5-Year Science Infusion Plan for WSR-88D Quantitative Precipitation Estimation

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A. Introduction

This science infusion plan identifies future scientific enhancements over the next five years to National Weather Service (NWS) operational radar-based quantitative precipitation estimation (QPE) algorithms running at the WSR-88D Open Radar Product Generator (ORPG) and Advanced Weather Interactive Processing System (AWIPS) to satisfy QPE needs at Weather Forecast Offices (WFOs), River Forecast Centers (RFCs), and for our customers external to the NWS. It is a living document that will be updated annually as driven by evolving user requirements.

The plan has been segregated into enhancements targeted for either the ORPG or AWIPS platforms because separate but fully integrated QPE algorithms run on each platform in an end-to-end processing stream that results in optimized multisensor rainfall products. The ORPG hosts the Precipitation Processing System (PPS) which produces single-radar-site precipitation products using the full volume scan reflectivity measurements provided by the WSR-88D, and the AWIPS hosts the follow-on Multisensor Precipitation Estimator (MPE) that generates regional mosaics of PPS output products in combination with rain gauge and satellite rainfall estimates to produce enhanced, real-time, quality-controlled mulitsensor rainfall products at the WFOs and RFCs for their use and for distribution to external customers.

B. Overview of Current Capabilities and Future Enhancements

Table 1 below summarizes the current state of NWS operational precipitation estimation techniques within the PPS and MPE algorithms and their real-time products as well as our corresponding future vision for technology and product enhancements. Some of the future technology enhancement items in the right-hand column identify specific algorithmic solutions to known technology deficiencies that are currently under development and explicitly targetted for implementation on NWS computer systems in the near future. Other items represent solutions that have not received much or any development attention and thus represent opportunities for research and development organizations interested in improving NWS quantitative precipitation estimation technology. Additional details for many of these items can be found in sections C, D, and E.

Table 1. Current and future planned operational QPE technologies in the National Weather Service.

Technology	**Current**	**Future**
Deterministic vs. probabilistic QPE algorithms and products	Deterministic algorithms and products that provide single best estimates of rainfall	Probabilistic and ensemble algorithms and products that provide best estimates plus uncertainty information
QPE products	<u>PPS (single radar products)</u> -graphical One Hour Precipitation (OHP) -graphical Three Hour Precip. (THP) -graphical Storm Total Precip. (STP) -graphical User-Selectable-duration Precip. (USP) <u>MPE (multiple-radar regional mosaicked products)</u> -Radar-only precip. -Raingauge-only precip. -Radar-raingauge mean-field-bias adjusted precip. -Radar-raingauge multisensor precip. -Radar-raingauge local bias adjusted precip. -Satellite-only precip. (infrared-based)	<u>PPS (single radar products)</u> -graphical One Hour Precipitation (OHP) -graphical Three Hour Precip. (THP) -graphical Storm Total Precip. (STP) -graphical User-Selectable-duration Precip. (USP) -Digital Storm Total Precip. (DSP) <u>MPE (multiple-radar regional mosaicked products)</u> -Radar-only precip. -Raingauge-only precip. -Radar-raingauge mean-field-bias adjusted precip. -Radar-raingauge multisensor precip. -Radar-raingauge local bias adjusted precip. -Satellite-only precip. (infrared- & microwave-based) -Satellite-raingauge local bias adjusted precip. -Radar-raingauge-satellite-lightning multisensor precip.
Spatial resolution of QPE products	- PPS: polar 2 km x 1 deg - MPE: cartesian 4 km	- PPS: polar ¼ km x ½ deg - MPE: cartesian 1 km
Update frequency of QPE products	-PPS: every 5 minutes (except once/hour for THP) -MPE: once/hour at H+00 mins	-PPS: every 3 minutes for all products -MPE: every 3-15 mins

Rainfall accumulation time periods	- PPS: 1, 3, 24 hrs, storm-total, & user-selectable durations - MPE: 1 hour	- PPS: 1, 3, 24 hrs, storm-total, & user-selectable durations - MPE: instantaneous rain rates, 5, 15, 30 mins, 1, 3, 6, 24 hrs, multiday accumulations
Data sources	-radar reflectivity Z -real-time hourly rain gauge data -satellite QPEs (infrared AutoEstimator products) -PRISM dataset	-radar reflectivity Z -real-time hourly, subhourly, and multihourly rain gauge data (15-min, 1, 3, 6, 24 hrs) -PRISM dataset -polarimetric radar measurements (K_{DP}, Z_{DR}) -derived radar products (VIL, hail probability) -satellite QPEs (microwave and infrared) -lightning data -observed meteorological data (surface observations and upper air soundings) -atmospheric model datasets (temperature, relative humidity, ...)
Techniques to use real-time rain gauge data to improve rainfall estimates	-hourly radar-gauge mean-field-bias correction -hourly radar-gauge local bias correction -optimal estimation and merging of radar & gauges	-improved radar-gauge mean-field-bias correction -improved radar-gauge local bias correction -satellite-gauge local bias correction -neural network and multiple regression techniques
Techniques to use satellite data to improve rainfall estimates	-use of NESDIS infrared-based AutoEstimator QPEs in blocked regions	-use of NESDIS microwave- and infrared-based QPEs -optimal merging with radar-gauge QPEs using neural network and/or regression techniques over all regions regardless of blockage -local gauge-adjusted satellite QPEs

Techniques to use other data sources (e.g., lightning, soundings and surface observations, atmospheric model)	- none	-use lightning data to assist delineation of convective and stratiform regions -use lightning data as additional data source in multisensor QPE regression models -use atmospheric model and observed data to delineate rain-snow boundaries in horizontal and vertical
Multisensor merging techniques for radar, rain gauge, & satellite estimates	-geostatistical linear optimal estimation (variance minimization)	-geostatistical linear optimal estimation (variance minimization) -neural network -multiple regression models -artificial intelligence
Radar rainfall rate & snowfall rate estimation techniques	-reflectivity Z to rain rate R (Z-R) or snow rate S (Z-S) conversion using empirical power law relations uniformly over entire radar domain	-locally applied Z-R or Z-S relations based on precipitation type classification (e.g., convective vs. stratiform, snow vs. rain) from CSSA or REC or observed meteorological data -use of locally-applied dual polarized K_{DP}-Z_{DR}-Z empirical power law relations tuned to specific precipitation type regimes to estimate rain rate

Quality control procedures for non-meteorological outlier data in raw reflectivity measurements and derived rainfall estimates	-automated RDA reflectivity clutter filtering using doppler radial velocities -automated point target filtering -automated Tilt Test to remove anomalous propagation -graphical user interface for manual identification and removal	-improved automated RDA reflectivity clutter filtering -automated point target filtering -use of Radar Echo Classifier products within PPS to identify bad data -use of dual polarization radar data to identify bad data -use of observed or model surface air temperatures together with satellite infrared brightness temperatures to identify anomalous propagation -improved graphical user interface for manual identification and removal
Automated quality control of real-time rain gauge data	-minimum and maximum range checks	-spatial consistency checks among neighboring rain gauges -radar-raingauge rainfall consistency checks
Interactive quality control procedures for radar, satellite and rain gauge data	-graphical user interface-based radar data quality control tools -graphical user interface-based rain gauge quality control tools -pseudo gauges available for insertion of non-routine reports	-improved GUI-based tools for quality control
Techniques to identify and eliminate hail contamination-related overestimation	-use of maximum reflectivity or rain rate threshold cap	-use of VIL products -use of Hail Algorithm products -use of dual polarized K_{DP}, Z_{DR}, and Z data to identify hail regions -use of hail-insensitive K_{DP}-derived rainfall estimates directly

Techniques to deal with radar blockages caused by terrain, etc.	-use of digital elevation model (DEM) data to locate terrain -beam occultation corrections to reflectivity for partial beam blockage -build best-available reflectivity hybrid scan from both unblocked and occultation-corrected radials at lowest elevation angles -use of long-term climatologies of rain products to identify other blockages (e.g., trees, buildings) -fill in blocked regions with rain gauge and satellite rainfall estimates	-improved beam occultation corrections using long-term reflectivity climatologies -build best-available hybrid scan of reflectivities from both unblocked and occultation-corrected radials at lowest elevation angles -use of K_{DP} dual polarization radar data for partially blocked and unblocked beams -fill in blocked regions with rain gauge and satellite data
Techniques to reduce range-related rainfall biases (e.g., bright band, nonuniform vertical reflectivity profiles, beam spreading)	-graphical user interface-based identification and removal -use of pseudo rain gauges	-Range Correction Algorithm -graphical user interface-based identification and removal -use of pseudo rain gauges
Techniques to correct for below-beam evaporation	- none	-use of atmospheric model fields (e.g., relative humidity) to reduce surface rainfall estimates
Correcting for orographic effects in mountainous regions	-use of PRISM datasets	-improved use of PRISM datasets

Correcting for missing radar data periods or regions	<u>PPS</u> -rain rate temporal interpolation for missing periods up to 30 mins -extrapolation for an additional 15 mins -no accumulation for periods beyond 45 mins (missing data) <u>MPE</u> -fill in missing radar rainfall regions with surrounding radar rainfall and rain gauge data	<u>PPS</u> -rain rate temporal interpolation for missing periods up to 30 mins -extrapolation for an additional 15 mins -no accumulation for periods beyond 45 mins (missing data) <u>MPE</u> -fill in missing radar rainfall regions with surrounding radar rainfall, rain gauge data, and satellite rainfall
Techniques to account for true effective radar coverage within the mosaicking logic	-use warm and cold seasonal radar rainfall climatologies to delineate coverage	-use monthly radar rainfall and reflectivity climatologies to delineate coverage
Multi-radar mosaicking techniques in regions of radar overlap	-use lowest-in-altitude unblocked radials masked using effective coverage maps	-use lowest-in-altitude unblocked radials masked using effective coverage maps
Techniques to remove spatial discontinuities in rainfall accumulations due to tilt transitions in hybrid scan	- none	-use of Range Correction Algorithm's vertical reflectivity profile to smooth across boundaries
Accounting for interscan rainfall movement to eliminate herringbone rainfall patterns	- none	-shorter volume coverage pattern (VCP) update times -implement interscan radar echo advection scheme
Snowfall estimation algorithms	-none	-merge incremental snow estimation functionality from prototype Snow Accumulation Algorithm into PPS

Rain-snow delineation	- none	-use of observed or model surface air temperatures -use of Range Correction Algorithm-defined rain-snow regions -use of dual polarization radar data
Algorithm parameter tuning	-manual tuning using forecaster judgement	-automated tuning using fuzzy logic techniques and environmental data
Real-time verification of QPE products	- 24-hr accumulation verification using independent 24-hr cooperative observer gauge data	-verification of 1 through 6 hr and 24-hr accumulations using independent gauge data (1, 3, 6, 24 hr)

C. Enhancements to the ORPG Precipitation Processing System

The items identified below and in sections D and E of this plan have been ordered chronologically based on expected implementation dates on each platform. Tentative software builds or dates, current status, and responsible organizations have been identified for each item if known at the time of writing of this plan. Most list items also include a short description that outlines the operational scientific need and presents potential science solutions.

Implement alternate rain gauge bias adjustment method in PPS using AWIPS-computed biases (ORPG2; OHD; COMPLETED)

> Implement a new methodology whereby raw rain gauge data is no longer needed within the ORPG in order for the PPS rainfall products to be calibrated. Instead the new methodology will involve passing of the hourly mean field radar-gauge bias adjustment factor from the AWIPS Multisensor Precipitation Estimator (MPE) at each colocated WFO to the PPS algorithm running on the ORPG where that bias is then applied to the radar rainfall products. This limits the amount of data that has to pass between the AWIPS and ORPG platforms and the associated data management since this is already implemented within the MPE.

Implement new Digital Storm-total Precipitation (DSP) product (ORPG3; OHD)

> The DSP product is a 256-data-level precipitation product containing the storm total precipitation accumulation since rain first started at each radar. It will be a polar 2 km x 1 deg product updated every volume scan. Differencing of consecutive products will permit generation of rainfall accumulations at any

arbitrary duration. This product will be used as input to the next-generation MPE algorithm at the WFO to replace the existing DPA product. This allows the MPE algorithm to produce rainfall products at shorter durations than one hour and at frequencies exceeding once per hour (as currently done at the RFCs) in order to support flash flood monitoring and forecasting operations at the WFOs.

Implement full correction to truncation problems to eliminate rainfall underestimation (ORPG4; OHD; QUICK FIX WAS IMPLEMENTED IN ORPG1)

The PPS logic needs to be fixed so that all occurrences of mathematical truncation and residuals are eliminated to alleviate associated rainfall underestimation.

Enhance PPS to accommodate new VCPs (ORPG4; ROC/OHD)

The legacy PPS contains software logic that precludes it from functioning properly with the new Volume Coverage Patterns (VCPs) being proposed to optimize radar scan strategies. Significant modifications are required in the PPS Preprocessing, Rate, and Accumulation subalgorithms to allow the software to provide reliable and accurate rainfall estimates using the new VCPs. The changes will include the implementation of an enhanced Preprocessing (EPRE) algorithm to replace the legacy Preprocessing algorithm and extensive modification of the logic within the Rate and Accumulation algorithms.

Enhance PPS Preprocessing subalgorithm to quantitatively utilize Radar Echo Classifier (REC) output (ORPG4; ROC/OHD)

The PPS's logic to remove false rainfall caused by anomalous propagation (AP) is based on a radar-umbrella-wide echo area comparison between the first and second elevation angles called the "Tilt Test". This logic is often successful in removing classic clear-air AP, but it suffers from deficiencies when AP is mixed with rain. Improved ways to remove AP that are location-specific are needed. The new Radar Echo Classifier algorithm produces location-specific information that distinguishes precipitation and non-precipitation targets and therefore can be provided as input to the PPS to eliminate false rain echoes. The EPRE algorithm has been developed to utilize the output from the REC to eliminate false rain echoes.

Implement improved, alternate Precipitation Detection Function (PDF) logic within PPS to improve rainfall detection (ORPG4; ROC/OHD)

On occasions forecasters inadvertently makes changes to the PDF adaptable parameters (echo intensity and area) to eliminate AP or keep the radar in clear-air scanning mode that causes the PPS to not accumulate rainfall when real rainfall moves into range of the radar. This may result in an unrecoverable loss of rainfall that negatively impacts rainfall monitoring and hydrologic modeling. A more robust and automated way is needed to monitor the existence of rainfall and non-meteorological targets so that the PPS effectively estimates rainfall when rainfall echoes are present without the need for manual forecaster intervention within the PDF. One viable approach uses the REC algorithm output to determine the existence of precipitation within the AP-corrected reflectivity hybrid scan instead of the arbitrary thresholds applied to the four lowest base reflectivity tilts as currently done in the PDF. The PPS could then be run all the time as long as 1) the REC/PPS combination is effective in eliminating non-rain echoes and 2) the storm-total rainfall products are reset after some criteria are met such as the existing criteria requiring a one-hour rain-free period within the radar umbrella. The EPRE algorithm has incorporated this improved logic.

Implement Range Correction Algorithm (RCA) and utilize its products in PPS to eliminate bright band contamination and range degradation of rainfall estimates, and eliminate existing PPS range correction logic (ORPG4; OHD; PARTIALLY COMPLETED)

Range-dependent degradation of rainfall products is one of the biggest error sources in radar rainfall estimation, particularly in the cool seasons. Innovative and operationally robust algorithms are needed to remove these deleterious effects which include bright band contamination and conversion of radar measurements aloft (and perhaps above the freezing level) to quantitatively reliable rainfall estimates at ground level. The prototype RCA is a solution to this requirement.

Utilize observed vertical profile of reflectivity (VPR) from the RCA to delineate effective radar coverage in all PPS products (ORPG4; OHD)

Delineation of the effective coverage of the radar for rainfall estimation purposes is critical in order to optimize multisensor rainfall products. One possible way to do this is to utilize the VPR to estimate the range where the radar beam is at or above the freezing level and assume that rainfall estimates at farther ranges are quantitatively questionable and perhaps unusable. The delineation of the effective radar coverage should be identified in all PPS products in some manner so that follow-on processing in MPE will be able to use this information to produce the best-possible final products.

Utilize observed VPR from RCA to delineate regions of rain vs. snow and apply appropriate Z-R vs. Z-S relationships locally (ORPG5; OHD)

The RCA estimates the mean height of the freezing level each volume scan. This information could be used to determine at what range the radar beam is passing through rain or snow hydrometeors. Given this information, the PPS could then apply appropriate Z-R or Z-S relationships (if known) to various regions of the radar umbrella.

Implement Convective-Stratiform Separation Algorithm (CSSA) and/or enhanced REC to delineate convective-stratiform regions and support RCA (2004; OHD)

The RCA's performance depends on the nature of the rainfall regime (e.g., convective vs. stratiform) and its spatial distribution across the radar umbrella. Range corrections to rainfall products must take this information into account if there is hope in improving them relative to performing no range corrections at all. An algorithm is needed that effectively delineates convective and stratiform regions for this purpose. The prototype CSSA has been developed and shown to provide reliable results. There are also plans to enhance the REC in the future to do similar convective/stratiform delineation. This quantitative information should be sent to the RCA to improve the integrity of the RCA and resulting corrected rainfall products.

Enhance PPS to estimate snow liquid water content and depth (ORPG6; OST/OHD)

The PPS currently uses one single Z-R relationship to compute rainfall estimates. It needs to be enhanced so that snowfall can be estimated in addition to rainfall. This will require changes to PPS thresholds so that very light reflectivities common in snow echoes are not excluded from the computations, and Z-S relationships need to be specified for use in the PPS. Ultimately, application of simultaneous Z-R and Z-S relationships in localized regions of the radar umbrella depending on the observed precipitation type is necessary for events where both rain and snow are occurring within the range of the radar. It is necessary to merge the functionality of the current PPS with the prototype Snow Accumulation Algorithm so that one single algorithm can produce both rain and snow products.

Enhance PPS to generate higher resolution rainfall products on ½ deg X ¼ km grid (2005; OHD)

The NWS has plans to upgrade the Open RDA in the near future to collect base data at ½ deg x 1/4 km (vs. 1 deg x 1 km currently). Currently the PPS generates rainfall products at 1 deg x 2 km resolution. It needs to be enhanced to produce rainfall products at the highest resolution supported by the raw base data to support flash flood monitoring.

Implement Parallel/Ensemble/Probabilistic PPS and products to provide uncertainty information for rainfall estimates (2005; OHD)

Current PPS rainfall products are deterministic in nature, i.e., they present one estimate of rainfall for each grid point. These estimates can be in error due to a number of known error sources. They do not contain information on the uncertainty of the estimates. The PPS needs to be enhanced so that it produces probabilistic or ensemble rainfall products that provide information on not only the most likely rainfall estimates but the expected range of values and/or uncertainty bounds. A simple solution to this requirement is to run the PPS in an ensemble-like mode of operation where multiple parameter sets (e.g., sets of Z-R or Z-S relations, hail cap thresholds, dBZ calibration offsets, etc.) are used as input, but other more innovative techniques are needed. A part of this task is evaluating the most effective and terse way to present this quantitative information to forecasters and other users that provides enough information but not so much that it overwhelms them.

Use observed VPR from RCA to alleviate sharp transitions between tilts in hybrid scan (2005; OHD)

Abrupt tilt transitions in the PPS hybrid scan often show up in rainfall products as noticeable discontinuities. To alleviate these features, the VPR could be used along with some vertical interpolation logic to smooth across these transitions based on the observed mean VPR.

Implement improved beam blockage correction using observed, real-time blockages to compliment DEM-based blockage data files (2006; OHD)

Current procedures within the PPS account for radar beam blockages using Digital Elevation Model (DEM) terrain data. At each radar the beams at each nominal elevation angle within a defined VCP are merged with this local DEM data to determine where the beam is partially or totally blocked and to make adjustments as necessary according to defined criteria. Uncertainties in the true beam pointing angles (elevation and azimuth) and anomalous beam propagation can cause rainfall estimates to be improperly corrected near the ground or terrain blockages. Improved procedures are needed that account for actual blockages on-the-fly as determined using perhaps long climatologies of observed base reflectivity data at the lowest elevation angles at each radar site.

Utilize REC's and/or CSSA's mapping of convective-stratiform regions to apply appropriate Z-R relationships locally (2006; OHD)

It is possible that radar rainfall products could be improved if appropriate convective or stratiform Z-R relationships were applied in local regions identified as such. The REC or CSSA products that delineate convective and stratiform rainfall regions could be used for this purpose within the PPS.

Implement new polarimetric rainfall algorithm (2007; OHD)

Dual polarization radar holds promise to improve WSR-88D rainfall estimation products, and its implementation on the WSR-88D radars will be coming in the near future. A variety of polarimetric rainfall algorithms have been developed recently by several organizations. These algorithms need to be tested in the real-time operational environment of the NWS and integrated within existing end-to-end hydrologic processing (rainfall and streamflow) once the algorithms have been proven more robust and reliable than existing single polarization techniques employed in the PPS. The algorithm needs to generate at least the existing PPS products.

Implement a radar echo advection scheme to improve interscan interpolation of rainfall estimates (2007; OHD)

Herringbone-like patterns of radar rainfall are often produced in the springtime when small intense storms or squall lines move quickly. The 5-6 minute sampling of the radar is not sufficiently quick to resolve the true natural smooth motion and smooth rainfall fields. The PPS needs to be enhanced with a reliable echo advection scheme that performs interscan interpolation of rain rates to ameliorate the discrete radar scan sampling that results in anomalous herringbone rainfall patterns.

Develop capability to automatically monitor radar reflectivity calibration biases nationwide (2007; ROC)

WSR-88D radar calibration of the reflectivity measurements is critical to any Z-R-based rainfall estimation methodology. Improperly calibrated radars can produce rainfall estimates that can be significantly over- or underestimated when reflectivity is converted to rain rate. Automated techniques that can monitor absolute WSR-88D calibration biases across the U.S. are needed to alert radar technicians of the need to perform routine calibration procedures.

D. Enhancements to the AWIPS Multisensor Precipitation Estimator

Enhance MPE algorithm to provide WFOs with regionally-mosaicked, multisensor rainfall estimates updated every volume scan for flash flood applications.

Enhance existing MPE multisensor rainfall estimation techniques to incorporate satellite data in terrain-blocked regions (2003)

In the current MPE multisensor technique, it is difficult to estimate precipitation where radar beam is blocked by terrain. These regions need to be filled with rainfall estimates from other sources such as satellites (geostationary and/or polar orbiting) using proven infrared/visible/microwave techniques.

Utilize satellite infrared brightness temperatures, in-situ observed surface temperatures, and/or NWP model surface temperatures to eliminate anomalous propagation (AP) contamination of radar estimates (2003)

> The Radar Echo Classifier distinguishes precipitation from non-precipitation targets and eliminates false radar echos. Another layer of AP detection and quality control is needed to further remove AP contamination within MPE. This technique utilizes GOES IR brightness temperature (channel 4) and surface temperatures (observed or model-generated) to classify the sky condition as clear or cloudy. Radar echo is then compared with sky condition at each data pixel and classified as AP if there are no clouds.

Incorporate real-time NWP model analyses of freezing level height, atmospheric temperature sounding data, and/or VPR information from the RCA to mask radar rainfall estimates above the bright band and substitute snow water equivalent estimates

> One method to identify regions of the radar umbrella where radar rainfall estimates may be questionable is to locate regions where the radar beam is at or above the freezing level. Ancillary observed temperature data from surface and upper air measurements or analysis fields of temperature from numerical weather prediction (NWP) models could be used to delineate these regions so that users would know where rainfall estimates might be unreliable. Information on the observed vertical profile of reflectivity (VPR) from the Range Correction Algorithm could also be used. In regions where the beam is above the freezing level, snow water equivalent estimates could be computed and substituted instead.

Develop next generation precipitation analysis techniques for multisensor QPE

> New rainfall information sources such as lightning and improved multisensor merging techniques should be explored to improve multisensor QPE. New techniques may include multiple regression, neural networks, and artificial intelligence, and they should be validated in an operational environment (2005-2007).

Enhance existing MPE multisensor rainfall estimation techniques to incorporate lightning data

> Relationships between lightning flash rate and rainfall rate have been derived in the literature. Additionally, lightning (or absence of lightning) has been shown to be related to whether thunderstorms produce flash floods. The utility of lightning data for improving rainfall estimates needs to be investigated and techniques implemented within the existing rainfall estimation procedures at the RFCs and WFOs.

Develop procedures to derive PPS rainfall climatologies as a function of month to improve rainfall mosaicking and mean-field bias performance

Implement automated and manual rain gauge quality control preprocessing procedures within MPE

> Currently quality controlling of rain gauges is done mostly manually at the field offices. In order for the MPE algorithm to work more efficiently, automated or semi-automated quality control procedures are needed. A semi-automated Spatial Consistency Check procedure has been developed to quality control rain gauges. In order for this test to be applied more efficiently, it needs to be implemented in a Graphical User Interface within MPE. This tool can be enhanced by adding more tests such as point check, temporal consistency check, and model consistency check. To get the maximum benefit, all these quality control checks can be combined into a comprehensive tool that should be implemented in the MPE (2003-2004)

Develop procedures to perform objective, automated, on-the-fly verification of multisensor rainfall estimates against independent rainfall amounts to understand and quantify product accuracy and the improvements in service resulting from science infusion of improved QPE analysis techniques

Enhance mean-field-bias adjustment algorithm in MPE so that it accounts for changes to the rainfall statistics caused by changes to Z-R parameters or radar calibration

Enhance Flash Flood Potential (FFP) algorithm to generate regionally-mosaicked short-term multisensor rainfall nowcasts using volume-scan-based MPE products (Multisensor Precipitation Nowcaster MPN)

E. Enhancements for either ORPG PPS and/or AWIPS MPE

Incorporate ancillary AWIPS data (surface and sounding data, freezing level heights, NWP model output, satellite, lightning) to automatically improve/optimize/tune radar rainfall estimates as a function of storm type, season, geographic region, and climatology

Develop procedures to automatically adapt/optimize real-time QPEs and adaptable parameters based on observed data