EARTH'S ROTATION AND POLAR MOTION BASED ON GLOBAL POSITIONING SYSTEM SATELLITE DATA

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ABSTRACT

Using current procedures, polar motion and Earth's rotation can be computed from 7 days of observations from four stations to four Global Positioning System Satellites to an accuracy of 1.5 m and .3 msec/day, respectively. Improved computational techniques or instrument accuracy and/or measurements from additional satellites or stations would give significant improvements in accuracy.

INTRODUCTION

The Naval Surface Weapons Center computes orbits for satellites in the Global Positioning System to provide references for linearized up-dating and injection of predicted ephemerides into the satellite memory by the Master Control Station of the system, and to provide post-fit ephemerides for analyses conducted with data from geodetic positioning equipment. These ephemerides are normally based on pole positions and earth's rotation predicted from data distributed by the Bureau International de l'Heure. This report discusses a study conducted to determine the possibility of computing pole position and earth's rotation from the GPS data in the course of these calculations.

CURRENT COMPUTATIONAL PROCEDURES

The four monitor stations in California, Alaska, Hawaii and Guam make pseudo-range measurements on two frequencies and Doppler measurements on one frequency every six seconds that a satellite is in view. Six satellites are currently in orbit, and during the brief period that more than four are in view simultaneously, some reduction in the data rate per satellite occurs. The measurements are fit by polynomials by the master control station, and smoothed vacuum ranges at fifteen minute intervals are provided to NSWC. These pseudo-range measurements

O. Calame (ed.), High-Precision Earth Rotation and Earth-Moon Dynamics, 173–179.

typically have a noise level of about 50 cm for the four satellites whose clocks are performing normally (data from the remaining two satellites were not considered in this report because one is operating on a quartz clock and the Rubidium oscillator on the other satellite is no longer performing according to specifications). To make full use of the data, clock models should be fit to the pseudo range data from each station and each satellite. Instead, NSWC differences the ranges at 15 minute intervals and fits an ephemeris to the range difference data. This is done for two reasons. First, the major portion of the computations are done in near real time with little manual intervention. Clock resets and disturbances which occur occasionally are difficult to accommodate in automatic processing of pseudo-range data and, if undetected, can produce gross orbit errors; on the other hand, each such discontinuity affects only one observation of range difference, which is easily detected and rejected automatically. Secondly, NSWC computations are currently based on a batch processing least squares solution which assumes uncorrelated errors in the observations. However, normal variations in the ground and satellite oscillators are at a level comparable to the noise level; neglect of these variations (above the linear or quadratic clock models employed) would result in unrealistically optimistic standard errors of the parameters and incorrect relative weighting of data on different satellite passes. However, treatment of the data as range differences does produce a somewhat pessimistic estimate of the accuracy of the parameters. In another attempt to accommodate unmodeled errors in the solution, the station coordinates are considered unknown during each pass of the satellite over each station with a standard error of 1 m for the *a-priori* coordinates. The principal parameters of each solution are the six orbit constants, a solar radiation scaling factor, and an acceleration normal to the direction to the sun to accommodate a solar radiation force resulting from a small deviation between the normal to the solar panels on the satellite and the direction to the sun. Nominal values for these last two parameters are used based on the past history of solutions with a suitable standard error for the *a-priori* values.

RESULTS OF POLE POSITION AND EARTH'S ROTATION COMPUTATIONS

The computational procedures described above were applied to six seven-day spans of data acquired on four satellites in September and October 1980. Two solutions were obtained for each data span, one including only the components of pole position in addition to the dynamic parameters, and one including both pole and earth's rotational rate. The results of the latter solution are given in Table 1. The UT-1 values were obtained by integrating the solutions for the earth's rotation rate, W, initialized at the BIH value on day 252. Pole positions computed with the earth's rotation rate held fixed were within a decimeter or two of those in Table 1, as might be expected from the small correlation coefficients. The difference between these pole positions and BIH Circular D values are given in the right hand column of Table 2. The scatter in the solutions is reasonable considering the standard errors of the solution, which are about 1.5 m, but the X coordinates are clearly biased. Pole solutions computed using data from each satellite separately are also biased, as shown in the table. The correlation coefficients between the pole position components for the single satellite solutions and the orbital elements of the satellite are shown in Table 3. (The minimum and maximum values shown are selected from among the results for the six data spans.) Note that the correlations of the X component of pole with the orbital element E COS G (eccentricity times cosine of the argument of perigee) and with inclination are consistently high. The high values probably result from the fact that the observing stations are all in the northern/western hemisphere, and from the position of the orbit planes with respect to the X and Y axes. Tests will be conducted of the sensitivity of the pole bias to expected errors in the station coordinates, particularly their scale and z-axis origin. (The station coordinates used were determined in the DoD WGS-72 system, which is believed to be biased by 2 to 4 m in these two parameters (Anderle 1976, p75, Anderle 1980, p522,523).

SENSITIVITY OF POLE POSITION RESULTS TO COMPUTATIONAL MODEL

Even if the bias in pole solution is explained, the random error of 1.5 m for these 7 day solutions is too large for the results to be competitive with those obtained from other sources. Therefore a study was conducted to determine the sensitivity of the precision of the solution to three of the assumptions used in making the computations. The three assumptions tested were: (1) the use of a bias parameter for each coordinate of each station on each pass, (2) the use of a-priori data for the frequency of the satellite oscillators for each pass, which can be obtained from variations in range bias between passes; and (3) use of the pseudo-range data directly with a clock model for each satellite and station based on these observations, rather than the use of range differences constructed from the pseudo-ranges. Table 5 gives the results of the tests, which were conducted using a seven day span of data (days 88-94, 1981) for four satellites. Under the best conditions, the 1.5 m uncertainty is reduced to about 30 cm. Further reductions would be obtained if data for additional satellites or stations were included in the solutions.

SUMMARY

Current data and data processing techniques do not produce pole position or Earth's rotation results which are competitive in accuracy with those available from other techniques. A study will be conducted to determine the source of a systematic bias in the X component of the computed pole positions. It is possible that improvements in computational techniques and additional data would produce results of geophysical interest.

Table 1. Earth's rotation results based on GPS observations

YR	DAYS	SAT	X	Y	W	SX	SY	SW	RXY	RXW	RYW	WTD	UTC-UT1
			M	M	MS/D	M	M	MS/D				RES	MS
80	252258		-13.55	9.13	-14.21	2.41	1.24	.43	.33	-.024	-.051	.918	-11.2
80	259265		-6.74	11.01	-15.04	1.34	.96	.34	.02	-.025	.056	.918	-116.4
80	266272		-4.82	12.62	-15.99	1.41	1.01	.43	-.01	.040	.032	.914	-228.3
80	273279		-6.28	10.14	-16.25	1.50	.91	.35	.17	-.054	.071	.938	-342.1
80	280286		-7.16	11.90	-15.90	1.66	1.01	.10	.11	-.022	.011	.918	-453.4
80	287293		-4.03	14.79	-14.84	1.42	.94	.27	-.02	-.022	.037	.908	-557.3

Table 2. Pole solution, GPS-BIH

POLE SOLUTION
GPS-BIH

	SATELLITE				
SPAN	5	6	8	9	COMBINED
	(XCOORD/STD ERR)				
252	-15.1/8.8	-28.3/5.0	-6.2/3.3	-25.0/12.	-13.9/2.4
259	-7.6/2.1	-12.6/3.1	-3.8/3.2	-14.6/5.2	-7.1/1.3
266	-4.5/2.1	-13.6/3.7	-10.0/3.4	-	-5.1/1.4
273	-3.8/2.5	-12.7/3.8	-6.9/2.5	-13.3/5.8	-6.5/1.5
280	-7.3/2.9	-7.9/4.0	-6.9/3.0	-19.8/5.3	-7.3/1.7
287	-7.3/2.3	-3.2/3.2	-8.5/3.2	-16.9/5.0	-4.1/1.4
	(YCOORD/STD ERR)				
252	7.8/6.5	7.9/4.2	-1.0/1.4	10.3/7.2	-.7/1.2
259	10.7/2.7	-1.6/3.1	0.1/1.4	3.8/3.9	1.0/1.0
266	10.0/2.7	3.6/3.6	-.2/1.4	-	2.4/1.0
273	12.9/2.8	-2.5/3.6	2.3/1.1	7.4/4.4	-.4/0.9
280	10.8/4.3	1.8/3.7	-.3/1.2	9.5/4.1	-1.2/1.0
287	13.1/2.3	7.4/2.9	-.5/1.3	0.7/4.0	3.9/0.9

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Table 3. Single satellite correlation coefficients

ELEMENT	6	8	5	9
X COMPONENT WITH ORBITAL ELEMENTS (MIN,MAX)				
A	-.12 , .11	-.21 , .09	-.04 , .13	-.25 , .03
E COS G	.85 , .87	.31 , .89	.60 , .76	.85 , .87
E SIN G	.02 , .35	-.49 , -.39	-.14 , .26	.56 , .74
I	-.78 , -.64	-.90 , -.67	-.76 , -.53	-.93 , -.90
L+G	-.46 , -.33	.58 , .70	-.45 , -.03	-.53 , -.43
H	-.12 , .05	-.28 , .16	-.14 , .08	-.29 , .20
Y COMPONENT WITH ORBITAL ELEMENTS				
A	-.17 , .24	-.25 , -.07	-.09 , .29	-.05 , .21
E COS G	-.77 , -.65	.28 , .45	-.80 , -.27	-.45 , -.13
E SIN G	-.26 , -.16	-.33 , -.27	-.34 , -.11	-.13 , .42
I	.69 , .76	-.56 , -.35	.28 , .85	.01 , .45
L+G	-.58 , -.33	.09 , .25	.45 , .69	-.83 , -.55
H	-.14 , .06	-.26 , .11	-.10 , .16	-.18 , .15

(Column heads 6, 8, 5, 9 are under the spanning header SATELLITE.)

A = semi-major axis
E = eccentricity
G = argument of perigee
I = inclination
L = mean anomaly
H = right ascension

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Table 4. GPS pole position - precision of solution (CM)

DATA TYPE	STATION PASS BIAS (M)	FREQUENCY UNCERTAINTY	STD. DEV. X	STD. DEV. Y
Range Difference	2 m	large	131	95
"	2 m	10^{-12}	86	68
"	0	large	88	69
"	0	10^{-12}	61	48
Range	2 m	large	90	62
"	0	large	33	26

REFERENCES

Anderle, R. J., "Error Model for Geodetic Positions Derived from Doppler Satellite Observations", Bulletin Geodesique 50(1), pp.43-77, 1976.

Anderle, R. J., "Accuracy of Mean Earth Ellipsoid Based on Doppler, Laser and Altimeter Observations", Bulletin Geodesique 54, pp.521-527, 1980.

DISCUSSION

McCarthy : Was the simulated error model for 5 or 7-days solutions ?

Anderle : The six solutions for pole positions and earth's rotation during the MERIT campaign were for seven-day spans of data. The sensitivity studies to the assumed model were made for a six-day span of data.

Klepczynski : Will better (different) geographical distribution of monitor stations help you ?

Anderle : Yes. Observations better distributed in longitude and latitude will reduce the correlations between pole position components and orbital elements.