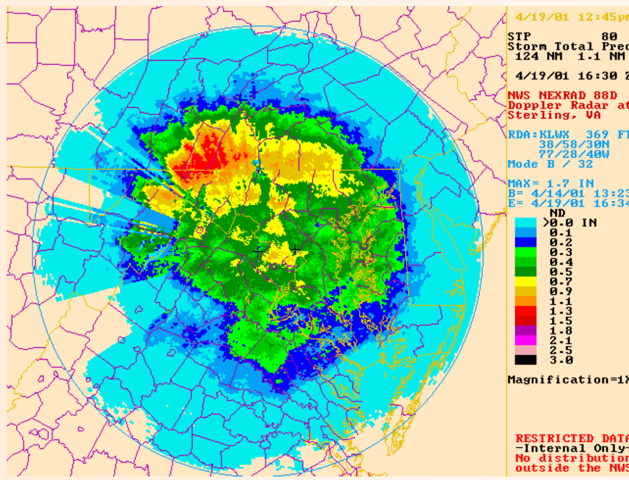
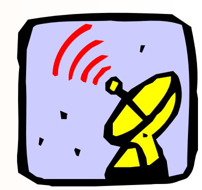
Hydrometeorology Group's Projects and Plans for Improving WSR-88D Rainfall Algorithms and Products



Richard Fulton, HG Team Leader
Hydrologic Science and Modeling Branch
NWS Hydrology Laboratory
Silver Spring, Maryland

Presented to HL on May 4, 2001



Mission Statement

Hydrometeorology Group

To develop and apply cutting-edge scientific rainfall analysis and forecast techniques using WSR-88D radar and hydrometeorological data sources to improve hydrologic operations and products

Hydromet Group Personnel

3.7 FTEs, 3.3 contractors

- Richard Fulton, Team Leader, meteorologist
- Dr. Chandra Kondragunta, meteorologist
- Jay Breidenbach, meteorologist
- Dr. Dong-Jun Seo, hydrologist (UCAR)
- Dennis Miller, meteorologist (0.7)
- Cham Pham, computer specialist (RSIS)
- Vacancy, scientist/programmer (RSIS)
- Vacancy, computer specialist (RSIS; 0.3)
- Wen Kwock, part-time student (0.1)
-
- Paul Tilles, computer specialist (not in HG but 0.1 support)
- Dr. Michael Fortune, NWS Int'l Tech. Transfer Center (not in HG but collaborator)

HG Funding Sources

Improvements require 

- NEXRAD Product Improvement (NPI) program
- AWIPS program
- WSR-88D Radar Operations Center (formerly OSF)
- Office of Operational Systems
- Advanced Hydrologic Prediction Services (AHPS) program (future)
- Thank you!

Current Major Projects

- 1) WSR-88D Quantitative Precipitation Estimation (on RPG system)
- 2) Multisensor Quantitative Precipitation Estimation (on AWIPS system)
- 3) Radar and Raingauge Quality Control
- 4) Flash Flood Monitoring and Prediction Development
- 5) Advanced Hydrometeorological Science

Reference: “FY2001 Projects, Personnel, Resource Allocation and Requirements Plan for Hydrometeorology Group” Dec. 2000

Project 1: WSR-88D QPE

Precipitation Processing System (PPS) on WSR-88D Radar Product Generator (RPG)

- a) Evaluation and validation of performance of current PPS algorithm and products
- b) Applied research and prototype development of new improved PPS algorithm
- c) Software engineering of PPS enhancements on ORPG
- d) Applied research and development of next-generation polarimetric rainfall algorithm

Project 1: WSR-88D QPE (cont.)

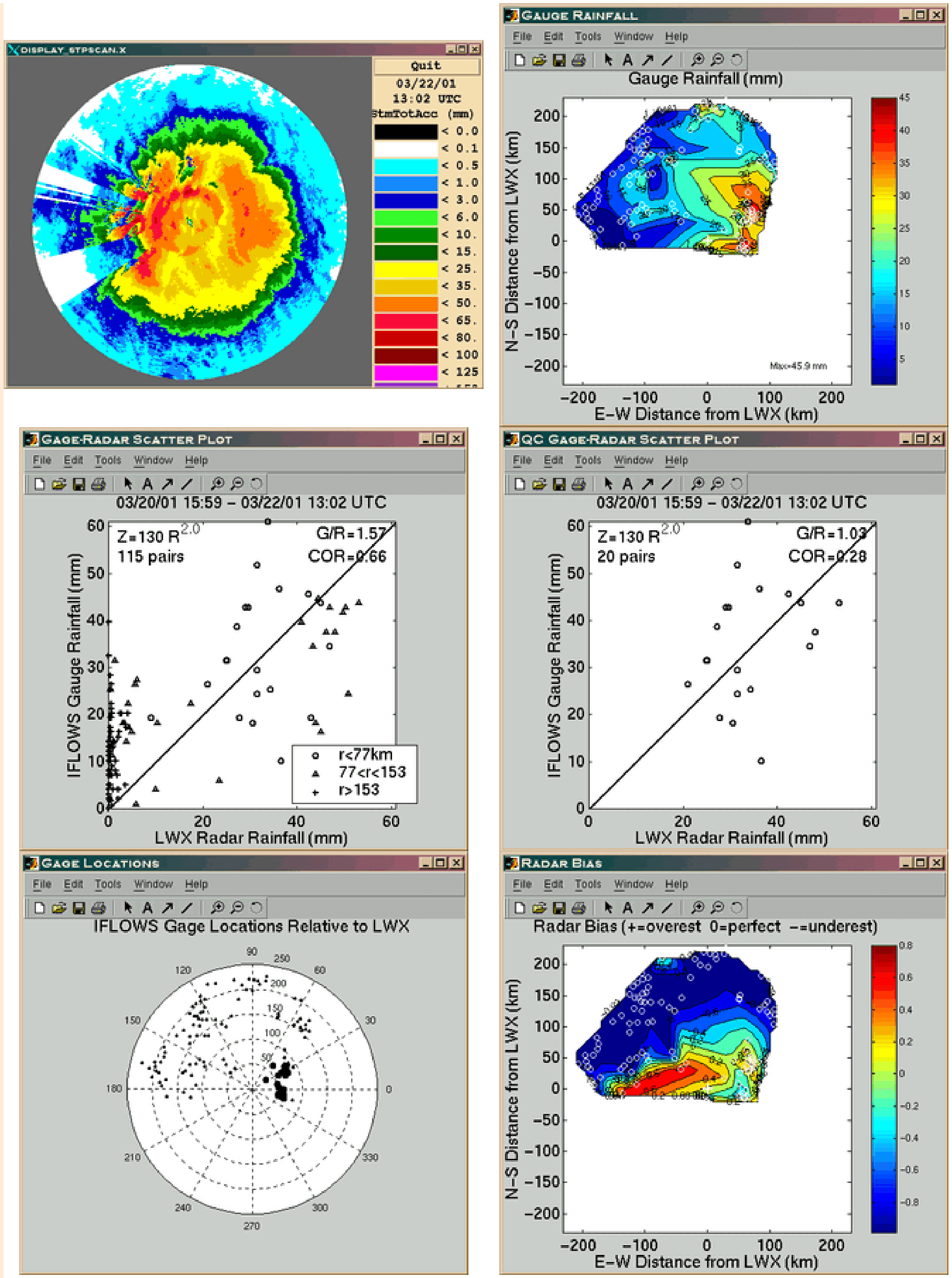
a) Evaluation and validation of performance of current PPS algorithm

Long-term verification of QPE products is critical to uncovering and resolving algorithm deficiencies and systematic rainfall biases

- 1) Evaluation of Sterling, VA WSR-88D (KLWX) rainfall estimates post-calibration, post-Hurricane Floyd (Fulton)

Reference: Chapter 1 of 2000 OSF-OH MOU Final Report
http://hsp.nws.noaa.gov/oh/hrl/papers/2000mou_pdf/Mou00_PDF.html

Example of KLWX gauge-radar analyses March 20-22, 2001



Project 1: WSR-88D QPE (cont.)

a) Evaluation and validation of performance of current PPS algorithm (cont.)

- 2) Quantitative long-term evaluation of impacts of a subtle PPS software design deficiency causing a small truncation of radar rainrates (Fulton, Miller)
  - Has existed since NEXRAD contractor first delivered the PPS software algorithm in early 1990s
  - Worst relative impact occurs during long-lasting, light stratiform rain events; least impact during intense convective events
  - May partially explain the well-known underestimation tendency for PPS during cool season stratiform rain events
  - Side-by-side comparisons of RPG Build 10 and ORPG Build 1 DPAs at KLWX will quantify impacts
  - Easy to fix...quick fix will appear in ORPG1, full fix in ORPG2

Reference: 2000 OSF-OH MOU Final Report, Chapter 3 "Precipitation Truncation Problem in the WSR-88D PPS Algorithm: Description, Quantification and Ramifications "
http://hsp.nws.noaa.gov/oh/hrl/papers/2000mou_pdf/Mou00_PDF.html

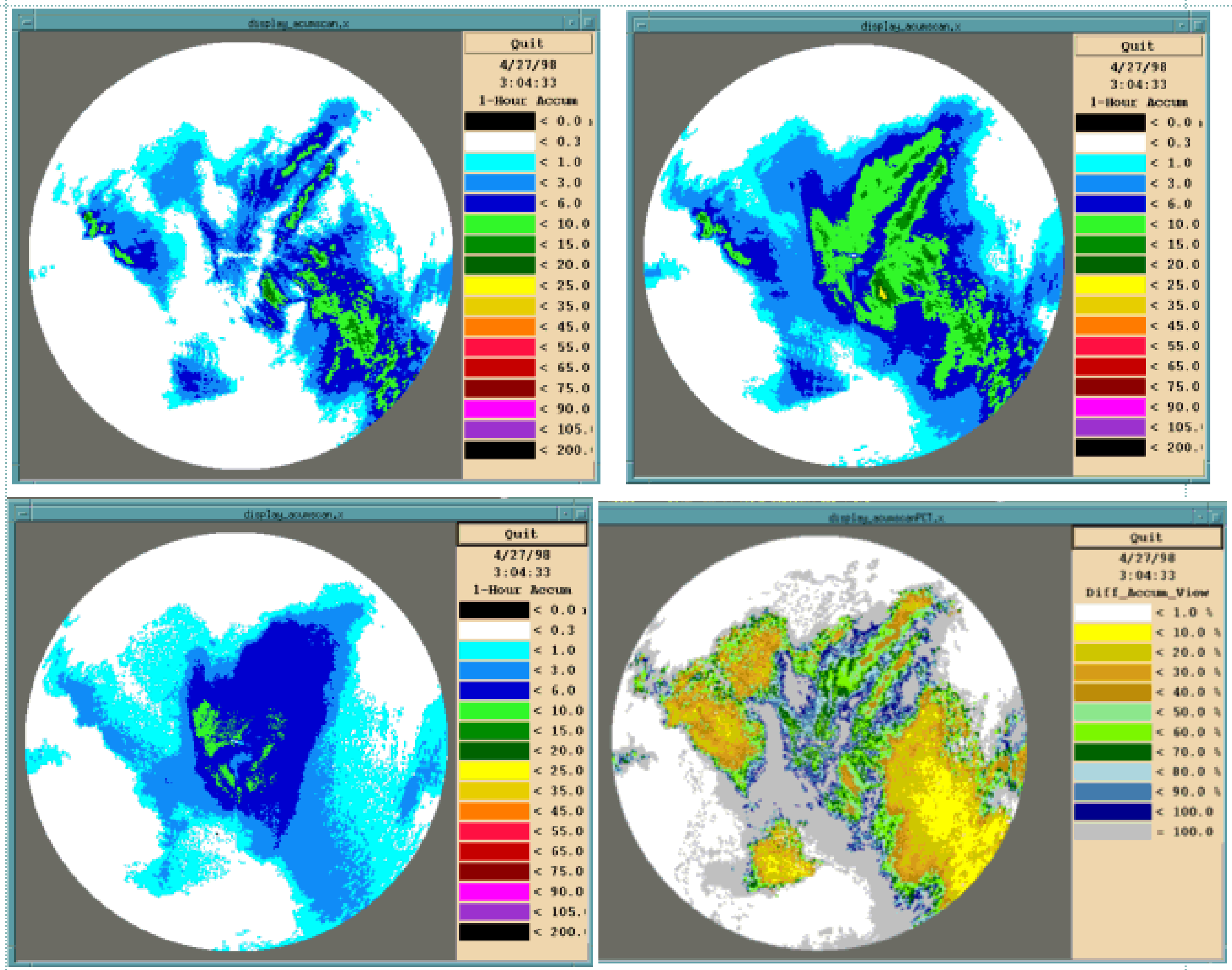
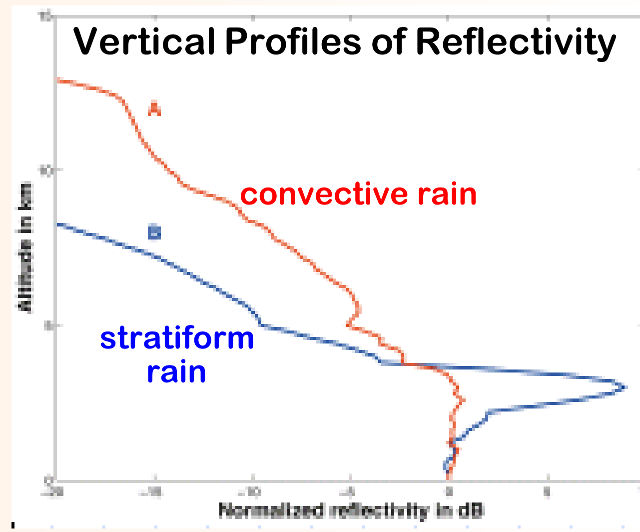


Fig. 3: One-Hour Precipitation (OHP) products and differences at Twin Lakes, OK for period ending 04/27/98 ~03 UTC. Upper left: OHP product from Original PPS algorithm (with Truncation problem); Upper right: OHP product from Prototype PPS algorithm (with problem Corrected); Lower left: Differences between them by amount; Lower right: Differences by percent.

Project 1: WSR-88D QPE (cont.)

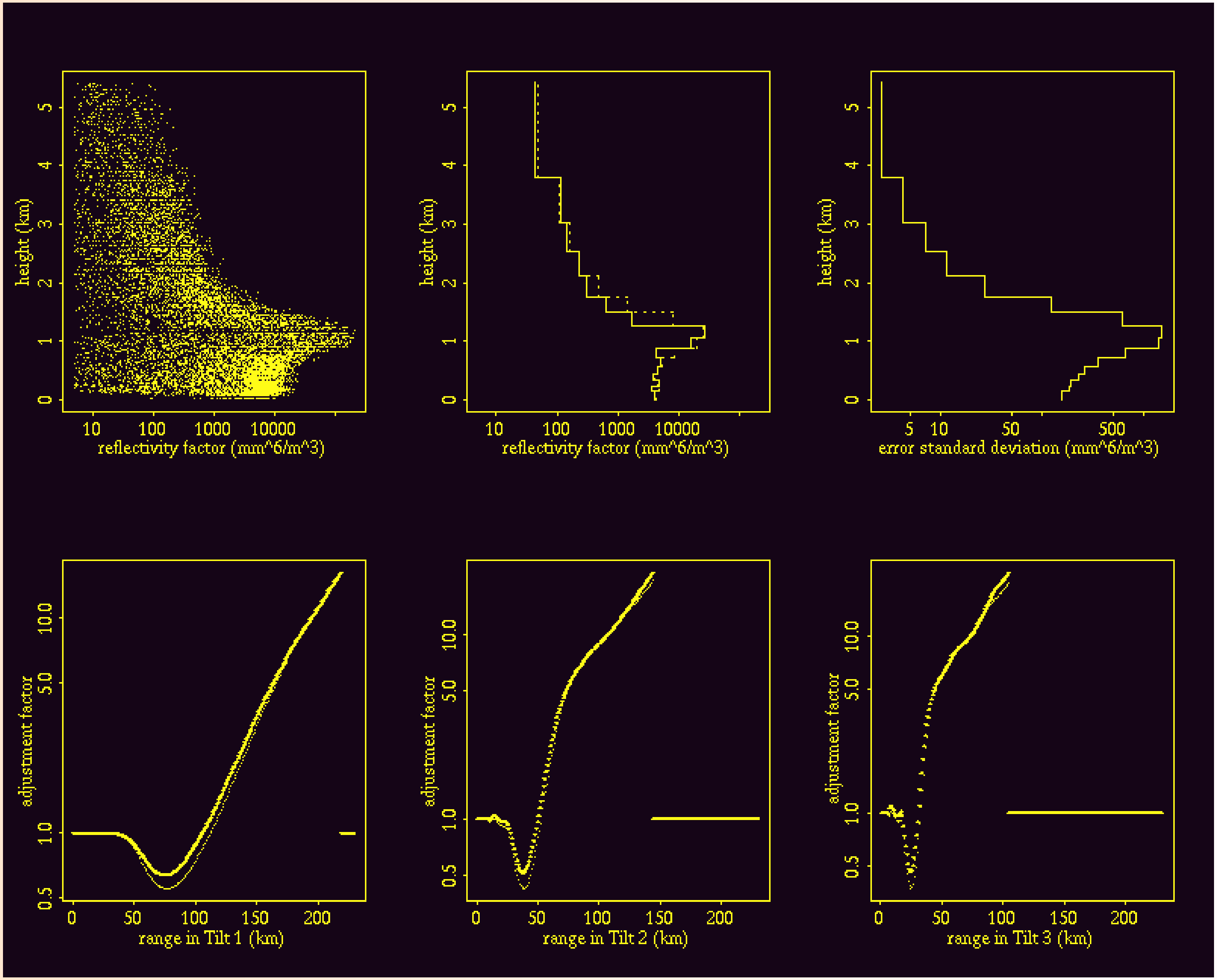
b) Applied research and prototype development of new improved PPS algorithm

- Prototype development of two new supporting algorithms for PPS (Seo)
  - **Range Correction Algorithm, RCA**, to correct PPS range-degradation errors in rainfall due to nonuniform vertical reflectivity profile (VPR)
  - **Convective-Stratiform Separation Algorithm, CSSA**, to delineate the stratiform regions to estimate VPR and apply range correction
- Benefits: Increased accuracy of rainfall products at mid-far ranges for stratiform rain systems, in cool seasons, and in northern U.S. latitudes; reduced bright band contamination

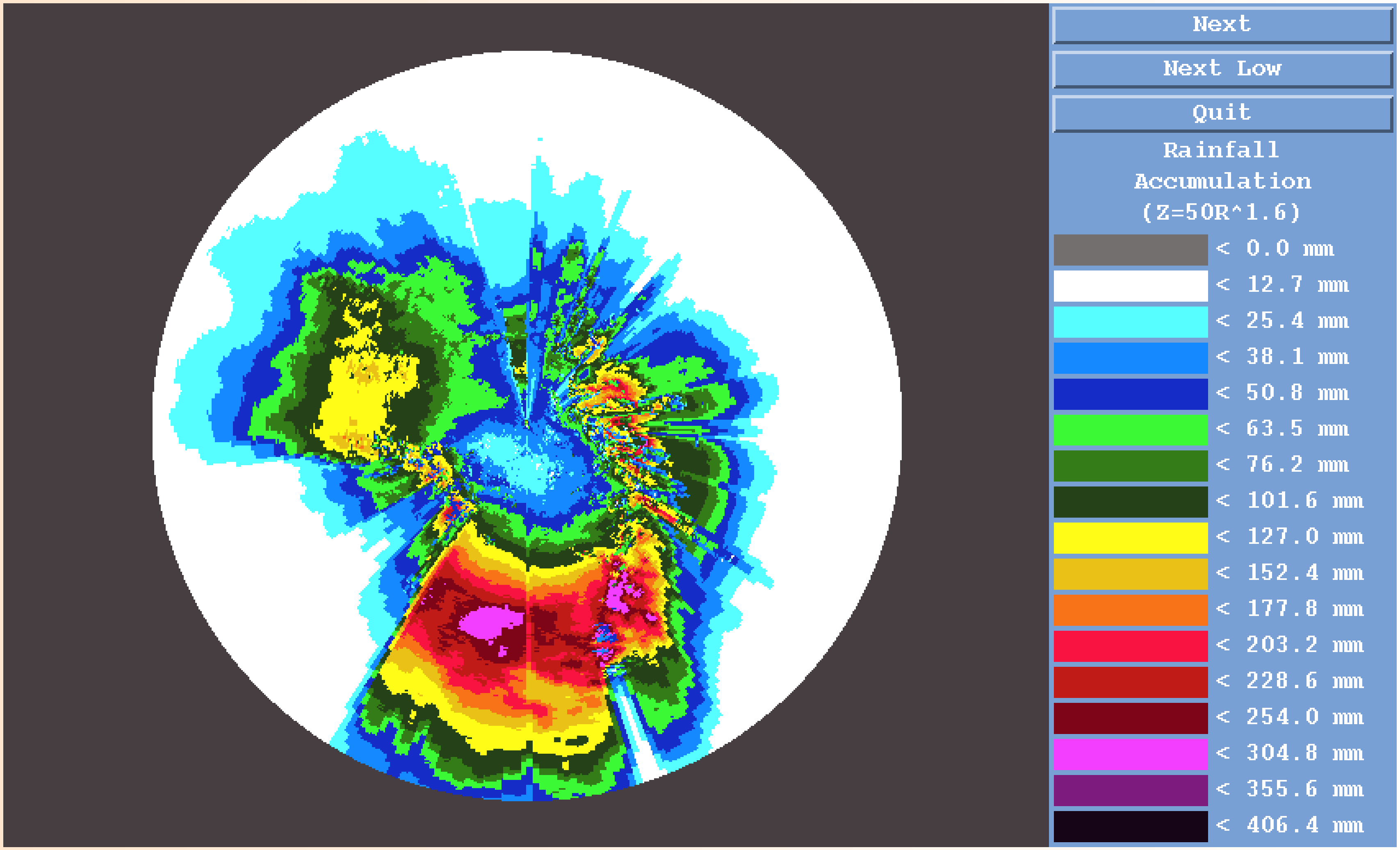


References:
Seo et al. (2000) "Real-time adjustment of range-dependent biases in WSR-88D rainfall estimates due to nonuniform vertical profile of reflectivity", J. Hydrometeorology, 1, pp. 222-240
Seo et al. (2000) "Convective-Stratiform Separation", Chapter 5 of OSF-OH MOU Final Report, http://hsp.nws.noaa.gov/oh/hrl/papers/2000mou_pdf/Mou00_PDF.html

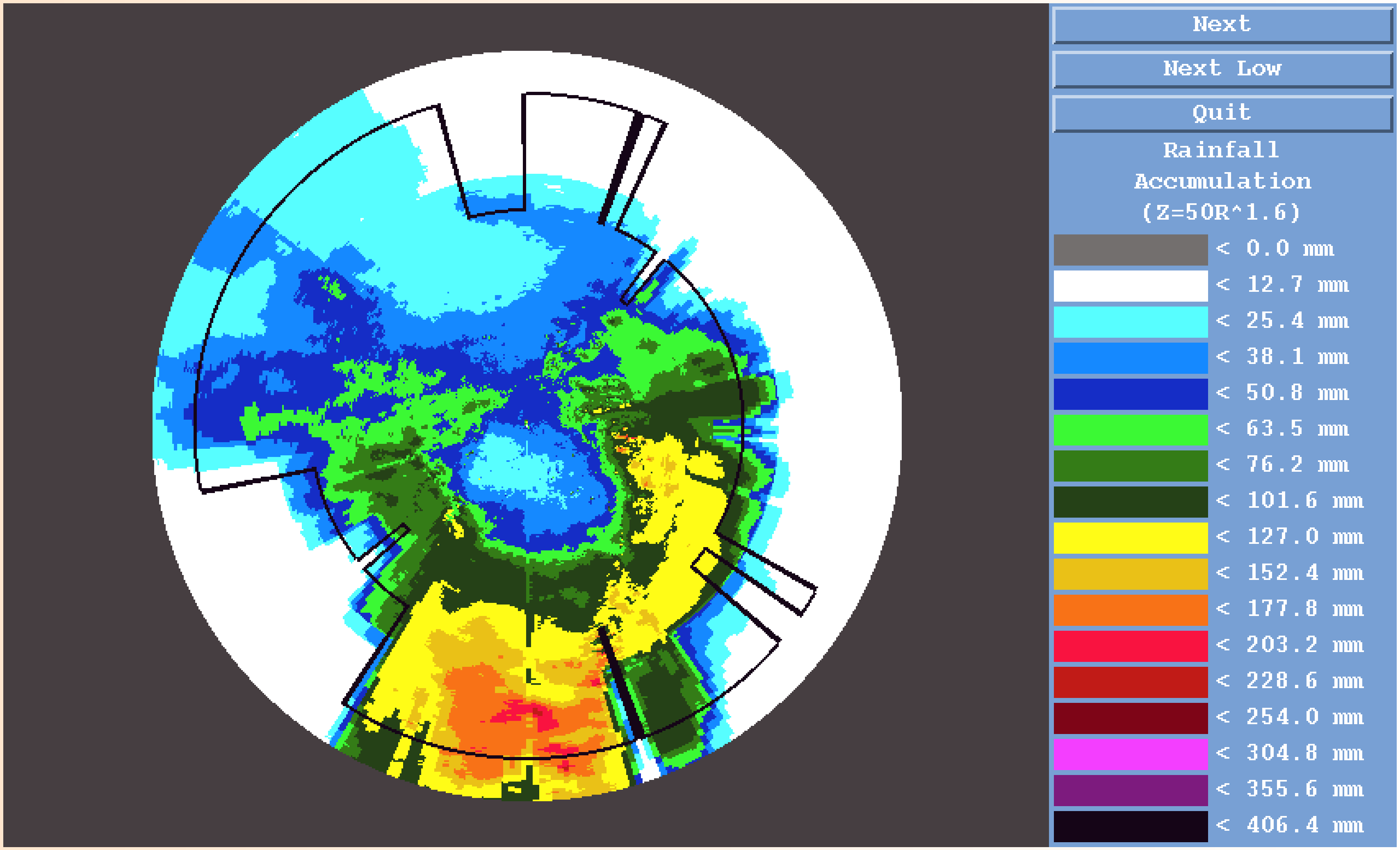
1 Volume Scan from Portland, OR WSR-88D 2/6/1996



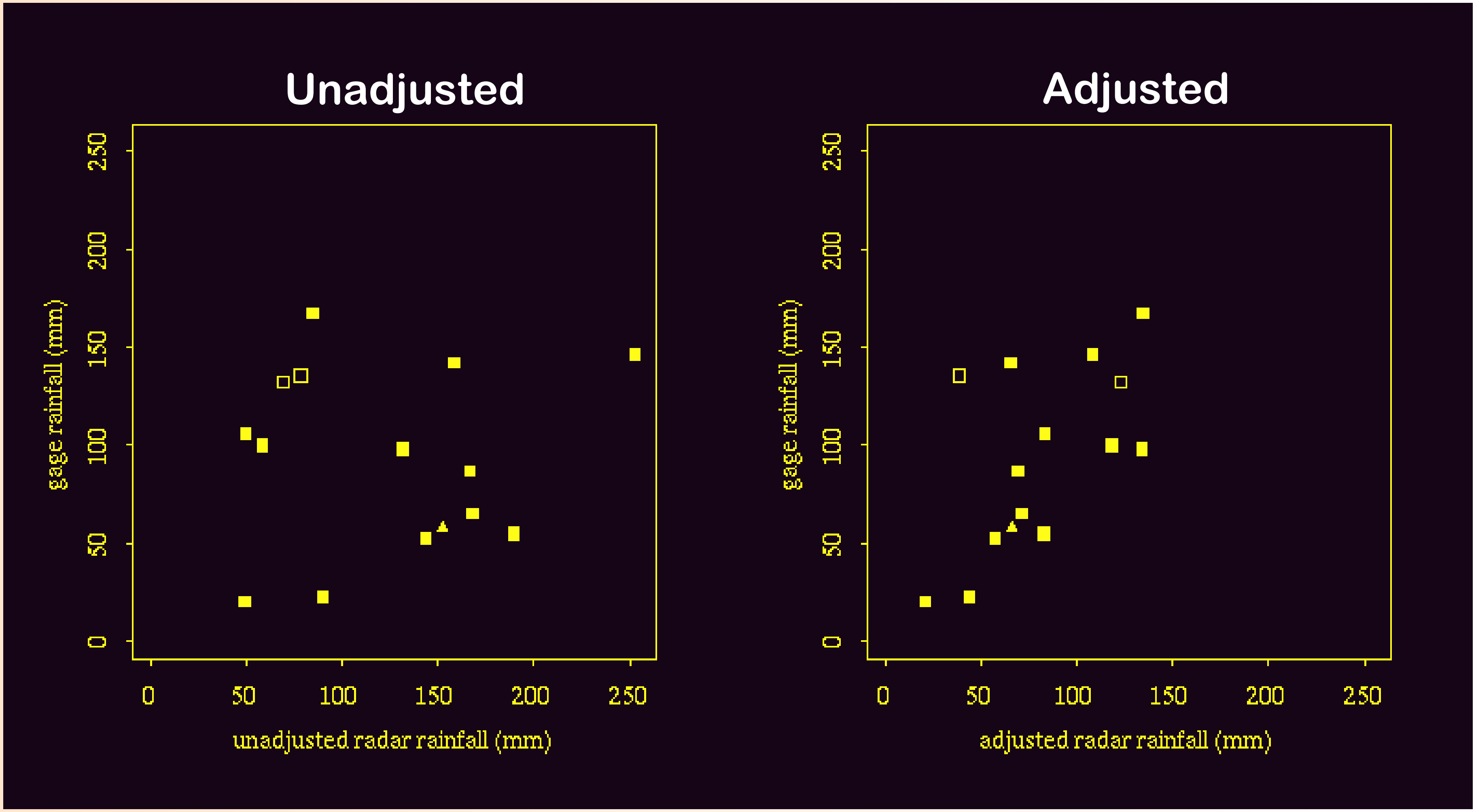
Unadjusted Storm-total Rainfall - Seattle, WA WSR-88D 2/6-8/96



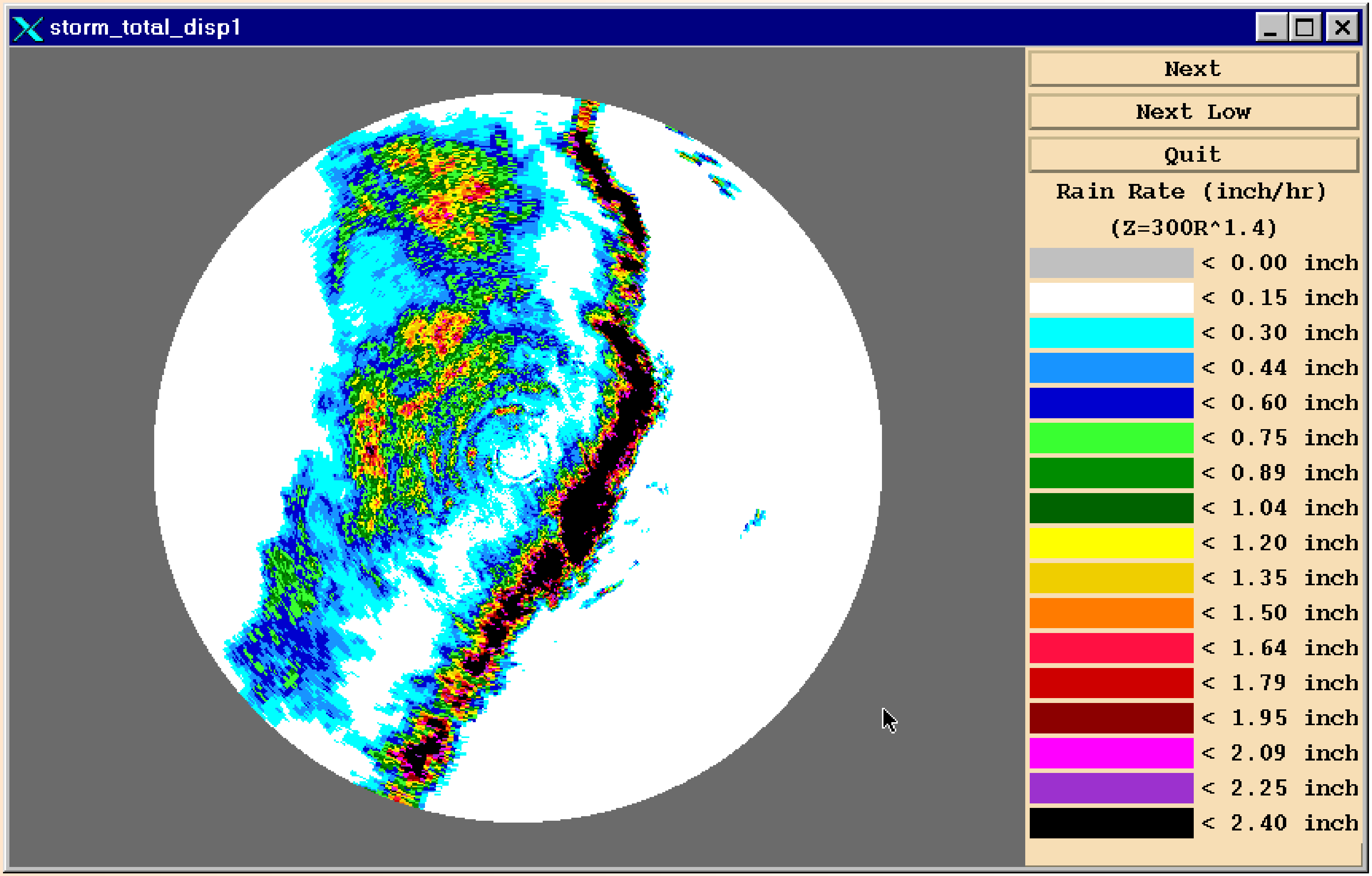
Adjusted Storm-total Rainfall - Seattle, WA WSR-88D 2/6-8/96



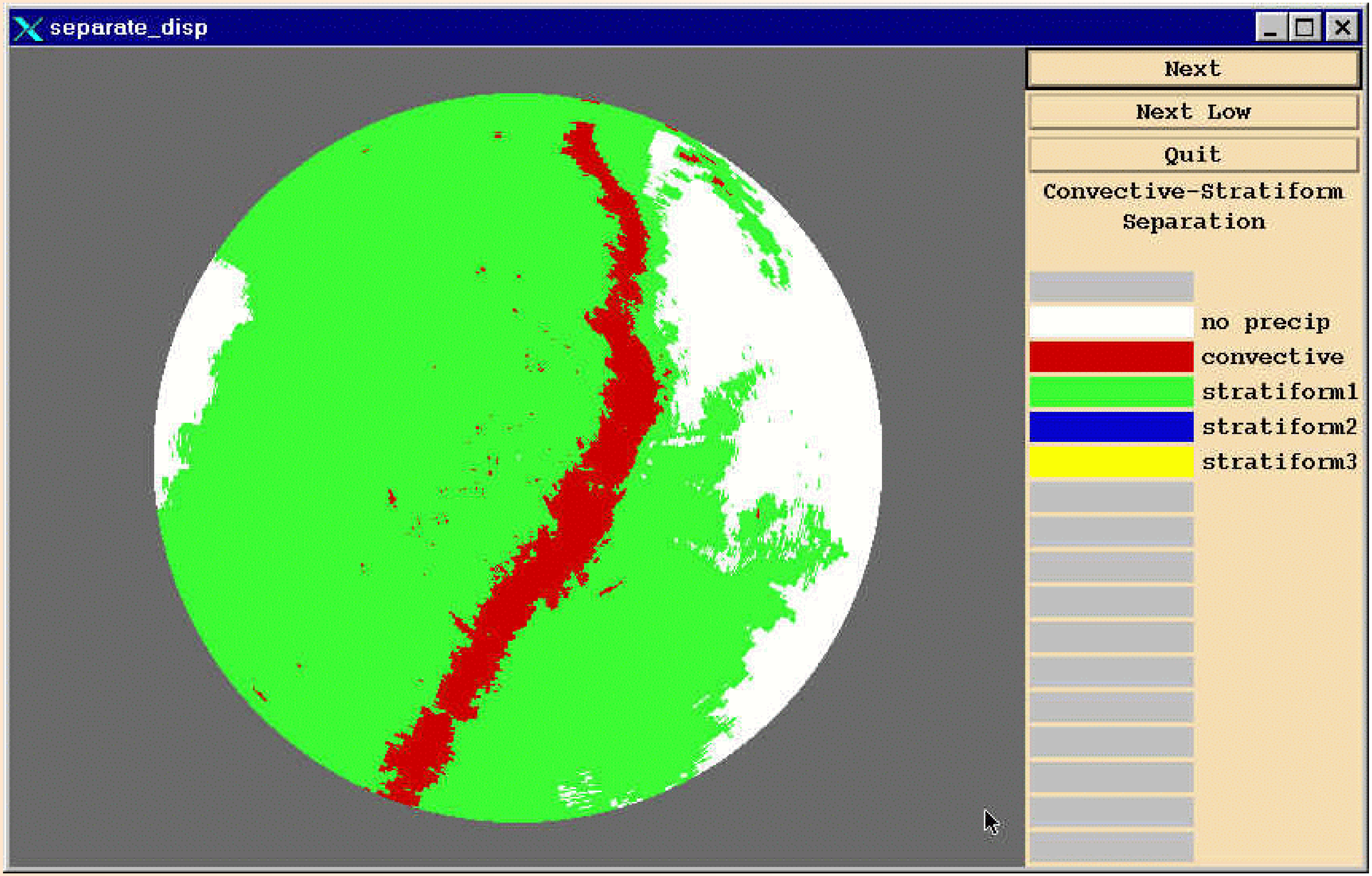
Storm-total gauge-radar rainfall scatter plot



Convective-Stratiform Separation Algorithm



Results of Separation



Project 1: WSR-88D QPE (cont.)

c) Software engineering of PPS enhancements on ORPG

Hydrology Lab is responsible for implementing and maintaining WFO WSR-88D QPE software

- 1) Implementation of RCA in Open RPG Build 2 (Pham/Vacancy, Seo, Miller)
  - Learn the new Open RPG architecture and software development environment on our HL Sun workstation
  - Port existing prototype RCA software from Hewlett-Packard workstations to Sun ORPG development platform at HL
  - Interface RCA with PPS and generate value-added products
  - Perform real-time beta-testing and proof-of-concept using live wideband base data feed from Sterling, VA WSR-88D (summer-fall 2001)

Reference: "WSR-88D Open RPG Implementation Plan for the Range Correction Algorithm in Build 2" January 2001

Project 1: WSR-88D QPE (cont.)

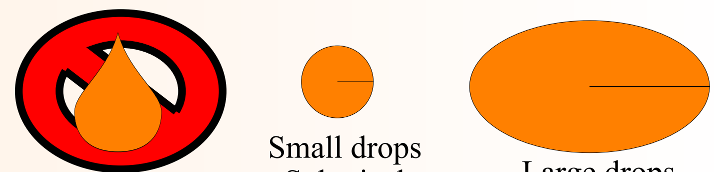
c) Software engineering of PPS enhancements on ORPG (cont.)

- 2) Fix PPS bugs causing truncation of rain rates (ORPG1,2) (Miller)
- 3) Implement capability for real-time WSR-88D gauge-radar bias adjustment at WFOs using mean field bias corrections passed from new WFO AWIPS MPE algorithm (ORPG2, AWIPS 5.2.2) (Miller, Tilles)
- 4) Implement new PPS Digital Storm-total Precipitation (DSP) product (ORPG2) (VacancyT)
  - Digital rainfall product (full data precision...0.1 mm) for follow-on quantitative applications to add to the existing Hourly Digital Precip. Array DPA product
  - Higher resolution 2-km national grid for ease of regional and national rainfall mosaicking
  - Differencing of consecutive DSPs produces rainfall products of any desired duration
  - Input for AWIPS SCAN Flash Flood Monitoring and Prediction algorithm and other value-added algorithms outside the NWS

Project 1: WSR-88D QPE (cont.)

d) Applied research and development of next-generation polarimetric radar rainfall algorithm for the ORPG

- Develop and evaluate new prototype polarization rainfall algorithms (Fulton, Vacancy)
  - Using differential reflectivity ($Z_{DR} = Z_H - Z_V$)
  - Using specific differential phase K_{DP}
  - Using reflectivity Z
  - Using rain gauges

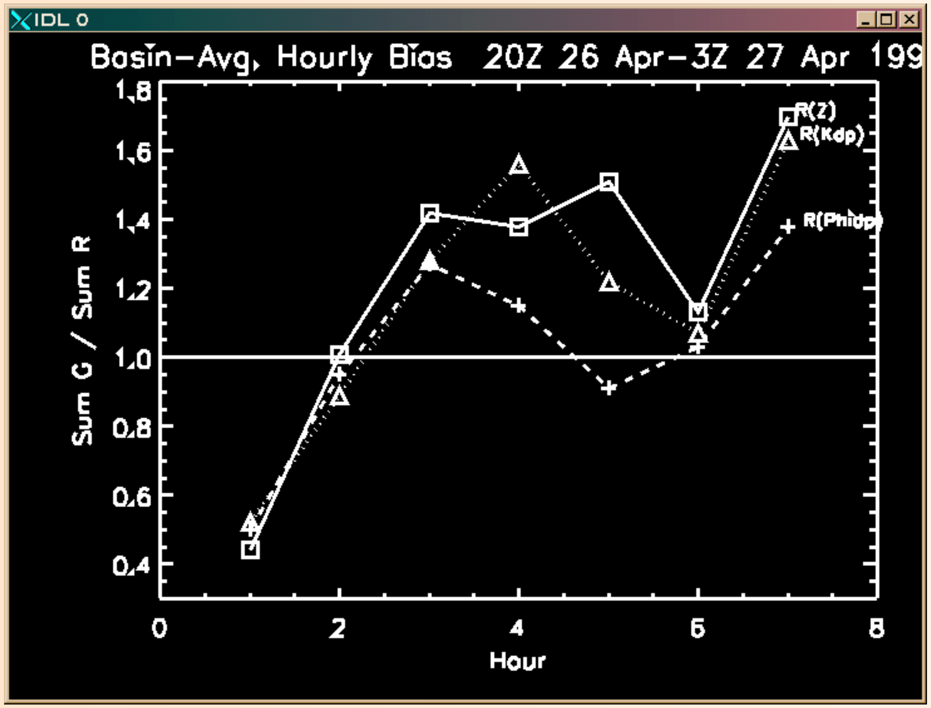


- Benefits: reduced biases, less tuning needed (e.g., Z-R parameters)
- Collaboration with NSSL (Ryzhkov, Zrnic', Schuur)
- Participation in Joint Polarization Experiment (JPOLE) in Oklahoma in 2002 and 2003 (planning, execution, data analysis)
  - Reference: Schuur et al. (2001) "JPOLE - An operational test of weather radar polarimetry", 30th AMS Radar Meteor. Conf.

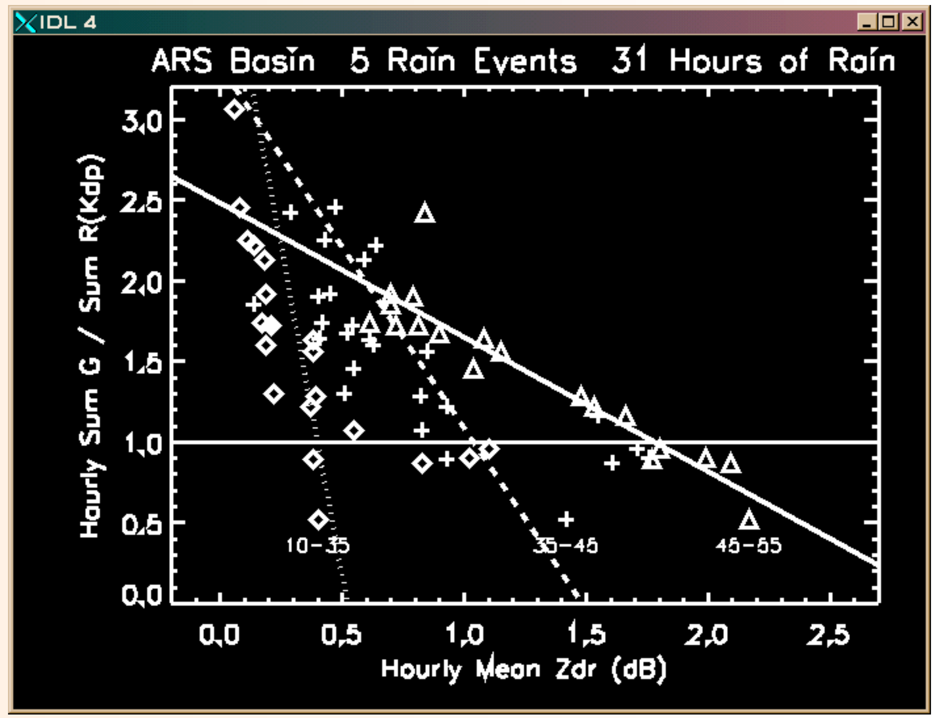
Development of a Polarization Rainfall Algorithm

$$R = 40.6\ K_{DP}^{0.866}\ B(Z_{DR})$$

$$\text{where } B(Z_{DR}) = a(Z) + b(Z)\ Z_{DR}$$



Little Washita River basin, Oklahoma



Project 2: Multisensor QPE

RFC-Wide Multisensor Precip. Estimator (MPE) On RFC AWIPS Platforms

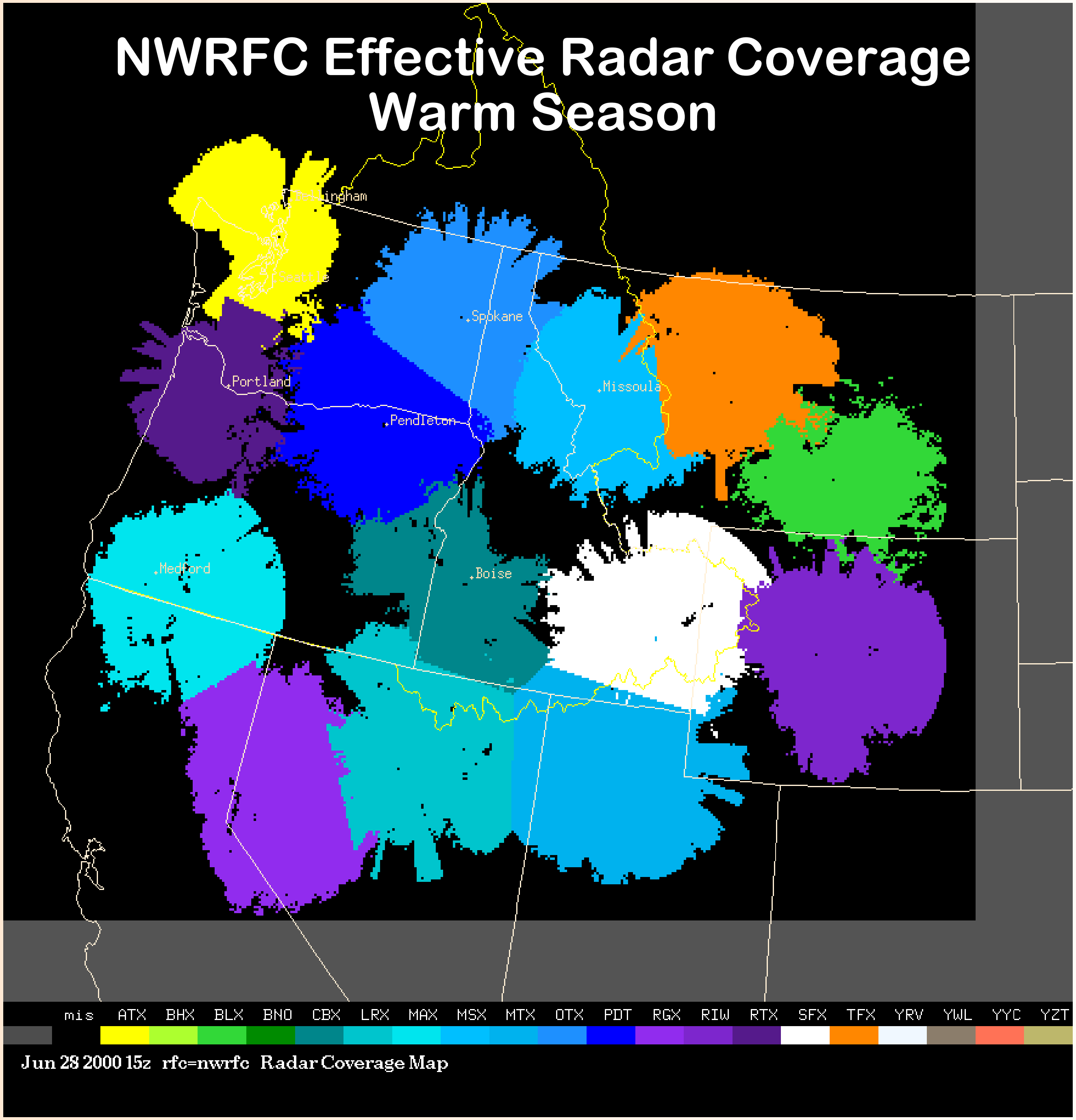
- a) Evaluation and validation of current Stage II & III Precip. Processing algorithms and next generation MPE algorithm and products
- b) Applied research and prototype development of improved rainfall analysis techniques
- c) Software engineering of MPE enhancements on AWIPS platforms
- d) Retrospective MPE reanalyses of historic data and validation

Project 2: Multisensor QPE

New RFC-Wide MPE algorithm v1.0 will be deployed to RFCs in AWIPS Build 5.1.1 beginning this June

- MPE replaces Stage II and III Precip. Processing algorithms deployed at the RFCS in early 1990s
- Improved mosaicking technique using lowest unobstructed tilt and actual effective radar coverage
- Improved gauge-radar bias adjustment techniques
  - Improved mean-field-bias-adjusted rainfall product using gauge-radar pairs from past hours and more limited radar ranges
  - New *local* bias-adjusted rainfall product (5.1.2)
- Use of PRISM rainfall in mountainous regions during G-R merging
- Use of satellite QPEs from NESDIS (5.2.1)
- Beta-tested at MARFC and WGRFC since 9/1999 and 3/2000 resp.
- RFC HAS training course to be given at COMET June 19-20

NWRFC Effective Radar Coverage
Warm Season



Project 2: Multisensor QPE (cont.)

a) Evaluation and validation of current Stage II & III Precip. Processing algorithms and next generation MPE algorithm

- Case study comparisons of QPE products against independent raingauge datasets (Breidenbach)
- Side-by-side comparisons of Stage II & III products with MPE products to quantify marginal improvement (Breidenbach)
- Development of **real-time, automated** procedures within MPE algorithm to continuously & objectively measure quality of the rainfall analyses for long-term statistical verification purposes (Breidenbach)
- Human factors evaluation (ease of use, robustness and immunity to failures, forecaster feedback)

Project 2: Multisensor QPE (cont.)

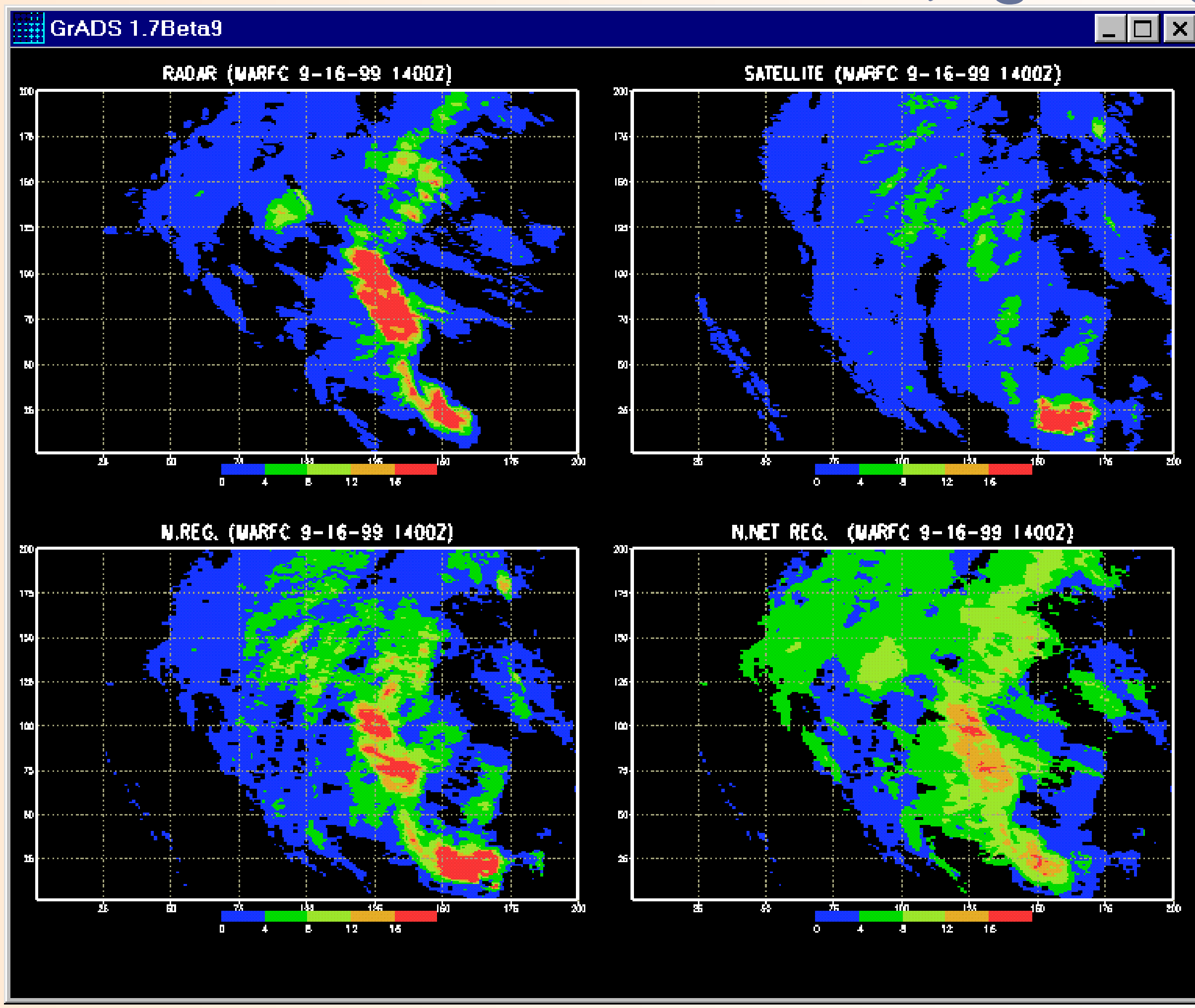
b) Applied research and prototype development of improved rainfall analysis techniques

- Refine & edit seasonal effective WSR-88D coverage maps (RFCs)
- Utilize multihourly gages in hourly analyses (time distribution)
- Use of model, surface, sounding, and lightning data to improve rainfall analyses (e.g., delineation of the freezing height)
- Future use of VPR-corrected rainfall products from ORPG
- Incorporate satellite rainfall estimates (Kondragunta, Breidenbach, Fortune)
  - Another source of rainfall estimates for HAS forecasters besides existing gauge-adjusted radar estimates
  - Active collaboration with NWS/ITTC and NESDIS
  - NESDIS Autoestimator, GMSRA, microwave algorithms
  - Use in data-poor regions (radar shadows behind mountains, far ranges, gauge-sparse regions)
  - Local satellite-gauge bias-adjusted rainfall product
  - Multiple regression & neural network techniques to combine satellite, radar, gauge

Multiple Regression and Neural Network Rainfall Estimation Approaches

Predictand: rain gauge rainfall
Predictors: radar & satellite rainfall, lightning data

Example: Hurricane Floyd over Mid Atlantic RFC forecast area



Project 2: Multisensor QPE (cont.)

c) Software engineering of MPE enhancements on AWIPS platform

Hydrology Lab is responsible for implementing and maintaining RFC QPE software within AWIPS

- Prototypes and operational algorithms
- Design and design reviews
- Coding and testing
- Integration within AWIPS environment (database, D2D)
- Real-time beta-testing at RFCs
- On-going software maintenance (bug fixes, new functionality)
- RFC Hotline support
- Development of training materials

Project 2: Multisensor QPE (cont.)

d) Retrospective MPE reanalyses of historic data and validation

- Rerun MPE regionally or nationally using WSR-88D and rain gauge data for the available archive period of record
  - Collaboration with Florida State University, SERFC, and Florida Dep't of Environmental Protection for reanalysis in the southeast U.S.
- Resulting products may serve as a future benchmark for hydrologic model calibration or climatological studies
- Challenge: How to automatically quality control rain gauge dataset?
- Develop off-line MPE verification procedures to objectively measure the marginal benefit of incremental improvements to the algorithm
  - Gauge QC vs. no-QC
  - Multisensor vs. radar-only vs. gauge-only rainfall analyses
  - Gauge-adjusted radar vs. unadjusted radar estimates
  - Incorporation of multihourly gauge data

Project 3: Radar & Raingauge Quality Control

RFC-Wide MPE on RFC AWIPS platforms

- Develop and implement operational QC procedures for radar rainfall (Kondragunta)
  - Automatically remove false rainfall caused by anomalous propagation
  - Refine existing automated technique that uses satellite IR brightness temperatures and surface air temperatures
  - Reduce need for manual HAS forecaster QC
- Develop and implement operational QC procedures for hourly and daily raingauge data (Kondragunta)
  - Very important!
  - Improve & validate Spatial Consistency Check algorithm
  - Many reasons why gauge rainfall often disagrees with radar
    - Wind-induced gauge undercatch
    - Mismatch of spatial scales of measurement
    - Poor calibration and infrequent maintenance (clogged gauges)
    - Clock timing errors (radar vs. gauge)
    - Poor gauge siting (trees overhanging the gauge, rooftops)

Example of Tree Blockages

Beaverdam ALERT gauge in Baltimore County, MD

Project 4: Flash Flood Monitoring and Prediction (FFMP) Development

Flash Flood Potential (FFP) algorithm on WFO AWIPS platforms

- a) Performance evaluation of current FFP algorithm based on 21 flash flood case studies (Fulton)
- b) Applied research and prototype development of improved short-term WSR-88D quantitative precipitation nowcast algorithm (0-3 hours) (Fulton)

Creekside Park

Flash Flood Potential (FFP) algorithm

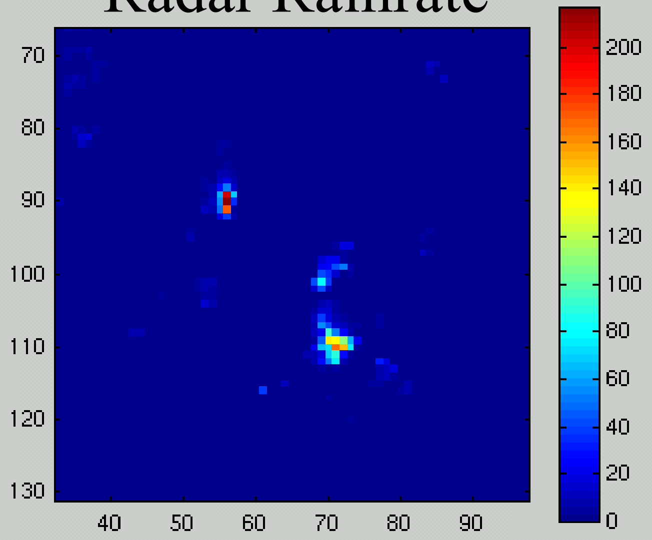
A WSR-88D-based forecaster tool to provide guidance on flash flood threat

- Computes 1,3,6-hr bias-adjusted radar rainfall estimates and compares with gridded Flash Flood Guidance on HRAP grid or basin averages (M in FFMP)
- Observed rainfall approaching FFG implies flooding threat
- Computes a 1-hr rainfall forecast using current and past radar images to estimate local storm motion vectors (P in FFMP)
- Currently evaluating and improving performance for archived flash flood events across U.S.
- Real-time beta-testing in progress since November 2000 for Sterling, VA WSR-88D on HL workstations
- Scheduled for AWIPS implementation within SCAN/FFMP (5.3?)

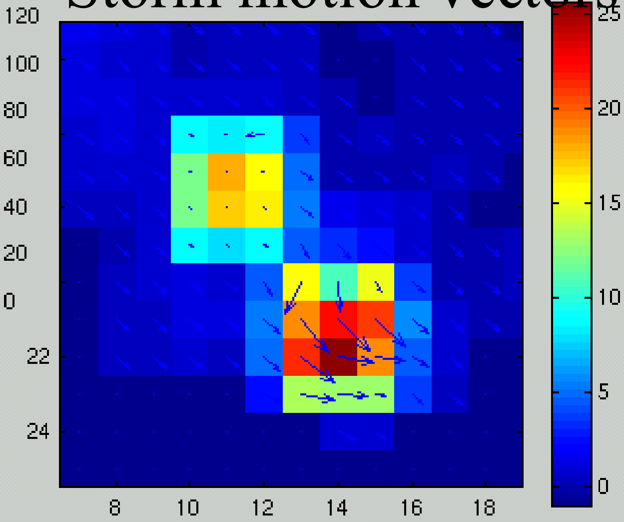
Rapidan River Flash Flood, VA

FFP products on 4-km HRAP grid
1747 UTC 27 June 1995

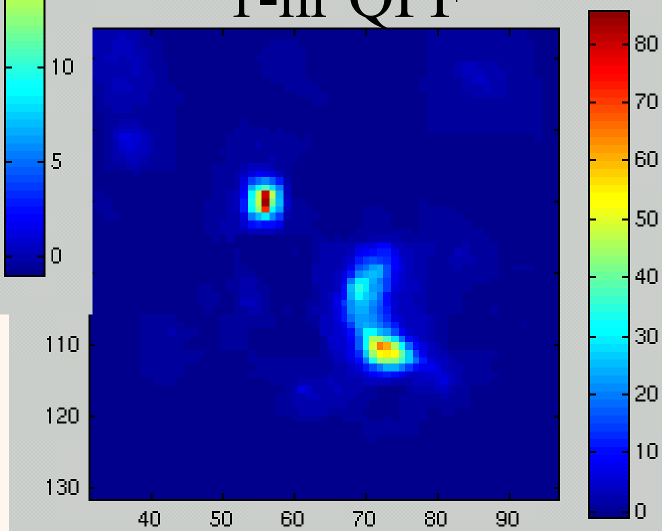
Radar Rainrate



Storm motion vectors

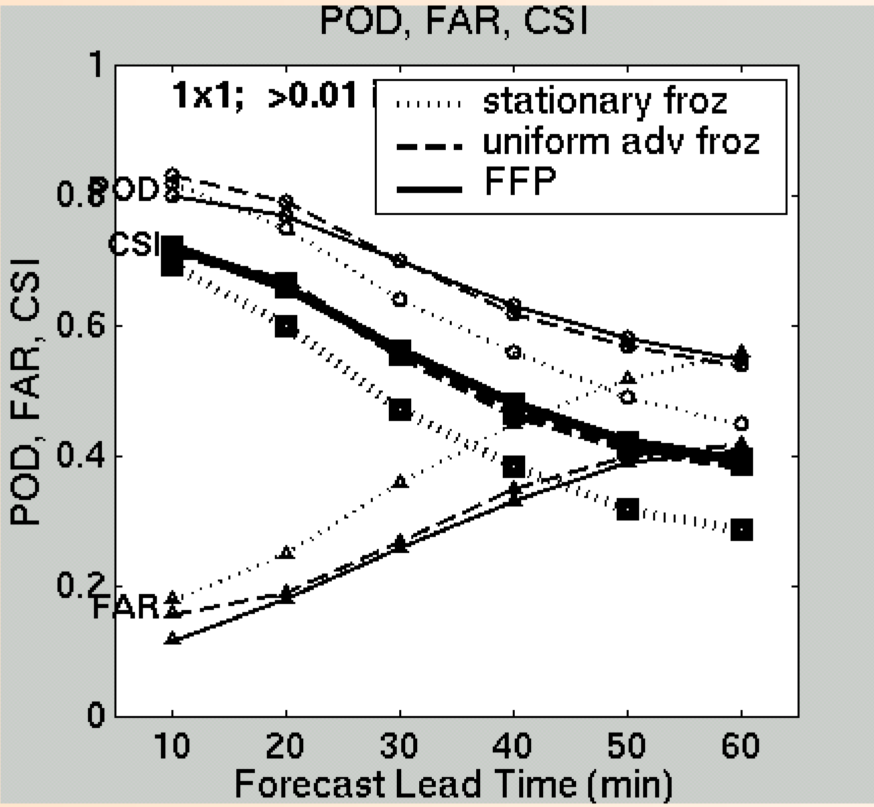


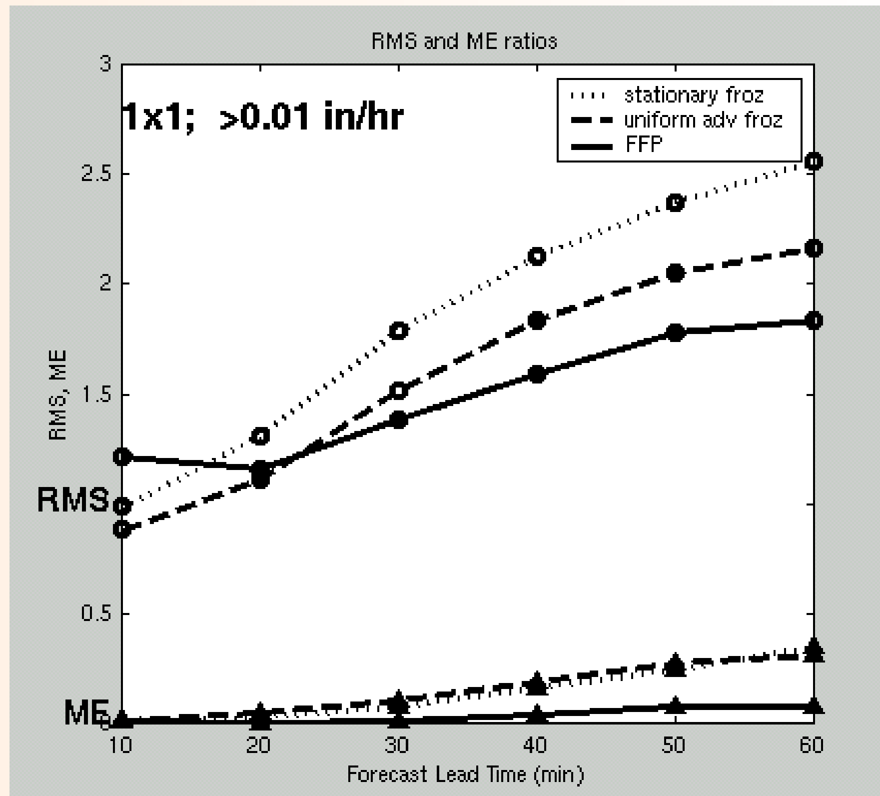
1-hr QPF



Verification of FFP Forecasts; Limits of Predictability

POD, FAR, CSI, RMSE, ME fcst-vs-obs rainrate statistics
Buffalo Creek, CO flash flood on 12 July 1996





Long-term QPE enhancement plans

- Increased use of ancillary data sources in PPS and MPE algorithms
  - Satellite data
  - NWP model analyses and forecasts
  - Lightning data
  - Surface and upper air data
- Use of NCAR's Radar Echo Classifier in ORPG Build 3
  - To improve quality control of anomalous propagation echoes
  - To replace the PPS Tilt Test
  - To eliminate WSR-88D Precip. Detection Function
- Regional & national multisensor rainfall mosaics at WFOs updated every 5-6 minutes using 2-km Digital Storm-total Precipitation products (SCAN FFMP)
- Improved quality control of rain gauge data
- Probabilistic QPE products
- Polarimetric QPE products

External R&D Collaboration

- Princeton University (Prof. James Smith)
  - Long-term radar-gauge verification studies using archived DPAs from across the U.S.
  - Use of environmental data to automatically tune PPS parameters (e.g., Z-R parameters, hail threshold)
  - Flash flood rainfall analyses
- University of Iowa (Prof. Witold Krajewski)
  - Comparative evaluation of three VPR algorithms: a) Seo, b) Vignal, c) Swiss operational
  - Evaluation of partial beam blockage correction techniques
- National Severe Storms Laboratory (Dr. Dusan Zrnic')
  - Polarimetric rainfall estimation
- Florida State University, SERFC, Florida Dep't of Env. Protection
  - MPE reanalysis for southeast U.S.
- NASA Goddard, Princeton U., Nat'l Center Atmos. Research
  - Comparative evaluation of radar rainfall QC techniques
- Czech Republic Hydrometeorological Institute
  - Technology transfer

Relevance of HG Activities to NWS Strategic Plan

1.0 Deliver Better Products and Services

- Increase the accuracy and timeliness of NWS warnings
- Increase flash flood warning lead time from 52 to 65 minutes

- Approach
  - Delivery of improved radar precipitation processing capabilities
  - Integration of advanced technologies (radar, satellite, gauges)
- Technology
  - Accelerate improvements to accuracy of WSR-88D Precip. Processing System (PPS) precipitation estimates
  - Improve satellite precip. estimates, and calibrate and integrate them with radar and rain gauge data to generate an optimal multisensor QPE in real-time
  - Incorporate diverse environmental data into rainfall algorithm to improve QPE
  - Accelerate development and evaluation of techniques for short-term (0-3 hour) prediction of heavy rain events

Conclusions

- The Hydrometeterology Group is involved in a wide variety of WSR-88D QPE and QPF activities that will lead to improved NWS hydrologic operations
- A long history of operational experience and scientific innovation in the HG combined with NWS, OHD, and HL backing and financial support has made this possible
- Much more remains to be done…