COMET FINAL REPORT

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Type of Project: Partner

Project Title: A validation study of the NWS/MPE products using a dense rain gauge network in south Louisiana

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Section 1: Summary of Project Objectives

With high spatial and temporal resolution of rainfall data being provided by radar, there is a current need for radar validation and assessment. Multi-sensor Precipitation Estimator (MPE), which is an hourly product based upon the merging of WSR-88D radar, surface rain gauge, and occasionally geo-stationary satellite date, was developed by the National Weather Service (NWS) and used by the River Forecast Center (RFC). A process called Stage IV consists of mosaicking the MPE output over the contiguous United States on a 4 km^2 grid termed Hydrologic Rainfall Analysis Project (HRAP) grid. The resulting data was obtained through the National Center for Environmental Prediction (NCEP) Stage IV archives. The study mainly focuses on the capabilities of MPE to predict rainfall over south Louisiana. One of the main attractions to this research project is the availability of independent hourly rain gauge measurements which were not used in the bias correction procedure associated with MPE. Another unique feature of the rain gauge network is the super-density of the network where MPE HRAP pixels contain multiple gauges (up to 4 gauges per pixel). The gauge data is also of high-quality because of to two factors: (1) dual-gauge design where two gauges are located side-by-side in each site, and (2) regular maintenance (at least once a month).

Section 2: Project Accomplishments and Findings

Note: in the following we provide a summary of the findings and some sample results; detailed results will be included in the Masters student's thesis and in a journal paper that is under preparation.

The study site is located in south Louisiana close to the Gulf of Mexico. An independent surface rain gauge network is operated by University of Louisiana at Lafayette and consists of 13 rain gauges located within 30km^2 of each other. The close proximity of the gauges to one another allows for multiple gauges to lie within a single HRAP pixel. All of the gauges are within six different pixels with two pixels each containing four gauges, one pixel containing two gauges, and three pixels each containing one gauge (Figure 1). Spatial orientation of the six HRAP pixels along with their corresponding HRAP row and column number is also shown in the figure (1). Though not used in this project, four recently installed gauges are also within the same area and will increase the density of this rain gauge network in future research. Having a resolution of 4 km^2, MPE measurements are assumed to represent the total area of the grid pixel. Keeping with this convention, gauges located within the same pixel were averaged to obtain a measurement representative of the whole pixel area. Rain gauge measurements were considered as the true rainfall. Approximately three years of rain gauge data (2004-2006) was used in the study and analyzed over hourly, daily, and monthly temporal scales. MPE data availability was not a problem. On the other hand, given that the rain gauges were installed on different dates, not all rain gauges within the network were available for the entire three year period. Figure (2) depicts the maximum number of days available in each month during year 2004 for all six pixels combined. A large amount of the data is missing in all six pixels for the early part of year 2004. Gauge data was also lacking in the early part of year 2005 and the end of year 2006. Only two 4-gauge pixels were used in the hourly analysis. The hourly analysis represents the highest occurrences of spatial and temporal error. By using only two pixels in the hourly analysis, this would ensure the best representation of average rain gauge measurement possible. An example comparison is shown in figure (3) between the MPE pixel (723-201) and the average of the two gauges within the pixel. Monthly accumulations are reasonably similar with most of the differences lying within 10%. However, there are a few larger differences that occur in April and October of 2004 and October of 2006.

Detection sensitivity of radar-based MPE measurement was assessed (Table 1). When the rain gauge measurement is between the intervals 0-1 millimeters, we have 69% of MPE measurement showing greater than zero. The detection percentage is greatly enhanced to 97% by increasing the interval to 1-2 millimeters. Beyond a rain gauge measurement of 2 millimeters, gradual increases are noted with 100% being reached at greater than 5 millimeters. Similarly, detection sensitivity was analyzed for the rain gauge measurement (Table 2). A detection percentage of 55% is seen at the 0-1 millimeter interval. The percentage is quite lower than the percentage shown at this interval for MPE data. However, the percentage does increase greatly (98%) by the 1-2 millimeter interval. The rain gauge results are very similar to the results seen in the MPE detection data. As in MPE results, 100% detection is not seen until reaching a MPE measurement greater than 5 millimeters. Similar results are also shown in the two previous years of data.

The following statistical measures were included in the analysis:

I. Normalized Bias:

$$Bias = \frac{R_{i(MPE)} - R_{i(RG)}}{R_{i(RG)}}$$

II. Normalized RMSE: $$RMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\left(R_{i\,MPE} - R_{i\,RG}\right)^2 - \left(\overline{R_{RG}} - \overline{R_{MPE}}\right)^2\right)}}{\frac{1}{n}\sum_{i=1}^{n} R_{i\,RG}}$$

III. Efficiency: $$E = 1 - \frac{\left(\sum_{i=1}^{n}\left(R_{i\,MPE} - R_{i\,RG}\right)^2\right) \Big/ n}{\left(\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(R_{i\,RG} - \overline{R_{RG}}\right)^2}\right)^2}$$

Where R_i is the rainfall at month i (for either MPE or Rain Gauge), and n is the number of measurements in the data set. The over-bar symbol represents the arithmetic average. Normalization was based upon the assumed true rainfall.

A statistical table is shown in figure (4) for MPE and rain gauge measurements during year 2006. Overall, the statistics look similar. The standard deviation results for MPE and rain gauge are more alike at the monthly scale than the hourly scale. Normalized bias is minimal over each time scale. Due to the inherent averaging of random error in accumulating measurements from hourly to monthly time scale, the normalized RMSE is seen to decrease with coarser temporal resolution. Correlations are all above 90% with a maximum at the monthly scale being 96%. A second correlation value is mentioned and is based upon the removal of zero MPE and rain gauge data values. Removal of the zeros decreased correlations, which was expected, but did not decrease them below 90%. Monthly correlation remained the same since there are no months showing zero rainfall in year 2006. Efficiencies were also calculated and show similar results to correlations. Including and excluding zeros at the monthly scale resulted in efficiencies equaling 96%. Figure (5) shows scatter plots of MPE versus rain gauge data for year 2006 at hourly, daily, and monthly time scales. A regression line is also represented in each of the scatter plots. As mentioned earlier, the hourly analysis consisted of data only from the two 4-gauge pixels. The mean values taken from the statistics in table (1) for MPE and rain gauge are both 0.16 mm. As shown in the plot, a large number of the hourly data points are below the 5 millimeters with a few hourly gauge measurements showing as high as 75 millimeters corresponding to approximately 55 millimeters in MPE measurement. At the daily scale, the comparisons seem to center more on the regression line while there are a couple of hourly data points where gauge and MPE are not detecting much rainfall. One particular point of interest is the gap between the lower values and a couple of very high rainfall values (approximately 115 millimeters). High rainfall must have occurred on a couple of days during year 2006 to produce these results. With the exception of a few grouped values mid-way in the plot, the data seem to converge more toward the regression line at the monthly scale.

Cumulative probability distribution function plots for year 2006 were also calculated (Figure 6). The temporal scales are hourly (left) and daily (right). The plots are also based upon the condition of rain gauge or MPE value being larger than zero. This condition excludes all zero gauge and corresponding MPE rainfall hours from the plot. Rain gauge data contains a larger quantity of smaller values than does MPE data. Interestingly, this tendency is also seen within the two previous years (not shown). The quantity of large hourly and daily values is greater in MPE than rain gauge. Figure (7) was plotted to infer any seasonal trends within the data sets. The plot shows statistical measures including mean difference, standard deviation of the difference (RMSE), and correlations. The rainfall for one of the 4-gauge pixels (724-200) is shown in the fourth plot. Data for year 2004 was not available for some months and was not included.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

i) LMRFC personnel became familiar with the ULL rain gauge network for use in validating and assessing MPE. Opportunities for continued study will allow further insight into future MPE operations.

ii) The project provided a better understanding of MPE rainfall discontinuities in South Louisiana and allowed LMRFC personnel to gain knowledge in mitigating the discontinuities.

iii) The collaboration with ULL personnel and awareness of the ULL disdrometer provides the opportunity to share and gain knowledge on future projects.

Section 4: Benefits and Lessons Learned: University Partner Perspective

i) The project provided more knowledge in the area of radar-based MPE validation and assessment. Further studies can be built upon the findings that we have shown and discussed earlier.

ii) University personnel became familiar with the data format of MPE files and developed software to process large amounts of data in an efficient and automated way. This will be useful for applications of MPE data in other hydrologic forecasting studies.

iii) Training a graduate student on analysis of radar-rainfall data and assessment of their accuracy for forecasting purposes. The study provided the graduate student with an opportunity to gain understanding in the area of operational hydrologic forecasting. The analysis and results found while working with the RFC will be a main portion of the graduate student's master's thesis.

iv) Training undergraduate students on operation of in-situ rain gauge stations. The students were also involved in performing quality control of the downloaded data.

v) Use of the project data and analysis in a graduate class to introduce concepts of statistical validation of remote sensing data

vi) Interaction with LMRFC personnel and gaining more insight on operational issues regarding the development of real-time MPE for forecasting purposes. The relationship established between the local RFC and the university provides greater opportunities for further collaboration.

Section 5: Publications and Presentations

The results of this project will be presented in a conference and a journal paper:

(a) The results of the project will be presented in the fall meeting of the American Geophysical Union (AGU) conference San Francisco, California, December 10-14, 2007 (presentation on December 11, 2007). The title of the presentation is "A validation study of the NWS/MPE precipitation products using a dense rain gauge network in south Louisiana". The authors are: Boone Larson (graduate student), Emad Habib (University Investigator), and Jeff Graschel (LMRFC Forecaster).
(b) The investigators are preparing a manuscript to be submitted to either one of the two journals: Journal of Hydrometeorology, or Journal of Hydrology.

Section 6: Summary of University/ Operational Partner Interactions and Roles

The University of Louisiana at Lafayette and the LMRFC had two project meetings at the University site and at the LMRFC site. Each meeting consisted of graduate students, hydrologic forecasters, as well as the primary research investigators. These meetings were critical in understanding the role of each person for the COMET project. In the second meeting, the university was able to present and discuss preliminary results with the LMRFC group. Both partners have also interacted through conference phone conferences as well as email.

The roles of academic and forecaster partners can be summarized as follows:

Academic partner: collection and processing of rain gauge data and MPE data; development of statistical procedure for assessment of MPE data; validation analysis of MPE data

Forecaster partner: identifying MPE and other gauge data sources, verification of MPE comparisons against rain gauge data; development of GIS-based images of MPE data over the LMRFC domain; participation in design of overall methodology, assessment of experimental setup, among others.

2006 Hourly Data Probability (Average Gauge>0 | MPE > x)	
X (mm)	Fraction of Average Gauge hours > 0
0	0.69
1	0.97
2	0.98
5	1.00

2006 Hourly Data Probability (MPE>0 | Average Gauge > x)	
X (mm)	Fraction of MPE hours > 0
0	0.55
1	0.98
2	0.99
5	1.00

Tables 1 and 2: Probability of detection for the fraction of MPE (left) and rain gauge (right) greater than zero.

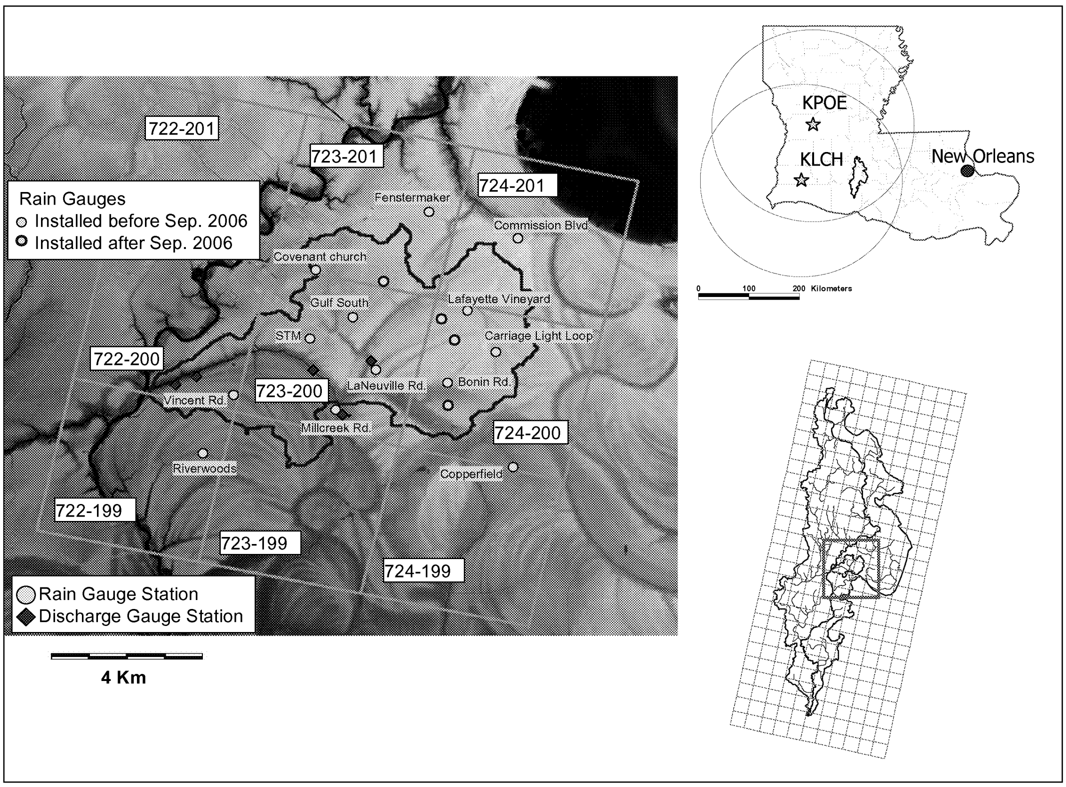

Figure 1: Rain gauges (yellow circles) and Discharge gauges (red circles) within the Isaac Verot watershed in Lafayette, LA. Recently installed gauges (maroon outline circles) along with the HRAP grid (teal squares) is also shown. Pixel row and column number are shown in white within each pixel.

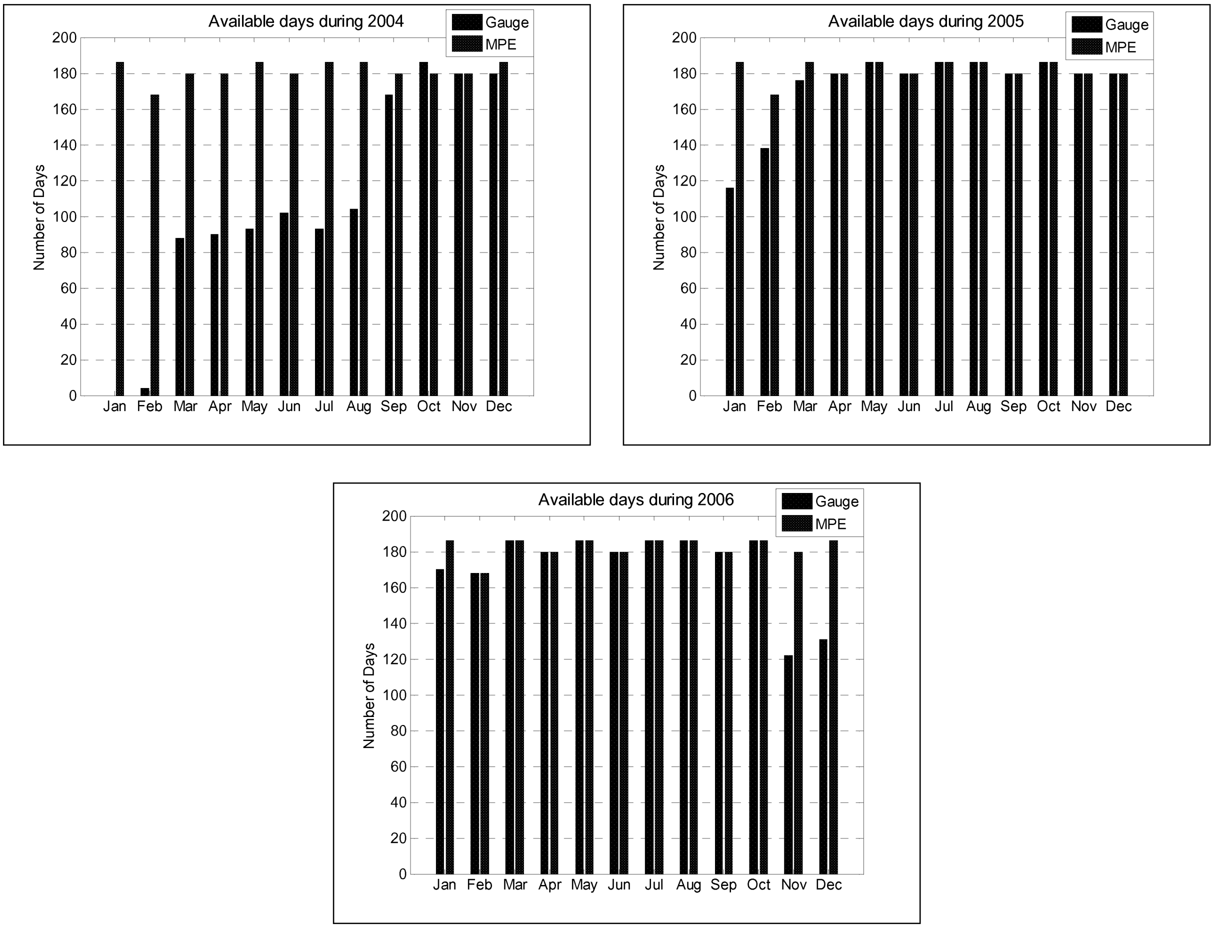

Figure 2: Available days within all 6 pixels on a monthly scale for years 2004 (top-left), 2005 (top-right), and 2006 (bottom).

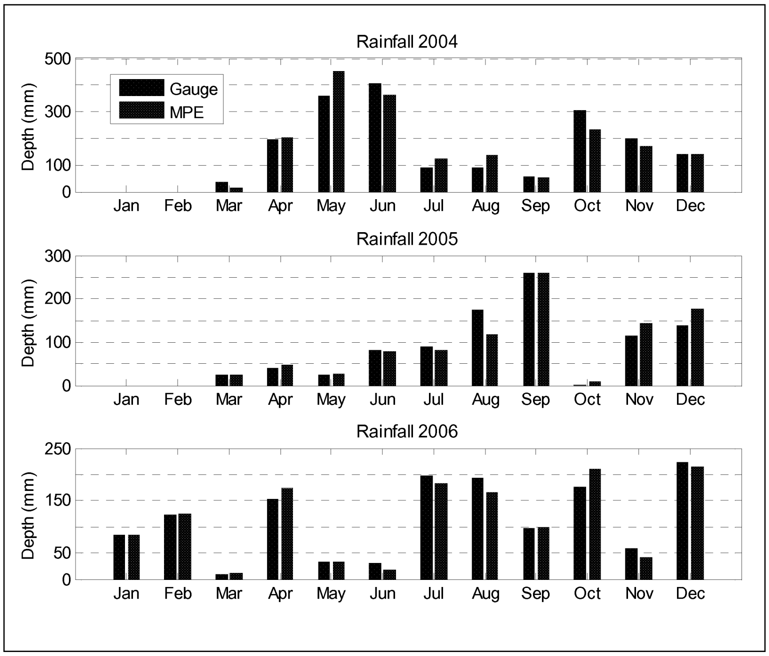

Figure 3: Bar plot of monthly accumulations for radar-based MPE rainfall data (pixel 723-201) along with corresponding rain gauge rainfall over Lafayette, LA.

MPE and Gauge Statistical Analysis 2006			
	Hourly	**Daily**	**Monthly**
Mean (MPE) (mm)	0.16	3.69	108.63
Mean (gauge) (mm)	0.16	3.70	108.81
Standard Deviation (MPE) (mm)	1.36	10.08	69.15
Standard Deviation (gauge) (mm)	1.59	10.60	67.98
Normalized Bias w.r.t gauge average	-0.04	0.00	0.00
Normalized RMSE w.r.t gauge average	3.63	0.98	0.19
Correlation Coefficient (All of MPE vs gauge)	0.93	0.94	0.96
Correlation Coefficient (non-zeros)	0.93	0.93	0.96
Efficiency (All of MPE vs gauge)	0.86	0.88	0.91
Efficiency (non-zeros)	0.85	0.87	0.91

Figure 4: Statistics for year 2006 for hourly, daily, and monthly time scales.

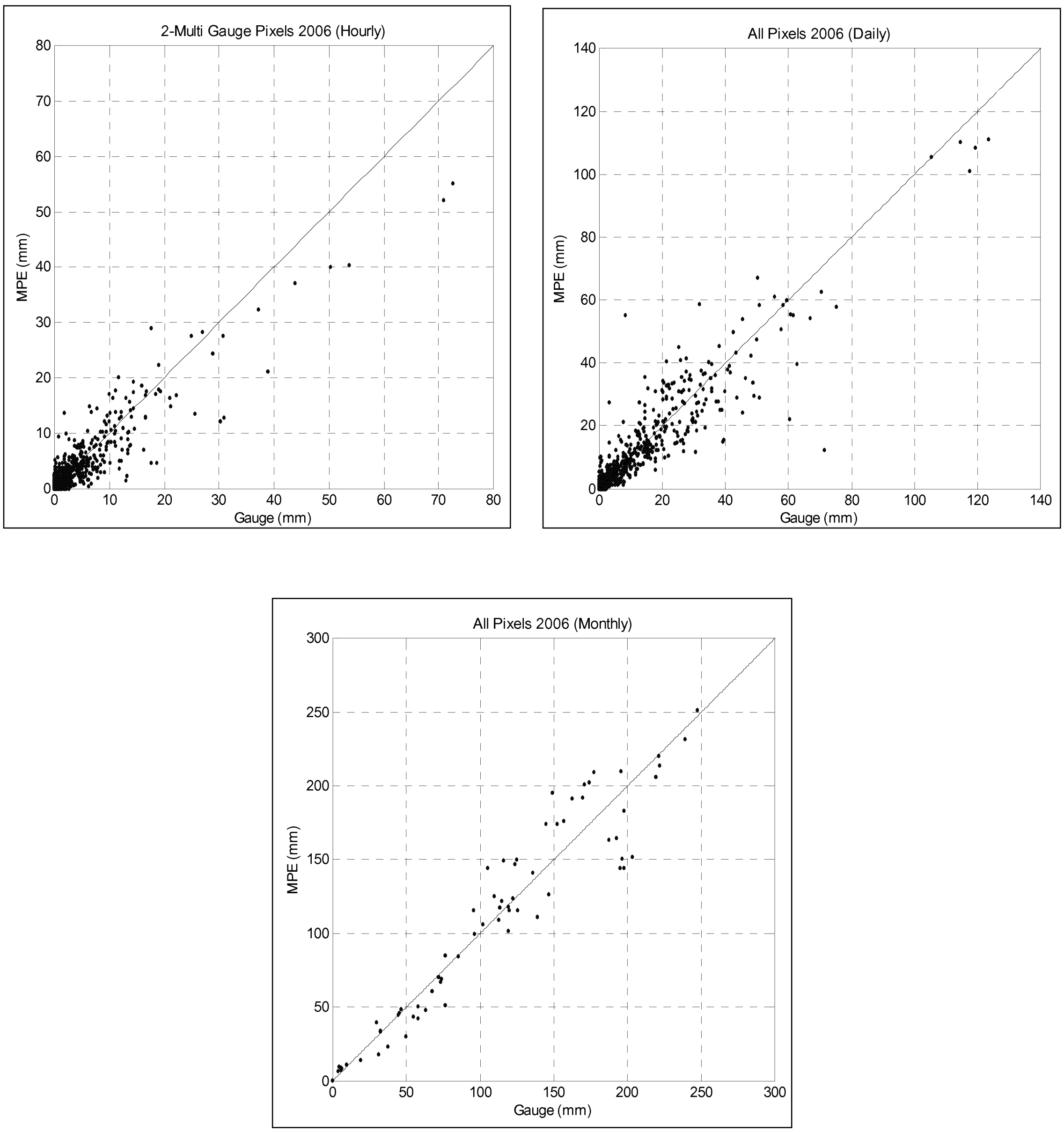

Figure 5: Scatter plots for year 2006 at hourly (top-left), daily (top-right), and monthly (bottom) time scales.

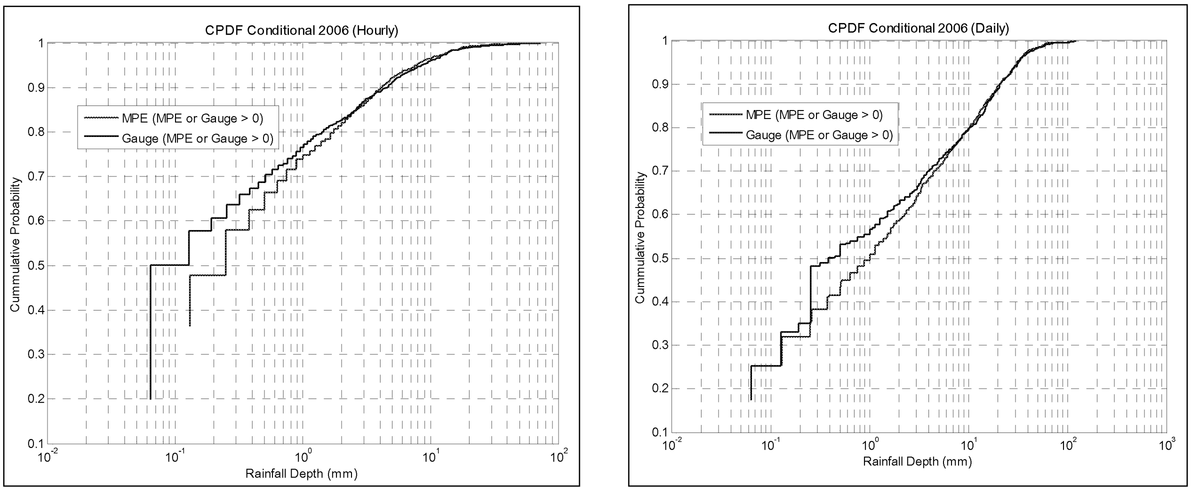

Figure 6: Hourly (left) and daily (right) conditional cpdf plots for year 2006.

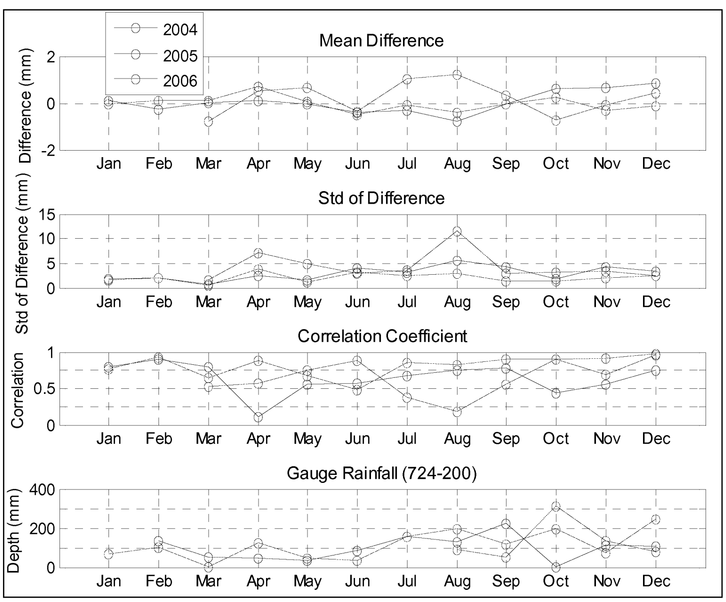

Figure 7: Plot of monthly statistical data for years 2004-2006 along with monthly rain gauge rainfall for a 4-gauge pixel (724-200).