P 2.4 Automated Real-Time Operational Rain Gauge Quality-Control Tools in NWS Hydrologic Operations

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1. Introduction

One of the operational missions of the National Weather Service (NWS) is collecting hydrometeorological data and disseminating it to the field operations. The Office of Hydrologic Development (OHD), a division of the NWS, supports the NWS hydrological operations by developing, implementing and maintaining hydrological and hydrometeorologcal models and systems. Inaccurate and inconsistent hydrometeorological data can significantly degrade forecasting hydrometeorological processes. Therefore, quality control and development of quality-control tools to support the NWS hydrologic operations have become one of the missions of the OHD. Because of the need to handle high volumes of data and need to give timely forecast, it is necessary to automate these quality-control procedures. This study focuses on the development of automated rain gauge quality-control tools. Due to the nature of the rainfall characteristics, which is highly variable in space and time, it is extremely difficult to develop fully automated rain gauge quality-control tools. Therefore, the automated or semi-automated tools developed in this study are to flag the suspect rain gauges in order to reduce the number of observations that must be manually reviewed and to allow the Hydrometeological Analysis Support (HAS) forecaster at a River Forecast Center (RFC) to focus his or her judgment on the problem cases.

In section 2, a conceptual rain gauge quality-control model is presented and this conceptual model is discussed in the context of current hydrologic data flow in the NWS operations. In section 3, some of the quality-control tools currently in operations or proposed for future implementation are discussed. In section 4, results from the Spatial Consistency Check applied to actual data from the Mid-Atlantic RFC (MARFC) are discussed and in section 5, conclusions and future plans are discussed.

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2. Conceptual model of rain gauge Quality Control

The quality issues of rain gauge or hydrometeorological data in general come from the fact that these data are collected at a remote location using an automated device, and then transmitted electronically through several ports before actually being used in an application. In this path of data flow, there is lot of scope for a report to go bad before use in an application. Therefore, quality-control tools need to be developed and applied at several stages in this data path. Also, because of the highly variable nature of precipitation in space and time, a single check to quality-control rain gauge data is not sufficient. Several QC checks at several different stages of data flow in the operations are needed. Therefore, a four level conceptual quality control model is envisioned to quality-control rain gauge data. These levels vary in the degree of complexity of the checks performed on them.

2.1 Level - I QC

Checks in this level are performed on an individual datum observed by a sensor. Level - I checks are performed on single observation for a given location for an observation time. These checks look for gross errors caused by instrument malfunction, transmission errors such as parity errors (all bits not being reported properly), coding/decoding errors due to format changes or incorrect formatting etc.

Example: A negative number for rainfall is meaningless.

This "gross error check" is the most preliminary check that can be performed on an observation. If an observation fails this preliminary check, that observation may not go through any further checking, unless a user manually wants to modify this observation using his/her own judgment.

2.2 Level - II QC

Checks in this level also involve a single observation. Observations in this level are checked against some boundaries for their validity. These boundary values may be dependent on space and time. So the boundary values are fixed for a location and for a time of the year. These values can be derived from the climatology of a location. Because the boundary limits are set based on the climatology of the location and the observed value has to fall within these limits, this check is called "Range Check" or "Climatological Range Check"

2.3 Level - III QC

Checks in this level are more advanced than in the previous levels. The checks in this level are based on an observation being checked against other independent observations of the same type or different type from different source. An observation at a point is checked against observations from the neighboring observations, at the same time or from the past, of the same source type or observations from the different source types at the same time or from the past. In general the data that are being checked in this level must already pass the first two levels of checking. The type of checks that fall in this level are called multi sensor checks because they use observations from different sensors at different times. The quality control checks discussed in this paper fall in this level. These checks are Spatial Consistency check, Multi Sensor Check and Temporal Consistency Check.

2.4 Level - IV QC

The procedures in this level are based on human expert judgment. The expert judgment can be based on the person's knowledge about the history of the gauge or using ancillary information from other sources or personal telephone calls about the weather situation at the location in question.

Figure 1 explains how the conceptual model described so far fits in the NWS operational hydrologic data flow. Rain gauge data come in Standard Hydrometeorological Exchange Format (SHEF) encoded format and get posted to the Integrated Hydrologic Forecast System (IHFS) database which is the data repository for all point values in RFC operations (Glaudemans, et al, 2002). Hydrologic applications extract data from this database and use it. Mostly the applications that use rain gauge data are preprocessors, such as precipitation processing software called Multi-sensor Precipitation Estimator (MPE), or NWS River Forecast System (NWSRFS) software for Mean Areal Precipitation (MAP). These pre-processors prepare the actual input data needed by the hydrologic models. As one can see, the rain gauge data flows asynchronously through several stages from the place of observation to the final application. Because the data flow through several stages from the point of observation to the final application, several QC checks at several different stages in the data flow are needed. Therefore, a complex QC system such as the one discussed above is necessary.

The level - I QC can be best applied at the data collection stage, because at this stage only one observation is available at any given time. In the NWS hydrologc operations, this level of QC is performed by the Hydrometeorological Automated Data System (HADS), which collects data from the DCPs (Data Collection Platform), checks for gross errors and encodes them in the SHEF format with a data quality qualifier.

At the entry point to the database, SHEF-encoded information is decoded. The QC information that comes with the SHEF message is sometimes used to determine whether to post the data to IHFS database or reject it to the "Rejected Data" table in the IHFS data base. A range check and a climatological range check are applied to each observation before posting to the database. At this stage, the observations are still available as single pieces of information. So the QC checks applied at this stage come under level - II QC.

Once data are posted to the database, gauge data from multiple hours, multiple locations are available. Also several different types of observations are available. Checks which are dependent on multiple observations, multiple variables and multiple observation times can be applied at this stage. So multi-sensor checks discussed under level - III QC are applied at this stage in the data flow. The QC procedures discussed in this paper come under this level - III QC. Just before using the data in an application (or preprocessor), a human being can manually check the observations and make final decision as to the quality of the data. This manual QC process comes under level - IV QC.

3. Quality Control Tools

3.1 Spatial Consistency Check

Spatial consistency checking is used to identify outliers which are not spatially consistent with the neighboring gauges (Kondragunta, 2001). This is also called "buddy check". There are several steps involved in the spatial consistency check implemented in the operations. In the first step, outliers are identified following a statistical procedure for a small region ($1^0 x1^0$ latitude-longitude grid box) of the service area. Since, rainfall is highly variable in space and time, and a rain gauge received rainfall from a convective system does not have to be spatially consistent with the neighbors, a convective screening test was developed. In the second step, a convective screening checks if a gauge received rainfall from a convective system based on lightning information. In the third step, the entire procedure was repeated and automated for a service area i.e an RFC.

3.1.1 Identification of Outliers

There are four steps involved in the identification of outliers.

(i) First step involves calculation of median, 25^{th} and 75^{th} percentile of the data set under consideration.

(ii) Second step involves calculation of Mean Absolute Deviation (MAD) as follows:

$$MAD = \frac{1}{N}\sum_{i=1}^{N} | X_i - X_{med}|$$

where X_{med} is the median of the data
N is the total number of stations
X_i is the i^{th} value of the data

(iii) Third step involves calculating an Index (Madsen, 1993) for each station as follows:

if (MAD=0) Index=0.

Else

If ($Q_{75} \neq Q_{25}$) then
Index=$|X_i - Q_{50}| / (Q_{75} - Q_{25})$
Else
Index=$|X_i - Q_{50}| / MAD$

Where Q_k is the k^{th} percentile.

(iv) In the final step, the index calculated in the step three is compared to a predefined (user defined) threshold value. If the index is greater than the predefined threshold value, then the rain gauge data is flagged as an outlier.

The procedure described so far is applied to all gauges that fall in a 1^0x1^0 latitude-longitude grid box. Section 3.1.3 describes how this check is applied to entire service area.

3.1.2 Convective Screening

If a gauge is under the influence of an intense thunderstorm, theoretically, it does not have to be spatially consistent with its neighbors. Therefore, in order to screen gauges which receive rainfall from an intense thunderstorm, a gauge identified as an outlier from the spatial consistency check, discussed in the previous section, is compared against the lightning data. If there existsat least one lightning strike within approximately 10 km radius from the gauge during the past one hour, then that gauge is removed from the outlier list and the observation is considered valid.

3.1.3 Automation of the Spatial Consistency Check

As mentioned in the introduction, the quality control checks need to be automated as much as possible in order for them to be efficient and to reduce the manual labor and subjectivity of the quality control process. The Spatial Consistency Check (SCC) discussed above is automated for an RFC or WFO region in the following way.

The entire service area is divided into $1^0 x 1^0$ latitude-longitude gird boxes. Starting from the top left corner box, the SCC was applied to each ($1^0 x 1^0$) box, moving to right by a half box each time (0.5^0). After reaching the end of the first row, moving down by a 0.5^0 and again starting from the left and moving to right, the SCC is applied to each box in this row. These steps are repeated for the entire service area. Except for the gauges that fall in the outermost ½ deg. region at the periphery of the service area, this procedure ensures every gauge in the entire service region is tested for its spatial consistency in all four directions by the SCC. If a gauge is picked as an outlier four times (i.e. a gauge is tested by SCC by neighboring gauges in all four quadrants), then that gauge is finally flagged as an outlier. Once the outliers are flagged from this procedure, convective screening technique discussed in section 3.1.2 is applied to check if any of these flagged gauges received rainfall from a thunderstorm. If a gauge received rainfall from a convective system, as evidenced by convective screening test, then that gauge is removed from the flagged gauges list.

3.2 Multi-Sensor Check:

The Multi-Sensor Check (MSC) designed in this study is intended to identify rain gauges that are stuck i.e. rain gauges that report zero rainfall even thought there is an indication of rainfall from other sensors such as radars. This type of malfunction is not detected by gross range or climatological range checks because zero rainfall is a valid rainfall value and falls within the limits set be these checks. One way to identify these stuck gauges is to compare the zero rainfall value with rainfall from the other sensors such as radar and/or satellite.

Two types of multi-sensor checks are discussed here. The first one is to compare a given zero rain gauge report with the estimated rainfall values from radar. If the difference between the rain gauge value and the radar value is greater than a threshold, then that particular gauge is flagged as stuck. The particular check discussed here involves comparing zero valued gauge reports with radar rainfall estimates from collocated as well as neighboring eight grid boxes around the gauge. If a rain gauge value is zero and the corresponding radar or satellite values are greater than or equal to a 1 mm threshold, then that particular rain gauge value is flagged as a stuck gauge. This threshold is an adaptable parameter and can be varied depending upon the season and location.

The second type of test involves comparing the zero-valued rain gauge reports with the rainfall from the neighboring gauges. The idea behind this type of check is, if rainfall is reported in all four directions and a gauge in the middle is reporting zero rainfall value, then that gauge is probably malfunctioning. The result from this test should be used in conjunction with gridded rainfall information from the other sensors such as radar or satellite. The particular check developed in this study involve checking a zero-valued gauge report with the rainfall from the neighboring eight Hydrologic Rainfall Analysis Project (HRAP) grid boxes. If rainfall is reported in at least one box in each side surrounding the gauge in question, then that particular gauge is flagged as a stuck gauge.

3.3 Temporal Consistency Check

Similar to MSC, the Temporal Consistency Check (TCC) is also designed to identify stuck rain gauges. Compared to MSC, this check is more robust and involves more complexity in flagging stuck gauges. However, there are some downsides for this test to become operationally effective. One of them is, it is computationally more intensive than the MSC.

Another one is, this check requires continuous measurements of both rain gauge and radar data are for a specified time period in order for the check to be more effective. The longer the time period chosen, the more effective the test is, but the more difficult it is to get continuous data without any missing observations and more computationally intensive. Following are the steps involved in this test.

In the first step, cumulative time series for hourly gauge rainfall (G) and hourly radar rainfall (R) are obtained for the time period chosen, in this case a day, as follows:

$$G_i = \sum_{i=i-23}^{i} g_i$$

$$R_i = \sum_{i=i-23}^{i} r_i$$

where i is the current hour.

In the second step, daily differences of the cumulative gauge rainfall and radar rainfall are calculated as follows:

$$\Delta G_i = G_i - G_{i-23}$$

$$\Delta R_i = R_i - R_{i-23}$$

In the third step, certain conditions are applied and a threshold value (i.e. 2 mm) is used to identify the stuck gauges.

The conditions applied are:

If $\Delta G_i > 0$ and $\Delta R_i > 0$, then the gauge is considered functioning.

If $\Delta G_i = 0$ and $\Delta R_i = 0$, then the gauge is considered functioning.

If $\Delta G_i = 0$ and $\Delta R_i >$ threshold, then the gauge is considered stuck or malfunctioning.

The threshold is an adaptable parameter and can be varied depending on season and location.

4. Results and Discussion

In order to show the effect of the SCC on the real time analysis, this check was applied to a case on August 09 2005 in the MARFC area of responsibility. On average, there were about 560 gauge reports for this case. Out of which, about 20 rain gauges were flagged as outliers from the SCC. The flagged gauge reports were manually edited using the Graphical User Interface tool available in the Multi-sensor Precipitation Estimator (MPE) software (Lawrence, 2003). The MPE was run before and after editing the gauges reports. Two of the MPE outputs Gauge-Only analysis (Seo, 1998) and Multi-sensor analysis (Seo, 1998), were validated against daily cooperative rain gauge data. Approximately 25% of these rain gauges become part of operational gauges.

Presented in Figures 2a-b are the scatter plots between validation gauges and gauge-only analysis and multi-sensor analysis from MPE before the rain gauge data were quality controlled. Presented in Figures 2c-d are the same as Figures 2a-b, except for the MPE output after rain gauge data were manually quality controlled by removing gauges flagged by the SCC. Bias Ratio, Root Mean Square Error (RMSE) and Correlation Coefficient (RHO) are calculated and presented in the scatter diagrams. These results indicate that RMS error and correlation coefficient have improved considerably for the gauge-only analysis from before SCC QC to after SCC QC. There is also improvement in the Mulit-sensor field, but the improvement is less than gauge only because, the multi-sensor field tends to minimize the errors. The bias ratio has not improved in either case. This is because only outlying gauge values were quality controlled from this test and not the zero reports. In real operations, both outlying and zero reports are quality controlled.

5. Conclusions

On average Spatial Consistency Check flagged 3.6% of gauges as outliers. Validation results indicate considerable improvement in the RMS error and correlation coefficient for both gauge only analysis and multi-sensor analysis. Bias did not improve because, in this case, only outliers were quality controlled. Quality controlling zero values would show improvement in the bias value also.

More cases of data will be analyzed and presented at the conference. Also, results from the Multi sensor check will be presented at the conference. The Temporal Consistency Check is under consideration for operational implementation.

6. References

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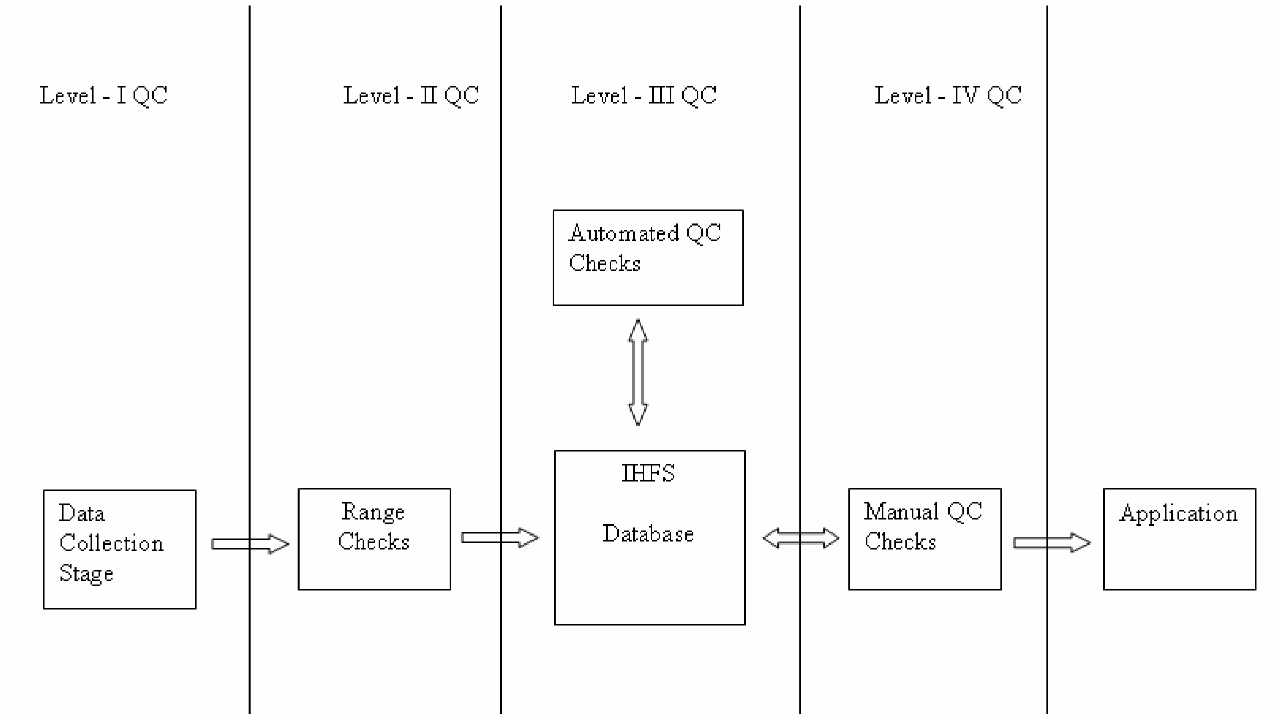


Figure 1. Operational hydrologic data flow and conceptual QC model

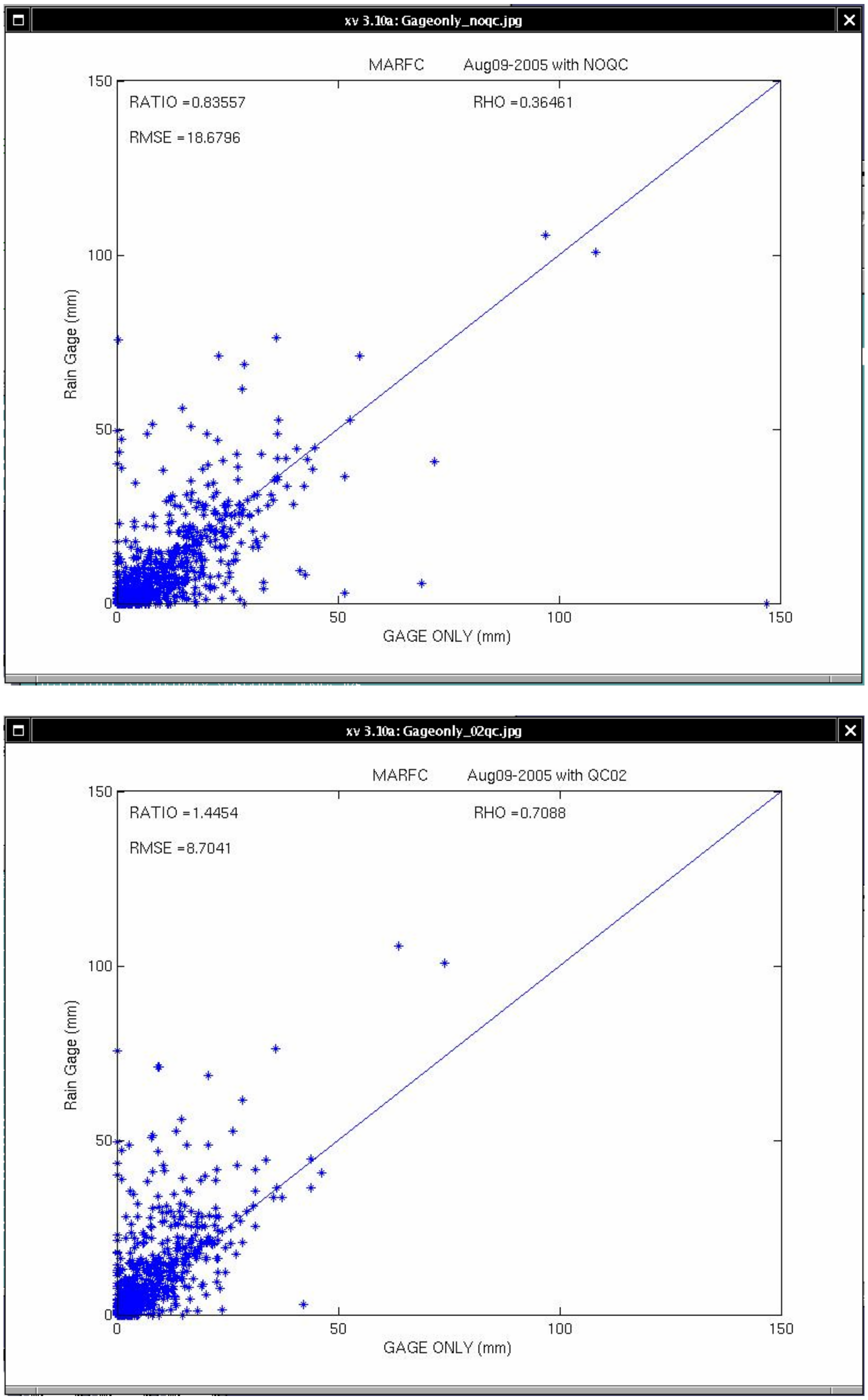
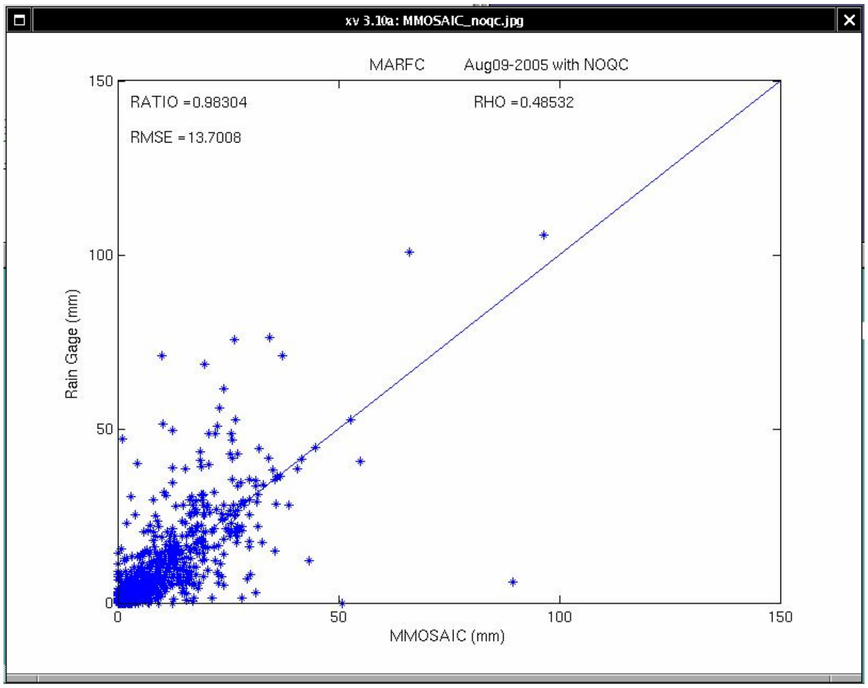


Figure 2a-b Scatter plot between co-op gauges (Y-axis) and gauge-only analysis (X-axis) before quality control (top) and after quality control (bottom) for August 09, 2005



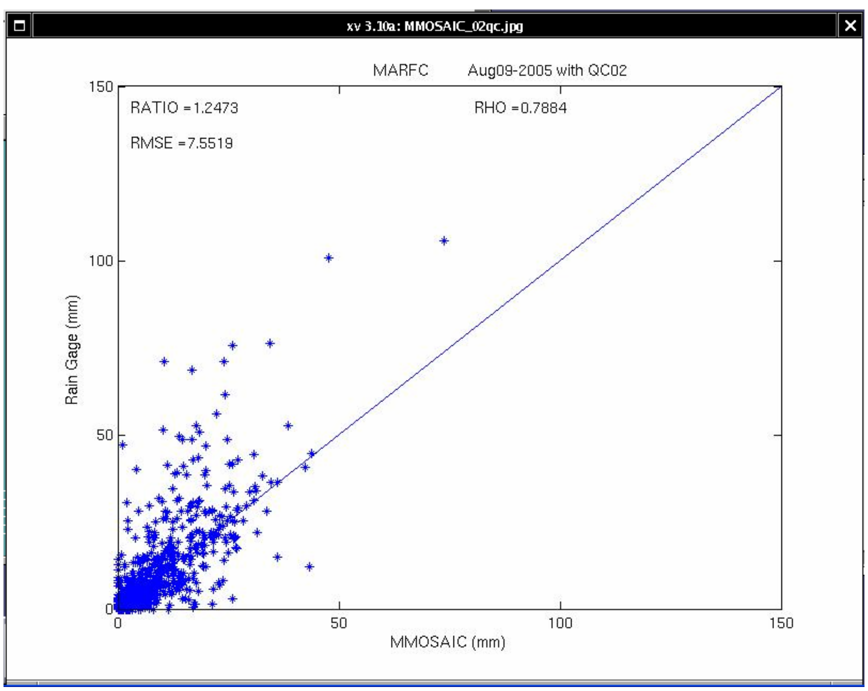


Figure 2c-d Same as figure 2a-b, except for multi-sensor mosaic field.