Multisensor Precipitation Estimator (MPE) Workshop

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Silver Spring, Maryland

Advanced Hydrologic Applications Course
National Weather Service Training Center
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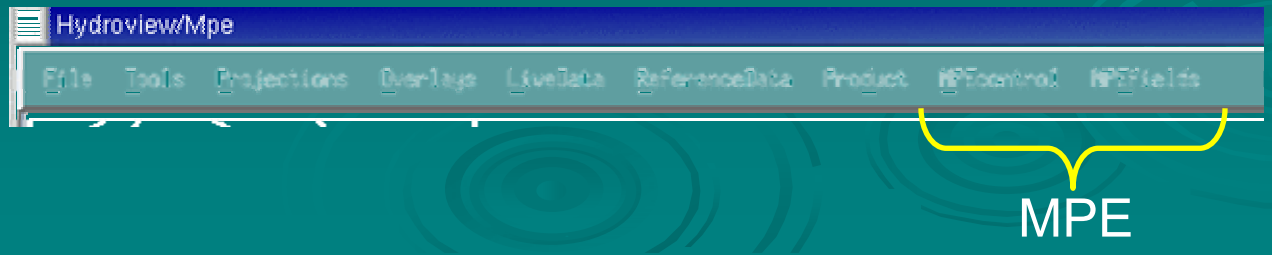
Objectives

- Understand the overarching science behind MPE
- Provide hands-on training on how to use MPE software, including 4 lab exercises
- Understand how MPE fits into WFO operations
- Gain your feedback on MPE features

- Note: The Hydroview features of the Hydroview/MPE software application will not be discussed here



What is MPE?

An interactive software tool within the AWIPS WFO Hydrologic Forecast System (WHFS) that:

- Adds value to radar-only rainfall estimates from the WSR-88D ORPG's Precipitation Processing System (PPS)
- Integrates rain gauge and satellite rainfall estimates with the radar-only estimates
- Produces high-resolution gridded rainfall products that are used quantitatively in hydrologic operations at WFOs and RFCs
  - Hydrologic forecast models (Site Specific Hydrologic Model at WFOs; River Forecast System at RFCs)
  - Flash Flood Monitoring and Prediction (future)

Brief History of MPE

- Developed by the NWS Hydrology Lab
- A descendant of “Stage II and Stage III Precipitation Processing” at the RFCs
- S-II and S-III were developed side-by-side with the WSR-88D Precip. Processing System (PPS=Stage I) and integrated with it in late 1980s (pre-NEXRAD)
- S-II and S-III were born about 1990 and were deployed operationally first at ABRFC in Tulsa, OK in early 1990s associated with the NWS AWIPS modernization
- MPE replaced Stage II and III in 2002 at the RFCs with new improved functionality and science
- MPE was adapted and delivered to WFOs within WHFS around 2003
- Enhancement of MPE by the Hydrology Lab to better serve the WFO flash flood program is currently on-going

MPE User Documentation

http://www.nws.noaa.gov/om/whfs/

WHFS Field Support Group: whfs@noaa.gov

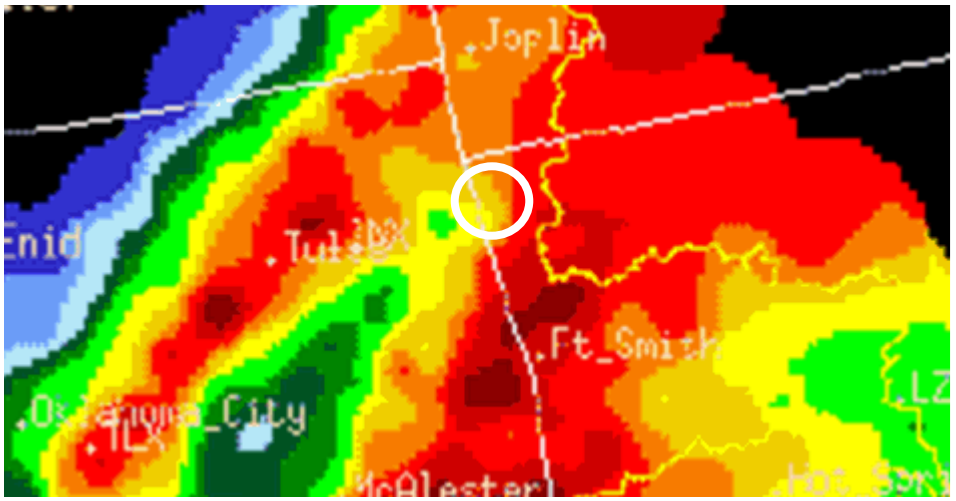
- Hydroview/MPE User's Guide – Build OB5 (2/28/05)
- MPE Field Generation System Document – Build OB4 (3/11/05)
- Hydroview/MPE Implementation Document – OB5 (2/28/05)
- Gage Precipitation Processing Operations Guide (2/28/05)
- Real-time Rain Gauge Quality Controlling
- Radar Climatology Analysis and Display RADCLIM Software Documentation (3/14/05)
- Hydroview documentation
- WHFS Release Notes
- This presentation at http://www.nws.noaa.gov/oh/hrl/papers/papers.htm#wsr88d

Why use MPE?

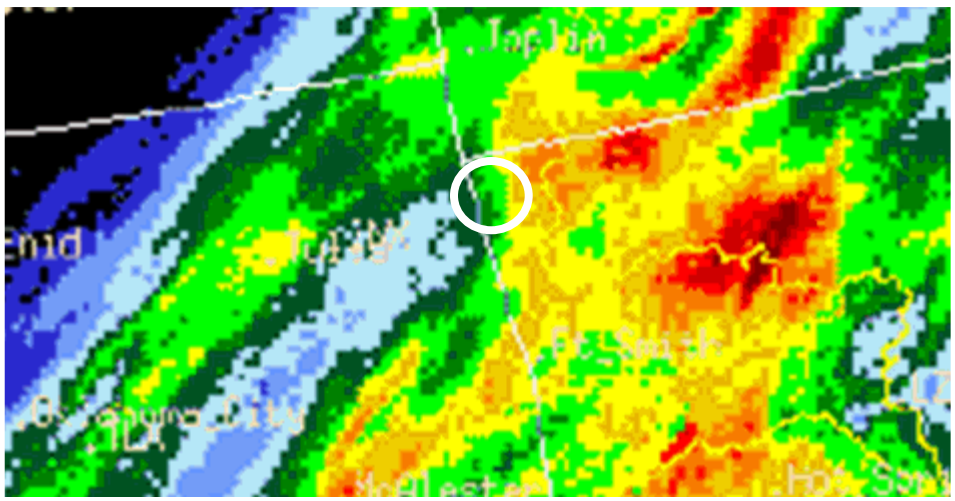
- Radar-only rainfall estimates are plagued with systematic biases that can and must be removed or reduced
- Automated rain gauges and satellites provide independent rainfall estimates to improve radar estimates
- With hydrologic operations and models:
  - Garbage precip. in = garbage streamflow out
  - See example below

MPE Rainfall for Illinois River basin near Watts, OK

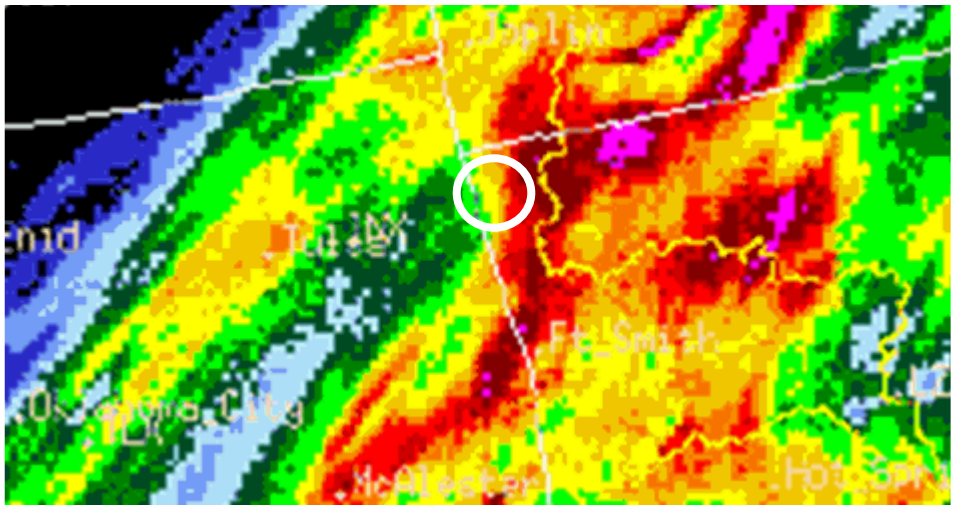
MPE Gauge-only Rainfall (~2.3 in.)



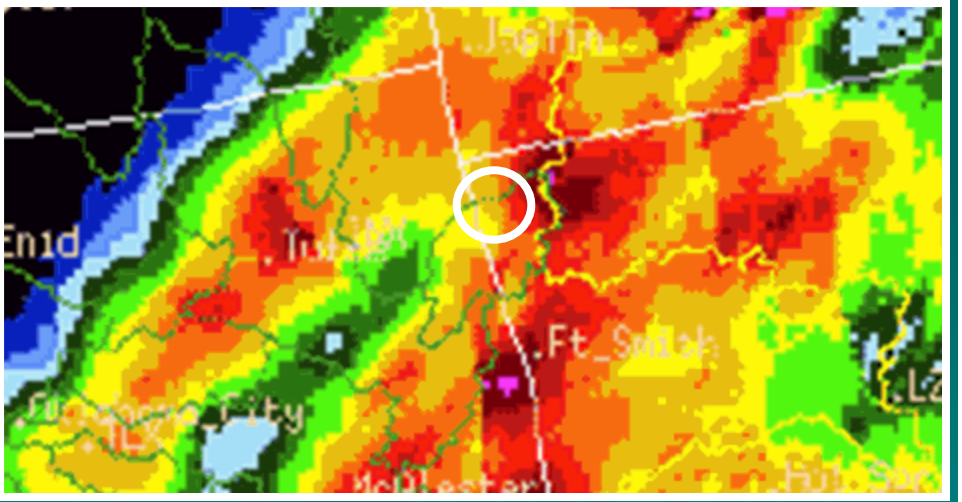
MPE Radar-only Rainfall (~1.0 in.)



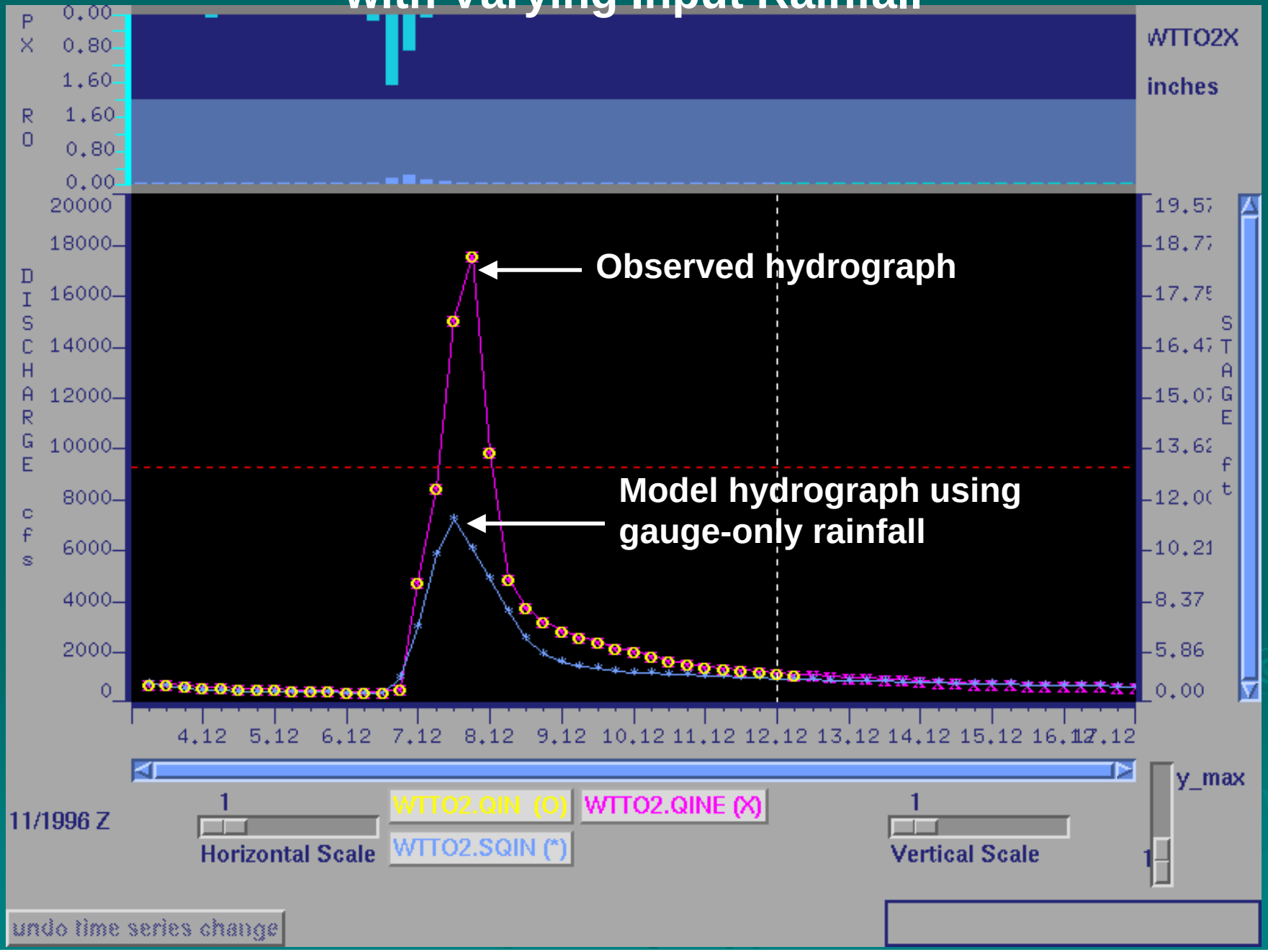
Bias-adjusted Radar Rainfall (~1.7 in.)



MPE Multisensor Rainfall (~2.2 in.)



NWSRFS Lumped Model Hydrographs with Varying Input Rainfall



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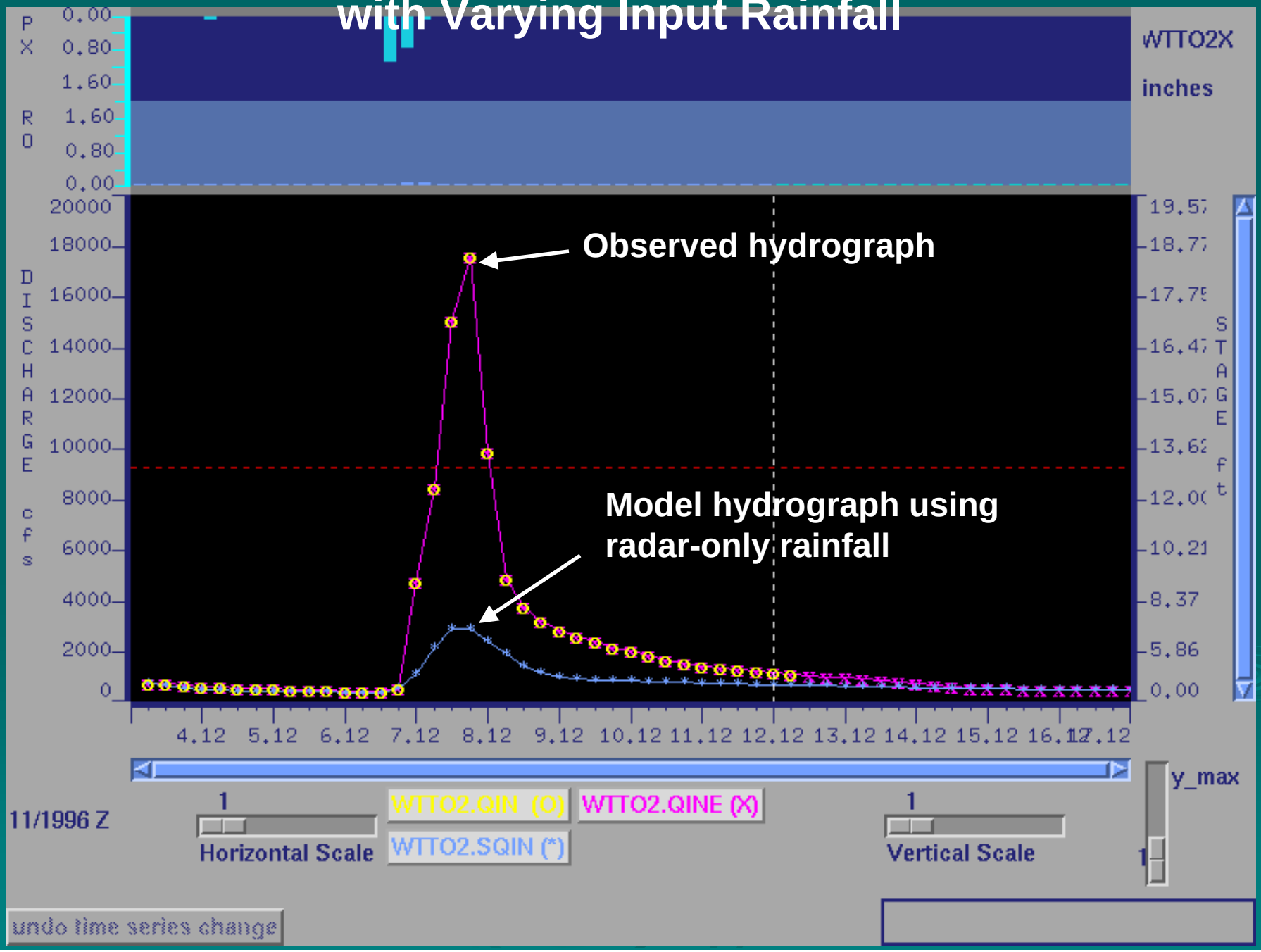
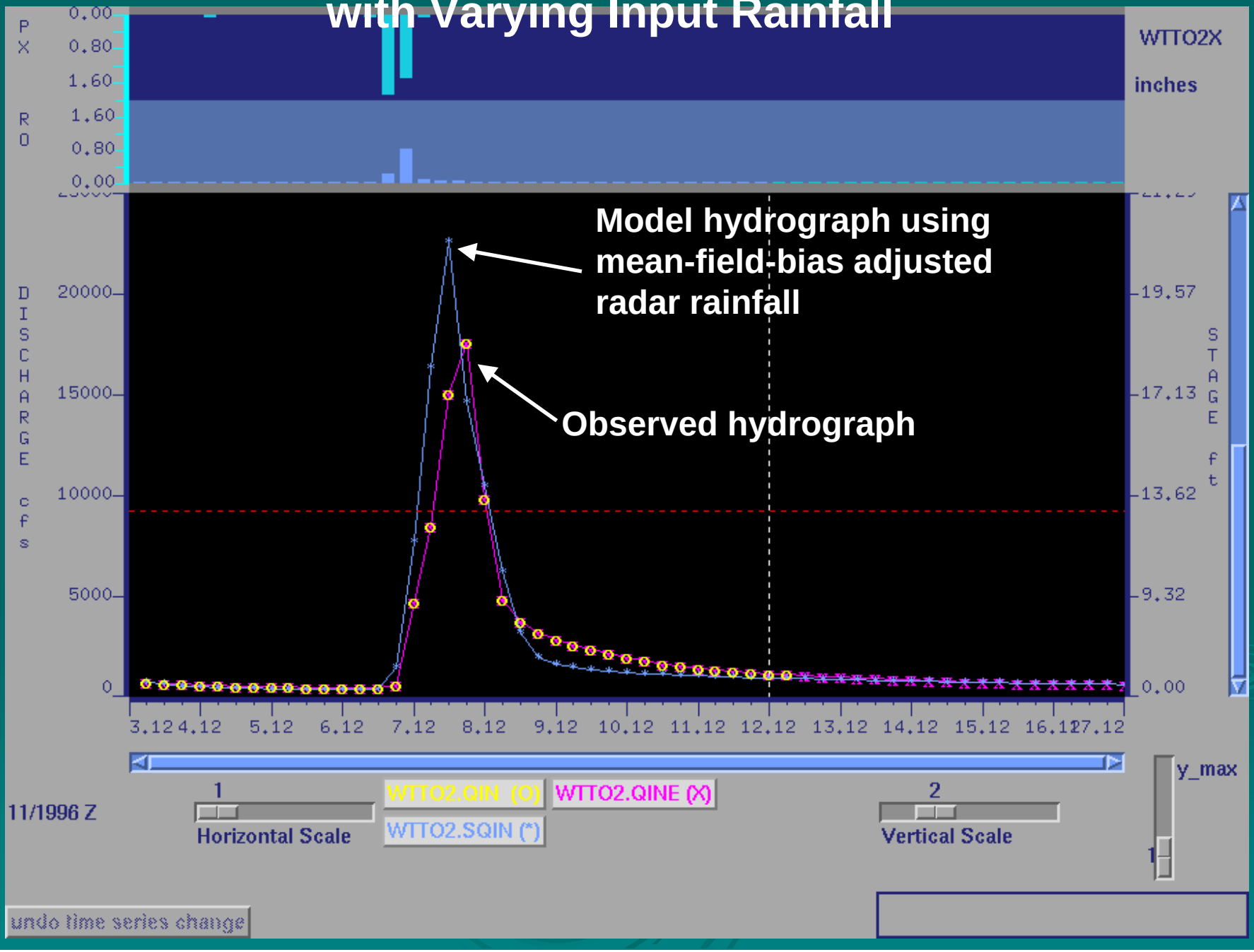


NWSRFS Lumped Model Hydrographs with Varying Input Rainfall



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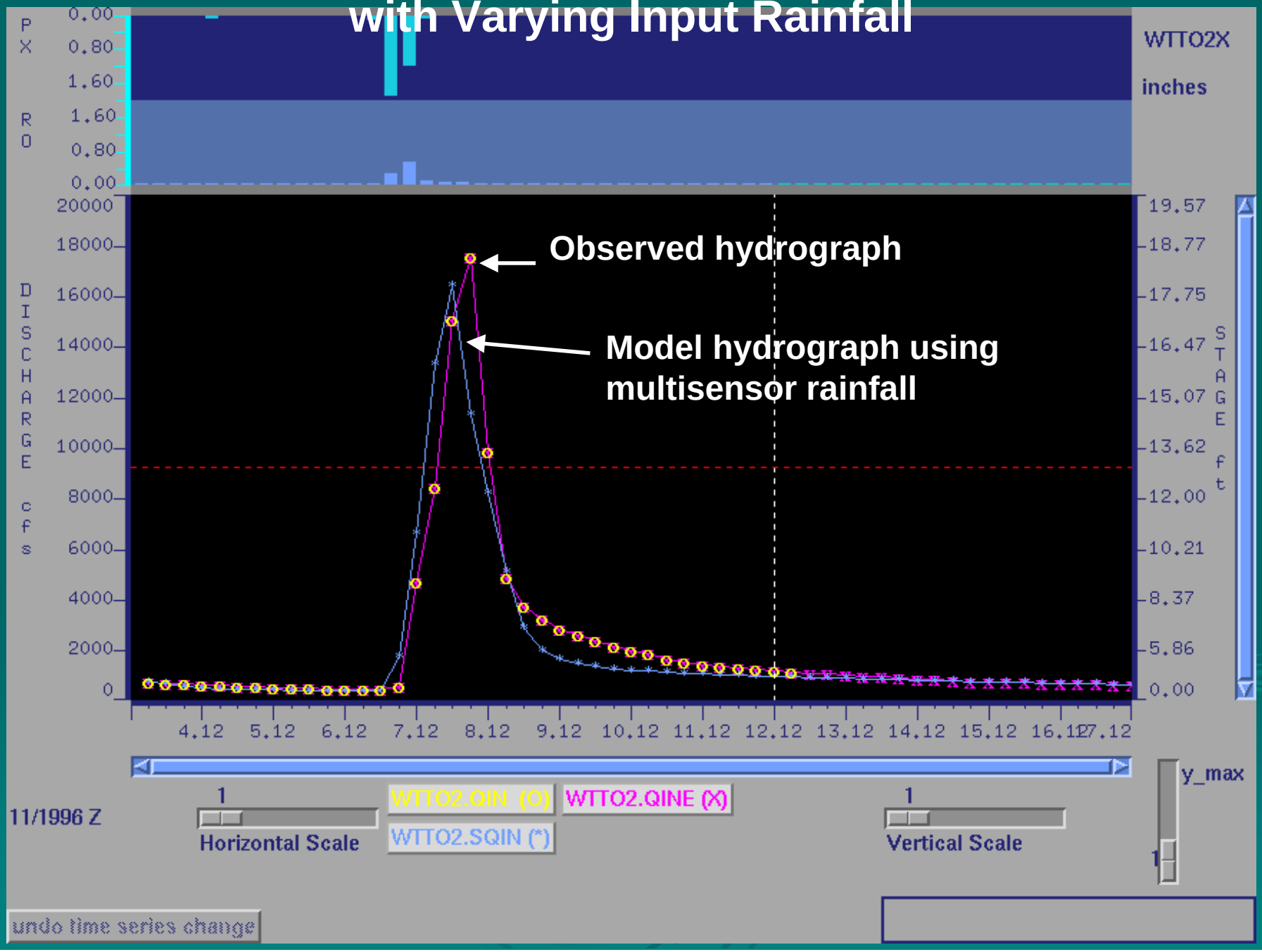


MPE Input Data Sources

- Radar rainfall estimates
  - Digital Precipitation Arrays (DPA…1-hour accumulations) from PPS at top of hour from all WSR-88D/ORPGs covering your forecast/warning area
- Rain gauge rainfall estimates
  - All available automated accumulator (PC) or incremental (PP) gauges
- Satellite rainfall estimates
  - Hourly NESDIS HydroEstimator products at top of hour
- User-defined adaptable parameters and configuration data stored in AWIPS MPE databases
- You…MPE is interactive

Digital Precipitation Array (DPA) Refresher

- A one-hour radar-only rainfall accumulation product from the Precipitation Processing System (PPS) on the WSR-88D Open RPG
- A small digital gridded product on a 256-data-level logarithmic rainfall scale from 0-14 inches
- ~4 km grid: Hydrologic Rainfall Analysis Project (HRAP) polar stereographic grid projection
- Produced every volume scan by PPS, but currently MPE only uses the single product at the top of each hour

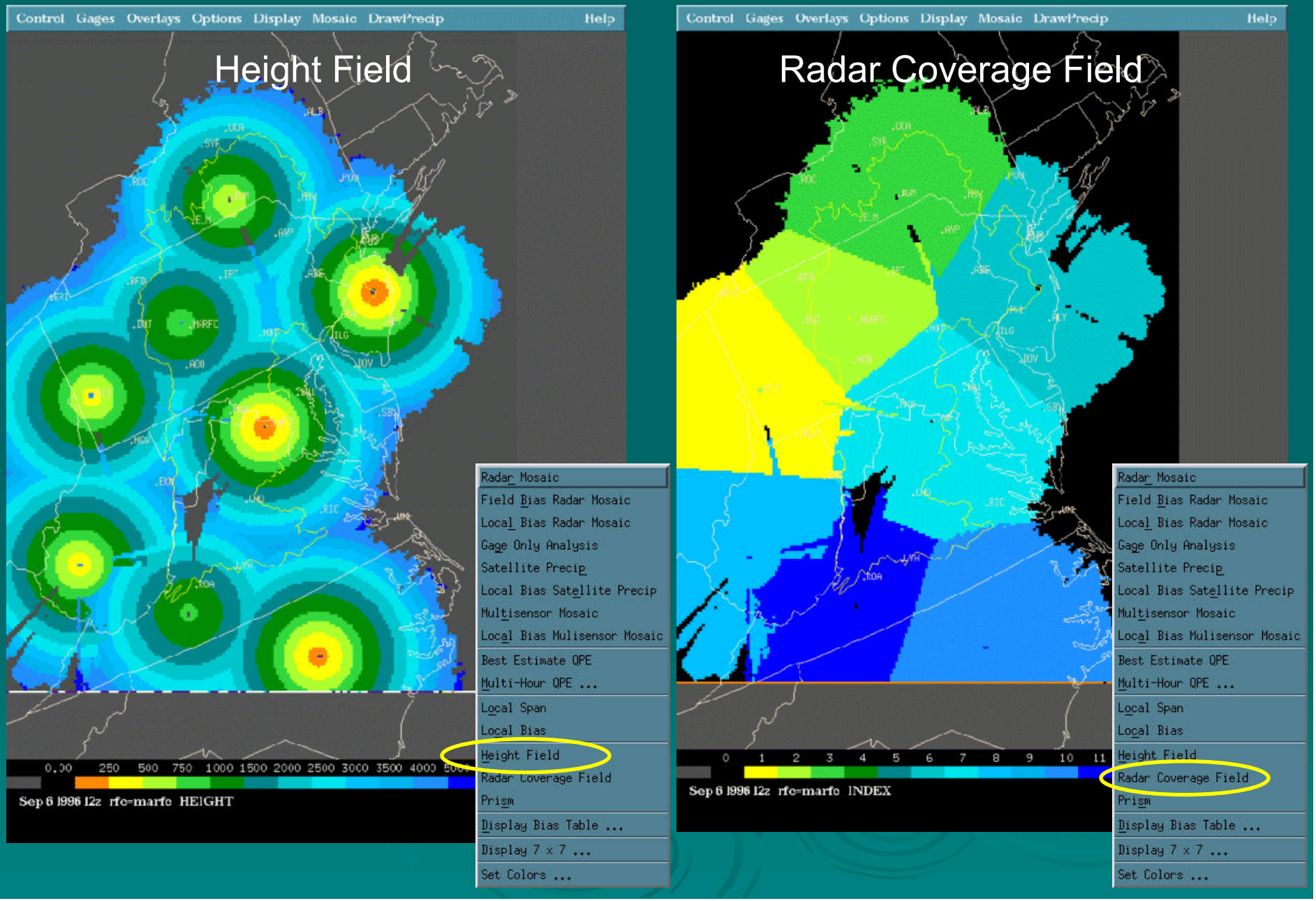
How is MPE Mosaicking Done?

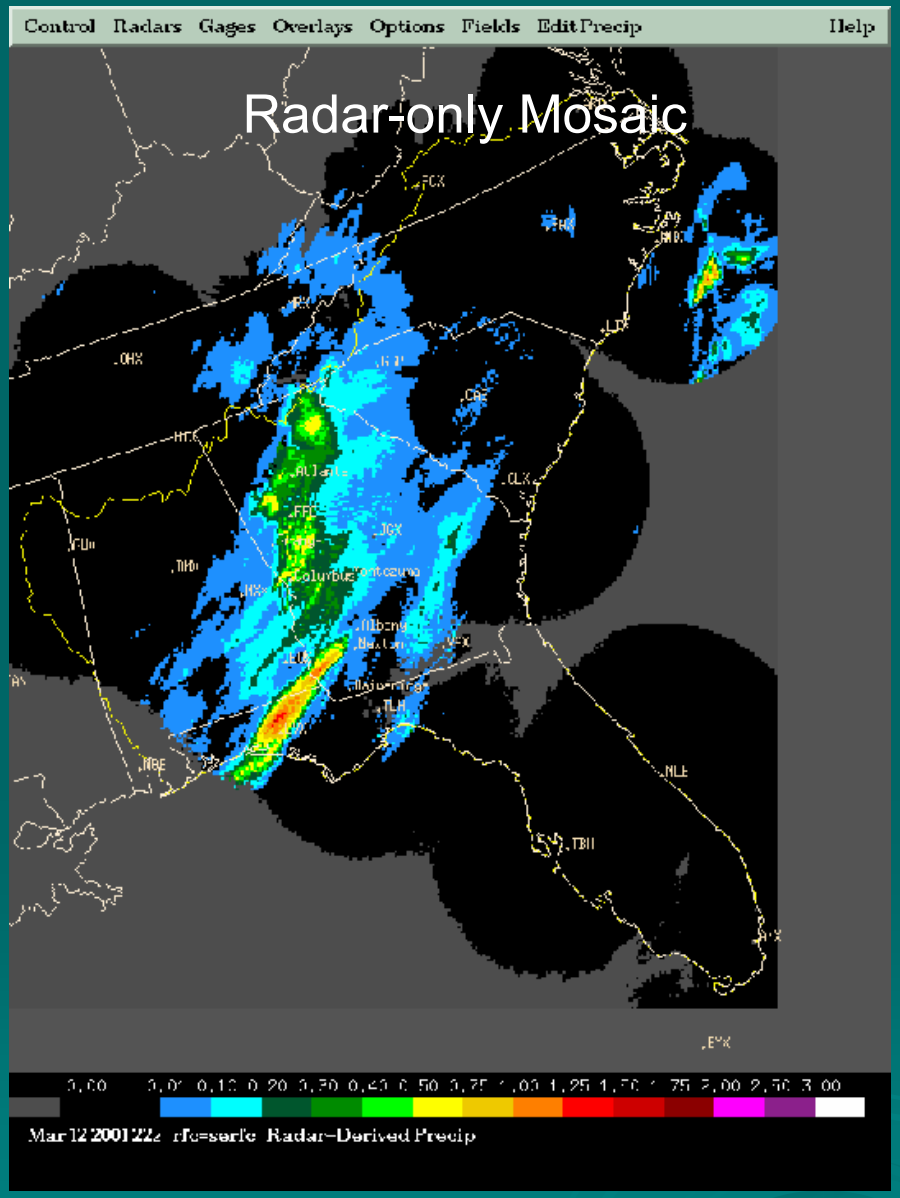
MPE Mosaicking Requirements:

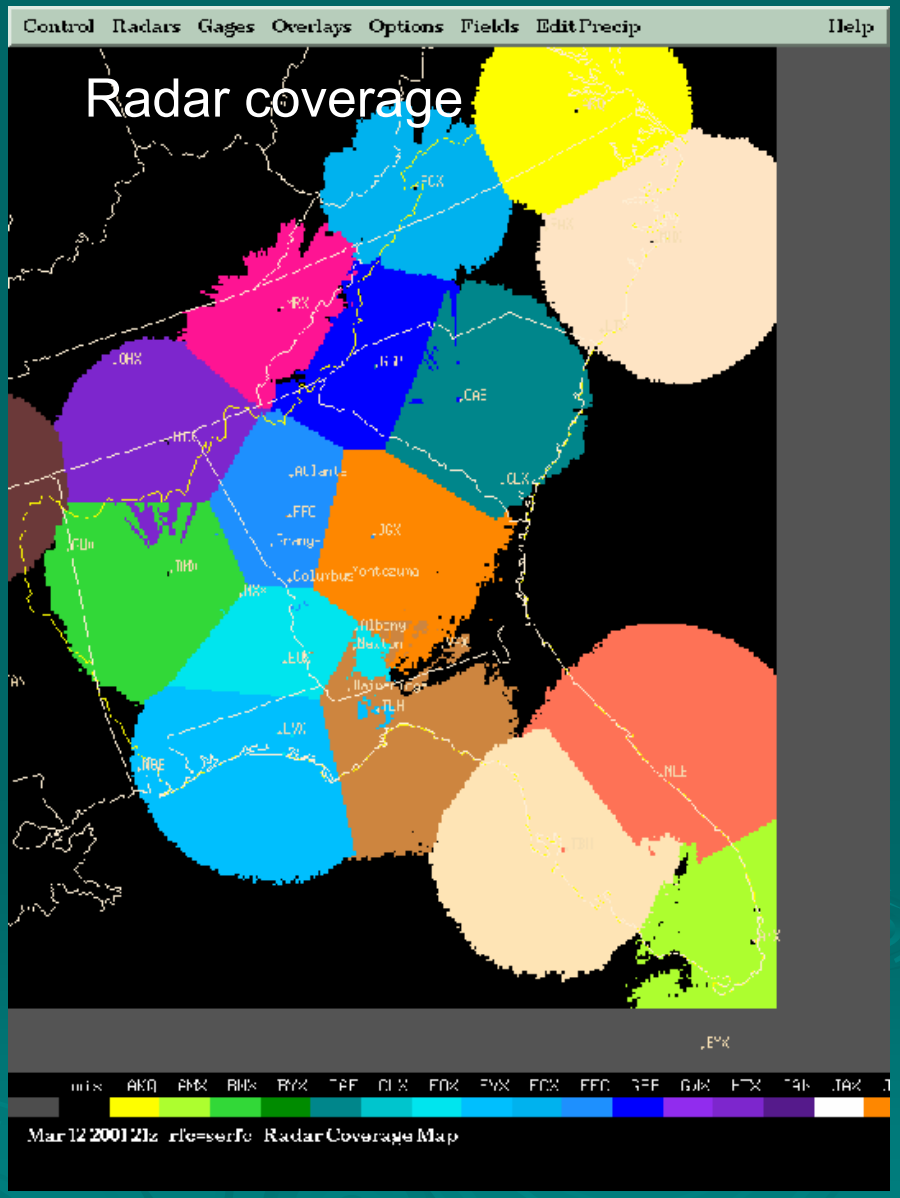
- In overlap areas, use the rainfall from the radar whose pixel is closest to the ground
  - Using mean or maximum exacerbates bright band, range degradation, and beam blockage problems
- Don't use data beyond the "effective coverage[1]" of each radar, i.e.,
  - Don't use radar data at far ranges
  - Don't use terrain-blocked radar data
- If a radar's DPA drops out for one or more hours, then MPE automatically fills in that area with an adjacent radar's DPA data
- Mosaicking can reduce rainfall underestimation problems at far ranges plaguing individual radars

1 To be discussed later

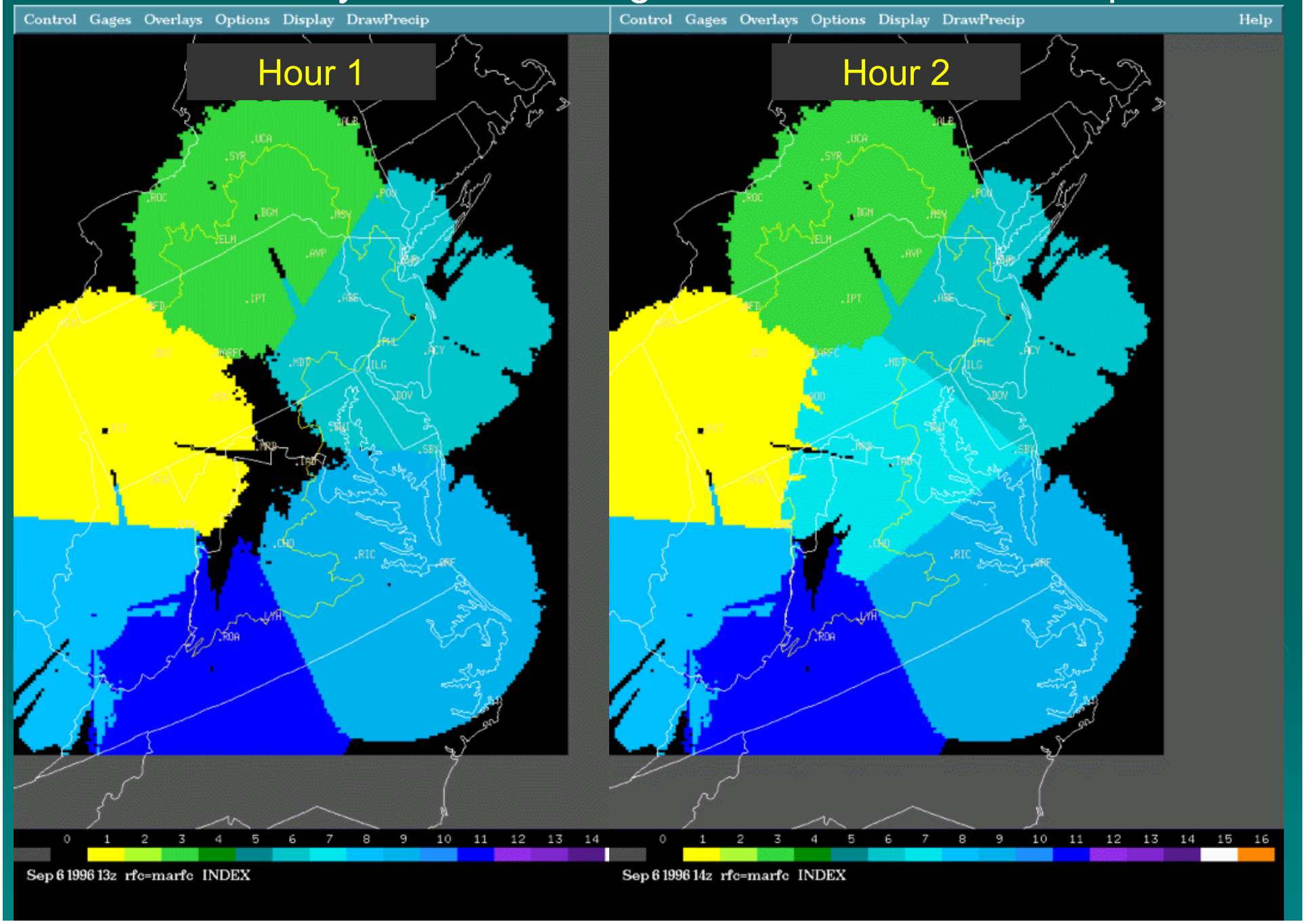
MPE's Mosaicking Technique



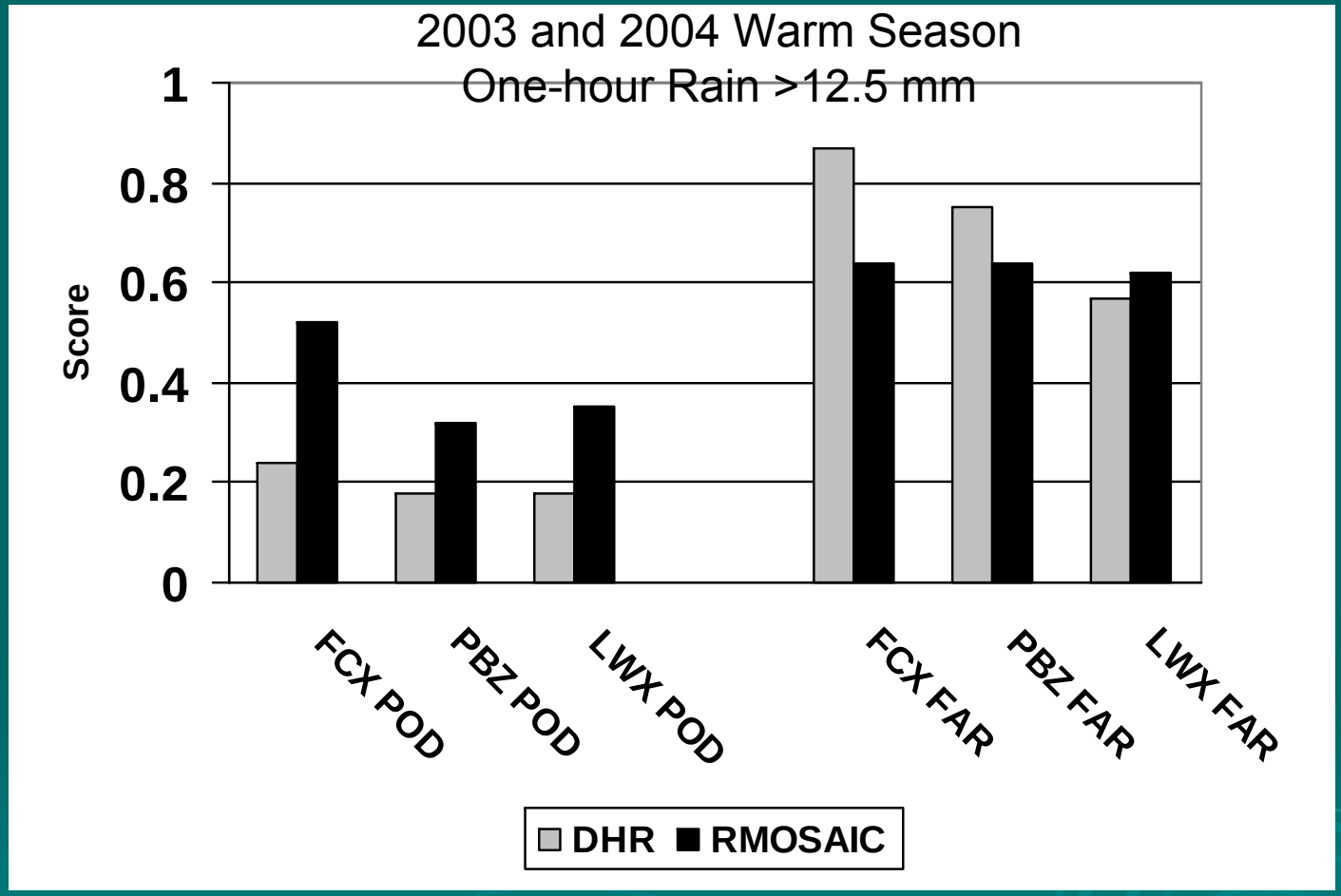

Control Radars Gages Overlays Options Fields Edit Precip Help
Radar-only Mosaic
Mar 12 2001 22z rfc=serfc Radar-Derived Precip


Control Radars Gages Overlays Options Fields Edit Precip Help
Radar coverage
Mar 12 2001 21z rfc=serfc Radar Coverage Map

Automatically Fills in Missing Areas When DPAs Drop out



Mosaicked Radar Detects Rain Far Better than a Single Radar When Compared to Rain Gauges



POD: Probability of Detection FAR: False Alarm Ratio
DHR: Digital Hybrid Scan Reflectivity RMOSAIC: Radar-only MPE Mosaic
FCX: Blacksburg, VA PBZ: Pittsburgh, PA LWX: Sterling, VA

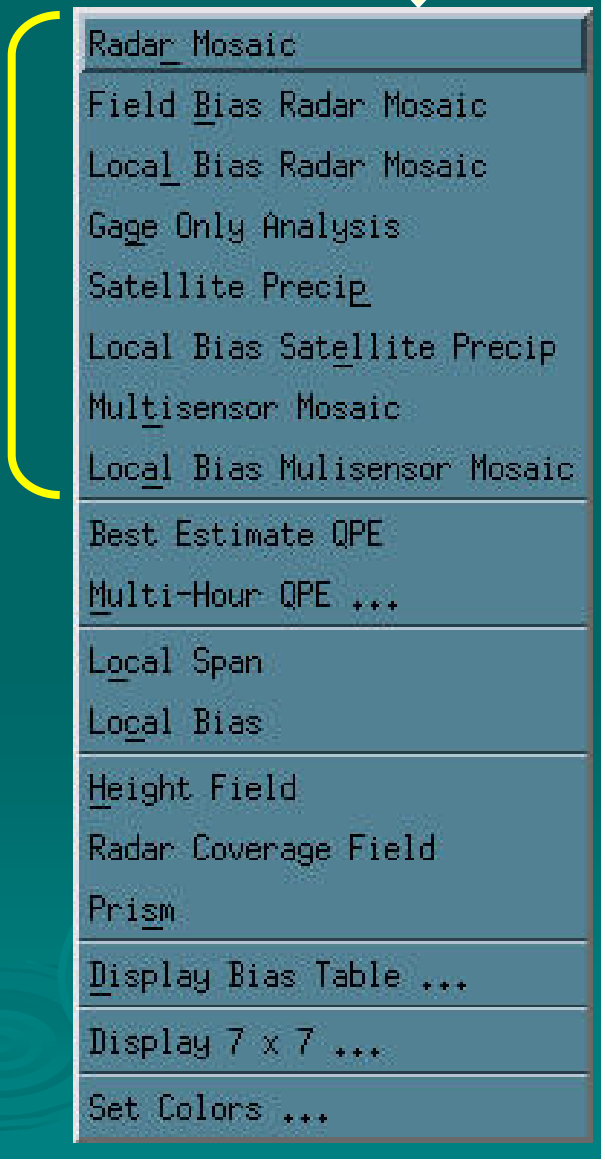
Lab Exercise #1

- Objective: Gain familiarity with the MPE graphical user interface (GUI) using a Hurricane Floyd case study of September 16, 1999

MPE Hourly Rainfall Products

. . . under the “MPEfields” pull-down menu

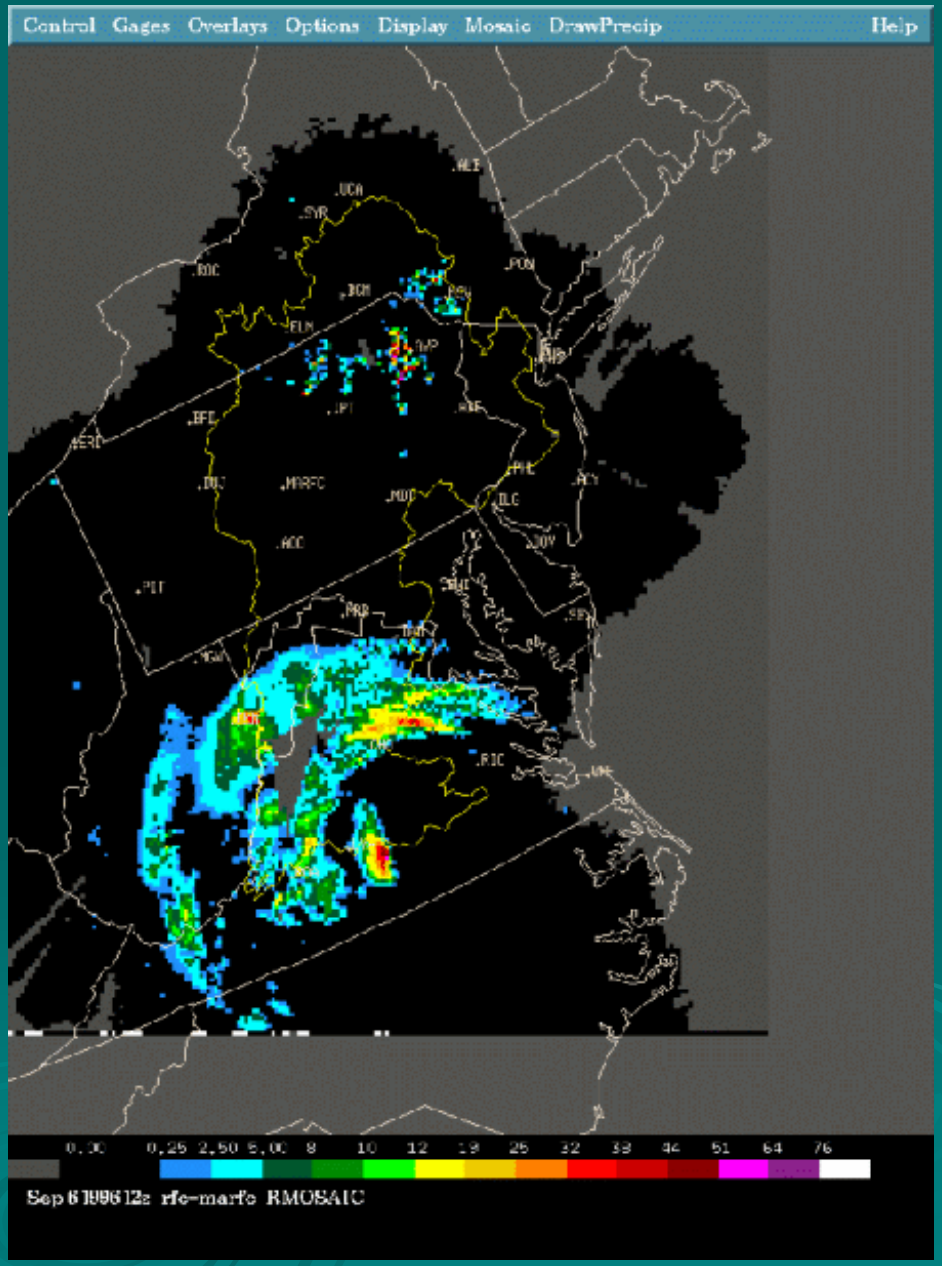
- Radar(-only) mosaic
- (Mean-)field-bias (adjusted) radar mosaic
- Local bias(-adjusted) radar mosaic
- Gauge-only analysis
- Satellite(-only) precipitation
- Local bias(-adjusted) satellite precipitation
- Multisensor mosaic
- Local bias(-adjusted) multisensor mosaic



These products are automatically generated at about 25 minutes past every hour.

Radar-only Mosaic (RMOSAIC)

- A simple mosaic of raw DPAs



Mean-field-bias Adjusted Radar Mosaic (BMOSAIC)

- Compute the mean-field-bias (MFB) between hourly gauge and radar rainfall for each radar (MFB=ΣG / Σ R)
  - A single multiplicative ratio that varies from radar to radar and hour to hour such that
    - =1.0 means radar matches gauges on average
    - >1.0 means radar is underestimating on average
    - <1.0 means radar is overestimating on average
  - Note: adjusting radar using MFB has exactly the same effect as altering the "A" parameter in $Z=A R^b$
- Multiply MFB X DPA for each radar
- Mosaic these products together

DPAs + Point Rain Gauges

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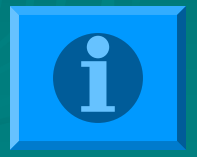
BMOSAIC

Computing Mean-Field Bias between Radar and Gauges

- Use only raining gauge-radar pairs (G>0 and R>0)
- Select only G-R pairs within the “effective radar coverage” of each radar
- Use at least a minimum threshold number of hourly gauge-radar pairs per radar (adaptable parameter…10 is default)
  - If <10 in current hour, go back in time long enough to accumulate at least 10 raining pairs
- Gauge-radar bias table stores this information for each radar



Gauge-Radar Bias Table

Compute biases once an hour for many different memory spans ranging from short-term (1-hr) to long-term (months)

1 week →

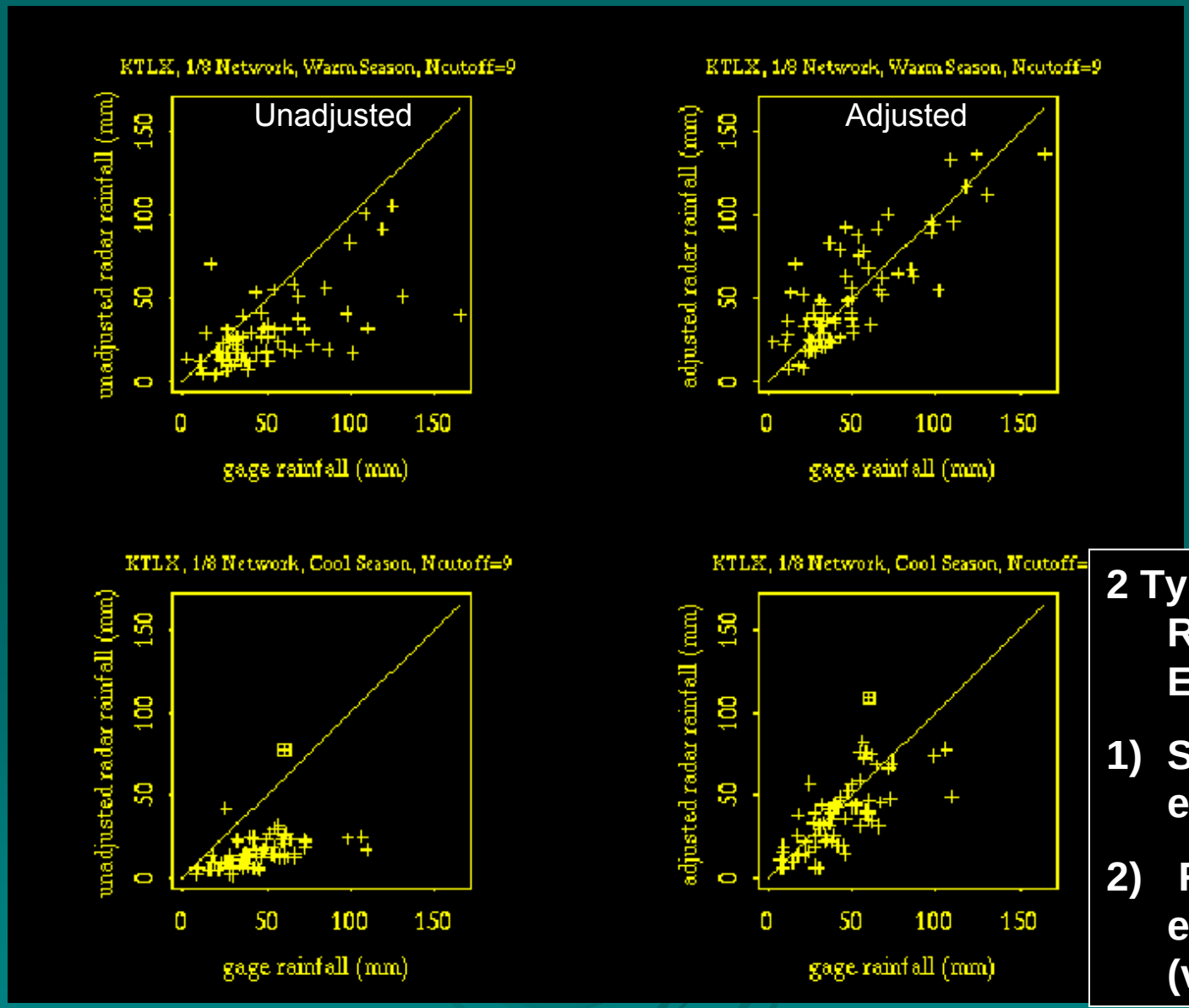
3 months →

Located under MPEfields, *Display Bias Table* menu, then click on a radar ID

Effects of Mean-field-bias Adjustment

Warm season

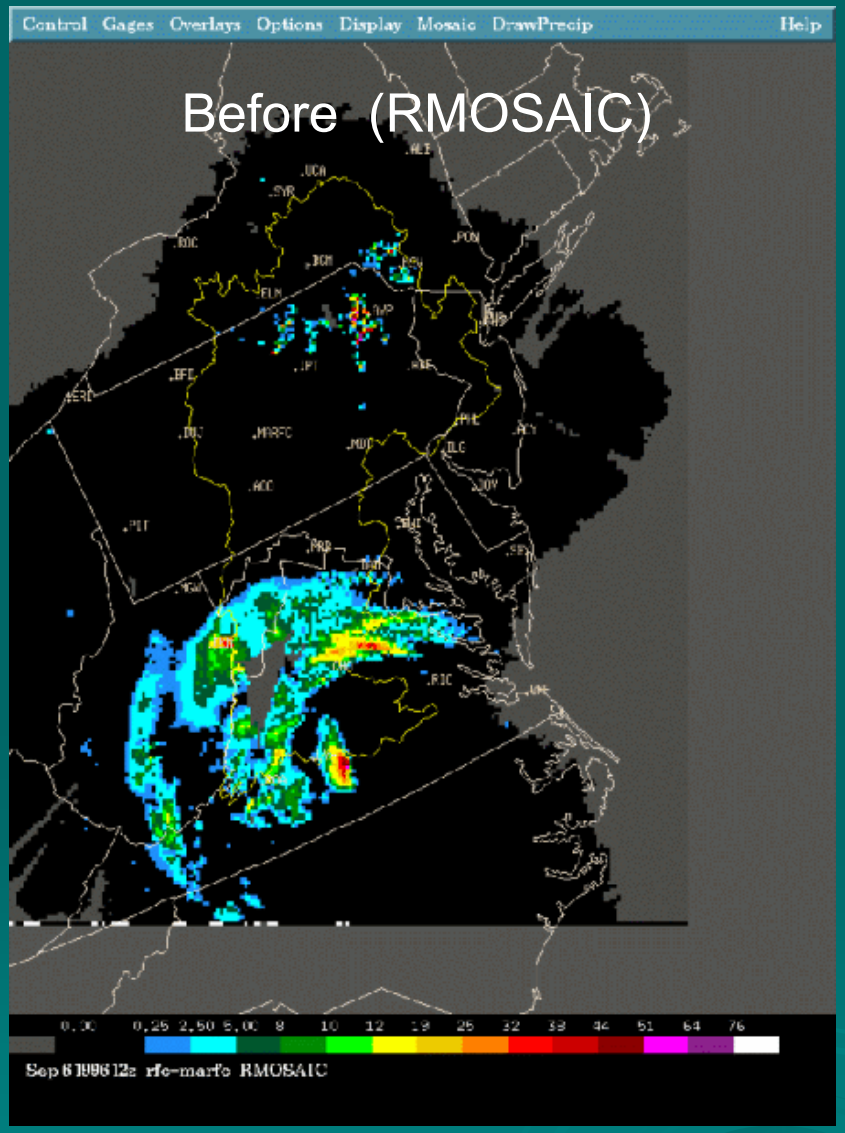
Cold season

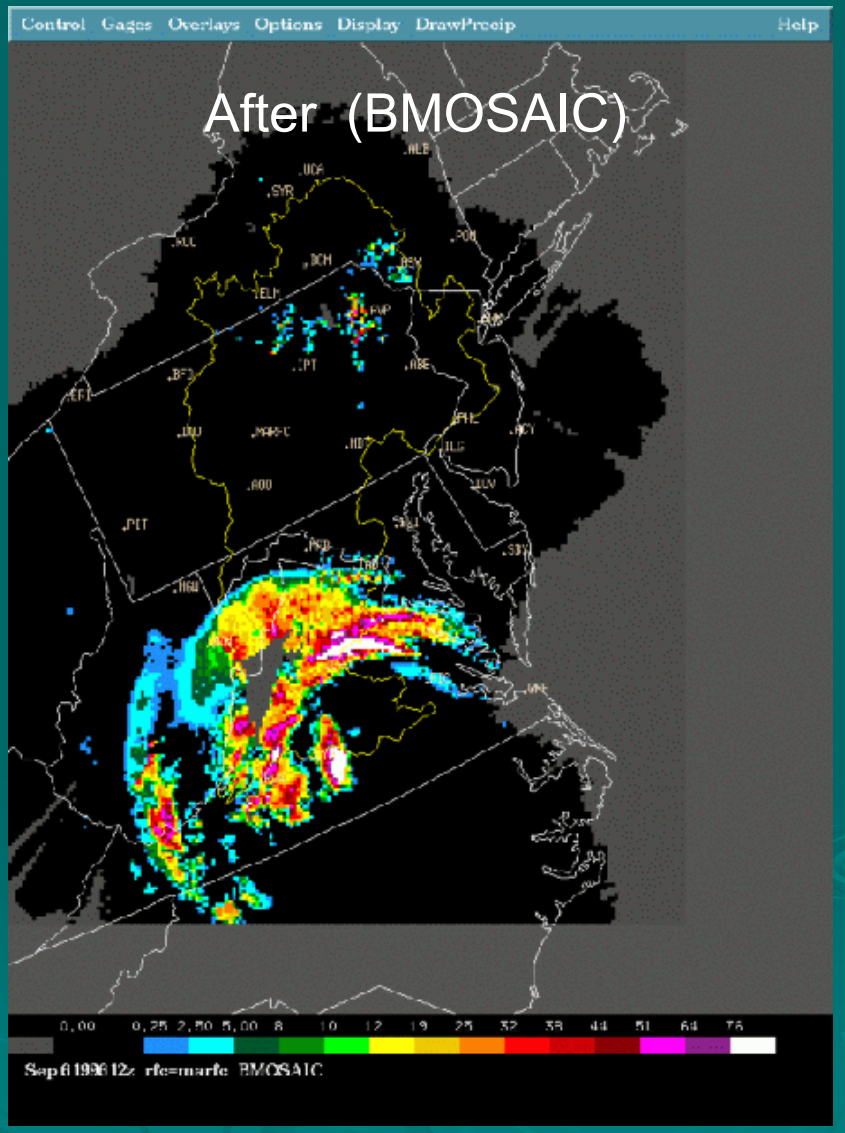


2 Types of Rainfall Errors:

1) **Systematic errors (bias)**
2) **Random errors (variance)**

Results of Mean-field-bias Adjustment





Passing Bias Tables from MPE back to the WSR-88D ORPGs

- MPE automatically transmits the gauge-radar bias table back to each WSR-88D that is designated for each WFO
  - Different tables go to each radar
  - Currently done only once per hour from automatic MPE runs at H+25, but will also be done for manual runs of MPE in OB6
- Then ORPG's PPS ingests and applies the mean field bias to the radar products immediately if you so choose
  - PPS's *Bias-applied flag* adaptable parameter used here
  - Bias is chosen from bias table using the PPS *threshold minimum number of gages* adaptable parameter (10)…same methodology as in MPE
- Slightly different ways of applying the bias to OHP, THP, STP, USP and DPA products
  - Bias is not applied to the DPA products but is appended in its header

Local Bias-adjusted Radar Mosaic (LMOSAIC)

- Mosaic the raw DPAs (= RMOSAIC)
- Compute local gauge-radar biases (LB) at every HRAP pixel on RMOSAIC
  - At each pixel, search out about 40 km (adaptable parameter) for all available rain gauges
  - Like BMOSAIC, go back in time until you have at least 10 raining G-R pairs for that subset of gauges near the grid point
  - Compute the multiplicative ratio $LB(i,j) = \Sigma G(i,j) / \Sigma R(i,j)$
- Multiply LB(i,j) by RMOSAIC(i,j)

RMOSAIC + Point Rain Gauges

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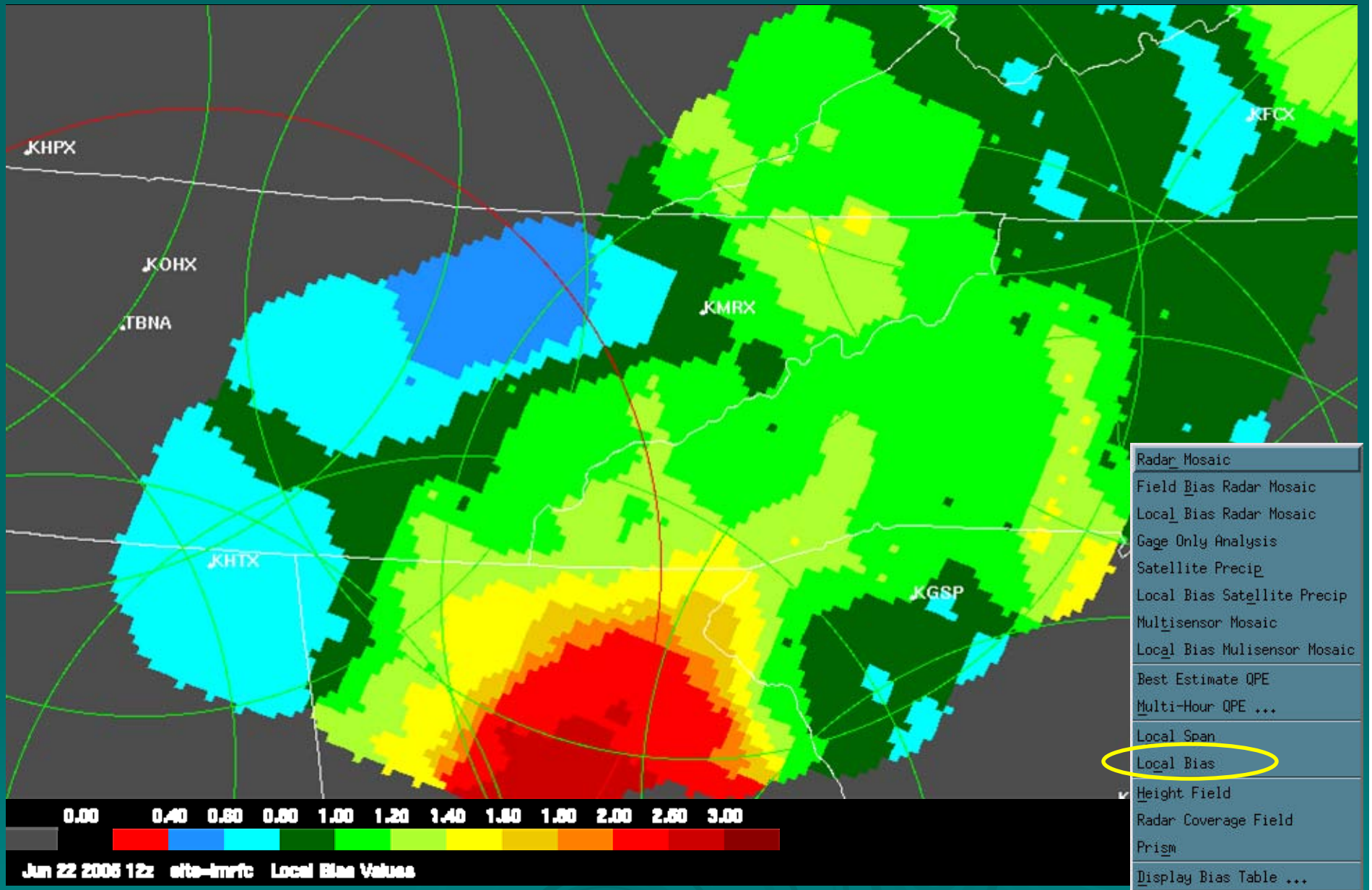
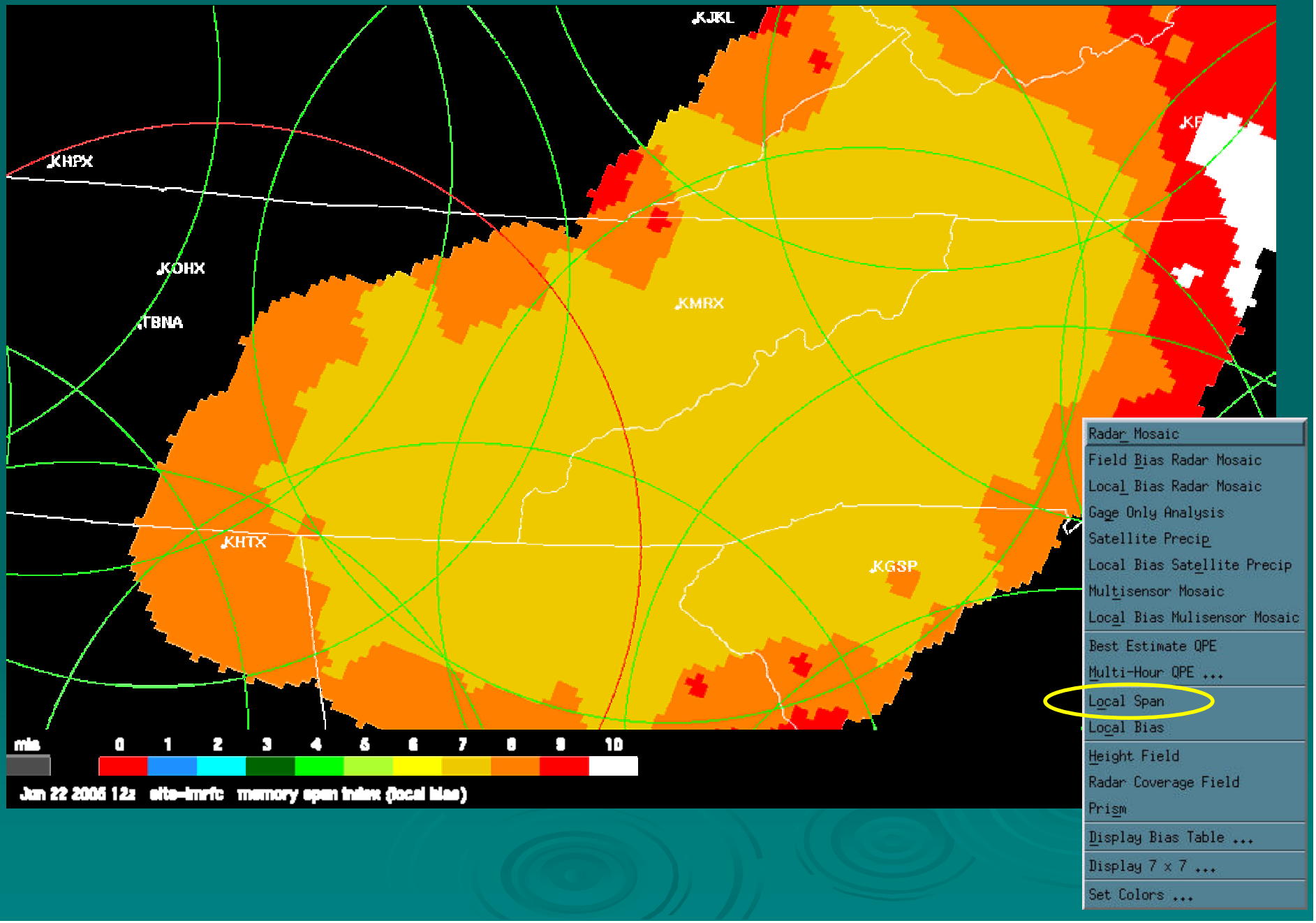
LMOSAIC

Local Bias Grid

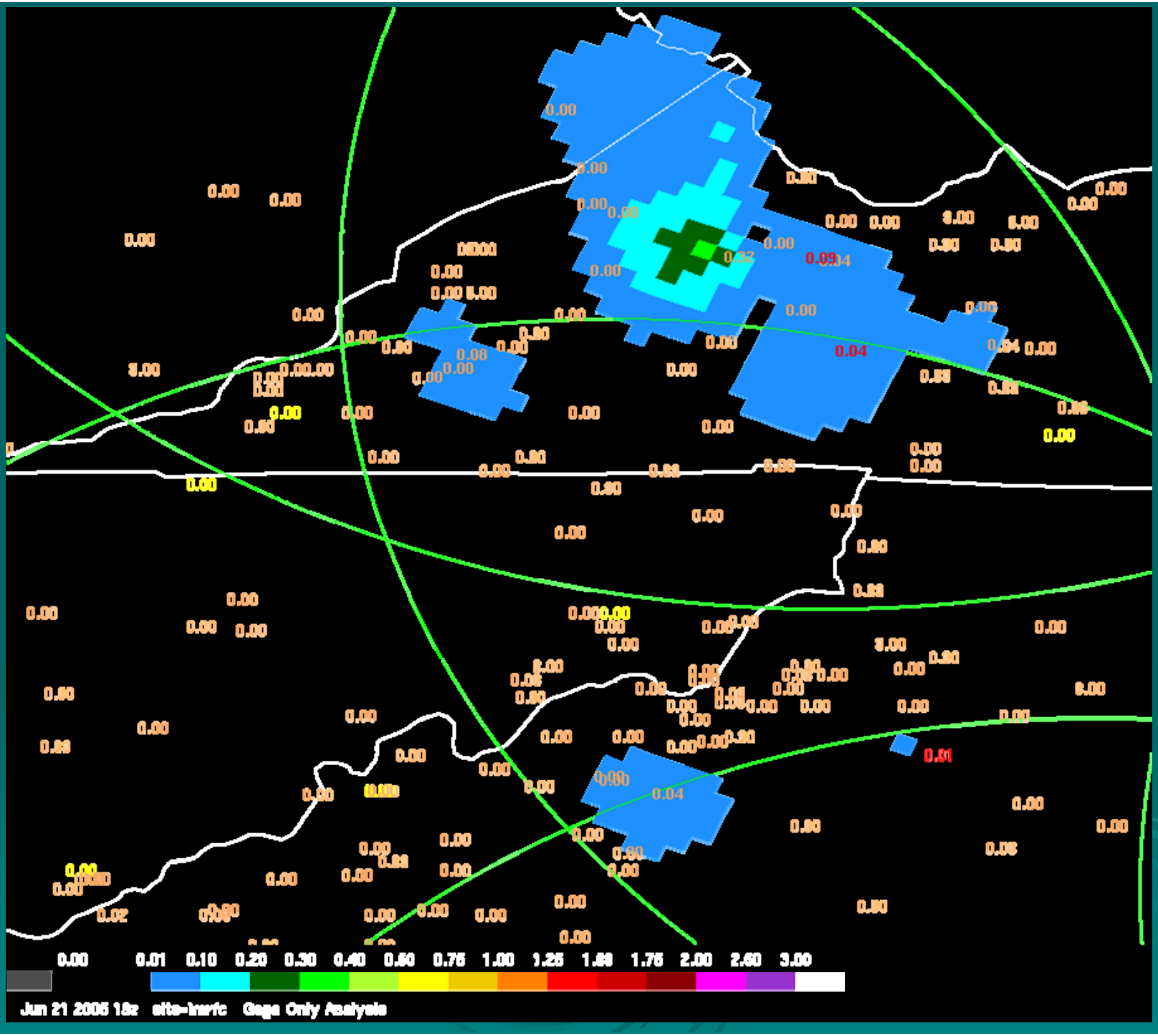


Local Span Index Grid



Gauge-only Analysis

- A gridded objective analysis of rain gauge data alone
  - Uses “optimal linear estimation” techniques
- Currently uses a 60 km radius of influence when searching for nearby gauges
  - Isolated gauges appear as circular rain areas
  - In future, this will be an adaptable parameter

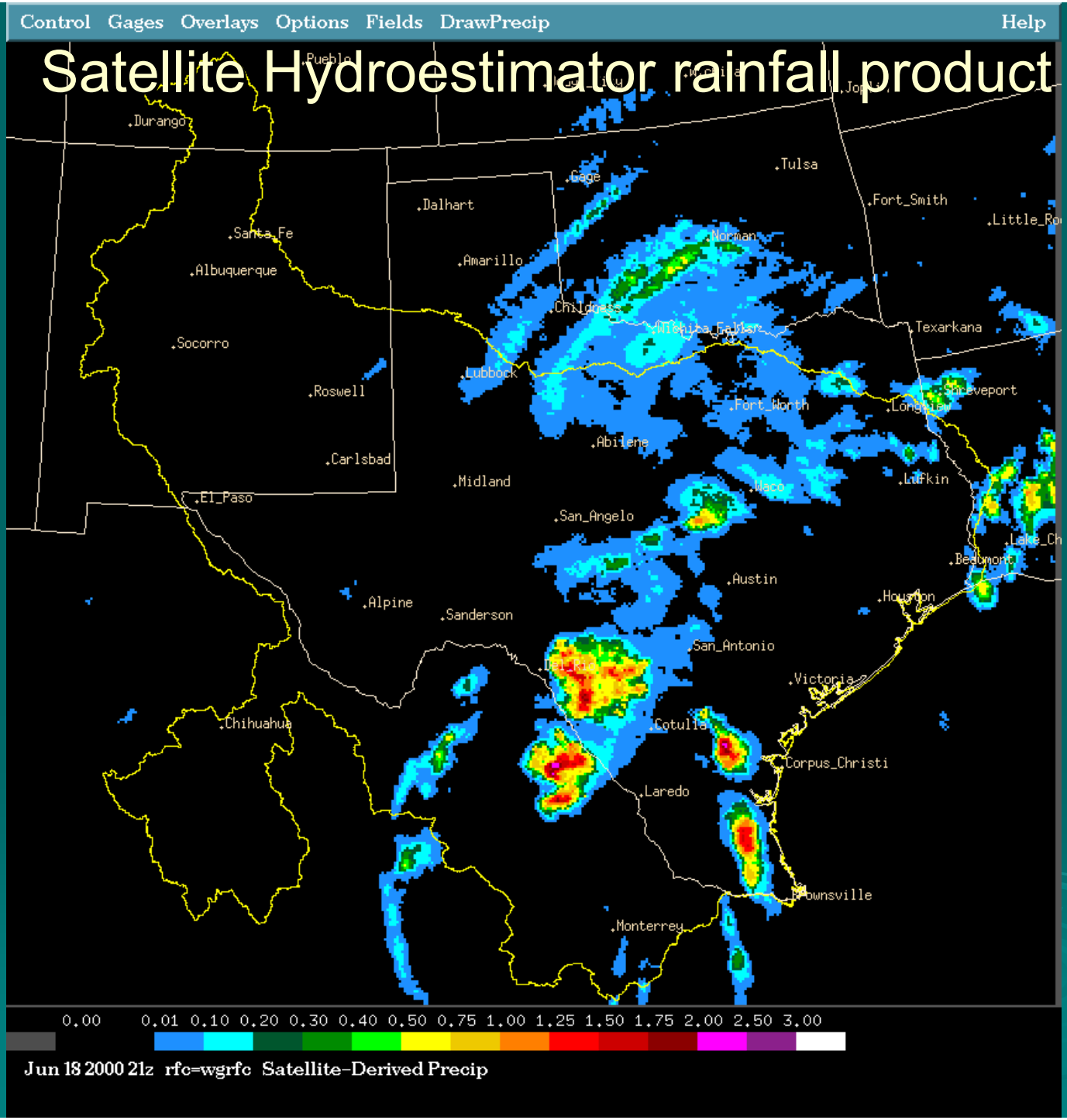

0.00 0.01 0.10 0.20 0.30 0.40 0.60 0.75 1.00 1.25 1.50 1.75 2.00 2.50 3.00
Jun 21 2005 18z stia-lmvic Gage Only Analysis

Satellite Precipitation Estimates (SPE)

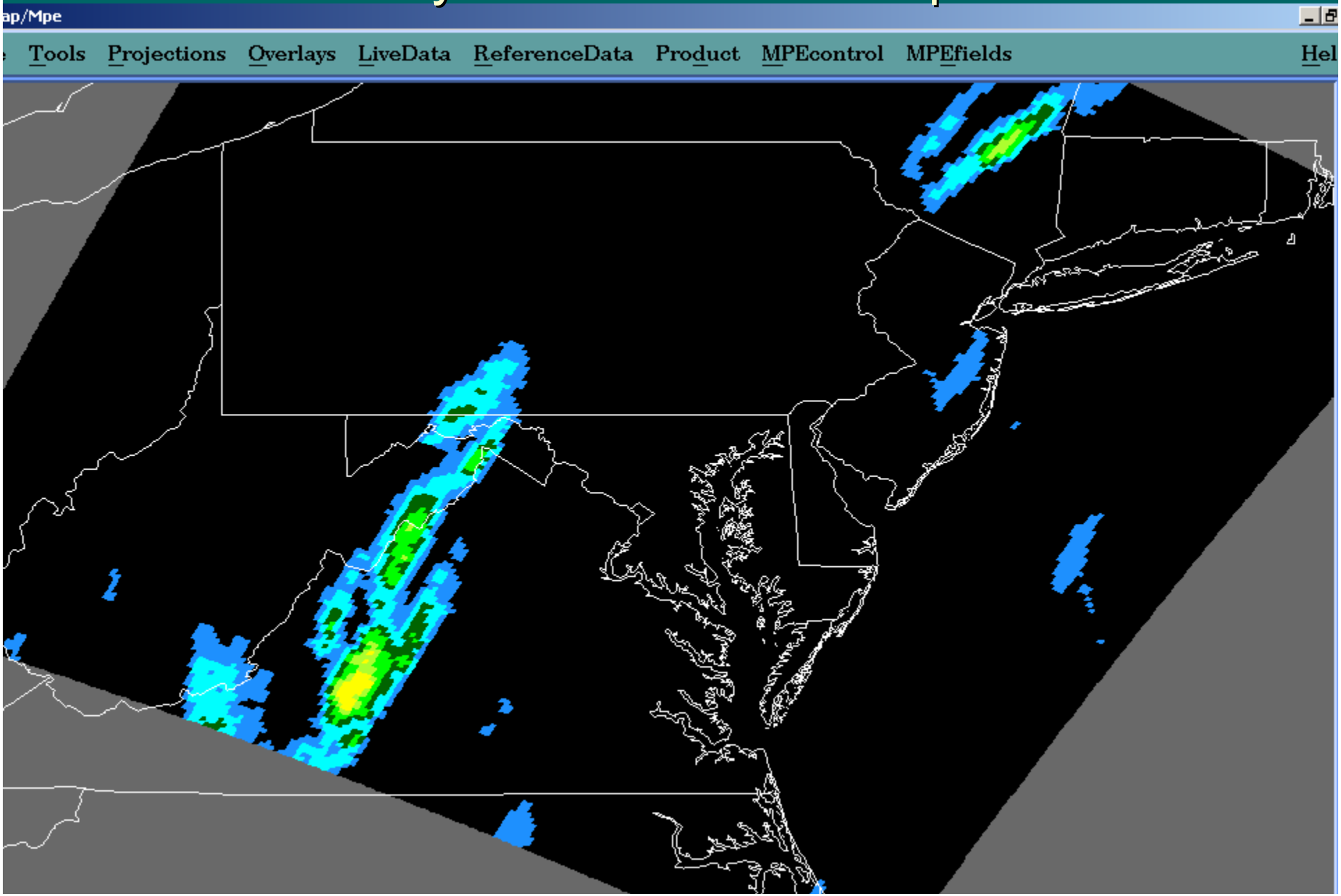
- Operational HydroEstimator hourly products from NESDIS
- Uses 10.7 micron GOES infrared brightness temperatures to estimate rainrates
- Moisture and orographic corrections using model-based precipitable water, relative humidity, equilibrium level, and wind data from Eta/AVN
- No screening by radar
- Remapped to 4 km HRAP grid for use in MPE
- Best for convective events of significant duration/intensity
- Nice for filling in where radar and gauges are unavailable
- http://www.orbit.nesdis.noaa.gov/smcd/emb/ff/auto.html

- Reference: Scofield, R. A., and R. J. Kuligowski, 2003: Status and outlook of operational satellite precipitation algorithms for extreme-precipitation events. Wea. Forecasting, 18, 1035-2051.

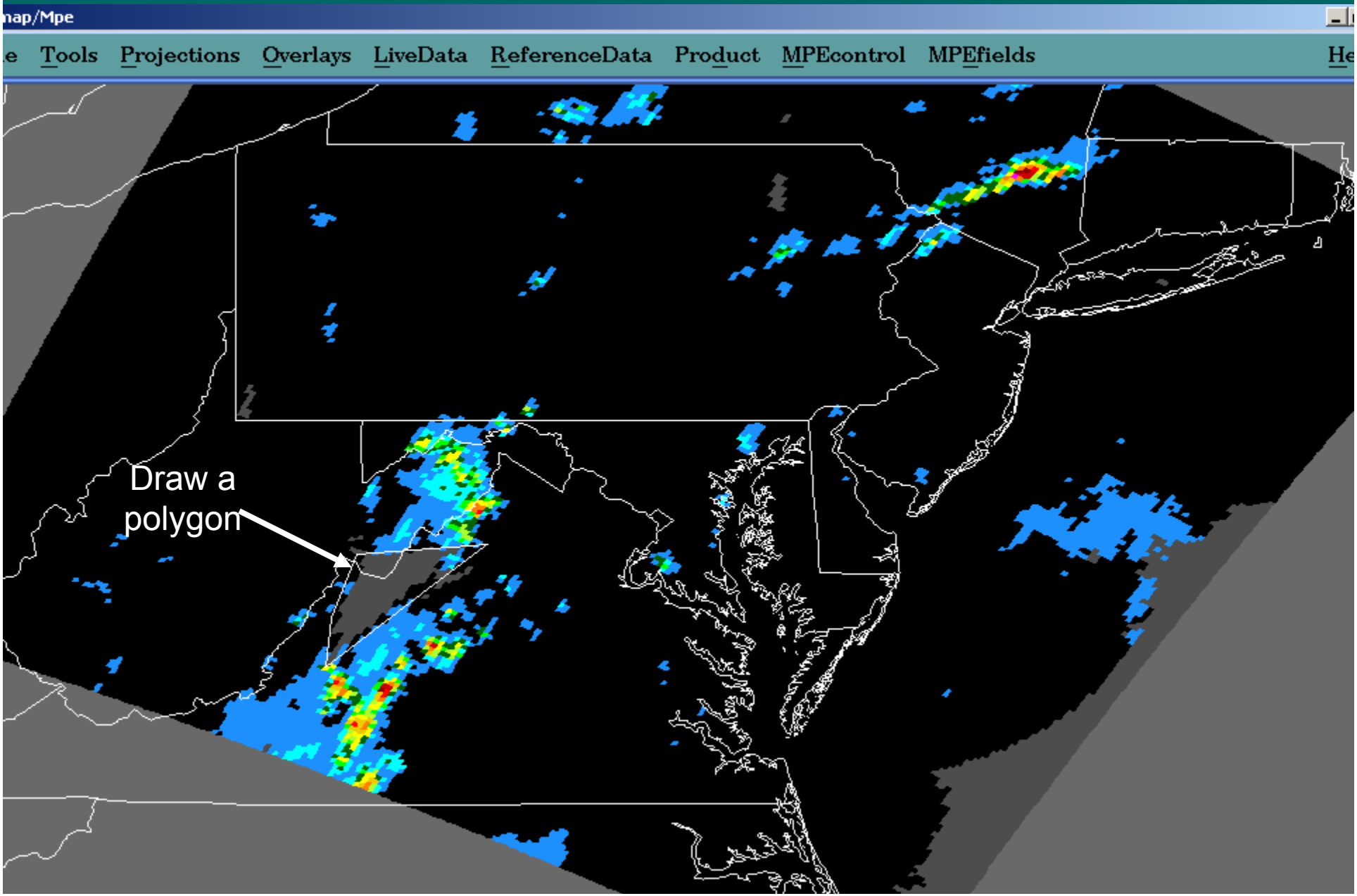
Satellite Hydroestimator rainfall product



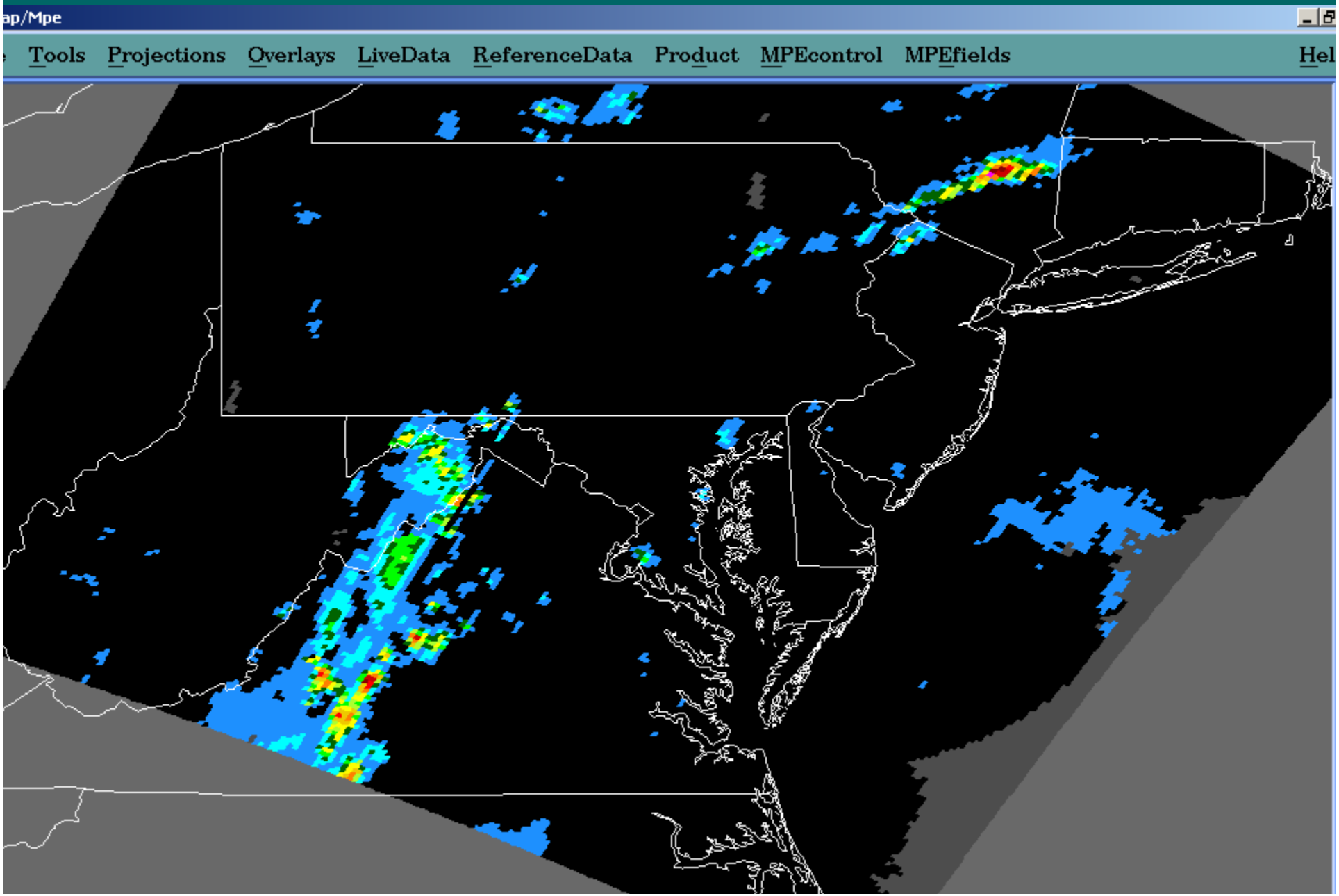
Satellite Hydroestimator rainfall product



Radar mosaic (RMOSAIC) rainfall product



After substituting satellite data into radar gap



Local Bias-adjusted Satellite Precipitation (LSPE)

- Same exact concept as local bias-adjusted radar mosaic (LMOSAIC) except that it uses the satellite precipitation array (SPE) instead of the radar mosaic (RMOSAIC)

SPE + Point Rain Gauges

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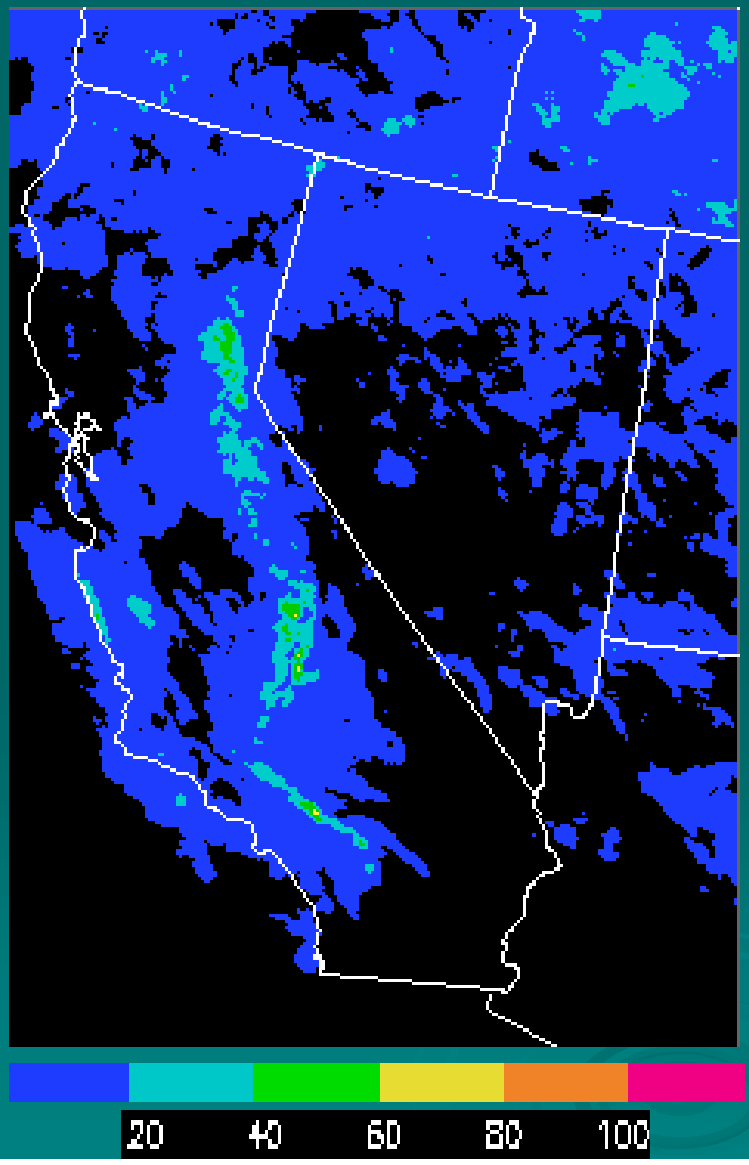
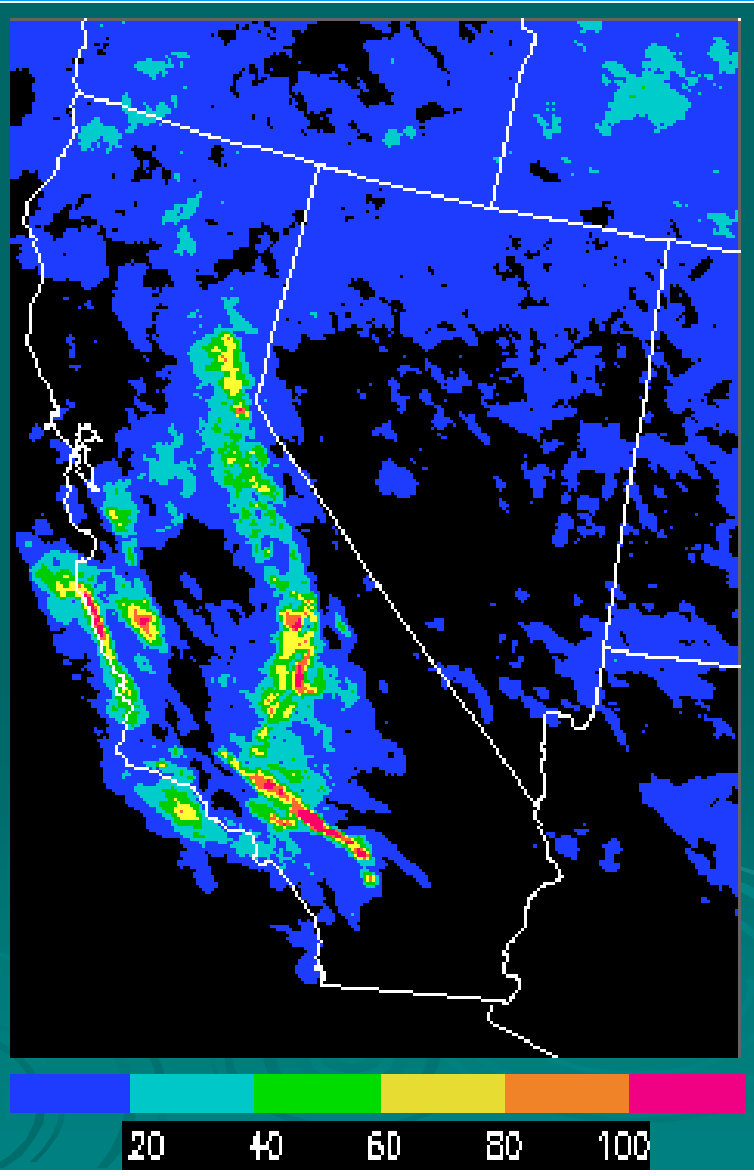
LSPE

CNRFC 24-Hour Precipitation, 17 Dec 2002

Hydroestimator (mm)



Local-Bias Adjusted Hydroestimator



Multisensor Mosaic (MMOSAIC)

- Uses as input the MFB-adjusted Radar Mosaic (BMOSAIC) and the rain gauge data (plus satellite-only rainfall grid SPE in near future)
- At each local HRAP gridpoint, linearly merge the BMOSAIC's rainfall pixel value and nearby gauge observation(s) using a relative weighting based on distance away from the gauges
  - Far from gages, heavily weight BMOSAIC value
  - Near gauges, heavily weight gauge value
- Big benefit: It fills in missing holes in the radar coverage

BMOSAIC + Point Rain Gauges

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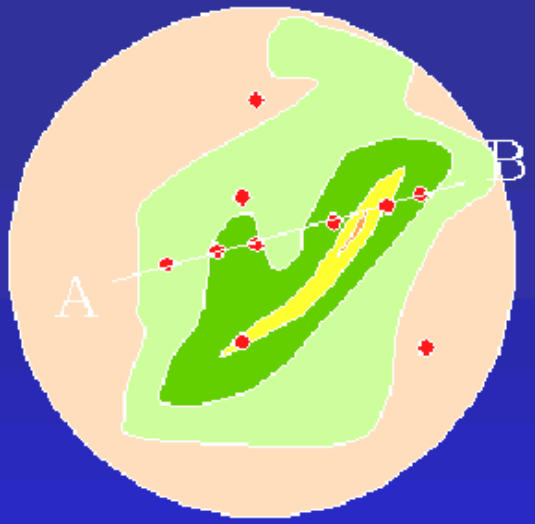
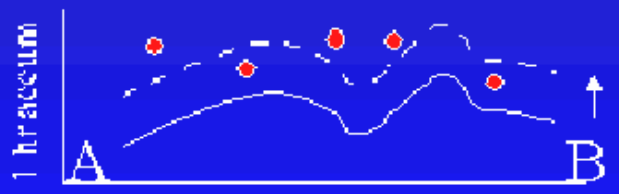
MMOSAIC

Multisensor Rainfall Field Generation



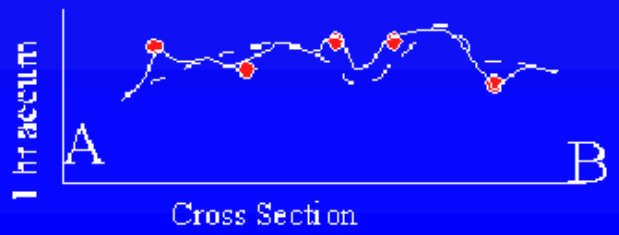
1) Start with 1 hour radar accumulations (HDP) which may contain mean and local biases



BIAS

2) Remove mean field bias

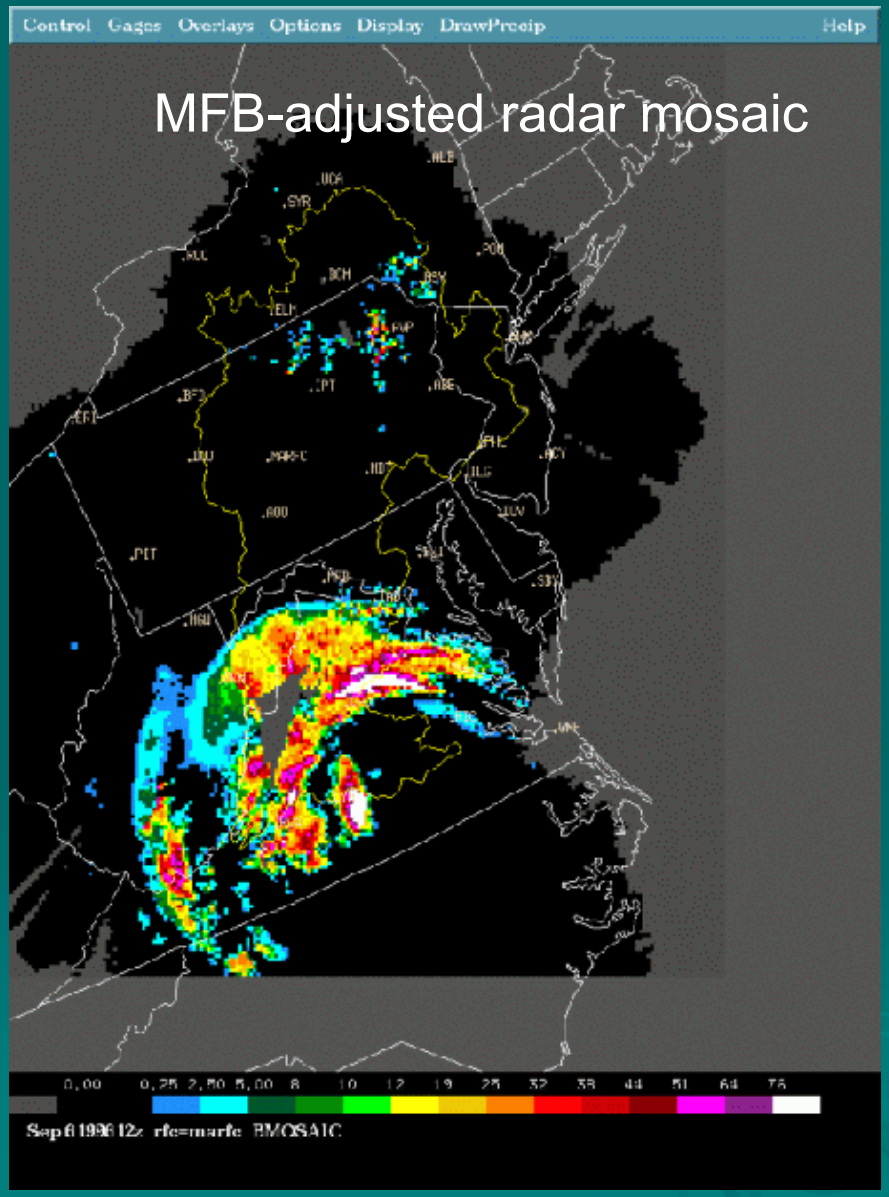
$R = Bias * R$

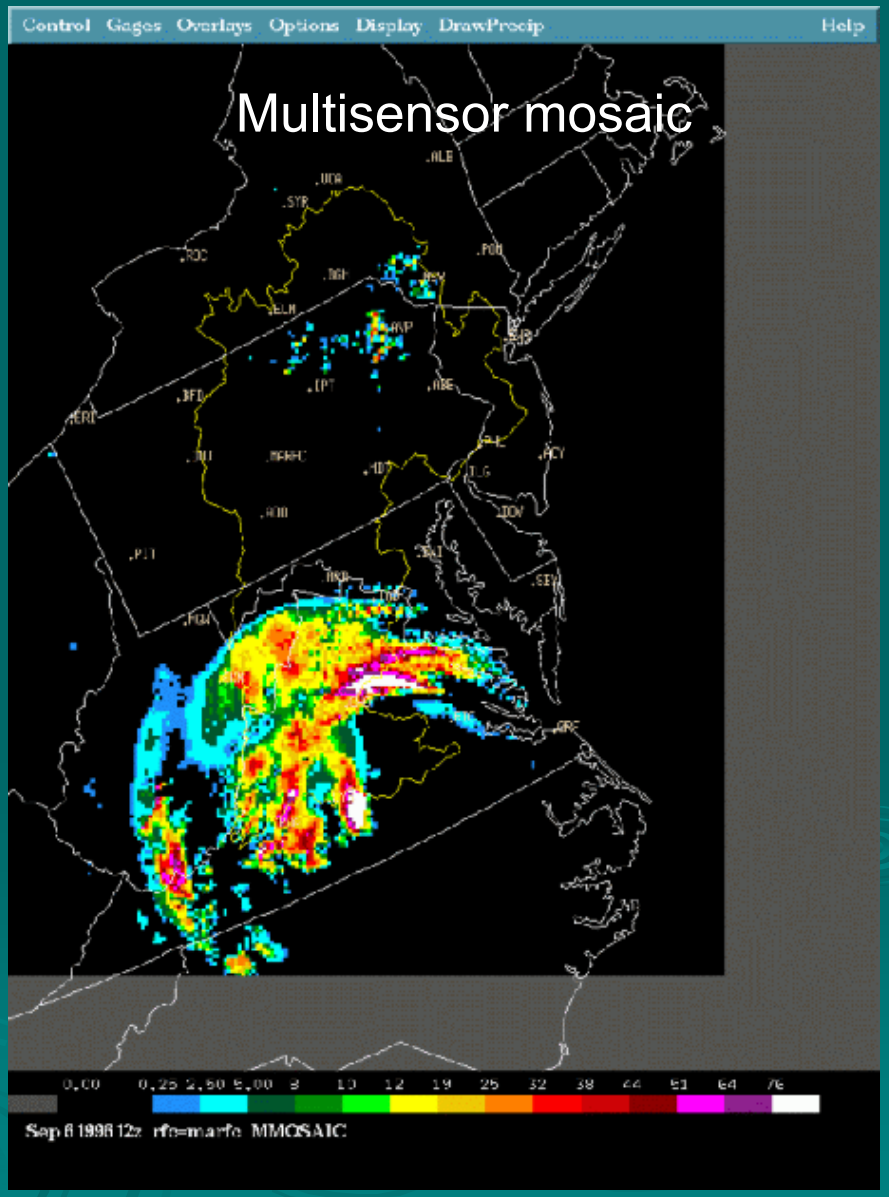


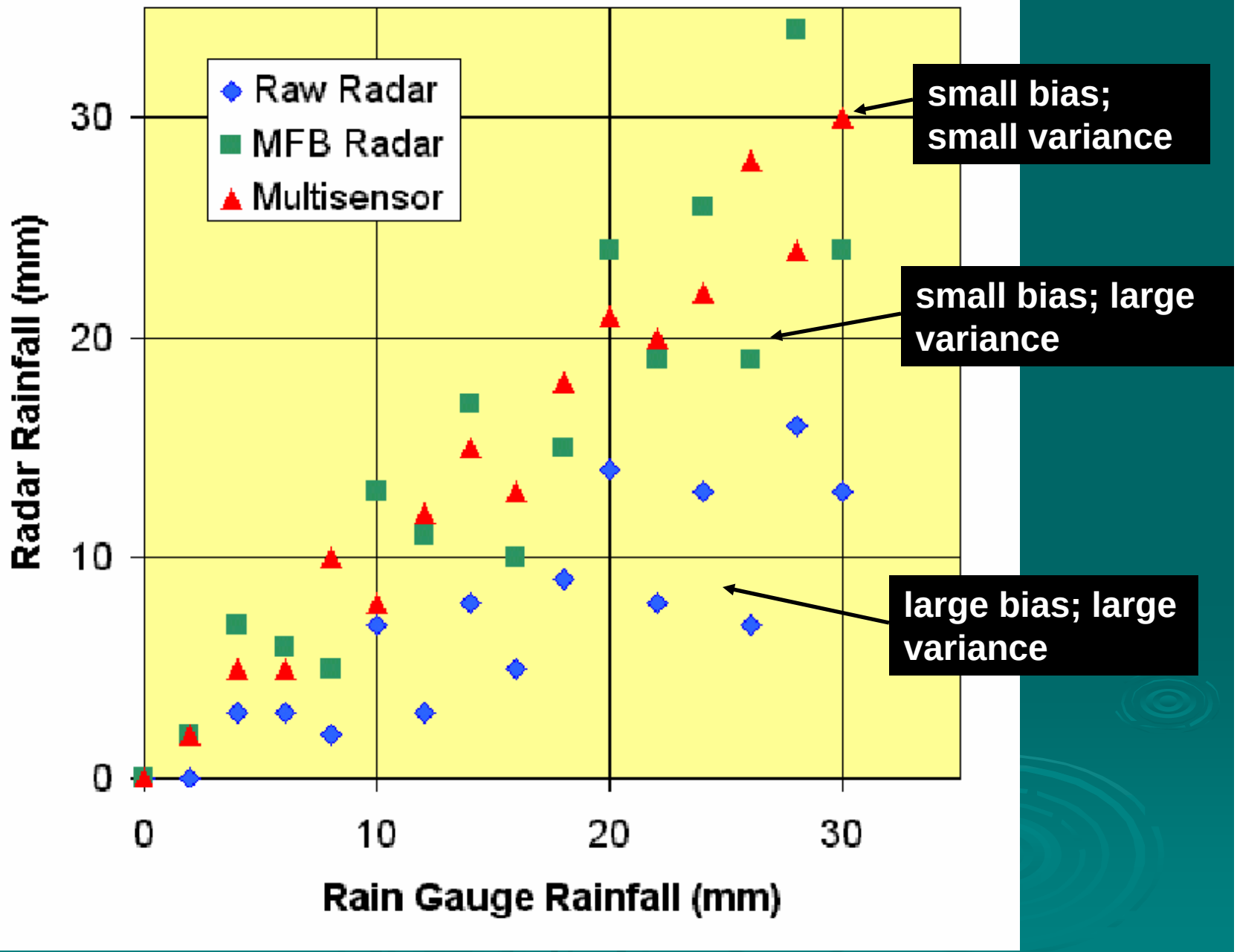
3) Merge Gage and Radar Observations

$Re = w_1 G_1 + w_2 G_2 + w_3 G_3 + w_4 R$

Multisensor Estimation Fills in Missing Areas



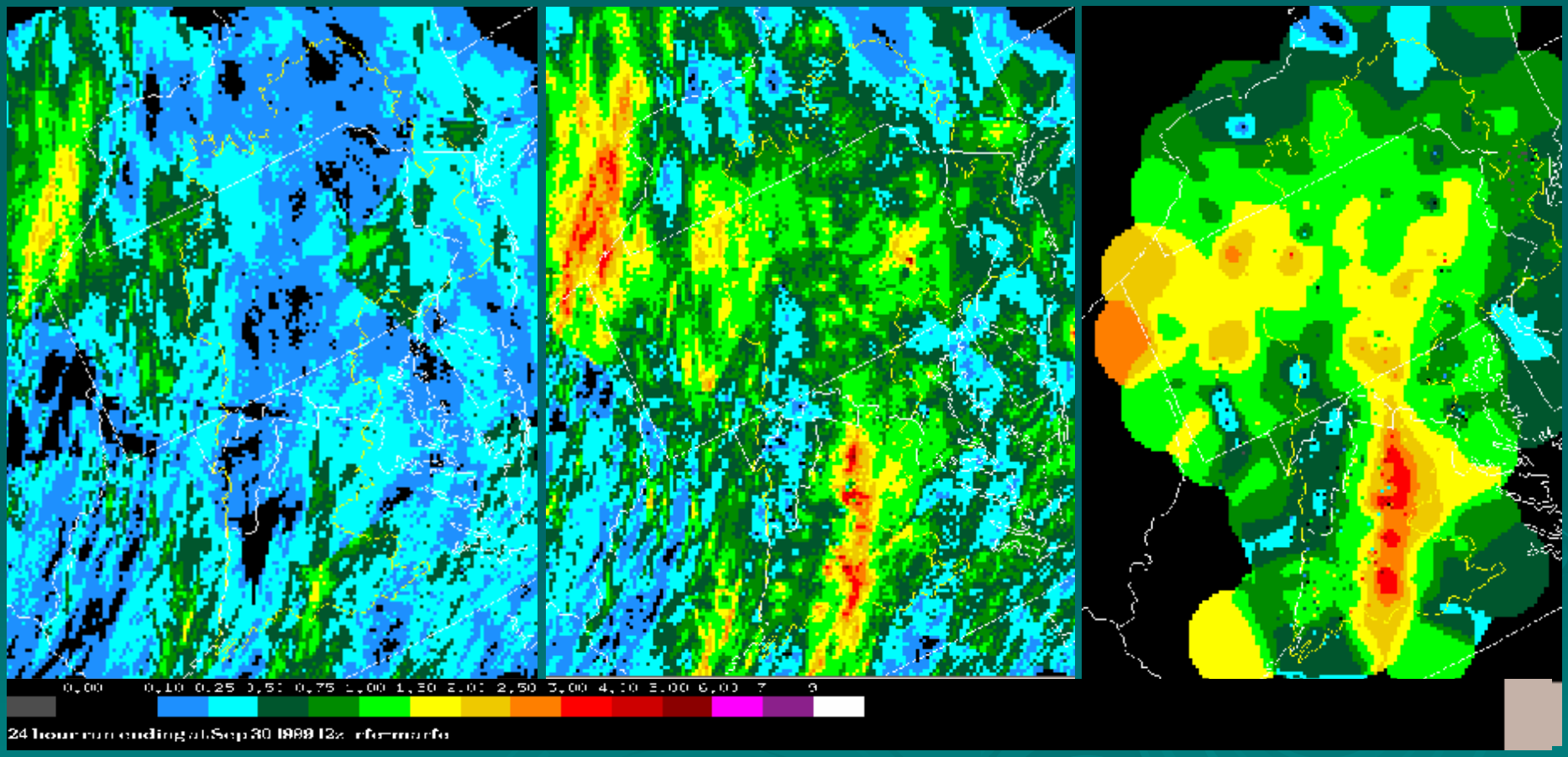



Raw Radar
MFB Radar
Multisensor
Radar Rainfall (mm)
Rain Gauge Rainfall (mm)
0
10
20
30
small bias; small variance
small bias; large variance
large bias; large variance

24-hr Raw Radar Estimate

24-hr MPE Multisensor Estimate

24-hr Rain Gauge Estimate



Local-bias Adjusted Multisensor Mosaic (MLMOSAIC)

- Same exact concept as the previous Multisensor Mosaic except that it uses the *Local-bias* Adjusted Radar Mosaic (LMOSAIC) instead of the *mean-field-Bias* Adjusted Radar Mosaic (BMOSAIC) as input

LMOSAIC + Point Rain Gauges

=

MLMOSAIC

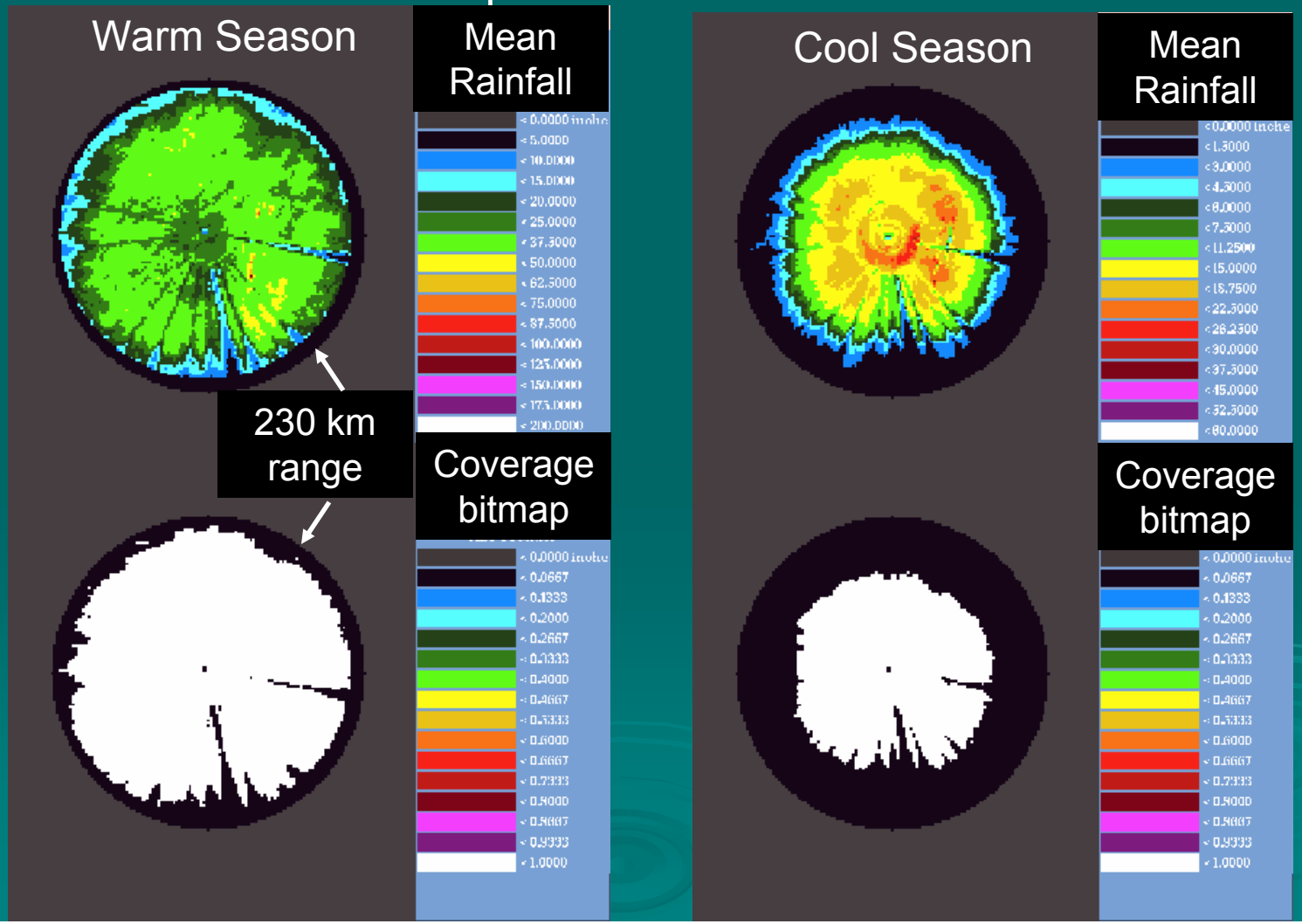
What is the “effective radar coverage” for rainfall estimation?

230 km is WSR-88D PPS’s maximum range for rainfall estimation, but is it always good that far away??

- Depends on
  - Maximum height of radar echoes
  - Mountain blockages…cause rainfall “shadows”
  - Height of the freezing level
  - Season, month, etc.
- Changes with each passing rainfall system
- Conclusion: Do not use rainfall estimates beyond a radar’s effective coverage…use adjacent radar data to fill in

Long-term Climatological Radar Coverages using Hourly DPA Products

Pittsburgh WSR-88D effective radar range depends on season

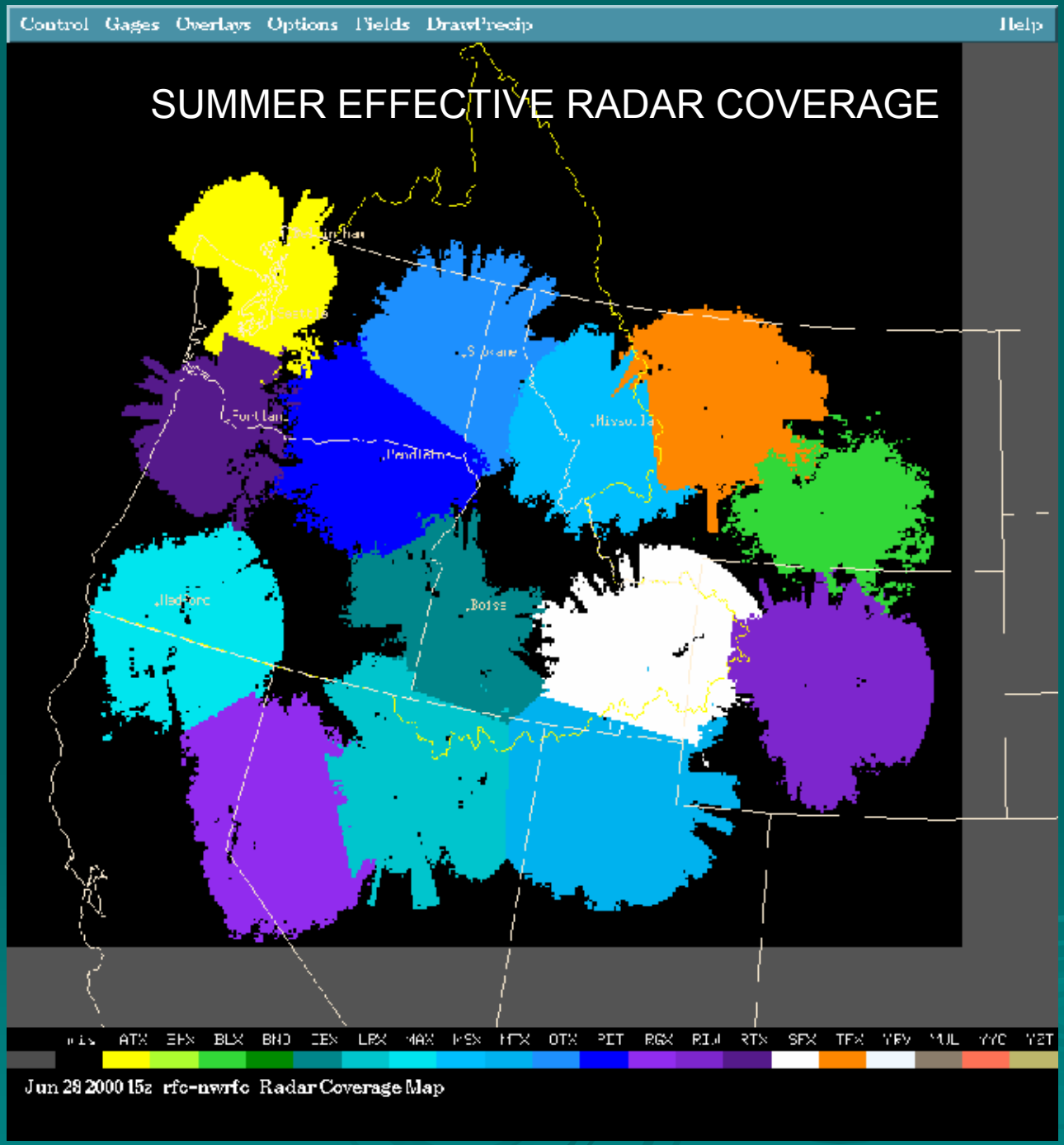


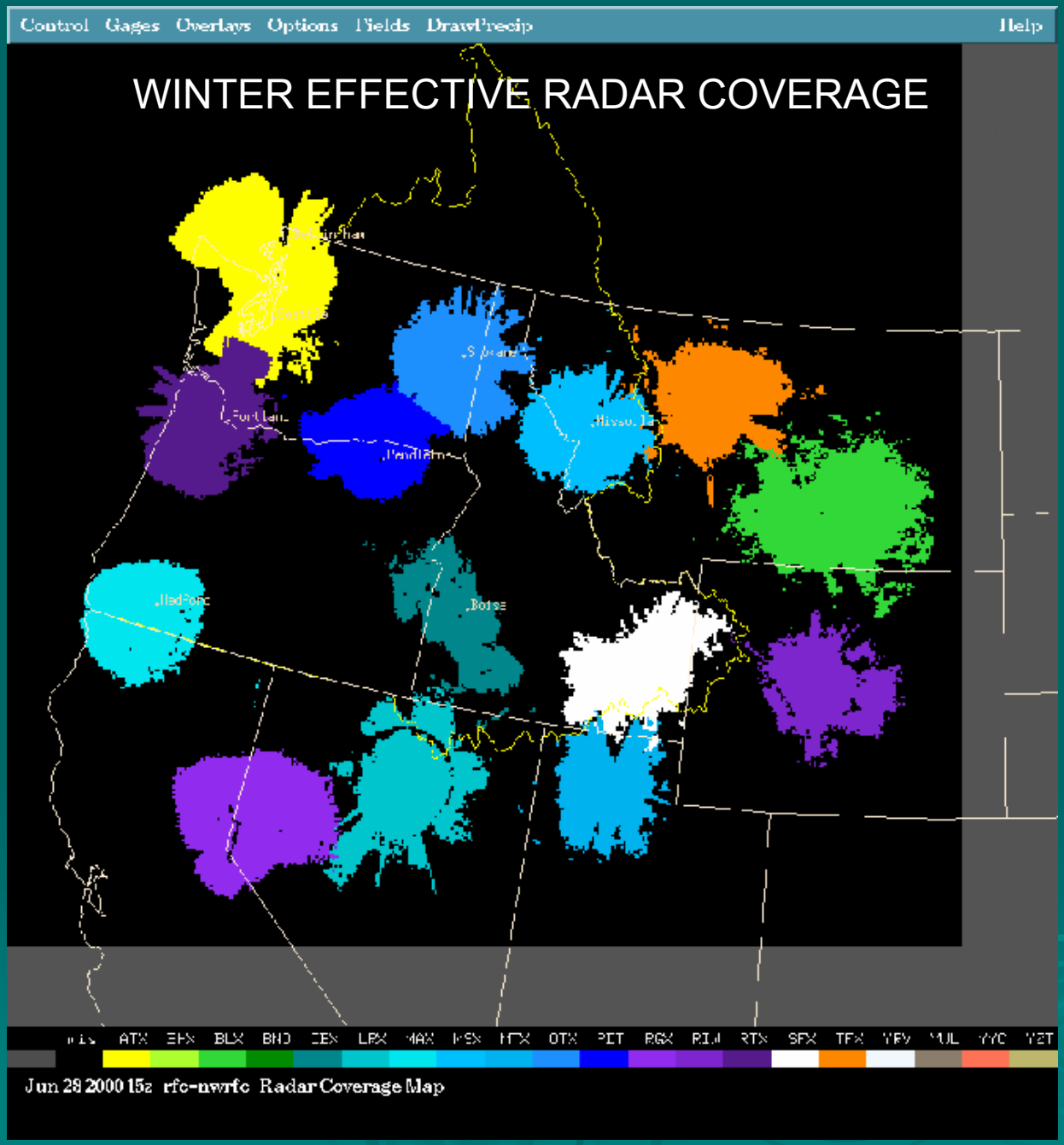
MPE's MISBIN array

RADCLIM Allows Users to Define Effective Radar Coverages

- RADCLIM=Radar Climatology Analysis and Display Program…now available in OB5
- Computes monthly or seasonal DPA rainfall climatologies at a given WSR-88D using archived DPA products
- Permits user to objectively define each radar's effective coverage bitmap (MISBIN array) as a function of month or season
- MISBIN used as a mask in MPE mosaicking algorithm (only one file used currently)
- When computing gauge-radar mean-field-biases, MPE only uses gauges within the effective radar coverage

SUMMER EFFECTIVE RADAR COVERAGE




Control Gages Overlays Options Fields DrawPrecip Help
WINTER EFFECTIVE RADAR COVERAGE
Jun 28 2000 15z rfc-nwrfc Radar Coverage Map

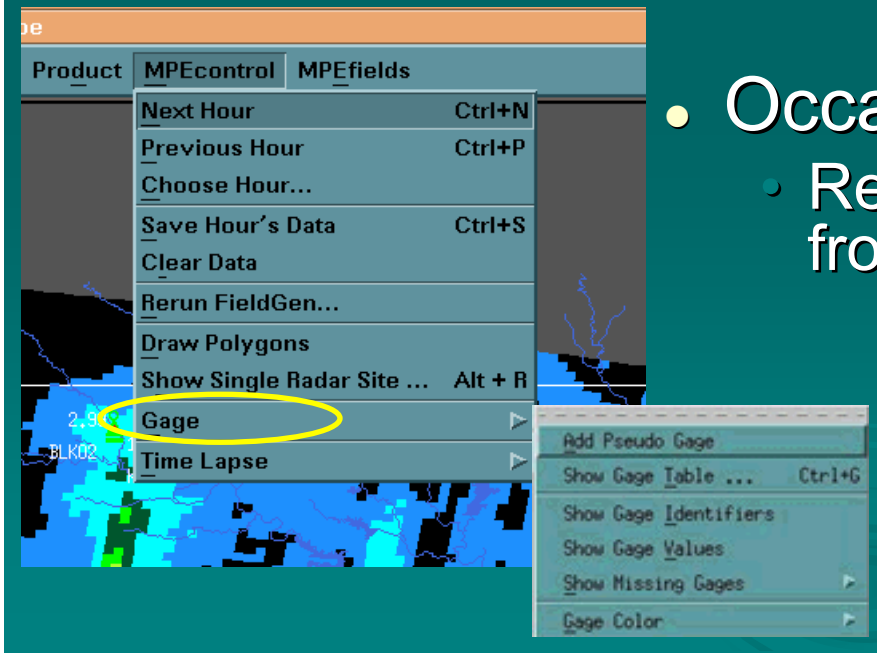
How Do YOU Fit into the MPE Equation?

- Edit rain gauge data as needed
- Edit radar data as needed
- Then rerun MPE's "FieldGen" program to redo all the rainfall analyses to incorporate your edits
- Decide on the "Best Estimate QPE" field from available choices
- Save it for later use

- It is understood that this all may not be possible in real-time during a flash flood event!

Editing Rain Gauge Data

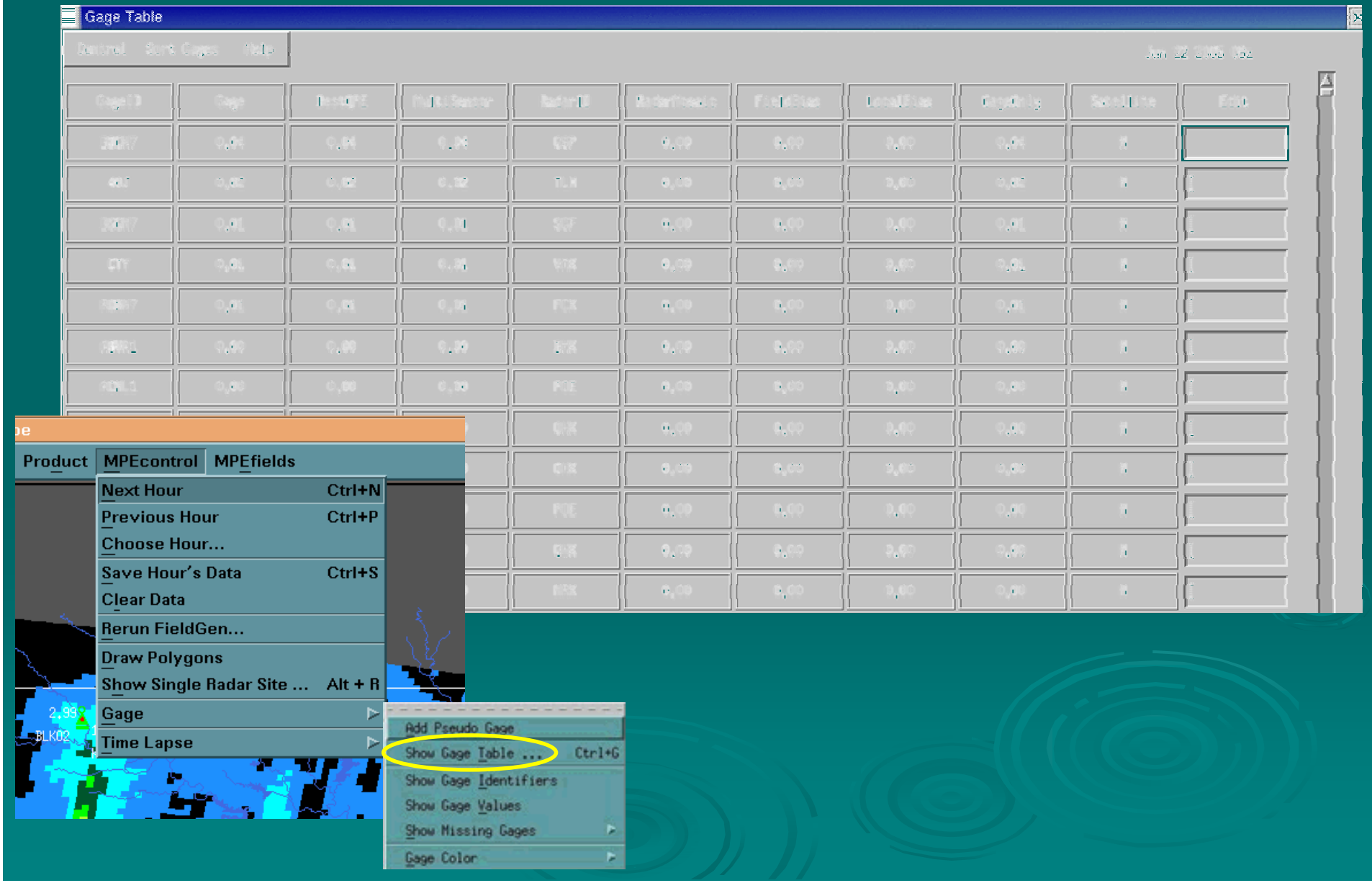
- Hourly
  - Review automated gauge QC algorithm's results
  - Manually remove bad or flagged data as necessary
  - Add new "pseudo gauges" if necessary



- Occasionally
  - Remove consistently bad gauges from the incoming data stream

Gauge errors →

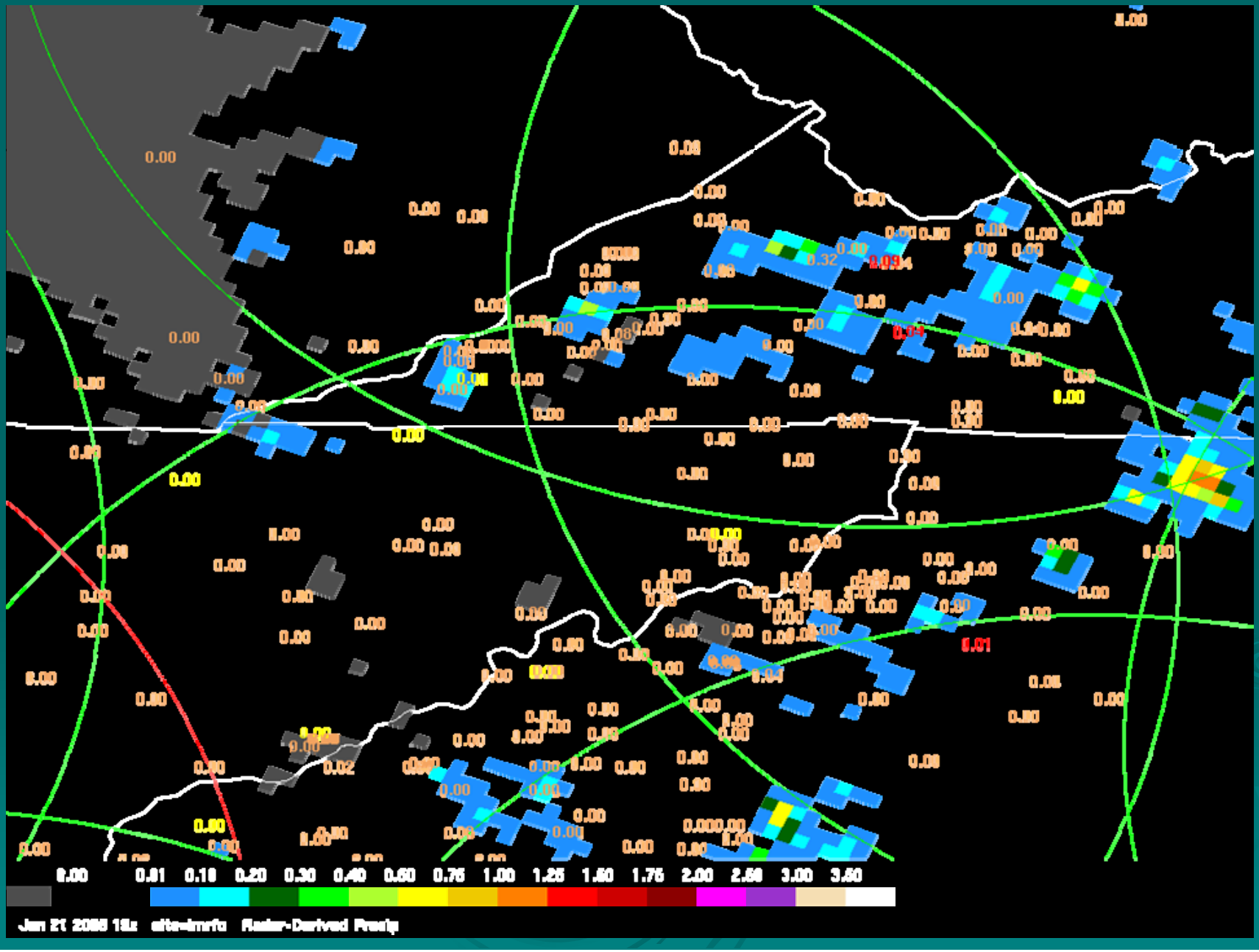
Gauge Table


Gage Table
Product
MPEcontrol
MPEfields
Next Hour Ctrl+N
Previous Hour Ctrl+P
Choose Hour...
Save Hour's Data Ctrl+S
Clear Data
Rerun FieldGen...
Draw Polygons
Show Single Radar Site ... Alt + R
Gage
Time Lapse
Add Pseudo Gage
Show Gage Table ... Ctrl+G
Show Gage Identifiers
Show Gage Values
Show Missing Gages
Gage Color

MPE Automated Rain Gauge Quality Control Procedures

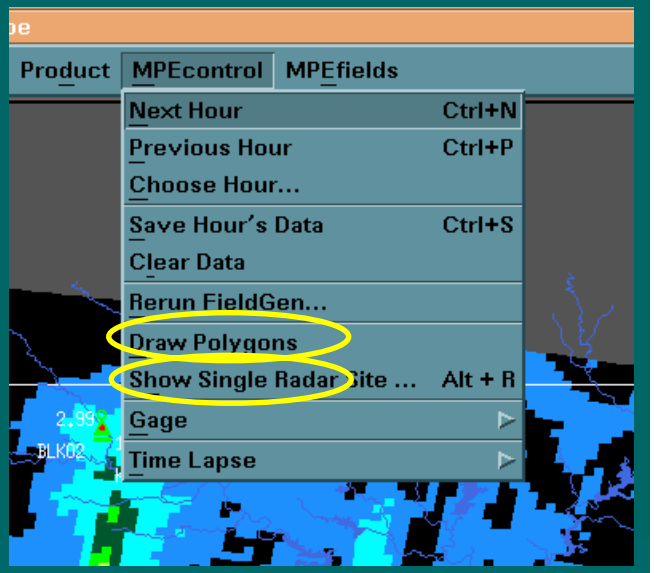
- Spatial Consistency Check
  - Compares with neighboring gauges and lightning data to find outliers
- Multisensor Check
  - Finds “stuck” gauges by comparing with Radar-only Mosaic
    - At a gauge location, if RMOSAIC>0. and G=0., flag gauge as bad
- Suspect data is flagged but not automatically deleted
  - Choose “Color by QC” option under the “Gage” menu to see questionable gauges (SCC=red, MC=yellow)
- User must *manually* delete all bad gauges

Gage QC by Color

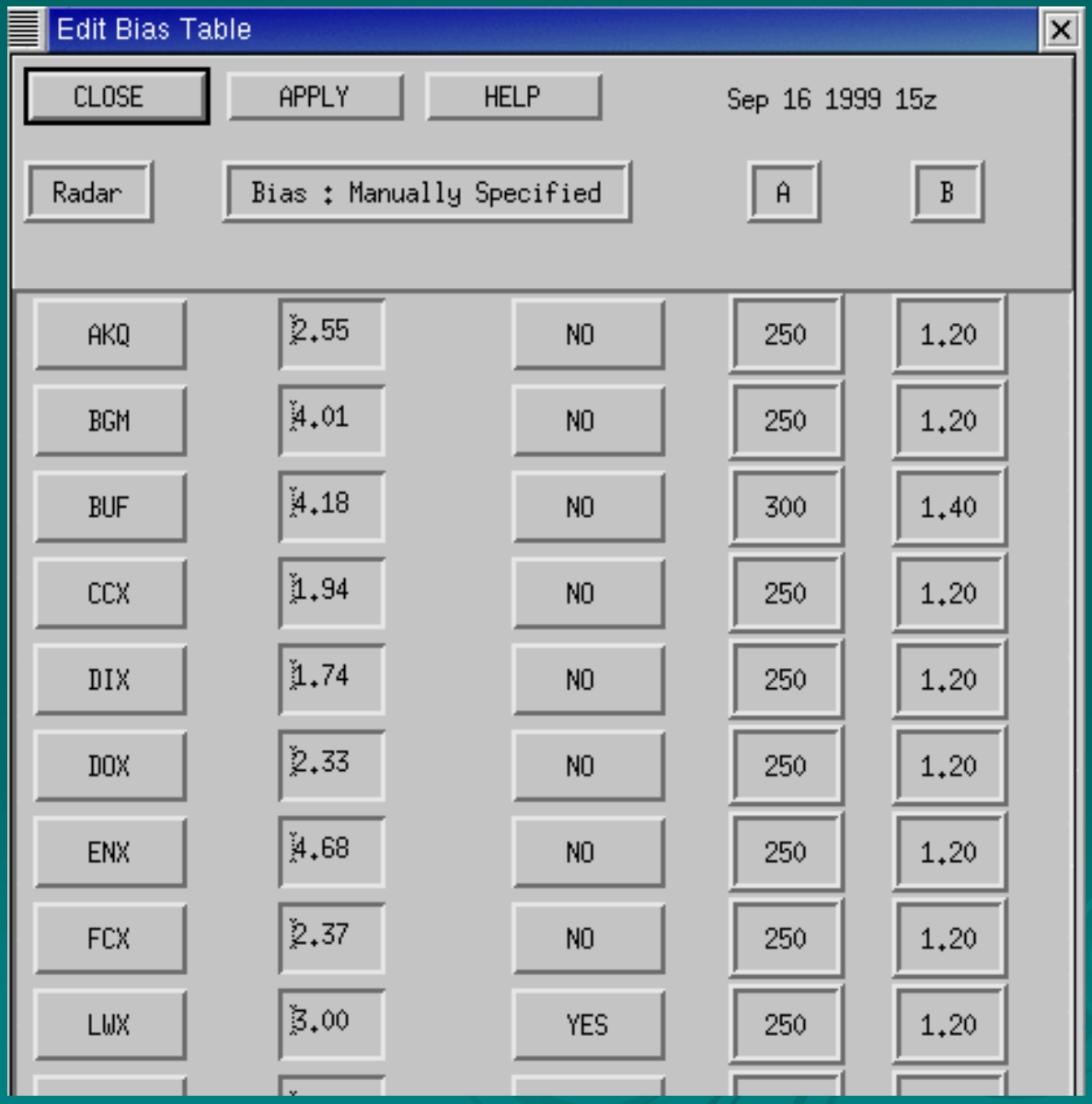


Editing Radar Data

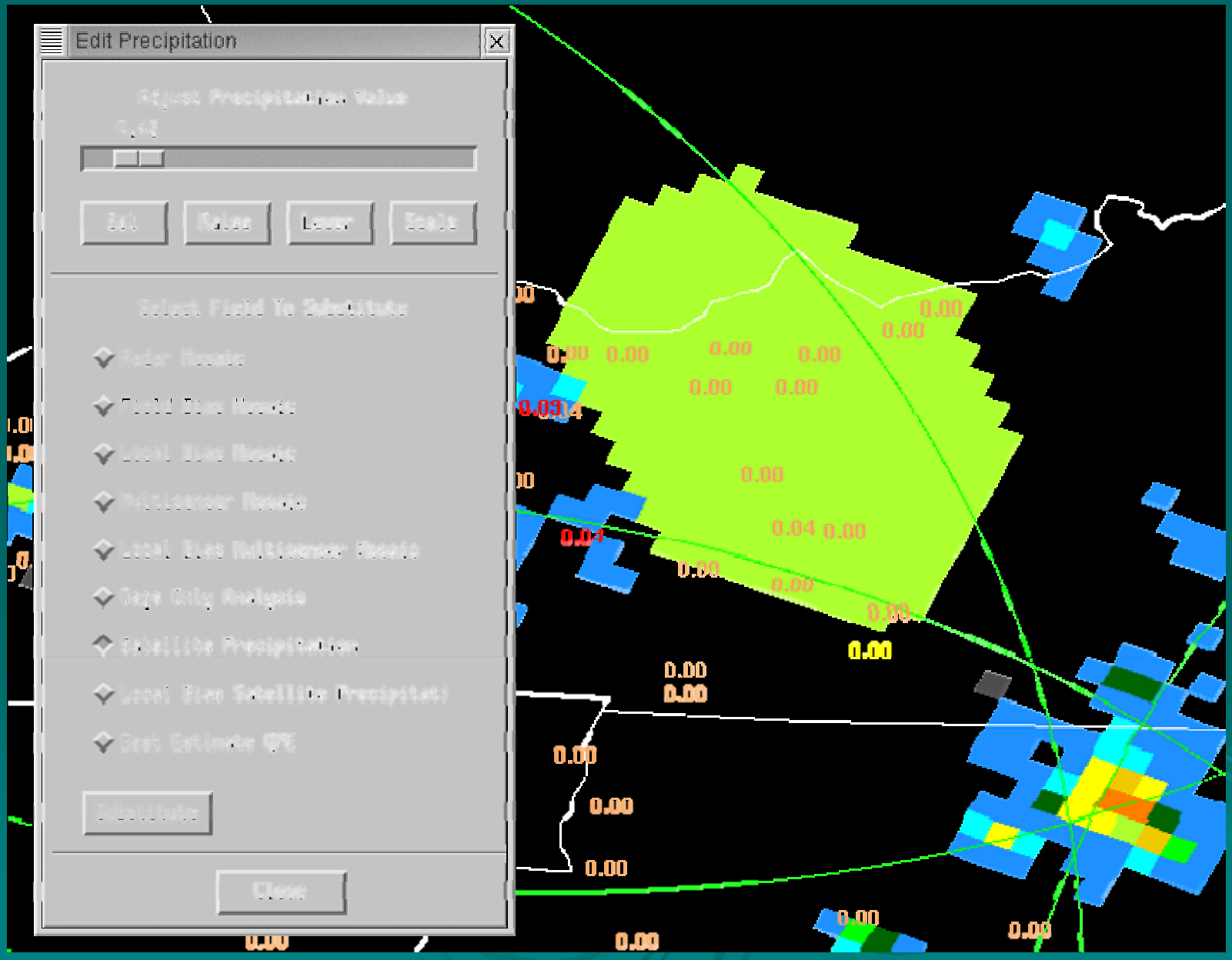
- Delete bad DPAs
  - "Ignore Radar" option under "Show Single Radar Site"
- Identify arbitrarily-shaped polygon regions of bad data to substitute new data for
  - "Draw Polygons"
- Edit single-radar mean-field-biases
  - "Display Bias Table" or "Edit Bias Value" under "Show Single Radar Site"



Mean-Field-Bias Table for All Radars

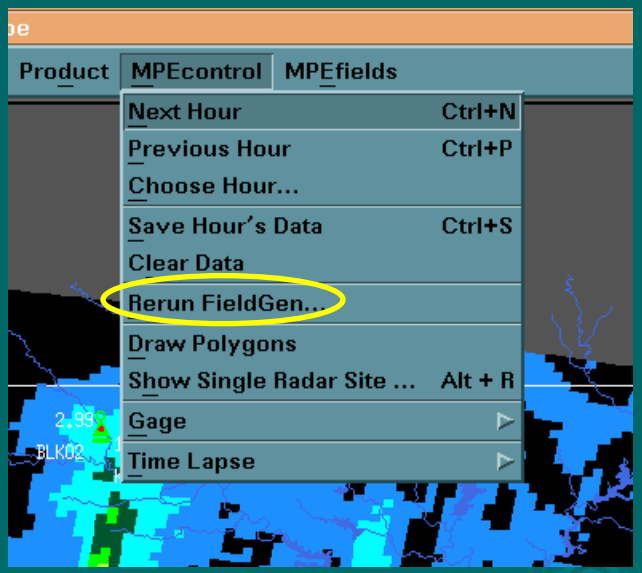


Draw Polygons and Substitute Data



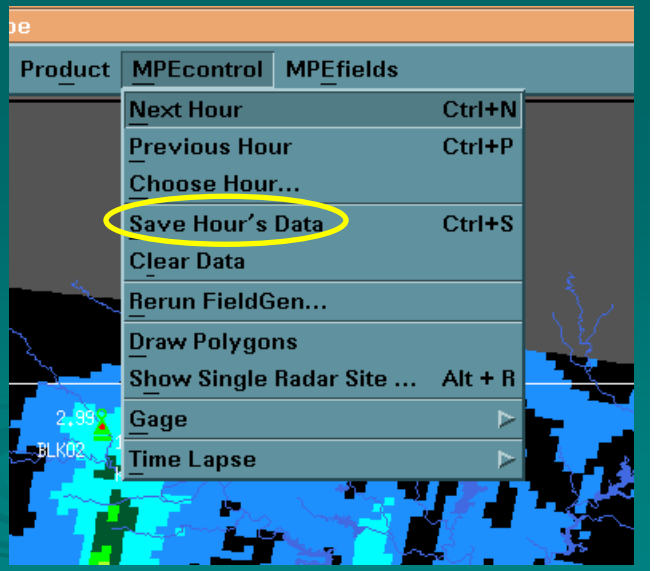
Regenerate MPE Rainfall Products

- Your edits will not show up in rain products without rerunning “FieldGen” !
- After one or more edits, rerun FieldGen program to redo all rainfall analyses and incorporate your edits
  - Takes about 15-30 seconds to complete
- Iterate editing and rerunning as needed



Best Estimate QPE

- You must decide which of the rainfall fields is the “best” after completing all manual editing
- Choose one for display then “Save Hour’s Data” under the *MPEcontrol* menu
- This saves the currently displayed field as the Best Estimate QPE field for that hour
- View it later by selecting “Best Estimate QPE” menu item
- Used as input to SSHP
- Used in computing “Multi-Hour QPE”
- Best Estimate QPE = MMOSAIC by default if you don’t manually save any field (adaptable)



Climatological Unbiasedness

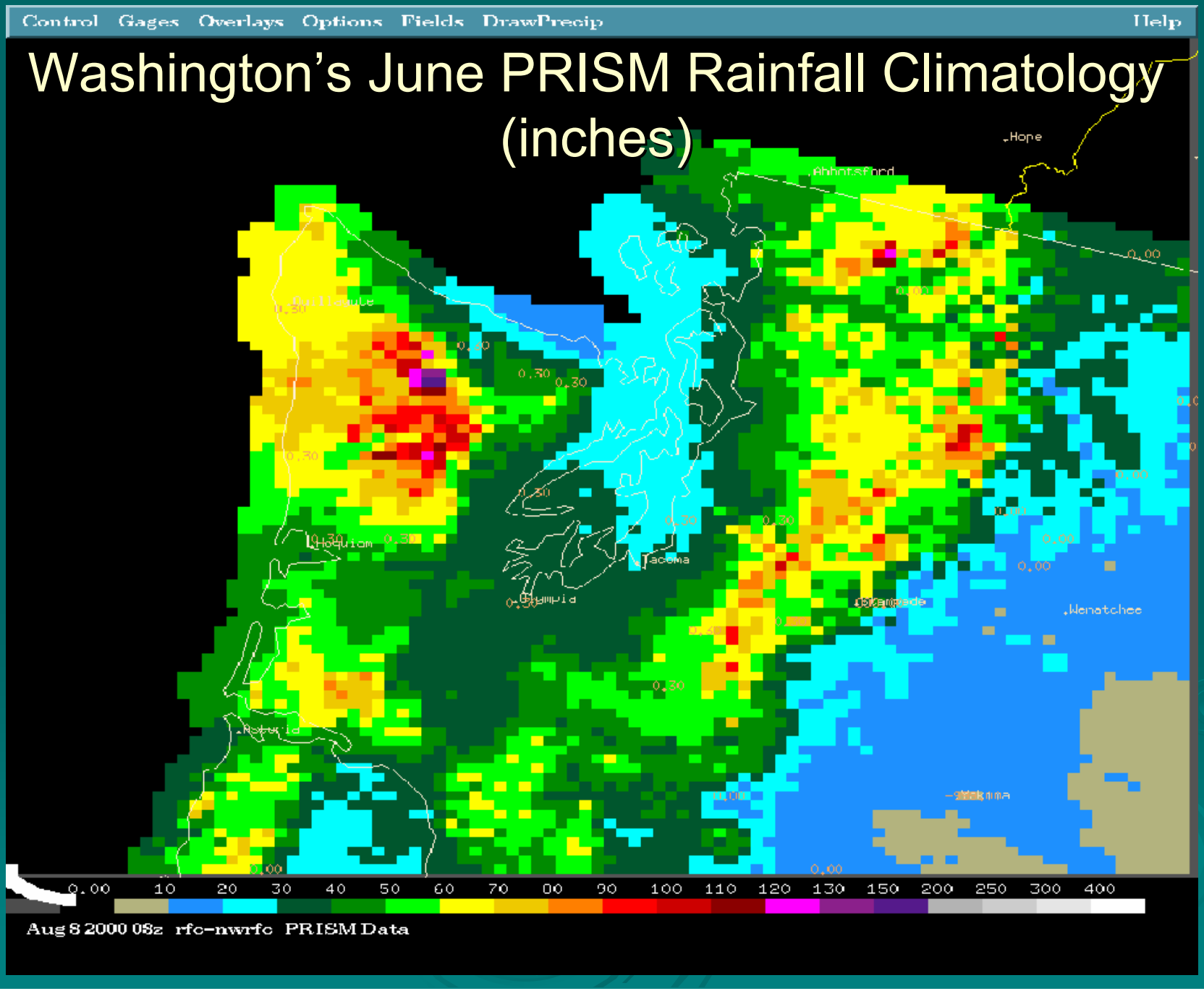
The goal in MPE is to produce multisensor rainfall products that are climatologically unbiased over long periods of time relative to rain gauges

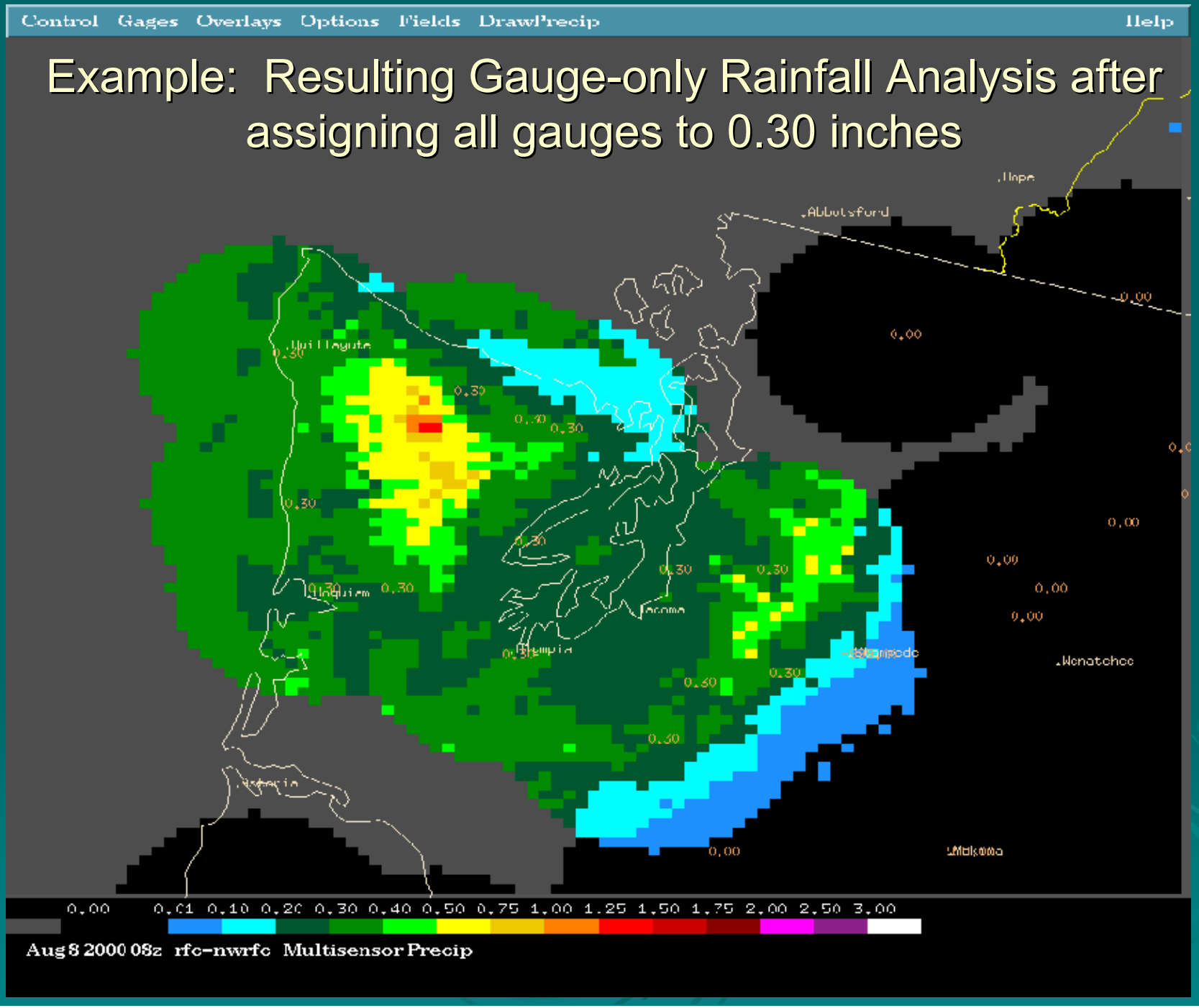
- How? Utilize climatological rain gauge information in the MPE rainfall estimation analysis techniques
- PRISM rainfall data is used as a proxy for climatological rainfall data
  - PRISM=Parameter-elevation Regressions on Independent Slopes Model
- PRISM incorporates observed rain gauge data, topography, wind direction/speed information to derive mean annual and monthly rainfall
- http://www.ocs.orst.edu/prism/prism_new.html

MPE Methodology for Using Climatological Monthly Rainfall Data (PRISM)

- PRISM data is useful primarily in mountainous regions where rainfall gradients are large
- PRISM is used in computing the Gage-only Analysis, the MMOSAIC, and the LMMOSAIC products
- Grid points with no radar coverage or rain gauge data are estimated from nearby gridpoints that have good coverage and then scaled by the PRISM data
- Grid points that are well covered by a radar or nearby rain gauge are not scaled

Washington's June PRISM Rainfall Climatology (inches)




Control Gages Overlays Options Fields DrawPrecip Help
Example: Resulting Gauge-only Rainfall Analysis after assigning all gauges to 0.30 inches
Hope
Abbotsford
Bellingham
Tacoma
Olympia
Wenatchee
Makah
0.00 0.01 0.10 0.20 0.30 0.40 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.50 3.00
Aug 8 2000 08z rfc-nwrfc Multisensor Precip

Future MPE Enhancements

- Higher resolution (1 km, 5-15 minutes)
- MPE will be used as input to FFMP
- Rainfall nowcasting capability out to 1 hour in future
- New products and techniques (use of lightning, NWP model data, etc.)
- Range-corrected rainfall products from PPS (remove bright band overestimation and underestimation at far ranges)
- Include satellite precipitation in the Multisensor Mosaic analysis

The End

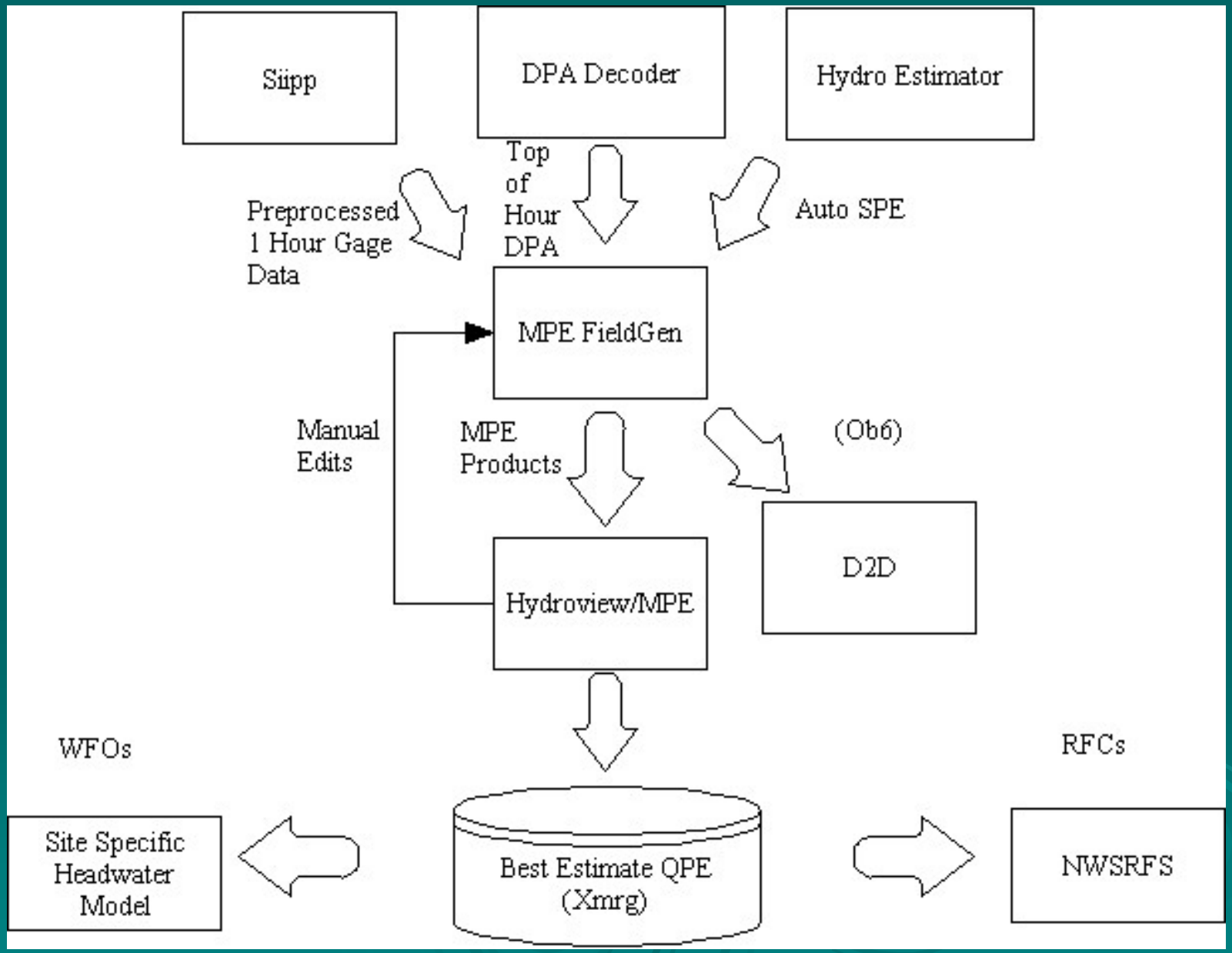
- Questions?
- Comments?
- Suggestions?

Lab Exercises #2, 3, and 4

- Lab 2 – Explore other features available through the MPE GUI
- Lab 3 – Investigate and compare mean-field-bias mosaic and local bias mosaic
- Lab 4 – Understand radar climatology and radar effective coverage concepts

Extra Slides if you Really Want to Get Down to the Hard-Core Details (linked to earlier slides)

MPE Data Flow



MPE Mean-field-bias Adjustment

$$\beta_k^* = \frac{{}^1\!/_N \sum_{i=k-L}^{k} \sum_{j=1}^{n_i} g_{ij}}{{}^1\!/_N \sum_{i=k-L}^{k} \sum_{j=1}^{n_i} r_{ij}}$$

β_k^* = estimate of the mean-field bias for hour k for a given radar
g_{ij} = gauge rainfall for hour i and gauge j
r_{ij} = radar rainfall for hour i and the radar pixel over top of gauge j
N =number of positive gauge-radar pairs within the effective radar coverage
L = moving-average window (hours)

Seo et al., 1999: Real-time estimation of mean field bias in radar rainfall data. J. Hydrology, 223, 131-147

Gauge-only Analysis

$$G_{ko}^{*} = \sum_{i=1}^{n_{Gk}} \lambda_{Gki} G_{ki}$$

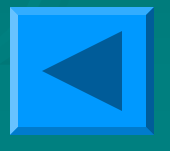
The gauge weights lambda_Gki are solved by minimizing error variance

$$E[G_{ko}^{*} - G_{ko}]^2$$

subject to $$\sum_{i=1}^{n_{Gk}} \lambda_{Gki} = 1$$

G_{ko}^{*} = estimated hourly gauge rainfall at the gridpoint of estimation at hour k
G_{ki} = observed hourly rainfall for gauge i at hour k
n_{Gk} = number of gauges within the decorrelation distance of the gridpt of estimation
λ_{Gki} = gauge weights...dependent on time and space

Reference: Seo, 1998: Real-time estimation of rainfall fields using rain gage data under fractional coverage conditions. J. Hydrology, 208, p. 25-36.



MPE Multisensor Gauge-Radar Merging

Optimal Linear Estimation

$$G_{ko}^{*} = \sum_{i=1}^{n_{Gk}} \lambda_{Gki} G_{ki} + \sum_{j=1}^{n_{Rk}} \lambda_{Rkj} (\beta_k R_{kj})$$

Weights λ_{Gki} and λ_{Rkj} are solved by minimizing

$$E[G_{ko}^{*} - G_{ko}]^2$$

subject to $\sum_{i=1}^{n_{Gk}} \lambda_{Gki} + \sum_{j=1}^{n_{Rk}} \lambda_{Rkj} = 1$

G_{ko}*=estimate of unknown gauge rainfall at hour k at gridpoint of estimation o
G_{ki}=observed gauge rainfall at hour k for gauge i
R_{kj}=observed radar rainfall at hour k for radar pixel j
β_k=mean-field bias adjustment factor for hour k
λ_{Gki}=weight for gauge i at hour k
λ_{Rkj}=weight for radar pixel j at hour k
n_{Gk}=number of gauges at hour k within a certain radius of gridpoint o
n_{Rk}=number of radar pixels at hour k within a certain radius of gridpoint o

Reference: Seo, 1998: Real-time estimation of rainfall fields using radar rainfall and rain gauge data. J. Hydrology, 208, 37-52

Common problems in estimating rainfall using rain gauges

- Measurement errors
  - Wind effects...underestimation
  - Gauge exposure blockages (trees, buildings, other instruments)...underestimation
  - Clogged funnel or hardware failure...underestimation
  - Solid precipitation (snow, hail)...underestimation
  - Small loss during high rainrates...underestimation
- Sampling errors in space and time
  - Point measurements (typical 4-12 inch diameter orifice)
  - Sparse gauge networks
  - Imprecise knowledge of gauge locations
  - Clock time errors
  - Spatial correlation scale of rainfall (convective vs. stratiform)
- UCAR/COMET webcast: http://meted.ucar.edu/qpf/rgauge/index1.htm

Climatological Unbiasedness in MPE

$$G_{ko}^{*} = \sum_{i=1}^{n_{Gk}} \lambda_{Gki} \left(\frac{m_{Go}}{m_{Gi}} \right) G_{ki} + \sum_{j=1}^{n_{Rk}} \lambda_{Rkj} \left(\frac{m_{Go}}{m_{Gj}} \right) \left(\frac{m_{Gj}}{m_{Rj}} R_{kj} \right)$$

Weights λ_{Gki} and λ_{Rkj} are solved by minimizing

$$E[G_{ko}^{*} - G_{ko}]^2$$

subject to $$\sum_{i=1}^{n_{Gk}} \lambda_{Gki} + \sum_{j=1}^{n_{Rk}} \lambda_{Rkj} = 1$$

G_{ko}*=estimate of unknown gauge rainfall at hour k at gridpoint of estimation o
G_{ki}=observed gauge rainfall at hour k for gauge i
R_{kj}=observed radar rainfall at hour k for radar pixel j
λ_{Gki}=weight for gauge i at hour k
λ_{Rkj}=weight for radar pixel j at hour k
n_{Gk}=number of gauges at hour k within a certain radius of gridpoint o
n_{Rk}=number of radar pixels at hour k within a certain radius of gridpoint o
m_{Gi}=climatological mean gauge rainfall at gauge i
m_{Go}=climatological mean gauge rainfall at gridpoint o
m_{Gj}=climatological mean gauge rainfall at radar pixel j
m_{Rj}=climatological mean radar rainfall at radar pixel j
$(m_{Gj}/m_{Rj})R_{kj}$ =climatologicallyl bias-adjusted radar rainfall at hour k at radar pixel j