Ensemble Post-Processing and Verification of Short-Range Rainfall Forecast

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Acknowledgments

• Chandra Pathak, SFWMD
• Geoff Shaughnessy, SFWMD
• Muluneh Imru, SFWMD
• Terri Bennett, SFWMD
• Scott Huebner, SFWMD
• James D. Brown, NWS/OHD
• Jun Du, NWS/NCEP
Objectives

- Develop a prototype statistical post processor which, given the SFWMD-produced Day-1 QPF, estimates the conditional probability distribution of the (unknown) observed rainfall and generates an ensemble forecast from it
  - Correct/Reduce bias
  - Quantify uncertainty
- Formulate prototype graphical products that may best capture the probabilistic information for use by the District’s water managers and meteorologists
Why hydrologic ensemble forecasting?

1) Provide an estimate of the forecast (i.e. predictive) uncertainty
   - Confidence information (for the forecasters)
   - For user-specific risk-based decision-making (for the customers)

2) Improve forecast accuracy
   - An (optimally weighted) average of two good (or bad) forecasts is better than either of the two

3) Extend forecast lead time
   - Weather and climate forecasts are highly uncertain and noisy; they cannot practically be conveyed as single-valued

4) Cost-effective improvement of forecast systems, science and process
Theoretical framework

\[ f_1(q_f | q_o) = \int f_2(q_f | q_o, s_f) f_3(s_f | q_o) \, ds_f \]

Predictive uncertainty in streamflow  Residual hydrologic uncertainty  Uncertainty in model-predicted streamflow

where

- \( q_f \): Streamflow at some future times
- \( q_o \): Observed flow up to and including the current time
- \( s_f \): Model-predicted streamflow at the future times

Krzysztofowicz (1999)

\[ f_3(s_f | q_o) = \iiint f_4(s_f | b_f, i, p, q_o) \, f_5(b_f | i, p, q_o) \, f_6(p | i, q_o) \, f_7(i | q_o) \, db_f \, di \, dp \]

Uncertainty in model-predicted streamflow  Conditional hydrologic model simulation  Future forcing uncertainty  Parametric uncertainty  Initial condition uncertainty

where

- \( b_f \): Future boundary conditions (precipitation, temperature)
- \( i \): Initial conditions
- \( p \): Model parameters

Seo et al. (2006)
Elements of a hydrologic ensemble prediction system

Demargne et al. (2010)

Hydrology & Water Resources Models

Ensemble Pre-Processor

QPF, QTF

Ensemble Post-Processor

QPE, QTE, Soil Moisture

Data Assimilator

Streamflow

Input Uncertainty Processor

Parametric Uncertainty Processor

Hydrologic Uncertainty Processor

Hydrology & Water Resources Ensemble Product Generator

Ensemble Verification System
Rain areas analyzed:
BCP    (Jan 1997-Mar 2011)
ECAL   (Jan 1997-Mar 2011)
LK     (Jan 1993-Mar 2011)
LO     (Jan 1993-Mar 2011)
MSL    (Jan 1993-Mar 2011)
SWC    (Jan 1993-Mar 2011)
UK     (Jan 1993-Mar 2011)
Seasonal stratification

- Dry: Nov-Apr
- Wet: Jun-Sep
- Transition: May, Oct
The ensemble post-processor

• Models the conditional probability distribution of observed rainfall given (single-valued) forecast rainfall
  – Normal quantile transform
  – Linear regression in bivariate normal space
  – Parameter optimization
  – Inverse-transform
• Samples random deviates from the conditional distribution
• Seo et al. (2006), Schaake et al. (2007), Wu et al. (2011)
Ensemble Post-Processor

Off line, models joint distribution between single-valued QPF for each lead time and verifying observation

Multi-year archive of single-value QPF necessary
Ensemble Post-Processor

In real-time, given single-value QPF, generates ensemble traces from the conditional distribution for each lead time.

Obtain conditional distribution given a single-value forecast $x_{fcst}$

Conditional distribution given $x_{fcst}$

Ensemble forecast (for that particular timestep)
Evaluation

• All results are based on leave-one-year-out cross validation
• Parameter estimation used data from all seasons
• Results
  – Scatter plots
  – Verification of single-valued forecasts
  – Verification of ensemble forecast
Big Cypress Preserve

- Hurricane Mitch (1998)
- Hurricane Irene (1999)
- Tropical Storm Leslie (2000)
East Caloosahatchee

![East Caloosahatchee](image-url)
Lower Kissimmee

![Graphs showing forecasted vs. observed precipitation](image.png)
Lake Okeechobee

![Scatter plots showing forecasted vs observed precipitation](image)
Martin/St. Lucie Counties

![Scatter plots showing observed versus forecasted precipitation for Martin/St. Lucie Counties.](image-url)
Southwest Coast

Tropical Storm Fay (2008)
Tropical Storm Jerry (1995)
## All seasons, All amounts

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<tr>
<th>ID</th>
<th>N</th>
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<th>MSE (IN²)</th>
<th>COR</th>
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Bias = \( \frac{\Sigma \text{Obs}}{\Sigma \text{Fct}} \)
All seasons, Obs. rainfall > 0.5 (in)

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All seasons, Obs. rainfall > 2 (in)

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Mean= 3.10

Mean= 2.38
Wet season, All amounts

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Recall that parameter estimation used data from all seasons
Wet season, Obs. rainfall > 0.5 (in)

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Wet season, Obs. Rainfall > 1 (in)

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Wet season, Obs. Rainfall > 2 (in)

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<td>2.08</td>
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<td>1.79</td>
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<td>1.80</td>
<td>0.69</td>
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<td>1.67</td>
<td>0.61</td>
<td>1.87</td>
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<td>4.11</td>
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<td>2.87</td>
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<td>0.67</td>
<td>3.40</td>
<td>2.18</td>
<td>0.71</td>
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</table>

Mean= 3.39  
Mean= 2.56
Ensemble results

Tropical Storm Leslie
Tropical Storm Leslie over BCP

QPF=1.50 (IN)
Ens. Mean=2.36 (IN)
Ens. St. Dev.=2.63 (IN)
Obs.=4.38 (IN)
Ensemble verification

Reliability diagram

Relative operating characteristic (ROC)
If you “scatter-plotted” ensemble forecasts with box-and-whisker plots:

Modified box-and-whisker plot
Reliability

When my ensemble forecast says 90% chance of a 1/10 inch or more precipitation, does it actually happen 90% of the times?

Yes! (9/10)
Reliability

When my ensemble forecast says 50% chance of an inch or more precipitation, does it actually happen 50% of the times?

Yes! (5/10)
Reliability (cont.)

When my ensemble forecast says 10% chance of 2 inches or more precipitation, does it actually happen 10% of the times?

Yes! (1/10)
Can my ensemble forecast differentiate different outcomes?

No discrimination (the forecast cannot tell them apart)

Small events

Large events
Discrimination (cont.)

Can my ensemble forecast differentiate different outcomes?

Good discrimination! (the forecast can tell them apart)

Forecast

Observed

Small events

Large events
If you “scatter-plotted” ensemble forecasts with box-and-whisker plots:

Modified box-and-whisker plot
1) Subtract verifying obs from ensemble members, and
2) sort all “residual” ensemble forecasts in the ascending order of obs
(Just about) Perfect ensemble forecast

- False Alarm Rate
- Hit Rate
- Predicted probability
- Observed frequency

Reliability Diagram
Relative Operating Characteristic (ROC) curve
Climatological ensemble forecast is unconditionally reliable, and has no resolution or discrimination.
GEFS 12hr QPF (2000-2005) – Lead time=60 hrs

Reliability Diagram

ROC curve

Ivan
(09/18/04)

Frances
(09/09/04)

Ivan
Reliability Diagram, ROC - BCP

THRESHOLD=1.00 (IN)

THRESHOLD=1 (IN)
Reliability Diagram, ROC - ECAL

ECAL_

THRESHOLD=1.00 (IN)

OBSERVED FREQUENCY

PREDICTED PROBABILITY

ECAL_

HIT RATE

FALSE ALARM RATE

PP Ensemble Prediction
Ensemble Mean Prediction
Single-Valued QPF

THRESHOLD=1 (IN)
Reliability Diagram, ROC - LK
Reliability Diagram, ROC - LO

LO____

THRESHOLD=1.00 (IN)

OBSERVED FREQUENCY

PREDICTED PROBABILITY

LO____

HIT RATE

FALSE ALARM RATE

PP Ensemble Prediction
Ensemble Mean Prediction
Single-Valued QPF

THRESHOLD=0.8 (IN)
Reliability Diagram, ROC - MSL
Reliability Diagram, ROC - SWC

![Reliability Diagram](image)

The diagram on the left shows the observed frequency against the predicted probability, with a threshold of 1.00. The right diagram is a ROC curve, showing hit rate against false alarm rate, with different predictions represented by different markers.
Reliability Diagram, ROC - UK

UK__

THRESHOLD=1.00 (IN)

OBSERVED FREQUENCY

PREDICTED PROBABILITY

UK__

HIT RATE

FALSE ALARM RATE

PP Ensemble Prediction
Ensemble Mean Prediction
Single-Valued QPF

THRESHOLD=1 (IN)
Possible graphical real-time products

Adapted from Perkins et al. 2011
EPP 24-hr QPF/Hindcast (Oct 2002-Jul 2008) – Lead time=24 hrs

Possible graphical verification products

Hurricane A (mm/dd/yyyy)

Hurricane B (mm/dd/yyyy)

Reliability Diagram

ROC curve
Conclusions and recommendations

- Ensemble post-processing of SFWMD-produced Day-1 QPF is generally successful in reducing bias and quantifying uncertainty
  - Reduction in MSE by ensemble mean over the original forecast ranges from 4 to 15% for the 7 rain areas analyzed for observed rainfall > 2 in
- A number of missed (and very difficult) forecasts for very large rainfall amounts associated with hurricanes and tropical storms/depressions compromise reliability and skill of the ensemble forecast
  - Uncertainty modeling specifically for such events is necessary to improve performance
Conclusions and recommendations (cont.)

• A number of graphical products may be produced from ensemble post-processing to provide (initially) supplemental info on single-valued QPF
  – Bias
  – Uncertainty bound, confidence interval
  – Verification information
• Additional sources of info for future rainfall (e.g. SREF) should be sought to help reduce missed QPFs for very large rainfall amounts
  – The skill in such information is usually small
  – The only way to make use of such info is through ensemble forecasting
References

Thank you

For more information, contact:

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