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# Validating NEXRAD MPE and Stage III precipitation products for uniform rainfall on the Upper Guadalupe River Basin of the Texas Hill Country

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**Summary** This study examines the performance of the Next Generation Weather Radar (NEXRAD) Multisensor Precipitation Estimator (MPE) and Stage III precipitation products, using a high-density rain gauge network located on the Upper Guadalupe River Basin of the Texas Hill Country. As point-area representativeness error of gauge rainfall is a major concern in assessment of radar rainfall estimation, this study develops a new method to automatically select uniform rainfall events based on coefficient of variation criterion of 3 by 3 radar cells. Only gauge observations of those uniform rainfall events are used as ground truth to evaluate radar rainfall estimation. This study proposes a new parameter probability of rain detection (POD) instead of the conditional probability of rain detection (CPOD) commonly used in previous studies to assess the capability that a radar or gauge detects rainfall. Results suggest that: (1) gauge observations of uniform rainfall better represent ground truth of a $4 \times 4\ \mathrm{km}^2$ radar cell than non-uniform rainfall; (2) the MPE has higher capability of rain detection than either gauge-only or Stage III; (3) the MPE has much higher linear correlation and lower mean relative difference with gauge measurements than the Stage III does; (4) the Stage III tends to overestimate precipitation (20%), but the MPE tends to underestimate (7%).


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## Introduction

Precipitation, characterized by high spatial and temporal variation, is one of critical inputs for hydrological modeling. It is also an important factor influencing agriculture, water resources and ecosystems. Accurate measurements of precipitation are very important for all rainfall-related applications. Traditionally, rain gauges physically measure rainfall accumulation at a point ($\sim$324 $cm^2$) and generally provide good quality data for a small area. These point measurements of precipitation have been used in all kinds of hydrological models (Jayakrishnan et al., 2004). Problems with gauge rainfall measurements were documented in several studies (e.g., Legates and DeLiberty, 1993). Another problem with rain gauge networks is that they are subject to degraded levels of accuracy with increased rainfall intensities such as those associated with flood producing storms. In general, rain gauge networks are not capable of detecting precipitation at the resolution and extent necessary for most hydrometeorology application. Errors caused by inadequate gauge representation of precipitation fields are typically amplified in runoff predictions (e.g., Finnerty et al., 1997).

Weather radar measurements of precipitation, which provide precipitation data with much higher spatial resolution compared to rain gauges, have served meteorology for over 40 years and hydrology around 20 years (Krajewski and Smith, 2002). The installation of the Next Generation Weather Radar (NEXRAD) system across the United States in the early to mid 1990s by National Weather Service (NWS), which includes more than 160 WSR-88D (Weather Surveillance Radar-1988 Doppler) radars, has revolutionized the NWS forecast and warning programs through improved detection of severe wind, rainfall, hail, and tornadoes (Fulton, 2002). NEXRAD rainfall products in the river forecast centers have four stages (I—IV) according to the sequentially increasing amount of preprocessing, calibration, and quality control performed (Fulton, 2002; Jayakrishnan et al., 2004; Xie et al., 2006). The radar Stage III precipitation products are hourly accumulation and have a spatial resolution of 4 km by 4 km with Hydrologic Rainfall Analysis Project (HRAP) after being calibrated with gauge observation and combined individual radar observations to cover an entire river forecast center.

The Multisensor Precipitation Estimator (MPE), developed by the NWS Office of Hydrology in March 2000, is a product that merges rainfall measurements from rain gauges, and rainfall estimates from NEXRAD and Geostationary Operational Environmental Satellite (GOES) products. The NWS West Gulf River Forecast Center (WGRFC) switched from Stage III to MPE as the preferred precipitation estimation program in October 2003, and ended Stage III in December, 2004. Thus, since January 1, 2005, only MPE has been produced and distributed by the WGRFC (Greg Story, personal communication, April 2005).

In spite of better spatial representation of rainfall variability by radar compared with rain gauge networks, there are limitations of radar estimates due to data contamination and uncertainty issues (Smith et al., 1996; Legates, 2000; Xie et al., 2006). In particular, radar rainfall overestimation is caused by the presence of hail, large raindrops, or melting; underestimation occurs due to small raindrops, dry ice, attenuation, truncation error, and beam blockage. Minimizing these errors has been one of the major tasks in radar meteorology for decades (Schmid and Wuest, 2005).

Many approaches have been developed to validate NEXRAD rainfall using rain gauge data (Xie et al., 2006; Habib et al., 2004; Jayakrishnan et al., 2004; Ciach et al., 2003; Habib and Krajewski, 2002; Ciach and Krajewski, 1999a). In the course of validation for different rainfall measurements, time-space ambiguities and sampling volume difference are major causes for the difference between different instruments (Ciach and Krajewsk, 1999b). The impact of the rain gauge representativeness error on the radar—gauge difference can be as large as 50—80% for instantaneous and hourly rainfall at a grid size of 3 km by 3 km (Kitchen and Blackall, 1992). Thus, a critical issue is how to get a measurement representing areal rainfall within a radar cell. The most accurate method is to use a very high-density rain gauge network (4—10 gauges) within each radar cell (Habib et al., 2004; Ciach et al., 2003; Habib and Krajewski, 2002; Ciach and Krajewski, 1999a). However, this can be costly in terms of equipment and labor to maintain and implement.

As suggested by Gage et al. (1999) that uniform rainfall, like light widespread stratiform rain, would minimize the time-space ambiguities and sampling volume difference between different instruments, thus is preferred for calibration purpose. In this study, the assumption is that hourly point rain gauge measurement could represent areal rainfall within a radar cell only for spatially uniform rainfall events, and that the point-area error can be best mitigated in uniform rainfall events. For rainfall events with high spatial variability, point rain gauge measurements cannot be directly assumed to be representative of conditions across a radar grid cell. However, they can be used to some extent to assess the spatial uncertainty (i.e., as representing a single realization from a grid cell probability density function) and the difference of probability of rain detection between radar and gauge. To test the assumption, this study develops algorithms to (1) select spatially uniform rainfall events based on hourly radar rainfall measurements and (2) use geospatial statistics to quantify the rainfall difference between gauge network and radar for those uniform events. To the best of our knowledge, this is the first time that the MPE product is quantitatively evaluated for its performance in a period of a full year (2004). The same rain gauge network is also used for validating the Stage III product for 2001. The quality of MPE and Stage III can thus be indirectly compared.

## Study area

The selected study area was determined by the availability of high-density rain gauge data. The area lies in the Hill Country of central Texas, covering the Upper Guadalupe River Basin and partly intersecting the recharge zone of the Edwards Aquifer (Fig. 1). Central Texas has a high occurrence of flash flooding, especially in the rapidly growing and urbanizing corridor from San Antonio to Austin, where enhanced orographic lift along the Balcones Escarpment is co-located with the greatest elevation gradient (thus concentrating runoff and flood potential) from the Texas Coastal Plains to the Hill Country. The Edwards Aquifer is