UNAVCO 2004 GPS Campaign System Testing in Support of the Plate Boundary Observatory (PBO)

Victoria Andreatta

Charles Meertens

Jim Greenberg

Warren Gallaher

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Cover (left to right/top to bottom): - Death Valley, Nevada; Yellowstone Geyser Basin, Wyoming; UNAVCO personnel inquiring about Campaign systems being tested, Colorado; and San Simeon Earthquake response, California.

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1.0 Introduction

The UNAVCO Facility in Boulder has been involved in receiver and antenna testing to support UNAVCO Community equipment purchases including: the community Academic Research Infrastructure (ARI) procurement of over 250 systems in the mid-1990's, the SuomiNet Major Research Infrastructure (MRI) purchase of over 100 systems in 2000, and the Plate Boundary Observatory (PBO) purchase of 875 permanent GPS systems stretching from 2004-2008. Another competitive Plate Boundary Observatory Request for Proposal (RFP) was released early in 2004. This RFP was issued to the major commercial GPS vendors that develop and manufacture high-end dual-frequency Campaign GPS receivers and geodetic quality antennas. The UNAVCO Facility in Boulder was tasked with evaluating the various receivers submitted by manufacturers in response to the PBO Campaign System RFP, as well as providing a technical recommendation to the PBO Principal Investigators.

This document represents the test results upon which the technical recommendation will be based. Manufacturers who responded to the bid specification and who were chosen for evaluations provided the systems listed in Table 1.1.1. It should be noted that these receivers mark a significant improvement in GPS technology with some having: direct Ethernet connectivity, low power consumption (< 3 watts), new observable (L2C) tracking capability, compact size, and superior tracking performance.

Table 1.1.1 - Receiver and antenna pairs tested.

Receiver	Part Number	Firmware	Antenna	Part Number
Sokkia GSR2600	502-0-0033	2.11	SOK600	500-0-0005
Topcon Odyssey RS	01-830111-01	2.3 July 08, 2003 p2u1	TPS PG-A1 Geodetic	01-840201-01
Trimble R7	50157-00	2.10 Sept.03	Trimble Zephyr Geodetic	41249-00
Topcon GB-1000	n/a	2.3 July 08, 2003 p2u1	TPS PG-A1 Geodetic	01-840201-01
Topcon GB-1000	n/a	2.3 July 08, 2003 p2u1	TPS PG-A1 Geodetic + GRNDPL	01-040201-01

Each receiver/antenna pair was tested and scored independently. The technical tests can be summarized in four main categories:

(1) Receiver Tracking and Data Quality Tests. These tests are based on statistics determined from UNAVCO's Translation, Editing, and Quality Checking program (TEQC), and contain information that can be determined from a single GPS file (one receiver/antenna). Included are tracking percentages, cycle slip counts, multipath statistics, and signal-to-noise ratio strength for L1 and L2.

(2) Baseline processing tests. For this part of the test, short baseline processing was performed using the Bernese 4.2 processing software. These results resemble actual geodetic processing results. On very short baselines, most propagation effects cancel, putting the emphasis on receiver/antenna performance. All observation files were also run through AutoGIPSY (http://milhouse.jpl.nasa.gov/ag), JPL's automated point positioning processing software to compare repeatability's with Bernese results.

(3) Power testing was completed using custom made hardware and LabView.

(4) System weight, size, and the amount of onboard memory were also taken into account.

These test results are summarized in each section and will be used to generate a numerical ranking of relative receiver/ antenna technical performance. The results will be included in a separate and confidential response to the PBO Principal Investigators. Additionally, a series of mandatory requirements were tabulated and are presented throughout this report. The summary contains the mandatory pass/fail specifications as stated in the RFP. The appendices contain information relating to receiver interfacing and configuration, transport case photographs, and the antenna phase center patterns used in processing.

2.0 Test Configuration

All tests were conducted on the roof of the UNAVCO, Inc. building. Figure 2.1.1 shows the rooftop mounting system and benchmark names used during testing. An Ashtech Z-XII3 was run on benchmark INA0 for the entire duration of testing in case any problems were encountered with the test receivers. This data is included for reference and was not scored. Short baseline testing was conducted on mounts IND0 and INE0. Each mount was equipped with a UNAVCO leveling mount (Figure 2.1.2) to ensure proper horizontal and vertical alignment of the antenna. The mounts used for testing had RG-58, 30 meter cables which remained the same for the entire duration of testing.

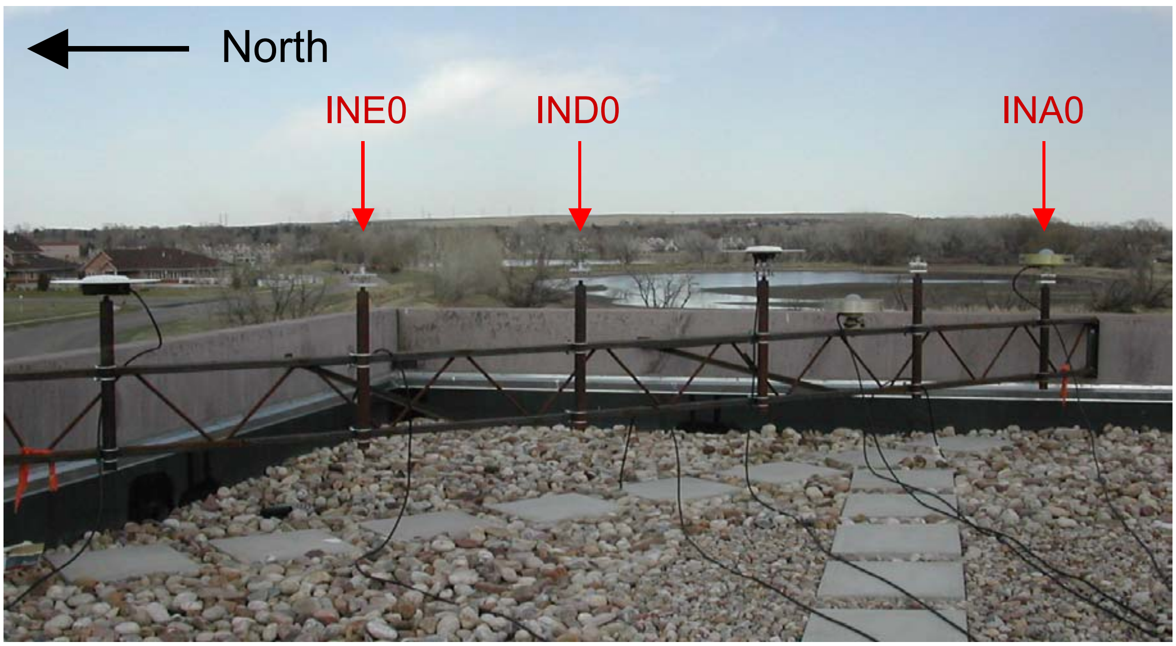


Figure 2.1.1 - Rooftop testing area at UNAVCO, Inc. Facility. INA0 is pictured on far right. The two mounts used for testing, IND0 and INE0, are pictured on the left.

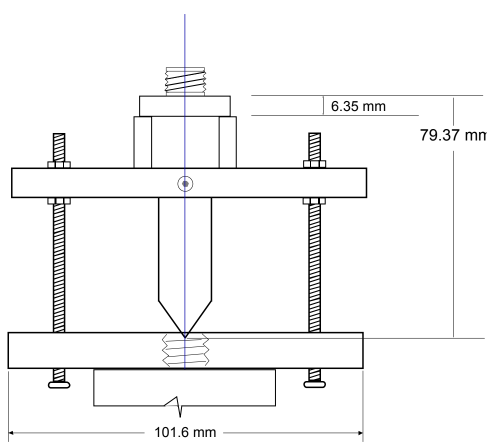


Figure 2.1.2 - Each benchmark was fitted with a UNAVCO leveling mount. This provided a way to align the antennas to North, and a method to lock the antennas in place to prevent any unwanted movement.

Table 2.1.1 shows the abbreviations that will be used throughout this report for each receiver and antenna. Figure 2.1.3 shows each system tested.

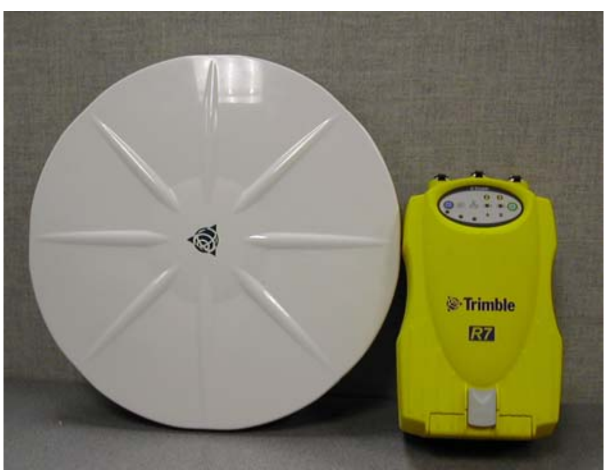
Table 2.1.1 – Receiver and antenna abbreviations used.

Receiver	Abbreviation	Antenna	Abbreviation
Sokkia GSR2600	SOK GSR2600	Sokkia 600 dual frequency	SOK600
Topcon Odyssey RS	TPS Odyssey RS	Topcon PG-A1 Geodetic	TPS PG-A1 Geod
Trimble R7	Trimble R7	Trimble Zephyr Geodetic	TRM 41249 Geod
Topcon GB-1000	TPS GB-1000	Topcon PG-A1 Geodetic	TPS PG-A1 Geod
Topcon GB-1000	TPS GB-1000+GRNDPL*	Topcon PG-A1 Geodetic + Groundplane	TPS PG-A1 Geod+GRNDPL

* - TPS GB-1000+GRNDPL will be used when referring to the system with groundplane if no reference to the antenna is made.

Sokkia GSR2600 GPS receiver and SK-600 dual frequency antenna (SOK600).

Topcon Odyssey RS receiver and PG-A1 Geodetic antenna (TPS PG-A1 Geod).



Trimble R7 GPS receiver and Zephyr Geodetic antenna (TRM 41249 Geod).

Topcon GB-1000 receiver and PG-A1 Geodetic antenna with and without groundplane (TPS PG-A1 Geod & TPS PG-A1 Geod+GRNDPL).

Figure 2.1.3 – Equipment submitted for PBO Campaign system testing.

An Ashtech Z-XII3 with antenna ASH701945E_M was run on benchmark INA0 during the entire testing phase. This receiver was run as a reference should any problems with the test receivers been found. The data will also be used for future mixing studies. Each system was tested using the following parameters: 15 second sampling interval, elevation cutoff mask set to zero, multipath mitigation enabled, and pseudorange smoothing disabled. Data files were logged to the internal memory of the receiver and downloaded via software provided by the manufacturer.

Table 2.1.2- Receiver serial number, antenna serial number, test days, and marker name.

Receiver	Receiver Serial #	Antenna	Antenna Serial #	Days	Marker Name
SOK GSR2600	NUA03480011	SOK600	NRK03480039	35, 36, 37	IND0
SOK GSR2600	NUA03480019	SOK600	NRK03480035	35, 36, 37	INE0
TPS Odyssey RS	231-0105	TPS PG-A1 Geod	268-0494	41, 42, 43	IND0
TPS Odyssey RS	231-0102	TPS PG-A1 Geod	268-0663	41, 42, 43	INE0
Trimble R7	220326017	TRM 41249 Geod	12578598	49, 50, 51	IND0
Trimble R7	220326020	TRM 41249 Geod	12560273	49, 50, 51	INE0
TPS GB-1000	220073	TPS PG-A1 Geod	268-0494	55, 56, 57	IND0
TPS GB-1000	220072	TPS PG-A1 Geod	268-0663	55, 56, 57	INE0
TPS GB-1000	220073	TPS PG-A1 Geod+GRNDPL	268-1590	108,109,110	IND0
TPS GB-1000	220072	TPS PG-A1 Geod+GRNDPL	268-0344	108,109,110	INE0
Ashtech Z-XII3	LP01193	ASH701945E Choke	CR520022104	35-57 ; 108-110	INA0

The TPS GB-1000/TPS PG-A1 Geod+GRNDPL was tested and added at a later date in response to comments received by the manufacturer.

After the raw data files were transferred to a PC, they were converted to RINEX using manufacturers supplied data converters. TEQC [Estey and Meertens, 1999] was used to quality check each file using an elevation cutoff of 10°. Each file was windowed to start at 00:00:00 UTC and end at 21:59:45 UTC. Short baselines were processed using the Bernese 4.2 GPS processing software. A custom made LabView VI interface was used for all power tests. Below is a table that presents a summary of all data files collected including: day of year, receiver type, antenna type, marker number, and corresponding filename.

Table 2.1.3 – Day by day summary of data files

DOY	Receiver	Antenna	Rec. Int. (sec)	Mark	File Name	Mark	File Name
35	SOK GSR2600	SOK600	15	IND0	IND00350.04O/N	INE0	INE00350.04O/N
36	SOK GSR2600	SOK600	15	IND0	IND00360.04O/N	INE0	INE00360.04O/N
37	SOK GSR2600	SOK600	15	IND0	IND00370.04O/N	INE0	INE00370.04O/N
41	TPS Odyssey RS	TPS PG-A1 Geod	15	IND0	IND00410.04O/N	INE0	INE00410.04O/N
42	TPS Odyssey RS	TPS PG-A1 Geod	15	IND0	IND00420.04O/N	INE0	INE00420.04O/N
43	TPS Odyssey RS	TPS PG-A1 Geod	15	IND0	IND00430.04O/N	INE0	INE00430.04O/N
49	Trimble R7	TRM41249 Geod	15	IND0	IND00490.04O/N	INE0	INE00490.04O/N
50	Trimble R7	TRM41249 Geod	15	IND0	IND00500.04O/N	INE0	INE00500.04O/N
51	Trimble R7	TRM41249 Geod	15	IND0	IND00510.04O/N	INE0	INE00510.04O/N
55	TPS GB-1000	TPS PG-A1 Geod	15	IND0	IND00550.04O/N	INE0	INE00550.04O/N
56	TPS GB-1000	TPS PG-A1 Geod	15	IND0	IND00560.04O/N	INE0	INE00560.04O/N
57	TPS GB-1000	TPS PG-A1 Geod	15	IND0	IND00570.04O/N	INE0	INE00570.04O/N
108	TPS GB-1000	TPS PG-A1 Geod + GRNDPL	15	IND0	IND01080.04O/N	INE0	INE01080.04O/N
109	TPS GB-1000	TPS PG-A1 Geod + GRNDPL	15	IND0	IND01090.04O/N	INE0	INE01090.04O/N
110	TPS GB-1000	TPS PG-A1 Geod + GRNDPL	15	IND0	IND01100.04O/N	INE0	INE01100.04O/N
35-57; 108-110	Ashtech Z-XII3	ASH701945E_M	15	INA0	INA00DOY0.04O/N*	*DOY- Day of Year	

3.0 TEQC QC Statistics for 10° - 90°

Data quality and receiver tracking statistics were compiled for RINEX files at high (10°-90°) elevation ranges. All quality control (QC) statistics are based on all 6 data files for any given particular receiver/antenna combination. Comparisons are based on: the total expected data volume verses the observed data volume, the total number of observations recorded divided by the total number of cycle slips, pseudorange and multipath noise statistics, and signal-to-noise ratios for L1 and L2.

3.1 Total Expected and Observed Data

Figure 3.1.1 and Table 3.1.1 on the following page represent a cumulative summary of the amount of expected observations verses the amount of completed observations. The amount of expected observations is based on total data acquisition time for the actual number of satellites tracked. Due to the high number of unhealthy satellites during this time period (6 spanning the entire duration of testing), the following satellites were removed from all observation and navigation files: 02, 06, 13, 23, 27, 31, and 19. Satellites that could not be observed by all systems tested during the testing period were removed. Satellite 19 was removed from days 108-110 only. Removing un-healthy satellites helped eliminate possible erroneous data, or strange behavior the receiver might experience due to the changing health of one or multiple satellites.

Summary:

All receiver/ antenna combinations had greater than 99% observed to expected data acquisition. The TPS GB-1000 and the Trimble R7 both had a 100% data success rate, with zero cycle slips. The SOK GSR2600 had the lowest ratio of observed to expected data acquisition, and a total of 351 cycle slips.

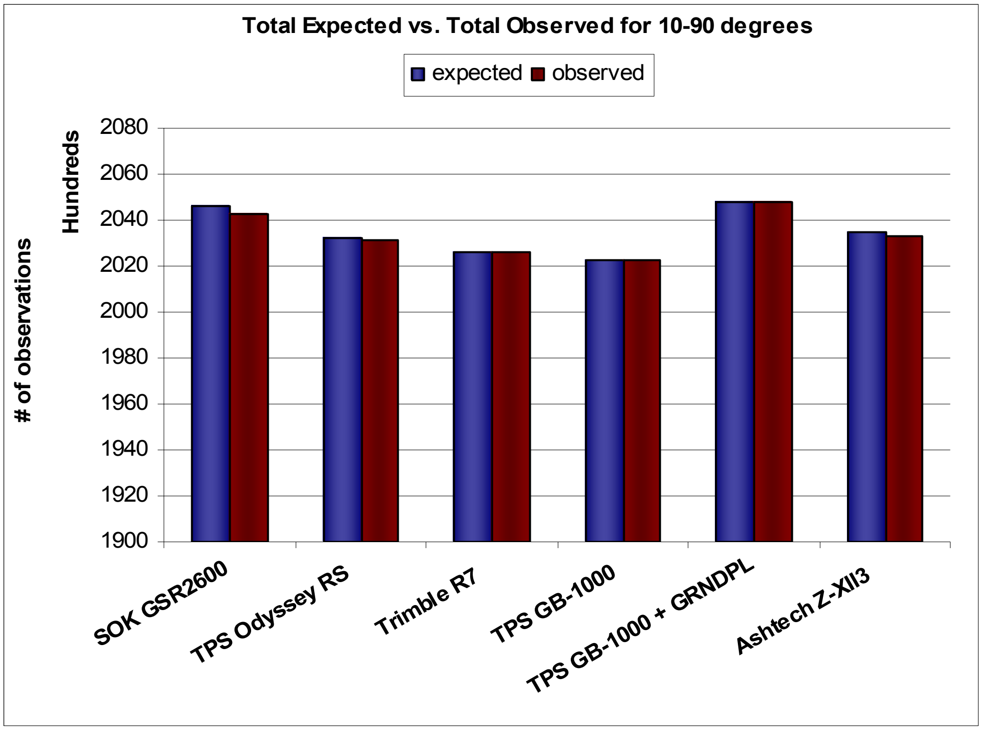


Figure 3.1.1 – Expected data volume verses observed data volume for all receiver/antenna pairs tested. Ashtech Z-XII3 is shown for reference and has been scaled down to represent 6 days of data instead of 15 days. The Ashtech Z-XII3 has the approximate mean value of the five systems tested, its total expected and total observed span the entire testing period.

Table 3.1.1 – Total Expected, total observed, and percentage of observed to expected data acquisition.

Receiver	Antenna	Total Expected	Total Observed	% obs/exp
SOK GSR2600	SOK600	204634	204252	99.81%
TPS Odyssey RS	TPS PG-A1 Geod	203176	203146	99.99%
Trimble R7	TRM 41249 Geod	202578	202577	100.00%
TPS GB-1000	TPS PG-A1 Geod	202272	202272	100.00%
TPS GB-1000	TPS PG-A1 Geod + GRNDPL	204771	204759	99.99%
Ashtech Z-XII3	ASH701945E_M	203452	203313	99.93%

3.2 Observations per Slip

Figure 3.2.1 and Table 3.2.1 on the following page summarize the TEQC observation per slip tracking statistics using a 10° elevation cutoff angle. Figure 3.2.1 represents the number of observations recorded divided by the number of slips for each day of testing. Table 3.2.1 represents the daily mean observation per slip value for the 3 days of data, both receivers.

Summary

Four out of five systems tested had greater than 33,000 observations per slip with no cycle slips. The Sokkia GSR2600 had 580 observations per slip. This low value was due to the large number (351) of cycle slips for the three days of data collected. In order to determine if the slips were primarily at low elevations, the daily mean observation per slip value was also calculated using a 15° cutoff. Table 3.2.2 shows that there are only 26 cycle slips when a 15° elevation angle cutoff is used, indicating that many of the SOK GSR2600 cycle slips are below 20°.

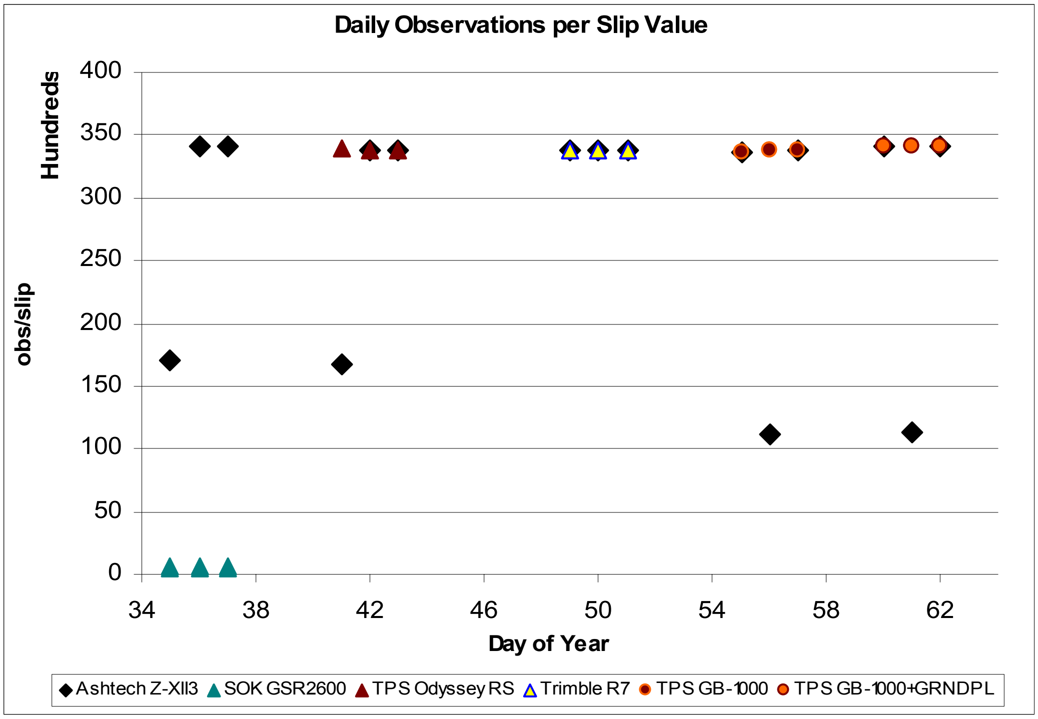


Figure 3.2.1 – Total number of observations divided by total number of slips for each day of testing. The SOK GSR2600 had a lower daily mean observation per slip value due to the high number of cycle slips. The day numbers for the TPS GB-1000+GRNDPL have been changed to 60-62 for visual plotting purposes only.

Table 3.2.1 – Daily mean observation per slip value and total number of cycle slips for each system tested. The Ashtech Z-XII3 daily mean observation per slip is based on the mean of 15 data files.

Receiver	Antenna	Total Slips (IOD + MP)	Daily Mean obs/slip	Sigma	Min	Max
SOK GSR2600	SOK600	351	580	74.7	493	667
TPS Odyssey RS	TPS PG-A1 Geod	0	33858	14.8	33841	33874
Trimble R7	TRM 41249 Geod	0	33763	14.6	33747	33780
TPS GB-1000	TPS PG-A1 Geod	0	33712	11.7	33700	33726
TPS GB-1000	TPS PG-A1 Geod + GRNDPL	0	34127	3.1	34122	34130
Ashtech Z-XII3	ASH701945E_M	6	28612	9170.8	11234	34130

Table 3.2.2 – Daily Mean observation per slip values and total number of cycle slips using a 15° cutoff.

Receiver	Antenna	Total Slips	Mean obs/slip
SOK GSR2600	SOK600	26	5920
TPS Odyssey RS	TPS PG-A1 Geod	0	29765
Trimble R7	TRM 41249 Geod	0	29678
TPS GB-1000	TPS PG-A1 Geod	0	29656
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	0	29670
Ashtech Z-XII3	ASH701945E_M	1	28503

3.3 MP1 and MP2 Tracking Statistics

Multipath occurs when an RF signal arrives at the receiving antenna from more than one propagation route. This is due to the signal being refracted or reflected off nearby objects. Multipath values are directly related to the environment surrounding the receiving antenna. An estimate of multipath is calculated in the TEQC QC algorithm by utilizing a combination of L1 and L2. MP1 is a linear combination of P1 (or C1 if P1 is unavailable), L1 phase, and L2 phase. MP2 is a linear combination of P2, L1 phase, and L2 phase [Estey and Meertens, 1999]. Figures 3.3.1 and 3.3.2 show MP1 and MP2 multipath values as reported in the TEQC summary file. These values can be good indicators of receiver noise plus pseudorange multipath.

Summary

All antenna/receiver combinations had values less than 0.501 meters for MP1 and MP2 multipath. Multipath mitigation was enabled for this test for all manufacturers. The Trimble R7 had the lowest MP1 multipath values, while the TPS GB-1000+GRNDPL had the highest. The SOK GSR2600 had the lowest MP2 multipath values, while the Trimble R7 had the highest. All Topcon systems tested had lower multipath values on L2 verses L1. Sensitivity to site-specific multipath can be seen for all receiver/antenna combinations on the L2 frequency in Figure 3.3.2, also denoted by the larger sigma's seen in Table 3.3.2. The TPS GB-1000+GRNDPL is the least sensitive to site specific multipath on L2 compared to the rest of the systems tested. Only the MP1 values for the Trimble R7 stand out as particularly low (Table 3.3.1 and Figure 3.3.1).

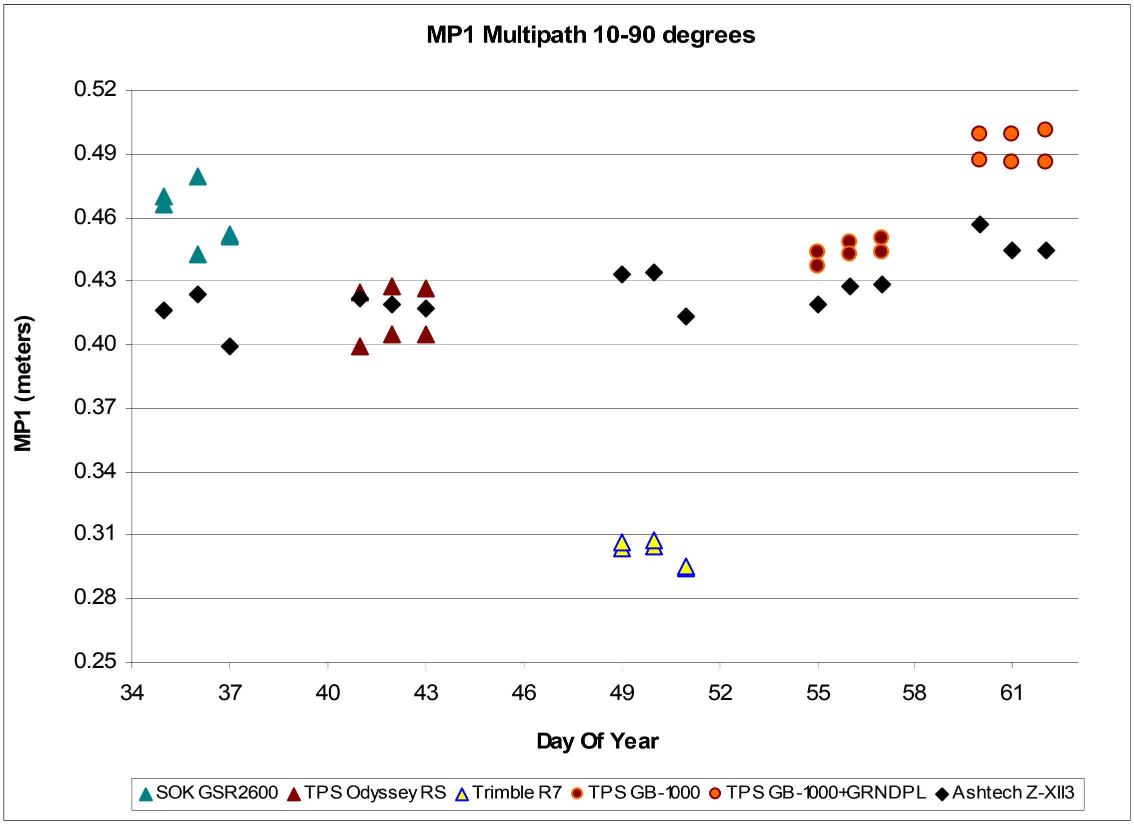


Figure 3.3.1 – Daily MP1 values for each receiver/antenna combination. MP1 is a linear combination of P1 (or C1), L1 phase, and L2 phase, which helps to provide an estimate of pseudorange multipath. The slightly larger sigma's seen by the SOK GSR2600, and the TPS Odyssey RS, indicate that these systems are more sensitive to site specific MP1 multipath than the other systems tested.

Table 3.3.1 – Mean MP1 multipath values for all receiver/antenna pairs tested shown in Figure 3.3.1. Ashtech Z-XII3 is included for reference.

Receiver	Antenna	Mean MP1 (m)	Sigma	Min	Max
SOK GSR2600	SOK600	0.460	0.014	0.442	0.480
TPS Odyssey RS	TPS PG-A1 Geod	0.415	0.013	0.399	0.427
Trimble R7	TRM 41249 Geod	0.302	0.006	0.294	0.308
TPS GB-1000	TPS PG-A1 Geod	0.444	0.005	0.437	0.450
TPS GB-1000	TPS PG-A1 Geod + GRNDPL	0.493	0.007	0.486	0.501
Ashtech Z-XIII	ASH701945E_M	0.427	0.014	0.400	0.457

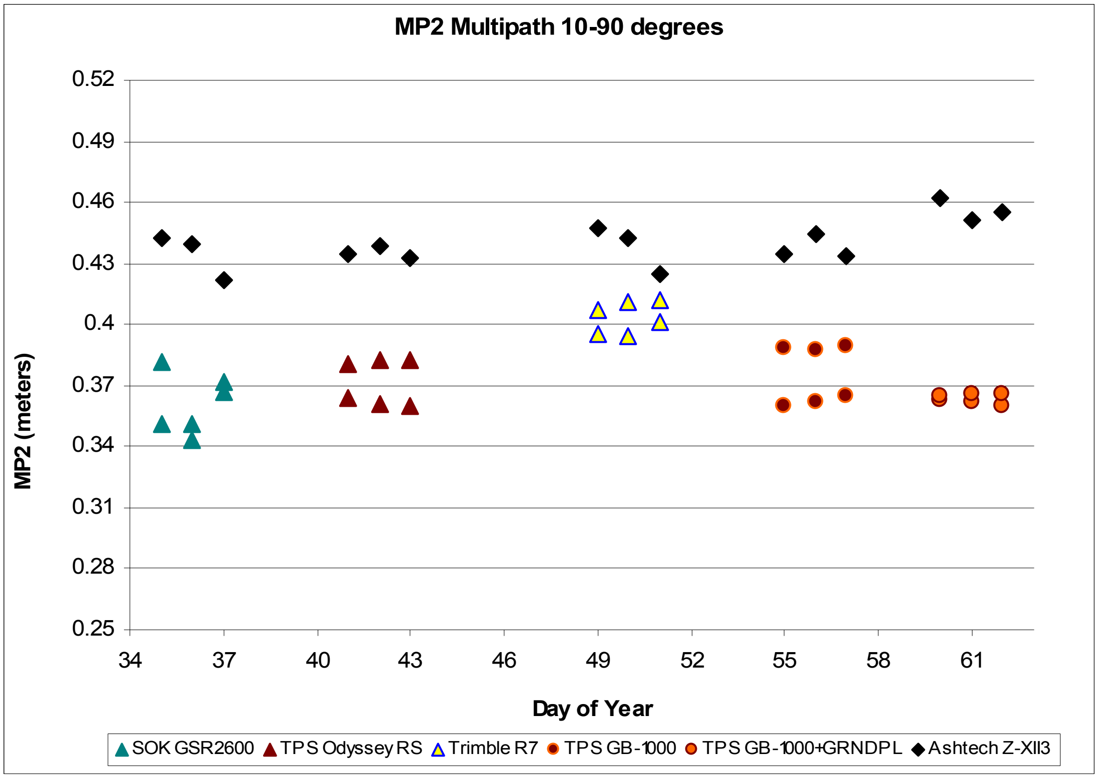


Figure 3.3.2 – Daily MP2 values for each system tested. MP2 is the linear combination of P2, L1 phase, and L2 phase, and provides an estimate of pseudorange multipath plus receiver noise. The smaller sigma seen by the TPS GB-1000+GRNDPL indicates that it is the least sensitive to site specific MP2 multipath compared to the other systems tested.

Table 3.3.2 – Mean MP2 multipath values for each system tested as shown in Figure 3.3.2. Ashtech Z-XII3 is included for reference.

Receiver	Antenna	Mean MP2 (m)	Sigma	Min	Max
SOK GSR2600	SOK600	0.361	0.015	0.343	0.382
TPS Odyssey RS	TPS PG-A1 Geod	0.372	0.011	0.360	0.382
Trimble R7	TRM 41249 Geod	0.403	0.008	0.395	0.412
TPS GB-1000	TPS PG-A1 Geod	0.375	0.014	0.360	0.390
TPS GB-1000	TPS PG-A1 Geod + GRNDPL	0.363	0.002	0.360	0.366
Ashtech Z-XIII	ASH701945E_M	0.441	0.011	0.422	0.463

3.4 MP1 and MP2 Tracking Plots

The following four TEQC plots will show examples of multipath comparisons of representative high and low elevation satellites. It is clear from geometry that signals received from low satellites will be more susceptible to multipath than signals received from high elevations. The following figures are the epoch-to-epoch tracking plots for MP1 and MP2. The first two plots are example MP1 and MP2 traces for a satellite that rises above the horizon, travels directly over the receiving antennas, and drops below the horizon directly across from where it rose (180°). This will also be referred to as a high elevation satellite. Figures 3.4.3 and 3.4.4 are example MP1 and MP2 multipath traces for a satellite that reaches a maximum elevation of roughly 35° above the horizon before setting, also called a low elevation satellite. The vertical blue lines on each plot are located at approximately 10°. Data acquired from lower elevations is noisier and has more multipath (more sinusoidal variation than linear). The vertical scale on all plots is from -4 to 4 meters. The horizontal axis indicates number of epochs. The plots were aligned horizontally by changing the start time of each file used. The time progression of the constellation (4 minutes a day) was then calculated and added to each subsequent file corresponding to the number of days between files. The bottom trace shows satellite elevation angle as a function of time.

Summary

The example MP1 and MP2 multipath plots are similar among the different manufacturers for a high elevation satellite. Figures 3.4.1 – 3.4.4 are examples showing that lower elevation angles have higher multipath values. Higher multipath values will have a larger amplitude than lower multipath values which will appear more linear.

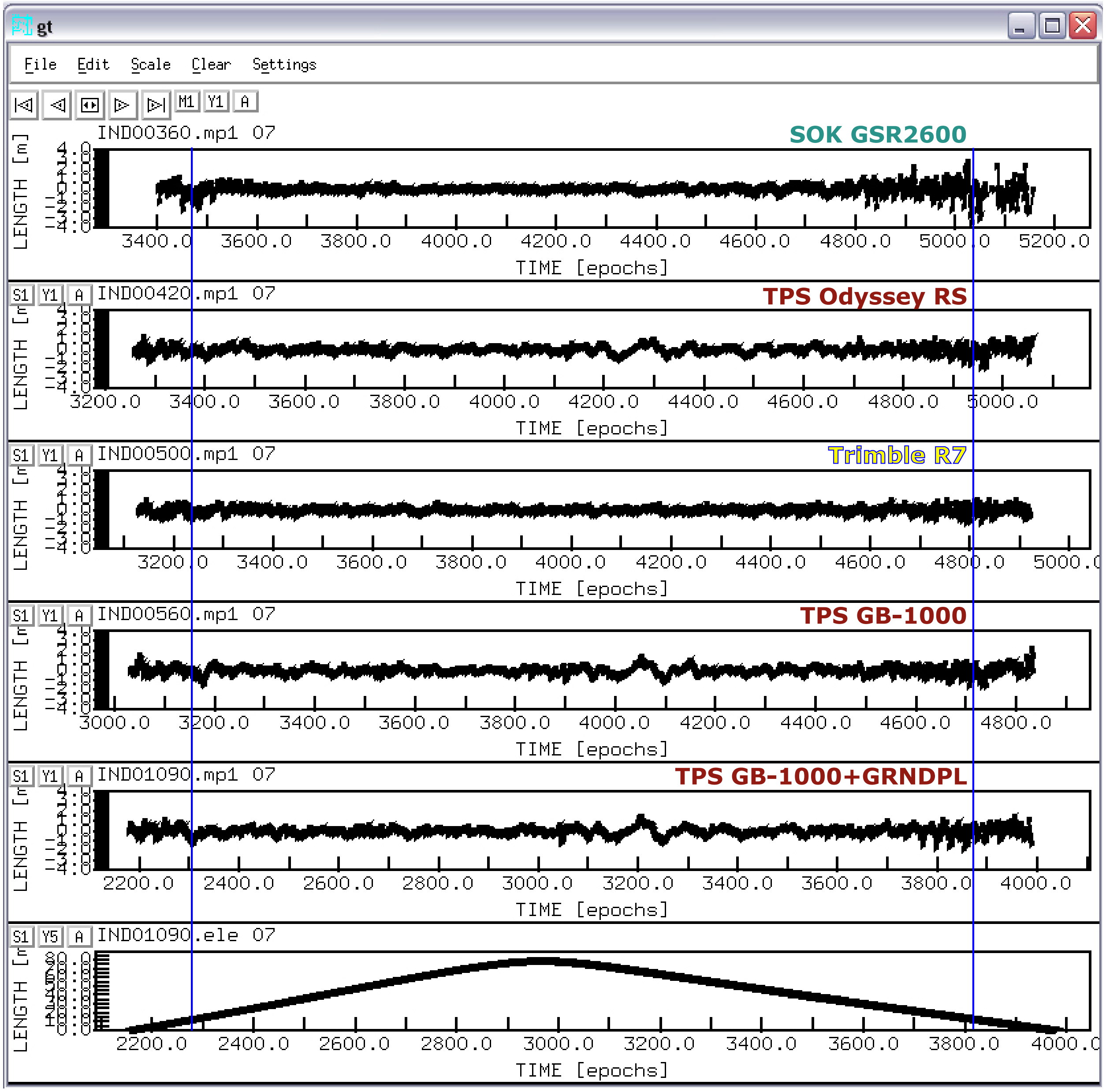


Figure 3.4.1 – An example of MP1 multipath for satellite 07. The vertical blue lines are approximate indicators of a 10 degree elevation angle. Multipath and receiver noise increase at lower elevation angles, shown by the larger amplitude on the traces (more sinusoidal variation than linear). Vertical scale is from -4 m to 4 m. Traces from top to bottom are: SOK GSR2600, TPS Odyssey RS, Trimble R7, TPS GB-1000, TPS GB-1000+GRNDPL, and satellite elevation angle as a function of time.

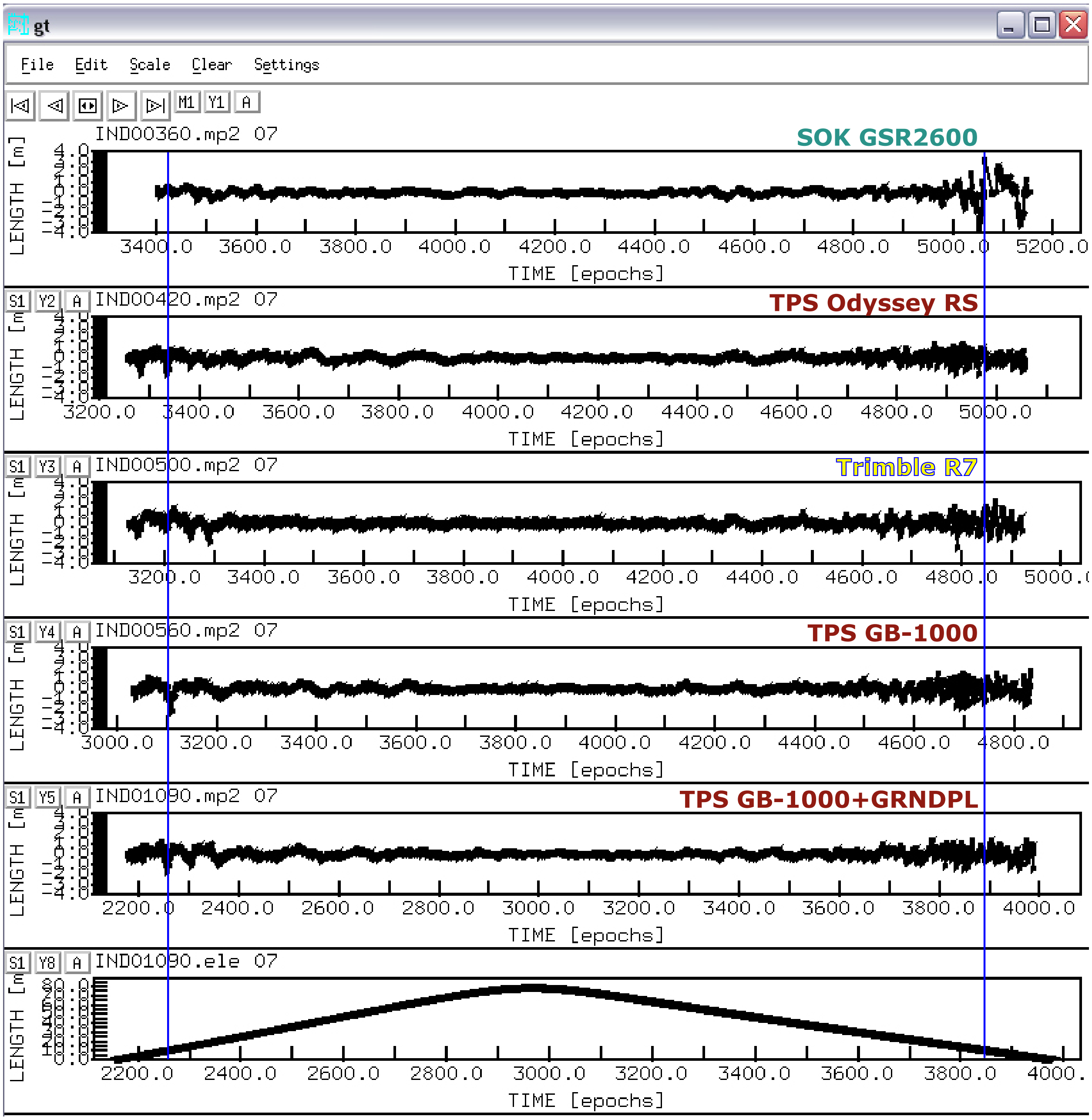


Figure 3.4.2 – Example MP2 tracking plot for satellite 07. The vertical blue lines are approximate indicators of a 10 degree elevation angle. The more sinusoidal features can be seen outside the vertical blues lines. Multipath and receiver noise increase at lower elevation angles. Smoother lines at approximately 90° elevation (middle of plot), indicate lower multipath values. Vertical scale is from -4 m to 4 m. Traces from top to bottom are: SOK GSR2600, TPS Odyssey RS, Trimble R7, TPS GB-1000, TPS GB-1000+GRNDPL, and satellite elevation angle as a function of time.

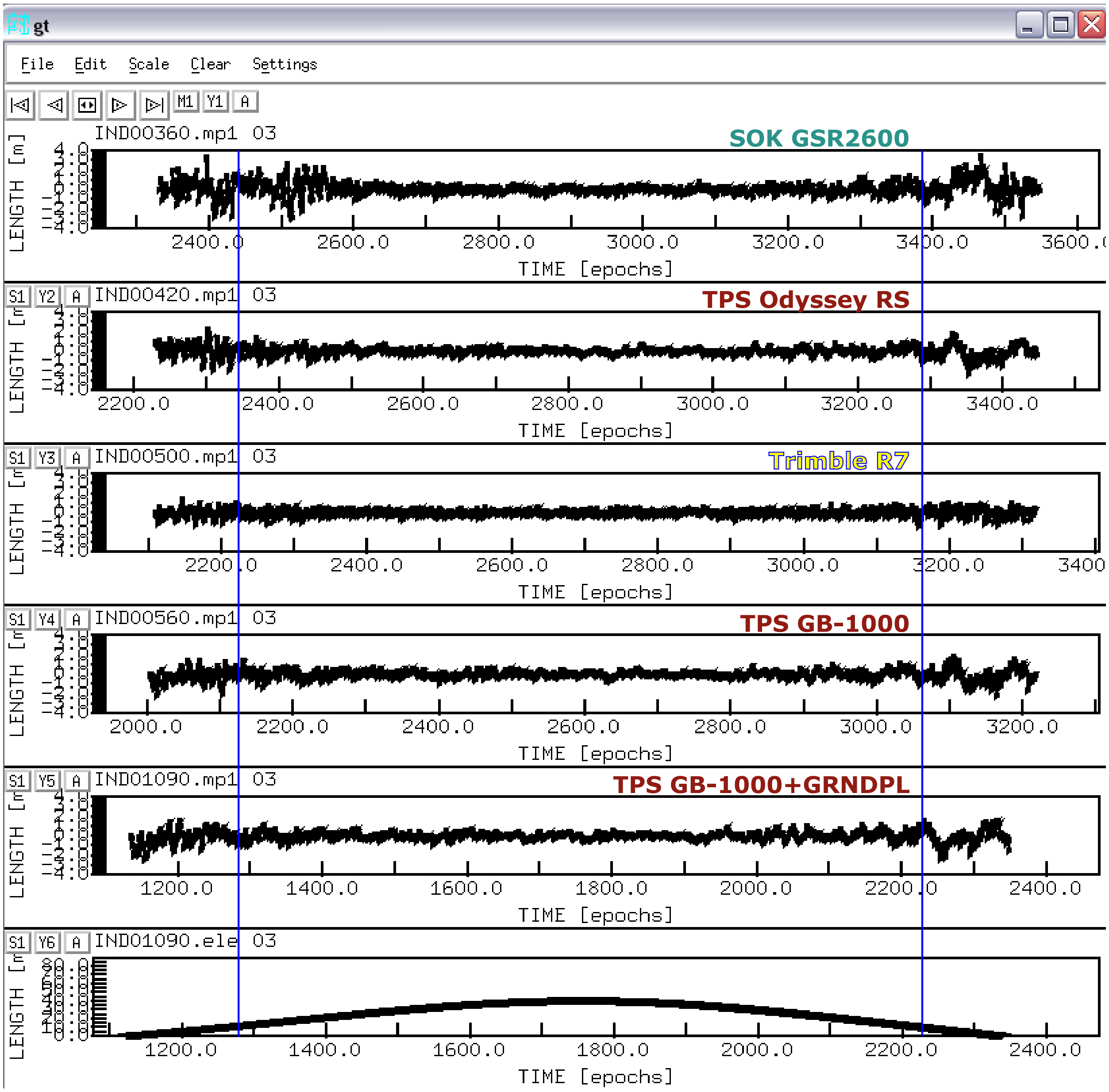


Figure 3.4.3 – An example MP1 tracking plot for satellite 03 which reaches a maximum elevation of approximately 35°. Traces have more sinusoidal variation below approximately 10° than seen in Figures 3.4.1 and 3.4.2 which indicate higher noise and more multipath. Vertical scale is from -4 m to 4 m. Traces from top to bottom are: SOK GSR2600, TPS Odyssey RS, Trimble R7, TPS GB-1000, TPS GB-1000+GRNDPL, and satellite elevation angle as a function of time.

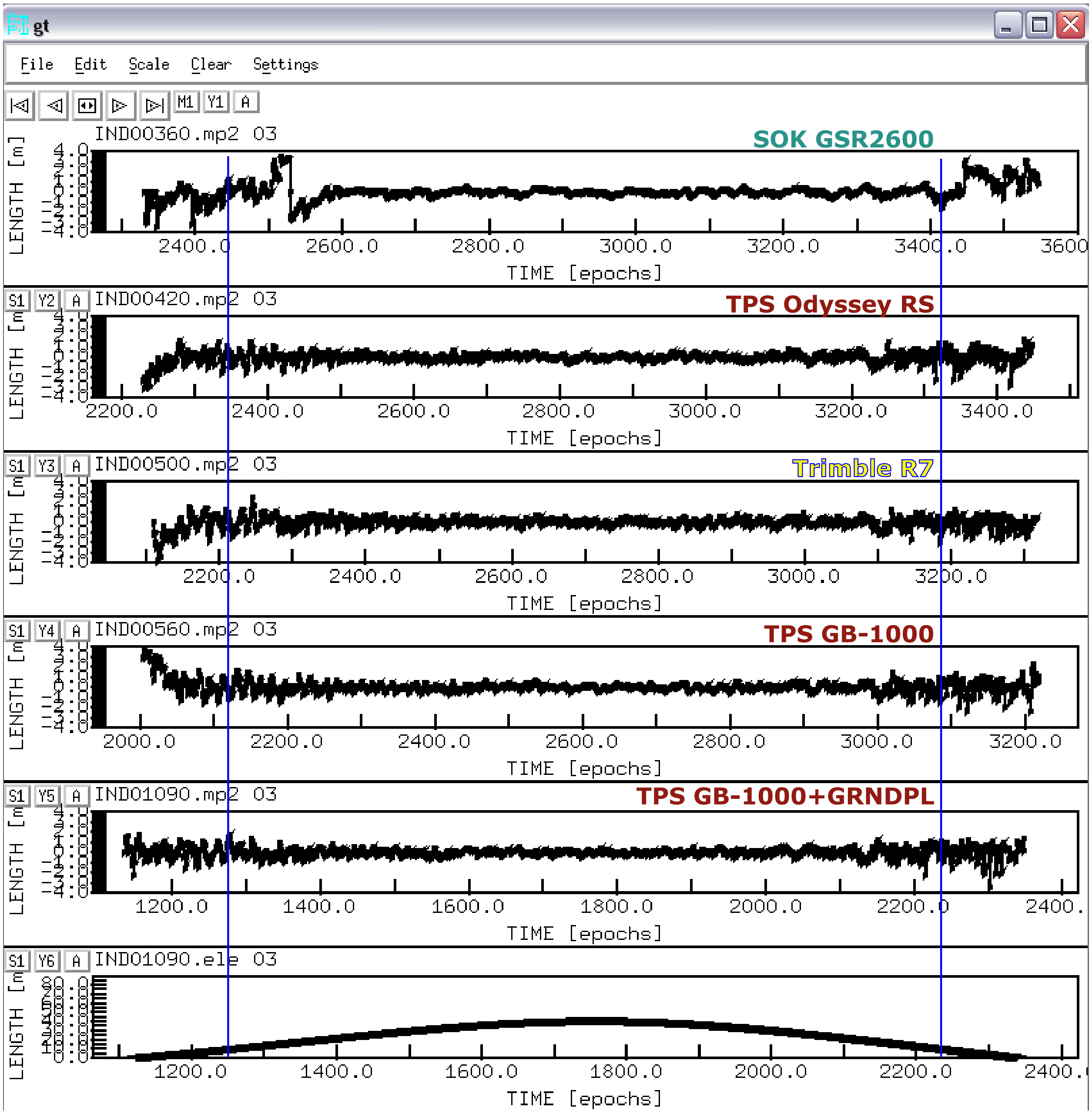


Figure 3.4.4 – An example MP2 tracking plot for satellite 03 which reaches a maximum elevation of approximately 35°. Traces have more sinusoidal variation compared to Figures 3.4.1 and 3.4.2, indicating higher noise and more multipath. Vertical scale is from -4 m to 4 m. Traces from top to bottom are: SOK GSR2600, TPS Odyssey RS, Trimble R7, TPS GB-1000, TPS GB-1000+GRNDPL, and satellite elevation angle as a function of time.

3.5 Signal-to-Noise Ratio Statistics

Signal-to-noise ratio (SNR) values can provide a useful indication of receiver/antenna tracking performance. A requirement of the bid specification was that all receivers report SNR in units of db-Hz so that a direct comparison between systems could be made. For each data file, the SNR values were binned into 2-degree elevation increments using TEQC. The figures on the following two pages show the average signal-to-noise ratio for each receiver/antenna combination plotted as a function of elevation angle. The average for all systems is denoted by the black diamonds (mean SN1/SN2). In order to compare the SNR values, the weighted average difference of the observed SNR from the mean SNR was calculated, resulting in a single number. The weighting (Figure 3.6.1) was determined by the number of observations for that elevation bin. Positive values indicate the observed SNR was higher than the mean SNR of all systems tested. The Ashtech Z-XII3 data is not included because the receiver outputs SNR in I-Counts which must then be converted to db*Hz.

Summary:

All antenna/receiver combinations show similar results for signal-to-noise ratio strength on L1. The TPS Odyssey RS and the TPS GB-1000 have a higher signal-to-noise ratio than the SOK GSR2600 and Trimble R7 for L1. The SOK GSR2600 has the highest signal-to-noise ratio for L2 and is higher than the mean of all systems tested at numerous elevation angles. The TPS Odyssey RS and TPS GB-1000 closely follow the mean for signal-to-noise ratio on L2. The Trimble R7 and TPS GB-1000+GRNDPL are below the mean of all systems tested for signal-to-noise ratio on L2.

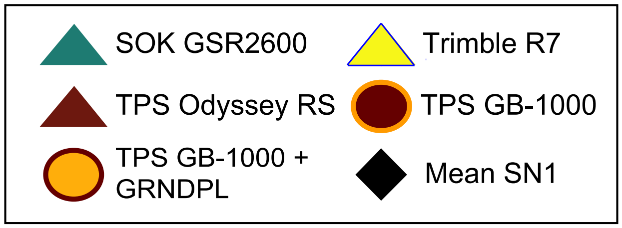


Figure 3.5.1 – Legend for L1 signal-to-noise ratio plot

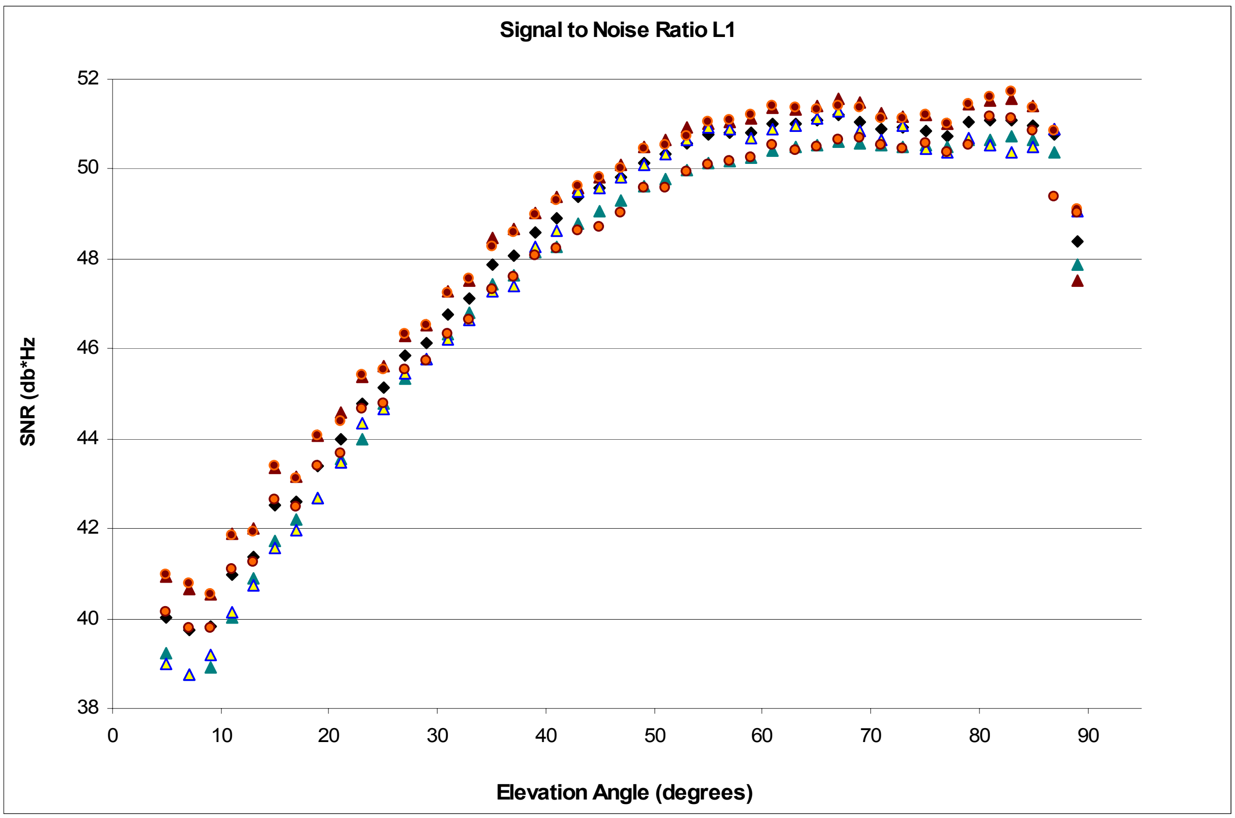


Figure 3.5.2 – Signal-to-noise ratio for L1. The average of all SN1 values is denoted by the black diamonds. All systems are within a few db*Hz of the mean. The TPS Odyssey RS and the TPS GB-1000 are slightly above average for signal-to-noise ratio on L1. The SOK GSR2600, TPS GB-1000+GRNDPL, and the Trimble R7 are slightly below the mean of all systems tested at higher elevation angles.

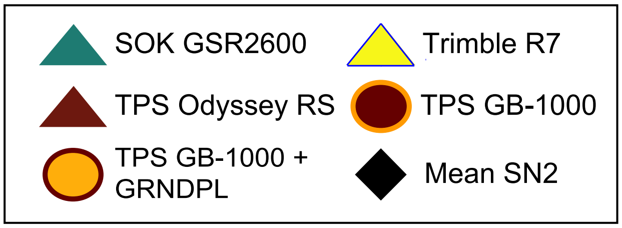


Figure 3.5.3 – Legend for L2 signal-to-noise ratio plot.

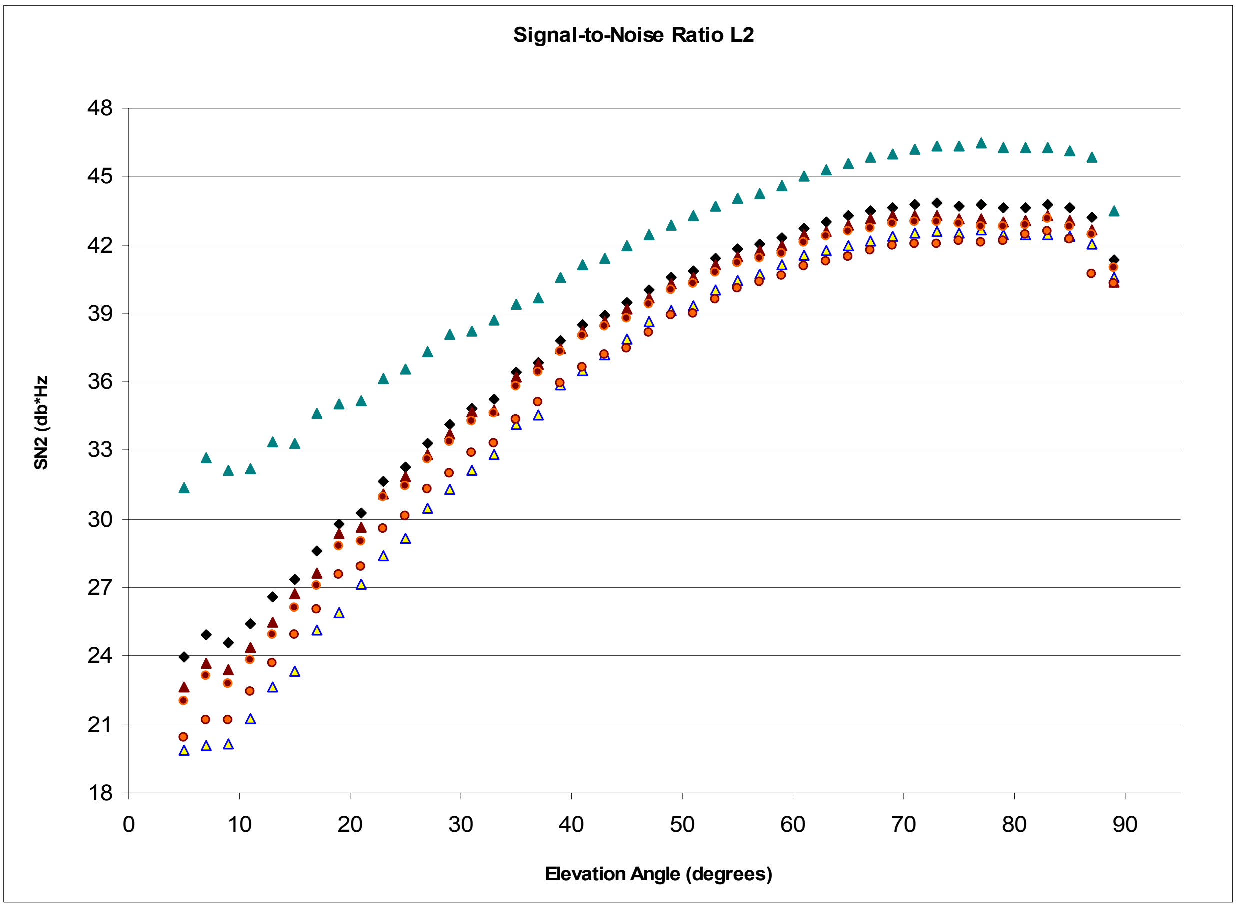


Figure 3.5.4 – Signal-to-noise ratio for L2. The mean SN2 values are denoted by the black diamonds. The SOK GSR2600 has a signal-to-noise ratio on L2 which is noticeably higher than the rest of the systems tested. The TPS GB-1000 and the TPS Odyssey RS follow the mean signal-to-noise ratio values closely while the Trimble R7 and TPS GB-1000+GRNDPL are below average for signal-to-noise ratio on L2.

3.6 Signal-to-noise Ratio Weighted Means

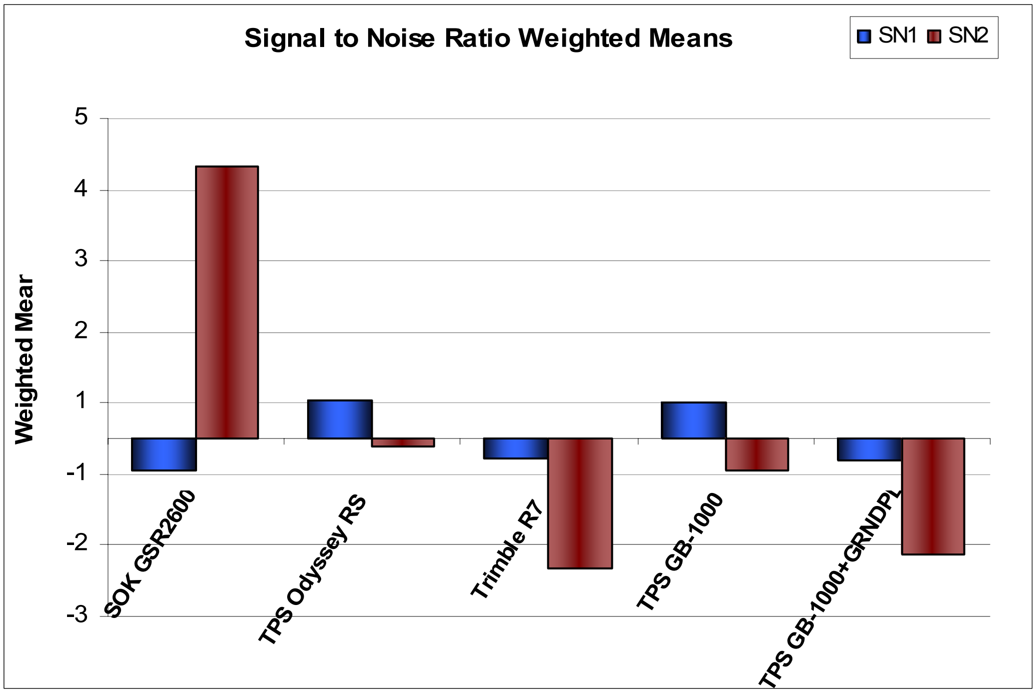


Figure 3.6.1 – Signal-to-noise ratio weighted means for L1 (blue) and L2 (red). The SOK GSR2600 had the highest weighted mean for L2 (overall SN2), which can be seen in Figure 3.5.4. The Trimble R7 and TPS GB-1000+GRNDPL have a the lowest signal to noise ratio weighted means for L2.

Table 3.6.1 - Signal-to-noise ratio weighted means for L1 (SN1) and L2 (SN2).

Receiver	Antenna	SN1 W.M.	Sigma	SN2 W.M.	Sigma
SOK GSR2600	SOK600	-0.459	0.120	3.833	0.157
TPS Odyssey RS	TPS PG-A1 Geod	0.537	0.100	-0.103	0.143
Trimble R7	TRM 41249 Geod	-0.278	0.087	-1.820	0.133
TPS GB-1000	TPS PG-A1 Geod	0.514	0.098	-0.446	0.145
TPS GB-1000	TPS PG-A1 Geod + GRNDPL	-0.304	0.110	-1.630	0.144

4.0 Power Consumption

4.1 Average Steady State Power Consumption

Power consumption was tested using custom data acquisition hardware and LabView. All receivers were tested with internal batteries removed and/or disconnected. Two tests were run, the first to measure the steady state power consumption and the second to measure the approximate power on and power off voltages. Also noted are the antenna bias voltages from the receiver, the operating range of the receiver and antenna, and the power port configuration.

The antenna was mounted on the roof of the UNAVCO, Inc. building and isolated from any ground loops. The DC power cables provided by each manufacturer were connected to mating plugs on the test hardware. Each receiver/antenna combination was tested as a unique and separate entity except for the TPS GB-1000+GRNDPL. The TPS GB-1000+GRNDPL was not independently tested since the addition of a groundplane does not change the power consumption of the receiver. For the first test, sampling was started after 12.5 minutes allowing the receiver to acquire all available satellites and begin performing normal internal operations. Data was sampled at 30Hz for 5 minutes then averaged to get the steady state power consumption. The average value was then calculated for each system by averaging the two unique values obtained for each manufacturer. For the second test, sampling was run continuously as the input voltage was slowly increased through the turn on point then slowly decreased through the turn off point. This was repeated several times to observe repeatability and receiver operation at the turn on/turn off points.

Summary:

The Trimble R7 and the SOK GSR2600 had the lowest power consumption of the five systems tested, consuming less than 3 Watts while tracking all available satellites. The TPS GB-1000 with and without groundplane had the highest steady state power consumption of 4.7 Watts. All systems tested consumed less than 5 Watts as per the requirements in the RFP.

The SOK GSR2600 does not automatically power on after a power failure. The user must depress the power button on the front of the receiver to power the unit on after a power failure. Sokkia has stated that they have a firmware version which will fix this problem, although it was not provided for testing. Please see vendor response for more information. The TPS GB-1000 has a shutoff voltage of 5.7 Volts. However, in order for the receiver to automatically power on when power is restored to the system, the input voltage to the receiver must drop below 2.5 Volts. Once the receiver shuts off, there is no load draining the battery, therefore the battery voltage will not drop to 2.5 Volts and thus the receiver will not automatically power on when power is restored to the system. Please see vendor response for more details. The Trimble R7 and the TPS Odyssey RS both automatically power on when power is restored to the system.

Powers on/off voltages are a concern in medium to long term deployments where a battery/solar panel combination is used. Permanent damage to a 12 Volt battery will occur if it is discharged below about 10 Volts. User interaction to power the unit on after a power failure and with drained batteries is difficult when the system is deployed remotely.

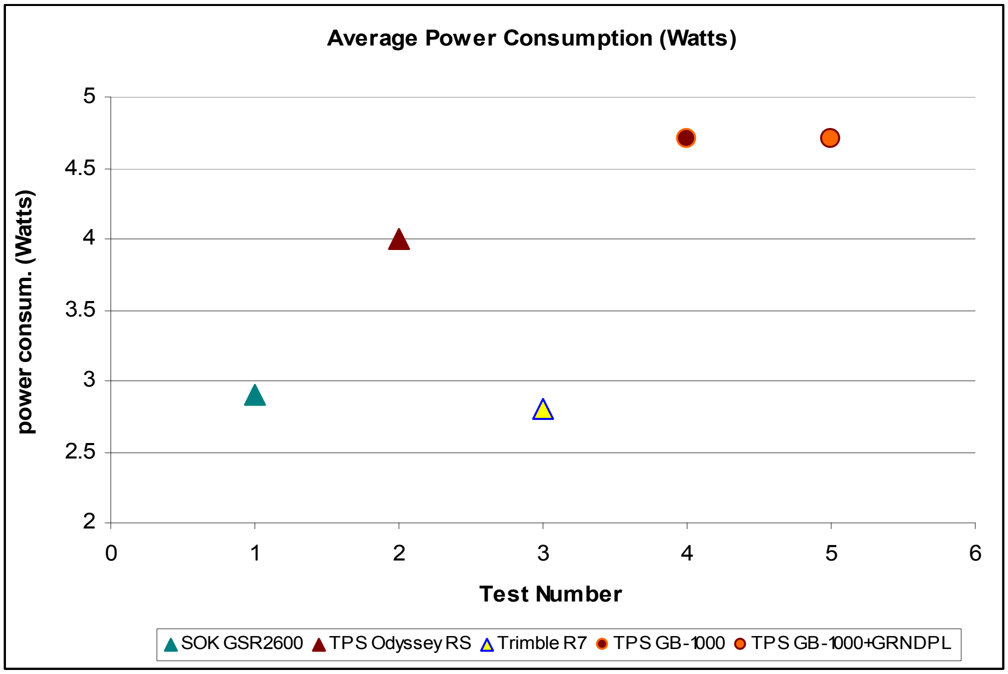


Figure 4.1.1 - Average power consumption while the receivers were tracking all available satellites to an elevation angle of 0° and logging data at 30 hertz.

Table 4.1.1 – Average power consumption for all systems tested shown in second to last column from right. All receivers were tested with internal batteries disconnected/removed.

Receiver	Receiver Serial #	Antenna	Antenna Serial #	Power Consumption (Watts)	Sigma	Average	Sigma
SOK GSR2600	NUA03480011	SOK600	NRK03480039	2.9	0.13	2.9	0.08
SOK GSR2600	NUA03480019	SOK600	NRK03480035	3.0	0.14		
TPS Odyssey RS	231-0105	TPS PG-A1 Geod	268-0494	4.1	0.51	4.0	0.01
TPS Odyssey RS	231-0102	TPS PG-A1 Geod	268-0663	4.0	0.52		
Trimble R7	220326017	TRM 41249 Geod	12578598	2.8	0.34	2.8	0.03
Trimble R7	220326020	TRM 41249 Geod	12560273	2.8	0.36		
TPS GB-1000	220072	TPS PG-A1 Geod	268-0663	4.8	0.36	4.7	0.08
TPS GB-1000	220073	TPS PG-A1 Geod	268-0494	4.6	0.40		

Table 4.1.2 - Receiver power on and power off values.

Receiver	Serial #	Antenna	Power On	Power Off	Avg pwr on (volts)	Sigma	Avg pwr off (volts)	Sigma
SOK GSR2600	NUA03480011	SOK600	*	Variable	*	n/a	**	n/a
SOK GSR2600	NUA03480019	SOK600	*	Variable				
TPS Odyssey RS	231-0105	TPS PG-A1 Geod	5.6	5.5	**5.6**	0.01	**5.5**	0.00
TPS Odyssey RS	231-0102	TPS PG-A1 Geod	5.6	5.5				
Trimble R7	220326017	TRM 41249 Geod	12.0	11.2	**12.0**	0.06	**11.1**	0.10
Trimble R7	220326020	TRM 41249 Geod	11.9	11.0				
TPS GB-1000	220072	TPS PG-A1 Geod	6.4	5.7	**6.3**	0.04	**5.7**	0.00
TPS GB-1000	220073	TPS PG-A1 Geod	6.3	5.7				

* - The SOK GSR2600 does not power on after a power failure. The user must manually push the button on the front of the receiver. Sokkia has stated that they have firmware which allows this functionality, but it was not provided for testing.
** - User defined

Two power ports allow for the possibility of changing batteries without powering down the receiver or otherwise disrupting receiver operations. The SOK GSR2600 has one physical power port which has four pins, two each for two power sources. The two power ports are not connected internally. The Trimble R7 has two external power ports which are shared with two of the communication ports. Both of these receivers treat the two ports as independent and switch between them as necessary. The TPS Odyssey RS and the TPS GB-1000 have one physical power port which contains four pins, two each for two power sources. The power sources are internally connected so the receiver will only see one external source. You can not switch or choose which power source to use. One concern with this configuration is equalization of the batteries, if only one new battery is installed with one very dead battery this will cause high currents to flow through the receiver. Please see vendor comments for more information. All receivers can have batteries “hot swapped” so that normal operation continues. Power cables to access the two ports on the SOK GSR2600, the TPS Odyssey RS, and the TPS GB-1000 were not provided for testing.

Table 4.1.3 – Antenna Bias voltages.

Receiver	Receiver Serial #	Antenna	Antenna Serial #	Antenna Bias Voltage	Avg Ant. Bias Voltage	Sigma
SOK GSR2600	NUA03480011	SOK600	NRK03480039	4.9	4.9	0.01
SOK GSR2600	NUA03480019	SOK600	NRK03480035	4.9		
TPS Odyssey RS	231-0105	TPS PG-A1 Geod	268-0494	4.7	4.6	0.01
TPS Odyssey RS	231-0102	TPS PG-A1 Geod	268-0663	4.6		
Trimble R7	220326017	TRM 41249 Geod	12578598	5.0	5.0	0.04
Trimble R7	220326020	TRM 41249 Geod	12560273	5.0		
TPS GB-1000	220072	TPS PG-A1 Geod	268-0663	4.7	4.7	0.01
TPS GB-1000	220073	TPS PG-A1 Geod	268-0494	4.7		

Antenna bias voltage from the Trimble R7 can be set by the user while in GPS Configurator by choosing the antenna type. Table 4.1.3 indicates the antenna type tested with each receiver.

Table 4.1.4 – Manufacturer specified receiver and antenna operating range voltages.

Receiver	Receiver Operating Range Voltage (V DC)	Antenna	Antenna Operating Range Voltage (V DC)
SOK GSR2600	6-18	SOK600	4.5-18
TPS Odyssey RS	6-28 (9-28)*	TPS PG-A1 Geod	2.7-12
Trimble R7	11-28*	TRM 41249 Geod	4.8-22
TPS GB-1000**	6-28 (9-28)*	TPS PG-A1 Geod	2.7-12

* while internal batteries are charging
** same for TPS PG-A1 Geod+GRNDPL

5.0 Short Baseline Tests

Each receiver/antenna combination was run for three days with a 15 second sampling interval. Data were processed using the Bernese GPS 4.2 software, with double difference processing and IGS Rapid Orbits and Pole files. The IND0 end of the baseline was held fixed. A 10° elevation angle cutoff was used and all ambiguities were resolved. The following graphs present a summary of coordinate solution statistics for the short baseline data.

5.1 Short Baseline RMS Scatter L1, L2, & L3

The following section presents L1, L2, and L3 (ionosphere-free) coordinate RMS scatter results for a baseline of 1.219 meters in length. The RMS scatter is calculated about the mean of each 3 days of L1, L2, and L3 Bernese daily baseline solutions, and is an estimate of the precision. The results are plotted and tabulated in Figures 5.1.1-5.1.4(a)(b)(c), and Tables 5.1.1(a)(b)(c)- 5.1.4(a)(b)(c). Figure 5.1.4 is the most representative linear combination of frequencies used for typical high-precision geodetic processing. Since propagation effects are minimal on short baselines, these results also indicate the optimal baseline precision of the antenna/receiver systems.

Summary

The L1 and L2 solution RMS scatter about the mean for the short baseline tests was excellent for all receiver/antenna systems tested. The L1/L2 RMS scatter was less than 0.1 mm for all comments (North, East, Vertical) for all systems, except the SOK GSR2600 L1 vertical and the L1 East component for the TPS Odyssey RS, which was 0.2 mm RMS. The precision of the L3, ionosphere-free linear combination was very good, less than 0.2 mm RMS scatter in North and East, and less than 0.4 mm in the vertical components. All systems passed the mandatory requirement of 0.5 mm or better in the North and East and 1.0 cm in the vertical for L1, L2 and L3 components for short baseline RMS scatter. Please note that the values for the TPS GB-1000+GRNDPL are shown for days 60-62 for plotting purposes only.

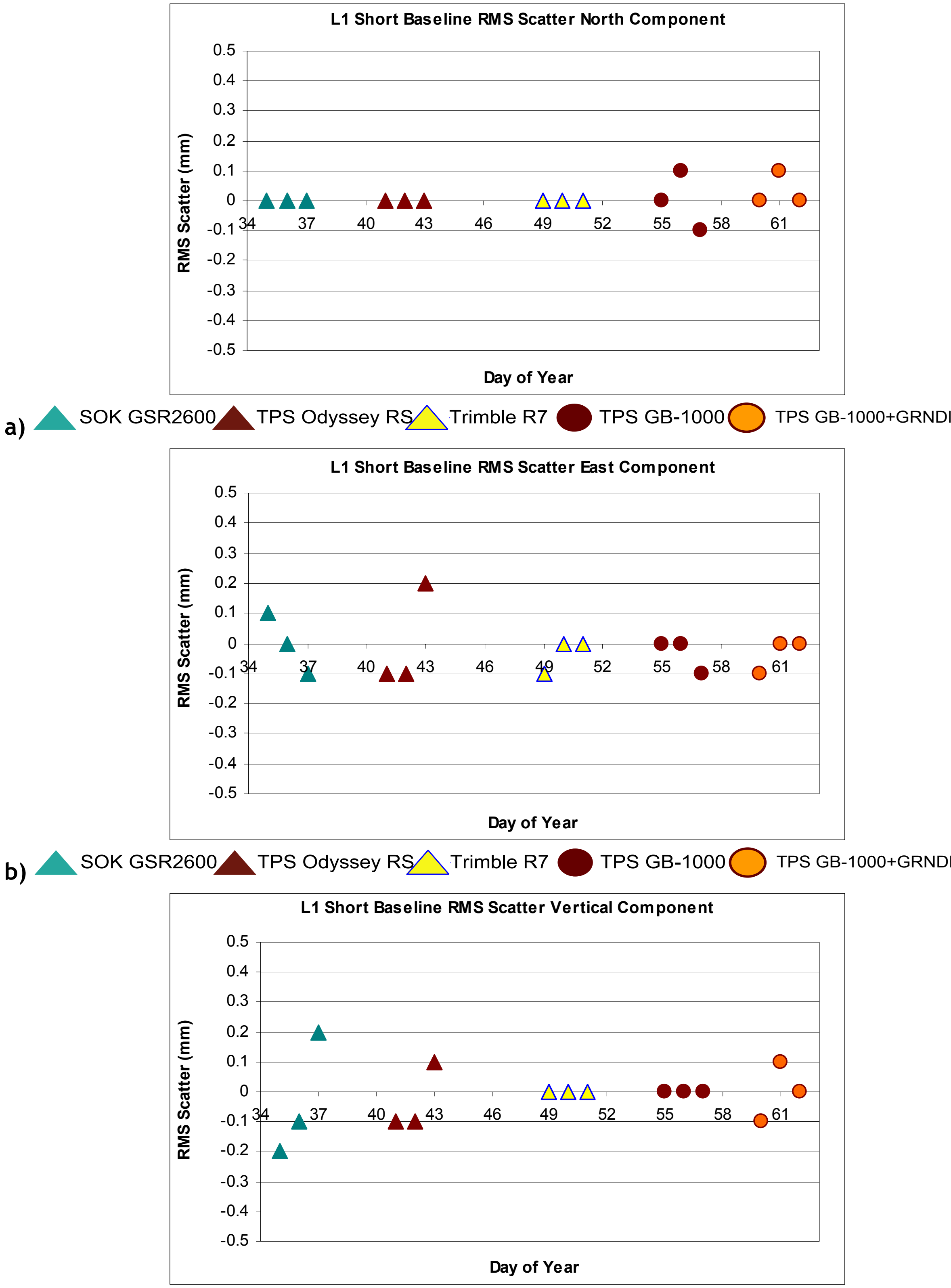


Figure 5.1.1 (a)(b)(c) - L1 carrier phase short baseline daily solution scatter about the mean for North, East, and Vertical components.

Table 5.1.1 – L1 carrier phase short baseline daily solution scatter about the mean for North, East, and Vertical.

Receiver	Antenna	DOY	North (mm)	East (mm)	Vertical (mm)
SOK GSR2600	SOK6000	35	0.0	0.1	-0.2
		36	0.0	0.0	-0.1
		37	0.0	-0.1	0.2
	RMS Scatter		0.0	0.1	0.2
TPS Odyssey RS	TPS PG-A1 Geod	41	0.0	-0.1	-0.1
		42	0.0	-0.1	-0.1
		43	0.0	0.2	0.1
	RMS Scatter		0.0	0.1	0.1
Trimble R7	TRM 41249 Geod	49	0.0	-0.1	0.0
		50	0.0	0.0	0.0
		51	0.0	0.0	0.0
	RMS Scatter		0.0	0.1	0.0
TPS GB-1000	TPS PG-A1 Geod	55	0.0	0.0	0.0
		56	0.1	0.0	0.0
		57	-0.1	-0.1	0.0
	RMS Scatter		0.1	0.0	0.0
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	108	0.0	-0.1	-0.1
		109	0.1	0.0	0.1
		110	0.0	0.0	0.0
	RMS Scatter		0.1	0.1	0.1

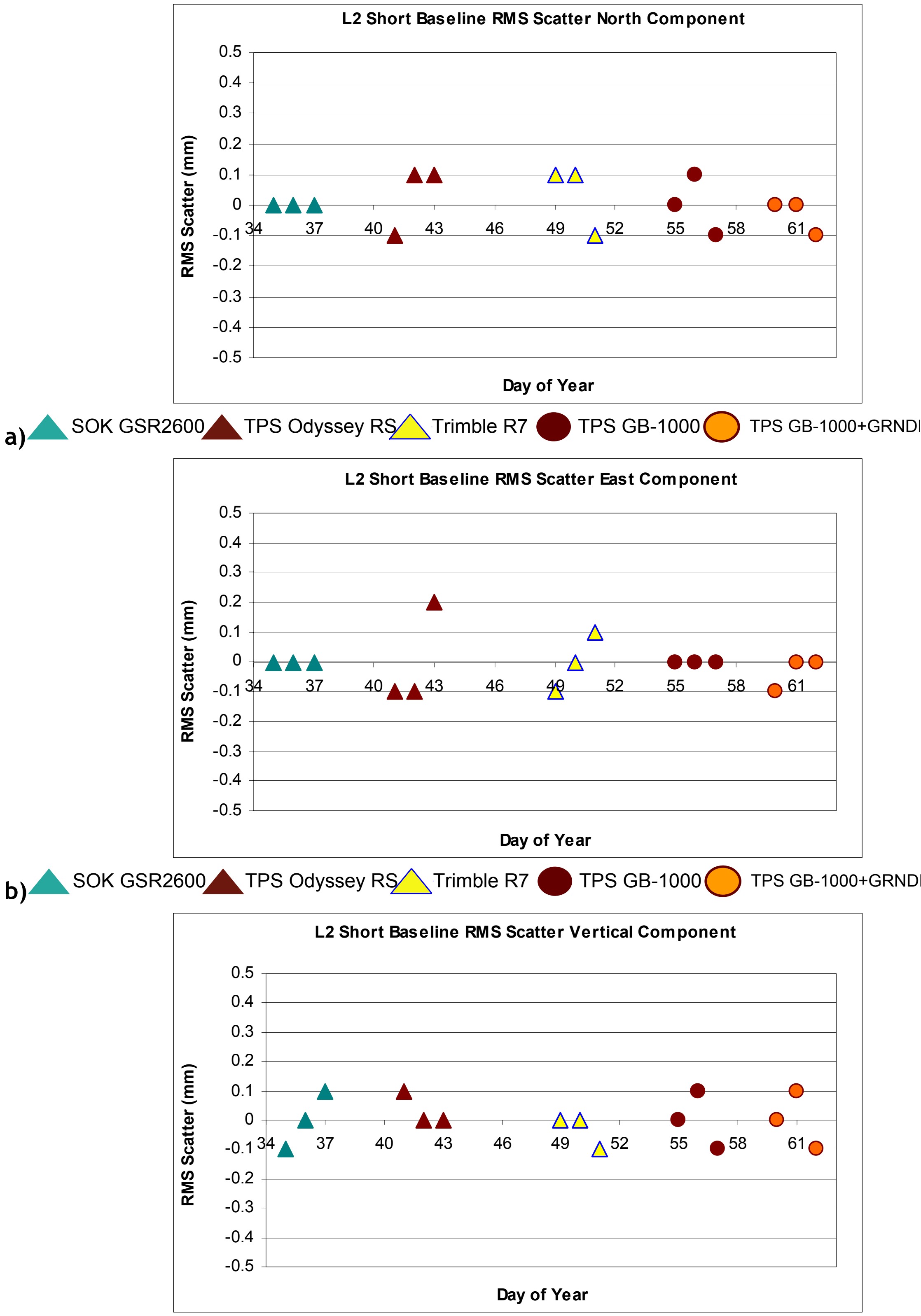
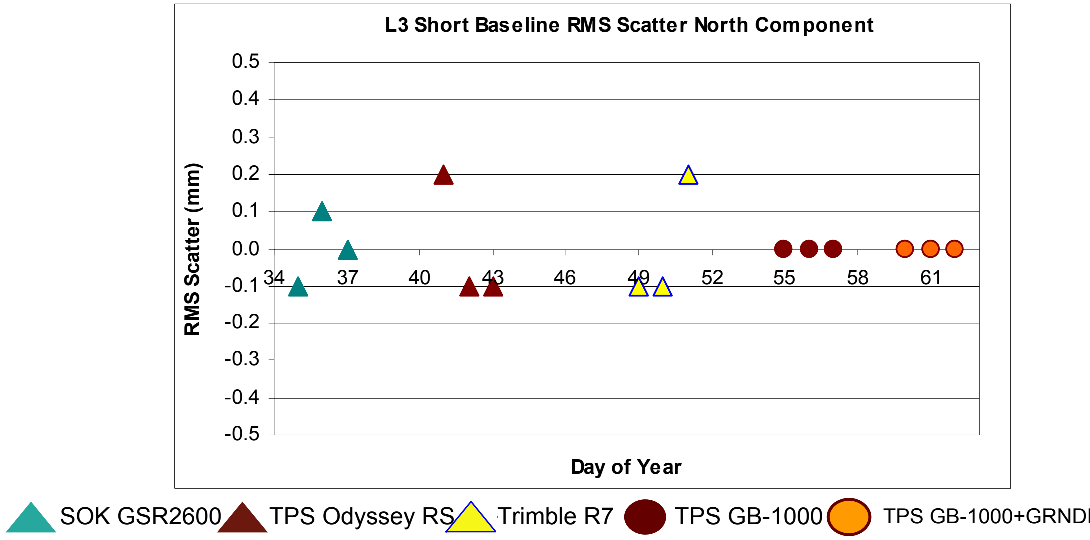


Figure 5.1.2 (a)(b)(c) – L2 carrier phase short baseline daily solution scatter about the mean for North, East, and Vertical components.

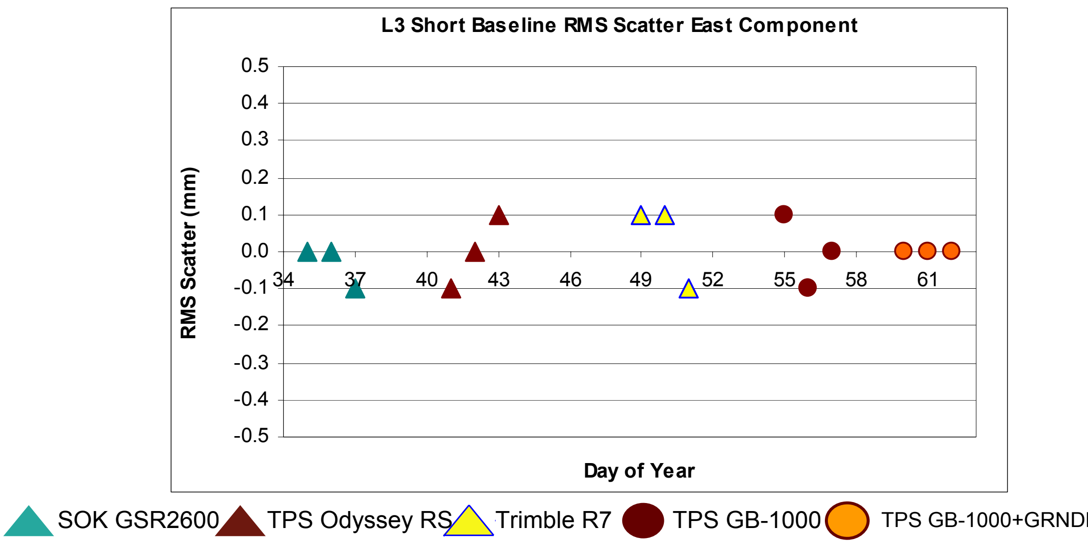
Table 5.1.2 – L2 carrier phase short baseline daily solution scatter about the mean for North, East, and Vertical components.

Receiver	Antenna	DOY	North (mm)	East (mm)	Vertical (mm)
SOK GSR2600	SOK6000	35	0.0	0.0	-0.1
		36	0.0	0.0	0.0
		37	0.0	0.0	0.1
	RMS Scatter		0.0	0.0	0.1
TPS Odyssey RS	TPS PG-A1 Geod	41	-0.1	-0.1	0.1
		42	0.1	-0.1	0.0
		43	0.1	0.2	0.0
	RMS Scatter		0.1	0.1	0.1
Trimble R7	TRM 41249 Geod	49	0.1	-0.1	0.0
		50	0.1	0.0	0.0
		51	-0.1	0.1	-0.1
	RMS Scatter		0.1	0.1	0.1
TPS GB-1000	TPS PG-A1 Geod	55	0.0	0.0	0.0
		56	0.1	0.0	0.1
		57	-0.1	0.0	-0.1
	RMS Scatter		0.1	0.0	0.1
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	108	0.0	-0.1	0.0
		109	0.0	0.0	0.1
		110	-0.1	0.0	-0.1
	RMS Scatter		0.0	0.1	0.1

a)



b)



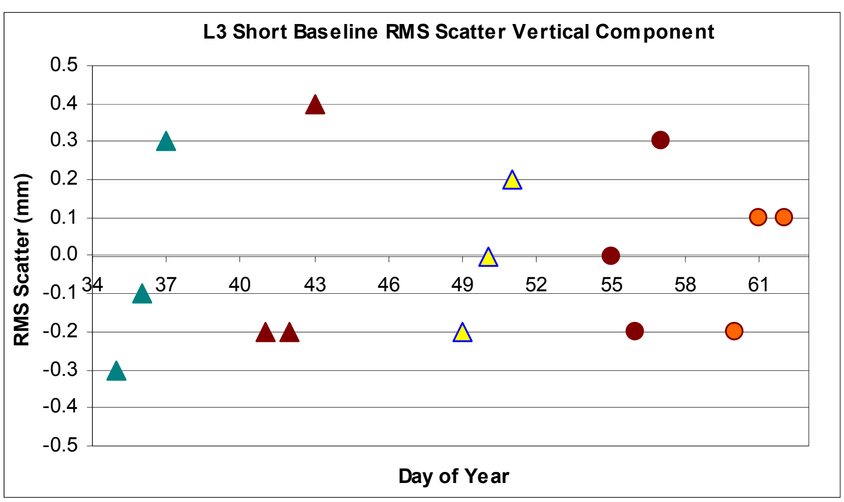
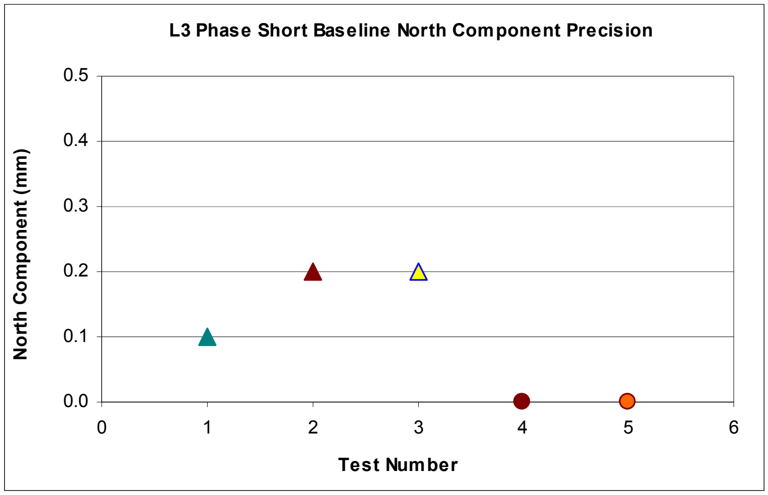


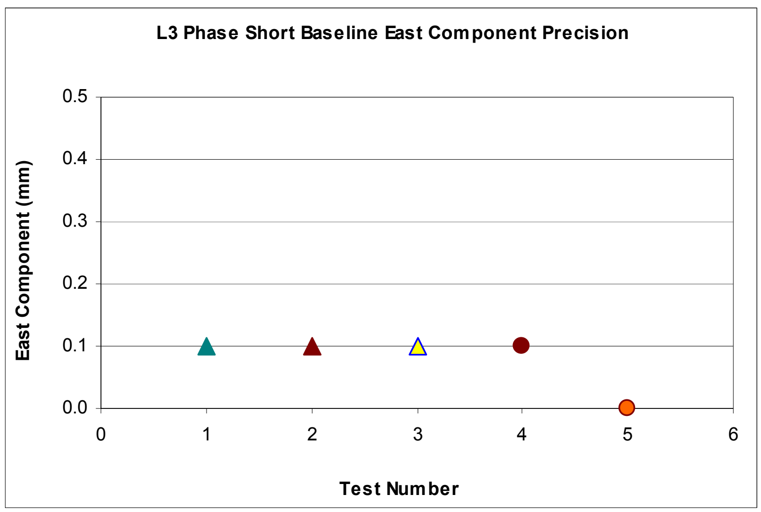
Figure 5.1.3 (a)(b)(c) – L3 carrier phase short baseline daily solution scatter about the mean for North, East, and Vertical components.

Table 5.1.3 – L3 carrier phase short baseline daily scatter about the mean for North, East, and Vertical components.

Receiver	Antenna	DOY	North (mm)	East (mm)	Vertical (mm)
SOK GSR2600	SOK6000	35	-0.1	0.0	-0.3
		36	0.1	0.0	-0.1
		37	0.0	-0.1	0.3
	RMS Scatter		0.1	0.1	0.3
TPS Odyssey RS	TPS PG-A1 Geod	41	0.2	-0.1	-0.2
		42	-0.1	0.0	-0.2
		43	-0.1	0.1	0.4
	RMS Scatter		0.2	0.1	0.4
Trimble R7	TRM 41249 Geod	49	-0.1	0.1	-0.2
		50	-0.1	0.1	0.0
		51	0.2	-0.1	0.2
	RMS Scatter		0.2	0.1	0.2
TPS GB-1000	TPS PG-A1 Geod	55	0.0	0.1	0.0
		56	0.0	-0.1	-0.2
		57	0.0	0.0	0.3
	RMS Scatter		0.0	0.1	0.2
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	108	0.0	0.0	-0.2
		109	0.0	0.0	0.1
		110	0.0	0.0	0.1
	RMS Scatter		0.0	0.0	0.2



a) SOK GSR2600 TPS Odyssey RS Trimble R7 TPS GB-1000 TPS GB-1000+GRNDI



b) SOK GSR2600 TPS Odyssey RS Trimble R7 TPS GB-1000 TPS GB-1000+GRNDI

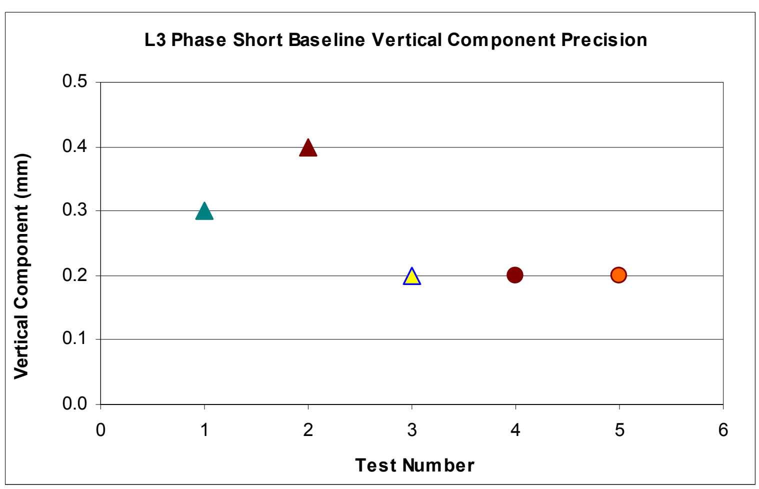


Figure 5.1.4 (a) (b) (c) – L3 carrier phase RMS scatter about the mean for North, East, and Vertical components.

Table 5.1.4(a) – L1 phase short baseline solution RMS (mm).

Receiver	Antenna	North	East	Up	Norm
SOK GSR2600	SOK600	0.00	0.10	0.20	0.22
TPS Odyssey RS	TPS PG-A1 Geod	0.00	0.10	0.10	0.14
Trimble R7	TRM 41249 Geod	0.00	0.10	0.00	0.10
TPS GB-1000	TPS PG-A1 Geod	0.10	0.00	0.00	0.10
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	0.00	0.10	0.20	0.22

Table 5.1.4(b) – L2 phase short baseline solution RMS (mm).

Receiver	Antenna	North	East	Up	Norm
SOK GSR2600	SOK600	0.00	0.00	0.10	0.10
TPS Odyssey RS	TPS PG-A1 Geod	0.10	0.10	0.10	0.17
Trimble R7	TRM 41249 Geod	0.10	0.10	0.10	0.17
TPS GB-1000	TPS PG-A1 Geod	0.10	0.00	0.10	0.14
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	0.00	0.10	0.10	0.14

Table 5.1.4(c) – L3 phase short baseline solution RMS (mm).

Receiver	Antenna	North	East	Up	Norm
SOK GSR2600	SOK600	0.10	0.10	0.30	0.33
TPS Odyssey RS	TPS PG-A1 Geod	0.20	0.10	0.40	0.46
Trimble R7	TRM 41249 Geod	0.20	0.10	0.20	0.30
TPS GB-1000	TPS PG-A1 Geod	0.00	0.10	0.20	0.22
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	0.00	0.00	0.20	0.20

5.2 Short Baseline Double Difference Phase Residuals

Examples of the short baseline L3 (ionosphere-free) carrier phase double difference residuals are presented below along with the RMS scatter and number of points for each plot. The residuals are sensitive to antenna performance and multipath, and are typically 5 to 10 times noisier than zero baseline residuals (not shown in this study). Figure 5.2.1 shows the double difference residuals for all satellite combinations formed, and Figure 5.2.2 shows residuals for satellite pair 20:01. Qualitatively, the residual traces in Figure 5.2.1 with all the observations do not look dramatically different from each other and the RMS differences are small (Table 5.2.1). This is in contrast to the larger difference between systems found in earlier tests (ARI, SuomiNet). The multipath effects are evident from the repeating variations shown in Figure 5.2.2 of the single satellite pair and are similar between systems tested.

Summary

The example RMS residuals for the L3 phase double differences on the short baseline are very similar for each of the tested systems, both qualitatively from the time variations in the plots (Figures 5.2.1 and 5.2.2), and quantitatively in the RMS residuals determined from the plots (Table 5.2.1).

Table 5.2.1 – An example of short baseline L3 double difference phase residual RMS and number of points determined from Figures 5.2.1 and 5.2.2.

Receiver	Antenna	Mean STD SV pair 20:01 (mm)	# of points	Mean STD All SV's (mm)	# of points
SOK GSR2600	SOK600	11.8	1050	14	37481
TPS Odyssey RS	TPS PG-A1 Geod	12.5	1026	13.2	36348
Trimble R7	TRM 41249 Geod	12.9	1058	14.5	34628
TPS GB-1000	TPS PG-A1 Geod	12.1	1001	13.1	32189
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	13.4	1082	13.4	35662

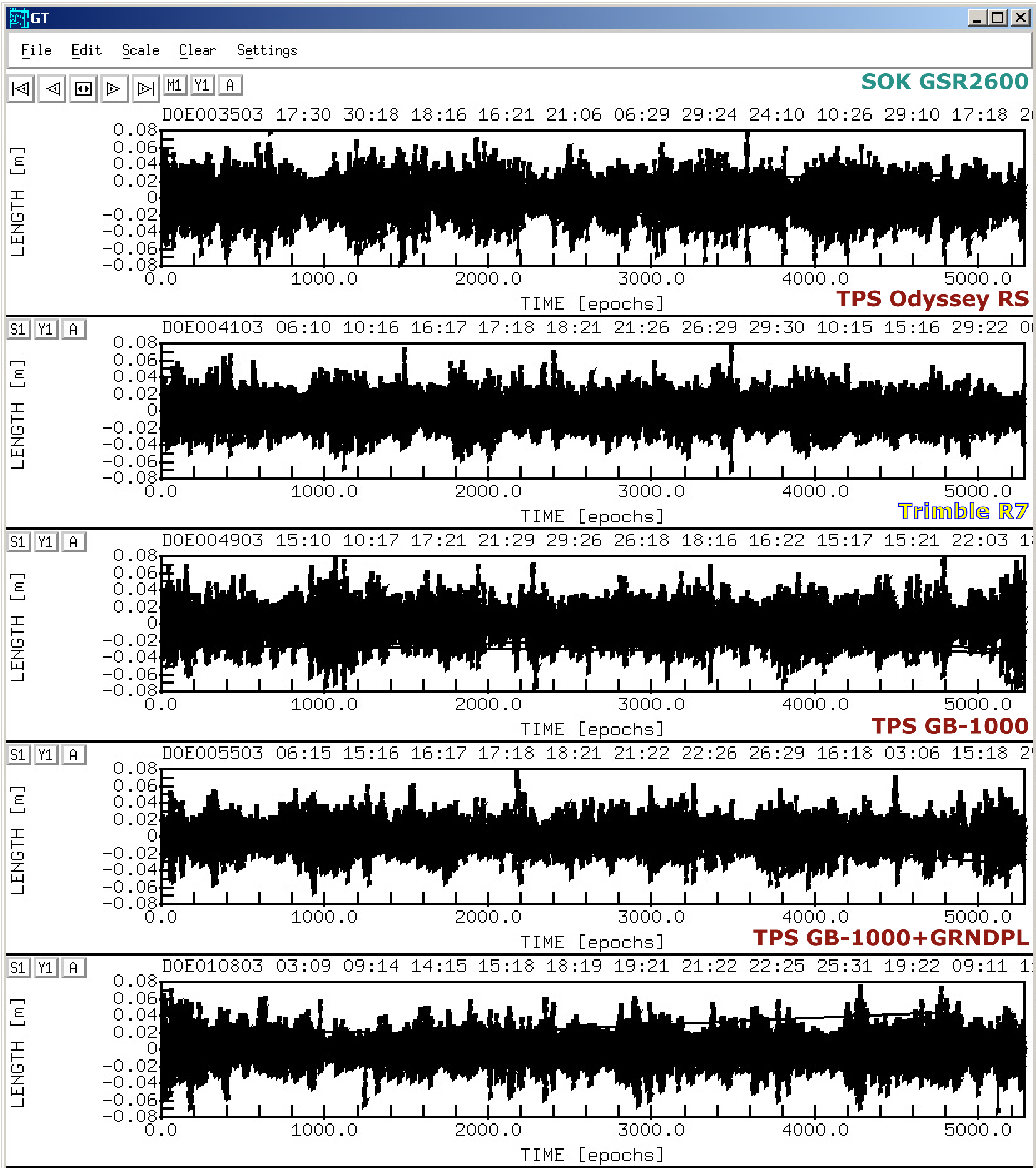


Figure 5.2.1 - An example of the short baseline L3 (ionosphere-free) carrier phase double difference residuals showing all satellite combinations that were formed. A single day of residuals is presented for each receiver/antenna combination tested. Vertical scale is ± 8 cm. Residuals from top to bottom: SOK GSR2600, TPS Odyssey RS, Trimble R7, TPS GB-1000, and TPS GB-1000+GRNDPL.

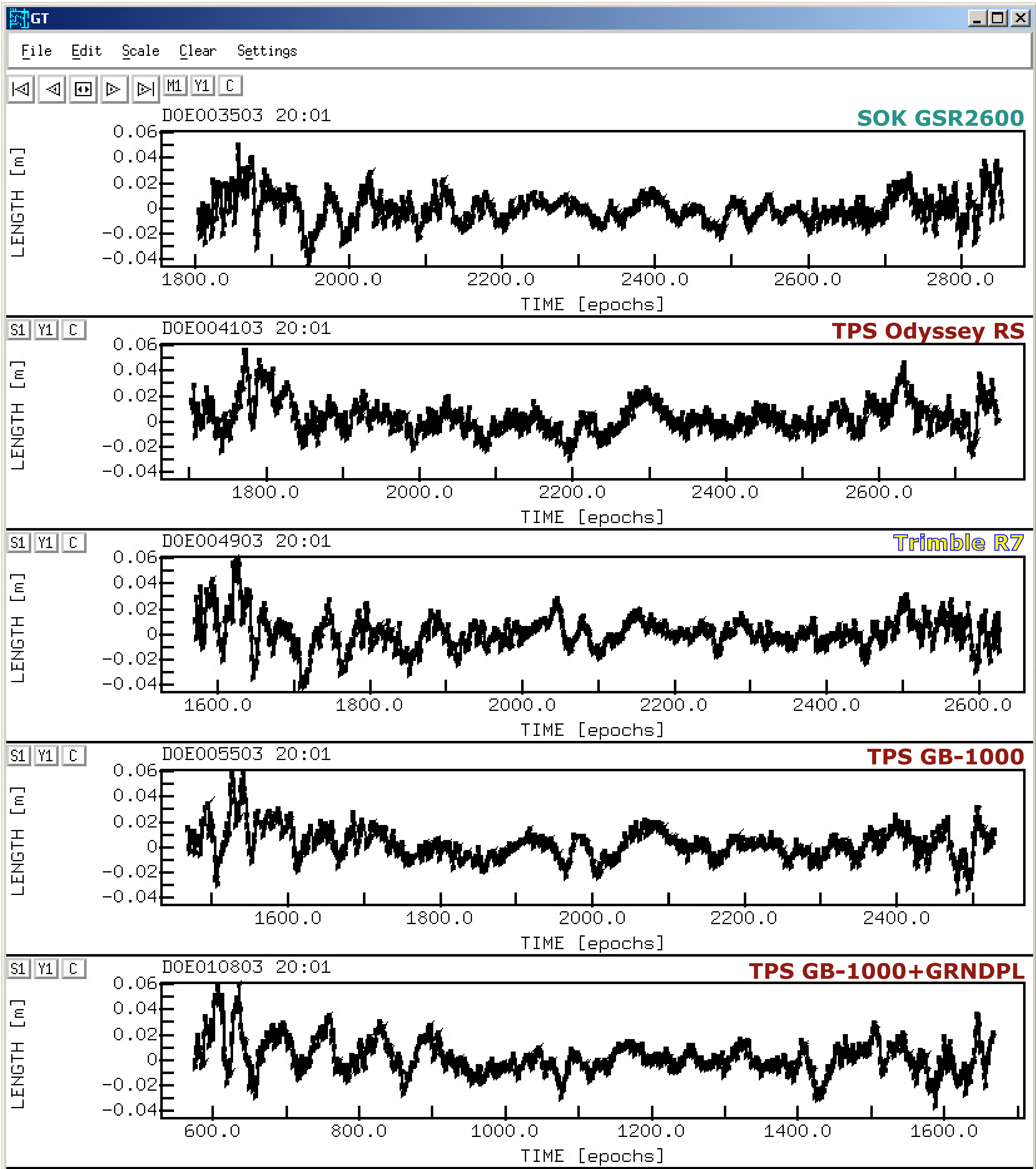


Figure 5.2.2 - An example of the short baseline L3 carrier phase double difference residuals for each receiver/antenna combination tested showing only satellite pair 20:01. Vertical scale is 6 cm to -4 cm. Residuals from top to bottom: SOK GSR2600, TPS Odyssey RS, Trimble R7, TPS GB-1000 and TPS GB-1000+GRNDPL.

6.0 Automated GIPSY (AUTOGIPSY) Processing

All data files were processed using the Jet Propulsion Laboratory's (JPL) AUTOGIPSY service available on the Internet (http://milhouse.jpl.nasa.gov/ag/agfaq.html). GIPSY is a substantially different processing package compared to the Bernese package since it is point positioning and Kalman Filter based, whereas Bernese is double difference and least squares based. With GIPSY, cycle-slips are cleaned on a single file basis whereas with Bernese this is done in double difference mode. We used AUTOGIPSY which provides only point positioning without ambiguity resolution. Ambiguity resolution requires full GIPSY processing which was not available for this test. The purpose of this test was to make sure that the files could be processed with GIPSY.

We submitted each RINEX file (as logged, tracking down to 0 degrees) from IND0 and INE0 for each of the test days. The returned output solution files were then reviewed. All of the files could be processed successfully. The coordinate solutions from the ".gd" files show a formal error of less than 2 mm North, 4 mm East and 10 mm Vertical, which are within expected AUTOGIPSY uncertainties.

7.0 Memory, Weight, and Size of Each System

A system as described in this section includes: the hard-shell transport case, receiver, antenna, cables, and battery. The amount of memory that each receiver arrived with for testing is shown in Table 7.1.1. The vendor responses to the RFP were also checked to see how much memory was included in the pricing matrix. Each system was packed up into the transport case and a total system weight was recorded, shown in Table 7.2.1. The sizes listed in Table 7.3.1 are the dimensions of the transport case which was delivered with each system.

7.1 Receiver Memory

Table 7.1.1 shows the amount of memory that each receiver arrived with for testing. The vendor responses to the RFP were also checked in order to see how much memory was actually included in the pricing matrix. The SOK GSR2600, Trimble R7, and TPS GB-1000 all have easily removable compact flash cards. The SOK GSR2600 arrived for testing with a 16 Mb flashcard, which could only store 4 data files, as each data file was approximately 4 Mb. Data file size is dependent on many factors including: sampling rate, number of satellites tracked, elevation angle cutoff, etc. By changing some of these parameters and using a larger compact flashcard, more data files could be stored on the receiver.

The TPS GB-1000 arrived with 1 GB of internal memory and a 256 Mb removable compact flashcard. Files can be easily dumped from the internal memory to the compact flashcard by using the front panel interface. The TPS GB-1000 also contains an Ethernet port and a USB port. The TPS Odyssey RS arrived with 1 Gigabyte of internal memory contained within an internal compact flash card. The compact flashcard can not be easily removed by a field operator. The TPS Odyssey RS does have direct Ethernet connectivity and a USB port allowing for quick downloads. The Trimble R7 arrived with a 512 Mb compact flashcard for testing and was able to store 500 data files with each file consuming roughly 750 Kb.

Table 7.1.1 - Value indicates memory contained on/within one receiver in Megabytes. Vendor responses to the RFP were also checked to see how much memory was specified in pricing matrix.

Receiver	Antenna	Memory ATOT* (Mb)
SOK GSR2600	SOK600	16
TPS Odyssey RS	TPS PG-A1 Geod	1000
Trimble R7	TRM 41249 Geod	512
TPS GB-1000	TPS PG-A1 Geod	1256
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	1256

*** ATOT** – At time of testing

7.2 Weight of each system

Table 7.2.1 gives the weight of each system. A system is defined as (one of each): transport case, receiver, antenna, battery, and cabling. The TPS GB-1000 was the lightest system, though the transport case is not suitable for shipping or using as a field enclosure. The Trimble R7 was the heaviest system but the transport case was durable and could be used as a field enclosure. The cases for the SOK GSR26000 and the TPS Odyssey RS were durable but would need some minor modifications in order to serve as a field enclosure.

Table 7.2.1 - Weight of each system.

Receiver	Antenna	System Weight (lbs)
SOK GSR2600	SOK600	14.5
TPS Odyssey RS	TPS PG-A1 Geod	19.0
Trimble R7	TRM 41249 Geod	21.0
TPS GB-1000	TPS PG-A1 Geod	13.0
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	13.5

7.3 Dimensions of Each System

The dimensions (length, width, height) of the transport case that was shipped with the system are listed in Table 7.3.1. Campaign systems occupy points for shorter periods of time thus favoring a smaller, more transportable system.

Table 7.3.1 - Dimensions of each transport case in inches.

Receiver	Antenna	Length (in)	Width (in)	Height (in)
SOK GSR2600	SOK600	16.5	13.0	10.0
TPS Odyssey RS	TPS PG-A1 Geod	18.0	13.0	7.5
Trimble R7	TRM 41249 Geod	19.0	15.0	8.5
TPS GB-1000	TPS PG-A1 Geod	16.5	14.0	9.5
TPS GB-1000	TPS PG-A1 Geod+GRNDPL	16.5	14.0	9.5

8.0 Summary

The following tables summarize pass/fail criteria for each system tested. Definitions for passing and failing are listed below the first Table. The number on the left hand side of the table pertains to the numbered explanation below each table. Note that a failing mark means that the system, at time of testing, did not meet specific criteria as stated in the PBO Campaign RFP. Items may require only a minor change by the manufacturer to fix any failing mark. **All environmental specifications were taken directly from the user manuals provided for each system.**

Table 8.1.1 - Receiver mandatory functionality.

Ref. #	Receiver Mandatory Functionality	Sokkia GSR2600	TPS Odyssey RS	Trimble R7	TPS GB-1000	TPS GB-1000+grndpl
1	Receiver must be able to simultaneously track 12 channels L1 and 12 channels L2	P	P	P	P	P
2	Unsmoothed pseudorange must be recoverable from receiver	P	P	P	P	P
3	All receivers must be post-processed kinematic enabled and RTK base enabled	P	P	P	P	P
4	Receiver must be able to track ALL available satellites to zero degrees elevation	P	P	F	P	P
5	L1/L2 SNR in db*Hz referenced to a 1 Hz or better bandw idth	P	P	P	P	P
6	Receiver memory must be removable or easily dow nloadable	P	P	P	P	P
7	Receiver memory must be capable of storing 370+ days w orth data at 30 sec sample rate w ith 9 SV's	F	P	P	P	P
8	Receiver memory file system must be capable of storing a minimum of 500 data files	P	P	P	P	P
9	Receiver must be able to output 1 PPS and RTCM SC104 v 2.2 base station corrections	P	P	P	P	P
10	Receiver must have 2 data ports w ith standard serial DB9 or USB connectors (or custom to DB9/USB)	P	P	P	P	P
11	Receiver must have a total of 2 pow er ports for 12V DC external batteries and AC pow er	F	F	P	F	F
12	RINEX V2.0 translator softw are must be supplied - output must be compatible w /TEQC	P	P	P	P	P
13	Receiver must have remote data dow nload capability	not tested	not tested	not tested	not tested	not tested
14	Receivers Mean Time Betw een Failure (MTBF) must be at least 57,500 hours	P	P	P	P	P
15	Receiver pow er consumption must be < 5 Watts w hile tracking all available satellites	P	P	P	P	P
16	Receiver must automatically restart in same configuration after pow er loss	F	P	P	F	F
17	Receiver must meet the follow ing environmental specifications					
18	Operating Temperature: -40 deg Celsius to +65 deg Celsius	F	F	P	F	F
19	Humidity: 100% fully sealed	F	P	P	F	F
20	Shock: 1 meter drop to hard surface	P	P	P	P	P
21	Receiver must have a front panel interface indicating that data are being logged and # of SV's being tracked	P	P	P	P	P
22	Receiver must be able to pow er a standard choke ring antenna	not tested	not tested	not tested	not tested	not tested

P - Pass - Receiver/antenna (as delivered for testing) meets criteria for UNAVCO Campaign applications.
F - Fail - Receiver/antenna (as delivered for testing) does not meet requirements for UNAVCO Campaign applications.

Explanations of failures for Table 8.1.1:

4 - UNAVCO was advised by Trimble not to configure the R7 to track unhealthy satellites, see vendor response for more information.

7 - The SOK GSR2600 receivers arrived with a 16 Mb compact flashcard which was only capable of storing roughly four data files. Each raw data file was approximately 4.0-4.5 Mb, allowing for storage of only 4 data files while testing was going on. A larger compact flashcard could be installed in the receiver to allow more data to be collected. Under the testing conditions that were present for the duration of testing (# of satellites, sampling interval, etc), even a 1 GB compact flashcard would only hold 250 data files if each file was approximately 4 Mb, as were the files for this testing period. This value could change depending on the logging parameters of the receiver.

11 - The SOK GSR2600, TPS Odyssey RS, and TPS GB-1000 have only one physical external power port but these three systems contain two separate pins outs for power (ie. 2 power ports). The RFP requirements were for two external power ports. UNAVCO welcomes ideas and solutions that the manufacturer may have in order to utilize the 2 internal power ports. Please see the Power section and vendor responses for more information.

16 - The SOK GSR2600 does not automatically restart after a power failure. The button on the front of the receiver must be depressed for the unit to power on. Sokkia has stated that they have firmware that will fix this problem though it was not loaded prior to testing. The TPS GB-1000 will not automatically power on after a power failure unless the input voltage to the receiver drops below 2.5 Volts. This is unlikely due to the fact that the shutoff voltage on the receiver is 5.7 Volts. Once the receiver shuts off, there is no load draining the battery so the voltage will never drop below 2.5V. Please see the Power section of the testing report and the vendor response for more detailed information pertaining to this topic.

18 – ***Operating Temperature ranges were taken directly from the user manual's supplied for testing:***
Sokkia GSR2600 (pg. 91) – Operating Temperature: Receiver: -40° C to +55° C
TPS Odyssey RS (pg. B - 4) – Operating Temperature: Receiver with batteries: -40 C to +60 C
Trimble R7 (pg. 90) – Operating Temperature: Receiver: -40° C to +65° C
TPS GB-1000 (pg. C-3) - Operating Temperature: Receiver: -20° C to +55° C

19 – ***Humidity Ratings were taken directly from user manuals supplied for testing:***
Sokkia GSR2600 (pg. 91) – Dust and water resistant, Humidity: 85% RH at +38° C, 95% RH at +65° C
TPS Odyssey RS (pg. B – 4) – Aluminum extrusion, rainproof
Trimble R7 (pg. 90) – 100% condensing, unit fully sealed
TPS GB-1000 (pg. C-3) – IP66 (based on IEC60529)

Table 8.1.2 - Receiver mandatory functionality for data quality.

Ref. #	Receiver Mandatory Functionality - Data Quality	Sokkia GSR2600	TPS Odyssey RS	Trimble R7	TPS GB-1000	TPS GB-1000+grndpl
	QC Statistics (10-90 degrees)					
1	Rcvr must have at least 99% obs/exp	P	P	P	P	P
2	Rcvr must have MP1 values < 0.8m	P	P	P	P	P
3	Rcvr must have MP2 values < 0.8 m	P	P	P	P	P
4	Rcvr must have > 20,000 observations / slip (total obs / total slips)	F	P	P	P	P
	Processing Results					
5	L1 Short baseline precision must be < 0.5 mm North	P	P	P	P	P
6	L1 Short baseline precision must be < 0.5 mm East	P	P	P	P	P
7	L1 Short baseline precision must be < 1.0 cm Vertical	P	P	P	P	P
8	L2 Short baseline precision must be < 0.5 mm North	P	P	P	P	P
9	L2 Short baseline precision must be < 0.5 mm East	P	P	P	P	P
10	L2 Short baseline precision must be < 1.0 cm Vertical	P	P	P	P	P
11	L3 Short baseline precision must be < 0.5 mm North	P	P	P	P	P
12	L3 Short baseline precision must be < 0.5 mm East	P	P	P	P	P
13	L3 Short baseline precision must be < 1.0 cm Vertical	P	P	P	P	P

Failure explanations:

4 - The SOK GSR2600 had 580 observations per slip due to the high number of cycle slips below 20°.

Table 8.1.3 - Antenna mandatory functionality.

Ref. #	Antenna Mandatory Functionality	SOK600	TPS PG-A1 Geod	TRM 41249 Geod	TPS PG-A1 Geod	TPS PG-A1 Geod+grndpl
1	Antenna must be a geodetic antenna capable of receiving dual frequency (L1/L2) data	P	P	P	P	P
2	Antenna must be separate from receiver	P	P	P	P	P
3	Antenna must have an internal or external groundplane supporting multipath mitigation	P	P	P	P	P
4	Antenna must have a w ell defined phase (and gain) pattern to allow ing mixing w ith other standard antennas	P	P	P	P	P
5	Must have standard survey (5/8" -11) thread mounting for attaching to a tribrach or other mounting hardw are	P	P	P	P	P
6	Antenna must have a preamplifier that provides enough gain to operate the antenna up to 30 m aw ay w ithout an inline amplifier	P	P	P	P	P
7	Antenna must meet follow ing environmental specifications					
8	Operating temperature: -40 deg Celsius to +65 degrees Celsius	P	P	P	P	P
9	Humidity: 100% fully sealed	P	P	P	P	P

Table 8.1.4 - Software mandatory functionality.

Software Mandatory Requirements	Sokkia GSR2600	TPS Odyssey RS	Trimble R7	TPS GB-1000	TPS GB-1000+GRNDPL
Data download and configuration tools must be accessible without needing any special keys, tools, or dongles to unlock, configure, or download the receiver	P	P	P	P	P
Systems must include data download solution for Windows 2000/XP	P	P	P	P	P
Systems must include receiver configuration software for Windows 2000/XP	P	P	P	P	P

Table 8.1.5 - Miscellaneous mandatory functionality.

Miscellaneous Mandatory Requirements	Sokkia GSR2600	TPS Odyssey RS	Trimble R7	TPS GB-1000	TPS GB-1000+GRNDPL
Statement defining manufacturer's intentions for implementing new observables on the offered receiver based on planned GPS modernization	P	P	P	P	P

9.0 Acknowledgements

Funding for receiver specification and testing was made possible through the EAR 0321760 grant to UNAVCO, Inc. from the National Science Foundation (NSF). We wish to thank: Tom Morris, Morgan Smith, Sergey Organov, and Dmitry Kolosov from Topcon Positioning Systems; Brian Frohring and Daniel Wallace from Trimble Navigation Ltd.; and Kirk Burnell, Wil Anderson, and Naush Ladha from Point, Inc. for their assistance during the receiver / antenna testing.

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11.0 Vendor Responses

11.1 - Point, Inc.

POINT INC.

Point, Inc.'s Response to the UNAVCO Receiver Evaluation in Support of the Plate Boundary Observatory (PBO)

1.0 General

POINT, Inc., manufacturers of the Sokkia GSR2600 GPS receiver system would like to thank UNAVCO for the opportunity to take part in the tender for the 2004 GPS Campaign in support of the Plate Boundary Observatory (PBO).

2.0 Response to UNAVCO Report

With regards to the GPS system evaluation, there are several items that need to be clarified:
2.1 Receiver Mandatory Functionality (Table 8.1.1)

2.1.1 Item 7 - Receiver Memory

For the evaluation, POINT supplied a standard GSR2600 with our standard 16MB Compact Flash card. The GSR2600 supports various capacity CF cards. For the first article delivery we intend to ship a 1 GB CF Card, which suitable for 500 days of logging at a 30 second rate. The CF Card bay on the GSR2600 is user accessible and new cards can easily be installed.

2.1.2 Item 8 – File System

This was either not tested or not tested correctly. The supplied 16 MB CF Card is capable of storing many files – pending overall storage. It is quite capable of storing 500 files as it operates on the receiver the same as it does on a PC.

2.1.3 Item 10 – Enable/Disable Multipath Rejection

This requirement was not included in the original technical requirements document – we were not aware that it was a requirement.

2.1.4 Item 12 – 2 Power Ports

The GSR2600 is capable of input power from 2 separate batteries and is capable of in the field "hot-swapping" while the receiver is powered on and tracking satellites without interruption. When the receiver is running and connected to 2 batteries, each battery is treated as an independent power source.

2.1.5 Item 17 – Restart Configuration After Power Loss

The supplied receiver firmware is suited to our typical customers and was not modified to for this functionality. This firmware enables receivers to power-on only when the power button is pressed. Thus, if power is lost, the receiver will only power-on after the power button is pressed.

For the first article delivery we intend to provide firmware that will power-on the receiver as soon as adequate voltage is supplied. Thus, if power is lost, the receiver will power-on as soon as adequate voltage is supplied. (Adequate voltage to either of the two power inputs on the power port would work.) This configuration would work appropriately with a solar powered battery array and with one of the lowest power requirements of the receivers tested, the GSR2600 is an ideal candidate for remote applications.

2.1.6 Item 20 - Humidity

The GSR2600 meets the requirement of 100% humidity and is fully sealed. The receiver was also tested to the IPX-7 standard that includes submersion under 1 meter of water for 30 minutes.

2.2 Receiver Mandatory Functionality – Data Quality (Table 8.1.1)

2.2.1 Cycle Slips

The supplied receiver firmware has been optimized for typical survey fieldwork in support of RTK and post-processing applications. It has performed very well and has passed the test of our standard customers, surveyors who perform fieldwork on a day-in and day-out basis.

However, the firmware was not modified to suit the very specific testing and evaluation as required by UNAVCO and as such, on the surface, the performance of the receiver firmware did not meet UNAVCO's criteria. This was somewhat expected and we believe that additional work on our part in tuning the firmware will improve the observations per slip performance that UNAVCO uses as an evaluation criteria.

2.3 Appendix A Issues

The appendix has several misrepresentations in it, likely due to product unfamiliarity. To set the record straight:

2.3.1 Compact Flash Door Construction

The design of the door was intended so that customers have convenient access to the CF Card and for field-worthiness. The GSR2600 has been in service for over 2 years now with no Compact Flash door failures.

2.3.2 Antenna Height Measurement

A customized tape measure is provided to simplify measuring so only one hand is needed. However, a standard construction tape measure can and is frequently used by our customers.

2.3.3 Download Software Com Port Selection

This item has been addressed in more recent build of the evaluation software that was provided.

2.3.4 File Logging and Naming Convention

The issue of a new file creation at UTC rollover has been addressed in a more recent build of the evaluation software. And as mentioned, session programming is possible to take into account UTC rollover.

2.3.5 AC Power

The GSR2600 can be run from an AC power source. However, an AC power adaptor was not included in the test configuration sent to UNAVCO but is available on request.

2.3.6 Field Shipping Case

The field shipping case provided is a customized shipping case intended to house all components of a standard system and to be used for transporting the equipment. It includes cutouts for the receiver, antenna, tribrach, tape measure and other various pieces. It was not designed to be used as a field operating case and was not intended to house the specific larger capacity battery shipped as part of the test configuration for UNAVCO.

2.4 Miscellaneous

2.4.1 GIPSY Processing

We suspect that the cause for the processing issues here are possibly due to some mismatch between the RINEX produced by the evaluation software and the GIPSY software. We'd like the opportunity to provide another set of RINEX files from an updated version of software.

3.0 Summary

Once again, POINT would like to thank UNAVCO for the opportunity to take part in the tender for the 2004 GPS Campaign in support of the Plate Boundary Observatory (PBO). Being involved in this exercise has been a worthwhile experience and we look forward to participating in future tenders/evaluations.

If there are any follow-up questions, please contact us, as we are more than willing to discuss.

A special thanks to the UNAVCO staff in the Boulder office who were involved in the product evaluation including: Victoria Andreatta, Charles Meertens, Jim Greenberg and Warren Gallaher.

Best Regards,

Wil Anderson, President

Kirk Burnell, Application Engineer – Product Specialist

Naush Ladha, Calgary Operations

11.2 - Topcon

TOPCON

Topcon Positioning Systems

Response to UNAVCO Campaign Receiver Test Report

Topcon Positioning Systems wishes to express our appreciation to UNAVCO for the invitation to participate in the PBO Campaign Receiver evaluation. It is our continued pleasure to work with the staff at UNAVCO. The UNAVCO approach to evaluation campaigns always attempts to be thorough and unbiased. Topcon continues to benefit from participating in such tests.

Topcon has provided two receiver systems for evaluation; the Odyssey RS and the new GB1000. Topcon is committed to using the most advanced techniques possible for tracking all available and useful signals. This is reflected in the overall performance of our receivers and their ability to provide not only quality GPS results, but also, with the addition of GLONASS observables, superior GNSS based results as well. The GLONASS constellation now enjoys a long-term commitment from the International Community and is becoming well populated. Recent tests conducted globally in several locations in the United States, Russia, and Munich, Germany have yielded repeatable, precise results where a GPS only solution would have been impossible. Our performance demonstrates Topcon's commitment to pursue available signals and our experience allowing us to successfully combine this data from different systems.

Though the UNAVCO's present receiver requirements are for GPS only, the Topcon receivers proposed are immediately capable of GPS+ performance (all signals available, specifically GLONASS). This performance is readily available if UNAVCO decides in the future to pursue such benefits.

The UNAVCO report indicates how far our community has advanced in such technologies. Topcon appreciates UNAVCO for recognizing the new innovations of our industry and the performance of our product.

Topcon would like to address some specific items from the UNAVCO Campaign Receiver test report.

Signal Tracking and Receiver Performance:

- The ability to provide quality observations and raw data from Topcon receivers-antennas has been demonstrated in the report. The results demonstrated by the UNAVCO test are specific to GPS. However, Topcon systems enjoy this same performance for all other signals presently available; GLONASS being the primary other than GPS.

Odyssey RS Removable Memory

- The Odyssey RS is capable of 1GB of memory storage. However, as noted in the report, there is no easy access to removing memory cards. This design is inherently more rugged as there are no external openings required to provide access to a removable card. The receiver does come standard with both USB and Ethernet ports, either of which provide for very rapid data download without having to disturb the receiver. In addition, Topcon PDA CE-based software for receiver download is readily available for simplicity in managing receivers and data in the field, via a simple handheld device.

PG-A1 Antenna Height Measurement

- The original design requirements of the PG-A1 antenna were for an easy to use Rover antenna with geodetic qualities. This still pertains but a concern was listed in the report of measuring antenna heights on a traditional tripod set at short setups. This does not appear to be an issue for most standard sets. However, Topcon does provide now, as noted in the UNAVCO report, a variation to this antenna with slightly larger, removable ground-plane. This configuration allows for easy HI measurements. The small, but efficient, ground-plane behaves geodetically with the benefit of being removable for mobile applications but allows for easy HI measurements of any slant measurements regardless of the short tripod setup.

- Pictures, dimensions, and sample antennas/ground-planes have been provided to UNAVCO to confirm HI measurements are no longer an issue. Furthermore, the removable ground-plane provides a tidy ergonomic solution, behaving consistently with industry expected geodetic multi-path mitigation standards.

GB1000 Power Management

- Topcon understands UNAVCO's power requirements. A remote receiver, even semi-permanent, must automatically power-on again after a power-down event.

- The GB1000 test receivers provided for testing were first line prototypes. The goal was to provide a receiver with removable memory. These receivers were provided to meet UNAVCO testing deadlines but were not complete in our internal power board functionality testing. We provided these receivers ahead of schedule for UNAVCO's test. After further review, we acknowledge the incorrect power board configurations for these prototypes. We (Topcon) fully understand the requirement of "power down" and "automatic power-up" behavior. In regards to the GB1000 receiver, Topcon guarantees proper automatic power-up of the receiver in the release version of the GB1000 receiver. We can provide confirmation of this behavior if the Topcon GB1000 is further considered as a final solution for UNAVCO.

GB1000 Transport Case

- The present transport case for the GB1000 is an adaptation of existing Topcon Total Station cases. The design has proven to work well historically with the sensitive optical equipment Topcon manufactures and ships. However, if there are concerns regarding the case quality of the GB1000, a modified case, as used for the Odyssey RS, will be substituted.

Topcon is most appreciative of the opportunity to participate in the PBO Campaign Receiver bid. We welcome any additional requests for clarification on items in your report, comments by your team, or other participants in the evaluation.

11.3 - Trimble

Trimble Navigation Limited
7403 Church Ranch Blvd.
Suite #100
Westminster, CO 80021
(720) 887 6100 phone
(720) 887 6101 fax

Formal Response to
UNAVCO 2004 GPS Campaign System Test Report
For the Plate Boundary Observatory (PBO)

Submitted by Trimble Navigation Limited
22 April 2004

Trimble would very much like to thank UNAVCO, Inc., for the opportunity to participate in the PBO Campaign System testing and evaluation program. We are pleased to be able to provide additional comments regarding the Trimble R7 receiver which was tested along with the Trimble Zephyr Geodetic antenna.

The Trimble R7 incorporates Maxwell 5 technology and design enhancements into the established Trimble 5700 platform. The Trimble 5700 set the standard for combining low power operation with exceptional GPS performance. In addition, the Trimble 5700 has proven reliability in reference station and field system applications worldwide. Building on this base, the Trimble R7 adds Maxwell 5 technology to support L2C tracking along with other enhancements including flexible antenna power to support any survey quality antenna model produced by Trimble.

We believe that the enhanced power levels and signal characteristics of L2C will be especially useful in UNAVCO campaign applications. We have verified operation of the Trimble R7, R8 and NetRS receivers with the L2C signal using a GPS simulator. We are also very pleased that the Trimble R7 has been used by the Joint Program Office (JPO) to perform interoperability testing of the Block IIR-M GPS satellite payload prior to launch. By verifying that the signal from the Block IIR-M satellite could be acquired and tracked and that survey quality GPS observables could be logged, we can provide additional assurance of L2C performance when the Block IIR-M space vehicles (SVs) are launched.

The Zephyr Geodetic antenna has been designed and manufactured to meet the most demanding GPS environments. This antenna incorporates patented Stealth multipath reduction technology and our multi-point feed antenna element in a lightweight sealed enclosure. We believe the Trimble Zephyr Geodetic GPS antenna fits the UNAVCO campaign needs extremely well.

As mentioned in the test report, Trimble did not recommend enabling the "ignore health" mode for the purposes of this test campaign. Although the Trimble R7 supports the use of data from SVs that are flagged as unhealthy for position estimation, this mode has not been fully qualified for GPS observables logging. The addition of a mode to support the logging of GPS observables from unhealthy SVs while not using those observables in position estimation is a straightforward firmware revision that will be provided with the BINEX logging firmware release.

As can be seen from the test report, the Trimble R7 meets or exceeds all other functional and performance requirements. The receiver provides full support for the specified turn-on and turnoff voltages for proper support of operation with 12V lead acid battery based power supplies in campaign or reference station applications. In addition to the stated requirements, the Trimble R7 system supports dual file logging, local or remote configuration using Windows or Unix/Linux based software, and support for remote firmware update. Data can be transferred to a PC via the Compact Flash card or via serial or USB. The Trimble T01 internal file format offers an alternative with a 60% greater storage capacity than the standard BINEX format.

Further, with the addition of appropriate accessories, the Trimble R7 can be used as a high performance RTK rover, making the Trimble R7 a flexible choice to meet the varying needs of UNAVCO, Inc., campaign projects. We again thank UNAVCO, Inc., for the opportunity to participate in this test effort. We are very pleased to offer the Trimble R7 receiver and Zephyr Geodetic antenna, as this system has been developed to support geodetic accuracy in a wide range of fixed station and field applications.

We are committed to the continued support of scientific applications and will make every necessary effort to ensure the success of the PBO project.

If you have any questions, please do not hesitate to contact either of us at any time. It would be a pleasure to be a partner of UNAVCO, Inc., in support of PBO campaign system operations.

Kind regards,
Brian Frohring
Daniel Wallace
Trimble Navigation Limited

Appendix A – User observations of Campaign Systems Tested

Systems were operated in field settings and the testing lab by a number of UNAVCO engineers. The observations below are based on their comments.

Sokkia GSR2600 with SOK600 Geodetic antenna

The SOK GSR2600 has an extruded powder coated aluminum housing which is resistant to dust and water. It can handle 85% relative humidity at 38° C, and 95% relative humidity at 65° C. The door protecting the compact flash is made of plastic and seems flimsy. The receiver arrived for testing with a 16 Mb compact flashcard, enabling storage of four data files which does not meet the RFP requirement. The GSR2600 does not automatically power on after a power failure. The user must depress the button on the front of the receiver to power it on. Sokkia has stated that they have firmware which solves this problem, but it was not supplied for testing. Multipath mitigation can not be configured because it is embedded in the hardware of the receiver.

The antenna height can not be measured with a standard height stick when the antenna is setup on a tripod with a standard UNAVCO tribrach (Leica tribrach with Sokkia rotating optical plummet). The height is measured with a special measuring tape which was not provided for testing.

Some users had problems getting the receiver to communicate with the software through the USB to serial adapter. The DL4 software does not recognize anything above COM2. Newer computers do not come with a standard DB9 serial port; a USB to serial adapter must be used. These devices get assigned numbers greater than 2 (COM3, COM4, COM5). There is no direct USB download capability on the receiver. The compact flashcard can be removed and placed in a PC card reader in order to download the data. Once a logging session was started, the receiver continued to log to the same data file, and did not create a new file at UTC rollover. The SOK GSR2600 does not have internal batteries. The unit can be powered directly by an AC power source but one was not provided for testing. The unit has one physical power port which contains 2 sets of pin outs for a total of two ports. These two power ports are not internally connected.

The hard-shell transport case is durable but would need modifications to the foam inserts to accommodate the receiver while connected to the battery and antenna. The box would also require a cable port for the antenna cable. The only obvious cutout in the box was for the antenna. It was not obvious where the other pieces of equipment should go.

Topcon Odyssey RS with PG-A1 Geodetic Antenna

The Topcon Odyssey RS has an extruded aluminum housing and is fully sealed. The receiver is shock and vibration resistant. The receiver arrived for testing with 1 GB of onboard memory installed. The memory card and internal batteries can not be easily removed by an operator in the field. The Odyssey RS has 3 serial ports, a USB port, and an Ethernet port. Dongles are used to access these ports, and are included with each system. The receiver has two LED’s on the front, one indicating that data is being recorded to the internal memory, and the other indicating number of satellites being tracked.

The antenna connector is on the opposite side of the receiver housing. This makes the unit difficult to transport in a backpack when cables are attached and will place undue stress on the cables.

The antenna height could not be measured with a standard height stick when the antenna is setup on a tripod with a standard UNAVCO tribrach (Leica tribrach with Sokkia rotating optical plummet). The small diameter of the antenna made it impossible to measure directly from a point on the ground to the reference mark on the antenna. Topcon has stated that they have a fixed height tripod to use with the antenna, and recently developed an attachable groundplane. The attachable groundplane was provided to UNAVCO in order to verify that the antenna height could be measured, the results have been included in this testing report.

The software provided was intuitive and easy to use. There is a GUI interface in PC-CDU, or a user can choose manual mode in which individual GRIL commands are sent. A configuration file can also be uploaded to the receiver in manual mode using PC-CDU. Data logging can also be commenced by depressing the function button on the front of the receiver (MINTER mode).

The hard-shell transport case provided for testing is durable, but would require modifications to the foam inserts in order to accommodate the cables coming out of both ends of the receiver. The box would also require a cable port for the antenna cable to pass through while the case is shut.

The Odyssey RS has one external power port, and one internal power port that supports the internal batteries. The power ports are connected internally and there is no way to tell the receiver which one to use. The batteries (and memory) can not be easily removed by an operator in the field.

Trimble R7 with Zephyr Geodetic Antenna (TRM 41249 Geod)

The Trimble R7 has a cast aluminum housing and is fully sealed. The unit is submersible to one meter for 30 minutes. The unit is shock and vibration resistant. The access doors to the compact flash and batteries are metal and seal with a mechanical click. Each receiver arrived for testing with 512 Mb of memory.

Communication with the receiver is accomplished using Trimble propriety software using a GUI interface or command line syntax. A configuration file can also be uploaded to the receiver, and data logging can also be commenced by depressing the button on the front of the receiver. The software provided was intuitive and easy to use.

The antenna height was obtained using a standard height stick while the antenna was situated on a UNAVCO tribrach and standard tripod. The storage box requires little modification to be used as a field enclosure. The box already has cable cutouts and can be latched and completely closed while the receiver is inside and connected to the antenna.

Topcon GB-1000 with TPS PG-A1 Geodetic Antenna

The Topcon GB-1000 has an injection molded plastic housing and is shock and vibration resistant. The receivers arrived with 1 gigabyte of internal memory and a 256 megabyte removable compact flashcard. The receiver has a front panel interface which has eight operating keys, and a cursor key used for selecting parameters and navigating menus. The GB-1000 has a serial port, a USB port, and an Ethernet port. The ports are protected by rubber dustcovers that do not seem to be securely attached.

If the unit were dropped, the battery door has the potential to break off. It was noted that the voltage for the TPS GB-1000 must drop below 2.25-2.5 Volts in order for the unit to automatically power on after a power failure. If the input voltage fails to fall below this level the receiver will not auto power on.

The antenna height could not be measured with a standard height stick when the antenna is setup on a tripod with a standard UNAVCO tribrach (Leica tribrach with Sokkia rotating optical plummet). The small diameter of the antenna made it impossible to measure directly from a point on the ground to the reference mark on the antenna. Topcon has stated that they have a fixed height tripod to use with the antenna, and recently developed an attachable groundplane. The attachable groundplane allows the antenna height to be measured and the data has been included in this testing report.

The software provided was intuitive and easy to use. There is a GUI interface in PC-CDU, or a user can choose manual mode in which individual GRIL commands are sent. A configuration file can also be uploaded to the receiver in manual mode using PC-CDU. Data logging can also be commenced by depressing the function button on the front of the receiver (MINTER mode).

The hard-shell transport case shipped with the receiver can fit a survey controller and tribrach, but is not durable enough for shipping or for use as a field enclosure. The overall quality of the box is poor. The quality and design of the clips that keep the box closed are not adequate for UNAVCO campaign applications.

Appendix B – Equipment Photographs

	
SOK GSR2600 receiver and SOK600 transport case	TPS Odyssey RS receiver and TPS PG-A1 Geod transport case.
	
Trimble R7 GPS receiver and TRM 41249 Geod transport case.	TPS GB-1000 receiver and TPS PG-A1 Geod transport case.

Figure B.1 - Transport case photographs

Appendix C - Antenna Phase Center Patterns

The antenna phase center patterns listed in Tables C.1 - C.3 were taken from the PHAS_IGS.01 file from the Bernese processing software. These are the antenna phase center patterns used in the short baseline processing. The phase center pattern for the TPS PG-A1 Geodetic antenna plus groundplane is not listed here because it was still being tested at the National Geodetic Survey (NGS) by Gerry Mader.

Table C.1 - TPS PG-A1 Geod antenna phase center pattern.

TPS PG-A1 Geodetic										
	North	East	Vertical							
L1 Phase Offset (mm)	0.7	2.2	54.3							
L2 Phase Offset (mm)	0.4	-0.2	60.5							
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
L1 Phase Offset (mm)	0.0	-0.8	-0.5	0.6	2.2	3.9	5.4	6.7	7.5	7.8
L2 Phase Offset (mm)	0.0	-2.1	-3.2	-3.4	-3.1	-2.5	-1.6	-0.6	0.2	0.8
		50	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**
L1 Phase Offset (mm)		7.5	6.8	5.7	4.3	2.9	1.7	1	0.0	0.0
L2 Phase Offset (mm)		1.1	0.9	0.3	-0.9	-2.6	-4.9	-7.8	0.0	0.0

Table C.2 - TRM 41249 Geod antenna phase center pattern.

TRM 41249 Geod (TRM41249.00)										
	North	East	Vertical							
L1 Phase Offset (mm)	0.3	0.5	71.4							
L2 Phase Offset (mm)	-0.4	0.1	68.2							
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
L1 Phase Offset (mm)	0	0.6	1.4	2.3	3.2	4.1	4.9	5.6	6.1	6.4
L2 Phase Offset (mm)	0	-0.5	-0.6	-0.5	-0.2	0.1	0.5	0.8	1	1.1
		50	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**
L1 Phase Offset (mm)		6.4	6.1	5.5	4.5	3.1	1.3	-0.9	0	0
L2 Phase Offset (mm)		1	0.9	0.6	0.2	-0.2	-0.6	-0.8	0	0

Table C.3 - SOK600 antenna phase center pattern.

SOK600										
	North	East	Vertical							
L1 Phase Offset (mm)	-1.3	0.3	90.5							
L2 Phase Offset (mm)	0.2	-0.4	91.8							
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
L1 Phase Offset (mm)	0.0	0.7	1.6	2.7	4.0	5.2	6.2	7.1	7.8	8.1
L2 Phase Offset (mm)	0.0	-0.6	-0.6	-0.2	0.5	1.4	2.2	2.9	3.3	3.6
		50	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**
L1 Phase Offset (mm)		8.1	7.6	6.7	5.4	3.6	1.4	-1.2	0.0	0.0
L2 Phase Offset (mm)		3.5	3.1	2.4	1.4	0.2	-1.2	-2.7	0.0	0.0