PRELIMINARY EVALUATION OF DOPPLER-DETERMINED POLE POSITIONS COMPUTED USING WORLD GEODETIC SYSTEM 1984

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ABSTRACT. Since 1975, the Defense Mapping Agency (DMA) has been determining polar motion as a byproduct of computing the precise orbits of the Navy Navigation Satellite System (NNSS) satellites. The orbit determination process currently incorporates the NSWC 9Z2 terrestrial reference system and the NWL 10E-1 Earth Gravitational Model (EGM) to degree 28 and order 27. The World Geodetic System 1984 (WGS 84), developed by DMA, will replace the NSWC 9Z2/10E-1 system for NNSS orbit determination. The WGS 84 EGM to degree and order 41 will be utilized. This paper presents the results of two experiments which compared pole positions computed in the two systems. These comparisons indicate that use of WGS 84 improves agreement between pole position values resulting from the Nova-class satellite orbit solutions and the values determined by other modern techniques.

1. INTRODUCTION

There are two classes of Navy Navigation Satellite System (NNSS) satellites: the "Oscar" type and the "Nova" type. The Nova satellites represent the latest generation and incorporate a sensor/thruster system to compensate for atmospheric drag (Ziegler 1982). The Defense Mapping Agency (DMA) has routinely produced precise orbits of the NNSS satellites since 1975. These orbits are computed by combining Doppler observations of the NNSS satellites gathered by a worldwide network of tracking stations in a batch least squares solution using the CELEST program (O'Toole 1976). Since 1977, the precise orbits have been computed in the NSWC 9Z2 coordinate system utilizing the NWL 10E-1 Earth Gravitational Model (EGM) to degree 28 and order 27 (Kumar 1982). As a byproduct of the precise orbit computations, the position of the Earth's spin axis with respect to the pole of the NSWC 9Z2 system is also determined. The Doppler-determined pole coordinates (x and y) have been utilized by the Bureau International de l'Heure (BIH) in their global solutions since 1972.

The World Geodetic System 1984 (WGS 84) and its associated EGM have been discussed by Decker (1986) and White (1986). WGS 84 will replace the NSWC 9Z2/10E-1 system in the computation of NNSS precise orbits at DMA. The defining parameters of the WGS 84 ellipsoid are

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those of the Geodetic Reference System 1980 (GRS 80) adopted by the International Union of Geodesy and Geophysics in 1979 (Moritz 1984). The WGS 84 EGM was developed at DMA and is complete through n=m=180. The $n=m \leq 41$ part, which will be utilized in NNSS orbit computations, was determined by combining surface mean free-air gravity anomalies, satellite radar altimetry, satellite tracking data (laser, Doppler, and Global Positioning System (GPS) range differences), and "lumped coefficient" data in a weighted batch least squares solution.

Both DMA and the Naval Surface Weapons Center (NSWC) have conducted studies involving the implementation of WGS 84 in the NNSS precise ephemerides computational process (e.g., Cunningham, et al. 1986). This paper reports the results of two studies which attempted to assess the impact of use of WGS 84 on the computed pole positions. Section 2 describes the results from an early test in which a preliminary set of WGS 84 positions (i.e., NSWC 9Z2 positions transformed to WGS 84) for the NNSS tracking stations were utilized to compute the orbits. Section 3 describes a more recent experiment in which the NNSS orbits were computed using a set of improved tracking station coordinates positioned directly in WGS 84. In each experiment, the truncated WGS 84 EGM was used. Pole positions resulting from the orbit solutions were compared to pole positions determined by other modern techniques. Section 4 presents a summary of results and conclusions.

2. POLE POSITIONS OBTAINED USING THE WGS 84 EGM AND A STATION COORDINATE SET TRANSFORMED FROM NSWC 9Z2 TO WGS 84

A discussion of this experiment was presented earlier by Wooden, et al. (1986) and is repeated here. WGS 84 versions of CELEST input files were utilized to produce precise ephemerides of five NNSS satellites from day 149 to day 154 and from day 161 to day 179, 1985. The program input included the WGS 84 EGM truncated to degree and order 41 as well as the WGS 84 ellipsoid parameters. The program also utilized a file of WGS 84 tracking station coordinates which were obtained by applying an established transformation to the "production" NSWC 9Z2 coordinates. Specifically, the NSWC 9Z2 coordinates were adjusted by a scale change of -0.6×10^{-6}, a Z-axis bias of 4.5 m, and a longitude shift of 0.5 arcsec. [Since the date of this test, the longitude shift between WGS 84 and the NSWC 9Z2 system has been changed to 0.814 arcsec for consistency with the North American Datum 1983.] Each orbit fit for satellites DMA 59, DMA 77, DMA 93, and DMA 115 was based on two days of tracking data, while each fit for satellite DMA 105 was based on one day of data.

During the test period, DMA also produced precise ephemerides of the same five NNSS satellites for routine production purposes. These fits utilized the NWL 10E-1 EGM and the NSWC 9Z2 tracking station coordinate set. Data editing occurred independently in the analogous CELEST solutions in the two systems (i.e., no attempt was made to enforce common data between the solutions).

The pole coordinates output in the two systems were compared to BIH Circular-D smoothed values of x and y. Daily values were derived from the BIH 5-day values by cubic spline interpolation, and differences were formed between the interpolated values and the Doppler-derived values. These differences were computed in the sense Doppler minus BIH. Unweighted mean differences and standard deviations were computed on a satellite-by-satellite basis and for each NNSS satellite type. The pole position solutions in both systems which resulted from the satellite DMA 105 fits on day 175 were outliers and were rejected from further study.

Table I presents statistics of the differences between the BIH and the Doppler-derived pole coordinates on a satellite-by-satellite basis. An examination of this table gave no conclusive evidence that use of WGS 84 systematically improved the agreement between the Doppler-derived values and the BIH values. However, when the satellites were grouped by type (i.e., Nova and Oscar), as in Table II, a correlation emerged. While the pole positions determined using the Oscar satellites and WGS 84 showed no improvement in agreement with the BIH values, pole positions determined using the Nova satellites and WGS 84 did show better agreement with BIH. The mean difference between the Nova pole positions and the BIH positions dropped from 0.0147 arcsec to -0.0007 arcsec for the x component, and from 0.0123 arcsec to 0.0099 arcsec through the use of WGS 84 versus NSWC 9Z2/10E-1. Additionally, there was less scatter in the Nova differences when WGS 84 was utilized, as evidenced by the smaller standard deviations. The scatter was reduced by a factor of 1.3 for the x component and by factor of 2.2 for the y component through use of WGS 84.

3. POLE POSITIONS OBTAINED USING THE WGS 84 EGM AND A STATION COORDINATE SET POSITIONED DIRECTLY IN WGS 84

As a part of studies related to the implementation of WGS 84 in NNSS processing, a set of tracking station coordinates positioned directly in WGS 84 was produced. The directly-computed WGS 84 station coordinate set was obtained iteratively as follows. Four 10-day spans of observational data from approximately 50 tracking stations, each span representing a season in 1985, were used. Two spans (days 77 to 86 and 139 to 148) incorporated observational data from satellite DMA 105 (Nova 1); two additional spans (days 264 to 273 and 347 to 356) incorporated satellite DMA 115 (Nova 3) observational data. Sets of orbits were computed using these data spans, the truncated WGS 84 EGM, and a preliminary (transformed) station coordinate set (see Section 2.) The orbit solutions for day 77 were eliminated from further use due to a suspected problem with some of the observational data. Holding these orbits fixed, the coordinates of the tracking stations were determined in a least squares adjustment. Then, orbits were recomputed using these improved station coordinates.

The pole coordinates resulting from the second set of orbit solutions were compared to the analogous values resulting from orbit solutions using the NSWC 9Z2/10E-1 system. Additional comparisons were made with BIH smoothed pole positions and pole positions determined from satellite laser ranging observations of LAGEOS. The pole positions from each source are plotted in four figures representing the four 10-day spans (Figures 1, 2, 3, and 4). The path of the pole between sequential time positions is represented by a straight line. In the plots, the mean pole position for each of the data sets is also shown. The NSWC 9Z2/10E-1 and WGS 84 Doppler positions and the LAGEOS positions were further compared to the analogous BIH smoothed values by computing the appropriate differences. The mean value, standard deviation, and root mean square (rms) value of the differences were computed 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. The statistical results are presented in Tables III, IV, and V.

An estimate of the noise associated with the pole positions from each source was obtained by combining the individual component standard deviations for all the data spans, as given in Tables III, IV, and V. The noise associated with the NSWC 9Z2/10E-1 pole positions was large (Table III), approximately 0.026 arcsec. Similarly, the WGS 84 pole positions were accompanied by large noise levels of approximately 0.021 arcsec (Table IV). The noise in the LAGEOS pole position was very small, approximately 0.006 arcsec (Table V). Figures 1, 2, 3, and 4 illustrate that the WGS 84 and NSWC 9Z2/10E-1 pole positions contained more noise than the LAGEOS pole positions.

These figures also show that the WGS 84 mean pole positions were consistently closer to the BIH mean pole positions than were the NSWC 9Z2/10E-1 mean pole positions. Annually, the NSWC 9Z2/10E-1 pole positions (Table III) were biased from the BIH pole positions by approximately 0.025 arcsec in both x and y components. Of the three data types studied, the NSWC 9Z2/10E-1 pole positions deviated the most from the BIH pole positions by measure of total rms difference. The figures also show that the NSWC 9Z2/10E-1 mean pole positions were systematically biased with respect to the BIH mean pole positions.

From Table IV, it is seen that the WGS 84 pole positions had an annual bias of approximately 0.003 arcsec relative to the BIH pole positions. This bias was not in a constant direction throughout the year. As seen in the figures, the WGS 84 mean pole positions oscillated around the BIH mean pole positions and showed no constant bias with respect to the BIH pole positions.

The LAGEOS mean pole positions were always closer to the BIH mean pole positions than the WGS 84 mean pole positions were to the BIH mean positions (Figures 1, 2, 3, and 4). The LAGEOS pole positions exhibited an annual bias of approximately 0.006 arcsec from the BIH pole positions. During all the seasons, the bias in the x-component of the LAGEOS positions was systematically negative. The

LAGEOS seasonal mean positions deviated less from their annual mean than either the WGS 84 or NSWC 9Z2 seasonal mean positions deviated from their annual mean positions.

Although the LAGEOS pole positions and WGS 84 pole positions had comparable biases from the BIH (both are biased by less than 0.007 arcsec), the LAGEOS bias had a systematic component while the WGS 84 bias did not. Also, the noise of the WGS 84 pole positions was much greater than that of the LAGEOS pole positions, as evidenced by the standard deviations.

4. SUMMARY AND CONCLUSIONS

The results presented in Section 2 suggest that the use of WGS 84 improves the accuracy of the pole positions resulting from the Nova satellite orbit solutions, but that its use in Oscar satellite orbit computations does not lead to improved accuracies. These results were obtained through the use of the $n=m\leq 41$ portion of the WGS 84 EGM and a preliminary (transformed) set of WGS 84 tracking station coordinates.

The results presented in Section 3 were based on the same truncated WGS 84 EGM and an improved set of WGS 84 tracking station coordinates. Data sets for two Nova satellites were chosen so as to provide coverage through the four seasons. The large systematic bias seen in the NSWC 9Z2/10E-1 pole positions with respect to the BIH positions no longer appeared in the WGS 84 pole positions. There was also less noise in the WGS 84 positions as compared to the NSWC 9Z2/10E-1 positions. These results support the suggestion that the use of WGS 84 improves the accuracy of the pole positions derived from the Nova satellite orbit solutions.

The conclusions presented in this paper should be considered preliminary since they are based on processing a limited amount of data. The routine processing of more data will be needed to substantiate these claims.

5. ACKNOWLEDGEMENTS

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Table I: Statistics of the Differences Between the Doppler-Derived Pole Coordinates and the BIH Pole Coordinates

Sat.		Δ x (arcsec)		Δ y (arcsec)	
		NSWC 9Z2	WGS 84	NSWC 9Z2	WGS 84
59 n=11	Δ	+ .0020	+ .0147	+ .0218	+ .0242
	σ	± .0239	± .0264	± .0180	± .0195
77 n=13	Δ	- .0016	+ .0120	+ .0191	+ .0195
	σ	± .0215	± .0189	± .0193	± .0182
93 n=11	Δ	+ .0304	+ .0342	+ .0269	+ .0256
	σ	± .0123	± .0155	± .0094	± .0154
105 n=21	Δ	+ .0138	- .0053	- .0032	+ .0048
	σ	± .0162	± .0101	± .0113	± .0107
115 n=13	Δ	+ .0160	+ .0068	+ .0374	+ .0180
	σ	± .0189	± .0138	± .0198	± .0063

Table II: Statistics of Pole Coordinate Differences Grouped by NNSS Type

Satellite Type		Δ x (arcsec)		Δ y (arcsec)	
		NSWC 9Z2	WGS 84	NSWC 9Z2	WGS 84
OSCAR (59,77,93) n=35	Δ	+ .0096	+ .0198	+ .0224	+ .0229
	σ	±.0241	± .0224	± .0163	± .0175
NOVA (105,115) n=34	Δ	+ .0147	- .0007	+ .0123	+ .0099
	σ	±.0170	± .0129	± .0250	± .0112

Notes: Δ = mean difference

σ = standard deviation

n = number of orbit fits

Table III: Statistics Comparing NSWC 9Z2 and BIH Pole Positions (Arcseconds)

DATA SPAN (1985)	RMS DIFFERENCE		MEAN BIAS		STANDARD DEVIATION	
DAY NUMBERS	x	y	x	y	x	y
78 - 86	.0235	.0471	.0199	.0441	± .0125	±.0165
139 - 148	.0406	.0257	.0373	.0230	±.0162	±.0114
264 - 273	.0257	.0129	.0242	.0002	± .0085	±.0129
347 - 356	.0130	.0258	.0091	.0228	± .0093	±.0121
ALL SPANS	.0275	.0305	.0226	.0225	± .0157	±.0205

Table IV: Statistics Comparing WGS 84 and BIH Pole Positions (Arcseconds)

DATA SPAN (1985)	RMS DIFFERENCE		MEAN BIAS		STANDARD DEVIATION	
DAY NUMBERS	x	y	x	y	x	y
78 - 86	.0201	.0283	-.0140	.0248	±.0144	±.0138
139 - 148	.0068	.0084	.0051	.0041	±.0045	±.0074
264 - 273	.0067	.0128	-.0008	-.0121	±.0067	±.0040
347 - 356	.0074	.0146	-.0036	-.0134	±.0064	±.0058
ALL SPANS	.0117	.0177	-.0033	.0008	±.0112	±.0177

Table V: Statistics Comparing LAGEOS and BIH Pole Positions (Arcseconds)

DATA SPAN (1985)	RMS DIFFERENCE		MEAN BIAS		STANDARD DEVIATION	
DAY NUMBERS	x	y	x	y	x	y
78 - 86	.0111	.0013	-.0110	.0008	± .0011	± .0011
139 - 148	.0028	.0038	-.0004	-.0030	± .0028	± .0024
264 - 273	.0036	.0072	-.0035	-.0072	± .0011	± .0006
347 - 356	.0032	.0075	-.0030	-.0075	± .0009	± .0008
ALL SPANS	.0062	.0056	-.0045	-.0042	± .0043	± .0037

FIGURE 1: DAYS 78 THRU 86

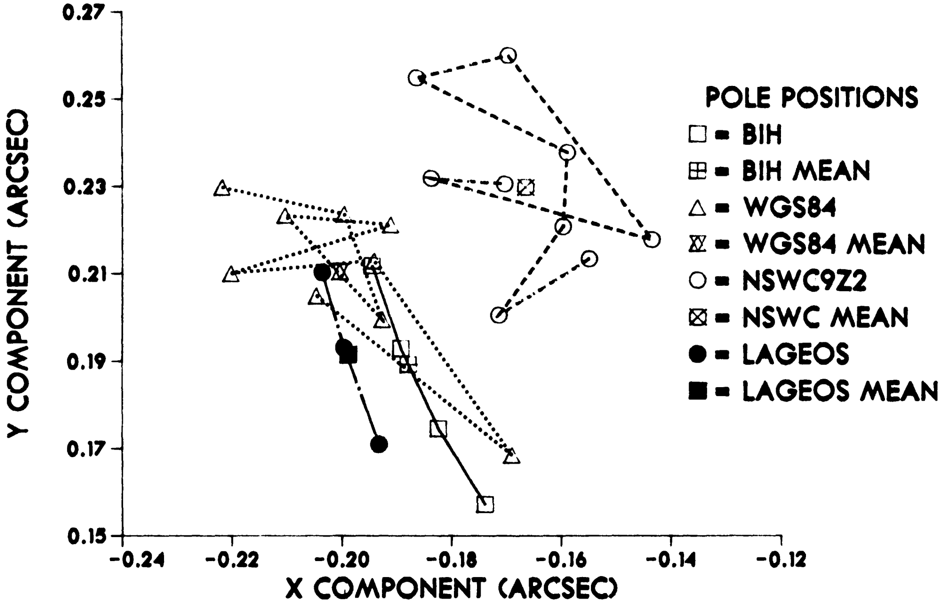

FIGURE 2: DAYS 139 THRU 148

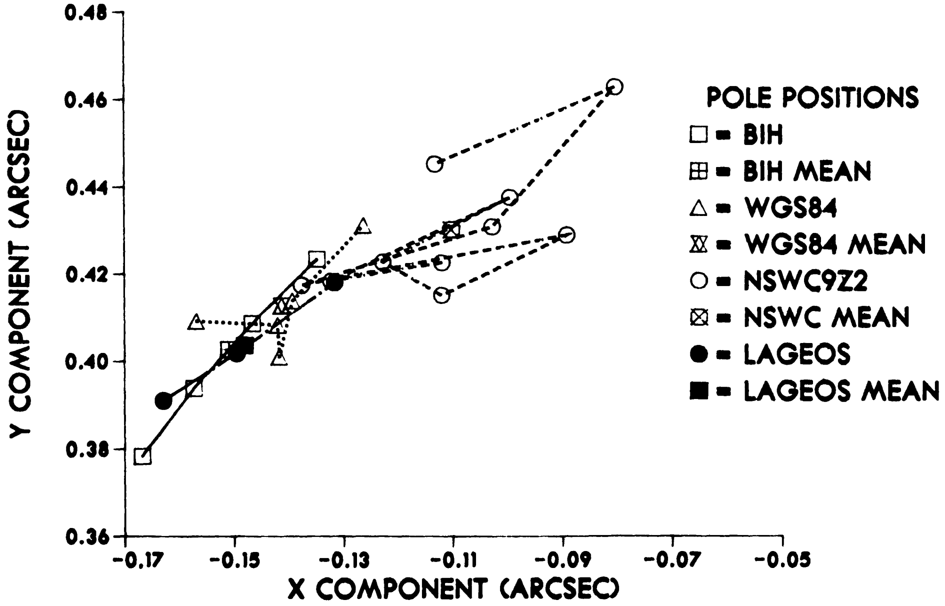

FIGURE 3: DAYS 264 THRU 273

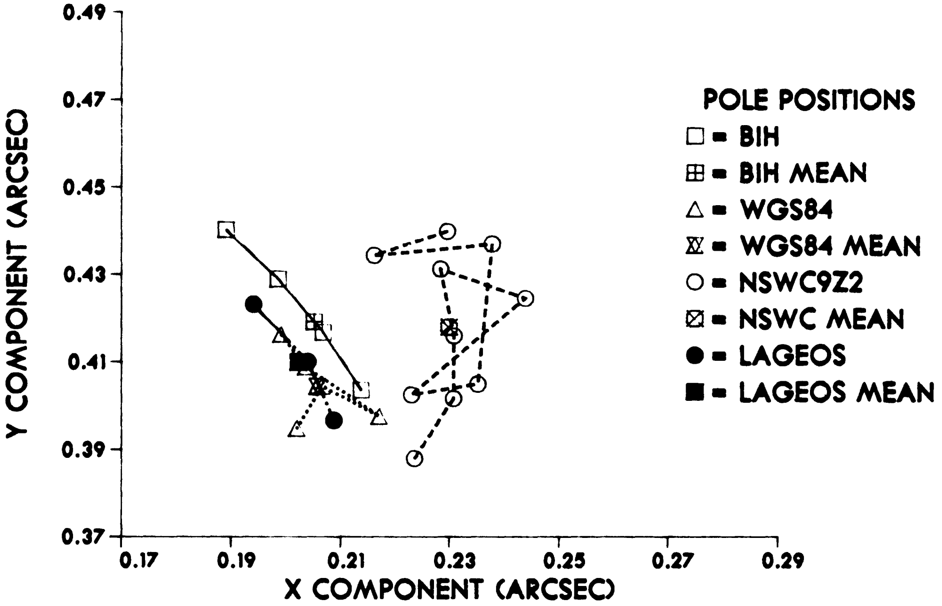

FIGURE 4: DAYS 347 THRU 356