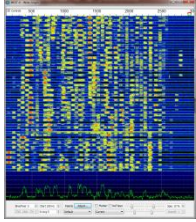

Real-World High Frequency Antenna Performance Comparisons Using the New FT-8 Digital Mode

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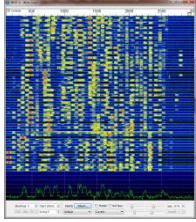
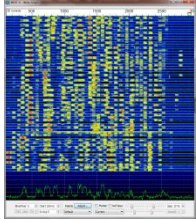
Outline



- Background
- Antenna and Radio Setup
- Comparison Approach And Software
- Comparison Data
  - Single counterpoise on homebrew vertical antenna
  - Dual counterpoise on homebrew vertical antenna
- Conclusions
- Comments
- Another Antenna (if time permits)

Background



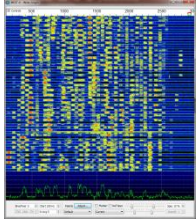
- We often want to compare antennas in real-world situations.
  - To choose the best antenna.
  - To make sure a particular antenna is working properly.
  - Experimentally determine relative performance of various antenna configurations such as the number of counterpoise wires on a vertical.
- HF antennas tend to be fairly large, especially on the lower HF bands.
- HF antennas require a lot of space to make reliable antenna measurements.
- FT-8 is a new digital mode which provides Signal-To-Noise Ratio (SNR) estimates on every received signal.
- Many transmissions in FT-8 include the 4-digit grid square of the transmitting station. This enables us to know the approximate location of the transmitter.
- If signals from 2 antennas that are nearly in the same location are decoded at the same time, the SNR and location information provided by FT-8 can be used for real-word antenna comparisons. This presentation shows one such approach.
- Because FT-8 estimates SNR and not just total signal strength, antennas which pickup a lot of noise will be appropriately penalized. SNR is really what matters to us, not just the signal gain of an antenna.

Homemade
20 M
Vertical
$40
1 band

Gap
Challenger
Vertical
$400
8 Bands

Background On FT-8

- A new digital mode was introduced in 2017 called FT-8.
- Steven **F**ranke (K9AN) and Joe **T**aylor (K1JT) worked together to create this new mode which uses **8** FSK tones.
- A complete transmission happens in just 12.6 seconds and sends a maximum of 13 random characters.
- An example waterfall and spectrum presentation is shown at right. Transmissions begin at 0, 15, 30, and 45 seconds.
- Your computer time must be very accurate (<1 second.) Free software is readily available which will synchronize your computer's time with the National Bureau of Standards (Dimension 4 is one example.)
- The bandwidth of the signals used in FT-8 is just 50 Hz.
- Signals with a Signal-To-Noise Ratio (SNR) of greater than -20 dB (measured in a 2500 Hz bandwidth) can be copied correctly. This is much smaller than we can easily hear and enables us to copy transmissions from many more stations around the world.
- To decode this mode you must have an interface from the audio output of a radio to a computer with WSJT-X software. This can be as simple as connecting the audio output of a receiver to a sound-card interface that is available on most computers. Inexpensive sound card interfaces are readily available if your computer does not have one. Some rigs have a USB interface for audio.
- Transmissions use Low Density Parity Check (LDPC) error correcting codes. Decode errors are very rare. Decoded transmissions are presented on the user interface.

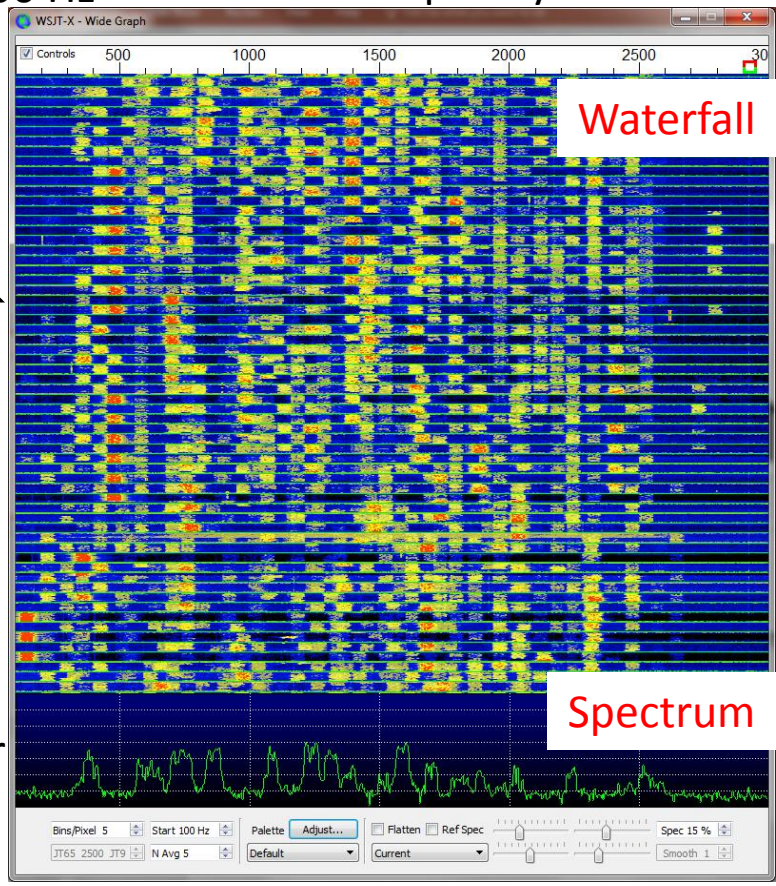


FT8.WAV

100 Hz Audio Frequency 3 kHz

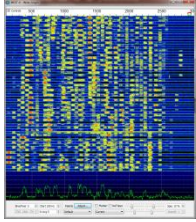
Time

~Pwr

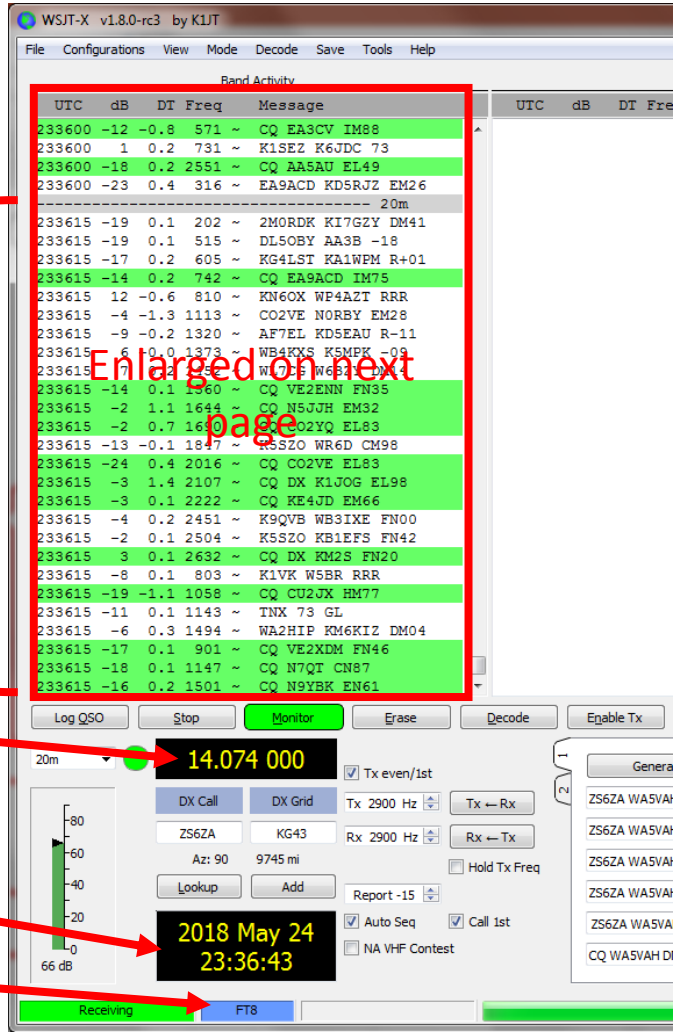


Each horizontal green line in the waterfall represents 15 seconds
The entire waterfall shown is >15 min.

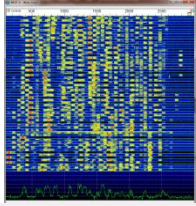
More Background On FT-8



- A portion of the user interface for WSJT-X is shown at right.
- The signals decoded from a single 15-second interval are shown here. Only 13 random character can be sent in 12.6 seconds. Special codes are used for call signs.
- The decoded signals are all written to a file (All.txt) on the computer.
- The frequency in use was 14.074 MHz (20m.)
- The current date and time are shown here.
- The software mode is shown here.



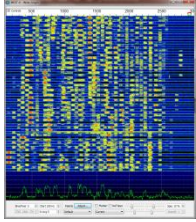
WSJT-X Output for Decoded Signals



- The first column under “UTC” is time in hours, minutes and seconds at the beginning of a 15-second interval.
- 15-second intervals are separated by a dashed line as shown here. The band in use is shown at right.
- The column under “dB” gives an estimate of the Signal-To-Noise Ratio, in dB, of each signal at my station. This is very useful for comparisons.
- The column under “DT” is the estimated time difference between my station and the transmitting station and should very often be < ±0.2 seconds.
- The column under “Freq” is the audio frequency of the decoded signal.
- The column under “Message” is the message received from the station during the 15-second interval. This message contains ≤ 13 random characters. Special codes are used for call signs.
- Rows in the table highlighted in green are CQ messages. All CQ messages include the call sign of the transmitting station and the 4-digit grid-square of the transmitting station enabling us to know the approximate location of the transmitter.
- The entire set of decoded messages are continuously recorded in a file “All.txt” We are going to look at this file in more detail on the following slides.

UTC	dB	DT	Freq		Message
233600	-12	-0.8	571	~	CQ EA3CV IM88
233600	1	0.2	731	~	K1SEZ K6JDC 73
233600	-18	0.2	2551	~	CQ AA5AU EL49
233600	-23	0.4	316	~	EA9ACD KD5RJZ EM26
---------- 20m					
233615	-19	0.1	202	~	2M0RDK KI7GZY DM41
233615	-19	0.1	515	~	DL5OBY AA3B -18
233615	-17	0.2	605	~	KG4LST KA1WPM R+01
233615	-14	0.2	742	~	CQ EA9ACD IM75
233615	12	-0.6	810	~	KN6OX WP4AZT RRR
233615	-4	-1.3	1113	~	CO2VE N0RBY EM28
233615	-9	-0.2	1320	~	AF7EL KD5EAU R-11
233615	6	-0.0	1373	~	WB4KXS K5MPK -09
233615	7	0.2	1452	~	WL7CG W6BZY DM14
233615	-14	0.1	1560	~	CQ VE2ENN FN35
233615	-2	1.1	1644	~	CQ N5JJH EM32
233615	-2	0.7	1690	~	CQ CO2YQ EL83
233615	-13	-0.1	1847	~	K5SZO WR6D CM98
233615	-24	0.4	2016	~	CQ CO2VE EL83
233615	-3	1.4	2107	~	CQ DX K1JOG EL98
233615	-3	0.1	2222	~	CQ KE4JD EM66
233615	-4	0.2	2451	~	K9QVB WB3IXE FN00
233615	-2	0.1	2504	~	K5SZO KB1EFS FN42
233615	3	0.1	2632	~	CQ DX KM2S FN20
233615	-8	0.1	803	~	K1VK W5BR RRR
233615	-19	-1.1	1058	~	CQ CU2JX HM77
233615	-11	0.1	1143	~	TNX 73 GL
233615	-6	0.3	1494	~	WA2HIP KM6KIZ DM04
233615	-17	0.1	901	~	CQ VE2XDM FN46
233615	-18	0.1	1147	~	CQ N7QT CN87
233615	-16	0.2	1501	~	CQ N9YBK EN61

Example 15-Second Portion of “All.txt”



- This file contains the same information that appears on the WSJT-X user interface.
- This file can be viewed using your favorite text editing software. Here I am using Windows notepad.
- Useful information for our purposes:
  - The time at the start of the 15-second interval
  - The SNR estimate (the second column)
  - The location of the transmitting station (last)

- Those stations who were transmitting CQ include their location represented by a 4-digit grid square as the last 4 characters of their transmission as highlighted in green at right.
- Those stations making an initial reply to a CQ send the station being called, their own call and their 4-digit grid square as the last 4 characters of their transmission as highlighted in yellow at right.
- A grid square is not sent on many other transmissions.

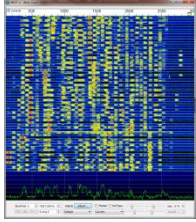
Example15Seconds.txt - Notepad

File Edit Format View Help

```
233615 -19  0.1  202 ~  2M0RDK KI7GZY DM41
233615 -19  0.1  515 ~  DL5OBY AA3B -18
233615 -17  0.2  605 ~  KG4LST KA1WPM R+01
233615 -14  0.2  742 ~  CQ EA9ACD IM75
233615  12 -0.6  810 ~  KN6OX WP4AZT RRR
233615  -4 -1.3 1113 ~  CO2VE N0RBY EM28
233615  -9 -0.2 1320 ~  AF7EL KD5EAU R-11
233615   6 -0.0 1373 ~  WB4KXS K5MPK -09
233615   7  0.2 1452 ~  WL7CG W6BZY DM14
233615 -14  0.1 1560 ~  CQ VE2ENN FN35
233615  -2  1.1 1644 ~  CQ N5JJH EM32
233615  -2  0.7 1690 ~  CQ CO2YQ EL83
233615 -13 -0.1 1847 ~  K5SZO WR6D CM98
233615 -24  0.4 2016 ~  CQ CO2VE EL83
233615  -3  1.4 2107 ~  CQ DX K1JOG EL98
233615  -3  0.1 2222 ~  CQ KE4JD EM66
233615  -4  0.2 2451 ~  K9QVB WB3IXE FN00
233615  -2  0.1 2504 ~  K5SZO KB1EFS FN42
233615   3  0.1 2632 ~  CQ DX KM2S FN20
233615  -8  0.1  803 ~  K1VK W5BR RRR
233615 -19 -1.1 1058 ~  CQ CU2JX HM77
233615 -11  0.1 1143 ~  TNX 73 GL
233615  -6  0.3 1494 ~  WA2HIP KM6KIZ DM04
233615 -17  0.1  901 ~  CQ VE2XDM FN46
233615 -18  0.1 1147 ~  CQ N7QT CN87
233615 -16  0.2 1501 ~  CQ N9YBK EN61
```

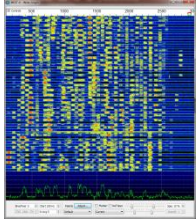
Ln 1, Col 1

Decoding the Information From a “CQ”

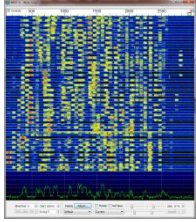


- The received SNR is always included which is the SNR at my station.
- Let’s look at the first CQ call on the previous page:
  - `233615 -14  0.2  742 ~  CQ EA9ACD IM75`
  - 233615 is the UTC time at the beginning of the 15-second reception period ⇒ 23 hours, 36 minutes, 15 seconds.
  - -14 is the SNR estimate, in dB, for this signal at my station ⇒ -14 dB.
  - 0.2 is the time difference estimate, in seconds, between my clock and the signal received, ⇒ 0.2 seconds.
  - 742 is the audio frequency, in Hz, of the signal ⇒ 742 Hz.
  - EA9ACD is the station transmitting (the “FROM” station) ⇒ EA9ACD was transmitting.
  - IM75 is the 4-digit grid square of the transmitting station ⇒ latitude ~35.5°, longitude ~-5.0°.
- The SNR and transmitter location information recorded from 2 radios with 2 different antennas enables us to compare the SNR from the same transmitting station at the same time.

Comments on SNR and Location

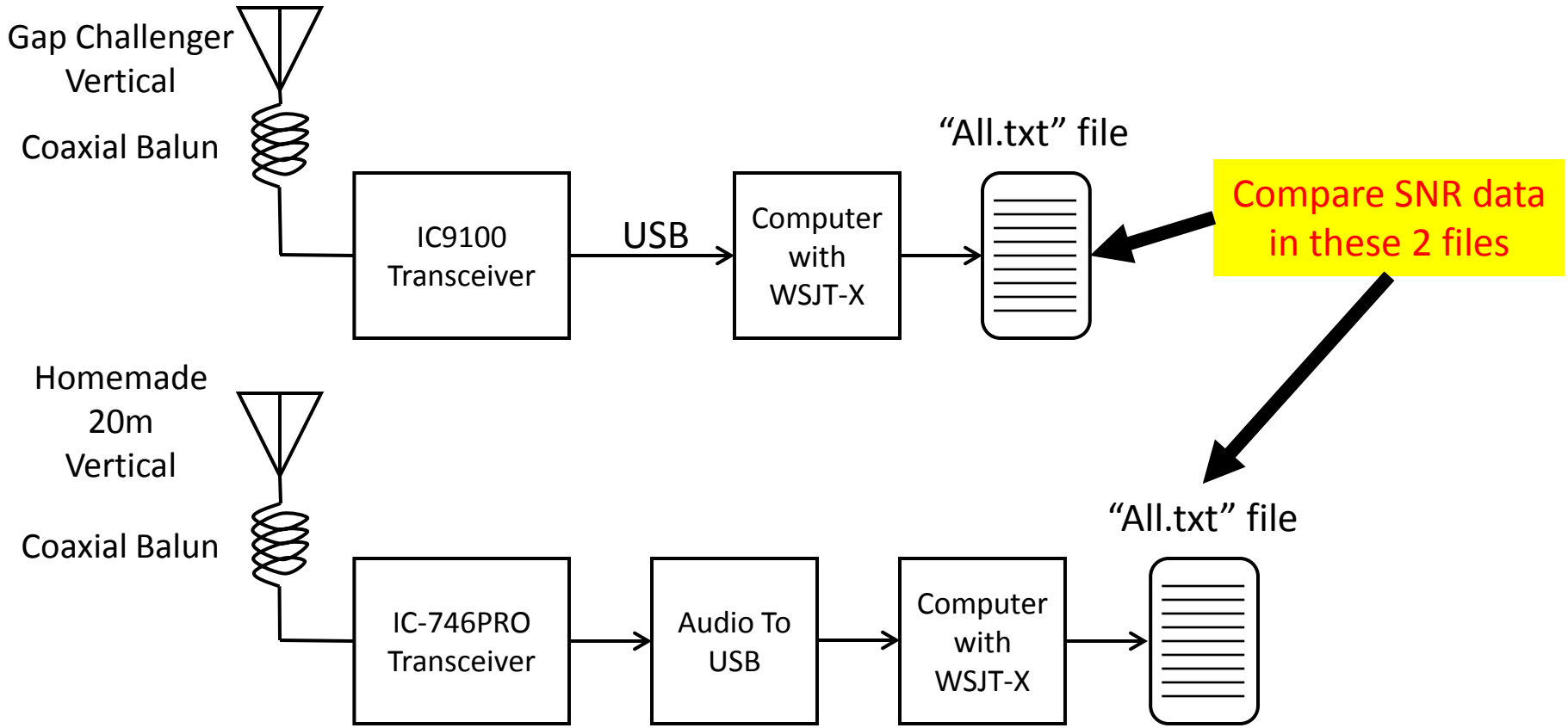


- The SNR estimates in the WSJT-X software are not very accurate.
  - They are reported only to the nearest dB.
  - Averaging a lot of differences in SNR from the 2 antennas can greatly improve the accuracy of our comparative estimates of performance. For this to be true we have to assume that the SNR estimate in WSJT-X is a non-biased estimator of SNR.
- The 4-digit grid square gives us the approximate location of the transmitter
  - ±0.5 degrees of latitude or ±30 nm north to south
  - ±1 degrees of longitude or ±60 nm at the equator east to west, the east-west error reduces at latitudes away from the equator.
  - The worst-case distance error is about 73 nm.
  - This is quite sufficient for our purposes in calculating:
    - The approximate **distance** from my station to the transmitter.
    - The approximate **direction** from my station to the transmitter.



Antenna and Radio Setup Used

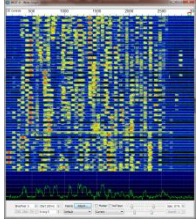
Hardware Schematic

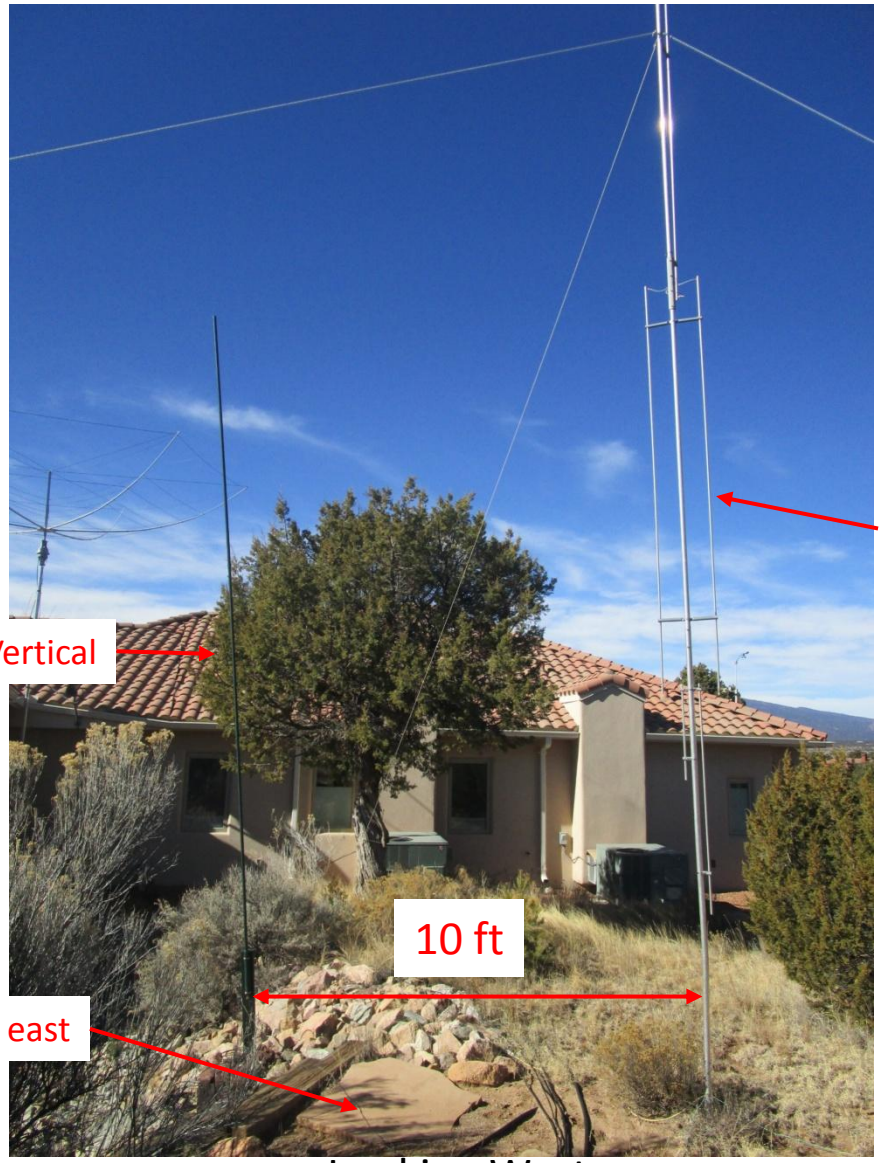


Any two receivers should work for this type of comparison assuming that when you connect the antenna being tested noise coming out of the receiver increases on a frequency with no signal.

Receivers Used in Comparison

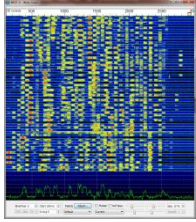
View Of Both Antennas



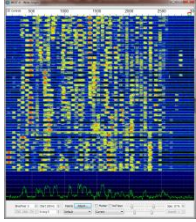


Looking West

Why Use This Approach?

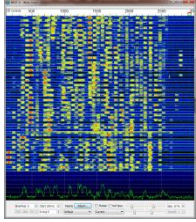


- All of the equipment for the comparison is under my control.
- Signals are recorded at the same time.
  - Eliminates issues with fading signals as a function of time.
  - Eliminates issues with transmitter power variation with time.
  - Noise in the environment is identical for both antennas.
- SNR is really what we are interested in comparing.
  - Some antennas seem to “hear” more noise than others and this impact is included in the measurement.
  - Antennas with directivity that are pointed away from noise sources will show an advantage.
  - Directivity of antennas can be directly compared on an SNR basis and not just on signal strength.



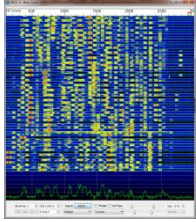
Software Approach for Comparing Reports

Software Issues for Comparing Reports

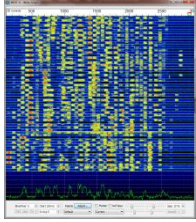


- We only want to compare SNR reports from:
  - The same transmitter.
  - At the same time.
  - We want to use messages that include the grid square of the transmitter to enable more complete performance comparisons.
- The two text files may begin at different times. Must find the same time in both files.
- Sometimes a report will not be decoded in both receivers. A variety of reasons cause this to happen.
- The software must find the same transmitter from the same time in both files and then take the difference of the 2 SNR estimates.
- All of this needs to be done by software and not by a manual comparison! Clearly this can be done manually but is really hard.
- A large number of reports can be compared using a software approach which would be impossible with a manual comparison approach.
- Multiple comparisons types are possible and discussed next.
- Matlab Software was created to match reports and create plots.

Several Types of Comparisons



- A direct comparison of the SNR estimates in all matching reports. This comparison finds the same time and the same transmitter; however, may not know the transmitter's location.
  - Regardless of SNR.
  - Those where the comparison antenna reported an SNR > 0 dB.
- Reports containing a grid square, typically "CQ" decodes and first response to a CQ by the replying station.
  - Plot the direct comparison of matching reports, same time, transmitter, and grid.
    - Regardless of SNR.
    - Those where the comparison antenna reported an SNR > 0 dB.
  - Plot the report comparisons by distance from the transmitter to my station.
    - Is a particular antenna better for "DX" stations?
    - Is a particular antenna better for nearby stations?
    - Averaging reports over 500 nm of distance helped reduce noise in comparisons.
    - Ignore comparisons with less than 30 reports at a 500 mile distance bin.
  - Plot the report comparisons by azimuth direction to the transmitter from my station.
    - Compares directivity of the antennas
    - Determines if one antenna works better in a particular direction.
    - Averaging measurements over 10° of angle helped reduce noise in comparisons.
    - Ignore azimuth angles with less than 30 reports in a given 10 degree bin.



Comparison Data

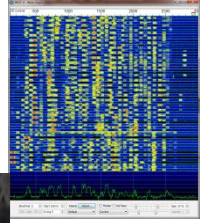
Data from 2/1/2018

One counterpoise wire 12’ 3” long as shown on next slide deployed on the Homebrew Vertical.

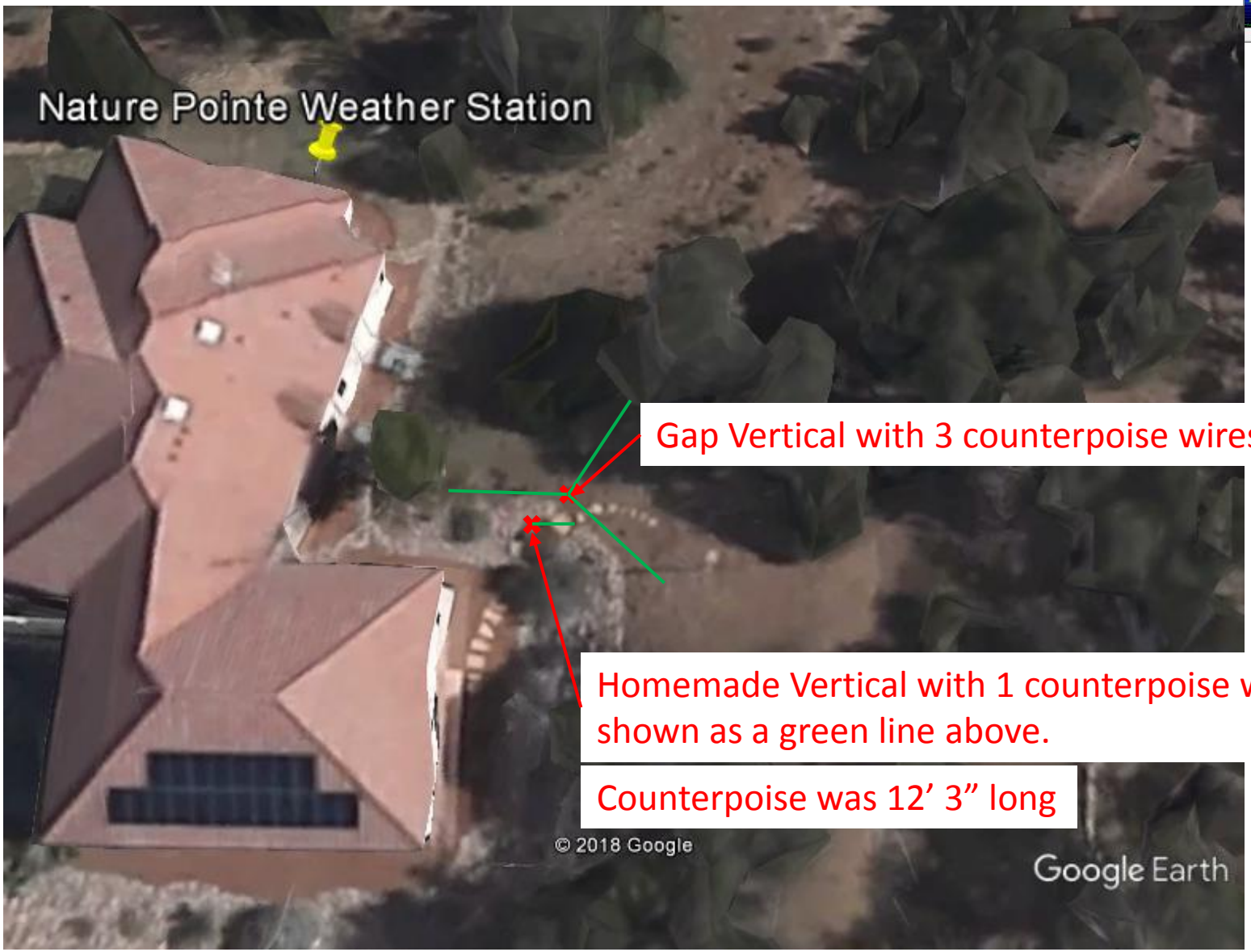
Data from 15:21 to 23:00 UTC

Total time of measurements 7:39.

Layout for 2/1/2018



N

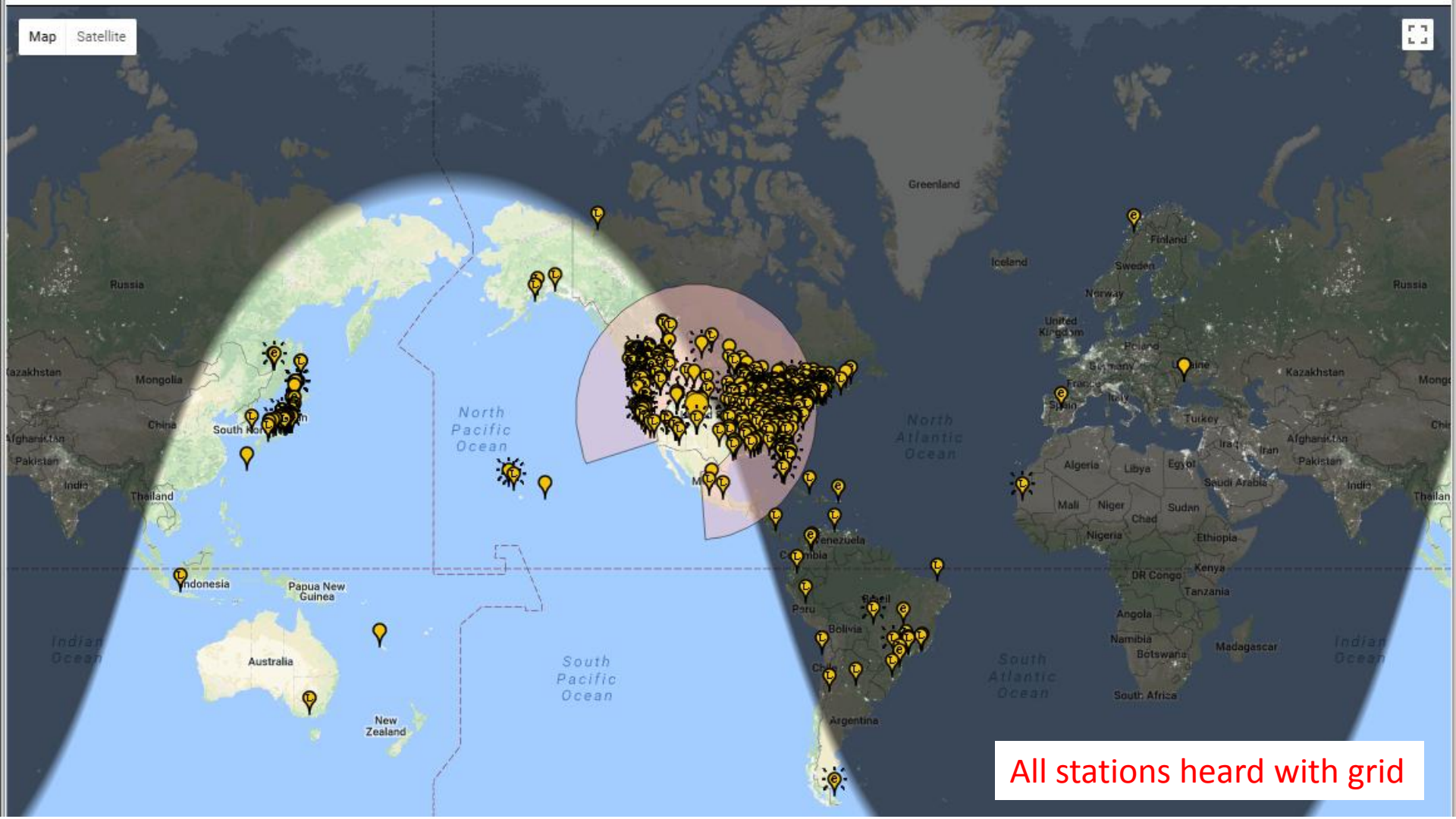


PSK Reporter Screen Shot From 2/1/2018

On 20m, show signals, sent/rcvd by, the callsign, wa5vah using all modes over the last 24 hours Go! Display options Permalink

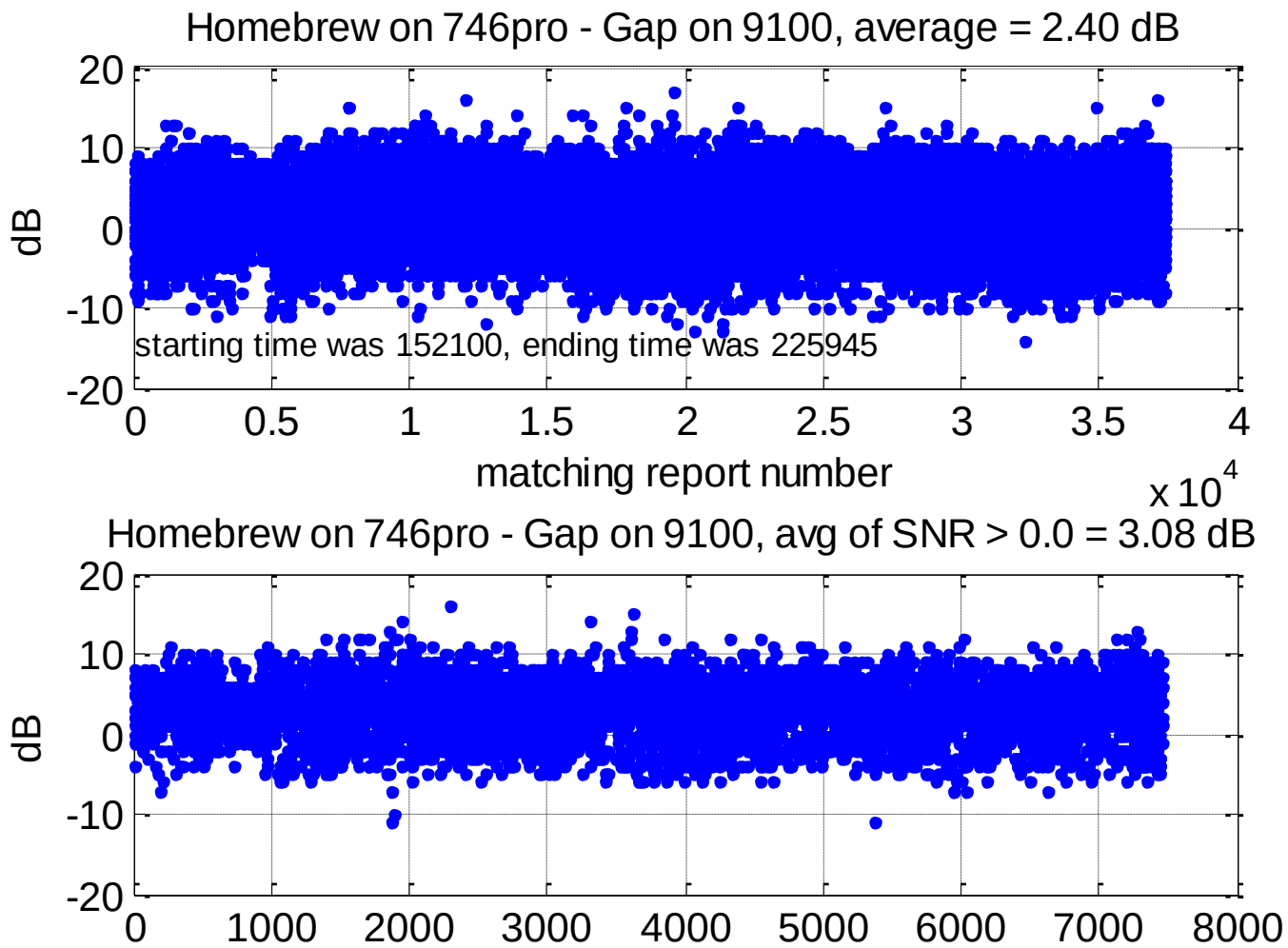
Monitoring WA5VAH (last report 0 mins ago). Automatic refresh in 5 minutes. Small markers are the 524 transmitters (show logbook) heard (distance chart) at WA5VAH (12448 reports, 90 countries last 24 hours; 24907 reports, 109 countries last week).

There are 660 active monitors on 20m. Show all on all bands. Legend



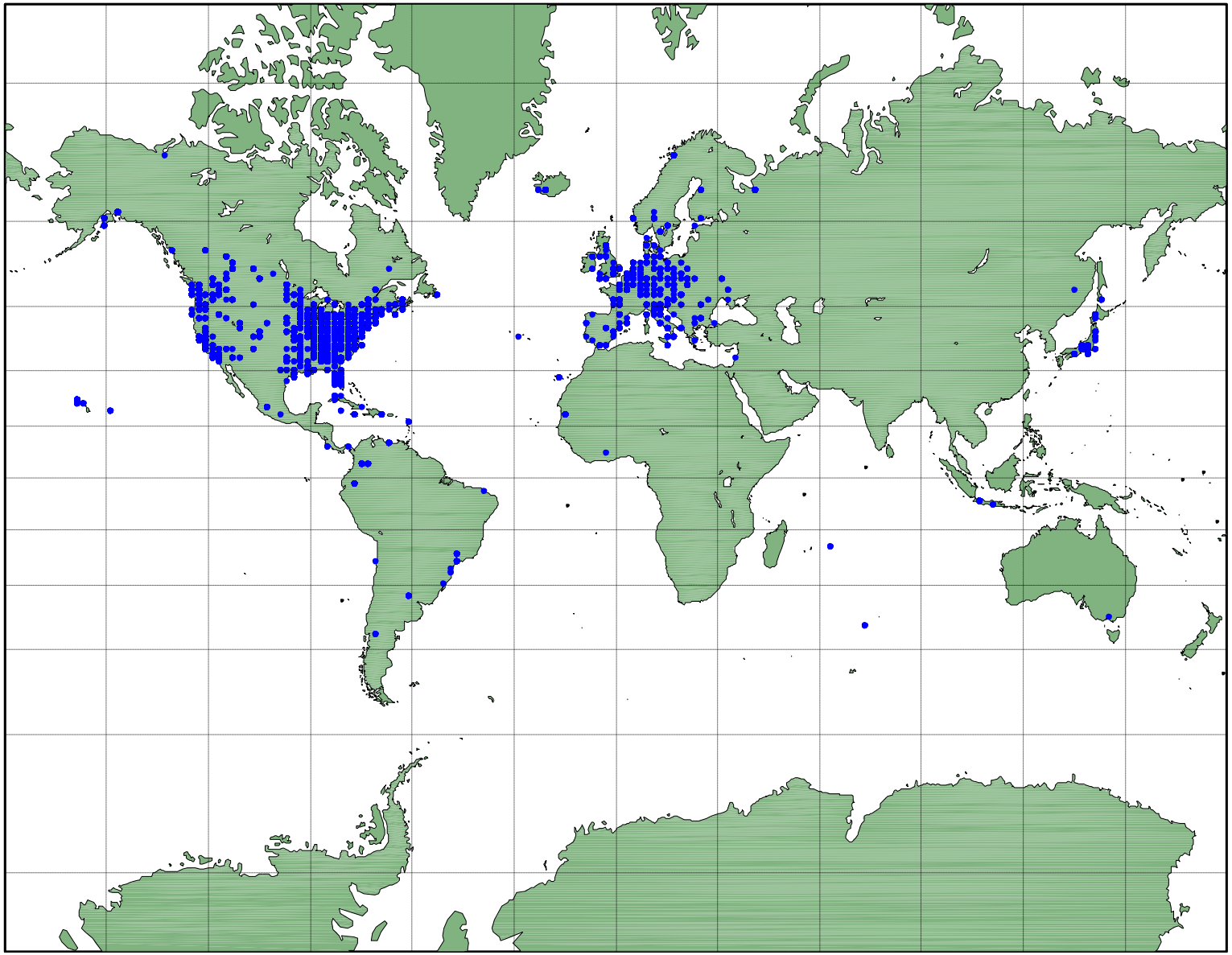
All stations heard with grid

Comparison of All Matching (37,397) Data from 2/1/2018

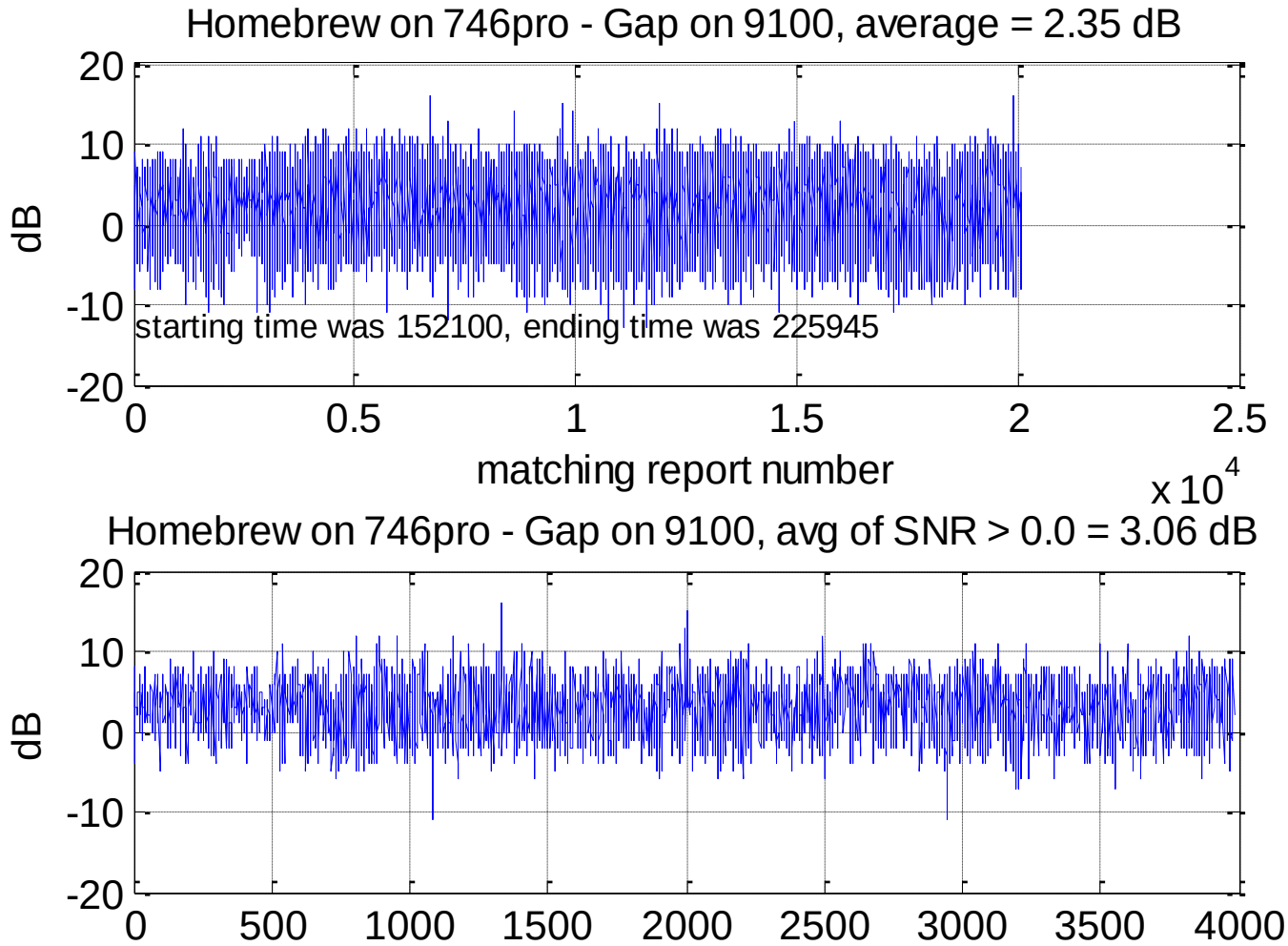


Positive numbers indicate the Homebrew antenna has higher SNR.
Negative numbers indicate the Gap antenna has higher SNR.

Location of Reports With Grid Data From 2/1/2018

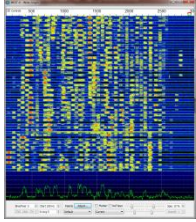


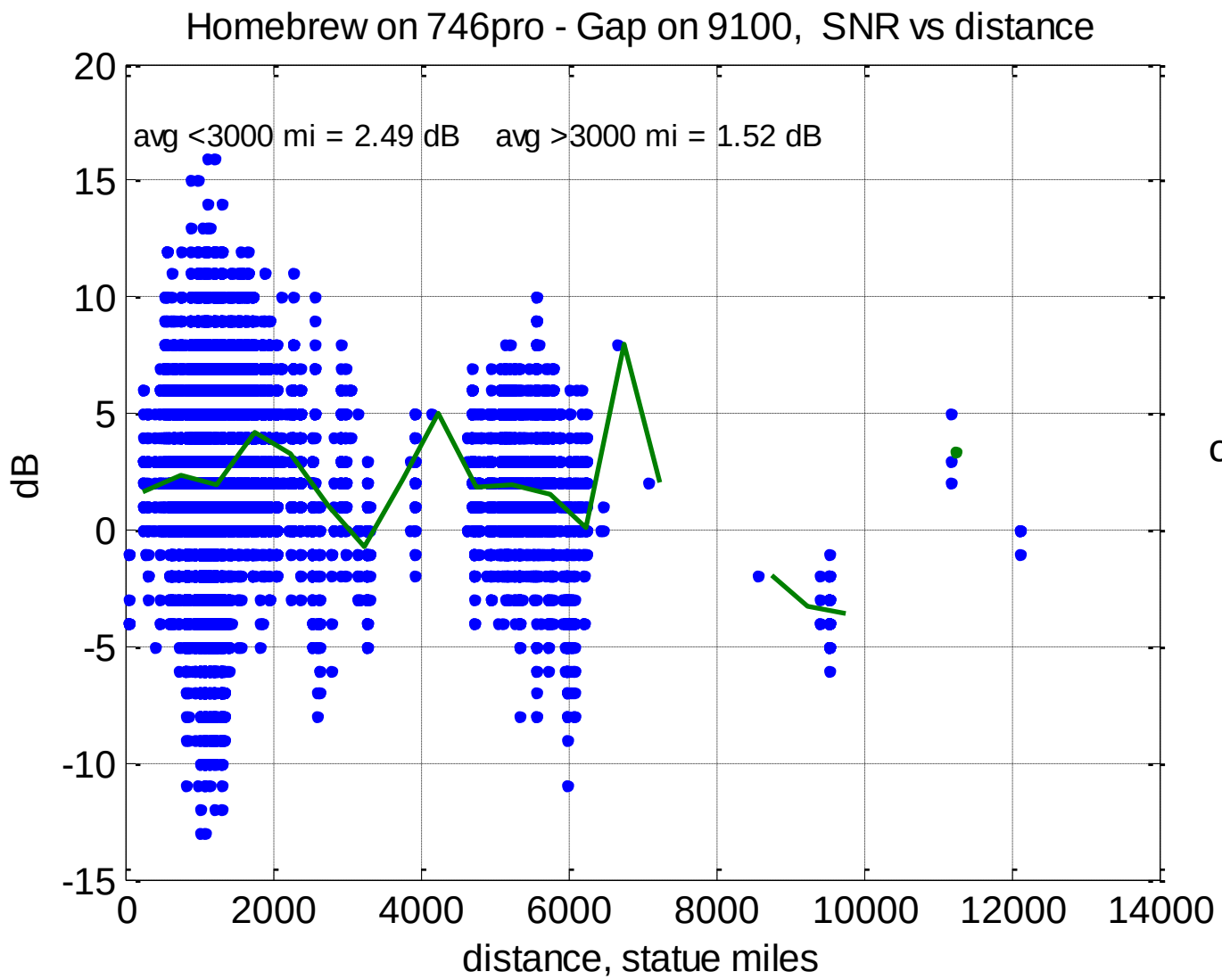
Comparison of Reports With Grid Data From 2/1/2018



Positive numbers indicate the Homebrew antenna has higher SNR.
Negative numbers indicate the Gap antenna has higher SNR.

SNR Comparison Versus Distance
2/1/2018 Data

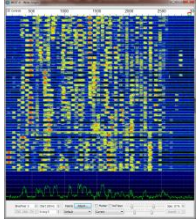


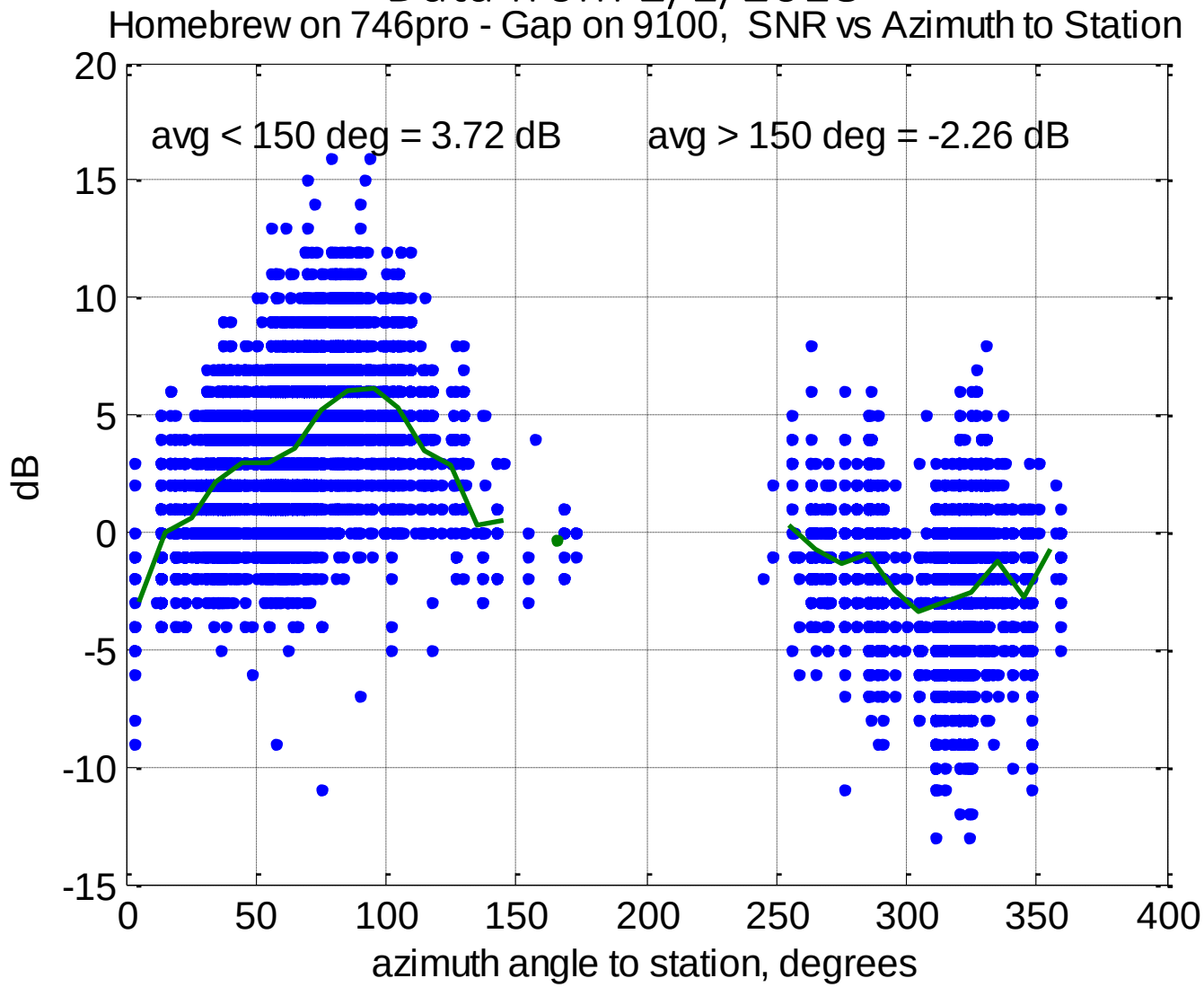


Green line is average over 500 nm intervals

Positive numbers indicate the Homebrew antenna has higher SNR.
Negative numbers indicate the Gap antenna has higher SNR.

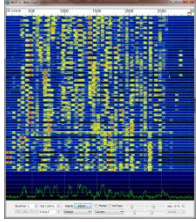
SNR Comparison Versus Azimuth Angle
Data from 2/1/2018





Green line is average over 10° intervals

Positive numbers indicate the Homebrew antenna has higher SNR.
Negative numbers indicate the Gap antenna has higher SNR.



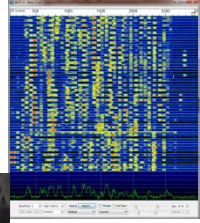
Homemade Vertical with 2 Counterpoise Wires

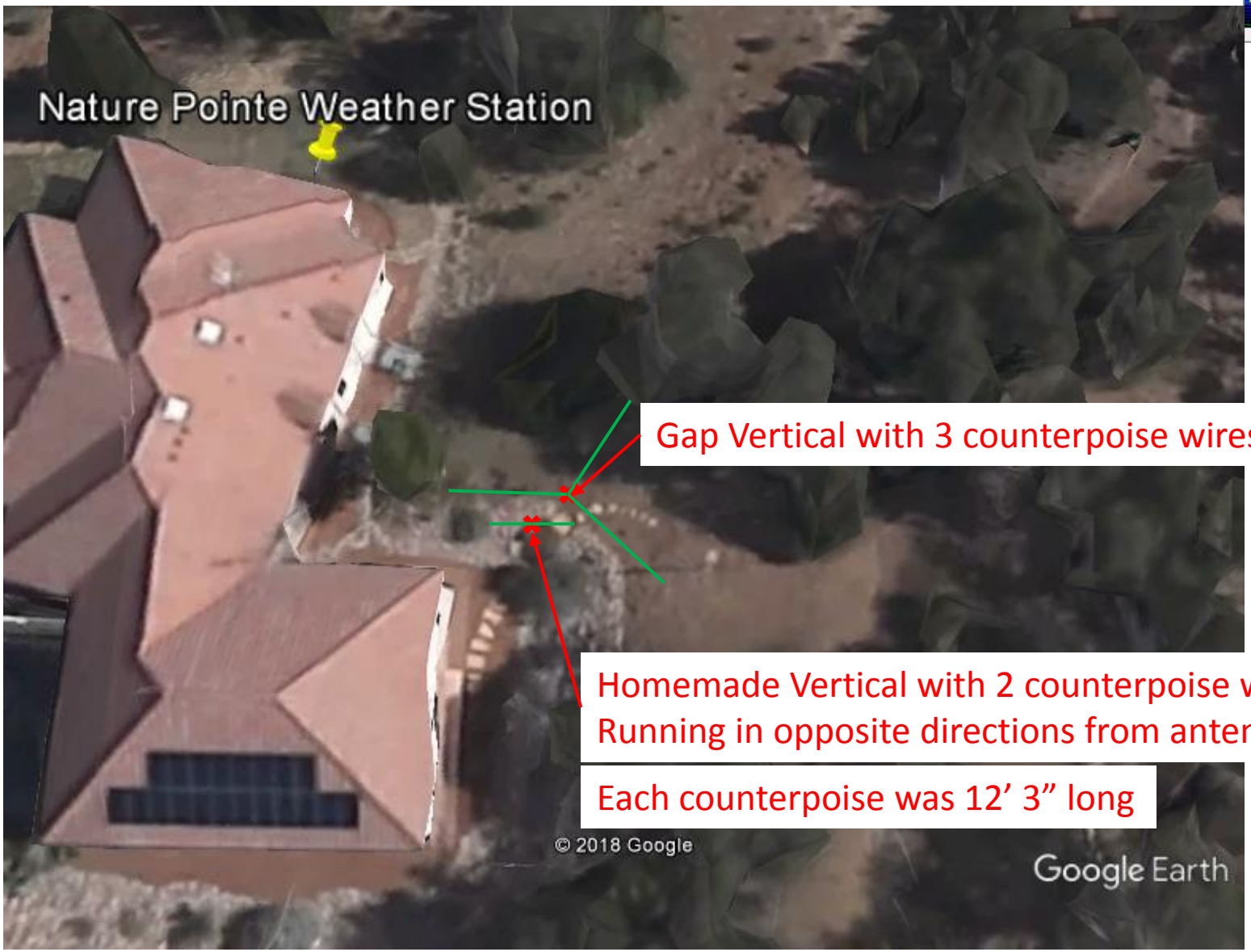
Counterpoise wires on opposite sides as shown on next slide deployed on the Homebrew Vertical.

Data from 2/3 at 14:47 to 23:11 UTC

Total time of measurements 9:24.

Layout for 2/3/2018





N

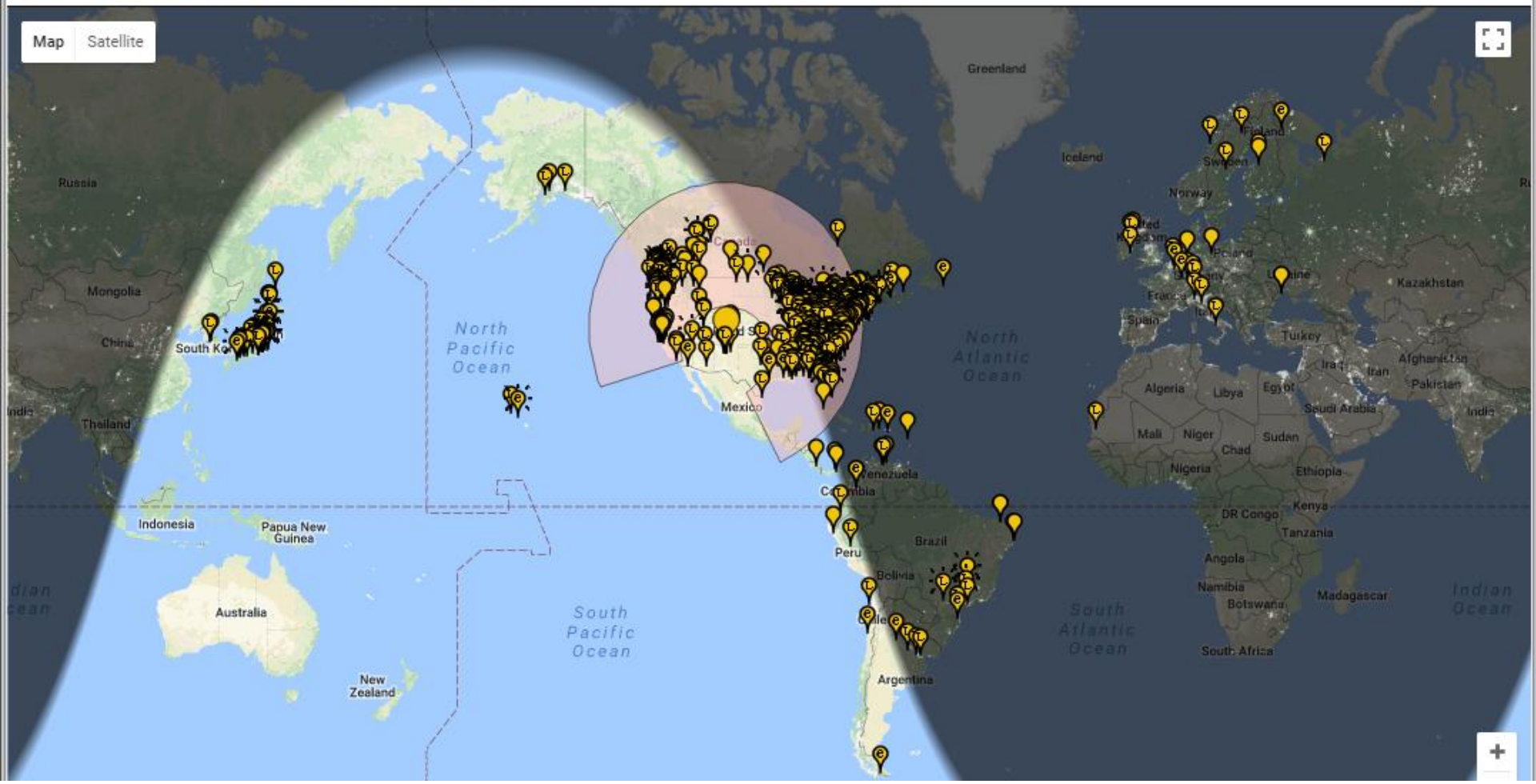
PSK Reporter Screen Shot From 2/3/2018

On 20m, show signals sent/rcvd by the callsign wa5vah using all modes over the last 24 hours Go!

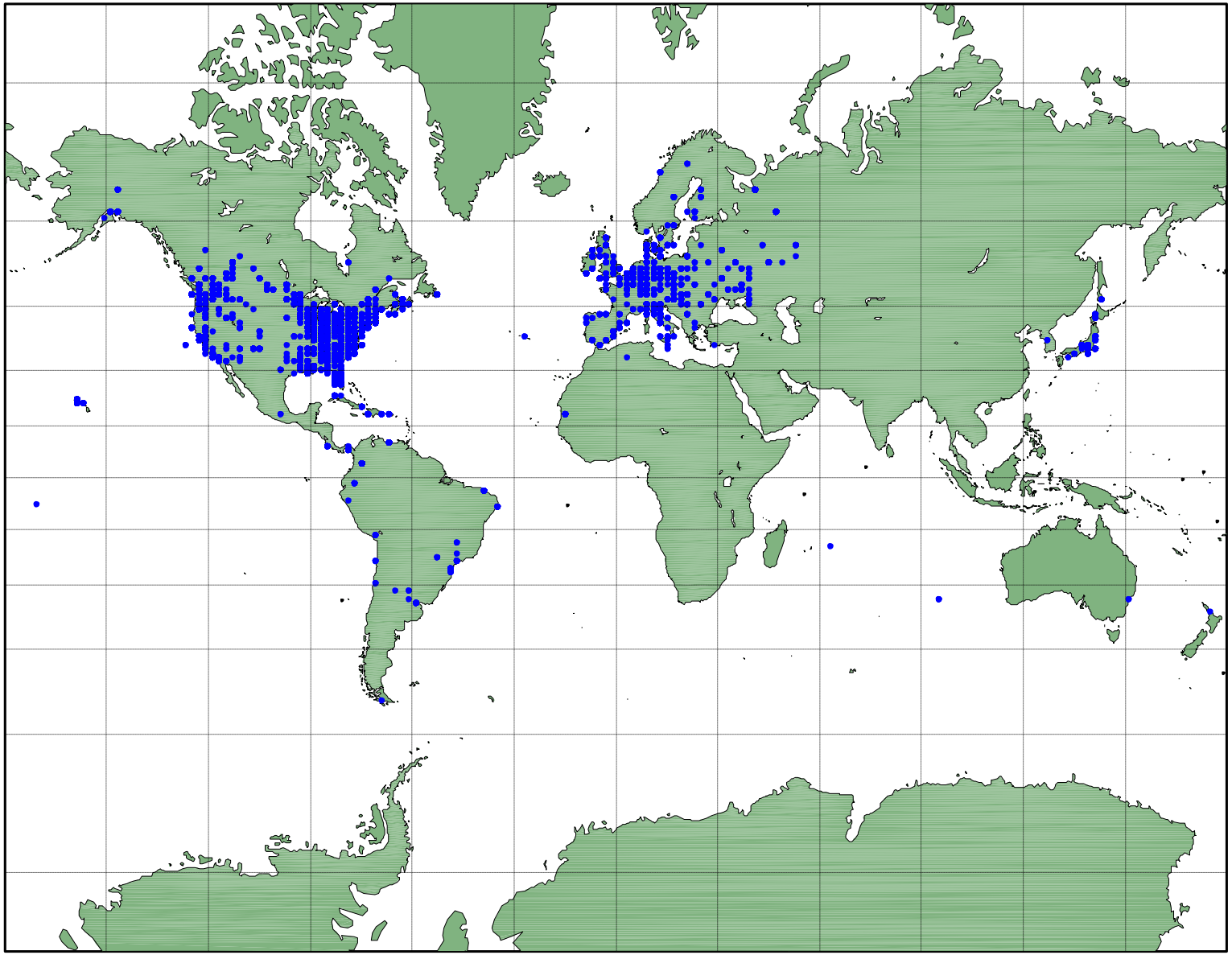
Display options Permalink

Monitoring WA5VAH (last report 7 mins ago). Automatic refresh in 2 minutes. Small markers are the 567 transmitters (show logbook) heard (distance chart) at WA5VAH (12095 reports, 92 countries last 24 hours; 48447 reports, 107 countries last week).

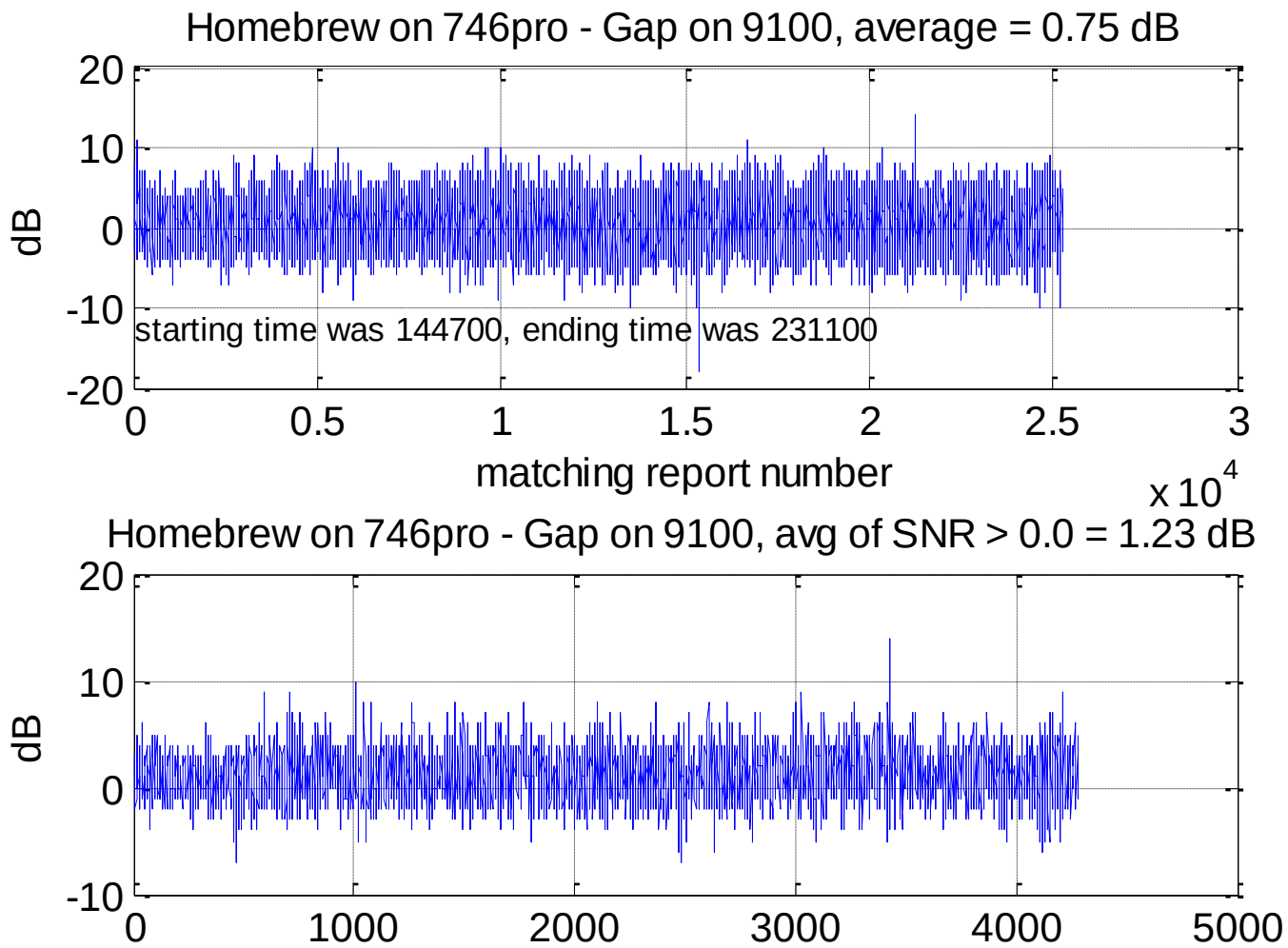
There are 853 active monitors on 20m. Show all on all bands. Legend



Location of Reports With Grid Data From 2/3/2018

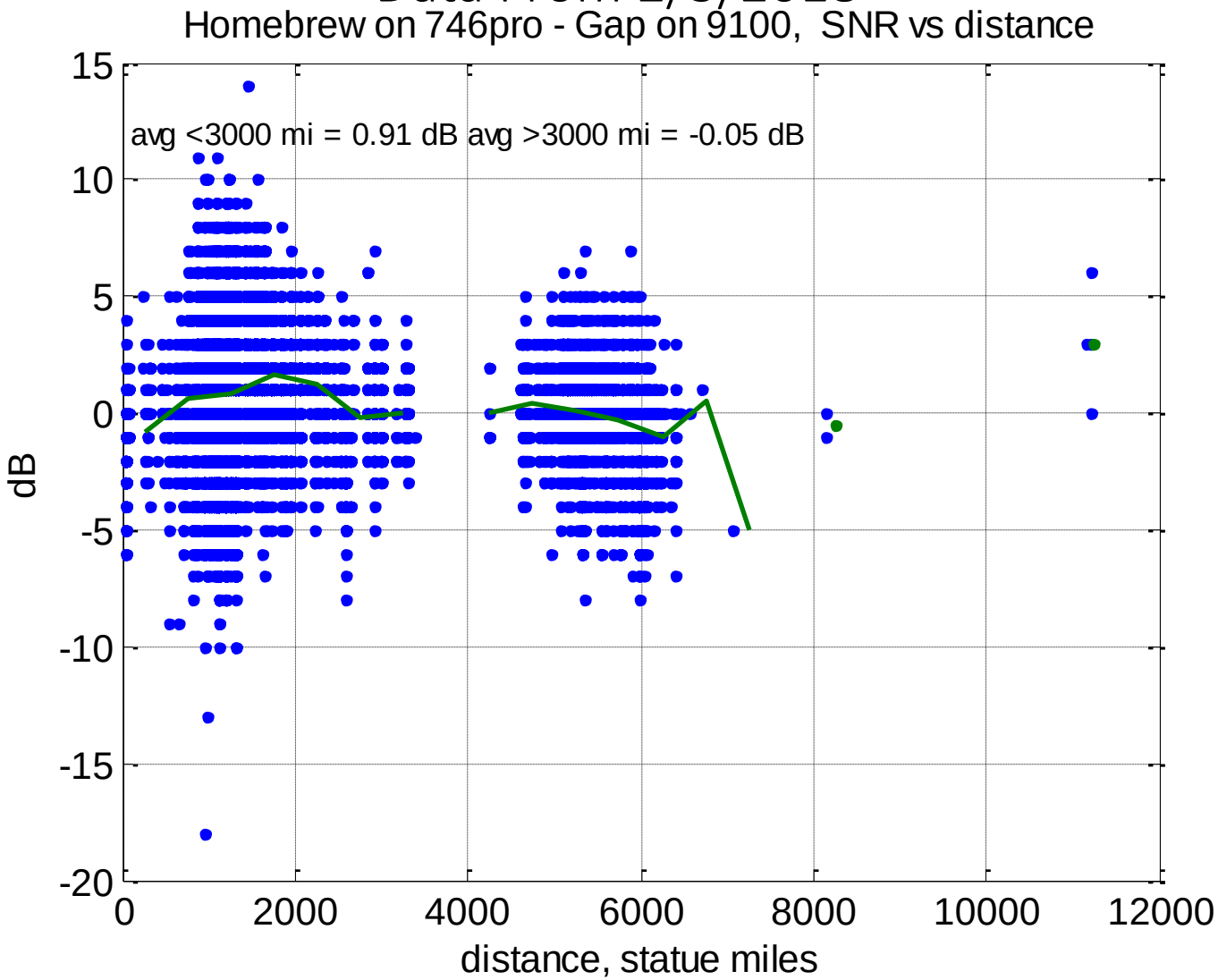


Comparison of Reports With Grid Data From 2/3/2018



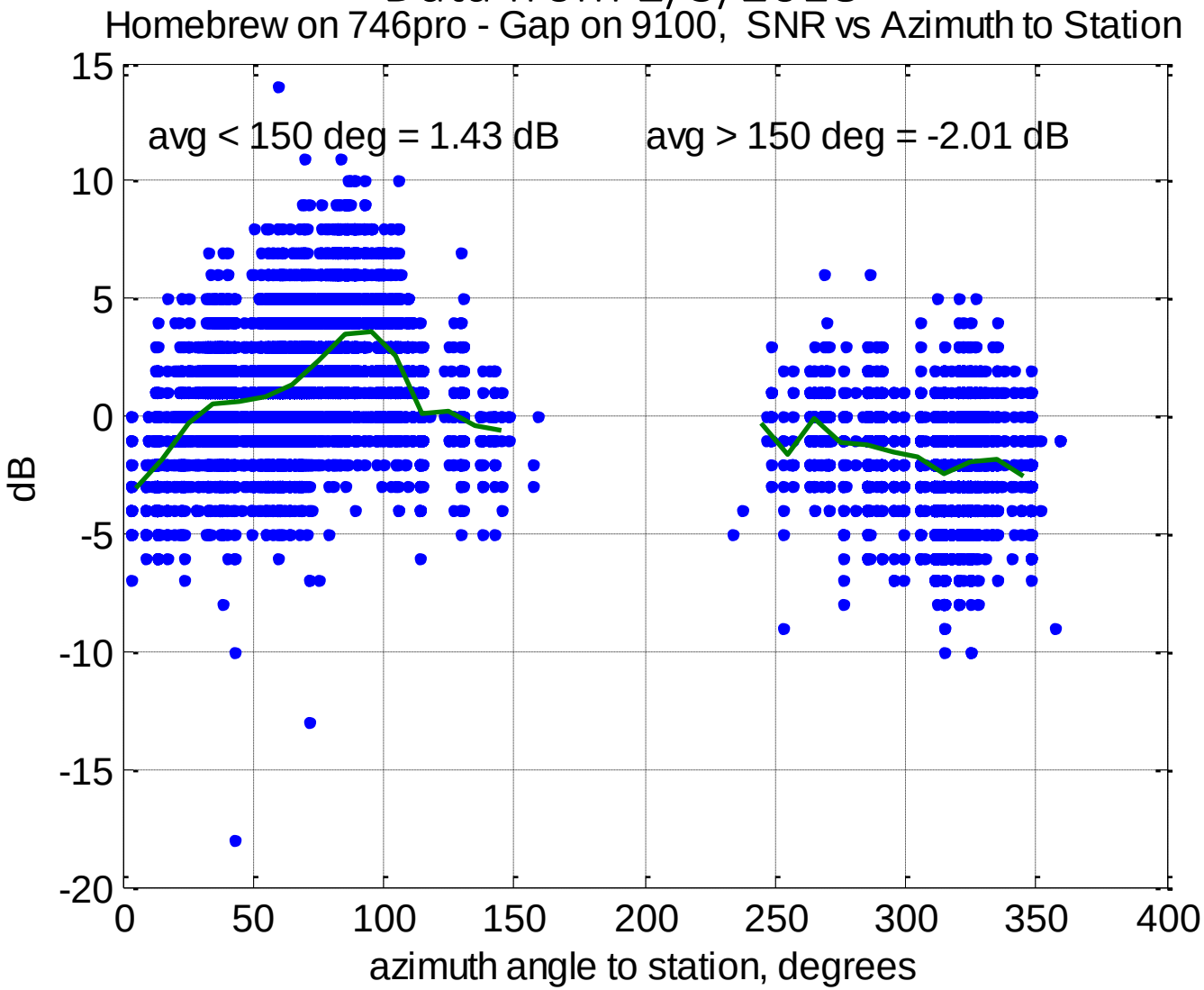
Positive numbers indicate the Homebrew antenna has higher SNR.
Negative numbers indicate the Gap antenna has higher SNR.

SNR Comparison Versus Distance
Data From 2/3/2018



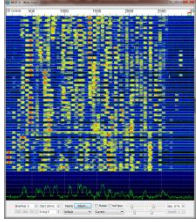
Green line is the average of all reports in 500 nm intervals.

SNR Comparison Versus Azimuth Angle
Data from 2/3/2018



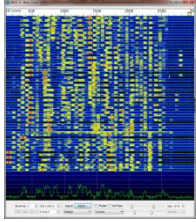
Positive numbers indicate the Homebrew antenna has higher SNR.
Negative numbers indicate the Gap antenna has higher SNR.

Conclusions



- All matching signals.
  - The homebrew antenna measured to be better by ~0.75 dB to ~1.25 dB overall using both counterpoise wires.
- SNR comparison with reports containing the grid square for Homebrew Antenna with 2 counterpoise wires:
  - Transmitter distance comparison
    - Stations <3000 miles away – Homebrew Antenna better by **~0.9 dB** with a peak around 1750 miles of **~1.5 dB**.
    - Stations >3000 miles away – the antennas were less than **0.1 dB** different.
  - Transmitter azimuth direction comparison
    - 0° - 150° the homebrew antenna measures about **1.4 dB** better with a peak difference of about **3.5 dB** in an easterly direction.
    - 150° - 250° no information – Pacific Ocean.
    - 250° to 360°, the Gap Challenger antenna was better by about **2 dB**.
    - These differences are likely environmental (trees, house, etc.)
- This homebrew 20 m antenna is ready for service.

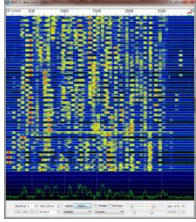
Homebrew Vertical Deployed



Looking West

I deployed it with 2 counterpoise wires spaced 180° apart (N/S). I have heard over 130 countries on FT-8 in 1 week using the homebrew vertical shown above.
I think it works.

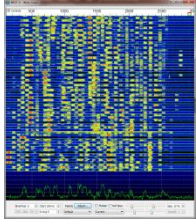
Comments



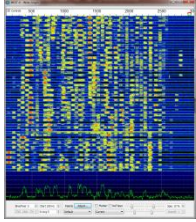
- I was surprised by the fairly large differences on the individual reports at the same time from the two hardware & software systems. I observed differences as high as ±10 dB and the standard deviation of the difference was about 2.5 dB which was higher than I expected.
- There is room for improvement in the comparison approach.
  - Hardware
    - Make sure transmission line losses are not impacting the results.
    - Use the exact same time standard for both decoding programs. As it was, the time difference could be 0.1-0.2 seconds. Time difference estimates are in the files.
  - Software
    - Run 2 instances of the software on a single computer.
    - Determine the reason for the fairly large differences found in individual reports.
    - Understand the SNR estimation process in WSJT-X better.

References

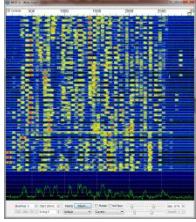
(Valid as of June 8, 2018)



- FT8
  - http://www.arrl.org/news/ft8-mode-is-latest-bright-shiny-object-in-amateur-radio-digital-world
  - Barry Feierman, K3EUI, "Join the FT8 Revolution", QST, January 2018, pp. 41-44
  - http://www.physics.princeton.edu/pulsar/K1JT/FT8_Operating_Tips.pdf
  - http://www.physics.princeton.edu/pulsar/K1JT/wsjtx-doc/wsjtx-main-1.9.1.html
- WSJT-X Software
  - Joe Taylor, K1JT, Steve Franke, K9AN, and Bill Sommerville, G4WJS, "Work the World with WSJT-X, Part 1: Operating Capabilities", QST, October 2017, pp. 30-36.
  - Joe Taylor, K1JT, Steve Franke, K9AN, and Bill Sommerville, G4WJS, "Work the World with WSJT-X, Part 2: Codes, Modes, and Cooperative Software Development", QST, November 2017, pp. 34-39.
- Computer Timekeeping Software
  - Dimension 4: http://www.thinkman.com/dimension4/download.htm
  - Meinberg NTP: https://www.meinbergglobal.com/english/sw/ or http://www.satsignal.eu/ntp/setup.html



BACKUP SLIDES



Hex Beam Example Data

Collected on 5/26/2018

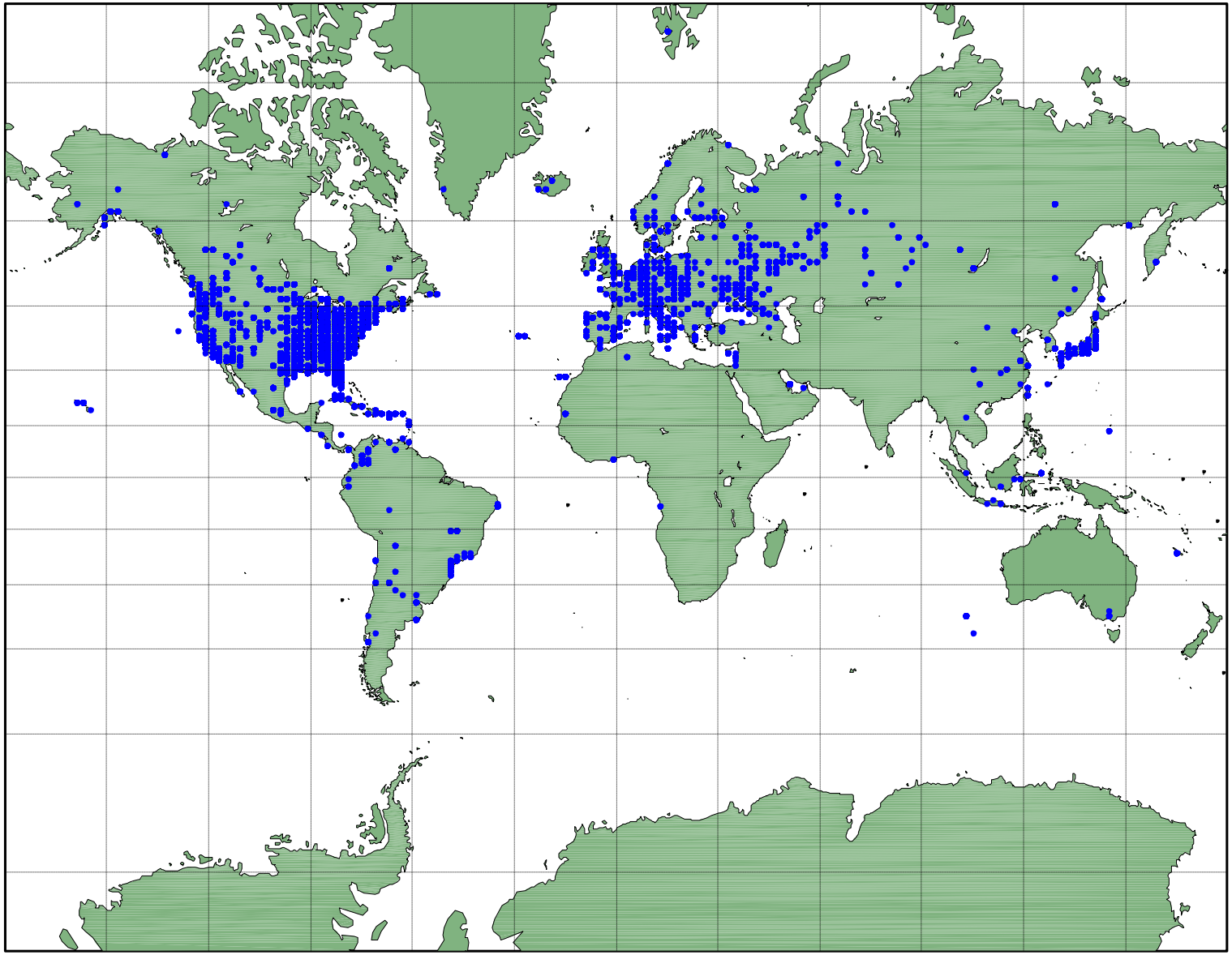
Start Time was 1524 UTC on 5/26

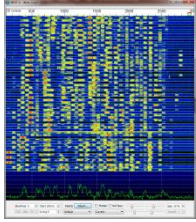
End time was 2304 UTC on 5/27

Total collection time was 31:40

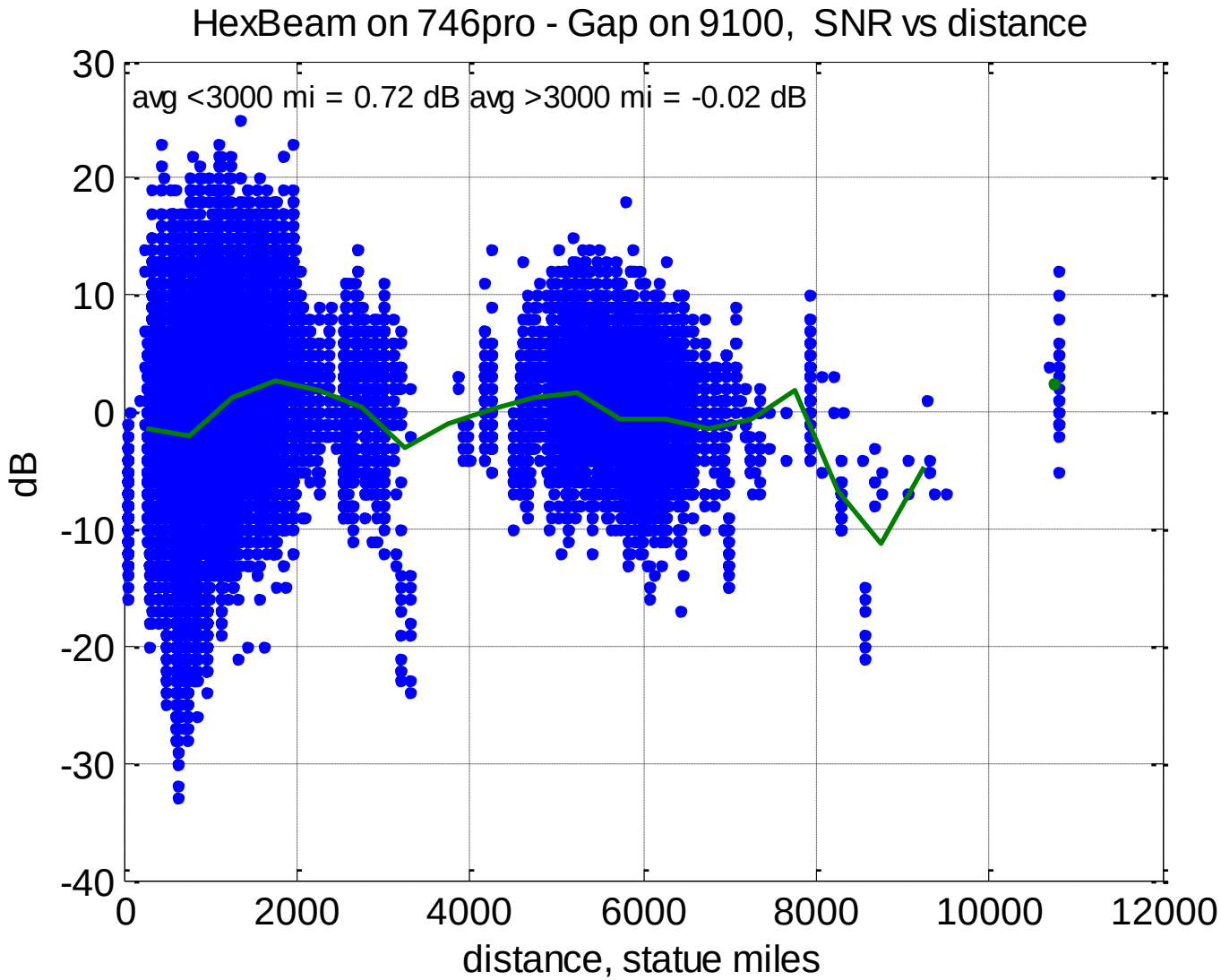
Hex Beam and Gap Vertical

Transmitter Locations for Hex Beam Test



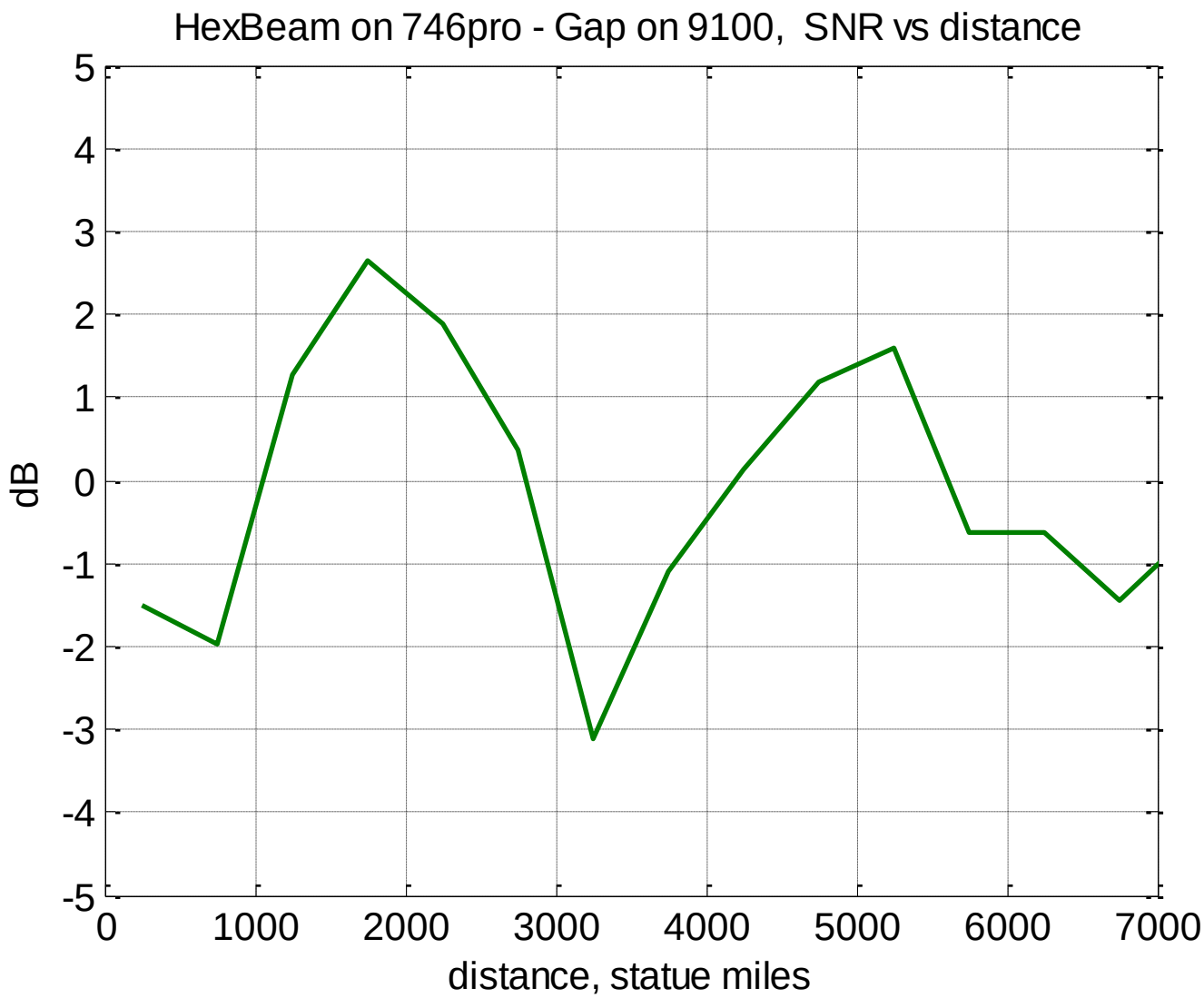


Range Plot for Hex Beam

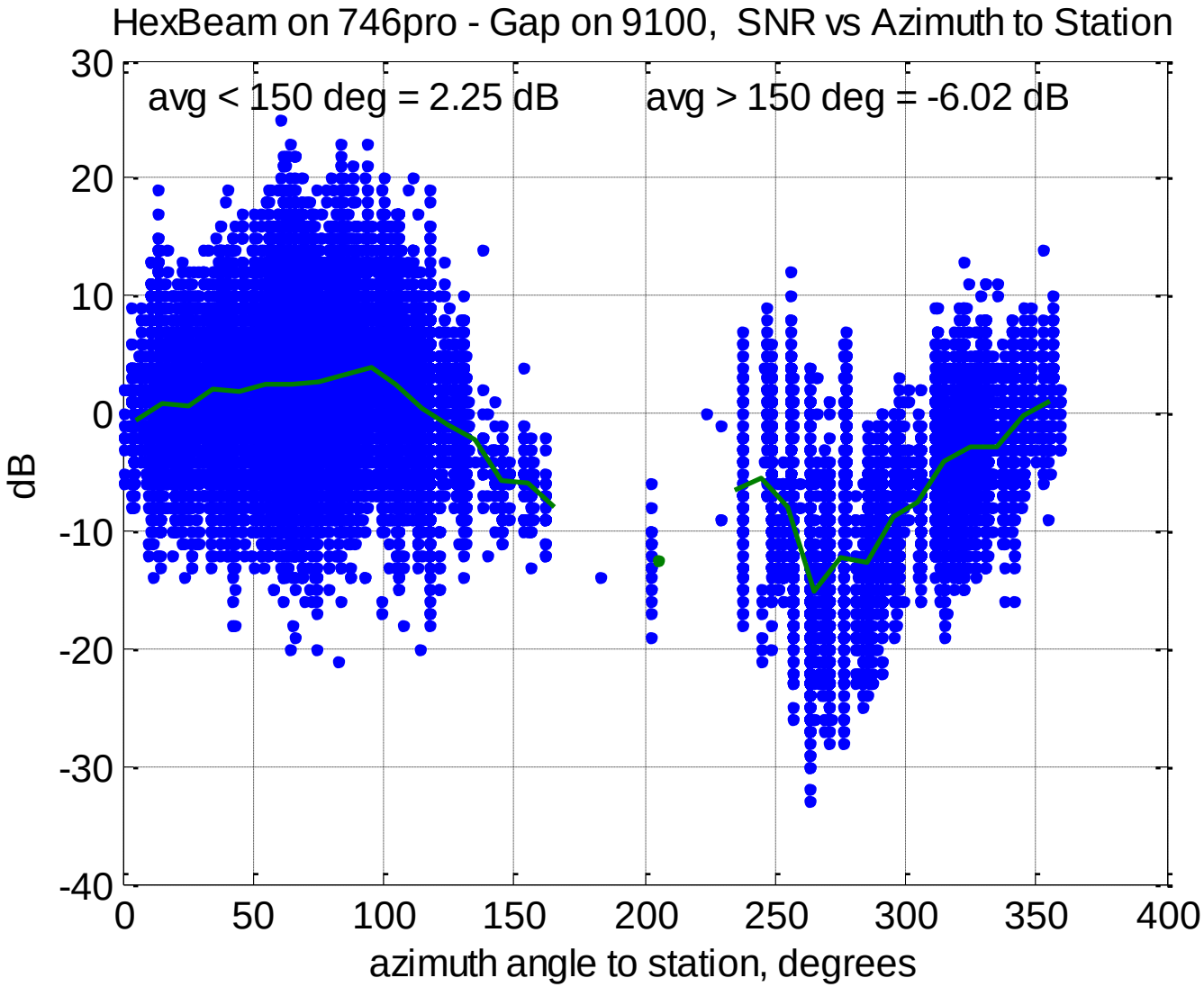


Positive numbers indicate the Hex Beam antenna has higher SNR.
Negative numbers indicate the Gap antenna has higher SNR.

Range Comparison Plot Expanded

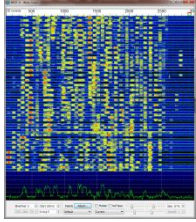


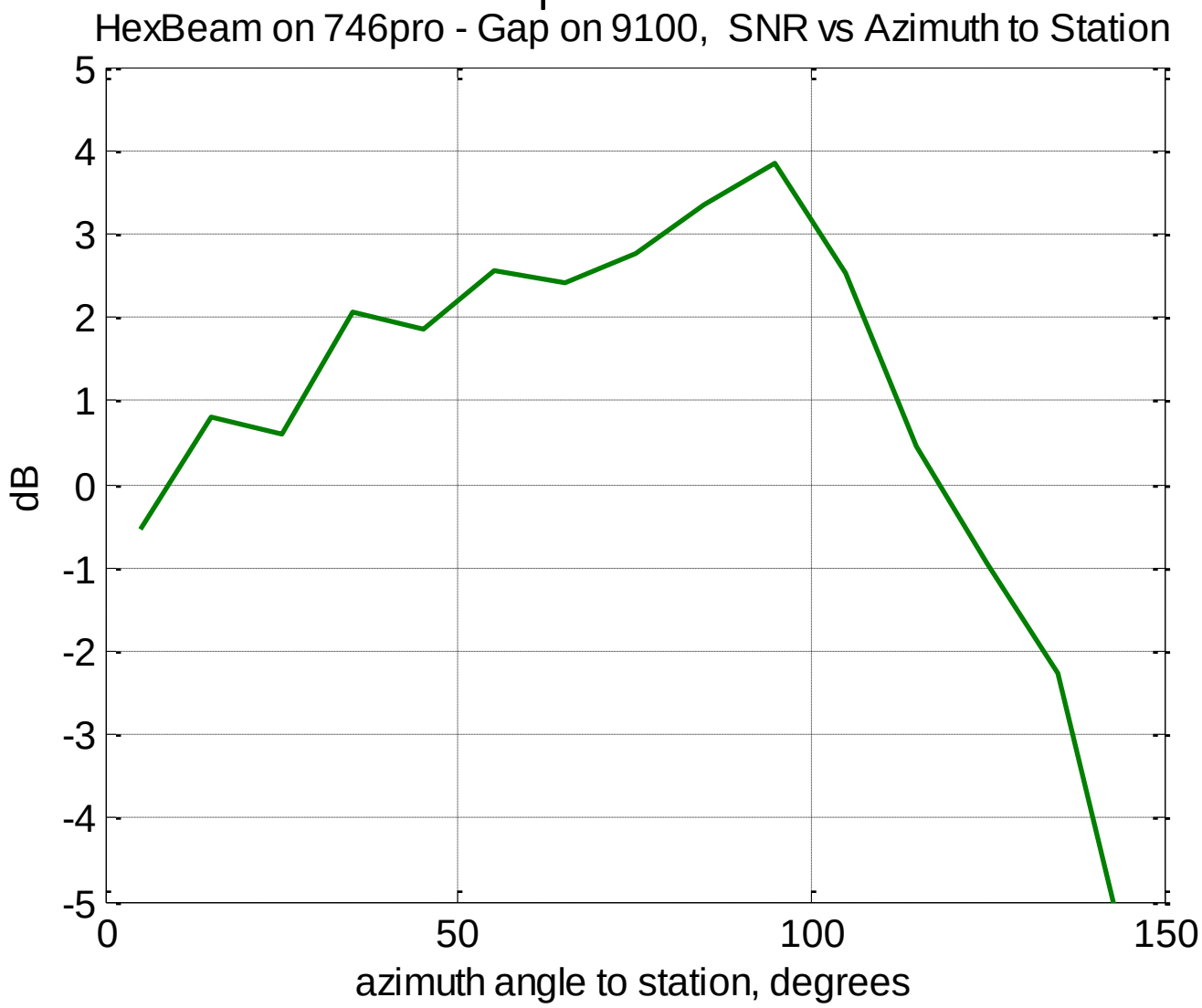
Azimuth Plot for Hex Beam



Positive numbers indicate the Hex Beam antenna has higher SNR.
Negative numbers indicate the Gap antenna has higher SNR.

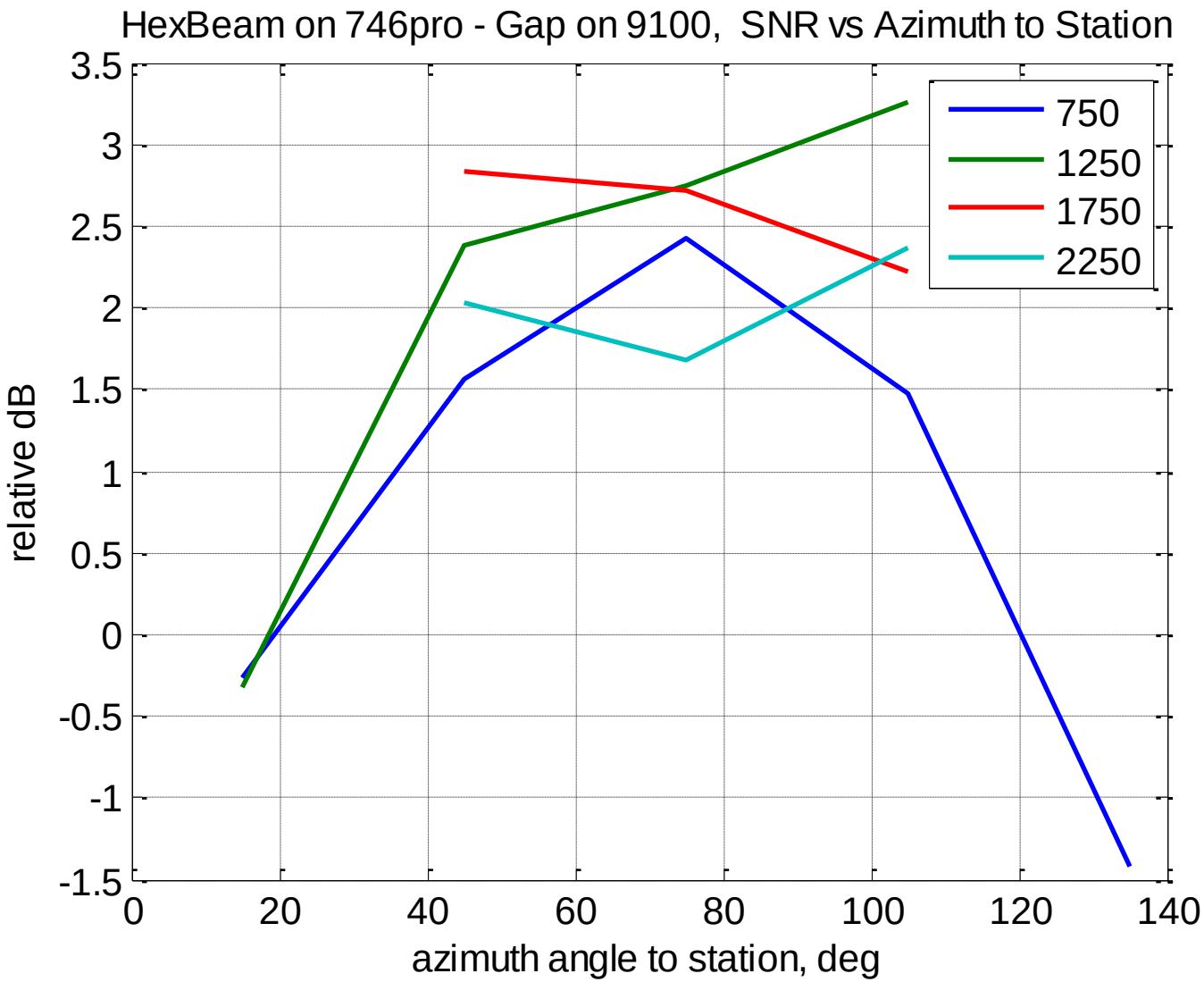
Azimuth Comparison Plot for Hex Beam Expanded





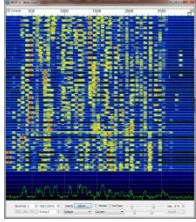
Positive numbers indicate the Hex Beam antenna has higher SNR.
Negative numbers indicate the Gap antenna has higher SNR.

Azimuth Angle Plots at Ranges



Required a minimum of 30 reports at a given range (500 nm group of ranges) and azimuth (10° set of azimuth angles)

Example 15-Second Interval for Comparison



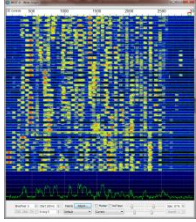
From Gap Antenna on IC9100

152100	9	0.1	500	~	G4VJI KC9OFJ EM57
152100	-11	0.2	578	~	CQ K9IG EM69
152100	-12	0.1	813	~	N1RKT K5TEE DM65
152100	-6	0.1	974	~	LZ2II K0TJF EM73
152100	6	0.1	1225	~	K3KO KY7LE CN86
152100	-19	1.9	1346	~	N8NVI DL6ON JO52
152100	-17	0.3	1442	~	CQ DF2KD JO30
152100	0	0.1	1519	~	R3FO PD8DX RR73
152100	-24	0.2	1693	~	OH4NDU G4KCM 73
152100	3	0.1	1884	~	KD7VZW N9LIS -16
152100	-14	0.4	1961	~	CQ NM PA3GPS JO31
152100	-5	0.1	2010	~	TA1BX KC4LGM EM83
152100	0	1.8	2242	~	SP8BJU K4BWG R-03
152100	-5	0.1	2349	~	DL6ON KD8JV -15
152100	5	1.0	2783	~	WB0UNB/IMAGE
152100	-4	-0.2	1558	~	WF4W SP7TF -16
152100	-17	0.1	2165	~	LZ2II WA1FXK FN23
152100	-20	0.1	1550	~	K5TEE KD2NOM -03

From Homebrew Antenna on IC746PRO

152100	14	0.1	519	~	G4VJI KC9OFJ EM57
152100	-8	0.2	598	~	CQ K9IG EM69
152100	-16	0.1	832	~	N1RKT K5TEE DM65
152100	1	0.1	994	~	LZ2II K0TJF EM73
152100	-11	0.2	1189	~	VA3TTB PA5DX -12
152100	2	0.1	1244	~	K3KO KY7LE CN86
152100	-17	1.9	1365	~	N8NVI DL6ON JO52
152100	-15	0.3	1462	~	CQ DF2KD JO30
152100	2	0.1	1539	~	R3FO PD8DX RR73
152100	-24	0.2	1713	~	OH4NDU G4KCM 73
152100	8	0.1	1903	~	KD7VZW N9LIS -16
152100	-12	0.4	1981	~	CQ NM PA3GPS JO31
152100	3	0.1	2030	~	TA1BX KC4LGM EM83
152100	6	1.8	2262	~	SP8BJU K4BWG R-03
152100	-1	0.1	2368	~	DL6ON KD8JV -15
152100	8	1.0	2803	~	WB0UNB/IMAGE
152100	-13	0.1	1194	~	CQ F5SSQ JN06
152100	-13	2.0	1253	~	SP1TJ W2RES FM29
152100	0	-0.2	1578	~	WF4W SP7TF -16
152100	-22	0.6	2529	~	C8X PA3DJY JO22
152100	-17	0.0	1185	~	CQ SP1KRF JO72
152100	-16	0.1	1569	~	K5TEE KD2NOM -03

Understanding Other Reception Reports



- Let's take a look at the first report:
  - `233615 -19  0.1  202 ~  2M0RDK KI7GZY DM41`
  - 233615 is the UTC time at the beginning of the reception.
  - -19 is the SNR estimate for this signal.
  - 0.1 is the time difference between my clock and the signal received, in seconds.
  - 202 is the audio frequency of the signal, in HZ.
  - 2M0RDK is the station receiving (the "TO" station.)
  - KI7GZY is the station transmitting (the "FROM" station.)
  - DM41 is the 4-digit grid locator of KI7GZY, the station transmitting.
- Let's take a look at the second report.
  - `233615 -19  0.1  515 ~  DL5OBY AA3B -18`
  - 233615 is the UTC time at the beginning of the reception
  - -19 is the SNR estimate for this signal, in dB
  - 0.1 is the time difference between my clock and the signal received, in seconds.
  - 515 is the audio frequency of the signal, in HZ.
  - DL5OBY is the receiving station (the "TO" station.)
  - AA3B is the transmitting station (the "FROM" station.)
  - -18 is the SNR report in dB from AA3B for the signal sent by DL5OBY.
  - Notice that no location information for either station is present in this transmission.