Real-time Quality Control of 1-hour Rain Gauge Data Using a Multi-Senor Approach

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ABSTRACT

The acquisition and quality control (QC) of real-time precipitation gauge data is a critical element of effective operational flood monitoring systems and accurate precipitation products/tools. **To address the rapidly growing amount of available precipitation gauge data, a systematic method of acquiring, consolidating and QCing 1-hour precipitation data in real-time has been developed. METSTATs QC system operates in two modes: (1) Real-time in order to provide immediate results and (2) Real-time with delay to allow additional datasets and gauges to become available for more thorough QCing.**

Although acquisition of real-time precipitation data into a consolidated database has already been accomplished for many of the major gauge networks across the U.S., there are still numerous networks, such as ALERT, that are yet to be included in MesoWest and MADIS systems. A **strategic partnership** with JE Fuller, Inc. and METSTAT has incorporated nearly 800 ALERT gauges across Arizona alone into the METSTAT consolidated database. METSTATs QC algorithm operates in real-time on over **18,000+ gauges** across the United States and adjacent portions of Canada and Mexico each hour.

Real-time quality control of rain gauge data is among the most challenging elements in development of accurate, timely, and high-resolution spatial rainfall data products, gauge-adjusted radar precipitation and alert notifications. Gauges can suffer from a number of problems including radio transmission errors, freezing precipitation, wind-induced under-catch, rainfall loss during high intensity rain rates, clogs and/or poor gauge maintenance. Given the high temporal and spatial variability of rainfall data, most systematic QC methodologies simply impose a threshold for which to accept or reject the value. However, this approach utilizes real-time spatial meteorological data for a more accurate multi-sensor approach to QCing 1-hour gauge data.

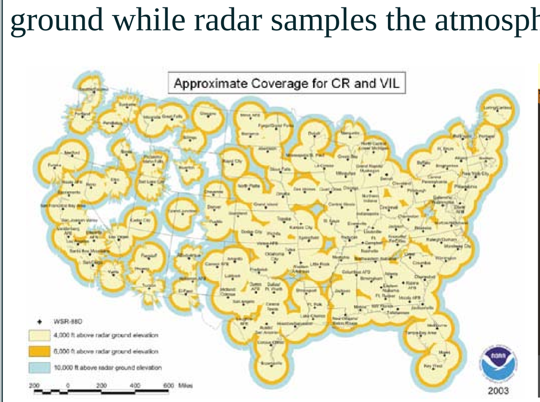
The complexities of gauge QC often prevent a binary (correct or not correct) decision to be made, therefore **METSTATs** QC algorithm provides a QC confidence flag to each 1-hour gauge value ranging from 0.0 to 1.0, where 1.0 suggests the value is likely correct while 0.0 means the value is likely incorrect. **The multi-sensor QC algorithm is based on (1) NEXRAD radar data, (2) Neighboring gauges, (3) National Weather Service Stage IV gauge-adjusted radar-estimated precipitation and (4) satellite-estimated precipitation. (1) and (2) are used for immediate QC, while 1–4 are used for delayed, more thorough QC.**

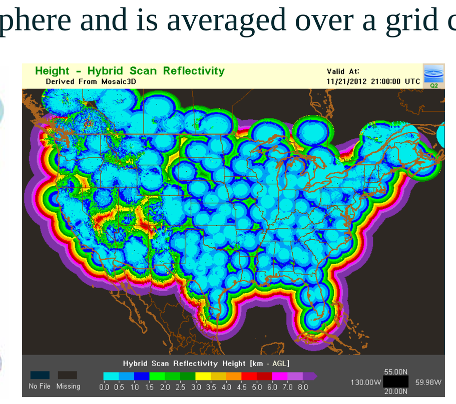
The resulting precipitation data and QC flag can be used in a variety of hydrologic applications, including gauge-adjusted radar-estimated precipitation algorithms, identification of gauge malfunctions, alert notifications of rainfall intensities that meet/exceed thresholds, detailed post-event analyses and climatological studies.

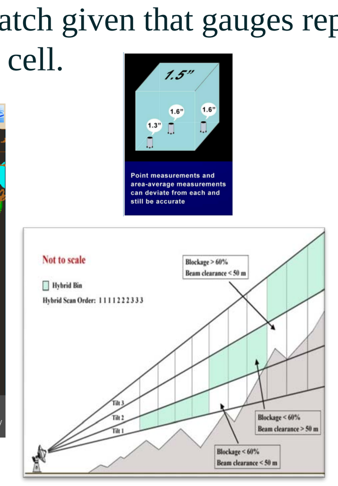
RADAR BASED QC

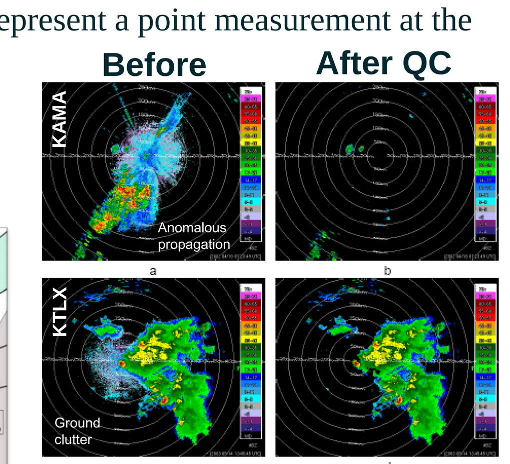
LATENCY	RESOLUTION
5 minutes	1-km²

Real-time radar reflectivity is amongst the best tools for QCing rain gauge data in real-time given its high spatial resolution and low latency. However, reliable radar data is not available for all locations, especially in complex terrain and across a few out-of-range areas of the western U.S.. In order to determine if radar data is reliable, the corresponding reflectivity scan height (above ground level) is used as a weighting factor when comparing the gauge measurement with a radar-derived rainfall amount. The radar-derived rainfall amount is determined by applying a standard Z-R equation to quality controlled radar mosaics from Weather Decision Technologies (WDT). Large differences between the radar-derived and gauge rainfall equate to a lower confidence flag, however the QC algorithm does not expect an exact match given that gauges represent a point measurement at the ground while radar samples the atmosphere and is averaged over a grid cell.









SPATIAL QC

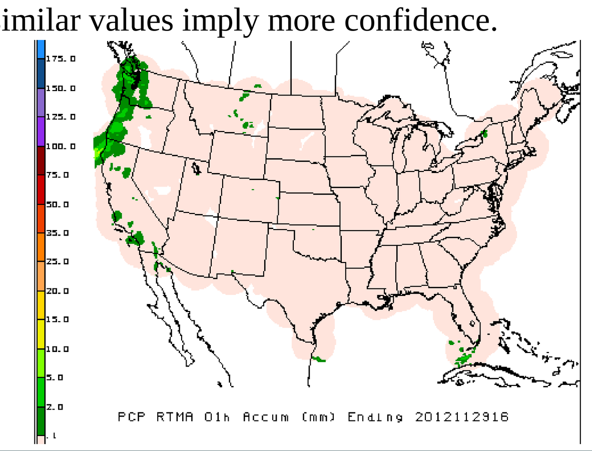
LATENCY	RESOLUTION
5 minutes	1-km²

Neighboring rain gauge observations can provide a "buddy" check for comparing rainfall observations, but the high spatial and temporal variability of rainfall reduce the confidence in determining the validity of an observation with this method alone. To overcome some of these limitations, **a unique spatial QC approach** objectively evaluates **the difference between the target rainfall measurement and the overall rainfall pattern.** In order to decrease the spatial sampling variability, each 1-hour rainfall measurement is normalized by the mean monthly precipitation; these "iso-percental" values are spatially interpolated to a grid using standard inverse distance weighting. The difference between the initial iso-percental grid and a spatially smoothed iso-percental grid objectively measures how well the target rainfall measurement compares to the overall pattern. An intermediate confidence flag is computed from the absolute iso-percental difference with large differences equating to lower confidence flags.

QUANTATIVE PRECIPITATION ESTIMATE (QPE) BASED QC

LATENCY	RESOLUTION
1-6 hours	4-km²

The National Weather Service (NWS) Stage IV product is an hourly consolidation of gauge-adjusted radar-precipitation products from each of the NWS River Forecast Centers (RFCs). East of the Continental Divide, RFCs derive the precipitation using a multi-sensor approach. Hourly precipitation estimates from NEXRAD radars are compared to ground rainfall gauge reports; a bias (correction factor) is calculated and applied to the radar field to obtain an initial map. In areas with limited or no radar coverage, satellite precipitation estimates (SPE) are incorporated. Meanwhile, in the mountainous areas of the western U.S., gauge reports are plotted against long term climatologic precipitation and derived amounts are interpolated between gauge locations. The end product is a contiguous precipitation grid/map for the U.S. at a spatial resolution of about 4-km². Given the complexities of resolving precipitation across the West, the Stage IV product is often not available for up to 6 hours from the valid time of the target observation. **METSTATs QC algorithm leverages the knowledge instilled in the Stage IV product to make objective comparisons between the gauge and Stage IV gridcell values.** Large deviations equate to less confidence, whereas similar values imply more confidence.

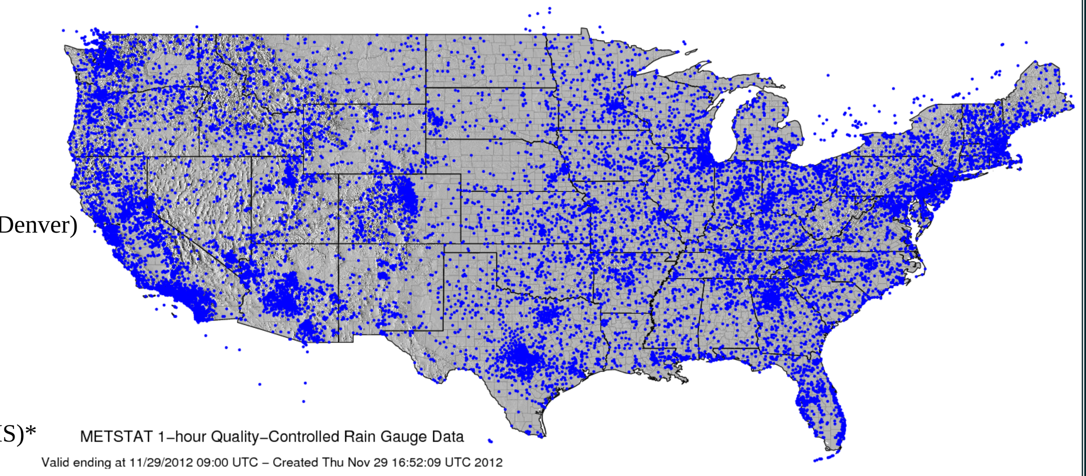


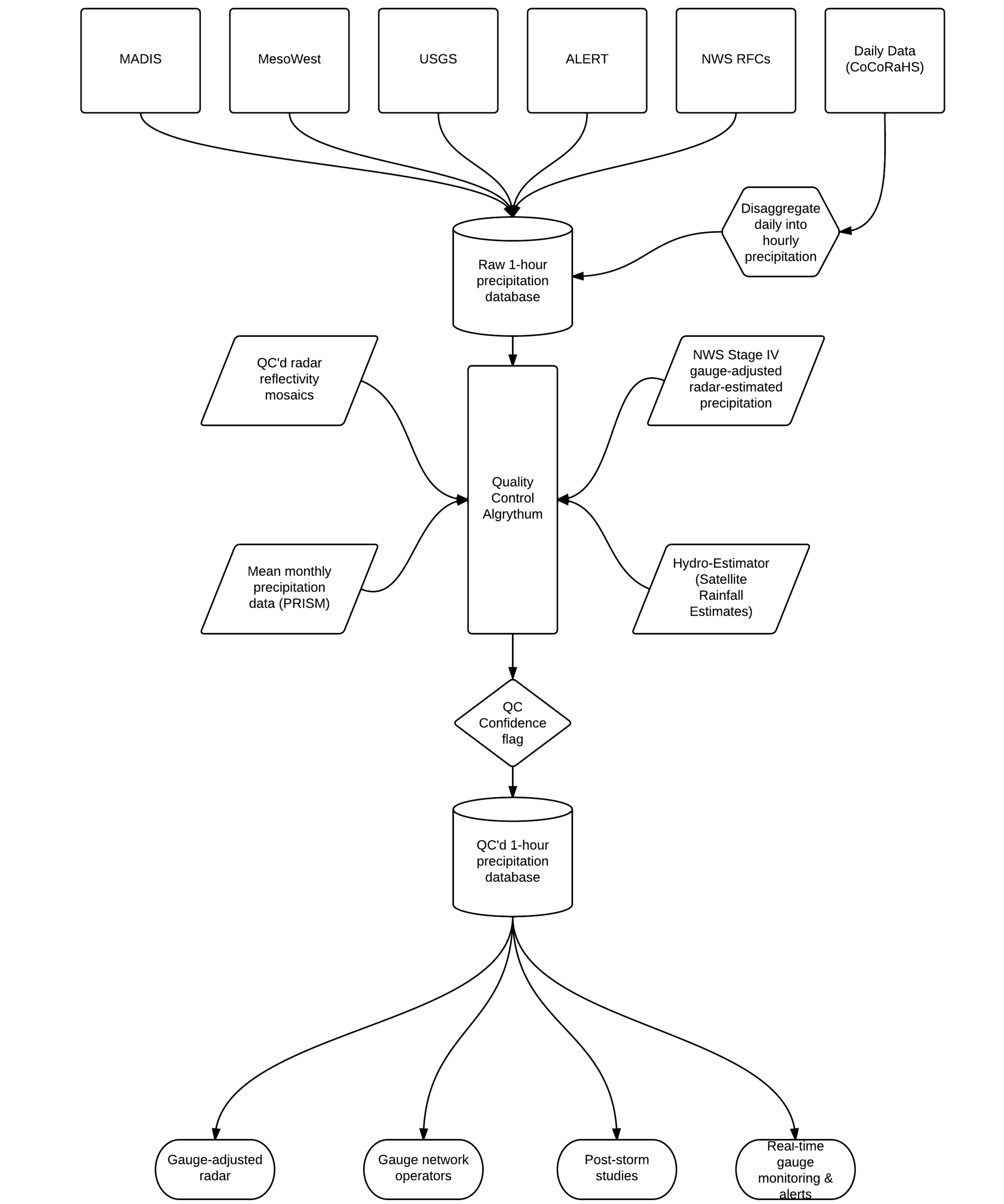
GAUGE DATA ACQUSITION AND CONSOLIDATION

Data from over 18,000+ rain gauges are acquired, consolidated and QC'd each hour. Real-time rain gauge data are accessed from a variety of real-time sources, but largely from the Meteorological Assimilation Data Ingest System (MADIS) and MesoWest, both of which collect and integrate weather observations from government and non-government gauge networks. Strategic alliances with other data providers allow unique and exclusive access to data sources otherwise difficult to attain. **Pooled data from the increasing number of sources makes this one of the largest known real-time QC'd rain datasets available in the United States.** Currently, 1-hour rain data is acquired from the following sources:

- Meteorological Assimilation Data Ingest System (MADIS)
- MesoWest (University of Utah)
- United States Geologic Survey (USGS) Rainfall Network
- NOAA's California Nevada River Forecast Center (CNRFC)
- Lower Colorado River Authority Hydromet (LCRA)
- Flood Control Districts (e.g. Urban Drainage & Flood Control Dist, Denver)
- City of Portland, Oregon HYDRA Rainfall Network
- **Arizona ALERT Systems**
  - **Yavapai County**
  - **Pima County**
  - **Navajo County**
  - **Maricopa County**
- Community Collaborative Rain, Hail and Snow Network (CoCoRaHS)*
- NWS COOP* (in 2013)

** Daily data.*





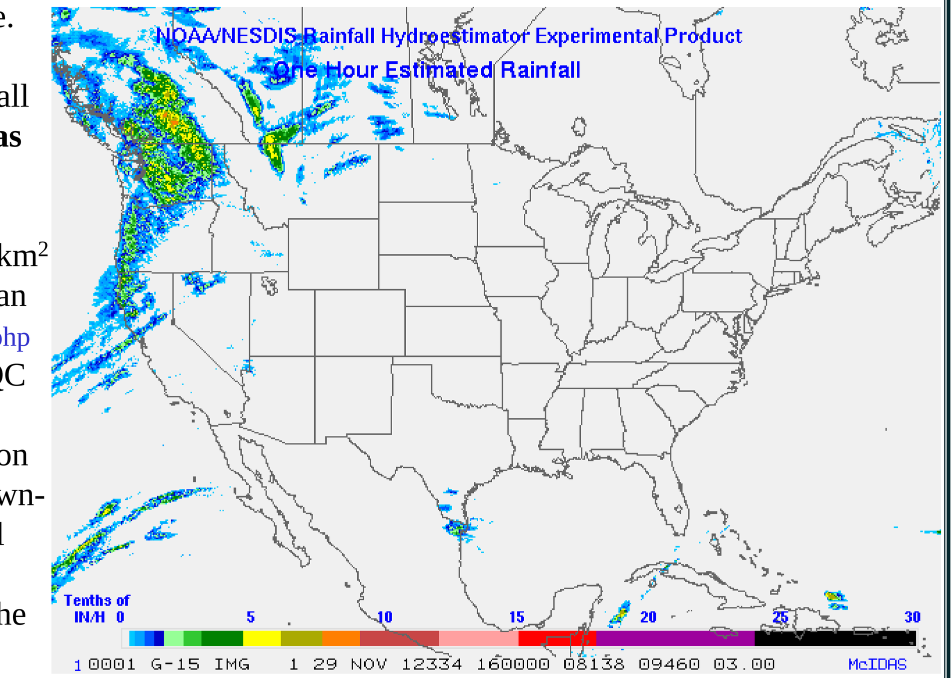
SATELLITE RAINFALL BASED QC

LATENCY	RESOLUTION
2 hours	4 km²

The Center for Satellite Applications and Research (STAR), computes the Hydro-Estimator (H-E) in near-real time. The H-E uses infrared (IR) data from NOAA's Geostationary Operational Environmental Satellites (GOES) to estimate rainfall rates. The H-E product is **especially important for QC in areas where data from nearby rain gauges and/or radar are unavailable or unreliable.**

The H-E is a global product at a spatial resolution of 4-km² and available about 2 hours past the valid hour. More details can be found at: http://www.star.nesdis.noaa.gov/smcd/emb/ff/HEtechnique.php

Similar to the radar-based QC algorithm, METSTATs QC system compares the gauge observation to the corresponding H-E value. The spatial resolution of the H-E product, in addition to its assumptions of cloud physics and precipitation justify down-weighting the influence of the satellite-based QC on the overall QC confidence flag, unless however it is the only data layer to evaluate the reported rainfall against, then it weights more on the final QC confidence flag.

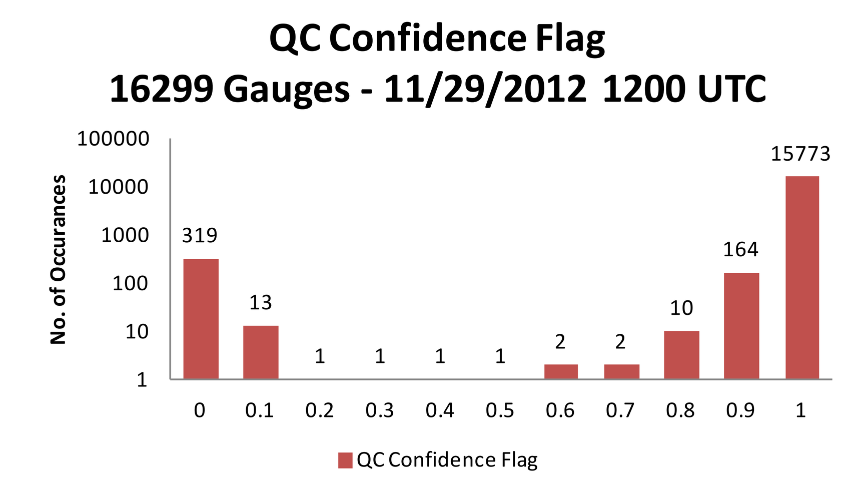


QC CONFIDENCE FLAG

METSTATs QC algorithm provides a QC confidence flag for each 1-hour measured gauge precipitation value. **The QC confidence flag ranges from 0.0 to 1.0, where 1.0 suggests the value is likely correct while 0.0 means the value is likely incorrect.** The QC confidence flag is computed by weighting each of the independently computed confidence measures from the various "sensors" (radar, satellite, other gauges, and QPE) by how much accuracy they carry. For instance, if radar data at a particular gauge location is largely blocked, then radar data is down-weighted while the satellite and spatial-based QC dominate the QC confidence flag. The weighting also depends on what sensor data is available; sometimes satellite data is the only reliable means of QCing.

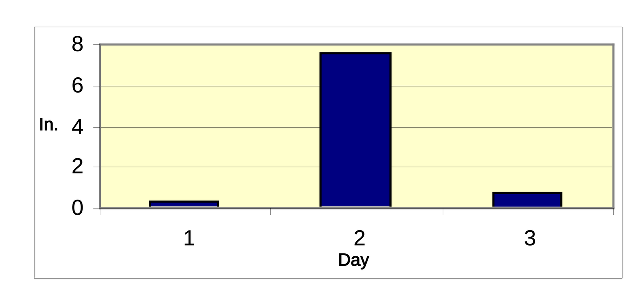
A few special cases exist. For example, if all of the sensors suggest 0" of rainfall, then the QC confidence flag is automatically set to 0.0. Likewise, if radar data at a particular location reporting precipitation is considered reliable, yet the NEXRAD is operating in "clear-air mode" then the QC confidence flag is automatically set to 0.0.

Below is a typical histogram of QC confidence flags for a single, typical hour. **In general, about 2% of the values QC'd are considered erroneous** (flag <= .80).



DAILY TO HOURLY

There are roughly two times as many daily rain gauges as hourly recording rain gauges in the United States. Daily precipitation reports can not be ignored and provide critical information across areas of complex terrain and among highly localized thunderstorm events where hourly data may not be available. **In order to integrate daily reports into the acquisition and QC system, it is necessary to disaggregate the daily observations into estimated hourly amounts.** This is accomplished by applying the hourly temporal distribution of precipitation extracted from previously computed gauge-adjusted radar-precipitation grids to the daily precipitation measurements. Knowing the observation time of the daily measurement, a sequentially complete period of 24 hourly precipitation estimates are computed. These so-called hourly estimated values are then included in the hourly precipitation database and QC'd as any other hourly report.



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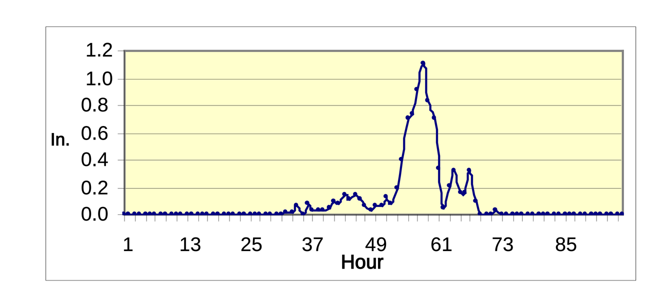
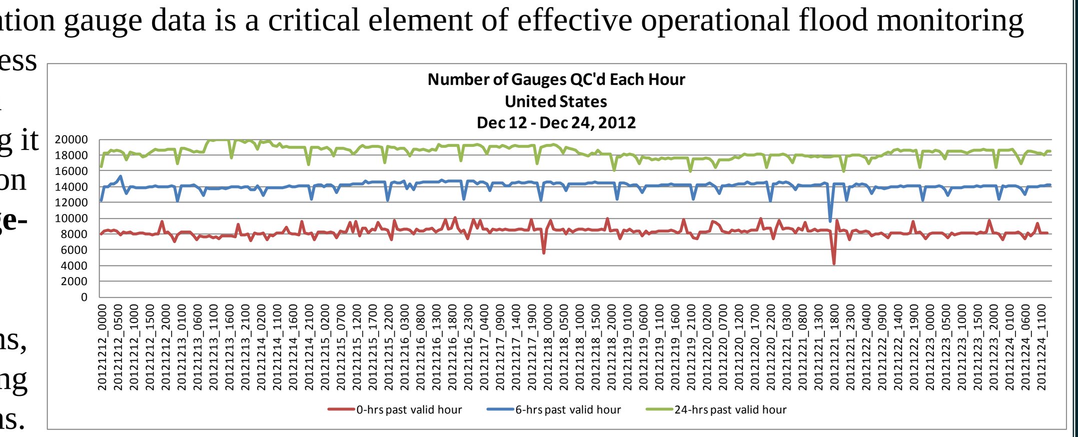


SUMMARY

The multi-sensor approach computes a QC confidence flag for over 18,000 1-hour rainfall observations across the U.S. in real-time every hour. The acquisition and QC operates 7 times for each valid hour in order to capture gauge data and multi-sensor products with longer latencies. In general **125% more gauges are accessed and QC'd 24-hours past the valid hour** than at the valid hour. (see plot below). Meanwhile, the **average run-time for acquisition and QC of gauges at the top of the hour is only about 9 minutes**, increasing to **26 minutes and 40 minutes** for the same valid hour 6 and 24 hours later respectively; the increase in run-time is a function of the increased number of gauges and additional multi-sensor data calculations.

The acquisition and QC of real-time precipitation gauge data is a critical element of effective operational flood monitoring systems and accurate precipitation products. To address the rapidly growing amount of available precipitation gauge data, a systematic method of quality controlling it is a vital and often lacking component. The motivation for this system was to supply **WDT's real-time gauge-adjusted radar precipitation product with quality "ground truth" precipitation data**, but quality precipitation data has a numerous of other applications, including post storm studies, gauge monitoring/alerting for network operators and flash flood warning systems.



Contact: tyep@metstat.com January 2013

LATENCY

- 0 MINUTES

SPATIAL RESOLUTION

- 1-KM

QC SKILL

- High

LATENCY	RESOLUTION
5-minutes	1-km^2