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Test and Demonstration of the Wild GPS-System 200 Surveying System: June 1992

FGCS Report: FGCS-IG-92-2

June 1994

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TEST AND DEMONSTRATION OF THE WILD GPS-SYSTEM 200 SURVEYING SYSTEM: June 1992

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WILD GPS-SYSTEM 200 SURVEYING SYSTEM and ASSOCIATED PROCESSING SOFTWARE

Instrument Working Group
Federal Geodetic Control Subcommittee
June 1994

ABSTRACT

The Federal Geodetic Control Subcommittee (FGCS) tested and evaluated the WILD GPS-System 200 surveying system and associated receiver processing software, in June, 1992. The dual frequency receivers were tested in several independent operational tests: static, rapid static, reoccupation (pseudo-kinematic), and stop-and-go kinematic. The post-processing software, SKI, was employed to process data in the field using the predicted broadcast ephemerides. Results, presented in the form of repeat vectors and adjustment errors, are compared with FGCS geometric accuracy standards and specifications for GPS relative positioning. Baselines varied in length from 183 m to 108 km. Overall, the results from the use of the predicted ephemeris in the solutions indicate that the WILD GPS-System 200 Surveying System will yield accuracies that meet or exceed the vendor's specifications.

INTRODUCTION

In June 1992 the Federal Geodetic Control Subcommittee (FGCS) conducted a test and demonstration of the WILD GPS-System 200 surveying system, a dual-band (L_1 and L_2) receiver developed by Leica, Heerbrugg, Switzerland. This was the sixteenth in a series of tests by FGCS to evaluate the performance of Global Positioning System (GPS) geodetic satellite survey system and associated vector processing software.

TEST DESCRIPTION

The test and demonstration were conducted over a 5-day period beginning Monday, June 8, and ending Friday, June 12, 1992, on stations of the FGCS test network located in the vicinity of Washington, DC (Hothem and Fronczek 1983). Selective Availability (SA) was activated throughout the test period. Except on June 12th, Anti-Spoofing (AS) was not activated. The measured vectors ranged in lengths of: short from 183 to 1322 m, medium from 7 to 19 km, and long from 35 to 108 km. Figure 1 is a sketch of the general layout of the FGCS test network. Many closely spaced stations are located within the grounds of the National Institute of Standards and Technology in Gaithersburg, Maryland (Figure 2).

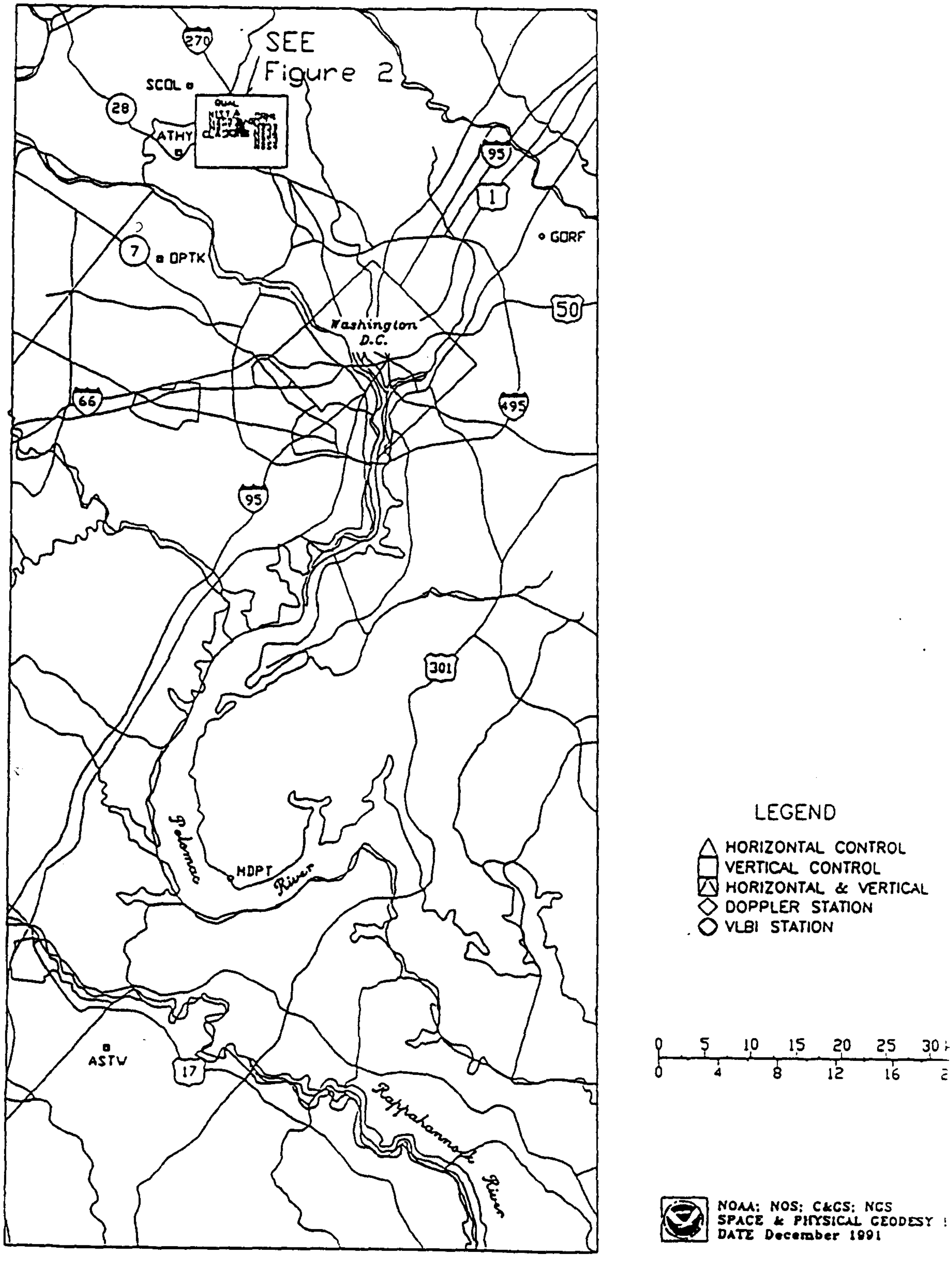

Figure 1. FGCS test network located in the vicinity of Washington, D.C.

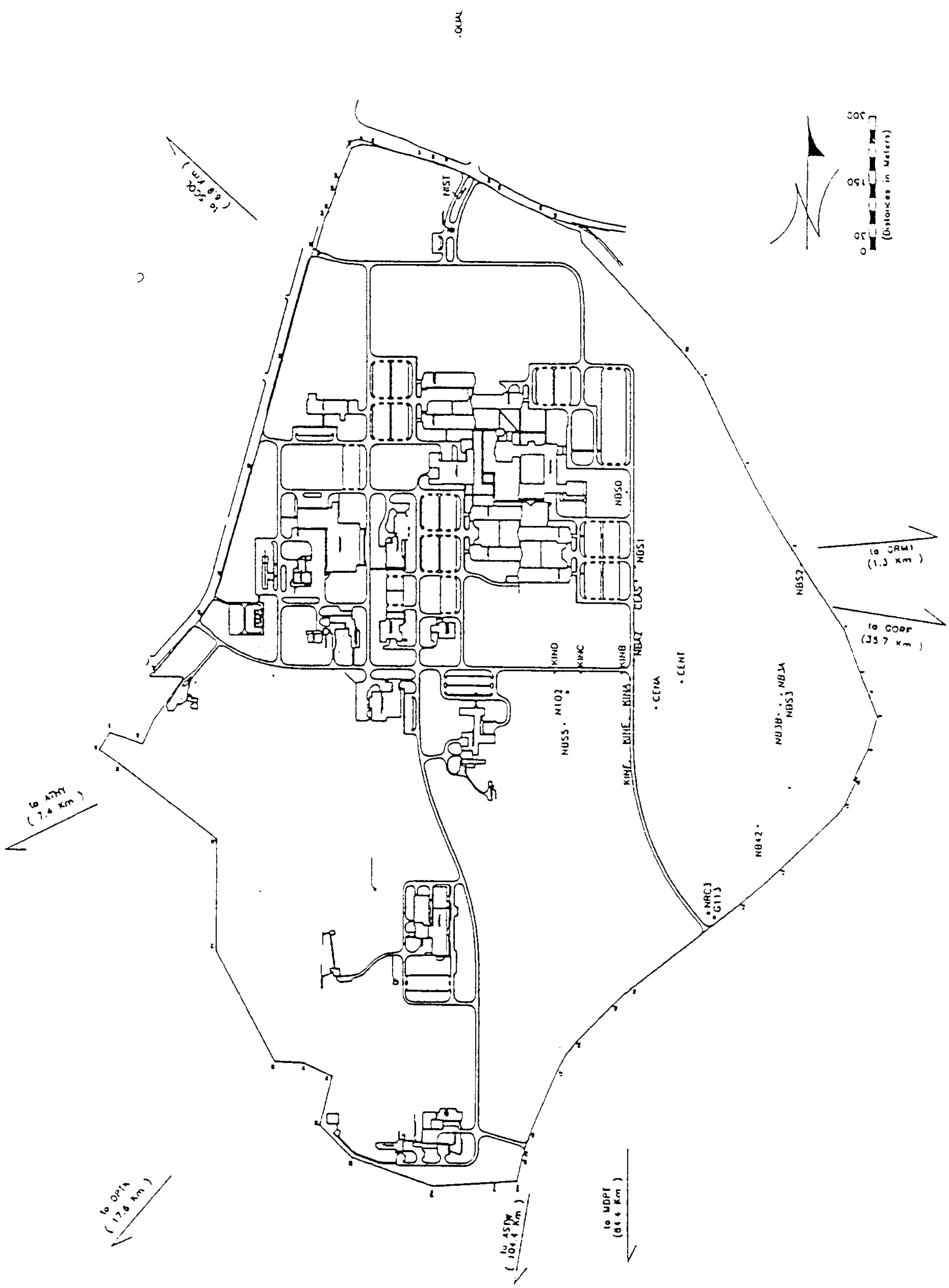

Figure 2. Portion of the FGCS test network near Gaithersburg, Maryland.

The WILD GPS-System 200, as configured for the test, independently tracks full-wavelength carrier phases on nine L_1 and nine L_2 fully independent satellite tracking channels. The modulation codes are coarse/acquisition (C/A) and P_2. The receivers tested have been designed to switch to a code-aided squaring mode from a P_2 demodulation mode in the event that AS is activated, using the unaffected C/A code to recover a high quality L_2 squared signal. When AS is activated, the carrier measurements on the L_2 are half-wavelength. The intent of the System 200 design is to provide this mode switching bi-directionally, to squaring mode and back again, for each individual satellite as AS is on or off. Because the activation of AS was sporadic on June 12th and the receivers could not be switched manually, it was not possible to test the receiver in its squaring mode. All results from this test are based on the default P-code recovery of L_2.

The versions for the hardware, firmware and software tested in June, 1992, are the CR233 version 1.03, SR299 version 1.22, and SKI processing software version 1.04.

The WILD GPS-System 200 consists of two parts: a controller (CR233, version 1.03) and a sensor (SR299, version 1.22). The controller, in effect, is a wand-shaped terminal. A battery-backed static ram card also known as a "flashcard" is plugged into the controller for logging data. The flashcard is interchangeable with other flashcards in the same manner one uses a floppy disk, but it is also an integral part of the controller, its presence being necessary for the controller to function. Optionally, the operator may select to log data onto an internal memory module. The sensor has an antenna mounted atop a housing which contains an INTEL based microprocessor for data acquisition. The advantage of placing the antenna atop the signal recovery electronics is to suppress interference and noise between the antenna and preamplifier. More information on the specifications of the System 200 hardware can be found in Appendix 1.

As of April, 1993, the following improvements are featured in the firmware and software (CR233 version 1.10, SR200 version 1.43, and SKI version 1.06):
- manually switching to a squaring tracking mode
- manually overriding the transmitted health status of a satellite
- and in the SKI software, adjustment of GPS baseline vectors

All data collected with the System 200 receiver were processed with the predicted broadcast satellite orbital coordinates. Data collected simultaneously with one or more other receivers are processed to determine relative positions ($\Delta X, \Delta Y, \Delta Z$) between occupied station points.

Various observational modes were tested that employ one or more stationary receivers, and one or more mobile or roving receivers. These modes included conventional static, rapid static, reoccupation, stop-and-go, and kinematic. Following is a brief description of each mode of observing.

Conventional static mode generally refers to the simultaneous collection of data at two or more stations for at least an hour. *Rapid static* observations are similar but of much shorter duration, often only a few minutes. One or more reference tracking stations may be occupied continuously, while one or more mobile receivers move from mark to mark in the general area. No phase tracking is necessary in traversing from one location to another. *Reoccupation* observations (also known as pseudo-kinematic) are similar to rapid static observing except the mobile receivers will reobserve at a site an hour or more later to take advantage of the changing satellite geometry. Each mobile observation is similar in duration to a rapid static observation. Table 1 summarizes the stations occupied and the observations attempted and achieved, for both reference trackers and rovers.

Table 1. Observations attempted and achieved

Station 4-char. identification	Date (Month/Day-of-Month/Year)							
	06/08/92	06/09/92	06/09/92	06/09/92	06/10/92	06/10/92	06/11/92	06/12/92
	Day of Year / Session							
	160A	161A	161B	161C	162A	162B	163A	164A
NBS0	S	S						
NBS1	S	S						
NBS3	S,FS,KS	S,FS	S	S,KS	S		S	
NBS5	S,FS	S,FS	S	S,FS,KS	S,FS	S	S	S
ORM1	S,FS	S,FS	S					
ATHY			S				S	
SCOL			S	S,FS	S,FS	S		
OPTK			S			S	S	
GORF						S	S	S
MDPT						S		S
ASTW						S		S
CAM1	RFS	RFS						
CENA	RFS,RKS	RFS		RFS				
GH3	RFS	RFS		RFS	RFS			
KINC	RFS,RKS	RFS		RKS	RFS			
NBS2	RFS	RFS		RFS	RFS			
NB42	RFS	RFS		RFS	RFS			
H113					RFS			
N102	RKS			RFS	RFS			
N104					RFS			
ROD1					RFS			
KINA	RKS			RKS				
KINF	RKS			RKS				
KINE	RKS			RKS				
KINB	RKS			RKS				
KIND	RKS			RKS				

S : Conventional Static station FS : Fast Static
KS : Stop and Go Kinematic reference tracker
RFS : Roving point for Fast-Static occupation
RKS : Roving point for Stop-and-Go occupation

Kinematic refers to the determination of the trajectory of some moving object. One or more "roving" receivers are operated simultaneously with one or more continuous trackers. After initializing the system by resolving integer ambiguities on fixed baselines, the rovers can move along any path with the restriction that phase lock on the satellites be maintained. By maintaining phase lock the ambiguities remain constant for the entire trajectory. More elaborate scenarios are possible where receivers periodically revisit points to ensure that either continuity in phase exists or is reestablished. *Stop-and-Go* is an application of the kinematic method. Processed solutions are not generated every epoch along a trajectory, however, but rather only at discrete points where the roving receiver stops.

Data were collected for each of the observing modes and processed with the software SKI (static-kinematic). Since it was impractical to establish a method for evaluating positions for each individual epoch along a kinematic trajectory, kinematic trajectories were not evaluated. Only a single receiver was used as a mobile receiver in the rapid static, reoccupation, kinematic, and stop-and-go tests. All modes were successfully tested as planned. Broadcast ephemerides were used to forecast satellite positions for the scheduling of observing sessions. The observation windows were modified, however, because of a malfunctioning satellite and because the receiver had no option for overriding the transmitted health status of a satellite. Data were acquired independently for each mode tested. There were two exceptions: (1) the reoccupation mode consisted of combining the data from two rapid static sessions for sessions 160A and 161A and (2) receivers used for conventional static testing were also used as the reference trackers for other tests.

Table 2 summarizes for each session the approximate starting and ending time in UTC (Coordinated Universal Time), number of stations occupied, the PRN (pseudorandom noise) code for the satellites tracked, number of satellites at beginning and end of each session, and maximum and minimum number of satellites observed during each session.

Table 2. Observation summary, WILD GPS-System 200 FGCS test survey

Session	Starting and ending time (UTC) [1]	Number of static stations	Number of rover stations	Satellites observed (PRN code)	Number of Satellites S/Max/Min/E
160A	20:50 - 22:50	5	12	2 12 13 14 15 16 18 20 24	5/6/4/5
161A	23:50 - 01:50	5	6	3 12 13 16 18 20 24	5/6/3/5
161B	08:00 - 11:00	6	-	12 14 15 20 21 23 25	6/8/3/5
161C	21:50 - 22:50	3	11	2 12 13 14 16 18 20 24	5/7/3/5
162A	23:50 - 01:50	3	8	3 12 13 16 18 20 24	6/6/6/6
162B	08:00 - 11:00	6	-	11 12 14 15 17 20 21 23 25	5/8/4/5
163A	08:00 - 11:00	4	-	11 12 14 15 17 20 21 23 25	5/8/3/5
164A	08:00 - 11:00	4	-	11 12 14 15 17 20 21 23 25	5/8/4/5
TOTALS		37	37		

[1] Subtract 4 hours to convert UTC to local time.

The status of the GPS satellite constellation, based on information available from the NAVSTAR GPS Information Center Bulletin Board on June 5, 1992, is summarized in Table 3. The accuracy for the predicted (broadcast) satellite orbital coordinate data used in the baseline solutions was estimated to be about 1 mm/km (1 ppm) at the 1-σ level.

Table 3. Status of GPS satellite constellation on June 5, 1992

	Block I satellites	Block II satellites
PRN Code	3 11 12 13	2 14 15 16 17 18 19 20 21 23 24 25 28
Plane-slot	C4 C3 A1 C1	B3 E1 D2 E3 D3 F3 A4 B2 E2 E4 D1 A2 C2
Clock	RB RB RB CS	CS CS CS CS CS CS CS CS CS CS CS RB CS

Plane: six planes, A through F; Slot: four slots in each plane; CS = cesium; RB = rubidium.

DATA PROCESSING

Partial processing had been completed by Leica at noon on Friday, June 12. This processing included the conversion of all data (except kinematic data) to Receiver INdependent EXchange (RINEX) version 2 format, and the processing of n-1 independent radial vectors. A full set of n*(n-1)/2 vectors and adjusted results were provided after the test. Preliminary results were provided for analysis and presentation at a public meeting held on Friday afternoon, June 12, 1992.

Leica's SKI software, version 1.04, was used to generate vector results. Compatible output files were generated by SKI for input to "GEOLAB" (GEOLAB, 1990), a 3-dimensional least squares adjustment program.

SKI processes data from multiple baselines using software chains in a linked architecture. This chained organization makes it possible to handle, as transparently as possible, diverse data streams, whether kinematic data is processed or conventional static data. Filenames and file structures are invisible to the user, making data management easy. The use of Microsoft WINDOWS with SKI application programs makes stepping through the processing steps via pulldown menus feel friendly. SKI runs under Microsoft Windows 3.0 or 3.1.

Two commonly available output file formats, compatible with public domain adjustment software developed and used by the National Geodetic Survey (NGS) for the inclusion of GPS data into the National Geodetic Reference System (NGRS) database, are the GFILE and BFILE (White and Love, 1991; FGCC, 1991). The GFILE, a file containing solved vectors for a GPS project, was not supported by SKI software. An independent piece of software had been invoked to reformat SKI output files into the standard GFILE format. The BFILE, a compendium of site-specific data for a GPS project, was constructed manually from observer log sheets. Code support within SKI for NGS file formats may be available in the future.

RINEX version 2 allows the processing of mixed receiver types. As the number of receivers on the market increases, the number of people co-observing with different receiver types is also increasing. Data in RINEX version 2 format were provided by Leica. Though an option to SKI is available to import RINEX version 2 data from mixed receivers, this was not tested.

SKI processing is automatic after setting some processing parameters, session sites, and reference stations. For the test the processing parameters were set to the following values, unless otherwise indicated:

Cut-off angle (degrees)	:	15
Tropospheric model	:	Hopfield
Ionospheric model	:	Standard
Ephemeris	:	Broadcast
Data used	:	Use Code and Phase
Frequency	:	L1 + L2
Limit to resolve ambiguities (km)	:	20
Kinematic chain computation rate (epoch)	:	1
a priori rms (mm)	:	31

The SKI software uses standard weather data with either the Hopfield or Saastamoinen model, to compensate for the effect of tropospheric propagation delays due to the troposphere. Surface weather measurements for temperature, humidity, and atmospheric pressure were not used in the solutions.

Independent data from one or both frequencies can be used in generating a vector solution. A distance limit determines if an attempt is made to resolve integer ambiguities using the Fast Ambiguity Resolution Approach (FARA). In brief, FARA searches a volume to determine integer ambiguities, imposing statistical tests and compatibility constraints. See Eckels (1992) for details on the FARA. If a baseline length is greater than this limit, an ionospheric-free combination solution is generated that is a float solution without fixed integers. An input field is available, germane to processing kinematic data only, that sets the solution interval, as a multiple number of recording epochs, for position solutions. Finally one must set a value for the anticipated RMS solution error. This parameter, the a priori RMS, is used in the FARA algorithm to constrain ambiguities and must be set carefully to ensure proper integer fixing and solution convergence for baseline lengths less than the distance limit. If the formal estimate of the solution's RMS error is greater than the a priori RMS then the fixed ambiguity solution is rejected and a float solution provided. For baselines less than 20 km in length the FARA algorithm had indicated it solved for all sets of integer ambiguities. The a priori RMS parameter, however, was varied from 10 to 31 mm. Guidelines are given in the SKI manual for setting the a priori RMS value.

A sample of the changes in propagation delay encountered in the test is shown in Figure 3. This is a double-difference residual plot made with an independent software package, OMNI, for the longest baseline of 108 km between stations ASTW and SCOL on day 164. The magnitude of residuals for double-difference solutions using single frequency data, either L_1 or L_2, is approximately one cycle peak to peak. A linear-combination solution (L_c) of the L_1 and L_2 observables provides a first order estimate for the atmospheric refraction correction. In Appendix 3 are tables containing results provided by Leica for conventional static, rabid static and stop-and-go solutions.

RESULTS

The quality of the solutions are evaluated by examining repeat vectors and residuals from a minimally-constrained least-squares adjustment. First, the components of repeat vectors are compared. This is given as the minimum and maximum component difference., Secondly, the residuals of the minimally constrained adjustments are compared with FGCS geometric accuracy standards (FGCS, 1988). These standards are summarized in Table 4. Lastly, the test results are evaluated with respect to the expected (a). L1 solution.

(b) L2 solution.

(c) Ionospheric-free linear combination.

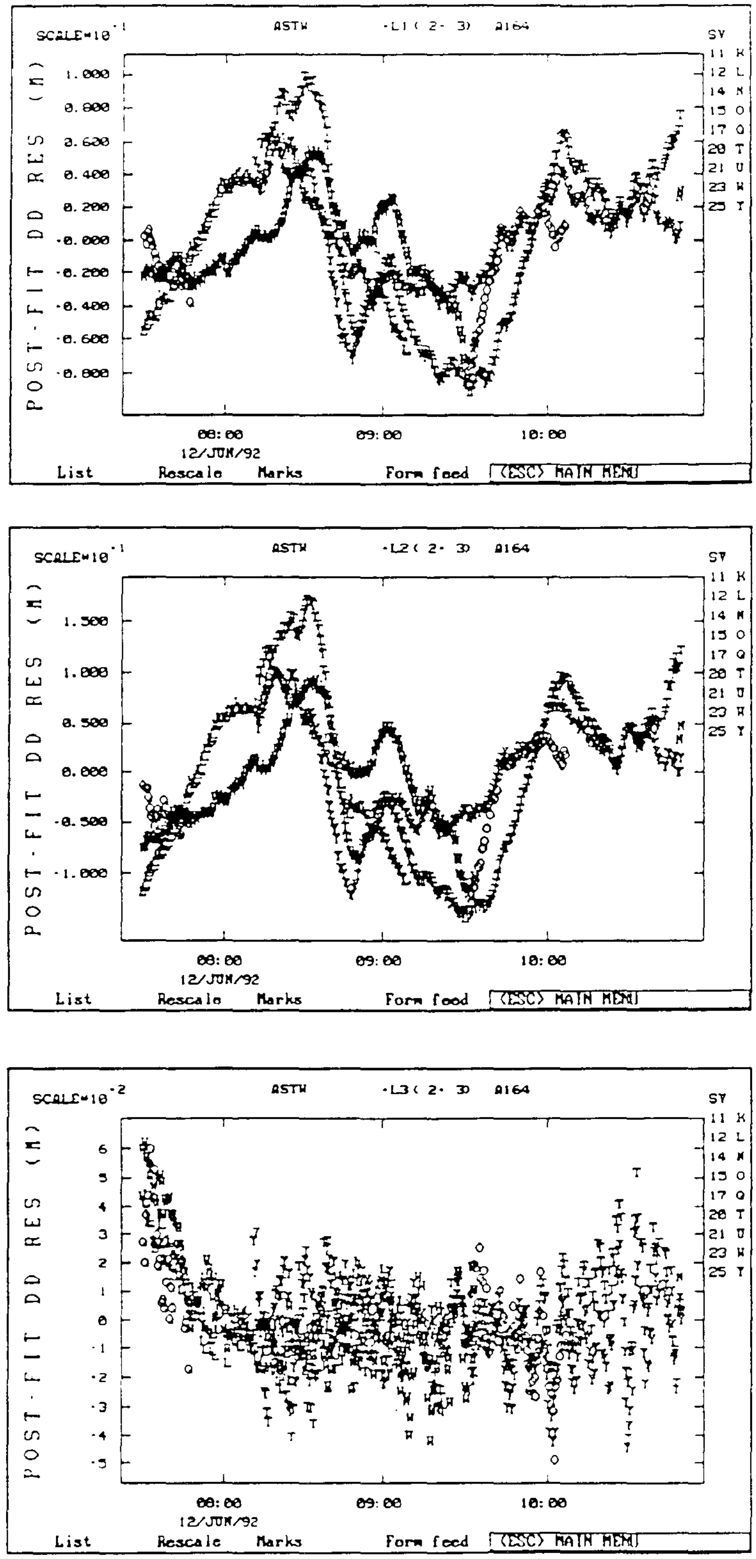

Figure 3. Double difference residuals for 108 km baseline using the OMNI software.

baseline precision as specified by the vendor. The baseline precision with SKI software for static, rapid static, reoccupation, and stop-and-go kinematic, are stated in the Leica technical specifications for the WILD GPS-System 200 receiver which can be found in Appendix 1.

Environmental factors may have influenced the test results. The results may have been affected by trees, buildings, nearby power transmission lines, and terrain at some of the FGCS test station sites. These test conditions are uniform from test to test, however, and frequently characterize GPS survey conditions. Thus, the FGCS stations and ambient conditions are useful in determining the effectiveness and capabilities of the GPS survey instruments and processing software.

Table 4. FGCS geometric accuracy standards

FGCS Accuracy Standards (2 sigma or 95% confidence limit) Reference: Version 5.0, May 11, 1988, reprinted with corrections August 1, 1989. (Where d is the length of the baseline)	
Order	Definition
1	$\pm\sqrt{[(10\ mm)^2 + (d \cdot 10\ mm/km)^2]}$
B	$\pm\sqrt{[(8\ mm)^2 + (d \cdot 1\ mm/km)^2]}$
A	$\pm\sqrt{[(5\ mm)^2 + (d \cdot 0.1\ mm/km)^2]}$
AA	$\pm\sqrt{[(3\ mm)^2 + (d \cdot 0.01\ mm/km)^2]}$

CONVENTIONAL STATIC

From a set of 24 baselines, repeated at least twice in 9 total sessions, the vector components were compared for each set (Table 5). Using all 72 observed baselines, a minimally-constrained adjustment yielded mean component (ΔX,ΔY,ΔZ) residuals of 0.012m, 0.022m, and 0.013m, respectively. Figure 4 graphically presents the component residuals and FGCS geometric accuracy standards.

Table 5. Variations in components of repeat baselines: conventional static observations

Vector Component	Minimum (m)	Maximum (m)
X	0.0008	0.0544
Y	0.0058	0.0687
Z	0.0003	0.0499

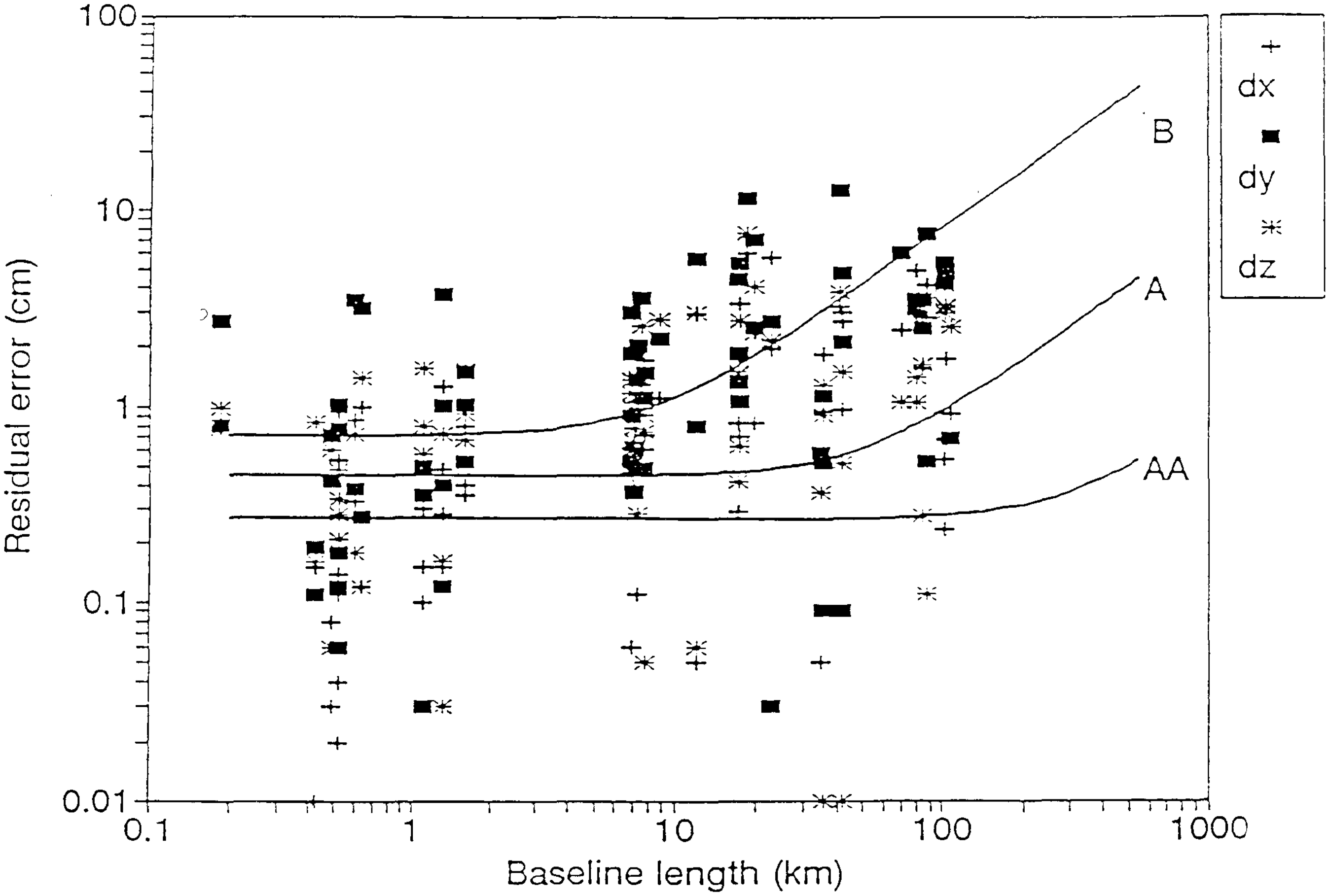

Figure 4. Residuals from least-squares adjustment: conventional static observations.

RAPID STATIC

Rapid static observations were taken at 14 stations in 4 sessions. A summary is given in Table 6. The analysis of vector components, independent of recording duration, for all 22 repeat rapid static vectors is found in Table 7.

Table 6. Summary of rapid static observations

Session	Number of Stations	Number of Reference Stations	Average Duration (min)	Satellites Start/Min/Max/End
160A	6	3	6	5/4/5/5
161A	6	3	6	4/4/5/5
161C	5	2	12	5/3/5/3
162A	8	2	12	5/4/5/5

For the 70 rapid static vectors observed, adjustment residuals are plotted as a function of baseline length in Figure 5. All rapid static vectors are less than 7.5 km in length. Superimposed on this are the FGCS accuracy standards for orders B, A, and AA. The mean residuals of cartesian components from the adjustment are 0.004m, 0.008m, and 0.007m, respectively.

Table 7. Variations in components of repeat baselines: rapid static observations

Vector Component	Minimum (m)	Maximum (m)
X	0.0006	0.0093
Y	0.0026	0.0280
Z	0.0008	0.0071

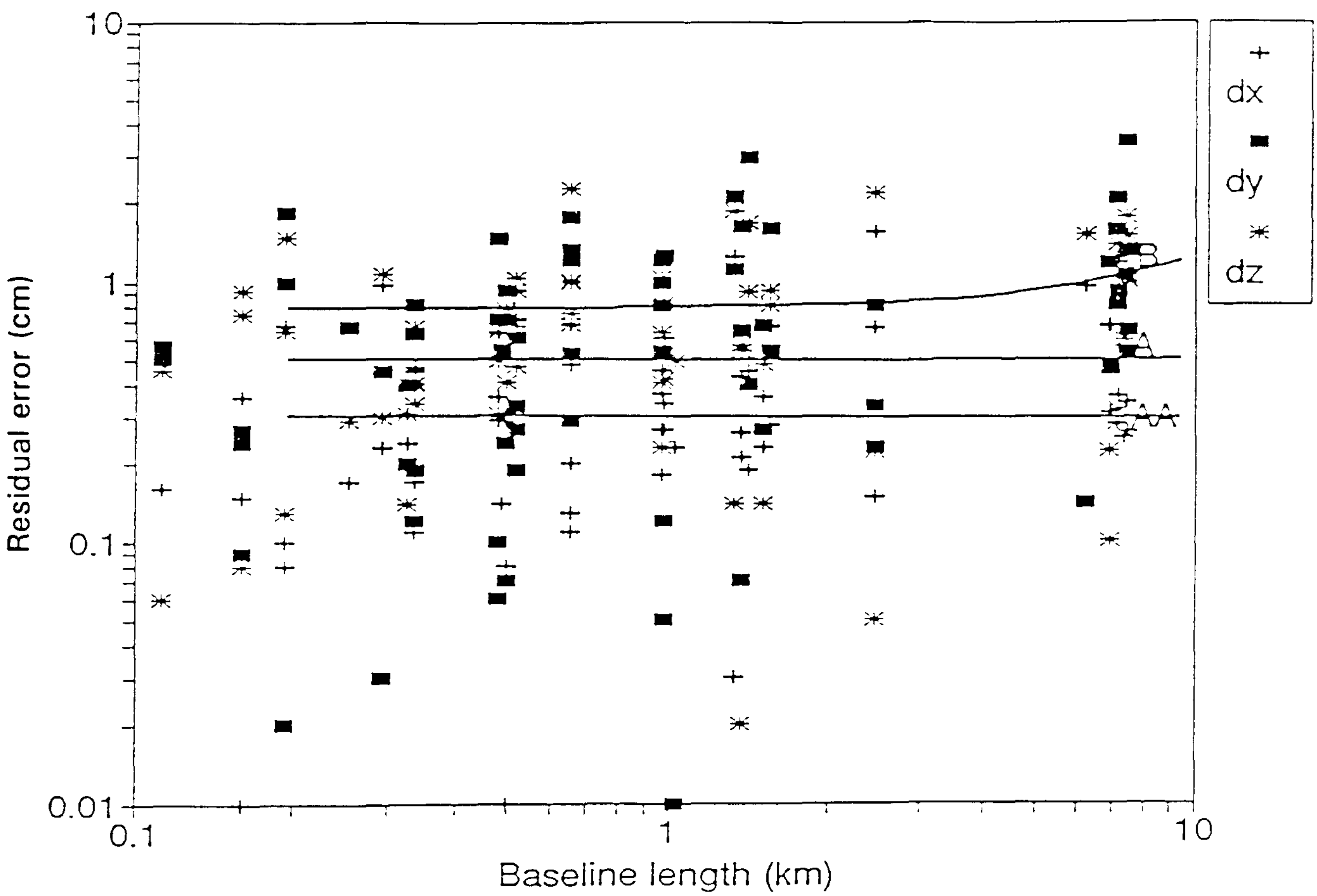

Figure 5. Residuals from least-squares adjustment: rapid static observations.

REOCCUPATION

Rapid static observations acquired approximately 3 hours apart at the same stations in sessions 160A and 161A were processed in the reoccupation mode. This resulted in 6 common baselines with lengths less than 2.5 km. The components were evaluated by comparing the residuals from the rapid static adjustment against the differences between the adjusted rapid static baseline and the reoccupation baseline solutions. A summary of these comparisons is given in Table 8. The reoccupation processing method produced slightly better results compared with the rapid static solutions.

Table 8. Comparison of baseline solutions: rapid static observations and reoccupation

	Minimum (m)	Mean (m)	Maximum (m)
Rapid static			
Res_x	0.000	0.005	0.015
Res_y	0.003	0.010	0.030
Res_z	0.001	0.009	0.022
Reoccupation			
Res_x	0.000	0.002	0.008
Res_y	0.002	0.010	0.026
Res_z	0.000	0.008	0.019

STOP-AND-GO KINEMATIC

Twelve stop-and-go vectors were repeated at least twice, their maximum length being approximately 0.55 km. The technique requires continuous phase lock on four or more satellites. The data acquisition interval is usually short, in this case 30-60 seconds. Table 9 shows that the minimum and maximum differences for the results from the repeat baselines.

Table 9. Variations in components of repeat baselines: stop-and-go observations

Vector Component	Minimum (m)	Maximum (m)
X	0.002	0.016
Y	0.000	0.010
Z	0.000	0.009

A least-squares minimally-constrained adjustment of 31 vectors from 10 stations, yielded mean residuals for cartesian vector components ($\Delta X, \Delta Y, \Delta Z$) of 0.003m, 0.003m, and 0.003m, respectively.

CONCLUSIONS

Based on the analysis of observations from the FGCS test survey, the FGCS geometric relative positioning accuracy standards are compatible with the performance of the System 200 for the various observation modes is shown in Table 10. The comments qualify the conditions upon which the classifications are based. To achieve orders A and AA, it is assumed that SKI software is capable of producing results from fixed orbital coordinate data solutions that are limited only by the accuracy of the orbit coordinate data.

Overall, the results from the predicted ephemeris solutions indicate that the WILD GPS-System 200 survey system will produce accurate results that meet or exceed the vendor's specifications. (See Appendix 2).

In conclusion, analysis of the results from the FGCS test survey conducted in June 1992 on the WILD GPS-System 200 surveying system, collected with four or more satellites in an acceptable geometric configuration, processed with double-difference software using orbital coordinate data accurate to 2 mm/km (2 ppm) or better, will yield accuracies that should meet requirements for most geodetic surveying needs.

Table 10. FGCS accuracy standards achieved for tested survey modes

Observation Type	Standard Achieved (1) (2)	Maximum Baseline Length (km)	Observation Duration (min)
Conventional Static	B	108	120-180
Rapid static	B	7.5	6-12
Reoccupation	B	2.5	6
Stop-and-Go kinematic	B	0.55	0.5-1

(1) Results from data collected when AS is not activated.
(2) Solutions employ L_1 and L_2 data from ionospherically free fixed integers for baselines less than 20 km and non-fixed integers for baselines greater than 20 km.

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APPENDIX 1

WILD GPS-System 200 Surveying System

Components:

1. ***GPS Sensor WILD SR299 with built-in antenna***
2. ***GPS Sensor WILD SR299E with external antenna***
3. ***GPS Controller WILD CR233***
4. ***SKI Static-Kinematic Software***
5. ***SPCS Sensor PC-Control Software***

?S Sensors WILD SR299 and WILD SR299E

Satellite Reception	Dual frequency
Receiver channels:	9 L1 continuous tracking
	9 L2 continuous tracking
L1 carrier tracking:	Reconstructed carrier phase via C/A code
L2 carrier tracking:	Reconstructed carrier phase via P code or using Magnavox proprietary code-aided squaring
L2 carrier tracking:	Switches automatically to code-aided squaring when P code encrypted
Code measurements on L1:	Carrier-phase smoothed C/A code measurements
Code measurements on L2:	Carrier-phase smoothed P code measurements
Code measurements on L2 when P code encrypted:	Carrier-phase smoothed code measurements available on L2 even when P code encrypted
Satellites tracked:	Up to 9 simultaneously on L1 and L2
Time to first phase measurement after switching on:	Typically less than 60 seconds
Data collection interval:	Selectable 1 to 60 seconds, via Controller
Cut-off angle:	Selectable via Controller
Satellite health and tracking criteria:	Automatically acquired, but with user override capability via Controller
Time-mark (pps) output:	Optional
Accuracy of pps output:	100 nsec (3 sigma, without SA)
Selectability of pps output:	Selectable from 1 to 20 seconds, via Controller

GPS Sensor WILD SR299 with built-in antenna

Antenna type:	Microstrip L1/L2 antenna with groundplane, built into Sensor
Mounting:	Tripod with tribrach and carrier.
	Ranging pole and Quickstand
Height of phase center:	
Tripod mounted:	Measured with height hook
Ranging pole/Quickstand:	Fixed heights
Weight (SR299 + adapter):	2.3 kg (5.0 lb)

GPS Sensor WILD SR299E with WILD AT202 External Antenna

GPS Sensor WILD SR299E	Receiver only
Weight (SR299E only):	2.0 kg (4.4 lb)

WILD AT202 External Antenna for SR299E

Antenna type:	Microstrip L1/L2 antenna with groundplane
Standard cables SR299E to AT202:	2.8 m and 10 m
Optional cable SR299E to AT202:	30 m
Optional 30 cm groundplane:	Detachable
Mounting:	Tripod with tribrach and carrier.
	Ranging pole and Quickstand
Height of phase center:	
Tripod mounted:	Measured with height hook
Ranging pole/Quickstand:	Fixed heights
Weight (AT202 + adapter):	0.6 kg (1.3 lb)

Code and Phase Measurements

Carrier-phase measurement accuracy

L1 frequency:	0.2 mm (rms)
L2 frequency:	0.2 mm (rms)

rential phase
nal baseline accuracy
ifferential phase

in static mode:	5 mm + 1 ppm (rms)

Code-measurement accuracy

C/A code:	45 cm (rms)
P code:	20 cm (rms)
Code on L2 when P-code encrypted:	25 cm (rms)

Differential code

Nominal baseline accuracy for differential code on L2 with or without P-code:	about 50 cm to 1 m (rms)

Baseline Precision with SKI Software (post-processing)

Differential phase	Baseline rms (root mean square)
Static	5 mm + 1 ppm
Rapid static	5 to 10 mm + 1 ppm
Reoccupation	5 to 10 mm + 1 ppm
Stop and Go	10 to 20 mm + 1 ppm
Kinematic	10 to 20 mm + 1 ppm

Differential code	Baseline rms (root mean square)
Static	50 cm
Kinematic	about 50 cm to 1 m

Note on baseline precision

line precision is dependent upon various factors including the number of ites tracked, constellation geometry, observation time, ephemeris racy, ionospheric disturbance, and resolved ambiguities.

Single-Point Position Accuracy with SKI Software

Single-point position 3D:	1 m to 5 m for each coordinate provided that observation time is sufficient to reduce influence of Selective Availability (SA)

Navigation Position Accuracy in Controller

Navigation position 3D:	15 m rms for each coordinate

Note: Navigation position accuracy is subject to degradation by DoD Selective Availability (SA) policy. DoD policy is that there is 95% guarantee of 100 m accuracy with SA.

Observation Times for GPS Baselines

Observation times cannot be defined exactly. Observation times depend upon baseline length, number of satellites, satellite geometry (GDOP), ionospheric conditions, expected accuracy etc. The following provide only a guide:

Differential phase:	With at least 4 satellites, GDOP ≤ 8, good conditions
Rapid Static:	Typically 5 minutes for up to 5 km Typically 10 minutes for 5 km to 10 km
op and Go:	Typically 2 epochs per point
matic:	1 epoch
ferential code:	With at least 4 satellites, GDOP ≤ 8, good conditions
Static:	Typically 0.5 to 3 minutes
Kinematic:	1 epoch

GPS Controller WILD CR233

Function:	Controls GPS Sensor WILD SR299 or GPS Sensor WILD SR299E Steers survey operation Logs data
Display:	Liquid-crystal display 8 lines of 40 characters Can be illuminated
Keyboard:	Full alphanumeric plus personal computer functions. All functions and alphanumeric input via single-key entries. No double-function or treble-function keys.
User interface:	Easy-to-follow menus
Displayed information:	Satellite status / satellite health Satellite-tracking information Azimuth, elevation, signal-to-noise ratio etc. Data-logging information Receiver information Point numbers Attributes Loss of lock information Stop and Go information Real-time Navigation position Latitude, longitude, ellipsoidal height WGS84 datum GDOP / PDOP Local time/GPS time/time zone Real-time Navigation Waypoints, course, bearing, distance, speed
Observation types supported:	Static, Rapid Static, Reoccupation Stop and Go, Kinematic, Navigation
Start sequence:	Manual or automatic
Automatic wake up:	Multiple timer missions with wake up times and duration
Programable:	User programable missions, configuration, start up sequence etc
Stop and Go indicator:	Informs operator when sufficient measurements have been taken
Point id and height entry:	16-character alphanumeric point identifier plus height and antenna offset
Attributes:	Free-form attribute and 3 attribute files
Free-form attribute:	4 lines of 40 characters
3 attribute files:	Generated on PC, and transferred to Controller Accessed by pull-down menus Up to 255 attributes per file Each attribute: 40 characters
Weight without battery:	1.0 kg (2.2 lb)
Plug-in battery:	0.2 kg (0.4 lb)

Data logging via Controller

Plug-in memory cards:	512 KB, 1 MB, 2 MB
Optional internal memory:	1 MB

Capacity	5 sats L1/L2 at 15 sec rec rate	5 sats L1/L2 at 30 sec rec rate	5 sats L1/L2 at 60 sec rec rate
512 KB	about 9 hours	about 18 hours	about 36 hours
1 MB	about 18 hours	about 36 hours	about 72 hours
2 MB	about 36 hours	about 72 hours	about 144 hours

Input / Output

I/O:	RS-232 and LAN capability

Power Requirements (Sensor and Controller)

Power consumption:

Sensor only:	maximum 9 Watts
Sensor plus Controller:	maximum 12 Watts
Supply voltage:	Nominal 12V DC
Recommended battery:	WILD GEB 71, 12V 7Ah NiCd, for up to about 5 to 6 hours continuous operation at 20°C
Can also be used:	WILD GEB70, 12V 2Ah NiCd, for up to about 1.5 hours continuous operation at 20°C
	Or any other suitable 12V power supply

Environmental Specifications

Temperature:	Operation	Storage
WILD SR299 Sensor:	-20°C to +55°C	-40°C to +70°C
WILD CR233 Controller:	-20°C to +50°C	-40°C to +70°C
Plug-in memory cards:	-10°C to +50°C	-40°C to +70°C
Internal memory 1MB (optional):	-20°C to +50°C	-40°C to +70°C
WILD SR299E Sensor:	-20°C to +55°C	-40°C to +70°C
WILD AT202 External Antenna:	-40°C to +75°C	-40°C to +75°C
Humidity:	Up to 95% non-condensing	
Weather:	Withstand rain, snow, dust, sand	

Separation Distance Sensor to Controller

Standard survey applications:

With standard cables:	2.8 m
With optional 10 m extension cable:	12.8 m

Special applications:

With 30m extension cables: Up to 150 m
Communication cable only,
power needed at both Sensor and Controller

Separation Distance WILD SR299E to WILD AT202 External Antenna

With standard cables:	2.8 m and 10 m
With optional cable:	30 m

Transport Case for Sensor and Controller

The equipment is delivered in a sturdy, waterproof transport case. The case has place for the Controller, Sensor, battery, height hook, cables, memory cards, tribrach and carrier.

Transport Case for External Antenna

The WILD AT202 External Antenna is delivered in a separate case. The case has place for the external antenna, cables, and optional groundplane.

SKI Static Kinematic Post-Processing Software

For accurate, fast and efficient production work

Major Components

System configuration:	Configure to user requirements
Planning component:	Includes: Satellite visibility PDOP and GDOP, Azimuth and elevation Graphical and tabular forms Sky plots etc.
Data management:	Full data-base system. User not be concerned with file handling etc. Full project management.
Import of data:	Data transfer from Controller, from stand-alone reader, and from back-up disks. Data back-up in System 200 format and RINEX format.
Data processing:	Graphical interface facilitates selection of baselines and processing parameters etc. Data processing fast and fully automatic. Multi-baseline batch processing. User not concerned with data screening, outlier detection, cycle-slip fixing etc. Software handles differential phase and differential code, and all GPS survey modes: Static Rapid Static Reoccupation Stop and Go Kinematic Single-Point Position No restriction to number of baselines.
View and Edit:	Graphical display of observed points, baselines, stop and go chains, and kinematic chains. Comprehensive view and edit facility.
Network Adjustment: (optional)	Least-squares adjustment of networks of GPS baselines. Free or constrained adjustment. Output: adjusted coordinates and related statistical information.
Datum and Map: (optional)	Comprehensive map projection, ellipsoid, and data transformation package. Permits the input and output of coordinates, and defining of ellipsoids and map projections. Converts Cartesian to Geodetic coordinates and vice versa. Also conversion to grid coordinates on a defined map projection and vice versa. Two transformation approaches: i) Classical 7-parameter transformation between 2 Cartesian coordinate systems ii) Direct transformation from WGS84 to grid coordinates without knowledge of projection, spheroid, geoid.
RINEX Import (optional):	Import of data in RINEX format from non-Wild receivers.

Minimum PC Configuration for SKI software

Note that SKI software runs under Microsoft® Windows™ 3.0 or 3.1.

Minimum configuration SKI nced configuration ferable):	IBM 386 or compatible Math Co-processor 4 MB RAM or more Asynchronous communication adapter Parallel port (needed for software-protection device) 30 MB – 60 MB hard disk 1.2 MB 5.25" floppy disk drive or 1.4 MB 3.5" drive VGA color monitor DOS 3.0 or higher Mouse installed Microsoft Windows Version 3.0 or 3.1

SPCS Sensor PC-Control Software
For controlling Sensor from a PC

PC with SPCS software functions as Controller
Controls Sensor, steers survey operation, logs data
Display, control and operation almost exactly as with CR233 Controller
Data logging on hard disk
Capacity depends largely on disk
Ideal for permanent reference stations and certain kinematic applications

Minimum PC Configuration for SPCS software

Minimum PC configuration for SPCS software (enhanced configuration is preferable):	IBM 286 or compatible Math Co-processor 640 KB RAM Asynchronous communication adapter Parallel port (needed for software-protection device) 10MB hard disk 1.2MB 5.25" floppy disk drive or 720 KB 3.5" drive EGA or VGA color or monochrome monitor DOS 3.0 or higher

G1 926e – III.93

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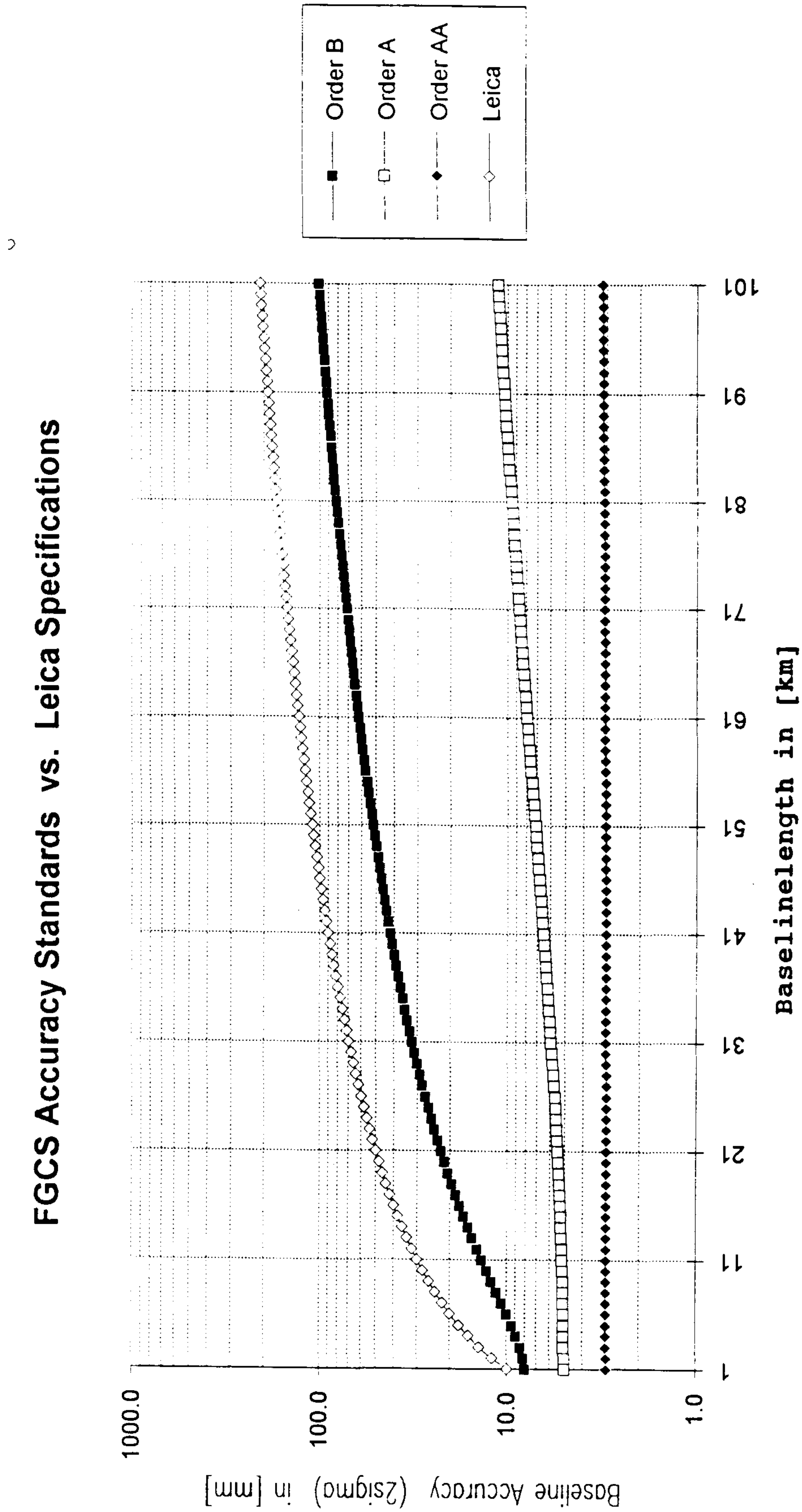
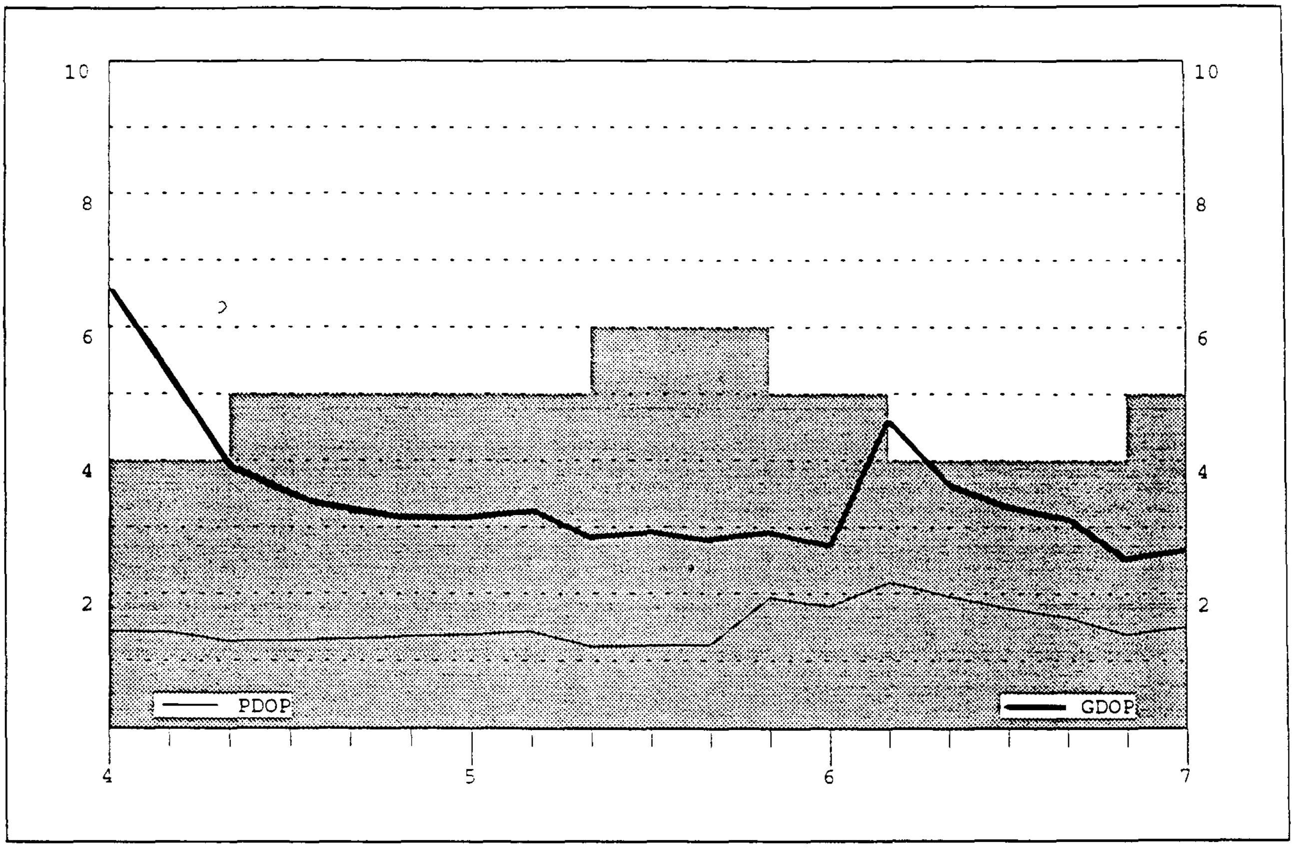
APPENDIX 2

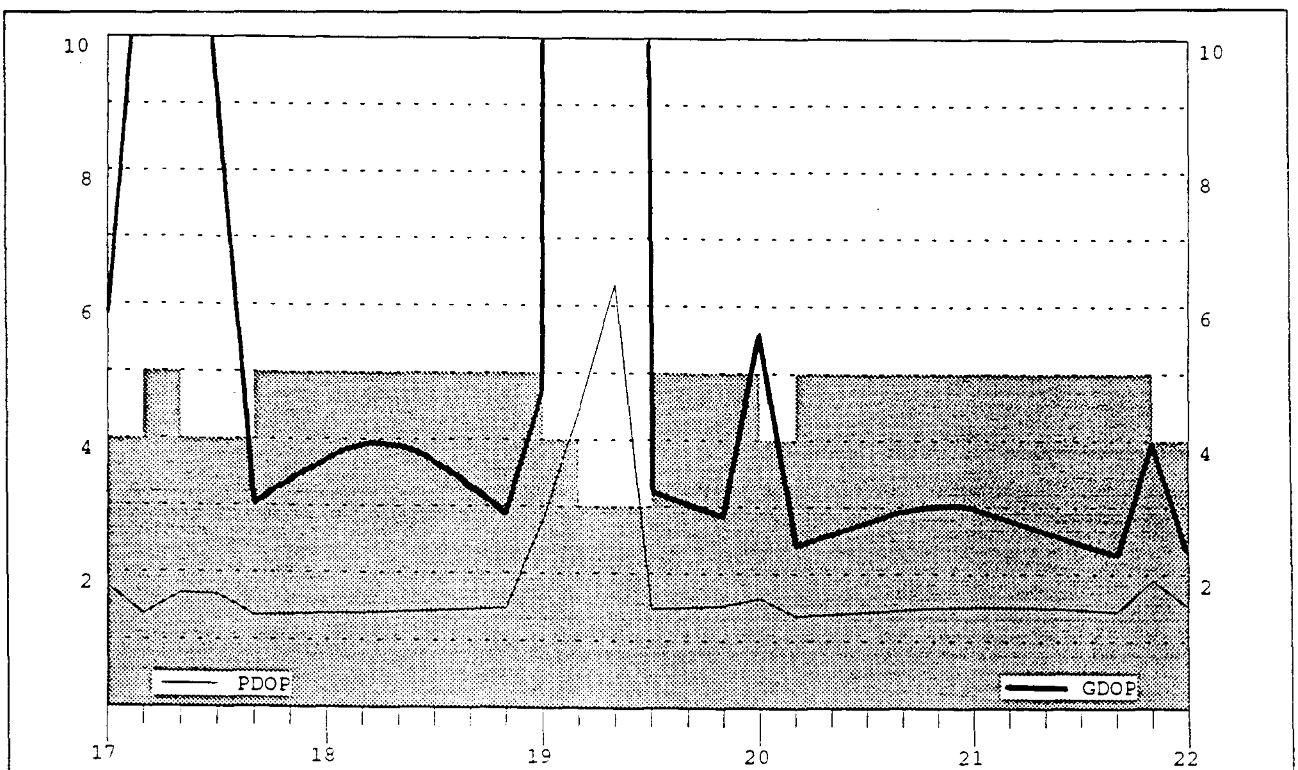
FGCS Geometric Accuracy Standards vs. Leica Specifications


FGCS Accuracy Standards vs. Leica Specifications
Order B
Order A
Order AA
Leica
Baseline Accuracy (2sigma) in [mm]
1000.0
100.0
10.0
1.0
Baselinelength in [km]
1
11
21
31
41
51
61
71
81
91
101

APPENDIX 3

Figures and Tables Provided by Leica, Inc.





Satellite coverage for Monday, 08.06.1992
The plots show the three windows used

Site	Session	X (m)	Y (m)	Z (m)	Reference Site	Slope Distance (m)
CAM1	1	1095998.0181	-4832100.3506	4002927.5361	ORM1	2471.0708
	2	.0093	.3391	.5598	ORM1	.0584
	2	.0013	.3496	.5582	ORM1	.0704
CENA	1	1096529.8913	-4831407.8623	4003621.7561	ORM1	1410.5409
	2	.8888	.8286	.7487	ORM1	.5296
	3	.8989	.8183	.7252	SCOL	7072.1130
G113	1	1096699.5926	-4831625.1758	4003304.6903	ORM1	1557.3743
	2	.5831	.1653	.6892	ORM1	.3746
	3	.5954	.1256	.6600	SCOL	7420.2917
	4	.5822	.1651	.6828	SCOL	.2782
KINC	1	1096351.3866	-4831373.6139	4003719.0582	ORM1	1509.2847
	2	.3806	.6044	.0550	ORM1	.2868
	4	.3773	.6228	.0517	SCOL	6866.2103
NBS2	1	1096785.6216	-4831107.8632	4003921.2178	ORM1	967.1770
	2	.6299	.8605	.2325	ORM1	.1649
	3	.6283	.8607	.2196	SCOL	7096.6205
	4	.6382	.8359	.2059	SCOL	.6311
NBS4/2	1	1096840.7832	-4831493.6056	4003430.0147	ORM1	1327.2765
	2	.7712	.5734	29.9978	ORM1	.2747
	3	.7675	.5688	.9756	SCOL	7447.0812
	4	.7567	.5764	.9815	SCOL	.0708

Rapid Static: Comparison of coordinates for points occupied at least twice.
FGCS Test: WILD GPS - System 200, 08.06-12.06.1992

Site	Session	dX (m)	dY (m)	dZ (m)	Slope Distance (m)
KIND	1	-547.1002	-72.8260	55.8914	554.7487
	2	.1158	.8089	.8877	.7615
	4A	.1047	.8305	.8909	.7537
	4B	.0981	.8262	.8867	.7462
	Spread	.0177	.0216	.0047	.0153
	Rms	± 7.9 mm	± 9.6 mm	± 2.3 mm	± 6.7 mm
KINC	1	-488.9255	-60.3362	57.9188	496.0274
	2	.9370	.3159	.9131	.0356
	4A	.9211	.3508	.9181	.0248
	4B	.9248	.3345	.9078	.0252
	Spread	.0159	.0349	.0110	.0108
	Rms	± 6.9 mm	± 14.3 mm	± 5.1 mm	± 5.0 mm
KINB	1	-401.6279	-40.4277	57.9552	407.7967
	2	.6412	.4112	.9384	.8058
	4A	.6339	.4306	.9535	.8027
	4B	.6326	.4302	.9498	.8008
	Spread	.0133	.0194	.0168	.0091
	Rms	± 5.5 mm	± 9.2 mm	± 7.6 mm	± 3.8 mm
KINA	1	-381.5593	-44.0484	47.1603	386.9778
	2	.5614	.0255	.1528	.9764
	4A	.5626	.0518	.1559	.9810
	4B	.5656	.0496	.1490	.9828
	Spread	.0063	.0263	.0113	.0049
	Rms	± 2.6 mm	± 12.3 mm	± 4.8 mm	± 2.9 mm
KINE	1	-368.6302	-96.2810	-22.5911	381.6656
	2	.6253	.2684	.5894	.6576
	4A	.6276	.2834	.5886	.6635
	4B	.6263	.2913	.5895	.6643
	Spread	.0049	.0229	.0025	.0080
	Rms	± 2.1 mm	± 9.5 mm	± 1.0 mm	± 3.5 mm
KINF	1	-354.1131	-154.4092	-99.7970	398.9959
	2	.0952	.4038	.8058	.9801
	4	.0909	.4237	.7931	.9808
	Spread	.0222	.0145	.0127	.0158
	Rms	± 11.8 mm	± 10.3 mm	± 6.5 mm	± 8.9 mm

Stop and go Surveying: Coordinate differences and length of spatial vectors relative to the reference site NBS3
FGCS Test: WILD GPS - System 200, 08.06-12.06.1992