

# High Resolution Rainfall Mapping with a Regional Network of Polarimetric Radars at S- and X-band Frequencies

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## Abstract

Since spring 2012, the Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) has been transformed from a research to operational demonstration emphasis, and has started the development of Dallas-Fort Worth (DFW) urban remote sensing network. Radar-based Quantitative Precipitation Estimation (QPE) is one of the major research activities in the deployment of this urban test bed. In this paper, the polarimetric rainfall algorithms have been investigated for the X-band CASA/XUTA radar and the local S-band KFWS radar. A demonstration QPE system fusing the data of X-band radars and the S-band radar has been developed. In order to validate and evaluate the dual-polarization radar rainfall products, 20 rain gauges operated by the City of Grand Prairie are used for cross comparison between the radar measurements and gauge observations. The QPE system evaluation results presented here show excellent performance of the rainfall products with low bias and normalized standard error.

## 1. Introduction

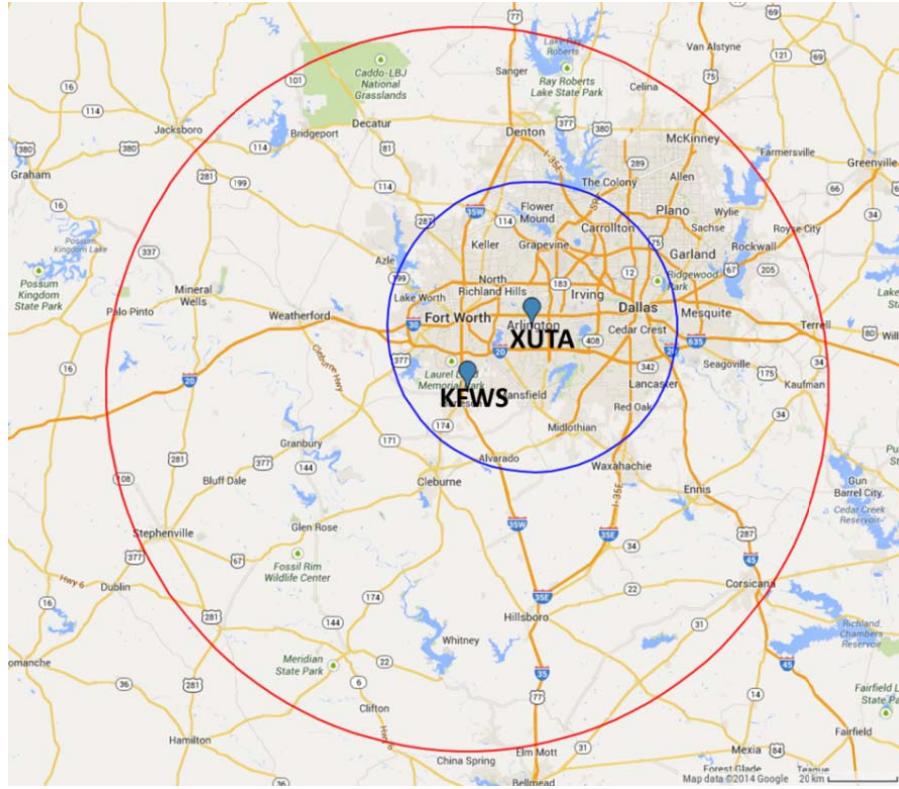
Accurate monitoring of rainfall and stream flow is critical to human life and civilizations. Numerous infrastructures have been installed to directly or indirectly measure rainfall rate and amounts such as rain gauges, meteorological satellites and radars. Among these tools, radar has shown great advantages to conduct spatially continuous observations in a large area with small temporal sampling intervals [1]. Over the past two decades, many radar networks have been deployed at a nationwide scale to track the changing atmospheric conditions, such as the United States National Weather Services (NWS) Weather Surveillance Radar - 1988 Doppler (WSR-88D) network (at S-band) and the China New Generation Weather Radar (CINRAD) network (at S- and C-band). In addition, a large number of regional radars have been installed to study the local weather phenomenon and statistical properties of precipitations, such as the X-band dual-polarization radar network developed by the U.S. National Science Foundation Engineering Research Center (NSF-ERC) for Collaborative Adaptive Sensing of the Atmosphere (CASA) and the X-band research radar network (X-NET) implemented by Japan's National Research Institute for Earth Science and Disaster Prevention (NIED).

To study and mitigate the urban weather disasters, CASA and the North Central Texas Council of Governments (NCTCOG) have been developing its first urban test bed in Dallas-Fort Worth (DFW) area. This urban remote sensing network, centered by the deployment of 8 dual-polarization X-band radars, is expected to demonstrate the operational feasibility of dense radar network in a metropolitan environment and provide weather forecasts and flash flooding warnings according to the local user needs [2]. It is also expected to be an excellent platform for quantitative precipitation estimation (QPE).

In this paper, we have developed a  $K_{dp}$ -based QPE system for the CASA/DFW X-band radars to estimate the rainfall intensity and accumulations. In addition, the local S-band WSR-88D site (i.e., KFWS radar), which has been upgraded to have dual-polarization capability since November 2012, is also used to generate the dual-polarization rainfall products. Figure 1 shows the layout of the KFWS radar and one of the CASA radars installed at University of Texas Arlington.

## 2. Dual-polarization Radar Rainfall Algorithms for DFW Network

Traditionally, radar rainfall estimators start with the radar reflectivity ( $Z$ ) and rainfall rate ( $R$ ) relationships which are also known as  $Z$ - $R$  relations. Nevertheless, a few uncertainty factors make the  $Z$ - $R$  relations imprecise to capture the rainfall variability. These uncertainty factors include partial beam blockage, radar signal attenuation at high frequencies, anomalous propagation of the electromagnetic waves, and radar system calibration errors. These uncertainties limit the capability of single polarization radar for accurate rainfall estimation. In addition, the commonly used power law relationship ( $Z = aR^b$ ) greatly relies on the rain drop size distribution (DSD), which can be very different for various climatological regions, even within a single storm. Accordingly, it is often a nontrivial task to find



**Figure 1: Layout of KFWS and CASA/XUTA radars. The XUTA coverage circle (in blue) is 40 km in radius. The KFWS coverage circle (in red) is 100 km in radius.**

an ideal  $Z$ - $R$  relation to satisfy all local meteorological phenomena. Since the introduction of dual-polarization concept, a lot of efforts have been devoted to polarimetric radar QPE [3][4]. The dual-polarization radar observations derived from the covariance matrix of polarized radar return signals offer a number of advantages over single polarization radar by gleaning more information about the DSD [5] and providing indicative characteristics for discriminating smoke from fires, birds, bats, and bugs, etc.

In this paper, we have developed a blended algorithm for rainfall rate retrieval based on the dual-polarization measurements from the KFWS WSR-88D S-band radar. This blended algorithm is based on the hydrometeor classification results that are derived from a fuzzy logic approach based upon the information of temperature and polarimetric radar moments, including  $Z$ ,  $Z_{dr}$ ,  $K_{dp}$ , and correlation coefficient  $\rho_{hv}$  [6]. The fuzzy logic technique is well suited for hydrometeor classification for the capability of identifying hydrometeor types with overlapping and noise-contaminated measurements. Nonetheless, compared to the work by [6], only three hydrometeor categories are classified for the purpose of rainfall estimation, namely, “rain”, “others”, and “mixture” of hail and rain. The hydrometeor categories are then used to guide the choice of the particular rainfall estimation algorithms.

For the CASA X-band radar, the  $R(K_{dp})$  estimator is used for QPE, which is in the form:

$$R = aK_{dp}^b \quad (1)$$

where  $a = 16.33$  and  $b = 0.8$ .

The  $R(K_{dp})$  relation is immune to attenuation, hail contamination, and calibration factors relative to the power related term such as  $Z$  and  $Z_{dr}$ , especially at higher frequency such as X-band.

### 3. QPE Validations Using Rain Gauges

In order to validate and evaluate the rainfall products, 20 rainfall gauges in the City of Grand Prairie are used for cross comparisons. Figure 2 shows the locations of the 20 gauge under the coverage of CASA/XUTA and KFWS radars. The gauge measurements are archived each time one millimeter of rainfall occurs. The CASA/XUTA rainfall products are in 1 minute temporal resolution, and 250 meters spatial resolution. To address the scale mismatch, we have used the piecewise cubic interpolation methodology to interpolate the rainfall field from KFWS radar (in 5-6 minutes

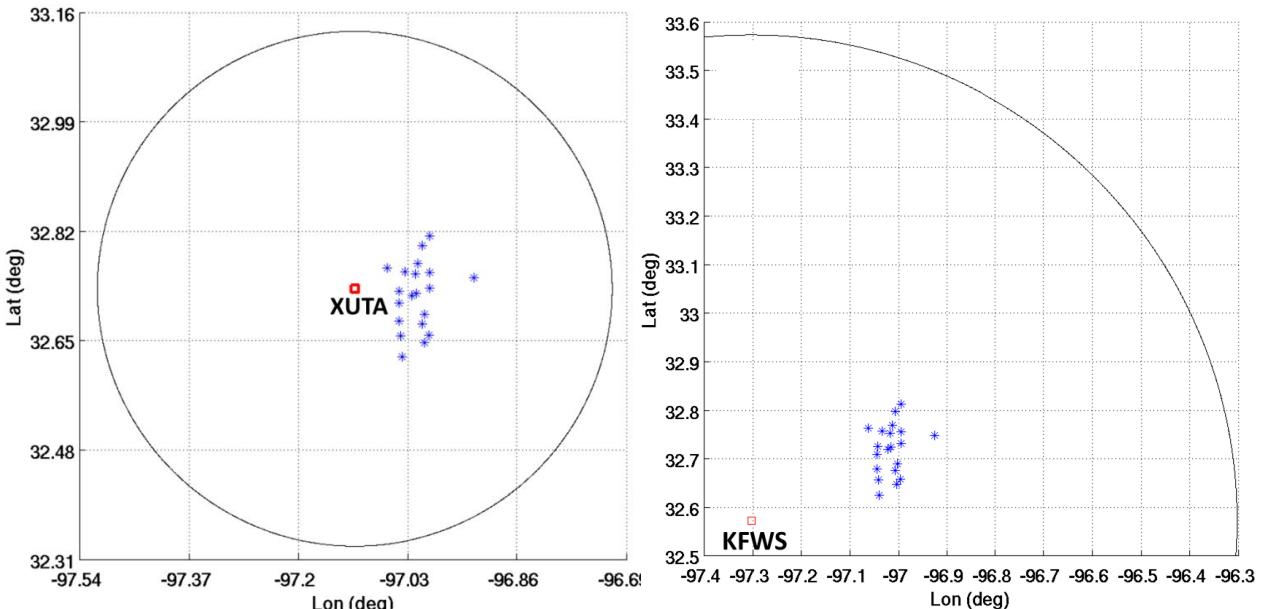
resolution) to the same temporal scale with the CASA/XUTA radar observations (i.e., 1-minute). Then, the rainfall amounts, such as the 5-minutes rainfall and 1-hour rainfall accumulations, are computed based on the interpolated results in 1-minute resolution. For comparison, we have computed the gauge rainfall accumulations in 5-minute intervals, and the radar measurements are chosen at the location of rain gauges. Assuming the gauge observations as ground truths, we have calculated a set of evaluation statistics that include the Pearson correlation coefficient (CORR), normalized bias (NB), and the normalized standard error (NSE), respectively defined as follows:

$$\text{CORR} = \frac{\sum_{n=1}^N (r_n - \bar{r})(g_n - \bar{g})}{\sqrt{\sum_{n=1}^N (r_n - \bar{r})^2 \sum_{n=1}^N (g_n - \bar{g})^2}} \quad (2)$$

$$\text{NB} = \frac{\bar{r}_n - \bar{g}_n}{\bar{g}} \quad (3)$$

$$\text{NSE} = \frac{|r_n - g_n|}{\bar{g}} \quad (4)$$

where  $r_n$  and  $g_n$  denote the radar estimate and gauge measurement of rainfall (mm) at time frame  $n$ , respectively.  $\bar{r}$  and  $\bar{g}$  stand for the averages of total  $N$  samples of radar and gauge measurements, respectively.



**Figure 2: Locations of the 20 gauge under coverage of (a) CASA/XUTA and (b) KFWS radars, where “■” denotes the location of radars, and “\*” denote the location of gauges.**

In this paper, the rainfall event occurred on June 9th, 2013 is taken as an example to demonstrate the performance of the DFW rainfall products. The rainfall observations from 20 gauges during a one hour period (11:35UTC to 12:35UTC) and corresponding radar measurements are computed for cross comparisons. Shown in Table 1 are the evaluation results for 1-hour rainfall and the 5-minutes rainfall accumulations during this 1-hour period. The low NB and NSE demonstrate the excellent performance of the high-resolution rainfall products from both S- and X-band radars in this urban region.

**Table 1. Evaluation results of 1-hour rainfall and the 5-minutes rainfall accumulations for the rainfall measurements during 11:35UTC-12:35UTC, June 9th, 2013.**

	KFWS Radar			CASA/XUTA Radar		
	CORR (%)	NB (%)	NSE (%)	CORR (%)	NB (%)	NSE (%)
1-hr rainfall accumulation	96.90	1.80	11.90	91.00	2.20	17.90
5-minutes rainfall estimates	73.56	-11.42	39.1	75.63	-1.11	33.49

## 4. Conclusions and Future Work

In this paper, we have described the high resolution rainfall mapping methodologies using polarimetric radars at S- and X-band frequencies in Dallas-Fort Worth metropolitan area. The preliminary evaluation results based on the local rain gauge observations have shown the superior performance of the rainfall estimation methods. In future, more cases studies will be done to further demonstrate the accuracy of the rainfall products. In addition, the integrated rainfall products based on the KFWS radar and multiple X-band radars will be the focus of the QPE studies in this urban radar network with more X-band radars are being deployed. The high-resolution rainfall products will also be used for characterizing the complex hydrologic and hydraulic processes in this urban environment.

## 5. Acknowledgments

This work is supported by the National Science Foundation, NOAA/NWS, and the North Central Texas Council of Governments (NCTCOG). The gauge data was obtained from the City of Grand Prairie.

## 6. References

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