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](http://www.nws.noaa.gov/oh/hrl/papers/papers.htm#wsr88d)
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
Radar-only 15-min. Rainfall Mosaic

1-km grid (EMPE)  4-km grid (MPE)

RMOSAIC (mm)  15min  12/17/2000  10:45Z
1-km Radar-only 15-min. Rainfall Mosaic

RMOSAIC (mm) 15min 12/17/2000 10:45Z
1-km Mean field bias-adjusted Radar
15-min. Rainfall Mosaic

BMOSAIC (mm) 15min 12/17/2000 10:45Z
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

- WSR-88D reflectivity
- PPS
- DHR$_i$ and DSP$_i$
- Rain gauges
- User params.
- Lightning data
- Satellite rain products
- Multisensor Rain Products

User params.
Multisensor Precipitation Estimation and Nowcasting for Flash Floods

A Radar Nowcasting Demonstration Project to Improve Flash Flood Forecast and Warning Services of the National Weather Service

Quantitative precipitation estimation and nowcasting are important components of National Weather Service (NWS) flash flood warning services. They refer to the estimation of rainfall up to the current time using multiple sensors (WSR-88D, rain gauges, satellite, etc.) data. It is in this near-real-time forecast skill that:

Sample EMPE products

The Enhanced Multisensor Precipitation Estimator (E-MPE) is a new prototype algorithm developed by the Hydrology Laboratory (HL) based on the existing operational Multisensor Precipitation Estimator (MPE) that is running at most River Forecast Centers and Weather Forecast Offices. However, it has the advantage of higher spatial and temporal resolution than the current MPE, a factor that is necessary if the products are to be useful for flash flood monitoring and warning purposes. Instead of one-hour multisensor rainfall estimates at a nominal 4-km (HRAP) grid scale with updates once per hour as with the current MPE, the E-MPE is more flexible and generates multi-duration rainfall products on a 1-km grid (14th HRAP) with updates as often as every 5-15 minutes based on what the user chooses. Details of the current MPE algorithm can be found under the “MPE Training Workshop” link at http://www.nws.noaa.gov/oh/hr/papers/papers.htm#wrs88d.

The Multisensor Precipitation Nowcaster (MPN) algorithm is a prototype rainfall nowcasting algorithm that produces regional, gridded, one-hour rainfall nowcasts using input data generated by the E-MPE. The MPN is an enhancement of the Flash Flood Potential (FFP) algorithm, also developed at the HL, that uses current and recent past WSR-88D radar data to estimate the future location of storms, their associated rainfall, and flash flood threat up to one hour into the future.

These E-MPE and MPN products can be used as input to distributed hydrologic forecast models, or other flash flood monitoring tools at the Weather Forecast Offices. Short-term rainfall nowcasts can provide forecasters with additional information to make the best possible and most timely decisions.
EMPE User Configuration

Vision is One Configurable EMPE that Serves both WFOs and RFCs

- Choose desired spatial grid resolution
  - \(\frac{1}{4}\) 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…
### EMPE User Configuration (cont.)

A Sample Product Generation Schedule

<table>
<thead>
<tr>
<th>Time (min.)</th>
<th>Rain Rate (mm/hr)</th>
<th>RMOSAIC 15 min (mm)</th>
<th>BMOSAIC 30 min (mm)</th>
<th>BMOSAIC 60 min (mm)</th>
<th>MMOSAIC 60 min (mm)</th>
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<tr>
<td>H+0</td>
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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

Rainfall

PPS
- Radar Total Rain
  "DSP"
  - single radar
  - polar grid
  - no adjustments

PPS
- Range-corrected Radar Total Rain
  "DSPR"
  - apply RCA corrections scan-to-scan in PPS if desired

EMPE
- Range-corrected Radar Increm. Rain
  "RainR_d"
  - compute incremental rain for any duration d by differencing

EMPE
- Range-corrected Inc. Rain Mosaic
  "RmosaicR"
  - mosaic multi-radars on 1/4th HRAP grid

Rain rates

PPS
- Radar Rainrates
  "DHR"
  - single radar
  - polar grid
  - no adjustments

PPS
- Range-corrected Rainrates
  "DHRR"
  - Apply RCA corrections if desired

EMPE
- Range-corrected Rainrate Mosaic
  "RRmosaicR"
  - mosaic multi-radars on 1/4th HRAP grid

RCA/CSSA
- Range Adjustment Factor Array
  "AFA"

ORPG

AWIPS

Implemented
Not Yet Implemented
Proposed End-to-End Sequence of Bias Correction Procedures in EMPE/MPN (cont.)

- **Local Bias & Range Adjusted Increm. Rain Mosaic “LmosaicR_d”**
  - Apply local gauge bias corrections for duration d

- **Mean Field Bias & Range Adjusted Increm. Rain Mosaic “BmosaicR_d”**
  - Apply MFB gauge bias corrections for duration d for each radar

- **Mean Field Bias & Range Adjusted Rainrate Mosaic “RRmosaicRB”**
  - Apply MFB gauge bias corrections for each radar

  - Apply rainrate bias corrections for duration d

- **Rainrate Adjusted & MFB/Rng Adjusted Rainrate Mosaic “RRmosaicRBR”**
  - Apply rainrate bias corrections

- **Rate/MFB/Rng Adj. Multisensor Rain Mosaic “MmosaicRR_d”**
  - Apply multisensor merging using gauges for duration d

- **LB/Rng Adjusted Multisensor Rain Mosaic “MLmosaicR_d”**
  - Apply multisensor merging using gauges for duration d

- **EMPE**

- **AWIPS**

- **EMPE**

- **FFMP**
  - Implemented

- **HL-RDHM**
  - Not Yet Implemented

- **NWSRFS**
  - Implemented

- **SSHP**

- **MPN**

The diagram illustrates the sequence of bias correction procedures, starting with local and mean field bias adjustments, followed by rainrate adjustments, and finally multisensor merging.
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

- EMPE
  - Bias-adj rain rate mosaics
  - Bias-adj 15-min rainfall mosaics
  - RFC1 FFG
  - RFC2 FFG
  - RFC3 FFG
  - Gridded FFG mosaic

- Multisensor Precipitation Nowcaster
  - Projection
  - Assessment

- User adaptable params

- Products
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

1-HR FORECAST RAINFALL (mm)

08:30:00 UTC 12/17/2000
MPN Projection Products
One-hour Rain Rate Forecast

1-HR RAINRATE FORECAST (mm/hr)

08:30:00 UTC 12/17/2000
MPN Projection Products
Storm Motion Vectors and Reliability

STORM CELL MOTION AND RELIABILITY

08:30:00 UTC  12/17/2000
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

MAX OBS+PROJ PROBABILITY OF FFG EXCEEDANCE

11:45:00 UTC 12/17/2000

1-HR OBSERVED RAINFALL (mm)

11:45:00 UTC 12/17/2000

20
15
12.5
10
9
8
7
6
5
4
3
2
1
0.5
0.05
0
At end of the rain event
Real-time Web Page
http://www.nws.noaa.gov/ohd/hrl/hag/empe_mpn/

Multisensor Precipitation Estimation and Nowcasting for Flash Floods

A Radar Nowcasting Demonstration Project
to Improve Flash Flood Forecast and Warning Services
of the National Weather Service

Introduction
Quantitative precipitation estimation and nowcasting are important components of National Weather Service (NWS) flash flood warning services. They refer to the estimation of rainfall up to the current time using multiple sensors (WSR-88D, rain gauges, satellite estimates) and data. It is believed in the near future based on current observation models that soon, current observation models currently have lesser precipitation forecasts skill than the MPN products.

MPN products

The Enhanced Multisensor Precipitation Estimator (E-MPE) is a new prototype algorithm developed by the Hydrology Laboratory (NL) based on the existing operational Multisensor Precipitation Estimator (MPE) that is running at most River Forecast Centers and Weather Forecast Offices. However, it has the advantage of higher spatial and temoz resolution than the current MPE, a factor that is necessary if the products are to be useful for flash flood monitoring and warning purposes. Instead of one-hour multisensor rainfall estimates at a nominal 4-km (HRAP) grid scale with updates once per hour as with the current MPE, the E-MPE is more flexible and generates multi-duration rainfall products on a 1-km grid (14th HRAP) with updates as often as every 5-15 minutes based on what the user chooses. Details of the current MPE algorithm can be found under the "MPE Training Workshop" link at http://www.nws.noaa.gov/ohf/papers/papers.htm#wsr88d.

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These E-MPE and MPN products can be used as input to distributed hydrologic forecast models or other flash flood monitoring tools at the Weather Forecast Offices. Short-term rainfall nowcasts can provide forecasters with additional information for more timely decisions.
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.

Case 5

NFL
Example 2 – Visually Comparing Forecasts and Observations

Obs.

Fcst.

NFL
Comparison of average POD, FAR, and CSI of 1-hour accumulated precipitation forecast > 5 mm between persistence and MPN

- POD: +77%
- FAR: -43%
- CSI: +106%

Statistics computed on HRAP grid

27 historical flash flood events examined from 18 locations around the U.S. over ten years
Bias = $\Sigma(\text{fcst rain})/\Sigma(\text{obs rain})$

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

- Lead times are computed relative to the simulated peak time.
- All results shown are for CAVESP (90 km²) and single Event (7/2004)

Lead time gained over zero QPF

Peak errors of different forecasts relative to simulated flows as a function of lead time
Historical Performance of NWS Flash Flood Warning Lead Time

National Average Annual Flash Flood Warning Lead Time

Lead Time in Minutes


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

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<th>FY03 Actual</th>
<th>FY04 Actual</th>
<th>FY05 Actual</th>
<th>FY06 Goal</th>
<th>FY12 Goal</th>
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<td>41</td>
<td>48</td>
<td>54</td>
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<td>Accuracy (%)</td>
<td>89</td>
<td>89</td>
<td>88</td>
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**EMPE and MPN, when integrated with other WFO hydrology tools, have the potential to greatly increase future performance**
An Integrated Future Vision for QPE/QPN

Current HOSIP Projects in Hydromet Group

External Users

Distrib./Ensemble Hydro. Models, E-FFMP

Enhanced PPS
- Single radar
- Polarimetric
- Probabilistic
- ¼ km x ½ deg
- 4 min. updates

Enhanced MPE
- Multi-radar
- Multisensor
- Probabilistic
- ¼ HRAP (1 km)
- 5-60 min. rain durations
- 5-15 min. updates

HCA (REC)

RCA

CSSA

ORPG

Deterministic Radar-only QPE + Uncertainty Info

Auto-QC

Rain Gauges

AWIPS

Satellite QPE

Q2

NWP Analyses

Enhanced PPS

MPN
- 1-3 hr rainfall nowcasts
- HRAP (4 km)
- Multi-radar
- Multisensor
- Probabilistic
- 5-15 min. update

Deterministic Multisensor QPE + Uncertainty Info

PQPE Bias & Uncertainty Processor

Radar-only + Multisensor

Deterministic Radar-only QPE + Uncertainty Info

PQPN Bias & Uncertainty Processor

Short-term Deterministic Rainfall Nowcasts + Uncertainty Info

Satellite QPN

NWP Forecasts

QC Rain Gauges

AWIPS

AWIPS

AWIPS

AWIPS

Current

5 Yrs

10 Yrs

* = Current HOSIP Projects in Hydromet Group
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

- 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