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AN INTERCOMPARISON OF NAVY TRANET DOPPLER DATA AND OPTICAL DATA FROM THE GEOS-I SATELLITE

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DECEMBER 1969

GSFC — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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Mission Trajectory Determination Branch
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GODDARD SPACE FLIGHT CENTER
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ABSTRACT

Orbital solutions for the GEOS-I satellite obtained from U. S. Navy TRANET Doppler data and those from optical flash data recorded by the NASA Space Tracking and Data Acquisition Network and Smithsonian Astrophysical Observatory systems were intercompared. The orbital arcs used for this study were two days in length and were in the period July 9 through August 7, 1966. RMS of fits for the orbital solutions were on the order of 1.9 seconds of arc for the optical solutions and 2.7 cm/sec for the Doppler solutions. Comparisons of the corresponding optical and Doppler orbital ephemerides showed total RMS position differences ranging from 20 to 40 meters. Biases in the base frequency value of the Doppler data were solved for; consistent biases in the base frequency around 9 cm/sec ±3 cm/sec were found.

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AN INTERCOMPARISON OF NAVY TRANET DOPPLER DATA AND OPTICAL DATA FROM THE GEOS-I SATELLITE

by
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I. INTRODUCTION

This report presents the results of an intercomparison between orbits determined from Navy TRANET Doppler data and those determined from optical flash data from the GEOS-I satellite. This investigation was conducted for the purpose of establishing our capability to handle the Doppler data for geodetic purposes. In the past, our geodetic studies have used optical data as a standard.

The NONAME Orbit and Geodetic Parameter Estimation System (Reference 1) was used to determine all orbital solutions and to generate the intercomparisons. All of the data were obtained from the National Space Sciences Data Center at Goddard Space Flight Center. It was taken during the periods July 9—July 26 and July 31—August 7 of 1966.

In addition to evaluating orbits generated from Doppler data, the data were examined for biases in the base frequency value and in the time tags associated with each measured frequency (or observation).

II. OBSERVATIONAL DATA AVAILABLE

Table 1 presents the orbital characteristics of the GEOS-I satellite; all data used in this study were from this satellite.

GEOS-I was launched by the National Aeronautics and Space Administration under their National Geodetic Satellite Program. The orbit was chosen to minimize the perturbative effects of air drag and solar radiation pressure. On board the satellite were flashing lamps, Doppler transponders, laser corner reflectors and

Table 1

Orbital Characteristics of the GEOS-I Satellite.

Apogee Height	2273.0 Kilometers
Perigee Height	1116.0 Kilometers
Eccentricity	.07
Inclination	59.4 Degrees
Anomalistic Period	120.3 Minutes

other electronic tracking instruments which enabled the numerous participating agencies to record large amounts of valuable tracking data.

Optical Data

The GEOS-I optical flash data used in this analysis were obtained from the Geodetic Satellite Data Services of the National Space Science Data Center located at Goddard Space Flight Center. It is composed of observations from the NASA STADAN Minitrack Optical Tracking System (MOTS), the Goddard Special Optical Tracking System (SPEOPT), and the Smithsonian Astrophysical Observatory (SAO) Baker-Nunn camera stations. All optical station positions are referenced to the SAO C-7 system (a_e = 6378142 meters, Reference 2).

The orbits generated from this optical data are used as the standard to which the TRANET Doppler orbits are compared because it is generally felt that the optical flash (or active) data from GEOS-I forms a very high-precision data set. The accuracy of the optical data is on the order of 2 seconds of arc which amounts to a positional error of approximately 15 meters for GEOS-I. Among the reasons for this confidence are the use of a stable on-board clock to set off the optical beacon flash intervals, exacting the time of observation to millisecond accuracy, and the short duration (about 1.3 ms.) of the flashes, enabling the cameras to record the observations as point images against a background of reference stars rather than less exacting streak images (Reference 3).

Substantial evidence of this quality is seen in the orbital RMS's of fit; for each of the thirteen 2-day arcs generated from optical data, the RMS of fit is on the order of 2 seconds of arc. This is a very good fit considering that the NASA (MOTS and SPEOPT) and SAO (Baker-Nunn) data were processed through independent systems, yet weighted equally in the orbital solutions. The MOTS and SPEOPT data were obtained by MOTS 40 and PTH-100 cameras and all plates were reduced at the New Mexico State University to yield right ascension and declination pairs and U.T.C. time tags. The SAO data were taken by Baker-Nunn cameras on film and reduced by SAO to yield right ascension and declination pairs and time tags in A.S. atomic time (Reference 4).

Some preprocessing of the data received from the Space Science Data Center is done using the NONAME orbit determination system. MOTS and SPEOPT data time tags are corrected for flash buildup time; no other preprocessing is necessary. SAO data has atomic time (A.S.) tags and NONAME is used to apply the conversion to Universal Time Coordinated (U.T.C.). Also, a transit time correction is applied to the SAO data to refer the observation from station time to satellite time. Finally, SAO observations are referred to the mean equator and equinox of 1950.0, and it is necessary to apply precession and nutation from that epoch to the true equator and equinox of epoch of the observations (Reference 1).

Station network, name, number, location, and camera type are presented in Table 2 for all of the optical stations used in this study.

Table 2

Optical and Doppler Stations Used in the Analysis.

Network	Station	Number	Camera Type (optical)	Location
STADAN	1BPOIN	1021	MOTS 40"	Blossom Point, Md.
	1FTMYR	1022	MOTS 40"	Fort Myers, Fla.
	1OOMER	1024	MOTS 40"	Woomera, Australia
	1MOJAV	1030	MOTS 40"	Mojave, Calif.
	1JOBUR	1031	MOTS 40"	Johannesburg, Union of S. Africa
	1GFORK	1034	MOTS 40"	East Grand Forks, Minn.
	1ROSMA	1042	MOTS 40"	Rosman, N. C.
	1TANAN	1043	MOTS 40"	Tananarive, Madagascar
SPEOPT	1EDINB	7036	MOTS 40"	Edinburg, Texas
	1COLBA	7037	MOTS 40"	Columbia, Mo.
	1BERMD	7039	MOTS 40"	Bermuda
	1PURIO	7040	MOTS 40"	San Juan, Puerto Rico
	1GSFCP	7043	PTH-100	GSFC, Greenbelt, Md.
	1DENVR	7045	MOTS 40"	Denver, Calif.
	1SUDBR	7075	MOTS 40"	Sudbury, Ontario
	1JAMAC	7076	MOTS 40"	Jamaica, B.W. I.
SAO	1ORGAN	9001	Baker-Nunn	Organ Pass, N. M.
	1OLFAN	9002	Baker-Nunn	Olifantsfontein, Union of S. Africa
	1SPAIN	9004	Baker-Nunn	San Fernando, Spain
	1NATOL	9006	Baker-Nunn	Naini Tal, India
	1QUIPA	9007	Baker-Nunn	Arequipa, Peru
	1SHRAZ	9008	Baker-Nunn	Shiraz, Iran
	1CURAC	9009	Baker-Nunn	Curacas, Lesser Antilles
	1JUPTR	9010	Baker-Nunn	Jupiter, Fla.
	1VILDO	9011	Baker-Nunn	Villa Dolores, Argentina
	1MAUIO	9012	Baker-Nunn	Maui, Hawaii
	AUSBAK	9023	Baker-Nunn	Woomera, Australia
NAVY TRANET DOPPLER	ANCHOR	2014		Anchorage, Alaska
	WAHIWA	2100		South Point, Hawaii
	LACRES	2103		Las Cruces, N. M.
	LASHM2	2106		Lasham, England
	APLMND	2111		APL Howard County, Md.

Doppler Data

The GEOS-I TRANET Doppler data used in this study were also obtained from the National Space Science Data Center. Data from only the 5 stations listed in Table 2 are used for the period under consideration. Data are available from the Doppler station in American Samoa (TAFUNA, #2017) but it is not used because of uncertainties in the station position. The data available from McMurdo Sound, Antarctica (MCMRDO, #2019) are not used because of the very low maximum elevation angles on all of the passes. The 5 Doppler stations used are referenced to the SAO-C7 system.

All of the Doppler data used in this study are converted from frequency measurements to range rate using the following equation for one-way Doppler data:

$$\dot{R} = \frac{c(F_B - F_M)}{F_M}$$

where

F_B = base frequency

F_M = measured frequency

c = speed of light $(2.997925 \times 10^8 \text{ m/sec})$

Among the preprocessing done on the data before it was submitted to the Data Center was a first-order ionospheric refraction correction applied at the tracking stations (Reference 5). The NONAME system is used to further correct on the range rate values for tropospheric refraction as follows (Reference 1):

$$\Delta\dot{R} = \left[\frac{2.77 N_s \cos E}{328.5(.026 + \sin E)^2}\dot{E}\right] \text{ meters/second}$$

where

N_s = (surface index of refraction - 1.) $\times 10^6$. = 328.5 in the absence of a better value for the surface index of refraction

E = elevation angle computed from the initial estimate of the trajectory

$\dot{E}$ = computed rate of change of elevation

A transit time correction is also applied to the observations to put the time tags at the satellite.

In addition, it is felt necessary to include in the NONAME preprocessing an adjustment to the base frequency (of the spacecraft oscillator) for each pass over a station. Even though a nominal value of the satellite oscillator frequency exists for GEOS-I, it was modified by NWL for each pass of data (Reference 6). NWL computed a reference orbit with their ASTRO Computer Program and derived an expected satellite frequency for each observation time. Then (o-c) values were calculated and used to produce a corrected nominal satellite oscillator frequency for each pass of data. This "base frequency" was included in the Doppler data submitted to the Data Center. Due to the differences (gravity model, station positions, and other constants) between the ASTRO and NONAME Orbital Computation Systems, better orbits are obtained in NONAME when the base frequency for each pass of Doppler data is adjusted along with the six orbital elements ($\bar{R}$ & $\bar{V}$). This is done in NONAME by adjusting on the range rate measurement bias for each pass of data since a linear relationship exists between $\dot{R}$ and F_B in the formula for converting Doppler data to range rate. It is recognized that residual refraction effects, unmodelled orbital errors, and other small unknown biases may be absorbed into this base frequency adjustment.

III. INTERCOMPARISON OF DOPPLER AND OPTICAL ORBITS

NONAME and Perturbations Applied

Designed to provide accuracy in geodetic studies, the NONAME system at Goddard consists of a definitive orbit and geodetic parameter estimation program with a number of auxiliary programs. The main program of the system, the NONAME ODP, can operate in either the data reduction or orbit generation modes (Reference 2).

In the data reduction mode, the NONAME ODP can estimate the following parameters from satellite tracking data:

1. the six orbital parameters x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ for some specified epoch
2. certain physical constants relating to atmospheric drag or solar radiation pressure
3. tracking station co-ordinates relative to the center of mass of the earth
4. tracking instrument errors—zero set bias or timing bias
5. geopotential coefficients

All observation time tags are transformed to U.T.C. time at the satellite and numerous preprocessing options exist for various data types (i.e. right ascension, declination, range, range rate, direction cosines, X and Y angles, azimuth, elevation).

The orbit is numerically integrated (Cowell's method) in fixed steps and interpolated to get computed observations for residuals, (o-c) values. A Bayesian least squares estimation scheme and a Newton-Raphson iteration formula are used in correcting on the six orbital elements and any other specified parameters. There are convergence criteria for the iterations, rejection criteria for observations, and observational data weighting schemes optional to the user.

In the orbit generation mode, an initial epoch and position and velocity vectors are input and the equations of motion are numerically integrated (Cowell) to give an ephemeris of position, velocity, and time.

The potential of the earth is represented by a normal potential of an ellipsoid of revolution (SAO C-5, C-6, C-7, etc.) and small variations, expressed by a set of spherical harmonics (SAO M-1, APL 3.5, etc.). In addition, the following perturbations may be represented as disturbing functions as optioned by the user:

1. solar gravitation
2. lunar gravitation

3. solar radiation pressure
4. atmospheric drag force (NONAME uses the Jacchia-Nicolet model for the atmosphere)

In this study, the earth ellipsoid used is that of the SAO C-7 system and the gravity model used is the SAO-M1 modified by the 12th order terms of Gaposchkin and Veis (References 2 and 7). The perturbations applied in NONAME are solar gravitation (M_s/M_e = 332951.25), lunar gravitation (M_m/M_e = .01[illegible]) and solar radiation pressure (4.5×10^{-6} Newtons/m^2).

Discussion of Comparison

The period of data that was intercompared covers from July 9th through July 26th and from July 31st through August 7th of 1966. The data were separated into thirteen 2-day arcs since any longer arcs are more affected by errors due to uncertainties in the earth's gravity model, solar radiation pressure or other parameters.

Both the optical and Doppler data were run separately on the NONAME ODP in the data reduction mode. All optical observations were assigned a weight of 2 seconds of arc, and the right ascension measurements were further down-weighted by the cosines of the corresponding declination measurements due to the geometry of the pair (i.e. the higher the declination, the larger the uncertainties introduced into the right ascension). The Doppler data, converted to range rate, were assigned a weight of 10 cm/sec. Based on an editing criteria of 3σ there was approximately a 1% rejection rate on both data types.

The converged solution state vectors for both the optical and Doppler coincident arcs were then input into the NONAME ODP in the orbit generation mode. The orbits generated were compared to obtain the position differences every ten minutes. Table 3 presents the RMS of solution values for the data reduction runs and the summary data of the orbit intercomparisons. Appendix B shows position difference plots of five of these 2-day arc intercomparisons.

See Appendix A for a complete breakdown of the optical and Doppler data used in these 2-day arc studies.

As seen from Table 3, the RMS of total position differences over the 2-day arcs is on the order of 20 to 40 meters with maximum position differences on the order of 30 to 70 meters. It is important to note that only 5 stations in the Northern global hemisphere were used to obtain the Doppler orbits and all low elevation data was included, indicating good-quality refraction corrections. The large amplitude of some of the cross track position differences might seem odd at first glance since the along track errors usually dominate; however, this could possibly be attributed to difficulty in determining the inclination of the orbit in the Doppler solution since, again, the five Doppler stations are poorly distributed around the globe. These consistent results show that the capability to handle Doppler data and determine orbits of the quality demanded in geodetic studies from such data exists in the NONAME System at Goddard.

Table 3

Position Differences Between Orbits Generated From TRANET Doppler Data and Orbits Generated From Optical Data (2 day arcs).

Arc of Compare (1966)	*RMS of Fit		RMS of Position Differences (meters)				Maximum Difference (meters)
	Doppler (cm/sec)	Optical (secs. arc)	Radial	Cross Track	Along Track	Total	
July 9-10	2.7	1.8	12	7	38	41	70
July 11-12	2.8	1.9	7	16	19	26	36
July 13-14	2.8	1.8	13	9	26	30	44
July 15-16	2.8	1.8	10	23	23	33	51
July 17-18	2.7	1.9	7	10	20	23	35
July 19-20	2.6	1.9	12	10	36	39	67
July 21-22	2.7	2.1	12	10	38	41	77
July 23-24	2.7	1.8	3	14	11	19	27
July 25-26	2.7	1.7	7	9	16	20	38
July 31—August 1	2.8	1.9	6	5	18	20	39
August 2-3	3.0	2.1	5	9	18	21	47
August 4-5	2.7	2.0	6	25	32	41	66
August 6-7	2.7	1.9	11	21	32	40	60

*Approximate number of observations per arc: Doppler – 1880, Optical – 870.

IV. EFFECT OF STATION POSITIONS ON THE DOPPLER ORBITAL SOLUTIONS

As previously mentioned, the 5 Doppler tracking stations are in the Northern hemisphere of the globe; Figure 1 shows the locations of all the optical and Doppler tracking stations from which data were used for this study. It is interesting that all optical stations tracked the satellite only as it passed from south to north over the station. Thus the South American optical stations were often tracking just minutes before the Doppler stations in Maryland and England started tracking. The reason for this consistent south to north tracking by the optical stations lies in the facts that for the GEOS-I satellite, the right ascension of the ascending node traverses the celestial sphere at a rate of approximately 2-1/4 degrees per day, and only night tracking of the flash sequences is possible. Thus, for this month long period, the right ascension of the node was in the earth's shadow, causing the consistent south to north tracking. The Doppler stations have no such restriction and were able to track whenever the satellite passed over their vicinity.

It was thought that perhaps the poor global distribution of the available Doppler stations caused the Doppler orbit to be weakened in the southern hemisphere where no stations existed and thus where no (o-c) values could be determined to correct on the state vector. Thus it was decided to take 4 of the 2-day Doppler and optical arcs and examine how accurately the Doppler determined orbits fit the optical data from each optical station around the entire globe.

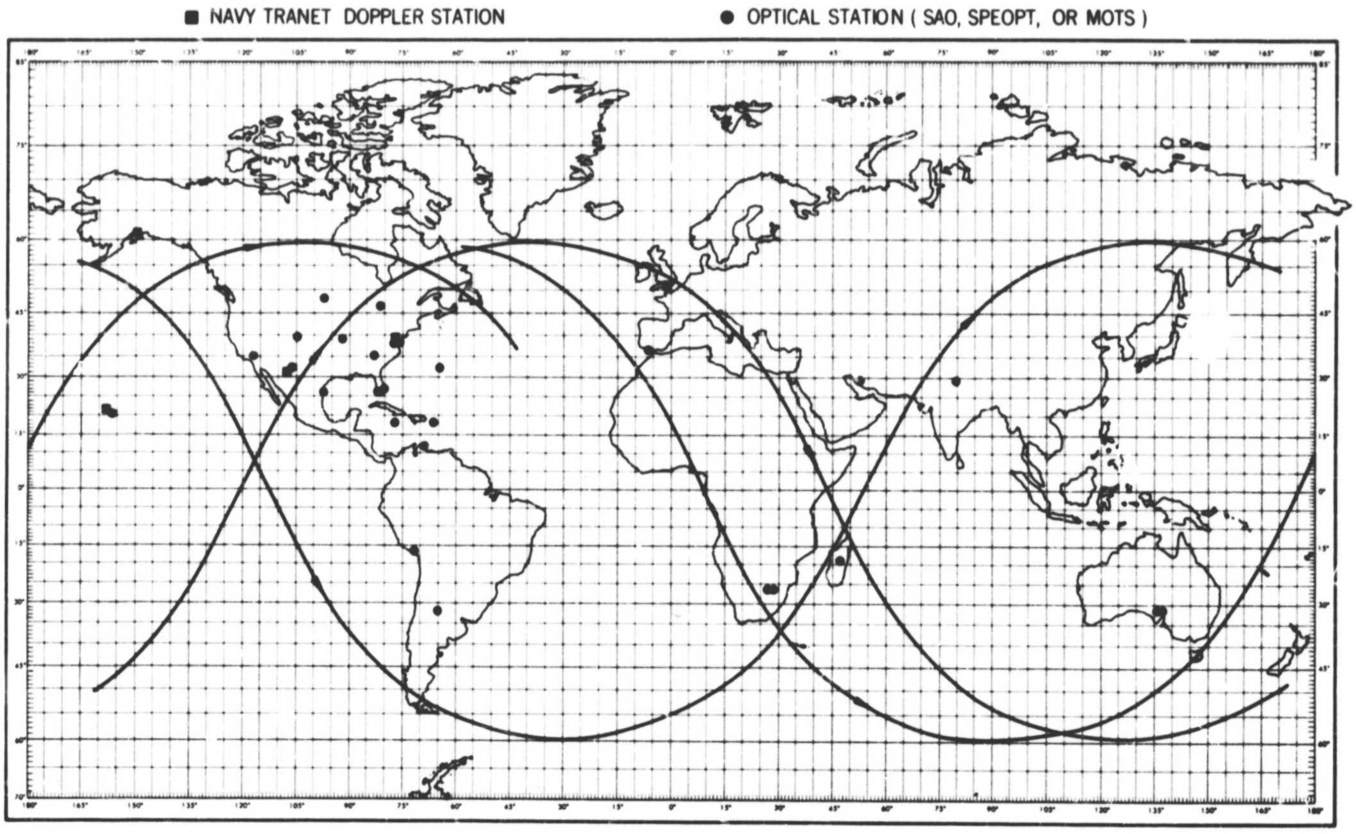

Figure 1—Locations of all TRANET Doppler and optical stations used in intercomparisons and typical GEOS-I orbital paths July-August, 1966.

The approach is to take the converged vector solution, for each of the arcs, as determined by the Doppler arc and input it as the state vector for the corresponding optical arc. The Doppler solution is passed through the optical data to note the optical station data fits to the Doppler determined orbit. The observation residual summary by optical station is examined to see which groups of stations representing areas of the globe have the largest increases in the RMS of solution when compared to the final iteration of the original optical solution for that arc. For each station appearing in two or more of the four arcs, the RMS's of fits were combined to yield one summary value for that station. As an example, if a station appeared in two of the arcs and had respective RMS values of RMS_1 and RMS_2, where:

$$RMS_1 = \sqrt{\frac{\sum_{i=1}^{m} (o - c)_i^2}{m - 1}} \quad ; \quad RMS_2 = \sqrt{\frac{\sum_{i=1}^{k} (o - c)_i^2}{k - 1}}$$

then the combined RMS would equal:

$$\sqrt{\frac{(m - 1)(RMS_1)^2 + (k - 1)(RMS_2)^2}{m + k - 1}}$$

Table 4 shows all of the optical stations used, the number of observations each has over the four 2-day arcs of this station position study, what arcs the data appear in, the combined RMS values

Table 4

Summary, by Station, of Optical Data Fits to the Optical and Doppler Orbital Solutions (July 9-16, 1966).

Optical Station	Latitude (degrees)	Observations		RMS of Fit (secs. arc)	
		Total Number	*From Arcs	To Optical Orbit	To Doppler Orbit
1GFORK	48	73†	I, II	1.9	2.0
		73‡		1.5	1.7
1SUDBR	46	60	II, IV	1.9	2.3
		60		1.5	1.9
1DENVR	40	20	I	2.4	2.7
		20		1.3	1.2
1COLBA	39	93	I, II	1.3	1.6
		94		1.2	1.7
1BPOIN	38	45	I, II	1.3	1.5
		44		2.1	2.1
1SPAIN	36	73	I, II, III, IV	2.7	3.3
		77		1.7	2.1
1MOJAV	35	35	II	1.8	2.4
		35		1.5	1.9
1ROSMA	35	33	I, II	1.3	1.3
		32		2.3	2.2
1ORGAN	32	224	I, II, III, IV	1.6	1.6
		224		1.6	1.8
1BERMD	32	49	II, IV	2.6	2.6
		48		3.2	2.5
1SHRAZ	30	28	II, III	1.8	2.1
		25		2.8	2.4
1NATOL	29	25	III	1.4	1.4
		25		1.7	2.3
1JUPTR	27	305	I, II, III, IV	1.7	1.8
		304		1.8	2.3
1EDINB	26	69	I, II	0.7	1.2
		70		1.1	1.6
1MAUIO	21	56	I, IV	2.2	2.5
		56		1.4	1.4
1JAMAC	18	35	II	1.3	1.4
		34		1.9	2.6
1CURAC	12	27	I	1.7	1.6
		27		2.3	2.6
1QUIPA	-16	69	I, II, III, IV	2.0	2.0
		69		2.7	3.6
1TANAN	-19	14	II	1.8	1.6
		14		0.9	1.2

*I - July 9-10, II - July 11-12, III - July 13-14, and IV - July 15-16.
†declination
‡right ascension

Table 4 (Continued)

Optical Station	Latitude (degrees)	Observations		RMS of Fit (secs arc)	
		Total Number	*From Arcs	To Optical Orbit	To Doppler Orbit
1JOBUR	-26	61†	I, II, III, IV	1.7	3.4
		52‡		2.0	2.9
1OLFAN	-26	132	I, II, III, IV	1.7	3.4
		130		2.1	3.0
1OOMER	-31	42	I, II	1.8	3.0
		41		2.1	3.6
AUSBAK	-31	69	I, II, III, IV	1.6	2.5
		69		2.2	2.8
1VILDO	-32	31	II, IV	3.0	3.5
		33		3.3	3.9

*I - July 9-10, II - July 11-12, III - July 13-14, and IV - July 15-16.
†declination
‡right ascension

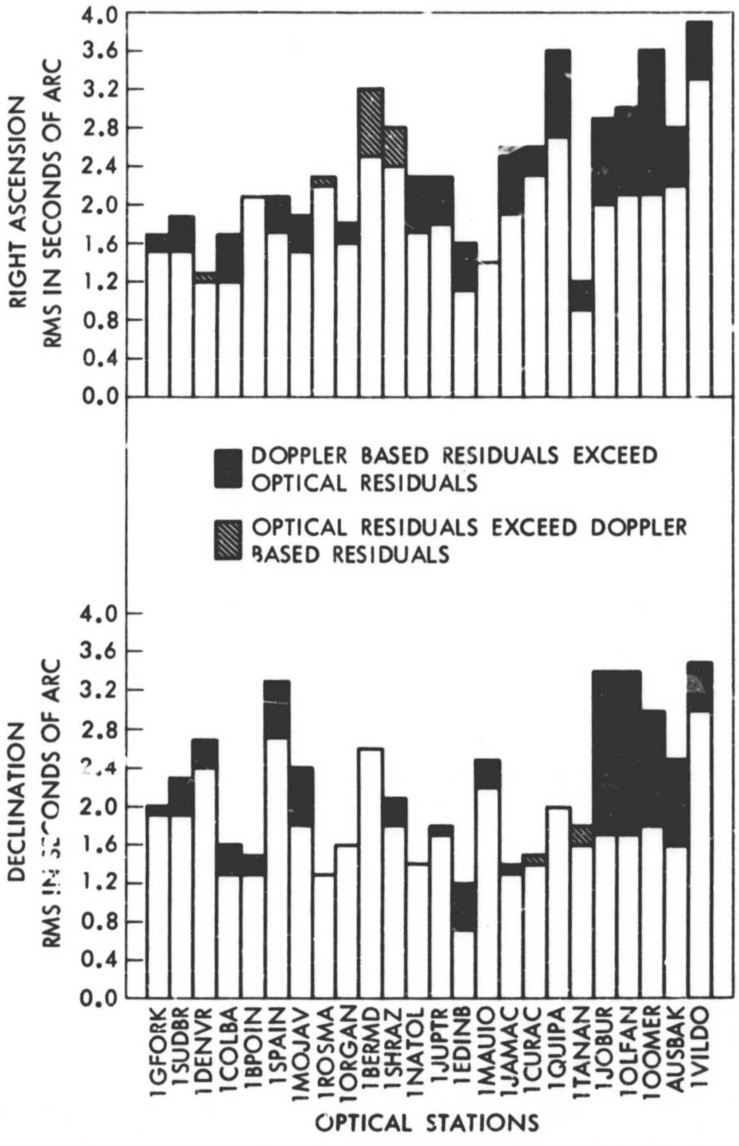

Figure 2—Summary of optical residuals based upon TRANET Doppler orbits for the period July 9-16, 1966.

from the original optical solutions, and the combined RMS values when the Doppler state vector was passed through the optical data. The stations are grouped according to hemispheric location. By comparing the optical based RMS values against the Doppler based RMS values for a given station, some feeling for the relative strengths of the two solutions can be obtained.

Figure 2 presents the RMS differences in graphical form. For a few stations, the Doppler orbit fits the optical data slightly better than the optical orbit. This could be due to errors in the station position, instrument errors, or other factors. However, the general trend for northern hemisphere optical stations is for the optical orbit to fit the optical data a little better than the Doppler orbit. In the southern hemisphere, the Doppler orbit has obvious difficulty fitting the optical data. Thus, it seems that the good orbital comparisons that were achieved would have been even better if data were available from Doppler stations in the southern hemisphere to tie down that half of the GEOS-I orbit.

Figure 2 should be interpreted with the information presented in Table 4 in mind. As an example, the histogram for the station in

Madagascar (1TANAN) seems to disagree with those of the two nearby South African stations in Olifantsfontein and Johannesburg. However, data from Tananarive consists of 28 observations in only one arc while there are 113 observations from Johannesburg and 262 from Olifantsfontein and these data are distributed through all 4 arcs. Thus, this indicates that the Tananarive results should be discounted.

V. FURTHER STUDY OF THE INTERCOMPARISONS

Evaluation of Atmospheric Refraction Corrections on Low Elevation Doppler Observations

It was thought that the optical and Doppler solutions might be brought into even better agreement by dropping the low elevation measurements from the Doppler data. The logic behind this is that perhaps the refraction effects, which are greatest at low elevations, are not sufficiently modelled. Additional NONAME solutions were generated with all Doppler observations of elevation less than 20° dropped from the data; two 2-day arcs were tested. Table 5 indicates a very slight drop in the RMS of solution and shows the results of the position comparisons against the corresponding optical arcs. These "elevation cut-off" Doppler versus optical comparisons show an

Table 5

Effects of Removing Low Elevation Observations From Doppler Data on the Doppler Solutions and on the Doppler Versus Optical Orbital Comparisons.†

Navy TRANET Doppler Solutions					
2-Day Arc 1966	Station	Total Number of Observations Used	Total Number of Observations > 20° Elevation Used	Original RMS of Fit (cm/sec)	RMS of Fit (>20°) (cm/sec)
July 17-18	ANCHOR	429	272	3.1	3.0
	WAHIWA	227	111	2.5	2.6
	LACRES	387	187	2.9	2.8
	LASHM2	447	298	2.5	2.2
	APLMND	423	266	2.4	2.3
	ALL	1913	1134	2.7	2.6
July 19-20	ANCHOR	522	303	2.8	2.6
	WAHIWA	234	149	2.7	2.5
	LACRES	307	190	2.7	2.3
	LASHM2	410	277	2.1	2.0
	APLMND	483	271	2.6	2.5
	ALL	1956	1190	2.6	2.4

Table 5 (Continued)

Doppler Versus Optical Orbital Comparisons							
2-Day Arc of Compare (1966)	RMS of Fit		RMS of Position Differences (meters)				Maximum Difference (meters)
	Doppler (cm/sec)	Optical (secs. arc)	Radial	Cross Track	Along Track	Total	
July 17-18	2.6*		7	11	21	24	38
		1.9					
	2.7		7	10	20	23	35
July 19-20	2.4*		13	10	37	41	68
		1.9					
	2.6		12	10	36	40	67

*Observations with $> 20^\circ$ elevation only.
†Note: the inclusion of low elevation Doppler data does not degrade the solution.

increase in the total RMS of position differences of about 1 meter over the original Doppler versus optical comparisons presented in Table 3. Thus it is felt that the inclusion of low elevation Doppler data does not degrade the solution. In fact, the low elevation points add to the geometry of the Doppler solutions since they increase the tracking range in the GEOS-I satellite by approximately 60 miles/degree of elevation on both ends of any specific pass.

Effect of Arc Length on Solution

Two day arc lengths may be less accurate than shorter arc lengths due to the effects of data distribution, gravity model errors, perturbation model errors, and unmodelled parameters. However, two day arc lengths were chosen for this study because it was thought that none of these errors would have an adverse effect over a 2-day period. This section presents the results of a check made to determine the quality of 2-day versus shorter length orbital solutions.

In order to assess the accuracy of orbital arc solutions of less than 2-day length, two arcs (July 17-18, July 19-20) are broken into smaller arcs of length 1-1/2, 1, and 1/2 day length as shown in Figure 3. Doppler and optical orbits are determined for these 16 shorter arcs and then intercompared as in the initial 2-day orbital solutions.

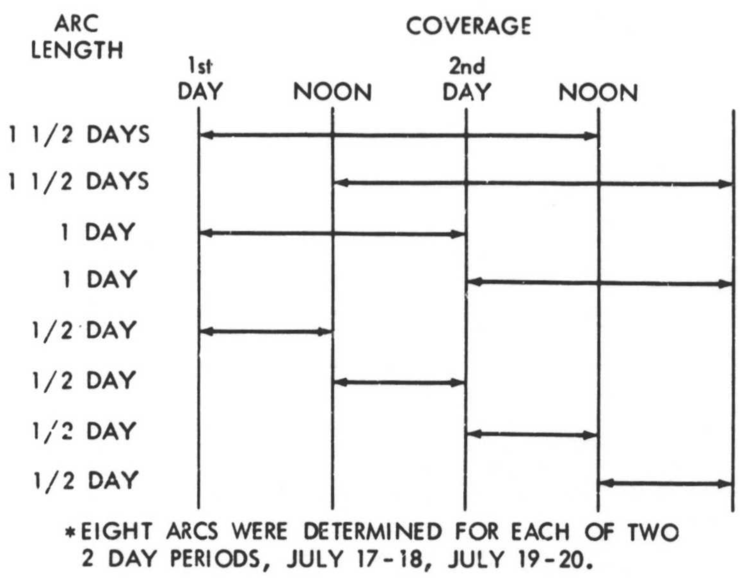

Figure 3—Reduction of two day arcs into shorter arc lengths.*

The results of 9 of these 16 intercomparisons along with the results of the two 2-day intercomparisons are presented in Table 6. Seven results are not presented since very poor data distribution over the arc length prevented the determination of sufficiently accurate orbits. The results indicate that the fit of the data to the orbit does not appreciably improve as the arc length of solution decreases; thus, the orbital solutions of length less than 2-days are not of better quality than the 2-day solutions.

Table 6

Position Differences Between TRANET Doppler Orbits and Optical Orbits for Arc Lengths Less Than 2 Days.

Arc of Compare			RMS of Fit		RMS of Position Differences (meters)				Maximum Difference
Epoch (1966)		Length in Days	Doppler (cm/sec)	Optical (secs. arc)	Radial	Cross Track	Along Track	Total	
Day	Hour								
July 17	0	2	2.7	1.9	7	10	20	23	35
July 17	0	1-1/2	2.7	1.9	5	9	18	21	34
July 17	12	1-1/2	2.7	1.9	8	2	27	29	54
July 17	0	1	2.5	1.8	8	11	23	27	53
July 18	0	1	2.8	1.9	8	8	22	25	49
July 17	0	1/2	2.5	1.8	1	16	7	17	26
July 18	0	1/2	2.6	1.9	4	2	13	13	26
July 19	0	2	2.6	1.9	12	10	36	39	67
July 19	0	1-1/2	2.7	1.8	10	11	29	32	53
July 19	0	1/2	2.5	1.6	11	6	38	40	65
July 20	0	1/2	2.2	1.7	12	11	33	37	62

The position comparisons of the Doppler and optical orbits are generally in the same range. The two comparisons having very low RMS of position differences over the half day solutions on July 17th and July 18th are the results of very dense data in the period. Each of the thirteen 2-day arcs composed of optical data have an average of 870 observations in it, but both of the above mentioned half day arcs have over 400 optical observations in them. They also have over 400 Doppler observations. These comparisons are further evidence of the quality of the Doppler orbits.

The plots of position differences for these 9 shorter arcs appear in Appendix C.

VI. BIAS STUDY OF DOPPLER DATA

Timing Errors

One of the ancillary programs in the NONAME system processes the residuals calculated in the last iteration of a NONAME ODP data reduction run to determine zero-set and timing errors (Reference 1).

Table 7

Summary of Timing Biases (Δt)* Found in the TRANET Doppler Data

2-Day Arc (1966)	Station	Number of Passes	Timing Error (Δt) ± 1 Standard Deviation (msecs.)
July 17-18	APLMND	10	0.6 ± 4.2
	LASHM2	10	0.0 ± 3.2
	ANCHOR	10	-0.8 ± 3.2
	LACRES	9	-0.4 ± 5.5
	WAHIWA	5	2.7 ± 5.5
July 19-20	APLMND	11	0.4 ± 5.8
	LASHM2	9	-2.1 ± 3.0
	ANCHOR	12	-1.7 ± 2.7
	LACRES	7	2.9 ± 1.5
	WAHIWA	5	3.5 ± 6.3

*$\Delta R = \Delta B + \Delta t\,\dot{O}$ where ΔR = Residual (o-c), ΔB = Zero Set Bias, Δt = Timing Error, and $\dot{O}$ = Rate of Change of Observation.

The residuals are investigated with the following regression model:

$$\Delta R = \Delta B + \Delta t\,\dot{O}$$

where

ΔR = the residual for a specific observation.

ΔB = the zero-set error in the observing instrument.

Δt = the timing error in the observing instrument.

$\dot{O}$ = the rate of change of the observation.

This program, GEORGE, was used to determine the timing errors for the July 17-18 and July 19-20 Doppler arcs. Table 7 summarizes the results which appear in full in Appendix D. Although zero-set errors were computed by GEORGE, they are neglected because such errors were absorbed into the adjustment of the range rate measurement bias (the base frequency adjustment).

It is obvious from the table that no significant timing errors were found.

Results of the Range-Rate Bias Adjustment on TRANET Doppler Data

As mentioned previously, the NONAME Orbit and Geodetic Parameter Estimation System is used to adjust on a range-rate or base frequency bias for each pass of data in all Doppler orbital solutions (refer to Section II).

Table 8

Summary of Biases Found in the TRANET Doppler Data Over the Period July 9-26 July 31-August 7, 1966.

Station	Number of Passes	Range Rate Bias ± 1 Standard Deviation (cm/sec)
APLMND	140	10.2 ± 3.4
LASHM2	138	8.2 ± 2.6
ANCHOR	138	8.3 ± 3.1
LACRES	94	8.2 ± 3.2
WAHIWA	60	9.3 ± 2.4
ALL	570	8.8 ± 3.1

The bias values that are determined in the NONAME System are consistent throughout all of the Doppler orbital solutions. Table 8 presents a summary of all range-rate biases determined over the entire period of the study. Appendix D presents the determined biases in more detail. The biases for each station generally range from 8 to 10 cm/sec with standard deviations of 2 to 3 cm/sec.

Analysis of simultaneous GEOS-II Doppler and laser data at Wallops Island by Berbert and Parker (Reference 8) also indicated the presence of a positive bias in the Doppler data. Using 10 passes of laser data to determine reference orbits, Berbert and Parker noted TRANET range rate biases averaging +16 cm/sec. Discussions between the investigators and NWL personnel uncovered a procedure in the preprocessing program at NWL which was responsible for the large positive biases. After NWL provided corrections to the base frequency, the average bias dropped to +4 cm/sec.

Effect of Arc Length on the Range-Rate Bias Adjustment

The question of independence of the range-rate bias adjustment on arc length is investigated Two of the 2-day arcs, July 17-18 and July 19-20 are broken into smaller arcs of 1-1/2, 1, and 1/2 day lengths (see Figure 3); 8 arcs are thus formed in each 2-day period. If a particular pass lasts from morning into the afternoon (G.M.T.), then only two of these shorter arcs can be used to get a range-rate bias for that pass, the reason being that the pass must fall completely within an arc in order to get a bias adjustment for the entire pass. For passes within the first and last quarters of the 2-day period, 3 of these shorter arcs can be used to determine a range-rate bias, and for passes within the center quarters of the 2-day period, 4 shorter arc solutions for range-rage bias are possible.

Table 9

Dependency of the TRANET Doppler Range Rate Bias Adjustment on Arc Length.

Pass for Which Bias is Computed		Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean Bias ± 1 Standard Deviation (cm/sec)
Station Day		Epoch (1966)		Length in Days		
Start	End	Day	Hour			
APLMND		July 17	0	2	5.6	
July 17		July 17	0	1-1/2	5.6	
9:48	10:17	July 17	0	1	5.9	6.0 ± 0.5
		July 17	0	1/2	6.7	
ANCHOR		July 17	0	2	7.5	
July 17		July 17	0	1-1/2	7.7	
15:49	16:18	July 17	12	1-1/2	6.5	7.1 ± 0.5
		July 17	0	1	6.8	
		July 17	12	1/2	6.9	
LASHM2		July 17	0	2	8.3	
July 18		July 17	0	1-1/2	7.8	
3:48	4:17	July 17	12	1-1/2	8.0	7.8 ± 0.4
		July 18	0	1	7.7	
		July 18	0	1/2	7.3	
WAHIWA		July 19	0	2	12.4	
July 19		July 19	0	1-1/2	12.7	
16:06	16:35	July 19	12	1-1/2	11.9	11.8 ± 0.8
		July 19	0	1	11.3	
		July 19	12	1/2	10.7	
LACRES		July 19	0	2	11.9	
July 20		July 19	12	1-1/2	12.5	
12:04	12:33	July 20	0	1	12.7	11.9 ± 0.9
		July 20	12	1/2	10.6	

Table 9 presents the results for 5 representative passes to show the general consistency of the range-rate or base frequency adjustment. Appendix E presents the results for all 88 passes covering the 4 days of July 17-20, 1966. Most of the passes show a mean bias value with a standard deviation of about 2-10% of the mean. This result indicates a strong level of independence between arc length and the bias adjustment on range-rate, and it provides further evidence that the TRANET Doppler data are being processed properly in the NONAME System.

VII. CONCLUSIONS

The thirteen 2-day optical orbits and the thirteen 2-day Doppler orbits have RMS of fits in the ranges of 1.9 seconds of arc and 2.7 cm/sec respectively, indicating for both data types that the fits of the data to the orbits are almost down to the noise level of the data. The RMS of position differences between corresponding optical and Doppler orbits range from 20-40 meters, and maximum position differences are from 27-77 meters for the thirteen 2-day arcs. Since the noise level on both data types is from 10-15 meters, it is felt that these results are very consistent and that they demonstrate the ability to generate Doppler orbits of quality comparable to the optical orbits that are being used in geodetic studies at Goddard.

Furthermore, the study of the effects of station positions on the Doppler orbital solutions indicates that even better agreement between the Doppler and optical orbits would have been attained if there had been data available from Doppler stations located in the southern hemisphere to tie down those halves of the Doppler orbits.

It is felt that the NONAME ODP models tropospheric refraction well enough to enable the use of Doppler observations far below 20° in elevation. The use of observations in the range of 10°-20° elevation increases the geometry of any pass of the GEOS-I satellite by approximately 60 miles per degree of elevation on either end of the pass; thus, this ability is quite valuable in determining orbits of geodetic quality.

Biases in the base frequency values sent along with each pass of Doppler data were consistently on the order of 8-10 cm/sec ±2-3 cm/sec for each of the 5 stations used in this study. Also, the range-rate biases adjustment in the NONAME System was found to be highly independent of arc length of solution. No significant timing biases were found in the Doppler data.

Finally, this report indicates that Navy TRANET Doppler data can currently be used to supplement optical data in geodetic studies using the NONAME Orbit and Geodetic Parameter Estimation System at Goddard or in a system having similar capacity to handle Doppler data.

Work is currently in progress performing additional studies of this nature using data from other satellites (GEOS-II, BEB, BEC).

VIII. ACKNOWLEDGMENT

The authors wish to thank Mr. Thomas David Meadows for performing the NONAME computer runs used in this report.

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Appendix A

Optical and Doppler Data Used in the Analysis

The tables herein present the thirteen 2-day optical orbital solutions (Table A1) and the thirteen 2-day TRANET Doppler orbital solutions (Table A2) in detail. The number of observations from each station that were used to determine the orbit and the RMS of fit of the orbit to the data from each station is shown.

Table A1

2-Day Optical Orbital Solutions.

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
July 9-10	AUSBAK	14*		1.5
		14†		2.2
	1BPOIN	20		1.5
		19	1	2.3
	1COLBA	28		1.1
		28		1.3
	1CURAC	27	1	1.7
		27	1	2.3
	1DENVR	21		2.4
		21		1.3
	1EDINB	20	1	0.7
		21		1.3
	1GFORK	25		2.1
		25		2.0
	1GSFCP	6		-
		1	5	-
	1JOBUR	21		2.0
		18	3	2.5
	1JUPTR	35		1.8
		35		1.3
	1MAUIO	28		2.0
		28		1.5
	1OLFAN	14		2.0
		14		1.6

*First line is for declination observations.
†Second line is for right ascension observations.

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
July 9-10 (continued)	1OOMER	21		2.0
		21		2.1
	1ORGAN	56		1.8
		56		1.6
	1QUIPA	14		1.2
		14		3.7
	1ROSMA	21		1.3
		20	1	2.5
	1SPAIN	14		1.2
		14		3.7
	1TANAN	7		-
		7		-
	ALL	775	13	1.8
July 11-12	AUSBAK	21		1.4
		21		2.4
	1BERMD	35		2.9
		35		2.7
	1BPOIN	25		1.2
		25		2.0
	1COLBA	65	1	1.4
		66		1.2
	1EDINB	49		0.7
		49		1.1
	1GFORK	48		1.8
		48		1.2
	1JAMAC	35		1.3
		34	1	1.9
	1JOBUR	14		1.6
		10	4	1.4
	1JUPTR	55		2.1
		55		2.4
	1MAUIO	3		-
		3		-
	1MOJAV	35		1.8
		35		1.5
	1NATOL	7		-
		6	1	-
	1OLFAN	21		1.7
		20	1	2.8

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
July 11-12 (continued)	1OOMER	21		1.7
		20	1	2.2
	1ORGAN	35		1.5
		35		1.6
	1PURIO	7		-
		7		-
	1QUIPA	14		1.9
		14		3.1
	1ROSMA	12		1.2
		12		1.8
	1SHRAZ	14		2.2
		11	3	3.0
	1SPAIN	24	4	3.6
		28		2.1
	1SUDBR	46		2.0
		46		1.7
	1TANAN	14		1.8
		14		0.9
	1VILDO	17	4	3.8
		19	2	3.6
	ALL	1230	22	1.9
July 13-14	AUSBAK	20		1.8
		20		1.3
	1JOBUR	12	1	1.7
		10	3	1.8
	1JUPTR	105		1.7
		104	1	1.7
	1NATOL	25		1.4
		25		1.7
	1OLFAN	48	1	1.8
		47	2	2.0
	1OOMER	7		-
		7		-
	1ORGAN	59	2	1.9
		59	2	1.7
	1QUIPA	20		2.7
		20		2.0
	1SHRAZ	14		1.5
		14		2.8

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
July 17-18	AUSBAK	49		1.7
		46	3	2.3
	1BERMD	42		2.9
		41	1	3.0
	1BPOIN	12		1.4
		12		2.7
	1COLBA	28		1.3
		28		1.5
	1EDINB	35		1.1
		35		1.8
	1GFORK	18		2.5
		17	1	2.1
	1JAMAC	13		1.2
		13		1.7
	1JOBUR	13		2.1
		13		1.5
	1JUPTR	112		1.9
		112		1.9
	1MAUIO	29		1.4
		29		1.6
	1MOJAV	14		2.0
		14		1.1
	1OLFAN	35		1.8
		35		1.9
	1ORGAN	71	2	1.6
		71	2	1.4
	1PURIO	13		1.0
		12	1	3.3
	1QUIPA	21		1.7
		21		2.8
	1SPAIN	47	2	1.9
		47	2	2.0
	1TANAN	14		2.3
		14		2.6
	1VILDO	14		1.4
		14		2.0
	ALL	1154	14	1.9

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
July 19-20	AUSBAK	6		-
		6		-
	1BERMD	7		-
		7		-
	1BPOIN	33		1.7
		33		1.8
	1COLBA	43		1.0
		43		1.4
	1EDINB	56		1.0
		56		1.3
	1FTMYR	7		-
		7		-
	1GFORK	62		1.5
		62		1.3
	1GSFCP	7		-
		7		-
	1JAMAC	14		0.6
		14		2.6
	1JOBUR	32	3	1.9
		33	2	1.8
	1JUPTR	62	1	2.3
		62	1	2.3
	1MAUIO	12		2.6
		12		2.6
	1MOJAV	35		1.3
		35		1.9
	1OLFAN	21		1.6
		21		2.3
	1ORGAN	8		-
		8		-
	1QUIPA	27	1	3.0
		25	3	2.8
	1SPAIN	75	1	2.7
		75	1	1.9
	1SUDBR	42		2.1
		41	1	2.0
	1VILDO	7		-
		1	6	-
	ALL	1104	20	1.9

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
July 21-22	AUSBAK	21		1.5
		21		2.6
	1COLBA	21		2.1
		21		1.5
	1EDINB	13		2.4
		13		1.3
	1FTMYR	7		-
		7		-
	1JOBUR	7		-
		7		-
	1JUPTR	31		1.7
		31		2.0
	1MAUIO	14		2.6
		14		1.1
	1OLFAN	42		1.8
		42		2.1
	1ORGAN	66		1.9
		66		2.5
	1QUIPA	47		1.7
		47		2.6
	1ROSMA	14		2.4
		14		1.2
	1SPAIN	62	1	2.7
		63		1.8
	1SUDBR	21		3.3
		21		2.0
	1VILDO	7		-
		7		-
	ALL	747	1	2.1
July 23-24	AUSBAK	49		1.4
		48	1	2.1
	1BERMD	18		1.3
		18		3.8
	1BPOIN	14		1.1
		14		1.9
	1DENVR	7		-
		7		-
	1EDINB	21	12	0.9
		21	12	1.3

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
July 23-24 (continued)	1FTMYR	7		-
		7		-
	1GFORK	26		2.2
		26		1.5
	1GSFCP	7		-
		7		-
	1JAMAC	14		1.6
		14		2.2
	1JOBUR	21		1.1
		21		1.5
	1MAUIO	8		-
		8		-
	1MOJAV	14		1.5
		14		2.1
	1OLFAN	21		1.6
		21		2.0
	1ORGAN	132		1.7
		132		1.6
	1PURIO	14		1.9
		14		1.6
	1QUIPA	28		1.6
		28		2.8
	1ROSMA	38		1.0
		38		1.4
	1SPAIN	14		1.8
		14		1.7
	1SUDBR	21		2.3
		21		1.8
	1VILDO	21		1.7
		21		2.2
	ALL	989	25	1.8
July 25-26	AUSBAK	35		1.8
		33	2	2.3
	1BPOIN	7		-
		7		-
	1COLBA	21		0.8
		21		1.2
	1DENVR	19		1.4
		19		1.3

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
July 25-26 (continued)	1EDINB	35		1.0
		35		1.2
	1GFORK	13		1.9
		11	2	1.6
	1MAUIO	49		1.8
		49		1.6
	1MOJAV	32	1	1.1
		33		1.7
	1ORGAN	73	1	1.4
		73	1	1.6
	1QUIPA	6	1	-
		3	4	-
	1ROSMA	7		-
		7		-
	1SPAIN	70	7	2.3
		77		1.6
	1SUDBR	14		2.3
		14		1.6
	ALL	763	19	1.7
July 31— August 1	1BPOIN	27	1	1.3
		26	2	1.8
	1COLBA	27		0.9
		27		1.4
	1EDINB	35		1.1
		35		1.4
	1FTMYR	7		-
		7		-
	1GSFCP	21		2.4
		21		3.0
	1JUPTR	25	3	2.9
		28		2.4
	1ORGAN	142	2	2.0
		144		1.8
	1PURIO	7		-
		7		-
	1SPAIN	67		1.9
		67		1.8
	1SUDBR	34		1.3
		34		1.9
	ALL	788	8	1.9

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
August 2-3	JOHNST	0	2	-
		1	1	-
	1BERMD	7		-
		4	3	-
	1BPOIN	21		1.5
		21		1.9
	1COLBA	63		2.0
		63		1.2
	1FTMYR	28		1.7
		28		1.5
	1GFORK	42		1.9
		42		1.5
	1GSFCP	19		2.1
		17	2	3.8
	1JUPTR	56		1.6
		56		1.4
	1MAUIO	27		2.0
		27		2.6
	1MOJAV	14		2.4
		14		2.0
	1SPAIN	63		2.3
		63		2.5
	1SUDBR	53		2.1
		51	2	2.8
	ALL	780	10	2.1
August 4-5	AUSBAK	35		2.3
		35		1.7
	1BERMD	7		-
		0	7	-
	1COLBA	41		2.3
		41		2.9
	1EDINB	21		1.6
		21		1.9
	1GFORK	32		1.7
		32		3.4
	1JOBUR	21		1.5
		21		1.6
	1JUPTR	75		2.2
		74	1	1.9

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
August 4-5 (continued)	1MAUIO	53		1.9
		53		1.7
	1MOJAV	27		2.0
		27		1.9
	1OLFAN	21		1.8
		21		2.8
	1ORGAN	56		1.5
		56		1.5
	1QUIPA	14		1.8
		14		1.6
	1SPAIN	90		1.8
		90		2.2
	1VILDO	7		-
		7		-
	ALL	992	8	2.0
August 6-7	AUSBAK	14		1.4
		14		1.8
	JOHNST	0	1	-
		1		-
	1BERMD	14		2.0
		11	3	3.3
	1BPOIN	28		1.7
		28		1.5
	1COLBA	35	7	1.1
		37	5	2.2
	1DENVR	7		-
		7		-
	1EDINB	14		1.7
		14		3.0
	1GFORK	7		-
		7		-
	1JAMAC	7		-
		7		-
	1JOBUR	13	1	1.9
		13	1	1.9
	1MOJAV	14		2.3
		14		1.6
	1OLFAN	14		1.3
		14		2.2

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
August 6-7 (continued)	1ORGAN	7		-
		7		-
	1PURIO	4		-
		4		-
	1QUIPA	14		2.2
		14		2.1
	1SPAIN	63		1.8
		62	1	1.8
	1SUDBR	17		1.6
		17		2.0
	1VILDO	14		2.1
		14		1.9
	ALL	571	19	1.9

Table A2

2-Day TRANET Doppler Orbital Solutions.

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (cm/sec)
July 9-10	ANCHOR	363	4	2.9
	WAHIWA	214	6	2.8
	LACRES	352	2	2.5
	APLMND	500	3	2.8
	LASHM2	548	3	2.3
	ALL	1977	18	2.7
July 11-12	ANCHOR	449	11	3.2
	WAHIWA	98	0	2.4
	LACRES	420	2	2.7
	APLMND	409	4	2.9
	LASHM2	515	5	2.5
	ALL	1891	22	2.8
July 13-14	ANCHOR	522	7	3.1
	WAHIWA	154	1	2.6
	LACRES	326	5	2.6
	APLMND	321	5	2.9
	LASHM2	535	5	2.6
	ALL	1858	23	2.8

Table A2 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (cm/sec)
July 15-16	ANCHOR	494	3	2.9
	WAHIWA	182	3	2.9
	LACRES	274	3	3.0
	APLMND	487	7	2.9
	LASHM2	528	2	2.4
	ALL	1965	18	2.8
July 17-18	ANCHOR	429	25	3.1
	WAHIWA	227	3	2.5
	LACRES	387	5	2.9
	APLMND	423	0	2.4
	LASHM2	447	3	2.5
	ALL	1913	36	2.7
July 19-20	ANCHOR	522	13	2.8
	WAHIWA	234	3	2.7
	LACRES	307	2	2.7
	APLMND	483	5	2.6
	LASHM2	410	2	2.1
	ALL	1956	25	2.6
July 21-22	ANCHOR	440	11	2.8
	WAHIWA	192	0	3.0
	LACRES	429	3	2.6
	APLMND	520	2	2.8
	LASHM2	307	41	2.0
	ALL	1888	57	2.7
July 23-24	ANCHOR	440	11	3.2
	WAHIWA	287	2	2.7
	LACRES	328	2	2.6
	APLMND	467	3	2.6
	LASHM2	275	2	2.3
	ALL	1797	20	2.7
July 25-26	ANCHOR	375	15	3.2
	WAHIWA	284	1	2.5
	LACRES	208	7	2.9
	APLMND	494	31	2.6
	LASHM2	501	3	2.1
	ALL	1862	57	2.7
July 31 —	ANCHOR	438	13	3.3
August 1	WAHIWA	316	1	2.3
	LACRES	160	2	3.1
	APLMND	484	4	2.8
	LASHM2	471	4	2.1
	ALL	1869	24	2.8

Table A1 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (secs. arc)
July 13-14 (continued)	1SPAIN	21		2.5
		21		1.2
	1TANAN	7		-
		7		-
	1VILDO	6		-
		0	6	-
	ALL	678	18	1.8
July 15-16	AUSBAK	14		1.9
		14		2.9
	1BERMD	14		1.8
		13	1	4.5
	1CURAC	6		-
		6		-
	1JOBUR	14		1.3
		14		2.2
	1JUPTR	110		1.5
		110		1.6
	1MAUIO	28		2.5
		28		1.2
	1OLFAN	49		1.6
		49		2.1
	1ORGAN	74		1.3
		74		1.4
	1PURIO	7		-
		7		-
	1QUIPA	21		1.6
		21		2.3
	1SPAIN	14		2.0
		14		1.4
	1SUDBR	14		1.8
		14		0.8
	1TANAN	7		-
		7		-
	1VILDO	14		1.9
		14		2.8
	ALL	771	1	1.8

Table A2 (Continued)

2-Day Arc	Station	Number of Observations Used	Number of Observations Rejected	RMS of Fit (cm/sec)
August 2-3	ANCHOR	517	6	3.3
	WAHIWA	268	1	2.5
	LACRES	158	2	2.6
	APLMND	519	3	3.1
	LASHM2	391	36	2.7
	ALL	1853	48	3.0
August 4-5	ANCHOR	491	20	3.1
	LACRES	407	5	2.8
	APLMND	392	0	2.9
	LASHM2	532	4	2.1
	ALL	1822	29	2.7
August 6-7	ANCHOR	442	13	3.1
	WAHIWA	180	0	2.4
	LACRES	174	40	2.8
	APLMND	511	4	2.8
	LASHM2	541	3	2.2
	ALL	1848	60	2.7

Appendix B

Position Differences Between Doppler and Optically Determined Orbits

Figures are presented for five of the thirteen 2- day orbital intercomparisons showing plots of the satellite position differences between the optically determined and Doppler determined orbits over the span of the arc.

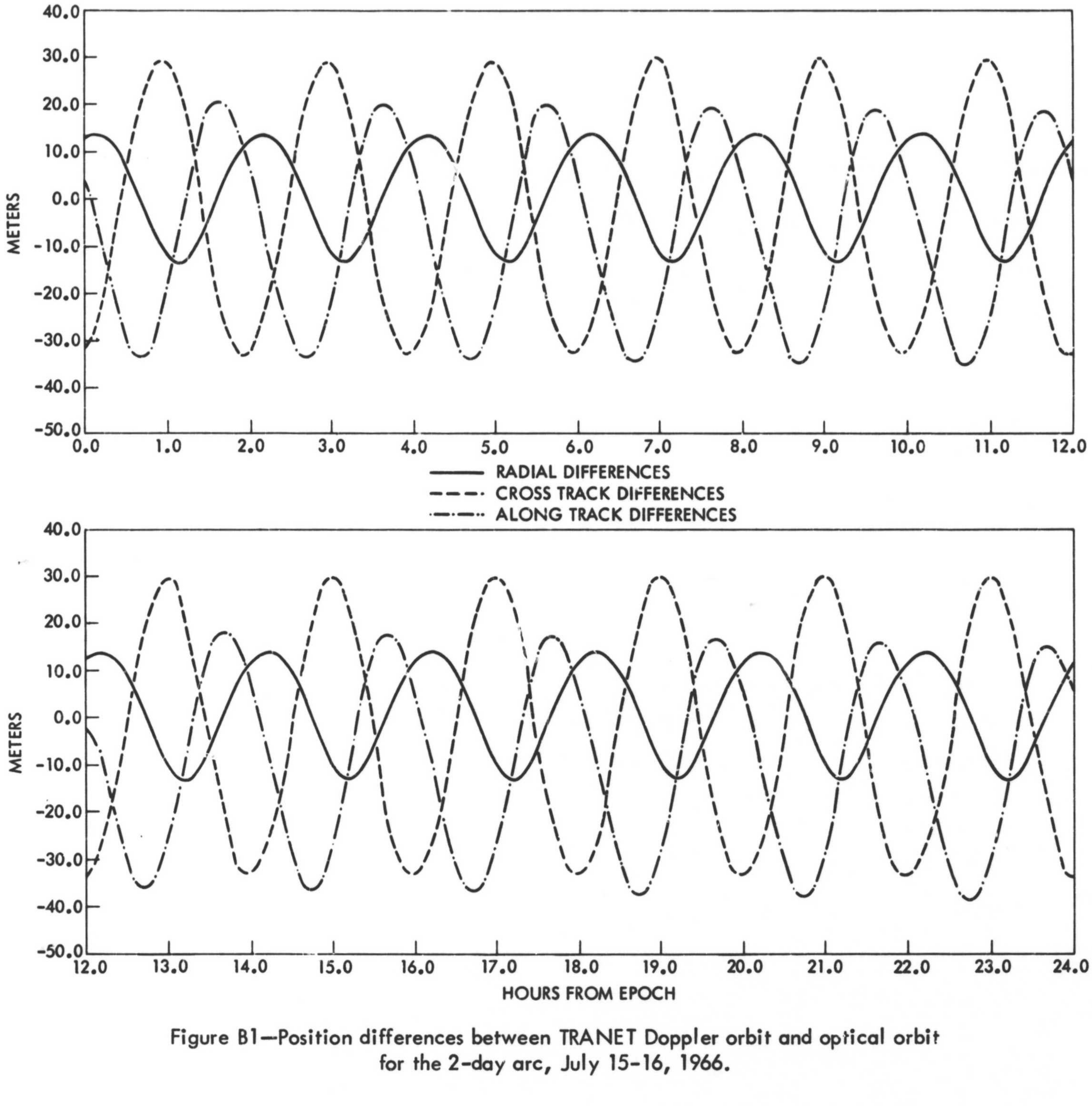

Figure B1—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, July 15-16, 1966.

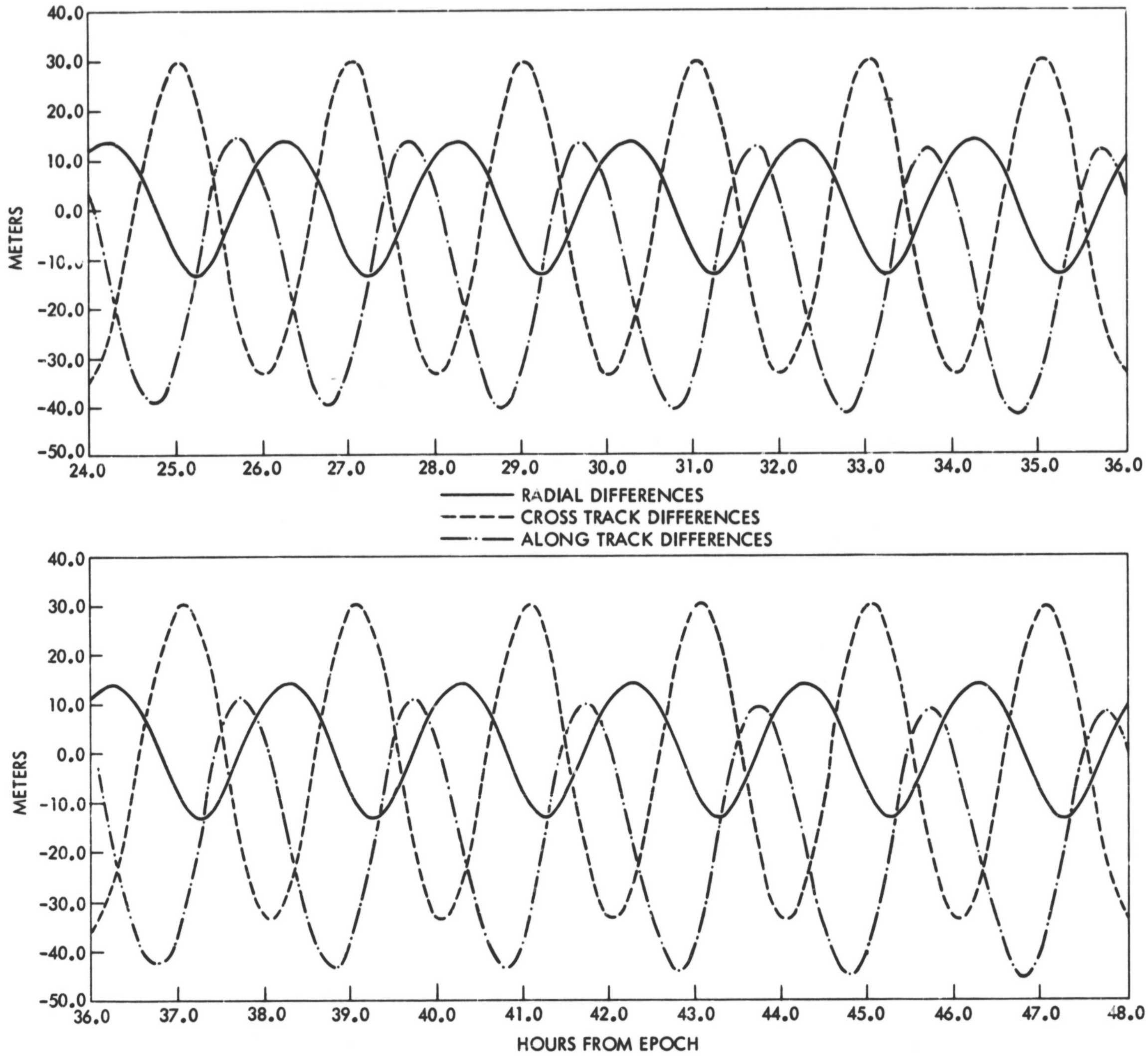

Figure B1 (continued)—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, July 15-16, 1966.

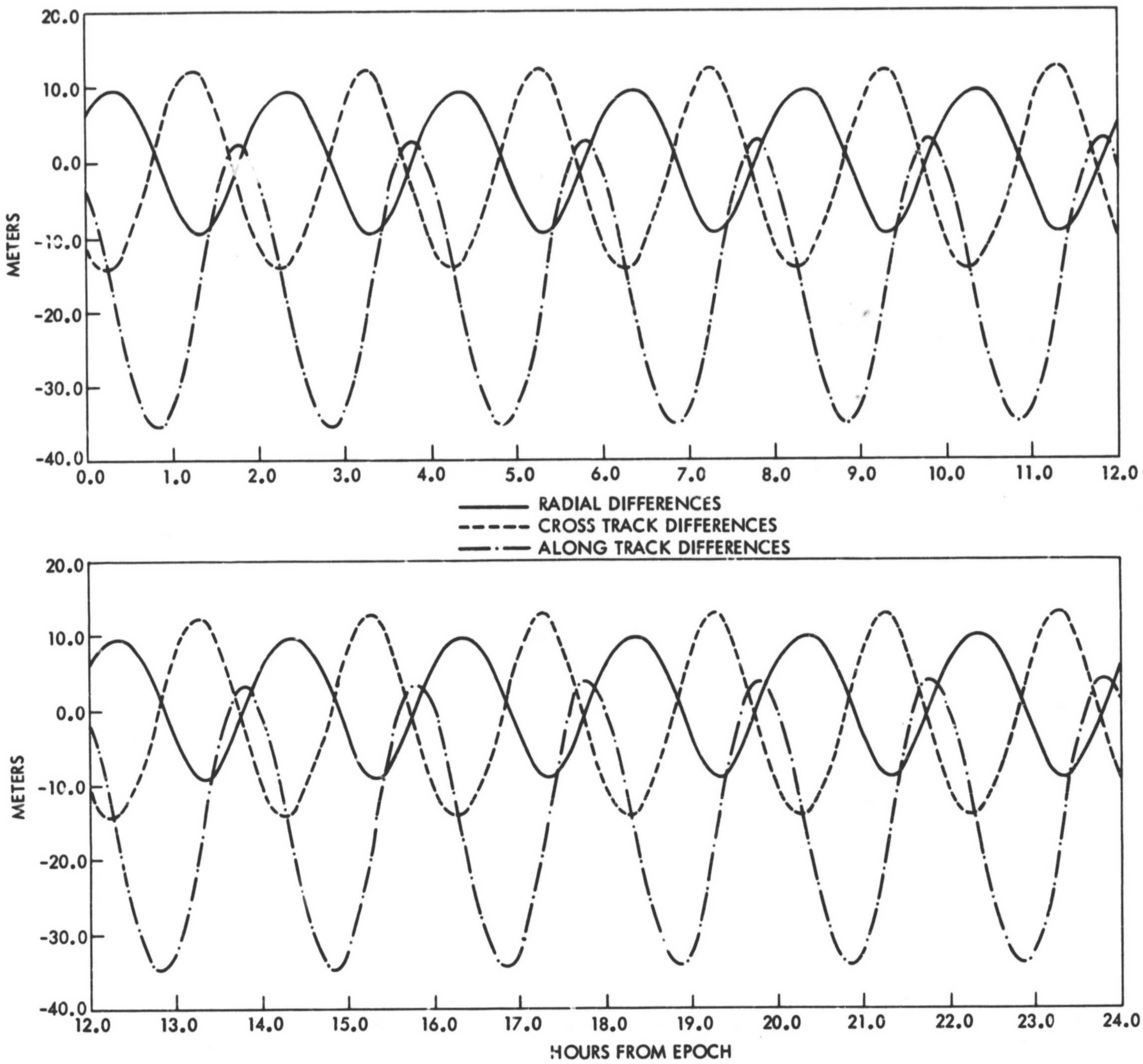

Figure B2—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, July 17-18, 1966.

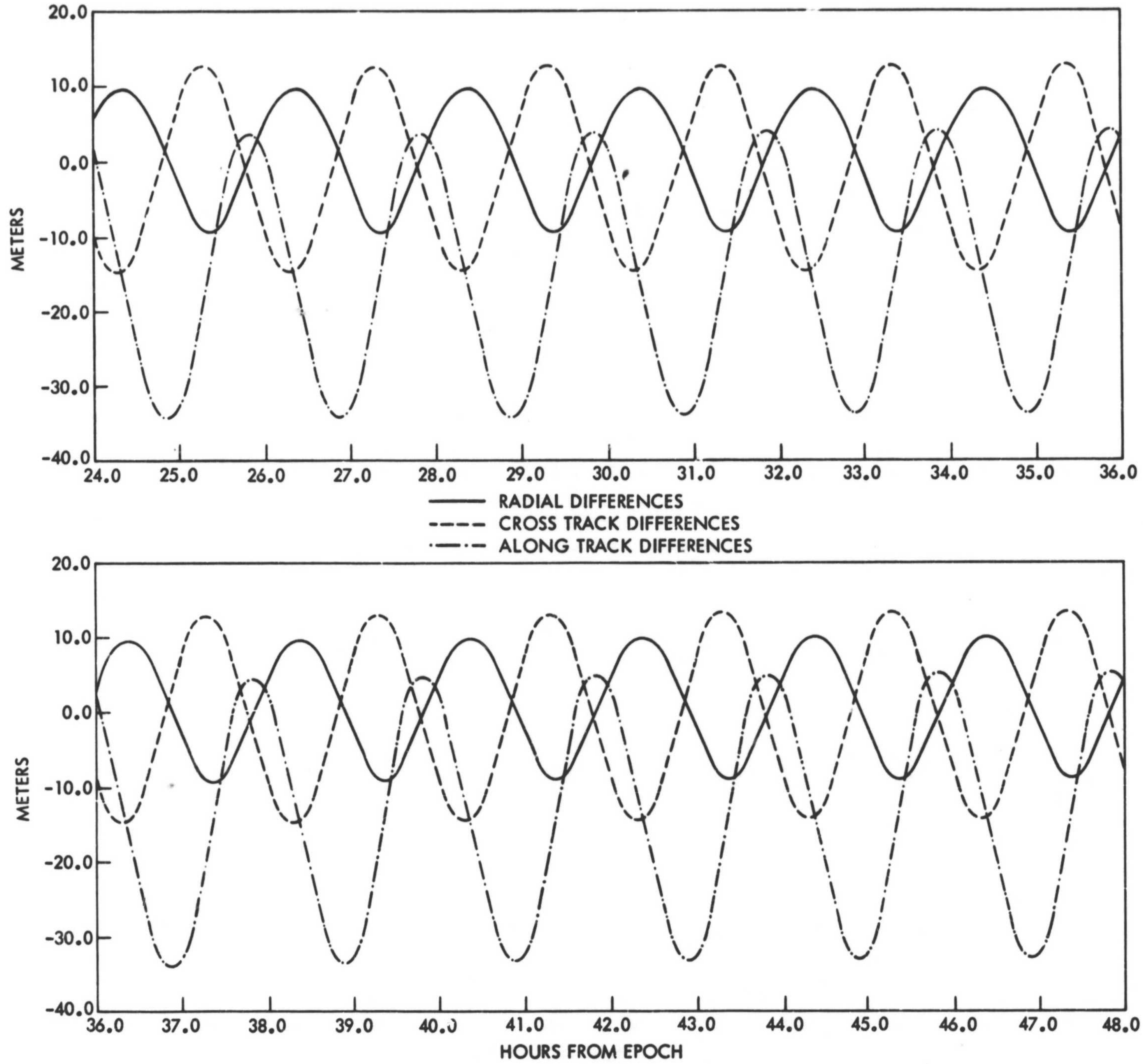

Figure B2 (continued)—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, July 17-18, 1966.

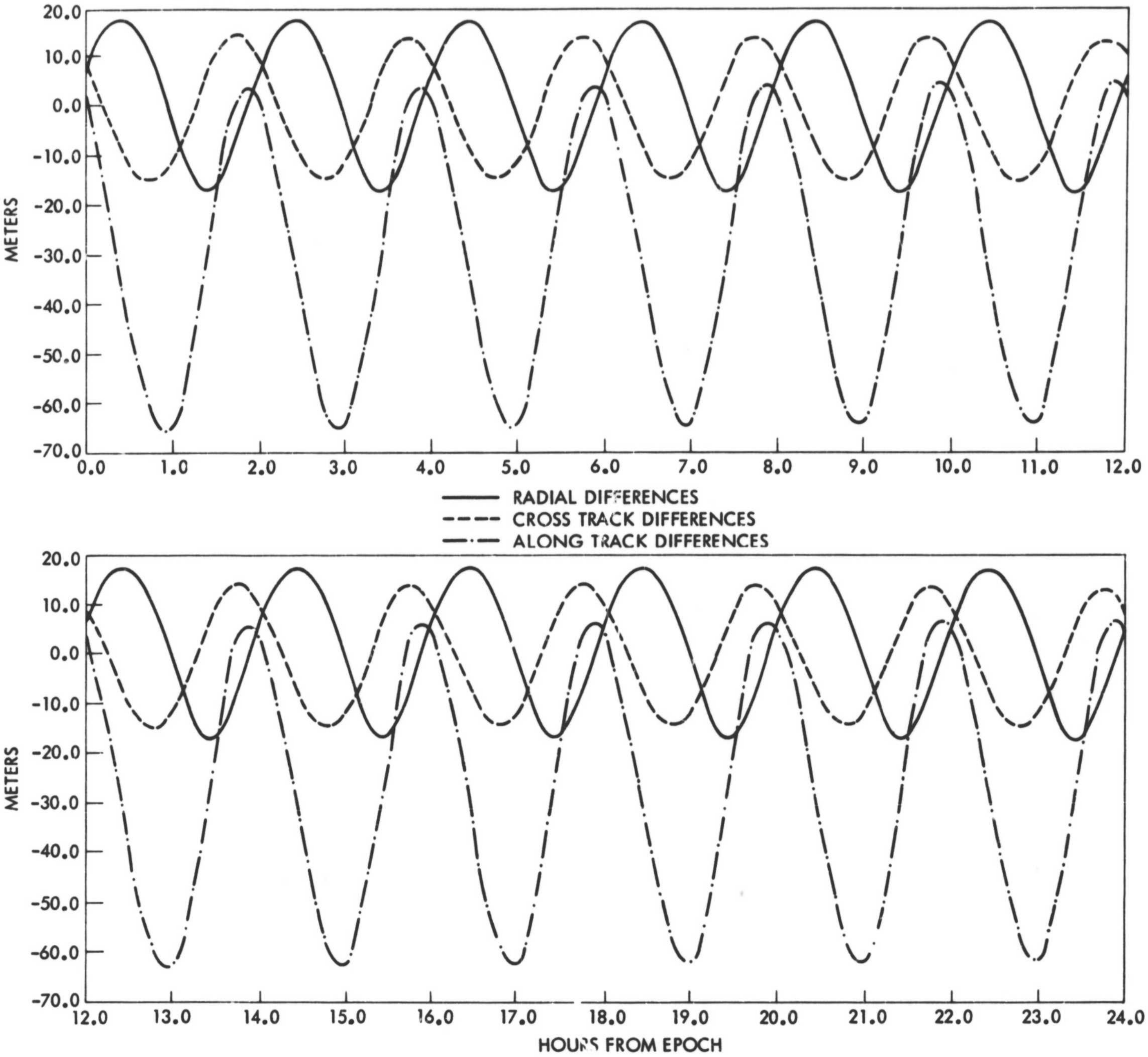

Figure B3—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, July 19-20, 1966.

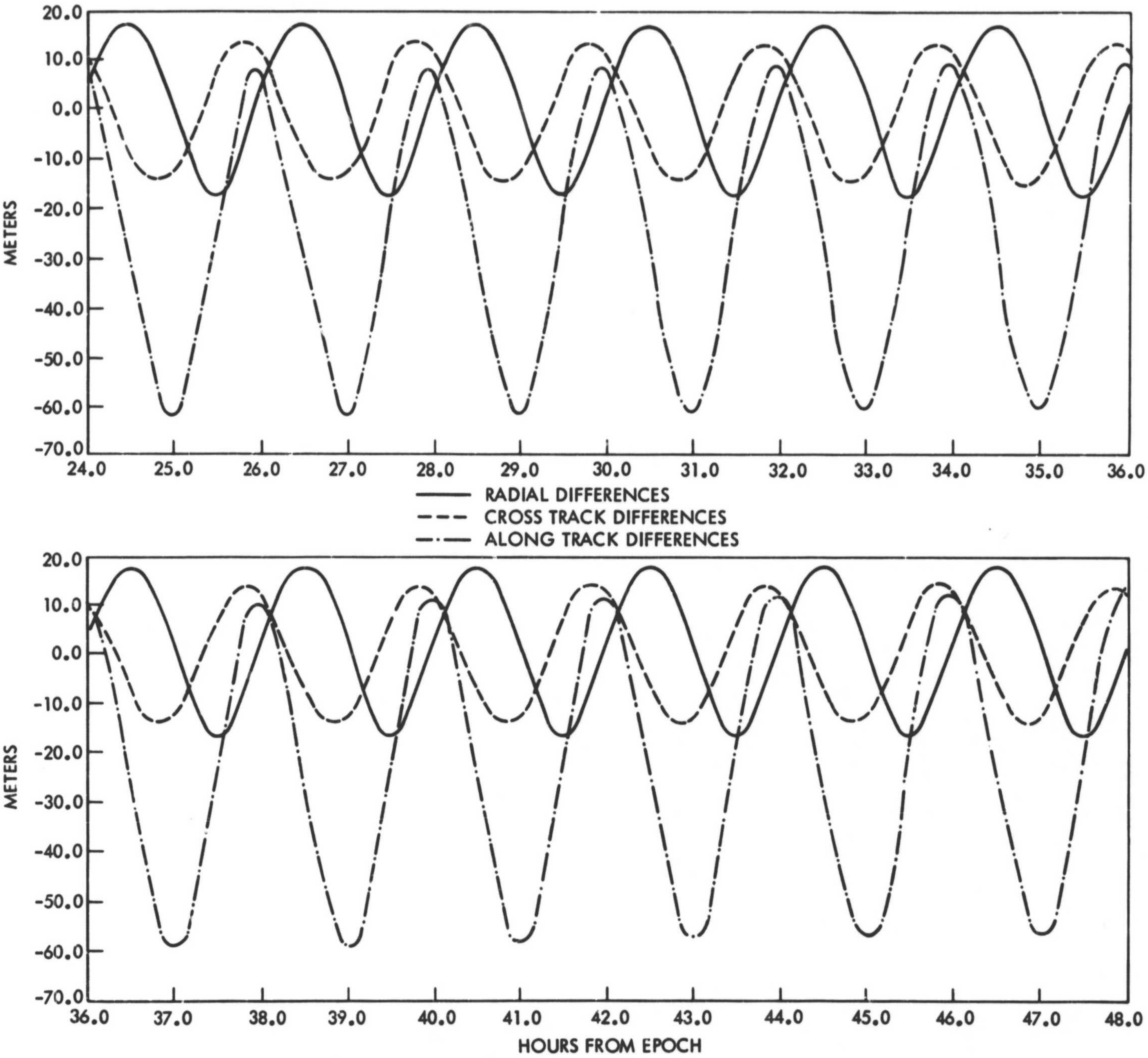

Figure B3 (continued)—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, July 19-20, 1966.

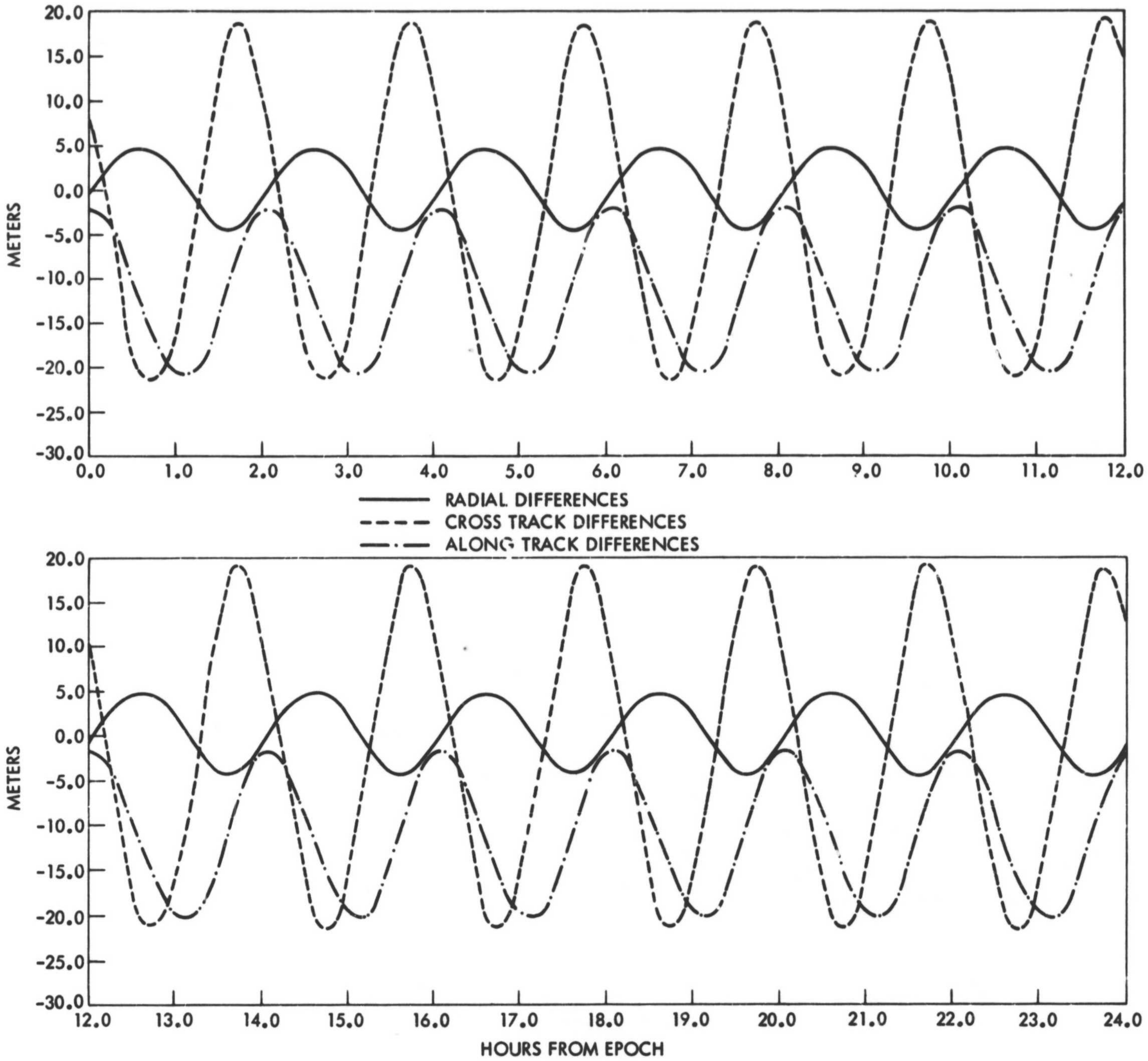

Figure B4—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, July 23-24, 1966.

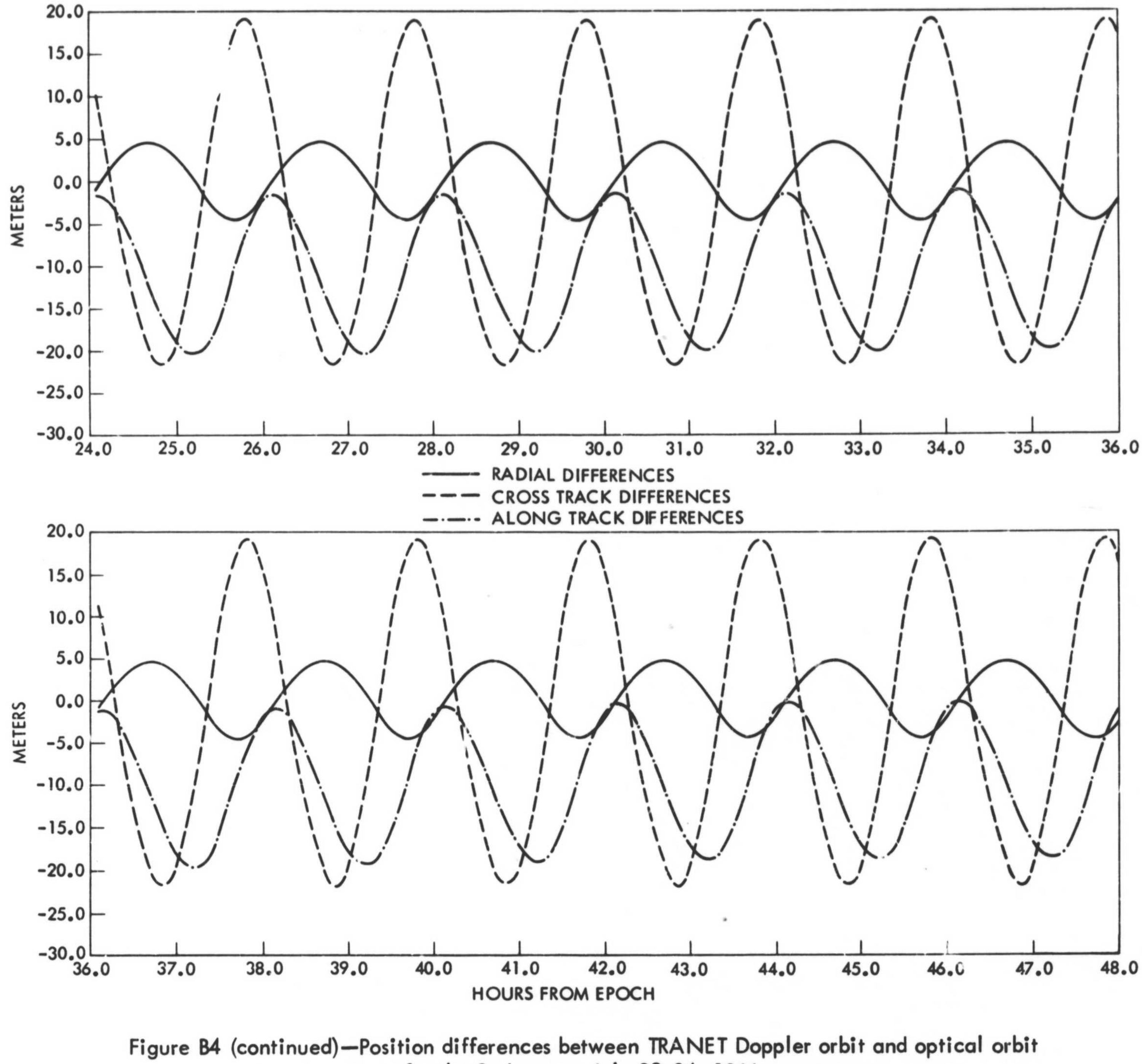

Figure B4 (continued)—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, July 23-24, 1966.

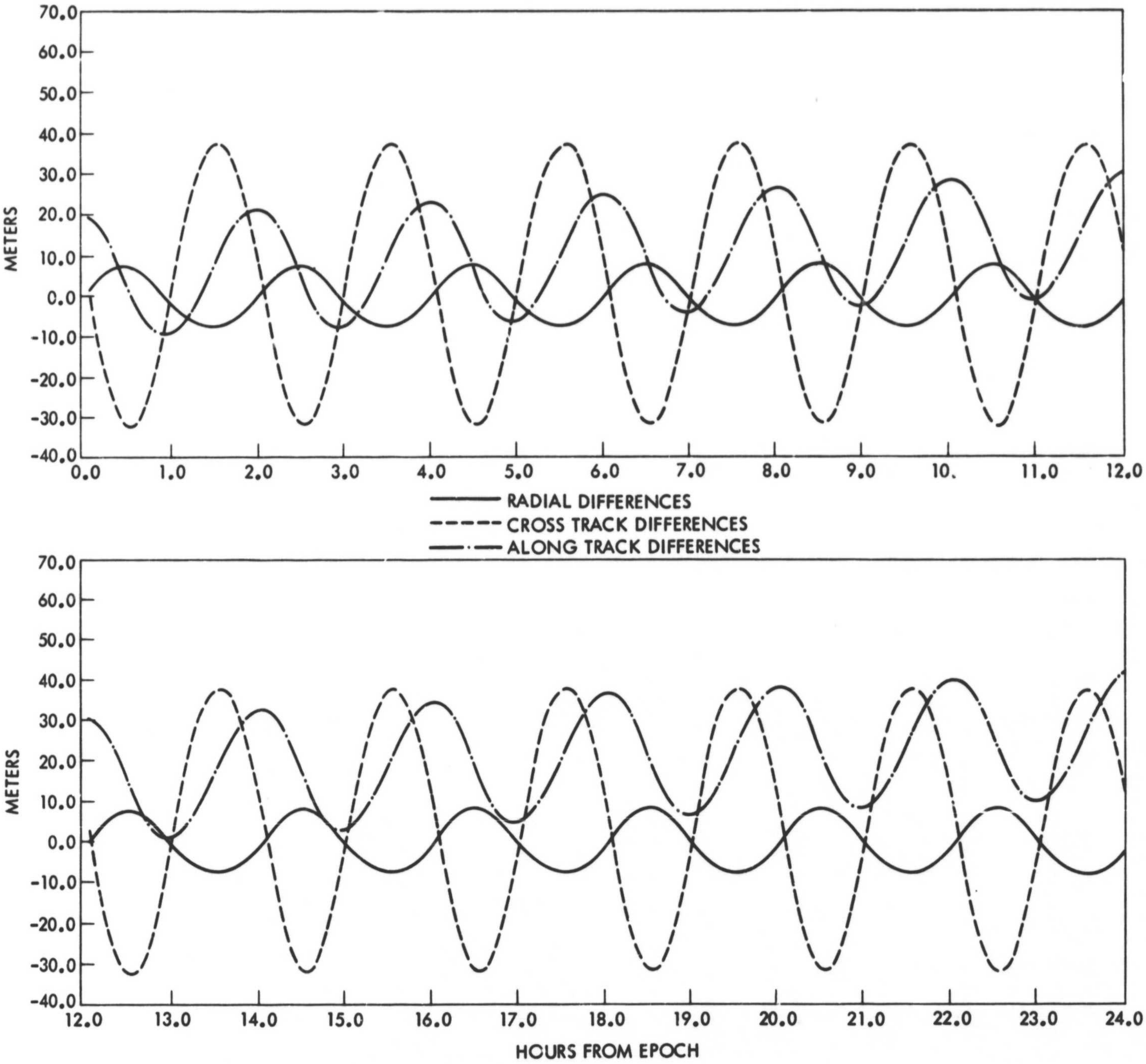

Figure B5—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, August 4-5, 1966.

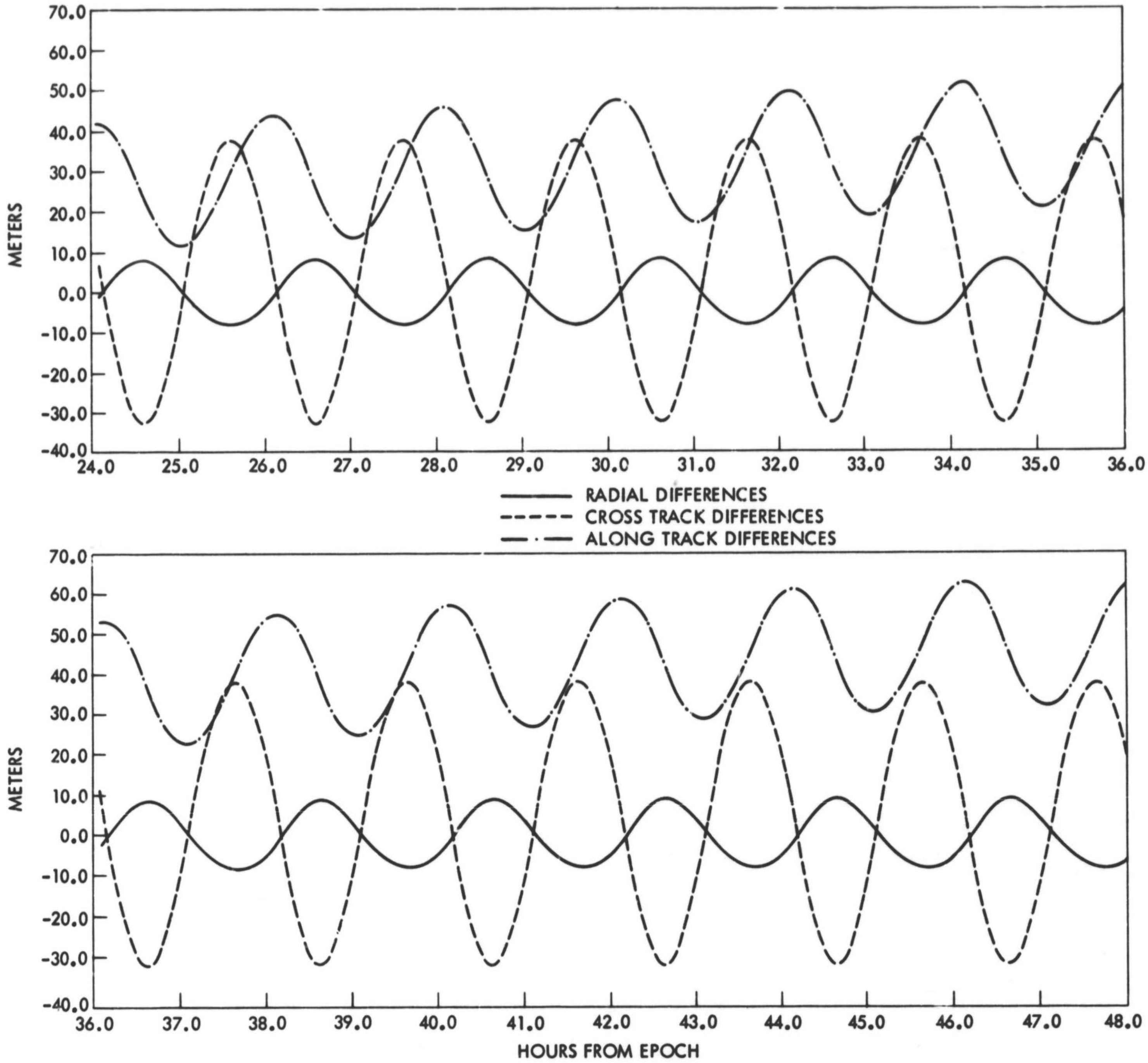

Figure B5 (continued)—Position differences between TRANET Doppler orbit and optical orbit for the 2-day arc, August 4-5, 1966.

Appendix C

Position Differences Between Doppler and Optically Determined Orbits for Selected Arc Lengths

Figures are presented for 9 selected arc lengths showing plots of the satellite position differences between the optically determined and Doppler determined orbits over the span of the particular arc.

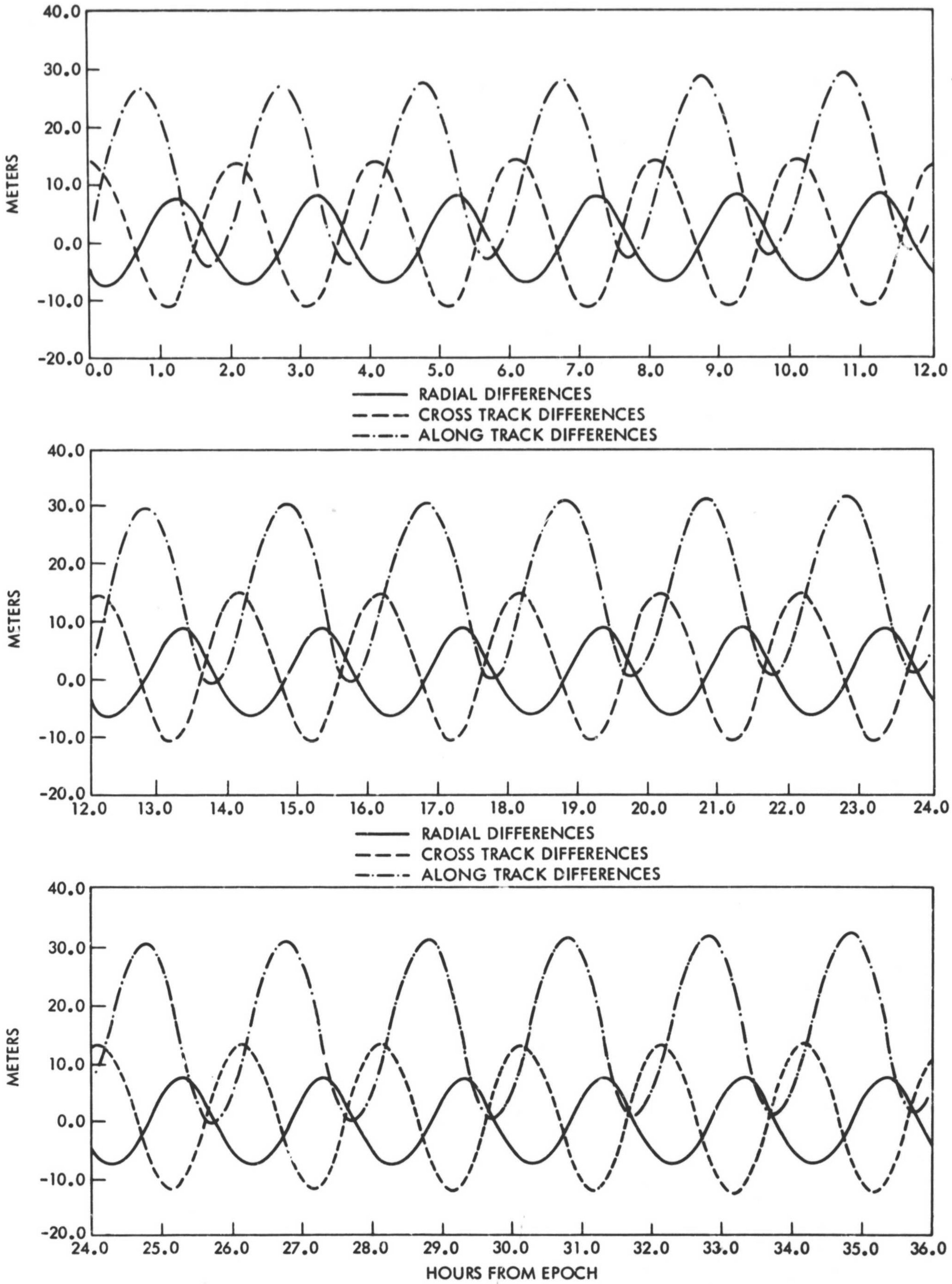

Figure C1—Position differences between TRANET Doppler orbit and optical orbit for the 1-1/2-day arc, July 17, 0 hrs—July 18, 12 hrs, 1966.

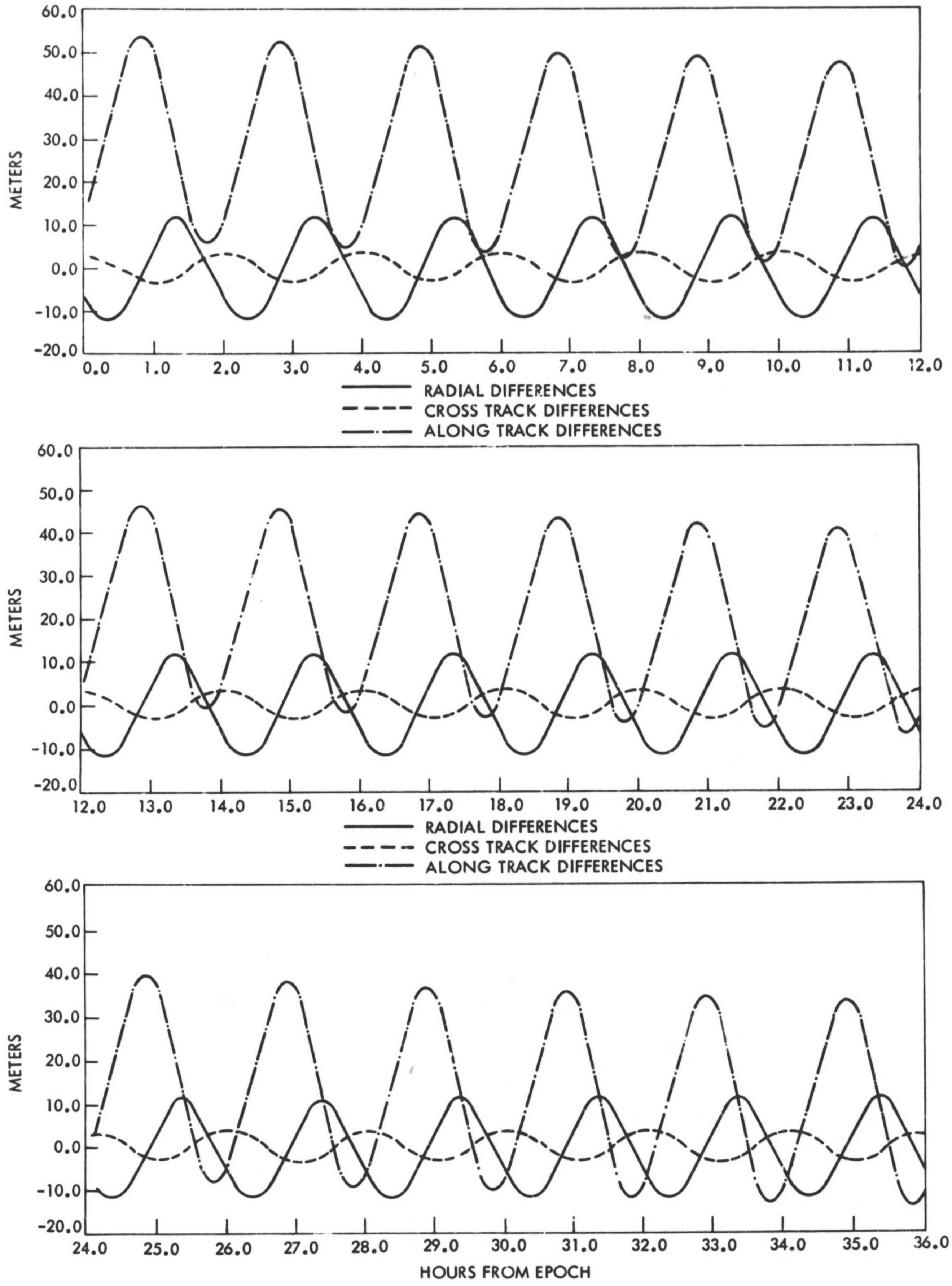

Figure C2—Position differences between TRANET Doppler orbit and optical orbit for the 1-1/2-day arc, July 17-12 hrs—July 19, 0 hrs, 1966.

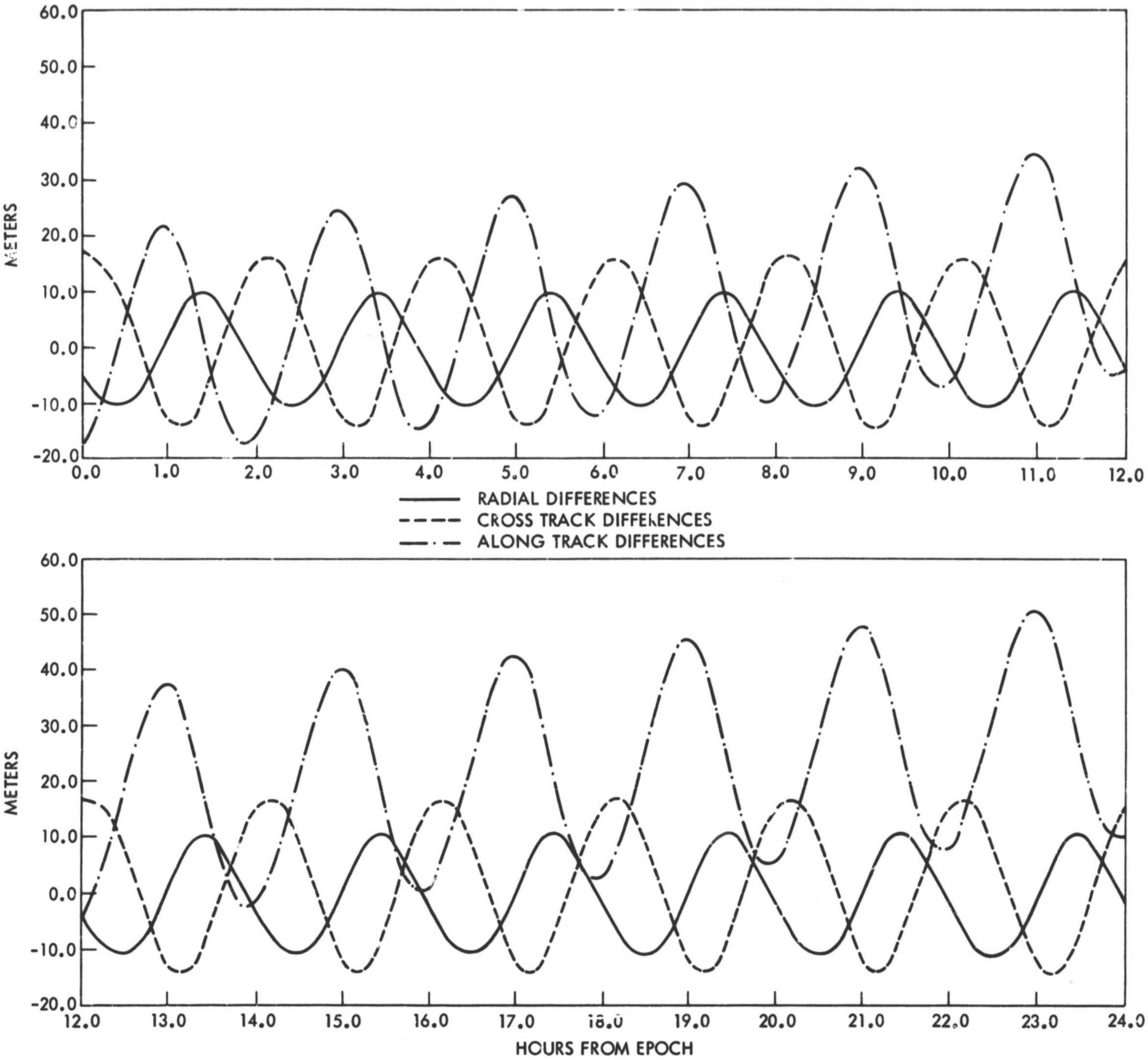

Figure C3—Position differences between TRANET Doppler orbit and optical orbit for the 1-day arc, July 17, 0 through 24 hrs, 1966.

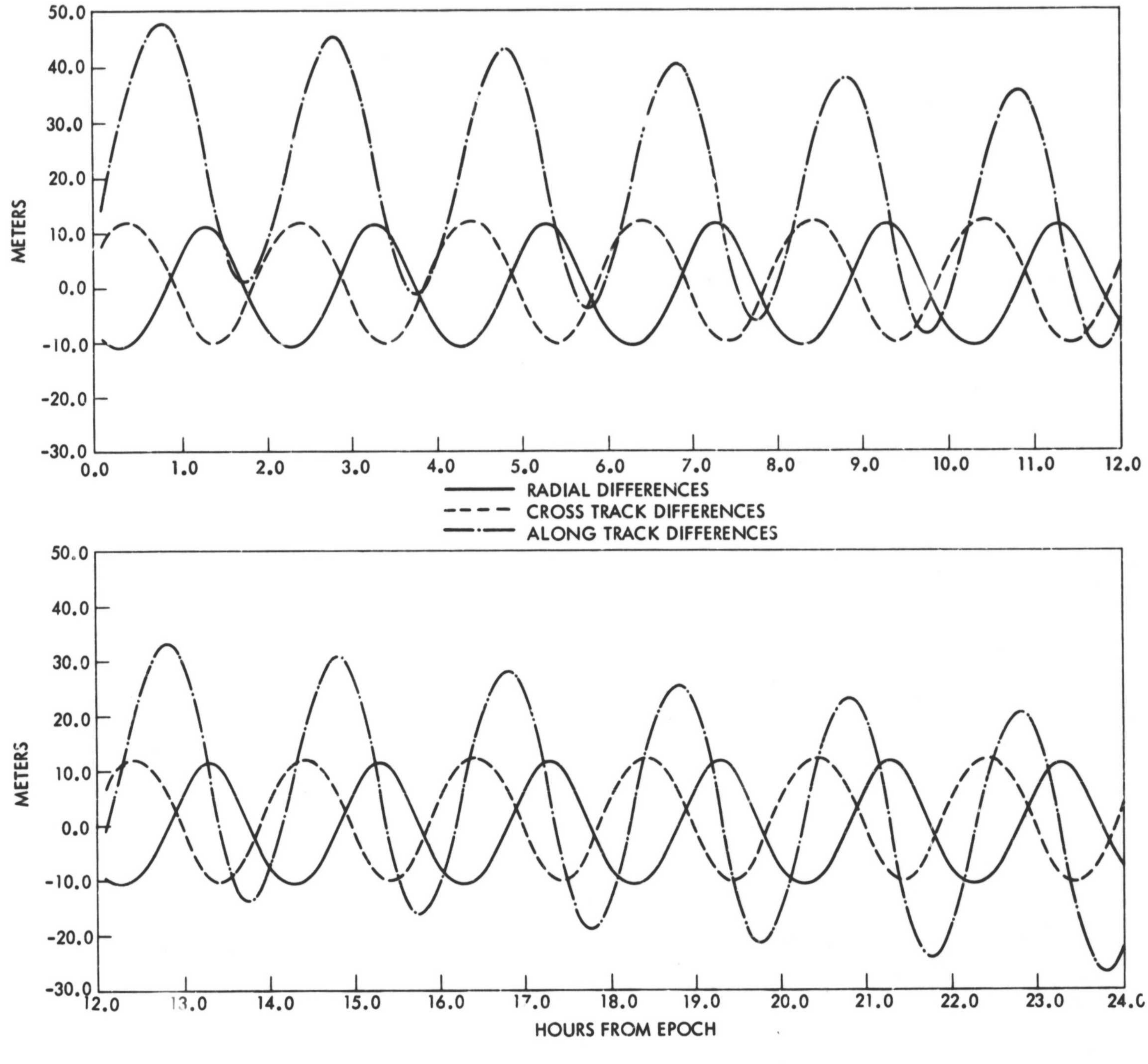

Figure C4—Position differences between TRANET Doppler orbit and optical orbit for the 1-day arc, July 18, 0 through 24 hrs, 1966.

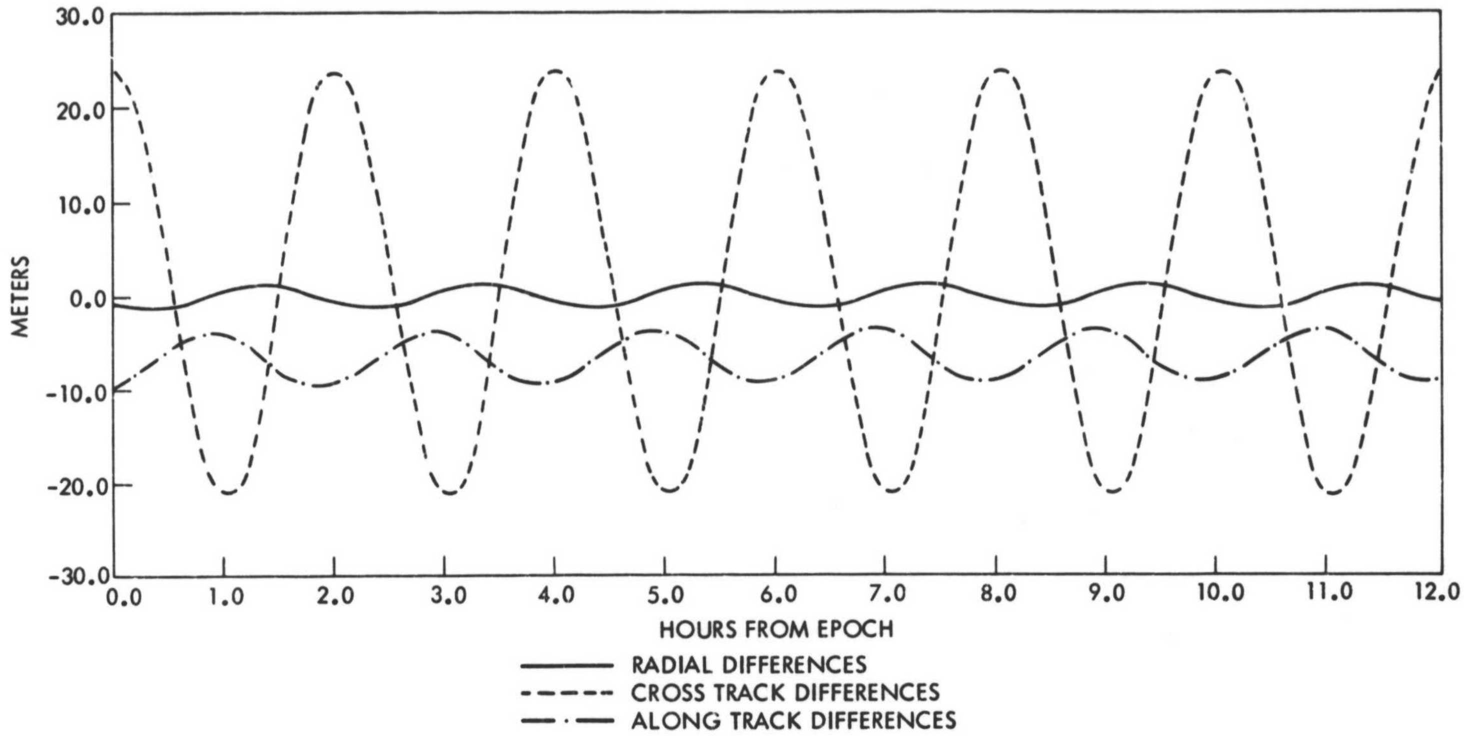

Figure C5—Position differences between TRANET Doppler orbit and optical orbit for the 1/2-day arc, July 17, 0 through 12 hrs, 1966.

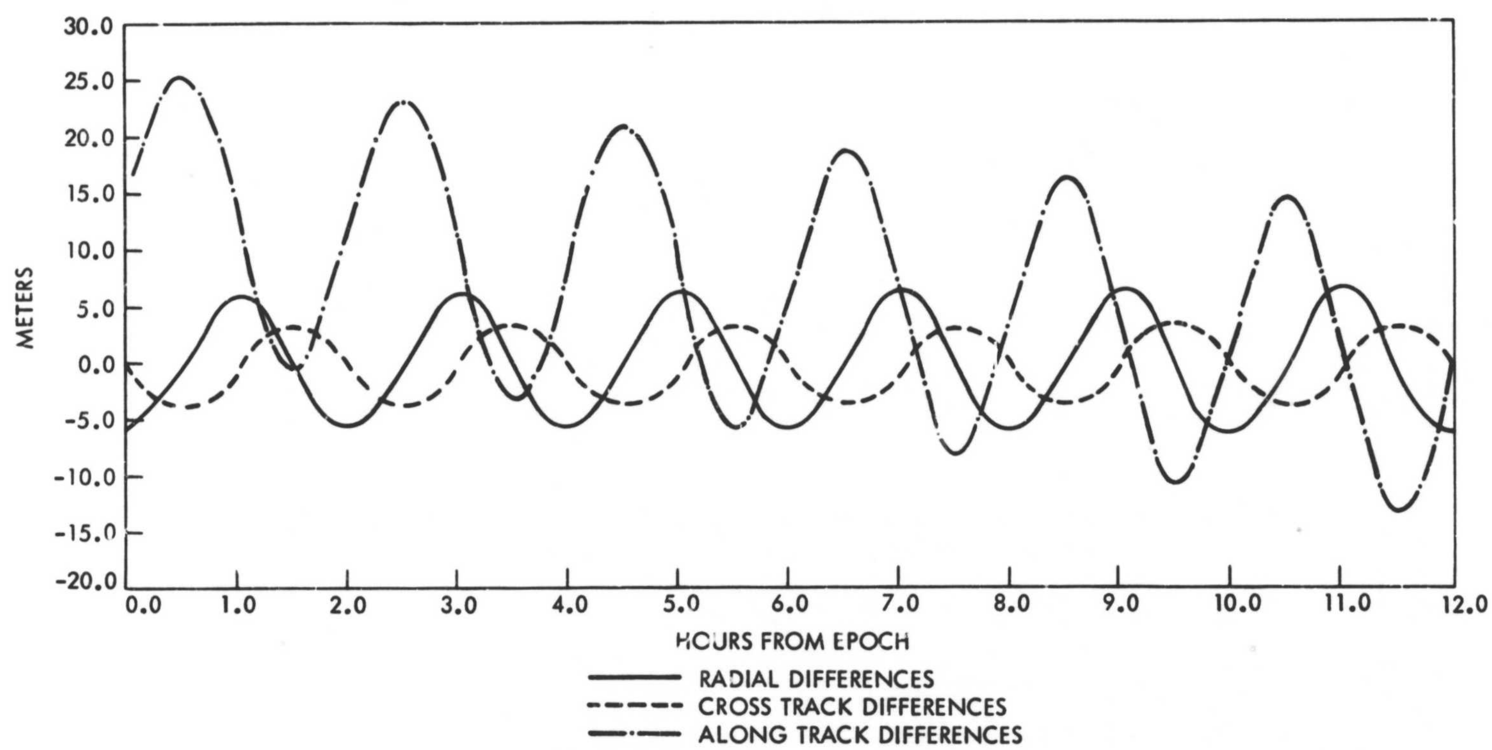

Figure C6—Position differences between TRANET Doppler orbit and optical orbit for the 1/2-day arc, July 18, 0 through 12 hrs, 1966.

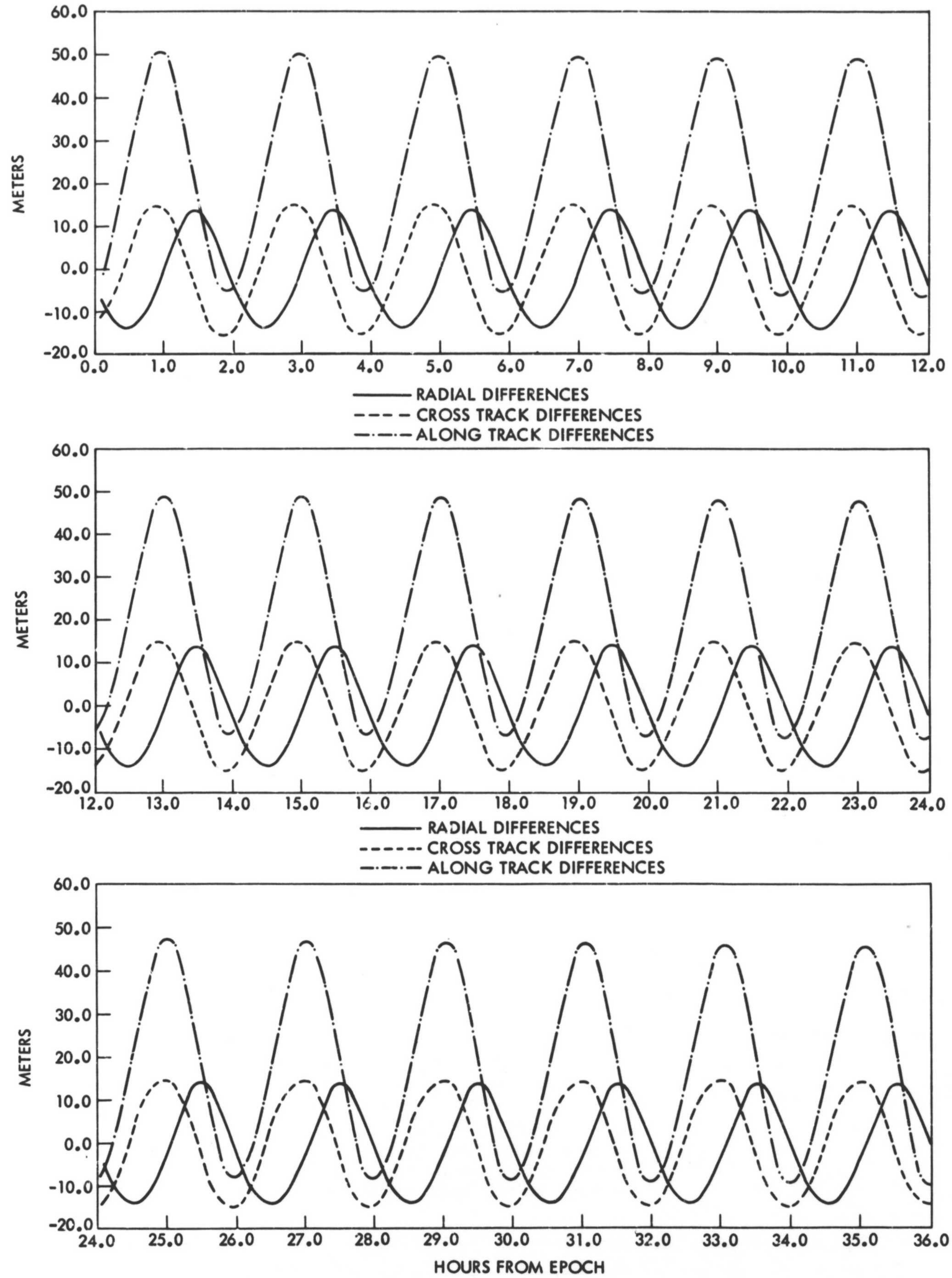

Figure C7—Position differences between TRANET Doppler orbit and optical orbit for the 1-1/2-day arc, July 19, 0 hrs—July 20, 12 hrs, 1966.

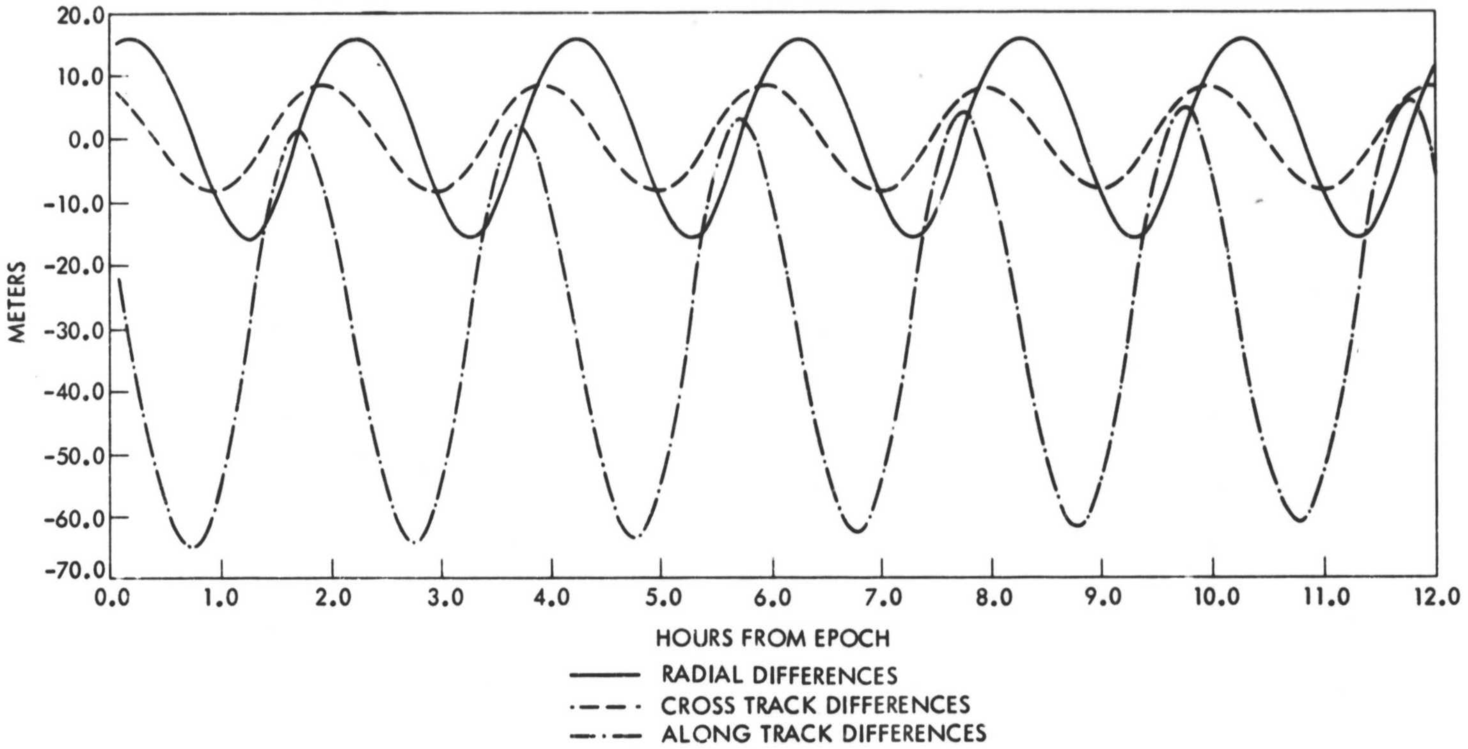

Figure C8—Position differences between TRANET Doppler orbit and optical orbit for the 1/2-day arc, July 19, 0 through 12 hrs, 1966.

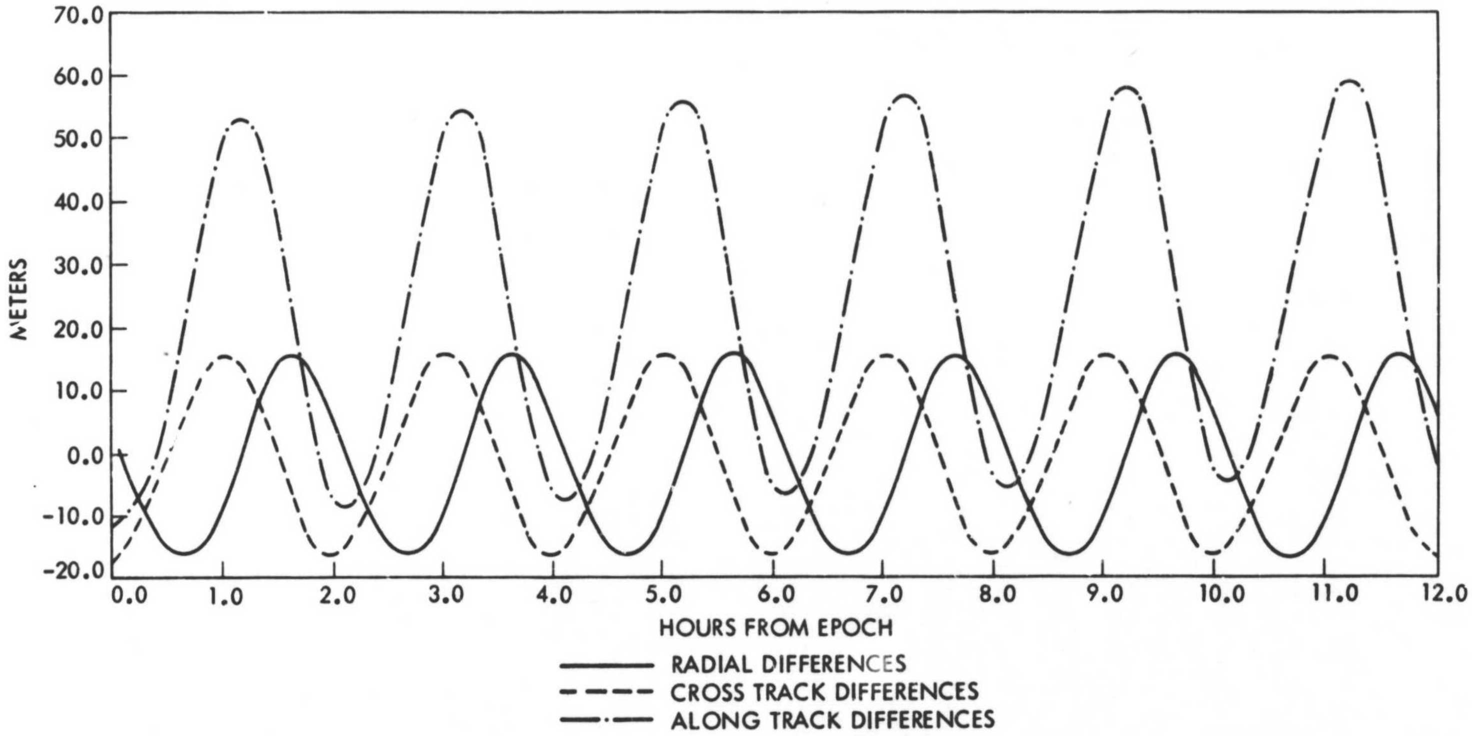

Figure C9—Position differences between TRANET Doppler orbit and optical orbit for the 1/2-day arc, July 20, 0 through 12 hrs, 1966.

Appendix D

Timing Biases and Range-Rate (Base Frequency) Biases in the Doppler Data

Table D1 presents timing biases,* calculated for each pass of TRANET Doppler data in the period July 17-20, 1966. The timing biases were determined by fitting the residuals from each pass to the formula:

$$\Delta\dot{R} = \Delta B + \Delta t \ddot{R} ,$$

where

$\Delta\dot{R}$ = residual (o-c)

ΔB = zero set bias

Δt = timing error

$\Delta\ddot{R}$ = rate of change of the observation.

Table D2 presents a summary of the (base frequency) range rate biases determined for each pass of TRANET Doppler data over the entire period of the study, July 9-26, July 31—August 7, 1966. In each 2-day Doppler orbital solution, the range rate biases for every pass were dynamically determined along with the state vector.

*These timing biases could possibly be attributed to hardware or to an orbital error or a combination of both.

Table D1

Timing Biases Found in the TRANET Doppler Data, July 17-20, 1966.

Station	Day (1966)	Pass Start	Pass End	Timing Error (msecs.)	Mean Timing Error ± 1 Standard Deviation (msecs.)
APLMND	July 17	3:28	3:47	-0.6	
		5:36	5:54	-1.5	
		7:40	8:03	1.8	
		9:49	10:14	-7.3	
		11:55	12:23	-4.1	
		14:02	14:26	4.1	0.6 ± 4.2
	July 18	3:30	3:52	1.2	
		5:38	5:59	1.4	
		7:45	8:08	4.4	
		14:06	14:28	6.6	
LASHM2	July 17	3:42	4:09	-2.2	
		5:48	6:16	-1.8	
		7:54	8:20	-1.8	
		21:33	21:51	4.4	
		23:34	23:58	5.5	
	July 18	1:40	2:05	1.9	0.0 ± 3.2
		3:49	4:14	-0.5	
		5:53	6:20	0.6	
		7:58	8:24	-5.0	
		21:38	21:56	-1.2	
ANCHOR	July 17	7:34	7:52	-1.7	
		9:35	9:58	3.8	
		11:40	12:04	-1.7	
		13:43	14:10	4.8	
		15:49	16:15	-1.0	
		17:53	18:17	-5.4	-0.8 ± 3.2
	July 18	9:39	10:03	-3.3	
		11:45	12:09	-0.4	
		13:48	14:15	0.6	
		15:53	16:19	-3.6	
LACRES	July 17	9:43	10:01	7.4	
		11:51	12:15	-3.1	
		13:57	14:25	5.6	
	July 18	5:29	5:50	1.6	
		7:37	7:57	1.9	-0.4 ± 5.5
		9:48	10:07	-0.1	
		11:56	12:21	-7.3	
		14:01	14:29	-0.6	
		16:08	16:32	-9.3	
WAHIWA	July 17	15:59	16:20	9.3	
		18:03	18:31	2.1	
	July 18	7:24	7:43	-3.9	2.7 ± 5.5
		16:03	16:26	7.0	
		18:07	18:35	-1.1	

Table D1 (Continued)

Station	Day (1966)	Pass		Timing Error (msecs.)	Mean Timing Error ± 1 Standard Deviation (msecs.)
		Start	End		
APLMND	July 19	3:34	3:57	2.2	
		5:41	6:03	0.5	
		7:50	8:14	1.6	
		9:58	10:25	-6.7	
		12:04	12:32	4.9	
		14:11	14:32	10.6	0.4 ± 5.8
	July 20	5:46	6:08	1.1	
		7:55	8:18	1.7	
		10:04	10:30	-9.3	
		12:08	12:35	4.0	
		14:16	14:35	-6.5	
LASHM2	July 19	3:55	4:18	0.1	
		5:58	6:25	-3.6	
		8:03	8:27	-4.8	
		21:40	22:00	2.0	
	July 20	1:49	2:15	-1.1	-2.1 ± 3.0
		3:55	4:23	-2.1	
		6:02	6:29	-4.4	
		8:07	8:31	-6.5	
		21:45	22:05	1.9	
LACRES	July 19	5:33	5:55	1.6	
		12:00	12:26	1.2	
		14:08	14:34	3.5	
	July 20	5:38	5:59	1.9	2.9 ± 1.5
		7:47	8:06	4.6	
		12:05	12:31	4.9	
		14:10	14:39	2.7	
WAHIWA	July 19	7:29	7:47	-3.1	
		16:07	16:31	11.3	
		18:12	18:40	2.4	3.5 ± 6.3
	July 20	16:11	16:36	8.5	
		18:12	18:44	-1.8	
ANCHOR	July 19	7:41	8:01	-2.6	
		9:43	10:07	-3.9	
		11:47	12:12	3.4	
		13:52	14:19	-0.5	
		15:57	16:24	-2.7	
		18:02	18:24	-4.4	
	July 20	7:45	8:05	-0.1	-1.7 ± 2.7
		9:48	10:11	-2.6	
		11:52	12:18	1.8	
		13:56	14:22	0.5	
		16:01	16:27	-5.1	
		18:07	18:28	-4.0	

Table D2

Summary of Range Rate Biases Found in the TRANET Doppler Data.

2-Day Arc (1966)	Station	Number of Passes	Mean Range Rate Bias ± 1 Standard Deviation (cm/sec)
July 9-10	ANCHOR	8	8.0 ± 2.3
	WAHIWA	5	7.7 ± 2.2
	LACRES	8	6.0 ± 2.9
	APLMND	11	8.7 ± 3.1
	LASHM2	12	7.7 ± 3.2
July 11-12	ANCHOR	11	8.2 ± 3.4
	WAHIWA	2	11.1 ± 1.8
	LACRES	10	8.9 ± 2.1
	APLMND	10	10.6 ± 3.1
	LASHM2	11	9.3 ± 2.3
July 13-14	ANCHOR	12	7.8 ± 3.2
	WAHIWA	4	9.7 ± 0.4
	LACRES	8	7.5 ± 2.8
	APLMND	8	10.1 ± 5.3
	LASHM2	12	8.5 ± 2.9
July 15-16	ANCHOR	11	8.3 ± 3.5
	WAHIWA	4	9.2 ± 2.7
	LACRES	6	7.7 ± 2.8
	APLMND	11	10.4 ± 3.0
	LASHM2	12	8.0 ± 2.9
July 17-18	ANCHOR	10	9.3 ± 2.2
	WAHIWA	5	9.9 ± 1.5
	LACRES	9	8.6 ± 2.7
	APLMND	10	10.2 ± 2.9
	LASHM2	10	9.2 ± 2.6
July 19-20	ANCHOR	12	8.5 ± 2.3
	WAHIWA	5	10.3 ± 2.0
	LACRES	7	11.1 ± 1.2
	APLMND	11	10.4 ± 4.0
	LASHM2	9	8.3 ± 1.5
July 21-22	ANCHOR	9	7.7 ± 3.0
	WAHIWA	4	9.3 ± 1.0
	LACRES	10	8.5 ± 3.6
	APLMND	12	9.9 ± 3.0
	LASHM2	8	6.7 ± 0.5
July 23-24	ANCHOR	11	7.9 ± 3.4
	WAHIWA	7	8.3 ± 3.1
	LACRES	8	7.3 ± 3.3
	APLMND	11	9.0 ± 3.3
	LASHM2	7	7.0 ± 2.1
July 25-26	ANCHOR	9	8.7 ± 3.3
	WAHIWA	7	9.3 ± 2.6
	LACRES	5	10.5 ± 1.7
	APLMND	12	11.5 ± 3.2
	LASHM2	11	8.8 ± 2.5
July 31 — August 1	ANCHOR	11	9.1 ± 2.4
	WAHIWA	7	9.7 ± 2.7
	LACRES	4	8.9 ± 3.1
	APLMND	11	10.8 ± 3.5
	LASHM2	11	9.7 ± 3.5
August 2-3	ANCHOR	12	8.7 ± 3.3
	WAHIWA	6	9.2 ± 3.7
	LACRES	4	9.0 ± 2.4
	APLMND	12	11.3 ± 3.5
	LASHM2	10	8.4 ± 2.7
August 4-5	ANCHOR	12	7.9 ± 5.1
	WAHIWA	0	
	LACRES	10	7.5 ± 4.5
	APLMND	9	9.2 ± 3.1
	LASHM2	12	6.9 ± 2.5
August 6-7	ANCHOR	10	8.0 ± 2.9
	WAHIWA	4	8.5 ± 2.6
	LACRES	5	6.6 ± 4.5
	APLMND	12	10.5 ± 3.4
	LASHM2	13	7.7 ± 2.5

Appendix E

Range-Rate (Base Frequency) Biases in the Doppler Data as Determined in Varying Arc Length Solutions

The two tables of this appendix present the results of the study to determine the independence of the range rate bias adjustment on the TRANET Doppler data with respect to orbital arc length. Table E1 presents the 44 Doppler passes in the 2-day period of July 17-18, 1966 which were used in this report and the range rate biases that were dynamically determined for each pass in differing arc length solutions (2, 1-1/2, 1, and 1/2 day arcs). Table E3 presents the same information for the 44 Doppler passes used in the 2-day period of July 19-20, 1966.

Table E1

TRANET Doppler Range Rate Bias Adjustment as Determined in Various Arc Length Solutions Over July 17-18, 1966.

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
ANCHOR	July 17		17	0	2	11.8	
	7:34	8:03	17	0	1-1/2	12.1	12.3 ± 0.5
			17	0	1	12.3	
			17	0	1/2	12.9	
	July 17		17	0	2	10.8	
	9:35	10:03	17	0	1-1/2	11.2	11.4 ± 0.7
			17	0	1	11.0	
			17	0	1/2	12.4	
	July 17		17	0	2	8.3	
	11:40	12:08	17	0	1-1/2	8.3	8.2 ± 0.1
			17	0	1	8.1	
	July 17		17	0	2	12.6	
	13:43	14:12	17	0	1-1/2	12.6	
			17	12	1-1/2	11.5	12.3 ± 0.5
			17	0	1	12.1	
			17	12	1/2	12.5	

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Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
ANCHOR	July 17		17	0	2	7.5	
(continued)	15:49	16:18	17	0	1-1/2	7.7	
			17	12	1-1/2	6.5	7.1 ± 0.5
			17	0	1	6.8	
			17	12	1/2	6.9	
	July 17		17	0	2	5.5	
	17:53	18:22	17	0	1-1/2	5.5	
			17	12	1-1/2	4.5	4.8 ± 0.6
			17	0	1	4.3	
			17	12	1/2	4.3	
	July 18		17	0	2	8.5	
	9:38	10:07	17	0	1-1/2	8.0	
			17	12	1-1/2	8.7	8.8 ± 0.7
			18	0	1	8.7	
			18	0	1/2	10.0	
	July 18		17	0	2	9.1	
	11:44	2:13	17	12	1-1/2	9.2	9.2 ± 0.1
			18	0	1	9.4	
	July 18		17	0	2	10.7	
	13:47	14:16	17	12	1-1/2	11.1	11.1 ± 0.3
			18	0	1	11.3	
			18	12	1/2	11.2	
	July 18		17	0	2	7.7	
	15:52	16:21	17	12	1-1/2	8.2	8.2 ± 0.3
			18	0	1	8.5	
			18	12	1/2	8.3	
WAHIWA	July 17		17	0	2	11.4	
	15:58	16:27	17	0	1-1/2	11.3	
			17	12	1-1/2	10.3	10.8 ± 0.6
			17	0	1	10.9	
			17	12	1/2	10.0	
	July 17		17	0	2	9.9	
	18:02	18:31	17	0	1-1/2	10.0	
			17	12	1-1/2	8.9	9.2 ± 0.8
			17	0	1	8.8	
			17	12	1/2	8.2	

Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
WAHIWA (continued)	July 18		17	0	2	8.1	
	7:24	7:53	17	0	1-1/2	7.9	
			17	12	1-1/2	8.0	8.4 ± 0.7
			18	0	1	8.3	
			18	0	1/2	9.6	
	July 18		17	0	2	11.3	
	16:02	16:31	17	12	1-1/2	11.5	11.3 ± 0.3
			18	0	1	11.7	
			18	12	1/2	10.9	
	July 18		17	0	2	8.9	
	18:07	18:36	17	12	1-1/2	9.2	9.1 ± 0.3
			18	0	1	9.5	
			18	12	1/2	8.9	
LACRES	July 17		17	0	2	7.3	
	9:42	10:11	17	0	1-1/2	7.0	7.3 ± 0.3
			17	0	1	7.3	
			17	0	1/2	7.7	
	July 17		17	0	2	5.9	
	11:51	12:20	17	0	1-1/2	5.8	5.9 ± 0.1
			17	0	1	5.9	
	July 17		17	0	2	11.9	
	13:57	14:25	17	0	1-1/2	11.9	
			17	12	1-1/2	10.5	11.4 ± 0.6
			17	0	1	11.5	
			17	12	1/2	11.2	
	July 18		17	0	2	12.1	
	5:28	5:57	17	0	1-1/2	11.6	
			17	12	1-1/2	12.0	12.0 ± 0.3
			18	0	1	12.2	
			18	0	1/2	12.3	
	July 18		17	0	2	11.1	
	7:36	8:05	17	0	1-1/2	10.4	
			17	12	1-1/2	11.4	11.1 ± 0.4
			18	0	1	11.4	
			18	0	1/2	11.2	
	July 18		17	0	2	8.0	
	9:47	10:16	17	0	1-1/2	7.2	
			17	12	1-1/2	8.2	7.9 ± 0.4
			18	0	1	8.2	
			18	0	1/2	8.1	

Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
LACRES (continued)	July 18		17	0	2	5.9	
	11:55	12:24	17	12	1-1/2	6.0	6.0 ± 0.1
			18	0	1	6.1	
	July 18		17	0	2	9.7	
	14:01	14:30	17	12	1-1/2	9.9	9.8 ± 0.3
			18	0	1	10.1	
			18	12	1/2	9.6	
	July 18		17	0	2	5.2	
	16:08	16:37	17	12	1-1/2	5.5	5.5 ± 0.2
			18	0	1	5.8	
			18	12	1/2	5.5	
APLMND	July 17		17	0	2	9.6	
	3:28	3:57	17	0	1-1/2	10.0	10.4 ± 0.7
			17	0	1	11.2	
			17	0	1/2	10.7	
	July 17		17	0	2	7.0	
	5:36	6:05	17	0	1-1/2	7.0	7.4 ± 0.5
			17	0	1	8.0	
			17	0	1/2	7.7	
	July 17		17	0	2	10.2	
	7:40	8:09	17	0	1-1/2	10.1	10.4 ± 0.3
			17	0	1	10.6	
			17	0	1/2	10.8	
	July 17		17	0	2	5.6	
	9:48	10:17	17	0	1-1/2	5.6	6.0 ± 0.5
			17	0	1	5.9	
			17	0	1/2	6.7	
	July 17		17	0	2	7.6	
	11:54	12:23	17	0	1-1/2	7.7	7.6 ± 0.1
			17	0	1	7.5	
	July 17		17	0	2	11.8	
	14:01	14:30	17	0	1-1/2	12.1	
			17	12	1-1/2	10.5	11.4 ± 0.6
			17	0	1	11.3	
			17	12	1/2	11.5	

Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
APLMND	July 18		17	0	2	12.5	
(continued)	3:30	3:59	17	0	1-1/2	12.1	
			17	12	1-1/2	12.2	12.2 ± 0.2
			18	0	1	12.2	
			18	0	1/2	12.0	
	July 18		17	0	2	9.6	
	5:38	6:07	17	0	1-1/2	8.9	
			17	12	1-1/2	9.6	9.3 ± 0.3
			18	0	1	9.5	
			18	0	1/2	9.0	
	July 18		17	0	2	13.8	
	7:45	8:14	17	0	1-1/2	13.2	
			17	12	1-1/2	13.9	13.7 ± 0.3
			18	0	1	13.9	
			18	0	1/2	13.7	
	July 18		17	0	2	13.9	
	14:06	14:34	17	12	1-1/2	14.1	14.1 ± 0.2
			18	0	1	14.3	
			18	12	1/2	14.1	
LASHM2	July 17		17	0	2	8.0	
	3:41	4:10	17	0	1-1/2	8.1	8.6 ± 0.7
			17	0	1	9.3	
			17	0	1/2	8.9	
	July 17		17	0	2	8.0	
	5:47	6:16	17	0	1-1/2	8.2	8.5 ± 0.6
			17	0	1	8.9	
			17	0	1/2	9.2	
	July 17		17	0	2	8.8	
	7:54	8:23	17	0	1-1/2	9.1	9.4 ± 0.7
			17	0	1	9.4	
			17	0	1/2	10.4	
	July 17		17	0	2	13.9	
	21:32	22:01	17	0	1-1/2	13.8	
			17	12	1-1/2	12.9	12.5 ± 1.5
			17	0	1	10.9	
			17	12	1/2	10.9	
	July 17		17	0	2	13.0	
	23:34	24:03	17	0	1-1/2	13.0	12.9 ± 0.2
			17	12	1-1/2	12.6	

Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
LASHM2 (continued)	July 18		17	0	2	9.2	
	1:39	2:08	17	0	1-1/2	8.7	
			17	12	1-1/2	8.7	8.5 ± 0.7
			18	0	1	8.3	
			18	0	1/2	7.4	
	July 18		17	0	2	8.3	
	3:48	4:17	17	0	1-1/2	7.8	
			17	12	1-1/2	8.0	7.8 ± 0.4
			18	0	1	7.7	
			18	0	1/2	7.3	
	July 18		17	0	2	10.4	
	5:52	6:21	17	0	1-1/2	10.0	
			17	12	1-1/2	10.1	10.2 ± 0.2
			18	0	1	10.0	
			18	0	1/2	10.5	
	July 18		17	0	2	7.8	
	7:58	8:27	17	0	1-1/2	7.6	
			17	12	1-1/2	7.7	7.9 ± 0.5
			18	0	1	7.6	
			18	0	1/2	8.8	
	July 18		17	0	2	5.1	
	21:37	22:06	17	12	1-1/2	6.4	6.6 ± 1.1
			18	0	1	7.5	
			18	12	1/2	7.3	

Table E2

TRANET Doppler Range Rate Bias Adjustment as Determined in Various Arc Length Solutions Over July 19-20, 1966.

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
ANCHOR	July 19 7:41	8:09	19	0	2	9.7	10.0 ± 0.5
			19	0	1-1/2	9.7	
			19	0	1	9.9	
			19	0	1/2	10.8	
	July 19 9:42	10:11	19	0	2	7.7	8.1 ± 0.9
			19	0	1-1/2	7.7	
			19	0	1	7.6	
			19	0	1/2	9.5	
	July 19 11:46	12:15	19	0	2	11.9	11.8 ± 0.1
			19	0	1-1/2	11.9	
			19	0	1	11.8	
	July 19 13:51	14:20	19	0	2	9.5	9.0 ± 0.5
			19	0	1-1/2	9.6	
			19	12	1-1/2	8.6	
			19	0	1	8.9	
			19	12	1/2	8.4	
	July 19 15:56	16:25	19	0	2	7.1	6.7 ± 0.5
			19	0	1-1/2	7.3	
			19	12	1-1/2	6.3	
			19	0	1	6.6	
			19	12	1/2	6.2	
	July 19 18:02	18:31	19	0	2	5.0	4.7 ± 0.4
			19	0	1-1/2	5.3	
			19	12	1-1/2	4.2	
			19	0	1	4.6	
			19	12	1/2	4.4	
	July 20 7:45	8:14	19	0	2	11.1	11.4 ± 0.7
			19	0	1-1/2	12.0	
			19	12	1-1/2	10.6	
			20	0	1	11.0	
			20	0	1/2	12.4	
	July 20 9:47	10:16	19	0	2	6.4	6.9 ± 0.9
			19	0	1-1/2	7.4	
			19	12	1-1/2	6.2	
			20	0	1	6.1	
			20	0	1/2	8.3	

Table E2 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
ANCHOR (continued)	July 20		19	0	2	9.9	
	11:52	12:21	19	12	1-1/2	10.1	10.1 ± 0.1
			20	0	1	10.1	
	July 20		19	0	2	11.0	
	13:56	14:25	19	12	1-1/2	11.3	10.9 ± 0.5
			20	0	1	11.1	
			20	12	1/2	10.1	
	July 20		19	0	2	6.3	
	16:01	16:30	19	12	1-1/2	6.6	6.3 ± 0.3
			20	0	1	6.3	
			20	12	1/2	5.9	
	July 20		19	0	2	5.9	
	18:06	18:35	19	12	1-1/2	6.2	6.0 ± 0.2
			20	0	1	5.8	
			20	12	1/2	6.0	
WAHIWA	July 19		19	0	2	8.3	
	7:29	7:57	19	0	1-1/2	8.2	8.9 ± 1.1
			19	0	1	8.8	
			19	0	1/2	10.5	
	July 19		19	0	2	12.4	
	16:06	16:35	19	0	1-1/2	12.7	
			19	12	1-1/2	11.9	11.8 ± 0.8
			19	0	1	11.3	
			19	12	1/2	10.7	
	July 19		19	0	2	9.9	
	18:11	18:40	19	0	1-1/2	10.2	
			19	12	1-1/2	9.1	9.4 ± 0.6
			19	0	1	9.3	
			19	12	1/2	8.6	
	July 20		19	0	2	12.5	
	16:11	16:39	19	12	1-1/2	13.0	12.5 ± 0.7
			20	0	1	12.8	
			20	12	1/2	11.5	
	July 20		19	0	2	8.4	
	18:16	18:45	19	12	1-1/2	8.6	8.4 ± 0.2
			20	0	1	8.3	
			20	12	1/2	8.1	

Table E2 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
LACRES	July 19		19	0	2	12.7	
	5:33	6:02	19	0	1-1/2	12.6	12.9 ± 0.2
			19	0	1	13.1	
			19	0	1/2	13.0	
	July 19		19	0	2	9.6	
	12:00	12:29	19	0	1-1/2	9.7	
			19	12	1-1/2	9.0	8.9 ± 0.8
			19	0	1	8.5	
			19	12	1/2	7.8	
	July 19		19	0	2	10.0	
	14:07	14:36	19	0	1-1/2	10.2	
			19	12	1-1/2	9.0	9.4 ± 0.7
			19	0	1	9.2	
			19	12	1/2	8.4	
	July 20		19	0	2	12.0	
	5:37	6:06	19	0	1-1/2	12.8	
			19	12	1-1/2	11.4	12.0 ± 0.5
			20	0	1	11.9	
			20	0	1/2	12.0	
	July 20		19	0	2	10.1	
	7:46	8:15	19	0	1-1/2	10.7	
			19	12	1-1/2	10.4	10.7 ± 0.5
			20	0	1	10.7	
			20	0	1/2	11.5	
	July 20		19	0	2	11.9	
	12:04	12:33	19	12	1-1/2	12.5	11.9 ± 0.9
			20	0	1	12.7	
			20	12	1/2	10.6	
	July 20		19	0	2	11.2	
	14:10	14.39	19	12	1-1/2	11.5	11.1 ± 0.5
			20	0	1	11.4	
			20	12	1/2	10.3	
APLMND	July 19		19	0	2	14.3	
	3:34	4:03	19	0	1-1/2	13.9	14.0 ± 0.5
			19	0	1	14.5	
			19	0	1/2	13.4	
	July 19		19	0	2	11.0	
	5:41	6:09	19	0	1-1/2	10.7	10.7 ± 0.3
			19	0	1	10.6	
			19	0	1/2	10.3	

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Table E2 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
APLMND	July 20		19	0	2	6.5	
(continued)	14:16	14:44	19	12	1-1/2	6.5	6.4 ± 0.2
			20	0	1	6.6	
			20	12	1/2	6.2	
LASHM2	July 19		19	0	2	6.2	
	3:55	4:24	19	0	1-1/2	6.0	5.7 ± 0.5
			19	0	1	5.4	
			19	0	1/2	5.1	
	July 19		19	0	2	7.2	
	5:57	6:26	19	0	1-1/2	7.1	7.1 ± 0.4
			19	0	1	6.6	
			19	0	1/2	7.6	
	July 19		19	0	2	8.4	
	8:02	8:31	19	0	1-1/2	8.4	8.8 ± 0.9
			19	0	1	8.1	
			19	0	1/2	10.1	
	July 19		19	0	2	10.6	
	21:40	22:08	19	0	1-1/2	11.1	
			19	12	1-1/2	9.3	10.4 ± 0.7
			19	0	1	10.5	
			19	12	1/2	10.5	
	July 20		19	0	2	8.1	
	1:48	2:17	19	0	1-1/2	8.6	
			19	12	1-1/2	7.9	8.5 ± 0.5
			20	0	1	9.1	
			20	0	1/2	8.6	
	July 20		19	0	2	8.6	
	3:55	4.24	19	0	1-1/2	9.2	
			19	12	1-1/2	8.6	9.2 ± 0.6
			20	0	1	9.6	
			20	0	1/2	9.8	
	July 20		19	0	2	7.7	
	6:02	6:30	19	0	1-1/2	8.4	
			19	12	1-1/2	7.6	8.4 ± 0.9
			20	0	1	8.4	
			20	0	1/2	9.8	

Table E2 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
LASHM2 (continued)	July 20 8:07	8:36	19	0	2	7.6	
			19	0	1-1/2	8.3	
			19	12	1-1/2	7.4	8.4 ± 1.2
			20	0	1	8.1	
			20	0	1/2	10.5	
	July 20 21:44	22:13	19	0	2	10.7	
			19	12	1-1/2	11.1	
			20	0	1	9.2	10.5 ± 0.9
			20	12	1/2	11.1	

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Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
ANCHOR (continued)	July 17		17	0	2	7.5	
	15:49	16:18	17	0	1-1/2	7.7	
			17	12	1-1/2	6.5	7.1 ± 0.5
			17	0	1	6.8	
			17	12	1/2	6.9	
	July 17		17	0	2	5.5	
	17:53	18:22	17	0	1-1/2	5.5	
			17	12	1-1/2	4.5	4.8 ± 0.6
			17	0	1	4.3	
			17	12	1/2	4.3	
	July 18		17	0	2	8.5	
	9:38	10:07	17	0	1-1/2	8.0	
			17	12	1-1/2	8.7	8.8 ± 0.7
			18	0	1	8.7	
			18	0	1/2	10.0	
	July 18		17	0	2	9.1	
	11:44	12:13	17	12	1-1/2	9.2	9.2 ± 0.1
			18	0	1	9.4	
	July 18		17	0	2	10.7	
	13:47	14:16	17	12	1-1/2	11.1	11.1 ± 0.3
			18	0	1	11.3	
			18	12	1/2	11.2	
	July 18		17	0	2	7.7	
	15:52	16:21	17	12	1-1/2	8.2	8.2 ± 0.3
			18	0	1	8.5	
			18	12	1/2	8.3	
WAHIWA	July 17		17	0	2	11.4	
	15:58	16:27	17	0	1-1/2	11.3	
			17	12	1-1/2	10.3	10.8 ± 0.6
			17	0	1	10.9	
			17	12	1/2	10.0	
	July 17		17	0	2	9.9	
	18:02	18:31	17	0	1-1/2	10.0	
			17	12	1-1/2	8.9	9.2 ± 0.8
			17	0	1	8.8	
			17	12	1/2	8.2	

Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
WAHIWA	July 18		17	0	2	8.1	
(continued)	7:24	7:53	17	0	1-1/2	7.9	
			17	12	1-1/2	8.0	8.4 ± 0.7
			18	0	1	8.3	
			18	0	1/2	9.6	
	July 18		17	0	2	11.3	
	16:02	16:31	17	12	1-1/2	11.5	
			18	0	1	11.7	11.3 ± 0.3
			18	12	1/2	10.9	
	July 18		17	0	2	8.9	
	18:07	18:36	17	12	1-1/2	9.2	
			18	0	1	9.5	9.1 ± 0.3
			18	12	1/2	8.9	
LACRES	July 17		17	0	2	7.3	
	9:42	10:11	17	0	1-1/2	7.0	
			17	0	1	7.3	7.3 ± 0.3
			17	0	1/2	7.7	
	July 17		17	0	2	5.9	
	11:51	12:20	17	0	1-1/2	5.8	5.9 ± 0.1
			17	0	1	5.9	
	July 17		17	0	2	11.9	
	13:57	14:25	17	0	1-1/2	11.9	
			17	12	1-1/2	10.5	11.4 ± 0.6
			17	0	1	11.5	
			17	12	1/2	11.2	
	July 18		17	0	2	12.1	
	5:28	5:57	17	0	1-1/2	11.6	
			17	12	1-1/2	12.0	12.0 ± 0.3
			18	0	1	12.2	
			18	0	1/2	12.3	
	July 18		17	0	2	11.1	
	7:36	8:05	17	0	1-1/2	10.4	
			17	12	1-1/2	11.4	11.1 ± 0.4
			18	0	1	11.4	
			18	0	1/2	11.2	
	July 18		17	0	2	8.0	
	9:47	10:16	17	0	1-1/2	7.2	
			17	12	1-1/2	8.2	7.9 ± 0.4
			18	0	1	8.2	
			18	0	1/2	8.1	

Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
LACRES (continued)	July 18		17	0	2	5.9	
	11:55	12:24	17	12	1-1/2	6.0	6.0 ± 0.1
			18	0	1	6.1	
	July 18		17	0	2	9.7	
	14:01	14:30	17	12	1-1/2	9.9	9.8 ± 0.3
			18	0	1	10.1	
			18	12	1/2	9.6	
	July 18		17	0	2	5.2	
	16:08	16:37	17	12	1-1/2	5.5	5.5 ± 0.2
			18	0	1	5.8	
			18	12	1/2	5.5	
APLMND	July 17		17	0	2	9.6	
	3:28	3:57	17	0	1-1/2	10.0	10.4 ± 0.7
			17	0	1	11.2	
			17	0	1/2	10.7	
	July 17		17	0	2	7.0	
	5:36	6:05	17	0	1-1/2	7.0	7.4 ± 0.5
			17	0	1	8.0	
			17	0	1/2	7.7	
	July 17		17	0	2	10.2	
	7:40	8:09	17	0	1-1/2	10.1	10.4 ± 0.3
			17	0	1	10.6	
			17	0	1/2	10.8	
	July 17		17	0	2	5.6	
	9:48	10:17	17	0	1-1/2	5.6	6.0 ± 0.5
			17	0	1	5.9	
			17	0	1/2	6.7	
	July 17		17	0	2	7.6	
	11:54	12:23	17	0	1-1/2	7.7	7.6 ± 0.1
			17	0	1	7.5	
	July 17		17	0	2	11.8	
	14:01	14:30	17	0	1-1/2	12.1	
			17	12	1-1/2	10.5	11.4 ± 0.6
			17	0	1	11.3	
			17	12	1/2	11.5	

Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
APLMND	July 18		17	0	2	12.5	
(continued)	3:30	3:59	17	0	1-1/2	12.1	
			17	12	1-1/2	12.2	12.2 ± 0.2
			18	0	1	12.2	
			18	0	1/2	12.0	
	July 18		17	0	2	9.6	
	5:38	6:07	17	0	1-1/2	8.9	
			17	12	1-1/2	9.6	9.3 ± 0.3
			18	0	1	9.5	
			18	0	1/2	9.0	
	July 18		17	0	2	13.8	
	7:45	8:14	17	0	1-1/2	13.2	
			17	12	1-1/2	13.9	13.7 ± 0.3
			18	0	1	13.9	
			18	0	1/2	13.7	
	July 18		17	0	2	13.9	
	14:06	14:34	17	12	1-1/2	14.1	14.1 ± 0.2
			18	0	1	14.3	
			18	12	1/2	14.1	
LASHM2	July 17		17	0	2	8.0	
	3:41	4:10	17	0	1-1/2	8.1	8.6 ± 0.7
			17	0	1	9.3	
			17	0	1/2	8.9	
	July 17		17	0	2	8.0	
	5:47	6:16	17	0	1-1/2	8.2	8.5 ± 0.6
			17	0	1	8.9	
			17	0	1/2	9.2	
	July 17		17	0	2	8.8	
	7:54	8:23	17	0	1-1/2	9.1	9.4 ± 0.7
			17	0	1	9.4	
			17	0	1/2	10.4	
	July 17		17	0	2	13.9	
	21:32	22:01	17	0	1-1/2	13.8	
			17	12	1-1/2	12.9	12.5 ± 1.5
			17	0	1	10.9	
			17	12	1/2	10.9	
	July 17		17	0	2	13.0	
	23:34	24:03	17	0	1-1/2	13.0	12.9 ± 0.2
			17	12	1-1/2	12.6	

Table E1 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
LASHM2 (continued)	July 18 1:39	2:08	17	0	2	9.2	8.5 ± 0.7
			17	0	1-1/2	8.7	
			17	12	1-1/2	8.7	
			18	0	1	8.3	
			18	0	1/2	7.4	
	July 18 3:48	4:17	17	0	2	8.3	7.8 ± 0.4
			17	0	1-1/2	7.8	
			17	12	1-1/2	8.0	
			18	0	1	7.7	
			18	0	1/2	7.3	
	July 18 5:52	6:21	17	0	2	10.4	10.2 ± 0.2
			17	0	1-1/2	10.0	
			17	12	1-1/2	10.1	
			18	0	1	10.0	
			18	0	1/2	10.5	
	July 18 7:58	8:27	17	0	2	7.8	7.9 ± 0.5
			17	0	1-1/2	7.6	
			17	12	1-1/2	7.7	
			18	0	1	7.6	
			18	0	1/2	8.8	
	July 18 21:37	22:06	17	0	2	5.1	6.6 ± 1.1
			17	12	1-1/2	6.4	
			18	0	1	7.5	
			18	12	1/2	7.3	

Table E2

TRANET Doppler Range Rate Bias Adjustment as Determined in Various Arc Length Solutions Over July 19-20, 1966.

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
ANCHOR	July 19		19	0	2	9.7	
	7:41	8:09	19	0	1-1/2	9.7	10.0 ± 0.5
			19	0	1	9.9	
			19	0	1/2	10.8	
	July 19		19	0	2	7.7	
	9:42	10:11	19	0	1-1/2	7.7	8.1 ± 0.9
			19	0	1	7.6	
			19	0	1/2	9.5	
	July 19		19	0	2	11.9	
	11:46	12:15	19	0	1-1/2	11.9	11.8 ± 0.1
			19	0	1	11.8	
	July 19		19	0	2	9.5	
	13:51	14:20	19	0	1-1/2	9.6	
			19	12	1-1/2	8.6	9.0 ± 0.5
			19	0	1	8.9	
			19	12	1/2	8.4	
	July 19		19	0	2	7.1	
	15:56	16:25	19	0	1-1/2	7.3	
			19	12	1-1/2	6.3	6.7 ± 0.5
			19	0	1	6.6	
			19	12	1/2	6.2	
	July 19		19	0	2	5.0	
	18:02	18:31	19	0	1-1/2	5.3	
			19	12	1-1/2	4.2	4.7 ± 0.4
			19	0	1	4.6	
			19	12	1/2	4.4	
	July 20		19	0	2	11.1	
	7:45	8:14	19	0	1-1/2	12.0	
			19	12	1-1/2	10.6	11.4 ± 0.7
			20	0	1	11.0	
			20	0	1/2	12.4	
	July 20		19	0	2	6.4	
	9:47	10:16	19	0	1-1/2	7.4	
			19	12	1-1/2	6.2	6.9 ± 0.9
			20	0	1	6.1	
			20	0	1/2	8.3	

Table E2 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
ANCHOR (continued)	July 20		19	0	2	9.9	
	11:52	12:21	19	12	1-1/2	10.1	10.1 ± 0.1
			20	0	1	10.1	
	July 20		19	0	2	11.0	
	13:56	14:25	19	12	1-1/2	11.3	10.9 ± 0.5
			20	0	1	11.1	
			20	12	1/2	10.1	
	July 20		19	0	2	6.3	
	16:01	16:30	19	12	1-1/2	6.6	6.3 ± 0.3
			20	0	1	6.3	
			20	12	1/2	5.9	
	July 20		19	0	2	5.9	
	18:06	18:35	19	12	1-1/2	6.2	6.0 ± 0.2
			20	0	1	5.8	
			20	12	1/2	6.0	
WAHIWA	July 19		19	0	2	8.3	
	7:29	7:57	19	0	1-1/2	8.2	8.9 ± 1.1
			19	0	1	8.8	
			19	0	1/2	10.5	
	July 19		19	0	2	12.4	
	16:06	16:35	19	0	1-1/2	12.7	
			19	12	1-1/2	11.9	11.8 ± 0.8
			19	0	1	11.3	
			19	12	1/2	10.7	
	July 19		19	0	2	9.9	
	18:11	18:40	19	0	1-1/2	10.2	
			19	12	1-1/2	9.1	9.4 ± 0.6
			19	0	1	9.3	
			19	12	1/2	8.6	
	July 20		19	0	2	12.5	
	16:11	16:39	19	12	1-1/2	13.0	12.5 ± 0.7
			20	0	1	12.8	
			20	12	1/2	11.5	
	July 20		19	0	2	8.4	
	18:16	18:45	19	12	1-1/2	8.6	8.4 ± 0.2
			20	0	1	8.3	
			20	12	1/2	8.1	

Table E2 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
LACRES	July 19		19	0	2	12.7	
	5:33	6:02	19	0	1-1/2	12.6	12.9 ± 0.2
			19	0	1	13.1	
			19	0	1/2	13.0	
	July 19		19	0	2	9.6	
	12:00	12:29	19	0	1-1/2	9.7	
			19	12	1-1/2	9.0	8.9 ± 0.8
			19	0	1	8.5	
			19	12	1/2	7.8	
	July 19		19	0	2	10.0	
	14:07	14:36	19	0	1-1/2	10.2	
			19	12	1-1/2	9.0	9.4 ± 0.7
			19	0	1	9.2	
			19	12	1/2	8.4	
	July 20		19	0	2	12.0	
	5:37	6:06	19	0	1-1/2	12.8	
			19	12	1-1/2	11.4	12.0 ± 0.5
			20	0	1	11.9	
			20	0	1/2	12.0	
	July 20		19	0	2	10.1	
	7:46	8:15	19	0	1-1/2	10.7	
			19	12	1-1/2	10.4	10.7 ± 0.5
			20	0	1	10.7	
			20	0	1/2	11.5	
	July 20		19	0	2	11.9	
	12:04	12:33	19	12	1-1/2	12.5	11.9 ± 0.9
			20	0	1	12.7	
			20	12	1/2	10.6	
	July 20		19	0	2	11.2	
	14:10	14:39	19	12	1-1/2	11.5	11.1 ± 0.5
			20	0	1	11.4	
			20	12	1/2	10.3	
APLMND	July 19		19	0	2	14.3	
	3:34	4:03	19	0	1-1/2	13.9	14.0 ± 0.5
			19	0	1	14.5	
			19	0	1/2	13.4	
	July 19		19	0	2	11.0	
	5:41	6:09	19	0	1-1/2	10.7	10.7 ± 0.3
			19	0	1	10.6	
			19	0	1/2	10.3	

Table E2 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
APLMND	July 20		19	0	2	6.5	
(continued)	14:16	14:44	19	12	1-1/2	6.5	6.4 ± 0.2
			20	0	1	6.6	
			20	12	1/2	6.2	
LASHM2	July 19		19	0	2	6.2	
	3:55	4:24	19	0	1-1/2	6.0	5.7 ± 0.5
			19	0	1	5.4	
			19	0	1/2	5.1	
	July 19		19	0	2	7.2	
	5:57	[illegible]	19	0	1-1/2	7.1	7.1 ± 0.4
			19	0	1	6.6	
			19	0	1/2	7.6	
	July 19		19	0	2	8.4	
	8:02	8:31	19	0	1-1/2	8.4	8.[illegible] ± 0.9
			19	0	1	8.1	
			19	0	1/2	10.1	
	July 19		19	0	2	10.6	
	21:40	22:08	19	0	1-1/2	11.1	
			19	12	1-1/2	9.3	10.4 ± 0.7
			19	0	1	10.5	
			19	12	1/2	10.5	
	July 20		19	0	2	8.1	
	1:48	2:17	19	0	1-1/2	8.6	
			19	12	1-1/2	7.9	8.5 ± 0.5
			20	0	1	9.1	
			20	0	1/2	8.6	
	July 20		19	0	2	8.6	
	3:55	4.24	19	0	1-1/2	9.2	
			19	12	1-1/2	8.6	9.2 ± 0.6
			20	0	1	9.6	
			20	0	1/2	9.8	
	July 20		19	0	2	7.7	
	6:02	6:30	19	0	1-1/2	8.4	
			19	12	1-1/2	7.6	8.4 ± 0.9
			20	0	1	8.4	
			20	0	1/2	9.8	

Table E2 (Continued)

Pass for Which $\dot{R}$ Bias is Computed			Arcs Used			Adjusted $\dot{R}$ Bias (cm/sec)	Mean $\dot{R}$ Bias ± 1 Standard Deviation (cm/sec)
Station	Day		Epoch (July, 1966)		Length in Days		
	Start	End	Day	Hour			
LASHM2 (continued)	July 20 8:07	8:36	19	0	2	7.6	8.4 ± 1.2
			19	0	1-1/2	8.3	
			19	12	1-1/2	7.4	
			20	0	1	8.1	
			20	0	1/2	10.5	
	July 20 21:44	22:13	19	0	2	10.7	10.5 ± 0.9
			19	12	1-1/2	11.1	
			20	0	1	9.2	
			20	12	1/2	11.1	