EARTH ORIENTATION FROM DOPPLER TRACKING OF THE NAVY NAVIGATION SATELLITE SYSTEM

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ABSTRACT. For more than a dozen years, Doppler tracking of the Navy Navigation Satellite System (NNSS) has demonstrated the ability to give solutions for polar motion as a byproduct of precise ephemerides generation. The polar motion estimation process at the Defense Mapping Agency is reviewed and comparisons of the Doppler results with the polar motion series of the newer observational techniques and the Bureau International de l'Heure (BIH) Circular-D are made. This paper extends the analyses and comparisons done during the MERIT Main Campaign for one additional Chandler period.

1. INTRODUCTION

Since the late nineteenth century, it has been recognized that the instantaneous spin axis of the Earth moves with respect to the geographic pole of the Earth's crust. This "polar motion" was predicted by Euler in 1752, but was not conclusively observed until Kuenstner's work in 1884-86. Research at the Naval Weapons Laboratory (now the Naval Surface Weapons Center) by Anderle and Beuglass [1] demonstrated that it was possible to use Doppler observations of Navy Navigation Satellite System (NNSS) satellites to compute pole positions. Doppler solutions of pole position have been distributed by the Dahlgren Polar Monitoring Service since 1969. Since 1972, pole positions based on Doppler observations of the NNSS satellites have been incorporated into the Bureau International de l'Heure (BIH) global solution. The methods used by the BIH in the treatment of data are given by Feissel [2].

The pole positions are a byproduct of the orbit computation process. Hence, when the responsibility of computing the NNSS satellite orbits was transferred to the Defense Mapping Agency (DMA) in 1975, the derivation of

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pole position was continued by DMA. The DMAHTC Polar Monitoring Service (DPMS) reports are distributed by the Hydrographic/ Topographic Center of DMA to users on a weekly or monthly basis.

Project MERIT [3] was a program of international collaboration to monitor Earth rotation and intercompare techniques of observation and analysis. The MERIT Main Campaign of observations was held during the period September 1, 1983, to October 31, 1984 and included a variety of techniques for determining polar coordinates.

This study concentrates on the two types of NNSS satellites processed at DMAHTC: the "Oscar-type" satellites (DMA 60=1967-92A, DMA 68=1970-67A, DMA 77=1973-81A, and DMA 59=1967-48A) and the "Nova-type" satellites (DMA 105=1981-44A and DMA 115=1984-110A). The Nova satellites are equipped with sensors and thrusters which compensate for non-conservative forces in the direction of the velocity vector. Thus, polar motion results from the Nova satellites are largely unaffected by variations in solar activity.

2. COMPUTATIONAL METHODS FOR DOPPLER DATA

The pole determination method utilized by DMA is the method adopted by the Naval Surface Weapons Center (NSWC) in August 1971. The summary that follows is taken from the detailed description of the observational procedures and the data reduction techniques given by Anderle [4].

Doppler observations are made daily by a network of approximately 20 worldwide tracking stations controlled by DMA and a network of 4 U.S. tracking stations controlled by the Navy Astronautics Group. All observations taken in a 48-hour period are processed with the CELEST computer program. A least-squares solution is obtained which includes the six constants of orbital integration, a drag scaling factor for each day, a frequency and a tropospheric refraction scaling factor for each pass, the two components of the pole position, and the coordinates of any mobile observing station. The least-squares solution is based on differences between the observations and computed data, which correspond to a predicted satellite orbit. The initial conditions for the equations of motion come from the previous day's orbit fit. The integration scheme is a 12th-order Cowell with a one-minute stepsize. The mathematical model includes the Earth's gravitational field, atmospheric drag, solar radiation pressure, luni-solar gravity perturbations, and solid Earth tidal forces. The integration is done in the true-of-date system.

The accuracy of the orbit determination process is reflected by two statistics: the discontinuity in the ephemeris at the ends of each 2-day span and the root mean square of the residuals of the least-squares adjustment process. The current accuracy of the ephemerides is approximately three meters according to Murphy and Fell [5]. This value agrees with the previous values given by Bowman and Leroy [6] and Wooden [7].

3. ANALYSIS OF DOPPLER POLAR MOTION VALUES

The most important components of polar motion are terms with a Chandler period (420-435 days) and terms with an annual period. In an attempt to highlight residual geophysical properties of the motion and instrumental errors between series of Earth orientation parameters, the dominant annual and Chandler motions and a bias were removed by fitting a five-parameter expression to each component of polar motion. In the analysis that follows, the two types of NNSS satellites are compared with each other, the BIH Circular-D, and other Earth orientation parameter series.

3.1 Comparison of OSCAR-type and NOVA-type NNSS Satellites

The differences between the bi-daily values for each individual NNSS satellite and the BIH Circular-D values for the Main MERIT Campaign are shown in Figure 1 (taken from Wooden et al [8]). Although the x and y curves for Nova satellite (DMA 105) have different biases, they show similar behavior with a time offset of approximately 30 days. The x components of Oscar satellites, DMA 59 and DMA 60, tend to follow the Nova satellite curve, while DMA 68 appears to have periodic oscillations about a constant offset. The y components of the Oscar satellites show less variation than the x components. The scatter associated with the Nova satellite values is about 35 percent smaller than the scatter in the Oscar satellite values. The statistics associated with these comparisons are given in Table 1. The means and standard deviations in the table are in arc seconds, while n is the number of observations.

TABLE 1. Statistics for the OSCAR-NOVA Comparisons (arcsec)

SERIES	X-MEAN	X-SIGMA	Y-MEAN	Y-SIGMA	N
105-BIH	-.009	.015	.007	.015	217
59-BIH	.005	.016	.007	.013	65
60-BIH	-.003	.025	.002	.016	103
68-BIH	-.010	.018	.012	.015	154

In addition to examining the raw observations of the individual satellites, special data sets of 5-day means, designated OSCAR and NOVA, were created from the individual bi-daily values for the Oscar satellite and for the Nova satellite to make comparisons on the standard polar motion days.

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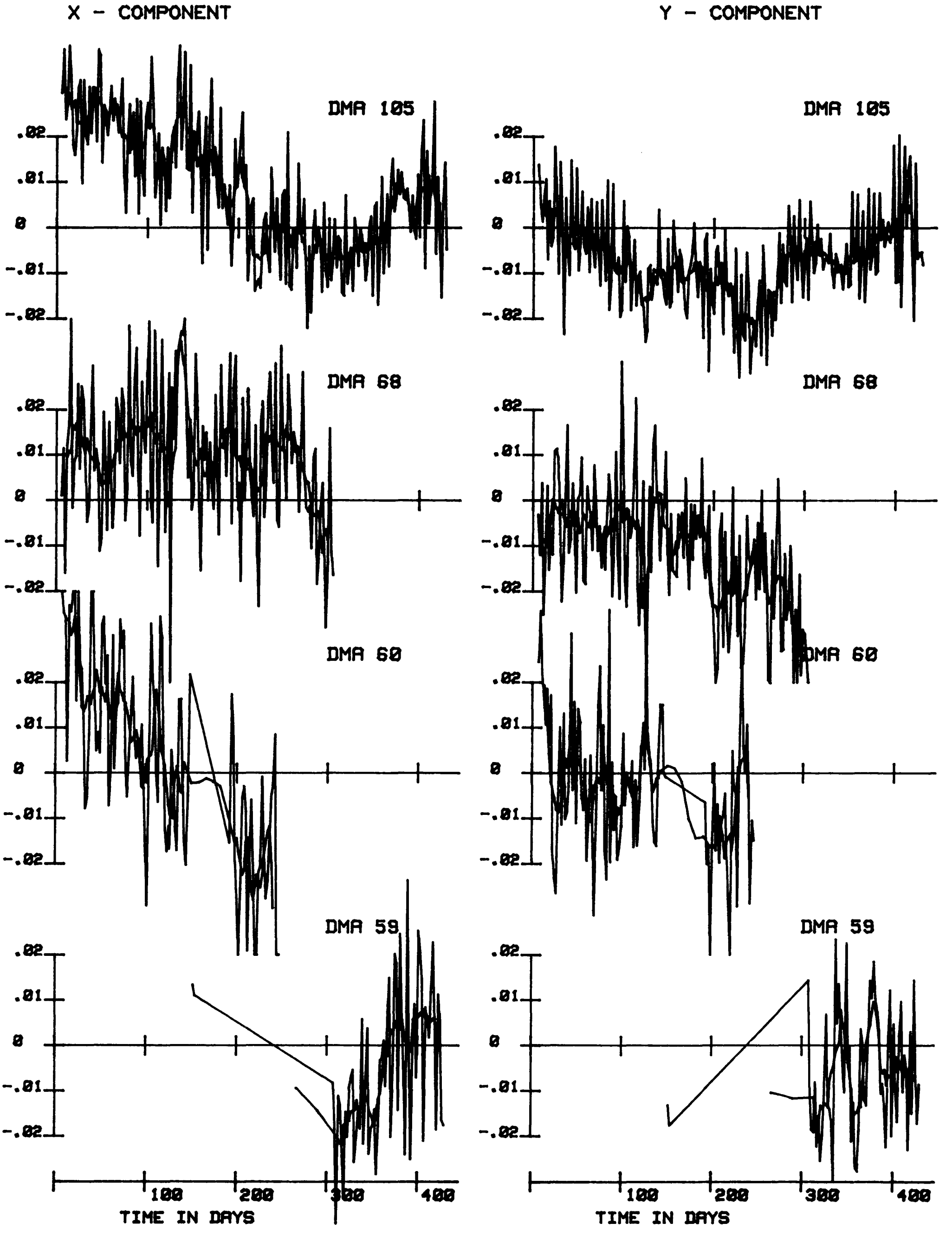
FIGURE 1. DIFFERENCES BETWEEN NNSS AND BIH POLE VALUES
(UNITS IN ARC SECONDS)



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3.2 Comparison of Doppler Satellite Observations with Other Earth Orientation Data types

To examine the geophysical information in each Earth orientation series, separate least-squares fits for the x and y components of pole position were made to remove the annual and Chandler information. Table 2 gives the results of these fits for each data type. The entries of Table 2 are expressed in arc seconds. The BIH data are the Circular-D final values. SLR is the satellite laser ranging series of the University of Texas. VLBI is the Very Long Baseline Interferometry series of the National Geodetic Survey. The SLR and VLBI data were taken from a magnetic tape provided by the U.S. Naval Observatory. NOVA and OSCAR are the special 5-day means discussed previously.

TABLE 2. Amplitudes of the Fitted Parameters (arcsec)

	X-COMPONENT						Y-COMPONENT					
Data	bias	cos A	sin A	cos C	sin C	sigma	bias	cos A	sin A	cos C	sin C	sigma
BIH	.044	.090	-.001	.175	-.083	.008	.283	-.001	-.074	-.093	-.174	.007
SLR	.041	.092	.002	.171	-.082	.009	.276	-.001	-.076	-.091	-.173	.007
VLBI	.051	.095	.002	.168	-.084	.007	.279	-.006	-.080	-.093	-.172	.006
NOVA	.042	.086	-.009	.173	-.092	.013	.294	-.009	-.076	-.094	-.176	.009
OSCAR	.039	.088	.003	.171	-.095	.016	.294	-.003	-.077	-.096	-.174	.013

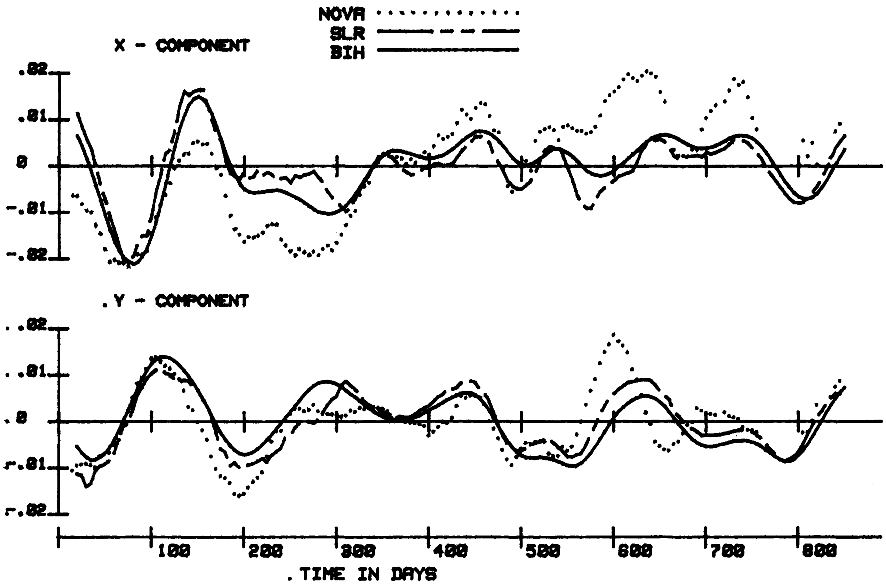
Figure 2 shows the residuals of the fits whose fitted parameters are given in Table 2. As is evident from the figure, the geophysical information is similar for all data types, i.e., the major peaks agree. However, the Doppler data (particularly the OSCAR data) do exhibit minor differences - the OSCAR data show extra humps at 30 and 390 days (y-comp) and 200 days (x-comp). Paquet et al [9] also note the similarity of the geophysical information in their residual plots for the period of the Main MERIT Campaign.

To further differentiate subtle differences between the Earth orientation parameter series shown in Figure 2, the residuals of the fits were differenced. Figures 3 and 4 give the results of this process for Doppler and BIH data.

4. CONCLUSIONS

The polar motion derived from Doppler tracking of the NNSS satellites has provided and continues to provide valuable Earth orientation information. When the annual and Chandler components of polar motion are removed from the observational data of each Earth orientation series, the same geophysical information remains. The estimates of pole position provided by Nova satellites are about 35 percent more precise than the estimates from the Oscar satellites.

FIGURE 2. RESIDUALS OF THE FIVE-PARAMETER FITS FOR THE EOP SERIES
(UNITS IN ARC SECONDS)



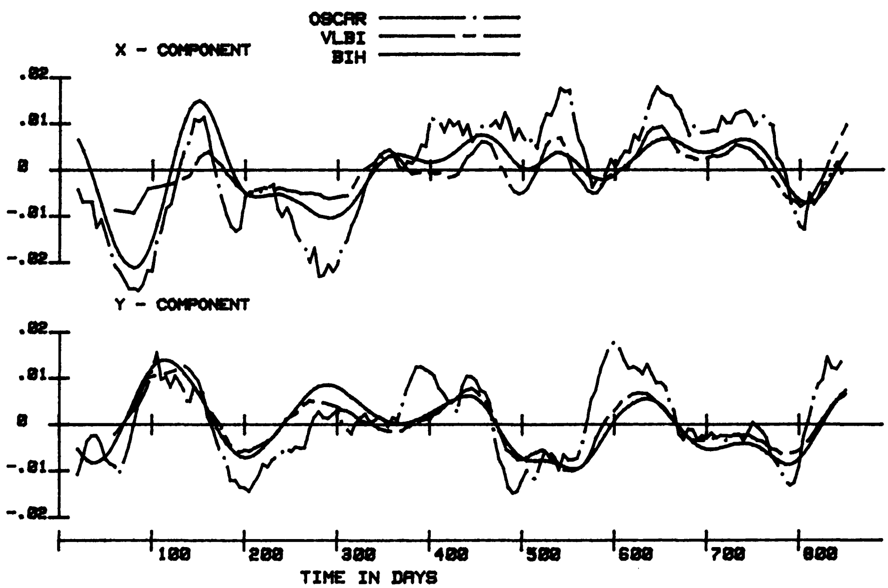


FIGURE 3. OSCAR - BIH RESIDUALS WITH PERIODS REMOVED
(UNITS IN ARC SECONDS)

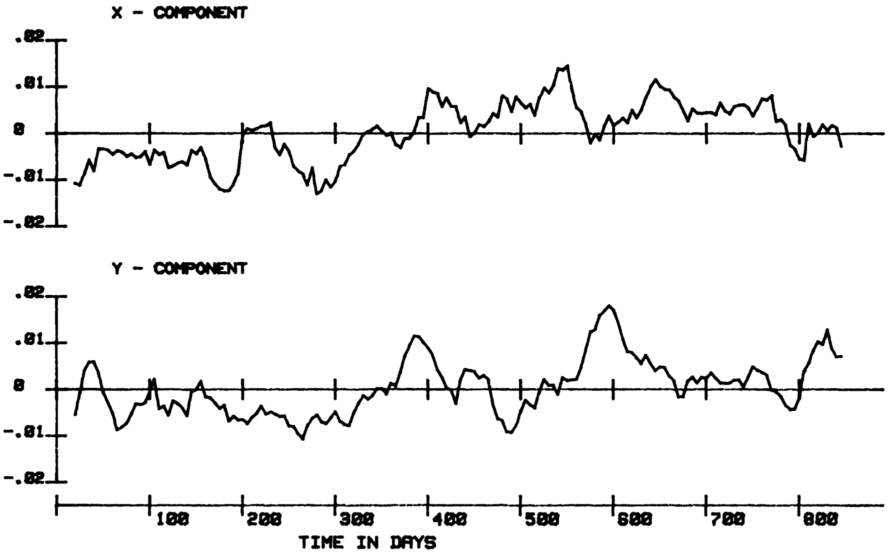
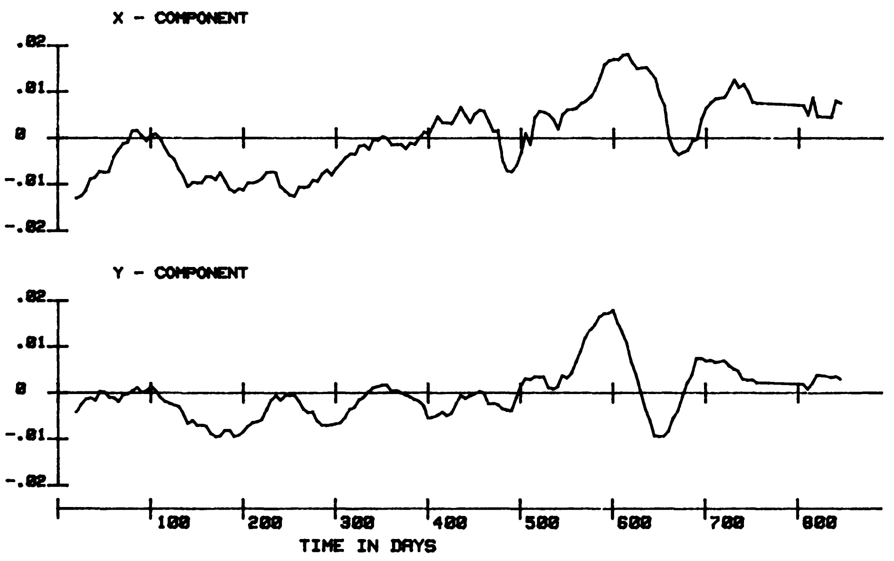


FIGURE 4. NOVA - BIH RESIDUALS WITH PERIODS REMOVED
(UNITS IN ARC SECONDS)



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DISCUSSION

Pâquet: The new gravity field WGS84 reduces most of the bias noted with the model currently used (NWL10E). To what degree is the internal error reduced, for the NOVA satellite?

Reply by Wooden: Preliminary analysis show that the internal error is reduced by 30 to 35% but longer periods of observations with the new model have to be considered to fix a more precise value.

Feissel: When does DMA intend to implement the WGS84 system in the current computation of pole positions?

Reply by Wooden: Currently, the testing of the new parameters is underway. It is anticipated that the new system will be implemented near the beginning of 1987.

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