NSWC TR 87-61

DETERMINATION OF TRANET AND SMTP TRACKING STATION COORDINATES FOR USE IN THE WGS 84

BY JAMES P. CUNNINGHAM
STRAEGIC SYSTEMS DEPARTMENT

JUNE 1987

Approved for public release; distribution unlimited.

DESTRUCTION NOTICE -- For classified documents, follow procedures as outlined in Chapter 17 of OPNAVINST 5510.1G. For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

NAVAL SURFACE WEAPONS CENTER
Dahlgren, Virginia 22448-5000 • Silver Spring, Maryland 20903-5000

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

AD-A185 562

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): NSWC TR 87-61	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Naval Surface Weapons Center; 6b. OFFICE SYMBOL (If applicable): K12	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Dahlgren, VA 22448-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Defense Mapping Agency; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): Washington, DC 20362	10. SOURCE OF FUNDING NOS.: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.

11. TITLE (Include Security Classification)
Determination of TRANET and SMTP Tracking Station Coordinates for Use in the WGS 84

12. PERSONAL AUTHOR(S)
Cunningham, James P.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Final	FROM TO	1987, June	33

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Doppler tracking station coordinates; random and systematic errors; Navy Navigation Satellite System (NNSS); orbit determination; TRANET; SMTP; WGS 84; OPNET; doppler pole positions; earth's spin axis; satellite geodesy; point positioning

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

In collaboration with the Defense Mapping Agency (DMA), an effort to prepare Doppler tracking station coordinates for precise NNSS orbit computation in the World Geodetic System 1984 (WGS 84) has been concluded. The level of random and systematic errors in the new coordinates is believed to be significantly lower than in any previous coordinate set, including those used for production orb... computation at DMAHTC. Additionally, the accuracy of Doppler determination of the earth's instantaneous spin axis in the orbit computation has been similarly improved.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED SAME AS RPT. DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code)	22c. OFFICE SYMBOL
James P. Cunningham	(703) 663-8406	K12

DD FORM 1473, 84 MAR EDITION OF 1 APR 83 IS OBSOLETE.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

FOREWORD

This document describes the procedures and analyses used in the developemcnt of the official WGS 84 coordinates. This project was funded by the Defense Mapping Agency under MIPR number HM0027-86-C048.

The success of this project is, in part, attributed to the high quality work contributed by Carol W. Malyevac and Mark G. Tanenbaum of the Space and Ocean Geodesy Branch, and Louis B. Decker and John A. Bangert of the Defense Mapping Agency. This document has been reviewed by J. Ralph Fallin, Head of the Space and Surface System Division.

Approved by:

D. B. COLBY, Head
Strategic Systems Department

ACKNOWLEDGMENT

Special gratitude is given to Mark G. Tanenbaum for the extended effort he contributed to every aspect of this work. His expert help in the design, implementation, and analysis of this experiment as well as his detailed review of this technical report are well appreciated.

CONTENTS

ILLUSTRATIONS

TABLES

TABLES (CONTINUED)

INTRODUCTION

Precise orbit determination for the Navy Navigation Satellite System (NNSS) requires a well defined geodetic system to satisfy the Navy's accuracy requirements. The Defense Mapping Agency (DMA), currently assigned the orbit determination task, has used the Naval Surface Weapons Center's 10E1[1] (NWL10E1) earth gravity model (maximum degree 28 order 27) and 9Z2 tracking station coordinates for nearly a decade.[2] The introduction of the World Geodetic System 1984 (WGS 84) to NNSS precise orbit determination necessarily includes an earth gravity model and a set of well defined satellite tracking station coordinates. The transition from the NWL10E1-9Z2 geodetic system to the WGS 84 for NNSS orbit computations has revealed problems and opportunities not fully recognized by the WGS 84 development committee at the adoptation of the original definition WGS 84 coordinates. This document describes the procedure and analysis used in defining WGS 84 tracking station coordinates for tracking network (TRANET), Special Mission Tracking Program (SMTP), and Operation Network (OPNET) stations.

Fortunately, during the study, all but one of the problems were completely solved, and this unresolved discrepancy (the Z-axis bias) has been reduced to a level of experimental uncertainty. The WGS 84 coordinates adopted as a result of this study also improve the capability of determining the positions of the Earth's pole of rotation. The WGS 84 tracking station coordinates adopted as the official set nearly coincide with the geometrically transformed NWL9Z2 coordinates defined by the WGS 84 development committee. Close agreement between the official WGS 84 coordinates and the NWL9Z2 transformed set was desired because the transformed set was calibrated to remove known errors in the NWL9Z2 system.

The WGS 84 Earth Gravitational Model (EGM) is the superior product of a geophysical effort by DMA. The spherical harmonic coefficients of the WGS 84 up to degree and order 41, were solved by a least squares method after combining the following data types: Doppler satellite tracking (including some NNSS tracking data), satellite laser ranging data, surface gravity data, oceanic geoid heights determined by satellite radar altimeter data, NAVSTAR GPS data, and "lumped coefficients."[3,4]

Although the Doppler NWL10E1/9Z2 geodetic system is one of the most accurate in use, it is known to be in error in scale and Z-axis; its longitudes also disagree with the accepted standard established by the Bureau International de l'Huere (BIH). This geodetic system is the one employed currently by DMAHTC in NNSS precise orbit determination. The scale error[5] is related in part to the error in the central mass term of the gravity field used in this system's development and partially to neglecting the offset of the satellite's antenna from its center of mass in the calculation of tracking station coordinates. It is also suspected that neglected ionospheric refractions effects contributed to the scale error. The source of the Z-axis offset is unexplained but it has been determined that the origin of the NWL9Z2 coordinate system lies above the equatorial plane.[6,7] The zero meridian of the NWL10E1/9Z2 does not coincide with that of the BIH. Evidence indicates that a correction should be added in an eastward direction to the Doppler stations but the amount of the correction is scientifically disputed.[8] To ensure that the North American Datum of 1983 (NAD 83) and the WGS 84 agree in longitude, its correction has been administratively resolved.

Pole positions determined with the NWL9Z2 geodetic system are known to be systematically biased from the internationally accepted BIH pole positions. The source of this bias is not well known,[9] but it was estimated to be a half-meter in both X and Y positions.

DATA

Four 10-day spans of observation data from 1985 were used in this experiment. The four spans are identified in Table 1. Two Navy Navigation Satellites (NNS) were observed and are also identified in Table 1.

Three criteria were used to select these spans:

1. total number of passes
2. number of passes from McMurdo, Antarctica
3. time of year of observation

The total number of passes was considered to achieve the highest density of observations per span as possible. Passes from McMurdo, Antarctica were desired to obtain observations from this isolated part of the world. Each span was chosen to represent a season in order to expose any seasonally related biases. Table 1 shows that each 10-day span had more than 2000 passes. This represents excellent tracking data density. Also, in Table 1 the density of tracking data for all four spans is excellent for the station at McMurdo, Antarctica. Each 10-day span represents a season. There were 60 tracking stations (either TRANET, SMTP, or OPNET) that observed the two satellites during the 40 days.

TABLE 1. PASS SUMMARY OF FOUR 10-DAY DATA SPANS IN 1985

Days	Satellite	Total Number of Passes	Passes from Station at McMurdo, Antarctica
77-86 (March 18- March 27)	NSWC 105 NOVA 1	2183	113
139-148 (May 19- May 28)	NSWC 105 NOVA 1	2217	125
264-273 (September 21- September 26)	NSWC 115 NOVA 3	2072	95
347-356 (December 13- December 22)	NSWC 115 NOVA 3	2065	82

TECHNIQUES

In this section Doppler point positioning is discussed. Because this involves the computations of orbits (ephemerides), point positions, and the comparison of station coordinates the methods of these computations are also discussed. Some geophysical constants and statistical methods used in this study are also summarized.

Finding good WGS 84 station coordinates began with defining the NWL9Z2 tracking station coordinates. After geometrically transforming the NWL9Z2 coordinates to the WGS 84 coordinates an iterative process of forming better WGS 84 coordinates began. An iteration in this experiment consists of orbit determination followed by point positioning. Comparing the starting coordinates of each iteration to the solution coordinates (point positions) of that iteration, the inconsistencies of the starting coordinates were identified. After iterations had been made, persistently large inconsistencies in any parameter (longitude, Z-axis, or scale) indicated lack of convergence in that parameter.

The calculation of point positions requires a precise orbit and a corresponding set of observation data. The point positions of the NWL9Z2 were determined with orbits computed at DMAHTC and their observation data. The coordinates used currently by DMAHTC in NNSS orbit determination were the NWL9Z2 starting coordinates in this study. The geometric transformation for obtaining WGS 84 coordinates is to apply

1. 0.814 arcsec in longitude
2. −0.6 ppm in scale
3. 4.5 m to the Z-axis

to the NWL9Z2 coordinates. Using these geometrically transformed coordinates, orbits were calculated in the WGS 84 with the same observations (with a small number of exceptions discussed below) used to generate NWL9Z2 orbits. With similar observation data and these WGS 84 orbits, point positions were made with their starting coordinates being those used to generate the orbits. Both orbits and point positions were determined in similar iterative least squares calculations based on the same principles of data editing and geodetic modeling of observations, stations, and orbits.

The current iteration's starting coordinates and point positions were compared in a least squares sense to expose systematic biases between them. When the systematic differences in any of the parameters became large enough to indicate divergence from the starting coordinates, the procedure was repeated, recomputing orbits using these current point positions; using these orbits, new point positions, and a new analysis of systematic differences, as described above, were made. In this way the method of producing point positions was iterated until a satisfactory solution was reached.

Observation data used in both point positioning and orbit calculations were obtained after a preprocessor had removed garbled data, applied time corrections, and converted raw data to range-difference measurements. The data were iteratively edited in two phases, point editing and pass editing, in both the point positioning and orbit calculations. Initially in both these calculations, point and pass editing were not controlled; differences exist between the points and passes used in orbit and point positioning calculations of the NWL9Z2 and WGS 84 coordinates. Not until after the third iteration of the WGS 84 coordinate calculations, were data editing controls introduced and only in the last iteration were point and pass editing controls applied in both orbit and point positioning calculations.

In the orbit computation program CELEST,[10] a least squares solution is made in an Earth-centered coordinate system for the orbital elements and other chosen parameters. Point editing, on the basis of a single pass, rejects observation data points if their residuals from a previous navigation exceed a constant multiple of the estimated errors of that pass. This process, called point filtering, continues iteratively until data and observation accuracies of the previous cycle are obtained or the maximum number of cycles is encountered. A "filtered" observation file, created from this process contains good observations and best estimates of their standard errors.

Point editing described above and pass editing both utilize navigation, which is a least squares solution based on each satellite pass where bias parameters and directional displacements of station position are solved. At the time of the satellite's closest approach to the station, the two directional displacements defined are the navigation's tangential and radial residuals. The tangential direction is parallel to the satellite's velocity, and the radial direction is along the line of sight from the satellite to the station. The navigation's tangential residuals are conventionally taken as a measure of the orbit's quality, though they represent a combination of orbit, station and timing errors, and noise. These residuals' statistics, particularly the rws defined later in this section, are quoted in the results.

At the conclusion of point filtering, a new orbit, defined by acceptable passes, and a new navigation are computed; beginning the iterative process of editing passes called pass filtering. Passes are rejected from the orbit computation if either the navigation's tangential or radial residuals deviate significantly from their estimated values. Pass filtering converges when the same passes are rejected in two consecutive iterations and ends with convergence or when the maximum number of iterations is encountered.

Orbit determination made in each of the iterations allowed six iterations of pass filtering before it terminated. Usual parameters solved for in orbit computation are the six orbital elements, some station coordinates, frequency and refraction corrections for each pass, polar motion, drag coefficients, and model error compensation. The satellites studied in this experiment are drag-free, so an along-track acceleration was solved instead of drag.

A least squares solution for the Earth-fixed coordinates of each Doppler tracking station for each pass was made in the point positioning program GEOCEIVER. For each pass, an iterative procedure of point editing was done. In a least squares calculation for only two parameters of station position, data points were rejected if their range difference residuals exceeded a multiple of their estimated errors. In this procedure, a frequency bias and a tropospheric refraction parameter with a priori model assigned a standard error of 10 percent were also solved for each pass. Point editing stopped when the range difference residuals from two consecutive iterations matched; otherwise it continued until an insufficient number of points were present to make a solution, and the pass was rejected. After point editing, an iterative procedure of pass editing followed. With the orbit held fixed, a navigation was made using the current station coordinates. Passes were rejected if this navigation's residuals were greater than a multiple of the rms of these deviations for all passes. Station positions and the pass parameters were solved with the remaining passes. Point editing varied slightly in each system.

In the program MODSKIJ, seven parameters (three translations, three rotations, and scale) of the point positions' displacements from their starting coordinates were determined in a least squares sense to expose systematic changes. Only three of these parameters (Z-axis, longitude, and scale), representing known systematic errors in the NWL9Z2, are reported here. If their displacements were significantly larger than the norm, stations were rejected from the set in an iterative procedure. The remainder of stations defined the displacements in the seven parameters. All comparisons of coordinates in this study were made with the MODSKIJ program.

During orbit determination in the NWL10E1-9Z2 geodetic system spherical harmonic coefficients of degree 28 and order 27 were used. In the WGS 84 orbit calculations, spherical harmonic coefficients to degree and order 41 were used. The value of GM (G is the gravitational constant; M is the mass of the earth) used with the NWL10E1-9Z2 was 398601.0 $km^3 s^{-2}$; the value associated with the WGS 84 was 398600.5 $km^3 s^{-2}$. In the computations of the ephemerides an antenna offset of 1.6 m was applied in both systems. When adjusting station coordinates, this antenna offset was applied only to the WGS 84. The speed of light used throughout the experiment was 299792.458 $km\ s^{-1}$.

The root weighted squares (rws) of the navigation tangential residuals were calculated as follows:

$$rws_T = (\Sigma_i (\Delta N_{Ti}\, w_{Ti})^2 / (w_{Ti})^2)^{\frac{1}{2}} \tag{1}$$

with

$$w_{Ti}^2 = \frac{1}{\sigma_{Ti}^2 + (\sigma_{bias\ i}^2)} \tag{2}$$

The tangential rws is considered a good overall measure of residual orbit or station errors. The rws of the navigation radial residuals were calculated in this similar manner:

$$rws_R = (\Sigma_i (\Delta N_{Ri}\, w_{Ri})^2 / (w_{Ri})^2)^{\frac{1}{2}} \tag{3}$$

with

$$w_{Ri}^2 = \frac{1}{\sigma_{Ri}^2 + (\sigma_{bias\ i}^2)} \tag{4}$$

In these equations the set of the navigation's tangential residuals are represented by N_T and the navigation's radial residuals by N_R. The bias applied in this experiment was 3 m.

The signal-to-noise ratios presented as statistics of the orbits indicate how well each complete Doppler data set fits the entire long arc solution; a value of one is a perfect fit.

DISCUSSION

This section is divided into three subsections. The first subsection reviews the results of the NWL9Z2 point positioning and the first three WGS 84 iterations. The second subsection reviews the six later WGS 84 iterations, and the third subsection reviews results of a preliminary polar motion study.

Comparisons of starting coordinates and point positions were made to identify inconsistencies in the NWL9Z2 coordinates and in the iterations that lead to development of the WGS 84 coordinates. The comparisons were made for each of the four data spans and the combined solutions. Analysis of these comparisons formed the basis of most conclusions. The locations of the Earth's instantaneous spin axis (pole of rotation) determined in the WGS 84 were compared with those determined in the NWL10E1-9Z2 and with other systems' pole positions obtained from the open literature. Conclusions about the tracking stations coordinates were drawn based on these comparisons.

ITERATIONS ONE, TWO, THREE

Point positions were made with the four 10-day spans described above. In the WGS 84 iterations and the solitary NWL9Z2 procedure, point positions were made in each span separately and then in a combined 40-day solution. The 40-day combined solution coordinates were the only candidates for defining the WGS 84 tracking station coordinates. Comparisons within each 10-day span were made only to enhance the experiments analysis. Orbits were computed for most iterations except when the effects of data editing in the point positioning program were studied. When orbits were computed, they were made in one-day durations in the span of days 77-86, and two-day durations in the remaining three 10-day spans. The 5- or 10-short arcs corresponding to a data span were merged into a 10-day long arc used in point positioning.

The solution NWL9Z2 point positions differed from their starting coordinates (the same used by DMAHTC in production orbit computations) in the Z-axis parameter by 80 cm (Table 2) and were consistent in scale and longitude. The NWL9Z2 coordinates rotated a half-meter about the X and Y axes relative to their starting coordinates. The meaning of this rotation will be discussed later in the section concerning the location of the earth's instantaneous spin axis.

The geometric transformation applied to the redefined NWL9Z2 coordinates was

1. 0.814 arcsec in longitude
2. 3.7 m in Z-axis
3. −0.6 ppm in scale

The reduction in the Z-axis parameter transformation, from the official WGS 84 value of 4.5 m, was to compensate for the systematic differences seen in that parameter in Table 2. When this transformation was applied to the NWL9Z2 point positions the systematic differences between the NWL9Z2 starting coordinates and the transformed WGS 84 coordinates (Table 3) were exactly the transformation defined in the TECHNIQUES section.

TABLE 2. SYSTEMATIC DIFFERENCES BETWEEN NWL9Z2 STARTING COORDINATES AND NWL9Z2 POINT POSITIONS*

Data	X	Y	Longitude	Z-Axis	Scale
40 days	0.5	0.5	−0.1	0.8	0.0

*All differences in meters

TABLE 3. SYSTEMATIC DIFFERENCES BETWEEN NWL9Z2 STARTING COORDINATES AND "TRANSFORMED" WGS 84 COORDINATES*

Data	Longitude	Z-Axis	Scale
All spans	25.0	4.5	−3.8

*All differences in meters

The first iteration in the WGS 84 used these transformed coordinates in orbit determination. The statistics of the orbits are presented in Table 4. Using the tangential direction residuals as a measure of orbit quality, the orbits of NOVA 3 (NSWC 115) were better than those of NOVA 1 (NSWC 105). The predicted signal-to-noise ratios associated with NOVA 3 were more often closer to unity than they were for NOVA 1. This is another indication that NOVA 3 orbits were better than NOVA 1 orbits.

The orbit and observation data of day 77 were omitted from the point positioning procedure because of inexplicable peculiarities seen in that day's orbit navigation statistics. The last 13 passes observed for day 77 had negative residuals. Because the probability of such an occurrence is remote, it was suggested a problem existed with that day's data. For consistency throughout the experiment, data from day 77 was excluded from any further orbit or point positioning calculations.

TABLE 4. STATISTICS OF ORBIT NAVIGATION
WGS 84 FIRST ITERATION

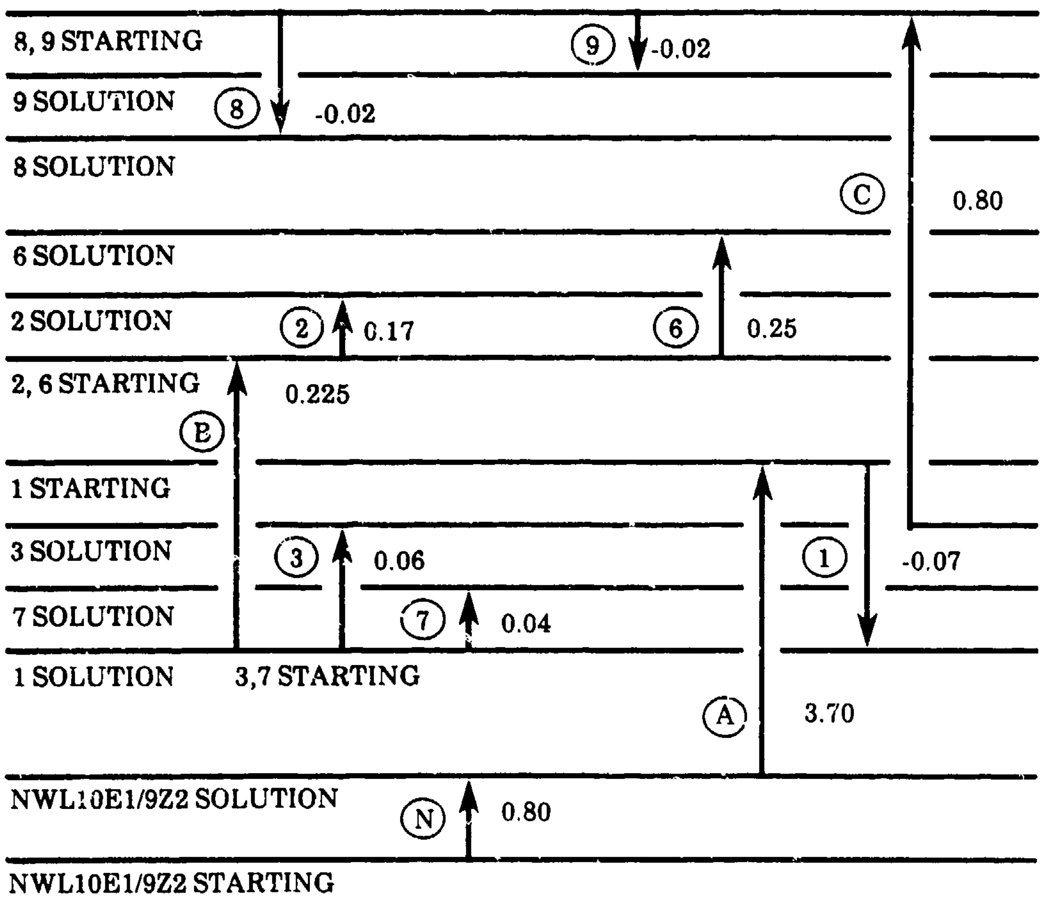
Days	Radial RWS (m)	Tangential RWS (m)	Predicted S/N
NSWC 105			
77	1.4	1.7	1.080
78	1.1	1.5	1.120
79	1.3	1.0	1.101
80	1.1	1.6	1.155
81	1.2	1.0	1.064
82	1.1	1.2	1.104
83	1.1	1.3	1.147
84	1.0	1.0	1.092
85	1.3	1.2	1.119
86	1.1	1.1	1.097
139-140	1.2	1.1	1.041
141-142	1.1	1.1	1.056
143-144	1.1	1.1	1.058
145-146	1.1	1.2	1.060
147-148	1.1	1.0	1.057
NSWC 115			
264-265	1.2	0.6	1.040
266-267	1.1	0.7	1.045
268-269	1.2	0.7	1.057
270-271	1.1	0.7	1.046
272-273	1.1	0.6	1.034
347-348	1.3	1.0	1.064
349-350	1.2	0.8	1.093
351-352	1.1	0.7	1.060
353-354	1.2	0.7	1.047
355-356	1.0	0.7	1.045

The comparisons of starting coordinates and point positions of iteration one are in Table 5. In the individual data spans and the 39 days combined solution, the scale parameter showed an inconsistency of 1m, which is attributed to uncompensated ionospheric refraction. The sign of this inconsistency indicated that the point positions have a greater radii than the transformed NWL9Z2 coordinates. The longitude parameter shows consistency between starting coordinates and point positions. Throughout the remainder of the experiment, the stations' longitude remained consistent, so discussion of it will be postponed until conclusions are made. The Z-axis parameter exhibited a small inconsistency. The negative sign of this inconsistency means the point positions are below their starting coordinates on the Z-axis (Figure 1). Although the Z-axis and longitude parameters both exhibit very small inconsistencies, the Z-parameter was suspected to have a greater inconsistency than was exposed (see below). However, the entire longitude inconsistency was believed exposed here and so deemed insignificant. In this iteration, there were also rotations about the X and Y axes (Table 5).

TABLE 5. SYSTEMATIC DIFFERENCES BETWEEN STARTING COORDINATES AND POINT POSITIONS FOR ITERATION ONE*

Year 1985 Data Spans	X	Y	Longitude	Z-Axis	Scale
77-86	−1.4	−0.2	−0.2	0.7	0.9
139-148	−1.2	−0.8	−0.1	0.1	0.9
264-273	−0.9	−0.6	0.1	−0.4	1.1
347-356	−1.0	−0.6	−0.2	−0.5	1.1
Combine 39 Days**	−1.0	−0.6	−0.1	−0.1	1.0

*All differences in meters
**Day 77 omitted from solution



(N) NWL9Z2 STARTING COORDINATES 80 CM BELOW NWL9Z2 SOLUTION
(A) TRANSFORMATION FROM NWL9Z2 TO WGS 84
(B) 22.5 CM ADDED TO START ITERATION 2
(C) 80 CM APPLIED TO START ITERATIONS 8 AND 9
(1) CIRCLED NUMBER REPRESENTS WGS 84 ITERATION

FIGURE 1. REPRESENTATION OF SYSTEMATIC DIFFERENCES IN Z AXIS BETWEEN STARTING COORDINATES AND SOLUTION POINT POSITIONS (ALL DIFFERENCES IN METERS, NO SCALE)

Inconsistencies in the NWL10E1/9Z2 system were expected; earlier studies indicated the Z-axis offset by about 4 m.[5,6,7] In this experiment, an inconsistency in the Z-axis of about 1 m was observed (Table 2), which indicates that this experiment lacks the sensitivity to bare the entire inconsistency. This lack of sensitivity may stem from the employed method of determining orbits and point positions. In the orbit determinations, most of the stations were held fixed causing a loss in the Z-axis component of the satellite's orbit. Further, in the point positioning procedures similar losses occurred in the Z-axis of the station positions because the orbits were held fixed. These losses during orbit determination and point positioning, may account for this study's partial detection of the Doppler system's Z-axis error; at most, only 25 percent of the offset found by others was detected here.

On the basis that only 25 percent of the Z-axis inconsistency was exposed, improvement to the Z-axis coordinate of the first iteration's point positions was attempted. To accelerate convergence, increasing by a factor of four, the difference between starting coordinates and point positions of iteration one was suggested before they were used as starting coordinates of iteration two. Erroneously, 22.5 cm was added to the −0.7 cm inconsistency instead of subtracted. This meant the starting coordinates of iteration two were higher than the point positions of iteration one, instead of being lower as desired. This was not discovered until an analysis was made. However, the second iteration's results are valuable evidence and will be discussed.

The orbit statistics of iteration two are found in Table 6. The navigation statistics in the tangential direction decreased slightly from, or were consistent with, those of iteration one. In nearly all the signal-to-noise ratios, the second iteration's statistics are better than the first statistics iteration. These results suggest the second iteration's orbits are better than those of the first. The rms orbital difference for the same data spans of these two iterations is about 20 cm. Thus, any improvement that has been obtained is also small. However, in the navigation radial-direction residuals, a dramatic decrease occurred from iteration one to iteration two. These residuals are at least 40 percent smaller in the second iteration.

The geometrically transformed NWL9Z2 coordinates were supposed to eliminate scale errors; but, as stated in discussion of iteration one, they were obviously inconsistent in that parameter. The decrease in the navigation radial direction residuals in the second iteration is the result of the meter increase to the station's radii made in the first iteration. The iterated definition of the WGS 84 tracking set is clearly self-consistent in scale (Table 7). The new station's radii agree better with the observation data. However, the new radii may be farther from their true positions since these new positions are believed to be the result of uncompensated model errors, as suggested above.

The Z-axis parameter in iteration two is inconsistent by approximately 17 cm (Table 7), and the direction of this inconsistency called for positions above those of their starting coordinates (Figure 1). Unlike the scale parameter where corrections made in iteration one were consistent with the point positions of iteration two, the point positions of iterations one and two diverge in the Z-axis parameter.

There was no rotation by the set of coordinates about the X and Y axis in the second iteration; the station positions remained consistent relative to the Earth's instantaneous spin axis. In all the remaining iterations, no rotations about the X and Y axes were observed. Any inconsistency in these parameters was removed with the creation of point positions in the first iteration. A discussion of the pole positions determined with these new X and Y rotations is made below.

The results of the first two iterations gave conflicting signals on the direction in which the parameters of the Z-axis would converge. Because of this lack of direction, the third iteration's starting coordinates were chosen to be the first iteration's point positions.

TABLE 6. STATISTICS OF ORBIT NAVIGATION
WGS 84 SECOND ITERATION

Days	Radial RWS (m)	Tangential RWS (m)	Predicted S/N
NSWC 105			
78	0.7	1.4	1.113
79	0.8	0.9	1.099
80	0.6	1.6	1.143
81	0.6	0.9	1.052
82	0.7	1.1	1.109
83	0.7	1.1	1.139
84	0.5	0.9	1.064
85	0.8	1.2	1.116
86	0.6	1.1	1.088
139-140	0.5	1.0	1.037
141-142	0.7	1.0	1.050
143-144	0.6	1.0	1.050
145-146	0.7	1.2	1.051
147-148	0.7	1.1	1.048
NSWC 115			
264-265	0.6	0.6	1.038
266-267	0.5	0.6	1.040
268-269	0.6	0.7	1.051
270-271	0.5	0.7	1.032
272-273	0.5	0.6	1.033
347-348	0.8	1.0	1.062
349-350	0.6	0.8	1.089
351-352	0.6	0.7	1.051
353-354	0.6	0.7	1.042
355-356	0.5	0.7	1.037

TABLE 7. SYSTEMATIC DIFFERENCES BETWEEN STARTING COORDINATES AND POINT POSITIONS FOR ITERATION TWO*

Year 1985 Data Spans	Longitude	Z-Axis	Scale
78-81	0.1	0.9	−0.2
139-148	0.0	0.2	−0.1
264-273	0.2	−0.2	0.0
347-356	−0.1	−0.2	0.1
Combine 39 Days	0.1	0.2	0.0

* All differences in meters

The orbit statistics of iteration three are presented in Table 8. Because the orbits of iteration two and three differ by approximately 20 cm (rms), the orbit statistics between these two iterations were nearly identical. The tangential direction navigation statistics and the signal-to-noise ratios changed insignificantly indicating these orbits are of equal quality. The navigation radial-direction residuals of iteration three remained at the reduced levels of iteration two.

TABLE 8. STATISTICS OF ORBIT NAVIGATION
WGS 84 THIRD ITERATION

Days	Radial RWS (m)	Tangential RWS (m)	Predicted S/N
NSWC 105			
78	0.7	1.5	1.114
79	0.8	0.9	1.099
80	0.6	1.5	1.157
81	0.6	0.9	1.053
82	0.7	1.2	1.110
83	0.7	1.1	1.140
84	0.5	0.9	1.065
85	0.8	1.2	1.117
86	0.6	1.0	1.088
139-140	0.5	1.0	1.037
141-142	0.7	1.0	1.051
143-144	0 6	1.0	1.050
145-146	0.7	1.2	1.052
147-148	0.7	1.1	1.048
NSWC 115			
264-265	0.5	0.6	1.038
266-267	0.5	0.6	1.040
268-269	0.6	0.7	1.051
270-271	0.5	0.7	1.032
272-273	0.5	0.6	1.032
347-348	0.8	1.1	1.062
349-350	0.6	0.8	1.089
351-352	0.6	0.7	1.051
353-354	0.5	0.7	1.041
355-356	0.5	0.7	1.037

The systematic differences between the starting coordinates and point positions of iteration three are presented in Table 9. The scale parameter is consistent, however, the Z-axis parameter is inconsistent by 6 cm The point positions of the third iteration moved closer to the starting coordinates of the first iteration (Figure 1). The inconsistency in the Z-parameter of the third iteration is small in comparison to both the second iteration's inconsistency and that of the NWL9Z2 system.

TABLE 9. SYSTEMATIC DIFFERENCES BETWEEN STARTING COORDINATES AND POINT POSITIONS FOR ITERATION THREE*

Year 1985 Data Spans	Longitude	Z-Axis	Scale
78-86	0.1	0.9	−0.2
139-148	0.0	0.2	−0.1
264-273	0.2	−0.2	0.1
347-356	−0.1	−0.2	0.1
Combine 39 Days	0.1	0.1	0.0

* All differences in meters

The results of this iteration revealed a pattern in the systematic differences recorded in Tables 5, 7, and 9. In all three of these tables, the Z-axis parameter shows a bias that seems to be related to the season of the year when the observation data were collected. Concentrating only on the discrete 10-day spans: in the spring (days 78-86) and summer (days 139-148), the systematic differences in the Z-parameter are positive (the point positions are systematically biased above their starting coordinates); and in the autumn (days 264-273) and winter (days 347-356), the systematic differences in the Z-parameter are negative. A similar seasonal bias is evident in earlier work [11] where only one satellite was studied, supporting the contention that this seasonal bias is not satellite dependent. Orbits made from spring and summer observation data using these third iteration coordinates will probably be biased differently than orbits made with autumn or winter observation data with these same coordinates.

ITERATIONS FOUR THROUGH NINE

Iterations four, five, six, and seven examined the effect of data editing on orbits and point positions. It was the objective of these iterations to explain the differences in the Z-axis parameter seen in the point positions of previous iterations. Iterations four, six, and seven were made to examine the effect data editing had in the point positioning program. Because only the point positioning program was investigated in iterations four, six, and seven new orbits were not made, so new navigation statistics were not compiled.

Iteration four used the orbits of iteration three. In point positioning, the passes used were the same passes used in iteration two. The program was allowed to edit pass observations, however; so small differences in editing existed between iteration two and iteration four. Because of these small differences, the effect of controlling the editing of observations within a pass were not measured in this iteration. The systematic differences between the starting coordinates and point positions of iteration four are presented in Table 10. The systematic differences of the 39 days combined solutions of iteration three (Table 9) and iteration four were identical. Therefore, the systematic difference in the Z-axis parameter between iteration two and iteration three (about 34 cm) was probably not due to the different passes used in their point positionings.

TABLE 10. SYSTEMATIC DIFFERENCES BETWEEN STARTING COORDINATES AND POINT POSITIONS OF ITERATION FOUR*

Data	Longitude	Z-Axis	Scale
39 Days	0.1	0.1	0.0

*All differences in meters

Iteration five was a test to estimate the effect of not controlling pass editing, an unconstrained variable in most of this experiment, during orbit determination. The starting coordinates of this iteration were the same as those of iteration three (i.e, the point positions of iteration one). Only one 10-day span was used. days 264-273. In this one test, only five iterations (versus this experiment's standard six iterations) of pass editing during orbit determination were allowed. So that the passes used in this test differed from the passes used in iteration three only by those rejected in its last iteration of editing. The statistics of orbit navigation of iteration five are presented in Table 11. All the statistics of orbit navigation of iteration five are nearly identical to those of iteration three (Table 8). The small differences in these statistics are the result of differences in the passes used. In iteration three, 376 passes were rejected from the orbit determination while in iteration five only 325 passes were rejected. However, the orbits of iteration five and iteration three differed totally by only 6 cm (rms). This result indicates that even a relatively large (14 percent) difference in the passes used in orbit determination had a small effect on the orbits. It is possible that small changes in the orbits are indistinguishable in their point positions.

TABLE 11. STATISTICS OF ORBIT NAVIGATION
WGS 84 ITERATION FIVE

Days	Radial RWS (m)	Tangential RWS (m)	Predicted S/N
264-265	0.6	0.6	1.038
266-267	0.6	0.6	1.041
268-269	0.6	0.7	1.053
270-271	0.5	0.7	1.042
272-273	0.5	0.6	1.032

Iteration six began with the orbits determined in iteration two. In point positioning, the same passes were used as in iteration two; however, no editing of the observation data in these passes was allowed. The systematic differences of iteration six are presented in Table 12. Iteration seven began with the orbits of iteration three and in point positioning used the same passes and observation data as iteration six (i.e., the same passes as used in iteration two and no editing of observation data in these passes allowed). The systematic differences of iteration seven are presented in Table 13. By controlling the data editing like above, convergence of the Z-axis parameter was anticipated. As Figure 1 illustrates, greater divergence resulted between these two iterations than between their counterparts, iterations two and three, where data editing was unrestricted. The point positions of iteration six moved farther above their starting positions than did the point positions of iteration two. The point positions of iteration seven remained nearer to their starting coordinates than did the point positions of iteration three. Recomputing iterations two and three (respectively, iterations six and seven), so their point positions were made with identical passes and pass data, did not produce convergence in the Z-axis parameter.

TABLE 12. SYSTEMATIC DIFFERENCES BETWEEN STARTING
COORDINATES AND POINT POSITIONS OF ITERATION SIX*

Data	Longitude	Z-Axis	Scale
39 Days	0.1	0.25	0.0

*All differences in meters

TABLE 13. SYSTEMATIC DIFFERENCES BETWEEN STARTING COORDINATES AND POINT POSITIONS OF ITERATION SEVEN*

Data	Longitude	Z-Axis	Scale
39 Days	0.1	0.0	0.0

*All differences in meters

Two further iterations were made in anticipation of forcing the experimental procedure to educe a large correction in the Z-parameter. The starting coordinates of iteration eight and iteration nine were, in the Z coordinate, 80 cm above the point positions of iteration three (Figure 1) but identical to the third iterations point positions in all other parameters. The orbits of iteration eight were made with no restrictions on data editing. The orbits of iteration nine were made with the same passes and pass data as used in the orbit computations of iteration three. During point positioning, the exact passes were used in both of these iterations as used in iteration two; no editing of observation data was made.

The statistics of orbit navigation for iteration eight (Table 14) and iteration nine (Table 15) showed great similarity. The tangential direction navigation residuals (taken as a measure of orbit quality) of iteration nine were slightly better than those of iteration eight. The predicted signal-to-noise ratios of iteration nine were all closer to unity than those of iteration eight. These ratios indicated the orbits of iteration nine fit the data better than iteration eight orbits. Any improvements in the orbits of iteration nine over the orbits of iteration eight were small, however, since these orbits differ by less than 30 cm (rms).

TABLE 14. STATISTICS OF ORBIT NAVIGATION WGS 84 EIGHTH ITERATION

Days	Radial RWS (m)	Tangential RWS (m)	Predicted S/N
NSWC 105			
78	0.6	1.5	1.111
79	0.8	0.9	1.097
80	0.6	1.5	1.144
81	0.7	0.9	1.062
82	0.6	1.1	1.107
83	0.7	1.1	1.138
84	0.5	0.9	1.063
85	0.8	1.2	1.118
86	0.6	1.1	1.086
139-140	0.5	1.0	1.036
141-142	0.7	1.0	1.050
143-144	0.6	1.0	1.050
145-146	0.7	1.2	1.051
147-148	0.7	1.0	1.047

TABLE 14. STATISTICS OF ORBIT NAVIGATION WGS 84 EIGHTH ITERATION (CONTINUED)

Days	Radial RWS (m)	Tangential RWS (m)	Predicted S/N
NSWC 115			
264-265	0.5	0.6	1.039
266-267	0.5	0.6	1.040
268-269	0.6	0.7	1.052
270-271	0.6	0.7	1.032
272-273	0.6	0.6	1.033
347-348	0.8	1.0	1.063
349-350	0.7	0.8	1.090
351-352	0.6	0.8	1.053
353-354	0.6	0.8	1.042
355-356	0.6	0.8	1.037

TABLE 15. STATISTICS OF ORBIT NAVIGATION WGS 84 NINTH ITERATION

Days	Radial RWS (m)	Tangential RWS (m)	Predicted S/N
NSWC 105			
78	0.6	1.4	1.091
79	0.8	0.9	1.077
80	0.6	1.4	1.118
81	0.6	0.9	1.024
82	0.6	1.1	1.085
83	0.7	1.1	1.107
84	0.5	1.0	1.039
85	0.8	1.2	1.085
86	0.6	1.1	1.054
139-140	0.5	1.0	0.960
141-142	0.7	1.0	0.968
143-144	0.6	1.0	0.973
145-146	0.8	1.3	0.993
147-148	0.6	1.1	0.970
NSWC 115			
264-265	0.6	0.6	1.029
266-267	0.6	0.6	1.028
268-269	0.6	0.7	1.044
270-271	0.5	0.6	1.019
272-273	0.6	0.6	1.015
347-348	0.8	1.0	1.056
349-350	0.6	0.8	1.079
351-352	0.6	0.7	1.045
353-354	0.6	0.7	1.034
355-356	0.6	0.7	1.024

The systematic differences between starting coordinates and point positions of iteration eight (Table 16) and iteration nine (Table 17) also showed great similarity. In the discrete 10-day spans, the seasonal pattern discussed above was found in both of these later iterations. During the spring and summer spans, the systematic differences in the Z-parameter are positive; and during the autumn and winter the systematic differences are negative. The 39 days combined solutions of these two iterations are nearly identical, indicating that controlling the passes used in making orbits for these iterations had a small effect on the point positions. It is likely then that making the passes identical in all the iterations would have changed the point positions of each iteration an insignificant amount.

TABLE 16. SYSTEMATIC DIFFERENCES BETWEEN STARTING COORDINATES AND POINT POSITIONS FOR ITERATION EIGHT*

Year 1985 Data Span	Longitude	Z-Axis	Scale
78-86	0.0	0.9	−0.2
139-148	0.0	0.1	−0.1
264-273	0.2	−0.3	0.0
347-356	−0.2	−0.3	0.1
Combine	0.1	−0.02	0.0

*All differences in meters

TABLE 17. SYSTEMATIC DIFFERENCES BETWEEN STARTING COORDINATES AND POINT POSITIONS FOR ITERATION NINE*

Year 1985 Data Span	Longitude	Z-Axis	Scale
78-86	0.0	0.9	−0.2
139-148	−0.1	0.2	−0.2
264-273	0.2	−0.3	0.0
347-356	−0.2	− 0.3	0.1
Combine	0.1	−0.02	0.0

*All differences in meters

The most disturbing aspect of these last two iterations was the weak response of the correction in the Z-axis parameter to large changes in it. By introducing a large perturbation along the Z-axis of the starting coordinates, a proportionate correction (approximately 25 percent) was expected in the point positions. The small correction, recorded for iterations eight and nine, in the Z-axis parameter can be explained by either the presence of large noise components in the point positions or irresolvable uncertainties in defining their Z-axis parameters. By introducing an 80-cm change to the starting coordinates, a 20-cm change was expected along the point positions Z-axis but only 2 cm were seen. This 20-cm correction could have been masked by noise levels of an equal magnitude. When controlling data editing in orbit determination and point positioning, the level of noise was estimated at a maximum of 20 cm [11] in the Z-axis parameter. Alternately, the resolution of the observation data may have been met, making efforts to further refine the coordinates in the Z-axis parameter futile. The resolution of the data and their noise were probably the reasons the Z-axis parameter showed consistency over a great range of starting positions. With this conclusion, the iterative procedure of developing WGS 84 tracking station coordinates ceased.

A summary of the similarities in the iterations is given in Table 18. This table lists the starting coordinates and data editing restrictions during both orbit determination and point positioning for all of the above iterations.

TABLE 18. SUMMARY OF ITERATIONS

Iteration	Starting Coordinates	Orbit Determination Point/Pass Editing	Point Positioning Point/Pass Editing
I1	Transformed WGS-84 Set	Unrestricted	Unrestricted
I2	Solution I1 plus .225 m to Z coordinate	Unrestricted	Unrestricted
I3	Solution I1	Unrestricted	Unrestricted
I4	Solution I1 (Same as I3)	Same Orbits as I3	Point Editing Unrestricted/Passes same as I2 Passes
I5	Solution I1 Only Span days 264-273	Only 5 iterations in cross pass filter	No Point Positions Made
I6	Solution I1 plus .225 m to Z Coordinate	Same Orbits as I2	No Point Editing/ Passes same as I2 Passes
I7	Solution I1 (Same as I3)	Same orbits as I3	No Point Editing/ Passes same as I2 Passes
I8	Solution I3 Plus 0.80 m to Z Coordinate	Unrestricted	No Point Editing/ Passes same as I2 Passes
I9	Solution I3 Plus 0.80 m to Z Coordinate	I3 Points and Passes	No Point Editing/ Passes same as I2 Passes

PRELIMINARY POLE DETERMINATION

Because of the large rotations about the X and Y axes during point positioning in the NWL9Z2 system and during the WGS 84 iteration one, the effects of these rotations were studied. The Doppler positions of the Earth's instantaneous spin axis (pole of rotation) are calculated during precise orbit computations, (discussed above). The pole positions determined during the NWL9Z2 geodetic system's orbit computations and the WGS 84 third iteration orbits were compared. The smoothed pole positions determined at the BIH, obtained from the BIH Annual Report for 1985, and the pole positions determined from observations of the Laser Ranging Satellite 1976-391 (LAGEOS), obtained from the BIH Circular D, were also compared with the Doppler positions.

Comparisons were made with the BIH smoothed pole taken as the standard. The mean value, the standard deviation, and rms value of the total differences between the BIH and the three other pole positions were made for each span. The same statistics were computed by combining the differences from all spans. The combined statistics will be referred to as "annual" statistics. These results are presented in Tables 19, 20, and 21. The rms of the two components of the annual standard deviation was taken as an estimate of the noise associated with each system.

TABLE 19. STATISTICS COMPARING NWL9Z2 AND BIH POLES IN METERS

Data Span	Total RMS		Mean		Standard Deviation	
	X	Y	X	Y	X	Y
78-86	0.7268	1.4562	0.6149	1.3634	0.3875	0.5115
139-148	1.2559	0.7944	1.1523	0.7118	0.4995	0.3526
264-273	0.7935	0.3996	0.7484	0.0075	0.2635	0.3996
347-356	0.4025	0.7992	0.2821	0.7054	0.2871	0.3756
Annual	0.8511	0.9421	0.6994	0.6970	0.4848	0.6337

TABLE 20. STATISTICS COMPARING WSG 84 AND BIH POLES IN METERS

Data Span	Total RMS		Mean		Standard Deviation	
	X	Y	X	Y	X	Y
78-86	0.6202	0.8763	−0.4323	0.7662	0.4447	0.4254
139-148	0.2100	0.2613	0.1584	0.1255	0.1379	0.2292
264-273	0.2073	0.3952	−0.0244	−0.3754	0.2058	0.1235
347-356	0.2285	0.4507	−0.1128	−0.4133	0.1988	0.1798
Annual	0.3619	0.5467	−0.1028	0.0257	0.3470	0.5461

TABLE 21. STATISTICS COMPARING LASER AND BIH POLES IN METERS

Data Span	Total RMS		Mean		Standard Deviation	
	X	Y	X	Y	X	Y
78-86	0.3421	0.0409	−0.3405	0.0243	0.0327	0.0329
139-148	0.0881	0.1184	−0.0120	−0.0921	0.0873	0.0744
264-273	0.1123	0.2240	−0.1072	−0.2233	0.0336	0.0185
347-356	0.0980	0.2329	−0.0940	−0.2316	0.0276	0.0250
Annual	0.1917	0.1733	−0.1384	−0.1307	0.1326	0.1138

The pole positions from each data set are plotted in four figures representing the four 10-day spans. The path of the pole between sequential time positions is represented by a straight line. In the plots, mean position of each data set for the represented time is shown.

Figures 2, 3, 4, and 5 illustrate that the WGS 84 and NWL9Z2 pole positions contain more noise than LAGEOS pole positions. The noise associated with the NWL9Z2 pole is large (Table 19), approximately 56-cm rms; similarly, the WGS 84 pole positions are accompanied by large noise levels of about 45-cm rms (Table 20). The noise in the LAGEOS pole position is very small, about 12-cm rms (Table 21).

The figures also show that the mean pole positions of the WGS 84 are consistently nearer than the NWL9Z2 mean pole positions are to the BIH mean pole positions. Annually, the NWL9Z2 poles (Table 19) are biased from the BIH poles by a constant nearly 70 cm in magnitude in both X and Y components; and of the three data types studied, the NWL9Z2 poles deviated the most, by measure of total rms difference from the BIH poles. The figures show that the NWL9Z2 mean poles were systematically biased (to the right and above) with respect to the BIH.

In Table 20 the WGS 84 pole positions have an annual bias of about 10 cm relative to the BIH poles. However, this bias is not in a constant direction through the year. As seen in the figures, the WGS 84 mean poles oscillate around the BIH mean poles and show no constant bias toward the BIH poles. The total rms difference from the BIH is greater for the WGS 84 pole positions (Table 20) than it is for the LAGEOS pole positions (Table 21).

The LAGEOS mean pole is always closer to the BIH mean pole than the WGS 84 mean pole is to the BIH (Figures 2, 3, 4, and 5). The LAGEOS pole exhibits an annual bias of about 15 cm from the BIH poles. During all the seasons, this bias is systematically negative in the X-component of position. The LAGEOS seasonal means deviate less from their annual mean than either the WGS 84 or NWL9Z2 seasonal means deviate from their annual means. The reliability of LAGEOS data is supported by the agreement of its means and the low noise levels exhibited in both the seasonal and annual statistics.

Although the LAGEOS poles and WGS 84 poles have comparable biases from the BIH (both are biased by less than 15 cm) the LAGEOS poles' bias has a systematic component while the WGS 84 poles' bias does not. Conversely the noise, and consequently the total rms difference from the BIH, of the WGS 84 pole positions were much greater than those of LAGEOS pole positions.

Pole positions determined with the NWL9Z2 starting coordinates were biased by about a half-meter in X and Y. During the point positioning of the NWL9Z2 coordinates in this experiment, half-meter systematic adjustments to the X and Y coordinates occurred (Table 2). Then in positioning the stations in the WGS 84 during the first iteration, rotations about the X and Y axes also occurred (Table 5). The systematic adjustment seen in the NWL9Z2 station coordinates probably removed the half-meter biases in their pole positions. The further refinement of the WGS 84 station coordinates in X and Y during iteration one of this experiment was probably a systematic adjustment in response to the new geodetic system. After the first iteration, no further adjustments to the station coordinates in X and Y were seen. The systematic adjustments made during point positioning in both the NWL9Z2 and the WGS 84 first iteration are credited with improving the agreement between the Doppler-determined pole positions and BIH pole positions. The results of this preliminary pole study were presented at an IAU Symposium.[12]

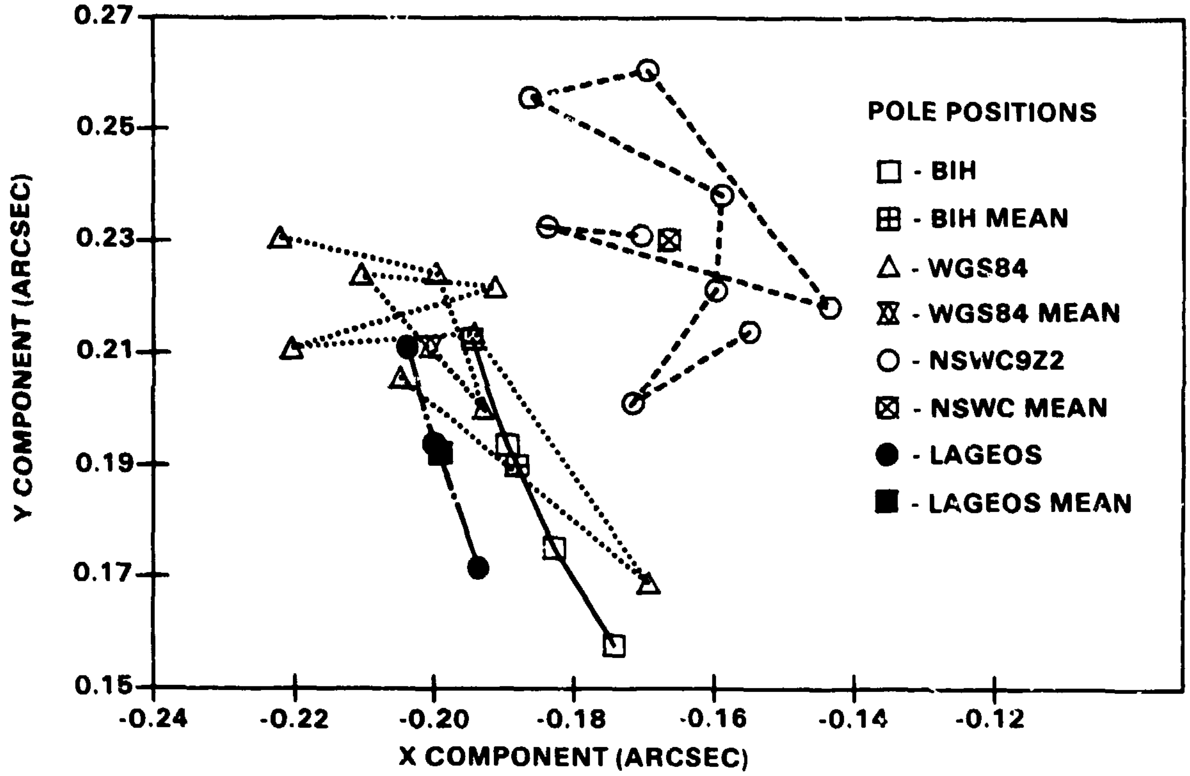


FIGURE 2. DAYS 78 THROUGH 86

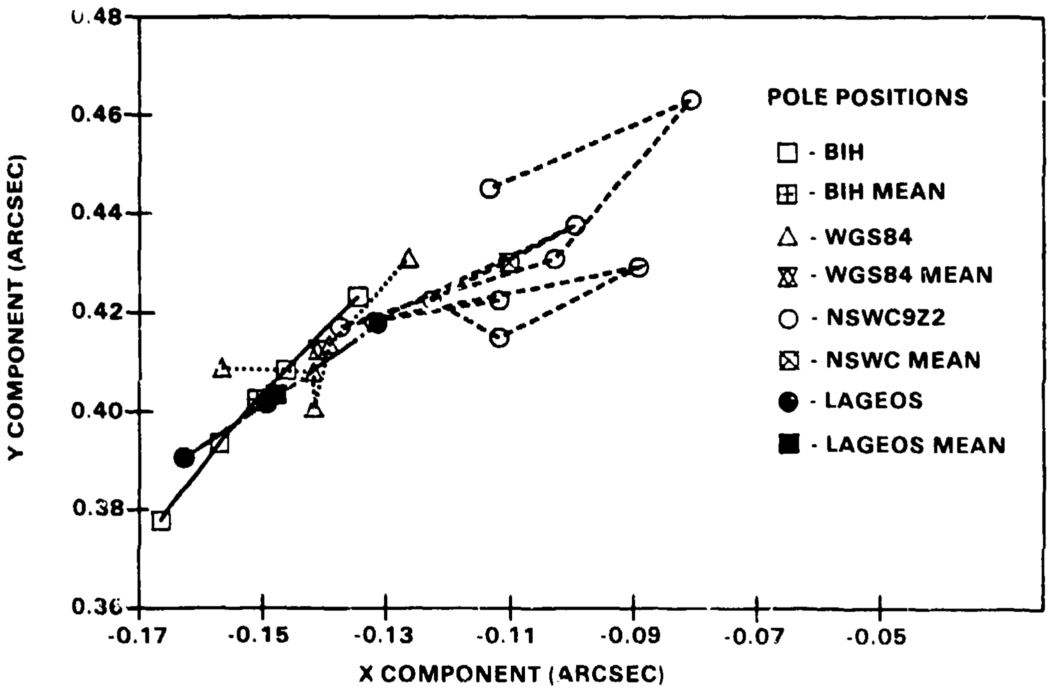


FIGURE 3. DAYS 139 THROUGH 148

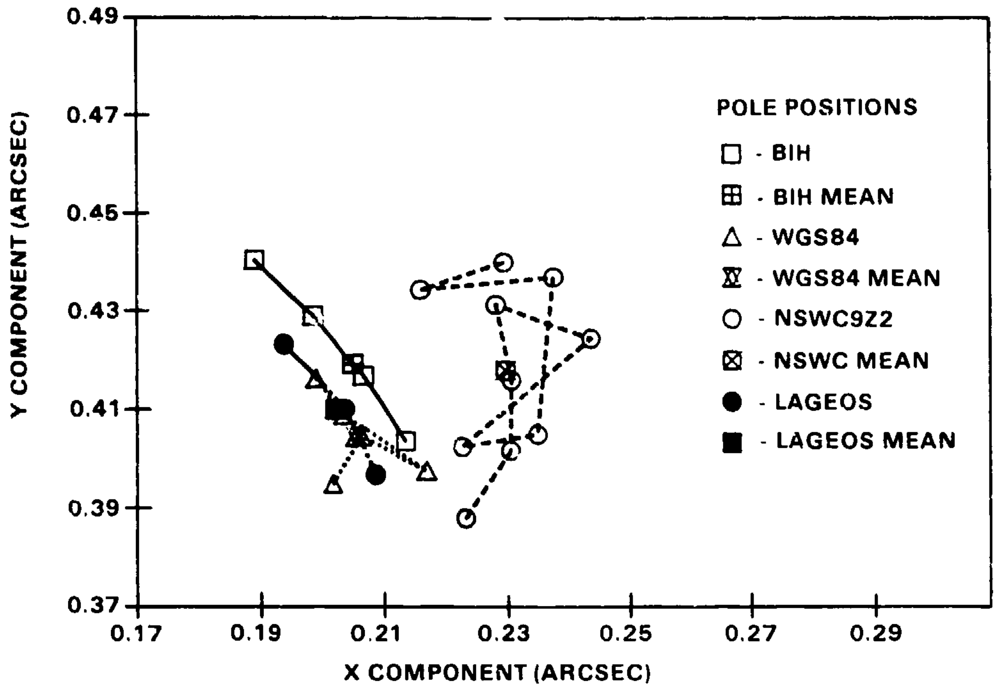


FIGURE 4. DAYS 264 THROUGH 273

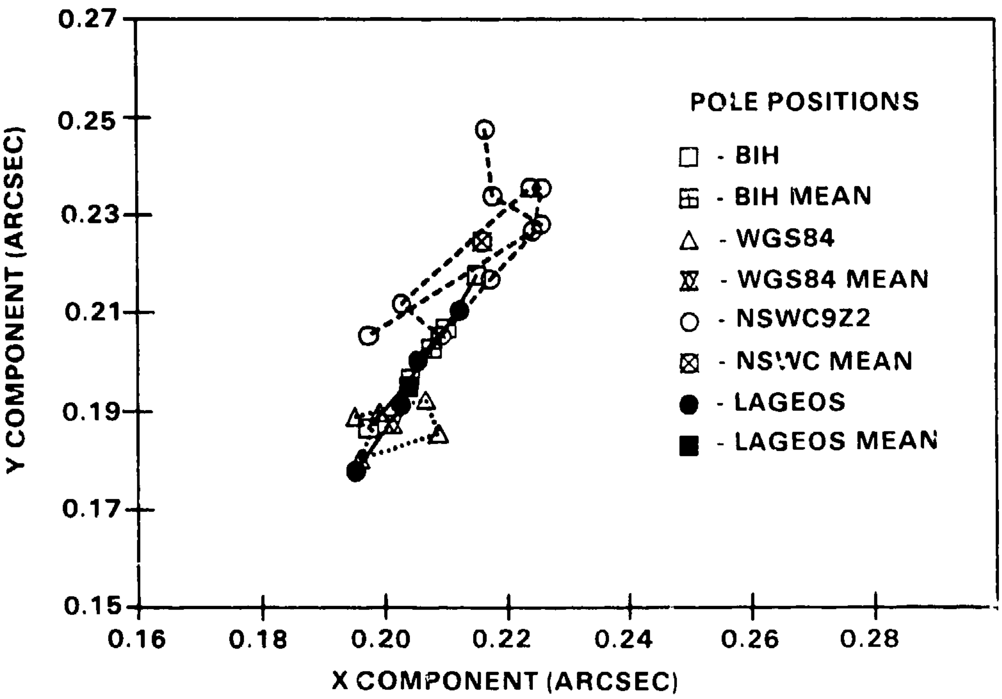


FIGURE 5. DAYS 347 THROUGH 356

SUMMARY

Through an iterative procedure of orbit determination and point positioning, satellite tracking stations (SMTP, TRANET, and OPNET) were developed for the World Geodetic System 1984 (WGS 84). The coordinates determined in the third iteration of this procedure and the geometrically transformed NWL9Z2 coordinates are consistent to within a meter in the scale and Z-axis parameters and consistent in longitude. The WGS 84 coordinates determined in the iterative procedure had radii a meter greater than the transformed NWL9Z2 coordinates. This scale difference was attributed to uncompensated ionospheric refraction in the WGS 84 station coordinate development. With a period related to the seasons, the iteratively determined WGS 84 coordinates varied cyclically by a meter in the Z-axis parameter. The WGS 84 coordinates determined in the third iteration were the most consistent with the geometrically transformed NWL9Z2 coordinates in the Z-axis parameter. Because of this consistency, the third iteration coordinates were chosen as the official WGS 84 station coordinates.

Positions of the Earth's instantaneous spin axis (pole) determined with WGS 84 coordinates contained no systematic bias relative to the BIH positions; the NWL9Z2 pole positions had always exhibited a large systematic bias toward the BIH poles. The removal of this bias from the WGS 84 pole positions was credited to the rectified WGS 84 station coordinates. These preliminary test results indicate the third iteration WGS 84 station coordinates are well defined.

REFERENCES

1. Beuglass, Larry K. and Anderle, R. J., "Refined Doppler Satellite Determinations of the Earth's Polar Motion," *Use of Artificial Satellites for Geodesy*, AmericanGeophysical Union Monograph,Vol. 15, 1972, pp. 181-186.

2. Kumar, Muneendra,"An Unbiased Analysis of Doppler Coordinate Systems," *Proceedings of the Third International Geodetic Symposium on Satellite Doppler Positioning*, New Mexico State University, 1982, pp. 169-182.

3. Decker, Louis B.,"World Geodetic System 1984," *Proceedings of the Fourth International Geodetic Symposium on Satellite Positioning*, Austin, Texas, 1986, pp. 69-92.

4. White, Haschal L., "The World Geodetic System 1984 Earth Gravitational Model," *Proceedi... of the Fourth International Geodetic Symposium on Satellite Positioning*, Austin, Texas, 1986, pp. 92-116.

5. Hothem, Larry D., Vincenty, T., and Morse, R. E.,"Relationship Between Doppler and Other Advanced Geodetic Systems Measurements Based on Global Data," *Proceedings of the Third International Geodetic Symposium on Satellite Doppler Positioning*, New Mexico State University, 1982, pp. 109-128.

6. Marsh, James G. and Williams, R. G.,"Precise Orbit Analysis in Support of the SEASAT Altimeter Experiment," *Journal of the Astronautical Sciences*, Vol. 28, No. 4, 1980, pp. 345-369.

7. West, Gladys B., "Mean Earth Ellipsoid Determined from the SEASAT 1 Altimeter Observations," *Journal of Geophysical Research*, Vol. 82, No. B7, 1982, pp. 5538-5540.

8. Tscherning, C. C., "Estimation of the Longitude Bias of the NWL9D Coordinate System from Deflections of the Vertical, Satellite Altimetry and High Degree Spherical Harmonic Expansions," Bulletin Geodesique. Vol. 60, 1986, pp. 29-36.

9. Anderle, R. J., and Malyevac, C. A., *Pole of the Doppler Coordinate System*, NSWC/DL TN 83-261, 1983, NSWC, Dahlgren, VA.

10. O'Toole, James W., *CELEST Computer Program for Computing Satellite Orbits*, NSWC/DL, TR-3565, 1976, NSWC, Dahlgren, VA.

11. Cunningham, J. P., Malyevac, C., Whitesell, R., and Malys, S., " Testing of the World Geodetic System-1984 In Precise Orbit Determination and Point Positioning," *Proceedings of the Fourth International Geodetic Symposium on Satellite Positioning*, Austin, Texas, 1986, pp. 116-132.

12. Bangert, John A.and Cunningham, J. P., "Preliminary Evaluation of Doppler-Determined Pole Positions Computed Using World Geodetic System 1984," *Proceedings of IAU Symposium No. 128: Earth Rotation and Reference Frames for Geodesy and Geodetic Dynamics*, Coolfont, WV, 1986, (in publishing).

DISTRIBUTION

	Copies
Director DMA Systems Center Attn: Dr. Randall Smith, PIO Suite 800 8301 Greensboro Drive McLean, VA 22102	1
Director DMA Aerospace Center Attn: B. Louis Decker, RED	1
Haschal L. White, PRS 3200 S. Second St. St. Louis, MO 63118-3399	1
Director DMA Hydrographic/Topographic Center Attn: Dr. William Wooden, RET 6500 Brookes Lane Washington, DC 20315-0030	1
USNO Nautical Almanac Division Attn: John Bangert 34th St. and Massachusetts Ave., NW Washington, DC 20390	1
General Electric Corporation Attn: Dr. Richard Anderle P.O. Box 8048-Rm 38D41, Bldg. D Philadelphia, PA 19101	1

Internal Distribution:

E211	1
E231	10
E31 (GIDEP)	1
K10	1
K12	1
K12 (Tanenbaum)	1
K12 (Cunningham)	12