# Improving NWS WSR-88D Rainfall Algorithms and Products at the Hydrology Laboratory

Richard Fulton

Hydrometeorology Group
Hydrology Laboratory
Office of Hydrologic Development
National Weather Service

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# Outline

- Background information

- RFC and WFO use of WSR-88D-based precipitation products

- Recent and near-term WSR-88D Precipitation Processing System (PPS) and AWIPS Multisensor Precipitation Estimator (MPE) enhancements

- Long-term Quantitative Precipitation Estimation (QPE) science frontiers
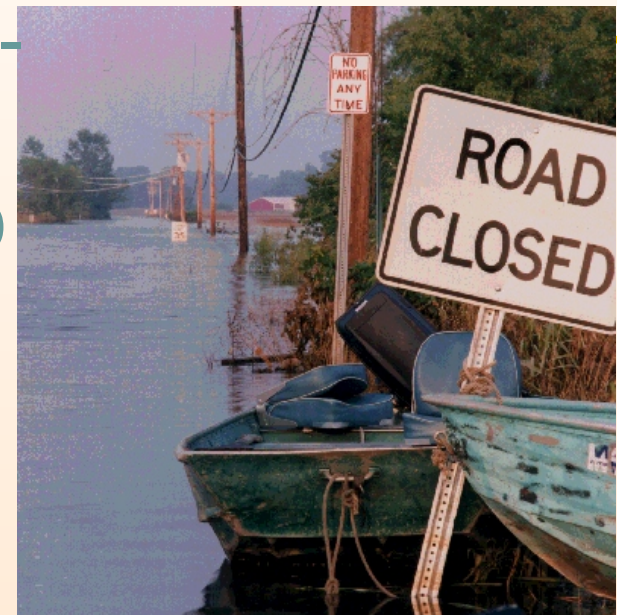
# Mission Statement

**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 for our customers**

# WSR-88D rainfall estimation educational materials 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 presented to forecast offices

- 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*

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

- Annually-updated plan located at http://www.nws.noaa.gov/oh/hrl/papers/papers.htm#wsr88d

- Related paper for July 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

# HL's 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**
  - ▸ Ensemble/probabilistic QPE algorithm development
  - ▸ 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, University of Maryland, WFO Baltimore/Washington, Baltimore city & 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 radar-based QPE algorithm 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

# Use of Radar-based Precipitation Products at the RFCs

| River Forecast Center (office location) | What radar-based precipitation algorithms are currently used? | Are radar-based precip. products currently used in NWS River Forecast System? | Perceived problems |
|---|---|---|---|
| Southeast RFC (Georgia) | PPS-MPE | Yes | |
| Lower Mississippi RFC (Louisiana) | PPS-StageII/III & PPS-MPE | Yes (PPS-StageII/III) | |
| West Gulf RFC (Texas) | PPS-StageII/III & PPS-MPE | Yes (PPS-StageII/III) | |
| Arkansas-Red Basin RFC (Oklahoma) | PPS-P1/P2 (MPE in future pending winter precip. enhancements) | Yes (since 1993) | -Brightband & snow |
| Missouri Basin RFC (Missouri) | PPS-MPE | Yes (May-Sept), gauge-only (Oct-Apr) | |
| North Central RFC (Minnesota) | PPS-MPE | Yes (15% Apr-Sept), gauge-only otherwise | -Limited hourly gauges -Brightband and snow |
| Alaska Pacific RFC (Alaska) | None (MPE being set up to use next year) | No | -Lack of automated gauges -Poor radar coverage |
| Middle Atlantic RFC (Pennsylvania) | PPS-MPE | Qualitatively (quantitatively pending MPE vs. gauge product evaluations) | -Underestimation biases relative to gauges & impacts on calibrated hydrologic models |

# Use of Radar-based Precipitation Products at the RFCs (cont.)

| | | | |
|---|---|---|---|
| Northeast RFC (Massachusetts) | PPS-MPE | Occasionally (more in future as they move to 1-hr model timesteps | -Snow<br>-Variability in perform-ance event to event<br>-Blockages<br>-6-hr model timestep reduces value of radar |
| Ohio RFC (Ohio) | PPS-MPE | Yes | |
| Colorado Basin RFC (Utah) | PPS-MPE | Some basins | |
| Northwest RFC (Oregon) | PPS-MPE (runs automatically with no manual QC) | No | -Blockage, poor radar coverage<br>-Brightband and snow<br>-High radar/low-topped precip (range effects)<br>-Rain-snow delineation<br>-Fcst models calibrated with point gauge data |
| California Nevada RFC (California) | PPS-MPE (runs automatically; evaluation) | No | -Poor radar coverage<br>-Radar's spatial detail may not improve forecasts for gauge-calibrated basins using 6-hr timesteps |

# Summary of RFC Issues Limiting Quantitative Use of Radar-based Precipitation Estimates

- Beam blockage and radar coverage limitations
    - Especially in cool season

- Range degradation (VPR effects)

- Bad estimates in brightband and snow

- NWSRFS hydrologic models that are calibrated using historical rain gauge data
    - 6-hr model timesteps and value of radar's spatial-temporal detail
    - Biases between gauge MAPs and multisensor radar MAPXs
    - Biases between hourly and multihourly gauge data

# Weather Forecast Office Comments on PPS Rainfall Products from Flash Flood Events

## Taken from all official 2002 WFO FTR post-event summaries in which WSR-88D rainfall products were mentioned

- 9/16/02 Greenville, NC *"Radar rainfall estimates were accurate."*

- 9/12/02 Salt Lake City: *"KMTX WSR-88D indicated rainfall amounts consistent with report from automated observing station."*

- 9/10/02 Flagstaff: *"Tuba City lies on the northern edge of the radar, and thus precipitation estimates are questionable at best."*

- 8/26/02 Goodland, KS: *"WSR-88D precip products (OHP & STP) were especially useful during and after the event. Radar estimates of location and accumulation of heaviest rainfall were very close to observed values which allowed the hydrometeorologist to make accurate forecasts of flooding potential."*

- 8/26/02 Raleigh, NC: *"6 to 8 inches of rain (radar estimates) occurred in about 3 hours, resulting in flash flooding."*

- 8/23/02 Riverton, WY: *"Doppler estimates in excess of 6 inches supported by ground truth reports in excess of 4 inches near the heaviest rainfall area."*

# Weather Forecast Office Comments on PPS Rainfall Products from Flash Flood Events (cont.)

Taken from all official 2002 WFO FTR post-event summaries in which WSR-88D rainfall products were mentioned

- 8/22/02 Chicago: *"WSR-88D rainfall estimates used as basis for warnings. Estimates appear to be very good based on limited observations received."*

- 8/21/02 Quad Cities, IA: *"WSR-88D precip estimates used as basis for initial Flash Flood Warning. WSR-88D precip estimates were lower than observations received."*

- 5/29/02 Sterling, VA: *"WSR-88D volume derived products such as one-hour rainfall was lost for a few volume scans during a time when it was needed to evaluate extending the warning."*

- 5/12/02 Indianapolis: *"Radar accurately indicated widespread one inch rain with many areas receiving 2 to 4 inches of rain."*

- 5/12/02 St. Louis: *"WSR-88D precipitation estimates were key in issuance of numerous Flash Flood Warnings."*

- 5/12/02 Central IL: *"All systems worked well except the total storm precipitation product (STP) of the 88D RPG. STP was overestimating amounts."*

# Weather Forecast Office Comments on PPS Rainfall Products from Flash Flood Events (cont.)

Taken from all official 2002 WFO FTR post-event summaries in which WSR-88D rainfall products were mentioned

- 5/7/02 Central IL: *"Rainfall at these locations was estimated from 2.5 to 4 inches with isolated amounts up to 5 inches. Hail and anomalous propagation contamination caused some overestimation south of Decatur."*

- 4/25/02 San Angelo: *"The thunderstorms remained stationary over the county through 3:30 p.m. producing rainfall estimates between 5 and 10 inches. An observer near the town of Albany received 5.75 inches of rain during the 4.5 hour period."*

- 1/30/02 Dodge City (major ice storm): *"WSR-88D rainfall estimates were high where mixed phase precip occurred and light in areas which received heavy snowfall."*

- 1/29/02 Springfield, MO (major ice storm): *"Despite the known problems associated with bright banding in events such as this, the 88D precip algorithms correctly detected nearly 3 inches of rain as proven by ground truth readings."*

- CONCLUSION: WFOs are predominantly satisfied with the value of PPS rainfall products during flash flood events.

# What is the Hydrology Laboratory doing to make things better?

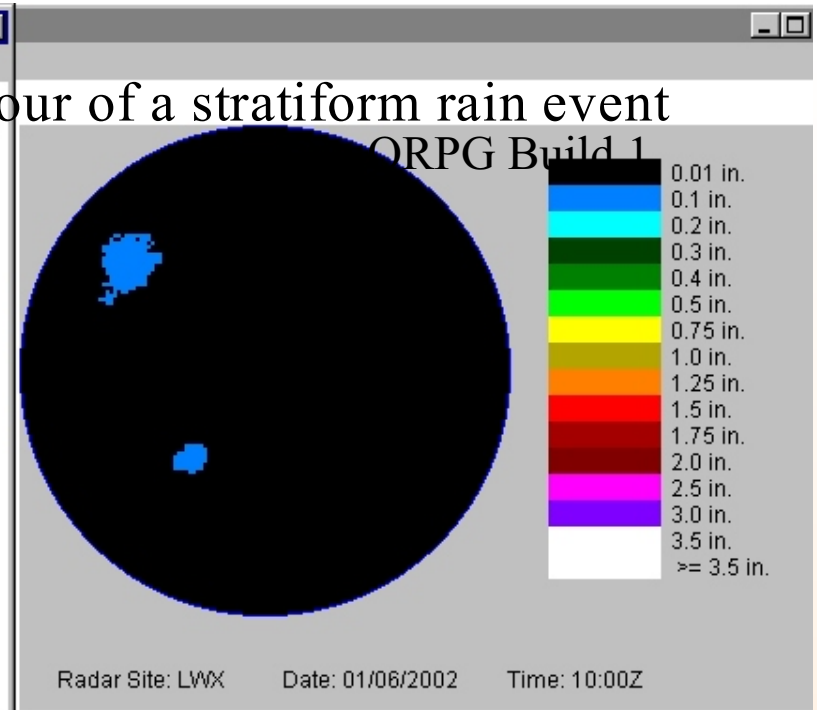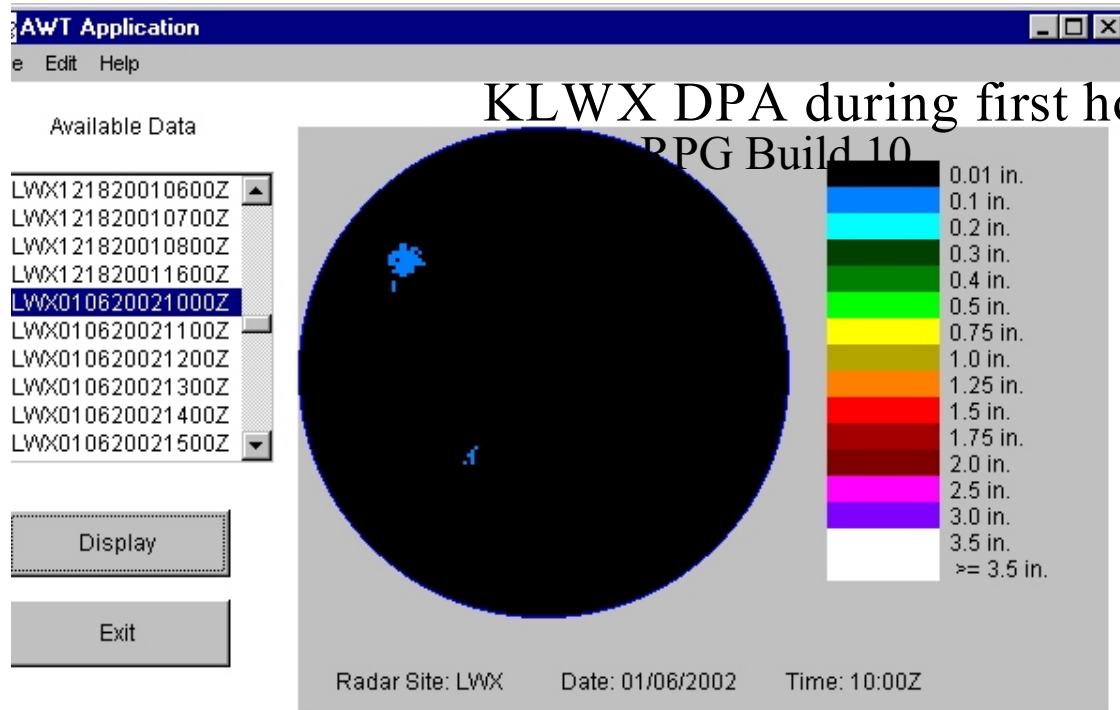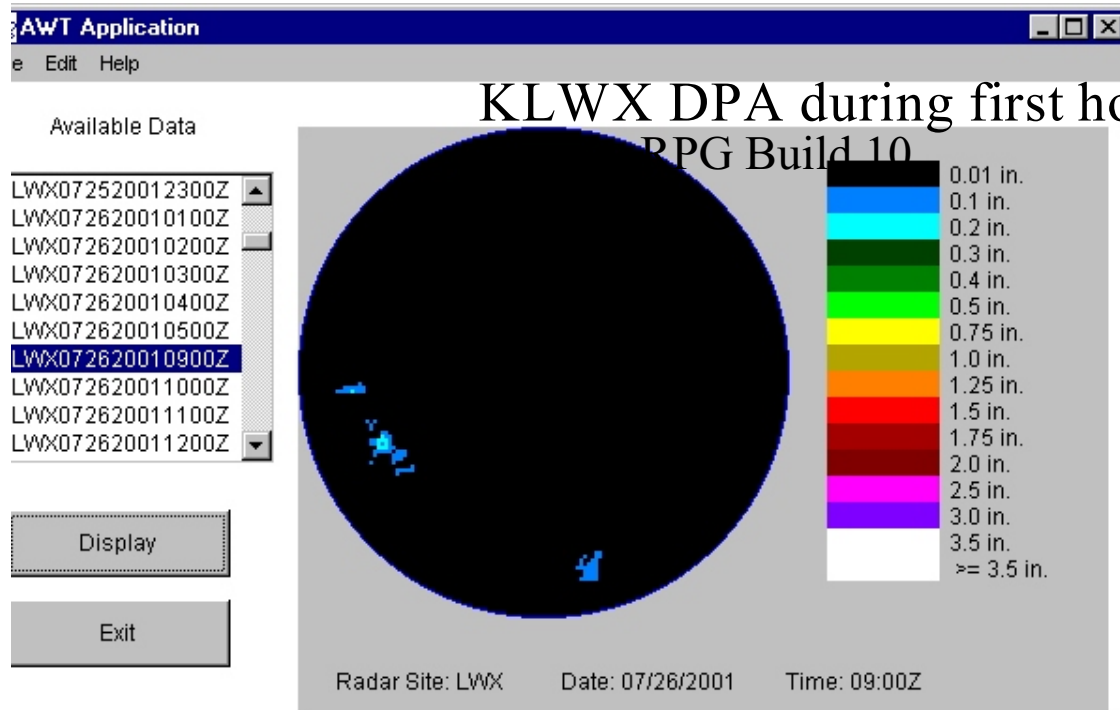# Summary of Recent WSR-88D Precipitation Processing System (PPS) Enhancements



- ## 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 product:  Digital Storm-total Precipitation (DSP)
  - ▸ Assorted code enhancements

# 1) Resolved PPS precipitation truncation problem

*ORPG Software Build 1*
*Field Deployment Completed in mid 2002*

- A subtle PPS software bug had been causing long-unexplained underestimation of rainfall (especially stratiform rainfall) since WSR-88Ds were first deployed

  - ▶ Why?  For details, 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
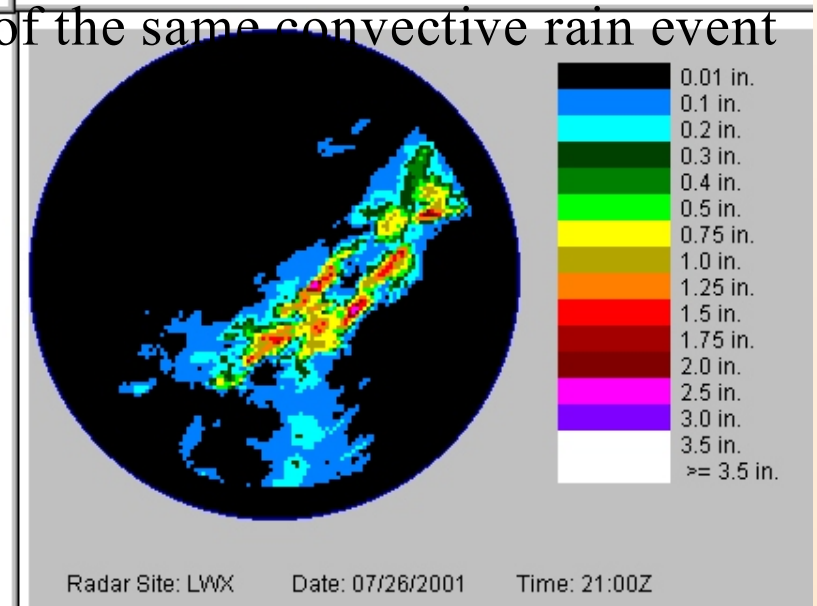    is at  *http://www.nws.noaa.gov/oh/hrl/papers/2002mou/MOU02_PDF.html*

KLWX DPA during first hour of a stratiform rain event

RPG Build 10

ORPG Build 1

KLWX DPA during 12th hour of the same stratiform rain event
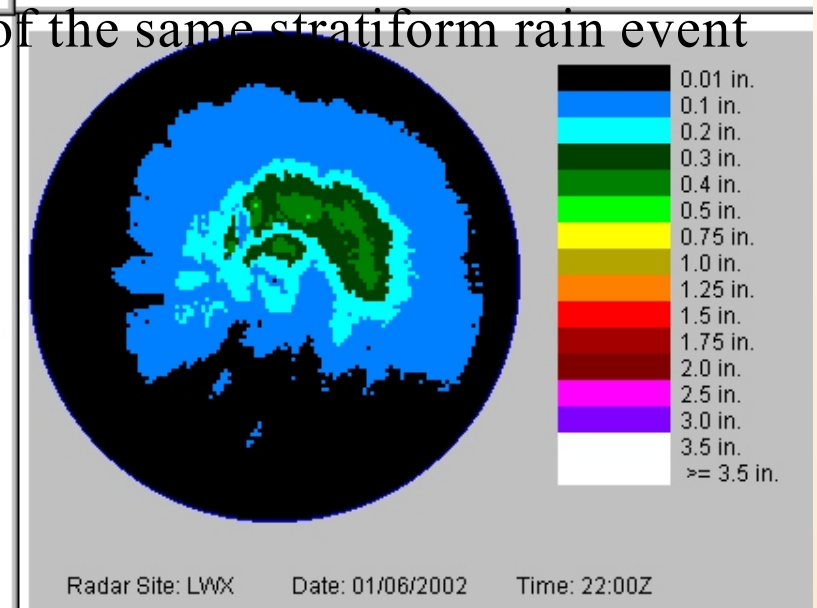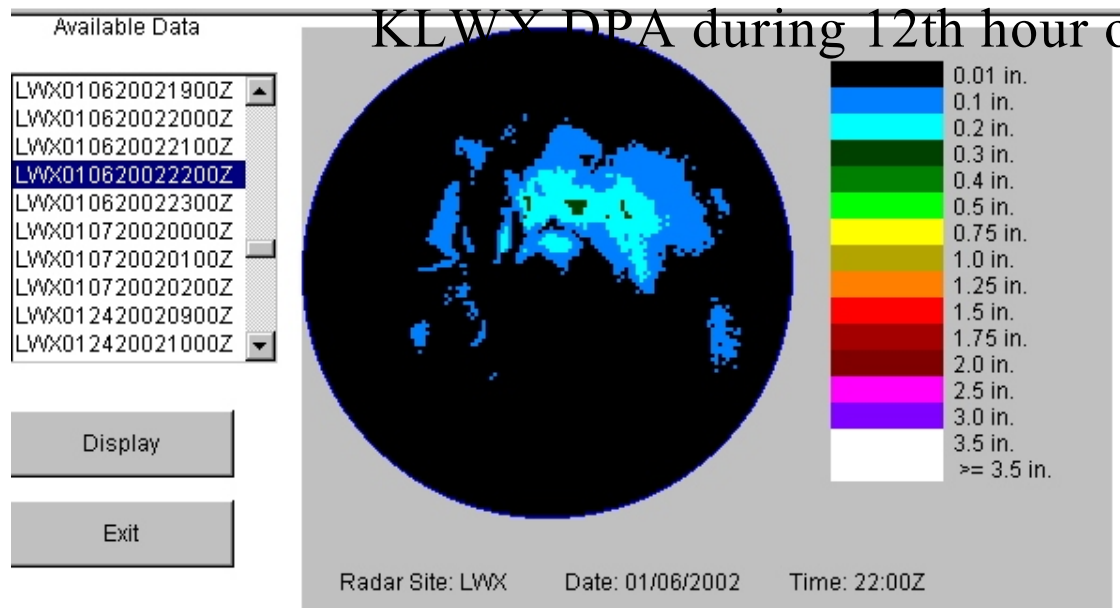
KLWX DPA during first hour of a convective rain event

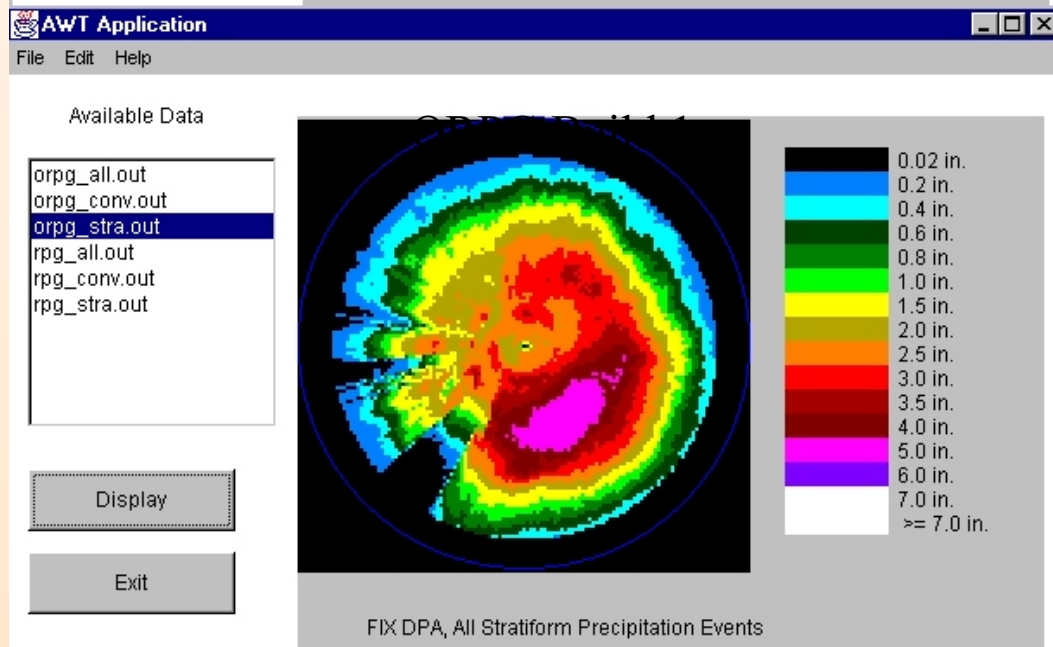RPG Build 10

ORPG Build 1
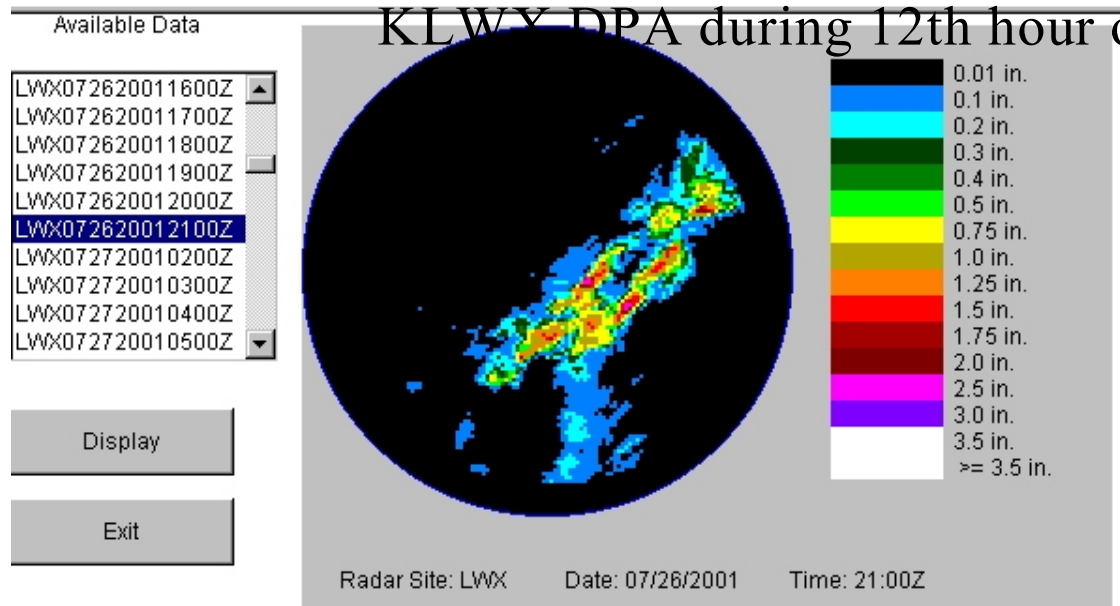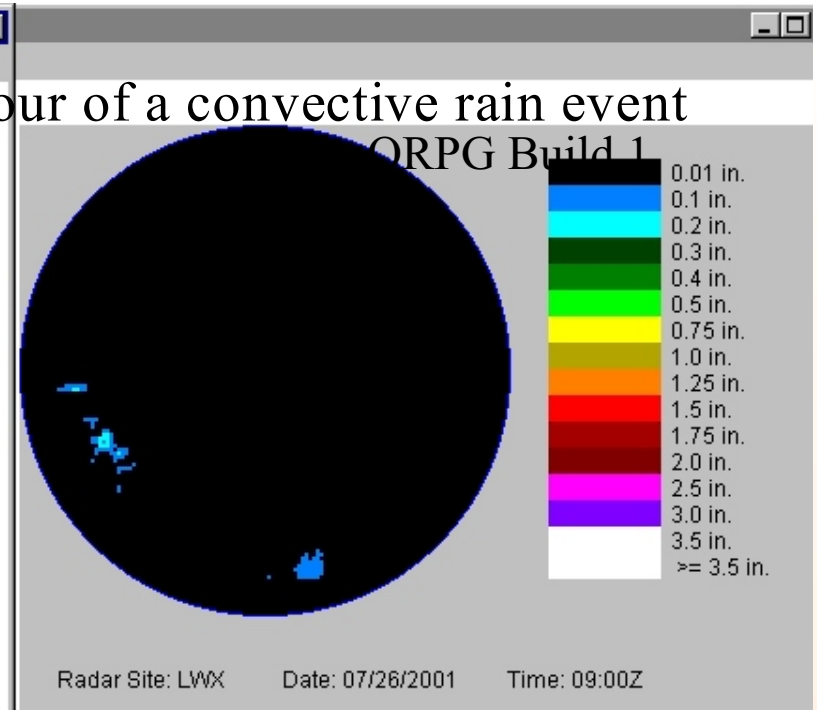
KLWX DPA during 12th hour of the same convective rain event

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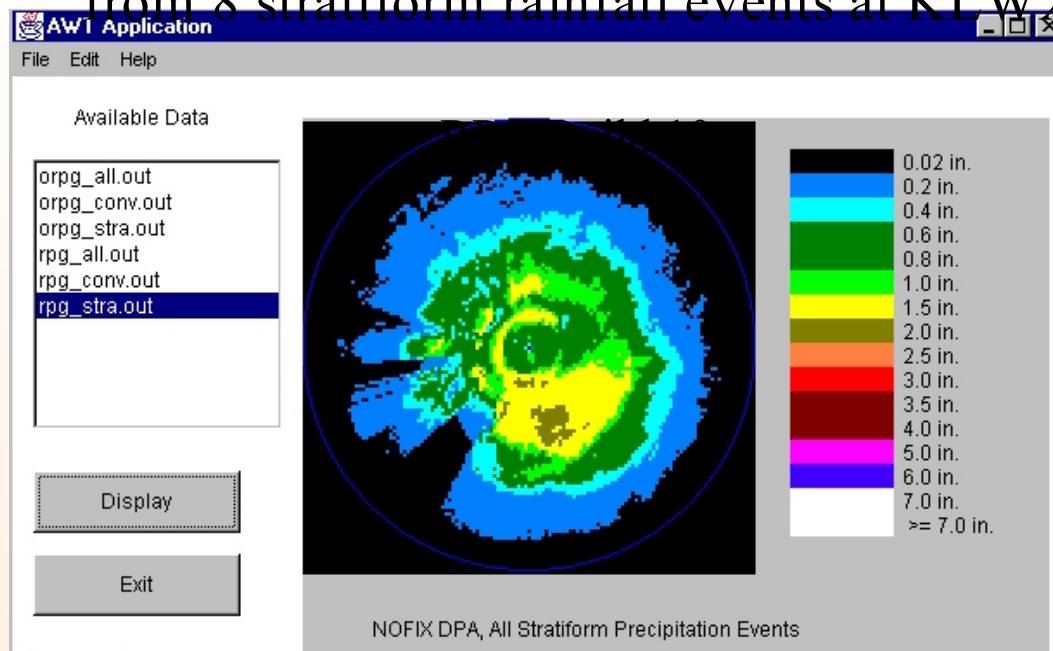
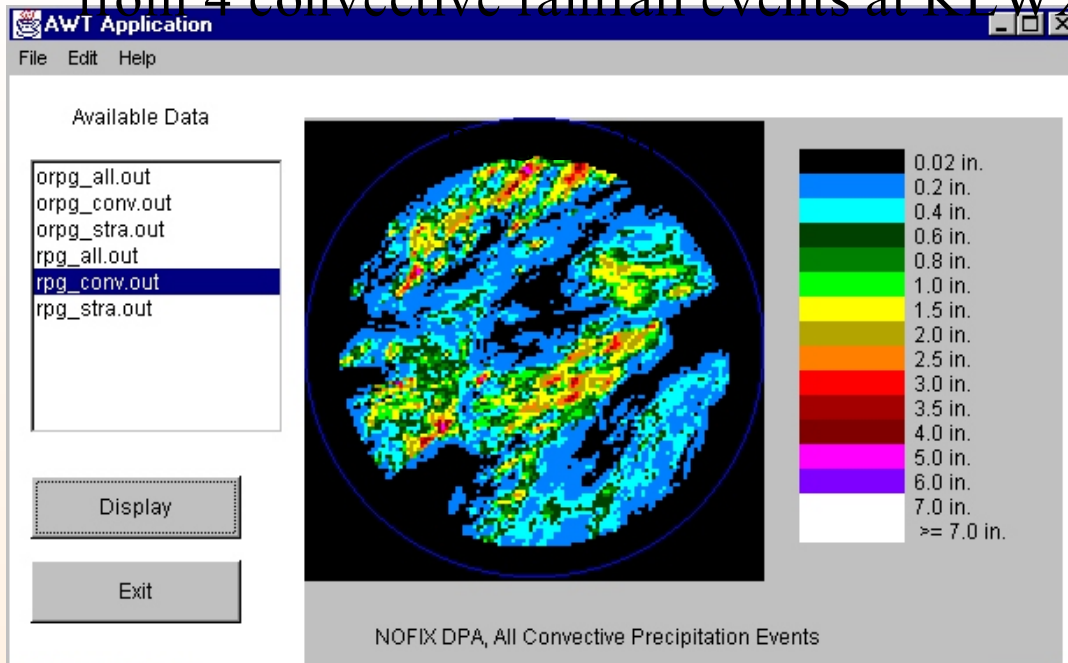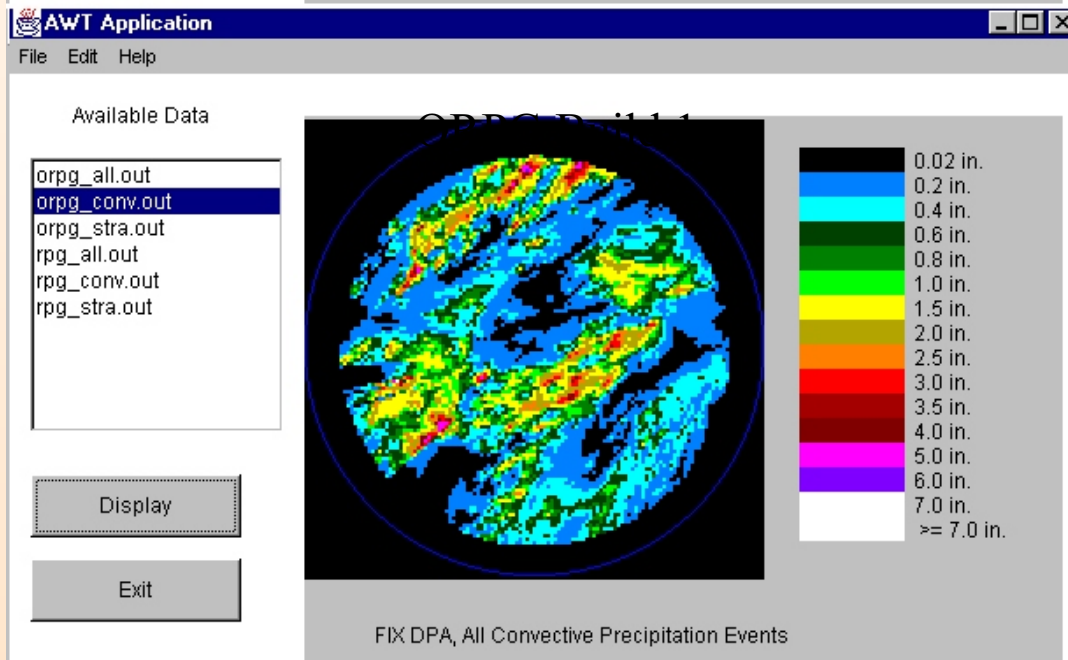

Max value =1.9 inches

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

# 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 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 hourly raingauge and radar data quality using 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 Spring 2003*

- An additional problem of scattered, persistent, small residual rainfall pixels (~0.01 inch) became evident in ORPG1 hourly rainfall products (OHP, DPA) from long-lasting multiday rain events

- Residuals automatically went away after one hour with no rain in the radar umbrella (i.e., when the PPS reinitializes)

- <span style="color:red">All occurrences of precipitation residuals have now been eliminated in the PPS software</span>

- Resulted in 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
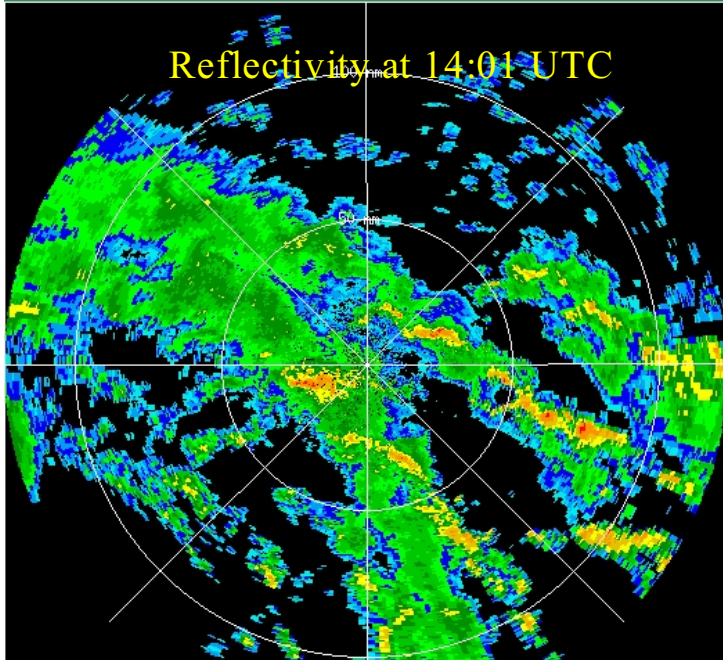
Houston, TX
Aug 22, 1998
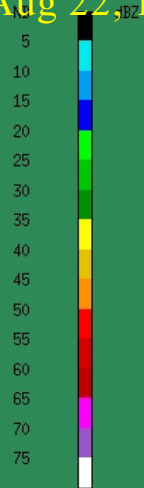
Reflectivity at 15:02 UTC
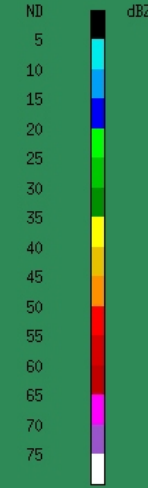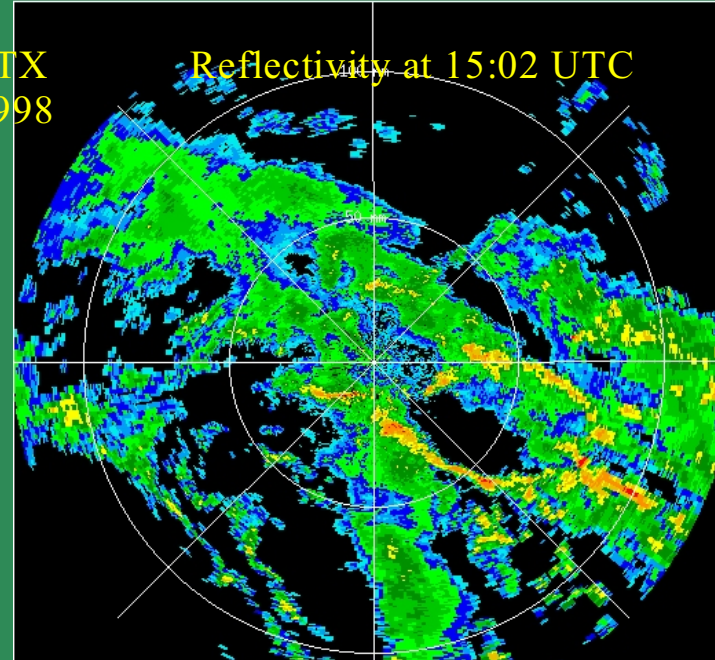
OHP ending at 15:00 UTC
ORPG1 Simple Fix with Filter
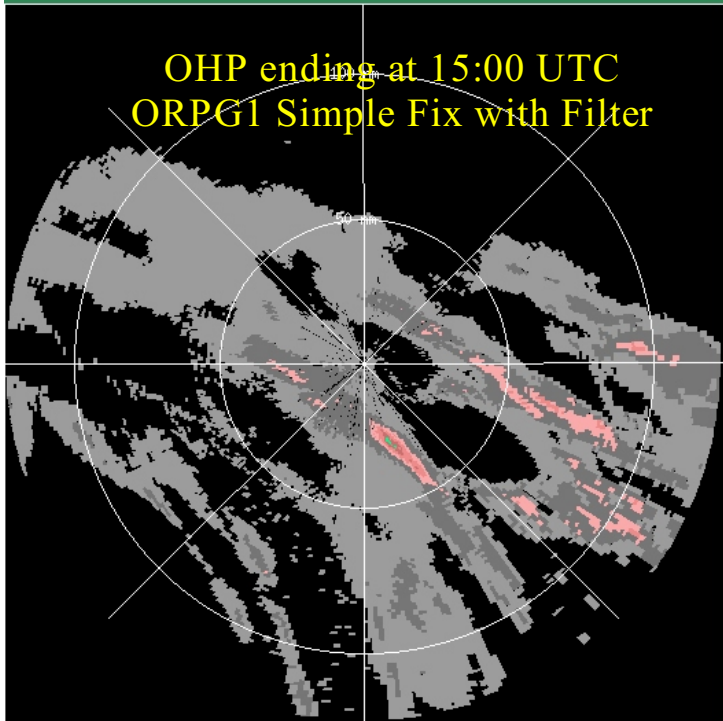
26 hours into
rain event
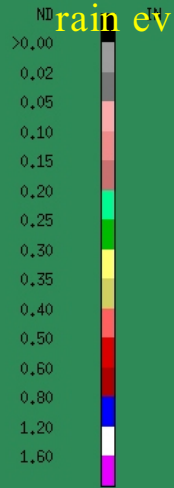
OHP ending at 15:00 UTC
ORPG3 Full Fix
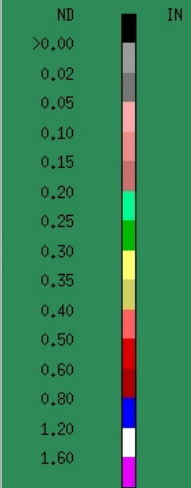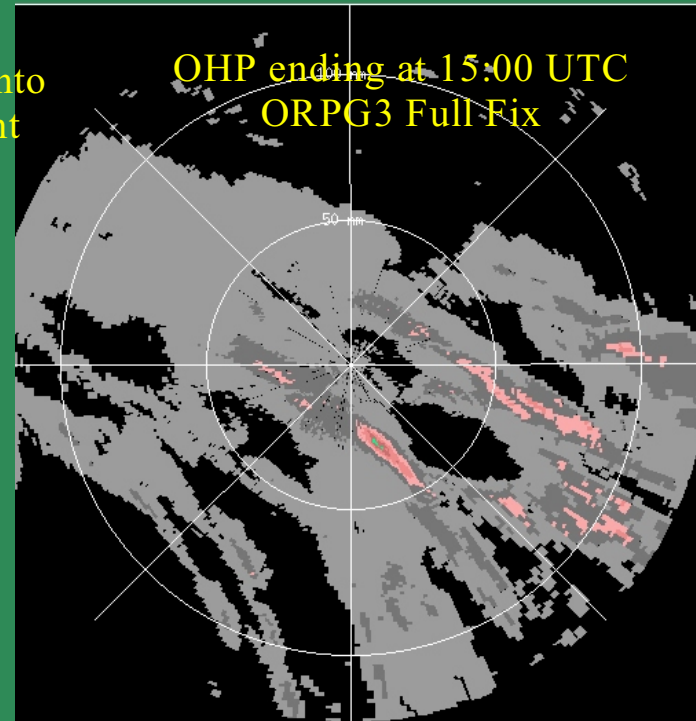
# 4) New PPS product:
# Digital Storm-total Precipitation (DSP)

*ORPG Software Build 3*
*Field Deployment 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 allow expansion of NWS precipitation processing potential beyond the existing MPE algorithm that uses 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 system

  ▸ Other value-added flash flood applications outside of NWS

# Near-term PPS Enhancements

*ORPG Software Build 4*
*Field Deployment in Fall 2003*

- Enhance PPS to accomodate new VCPs as short as 4 minutes

# Longer-term PPS Enhancements

*ORPG Software Build 5*
*Field Deployment in Spring 2004*

- 1) Implement new Range Correction Algorithm (RCA)
  - ▶ To correct rainfall products for nonuniform vertical reflectivity profiles VPRs
  - ▶ Biggest benefits for cool season, stratiform rain events with brightband
  - ▶ Initial deployment will only permit viewing of VPR correction factors
  - ▶ Build 6 deployment will apply quantitative corrections to PPS products and will implement the Convective-Stratiform Separation Algorithm (CSSA)
  - ▶ Real-time 24x7 alpha testing at HL using KLWX data this winter

- 2) Deliver Enhanced PPS Preprocessing sub-algorithm (EPRE)
  - ▶ To allow PPS to accomodate the proposed new, variable WSR-88D antenna scanning patterns

- 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 5 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

# 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)
  - ▸ AWIPS OB1: 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 (completed)

- 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's VPR 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 (5-15 minutes) and higher spatial resolution (1 km=1/4 HRAP)

# 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 (Univ Iowa)

- 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 (SAA) so we have one WSR-88D QPE algorithm that estimates both rain and snow

# Conclusions

- The OHD/HL Hydromet Group is involved in a wide variety of collaborative WSR-88D QPE and QPF science activities that will lead to improved RFC and WFO hydrologic operations

- Much more work remains to be done...