UNAVCO GNSS RFP Evaluation Report

Public Version: September 22, 2105
Originally submitted in confidence: May 18, 2015

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Introduction

On March 2nd, 2015, UNAVCO issued a formal Request for Proposals (RFP) to the manufacturers of high-precision GNSS hardware for the purpose of selecting a Preferred Vendor, who would provide equipment to UNAVCO and its community. An evaluation committee, convened by UNAVCO's Director of Geodetic Infrastructure and chaired by the Development and Testing Group's Project manager was convened for the purposes of defining the criteria for vendor selection, testing the hardware in detail over a six-week period, and making a recommendation to UNAVCO's Senior Management Team, who will make the final selection.

UNAVCO received three responses to the RFP. Septentrio Inc. proposed the use of the PolaRx receiver series, which is slated for an update in the fourth quarter of 2015 (with the option to purchase existing hardware in the interim), Manufacturer X offered the newly released "Receiver X", while Manufacturer Y has offered us "Receiver Y".

Following the initial receipt of the proposals, the evaluation committee met with representatives of each respondent, who then amended their proposals with clarifications and answers to questions posed by the committee. Each respondent delivered prototypes, which were subject to extensive testing by the Development and Testing staff, and were scored according to the technical criteria specified in the RFP. These scores were combined with those of other factors: Unit Price, Vendor Experience, Vendor Technical Support Staffing, Vendor's Ability to Adapt to New Technology, and Estimated Additional Costs and Savings, using weighting factors agreed upon by the committee. This report details the detailed testing and technical evaluation of the hardware.

Testing

In the following sub-sections we present the results from our testing that can not be presented effectively in the receiver evaluation table.

RF Interference Susceptibility

Radio Frequency (RF) interference, whether due to low-power near-band transmissions such as those from Iridium or BGAN data communication devices or high-power signals from commercial cellular towers, has been an increasingly prevalent issue at many UNAVCO GNSS stations. As new-generation broadband antennas designed to receive GNSS signals allow far more near-band signal to reach receivers than the older models designed specifically for dual-frequency GPS, so the ability of GNSS receivers to mitigate their effects is a critical factor in the selection of the model for use in UNAVCO's networks in the future. Iridium data communications devices utilize the frequency band closest to that of L1 GNSS, and its effects have been a problem at UNAVCO's Polar sites as GNSS upgrades have been performed. UNAVCO's Development and Testing group is very familiar with the issue, having performed tests and devised a cavity filter solution now in widespread use. As it is not possible to test all possible real-world RF interference scenarios in a limited time-frame, we have used the Iridium frequency as the best way to characterize the general RF interference susceptibility of our RFP respondent's receivers.

In our RF interference testing we employed a signal generator with a transmitting antenna placed within 1m of the test GPS antenna phase center at an elevation angle of ~20 degrees. An amplified 8-port GPS signal splitter was used to supply all receivers with a common input from the Trimble choke-ring (TRM59800.00) test antenna. We connected a spectrum analyzer to a free splitter port to monitor the signal during the test. A 1616 Mhz signal (low end of Iridium) was transmitted with a gain from -70 to -20 dB in 5 dB steps at 2 min intervals. The total length of the test was 24 minutes.

Figures 1 and 2 show the response of the Receiver Y's L1 and L2 SNR (signal-to-noise) observations to varying signal strength. Figure 3 shows the variation of the mean L1 and L2 SNR observables for all tracked satellites. Figures 4-9 show the response for the other receivers. For this experiment, we enabled interference mitigation on the PolaRx receiver.

Observations:

1) Of the 3 receivers tested the results show the Receiver Y receiver to be the most sensitive to interference at the 1616 MHz frequency. SNR values for both L1 and L2 start to decrease significantly when the interference reaches -65 dB and continues to decrease as the interference signal increases. At -35dB the receiver stops tracking all satellites. The other 2 receivers continued to record SNR observations for the majority of the visible satellites for all tested interference signal strengths.

2) Using a spectrum analyzer on the monitor port it was observed that at about -35 dB the low noise amplifier (LNA) in the antenna became saturated by the 1616 MHz signal and the LNA gain became flat as signal strength increased. Despite the reduced signal-to-noise of L1 and L2 due to this saturation, the Septentrio and Receiver X continued to track nominally.
3) The Spectrum View feature of the PolaRx receiver clearly displays the frequency and amplitude of the interfering signal. Configuration of a notch filter to mitigate the interference was well documented and the effect of the filter was visible in the control software. The spectrum view feature can help users to rapidly identify sources of RF noise and mitigate them using the built in mitigation tools.

Occurrences of Interference Are Increasing

Currently the number of known sites that experience interference issues is a small percentage of the total number of sites in UNAVCO's network. For example, of the 70 sites in PBO Southwest that are now fully GNSS capable (Trimble NetR9 + GNSS antenna), at least 4 (5.7%; P471, P612, CASE, LGWD) seem to be significantly affected by RF interference, leading to poor data qc and incomplete data sets. However, as the demand for spectrum in the US and abroad increases, RF interference will continue to impinge on the lower power GNSS spectrums. For polar applications where Iridium must be collocated with GNSS stations, engineers must plan to mitigate the interference at every site where NetR9 receivers are installed. In remote field campaigns investigators often utilize satellite phones and unknowingly reduce the quality of their data by placing calls within 500 m of logging NetR9 stations.

Identifying Interference is Difficult

It is often difficult to identify the source of the degraded data quality. Identification of RF problems typically requires field personnel to visit a suspect site and employ the use of a spectrum analyzer. Additionally, RF interference can be intermittent and can require a field engineer to make 24 hour or longer measurements to identify an offending signal.

Interference Can Be Mitigated Outside the Receiver But the Solution is Imperfect

The D&T group has developed a cavity filter to be placed inline between the antenna and receiver to mitigate Iridium interference. The filter solution, however, does not adequately protect GLONASS signals, as the GLONASS L1 center frequency is much closer to Iridium (1616 MHz) than that of GPS L1. We are certain that we will have sites where sources of interference will be in frequency bands other than Iridium. Those sites will require identification of the offending noise source and development of a custom filter for mitigation. We have already observed data quality issues that we believe to be the result of interference at COCONet sites equipped with BGAN terminals.

The Impact of Interference Depends on the Application

The impact of intermittent interference on positioning products depends on the frequency and duration of the offending transmissions. For daily processing, data editing will typically exclude any arcs with less than a specified amount of continuous slip free observations. If interruptions in tracking occur more than a few times per day then daily position accuracy will begin to suffer. Tracking interruptions due to interference have a much stronger effect on kinematic processing and can make ambiguity resolution difficult or impossible if too many interruptions occur during the processed time interval. The greatest impact however is on real-time PPP algorithms. If a tracking interruption occurs on all visible satellites then the PPP solution must reconverge, which can take ~10-30 mins. If a dynamic ground event occurs during that time, observations will be lost.

Signal-to-Noise Quality

Due to the computational complexity of SNR estimation inside a receiver (the SNR estimation algorithms used by the manufacturers are unknown) and the complex relationship between SNR and multipath, we did not have time to develop a comprehensive test method for characterizing SNR performance in GNSS reflectometry applications during this evaluation period. In this section we compare the signal-to-noise (SNR) resolution and amplitude of the observations to roughly characterize the SNR performance of each receiver. We find that the largest difference between the proposed receivers is in the SNR output resolution.

SNR Resolution

	Septentrio PolaRx	Receiver X	Receiver Y
Resolution (C/No)	¼ (verified), 1/32 (promised in future FW update)	1/16 (verified)	1/10 (verified)

Both the Receiver X and Receiver Y meet the minimum resolution of 1/10 C/No (carrier-to-noise ratio in dB-Hz) specified in the requirements. As tested, the PolaRx output a resolution of ¼ C/No, which does not meet our minimum resolution requirement of 1/10 C/No. Septentrio has stated, however, that the final version of the PolaRx will output signal-to-noise measurements with 1/32 C/No resolution. Once implemented, the PolaRx will have the highest resolution of the three receivers tested.

The most significant qualitative difference observed in signal-to-noise data quality between receivers was the S1 observation recorded by Receiver Y. When differencing the S1 observations from Receiver Y with the observations recorded by other tested receivers we see an increase in the noise of the signal-to-noise curve. We propose that this is the result of receiver Y's limitation of tracking only the C/A code on L1. The other receivers track both C/A and P1 codes on the L1 frequency, which may produce better SNR data.

The general character of each receiver's signal-to-noise observations is shown in figures 10, 11, 12, 13. A more detailed analysis of the ascending GPS PRN09 is shown in figures 23 and 24 as an example of multipath caused by horizontal planar reflection. In our analysis of L2C data from Receiver X we incorrectly plotted the L2 SNR because the logged files did not contain any L2C SNR data. We were not able to determine the correct configuration required for Receiver X to output L2C SNR data during our evaluation period. Please ignore the L2C results shown in figure 12.

The maximum signal-to-noise sampling rate for the PolaRx and Receiver X is equivalent to their maximum logging rate. The maximum signal-to-noise sampling rate for Receiver Y is limited to 10Hz; thus, observations output at 50Hz will have SNR data reported at 10Hz. This would likely only affect users who utilize SNR for ionospheric scintillation studies.

Kinematic Processing

We processed 30 second data from each receiver using MIT's Track kinematic processing software. Track was configured to use the L1+L2 mode (L1 and L2 are processed separately) for all processing. An equivalent LC analysis would have a factor of 3 more noise from the linear combination of L1 and L2. We did not estimate tropospheric delay. All receivers shared the same antenna (TRM59800.00 NONE) via an 8-way GPS Source splitter. A Trimble NetR9 receiver (DEVT) was used as the reference site, creating a zero-length baseline. Time series are shown in figures 14, 16, and 18. Figures 15, 17, and 19 show their respective normalized histograms. In a zero-length baseline most noise sources (orbits, receiver clocks, satellite clocks, tropo, ionosphere, multipath) should cancel out in the double difference. The remaining noise should primarily reflect the combined internal tracking noise of the reference and kinematic receivers. In this test we observed the lowest noise in the PolaRx time series. Receiver X produced the highest noise.

Time Series Results

	Septentrio PolaRx	Receiver X	Receiver Y
North std. dev. (mm)	1.25	1.64	1.26
East std. dev. (mm)	0.91	1.25	0.95
Up std. dev. (mm)	2.47	3.33	2.64

We noticed a subtle periodic signal in the PolaRx time series. To better determine the source of this signal we reprocessed the PolaRx data using another PolaRx test receiver as reference. The results are shown in Figure 20. The standard deviation of all components decreased significantly and the periodic noise was no longer present in the time series. We suspect this periodic signal is the result of how the receivers from different manufacturers treat multipath noise in their tracking algorithms. We can demonstrate that they are different, but we cannot distinguish which receiver's tracking performance is superior.

Daily Processing

We processed four days of 30 second data from each receiver with both GIPSY-OASIS (6.3) and GAMIT/GLOBK (10.5) software packages. We used IGS rapid orbit and clock products for the GAMIT processing as final products were not yet available. We used the flinnR_nf orbit and clock products for GIPSY-OASIS processing and applied an elevation cutoff angle of 7 degrees. A 10 degree elevation cutoff was used for all processing with GAMIT. The receivers shared the same TRM59800.00 antenna via an 8-way amplified GPS Source GNSS splitter. The processing ran with no complications for all of the receivers tested.

The GIPSY phase residuals, receiver clock bias and wet troposphere delay for each receiver are shown in figures 28, 29, 30, 31, 32, and 33. We observe similar character in the phase residuals and wet delay for each receiver. All three receivers were configured with clock steering enabled. We observe a slight negative bias in the clock bias results from Receiver Y. The Septentrio results exhibit the lowest variance. The Receiver X results show the most clock bias variance. The Septentrio clock bias results seem to exhibit higher frequency noise. We suspect that the variation of these clock noise characteristics between receivers is likely due to different steering algorithms implemented or possibly the quality of the onboard oscillator.

The GAMIT phase residual results for each receiver are shown in figures 34, 35, 36, 37, 38, and 39. We see no significant surprises in the quality of the processed results. The phase residual RMS for the PolaRx was lowest at 4.9 mm. Receiver Y had the highest RMS at 5.3 mm. All of these values would be considered acceptable when processing a regional network.

GAMIT Phase Residual RMS

	Phase Residual RMS (mm)
Septentrio PolaRx	4.9
Receiver X	5.1
Receiver Y	5.3

Data Quality

We utilized Teqc's Quality Control (QC) function to analyze the data quality logged by the test instruments. 4 daily files of 30 second each were processed from each receiver. Receivers were configured to track all available signals and satellites. RINEX translations and data QC's were performed with a development version of Teqc. For this evaluation, it was necessary for Dr. Lou Estey to add capabilities to Teqc for decoding several new Manufacturer X and Septentrio messages that contain data for non-GPS constellations. The three following tables show a few key QC parameters for: 1) all tracked constellations, 2) the GPS constellation, 3) and the GLONASS constellation. A default elevation cutoff of 10 degrees was used for all QC processing.

All Constellations*

	Septentrio PolaRx	Receiver X	Receiver Y
Expected Observations	200427	200521	200255
Observations Found	198254	198305	199226
Percent Complete	98.92%	98.89%	99.49%
IOD Slips > 10.0 deg	1	3	12
IOD & MP Slips > 10.0 deg	3	10	18
Observations per slip (spec requires >20,000)	66085	19831 (does not meet requirement)	11068 (does not meet requirement)
Mean S1	46.80 (sd=4.31 n=242852)	47.00 (sd=4.60 n=244168)	45.74 (sd=4.38 n=237556)
Mean S2	41.26 (sd=7.34 n=180235)	38.76 (sd=8.36 n=182702)	40.48 (sd=7.70 n=180254)
Mean S5	48.22 (sd=4.72 in=46617)	48.22 (sd=5.39 n=45855)	48.96 (sd=3.87 n=75139)
Mean S6	46.80 (sd=5.36 n=16392)	44.29 (sd=4.86 n=9836)	N/A
Mean S7	48.30 (sd=5.17 n=25004)	47.30 (sd=6.04 n=24315)	47.20 (sd=4.45 n=18972)
Mean S8	49.57 (sd=5.19 n=16401)	29.65 (sd=21.54 n=12804)	52.19 (sd=4.59 n=10367)

* Some values do not include all constellations. Teqc does not currently support predicted orbits for Galileo or Beidou. Those constellations are excluded from the slip count for elevations >10 degrees and observations per slip.

GPS Only

	Septentrio PolaRx	Receiver X	Receiver Y
Expected Observations	101156	101156	101156
Observations Found	101156	100956	100946
Percent Complete	100%	99.80%	99.79%
IOD Slips > 10.0 deg	1	2	3

IOD & MP Slips > 10.0 deg	2	1	5
Observations per slip (spec requires >20,000)	50578	50478	20189
Mean S1	46.40 (sd=4.54 n=101157)	46.40 (sd=4.72 n=103609)	46.25 (sd=4.67 n=100951)
Mean S2	39.04 (sd=8.20 n=101156)	34.98 (sd=8.46 n=103588)	39.13 (sd=9.08 n=100946)
Mean S5	49.39 (sd=4.05 n=30220)	34.98 (sd=8.46 n=103588)	50.94 (sd=3.94 n=30217)

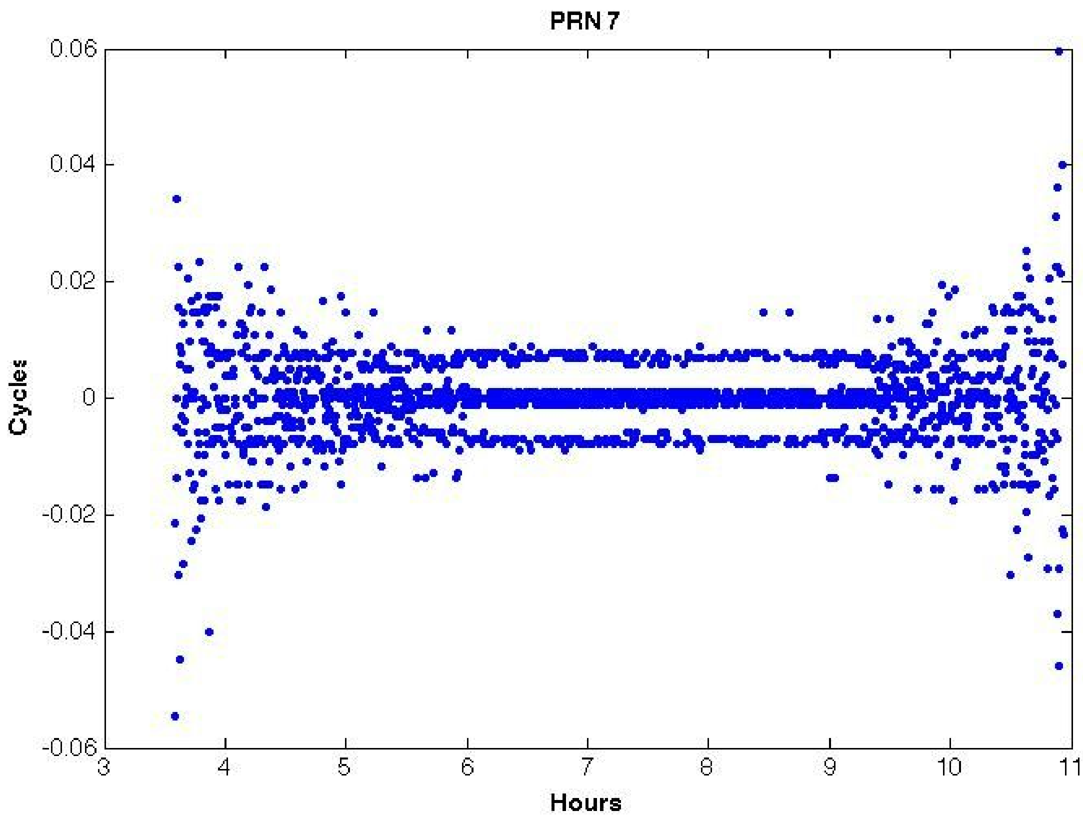
GLONASS ONLY

	Septentrio PolaRx	Receiver X	Receiver Y
Expected Observations	79175	79226	78960
Observations Found	77995	77987	78181
Percent Complete	98.51%	98.44%	99.01%
IOD Slips > 10.0 deg	1	1	9
IOD & MP Slips > 10.0 deg	1	4	13
Observations per slip (spec requires >20,000)	77995	19497 (does not meet requirement)	6014 (does not meet requirement)
Mean S1	47.58 (sd=4.36 n=79362)	48.27 (sd=4.83 n=79367)	45.13 (sd=4.58 n=79538)
Mean S2	44.07 (sd=4.75 n=79377)	43.70 (sd=4.94 n=79362)	42.17 (sd=4.97 n=79525)

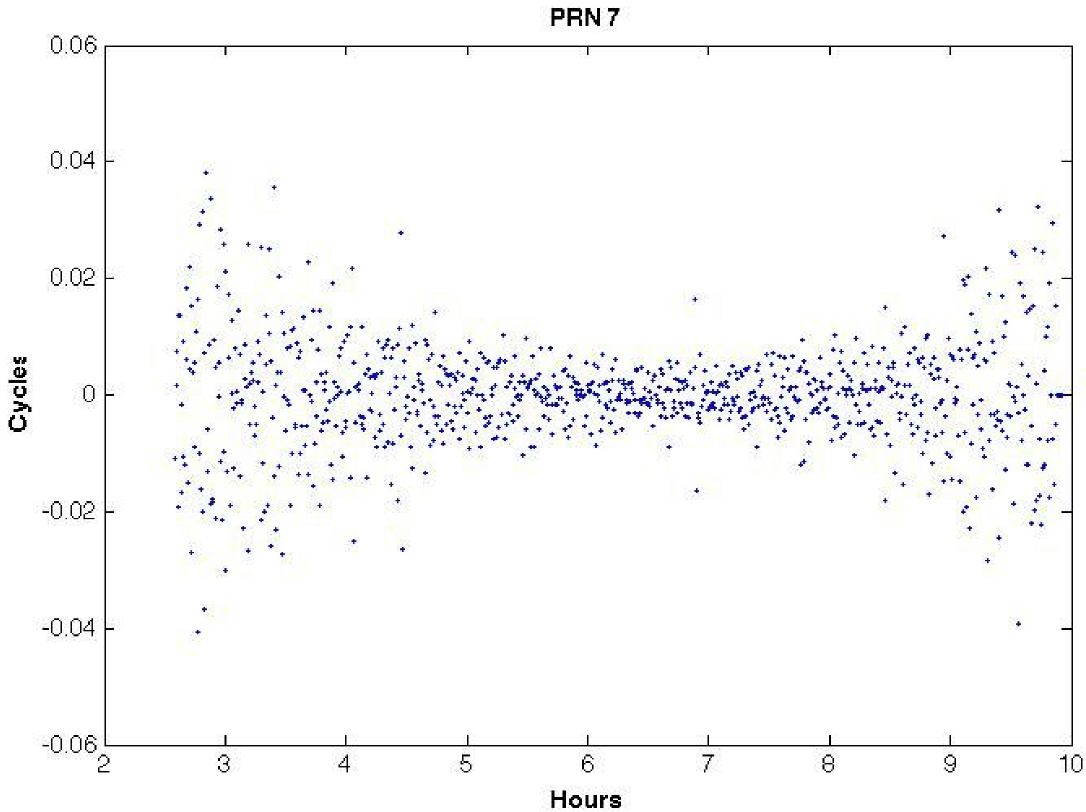
All receivers logged more than the required 99% of expected observables for GPS, and more than 98% for the remaining constellations. We observed the fewest number of detected slips in data obtained from the PolaRx receiver. Receiver Y recorded the highest number of detected slips over the course of 4 days. Figures 25, 26, and 27 show sky plots of where Melbourne-Wubbena slips were detected. For satellite elevations >10 degrees the results are very similar for all receivers tested. Receiver Y shows visibly more slips below 10 degrees in elevation. Interpretation of these results is difficult because Receiver Y may be tracking satellites to lower elevation angles and therefore record more slips. Receiver Y logged more total observations than the PolaRx and Receiver X logged over the same period. Neither Receiver X nor Receiver Y meet the required 20,000 observations per slip requirement of the RFP for all constellations; however, both instruments exceed that requirement when tracking GPS only.

Carrier Phase Tracking Noise

To evaluate carrier phase noise we computed the time derivative of the difference between the L2 and L2C carrier phase measurements. The L2 and L2C phases should be nearly identical except for the addition of internal intra-channel tracking noise in each receiver. We observed a fine banding pattern in each receiver tested. The minimum difference between each band demonstrates the minimum phase resolution written to the raw data files, which is much lower than the 0.001 cycle resolution contained in RINEX 2. This analysis was performed using a translation of raw data using extended resolution on the phase values beyond the usual 0.001 cycle resolution available in RINEX 2 observation format. The following figure shows the results from Receiver Y while it was tracking PRN7.



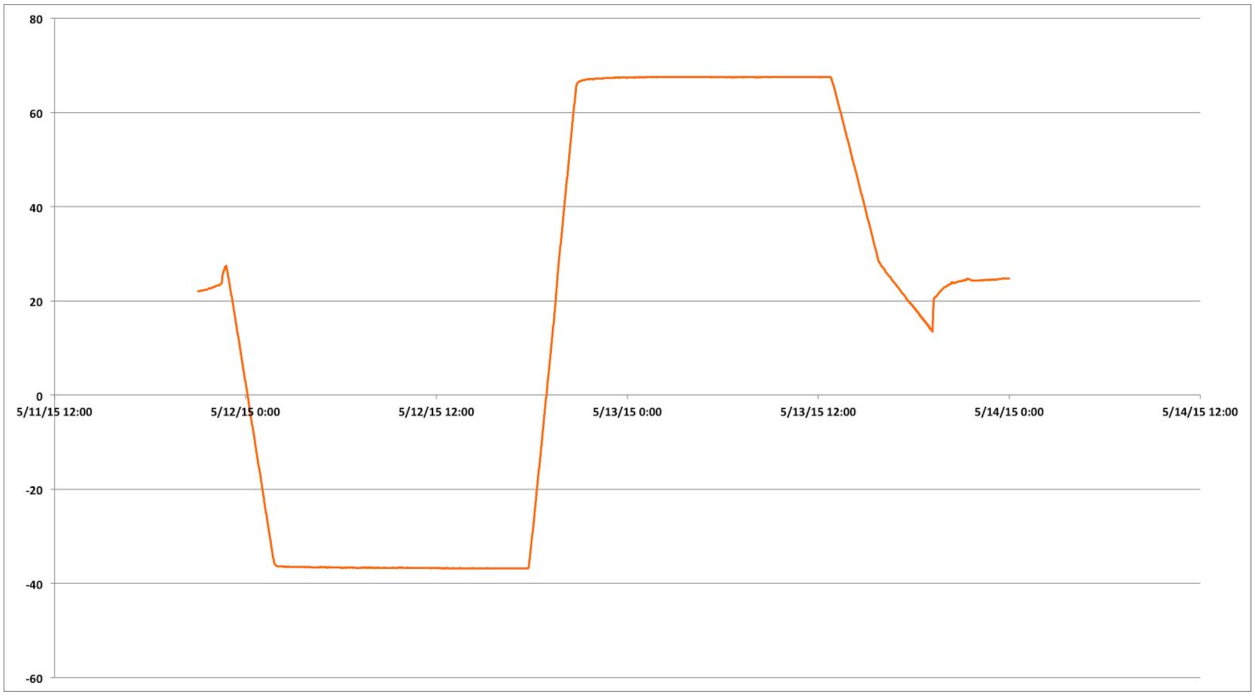
The increased noise as the satellite rises (hours 3.5 to 6) and sets (hours 9 to 11) is expected as tracking noise should increase as SNR decreases. However, we cannot explain why there is a courser banding, a trimodal like distribution, between the hours of 6 and 9 (all times relative to UTC midnight). We do not observe this behavior in other receiver types. For example, the figure below shows the same analysis for PRN 7 as tracked by a Septentrio PolaRx receiver. We interpret the banding as proof that the L2 and L2C tracking channels on Receiver Y are not fully independent. How this behavior would affect positioning or other geodetic applications is unknown. We suspect that the tracking algorithm used in Receiver Y is significantly different than what is employed by other manufactures.



Temperature Testing

Setup

The Septentrio PolaRx, Receiver X, and Receiver Y were placed in an environmental chamber. All receivers were connected to power, a gps signal splitter, and configured to track and log data. The chamber was configured to ramp down to -40 °C over 3 hrs, soak at -40 °C for 16 hrs, ramp up over 3 hrs to 65 °C, soak at 65 °C for 16 hrs, then ramp back down to room temperature, as shown in the figure below.



Manufacturer Specifications

Septentrio: specified a guaranteed operating temperature range of -40 to 60°C. Tests showed that the receiver continues to operate at 75°C but it may have a reduced lifetime if operated a long time at this temperature.

Manufacturer X:
Specified operating range -20°C to 61°C with battery and -40°C to 61°C without battery. Tests performed on power port 2.

Manufacturer Y:
Specified operating range -40°C to 65°C.

Results

Septentrio:
Ran OK, no gaps in QCed data. Receiver was not tested to full 75°C temperature specification.

Manufacturer X:
Appears to have shut off about 8 hrs into the -40°C soak stage. Once the unit was at room temperature it needed to be re-powered by pressing front panel power button. Gaps were observed in QCed data during this shutdown period.

Manufacturer Y:

Ran OK, no gaps in QC'd data. Receiver reported operation at high temperature and low temperature on display.

Power Consumption Tests

Setup and Manufacturer notes
Each vendor provided a table with power consumption measurements for a number of specific operating configurations. Vendor responses are shown in tables 1, 2 and 3. The values provided by the vendors were spot checked as best as possible with the provided hardware. These values have been added to the manufacture provided tables and are shown in ( ).

Septentrio:
The PolaRx receiver meets or exceeds our power draw requirement of <5 W in all configurations tested.

Manufacturer Y:
Receiver Y receiver meets power requirement for all configurations tested as long as all battery functions are disabled.

Manufacturer X:
Power port 2 was used for testing to eliminate battery charging load. When power is removed from this port the receiver will stay powered running on internal batteries. Once the internal batteries are dead the receiver will power off. Restoring power on port 2 will not charge the batteries so if power is is only applied to port 2 the batteries will remain dead. The receiver will not turn on when power is applied to the power ports; the power button must be pressed. The receiver defaults to power port 1 and will not switch to port 2 if it has the higher voltage. Charging will take place on port 1 whether the receiver is turned on or off and can draw up to 40 W. Minimum power observed on port 2 was above 5 W.

Receiver X does not meet our power draw requirement for any tested configurations.

File Size

	PolaRx	Receiver X	Receiver Y	BINEX
raw	~117 MB	~91 MB	~34 MB	~76 MB
compressed	~70 MB	~54 MB	N/A	~50 MB

File sizes were obtained by averaging four daily 1 Hz files downloaded from each receiver. Receivers were connected to a common test antenna through a splitter and configured to track all available signals and satellites. We assume that the quality of the signal to each receiver was equivalent. Receiver Y receiver does not currently track the Galileo L6 signals and may have a slight advantage in this comparison because it does not have to store those values. There are currently only two operational Galileo satellites, so the resulting difference in file size will be relatively small.

Smaller data files provides several benefits to UNAVCO's data flow operations:

- Data communication costs - UNAVCO data plans typically have data caps and if those caps are exceeded then our costs would naturally increase.
- Rapid recovery of files - smaller files will allow faster retrieval of high rate data after an event.
- Increases available onboard data storage - thus increasing the number of days that can be stored onboard the receiver for a given unit of storage capacity.
- Reduced archival costs

Results show Receiver Y file compression outperforms all other file formats in size by a factor of ~2 to 3. However, archival requirements for Manufacturer Y are approximately a factor of 2 greater than Manufacturer X and Septentrio's SBF formats because the GDS program at UNAVCO currently stores additional files for all sites with raw data and stores multiple format files for PBO, COCONet, and TLALOCNet. Thus, Manufacturer Y's format significantly outperforms the other formats for the first three benefits listed above, but lags behind Manufacturer X and Septentrio in archival storage efficiency. If Septentrio and Manufacturer X were to implement ZIP compression of onboard files, then the size advantage of the Manufacturer Y file size would decrease significantly (reduced to about a factor of 2).

The maximum internal memory available for Receiver X, Receiver Y and the PolaRx is 8 GB, 32 GB, 32 GB, respectively. All manufacturer's external storage support is 'work in progress'.

File size would not have an impact on UNAVCO's streaming operations as UNAVCO currently utilizes BINEX streams, which do not vary significantly in size between manufacturer's. Manufacturer Y's streaming format does not share the same compression as its onboard data storage format. The streamed SBF and Manufacturer Y formats are equivalent to their internal memory file formats.

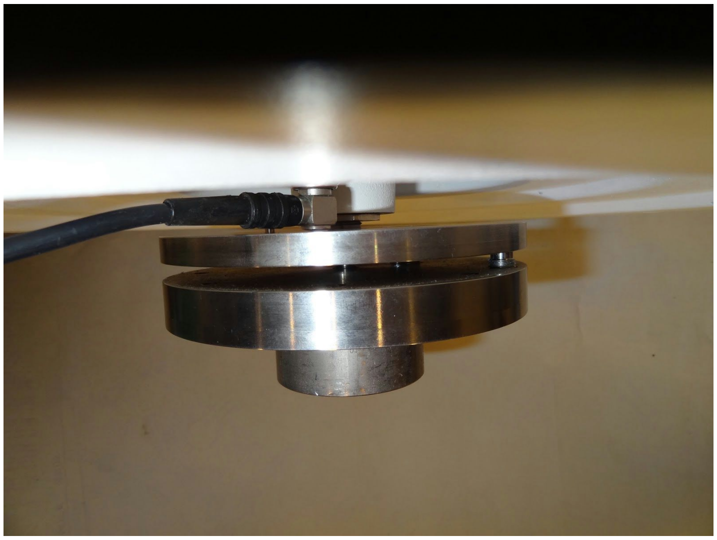
Antenna Compatibility

Septentrio

Septentrio has proposed the *SEPCHOKE_MC -* .

Issues:

1. The SCIGN mount is used at the majority of UNAVCO permanent stations. The antenna connector on this antenna is situated in such a way that the space is very limited between SCIGN mount and antenna. To connect a cable while using this mount a 90º connector is required on a smaller flexible cable and the tolerance is very tight.



2. Not compatible with SCIS dome.
3. Absolute PCV calibrations only exist for SEPCHOKE_MC without a dome (NONE) and with Septentrio's own dome (SPKE). UNAVCO will need absolute calibrations with a SCIT dome before the antenna can be deployed.

UNAVCO has previously tested the performance of this antenna's [susceptibility to site dependent error sources](http://facility.unavco.org/kb/questions/757) (http://facility.unavco.org/kb/questions/757).

Antenna Type	North	East	Up
SEPCHOKE	0.3 +- 0.2 mm	0.2 +- 0.2 mm	-2.7 +- 2.1 mm
Manufacturer X	0.4 +- 0.1 mm	0.0 +- 0.1 mm	2.1 +- 1.3 mm
TRM41249	-0.3 +- 0.2 mm	-0.3 +- 0.2 mm	0.3 +- 2.2 mm
TRM59800	-0.2 +- 0.4 mm	-0.5 +- 0.4 mm	-0.2 +- 3.4 mm
TRM59900	-0.2 +- 0.4 mm	-0.4 +- 0.4 mm	-0.2 +- 3.3 mm
TRM57971	0.5 +- 0.4 mm	0.4 +- 0.4 mm	-2.9 +- 3.2 mm

Horizontal stability while varying the near-field environment was acceptable. Vertical instability was higher than the Trimble TRM59800.00 antenna. The uncertainty in the vertical measurement, however, is much higher.

Manufacturer X
Manufacturer X has provided UNAVCO with pricing for 4 separate antenna models, a choke ring and multipath-mitigation proprietary design, each with and without a cavity filter preceding its LNA for RF interference mitigation.

UNAVCO has experience with Manufacturer X's previous choke ring design. It is compatible with the SCIGN mount and the SCIT and SCIS type domes. The newer choke ring has has similar dimensions and should also be fully compatible with the SCIGN mount and SCIT and SCIS domes. The new proprietary design has a very different form than the traditional choke ring and while it's compatible with the SCIGN mount, it may require the use of it's own dome. The models with a C appended to the IGS antenna type code indicate the addition of a cavity type band-pass filter. We did not have time to test the effectiveness of this filter for mitigating RF interference, but the design seems impressive.

There are no absolute phase center calibrations for the cavity filter equipped antennas. There are a limited set of calibrations for the other models. UNAVCO would need these antennas to be calibrated with SCIT domes before they could be deployed to the field.

Manufacturer Y
Manufacturer Y has provided UNAVCO with pricing for 3 separate antenna options.

D/M Choke Ring
Patch Element Choke Ring
LNA upgrade kit

Manufacturer Y has the advantage in this category as UNAVCO already uses the proposed) antennas in our daily operations. The IGS has absolute calibrations available for most dome configurations used with the D/M choke ring. The antenna is fully compatible with all our current infrastructure needs. Manufacturer Y did have a recall where a capacitor was removed from the LNA to prevent early failure of the L2 LNA. Antenna stability has been good, but we have seen some LNA failures over time. Antenna failure modes are notoriously difficult to diagnose, so we don't have detailed reports of frequency-of-failure vs. failure-mode for this model.

Data Flow Compatibility

If UNAVCO selects either Septentrio or Manufacturer X as the Preferred Vendor, then some changes in UNAVCO's data flow operations will be required.

Data File Downloading

All of the receivers currently support FTP. The GDS staff will need to refactor download scripts to account for differences in file naming and directory structure. We could not fully evaluate the impact of those differences as many of the features requested in the RFP regarding file naming and directory structure are promised by Septentrio and Manufacturer X in future FW updates. The largest impact to data flow will be increased bandwidth for vendors who utilize less efficient file compression.

State of Health

The PolaRx cannot yet report external voltage measurements. This would impact our ability to remotely monitor the health of our battery systems in the field. External voltage measurement and other state of health monitoring could be implemented with a reasonable cost and could augment voltage measurements with more sophisticated battery SOH capabilities. Septentrio will be implementing this capability prior to initial release.

Configuration and Firmware Updates

Manufacturer Y

Receiver configuration files can be downloaded and uploaded to restore receiver or copy to another receiver as a base configuration. Firmware updates are tied to receiver warranty status. When warranty ends firmware support ends. Firmware can safely be upgraded over telemetry.

Septentrio

Receiver configuration files can be downloaded and uploaded to restore receiver or copy to another receiver as a base configuration. Firmware can be uploaded and installed on a remote receiver.

Manufacturer X

Receiver configuration state can be download as a text file but an uploadable receiver configuration file cannot be downloaded as of FW version 5.0. Significant development effort would be needed to convert receiver state to a configuration file or Manufacturer X would need to resolve this issue with a FW update.

Impacts of multi-vendor GNSS units on current UNAVCO RT-GNSS operations.

It is expected that multi-constellation RT-GNSS operations provided by UNAVCO will have strong impacts on the emerging communities of Earthquake Early Warning and Hazard Response Science. These operations will have a direct and substantial impact on the relevance of UNAVCO-operated EarthScope facilities and PI networks beyond 2018.

The current UNAVCO RT-GNSS data collection, processing, and distribution system is based on the commercial product PIVOT provided by Trimble Navigation (Trimble). GNSS receivers that are not manufactured by Trimble will have an asymmetric fiscal and physical impact on UNAVCO resources compared to Trimble GNSS products. The selection process should be weighted appropriately to ensure a fair competition. The impacts associated with adding a non-Trimble GNSS receiver are enumerated as follows:

a) PIVOT currently supports other manufacturers' GNSS units, in this case Trimble charges a premium of $2800/per per receiver (this quote was obtained for a Leica unit). This quote also indicated that command and control may be limited based on the availability of protocols from the non-Trimble vendor. UNAVCO has not yet purchased or tested the compatibility or interoperability of non-Trimble GNSS instruments in the PIVOT RT-GPS system, and it is beyond the scope of this RFP evaluation process to do so.

b) According the to RFP, the vendor is required to provide a software similar to PIVOT. The impact to UNAVCO resources is high. UNAVCO must now operate and maintain and entirely parallel system from data collection to archiving and may have substantial one time development impacts. In addition there will be commensurate impacts on computer hardware and software as well as IT personnel, software licenses and facility impacts.

c) The RFP requires an "archival quality" stream protocol, it is assumed that these will not be the same for each vendor and will have real but unknown impacts on data flow development, operation and maintenance.

Tables

Table 1. Receiver Y Power Consumption

	GPS L1 and L2 only	GPS L1, L2, & L5	GPS and GLONASS	All Constellations in View
Minimum Power Consumption	3.5 W (3.2)	3.7 W (3.6)	3.7 W	4.5 W
Ethernet Off - Logging 15-sec session	3.8 W	4.0 W (3.6)	4.0 W	4.8 W
Ethernet Off - Logging 15-sec session and 1 Hz session	3.8 W	4.0 W	4.0 W	4.8 W
Ethernet Off - Logging 15-sec session and 10 Hz session	3.8 W	4.0 W	4.0 W (3.8)	4.8 W
Ethernet On - Logging 15-sec session and 1 Hz session	3.8 W	4.0 W (3.7)	4.0 W	4.8 W
Ethernet On - Logging 15-sec session and 1 Hz session + 1 Hz. TCP/IP stream	3.8 W	4.0 W	4.0 W (3.9)	4.8 W
Ethernet On - Logging 15-sec session and 1 Hz session + 10 Hz. TCP/IP stream	3.8 W	4.0 W	4.0 W	4.8 W
Ethernet On - Logging 15-sec session and 1 Hz session - USB host active and used for logging sessions instead of internal memory	6.0 W (3.9)	6.2 W (4.2)	6.2 W (4.4)	7.0 W
Maximum possible power consumption	21 W	21 W	21 W	22 W

Manufacture notes:

*maximum power draw due to charging the battery is 15W, unless the unit is powered through POE. The unit will adjust its power consumption to stay within the limits of the POE supply.

Unavco notes:

-Spot check power in ( ).
-Vin = 12.5V
-Tracking 12 GPS, 9 GLONASS

Table 2. PolaRx Power Consumption

	GPS L1 and L2 only	GPS L1, L2, & L5	GPS and GLONASS	All Constellations in View
Minimum Power Consumption	2.0 W	2.3 W	2.3 W	3.1 W
Ethernet Off - Logging 15-sec session	2.2 W	2.4 W	2.4 W	3.2 W
Ethernet Off - Logging 15-sec session and 1 Hz session	2.2 W	2.4 W	2.4 W	3.2 W
Ethernet Off - Logging 15-sec session and 10 Hz session	2.2 W	2.4 W	2.4 W	3.2 W
Ethernet On - Logging 15-sec session and 1 Hz session	2.9 W	3.1 W	3.1 W	4.0 W
Ethernet On - Logging 15-sec session and 1 Hz session + 1 Hz. TCP/IP stream	2.9 W	3.1 W	3.1 W	4.0 W
Ethernet On - Logging 15-sec session and 1 Hz session + 10 Hz. TCP/IP stream	2.9 W	3.1 W	3.1 W	4.0 W
Ethernet On - Logging 15-sec session and 1 Hz session - USB host active and used for logging sessions instead of internal memory	TBD	TBD	TBD	TBD
Maximum possible power consumption				4.3 W

Manufacturer notes:

1) Tests conducted with AsterRx OEM integrator kit (the same OEM board that will be integrated in Septentrio's proposed PolaRx GNSS receiver).
2) Tracking measurements under the following scenarios:
    a) GPS L1 and L2 only
    b) GPS L1, L2, & L5
    c) GPS and GLONASS corresponding to GPS L1/L2/L5 and GLONASS L1/L2.
    d) "All constellations in view".
3) Impact of internal logging: noticeably, logging rate and logging type (SBF/RINEX) has no effect on the power in our implementation.
4) Measured values given with 10% margin of error.

Unavco notes:

-Spot checking was not possible because testing was done on a demo kit board.

-Demo board power was measured with usb unplugged, all SVs in all constellations being tracked. Vin = 12.34V, Power = 4.4W.

Table 3. Receiver X Power Consumption

	GPS L1 and L2 only	GPS L1, L2, & L5	GPS and GLONASS	All Constellations in View
Minimum Power Consumption	5.73 W	5.74 W	5.89 W	6.25 W
Ethernet Off - Logging 15-sec session	6.21 W (6.5)	6.11 W (6.5)	6.32 W (6.6)	6.70 W
Ethernet Off - Logging 15-sec session and 1 Hz session	6.19 W (6.5)			
Ethernet Off - Logging 15-sec session and 10 Hz session	6.21 W			
Ethernet On - Logging 15-sec session and 1 Hz session	6.37 W (6.8)			
Ethernet On - Logging 15-sec session and 1 Hz session + 1 Hz. TCP/IP stream	6.34 W			
Ethernet On - Logging 15-sec session and 1 Hz session + 10 Hz. TCP/IP stream	6.46 W	6.47 W	6.69 W	6.99 W
Ethernet On - Logging 15-sec session and 1 Hz session - USB host active and used for logging sessions instead of internal memory	6.48 W			
Maximum possible power consumption	7.13 W (44 W with battery charging)	7.26 W	7.33 W	7.82 W

Unavco notes:
-Spot check power in ( ).
-Vin = 12.5V
-Tracking 11 GPS, 9 GLONASS

Figures

Figure 1

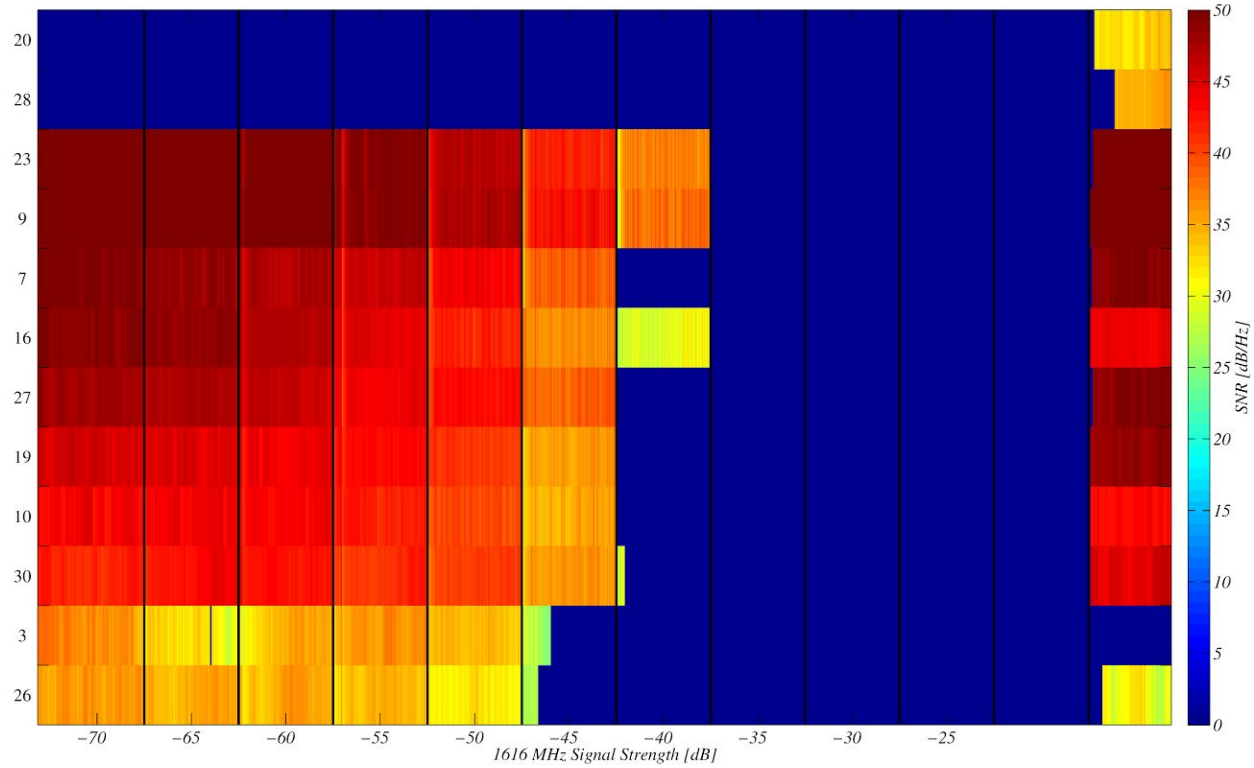


Figure 1. Receiver Y L1 signal-to-noise variation while undergoing varying levels of interference. The dark blue areas indicate epochs where the satellite was not tracked. The PRN's 20 and 28 were not above the horizon until the end of the test. The remaining PRN's were sorted by their initial SNR value. The black vertical lines indicate the boundary of each 2 min interval. The gain of the transmitted 1616 MHz signal is shown along the x-axis (there is a missing label at -20 dB). The signal was turned off for the last interval.

Figure 2

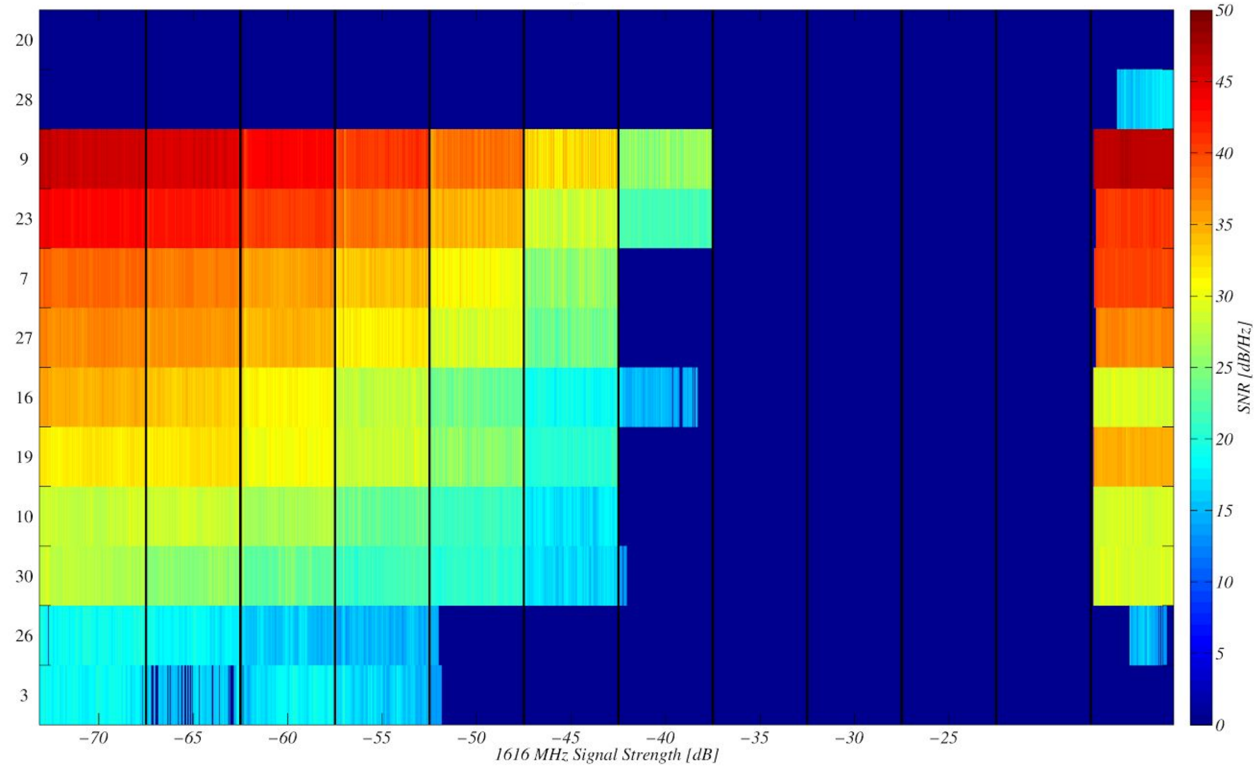


Figure 2. Receiver Y L2 signal-to-noise variation while undergoing varying levels of interference. The dark blue areas indicate epochs where the satellite was not tracked. The PRN's 20 and 28 were not above the horizon until the end of the test. The remaining PRN's were sorted by their initial SNR value. The black vertical lines indicate the boundary of each 2 min interval. The gain of the transmitted 1616 MHz signal is shown along the x-axis (there is a missing label at -20 dB). The signal was turned off for the last interval.

Figure 3

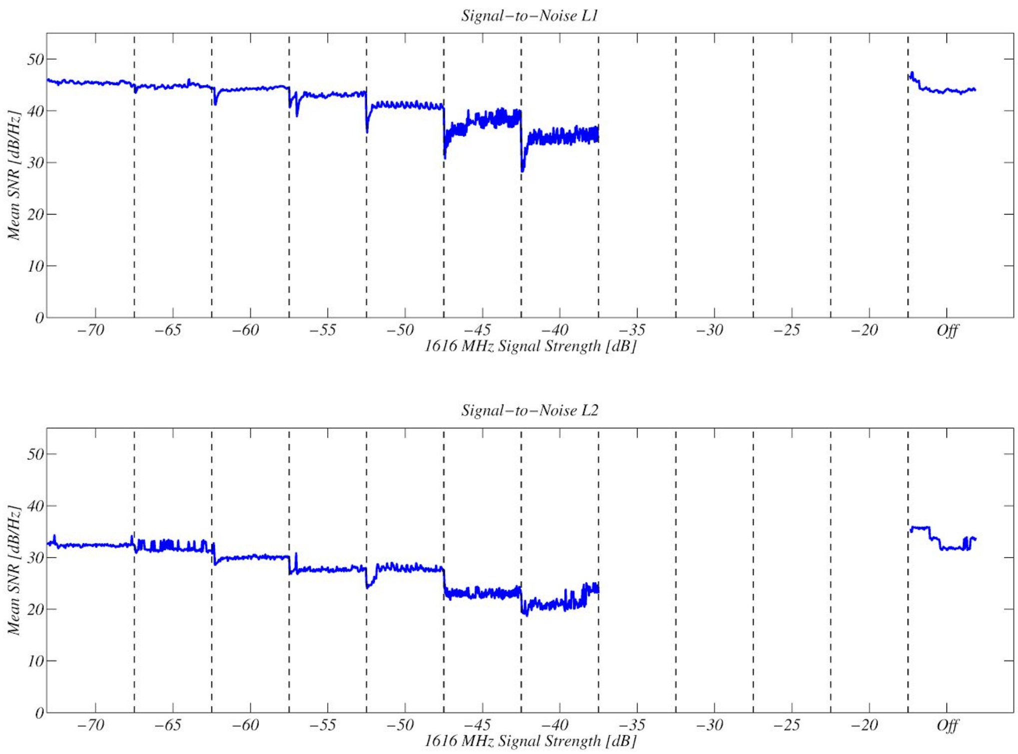


Figure 3. Mean Receiver Y L1 & L2 signal-to-noise variation while undergoing varying levels of interference. The SNR for all visible satellites was summed for every epoch and divided by the number of visible satellites in a given epoch.

Figure 4

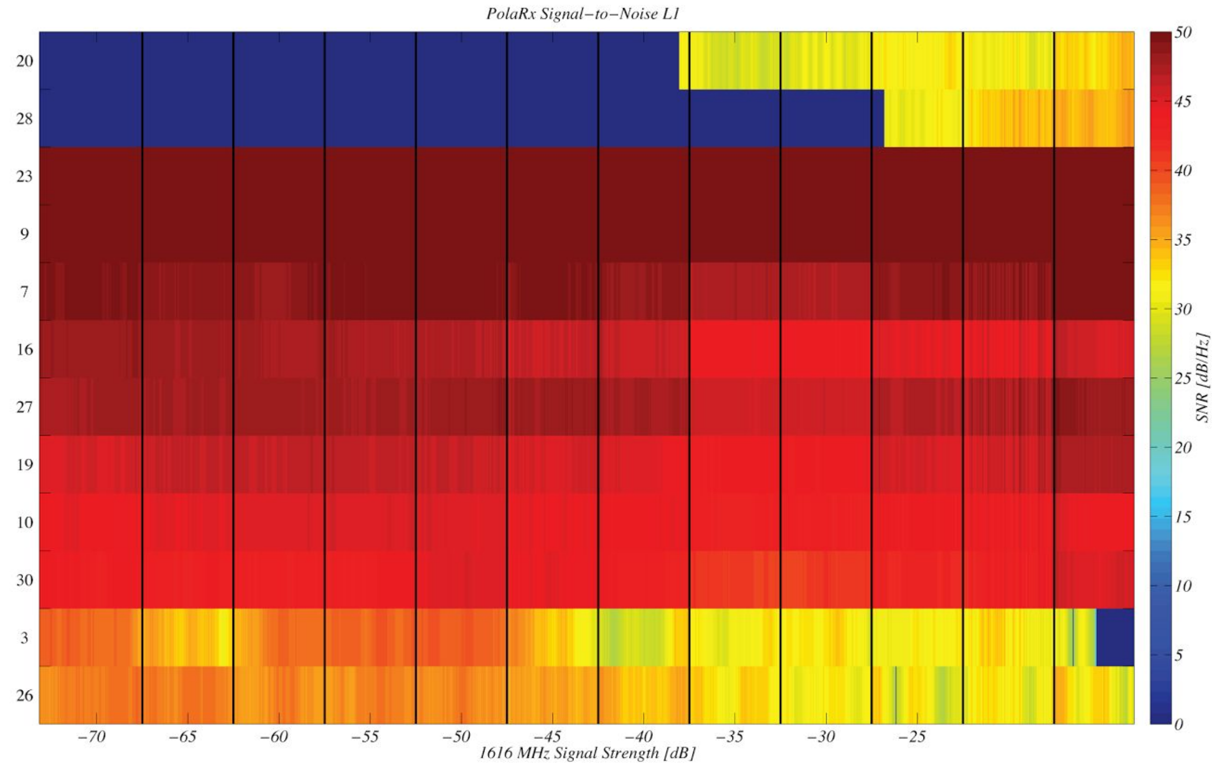


Figure 4. PolaRx GPS L1 signal-to-noise variation while undergoing varying levels of interference. The dark blue areas indicate epochs where the satellite was not tracked. The PRN's 20 and 28 were not above the horizon until the end of the test. The remaining PRN's were sorted by their initial SNR value. The black vertical lines indicate the boundary of each 2 min interval. The gain of the transmitted 1616 MHz signal is shown along the x-axis (there is a missing label at -20 dB). The signal was turned off for the last interval. The PolaRx continued to track L1 throughout the experiment

Figure 5

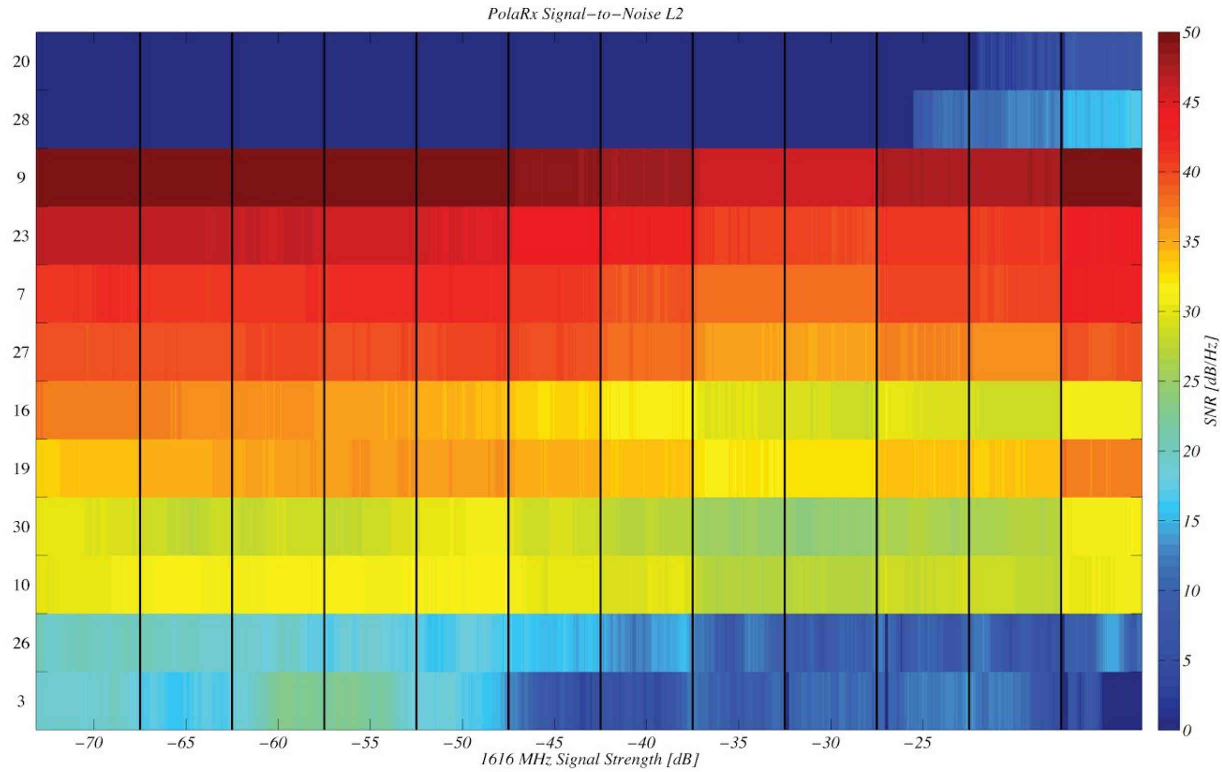


Figure 5. PolaRx L2 signal-to-noise variation while undergoing varying levels of interference. The dark blue areas indicate epochs where the satellite was not tracked. The PRN's 20 and 28 were not above the horizon until the end of the test. The remaining PRN's were sorted by their initial SNR value. The black vertical lines indicate the boundary of each 2 min interval. The gain of the transmitted 1616 MHz signal is shown along the x-axis (there is a missing label at -20 dB). The signal was turned off for the last interval.

Figure 6

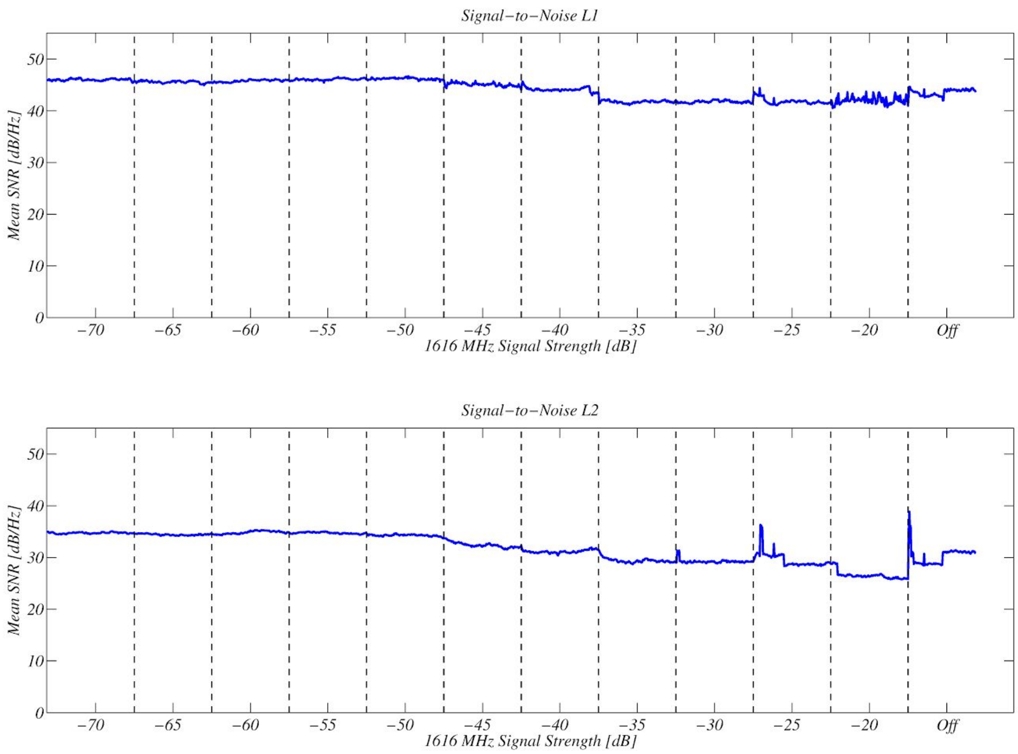


Figure 6. Mean PolaRx L1 & L2 signal-to-noise variation while undergoing varying levels of interference. The SNR for all visible satellites was summed for every epoch and divided by the number of visible satellites in a given epoch.

Figure 7

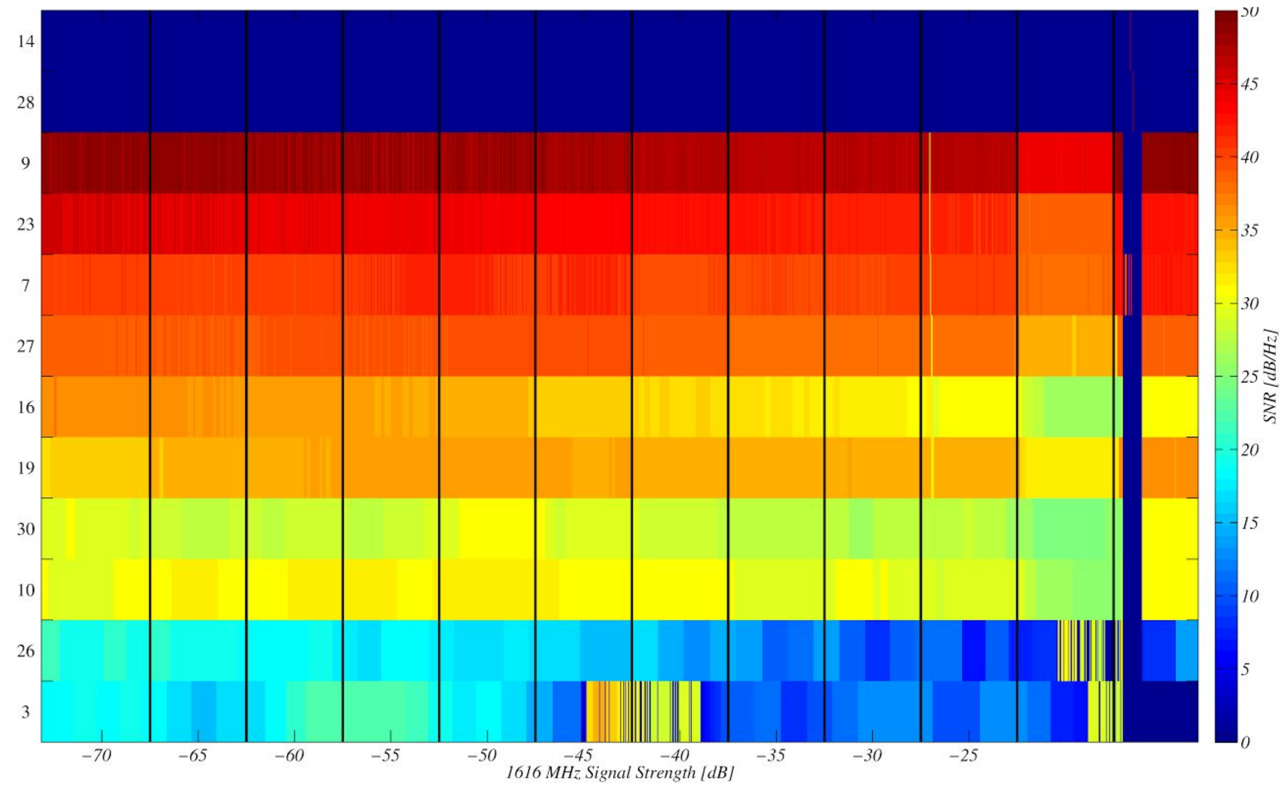


Figure 7. Receiver X L1 signal-to-noise variation while undergoing varying levels of interference. The dark blue areas indicate epochs where the satellite was not tracked. The PRN's 20 and 28 were not above the horizon until the end of the test. The remaining PRN's were sorted by their initial SNR value. The black vertical lines indicate the boundary of each 2 min interval. The gain of the transmitted 1616 MHz signal is shown along the x-axis (there is a missing label at -20 dB). The signal was turned off for the last interval. The antenna cable was disturbed in the last interval causing a disruption in tracking.

Figure 8

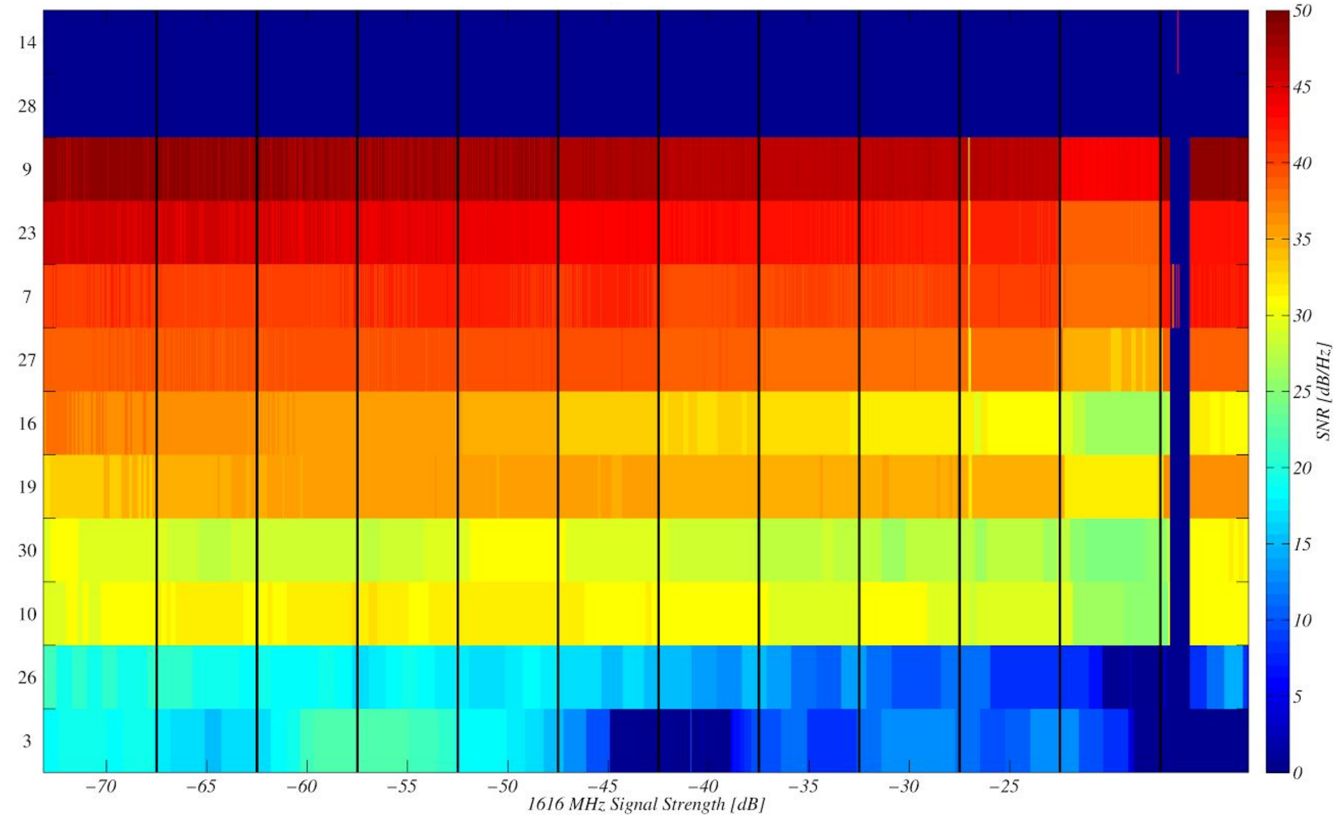


FIgure 8. Receiver X L1 signal-to-noise variation while undergoing varying levels of interference. The dark blue areas indicate epochs where the satellite was not tracked. The PRN's 20 and 28 were not above the horizon until the end of the test. The remaining PRN's were sorted by their initial SNR value. The black vertical lines indicate the boundary of each 2 min interval. The gain of the transmitted 1616 MHz signal is shown along the x-axis (there is a missing label at -20 dB). The signal was turned off for the last interval. The antenna cable was disturbed in the last 2 min interval causing a disruption in tracking.

Figure 9

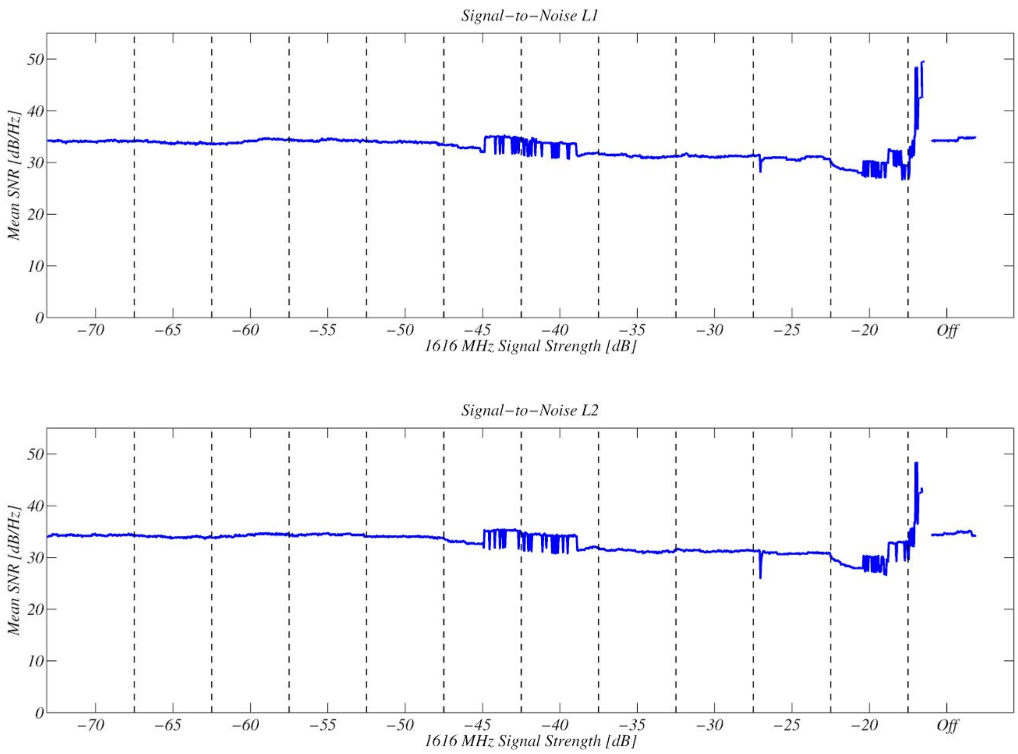


Figure 9. Mean Receiver X signal-to-noise variation for L1 (top) and L2 (bottom).

Figure 10

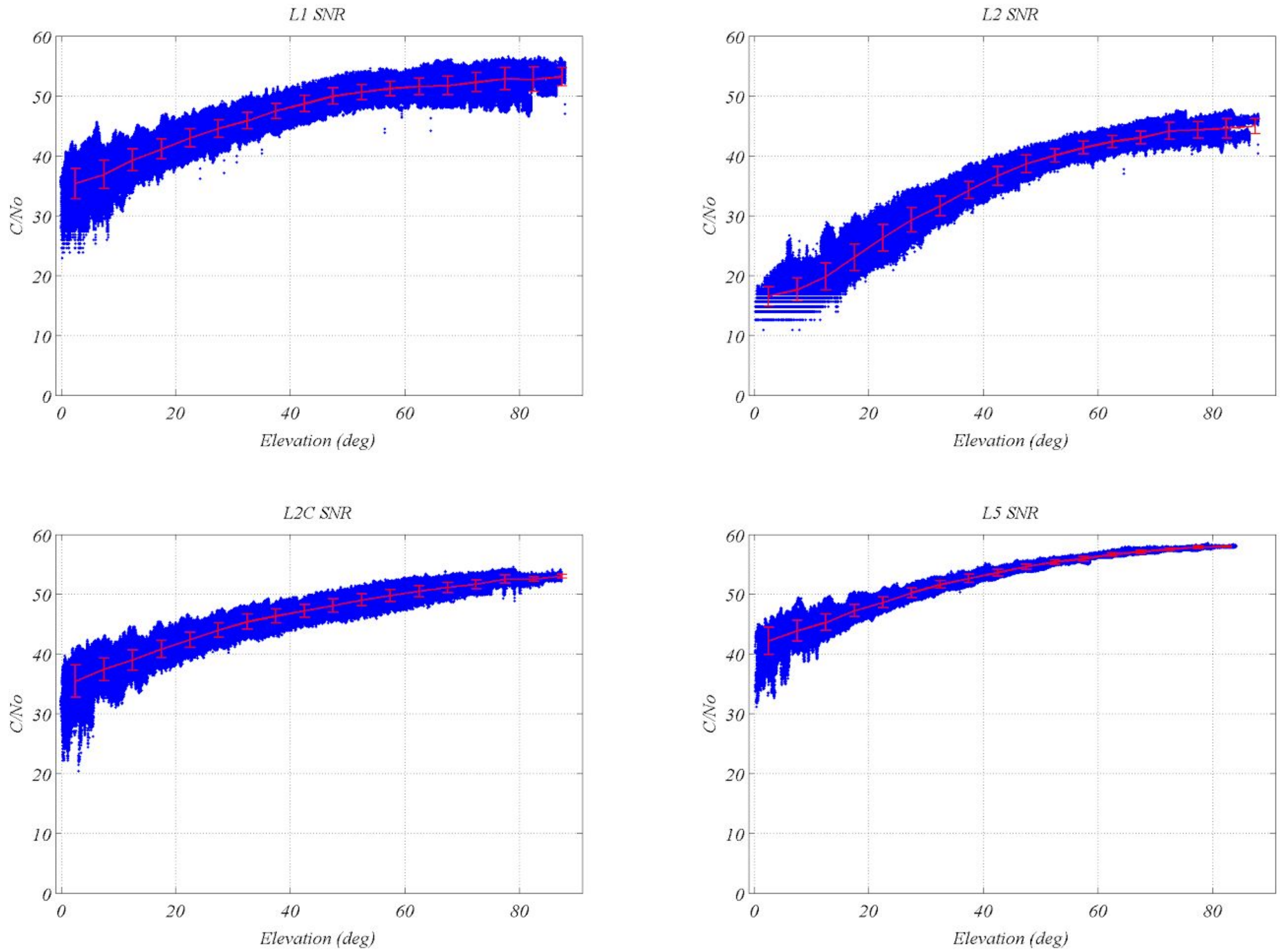


Figure 10. Receiver Y GPS signal-to-noise plotted vs. elevation angle. The four panes display the SNR for the four tracked GPS signals (L1, L2, L2C, & L5). The red line with error bars shows the mean SNR calculated for bins with 5 degree increments.

Figure 11

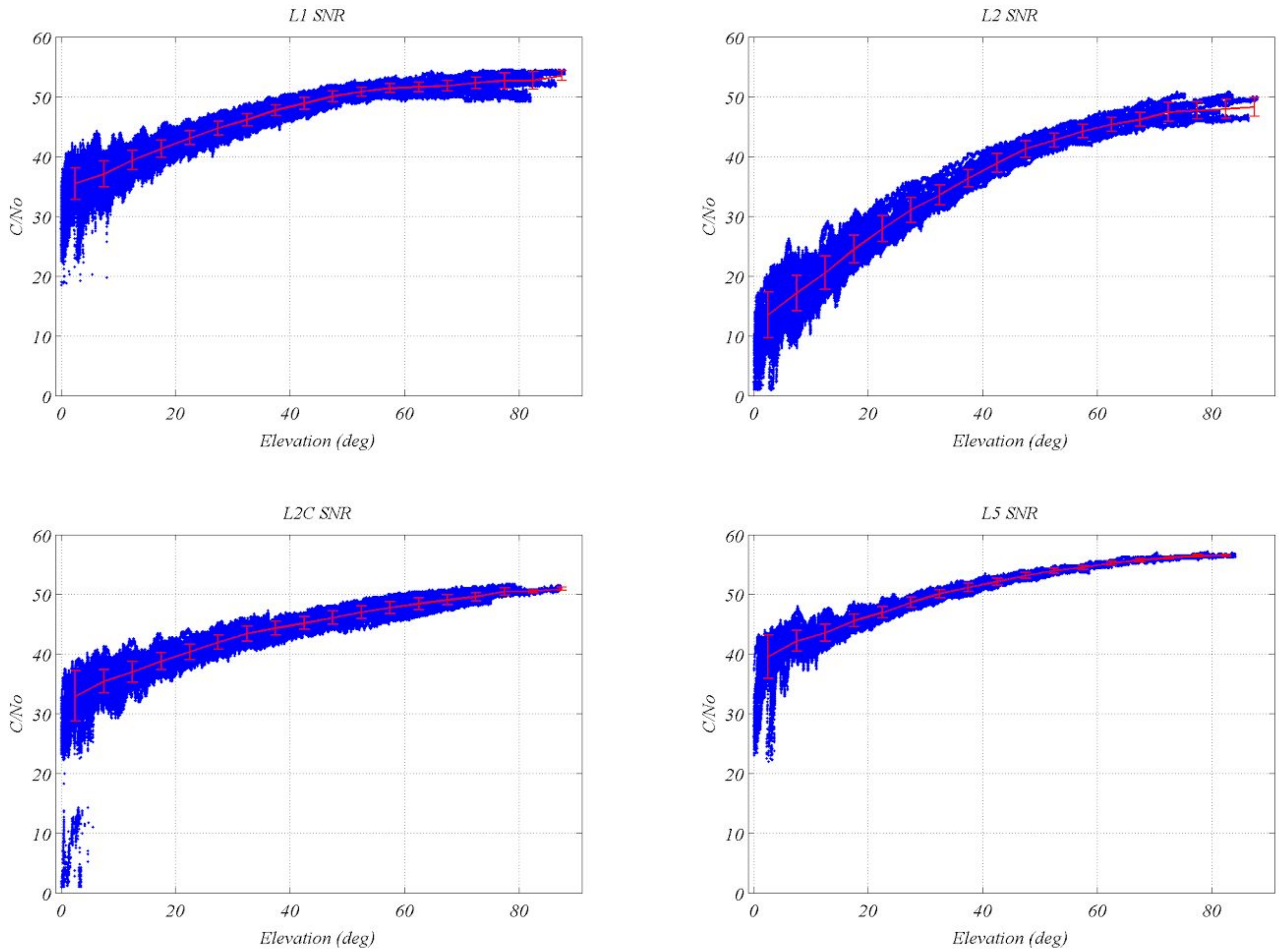


Figure 11. PolaRx GPS signal-to-noise plotted vs. elevation angle.

Figure 12

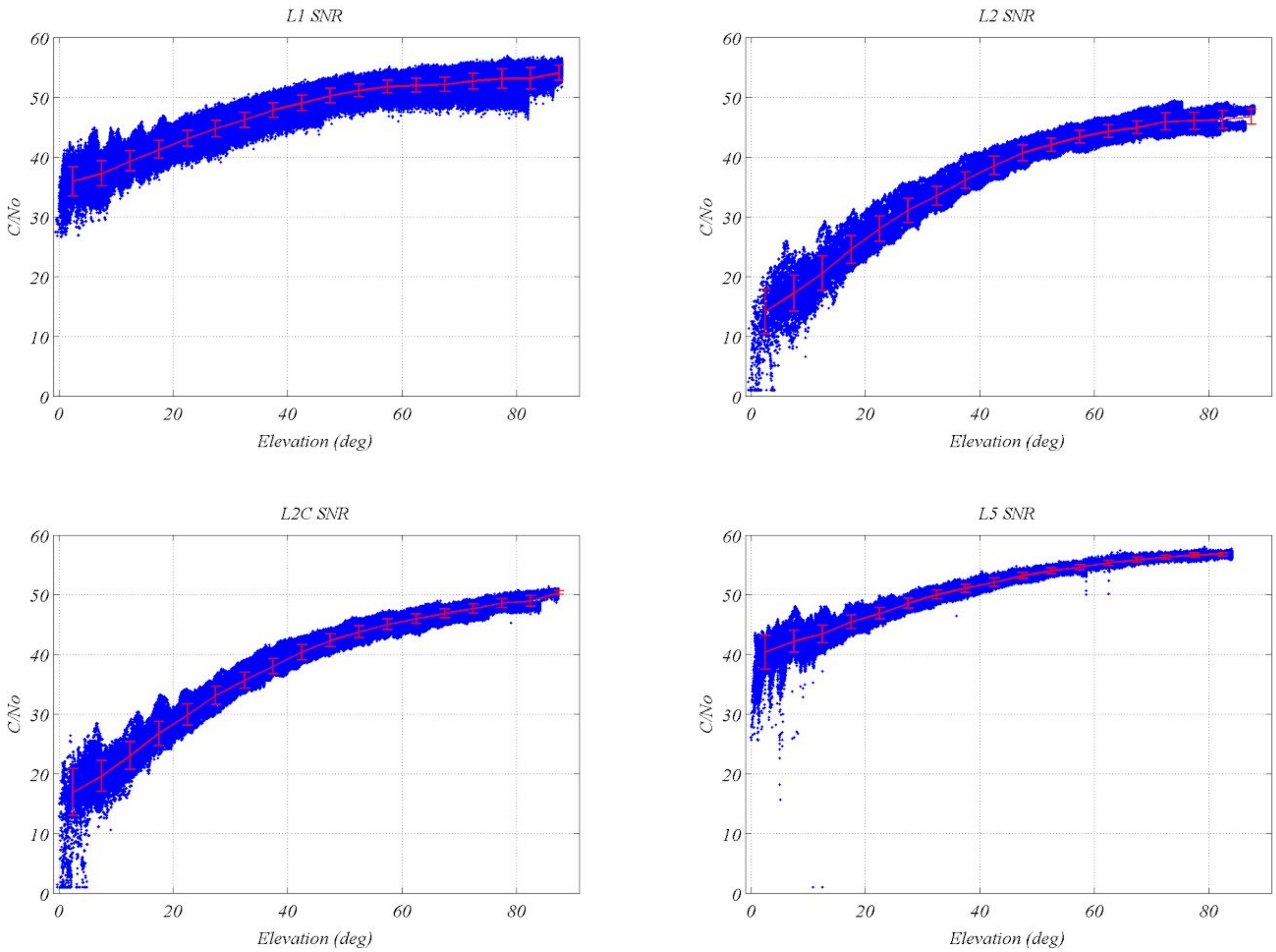
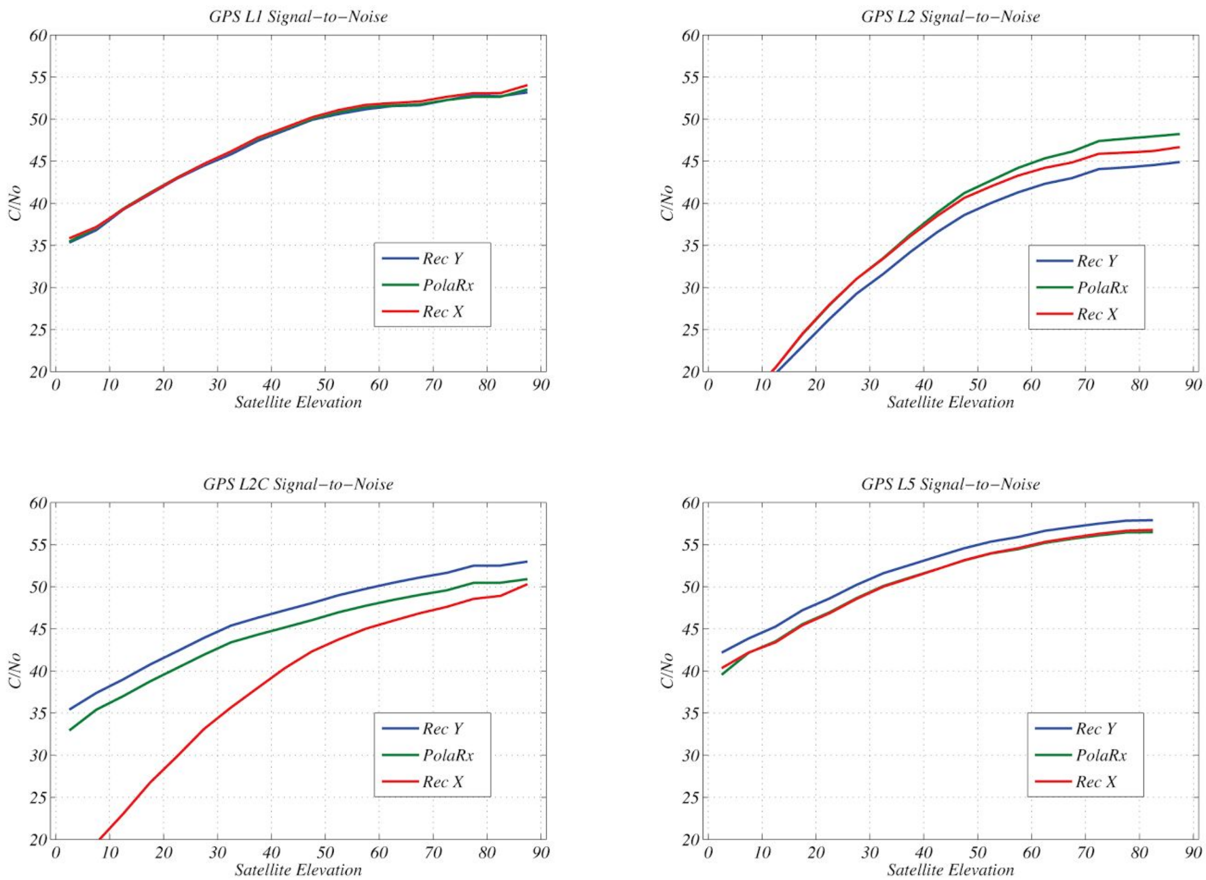


Figure 12. Receiver X GPS signal-to-noise plotted vs. elevation angle. Please ignore the results for the L2C SNR.

Figure 13

Figure 13. A comparison of mean SNR values binned every 5 degrees for the three receivers.



The Receiver X has the highest SNR amplitude for L5 and L2C. However, Receiver Y has the lowest SNR amplitude for L2. SNR amplitude does not necessarily reflect the quality of the observable data and may not affect GNSS reflectometry studies.

Figure 14

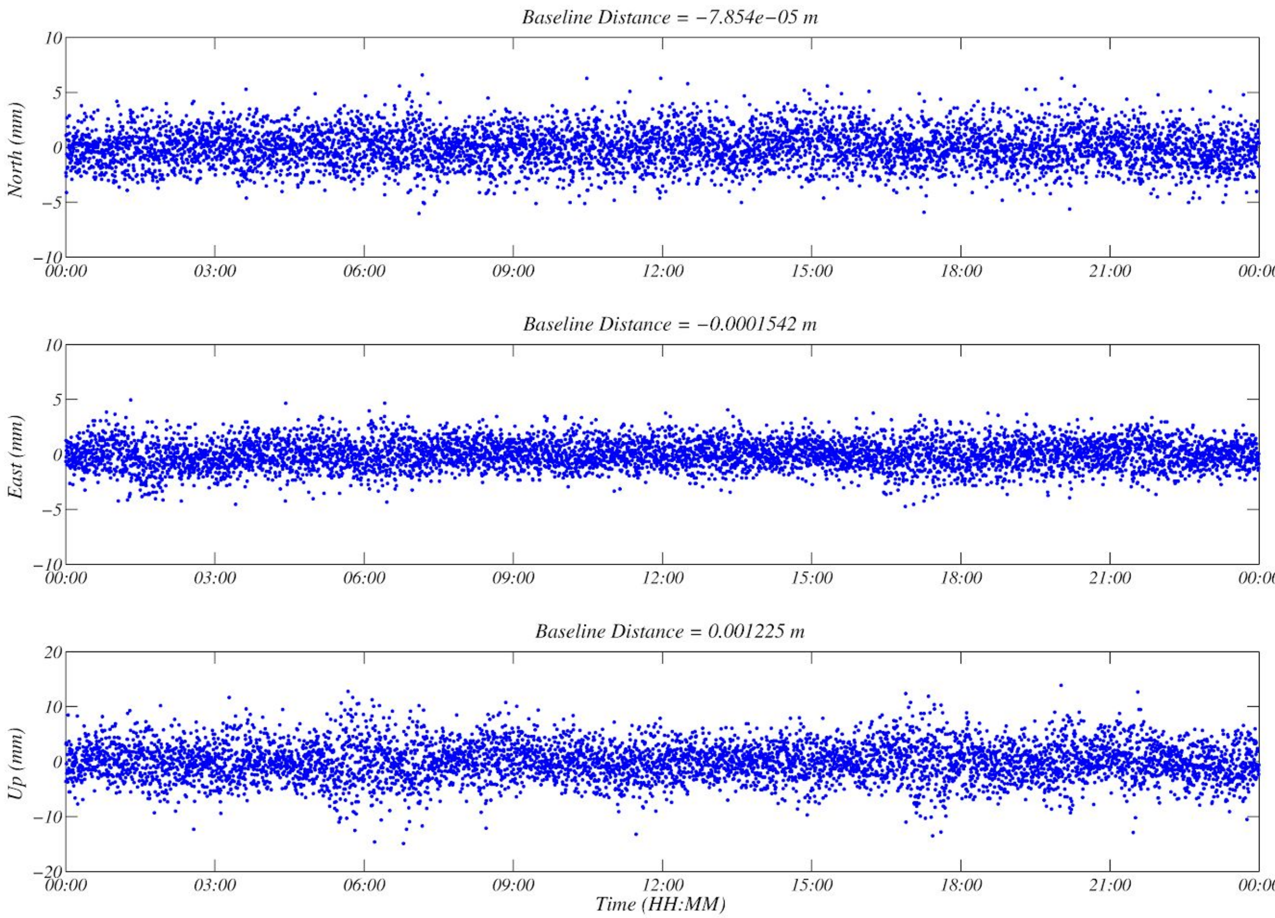


Figure 14. Zero length baseline position estimates (24 hr, 1 s) for Receiver X computed by TRACK. A NetR9 receiver (DEVT) was used as a reference receiver.

Figure 15

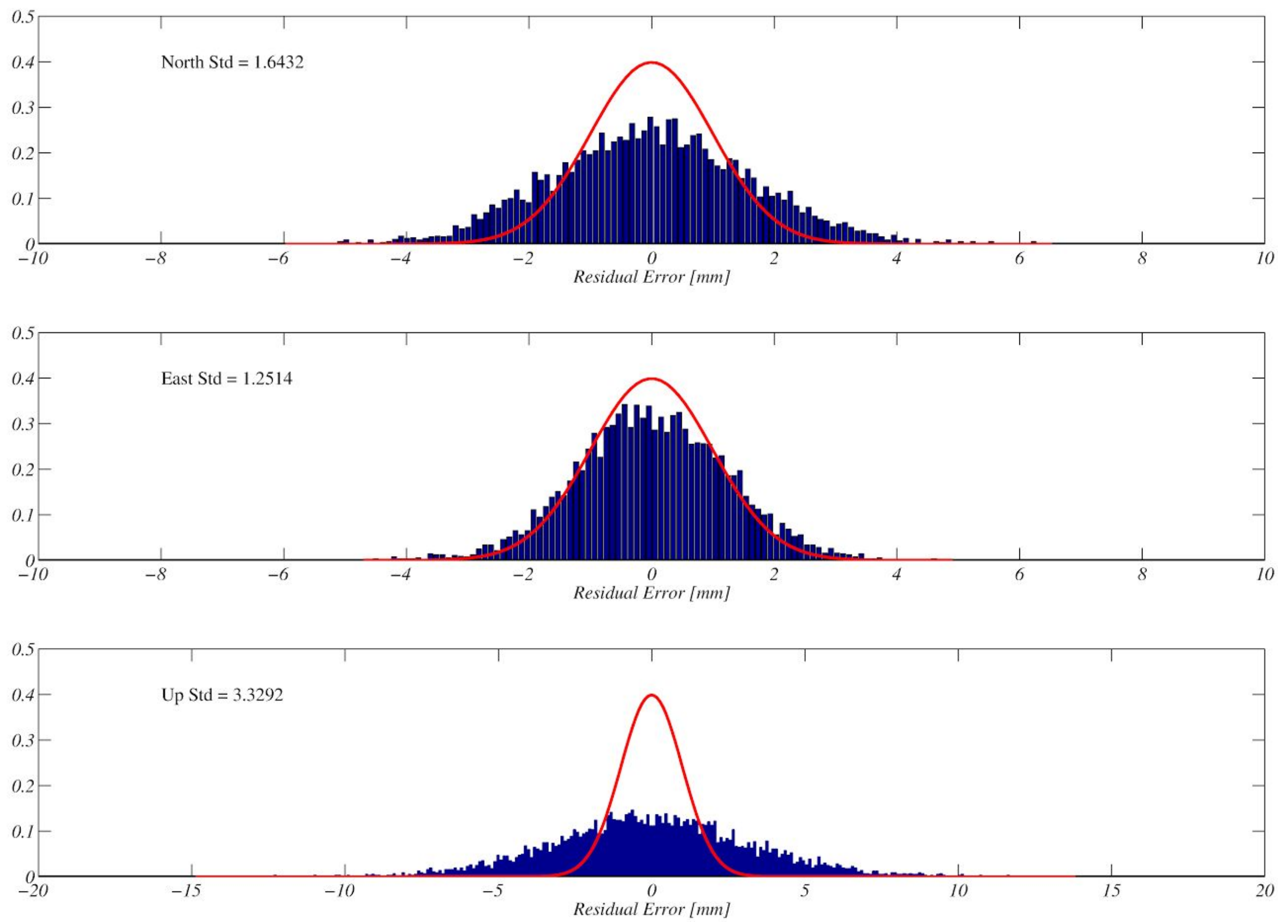


Figure 15. A normalized histogram of the zero-length-baseline position estimates (24 hr, 1 s) for the Receiver X. A NetR9 receiver (DEVT) was used as a reference receiver. The probability density function, assuming a Gaussian distribution with mean and standard deviation obtained from the sample, is shown in red.

Figure 16

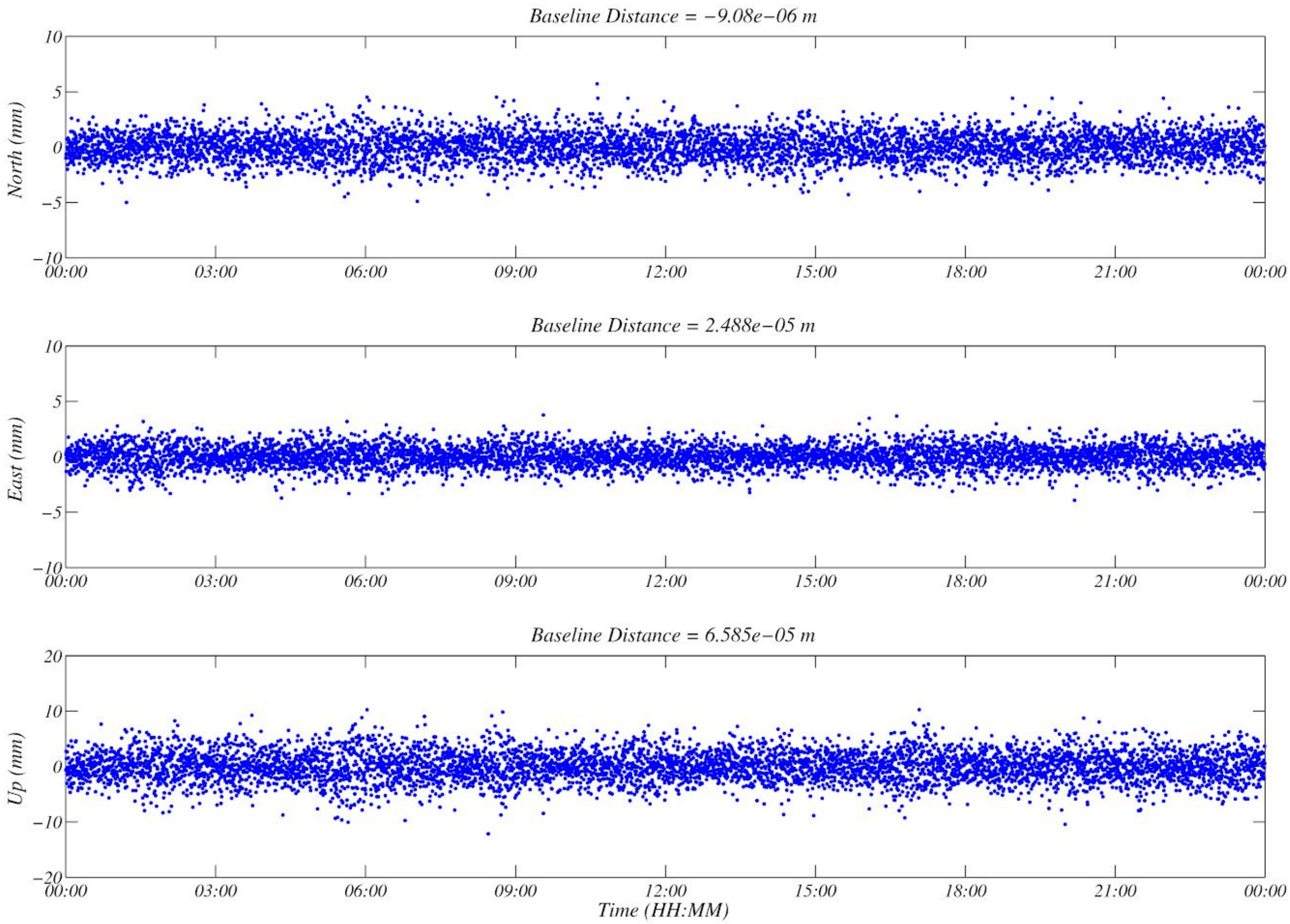


Figure 16. Zero length baseline position estimates (24 hr, 1 s) for Receiver Y computed by TRACK. A NetR9 receiver (DEVT) was used as a reference receiver.

Figure 17

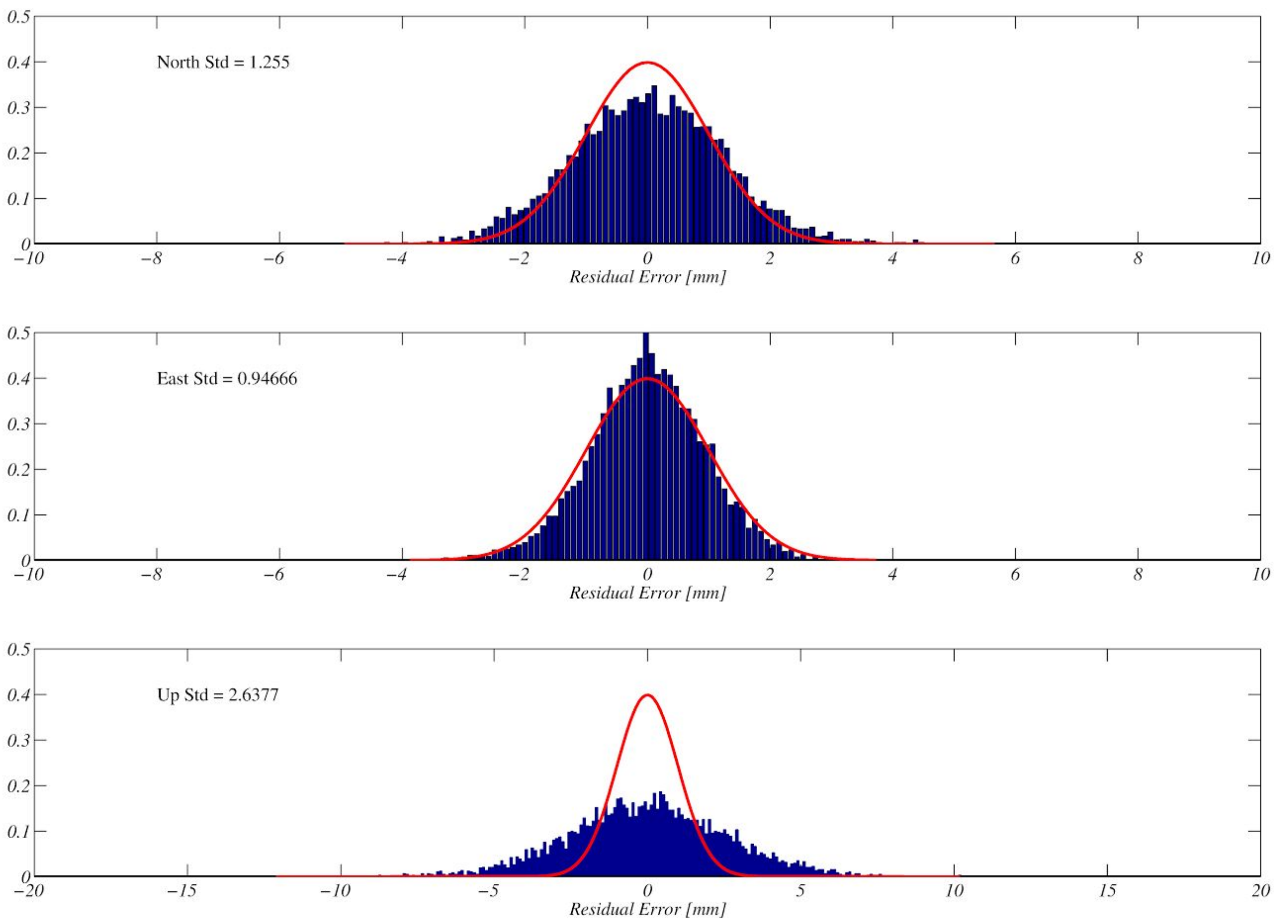


Figure 17. A normalized histogram of the zero-length-baseline position estimates (24 hr, 1 s) for Receiver Y. A NetR9 receiver (DEVT) was used as a reference receiver. The probability density function, assuming a Gaussian distribution with mean and standard deviation obtained from the sample, is shown in red.

Figure 18

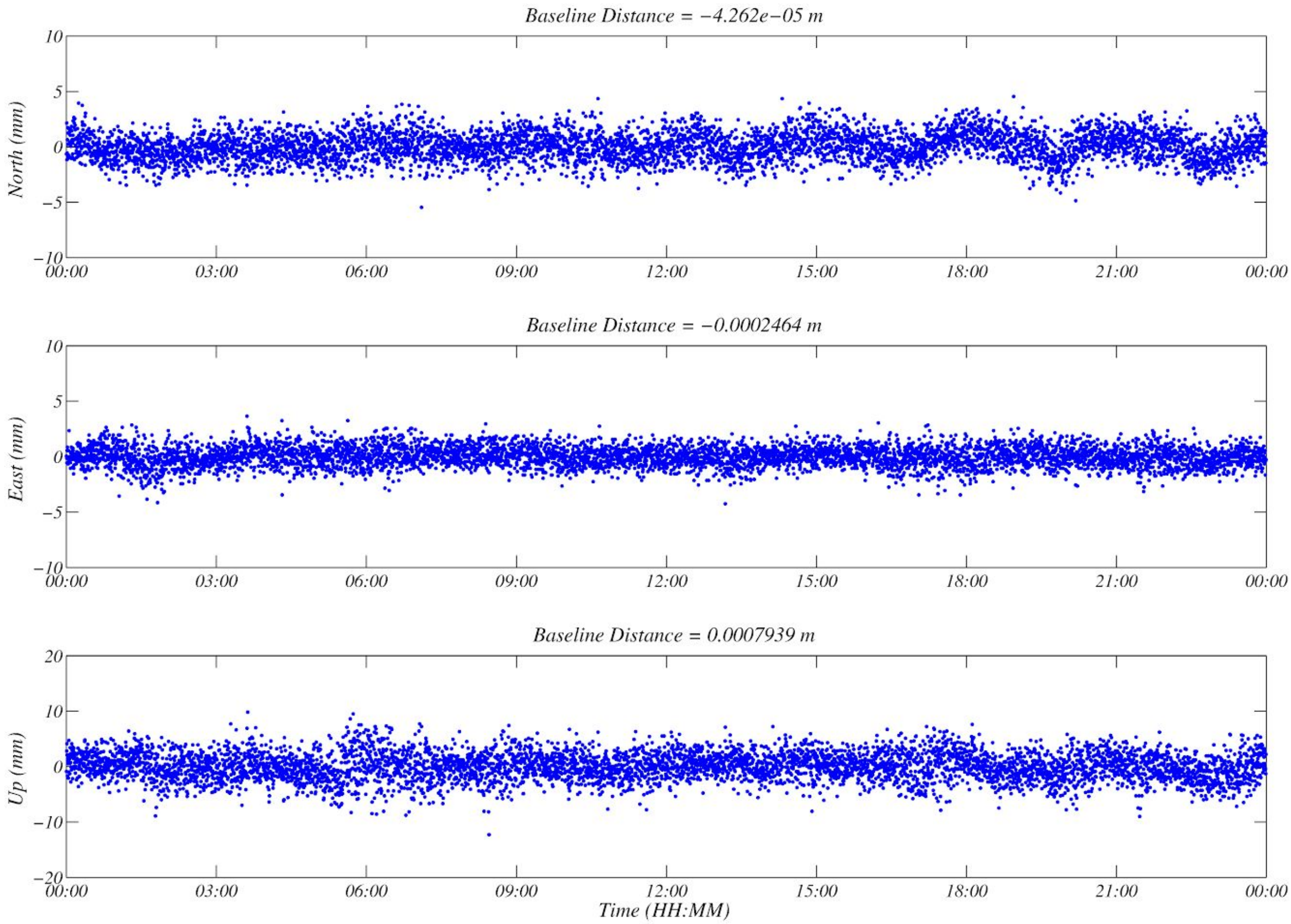


Figure 18. Zero length baseline position estimates (24 hr, 1 s) for the PolaRx computed by TRACK. A NetR9 receiver (DEVT) was used as a reference receiver.

Figure 19

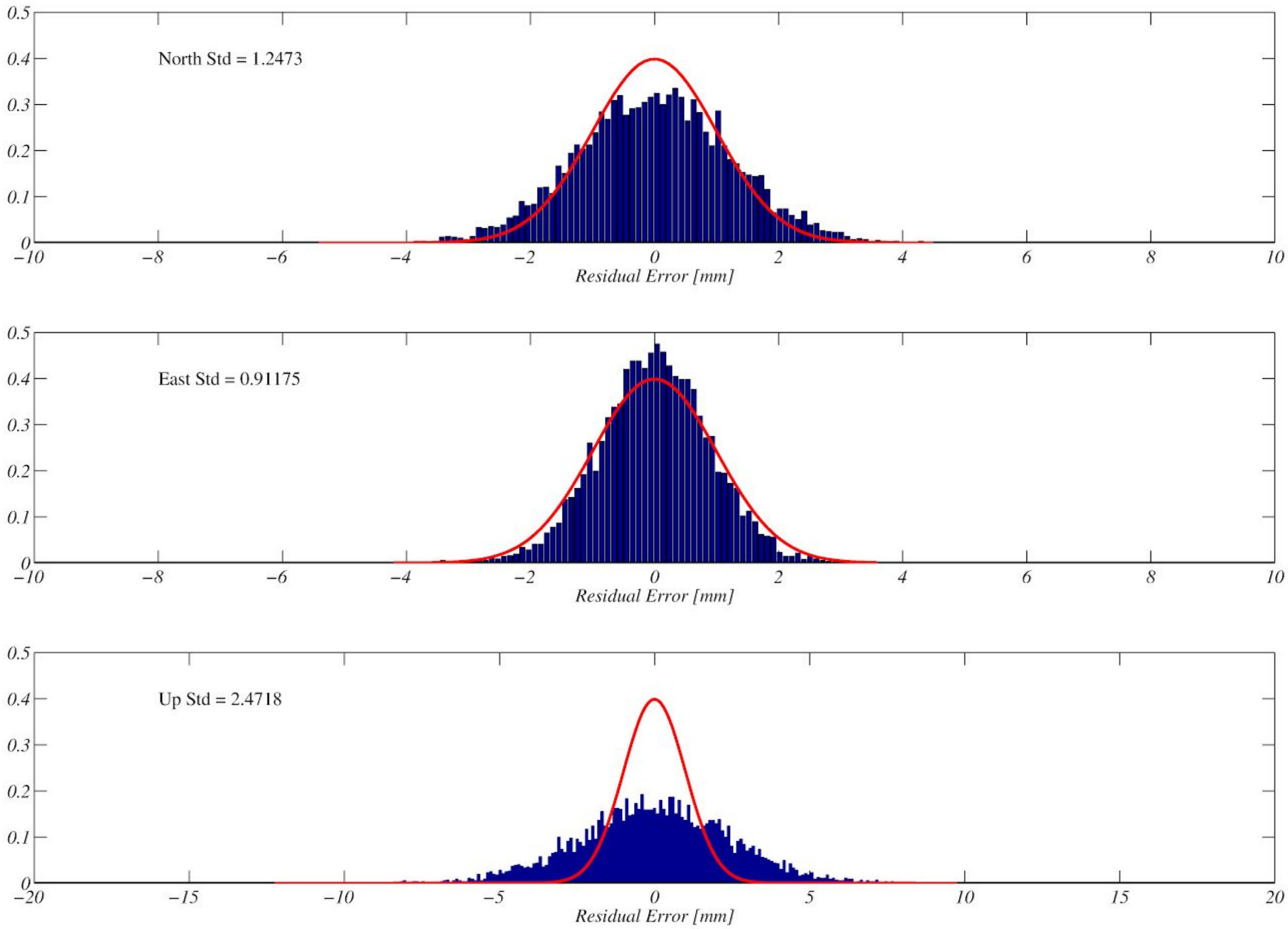


Figure 19. A normalized histogram of the zero-length-baseline position estimates (24 hr, 1 s) for the PolarRx. A NetR9 receiver (DEVT) was used as a reference receiver. The probability density function, assuming a Gaussian distribution with mean and standard deviation obtained from the sample, is shown in red.

Figure 20

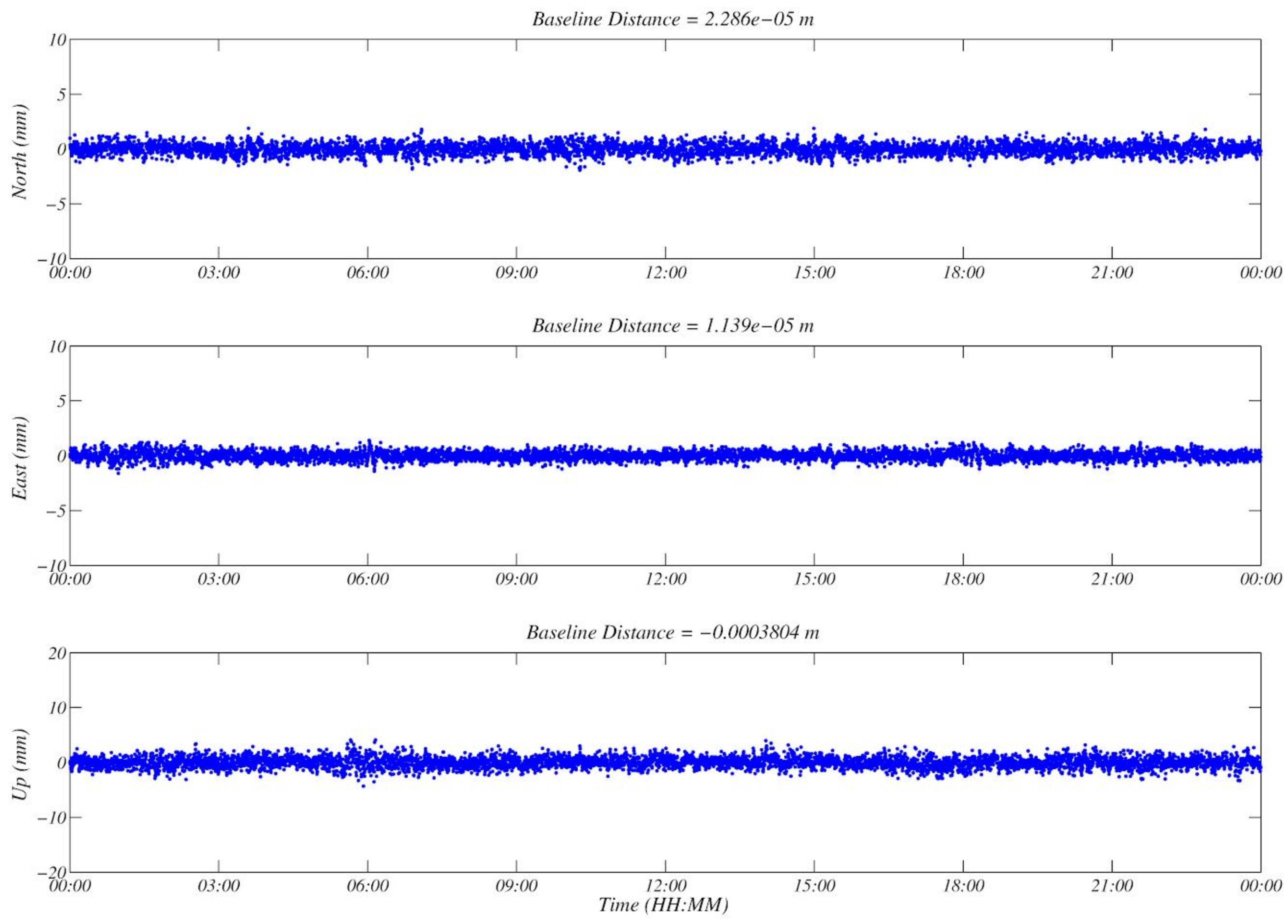


Figure 20. Zero length baseline position estimates (24 hr, 1 s) between two PolarRx receivers. Estimates were computed by TRACK.

Figure 21

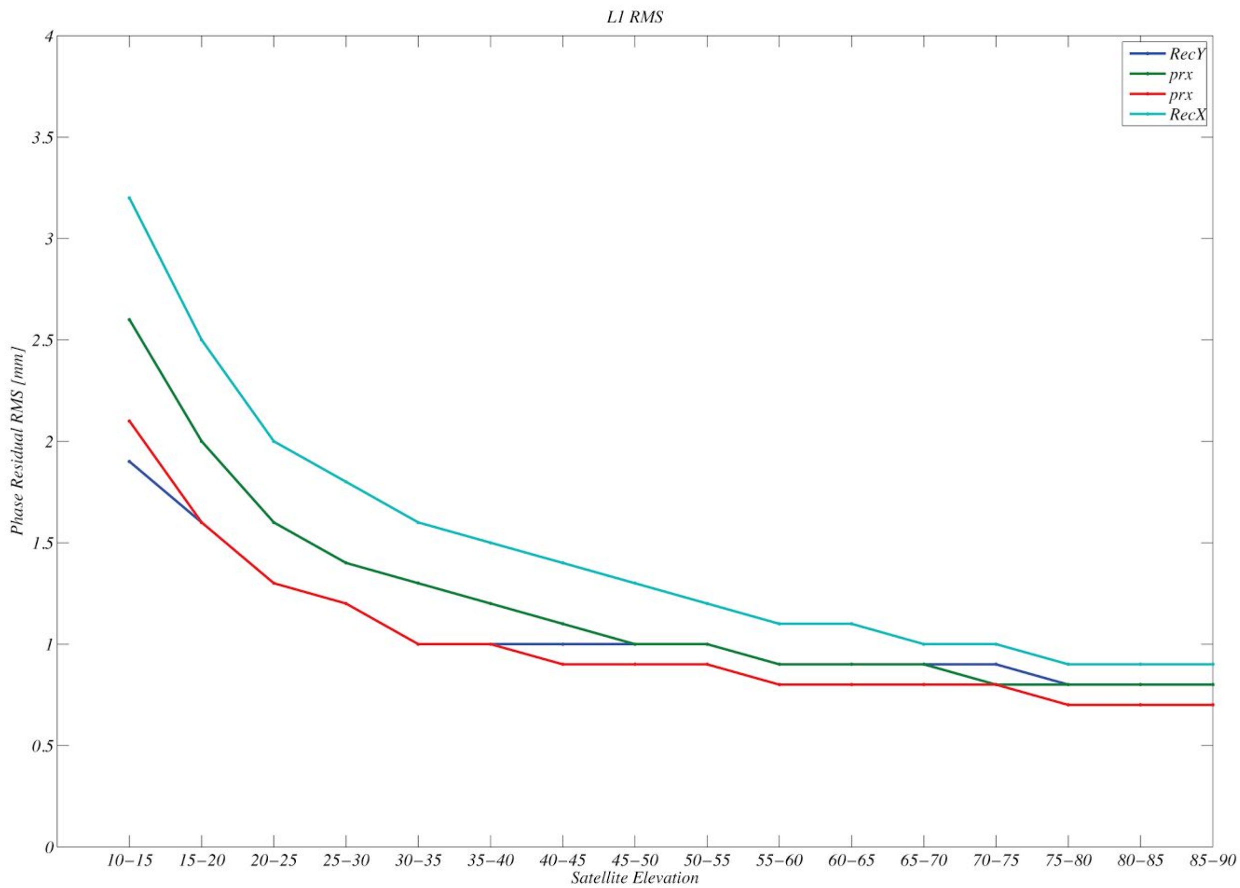


Figure 21. GPS L1 phase residual RMS vs. satellite elevation angle.

Figure 22

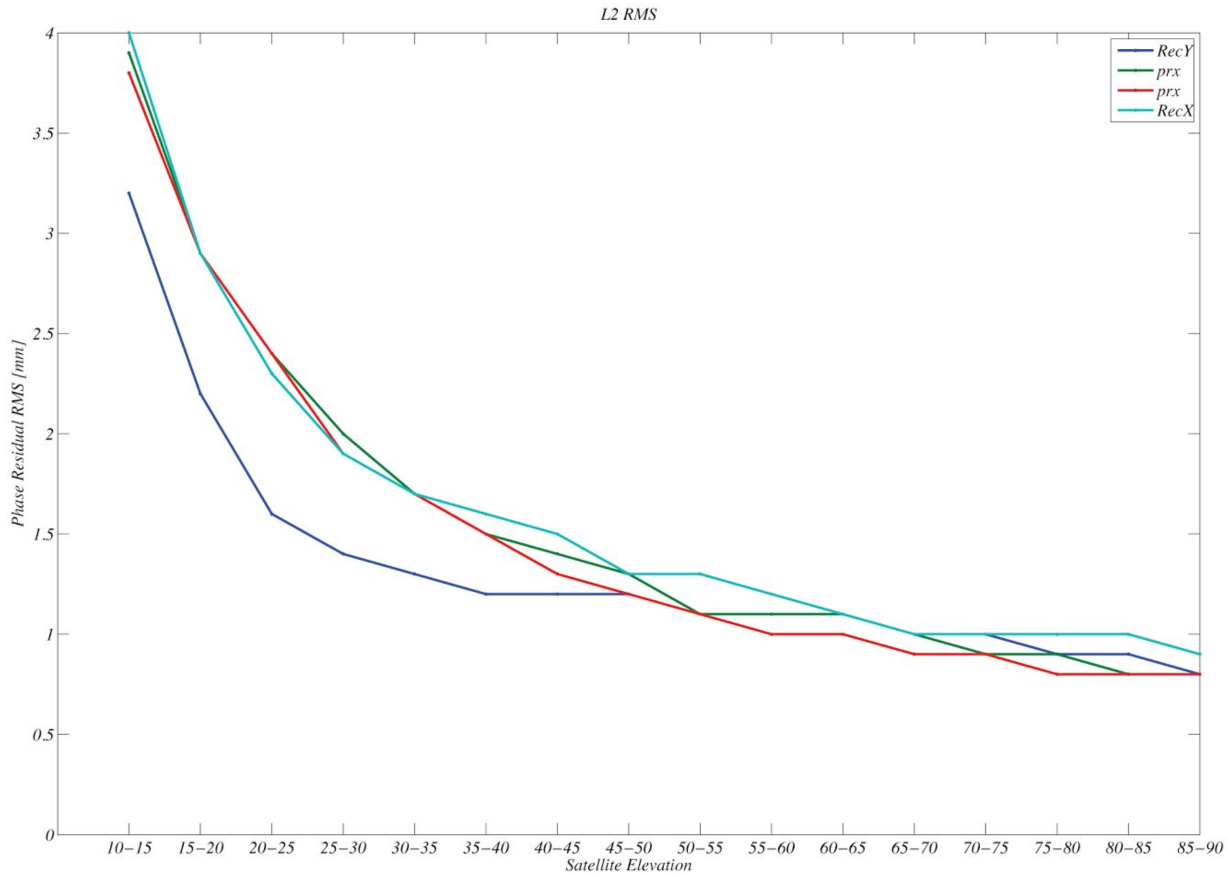


Figure 22. GPS L2 phase residual RMS vs. satellite elevation angle.

Figure 23

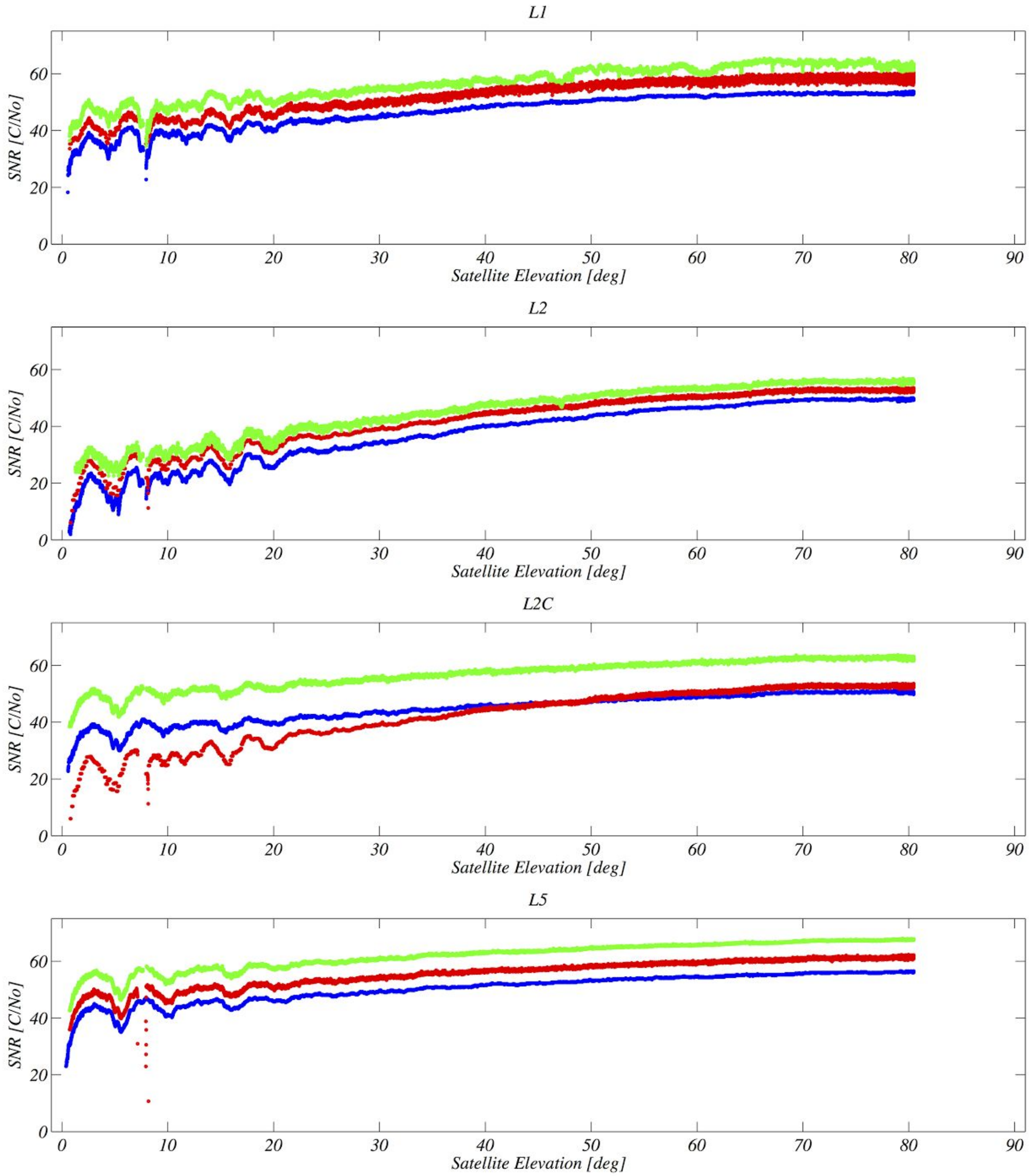


Figure 23. Signal-to-noise comparison for L1, L2, L2C and L5 frequencies. The ascending arc of GPS PRN09 was chosen as an example of multipath oscillation due to a horizontal planar reflector, in this case the UNAVCO roof south of the antenna. Receiver X (red); Receiver Y (green); PolaRx (blue). **The signal-to-noise curves for Receiver Y and Receiver X are offset by +5 C/No and -5 C/No, respectively, for clarity.** Due to a configuration error on the receiver the L2C results for Receiver X show L2 in place of L2C, resulting in a lower amplitude curve.

Figure 24

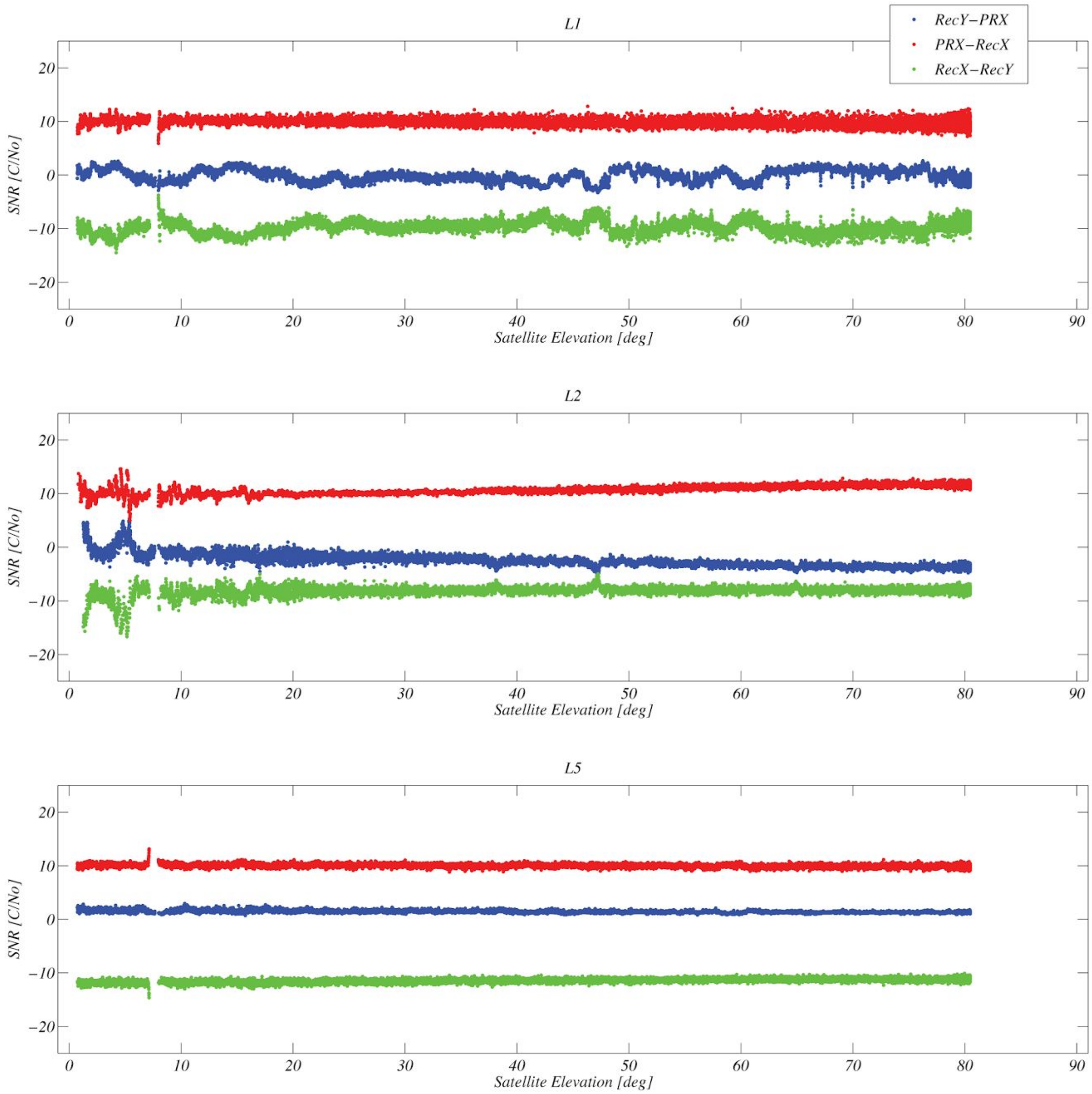


Figure 24. Signal-to-noise differences between receiver types for GPS PRN09. The signal-to-noise differences are offset by 10 C/No for clarity. The L1 differences that include Receiver Y receiver are noisier than differences without Receiver Y. That suggests the L1 SNR character of Receiver Y is significantly different than that of the PolaRx or Receiver X.

Figure 25

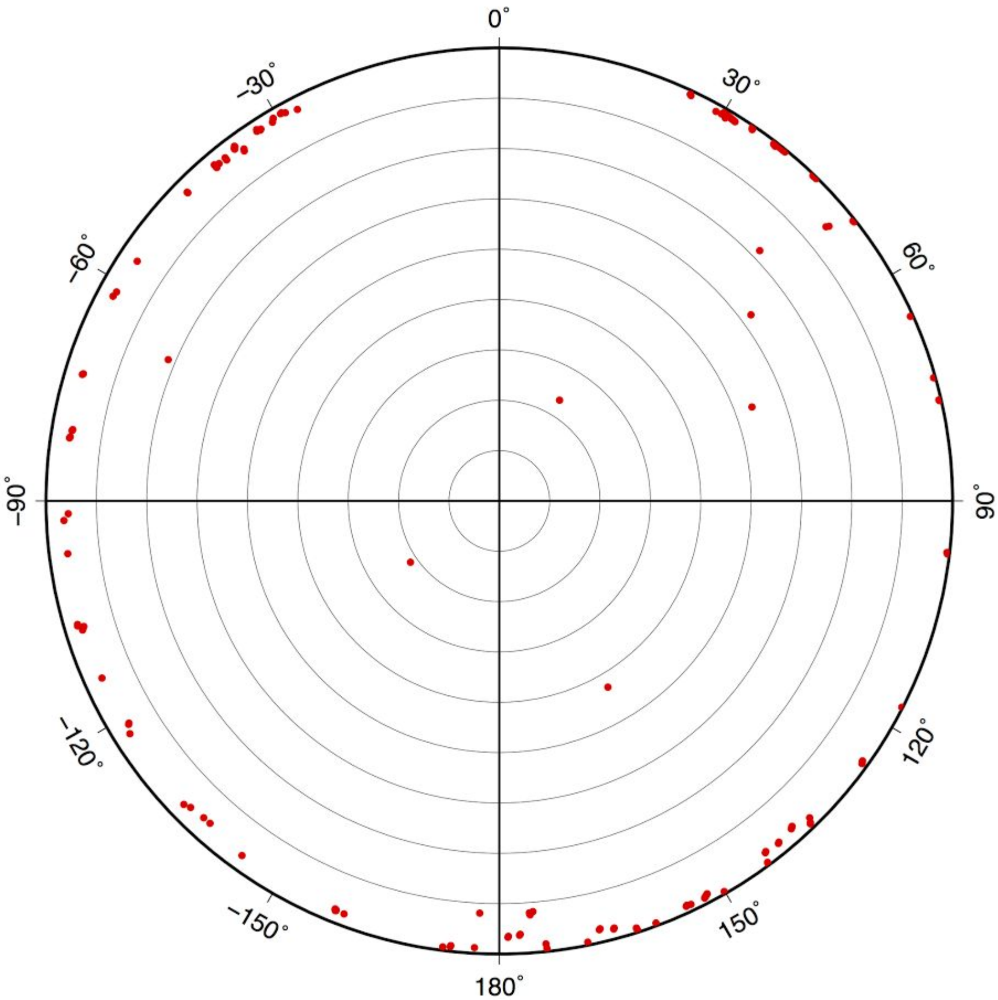


Figure 25. PolaRx L1 and L2 slips detected in four daily 1 Hz RINEX files using a Melbourne-Wubbena slip detection algorithm.

Figure 26

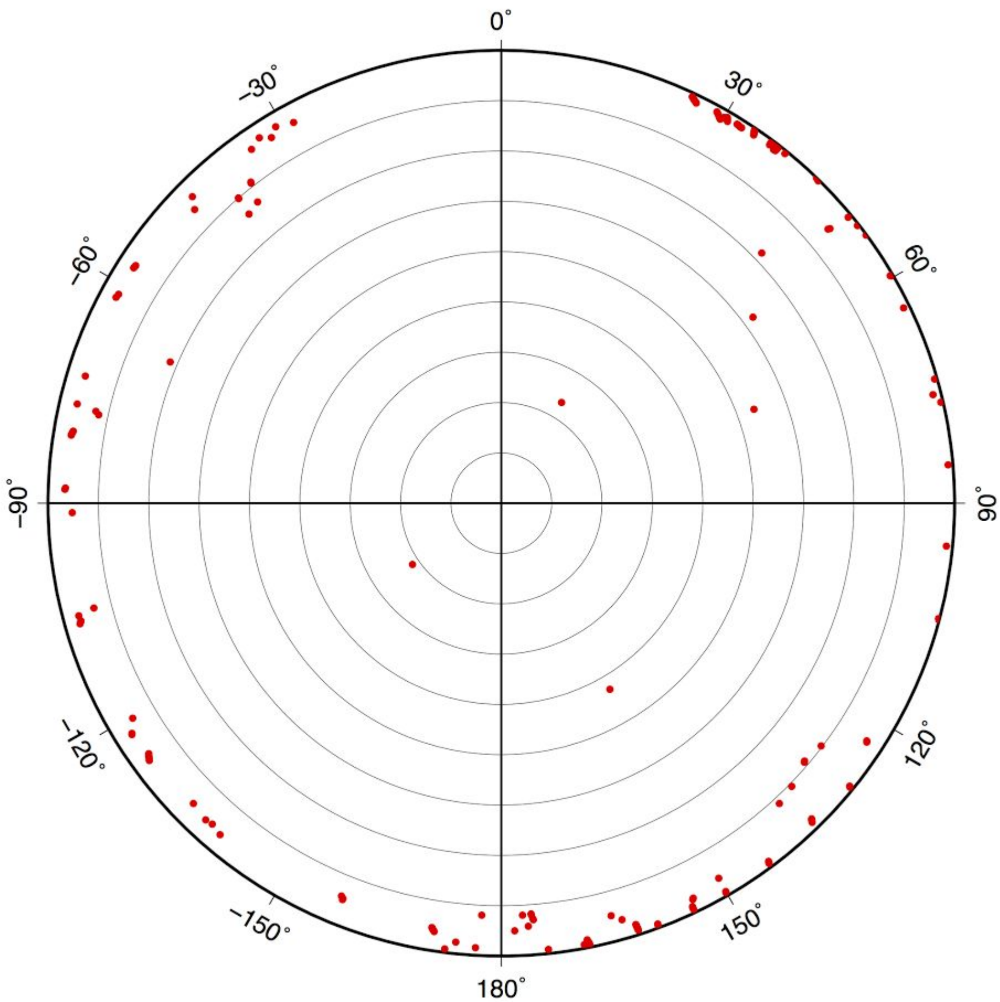


Figure 26. Receiver X L1 and L2 slips detected in four daily 1 Hz RINEX files using a Melbourne-Wubbena slip detection algorithm.

Figure 27

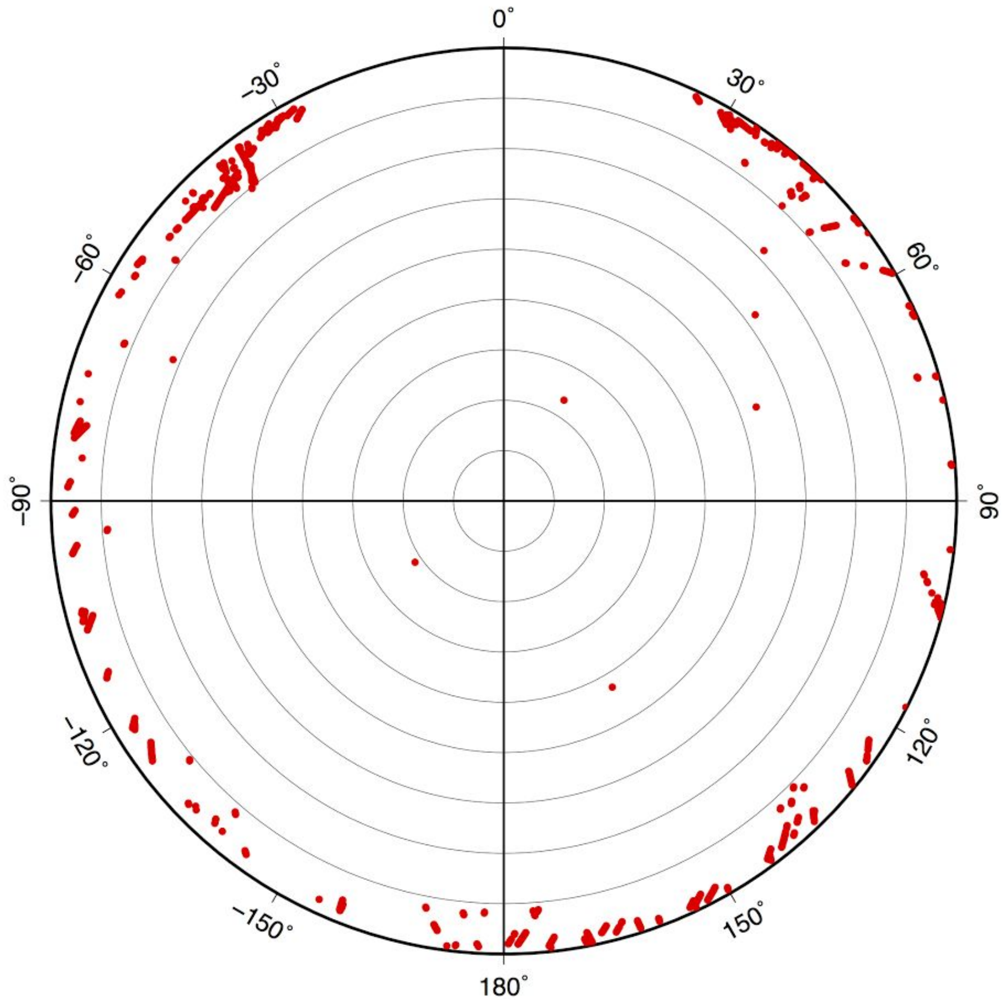


Figure 27. Receiver Y L1 and L2 slips detected in four daily 1 Hz RINEX files using a Melbourne-Wubbena slip detection algorithm.

Figure 28

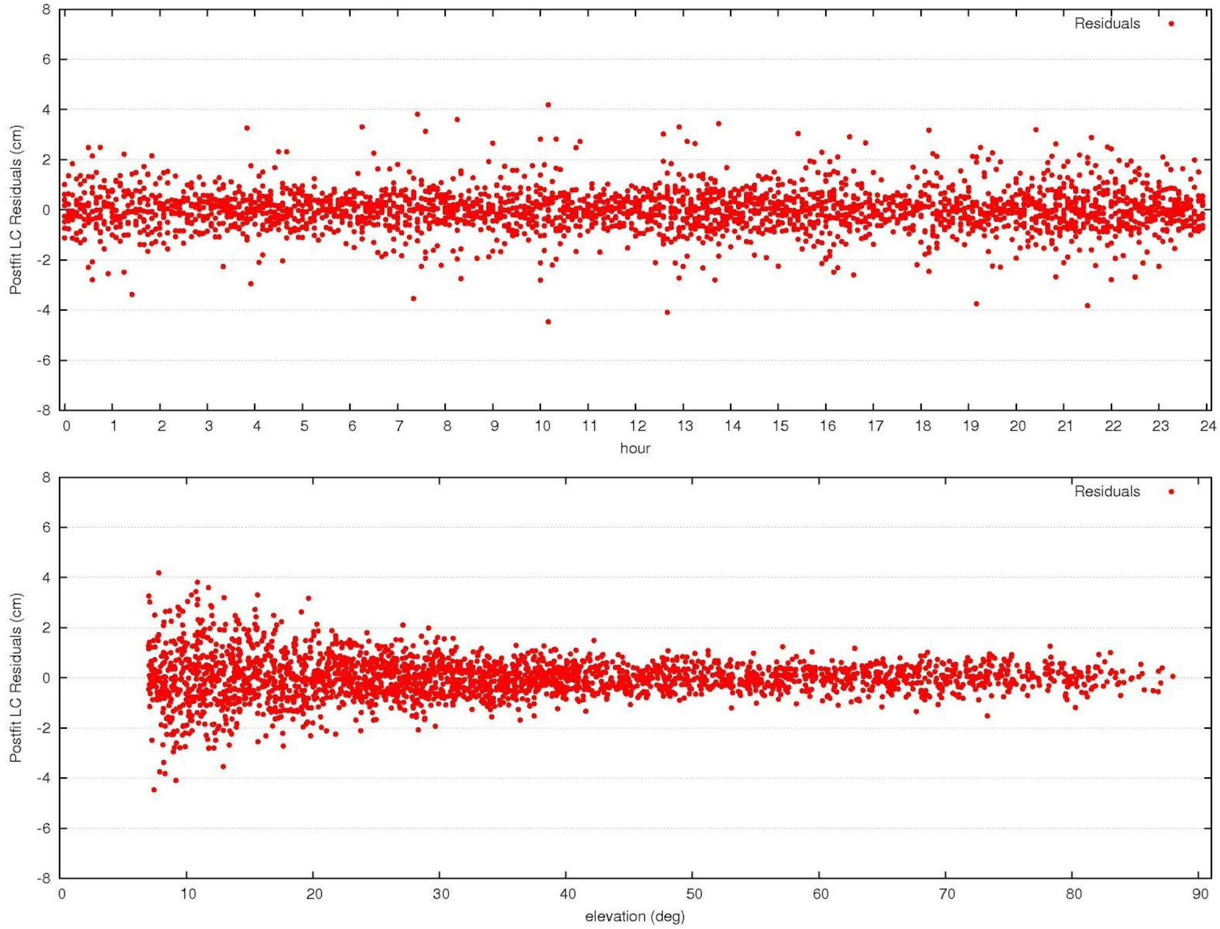


Figure 28. GIPSY-OASIS phase residuals for Receiver Y. We used 7 degree satellite elevation cutoff in processing

Figure 29

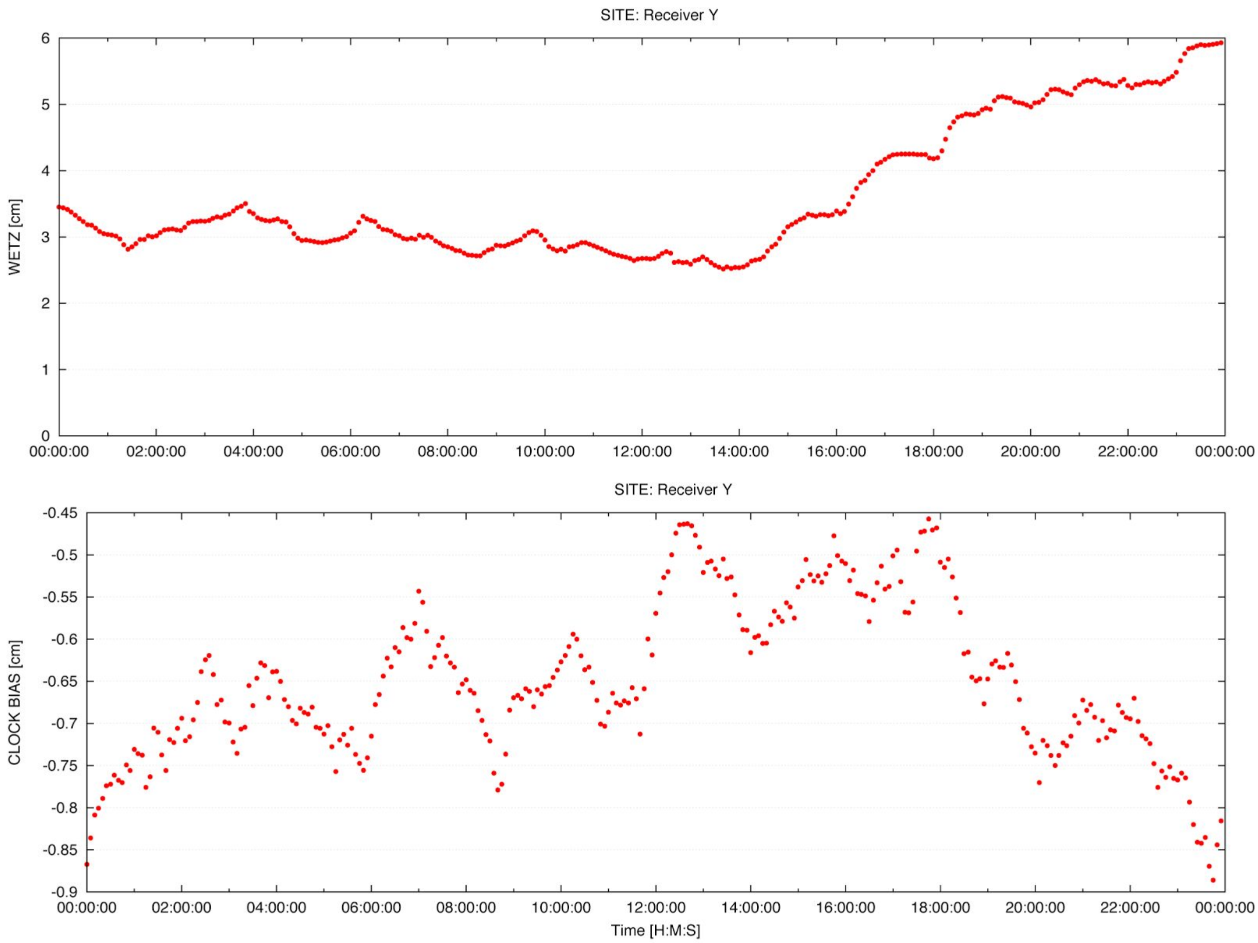


Figure 29. GIPSY-OASIS wet troposphere delay and clock bias estimates for Receiver Y.

Figure 30

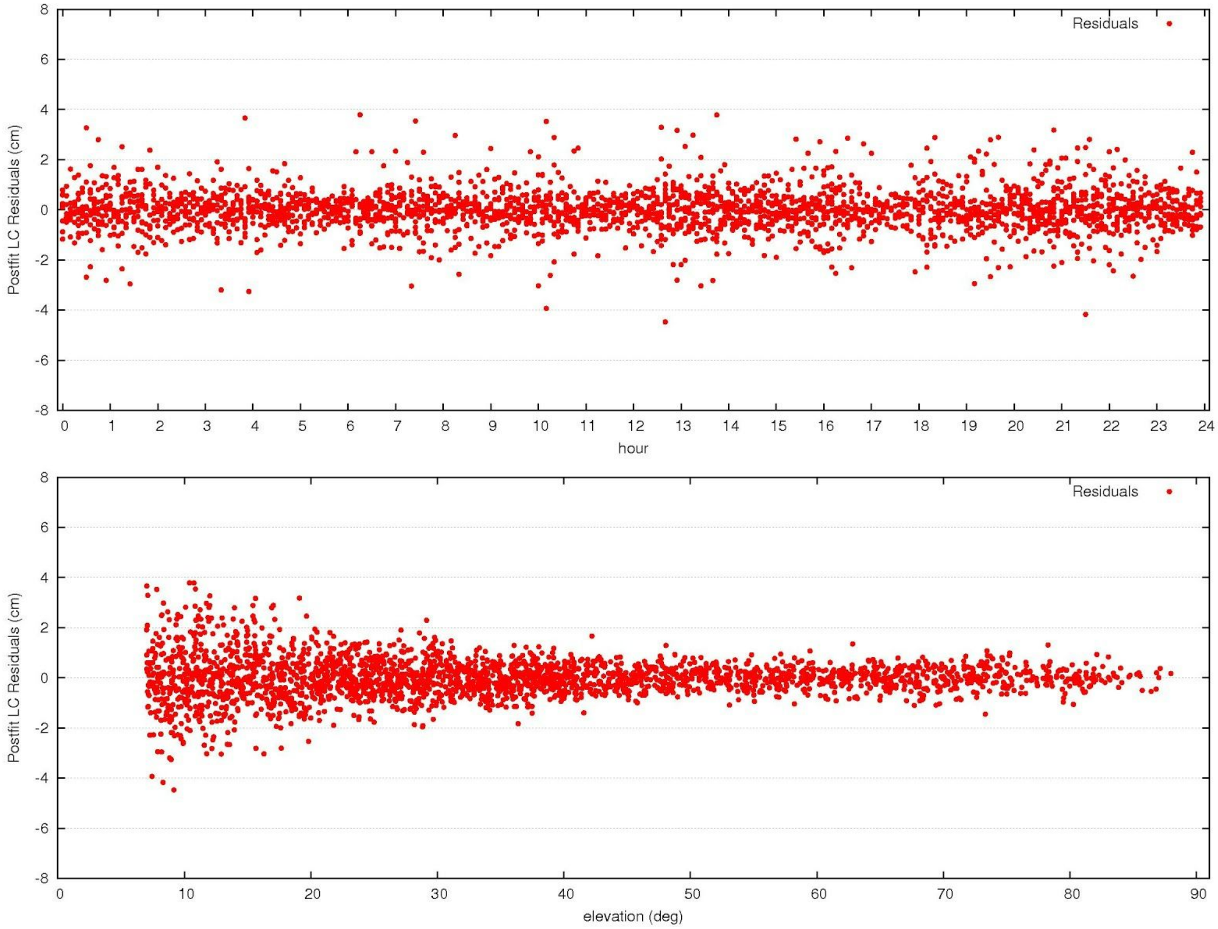


Figure 30. GIPSY-OASIS phase residuals for the PolaRx receiver.

Figure 31

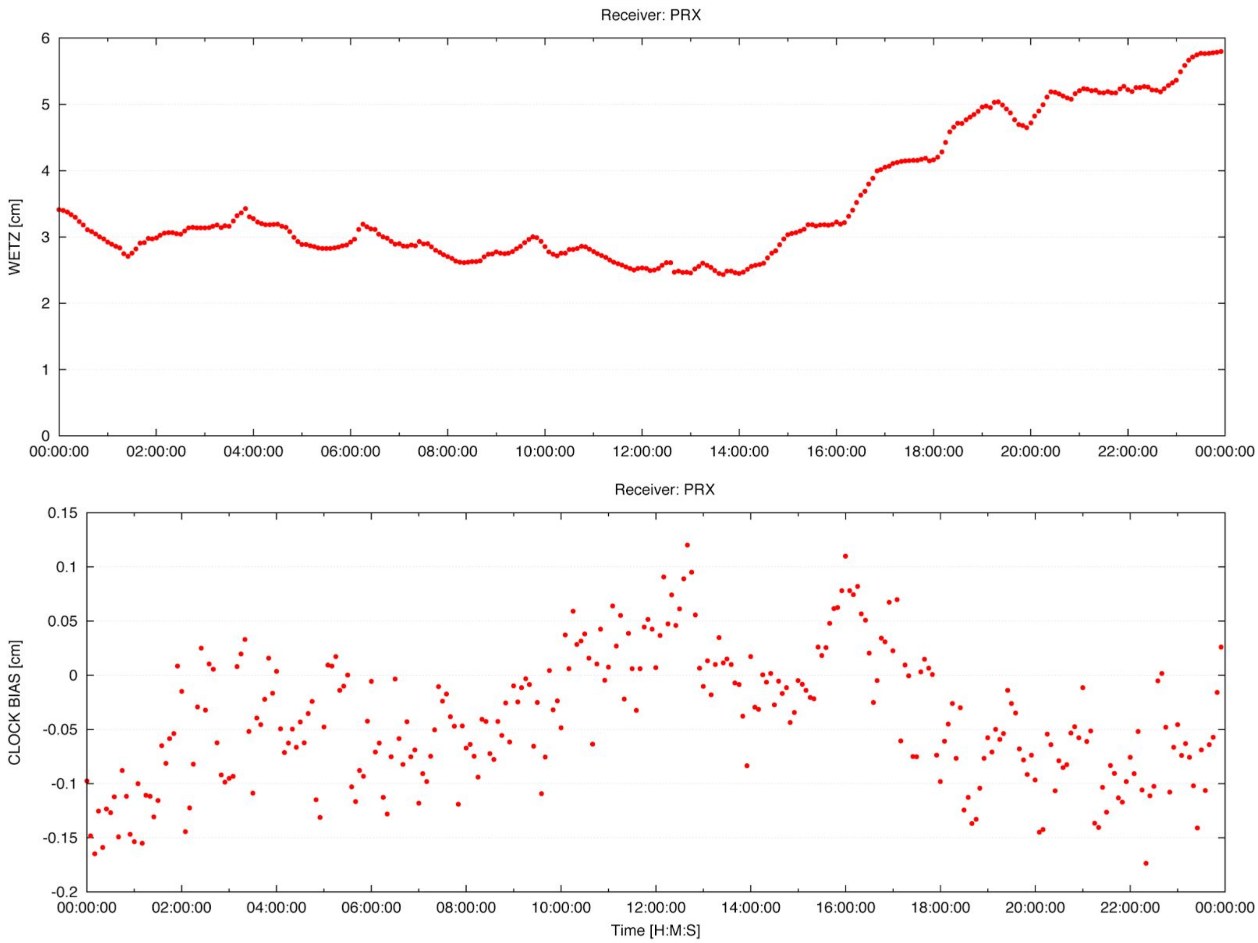


Figure 31. GIPSY-OASIS wet troposphere delay and clock bias estimates for the PolaRx receiver.

Figure 32

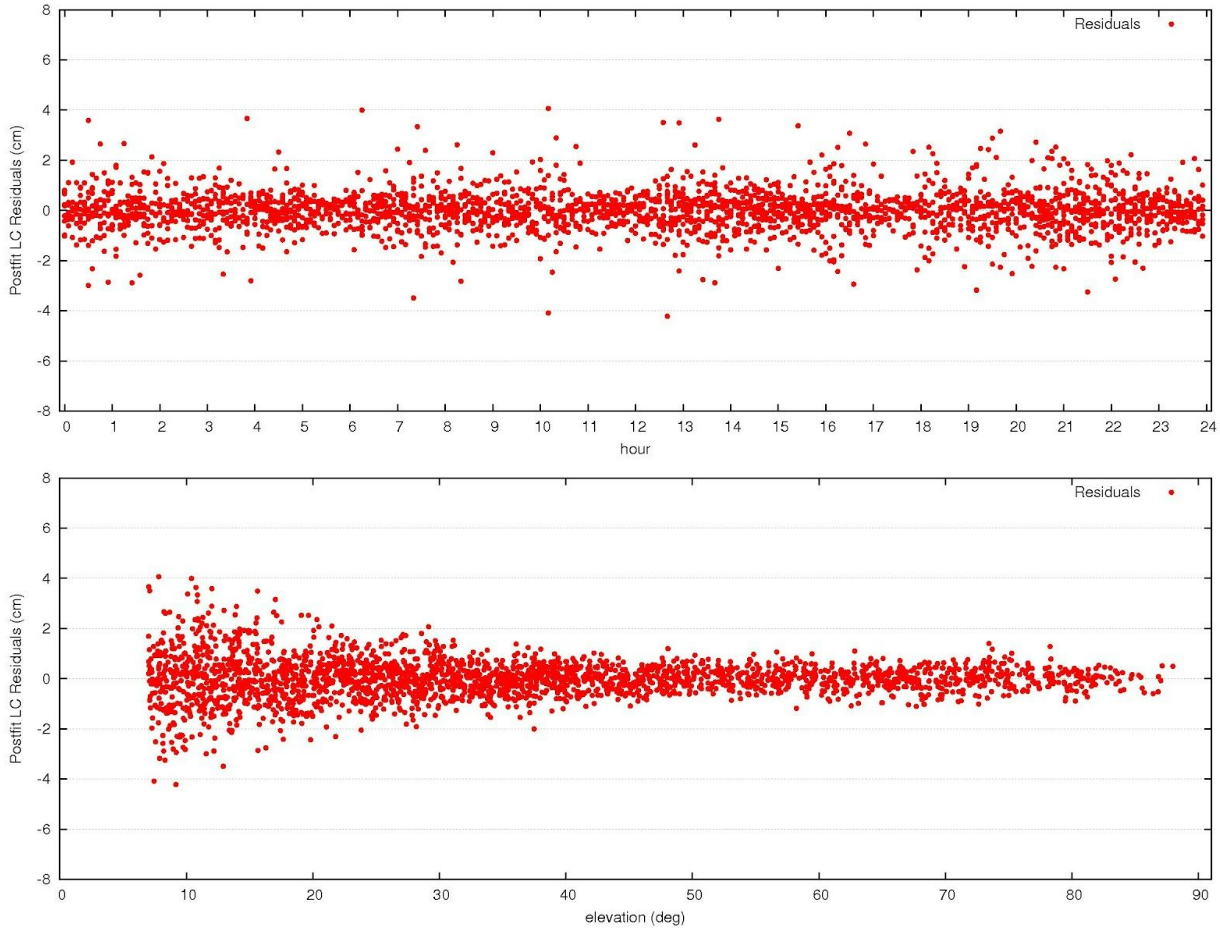


Figure 32. GIPSY-OASIS phase residuals for Receiver X.

Figure 33

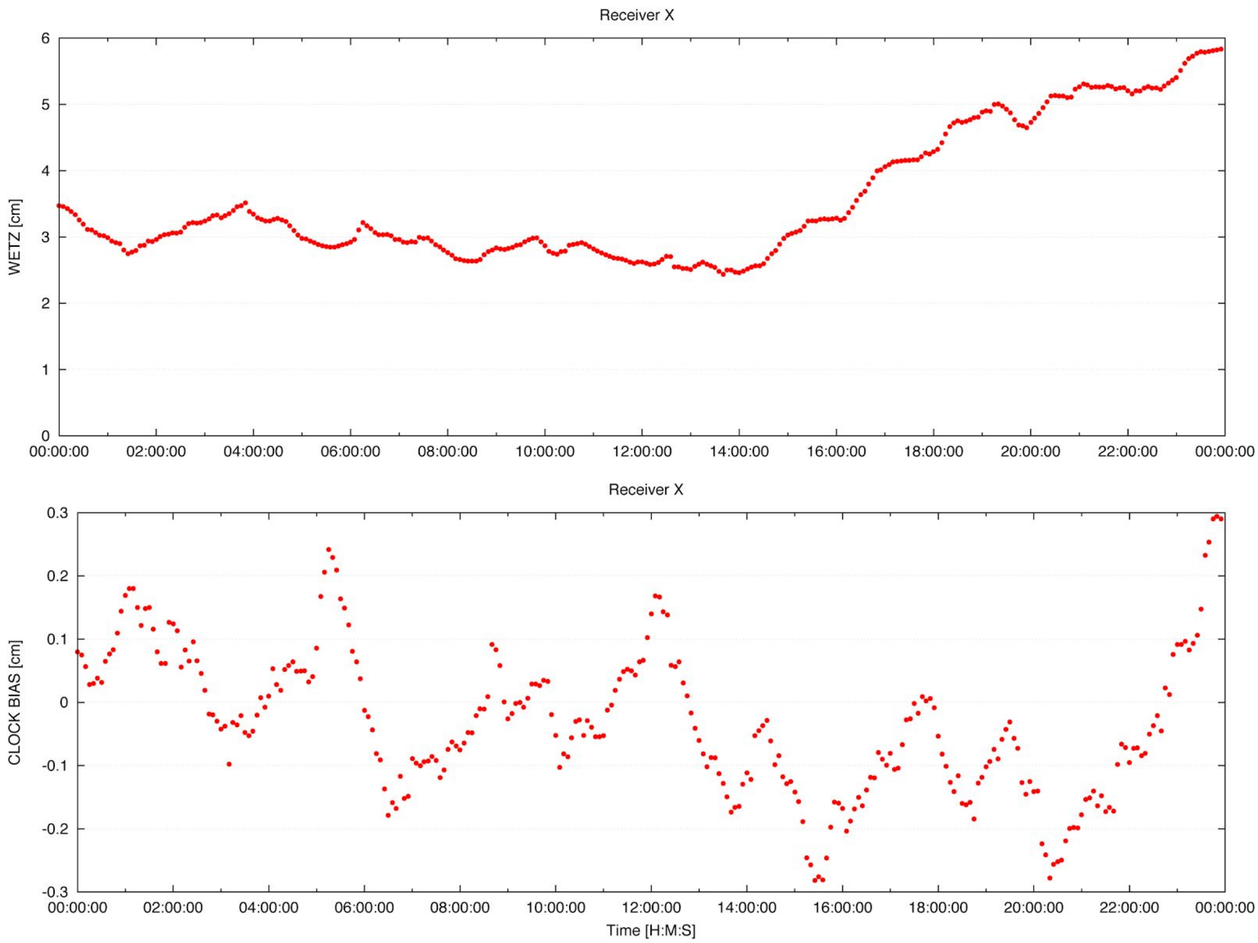


Figure 33. GIPSY-OASIS wet troposphere delay and clock bias estimates for Receiver X.

Figure 34

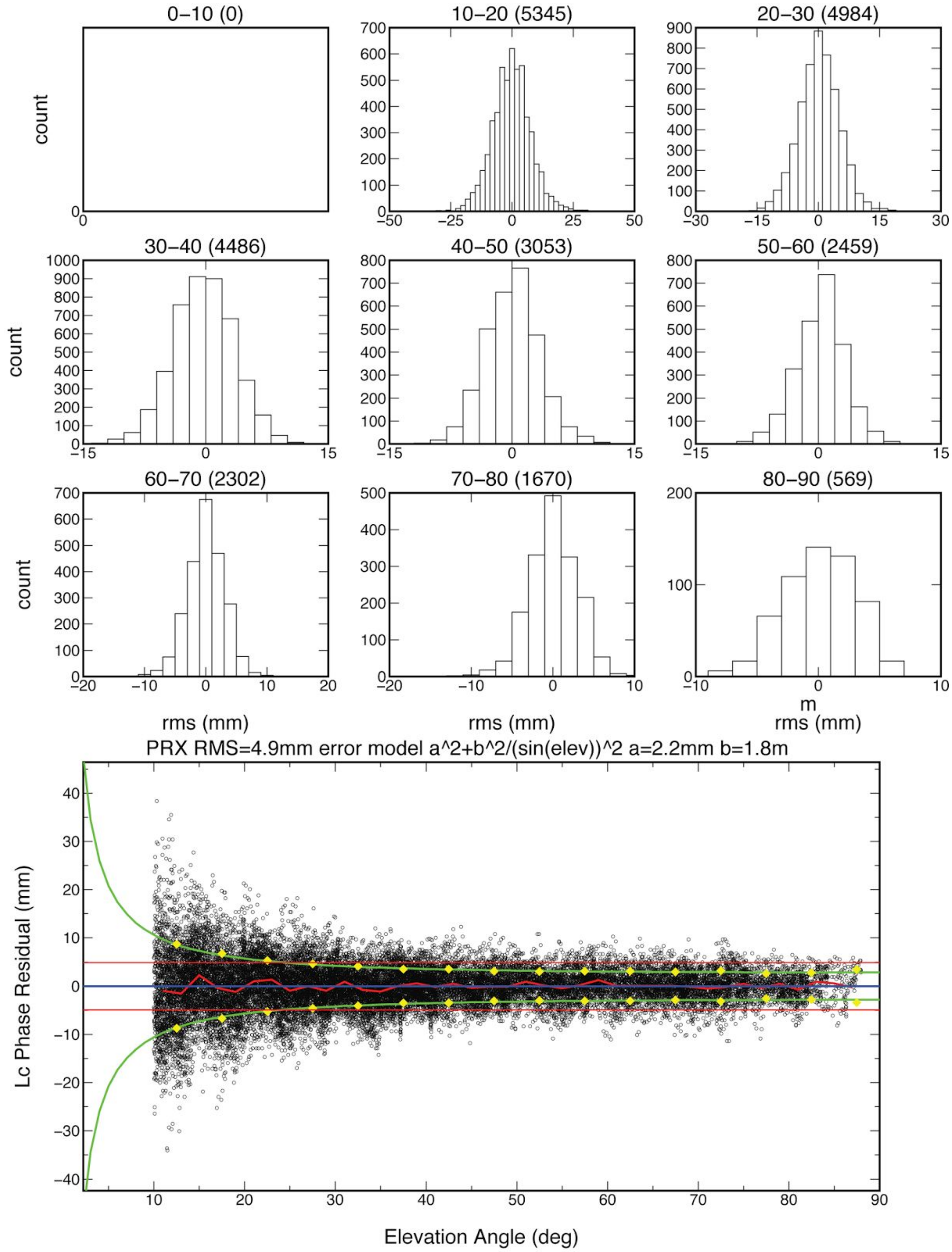


Figure 34. GAMIT LC Phase residuals for the PolaRx receiver on doy 120.

Figure 35

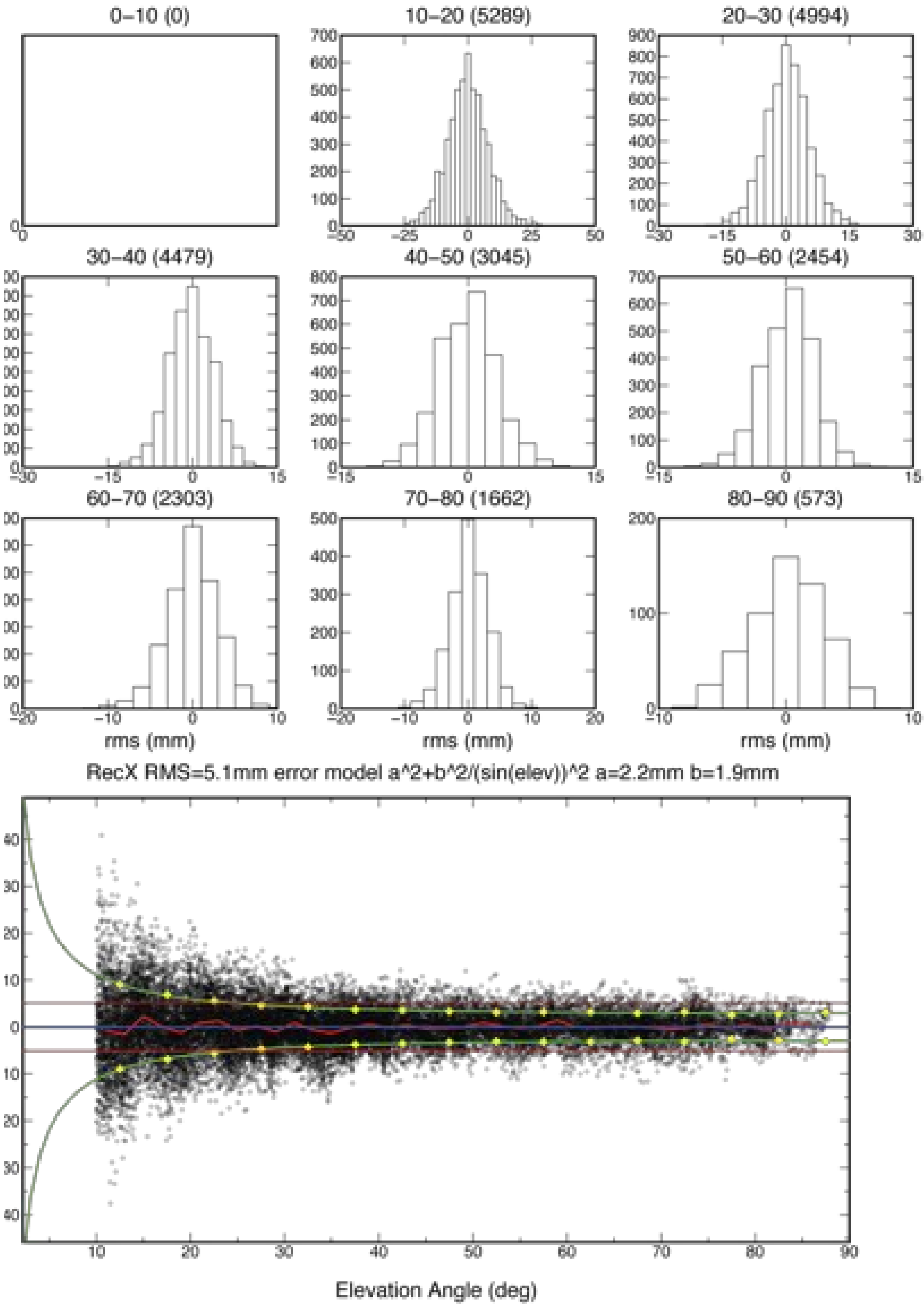


Figure 35. GAMIT LC Phase residuals for Receiver X on doy 120.

Figure 36

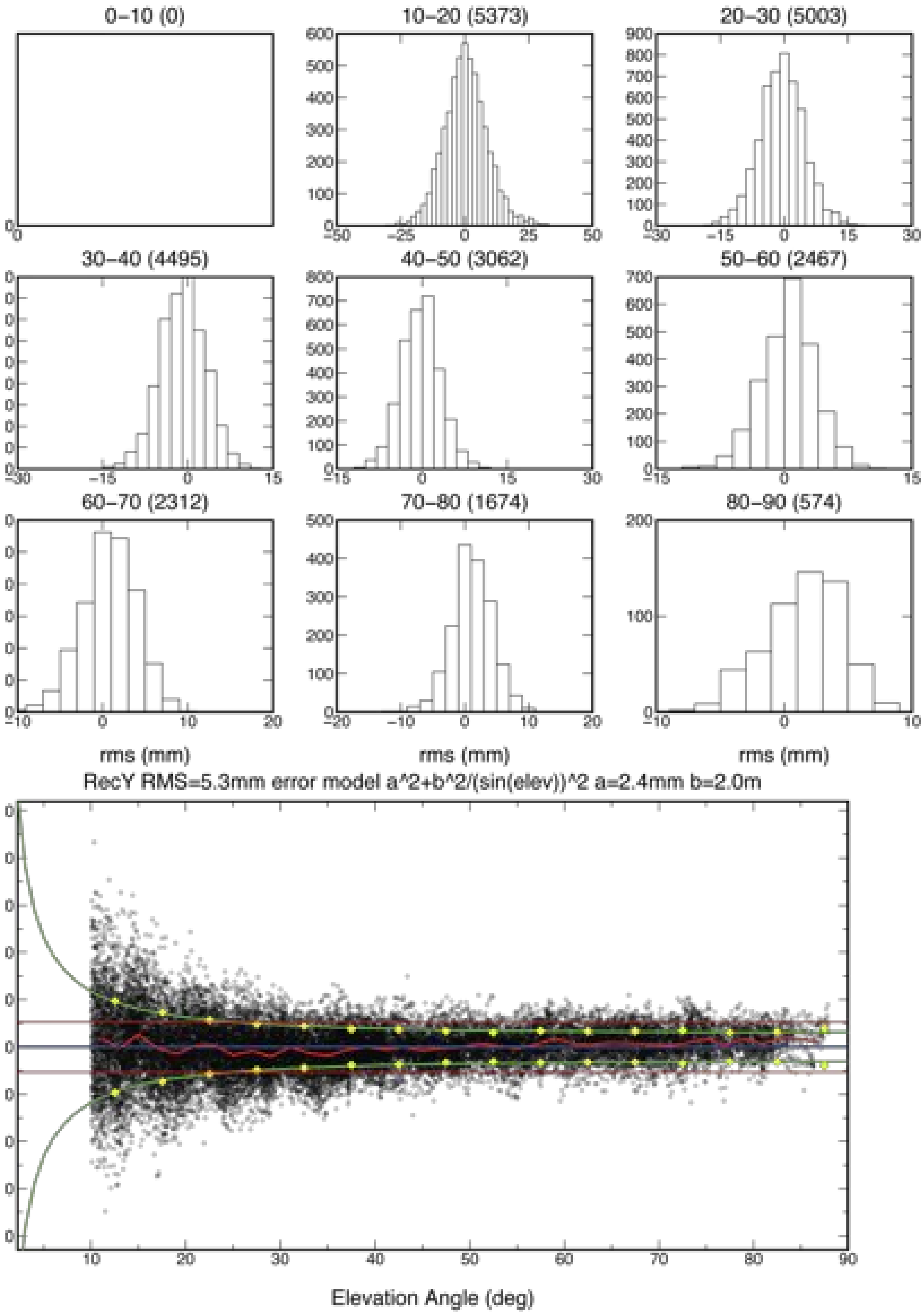


Figure 36. GAMIT LC Phase residuals for Receiver Y on doy 120.

Figure 37

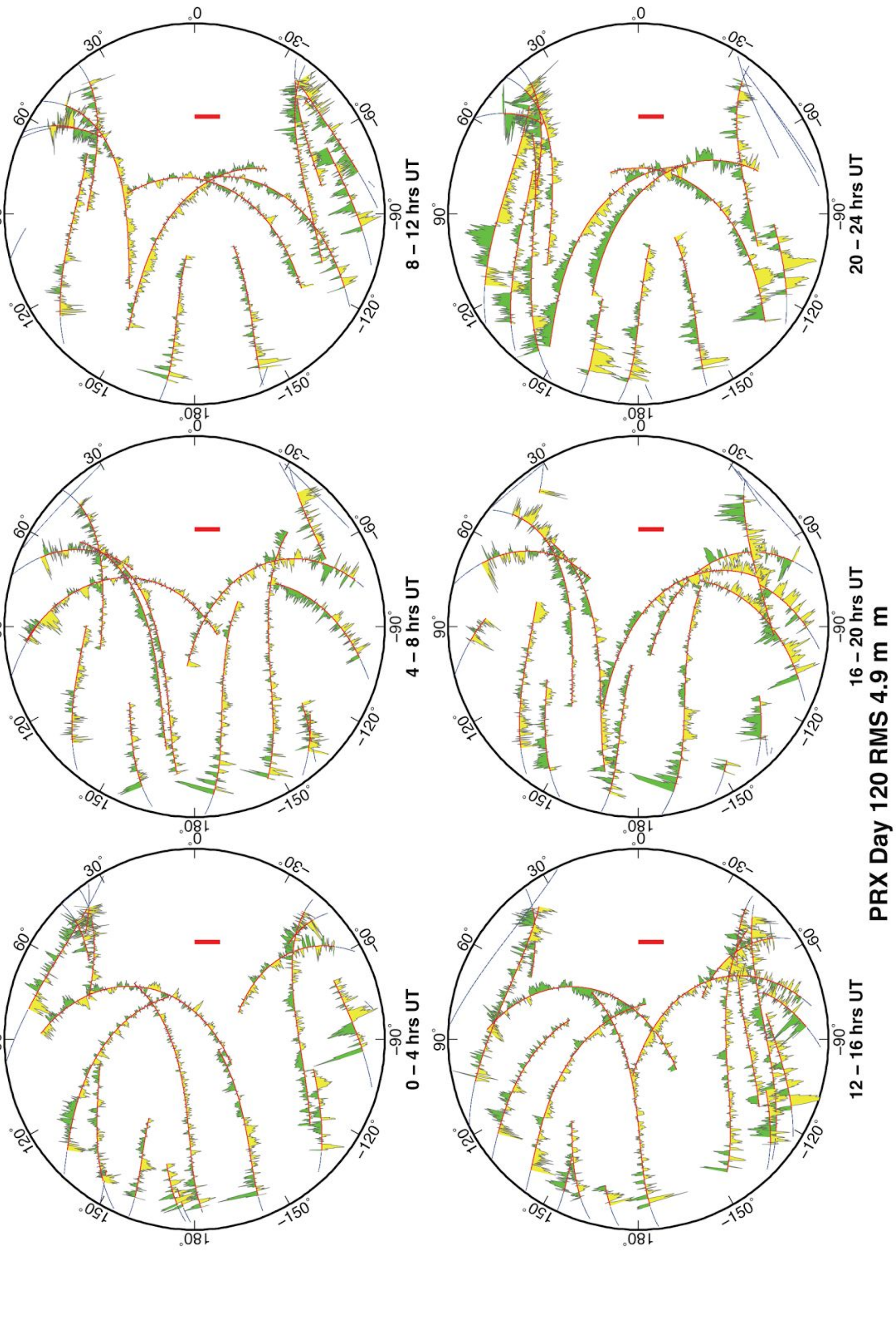

0 – 4 hrs UT
4 – 8 hrs UT
8 – 12 hrs UT
12 – 16 hrs UT
16 – 20 hrs UT
20 – 24 hrs UT
PRX Day 120 RMS 4.9 m m
PRX DPH LC Residual Scale 0.5 Tick 19 m m
2015 May 07 10:28:06

Figure 38

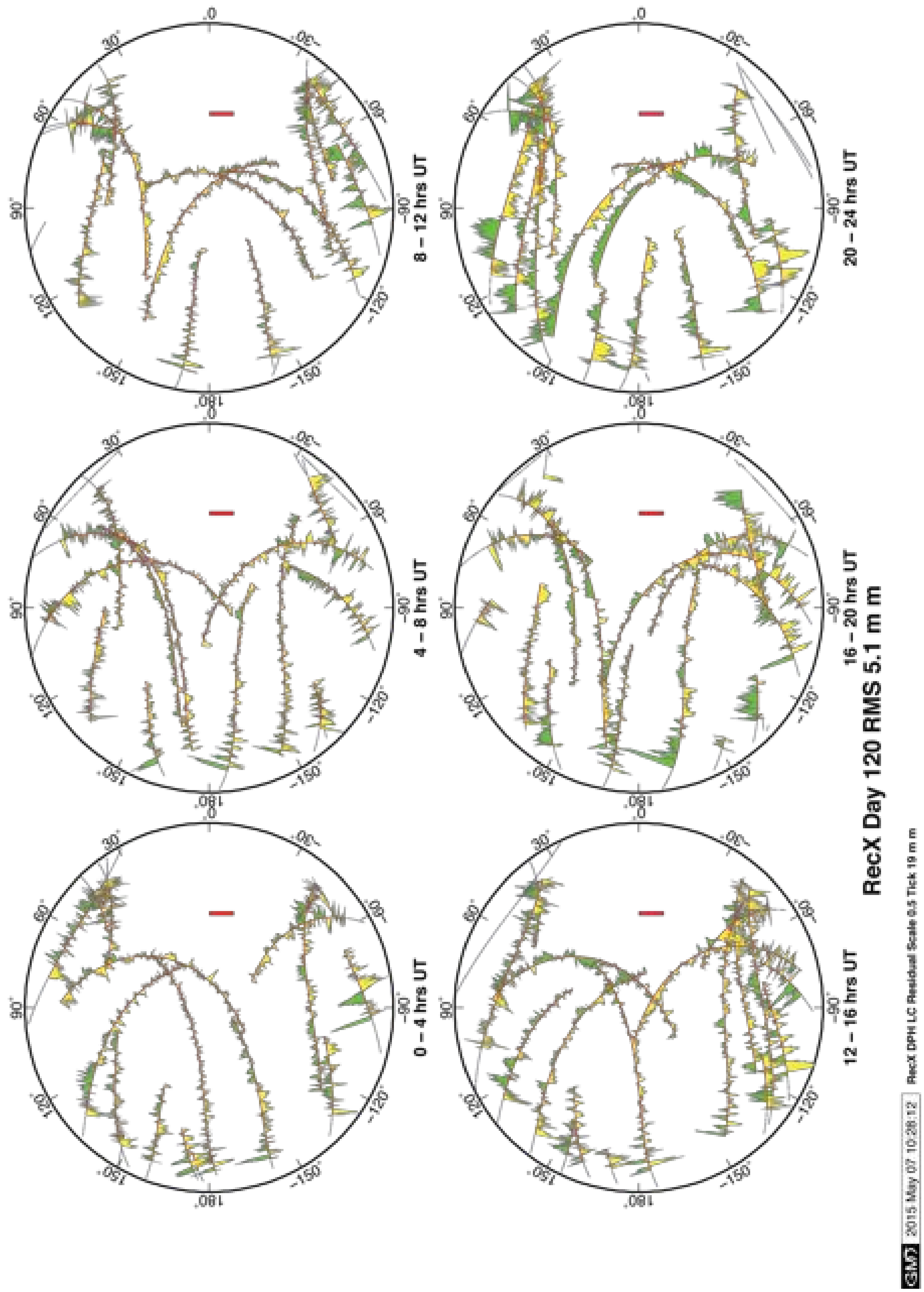

0 – 4 hrs UT
4 – 8 hrs UT
8 – 12 hrs UT
12 – 16 hrs UT
16 – 20 hrs UT
20 – 24 hrs UT
RecX Day 120 RMS 5.1 m m
2015 May 07 10:28:12

Figure 39

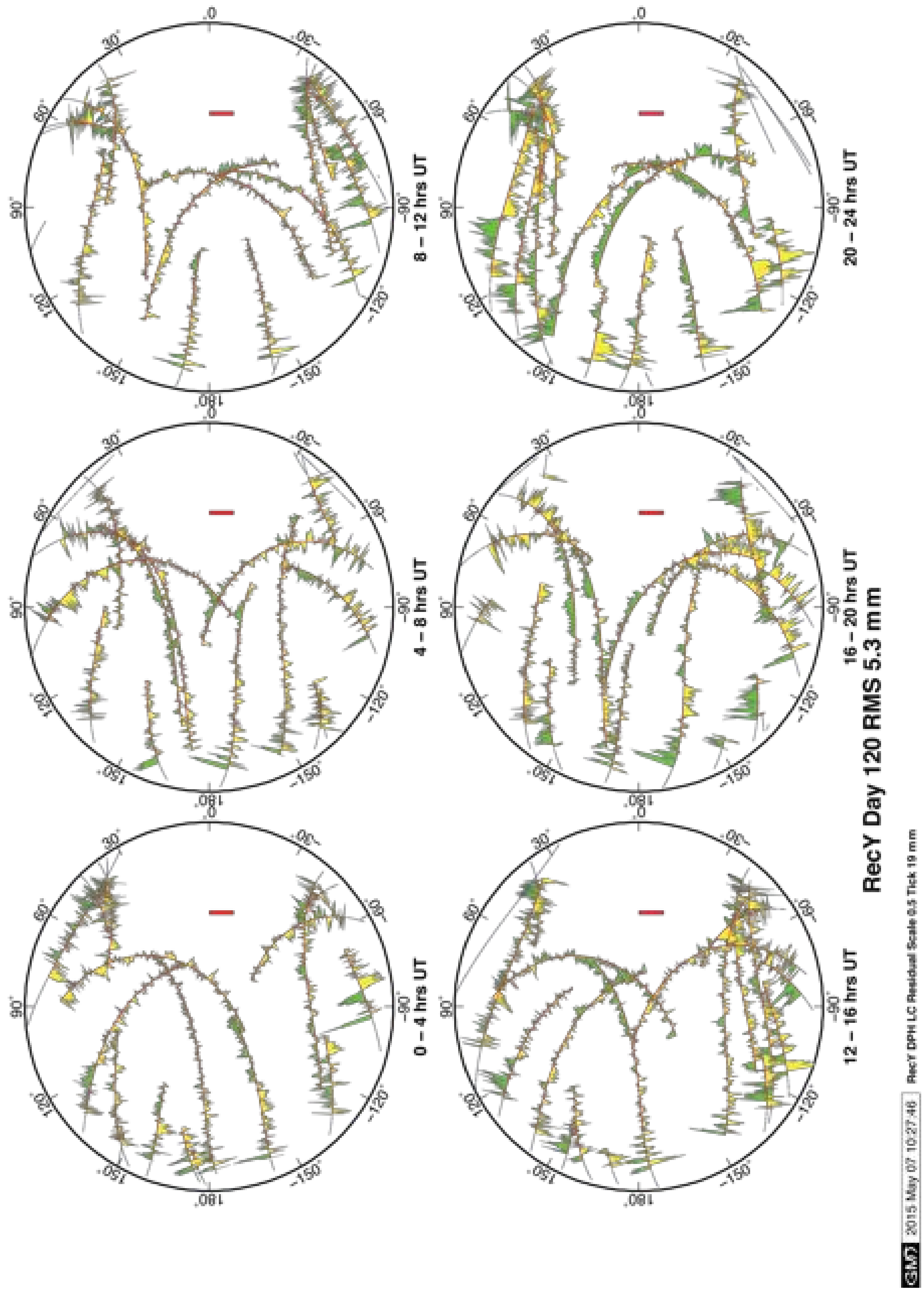

0 – 4 hrs UT
4 – 8 hrs UT
8 – 12 hrs UT
12 – 16 hrs UT
16 – 20 hrs UT
20 – 24 hrs UT
RecY Day 120 RMS 5.3 mm
2015 May 07 10:27:46

Table 4 - Required Technical Specifications

Required Technical Specification	Weight
General	
Multi-frequency GNSS (Global Navigation Satellite System) receiver able to track all signals on all available frequencies from the following constellations: GPS, GLONASS, Galileo, Beidou, and SBAS. Also desirable are the capabilities to track the regional QZSS and IRNSS signals. Unsmoothed pseudorange, signal-to-noise, Doppler, and carrier phase observables must be recoverable from the receiver.	5
Ability to purchase receivers with specific constellation tracking disabled (i.e. GPS-only or GPS-GLONASS only) at reduced price is preferred.	3
Receivers must be able to simultaneously track all available signals on all satellites, even if the SV is unhealthy, to an elevation angle of 0°.	5
Signal to noise observations should be measured and stored at a resolution of 0.1 dB*Hz or better.	3
The phase observations are measured and stored at a resolution of 0.001 cycle or better.	5
Pseudorange observations should be measured and stored at a resolution of 0.001 meter or better.	5
Ability to enable or disable any Vendor---defined code and carrier multipath rejection technology.	5
Receiver must meet the following environmental specification: Operating temperature: ---40° C to+75° C; Humidity: 100%, fully sealed; Shock: 1 m drop to hard surface	5
Receiver Performance	
Total Expected vs. Total Observed - Teqc does not break down expected/observed by elevation angle, so I'm not sure why the old RPF evaluators specified bins. I think that total expected/observed should be sufficent.	5
Number of slips above 10 degrees (lower is better)	
Number of slips 5 to 10 degrees (lower is better)	
Number of slips 0 to 5 degrees (lower is better)	
Observations per slip (Specification requires >20,000)	4
Zero baseline test	4
North standard deviation	

East standard deviation	
Up standard deviation	
Short baseline test	
Tracking during vibration	4
Proprietary data formats	
Proprietary formats used in data streams and logged files must be thoroughly documented so that UNAVCO can update software to translate all pertinent contents and messages, including metadata. Modifications to proprietary formats that occur within the receiver warranty period must documented and made available to UNAVCO at the time of firmware release.	4
Full support for translation of data files to RINEX 3.02 format must be provided. This may be either onboard the receiver, where a data file is written in RINEX 3.02 format or a user can downloada translated file on---the---fly, or in the form of software that will convert a native binary to RINEX 3.02 after downloading. All software executables must be compatible with LINUX operating systems.	3
Built-in Ethernet communications port allowing for TCP/IP configuration of all receiver features, data files, and data streams.	5
Receiver must be capable of producing data streams and downloadable logged data files in BINEX format, containing all GNSS observables, navigation messages, attached met/tilt and other ancillary serial devices, site metadata, and system status records. Minimum requirement is BINEX 0x7f---05 (ornewBINEX0x02tosupersede0x7f---05 and 0x7f---04) with support for all GNSS observables, 0x00 for metadata and comments, and 0x01 for GNSS navigation messages. BINEX 0x7d for receiver state information is preferred, but not required. Streaming protocols supported should include TCP/IP, UDP, and NTRIP.	3
Receiver must be capable of producing data streams in RTCM3 format with support for IGS--- standard Multi---System Messages (MSM), using the protocols noted above.	4
Serial port support for connection of at least 4 RS---232 meteorological devices, tiltmeters, or other sensors with data output integrated into both logged and streamed data.	5

4-ports	
Met Support	
Serial port support for connection of at least 4 RS---232 meteorological devices, tiltmeters, or other sensors with data output integrated into both logged and streamed data.	6
4-ports	
Sample Rate (50Hz)	4
Pseudorange	
Carrier Phase	
Signal-to-Noise	
FTP	5
TCP port configurable	
REST Support	
MDTM Support	
Delete Support	
Data Logging	
6mo storage at 1Hz	5
Industrial Memory	4
USB, SATA or other IEEE external hosting	3
Hardware failure protection	
Logging Sessions	
8 sessions	3
met/tilt separate and not dependent on GNSS SV tracking	2
File names must include either the ordinal date (e.g. YYYYDDD) or the Gregorian date (e.g. YYYYMMDD) from the time of creation of the file. A user specified station name must also be included in the file name or must default to some known token such as the receiver serial number or some portion thereof. File names must also include characters to distinguish when multiple files are created on the same day.	
Date in name	5
User specified station name	4
Managed Data Partitions	
Data storage for each logging session must be independently managed in partitions of user-configurable size using ring buffers or memory pools, i.e. automatic deletion of older data files will occur while newer files of lower sample rates are preserved.	5

Option to stop logging a particular session when its memory pool has reached designated capacity instead of overwriting older files is required.	4
A user specified data directory structure that allows for: 1) separate directories for each calendar month; 2) user-specified naming of the directories; and 3) user-specified structure of the directories. At a minimum, each data logging session should be stored in a unique directory. This is critical in order to facilitate data flow strategies that commonly involve directory content queries.	5
Separate directories for different sessions/months	
User specified naming	
User specified structure	
Event-triggered data logging sessions (e.g. a session that would activate if an attached accelerometer detects strong ground motion at the site) is desired.	3
The ability to save the configuration of the receiver in a downloadable file and upload it to other receivers remotely is required.	5
Savable config file	
Download config file	
Upload config file	
Configuration files should have the option of retaining network IP configuration or applying new user- specified IP settings.	
Power consumption of less than 5 watts when tracking all GNSS signals and logging two data sessions of 10 Hz and 15 sec sample rates to onboard memory. Receivers with lower power consumption are preferred. Ability for the user to further reduce power consumption by disabling any receiver functions (e.g. limiting tracking to GPS-only, or disabling specific network interfaces) is strongly preferred.	5
User-programmable reboot timer or other "watchdog" system that provides for automated system restarts without active user interaction	4
Auto restart following power interruption	5
Power on Voltage	4
DC Power ports (2)	3
Power port logic	

AC adaptor	
Voltage range: Unit should operate properly if external DC voltage of greater than 10.8 and less than 28 volts is applied. Wider operational power specifications are preferred.	4
On-board battery or UPS is not required, and if present, should be removable at user option OR must include user- configurable settings to control the circumstances under which power is used to maintain its charge. If a battery backup is present, the receiver must function properly if it loses its ability to maintain a full or partial charge to the backup system.	4
Network firewall or IP filtering scheme to protect the receiver from on-line attacks or unwanted access is required.	5
A command-line API for uploading and application of receiver configuration files and firmware updates over TCP/IP and serial interfaces.	5
Desired Technical Specification	**Weight**
FTP Push	2
Anonymous FTP Support	2
Rsync	2
SFTP Support	1
Data Logging	
Resume logging to file after interruption	
Support for onboard data compression	2
A command-line API for gathering receiver state of health (e.g. temperature, voltage, and uptime).	3
Temperature	
Voltage	
Uptime	
User-accessible activity log files to aid in system troubleshooting that records system reboots, boot sequences, voltages, low voltage shutdown activity, temperature and shutdown	2

sequences. The log file directory must be able to record the last 180 days of activity	
Antenna Required	**Weight**
Separate pricing for receiver & antenna	
Compatible with existing PBO Network	
Phase Center	
Preamplifier (14 dB)	
Temperature testing (-40 to 75C)	
GNSS Support	
Compatibility	4
Monument	
Dome	
Connectors	
Accessories	**Weight**
DC Power Cable	
Antenna Cable	
Optional AC Power Supply	
Miscellaneous	**Weight**
User Manual	3
Online Help	3
GLONASS Outage	1
Wifi	
GSM Modem	
Questions	**Weight**
Configurable Tracking Loops	2
Signal-to-Noise	
Ionosphere analysis capabilities	1
RF Interference	4

List of Tables and Figures