Estimating LF–HF Band Noise While Acquiring WSPR Spots

KiWiSDRs at KPH with filters, splitter and GPS distribution

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Our informal collaborative project

- ◆ Rob Robinett, AI6VN: Software, KiwiSDR, installation at KPH
- ◆ Glenn Elmore, N6GN: RF engineering, propagation, KiwiSDR
- ◆ Gwyn Griffiths, G3ZIL: Data analysis

❑ Use of SDR and analysis software to measure and understand LF-HF band noise in conjunction with WSPR

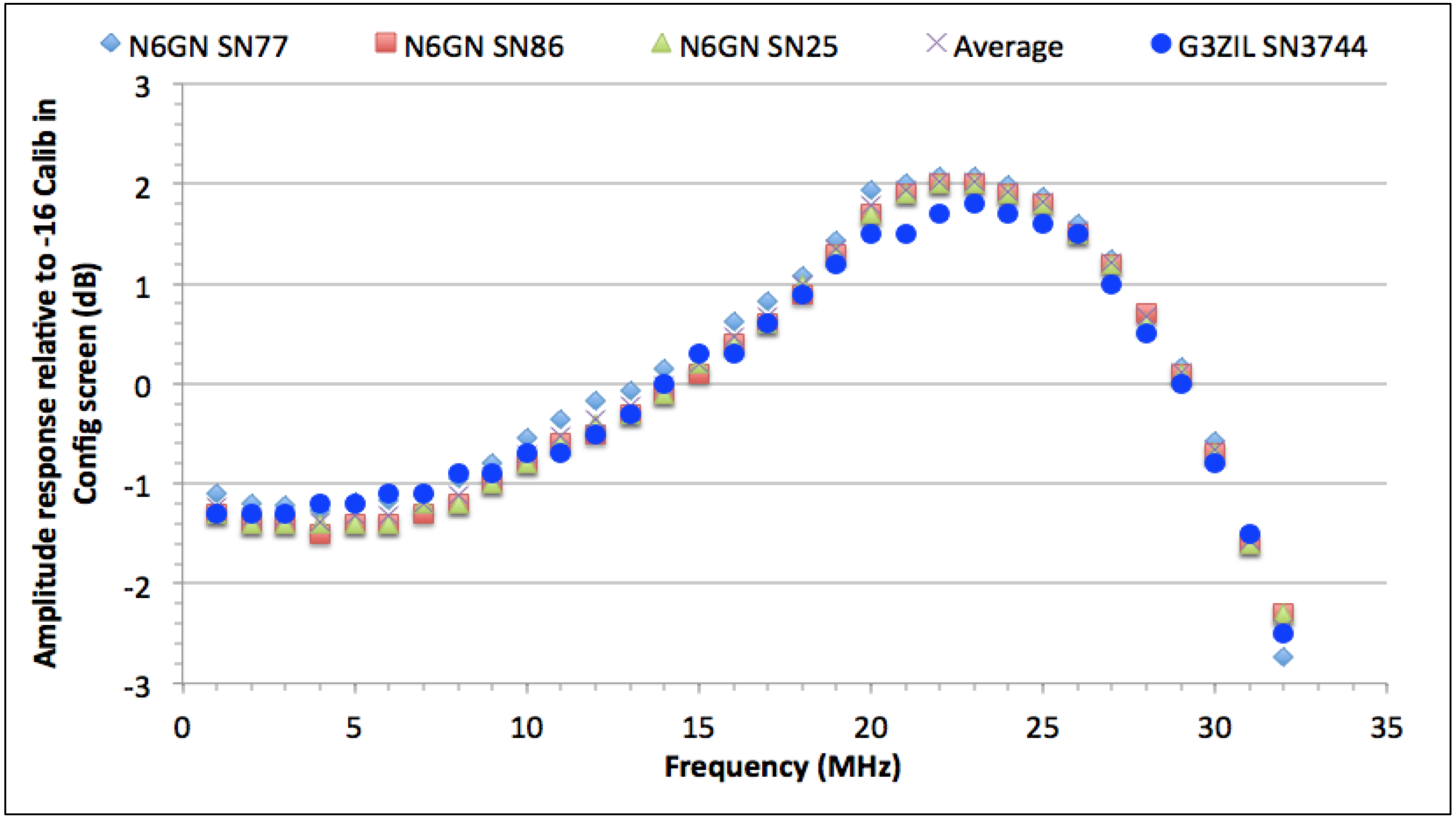
❑ Methods

- ◆ KiwiSDR with GPS corrected frequency, and preamps as needed
- ◆ wsprdaemon bash and Python software on Linux for robust WSPR reporting and contemporaneous noise analysis
- ◆ Noise reporting to Influx time-series database and Grafana web interface, to local web page and optionally to wsprdaemon.org
- ◆ Currently operating at 16 sites: N. America, Europe, Russia

Synopsis

- Part 1: SDR hardware related
  - Amplitude response calibration with frequency: Antenna socket to data file
  - Noise factor with frequency
  - Comparison of predicted and actual min. discernible signal
  - Effect on narrow-band noise level from out-of-band signals
- Part 2: Noise Analysis
  - What type of noise are we trying to measure?
  - Measuring in WSPR bands while receiving signals
- Part 3: Examples for sites with low local noise
  - Diurnal variation of propagated-in noise
  - Galactic noise on 17 – 10m
  - Coherent fluctuations in noise at stations 980km apart
  - Fluctuations with periods of ~1hour that may be Transient Ionospheric Disturbances.

Kiwi amplitude response calibration with frequency



- Consistent deviation from flat amplitude response across four units measured in US and UK, not simply the transfer function of the LPF.
- Band-specific corrections are therefore applied to the measured amplitudes
- Detailed draft report on all our results available at: https://www.researchgate.net/publication/334612025_Estimating_LF-HF_band_noise_while_acquiring_WSPR_spots

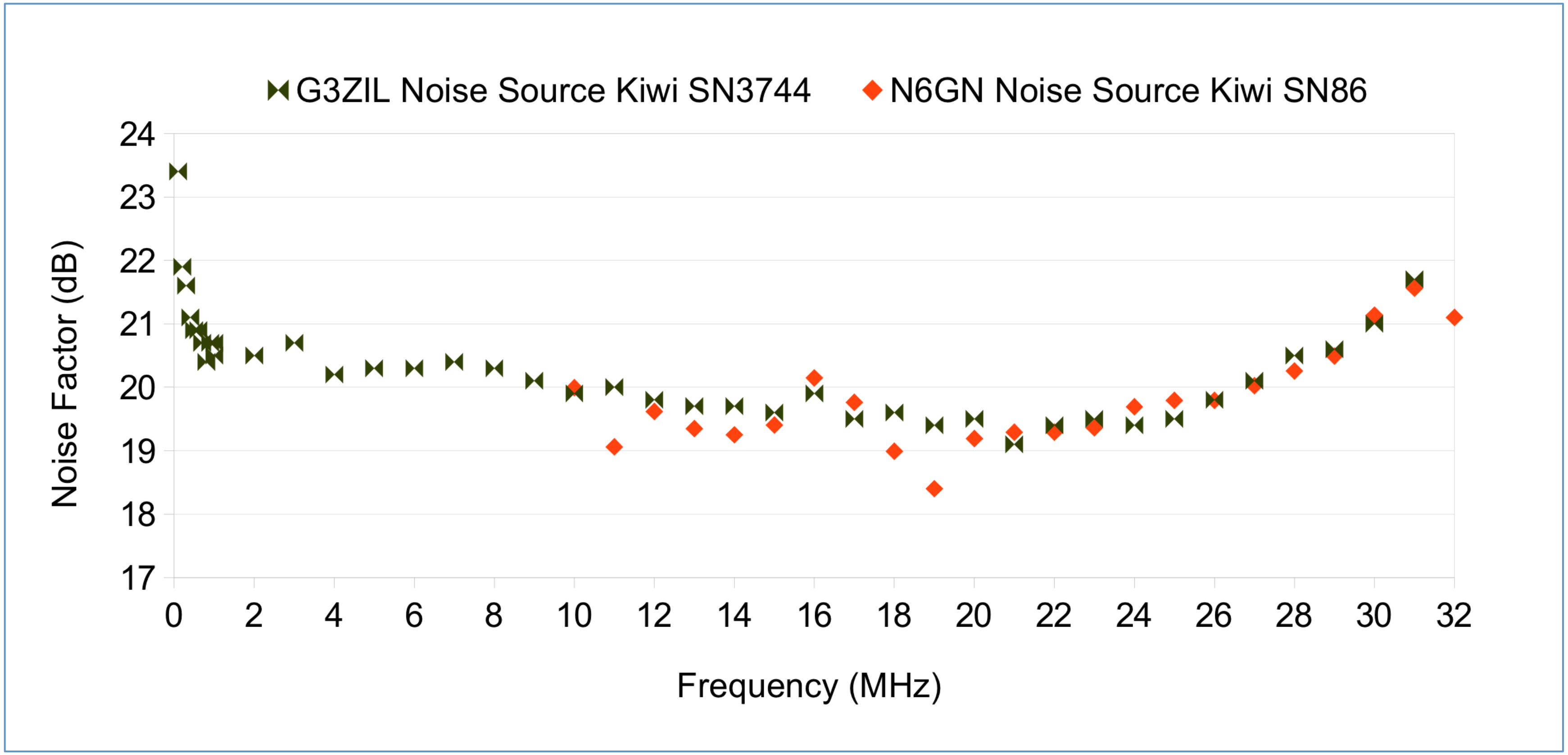
Derivation of MDS: Perseus, Kiwi and Tangerine*

Parameter	Perseus	KiwiSDR	Tangerine	Units	Notes
ADC Full Scale	11	4	4	dBm	Perseus: LT2206 at 2.25v p-to-p
$SINAD_{ACTUAL}$	77	74.3	73	dB re FS	KiwiSDR: LT2248
Samp. Freq.	80	66.67	122.88	MHz	Tangerine: LT2145 Illustrative at 1v p-to-p
Proc. Gain G_p	79.2	78.4	80.9	dB	Processing gain calculated for BW_{ref} = 1Hz
NF_{ADC}	29	25.3	24.1	dB	Calculated
NF_{pre}	15	6.2	6.2	dB	Perseus: THS4509
$Gain_{preamp}$	15	20	20	dB	KiwiSDR: LTC6401-20 (lower pwr than LTC6400-20) Tangerine: LTC6400-20 Illus.
NF_{RX} anal.	17.5	10.8	8.3	dB	Calculated. Kiwi includes 2dB for LPF.
NF_{RX}meas.	–	20	TBD	dB	Measured by N6GN and G3ZIL, +/-1.5dB with freq.
MDS anal.	-156.5	-163.3	-165.7	dBm	Calculated in 1Hz
MDS anal.	-122.5	-129.3	-131.7	dBm	Calculated in 2.4kHz
MDS meas.	-122.0 –	– –154	TBD	dBm	Measured by VA7OJ IN 2.4kHz Measured by N6GN and G3ZIL in 1Hz

* NF of 6.5dB expected. From provisional information 9 August 2019 at
tangerinesdr.com/TangerineSDR_documents/TSDR_RXM_5001D_ICD_TangerineSDR_RF_Module_V0.1.pdf

- Analytical and measured MDS for Perseus match well at 2.4kHz bandwidth
- KiwiSDR MDS is about 9dB higher than analytical
- “Noise Factor” degradation from ADC nonlinearity with strong signals

KiwiSDR Noise Factor Estimates



- Two different units, two different (homebrew, calibrated avalanche diode) noise sources, two continents
- Noise Factor is higher by ~9dB than implied by calculation from component data
- ~3dB change with frequency is important to proper interpretation of results, e.g. NF at 28MHz (10m) is 0.7dB higher than at 25MHz (12m)

Possible noise ingress pathways in the KiwiSDR

- **Internal** unwanted signals, IMD and aliased, not usually dominant in most environments. But note KiwiSDR anti-alias LPF is only 15dB down at 40MHz.
- **External** unwanted inputs showing up at ADC input:
  - **Radiated**, Electric or Magnetic coupling, can be provoked but not dominant.
  - **Coupled** via Kiwi interconnects:

    1)Differential, Kiwi generally appears to have high PSRR, LANRR.

    2)Common Mode, the most significant and common cause:

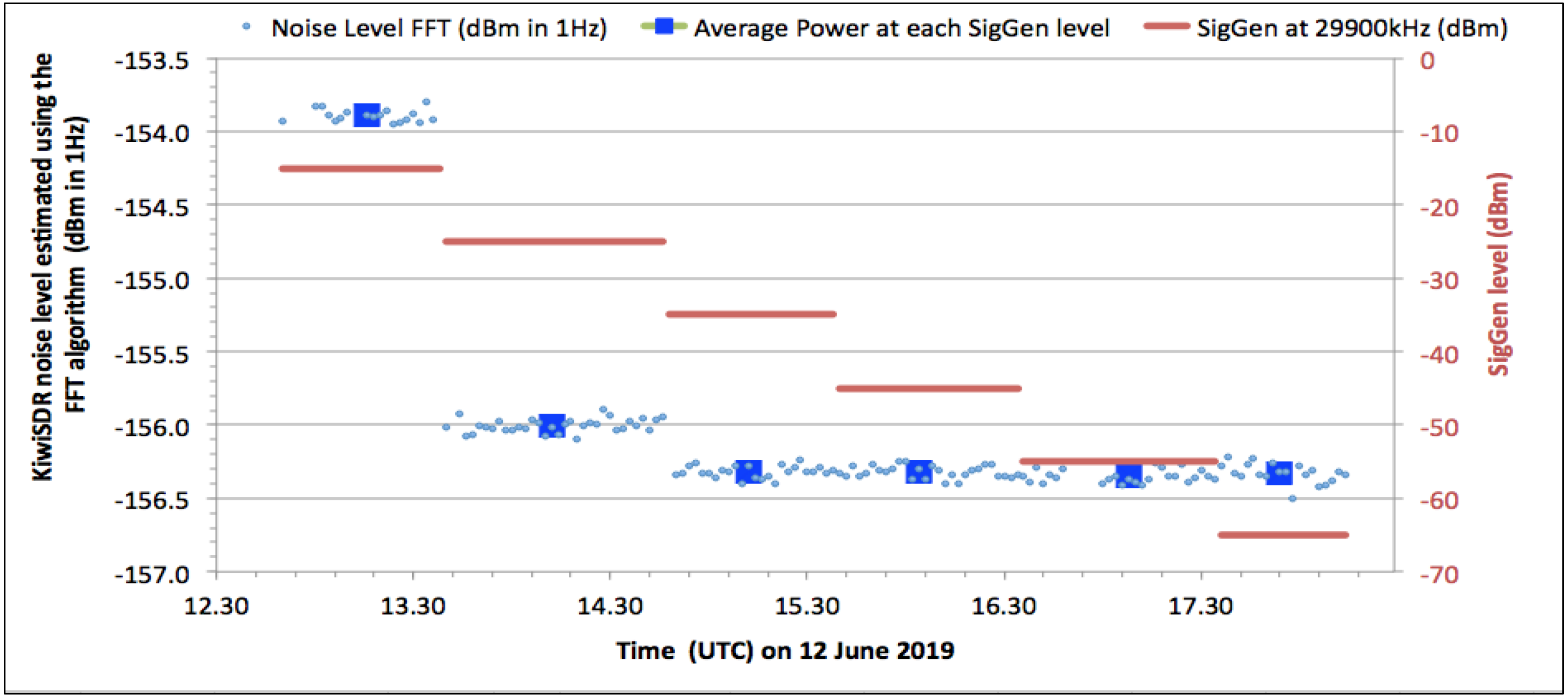
    Imperfect balance on antenna, LAN & PS provides current paths in & out.

    Sensitivity requires tremendously large rejection/balance, more than is possible from commercial antenna baluns, LAN cores etc.

    Current injected into one “ground” through PCB and exiting from a different “ground” develops voltage across internal ADC I/P vs. reference.

    e.g. 2 mOhm (at DC, much greater at 30 MHz) PCB reactance with, say, 1 mA unwanted CM current develops > 2uV or -101dBm . Compared to Kiwi sensitivity floor of -154 dBm in 1Hz, may require of order 50 – 90 dB isolation and symmetry. Very Difficult to achieve.

Excess noise in measured band with single out-of band coherent signal



- Noise measurement at 28126kHz in 320Hz bandwidth with single frequency at 29900kHz stepped from -15dB (near -14dB clipping of KiwiSDR) to -65dBm.
- Noise of the HP8640B signal generator was about -168dBm in 1Hz.
- KiwiSDR noise increase of 2.4dB at -15dBm and 0.3dB at -25dBm.
  Noise Power Ratio method gave similar result (details from authors).

What type of noise are we trying to measure?

Our current aim is to measure sources in **green**:

- External radio noise
  - Anthropogenic
    - **Gaussian**
    - Impulsive
    - Structured (Other signals, e.g. WSPR, PSK, RTTY, Interference)
  - Lightning discharges (**atmospheric noise**, local, **regional, global**)
  - **Galactic noise from the sun or other celestial radio sources**
- Simple RMS could result in impulsive or structured noise being included.
- Use KiwiSDR *kiwirecorder* extension to capture a .wav file on a Linux machine, use *sox* sound processing program to extract information in time and frequency domains.

Approach 1: Measure within gaps in the time domain

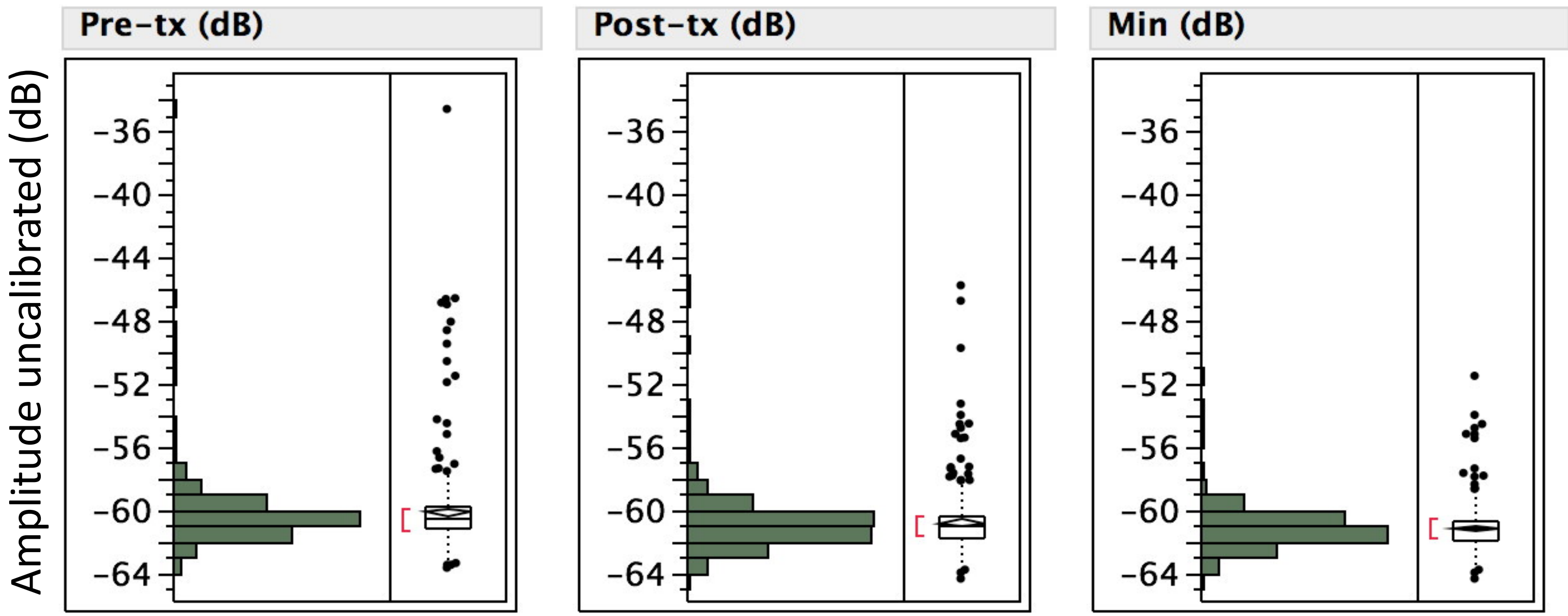
WSPR transmissions start 1s after an even minute and end about 111s later.

Use *sox* stats

Calculates the RMS trough – a period of 50ms with minimum RMS – in a set interval.

Use intervals 0.25 – 0.75s pre-tx and 113 – 118s post-tx and take the minimum.

Histograms from 405 two-minute intervals 14 – 15 March 2019 on 40m. Outliers are from transmissions that start early, or end late, or from interference.



	Pre-tx	Post-tx	Min
Median (dB):	-60.61	-60.96	-61.19
Std dev (dB):	2.56	1.87	1.37

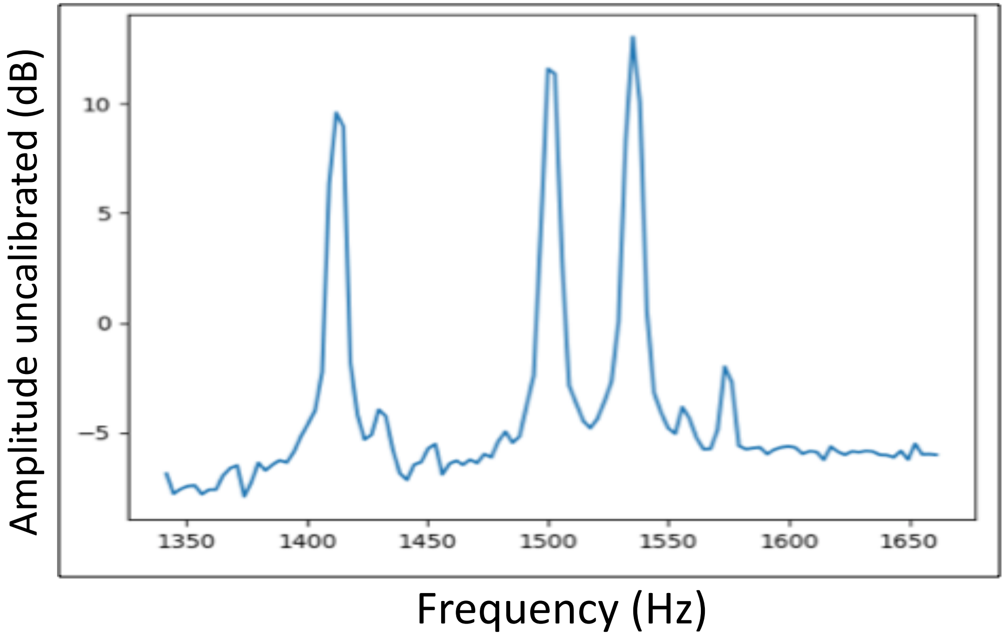
Approach 2: Measure in gaps in the frequency domain

Use *sox* stat -freq

Top: Example spectrogram over 1339-1661Hz on 40m WSPR at KPH at 1116 on 19 Apr 2019.

Six transmissions decoded.

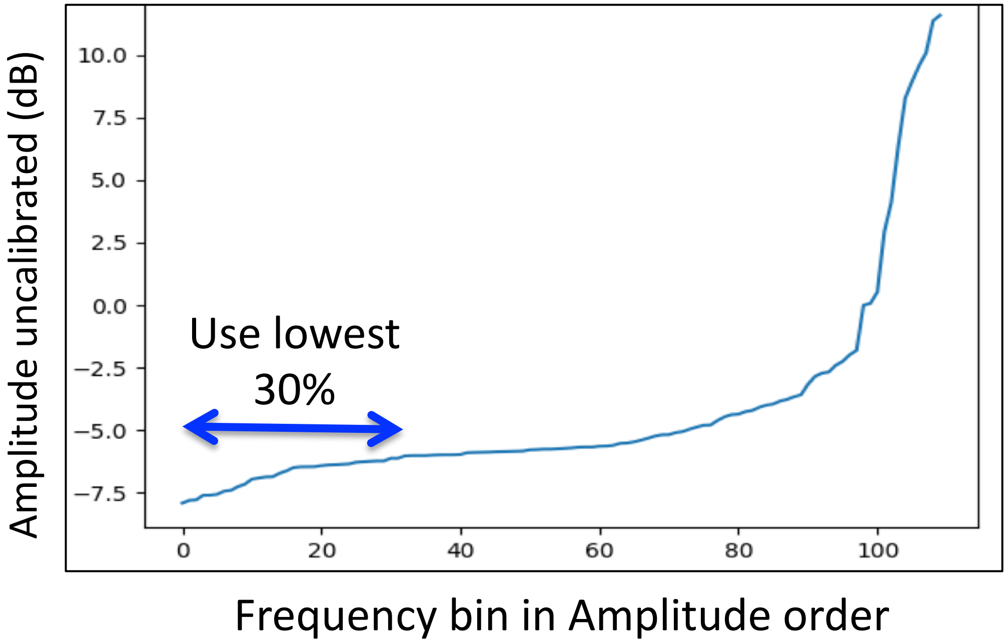
An average of 352 sections over 2 minutes and with 111 frequency bins.



Bottom: Sort amplitudes of Fourier coefficients in the 111 frequency bins in increasing order. Take total RMS power over a range of bins with lowest coefficients for an estimator of noise.

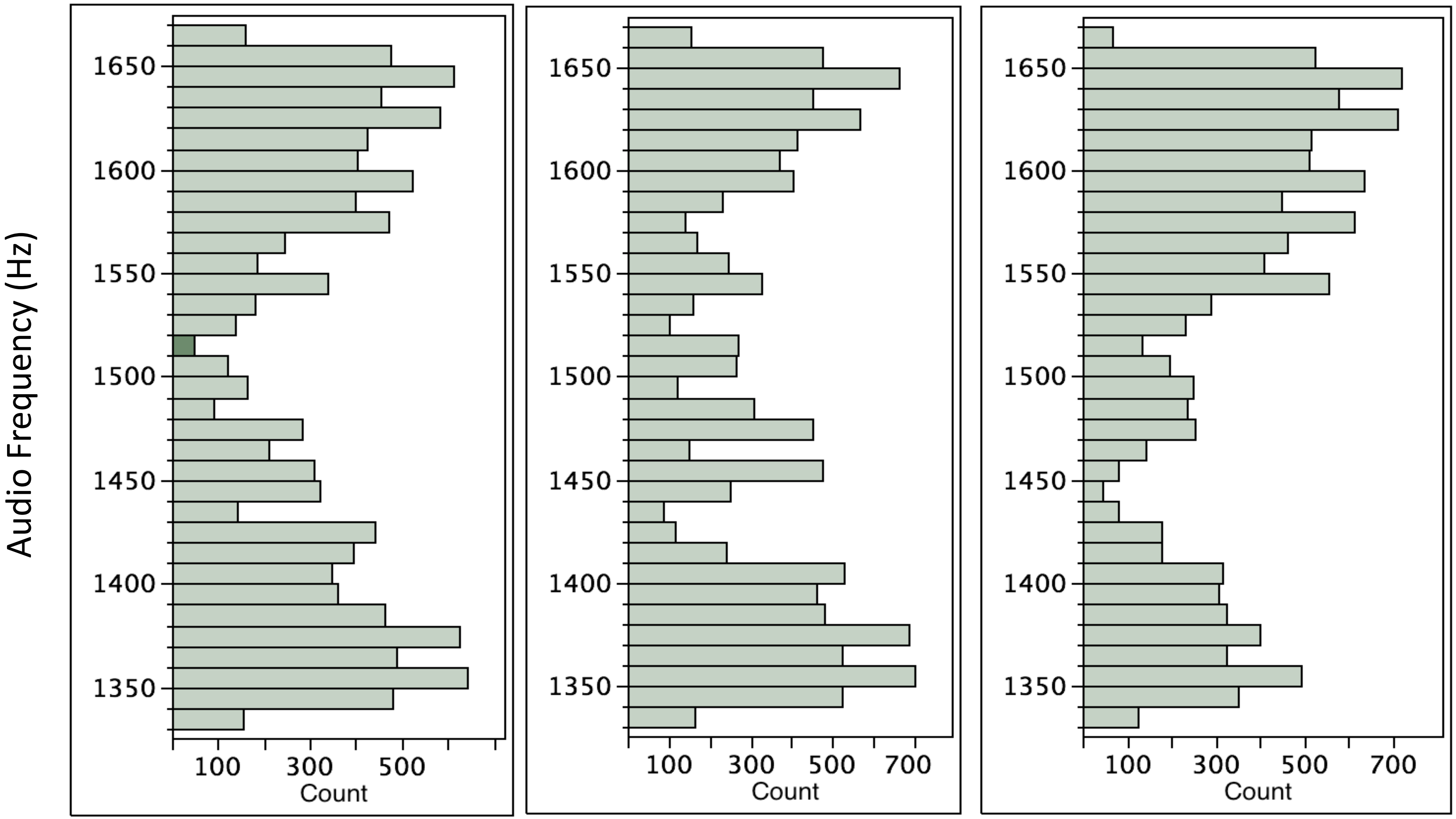
We do this over 322Hz, wider than the 200Hz WSPR band.

Currently, we use lowest 30%, and do so for coefficients across all 352 sections; not constrained to accept lowest coefficients in a section, e.g. if there was a lightning crash.

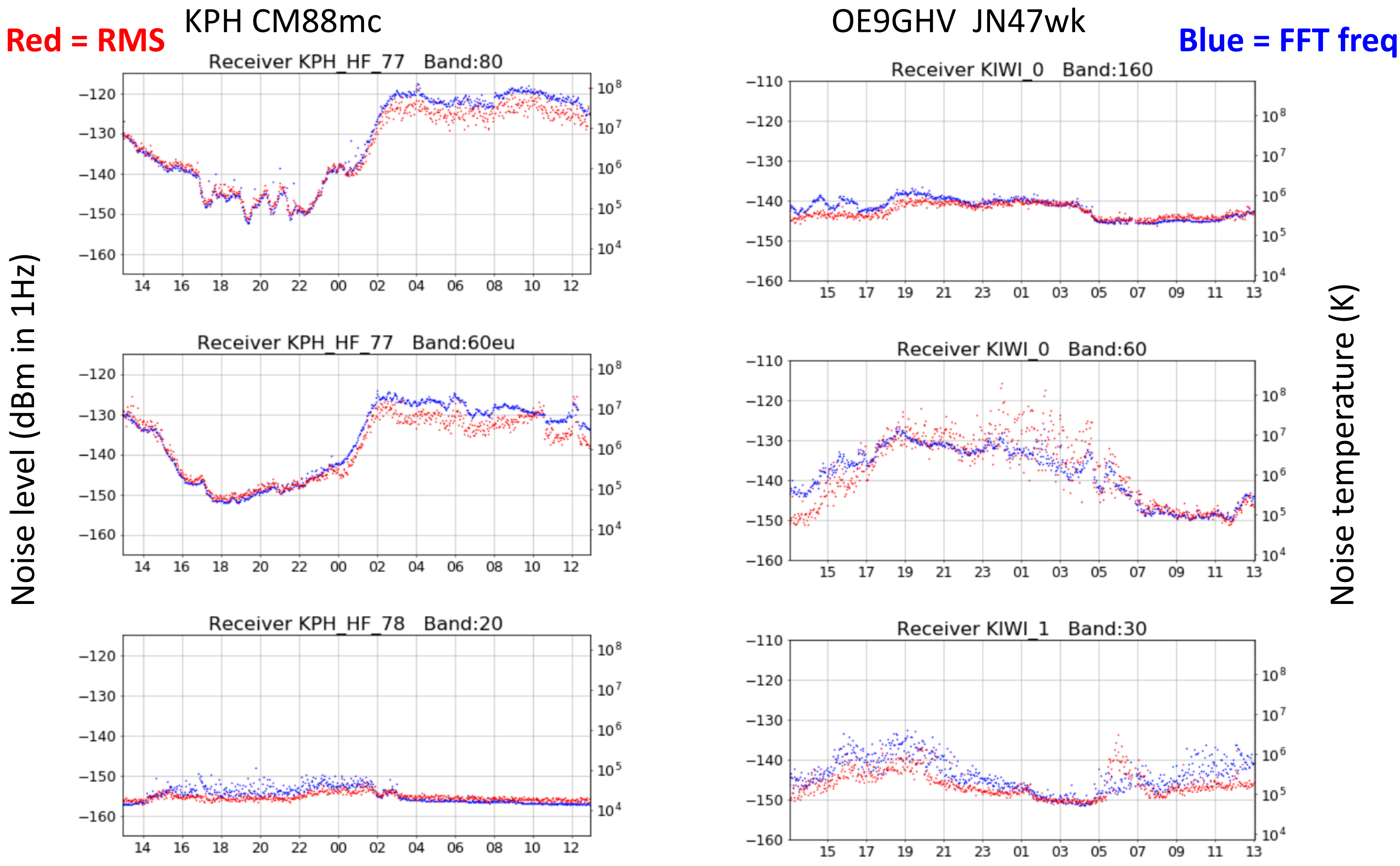


Histograms of distributions of auto-selected bins

In these plots of three successive 2-minute WSPR intervals three consecutive frequency bins have been averaged. Interval-to-interval differences, but as expected, dip within WSPR range.



Diurnal variation of propagated-in noise

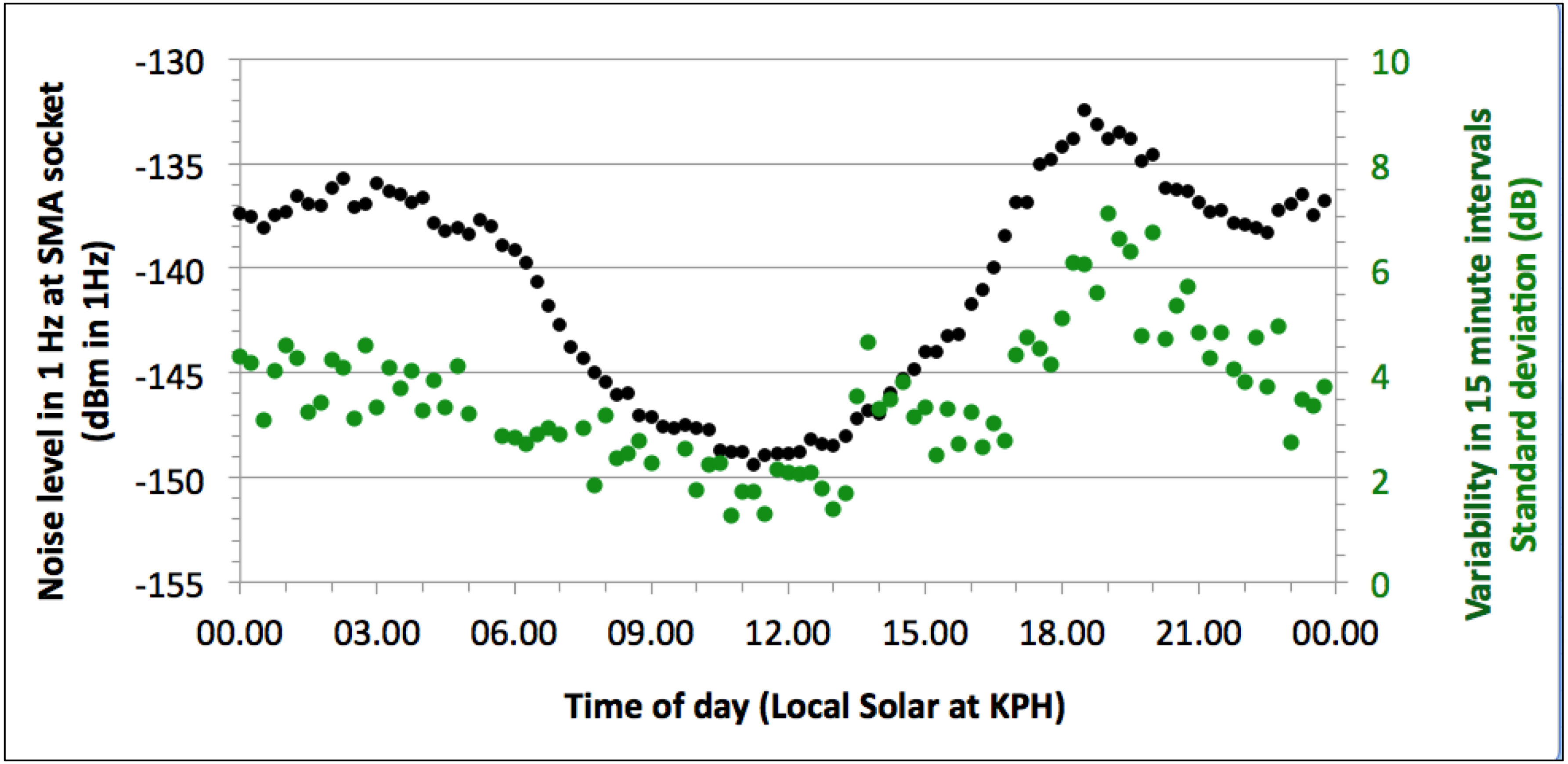


Hour of day (UTC)

Data shown is for 29-30 August 2019 from open access wsprdaemon.org updated in real time

Presence at KPH by kind permission of MHRS

Diurnal pattern and variability of propagated-in noise



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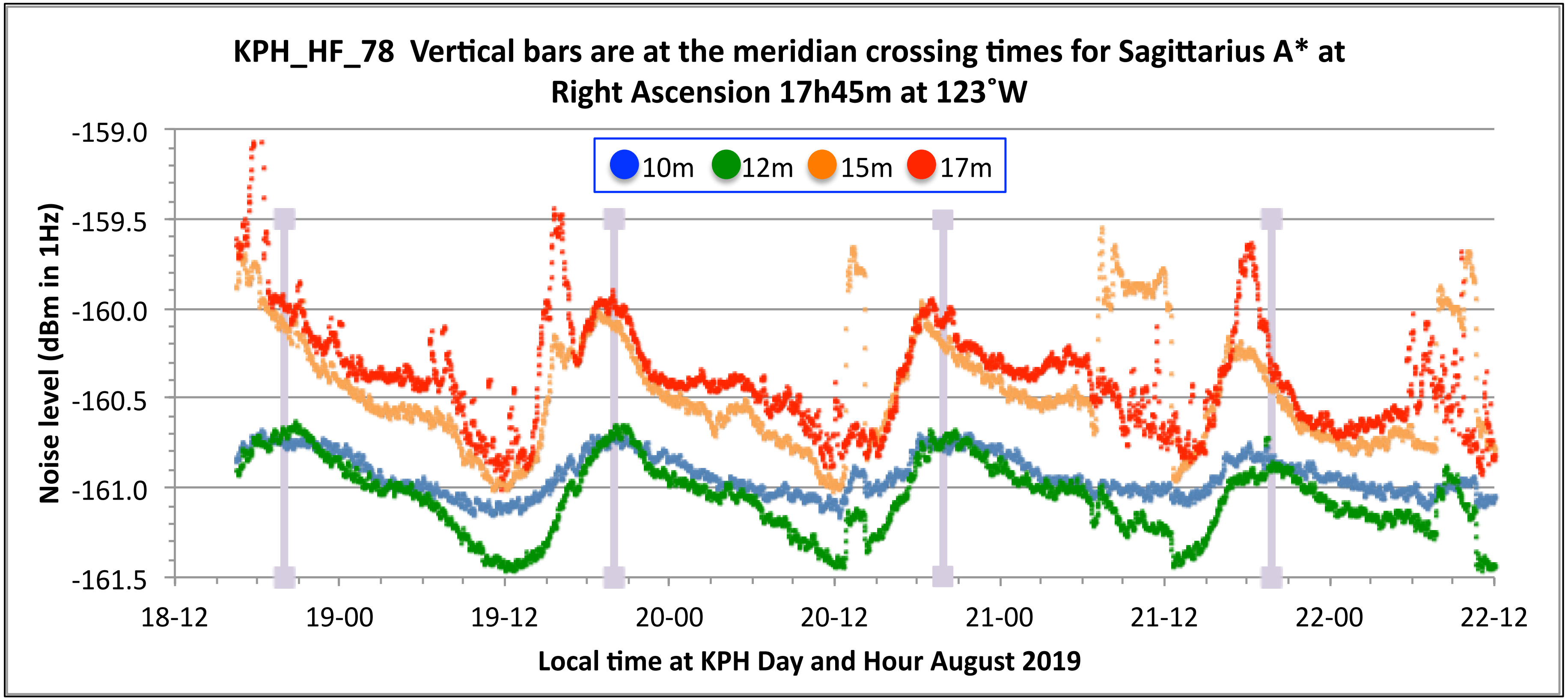
Median noise in 15 minute intervals on 40m WSPR band at KPH for 15 days 13 –28 April 2019 showing minimum around local noon when ionospheric absorption is greatest.
Also shown is the variability, here as the standard deviation, in each 15 minute interval, following the pattern of the mean.

Galactic noise at KPH 10 – 17m?



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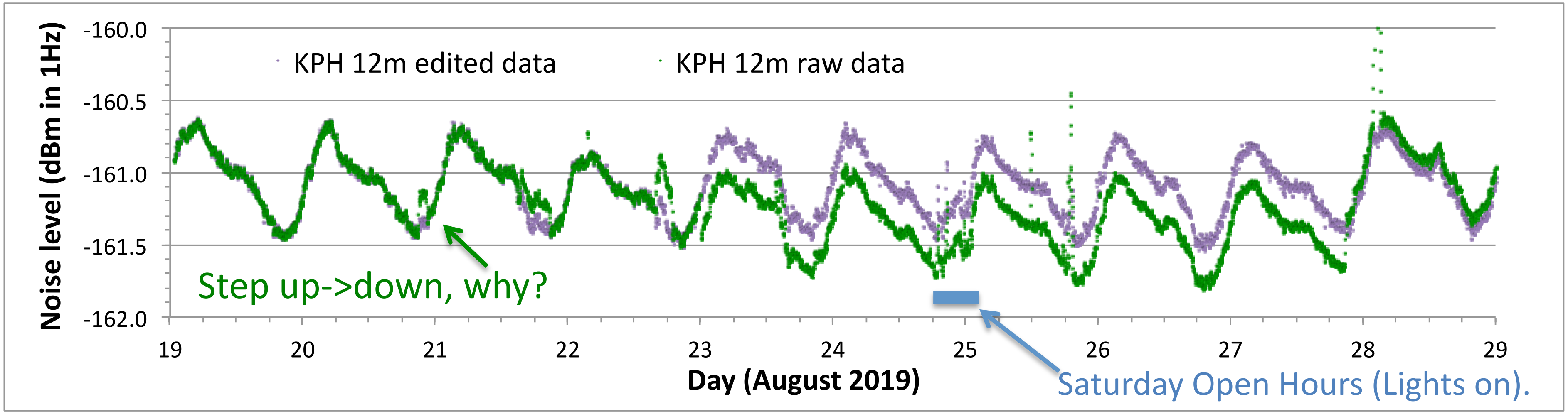
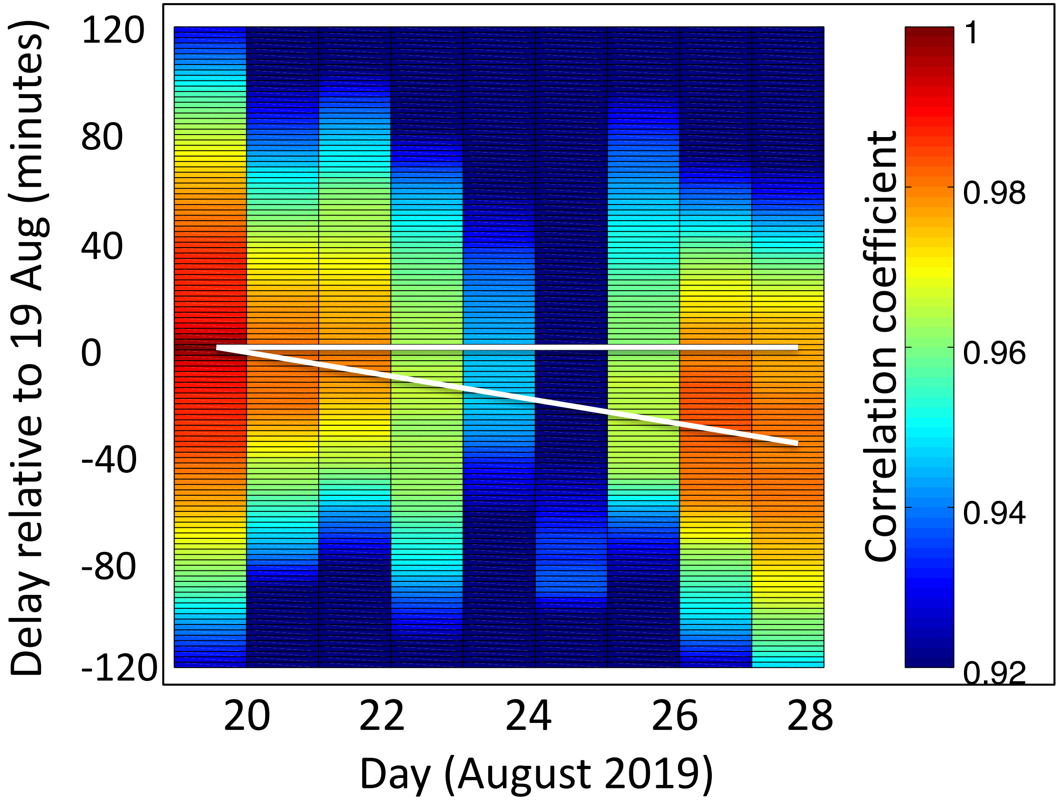
Running mean of five measurements at two minute intervals, no outlier rejection needed

- Uncertainty in absolute calibration, certainly exceeds 10m peak to peak of ~0.4dB.
- Daily peak close to when the bright radio sources Sagittarius A* and Cygnus straddle meridian altitude. TCI530 antenna pattern is almost omnidirectional.
- Suggests 12m system noise level lower than at 10m by at least 0.4dB. Noise Factor for KiwiSDR alone is 0.7dB lower at 12m than at 10m.

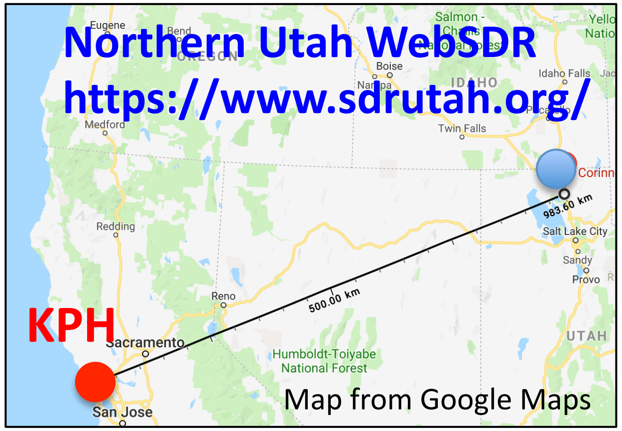
Is the noise pattern locked to sidereal time?



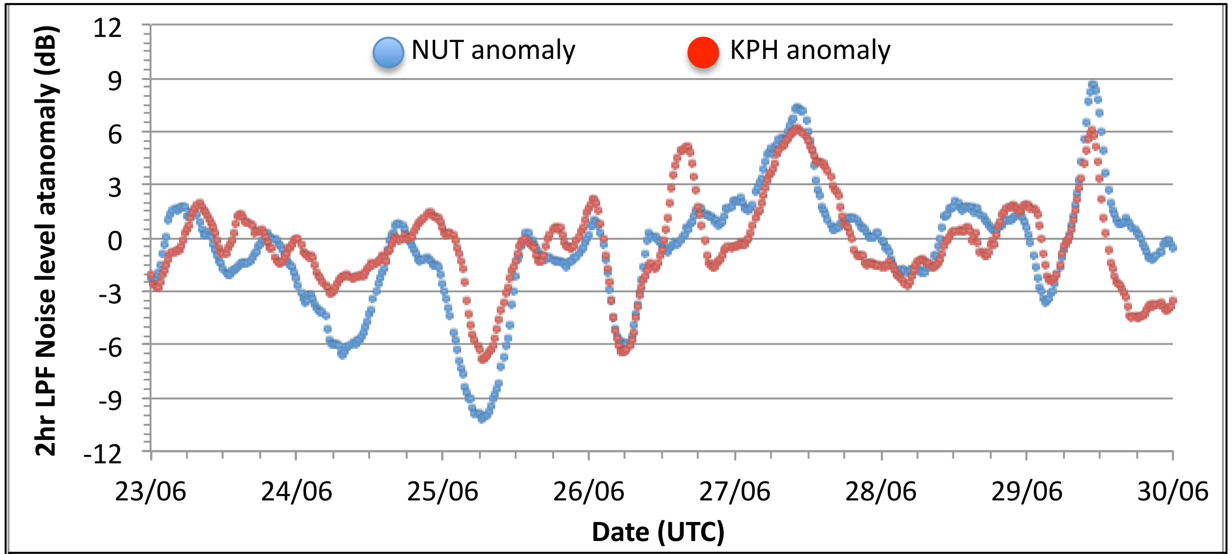


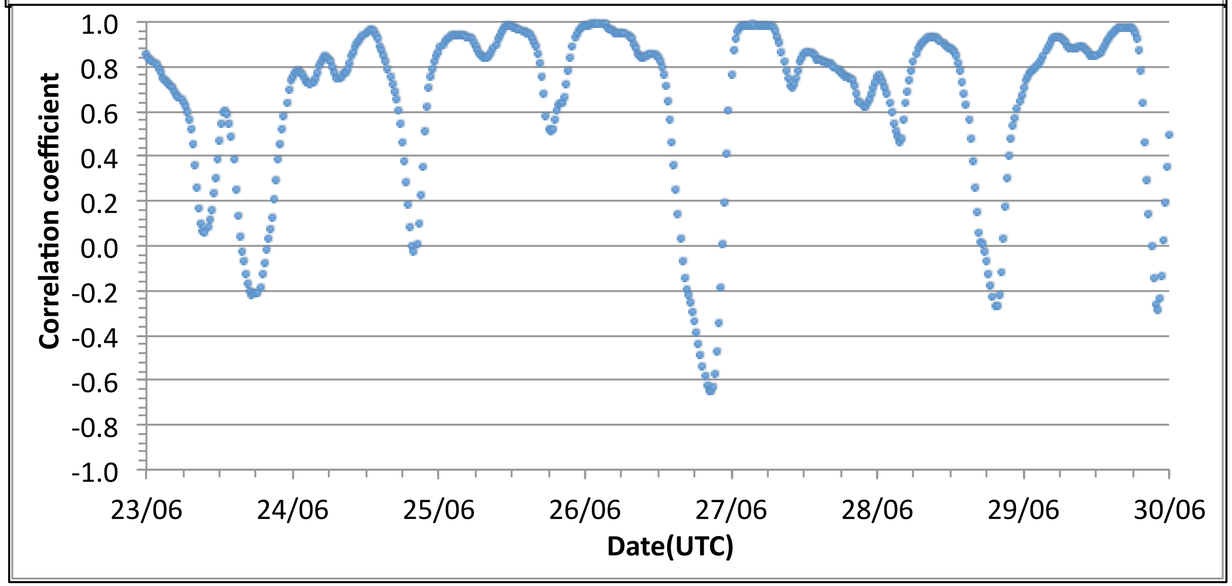
- Short sequence make this difficult.
- Steps and "other" noise do not help, inc. lighting on Saturday 24th.
- Manual edits of raw data.
- For cross-correlation of 19 August to subsequent days, for lags of -120 to +120 minutes.
- Plot correlation coefficient.
- Which better describes the trend of the correlation peak? Horizontal line, locked to solar day, or line sloping at -4 minutes per day, locked to sidereal day?

Long period coherent fluctuations in noise on 80m at KPH and Northern Utah, 980km apart



80m noise dominated by diurnal variation at both sites. Form 21-day medians for each 20 minutes, then take the anomaly for that interval each day.
Clear, visual coherence at times in the time series.
Confirmed in sliding correlation coefficient plot, but with low or negative correlations 1800-2100 UTC each day, local afternoon.





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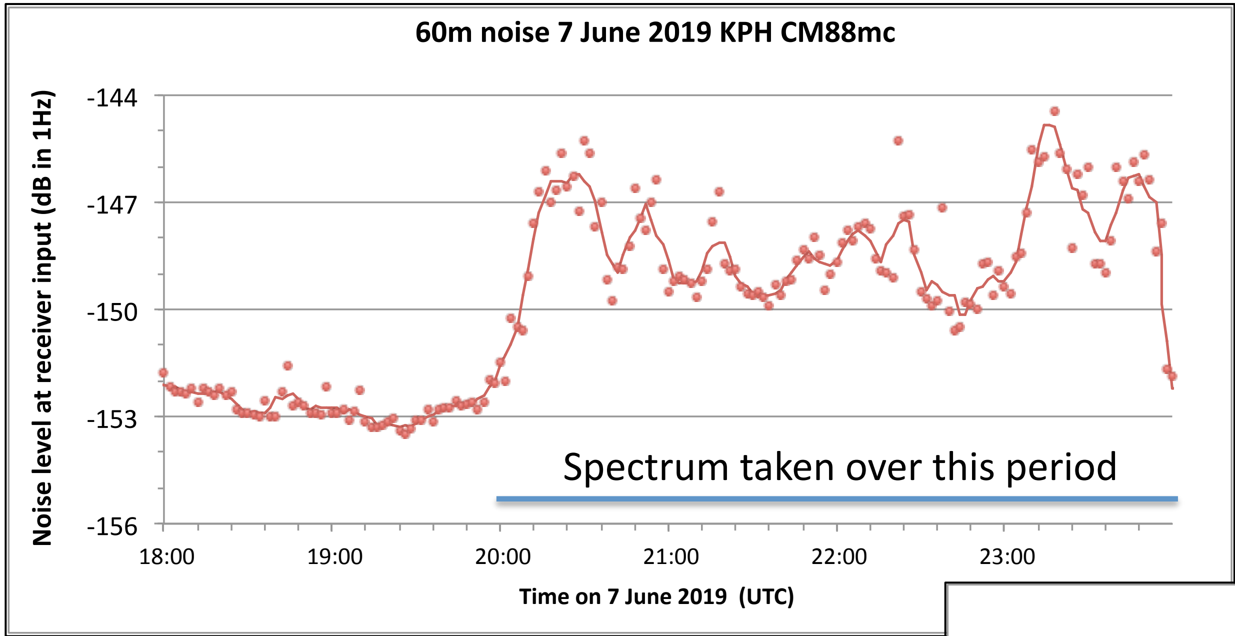
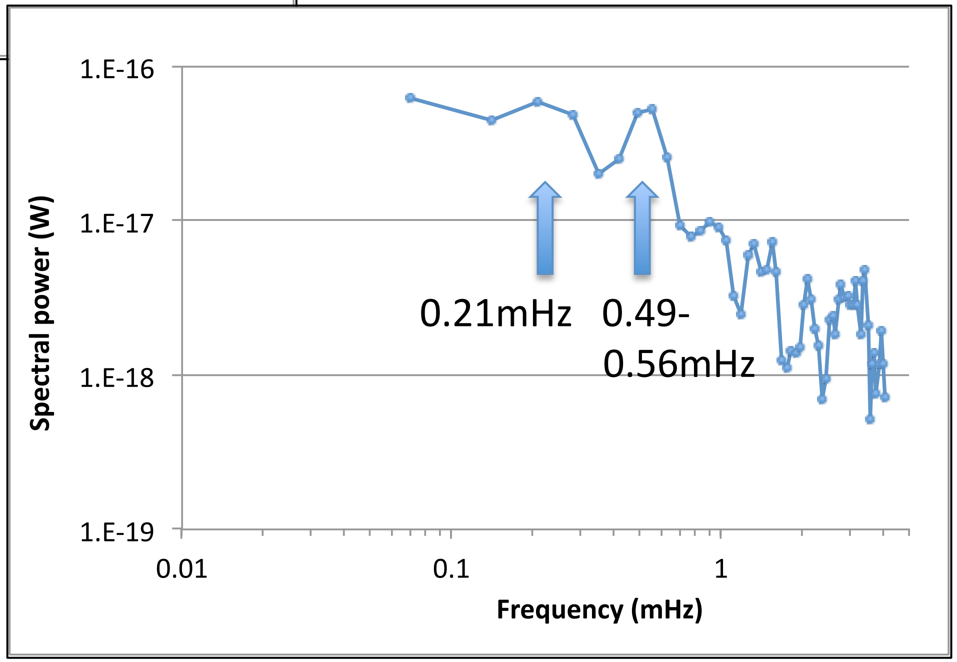
Wave-like fluctuations and phase differences need more work.

Travelling Ionospheric Disturbances seen on 60m at KPH?



Left: Dots show 2 minute time series measurements of the noise at KPH (FFT algorithm), with the line after a 10 minute filter. Note the low variability until ~2000UTC, followed by a rise and what appears to be a wave train.

Right: Power spectrum of the 60m noise time series amplitude from 2000–2358UTC, with frequency in milliHz.
The two main peaks are at 0.21mHz and 0.49–0.56mHz equivalent to periods of 79 minutes and 34-30 minutes. The shorter period fluctuations catch the eye in the time series, and may be Medium Scale Travelling Ionospheric Disturbances .



Conclusions

- The KiwiSDR, with careful attention to amplitude response and noise factor calibration, and a preamp above 14MHz, is a very capable receiver for WSPR and noise / space weather studies.
- wsprdaemon software combines robust WSPR reporting with time and frequency domain noise analysis algorithms that have sufficient immunity to interference such that we can see:
  - Consistent diurnal patterns of propagated-in noise on the MF–HF bands at quiet sites that vary with local solar time.
  - Galactic noise at a quiet site on 17–10m that varies with local sidereal time, with peak to peak amplitudes of the order of 1dB.
  - Wave-trains with periods of 30 to 80 minutes, the example shown lasting 4 hours, suggestive of travelling ionospheric disturbances modulating the ionosphere and thereby the propagated-in noise.
- Absolute calibration remains a real challenge, especially when the chain from the antenna to the receiver has several splitters, filters, amplifiers.