# **Cross-evaluate Precipitation Errors in Extreme Events using Triple Collocation**

## ABSTRACT

## INTRODUCTION

Extreme weather conditions

Extreme rainfall events associated with flash flood, landslide are resulting in tremendous damages including properties, casualties etc. According to (references), extreme weather condition tends to intensify and frequent including droughts, floods, hurricanes. Hurricane/cyclone storms is one of the typical excessive rainfall producer because it carries water moisture from costal towards inland. Hurricane Harvey is termed as category 4 hurricane that made landfall on Texas and impacted Louisiana, Oklahoma with flooding and deaths in August 2017. With data delivered by Texas state (Emanuel 2017), it produced the largest rainfall of hurricane in the recorded history of the US, and caused at least 70 casualties, economic damages above 150 million(Emanuel 2017, Omranian, Sharif et al. 2018). More recently, tropical cyclone Imeda made a landfall in Texas on 17, September, with similar track as Harvey. It produced 1096 mm total amount of rainfall in Texas, which is ranked as 4th in the history (contributors). Damages in Texas were reported to be beyond $3 million in this disaster while $1 billion over whole country(News 2019).

Data Uncertainties

Traditionally, rainfall rate was captured by gauges as a direct measurement but only in point scale. Even though gauge data are often treated as reference, it is still not impeccable as it suffers from tipping mechanisms, wind-catching, and evaporations (Molini, Lanza et al. 2005). Especially in heavy rain events, (Berlamont 2001, Molini, Lanza et al. 2005) demonstrated the error caused by these factors is not negligible.

Recently, with the emerging of radar technology since world war two, it has been applied in measuring rain rate by emitting and receiving electromagnetic signals. The advantage of radar over gauge is that radar provides a more refined spatial temporal scale and larger area coverage (He, Sonnenborg et al. 2013). Radar data uncertainties can be categorized as incorrect calibration, sampling representativeness, non-weather echo and errors in Z-R relation. These intrinsic properties are challenging to correct for radar-only products. Thus, many researchers tend to couple radar with gauges and satellite to improve the radar performance.

Another commonly used data source for retrieving precipitation is satellite since 1970s (ref) attributing to the advantage of global coverage. satellite data utilizes the combination of near-infrared (NIR) imagery, infrared (IR) and passive/active microwaves (AMW/PMW). With analogy to radar product, satellite rainfall retrieval is again the indirect measurement of rainfall. Thus, even though lots of efforts have been taken to infer rain rate with improving accuracy, it is ill-posed problem since we lack of reference especially in extreme events. (Hong, Hsu et al. 2006) demonstrated satellite performance decreased with the increase of rain rate but more relative errors shown in light rain conditions.

Given this context that no either source of product can be trustable, researchers performed some stochastic approach to analyze these uncertainties with these data sources (Tian and Peters-Lidard 2010). Triple Collocation (TC) has been proven to be a powerful statistical approach to extract errors with each product (Stoffelen 1998, McColl, Vogelzang et al. 2014, Massari, Crow et al. 2017, Li, Tang et al. 2018). The concept behind is that three independent products are digested and to estimate relative error without knowing the “truth”. TC was firstly applied to evaluate ocean surface wind variability by inputting different products (Stoffelen 1998). Thereafter, it has been extended to measure errors of sea surface temperature (Gentemann 2014), sea surface salinity, wave height, leaf area index and soil moisture. (Roebeling, Wolters et al. 2012) was the first to incorporate TC with hydrology by incorporating remote sensing, weather radar and rain gauges in Europe. (Massari, Crow et al. 2017) compared performance of five satellite data for collecting rainfall over US, and extended the correlation performance towards globe by the use of correlation coefficient. (Alemohammad, McColl et al. 2015) introduced multiplicative triple collocation method (MTC), suggesting its appropriateness in rainfall error evaluation and decomposed the error term in order to investigate the violation of assumptions. (Li, Tang et al. 2018) used TC to perform uncertainty analysis over ungauged regions Tibetan in China. To the best of our knowledge, rare attention has been drawn to extreme events associated with aforementioned uncertainties. Our overarching objectives are three-folds:

1. Compare differences and performance of three independent products during multiple events.

2. Perform uncertainty estimation over multiple extreme events with special emphasis on hurricane Harvey.

3. Evaluate the applicability of TC during extreme events.

We organize this article into four sections: section 1 will introduce the study domain and briefly review the three datasets been used in this study. Section 2 will describe in detail the formula to derive differences. Section 3 and 4 will follow up with performed results and conclusion from this study. The structure of showing results will follow an overall to detail structure, which firstly concatenate all extreme events and then separate Harvey out to scrutinize the differences.

## STUDY AREA and DATASET

### Study domain

The area we are focusing on in Southern America is where endures several events recently and also one of the most frequently impacted areas by hurricanes, tropical cyclones, experienced huge disaster like hurricane Harvey, and storms e.g. Imeda, Bill, Cindy. (Figure 1) illustrates the relative location of the domain, containing state of Texas, Oklahoma, Louisiana, Arkansas, Tennessee, Mississippi and Alabama. Hurricane/Storm tracks including Harvey (2017), Bill (2015), Cindy (2017) and Imeda (2019) are also shown up in (Figure 1), and these events share the similar tracks, starting from Gulf of Mexico and bending towards North West except for Imeda which was dissipated in the region of Texas. (Figure 1) also depicted the accumulative rainfall derived from MRMS (Multi-Radar Multi-Sensor) products.

### Dataset descriptions

Because of the requirement of independence, three products injected to TC should not be coupled or integrated. Hence, we chose National Centers for Environmental Prediction (NCEP) gridded gauge only hourly data, Multi-Radar Multi-Sensors (MRMS) radar only data, and Integrated Multi-satellitE Retrievals for GPM (IMERG) data for evaluation.

#### NCEP gridded gauge only product

NCEP gridded gauge only product is an operational product (Lin 2011) covering the US and part of Puerto Rico. It is automatically derived from approximately 3000 hourly raingauge observations across 48 states to produce 4km/hour rainfall field. The interpolation techniques behind are described by (Seo 1998), which introduced Double Optimal estimation (DO) and Single Optimal estimation (SO) to gain conditional expectation of estimation.

#### MRMS radar only product

MRMS has around 180 integrated operational radars including 146 S-band and 30 C-band radar, and created seamless 3D radar mosaic across the conterminous United States (CONUS) and Southern Canada at 1km spatial resolution and 2-min temporal resolution (Zhang, Howard et al. 2016). It produces both radar based QPE and radar gauge calibrated QPE to improve performance. For our study, 1km/2min radar based QPE are retrieved and processed to upscale by average and aggregated to 4km/hourly to be comparable with NCEP gauge only data.

#### IMERG satellite product

IMERG satellite precipitation product (Huffman 2019) is integrated from its core satellite (GPM), microwave constellations, Infrared constellations and additional constellations, aiming at providing global coverage of rainfall field beyond its predecessor Tropical Rainfall Measurement Mission (TRMM). It produces three stages: early run, late run and final run with 4 hours latency, 12 hours latency and 3 months latency respectively at a half-hour and 0.1-degree scale. Early run provides near real-time brief observations with inter-calibrated satellite products, and late run adds up the climatological calibration. Final run compares late run product with global quality controlled gauge data, and adjust the factor to compensate for under/over-estimation. To account for independency, final run without calibration/late run with calibration is utilized in this study. In order to perform pixel-wise analysis, IMERG data needs to be downscaled by nearest neighbor and then accumulate to 1 hour.

## METHODOLOGY

## RESULTS

### Overall behaving

### Harvey and non-Harvey

### Detailed Harvey Analysis

## CONCLUSIONS

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