

An Historic Rainfall at San Juan Puerto Rico

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Historical Synopsis

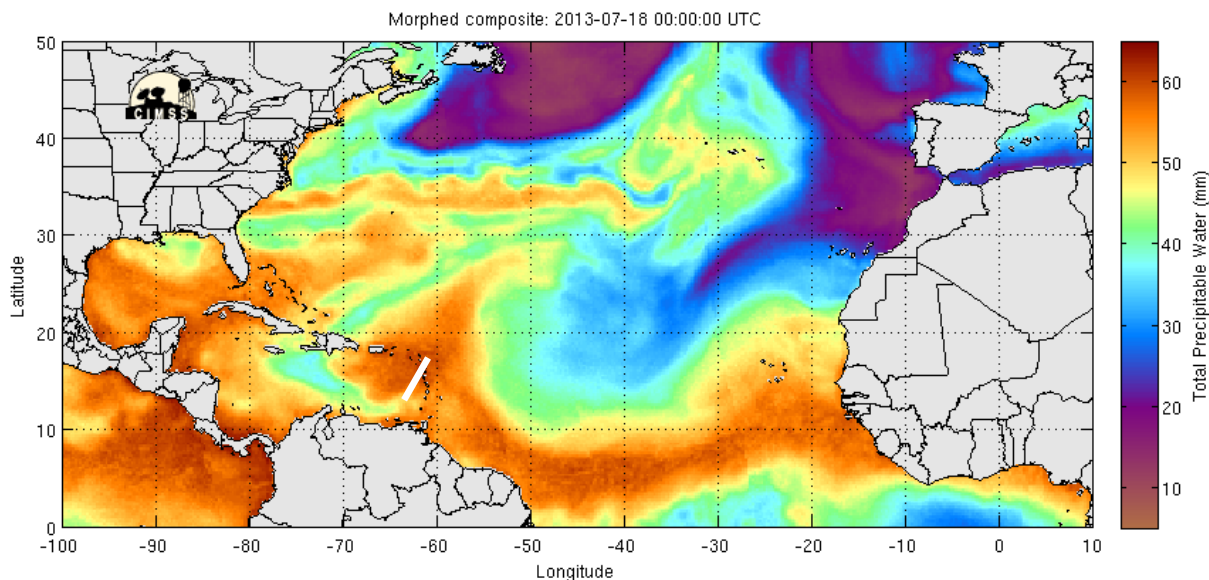


Fig. 1. Microwave imagery from satellite showing precipitable water at 800 pm AST July 17, 2013. Approximate location of the tropical wave, as analyzed by the Ocean Prediction Center (OPC) is shown by the white line.

A high amount of moisture associated with an otherwise ordinary looking tropical wave passed through the Lesser Antilles on Wednesday, July 17, 2013 (Fig. 1). The forecaster on duty late in the afternoon at the National Weather Service in San Juan Puerto Rico had become concerned that showers were going to arrive earlier than the ongoing forecast was anticipating and that they may be enhanced by orographic effects over eastern Puerto Rico. A flash flood watch was issued by 656 pm AST, to be in effect beginning at midnight that night and lasting through the following afternoon. The forecast included 1 to 3 inches of rainfall and local amounts to 5 inches. Later that night the trend in concern continued. The early morning discussion stated that the large amount of showers could be expected to produce “2 to 3 inches, with higher amounts of up to 5 inches, especially across portions of eastern Puerto Rico and the Cordillera Central.” There was potential for afternoon heating to cause flooding rains to spread westward across Puerto Rico, so the flash flood watch was updated to include the entire island.

No unusual amount of wind had developed in the wave, and its fast forward speed (about 20 knots) suggested that it would not easily develop a closed center. The Hurricane Prediction Center at Miami was not issuing statements suggesting that this wave might develop within the

next couple days. Figure 2 shows the OceanSAT image from the satellite passing over Puerto Rico around midnight. While there may have been a few localized winds approaching 30 knots (red) north of the main island there was little concern about wind. Buoys in the area were not recording velocity that strong actually occurring on the water surface, and there was no indication that a cyclonic closed low was developing.

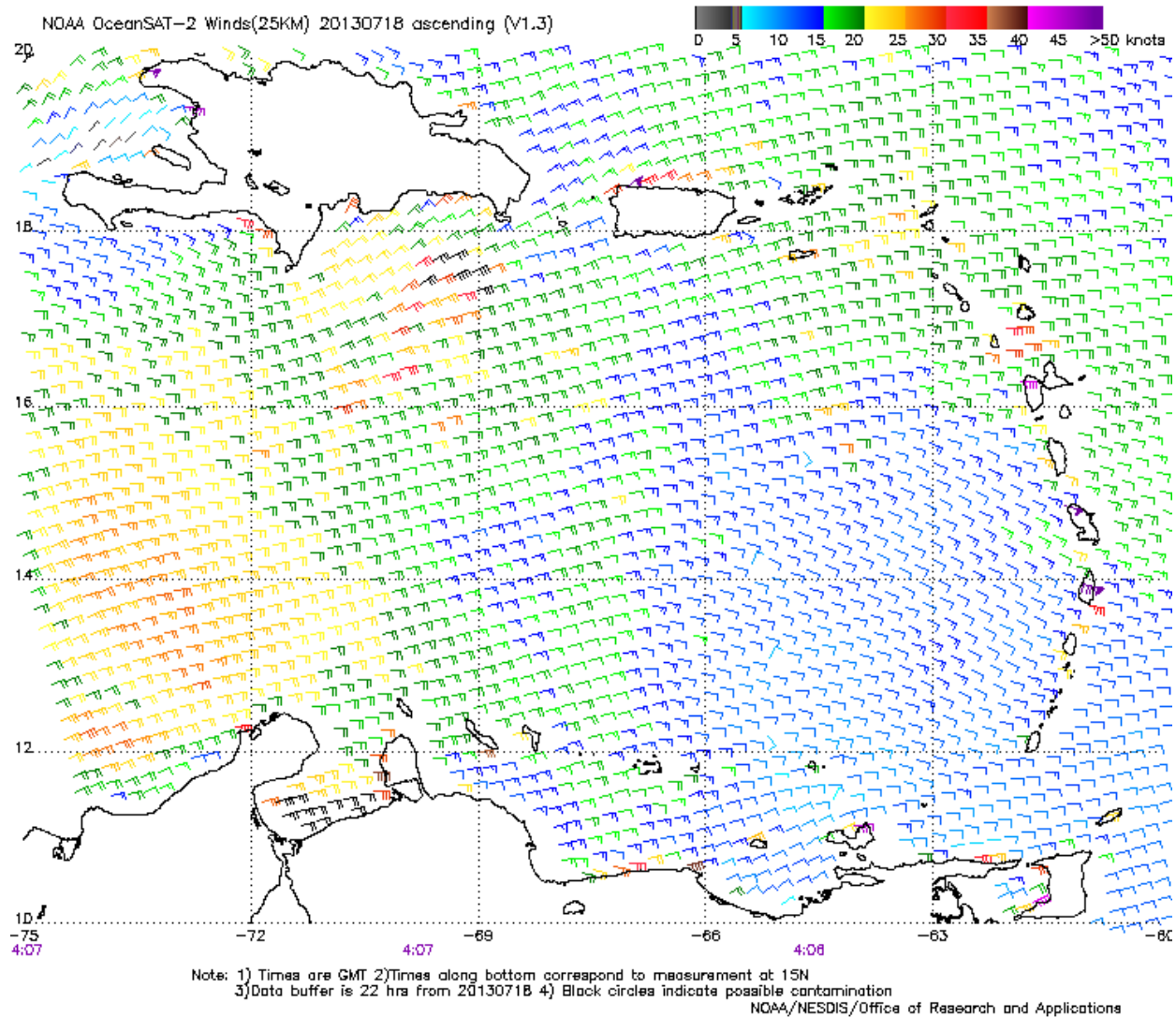
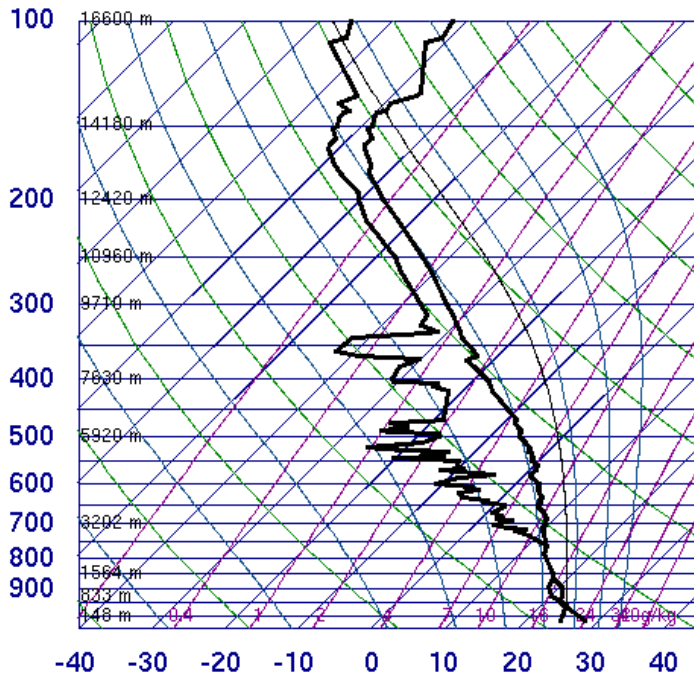


Fig. 2. OceanSAT satellite image of winds over the Caribbean Sea and the Antilles.

The routine upper air sounding (Fig. 3) completed at the Weather Forecast Office (WFO) San Juan during Wednesday evening showed that 29 knots of wind had developed only 2,000 feet above ground. While this pointed out that this was a strong wave the associated moisture was still the larger concern, with 2.28 inches of precipitable water on that sounding and it was expected to rise slightly more by morning.

78526 TJSJ San Juan



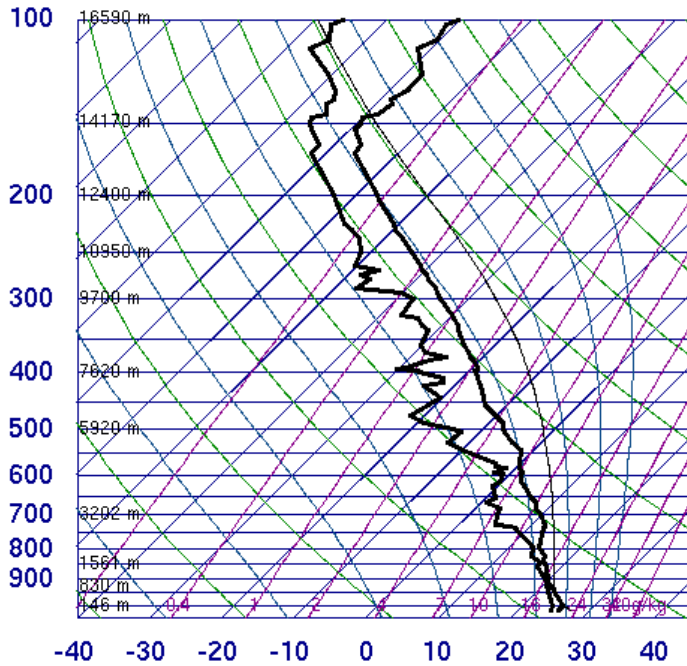
SLAT	18.43
SLON	-66.00
SELV	3.00
SHOW	-2.50
LIFT	-5.24
LFTV	-6.12
SWET	270.8
KINX	34.70
CTOT	23.30
VTOT	23.30
TOTL	46.60
CAPE	3271.
CAPV	3500.
CINS	0.00
CINV	0.00
EQLV	142.2
EQTV	142.2
LFCT	963.1
LFCV	965.7
BRCH	728.5
BRCV	779.6
LCLT	296.8
LCLP	966.3
MLTH	299.7
MLMR	19.52
THCK	577.2
PWAT	57.91

00Z 18 Jul 2013

University of Wyoming

Fig. 3. Upper air sounding at 00z July 18, 2013 (800 pm AST, July 17).

78526 TJSJ San Juan



SLAT	18.43
SLON	-66.00
SELV	3.00
SHOW	-2.78
LIFT	-5.54
LFTV	-6.25
SWET	265.0
KINX	35.00
CTOT	23.60
VTOT	24.50
TOTL	48.10
CAPE	2847.
CAPV	3034.
CINS	-1.07
CINV	-0.47
EQLV	145.6
EQTV	145.8
LFCT	942.5
LFCV	949.4
BRCH	312.5
BRCV	333.1
LCLT	296.4
LCLP	970.8
MLTH	298.9
MLMR	18.94
THCK	577.4
PWAT	58.65

12Z 18 Jul 2013

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Fig. 4 Upper air sounding at 12z (800 am AST) on July 18, 2013.

On Thursday morning, the 18th, convective showers were moving onshore and were moving towards the northwest. The morning sounding at WFO San Juan (Fig. 4) showed winds from the southeast above 300 ft MSL. This indicated that the trough axis was somewhere northwest of San Juan but it was also likely that the wave was slowing down. After OPC analyzed all available data the wave was indeed thought to be slightly west and northwest of San Juan. The trough provided low level convergent flow while upper level was divergent, ideal for developing thunderstorms.

Heavy showers and thunderstorms had occurred during that Wednesday night but were not widespread. Late in the morning on Thursday (the 18th) convection was increasing, especially across San Juan Metro. San Juan Luis Munoz Marin International Airport already had almost an inch of rainfall (0.85) by 1100 am but was unprepared for what was to come. The next four hours would bring over 7½ more inches of rainfall (Fig. 5). Unofficially, the 2.89 inches recorded between noon and 100 pm was highest hourly total ever recorded at this airport (since 1967).

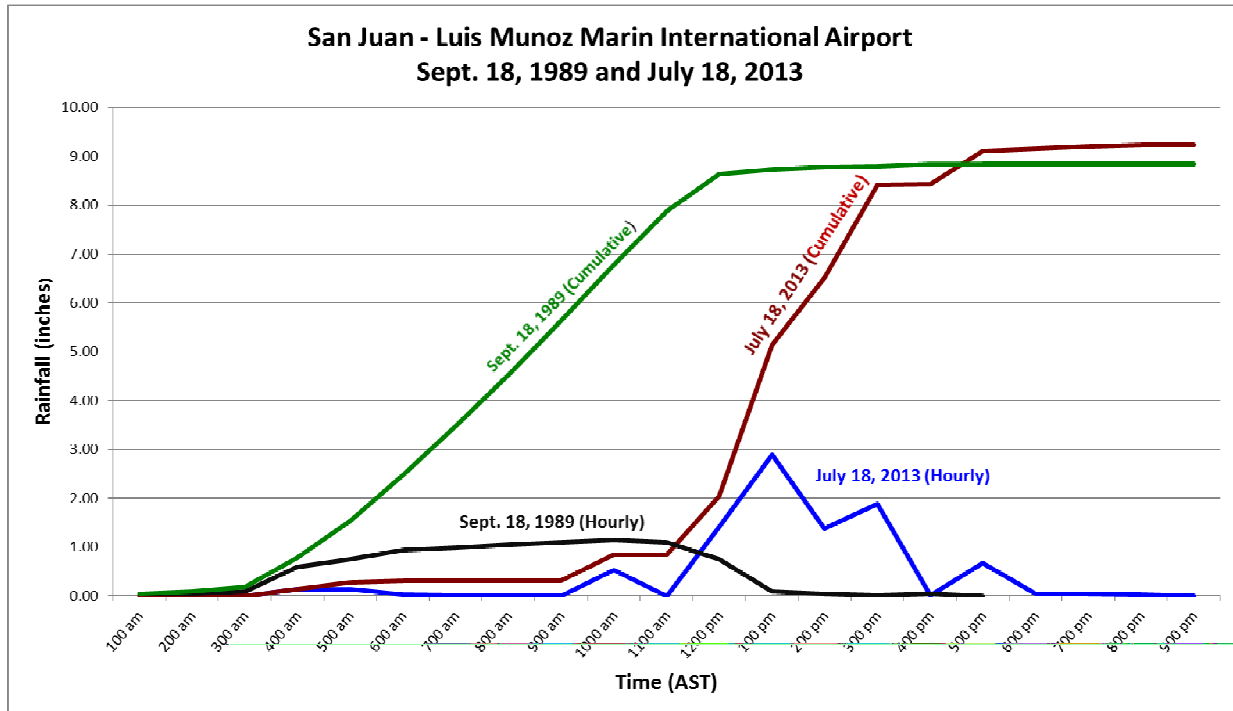


Fig. 5. Recorded rainfall at the San Juan Airport, for September 18, 1989 and July 18, 2013.

When the afternoon had finished 9.23 inches of rain had fallen at the airport, breaking the previous record of 8.84 inches which occurred as Hurricane Hugo came onshore on September 18, 1989. In comparison to the September 18 event with Hugo, the rainfall on July 18 occurred more quickly and later in the day. The only day on which more rainfall was observed in the San Juan area, back to 1898, was the 9.67 inches on August 15, 1944. Incidentally, the day with the third most rainfall ever at the airport was on September 10, 1996, when Hurricane Hortense passed over the southwest corner of the island. That rainfall also occurred over a longer period.

From a perspective of how often this should be expected to occur, Table 1 shows the frequency of 24 hour precipitation at the San Juan International Airport, suggesting this was about a 50 year event. That is not to say it cannot happen again tomorrow, only that is how often it can be expected when a much longer period is considered. Unofficially, another record was broken, that of the highest one-hour rainfall recorded at the airport, of 2.89 inches.

Average recurrence (years)	Probability of occurrence in any given year (and percent chance of occurring in that year)	Precipitation frequency estimates with 90% confidence intervals (in inches)
5	1 in 5 (20%)	5.66 (5.04-6.39)
10	1 in 10 (10%)	6.77 (6.00-7.62)
25	1 in 25 (4%)	8.30 (7.35-9.36)
50	1 in 50 (2%)	9.50 (8.38-10.7)
100	1 in 100 (1%)	10.80 (9.45-12.2)
200	1 in 200 (0.5%)	12.00 (10.5-13.7)
500	1 in 500 (0.2%)	13.80 (12.0-15.8)
1000	1 in 1000 (0.1%)	15.20 (13.2-17.6)

Table 1. 24 hour precipitation frequency and probability of recurrence, based on San Juan International Airport.

Average recurrence (years)	Probability of occurrence in any given year (and percent chance of occurring in that year)	Precipitation frequency for selected 90% confidence intervals (in inches)			
		1 Hour	2 Hours	3 Hours	6 Hours
5	1 in 5 (20%)	2.15 (1.98-2.33)	2.70 (2.47-2.92)	2.95 (2.69-3.22)	3.89 (3.48-4.34)
10	1 in 10 (10%)	2.31 (2.12-2.51)	2.95 (2.69-3.17)	3.26 (2.96-3.55)	4.42 (3.94-4.94)
25	1 in 25 (4%)	2.51 (2.30-2.73)	3.25 (2.96-3.50)	3.62 (3.29-3.96)	5.09 (4.47-5.71)
50	1 in 50 (2%)	2.65 (2.42-2.89)	3.45 (3.13-3.75)	3.89 (3.51-4.29)	5.58 (4.86-6.31)
100	1 in 100 (1%)	2.76 (2.51-3.04)	3.65 (3.29-4.00)	4.14 (3.70-4.60)	6.06 (5.23-6.93)
200	1 in 200 (0.5%)	2.87 (2.61-3.19)	3.83 (3.43-4.25)	4.38 (3.88-4.93)	6.54 (5.57-7.56)
500	1 in 500 (0.2%)	3.01 (2.69-3.37)	4.06 (3.59-4.56)	4.69 (4.10-5.34)	7.18 (5.99-8.40)
1000	1 in 1000 (0.1%)	3.10 (2.77-3.50)	4.23 (3.69-4.79)	4.91 (4.25-5.67)	7.64 (6.33-9.05)

Table 2. Precipitation Frequency and probability of recurrence, based on San Juan International Airport for 1, 2, 3 and 6 hours.

Usually in a tropical environment the lower part of the atmosphere is conditionally unstable, meaning that layer requires some force acted upon it to become unstable. Often, an oceanic air mass passing over an island becomes unstable due to the added heat it acquires from the daytime heating of the ground it passes over. We might then have a “streamer” of showers downwind of

that island. Usually the showers are not extremely heavy and have a limited vertical extent. One curious aspect of the spatial distribution of the rainfall in this event (Fig. 6) is that the highest rainfall occurred downwind of both the Cayey and Luquillo Mountain Ranges. It is probable that the mountains played a role in repeated development of convection over the same areas on this day, but, it is difficult if not impossible to confirm this process did occur or would in the future. Due to thick clouds and frequent rain the airport also set a record for the coolest July 18th.

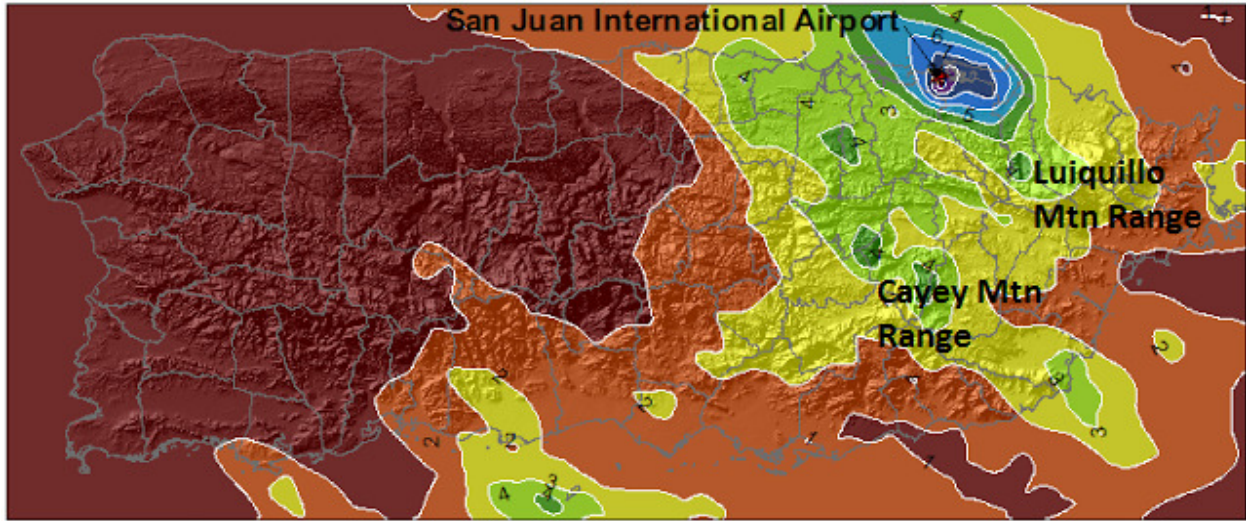


Fig. 6. Total rainfall overlaid onto a topographic map of mainland Puerto Rico.

New Records

Location	Record Type	Date/Year	New Record	Previous Record	Date/Year
Luis Muñoz Marín Intl Airport	24 hr maximum rainfall	July 18th, 2013	9.23"	2.17"	1969
San Juan Metro Area	24 hr maximum rainfall	July 18th, 2013	9.23"	3.19"	1950
Luis Muñoz Marín Intl Airport	Wettest day on record for any given day	July 18th, 2013	9.23"	8.84"	September 18th, 1989 (Hurricane Hugo)
San Juan Metro Area	2nd wettest day on record for any given day	July 18th, 2013	9.23"	9.67"	August 15th, 1944
Luis Muñoz Marín Intl Airport	Lowest maximum temperature	July 18th, 2013	82°F	83°F	1995
San Juan Metro Area	Lowest maximum temperature (tied)	July 18th, 2013	82°F	82°F	1950

Table 3. New official climatology records set for San Juan International Airport.



24hr Rainfall Total July 18, 2013

Max Amount: 9.71 inches

Source: NOAA NWS SERFC

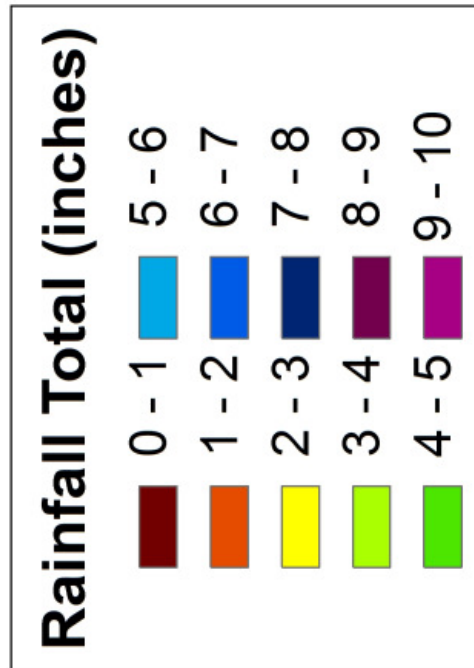
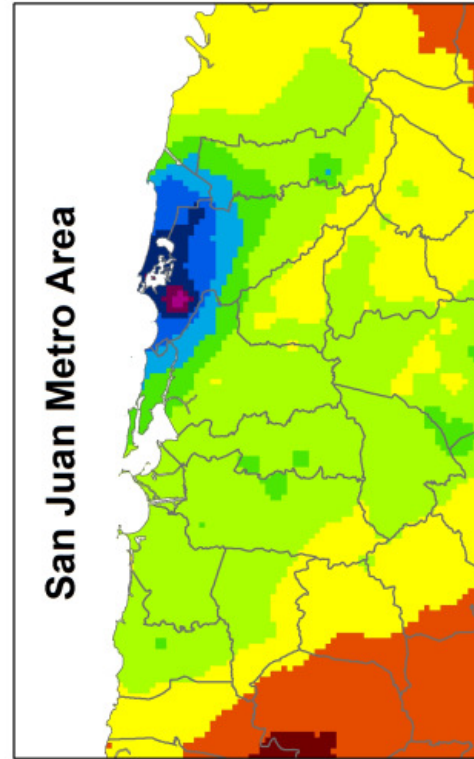
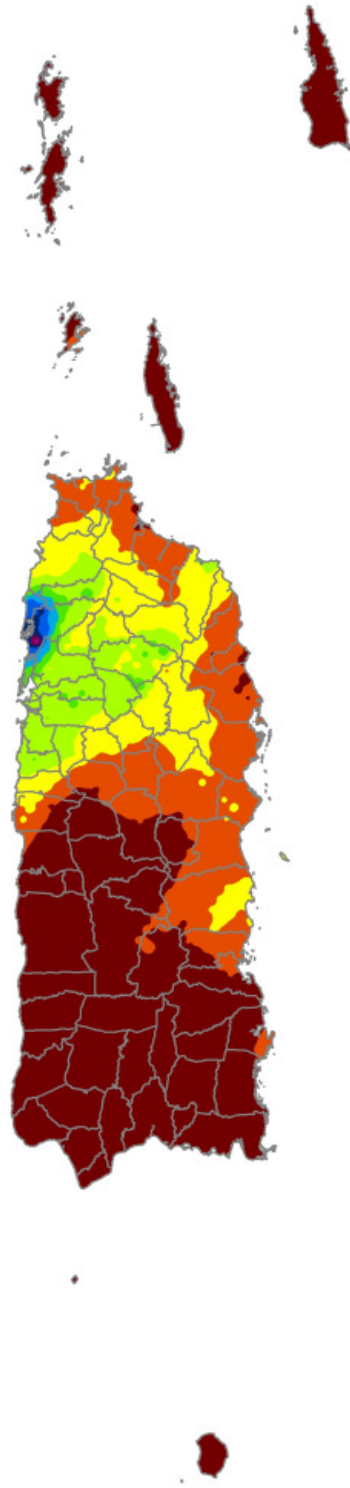


Fig. 7. Spatial distribution of rainfall on July 18th, with greatest rainfall occurring over San Juan Metro (inset).

Spatially, the heaviest rain did fall on eastern Puerto Rico (Fig. 7). Contrary to concerns, heavy rain did not develop on the west end of the island. This was due in part to the thick clouds and lack of sunshine produced by ongoing convection over the east, and in part because outflow at high levels from convection was causing subsistence over the west.

Lightning

Almost 3,500 lightning strikes were recorded within 40 km of the airport on this day in the EarthNetworks web site (<http://weather.weatherbug.com/weatherbug-professional/about-weatherbug>). It was so often and so close that some wondered if it was an unusual amount of lightning or that it was more fierce than normal. Even Saharan dust, which was following closely behind this system, was suspected to be playing a role. Or, was the lightning appropriate given the storm intensity? It is well known that the number of lightning strikes can be closely related to the intensity of rain. The ratio of rainfall to lightning has been studied at several locations. One of these (Tapia, Smith & Dixon, 1997) was done across east-central Florida during 1992-1993. In that study, the number of cloud-to-ground lightning flashes was counted and correlated with how much rain fell. In Figure 8 below, rainfall rate (vertical axis) and the number of lightning strikes (horizontal) are compared in 5-minute intervals. On a few of these days a high rainfall to lightning ratio (High RLR), represented by the blue line, was recorded on a few days in Florida during these thunderstorms. Heavy rain fell on these days but with relatively few lightning strikes. For most of their studied days, less rain and more lightning was noted (red Low RLR line). The median RLR for their study is the orange line. For the actual ratio for the storms in San Juan on July 18, the raw data is rather noisy (green) line. There were no 5-minute periods when

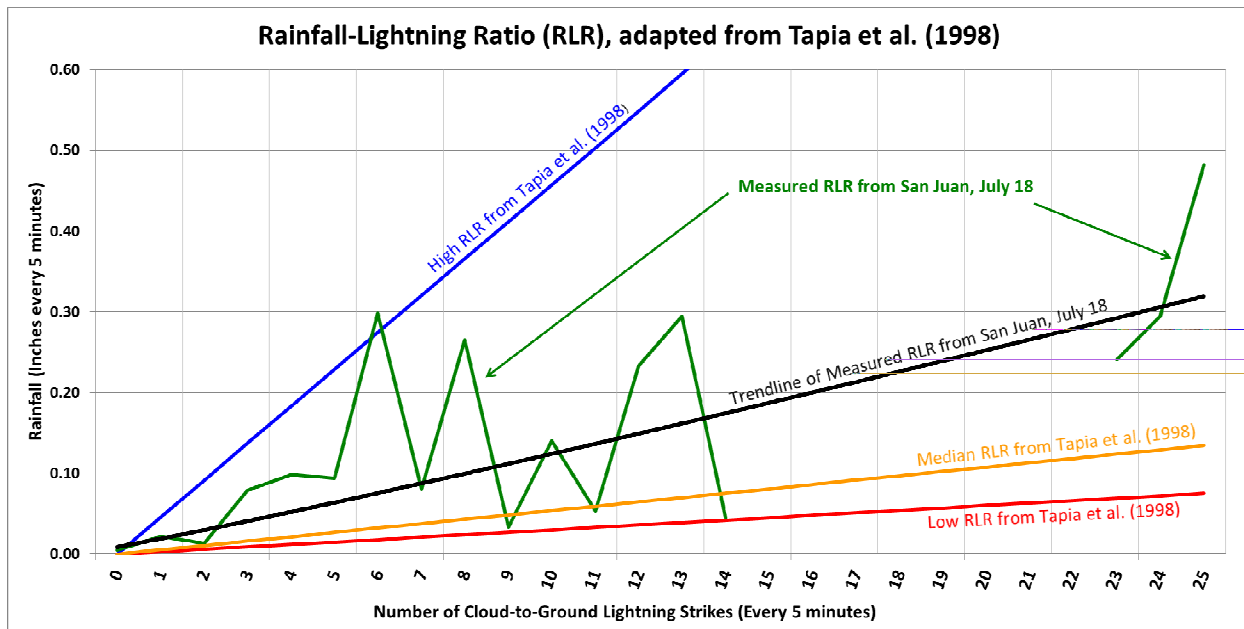


Fig. 8. Ratio of rainfall to number of lightning strikes, comparing rainfall recorded every 5 minutes with the number of lightning strikes over the same period.

lightning strikes numbered between 15 and 22 so no measured data is shown there. The black trend line (derived from the measured data) shows that the RLR for July 18 in San Juan was somewhere in the middle, between the extremes observed in Florida. Though it did not seem so, for the amount of rain that occurred, the lightning activity was appropriate or possibly even slightly below what might have been expected!

An infra-red image during the peak of the convection (Fig. 9) shows some yellows over San Juan Metro, indicating that temperatures at the top of clouds were in excess of -80°C . No environmental conditions that cold were measured on the TJSJ sounding that morning and the coldest it did measure (-73.5°C) was at 17,138 m MSL (56,227 ft MSL), higher than Figure 4 shows. These convective towers were likely exceeding even this height and it is not unusual for colder temperatures to be measured at the tops of extreme thunderstorms.

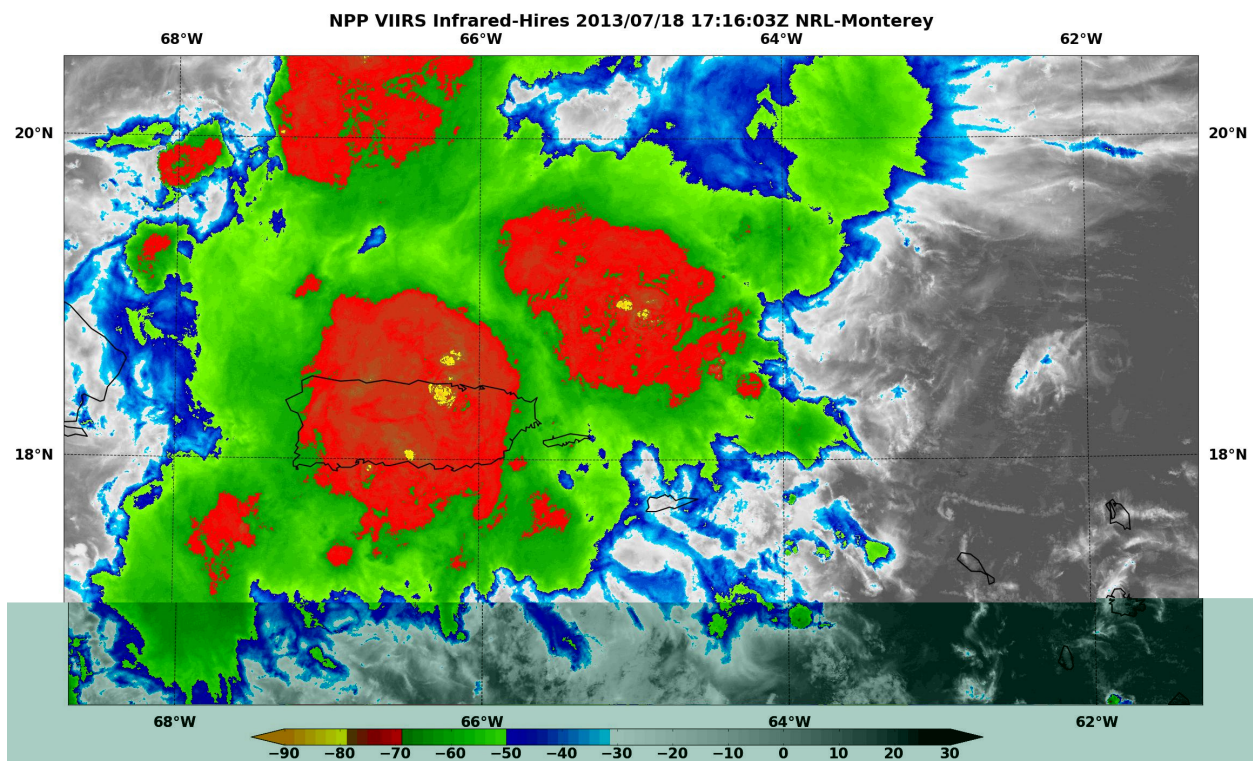


Fig. 9. Infra-red satellite image over Puerto Rico at 116 pm AST. The colors correspond to the temperature at cloud top. They are located where particularly strong thunderstorms were located at the time, and are usually located where intense lightning has been occurring.



Warnings and Advisories Issued

Flash Flood Warnings

Begin Time	Until	Municipalities (or portions of)
1226 pm	300 pm	Canovanas, San Juan, Carolina, and Loiza
1235 pm	300 pm	Dorado
1252 pm	315 pm	Caguas, Guaynabo, Gurabo, San Juan, Tujillo Alto, and Aguas Buenas
140 pm	430 pm	Bayamon, Guaynabo, Naranjito, San Juan, Toa Alta, Toa Baja, and Catano
331 pm	630 pm	Canovanas, Trujillo Alto, Carolina, Rio Grande, and Loiza

Urban and Small Stream Flood Advisories

Begin Time	Until	Municipalities (or portions of)
1146 am	245 pm	Caguas, Canovanas, Guaynabo, Gurabo, San Juan, San Lorenzo, Trujillo Alto, Yabucoa, Aguas Buenas, Carolina, Rio Grande, and Loiza
1229 pm (corrected at 1250 pm)	1245 pm (corrected at 345 pm)	Barranquitas, Bayamon, Caguas, Cayey, Cidra, Coamo, Comerio, Naranjito, Salinas, Santa Isabel, Aguas Buenas, and Aibonito
219 pm	515 pm	Coamo, Guayanilla, Jayuya, Juana Diaz, Orocovis, Penuelas, Ponce, Santa Isabel, Utuado, Villalba, and Adjuntas
229 pm	530 pm	Canovanas, San Juan, Trujillo Alto, Carolina, and Loiza
313 pm	615 pm	Canovanas, Cieba, Naguabo, San Juan, Trujillo Alto, Fajardo, Carolina, Luquillo, Rio Grande, and Loiza
423 pm	715 pm	Canovanas, Naguabo, Juncos, Las Piedras, Maunabo, Patillas, San Lorenzo, Yabucoa, and Humacao

Special Marine Warnings

1156 am	130 pm	Coastal waters of northern Puerto Rico out 10 nm, Atlantic waters of Puerto Rico and USVI from 10 nm to 19.5N
446 pm	545 pm	Coastal waters off of southeast Puerto Rico
951 pm	1115 pm	Coastal waters of northern Puerto Rico from Arecibo west to Aguadilla and out 15 nm

Reports and Damage

Location	Time	Report
Hatillo/ Camuy	1100 am	Lightning struck a balcony and knocked down a power line in Barrio Pajuil
Ponce	1100 am	Lightning broke light post in Barraida Clausell No. 19 Calle
Vega Baja	1110 am	Tree down over highway 688, street flooded in front of Puma Gas Station at Highway 2
Vega Alta	1112 am	Flash flood - Rio Machchal and Ponderosa out of their banks, trees down at Highway 2 near Vista Santa Rosa sector, and at Highway 686
Vega Alta	1116 am	Various streets in Barrio Ponderosa were flooded, Highway 2 flooded in front of clinic
Carolina	1140 am	Heavy rain, 0.50-0.74 inches in 15 minutes at Los Colobos
Carolina	1203 pm	Heavy rain, 1.00-1.24 inches in 15 minutes near Los Colobos
Carolina	1240 pm	House flooded at Villa Mar sector and Road Mar Del Norte
Vega Alta	1240 pm	Highway 2 closed due to flooding
San Juan	119 pm	Kennedy Ave reported flooded
San Juan	135 pm	House reported flooded at Cacique Street in Ocean Park sector
Guaynabo	150 pm	San Patricio Shopping Center was flooded
San Juan	200 pm	House flooded at Antarctica Street in Puerto Nuevo sector
Yabucoa	200 pm	Mudslide in Barrio la Pica
Vega Alta	200 pm	Rio Cibuco out of its banks and flooding roads 620 and 647
San Juan	210 pm	House flooded in Betances Street at Villa Palmeras sector
Carolina	230 pm	Isla Verde Ave flooded and impassable
Carolina	244 pm	Roberto Clemente Ave flooded in front of Julia de Burgos Park
Guaynabo	259 pm	Tabonucco Ave near San Patricio Mall flooded at Longhorn Restaurant
San Juan	259 pm	Barrio Las Monjas in Hato Rey sector flooded
Vega Alta	300 pm	Highways 620 at Fatima, 677 at Cadelaria, 647 at Vega Alta, 667 and 675 at Bajura, 690 and 2 in Sabana
Naguabo	356 pm	Flooded Highways 31 in La Pitina sector, and Exit 22 on Highway 53
San Juan	400 pm	Many streets flooded and impassable at Ocean Park sector
Yabucoa	415 pm	Flash flood
Las Piedras	530 pm	Flash flood - Barrio Tejas reported torrential rainfall (3.00 inches)

Conclusion



In recorded weather back to 1898, only August 15, 1944, when the U.S. Weather Bureau office was located in Old San Juan, saw more rain than this day in the metro area. This tropical wave placed San Juan in a prime location for streamer showers to build into monster thunderstorms with ultra-intense lightning and torrential rain. Actual recorded rainfall amounts were higher than initial forecasts, but the warnings issued by WFO San Juan were timely and on target.

