technical note technical

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Differential GPS Terminal Area Test Results

L. Frank Persello

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16. Abstract

This report describes flight tests conducted by the Federal Aviation Administration (FAA) Technical Center to examine the performance of the Differential Global Positioning System (DGPS) in the Terminal Area. The tests employed a Convair 580 (CV-580) and a pair of Motorola Eagle Mini Rangers.

With the advent of a maturing Global Positioning System (GPS) constellation, the FAA is assuming a more intensive stance in addressing the many questions/problems associated with GPS. These DGPS tests investigated the obtainable accuracy under static and dynamic conditions. The static tests employed survey points as a base-line. The dynamic tests incorporated Terminal Area flight profiles and nonprecision approaches using a laser tracker as a base line. The accuracy performance of DGPS showed an order of magnitude improvement in the static environment and a 4-5 fold improvement in the dynamic environment over stand alone GPS. The DGPS tests were conducted in an effort to build an FAA DGPS data base to aid in addressing GPS questions/problems.

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EXECUTIVE SUMMARY

This technical note describes flight tests conducted by the Federal Aviation Administration (FAA) Technical Center to investigate the Global Positioning System (GPS) in the Differential (DGPS) mode of operation.

The objective of these tests was to examine the obtainable accuracy and general performance characteristics of DGPS in the Terminal Area.

The GPS receivers used in these tests, the Motorola Eagle Mini Rangers, were first tested in a lab environment until satisfactory performance was observed. A reference station was installed on the roof of building 301 and a user unit was configured in an FAA test van. The test van was driven to an airport survey point where it remained stationary while collecting data. This static portion of the test was run in the GPS and DCPS modes of operation. The purpose of the tests conducted in the van were to examine the static performance and accuracy of DGPS/GPS, and to confirm the proper working order of the equipment prior to the flight test.

The flight tests were conducted in an FAA Convair 580 (CV-580). The Convair was modified to accept a GPS antenna and a very high frequency (VHF) DGPS data link antenna. The Technical Center's precision automated laser tracking system was employed as a baseline, or truth source. The flightpath incorporated a terminal area helix and nonprecision approaches. Three DGPS and three GPS flights were flown in terminal area. A final DGPS flight was conducted on a 272 degree radial from the Technical Center to examine the maximum operational distance of the DGPS reference station.

The results showed that DGPS provided a marked improvement in accuracy over GPS as expected. The static GPS test results were comparable with the dynamic GPS results, but static DGPS provided much better accuracy than the dynamic DGPS.

The DGPS tests were conducted in an effort to build an FAA data base to aid in addressing DGPS issues.

1. INTRODUCTION.

1.1 OBJECTIVE.

The primary objective of the test was to demonstrate the achievable accuracy of the Global Positioning System (GPS) in the Differential (DGPS) mode of operation. A comparison between GPS and DGPS was made for both static and dynamic tests. The dynamic tests examined GPS/DGPS performance in the terminal area and nonprecision approaches. The test results will supplement the Federal Aviation Administration (FAA) GPS data base which will aid in answering present and future National Air Space (NAS) questions regarding GPS. Such a data base could address GPS standards and requirements for reduction in aircraft separation and GPS/DGPS supported Terminal Area Operations.

1.2 BACKGROUND.

The U.S. Air Force and the U.S. Navy have had satellite programs that date back to the early 1960's. In April 1973, the U.S. Deputy Secretary of Defense issued a memorandum directing the U.S. Air Force to consolidate the existing satellite programs into a global, 24-hour, three-dimensional, all-weather navigation system. This system is named: Navigation by Satellite Timing and Ranging Global Positioning System (NAVSTAR GPS), better known as GPS.

There are presently six operational Block I and seven operational Block II satellites in orbit. The present orbit configuration is such that full GPS service (four or more satellites with good geometry accessible to the user) is available approximately 10 hours a day. Although this 10-hour window is limited, it is used extensively for debugging and early evaluation of the system. Block I satellites will be phased out and replaced by a constellation of Block II satellites. The present Block II schedule provides for a satellite launch every 2 - 3 months. This schedule will configure the full constellation by 1993.

GPS is partitioned into three primary segments: space, control, and user. The space segment consists of a planned constellation of 21 operational and three active spare Block II satellites. The spares are provisioned to secure the probability of having 21 or more operational satellites at least 98 percent of the time. The probability of having 24 operational satellites is 70 percent. The GPS signal is transmitted using spread spectrum techniques on two frequencies: L1 at 1575.42 megahertz (MHz) and L2 at 1227.60 MHz. Two types of signal spreading functions are utilized: Course/Acquisition (C/A) code and Precise (P) code on the L1 carrier and P-code only on the L2 carrier. The C/A-code is available to all users, but the encrypted P-code is only available to U.S. military, North Atlantic Treaty Organization (NATO) military, and Department of Defense (DOD) approved civilians. All FAA GPS tests discussed in this report employ C/A-code only. The control segment incorporates a network of five monitoring stations and one master control station. The Master Control Station (MCS) is collocated with a monitor station at Falcon Air Force Station in Colorado Springs, CO, and is linked with the monitor stations via the Defense Satellite Communication System (DSCS). GPS has the versatility to meet the needs of many users such as a navigation aid for space, air, land, and sea; attitude reference, time transfer, precise positioning, surveying, etc. The GPS user is passive, therefore, GPS can facilitate an unlimited number of users. The GPS user segment usually consists of an L-band receiver, an L-band antenna, and a control-display unit.

For most users, GPS navigation accuracy is sufficient to meet their needs, but there are some users who demand even higher accuracies. Such improved accuracies can be obtained from DGPS. DGPS is implemented by placing a GPS receiver at a known location and configuring it to determine pseudorange errors. These errors are then broadcast to local users as corrections to facilitate a greatly improved navigation solution. The differential method can reduce or eliminate Selective Availability (S/A), atmospheric delay, ephemeris and satellite clock errors. With the advent of S/A greatly degrading civilian accuracy, this format would be a true benefit, especially to terminal area operations.

The FAA has been testing GPS since 1979 to define and determine the potential role of GPS as a civil navigation system. The FAA has examined: masking angle criteria, rotor modulation effects, multichannel systems, and multipath characteristics to aid in the defining of Minimum Operational Performance Standards (MOPS) for GPS receivers. Although overall GPS performance outshines existing navigation systems, the advent of S/A and the continuing increase of air traffic demands the best accuracy available. DGPS has the potential to negate S/A and support nonprecision approaches, via its highly accurate positioning.

1.3 RELATED DOCUMENTATION.

1. Introduction to Navstar GPS, NAVSTAR GPS Joint Program Office, June 1987.

2. Kramer, Gregory T., Rudolph M. Kalafus, Peter V. W. Loomis, and James O. Reynolds, Proceedings of ION GPS-89, "The Effect of Selective Availability on Differential GPS Corrections"; September 1989.

3. Mini-Ranger GPS Receiver Users Manual, Motorola Inc., Document No. 68-P29027U, November 1986.

4. Conner, Jerome T., Global Positioning System GPS Performance Parameters Test Plan, DOT/FAA/CT-TN83/50, June 1984.

5. Persello, Frank, Integrity Monitoring Methods for the Global Positioning System, DOT/FAA/CT-ACD330/13, May 1989.

6. Precision Automated Tracking System, Operation and Maintenance Manual, GTE, May 1976.

2. DISCUSSION.

2.1 EQUIPMENT DESCRIPTION.

2.1.1 Aircraft.

The aircraft employed in the tests was a Convair 580 (CV-580), tail number N-91. This aircraft was primarily chosen for two reasons: its availability and the engineering that already existed for a GPS antenna, preamp, and a secondary very high frequency (VHF) link. The VHF link was necessary to facilitate a DGPS update from the reference station. The DGPS update carrier signal was transmitted at 165.64 MHz, and the update itself was transmitted once every 5 seconds. The 165.64 MHz carrier wave is just above the VHF band and the 3 decibel (dB) roll off point on the aircrafts' VHF antenna. The VHF antenna was mounted on top of the Convair fuselage, 592 inches from the nose of the aircraft (see appendix C). The high power Mitrek radio (110 watts transmitting power) has proven to compensate for the reduced antenna response.

2.1.2 GPS Set.

The GPS set is comprised of a Motorola Eagle Mini Ranger Receiver, antenna, preamp, and a Tandy TRS-80 lap top computer. The TRS-80 was used as a Control Display Unit (CDU). The GPS antenna is right-hand circularly polarized, omnidirectional in azimuth, and hemispherical in elevation. The GPS antenna was mounted on the top of the Convair fuselage skin, 352 inches from the nose. The GPS preamp was mounted 6 inches below the GPS antenna on an interior shelf. The distance between the GPS antenna and preamp was minimized in order to limit coaxial line signal loss. The airborne rack on which this equipment was mounted can be seen in detail in appendix C. The GPS set can assume one of two modes of operation: autonomous or differential. The autonomous mode is the standard GPS configuration which obtains position information solely from the satellites. The differential mode of operation is described in the "Background" section. The Eagle Receiver specifications and diagrams are provided in appendix A.

2.1.3 Radar Facility.

The General Telephone & Electronic (GTE) Precision Automated Tracking System (PATS) uses an infrared laser beam to illuminate an aircraft mounted retroflector and automatically track cooperative targets. The retroflector was mounted on the fuselage skin, 145 inches from the nose of the aircraft. System accuracy is 20 arc seconds in azimuth and elevation angle. Range accuracy is 1 foot for target ranges to 5 nautical miles (nmi), 2 feet for target ranges from 5 to 10 nmi, and 5 feet for target ranges at 25 nmi. The stated accuracies extrapolate to a root mean square (rms) error of 2.6 meters at 10 nmi. Due to visibility conditions, range is limited to between 7 and 11 nmi during normal operations at the FAA Technical Center.

2.2 DATA COLLECTION SYSTEM.

The tests incorporated two sources of data: the GPS data from the Eagle Receiver and the base line, or truth data from the laser tracker facilities. The GPS data was collected by tapping the transmit and signal ground lines from the Eagle Receivers' control port. A line tap or "T" had to be employed due to the control port being occupied by the CDU cable and the auxiliary port being occupied by the DGPS data input. The two tap lines connected to an RS232 port on a Compaq SLT/286 lap top computer. The Compaq utilized Smart Term 240 communication software to collect the data. The Eagle Receiver data parameters and format that were collected can be seen in appendix B. The base line data were collected on a 9-track tape and converted to VAX binary in the Clark 1866 reference ellipsoid X,Y,Z coordinates and locally compensated WWV time tags.

2.3 DATA REDUCTION AND ANALYSIS.

The GPS receivers were employed in both the differential and autonomous modes of operation, but the output data streams are identical (see figure B-1, Recorded Eagle Data Parameters). This section describes the data processing path, from the GPS receiver and laser tracker to a final statistical format. The GPS data stream is stripped of all parameters but the latitude, longitude, height, and time tag. This reduced data stream is then merged with the "truth" data from the laser tracker. The laser tracker data stream measured as X,Y,Z coordinates (with respect to Clark 1866 ellipsoid) and time is converted to latitude, longitude, height, and time before merging with the GPS data. The merged data are processed by statistical software which provides mean error and standard deviation for; X Y Z coordinates, latitude, longitude, and height. The statistical software also provides 2 distance root mean square (2 drms), circular error probability (CEP), and spherical error probability (SEP). The GPS and DGPS position error, as defined by the laser tracker, are plotted as latitude, longitude, and altitude error. The results will become part of a data base being established to aid in the analysis of DGPS for terminal flight and nonprecision approaches.

3. TEST PROCEDURES.

3.1 BENCH TESTS.

The objectives of the bench tests were twofold: develop a working knowledge of equipment characteristics, and assure proper performance as stated in the user's manual. The bench tests began in the lab by configuring the Motorola receivers in the autonomous mode and monitoring the performance. An RG-58 coaxial cable was run from the lab to a GPS microstrip antenna on the hanger roof. The antenna location was surveyed by a Hewlett Packard Total System Surveyor to an accuracy of +/- 5 centimeters (cm). One hundred position fixes were recorded over a period of 3 days. The fixes were during periods of four or more satellites and a Position Dilution of Precision (PDOP) of 6 or less. The GPS antenna employed in these tests was configured for a mask angle of 5 degrees. The satellite mask angle was set during the receivers initialization mode, and dictates the minimum acceptable elevation angle at which satellites will be tracked. When the autonomous performance was judged satisfactory, the equipment was then configured in the differential mode. The differential mode of operation infers that a minimum of two receivers (reference and user) be employed, but this test utilized a differential reference station only. The reason for this configuration was to observe the transmitted position correction signal. The signal strength, duty cycle, and voltage standing wave ratio (VSWR) measured to the antenna was verified. The antenna for the differential correction link was modified to minimize signal reflections (VSWR = 1.3).

3.2 GROUND TESTS.

Ground test objectives included full implementation of DGPS and GPS in a static environment, collecting GPS and DGPS data, and a final shake down of equipment prior to the flight tests. The Motorola receivers were first installed in the FAA test van in the autonomous configuration. Two existing FAA survey points were used as a truth source. For comparison and baseline purposes, the test van parked directly above a survey point, and approximately

100 data records per point were obtained before moving to the next point. Collecting data from the two survey points was referred to as a "run." Five runs a day for 3 days were conducted to collect enough data for a complete statistical analysis and to provide a thorough check of the equipment. The differential mode was then employed with the installation of a master station in the hanger roof meteorological booth and the slave station in the test van. The master station transmits a correction message as shown in figure B-2. The correction format employs X, Y, and Z Earth Centered Earth Fixed (ECEF) errors. The correction message also dictates what satellites the slave station tracks. This is a necessary feature because the X, Y, and Z corrections sent by the master station correspond to a specific set of satellites; so for the error corrections to be valid, the slave station must track the same satellites. The distance between the master station and slave station was 1.3 miles. Five runs a day for 3 days were conducted in a similar manner as described for the autonomous mode.

3.3 FLIGHT TESTS.

The objectives for the flight tests were to demonstrate the achievable accuracy of GPS and DGPS in a dynamic environment. A GPS/DGPS equipment rack was constructed to meet all aircraft installation requirements. The aircraft rack consisted of the Motorola Eagle Receiver and associated 18 volts of direct current (Vdc) power supply, a TRS 80 lap top computer, a Compaq SLT/286 lap top computer, a Mitrek radio and associated power supply, a Mitrek speaker, control head, and modem (see Appendix C: Flight Hardware Configurations). The rack required inputs from a VHF antenna, a GPS antenna, and 110 volts of alternating current (Vac) at 60 hertz (Hz). The equipment rack was then installed in N-91 as shown in appendix C. Due to the anticipated high level of DGPS accuracy, the laser tracker was utilized as a baseline. The flightpath was limited to approximately 10 nmi from the laser tracker. This is due to the laser trackers' limited ability to track at a distance. The equipment was initially configured in the autonomous mode, tested, then switched to the differential mode. The flightpath was an ascending spiral centered at the tracker with a radius of approximately 7 nmi The second phase of the flightpath consisted of nonprecision approaches. Three DGPS and three GPS flights were performed. Upon completion of one GPS and one DGPS flight, there existed concern over the reduced level of accuracy as compared with the static tests. To assure that the airborne configuration and data analysis software was performing properly, a 1-day test was developed. The Convair was parked with its laser retroflector directly over a ramp survey point. DGPS data were collected so that DGPS versus survey point and analysis could be performed. The survey point was employed as the optimum base line with an accuracy of +/- 2 inches. The airborne configuration in the DGPS mode was compared to the survey point utilizing our data analysis software. Results of this test are discussed in the "Results and Conclusions, Flight Tests" portion of this paper.

The final flight attempted to determine the effective range of the master station transmission of pseudorange corrections. Several problems were experienced while conducting the range decorrelation tests. The laser tracker has a typical range of 10 nmi, so the NIKE radar, with a typical range of 150 nmi plus, was employed as a baseline. Unfortunately, the NIKE Radar facility was experiencing technical problems during our test period. In addition to NIKE problems, the 3 decibel (dB) data link loss reduced the useful range to provide differential corrections. Although the Data Link segment of the test configuration is advertised to have a 200 mile range, the data collected were meaningless and, as such, is excluded from this report. At the writing of this report the NIKE radar problems have all been corrected. The DGPS range decorrelation tests have been rescheduled and will be documented in an ensuing report. Nonprecision approaches were flown to investigate potential deviations from normal GPS/DGPS operations.

4. RESULTS AND CONCLUSIONS.

4.1 BENCH AND GROUND TESTS.

Although the primary objectives of the bench tests were to assure proper performance and develop a working knowledge of the equipment, position fixes were recorded and compiled. The position error of the GPS bench tests that were observed over a 3-day period were 22.09 CEP and 31.43 SEP (meters). This accuracy was judged to be within the range of typical GPS performance.

The primary objective of the ground test was to establish the GPS and DGPS performance in a static environment and, as such, the collected data were analyzed more fully. A complete statistical analysis of the static DGPS and GPS test results can be found in table 1. Two DGPS and two GPS runs judged to be typical in both waveform and accuracy are plotted as latitude, longitude and altitude error with respect to the laser tracker in appendix D. Both the GPS and DGPS accuracies were in the range of expected performance. The DGPS accuracy was approximately a magnitude of improvement over GPS. The GPS vertical performance contributed the largest error as expected. The vertical weakness in GPS performance is due to the satellite-user geometry. Studies have shown that a GPS signal from below an airborne user, such as a pseudolite, would greatly improve the vertical error.

4.2 FLIGHT TESTS.

The ground tests established the GPS/DGPS accuracies in a static environment while the flight tests investigated dynamic environment performance. The statistical analysis of the flight data can be found in tables 2 - 5. The latitude, longitude, and altitude error plots can be seen in appendix E. It should be noted that Selective Availability was disabled during the entire test period. It should be further noted that a degraded navigation data warning was continuously in effect during the tests. The dynamic performance of both GPS and DGPS was much worse than the static performance. GPS static accuracy (2 drms) was 52 percent better than GPS dynamic accuracy. DGPS static accuracy (2 drms) was 75 percent better than dynamic DGPS accuracy. The decrease in accuracy from a static to dynamic environment is partially due, to carrier phase monitoring. The receiver calculates pseudoranges and employs carrier phase measurements as part of the position solution. The more confidence in the carrier phase measurement, the higher it is weighted and the more accurate the solution. The cause of the worsened dynamic accuracy is due, in part, to the inability of the receiver to maintain lock on the carrier phase during dynamics. Additional error was introduced by the laser tracker. The laser tracker rms error at 10 nmi is approximately 2.6 meters.

TABLE 1. STATIC GPS AND DGPS ERROR STATISTICS

STATIC DATA

DIFFERENTIAL GPS

	X	Y	Z
Mean Error	-0.3361425	-0.9848636	1.1003071
Standard Dev	1.3723733	1.3352745	2.2603915

	Lat	Lon	Hgt
Mean Error	1.6429585	1.0810999	1.0877115
Standard Dev	2.0252890	1.4054978	1.6442578

2d (rms).........	3.4863217
CEP..............	2.0197042
SEP..............	2.6000221

(statistics in meters)

(1519 records)

STANDARD GPS

	X	Y	Z
Mean Error	-1.5736509	-6.0737529	-28.969485
Standard Dev	6.2176459	15.188217	30.382017

	Lat	Lon	Hgt
Mean Error	18.406706	6.3570435	23.983041
Standard Dev	20.680982	7.5624047	26.584372

2d (rms).........	31.141387
CEP..............	16.626882
SEP..............	28.093068

(statistics in meters)

(2939 records)

TABLE 2. INDIVIDUAL GPS FLIGHT STATISTICS

1227_stat.asc (GPS)

	X	Y	Z
Mean Error........	-6.5323	-25.0121	-25.2731
Standard Dev......	73.3793	49.7090	54.1723

	Lat	Lon	Hgt
Mean Error........	53.4652	62.7465	36.0174
Standard Dev......	62.8956	76.2107	40.8575

2d (rms)..........	139.7422
CEP...............	81.8919
SEP...............	90.8118

(statistics in meters)
(784 records)

305_stat.asc (GPS)

	X	Y	Z
Mean Error........	3.8250	-6.3398	-20.7173
Standard Dev......	10.3307	29.1868	32.4813

	Lat	Lon	Hgt
Mean Error........	12.8563	7.1140	17.3691
Standard Dev......	14.3988	9.1199	41.8950

2d (rms)..........	24.1038
CEP...............	13.8454
SEP...............	36.8902

(statistics in meters)
(3176 records)

313_stat.asc (GPS)

	X	Y	Z
Mean Error........	-11.6363	-45.2269	-64.8403
Standard Dev......	27.5909	95.5361	101.1171

	Lat	Lon	Hgt
Mean Error........	20.7089	16.6852	80.2430
Standard Dev......	23.4865	24.7183	138.9507

2d (rms)..........	48.2205
CEP...............	28.3782
SEP...............	114.8965

(statistics in meters)
(3159 records)

TABLE 3 CUMMULATIVE GPS FLIGHT STANDARDS

305, 313, 1227 (GPS)

	X	Y	Z
Mean Error........	-4.1765	-25.6520	-40.7983
Standard Dev......	32.1175	70.9767	76.1100

	Lat	Lon	Hgt
Mean Error........	20.8130	17.4879	47.3226
Standard Dev......	30.2993	34.9427	102.1169

2d (rms)..........	65.4071
CEP...............	38.4080
SEP...............	85.7621

(statistics in meters)

(7119 records)

TABLE 4. INDIVIDUAL DGPS FLIGHT STATISTICS

1215_stat.asc (DGPS)

	X	Y	Z
Mean Error........	2.2151	3.1224	5.5760
Standard Dev......	5.3201	6.1686	9.3690

	Lat	Lon	Hgt
Mean Error........	4.3030	4.4688	8.8568
Standard Dev......	5.2669	5.5951	10.5288

2d (rms)..........	10.8669
CEP...............	6.3944
SEP...............	10.6869

(statistics in meters)
(438 records)

0111_stat.asc (DGPS)

	X	Y	Z
Mean Error........	1.1281	-5.6888	1.8526
Standard Dev......	1.2507	6.0173	2.0035

	Lat	Lon	Hgt
Mean Error........	4.7283	6.5031	2.8253
Standard Dev......	4.8622	6.7214	3.2729

2d (rms)..........	11.7318
CEP...............	6.8192
SEP...............	4.7495

(statistics in meters)
(308 records)

222_stat.asc (DGPS)

	X	Y	Z
Mean Error........	1.0985	3.1582	1.4353
Standard Dev......	7.0897	5.8220	6.2664

	Lat	Lon	Hgt
Mean Error........	5.3899	6.2017	3.8982
Standard Dev......	6.9410	7.8749	5.0643

2d (rms)..........	14.8453
CEP...............	8.7221
SEP...............	9.8252

(statistics in meters)
(2277 records)

TABLE 5. CUMMULATIVE DGPS FLIGHT STATISTICS

1215, 0111, 222 (DGPS)

	X	Y	Z
Mean Error........	1.2633	2.2516	2.0778
Standard Dev......	6.5009	6.4703	6.6907
	Lat	**Lon**	**Hgt**
Mean Error........	5.1650	5.9813	4.5073
Standard Dev......	6.5470	7.4979	6.3043
2d (rms)..........	14.0770		
CEP...............	8.2682		
SEP...............	10.4250		

(statistics in meters)

(3023 records)

Several of the GPS and DGPS error plots exhibit sinusoidal characteristics. Unsuccessful attempts were made to correlate the wave period with the flight-path and other physical occurrences.

As mentioned in the "Test Procedures" portion of this report, a test to verify the airborne configuration and software was performed following the initial GPS and initial DGPS flight tests because of lower than expected accuracy performance. The statistical results of this test can be seen in table 6. The accuracy results of this static DGPS test were slightly lower than the results shown in the ground DGPS tests. Although the accuracy was lower, they were very comparable and did not indicate a problem substantial enough to greatly influence the reduced dynamic performance.

5. SUMMARY.

The test results contained in this paper substantiate and document GPS/DGPS performance through independent tests conducted by the FAA, and compare favorably with similar tests completed by private industry and universities. These test results will contribute to the FAA GPS/DGPS data base which will aid the FAA in addressing future NAS requirements and standards. The GPS/DGPS test results revealed no major surprises, but instead, reinforced existing data. DGPS has displayed a very high level of accuracy, but can be further improved with sophisticated techniques. These techniques will be examined in follow-on programs.

TABLE 6. DGPS CONVAIR VS. SURVEY POINT

dgps220.bil (DGPS)

	Lat	Lon	Hgt
Mean Error........	2.3862	2.5763	1.2868
Standard Dev......	2.5579	2.6413	1.7326
2d (rms)..........	5.2000		
CEP...............	2.0607		
SEP...............	3.9796		

(statistics in meters)
(2822 records)

APPENDIX A

GPS RECEIVER SPECIFICATIONS

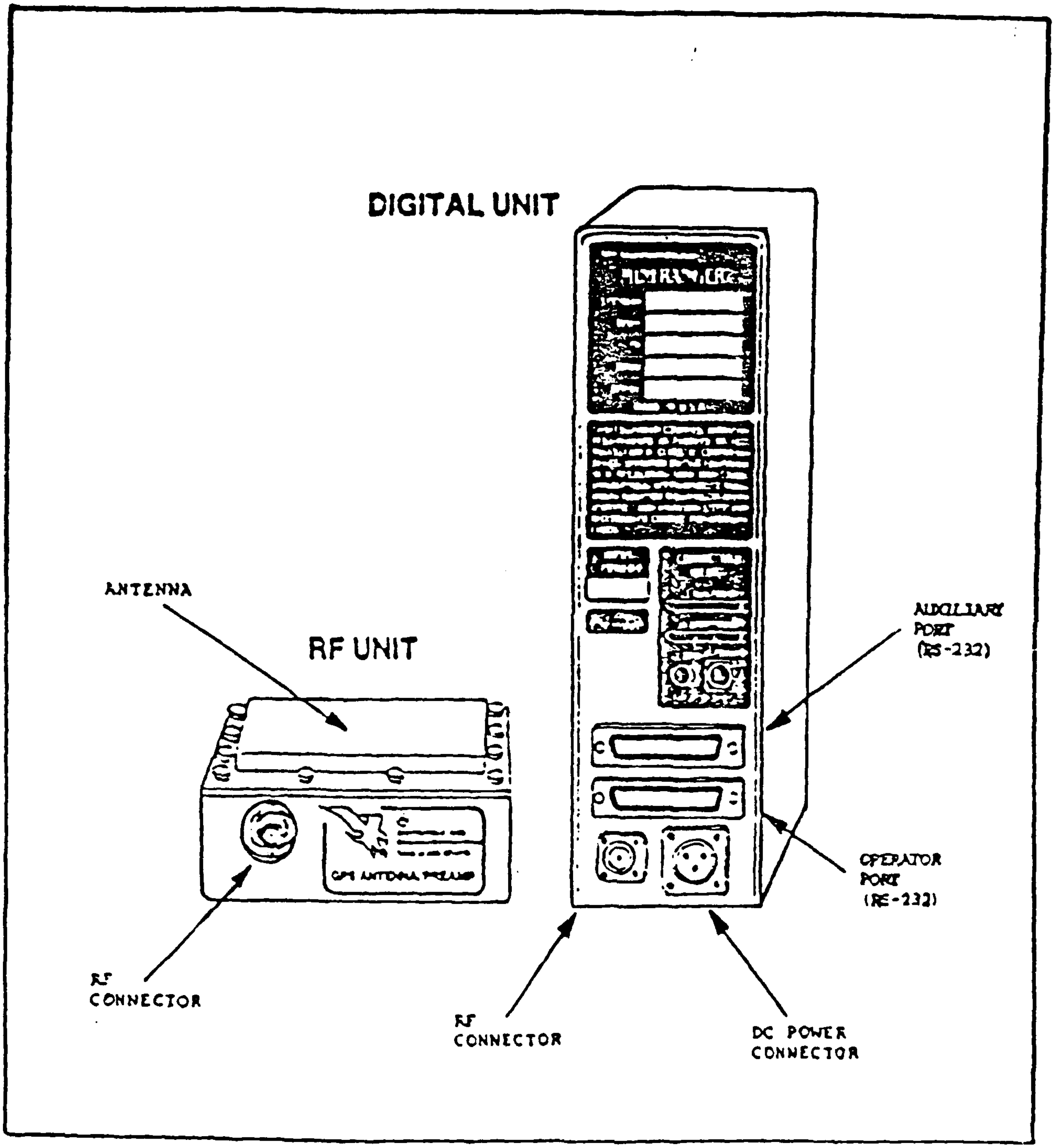

FIGURE A-1. EAGLE GPS RECEIVER

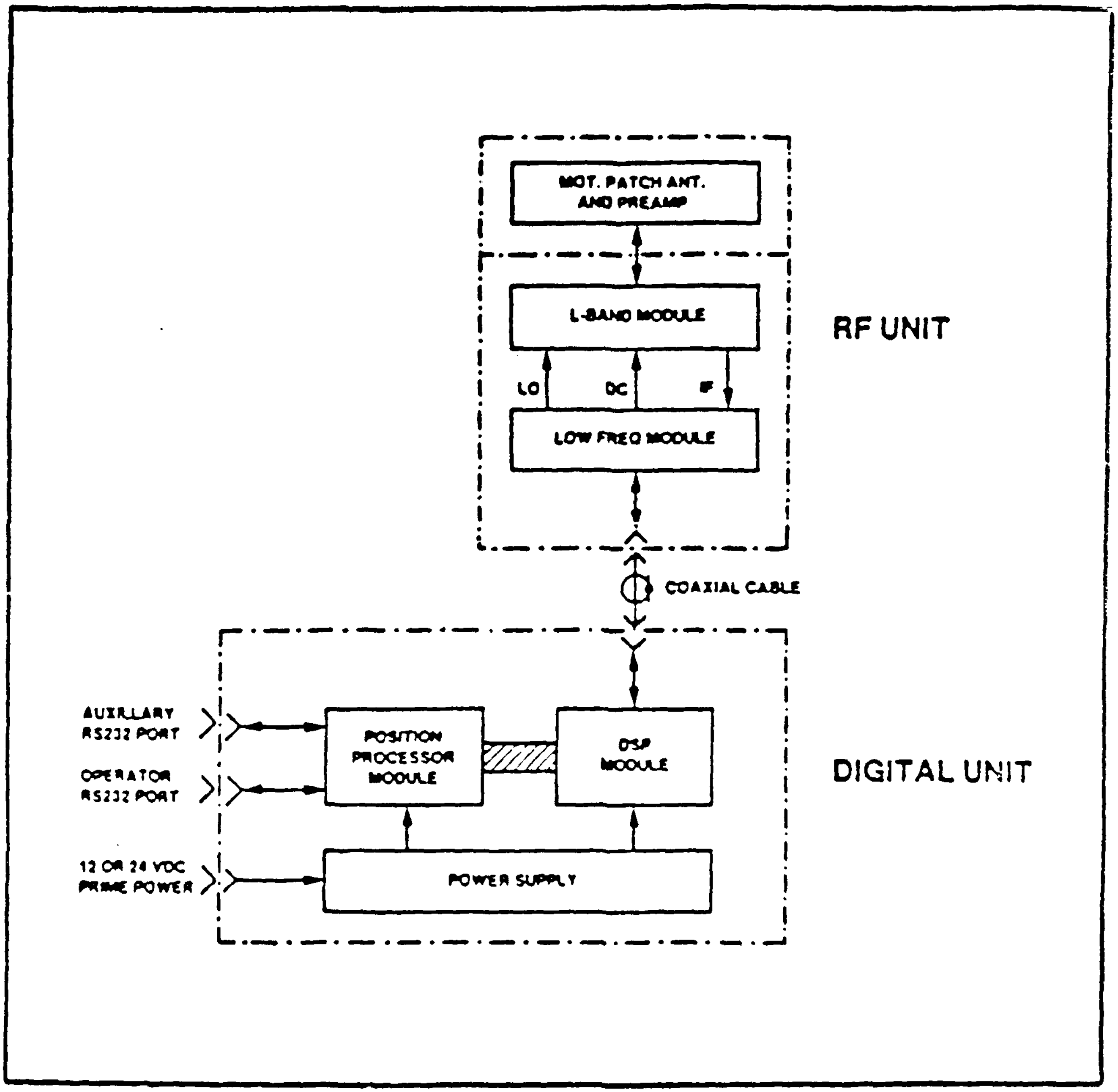

FIGURE A-2. EAGLE GPS RECEIVER BLOCK DIAGRAM

Eagle

GPS Receiver

MINI-RANGER

GPS RECEIVER SPECIFICATIONS

SYSTEM PERFORMANCE

Receiver Type	4-channel simultaneous, L₁, C/A code with carrier tracking
Operating Modes	Autonomous/real-time differential
Solution Type 3 Dimensional 2 Dimensional (altitude hold)	8-state Kalman update With 4 SV's With 3 SV's
Accuracy Autonomous Real Time Differential	 Less than 25 meters SEP 2–5 meters SEP
Position/Velocity Update Rate	1 second
Interrogation time to: First Fix (with almanac available)	2 minutes nominal
Position Output Types	Geodetic (Latitude, Longitude, Height) Earth-Centered-Earth-Fixed (ECEF) Local XYZ (feet or meters) Universal Transverse Mercator (UTM) – All zones State Plane Coordinates (CONUS, Alaska and Hawaii)
Position computed utilizing alternate ellipsoids embedded in the receiver	WGS-84 datum WGS-72 Clarke 1866 (NAD27) Clarke 1880 Australian National Airy Bessel Everest Fischer 1960 Hough International South American 1969 Special (user entered)
Dynamic Maximums Velocity Acceleration	 600 knots max 1g max
Shock	15g, 11 msec, 1/2 sine wave
Vibration	1g, 50 to 500 Hz

GPS RECEIVER SPECIFICATIONS

ELECTRICAL PARAMETERS

Operating Voltage	10 to 17 volts dc standard 18 to 32 volts dc optional (no charge)
Operating Power	19 watts maximum (antenna/preamplifier unit powered from receiver)

PHYSICAL PARAMETERS

System Part Number	01-P28960U001
Size and Weight Receiver-Processor (P/N 01-P28923U001) Antenna/Preamplifier (P/N 01-P28924U001) Antenna/Preamplifier Cable (P/N 30-P29030U050)	 7.7 × 2.3 × 12.4 inches H.W.D. (19.6 × 5.8 × 31.5 cm) 4.5 lbs (2.0 Kg) 2.0 × 4.5 × 4.5 inches H.W.D. (5.1 × 11.4 × 11.4 cm) 2.5 lbs (1.14 Kg) 50 ft. standard (150 ft. maximum, optional)
Temperature Receiver Operating Storage Antenna/Preamplifier Operating Storage	 −20°C to +55°C −40°C to +100°C −40°C to +65°C −55°C to +100°C
Humidity	0 to 90% noncondensing

Specifications subject to change upon product improvement.

User achievable position, time, and velocity accuracies are dependent on G.P.S. system control and space segment integrity and assumes a G.D.O.P. of less than four.

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FIGURE A-3. EAGLE SPECS.

APPENDIX B

EAGLE DATA PARAMETERS AND FORMATS

HEADER	L4,	
TIME	hh_mm_ss,	
TOTAL REJECTS	rr,	
LATITUDE	_-dd_mm_ss.sss,	
LONGITUDE	-ddd_mm_ss.sss,	
NORTH or X	-ddddddd.dd,	(Coordinate type
EAST or Y	-ddddddd.dd,	set in Set
HEIGHT OR Z	-hhhhhhh.hh,	Configuration
SPEED	sss.ss, Mode,	
HEADING	hhh.h,	Section 5.6.1)
PDOP	ppp.p,	
# OF SATELLITES USED	n,	
MESSAGE ID	dd (see message table in 6.1)	
TERMINATOR	R	

dd - is a receiver status message identification number and is interpreted as follows:

FIGURE B-1. RECORDED EAGLE DATA

This the message transmitted by the Eagle receiver master station for real time differential operation. When used with the Motorola data link this message would be sent every 5 seconds at 1200 baud. The format for the message is:

CONTENT	FORMAT	SIZE	DESCRIPTION
HEADER	Lhhhh,	6	master station ID string
TIME	tttttt,	7	GPS time in seconds
XERROR(0)	-xxxxxx.xx,	11	ECEF X error, meters
XERROR(1)	-xxxxxx.xx,	11	ECEF Y error, meters
XERROR(2)	-xxxxxx.xx,	11	ECEF Z error, meters
CHANNEL STATUS	c,	3	See note
FRAME #	ff,	3	See Table 8-3
FRAME WORD 1	-dd,	4	See Table 8-3
FRAME WORD 2	-dddddddddd,	12	See Table 8-3
FRAME WORD 3	-dddddddddd,	12	See Table 8-3
FRAME WORD 4	-dddddddddd	11	See Table 8-3
TERMINATOR	R	1	

		93	

NOTE: CHANNEL STATUS - number of good channels.

FRAME #/FRAME WORD n

The frame word parameters and formats are given in table 8-3. Frame word 1 contains the ID numbers of the satellites being tracked. Frame words 2 through 4 contain the ephemeris parameters for the satellites being tracked. The emphemeris parameters are defined in Table 8-2. The number preceding the emphemeris parameter name in Table 8-3 indentifies the receiver channel for which that emphemeris parameter is valid. Section 8.1.3 provides the information necessary to convert the emphemeris values contained in the data message to the values required for satellite position computation.

FIGURE B-2. REFERENCE STATION DATA LINK FORMAT

APPENDIX C

FLIGHT HARDWARE CONFIGURATIONS

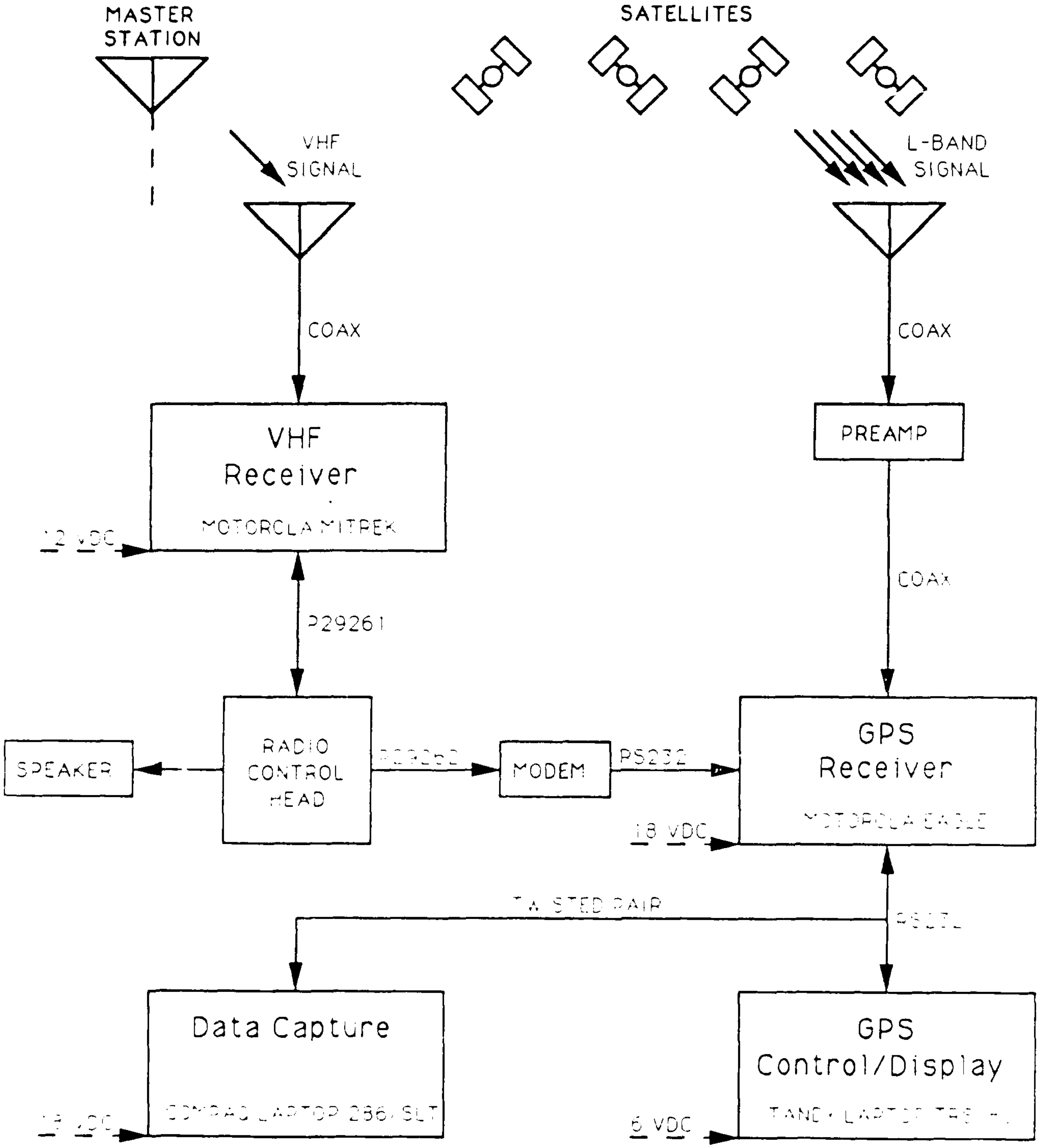


FIGURE C-1. AIRBORNE RACK BLOCK DIAGRAM

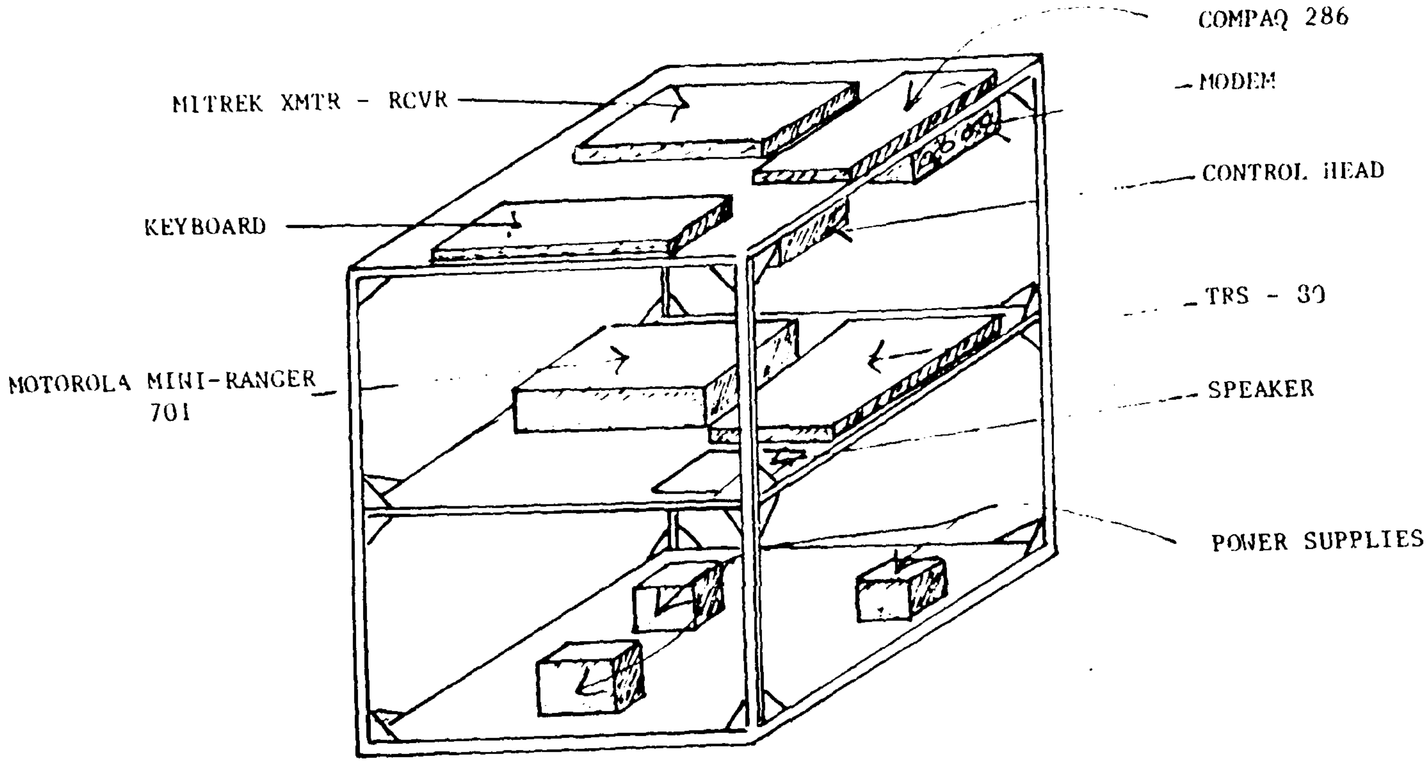


FIGURE C-2. EQUIPMENT RACK LAYOUT

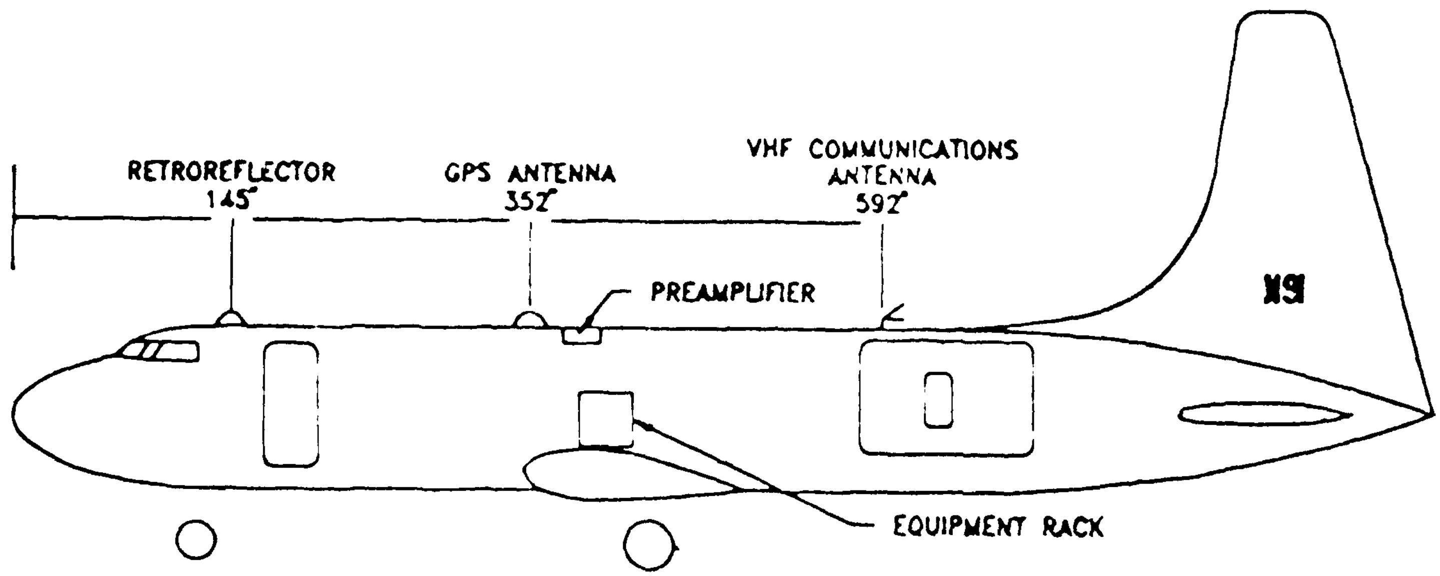


FIGURE C-3. CONVAIR 580 CONFIGURATION

APPENDIX D

GROUND TEST STATISTICS AND ERROR PLOTS

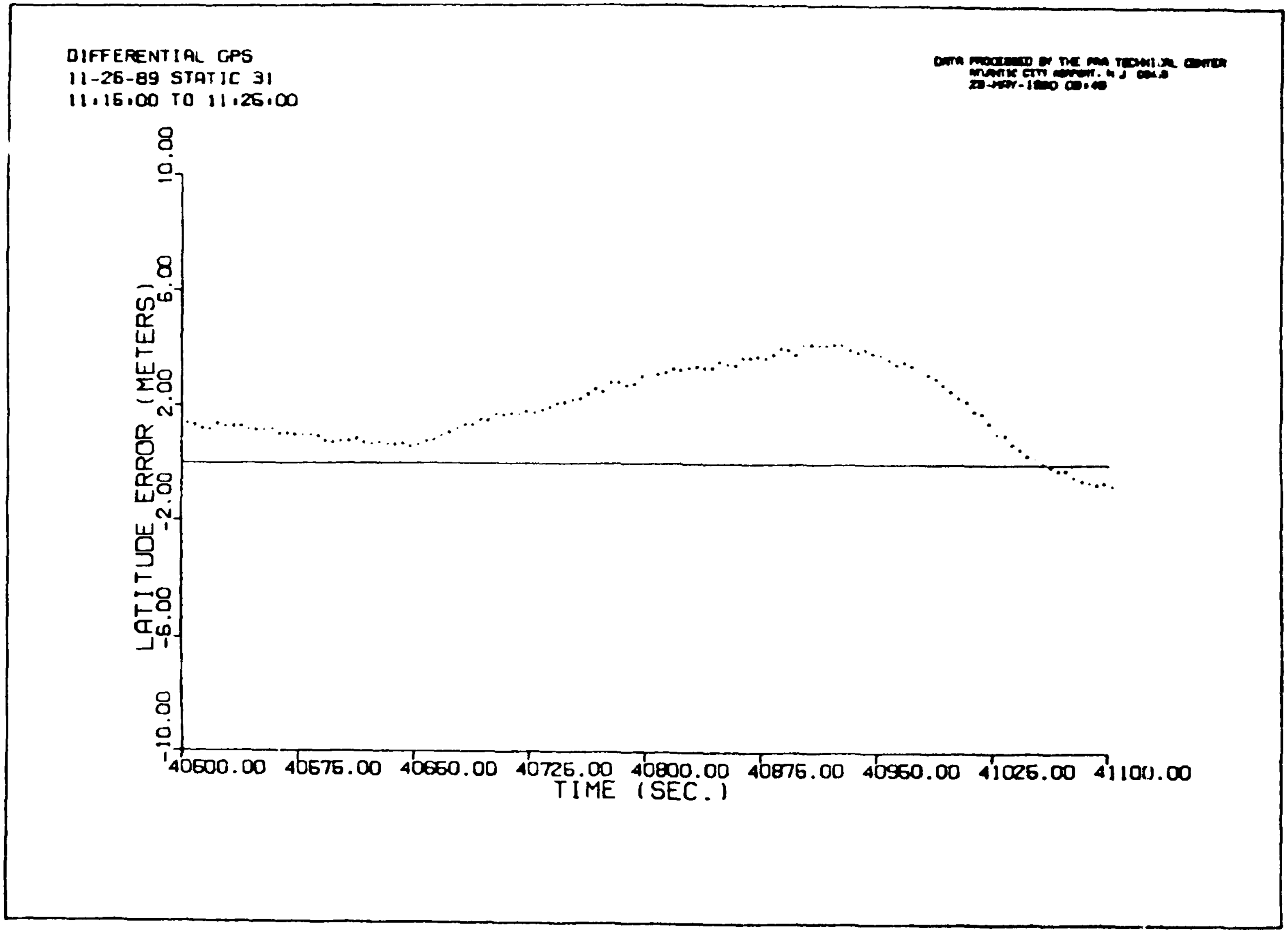


FIGURE D-1. STATIC DGPS LATITUDE ERROR - RUN 11/26

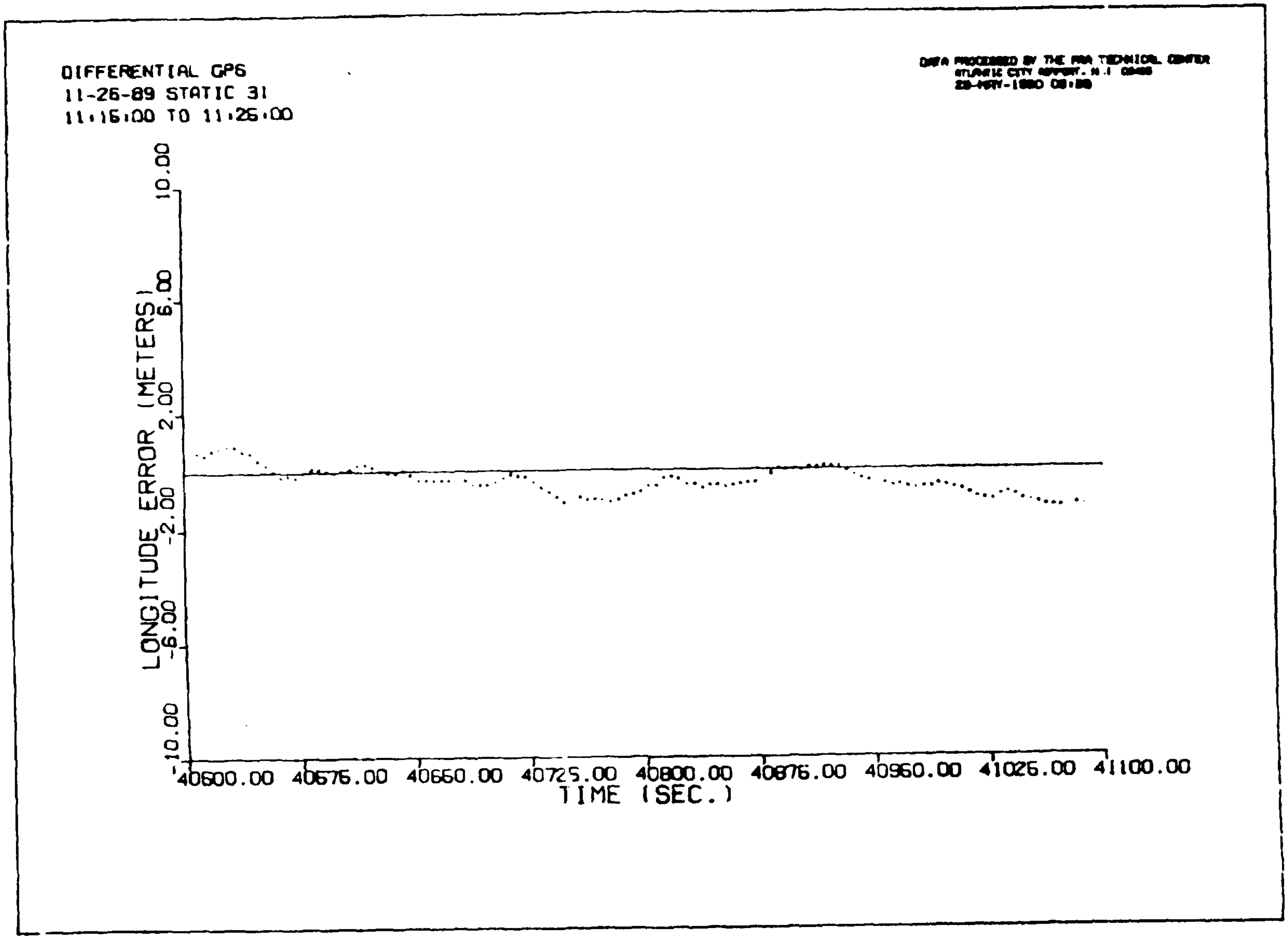


FIGURE D-2. STATIC DGPS LONGITUDE ERROR - RUN 11/26

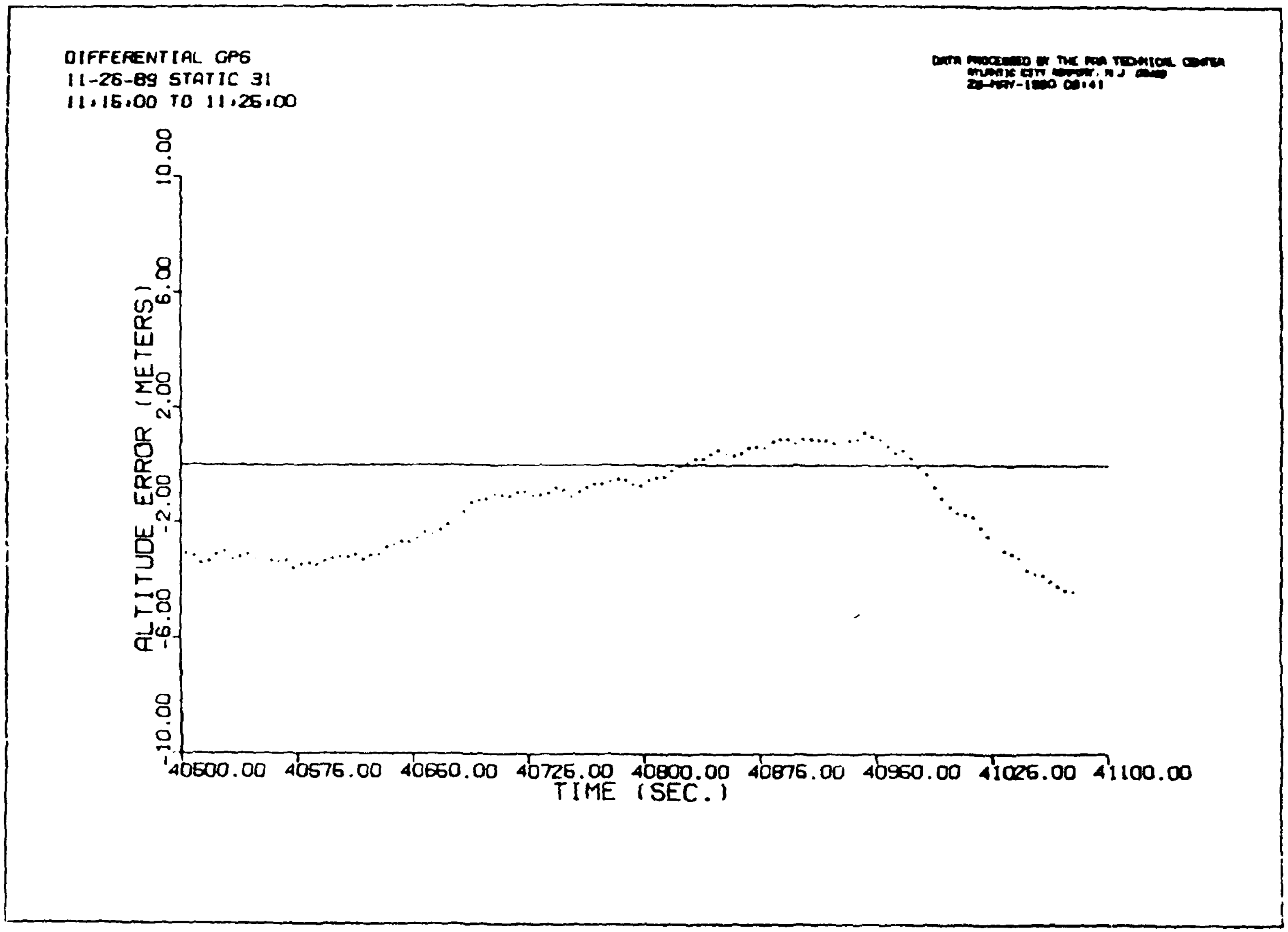


FIGURE D-3. STATIC DGPS ALTITUDE ERROR - RUN 11/26

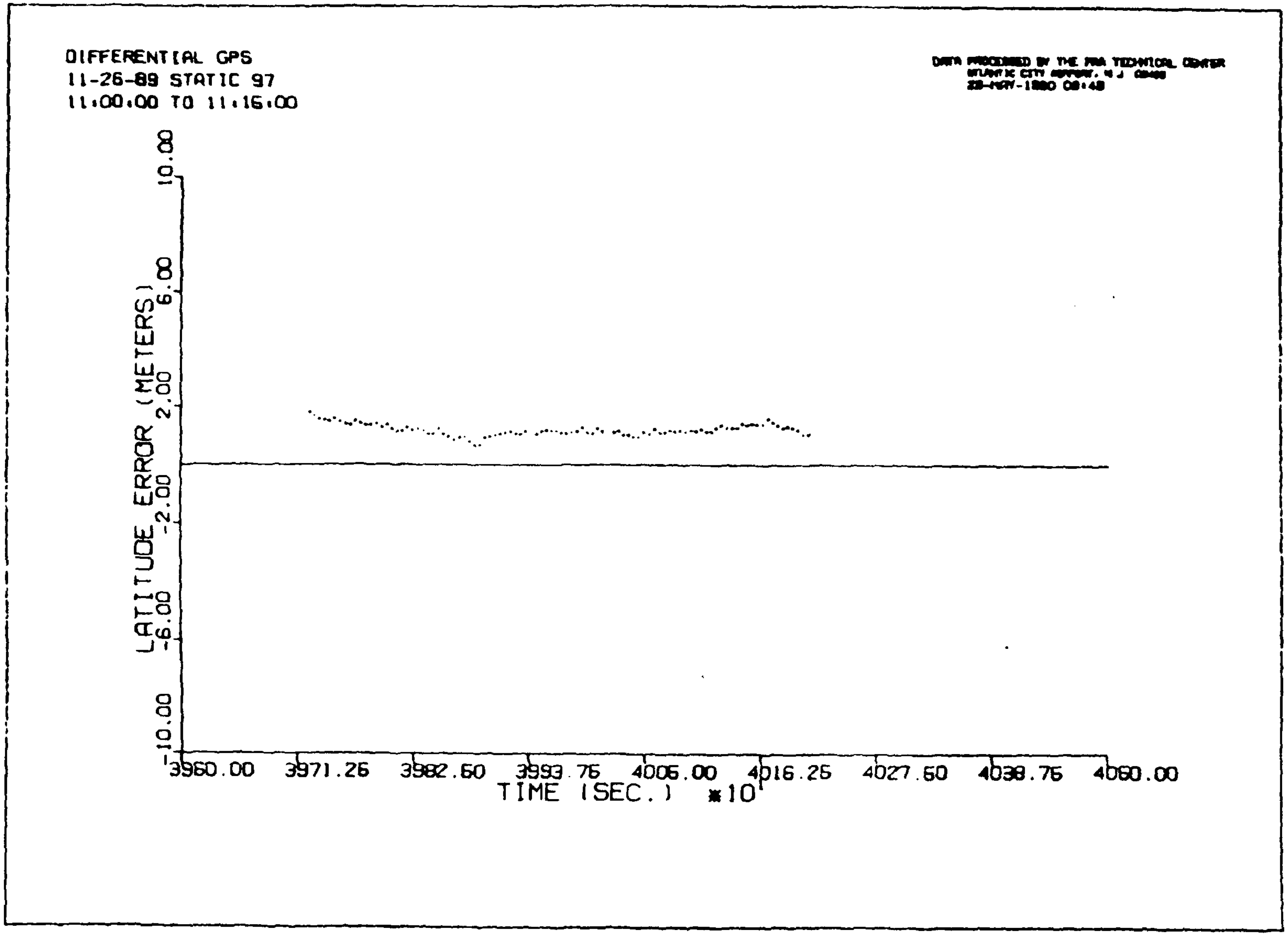


FIGURE D-4. STATIC DGPS LATITUDE ERROR - RUN 11/26

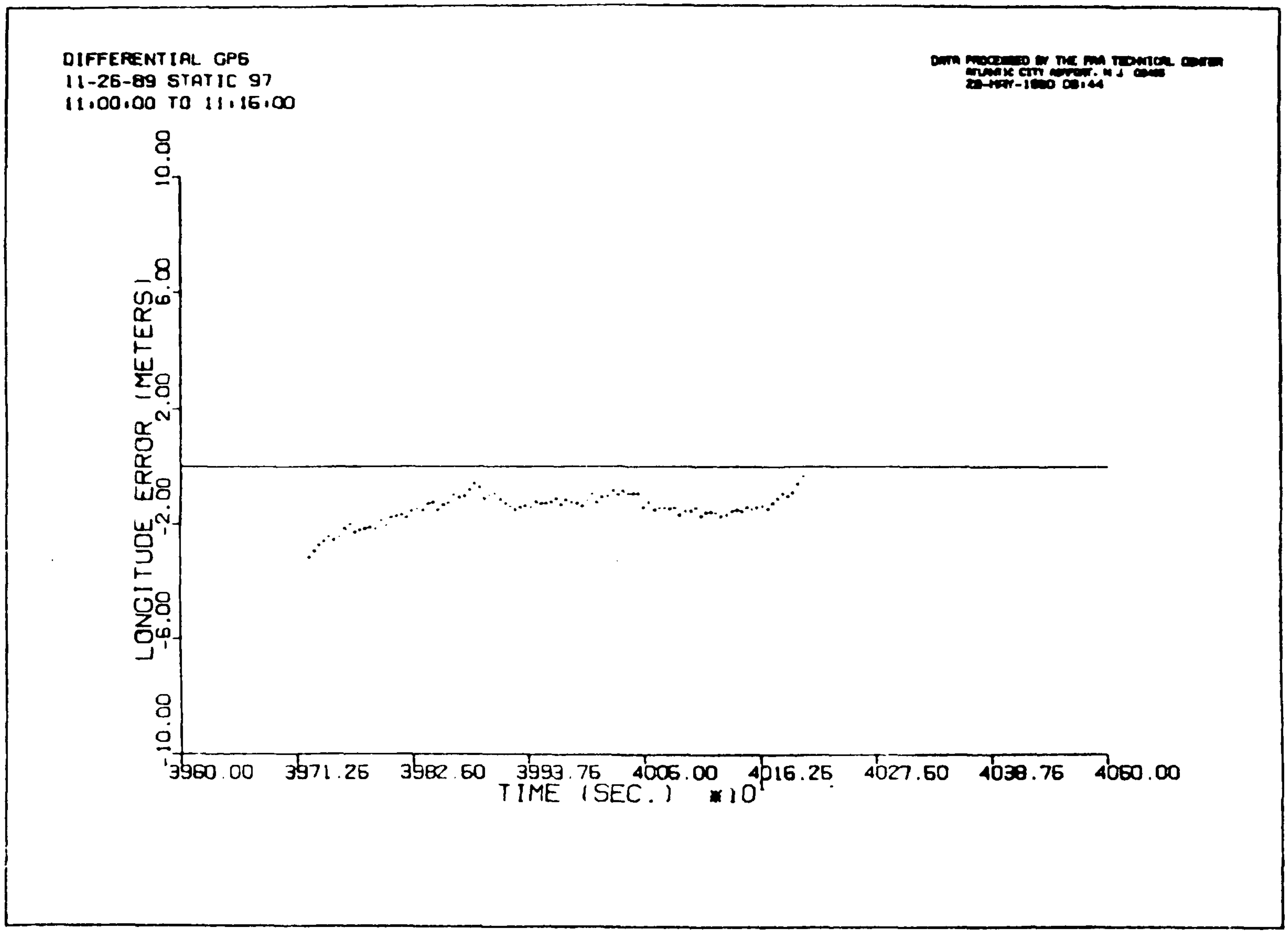


FIGURE D-5. STATIC DGPS LONGITUDE ERROR - RUN 11/26

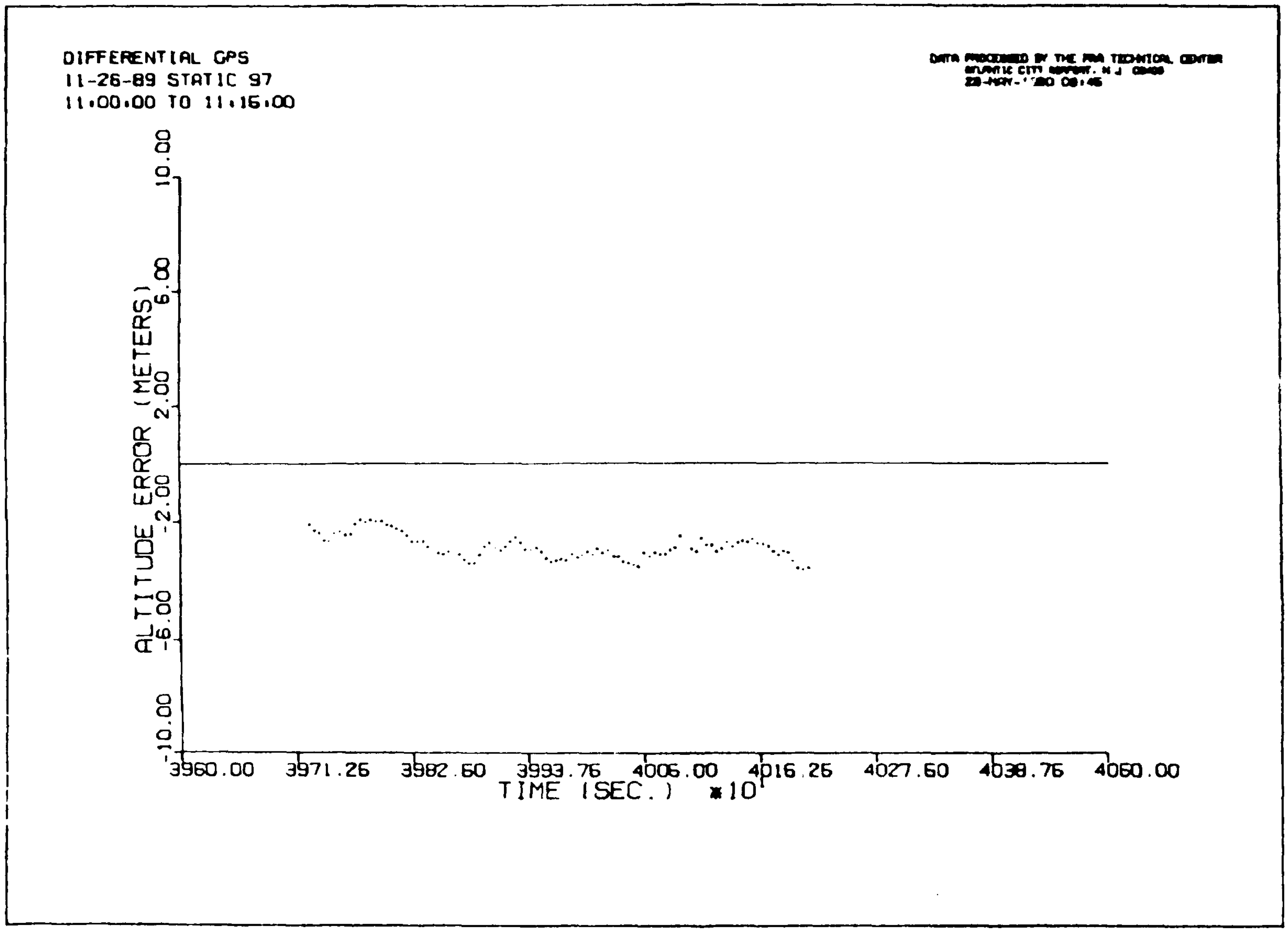


FIGURE D-6. STATIC DGPS ALTITUDE ERROR - RUN 11/26

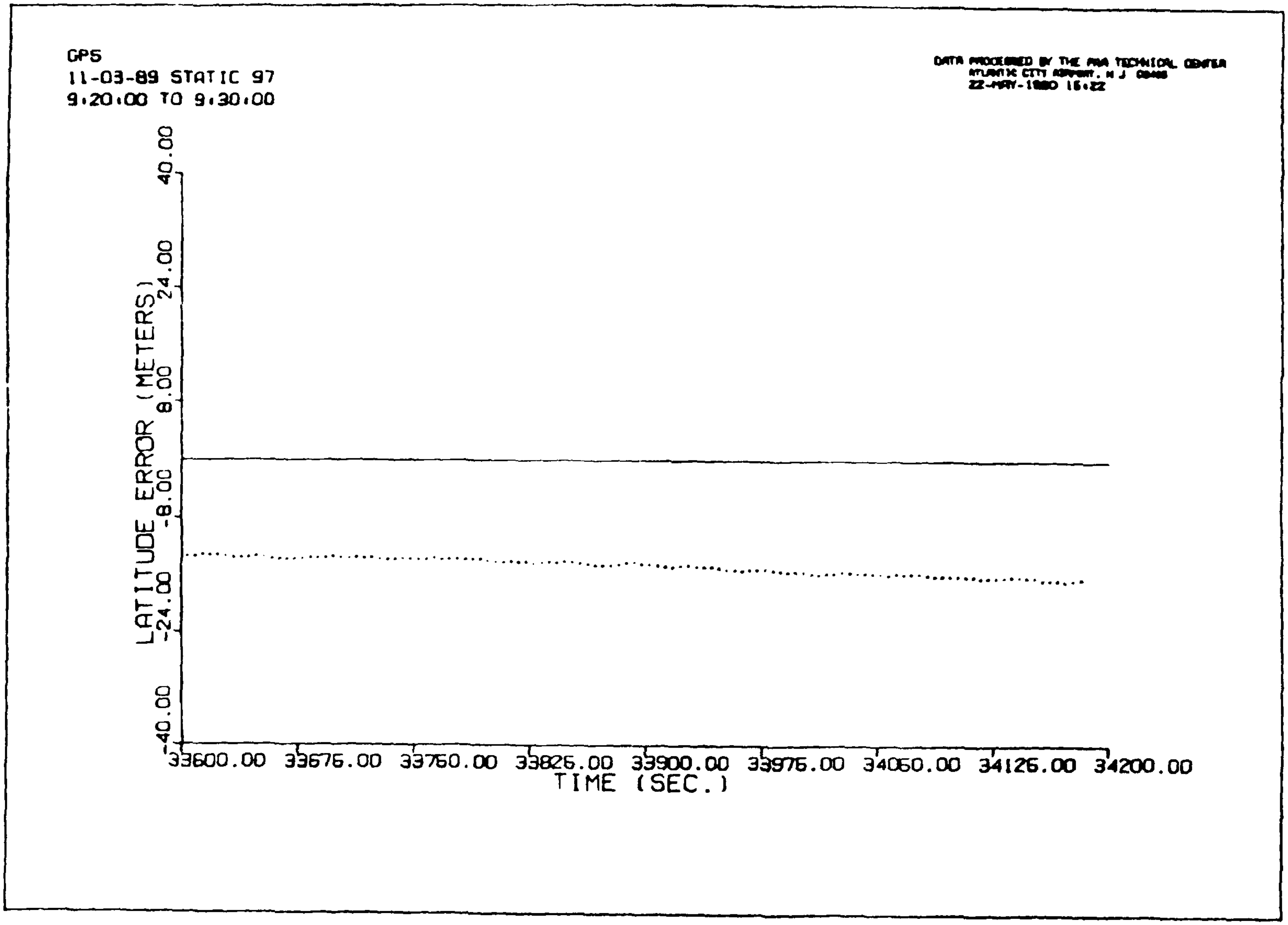


FIGURE D-7. STATIC GPS LATITUDE ERROR - RUN 11/3

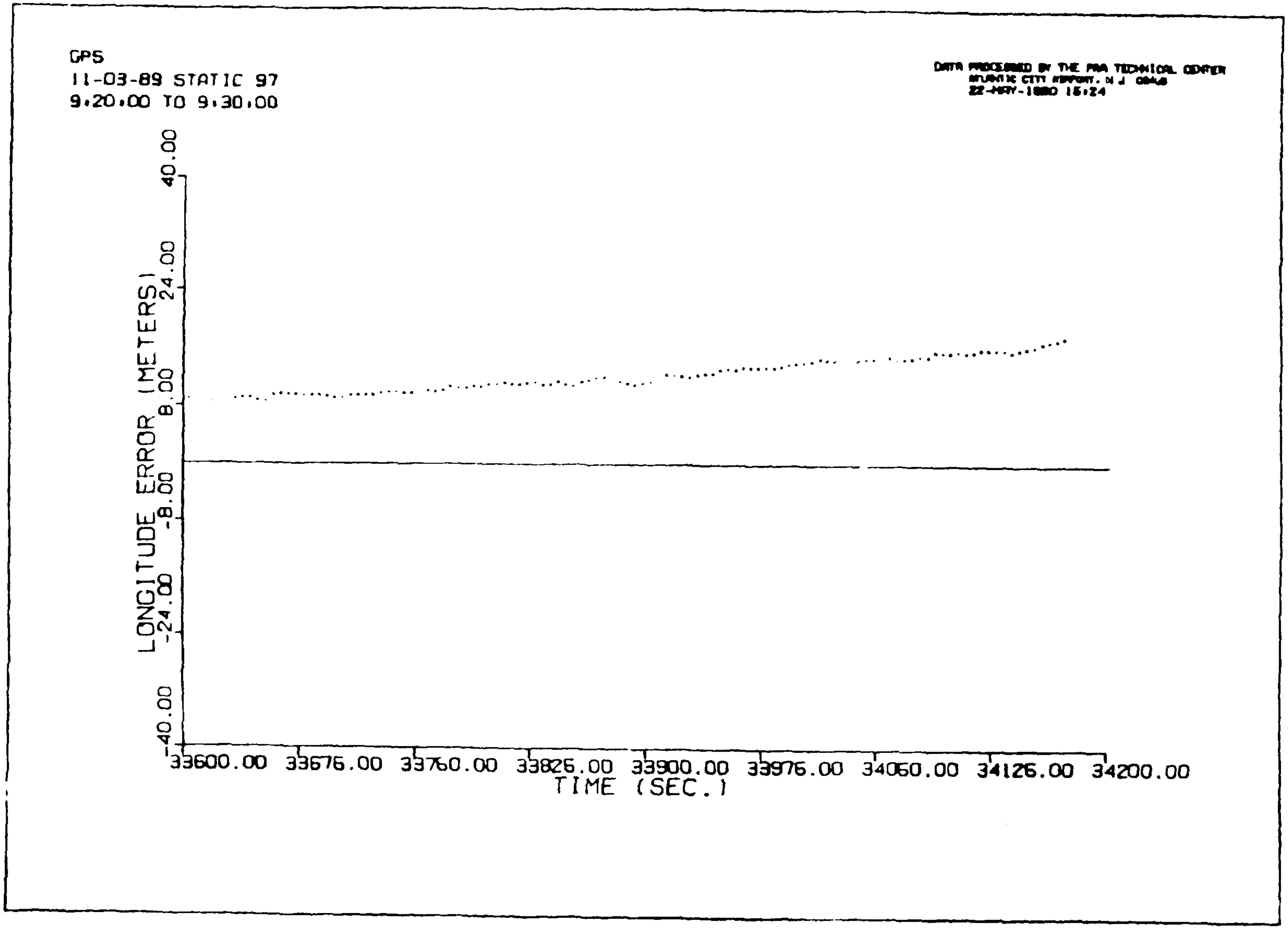


FIGURE D-8. STATIC GPS LONGITUDE ERROR - RUN 11/3

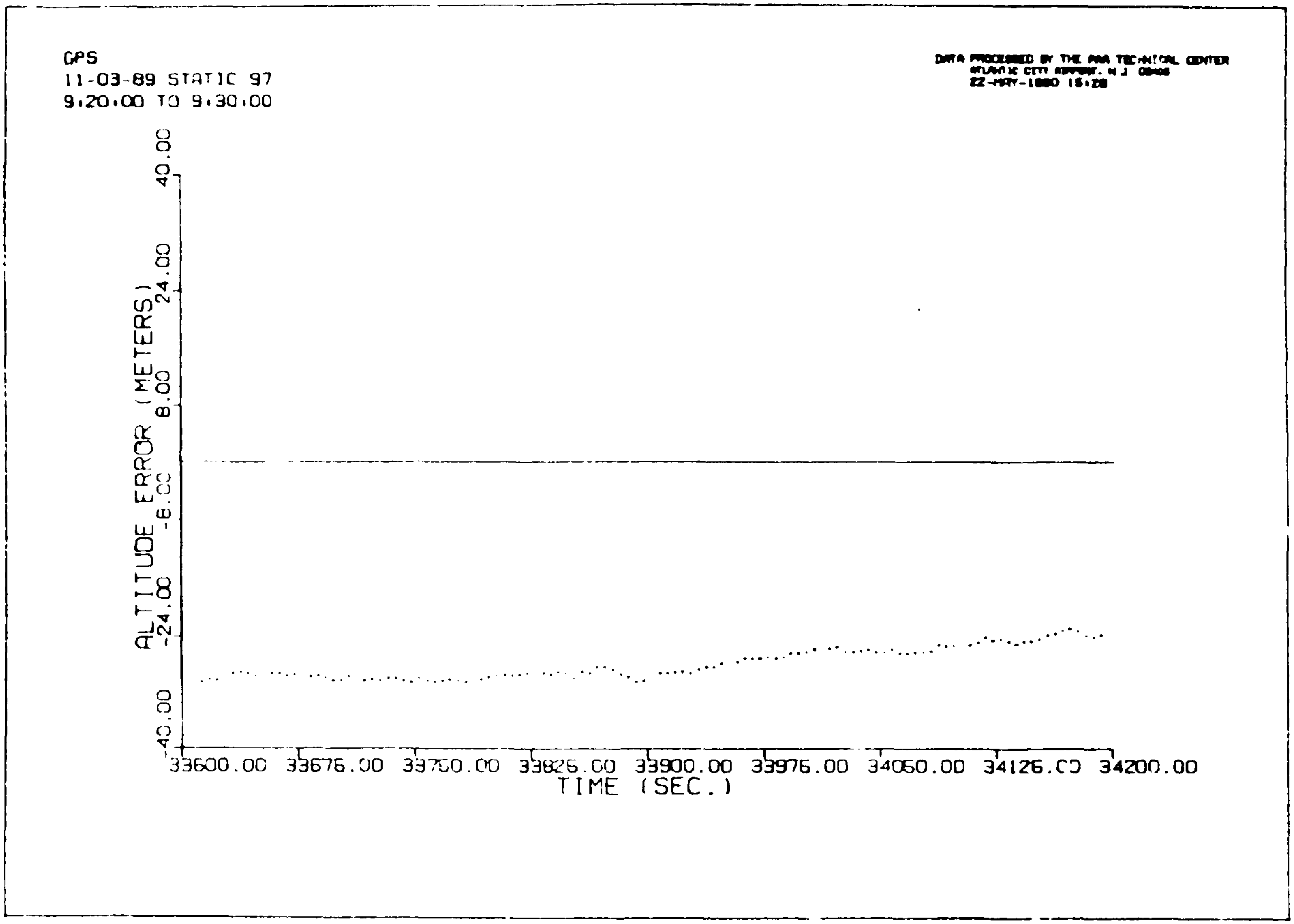
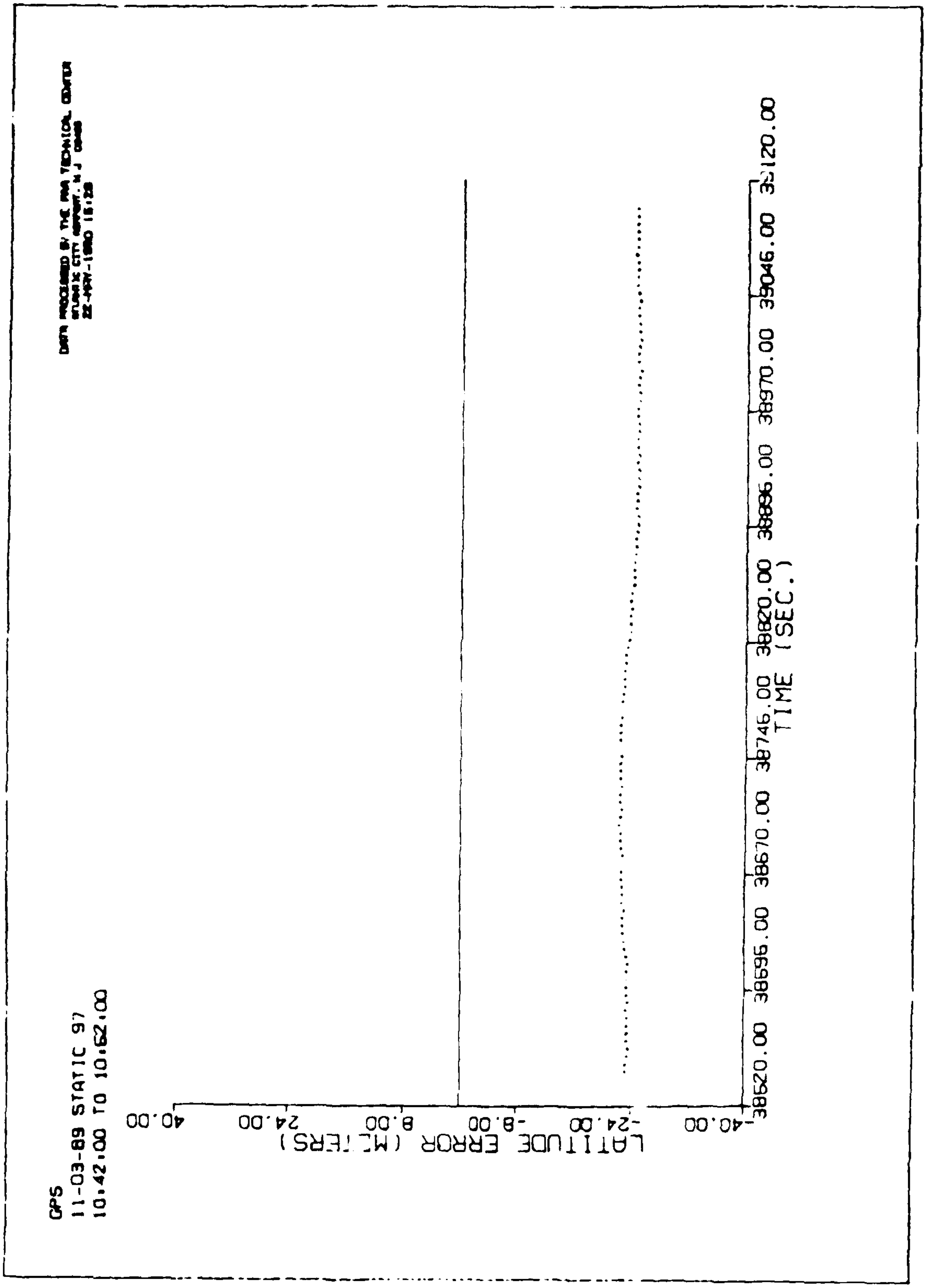


FIGURE D-9. STATIC GPS ALTITUDE ERROR - RUN 11/3



DATA PROCESSED BY THE FAA TECHNICAL CENTER
GPS
11-03-89 STATIC 97
10:42:00 TO 10:62:00
LATITUDE ERROR
40.00
24.00
8.00
-8.00
-24.00
-40.00
38520.00
38595.00
38670.00
38746.00
38820.00
38896.00
38970.00
39046.00
TIME (SEC.)

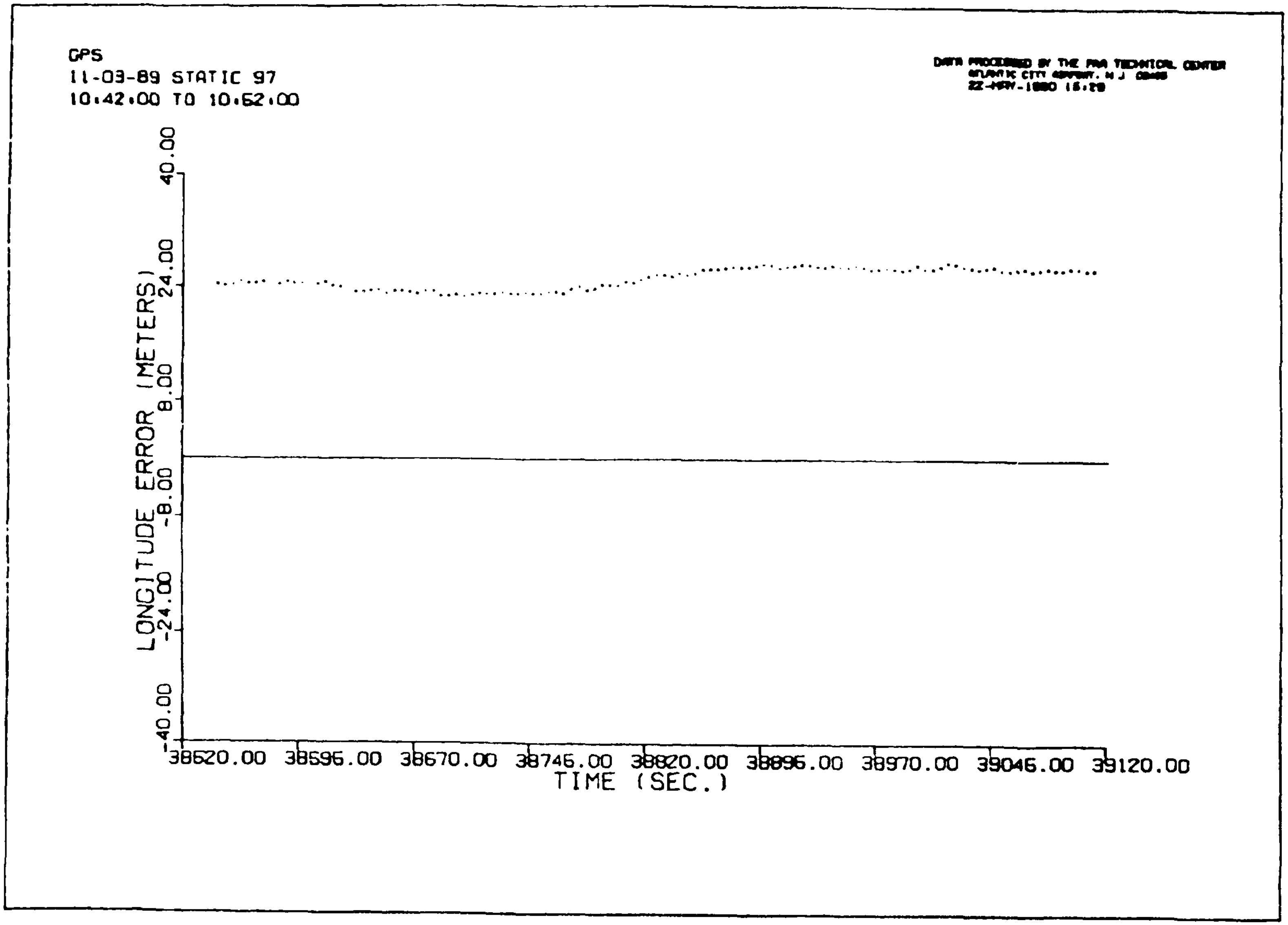


FIGURE D-11. STATIC GPS LONGITUDE ERROR - RUN 11/3

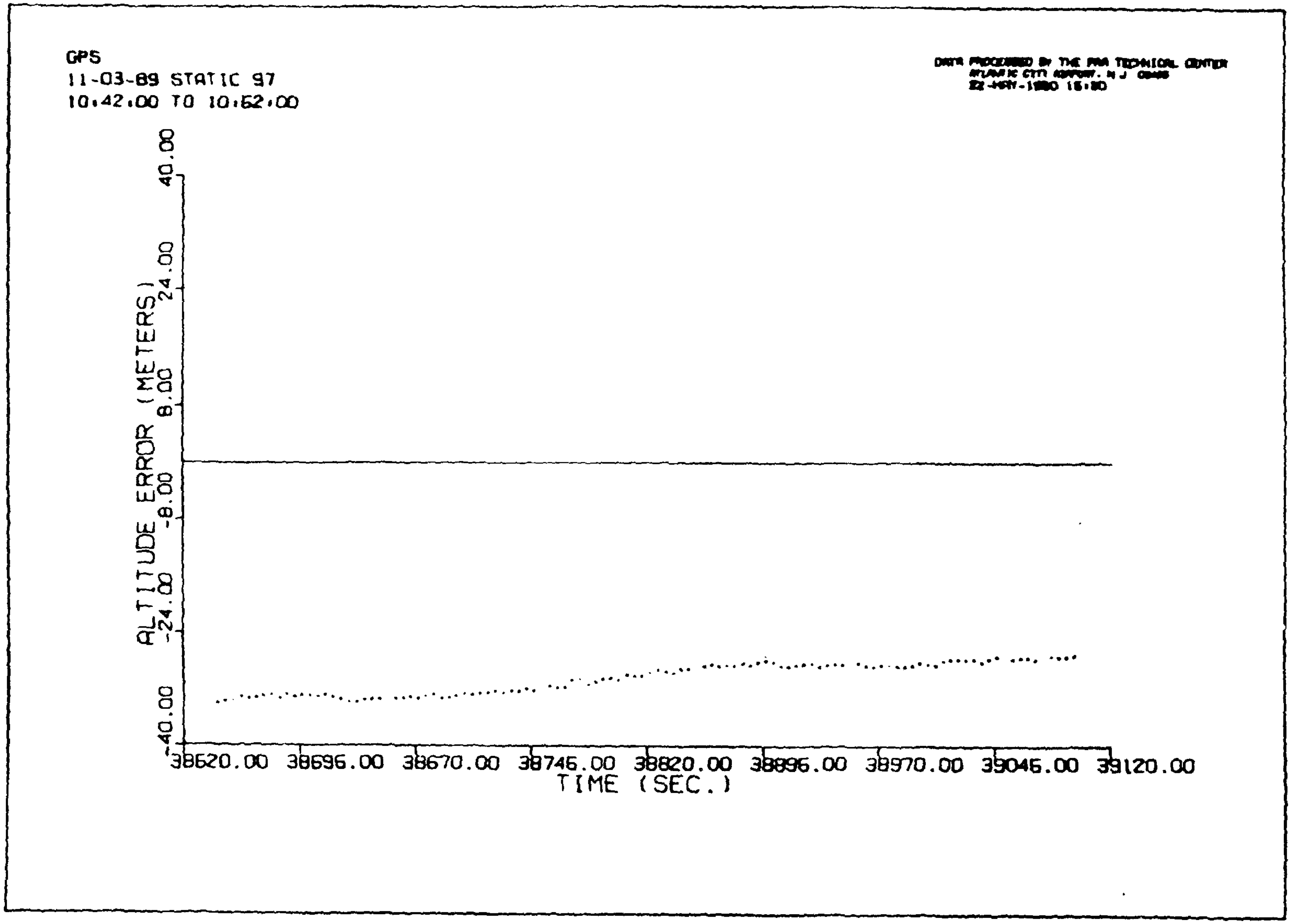


FIGURE D-12. STATIC GPS ALTITUDE ERROR - RUN 11/3

APPENDIX E

FLIGHT TEST STATISTICS AND ERROR PLOTS

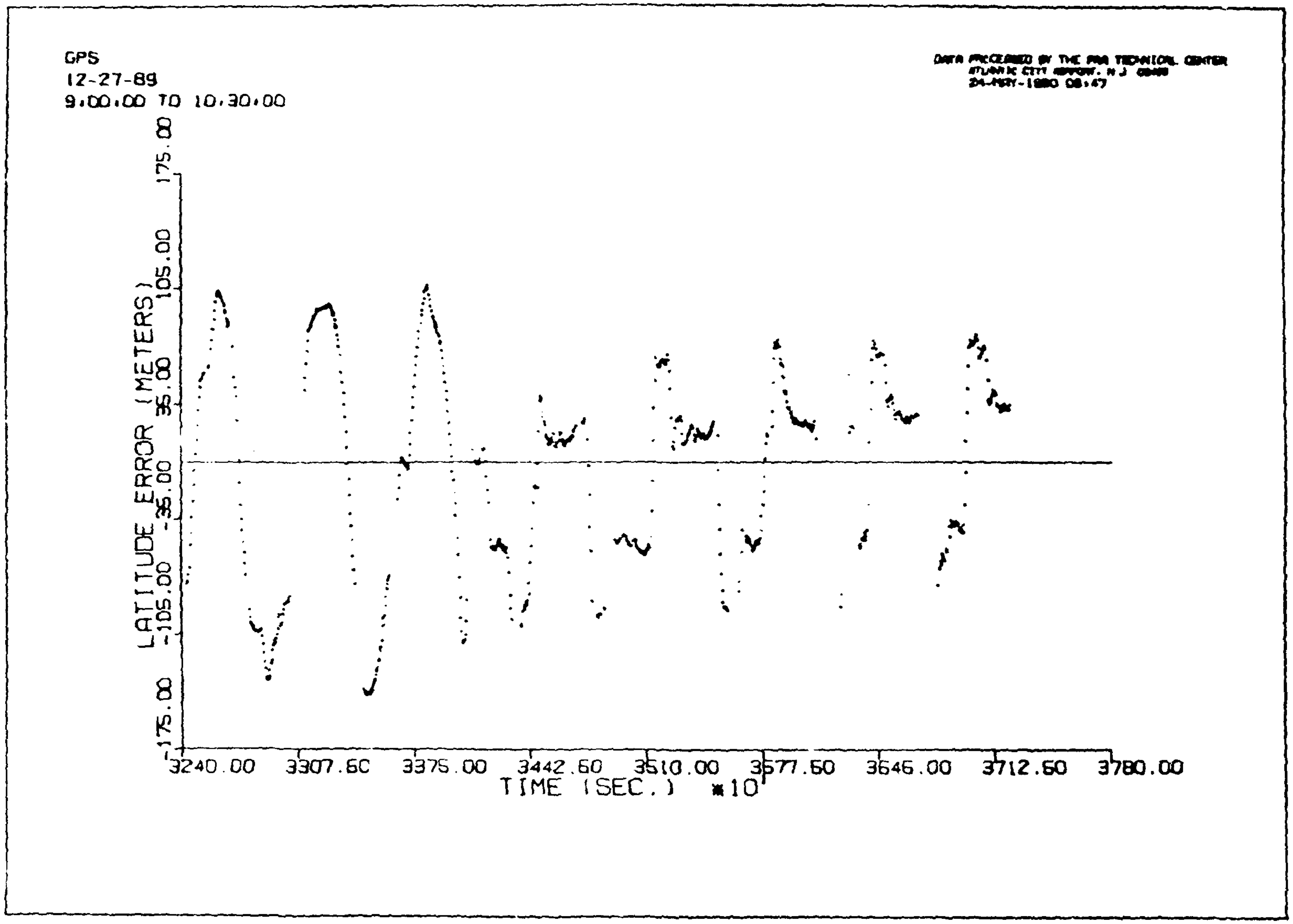


FIGURE E-1. GPS LATITUDE ERROR - FLIGHT 12/27

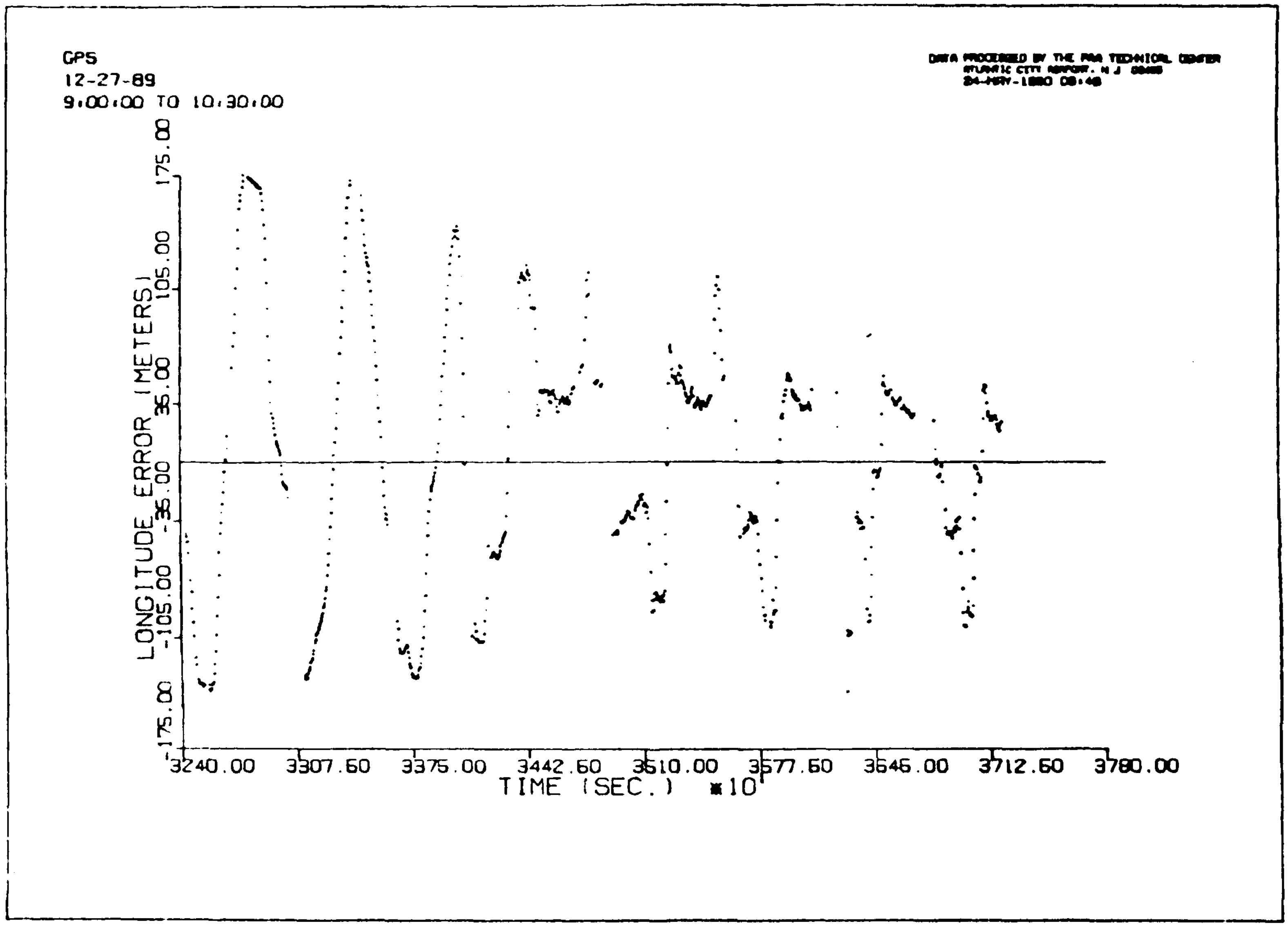


FIGURE E-2. GPS LONGITUDE ERROR - FLIGHT 12/27

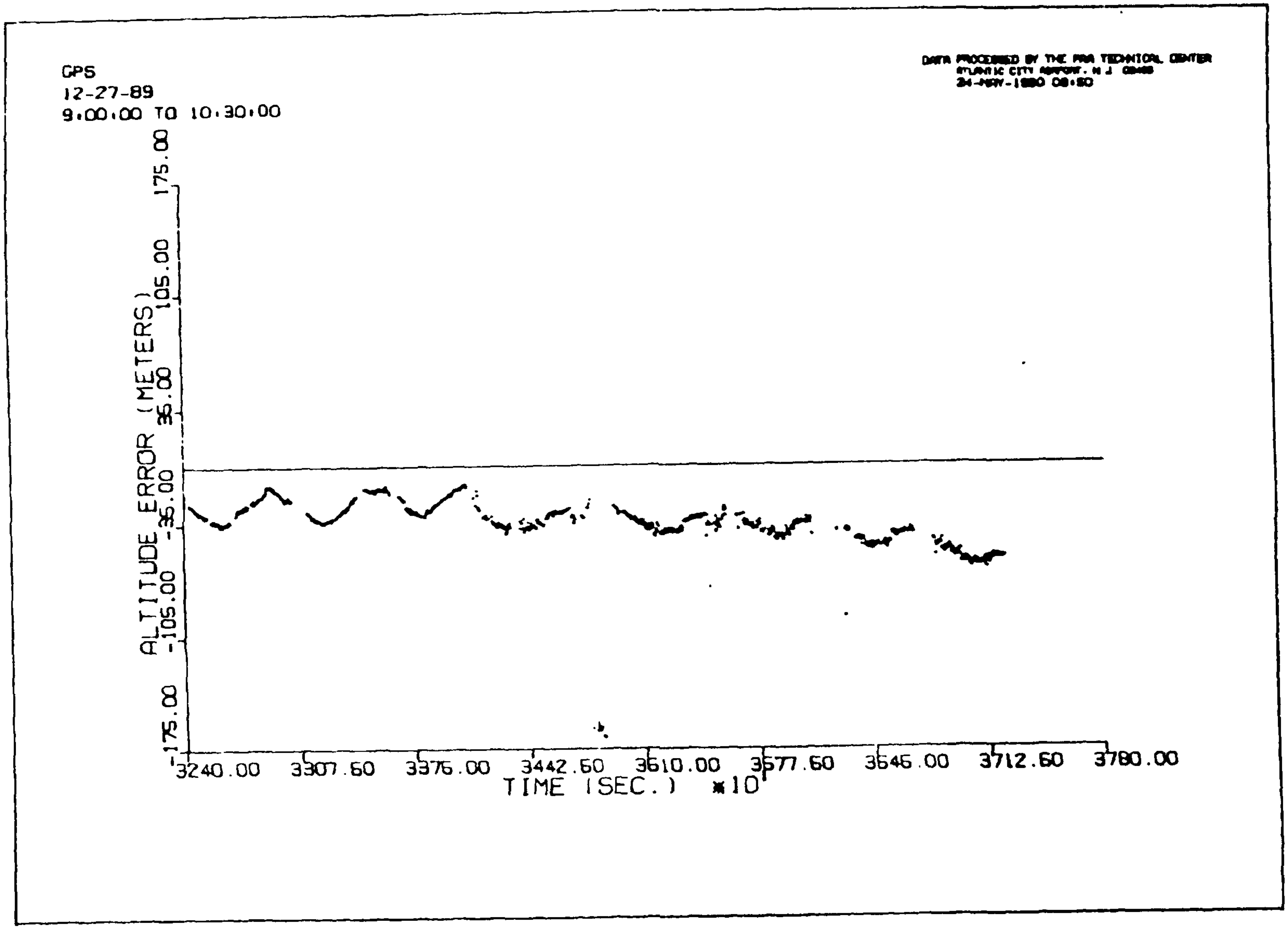


FIGURE E-3. GPS ALTITUDE ERROR - FLIGHT 12/27

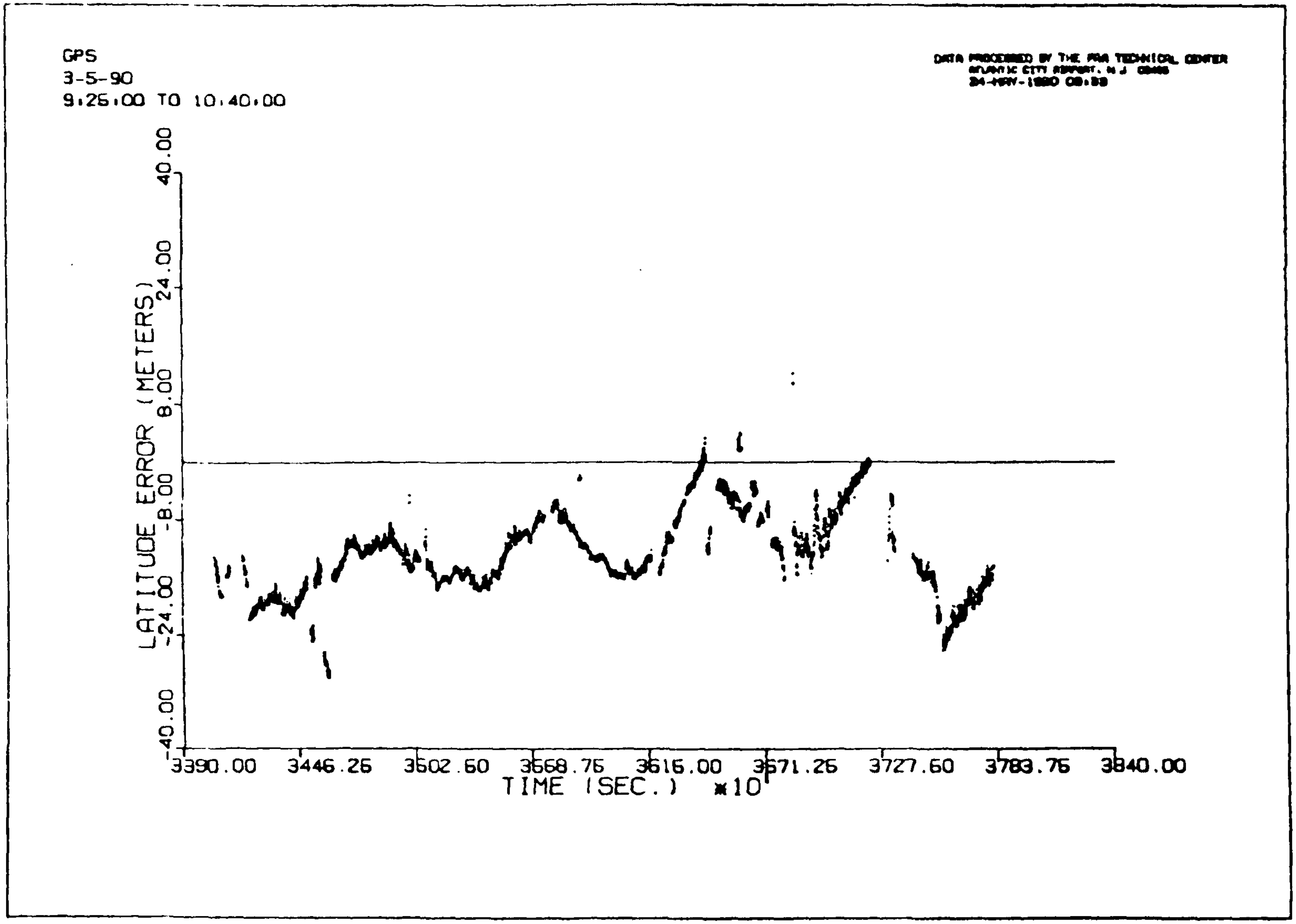


FIGURE E-4. GPS LATITUDE ERROR - FLIGHT 3/5

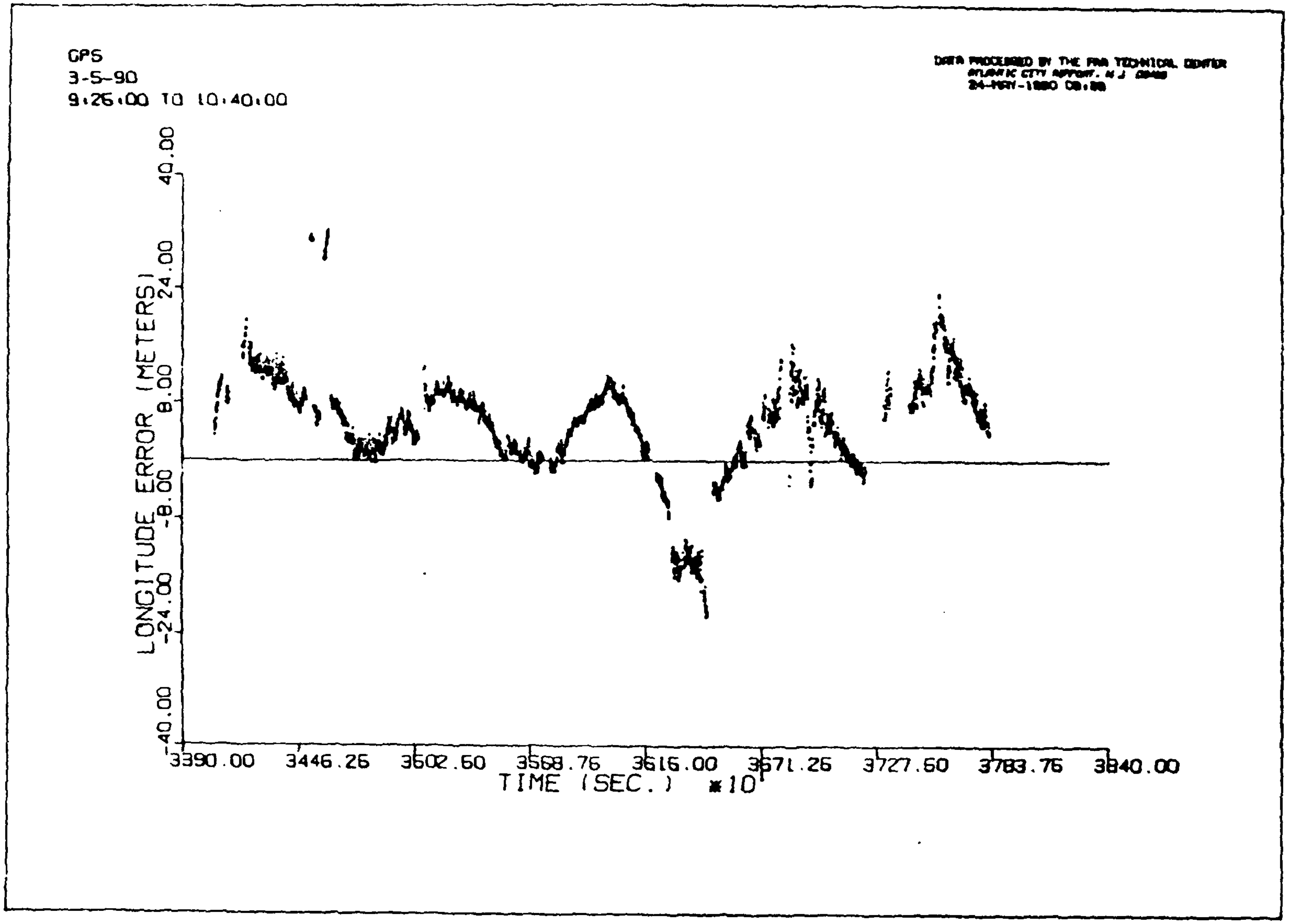


FIGURE E-5. GPS LONGITUDE ERROR - FLIGHT 3/5

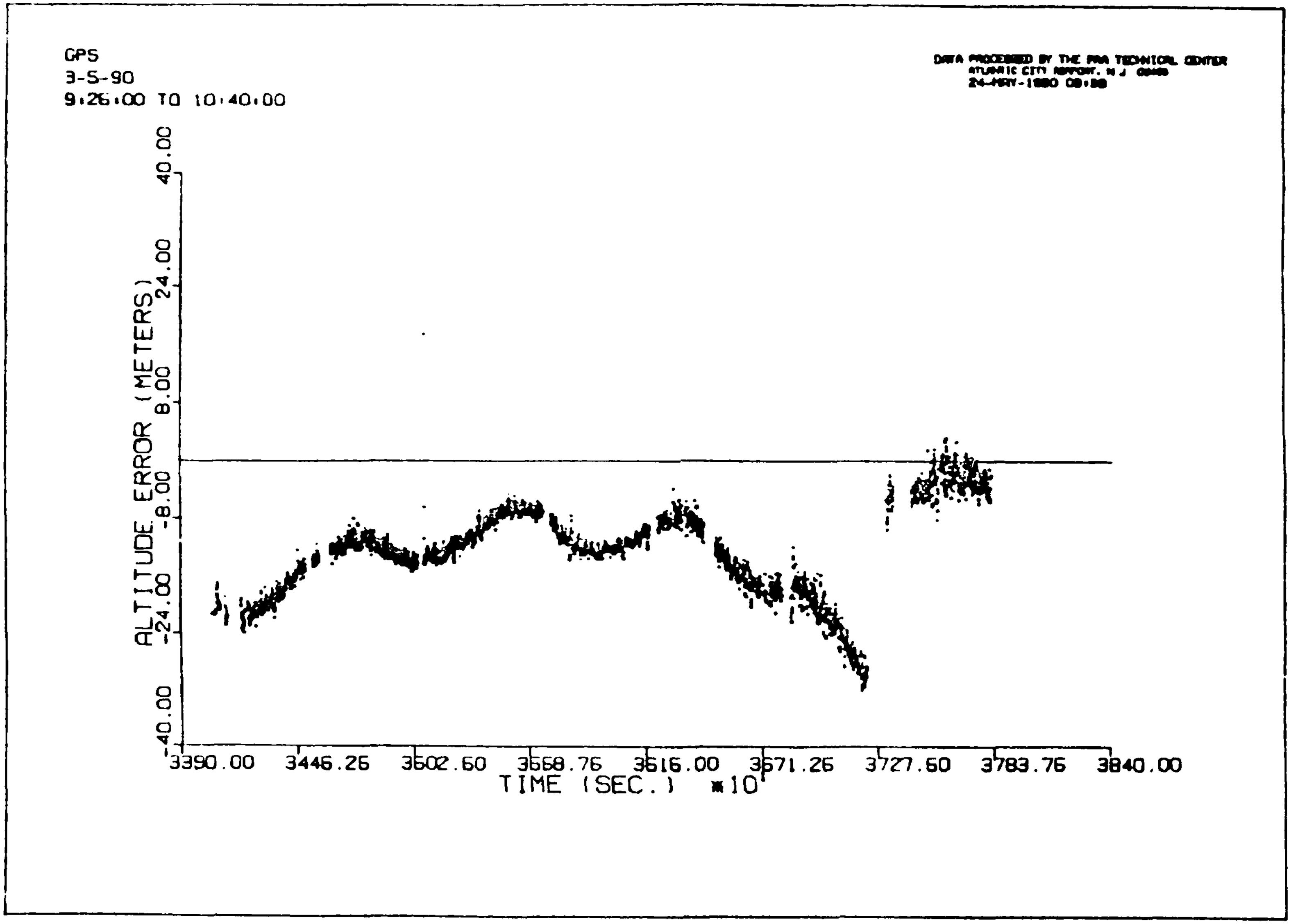


FIGURE E-6. GPS ALTITUDE ERROR - FLIGHT 3/5

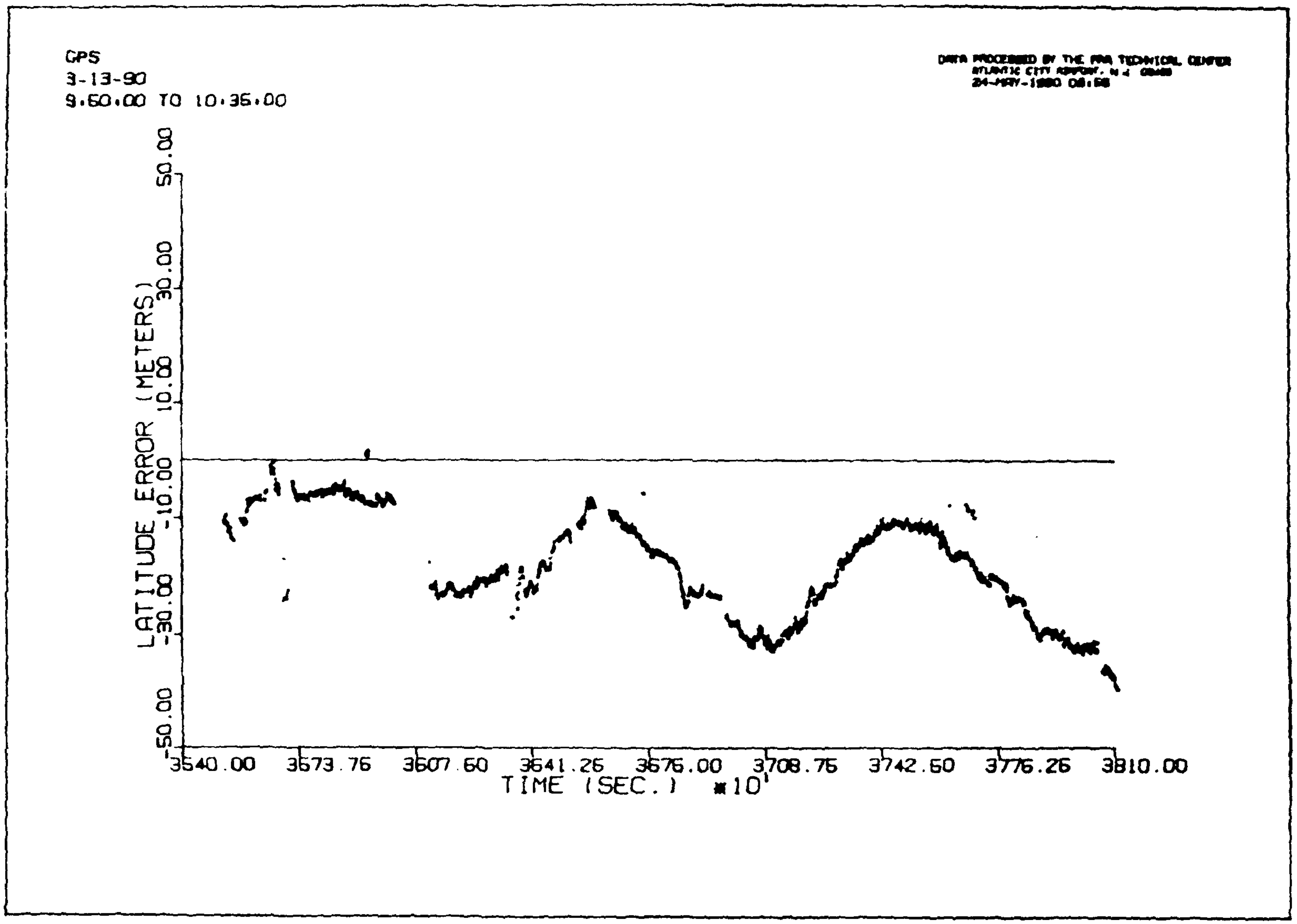


FIGURE E-7. GPS LATITUDE ERROR - FLIGHT 3/13

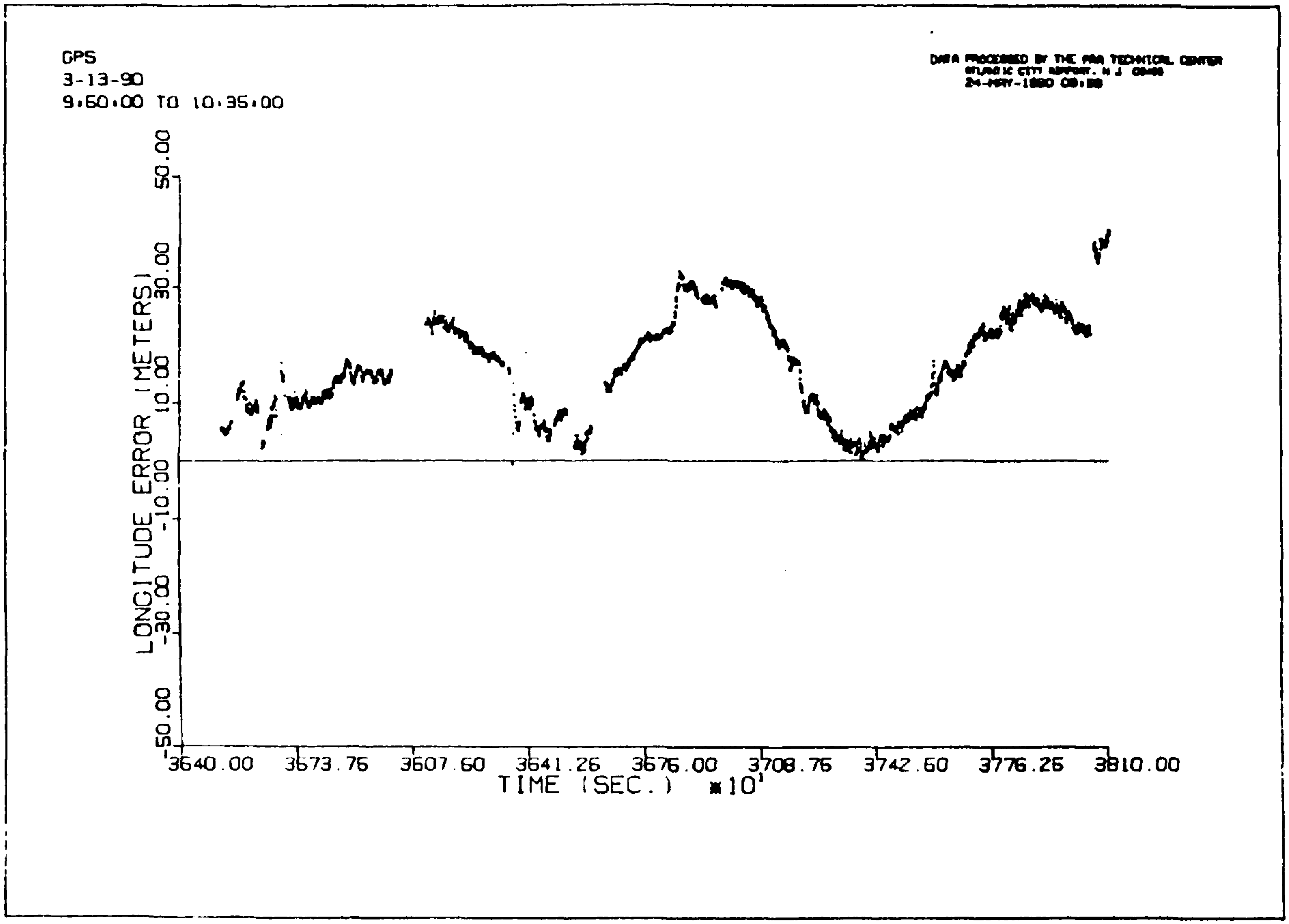


FIGURE E-8. GPS LONGITUDE ERROR - FLIGHT 3/13

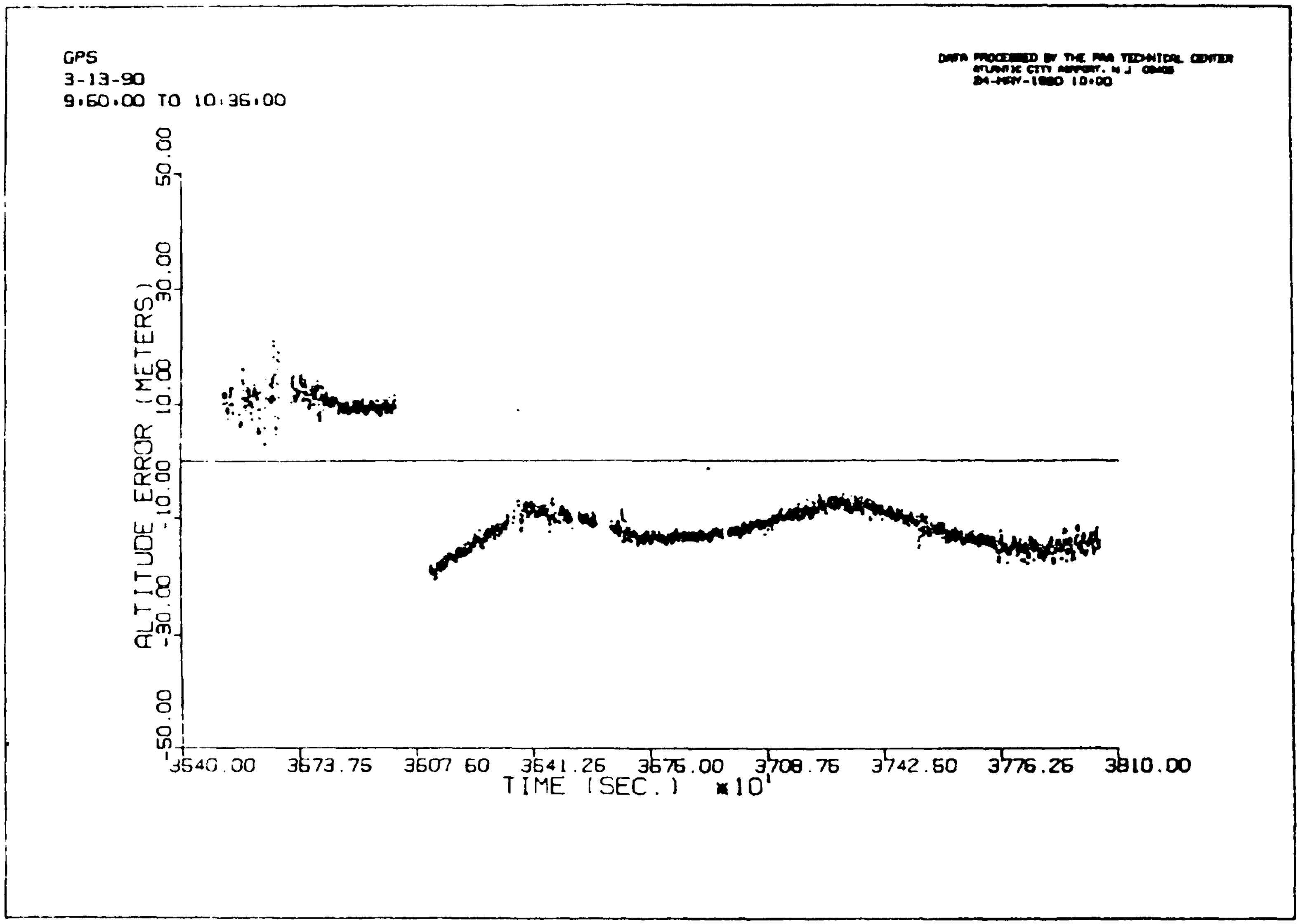


FIGURE E-9. GPS ALTITUDE ERROR - FLIGHT 3/13

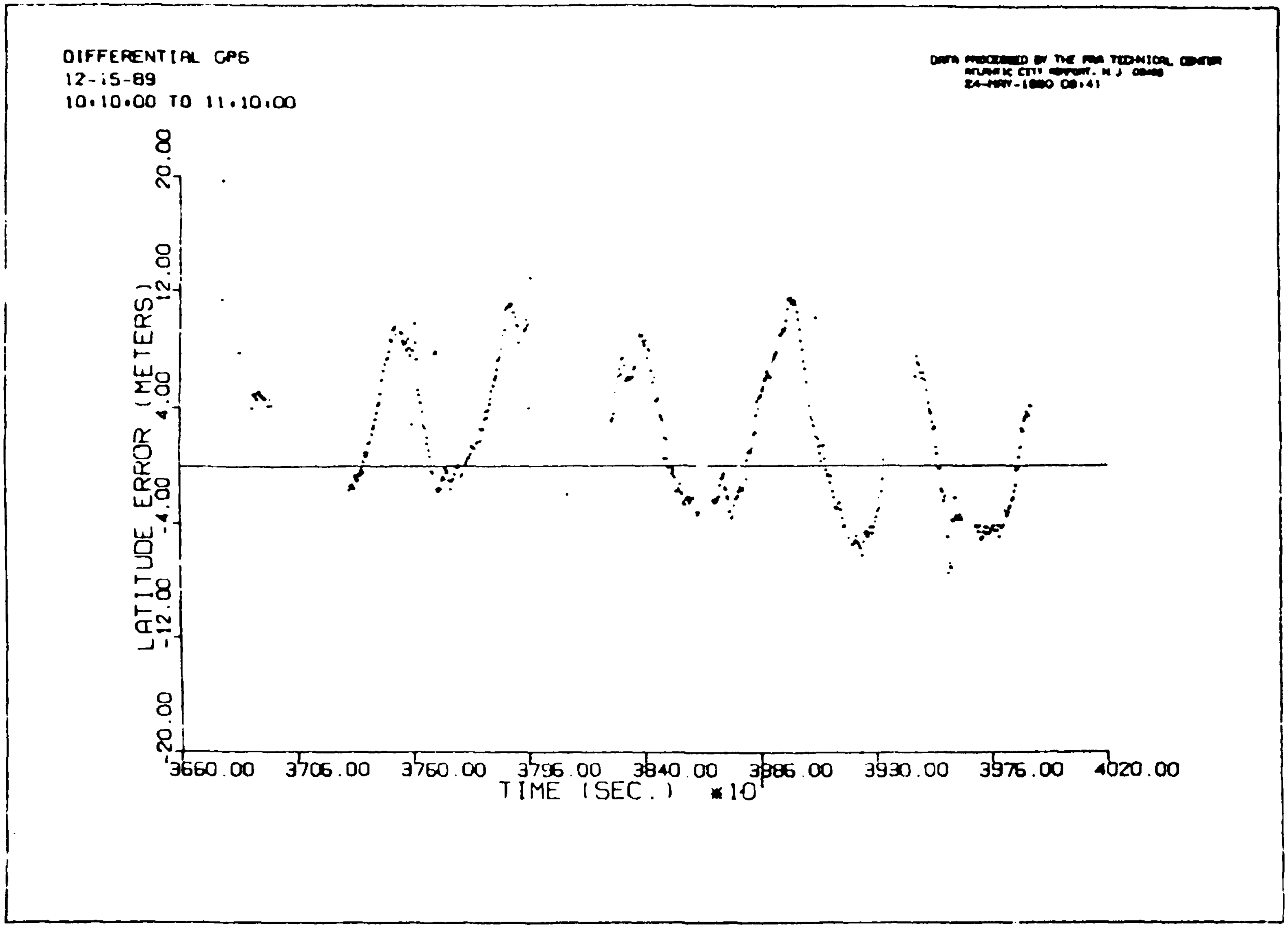


FIGURE 5-10. DGPS LATITUDE ERROR - FLIGHT 12/15

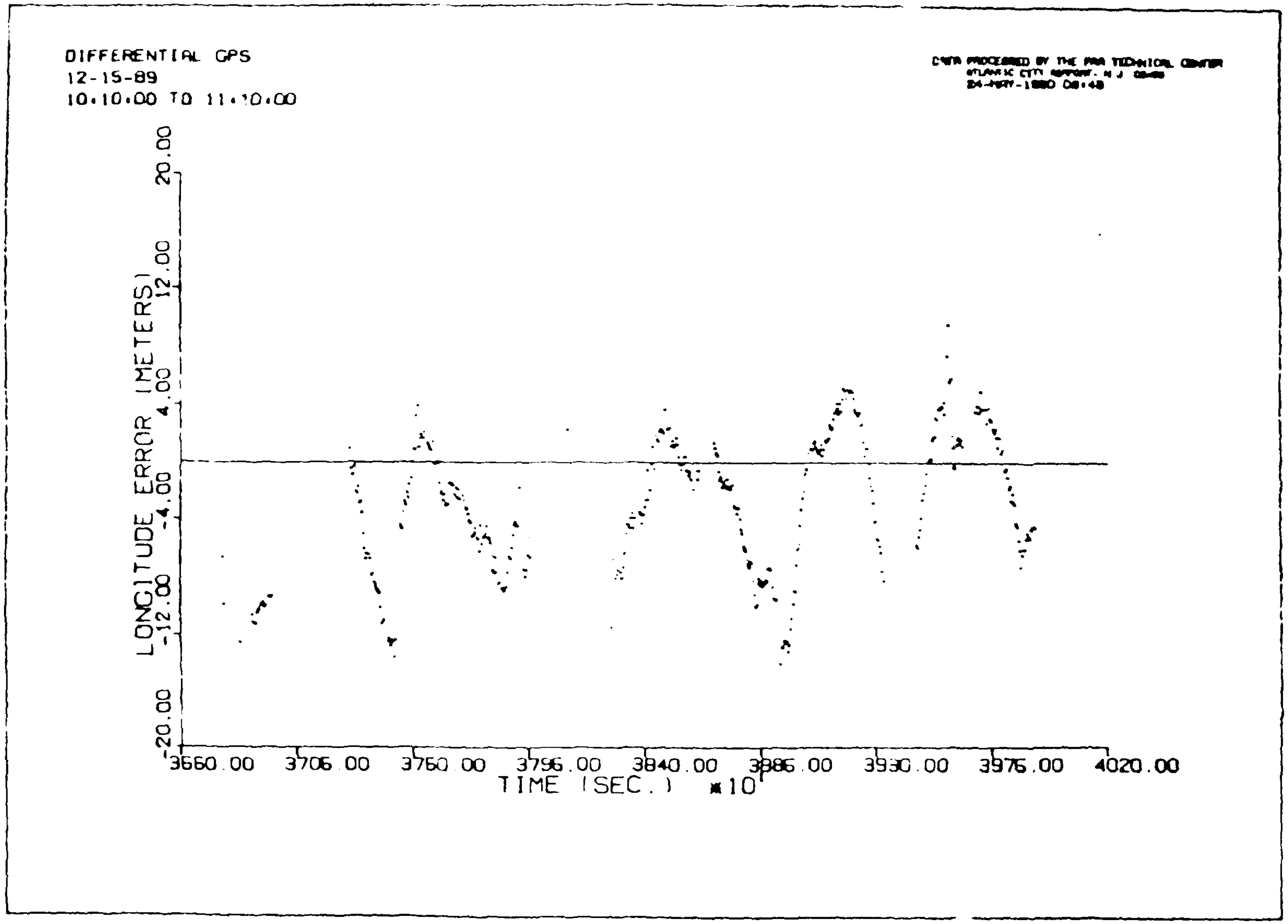


FIGURE E-11. DGPS LONGITUDE ERROR - FLIGHT 12/15

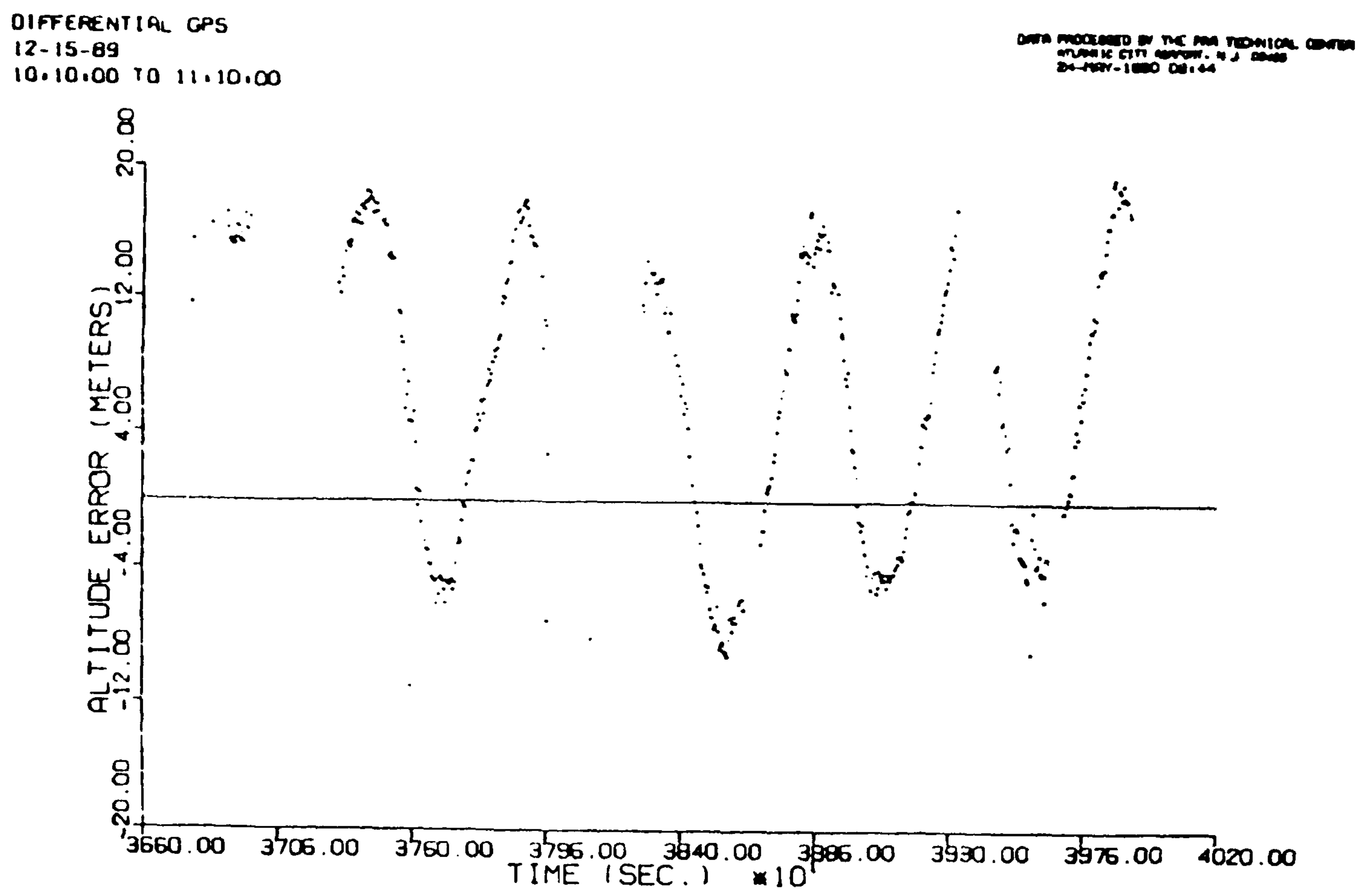


FIGURE E-12. DGPS ALTITUDE ERROR - FLIGHT 12/15

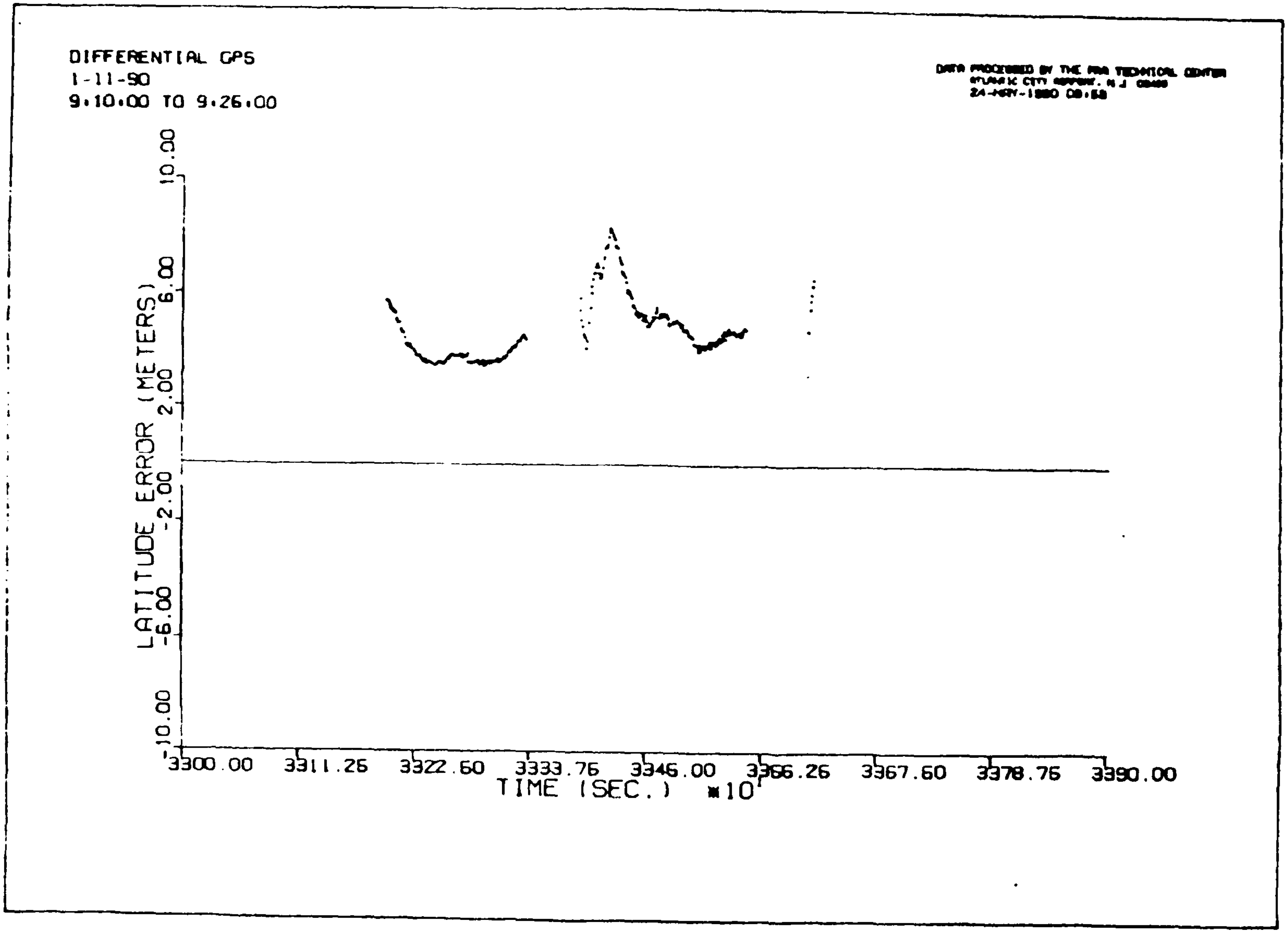


FIGURE E-13. DGPS LATITUDE ERROR - FLIGHT 1/11

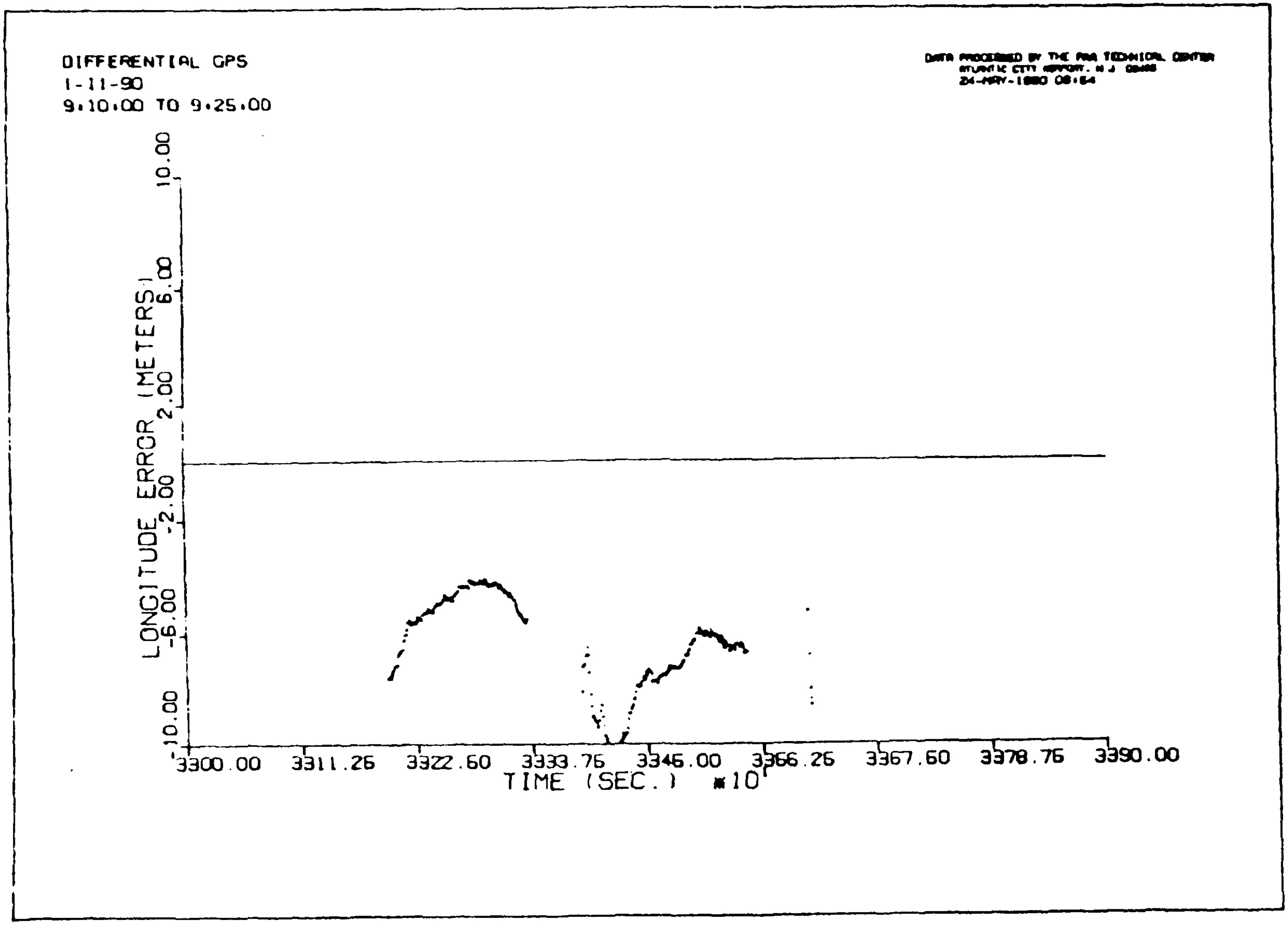


FIGURE E-14. DGPS LONGITUDE ERROR - FLIGHT 1/11

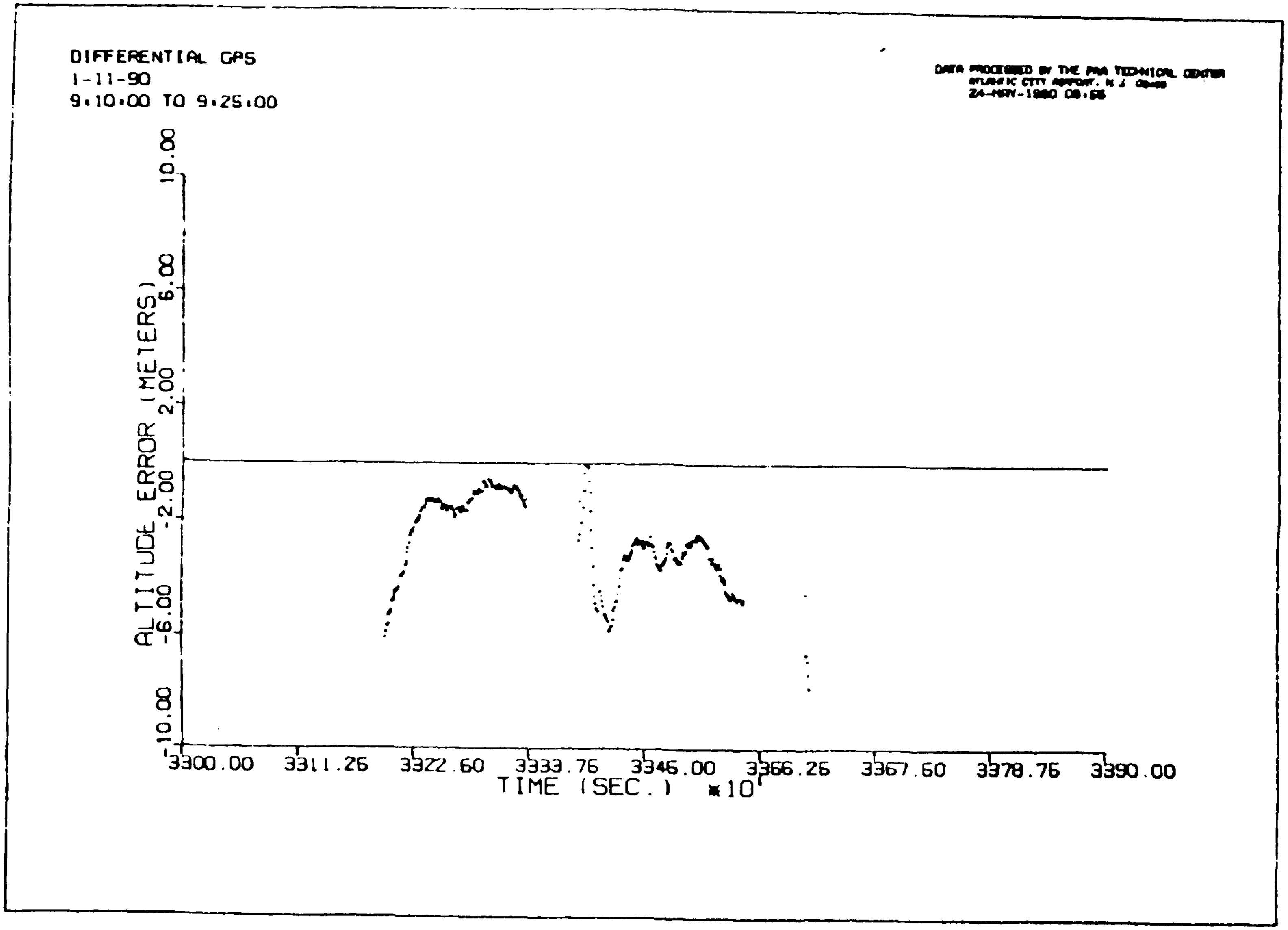


FIGURE E-15. DGPS ALTITUDE ERROR - FLIGHT 1/11

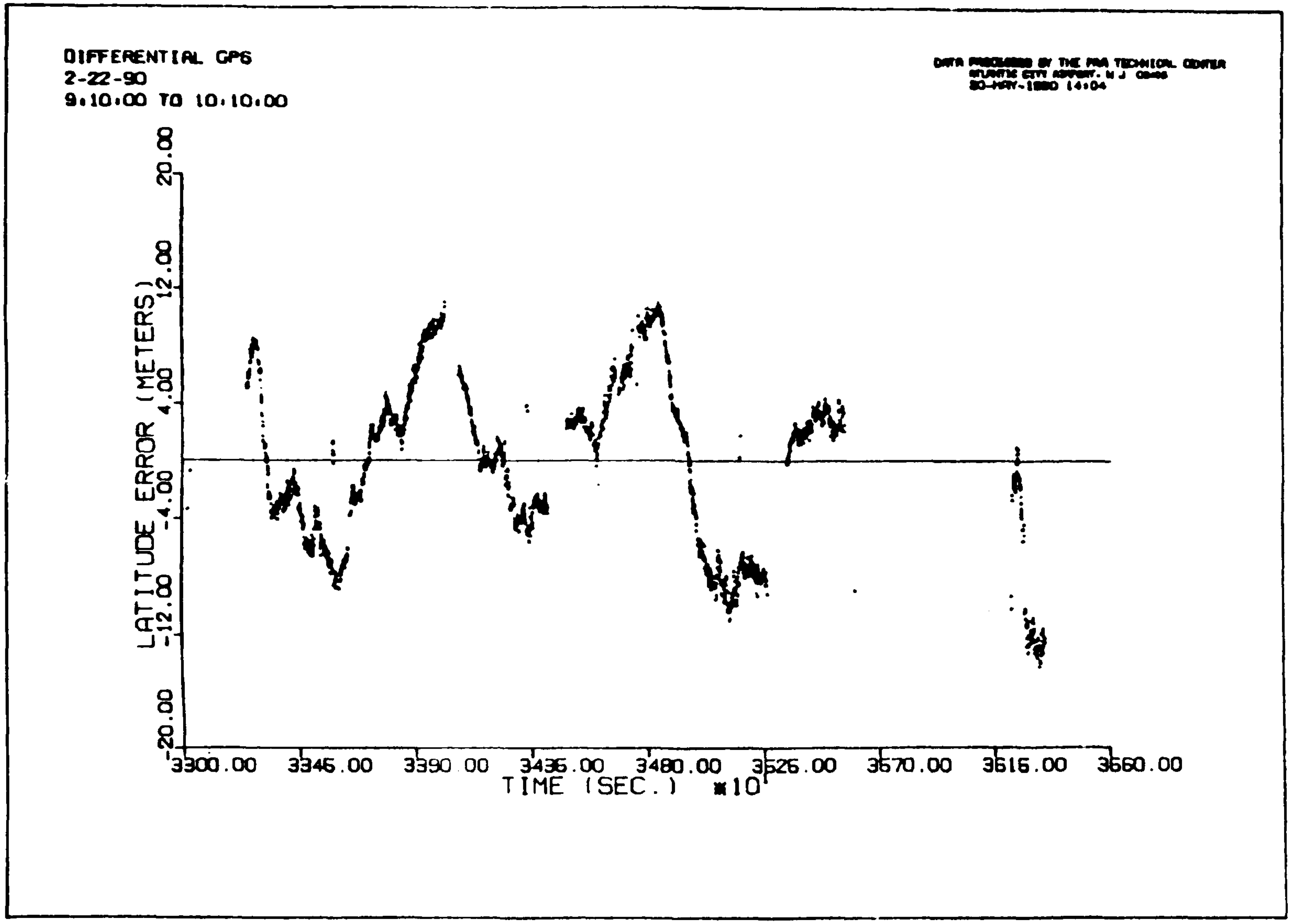


FIGURE E-16. DGPS LATITUDE ERROR - FLIGHT 2/22

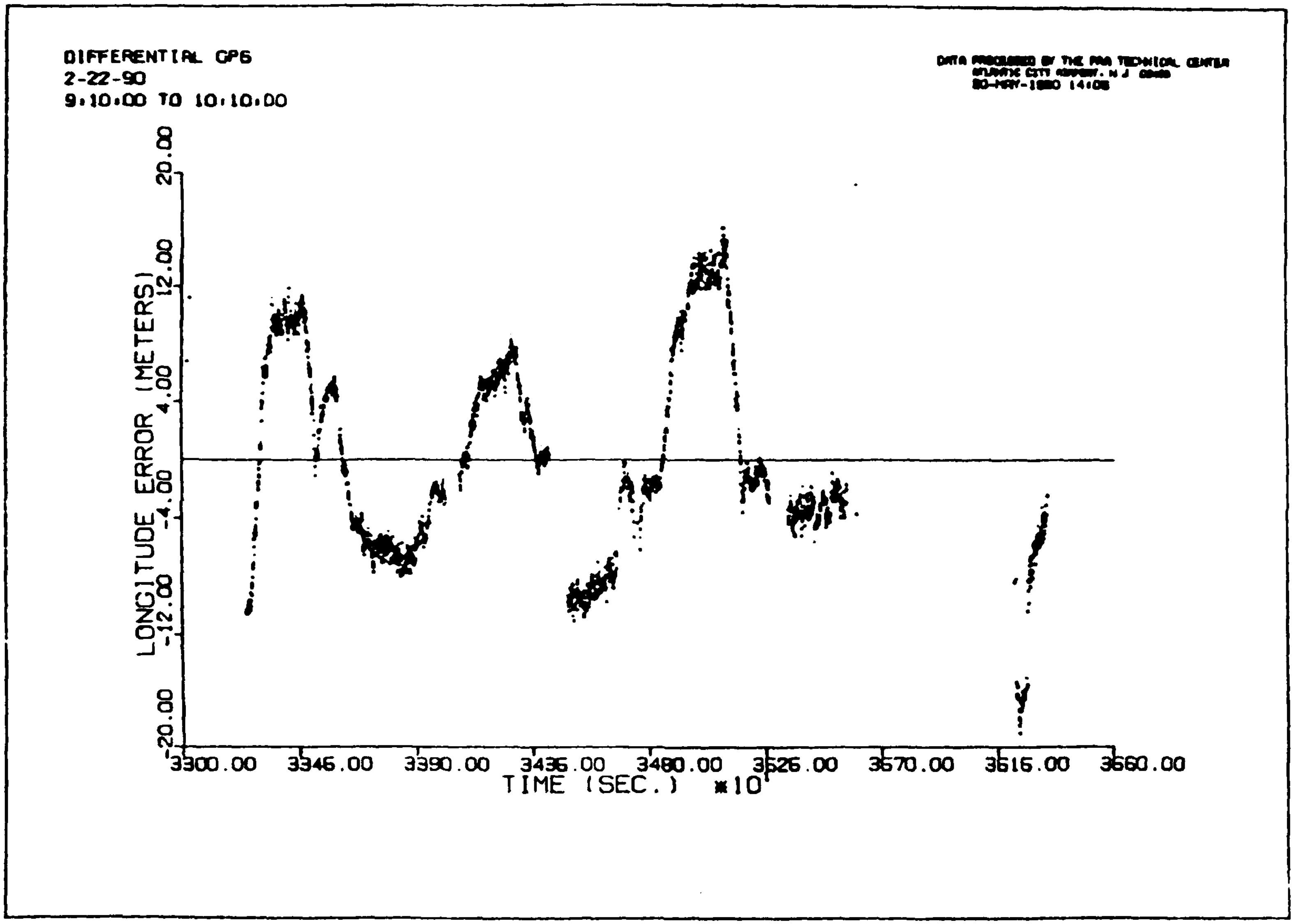


FIGURE E-17. DGPS LONGITUDE ERROR - FLIGHT 2/22

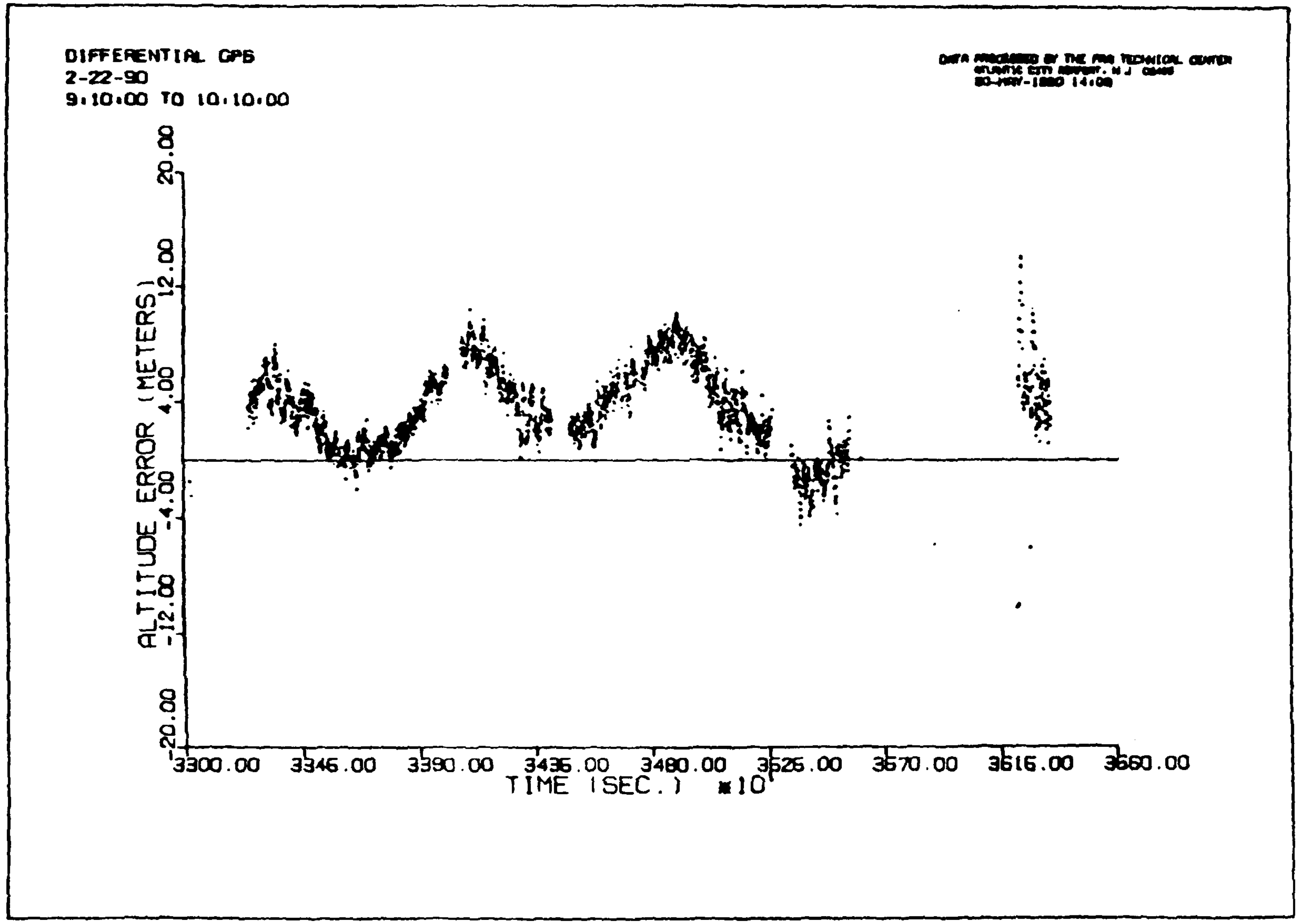


FIGURE E-18. DGPS ALTITUDE ERROR - FLIGHT 2/22