Radar and Rain-Gauge Data Quality and Processing

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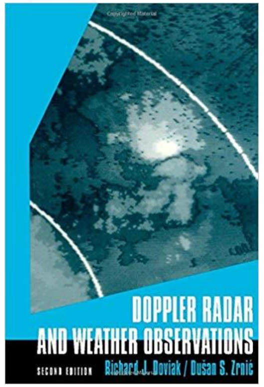
Typhoon Committee Roving Seminar

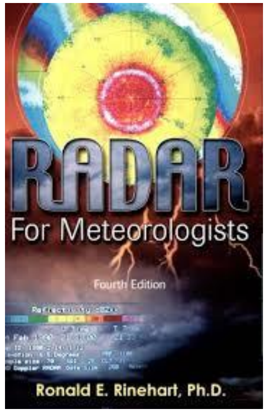
11 November 2019

Lecture Topics



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

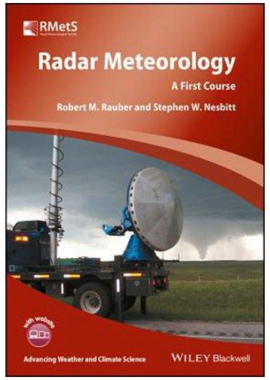
Goal: Scrutinise the radar processing chain for accurate QPE and QPF



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:

- Doviak, Richard J, and Dusan S. Zrnic, 1993, ***Doppler Radar and Weather Observations***, Second Edition, San Diego, Academic Press, Inc., 562pp
- Rinehard, R. E., 2004, ***Radar For Meteorologists***, Fourth Edition, 2004
- Rauber, Robert & Nesbitt, Stephen. (2018). ***Radar Meteorology: A First Course.*** 10.1002/9781118432662.



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

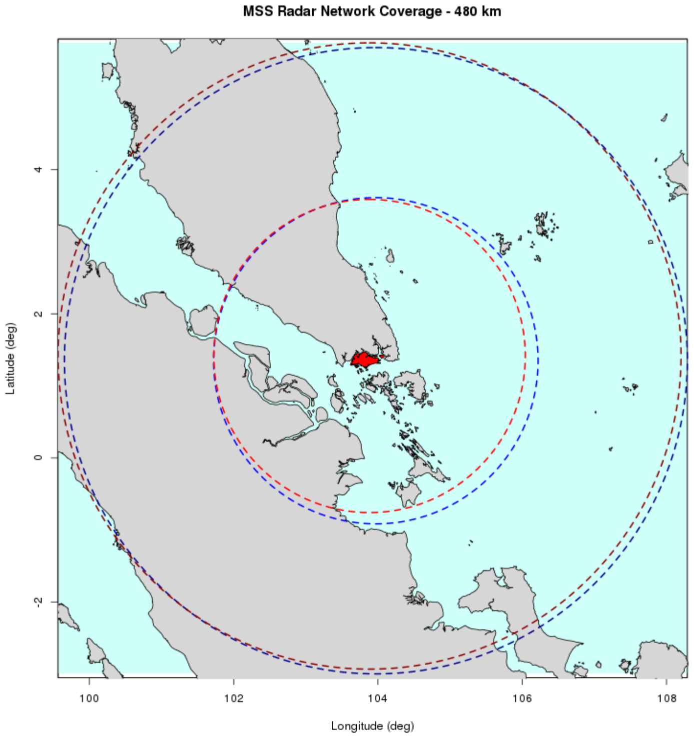
Useful Tools

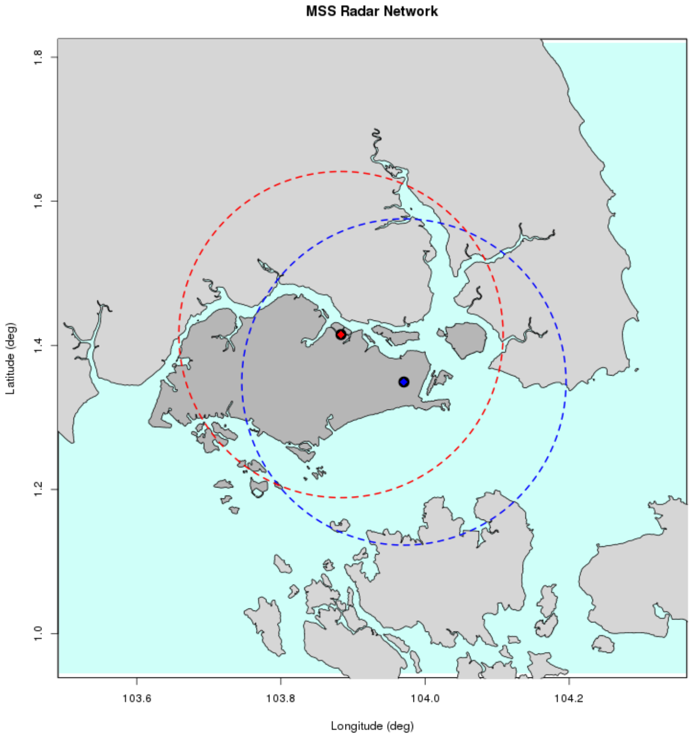
- **wradlib**: wradlib.org/tag/python
- **PyART**: arm-doe.github.io/pyart/
- **rack**: baldrad.fmi.fi/software/rack/doc/rack/html/index.html
- **Baltrad**: git://git.baltrad.eu/
- **LROSE**: https://github.com/NCAR/lrose-core

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

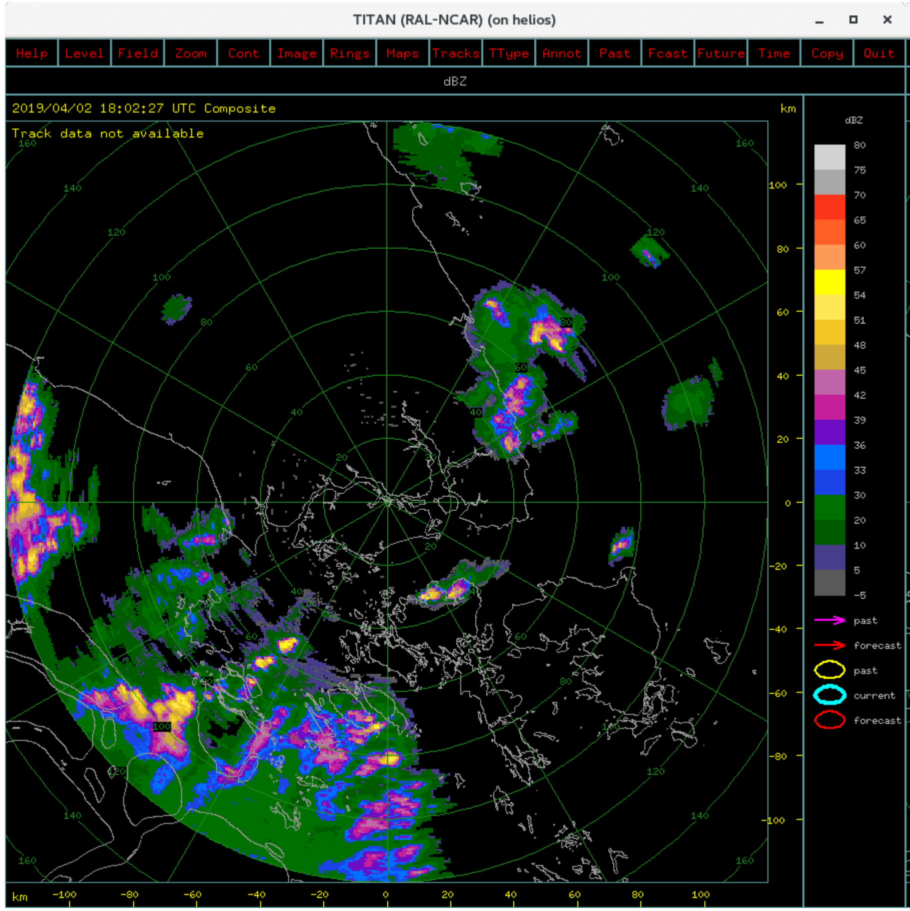
RADAR: QC'ed data
Range: 125km
Products: CMAX

COMPARISON:
C-band and S-band

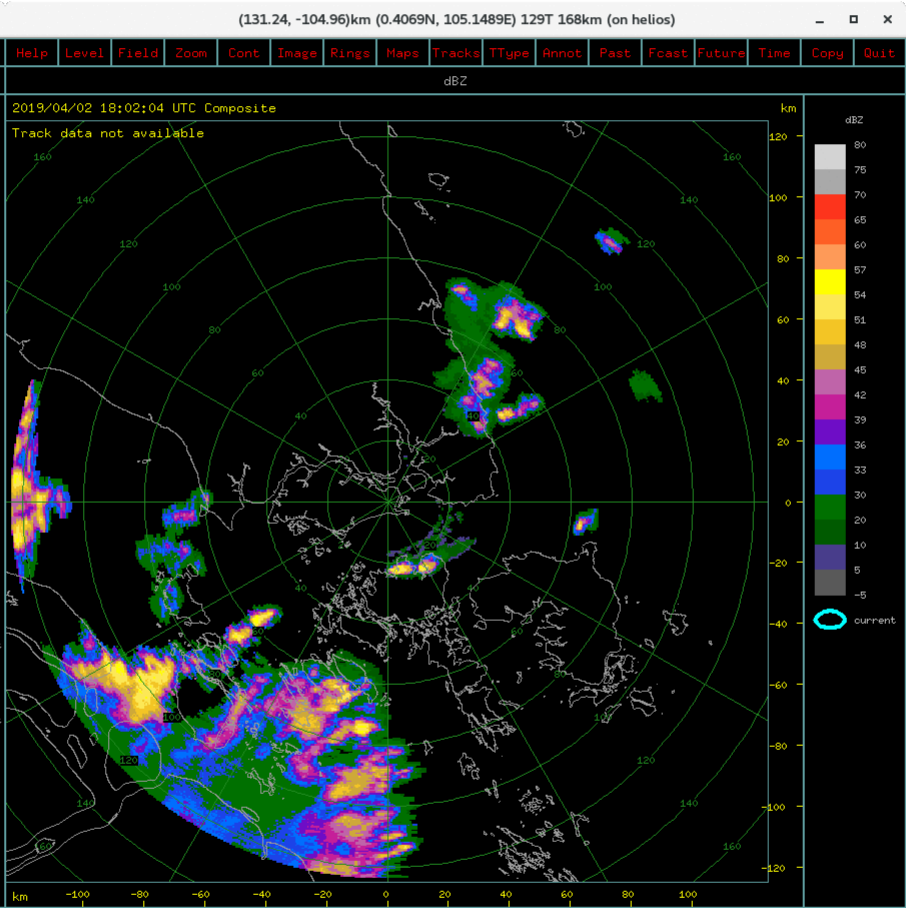
- Attenuation
- Beam Blockage
- Bright Band

A radar in the WEST of Singapore could potentially provide good data for Sumatra squall events.

Seletar: C-band



Changi: S-band



Radar Quality Monitoring

What are you working with?

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

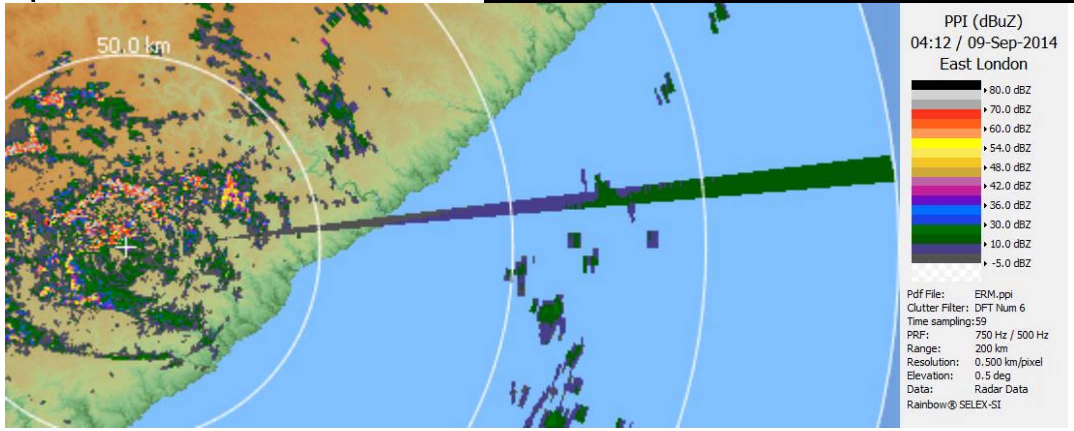
- What is the quality like?
  - Relative term that depends on purpose of radar
  - TDWR, QPE, DA, etc.

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

dBZ	Corrected / Uncorrected Reflectivity
V	Velocity
W	Spectrum Width
ZDR	Differential Reflectivity
PhiDP	Corrected / Uncorrected Differential Phase
KDP	Differential Phase with Range
RhoHV	Correlation

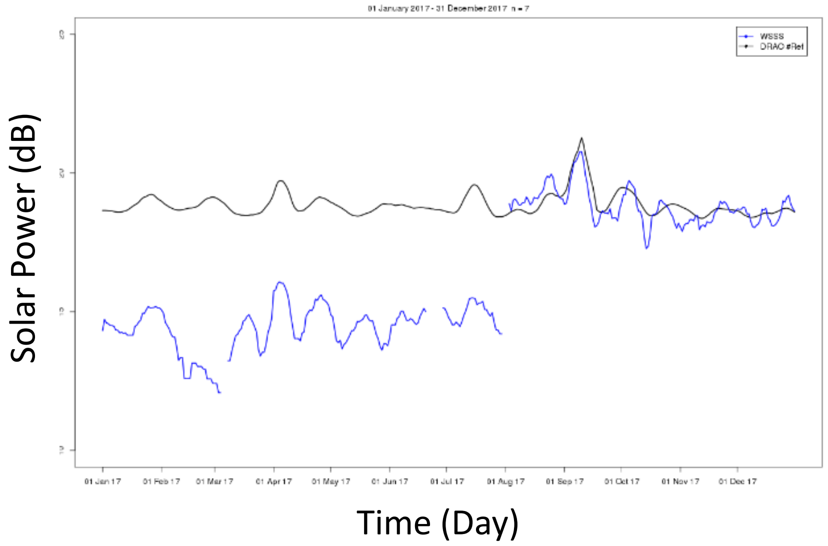
Calibration: Solar Monitoring

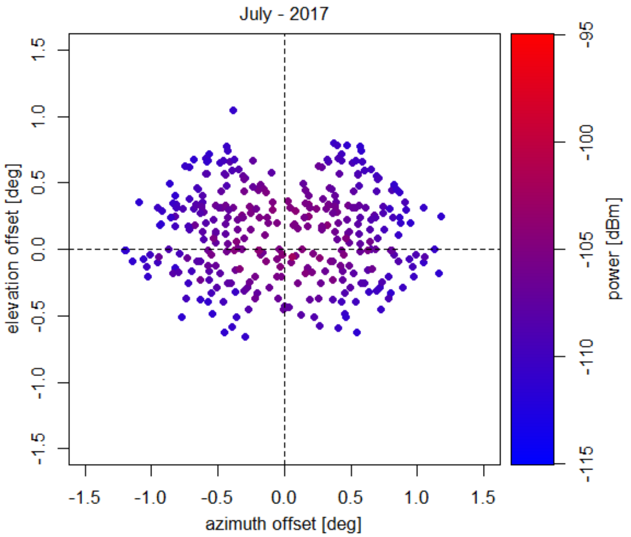
- Antenna alignment (TRUE NORTH)
- Apparent beam width
- Received Power
- Dual-Pol monitoring possible

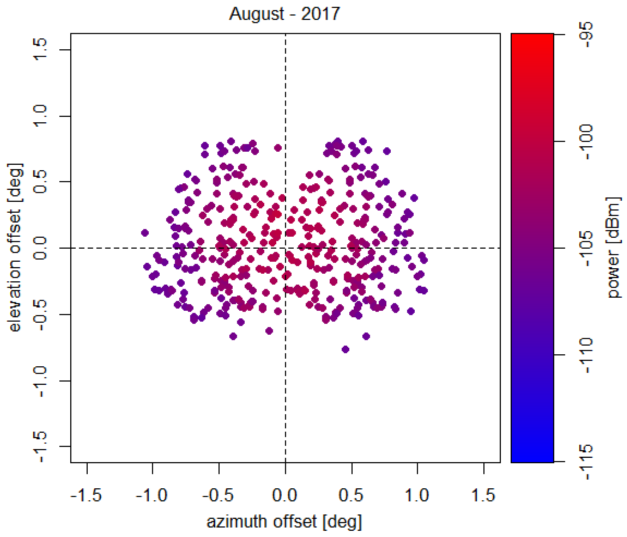


- Data: January to December 2017
- 7 day rolling average due to limited sun spike hits.
- Down time end July due to system upgrade.

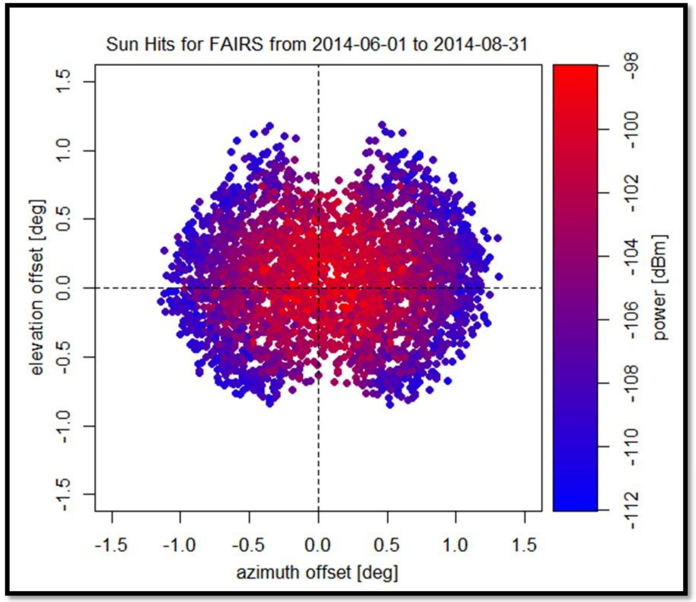
Average Daily Received Solar Power - 2017





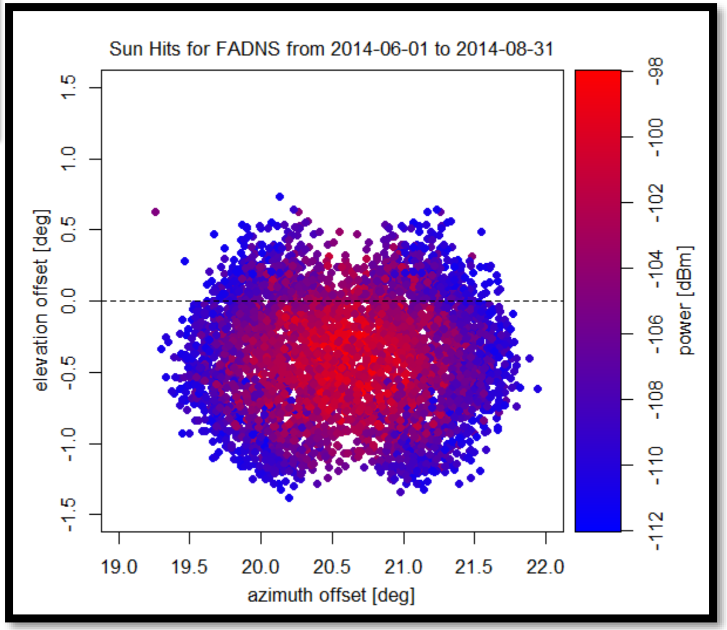


Calibration Monitoring - Sun spike



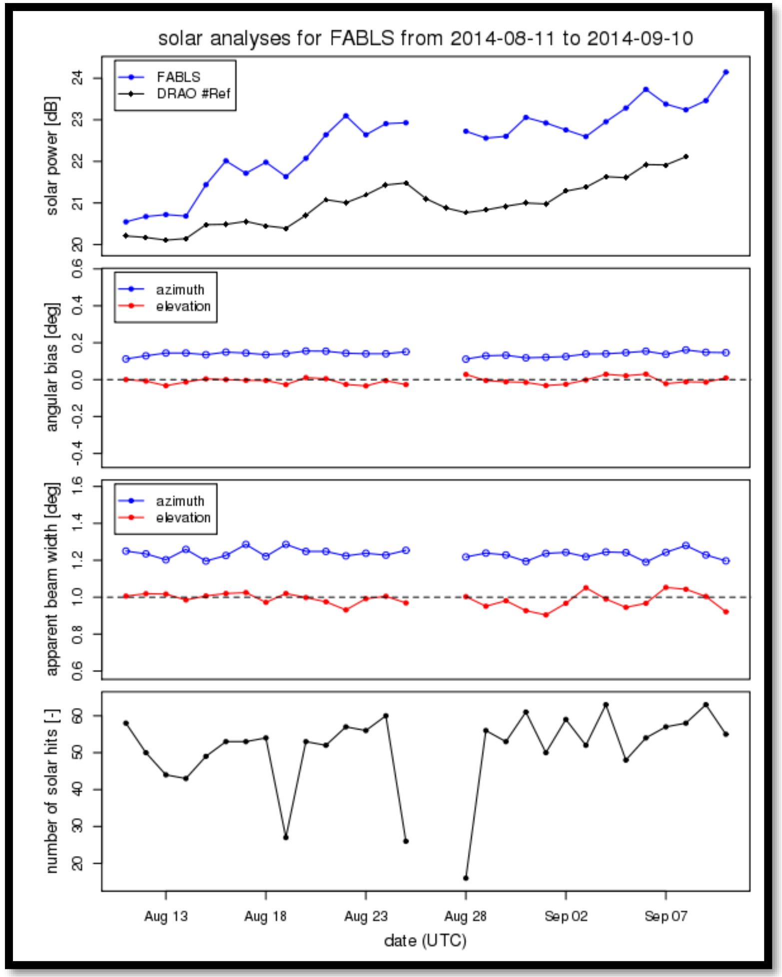
Sun Hits over a 3 Month period:

- Antenna alignment to true North



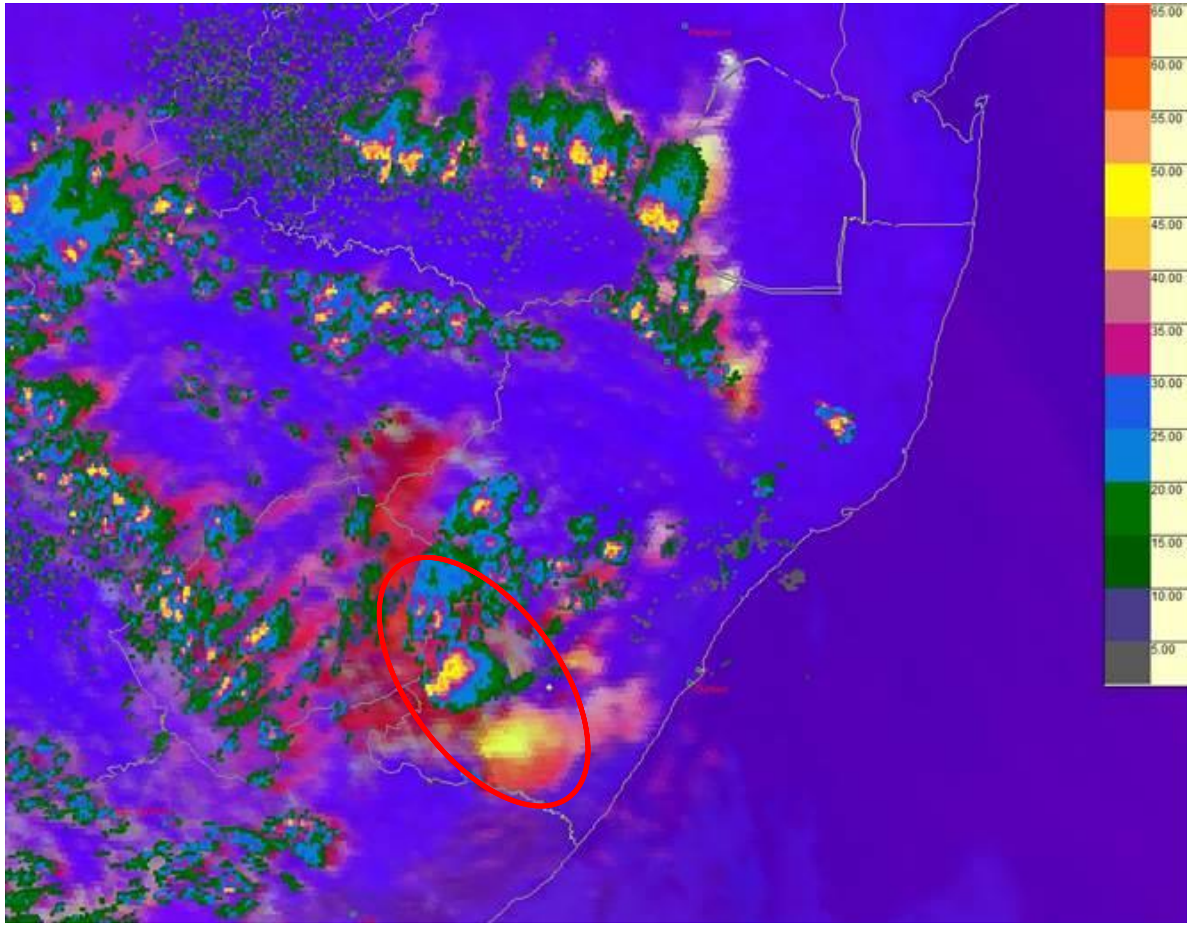
Monitor over 30 day period:

- Received solar power
- Angular bias
- Apparent beam width
- Number of solar hits per day



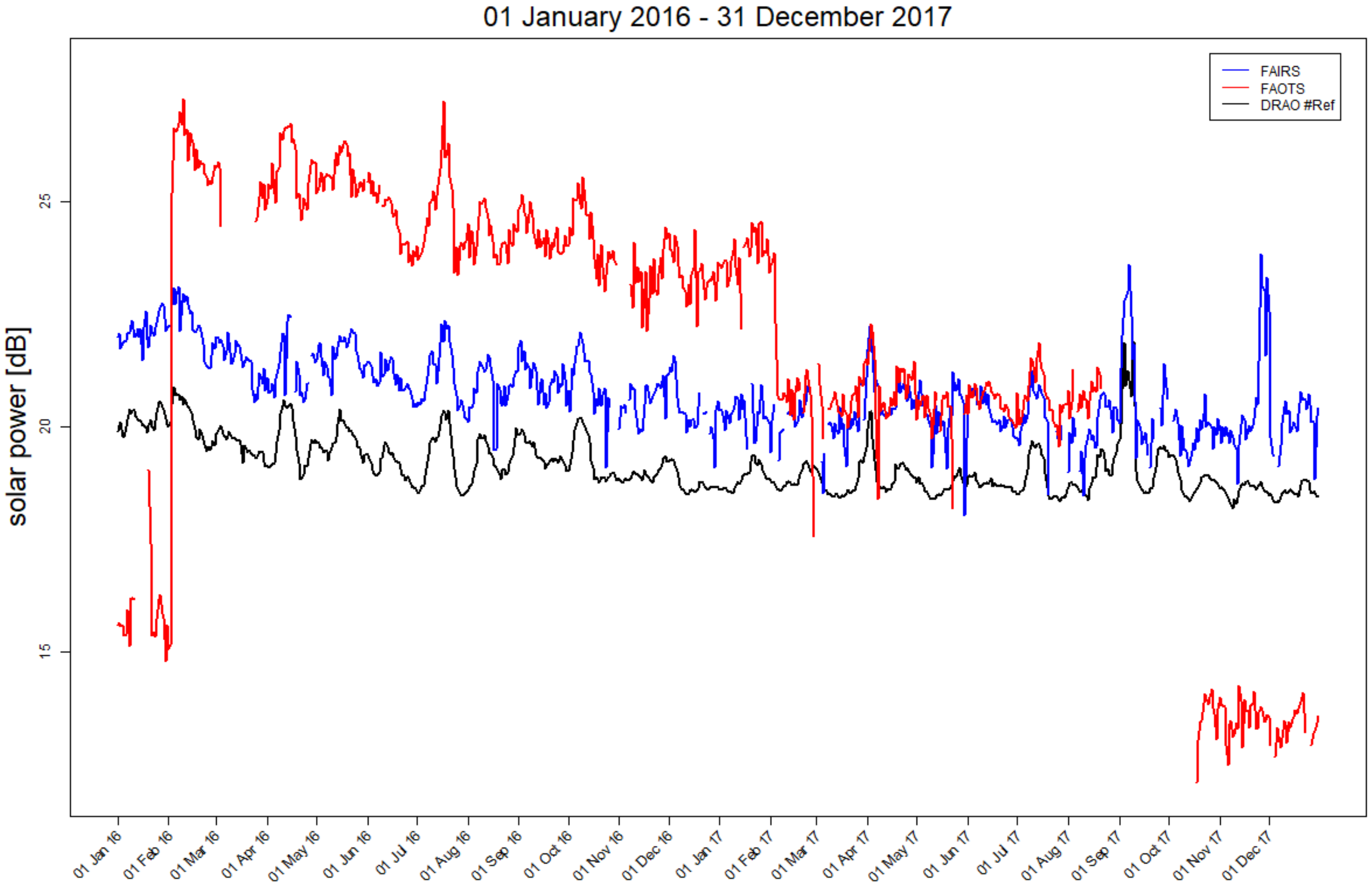
Example – Radar/Satellite Comparison

- Radar Composite overlaid with MSG convective RGB

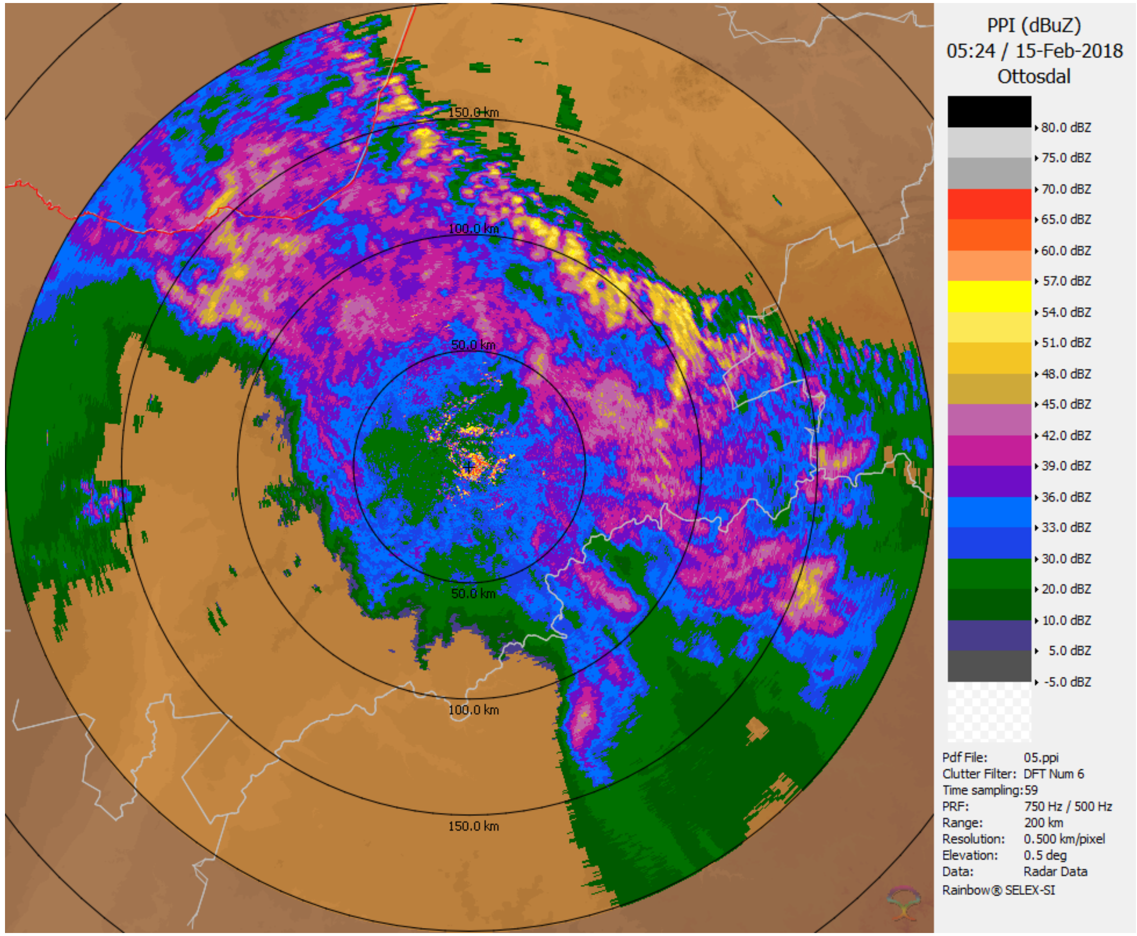


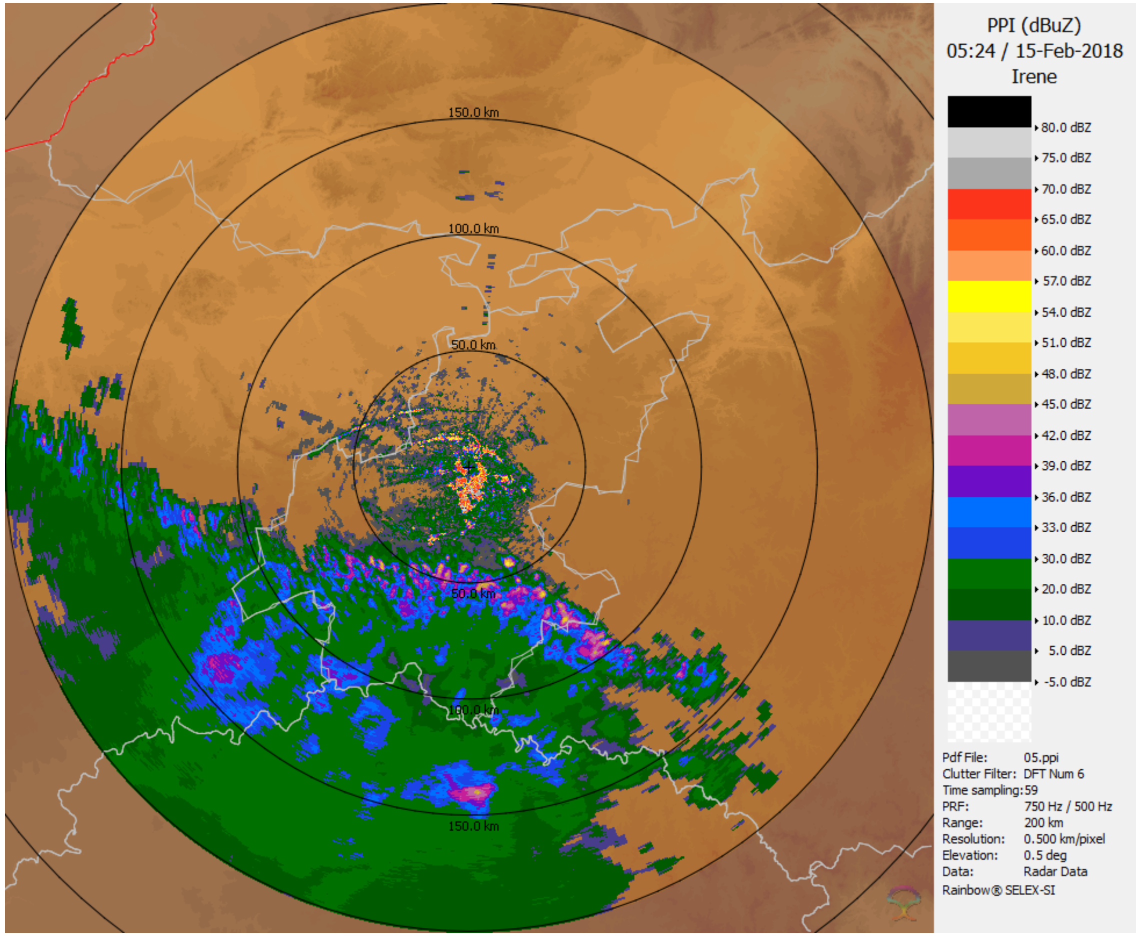
- **Clear Durban radar is not aligned to TRUE North**

Calibration Monitoring - Sun spike



Example - Calibration





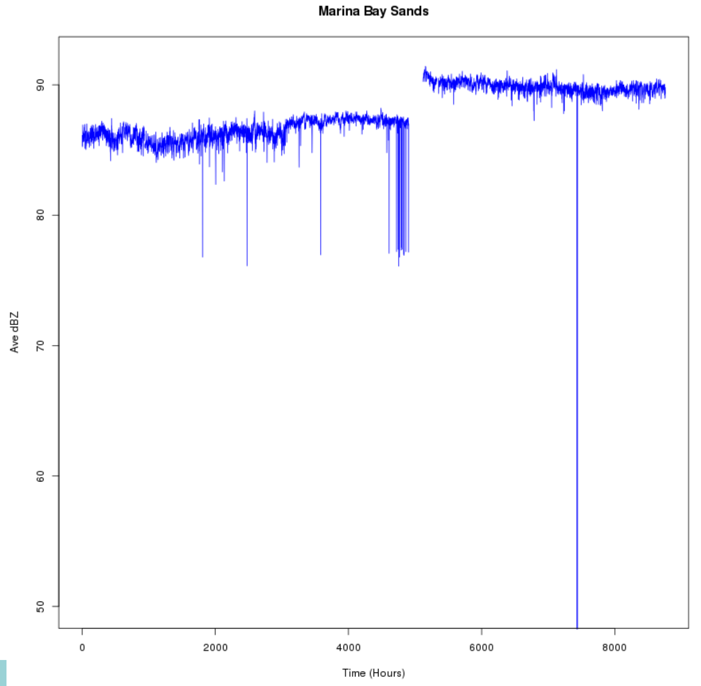
Calibration: Best Practices

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

Table 2. A summary of calibration practices.

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

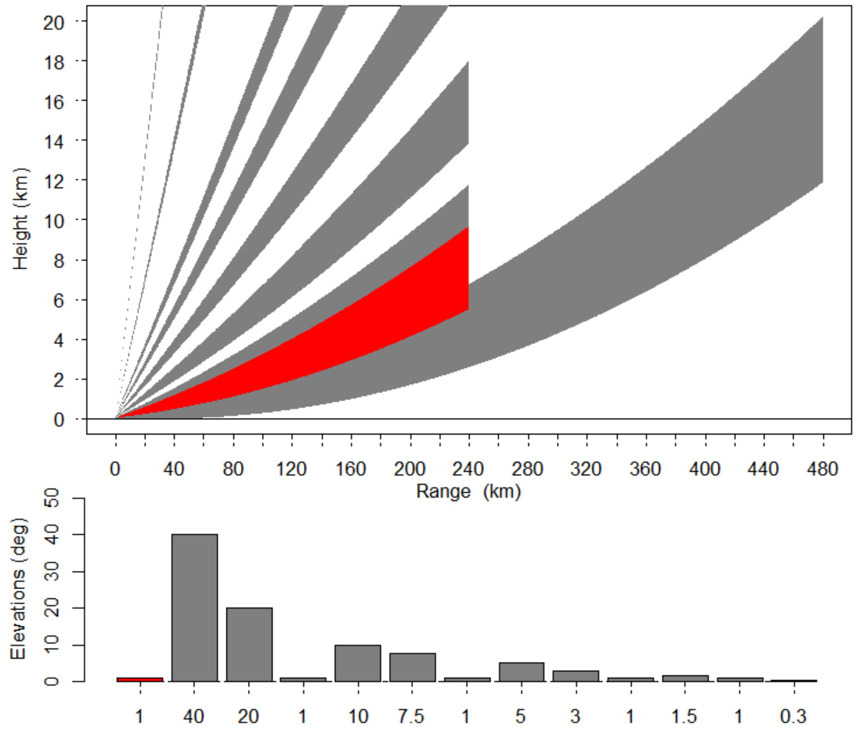
- Document calibration results.
- Solar monitoring, only Rx chain and Antenna pointing.
- Need for Tx and DP monitoring
- Work towards Vertical Scans (Brid-Bath) and BITE figures
- Started working towards Stable Clutter:



Signal Processing

Scan Strategy

Scan Sequence



Changi

Parameters	Value
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	Value
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

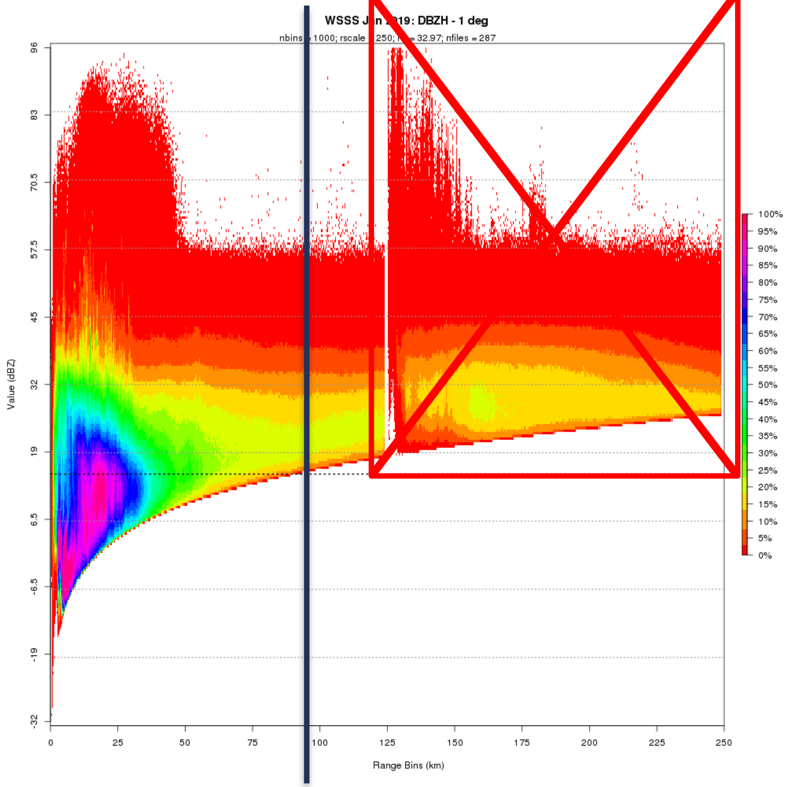
Filter Settings

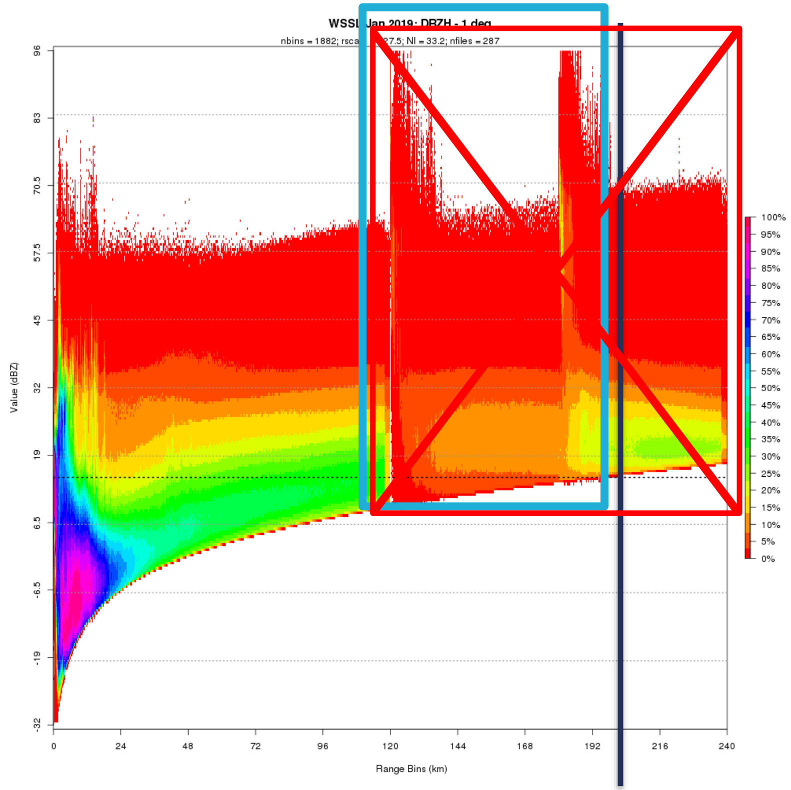
Filter	Changi - Volume	Changi – Long Range	Seletar - Volume	Seletar – Long Range
Trip Recovery	Active	OFF	Active	OFF
Staggering	None	None	3/2	None
Dual PRF Correction	Active	Active	Active	Active
Doppler Filter	OFF	OFF	OFF	OFF
DFT Filter	Active	Active	Active	Active
Clutter Filter GIP	NA	NA	OFF	OFF
Interference Filter	NA	NA	SAFE MODE	SAFE MODE
Spatial Filter	Active	Active	Active	Active
Speckle Filter	Active	Active	Active	Active

Signal Processing: Reflectivity

Frequency vs Range: January 2019

Changi: S-band 1° Elevation DBZH Seletar: C-band

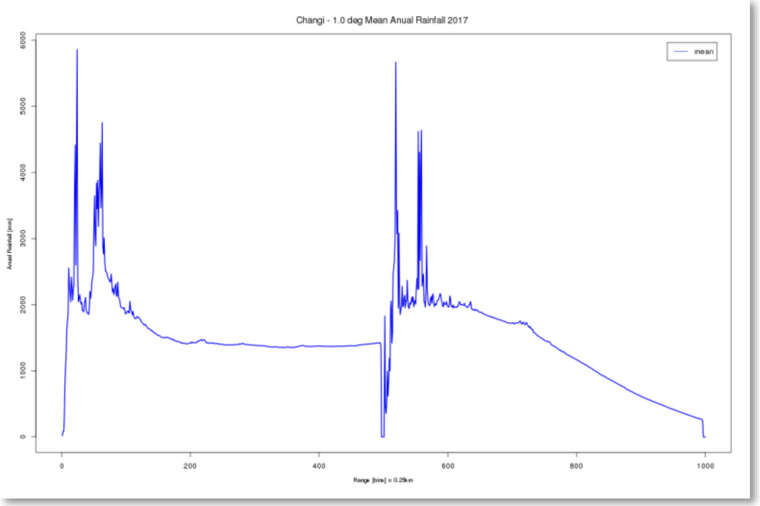




- Frequency vs. Range plots:
  - Second Trip Echo
  - Errors in software (KDP/uPhiDP?)
  - Minimum Detectable Signal

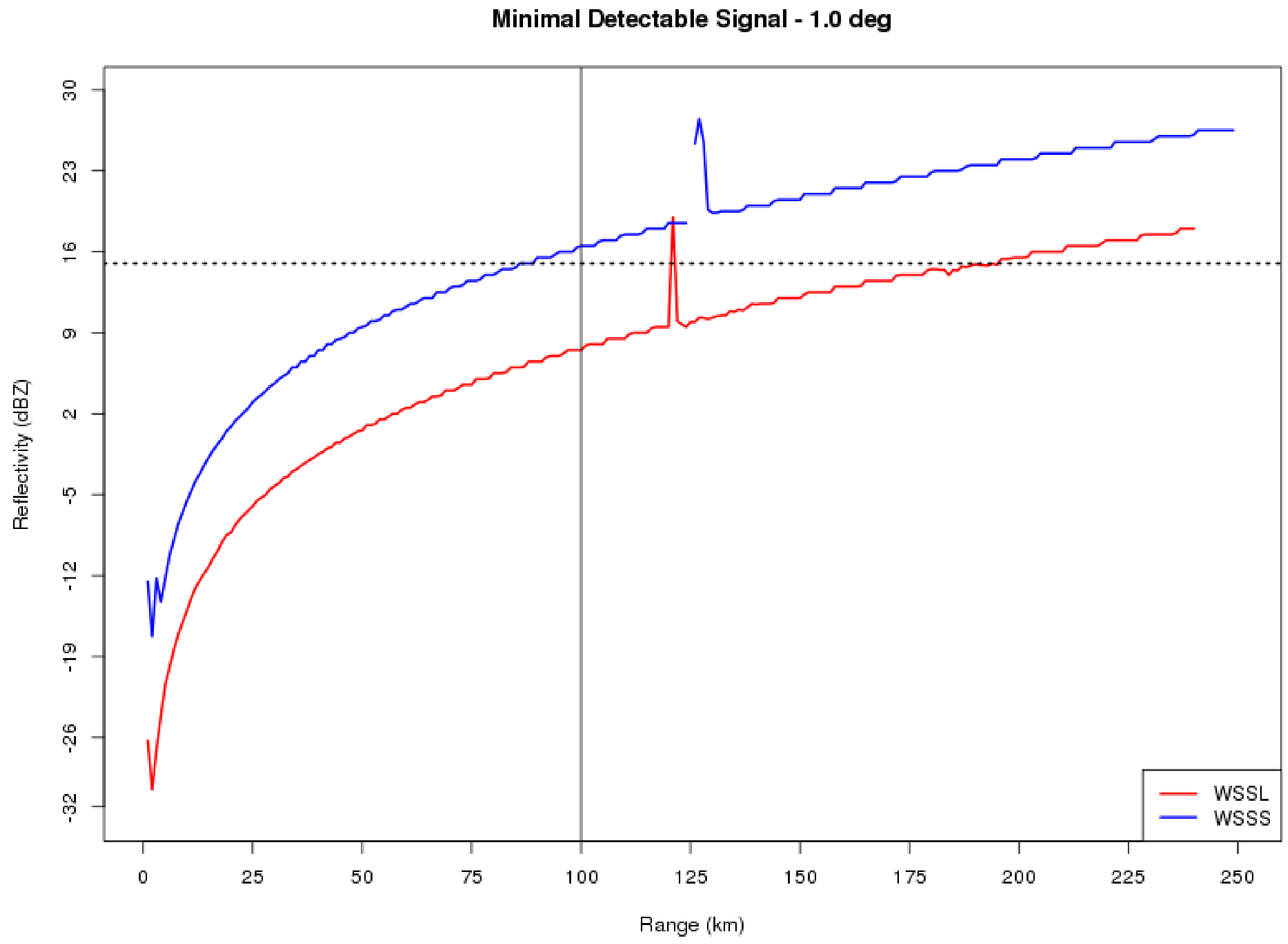
  15dBZ ≈ 0.16 mm/h

$z = 328.64R^{1.29}$ Kumar et al. 2011



Changi Annual Rainfall vs Range - 2017

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: $P_r = \frac{\pi^3}{1024\ln(2)} \cdot \frac{P_t G^2 \theta \varphi \tau}{\lambda^2} \cdot \frac{|K|^2}{r^2} Z$

Signal Processing: Second Trip

Sachidananda, M, and Zrnic, D.S., 1999, *Systematic phase codes for resolving range overlaid signals in a Doppler weather radar*, J. Atmos. Oceanic Technol., **16**, 1351-1363

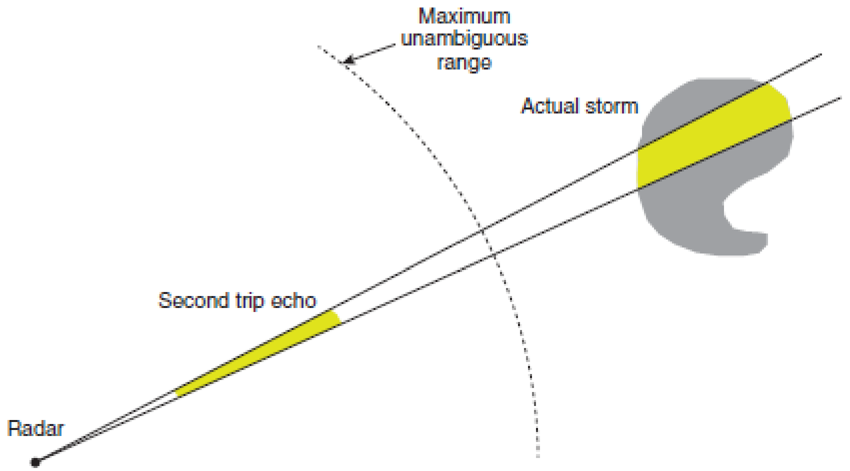
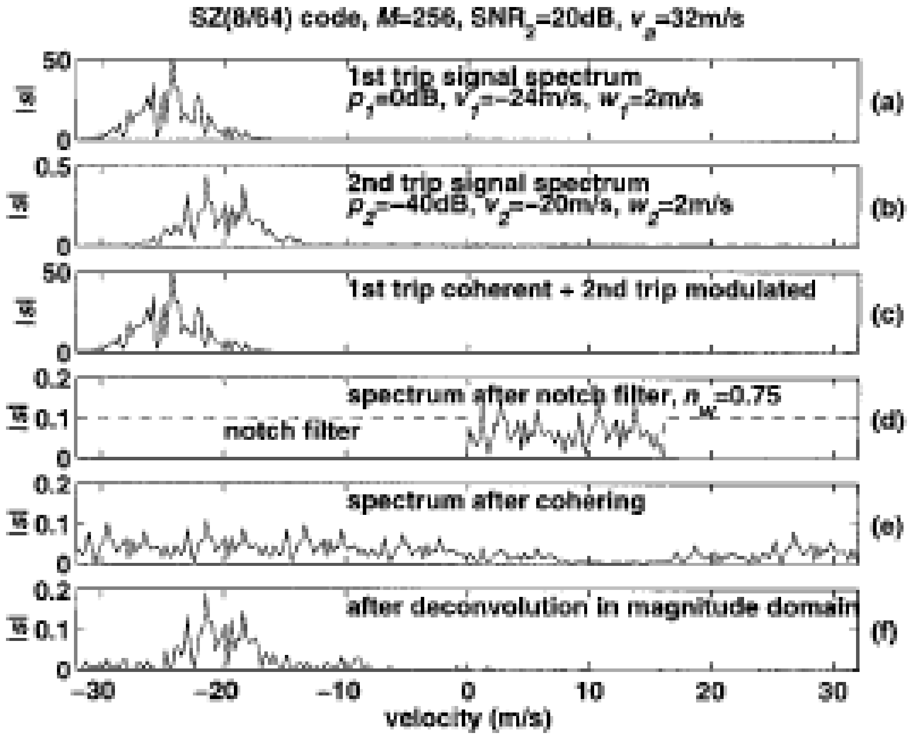


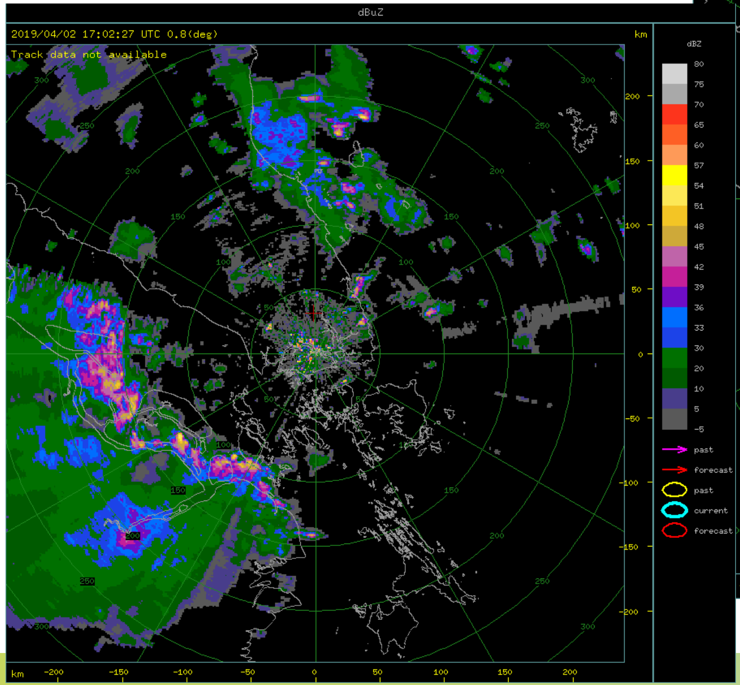
Figure 3.4 The long, narrow shape of a second-trip echo arises because the echo is constrained into the solid angle of the beam, but much closer to the radar



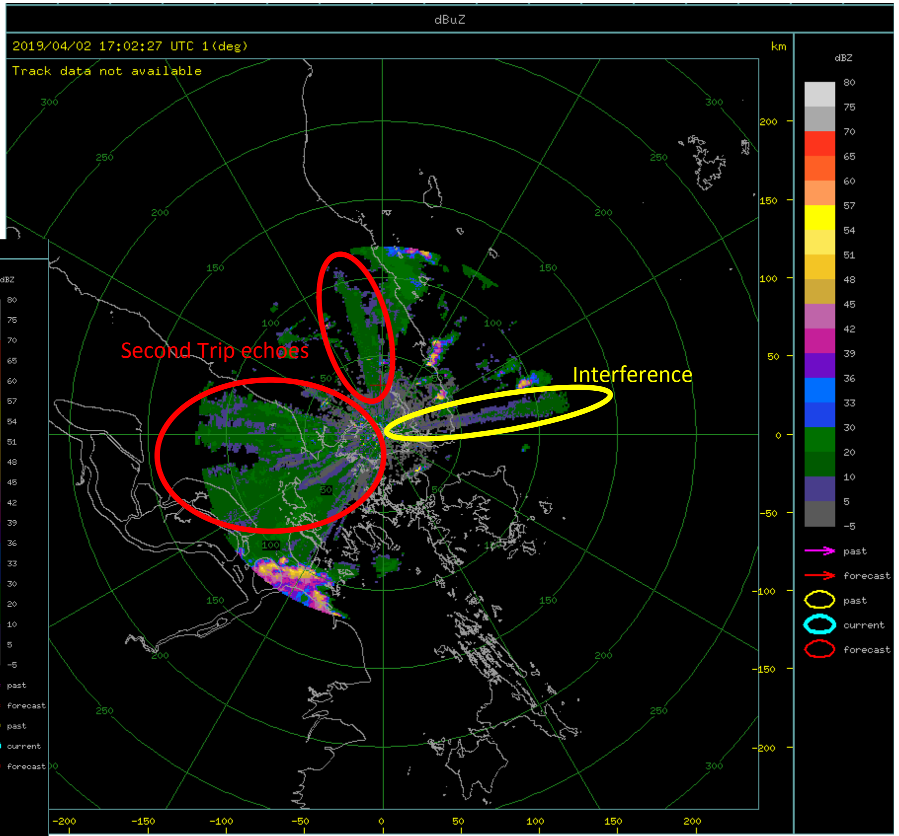
Signal Processing: Second Trip

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

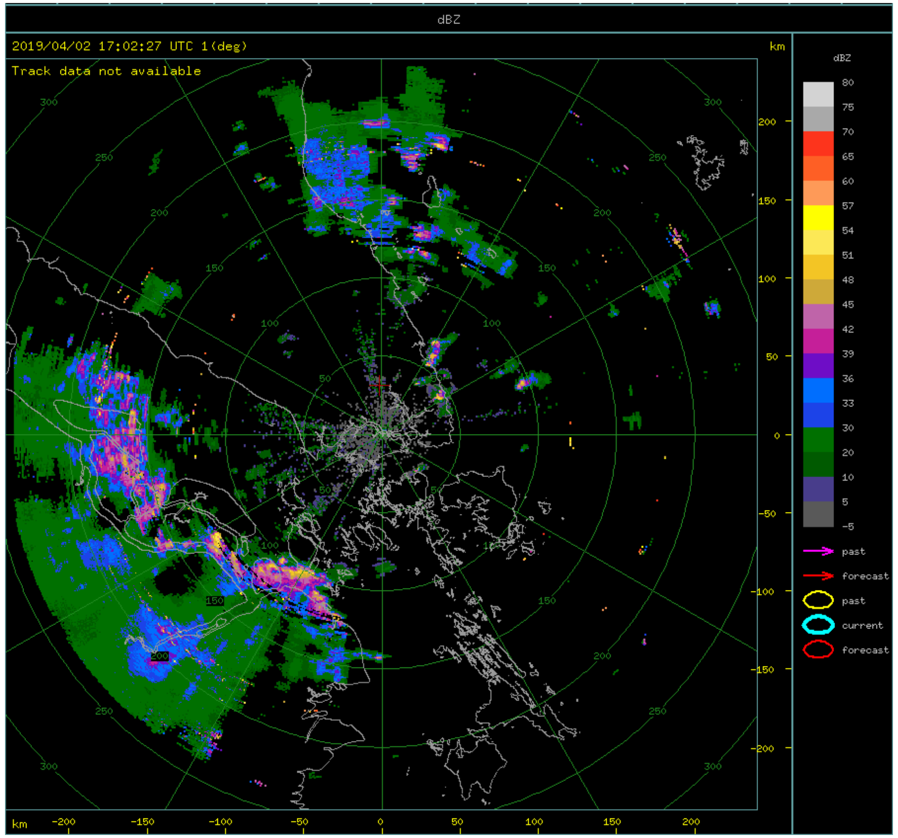
- dBuZ – Uncorrected
- dBZ – Corrected



dBuZ



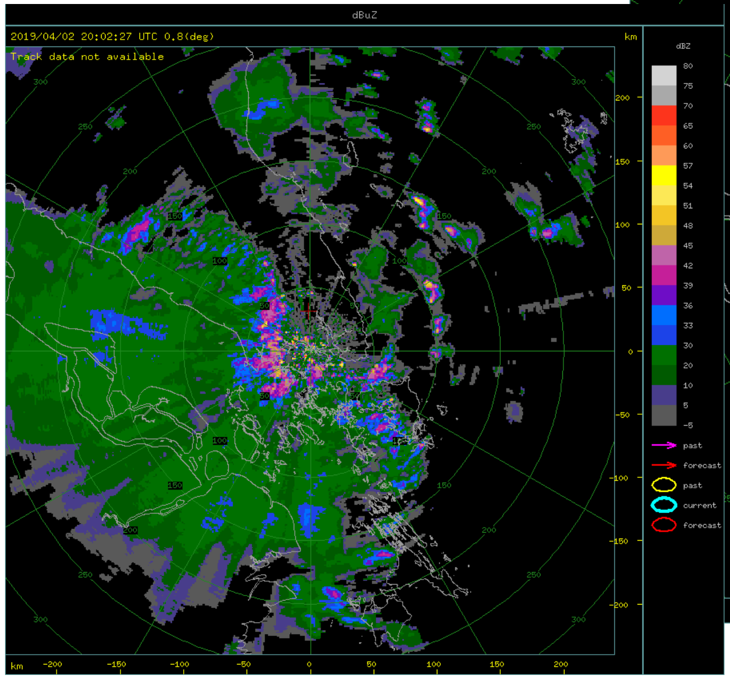
dBZ



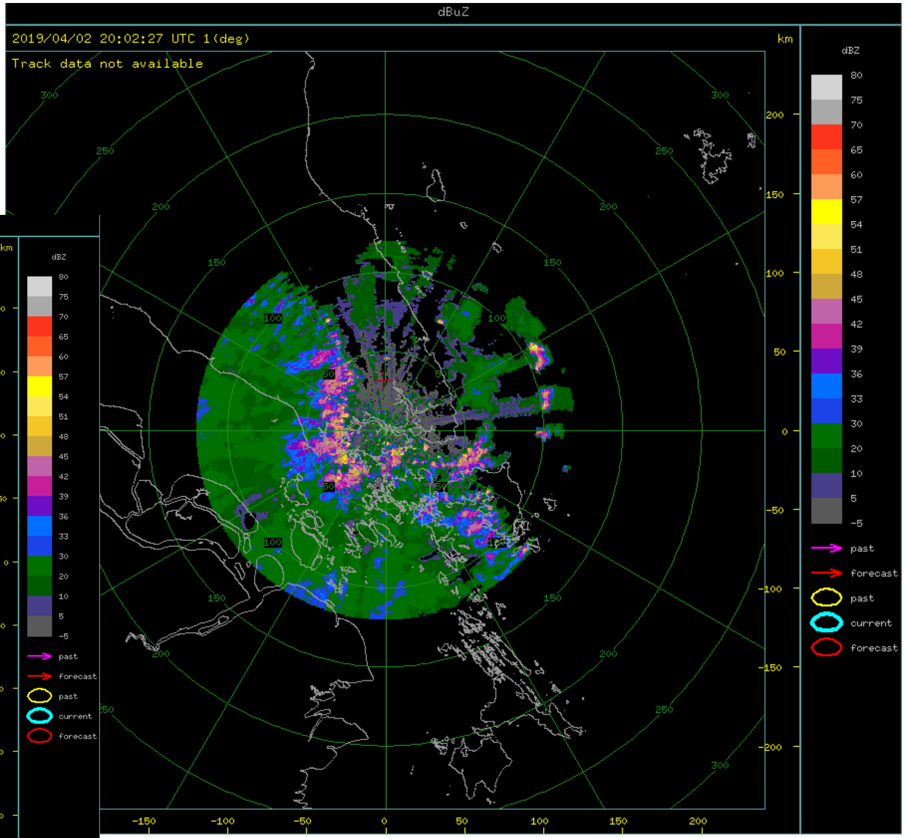
Signal Processing: Second Trip

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

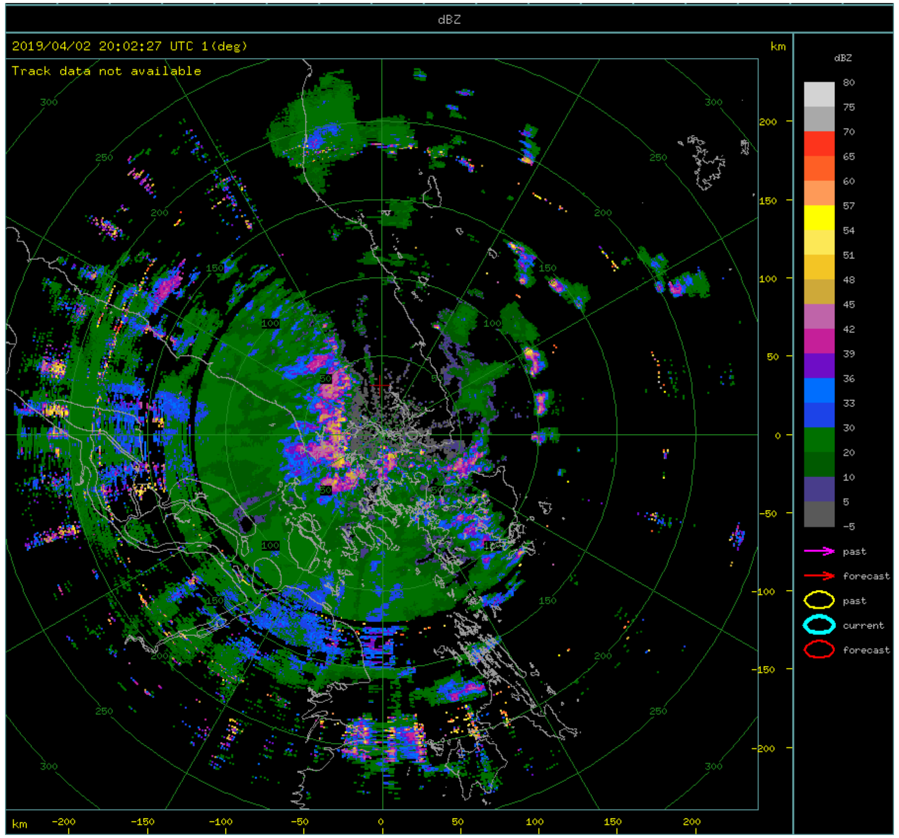
- dBuZ – Uncorrected
- dBZ – Corrected



dBuZ



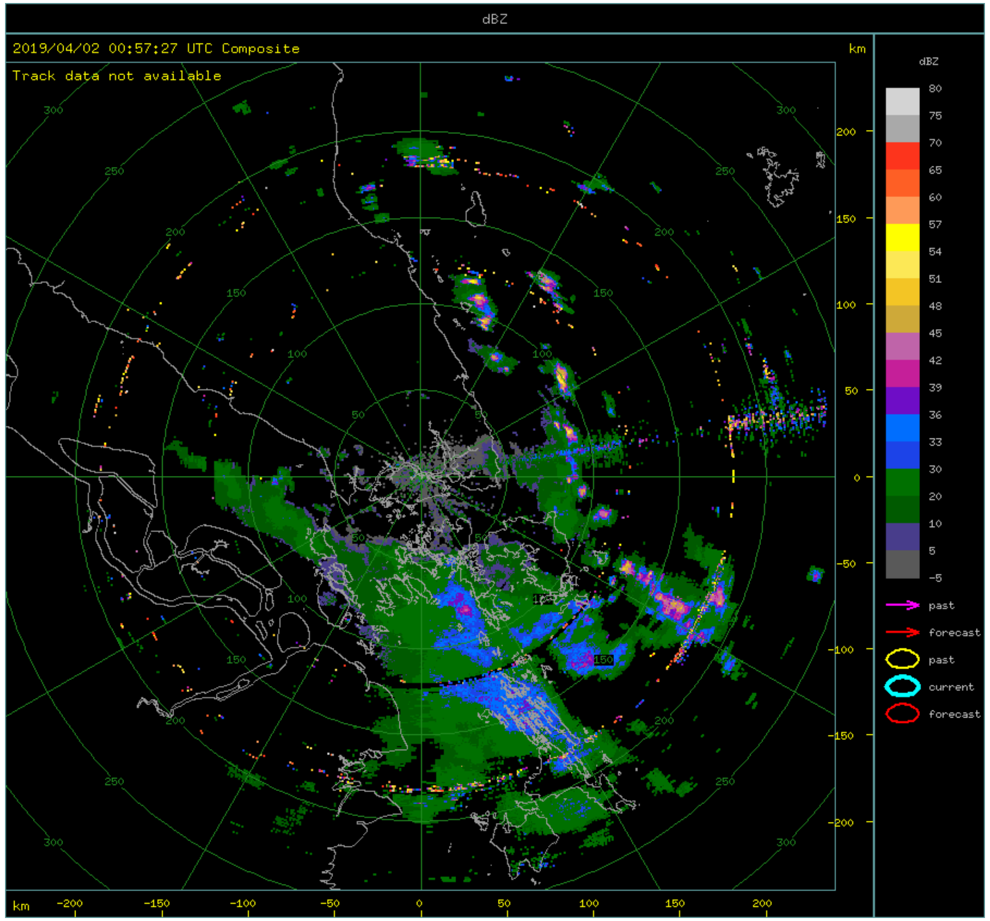
dBZ



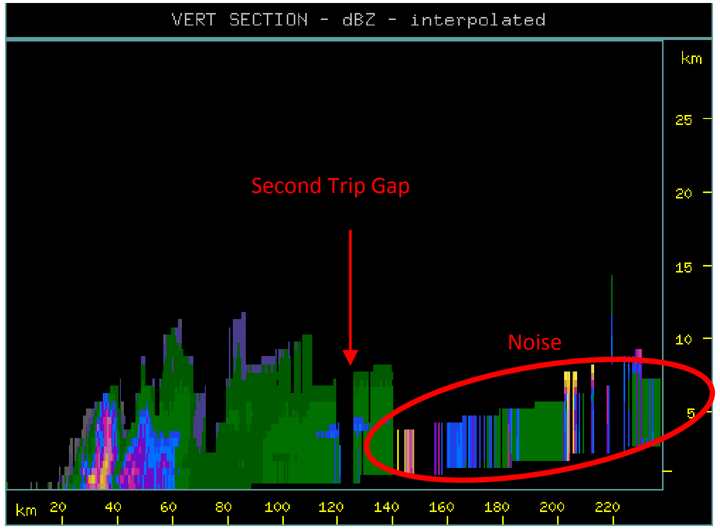
Signal Processing: Second Trip

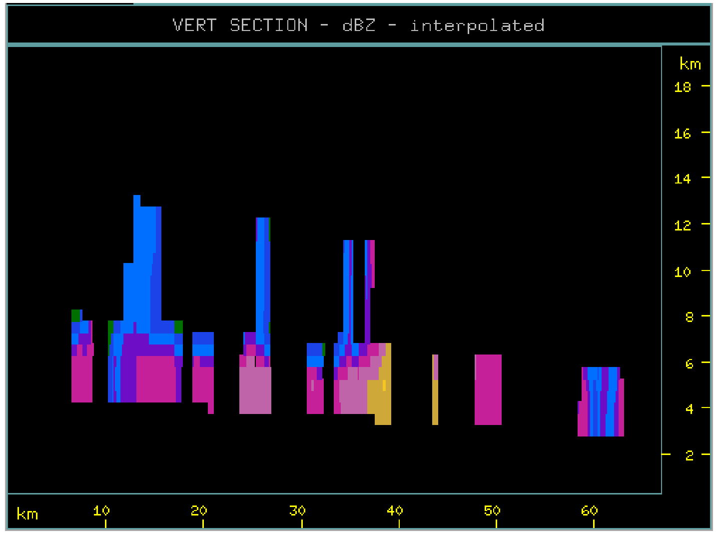
RADAR: Seletar C-band
Range Scan: 250km
Product: CMAX
V nyquist: ≈ ±32 m/s

ISSUES:
- RLAN interference
- Second Trip



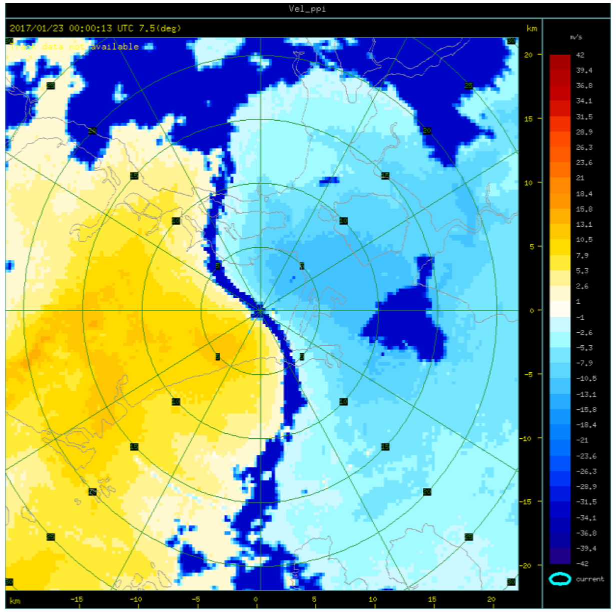
dBZ – Cross Sections

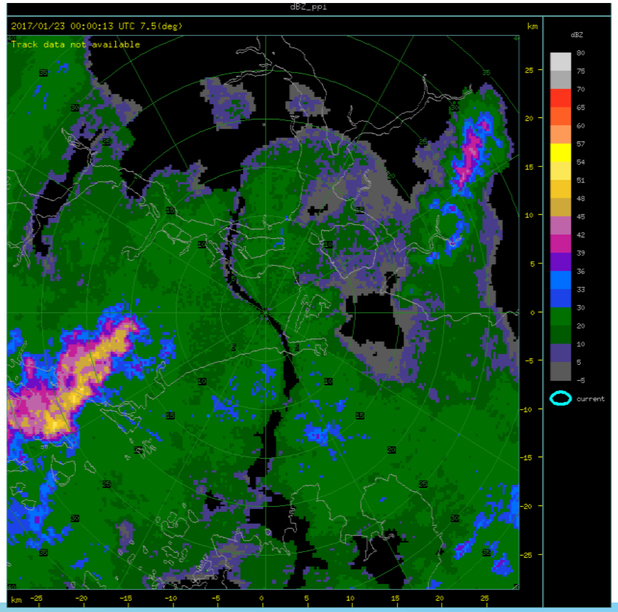




Signal Processing: Velocity

Changi PPI: 7.5°

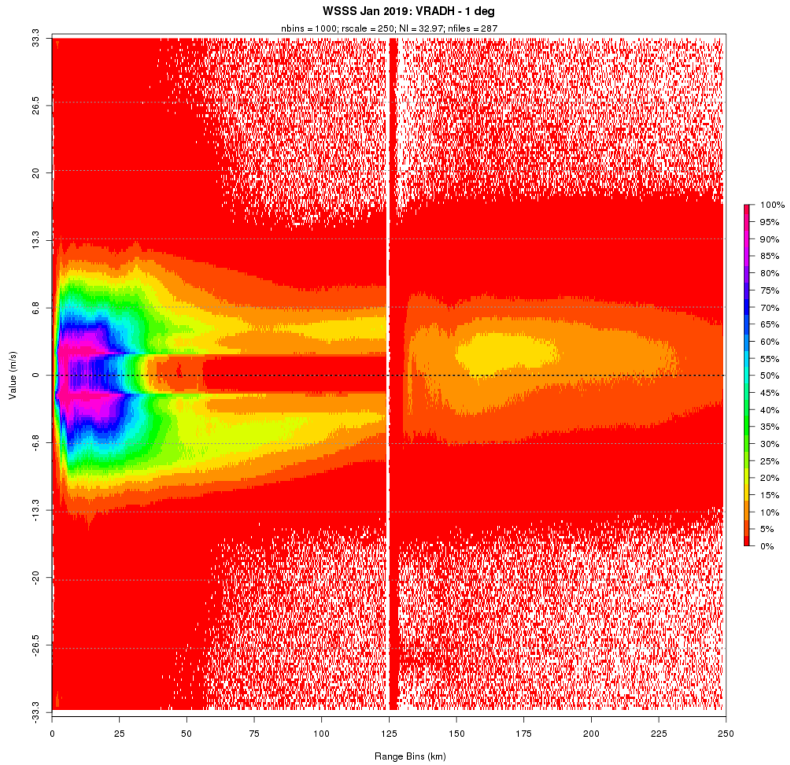




Frequency vs Range: January 2019

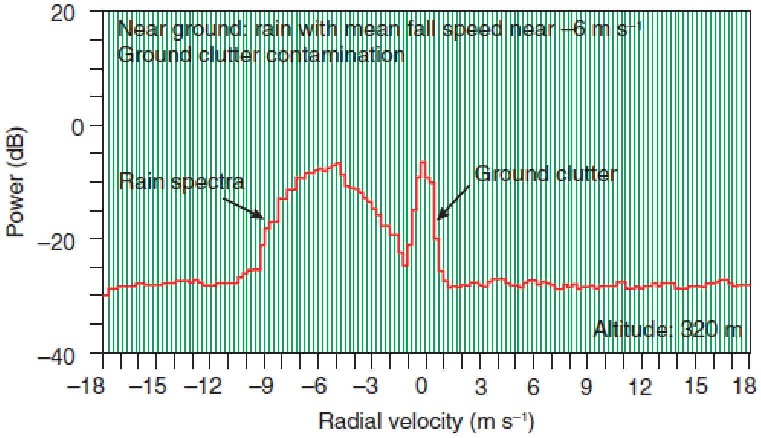
Changi: S-band

1° Elevation VRADH



- Second Trip Filter
- Errors in software
- Aggressive filtering

Doppler Spectrum



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?

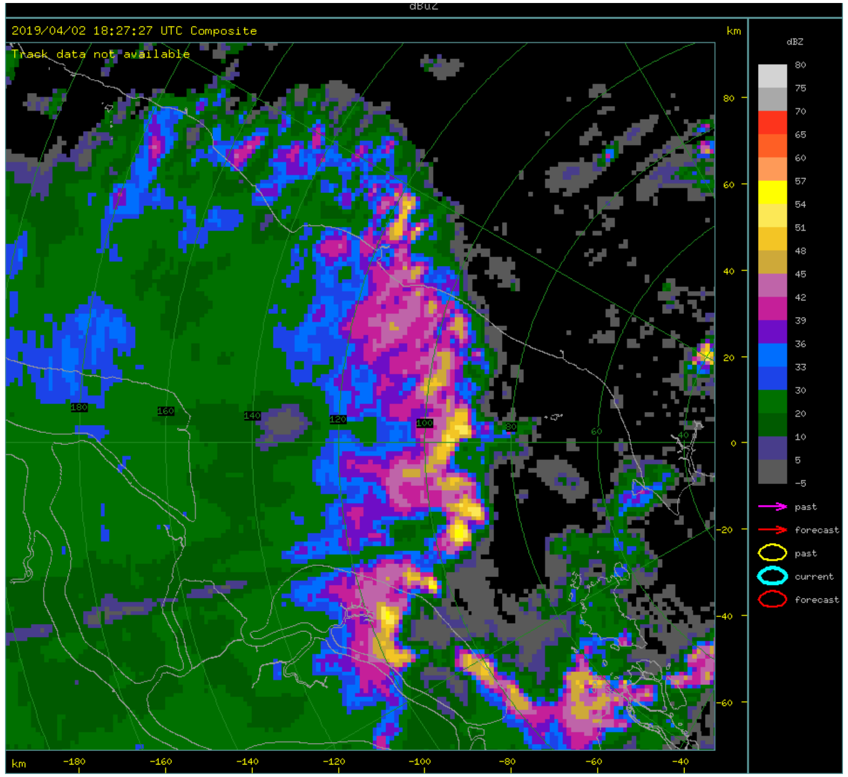
Signal Processing: DFT Filter

RADAR: Seletar C-band
Range Scan: 480km
Elevation: 0.8°
V nyquist: ≈ ±8 m/s

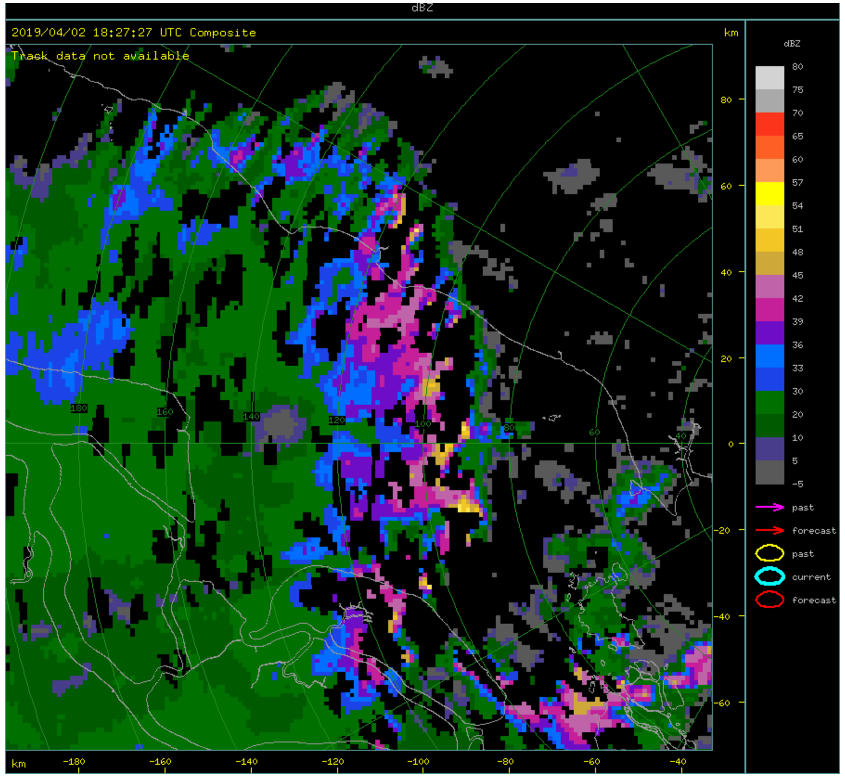
ISSUES:

- DTF Filter removing to much info

dBuZ

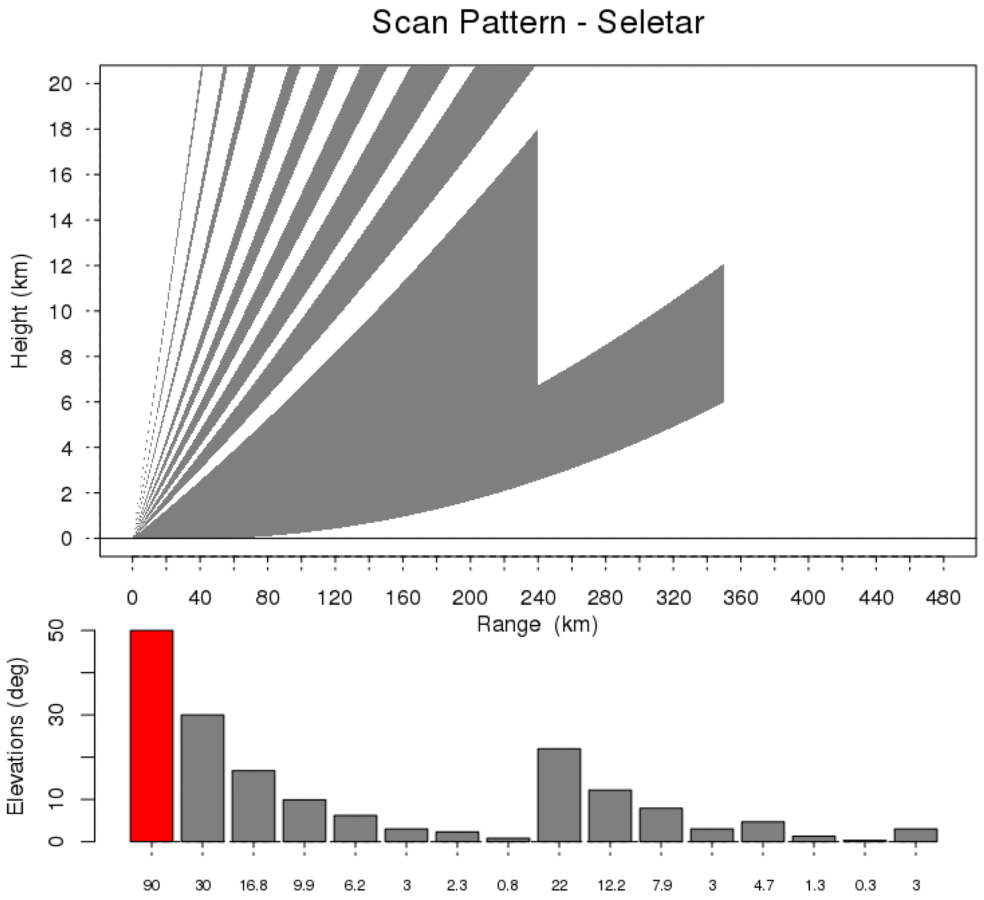


dBZ



Signal Processing: Recommendation

Ideal Scan…



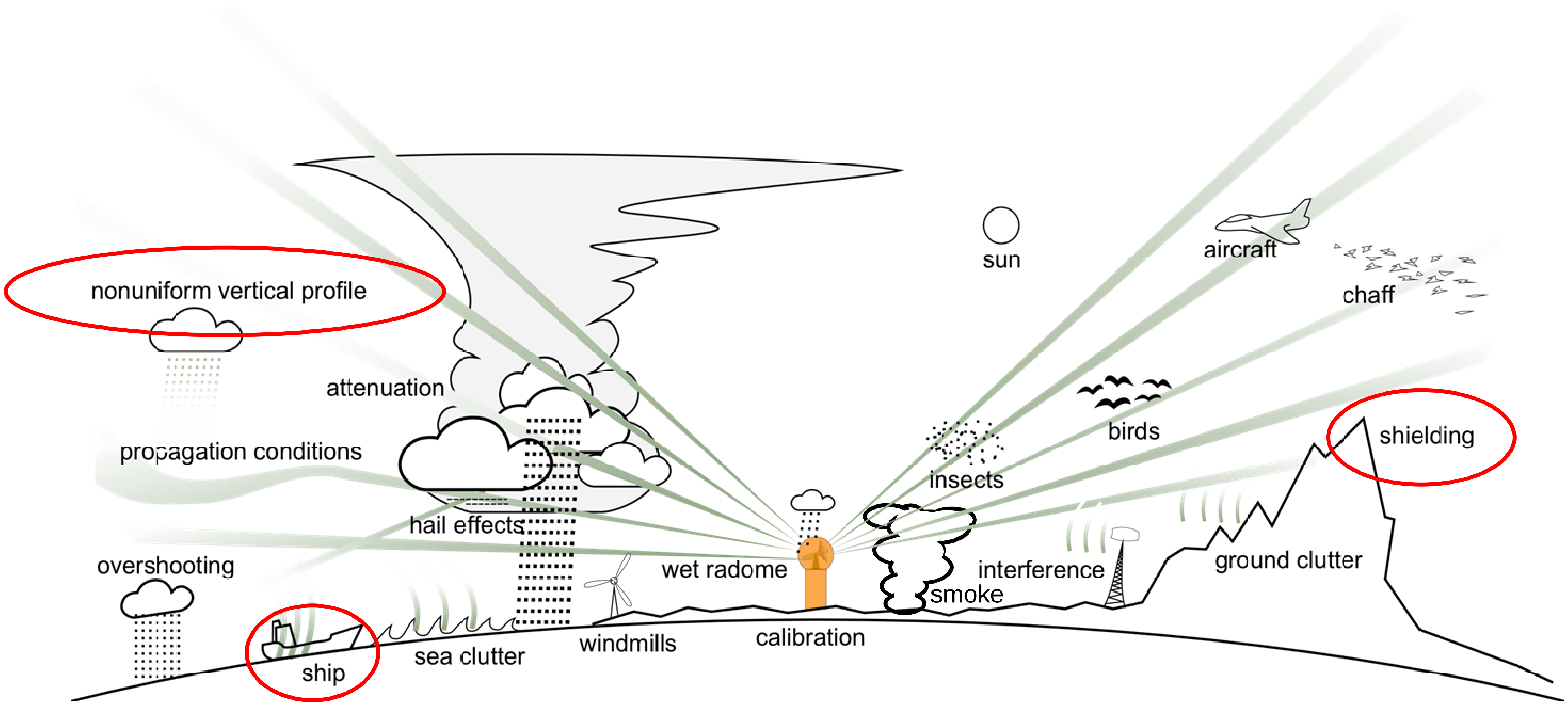
Balanced Scan strategy (compromise):

- 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)

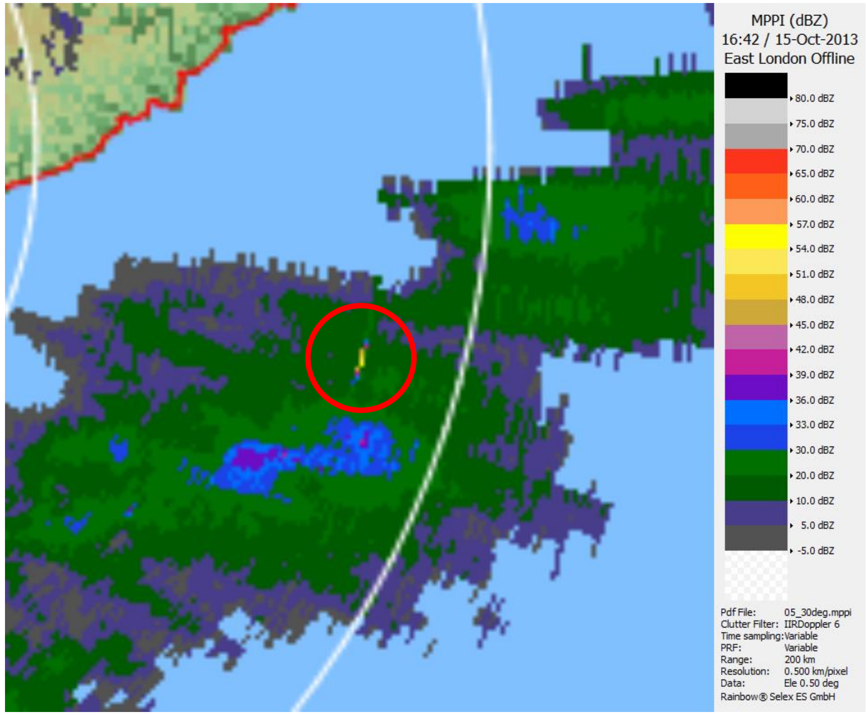
- Need to get this part right, can’t rerun

Quality Control and Processing

Factor Influencing Radar Quality

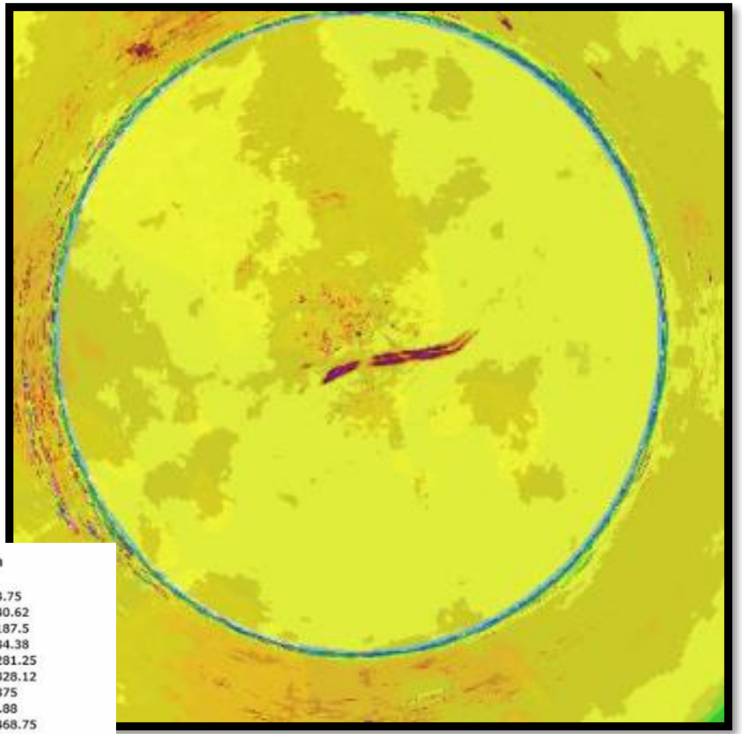


Example - Ships

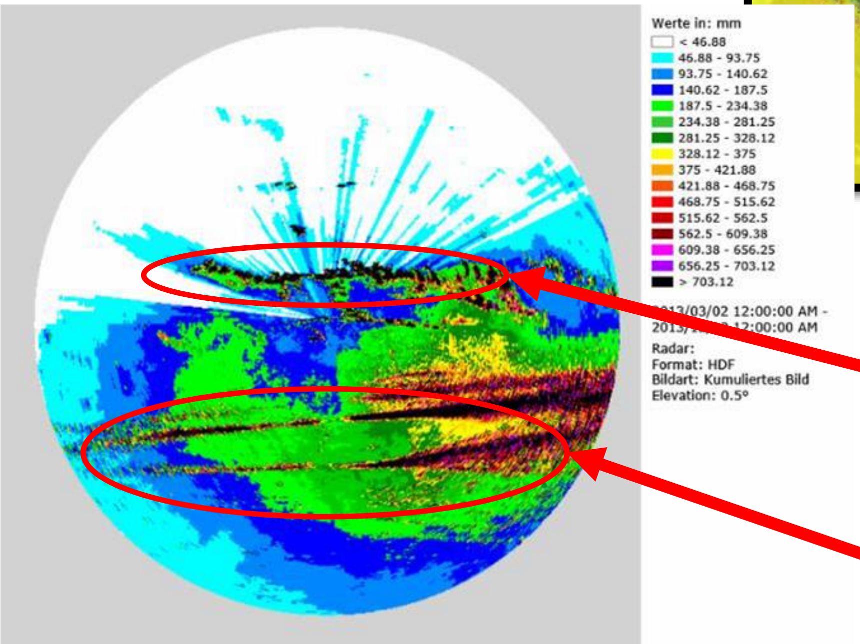


Ship detected within Sea Clutter

2017 Accumulated Rainfall
Singapore Changi



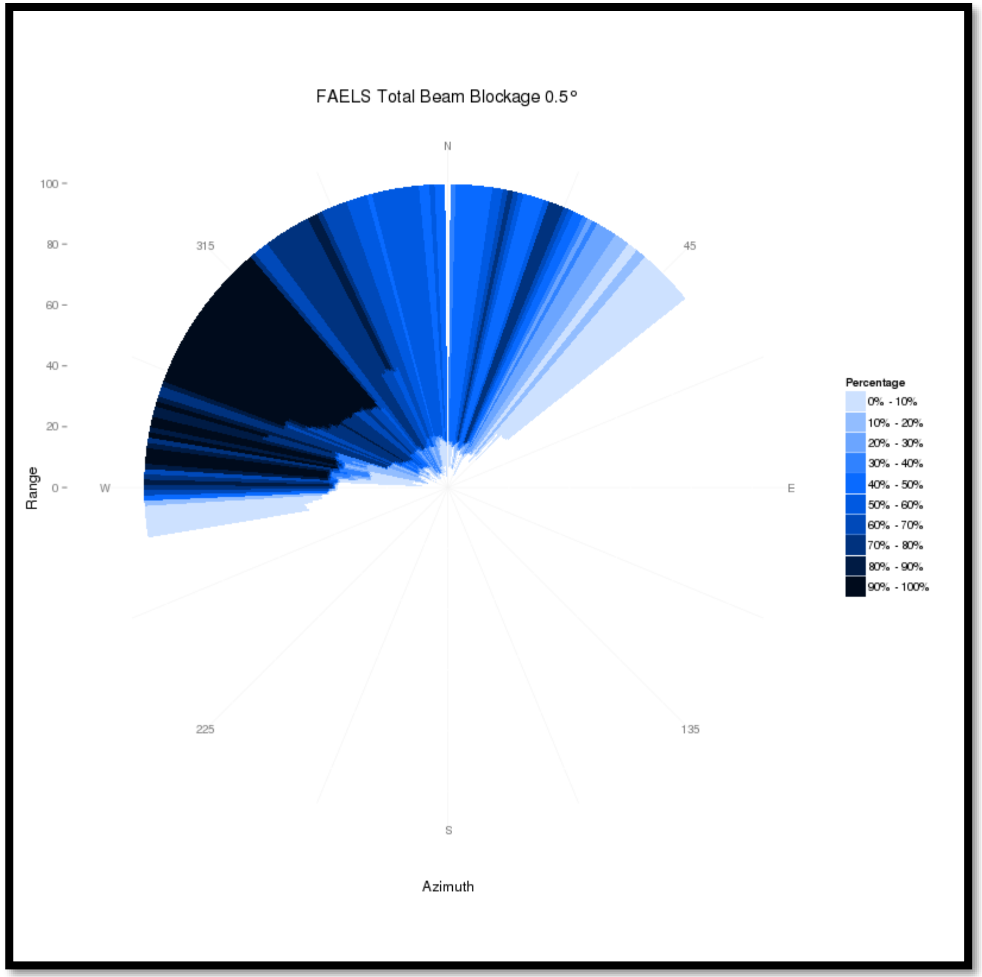
> 10 Months Accumulated Rainfall
George radar SA

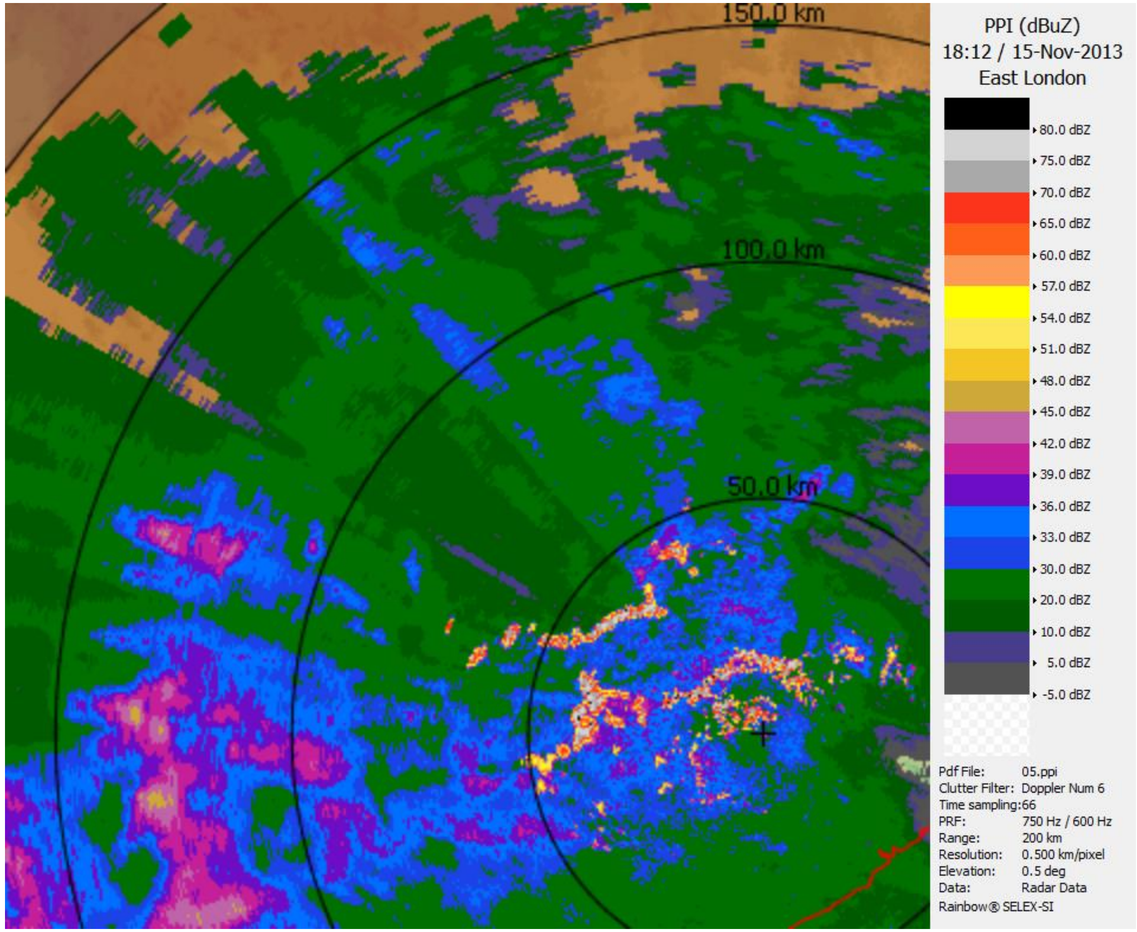


Mountain Range to the North causing beam blockage

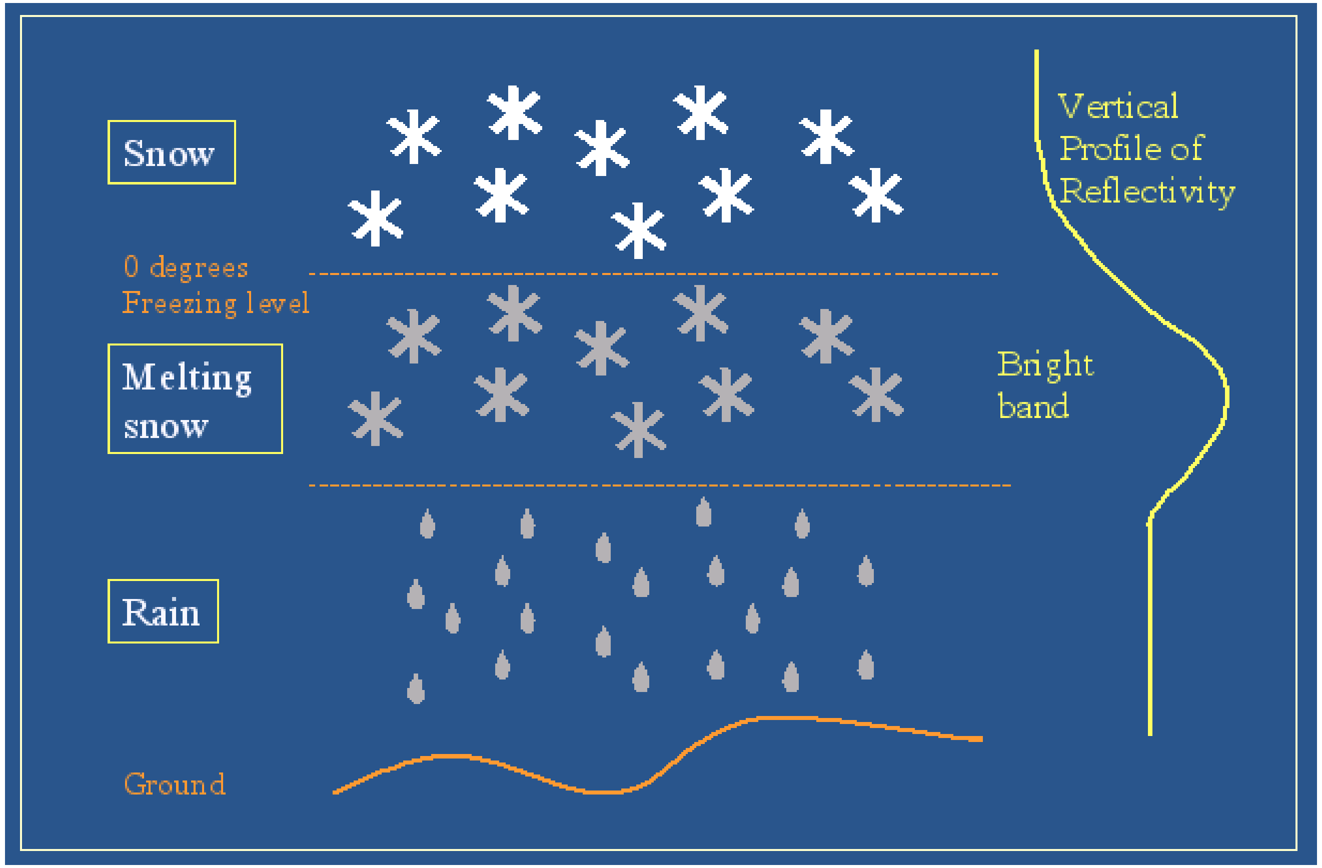
Shipping lanes

Example - Beam Blockage





Bright Band



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

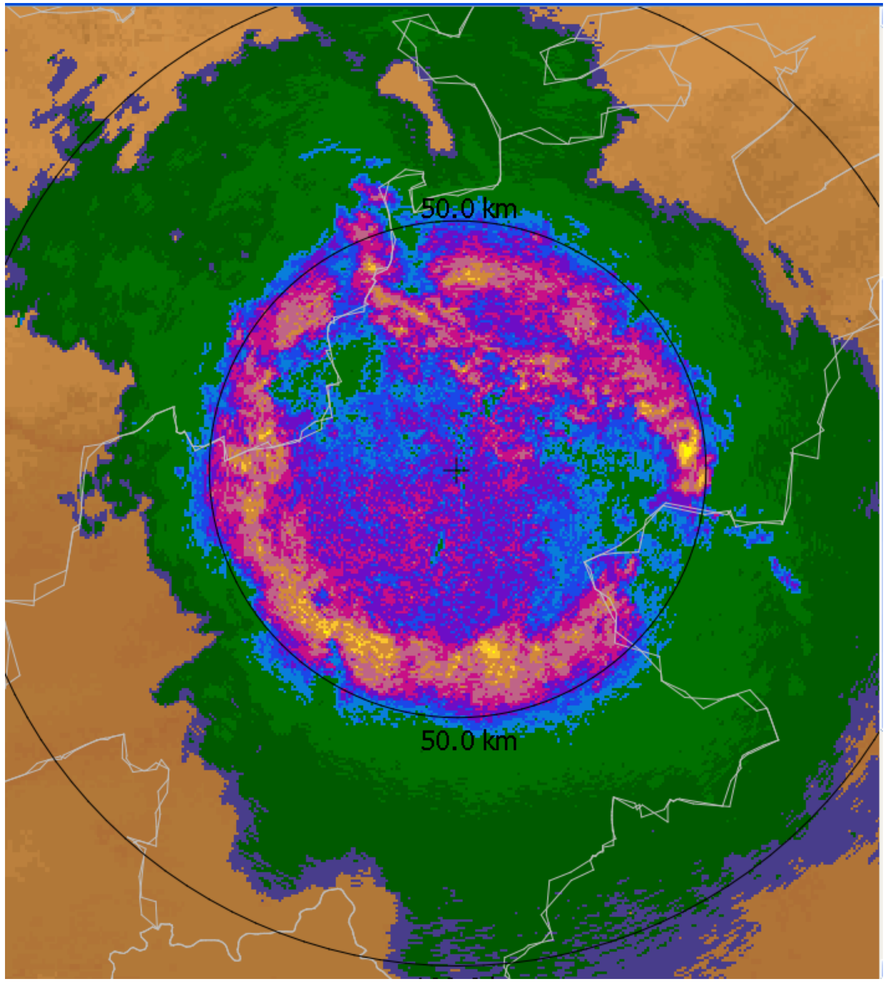
Bright Band Filter - Result

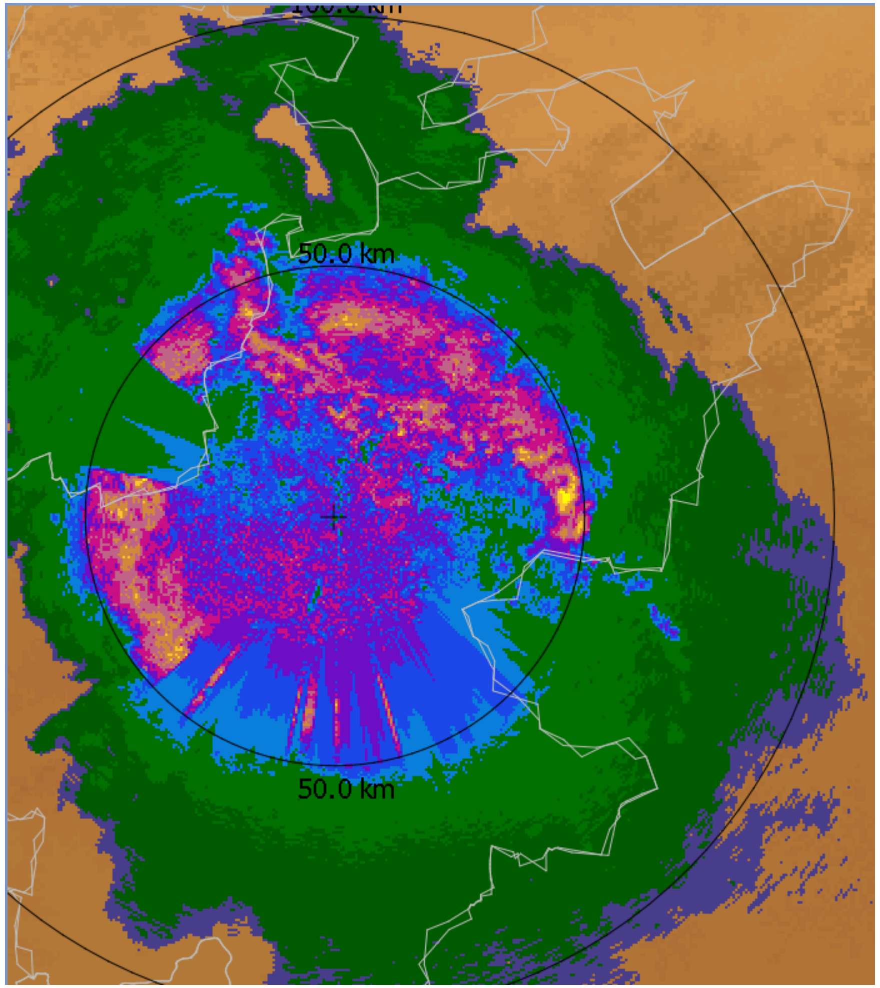
PPI 3.4

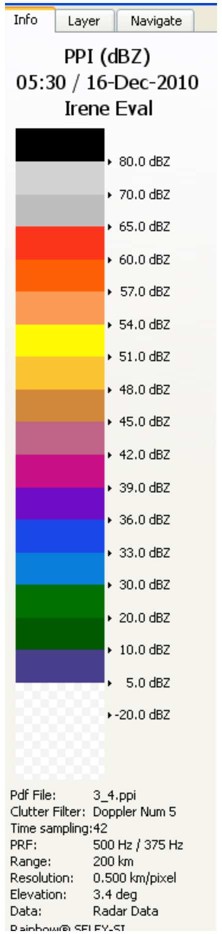
BBC

No BBC

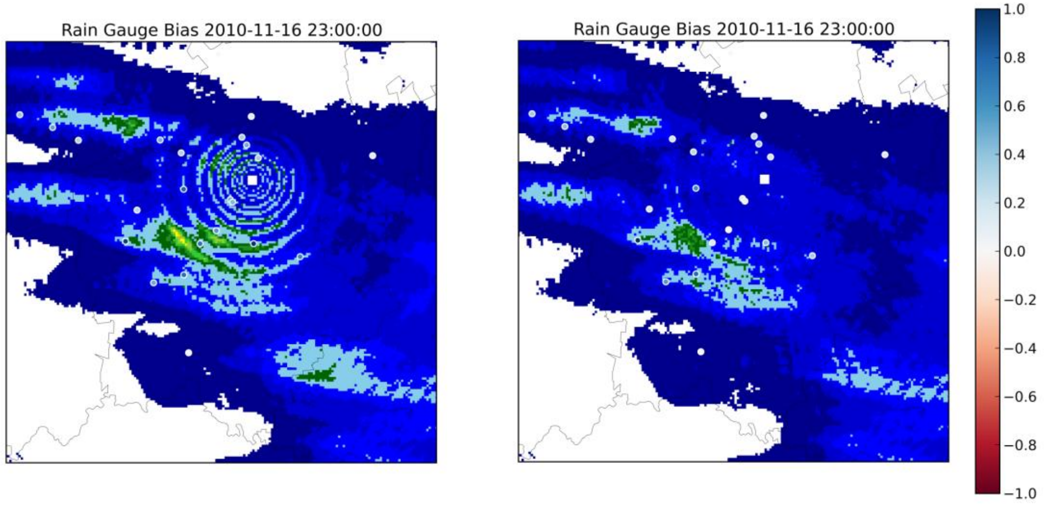
Stratiform rain

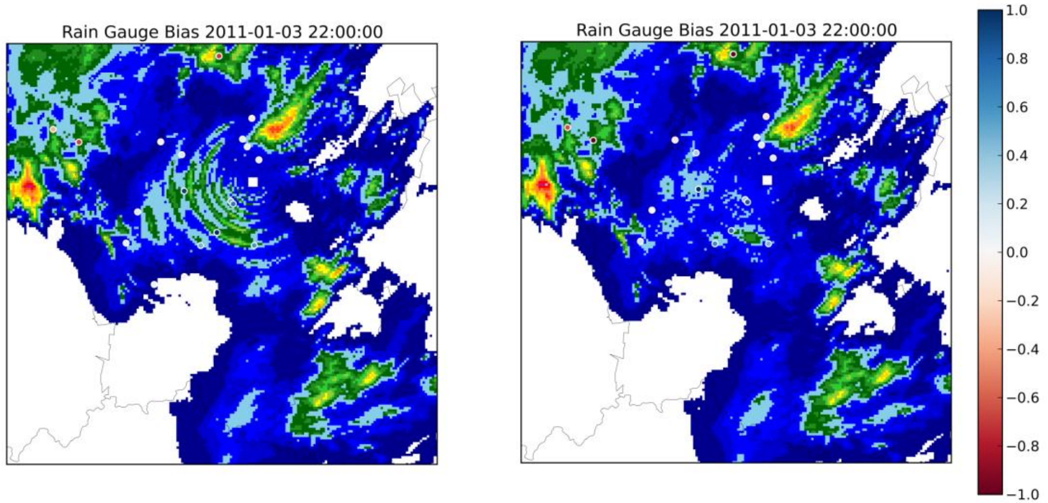




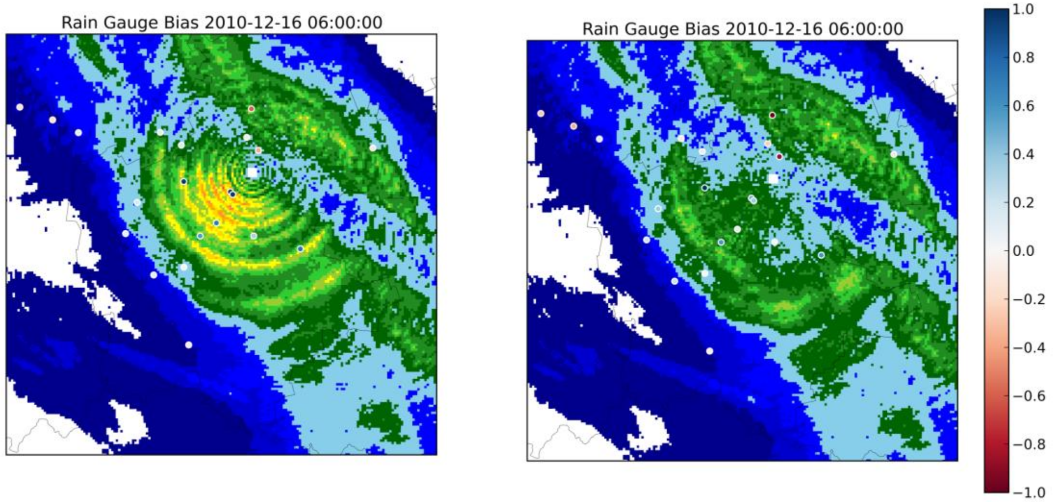


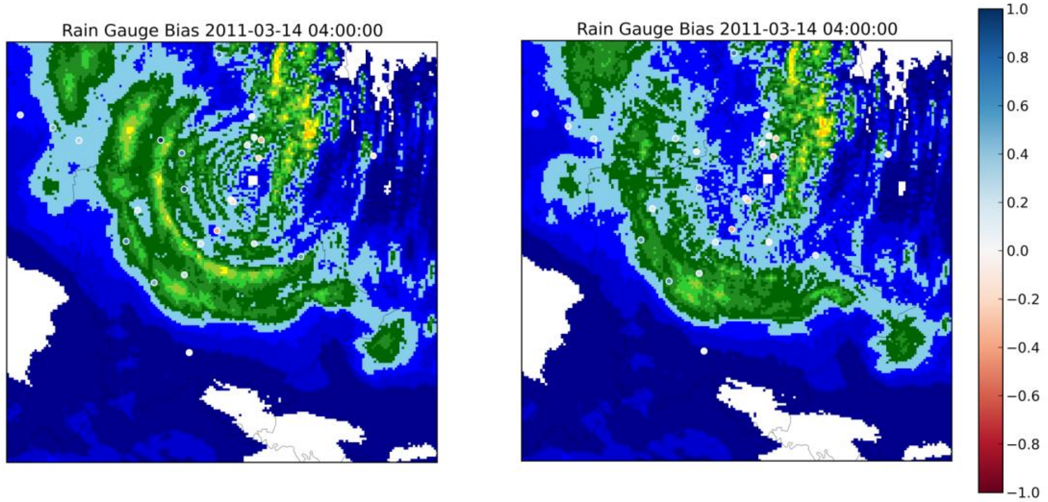
Hourly Accumulations – Bright Band Cases





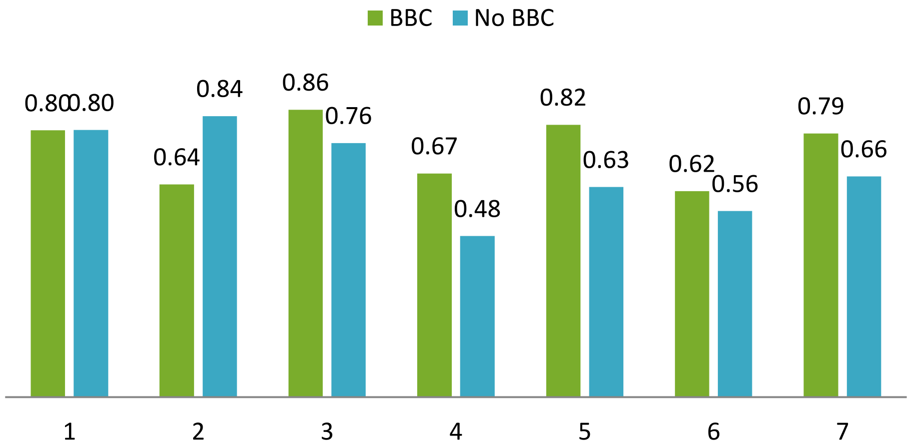
No BBC BBC No BBC BBC



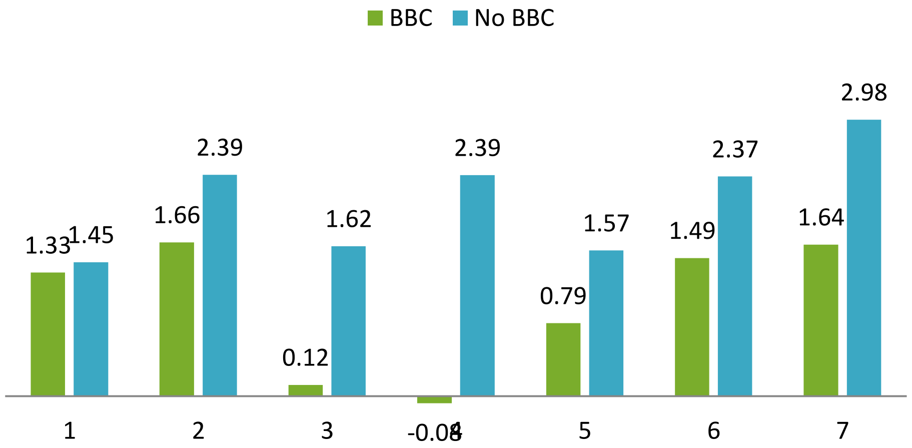


Verification – Bright Band Cases

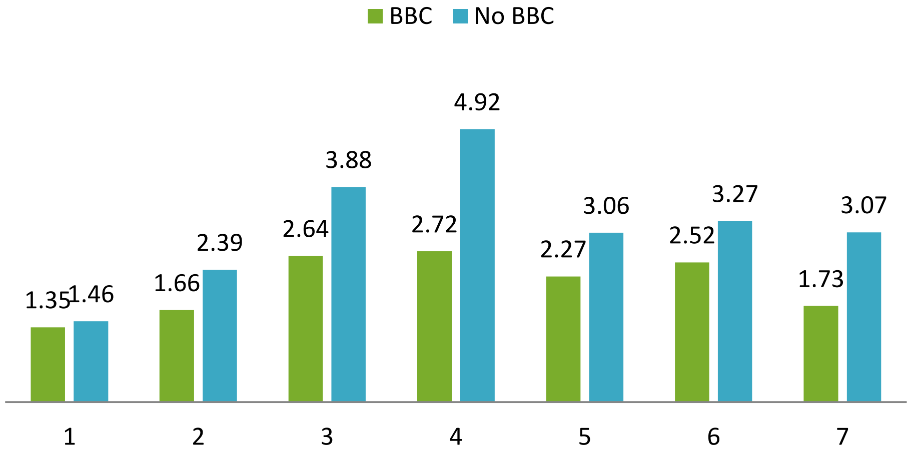
Correlation 1 Hour Gauges



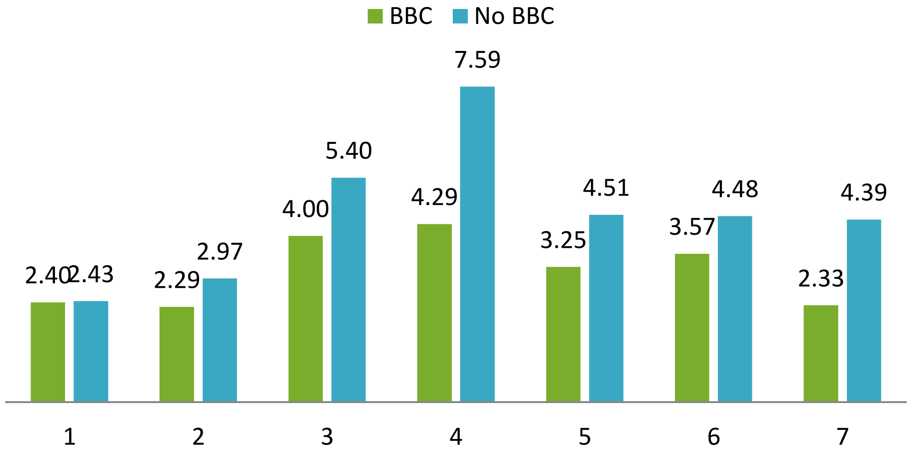
BIAS 1 Hour Gauges



MAE 1 Hour Gauges

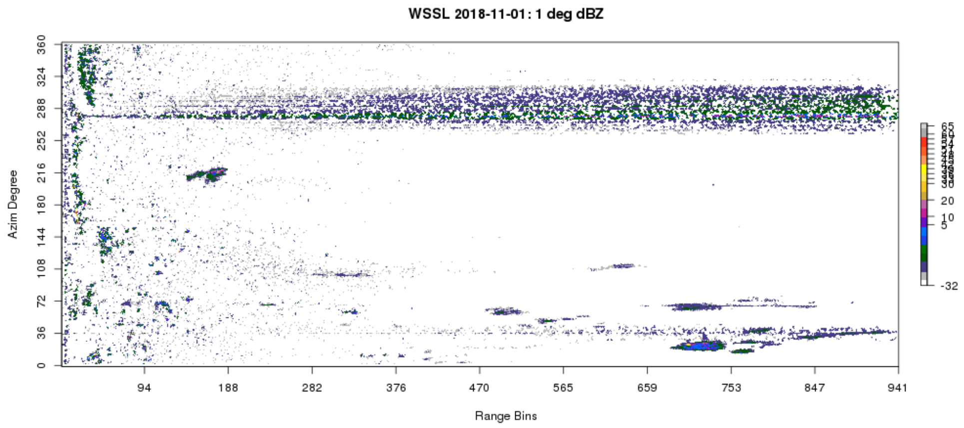


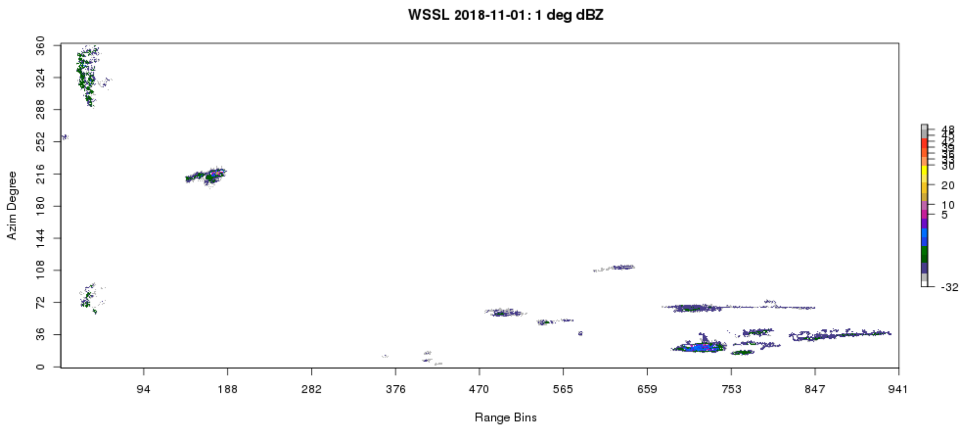
RMSE 1 Hour Gauges



Quality Control

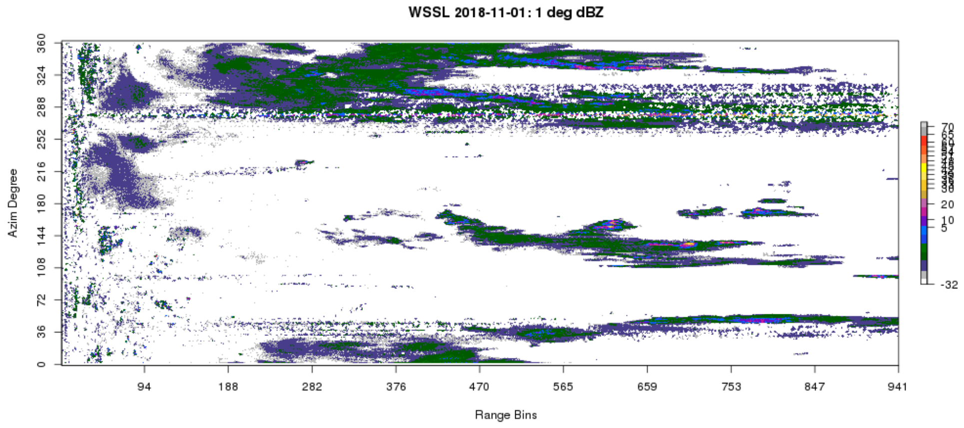
Unfiltered - DBZH   Seletar:1° Elevation   Filtered - DBZH

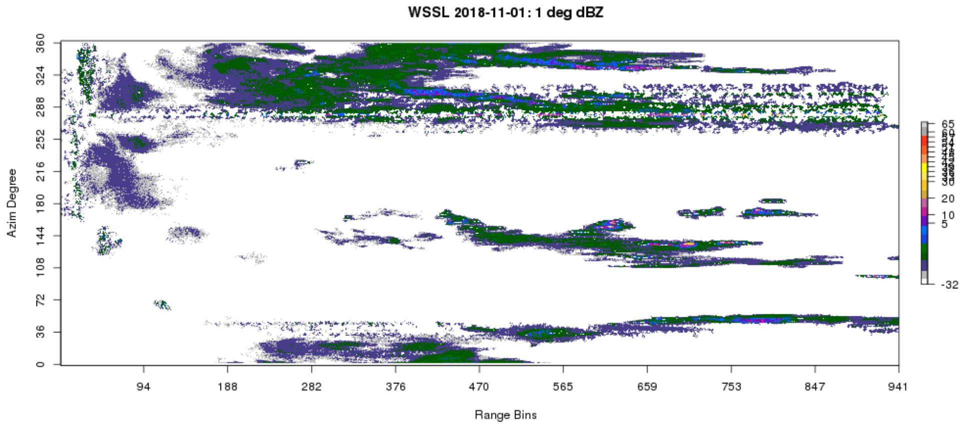




QC Filters Applied:

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

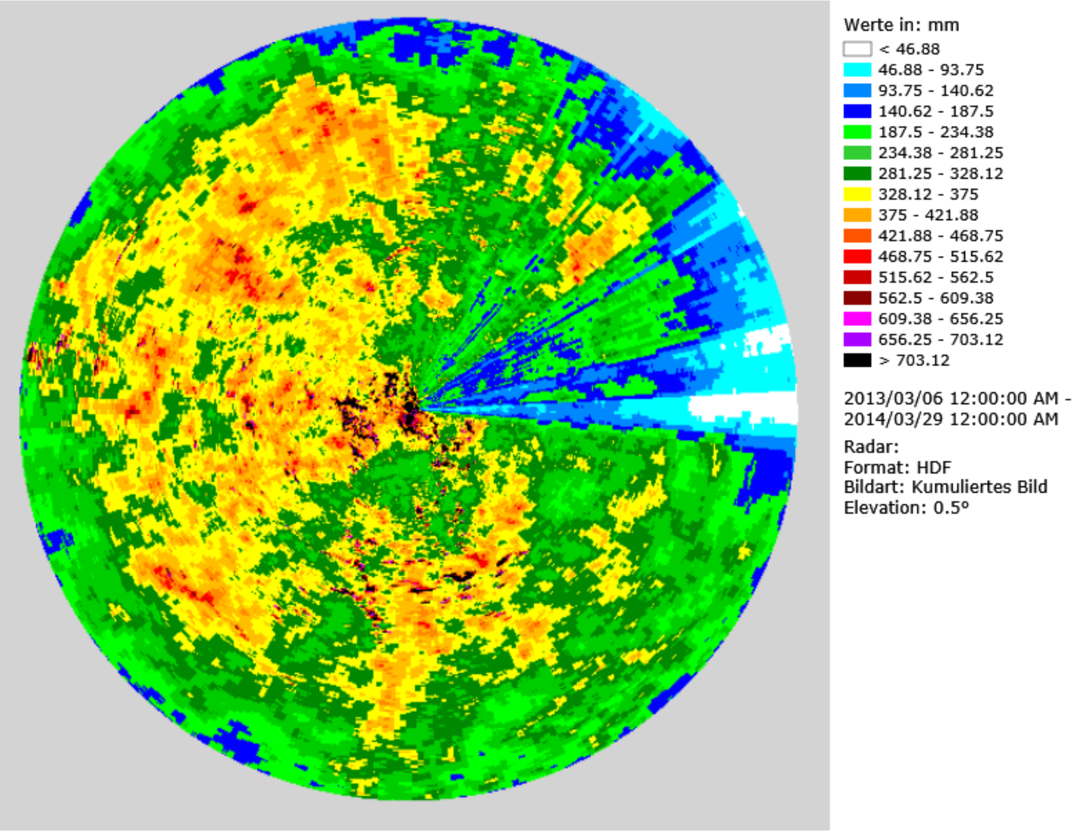
Interference filter active on Signal Processor

***rack**: baldrad.fmi.fi/software/rack/doc/rack/html/index.html*
***PyART**: arm-doe.github.io/pyart/*
***wradlib**: wradlib.org/tag/python*

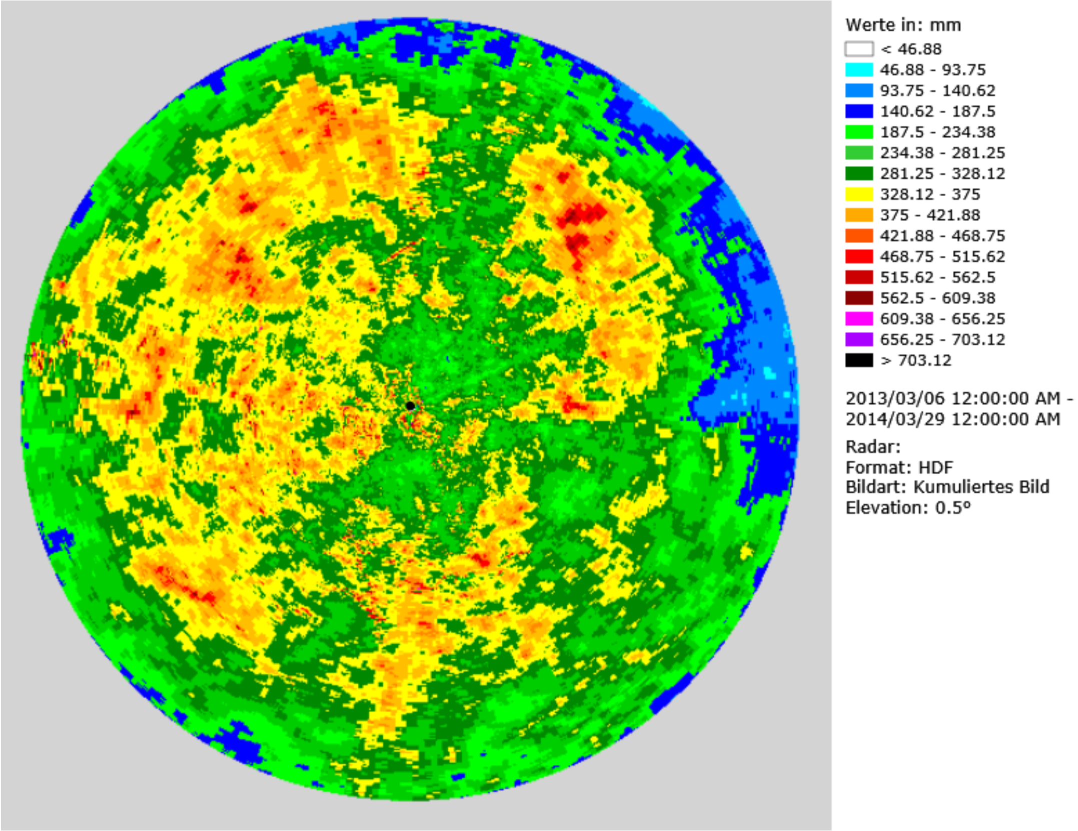
QC using SCOUT

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

Ermelo – No QC



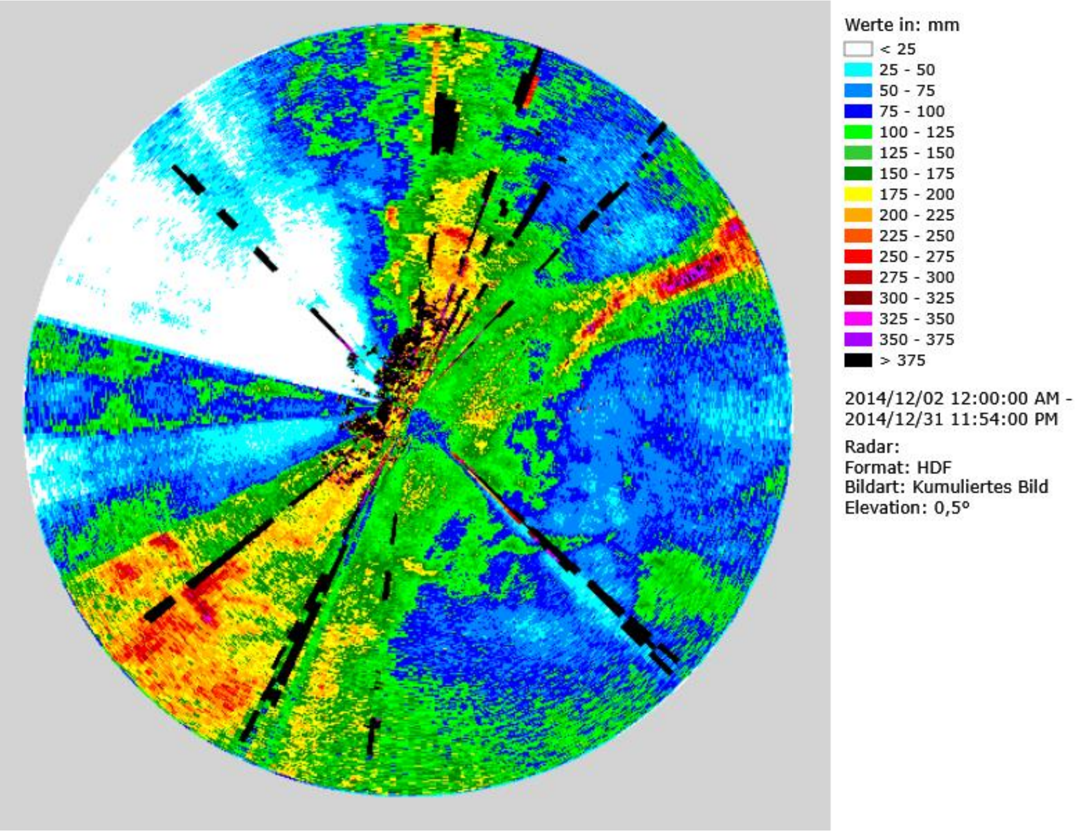
Ermelo – QC



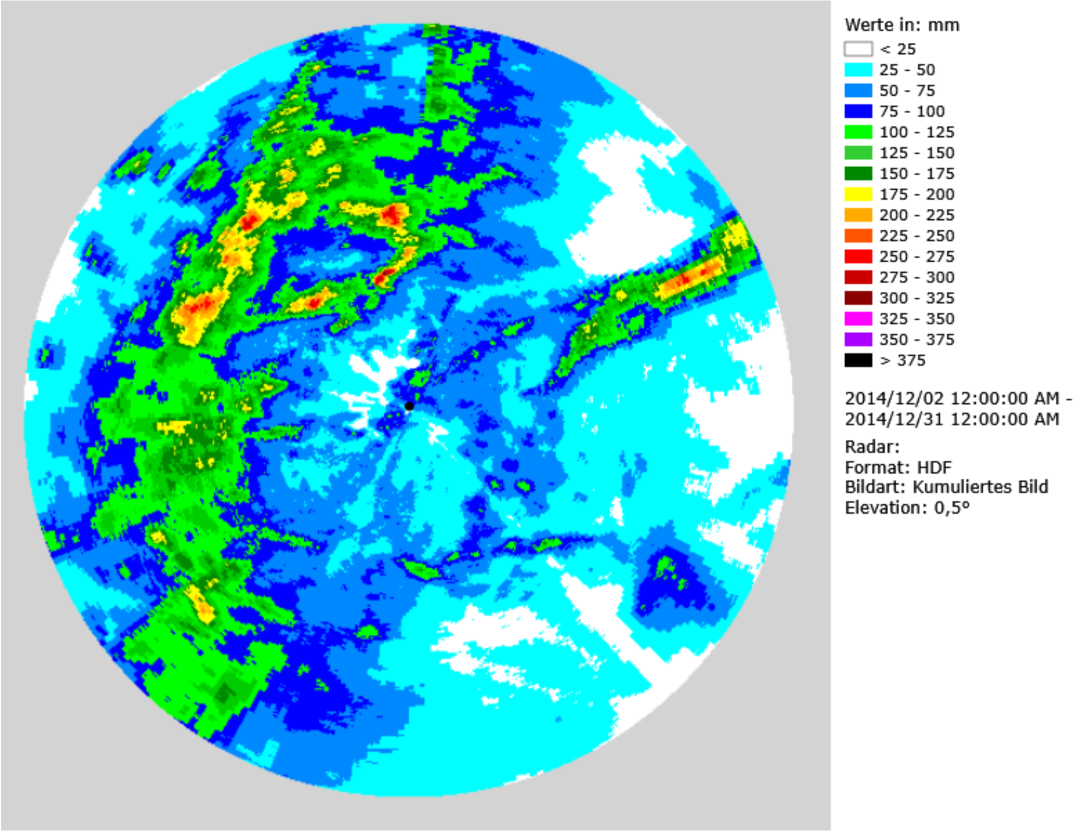
QC using SCOUT

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

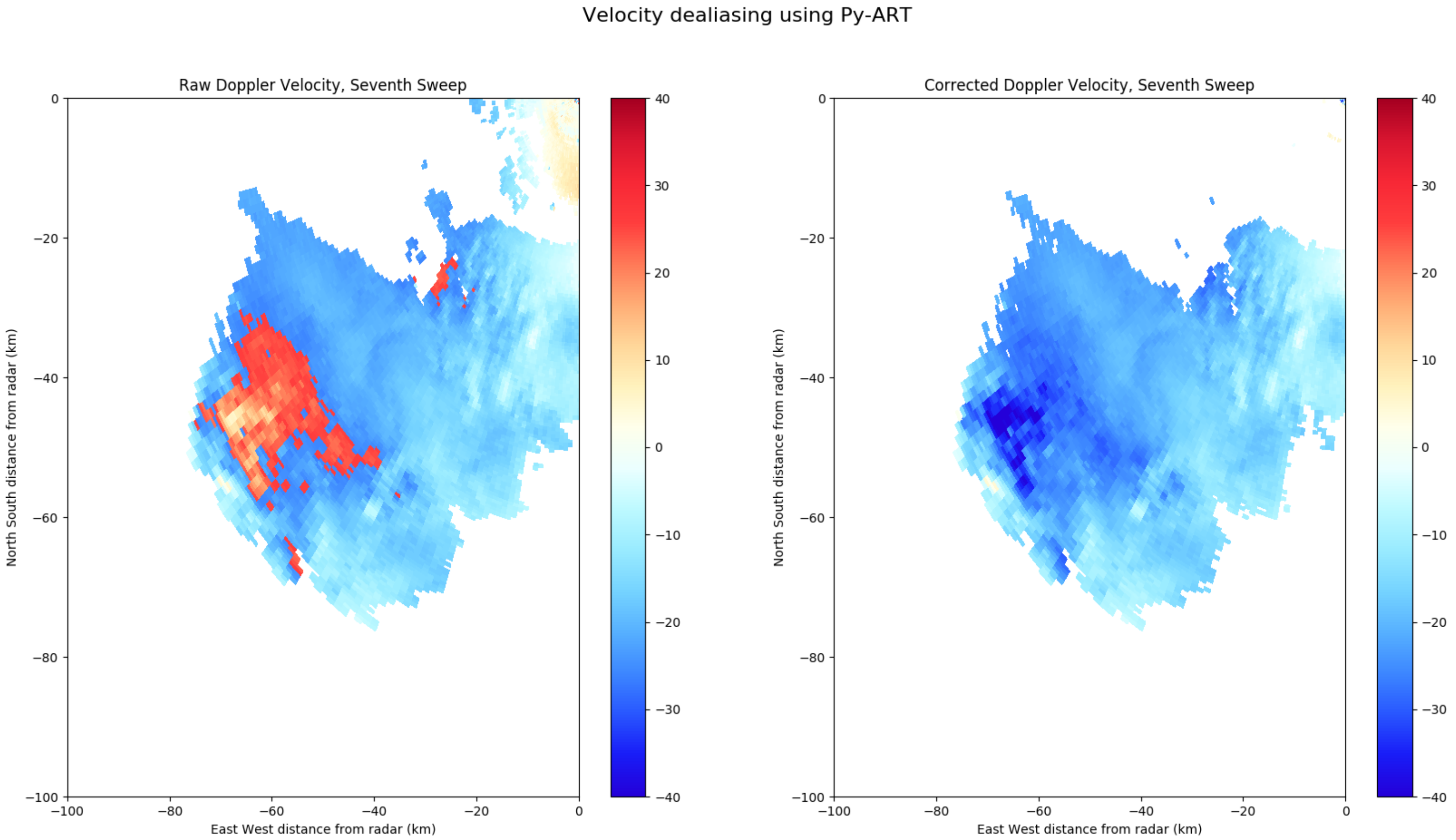
Durban – No QC



Durban - QC

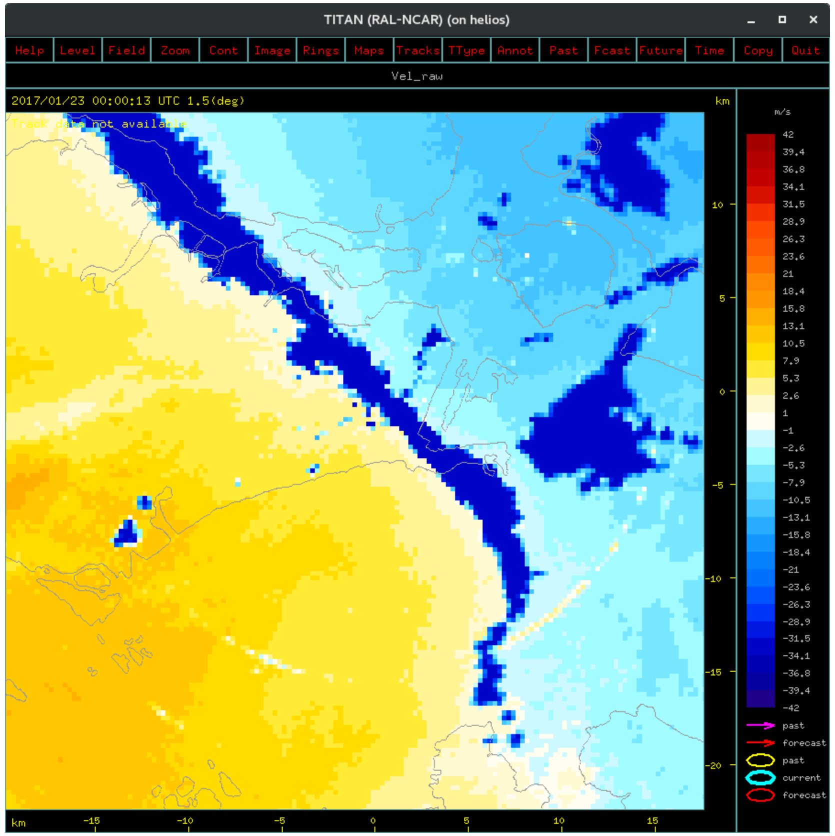


Velocity Folding – Dealiasing

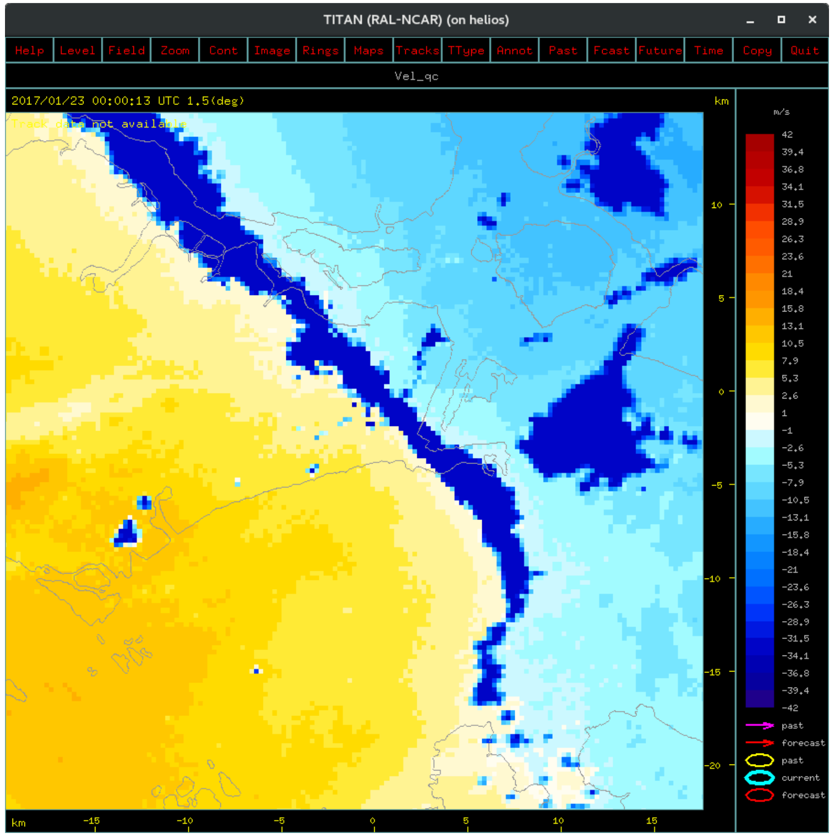


Quality Control (QC)

Before



After



Quality Index (QI) Field

Dynamic QI (Weather related)

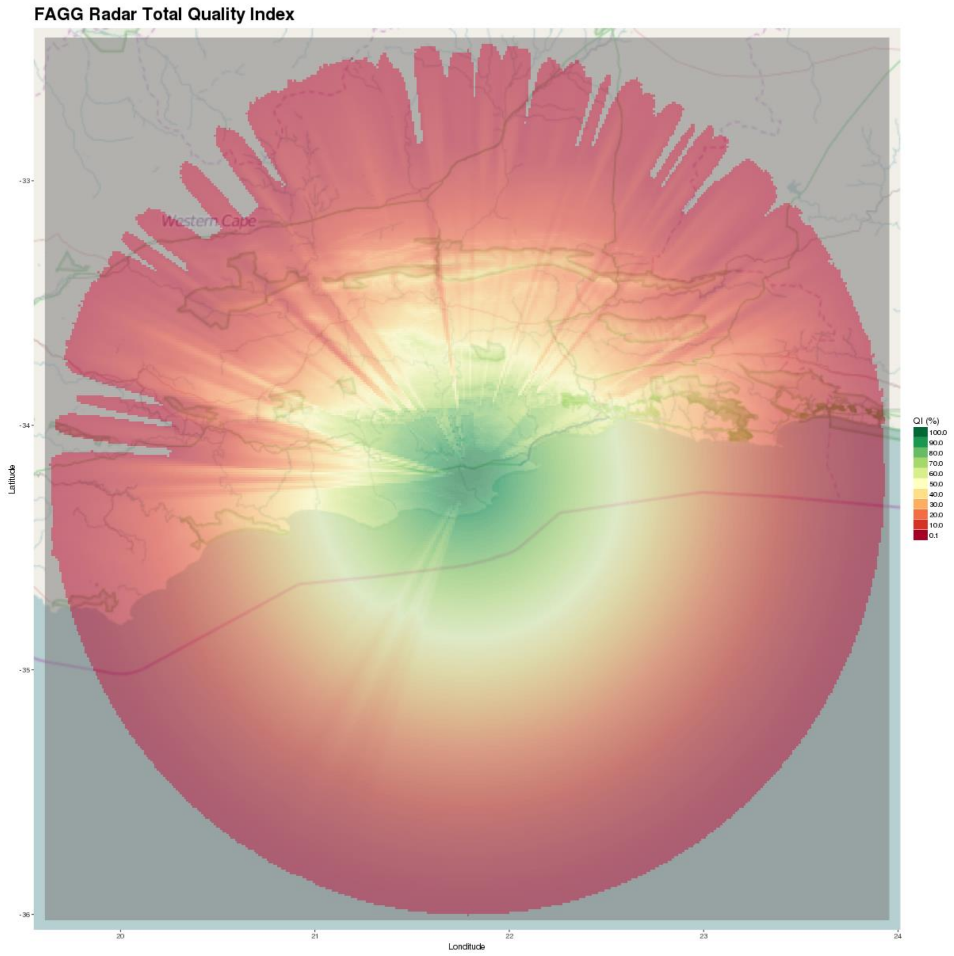
- Attenuation
- Bright Band
- Aircraft
- Birds, insects (bio)
- Vertical variability
- Anomalous propagation

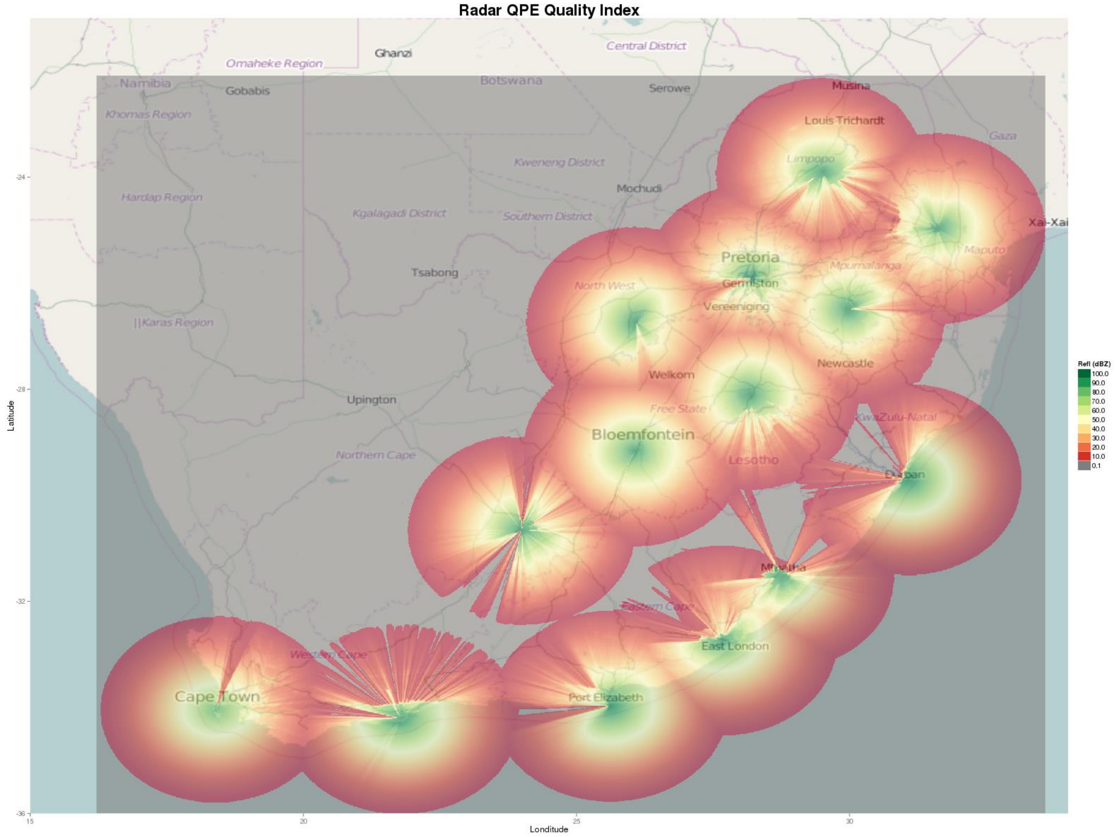
Static QI (properties of radar)

- Range
- Beam blockage
- Beam height
- Ground clutter

- Good to use in network planning

QI (static) example – compositing

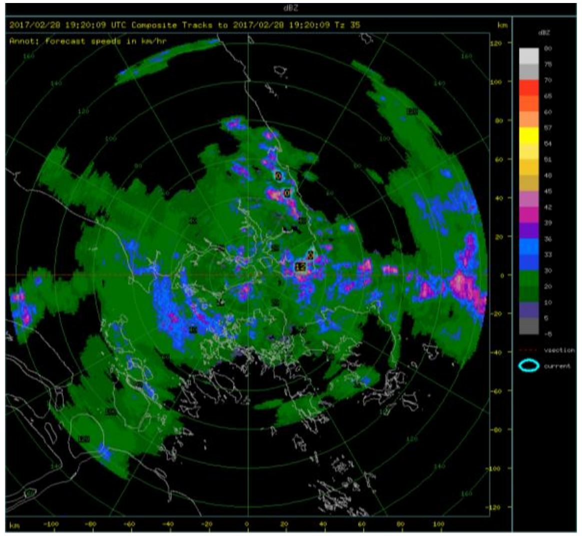


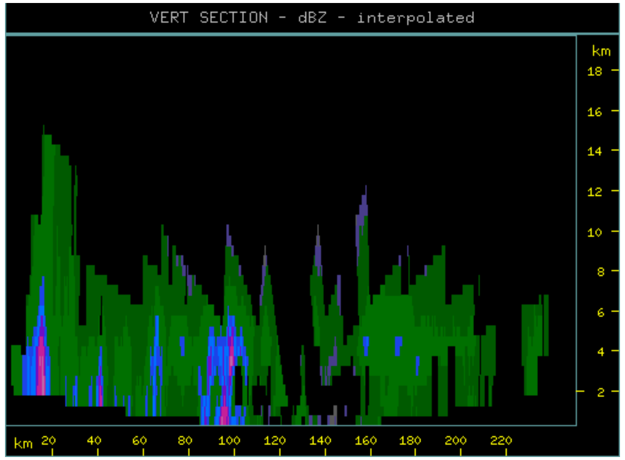


Data Processing

Convert to 3D Cartesian

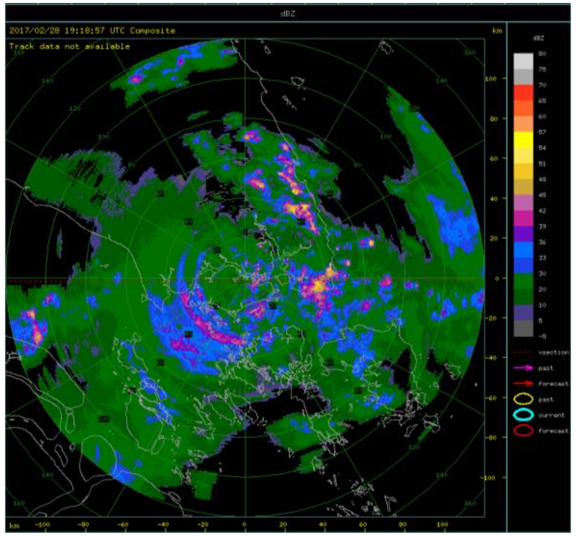
WSSS

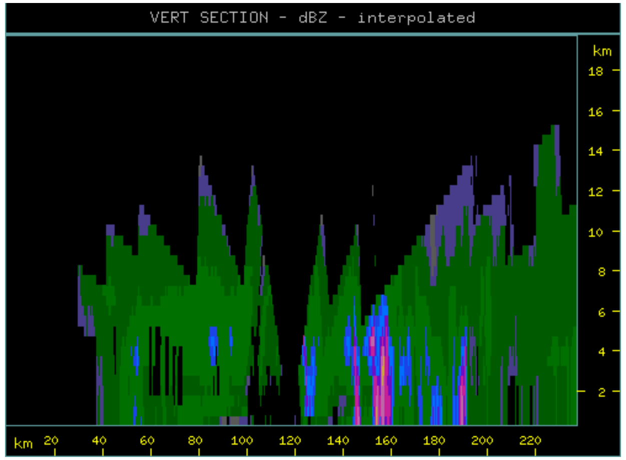




500 X 500 X 39 pixel,
±125km,
500m resolution
Proj: azeq

WSSL



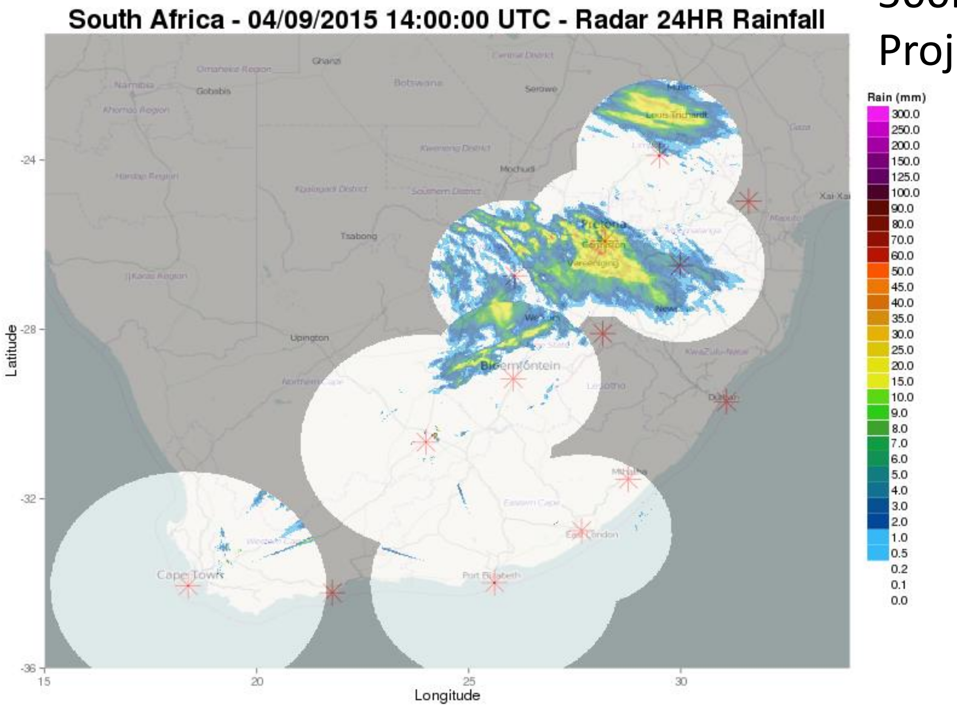


480 X 480 X 39 pixel,
±120km,
500m resolution
Proj: azeq

Composite Domain

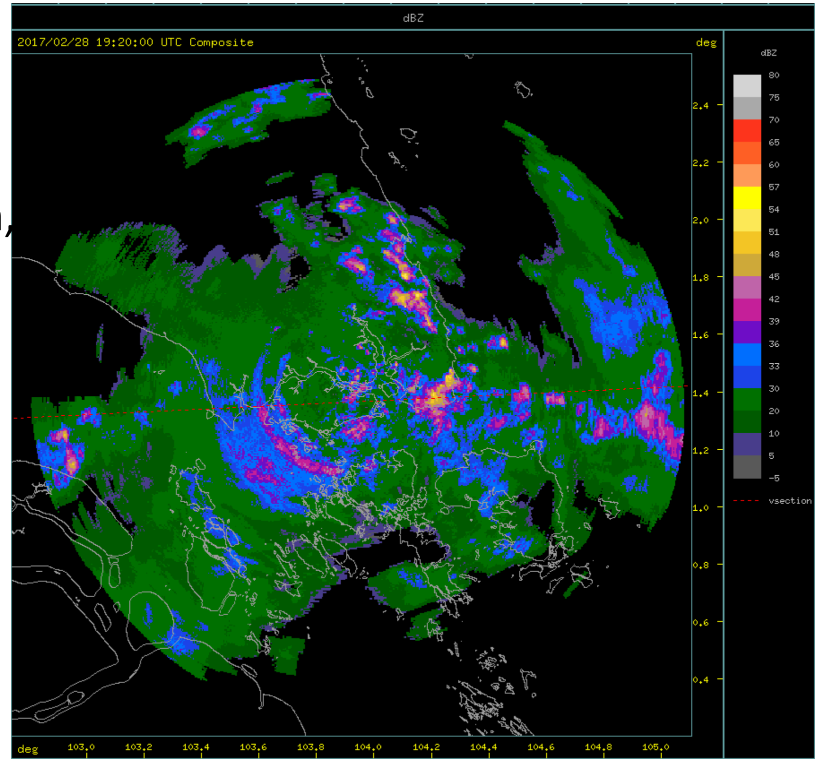
Methods:
- Max
- Mean
- QI Weights
- Timing sync scans

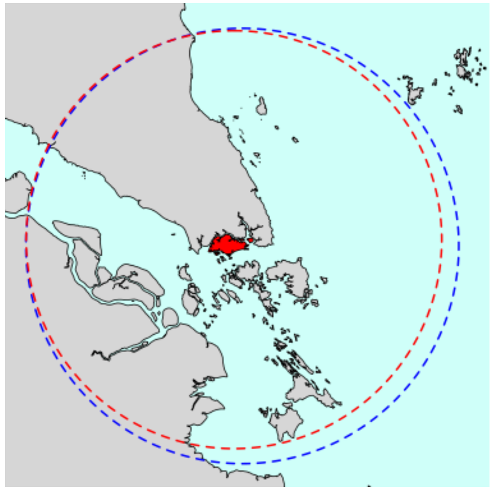
Data sources:
- PPI
- CAPPI
- 3D Cart

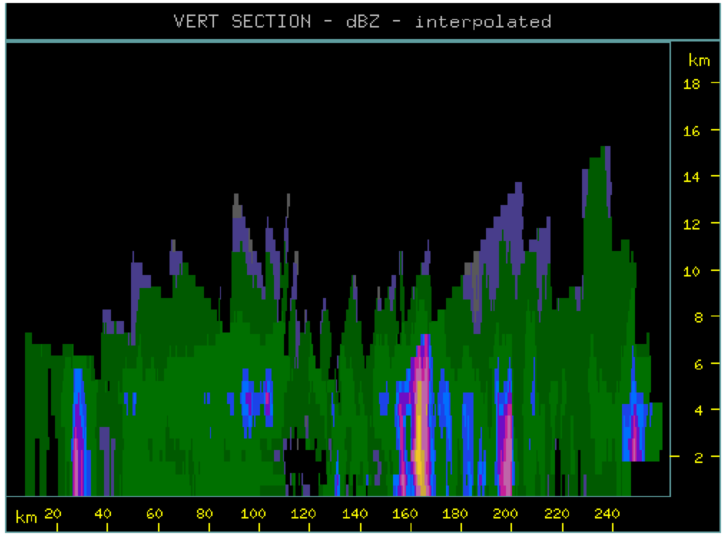


COMP MAX:
3697X3215 pixel,
500m resolution,
Proj: latlon

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







Rain Gauge Quality Control

Rain Gauge Quality Control Procedure

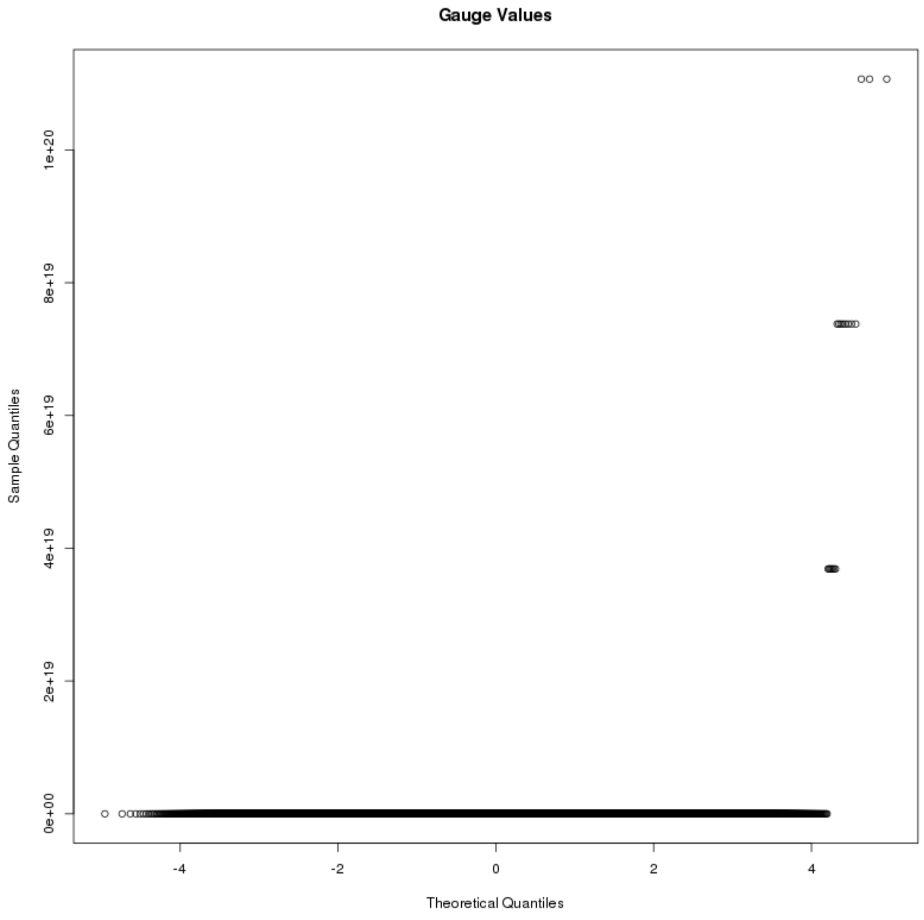
Possible sources of error

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.

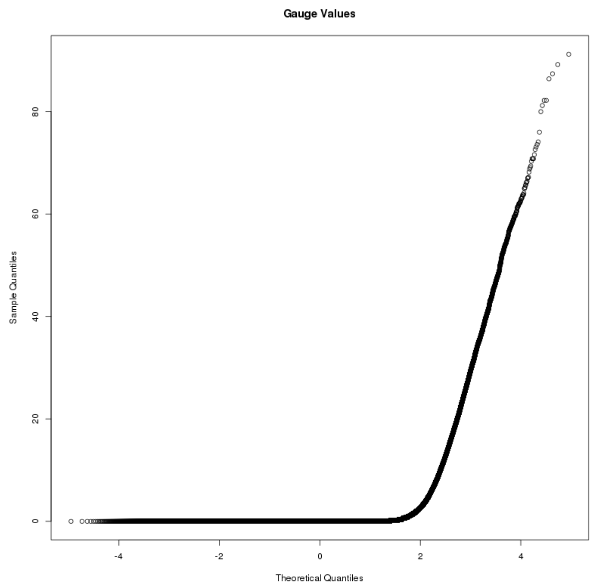
Analysis

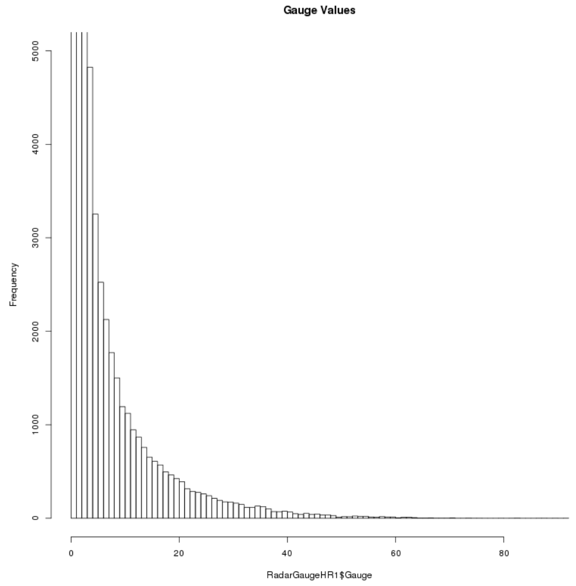
- Calculate univariate and bivariate statistics
- QQ-plots, Bubble-plots, Histograms, etc.
- Threshold unrealistic values
- Round to the nears 10^{th} (floating point errors)
- Find Correlations, Medians, Averages, Accumulation, Availability

Rain Gauge Data

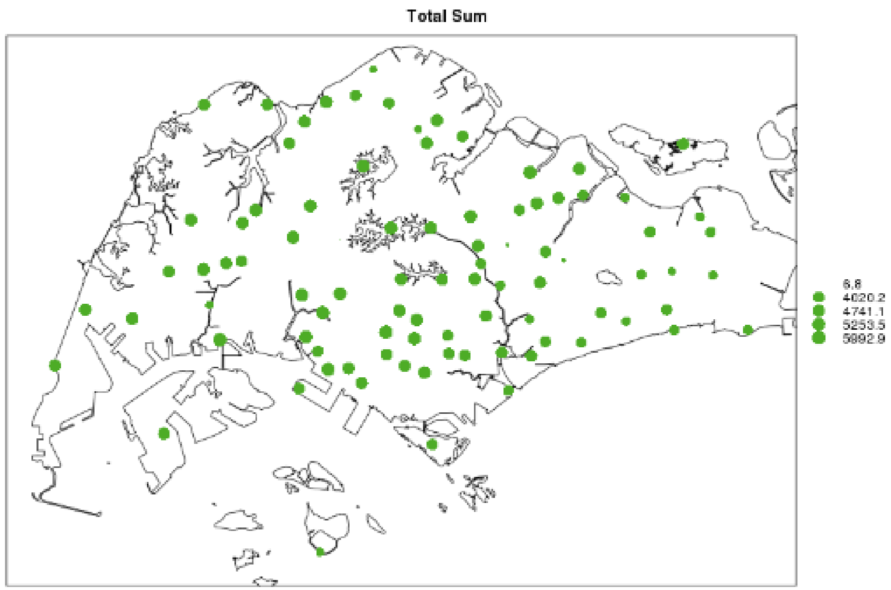


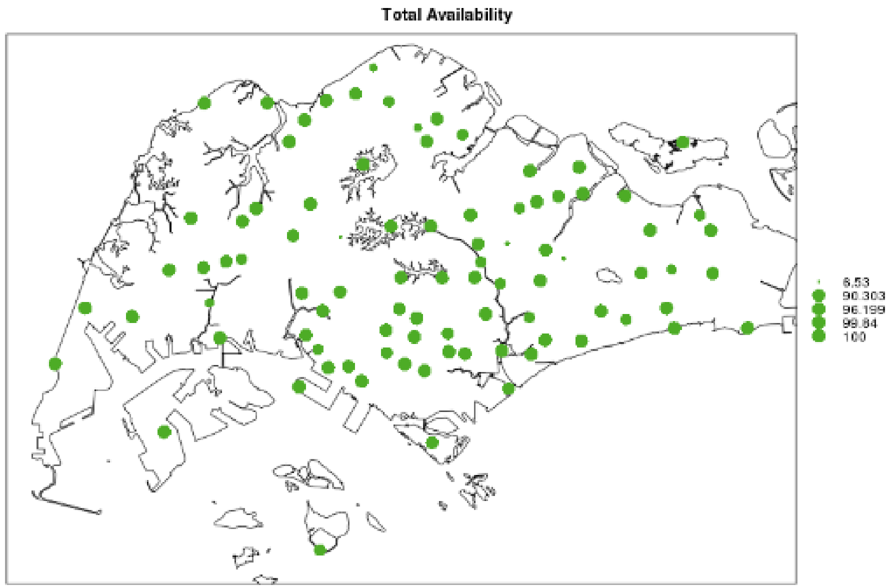
- Univariate Statistics:
- QQ plot
- Extreme values thresholding
- Set to missing
- QQ-plot now showing more realistic values
- Histogram showing log distribution



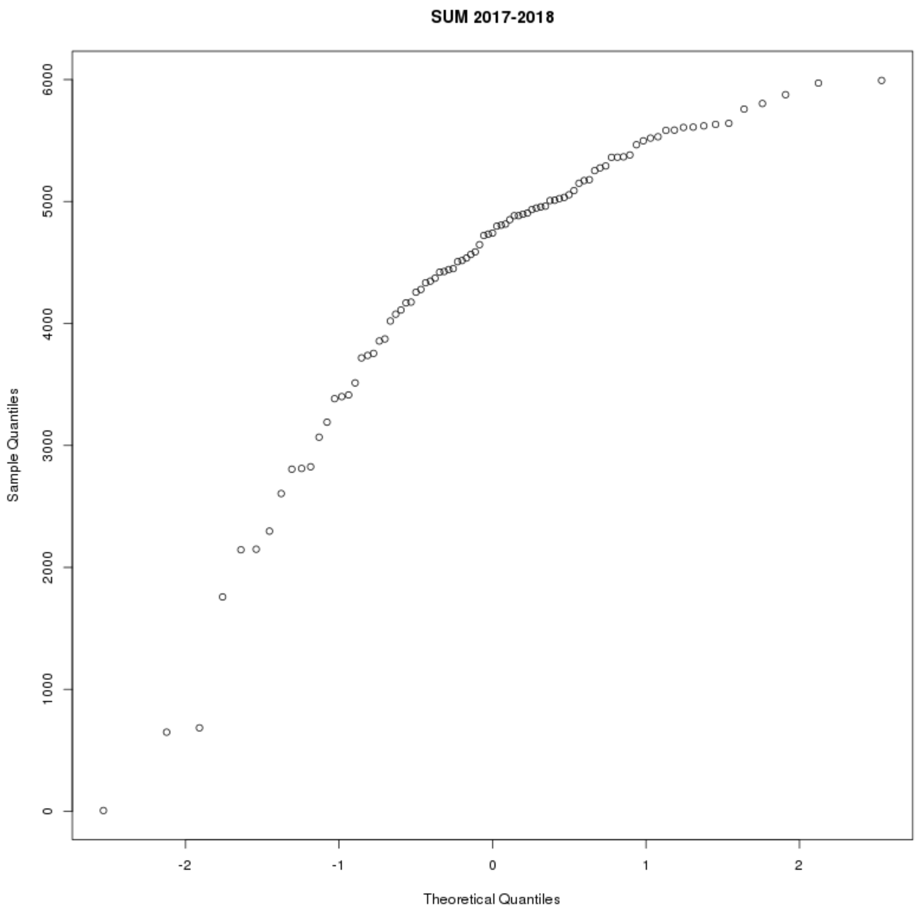


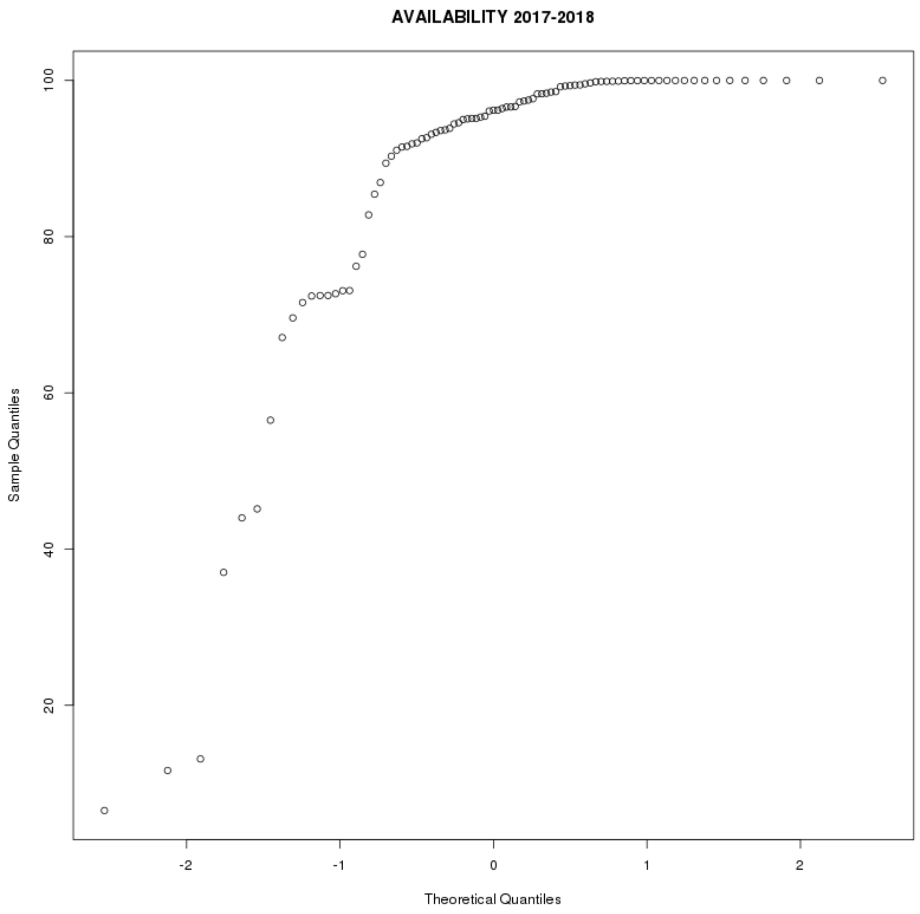
Rain Gauge Data



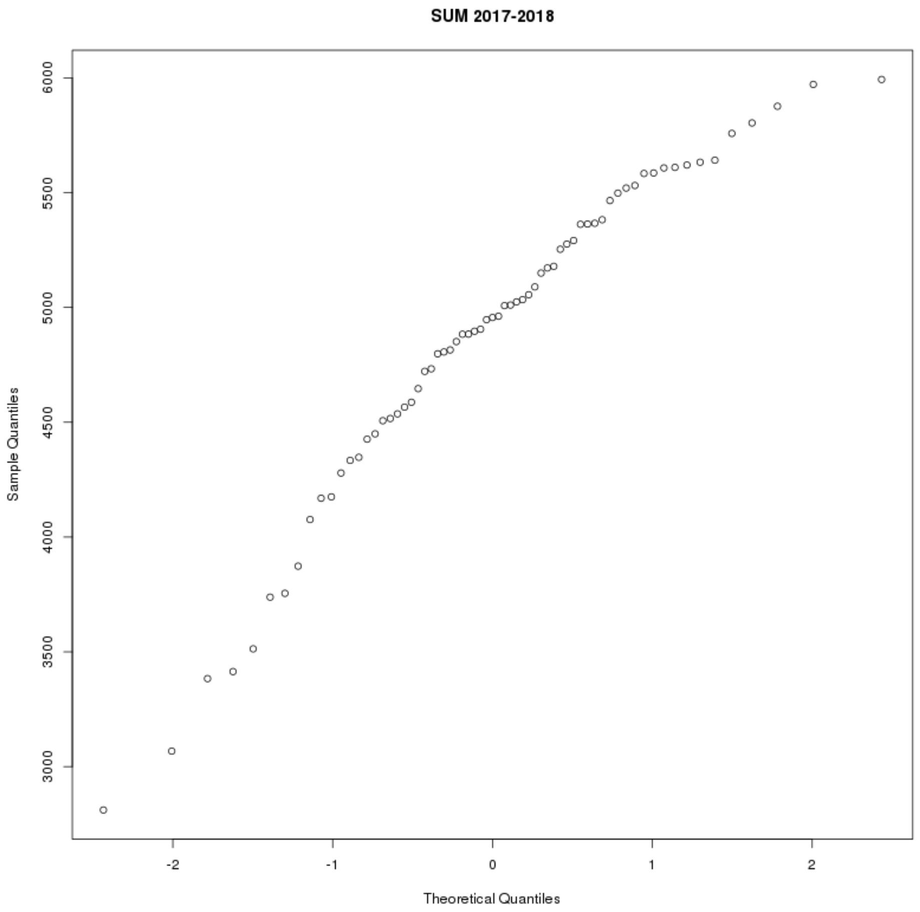


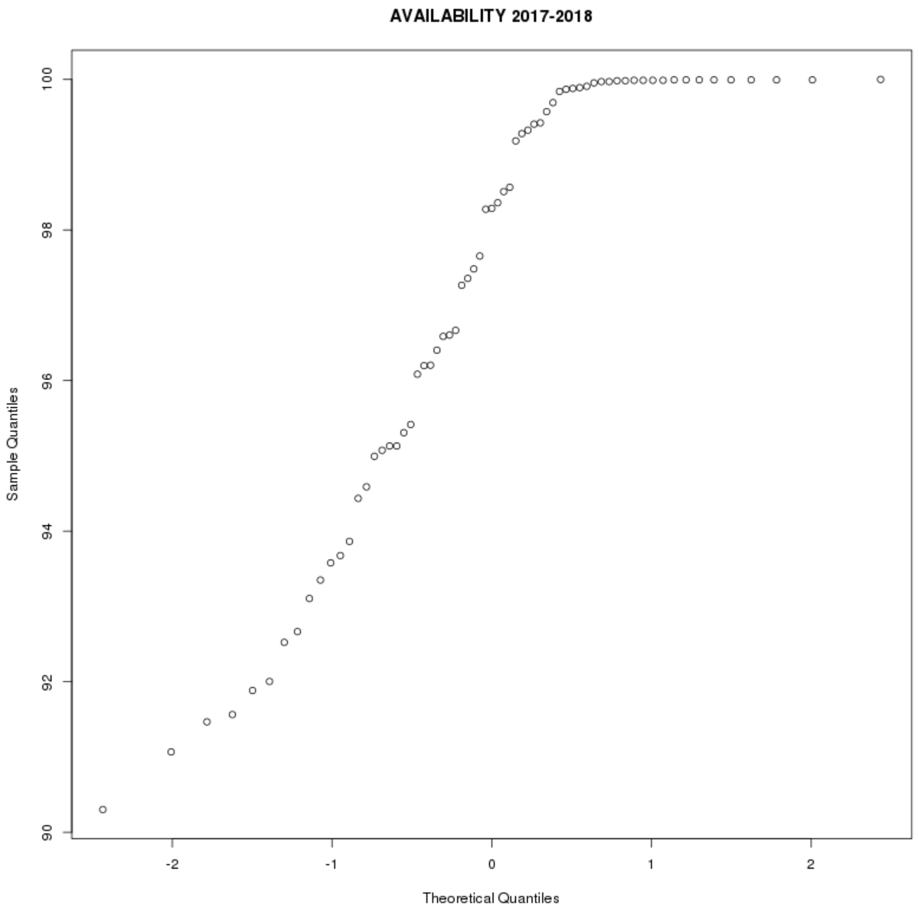
Rain Gauge Data



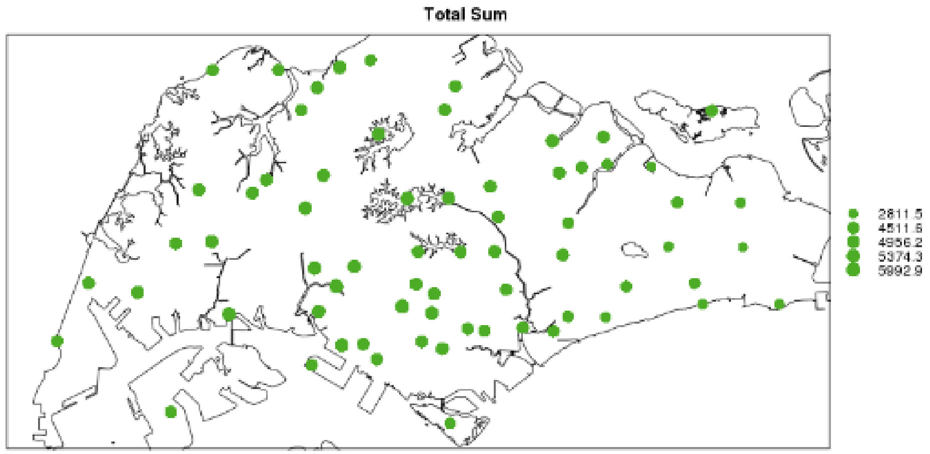


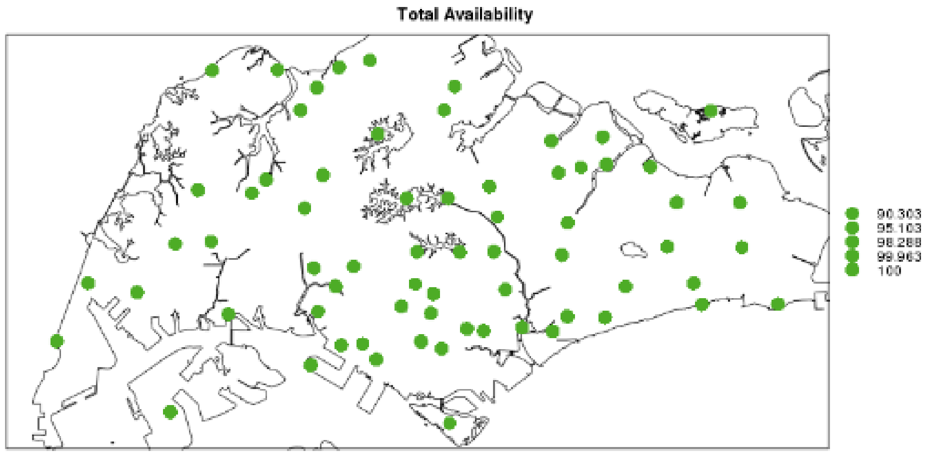
Rain Gauge Data





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**
- T. Einfalt, J. Szturc, K. Ośródka, Atmos. Sci. Lett. **11**, 139–144 (2010)
- Any good Geostatistics Textbook

Thank You

Questions?

Meteorological Service Singapore

Centre for Climate Research Singapore

Erik_BECKER@nea.gov.sg