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ABSTRACT

The weighted least squares processing of Doppler shifted signals transmitted from Fairbanks to the NIMBUS 6 satellite is examined. The paper represents research conducted in support of the NASA satellite aided Search and Rescue program. An estimated NIMBUS 6 ephemeris, accurate to 1.5 - 2.5 km and 0.5 - 2.5 m/s relative to a reference orbit, is obtained during the three day signal transmission period. This suggests updating the knowledge of the relay satellite ephemeris by one reference beacon is needed during the Search and Rescue demonstration. Per pass frequency offsets are recoverable on the order of 600 - 610 Hz ±0.4 Hz. Residual statistics indicate an excellent data fit with a near zero mean and an observed noise generally less than 2.0 Hz.

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NIMBUS 6 DOPPLER PROCESSING USING THE FAIRBANKS CALIBRATION PLATFORM

1. INTRODUCTION

This paper examines the processing of some actual one-way Doppler shifted signals transmitted by the Fairbanks, Alaska calibration platform to the NIMBUS 6 meteorological satellite for three days during June 1977. Processing consisted of the weighted least squares estimation of the NIMBUS 6 epoch state and frequency offsets for individual satellite passes over the platform. The accuracy of results is measured by a 6 day comparison of the estimated NIMBUS 6 ephemeris with a reference orbit of known accuracy and examination of residual statistics.

Several considerations motivated the paper:

(1) to provide an example of the orbit determination accuracies obtainable for NASA applications satellites using only uplink signals transmitted from fixed platforms. The use of reference beacons co-located with local user terminals (LUT) to update the relay satellite knowledge during Search and Rescue operations is under consideration (Ref. 1).

(2) to observe the long term behavior of individual radial, along track, and cross track orbital position errors during both tracking and free propagation. Such behavior is of particular importance for the Search and Rescue demonstration onboard the Television Infra-Red Observation Satellite (TIROS-N) for which each orbital position component must satisfy a different accuracy level.

(3) to extract from real data a measure of frequency offset. During Search and Rescue operations the emergency beacon emits distress signals accurate to only several kHz. Consequently the offset must be extracted from the data to remove its degrading influence upon beacon location estimates.

The processing was performed using a weighted least squares parameter estimation program (Ref. 2–4). The program is coded in FORTRAN-H with double precision arithmetic and resides on permanent disk on an IBM 360/95 digital computer at Goddard Space Flight Center (GSFC). A typical data reduction required 400 K bytes of core storage and three minutes each of Central Processing Unit (CPU) and Input/Output (I/O) time.

2. DATA PROCESSING APPROACH

A nominal NIMBUS 6 ephemeris from June 1 – 4, 1977 was generated from a typical epoch state selected from predicted vectors available at GSFC. The ephemeris was numerically integrated with variable stepsize using a power series solution through 16th order to the equations of motion.

The Earth's gravitational field was modeled by the spherical harmonic coefficients from the Goddard Earth Model-7 (GEM-7) (Ref. 5) truncated at degree and order 8. Constants for the Earth's mass, radius, and flattening corresponding to GEM-7 were included.

The calibration platform at Fairbanks, Alaska nominally transmitted signals on a carrier frequency of 401.2 MHz ±5 kHz to the NIMBUS 6 meteorological satellite throughout June 1977 in conjunction with the Tropical Wind Energy Conversion and Reference Level Experiment (TWERLE) (Ref. 6). The platform is one of five worldwide employed to correct the NIMBUS 6 orbital along track error during daily operations. The transmitted signal experiences a frequency shift upon reception by NIMBUS 6 because of the satellite's motion relative to the platform. These Doppler shifted signals constituted the data type processed. Twelve passes of data scattered over the first three days of June 1977 were selected. These passes contained 140 data points collectively with an individual pass including between 8 and 15 points separated by one minute. Near horizon data points were ignored.

A weighted least squares adjustment process was used to reduce these data. Software constraints necessitated the conversion of the data from Doppler shift to metric range rate by multiplication with the negative of the signal wavelength. The signals were transmitted at 401.2 MHz on a wavelength of 0.75 meters. The eighteen adjusted parameters included the 6-dimensional NIMBUS 6 epoch state and one frequency offset for each of the twelve passes. The a priori state chosen to initiate the iterative adjustment process was assumed poorly known. Individual components were weighted with uncorrelated uncertainties of 10 km and 100 m/s. For each pass a zero value for the initial frequency offset with an uncertainty of 1.3 kHz was postulated.

The adjusted NIMBUS 6 epoch state was subsequently propagated forward for six days using modelling identical to that of the data processing. This propagated ephemeris was then differenced over this same interval from the most accurate available estimate of the true NIMBUS 6 ephemeris. This estimate was independently derived from Minitrack interferometer tracking data and has an advertised accuracy of 500 meters RMS. Thus the errors in the estimate during both signal transmission and free propagation can be examined.

3. RESULTS

The primary parameters extracted from the Doppler shift data were the six components of the NIMBUS 6 epoch state. Figure 1 illustrates the successive corrections to the current position epoch state at each iteration during the processing. Corrections to individual components (ΔX, ΔY, ΔZ) and total position (Δr) are displayed. Corresponding corrections to the velocity vector are found in Table 1 within the Appendix.

The initial epoch state was adjusted by 7 km in total position after the first iteration. Thereafter the total corrections decrease rapidly to less than 30 meters after three iterations. Corrections to individual position components vary widely. After the third iteration the adjustment process stabilizes with only minor (i.e., less than 10 meters) corrections. Convergence occurs within five iterations to an estimated epoch state accurate to 412 meters and 38 cm/s RSS. Each velocity component is estimated to an equal degree of accuracy.

Subsequent to adjustment, the estimated epoch state was propagated forward for six days under assumptions identical to those of the data processing. To obtain a measure of the long term accuracy of this propagated ephemeris, it was subtracted over this same time interval from the most accurate available estimate of the true NIMBUS 6 ephemeris. Figure 2 depicts the differences between the two ephemerides and is an accurate measure of the error in the estimated NIMBUS 6

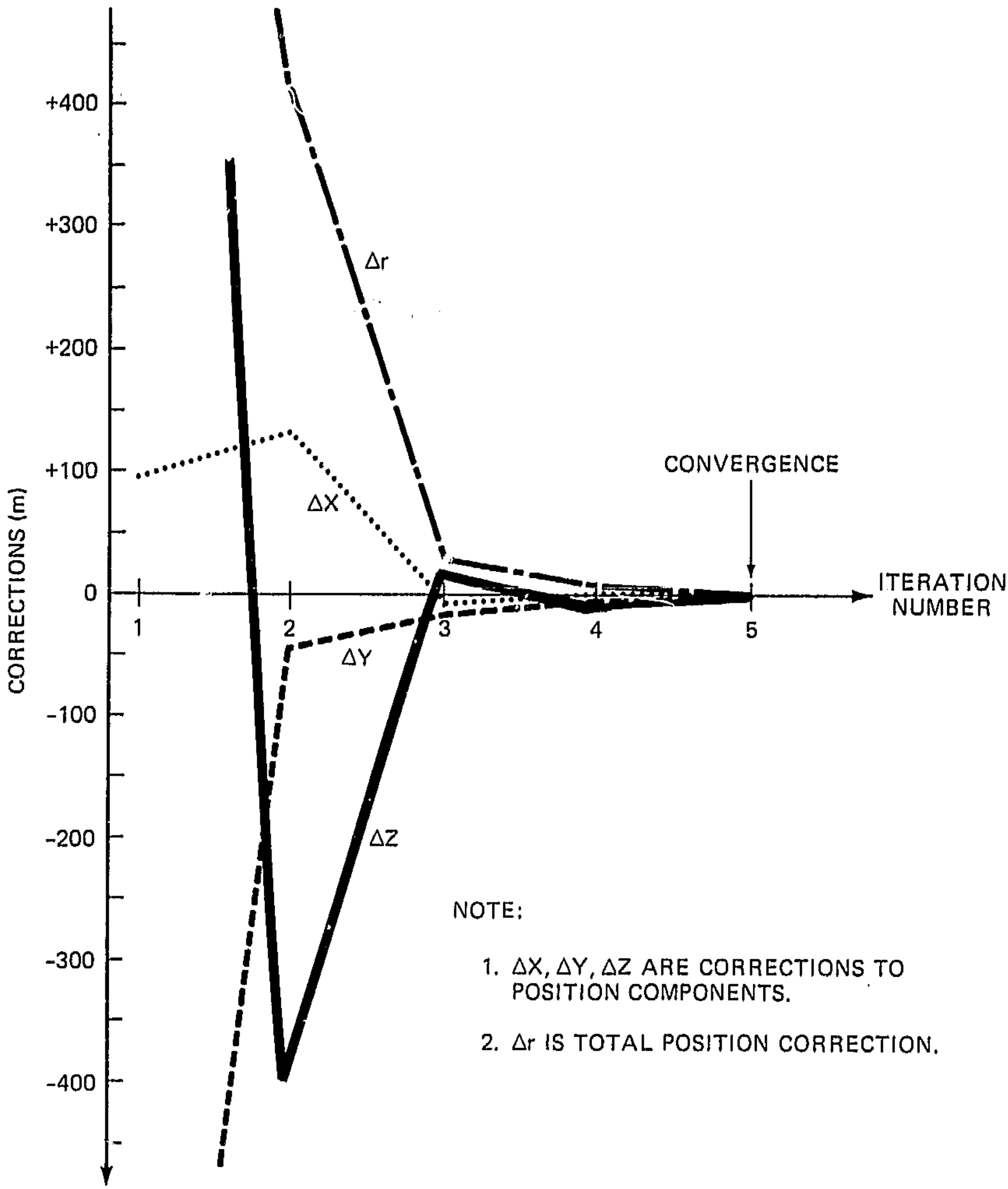

Figure 1. Corrections to Current NIMBUS 6 Position Vector vs Iteration Number During Doppler Processing

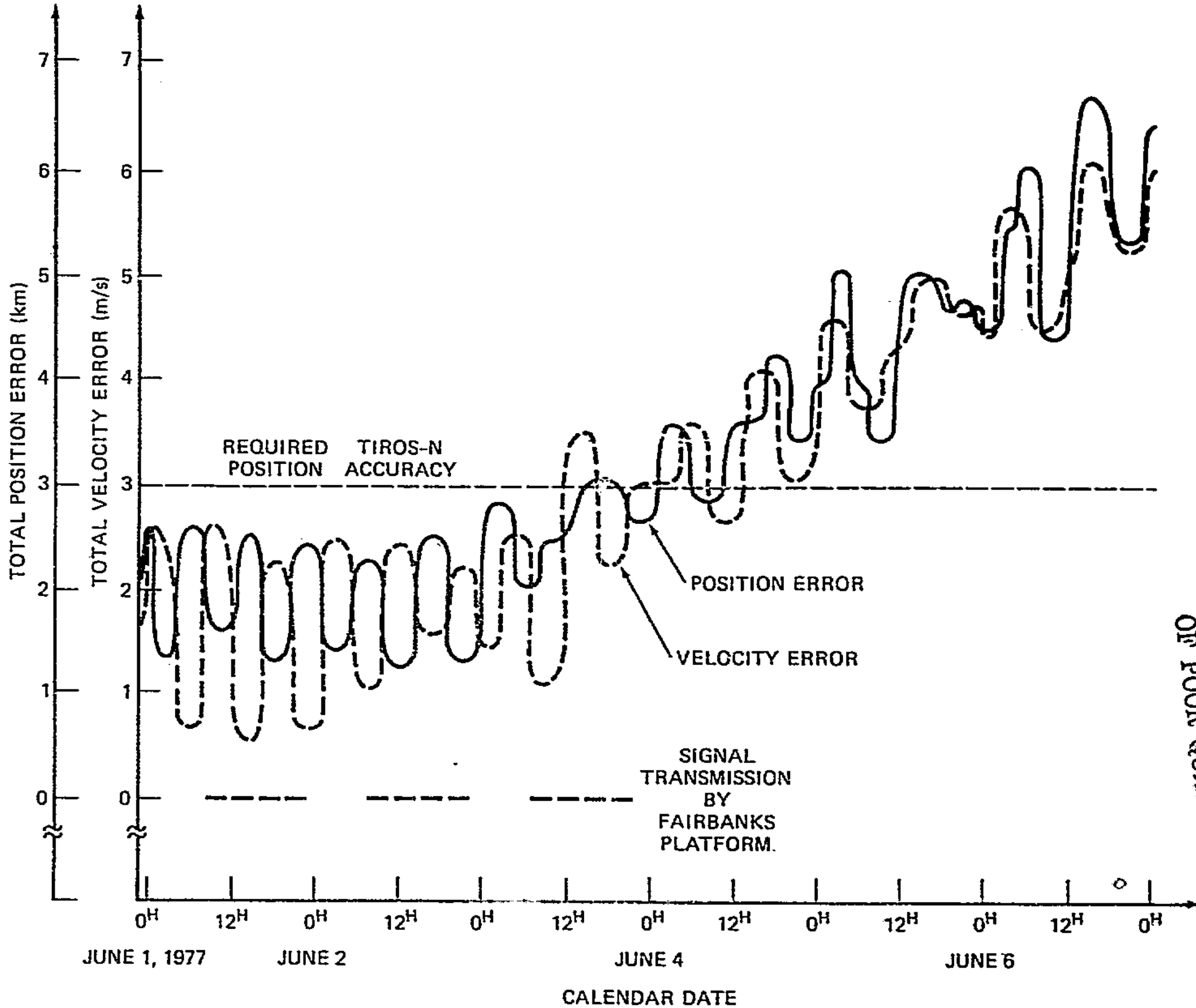

Figure 2. Accuracy of NIMBUS 6 Ephemeris Estimate

ephemeris. The corresponding radial, along track, and cross track position errors are found in the Appendix. The 3 km level represents the TIROS-N orbital position accuracy requirement for the Search and Rescue demonstration. During the signal transmission period from June 1 – 3, both position and velocity errors are periodic. The former oscillates between 1.5 and 2.5 km and the latter between 0.5 and 2.5 m/s. Their complementary behavior typifies the conservation of angular momentum of the NIMBUS 6 orbit. Outside the transmission period both errors exhibit continued oscillation superimposed upon a strong secular growth. Note the required TIROS-N accuracy requirement is easily achieved but only during periods of signal transmission. Thus during the Search and Rescue demonstration continuous updating by at least one reference beacon is necessary.

The transmitter at the Fairbanks, Alaska calibration platform has a nominal frequency of 401.2 MHz ±5 kHz. In reality, the true transmit frequency deviates continuously from this nominal. Deviations occur even over very short time periods such as the 15 minutes required for a typical satellite pass over a transmitter. They are caused by crystal oscillator instability and normal degradation of hardware components. The deviation between the true and nominal frequency is termed frequency offset. During Search and Rescue operations, an emergency beacon will transmit signals accurate to only several kHz. Thus the offset must be adjusted to remove its degrading effect upon the more important beacon location estimates.

Table 1 lists estimates of the frequency offsets with their accuracies for each of the 12 passes of NIMBUS 6 over the Fairbanks platform during June 1 – 3, 1977. A remarkable uniformity in magnitudes of estimates is evident. All offsets are approximately recoverable between 600 to 610 Hz accurate to 0.4 Hz. Estimates are independent of the number of data points processed.

The accuracy of the estimated NIMBUS 6 ephemeris was determined previously by comparison with a reference orbit (Fig. 2). Another technique commonly employed to assess the accuracy of estimates is examination of data residuals. A parameter estimation program uses geometry to generate data. These internally generated data, i.e. the "computed" measurements, are then compared point by point to the data being processed,

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Table 1

Estimates of Frequency Offsets and their Accuracy for
NIMBUS 6 Passes over Fairbanks, Alaska Calibration Platform June 1 – 3, 1977

Pass No.	Length of Pass (min)	No. of Data Points	Estimates	
			Frequency Offset (Hz)	Accuracy (Hz)
1	9	9	607	0.4
2	10	8	611	0.5
3	12	12	608	0.4
4	13	13	601	0.4
5	11	12	608	0.4
6	10	9	611	0.4
7	12	11	605	0.4
8	14	13	605	0.4
9	11	12	601	0.4
10	13	14	604	0.4
11	14	15	596	0.4
12	9	10	595	0.4

i.e. the "observed" measurements. The differences between the two are labelled "residuals" and their magnitudes reflect the quality of the data fit. The smaller the residuals implies the better the fit. Table 2 lists the mean value (μ) and standard deviation (σ) of the Doppler shift residuals for the 12 NIMBUS 6 passes over the Fairbanks platform. The near zero mean value indicates an excellent least squares fit to the data. The magnitude of this statistic is relatively independent of the number of data points. The standard deviation is a measure of the noise on the actual data. Table 2 reveals their magnitudes are generally less than 2 Hz, a value consistent with TWERLE frequency resolution of ±1 Hz.

Table 2

Mean Value (μ) and Standard Deviation (σ) of Doppler Shift Residuals for NIMBUS 6 Passes over Fairbanks, Alaska Calibration Platform June 1 – 3, 1977

Pass No.	Length of Pass (min)	No. of Points	μ* (10^{-4} Hz)	σ** (Hz)
1	9	9	0.68	1.60
2	10	8	0.77	1.84
3	12	12	0.51	0.77
4	13	13	0.47	1.35
5	11	12	0.52	0.72
6	10	9	0.70	1.29
7	12	11	0.57	1.03
8	14	13	0.48	2.00
9	11	12	0.54	1.33
10	13	14	0.48	1.20
11	14	15	0.46	1.27
12	9	10	0.67	0.97

*estimate of quality of fit
**estimate of data noise

4. CONCLUSIONS

This paper has presented results of weighted least squares processing of actual NIMBUS 6 Doppler shift data resulting from transmission by the Fairbanks, Alaska calibration platform on June 1 – 3, 1977. The paper was prompted primarily by considerations arising from satellite aided Search and Rescue operations. Results indicate that a NIMBUS 6 ephemeris accurate to 1.5 – 2.5 km in position and 0.5 – 2.5 m/s in velocity is possible during periods of signal transmission. Outside this period both errors grow without bound. This implies that updating by one reference beacon is needed to meet orbital accuracy requirements during the Search and Rescue demonstration onboard TIROS-N. The frequency of an emergency transmitter will usually only be known to several kHz.

Hence position location software must estimate frequency offsets in addition to the emergency transmitter location. This paper has shown that offsets are recoverable on the order of 600 – 610 Hz to an accuracy of 0.4 Hz. Finally, statistics of the measurement residuals indicate an excellent least squares fit to the Doppler data and an observed noise consistent with expected values.

5. REFERENCES

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5. C. A. Wagner, et al., "Improvement in the Geopotential Derived from Satellite and Surface Data (GEM 7 and 8)," GSFC Report X-921-76-20, January 1976.
6. The NIMBUS 6 User's Guide, GSFC, February 1975.

APPENDIX

Table A-1

Corrections to Current NIMBUS 6 Velocity Vector vs Iteration Number During Doppler Processing

Iteration Number	$\Delta\dot{X}$ (cm/s)	$\Delta\dot{Y}$ (cm/s)	$\Delta\dot{Z}$ (cm/s)	$\Delta\overline{V}$ (cm/s)
1	-356	-423	-355	657
2	+4	-1	+18	18
3	-1	-2	-1	2
4, 5	0	0	0	0

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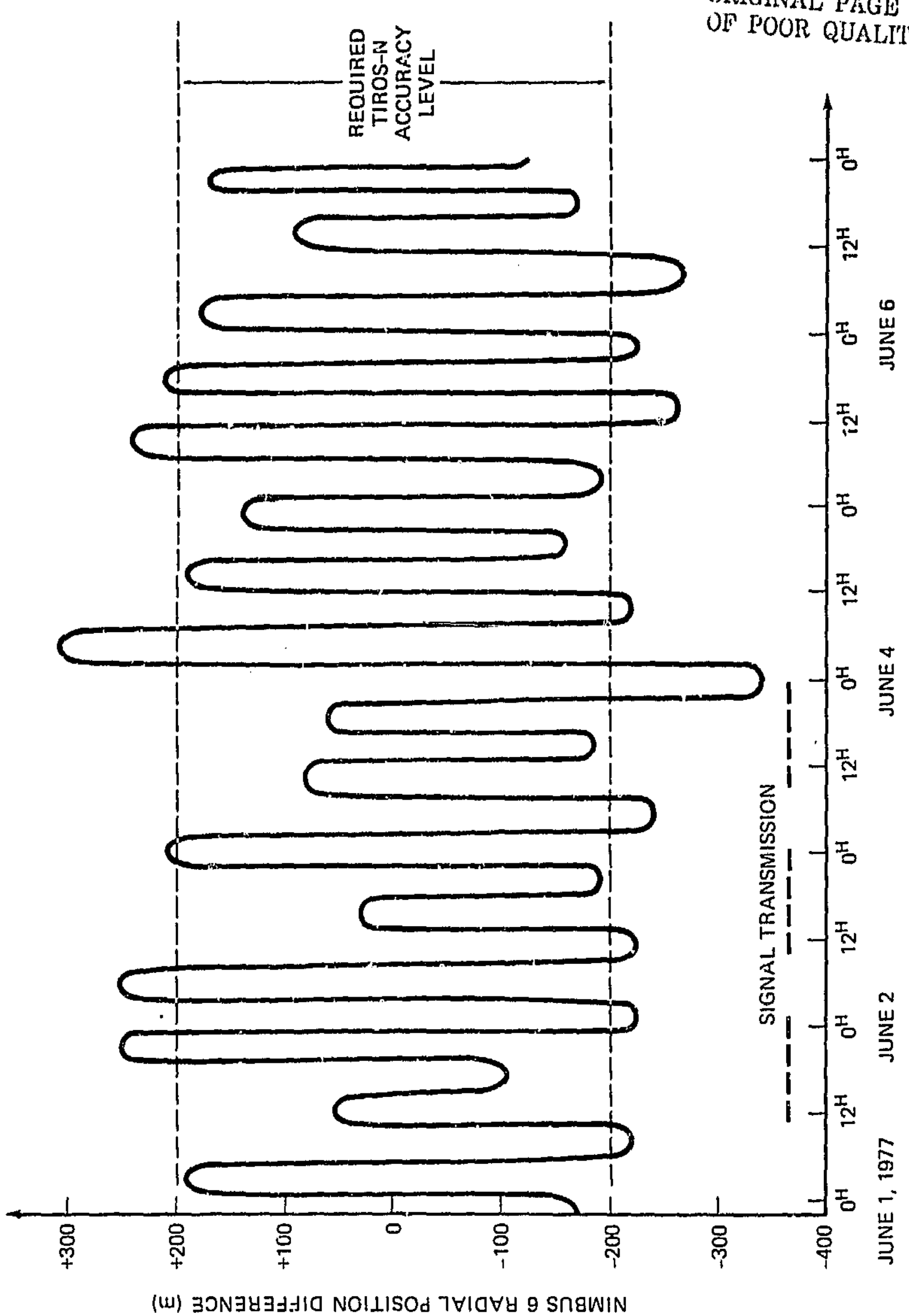

Figure A-1. Accuracy of NIMBUS 6 Radial Position Estimate

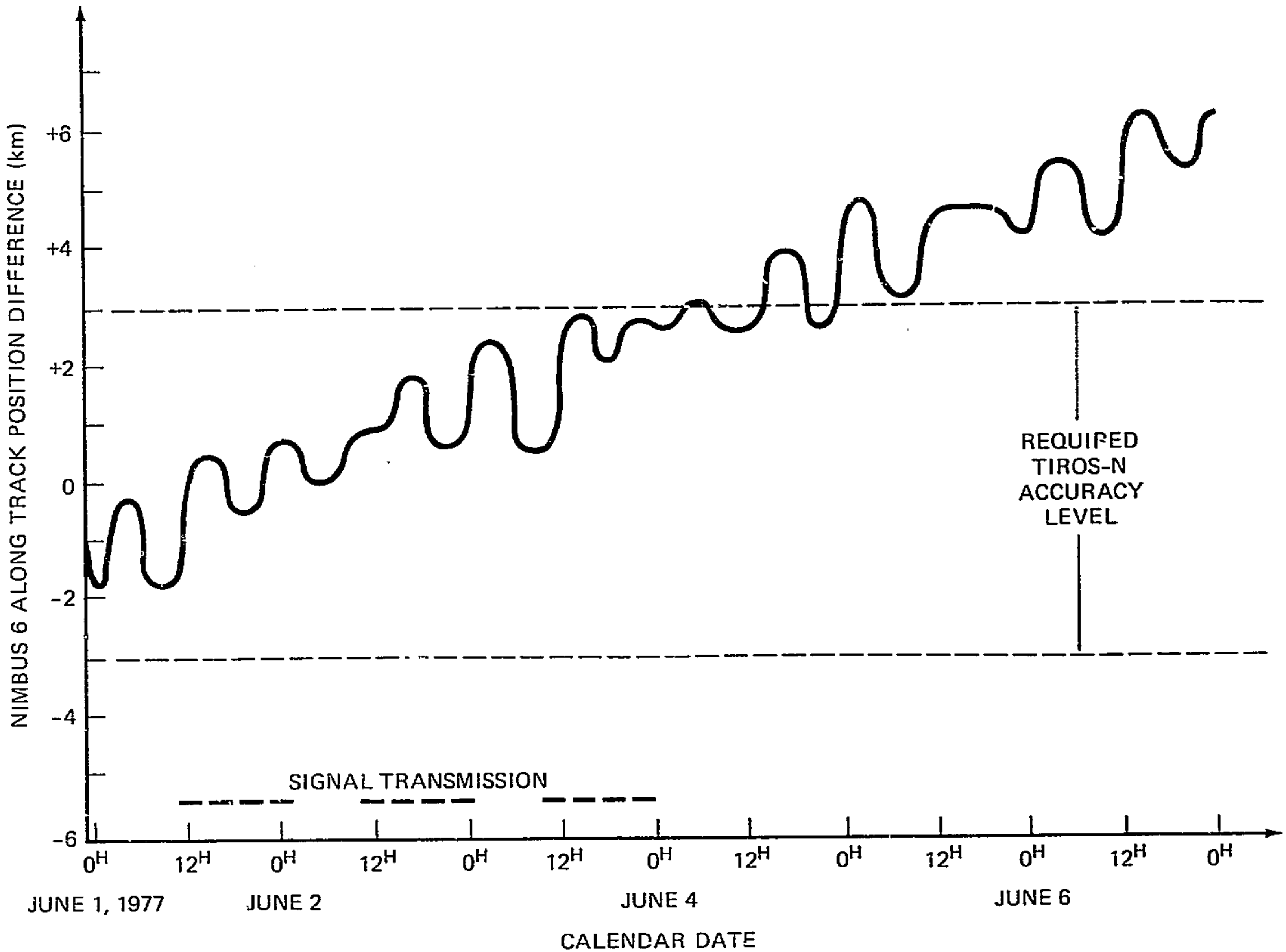

Figure A-2. Accuracy of NIMBUS 6 Along Track Position Estimate

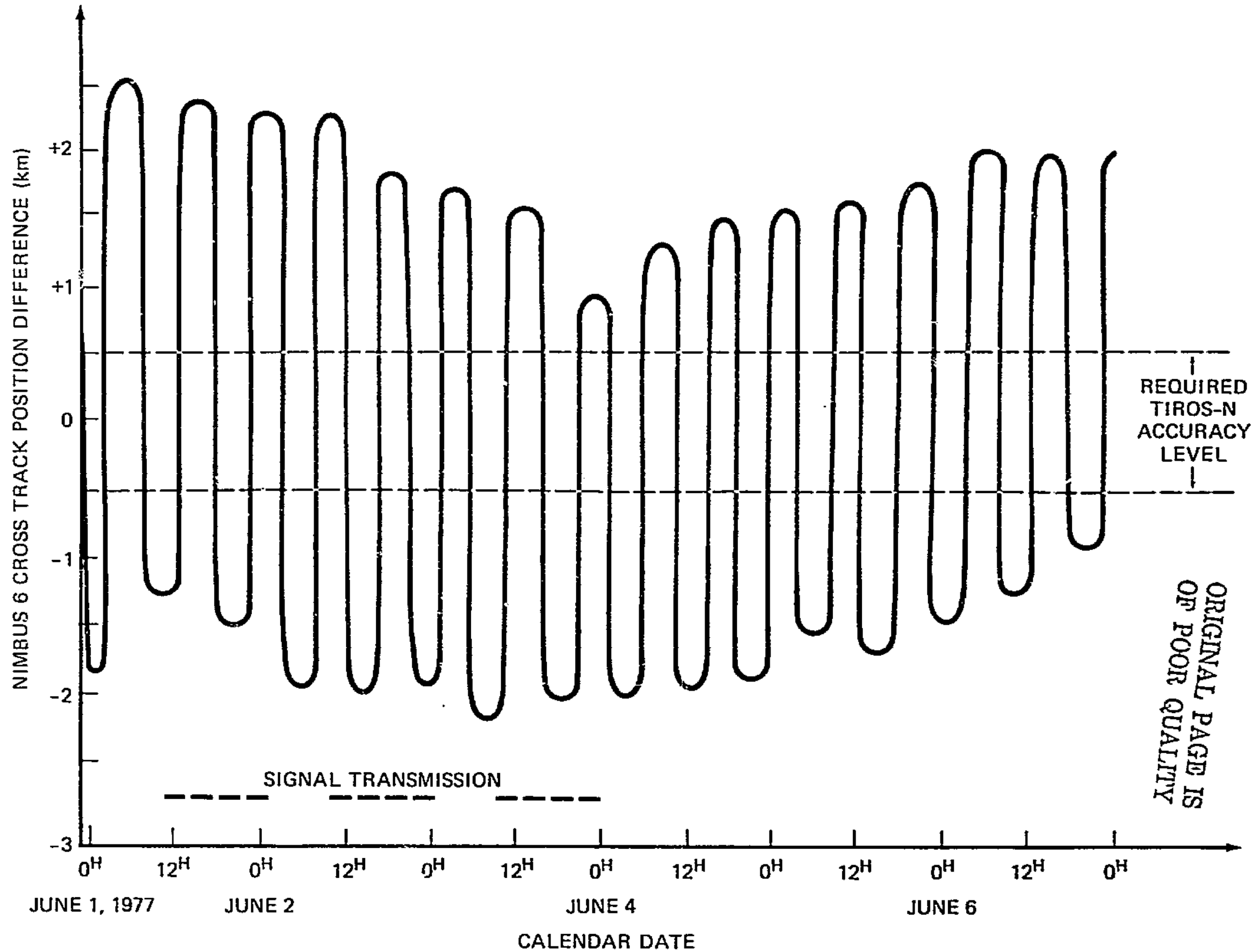

Figure A-3. Accuracy of NIMBUS 6 Cross Track Po-ition Estimate

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