Radar and Rain-Gauge Data Quality and Processing

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Typhoon Committee Roving Seminar

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Lecture Topics

**Topic B** – Rain gauge and radar data processing for QPE/QPF

**Goal:** Scrutinise the radar processing chain for accurate QPE and QPF

1. Radar and Rain-Gauge Data Quality and Processing
2. Radar Precipitation and Rain-Gauge Adjustment Techniques
3. Radar-Based Nowcasting and Verification Techniques

**Reading Material:**

Examples from SAWS and MSS Radar networks.
Outline

Radar Data Quality

- Network Design (Attenuation)
- Radar Data Quality Monitoring
- Signal Processing (Second Trip)
- Radar Data Quality Control
  - Reflectivity
  - Velocity
  - QI
- Radar Data Processing (Composite)
- Rain Gauge Quality Control

Useful Tools

- wradlib: wradlib.org/tag/python
- PyART: arm-doe.github.io/pyart/
- Baltrad: git://git.baltrad.eu/
- LROSE: https://github.com/NCAR/lrose-core

Each radar/network is unique. It will take some investigation into what works best.
Radar Network Design
Singapore Radar Network

- Long Range Scan = 480 km
- Changi = 125km; extended to 250 km
- Seletar = 120km; extended to 240 km

MSS Radar Network:
- Changi S-band (Blue)
- Seletar C-band (Red)
- 1° beam width
- Doppler, Dual-Polarised

Limitation associated with:
- C-band; attenuation, RLAN
- S-band; Drizzle

Data quality starts with network design and implementation
Radar Data Quality: Changi & Seletar Comparison

RADAR: QC’ed data
Range: 125km
Products: CMAX

COMPARISON:
C-band and S-band

• Attenuation
• Beam Blockage
• Bright Band

A radar in the WEST of Singapore could potentially provide good data for Sumatra squall events.
Radar Quality Monitoring
What are you working with?

- A Dual-Polarized Doppler Weather Radar will typically produce several radar moments.

- What is the quality like?
  - Relative term that depends on purpose of radar
  - TDWR, QPE, DA, etc.

- Quality in measurement can be divided into 2 categories:
  - On-site: Radar related
  - Off-site: Atmosphere related

Calibration: Solar Monitoring

- Antenna alignment (TRUE NORTH)
- Apparent beam width
- Received Power
- Dual-Pol monitoring possible

Data: January to December 2017
- 7 day rolling average due to limited sun spike hits.
- Down time end July due to system upgrade.

Average Daily Received Solar Power - 2017

Dominion Radio Astrophysical Observatory (DRAO, Canada)
Calibration Monitoring - Sun spike

Sun Hits over a 3 Month period:
- Antenna alignment to true North

Monitor over 30 day period:
- Received solar power
- Angular bias
- Apparent beam width
- Number of solar hits per day
Example – Radar/Satellite Comparison

- Radar Composite overlaid with MSG convective RGB
- Clear Durban radar is not aligned to TRUE North
Calibration Monitoring - Sun spike
Example - Calibration
Calibration: **Best Practices**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>How to Conduct</th>
<th>Recommended Frequency</th>
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</thead>
<tbody>
<tr>
<td>Transmitting frequency</td>
<td>Counter, frequency meter, or spectrum analyzer</td>
<td>Daily</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>Crystal detector and oscilloscope</td>
<td>Weekly</td>
</tr>
<tr>
<td>Transmitted spectrum</td>
<td>Spectrum analyzer</td>
<td>Once a year, unless transmitted signal changes</td>
</tr>
<tr>
<td>Transmitted power</td>
<td>Power meter</td>
<td>Daily</td>
</tr>
<tr>
<td>Transmitted power stability</td>
<td>BITE</td>
<td>Continuous</td>
</tr>
<tr>
<td>Receiver calibration</td>
<td>Signal generator</td>
<td>Weekly</td>
</tr>
<tr>
<td>Receiver calibration stability</td>
<td>BITE</td>
<td>Once every scan</td>
</tr>
<tr>
<td>Antenna orientation</td>
<td>SSU</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Antenna return loss (VSWR)</td>
<td>Power meter</td>
<td>Weekly</td>
</tr>
<tr>
<td>Corner reflector</td>
<td>Fixed setup as in Section 3.1.1</td>
<td>Continuous when possible</td>
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<tr>
<td>Sphere calibration</td>
<td>Tethered or free-floating sphere, depending on logistics</td>
<td>Once a year</td>
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<tr>
<td>$Z_D$ calibration, vertical-looking scans</td>
<td>Section 3.3.1</td>
<td>When suitable precipitation occurs overhead</td>
</tr>
<tr>
<td>$Z_D$ calibration, solar measurements</td>
<td>Solar measurements</td>
<td>Can be done routinely every day.</td>
</tr>
<tr>
<td>Solar calibration monitoring</td>
<td></td>
<td>Can be done very regularly and frequently</td>
</tr>
<tr>
<td>Ground target monitoring</td>
<td>Routine or special scans</td>
<td>Can be done every scan if target is routinely visible</td>
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<tr>
<td>Calibration campaign</td>
<td>As described in Section 2, including standard-gain horn measurements</td>
<td>Once a year</td>
</tr>
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</table>

- Document calibration results.
- Solar monitoring, only Rx chain and Antenna pointing.
- Need for Tx and DP monitoring
- Work towards Vertical Scans (Brid-Bath) and BITE figures
- Started working towards Stable Clutter:

**Table 2. A summary of calibration practices.**

Chandrasekar et al., 2015: Calibration Procedures for Global Precipitation-Measurement Ground-Validation Radars
Signal Processing
Scan Strategy

Scan Sequence

- **Changi**
  - Parameters
    - Temporal resolution [min]: 5
    - Elevations [deg]: 0.3, 1.0, 1.5, 3.0, 5.0, 7.5, 10.0, 20.0, 40.0
    - Stop range [km]: 250 and 480
    - Bin resolution [m]: 250
    - PRF [Low, High] [Hz]: 0/1200
    - Pulse width [μs]: 0.85, 3.3
    - Antenna Speed [deg/s]: 24, 30, 12
    - Angle Step [deg]: 1
    - Time Sample: 49/39, 24

- **Seletar**
  - Parameters
    - Temporal resolution [min]: 5
    - Elevations [deg]: 0.3, 1.0, 1.5, 3.0, 5.0, 7.5, 10.0, 20.0, 40.0
    - Stop range [km]: 240 and 480
    - Bin resolution [m]: 127.5
    - PRF [Low, High] [Hz]: 833/1250
    - Pulse width [μs]: 0.45, 3.5
    - Antenna Speed [deg/s]: 18, 15
    - Angle Step [deg]: 1
    - Time Sample: 29, 20

Filter Settings

<table>
<thead>
<tr>
<th>Filter</th>
<th>Changi - Volume</th>
<th>Changi – Long Range</th>
<th>Seletar - Volume</th>
<th>Seletar – Long Range</th>
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<td>OFF</td>
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<td>SAFE MODE</td>
<td>SAFE MODE</td>
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<td>Spatial Filter</td>
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<tr>
<td>Speckle Filter</td>
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<td>Active</td>
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</table>
Signal Processing: Reflectivity

- Frequency vs. Range plots:
  - Second Trip Echo
  - Errors in software (KDP/uPhiDP?)
  - Minimum Detectable Signal
    \[ z = 328.64 R^{1.29} \]
    Kumar et al. 2011

Changi: S-band
1° Elevation DBZH

Seletar: C-band

Changi Annual Rainfall vs Range - 2017

\[ 15 \text{dBZ} \approx 0.16 \text{ mm/h} \]
Signal Processing: Minimal Detectable Signal

Ideal: below 15 dBZ

15dBZ ≈ 0.15 mm/h

Has to do with pulse width
How to possibly fix this?

The radar equation:

\[ P_r = \frac{\pi^2}{1024 \ln(2)} \cdot \frac{P_i G^2 \theta \phi \tau}{\lambda^2} \cdot \frac{|K|^2}{r^2} Z \]
Signal Processing: Second Trip


Figure 3.4 The long, narrow shape of a second-trip echo arises because the echo is constrained into the solid angle of the beam, but much closer to the radar.
Signal Processing: **Second Trip**

RADAR: Seletar C-band  
Range Scan: 250km  
Elevation: 1.0°  
V nyquist: $\approx \pm 32 \text{ m/s}$

- dBuZ – Uncorrected
- dBZ – Corrected
Signal Processing: Second Trip

RADAR: Seletar C-band
Range Scan: 250km
Elevation: 1.0°
V nyquist: ≈ ±32 m/s

- dBUZ – Uncorrected
- dBZ – Corrected
Signal Processing: Second Trip

RADAR: Seletar C-band
Range Scan: 250km
Product: CMAX
V nyquist: $\pm 32$ m/s

ISSUES:
• RLAN interference
• Second Trip

dBZ – Cross Sections
Signal Processing: Velocity

Frequency vs Range: January 2019

Changi: S-band 1° Elevation VRADH

- Second Trip Filter
- Errors in software
- Aggressive filtering

Discrete Fourier Transform (DFT) Filter Width:
- Changi: 3.96 m/s [-1.98 – 1.98]
- Seletar: 3.32 m/s [-1.66 – 1.66]
- IMPACT ON SHEAR AND PHENOMENA DETECTION?
Signal Processing: DFT Filter

RADAR: Seletar C-band
Range Scan: 480km
Elevation: 0.8°
V nyquist: $\approx \pm 8 \text{ m/s}$

ISSUES:
- DTF Filter removing too much info
Signal Processing: **Recommendation**

**Balanced** Scan strategy (compromise):
- Time sampling important
- Balance between (pulse width, PRF, staggering, etc...)
- Can combine multiple “scans”
  - Shear (100sec)
  - PCAPPI (2.5 min)
  - Long Range (5 min)
  - Volume (14 unique elevations, 5 min)
  - Bird Bath (5 min)
- Need to get this part right, can’t rerun
Quality Control and Processing
Factor Influencing Radar Quality
Example - Ships

Ship detected within Sea Clutter

> 10 Months Accumulated Rainfall
George radar SA

2017 Accumulated Rainfall
Singapore Changi

Mountain Range to the North causing beam blockage

Shipping lanes
Example - Beam Blockage
Bright Band

- Common in stratiform precipitation.
- Happens when ice starts to melt falling through freezing level.
- Result due to inherent differences in reflective properties of ice and water.
- Dielectric constant water = 0.93 and ice = 0.197
Bright Band Filter - Result

- BBC
- PPI 3.4
- No BBC
- Stratiform rain
Hourly Accumulations – Bright Band Cases
Verification – Bright Band Cases

Correlation 1 Hour Gauges

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BIAS 1 Hour Gauges

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MAE 1 Hour Gauges

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RMSE 1 Hour Gauges

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Verification – Bright Band Cases

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<thead>
<tr>
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<th>Bright Band Cases</th>
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<tr>
<td>1</td>
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<tr>
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<td>3.27</td>
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<tr>
<td>7</td>
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Quality Control

QC Filters Applied:
1. Cut second trip
2. Ships (rack)
3. Non-Met echoes (rack)
4. Speckle (pyart)
5. Threshold extremes
6. Gabella (wradlib)
7. Interpolate Missing Values (wradlib)

There is no one size fits all scenario with QC parameters.

Will require a cautious approach

Interference filter active on Signal Processor

PyART: arm-doe.github.io/pyart/
wradlib: wradlib.org/tag/python
QC using SCOUT
Beam Blockage Correction, Ground Clutter Removal, Speckle Filter, Reverse Speckle, Gabella Filter, Interpolation

Ermelo – No QC

Ermelo – QC
QC using SCOUT

Beam Blockage Correction, Ground Clutter Removal, Speckle Filter, Reverse Speckle, Gabella Filter, Interpolation

Durban – No QC

Durban - QC
Velocity Folding – Dealing with aliasing

Velocity dealiasing using Py-ART

Raw Doppler Velocity, Seventh Sweep

Corrected Doppler Velocity, Seventh Sweep
Quality Control (QC)

Before

After
Quality Index (QI) Field

Dynamic QI (Weather related)
- Attenuation
- Bright Band
- Aircraft
- Birds, insects (bio)
- Vertical variability
- Anomalous propagation

Static QI (properties of radar)
- Range
- Beam blockage
- Beam height
- Ground clutter
- Good to use in network planning
QI (static) example – compositing
Data Processing
Convert to 3D Cartesian

WSSS

500 X 500 X 39 pixel, ±125km, 500m resolution
Proj: azeq

WSSL

480 X 480 X 39 pixel, ±120km, 500m resolution
Proj: azeq
Composite Domain

Methods:
- Max
- Mean
- QI Weights
- Timing sync scans

Data sources:
- PPI
- CAPPI
- 3D Cart

COMP MAX:
- 525X531 pixel, ±125km, 500m resolution,
- Proj: latlon

COMP MAX:
- 3697X3215 pixel, 500m resolution,
- Proj: latlon

South Africa - 04/09/2015 14:00:00 UTC - Radar 24HR Rainfall
Rain Gauge Quality Control
Rain Gauge Quality Control Procedure

Possible sources of error
1. Detection of gaps in the data.
2. Detection of physically impossible values.
3. Control of measurement variability.
4. Detection of constant values.
5. Control of internal consistency.
6. Control of spatial consistency.

Analysis
- Calculate univariate and bivariate statistics
- QQ-plots, Bubble-plots, Histograms, etc.
- Threshold unrealistic values
- Round to the nears 10\textsuperscript{th} (floating point errors)
- Find Correlations, Medians, Averages, Accumulation, Availability
Rain Gauge Data

- Univariate Statistics:
- QQ plot
- Extreme values thresholding
- Set to missing
- QQ-plot now showing more realistic values
- Histogram showing log distribution
Rain Gauge Data
Rain Gauge Data
Rain Gauge Data
Rain Gauge Data
More Quality Control techniques

1. Gross error checking (unrealistic values)
2. Range Test Check (statistical Distributions, Probability of occurrence)
3. Spatial Consistency Check (SCC) (declustering)
4. Temporal Consistency Check (Constant Values)
5. Radar and Satellite Conformity Check (Correlation, Rolling accumulations)

• Irena Otop1,* , Jan Szturc1, Katarzyna Ośródka1 and Piotr Djaków1 Automatic quality control of telemetric rain gauge data for operational applications at IMGW-PIB
• Any good Geostatistics Textbook
Thank You
Questions?

Erik_BECKER@nea.gov.sg