

NEXRAD Downscaling

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ABSTRACT

Common remotely-sensed precipitation products have a spatial resolution that is often too coarse to reveal hydrologically important spatial variability. A regression model using the topological condition to interpolate the rainfall variability is developed for downscaling low-resolution spatial precipitation fields to a higher resolution. This algorithm auto-searches precipitation spatial structures (e.g., rain cells) and atmospheric and orographic effects, estimating precipitation distribution without prior knowledge of the atmospheric setting. In this study, 4km * 4km NEXRAD MPE ((Multi-sensor precipitation Estimator) of the year 2004 of the San Antonio and Guadalupe River Basin with its a digital elevation model (DEM) map were input into the model. To validate the downscaling accuracy, we compare the precipitation of both 1km * 1km and 4km * 4k precipitation data with the rain gauge. Generally, MPE rainfall has high correlation with the rain gauges. The 1km * 1km downscaled precipitation was believed to be accurate, since it preserved the high correlation. And the precipitation map of the 1km * 1km tend to be the same as the original 4km *4km rainfall map.

1. INTRODUCTION

NEXRAD (Next Generation Radar) refers to the nationwide network of Doppler radar sites installed by the National Oceanographic and Atmospheric Administration (NOAA). These sites are specifically designed to provide meteorological data so the

official designation is WSR-88D (WSR88D = Weather Surveillance Radar - 1988 - Doppler). The NEXRAD project was started in the late 1980's and was designed to provide comprehensive radar coverage of the United States and to replace older WSR-57 and WSR-74 radar systems. The NEXRAD system is superior to the old ones because it is much more sensitive and allows meteorologists to acquire a much wider range of data. Each NEXRAD site has a 28 ft diameter dish antenna which is used to transmit and receive radio signals. This dish has the capability to rotate 360 degrees in azimuth and up to 20 degrees in elevation allowing the radar to cover a huge volume of atmosphere. The system normally collects data by rotating the dish through 360 degrees at a prescribed elevation. When that scan is completed, the elevation is increased slightly and another scan is performed at the new elevation.

Each NEXRAD site operates in one of two modes, "Clear Air" mode or "Precipitation" mode. Clear air mode is the normal mode of operation and is used when there is no significant precipitation in the area. In this mode the radar is VERY sensitive and will detect even minute echoes. Clear air mode utilizes VCP31 or VCP32 and takes about 10 minutes to produce an image. Note that in the winter months, some radar sites will go to Clear Air mode even if there is light snow in the area. The added sensitivity of this mode allows the detection of snow showers since snow generally reflects much less energy than other forms of precipitation. When the radar detects significant precipitation in the area, it will automatically change to Precipitation mode. This mode is designed to provide higher resolution for relatively strong echoes so the radar becomes less sensitive. It generally utilizes VCP21 (Volume

Coverage Patterns) and produces an image every 6 minutes. There is also a special type of Precipitation mode sometimes called "Severe Weather" mode. This mode operates like normal precip mode, but utilizes VCP11 and produces an image about every 5 minutes. This mode is only used for research or for extreme weather events like hurricanes or tornadoes.

The radar cell is a radar-centered polar coordinate system, which can't be directly used for mosaic among different radar products. The polar coordinate system was transfer to a polar stereographic projection, which called hydrologic rainfall analysis project (HRAP), within the WSR-88D rainfall algorithm, which is called the Precipitation Processing System (PPS) (Fulton, 1998). The HRAP grid is utilized by the NWS so that the polar rainfall estimates from the WSR-88D radars can be mosaicked onto a common grid across the U.S. for follow-on hydrologic applications to support their river modeling activities and flood forecasting missions (Fulton, 1998). The Stage 3 Precipitation Processing and the new Multisensor Precipitation Estimate (MPE) are performed in the NWS River Forecast Center (RFC). The HRAP projection, which can't be input into GIS directly for further clipping rainfall data, of the MPE rainfall product, then transfer to Universal Transverse Mercator (UTM) coordinate system using a NAD 27 datum and Clarke 1866 spheroid for collocating the radar rainfall with gauge rainfall.

The current NEXRAD precipitation product (e.g., Stage III or MPE) has a spatial resolution of ~ 4 km is still too coarse to reveal hydrologically important spatial

variability and to be put into the hydrological models. Thus it is hydrologically valuable to spatially disaggregate low-resolution spatial precipitation fields. For the purpose of understanding past and future variability in the regional climate a nested, regional atmospheric model (WRF) is developed for the Gulf Coast region. Higher resolution precipitation data is needed as an input for the WRF model. A parsimonious physically-based multivariate-regression algorithm, referred to as multi-level cluster-optimizing ASOAdEK regression, is developed for downscaling low-resolution spatial precipitation fields in the Laboratory for Remote Sensing and Geoinformatics (Guan et al., to be submitted). They tested the algorithm by first directly aggregating the 4 km x 4 km NEXRDA rainfall into 16 km x 16 km and then downscaling the 16 km * 16 km precipitation fields back to 4 km * 4 km pixel precipitation using the developed algorithm for both daily and hourly precipitation in the northern New Mexico mountainous terrain and the central Texas hill country. The algorithm generated downscaled precipitation fields are in good agreement with the original 4 km * 4 km NEXRAD precipitation fields, as measured by precipitation spatial structures and the statistics between downscaling and the original NEXRAD precipitation maps.

According to the algorithm, the required input data for the downscaling algorithm are a large-pixel precipitation map and a digital elevation model (DEM) map for an area of interest. A study of validating the accuracy of downscaling NEXRAD data will be done by comparing with rain gauge data. Both original NEXRAD products with the spatial resolution of 4*4 km², and the downscaling products with the spatial resolution

of $1 \times 1 \text{ km}^2$ will be compared with the rain gauge products.

2. STUDY AREA

The study area is Gaudalupe River Basin and San Antonio River Basin highlighted in red color (Fig. 1). There are 50 gauges scattering in this area (green circles), which can be used as ground truth data for validation. San Antonio and Guadalupe watersheds provide an excellent study system for calibrating and testing our models, because their estuaries have strongly contrasting physical and biological attributes despite their physical proximity. The greatest difference is an extreme disparity in freshwater inflow resulting largely from differences in runoff caused by soil differences in the watersheds (Montagna and Kalke, 1995). This disparity in freshwater inflow leads to great differences in salinity and a strongly contrasting system in which to study how ecological processes differ due to inflow differences over broad spatial scales. Precipitation is an import input for many atmospheric or climate models. Besides, the Edwards Aquifer is the major water source for over 1.7 million people along this corridor, while precipitation is the only recharge water source. Thus, to improve the radar resolution and knowing its accuracy of precipitation mapping is crucial.

3. DATA USE

3.1 NEXRAD MPE

NEXRAD (Next Generation Radar) data was download from NOAA official website <http://dipper.nws.noaa.gov/hdsb/data/nexrad/nexrad.html>.

3.2 DEM (Digital Elevation Model)

The DEM data with the spatial resolution of 90m*90m were downloaded from the website <http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp>. The Shuttle Radar Topography Mission (SRTM) is a joint project between the National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA). The objective of this project is to produce digital topographic data for 80% of the Earth's land surface, with data points located every 1-arc-second (approximately 30 meters) on a latitude/longitude grid. The absolute vertical accuracy of the elevation data will be 16 meters (at 90% confidence). This radar system will gather data that will result in the most accurate and complete topographic map of the Earth's surface that has ever been assembled.

3.3 Rain Gauge

The Gauge data were provided by the Guadalupe River Authority.

4. METHODS

Generally, there are five steps to downscale the NEXRAD original 4*4 km² resolution data to 1*1 km² spatial resolution and extract MPE cell value collocated with rain gauges. They are: (1) Nexrad data preprocessing; (2) DEM data preprocessing; (3) Downscaling the 4 km to 1 km resolution. (4) Extract MPE cell value collocated with rain gauges; (5) Compare MPE rainfall with rain gauges.

4.1 NEXRAD Data preprocessing

NEXRAD precipitation data of year 2004-2005 are used for this study. The original data set is in Hydrologic Rainfall Analysis Project (HRAP) projection or secant polar stereographic projection (Reed and Maidment, 1995, 1999) in multitarred

and compressed binary formats. Batch processing procedures were developed (Xie et al. 2005) to automatically multiuntar and uncompress the binary (XMRG) files in LINUX system, and transfer the XMRG format to ASCII. The second step is to convert the ASCII data to GIS grid format using AML scripts in Arcinfo. Meanwhile, the grid data was reprojected to Universal Transverse Mercator (UTM), Zone 14 North, on the World Geodetic System 1984 (WGS84) datum with the output units of meters (required for downscaling in Matlab). In the same procedure, the grid file is clipped to a rectangular area covering the study area of San Antonio and Guadalupe River Basin (Figure 1). Finally, the grid data was converted to txt file for downscaling.

4.2 DEM data preprocessing

DEM data covering an larger area than the NEXRAD data with a spatial resolution of 90*90 meter was downloaded from the CGIAR Consortium for Spatial Information website <http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp>. Four parts of the data were mosaic in ArcGIS In order to extract relevant portions of the DEM for processing. Here we projected the DEM grid to UTM 14N WGS 1984, which is the same projection as the NEXRAD data. And the DEM grid was extracted to a desired area, which covers the whole study area and a little bit larger than the NEXRAD grid file (the clipped and reprojected NEXRAD grid was used as the extracting file). Using the Matlab codes, it was further resampled to 1 kilometer (k) resolution, and the aspect of 1k, 3k 5k,7k ,9k ,11k were generated as input for the downscaling algorithm. The purpose of getting different scale of aspects is

to find the most optimal atmospheric window. Previous studies show that the orographic effect is represented at a certain optimal DEM window (Daly et al., 1994; Kyriakidis et al., 2001). Operationally, 6 different aspects were searched by regression and the one which has the smallest mean absolute errors will be picked out as the most optimal atmospheric window to be used for downscaling.

4.3 Downscaling

The downscaling procedure was done in Matlab. The preprocessed NEXRAD and DEM data are the input for this algorithm. Basically, Matlab works with matrixes, so all the input files should be matrixes, which means the head of each file should be taken out. Generally, there are 4 steps to complete the downscaling (1) multi-level raining pixel clustering, (2) ASOADeK regression, (3) cluster optimization, (4) constraining small pixel precipitation by the large pixel value. The outputs of the downscaling procedure are matrixed storing in .txt format. The cluster optimizing procedure and ASOADeK regression are two of the major components of the downscaling algorithm. The dynamics of the air mass, and the complicated interaction between the air mass and the underlying land surface, lead to irregular patterns of precipitation. The first step is clustering, which separate the rain pixels into different clusters by rain rates and their spatial connections, because the storm structure and the associated physical processes are believed to be more similar within one raining pixel cluster than between clusters. The second step is to examine alternative cluster structures, and find the one having the best agreement between the regression estimates and the original NEXRAD pixel values. For all identified clusters,

ASOAdEK regression is applied [Guan et al., 2005]. After regression, the sum of precipitation for the 16 small pixels (calculated from the regression function) is compared to the original large pixel value, and their correlation coefficient (r) is calculated for each cluster and assigned to each large pixel and small pixels within the cluster. Finally, the ASOAdEK regression is applied to each the optimized cluster structure. The ASOAdEK regression was developed to recover precipitation spatial variability from low-resolution precipitation maps by catching predictable processes (for example, those related to orography and atmospheric moisture distribution). [Guan et al., 2005],

The regression model is:

$$P = b_0 + b_1X + b_2Y + b_3XY + b_4X^2 + b_5Y^2 + b_6Z + b_7 \cos \alpha + b_8 \sin \alpha \quad ,$$

where P is precipitation rate, X the longitudinal geographic coordinate (or UTM easting), Y the latitudinal coordinate (or UTM northing), Z the elevation, α the terrain aspect, and the b_i 's are fitted coefficients.

4.4 Extract MPE Cell Value collocated with gauges

To extract the MPE cells value, the Matlab output from the downscaling procedure should be converted to ArcGIS grid files. An AML was revised to convert the text files back to grid file, and meanwhile the projection is defined as UTM Zone 14 North, with the datum WGS84. Rain gauge shape file was created by the longitude and latitude text file of each rain gauge scattered in the study area. Then the shape file

of rain gauge was projected to the same projection as the rainfall grid data. Further, the rain gauge coverage was created based on the shape file. In the AML scripts, the LATTICESPOT function was used to complete the extraction of cell value. Rain gauge coverage was used as a point coverage for which surface values were interpolated. The surface values were calculated by interpolation. Thus the cell values extracted collocated with gauges were weighted mean of the nearest 4 cells, rather than the exact point where the gauge is located.

4.5 Compare MPE and Rain Gauge Rainfall

Rain gauge data is provided by Guadalupe River Authority. The original data is in 50 separate excel files. For later on analysis, the gauge data has to be pre-processed. There are several steps to prepare the gauge data: (1) Combine monthly single gauge sheets into a sheet ; (2) Combine monthly sheets into yearly sheet ; (3) Compute hourly rainfall accumulation ; (4) Convert local time to UTC in radar ; (4) Remove zero rainfall records. Since the MPE data is in UTC time, the gauge data has to be converted from the local to UTC. Compared to the standard local time, UTC time is 7 hours faster.

Comparing Monthly MPE with rain gauge precipitation were completed in excel using a Visual Basic Model called "Match_Gauge_MPE". A threshold of 10 was used while matching the gauge with the MPE, which means, among the 50 gauges, if 10 of them have precipitation at the particular hour, that hour will be extracted and saved for further analysis and comparison. Both 4km *4 km and 1km *1k resolution MPE

data were matched and compared with gauge data..

5. RESULTS and CONCLUSION

5.1 Comparison of Monthly MPE and Rain Gauge Rainfall

Table 1 shows the general statistic of the 12 months MPE and Gauge rainfall comparison. “1kcc” and “4kcc” in the table represents correlation coefficient between 1km * 1km MPE and Rain gauge and 4km * 4km MPE and Rain gauge, respectively. According to the table, both 1km * 1km MPE and 4km * 4km MPE has the highest correlation coefficient with rain gauge rainfall in October, and followed by November, and April, which are the months with relatively higher precipitation. Generally, fewer hours of downscaled MPE carrying rainfall matched the rain gauge precipitation than the original data.

It’s For each month, there are more hours having rainfall for 4km * 4km resolution radar data than the 1km * 1km cells being extracted collocated with the rain gauge. It’s reasonable, because the extracted cell value of MPE is the weighted mean of the nearest 4 cells. Thus, the 4 km * 4km has higher opportunity to get a cell value with rainfall

5.2 Effectiveness of the downscaling algorithm

Figure 2, 3, 4, and 5 show the downscaled precipitation grid file in ArcMap. The downscaled 1km * 1km NEXRAD precipitation tend out to be the same as the 4 km * 4km original NEXRAD rainfall grid, which means the interpolation of precipitation

using the DEM as constraint captures the rainfall variability accurately.

5.3 Overall Accuracy of MPE precipitation

The overall correlation coefficient of downscaled 1k * 1k MPE with rain gauge precipitation is approximately 0.6425 and for 4k * 4k MPE is 0.6724. (Fig.9 and Fig.10)

5.4 Radar and gauge performance

Radar detects more total amount of rainfall than rain gauges. As showing in figure 6 and figure 7, both monthly and accumulative rainfall of 1k * 1k and 4k*4k MPE exceed rain gauge detection.

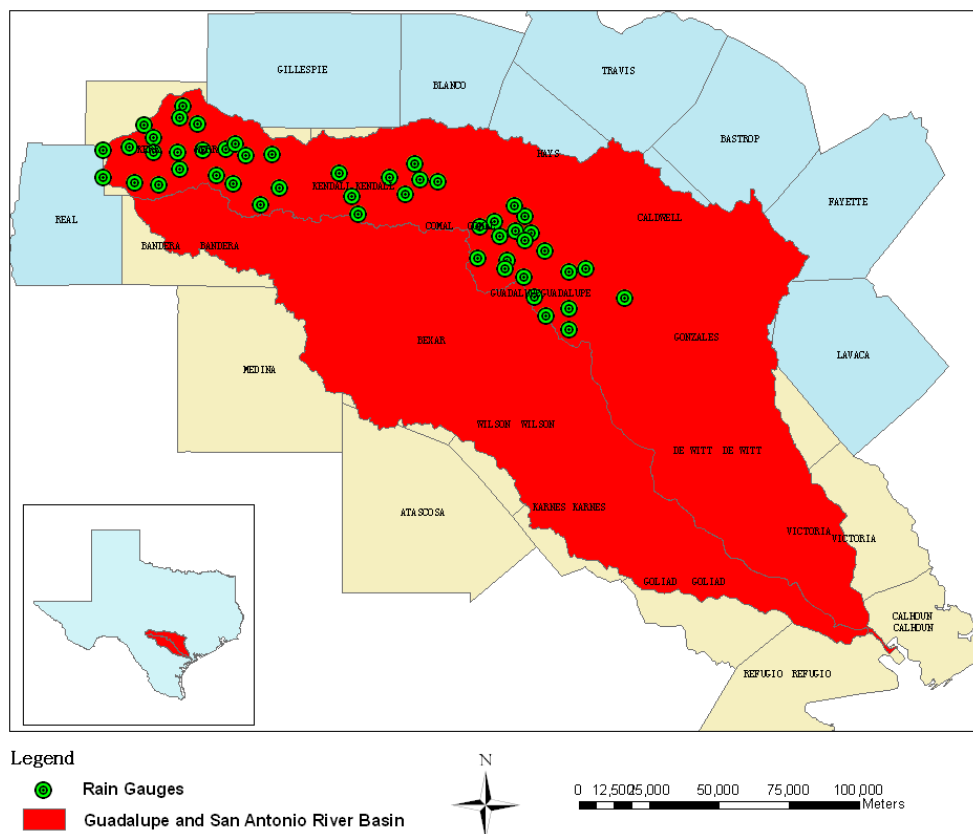


Figure 1 Study area: The Guadalupe River Basin and San Antonio River Basin

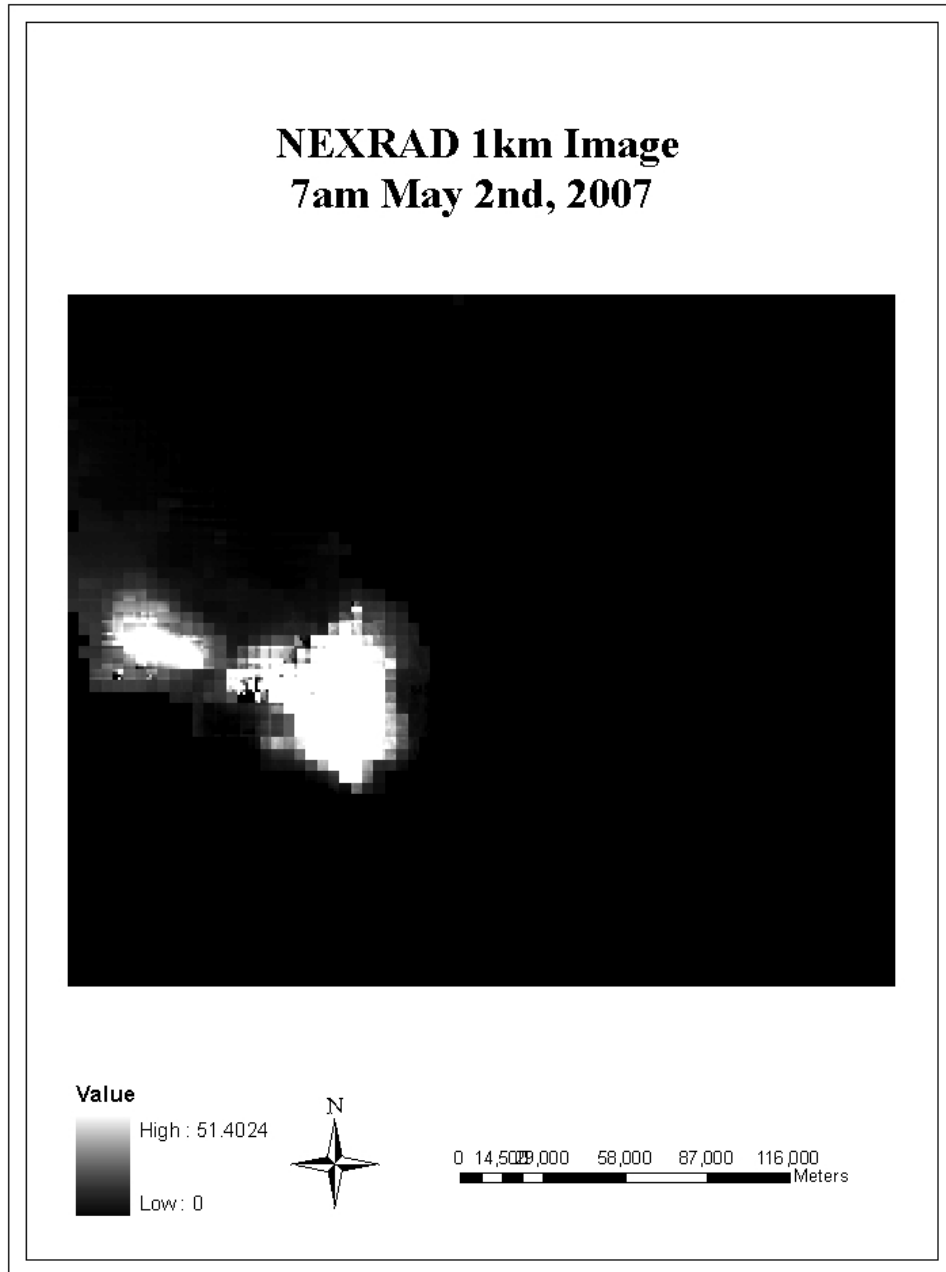


Figure 2. NEXRAD downscaled $1*1 \text{ km}^2$ resolution rainfall grid for the hour 05 (UTC) on May 2nd, 2007

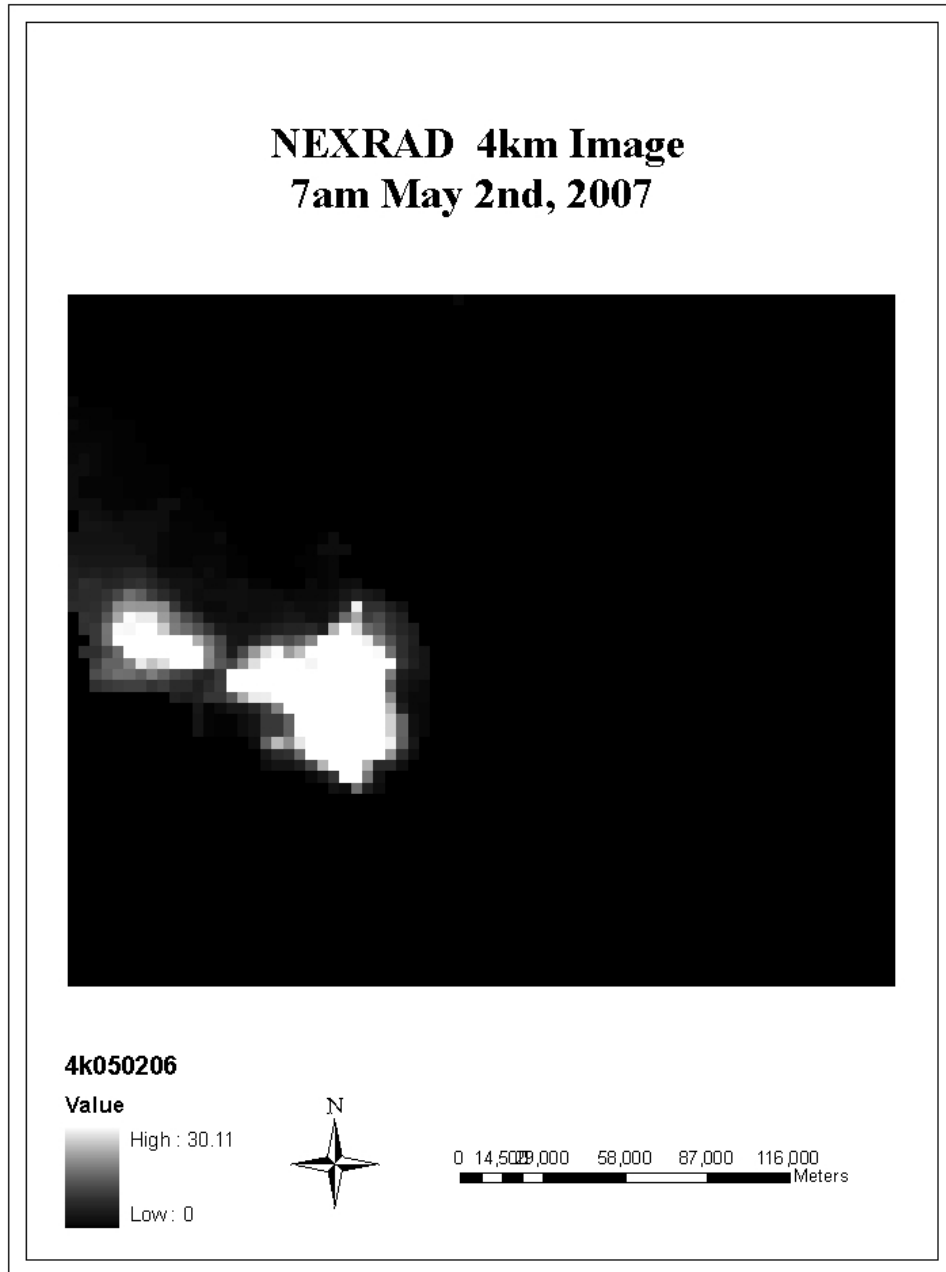


Figure 3. NEXRAD original 4*4 km² resolution rainfall grid for the hour 05 (UTC) on May 2nd, 2007

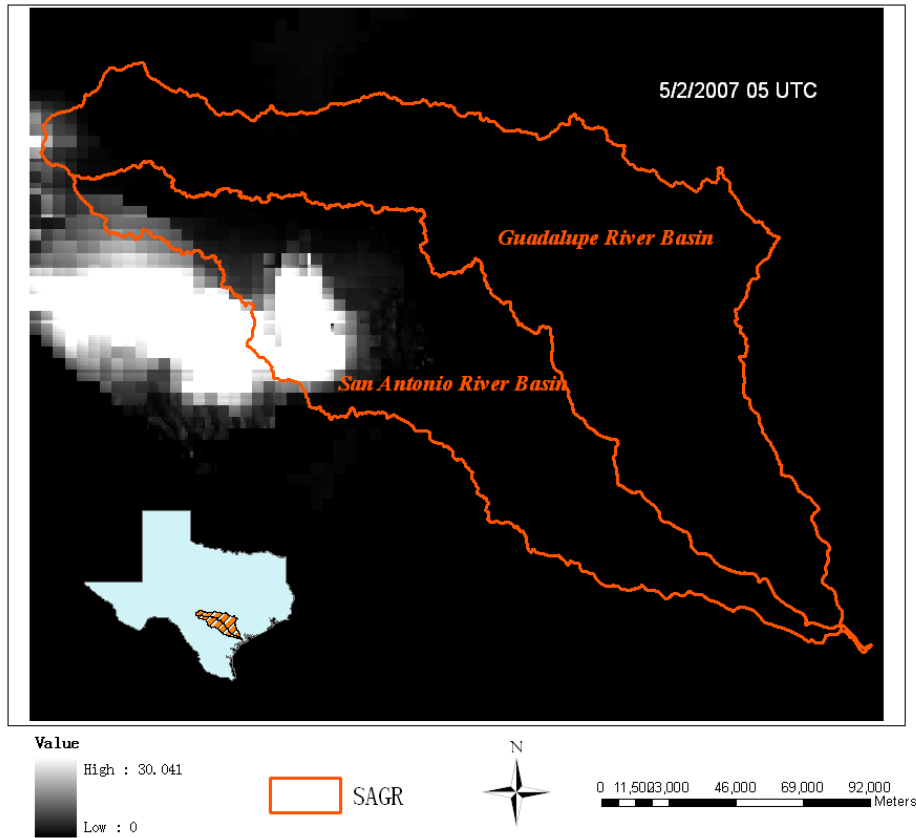


Figure 4. NEXRAD downscaled 1*1 km² resolution rainfall grid for the hour 05 (UTC) on May 2nd, 2007

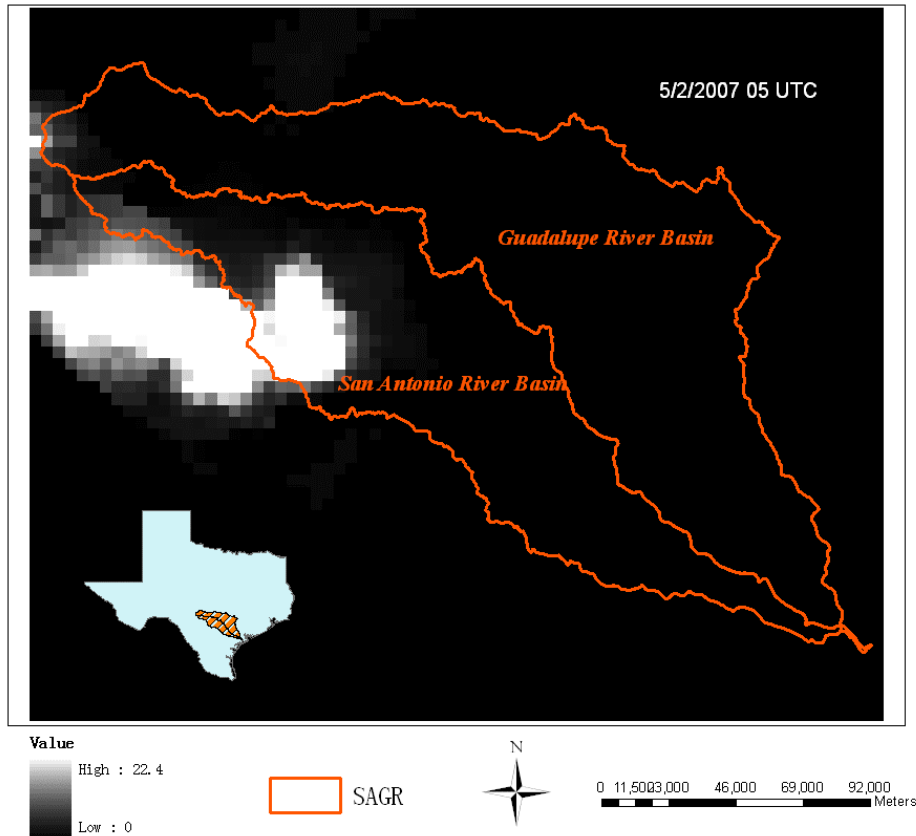


Figure 5 NEXRAD downscaled 4*4 km² resolution rainfall grid for the hour 05 (UTC) on May 2nd, 2007

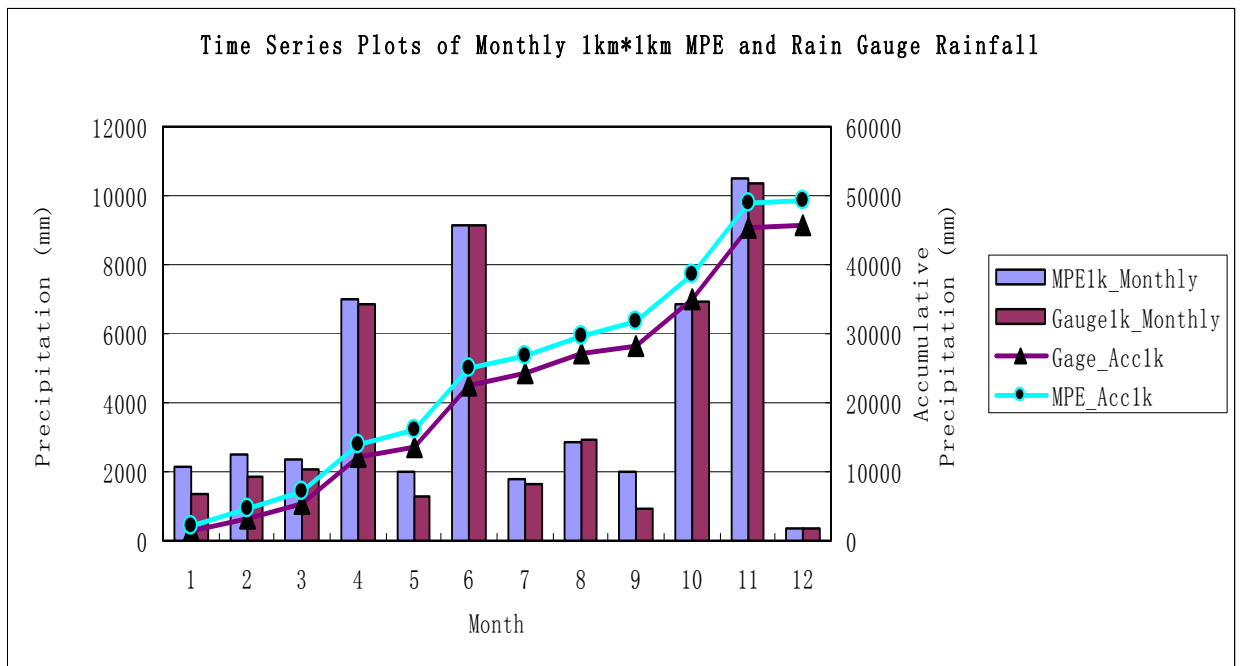


Figure 6 Time series plots of monthly and monthly accumulation of 50 collocated 1

km *1 km MPE and rain gauge rainfall in the year 2004-2005 at Guadalupe River Basin. and San Antonio River Basin. “Acc” in the legend is the abbreviation of “accumulation”. “1k” represents 1 km * 1 km spatial resolution of MPE data.

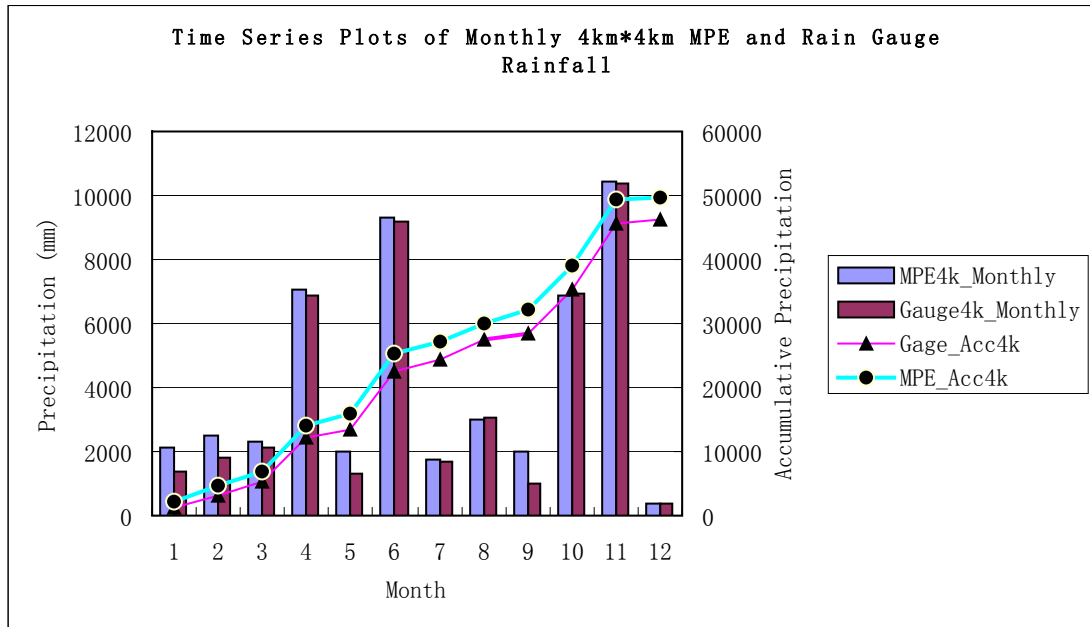


Figure 7 Time series plots of monthly and monthly accumulation of 50 collocated 4 km *4 km MPE and rain gauge rainfall in the year 2004-2005 at Guadalupe River Basin. and San Antonio River Basin. “Acc” in the legend is the abbreviation of “accumulation”. “4k” represents 4km * 4km spatial resolution of MPE data.

	1kcc	4kcc	MPE1k_Monthly	MPE4k_Monthly	hour1k	hour4k
January	0.2308	0.2484	2133.677	2131.295	111	115
Feburary	0.4801	0.4928	2509.079	2487.2	123	131
March	0.6814	0.7091	2322.818	2290.109	115	121
April	0.7541	0.7774	6987.246	7084.995	108	111
May	0.4365	0.4822	1968.511	1969.966	47	52
June	0.6066	0.6502	9130.666	9328.684	108	120
July	0.5066	0.5802	1755.961	1779.509	28	33
August	0.4328	0.4652	2854.293	3025.965	69	85
September	0.1645	0.1734	1979.991	2005.165	52	61
October	0.8026	0.8203	6886.54	6852.948	75	84
November	0.7681	0.78	10487.13	10426.53	165	168

Table 1 General statistic of monthly 1km* 1km and 4km *4km radar precipitation comparison

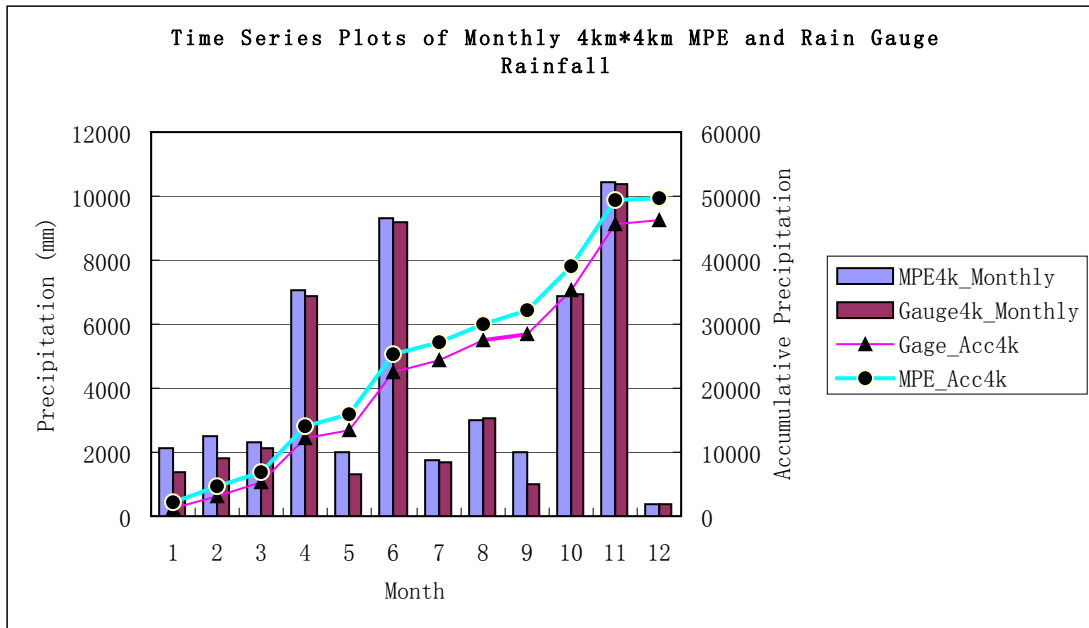


Figure 8 Monthly correlation coefficient between MPE and rain gauge precipitation in the year 2004-2005 at San Antonio and Guadalupe river basin.

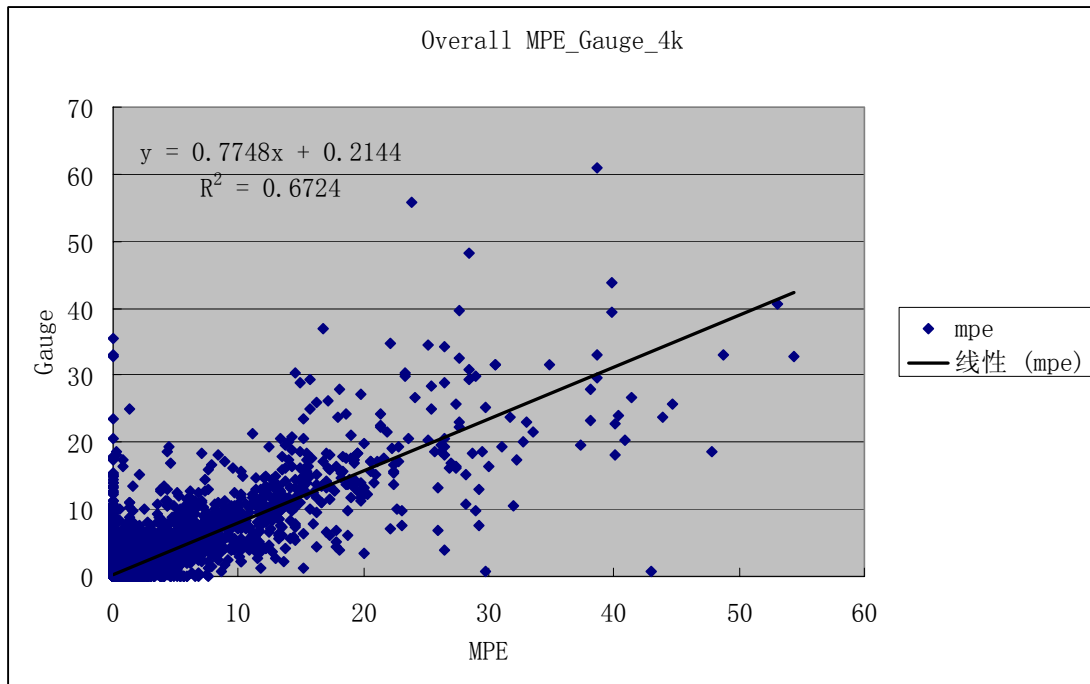


Figure 9 Overall Scatter plot of 4km * 4km hourly radar MPE and rain gauge precipitation in the year 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

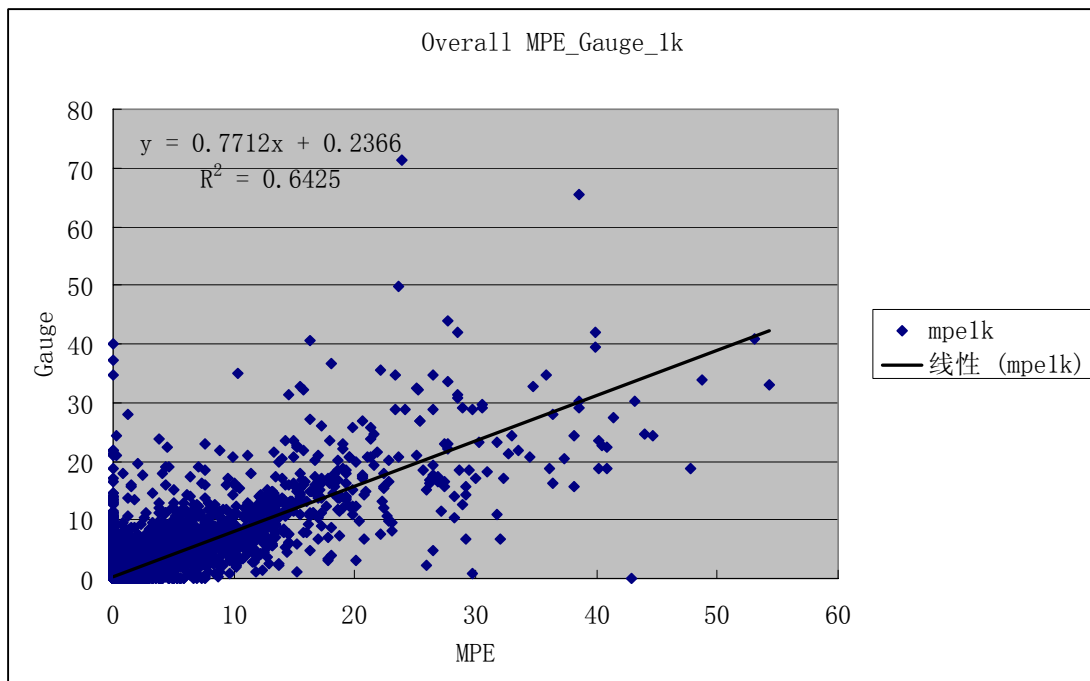


Figure 10 Overall Scatter plot of 1km * 1km hourly radar MPE and rain gauge precipitation in the year 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

Basin.

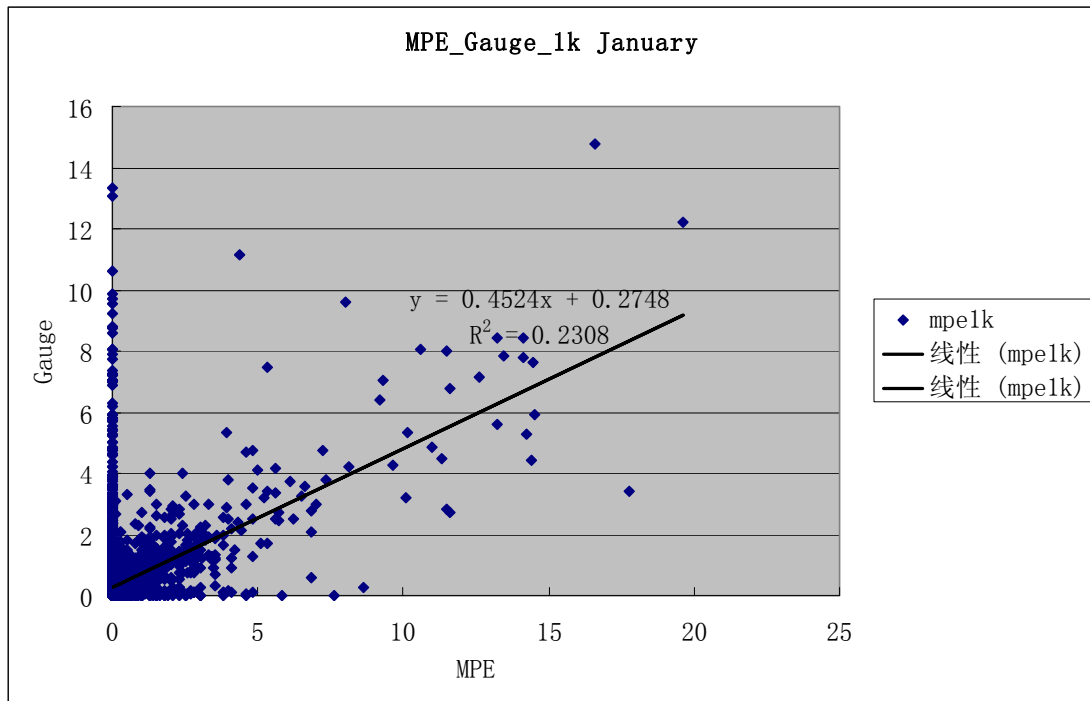


Figure 9 Scatter plot of 1*1 km hourly radar MPE and rain gauge precipitation in January, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

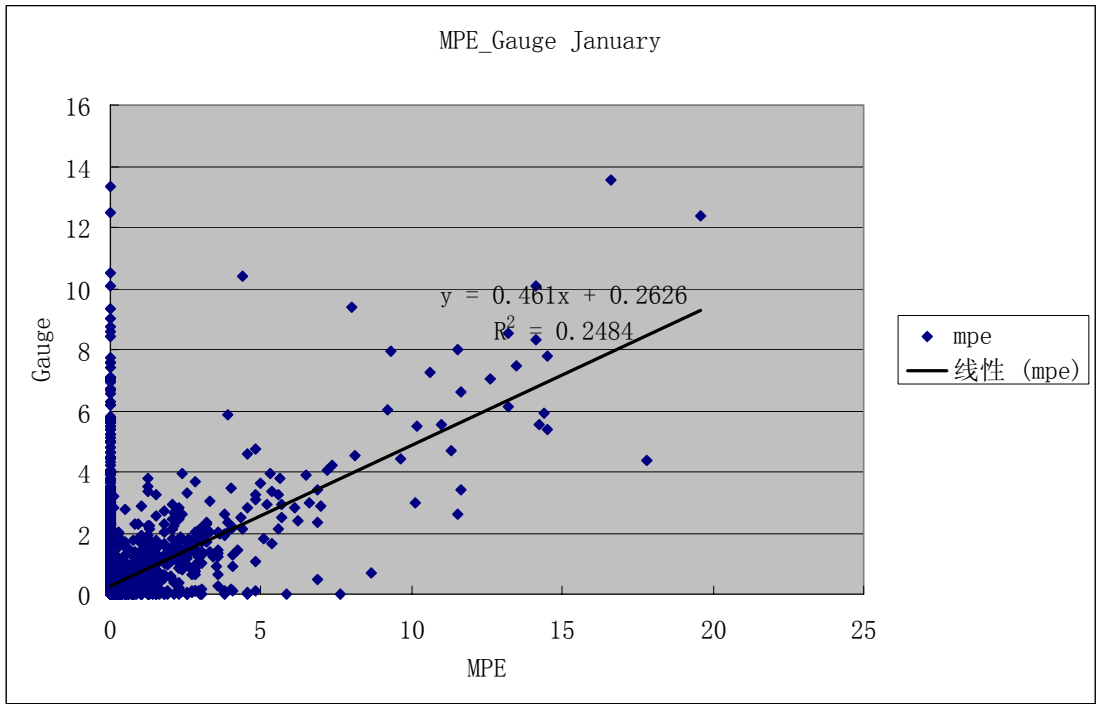


Figure 9 Scatter plot of 4*4 km hourly radar MPE and rain gauge precipitation in January, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

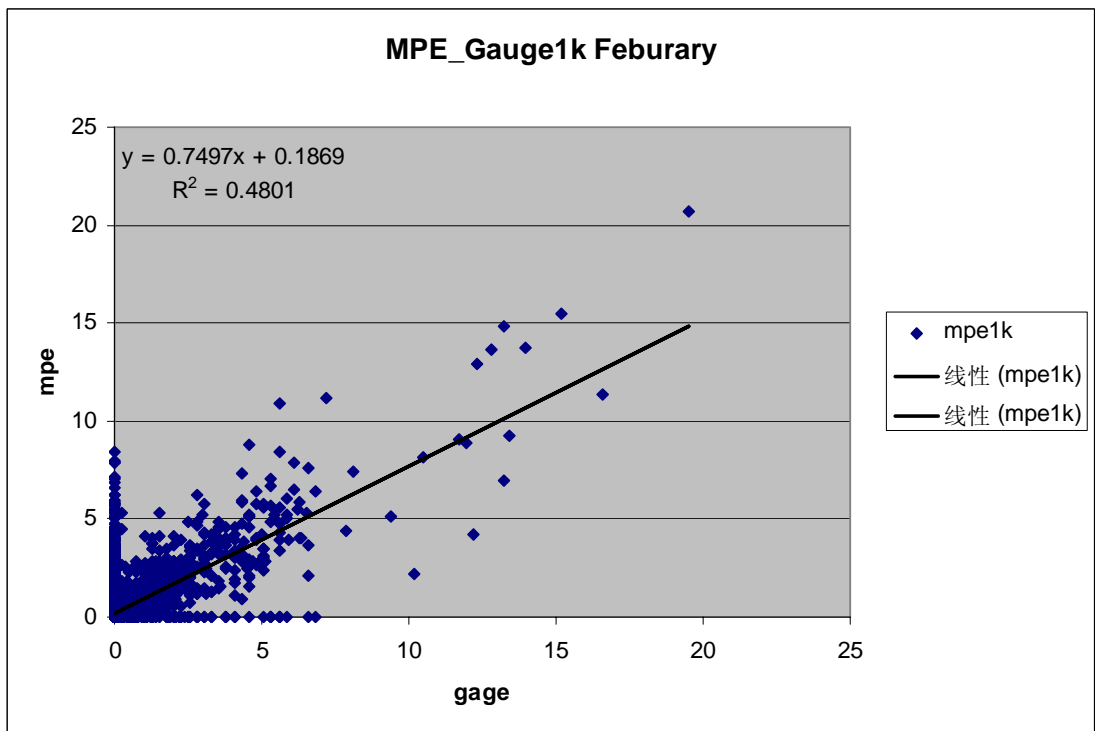


Figure 11 Scatter plot of 1*1 km hourly radar MPE and rain gauge precipitation in

February, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

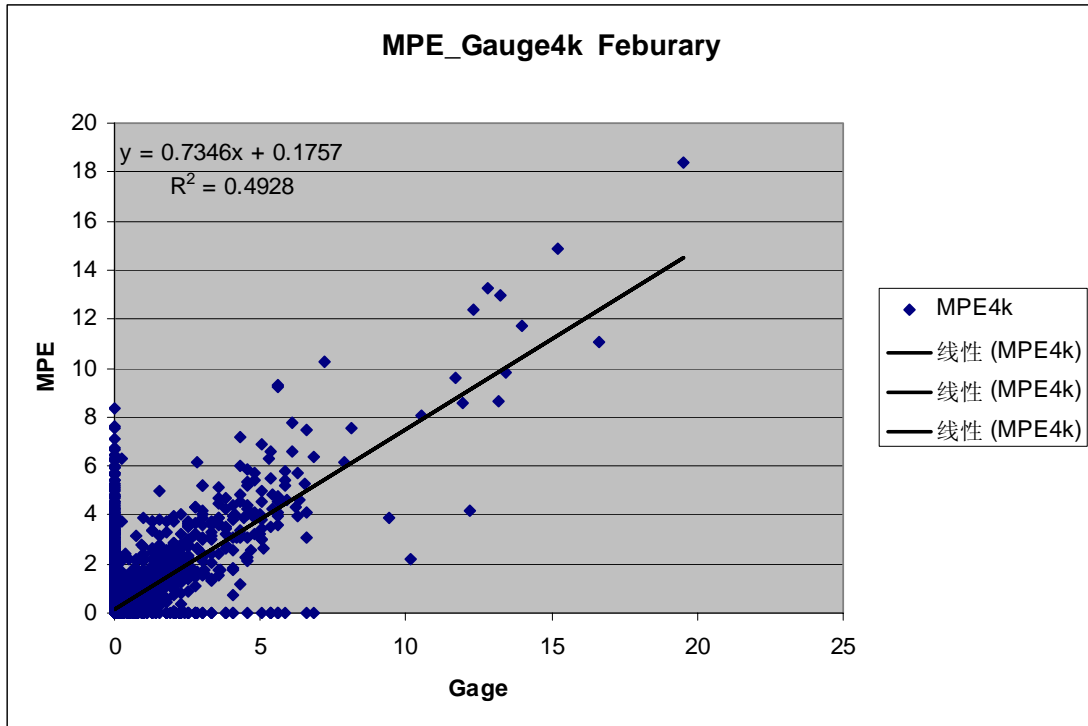
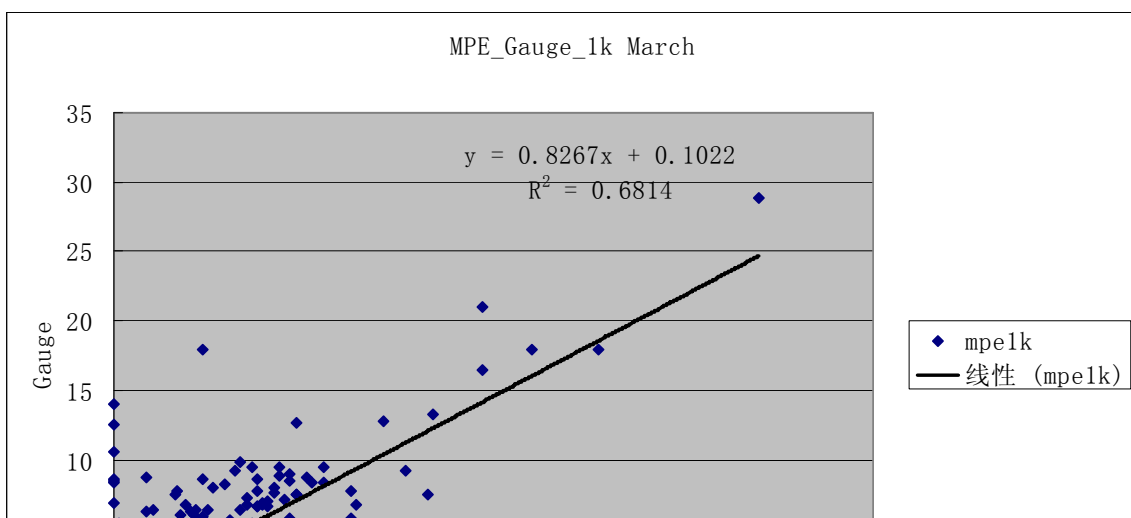


Figure Scatter plot of 4*4 km hourly radar MPE and rain gauge precipitation in February, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.



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Figure Scatter plot of hourly 1*1km radar MPE and rain gauge precipitation in March, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

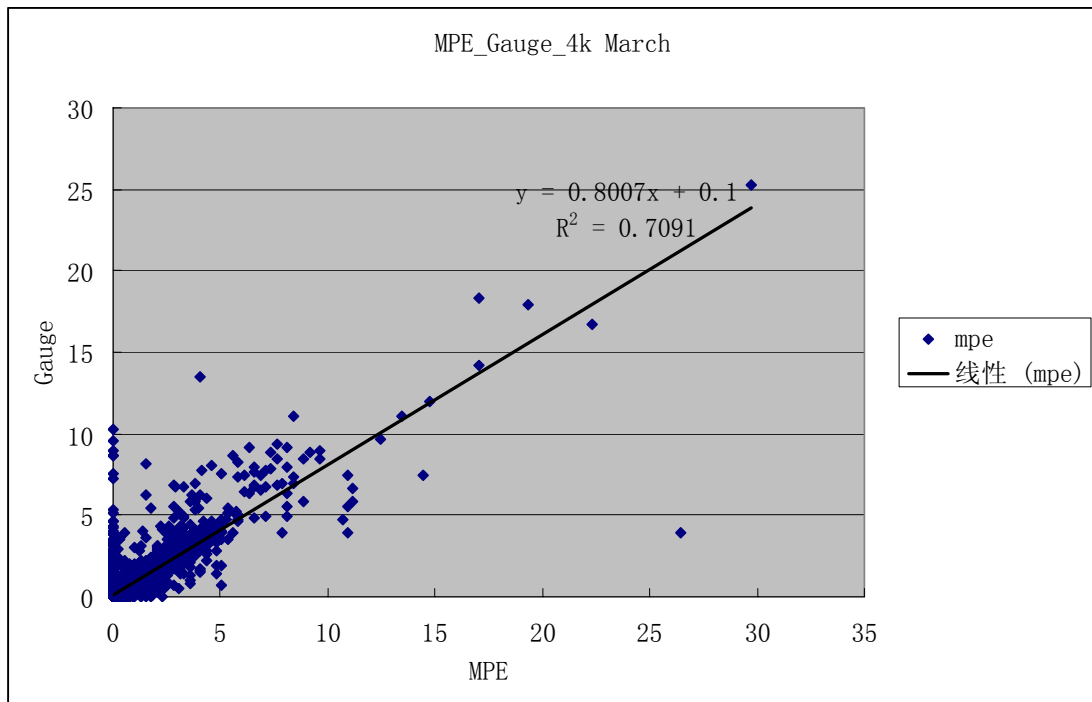


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in March, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

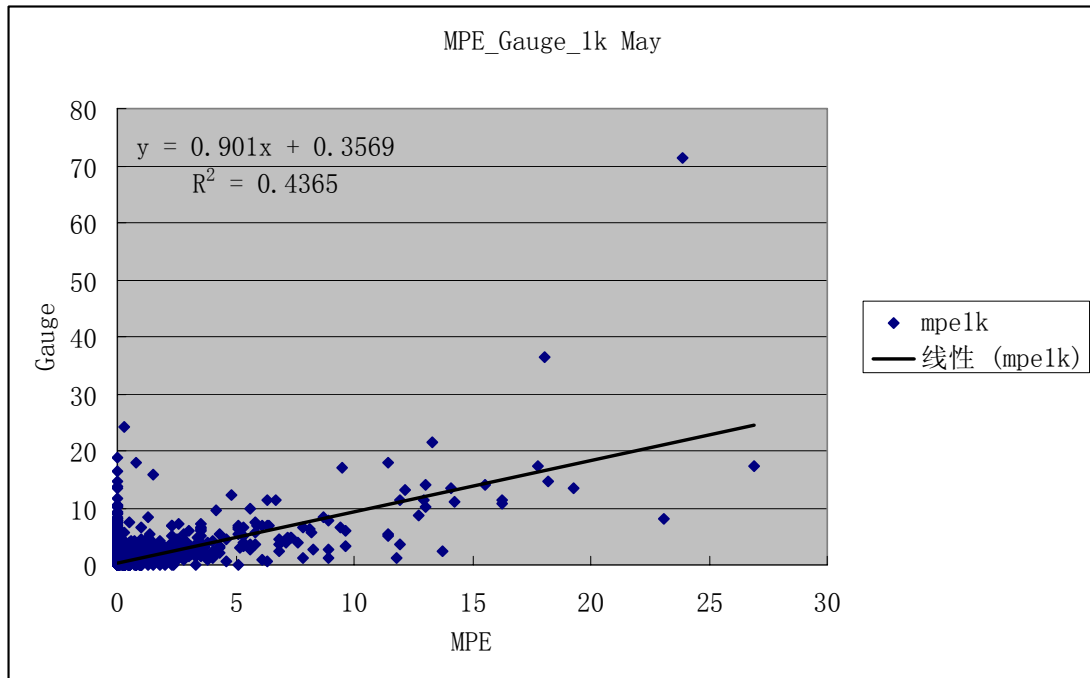


Figure Scatter plot of 1 km * 1 km hourly radar MPE and rain gauge precipitation in May, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

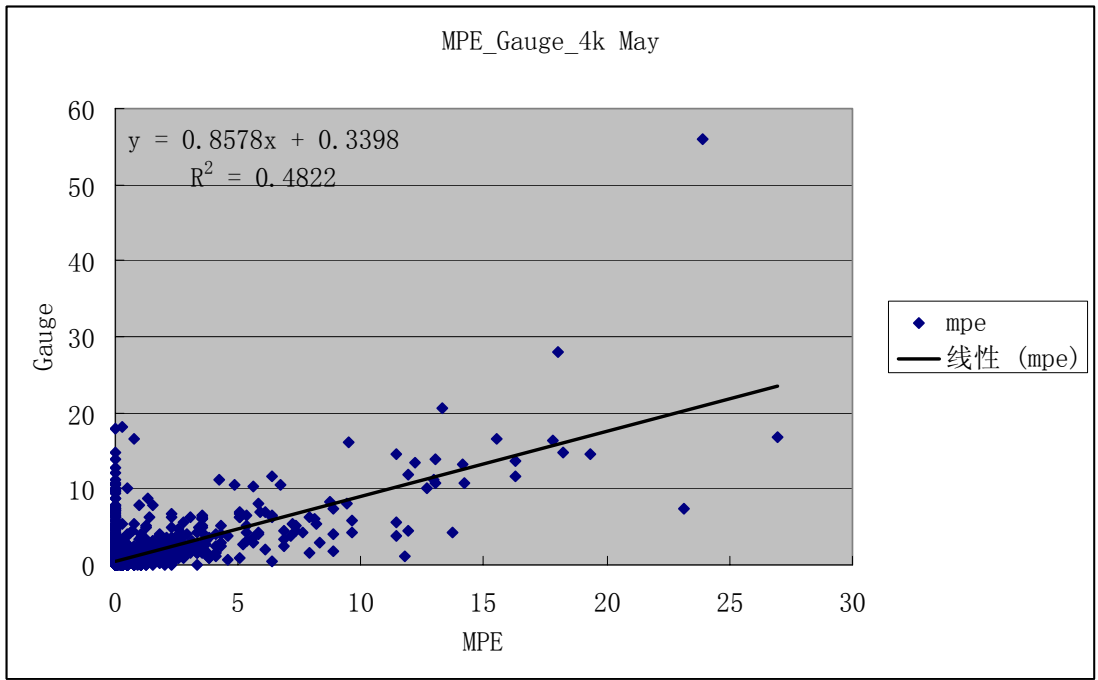


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in March, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

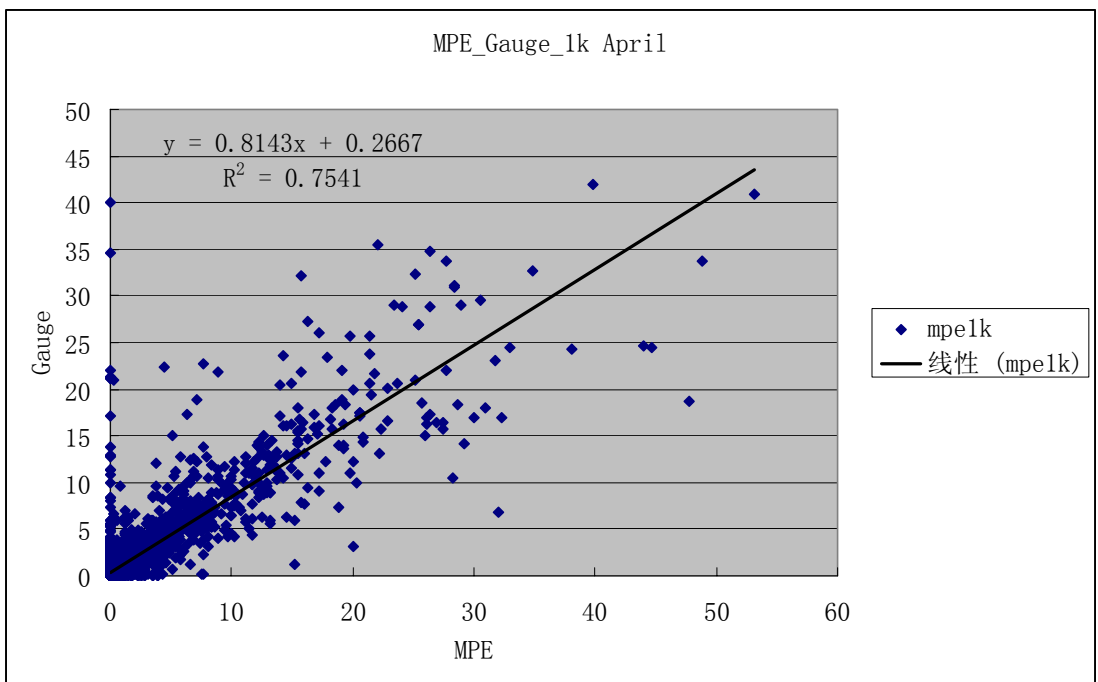


Figure Scatter plot of 1 km * 1 km hourly radar MPE and rain gauge precipitation in April, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

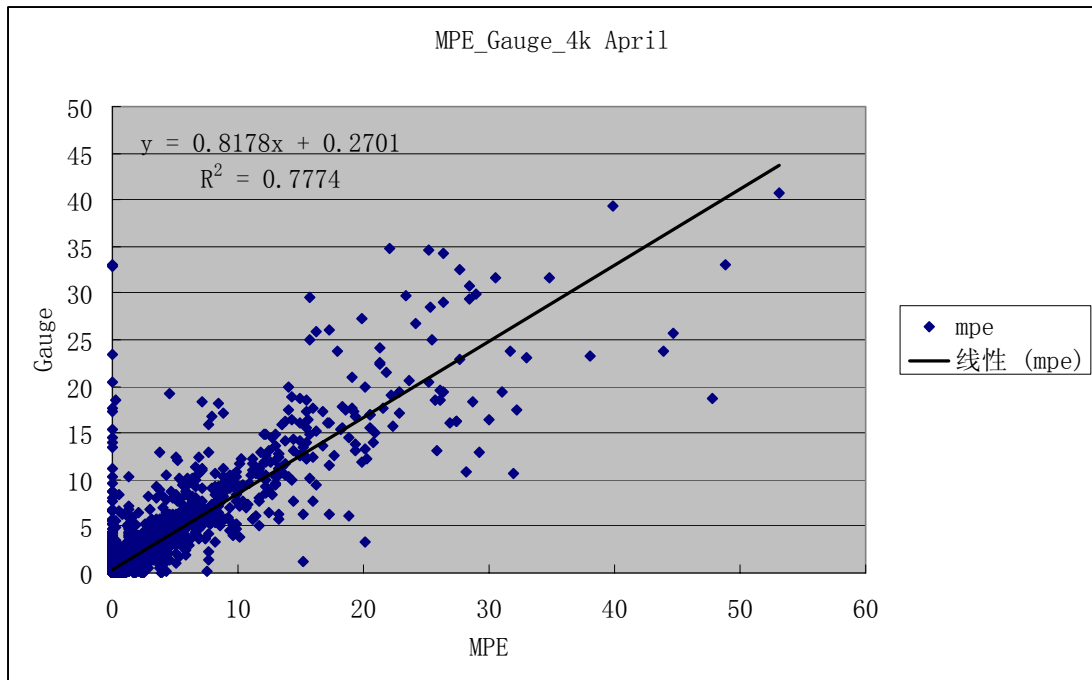


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in April, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

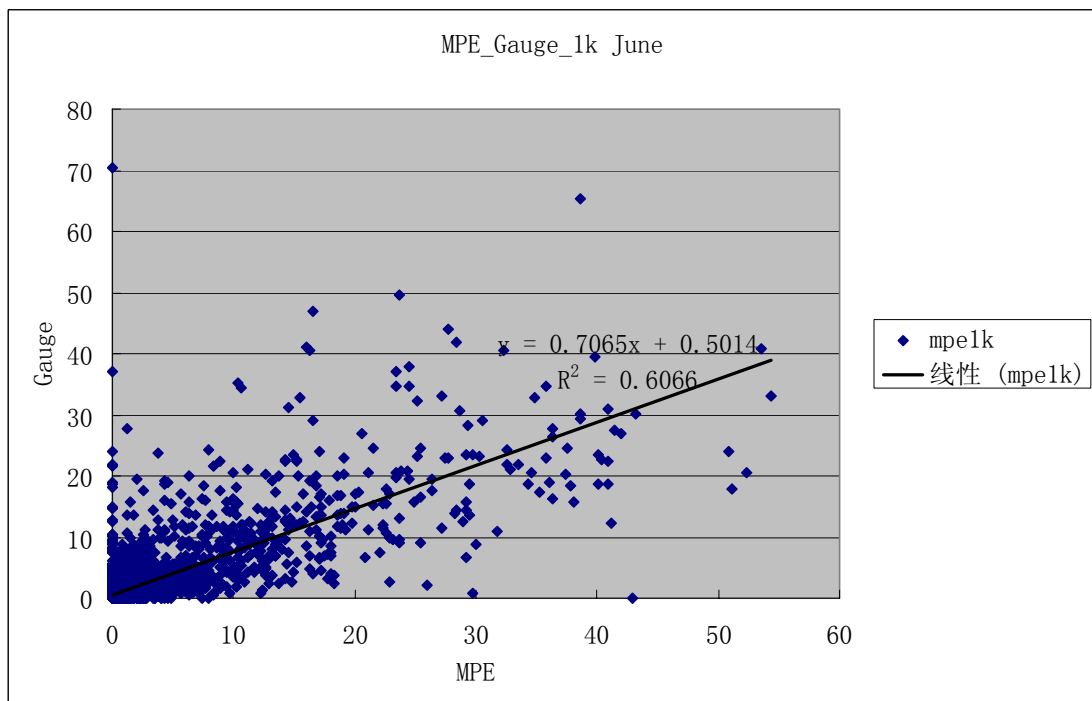


Figure Scatter plot of 1 km * 1 km hourly radar MPE and rain gauge precipitation in June, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

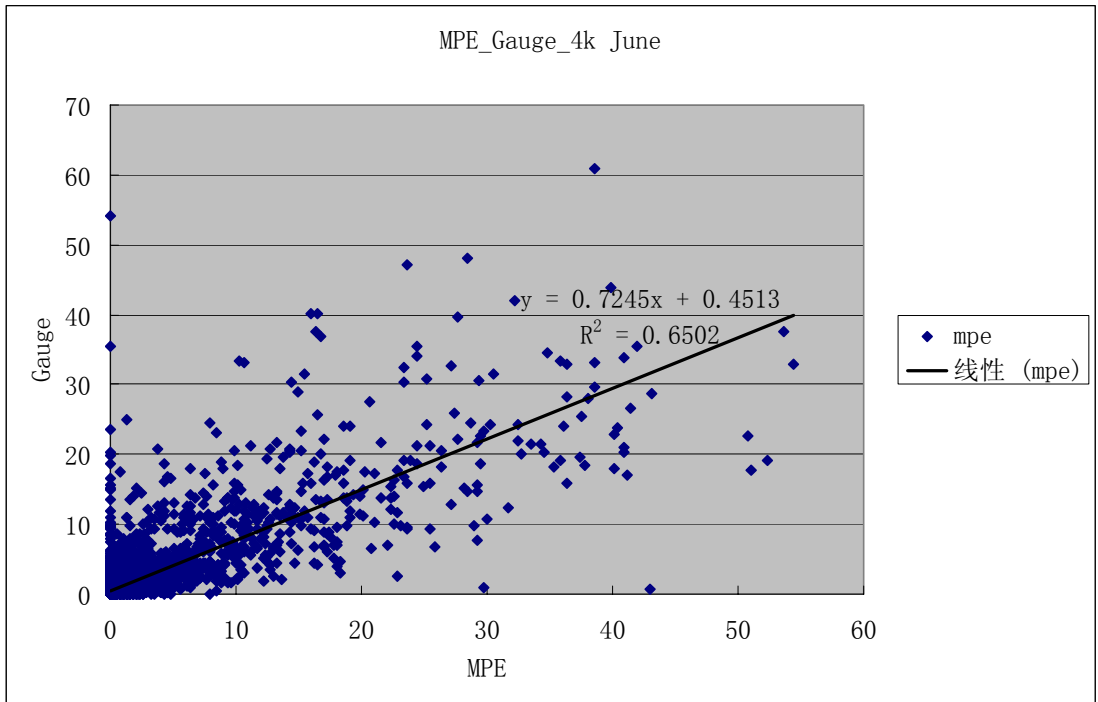


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in June, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

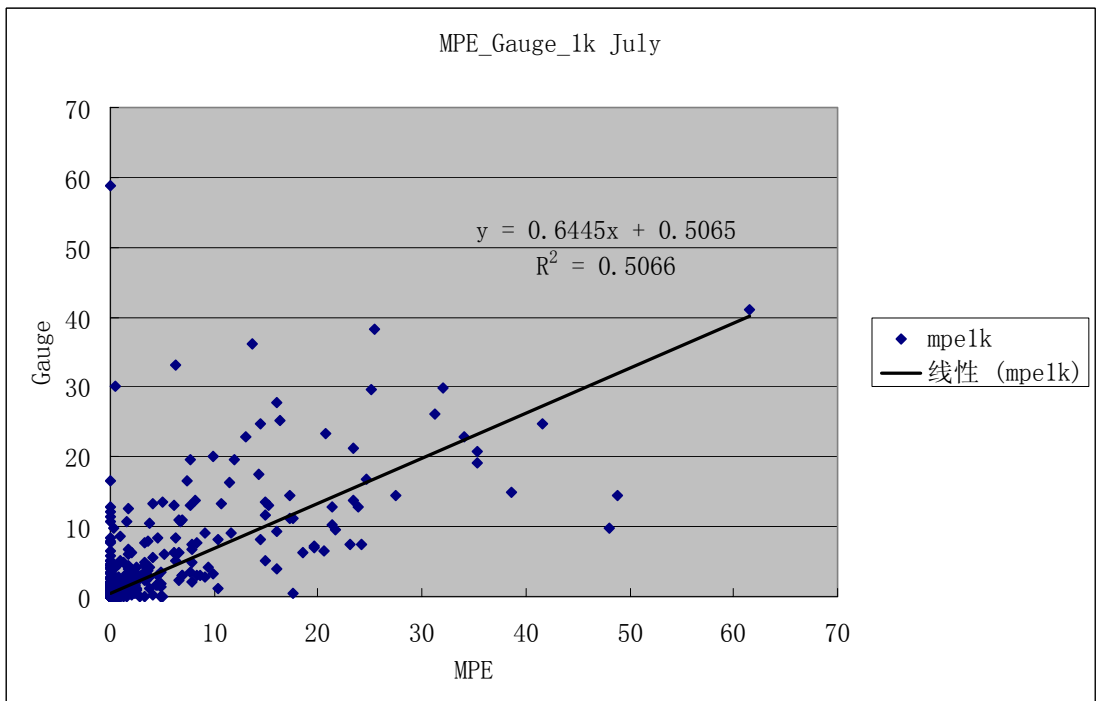


Figure Scatter plot of 1 km * 1 km hourly radar MPE and rain gauge precipitation in July, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

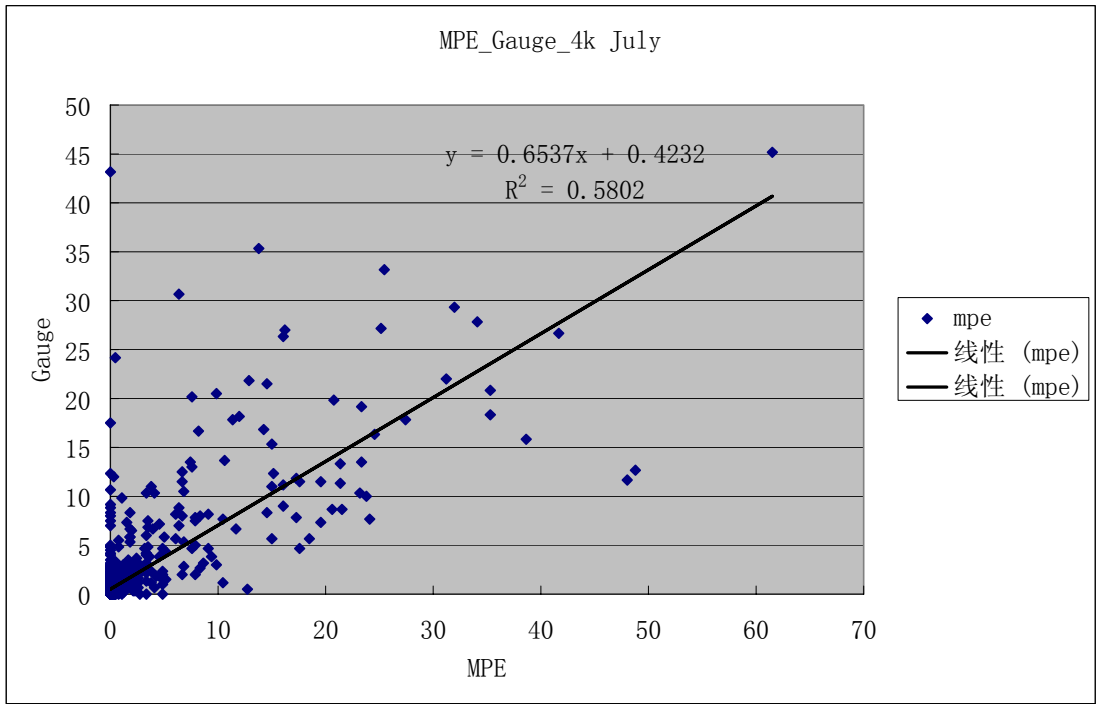


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in July, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

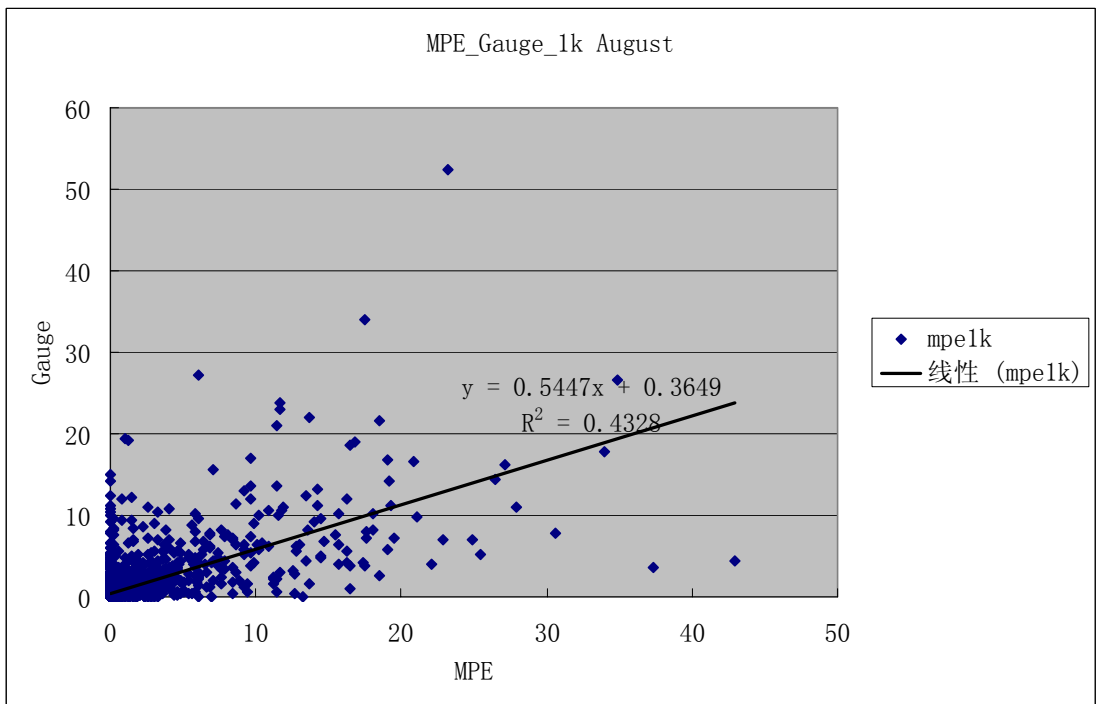


Figure Scatter plot of 1 km * 1 km hourly radar MPE and rain gauge precipitation in August, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

August, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

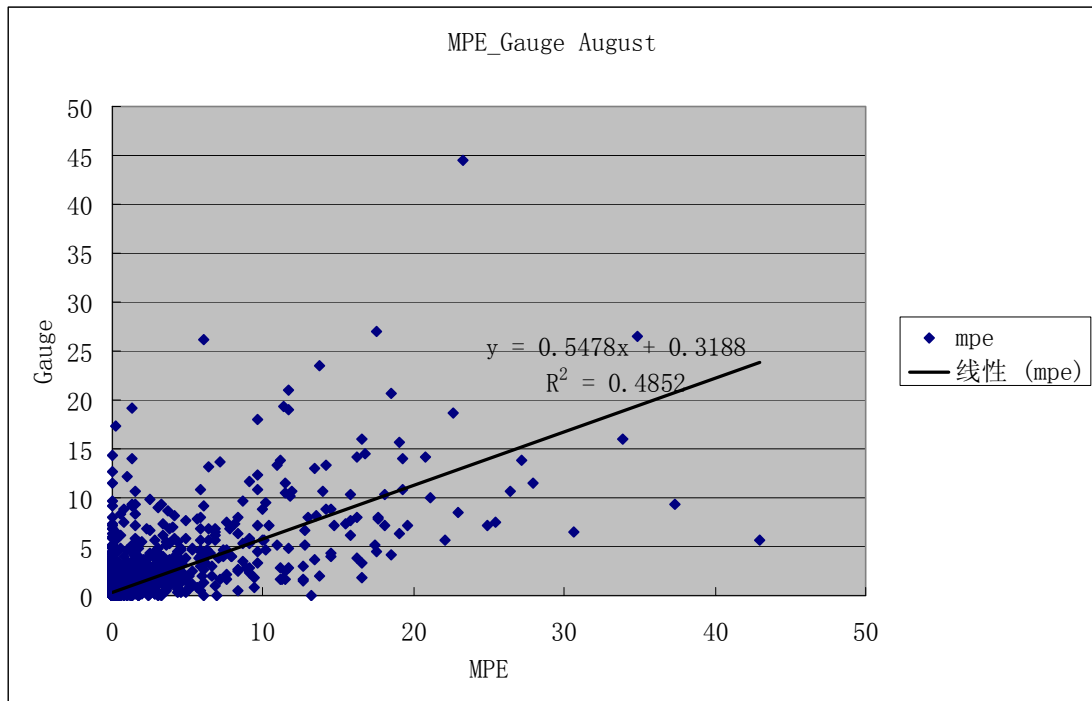


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in August, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

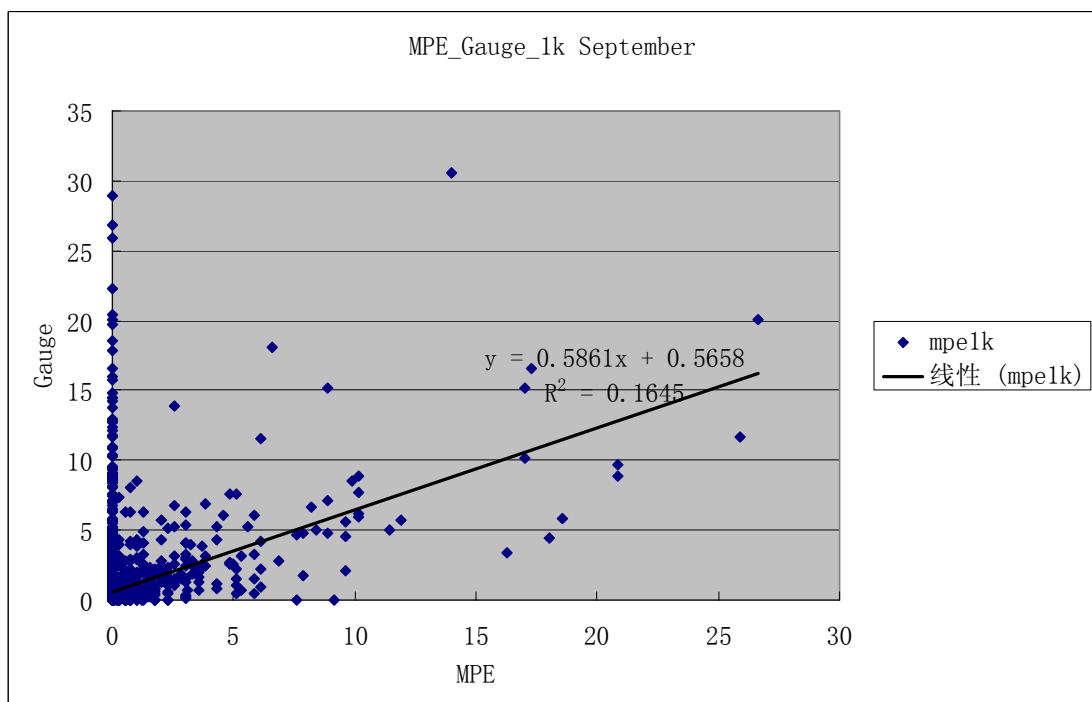


Figure Scatter plot of 1 km * 1 km hourly radar MPE and rain gauge precipitation in September, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

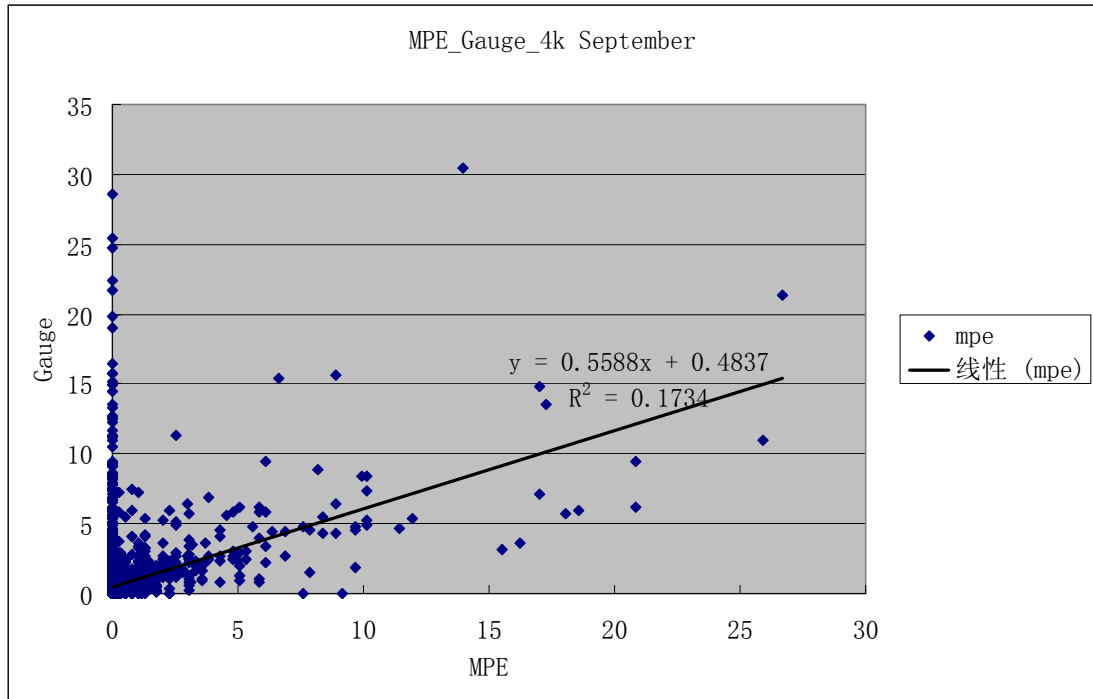


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in September, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

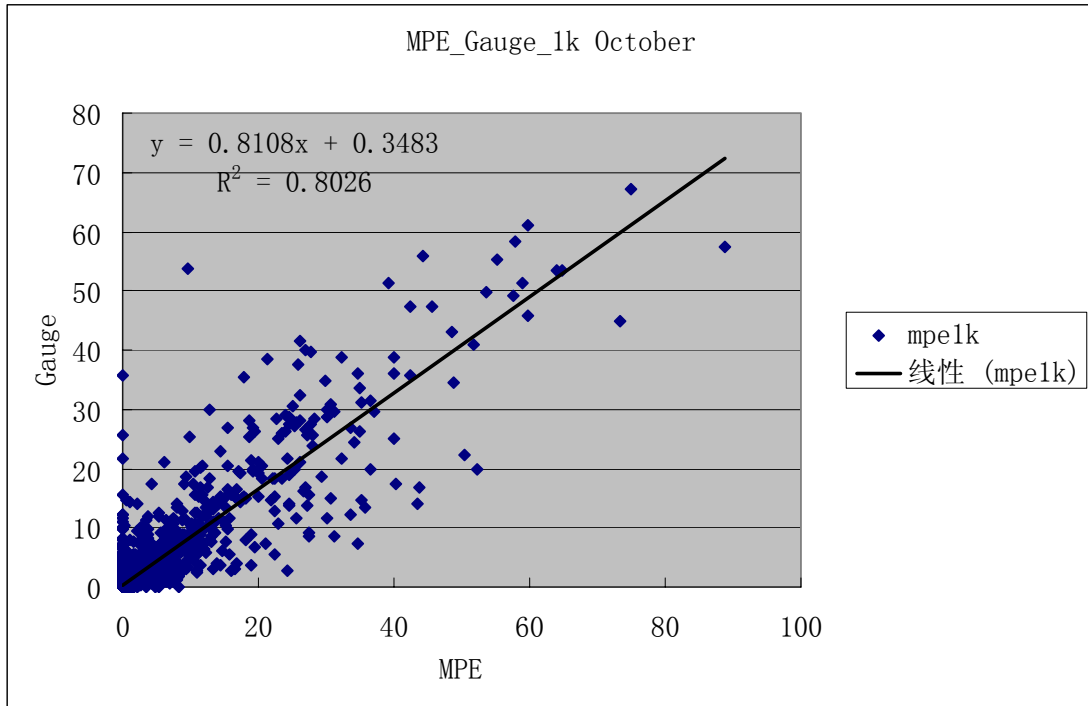


Figure Scatter plot of 1 km * 1 km hourly radar MPE and rain gauge precipitation in October, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

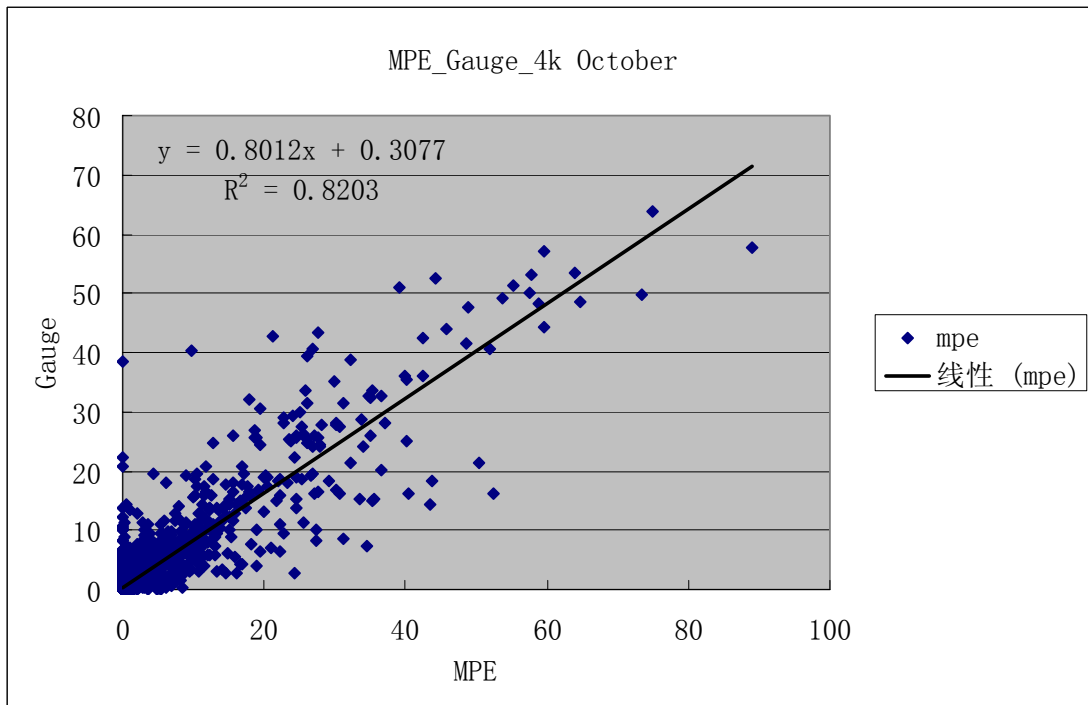


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in October, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

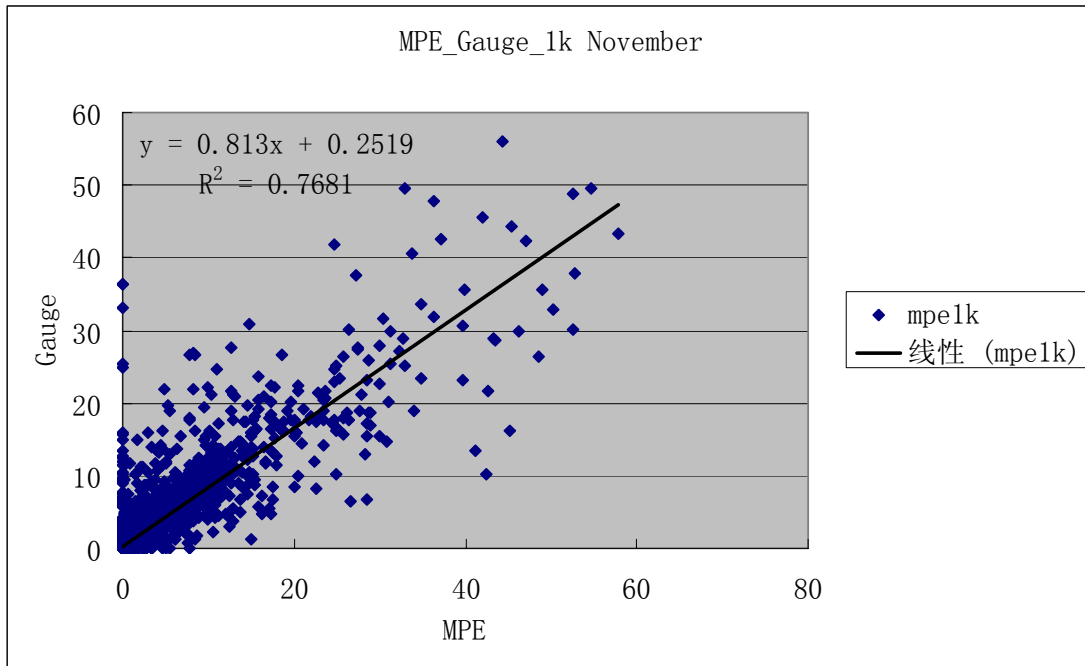


Figure Scatter plot of 1 km * 1 km hourly radar MPE and rain gauge precipitation in November, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

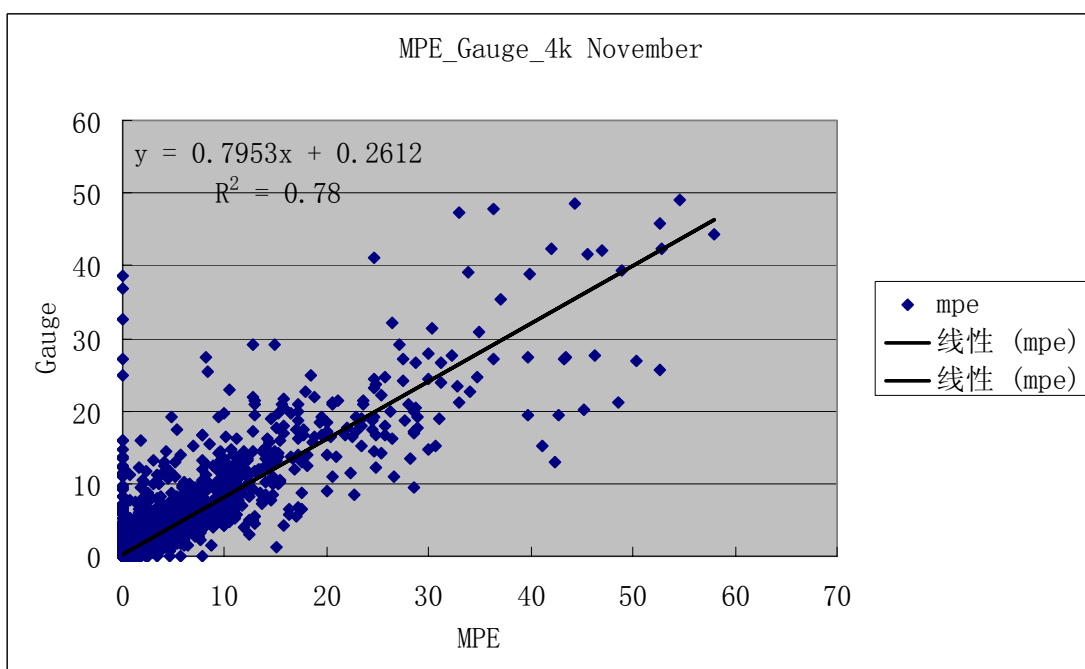


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in November, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

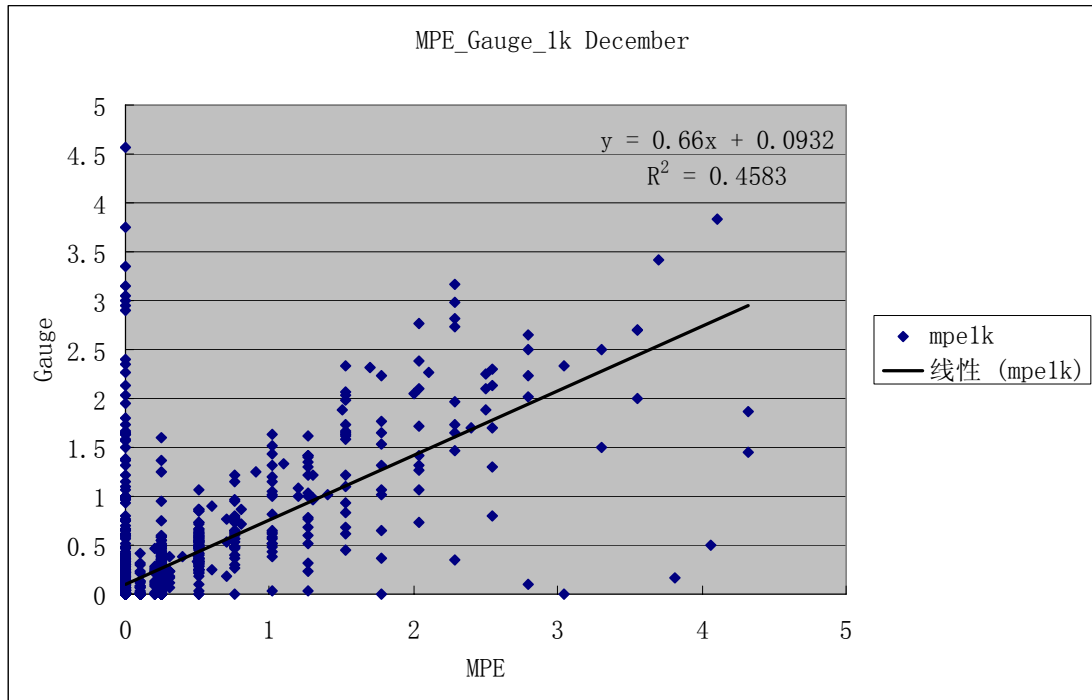


Figure Scatter plot of 1 km * 1 km hourly radar MPE and rain gauge precipitation in December, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

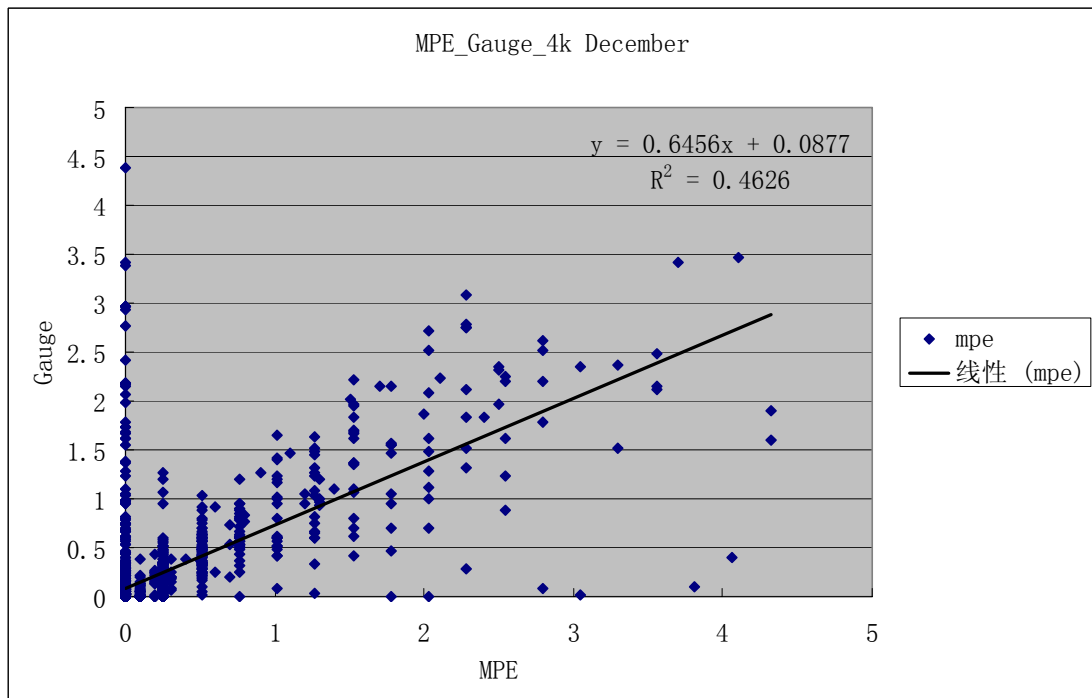


Figure Scatter plot of 4 km * 4 km hourly radar MPE and rain gauge precipitation in December, 2004-2005 at Guadalupe River Basin and San Antonio River Basin.

