1.3 The National Mosaic and Multisensor QPE (NMQ) Project – Status and Plans for a Community Testbed for High-Resolution Multisensor Quantitative Precipitation Estimation (QPE) over the United States

Dong-Jun Seo[1]*, Chandra R. Kondragunta[1], David Kitzmiller[1], Kenneth Howard[2], Jian Zhang[2] and Steven V. Vasiloff[2]

[1]Office of Hydrologic Development, National Weather Service
NOAA, Silver Spring, Maryland

[2]National Severe Storms Laboratory
NOAA, Norman, Oklahoma

1. INTRODUCTION

It is widely recognized that comprehensive hydrometeorological and hydrologic data assimilation and distributed hydrologic modeling are two of the most important components in hydrologic operations that are necessary to improve hydrologic monitoring and prediction and to produce high-resolution hydrometeorological and hydrologic information for a spectrum of water resources applications. In typical distributed hydrologic modeling, where the uncoupled land surface model is driven by the observed and predicted hydrometeorological forcings for the current and future boundary conditions, respectively, quantitative precipitation estimation (QPE) is very often the biggest source of uncertainty in the initial conditions of the model soil moisture states. The National Mosaic and QPE (NMQ) project is a joint initiative between the NOAA/National Severe Storms Laboratory and the NOAA/National Weather Service/Office of Hydrologic Development to address the pressing needs for high-resolution multisensor QPE for all seasons, regions, and terrains in support of comprehensive hydrometeorological and hydrologic data assimilation and distributed hydrologic modeling.

Though the primary focus of this paper is on QPE, the scope of the NMQ project is significantly larger, and includes short-term quantitative precipitation forecasting (QPF) and severe weather monitoring and prediction. The overarching objectives of the NMQ project are as follows:

- Create a framework for community-wide research and development (R&D) of hydrometeorological applications for monitoring and prediction of freshwater resources in the United States across a wide range of time and space scales,
- Through a testbed, facilitate community-wide collaborative R&D and research-to-operations (RTO) of new applications, techniques and approaches to precipitation estimation (QPE) and short-range precipitation forecasting (QPF), and
- Create a scientifically sound real-time system to develop and test methodologies and techniques for physically realistic high-resolution rendering of hydrometeorological and meteorological processes.

The purpose of this paper is to describe the progress of and plans for the NMQ project, and to seek community feedback, input, and participation, particularly in the context of comprehensive hydrometeorological and hydrologic data assimilation for operational hydrologic prediction, for developing the NMQ system as a community testbed.

2. QPE Goals and Science Objectives

The goals and science objectives for QPE in the NMQ project reflect the operational experience with multisensor QPE in the last decade (Smith et al. 1994, Young et al. 2000, Seo and Breidenbach 2002, just to name a few), and the outstanding science and technology challenges (see below) that must be addressed in order to produce operational high-resolution precipitation products for all seasons, regions, and terrains. Toward achieving the above overarching QPE objective, the NMQ project has the following QPE-specific goals:

- Develop a sustainable community hydrometeorological testbed for R&D of new QPE and short-term QPF science and technology, with particular focus on water resources applications, and
- Expedite RTO of new science and technology through the testbed, e.g., by facilitating testing and evaluation of QPE science for operational implementation in NEXRAD and the Advanced Weather Interactive Processing System (AWIPS).

The attendant QPE science objectives are:

- Gain understanding necessary to develop radar and multisensor QPE methodologies capable of producing high-resolution all-season, -region, and –terrain precipitation estimates, and
- Gain understanding necessary to integrate and assess new data sources from in-situ, radar, and satellite observing systems, and methodologies and techniques to improve QPE in support of hydrology and water resources monitoring and prediction at the national scale.

* *Corresponding author address:* Dong-Jun Seo, W/OHD1, 1325 East-West Highway, Silver Spring, MD 20910; e-mail: dongjun.seo@noaa.gov

3. The NMQ System

The NMQ system is intended to be a community testbed for R&D of QPE science and a proving ground for RTO of QPE applications, with a capability to generate experimental products over the U.S. To support this dual purpose, the NMQ system being developed is made of two subsystems, the Product Generation Subsystem (PGS) for generation of experimental products in (near-) real time, and the R&D Subsystem (RDS) for real-time data processing and analysis, with retrospective analysis (i.e. re-analysis) capabilities.

For many of the functionalities and components necessary for multisensor QPE, a number of competing or complementary algorithms exist, e.g. algorithms for vertical profile of reflectivity (VPR) correction in radar QPE, correction of bias in radar and satellite rainfall estimates, and merging radar and satellite rainfall estimates with rain gauge data in multisensor QPE. As such, in designing the NMQ, high premium is placed on modularity of the system so that different algorithms may be plugged in and out with ease and transparency. As a long-term strategy, such modularity and attendant flexibility are considered critical to keeping the system "open." Figure 1 shows the schematic of the PGS of the NMQ system. The PGS has been in operation for several months producing national radar reflectivity mosaics at the spatial scale of 1 km with a 5 to 6-min update cycle (see Figure 2 for an example).

For real-time high-resolution multisensor QPE, timely delivery and processing of radar data are critical. The feeder to the NMQ system of real-time radar data is the Collaborative Radar Acquisition Field Test (CRAFT) infrastructure (see Figure 1), which has recently been implemented by the NWS for real-time dissemination of WSR-88D base data (Crum et al. 2003). Currently, the Level II data from 124 (out of 143) radars in the CONUS are electronically collected, distributed, and archived through the CRAFT. The data are available to users in government agencies, universities, and the private sectors. The process has short data latency (< 1min) and low data outage (< 5%), and is expected to cover all 143 radars in the CONUS by the end of 2005.

4. NMQ Capabilities for QPE

For data processing, analysis, and evaluation, the following capabilities have been identified as necessary for the NMQ system:

- Real-time processing of radar, rain gauge, satellite, lightning, and NWP output data
- Post analysis (including verification)
- Long-term retrospective analysis (i.e. re-analysis)
- Estimation and updating of error statistics, and error modeling and analysis
- Hydrologic evaluation of QPE products
- Parallel computing
- Ensemble/probabilistic QPE
- Variable resolution.

Below we identify specific capabilities and functionalities considered necessary on the NMQ system for QPE R&D and RTO.

4.1. Radar QPE

For processing of radar reflectivity data, the following capabilities have been identified as necessary:

- Tilt-by-tilt processing for;
  - 4D-mosaicking (Zhang et al. 2004)
  - Generation and updating of reflectivity climatology
  - Precipitation detection function
  - Occultation identification and correction (O'Bannon and Ding 2003)
  - Merging of reflectivity climatology with DEM-based occultation maps
  - Radar Echo Classifier (REC, Kessinger et al. 2003)
  - Accounting of advection of precipitation echoes in precipitation accumulation
- Volume-scan processing for;
  - 3D-mosaicking of reflectivity data (Zhang et al. 2003)
  - Convective-stratiform separation (Seo et al. 2002, Ding et al. 2003)
  - Vertical profile of reflectivity (VPR) correction, including identification of melting layer height and areas of brightband enhancement (Seo et al. 2000, Gourley and Calvert 2003, Ding et al. 2004a,b)
- Monitoring and correction of inter-radar calibration differences
- Delineation of effective coverage of radar for QPE via;
  - static masking (Breidenbach et al. 1999)
  - Dynamic masking (Seo et al. 2000)
- Determination of microphysical parameters, e.g. Z-R and hail cap, with the aid of NWP output
- Polarimetric radar data
  - Ingest into the NMQ system
  - Use of polarimetric radar data for algorithm verification and enhancement, e.g. of the REC and convective-stratiform separation
  - Intercomparison and assessment of radar-only and multisensor QPE algorithms (Schuur et al. 2003).

4.2. Multisensor QPE

For multisensor QPE, the following capabilities have been identified as necessary:

- Full utilization of multi-hour gauge data in hourly multisensor analysis
- Daily gauge-only analysis
- Estimation of bias between daily and hourly gauge data
- Gauge data quality control (QC)
  - Real-time QC and monitoring of individual gauges (hourly and multi-hourly, and biases between them)

    - Spatial consistency checking (Kondragunta, 2001)
- Multisensor QPE
    - Mean field bias correction (Seo et al. 1999)
    - Local bias correction (Seo and Breidenbach 2001)
    - Radar-gauge merging (Seo 1998)
    - Distributed-parameter multisensor QPE
- Utilization of satellite data
    - HydroEstimator (Vicente et al. 1998)
    - GOES Multispectral Rainfall Algorithm (GMSRA, Ba and Gruber 2001)
    - Local bias correction of satellite precipitation estimates and merging them with rain gauges (Kondragunta and Seo, 2004)
    - Microwave precipitation estimates
- Utilization of lightning data
    - For convective-stratiform separation (Ding et al. 2004b)
    - For precipitation detection and estimation
- Utilization of NWP output
    - As additional input to multisensor QPE, particularly for estimation of cool-season precipitation
    - For estimation of microphysical parameters
- Estimation/optimization of multisensor QPE parameters
    - Via systematic retrospective analysis
- Rain gauge data QC
    - Incorporation of existing QC algorithms
    - Multisensor-based QC, e.g. via on-line monitoring and updating of individual rain gauge data statistics, including comparisons with radar, satellite, and NWP precipitation.

In the above, the need for distributed-parameter multisensor QPE is a reflection of the operational experience that, in order to produce high-resolution precipitation estimates that are consistently superior to or at least as good as single-sensor estimates for all seasons, regions and terrains, it is necessary to employ spatially-distributed and seasonally or dynamically-stratified parameters.

4.3. Verification

Due to the high space-time variability of precipitation, verification of QPE over a wide range of space-time scales relevant to various water resources applications is a large challenge. The following capabilities for verification of QPE, based on routinely available in-situ observations, have been identified as necessary:

- Real-time verification (see Figure 3 for an example from the NMQ system)
- Multi-scale verification
    - 1-hr (via cross validation)
    - 24-hr (via independent validation against Cooperative Observer data)
    - long-term/climatological
- Long-term retrospective verification and analysis, and derivation of error statistics
- Hydrologic verification.

The Distributed Model Intercomparison Project (DMIP, Smith et al. 2004) offers an excellent opportunity for hydrologic verification and uncertainty assessment using multiple distributed models.

4.4. Ensemble/Probabilistic QPE

Operational hydrologic forecasting is transitioning toward ensemble prediction to provide uncertainty information associated with the forecast. To support ensemble hydrologic prediction, it is necessary to develop ensemble or probabilistic methods for QPE (Krajewski et al. 2004). One of the challenges in quantification of uncertainty is the general lack of high-quality and -density precipitation gauge data for multiscale (from micro- to basin-scale) characterization and quantification of uncertainty. Quantification of additional observation needs for uncertainty-based monitoring and prediction of precipitation is expected to be an important part of the NMQ function.

Many of the capabilities identified above are currently available in some form on the PGS of the NMQ system, and additional capabilities are being implemented. It is expected that the RDS of the NMQ system will become functional in the spring of 2005. The design of the RDS is in progress, and is expected to evolve over time based on user requirements. The latest design details are available upon request, and comments, suggestions and input, and participation in the process are welcome.

5. The NMQ Environment for R&D and RTO

To support RTO through rapid prototyping and assessment, the Joint Applications Development Environment (JADE) is being developed as a part of the NMQ system. The JADE concept recognizes that no single system, application and/or technique provide the complete and definitive solution, and that the issues and complexities of precipitation estimation and severe storm identification and prediction require a community-based approach and effort. The overarching objectives of the JADE are as follows:

- Establish a ‘real time’ and ‘open’ environment for assessment of applications in their native ‘system’ environment,
- Provide modular and flexible environment for development, testing and implementation of ‘multisensor’ techniques, applications and algorithms,
- Support full integration and assimilation of nationally produced data sets and atmospheric, hydrometeorological and hydrologic models (operational and experimental), and
- Provide exposure of applications to the full spectrum of meteorological/hydrometeorological and ‘non’ meteorological/hydrometeorological regimes for regional tuning and calibration.

Figure 4 provides a schematic of the JADE depicting the R&D and RTO environment and pathways. It is expected that the configuration of the JADE on the NMQ system will be completed in the spring of 2005.

6. Summary and Conclusions

The status and plans for the National Mosaic and QPE (NMQ) project have been described. A joint initiative between the NOAA/NSSL and the NOAA/NWS/OHD, the NMQ project addresses high-resolution (1-km spatial scale with 5 to 6-min update cycle) multisensor quantitative precipitation estimation (QPE) for all seasons, regions and terrains in support of comprehensive hydrometeorological and hydrologic data assimilation and distributed hydrologic modeling.

The NMQ is being developed as a community testbed for research, development, and research-to-operations of QPE, short-range QPF and severe weather science and applications, and consists of the Research and Development Subsystem (RDS) for R&D of science, technology, methodologies, and techniques for improved estimation and short-range prediction of precipitation, and the Product Generation Subsystem (PGS) for routine generation of experiment products for testing, evaluation and validation of new science and applications for all seasons, regions and terrains. The PGS has been in operation for several months, and additional capabilities for QPE are being implemented. The RDS is expected to become functional in the spring of 2005. To enable joint development, testing and evaluation in an open and flexible environment for computations, data access and processing, and verification, the Joint Applications Development Environment (JADE) is being developed. It is expected that the JADE configuration on the NMQ system will become functional in the spring of 2005.

The many issues and complexities of precipitation estimation and short-range prediction require a community-based approach and effort. The NMQ system and the joint development environment, JADE, recognize that no single system, application and/or technique provides the complete and definitive solution. Toward building an open and flexible community testbed for QPE and other hydrometeorological applications, we invite comments, suggestions, input, and participation of the community.

ACKNOWLEDGMENTS

The National Mosaic and QPE (NMQ) Project is supported in part by the Federal Aviation Administration (FAA), by the NOAA/Office of Oceanic and Atmospheric Research, and by the NOAA/National Weather Service. These supports are gratefully acknowledged.

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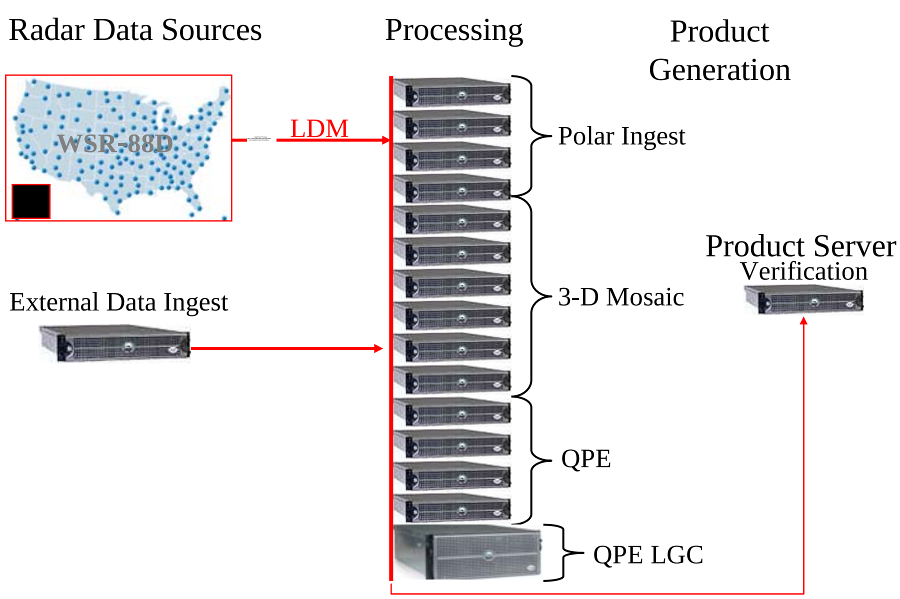

Figure 1. Schematic of the current configuration of the Product Generation Subsystem of the National Mosaic and QPE (NMQ) System.

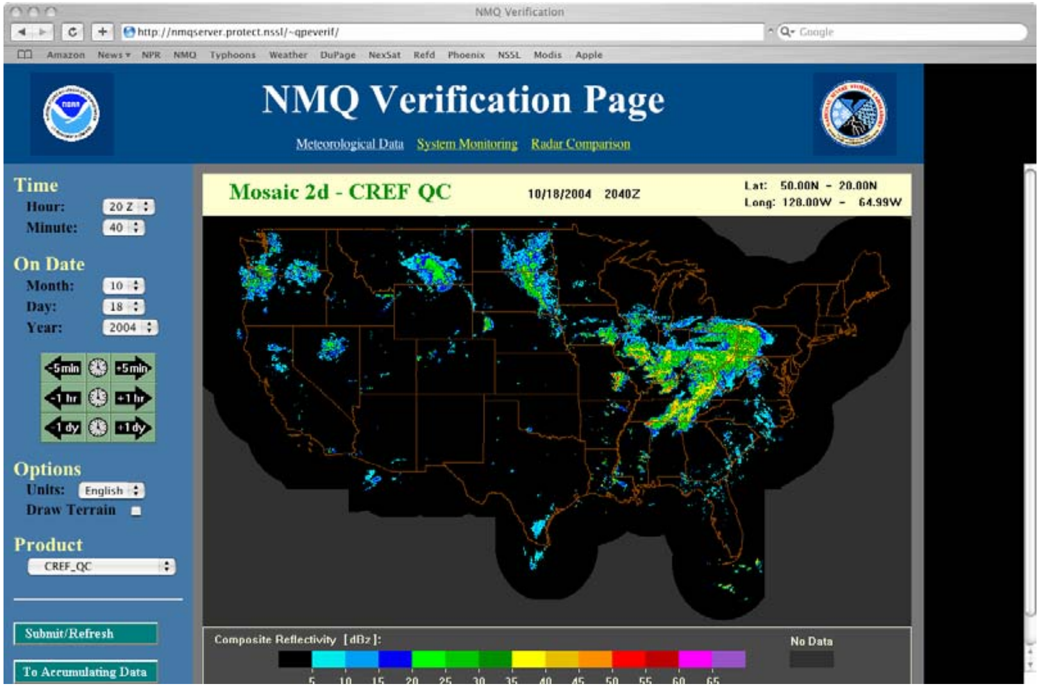

Figure 2. An example of the 2-D CONUS-wide mosaic of quality-controlled radar reflectivity data as displayed through the National Mosaic and QPE (NMQ)/Joint Applications Development Environment (JADE)'s verification web page.

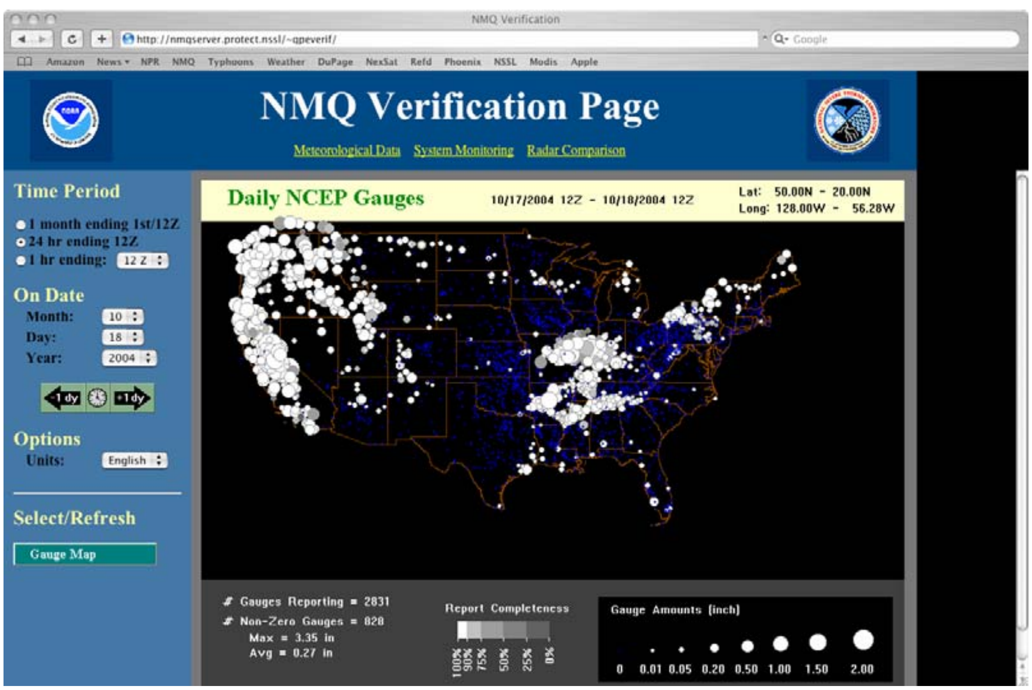

Figure 3. An example display of daily rain gauge observations through the National Mosaic and QPE (NMQ) System/Joint Applications Development Environment (JADE)'s verification web page. The inset shows the scatter plot of radar-only quantitative precipitation estimate (QPE) against the daily gauge observations.

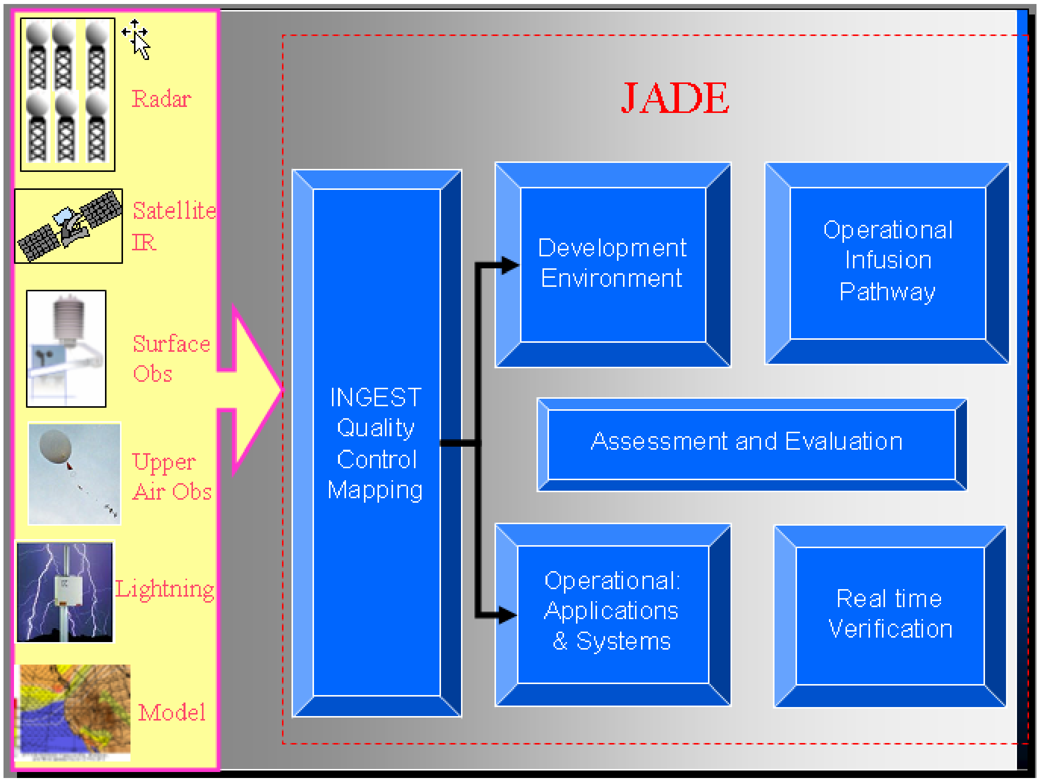

Figure 4. Schematic of the Joint Applications Development Environment (JADE) on the National Mosaic and QPE (NMQ) System.