NEXRAD/MPE Precipitation Estimation
Bias within the Ohio River Forecast Center Area of Operations — TAC Meeting Oct. 2004

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OHRFC Facts

- Staff of 16 hydrologists & meteorologists, 1 Administrative Support Assistant
- Ohio River drainage area = 453250 km²
- 29 major subbasins, subdivided into ~700 smaller subbasins
- Ohio River Mainstem highly regulated for navigation
- Also responsible for Lake Erie drainage
Topics

- Current OHRFC operations
- Sacramento Soil Moisture Accounting (SAC-SMA) model
- MPE Precipitation Estimation Bias
- Hydrologic Implications of Biased Precipitation Estimation
- OHD Proposed Range Correction Algorithm (RCA) & Convective-Stratiform Separation Algorithm (CSSA)
- Conclusions
Current OHRFC operations

- **Deterministic operations**
  - River flow & flood forecasting
  - 1 daily interactive forecast, partial evening update, & updates during flooding
  - 16 hours/day operations, 365 days/year — 24 hours/day during flooding
  - NWS River Forecast System (NWSRFS)
    - Operational Forecast System (OFS)
    - Calibration System
    - Ensemble Streamflow Prediction (ESP) System
    - Flash Flood Guidance System
  - 5-day forecasts
  - NEXRAD radar based precipitation estimation (MPE) with raingage correction
  - Forecasted precipitation & temperature
    - FFG (1-, 3-, 6-, 12-, 24-hr)
    - RRM/ESS product generation

- **AHPS/Probabilistic forecasts**
  - Provides estimates of forecast uncertainty
    - Model error
    - Uncertainty in initial model states
    - Hydrometeorological uncertainty
  - Long-term probabilistic forecasts using ESP
Hydrometeorological Data
The SAC-SMA model

- Conceptual hydrologic model derived from the **Stanford Watershed Model (circa 1960)**
- Lumped parameterization as opposed to distributed (e.g., a regular grid)
- 17 model parameters
  - Initial physically based estimates from NRCS STATSGO soil properties
- Requires calibration against observed streamflows
- Other models
  - Statistical (regression relationship, stochastic)
  - Physical (**TOPMODEL, DHSVM, SHE**)
  - Parametric (e.g., API)
- Lumped & distributed versions of the SAC-SMA out-performed all other participating **Distributed Modeling Intercomparison Project (DMIP)** models — results forthcoming in the **Journal of Hydrology**
SAC-SMA model Conceptualization
Model Calibrations

- Process by which model parameter values are adjusted to get **optimal** agreement between observations & simulation
- Many sources of error
  - Model is an inexact representation of reality, e.g., lumped vs spatially distributed models
  - Data biases, data inconsistency (e.g., station location changes, MAP vs MAPX), poor observational coverage, etc.
- Calibration periods normally exceed 20 years and span wet & dry climatic periods
- Significant effort is made to keep model parameter values regionally consistent
- Every effort made to not adjust physically estimated parameter values
- Not possible to calibrate **downstream** subbasins
- Some automatic model optimizations have been attempted, but generally a tedious manual process
Analysis of Precipitation & Temperature data
SAC-SMA Model Calibration
Lower Zone Tension Water Maximum (LZTWM)
MPE Precipitation Estimation Bias in the OHRFC Region

- Multisensor Precipitation Estimator (MPE) (and Stage-3) precipitation processing essential to OHRFC operations
- One of only 4 or 5 RFCs using either MPE or Stage-3 operationally
- NEXRAD radar derived precipitation used operationally for hydrologic model input since ~1997
- Significant biases apparent since early in ~1998
- Questions concerning sources of the biases
  - Random or systematic errors?
  - What adjustments are possible?
  - How much do these biases influence hydrologic forecast uncertainty?
Motivation for Radar Precipitation Study

- OHRFC operational commitment to Stage-3/MPE precipitation estimation
  - Operational use since 1997 using MAPX as sole precipitation input to NWSRFS hydrologic models
  - Inadequate raingauge support
    - Uneven spatial coverage
    - Reporting times too late to meet operational start
    - Complex terrain

- Operational biases apparent (known problem)
  - OHRFC operational experience
  - Other RFCs
  - NEXRAD radar precipitation estimation studies by Smith et al (Princeton Univ.) & others
    - Beam blockage
    - Beam over shooting
    - Range effect (spreading of the radar beam)
    - Non unique Z-R relationship
    - Hail contamination
    - Poor snow estimation
    - Orographic enhancement
    - Radar calibration
    - Truncation error (most apparent with stratiform precipitation)
    - Brightbanding

- Identify & understand all sources of biases and attempt to make corrections
- Use of nationally supported operational technology/software
Study Methodology

- Estimate MPE bias relative to raingauge-only estimate over the OHRFC area
  - \( \text{bias} = \frac{\text{XMRG}}{\text{raingauge}} \)
  - Uniform gridded field: \( \sim 5 \times 5 \text{ km}^2 \)
- Re-gridding of cell-centered (in lat-long coordinates) HRAP XMRG daily values
- IDW (inverse distance weighting) spatial interpolation to a new grid bounding the OHRFC area
- Spatial interpolation using \textit{Ordinary Kriging} (spherical model) of daily Co-op station reports (independent of hourly raingauge network used in MPE corrections)
- Summation of the new gridded fields
  - Annual total for 2002 & 2003
  - Seasonal DJF & JJA for 2002 & 2003
- Statistical analyses using R
- Tools — \textit{GRASS GIS 5.3}, \textit{R 1.7}, & \textit{GSTAT}
Not true independence of MPE XMRG precipitation estimates and raingauge precipitation estimates — the Co-op station reports also used in MPE estimation

Inconsistent set of raingauges used in raingauge fields — only 147 consistent for all 12 months out of ~600

Terrain effects (orographic enhancement) not included in raingauge field precipitation estimation — some underestimation?

Raingauge density inadequate to capture convective precipitation variability

Grid comparisons based on geographic rather than HRAP grid basis

HRAP grid missing a small portion of Lower Wabash River basin

The criteria for using raingauges may be too restrictive with respect to intolerance for missing data
Raingauge Stations

Precipitation Stations

Wednesday, October 20, 2004
OHRFC TAC Meeting Presentation
2002 MPE xmrg Precipitation Estimate
Co-op Raingauge Network
2002 Precipitation Estimate
Bias Calculation

MPE xmrg precipitation

Co-op gauge network precipitation

$$bias = \frac{MPE \, xmrg \, precipitation}{Coop \, raingauge \, network \, precipitation}$$
2002 Estimated MPE/xmrg Bias
MPE/xmrg Bias Comments

- **Bias = 1.0, implies perfect agreement**
  - Bias < 1.0, under-estimation
  - Bias > 1.0, over-estimation

- **Distinct regions of over- & under-estimation**
  - Under-estimation:
    - PBZ & BUF (Allegheny & Monongahela R. basins) and somewhat for CLE & IWX (Great Lakes drainage)
  - Over-estimation:
    - ILX, OHX, & ILN— Indiana & Ohio, Lower Cumberland R., Little Wabash, & Lower Wahash R. basins

- **Features due to radar index field (Thiessen polygons) boundaries**

- **Influence of local beam blockage apparent — IND, LVX, & PBZ**
MPE Radar Boundaries
MPE Radar Boundaries (cont.)
OHRFC Radar Heights Field
Seasonal Bias Comparison

DJF

JJA
Local Effects
2002 Bias Comparison (cont.)

$0.95 \leq \text{Acceptable Bias} \leq 1.05$

$0.90 \leq \text{Acceptable Bias} \leq 1.10$
Seasonal Bias Comparison (cont.)

DJF

0.95 ≤ Acceptable Bias ≤ 1.05

JJA

0.90 ≤ Acceptable Bias ≤ 1.10
Seasonal Bias Comparison (cont.)

DJF

JJA
Bias as a Function of Radar Beam Height
2002 & 2003 Comparison
2002 & 2003 Comparison (cont.)

2002 OHRFC XMRG Bias

2003 OHRFC XMRG Bias

XMRG Bias 2002

XMRG Bias 2003
2002 Seasonal Comparison
Hydrologic response is highly nonlinear

Impacts to daily forecasts
- Peak flows
- Flow volumes

Model states affected for long lead time ESP/AHPS forecasts

Impacts on weekly, monthly, annual water balance

Impacts FFG — Flash Flood watches & warnings

Timeliness of RFC forecasts delayed due to increased staff workload to make precipitation corrections
# Bias Summary 2002 by Basin

<table>
<thead>
<tr>
<th>Basin</th>
<th>Min.</th>
<th>1st-Qu.</th>
<th>Median</th>
<th>Mean</th>
<th>3rd-Qu.</th>
<th>Max.</th>
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<tbody>
<tr>
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## Bias Summary DJF 2002 by Basin

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<th>Min.</th>
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<tbody>
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## Bias Summary JJA 2002 by Basin

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<th>1st-Qu.</th>
<th>Median</th>
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Hydrograph without bias correction
Hydrograph with precipitation bias correction (~1.75)
# NWSRFS OFS Runtime Modifications

<table>
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<th>Mod Type</th>
<th>~Relative Frequency (%)</th>
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<td>RRIMULT</td>
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<td>UHGCHNG</td>
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<td>RRICNCHNG</td>
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<tr>
<td>SACBASEF</td>
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Approximately 1-year (227000 Mods)
<table>
<thead>
<tr>
<th>Precipitation Bias by Basin</th>
<th>% Bias</th>
<th>% MONTHLY VOL RMS ERROR</th>
<th>DISCHARGE RATIO (SIM/OBS)</th>
<th>MEAN % ERROR (AVGOBSQ-AVGSIMQ)/AVGOBSQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.80</td>
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</table>
### Precipitation Bias by Basin

<table>
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<th>Precipitation Bias by Basin</th>
<th>% Bias</th>
<th>% MONTHLY VOL RMS ERROR</th>
<th>DISCHARGE RATIO (SIM/OBS)</th>
<th>MEAN % ERROR (AVGOBSQ-AVGSIMQ)/AVGOBSQ</th>
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<td>1.20</td>
<td>45.44</td>
<td>64.65</td>
<td>1.50</td>
<td>51.10</td>
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## FLFK2N

<table>
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<th>Precipitation Bias by Basin</th>
<th>% Bias</th>
<th>% MONTHLY VOL RMS ERROR</th>
<th>DISCHARGE RATIO (SIM/OBS)</th>
<th>MEAN % ERROR (AVGOBSQ- AVGSIMQ)/AVGOBSQ</th>
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</thead>
<tbody>
<tr>
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<td>Precipitation Bias by Basin</td>
<td>% Bias</td>
<td>% MONTHLY VOL RMS ERROR</td>
<td>DISCHARGE RATIO (SIM/OBS)</td>
<td>MEAN % ERROR (AVGOBSQ-AVGSIMQ)/AVGOBSQ</td>
</tr>
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<td>--------</td>
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<td>----------------------------------------</td>
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</table>
Runoff Bias versus Precipitation Bias

Mean Annual Runoff Bias (%) as a function of Precipitation Bias
Selected Headwater Basins, OHRFC (1950 — 1999)
October 2002 Precipitation
Current SAC-SMA Model States
Indicated by Flow Probability of Exceedance
Flash Flood Guidance

Runoff

Precipitation

FFG_{T=1}  FFG_{T=2}

Drying

T = 1

T = 2
Case Example: Welsh, WV May 2 - 3, 2002

OHRFC-wide FFG

County FFG 05/01/2002

Gridded FFG 05/01/2002

County FFG 05/03/2002

Gridded FFG 05/03/2002
Case Example: Welsh, WV May 2 - 3, 2002
24-hr & 6-hr Precipitation Accumulation
Case Example: Welsh, WV May 2 - 3, 2002

3-day Time Evolution of FFG

05/01/2002

05/02/2002

05/03/2002

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Evansville XMRG Biases

VWX xmrng bias - 2002

VWX xmrng bias - 2003

VWX xmrng bias 2002 & 2003
JKL 2002 & 2003 Biases

JKL xmrg bias – 2002

JKL xmrg bias – 2003

XMRG bias

0 0.7 0.8 0.9 1.0 1.1 1.2 1.3

0 1 2 3 4

0.8 0.9 1.0 1.1 1.2 1.3

0 2 4 6
JKL 2002 & 2003 Biases (cont.)
JKL 2002 & 2003 Seasonal Comparison

- JKL xmr g bias DJF & JJA 2002
- JKL xmr g bias DJF & JJA 2003
JKL 2003 Biases by Month
PBZ (cont.)
PBZ 2003 XMRG Bias by Month
RLX (cont.)
RLX (cont.)
ILN (cont.)

Histogram of precipSdf.2002.xmrg.bias  Histogram of jja.bias$jja.2002.xmrg.bias
ILN (cont.)
Purposes of RCA/CSSA

- David Kitzmiller, Dongjun Seo, Feng Ding, David Riley (Hydrologic Science and Modeling Branch) and Christine Dietz, Cham Pham, Dennis Miller (Hydrologic Software Engineering Branch) — TAC Briefing, July 2004

- Range Correction Algorithm (RCA)
  - Mitigate rainfall overestimation associated with bright band
  - Mitigate rainfall underestimation at longer ranges

- Convective-Stratiform Separation Algorithm (CSSA)
  - Identify areas of shallow and deep convective precipitation
  - Data from convective zones is excluded from RCA adjustment
Errors in precipitation estimates are often magnified in runoff errors

Cool-season radar rainfall estimates often feature bright-band and range-degradation features that negatively affect:

- Operational precipitation analyses and verification
- Hydrologic forecasts
- River Forecast Center workload

Mosaic algorithms and local gauge corrections are often inadequate to mitigate these effects
Operational Needs

- Statement of Need from OS&T and OCCWS in June 2003
- NEXRAD Active Technical Needs, TAC TN-10 states:
  “Problems have been noted with VCP constraints, range-dependent effects, the radar bright band, ground clutter and beam occultation, ice-phase precipitation, and other factors.”
- Demands on radar data are increasing:
  - Implementing advances in hydrologic modeling requires utilization of radar input
  - National Digital Forecast Database verification also requires accurate radar input
  - Radar-based estimates are disseminated publicly
RCA Process

- Construct areal-mean Vertical Profile of Reflectivity (VPR) from latest volumetric scan
- Observations close to radar provide information on reflectivity near surface
- Use VPR to estimate near-surface reflectivity at ranges where lowest radar beam intersects melting layer, snow, or differing hydrometeor distribution aloft
By applying range adjustment and mean-field bias correction, obtained consistent and significant improvement in radar estimates, in terms of:

- Bias with respect to gauge amounts
- Mean absolute error (MAE)
- Root-mean squared (RMS) error
- Relative frequency of large errors
Improvement Due To Corrections: Radar/Gauge Mean Absolute Error (3-hour)

<table>
<thead>
<tr>
<th>Location</th>
<th>Original</th>
<th>Range+MFB correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>KRTX</td>
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<tr>
<td>KTLX</td>
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<td>KPBZ</td>
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<tr>
<td>KLWX</td>
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</tr>
<tr>
<td>ALL</td>
<td>0.45</td>
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</table>

Inch
Improvement Due To Corrections: Radar/Gauge RMS Error (3-Hour)

Inch

KRTX  KTLX  KEAX  KRLX  KPBN  KLWX  ALL

Original  Range+MFB correction

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Improvement Due To Corrections: Improvements in 1-h Verification

<table>
<thead>
<tr>
<th>Metric</th>
<th>Original</th>
<th>Range+MFB correction</th>
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<tbody>
<tr>
<td>Gauge/Radar Bias</td>
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<tr>
<td>RMSE, inch</td>
<td>0.2</td>
<td>0.4</td>
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<tr>
<td>MAE, inch</td>
<td>0.4</td>
<td>0.6</td>
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</table>
Improvement Due To Corrections: Reduction In Number of Large Errors

- 1-h error > .25"
- 3-h error > 0.5"
- 24-h error > 0.6"

% Cases

- Original
- Range+MFB correction
Improvements Apparent At All Ranges:

3-h Radar/Gauge Mean Absolute Error as Function of Range

*Inch*

- < 50 km
- 50-150 km
- > 150 km

Original

Range+MFB correction

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Improvements Apparent At All Ranges:

3-h Radar/Gauge RMS Error as Function of Range

<table>
<thead>
<tr>
<th>Inch</th>
<th>&lt; 50 km</th>
<th>50-150 km</th>
<th>&gt; 150 km</th>
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<tbody>
<tr>
<td>0.45</td>
<td>0.35</td>
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<td>0.4</td>
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<td></td>
<td>0.04</td>
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</table>

Original | Range+MFB correction

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Improvements Apparent At All Ranges:

3-h Radar/Gauge Bias

Inch

< 50 km  50-150 km  > 150 km

Gauge  Original Radar  Range+MFB correction
Conclusions

- OHRFC NEXRAD/MPE biases are significant — both over- & under-estimation
- The hydrologic impact of precipitation biases are very significant:
  - Hydrologic response is highly nonlinear
  - Impacts to daily forecasts
    - Peak flows
    - Flow volumes
  - Model states affected for long lead time ESP/AHPS forecasts
  - Impacts on weekly, monthly, annual water balance
  - Impacts FFG — Flash Flood watches & warnings
  - Timeliness of RFC forecasts delayed due to increased staff workload to make precipitation corrections
- Sources of biases are well documented in scientific literature
- Proposals made by the Office of Hydrologic Development (Hydrologic Science and Modeling Branch & Hydrologic Software Engineering Branch) for Range Correction Algorithm (RCA) and Convective-Stratiform Separation Algorithm (CSSA)
- RCA & CSSA will substantially reduce precipitation biases experienced at all RFCs, leading to substantial improvements in the accuracy of hydrologic forecasts and their timeliness