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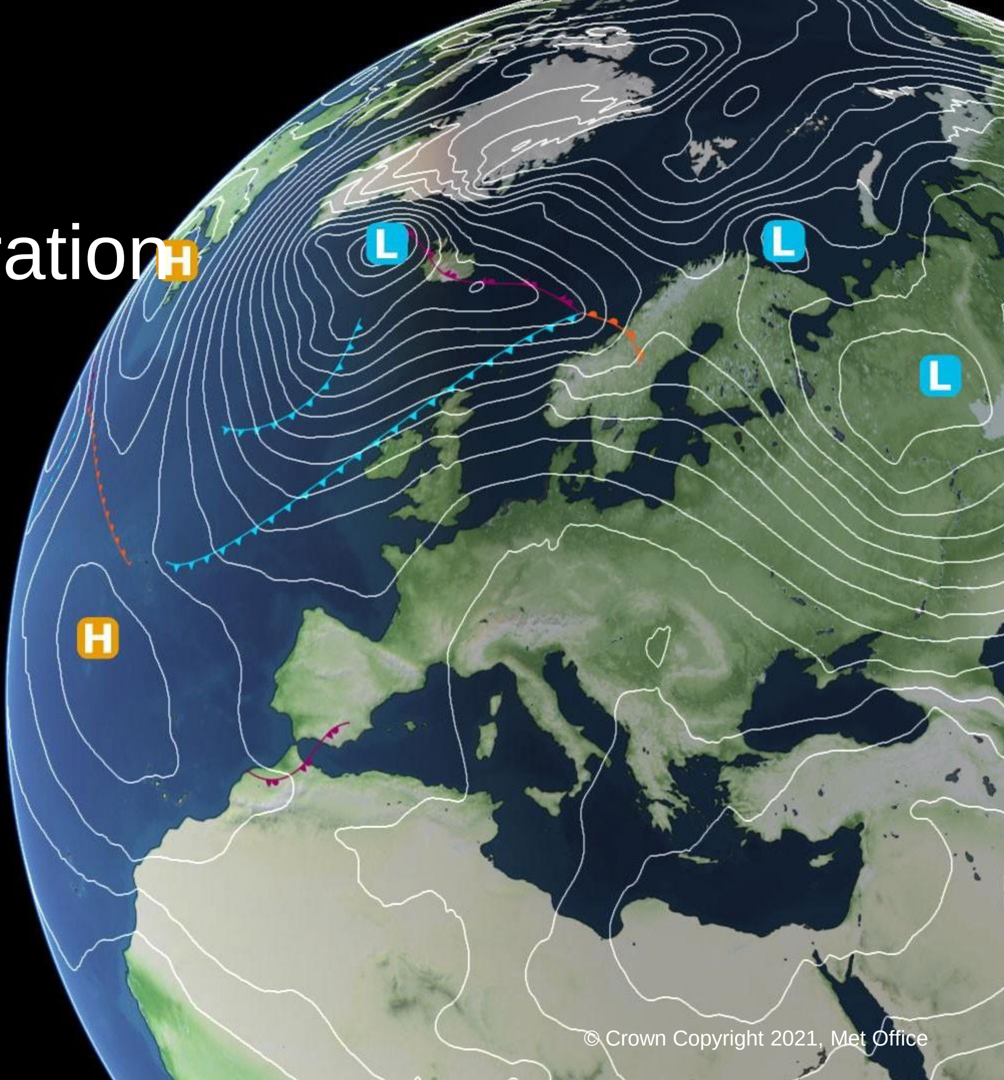
Benefits of automated receiver reflectivity calibration monitoring – an update



Tim Darlington

Radar R&D Team Leader

Overview

- Motivation
- Approach
- Use cases
- Next steps

Motivation

- Monitor changes in receiver calibration in real time
- Previously
  - Only updated at engineer visits (6 monthly)
  - Potential for human error
  - Historical record of faults/changes to system not easily accessible
  - Dependent on gauge adjustment factor to correct for calibration issues
  - Not simple to directly compare data sources when investigating a fault
- The Aim:
  Use all* available sources of information to develop a monitoring scheme

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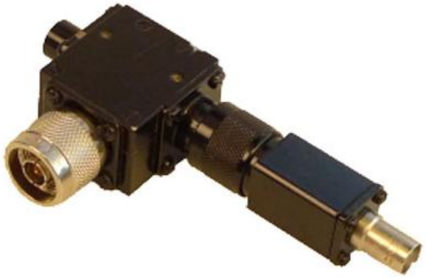
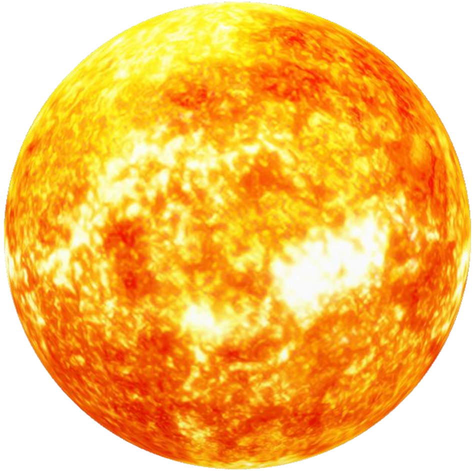
Data Sources



- Known sources of power to calibrate receiver.

Currently we use:

- Engineering site visit power injection



- Noise source
- Sun
- Tip curve (Radars as Radiometers*)

***Using radars as radiometers: promises and pitfalls** F. Fabry, McGill University, Montreal, PQ, Canada
https://ams.confex.com/ams/30radar/techprogram/paper_21576.htm

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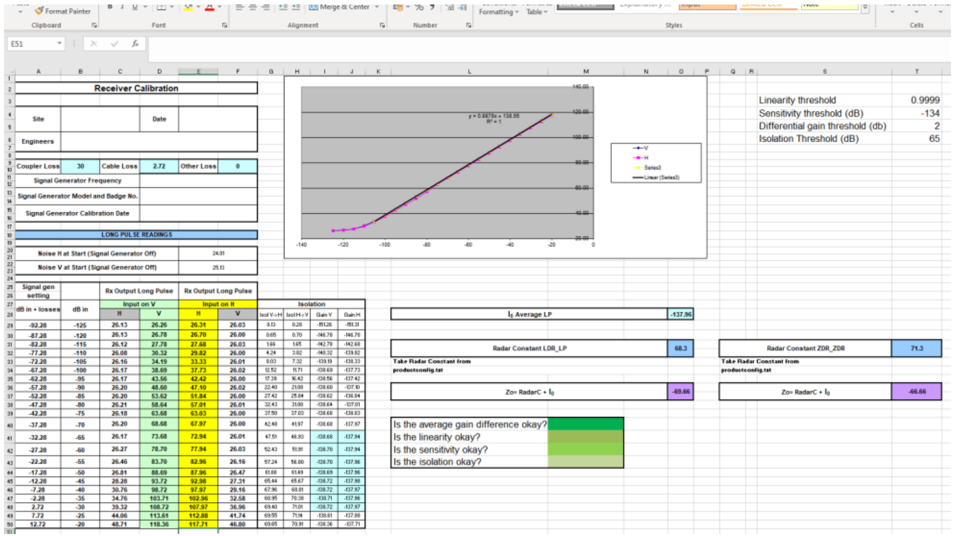
Engineer calibration

- ~ Every 6 months
- Engineers inject power to cover the dynamic range
- Values are recorded to spreadsheet
  - Automatically checks for:
    - Linearity
    - Sensitivity
    - Differential gain
    - Cross-channel isolation
- Sent to Exeter for review and update



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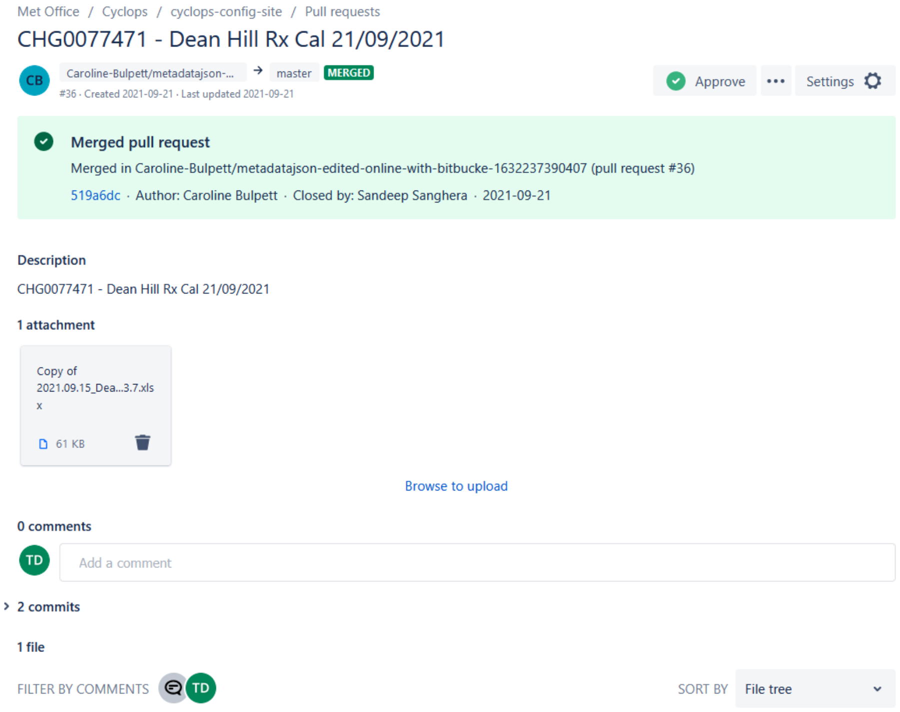
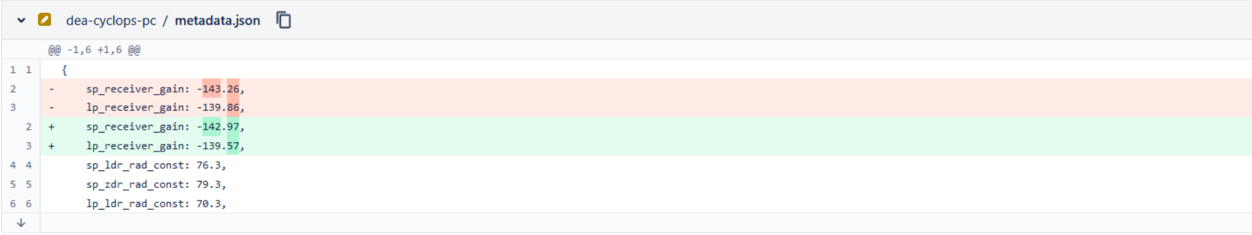
Calibration Process

- Git used as configuration management for all site config.
- Spreadsheet attached to Pull request
- Reviewed by network specialist
- Merged and pushed to site





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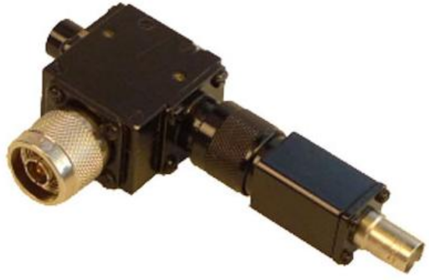
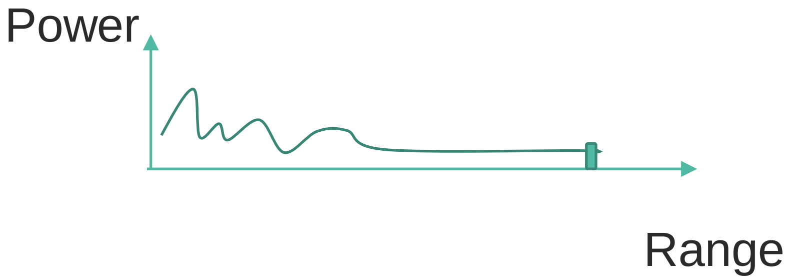
Injected noise source



- Ranatec 35dB ENR noise source
- Injected via -30dB directional coupler through waveguide into receiver
- Good temperature and temporal stability
- Injected for every pulse in distant range gates – scan averaged value used
- Can be contaminated by precip. in anaprop conditions



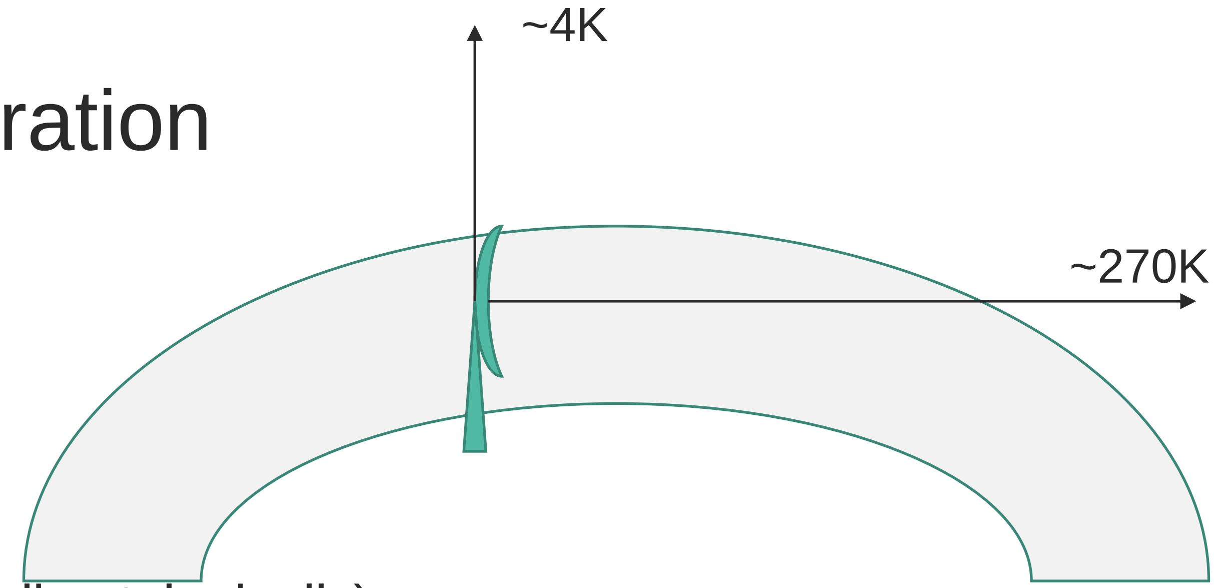
Sun Flux Comparison

- Sun Flux data is retrieved from observation source: currently using DRAO*10.7cm data.
  - Uses pre-existing software designed for azimuthal calibration of the radars
  - Software will detect the sun 5-20 times a day on average, returns the receiver measurement

- Calculation to transform from SFU to dBm includes:
  - Atmospheric attenuation
  - Scanning integration
  - Antenna gain
  - Sun and beam diameter

- Calculation to transform from SFU to dBm assumes:
  - The sun is a uniform disk
  - Antenna beam pattern is Gaussian
  - That the relationship between 10.7cm flux and 5.5cm (~ our wavelength) flux data is linear

Tip Curve calibration



- Developed for calibration of radiometers

- Atmospheric noise follows known profile (climatologically)
- Noise temperature varies seasonally but can be corrected for with simple model
- Fit to profile with standard atmosphere from radiative transfer model to find system gain

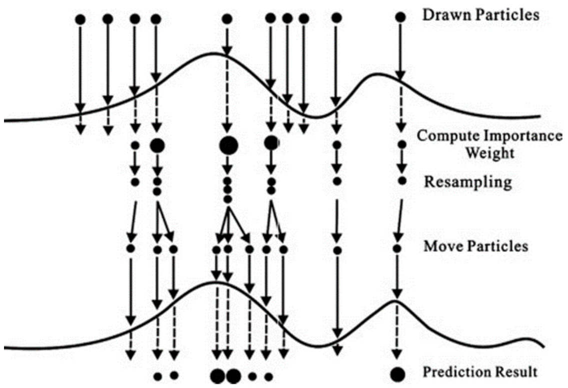
Tip Curve calculation

- This uses multi-elevation data over 10 minute window to find the gradient between noise temperature and the signal received
- Data is most variable of the three data sources, varies by up to ~2dB range on daily basis
- Code removes most of temporal temperature variation, but some remains
- Includes antenna in signal path, similarly to sun data
- Good long term averaged accuracy

Finding the Best Estimate

- Using a method called a ‘Particle Filter’ which is a sequential Monte Carlo method.

- Why?
  - Able to compute the conditional probability of a state given noisy and partial observations
  - The model can combine many different types of distribution
  - Ideal for “target” tracking – where our target is the ‘real’ calibration value
  - Flexible to the addition of new data sources



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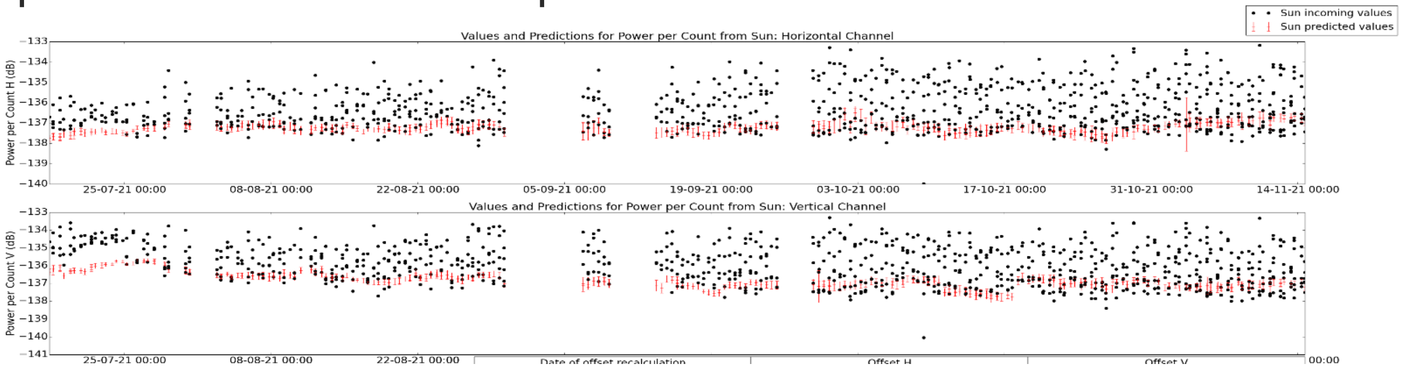
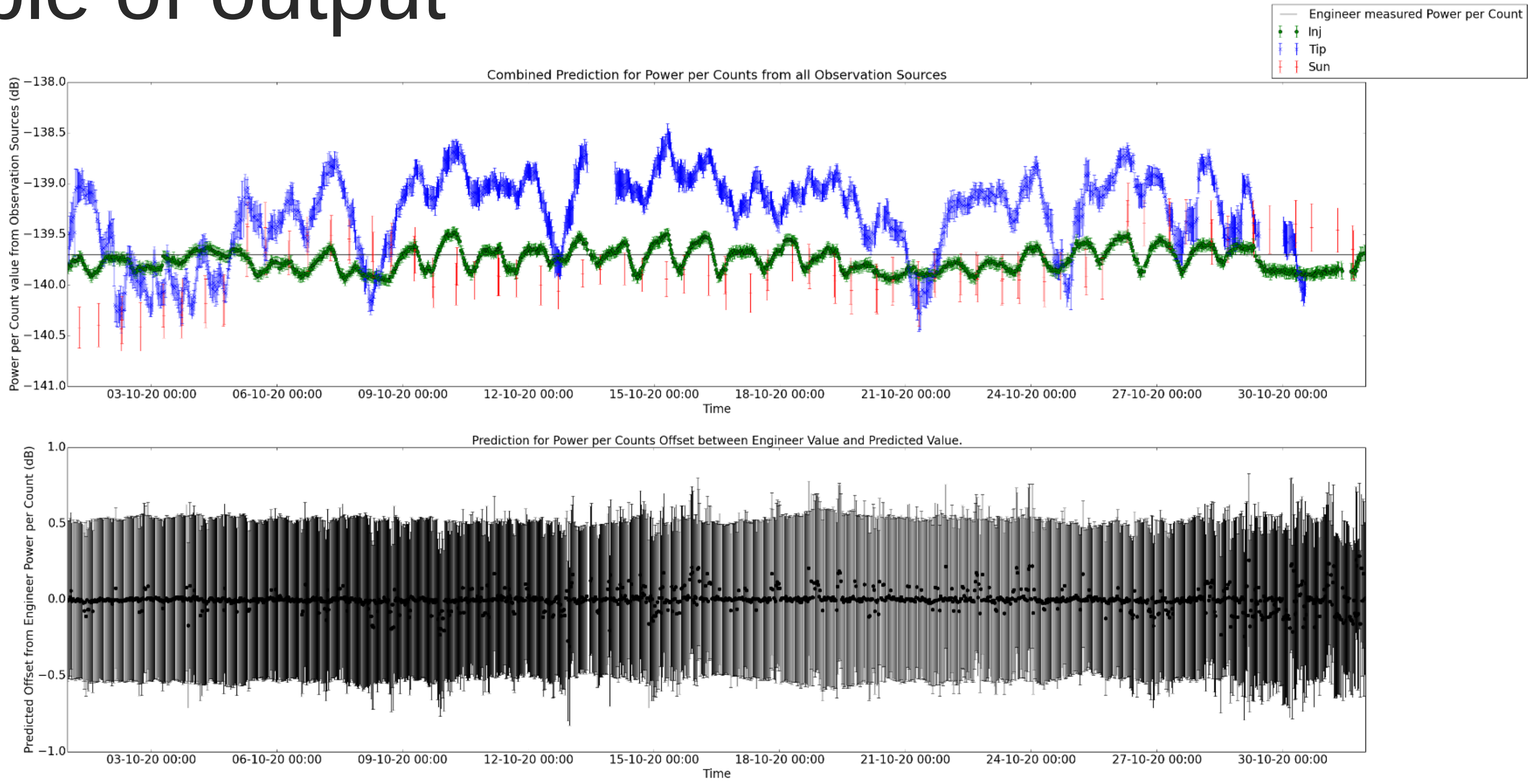
Particle filters use in solar power estimation

- Sun Detection
  - Only observed at certain times of day
  - As sun hits picked up with operational scans, center of sun and beam often displaced
  - Use particle filter to estimate peak



Example of output

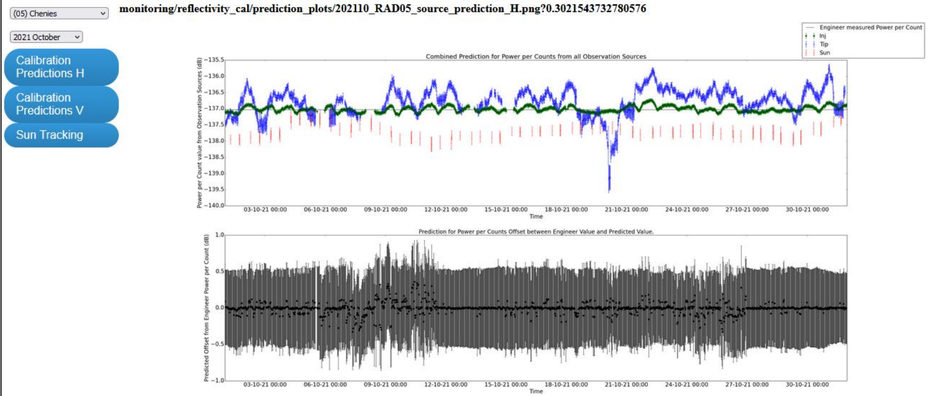


Example of use of calibration monitoring

- Routine monitoring
- Adjustment of radar constant

Routine monitoring

- System not currently fully automated – No alerts
- Regularly monitored by Network analysts
- Able to trigger further investigation, request engineer attendance at site, or in some cases implement correction directly



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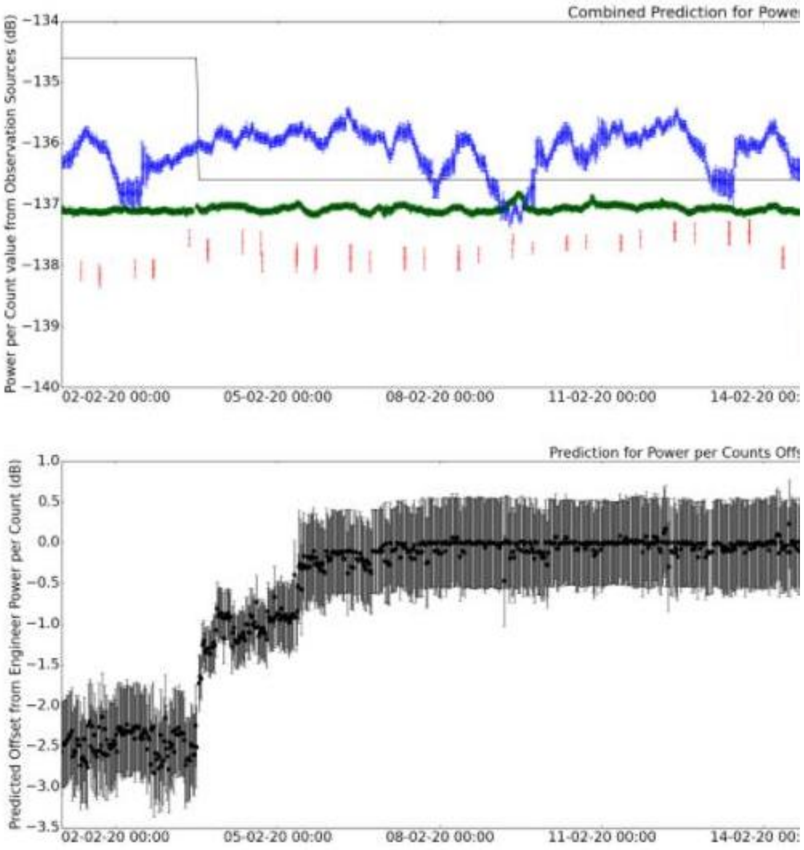
Crug-y : Feb 2020

- “This was around the time we started using Laura’s page operationally and it was decided a 2dB offset should be applied, improving the difference in the know power sources”



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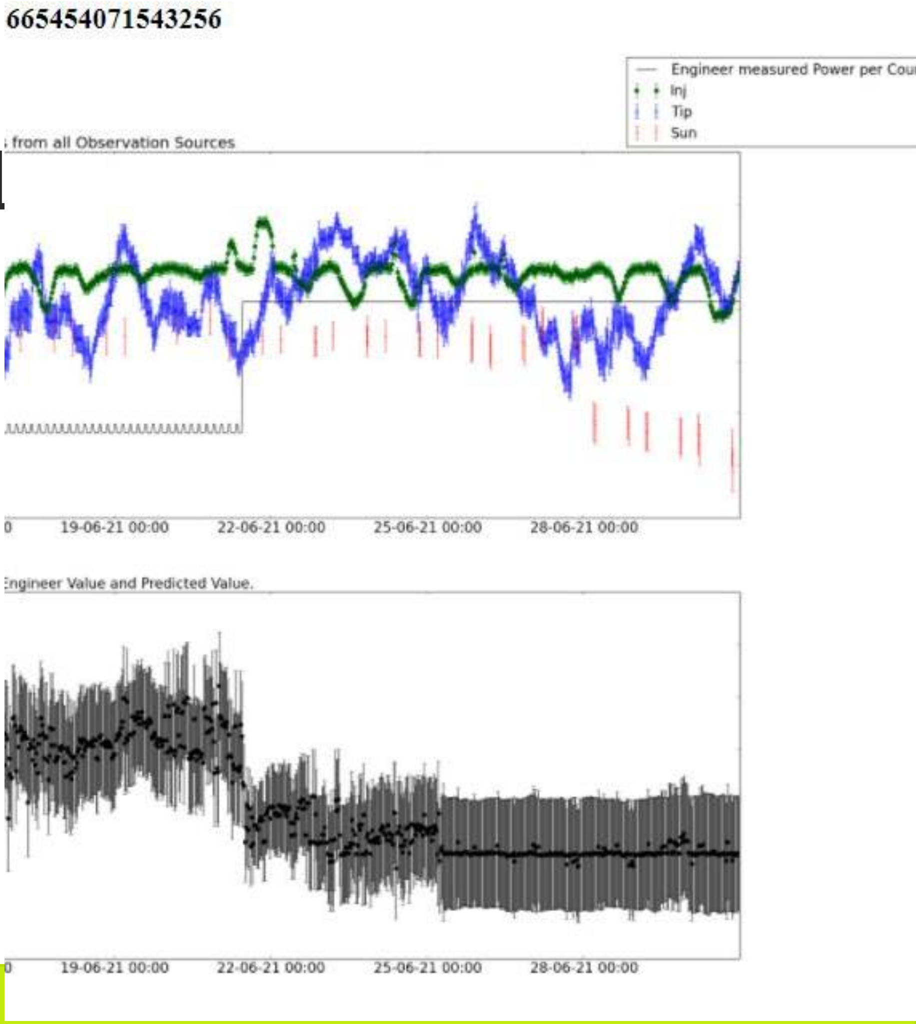
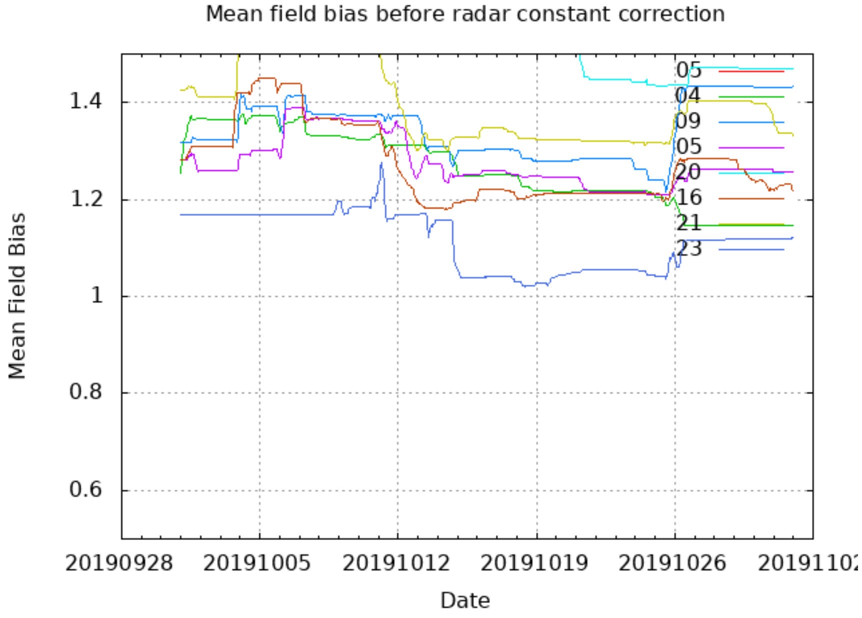
Cobbacombe: June 2021

- "In June we received a EA feedback form and it stated difference between the forecast and rain gauges close to Cobbacombe Radar, when Nawal looked into this the calibration had been questioned, here it was decided an offset of 1.25dB should be applied to the Rx cal figures. "



Mean Field Bias across the network

- Post dual polarisation upgrade an increase in mean field bias was seen
- Most sites affected
- A factor of ~1.3 required for agreement with rain gauges
- Is this due to errors in receiver calibration or in radar constant?



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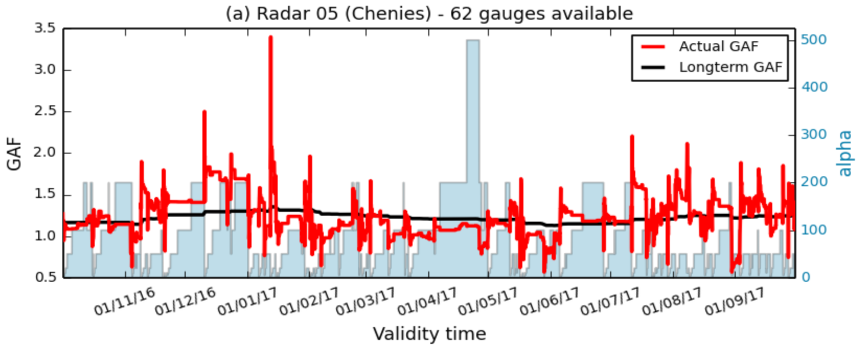
Mean Field bias correction

- “Correction of last resort”
- Mean field bias adjustment estimates
  - Modified NexRad Scheme (Kalman Filter)
  - Where radar and gauge both see rain
  - Within 100km of radar
  - Calculate bias
- AKA: Gauge Adjustment Factor (GAF)
- Using a varying time window (alpha) of comparisons apply correction to precipitation estimates



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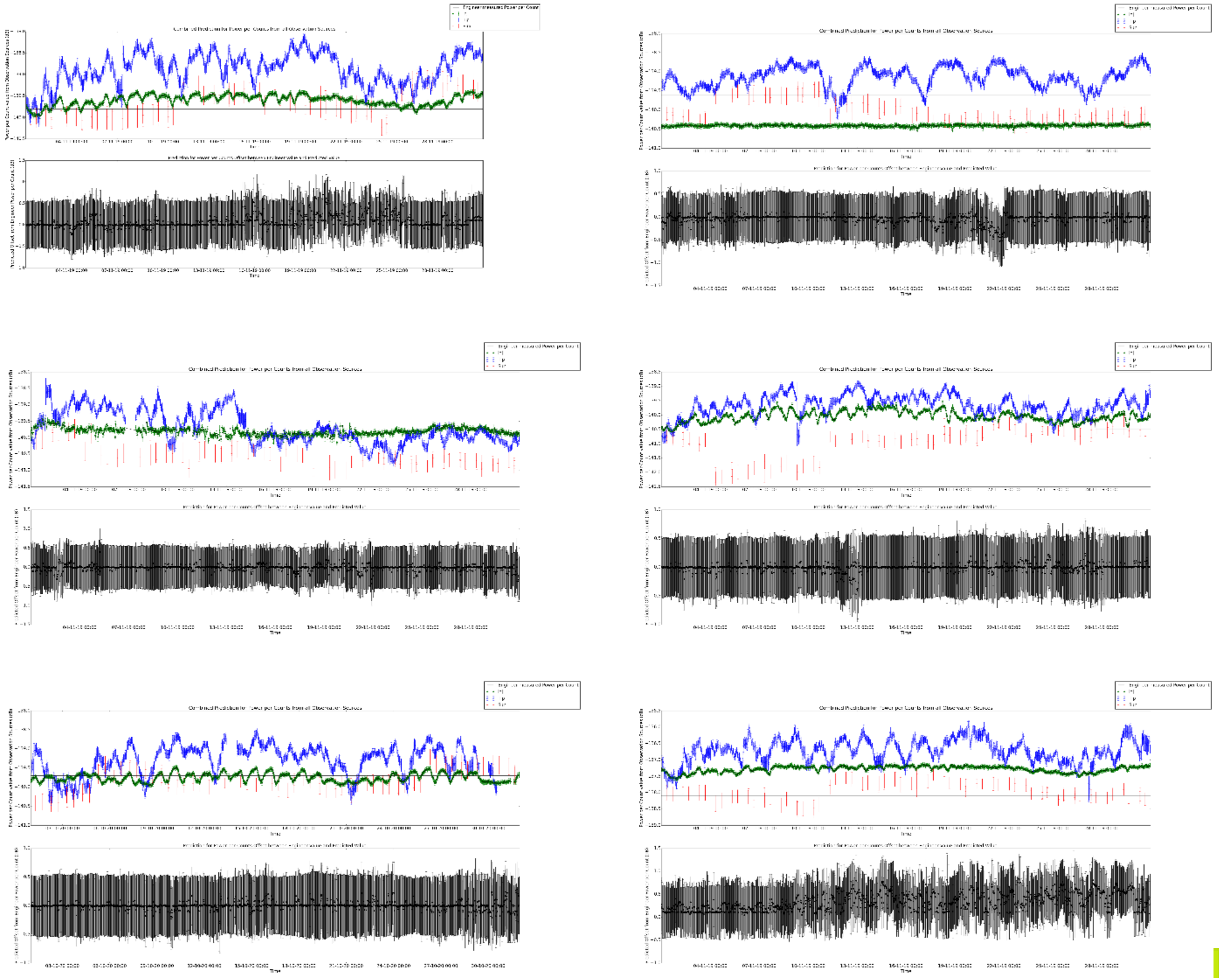
Rx calibration monitoring:

Suggests Rx well calibrated across many sites



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Update to all sites applied:

2 dB correction across the network

PB Paul Barnham	16552fd	MERGED Merge pull request #54 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575623734671 to maste...	2019-12-06
PB Paul Barnham	2474200	MERGED Merge pull request #55 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575623837636 to maste...	2019-12-06
PB Paul Barnham	edfabaf	MERGED Merge pull request #56 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575623894151 to maste...	2019-12-06
PB Paul Barnham	9b44419	MERGED Merge pull request #57 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624003117 to maste...	2019-12-06
PB Paul Barnham	cfd3fc2	MERGED Merge pull request #58 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624064300 to maste...	2019-12-06
PB Paul Barnham	fee919d	MERGED Merge pull request #59 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624114731 to maste...	2019-12-06
PB Paul Barnham	7abea95	MERGED Merge pull request #60 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624170140 to maste...	2019-12-06
PB Paul Barnham	4e3028c	MERGED Merge pull request #61 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624229377 to maste...	2019-12-06
PB Paul Barnham	bae2057	MERGED Merge pull request #62 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624281775 to maste...	2019-12-06
PB Paul Barnham	aa75951	MERGED Merge pull request #63 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624336873 to maste...	2019-12-06
PB Paul Barnham	ebcc123	MERGED Merge pull request #64 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624409557 to maste...	2019-12-06
PB Paul Barnham	805f466	MERGED Merge pull request #65 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624462301 to maste...	2019-12-06
PB Paul Barnham	3e1c85b	MERGED Merge pull request #66 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624526958 to maste...	2019-12-06
PB Paul Barnham	b9cf99c	MERGED Merge pull request #67 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624585656 to maste...	2019-12-06
PB Paul Barnham	567a147	MERGED Merge pull request #68 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624640523 to maste...	2019-12-06
PB Paul Barnham	a8d8bce	MERGED Merge pull request #69 in CYC/cyclops-config-site from carolinebulpett/metadata.json-1575624708945 to maste...	2019-12-06
CB Caroline Bulpett	9b59abd	Thurnham radar constant change 09/12/19	2019-12-06
CB Caroline Bulpett	0fa133e	Predannack radar constant change 09/12/19	2019-12-06
CB Caroline Bulpett	a300581	Munduff Hill radar constant change 09/12/19	2019-12-06
CB Caroline Bulpett	46555ce	Lewis radar constant change 09/12/19	2019-12-06
CB Caroline Bulpett	ef27398	Channel Islands radar constant change 09/12/19	2019-12-06
CB Caroline Bulpett	6bad5f2	Ingham radar constant change 09/12/19	2019-12-06
CB Caroline Bulpett	a68dafc	High Moorsley radar constant change 09/12/19	2019-12-06

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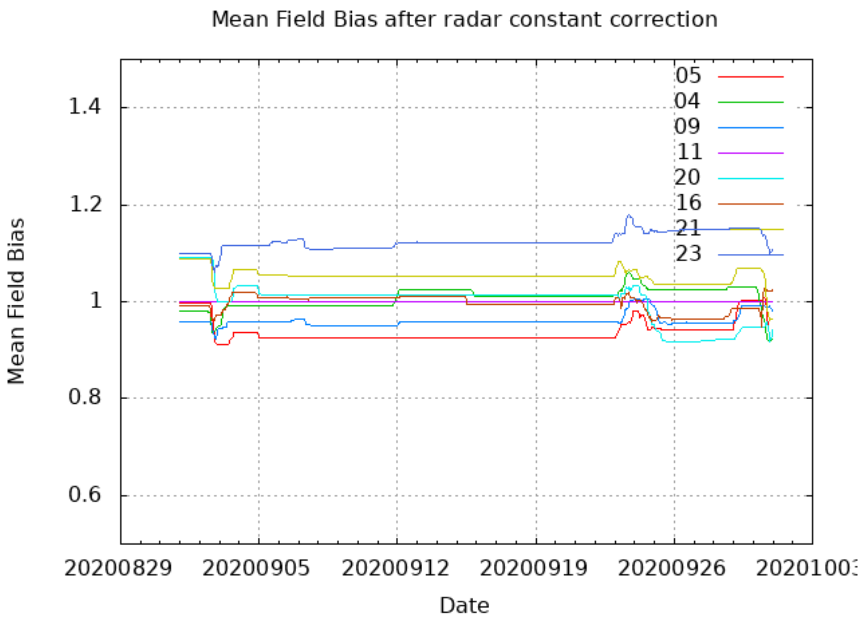
Radar constant correction

- After radar constant correction mean bias correction across sites ~1

- Thanks also to that analysis by Reading which added confidence to this course of action



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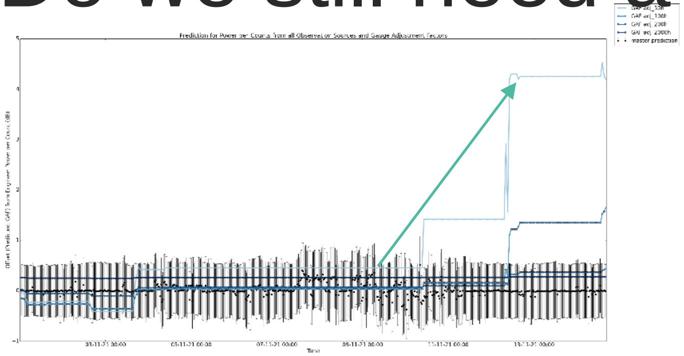
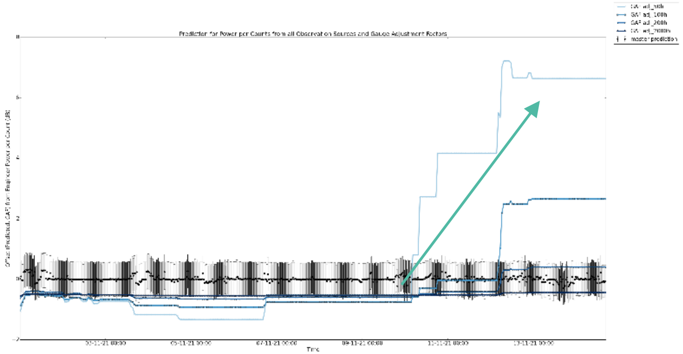
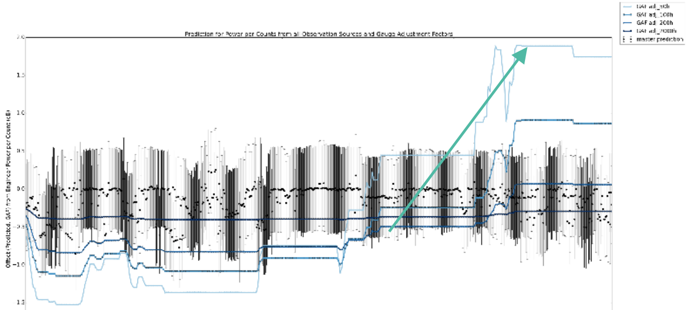
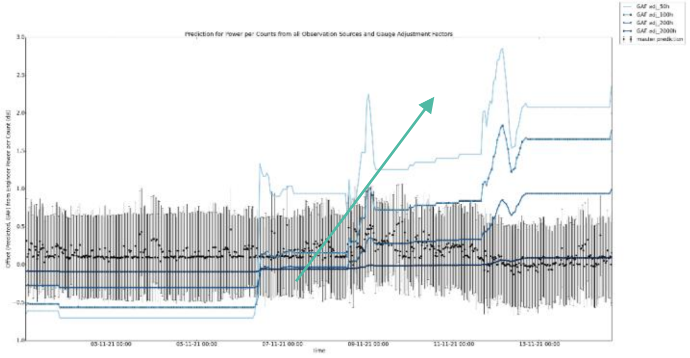
Do we still need a mean field bias adjustment?









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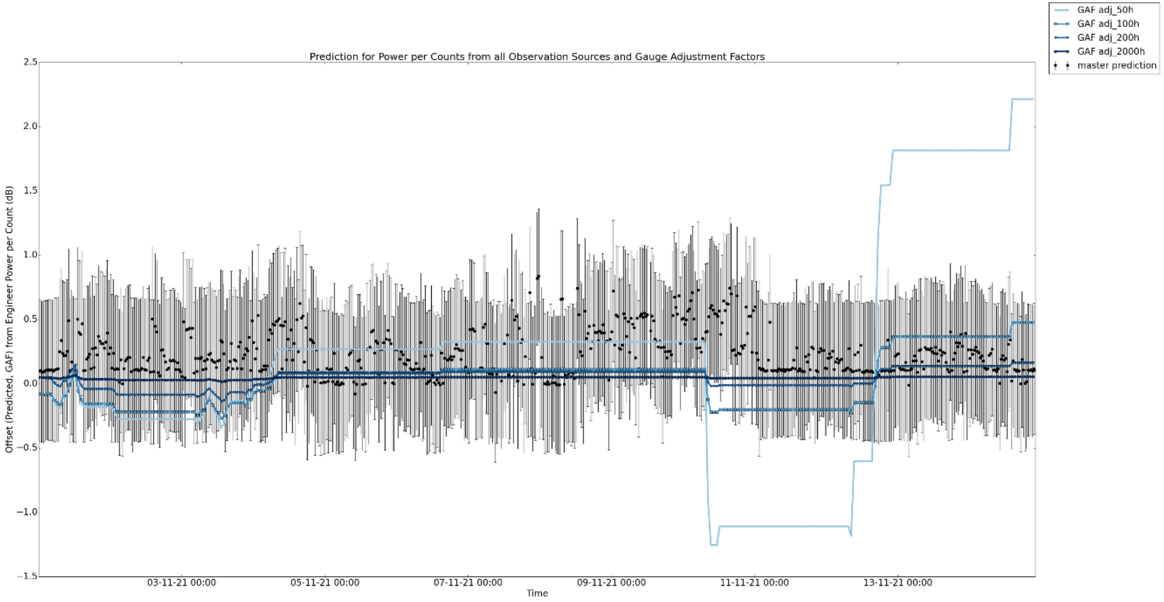
Addition of rain gauge data

- Not used in estimation of calibration error (concerns around introducing feedback loops)
- Useful for monitoring
- Contains information about DSD and Tx path



Next steps:

- Automated alerting to trigger investigation

- Add in more sources of data

  - Test signal generator
  - External Target generator

  - Include Tx path:
    - DP based Cal
    - Clutter target monitoring
    - Disdrometer data
    - Radar-Radar intercomparison
- Automated Correction

Conclusions

- Automated monitoring of Rx calibration is useful

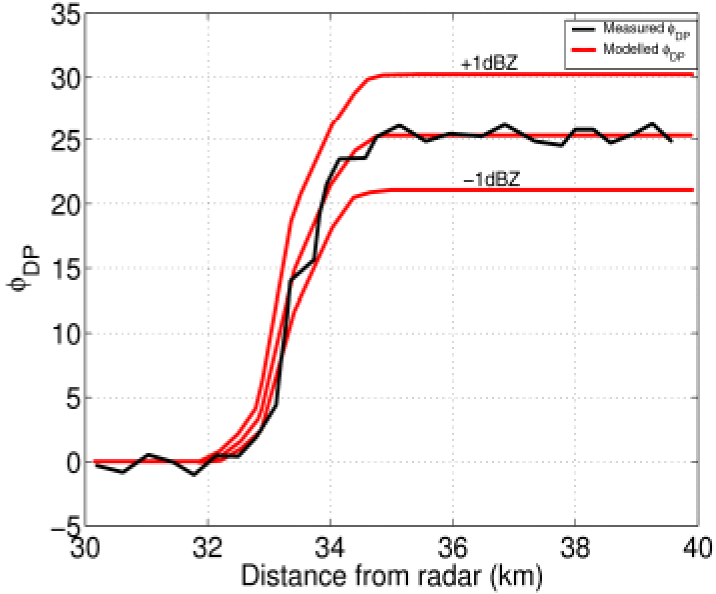
- Multiple sources of information out there – lets use them!
  - One source would be uncertain – more gives improved confidence

- Improvements to data quality across the entire network

Questions?

Why not add dual polarisation self-consistency ?

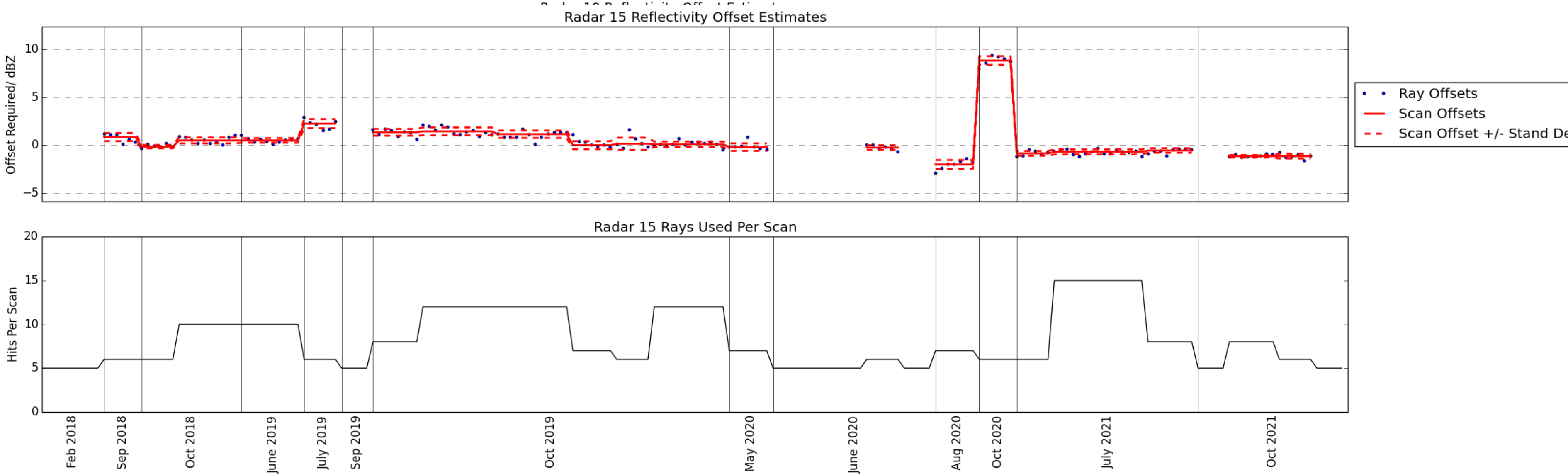
Problem source	Correction method, threshold, or ray rejection criterion
Miscalibration in Z_{DR}	Calibrate Z_{DR} using measurements at vertical incidence
Azimuthal dependence of Z_{DR} due to near-radome interference	Correct Z_{DR} using empirical mask
Reduced Z_H due to water-coated radome	Reject entire scan if mean Z_H at vertical incidence from 840 to 2760 m in altitude >20 dBZ
Reduced Z_H and Z_{DR} due to attenuation	$\Delta\Phi_{DP}^{obs} < 12°$
Mie scattering effects on Z_H, Z_{DR}, and Φ_{DP}^{obs}	Reject ray if a single observation in rain path has $Z_{DR} > 3.5$ dB
Φ_{DP}^{obs} at beginning of rain path $\neq 0°$	Find initial Φ_{DP}^{obs} for each ray by computing mean in 6-km window
Noisy Φ_{DP}^{obs} in light rain	$\Delta\Phi_{DP}^{obs} > 10°$; rain pathlength >15 km; smooth Φ_{DP}^{obs} and Φ_{DP}^{th} in 6-km window
Nonprecipitating echoes	Reject ray if >5% of gates in path were classified as nonprecipitating pixels using fuzzy logic classification algorithm (Gourley et al. 2007)
Presence of hail	Reject ray if a single observation in path has $Z_H > 50$ dBZ
Presence of partially melted or frozen hydrometeors	Range at end of path <65 km (or dip in ρ_{HV})



- Self-consistency scheme implemented and monitored
- Interesting for monitoring but operational application …?

*Absolute Calibration of Radar Reflectivity Using Redundancy of the Polarization Observations and Implied Constraints on Drop Shapes, Gourley et al.

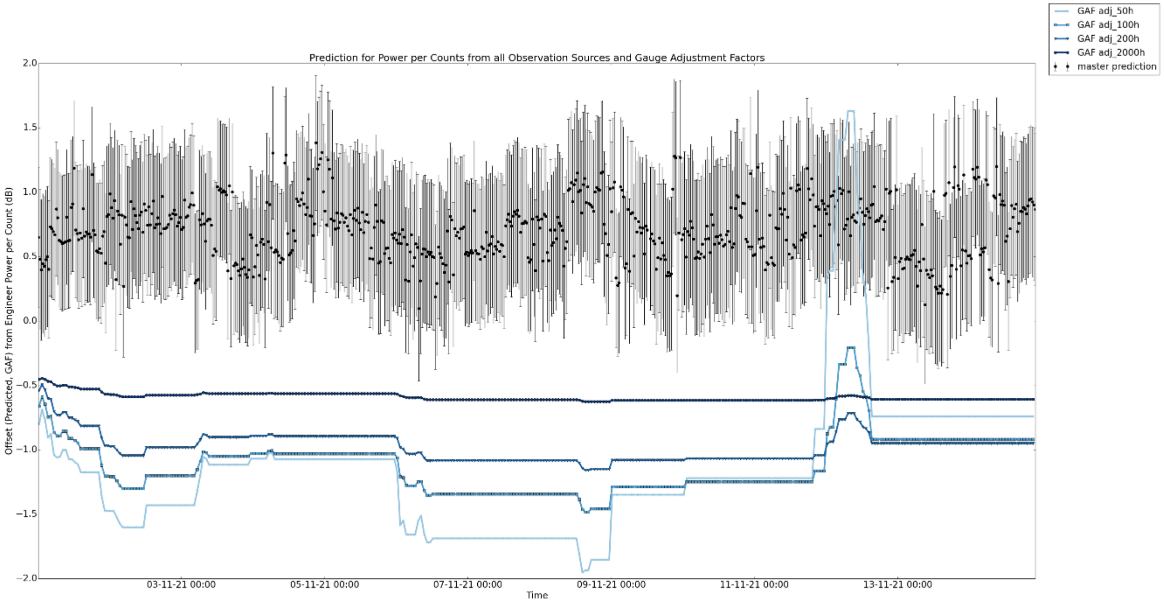
Examples of dual polarisation self-consistency monitoring



A question: Why not dual polarisation self-consistency ?

- Has anyone else seen this behaviour?
  - Any data led fix?
- Does this match other peoples experience of how often suitable rays are detected?

Dudwick odd behaviour – Rx can and gauges going opposite directions !!!!



- While Kalman filter can be used for linear or linearized processes and measurement system, the particle filter can be used for nonlinear systems. Also, the uncertainty of Kalman filter is restricted to Gaussian distribution, while the particle filter can deal with non-Gaussian noise distribution. In cases where abrupt sensor noise is rarely observed, both filters work fairly well. However, when sensor noise exhibits jerky error, Kalman filter results in location estimation with hopping while particle filter still produces robust localization.

- Autocal_RhoMin=0.96
- Autocal_ZdrMedian=0.5
- Autocal_ZdrMaxUpperlim=3.5
- Autocal_ZdrMaxLowerlim=1.5
- Autocal_PhiMaxUpperlim=12
- Autocal_PhiMaxLowerlim=8
- Autocal_ZMax=50
- Autocal_ZMin=15
- Autocal_TexThreshold=4
- Autocal_RainConseq=3
- Autocal_SmoothingWidth=1
- Autocal_SmoothingLength=10
- Autocal_TexWidth=3
- Autocal_TexLength=3
- Autocal_MinRainPath=25
- Autocal_GateMaxUpperlim=120
- Autocal_CloseRangeRainFlag=15
- Autocal_CloseRangeBinsMax=36
- Autocal_PhidpMinLowerlim=-1
- Autocal_PhidpMinUpperlim=1
- Autocal_PhidpEndGradMax=0.3
- Autocal_MaxIter=500
- Autocal_AcceptableTolerance=0.1
- Autocal_InitialZOffset=0
- Autocal_MinHitsPerScan=5
- Autocal_ConstantA=6.746
- Autocal_ConstantB=-2.97
- Autocal_ConstantC=0.711
- Autocal_ConstantD=-0.079

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Limitations of Data

- Injected Noise Source
  - Only monitors changes in path between source (@ -30dB coupler) and receiver
  - Can be contaminated by precipitation/anaprop
  - Single point measurement
  - Low power
- Sun Detection
  - Only observed at certain times of day
  - As sun hits picked up with operational scans, center of sun and beam often displaced
  - Power detected is low
- Tip Curve
  - Highly variable due to hard to remove diurnal variation, clutter, other emitters in atmosphere