airport building was completely destroyed. Extreme flooding and downed power lines were reported on Exuma, but only minor damage to homes was reported on Mayaguana.

In the 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.

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.

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 of Cuba in the state of Ciego de Avila.

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 VERIFICATION

The 2015 Atlantic hurricane season had below-normal activity, with 222 official forecasts issued. The mean NHC official track forecast errors in the Atlantic basin were slightly smaller than the previous 5-yr means from 12 to 36 h, near average at 48 h, but higher than the 5-yr mean at 72 to 120 h. The larger-than-average track errors on days 3-5 were due to incorrectly forecasting Hurricane Joaquin to move over or near the east coast of the United States. For the season as a whole, the official track forecasts (OFCL) were highly skillful and performed close to or better than the best-performing models, except for the ECMWF (EMXI) model. The EMXI outperformed OFCL forecasts at all forecast times, especially at 48 to 120 h, which was primarily due to the EMXI's success in forecasting Hurricane Joaquin to move away from the United States. Overall, the EMXI had track errors that were superior to the rest of the NHC model guidance, ranging from about 20% better at 48 h to about 80% better at 120 h. The Government Performance and Results Act of 1993 (GPRA) 48-h track forecast goal was met.

Mean official intensity errors for the Atlantic basin in 2015 were below the 5-yr means at 12 to 48 h, but were above the the 5-yr means at 72 to 120 h. Decay-SHIFOR errors in 2015 were also lower than their 5-yr means at 12 h and 24 h, but larger than average at the other forecast times. The NHC official forecasts outperformed all of the available intensity guidance at 12, 24, 36, and 120 h. Among the guidance, HWFI, IVCN, and FSSE were the best performers, followed by DSHP and LGEM. The GPRA 48-h intensity forecast goal was met.

Table 1. 2015 Atlantic hurricane season statistics.

| Storm Name | Class[a] | Dates[b] | Max. Winds (kt) | Min. Pressure (mb) | Deaths | U.S. Damage ($million) |
|---|---|---|---|---|---|---|
| Ana | TS | 8 – 11 May | 50 | 998 | 1 | minor |
| Bill | TS | 16 – 18 June | 50 | 997 | 2 | minor |
| Claudette | TS | 13 – 14 July | 45 | 1003 | | |
| Danny | MH | 18 – 24 August | 110 | 960 | | |
| Erika | TS | 24 – 28 August | 45 | 1001 | 30 | 17.4 |
| Fred | H | 30 August – 6 September | 75 | 986 | 9 | |
| Grace | TS | 5 – 9 September | 50 | 1000 | | |
| Henri | TS | 8 – 11 September | 45 | 1003 | | |
| Nine | TD | 16 – 19 September | 30 | 1006 | | |
| Ida | TS | 18 – 27 September | 45 | 1001 | | |
| Joaquin | MH | 28 September – 7 October | 135 | 931 | 34 | |
| Kate | H | 8 – 11 November | 75 | 980 | | |

[a] Tropical depression (TD), maximum sustained winds 33 kt or less; tropical storm (TS), winds 34-63 kt; hurricane (H), winds 64-95 kt; major hurricane (MH), winds 96 kt or higher.

[b] Dates begin at 0000 UTC and include all tropical and subtropical cyclone stages; non-tropical stages are excluded.

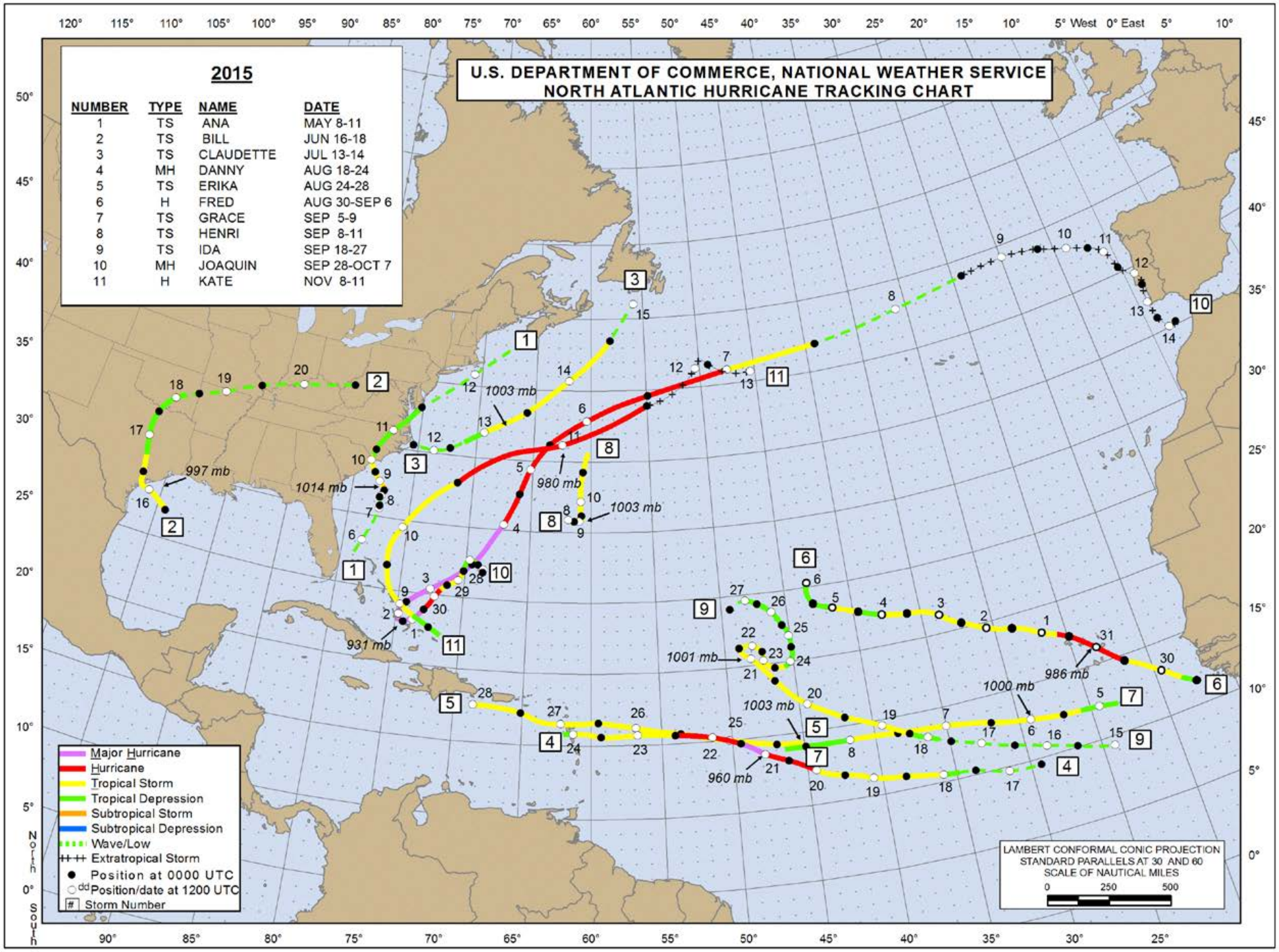


Figure 1: Tracks of the tropical storms and hurricanes of the 2015 Atlantic Hurricane Season.

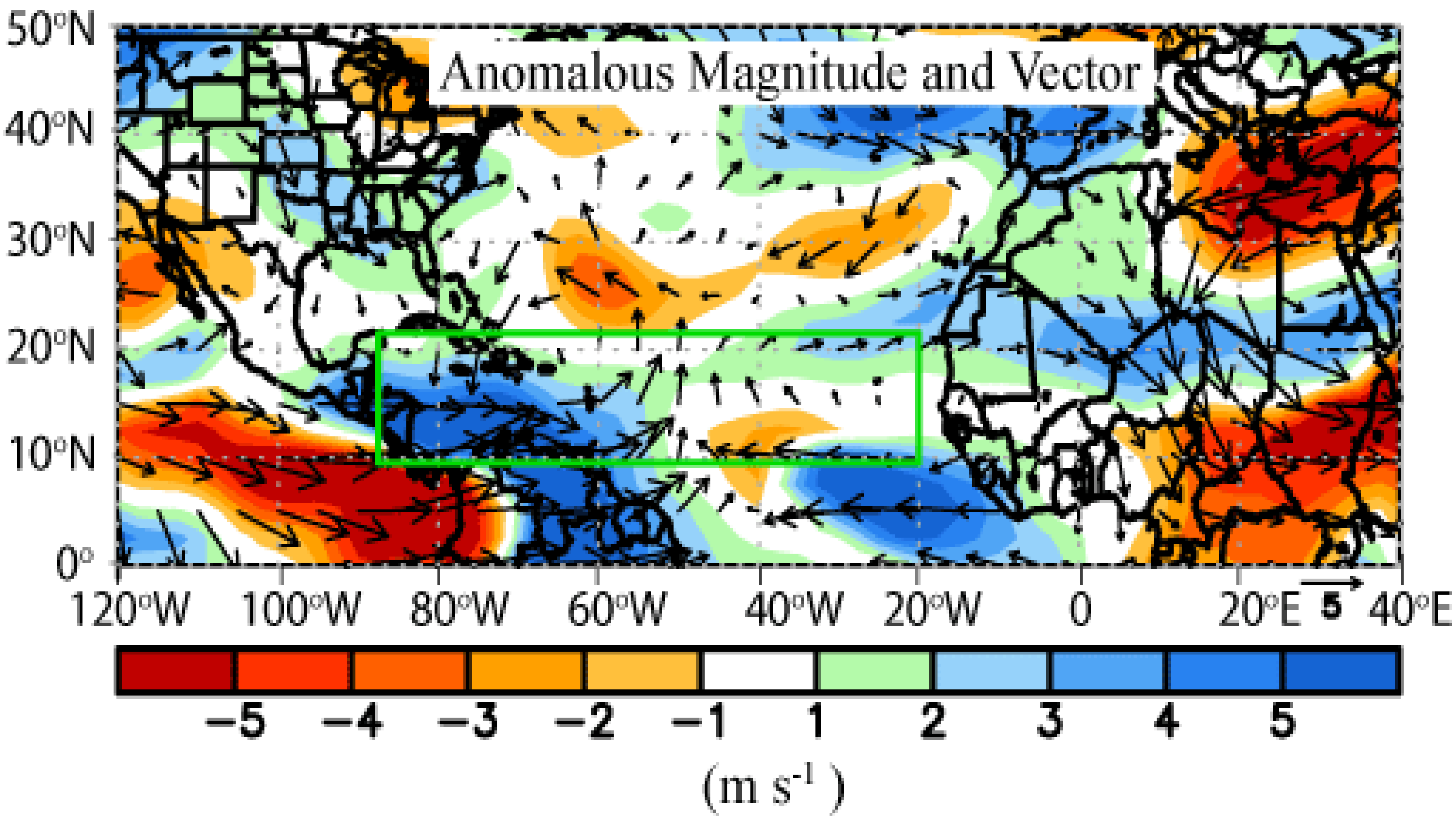


Figure 2. 200-850 mb anomalous magnitude of vertical wind shear and anomalous shear vector (m $s^{-1}$) for August through October of 2015. The green box indicates the Main Development Region. Anomalies are based on the 1981-2010 climatology. Figure courtesy of Gerry Bell (NOAA Climate Prediction Center).

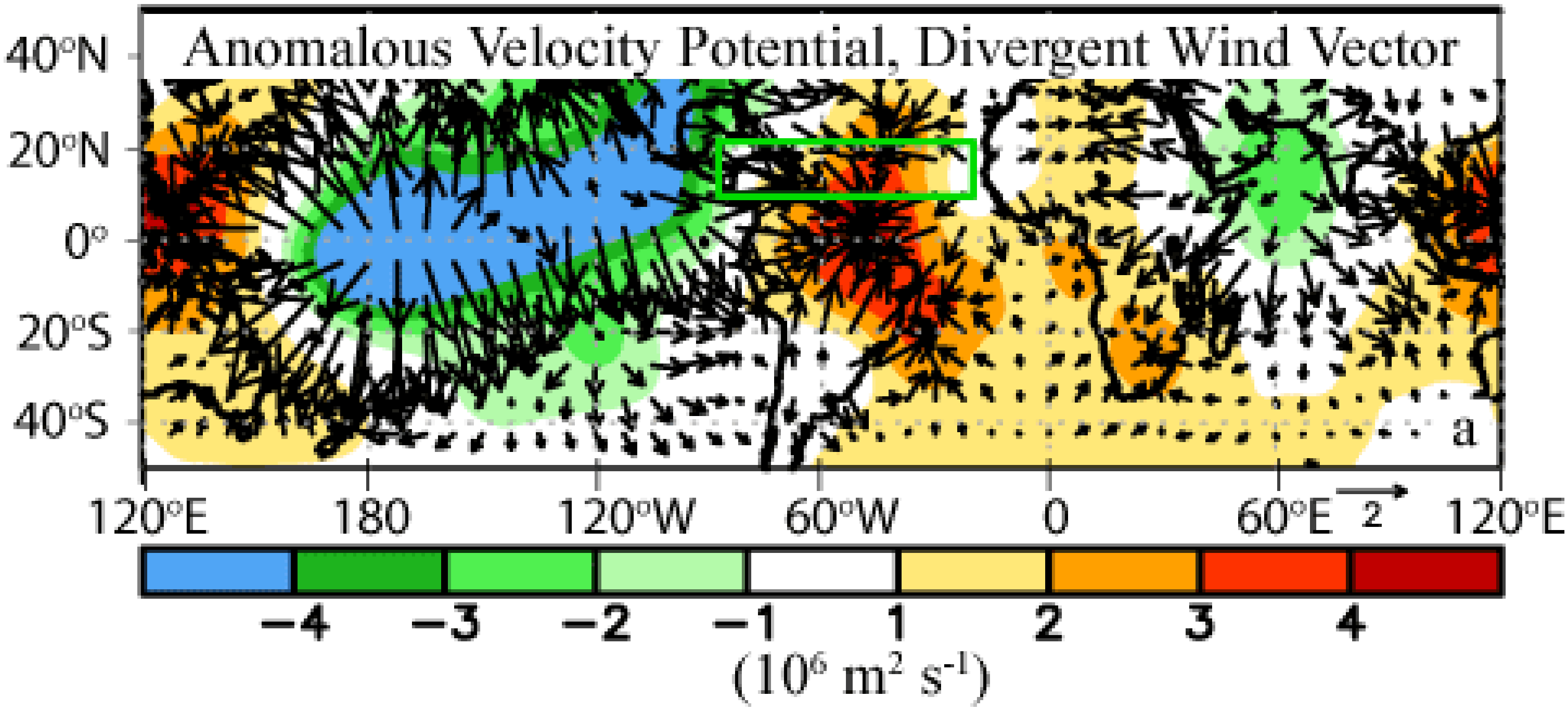


Figure 3. 200 mb anomalous velocity potential ($10^6$ $m^2$ $s^{-1}$) and divergent wind for August through October of 2015. The green box indicates the Main Development Region. Anomalies are based on the 1981-2010 climatology. Figure courtesy of Gerry Bell (NOAA Climate Prediction Center).

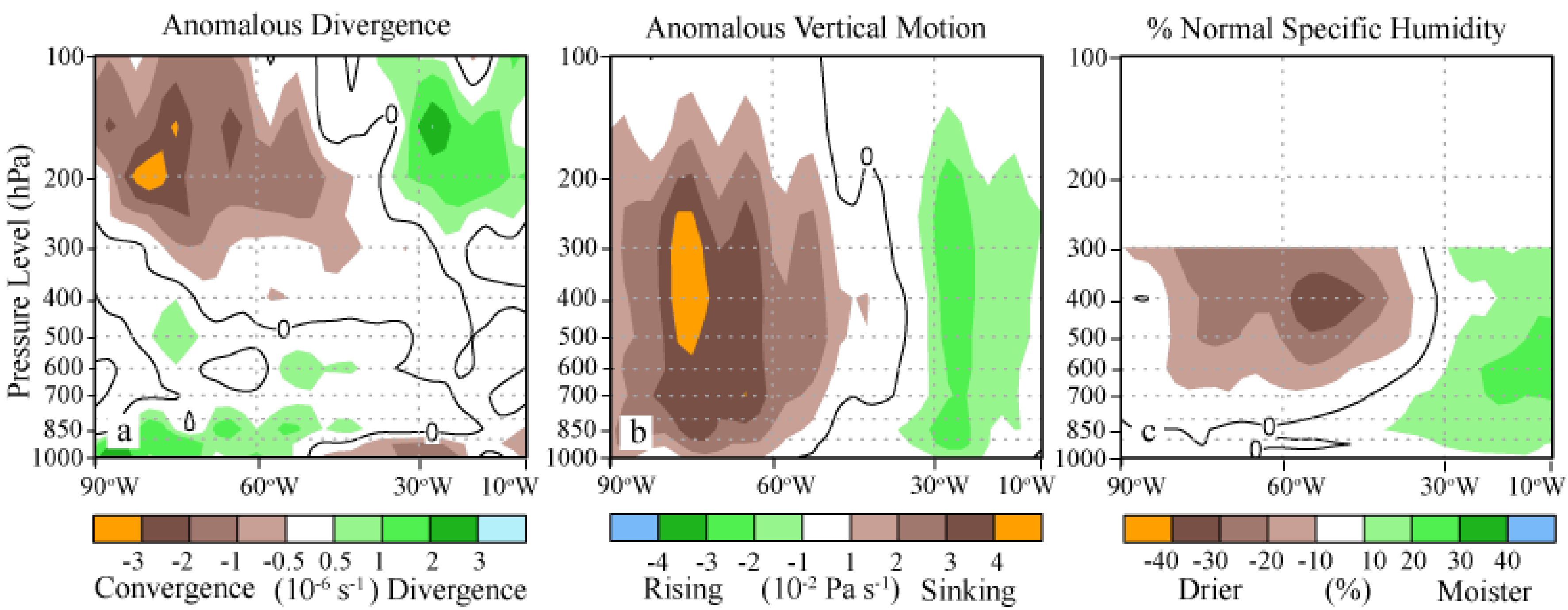


Figure 4. Atmospheric height-longitude sections averaged between 9.5$^{O}$N-21.5$^{O}$N of (a) anomalous divergence (x 10-6 $s^{-1}$), (b) anomalous vertical velocity (x 10-2 Pa $s^{-1}$), and (c) percent of normal specific humidity for August through October 2015. Green shading indicates anomalous divergence, anomalous rising motion, and increased moisture, respectively. Brown shading indicates anomalous convergence, anomalous sinking motion, and decreased moisture. Zero lines are drawn on each panel. Anomalies are departures from the 1981-2010 means. Figure courtesy of Gerry Bell (NOAA Climate Prediction Center).