

Buckets of Rain and Conditions Unknown

Gary S. Votaw

Jane Higgins blogged in stormCarib.com (605 am AST, December 1, 2013):
The thunder Gods roared and blinked white lightening for hours right over our heads last night. When the lights in the house flashed we knew it was past time to unplug everything. We can report that all appliances survived. The little orange boxes help ... but you never know.

Rain and wine buckets say about 8" fell overnight. The pool is maxed out. And the lettuce replanting will probably rot again. A small price to pay for not having a tree fall on the house. A new gut opened up a path of water to our downhill neighbors on the west side. The same storm seemed to be taking 2 steps west and one step east all night long. Shocking to see Culebra's report that they only received 2 inches. What a few miles can make in weather changes.

<http://stormcarib.com/reports/current/stthomas.shtml>

This after the fact blog entry shows that not all was well on that Saturday night, November 30, 2013. Employees at the National Weather Service (NWS) office in San Juan knew that heavy rain was occurring over Saint Thomas, U.S. Virgin Islands. The radar near Cayey, Puerto Rico was known by the warning forecasters to often be inaccurate regarding rainfall over the Virgin Islands due in part to being greater than 75 miles distant (causing less resolution), and because the radar sits on a mountain top; the radar "sees" greater than 3,000 feet less of the storm in the vertical direction. Also, in some directions the beam is partially blocked by mountains nearby the radar. The Terminal Doppler radar (FAA) at Punta Salinas had an even poorer view of the ongoing storm.

Even for locations where the radar is close, forecasters must always confirm what the radar indicates with ground truth reports in order to assess what is happening across their region. Several phone calls that night to the Virgin Islands Territorial Emergency Management Agency (VITEMA) were not very helpful since they had received "no reports" of flooding from the island residents and forecasters were sure of at least a little. The NWS issued urban and small stream advisories (Table 1) that were valid most of the night but were unaware, for sure, if any life threatening flood had occurred. The Cyril E. King Airport at Charlotte Amalie reported that 4.90 inches of rain had fallen, starting after 500 pm AST on November 30th and ending around daylight on December 1st.

Once the rain had finished, the Southeast River Forecast Center (SERFC) in Atlanta, GA analyzed radar data and observed reports available at the time. The estimated rainfall (Fig. 1) appears to validate Ms. Higgins report of eight inches, who was at West End Saint Thomas, near Fortuna Bay. However this low resolution image was quite high compared to the airport reading

of almost five inches, which was near the center of the image's area of eight inches or more, and it was much higher than the four inches that radar suggested occurring overnight. Admittedly, "rain and wine buckets" do not suggest precision instruments so we could say that reading was higher than ground truth. Data from the cooperative network showed that around one and one-half inches fell at the east end of St. Thomas and over St. John, indicating that the analysis might be a little high there too at two to three inches. At the west end of St. Thomas the eight inches was likely a high estimate, but even so, one would think that at least some flooding occurred.

San Juan, PR (SJU): 12/1/2013 1-Day Observed Precipitation
Valid at 12/1/2013 1200 UTC- Created 1/29/14 0:30 UTC

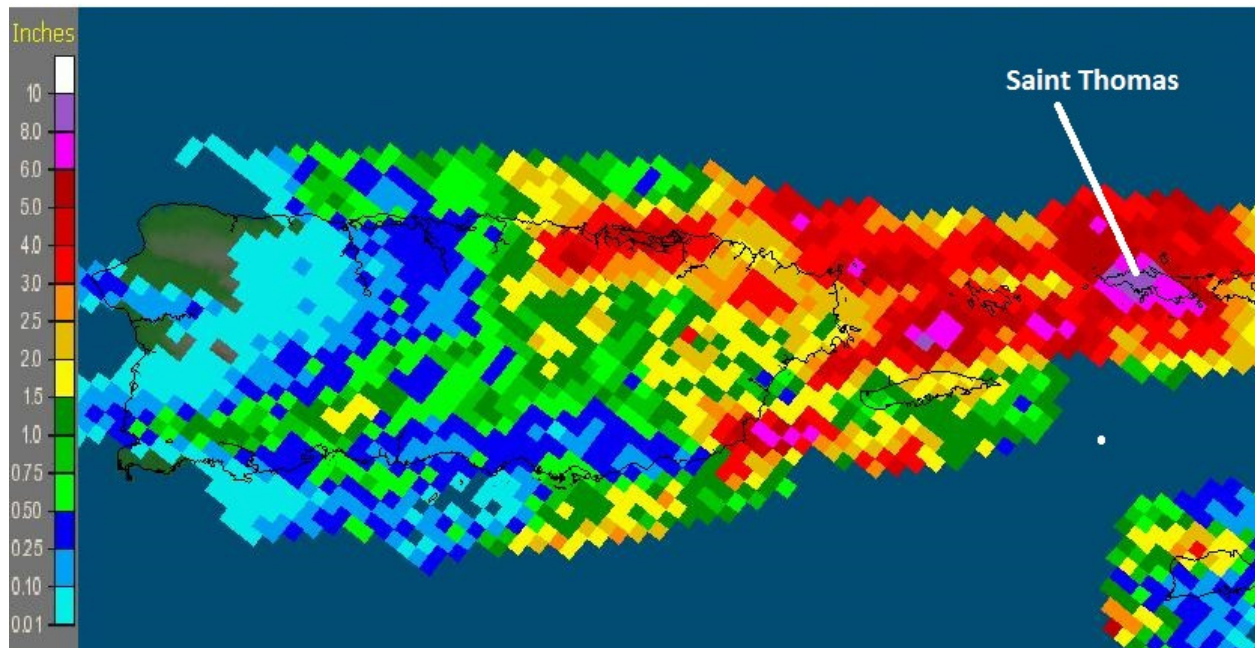


Fig. 1. Analysis by the SERFC, of observed and radar data, and represents precipitation for 24 hours ending 800 am AST December 1, 2013 (<http://water.weather.gov/precip/>).

More than three inches also fell across much of the San Juan Metropolitan Area according to SERFC's analysis which fit well with the nearly three and one-half inches measured at several stations across the area. Many flooded streets were noted in the San Juan area (Table 2) and was consistent with the amount of rain received. Many streets flooded and some were impassible. Rio Piedras at El Seniorial briefly crested at 11.27 feet, just above the minor flood stage for this location (Fig. 2) while the gage at Hato Rey was above its flood stage of 15 feet for a little over an hour, cresting at 18.48 feet (Fig. 3).

Figure 1 showed that Culebra probably received in excess of three inches of rain too, but like at Saint Thomas, no reports were received. Significant flooding very likely occurred (Table 1) on the night of November 30 as well as the following several days. Were the flood statements correct in their timing and choice of format? Were there problems in detection that may be corrected for in future events?

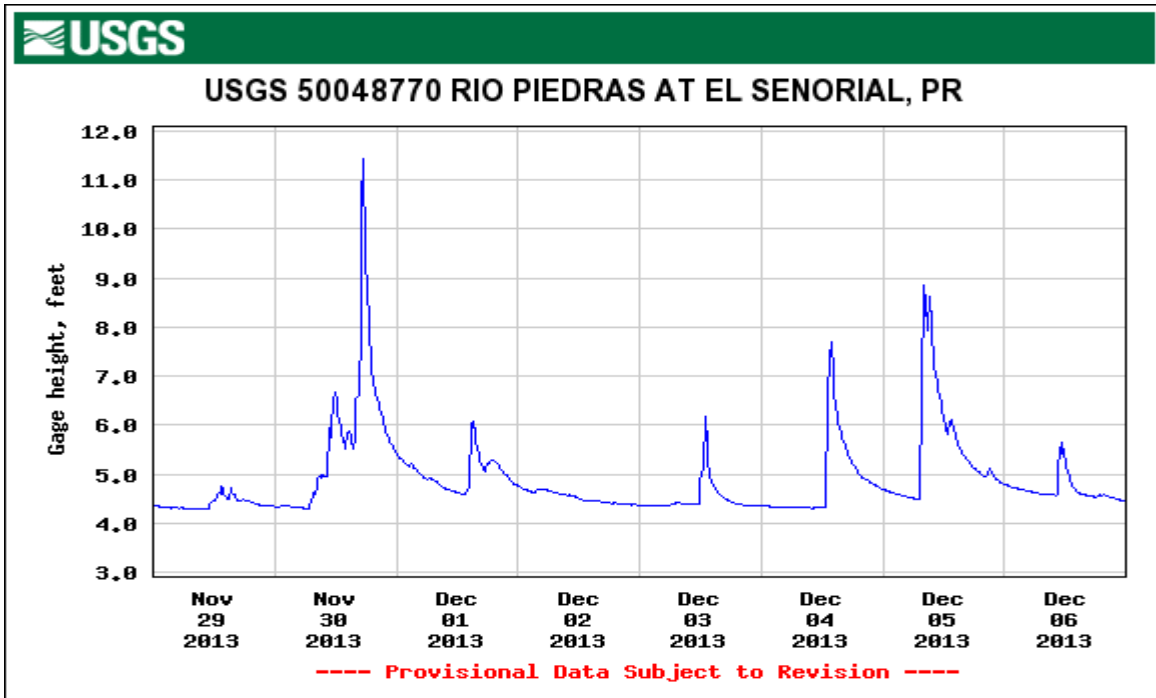


Fig. 2. Hydrograph for Rio Piedras at El Seniorial from Nov. 29 to Dec. 6, 2013. Flood stage is 11 feet
http://waterdata.usgs.gov/pr/nwis/uv/?site_no=50048770&PARAMeter_cd=00065.00060).

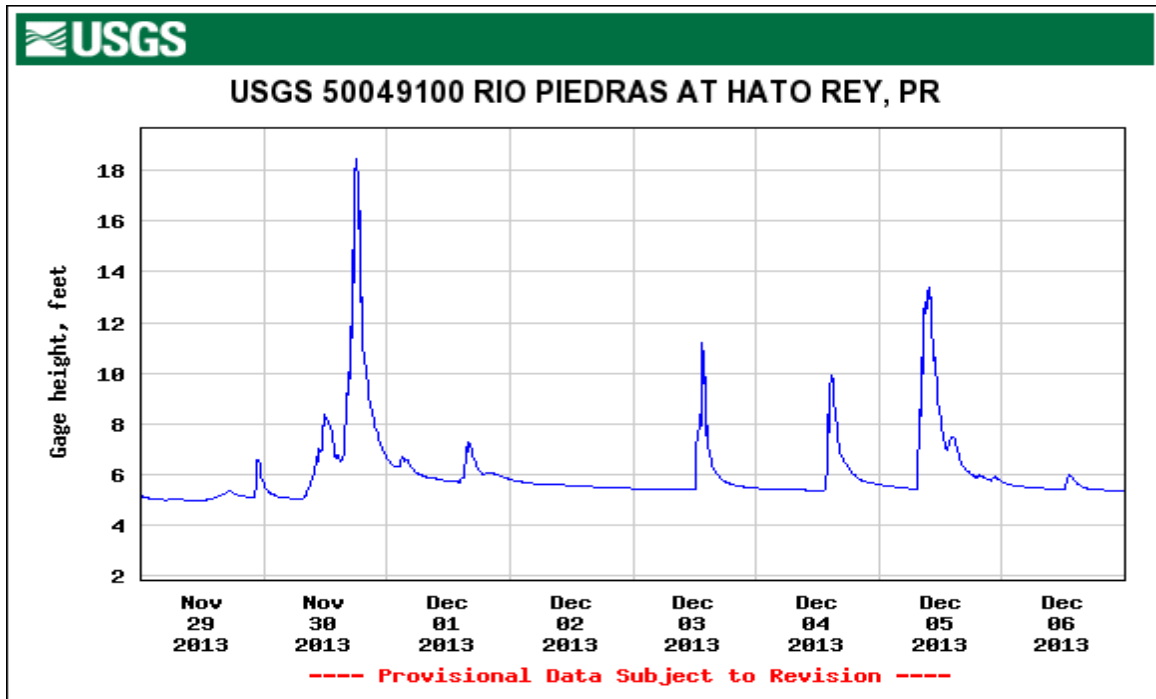


Fig. 3. Hydrograph for Rio Piedras at Hato Rey from Nov. 29 to Dec. 6, 2013. Flood stage is 15 feet
http://waterdata.usgs.gov/pr/nwis/uv/?site_no=50049100&PARAMeter_cd=00065.00060).

Historical Synopsis, Part One

On the morning of November 30th a relatively small area of high moisture had moved over the U.S. Virgin Islands and Puerto Rico (Fig. 4). Associated with the moisture was a weak low level trough moving westward towards the area while a small subtropical upper level jet streak moved east. The jet streak would be instrumental in enhancing divergence at that level. In conjunction with convergent low level flow underneath the jet streak the resulting coupled flow enhanced upward motion and thunderstorms later that day.

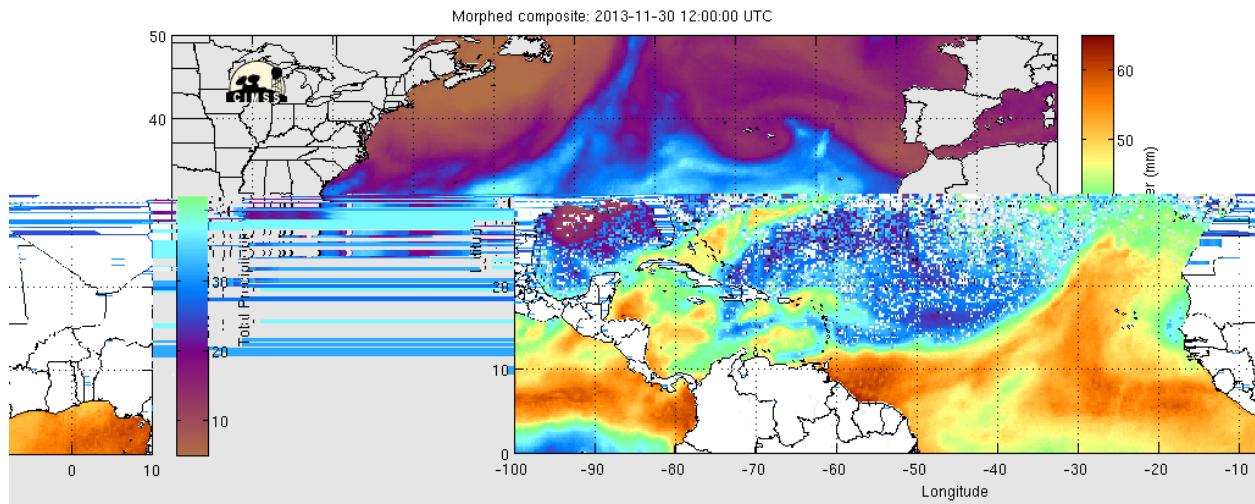


Fig. 4. Precipitable water image for 1200 UTC (800 am AST) on November 30, 2013 (<http://tropic.ssec.wisc.edu/real-time/mimic-tpw/global/main.html>)

Low level (convergent) to high level (divergent) moisture flow was in place according to the 18 UTC GFS model run but it insisted that these conditions would not persist. Figure 5 shows the initial conditions (200 pm AST) analyzed by that model (the latest available late in the day) for strong convergent flow in the 925-850 mb layer (about 2700 ft to 5100 ft AGL). The model showed the poorly defined trough moving west through the day and weakening. The upper divergent flow was moving eastward (Fig. 6). According to the GFS the associated divergence had almost cleared east of Puerto Rico by 1800 UTC (200 pm AST) and would be east of the U.S. Virgin Islands before the heavy rains began after 500 pm. Though the 18 UTC GFS was able to initialize and resolve both the lower level trough and upper level jet streak it almost certainly did not position or synchronize them correctly into the evening. It then failed to anticipate near term development of thunderstorms over the islands since it showed the coupled flow would have ended before this event actually began.

The 18 UTC GFS showed that most convection during the afternoon would occur well offshore and north of Puerto Rico. It was correct that convection would repeatedly develop north of the island and it continued well into the night. However activity also developed over Puerto Rico and U.S. Virgin Islands and it was difficult for forecasters to anticipate this since the model

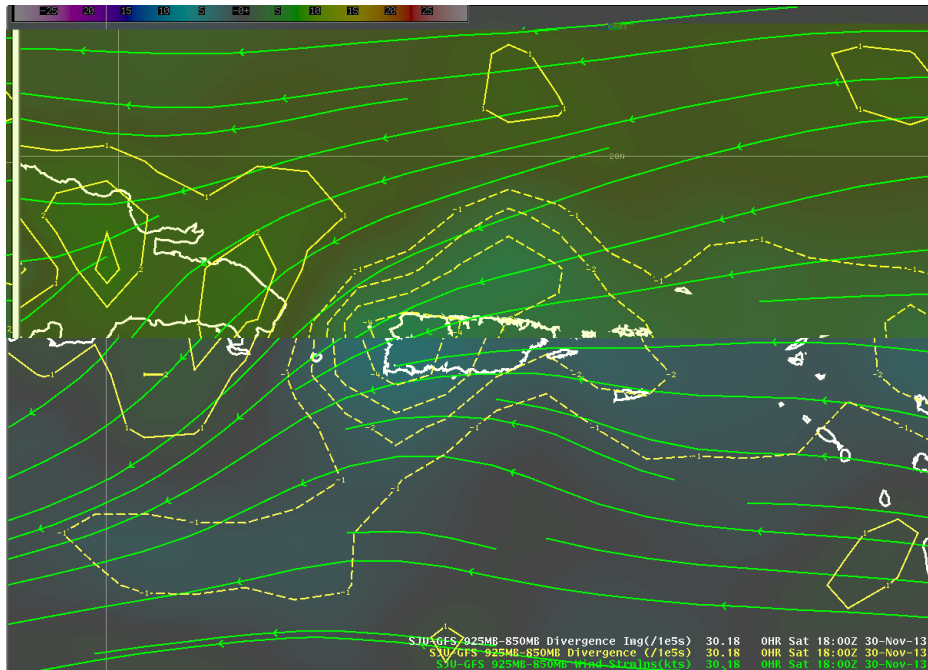


Fig. 5. 18 UTC GFS showing convergent flow at 925-850 mb over and north of Puerto Rico at 18 UTC (200 pm AST). Dashed lines show the amount of convergence ($10^{-5}/s$) while colored blue, along with streamlines and wind speed in knots (green).

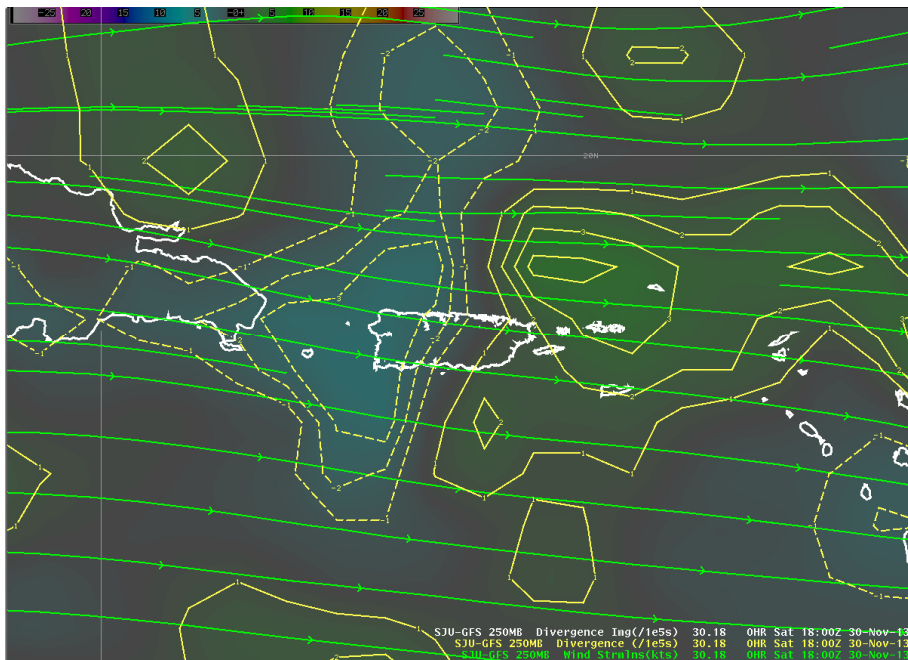


Fig. 6. 18 UTC GFS showing an eastward moving 250 mb jet streak already over the Leeward Islands with divergent flow behind it already moving into the U.S. Virgin Islands at 18 UTC (200 pm AST). Solid yellow lines (filled with green) are the values of divergence ($10^{-5}/s$). Also shown are the 250 mb streamlines (green).

failed to indicate that conditions leading to convection over the islands would occur. The next model run that evening also did not see the coupled flow even initially except that it did show another upper jet streak passing close by. The initial coupled flow of low level convergence and upper divergence, if it existed, was reason for concern. Except for the initial 18 UTC GFS model condition, valid much earlier than when the thunderstorms were occurring, the ongoing convection was the only evidence to that possibility. The satellite view (Fig. 7) shows thunderstorms redeveloping near Saint Thomas at 0845 UTC (445 am AST) on December 1st. Convection had been ongoing well north of Puerto Rico since the previous day but had ended by this time at San Juan.

Remote sensors, including satellite, over such an otherwise data sparse region can rarely resolve the details necessary to deduce where and when thunderstorms will develop. The GFS, while a good model for most other applications, cannot usually capture the details necessary in this type of scenario. Other models used by the NWS are useful for other applications but even they usually rely on the GFS for their large scale background.

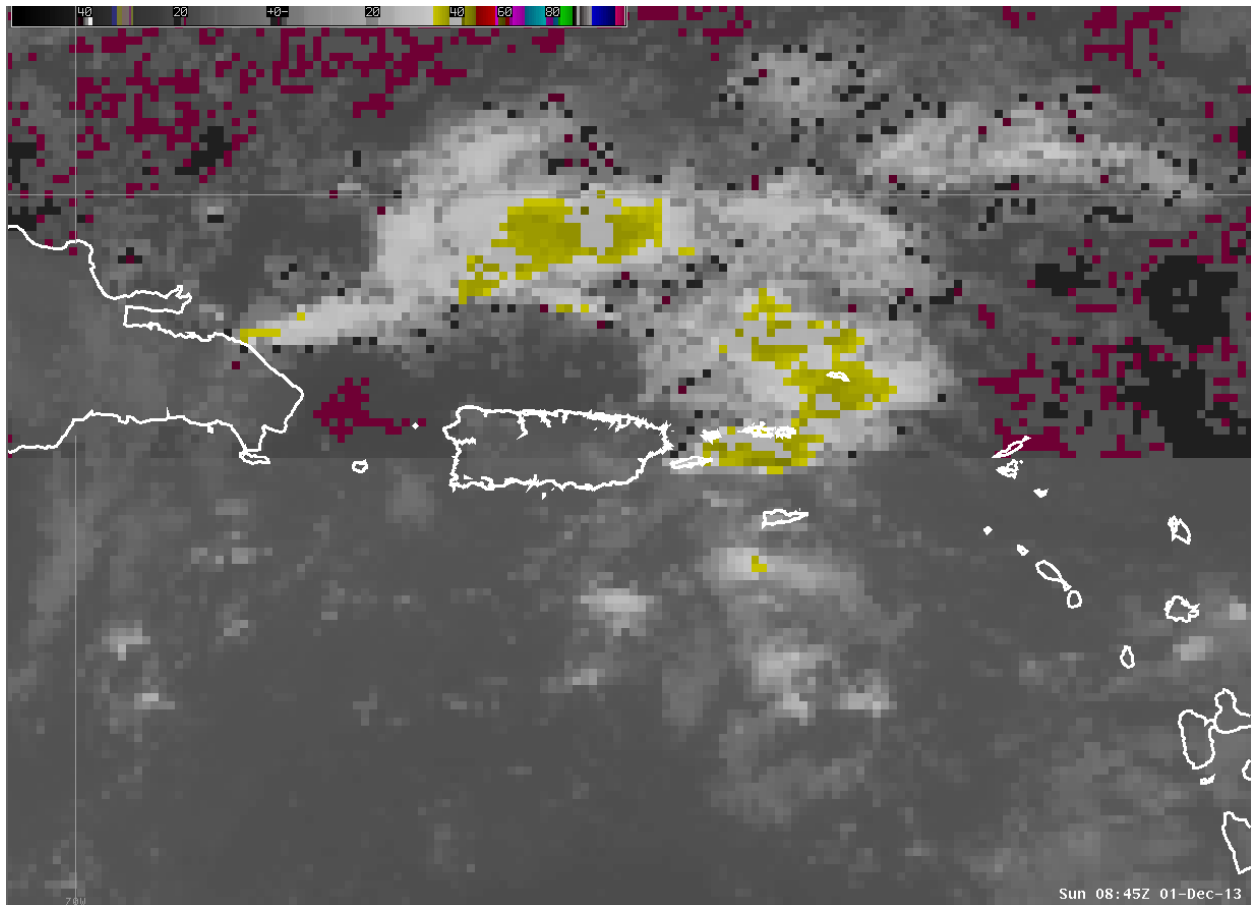


Fig. 7. The GOES Infra-red enhanced satellite image shows thunderstorms (yellow to red colors) still occurring near Culebra, Saint Thomas, and north of the islands at 0845 UTC (445 am AST) December 1, 2013.

Historical Synopsis, Part Two

The NWS and VITEMA do not know how much flooding occurred that Saturday night in Saint Thomas. However the rain over that island and San Juan Metro set antecedent, saturated soil conditions that would be instrumental to cause flooding over the next several days. Figures 8 through 12 show the increasing moisture streaming northwestward from the Windward Islands and South America, occurring as low level winds turned southeasterly by late Monday, December 2, 2013. The precipitable water recorded on the upper air soundings at San Juan peaked at 2.19 inches (55.55 mm) at 1200 UTC on the 5th (Fig. 13). This was almost 2 standard deviations above normal for the time of season at San Juan. On the morning of the 5th the low level winds were backing to east-northeast as the flow was changing.



Fig. 8. Precipitable water image for 1200 UTC (800 am AST) on December 1, 2013.

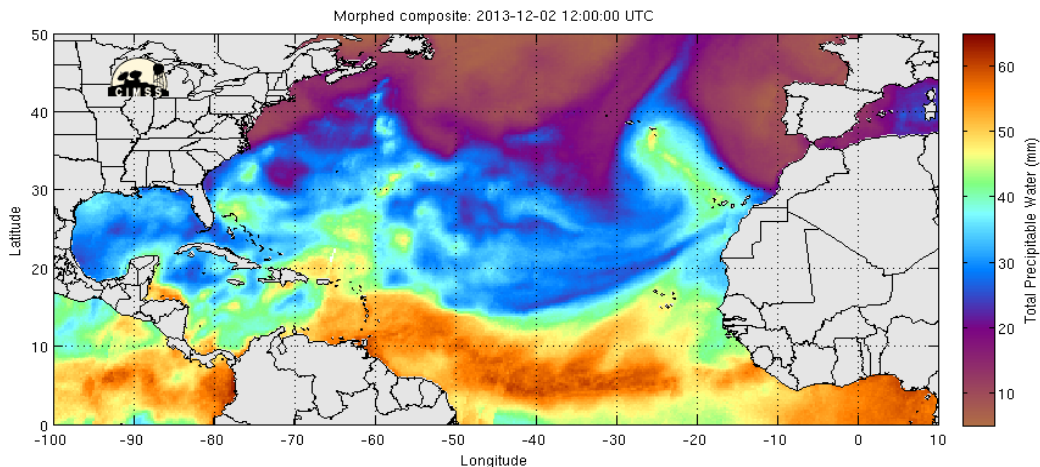


Fig. 9. Precipitable water image for 1200 UTC (800 am AST) on December 2, 2013.

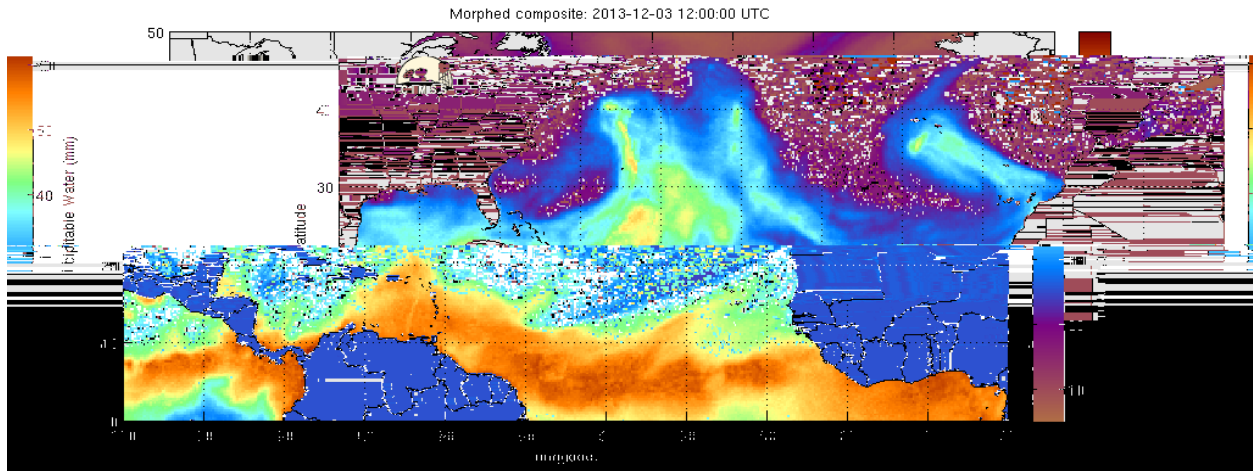


Fig. 10. Precipitable water image for 1200 UTC (800 am AST) on December 3, 2013.

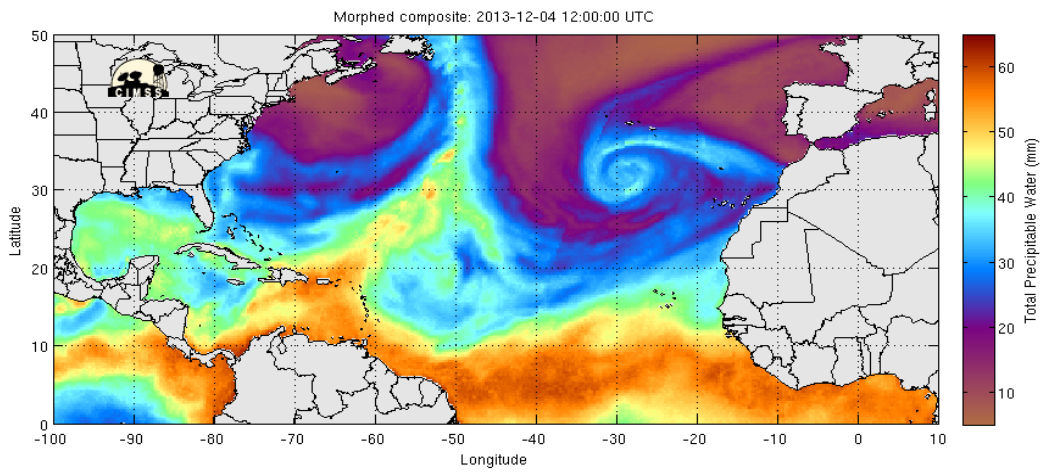


Fig. 11. Precipitable water image for 1200 UTC (800 am AST) on December 4, 2013.

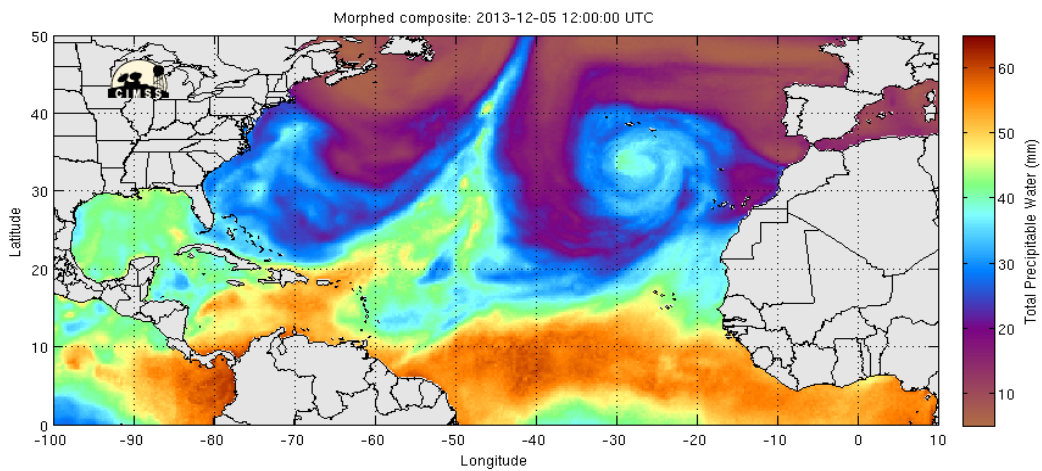
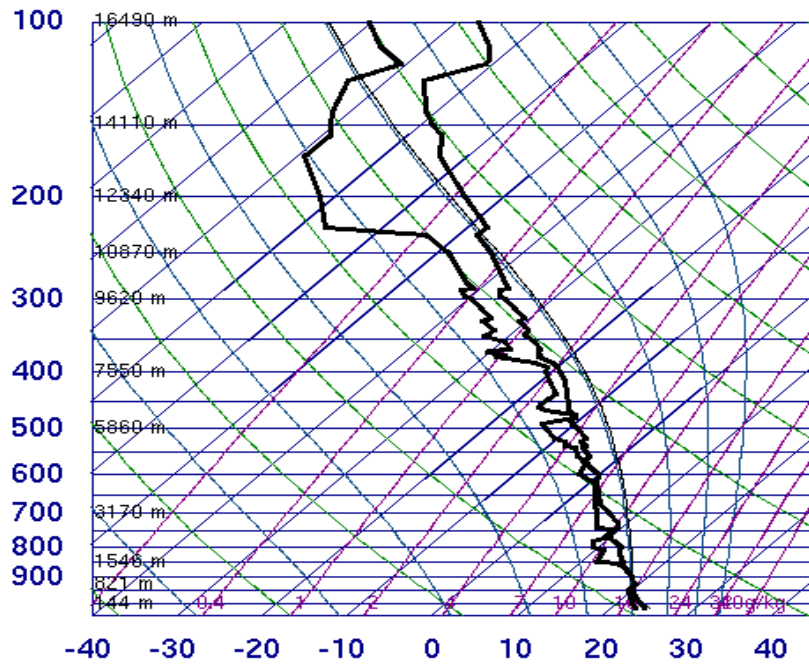


Fig. 12. Precipitable water image for 1200 UTC (800 am AST) on December 5, 2013.

78526 TJSJ San Juan



SLAT	18.43
SLON	-65.99
SELV	3.00
SHOW	-0.13
LIFT	-3.78
LFTV	-4.15
SWET	195.0
KINX	35.60
CTOT	22.10
VTOT	24.10
TOTL	46.20
CAPE	1060.
CAPV	1146.
CINS	0.00
CINV	0.00
EQLV	229.8
EQTV	229.7
LFCT	965.6
LFCV	968.2
BRCH	208.0
BRCV	225.0
LCLT	294.3
LCLP	977.2
MLTH	296.2
MLMR	16.49
THCK	5716.
PWAT	55.55

12Z 05 Dec 2013

University of Wyoming

Fig. 13. Upper air sounding for 12 UTC (800 am AST) December 5, 2013 at San Juan, PR, showing 2.19 inches (55.55 mm) of precipitable water.

San Juan, PR (SJU): 12/4/2013 1-Day Observed Precipitation
Valid at 12/4/2013 1200 UTC- Created 12/6/13 23:31 UTC

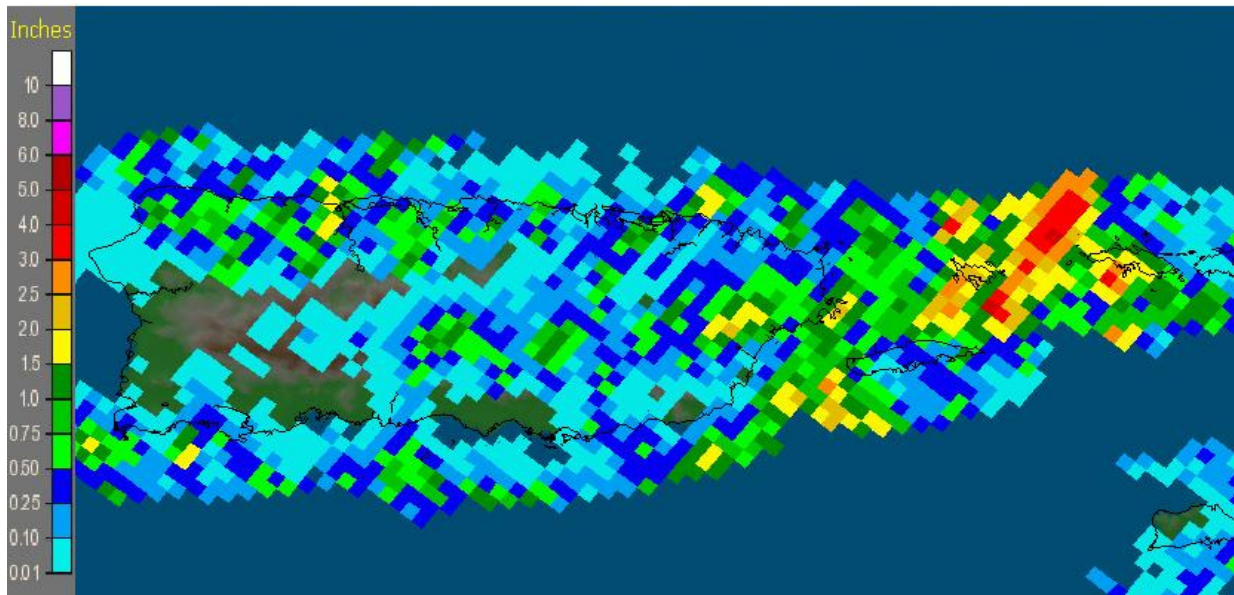


Fig. 14. Spatial analysis of recorded observations and radar from the SERFC. The image shows detected precipitation for 24 hours ending at 800 am AST December 4, 2013 (<http://water.weather.gov/precip/>).

Almost an inch and a half of rainfall occurred on Wednesday (the 3rd) at Cyril E. King Airport (Saint Thomas) but apparently it was not enough to renew flooding since none was reported and the rain did occur during the afternoon when many people were out and about. The rainfall analysis by the SERFC (Fig. 14) indicated that rainfall maximized slightly offshore from the airport so the island was spared the heaviest rainfall. Over San Juan Metro the rain that day was only enough to keep the ground saturated while slightly higher rainfall amounts caused minor flooding near Arecibo, Ceiba and Fajardo (Table 2). Atmospheric moisture continued to increase much of the week but jet dynamics apparently never became conducive for significant redevelopment. There were some showers and thunderstorms, enough to keep soils moist.

The afternoon of December 5th was the lone day of the week on which Saint Croix received flooding rains. An inch and a quarter of rain quickly fell at Henry E. Rohlsen (Christiansted) Airport while the SERFC analysis (Fig. 15) showed more than three inches farther east, between the airport and Christiansted. The heaviest rain occurred between Sunny Isles and Hovenså (Fig. 16).

San Juan, PR (SJU): 12/5/2013 1-Day Observed Precipitation
Valid at 12/5/2013 1200 UTC- Created 12/7/13 23:29 UTC

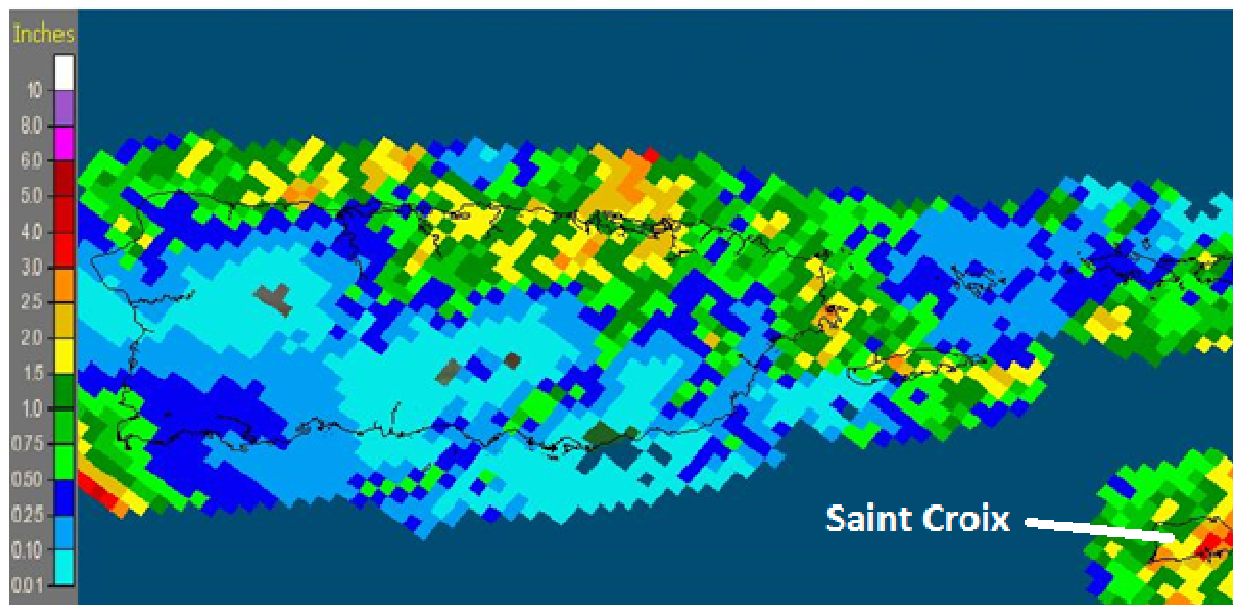


Fig. 15. Analysis of observed and radar from the SERFC. The image shows detected precipitation for 24 hours ending at 800 am AST December 5, 2013 (<http://water.weather.gov/precip/>).



Fig. 16. Flooding in Saint Croix on December 4, 2013, Sunny Isles, left, and Estate Strawberry, below.

https://www.facebook.com/pages/American-Red-Cross-of-the-Virgin-islands/199583476729980?id=199583476729980&sk=photos_stream



Very heavy rain on Saturday night and then more moderate rains repeating for days over northeastern Puerto Rico and Saint Thomas caused saturated soils and continued flooding events. But a major change in the upper level flow occurred on December 5th when the upper ridge built quickly from the western Caribbean Sea into the Gulf of Mexico. That turned the flow over Puerto Rico and the U.S. Virgin Islands to northerly by the end of the

day. Several waves in the upper flow moved south, not clearing out the high moisture at middle to low levels until late afternoon. Each wave generated a new round of showers and thunderstorms. The strongest wave developed thunderstorms north of the islands and pushed heavy showers across San Juan Metro and Saint Thomas during the morning (Fig. 17).



Fig. 17. Flooded Veterans Drive in Charlotte Amalie on the morning of December 5, 2013

https://www.facebook.com/pages/American-Red-Cross-of-the-Virgin-Islands/199583476729980?id=199583476729980&sk=photos_stream

Figure 18 shows the responsible wave beginning to develop the thunderstorms still offshore from Puerto Rico at 0600 UTC (200 am AST). Urban and small stream flood advisories were later issued by the NWS for 18 Puerto Rican municipalities and also for Saint Thomas and Saint John, for most of the morning until early afternoon. The NWS issued a flash flood warning for late morning covering 12 municipalities for northeastern and extreme eastern Puerto Rico.

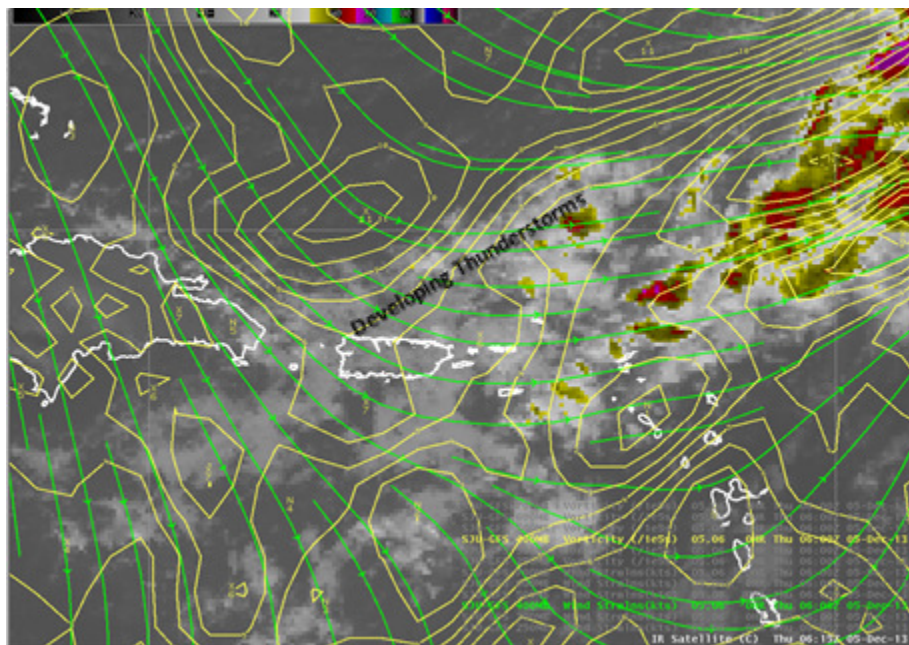


Fig. 18. Line of showers and thunderstorms developing north of the local islands, generated primarily from the wave, shown here in the 400 mb (7550 m or 24,770 ft AGL) streamlines (green) and vorticity (yellow), from the 06 UTC GFS. The infra-red satellite image is for 0615 UTC December 5, 2013 and the model valid time is 0600 UTC.

NWS Warnings and Advisories Issued
Flash Flood Warnings

Begin Time	Until	Municipalities (or portions of)
Nov. 30 / 531 pm	830 pm	San Juan
Dec. 5 / 903 am	noon	Bayamon, Guaynabo, San Juan, Trujillo Alto, Carolina, Catano, Loiza
Dec. 5 / 924 am	1130 am	Ceiba, Naguabo, Las Piedras, Fajardo, Luquillo

Urban and Small Stream Flood Advisories

Begin Time	Until	Municipalities (or portions of)
Nov. 30 / 433 pm	730 pm	Bayamon, Canovanas, Guaynabo, San Juan, Trujillo Alto, Toa Baja, Carolina, Catano, Rio Grande, Loiza
Nov. 30 / 522 pm	815 pm	Vega Alta, Vega Baja, Dorado, Toa Alta
Nov. 30 / 644 pm	945 pm	Naguabo, Fajardo, Luquillo
Nov. 30 / 713 pm	915 pm	Saint Thomas
Nov. 30 / 725 pm	1030 pm	Bayamon, Canovanas, Guaynabo, San Juan, Trujillo Alto, Toa Baja, Carolina, Catano, Rio Grande, Loiza
Nov. 30 / 756 pm	1015 pm	Vega Alta, Vega Baja, Dorado, Toa Alta
Dec. 1 / 1224 am	315 am	Saint Thomas, Saint John
Dec. 1 / 124 am	415 am	Canovanas, San Juan, Trujillo Alto, Carolina, Luquillo, Rio Grande, Loiza
Dec. 1 / 308 am	615 am	Saint Thomas, Saint John
Dec. 1 / 558 am	845 am	Saint Thomas, Saint John
Dec. 1 / 259 pm	600 pm	Lares, Utuado
Dec. 1 / 333 pm	630 pm	Anasco, Hormigueros, Maricao, San German, Las Marias, Mayaguez
Dec. 1 / 343 pm	645 pm	Barceloneta, Florida, Arecibo
Dec. 1 / 424 pm	615 pm	Cabo Rojo
Dec. 1 / 800 pm	1100 pm	Vega Alta, Vega Baja
Dec. 1 / 1045 pm	midnight	Vega Alta, Vega Baja
Dec. 2 / 1204 am	200 am	Vega Alta, Vega Baja
Dec. 3 / 355 pm	645 pm	Ceiba, Naguabo, Fajardo, Luquillo
Dec. 3 / 558 pm	745 pm	Hatillo, Arecibo, Camuy
Dec. 4 / 1253 pm	345 pm	Bayamon, Guaynabo, Naranjito, San Juan, Trujillo Alto, Toa Alta, Toa Baja, Carolina, Catano, Loiza
Dec. 4 / 154 pm	445 pm	Saint Croix, Vieques
Dec. 4 / 313 pm	615 pm	Barceloneta, Ciales, Corozal, Florida, Manati, Morovis, Vega Alta, Vega Baja, Dorado
Dec. 4 / 401 pm	600 pm	Bayamon, Caguas, Canovanas, Corozal, Guaynabo, Gurabo, Naranjito, San Juan, Trujillo Alto, Dorado, Toa Alta, Toa Baja, Carolina, Catano, Loiza
Dec. 5 / 717 am	915 am	Bayamon, Canovanas, Ciales, Corozal, Guaynabo, Manati, Morovis, San Juan, Trujillo Alto, Vega Alta, Vega Baja, Dorado, Toa Alta, Toa Baja, Carolina, Catano, Rio Grande, Loiza
Dec. 5 / 855 am	1215 pm	Bayamon, Canovanas, Ciales, Corozal, Guaynabo, Manati, Morovis, San Juan, Trujillo Alto, Vega Alta, Vega Baja, Dorado, Toa Alta, Toa Baja, Carolina, Catano, Rio Grande, Loiza
Dec. 5 / 1138 am	130 pm	Saint Thomas, Saint John

Table 1. Warnings and advisories issued by the NWS for November 30 to December 5, 2013.

Reports and Damage

Location	Time	Report
Nov. 30	530 pm	San Juan, flood – 5 th Street at Villa Nevares, several streets at Barrio Obrero including Lyn Street and Willian Street, several streets at Cupey including Betances Avenue and Winston Churchill Avenue, Pinero Avenue flooded in low lying areas, several streets flooded at Puerto Nuevo including Andalucia Avenue, 20 th Street, Matadero Street, 54 th NE Street, De Diego Avenue
Nov. 30	530 pm	San Juan, flash flood – Minillas Tunnel closed, Highway Las Americas closed
Nov. 30	530 pm	Guaynabo, flood – urban flooding at San Patricio area
Nov. 30	530 pm	Vega Alta, flood – Roads 620 and 647 flooded in low lying areas
Nov. 30	615 pm	San Juan, flood – Flooding in low lying areas along Munoz Rivera Avenue near UPR Rio Piedras and Kennedy Avenue near San patricio
Dec. 2	800 pm	Vega Alta, Road 620 flooded in low lying areas at Barrio Fatima
Dec. 4	noon	Charlotte Amalie, Saint Thomas, flood – Main Street
Dec. 4	230 pm	Christiansted, Saint Croix, flood – Gallows Bay area, Hovensa in the vicinity of Melvin Evans Highway, Sion Farm along Queen Mary Highway and in the vicinity of Lew Muckle Elementary School, Golden Rock area in the vicinity of the shopping center, Peters Restaurant in vicinity Juny’s Bar, Estate Strawberry along Queen Mary Highway, also Melvin Evans Highway in the vicinity of Home Depot.
Dec. 5	841 am	Bayamon, flood – Ramon Luis Rivera Avenue
Dec. 5	846 am	San Juan, flood – urban flooding at Shirley’s Plaza in Santurce
Dec. 5	858 am	Bayamon, flood – urban flooding at Rio Plantation
Dec. 5	916 am	Guaynabo, flash flood – PR-165 near San Patricio Plaza impassable
Dec. 5	924 am	San Juan, flash flood – Fernandez Juncos Avenue near Parada 18 th
Dec. 5	929 am	San Juan, flood – Roads flooded in the Sagrado Corazon Train Station area, also PR-1 underpass below Highway 22 impassable
Dec. 5	930 am	Catano, flood – Avenue Flor del Valle in Las Vegas, also in the Barrio Juana Matos
Dec. 5	930 am	San Juan, flood – Neighborhood Ocean Park, Street McLeary and vicinity
Dec. 5	939 am	San Juan, flood – urban flooding in vicinity of Clinica Las Americas
Dec. 5	946 am	San Juan, flash flood – Parada 26 th sector in Santurce flooded with car stranded
Dec. 5	1025 am	Catano, flash flood – Las Vegas sector impassable
Dec. 5	1037 am	San Juan, flash flood – Buena Vista sector in Santurce
Dec. 5	1000 am	Guaynabo, flood – Quebrada Altamira beyond its banks
Dec. 5	1027 am	San Juan, flood – Highway 26 impassable towards San Juan before and after tunnel towards Carolina
Dec. 5	noon	Charlotte Amalie, Saint Thomas, flood – Veterans Drive area of Griffith Park, Julian Jackson Drive, Kronprindens Gade area of Department of Labor, and rear of Gottlieb Gas Station
Dec. 5	258 pm	Guaynabo, mudslide of Mogote into Highway 22 towards west before exit to PR 165, one lane blocked

Table 2. Reports received at the NWS office for November 30 through December 5, 2013.

Summary and Conclusions

Almost eight inches of rain fell in less than six days from November 30th through December 5th at both San Luis Marin Munoz International Airport (San Juan) and Cyril E. King Airport (Charlotte Amalie). The combined climatological normal rainfall for these six days is 1.06 inches and 0.67 inches, respectively at these airports. Higher amounts very likely fell locally across San Juan Metro, Saint Thomas, and maybe over Culebra. Figure 19 shows a graphical summary of the rainfall at the airports.

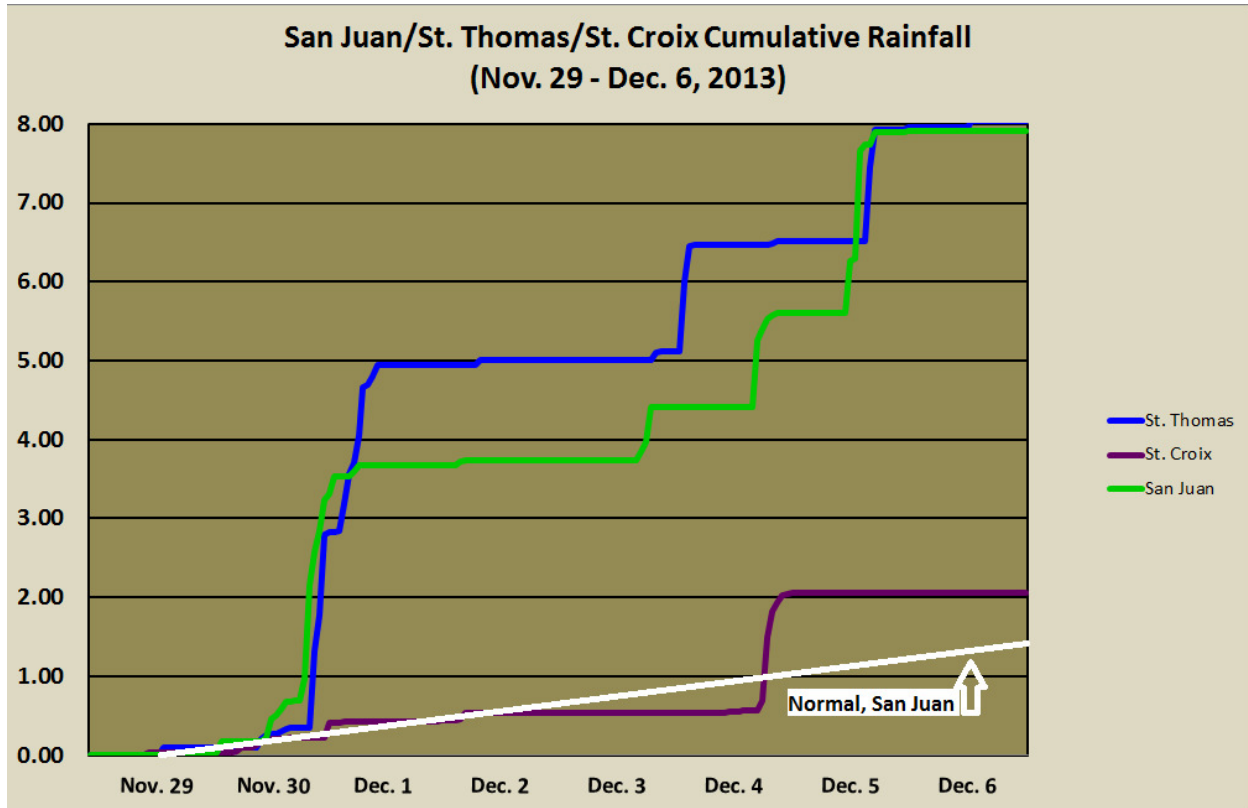


Fig. 19. Recorded hourly, precipitation accumulated at the three major airports during the period from November 29 to December 6, 2013.

The warnings and advisories that were issued were on target and addressed the issue, when the threats were known. An urban and small stream flood advisory implies non-life threatening situations and this appears to have been the case when they were issued. Drivers of automobiles were certainly inconvenienced and some businesses and homes had water in them which required cleaning, but lives were generally not threatened. A flash flood warning suggests a more serious condition when lives may be threatened in the warned area. A flash flood warning issued for San Juan on November 30th was issued when minor flooding began on the Rio Piedras at El Senorial (Fig. 2) but provided almost 25 minutes of advance warning of the flash flood at Hato Rey (Fig. 3). No reports were received during or after the flash flood warning on December 5th though a river quickly moving and above flood stage, as this was, is always dangerous.

What really happened over many of these areas, including the West End of Saint Thomas on the night of November 30th and over Culebra at any time during this week will never be fully realized. Regarding western Saint Thomas and Culebra, no remote sensors other than radar and satellite exist and no flooding was reported by residents or law enforcement personnel. Highly variable terrain, soil conditions, and convective rainfall that vary greatly over short distances make for exceptionally difficult analysis of conditions, especially when time is short and quick decisions must be made. It is recognized that just because no report was received that does not imply that no threatening weather related condition existed. Issued warnings and advisories, if they err, must do so on the side of caution, especially when there is little chance of gaining real time, ground truth knowledge.

Reporting procedures and communication of environmental hazards can always be improved. We must also be mindful that making a personal effort to report a dangerous situation can save a life nearby. For the National Weather Service, incremental improvement will always be a pillar for improving its warning program and it will never be good enough to fully protect all people all the time, but that is the goal.