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ORBITAL ANALYSES OF THE QUICK-LOOK ASTROSOVIET OPTICAL TRACKING DATA FROM THE ISAGEX PRELIMINARY EXPERIMENT

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GREENBELT, MARYLAND

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November 1970

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ABSTRACT

An International Satellite Geodesy Experiment (ISAGEX) will be conducted during the period of December 15, 1970 to June 30, 1971. This experiment will consist of a cooperative International effort involving more than twenty nations for the purpose of observing seven satellites (BE-B, BE-C, GEOS-I, GEOS-II, DI-C, DI-D, and PEOLE) with cameras and lasers. The data collected will be used for numerous scientific investigations in areas such as gravitation, geodetics, tracking systems, and orbital analyses. Four of these satellites are no longer active; therefore, tracking observations for the generation of pointing data for the cameras and lasers will come from the Baker-Nunn Optical and laser networks of the Smithsonian Astrophysical Observatory – United States and the Centre Nationale D'Etudes Spatiales – France, the Astrosoviet NAFA-25 Optical Network – Union of Soviet Socialist Republics, and the Goddard Space Flight Center (GSFC) lasers and Minitrack Networks – U.S.A. During the period of September 15 to October 30, 1970, a Preliminary ISAGEX Experiment was conducted as a test of the networks to provide timely accurate quick look data. This report presents some preliminary conclusions regarding this Pre-Experiment. Since Baker-Nunn data has been used for over a decade at Goddard for orbit determination, this study was primarily concerned with processing the NAFA-25 observations made available during this period which have heretofore never been available. Results are presented when these data are used in orbit computations and predictions along with other quick look data. Preliminary results indicate that the accuracy of these data are of the order of a few minutes of arc.

It is anticipated that orbital solutions using these data in combination with other quick-look data will be of significant value in supporting the tracking requirement of ISAGEX. We anticipate that the orbital solutions will be improved as more experience is gained in processing the new NASA-25 optical data.

ORBITAL ANALYSES OF THE QUICK-LOOK ASTROSOVIET OPTICAL TRACKING DATA FROM THE ISAGEX PRELIMINARY EXPERIMENT

1. INTRODUCTION

During the time period of January 5 to June 6, 1971, an International Satellite Geodesy Experiment (ISAGEX) will be conducted (Reference 1). Numerous scientific investigations are being planned by the many participating countries. These scientific investigations will be carried out using precision reduced optical data and refined laser range observations from seven earth satellites (BE-B, BE-C, DI-C, DI-D, GEOS-I, GEOS-II, and PEOLE). Progress in areas such as geopotential determination, polar motion, geometrical geodesy, tracking system analysis, orbital analysis, and others should be realized.

Preparatory to acquiring accurate tracking data, often times it is necessary to have an accurate orbit upon which to base predictions. This is the case for laser tracking, as the prediction orbit is based upon quick look tracking data.

With the exceptions of GEOS-II, BE-C, and PEOLE, the ISAGEX satellites do not have active electronics. Therefore tracking predictions for the Goddard lasers will be generated solely from quick look passive optical observations until quick look laser data are available. The networks contributing the quick look optical data are, Smithsonian Astrophysical Observatory (SAO), and Centre National D'Etudes Spatiales (CNES) with the Baker Nunn Cameras and the Astrosoviet Network with the NAFA-25 cameras.

In order for the Goddard lasers to be able to successfully track these satellites during the daytime, predictions must be accurate to the order of 100 milliseconds in time or better. Therefore the accuracy of predictions based upon quick look optical data is of great importance for the GSFC lasers. Since predictions based upon Goddard Minitrack data have been proven as a result of past experience to be of sufficient accuracy for daytime laser tracking and since we have been processing SAO Baker Nunn quick look optical observations for over a decade at Goddard, this report is mainly concerned with the use of quick look data from the Astrosoviet NAFA-25 optical tracking system.

During the period of September 15 to October 31, 1970 a Preliminary ISAGEX Experiment was conducted. The following sections present a discussion of the quick look data made available to Goddard during this experiment, preprocessing corrections which we applied to the data, and the results of orbital analyses which were performed with these data.

2. PRE-ISAGEX EXPERIMENT

2.1 Discussion of the Experiment

The Pre-ISAGEX Experiment started with a dynamic saturation period from September 15 through September 29, 1970 on GEOS-I, BE-C and GEOS-II. During the period between September 15 through October 31, 1970 quick look observations were to be provided by the SAO, CNES and Astrosoviet cameras on GEOS-I, BE-B, DI-C in preparation for the second saturation period. The second saturation period took place from October 6 through October 30. Figure 1 shows this tracking schedule.

The purposes of this experiment, presented in Reference 2, are listed below.

- To test communications
- To check the capabilities of the networks to provide quick look data
- To test the capability of new stations to acquire and provide accurate observations (Astrosoviet NASA-25 cameras, new lasers)
- To test the accuracy of the predictions generated with these data
- To provide data on higher satellites such as Pageos and MIDAS 4 in order to obtain the direction of lines between new stations and well-positioned stations.

Since Astrosoviet quick look observations had not heretofore been sent to Goddard and since we had no prior experience in processing these data the first four items were of great importance. The stations which provided quick look optical data during the Pre-ISAGEX Experiment are shown in Figure 2. Table 1 contains a list of the coordinates of these stations. The coordinates for the SAO and CNES stations were given in Reference 3 and are referenced to an ellipsoid with a_e = 6378.155 km and 1/f = 298.255. The coordinates for the Astrosoviet stations were contained in Reference 4. Since no information as to reference ellipsoid or datum transformations was available for these stations, the geodetic latitude, longitude and height were referenced to the ellipsoid described above.

It is felt that the Astrosoviet station coordinates currently available are probably one of the sources of error in these analyses. This is especially true for EREVAN and TARTU which are provided only to the nearest minute of arc. (1 minute of arc $\sim$ 1 nautical mile). From Figure 2, however, one can see that the Astrosoviet stations fill an important void as far as tracking coverage is concerned. This is especially true for the satellites with high orbital inclinations such as GEOS-II, and BE-B which have inclinations of 106° and 80° respectively.

2.2 Data Collected During the Experiment

Figure 3 is a frequency histogram showing the number of pairs of Astrosoviet data (right ascension and declination measurements) received for each day of the preliminary experiment. This plot contains data from all tracking stations on all the satellites. Even though DI-D was not scheduled as part of this experiment data were sent in for this satellite, providing us further basis upon which to test our capability to handle these data and also to evaluate the data for satellite prediction accuracy. These data covered the period of September 21 through October 12, 1970 with one pair of observations on October 25.

A total of 109 observation pairs were sent in from eight Astrosoviet Stations as shown in Table 2. The number of observation pairs per satellite is also presented in this table.

The best coverage by satellite with the Astrosoviet Network was on BE-B where 42 pairs of observations were received from six different stations. This is attributed to the high inclination of the BE-B orbit and the northern latitudes of the Soviet tracking sites. Some data were received from each of the eight stations and all six satellites were tracked by the Astrosoviet Network in the Pre-ISAGEX period. Five of these satellites were tracked by more than one station.

For orbit determination and prediction purposes, the number of station passes is more important than the number of observations. Many of the above observations were grouped in time and separated by only a few minutes. Table 3 presents a summary of these data tabulated in the form of station passes. Thus in terms of station passes the numbers in the previous table are reduced. Even though they do not contribute additional geometry to an orbital solution, they do provide an important means for removing bad observations.

Table 4 presents a summary of the quick look data from SAO and CNES (the station ISPAIN) during the preliminary experiment. Seven SAO stations and one station operated by CNES contributed observations. The data sent for GEOS-I consisted of 143 observation pairs. This amount of data permitted the computation of orbital solutions with good data coverage. The amounts of data sent in for the other satellites were much smaller. The GEOS-II and BE-C satellites were covered by Minitrack data during this time period. If the Minitrack data had not been available on these satellites, the orbits of these satellites could not have been maintained during this period. The Minitrack system provided several hundred observations on these satellites during this period, which permitted the computation of predictions for daytime tracking by the lasers with ease.

The ISAGEX operations plan (Reference 2) defined quick look data as being available for orbit computation forty-eight hours after the data were recorded at the tracking site. Most of the Baker-Nunn and NAFA-25 tracking data were received within this time constraint.

2.3 Data Preprocessing

The Astrosoviet quick look observations were sent via CNES to us in the SAO 222 quick look optical data format. They were processed by the Network Computation Section, Computation Division, and made available on the IBM 360/95 data base along with the SAO Baker Nunn data and the NASA Minitrack data. Before the Astrosoviet data could be used in orbital solutions certain preprocessing corrections were necessary. These included:

- The application of annual aberration and planetary aberration
- Timing corrections to convert the time tags from the Soviet timing system to UTC time (obtained from the B.I.H. circulars)
- Precession and nutation from the mean equator and equinox of 1950.0 to the true equator and equinox of date.

3. ORBITAL SOLUTIONS AND PREDICTION RESULTS

3.1 Orbital Solutions

In this section the results of combining the Astrosoviet quick look data with SAO data in orbital solutions are discussed. The orbital solutions were obtained with the NONAME Orbit and Geodetic Parameter Estimation System (Reference 5) on the IBM 360/95 computer. The NONAME system employs Cowell 10th order numerical integration techniques. In the orbital solutions the following perturbations were modeled:

- luni-solar perturbations
- earth's gravity – SAO 1969 Standard Earth
- solar radiation pressure
- air drag – parameter allowed to adjust on BE-B, DI-C and DI-D orbit solutions

In each case only the six orbit elements were solved for, except for BE-B, DI-C and DI-D where a drag parameter was permitted to adjust.

To evaluate the usefulness of the NAFA-25 optical observations, seven different sets of NAFA-25 data on a total of five different satellites were selected and used to establish the preliminary orbits that appear in Table 5. For each of the seven periods or arcs, two independent orbital solutions were obtained. The first was the standard orbit, determined with SAO quick look optical observations only, except for the GEOS-II satellite for which extensive amounts of NASA STADAN Minitrack observations were used to determine the standard orbital solution. The second solution was the test orbit, determined with SAO optical and available Soviet optical observations; for GEOS-II, the Soviet data was added to the Minitrack data to determine the test orbit. In all of the solutions, the optical data type was weighted at sixty seconds of arc; the Minitrack data carried a weight of 0.3 milliradians.

By comparing the RMS's of fit for the test orbit and the corresponding standard orbit over the common arc shown in Table 5, it is readily seen that the addition of the Astrosoviet optical data to the standard data arc resulted in an increase in the RMS of fit in six of the seven cases. However, the RMS of fit is not always a true indicator of the accuracy of an orbital solution. When data are poorly distributed in an orbital solution, the solution can possibly indicate a good fit to the data but the orbit can be inaccurate in the portions of the orbit where there are no data. The addition of data in these voids can result in an increase in the RMS of fit of the solution. Thus further tests are required to indicate the accuracy of the solutions.

In the field reduction of optical data, errors are inevitable since the data are not subject to the quality checks which are performed for precision reduced data. Table 6 provides an indication of the data rejection rates in the orbital solutions discussed previously. The rejection rate was calculated as 13% for the solutions containing only SAO data. For the solution's containing SAO and Astrosoviet data the rejection rates were 11% and 16% respectively. This difference is not considered significant in view of the size of the sample used. These low rejection rates are very favorable.

3.2 Satellite Position Comparisons

To establish some idea of how different the corresponding standard and test orbits were, ephemerides were generated over the definitive period and a 2-week prediction period immediately following the definitive period for all orbital solutions. The ephemerides for corresponding standard and test orbits were compared by calculating position differences every 10 minutes in time over the definitive span and then over the prediction span. The total root mean squares of the satellite position differences were tabulated in Table 7. It must be borne in mind that these comparisons are only relative comparisons as this test does not show agreement with a "true orbit." In almost all of the seven cases, the position differences in the definitive period were on the order of a few kilometers. In the prediction period, however, the along track position differences were much larger and the total position differences were on the order of 10-20 kilometers. By comparing the information appearing in Tables 5 and 7, it can be seen that the cases showing a considerable increase in the RMS of fit correspond to those showing large satellite position differences in the prediction period.

Figure 4 illustrates the separation in the prediction period of the DI-C standard and test orbits determined with SAO and Astrosoviet data taken during the period October 4-9, inclusive. The growth of along track position differences is very evident. The sinusoidal variation with the orbital frequency has been removed from this plot.

Figure 5 shows the orbital separation over the first 10 hours of the prediction period of the standard and test orbits for the GEOS-I satellite. Only the first 10 hours are shown since the comparison did not change significantly from this over the subsequent two weeks.

3.3 Residual Analyses

To this point it has been shown that the inclusion of NAFA-25 tracking data into several orbital solutions has resulted in an increase in the RMS of fit in each case (Table 5). In addition, it has been shown that definitive orbits including the NAFA-25 data differ from those not including these data by a few kilometers and prediction orbit comparisons of the same nature indicate differences on the order of 10 to 20 kilometers. However, these differences are only relative differences.

In Figures 6 and 7, all the SAO and Astrosoviet data residuals in both the definitive and prediction period are plotted for a BE-B orbital solution. Although the RMS of fit during the definitive period was much better when the Astrosoviet data was not included (76 arc seconds versus 338 arc seconds) both data types appear to be comparable during the definitive period when both are included in the solution.

The RMS's of fit for the "SAO only" orbits are usually about 1 or 2 minutes of arc (Table 5). This suggests the value of the noise level in these data. In the next fourteen plots (Figures 8 to 21) the residuals during both the definitive and prediction periods for various SAO stations in a number of the orbital solutions presented in Table 5 are depicted. In each case the residuals for both the SAO and the SAO plus Astrosoviet reference orbit solutions are given. It may be noted that in many cases the failure to model drag and radiation pressure properly results in a secular separation similar to that seen in some of the residual plots.

The final seven plots; Figures 22 to 28 depict the right ascension and declination residuals for Astrosoviet data when compared to reference Minitrack or SAO orbits. The shaded area in these plots contains the computed noise level of the reference orbit in each case.

4. CONCLUSIONS

The ISAGEX preliminary experiment is over and the material presented in this report represents our processing techniques, preprocessing corrections and initial findings in analyzing the

Astrosoviet NAFA-25 quick look optical tracking data. This represents the first time NAFA-25 optical data has been processed at Goddard. Thus we hope that by documenting our efforts, improvements will be suggested for our analysis procedures and also others will be able to profit from our experiences.

The main results and conclusions coming from this study are summarized below:

- During the ISAGEX preliminary experiment 109 NAFA-25 quick-look optical observation pairs were received from eight Astrosoviet Tracking Stations.

- These data were in the proper format for processing by GSFC computer programs.

- Most of this data was received within the forty-eight hour time frame prescribed for the quick look data.

- Considering this is the first time we have processed NAFA-25 data, it was encouraging to see that the observation residuals often fell within the general range required for orbit production to support optical and laser tracking. The data rejection rates were favorably low.

- The absence of information concerning the reference ellipsoid or datum transformation together with the fact that some stations are given to the nearest tens of minutes (Tartu) while others are given to the nearest hundreths of seconds (Kiev) has surely introduced some error into the NAFA-25 tracking data processing.

- Some evidence exists to suggest that there may still be some modification of the time tags for the Astrosoviet data that isn't being applied.

The usual experience when a new source of data is used for orbit determination is that as soon as the orbital analyst makes his initial results known to personnel associated with the tracking systems, suggestions will be made which generally result in an enhancement of the data. Such was the case concerning the NAFA-25 camera data. After this study was completed and these preliminary results reported to personnel associated with the Astrosoviet Network, a few modifications were sent to us. They are as follows:

- The coordinates for EREVAN and NOVOSIBIRSK were revised to the following values

	Geodetic Latitude	E. Longitude	Ellipsoid Height
EREVAN	40° 54'	44° 30'	960 m.
NOVOSIBIRSK	54° 59'	82° 51'	150 m.

- The equator and equinox of date is used for the NOVOSIBIRSK data; however, the rest of the data are referenced to 1950.0.

When the new coordinates and equator and equinox for Novosibirsk were used to process BE-B and GEOS-II arcs, an improvement was noted. The root mean square on the BE-B arc with only NAFA-25 data was 441 seconds of arc while the root mean square with both NAFA-25 and Baker-Nunn data was 423 arc seconds. For the GEOS-II arc the root mean squares were 386 and 374 arc seconds for these same two cases. The relative differences in rms for these two arcs are not significant. What is significant, however, is that the "Astrosoviet only" definitive orbit was better than the "Astrosoviet plus SAO" orbit in the prediction period. To illustrate this, a residual comparison similar to those appearing in Figures 9 to 21 is given in Figure 29. However, the residuals in the prediction period are not from a single station but rather from several stations in both the Astrosoviet and SAO networks. The main conclusion at this point is that the NAFA-25 camera data will become more valuable in orbit determination as we gain experience with the data and learn more about the Astrosoviet Network. We anticipate that the use of the NAFA-25 data will increase the total success of the ISAGEX.

TABLE 1
STATION COORDINATES FOR PRE-ISAGEX EXPERIMENT

STATION	STATION NUMBERS	EAST LONGITUDE	GEODETIC LATITUDE	HEIGHT
VOLOGD	1014	39°53′25.	59° 13′ 20.	150. m
EREVAN	1018	44 30	40 11	960.
KIEVAA	1023	30 30 7.05	50 27 11.43	184.
KRASNO	1027	38 58 42.	45 1 42.	40.
NOVOSI	1035	82 55 30.	55 2 24.	180.
RIAZAN	1042	39 45 10.	54 38 5.	114.
TARTU	1051	26 40	58 20	75.
TASHKI	1052	69 11 12.	41 21	440.8
HOPKIN	9021	249 7 18.38	31 41 2.86	2337.
AUSBAK	9023	136 52 43.28	−31−23−27.05	135.
DODAIR	9025	139 11 31.17	36 0 19.92	879.
BRAZIL	9029	324 50 7.38	−5−55−40.17	25.
GREECE	9091	23 55 57.81	38 4 44.63	466.
INATAL	9006	79 27 27.20	29 21 34.57	1862.
DEZEIT	9028	38 57 33.19	8 44 51.53	1877.
ISPAIN	9004	353 47 36.77	36 27 46.66	47.

TABLE 2
ASTROSOVIET DATA* RECEIVED BETWEEN
SEPT. 15 AND OCT. 31

STATION	GEOS-I	GEOS-2	BE-B	BE-C	DI-C	DI-D	Total
VOLOGDO		4	2				6
EREVAN	3				6	5	14
KIEV			19				19
KRASNODAR	2		4				6
NOVOSIBIRSK		14	9				23
RIAZAN			4				4
TARTU	4	4	4				12
TASHKENT				1	19	5	25
Total	9	22	42	1	25	10	109

* OBSERVATION PAIRS

TABLE 3
ASTROSOVIET STATION PASSES RECEIVED BETWEEN
SEPT. 15 AND OCT. 31

STATION	GEOS-I	GEOS-2	BE-B	BE-C	DI-C	DI-D	Total
VOLOGDO		2	1				3
EREVAN	2				4	4	10
KIEV			9				9
KRASNODAR	1		9				3
NOVOSIBIRSK		6	6				12
RIAZAN			2				2
TARTU	2	2	2				6
TASHKENT				1	10	3	14
Total	5	10	22	1	14	7	59

TABLE 4
SUMMARY OF SAO AND CNES OPTICAL DATA COVERING THE
PRE-ISAGEX EXPERIMENT
9/15/70 to 10/31/70 (Number of right asc., decl. pairs)

STATION NAME	SATELLITE					
	GEOS-I	GEOS-II(1)	BE-B	DI-C	DI-D	BE-C(1)
GREECE	12-(A)(2)	4-(A)	5-(A)	3-(A)	2-(A)	
	19-(B)	2-(B)	7-(B)	6-(B)	3-(B)	1-(B)
	0-(C)		0-(C)	0-(C)	0-(C)	
INATAL			4-(A)	3-(A)	0-(A)	1-(A)
			6-(B)	6-(B)	5-(B)	4-(B)
			4-(C)	9-(C)	22-(C)	2-(C)
DEZEIT	9-(A)		2-(A)	0-(A)	0-(A)	3-(B)
	1-(B)		0-(B)	0-(B)	1-(B)	
	1-(C)		3-(C)	0-(C)	0-(C)	2-(B)
AUSBAK	8-(A)		1-(A)	3-(A)	4-(A)	
	3-(B)		2-(B)	2-(B)	1-(B)	
	0-(C)		1-(C)	0-(C)	(C)	
BRAZIL	10-(A)		2-(A)	0-(A)	0-(A)	
	0-(B)		0-(B)	2-(B)	2-(B)	
	9-(C)	2-(C)	8-(C)	0-(C)	1-(C)	
HOPKIN	14-(A)		1-(A)	2-(A)	4-(A)	
	16-(B)		3-(B)	3-(B)	3-(B)	
	11-(C)		1-(C)	10-(C)	5-(C)	
DODAIR	0-(A)		0-(A)	2-(A)	1-(A)	
	1-(B)		0-(B)	0-(B)	0-(B)	
	1-(C)		0-(C)	1-(C)	0-(C)	
ISPAIN	3-(A)	1-(A)	3-(A)	1-(A)	0-(A)	
	23-(B)	3-(B)	5-(B)	6-(B)	0-(B)	
	2-(C)	2-(C)	2-(C)	3-(C)	2-(C)	
Total	143	14	60	62	56	12

(1) Minitrack data currently available
(2) (A) Period of Sept. 15 to Sept. 30, 1970
(B) Period of Oct. 1 to Oct. 15, 1970
(C) Period of Oct. 15 to Oct. 31, 1970

TABLE 5
PRELIMINARY ORBITS WITH SAO, ASTROSOVIET AND MINITRACK DATA—1970

Satellite	Data	Arc	Number of* Observations	RMS of Fit (Seconds of Arc)
GEOS-I	SAO	October 3-11	66	52
GEOS-I	SAO, Astrosoviet	October 3-11	66, 12	83
BE-B	SAO	Sept. 27-Oct. 4	40	76
BE-B	SAO, Astrosoviet	Sept. 27-Oct. 4	43, 9	338
BE-B	SAO	Oct. 5-12	14	114
BE-B	SAO, Astrosoviet	Oct. 5-12	22, 18	280
GEOS-II	Minitrack	Sept. 21-28	168	.27 mil
GEOS-II	Minitrack, Astrosoviet	Sept. 21-28	168, 10	.27 mil, 130
DI-C	SAO	Sept. 28-Oct. 3	25	106
DI-C	SAO, Astrosoviet	Sept. 28-Oct. 3	26, 20	525
DI-C	SAO	Oct. 4-9	22	42
DI-C	SAO, Astrosoviet	Oct. 4-9	22, 15	494
DI-D	SAO	Oct. 1-6	14	52
DI-D	SAO, Astrosoviet	Oct. 1-6	14, 12	483

*Right ascension and declination measurements.

TABLE 6
DATA REJECTION RATES IN DEFINITIVE ORBITAL SOLUTIONS

Satellite	Orbit Period	SAO Data Used	SAO Data Rejected	Soviet Data Used	Soviet Data Rejected
GEOS-I	Oct. 3-11	66	8	0	0
	Oct. 3-11	66	8	12	2
BE-B	Sept. 27-Oct. 4	40	6	0	0
	Sept. 27-Oct. 4	43	3	9	3
	Oct. 5-12	14	2	0	0
	Oct. 5-12	22	2	18	4
DI-C	Sept. 28-Oct. 3	25	3	0	0
	Sept. 28-Oct. 3	26	2	20	2
	Oct. 4-9	22	2	0	0
	Oct. 4-9	22	2	15	5
DI-D	Oct. 1-6	14	6	0	0
	Oct. 1-6	14	6	12	0
TOTALS	–	181	27	0	0
	–	193	23	86	16
%	–	13%		–	
	–	11%		16%	

TABLE 7
TOTAL POSITION DIFFERENCES BETWEEN DEFINITIVE AND TWO-WEEK PREDICTION ORBITS—SAO DATA VS. SAO AND SOVIET DATA

Satellite	Definitive Period	RMS Position Difference (km)	Predictive Period	RMS Position Difference (km)
GEOS-I	Oct. 3-11	1.2	Oct. 12-25	1.7
DI-C	Sept. 28-Oct. 3	3.4	Oct. 4-17	10.4
DI-C	Oct. 4-9	1.6	Oct. 10-23	38.5
DI-D	Oct. 1-6	1.0	Oct. 7-20	10.8
GEOS-II	Sept. 21-28	.1	Sept. 29-Oct. 12	.2
BE-B	Sept. 27-Oct. 4	6.7	Oct. 5-18	11.0
BE-B	Oct. 5-12	2.3	Oct. 13-26	19.7

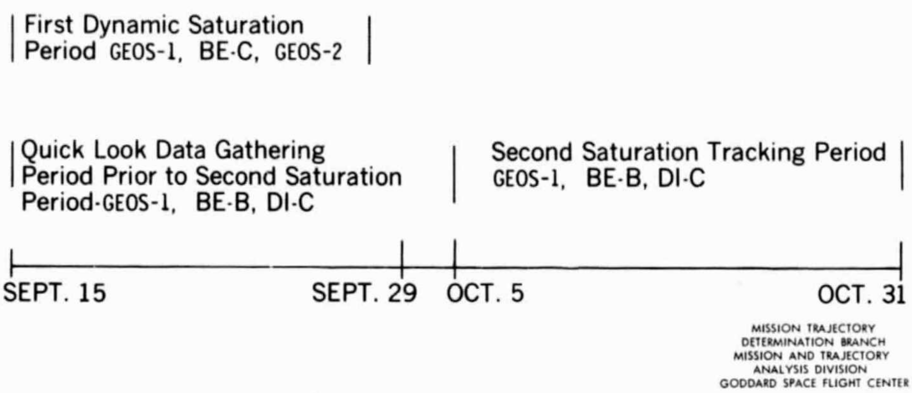

Figure 1. Tracking Schedule for Pre-ISAGEX Experiment – September 15–October 31, 1970

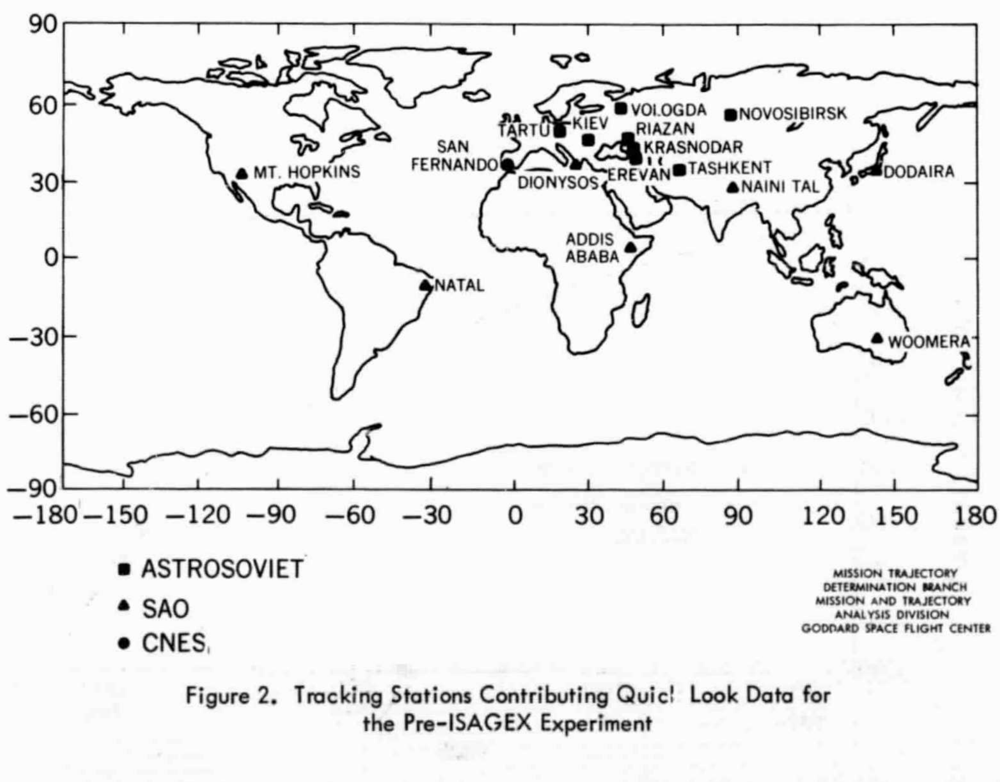

Figure 2. Tracking Stations Contributing Quick Look Data for the Pre-ISAGEX Experiment

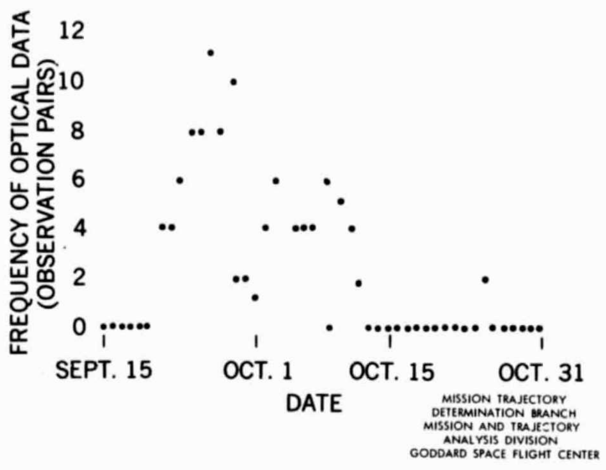

Figure 3. Frequency of Astrosoviet Data vs. Time

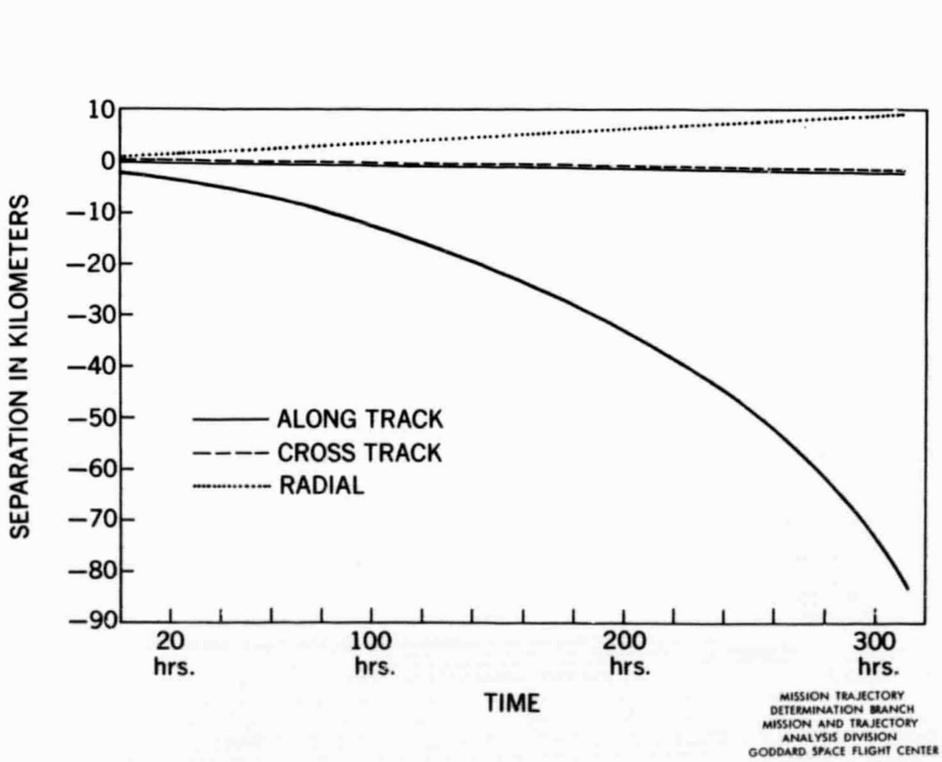

Figure 4. DI-C Satellite Position Comparison over the Prediction Period
Oct. 10-23, 1970 Based upon Definitive Orbits Oct. 4-9 – SAO vs. SAO + Astrosoviet

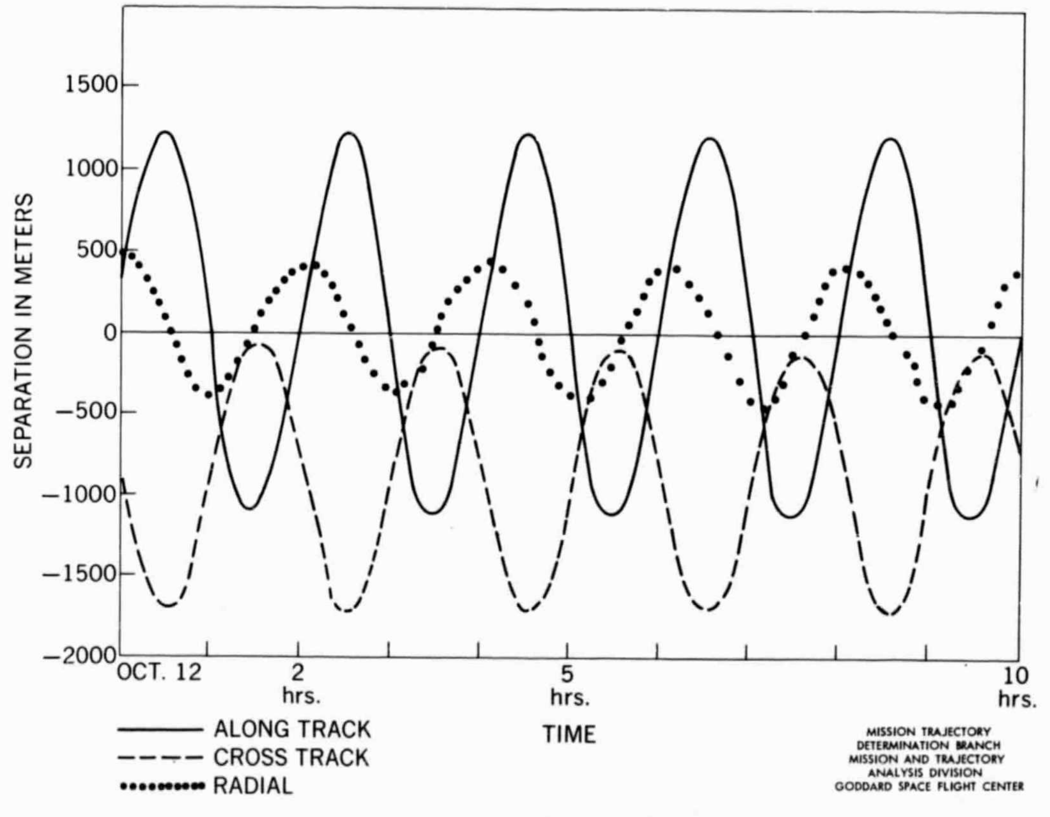

Figure 5. GEOS-I Satellite Position Comparison Over the Prediction Period Oct. 12-25, 1970 Based Upon Definitive Crbits Oct. 3-11 SAO vs. SAO + Astrosoviet

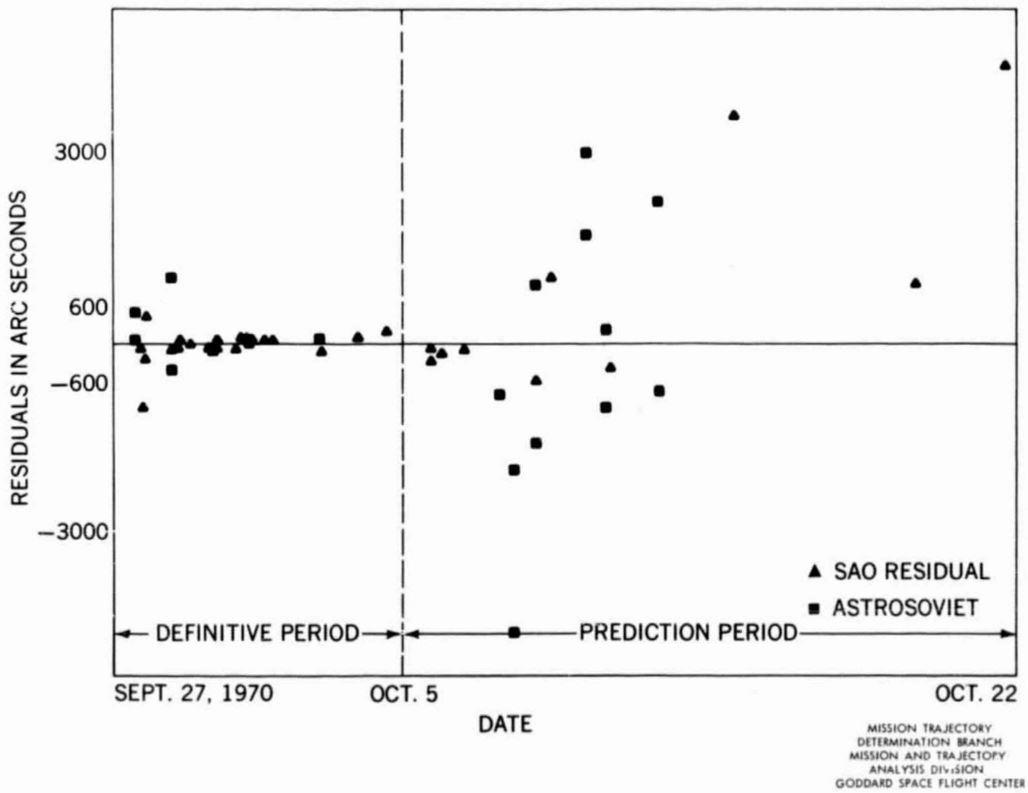

Figure 6. Declination Residuals BE-B Definitive and Prediction Orbits SAO + Astrosoviet Data Used to Determine Definitive Orbit

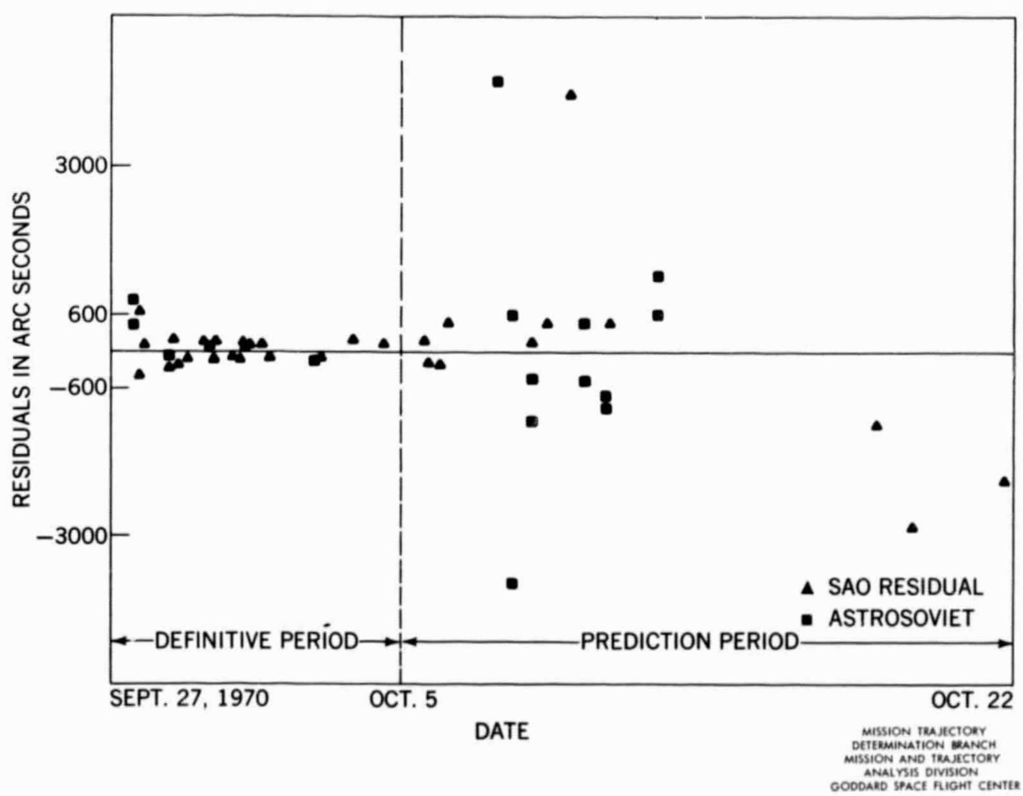

Figure 7. Right Ascension Residuals – BE-B Definitive and Prediction Orbits SAO + Astrosoviet Data Used to Determine Definitive Orbit

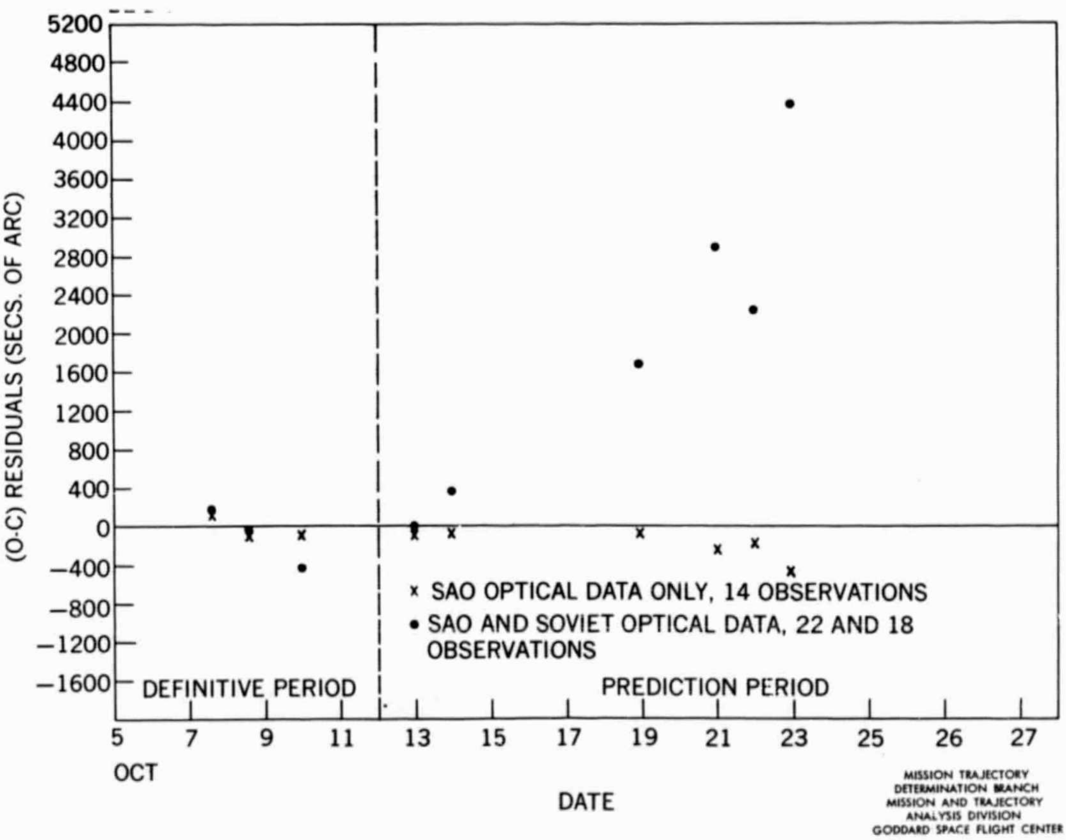

Figure 8. NAINI TAL (India) Declination Residuals Based on BE-B Definitive Orbits Over October 5-12

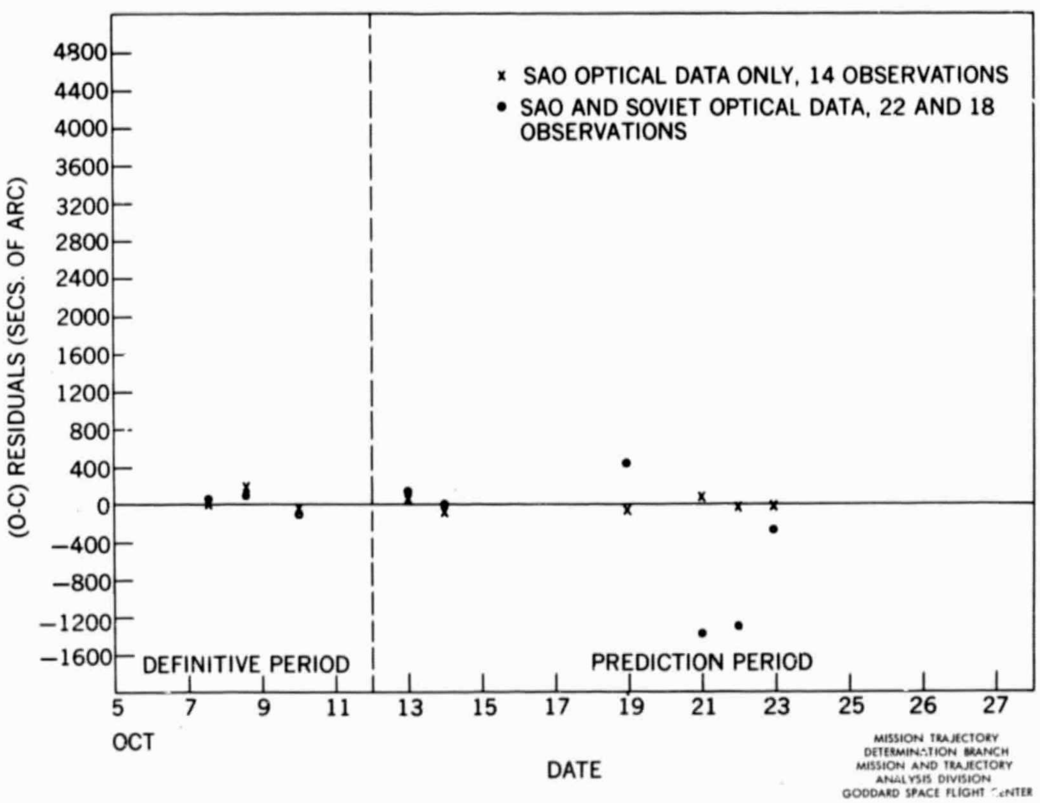

Figure 9. NAINI TAL (India) Right Ascension Residuals Based on BE-B Definitive Orbits Over October 5-12

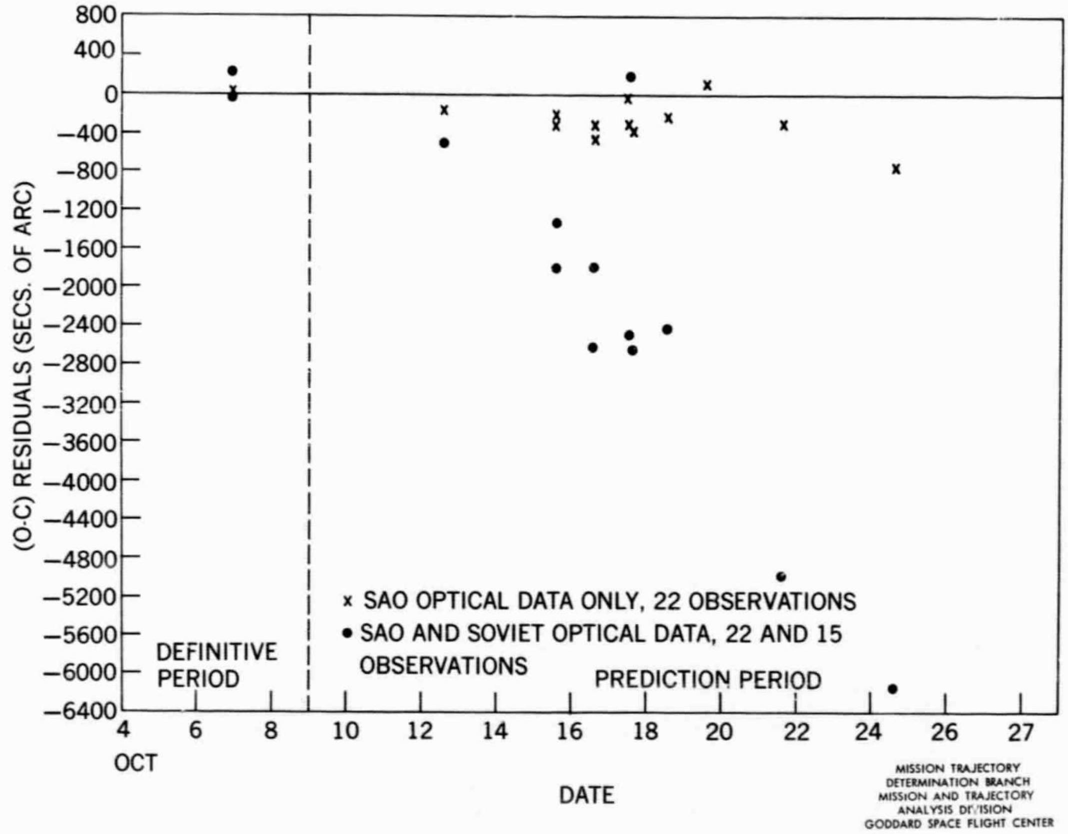

Figure 10. NAINI TAL (India) Declination Residuals Based on DI-C Definitive Orbits Over October 4-9

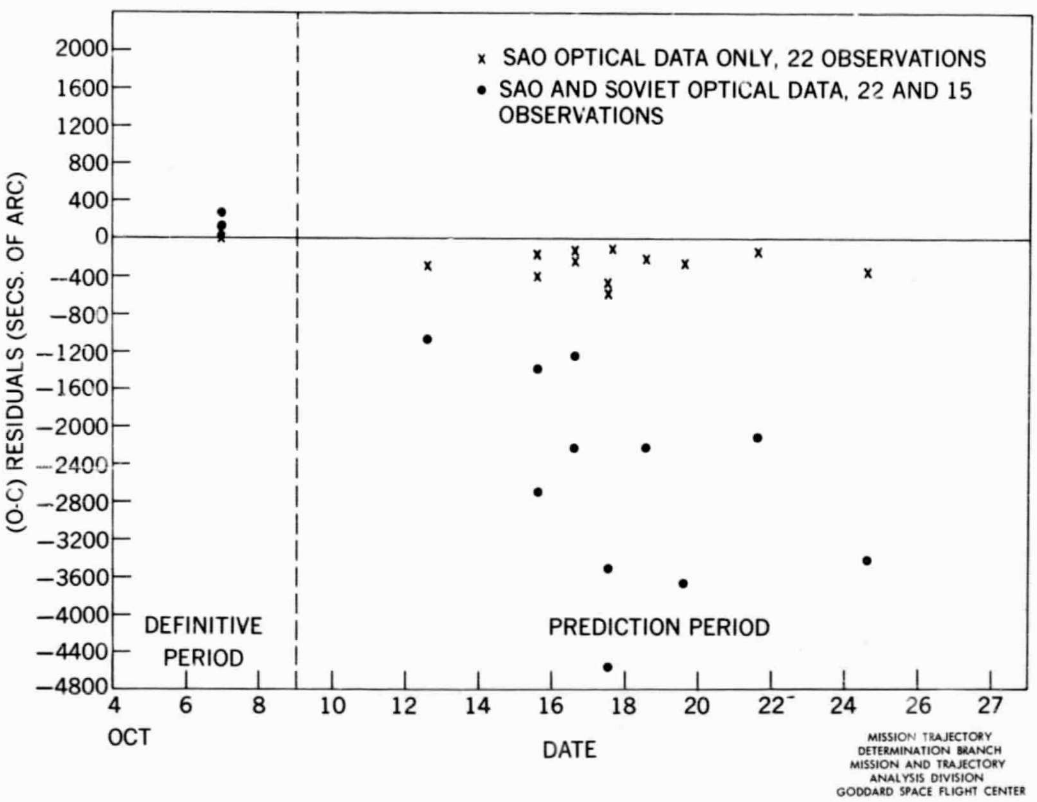

Figure 11. NAINI TAL (India) Right Ascension Residuals Based on DI-C Definitive Orbits Over October 4-9

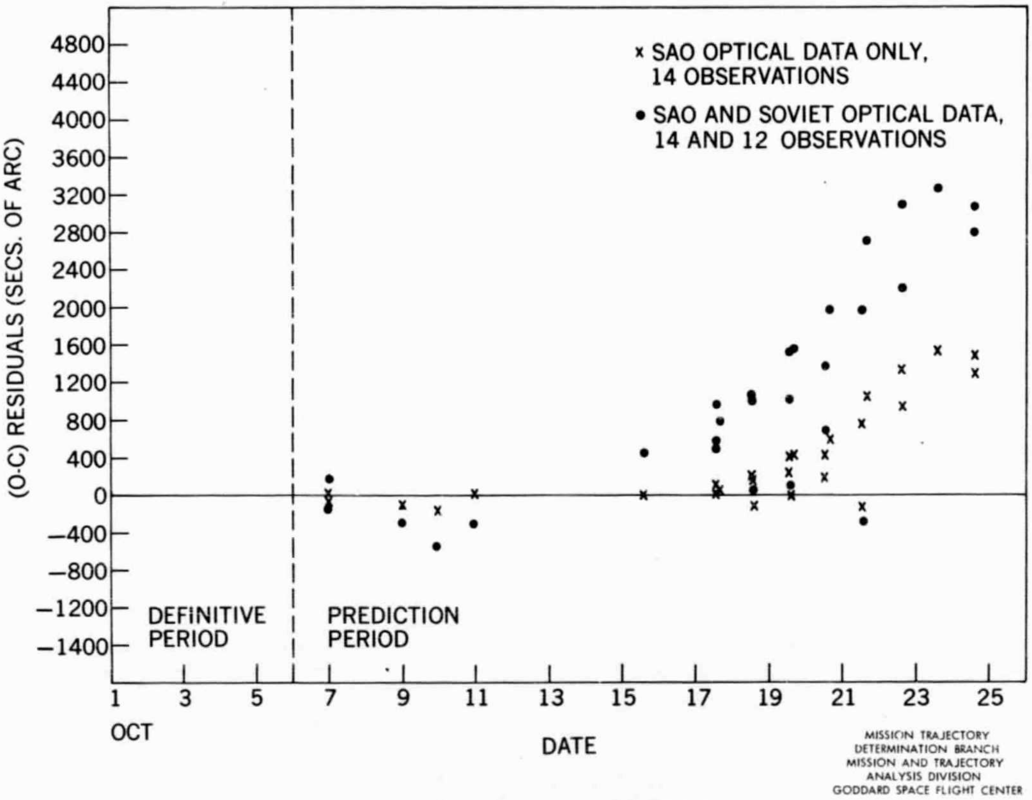

Figure 12. NAINI TAL (India) Declination Residuals Based on DI-D Definitive Orbits Over October 1–6

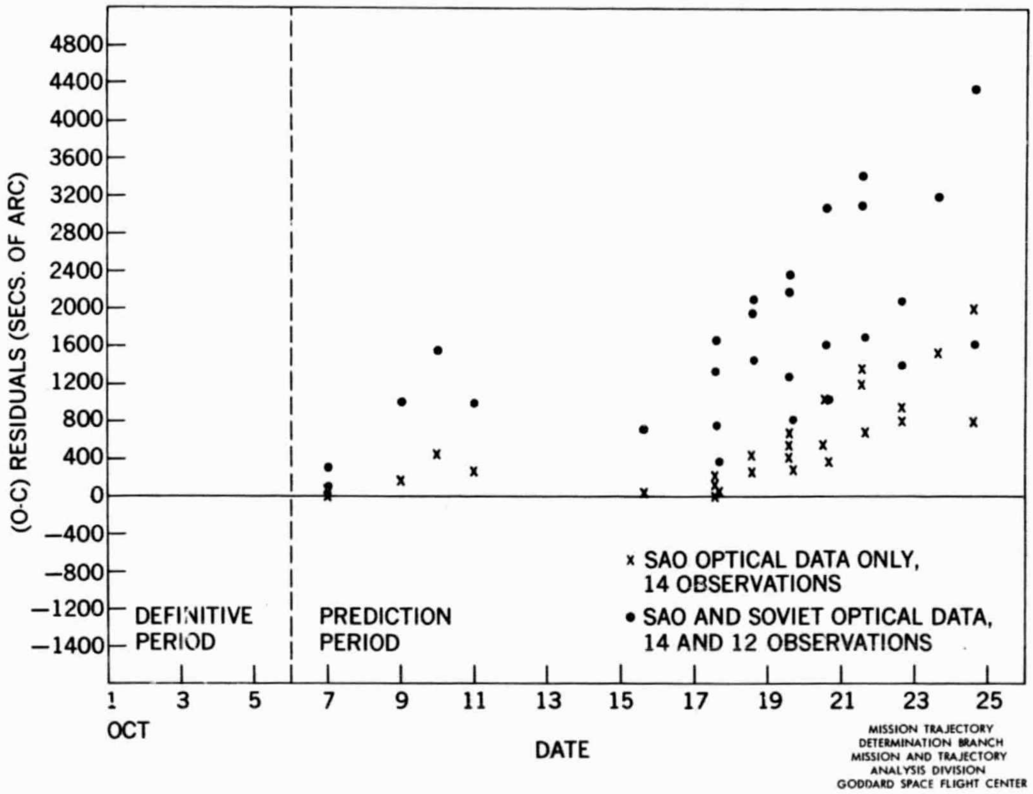

Figure 13. NAINI TAL (India) Right Ascension Residuals Based on DI-D Definitive Orbits Over October 1-6

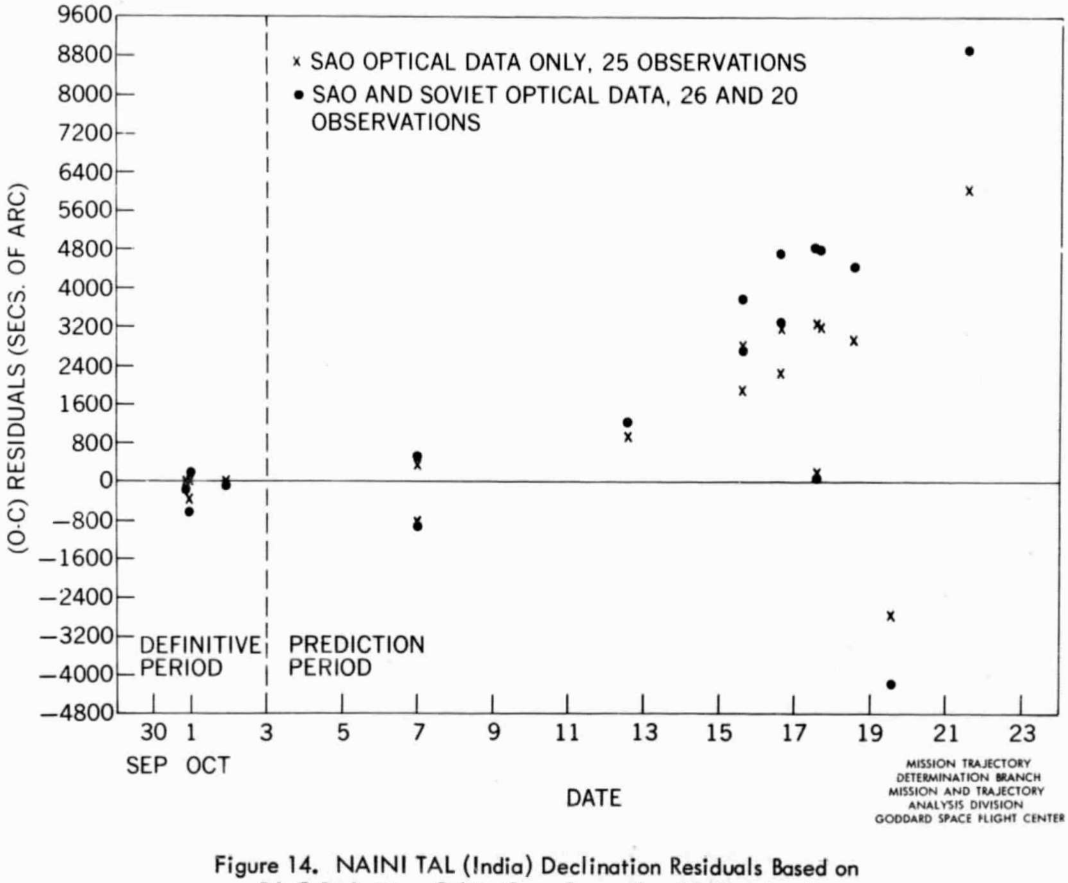

Figure 14. NAINI TAL (India) Declination Residuals Based on DI-C Definitive Orbits Over September 28–October 3

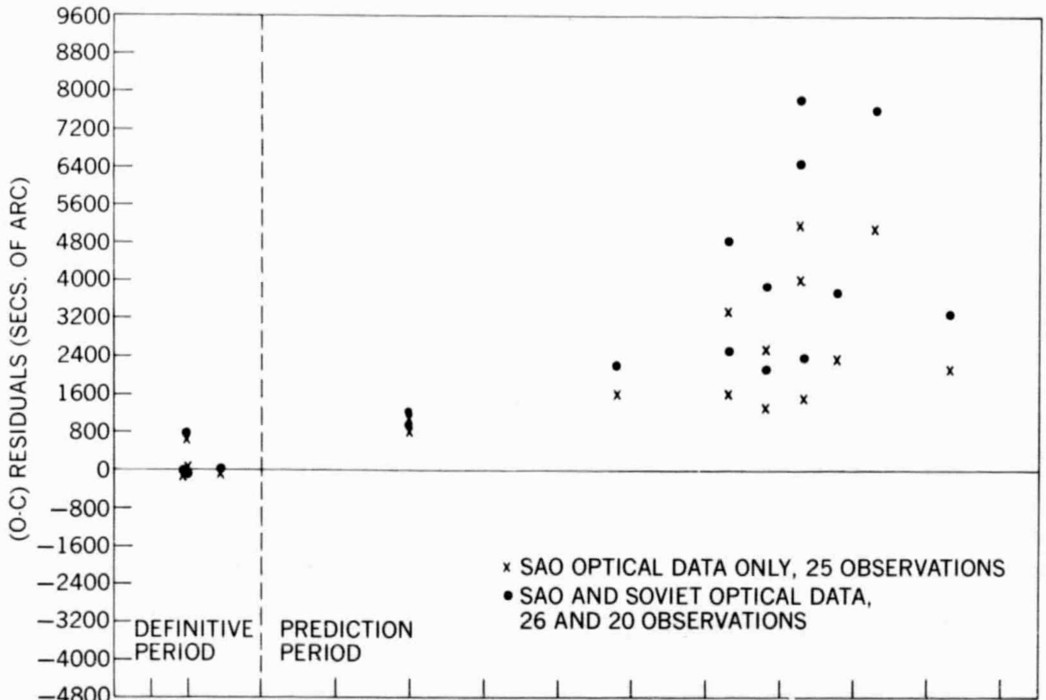

Figure 15. NAINI TAL (India) Right Ascension Residuals Based on DI-C Definitive Orbits Over September 28-October 3

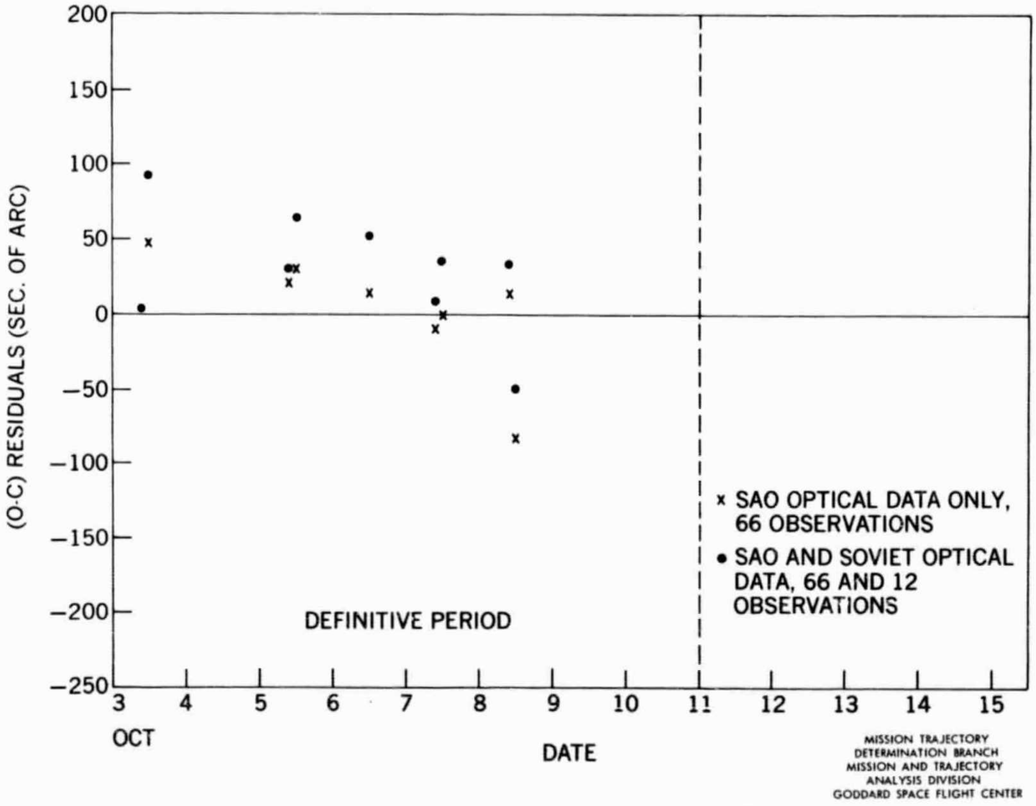

Figure 16. Mt. Hopkins Declination Residuals Based on GEOS-I Definitive Orbits Over October 3-11

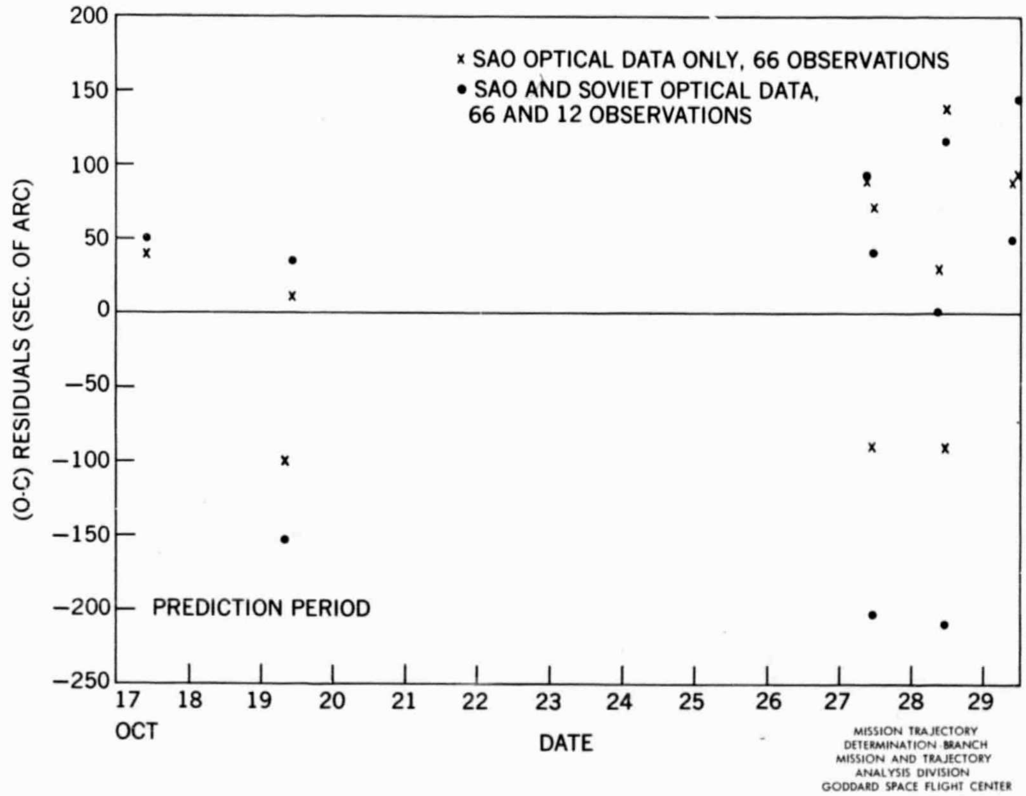

Figure 17. Mt. Hopkins Declination Residuals Based on GEOS-I Definitive Orbits Over October 3-11

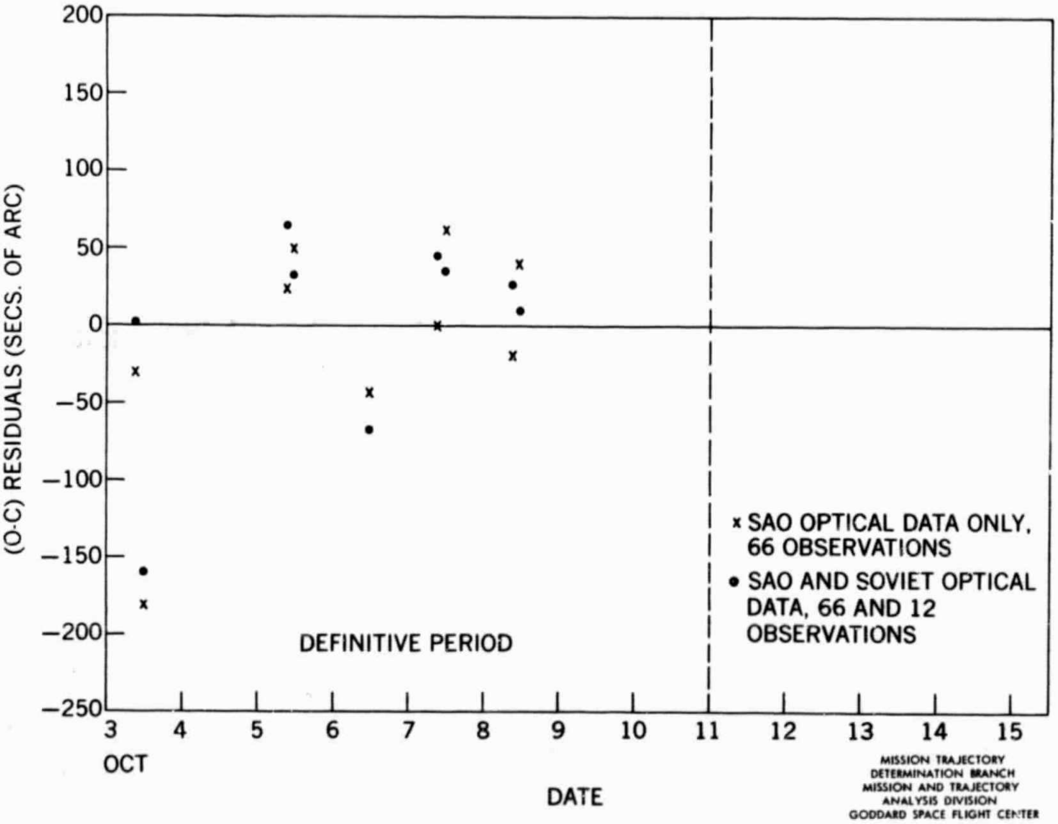

Figure 18. Mt. Hopkins Right Ascension Residuals Based Upon GEOS-I Definitive Orbits Over October 3-11

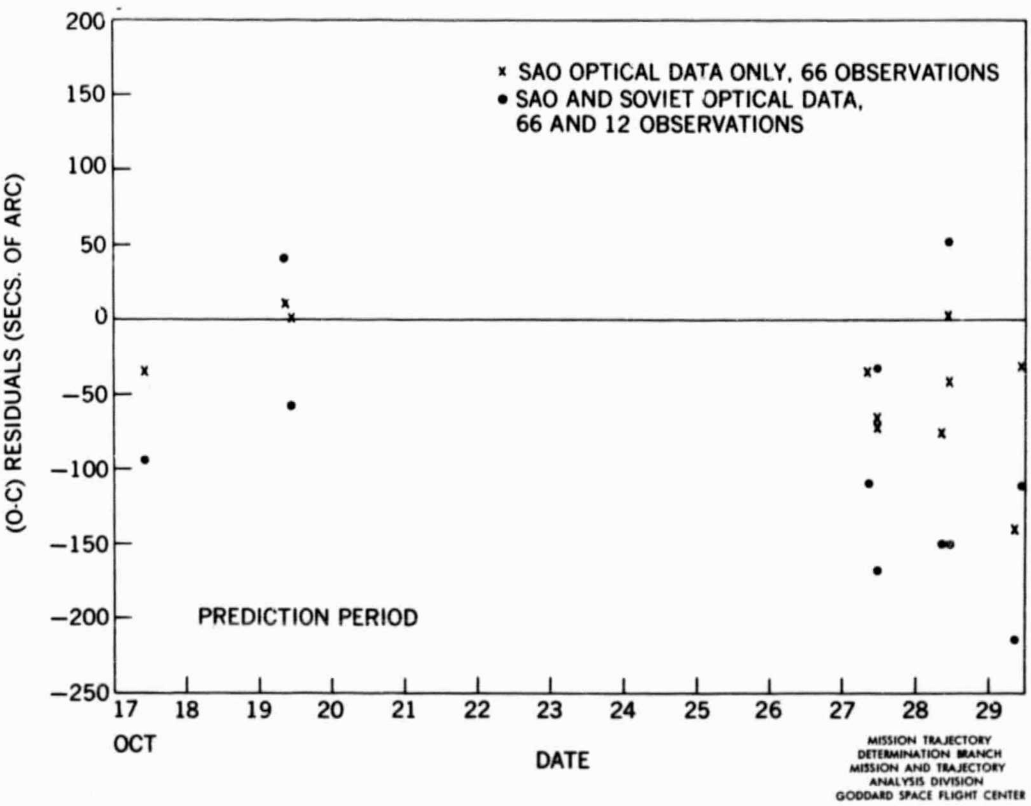

Figure 19. Mt. Hopkins Right Ascension Residuals Based Upon GEOS-I Definitive Orbits Over October 3-11

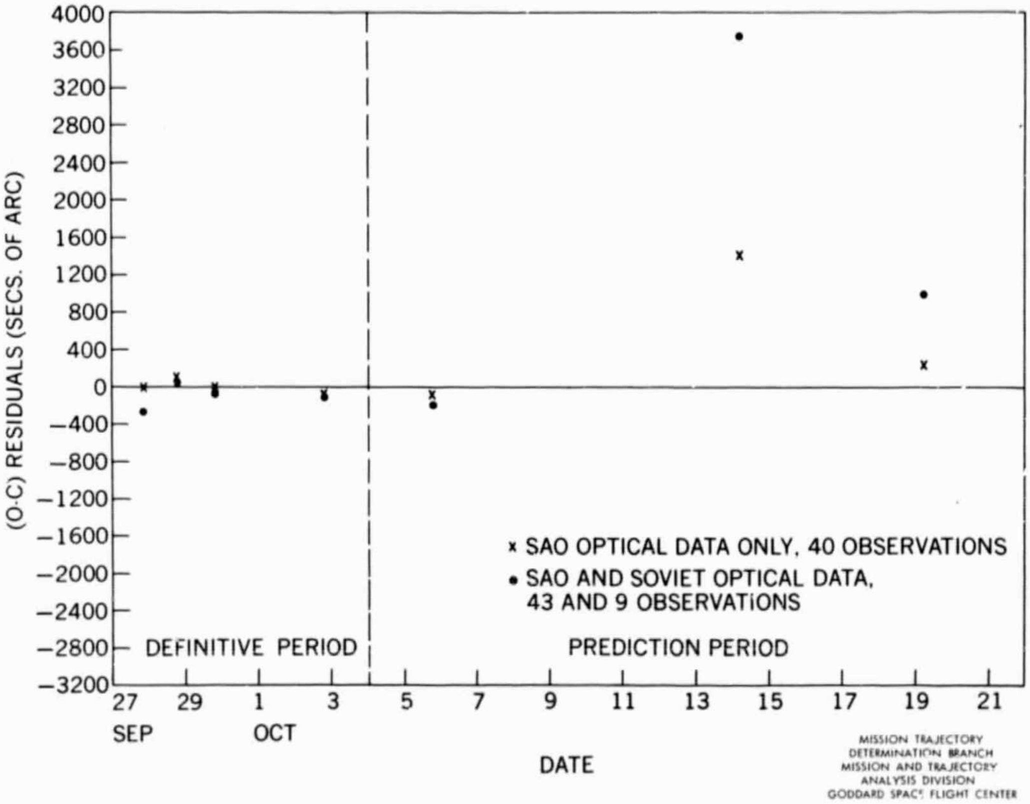

Figure 20. San Fernando (Spain) Declination Residuals Based on BE-B Definitive Orbits Over September 27–October 4

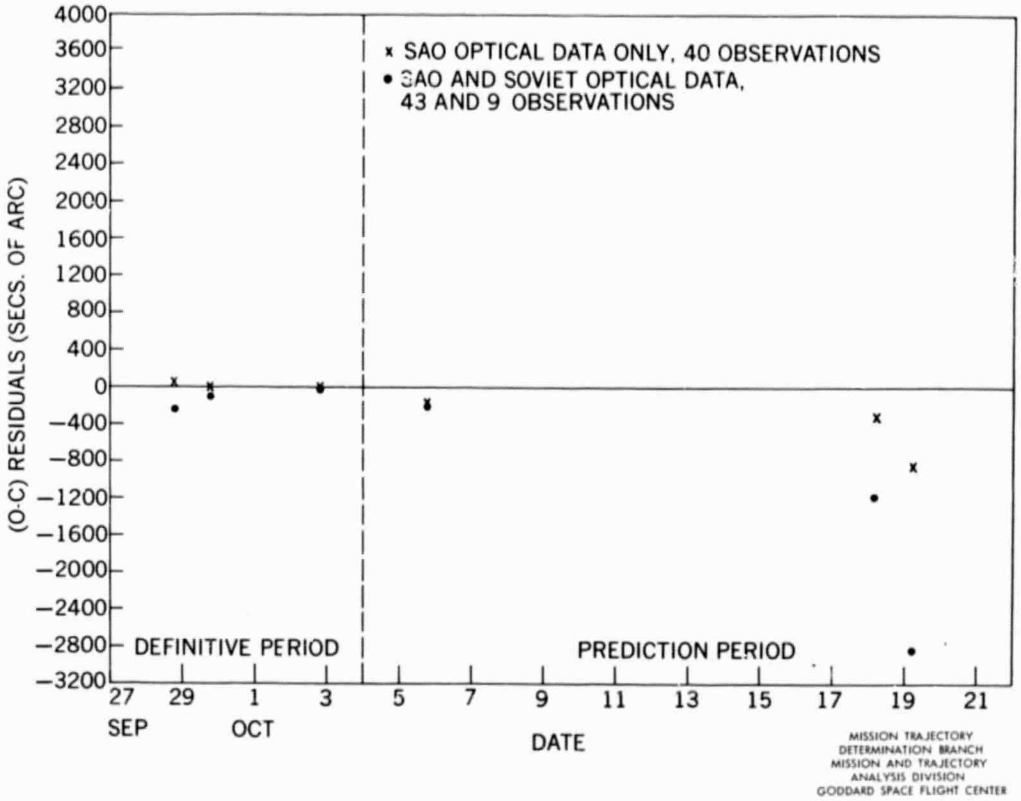

Figure 21. San Fernando (Spain) Right Ascension Residuals Based on BE-B Definitive Orbits Over September 27–October 4

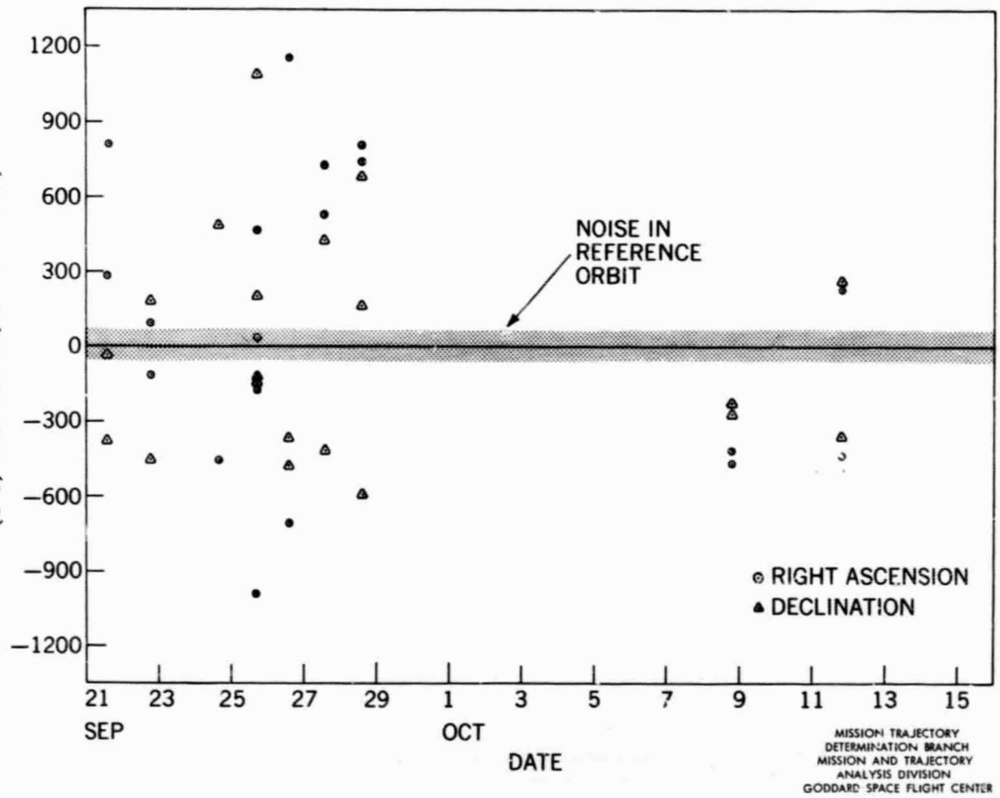

Figure 22. Soviet Residuals in GEOS-II Minitrack Definitive Orbits (Sep. 21-28 and Oct. 5-12)

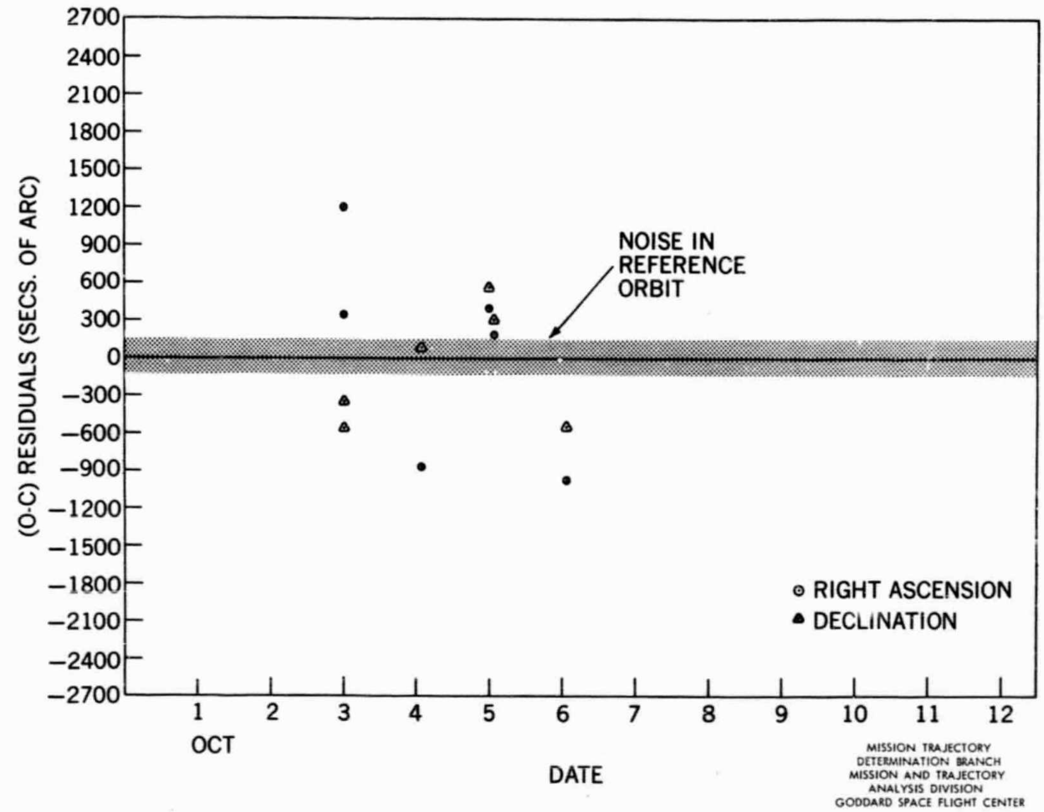

Figure 23. Soviet Optical Residuals and DI-D Definitive Orbit Determined with SAO Optical Data (October 1–6)

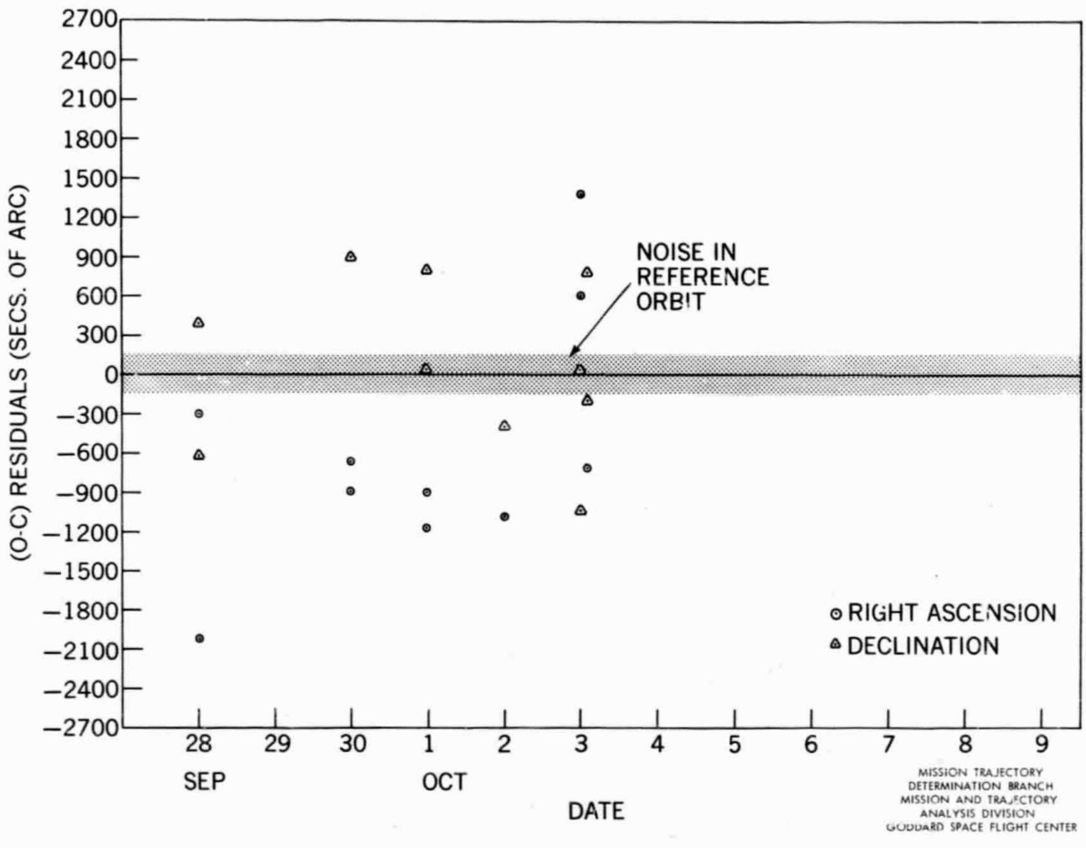

Figure 24. Soviet Data Residuals in DI-C Definitive Orbit Determined with SAO Optical Data (September 28–October 3)

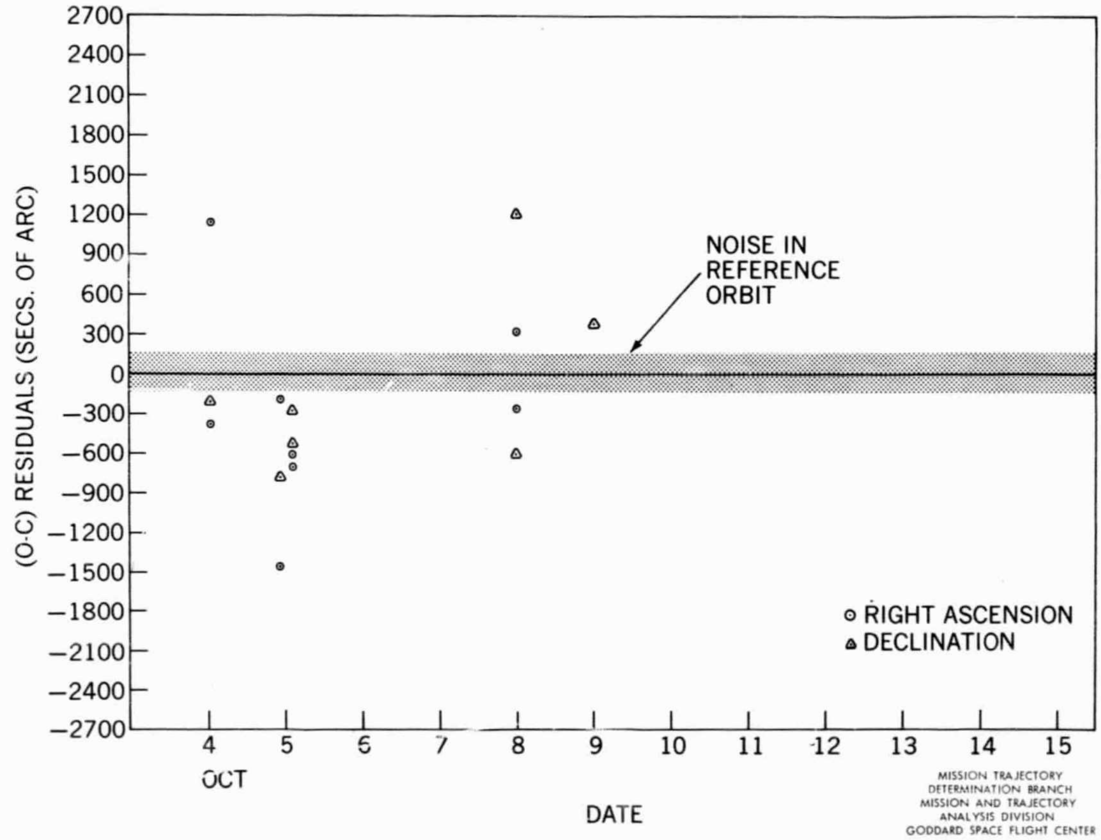

Figure 25. Soviet Data Residuals in DI-C Definitive Orbit Determined with SAO Optical Data (October 4-9)

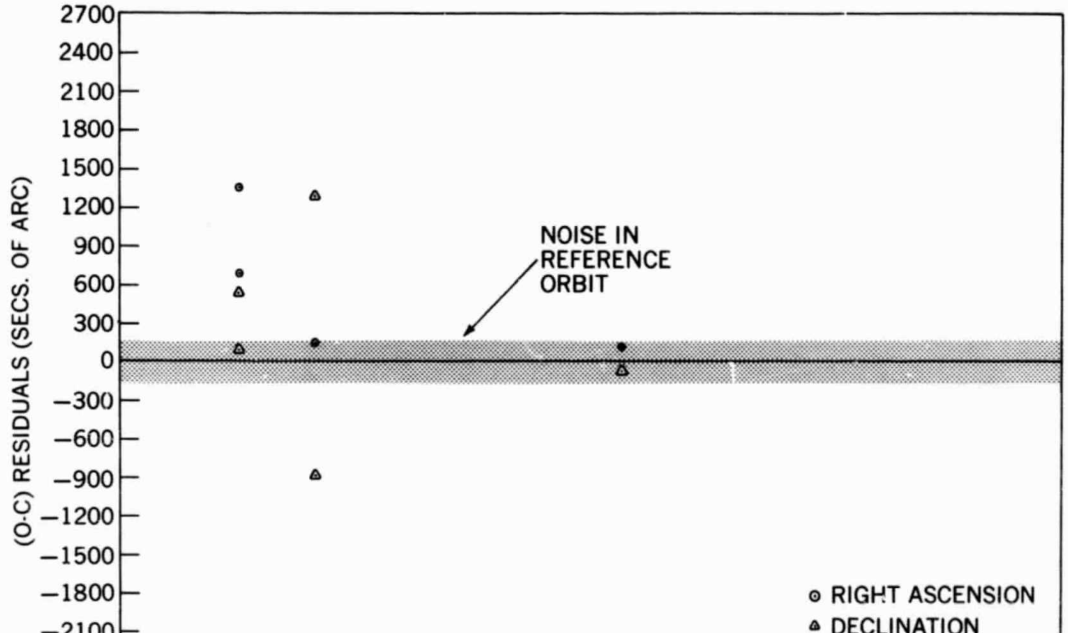

Figure 26. Soviet Data Residuals in BE-B Definitive Orbit Determined with SAO Optical Data (September 27–October 3)

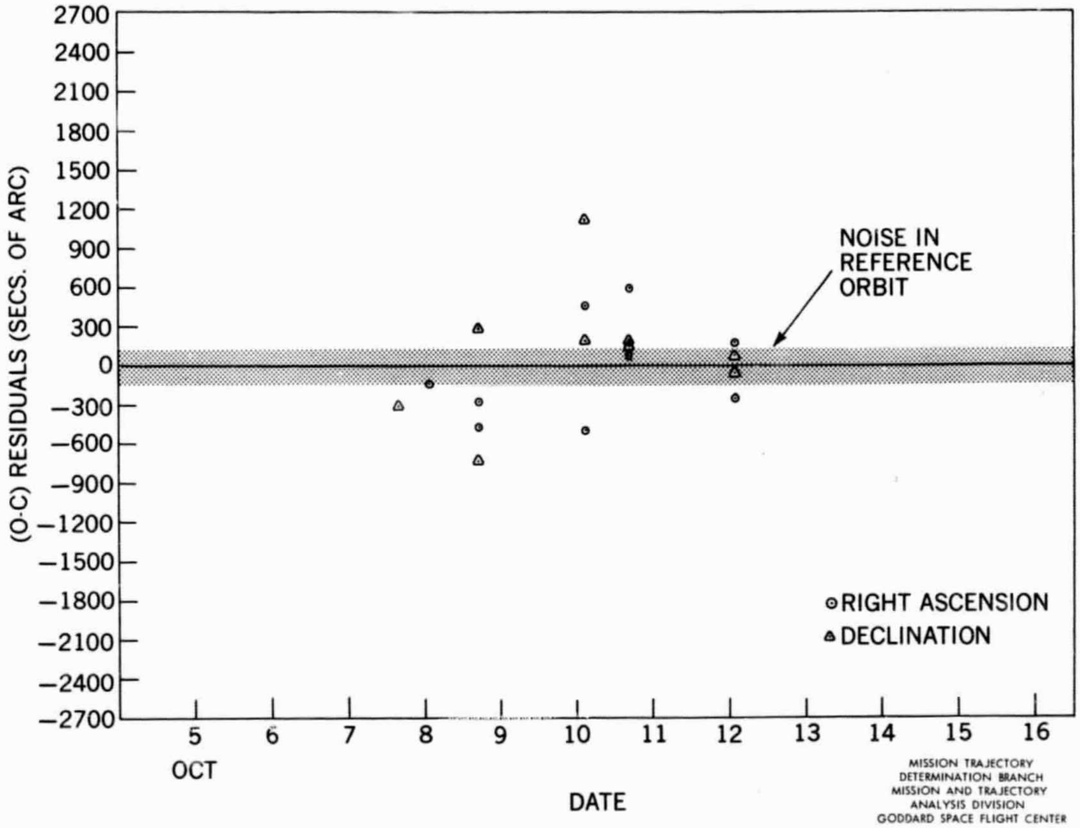

Figure 27. Soviet Data Residuals in BE-B Definitive Orbit Determined with SAO Optical Data (October 5-12)

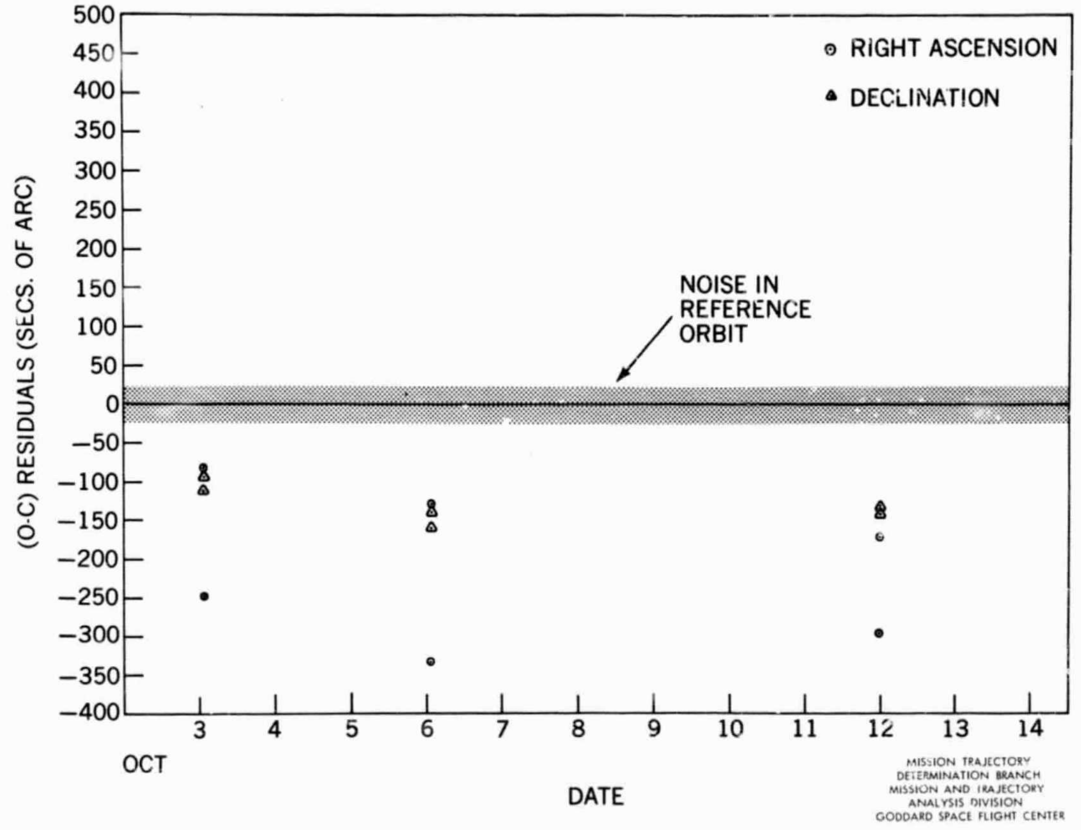

Figure 28. Soviet Data Residuals in GEOS I Definitive Orbit Determined with SAO Optical Data (October 3-11)

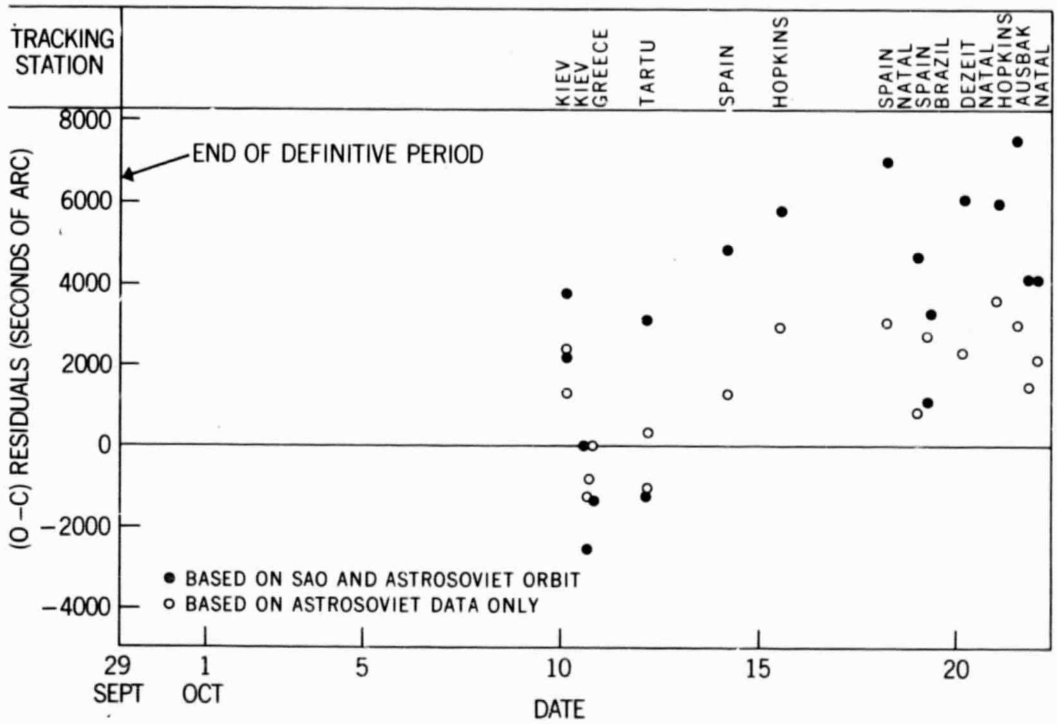

Figure 29. Declination Residuals for Astrosoviet and SAO stations in the prediction period based on two BE-B definitive orbits.