Impact of Range Correction on Precipitation Estimates and Hydrologic Model Simulations
and
Probabilistic Quantitative Precipitation Estimates From Radar

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Office of Hydrologic Development – Part I

Impact of Range Correction on Precipitation Estimates and Hydrologic Model Simulations

Long-term consequences of ignoring range effects in radar estimates

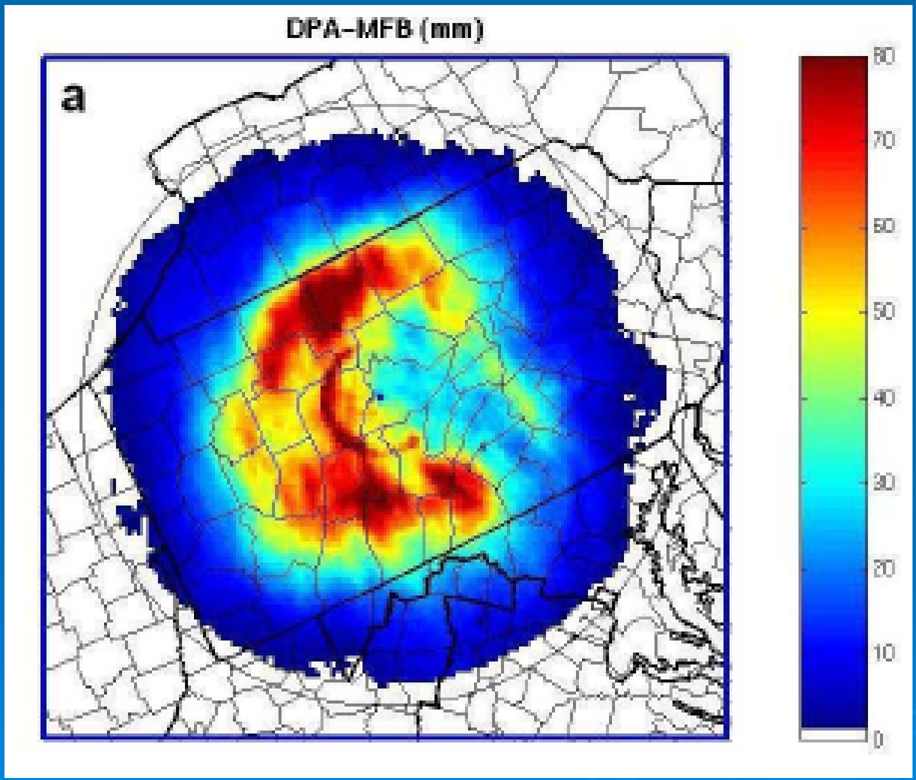
Impact on simulations of river flow

Effects of the Vertical Profile of Reflectivity (VPR) on Surface Rainfall Estimates from Radar

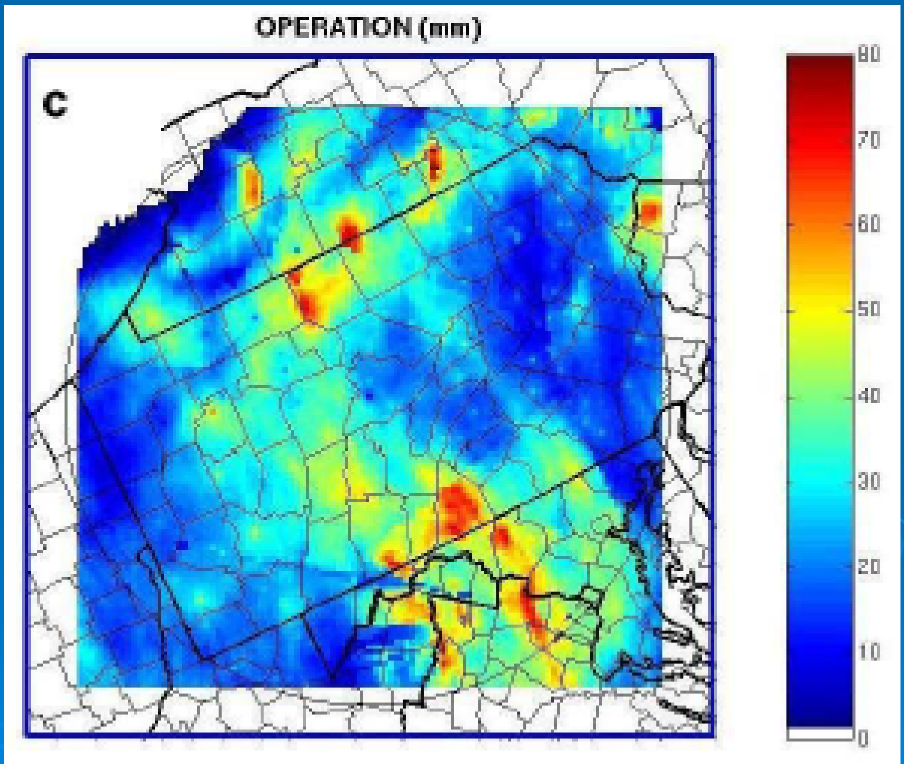
- Particularly in cool-season situations, radar estimates are biased high in the zone where the lowest radar beam intersects the melting layer
- At longer ranges, radar estimates are biased low because the radar detects only snow
- Range effects are clearly evident in rainfall estimate fields derived from a single radar

Range Effects on 22-h Rainfall Accumulation From WSR-88D KCCX, 2 January 2003

Estimate with mean-field bias correction, but no range correction



Operational estimate, from multiple radars and rain gauges



Range Correction Algorithm (RCA)
Convective-Stratiform Separation Algorithm (CSSA)

- Scientific algorithm (RCA/CSSA) documented by Seo et al. 2000 (Journal of Hydrometeorology)
- Impacts of range correction on radar/rain gauge correlations presented to NEXRAD TAC, July 2004
- Members of TAC suggested documenting impacts of range correction on hydrologic streamflow simulation

Study Methodology - I

- Sensitivity of hydrologic models can be documented with any reasonable estimates of precipitation
- We designed an observing systems simulation experiment (OSSE) to show the impact of range effects and range corrections in radar rainfall on hydrologic simulations of several stream basins

Study Methodology - II

- Can demonstrate that RCA/CSSA adjusts single-radar estimates and streamflow simulations toward those from the operational multisensor precipitation algorithm, which includes manual corrections by experienced hydrologic analysts
- Can also demonstrate sensitivity of runoff and stream discharge to precipitation input

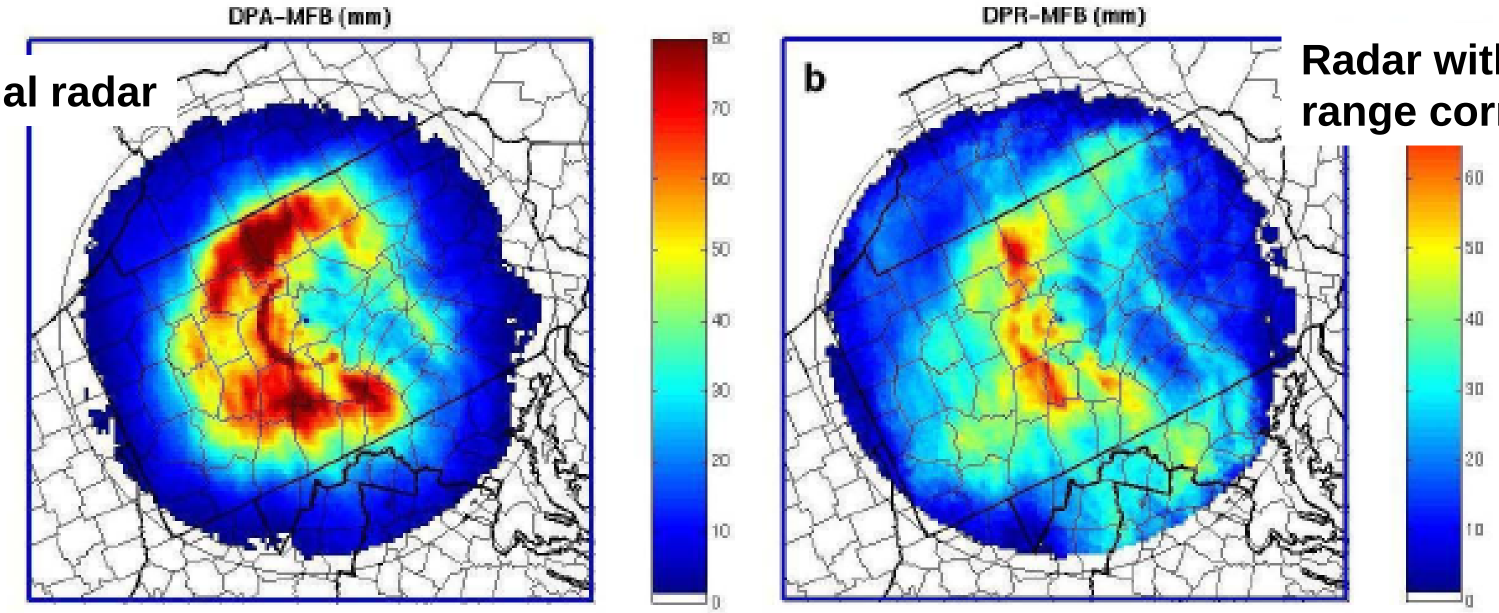
Study Methodology - III

- We selected a test radar umbrella in central Pennsylvania (KCCX) with a dense rain gauge network and coverage by overlapping radars
- Streamflow simulations for several basins at various ranges from the radar were made, with operational radar/gauge precipitation fields
- Simulations were repeated using only radar rainfall estimates from KCCX:
  - With original radar product (Digital Precipitation Array)
  - With mean-field bias adjustments only
  - With range correction and mean-field bias adjustments

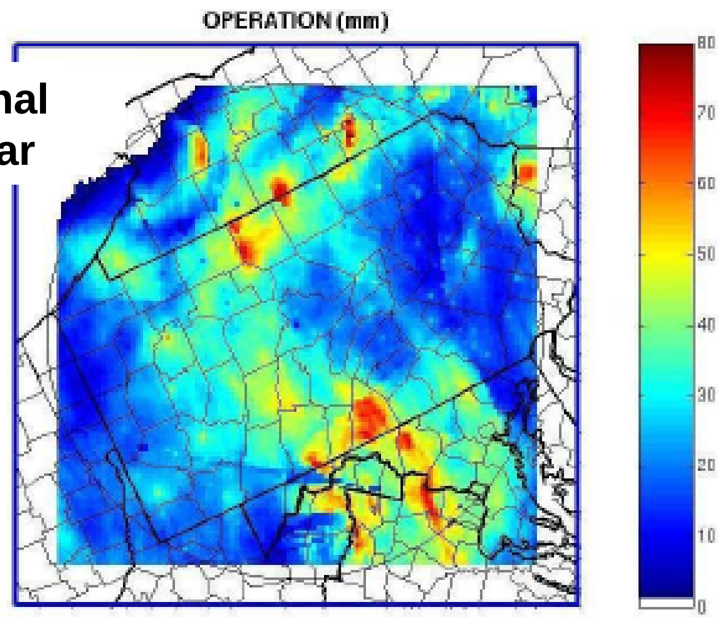
Impact of Range Correction on Estimates for 2 January 2003 Case

Original radar

Radar with range correction

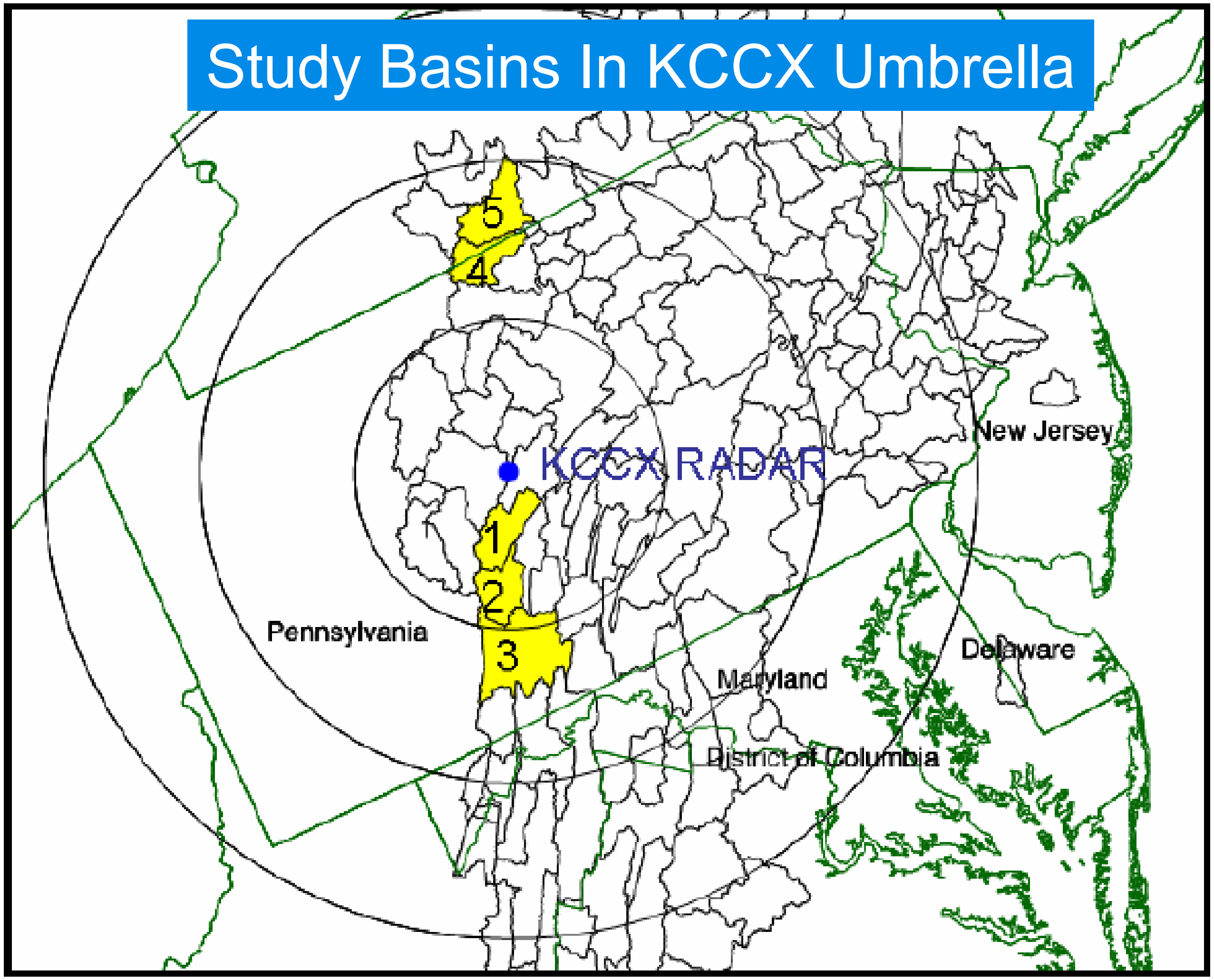


Operational multi-radar



Range correction mitigates bright band and recovers some spatial detail lacking in original radar estimates

Study Basins In KCCX Umbrella



No	Basin ID	River Name	Area (km^2)	Distance from KCCX (km)
1	SPKP1	Lit jun r-spruce ck	854	50
2	WLBP1	Jun r.-williamsburg	754	75
3	SXTP1	Fmk.br.jun-saxton	1,954	120
4	LWVP1	Cowan-lawrenceville	784	140
5	CRNN6	Chemung r at corning (tot area 5,273 km2)	1,077	170

Study Methodology - IV

- Streamflow was modeled for the period October 2002 – January 2003, a wet interval with several major rain events
- Radar precipitation estimates over the period exhibited classic behavior:
  - Best estimates near the radar
  - Overestimation at middle ranges, ~ 80-140 km
  - Underestimates beyond 140 km

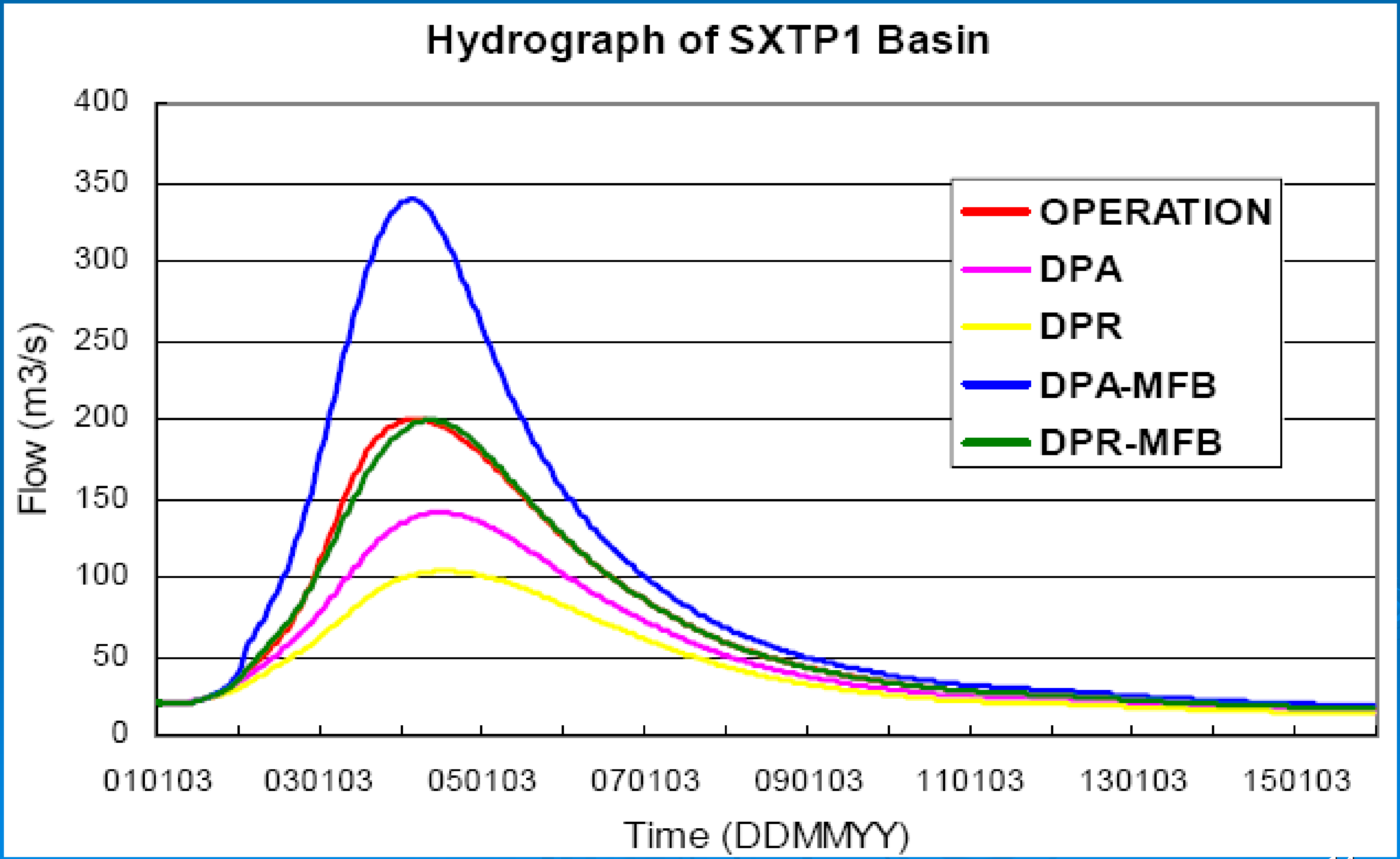
Hydrologic Model

- Hydrology Laboratory Research Distributed Hydrologic Model (HL-RDHM) (Reed et al. 2004)
- Distributed hydrologic model, 4-km grid mesh, one-hour time step
- Use of distributed HL-RDHM enabled rapid generation of streamflow simulations for multiple basins
- Employed *a priori* parameters for soil characteristics
- HL-RDHM does show impact of improving the accuracy of precipitation input

Study Methodology – Precipitation Inputs

- OPERATION: operational multisensor estimates, from Middle Atlantic River Forecast Center
- DPA: KCCX radar estimates
- DPA-MFB: KCCX radar estimates with mean-field bias applied (the only practical method in many areas with few rain gauges)
- DPR-MFB: KCCX radar estimates with range correction and subsequent mean-field bias adjustment

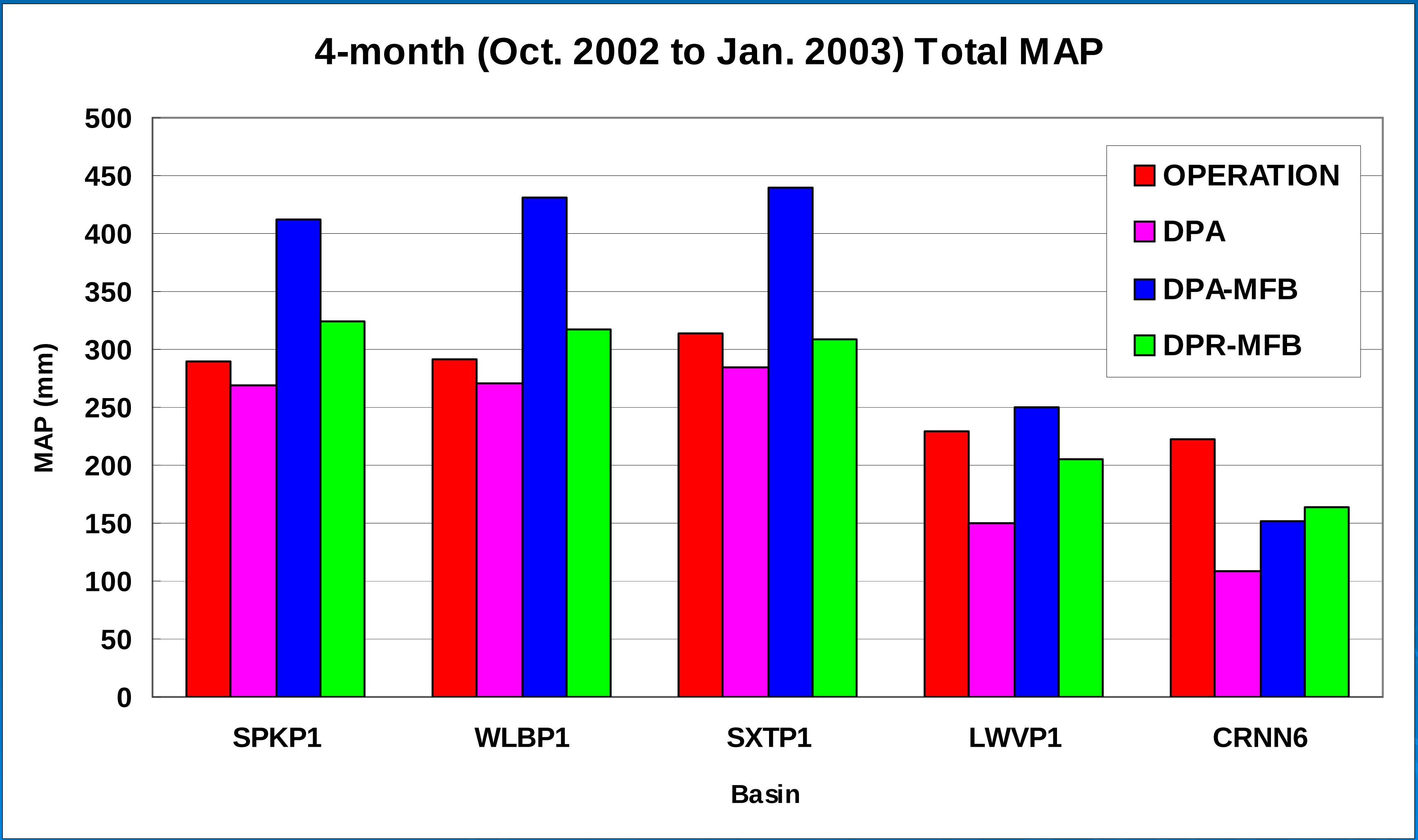
Sample Hydrograph For January 2003 Event



Precipitation Results:

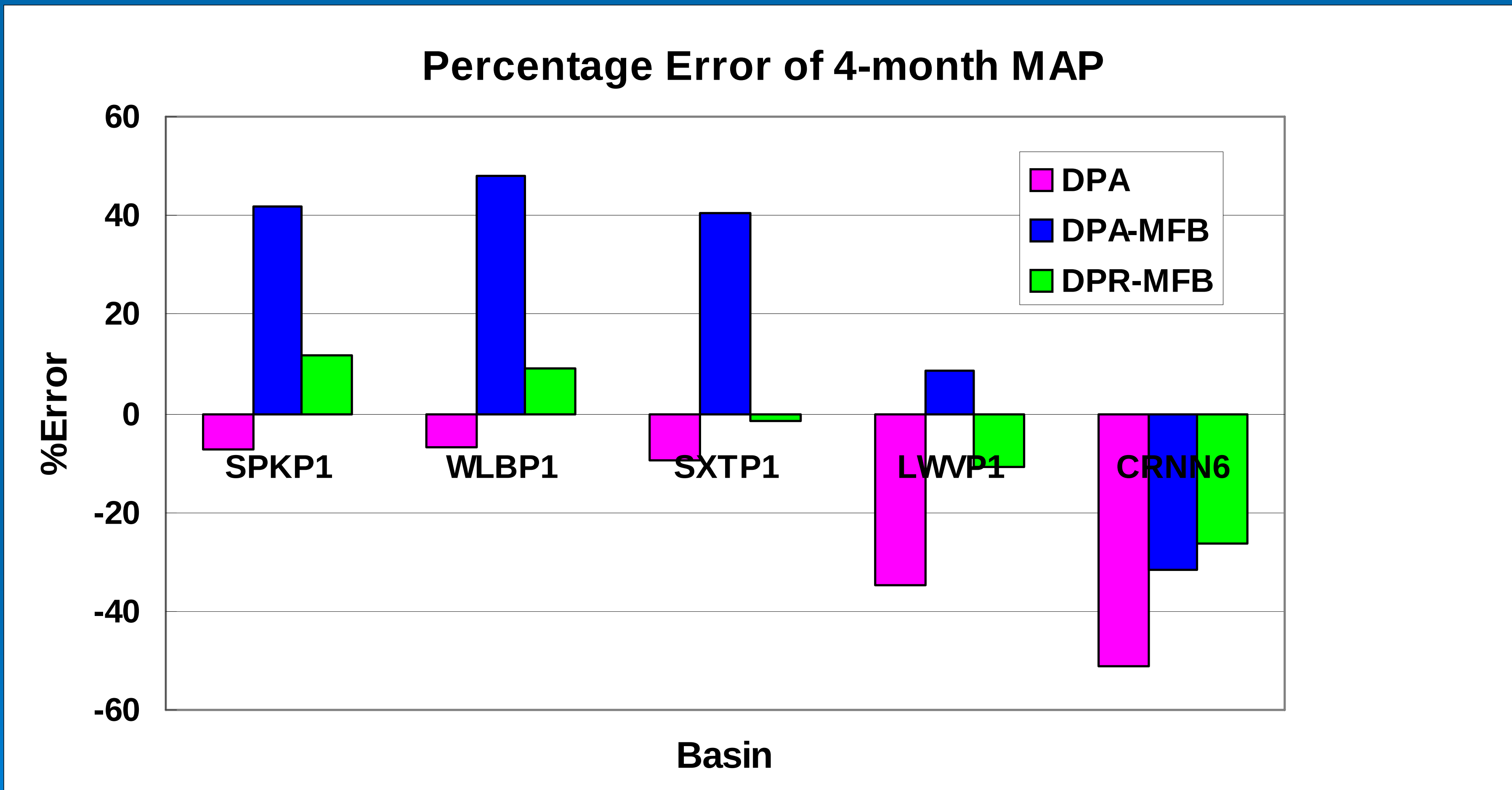
- For DPA (original radar product), KCCX umbrella as a whole is dominated by radar underestimation
- Mean-field bias correction (DPA-MFB) (the only correction that is possible in gauge-poor areas) overcorrects and causes overestimation in middle of umbrella
- Range-corrected radar estimates (DPR-MFB) do not suffer same degree of underestimation at long ranges, therefore mean-field bias adjustment does not lead to extreme overestimation closer to radar

Impact of Range Correction on Radar Rainfall
MEAN AREAL PRECIPITATION



Range from radar increasing →

Impact of Range Correction on Radar Rainfall MEAN AREAL PRECIPITATION % ERROR (relative to OPERATION analysis)

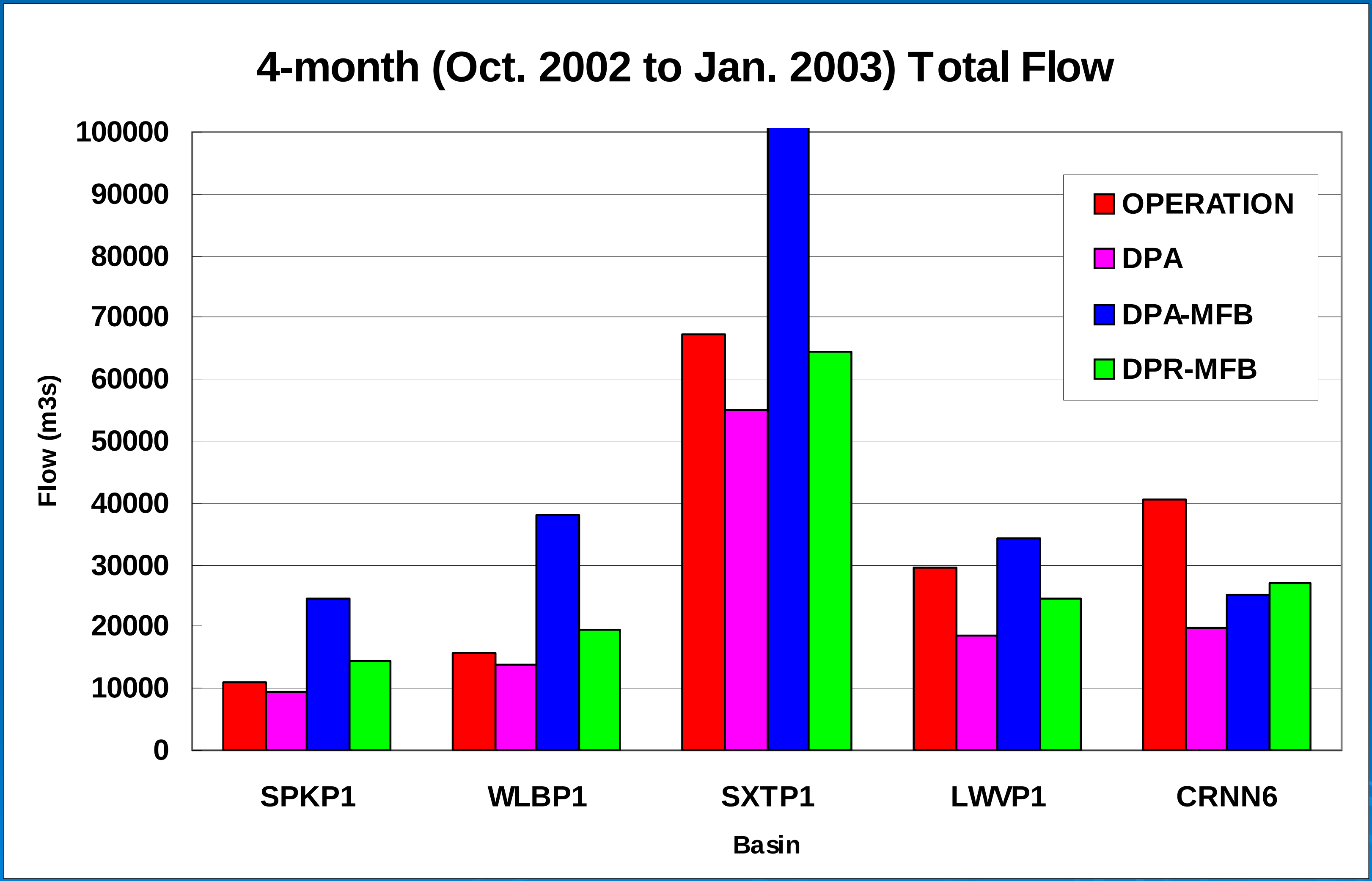


Range from radar increasing →

Streamflow Results:

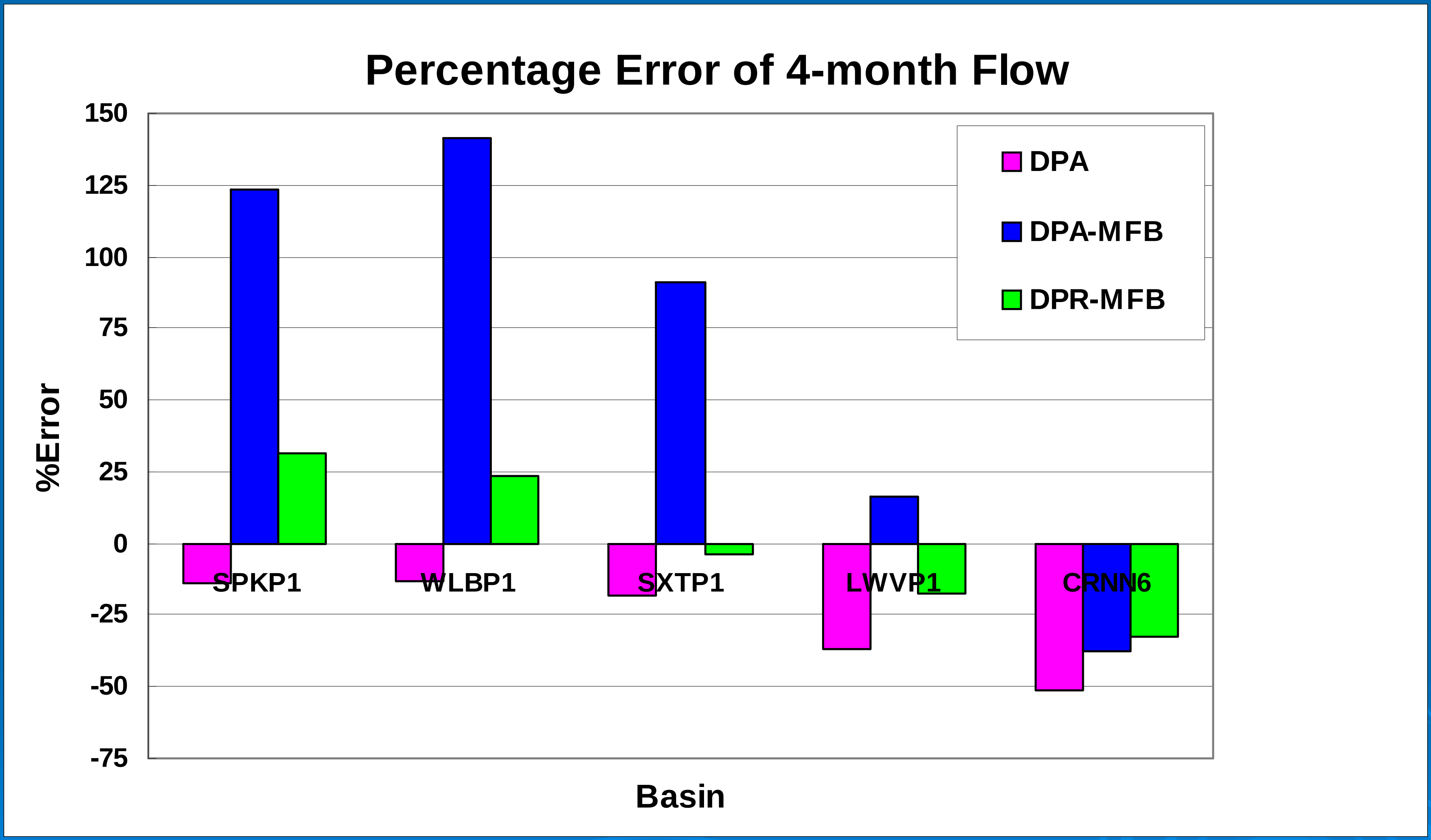
- Discharge has nonlinear response to precipitation (an effect generally observed in natural basins)
- In WLBP1, 50% overestimation of precipitation leads to 140% overestimation in discharge
- In operational practice, systematic over- or underestimation must be corrected manually by the hydrologic forecaster
- In some River Forecast Centers, radar range effects preclude direct use of radar estimates in hydrologic models, necessitating use of rain gauge data and a 6-h (vs. 1-h) time step

Impact of Range Correction on Radar Rainfall Total 4-month Stream Discharge



Range from radar increasing →

Impact of Range Correction on Radar Rainfall
Total 4-Month % Discharge Error Relative to OPERATION



Range from radar increasing →

Conclusions:

- RCA/CSSA consistently adjusted precipitation fields from a single radar toward reference fields derived from multiple radars, rain gauges, and expert input.
- Adjustment of single radar estimates to correct for mean-field bias alone led to degradation of streamflow simulations
- After adjustment by RCA/CSSA, single-radar precipitation provided streamflow simulations consistently closer to simulations based on reference precipitation input

Range Correction Will Still Be Needed in the Dual-pol Era:

- Horizontal Z-R rainfall will still be produced and possibly integrated with the dual-pol algorithm
- VPR still affects dual-pol estimates (e.g. difficult to estimate surface rainfall when the radar can detect only melting layer or dry snow)
- Techniques for conquering VPR effects with dual-pol observations alone will take some time

HOSIP Status of RCA/CSSA:

- **H**ydrologic **O**perations and **S**ervices **I**mprovement **P**rocess
- Internal Office of Hydrologic Development process similar to National Weather Service OSIP
- HOSIP Stage 2
  - Statement of Need approved
  - Concept of operations and general requirements now being documented
- Will apply for TAC approval when complete technical requirements have been developed

Office of Hydrologic Development – Part II

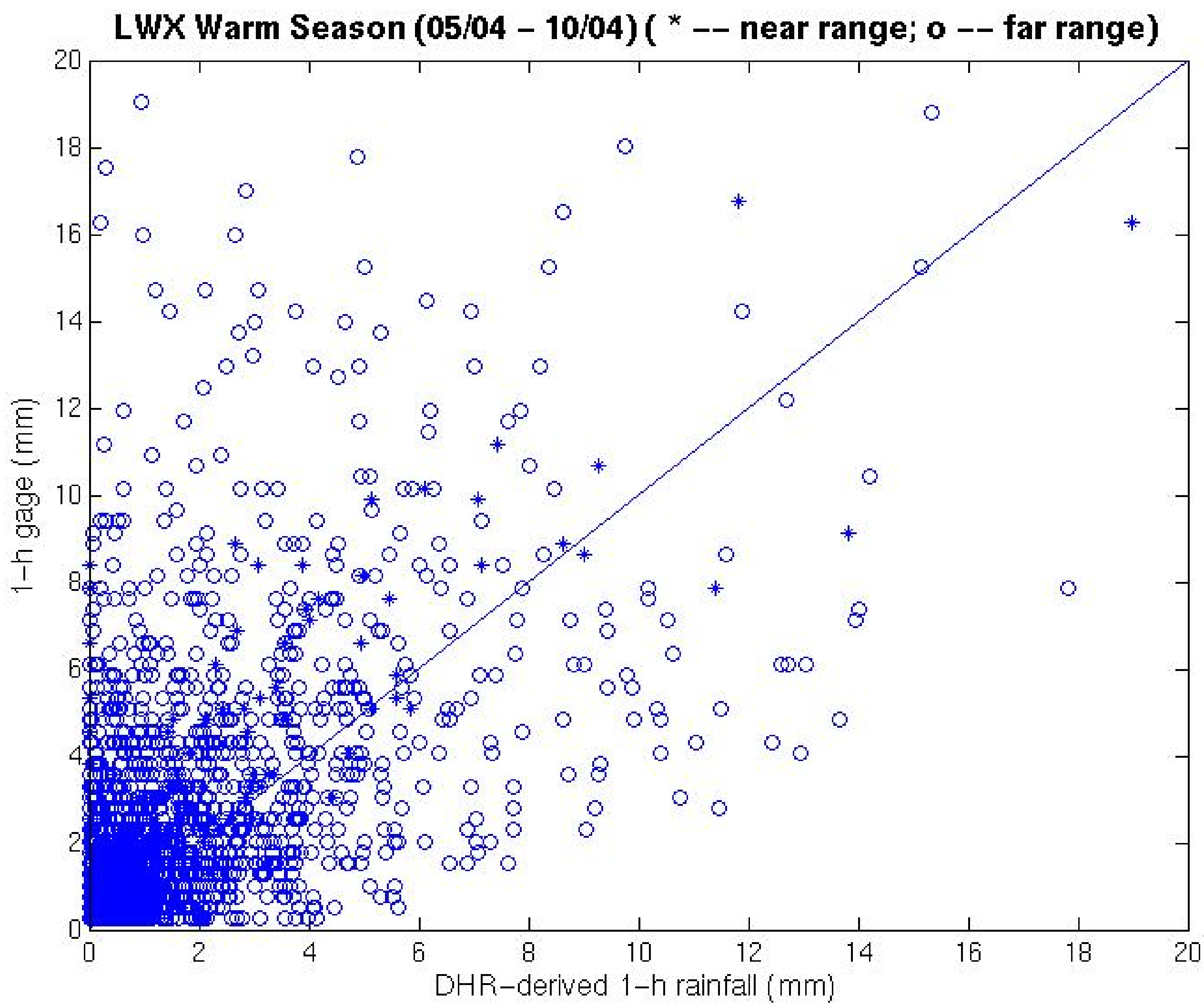
Probabilistic Quantitative Precipitation Estimates From Radar

Why do we need them?

How can they be used?

Collaboration Between OHD and University of Iowa

Radar-to-Raingauge Comparisons Are Often Discouraging…



One-hour rainfall, radar vs. gauge, KLWX, April-October 2004

We can produce radar rainfall estimates that are unbiased when summed over many hours, but:

- Large random errors remain;
- Radar appears to underestimate light amounts and overestimate heavy amounts, for accumulation intervals between 1 and 24 hours
- Where does probability information come in? *Distribution of possible rainfall values.*

If you are told:
"The average winning number is 499.5"
how do you play the game?

- In Pick 3, any number from 0 to 999 is equally likely to win *(uniform distribution)*
- But what if they generated numbers by drawing just two ping pong balls and adding 450 to the result? *(different uniform distribution)*
- But what if they generated numbers by tossing 9 coins? *(normal distribution)*

Knowledge of the error distribution is critical in decision making

- Classic examples include flash flood decisions, crop and irrigation management, firefighting
- Basic principle: if the probability of the event exceeds the cost/loss ratio, then take action as if the event were to happen

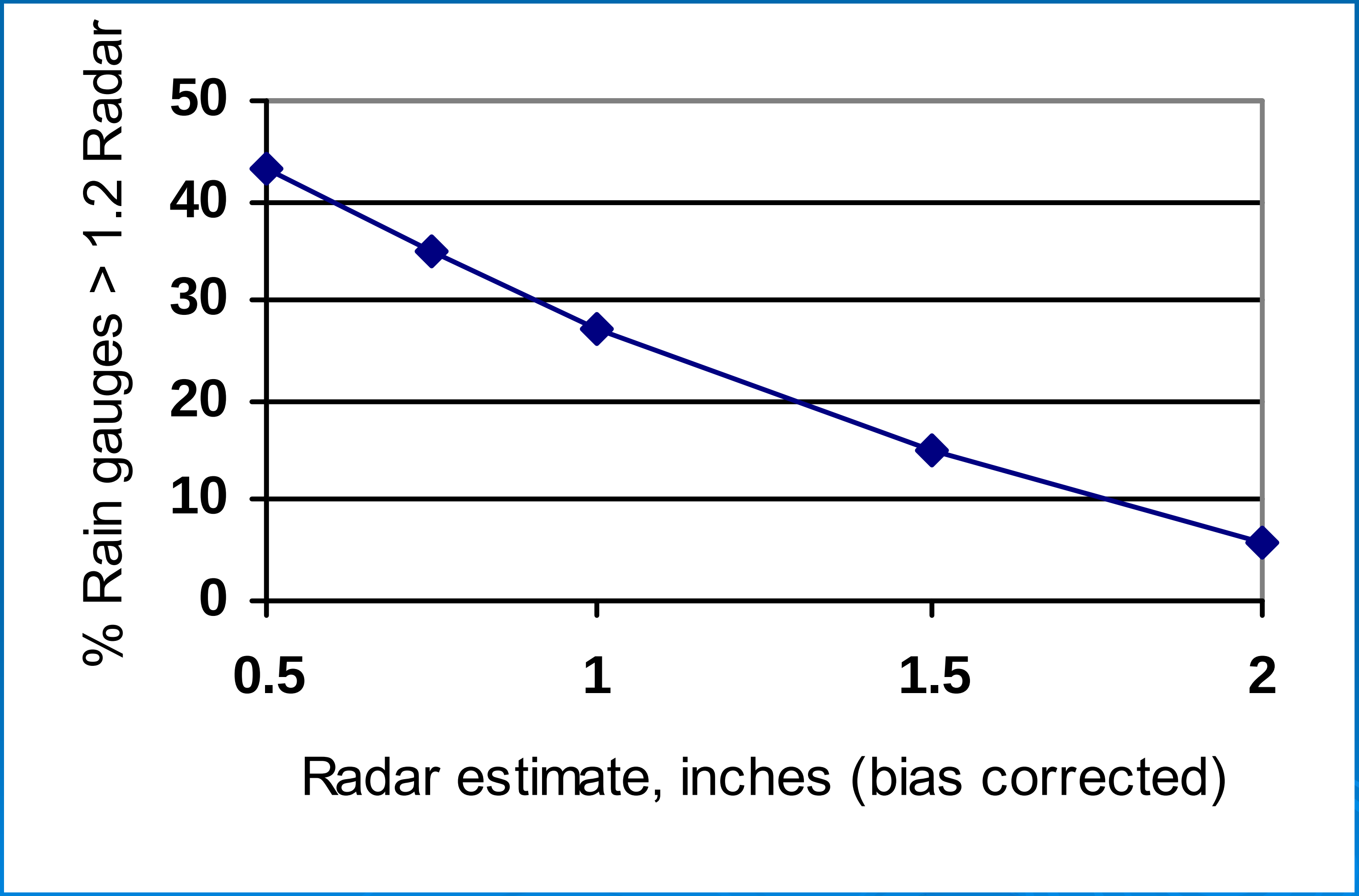
Probabilistic Relationships Between Radar and Rain Gauge Estimates

- Most common forms of bias correction are based on long-term collections of 1-h radar/gauge paired observations
- Actual bias between radar estimates based on Z-R and rain gauges depends on magnitude of the rainfall rate
- A common method of selecting radar rainfall alert thresholds (fraction of critical ground truth value) is not statistically reliable

Common Operational Strategy For Flash Flood Warnings

- Take action when radar rainfall estimate is 80% of Flash Flood Guidance (FFG) value
  - Closer examination of basin rainfall history
  - Call for spotter reports
- However, threat of actual rainfall exceeding FFG is strongly dependent on the radar estimate itself

Probability of Gauge Rainfall ≥ 120% of Radar Estimate



Data from KTLX, KINX, KSRX, 2004-2005 warm seasons

Probability of Gauge Rainfall ≥ 120% of Radar Estimate

- Probability of exceeding a given gauge/radar ratio decreases with radar rainrate
- For a radar estimate of 0.4 inch, there is a 45% chance that rainfall will exceed 0.5 inch
- For a radar estimate of 1.5 inches, there is only a 15% chance that rainfall will exceed 1.8 inches

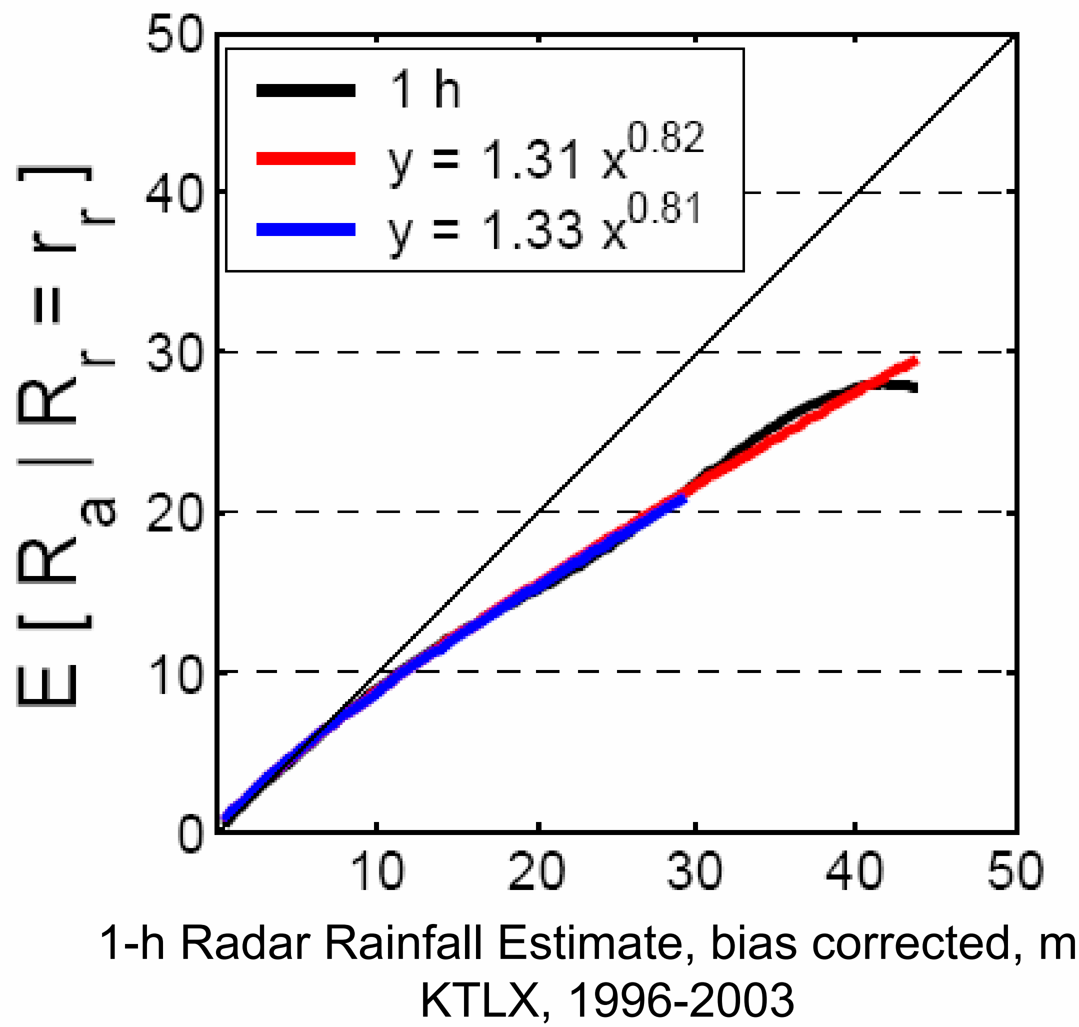
Probabilistic Relationships Between Radar and Rain Gauge Estimates

- Work carried out at University of Iowa (Krajewski, Ciach, Villarini) shows that radar rainfall errors can be modeled with a set of power-law functions
- Results confirmed on other data samples by OHD

After correcting radar estimates for overall long-term bias:

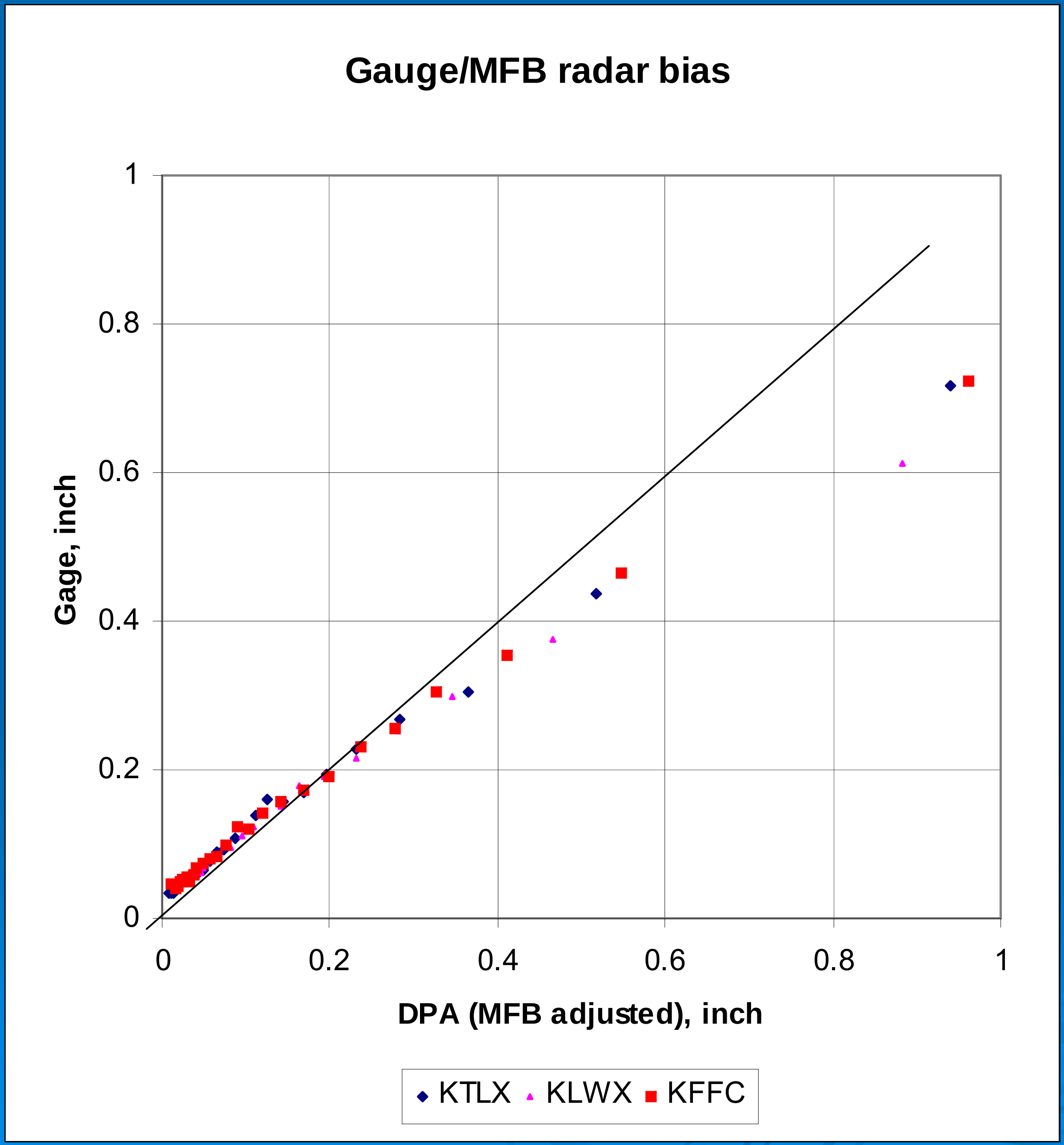
- Radar underestimates lighter amounts and overestimates higher amounts
- A simple power law relates expected rainfall to initial Z-R rainfall estimate

After Correcting Radar Estimates For Long-Term Bias, a Magnitude-Dependent Bias Remains…



From Krajewski and Ciach, 2005

Expected 1-Hour Rain Gauge Value As Function of Radar Estimate



Radar estimates adjusted for bias (gauge/radar):

KTLX bias: 0.7
KLWX bias: 1.07
KFFC bias: 0.93

May-Sep 2004

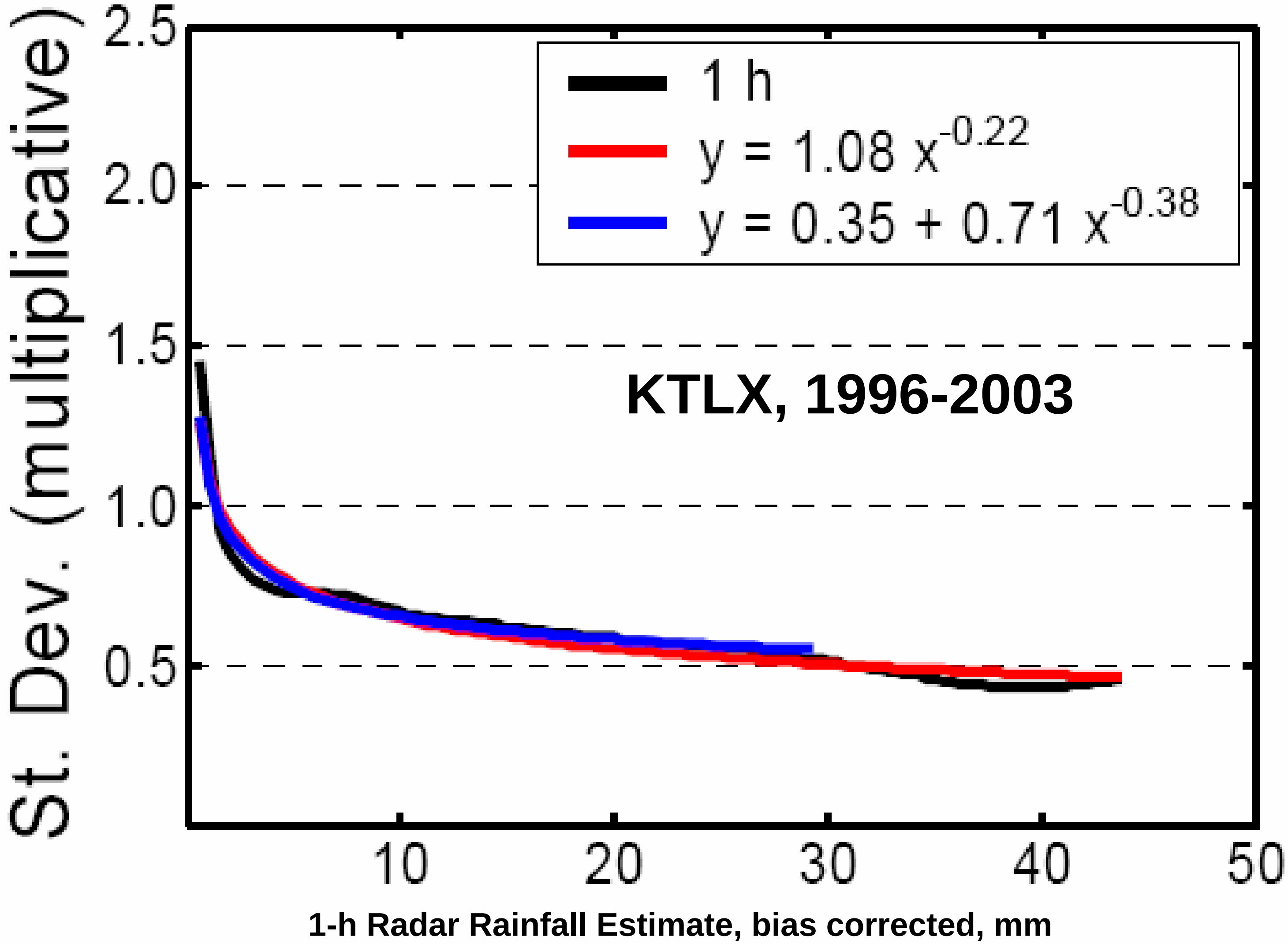
Plotted points represent 100-500 gauge-radar pairs

Representation of Random Errors

- It is possible to represent errors as *arithmetic* (gauge minus radar) or *multiplicative* (gauge divided by radar)
- Multiplicative form has some distinct statistical advantages
- Multiplicative errors have a near-normal (Gaussian) distribution, making estimation of probabilities relatively simple
- Magnitude of multiplicative error standard deviation is a power-law function of rainrate

Error = (Gauge precipitation) / (Radar precipitation)

Standard Deviation of The Radar Estimate Error (Spread of Estimates) Can Also Be Modeled As A Power-Law Function:



From Krajewski and Ciach, 2005

Summary of Statistical Model for Errors:

- Rainrate-dependent bias is approximated by a power-law curve
- Standard deviation of multiplicative error is also a power-law curve
- Distribution of multiplicative errors for any given radar estimate is approximately normal
- Formulation of probability of gauge rainfall exceeding a critical value:

Formulation of Probability of Rainfall (RR) Exceeding a Critical Value THRES

P (RR ≥ THRES) = 1 - Φ(X)

where:

$$\Phi(X) = \frac{1}{2} + \frac{1}{2} erf(X)$$

and

$$X = \frac{x-\mu}{\sigma\sqrt{2}} = \frac{\frac{THRES}{DPA^*} - 1}{\sigma\sqrt{2}} = \frac{\frac{THRES}{a(B \cdot RR)^b} - 1}{\left[c + d(B \cdot RR)^e\right]\sqrt{2}}$$

B is long-term gauge/radar bias;
a,b are parameters of bias power law;
c,d,e are parameters of standard deviation power law;
RR is initial radar estimate;
THRES is FFG or other critical rain amount

Dissemination of Probabilistic Information

- Power-law parameters (a,b,c,d,e) will be determined from extended gauge/radar sample
- Parameters have seasonal, site, and rainfall duration dependence
- Parameters would be included as part of Supplemental Precipitation Data product, and appended to digital precip products
- Documentation will be made available to end users

Application of Probabilistic QPE:

- Probability equation could be incorporated as new option in FFMP, along with (Radar-FFG) and (Radar/FFG) displays
- There is some interest in a new graphic product with probabilities of exceeding a given amount
- Individual users could apply to:
  - Irrigation, pesticide decisions
  - Vegetative wetting for agriculture, firefighting

PQPE In The Dual-Pol Era

- It appears that horizontal Z-R rainfall will still be produced and possibly integrated with the dual-pol algorithm
- Probability information derived from Z-R rainfall is still statistically valid
- When adequate samples of data from dual-pol rainfall algorithms have been collected, the same methodology used for current Z-R rainfall will be applied to dual-pol
- New probability parameters will reflect reduction in bias or magnitude of random errors

HOSIP Status of PQPE:

- **H**ydrologic **O**perations and **S**ervices **I**mprovement **P**rocess
- HOSIP Stage 2
  - Statement of Need approved
  - Concept of operations and general requirements now being documented
- Will apply for TAC approval when complete technical requirements have been developed

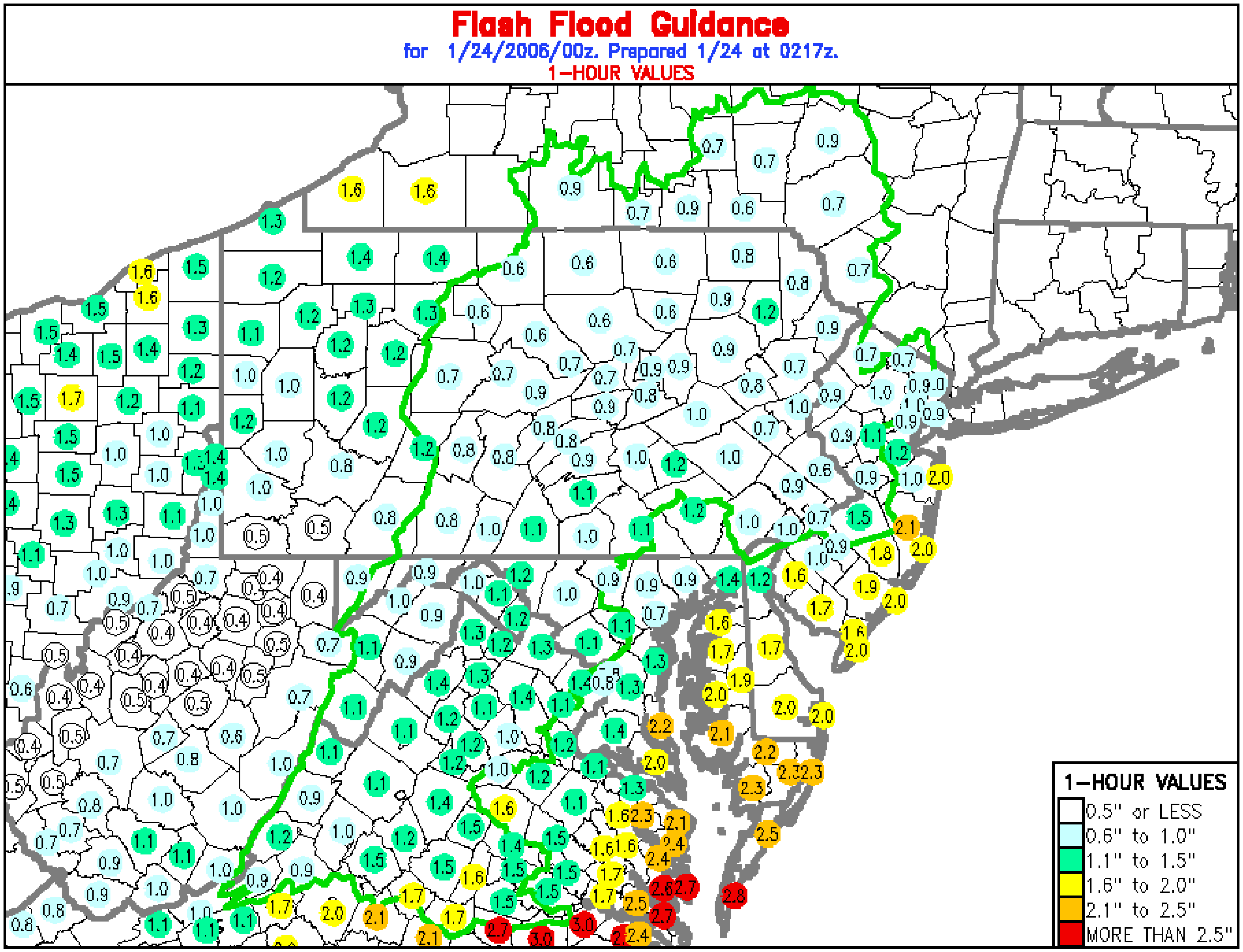
Questions?

Supplemental Slides

Flash Flood Guidance

- An estimate of the rainfall required to cause small headwater streams to reach bankfull
- Commonly expressed as 1-h, 3-h, 6-h amounts
- Routinely produced by River Forecast Centers based on soil type, antecedent rainfall

1-Hour FFG from MARFC, OHRFC



Document References

Krajewski, W. F., and G. J. Ciach, 2005: Towards probabilistic quantitative precipitation WSR-88D algorithms: Data analysis and development of ensemble generator model: Phase 4. Report to OHD under NOAA Contract DG133W-02-CN-0089, 99 pp.

Seo, D.-J., 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, 222-240.