Tropical Storm Emily Causes Flooding Rain over Puerto Rico

a. Synoptic History

Already showing signs of broad rotation a tropical wave moving off of the African coast early in the week of July 24, 2011 gradually traveled across the tropical Atlantic Ocean. Its rotation persisted during its trek but continued otherwise disorganized. Based largely on a report from Hurricane Hunter aircraft that a well-defined center had formed 50 miles west-southwest of Dominica (15.2N, 62.0W) the National Hurricane Center named the storm and issued the first advisory for Emily at 730 PM AST (2330 UTC) on Monday, August 1, 2011. It was moving west at 17 mph. A tropical storm warning was then issued for Puerto Rico, Vieques and Culebra, and a tropical storm watch was issued for the U.S. Virgin Islands (Fig. 1).

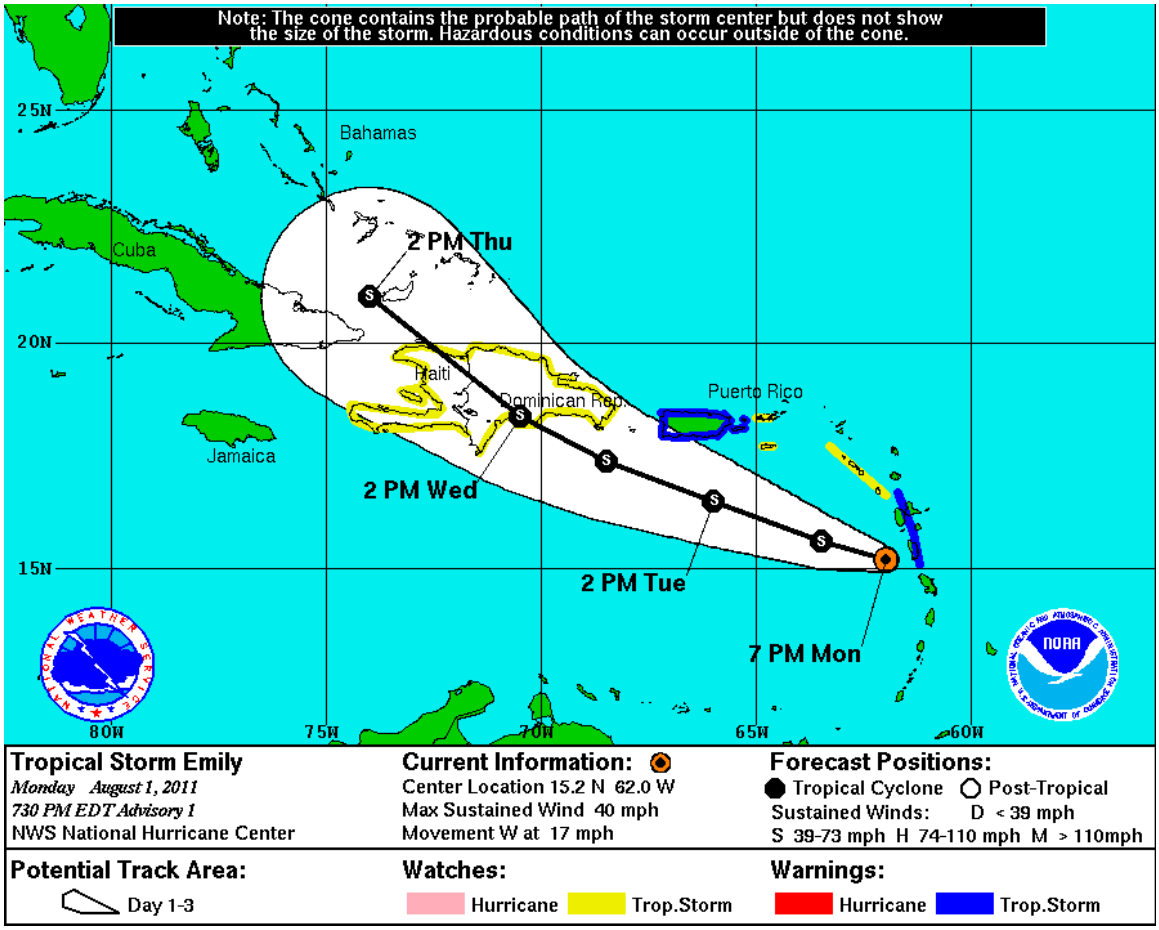

Fig. 1. Initial watches, warnings, and position forecast issued for Tropical Storm Emily.

The environment in advance of Emily was marginally favorable for development as dry air was entraining into the storm. The 00z August 2 San Juan, PR sounding (Fig. 2)

showed the dry air aloft that inhibited Emily's development with the IR satellite image (Fig. 3) showing its position. The advanced scatterometer (ASCAT) taken around midnight that night (Fig. 4) showed the storm had not developed a closed circulation.

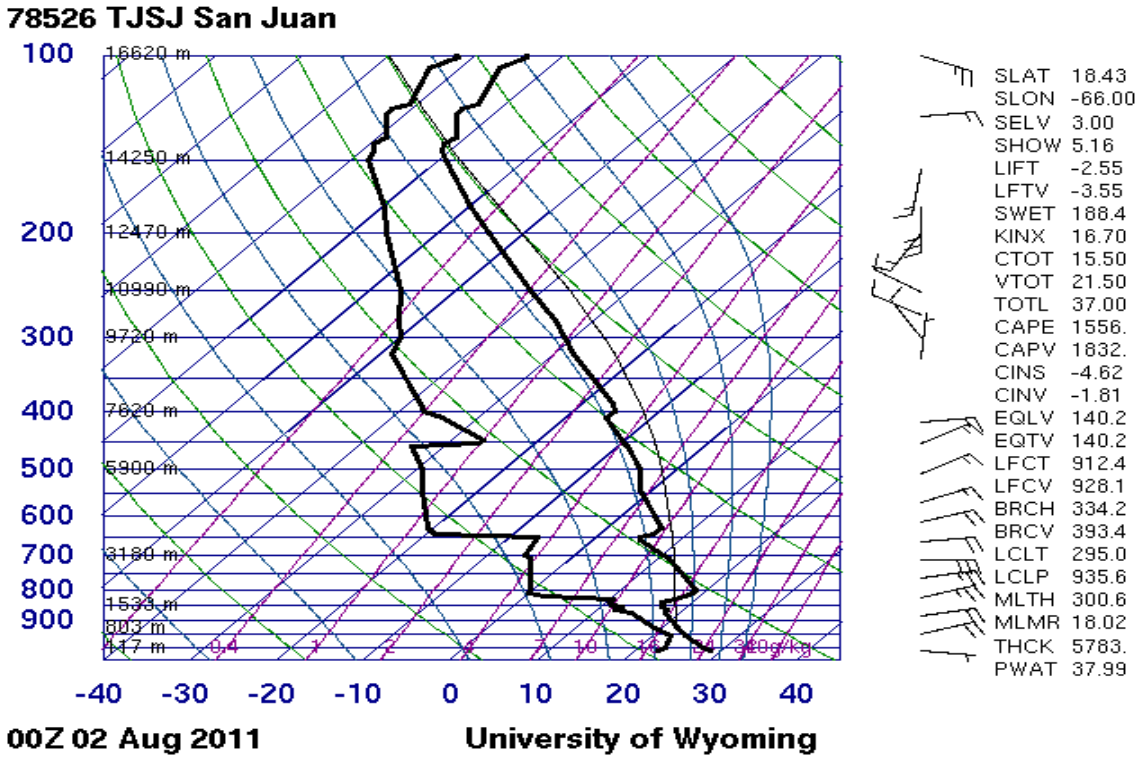

Fig. 2. 00z August 2, 2011 TJSJ rawinsonde (San Juan, PR).

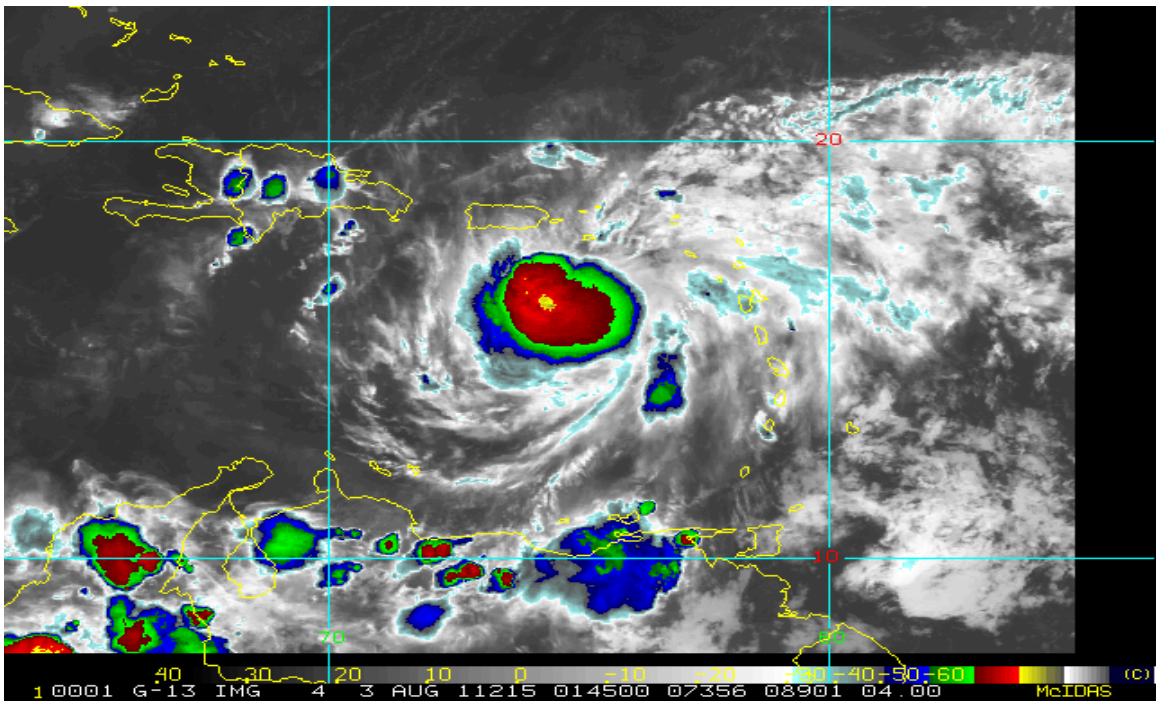

Fig. 3. 0145z August 3, 2011 IR satellite view of Emily.

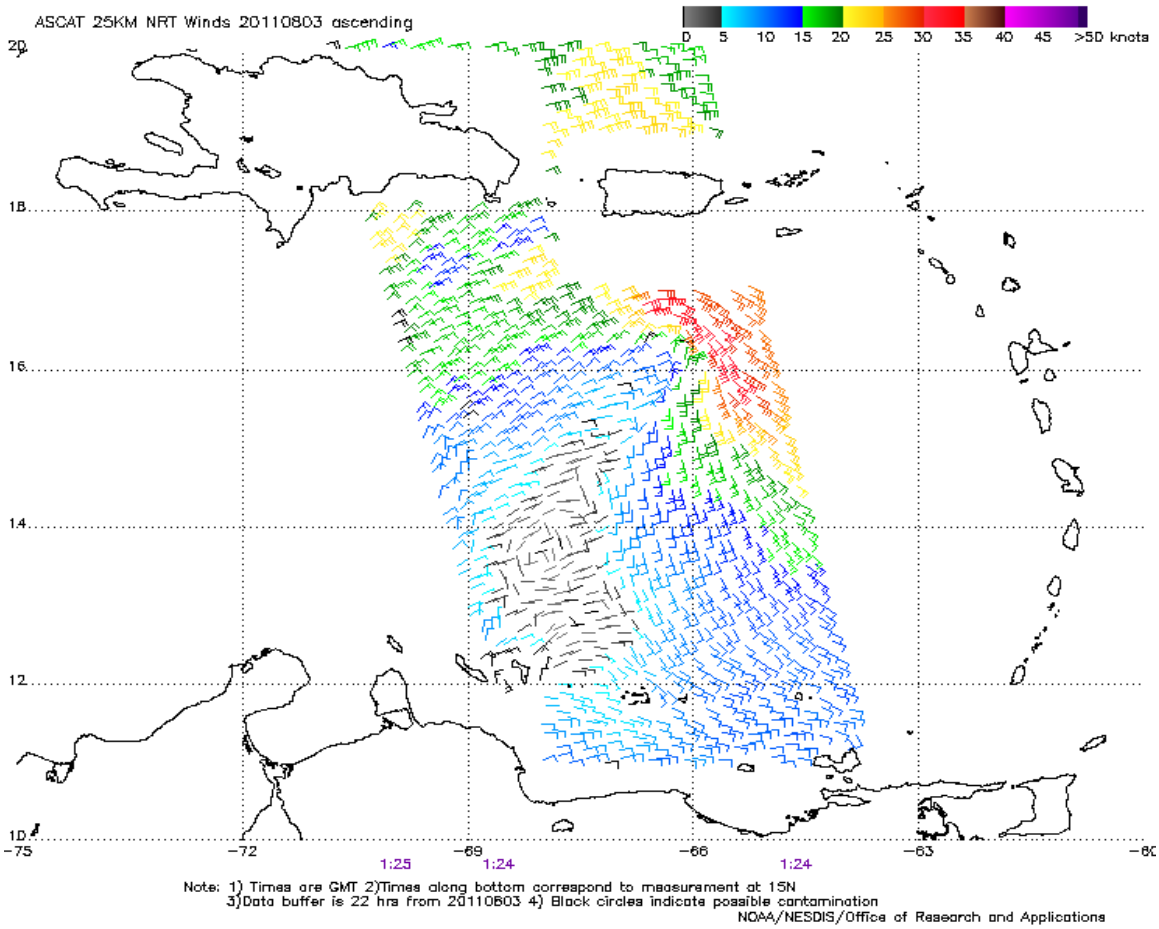

Fig. 4. ASCAT satellite image of Emily.

The first heavy showers did not arrive on the local islands until late on Tuesday night yet the peak winds during this event occurred earlier that day for most locations. Table 1 shows the higher wind gusts recorded at representative stations.

Location	Gust (mph)	Date/Time (AST)
Charlotte Amalie, Saint Thomas, USVI (TIST)	36	Aug. 02 - 802 am
Christiansted, Saint Croix, USVI (TISX)	41	Aug. 02 - 147 pm
Luis Munoz Marin Intl. Airport, San Juan, PR (TJSJ)	38	Aug. 02 - 206 pm
San Juan, PR NOS Station (SJNP4)	44	Aug. 02 - 518 pm
Roosevelt Roads, PR (TJNR)	40	Aug. 02 - 729 pm
La Parguera Lajas, PR icon station	48	Aug. 03 - 400 am

Table 1. Wind gusts recorded at selected stations and the times they occurred.

By Tuesday evening, August 2, Emily was still struggling to gain strength. At 1100 pm AST (03/0300 UTC) it was located at 16.2N 66.7W, 117 miles from the south shore of Puerto Rico. Not only was development of the storm still inhibited by dry air entrainment there were indications that it was tilted towards the east with increasing height, suggesting that wind shear was also aiding to keep the storm weak. The strongest of

Emily's winds came closest to Puerto Rico on the Wednesday morning of August 3 (Fig. 5)

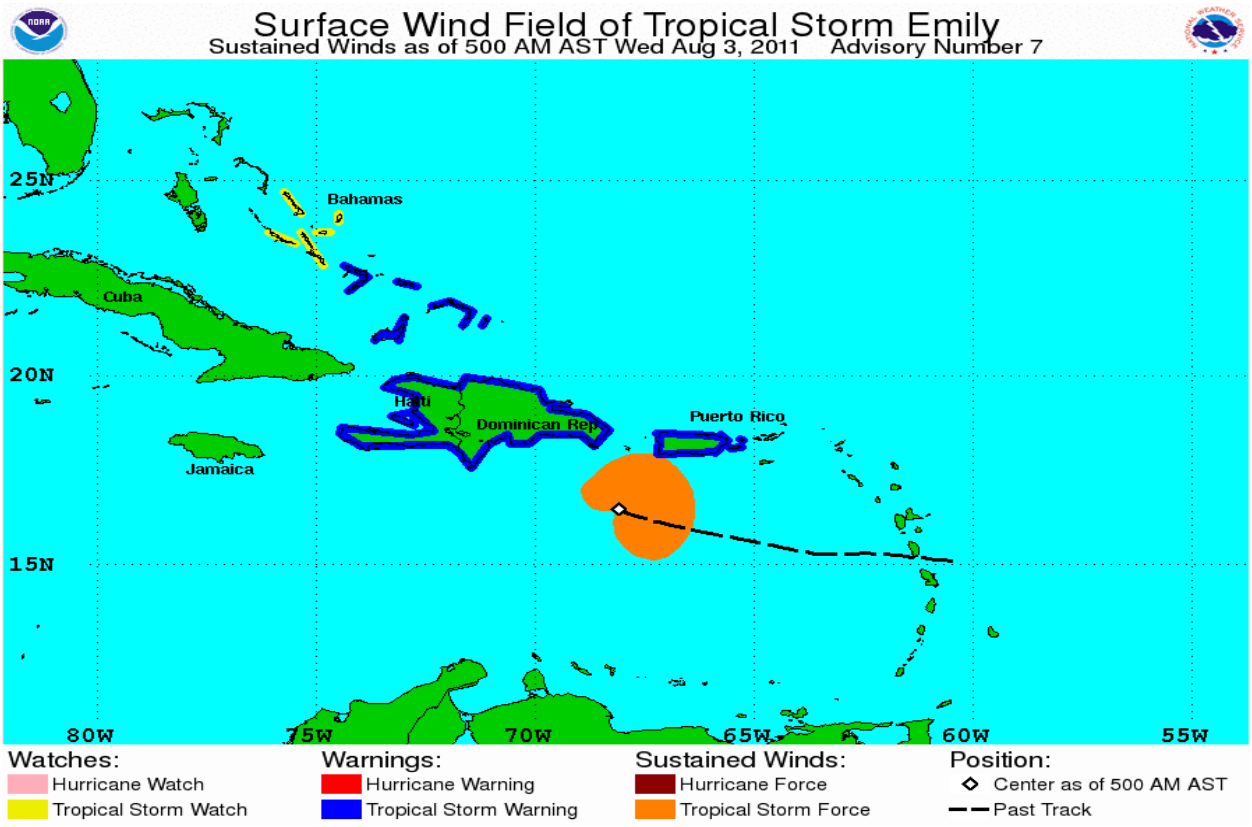

Fig. 5. Position of Tropical Storm Emily at 500 am AST (0900 UTC) on August 3, with warnings and watches in effect.

The highest wind gust directly recorded was 48 mph at 400 am AST on August 3 (0800 UTC) at the La Parguera Lajas, PR icon station (Table 1) as Emily was near its closest point to the island.

Emily was still entraining dry air from along the path which kept Emily from developing significantly. Although the 00z August 3 upper air sounding at Santo Domingo, Dominican Republic showed precipitable water climbing to 60.68 mm (2.39 inches) the sounding by 12z the following morning (Fig. 6) had dipped again to 48.81 mm (1.92 inches).

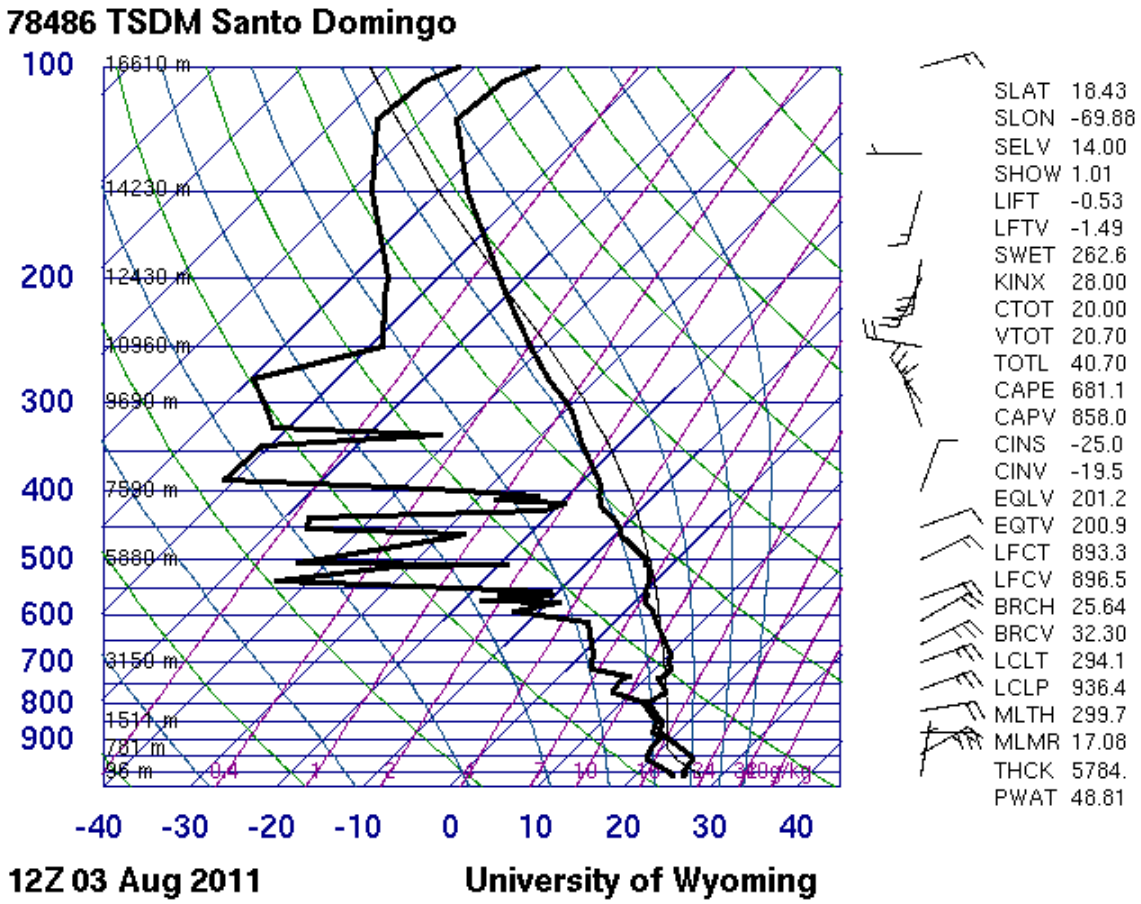

Fig. 6. 12z August 3, 2011 TSDM rawinsonde (Santo Domingo, Dominican Republic).

At 1100 am AST August 3 all tropical storm watches and warnings for Puerto Rico, U.S. Virgin Islands, and surrounding waters had been cancelled. A visual satellite photo of Emily (Fig. 7) shows the exposed center 110 miles south of the Dominican Republic along 70^{o}W. Wind shear had caused the low level circulation to become less organized and convection located well to the east. The ASCAT satellite image near this time shows the now closed circulation near 70^{o}W (Fig. 8). Though the maximum of surface winds were still estimated to be 45 knots Emily was no longer a wind threat to Puerto Rico, and the heavy rain had also abated.

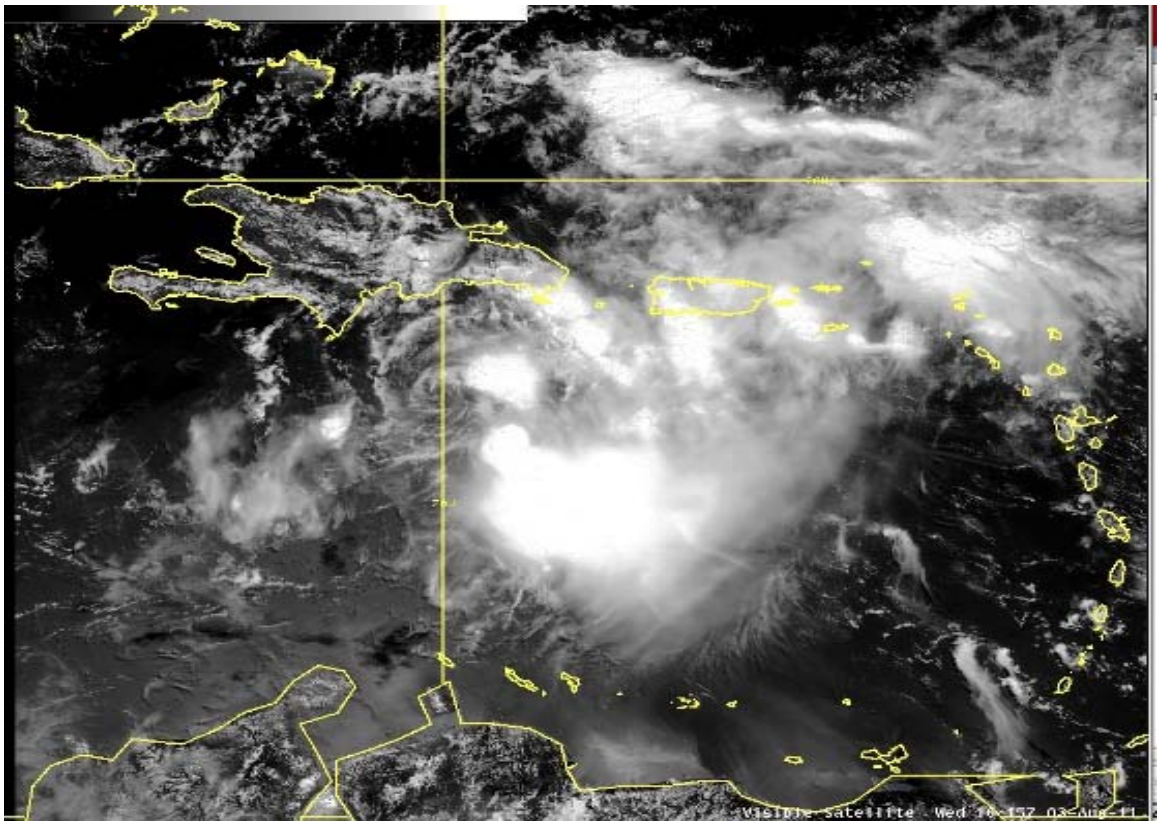

Fig. 7. Visual satellite image of Emily at 1215 pm AST (1615 UTC) August 3, showing its exposed closed circulation at 70W.

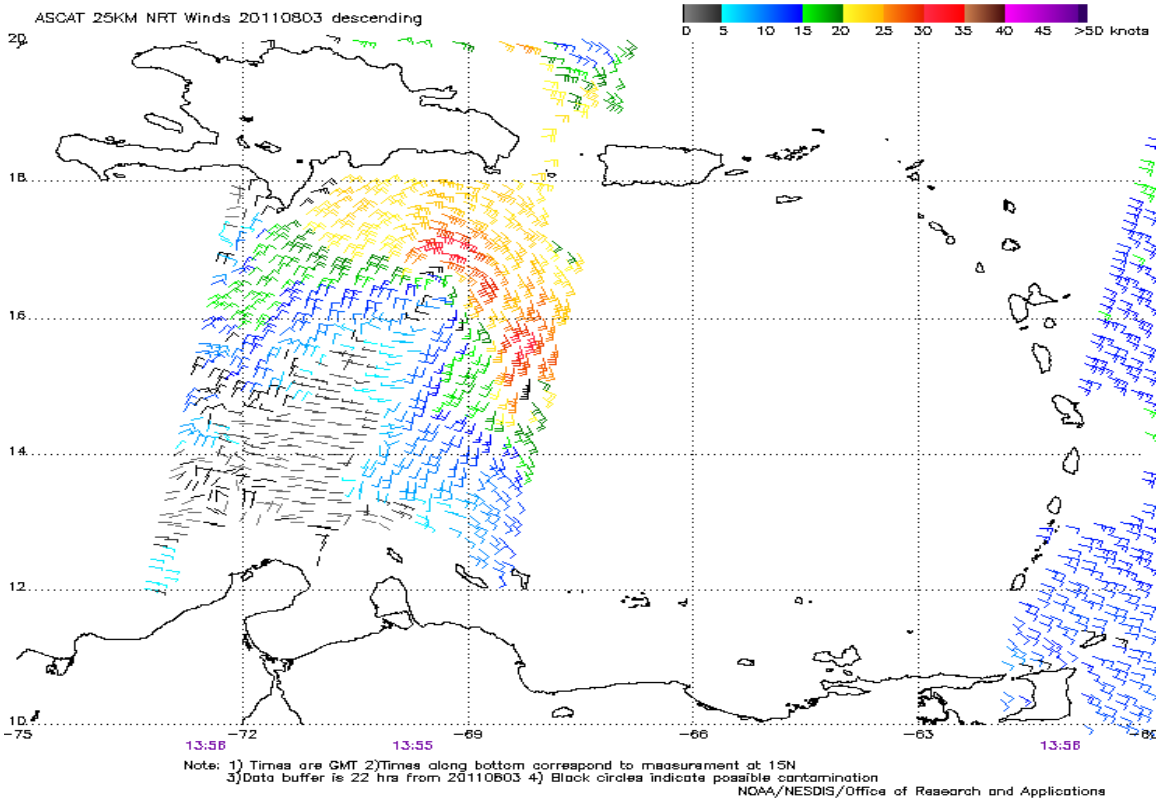

Fig. 8. ASCAT satellite image of Emily, about noon August 3.

b. Rainfall

Even during the evening of August 2 it was very unclear whether rain bands from the storm would significantly affect Puerto Rico and very little activity was noted on radar at that time. But this would quickly change. Table 2 shows recorded totals representative of the heavier rainfalls while Emily passed. Most of the rain for the eastern part of Puerto Rico occurred as heavy bands moved across the area between 200 am and 200 pm AST on August 3 while the heavy rain over southwest part of the island was during the morning and afternoon of that day.

Location (Latitude, Longitude in decimal degrees)	Rainfall (in.), 0600 UTC Aug 02 to 0200 UTC Aug 04
Naguabo (18.21, -65.74)	6.21
Luquillo (18.37, -65.72)	5.99
Roosevelt Roads (TNJR - 18.25, -65.63)	4.75
Las Piedras (18.18, -65.87)	4.57
Yabucoa (18.04, -65.87)	3.98
Patillas (18.00, -66.01)	3.80
Ceiba (18.26, -65.65)	3.71
San Lorenzo (18.19, -65.97)	3.68
Aguas Buenas (18.25, -66.11)	3.50
Canovanas (18.37, -65.91)	3.29
Caguas (18.23, -66.04)	3.23
Comerio (18.22, -66.22)	3.17
Luis Munoz Marin Airport, San Juan (TJSJ - 18.40, -65.98)	3.06
Christiansted Airport (TISX - 17.70, -64.80)	0.78
Location (Latitude, Longitude in decimal degrees)	**Rainfall (in.), 0600 UTC Aug 02 to 0600 UTC Aug 04**
Yuaco (18.05, -66.84)	5.68
Guayanilla (18.04, -66.80)	5.08

Table 2. Selected rainfall totals from 200 am AST August 2 (0600 UTC) to 1000 pm AST August 4 (0200 UTC), except including up to 200 am AST August 4 (0600 UTC) for Yuaco and Guayanilla.

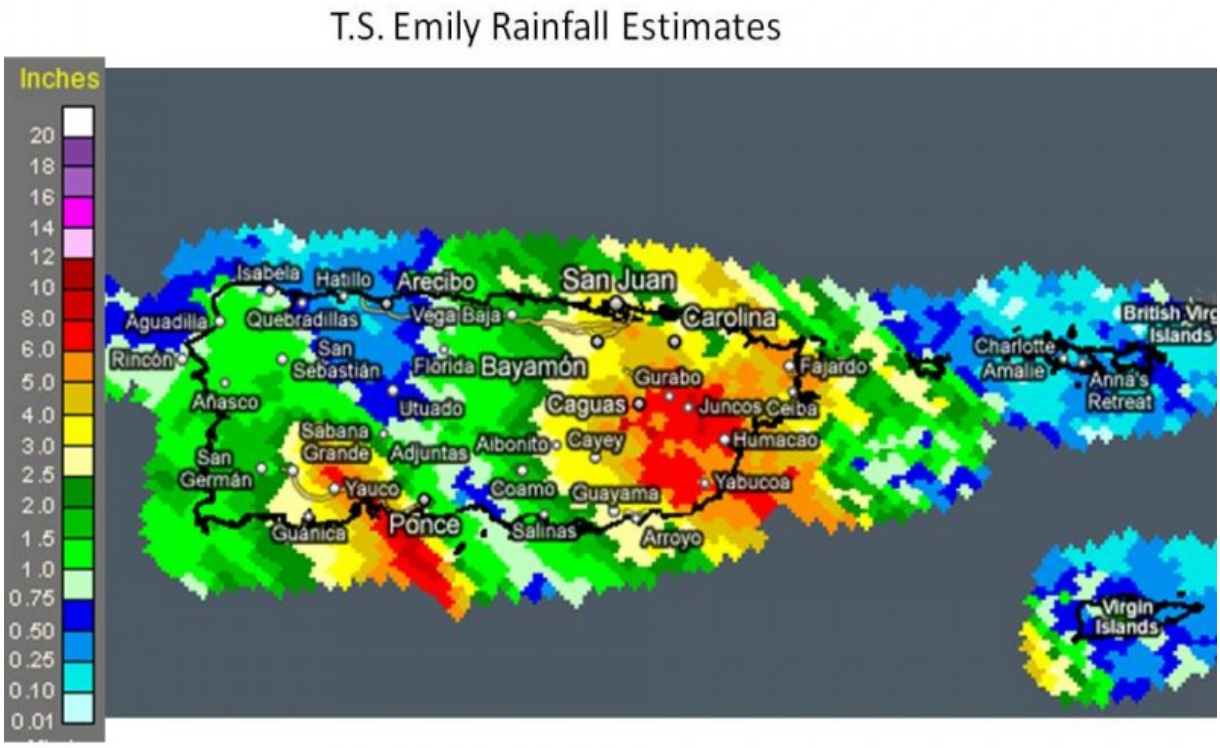

Fig. 9. Rainfall amounts estimated by WSR-88D TJUA radar and quality controlled.

c. Damage

The heavy rainfall resulted in many mud slides across Puerto Rico, especially where the heaviest rain occurred. Mud slides were reported to block or partially block roads in the eastern municipalities of Canovanas, Fajardo, Ceiba, Naguabo, Las Piedras, Yabucoa, Juncos, Caguas, San Lorenzo, Guayama, Patillas, while the La Plata River flooded portions of Dorado and Toa Baja. Also, trees were blown down in Humacao and Luquillo.

Over the western portion of the island flooded roads occurred in Cabo Rojo, Hormigueros, Lajas, Maricao, and Yauco, and a few mud slides also occurred. Trees were reported blown over in San German, Adjuntas, and Utuado.

d. Watches/Warnings

The initial tropical storm warning (and watch for USVI) was issued at 700 pm (2330 UTC) on August 1. It showed the center of Emily passing about 100 miles southwest of

the southwestern most part of Puerto Rico with tropical storm force winds (39 mph) reaching to within 40 miles. But it included a 48 percent chance of these winds extending as far as Ponce. The verified storm track was slightly farther to the southwest of forecast, due in part to its lack of intensification, and several hours slower than expected. However, tropical storm force winds extended to very near the southwest corner of Puerto Rico (Fig. 5). Winds over the island reached tropical storm force only in locally, causing tree damage mainly during the bands of rain showers that passed over.

The initial hurricane local statement issued from WFO San Juan at 910 pm AST August 1 included only the basic information necessary. However the update at 1201 am AST August 2 included total expected rainfall of 4 to 6 inches with locally higher amounts, very close to verified amounts (Table 2). It mentioned maximum winds of 40 mph, causing “tree limbs and branches to fall and cause isolated power outages,” somewhat less than the blown down trees that actually occurred. This update also included a forecast of offshore waters in the Caribbean building to 9 feet. This forecast verified well as Buoy 41052 (5 miles south of St. John, USVI) reported 2.7 m (8.9 ft) at 700 pm AST on August 2. Buoy 42085 10 miles southeast of Ponce, PR) reported 2.5 m (8.2 ft) at 200 am AST and 600 am AST on August 3.

The initial flood watch was for all of mainland Puerto Rico, issued at 537 am AST August 3. It included a total rainfall forecast of 4 to 6 inches with isolated maximum amounts of 10 inches. The actual rainfall (Table 2) validated the watch and the USGS rain gage at Las Piedras reported 9.91 inches of rain between 200 am and 200 pm on August 3.

Flash flooding became widespread in eastern Puerto Rico early on Wednesday morning as the first band of heavy rainfall moved onshore. The first flash flood warning was issued at 240 am AST on August 3 for the 5 easternmost counties in Puerto Rico (Table 3). But by 920 am almost the entire eastern third of the island was under a flash flood warning or river flood warning. In the east, the last warning expired at 215 pm AST. The Rio Grande de La Plata reached moderate flooding over its entire length. At Comerio, near the upper reaches of the river, Rio Grande de Loiza crested at 14.4 feet at noon AST on August 3 but the crest did not reach Highway 2 at Toa Alta until 230 pm AST, where it reached 20.2 feet. Most of the tributaries of Rio Grande de Loiza also reached either minor or moderate flood stage, but the only location in the area that reached major flood stage was the Rio Piedras at Hato Rey. There the gage briefly climbed above the major flood stage of 19 feet, reaching 19.18 feet at 1145 am AST.

Flooding became widespread over the southwest quarter of Puerto Rico by late morning on August 3 and it continued well into that night. Flash flooding was common westward from Adjuntas and Ponce while the Rio Guanajibo and its tributaries reached flood levels. Near Hormigueros the Rio Guanajibo surpassed its minor flood stage of 21.0 feet, cresting at 21.4 feet at 415 am AST August 4. But farther upstream the river at San German fell 3 inches short of flood stage.

Warning Type (River)	Issuance Time (AST)	Municipalities Affected
Flash Flood	**240 am Aug 3 (extended at 526 am) (extended at 828 am)**	Luiquillo, Naguabo, Ceiba, Fajardo, Rio Grande
Flash Flood	**502 am Aug 3 (extended at 759 am)**	Patillas
Flash Flood	**557 am Aug 3**	Juncos, San Lorenzo, Las Piedras, Maunabo, Naguabo, Humacao, Yabucoa
Flood (Rio Grande de Loiza)	**717 am Aug 3 (extended at 105 pm)**	Caguas, Canovanas, Carolina, Cayey, Gurabo, Juncos, Las Piedras, Loiza, Naguabo, Rio Grande, San Juan, San Lorenzo, Trujillo Alto
Flood (Areal flood)	**738 am Aug 3 (extended at 126 pm)**	Aguas Buenas, Aibonito, Barranquitas, Bayamon, Cayey, Cidra, Coamo, Comerio, Dorado, Naranjito, Toa Alta, Toa Baja
Flash Flood	**920 am Aug 3 (extended at 1057 am)**	Bayamon, Caguas, Cidra, Aguas Buenas, Trujillo Alto, Guaynabo, Catano, San Juan
Flash Flood	**1002 am Aug 3**	Maunabo, Humacao, Yabucoa
Flash Flood	**1040 am Aug 3 (extended at 1216 pm)**	Adjuntas, Maricao, Sabana Grande, San German, Yauco, Guayanilla, Guanica, Ponce, Penuelas, Lajas
Flash Flood	**1127 am Aug 3**	Luquillo, Naguabo, Ceiba, Fajardo, Rio Grande, Vieques
Flash Flood	**329 pm Aug 3 (extended 613 pm)**	Maricao, Sabana Grande, San German, Yauco, Guayanilla, Guanica, Penuelas, Lajas
Flood (Rio La Plata)	**730 pm Aug 3**	Dorado, Toa Alta, Toa Baja
Flood (Areal flood)	**936 pm Aug 3**	Guanica, Lajas
Flood (Rio Guanajibo)	**1222 am Aug 4**	Hormigueros, Mayaguez

Table 3. Flood and flash flood warnings for Puerto Rico as Emily passed by.

Only one severe thunderstorm warning was issued during this event, at 1052 am AST August 3, for Adjuntas, Anasco, Guayanilla, Lares, Las Marias, Maricao, Mayaguez, Sabana Grande, San German, San Sebastian, and Yauco municipalities. While there was tree damage in Adjuntas, San German, and Utuado, it was unclear whether the damage was due to thunderstorm winds or from gradient winds from the tropical storm.

e. Conclusion

Tropical Storm Emily was well forecast overall. The tropical storm warnings and watches were appropriate given the threat. Winds on the mainland of Puerto Rico were slightly less than expected and this system impacted the region primarily through rainfall. Though

the flash flood watch was probably posted later than it should have been given the expected heavy rain the flood warnings thereafter were well handled.