Texas Water Journal

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Integration of the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) observations into the West Gulf River Forecast Center operations

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Abstract: This article will introduce the Community Collaborative Rain, Hail and Snow (CoCoRaHS) network and illustrate its integration into the daily operations at the National Weather Service West Gulf River Forecast Center (WGRFC). An example will be shown on how the data were used during a specific flood event and will illustrate our extensive use of this data during Hurricane Harvey. The benefits of this network will be discussed. The network provides the WGRFC a source of rain gauge data where other sources of rainfall data are sparse and allows for verification of radar-based precipitation estimates. Members of CoCoRaHS provide observations that are vital in assisting the WGRFC with flood forecasting operations. Information on joining this important network is presented in this article.

Keywords: rainfall, observers, floods

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Terms used in paper

Acronyms	Descriptive name
CoCoRaHS	Community Collaborative Rain, Hail and Snow
HRAP	Hydrologic Rainfall Analysis Project
MPE	Multisensor Precipitation Estimate
NSF	National Science Foundation
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
RFC	River Forecast Center
UTC	Coordinated Universal Time
USGS	U.S. Geological Survey
WSR	Weather Service Radar
WGRFC	West Gulf River Forecast Center

INTRODUCTION

In Story (2016), Texas Water Journal readers were introduced to the mission of the hydrologic program of the National Weather Service (NWS). The NWS West Gulf River Forecast Center (WGRFC), in cooperation with numerous federal, state, and local government entities, uses the latest science and technology to provide timely and accurate river forecasts for most of the river drainages in Texas in an effort to protect life and property. River response and flood potential often depend on the magnitude of each rainfall event. Prior to real-time weather tracking systems, the river forecast centers (RFCs) were faced with using daily rainfall totals from sparse sources, such as airport rain gauges, automated river rain gauges, and NWS co-operative observers. Due to the limited spatial distribution of the gauges, often the most intense rainfall amounts would be missed. This lack of information limited the RFCs' ability to provide real-time or near-real-time flood forecasts, often resulting in the river forecast crests being too low and the timing of those crests being late.

Since the advent of the Weather Service Radar-1988 Doppler (WSR-88D) radars in the mid-1990s, forecasters have been able to receive precipitation estimates each hour. While these estimates give much improved spatial and temporal res-olution, the actual amounts of rainfall can be in considerable error. Therefore, dependable rainfall observations from gauges are still necessary. A rainfall network began 20 years ago that helps determine the accuracy of radar-based precipitation estimates. This is the Community Collaborative Rain, Hail and Snow (CoCoRaHS) network.

WHAT IS COCORAHS?

CoCoRaHS is a non-profit, community-based network of volunteers of all ages and backgrounds who work together to measure and map precipitation (rain, hail and snow). CoCoRaHS is now in all 50 states, Puerto Rico and the U.S. Virgin Islands, the Bahamas, and Canada. The network originated with the Colorado Climate Center at Colorado State University in 1998, inspired in part by the Fort Collins flood the prior year (Reges et al. 2016). Since the beginning of this network, the WGRFC has seen the benefits of this precipitation data (as the WGRFC has river forecast responsibility in southern Colorado). In the years since, more than 6,100 Texans have joined CoCoRaHS, and more than 62,000 volunteers have joined nationwide (CoCoRaHS website 2018). While many of these observers have moved, passed on, or lost interest over time, the WGRFC receives around 1,000 CoCoRaHS observervations

per day. Volunteers agree to take precipitation measurements and are asked to report even on days when no precipitation has occurred. We hope to receive rain reports from as many locations as possible. These precipitation reports are entered either through the CoCoRaHS website (www.cocorahs.org) or through an application on a mobile smart phone. The data are then recorded in a central archive at CoCoRaHS headquarters and made available to the public in near-real time on the CoCoRaHS website. The data are displayed and organized for many end users to analyze daily, with purposes ranging from water resource analysis and severe storm warnings to neighbors comparing how much rain fell in their backyards. CoCoRaHS is used by a wide variety of organizations and individuals. Aside from the NWS, meteorologists, hydrologists, and emergency managers routinely use this resource. Additionally, CoCoRaHS data benefit city utilities (for water supply, water conservation, or stormwater), insurance adjusters, agriculture, engineers, mosquito control personnel, ranchers and farmers, outdoor and recreation interests, teachers, students, and neighbors in the community.

CoCoRaHS has several goals: 1) to provide accurate high-quality precipitation data on a timely basis; 2) to increase the density of precipitation data available by encouraging volunteer weather observing; 3) to encourage citizens to have fun participating in meteorological science and heightening their awareness about weather; and 4) to provide enrichment activities in water and weather resources for teachers, educators and the community at-large. For its detailed mission statement, visit the link in the reference section (CoCoRaHS website 2018). Most importantly, this is a community project. The only requirements are that one have an enthusiasm for watching and reporting weather conditions, a desire to learn more about how weather can affect and impact our lives, and a good place to measure rainfall. By providing daily observations, one can help to fill in a piece of the weather puzzle that affects many across Texas. By using low-cost measurement tools, stressing training and education, and using an interactive website, the network's aim is to provide the highest quality data for natural resource, education and research applications, which can greatly aid flood forecasts and radar corrections. Both the National Oceanic and Atmospheric Administration (NOAA) and the National Science Foundation (NSF) are primary sponsors of CoCoRaHS. Other organizations have contributed financially and/or with supplies and equipment. The list of sponsors continues to grow. Many other organizations and individuals have contributed time and resources to help keep the network running.

COCORAHS OBSERVATIONS AT WGRFC

Hydrometeorologists at WGRFC continuously monitor rainfall over their area of responsibility. As stated in Story (2016), the NWS uses rainfall estimates from multiple sources, but primarily from radars, in generating river forecasts. Precipitation estimates from the more than 24 WSR-88D radars with observations within the WGRFC area have allowed for better analysis of timing and areal distribution of precipitation. These rainfall estimates are adjusted based on comparisons to rain gauge data from all sources. These "best estimates" are used in NWS river forecasts models. Now, hundreds of 24-hour CoCoRaHS rainfall reports are available for post-analysis of this best estimate. Direct comparisons of the estimates and observer rainfall totals are made shortly after 1200 Coordinated Universal Time (UTC) (7 AM Central Daylight Time) each morning. These reports allow WGRFC's hydrometeorologists to determine areas where the radar-based estimates may be too low or too high. Forecasters can adjust estimates in specific hours to reproduce a 24-hour estimate that is more consistent with 24-hour gauge reports. The goal is to achieve a "general" level of acceptable error in the estimates. Computations are performed that show the correlation coefficient and percent bias of radar estimates, which vary by time and location. The goal is to modify the estimates to achieve minimum correlation coefficients (r) of 0.85 (an arbitrary in-house goal). Originally, most initial estimates are biased low (e.g. the 24-hour gauge reports are higher) and frequently have poor correlation. When initial radar-based estimates are linearly adjusted, which are spatially variable, the inherent error of most estimates is improved to the desired correlation ($r > 0.85$). Removal of this bias is crucial to improve flood forecasts. If these biases are not mitigated, a false identification of a flood wave that is too low might occur over time. An example of the WGRFC Gauge Check program is shown in Figure 1.

There are two types of CoCoRaHS reports used at the WGRFC. First, CoCoRaHS spotters can submit intense rainfall reports whenever the situation warrants. These reports are invaluable to forecasters, so much so that we have these reports trigger an "alarm" on our NWS workstations. Any observer can make a significant weather report. An example of the form an observer fills out on the CoCoRaHS website is shown in Figure 2.

An example of an intense rainfall report from Hurricane Harvey is shown in Figure 3.

Such reports are often a preemptive warning that rainfall may be occurring or even exceeding remotely sensed data from radar. It also allows WGRFC forecasters to adjust hourly estimates in near real time, improving flood forecasts.
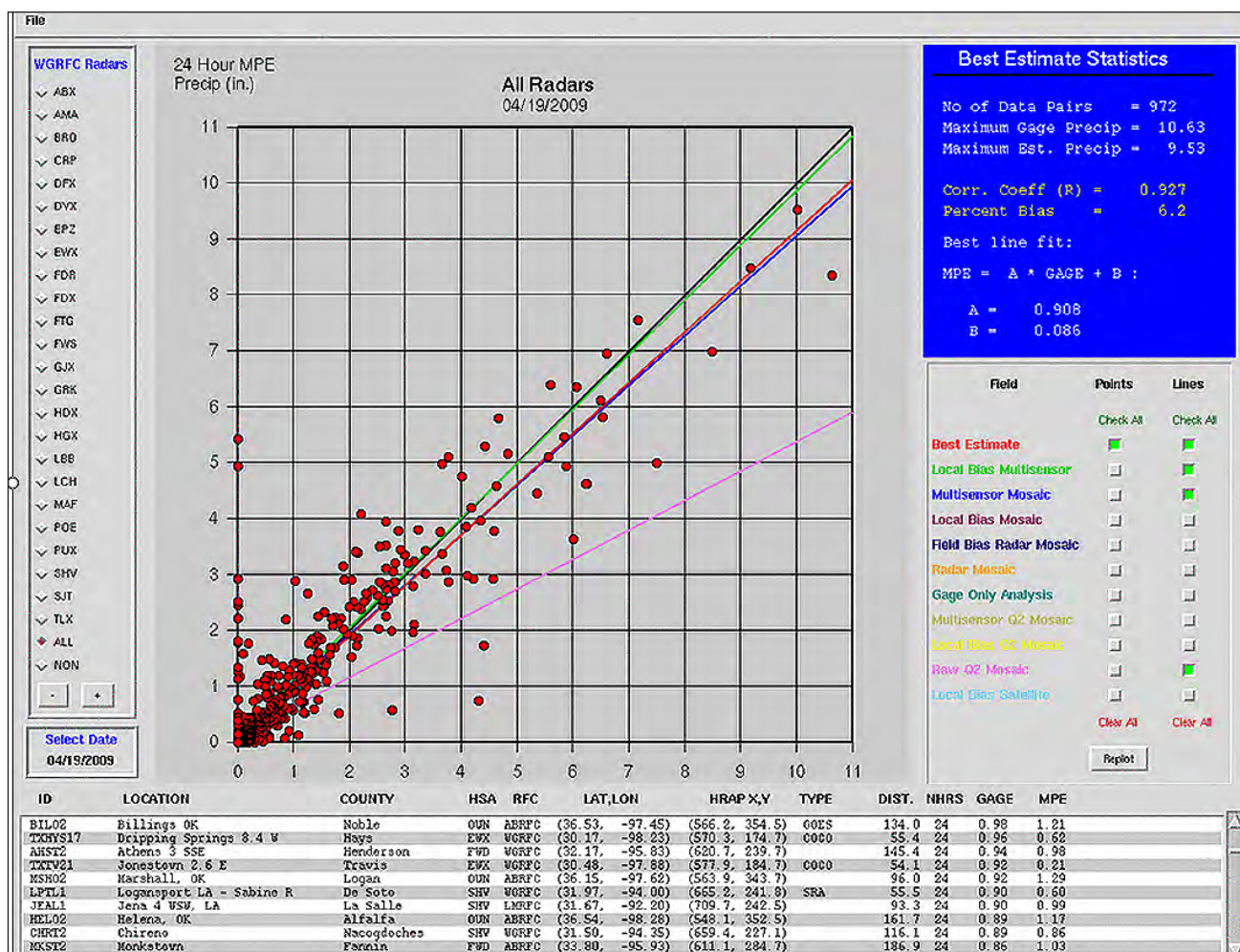
Figure 1. The Gauge Check Program used at WGRFC. Rain gauge values for the 24-hour period ending as 12 UTC (x-axis) are plotted against the associated Multisensor Precipitation Estimate (MPE) best estimate of precipitation (y-axis) at the location of that gauge. Values above the diagonal black line show an MPE overestimate, while values below indicate an underestimate. Colored lines show the calculation of MPE versus gauges for each radar-based field within MPE, with the red line being the final best estimate. The observations show a good correlation (R = 0.927) to radar estimates but is biased low by 6.2%. The MPE radar data are linearly adjusted to best match gauge data.

Second, the 24-hour CoCoRaHS rainfall measurements are ingested at the WGRFC through the morning, which are then compared to radar-based estimates (along with rain gauge observations from other sources). The CoCoRaHS rain gauge data are considered to be ground truth and one of the most readily available best data sources for radar corrections. Figure 4 shows an example from 2012 when CoCoRaHS reports from Ellis County helped improve a flood forecast:

In this example, the CoCoRaHS observer, who was located 0.6 of a mile west-southwest of Maypearl, gave us a rainfall reading of 4.51 inches. Our initial "best estimate" for that location was 2.60 inches, or about ½ the amount that fell. We went back to the hours it rained in this location and increased the radar-based estimates. This allowed us to match the CoCoRaHS amount in real time. This led to more runoff being calculated within our hydrologic model and produced a forecast hydrograph with higher runoff volumes than was originally produced. A small flood wave occurred on Chambers Creek that may have gone unforecasted had the CoCoRaHS gauge not shown the larger rainfall totals.

All 24-hour rainfall observations received from all sources, including the CoCoRaHS observations, are available each morning around 10 AM at: https://forecast.weather.gov/product.php?site=NWS&product=HYD&issuedby=FWR

This list can be used to compare all the rainfall readings in the WGRFC region.

Figure 2. The significant weather report form for CoCoRaHS observers. This form can be used to report rainfall or snowfall of a short duration.

Figure 3. An intense weather report from a CoCoRaHS observer during Hurricane Harvey reporting over 15 inches of precipitation and 0.28 inches in the last hour as received on a WGRFC text workstation.
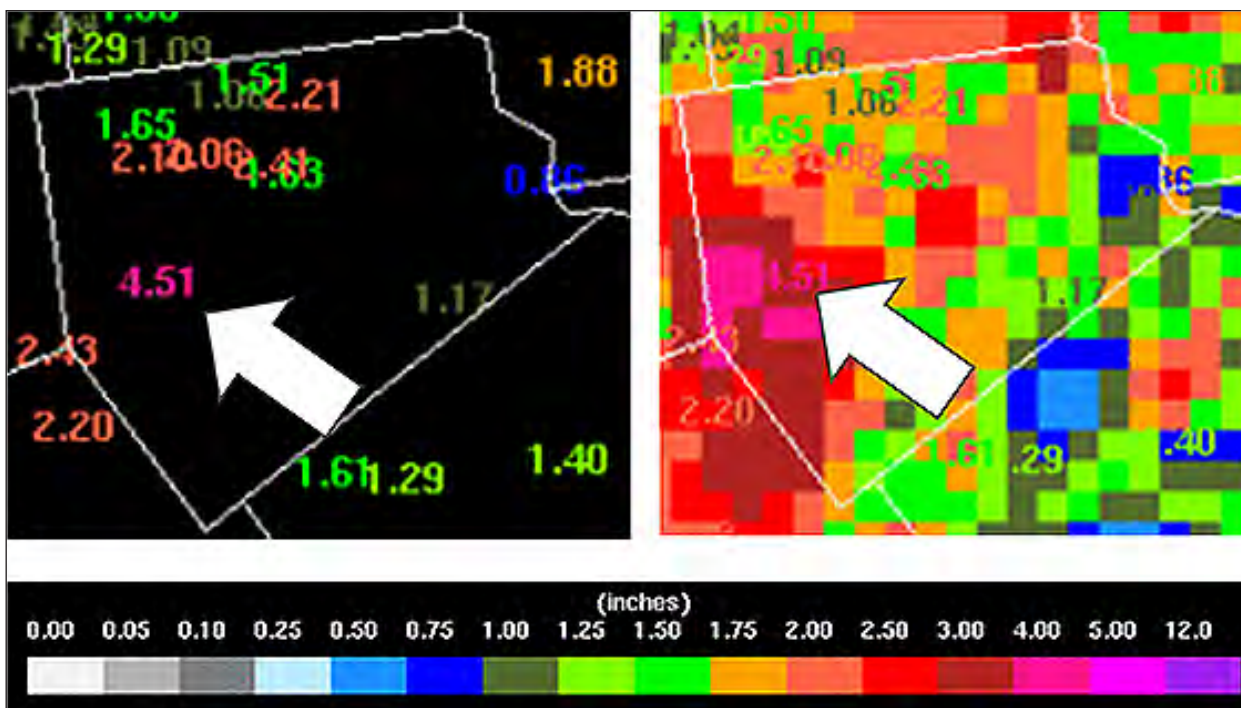
Figure 4. (Left) Location of CoCoRaHS gauge where initial underestimation was determined. Gauge values match the color scale. (Right) MPE final precipitation analysis with CoCoRaHS data overlaid after an adjustment was made to the 24-hour field. The arrow indicates where estimates were increased near Maypearl, Texas. The goal is to have the color of the MPE precipitation field match the color of the gauge reading.

EXAMPLES FROM HURRICANE HARVEY

Hurricane Harvey was the first major hurricane to make landfall in the United States since Wilma in 2005. The storm produced catastrophic impacts over southeast Texas and southwest Louisiana. Harvey made landfall near Rockport, Texas as a Category 4 hurricane. In a four-day period, many areas received more than 40 inches of rain as the cyclone meandered over southeast Texas and adjacent waters, with peak accumulations of over 60 inches (Blake and Zelinsky 2018). Hurricane Harvey produced the most rain on record for a tropical storm or other weather event in the contiguous United States. For more information, see the NWS Service Assessment on Harvey (NWS 2018), and see a scientific investigation report from the U.S. Geological Survey (USGS 2018).

Rainfall estimation from tropical systems is quite challenging. All sources of remote sensing have limitations during excessive rains and high winds. For an explanation of the reasons for these challenges, see Story (2012). Figure 5 shows Hurricane Harvey on the evening of August 25, 2017.

In the 24-hour period ending at 12 UTC on August 26, heavy rain from Harvey fell as it moved over parts of south central and southeast Texas. Figure 6 shows the CoCoRaHS reports, which were received just after 12 UTC.

The initial radar estimates ranged from 4 to 8 inches. However, the CoCoRaHS 24-hour readings had several contributors reporting 8.00 to 9.60 inches. The WGRFC initial estimates were too low, and these observations led us to increase final estimates. The final rainfall estimate from WGRFC software is shown in Figure 7:

The next day, for the 24-hour period ending at 12 UTC on August 27, we saw even larger underestimations. We initially estimated 8 to 13 inches of rain over southeast Texas, but the CoCoRaHS reports were much higher. The CoCoRaHS reports are shown in Figure 8 from day 2 of Hurricane Harvey and Figure 9 shows this graphically.
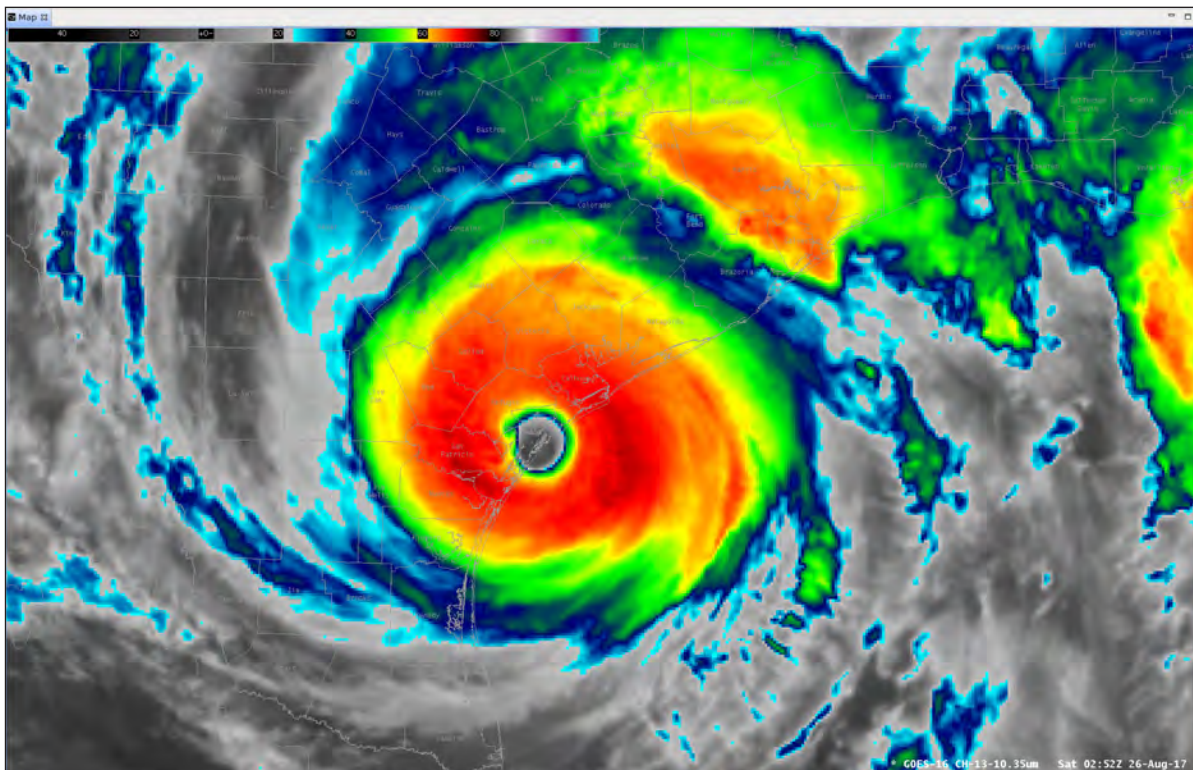
Figure 5. Hurricane Harvey at landfall as seen from GOES 16 satellite. The eye of Harvey is making landfall. The bright red colors around the eye indicate the eye wall and can be indicative of high rainfall rates.

LID		GAGE	MPE	LOCATION
TXFB17	:	9.60	8.63	Richmond 3.4 NE
TXGD15	:	8.92	5.35	Weser 1.9 NW
TXFB18	:	8.69	8.63	Richmond 2.9 NE
TXFB05	:	8.22	6.80	Sugar Land 3 SSE
TXFB12	:	7.61	6.74	Sugar Land 1 W
TXWH18	:	7.60	9.67	East Bernard 7.6 S
TXCLR10	:	7.50	4.99	New Ulm 5.1 S
TXCLR06	:	7.45	5.90	New Ulm 7.2 S
TXFB51	:	7.45	8.20	Richmond 4.4 NNE
TXDW19	:	7.41	5.31	Cuero 8.4 S

Figure 6. This table shows the ten highest August 26 CoCoRaHS reports. Alongside the gauge ID is the observed amount and our initial MPE estimate for that location.
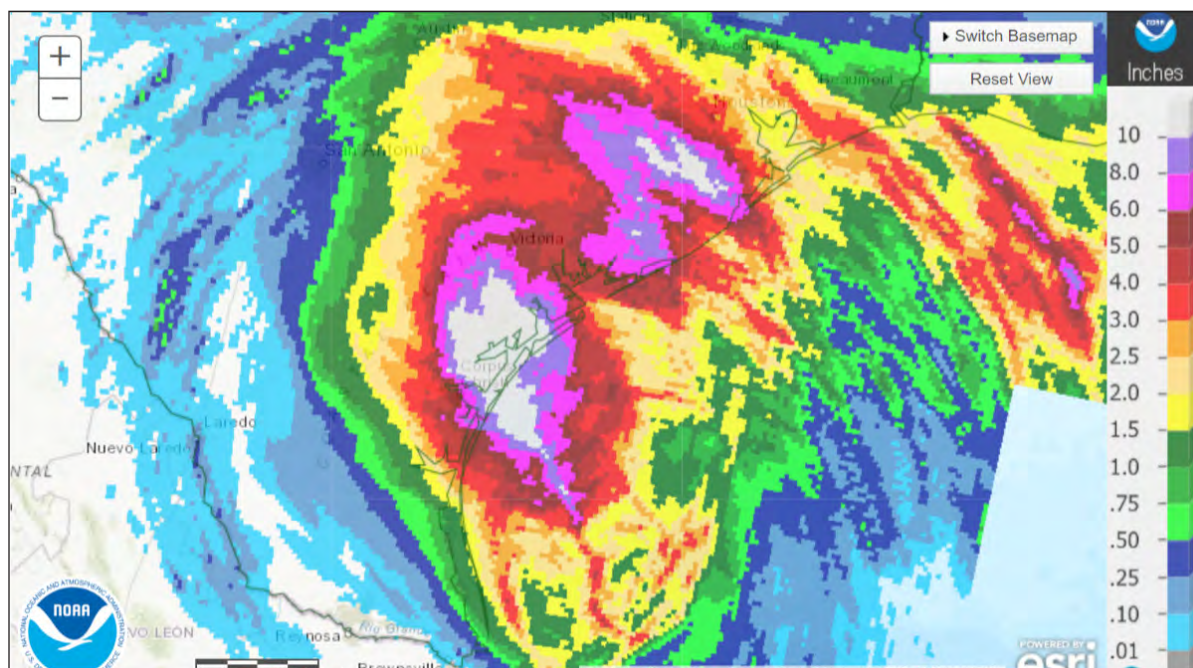
Figure 7. WGRFC best estimate of rainfall from the first day of Hurricane Harvey, 26 August 2017.

Again, since we were too low in our initial estimates, we increased them. This meant that increased flood volumes were forecasted. That resulted in many crest projections exceeding the major category (where extensive inundation of structures and roads occurs, with significant evacuations of people and property) or record category (where a river at a set forecast point had never been higher historically). Figure 10 shows our final estimate field from MPE after this increase.

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LID                 GAGE      MPE     LOCATION
TXGV44        :     21.62    12.90    Bacliff 0.5 SSE
TXHRR32       :     20.84    12.90    South Houston 4 SSW
TXHRR93       :     20.54    12.90    Pasadena 4.4 WNW
TXHRR31       :     19.41    12.90    Friendswood 2.5 NNE
TXGV60        :     19.38    12.90    Santa Fe 0.7 S
TXGV64        :     18.20    12.90    Hitchcock 1.6 NNW
TXHRR139      :     17.98    12.90    Cloverleaf 1.7 W
TXGV51        :     17.57     8.74    La Marque 1.8 E
TXHRR28       :     17.00    12.90    Webster 0.4 NW
TXGV63        :     16.59    12.90    Friendswood 1 SE
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Figure 8. This table shows the 10 highest CoCoRaHS reports ending 12 UTC 27 August 2017. The data indicate five readings in excess of 19.25 inches that correspond to initial MPE estimates of just under 13 inches over parts of Harris and Galveston counties in southeast Texas.[1]

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[1]The reason for the 12.90" matching so many gauges is two-fold. All have to do with the multisensor approach in MPE itself. MPE uses the Hydrologic Rainfall Analysis Project (HRAP) grid array. One HRAP grid is roughly 4 square kilometers. MPE arrives at just one value for an entire grid. You can have multiple CoCoRaHS gauge readings located in the same HRAP grid. That happens to be the case with a few of the gauges in Figure 8. Also, the HRAP grid value is derived from an hourly rain gauge if there is an hourly gauge located in that grid. Gauge values in the multisensor analyses actually have a sphere of influence, which is larger than one grid size, thus gauge readings can bleed over into other surrounding grids. Therefore, multiple grids can have the same value in a general location.
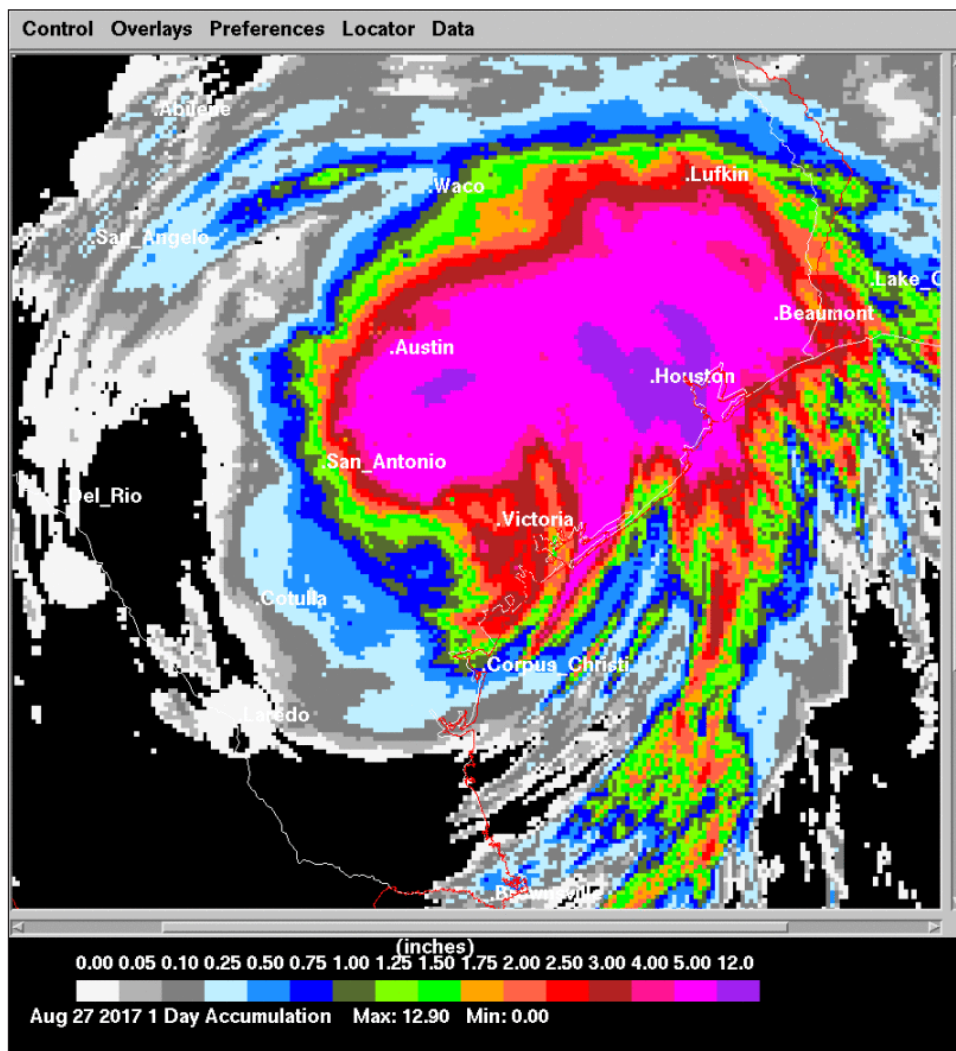
Figure 9. This was the initial estimate of rainfall from day two of Hurricane Harvey from WGRFC multisensor software.
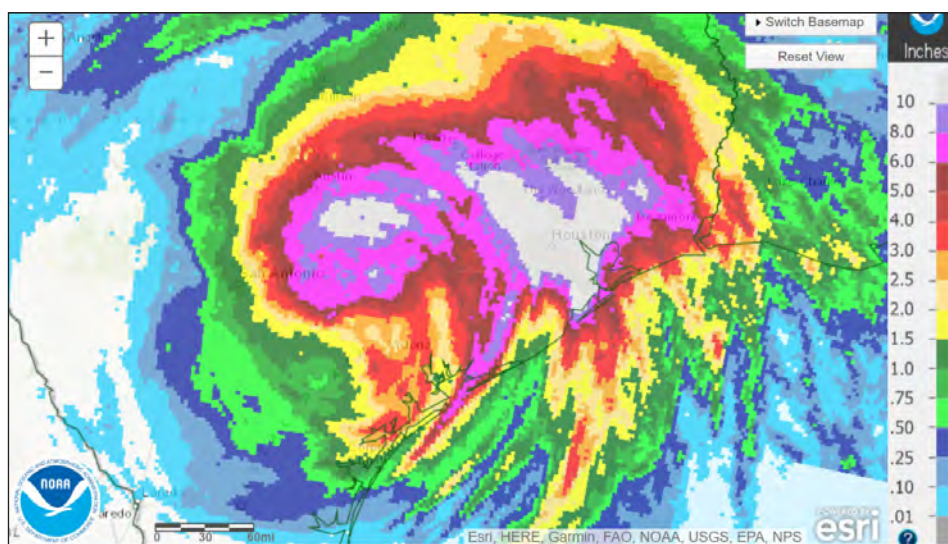

Figure 10. The final best estimate field from 12 UTC 27 August 2017. Note the sizable increase in the areal coverage of the heaviest rainfall over the initial estimates in Figure 9.
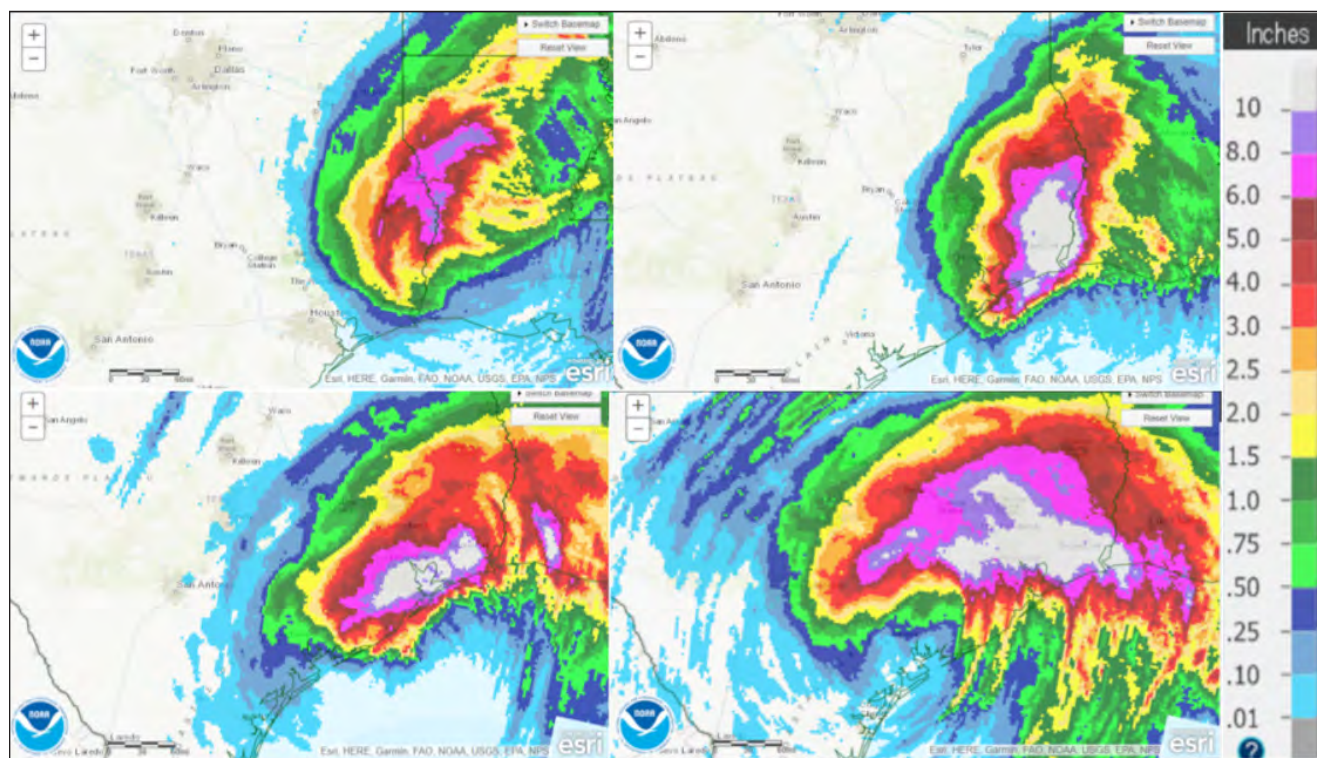
Figure 11. Final rainfall estimates. (Lower Right) August 28. The CoCoRaHS rain gauge data showed a maximum of 18.35 inches near Katy and a dozen observations in excess of 13.25 inches. The initial maximum MPE estimate was 12.90 inches, thus MPE showed severe underestimation and was adjusted higher. (Lower Left) August 29. CoCoRaHS rainfall readings showed a maximum rainfall of nearly 15 inches northeast of Friendswood, with ten observations in excess of 13 inches. Initial MPE rainfall estimates were in excess of 12 inches from south of Houston to near Beaumont/Port Arthur, showing the underestimation from radar-based MPE was not quite as severe. (Upper Right) August 30. CoCoRaHS rainfall readings indicated a maximum rainfall of over 15 inches about 5 miles south of Beaumont, with six observations in excess of 10.50 inches. The initial MPE estimates around 12 inches over extreme southeast Texas centered on Beaumont were too low and were adjusted upward for the final analysis. (Upper Left) August 31. CoCoRaHS rainfall readings confirmed the heaviest rainfall in excess of 7 inches had shifted into Sabine Parish, Louisiana. The initial MPE estimates were much closer as the rain rates decreased and shifted into western Louisiana, thus only limited adjustment upward was necessary for the final analysis.

Based on the CoCoRaHS observations, the initial MPE estimates were too low for the remainder of the Harvey rain event. The final daily rainfall for Harvey from August 28–31 are shown in Figure 11.

In the end, approximately 90% (60 out of the 67) of NWS river forecast locations in southeast Texas reached flood stage. Approximately 69% (46 out of the 67) reached major flood stage and approximately 46% (31 out of the 67) set flood records. The NWS issued more than 300 flood-related warnings at official river forecast points where USGS stream gauges measure flow volumes, out of 330 in the WGRFC area of responsibility (NWS 2018). The CoCoRaHS observations helped improve the NWS lead time on the magnitude of flooding. With initial estimates biased low, adjustments were made in real time to radar precipitation totals. These CoCoRaHS readings contribute greatly to the NWS WGRFC's mission of saving lives and property from floods here in Texas. Quite often the majority of the highest ten rainfall readings in the state on any given day come from CoCoRaHS observers. Figure 12

shows the gauge-corrected totals using CoCoRaHS and other data sources that gave the WGRFC its best estimate of rainfall from Hurricane Harvey.

CONCLUSION

CoCoRaHS is a volunteer, community-based organization that always needs more observers. The more reporting observers, the better the chances that the WGRFC can match the magnitude of rainfall. Even a daily report of no rainfall is useful information, as the final precipitation estimates that are computed also go into the state and national Drought Monitor maps each week (see http://droughtmonitor.unl.edu/CurrentMap.aspx).

To become a volunteer, you may follow these simple steps:

1. Read through the website and see what the project is about (https://www.cocorahs.org/). The website has information on "How To Measure Precipitation," "How To Measure Snow,"
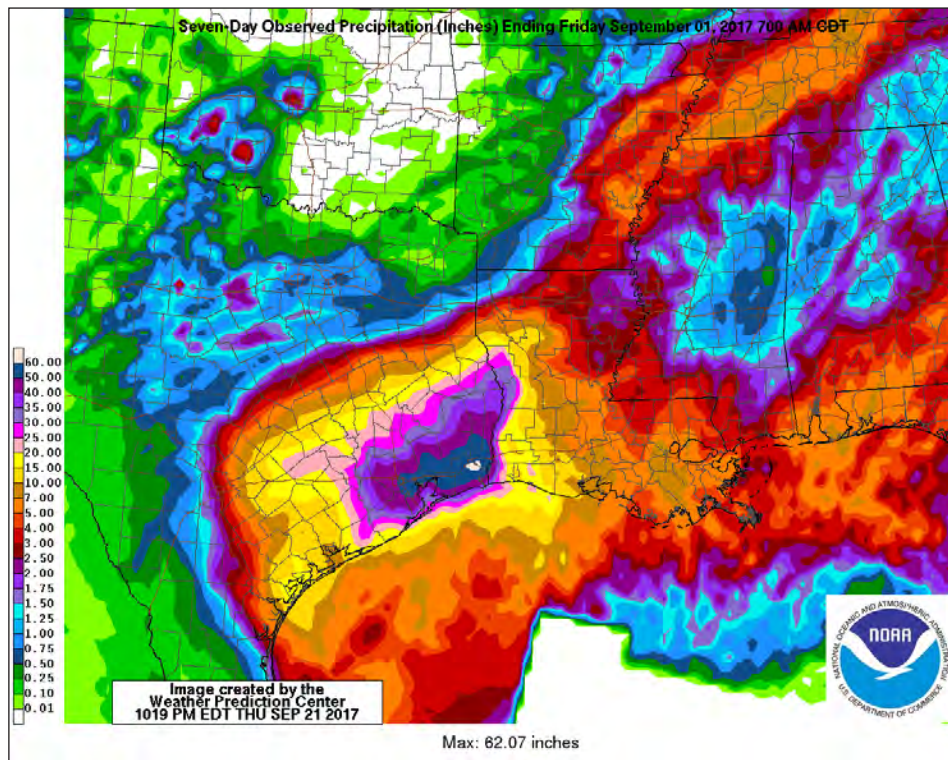
Figure 12. Total accumulated rainfall from Tropical System Harvey. Note the 62-inch final maximum total near Beaumont/Port Arthur.

and "How To Measure Hail" as well as information on the equipment used.

2. Make sure you have a rain gauge. You may purchase an official rain gauge from the link on the CoCoRaHS website for approximately $31.50 (see www.weatheryourway.com/coco-rahs). They are excellent gauges that measure in hundredths of an inch. It is asked that your rain gauge be a 4" diameter all-weather gauge or better.

3. Go to our "Join CoCoRaHS" web page and sign up (https://www.cocorahs.org/application.aspx).

4. Either attend a training session for volunteers in person, or view the "Training Slide Show" found on the CoCoRaHS home page. It is very beneficial to read through the website on-line training materials completely. It is important to know how CoCoRaHS observers make and report their measurements. Good training along with careful observing and reporting are very important to the network and the users of the data.

5. Contact CoCoRaHS with any questions that you may have. Coordinators are available at the state and regional levels as a resource to assist you in getting started. Texas coordinator contact information can be found at: https://www.cocorahs.org/Content.aspx?page=coord_tx

6. Report your data daily on the website (www.cocorahs.org/Login.aspx) or use the CoCoRaHS smart phone application (Apple or Android). If you are unable to report on the internet, you may obtain CoCoRaHS Precipitation measurement forms from CoCoRaHS headquarters (or you may print your own from the website) and mail them.

We look forward to receiving many new observers in the future.

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