Effect of Variations in Reflectivity-Rainfall Relationships on Runoff Predictions

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Motivation

• To use weather radar data in hydrological applications, radar reflectivity ($Z$) need to be transformed into surface rainfall estimates ($R$).

• Estimation of the $Z$-$R$ relationships is subject to several sources of uncertainties including the storm-to-storm and within the storm variations in raindrop size distributions (DSD).

• Previous studies demonstrated that accounting for temporal/spatial variability in DSD and $Z$-$R$ relations affect the overall accuracy of rainfall estimates.
  - (e.g., Uijelenhoet et al. 2003; Lee and Zawadzki 2005)

• Despite the recognized effect of DSD and $Z$-$R$ variability, less attention has been dedicated to their effect on hydrologic predictions.

• Some early analysis was reported (Winchell et al., 1998) but focused only on total aggregate runoff volumes.

• Most hydrologic modeling studies use a single $Z$-$R$ relationship.

• It is not well understood how the variability in DSD and $Z$-$R$ relationships affect the accuracy of the hydrologic predictions.
Overall Objective

• Investigate the effect of intra-storm and inter-storm variability in Z-R relationships on predictions of stream-flow.

Approach

• Perform the analysis using high-resolution disdrometer measurements along with WSR-88D reflectivity data over an experimental watershed.

• Employ a physically-based hydrologic model to ensure the physical representation of rainfall-runoff processes.
Experiment Site:
Isaac-Verot Watershed, Southern Louisiana

Coverage of Closest NEXRAD stations
KLCH = 116 km
KPOE = 143 km

Annual precipitation = 55-60 inches
Data are been continuously collected since early-2004
Hydrologic Model:
Gridded Surface Subsurface Hydrologic Analysis (GSSHA)

• GSSHA is a physically-based fully distributed hydrologic model (Ogden and Downer, 2002).

• GSSHA uses finite difference and finite volume methods to simulate different hydrologic processes.

• The modeling setup used in our study included:
  – two-dimensional diffusive wave for overland flow
  – one-dimensional explicit diffusive wave method for channel flow
  – Penman-Monteith equation for evapotranspiration.
  – Green and Ampt infiltration with redistribution method (Ogden and Saghafian, 1997) for flow simulation in the unsaturated zone.
  – This infiltration method includes soil moisture accounting and allows for a continuous long-term simulation of the selected periods that contain multiple runoff events.
Prior to being used in further analysis, the model was rigorously calibrated and validated.
Calibration/Validation of physically-based Hydrologic Model Using Historic Data

Select rainfall/runoff periods containing several events with various rainfall regimes/types.

Disdrometer DSD data
- calculate “reference/true” Rainfall ($R_{\text{ref}}$)
- Hydrologic model
- Produce “reference/true” stream-flow ($Q_{\text{ref}}$)

Reflectivity Data (Z) (disdrometer or radar)
- Use $Z$ and $R_{\text{ref}}$ to estimate $A$ & $b$ in $Z$-$R$
- Use $Z$-$R$ to estimate $R_{\text{est}}$
- Hydrologic model
- Produce stream-flow ($Q_{\text{est}}$)
Methodology (You can delete this slide if you like the previous one)

• Select rainfall/runoff periods that contain several events with various rainfall regimes/types.
• Use the disdrometer DSD data to calculate “reference/true” rainfall.
• Use the reference rainfall to drive the hydrologic model and produce “reference/true” stream-flow.
• Calculate Z from disdrometer DSD.
• Estimate A and b for Z-R using:
  – different scales for the estimation (e.g., climatological, event, storm, sub-storm)
  – different estimation methods (e.g., least-squares regression, min RMSE)
• Run the hydrologic model with each of the estimated rainfall to predict runoff.
• Assess how estimated rainfall and streamflow compare to the reference values.
• Repeat the analysis using Z from radar.
Different Time Scales for Estimating Coefficient and Exponent of $Z = A R^b$

- **Climatological:**
  - Estimate $A$ and $b$ using combined long-term disdrometer data (e.g., one year).
- **Storm scale:**
  - Estimate $A$ and $b$ using Z-R data from each storm.
- **Event scale:**
  - Estimate $A$ and $b$ for each event with a storm.
- **Sub-event scale:**
  - Split the event into convective/stratiform/transitional periods and estimate $A$ and $b$ for each period.
Different Methods for Estimating Coefficient and Exponent of $Z = A R^b$

- **Least Squares Fit (LSF):**
  - Estimate $A$ and $b$ using *linear* least squares regression fitting.

- **Bias corrected LSF:**
  - Fix $b$ (e.g., 1.2 or 1.4) and estimate $A$ by removing the overall bias.

- **BIAS_RMSE:**
  - Estimate $A$ and $b$ by removing the bias and optimization for minimum RMSE.

- **Default:**
  - $Z=300 \ R^{1.4}; \ Z=250 \ R^{1.2}$
Selected Storms

• June 22-27, 2004:
  – included of a sequence of high-intensity and short-duration convective squall line storms.
  – A total of ~ 7 inches of rainfall accumulations.

• October 7-10, 2004:
  – includes Tropical Storm Matthew (10 inches of rain).
  – Storm Matthew resulted in significant runoff as high as 2.6 m$^3$/sec/km$^2$.

• November 17-27, 2004:
  – An extensively wet period of scattered and squall line storms.
  – Five distinct rain storms are observed in this period.
  – A total of ~ 6 inches of rainfall accumulations.
  – Runoff generated not very high but had consistent response to rainfall.
October 2004 Storm (TS Matthew)
June 2004 Storm

Rainfall Accumulation (mm)

Julian day of 2004

Rainfall Intensity (mm h⁻¹)

Julian day of 2004

Reflectivity Z (dBZ)

Julian day of 2004

Radar

Disdrometer
Rainfall rate (mm h\(^{-1}\))

June 2004 Storm (Disdrometer)

Radar Reflectivity Z (mm\(^6\) m\(^{-3}\))
June 2004 Storm (Radar)

Rainfall rate (mm h\(^{-1}\))

Rainfall Intensity (mm h\(^{-1}\))

Radar Reflectivity Z (mm\(^6\) m\(^{-3}\))
Vertical Profile of Reflectivity
June 2004
June 2004 Storm (Disdrometer)

(LSF estimation method)

BIAS_RMSE estimation method
June 2004 Storm (radar)

(LSF estimation method)

BIAS_RMSE estimation method
June 2004 (Radar)

Reference Default Storm Event Sub-event

Runoff (m$^3$/sec)

 Julian day of 2004

LSF

BIAS_RMSE

Runoff (m$^3$/sec)

 Julian day of 2004
Conclusions

• Z-R parameters show strong dependence on the estimation time scale and on the method of estimation.

• Use of least-squares fitting resulted in relatively inaccurate rainfall estimates and poor runoff predictions especially when coarse estimation time scales were used (e.g., storm or event).

• The least-squares fitting method gives improved results only when the estimation is performed on a sub-event time scale that accounts for convective/stratiform classification.

• Estimation based on bias removal and minimization of random differences (BIAS_RMSE) shows superior accuracy even when using coarse estimation time scales.

• Estimation time-scales that account for variations in the sub-event rainfall physical processes do not necessarily result in significant improvements in runoff predictions.

• A simple estimation method based only on bias removing and selection of a climatological representative exponent has resulted in acceptable runoff predictions.
Thank You!

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