BIASES IN POLE POSITION COMPUTED FROM DATA FROM DIFFERENT NAVY NAVIGATION SATELLITES

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ABSTRACT

Biases have been noted in pole positions computed from Doppler observations of different Navy Navigation Satellites. Studies show that the differences in the orbits of the Navy Navigation Satellites, although small, are large enough so that uncertainties in knowledge of the earth's gravity field could produce the biases noted.

INTRODUCTION

The position of the earth's spin axis with respect to a coordinate system fixed in the earth has been computed on the basis of Doppler observations of Navy Navigation Satellites for the last ten years. Usually, results have been computed from data observed on two of the four or five satellites which are operating. Martine Feissel of the Bureau International de L'Heure noted that in some cases the results from one satellite are biased with respect to another. The average differences she noted are shown in Table 1 along with the orbital inclinations and eccentricities of the satellites. The differences for satellites 1967-92A and 1970-67A, which are among the largest, are plotted in Figure 1. The bias is about comparable to the random error for an individual 2 day solution, but is quite evident for a year's data. Although the satellites are in similar orbits, a study was conducted to determine if the differences in orbital conditions were sufficient so that uncertainties in the earth's gravity field could produce the bias. To test this hypothesis, orbit computations were performed for the same data for each of the two satellites, first with the NWL 10E1 gravity field normally used in orbit computations and then with a modification of the Goddard Space Flight Center gravity model PGS S4. The modification consisted of the replacement of the resonant coefficients of 13th, 14th and 15th order in the PGS S4 model by those in the NWL 10E1 model. The replacement was done for two reasons: Primarily, resonant coefficients produce effects on the orbit which are out of phase with pole position effects, so that a bias is not

O. Calame (ed.), High-Precision Earth Rotation and Earth-Moon Dynamics, 313–327.

Table 1. Mean difference in pole position

Satellite 1			Satellite 2			Time	Difference in Pole Position	
Number	Inclination	Eccentricity	Number	Inclination	Eccentricity	Interval	x	y
1967-92A	89.3°	.005	1967-48A	89.6°	.002	1972.50-1972.95	-″006	-″003
1967-48A	89.6	.002	1970-67A	90.1	.018	1974.45-1974.65	.002	-.001
1973-81A	90.1	.017	1970-67A	90.1	.018	1975.05-1976.40	.004	-.003
1967-34A	90.4	.002	1970-67A	90.1	.018	1976.45-1977.45	-.004	.003
1973-81A	90.1	.017	1970-67A	90.1	.018	1977.45-1978.25	-.004	-.008
1973-81A	90.1	.017	1970-67A	90.1	.018	1978.30-1978.15	.002	-.011
1967-92A	89.3	.005	1970-67A	90.1	.018	1979.20-1979.80	.018	-.020
1967-92A	89.3	.005	1967-48A	89.6	.002	1979.90-1980.15	-.011	-.002

likely to be produced by these coefficients. Secondarily, the PGS S4 resonant coefficients are likely to have significant errors in application to polar satellites because little data from these satellites were used in the development of the PGS S4 gravity field; the large errors would complicate the search for a bias.

COMPARISON OF NWL 10E1 AND PGS S4 POLE POSITIONS

Differences in pole position computed for the two satellites using the two gravity fields are shown in Table 2 for four data spans. Any bias between the satellites in the table due to the difference in gravity fields could be accidental. Although the same data were used in the computations for a given satellite using the two gravity fields, it was still felt that non-uniform distribution of observations of each satellite, varying some from day to day, would produce random effects which could mask a bias. Therefore another method of investigation was sought.

SENSITIVITY OF POLE POSITION TO ORDER OF GRAVITY COEFFICIENTS

Normal equations for gravity coefficients and pole position were available for navigation satellite 1970-67A and for the GEOS-3 satellite 1975-27A, which has an orbital inclination of 115^{o}, from the results of computations performed in the development of a new gravity model. These normal equations were analyzed to determine the sensitivity of pole position to various orders of the spherical harmonic expression for the earth's gravity field. Table 3 shows that pole positions computed from GEOS-3 satellite data are primarily sensitive to first order coefficients while the polar satellite is more sensitive to second order coefficients. (The corrections to pole position shown are due to random deviations in normalized gravity coefficients satisfying the observed decay rate of $10^{-5}/n^{2}$; that is, the total effect of the estimated gravity coefficients.) Note that the effects on the polar satellite are generally larger and are distributed among many different orders of coefficients. The results showed that satellites with widely different orbital inclinations would have different sensitivity to gravity errors, but did not directly answer the immediate question. It was finally decided that orbits computed for selected coefficients from the two gravity fields would be compared directly to isolate the size and character of the effects.

COMPARISON OF ORBITS WITH DIFFERENT FIRST OR SECOND ORDER COEFFICIENTS

Orbits for both satellites and one data span were computed with NWL 10E1 coefficients except with second order coefficients taken from the PGS S4 field. Differences in the along track position obtained with the two gravity fields are shown in figures 2 and 3 for the two satellites. The twelve hour period in the residuals is similar in

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Table 2. Differences in pole position, Satellite 1970-67A - Satellite 1967-92A

Data Span	PGS S4		NWL 10E1			PGS S4 - NWL 10E1	
	x	y	x	y		x	y
(days, 1980)	(m)	(m)	(m)	(m)		(m)	(m)
91- 92	-4.07	-1.74	-.53	.45		-3.54	-2.19
171-172	-1.95	1.03	-.29	.02		-1.66	.88
291-292	-.66	1.44	-1.32	.71		.66	.73
293-294	-.61	1.96	-1.01	.24		.40	1.72
					Mean	-1.03	.27
					Std Dev	1.97	1.70
					Std Error	.98	.84

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amplitude for the two satellites and quite large. Inspection of the residuals of fit revealed that the error is primarily in the PGS S4 coefficients and is many times the effect due to the expected error in the NWL 10E1 coefficients. Orbits were then computed for two data spans with the first order coefficients in the NWL 10E1 field replaced by PGS S4 coefficients and compared with orbits computed with complete NWL 10E1 coefficients. Comparison of the along track difference between orbits computed with the two fields is shown with respect to time in figures 4 and 5. Note the dramatic difference in the character of the differences for the two satellites, and the similarity of the difference for two data spans for a given satellite. The differences are displayed according to the geographic position of the sub-satellite point in figures 6 and 7. Note that the errors occur with about the same magnitude and at the same geographic location for the two data spans. Since the effects of tesseral coefficients can be expected to be earth-fixed, and are of a size which could exist in the NWL 10E1 gravity field, it is believed that the results demonstrate that the bias in pole position for the two satellites could be due to errors in the NWL 10E1 gravity field.

Table 3. Effect of random perturbations in gravity coefficients on computed pole position

Order of Coeff Perturbed	1970-67A Effect on x(m)	1970-67A Effect on y(m)	1975-27A Effect on x(m)	1975-27A Effect on y(m)
odd zonal	-49.6	-97.9	-1.3	0.0
even zonals	-1.2	-.5	-1.7	-1.1
odd 1st	-5.5	12.2	26.3	-7.1
even 1st	8.2	7.3	45.6	-40.7
odd 2nd	-32.3	-21.8	4.2	-.1
even 2nd	-122.4	-115.6	-4.9	2.5
odd 3rd	-8.7	-.6	.1	1.0
even 3rd	8.1	-6.5	-.6	-2.0
odd 4th	-24.2	-2.0	-1.3	3.5
even 4th	204.7	1.2	-.9	.7
5th	-10.6	-37.8	-2.7	3.1
6th	-13.1	-16.8	0.0	-0.7
7th	52.6	-4.5	.1	-.3
8th	-5.8	2.2		

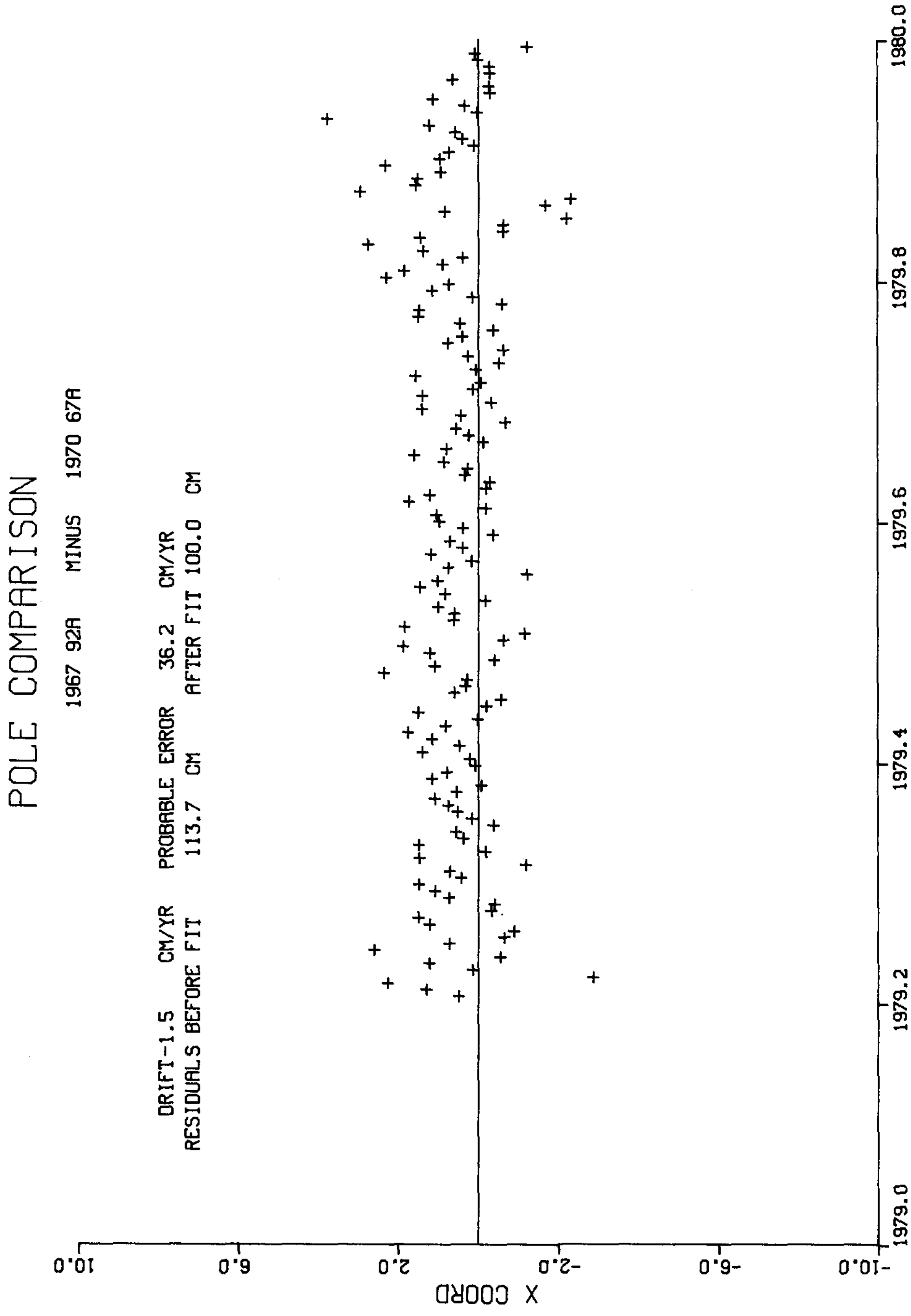

Figure 1a. Differences in the x component of pole position computed from 1967-92A and 1970-67A satellite data

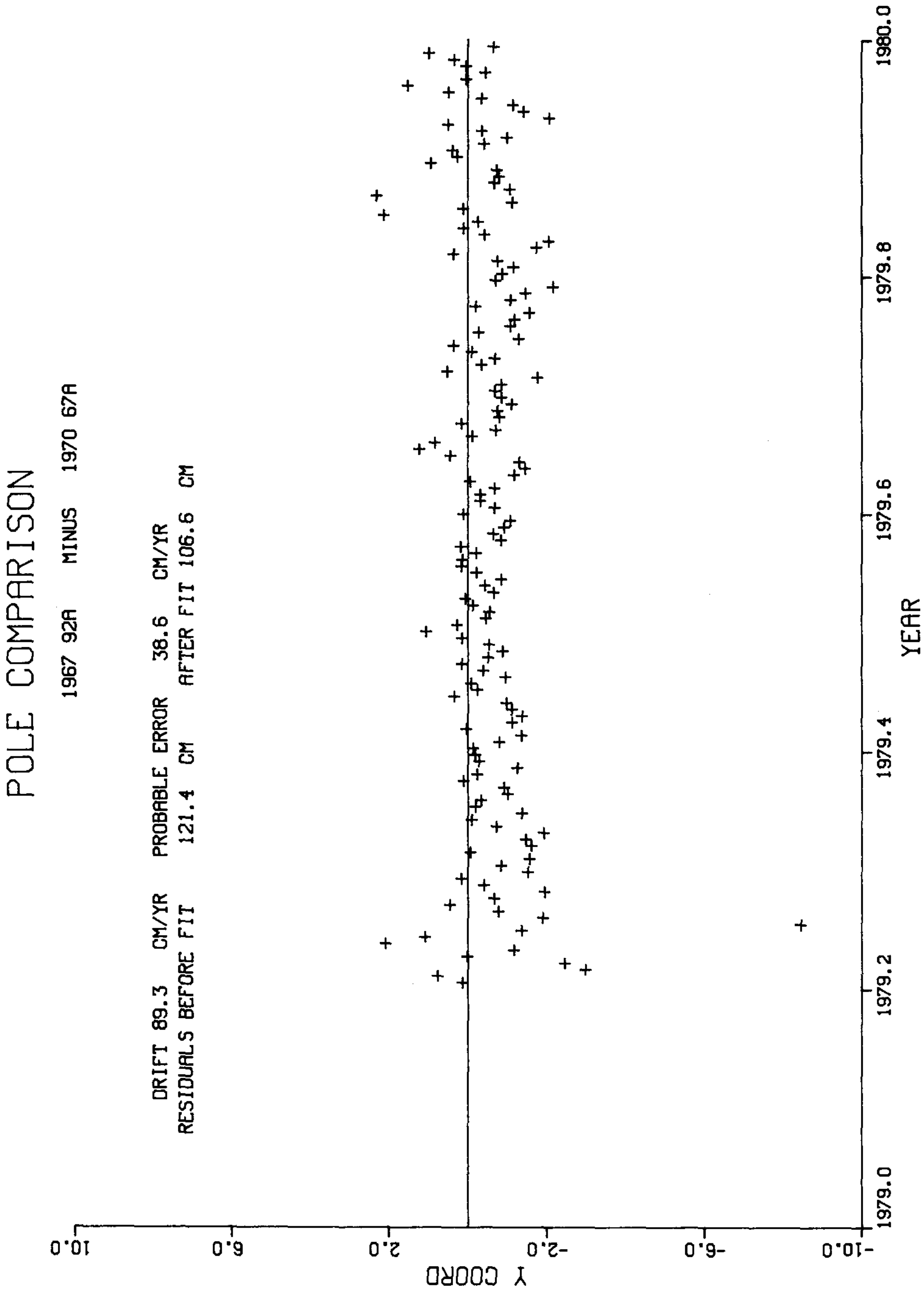

Figure 1b. Differences in y component of pole position computed from 1967-92A and 1970-67A satellite data

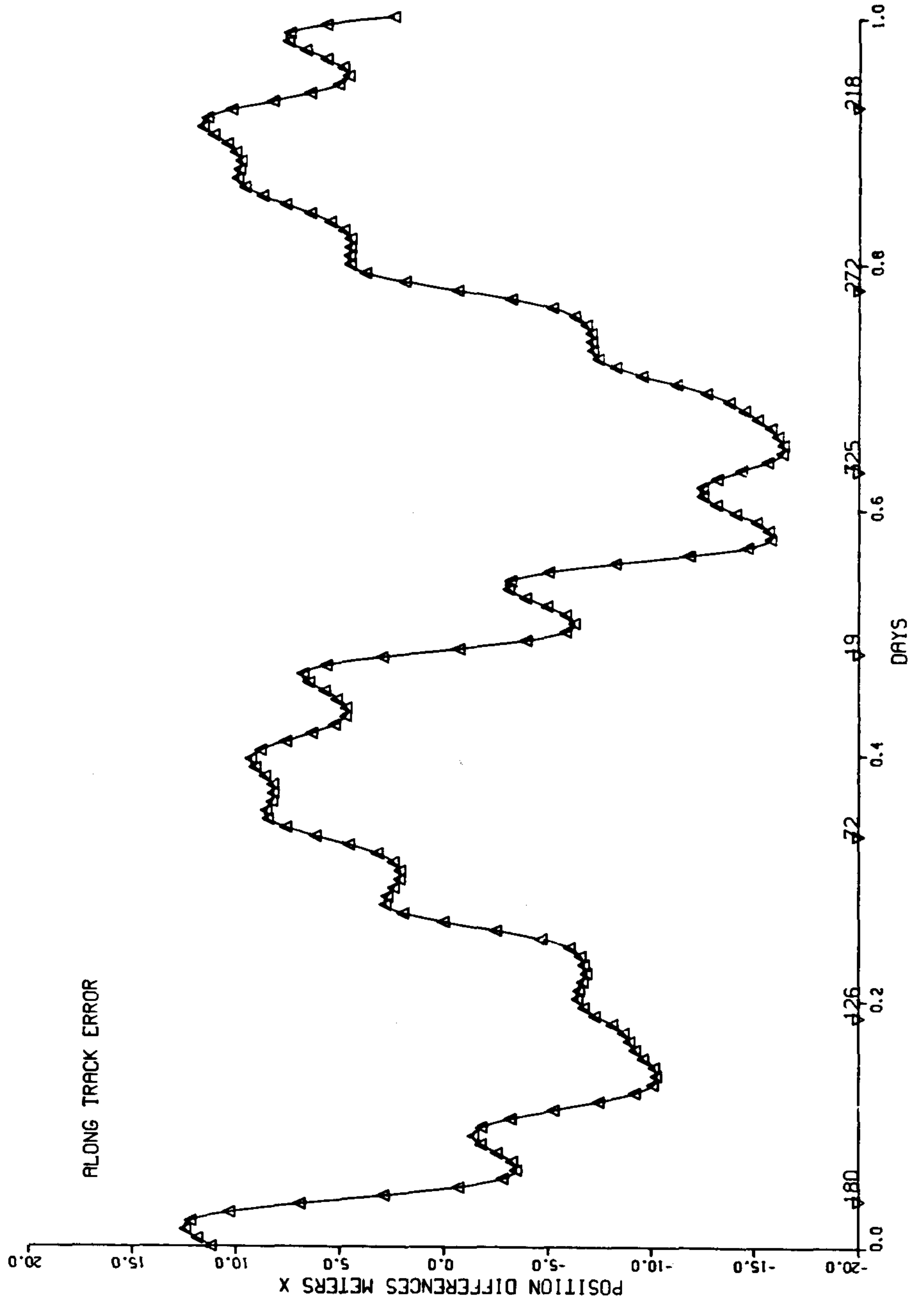

Figure 2. Position differences for 2nd order effects, satellite 1967 92A, day 291 1979

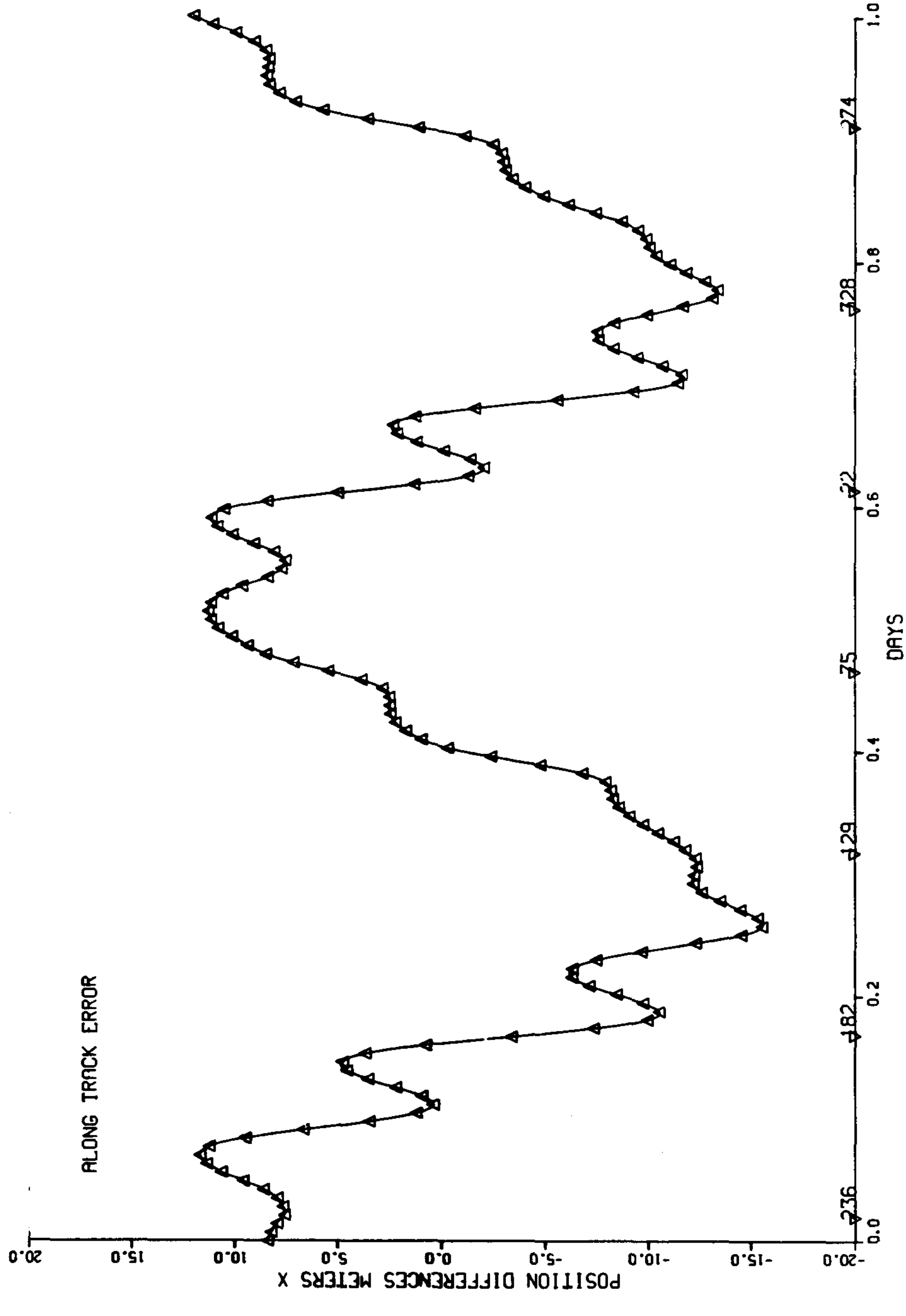

Figure 3. Position differences for 2nd order effects, satellite 1970 67A, day 291 1979

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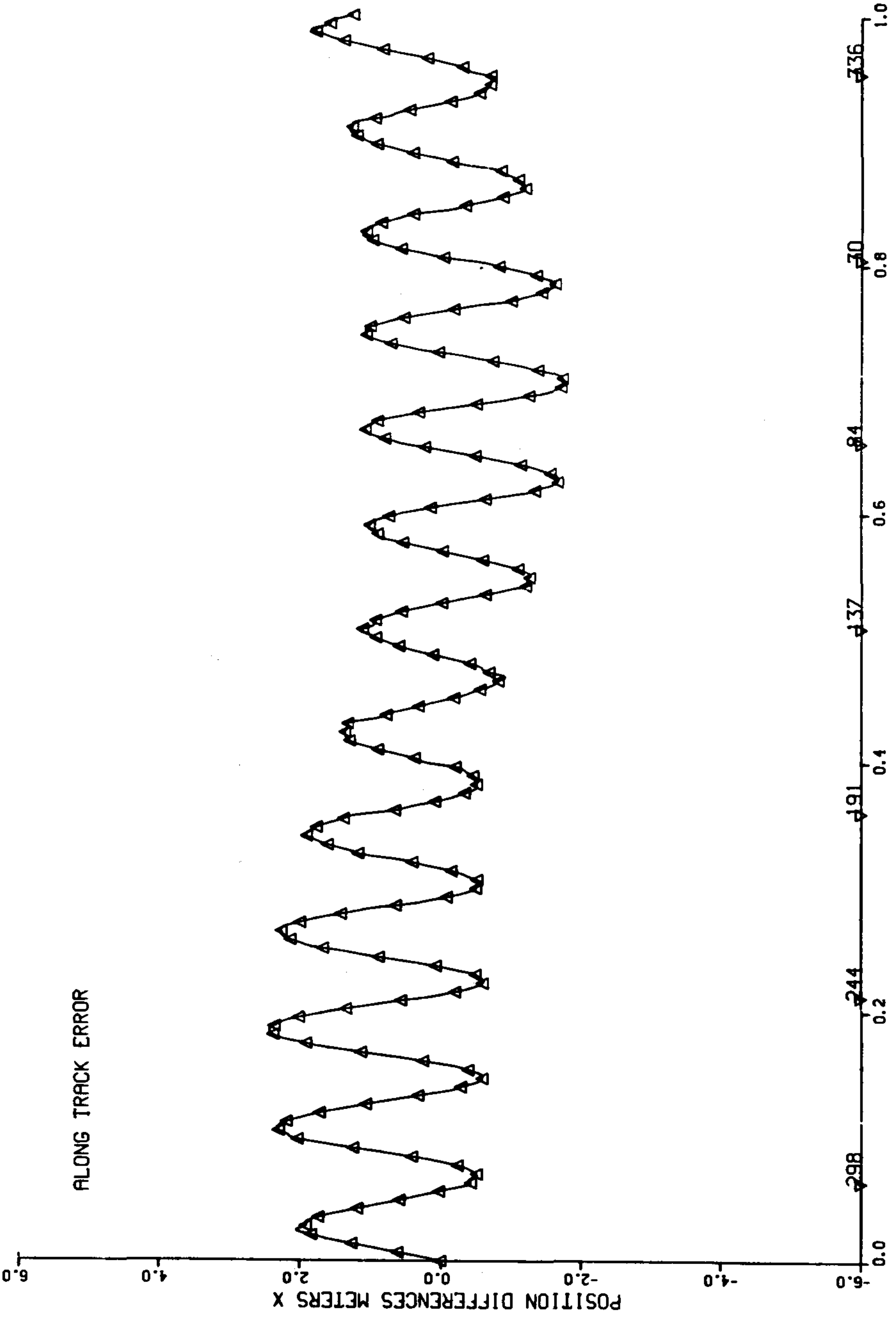

Figure 4a. Position differences for 1st order effects, satellite 1967 92A, day 171 1979

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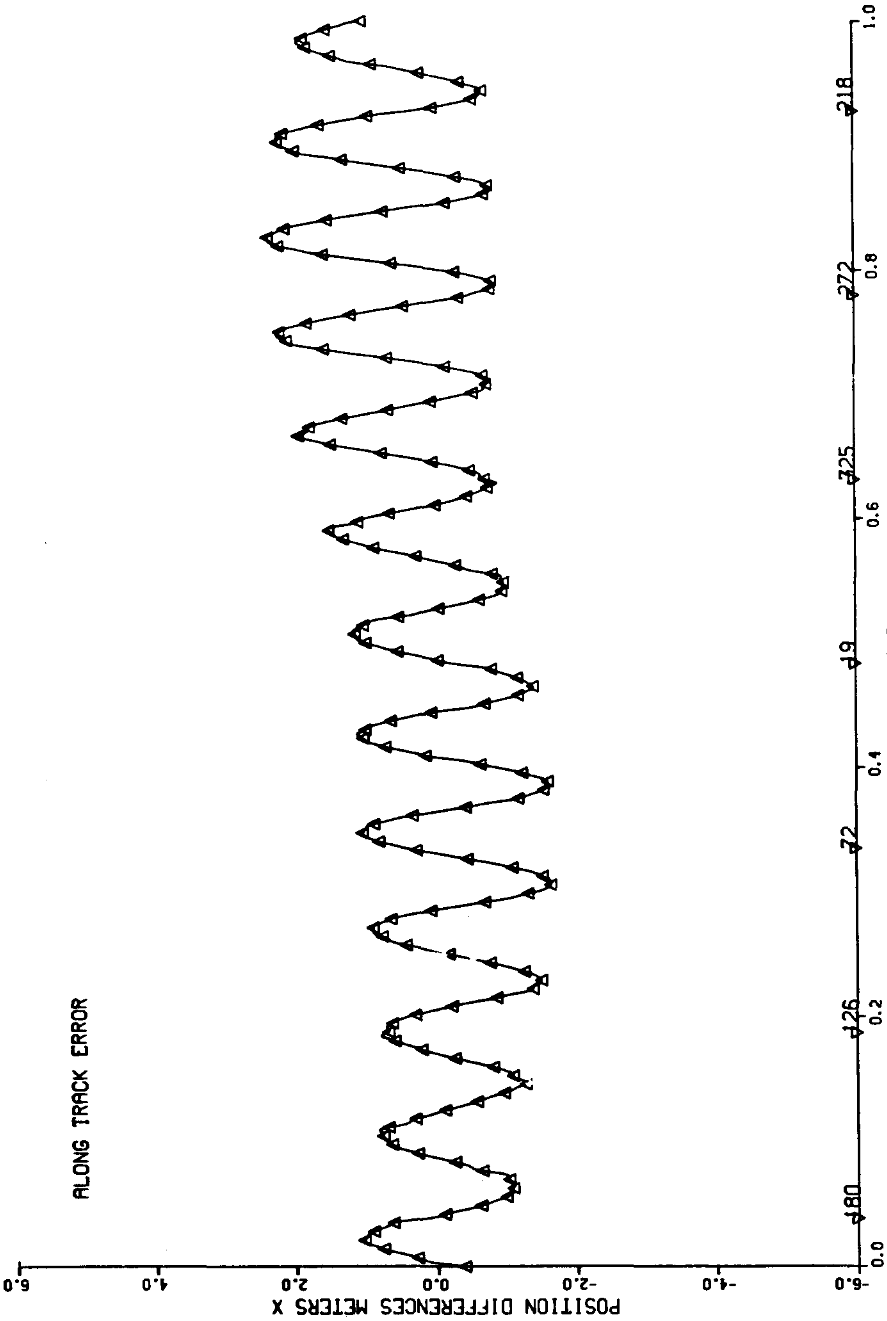

Figure 4b. Position differences for 1st order effects, satellite 1967 92A, day 291 1979

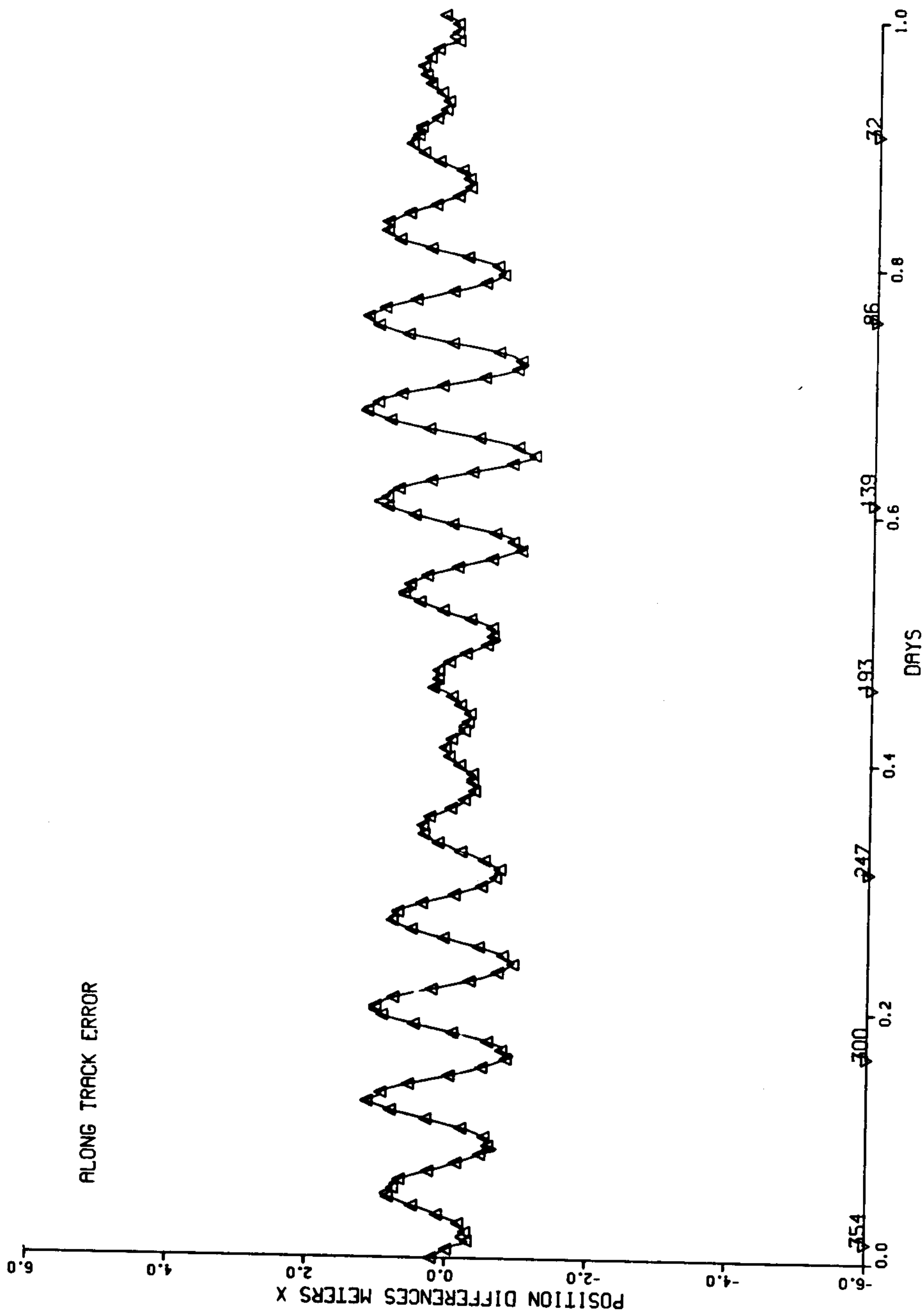

Figure 5a. Position differences for 1st order effects, satellite 1970 67A, day 171 1979

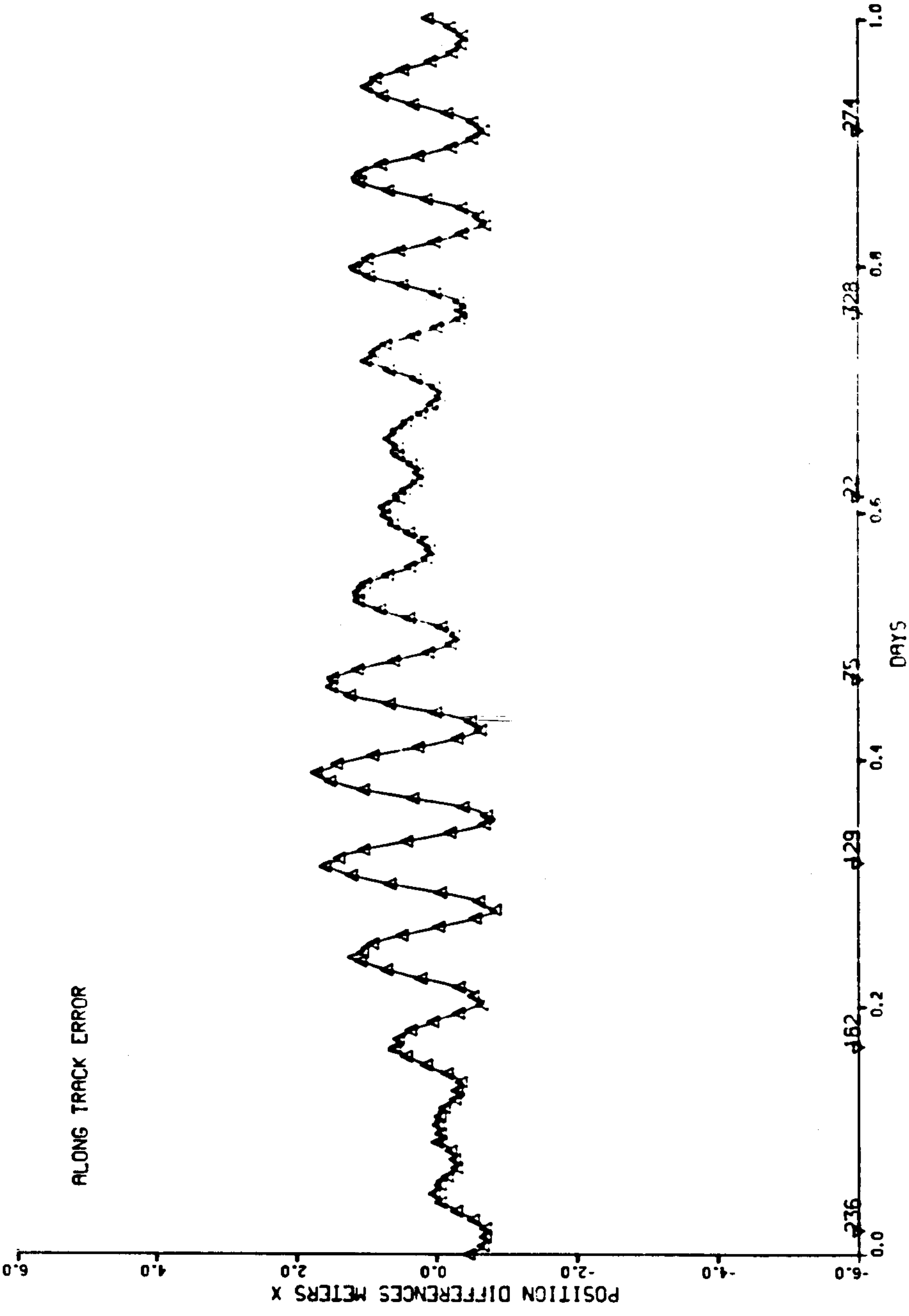

Figure 5b. Position differences for 1st order effects, satellite 1970 67A, day 291 1979

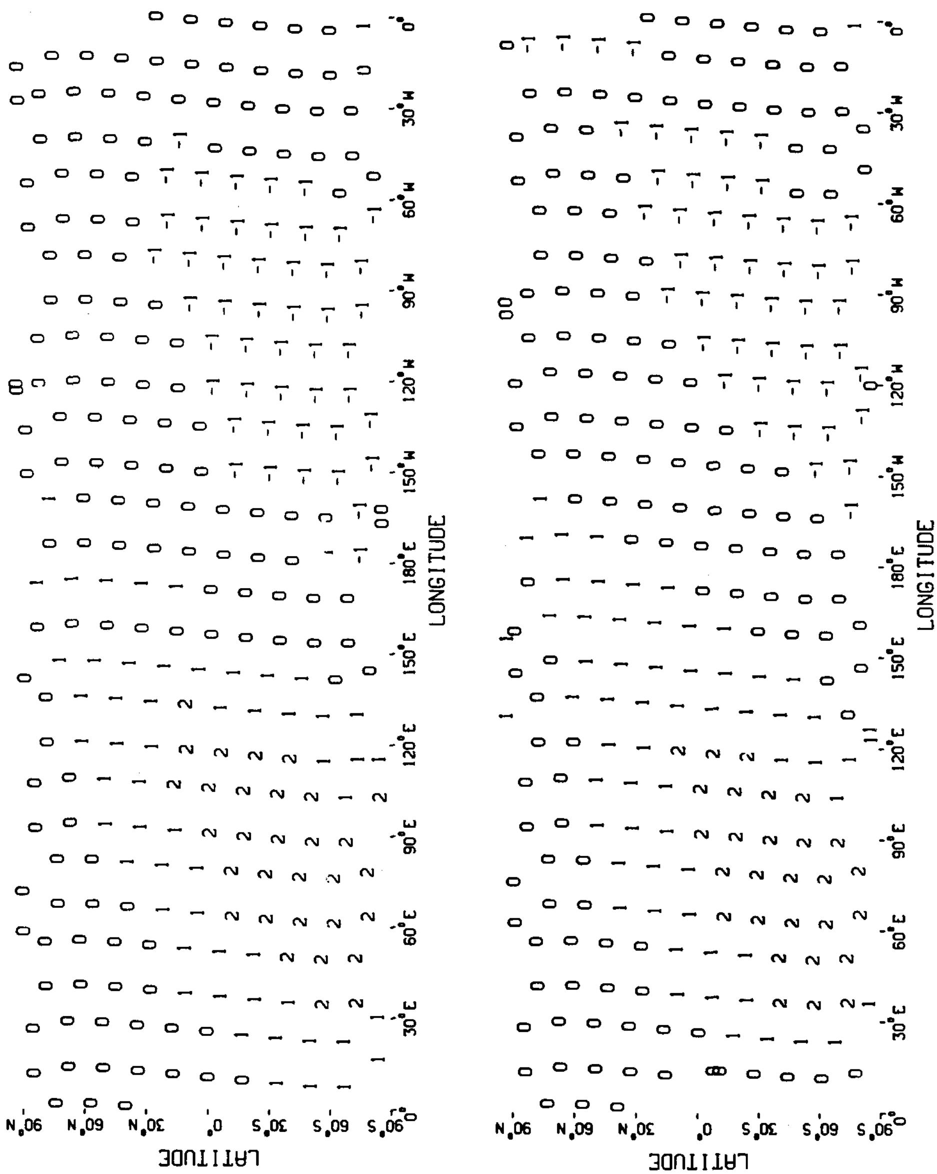

Figure 6. Satellite 1967 92A along track position differences on north-south tracks for 1st order effects. Upper chart for day 171 1979; lower chart for day 291 1979.

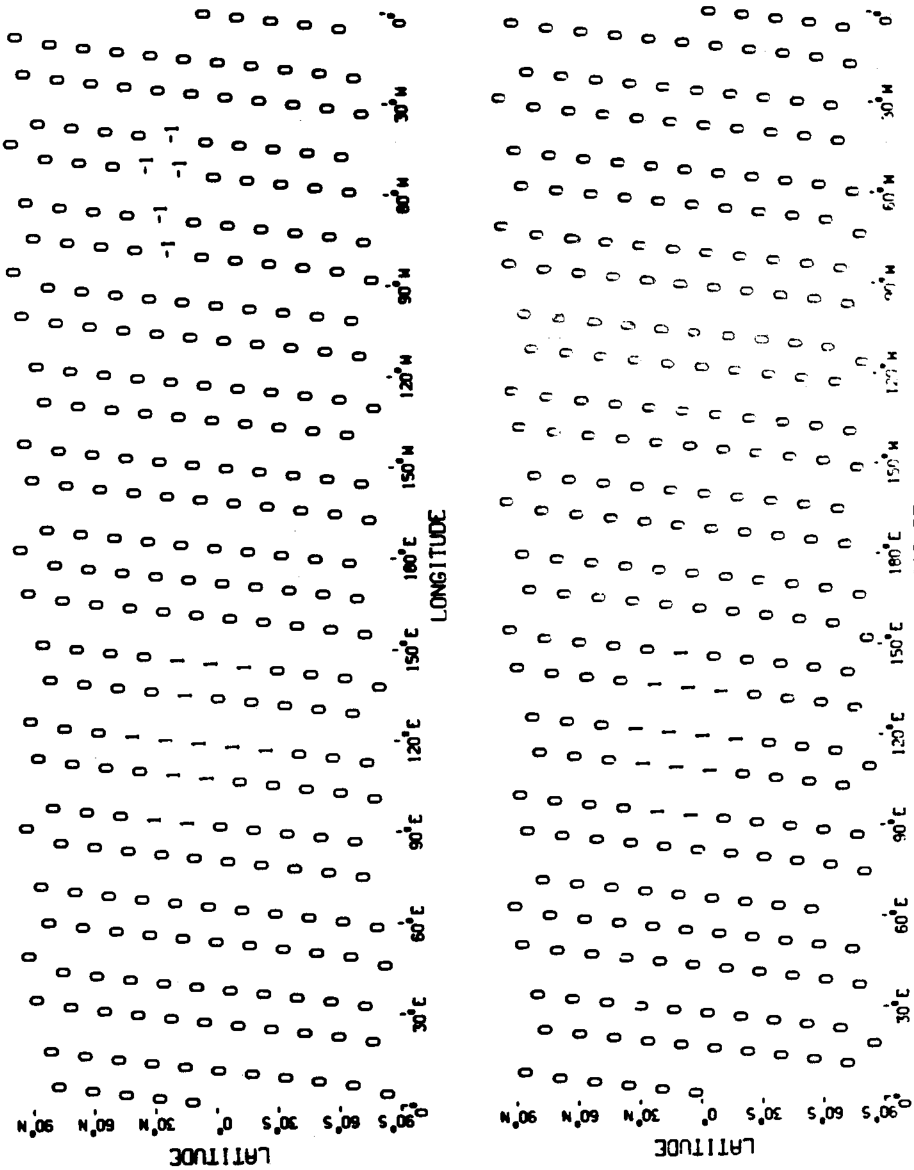

Figure 7. Satellite 1970 67A along track position differences on north-south tracks for 1st order effects. Upper chart for day 171 1979; lower chart for day 291 1979.