U. S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

Field test of two single-frequency GPS receivers

by

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Open-File Report 96-43

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ABSTRACT

The U.S. Geological Survey's Cascades Volcano Observatory (CVO) has been testing low-cost, low-power Global Positioning System (GPS) receivers for use in the monitoring of restless volcanoes. Field tests of two single-frequency (L1 only) receivers, the Ashtech SCA-12S and the Leica SR261 show that these units can measure positions precisely enough to meet our monitoring needs. For line lengths up to 10 kilometers, I have found repeatibilities to be less than a centimeter for horizontal coordinates. Hourly data using broadcast orbits was processed using manufacturer and Bernese software. Repeatibilities were similar for both data sets.

INTRODUCTION

The Global Positioning System (GPS) was established by the Department of Defense for accurate navigation in 1973 (Wells et al, 1986). The system utilizes ground-based units receiving signals broadcast from satellites orbiting the earth at known positions and using triangulation to locate points on the earth's surface. The full constellation consists of 24 satellites in six geosynchronous orbital planes, inclined 55° to the equator, and at an altitude of 20,183 km (Wells et al, 1986).

Each satellite transmits two frequencies, the L1 and L2 carrier waves, which are modulated by various signals. Over very long distances, both frequencies are needed to minimize the effects of ionosphere delay. However, in measuring shorter distances, the relative ionosphere should be the same at both locations, allowing the use of only one frequency. The L1 signal is the stronger of the two and is used in all single-frequency receivers. There are numerous L1-only receivers on the market, but most of these record only the coarse/acquisition code which modulates the L1 carrier wave. In order to achieve centimeter level accuracies, the carrier phase data is needed.

Recently, CVO has tested two receivers that meet our initial requirements: L1 only, carrier phase data, low power, and raw binary data output through a RS-232 port. Processing hourly data resulted in less than one centimeter repeatibilities for line lengths less than 10 km.

APPLICATION OF GPS TO VOLCANIC HAZARDS

Deformation monitoring at volcanoes is used to detect horizontal and vertical changes between points on the volcano and changes in inclination of the volcanic edifice as a means of detecting the movement of magma. GPS has already been proven effective in measuring deformation on volcanic edifices (Miklius, 1995). However, GPS has not been used to forecast eruptive activity. Because of the short time scale on which magma can migrate and erupt, continuously recording instruments linked by radio communication would be needed to record such events.

Existing methods of measuring volcano deformation include: 1) measuring distances between points on and off the volcano to detect horizontal movements, 2) determining changes in ground tilt with electronic tiltmeters, and 3) determining elevation changes between points with leveling. GPS can supply all three of these results without personnel being on site.

A radio telemetry system for GPS data has been designed at CVO and has been working at Augustine Volcano, Alaska since 1992 (Murray et al, 1992). The GPS system would allow a 3-dimensional view of the deformation at each site. An enormous advantage of using a telemetry system is that there is no need for personnel to be on site to collect data, reducing the cost of surveying in the long run, and preserving the safety of personnel in times of volcanic activity.

TESTING PARAMETERS

Baselines of various lengths were used for these tests. The reference mark was located on the roof at CVO. An Ashtech "M," dual-frequency, codeless receiver was deployed at the reference site for all tests. Data was collected every 30-seconds for up to 8-hours per session.

Each day, the receiver tested was set up over a monument and left on the entire session. The data was then downloaded along with the reference station and processed.

Owing to the limited time we had each unit and the length of each session, these tests were not ideal. The receivers on the same baselines were measured on different days, therefore ionospheric differences may have affected comparison between the two receivers. However, the test did give us a good indication of the capability of each receiver.

LEICA SR261

The Leica SR261 receiver was the first to be tested. The specifications for the SR261 are in Appendix A. The receiver tested was the fully configured version of the SR261 and beyond our cost limitations of $5,000. The reason this receiver was tested was to confirm that it meets our requirements. If so, the prospect of purchasing a stripped-down version could be discussed.

It has not been established that the SR261 will work with our telemetry system. We are awaiting news from Leica on further developments on the stripped-down version.

ASHTECH SCA-12S SENSOR

The SCA-12S meets all of our requirements (see Appendix A for specifications).

This SCA-12S with carrier phase option works with our current telemetry system without modification. The cost is close to the limit we are looking for.

PROCESSING DATA

For each session, data was collected for up to 8-hours. The long files were broken up to 1-hour sessions and then processed. This was done to determine repeatibilities for 1-hour sessions which would be the session length for monitoring active volcanoes.

One of the specifications we set is that we must be able to process the data using Ashtech GPPS software. GPPS software is DOS based and can be run automatically, hands-off. This is how we currently run the existing telemetered GPS processing. In addition, GPPS is the software we have the most experience with.

Data from the Ashtech SCA-12S automatically outputs Ashtech formatted files and can be processed with GPPS. Data collected from the Leica SR261 is initially in Leica format. The Leica format must first be converted to RINEX (Receiver Independent EXchange format) and then to Ashtech formatted files. The data then can be processed using GPPS.

The same hourly data was then processed using Bernese software, (Buetler et al, 1988). This processing was done on a UNIX based system. Bernese is more commonly used for dual frequency processing, but we thought it would be interesting to compare data sets. Broadcast orbits were used for both GPPS and Bernese processing.

DATA

The following tables show (XYZ) Cartesian coordinates and line length. Data was processed in hourly intervals. Both GPPS and Bernese outputs are shown. Table 1 is a compilation of average and standard deviations of all the data recorded. The reference station remained the same for all the tests. Three stations were occupied by both the Leica and Ashtech receivers. Two other stations were occupied only with the Leica.

Figures 1 and 2 show X, Y, and Z coordinates versus line length. Both GPPS and Bernese results are plotted side-by-side, on the same vertical scale. The results from both processing packages are very similar. Comparing figure 1 and 2, it appears that overall, the Leica performed better than the Ashtech. At the 8 km distance (ENGL), there are outliers that make the Ashtech data noisy. However, the Leica data were collected over one day, while the Ashtech collected data at the same site over 3 days. Most of the outliers in the Ashtech data occur on julian day 030 (Table 3D), so that the apparent lower precision of the Ashtech on this baseline may be due to, e.g. differing ionosphere between days, rather than the instruments capabilities. The data for the 11 km long baseline to VANC suffers from the same problem, but even the Leica data are noisy at this baseline length. We think 11 km is near the useful limit of this method.

On days 031 and 032 an Ashtech geodetic antenna was used at the VANC mark with a splitter sending the signal to both an Ashtech "M" model dual-frequency receiver and the SCA-12S. The processed "M" results were similar to those of the SCA-12S. In all coordinates, the differences between the "M" and SCA-12S were less than 2-3 mm.

RECB is a fixed bolt site, therefore the differences in coordinates between the Ashtech and Leica reflect differences in antenna heights (Table 1). No corrections were made to account for different antenna heights as we were more interested in the repeatibilities of the receivers.

CONCLUSION

These field tests, although not ideal, have shown that both the Ashtech SCA-12S and Leica SR261 meet our expectations and specifications. The field test show that line lengths up to 8 km have repeatibilities from 2-6 mm. The 11 km baseline had repeatibilities from 5-14 mm. The longer baseline is at the edge of what we expect, but would be acceptable. At this time, it is not known how the Leica SR261 will interface with the existing telemetry system we have in place. We did test the Ashtech SCA-12S with the software used in our telemetry system and did successfully log and process the data. There would be no need for any modifications to the Ashtech SCA-12S.

Table 1. Test results of X, Y, Z, line length, and standard deviations for data processed. # is the number of hourly data used to calculate the average and standard deviation. Same data was processed using Ashtech GPPS and Bernese software. RECB is a fixed bolt, therefore the differences in coordinates reflect different antenna heights.

	LEICA SR261		ASHTECH SCA-12S	
	GPPS (m)	Bernese (m)	GPPS (m)	Bernese (m)
VAR2 X	-2411293.7377 ±.0014	-2411293.7330 ±.0022		
Y	-3761756.7841 ±.0032	-3761756.7761 ±.0037		
Z	4536161.4197 ±.0034	4536161.4104 ±.0027		
LL	3536.0560 ±.0020	3536.0552 ±.0021		
#	7	7		
NSPK X	-2404421.3455 ±.0021	-2404421.3458 ±.0025		
Y	-3765174.8995 ±.0054	-3765174.8990 ±.0042		
Z	4537070.1731 ±.0038	4537070.1733 ±.0033		
LL	4246.5098 ±.0020	4246.5097 ±.0024		
#	6	7		
RECB X	-2412327.3564 ±.0040	-2412327.3519 ±.0040	-2412327.2910 ±.0020	-2412327.2873 ±.0021
Y	-3760434.2303 ±.0054	-3760434.2244 ±.0058	-3760434.1249 ±.0035	-3760434.1189 ±.0038
Z	4536722.3279 ±.0056	4536722.3202 ±.0049	4536722.3279 ±.0022	4536722.2014 ±.0024
LL	5176.0167 ±.0040	5176.0162 ±.0037	5176.0215 ±.0024	5176.0217 ±.0023
#	27	21	16	15
ENGL X	-2401198.2606 ±.0044	-2401198.2602 ±.0045	-2401198.2592 ±.0074	-2401198.2590 ±.0072
Y	-3767253.6690 ±.0057	-3767253.6673 ±.0039	-3767253.6624 ±.0060	-3767253.6619 ±.0073
Z	4537052.2195 ±.0087	4537052.2188 ±.0087	4537052.2246 ±.0117	4537052.2246 ±.0090
LL	8003.2006 ±.0023	8003.2001 ±.0021	8003.1993 ±.0021	8003.1990 ±.0061
#	7	6	15	15
VANC X	-2414793.9125 ±.0043	-2414793.9080 ±.0043	-2414793.9182 ±.0112	-2414793.9126 ±.0117
Y	-3755030.0007±.0065	-3755029.9934 ±.0078	-3755029.9914 ±.0129	-3755029.9813 ±.0143
Z	4539832.5219 ±.0123	4539832.5126 ±.0129	4539832.5232 ±.0180	4539832.5113 ±.0175
LL	11371.4789 ±.0048	11371.4705 ±.0051	11371.4816 ±.0134	11371.4821 ±.0143
#	7	6	25	23

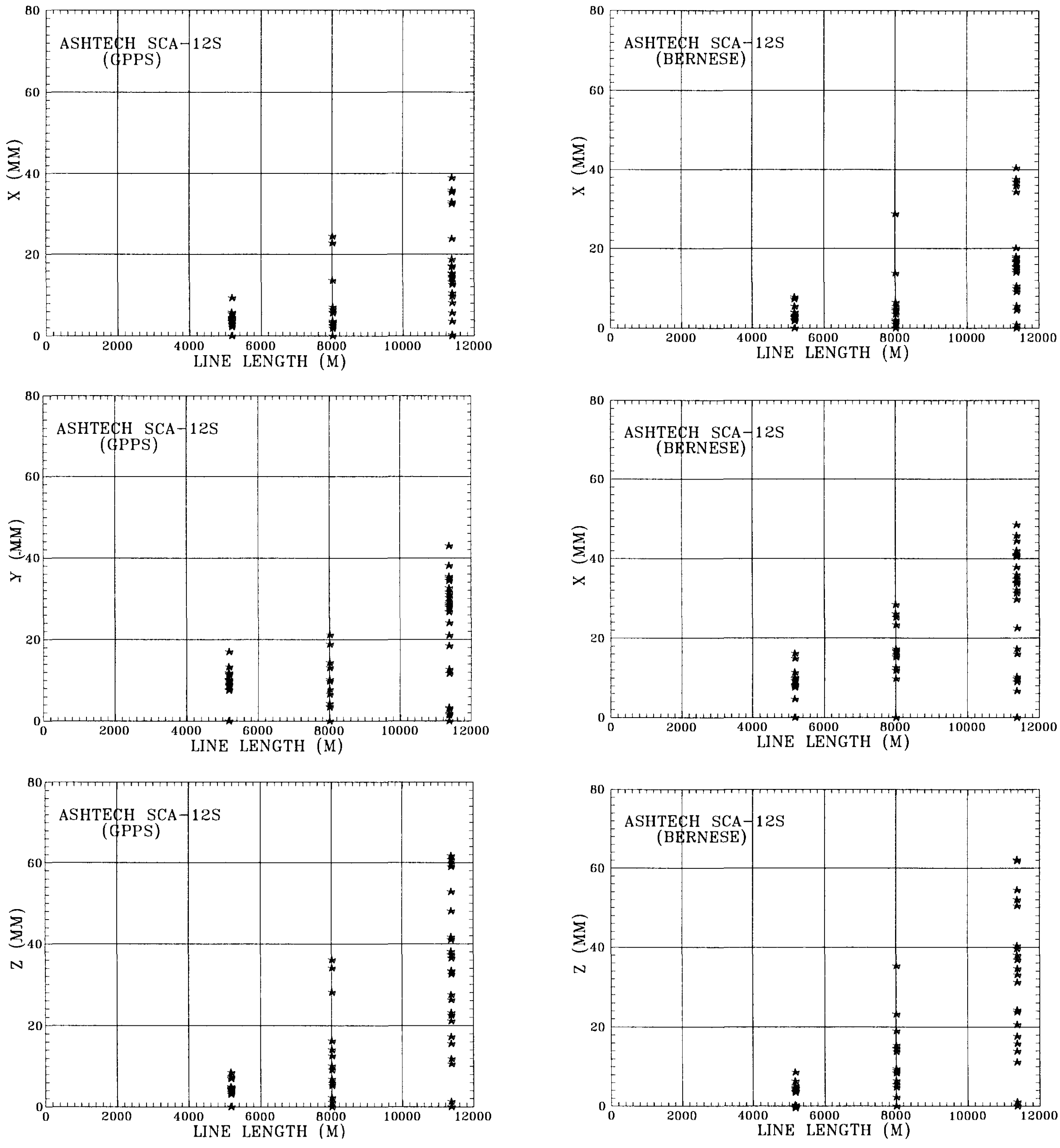

Figure 1. Comparison plots of repeatibilities of Ashtech SCA-12S one-hour data processed with GPPS and Bernese.

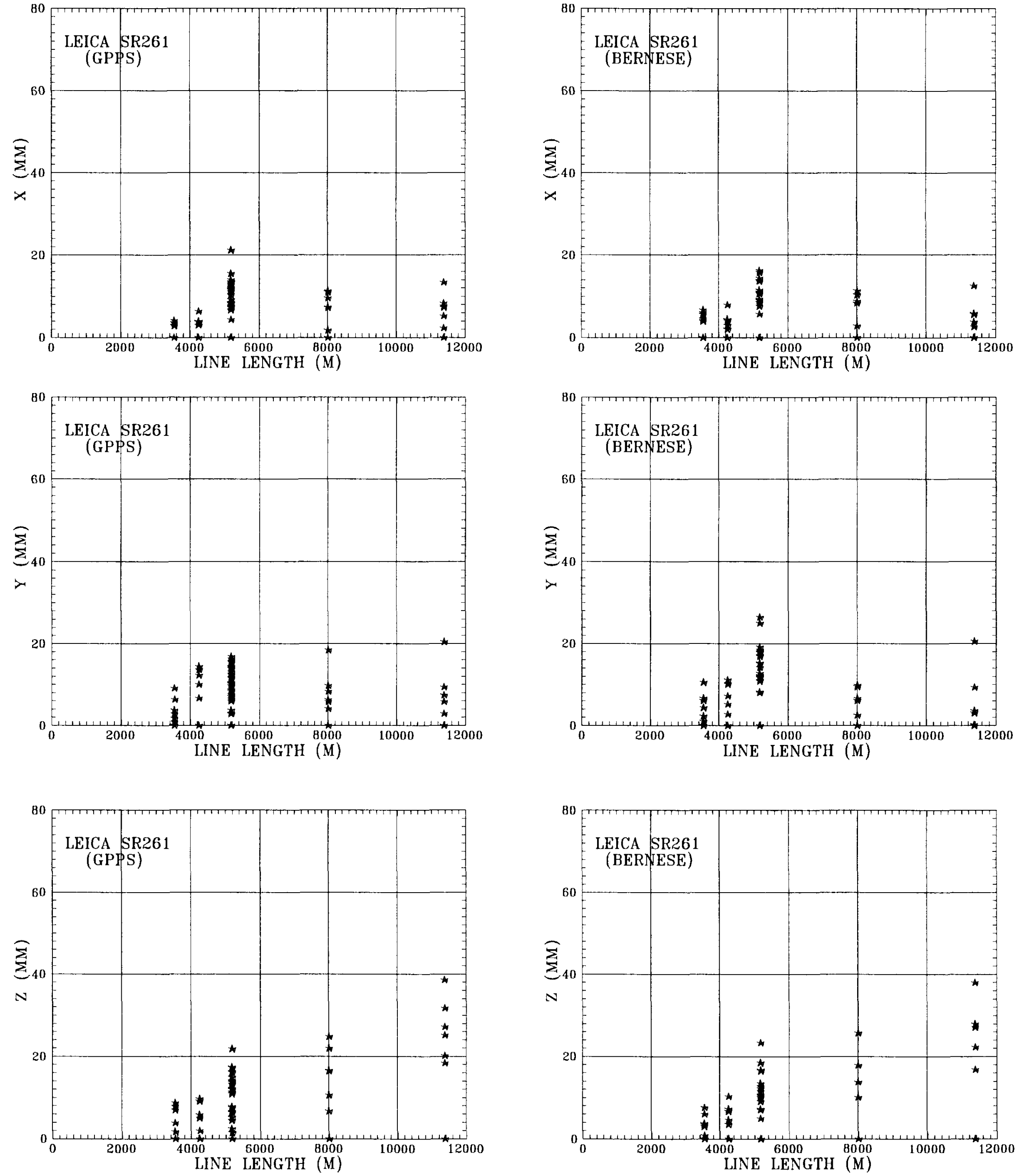

Figure 2. Comparison plots of repeatibilities of Leica SR261 one-hour data processed with GPPS and Bernese. These data were collected on different days than the data plotted in fig. 1.

Table 2A. Hourly Leica data processed with GPPS.

RECB

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
	-2412327.3576	-3760434.2365	4536722.3394	5176.0147
	-2412327.3545	-3760434.2348	4536722.3349	5176.0129
	-2412327.3537	-3760434.2283	4536722.3242	5176.0155
	-2412327.3553	-3760434.2279	4536722.3317	5176.0176
	-2412327.3528	-3760434.2292	4536722.3326	5176.0149
	-2412327.3543	-3760434.2268	4536722.3221	5176.0167
306	-2412327.3582	-3760434.2310	4536722.3255	5176.0174
	-2412327.3593	-3760434.2339	4536722.3286	5176.0168
	-2412327.3601	-3760434.2371	4536722.3297	5176.0155
	-2412327.3572	-3760434.2246	4536722.3192	5176.0201
	-2412327.3596	-3760434.2209	4536722.3298	5176.0252
	-2412327.3579	-3760434.2237	4536722.3243	5176.0216
	-2412327.3673	-3760434.2377	4536722.3337	5176.0210
	-2412327.3563	-3760434.2149	4536722.3218	5176.0256
307	-2412327.3565	-3760434.2273	4536722.3290	5176.0186
	-2412327.3601	-3760434.2324	4536722.3350	5176.0188
	-2412327.3616	-3760434.2363	4536722.3314	5176.0172
	-2412327.3589	-3760434.2353	4536722.3309	5176.0158
308	-2412327.3576	-3760434.2238	4536722.3228	5176.0212
	-2412327.3547	-3760434.2305	4536722.3296	5176.0154
	-2412327.3535	-3760434.2326	4536722.3252	5176.0127
	-2412327.3547	-3760434.2335	4536722.3229	5176.0129
	-2412327.3578	-3760434.2350	4536722.3339	5176.0154
	-2412327.3461	-3760434.2312	4536722.3339	5176.0086
	-2412327.3533	-3760434.2332	4536722.3240	5176.0121
	-2412327.3505	-3760434.2313	4536722.3177	5176.0105
AVG /SD	**-2412327.3564** ± .0040	**-3760434.2303** ± .0054	**4536722.3279** ± .0056	**5176.0167** ± .0040

Table 2B. Hourly Leica data processed with Bernese.

RECB

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
305	-2412327.3498	-3760434.2219	4536722.3088	5176.0151
	-2412327.3545	-3760434.2365	4536722.3322	5176.0122
	-2412327.3496	-3760434.2242	4536722.3252	5176.015
	-2412327.3514	-3760434.2208	4536722.3189	5176.0179
	-2412327.3464	-3760434.2182	4536722.3210	5176.0159
	-2412327.3491	-3760434.2217	4536722.3162	5176.0153
306	-2412327.3543	-3760434.2251	4536722.3192	5176.0160
	-2412327.3543	-3760434.2271	4536722.3203	5176.0160
	-2412327.3550	-3760434.2292	4536722.3195	5176.0155
	-2412327.3564	-3760434.2180	4536722.3138	5176.0231
	-2412327.3498	-3760434.2100	4536722.3193	5176.0235
	-2412327.3571	-3760434.2222	4536722.3173	5176.0213
307	-2412327.3550	-3760434.2227	4536722.3215	5176.0197
	-2412327.3568	-3760434.2284	4536722.3255	5176.0179
	-2412327.3564	-3760434.2350	4536722.3273	5176.0136
308	-2412327.3521	-3760434.2210	4536722.3192	5176.0183
	-2412327.3482	-3760434.2253	4536722.3179	5176.0126
	-2412327.3513	-3760434.2278	4536722.3158	5176.0132
	-2412327.3516	-3760434.2269	4536722.3223	5176.0146
	-2412327.3406	-3760434.2222	4536722.3223	5176.0090
	-2412327.3500	-3760434.2280	4536722.3215	5176.0125
AVG /SD	**-2412327.3519** ± .0040	**-3760434.2244** ± .0058	**4536722.3202** ± .0049	**5176.0162** ± .0037

Table 2C. Hourly SCA data processed with GPPS.

RECB

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
023	-2412327.2868	-3760434.1241	4536722.2094	5176.0187
	-2412327.2910	-3760434.1269	4536722.2121	5176.0204
	-2412327.2903	-3760434.1225	4536722.2097	5176.0225
	-2412327.2914	-3760434.1251	4536722.2136	5176.0220
	-2412327.2890	-3760434.1238	4536722.2096	5176.0206
	-2412327.2926	-3760434.1227	4536722.2090	5176.0241
024	-2412327.2908	-3760434.1249	4536722.2100	5176.0214
	-2412327.2904	-3760434.1265	4536722.2101	5176.0200
	-2412327.2926	-3760434.1150	4536722.2093	5176.0289
	-2412327.2898	-3760434.1246	4536722.2051	5176.0203
	-2412327.2912	-3760434.1263	4536722.2100	5176.0208
034	-2412327.2906	-3760434.1236	4536722.2101	5176.0221
	-2412327.2914	-3760434.1283	4536722.2082	5176.0196
	-2412327.2961	-3760434.1321	4536722.2125	5176.0212
	-2412327.2922	-3760434.1268	4536722.2086	5176.0211
	-2412327.2895	-3760434.1252	4536722.2051	5176.0198
AVG /SD	**-2412327.2910** ± .0020	**-3760434.1249** ± .0035	**4536722.2095** ± .0022	**5176.0215** ± .0024

Table 2D. Hourly SCA data processed with Bernese.

RECB

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
023	-2412327.2839	-3760434.1197	4536722.2024	5176.0187
	-2412327.2869	-3760434.1200	4536722.2041	5176.0209
	-2412327.2860	-3760434.1146	4536722.2012	5176.0234
	-2412327.2867	-3760434.1180	4536722.2021	5176.0218
	-2412327.2857	-3760434.1181	4536722.2016	5176.0209
024	-2412327.2872	-3760434.1175	4536722.2014	5176.0225
	-2412327.2865	-3760434.1197	4536722.2020	5176.0206
	-2412327.2894	-3760434.1099	4536722.2013	5176.0289
	-2412327.2857	-3760434.1182	4536722.1980	5176.0206
	-2412327.2879	-3760434.1213	4536722.2029	5176.0208
034	-2412327.2878	-3760434.1178	4536722.1972	5176.0224
	-2412327.2916	-3760434.1248	4536722.2063	5176.0220
	-2412327.2912	-3760434.1261	4536722.2016	5176.0202
	-2412327.2866	-3760434.1192	4536722.1977	5176.0206
	-2412327.2867	-3760434.1192	4536722.2012	5176.0210
AVG /SD	**-2412327.2873** ± .0021	**-3760434.1189** ± .0038	**4536722.2014** ± .0024	**5176.0217** ± .0023

Table 3A. Hourly Leica data processed with GPPS.

ENGL

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
306	-2401198.2537	-3767253.6615	4537052.2057	8003.2020
	-2401198.2609	-3767253.6673	4537052.2221	8003.1997
	-2401198.2554	-3767253.6656	4537052.2163	8003.2034
	-2401198.2647	-3767253.6677	4537052.2222	8003.1966
	-2401198.2633	-3767253.6712	4537052.2305	8003.2001
	-2401198.2611	-3767253.6698	4537052.2124	8003.1998
	-2401198.2650	-3767253.6799	4537052.2276	8003.2023
AVG /SD	**-2401198.2606** ±.0044	**-3767253.6690** ±.0057	**4537052.2195** ±.0087	**8003.2006** ±.0023

Table 3B. Hourly Leica data processed with Bernese.

ENGL

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
306	-2401198.2533	-3767253.6615	4537052.2046	8003.2023
	-2401198.2616	-3767253.6681	4537052.2224	8003.1996
	-2401198.2561	-3767253.6640	4537052.2184	8003.2022
	-2401198.2646	-3767253.6676	4537052.2224	8003.1967
	-2401198.2636	-3767253.6713	4537052.2303	8003.1999
	-2401198.2621	-3767253.6710	4537052.2147	8003.1996
AVG /SD	**-2401198.2602** ±.0045	**-3767253.6673** ±.0039	**4537052.2188** ±.0087	**8003.2001** ±.0021

Table 3C. Hourly SCA data processed with GPPS.

ENGL

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
025	-2401198.2558	-3767253.6631	4537052.2214	8003.2023
	-2401198.2548	-3767253.6599	4537052.2146	8003.2012
	-2401198.2555	-3767253.6611	4537052.2286	8003.2024
	-2401198.2579	-3767253.6664	4537052.2249	8003.2023
	-2401198.2592	-3767253.6635	4537052.2192	8003.1993
030	-2401198.2586	-3767253.6745	4537052.2484	8003.2076
	-2401198.2749	-3767253.6722	4537052.2404	8003.1913
	-2401198.2657	-3767253.6533	4537052.2134	8003.1856
	-2401198.2540	-3767253.6635	4537052.2464	8003.1884
	-2401198.2765	-3767253.6677	4537052.2176	8003.2065
033	-2401198.2552	-3767253.6568	4537052.2146	8003.1994
	-2401198.2521	-3767253.6567	4537052.2123	8003.2019
	-2401198.2558	-3767253.6567	4537052.2264	8003.2004
	-2401198.2578	-3767253.6631	4537052.2224	8003.2006
	-2401198.2545	-3767253.6568	4537052.2182	8003.2004
AVG /SD	**-2401198.2592** ±.0074	**-3767253.6624** ±.0060	**4537052.2246** ±.0117	**8003.1993** ±.0062

Table 3D. Hourly SCA data processed with Bernese

ENGL

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
025	-2401198.2546	-3767253.6624	4537052.2215	8003.2031
	-2401198.2554	-3767253.6615	4537052.2173	8003.2016
	-2401198.2552	-3767253.6610	4537052.2315	8003.2029
	-2401198.2601	-3767253.6690	4537052.2270	8003.2018
	-2401198.2584	-3767253.6630	4537052.2209	8003.2000
030	-2401198.2580	-3767253.6741	4537052.2478	8003.2079
	-2401198.2674	-3767253.6709	4537052.2357	8003.1969
	-2401198.2823	-3767253.6718	4537052.2190	8003.1825
	-2401198.2571	-3767253.6457	4537052.2279	8003.1890
	-2401198.2590	-3767253.6576	4537052.2271	8003.1976
033	-2401198.2571	-3767253.6576	4537052.2148	8003.2000
	-2401198.2536	-3767253.6583	4537052.2125	8003.2013
	-2401198.2557	-3767253.6555	4537052.2263	8003.1995
	-2401198.2571	-3767253.6626	4537052.2220	8003.2002
	-2401198.2546	-3767253.6576	4537052.2180	8003.2006
AVG /SD	**-2401198.2590** ±.0072	**-3767253.6619** ±.0073	**4537052.2246** ±.0090	**8003.1990** ±.0061

Table 4A. Hourly Leica data processed with GPPS.

VANC

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
305	-2414793.9115	-3755030.0027	4539832.4989	11371.4615
	-2414793.9196	-3755030.0137	4539832.5375	11371.4699
	-2414793.9062	-3755029.9933	4539832.5261	11371.4742
	-2414793.9086	-3755029.9991	4539832.5190	11371.4689
	-2414793.9138	-3755030.0007	4539832.5307	11371.4744
	-2414793.9145	-3755029.9991	4539832.5173	11371.4718
	-2414793.9135	-3755029.9962	4539832.5241	11371.4755
AVG /SD	**-2414793.9125** ±.0043	**-3755030.0007** ±.0065	**4539832.5219** ±.0123	**11371.4709** ±.0048

Table 4B. Hourly Leica data processed with Bernese

VANC

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
305	-2414793.9085	-3755029.9966	4539832.4905	11371.4619
	-2414793.9155	-3755030.0078	4539832.5286	11371.4693
	-2414793.9055	-3755029.9874	4539832.5176	11371.4728
	-2414793.9029	-3755029.9910	4539832.5074	11371.4682
	-2414793.9087	-3755029.9903	4539832.5184	11371.4755
	-2414793.9067	-3755029.9872	4539832.5129	11371.4750
AVG /SD	**-2414793.9080** ±.0043	**-3755029.9934** ±.0078	**4539832.5126** ±.0129	**11371.4705** ±.0051

Table 4C. Hourly SCA data processed with GPPS.

VANC

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
011	-2414793.9144	-3755029.9713	4539832.5524	11371.5038
	-2414793.9144	-3755029.9683	4539832.5436	11371.5033
	-2414793.9190	-3755029.9698	4539832.5504	11371.5069
	-2414793.9190	-3755029.9716	4539832.5388	11371.5019
	-2414793.9171	-3755029.9701	4539832.5514	11371.5059
012	-2414793.9342	-3755030.0064	4539832.5013	11371.4724
	-2414793.9371	-3755030.0037	4539832.5026	11371.4765
	-2414793.9348	-3755030.0027	4539832.4920	11371.4727
	-2414793.9376	-3755029.9993	4539832.5063	11371.4814
	-2414793.9407	-3755029.9999	4539832.5132	11371.4848
018	-2414793.9150	-3755030.0009	4539832.5232	11371.4725
	-2414793.9160	-3755029.9966	4539832.5272	11371.4776
	-2414793.9188	-3755029.9950	4539832.5241	11371.4887
	-2414793.9206	-3755030.0033	4539832.5317	11371.4795
	-2414793.9256	-3755029.9985	4539832.5497	11371.4765
031*	-2414793.9054	-3755029.9811	4539832.5280	11371.4835
	-2414793.9075	-3755029.9868	4539832.5118	11371.4753
	-2414793.9055	-3755029.9894	4539832.5080	11371.4711
	-2414793.9021	-3755029.9924	4539832.4907	11371.4614
	-2414793.9018	-3755029.9970	4539832.5138	11371.4650
032*	-2414793.9099	-3755029.9975	4539832.5240	11371.4724
	-2414793.9164	-3755030.0113	4539832.5324	11371.4683
	-2414793.9173	-3755029.9800	4539832.5288	11371.4914
	-2414793.9123	-3755029.9962	4539832.5170	11371.4726
	-2414793.9115	-3755029.9951	4539832.5183	11371.4734
AVG /SD	**-2414793.9182** ±.0112	**-3755029.9914** ±.0129	**4539832.5232** ±.0180	**11371.4816** ±.0134

* - SCA-12S using “M” model antennae.

Table 4D. Hourly SCA data processed with Bernese.

VANC

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
011	-2414793.9104	-3755029.9622	4539832.5421	11371.5053
	-2414793.9089	-3755029.9591	4539832.5320	11371.5036
	-2414793.9114	-3755029.9524	4539832.5345	11371.5109
	-2414793.9129	-3755029.9614	4539832.5305	11371.5036
	-2414793.9125	-3755029.9627	4539832.5418	11371.5060
012	-2414793.9292	-3755029.9982	4539832.4912	11371.4727
	-2414793.9325	-3755029.9968	4539832.4939	11371.4727
	-2414793.9307	-3755029.9929	4539832.4811	11371.4744
	-2414793.9317	-3755029.9902	4539832.4958	11371.4817
	-2414793.9353	-3755029.9932	4539832.5037	11371.4838
018	-2414793.9115	-3755029.9934	4539832.5131	11371.4731
	-2414793.9104	-3755029.9883	4539832.5168	11371.4775
	-2414793.9118	-3755029.9837	4539832.5112	11371.4800
	-2414793.9150	-3755029.9944	4539832.5204	11371.4766
031*	-2414793.8994	-3755029.9698	4539832.5146	11371.4836
	-2414793.9005	-3755029.9750	4539832.4977	11371.4759
	-2414793.8949	-3755029.9821	4539832.4800	11371.4619
	-2414793.8958	-3755029.9872	4539832.5006	11371.4649
032*	-2414793.9040	-3755029.9864	4539832.5180	11371.4734
	-2414793.9102	-3755030.0009	4539832.5196	11371.4687
	-2414793.9095	-3755029.9685	4539832.5130	11371.4908
	-2414793.9055	-3755029.9861	4539832.5043	11371.4725
	-2414793.9048	-3755029.9845	4539832.5043	11371.4733
AVG /SD	**-2414793.9126** ±.0117	**-3755029.9813** ±.0143	**4539832.5113** ±.0175	**11371.4821** ±.0143

* - SCA-12S using "M" model antennae.

Table 5A. Hourly Leica data processed with GPPS.

NSPK

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
307	-2404421.3450	-3765174.9034	4537070.1678	4246.5110
	-2404421.3457	-3765174.9026	4537070.1769	4246.5118
	-2404421.3459	-3765174.9012	4537070.1774	4246.5111
	-2404421.3484	-3765174.8957	4537070.1736	4246.5062
	-2404421.3420	-3765174.8890	4537070.1698	4246.5089
	-2404421.3457	-3765174.8990	4537070.1728	4246.5096
AVG /SD	**-2404421.3455** ±.0021	**-3765174.8985** ±.0054	**4537070.1731** ±.0038	**4246.5098** ±.0020

Table 5B. Hourly Leica data processed with Bernese

NSPK

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
307	-2404421.3462	-3765174.9024	4537070.1750	4246.5109
	-2404421.3441	-3765174.9025	4537070.1676	4246.5114
	-2404421.3451	-3765174.9034	4537070.1780	4246.5128
	-2404421.3465	-3765174.8951	4537070.1743	4246.5078
	-2404421.3501	-3765174.8976	4537070.1748	4246.5056
	-2404421.3421	-3765174.8923	4537070.1722	4246.5105
	-2404421.3462	-3765174.8995	4537070.1722	4246.5091
AVG /SD	**-2404421.3458** ±.0025	**-3765174.8990** ±.0042	**4537070.1733** ±.0033	**4246.5097** ±.0024

Table 6A. Hourly Leica data processed with GPPS.

VAR2

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
308	-2411293.7388	-3761756.7806	4536161.4144	3536.0590
	-2411293.7383	-3761756.7814	4536161.4213	3536.0579
	-2411293.7376	-3761756.7843	4536161.4161	3536.0559
	-2411293.7375	-3761756.7823	4536161.4222	3536.0567
	-2411293.7347	-3761756.7834	4536161.4231	3536.0537
	-2411293.7382	-3761756.7870	4536161.4183	3536.0549
	-2411293.7388	-3761756.7897	4536161.4222	3536.0538
AVG /SD	**-2411293.7377** ±.0014	**-3761756.7841** ±.0032	**4536161.4197** ±.0034	**3536.0560** ±.0020

Table 6B. Hourly Leica data processed with Bernese

VAR2

DAY	X (m)	Y (m)	Z (m)	LINE LENGTH (m)
308	-2414793.7331	-3761756.7760	4536161.4103	3536.0568
	-2414793.7341	-3761756.7717	4536161.4069	3536.0601
	-2414793.7345	-3761756.7778	4536161.4129	3536.0569
	-2414793.7325	-37617567727	4536161.4077	3536.0582
	-2414793.7328	-3761756.7784	4536161.4146	3536.0551
	-2414793.7285	-3761756.7740	4536161.4106	3536.0540
	-2414793.7352	-3761756.7822	4536161.4099	3536.0552
AVG /SD	**-2411293.7330** ±.0022	**-3761756.7761** ±.0037	**4536161.4104** ±.0027	**3536.0552** ±.0021

APPENDIX A

MANUFACTURER
SPECIFICATIONS

	Ashtech SCA-12S	**Leica SR261**
Tracking	12 channels - L1 (carrier phase - optional)	6 channels - L1 (carrier phase)
Size (WxHxD)	9.3 x 4.8 x 15.8 (cm)	20.1 x 9.9 x 5.3 (cm)
Weight	560 grams	821 grams
Operating Temperatures	-20 to +55 °C	-20 to +50 °C
Storage Temperature	-30 to +75 °C	-10 to +70 °C
Power consumption	4 watts	3.5 watts
Input voltage	5-16 VDC	12 VDC
Output	3 - RS232	3 - RS232
Antenna	External patch	Microstrip

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