Projects and Plans for Improving WSR-88D Rainfall Algorithms and Products in the National Weather Service

Richard Fulton

Hydrology Laboratory
Office of Hydrologic Development
National Weather Service

NWS HAS Forecaster Conference
August 21, 2002
Silver Spring, Maryland

Outline

- OHD staff and funding resources dedicated to Quantitative Precipitation Estimation (QPE) enhancement
- Near-term (0-2 yrs) Precipitation Processing System (PPS) and Multisensor Precipitation Estimator (MPE) enhancements
- Long-term (3+ yrs) QPE science frontiers

Mission Statement

Hydrometeorology Group

To provide leadership in the development and application of innovative scientific rainfall analysis and forecast techniques using WSR-88D radar and hydrometeorological data sources to improve NWS hydrologic operations and products

Scientific R&D Staff Resources

Hydrometeorology Group
Hydrologic Science and Modeling Branch

- Richard Fulton, meteorologist, group leader
- Chandra Kondragunta, meteorologist
- Dong-Jun Seo, hydrologist (UCAR) (60%)
- Feng Ding, meteorologist/computer specialist (RSIS Inc.)
- FTE GS-13 vacancy (not yet advertised)
- Scientist/programmer contractor vacancy

Software Engineering Staff Resources

NEXRAD and AWIPS Groups
Hydrologic Software Engineering Branch

- Paul Tilles (MPE)
- Bryon Lawrence (MPE)
- Moria Shebsovich (MPE) (contractor)
- Dennis Miller (PPS)
- Jihong Liu (PPS) (contractor)
- Cham Pham (PPS+MPE) (contractor)
- Scott Vandemark (PPS)

Scientific R&D Funding Support for QPE Enhancement

- Advanced Hydrologic Prediction Services (AHPS) FY02
  - Probabilistic/Ensemble QPE - $45k - external contractor
- AHPS FY03
  - Probabilistic/Ensemble QPE - $45k - external contractor
  - Enhance MPE to Support WFO Flash Flood Services -$100k - internal contractor
  - Multisensor Precipitation Nowcaster (MPN) -$40k -internal contractor
  - Polarimetric radar QPE - requested $60k, got $0k
- Other funding from NEXRAD Product Improvement (NPI) program, AWIPS, and WSR-88D Radar Operations Center

Valuable WSR-88D rainfall estimation educational materials are available at the Hydrology Laboratory's publications web page

http://www.nws.noaa.gov/oh/hrl/papers/papers.htm#wsr88d

- This and other Hydromet Group presentations related to future QPE planned enhancements
- 2000, 2001, & 2002 OHD-ROC MOU Final Reports on WSR-88D QPE scientific enhancements
- Conference papers and slide presentations
- Training course materials
  - American Meteorological Society's QPE/QPF short course
  - Multisensor Precipitation Estimator forecaster training course
- Science seminar presentations
- *Bookmark it and check back frequently as new materials are added*

American Meteorological Society's Short Course on QPE and QPF

13 January 2002 Orlando, Florida

http://www.nws.noaa.gov/oh/hrl/presentations/amsshortcourse/index.html

- Overview of operational rainfall estimation procedures
- Scientific techniques for estimating precipitation
- Improving radar rainfall estimates using rain gauges and satellite data
- Review of operational satellite rainfall estimation algorithms
- Introduction to quantitative precipitation forecasting
- Factors determining efficiency and rainfall intensity
- Forecasting precipitation associated with mesoscale convective systems
- Calibration of forecasts

National Weather Service's 5-Year Science Infusion Plan for Improved WSR-88D Quantitative Precipitation Estimation

- Recently-updated annual plan located at http://www.nws.noaa.gov/oh/hrl/papers/papers.htm#wsr88d
- Related paper for 2002 Federal Interagency Hydrologic Modeling Conference at http://www.nws.noaa.gov/oh/hrl/papers/wsr88d/qpe_hydromodelconf_web.pdf
- Comments on future directions of WSR-88D QPE algorithms and products are always welcome

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

Hydrology Laboratory
Office of Hydrologic Development
and
Applications Branch
WSR-88D Radar Operations Center

National Weather Service
NOAA

Version 1 - September 2000
Version 2 - September 2001
Version 3 - July 2002

On-going External Collaboration Activities related to Improving QPE Algorithms and Products

- Princeton University
  - Assessment of PPS rainfall products for heavy rain and flash flood events
- University of Iowa
  - Evaluation of algorithms to correct for nonuniform vertical profile of reflectivity
  - Improved methods to account for partial radar beam blockages
- Princeton University, USGS Baltimore district office, University of Maryland, WFO Balt/Wash, Baltimore city and county governments
  - Baltimore Flash Flood Project - urban flash flood forecasting system
- National Severe Storms Laboratory
  - Dual polarization radar rainfall algorithm development
  - PPS/MPE and QPESUMS algorithm and product comparisons
- Czech Republic Hydrometeorological Institute
  - Technology transfer of multisensor rainfall analysis techniques
- Florida State University, WFO Tallahassee, SERFC, FDEP
  - MPE rainfall reanalysis for Florida for 1996-today
- Forecast Systems Laboratory, Nat'l Center for Environmental Prediction
  - Improved rain gauge quality control procedures and data products

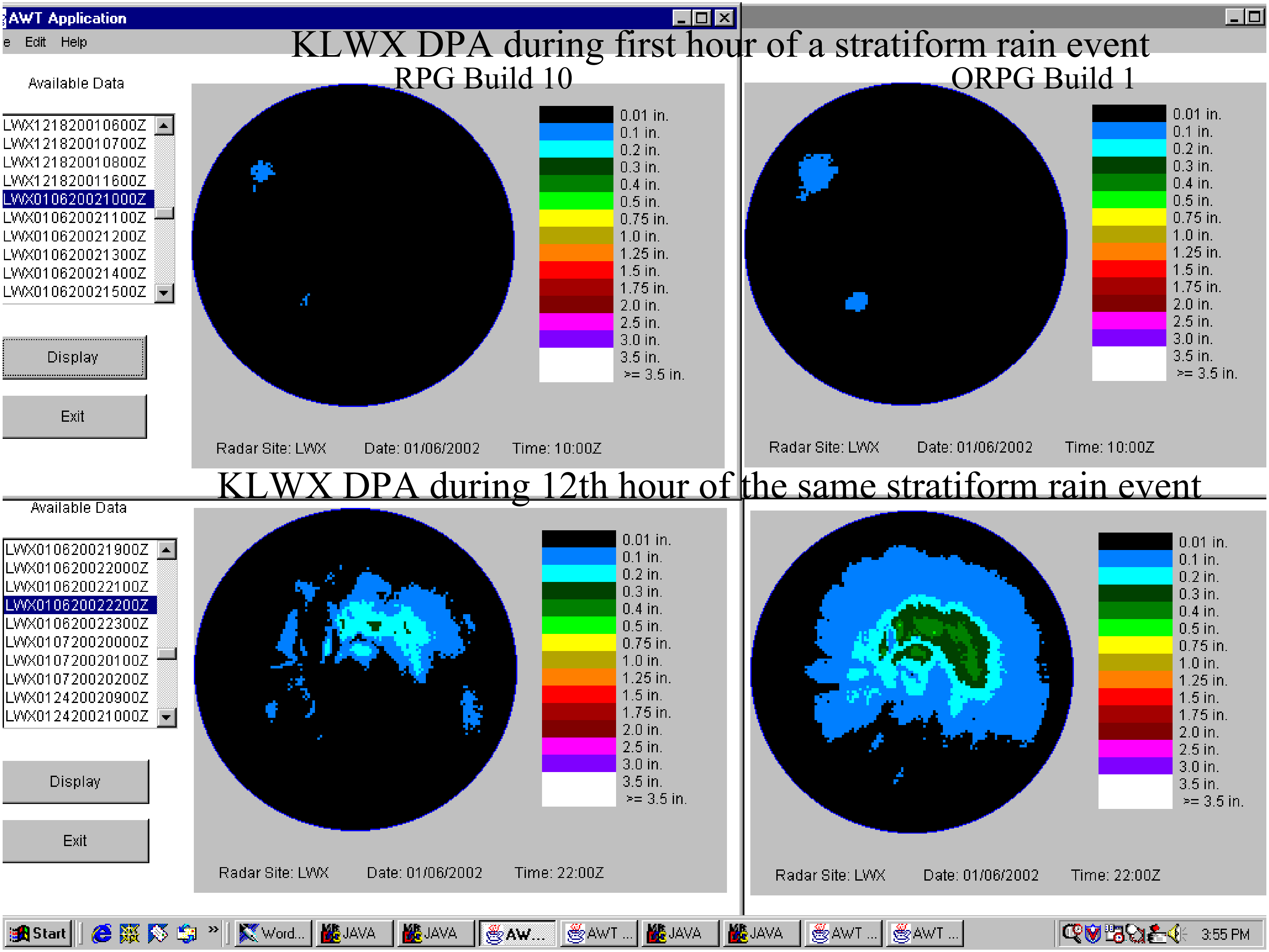
Summary of Near-term WSR-88D Precipitation Processing System (PPS) Enhancements

- Open RPG (ORPG) Software Build 1
  - Resolved PPS precipitation truncation problem
- ORPG Software Build 2
  - Raingauge-radar bias adjustment of PPS rainfall products at WFOs
- ORPG Software Build 3
  - Resolved PPS precipitation residual problem
  - New Digital Storm-total Precipitation (DSP) product

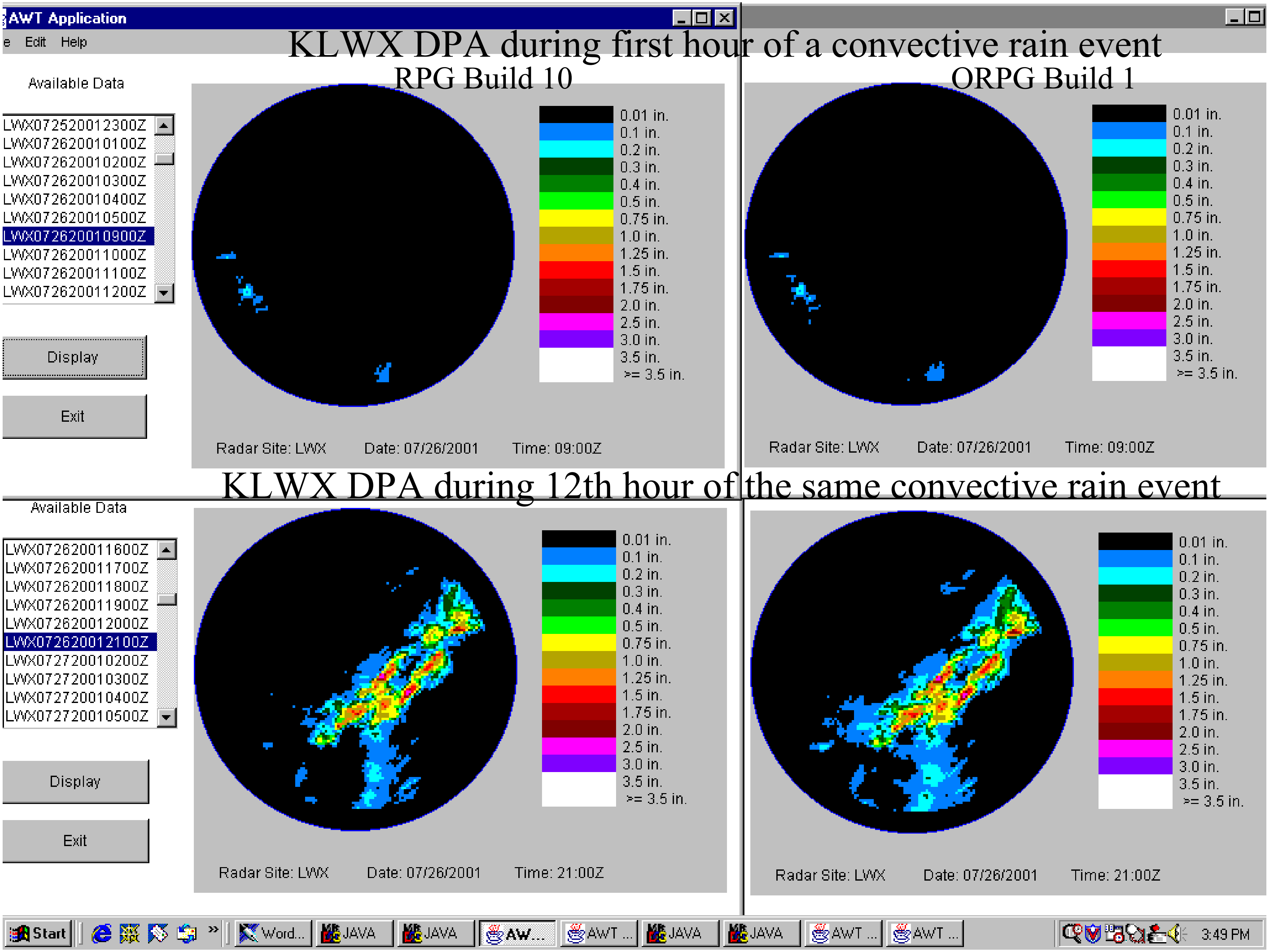
1) Resolved PPS precipitation truncation problem

ORPG Software Build 1
Field Deployment Nearly Complete

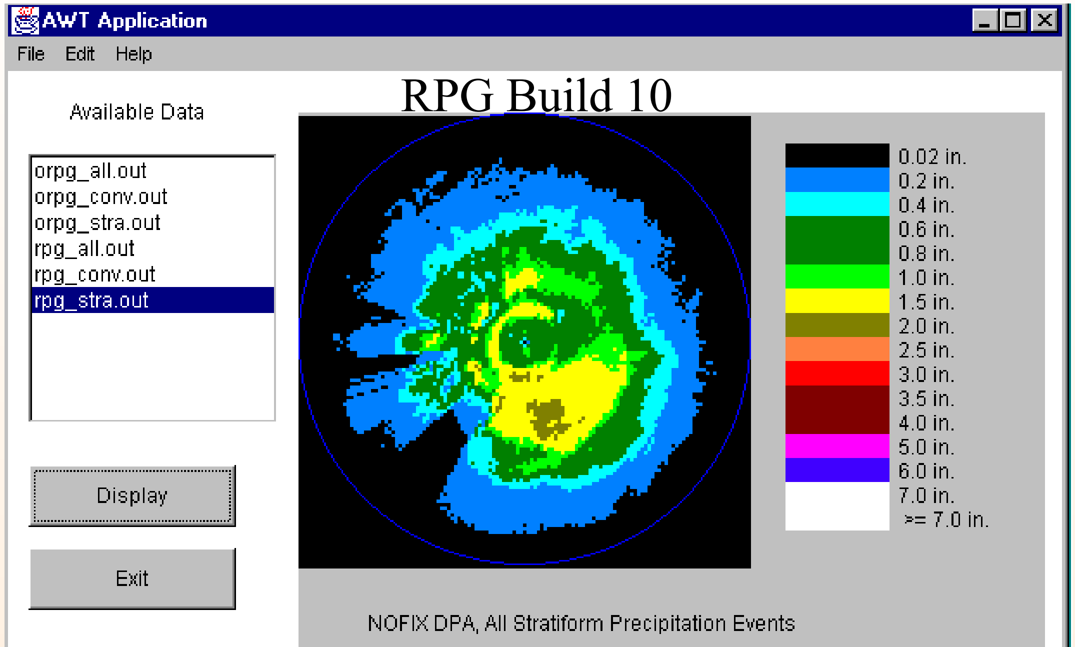
- A subtle PPS software bug had been causing long-unexplained underestimation of rainfall (especially stratiform rainfall) since WSR-88Ds were first deployed
  - Why? See http://www.nws.noaa.gov/oh/hrl/papers/2000mou_pdf/MOU00_PDF.html
  - How was it fixed? Details of the "simple fix with filter" solution at http://www.nws.noaa.gov/oh/hrl/papers/2001mou/MOU01_PDF.html
- The simple software fix in ORPG1 improves (increases) hourly rainfall products especially for light, long-lasting stratiform rainfall events
  - A sensitivity study illustrating the quantitative impacts as revealed in the hourly Digital Precipitation Array product (DPA) at Sterling, VA KLWX radar is at http://www.nws.noaa.gov/oh/hrl/papers/2002mou/MOU02_PDF.html



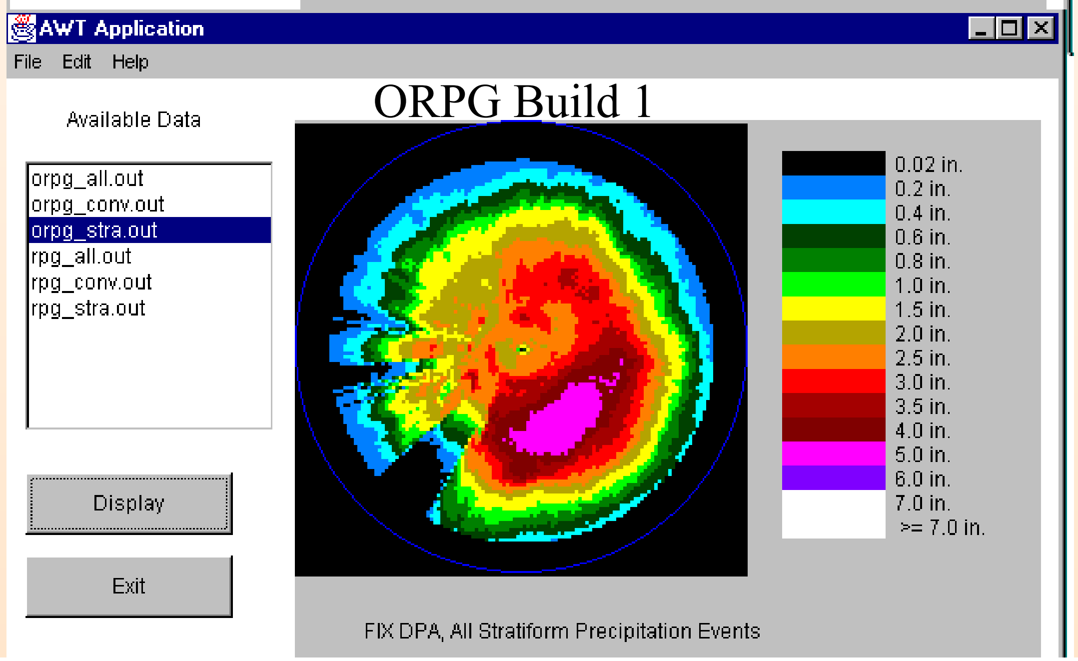
KLWX DPA during first hour of a stratiform rain event
RPG Build 10
ORPG Build 1
AWT Application
e Edit Help
Available Data
LWX121820010600Z
LWX121820010700Z
LWX121820010800Z
LWX121820011600Z
LWX010620021000Z
LWX010620021100Z
LWX010620021200Z
LWX010620021300Z
LWX010620021400Z
LWX010620021500Z
Display
Exit
0.01 in.
0.1 in.
0.2 in.
0.3 in.
0.4 in.
0.5 in.
0.75 in.
1.0 in.
1.25 in.
1.5 in.
1.75 in.
2.0 in.
2.5 in.
3.0 in.
3.5 in.
>= 3.5 in.
Radar Site: LWX Date: 01/06/2002 Time: 10:00Z
Radar Site: LWX Date: 01/06/2002 Time: 10:00Z
KLWX DPA during 12th hour of the same stratiform rain event
Available Data
LWX010620021900Z
LWX010620022000Z
LWX010620022100Z
LWX010620022200Z
LWX010620022300Z
LWX010720020000Z
LWX010720020100Z
LWX010720020200Z
LWX012420020900Z
LWX012420021000Z
Display
Exit
Radar Site: LWX Date: 01/06/2002 Time: 22:00Z
Radar Site: LWX Date: 01/06/2002 Time: 22:00Z
Start
Word...
JAVA
JAVA
AW...
AWT ...
JAVA
JAVA
AWT ...
AWT ...
3:55 PM


KLWX DPA during first hour of a convective rain event
RPG Build 10
ORPG Build 1
KLWX DPA during 12th hour of the same convective rain event
AWT Application
Edit
Help
Available Data
LWX07252001 2300Z
LWX07262001 0100Z
LWX07262001 0200Z
LWX07262001 0300Z
LWX07262001 0400Z
LWX07262001 0500Z
LWX07262001 0900Z
LWX07262001 1000Z
LWX07262001 1100Z
LWX07262001 1200Z
LWX07262001 1600Z
LWX07262001 1700Z
LWX07262001 1800Z
LWX07262001 1900Z
LWX07262001 2000Z
LWX07262001 2100Z
LWX07272001 0200Z
LWX07272001 0300Z
LWX07272001 0400Z
LWX07272001 0500Z
Display
Exit
0.01 in.
0.1 in.
0.2 in.
0.3 in.
0.4 in.
0.5 in.
0.75 in.
1.0 in.
1.25 in.
1.5 in.
1.75 in.
2.0 in.
2.5 in.
3.0 in.
3.5 in.
>= 3.5 in.
Radar Site: LWX
Date: 07/26/2001
Time: 09:00Z
Time: 21:00Z
Start
Word...
JAVA
AWT ...
3:49 PM

Summation of 76 hours of DPA rainfall from 8 stratiform rainfall events at KLWX

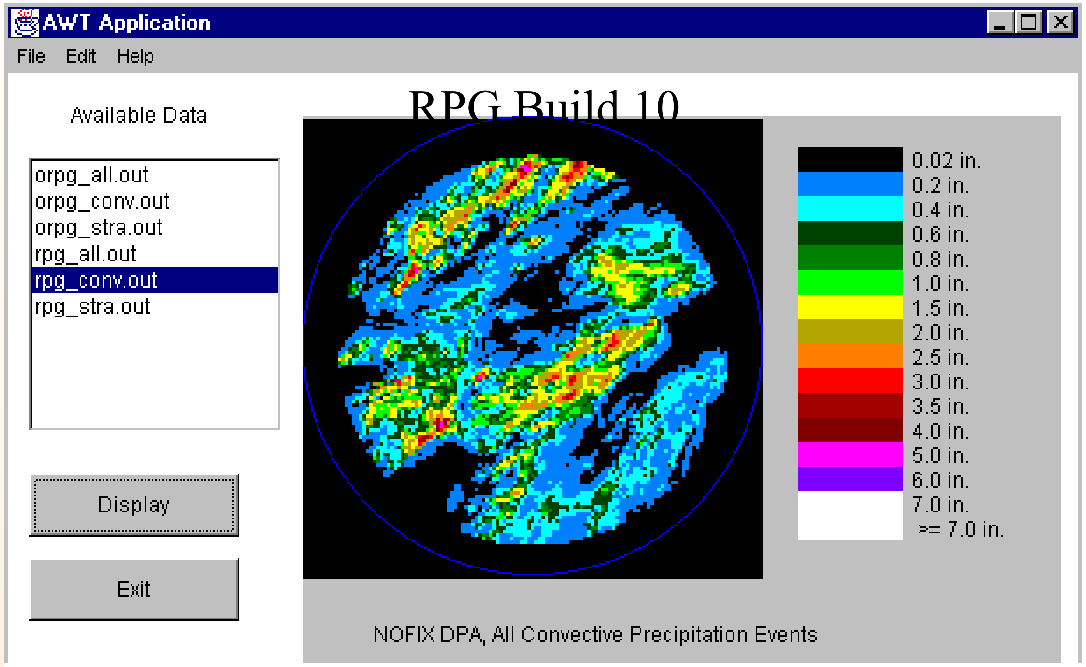


Max value =1.9 inches

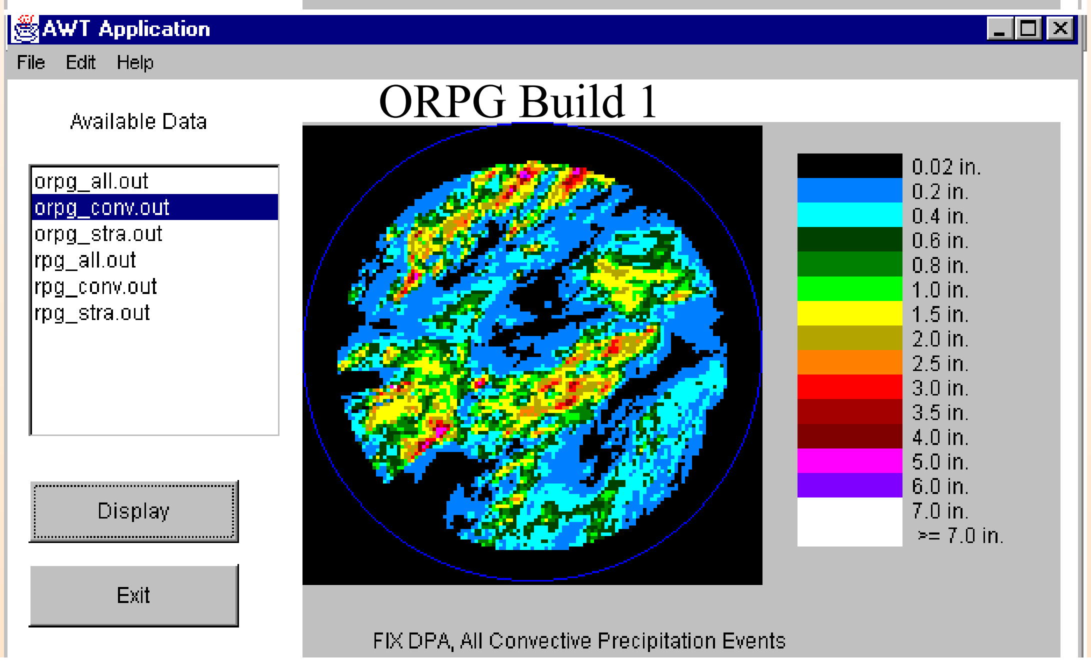


Max value =4.7 inches

Summation of 32 hours of DPA rainfall from 4 convective rainfall events at KLWX

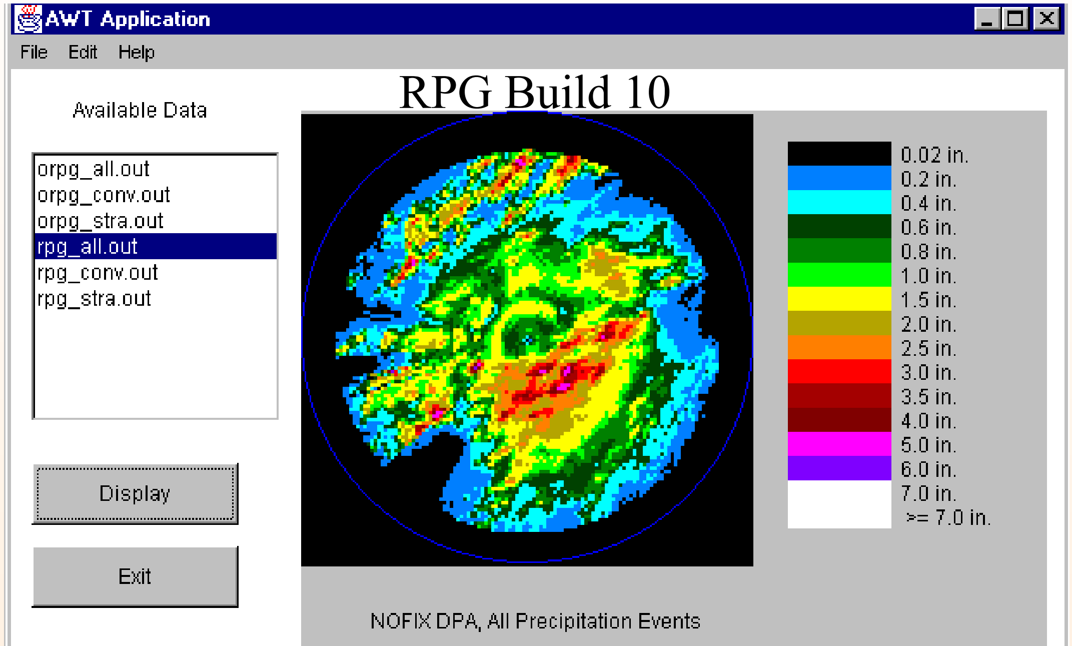


Max value =5.3 inches

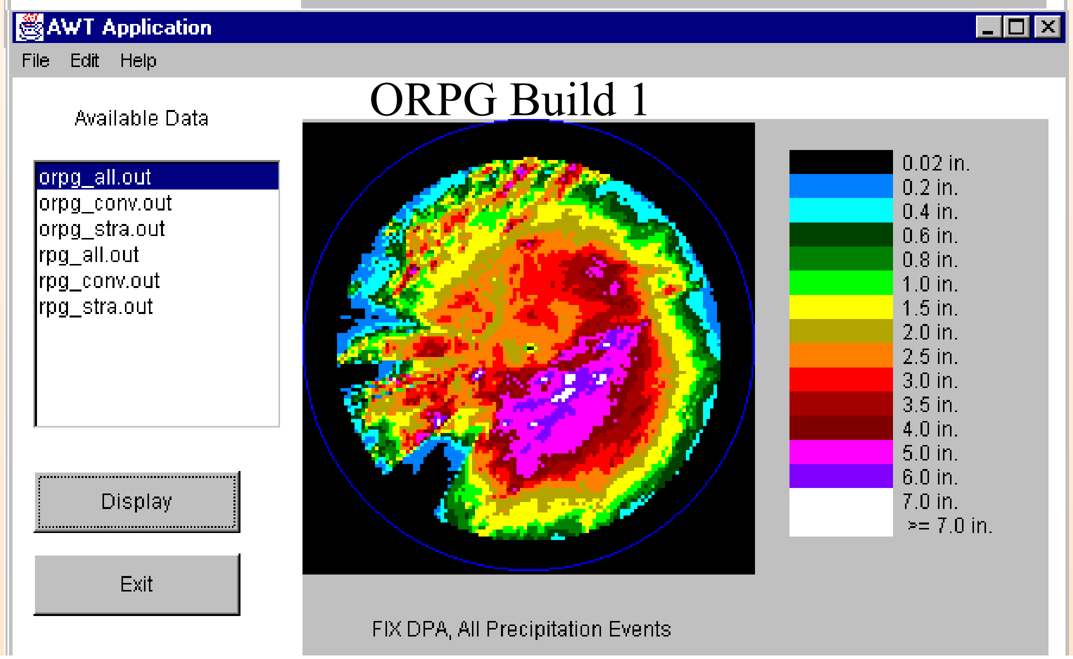


Max value =6.2 inches

Summation of 108 hours of DPA rainfall from 12 convective and stratiform rainfall events at KLWX



Max value =5.5 inches



Max value =7.8 inches

1) Resolved PPS precipitation truncation problem (cont.)

- Convective rainfall was not underestimated to the extent that stratiform and tropical rainfall was underestimated
  - Lost rainfall was proportional to total duration of the rain event and inversely proportional to the rain intensity
- Impact on hourly PPS rainfall products (DPA, OHP) was greater than on the storm-total rainfall product (STP), and the rate of precipitation loss increased as the event progressed
  - Stage II/III and MPE uses hourly DPA products
- Now we can expect much more quantitatively-reliable (larger) radar rainfall estimates in all rainfall types (stratiform, tropical, convective, ...) with the delivery of ORPG software build 1
- In the past, the gauge-radar mean-field-bias adjustment algorithm within the RFC’s Stage II and MPE should have reduced or eliminated these underestimation biases (if you had enough real-time hourly rain gauges)
  - However, typically-sparce real-time hourly rain gauge data has likely resulted in residual underestimation biases in historical Stage III and MPE products from stratiform rain events that have not been fully removed even after gauge-radar bias adjustment

2) Raingauge-radar bias adjustment of PPS rainfall products at WFOs

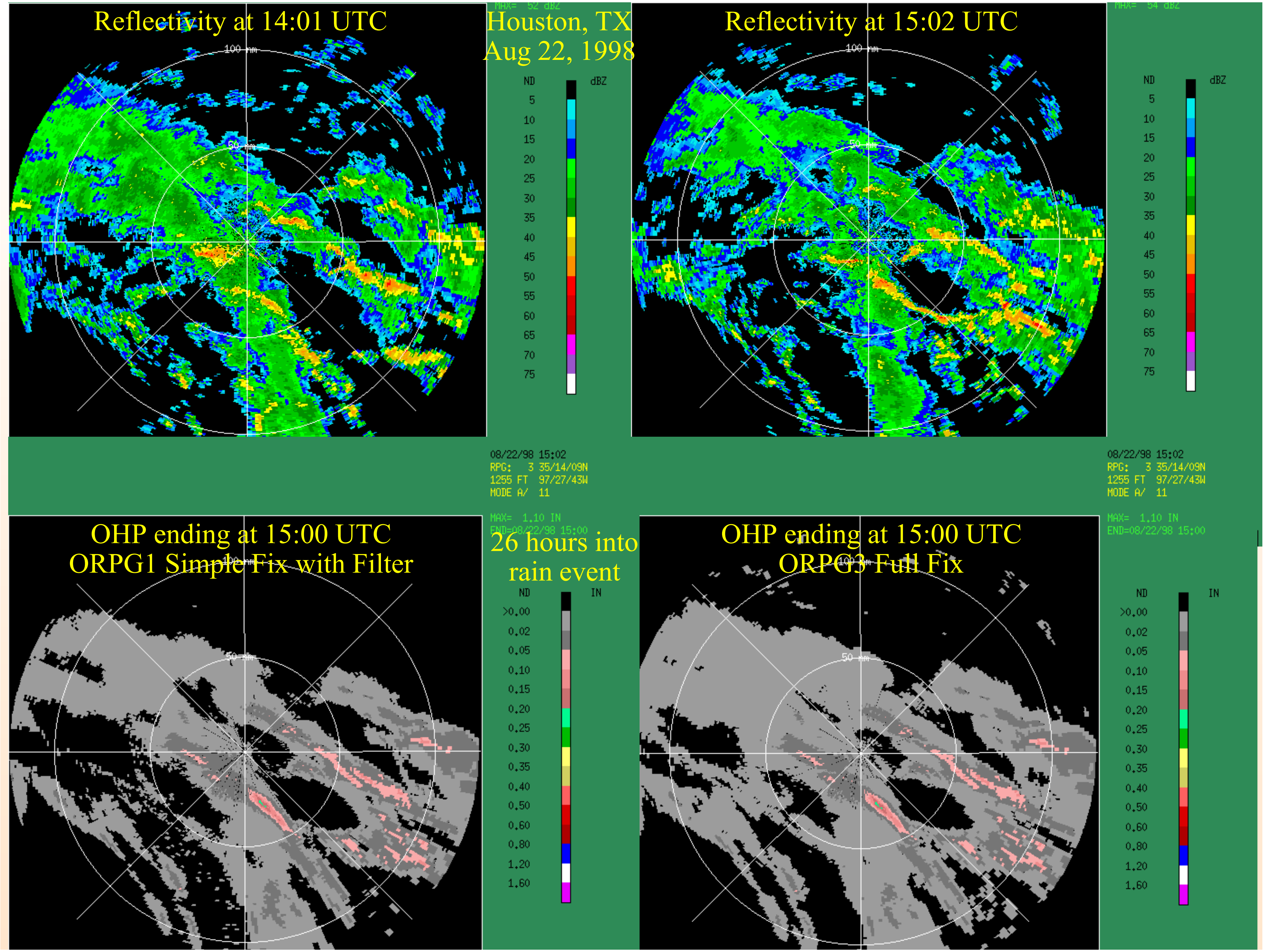
ORPG Software Build 2
Field Deployment beginning Fall 2002

- First time ever that WFO's PPS radar rainfall products will use real-time rain gauge data to remove hourly mean field gauge-radar biases
  - Original WSR-88D Gauge Data Support System plan was scrapped
  - WFO forecasters can choose to apply bias corrections to products or not
- How? Multisensor Precipitation Estimator MPE (to be delivered to WFOs in AWIPS 5.2.2) will automatically pass the local radar's hourly bias correction factor from AWIPS to the local ORPG/PPS
  - Once per hour (~H+25 mins.) or whenever forecaster manually reruns MPE
- Biases will not be applied to rainfall amounts in the Hourly Digital Precipitation Array (DPA) products
  - However the bias factor is written into product header for external users
- Will require that WFOs monitor and assure raingauge and radar data quality within AWIPS's MPE if they hope to make quantitative use of rain gauge data to calibrate their PPS radar rainfall products

3) Resolved PPS precipitation residual problem

ORPG Software Build 3
Field Deployment beginning Spring 2003

- An additional problem of scattered, persistent, small (~0.01 inch) residual rainfall pixels became evident in ORPG1 hourly rainfall products (OHP, DPA) from long-lasting multiday rain events
- Residuals automatically go away after one hour with no rain in the radar umbrella (i.e., when the PPS reinitializes)
- All occurrences of precipitation residuals have now been eliminated in the PPS software
- Improved detection and quantification of rainfall from low reflectivity echoes (below ~30 dBZ) around the edges of radar-estimated rainfall regions



Reflectivity at 14:01 UTC
Houston, TX
Aug 22, 1998
Reflectivity at 15:02 UTC
MAX= 52 dBZ
MAX= 54 dBZ
100 nm
50 nm
ND
dBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
08/22/98 15:02
RPG: 3 35/14/09N
1255 FT 97/27/43W
MODE A/ 11
OHP ending at 15:00 UTC
ORPG1 Simple Fix with Filter
26 hours into
rain event
OHP ending at 15:00 UTC
ORPG3 Full Fix
MAX= 1.10 IN
END=08/22/98 15:00
ND
IN
>0.00
0.02
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.50
0.60
0.80
1.20
1.60

4) New PPS product: Digital Storm-total Precipitation (DSP)

ORPG Software Build 3
Field Deployment beginning Spring 2003

- 256-data-level digital counterpart to the existing 16-level graphical Storm Total Precipitation (STP) product
- Polar 2-km x 1-deg grid (=raw spatial resolution of PPS algorithm)
- Generated and updated every volume scan
- Differencing of sequential DSP products can produce accumulations of any arbitrary duration desired (e.g., 5 min, 30 min, 1 hr, 2 hr, 24 hr,...)
- Will expand future NWS MPE hydrologic processing potential beyond existing algorithm dependent on the hourly DPA product
- Will be used in hydrology applications outside of the WSR-88D to enhance flash flood services, e.g.,
  - Future enhanced versions of MPE
  - Distributed hydrologic models
  - Flash Flood Monitoring and Prediction
  - Other value-added flash flood applications outside of NWS

Longer-term PPS Enhancements

ORPG Software Build 4
Field Deployment in Fall 2003

- 1) Implement new Range Correction Algorithm (RCA) and range-corrected rainfall products
  - To correct rainfall products for nonuniform vertical reflectivity profiles
  - Biggest benefits for cool season, stratiform rain events with brightband
  - Will be biggest scientific PPS enhancement to PPS yet
  - New Convective-stratiform Separation Algorithm (CSSA) under development
- 2) Enhanced PPS Preprocessing sub-algorithm (EPRE)
  - To allow PPS to accomodate the proposed new, variable WSR-88D antenna scanning patterns (no new science here, but improved processing efficiency)
- 3) Improved removal of anomalous propagation (AP) contamination
  - Use of new fuzzy-logic Radar Echo Classifier (REC) algorithm to define *local* regions of non-raining echoes
  - Will replace legacy PPS Tilt Test technique

Longer-term PPS Enhancements (cont.)

ORPG Software Build 4 and beyond

- 4) Improved automated Precipitation Detection Function for PPS
  - Use of REC's AP-corrected reflectivity hybrid scan (instead of base reflectivity) to determine when rainfall starts accumulating in PPS
  - Manual forecaster adjustment of WSR-88D's Nominal Clutter Area will no longer degrade PPS rainfall accumulations
  - No impacts on radar scanning since changes impact PPS only
- 5) Improved precision in PPS to allow light precipitation (e.g., snow) to accumulate below the existing PPS low reflectivity threshold of 22 dBZ
- 6) Multiple, parallel processing streams for multiple PPS products
  - With and without range correction
  - Using multiple Z-R relations
  - With and without gauge-radar bias adjustment
  - "Poor man's" ensemble QPE

Major Differences between old Stage II/III and new MPE Algorithms

- Improved mosaicking
  - In overlapping regions, use lowest-to-ground gridbin value instead of average or maximum values
  - Mosaicking is done “RFC wide” before multisensor merging, not after
  - Use of user-editable DPA-climatology-derived effective radar coverage bitmaps during mosaicking
- Improved raingauge-radar adjustment
  - Mean-field-bias computed over many hours instead of just one (Seo et al. 1999)
  - Use of gauge-radar pairs only in effective range of radar (minimizes negative effects of range degradation)
  - New local gauge-radar bias adjustment algorithm and product (Seo and Breidenbach 2002)
- PPS DPA products use terrain-based hybrid scan
- Use of truncation-corrected DPA products

Multisensor Precipitation Estimator (MPE) Enhancements

No longer called "RFC-Wide" MPE

- Incorporate satellite QPEs (SPEs) into MPE
  - AWIPS 5.2.2: HRAP-gridded NESDIS HydroEstimator SPEs can be displayed in D2D (but not yet in MPE)
  - Operational Build 1: Ability to view and interactively insert SPEs into missing or blocked regions within MPE
  - New local raingauge-satellite bias-corrected SPE product
  - New optimal estimation, regression, or neural network multisensor merging techniques using SPEs as a new additional data source
- Time distribution of multihour gauge reports into hourly amounts
- Use in MPE of range-corrected DPAs from RCA

MPE Enhancements (cont.)

- Automated rain gauge quality control techniques
- Residual clear air anomalous propagation removal using satellite infrared brightness temperatures and surface air temperatures (version 2)
- Delineation of areas observed above freezing level
  - Based on RCA delineation
  - Using NWP model temperature fields
- Real-time, on-the-fly validation and performance monitoring of MPE products using independent rain gauge data
  - 24-hr cooperative observer reports
  - 1- or 3-hr automated gauge reports

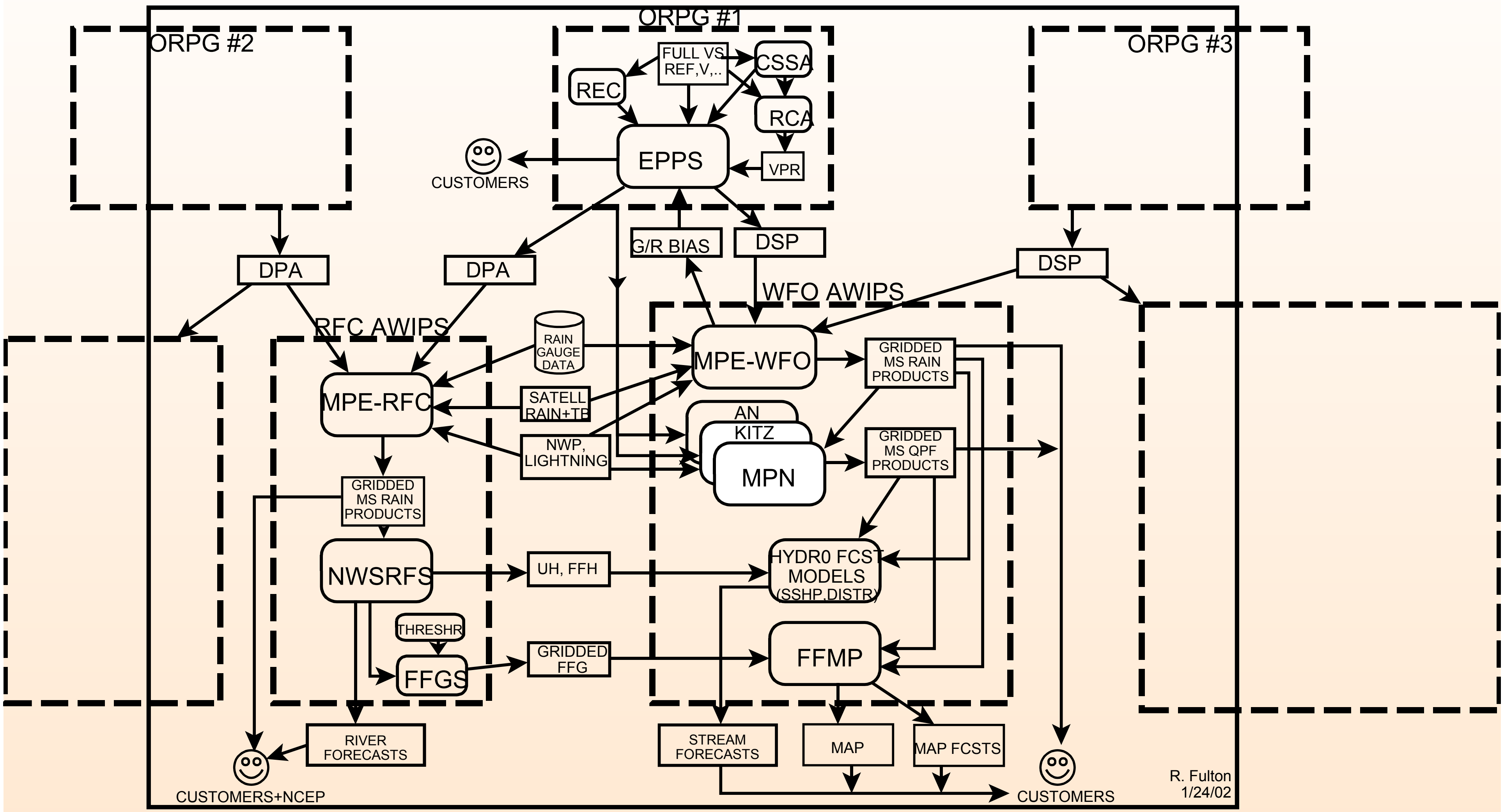
MPE Enhancements (cont.)

- Deliver MPE to WFOs and enhance it to serve flash flood monitoring needs of the WFOs
  - First version (AWIPS 5.2.2...this fall): Hourly 4-km regionally-mosaicked multisensor products (same as RFC capability)
  - Later version: Shorter accumulation periods and update times (minutes) and higher spatial resolution (1 km=1/4 HRAP)

Comparisons of future RFC and WFO implementations of the Multisensor Precipitation Estimator

	MPE-RFC	MPE-WFO
WSR-88D product input	DPA (range-corrected)	DSP (range-corrected)
Frequency of execution	Once/hour at H+00	Every 5-15 minutes
Rain accumulation durations	1 hour	15, 30 mins, 1, 3,6, 12, 24 hrs (user selectable)
Number of radars used	1 to many (to cover RFC)	1 to many (to cover CWA)
Spatial resolution	4 km (HRAP)	1 km (1/4 HRAP)
Rain gauge adjustment duration	Hourly to seasonal	Hourly to seasonal
Products	Hourly rainfall accumulation: 1) Multisensor (radar+gauge+satellite) 2) Radar-only 3) Gauge-only 4) Satellite-only 5) Mean-field-bias-adjusted radar 6) Local bias-adjusted radar 7) Local bias-adjusted satellite	15-minute through 24-hour rainfall accumulations: 1) Multisensor (radar+gauge+satellite) 2) Radar-only 3) Gauge-only 4) Satellite-only 5) Mean-field-bias-adjusted radar 6) Local bias-adjusted radar 7) Local bias-adjusted satellite
Purpose/Use	River monitoring and forecasting	Flash flood monitoring and forecasting

Future Vision for QPE in the NWS
Driven by Different RFC and WFO Requirements



Major NWS QPE-related Science Frontiers For Next 5-10 Years

- Higher spatial and temporal resolution QPE products to better support the WFO flash flood warning program (PPS: 1/4 km X 1/2 deg; MPE: 1/4 HRAP, 5-15 minute accumulations and updates)
- Probabilistic/Ensemble QPE algorithms and products
- Polarimetric radar QPE algorithms & products (beyond JPOLE)
- Automated tuning of QPE algorithm input parameters (e.g., Z-R parameters) based on meteorological data to optimize QPEs
- Use of other observed meteorological data (soundings, surface observations, lightning) and atmospheric model analysis fields to improve QPE analyses (e.g., rain vs snow, freezing level ident.)
- Merge PPS and Snow Accumulation Algorithm

Multisensor Precipitation Nowcaster (MPN)

An Extension of MPE that will Provide Short-term QPFs for Additional Flash Flood Warning Lead Time at WFOs

- Will generate gridded 1-km deterministic rainfall forecasts out to 30 minutes to 2 hours in the future, updated every 5-15 minutes
- Will use the observed DSP-based rainfall estimates from the new MPE as the main driving input
  - Leverages on MPE's rainfall estimation technology (multiradar mosaicking, multisensor rainfall from radar, rain gauges, & satellite, range- and bias-corrected estimates)
- Based on local extrapolation of MPE multisensor radar rainfall echoes
  - Accounting for local motion is important since flash flood-producing storms often exhibit anomalous movement relative to their neighbors
- Accounts for storm growth and decay (but not initiation)

Conclusions

- The OHD/HL Hydromet Group is involved in a wide variety of WSR-88D QPE and QPF science activities that will lead to improved RFC and WFO hydrologic operations
- Much more work remains to be done...