Use of Doppler Determinations of Polar Motion Using Artificial Satellites to Support JPL Planetary Missions

H. F. Fliegel
Tracking and Orbit Determination Section

Standard deviations and systematic differences are calculated between the U. S. Navy Weapons Laboratory (USNWL) determination of the X and Y coordinates of the pole, using artificial satellites, and the smoothed 5-day means published by the Bureau International de l'Heure (BIH). The results indicate slowly varying errors of about 1 meter in the conventionally obtained optical data of BIH, now used by JPL. Although current values of polar coordinates should be based upon the BIH Rapid Service, values for previous months might be improved with the help of USNWL doppler data.

An important factor in attaining the navigational accuracy realized in JPL deep space missions is precise knowledge of polar motion. To obtain such information during the Mariner Mars 1971 mission, JPL sponsored a contract with the Bureau International de l'Heure (BIH) to form a rapid time and polar motion service (Ref. 1). C. C. Chao and the author have considered the importance of using the U. S. Naval Weapons Laboratory (USNWL) polar motion values, obtained from doppler tracking data on navigational satellites, to check the results which are obtained by BIH using conventional astronomical means (Ref. 2). Here the biases and standard deviations of recent USNWL data are given with respect to BIH, thus updating the tables of Ref. 2.

The differences between the USNWL 5-day mean values of the X and Y coordinates of the pole and the BIH smoothed values interpolated to the same date are graphed in Figs. 1 and 2. The standard deviations and the mean values of these differences, calculated year by year from the inception of the USNWL service, are given in Tables 1 and 2. Notice that the values given here differ slightly from those given in Ref. 2. This is because in Ref. 2 we measured USNWL against unsmoothed BIH 5-day means and combined the results with other data to infer the standard deviations of USNWL and of BIH separately, whereas here are presented only the differences between USNWL and BIH smooth data. The BIH smoothed 5-day values are really more than averages; they are values from a highly smoothed function read off and published by BIH at 5-day intervals. Calculations were made by interpolating normal points formed first from sets of 2, then in subsequent computer runs from sets of 3 and from sets of 4 BIH 5-day values. They never differed significantly from calculations made by interpolating the 5-day values directly. On the other hand, combining USNWL data into normal points reduces the noise level in the manner shown by Table 1 and Fig. 3. Table 1 indicates that the standard deviations in Y (the axis through the U.S.) are larger than those on X (through Europe) in 1970 and 1971, which may reflect the deployment and relative accuracy of the naval tracking stations. However, these differences are no doubt smaller than the uncertainties of the standard deviations.

Figure 3 illustrates how the random error of the doppler data decreases with the number of days of doppler data combined to form normal points. The curve is much flatter than that appropriate to a Gaussian distribution, indicating a fair amount of nonwhite, time-correlated noise.

The values of Table 2 represent the average biases between BIH and doppler results; and these biases, unlike the standard deviations, cannot be ascribed entirely to the doppler data. In Figs. 1 and 2 are shown both the International Polar Motion Service (IPMS) and the USNWL doppler values for X and Y, minus the BIH values. Thus, the X axes in Figs. 1 and 2 would indicate zero difference from BIH. There is evidently strong correlation of the IPMS data with the doppler data against BIH, especially in Y during 1970–1971. This correlation indicates that the slowly varying errors which produce the biases of Table 2 are produced largely by systematic effects in the BIH data or reduction procedure.

Nevertheless, BIH Rapid Service data are still the source of polar motion information best suited to JPL mission support, since BIH data are virtually free of the very large random residuals which occur in the doppler results. In real-time mission support, one typically encounters either of two situations:

(1) A maneuver or some incident occurs only a few days before planetary encounter, as with Mariner 7. The orbit determination on which the success of the mission depends is based upon the short arc of tracking data obtained after the maneuver or incident. The accuracy of this determination depends on the exactness with which polar motion is known during that short interval. Large random errors are more serious than slowly varying errors of 1 meter or less. In this crucial situation, the BIH Rapid Service supplies our need.

(2) No maneuver or incident interrupts a long arc of tracking data, upon which the orbit determination may confidently be based, as with Mariner 9. Exact polar motion information is not so essential as in the former situation, because the characteristics of the orbit of the spacecraft around the Sun provide more information concerning its position than does the doppler signature produced by the rotation of the Earth. Nevertheless, determination of station locations are made more accurately if long-term errors in polar motion are minimized, and to this end the USNWL doppler data may be useful.

For future JPL missions such as MVM 73 and Viking, a mixed data set may be best, in which current values for polar position are based upon the BIH Rapid Service, and values for previous months are estimated with the help of USNWL doppler data. In future articles, we will discuss the best attainable models for polar motion, its physical characteristics, and optimal strategy for future missions.

The following conclusions have been drawn:

(1) The standard deviations of USNWL doppler determinations of the X and Y coordinates of polar position have held more or less constant during 1969.0–1972.0, at about 1 meter.

(2) The biases between USNWL and BIH are also at about the 1-meter level.

(3) The strong correlation between USNWL and IPMS against BIH indicates a slowly varying error in BIH data.

(4) Nevertheless, the BIH Rapid Service is still best suited to JPL needs. Both BIH and USNWL data should be used in support of future planetary missions.

References

1. Fliegel, H. F., "A Worldwide Organization to Secure Earth-Related Parameters for Deep Space Missions," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. V, pp. 66–73. Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1971.

2. Chao, C. C., and Fliegel, H. F., "Polar Motion: Doppler Determinations Using Satellites Compared to Optical Results," in *The Deep Space Network*, Space Programs Summary 37-66, Vol. II, pp. 23–28. Jet Propulsion Laboratory, Pasadena, Calif., Nov. 30, 1970.

Table 1. Standard deviations of USNWL data from smoothed 5-day means of BIH (meters)

Year	5-day means		10-day means		15-day means		20-day means	
	Coordinate							
	X	Y	X	Y	X	Y	X	Y
1968	1.575	1.390	1.448	1.045	1.409	0.974	1.369	0.882
1969	0.961	0.927	0.767	0.808	0.735	0.755	0.709	0.688
1970	0.960	1.006	0.871	0.934	0.844	0.881	0.823	0.823
1971	0.864	0.945	0.710	0.788	0.642	0.720	0.614	0.682

Table 2. Mean yearly differences (USNWL – BIH) (meters)

Year	Coordinate	
	X	Y
1968	+1.515	−1.911
1969	+1.037	−1.704
1970	−0.370	+0.000
1971	−0.290	−0.806

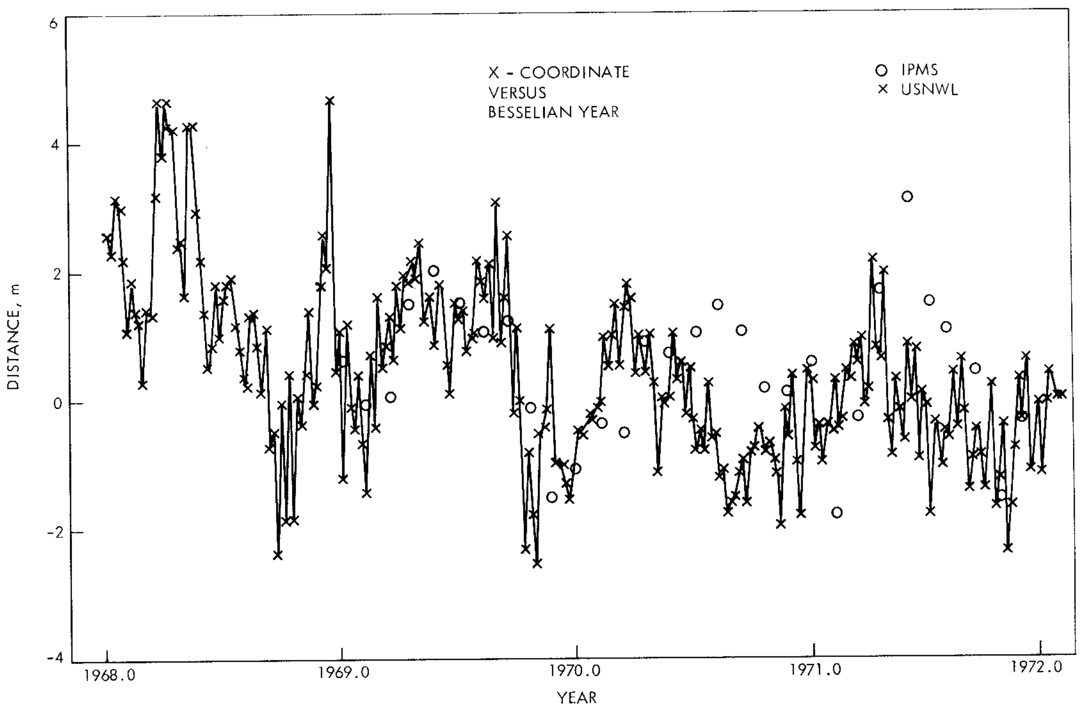

Fig. 1. Comparison between polar motion data types for X coordinate: USNWL/IPMS minus BIH values

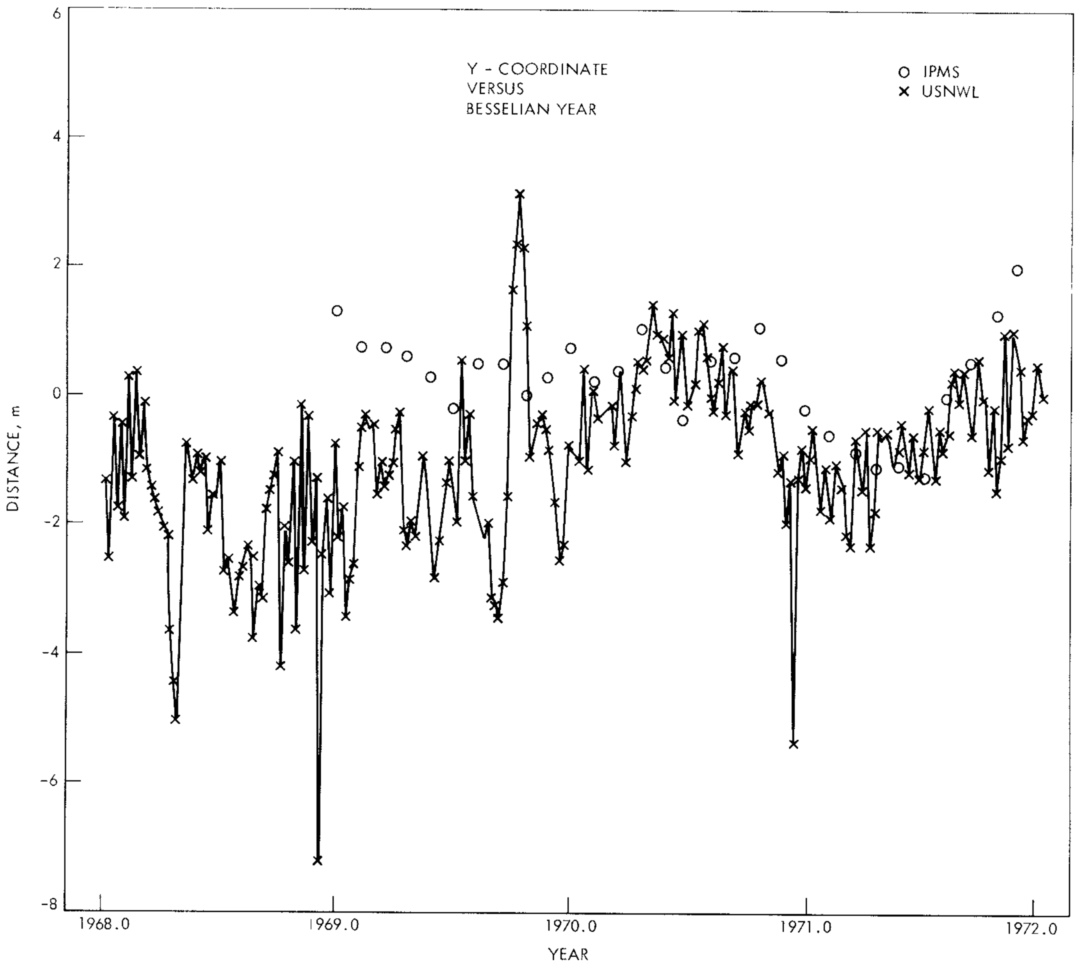

Fig. 2. Comparison between polar motion data types for Y coordinate: USNWL/IPMS minus BIH values

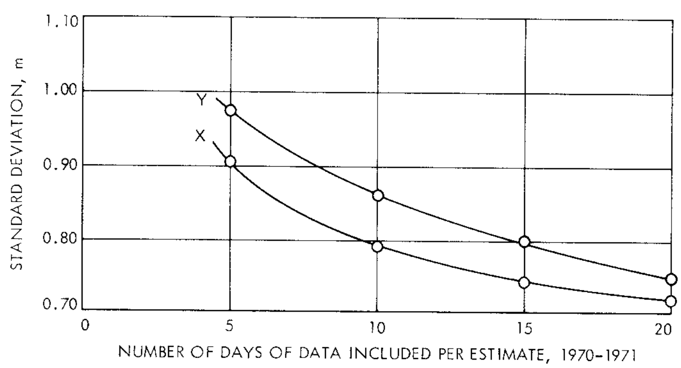

Fig. 3. Standard deviations of USNWL polar coordinates vs number of days of data included per estimate in 1970–1971