Radar/Surface Quantitative Precipitation Estimation

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Radar Sampling

- Accurate quantitative precipitation estimation (QPE) using radar requires an understanding of sampling characteristics and limitations of scanning weather radar

- Sampling is dependent on a variety of radar attributes:
  - Radar attributes
  - Scan strategy
  - Sample volume
  - Range dependency
  - Atmospheric conditions
  - Terrain
Sampling Considerations

- Difference in sample location: Radar is usually scanning above the surface where we want to know what is happening at the surface (e.g., surface rainfall).
- Fast moving storms or strong wind shear at low-levels, the precipitation that is located over a given location observed by radar aloft may propagate considerably downrange before reaching the ground.
- Precipitation from high based clouds may evaporate considerably or completely before reaching the ground.
- Partial or total beam blockage will reduce the amount of energy received to the radar, which will cause a significant underestimation in radar derived parameters such as storm intensity or surface rainfall estimates.
Radar-Derived QPE

Accurate radar rainfall estimates depends on a variety of precipitation conditions:

- Sub-radar sample volume precipitation variability
- Variations in particle size distributions
- Vertical profile variations
- Non-uniqueness in reflectivity-rainfall (Z-R) relationships
Sub-Radar Volume Rainfall Variability

- The natural variability of rainfall within a radar volume (~1 – 8 km²) can result in a significant overestimation of radar estimated error.
- The natural variability is dependent on precipitation type (convective/stratiform).
- The natural rainfall variability can be estimated using a dense network of rain gauges.
  - The spatial correlation function is used to separate the radar error from the natural variability of rainfall.
Sub-Radar Volume Rainfall Variability

- Example: Spatial correlation of rainfall in convective and stratiform rain observed in South Florida.

![Graph showing correlation coefficient vs. gauge separation distance in km.](image)

- Correlation coefficient decreases with increasing gauge separation distance.
- Two lines represent adjusted light rain and heavy rain scenarios.
Vertical Profile Variations

- The vertical profile of storm intensity will vary within a storm (i.e. convective-stratiform), from storm to storm, by season, climate region, etc.
- This can cause large uncertainty in radar rainfall estimates.
- This effect should be quantified if possible.
Vertical Profile Variations

- Example: Vertical profiles of reflectivity retrieved from NPOL and high resolution vertical profiler measurements
- Convective storm observed in South Florida
The relationship between radar reflectivity and rainfall rate is not unique. It depends on the drop size distribution. As mentioned before, drop size distribution can vary significantly over a broad range of spatial and temporal scales. Typically, a reflectivity to rainfall (Z-R) relationship is empirically fit using a power law: $Z=AR^b$. The $A$ coefficient can range from about 50 to 500 and $b$ ranges from 1.0 to about 3.0.
Z-R Relationships

The coefficients of the Z-R relation are found to have great natural variability. The variability is associated with numerous factors:

- Location: geographic and climate
- Latitude, humidity, instability, orographic and coastal effects, season, thermodynamic, dynamical, and microphysical processes
- Cloud structure: Convective or stratiform precipitation
# Z-R Relationships

<table>
<thead>
<tr>
<th>Source</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marshall &amp; Palmer</td>
<td>200 $R^{1.6}$</td>
</tr>
<tr>
<td>Joss &amp; Waldvogel</td>
<td>300 $R^{1.5}$</td>
</tr>
<tr>
<td>Sekhon and Srivastava</td>
<td>300 $R^{1.35}$</td>
</tr>
<tr>
<td>Short and Kucera Convective</td>
<td>120 $R^{1.43}$</td>
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<tr>
<td>Short and Kucera Stratiform</td>
<td>320 $R^{1.43}$</td>
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<tr>
<td>Kucera - Guam</td>
<td>103 $R^{1.5}$</td>
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<tr>
<td>NEXRAD</td>
<td>300 $R^{1.4}$</td>
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</table>
Z-R Relationships

- Marshall-Palmer
- Joss-Waldvogel
- Cain-Smith (ND)
- Laws-Parsons
- Sekhon-Srivastava (water)
- Sekhon-Srivastava (ice)
Summary of Z-R Relationships

In the Z-R relationship: $Z = AR^b$

- The A coefficient usually ranges from: 50 – 500
- The $b$ coefficient usually has a range: 1.0 – 3.0

Fig. 8.6 Sixty-nine $R$, $Z$ relationships from Battan (1973).
How to generate optimal radar rainfall estimates with minimum uncertainty?

- Rain gauges and disdrometers are the only reasonable ground reference standard
- Need to account for sampling differences: small scale rainfall variability
- Bias estimation (range dependence effects)
- Need to develop appropriate statistical methodologies to estimate uncertainties
- Direct validation using dense surface rain gauge network is usually the best approach, but observational uncertainties need to be considered
Radar-Rain Gauge Measurements

- The perennial question is: “Which is correct? radar or rain gauge?”
- Generally speaking, a rain gauge is considered the validation tool or the “truth” in comparisons with radar rainfall estimates.
- There are issues to consider when validating radar rainfall estimates using rain gauges.
Radar Rainfall Validation Issues

- Rain gauges are the only reasonable ground reference standard but…
- Acute problem in the sampling area difference: some 8 orders of magnitude!
- Measurement uncertainties or calibration errors
- Sample size
  - It may take 10 to hundreds of rain gauges to have a representative sample in convective rain but only a few or less in uniform (stratiform) rain
Error Sources Comparing Radar to Rain Gauges

- **Brightband** – this will cause significant overestimation of radar rainfall estimates
  - This can result in a “ring” of enhanced precipitation

- **Temporal differences:** rain gauges sample anywhere for 1 min to daily accumulations; radar scans an entire storm in seconds
  - Temporal averaging needs to be done with rain gauge or radar data or both
How Do We Effectively Compare Radar to Rain Gauges?
Central Florida

1 m 860 m 2300 m

5 min 15 min 60 min
Spatial and Temporal Variability of Rainfall

Key Results:
- Rainfall is more correlated at shorter distances.
- Rainfall is more correlated at longer integration (time) scales.
Need to Determine the Small Scale Variability Within a Radar Grid

- We need to determine the correlation of rainfall as function of distance

<table>
<thead>
<tr>
<th>Normalized distance (x/L)</th>
<th>Correlation coefficient</th>
<th>Variance ratio</th>
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<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0.25</td>
<td>0.8</td>
<td>0.75</td>
</tr>
<tr>
<td>0.5</td>
<td>0.6</td>
<td>0.5</td>
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<tr>
<td>0.75</td>
<td>0.4</td>
<td>0.25</td>
</tr>
<tr>
<td>1</td>
<td>0.2</td>
<td>0</td>
</tr>
</tbody>
</table>

- Correlation shape parameter $S_0 = 1.0$
- $S_0 = 3.0$

- $x/L = 0.1$
- $x/L = 0.5$
Other Issues…

- Space/time scale matching:
  “What temporal scale is adequate for evaluation of spatial average products?”
At what temporal scale do we compare radar to rain gauge?
Direct Validation

- Experimental design with *in-situ* observational network dense enough to give estimates of areal rainfall with very small errors
- Distributed along same azimuth to sample radar range effects
Technological Perspectives of Developing a Surface Network

- **Operational**
  - Networked radars
  - Develop dense rain gauge networks to examine small scale variability and large network to examine range dependent errors
  - Real-time availability

- **Research**
  - Development of new reference instruments (disdrometers vs. rain gauges, long-term sites for monitoring)
  - Perform detailed studies of error structure (statistical modeling studies)
Recommendation for Strategies

- Organize several sites for radar rainfall validation
  - High density independent clusters of rain gauges covering 1-10 radar product pixels
  - Commit their operation for extended periods (optimally 10-20 yrs) to develop a large statistical sample and climatology of rainfall

- Develop performance benchmarks for current and new instruments and methods

- Develop large databases of quality data & products

- Develop theories and methodologies

- Turn new technologies to operational meteorologists, hydrologists for testing and evaluation
How Do You Design a Rain Gauge Network?

- The best approach is to perform rainfall simulation studies (e.g. Monte Carlo approach) to see what would be the estimated radar rainfall error for a particular rain gauge network design for various rainfall regimes (i.e. convective/stratiform).
- Combine this information in a GIS framework to determine the optimal placement of the gauges.
- The next two slides show the reduction in error with the addition of gauges in dense network.
Designing a Rain Gauge Network

Convective Rainfall: $d_0 = 5$ km

8.2% 8.0% 7.4% 5.8%
Designing a Rain Gauge Network

Stratiform Rainfall: $d_0=15$ km

- 3.7%
- 3.6%
- 3.4%
- 3.2%
Rain Gauge Calibration

- The radar rainfall estimates will only be as good as the surface reference data: quality of rain gauge data
- It is important to calibrate the instruments before and after deploying them in the field
- Example: Dynamic rain gauge calibration
Dynamic Calibration Error

- Rain gauges should be calibrated to account for rainfall intensity effects
- Rain gauges will underestimate rainfall rates at high intensities
  - Splashing of water outside gauges
  - Buckets will tip before completely filled
  - This effect could cause an underestimation on the order of 20% for high rain rates (> 100 mm/h)
Dynamic Calibration Setup

- Dynamic calibration equipment

Laboratory Setup

Field Setup
Dynamic Calibration Error

- This calibration should be done for all research type rain gauges

Typical Dynamic calibration error of a tipping bucket rain gauge

\[ y = 0.0012x^2 + 0.9627x \]

\[ R^2 = 0.9984 \]