# Enhanced Multisensor Precipitation Estimator and Nowcaster

## Improving WFO Flash Flood Services


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# The *Current* Multisensor Precipitation Estimator (MPE)

- An automated & interactive algorithm that estimates one-hour rainfall ending at the top of the hour on a ~4-km HRAP grid using WSR-88D Precip. Processing System's (PPS) Digital Precipitation Array (DPA) products
- Multisensor…uses rain gauges and GOES satellite to reduce existing biases in WSR-88D rainfall estimates and produces a suite of radar-gauge-satellite rainfall products
- Produces regional mosaics from any desired number of WSR-88Ds

*For more details, see the Lab's MPE Training Workshop at http://www.nws.noaa.gov/oh/hrl/papers/papers.htm#wsr88d*

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# The *Current* Multisensor Precipitation Estimator (MPE) (cont.)

- Delivered in AWIPS to RFCs in 2002, WFOs in 2004, to replace and improve upon the existing Stages II & III Precipitation Processing algorithms
- Designed primarily for RFC use
- Primary input to RFC and WFO hydrologic forecast models (NWS River Fcst System NWSRFS and Site Specific Hydr. Predictor SSHP … but not Flash Flood Monitoring & Prediction FFMP)

# MPE Product Suite

- Radar-only rain mosaic
- Gauge-only rain mosaic
- Satellite-only rain mosaic (from NESDIS)
- Mean field bias-adjusted radar rain mosaic using rain gauges
- Local bias-adjusted radar rain mosaic using rain gauges (two different methods)
- Multisensor merged radar+gauge mosaic
- Multisensor merged radar+gauge+satellite mosaic (coming soon)

# WFO vs. RFC Requirements for Precipitation Products

## RFC

- Mainstem river forecasting
- 4 km resolution (HRAP)
- 1 hour updates of hourly rain
- Multisensor mosaics of rainfall accumulation
- Routine manual quality control is modus operandi
- MPE products

## WFO

- Flash flood monitoring & warning
- 1 km resolution (1/4 HRAP)
- 5-15 minute updates of sub-hourly and longer rain
- Multisensor mosaics of rainfall and rain rates
- Routine manual quality control may not be feasible
- Enhanced MPE (EMPE) products
- Multisensor Precipitation Nowcaster (MPN) products

# Enhanced MPE (EMPE) is an Experimental Prototype with New Features for WFOs

*Same multisensor rainfall estimation technology & products as in MPE, but with …*

- **Higher spatial resolution – ¼ HRAP (~1 km)**
  - *vs. 1 HRAP (~4 km) in current MPE*
- **Higher temporal rainfall resolution – 5-15+ minute rainfall duration**
  - *vs. one hour in current MPE*
- **More frequent updates - 5-15 minutes**
  - *vs. once per hour at top of hour in current MPE*
- **Greater flexibility**
  - *User configurable and "backward compatible"*

# History & Status of EMPE

- Initial need identified and AHPS EMPE funding proposal written by Fulton in 2002 and funded FY 2003-2006
- Project plan developed and distributed for review in 2002
- Initial EMPE prototype was completed in 2004 by HSMB's Hydrometeorology Group (F. Ding, S. Guan, R. Fulton)
- In 2004, we set up a real-time 24x7 demonstration in HL for 5 WSR-88Ds in mid-Atlantic region (Sterling KLWX, Pittsburgh KPBZ, Charleston KRLX, Blacksburg KFCX, Wakefield KAKQ)
  - *Web page displays real-time graphical output products*
- EMPE project is in OSIP Stage 2



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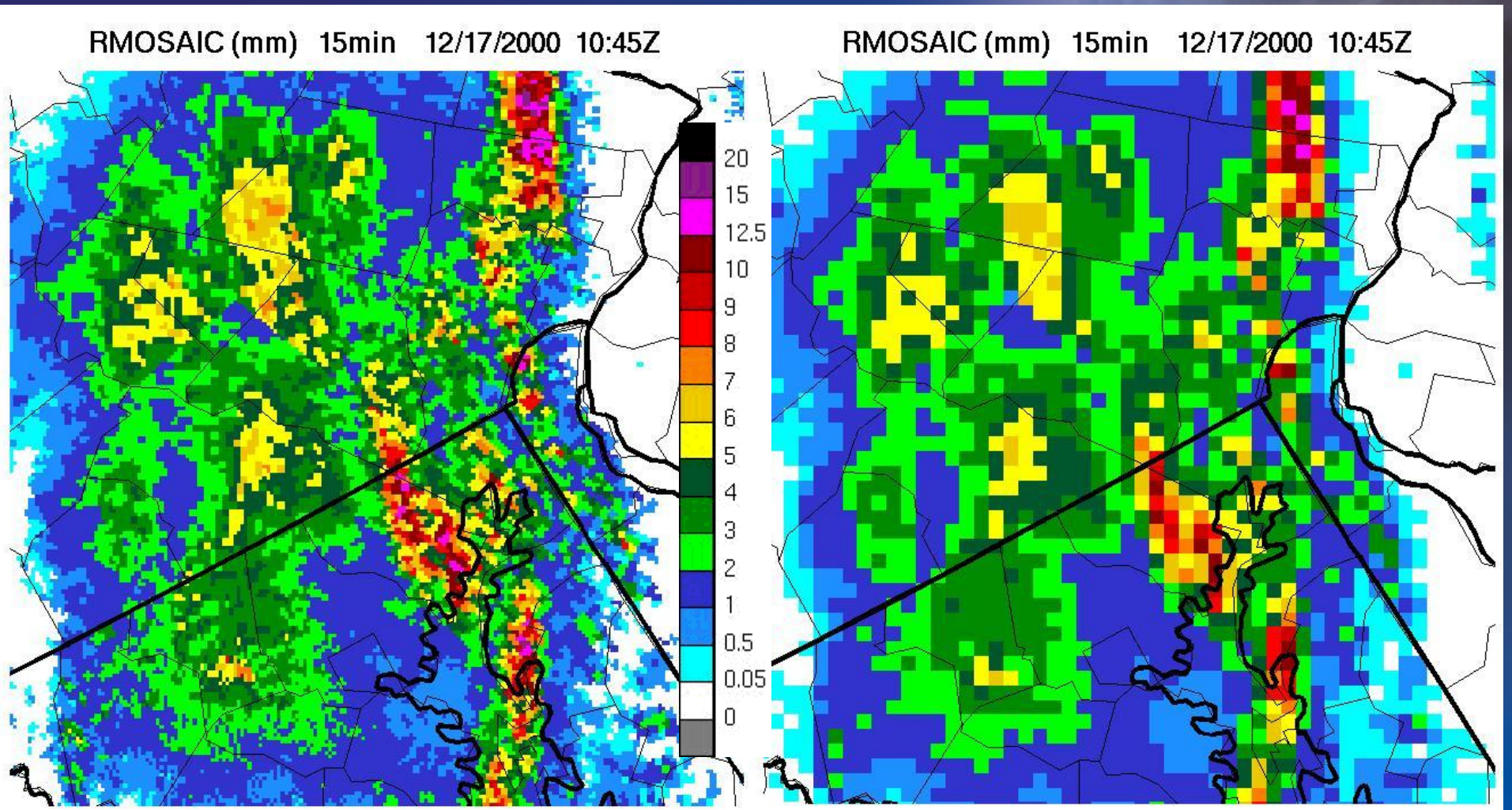
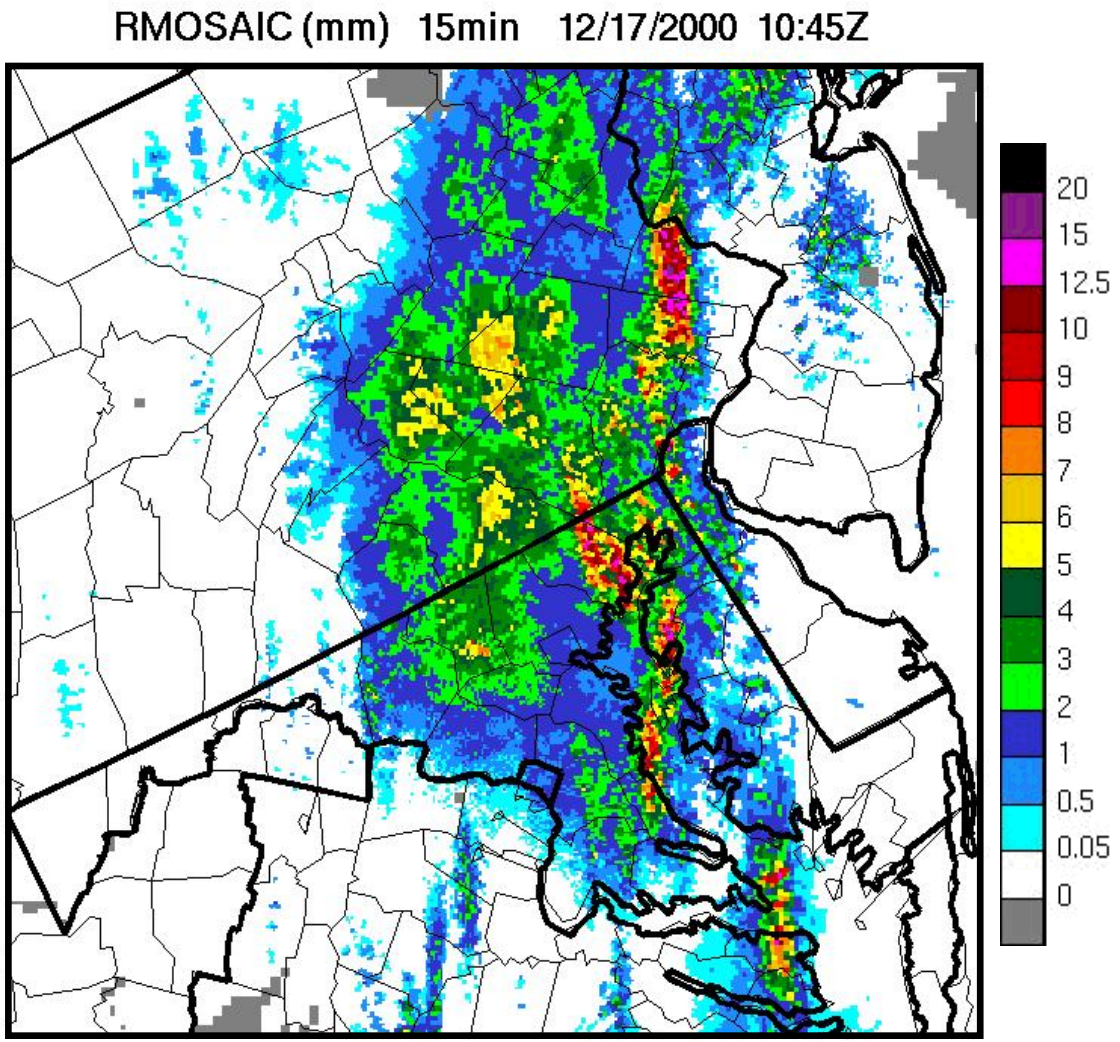
# Radar-only 15-min. Rainfall Mosaic

1-km grid (EMPE)

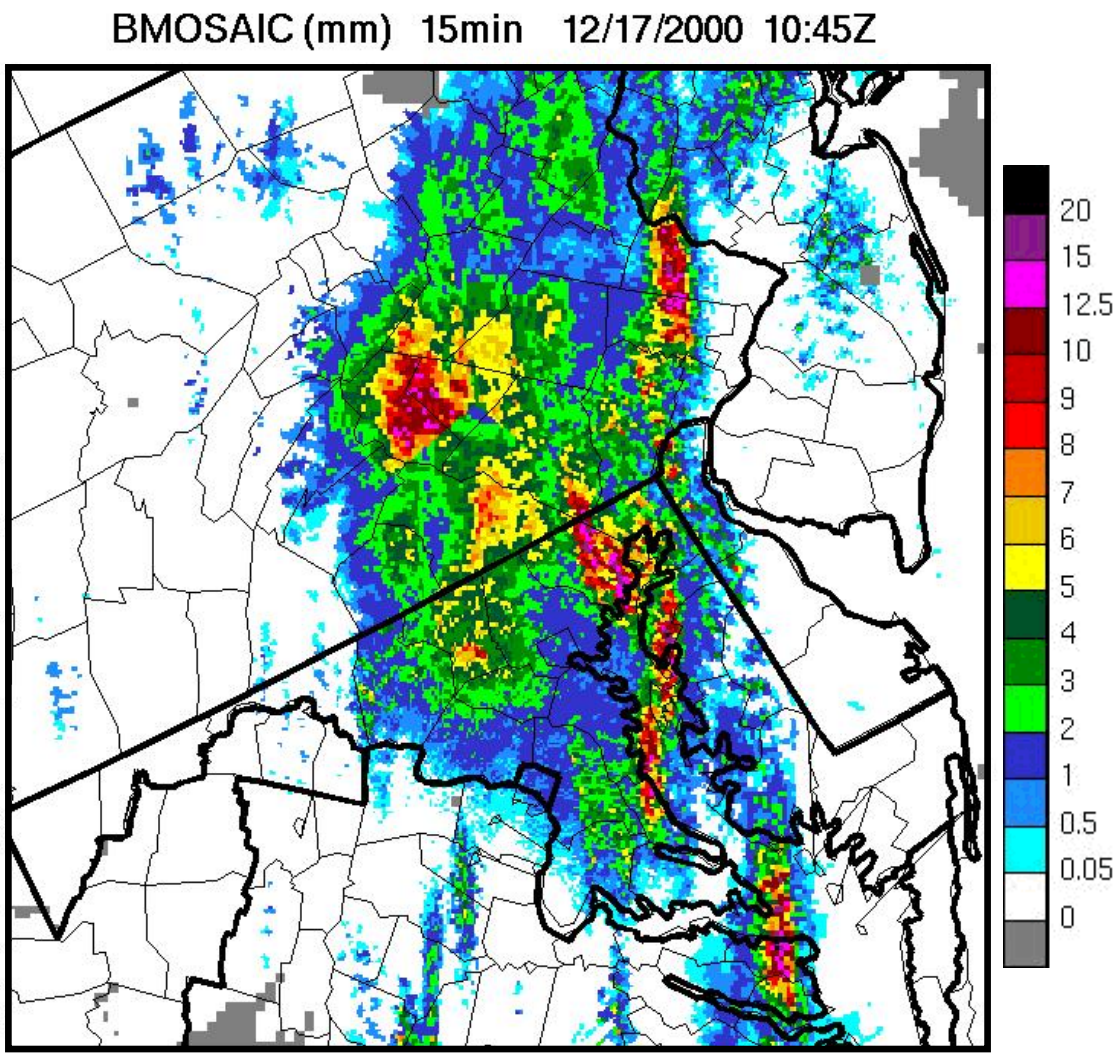
4-km grid (MPE)



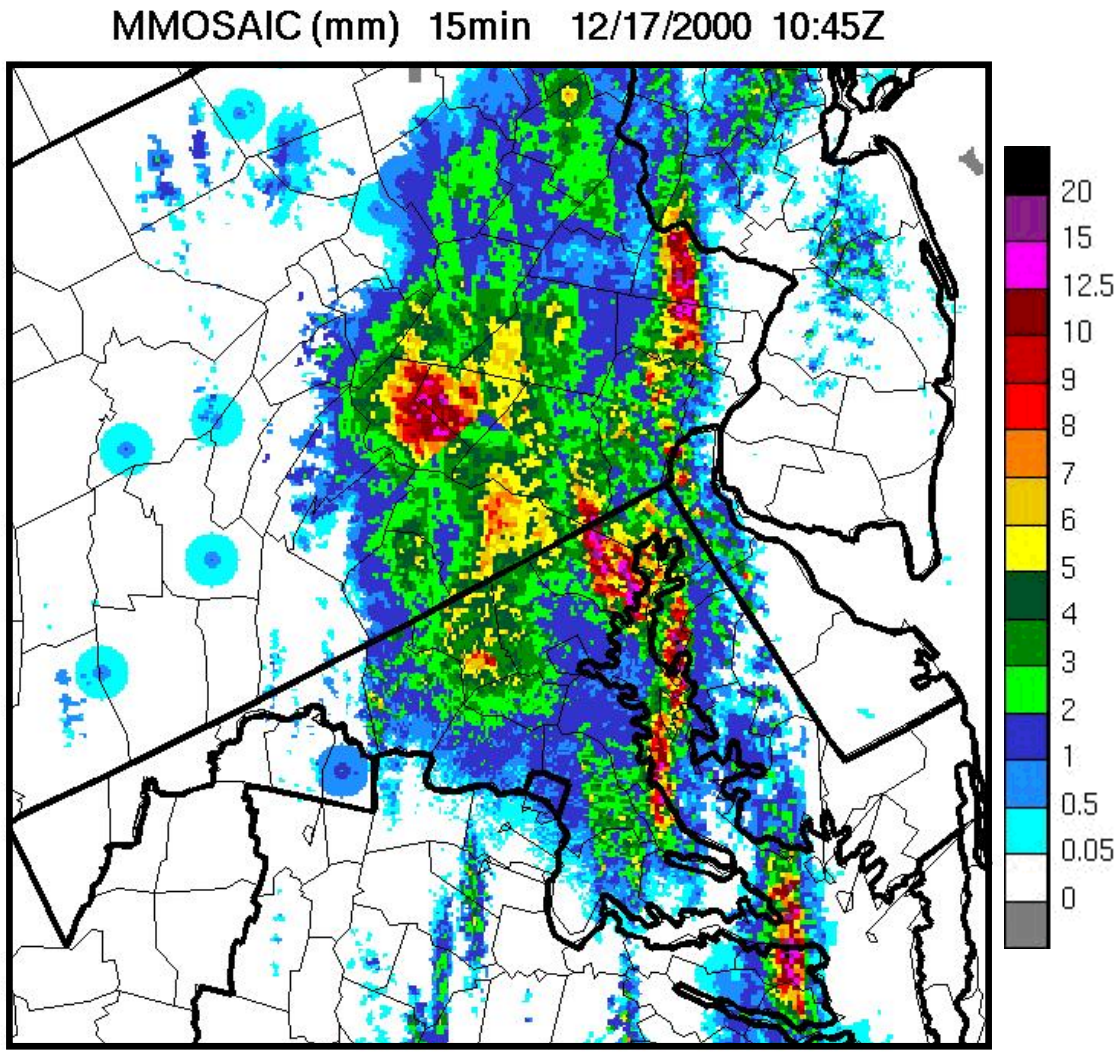
# 1-km Radar-only 15-min. Rainfall Mosaic



# 1-km Mean field bias-adjusted Radar 15-min. Rainfall Mosaic



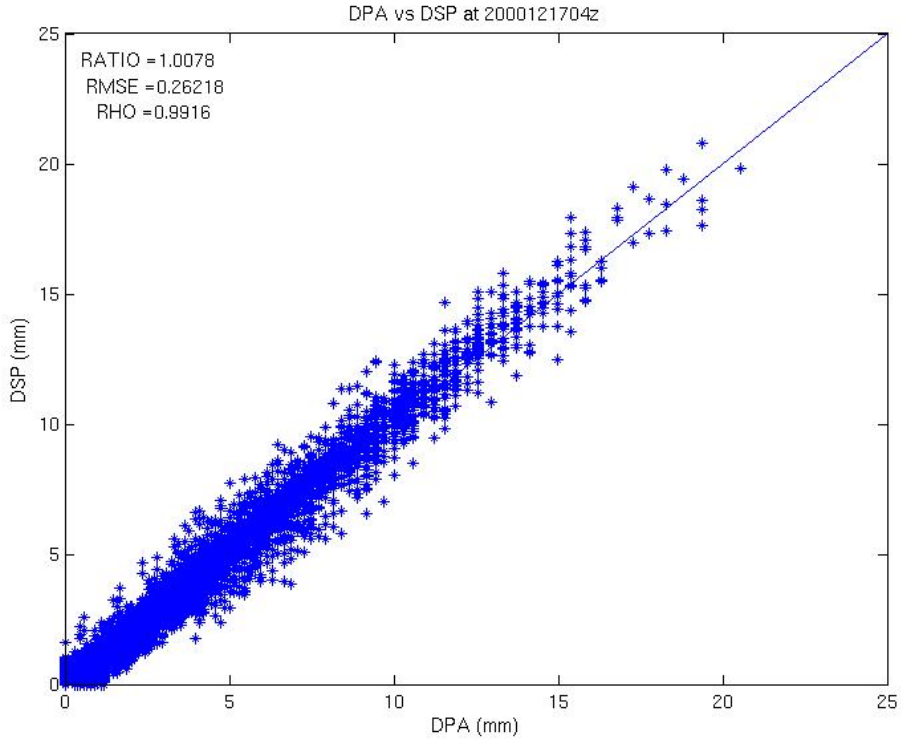
# 1-km Multisensor 15-min. Rainfall Mosaic



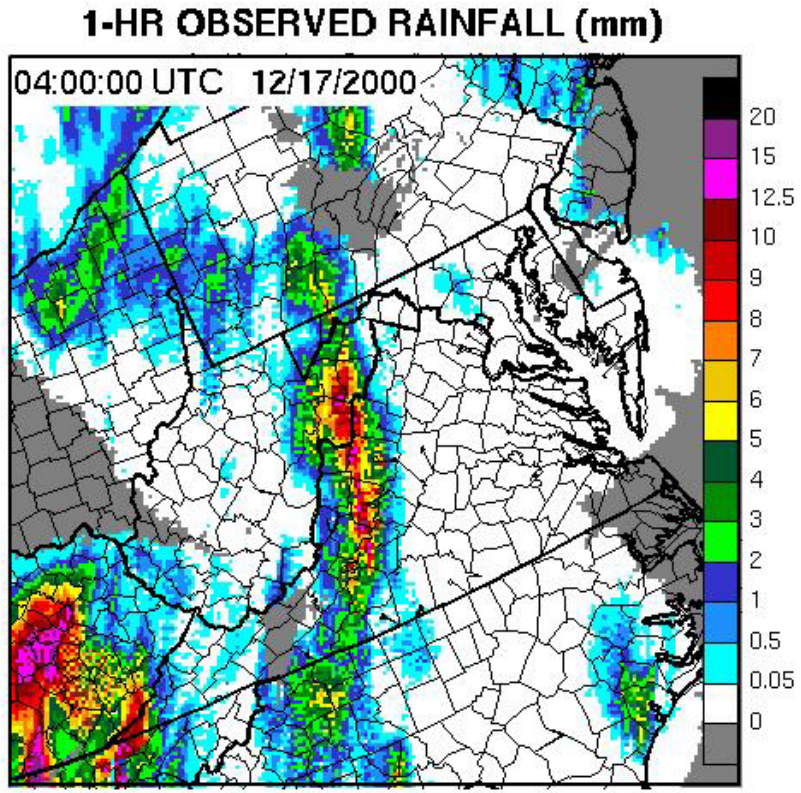
# EMPE Details

- Uses PPS's Digital Storm-total Precipitation (DSP) products from multiple radars covering CWA as input
  - *Cumulative rainfall updated every volume scan (~ 5 minutes)*
  - *1 deg x 2 km (higher resolution than 4-km DPA)*
    - 1 deg x 1 km in future (existing HOSIP project)
  - *Digital 256-level equivalent to the Storm Total Precip (STP) 16-level graphical product*
- Differencing of DSPs produces rainfall durations of any arbitrary duration (5 min. to 24+ hours)
  - *DPAs cannot provide durations other than whole 1, 2, 3, … hrs.*
- Demonstrated ability of differenced DSPs to replicate DPA hourly rainfall on HRAP grid
- Also uses PPS's Digital Hybrid Scan Reflectivity (DHR) products to compute instantaneous rain rates
- Both are remapped and mosaicked onto ¼ HRAP grid (~1 km)

# Hourly Rainfall from DPAs and Differenced DSPs Matches Well




One-hour rainfall for mid-Atlantic regional mosaic on 4-km HRAP grid

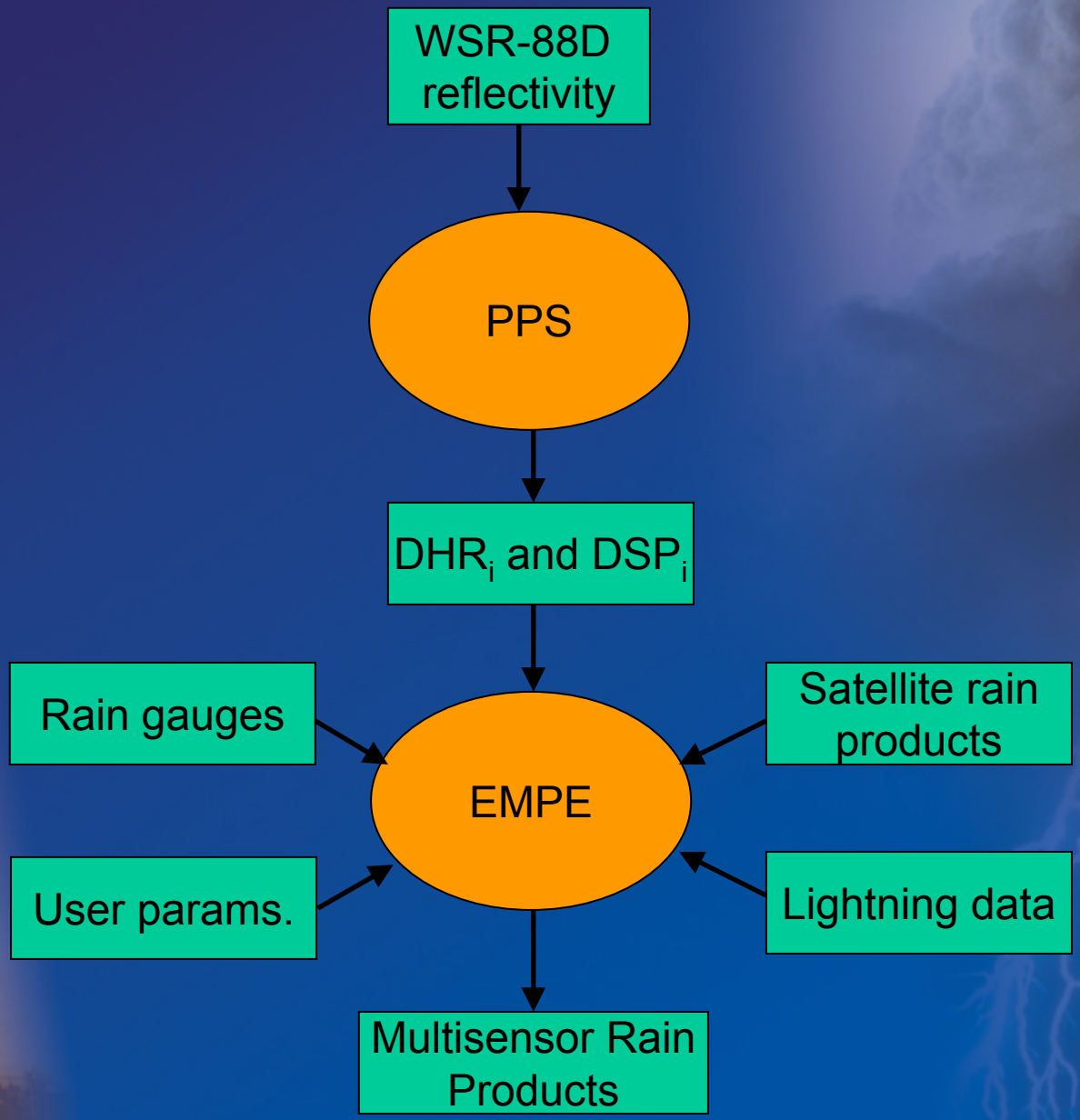



Random differences may be due to:

1) Slight differences in polar-to-HRAP remapping software between PPS and EMPE

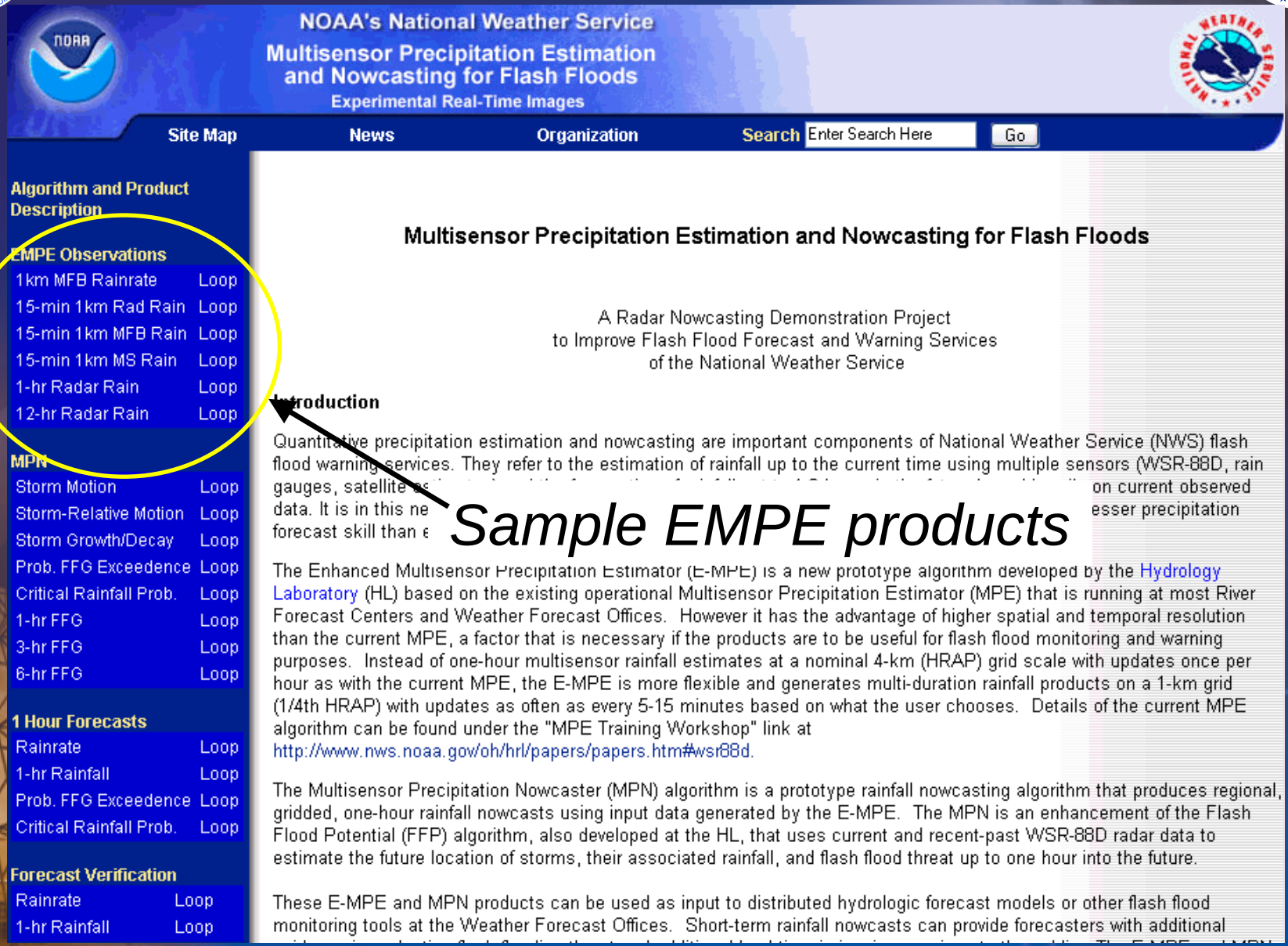
2) Temporal interpolation

# EMPE Data Flow



# Real-time Web Page

## http://www.nws.noaa.gov/ohd/hrl/hag/empe_mpn/




*Sample EMPE products*

# EMPE User Configuration

## Vision is One Configurable EMPE that Serves both WFOs and RFCs

- Choose desired spatial grid resolution
  - *¼ HRAP or 1 HRAP*
- Choose desired rainfall durations
  - *Rainrates, 15 min., 30 min., 1 hr., etc. rainfall durations*
- Choose desired run-time delay (~minutes)
  - *May depend on each product*
  - *Gauge-adjusted products may need longer time delays*
- Choose a product generation schedule that satisfies your requirements…



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# EMPE User Configuration (cont.)

## A Sample Product Generation Schedule

| Time (min.) | EMPE Products | | | | | |
|---|---|---|---|---|---|---|
| | Rain Rate (mm/hr) | RMOSAIC 15 min (mm) | BMOSAIC 30 min (mm) | BMOSAIC 60 min (mm) | MMOSAIC 60 min (mm) | Etc. |
| H+0 | √ | √ | √ | √ √ | √ | |
| H+5 | √ | | | | | |
| H+10 | √ | | | | | |
| H+15 | √ | √ | | | | |
| … | √ | | | | | |
| H+30 | √ | √ | √ | | | |
| … | √ | | | | | |
| H+45 | √ | √ | | | | |
| … | √ | | | | | |
| H+55 | √ | | | | | |

RMOSAIC: Radar Mosaic BMOSAIC: Bias-adjusted Radar MMOSAIC: Multisensor Mosaic

# EMPE Considerations

- Increased CPU, memory, disk space, and communication bandwidth requirements
- Digital Storm-total Precipitation (DSP) product issues
  - *Wide area distribution is necessary from multiple non-associated radars for mosaicking (DHR also)*
    - Revising an existing WSR-88D Request for Change (RC)
  - *Don't apply G-R bias to DSP*
    - PPS code needs to be revised; RC was submitted in Feb.
- Rain gauge issues
  - *Rain gauge data is a double-edged sword that requires QC before use*
  - *WFOs often don't have resources to do real-time manual gauge QC as at RFCs*
  - *Automated quality control methods are critical*
  - *Anticipated use of RFC QC'ed precipitation analyses for previous 1-6 hours*

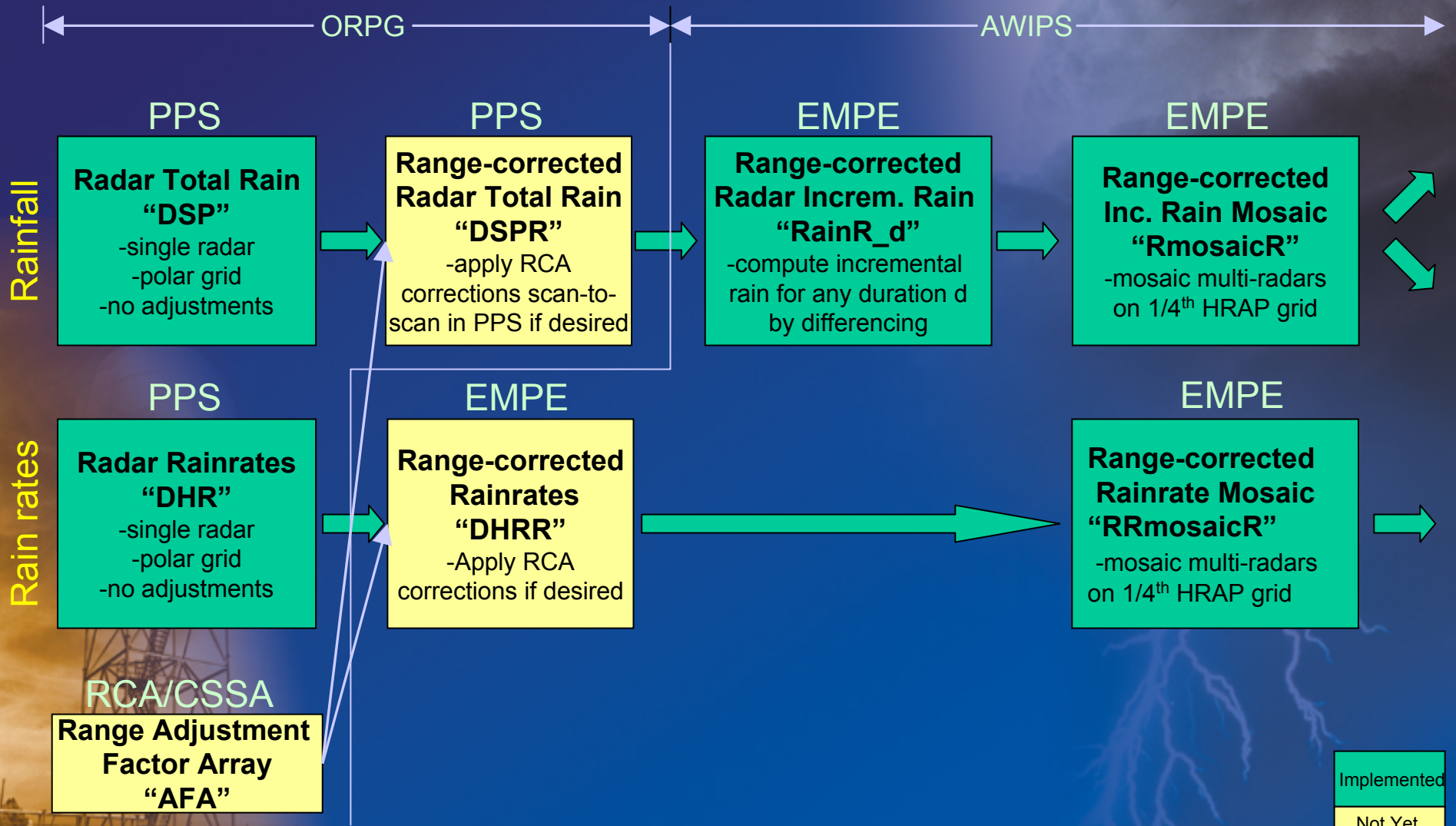
# EMPE will be Integrated within NWS Hydrologic Operations

- On-going science infusion in PPS will be reflected in downstream EMPE products (e.g., Range Correction Algorithm RCA, rainrate-dependent bias adjustment, dual polarization)
- Science infusion in MPE is on-going (e.g., probabilistic QPE, satellite QPE)
- Provides all necessary input to drive the Multisensor Precipitation Nowcaster
- Enables/enhances high resolution distributed hydrologic forecast modeling and other flash flood tools (distributed hydrologic forecast models, FFMP, flood inundation mapping)

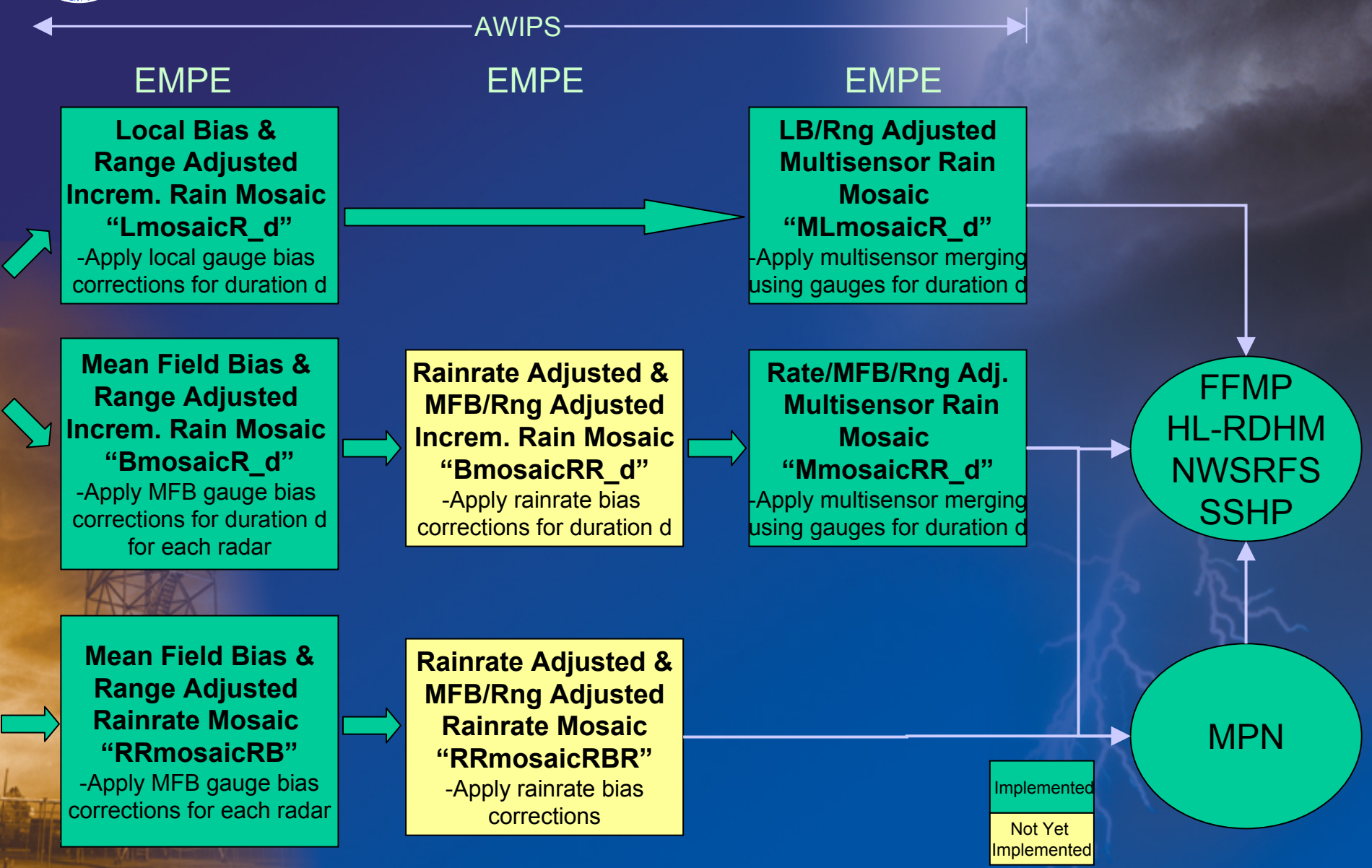
# Types of Radar QPE Adjustments

- **Adjustments using radar data**
  - ***Range-related biases***
    - Experimental Range Correction Algorithm (RCA)
    - Beam broadening
  - ***Rain rate-dependent biases***
    - see Probabilistic QPE final report on our web page
- **Adjustments using rain gauges**
  - ***Radar-wide mean field bias (MPE's Bmosaic)***
  - ***Local bias (MPE's Lmosaic, P3)***
  - ***Multisensor merging (MPE's Mmosaic)***
- **Adjustments using satellite QPE**
  - ***Multisensor merging (radar+gauge+satellite; under development for MPE)***

# Proposed End-to-End Sequence of Bias Correction Procedures in EMPE/MPN



# Proposed End-to-End Sequence of Bias Correction Procedures in EMPE/MPN (cont.)



# Looking into the Future to Increase Flash Flood Warning Lead Times

- **Rainfall nowcasting**: Extrapolating current (radar) rainfall observations into the very near future (1-3 hours)
  - *Predictability of rain depends on predictability of rainfall system…convective vs. stratiform & seasonal dependence*
- NWS currently has no rainfall nowcasting capability that is integrated quantitatively within hydrologic fcst operations
  - *SCAN Categorical QPF algorithm, WSR-88D Storm Cell Identification and Tracking (SCIT) used for visual analysis only*
  - *UK Met Office has been doing this for a while*
- Even simpler automated nowcast techniques have potential to move us to the next flash flood warning performance level (possibly ~ten minutes vs. current few minutes)
  - *We can automate and quantify what goes on in a forecaster's head when they view radar loops*

# Multisensor Precipitation Nowcaster (MPN)

*- For Flash Flood Forecasting -*

- Automatically produces deterministic 1-hr rainfall forecasts and flash flood threat probabilities using extrapolation techniques
- 4-km forecast grids, updated every 5-15 minutes as needed
- Multisensor – uses WSR-88D radar with rain gauge-based mean field bias adjustments
- Regional – uses mosaicked WSR-88Ds covering the county warning area
- Is integrated with EMPE; EMPE produces all necessary input data to drive it

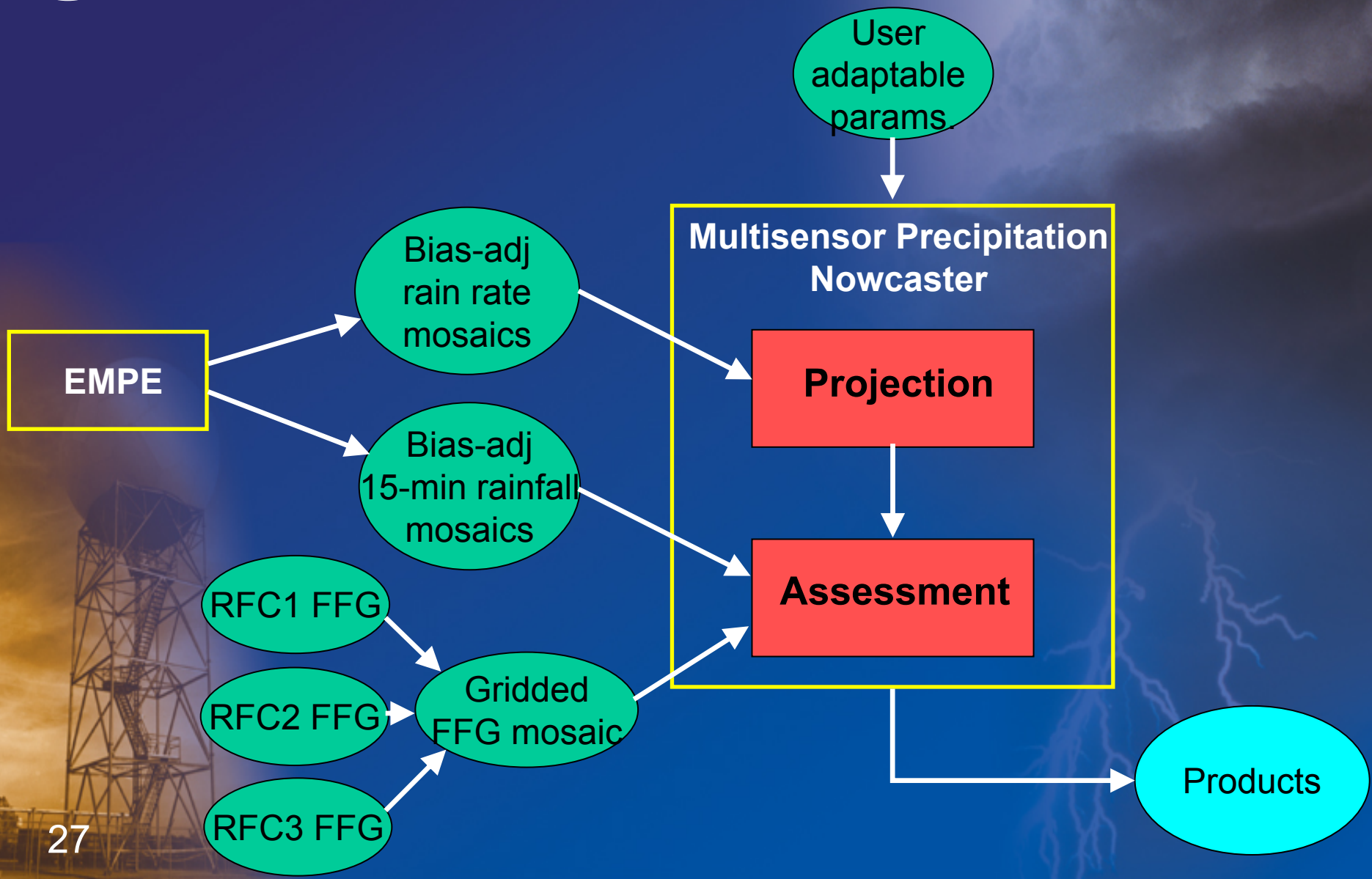
# History and Status of MPN

- MPN is an extension of HL's Flash Flood Potential (FFP) algorithm
  - *FFP was originally single-radar, single-sensor*
  - *AHPS supported the upgrade to multiradar, multisensor using EMPE product input*
- Initial AHPS funding proposal for MPN written by Fulton in 2002 and funded FY 2003-2006
- Project plan developed and distributed for review in 2002
- Initial MPN prototype was completed in 2004 by HSMB's Hydrometeorology Group (S. Guan, F. Ding, R. Fulton)
- In 2004, we set up a real-time 24x7 demonstration in HL for 5 WSR-88Ds in mid-Atlantic region (Sterling KLWX, Pittsburgh KPBZ, Charleston KRLX, Blacksburg KFCX, Wakefield KAKQ)
- Web page shows real-time graphical output products
- MPN project is in OSIP Stage 2

# MPN has Two Components

- **Rainfall Projection** algorithm
  - *Produces 1-hour gridded rainfall nowcasts based on extrapolation of recent WSR-88D and rain gauge observations*
- **Flash Flood Threat Assessment** algorithm
  - *Computes observed and forecasted gridded probabilities of exceeding 1-, 3-, and 6-hr Flash Flood Guidances (FFG)*

# MPN Data Flow

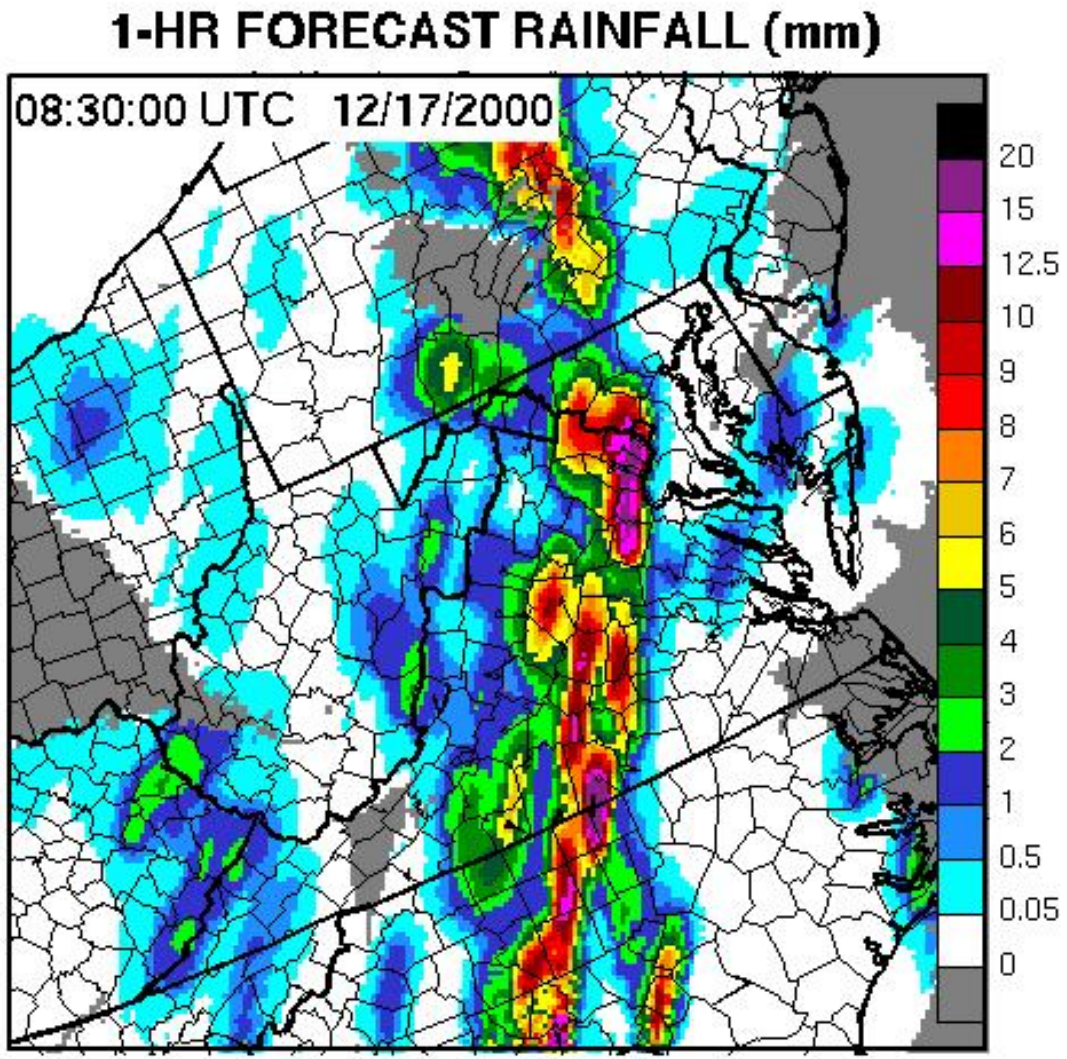


# MPN Details

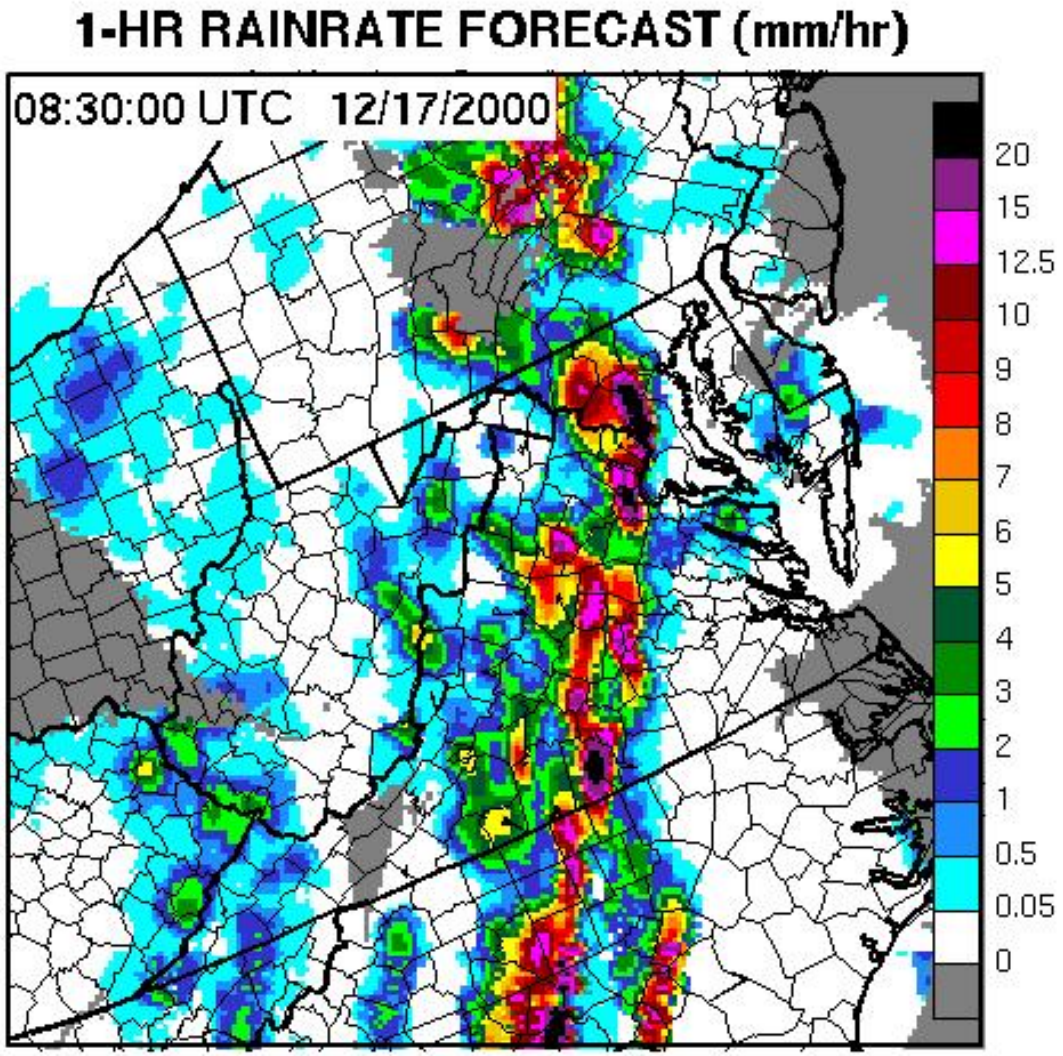
## *Pt. 1: Rainfall Projection Algorithm*

- **Generates one-hour rainfall nowcasts on HRAP grid (~4 km) with 5-15 minute update frequency as needed**
  - ***Meager justification currently for going to higher spatial resolution***
  - ***Extending forecasts beyond 1 hour is easily doable, but accuracy degrades quickly beyond ~1 hour in summer convection***
- **Local pattern matching technique using two consecutive gridded radar rain rate mosaics ~15-20 minutes apart produces local storm motion vectors**
  - ***Vectors delineate storm motion at a ~20 km grid scale***
  - ***Automated vector quality control***
- **Advect and integrate current mean field bias-adjusted rain rate mosaic one hour into future using observed storm vectors**
  - ***Several progressive spatial smoothing options are available to minimize forecast error***
- **Local lagrangian storm growth and decay can be accounted for in forecasts if desired**

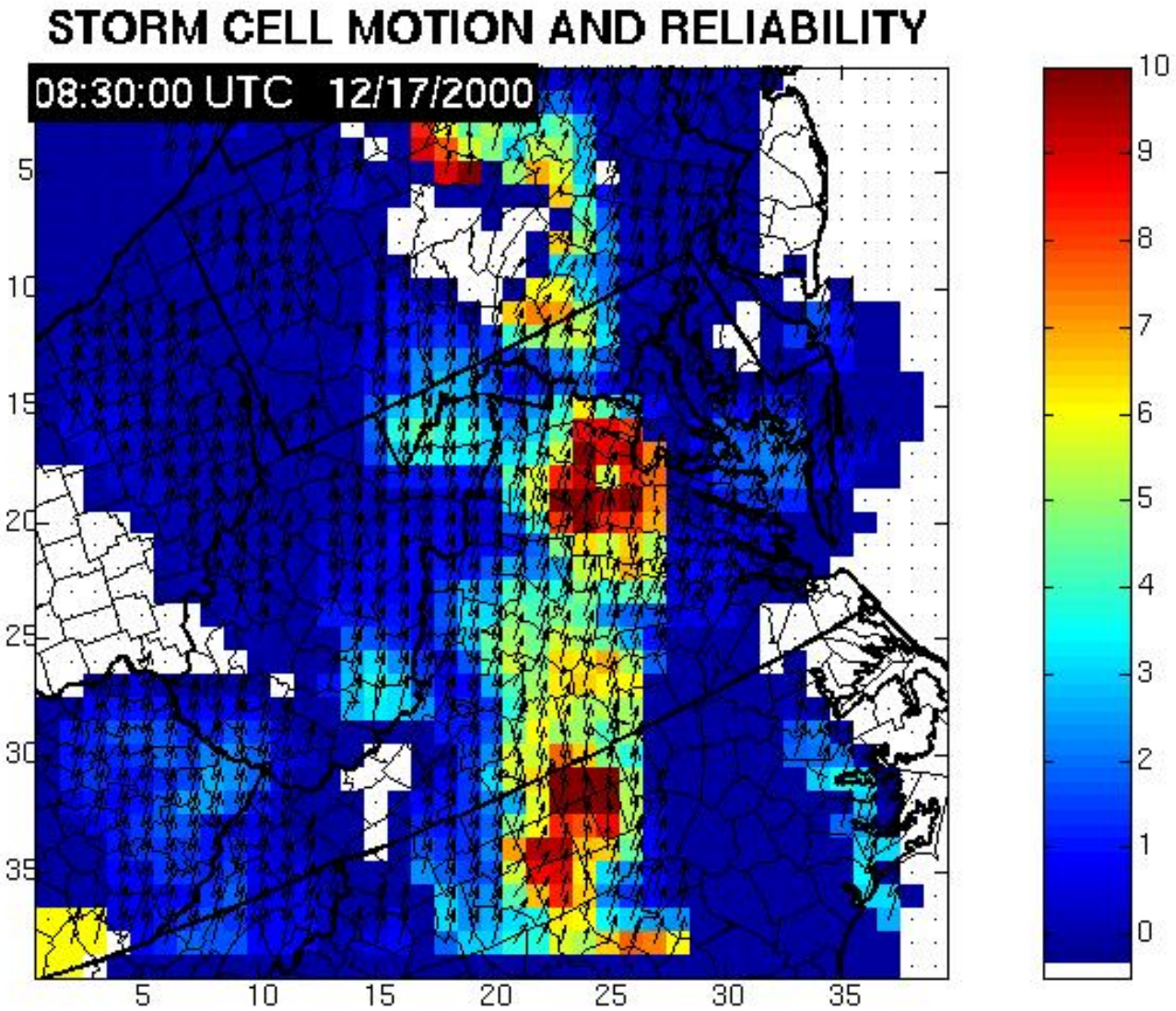
# MPN Projection Products
## One-hour Rainfall Forecast



# MPN Projection Products
## One-hour Rain Rate Forecast



# MPN Projection Products
## Storm Motion Vectors and Reliability

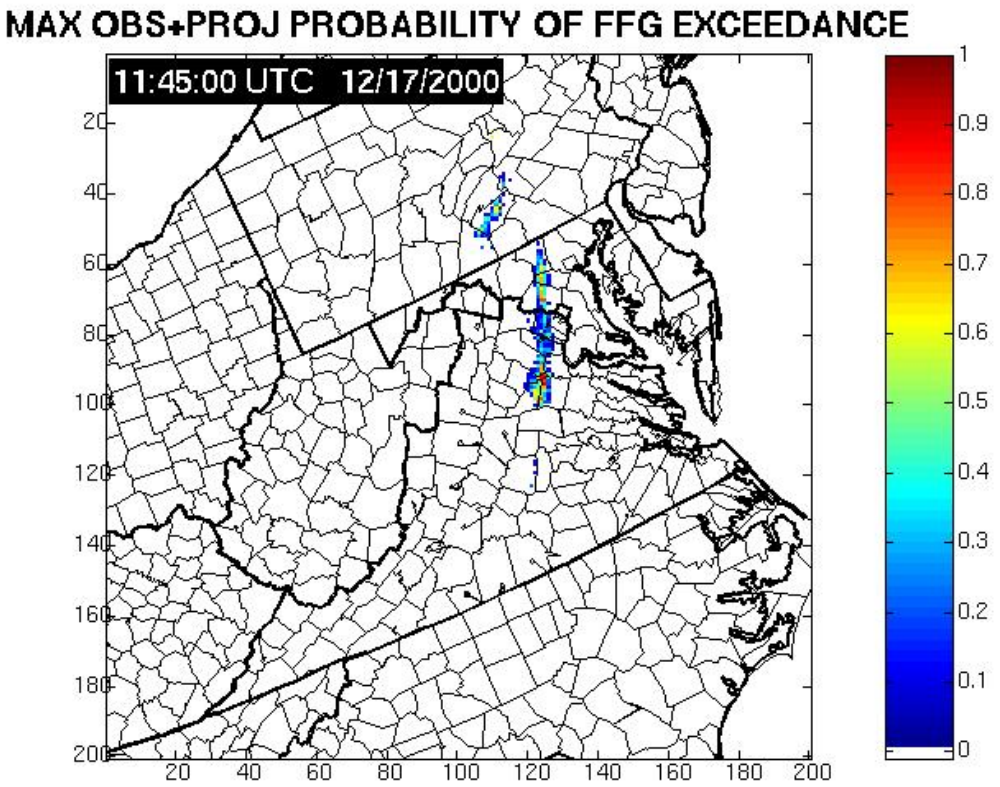


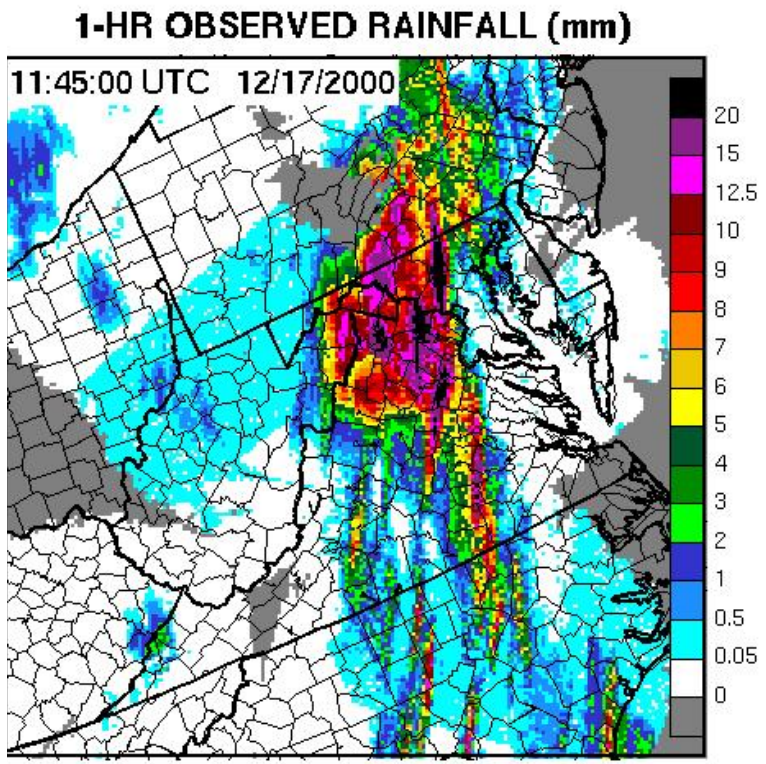
# MPN Details

## *Pt. 2: Flash Flood Threat Assessment Algorithm*

- **Compares both observed and forecasted rainfall with 1, 3, and 6-hr FFGs on the HRAP grid**
  - ***Could be enhanced to do basin averaging if integrated into FFMP***
- **Computes both observed and forecasted gridded probabilities of exceeding FFGs**
  - ***Maximum exceedance probabilities of all three durations (1-hr, 3-hr, 6-hr),***
    - **e.g., 3-hr forecast exceedance probabilities are computed from 2 hours of past observed rain and 1 hour of forecast rain and then compared with 3-hr FFGs**
  - ***"Storm-total" exceedance probabilities (Critical Rainfall Probabilities)***

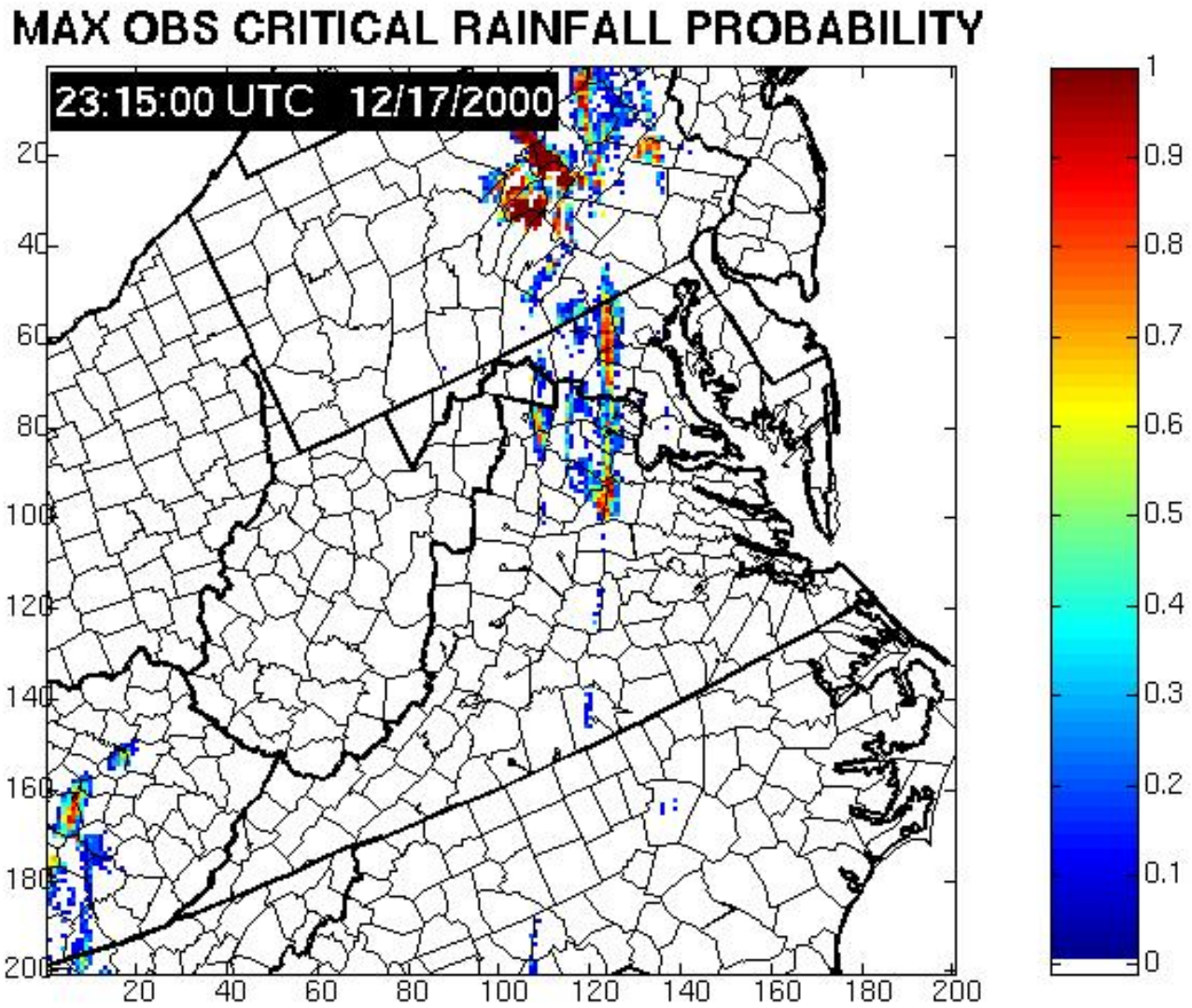
# MPN Assessment Products
## FFG Exceedance Probabilities



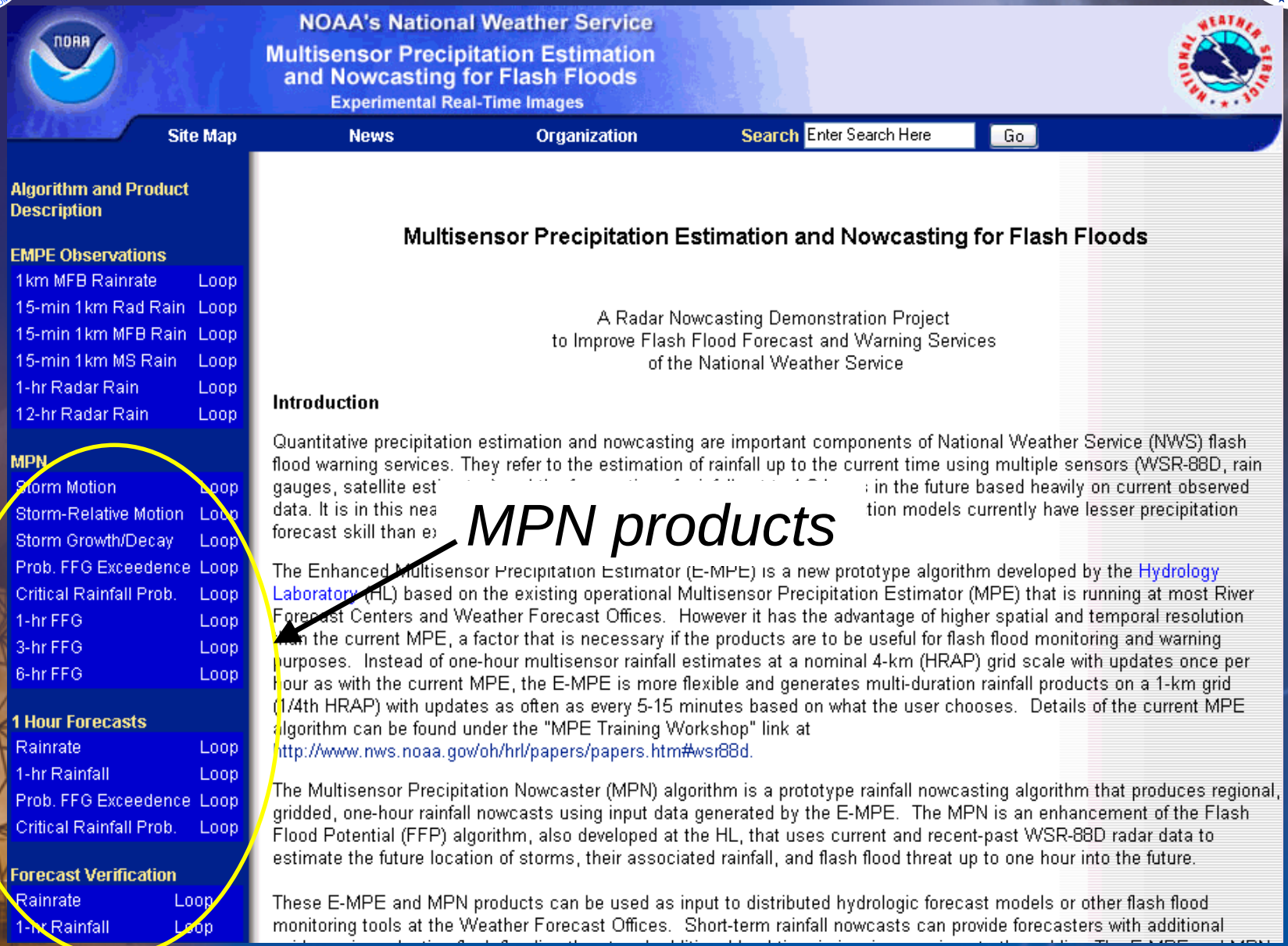
# MPN Assessment Products
## Critical Rainfall Probabilities

At end of the rain event



# Real-time Web Page

## http://www.nws.noaa.gov/ohd/hrl/hag/empe_mpn/



# MPN Verification:
# Are the Nowcasts Any Good?

- **Verification of forecasted instantaneous rain rates and hourly forecast accumulations…**
  - ***Against radar observations (completed)***
    - **Fulton and Seo (2000)**
    - **Guan, Ding, Fulton, Kitzmiller (2005)**
  - ***Against rain gauge observations (in progress)***

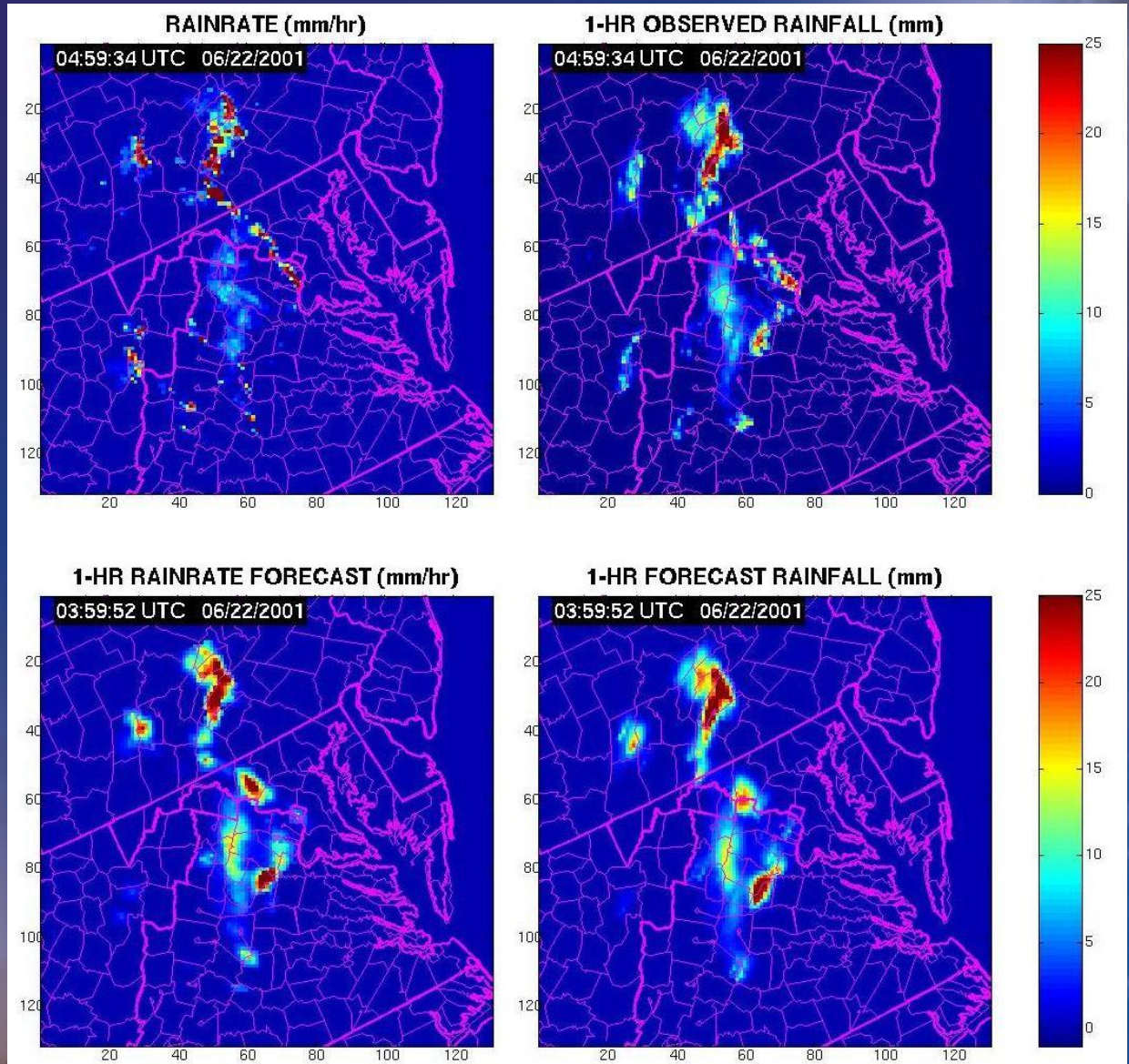

Fulton and Seo, 2000: A prototype operational 0-1 hour radar-based Flash Flood Potential algorithm. 15th Hydrology Conference.

Guan, Ding, Fulton, Kitzmiller, 2005: Preliminary results for the 0-1 hour Multisensor Precipitation Nowcaster. 32nd Radar Meteorology Conference.

# Example 1 – Visually Comparing Forecasts and Observations

Obs.

Fcst.

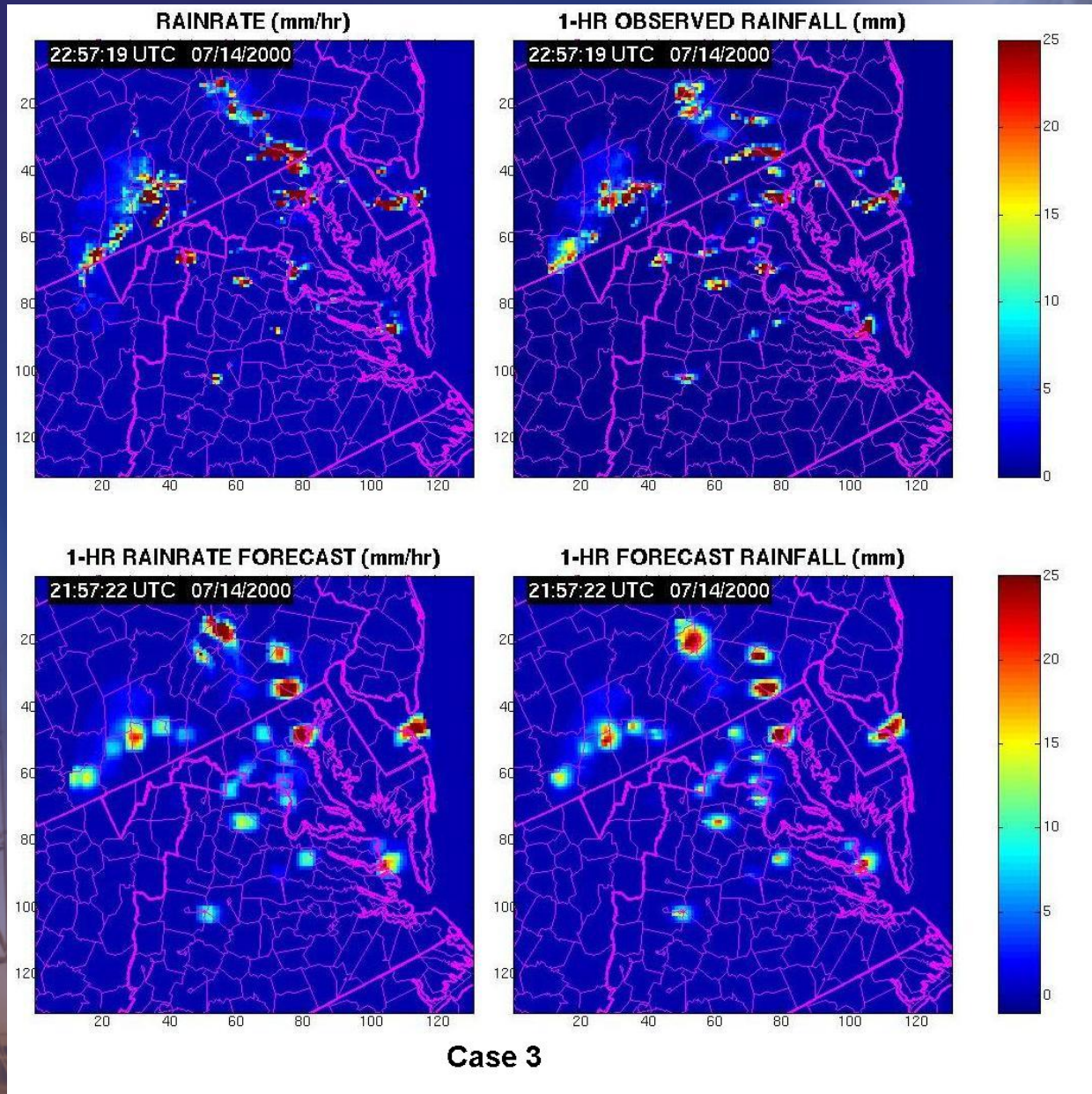



NFL

# Example 2 – Visually Comparing Forecasts and Observations

Obs.

Fcst.



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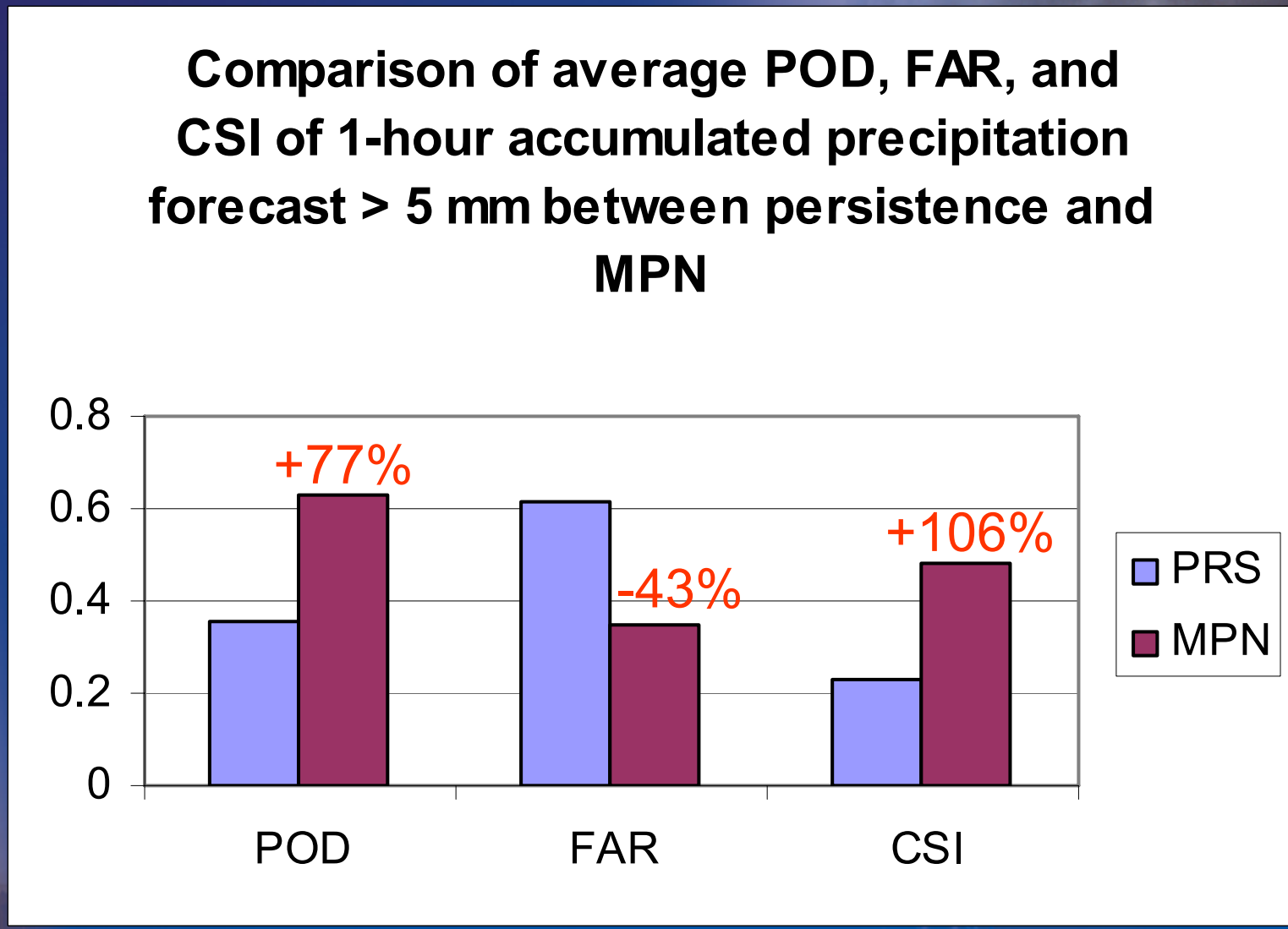
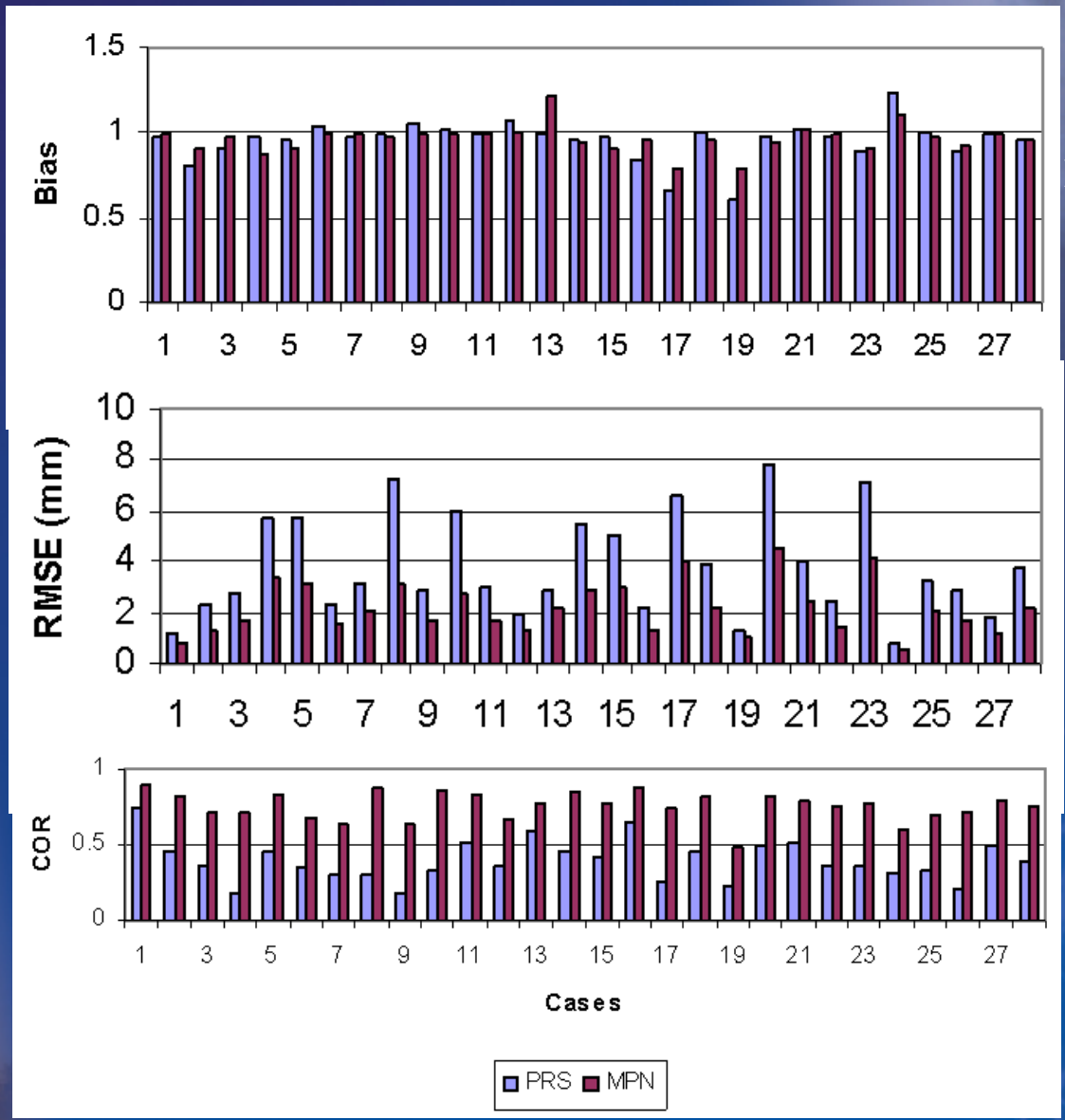
# MPN Forecast Verification Against Radar Rainfall Observations: 1-hr Rainfall

27 historical flash flood events examined from 18 locations around the U.S. over ten years

Statistics computed on HRAP grid



# MPN Forecast Verification Against Radar Rainfall Observations: 1-hr Rainfall




Bias=
Σ(fcst rain)/Σ(obs rain)

Rain gauge data was not used

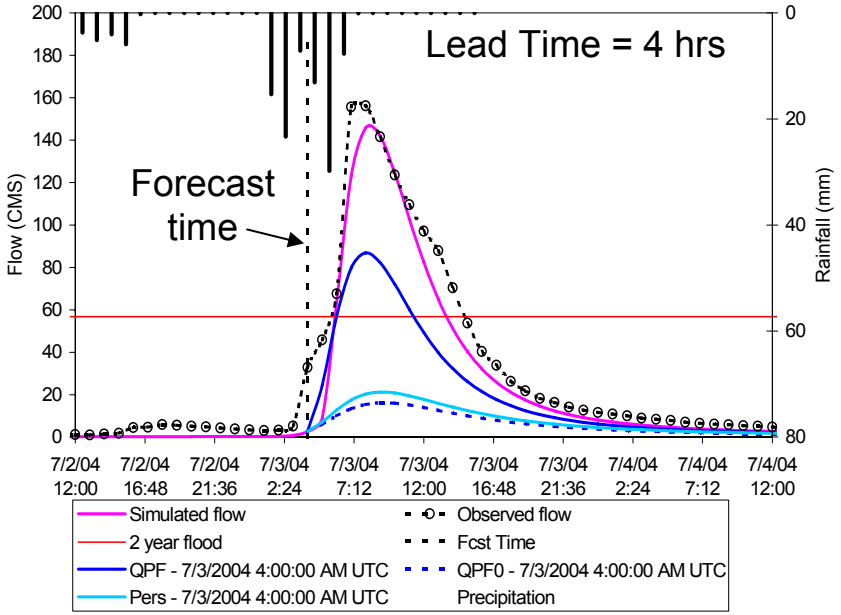
# Using Rainfall Nowcasts in a Distributed Hydrologic Forecast Model (HL-RDM)

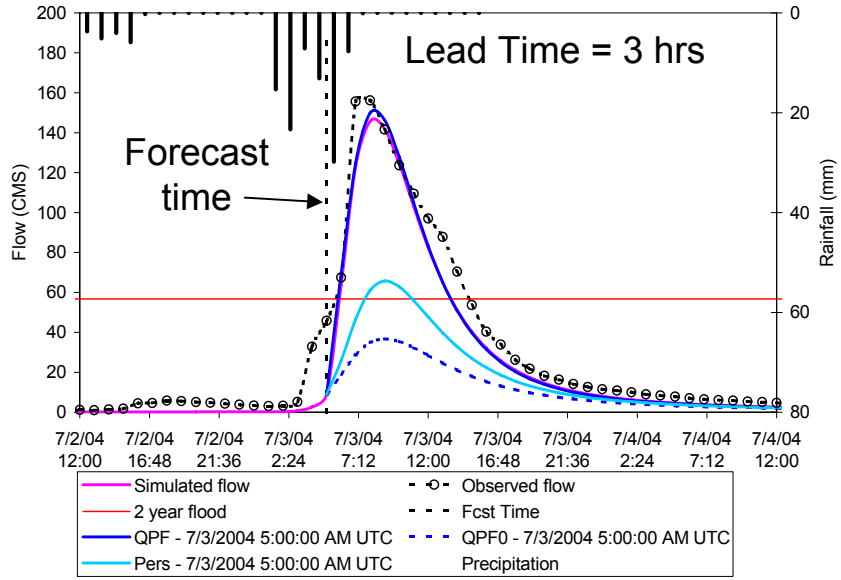
- Forecast hydrographs using 1-hr MPN rain nowcasts are consistently better than assuming zero QPF based on 9 intense rain events
  - *Reed, Fulton, Zhang, Guan (2006)*
- Demonstrated potential flash flood lead time gained
- A component of S. Reed's HOSIP project "Distributed Hydrologic Modeling for Flash Flood Forecasting"
- Potential for use in Site Specific Hydrologic Predictor (SSHP)
- Potential for linking hydro forecasts to high-res GIS-based flood inundation mapping capabilities for emergency managers

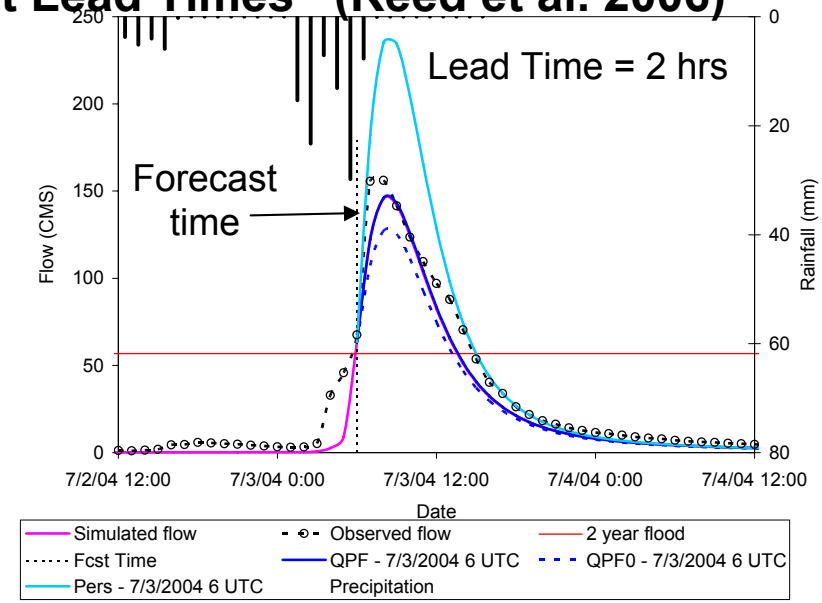
Reed, Fulton, Zhang, Guan, 2006: Use of 4-km, 1-hr precipitation forecasts to drive a distributed hydrologic model for flash flood prediction. 20th Hydrology Conference.

# Hydrograph Forecast Accuracy at Different Lead Times (Reed et al. 2006)

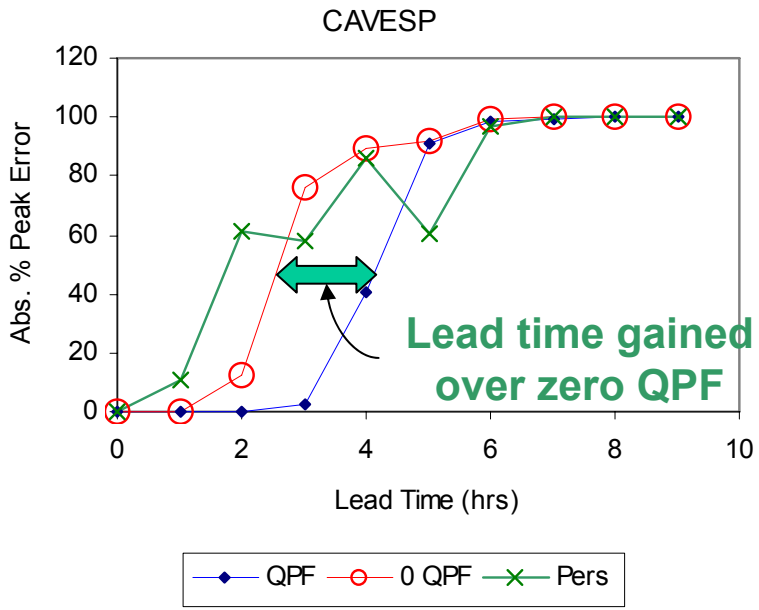
- Lead times are computed relative to the simulated peak time.
- All results shown are for CAVESP (90 km$^2$) and single Event (7/2004)



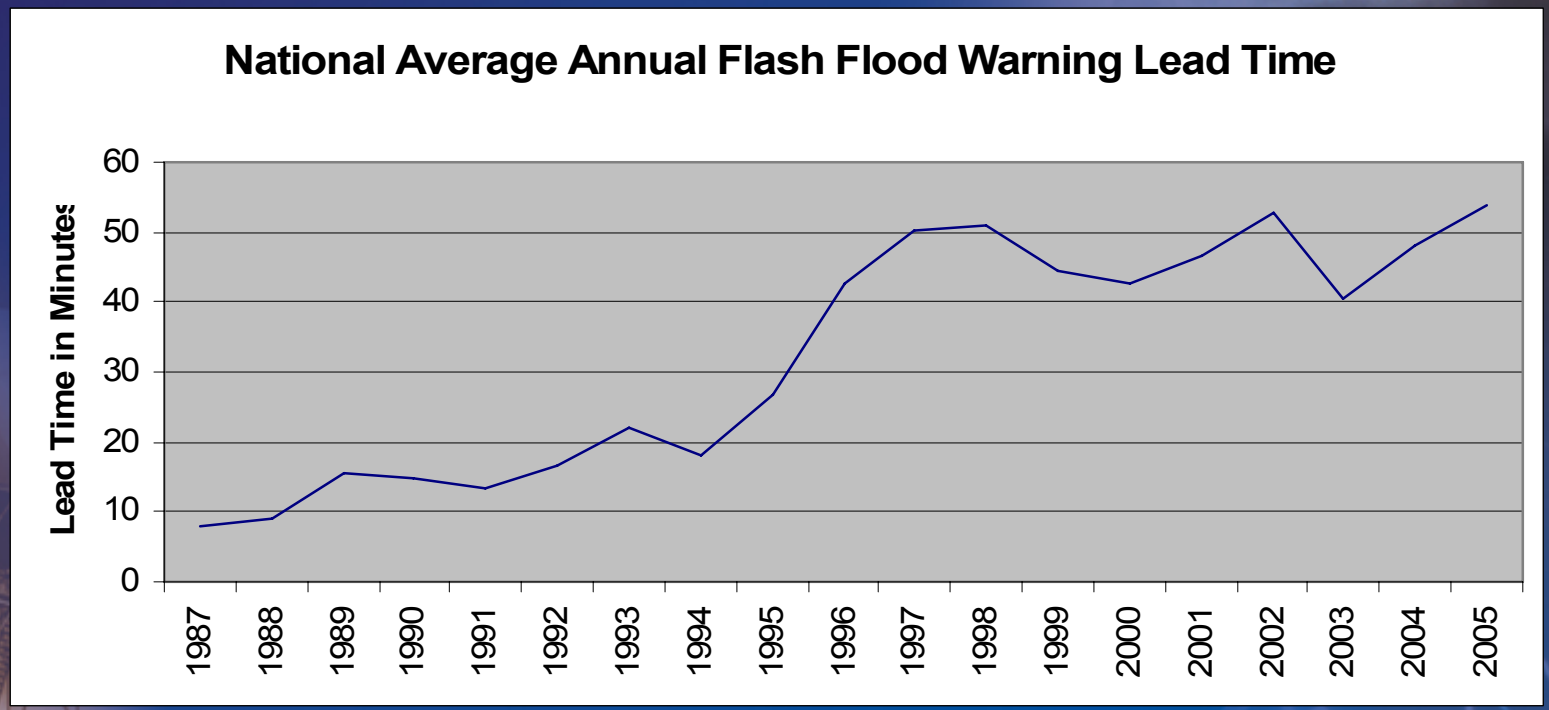




Peak errors of different forecasts relative to simulated flows as a function of lead time



# Historical Performance of NWS Flash Flood Warning Lead Time




NEXRAD Implementation

FFMP Implementation

# Recent and Projected WFO Flash Flood Warning Performance

- ***Flash Flood Warning verification statistics are based on product issuance information and confirmation of actual flash floods by the local WFOs***
  - *Flash Flood Warning Lead Time*
  - *Flash Flood Warning Accuracy*

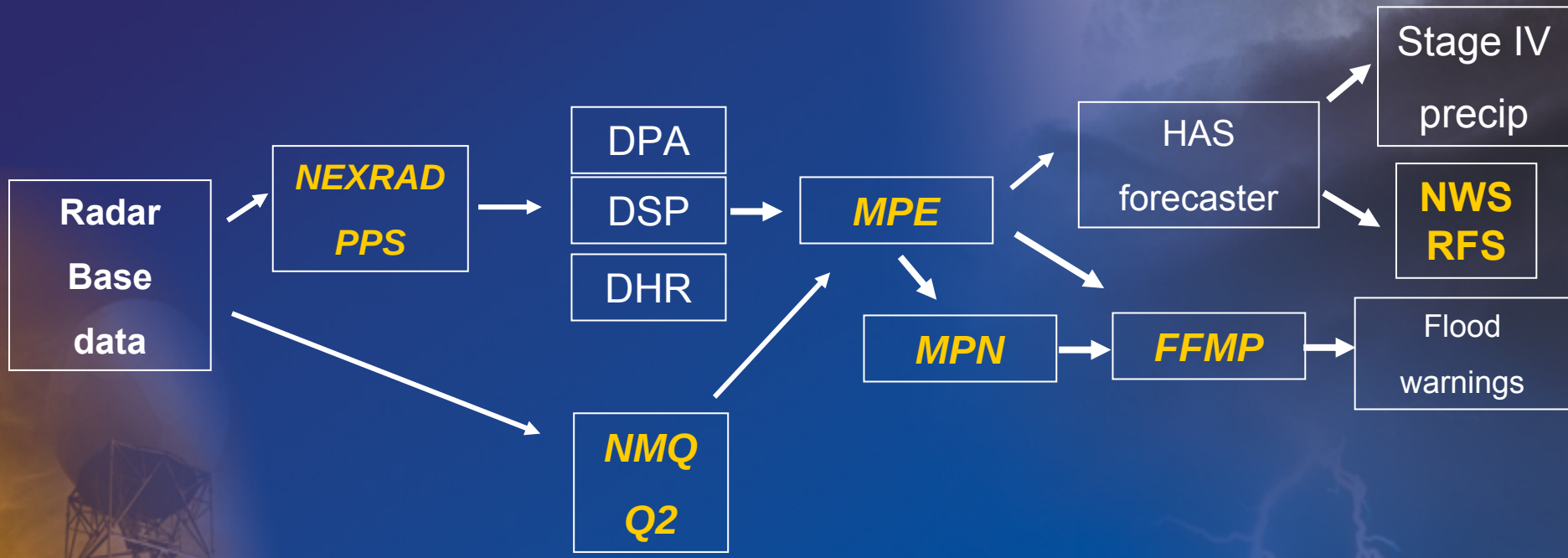
| | FY03 Actual | FY04 Actual | FY05 Actual | FY06 Goal | FY12 Goal |
|---|---|---|---|---|---|
| Lead Time (minutes) | 41 | 48 | 54 | 48 | 51 |
| Accuracy (%) | 89 | 89 | 88 | 89 | 91 |

***EMPE and MPN, when integrated with other WFO hydrology tools, have the potential to greatly increase future performance***

# NSSL-OHD Collaboration on Precipitation Estimation

- *Program goal:* **Improved precipitation estimates for RFC's and WFO's**
- *Current focus* **is on identifying best features of Next-Generation Multisensor Precipitation Estimation (Q2) and AWIPS Multisensor Precipitation Estimator (MPE) algorithms through a hydrologic simulation experiment**
  - ***Focus on Tar River basin in North Carolina***
  - ***Retrospective precipitation analyses will be prepared for North Carolina***
  - ***Q2 and MPE precipitation analyses incorporating different combinations of input and algorithms will be used to drive OHD's research distributed hydrologic model HL-RDHM***
  - ***Precipitation evaluation will be based on comparisons with a set of reference rain gauges and stream gauges***

# Anticipated Operational Data Flow
## *(Subject to Later Revision)*




**Radar input comes from WSR-88D, TDWR, other networks**

**Science improvements tested in Q2 will be implemented in Q2, NEXRAD PPS, and MPE**

# Conclusion

- The Enhanced Multisensor Precipitation Estimator and Nowcaster can enable improved WFO performance results and new diverse flash flood services

# For more information on activities to improve WSR-88D rainfall estimation in the Hydrology Lab…

- **Visit the Hydromet Group's web page**
  - http://www.nws.noaa.gov/oh/hrl/hag/hag.htm
- **Visit our WSR-88D publications web page**
  - http://www.nws.noaa.gov/oh/hrl/papers/papers.htm#wsr88d
  - All the papers referenced herein are located there

The End