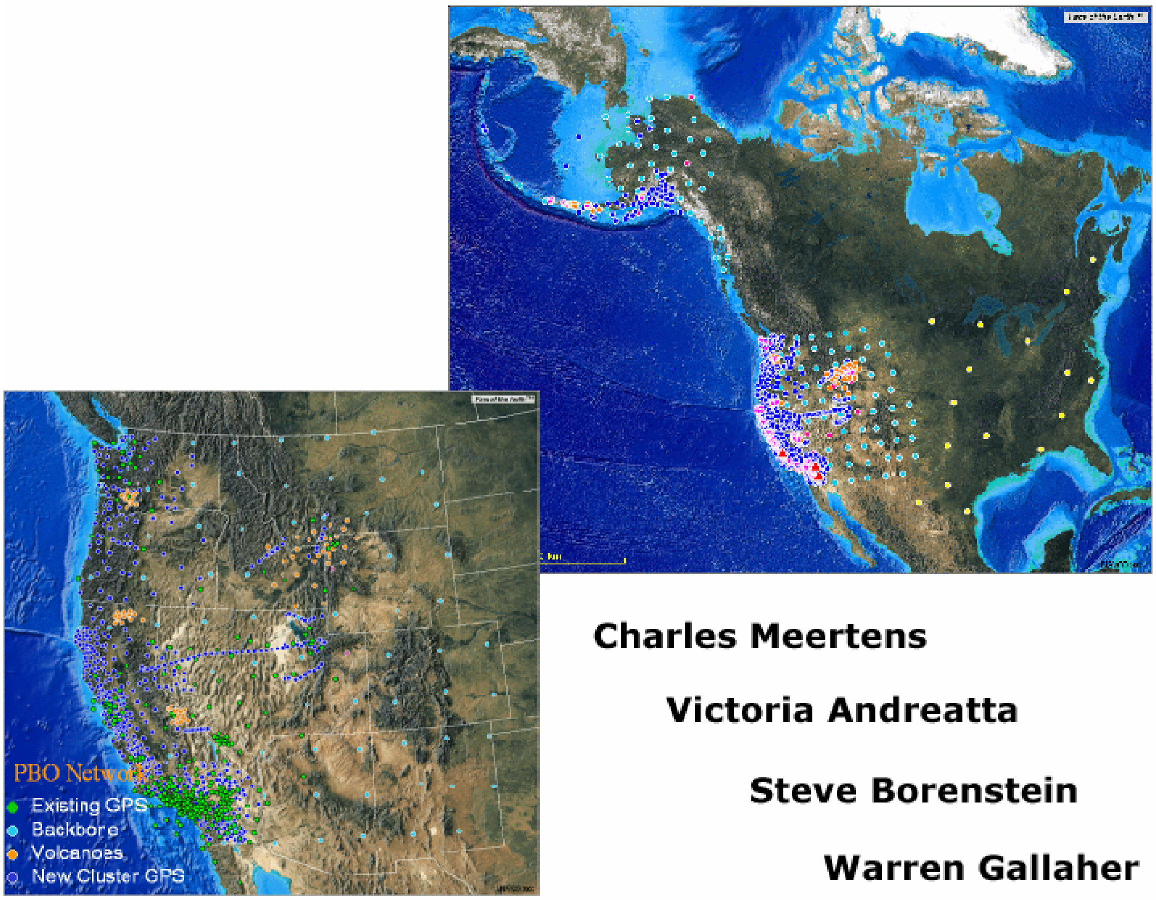
UNAVCO 2003 GPS Receiver and Antenna Testing in Support of the Plate Boundary Observatory (PBO)



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1.0 Introduction

The University NAVSTAR Consortium (UNAVCO) in Boulder has been involved in receiver and antenna testing to support UNAVCO Community equipment purchasing for over a decade. The most recent tests included the *UNAVCO Academic Research Infrastructure (ARI) Receiver and Antenna* Tests (1995), a community proposal to purchase GPS receivers for campaign and permanent station networks, and the *GPS Receiver and Antenna Testing Report for* SuomiNet (2000), a university-based, real-time GPS network. SuomiNet was intended primarily for atmospheric research and education, but contributes over 30 permanent stations for combined geodetic/atmospheric applications. Experiences and test procedures developed by the Facility have proven to be an effective means for evaluating GPS receivers and antennas, and have been adopted for this report. These tests are in support of the EarthScope Plate Boundary Observatory (PBO) and other new UNAVCO community permanent station installations over the coming years.

PBO is a distributed observatory of high-precision geodetic instruments designed to image the ongoing deformation of western North America. The geodetic network will extend from the Pacific coast to the eastern edge of the Rocky Mountains, and from Alaska to Mexico. PBO will have a backbone GPS network at 100-200 km spacing, surrounding about 20 dense clusters located at active volcanoes and the most active earthquake faults. Nearly 900 permanent GPS stations will be installed. These permanent stations will typically have only solar and wind power, and will have to operate anywhere from arctic to desert conditions.

The UNAVCO Facility in Boulder was tasked with evaluating various GPS receivers submitted by manufacturers in response to the PBO Permanent Station Request for Proposal, as well as providing technical recommendations 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. It should be noted that these receivers mark a significant improvement in GPS technology having direct Internet connectivity (no local computer is needed), low power consumption (<5watts), UNAVCO's standard data format (BINEX), compact size, and superior tracking performance.

Table 1.1 – Receiver and antenna pairs tested

Receiver	Part Number	Firmware	Antenna	Part Number
Topcon Odyssey RS	01-830111-01	2.3 Jul,08,2003 p2u1	TPS CR4 DM Choke	01-840002-01
Topcon Odyssey RS	01-830111-01	2.3 Jul,08,2003 p2u1	TPS PG-A1 Geod	01-840201-01
Topcon Odyssey RS	01-830111-01	2.3 Jul,08,2003 p2u1	TPS CR3 Choke	01-031401-01
Trimble NetRS	N/A	0.50	TRM 41249 Geod	41249.00
Trimble NetRS	N/A	0.50	TRM 49700 Choke	49700.00
Trimble NetRS	N/A	0.50	TRM 29659 DM Choke	29659.00

Each receiver/antenna pair was tested and scored independently. The technical tests can be summarized in three 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, and multipath statistics.

(2) Baseline processing tests. For this part of the evaluation, both zero and short baseline processing was performed using the Bernese 4.2 processing software. These results resemble actual geodetic processing results. However, on very short baselines most propagation effects are canceled, putting the emphasis on receiver/antenna performance.

(3) Receiver power tests and on-board memory configuration.

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. In addition, a series of mandatory PBO requirements were tabulated and are presented throughout this report. The appendix contains a section on receiver interfacing and configuration, photographs, and the antenna phase center patterns used.

2.0 Test Configuration

All tests were conducted on the roof of the UNAVCO building. Figure 2.1 shows the rooftop mounting system and benchmark names used during testing. All short baseline tests were conducted on mounts UV03 and UV04 with vendor supplied cables. All zero baseline tests were conducted on mount UV05 using a powered 8 by 1 splitter. Unused ports were terminated with 5-Ohm resistors. All markers used for testing were equipped with UNAVCO leveling mounts, see figure 2.2 for a diagram.

Figure 2.1 - Rooftop testing configuration looking southwest. UV06 is pictured at far left.

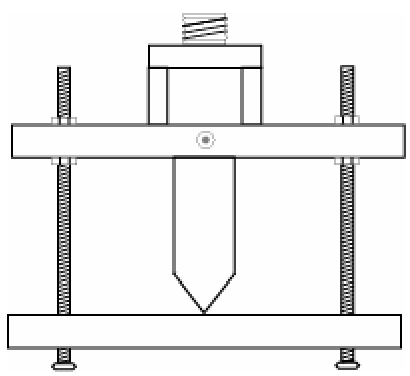


Figure 2.2 – Each benchmark used for testing was equipped with a UNAVCO leveling mount to ensure proper horizontal and vertical alignment of each antenna.

Figure 2.3- Antenna-mounting system on the roof of the UNAVCO building, looking northwest.

An Ashtech ZXII with antenna ASH701945B_M was run on benchmark UV06 during the entire testing phase. A Trimble 4000SSI was run with antenna TRM29659.00 on UV02 during the entire testing phase. These two receivers were run as references should any problems with the test receivers been found, and will be used for future mixing studies. Station UV06 is pictured on the far left, and UV02 on the far right. Each receiver/antenna combination was tested using the following parameters: 15 second sampling interval, elevation cutoff mask set to zero, multipath mitigation disabled, and pseudorange smoothing disabled. Twenty-two hour data logging sessions (00:00 UTC – 22:00 UTC) were used for all tests, enabling two hours for data downloading and equipment changes when applicable.

Each antenna/receiver combination was tested for four days on a short and zero baseline. Each manufacturer supplied 4-6 GPS receivers and 2 of each of these types of antennas: (1) a choke ring with a Dorne Margolin (DM) element, (2) a choke ring containing the manufacturer's own antenna element, and a (3) geodetic antenna. Two tests were run concurrently at all times, a short baseline, and a zero baseline. After four days of data were collected for a particular setup, the antenna's were moved to another mount so that a new set of tests could begin. Each antenna/receiver combination will be considered a set, totaling six independent systems. The table below lists the abbreviations for each receiver/antenna combination. The DM indicates the Dorne and Margolin antenna element.

Table 2.1 – Receiver and Antenna Abbreviations

Receiver	Abbreviation	Antenna	Abbreviation
Topcon Odyssey RS	Odyssey RS	Topcon CR-4 Choke Ring	TPS CR4 DM Choke
Topcon Odyssey RS	Odyssey RS	Topcon PG-A1	TPS PG-A1 Geod
Topcon Odyssey RS	Odyssey RS	Topcon CR3 GGD	TPS CR3 Choke
Trimble NetRS	NetRS	Trimble Zephyr Geodetic with Ground Plane	TRM 41249 Geod
Trimble NetRS	NetRS	Trimble Zephyr Choke Ring	TRM 49700 Choke
Trimble NetRS	NetRS	Trimble Choke Ring	TRM 29659 DM Choke

Equipment tested is pictured below for each manufacturer.

Figure 2.4 – Pictured above from left to right: TPS CR3 Choke, Odyssey RS (GPS receiver), TPS PG-A1 Geod, and TPS CR4 DM Choke.

Figure 2.5 - Pictured above from left to right: TRM 29659 DM Choke, TRM 41249 Geod, NetRS (GPS Receiver), and the TRM 49700 Choke.

Data were logged to the internal memory of each receiver and retrieved via ftp. A small 'internal' network was setup in the testing laboratory so that a Linux download computer could be connected to a hub that was directly connected to each receiver being tested. Each receiver was assigned a unique IP address upon initial configuration. After transferring the data, the computer was then disconnected from the hub, and re-connected to the network. This was the easiest method for data retrieval, and a good way to test the communications capability of the receivers.

After the raw data files were transferred, they were converted to RINEX using manufactures supplied data converters, TEQC [Estey and Meertens, 1999], or a combination of both. RINEX files were quality checked using an elevation cutoff of 0°, 5°, and 10°. Short and Zero baselines were processed using the Bernese GPS software. A custom made LabView VI interface was used for all power tests. Below are tables that present a summary of all data files collected including: receiver type, antenna type, and marker number.

Table 2.2 – Topcon Receiver serial number and Marker number matching.

Receiver	Days	Marker #	Receiver S/N
Odyssey RS	198 - 209	UV03	231-0106
Odyssey RS	198 - 209	UV04	231-0107
Odyssey RS	198 - 209	UV5A	231-0104
Odyssey RS	198 - 209	UV5B	231-0102

Table 2.3 – Day by day summary of Topcon data files

Day	Test	Receiver	Antenna	Rec. Int. (sec)	File Name	Mark	Antenna S/N	File Name	Mark	Antenna S/N
198	SBL	Odyssey RS	TPS CR3 Choke	15	UV031980.03O	UV03	217-0231	UV041980.03O	UV04	217-0225
198	ZBL	Odyssey RS	TPS CR4 DM Choke	15	UV5A1980.03O	UV05	265-PD04	UV5B1980.03O	UV05	265-PD04
199	SBL	Odyssey RS	TPS CR3 Choke	15	UV031990.03O	UV03	217-0231	UV041990.03O	UV04	217-0225
199	ZBL	Odyssey RS	TPS CR4 DM Choke	15	UV5A1990.03O	UV05	265-PD04	UV5B1990.03O	UV05	265-PD04
200	SBL	Odyssey RS	TPS CR3 Choke	15	UV032000.03O	UV03	217-0231	UV042000.03O	UV04	217-0225
200	ZBL	Odyssey RS	TPS CR4 DM Choke	15	UV5A2000.03O	UV05	265-PD04	UV5B2000.03O	UV05	265-PD04
201	SBL	Odyssey RS	TPS CR3 Choke	15	UV032010.03O	UV03	217-0231	UV042010.03O	UV04	217-0225
201	ZBL	Odyssey RS	TPS CR4 DM Choke	15	UV5A2010.03O	UV05	265-PD04	UV5B2010.03O	UV05	265-PD04
202	SBL	Odyssey RS	TPS CR4 DM Choke	15	UV032020.03O	UV03	265-PD04	UV042020.03O	UV04	265-PD03
202	ZBL	Odyssey RS	TPS PG-A1 Geod	15	UV5A2020.03O	UV05	253-0191	UV5B2020.03O	UV05	253-0191
203	SBL	Odyssey RS	TPS CR4 DM Choke	15	UV032030.03O	UV03	265-PD04	UV042030.03O	UV04	265-PD03
203	ZBL	Odyssey RS	TPS PG-A1 Geod	15	UV5A2030.03O	UV05	253-0191	UV5B2030.03O	UV05	253-0191
204	SBL	Odyssey RS	TPS CR4 DM Choke	15	UV032040.03O	UV03	265-PD04	UV042040.03O	UV04	265-PD03
204	ZBL	Odyssey RS	TPS PG-A1 Geod	15	UV5A2040.03O	UV05	253-0191	UV5B2040.03O	UV05	253-0191
205	SBL	Odyssey RS	TPS CR4 DM Choke	15	UV032050.03O	UV03	265-PD04	UV042050.03O	UV04	265-PD03
205	ZBL	Odyssey RS	TPS PG-A1 Geod	15	UV5A2050.03O	UV05	253-0191	UV5B2050.03O	UV05	253-0191
206	SBL	Odyssey RS	TPS PG-A1 Geod	15	UV032060.03O	UV03	253-0191	UV042060.03O	UV04	253-0233
206	ZBL	Odyssey RS	TPS CR3 Choke	15	UV5A2060.03O	UV05	217-0225	UV5B2060.03O	UV05	217-0225
207	SBL	Odyssey RS	TPS PG-A1 Geod	15	UV032070.03O	UV03	253-0191	UV042070.03O	UV04	253-0233
207	ZBL	Odyssey RS	TPS CR3 Choke	15	UV5A2070.03O	UV05	217-0225	UV5B2070.03O	UV05	217-0225
208	SBL	Odyssey RS	TPS PG-A1 Geod	15	UV032080.03O	UV03	253-0191	UV042080.03O	UV04	253-0233
208	ZBL	Odyssey RS	TPS CR3 Choke	15	UV5A2080.03O	UV05	217-0225	UV5B2080.03O	UV05	217-0225
209	SBL	Odyssey RS	TPS PG-A1 Geod	15	UV032090.03O	UV03	253-0191	UV042090.03O	UV04	253-0233
209	ZBL	Odyssey RS	TPS CR3 Choke	15	UV5A2090.03O	UV05	217-0225	UV5B2090.03O	UV05	217-0225

Table 2.4 – Trimble Receiver and marker number matching

Receiver	Days	Marker #	Receiver S/N
NetRS	217 - 228	UV03	9999990006
NetRS	217 - 228	UV04	9999990004
NetRS	217 - 228	UV5A	9999990002
NetRS	217 - 228	UV5B	9999990001

Table 2.5 – Day by day summary of Trimble data files

Day	Test	Receiver	Antenna	Rec. Int. (sec)	File Name	Mark	Antenna S/N	File Name	Mark	Antenna S/N
217	SBL	NetRS	TRM 49700 Choke	15	UV032170.03O	UV03	ENG0009	UV042170.03O	UV04	ENG0008
217	ZBL	NetRS	TRM 41249 Geod	15	UV5A2170.03O	UV05	12541988	UV5B2170.03O	UV05	12541988
218	SBL	NetRS	TRM 49700 Choke	15	UV032180.03O	UV03	ENG0009	UV042180.03O	UV04	ENG0008
218	ZBL	NetRS	TRM 41249 Geod	15	UV5A2180.03O	UV05	12541988	UV5B2180.03O	UV05	12541988
219	SBL	NetRS	TRM 49700 Choke	15	UV032190.03O	UV03	ENG0009	UV042190.03O	UV04	ENG0008
219	ZBL	NetRS	TRM 41249 Geod	15	UV5A2190.03O	UV05	12541988	UV5B2190.03O	UV05	12541988
220	SBL	NetRS	TRM 49700 Choke	15	UV032200.03O	UV03	ENG0009	UV042200.03O	UV04	ENG0008
220	ZBL	NetRS	TRM 41249 Geod	15	UV5A2200.03O	UV05	12541988	UV5B2200.03O	UV05	12541988
221	SBL	NetRS	TRM 29659 DM Choke	15	UV032210.03O	UV03	0220193253	UV042210.03O	UV04	0220193256
221	ZBL	NetRS	TRM 49700 Choke	15	UV5A2210.03O	UV05	ENG0009	UV5B2210.03O	UV05	ENG0009
222	SBL	NetRS	TRM 29659 DM Choke	15	UV032220.03O	UV03	0220193253	UV042220.03O	UV04	0220193256
222	ZBL	NetRS	TRM 49700 Choke	15	UV5A2220.03O	UV05	ENG0009	UV5B2220.03O	UV05	ENG0009
223	SBL	NetRS	TRM 29659 DM Choke	15	UV032230.03O	UV03	0220193253	UV042230.03O	UV04	0220193256
223	ZBL	NetRS	TRM 49700 Choke	15	UV5A2230.03O	UV05	ENG0009	UV5B2230.03O	UV05	ENG0009
224	SBL	NetRS	TRM 29659 DM Choke	15	UV032240.03O	UV03	0220193253	UV042240.03O	UV04	0220193256
224	ZBL	NetRS	TRM 49700 Choke	15	UV5A2240.03O	UV05	ENG0009	UV5B2240.03O	UV05	ENG0009
225	SBL	NetRS	TRM 41249 Geod	15	UV032130.03O	UV03	12518047.00	UV042130.03O	UV04	12541988.00
225	ZBL	NetRS	TRM 29659 DM Choke	15	UV5A2130.03O	UV05	0220193256	UV5B2130.03O	UV05	0220193256
226	SBL	NetRS	TRM 41249 Geod	15	UV032140.03O	UV03	12518047.00	UV042140.03O	UV04	12541988.00
226	ZBL	NetRS	TRM 29659 DM Choke	15	UV5A2140.03O	UV05	0220193256	UV5B2140.03O	UV05	0220193256
227	SBL	NetRS	TRM 41249 Geod	15	UV032150.03O	UV03	12518047.00	UV042150.03O	UV04	12541988.00
227	ZBL	NetRS	TRM 29659 DM Choke	15	UV5A2150.03O	UV05	0220193256	UV5B2150.03O	UV05	0220193256
228	SBL	NetRS	TRM 41249 Geod	15	UV032160.03O	UV03	12518047.00	UV042160.03O	UV04	12541988.00
228	ZBL	NetRS	TRM 29659 DM Choke	15	UV5A2160.03O	UV05	0220193256	UV5B2160.03O	UV05	0220193256

3.0 Receiver Tracking and Data Quality Tests

Data quality and receiver tracking statistics were compiled for RINEX files at high (10°-90°) and low (5°-10°, 0°-5°) elevation ranges. We compare observed data volume vs. cycle slip count, pseudorange and multipath noise, phase noise, and signal to noise for L1 and L2. All quality control (QC) statistics are based on all 16 data files (short and zero baseline) for any given particular receiver/antenna combination.

Total Expected and Observed Data

The following graphs and tables represent a cumulative summary of the amount of expected observations, the amount of completed observations, and the total number of cycle slips for the three elevation ranges: 0°-5°, 5°-10°, 10°-90°. The amount of expected observations is based on total data acquisition time for each antenna/receiver combination including short and zero baseline data for the actual number of satellites tracked. The total number of cycle slips is the combined total of MP1, MP2, and IOD slips. Note that the three antennas tested with the Odyssey RS receiver had less expected and observed observations compared to the NetRS. This was a result of the Odyssey RS not tracking satellite 17, which was listed as unhealthy for the entire duration of testing.[1] Each raw data file was translated with manufacturers supplied data converters in order to create the RINEX navigation and observation files. The translator that Topcon supplied did not include SV 17 in the navigation file so it was not counted as expected or observed. This does not impact the data analysis since the primary concern is the ratio of observed to expected data.

Summary:

All antenna/receiver combinations have at least 99% observed to expected data with no more than 0.05% slips to observations for 10°-90°. Five out of six combinations meet the requirement of 90% observed to expected data for 5°-10°, and all six combinations have less than 0.1% slips to observations for this tracking window. The TPS CR4 DM Choke and the TPS PG-A1 Geod have over 30% observed to expected data for 0°-5°. All six combinations have significantly less than 1% slips to observations for the lowest elevation-tracking window.

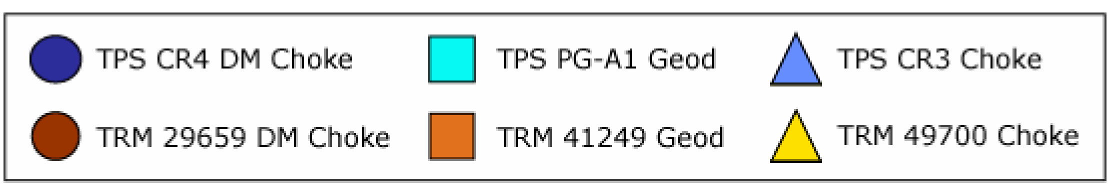


Figure 3.1 – Legend for all scatter plots presented in this report

1. The Odyssey RS receiver can be configured to use data from unhealthy satellites, but was not configured that way for these tests.

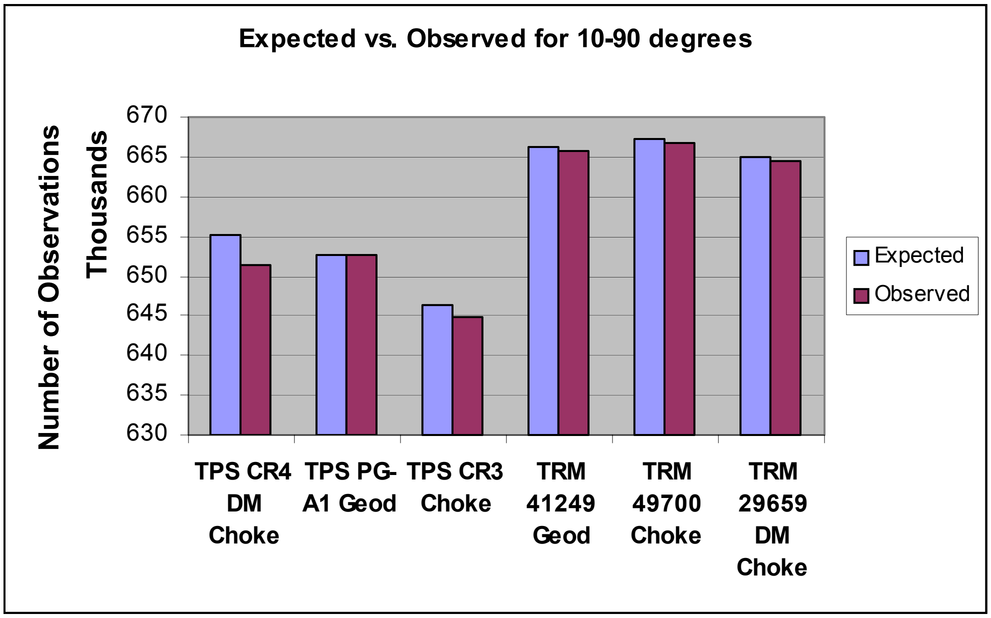


Figure 3.2 – Expected data vs. observed data for 10°- 90° elevation window.

Table 3.1 – Total expected, total observed, total cycle slips for 10°- 90°.

Receiver	Antenna	Expected	Observed	Total Slips (IOD + MP)	% (obs/exp)
Odyssey RS	TPS CR4 DM Choke	655242	651342	10	99.40%
Odyssey RS	TPS PG-A1 Geod	652660	652660	0	100.00%
Odyssey RS	TPS CR3 Choke	646312	644819	3	99.77%
NetRS	TRM 41249 Geod	666170	665666	16	99.92%
NetRS	TRM 49700 Choke	667308	666698	17	99.91%
NetRS	TRM 29659 DM Choke	664951	664547	5	99.94%

All antenna/receiver combinations have at least 99% of observed to expected observations for the tracking window 10°-90°. The Odyssey RS with TPS PG-A1 Geod had 0 cycle slips and recorded all expected observations.

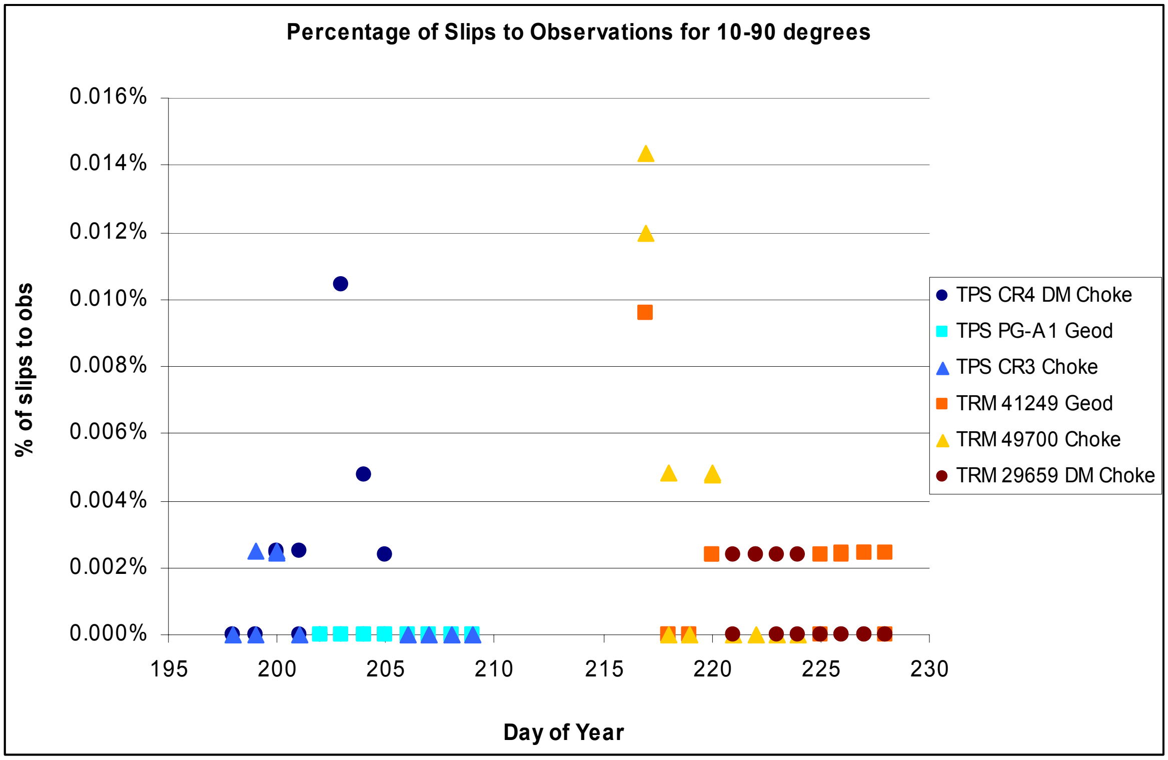


Figure 3.3 – Percentage of slips to observations to for 10°- 90°.

Table 3.2– Mean percentage of slips to observations for 10°- 90° as shown in Figure 3.3.

Receiver	Antenna	Mean % slips/obs	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.002%	0.000	0.000%	0.010%
Odyssey RS	TPS PG-A1 Geod	0.000%	0.000	0.000%	0.000%
Odyssey RS	TPS CR3 Choke	0.000%	0.000	0.000%	0.002%
NetRS	TRM 41249 Geod	0.002%	0.000	0.000%	0.002%
NetRS	TRM 49700 Choke	0.003%	0.000	0.000%	0.014%
NetRS	TRM 29659 DM Choke	0.001%	0.000	0.000%	0.002%

All antenna/receiver combinations have significantly lower than 0.05% slips to observations. The higher percentage of slips to observations for days 217-220 for the TRM 49700 Choke is a direct result of the large number of cycle slips. The TRM 49700 Choke had 17 cycle slips total for 10°-90°, all of which occurred while collecting data on the short baseline. The scatter seen in Figure 3.3 for the TPS CR4 DM Choke is from the number of cycle slips seen on days 203 (4 slips), and 204 (2 slips).

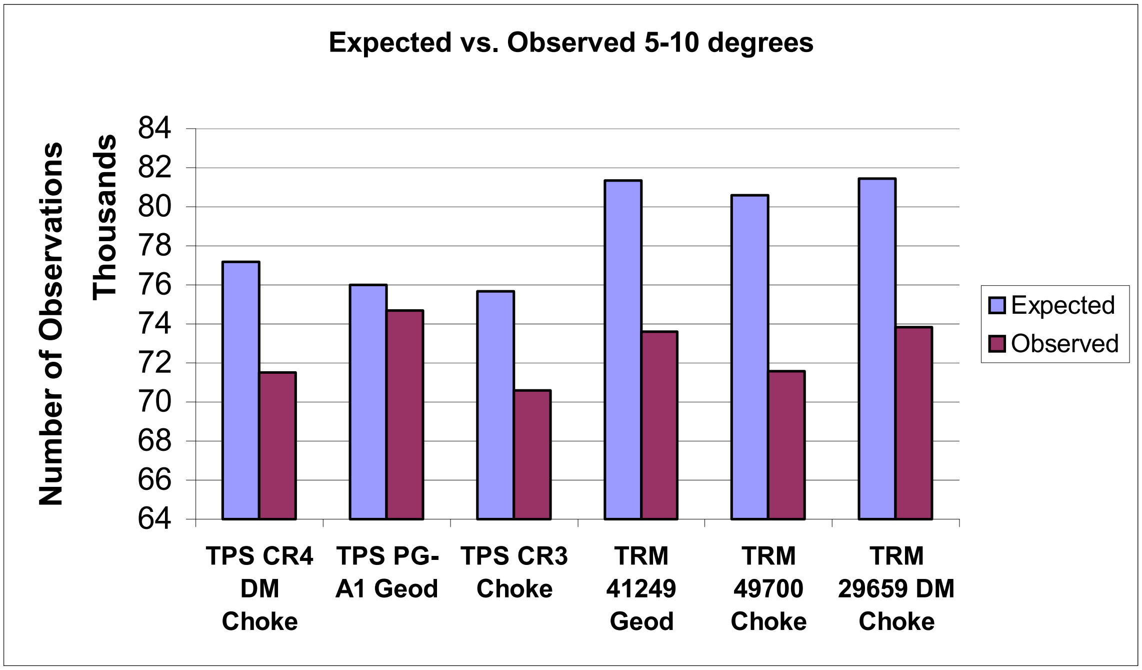


Figure 3.4- Expected and observed data for the elevation range 5°-10°.

Table 3.3- Total expected, total observed, total cycle slips for 5°-10°.

Receiver	Antenna	Expected	Observed	Total Slips (IOD + MP)	% (obs/exp)
Odyssey RS	TPS CR4 DM Choke	77178	71497	14	92.64%
Odyssey RS	TPS PG-A1 Geod	75984	74679	11	98.28%
Odyssey RS	TPS CR3 Choke	75668	70581	4	93.28%
NetRS	TRM 41249 Geod	81342	73597	1	90.48%
NetRS	TRM 49700 Choke	80580	71578	3	88.83%
NetRS	TRM 29659 DM Choke	81438	73831	1	90.66%

The TRM 49700 Choke has less than 90% of the observed to expected observations, while the other five combinations have over 90%. The TPS PG-A1 Geod had the highest ratio of observed to expected data for 5°-10°. The TRM 41249 Geod and the TRM 29659 DM Choke both had one cycle slip for 5°-10°, and had roughly 90% observed to expected.

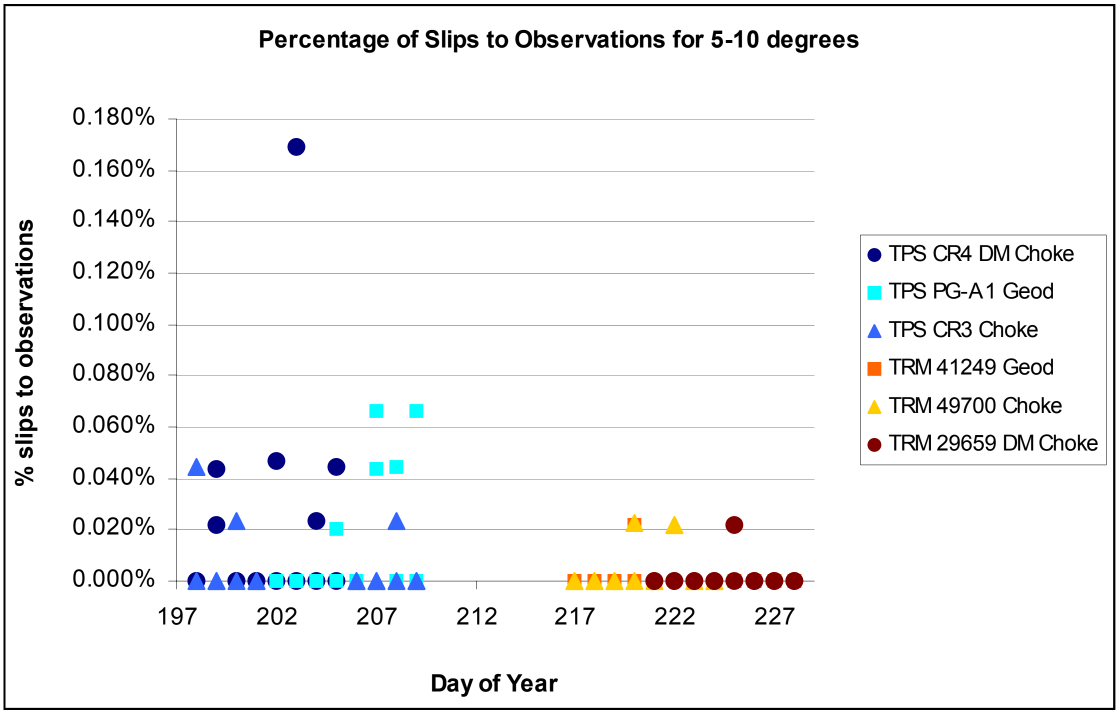


Figure 3.5 - Percentage of slips to observations for 5° - 10°.

Table 3.4 – Mean percentage of slips to observations for 5°-10°, as shown in Figure 3.5.

Receiver	Antenna	Mean % slips/obs	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.022%	0.0004	0.000%	0.169%
Odyssey RS	TPS PG-A1 Geod	0.015%	0.0003	0.000%	0.067%
Odyssey RS	TPS CR3 Choke	0.006%	0.0001	0.000%	0.044%
NetRS	TRM 41249 Geod	0.001%	0.0001	0.000%	0.022%
NetRS	TRM 49700 Choke	0.004%	0.0001	0.000%	0.022%
NetRS	TRM 29659 DM Choke	0.001%	0.0001	0.000%	0.022%

All combinations have significantly less than 0.1% slips to observations for 5° - 10°. The data point at 0.169% signifies the 6 cycle slips that the TPS CR4 DM Choke had on day 203 during data collection for the short baseline analysis. The scatter seen above for the TPS CR4 DM Choke is proportional to the 14 cycle slips total for this data set within this tracking window. The scatter seen above for TPS PG-A1 Geod on days 207, 208, and 209 is from the successive number of cycle slips (3, 2, 3) on those days.

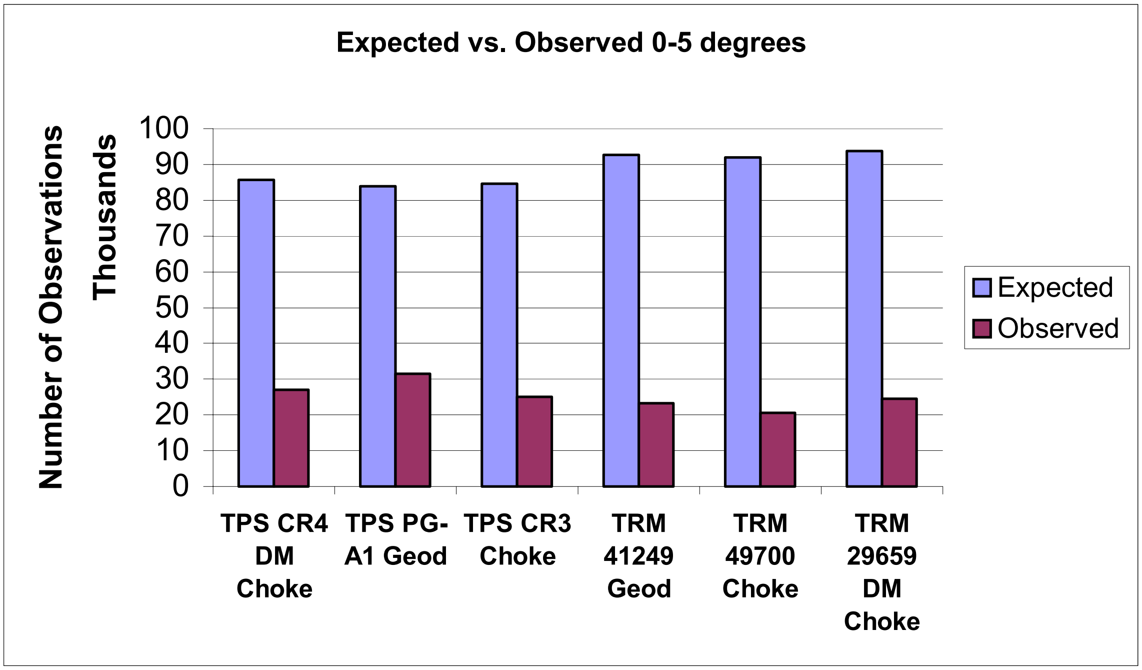


Figure 3.6 – Expected and Observed data for the elevation interval 0°-5°.

Table 3.5 – Total expected, total observed, and total cycle slips for 0°-5°.

Receiver	Antenna	Expected (Total)	Observed (Total)	Total Slips (IOD + MP)	% (obs/exp)
Odyssey RS	TPS CR4 DM Choke	85690	27031	26	31.55%
Odyssey RS	TPS PG-A1 Geod	83949	31405	26	37.41%
Odyssey RS	TPS CR3 Choke	84568	24995	14	29.56%
NetRS	TRM 41249 Geod	92580	23282	1	25.15%
NetRS	TRM 49700 Choke	91923	20532	10	22.34%
NetRS	TRM 29659 DM Choke	93805	24520	7	26.14%

Two of the combinations tested have over 30% observed to expected, while all six combinations have less than 1.0% slips to observations for 0°-5°. The NetRS with TRM 41249 Geod had 1 cycle slip for 0°-5°, but overall, had a lower percentage of observed to expected data. The TPS PG-A1 Geod had the highest percentage of observed to expected data, even though it had a large number of cycle slips. The TPS PG-A1 Geod completed 10,873 more observations than the TRM 49700 Choke for 0°-5°.

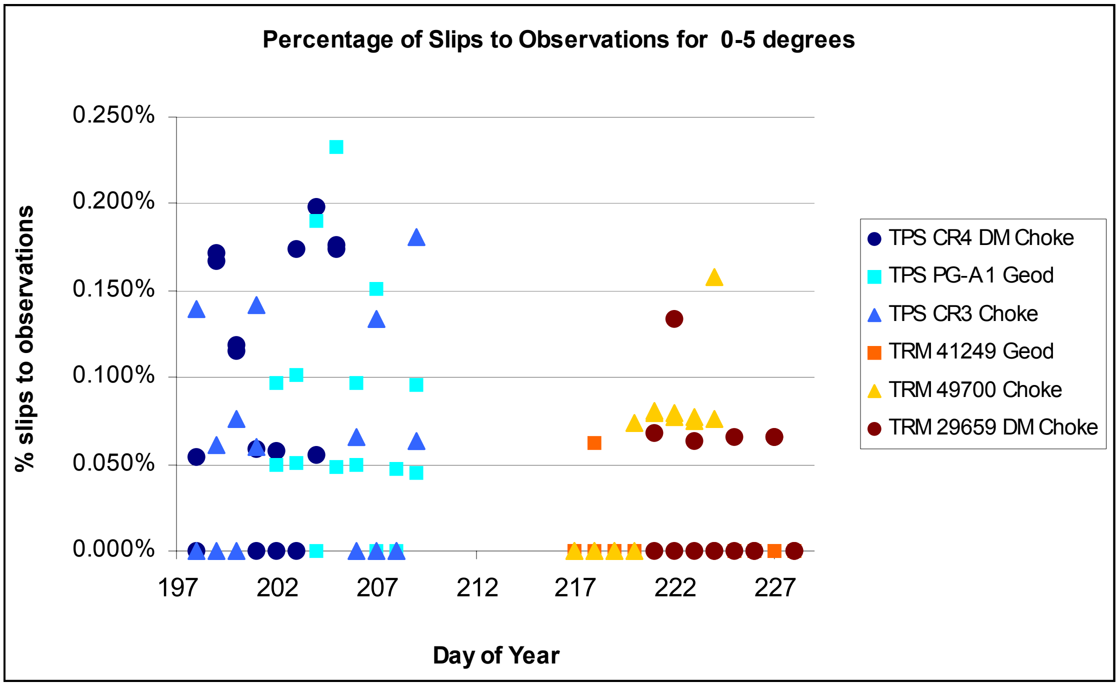


Figure 3.7 – Daily Percentage of slips to observations for 0°-5°.

Table 3.6 – Mean percentage of slips to observations for 0°-5°, as shown in Figure 3.7.

Receiver	Antenna	Mean % slips/obs	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.095%	0.0007	0.000%	0.198%
Odyssey RS	TPS PG-A1 Geod	0.078%	0.0007	0.000%	0.233%
Odyssey RS	TPS CR3 Choke	0.057%	0.0006	0.000%	0.181%
NetRS	TRM 41249 Geod	0.004%	0.0002	0.000%	0.063%
NetRS	TRM 49700 Choke	0.049%	0.0005	0.000%	0.157%
NetRS	TRM 29659 DM Choke	0.029%	0.0004	0.000%	0.133%

All antenna/receiver combinations have a larger number of slips for the window of 0°-5°. The TPS CR4 DM Choke and the TPS PG-A1 Geod had 26 cycle slips (Table 3.5) each for 0°-5°. The TPS CR3 Choke had 14 total cycle slips, but on average had a lower percentage of observed to expected than the TPS CR4 DM Choke. The TRM 41249 Geod and TRM 29659 DM Choke had similar percentages of observed to expected data, and both had a lower number of cycle slips compared to the other 4 combinations tested.

MP1 and MP2 Tracking Statistics

MP1 and MP2 for High Elevation Window (10° - 90°)

An estimate of multipath can be made by using a combination of L1 and L2. MP1 is a linear combination of P1 (or C1 if P1 is unavailable), L1, and L2. MP2 is a linear combination of P2, L1, and L2 [Estey and Meertens, 1999]. The linear combinations are computed in the QC algorithm and vary in time mainly due to the bias terms. The bias terms are assumed to be a constant unless there is a slip in the tracking of L1 or L2. MP1 and MP2 are therefore used as indicators of pseudorange multipath plus receiver noise. The following graphs and tables represent statistics that were compiled from averaging the 16 data files for each antenna/receiver combination. These were normalized to the number of observations present in that particular elevation range. The following tables and graphs provide a summary of TEQC MP1 and MP2 tracking statistics for all data collected. The first set of graphs represent the high elevation range, 10°-90°. Figures 3.8 and 3.9 show MP1 and MP2 values as they are reported on the TEQC summary line.

Summary

All antenna/receiver combinations had less than 0.7 meters for MP1 and MP2 values for 10°-90°. None of the antenna/receiver combinations had MP1 or MP2 values less than 0.7 meters for 5°-10°. The TRM 49700 Choke had MP1 and MP2 values less than 1.0 meter for 0°-5°. The three Trimble combinations had MP2 values less than 1.0 meter for 0°-5°. All choke ring antennas tested had lower multipath values than the geodetic antennas tested. Figure 3.9 clearly indicates site-specific multipath for the TPS PG-A1 Geod antenna/receiver combination. It is denoted by the difference in MP values from one test (zero baseline) to the next test (short baseline).
A smaller but noticeable amount of site-specific multipath can be seen in Figure 3.8 for the TPS CR3 Choke short baseline analysis. Summaries of all antenna/receiver combinations can be found in Tables 3.7-3.12.

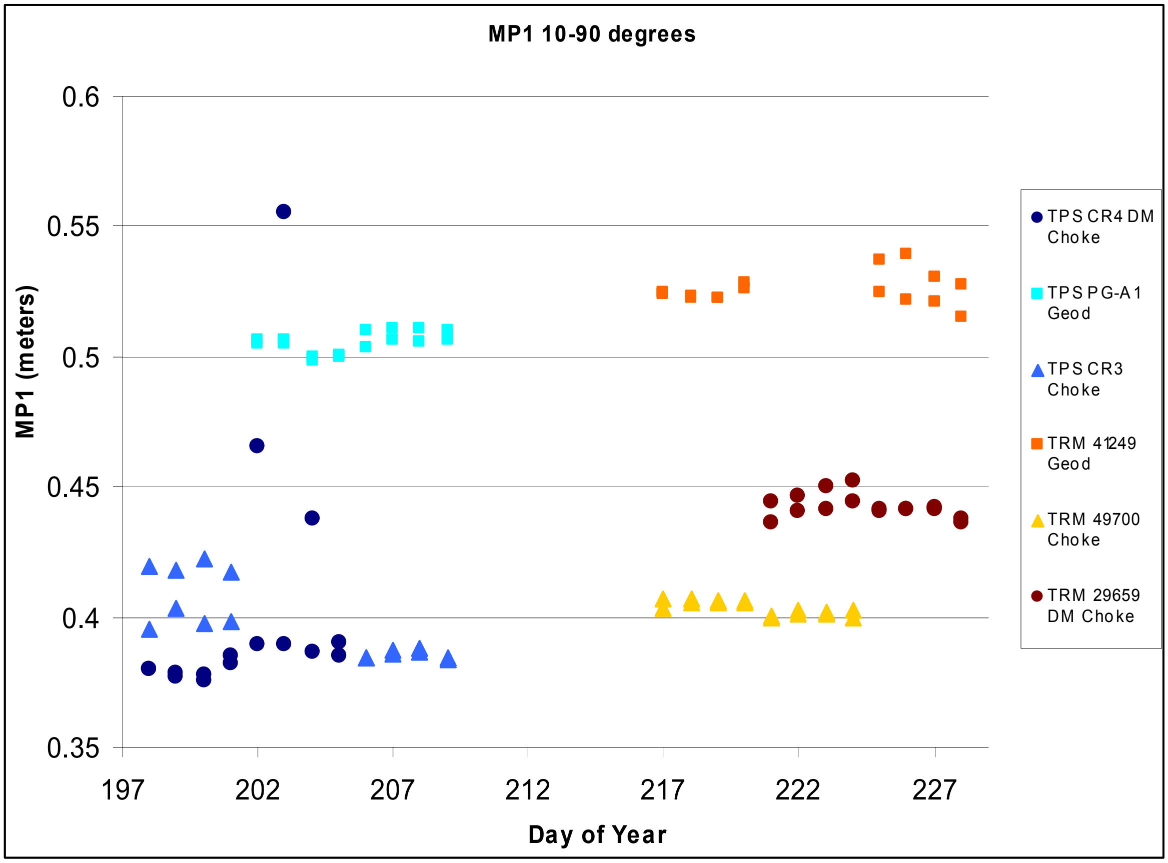


Figure 3.8 - MP1 values for each receiver/antenna combination in the elevation range 10°-90°. Topcon equipment is pictured on the left part of the graph, while the Trimble equipment is pictured on the right side of the graph. MP1 is a linear combination of P1 (or C1), L1, and L2, which help to provide an estimate of pseudorange multipath. There is a small difference in multipath values seen by the TPS CR3 Choke for days 198-201 while collecting data for the short baseline analysis. This difference indicates that TPS CR3 Choke is more sensitive to MP1 site-specific multipath.

Table 3.7 – Summary of MP1 for 10°- 90°

Receiver	Antenna	MP1	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.40	0.05	0.38	0.56
Odyssey RS	TPS PG-A1 Geod	0.51	0.00	0.50	0.51
Odyssey RS	TPS CR3 Choke	0.40	0.01	0.38	0.42
NetRS	TRM 41249 Geod	0.53	0.01	0.51	0.54
NetRS	TRM 49700 Choke	0.40	0.00	0.40	0.41
NetRS	TRM 29659 DM Choke	0.44	0.00	0.44	0.45

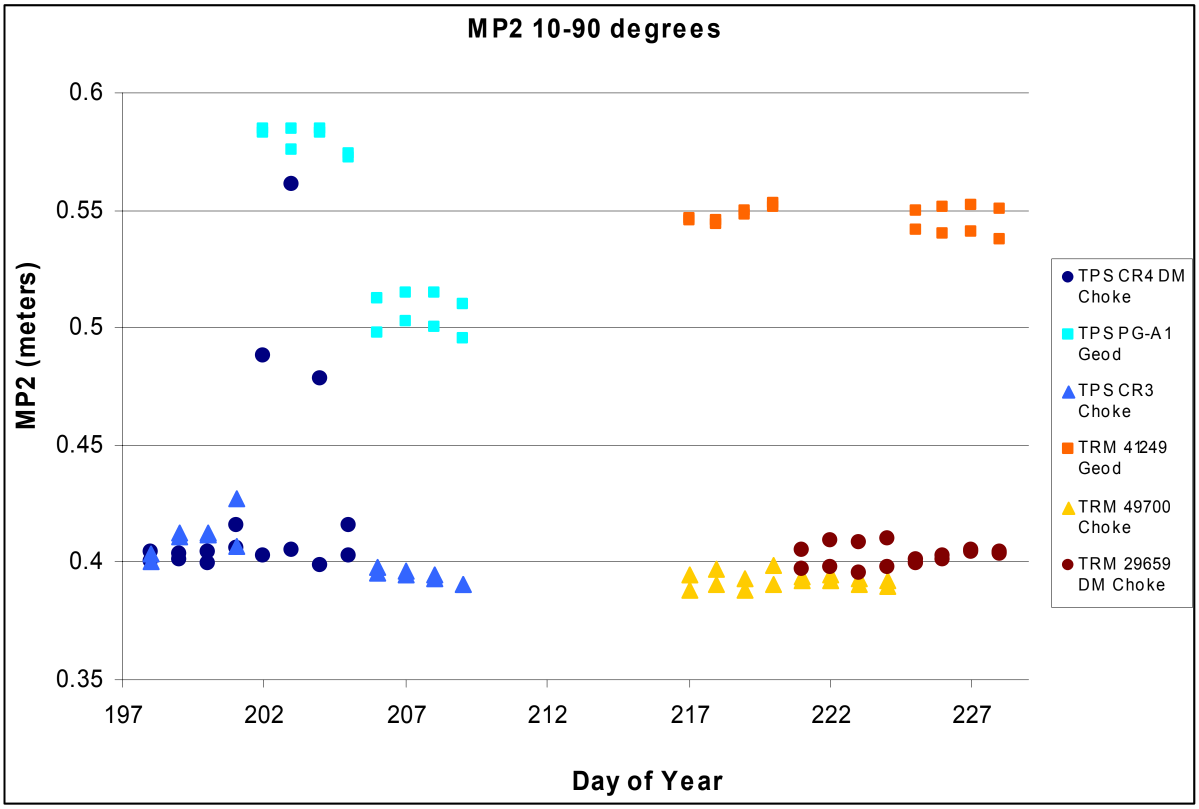


Figure 3.9 – MP2 values for each receiver/antenna pair in the elevation range 10°-90°. Topcon equipment is pictured on the left side of the graph, and the Trimble equipment is pictured on the right side of the graph. MP2 is the linear combination of P2, L1, and L2, and provides an estimate of pseudorange multipath. The difference in multipath values for the TPS PG-A1 Geod shown above, indicate that the TPS PG-A1 Geod is more sensitive to MP2 site-specific multipath.

Table 3.8 – Summary of MP2 for 10°- 90°

Receiver	Antenna	MP2	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.42	0.05	0.40	0.56
Odyssey RS	TPS PG-A1 Geod	0.54	0.04	0.50	0.58
Odyssey RS	TPS CR3 Choke	0.40	0.01	0.39	0.43
NetRS	TRM 41249 Geod	0.55	0.00	0.54	0.55
NetRS	TRM 49700 Choke	0.39	0.00	0.39	0.40
NetRS	TRM 29659 DM Choke	0.40	0.00	0.40	0.41

Table 3.9– Summary of MP1 for 5°-10°

Receiver	Antenna	MP1	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.94	0.20	0.78	1.42
Odyssey RS	TPS PG-A1 Geod	0.91	0.18	0.75	1.24
Odyssey RS	TPS CR3 Choke	0.97	0.18	0.83	1.33
NetRS	TRM 41249 Geod	0.94	0.02	0.91	0.98
NetRS	TRM 49700 Choke	0.82	0.01	0.80	0.84
NetRS	TRM 29659 DM Choke	0.86	0.01	0.84	0.89

Table 3.10 – Summary of MP2 for 5°-10°

Receiver	Antenna	MP2	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.90	0.06	0.84	1.07
Odyssey RS	TPS PG-A1 Geod	0.86	0.06	0.77	0.95
Odyssey RS	TPS CR3 Choke	0.99	0.05	0.93	1.11
NetRS	TRM 41249 Geod	0.82	0.03	0.76	0.87
NetRS	TRM 49700 Choke	0.71	0.03	0.66	0.76
NetRS	TRM 29659 DM Choke	0.71	0.04	0.62	0.76

Table 3.11 – Summary of MP1 for 0°-5°

Receiver	Antenna	MP1	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	1.21	0.12	1.01	1.52
Odyssey RS	TPS PG-A1 Geod	1.21	0.07	1.11	1.34
Odyssey RS	TPS CR3 Choke	1.24	0.13	1.10	1.51
NetRS	TRM 41249 Geod	1.16	0.05	1.09	1.25
NetRS	TRM 49700 Choke	0.93	0.03	0.87	0.98
NetRS	TRM 29659 DM Choke	1.06	0.04	0.99	1.11

Table 3.12 – Summary of MP2 for 0°-5°

Receiver	Antenna	MP2	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	1.17	0.15	0.90	1.40
Odyssey RS	TPS PG-A1 Geod	1.13	0.18	0.85	1.53
Odyssey RS	TPS CR3 Choke	1.21	0.16	0.92	1.49
NetRS	TRM 41249 Geod	0.78	0.04	0.72	0.89
NetRS	TRM 49700 Choke	0.72	0.06	0.63	0.85
NetRS	TRM 29659 DM Choke	0.71	0.05	0.61	0.80

Observations per Slip (MP Slips only) 0°-90°

The following graph and table provide a summary of TEQC observation per slip tracking statistics taken over the test period. The graph represents the total number of observations recorded, divided by the combined number of MP slips (MP1and MP2) for 0°-90°. The combined number of MP slips is defined as a slip on MP1 (code) and MP2 (code) at the same epoch for a particular satellite.

Summary

All antenna/receiver combinations have over 20,000 observations per slip for 0°-90°. The TRM 41249 Geod has 46,170 observations per slip, while the TPS PG-A1 Geod has 34,239 observations per slip. The scatter of various combinations between 0 and 30,000 indicate a larger number of cycle slips on MP1 and MP2.

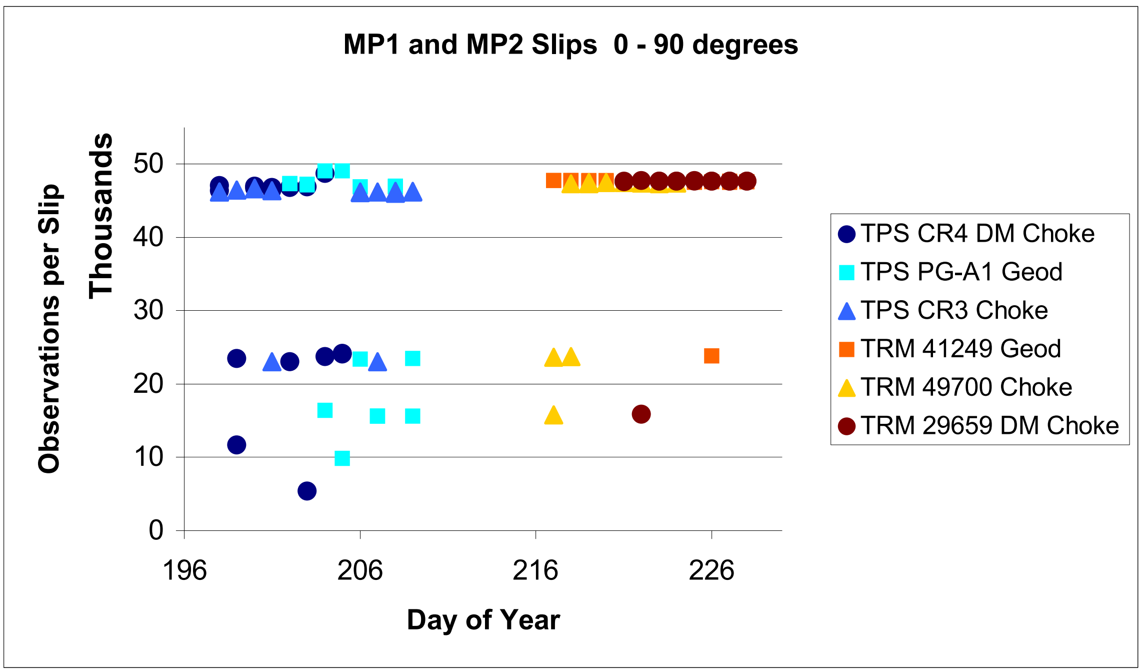


Figure 3.10 – Combined MP slips for 0° - 90°.

Table 3.13 – Total number of observations recorded divided by combined MP slips. Shown below are the mean, standard deviation, minimum, and maximum values for each pair.

Receiver	Antenna	Mean	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	34903	14949	5400	48695
Odyssey RS	TPS PG-A1 Geod	34239	15888	9832	49067
Odyssey RS	TPS CR3 Choke	43391	7935	23055	46666
NetRS	TRM 41249 Geod	46170	5959	23825	47765
NetRS	TRM 49700 Choke	42482	10743	15827	47483
NetRS	TRM 29659 DM Choke	45696	7952	15878	47754

MP1 and MP2 Tracking Plots

By taking the ionosphere-free code ranges and carrier phase differences, the residual plots below will illustrate the multipath effect. It is clear from geometry that signals received from low satellites will be more susceptible to multipath than signals from high elevations. Below are the epoch-to-epoch MP1 and MP2 tracking plots. Figures 3.11 and 3.12 represent MP1 and MP2 traces for satellite 7 for 0°-90°. Figures 3.13 and 3.14 represent MP1 and MP2 tracking plots for satellite 8 at a high elevation angle of approximately 75°-90°. Figures 3.15 and 3.16 are MP1 and MP2 tracking plots for satellite 10 for a low elevation-tracking window of approximately 0°-12°.

Summary:

Figures 3.11 and 3.12 are indicators of the elevation dependence of multipath. Less multipath is denoted by the smoother thin line at higher elevations (in the middle). At higher elevations, the antenna is more likely to receive the incoming signal with less multipath effect. As the elevation angle decrease, the multipath increases. This is due to geometry and is typically caused by buildings, and reflective surfaces such as water. Figures 3.13 and 3.14 are consistent with low multipath conditions since they represent the tracking window from approximately 75°-90°. The lower elevation figures 3.15 and 3.16 indicate higher multipath (more sinusoidal than linear). As a general comparison, the four choke ring antennas tested have lower multipath values at higher elevation angles than the geodetic antennas tested, Figures 3.7 and 3.8.

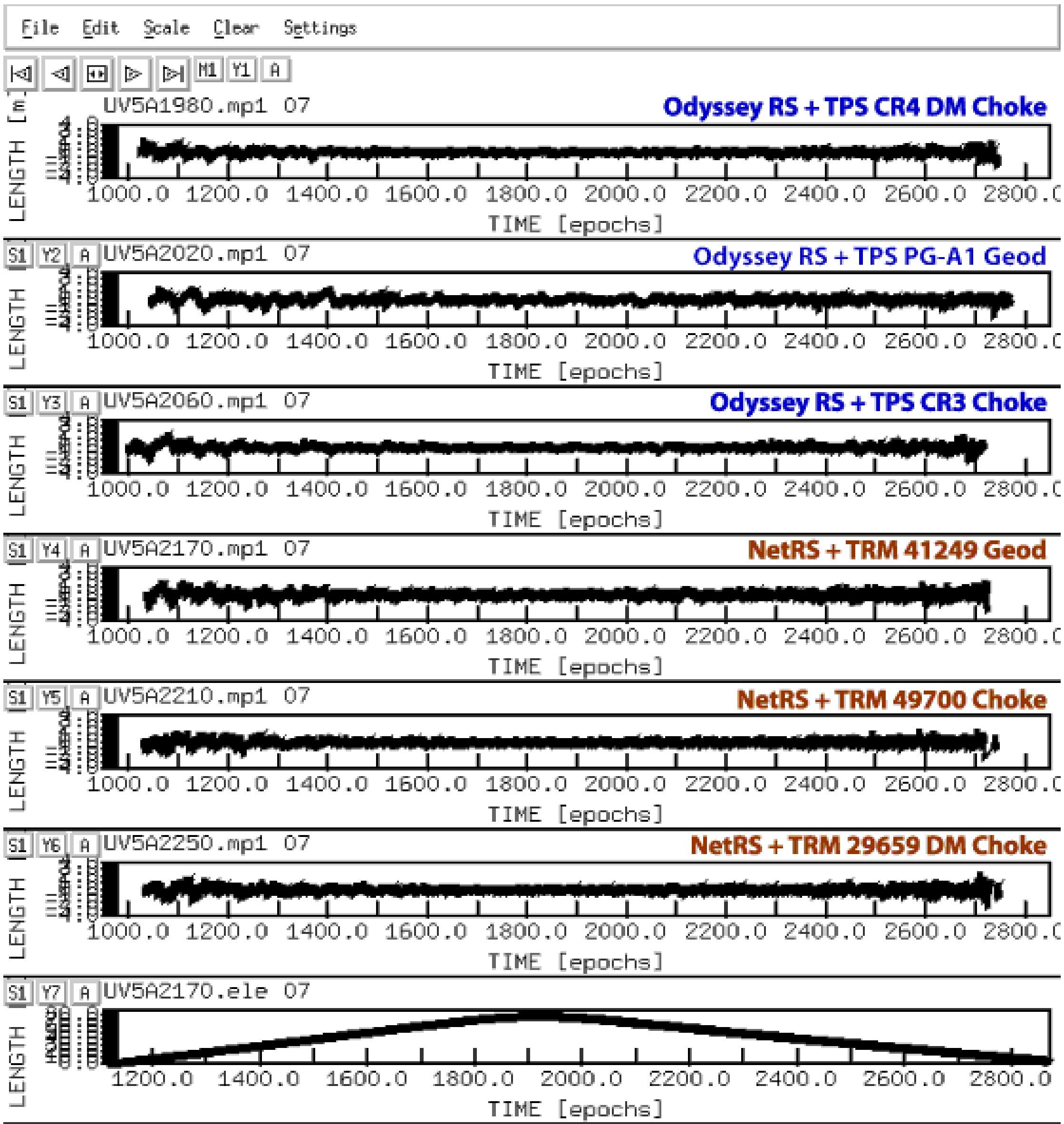


Figure 3.11 – MP1 trace for satellite 7 on marker UV5A from 0°-90°. Data are from receivers on the same monument but different days. Traces have been shifted so the tracking geometry is the same. The vertical scale is from –4 to 4 cm. Traces from top to bottom are: TPS CR4 DM Choke, TPS PG-A1 Geod, TPS CR3 Choke, TRM 41249 Geod, TRM 49700 Choke, TRM 29659 DM Choke. Bottom trace shows satellite elevation over the tracking period.

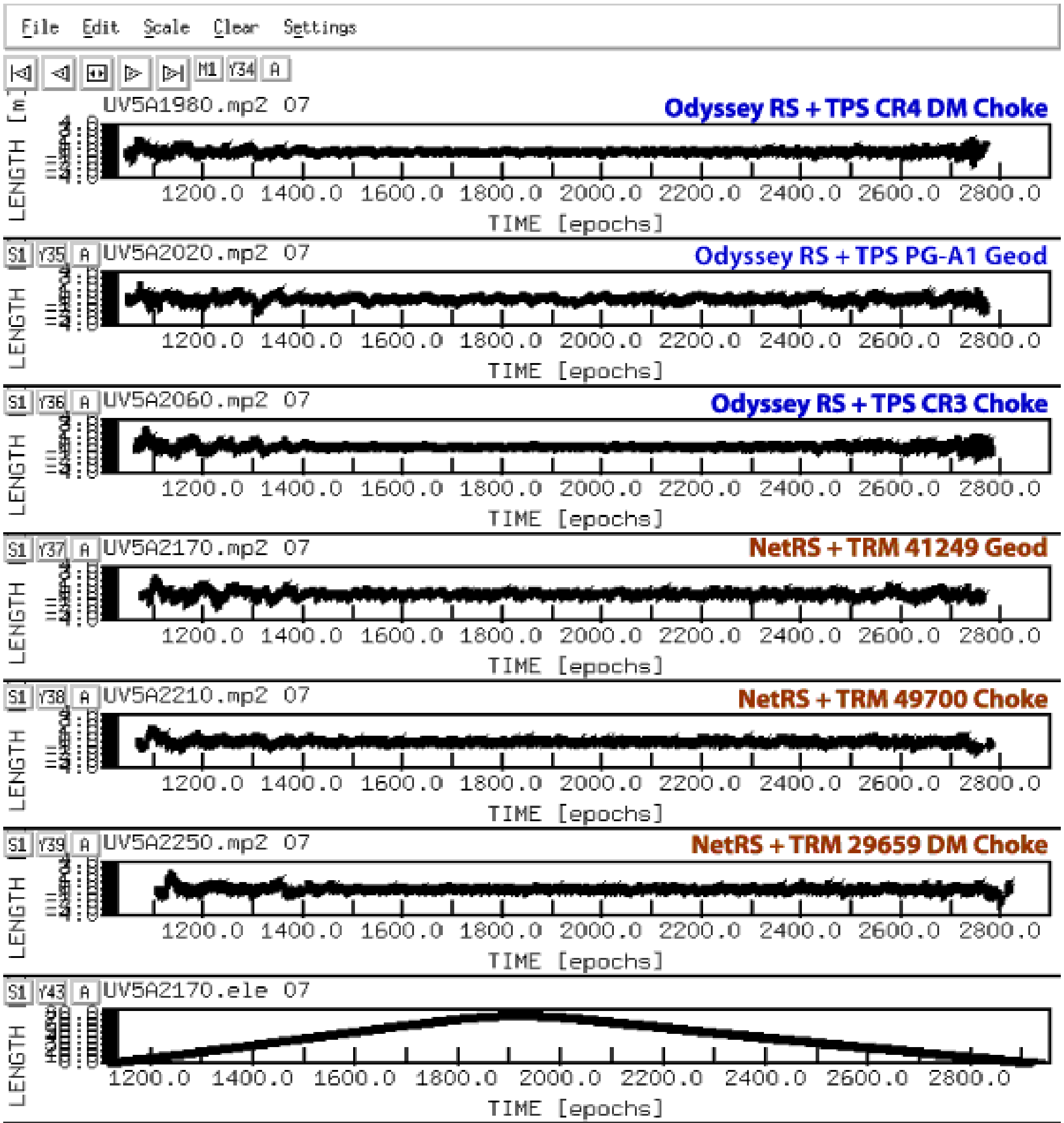


Figure 3.12 – MP2 trace for satellite 7 on marker UV5A from 0°-90°. Data are from receivers on the same monument but different days. Traces have been shifted so the tracking geometry is the same. The vertical scale is from –4 to 4 cm. Traces from top to bottom are: TPS CR4 DM Choke, TPS PG-A1 Geod, TPS CR3 Choke, TRM 41249 Geod, TRM 49700 Choke, TRM 29659 DM Choke. Bottom trace shows satellite elevation over the tracking period.

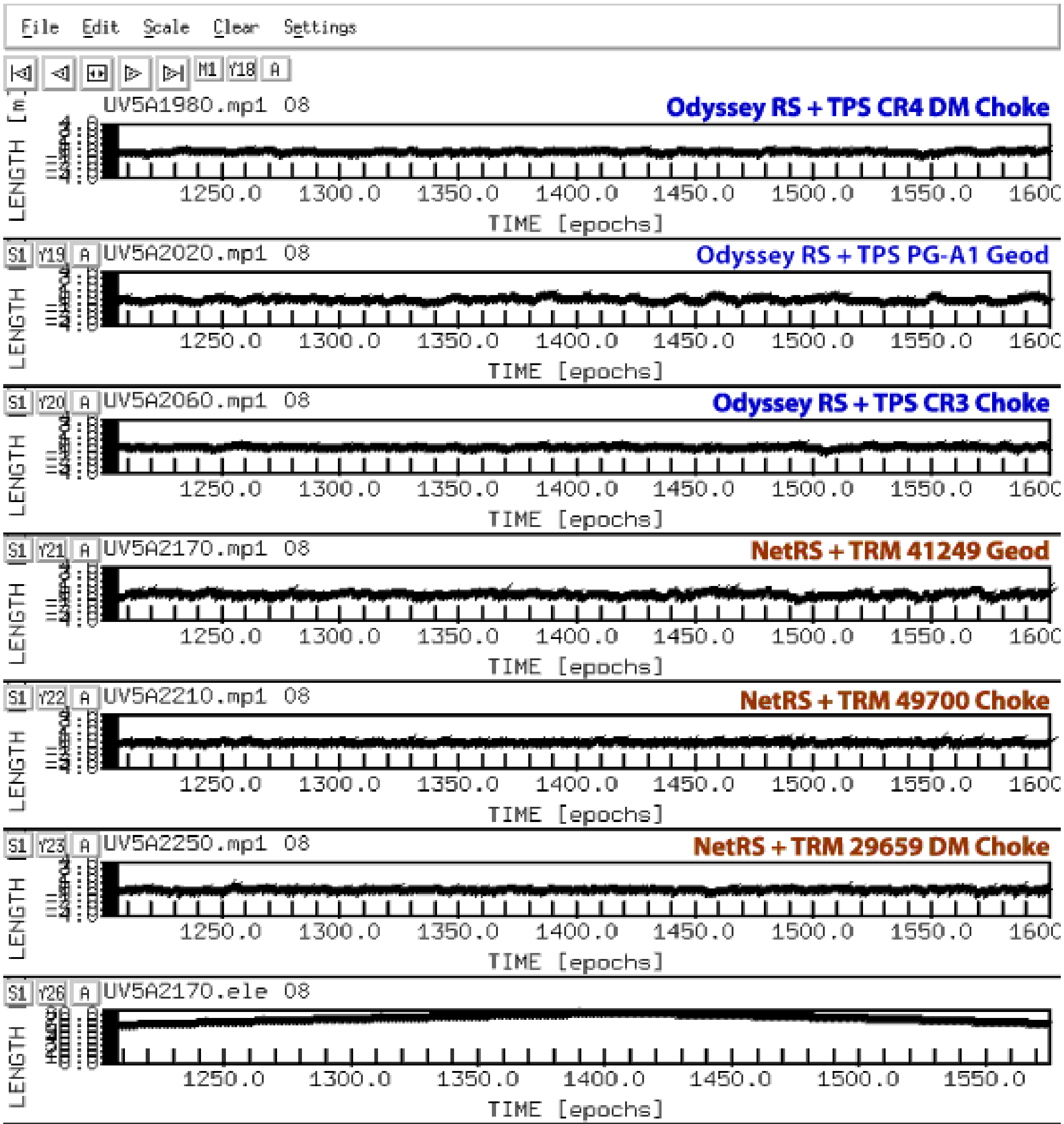


Figure 3.13 – MP1 high elevation trace for satellite 8 on marker UV5A. Zoomed area represents tracking from approximately 75°-90°. Data are from receivers on the same monument but different days. Traces from top to bottom are: TPS CR4 DM Choke, TPS PG-A1 Geod, TPS CR3 Choke, TRM 41249 Geod, TRM 49700 Choke, TRM 29659 DM Choke. Bottom trace shows satellite elevation over the tracking period.

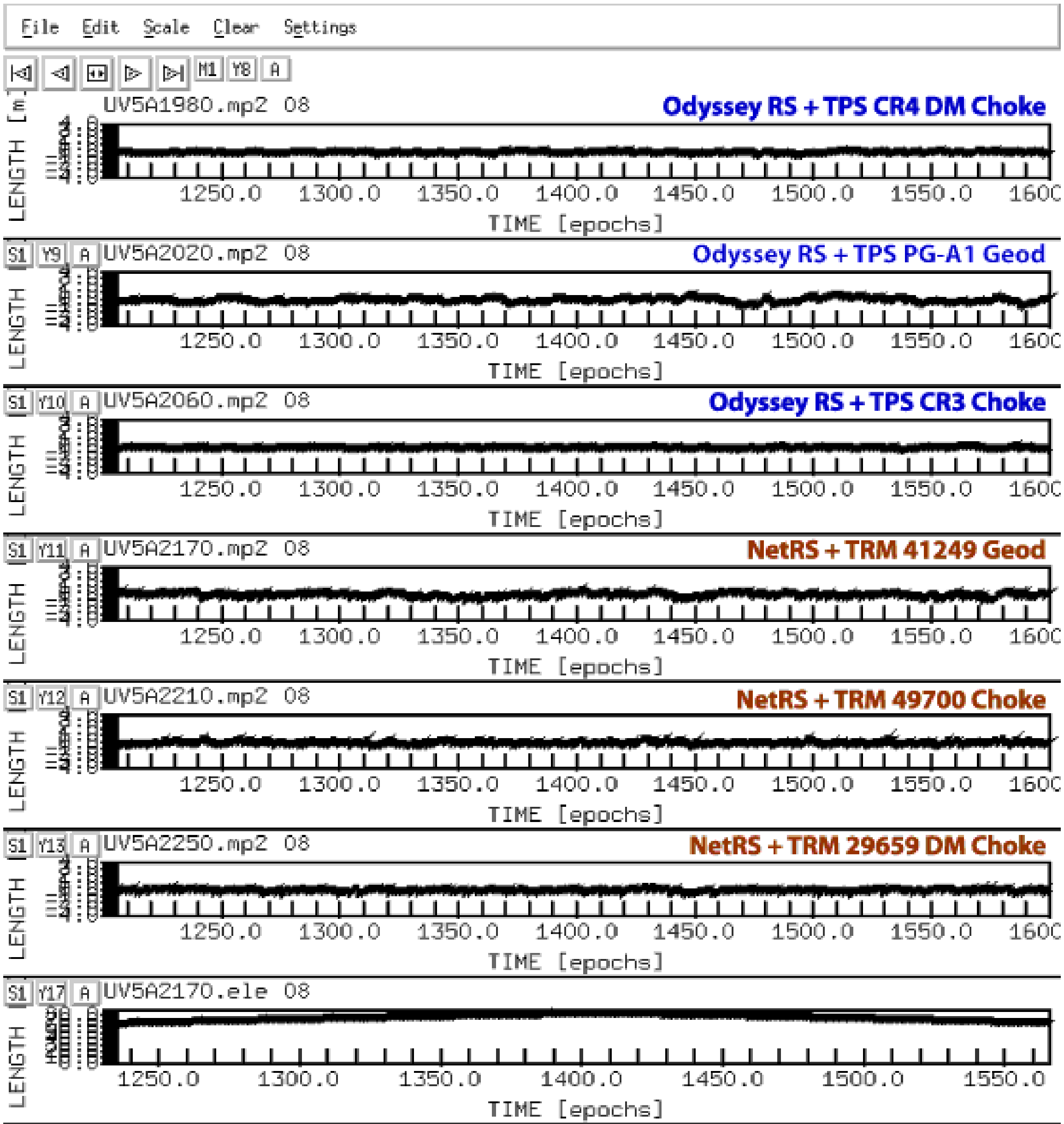


Figure 3.14 – MP2 high elevation trace for satellite 8 on marker UV5A. Zoomed area represents tracking from approximately 75°-90°. Data are from receivers on the same monument but different days. Traces from top to bottom are: TPS CR4 DM Choke, TPS PG-A1 Geod, TPS CR3 Choke, TRM 41249 Geod, TRM 49700 Choke, TRM 29659 DM Choke. Bottom trace shows satellite elevation over the tracking period.

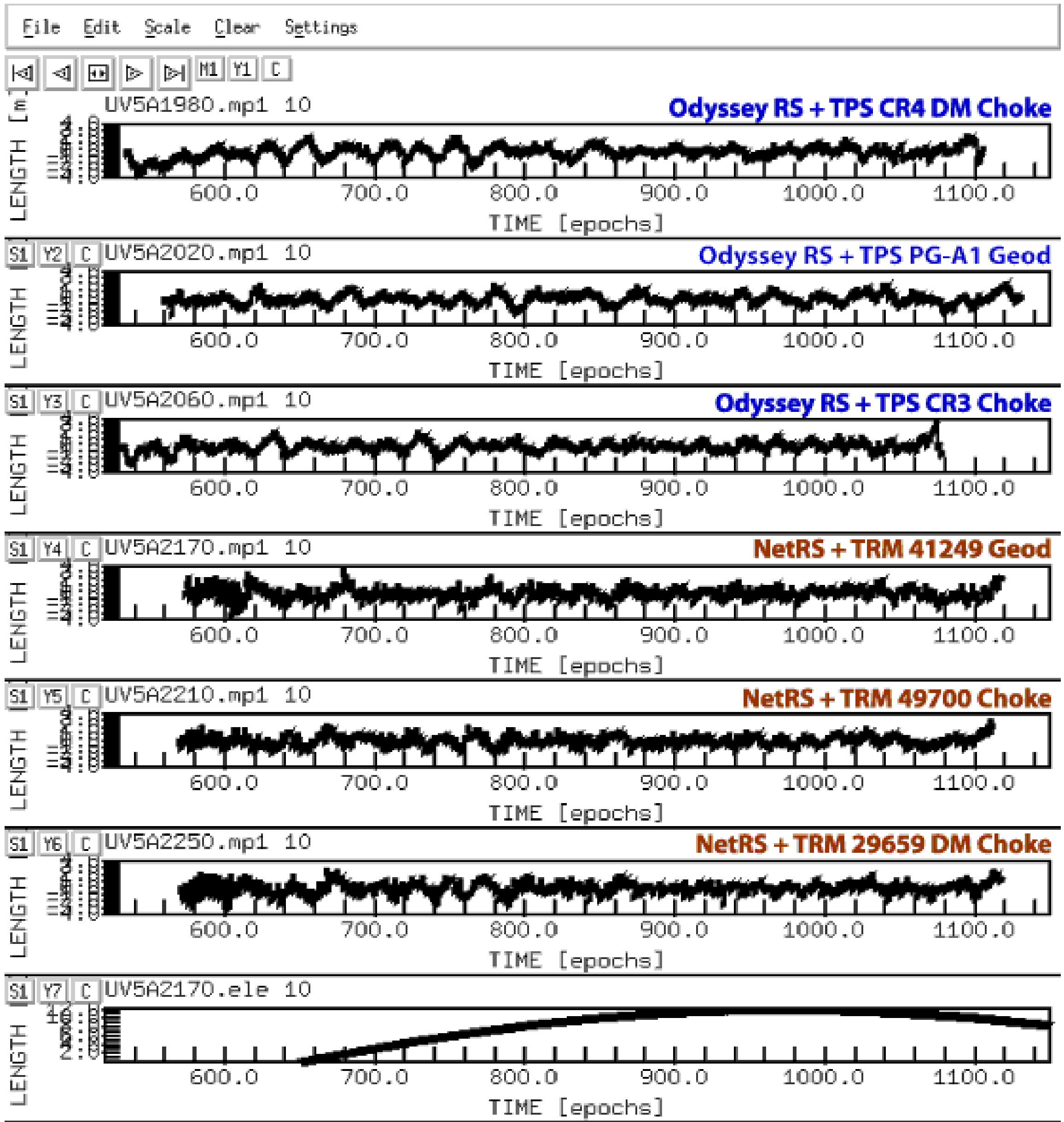


Figure 3.15 – MP1 low elevation trace for satellite 10 on marker UV5A from 0°-12°. Data are from receivers on the same monument but different days. Traces from top to bottom are: TPS CR4 DM Choke, TPS PG-A1 Geod, TPS CR3 Choke, TRM 41249 Geod, TRM 49700 Choke, TRM 29659 DM Choke. Bottom trace shows satellite elevation over the tracking period.

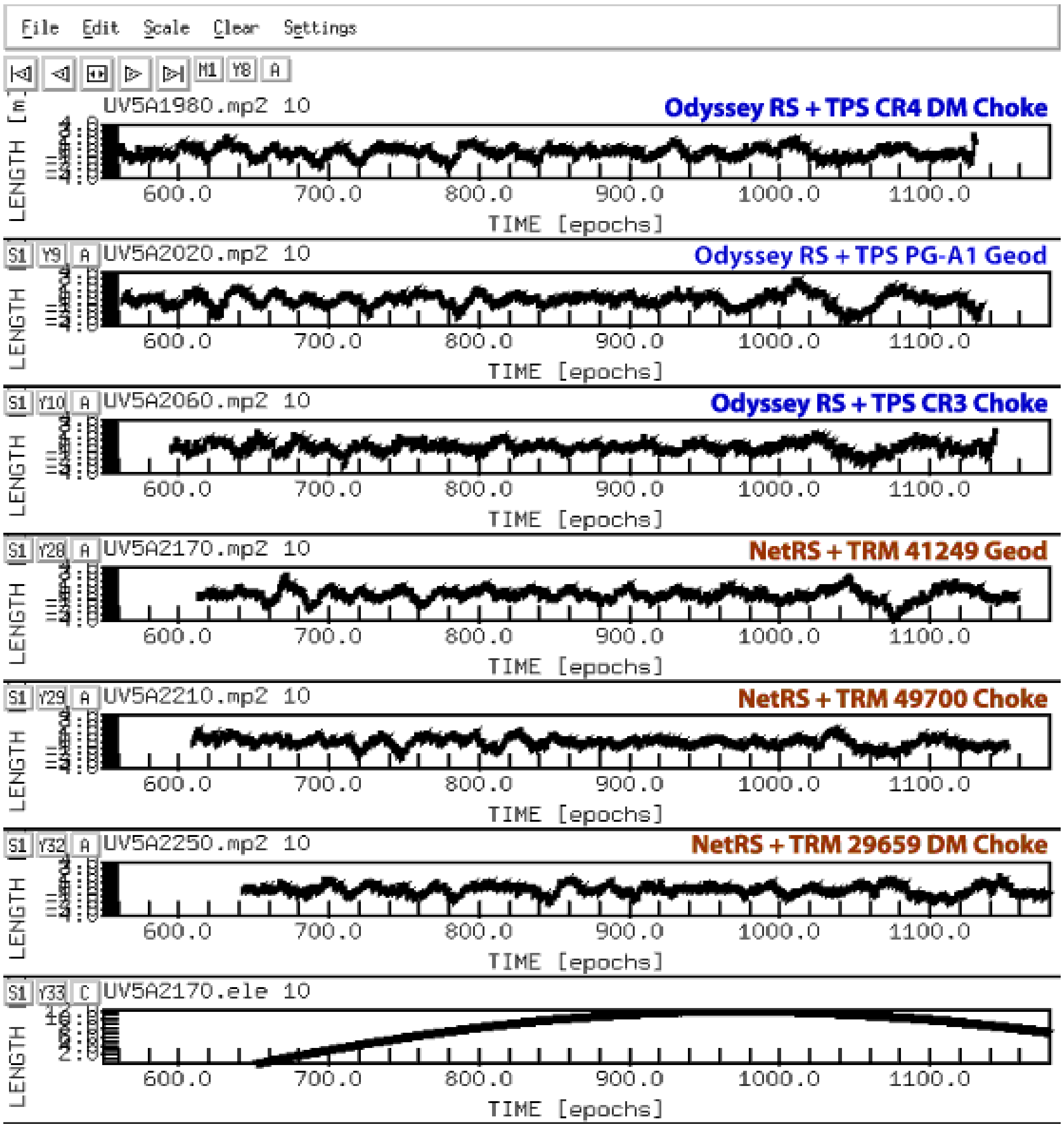


Figure 3.16 – MP2 low elevation trace for satellite 10 on marker UV5A from 0°-12°. Data are from receivers on the same monument but different days. Traces from top to bottom are: TPS CR4 DM Choke, TPS PG-A1 Geod, TPS CR3 Choke, TRM 41249 Geod, TRM 49700 Choke, TRM 29659 DM Choke. Bottom trace shows satellite elevation over the tracking period.

IOD Slips

IOD is defined as the time derivative of the ionospheric delay. This value is calculated and monitored epoch to epoch in order to detect large changes in phase ambiguities, or slips in tracking of L1 and L2. Since the paths of the signals from epoch to epoch have changed due to ionosphere, motion of the satellite, etc., a minimum amount of variability must be assumed. [Estey, and Meertens, 1999] For this analysis, we assume that a rate of change greater than 400 cm/min in IOD is a phase cycle slip. This value is the default value that TEQC will use unless otherwise specified. The following graphs provide a summary of IOD slips converted to percent for 10°-90°, 5°-10°, and 0°-5° tracking window.

Summary:

All antenna/receiver combinations exhibit significantly lower than 1% IOD slips for 5°-10° and 0°-5°. The difference of figures 3.7 and 3.19 would yield the percentage of MP slips to observations for each respective elevation-tracking window.

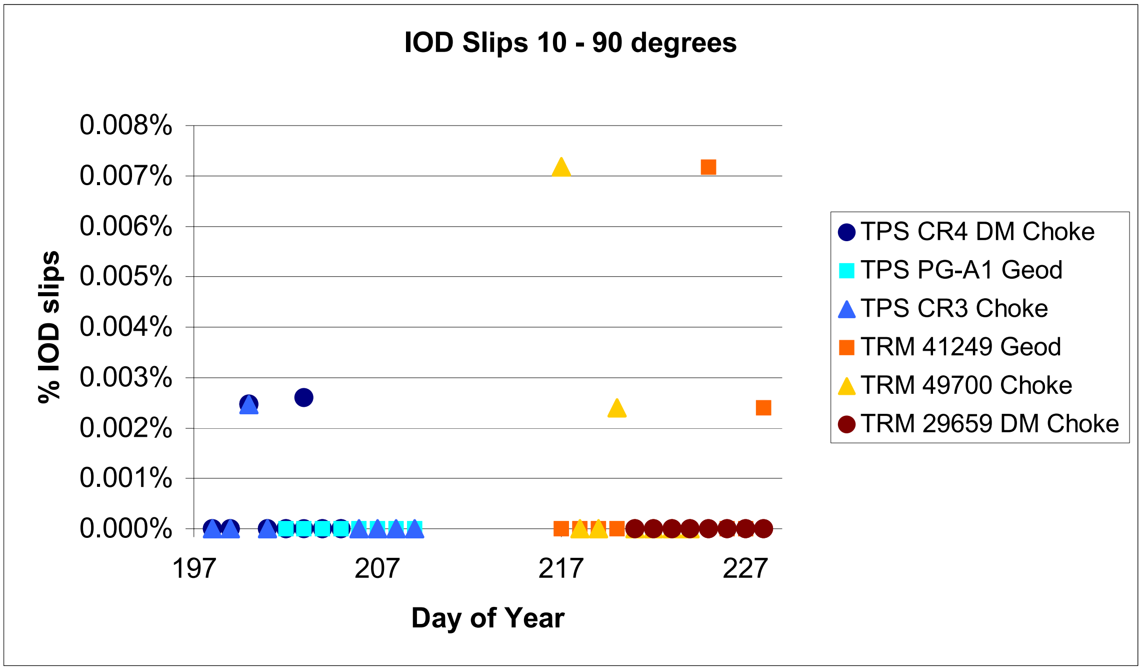


Figure 3.17 – IOD slips expressed as percentage from 10° – 90°

Table 3.14 – IOD Slips expressed as a percentage for 10°-90°

Receiver	Antenna	% IOD Mean	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.000%	0.001%	0.000%	0.003%
Odyssey RS	TPS PG-A1 Geod	0.000%	0.000%	0.000%	0.000%
Odyssey RS	TPS CR3 Choke	0.000%	0.001%	0.000%	0.002%
NetRS	TRM 41249 Geod	0.001%	0.002%	0.000%	0.007%
NetRS	TRM 49700 Choke	0.001%	0.002%	0.000%	0.007%
NetRS	TRM 29659 DM Choke	0.000%	0.000%	0.000%	0.000%

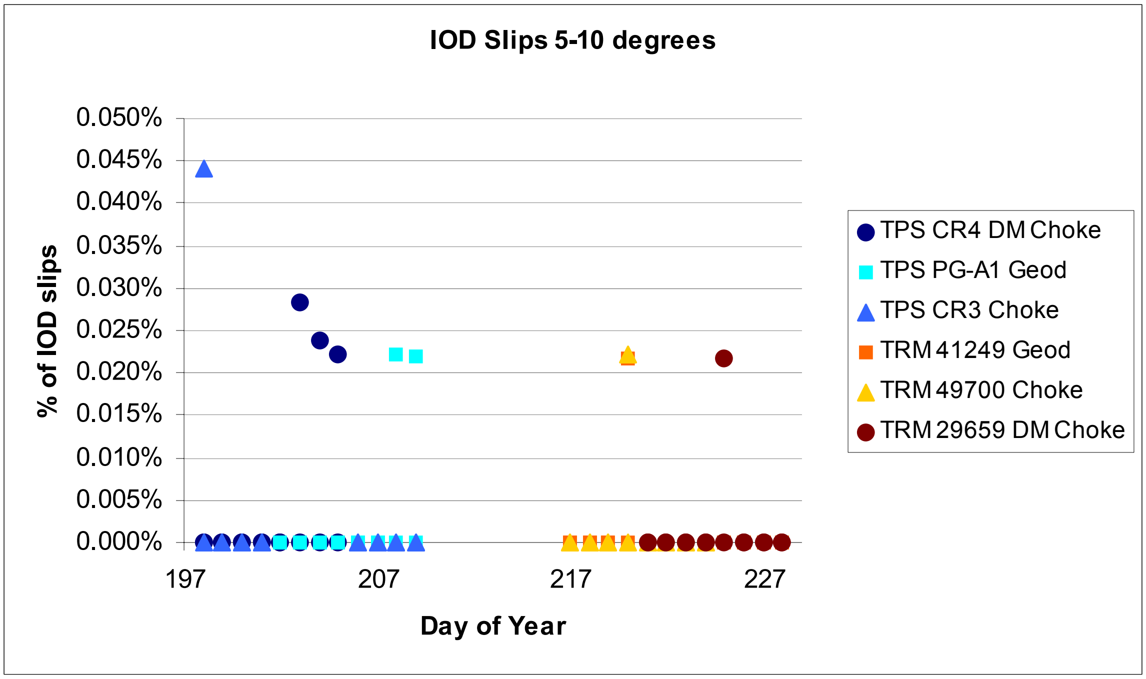


Figure 3.18 – IOD slips expressed as a percentage from 5° – 10°

Table 3.15 - IOD Slips expressed as a percentage for 5°-10°

Receiver	Antenna	% IOD Mean	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.005%	0.010%	0.000%	0.028%
Odyssey RS	TPS PG-A1 Geod	0.003%	0.008%	0.000%	0.022%
Odyssey RS	TPS CR3 Choke	0.003%	0.011%	0.000%	0.044%
NetRS	TRM 41249 Geod	0.001%	0.005%	0.000%	0.022%
NetRS	TRM 49700 Choke	0.001%	0.006%	0.000%	0.022%
NetRS	TRM 29659 DM Choke	0.001%	0.005%	0.000%	0.022%

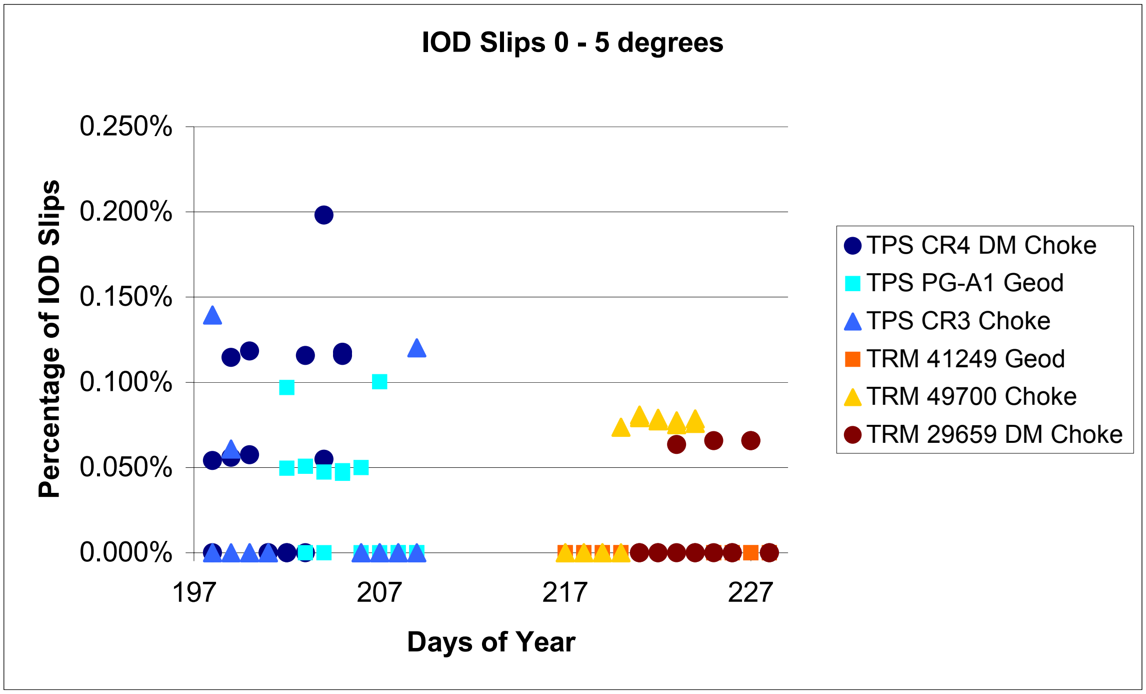


Figure 3.19 – IOD slips expressed as percentage from 0° – 5°

Table 3.16 - IOD Slips expressed as a percentage for 0°-5°

Receiver	Antenna	% IOD Mean	Sigma	Min	Max
Odyssey RS	TPS CR4 DM Choke	0.063%	0.061%	0.000%	0.198%
Odyssey RS	TPS PG-A1 Geod	0.031%	0.035%	0.000%	0.100%
Odyssey RS	TPS CR3 Choke	0.020%	0.046%	0.000%	0.139%
NetRS	TRM 41249 Geod	0.000%	0.000%	0.000%	0.000%
NetRS	TRM 49700 Choke	0.044%	0.040%	0.000%	0.081%
NetRS	TRM 29659 DM Choke	0.016%	0.029%	0.000%	0.066%

Signal to Noise Ratio

Signal to Noise (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 determined using TEQC and binned into 2-degree elevation increments. Figures 3.20 and 3.21 show the average signal to noise for each antenna/receiver combination as a function of elevation and the overall average for all systems tested (denoted by the black line). In order to compare the SNR values, the weighted average difference of the observed SNR from the overall average SNR was calculated resulting in a single number. The weighting was calculated by number of observations for that elevation bin (Table 3.17). Positive values indicate the observed SNR was higher than the overall average.

Summary:

All antenna/receiver combinations tested show similar results for signal to noise on L1. The TPS CR3 Choke ring antenna has the highest SNR for L1 at high elevations, and is near the average for lower elevations. Both geodetic antennas exhibit similar behavior for signal to noise on L1 and L2, with an above average SNR at lower elevations and a lower than average SNR at higher elevations. The TRM 49700 Choke has the highest signal to noise ratio for L2, and is approximately 3.7 db higher than the average value at an elevation angle of 89 degrees. The TPS CR4 DM Choke and the TPS CR3 Choke are below average for SN2 until approximately 40 degrees elevation, at which point, both antennas have a signal to noise ratio above average.

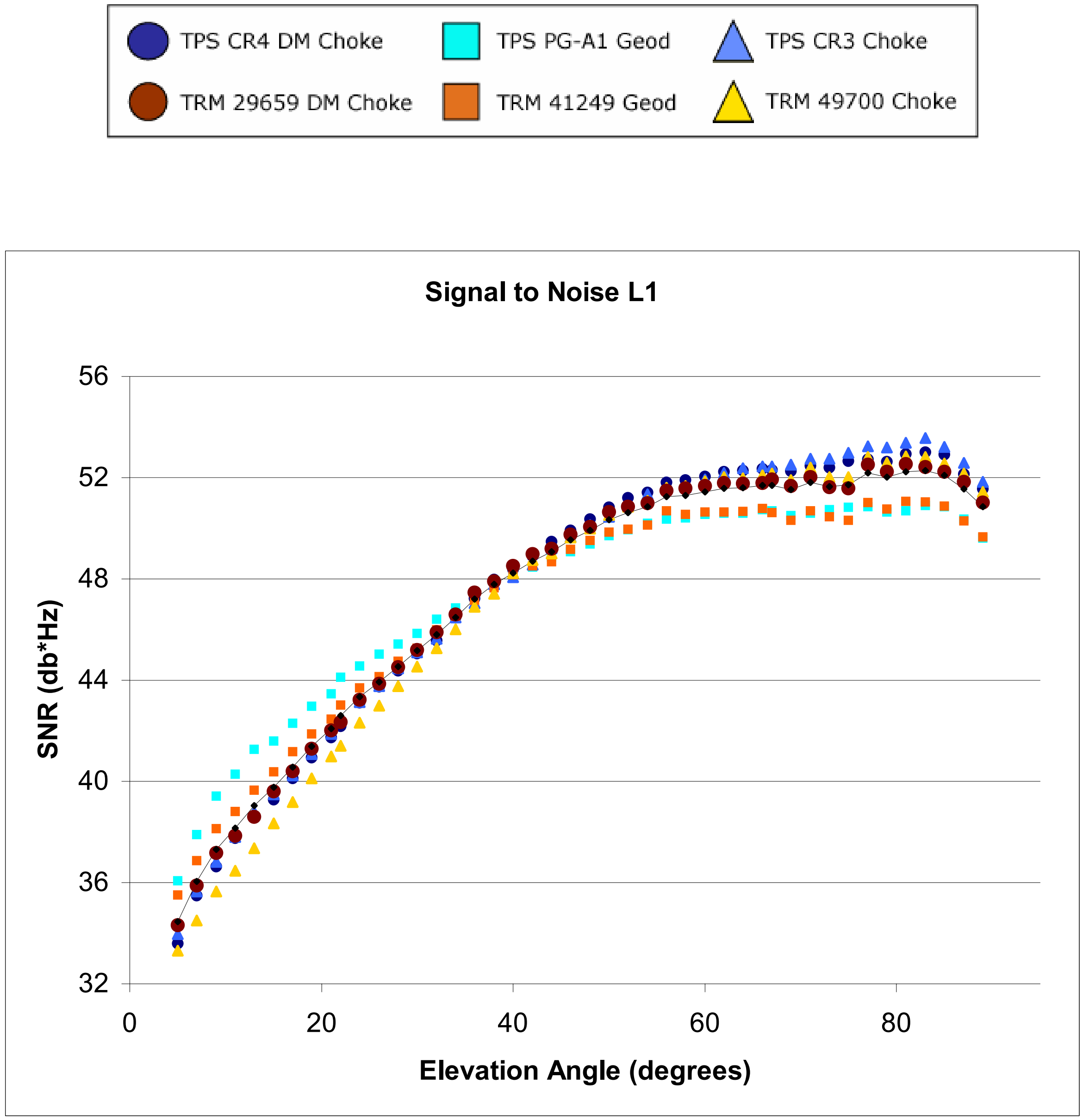


Figure 3.20 – Signal to Noise for L1. The average of all SN1 values is represented by the small black diamonds and are connected via a line.

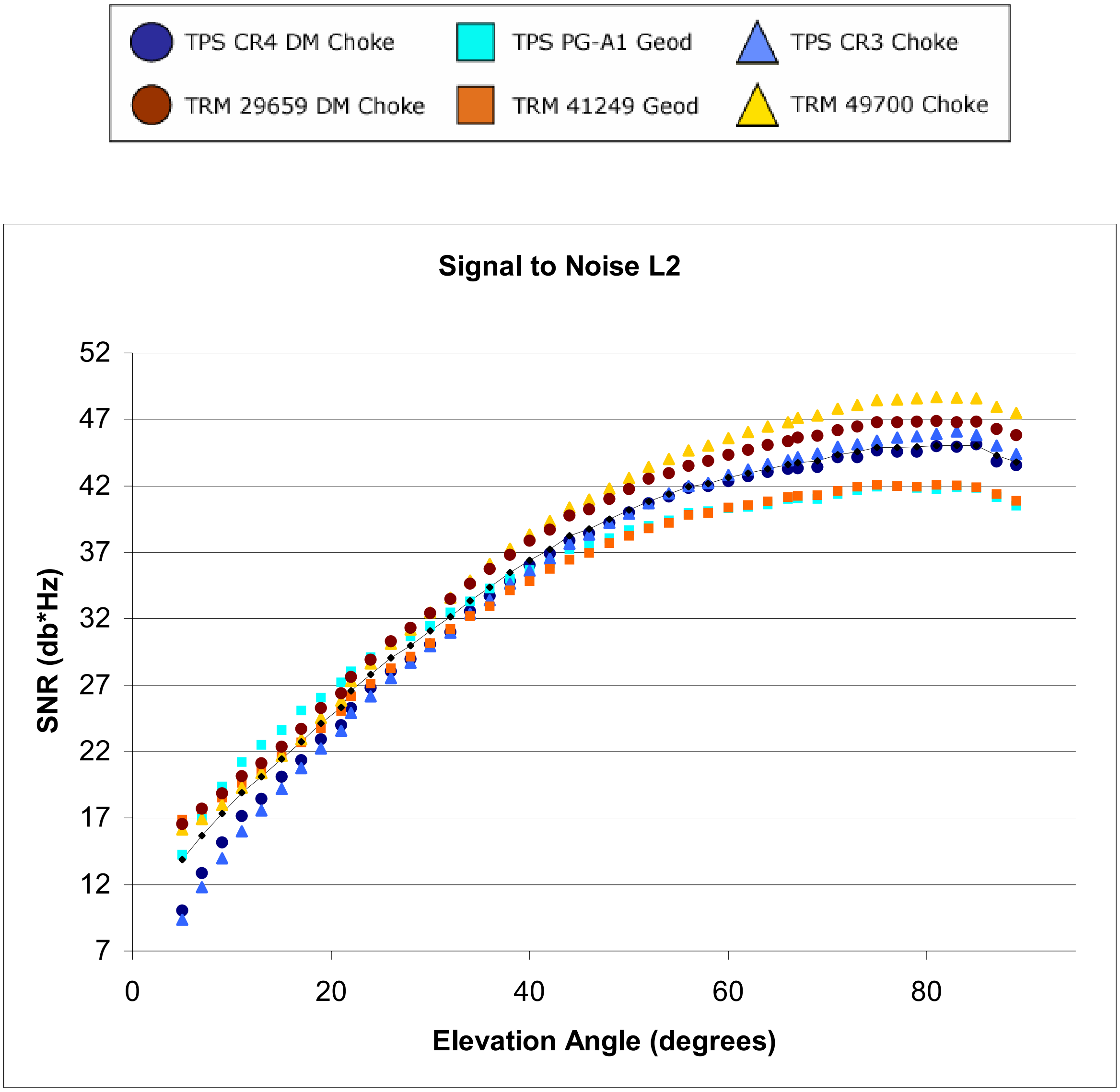


Figure 3.21 – Signal to Noise for L2, all data sets. The average for all SN2 values is represented by the small black diamonds and are connected via a line.

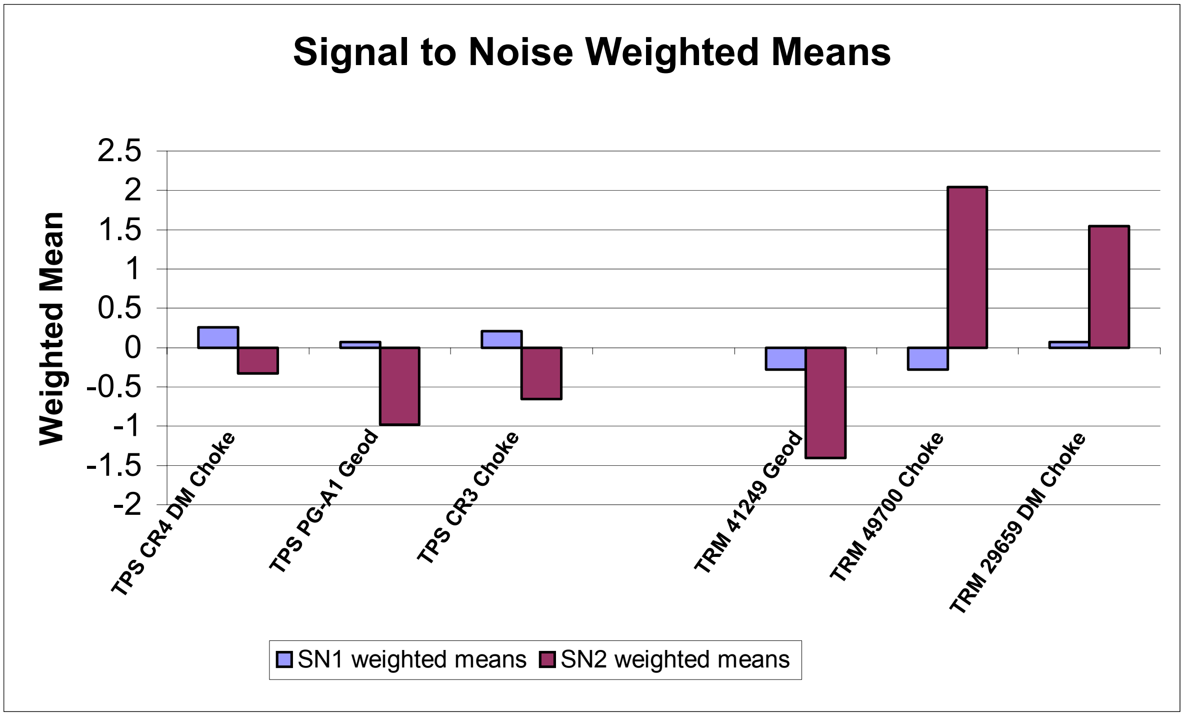


Figure 3.22 – Weighted Means for each antenna/receiver combination

Table 3.17 – Weighted Means for SN1 and SN2

Receiver	Antenna	SN1 W.M.	STD	SN2 W.M.	STD
Odyssey RS	TPS CR4 DM Choke	0.255	0.120	-0.331	0.195
Odyssey RS	TPS PG-A1 Geod	0.068	0.108	-0.981	0.147
Odyssey RS	TPS CR3 Choke	0.212	0.112	-0.655	0.158
NetRS	TRM 41249 Geod	-0.283	0.100	-1.407	0.127
NetRS	TRM 49700 Choke	-0.281	0.091	2.047	0.137
NetRS	TRM 29659 DM Choke	0.073	0.091	1.544	0.130

4.0 Power Tests

Average Steady State Power Consumption

Power consumption was tested using a custom made LabView VI interface. The first test was to determine the approximate power on and power off voltages of each receiver while tracking. The Odyssey RS powers on at approximately 5.6 Volts, and off at approximately 5.4 Volts. The NetRS powers on at approximately 11.92 V, and off at approximately 11.0 Volts. Each receiver was tested with each antenna. The antenna was mounted on the roof of the UNAVCO building on a fiberglass rod in order to isolate the antenna from any ground loops. The first test was run for 2 minutes. Data recording started as soon as the receiver was powered up and started searching for satellites. The second data logging session started ten minutes later, allowing enough time so that the receiver could acquire satellites and start logging data. The second data collection period was run for five minutes. This second data set gives a good indication of the average power consumption of the receiver while tracking and logging data.

Summary:

Both receivers tested have lower power consumption than 8.0 Watts while tracking. The Topcon Odyssey RS has an average power consumption of approximately 4.2 Watts (Table 4.1), and the Trimble NetRS receiver has an average power consumption of roughly 3.5 Watts (Table 4.2). One Topcon receiver (s/n 231-0106) demonstrated a 1-Watt difference in power consumption (shown in Table 4.1) when tested with each antenna. We feel that this is an anomaly since the other three receivers demonstrated similar results. Please see vendor comments about this specific issue. The Trimble receivers were tested at 18 Volts to match the output of the AC power adapter supplied for testing.

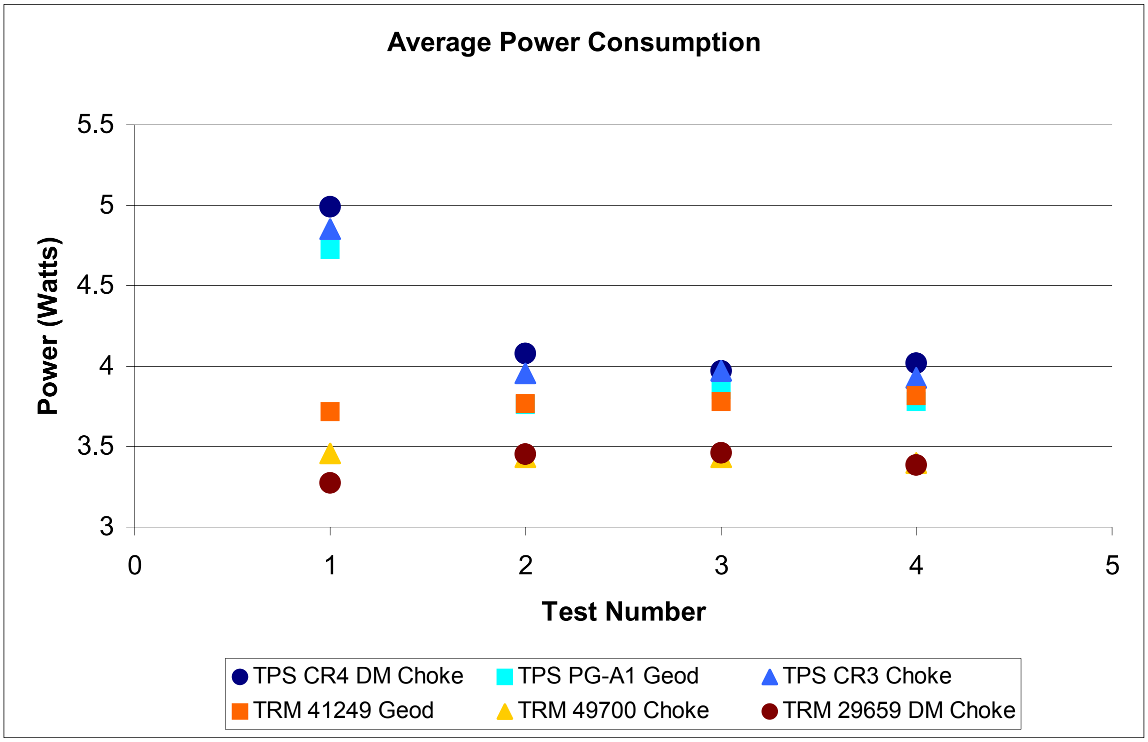


Figure 4.1 - Average power consumption while the receivers were tracking and logging data at a 15 second sampling interval.

Table 4.1– Average power consumption for Topcon Odyssey RS shown in second to last column from right. Topcon receivers were tested at 12.0 V with the internal batteries disconnected.

Receiver	UNAVCO #	Receiver S/N	Antenna Type	Antenna P/N	Antenna S/N	Steady State pwr cons.	Sigma	Avg Power	Sigma
Odyssey RS	51286	231-0106	TPS CR4 DM Choke	14-008016-03 rev 5	265-PD04	4.991	0.540		
Odyssey RS	51287	231-0107	TPS CR4 DM Choke	14-008016-03 rev 5	265-PD04	4.080	0.533	**4.265**	**0.487**
Odyssey RS	51284	231-0104	TPS CR4 DM Choke	14-008016-03 rev 5	265-PD04	3.970	0.523		
Odyssey RS	51285	231-0102	TPS CR4 DM Choke	14-008016-03 rev 5	265-PD04	4.017	0.528		
Odyssey RS	51286	231-0106	TPS CR3 Choke	01-031401-01	217-0225	4.853	0.533		
Odyssey RS	51287	231-0107	TPS CR3 Choke	01-031401-01	217-0225	3.954	0.537	**4.177**	**0.451**
Odyssey RS	51284	231-0104	TPS CR3 Choke	01-031401-01	217-0225	3.972	0.518		
Odyssey RS	51285	231-0102	TPS CR3 Choke	01-031401-01	217-0225	3.929	0.524		
Odyssey RS	51286	231-0106	TPS PG-A1 Geod	01-840201-01	253-0233	4.724	0.542		
Odyssey RS	51287	231-0107	TPS PG-A1 Geod	01-840201-01	253-0233	3.762	0.532	**4.030**	**0.464**
Odyssey RS	51284	231-0104	TPS PG-A1 Geod	01-840201-01	253-0233	3.854	0.528		
Odyssey RS	51285	231-0102	TPS PG-A1 Geod	01-840201-01	253-0233	3.780	0.516		

Table 4.2 – Average power consumption for Trimble NetRS, shown in second to last column from right. The NetRS was tested at 18.0 V, and did not have internal batteries.

Receiver	UNAVCO #	Receiver S/N	Antenna Type	Antenna P/N	Antenna S/N	Steady State pwr cons.	Sigma	Avg Power	Sigma
NetRS	51295	99999900006	TRM 29659 DM Choke	TRM29659.00	0220193253	3.274	0.222		
NetRS	51294	99999900004	TRM 29659 DM Choke	TRM29659.00	0220193253	3.454	0.143	**3.394**	**0.087**
NetRS	51297	99999900002	TRM 29659 DM Choke	TRM29659.00	0220193253	3.461	0.153		
NetRS	51296	99999900001	TRM 29659 DM Choke	TRM29659.00	0220193253	3.385	0.125		
NetRS	51295	99999900006	TRM 41249 Geod	49700-00	ENG0008	3.456	0.149		
NetRS	51294	99999900004	TRM 41249 Geod	49700-00	ENG0008	3.435	0.133	**3.430**	**0.025**
NetRS	51297	99999900002	TRM 41249 Geod	49700-00	ENG0008	3.435	0.134		
NetRS	51296	99999900001	TRM 41249 Geod	49700-00	ENG0008	3.396	0.131		
NetRS	51295	99999900006	TRM 49700 Choke	41249-00	12518047	3.717	0.126		
NetRS	51294	99999900004	TRM 49700 Choke	41249-00	12518047	3.769	0.128	**3.771**	**0.041**
NetRS	51297	99999900002	TRM 49700 Choke	41249-00	12518047	3.780	0.135		
NetRS	51296	99999900001	TRM 49700 Choke	41249-00	12518047	3.817	0.126		

Table 4.3 – Antenna Operating Range Voltages from Manufacturers.

Antenna	Operating Range Voltage (Volts)
TPS CR4 DM Choke	2.7 - 12
TPS PG-A1 Geod	2.7 - 12
TPS CR3 Choke	2.7 - 12
TRM 41249 Geod	4.8 - 22
TRM 49700 Choke	7 - 28
TRM 29659 DM Choke	7 - 28

5.0 Zero Baseline Results

Zero baseline and short baseline precision results were obtained using Bernese 4.2 double difference processing software using IGS Rapid Orbits and Pole files. Daily (22 hour) baseline solution components were determined using a 10 degree elevation angle cutoff, ambiguity resolution, and no tropospheric parameter estimation. GPS solutions were estimated from the double difference combinations of carrier phase (L1, L2, L3 ionosphere-free) and pseudorange (C1,C2,C3) observables holding coordinates of one station fixed. Zero baseline tests are conducted with two receivers connected to the same antenna using an antenna cable splitter. Zero baseline tests represent a measure of the optimal performance of the receiver itself. Common site-dependent errors due to multipath, low-noise amplifier (LNA), and propagation effects cancel.

For the zero baseline tests, the precision is considered to be the *a posteriori* rms error of the solution from the Bernese GPSEST estimation program normalized to the one-way L1 carrier phase observable at zenith. Lower values indicate higher precision. Note that the zero difference precision can be scaled to double difference values by multiplying by a factor of two. See also the double difference residual plot at the end of this section.

Summary:

All receiver/antenna combinations tested exceeded the precision requirements having <1 mm (L1, L2) and <3 mm (L3) for the carrier phase, and <30 cm (C1 and C2) and <100 cm on C3 for the unsmoothed pseudorange precision.

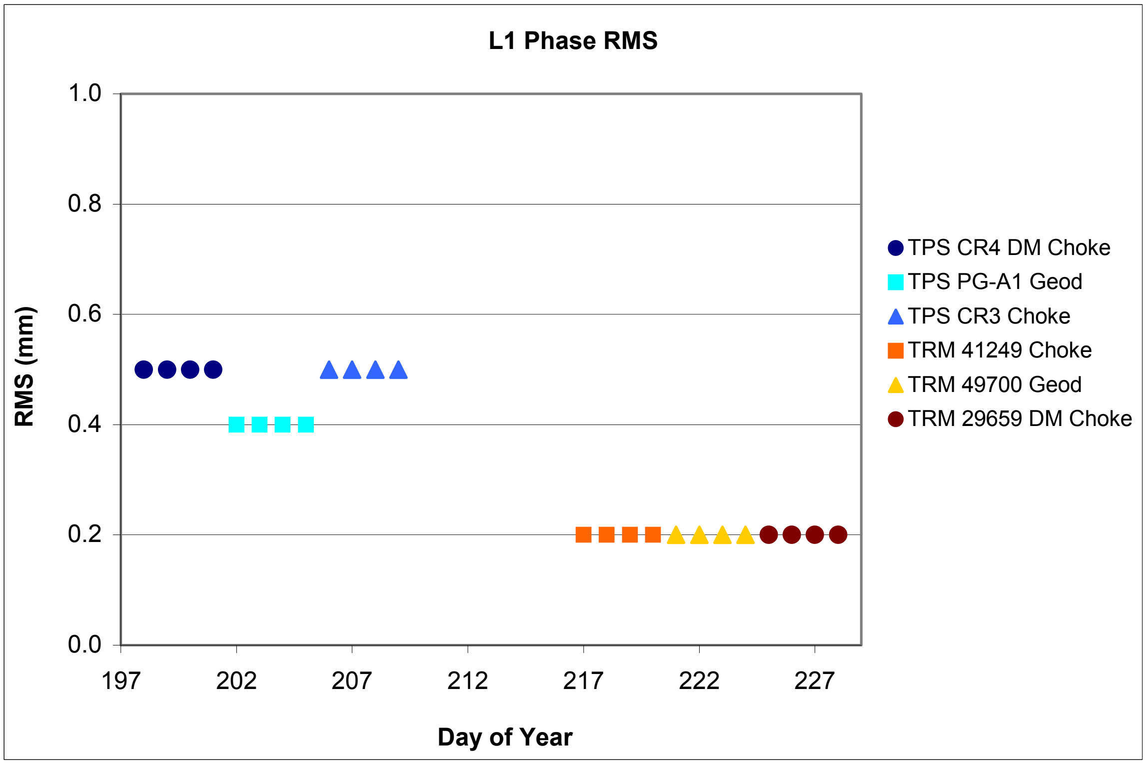


Figure 5.1 – Zero difference RMS value for L1 phase zero baseline solution.

Table 5.1 – Summary of L1 zero difference phase RMS (mm)

Receiver	Antenna	Mean
Odyssey RS	TPS CR4 DM Choke	0.50
Odyssey RS	TPS PG-A1 Geod	0.40
Odyssey RS	TPS CR3 Choke	0.50
NetRS	TRM 41249 Geod	0.20
NetRS	TRM 49700 Choke	0.20
NetRS	TRM 29659 DM Choke	0.20

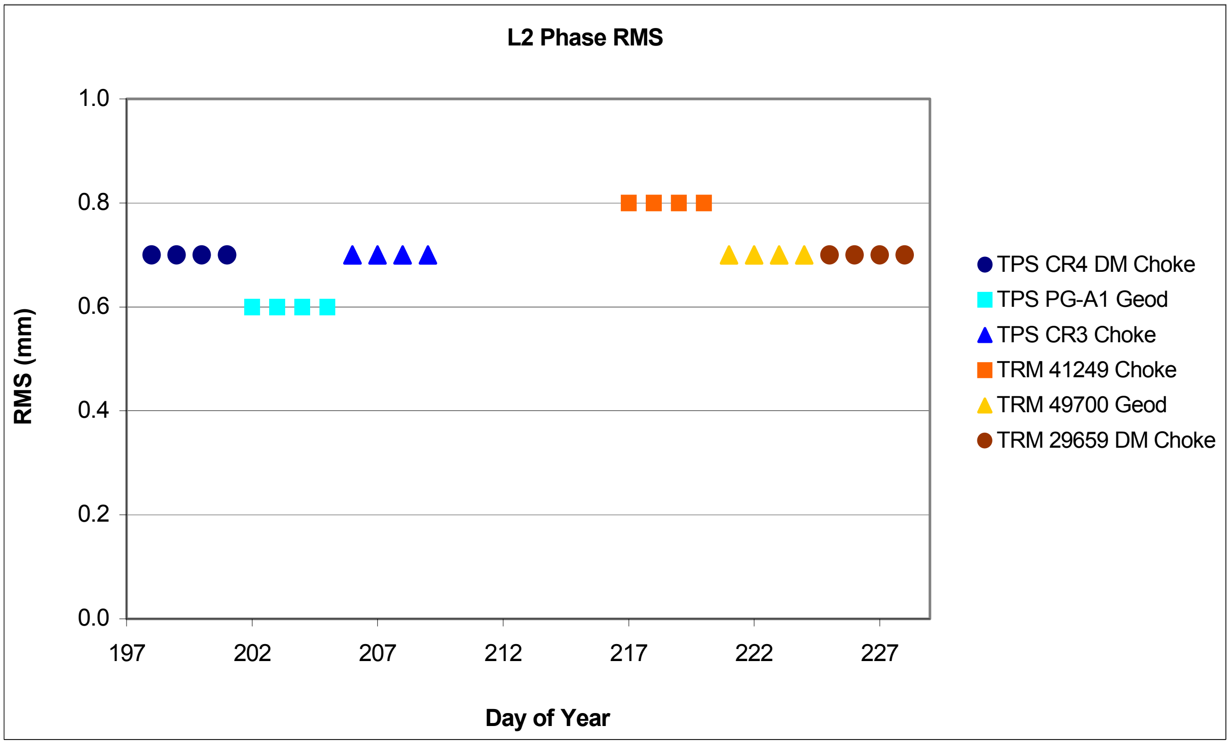


Figure 5.2 – Zero difference RMS value for L2 phase zero baseline solutions.

Table 5.2 – Summary of L2 zero difference phase RMS (mm).

Receiver	Antenna	Mean
Odyssey RS	TPS CR4 DM Choke	0.70
Odyssey RS	TPS PG-A1 Geod	0.60
Odyssey RS	TPS CR3 Choke	0.70
NetRS	TRM 41249 Geod	0.80
NetRS	TRM 49700 Choke	0.70
NetRS	TRM 29659 DM Choke	0.70

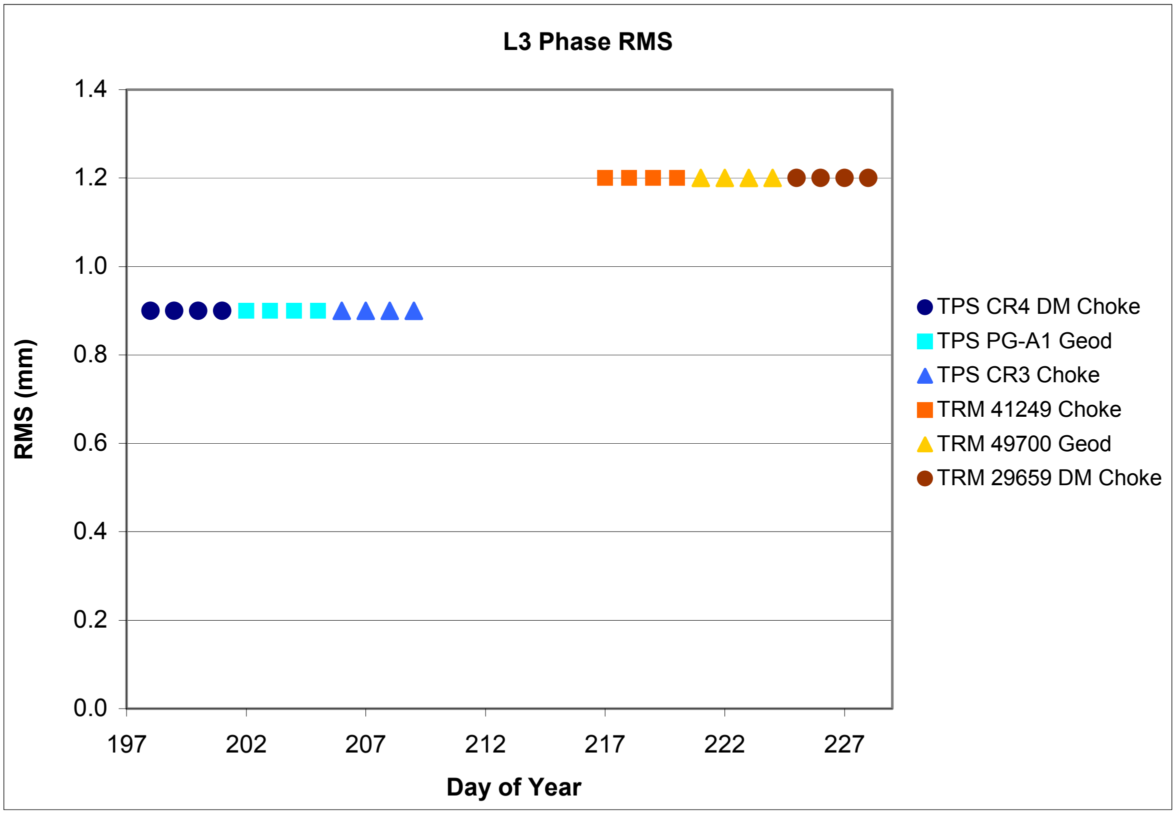


Figure 5.3 – Zero difference RMS values for L3 phase zero baseline solutions.

Table 5.3 – Summary of L3 zero difference phase RMS (mm).

Receiver	Antenna	Mean
Odyssey RS	TPS CR4 DM Choke	0.90
Odyssey RS	TPS PG-A1 Geod	0.90
Odyssey RS	TPS CR3 Choke	0.90
NetRS	TRM 41249 Geod	1.20
NetRS	TRM 49700 Choke	1.20
NetRS	TRM 29659 DM Choke	1.20

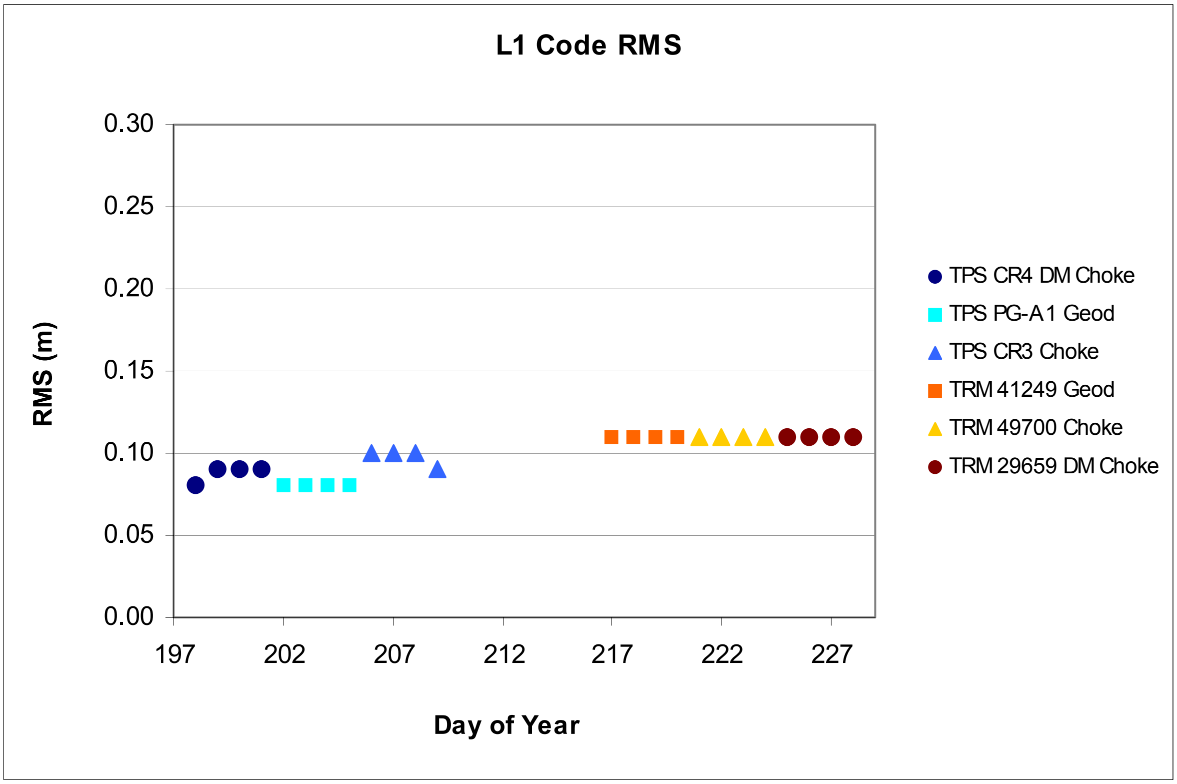


Figure 5.4 - Zero difference RMS value for L1 pseudorange zero baseline solution.

Table 5.4 – Summary of zero difference L1 pseudorange zero baseline RMS (meters).

Receiver	Antenna	Mean
Odyssey RS	TPS CR4 DM Choke	0.09
Odyssey RS	TPS PG-A1 Geod	0.08
Odyssey RS	TPS CR3 Choke	0.10
NetRS	TRM 41249 Geod	0.11
NetRS	TRM 49700 Choke	0.11
NetRS	TRM 29659 DM Choke	0.11

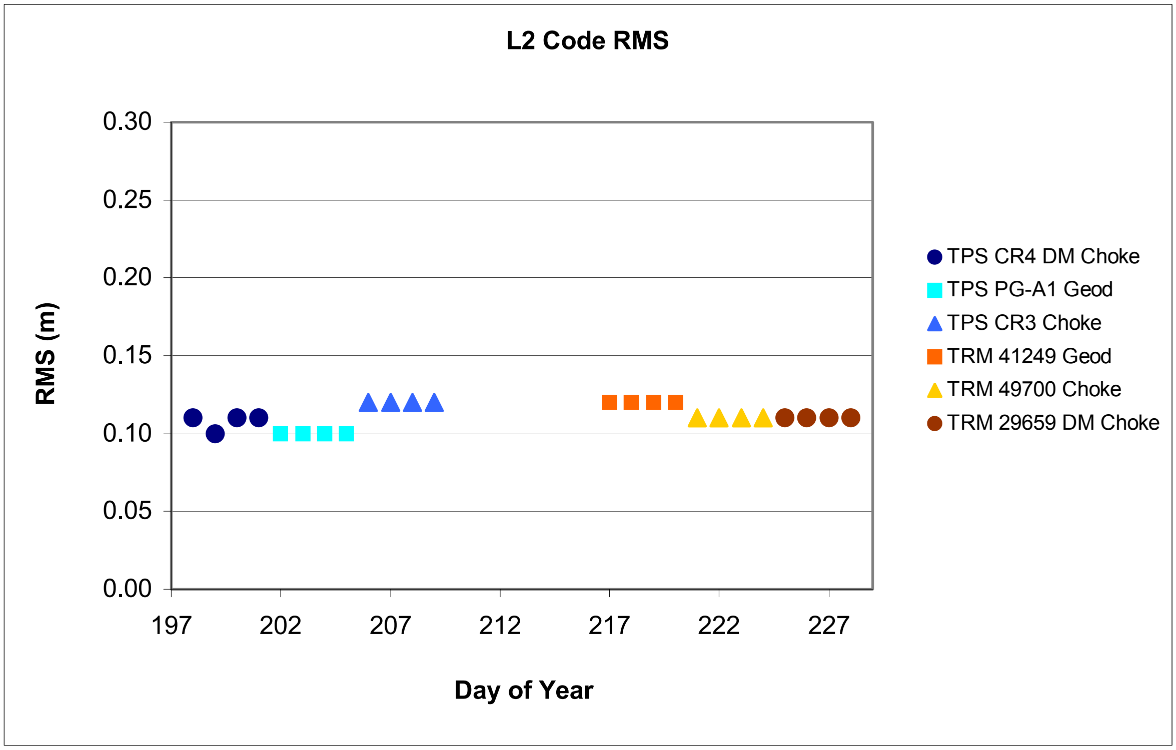


Figure 5.5 - - Zero difference RMS value for L2 pseudorange zero baseline solution.

Table 5.5 – Summary of zero difference L2 pseudorange zero baseline RMS (meters).

Receiver	Antenna	Mean
Odyssey RS	TPS CR4 DM Choke	0.11
Odyssey RS	TPS PG-A1 Geod	0.10
Odyssey RS	TPS CR3 Choke	0.12
NetRS	TRM 41249 Geod	0.12
NetRS	TRM 49700 Choke	0.11
NetRS	TRM 29659 DM Choke	0.11

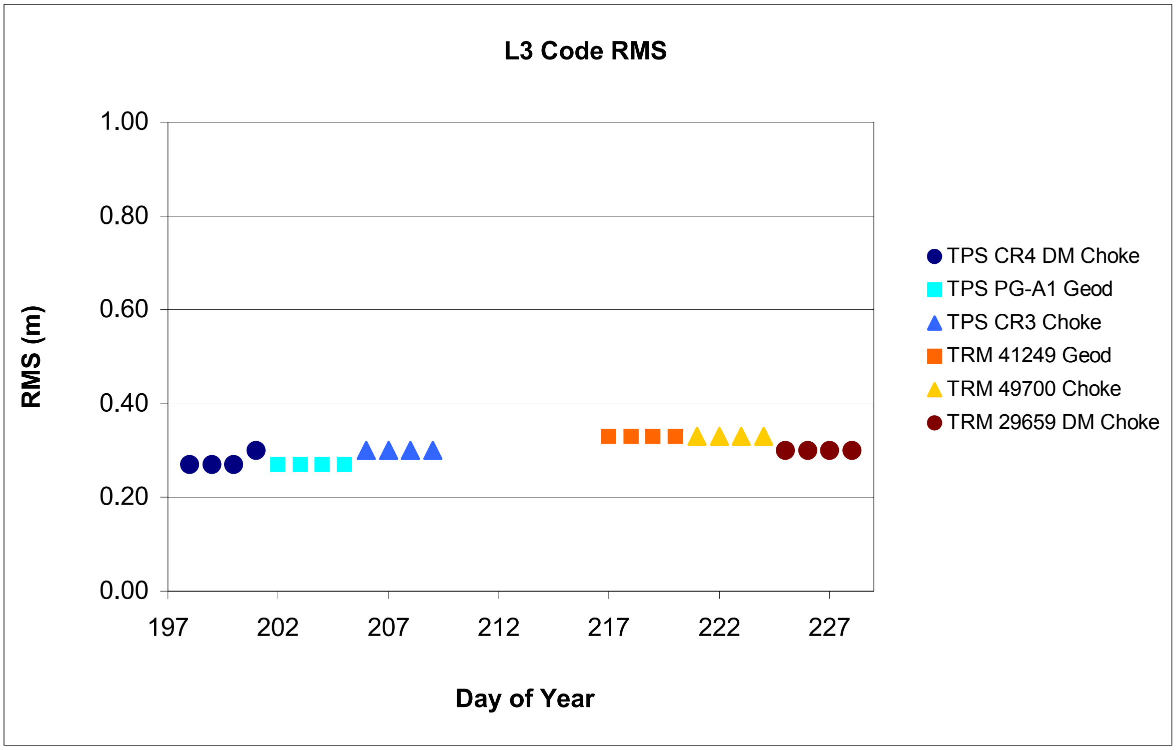


Figure 5.6 - - Zero difference RMS value for L3 pseudorange zero baseline solution.

Table 5.6 – Summary of zero difference L3 pseudorange zero baseline RMS (meters).

Receiver	Antenna	Mean
Odyssey RS	TPS CR4 DM Choke	0.28
Odyssey RS	TPS PG-A1 Geod	0.27
Odyssey RS	TPS CR3 Choke	0.30
NetRS	TRM 41249 Geod	0.33
NetRS	TRM 49700 Choke	0.33
NetRS	TRM 29659 DM Choke	0.30

Zero Baseline Carrier Phase Double Difference Residuals

Representative plots of the zero baseline L3 (ionosphere-free) carrier phase double difference residuals are presented below along with the RMS scatter for each plot. These figures show the residuals after double difference estimation of coordinates and ambiguities and illustrate unmodeled noise differences between the two receivers. Since the receivers are on a zero baseline using the same antenna, direct multipath effect and propagation errors cancel. Figure 5.7 has all the double difference satellite combinations. Figure 5.8 presents a single pair of satellites (15:23) over the course of rising and setting of the satellites. Qualitatively, the residuals in the plots for all receiver/antenna combinations tested are very similar; the RMS scatter is comparable and less than 2.4 mm for all observations.

Table 5.7 - Representative Zero Baseline L3 Phase Double Difference Residual RMS determined from Figures 5.7 and 5.8.

Receiver	Antenna	SV 15:23 Ave. mm	All SV Ave. mm
Odyssey RS	TPS CR4 DM Choke	1.5	2.0
Odyssey RS	TPS PG-A1Geod	1.4	1.7
Odyssey RS	TPS CR3 Choke	1.6	2.1
NetRS	TRM 41249 Geod	1.6	2.4
NetRS	TRM 49700 Choke	1.6	2.2
NetRS	TRM 29659 DM Choke	1.5	2.1

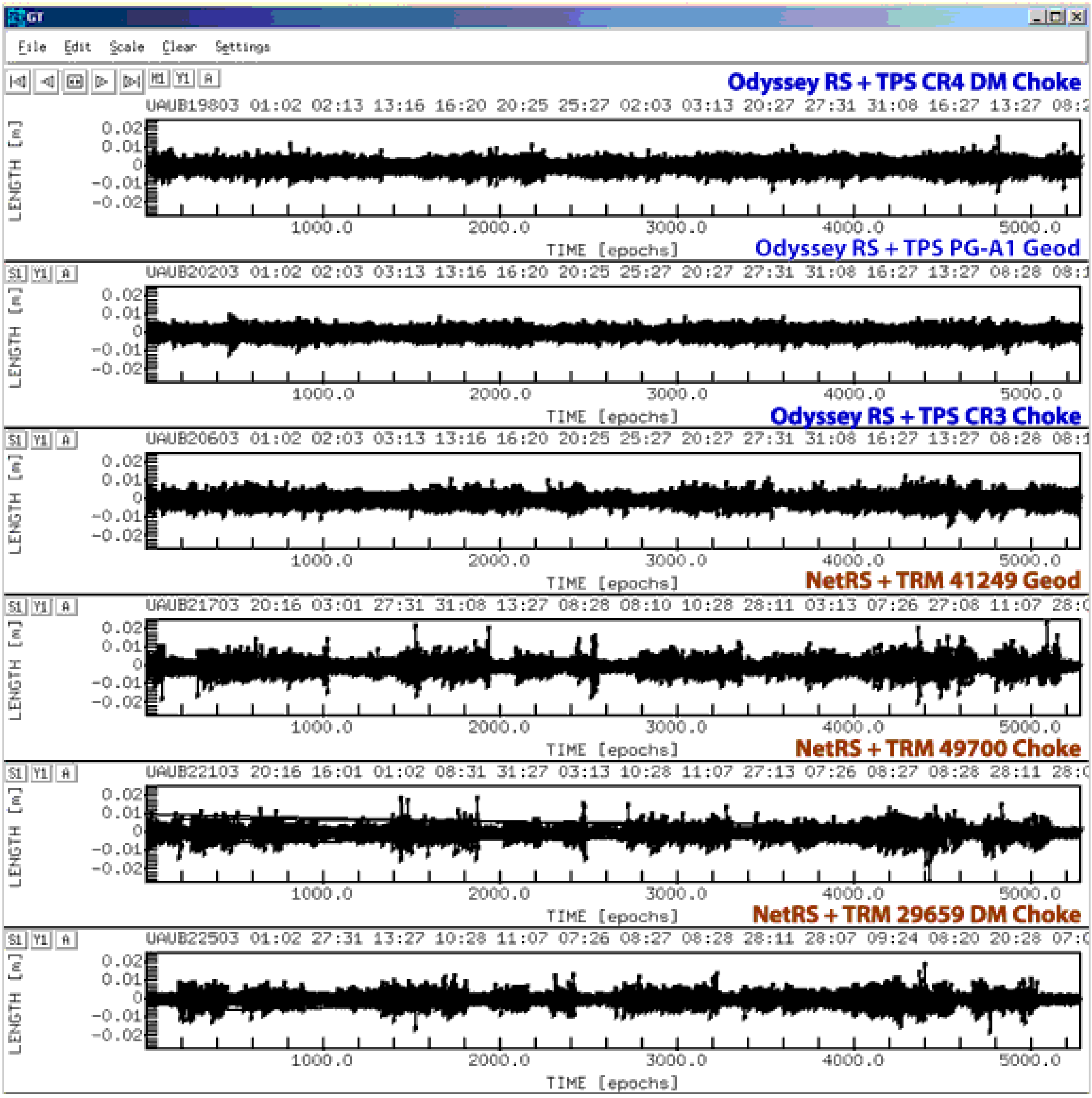


Figure 5.7 – A representative sample of the zero baseline L3 (ionosphere-free) carrier phase double difference residuals showing all satellite combinations that were formed. A single day of residuals is presented for each antenna/receiver combination tested. Vertical scale is ±2 cm.

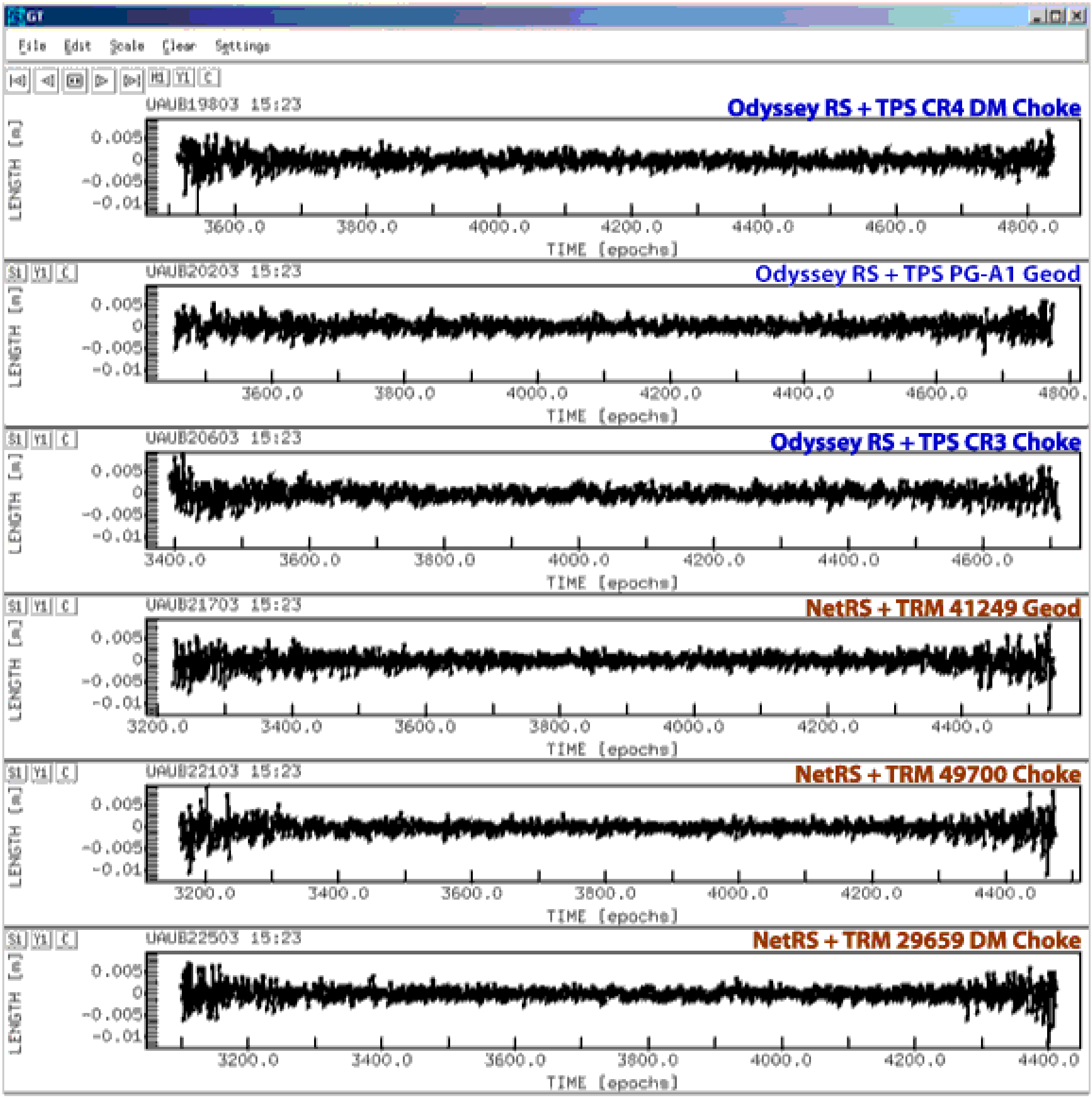


Figure 5.8 - A representative sample of the zero baseline L3 carrier phase double difference residuals for each antenna/receiver combination tested showing only satellite pair 15:23. Vertical scale is + 5 mm to –10 mm.

6.0 Short Baseline Tests

Short baseline tests were conducted on the roof of the UNAVCO building on station marks UV03 and UV04 (Figure 2.1) separated by 1.912 meters. These same mounts were used for the SuomiNet testing, so direct comparisons can be made. Each receiver/antenna combination was run for four days with 22-hour data logging sessions. All data were quality checked with TEQC and processed using the Bernese GPS 4.2 software with double difference processing software and IGS Rapid Orbits and Pole files. The UV03 end of the baseline was held fixed. The elevation cutoff was 10 degrees and all ambiguities were resolved. Tropospheric corrections were not estimated for the baseline solution tests, and conversely coordinates were fixed and not estimated for the tropospheric tests. The following graphs present a summary of coordinate solutions and troposphere correction parameters for the short baseline data.

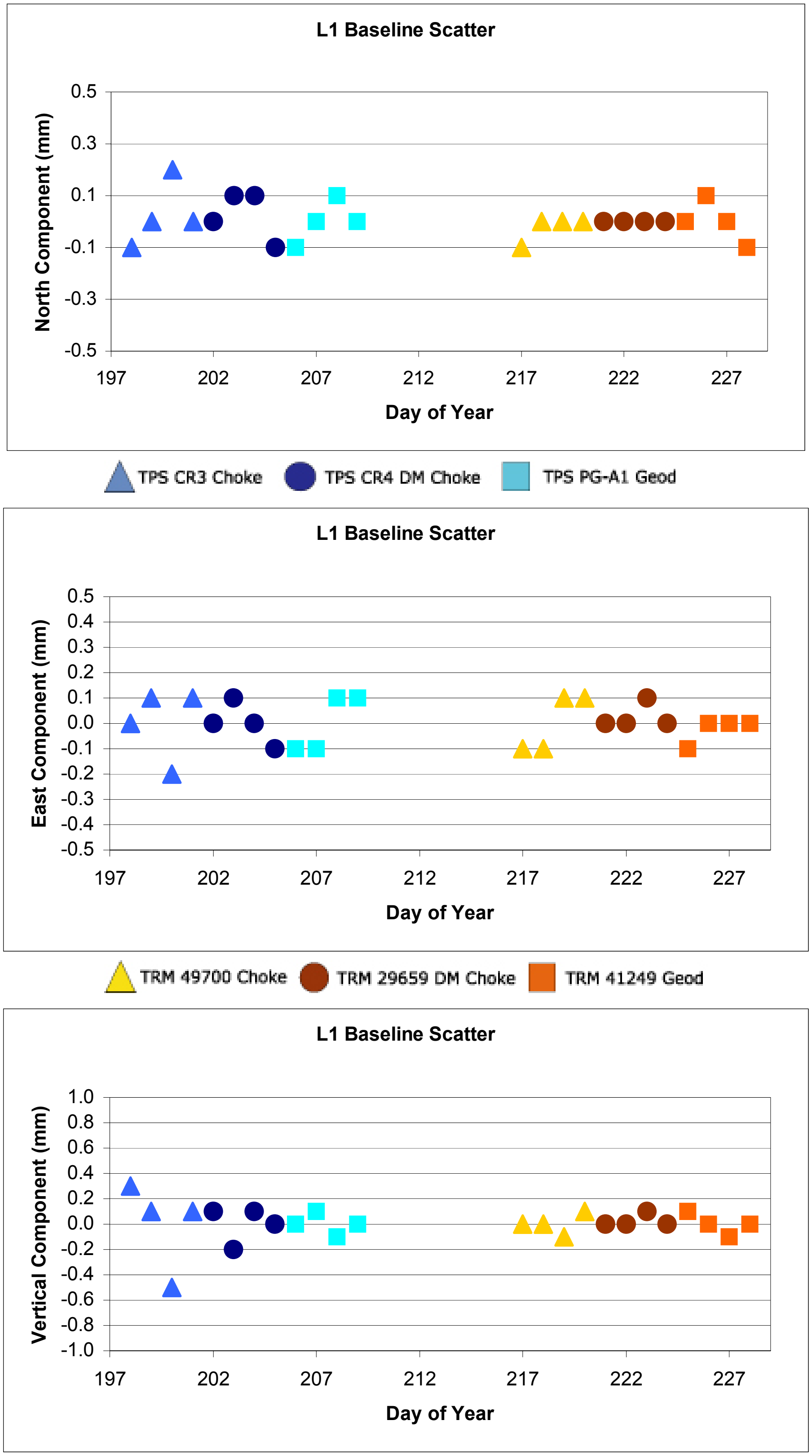
Short Baseline Solution Precision

The following section presents L1, L2, and L3 coordinate RMS scatter results for a baseline approximately 1.912 meters in length. The RMS scatter is calculated about the mean of each four days of L1, L2, and L3 Bernese daily baseline solutions and is an estimate of the precision. The results are tabulated in Tables 6.1-6.3 and plotted for the L3 ionospheric free solution, 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 RMS scatter of the L1 and L2 solutions (Tables 6.1 and 6.2) is typically less than 0.1 mm for all three components, North, East and Vertical and less than the mandatory requirement of 0.2 mm or better in the North and East and 0.4 mm in the vertical components. Similarly, the precision of the L3 solutions is typically 0.2 mm or less for all components and less than the mandatory 0.4 mm horizontal and 0.8 mm vertical components.

Notable exceptions are the Odyssey RS/TPS CR3 Choke (L2 0.3 mm East; L3 0.8 mm East) and the Odyssey/TPS CR4 DM Choke (L2 0.8 mm Vertical; L3 0.9 mm Vertical). The somewhat lower precision for the choke ring antennas compared to the TPS PG-A1 Geod, which contains a smaller internal groundplane, is somewhat unexpected. Over this short baseline, all ambiguities were resolved. A visual inspection of the double difference residuals for each file was performed, and no unfixed cycle slips were found that could have influenced the RMS scatter of the four solutions.



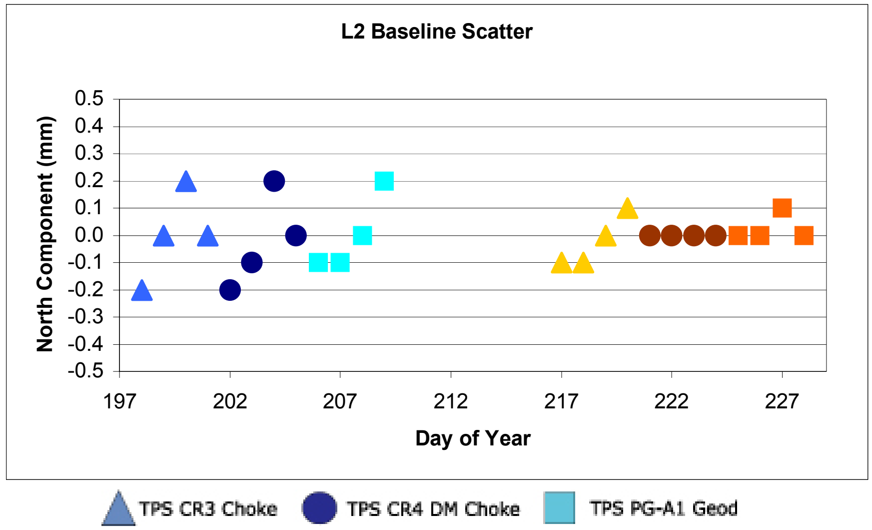
(a)

(b)

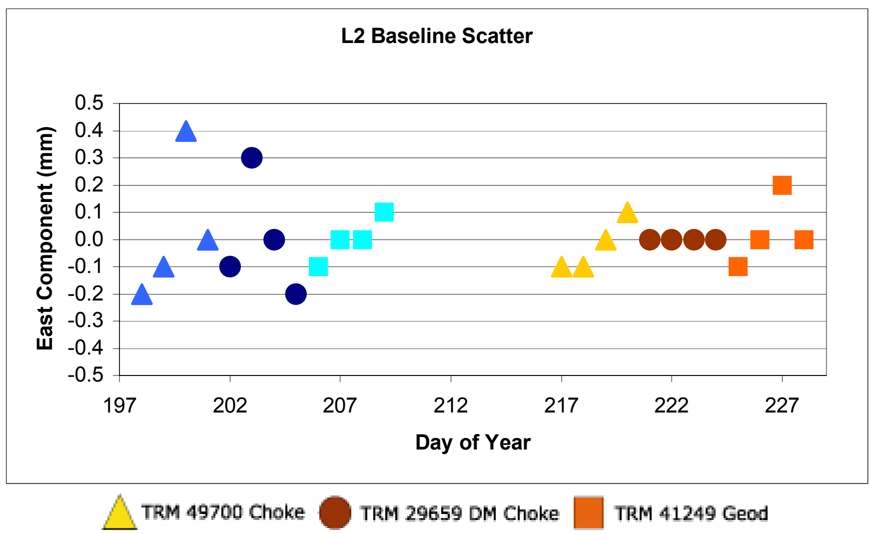
Figure 6.1 (a)(b)(c) – L1 carrier phase short baseline daily solution scatter about the mean for North, East, and vertical components.

Table 6.1 – L1 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)
Odyssey RS	TPS CR3 Choke	198	-0.1	0	0.3
		199	0	0.1	0.1
		200	0.2	-0.2	-0.5
		201	0	0.1	0.1
	RMS Scatter		**0.1**	**0.1**	**0.3**
Odyssey RS	TPS CR4 DM Choke	202	0	0	0.1
		203	0.1	0.1	-0.2
		204	0.1	0	0.1
		205	-0.1	-0.1	0
	RMS Scatter		**0.1**	**0.1**	**0.1**
Odyssey RS	TPS PG-A1 Geod	206	-0.1	-0.1	0
		207	0	-0.1	0.1
		208	0.1	0.1	-0.1
		209	0	0.1	0
	RMS Scatter		**0.1**	**0.1**	**0**
NetRS	TRM 49700 Choke	217	-0.1	-0.1	0
		218	0	-0.1	0
		219	0	0.1	-0.1
		220	0	0.1	0.1
	RMS Scatter		**0**	**0.1**	**0.1**
NetRS	TRM 29659 DM Choke	221	0	0	0
		222	0	0	0
		223	0	0.1	0.1
		224	0	0	0
	RMS Scatter		**0**	**0.1**	**0.1**
NetRS	TRM 41249 Geod	225	0	-0.1	0.1
		226	0.1	0	0
		227	0	0	-0.1
		228	-0.1	0	0
	RMS Scatter		**0.1**	**0**	**0.1**



(a)



(b)

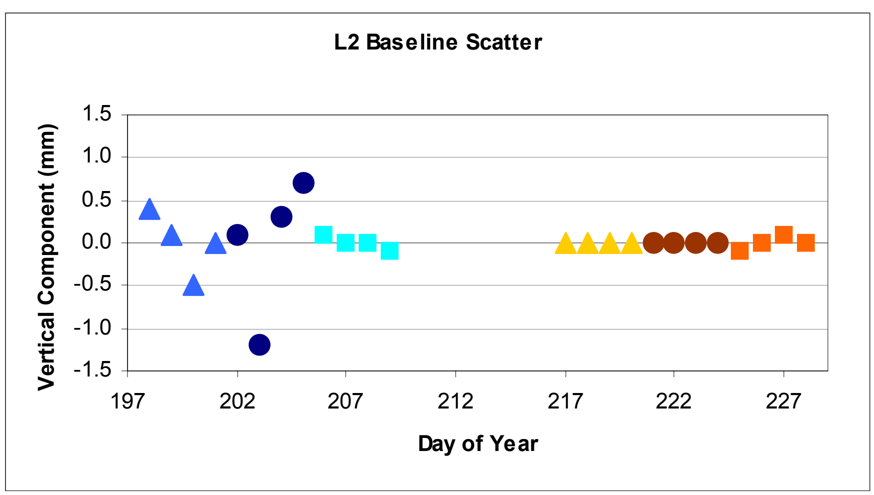
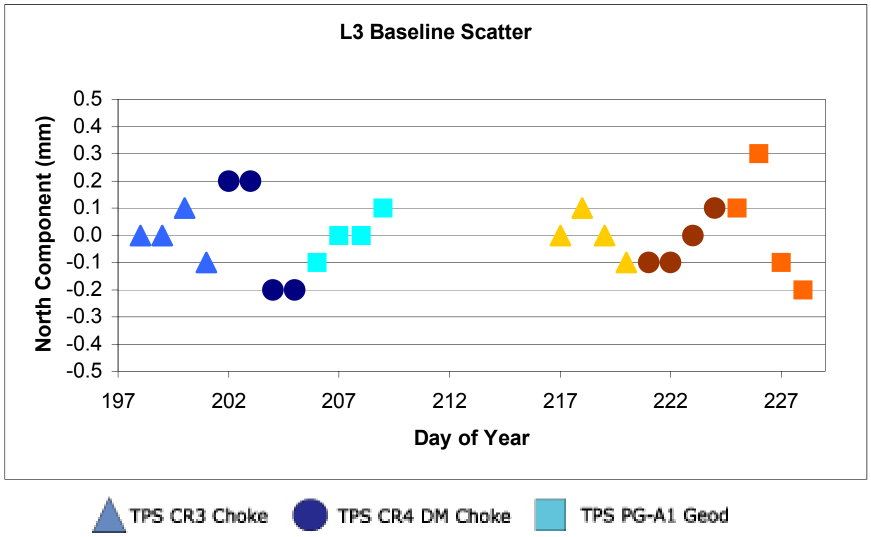


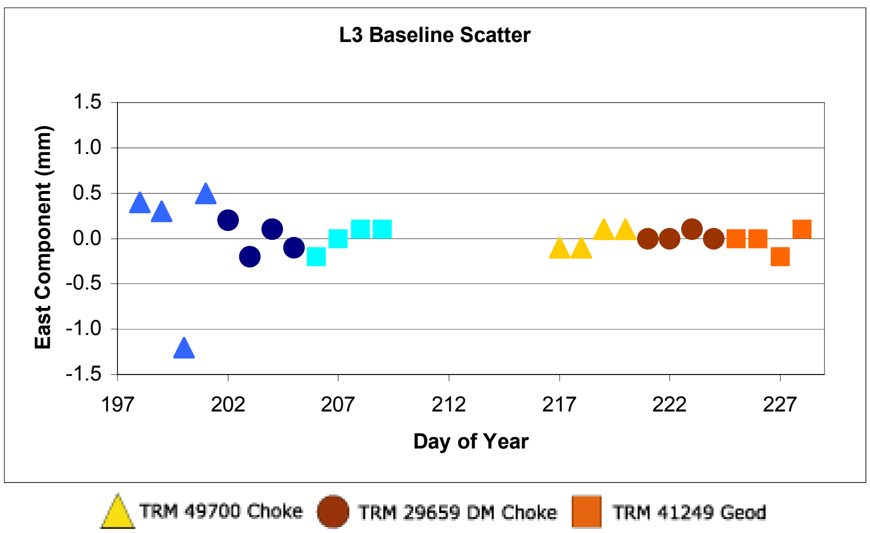
Figure 6.2 (a)(b)(c) – L2 carrier phase short baseline daily solution scatter about the mean for North, East, and vertical components.

Table 6.2 – 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)
Odyssey RS	TPS CR3 Choke	198	-0.2	-0.2	0.4
		199	0	-0.1	0.1
		200	0.2	0.4	-0.5
		201	0	0	0
	RMS Scatter		**0.1**	**0.3**	**0.4**
Odyssey RS	TPS CR4 DM Choke	202	-0.2	-0.1	0.1
		203	-0.1	0.3	-1.2
		204	0.2	0	0.3
		205	0	-0.2	0.7
	RMS Scatter		**0.2**	**0.2**	**0.8**
Odyssey RS	TPS PG-A1 Geod	206	-0.1	-0.1	0.1
		207	-0.1	0	0
		208	0	0	0
		209	0.2	0.1	-0.1
	RMS Scatter		**0.1**	**0.1**	**0.1**
NetRS	TRM 49700 Choke	217	-0.1	-0.1	0
		218	-0.1	-0.1	0
		219	0	0	0
		220	0.1	0.1	0
	RMS Scatter		**0.1**	**0.1**	**0**
NetRS	TRM 29659 DM Choke	221	0	0	0
		222	0	0	0
		223	0	0	0
		224	0	0	0
	RMS Scatter		**0**	**0**	**0**
NetRS	TRM 41249 Geod	225	0	-0.1	-0.1
		226	0	0	0
		227	0.1	0.2	0.1
		228	0	0	0
	RMS Scatter		**0.1**	**0.1**	**0.1**



(a)



(b)

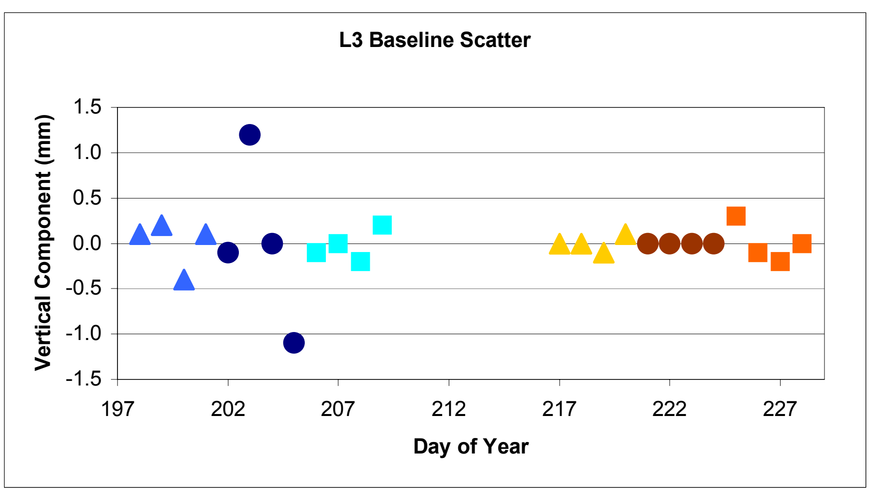


Figure 6.3 (a)(b)(c) – L3 carrier phase short baseline daily solution scatter about the mean for North, East, and vertical components.

Table 6.3 – L3 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)
Odyssey RS	TPS CR3 Choke	198	0	0.4	0.1
		199	0	0.3	0.2
		200	0.1	-1.2	-0.4
		201	-0.1	0.5	0.1
	RMS Scatter		**0.1**	**0.8**	**0.2**
Odyssey RS	TPS CR4 DM Choke	202	0.2	0.2	-0.1
		203	0.2	-0.2	1.2
		204	-0.2	0.1	0
		205	-0.2	-0.1	-1.1
	RMS Scatter		**0.20**	**0.10**	**0.90**
Odyssey RS	TPS PG-A1 Geod	206	-0.1	-0.2	-0.1
		207	0	0	0
		208	0	0.1	-0.2
		209	0.1	0.1	0.2
	RMS Scatter		**0.1**	**0.1**	**0.2**
NetRS	TRM 49700 Choke	217	0	-0.1	0
		218	0.1	-0.1	0
		219	0	0.1	-0.1
		220	-0.1	0.1	0.1
	RMS Scatter		**0**	**0.1**	**0.1**
NetRS	TRM 29659 DM Choke	221	-0.1	0	0
		222	-0.1	0	0
		223	0	0.1	0
		224	0.1	0	0
	RMS Scatter		**0.1**	**0**	**0**
NetRS	TRM 41249 Geod	225	0.1	0	0.3
		226	0.3	0	-0.1
		227	-0.1	-0.2	-0.2
		228	-0.2	0.1	0
	RMS Scatter		**0.2**	**0.1**	**0.2**

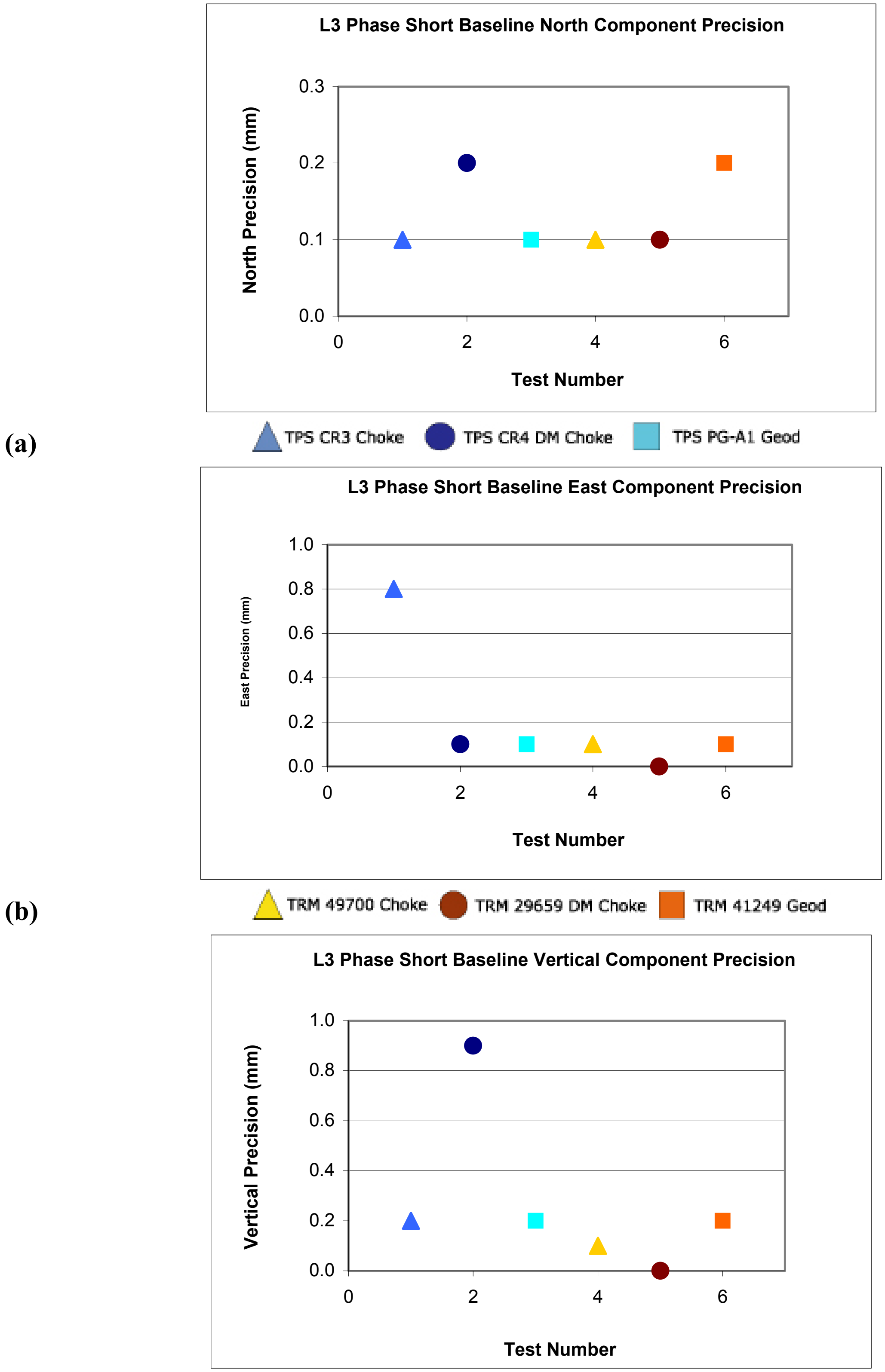


Figure 6.4 (a)(b)(c) – L3 phase short baseline solution precision RMS scatter of daily solutions shown in Figures 6.1- 6.3 and Tables 6.4 - 6.6. for North (a), East (b), and Vertical (c), for each antenna/receiver combination tested.

Table 6.4 – L1 phase short baseline solution RMS (mm).

Receiver	Antenna	North	East	Up	Norm
Odyssey RS	TPS CR3 Choke	0.1	0.1	0.3	0.3
Odyssey RS	TPS CR4 DM Choke	0.1	0.1	0.1	0.2
Odyssey RS	TPS PG-A1Geod	0.1	0.1	0.0	0.1
NetRS	TRM 49700 Choke	0.0	0.1	0.1	0.1
NetRS	TRM 29659 DM Choke	0.0	0.1	0.1	0.1
NetRS	TRM 41249 Geod	0.1	0.0	0.1	0.1

Table 6.5 – L2 phase short baseline solution RMS (mm).

Receiver	Antenna	North	East	Up	Norm
Odyssey RS	TPS CR3 Choke	0.1	0.3	0.4	0.5
Odyssey RS	TPS CR4 DM Choke	0.2	0.2	0.8	0.8
Odyssey RS	TPS PG-A1Geod	0.1	0.1	0.1	0.2
NetRS	TRM 49700 Choke	0.1	0.1	0.1	0.2
NetRS	TRM 29659 DM Choke	0.0	0.0	0.0	0.0
NetRS	TRM 41249 Geod	0.1	0.1	0.1	0.2

Table 6.6 – L3 phase short baseline solution RMS (mm).

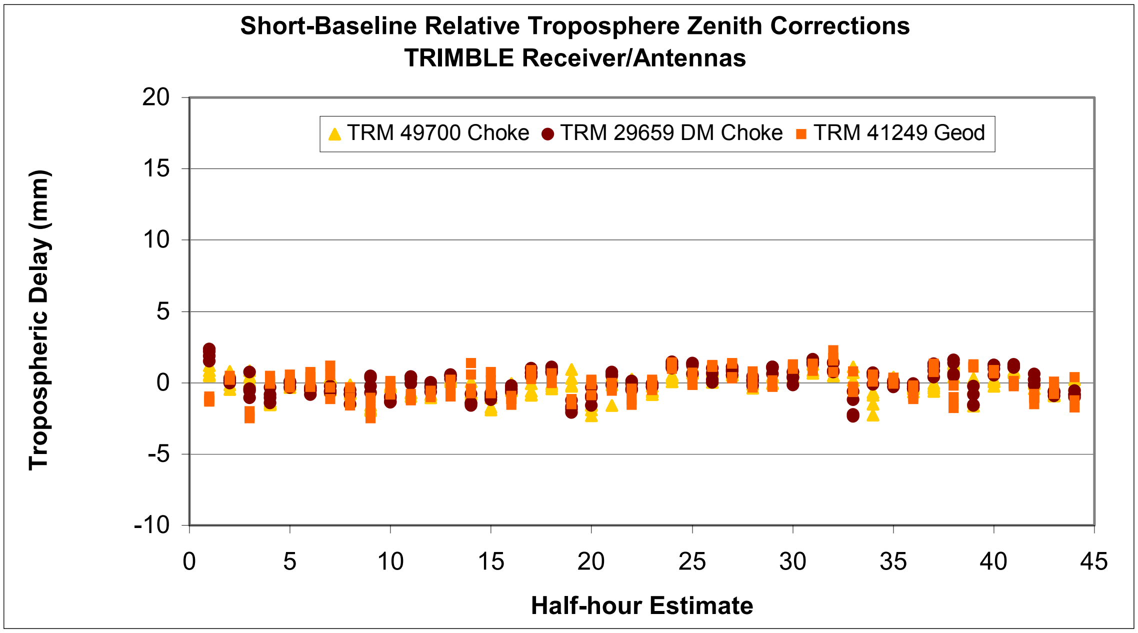
Receiver	Antenna	North	East	Up	Norm
Odyssey RS	TPS CR3 Choke	0.1	0.8	0.2	0.8
Odyssey RS	TPS CR4 DM Choke	0.2	0.1	0.9	0.9
Odyssey RS	TPS PG-A1Geod	0.1	0.1	0.2	0.2
NetRS	TRM 49700 Choke	0.1	0.1	0.1	0.2
NetRS	TRM 29659 DM Choke	0.1	0.0	0.0	0.1
NetRS	TRM 41249 Geod	0.2	0.1	0.2	0.3

Short Baseline Residual Troposphere Delay

Increasingly, GPS permanent stations have dual use, being deployed for atmospheric as well as geodetic applications. Approximately 100 of the Plate Boundary Observatory stations will have meteorological packages; the data from these stations will be used to estimate tropospheric delays. Tropospheric estimates are also sensitive to the low elevation tracking capability of the receiver and antenna, and therefore are useful indicators of their performance. Short baseline (~1.9 meter) data were processed and the ionosphere free (L3) half-hourly troposphere zenith corrections were estimated using a 0^o elevation angle cutoff. On such a short baseline there should be no relative tropospheric zenith delay so any residual is primarily due to noise in the carrier phase multipath. Figures 6.4a and 6.4b, below shows the tropospheric zenith correction and Table 6.4 the standard deviation of the corrections for each receiver/antenna combination tested.

Summary:

Evaluation of the receiver/antenna performance was based on the standard deviation of the short baseline relative troposphere zenith corrections. From the results in Table 6.4, all but the Topcon Odyssey RS with TPS PG-A1 Geod and TPS CR4 DM Choke have acceptable delays of 1 mm or less.



(a)

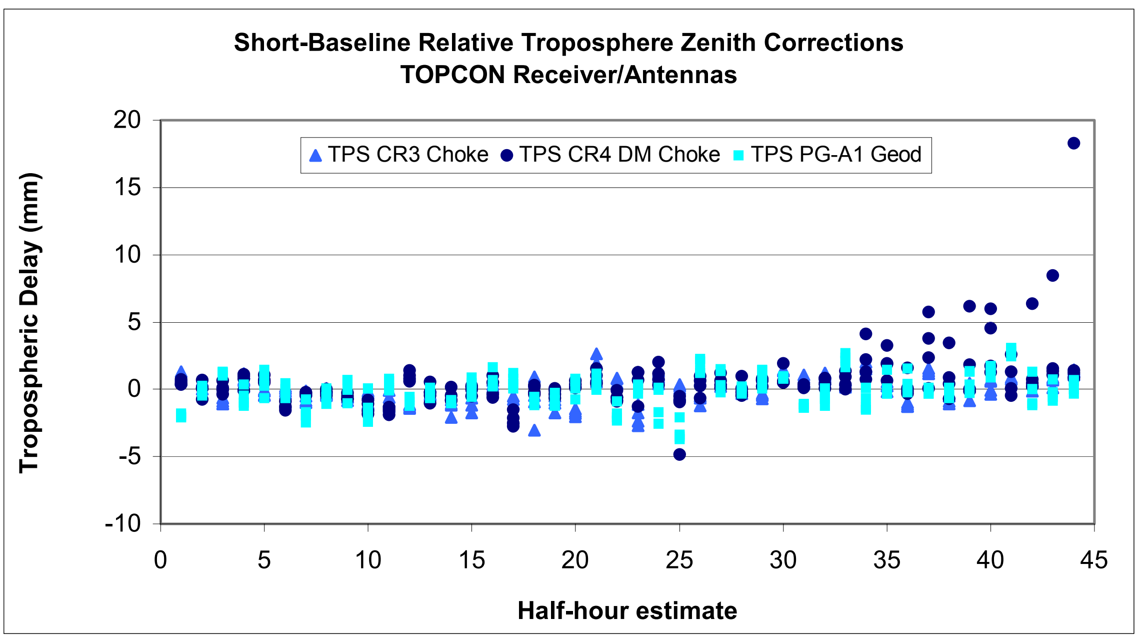


Figure 6.7 (a) (b) - (a). Topcon receiver/antenna combinations (b) Trimble receiver/antenna combinations. The relative troposphere zenith corrections were estimated at half-hour intervals over the course of each daily 22-hour observation period. Each receiver/antenna combination was observed for four consecutive days on a ~1.9 meter baseline on the UNAVCO roof. Apparent in the plots are repeating variations that are indicative of multipath effects on the carrier phase. We have no explanations for the Topcon TPS CR4 DM Choke observed at the end of the day.

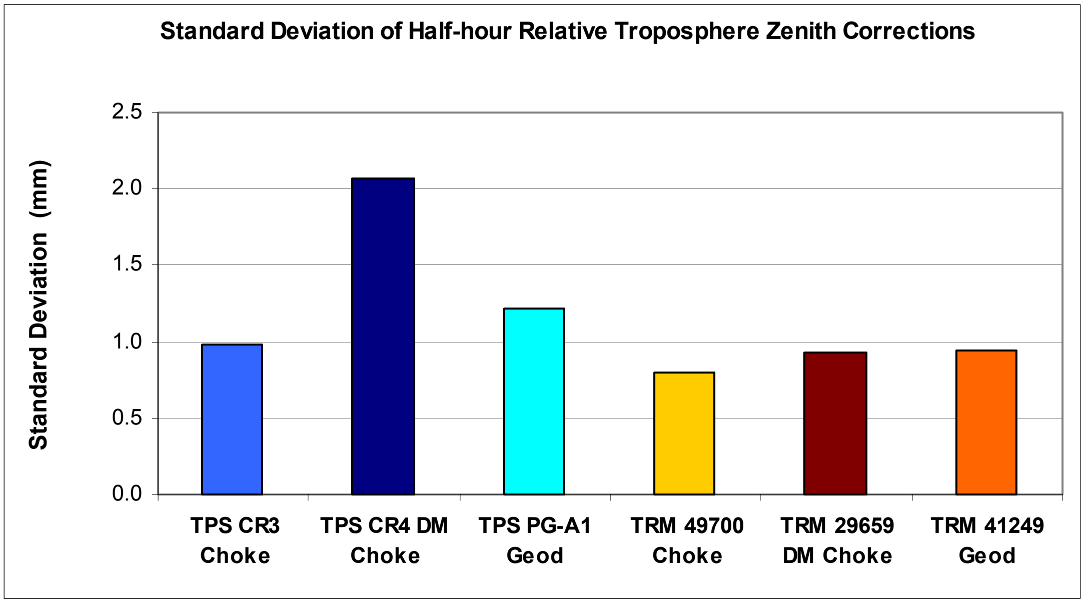


Figure 6.8 – Standard deviation of the half-hour relative troposphere zenith corrections shown in Figures 6.7(a) and 6.7(b) and summarized in Table 6.4 below. Lower values are better.

Table 6.4 – Standard Deviation of L3 Short Baseline Troposphere Zenith Corrections

Receiver	Antenna	Std. Dev. (mm)	Min (mm)	Max (mm)
Odyssey RS	TPS CR3 Choke	1.0	-3.0	2.6
Odyssey RS	TPS CR4 DM Choke	2.1	-4.9	18.3
Odyssey RS	TPS PG-A1 Geod	1.2	-3.7	3.1
NetRS	TRM 49700 Choke	0.8	-2.3	1.4
NetRS	TRM 29659 DM Choke	0.9	-2.4	2.4
NetRS	TRM 41249 Geod	0.9	-2.5	2.3

Short Baseline double difference phase residuals

Representative plots of the short baseline L3 (ionosphere-free) carrier phase double difference residuals are presented below along with the RMS scatter for each plot. As with the zero difference processing, coordinates and ambiguities were estimated and propagation effects cancel over the short 1.9 m baseline. In the case of short baseline (1.9m) tests, however, residual multipath effects do not cancel. The residuals are sensitive to antenna performance and are typically 5 to 10 times noisier than zero baseline residuals. Figure 6.6 shows the double difference residuals for all satellite combinations formed and Figure 6.7 shows satellite pair 15:23. Qualitatively, the residual traces in Figure 6.6 with all the observations do not look dramatically different from each other, in contrast to the larger difference between systems found in earlier tests (ARI, Suominet). The multipath effects are evident in the plots of the single satellite pair and are generally similar between receiver/antenna combinations with the possible exception of the Odyssey RS/TPS PG-A1 Geod, which also shows the largest RMS scatter in the residuals. The residuals for this combination show longer period fluctuations at the higher elevation angles (mid plot), which are not as evident in the other receiver/antenna pairs.

Summary

Overall, the largest RMS values were found with the two non-chokering antennas, the TPS PG-A1 Geod and the TRM 41249 Geod. The Odyssey RS/TPS CR3 Choke and NetRS/TRM 49700 Choke have the smallest RMS values (see Table 6.5 below).

Table 6.5 - Representative Short Baseline L3 Phase Double Difference Residual RMS determined from Figures 6.6 and 6.7.

Receiver	Antenna	Mean STD. Sv's 15:23 (mm)	Mean STD all sv's (mm)
Odyssey RS	TPS CR3 Choke	9.5	13.2
Odyssey RS	TPS CR4 DM Choke	10.3	13.5
Odyssey RS	TPS PG-A1 Geod	13.3	17.0
NetRS	TRM 49700 Choke	8.5	11.6
NetRS	TRM 29659 DM Choke	9.6	12.7
NetRS	TRM 41249 Geod	12.0	16.0

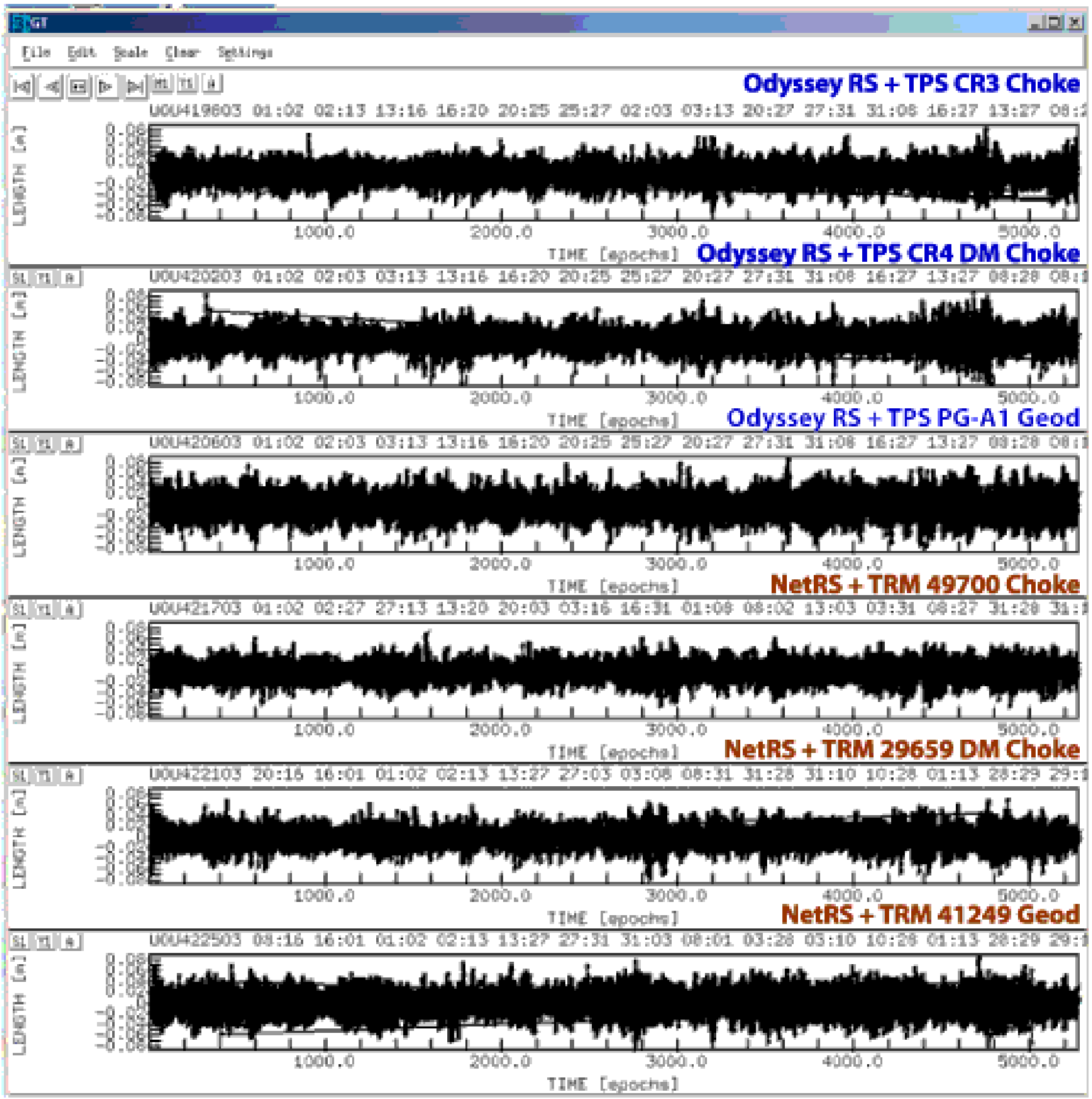


Figure 6.6 - A representative sample of the short baseline (1.9m) baseline L3 (ionosphere-free) carrier phase double difference residuals showing all satellite combinations that were formed. A single day of residuals is presented for each antenna/receiver combination tested. Vertical scale is ± 8 cm.

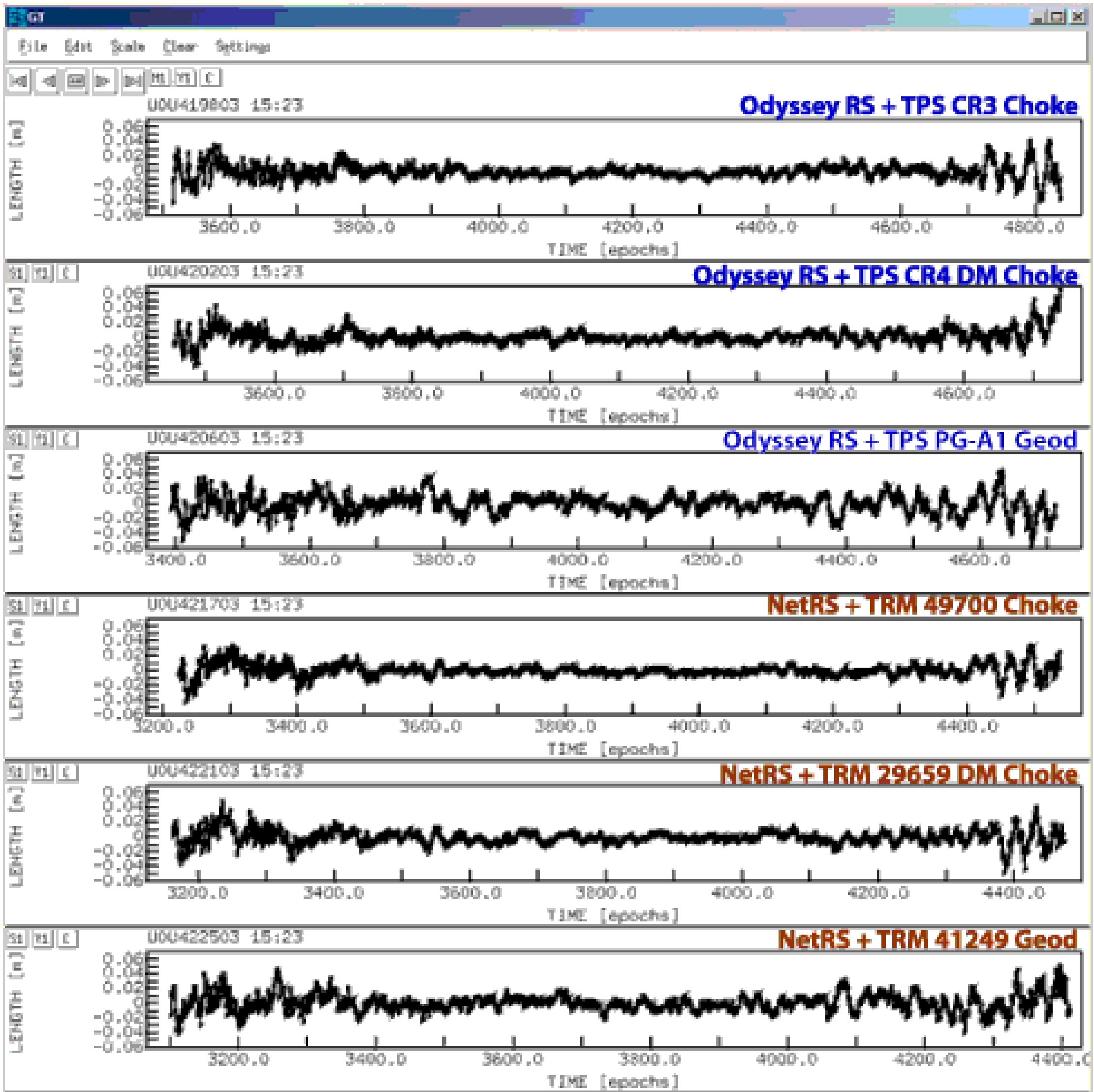


Figure 6.7 - A representative sample of the short baseline L3 carrier phase double difference residuals for each antenna/receiver combination tested showing only satellite pair 15:23. Vertical scale is ± 6 cm.

7.0 Summary

Table 7.1 – Receiver Mandatory Functionality - General

Receiver Mandatory Functionality	Odyssey RS	NetRS
Unsmoothed pseudorange	P	P
Environmental specifications (operating temp, shock proof 1 m)	P	P
Must track to 0 degree elevation angle	P	P
Simultaneously log 15 sec and 5 Hz data & stream 1 Hz observables	P	P
Stream and log observables at 5 Hz or greater	P	P
Streaming and logging rates must be configurable to 5Hz, 1Hz, 5, 10, 15, 30, 60, & 300 second intervals	P	P
L1/L2 SNR in db*Hz referenced 1 Hz or better bandwidth	P	P
Minimum 80 Mb internal memory	P	P
Output 1 PPS and RTCM SC104 v 2.2 base station corrections	P	P
Ability to enable/disable code and carrier multipath rejection	P	P
2 serial ports DB9 connectors or custom to DB9	P	P
2 power ports (one standard, one battery backup)	P	P
1 Ethernet enabled port	P	P
RINEX V2.0 translator software - output compatible w/TEQC	P	P
Mean Time Between Failure (MTBF) at least 57,500 hours	P	P
Power on 11.85-12.0V : Power off 11.0-11.15V	F	P
Power consumption while tracking < 8 Watts	P	P
Automatic restart in same configuration after power loss	P	P

Table 7.2 – Receiver Mandatory Functionality – Data Quality

Receiver Mandatory Functionality	Topcon TPS CR4 DM Choke	Topcon TPS PG-A1 Geod	Topcon TPS CR3 Choke	Trimble TRM 41249 Geod	Trimble TRM 49700 Choke	Trimble TRM 29659 DM Choke
Total Expected and Observed Data						
For 90-10 degrees, rcvr must have at least 99% obs/exp w/no more 0.05% slips/obs	P	P	P	P	P	P
For 10-5 degrees, rcvr must have at least 90% obs/exp w/no more 0.1% slips/obs	P	P	P	P	F	P
For 5-0 degrees, rcvr must have at least 30% obs/exp w/no more 1% slips/obs	P	P	F	F	F	F
For 90-10 deg, rcvr must have MP1 values < 0.7m	P	P	P	P	P	P
For 90-10 deg, rcvr must have MP2 values < 0.7m	P	P	P	P	P	P
10-5 deg, rcvr must have MP1 values < 0.7 m	F	F	F	F	F	F
10-5 deg, rcvr must have MP2 values < 0.7 m	F	F	F	F	F	F
For 5-0 deg, rcvr must have MP1 values < 1.0m	F	F	F	F	P	F
For 5-0 deg, rcvr must have MP2 values < 1.0m	F	F	F	P	P	P
90-0 deg, rcvr must have > 20,000 observations / slip (comb mp1/mp2 slips)	P	P	P	P	P	P
10-5 & 5-0 deg, rcvr must have < 1% IOD slips.	P	P	P	P	P	P
Zero Baseline L1 Carrier phase precision < 1 mm	P	P	P	P	P	P
Zero Baseline L2 Carrier phase precision < 1mm	P	P	P	P	P	P
Zero Baseline L3 Carrier phase precision < 1 mm	P	P	P	P	P	P
Zero Baseline L1 Pseudorange precision < 30 cm	P	P	P	P	P	P
Zero Baseline L2 Pseudorange precision < 30 cm	P	P	P	P	P	P
Zero Baseline L3 Pseudorange precision < 100 cm	P	P	P	P	P	P
L1 Short baseline precision North	P	P	P	P	P	P
L1 Short baseline precision East	P	P	P	P	P	P
L1 Short baseline precision Vertical	P	P	P	P	P	P
L2 Short baseline precision North	P	P	P	P	P	P
L2 Short baseline precision East	P	P	F	P	P	P
L2 Short baseline precision Vertical	F	P	P	P	P	P
L3 Short baseline precision North	P	P	P	P	P	P
L3 Short baseline precision East	P	P	F	P	P	P
L3 Short baseline precision Vertical	F	P	P	P	P	P
Residual Troposphere STD can't be > 1 mm for L3	F	F	P	P	P	P

Table 7.3 – Antenna mandatory functionality

	Topcon			Trimble		
Antenna Mandatory Functionality	**TPS CR4 DM Choke**	**TPS PG-A1 Geod**	**TPS CR3 Choke**	**TRM 41249 Geod**	**TRM 49700 Choke**	**TRM 29659 DM Choke**
L1/L2 Choke Ring Antenna	P	P	P	P	P	P
L1/L2 Geodetic Antenna	P	P	P	P	P	P
Antenna must be separate from receiver	P	P	P	P	P	P
Well defined phase and gain patterns	P	P	P	P	P	P
Repeatibility	P	P	P	P	P	P
Enough gain to operate 30 m away w/out amplifier	P	P	P	P	P	P
Environmental Specifications	P	P	P	P	P	P
Must be compatible with the SCIGN antenna mount	P	**	*	P	P	P
If chosen, choke ring must be compatible with SCIGN Tall radome	P	N/A	*	N/A	P	P

* - The TPS CR3_GGD antenna has a vertically oriented N connector (instead of horizontal) and a right angle connector was needed in order to be able to use this antenna on a UNAVCO leveling mount. The TPS CR3 Choke is not compatible with the SCIGN antenna mount without using an extension.

** - The TPS PG-A1 Geod is not compatible with the SCIGN antenna mount without using an extension.

7.0 References

Estey, L., Meertens, C., (1999). TEQC: The multipurpose toolkit for GPS/GLONASS data. GPS Solutions Vol. 3, No. 1 pp.44-49.

Jackson, M., Meertens, C., Andreatta, V., VanHove, T., (2000). SuomiNet GPS Receiver and Antenna Testing Report. UNAVCO Report.

Rocken, C., Meertens, C., Stephens, B., Braun, J., VanHove, T., Perry, S., Ruud, O., McCallum, M., & Richardson, J., (1995). UNAVCO Academic Research Infrastructure (ARI) Receiver and Antenna Test Report. UNAVCO Boulder Facility Internal Report.

Hofmann-Wellenhof B., Lichtenegger, H., and Collins, J. GPS Theory and Practice: Fourth edition. New York. Springer-Verlag Wien,. 1992. PP (93-95:206-216).

8.0 Acknowledgements

Funding for receiver specification and testing was made possible through the EAR 9903413 grant to UNAVCO/UCAR from the National Science Foundation (NSF). We wish to thank: Tom Morris, Morgan Smith, Sergey Organov, and Dmitry Kolosov from Topcon Positioning Systems; along with Terry Wortham and Brian Frohring from Trimble Navigation Ltd. for their assistance during the antenna/receiver testing.

9.0 Vendor Responses

Topcon Positioning Systems

Topcon Positioning Systems wishes to express our appreciation to UNAVCO for inviting us to participate in the PBO receiver evaluation. It was a pleasure to work with the professional staff of UNAVCO associated with the test campaign. We are very appreciative for the staff's willingness to review our Odyssey RS and antennas. The test campaign was a good exercise for Topcon Positioning Systems. The experiences gained from the UNAVCO evaluation have provided us with much useful information.

We make the following comments to items in the test report.

3.0 Receiver tracking and data quality tests

It is Topcon's approach to track the weakest satellite signals, even at the expense of additional cycle slips at low elevations. This is demonstrated by the good performance in the expected versus actual observations. We generally anticipate higher values for the 0-5 degree elevation range in open sky conditions (~75% for CR4 antenna). The lower, although acceptable, values demonstrated in this test may be due to the obstructed horizons of the test site, as seen in figures 2.1 and 2.3.

4.0 Power Test

The average power consumption is adversely affected by the values of the single receiver SN231-0106. The values measured for this receiver are above those expected and the receiver will be evaluated upon return. The test values of the other 3 receivers reflect expected power consumption.

Table 7.1 states the Odyssey RS failed the Power On-Power Off Voltage Range. However, from the UNAVCO PBO RFP Question & Answer website http://www.unavco.org/PBO/RFPs/PS_RFP_QandA.html, the answer was misinterpreted to be the Power Off range should be less than 11V-11.15V and the Power On range should be less than 12.2V.

"...The off voltage was chosen to be 11-11.15V to turn off the receiver just at the LVD point. This turn off voltage could be lower."

"...The receiver turn on voltage should be less than 12.2V."

Thus, our standard receiver defaults are much lower (5.4V and 5.6V) and we made no modifications. We can easily configure the Odyssey RS power board to the ranges listed in Table 7.1 if this is the desired for UNAVCO projects. However, we made no configuration changes for the PBO evaluation as assumptions concerning the published Q&A information indicated we were in compliance.

6.0 Short Baseline Test

The CR4 exceeded vertical target RMS values for L2 and L3 by sub-millimeter values (0.4 mm and 0.1mm). The CR3 exceeded the Easting target RMS values in L2 and L3 by sub-millimeter values (0.1mm and 0.4mm). Upon review, it is noted the RMS values are a function of the receiver's bandwidth of the guided loops. Topcon default firmware values are typically set to take advantage of GLONASS observables and GPS observables. Narrowing the bandwidth will yield lower RMS values. This can be easily accomplished by a receiver command. Topcon can further accomplish this by changing the firmware defaults to meet UNAVCO's GPS project requirements.

Appendix A

Topcon provides full control of receiver parameters, including tracking bandwidth, session programming, GLONASS/GPS tracking, co-op tracking, and other special features of our receivers, through our command language known as GRIL (GPS+ Receiver Interface Language). GRIL commands can be used in any communication software, including telnet, terminal, custom software running under any operating system, or Topcon's interfaced software. It was our assumption UNAVCO would want full control of their receivers using a low-level command language for the PBO evaluation.

Once again, Topcon Positioning Systems was pleased to receive an invitation to participate in the PBO evaluation. We are committed to reacting quickly and decisively to the requirements of the UNAVCO community.

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Formal Response to the UNAVCO PBO Test Report

Submitted by Trimble Navigation Limited

24 September 2003

Trimble Navigation Ltd.

Trimble would like to thank UNAVCO for the opportunity to participate in this very important GPS receiver testing and evaluation program. This testing campaign, conducted in support of the Plate Boundary Observatory project, has been very thorough, and we are pleased to comment on the performance of the Trimble NetRS GPS Reference Station receiver, which was tested in combination with the Trimble Zephyr Geodetic antenna, the Trimble Zephyr Choke Ring antenna and the Trimble Dorne and Margolin Choke Ring antenna.

The Trimble NetRS was designed specifically as a high performance GPS Reference Station intended for use in scientific, research, geodetic and network applications. The Trimble NetRS offers the performance, features, functionality and operational capabilities required in these demanding environments. The Trimble NetRS receiver with the antenna offerings tested for PBO provide performance and features, which meet the needs of high performance geodetic, network RTK, and commercial applications. The Zephyr Geodetic antenna incorporates patented Stealth multipath reduction technology in an integral sealed enclosure, the Trimble Choke Ring antenna based on the Dorne and Margolin element matches configurations used in certain legacy geodetic networks, and the Trimble Choke Ring antenna based on the Zephyr Geodetic multi point feed element provides the Zephyr technology in the choke ring framework.

The combination of the Trimble NetRS and any of the proposed geodetic antenna options provides exceptional GPS performance on a Linux-based receiver framework. The Linux operating system provides a platform that enables the Trimble NetRS to meet all of the PBO system, communications, and security requirements for initial deployment and provides the potential for future functional extensions not possible with other commercial or proprietary operating systems.

We also note that the Trimble NetRS released this month supports L2C tracking, ensuring maximal performance from the GPS constellation as SVs begin broadcasting this signal in late 2004. For more information, please refer to the Trimble NetRS product documentation at http://www.trimble.com in the Survey products section under "Scalable GPS Infrastructure Solutions".

Trimble is pleased to offer the Trimble NetRS with these geodetic antenna options as a solution optimized for GPS Reference Stations capable of meeting both real-time and post-processed requirements with the highest degree of performance, features and reliability.

MP1 and MP2 Tracking Statistics

The PBO MP1 and MP2 tests were made with multipath mitigation disabled as per the test requirements. Trimble would like to point out that in a typical Trimble NetRS configuration, Trimble's Everest proprietary real-time multipath reduction techniques would be enabled, and thus the resultant contribution of any multipath induced error component to the overall error would be greatly reduced.

Hardware Interfaces and Connections

Regarding the Compact Flash (CF) memory, the base configuration of the Trimble NetRS receiver proposed for the PBO application is a 256 MB card providing 150 MB for user and logged data storage. The receiver will support any of the larger size CF cards with memory capacities up to 4GB coming into volume production this year. We also note that although BINEX logging has been specified for the PBO application, a general comparison of receiver memory sizes would include consideration of storage efficiency. For example, using a DAT file as a reference for 1X storage, the increase in the amount of GPS data stored per unit of disk space is about 2.5X for R00, 3X for BINEX, >5X for Trimble T00, and 6X for Trimble T01 and WinZIP'ed Hatanaka RINEX formats.

The Trimble NetRS receiver memory can be upgraded by any Authorized Trimble Service Provider, including UNAVCO.

Appendix A – Receiver Interfacing and Configuration

The Trimble NetRS provides the complete spectrum of control, from comprehensive setup and operation via CGI scripts over HTTP, to interactive web-based control, to completely control-free operation for obtaining GPS measurements and information. In addition, configuration files may be created, downloaded, uploaded, or activated allowing any or all of the configuration of a single receiver to be "cloned" to one or more other receivers. We have combined flexible configuration as a "network appliance" and the capability to perform selectable "cloning" with the intent to shift the model for GPS receiver administration from configuring a single receiver to managing a network of receivers.

Final Comments

We again thank UNAVCO for the opportunity to participate in this series of GPS Reference Station receiver and antenna tests and for the opportunity to provide observations and comments on the results. We are very pleased to be introducing the Trimble NetRS receiver at this time, as this receiver has been optimized for network applications such as the PBO project. We found this to be a very worthwhile endeavor and we re-affirm our continued commitment to the scientific and commercial GPS user community as well as our commitment to continued research and development resulting in the release of products designed specifically for these demanding applications.

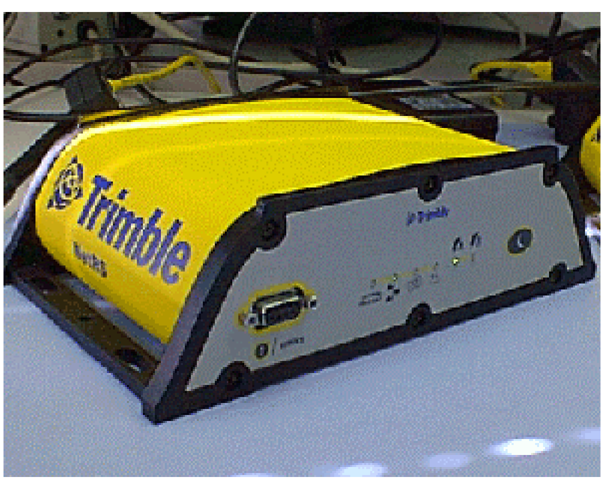
Appendix A – Receiver Interfacing and Configuration

The comments below reflect the usability of the two receivers tested; the Topcon Odyssey RS, and Trimble NetRS. The reporting testers had no prior experience with either receiver before testing began. This document details: hardware interfaces and connections, initial receiver configuration, session programming, file downloading, and viewing current receiver status and operations.

Hardware Interfaces and Connections

This section explains how the receiver is connected to power, data communications, and the antenna.

The Odyssey RS receiver uses an ODU (Fischer compatible) type connector for power and data communications. The power port on the front of the receiver can be used with DC (6-28 Volts) only. To use AC (120 or 220 V) power, the standard AC-DC power converter should be used. These are provided with each system. There are three serial ports on the front of the receiver, and an Ethernet port. Dongles are used to connect to each of these ports. The rear of the receiver has a TNC-type connector for the GPS antenna. The Odyssey RS arrived for testing with 1 Gigabyte of memory installed. Manufacturer's specifications state that it is weatherproof.



The NetRS receiver has four DB9 serial ports. A quick lock power port and an included dongle provide an RJ45 port for Ethernet and standard 5.0m x 2.1m coaxial jack for another power port (generally used with the AC adapter). The serial port on the front of the receiver is the service port. The rear of the receiver has an N-type connector for the GPS antenna. The NetRS runs a real-time version of LINUX as it's operating system. The NetRS arrived for testing with 256 MB of onboard memory, approximately 100 MB are used to run LINUX. There is roughly 150 MB open for data storage. The amount of storage can be upgraded by any authorized Trimble Service Provider. Manufacturer's specifications state that it is weatherproof.

Appendix A - Receiver Interfacing and Configuration

Initial Receiver Configuration

This section explains how the global parameters of the receiver are initially configured. This includes but is not limited to: setting the IP address, four-character receiver ID, multipath mitigation, etc.

There are multiple ways to program sessions on the Odyssey RS. Twenty-four hour sessions can be programmed through the GUI interface. We found that PC-CDU was not adequate for the purpose of this test because of specific parameters that needed to be configured. We worked with the Topcon engineers to write a set of GRIL commands to create the correct data logging session. The Odyssey RS uses the scheme of "jobs" and "commands" for session programming. You must define "commands" that are to be run by "jobs" at specific times using the GRIL syntax. Configuration of the Odyssey RS was not straightforward for this testing phase primarily due to the limited configuration options available within PC-CDU, and our lack of knowledge of the GRIL command syntax.

Configuration of the NetRS can be accomplished through a web browser (Netscape, Internet Explorer, etc.), or CGI configuration scripts can be sent via HTTP. Before configuring the receiver via the web interface, you must first obtain or assign the IP address of the receiver. This is accomplished by connecting to the service port on the front of the receiver using hyper terminal or some other communication software. The receiver can be configured to use DHCP or a static IP. The web interface is navigated with a side navbar on the left side of the screen. Category links open an indented list of available configuration options to choose from. All changes made through this interface take effect immediately. The setup of the NetRS through the web browser is straightforward and intuitive.

Both receivers allow automatic programming/cloning using an existing configuration file. With the Odyssey RS, this is done by creating a script of GRIL commands and saving them as a text file, or saving the current receiver parameters to a text file, which can then be loaded onto any receiver. For the NetRS, you can save the configuration of one receiver and upload the configuration file to another receiver through a web browser. The Odyssey RS can be programmed through a PDA; Topcon provides a windows CE version of their GUI interface (requiring a PDA with serial port). The NetRS currently does not support Windows CE based web browsers.

Session Programming

This section details how to configure data logging sessions on the receivers. The following parameters were used for testing: 22 hour logging sessions (00:00:00 UTC – 22:00:00 UTC), 15 second sampling interval, multipath mitigation disabled, pseudorange smoothing off. High rate data (1 Hz) was collected for a total of 2 hours at the end of the Odyssey RS testing phase, and two hours with the NetRS at the end of the Trimble testing phase.

There are multiple ways to program the Odyssey RS. Many basic parameters can be configured via the PC-CDU interface but certain parameters pertaining to this test had to be configured via GRIL commands. We worked with the Topcon engineers to write a set of GRIL commands that would configure the receiver for data logging. The Odyssey RS uses the scheme of "jobs" and "commands" for session programming. "Commands" need to be defined that will be run by "jobs" at specific times. The raw data files were automatically prefixed with the four-character id, month, day, and alphanumeric character. Raw data files were downloaded from the receiver in .jps format. A program called 'tps2rin' was used to convert the raw data files to RINEX.

Session programming on the NetRS can be accomplished via the web interface or by using CGI scripts over HTTP. The data-logging screen is where sessions can be configured. The raw data files were automatically prefixed with the four-character id, four-digit year, month, day, two-digit hour, two-digit minute, and a configurable alphanumeric character. The raw data files were in T00 format and runpkr00 was used to convert them to Trimble DAT files. The DAT files were then converted to RINEX navigation and observation files using TEQC.

File Downloading

Both receivers support two different methods for downloading data files. At the time of testing, the Odyssey RS data files could be downloaded via PC-CDU or via anonymous FTP. The NetRS data files can be downloaded via the web interface or FTP. The NetRS supports both anonymous or named FTP access for data file access, along with a separate named system account for firmware upload. The NetRS FTP accounts can be enabled with or without file deletion rights.

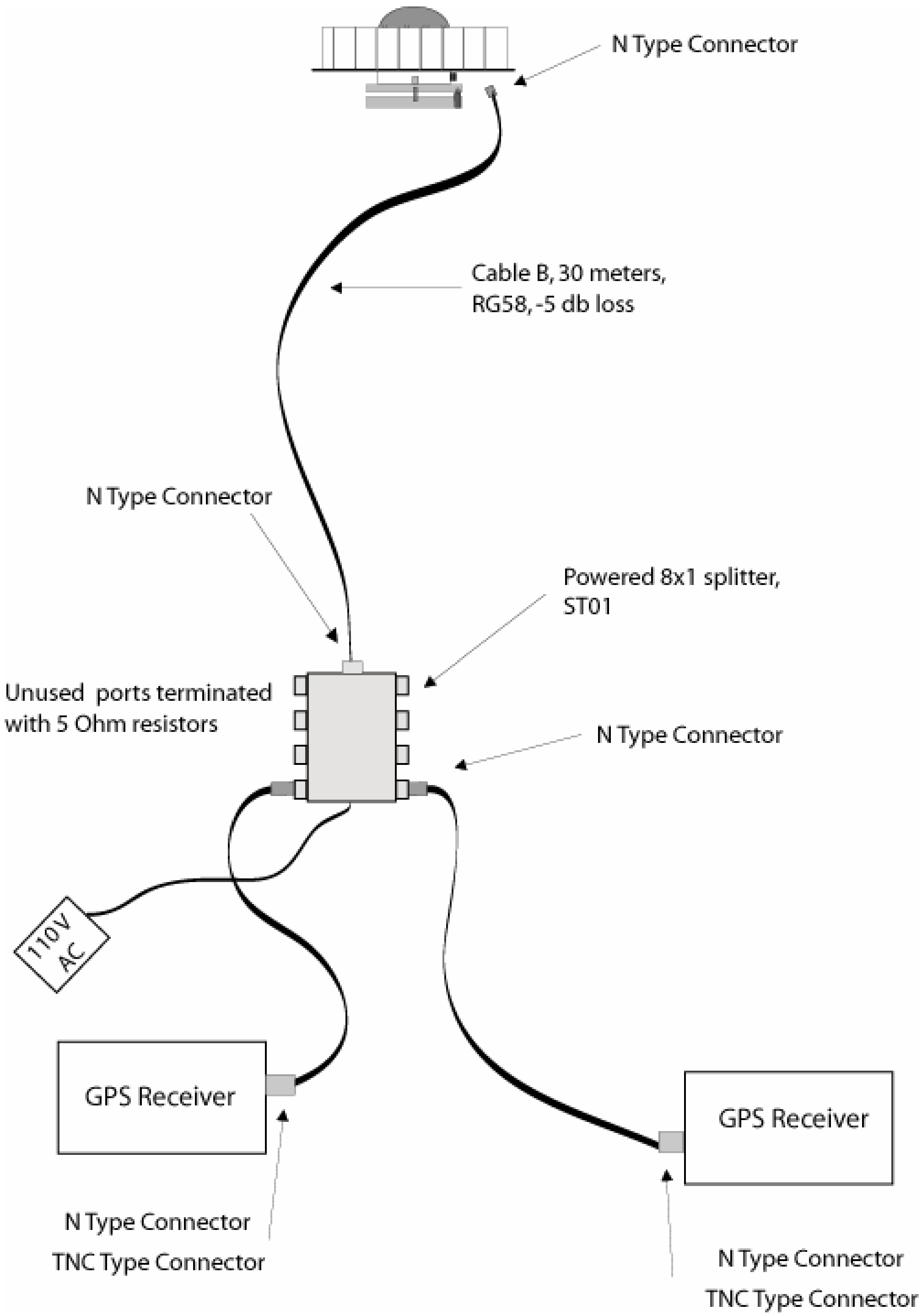
Viewing Status and Operation

This section covers the ability to view the receivers status, including satellite tracking, logging, session information, data files on receiver, etc. Both receivers have front panel LED's to display power, satellite tracking status, logging and Ethernet connectivity.

There are numerous ways to remotely view current receiver parameters such as session programming, data files, etc., for the Odyssey RS. One method is to use Topcon's window based software, PC-CDU, connected to the receiver via the Internet. GRIL commands can be used to obtain the same information.

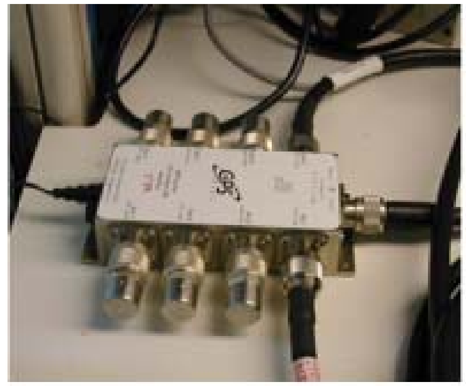
For the NetRS, the web interface can be used to view the status of the receiver, current satellite-tracking status, session information, data files, etc. This information is also available using CGI scripts over HTTP.

Appendix B – Block Diagram for Zero Baseline Testing



Appendix C – Photographs of testing setup and equipment

LINUX Download Computer in testing lab



8 x 1 powered splitter used in zero-baseline tests

UV06 (Ashtech ZXII) and UV02 (Trimble 4000SSI)

TPS CR3 Choke in box

Topcon equipment shown above. Equipment was packed into individual pelican cases.

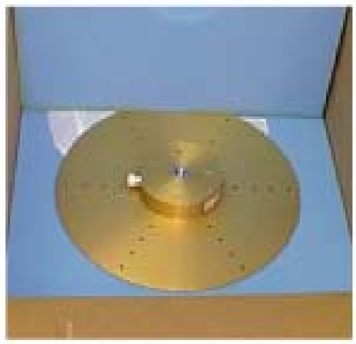
Appendix C cont. - Photographs of testing setup and equipment

Topcon Antenna Cables

TPS CR4 DM Choke Antenna

Trimble Antenna Cables

Topcon Odyssey RS receiver



TRM 49700 Choke

TRM 41249 Geod

Trimble NetRS receiver

Trimble NetRS receiver

Appendix D – Antenna Phase Center Patterns

TPS CR4 - Choke Ring (NGS 03/04/07)										
	North	East	Up							
L1 Phase Offset (mm)	0.3	0.2	109.9							
L2 Phase Offset (mm)	-0.1	-0.7	128.3							
	90	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**
L1 Phase at Elevation (mm)	0.0	0.3	0.3	0.4	0.3	0.3	0.2	0.2	0.2	0.2
L2 Phase at Elevation (mm)	0.0	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.4	-0.4	-0.4
		40	**35**	**30**	**25**	**20**	**15**	**10**	**5**	**0**
L1 Phase at Elevation (mm)		0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.0	0.0
L2 Phase at Elevation (mm)		-0.4	-0.4	-0.4	-0.5	-0.5	-0.4	-0.4	0.0	0.0

TPS PG-A1 (NGS 03/07/08)										
	North	East	Up							
L1 Phase Offset (mm)	0.7	2.2	54.3							
L2 Phase Offset (mm)	0.4	-0.2	60.5							
	90	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**
L1 Phase at Elevation (mm)	0.0	-0.8	-0.5	0.6	2.2	3.9	5.4	6.7	7.5	7.8
L2 Phase at Elevation (mm)	0.0	-2.1	-3.2	-3.4	-3.1	-2.5	-1.6	-0.6	0.2	0.8
		40	**35**	**30**	**25**	**20**	**15**	**10**	**5**	**0**
L1 Phase at Elevation (mm)		7.5	6.8	5.7	4.3	2.9	1.7	1.0	0.0	0.0
L2 Phase at Elevation (mm)		1.1	0.9	0.3	-0.9	-2.6	-4.9	-7.8	0.0	0.0

TPS CR3_GGD - Choke Ring (NGS 02/03/11)										
	North	East	Up							
L1 Phase Offset (mm)	0.1	0.0	80.5							
L2 Phase Offset (mm)	0.7	0.8	103.5							
	90	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**
L1 Phase at Elevation (mm)	0.0	0.8	1.3	1.6	1.7	1.8	1.8	1.8	1.8	1.8
L2 Phase at Elevation (mm)	0.0	-0.5	-0.5	-0.2	0.2	0.7	1.1	1.5	1.8	1.8
		40	**35**	**30**	**25**	**20**	**15**	**10**	**5**	**0**
L1 Phase at Elevation (mm)		1.9	2.0	2.0	1.8	1.5	0.9	-0.1	0.0	0.0
L2 Phase at Elevation (mm)		1.7	1.5	1.1	0.7	0.2	-0.1	-0.3	0.0	0.0

TRM41249.00 - Zephyr Geodetic (NGS 01/04/11)										
	North	East	Up							
L1 Phase Offset (mm)	0.3	0.5	71.4							
L2 Phase Offset (mm)	-0.4	0.1	68.2							
	90	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**
L1 Phase at Elevation (mm)	0.0	0.6	1.4	2.3	3.2	4.1	4.9	5.6	6.1	6.4
L2 Phase at Elevation (mm)	0.0	-0.5	-0.6	-0.5	-0.2	0.1	0.5	0.8	1.0	1.1
		40	**35**	**30**	**25**	**20**	**15**	**10**	**5**	**0**
L1 Phase at Elevation (mm)		6.4	6.1	5.5	4.5	3.1	1.3	-0.9	0.0	0.0
L2 Phase at Elevation (mm)		1.0	0.9	0.6	0.2	-0.2	-0.6	-0.8	0.0	0.0

Appendix D cont. – Antenna Phase Center Patterns Used

TRM49700.00 - Zephyr Choke Ring										
	North	**East**	**Up**							
L1 Phase Offset (mm)	1.1	1.5	121.2							
L2 Phase Offset (mm)	-0.1	-0.1	129.1							
	90	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**
L1 Phase at Elevation (mm)	0.0	0.1	0.4	0.8	1.3	1.7	2.1	2.5	2.7	2.8
L2 Phase at Elevation (mm)	0.0	-0.2	-0.2	-0.1	0.0	0.1	0.3	0.4	0.4	0.5
		40	**35**	**30**	**25**	**20**	**15**	**10**	**5**	**0**
L1 Phase at Elevation (mm)		2.7	2.6	2.3	1.8	1.2	0.5	-0.2	0.0	0.0
L2 Phase at Elevation (mm)		0.5	0.4	0.3	0.1	-0.1	-0.3	-0.5	0.0	0.0

TRM29659.00 - Trimble Choke Ring (NGS 97/10/27)										
	North	**East**	**Up**							
L1 Phase Offset (mm)	1.2	0.5	109.8							
L2 Phase Offset (mm)	1.2	0.6	128.0							
	90	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**
L1 Phase at Elevation (mm)	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
L2 Phase at Elevation (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
		40	**35**	**30**	**25**	**20**	**15**	**10**	**5**	**0**
L1 Phase at Elevation (mm)		0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.0	0.0
L2 Phase at Elevation (mm)		-0.1	-0.1	-0.1	-0.1	0.0	0.2	0.4	0.0	0.0