PRECISION ORBIT COMPUTATIONS FOR AN OPERATIONAL ENVIRONMENT

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ABSTRACT

Analyses have been performed at the Goddard Space Flight Center (GSFC) to establish the operational procedures that would be required to provide precision orbit computations to meet current and future operational requirements set forth by different NASA projects. Taking advantage of the improvements to the earth's gravitation field and tracking station coordinates, an orbital computational consistency of the order of 5 meters were achieved for total position differences between orbital solutions for the Seasat and GEOS-3. The main source of error in these solutions has been in the mathematical models that are required to generate these results, i.e., gravitation, atmospheric drag, etc. Different earth's gravitation fields and tracking coordinates have been analyzed and evaluated in obtaining these computational results.

Comparisons and evaluations of the Seasat results have been obtained in terms of different solution types such as the Doppler only, Laser only, Doppler and Laser, etc. Other investigation using the Seasat data have been made in order to determine their effect on the computational results at this particular level of consistency.

INTRODUCTION

It is expected that in the next few years that NASA missions will require additional computational precision in determining spacecraft position in order to support both project and scientific requirements. In order for the Goddard Space Flight Center to support these NASA mission in a precision orbit computations environment both methods and techniques for computations and operational procedures must be established.

The definitive orbit computations requirements for the Seasat mission were the most accurate in terms of consistency between orbital solutions that had been performed at the GSFC for any given mission prior to its launch in June 1978 by the Operations Support Computing Division (OSCD). The computations requirements set forth by the Seasat Project was to maintain a maximum deviation of 65 meters between orbital solutions for the mission lifetime. With these project requirements, the OSCD established the computational techniques, the operational procedures and the tracking data distribution in order to fulfill these commitments.

Due to the amount and distribution of USB/SRE and Laser tracking data required to support definitive orbit computations and precision orbit computations for the Seasat mission, the OSCD has taken the initiative to determine what level of consistency between orbital solutions can be reached for an operational environment. The results of these investigations for the Seasat and GEOS-III missions are based on the mathematical models and station geodetics that have

Introduction (continued)

been established at GSFC by the Geodynamics Branch. The computational procedures and observational tracking data distributions have been established through the analyses which have been performed for each of the satellites.

The information in this particular report is presented in three different areas, the method for precision orbit computations, Seasat precision computations and GEOS-III precision orbit computations.

METHODS FOR PRECISION COMPUTATIONS

Orbit Determination Procedure

The computations of the precision orbits for both Seasat and GEOS-III were performed at the GSFC on the 360 computer complex using the Goddard Trajectory Determination System (GTDS). GTDS has the capability to perform orbit determinations and generate spacecraft ephemeris data in the form of position and velocity to different levels of consistency based on force model representations, station geodetics and tracking data distributions. The orbital solutions obtained for Seasat and GEOS-III from GTDS used Cowell's method of integration for the equations of motion and the variational equations and a least squares adjustment technique for the improvement of orbital parameters. The earth's gravity field, the solar gravitational perturbations, the lunar gravitational perturbations and the solid earth tidal perturbations are modeled for these orbital computations. In addition, The nonconservative forces of solar radiation pressure and atmospheric drag have been modeled. It should be stated that the JPL planetary ephemeris DE-96 was adopted for these computations along with the BIH polar motion and the UT1 and A.1 corrections.

The Seasat and GEOS-III spacecraft were modeled in the GTDS as specularly reflecting spheres. In the precision orbit computations for Seasat a drag coefficient for each data arc was solved for.

In addition, an analysis was performed to determine the best integration step size for the equations of motion and the variational equations and in obtaining orbital solutions which are consistent in terms of numerical processes. The integraton step size which was established for Seasat and GEOS-III was 45 seconds.

Physical Parameters, Environmental Parameters and Tracking Station Geodetics For Precision Orbit Determination

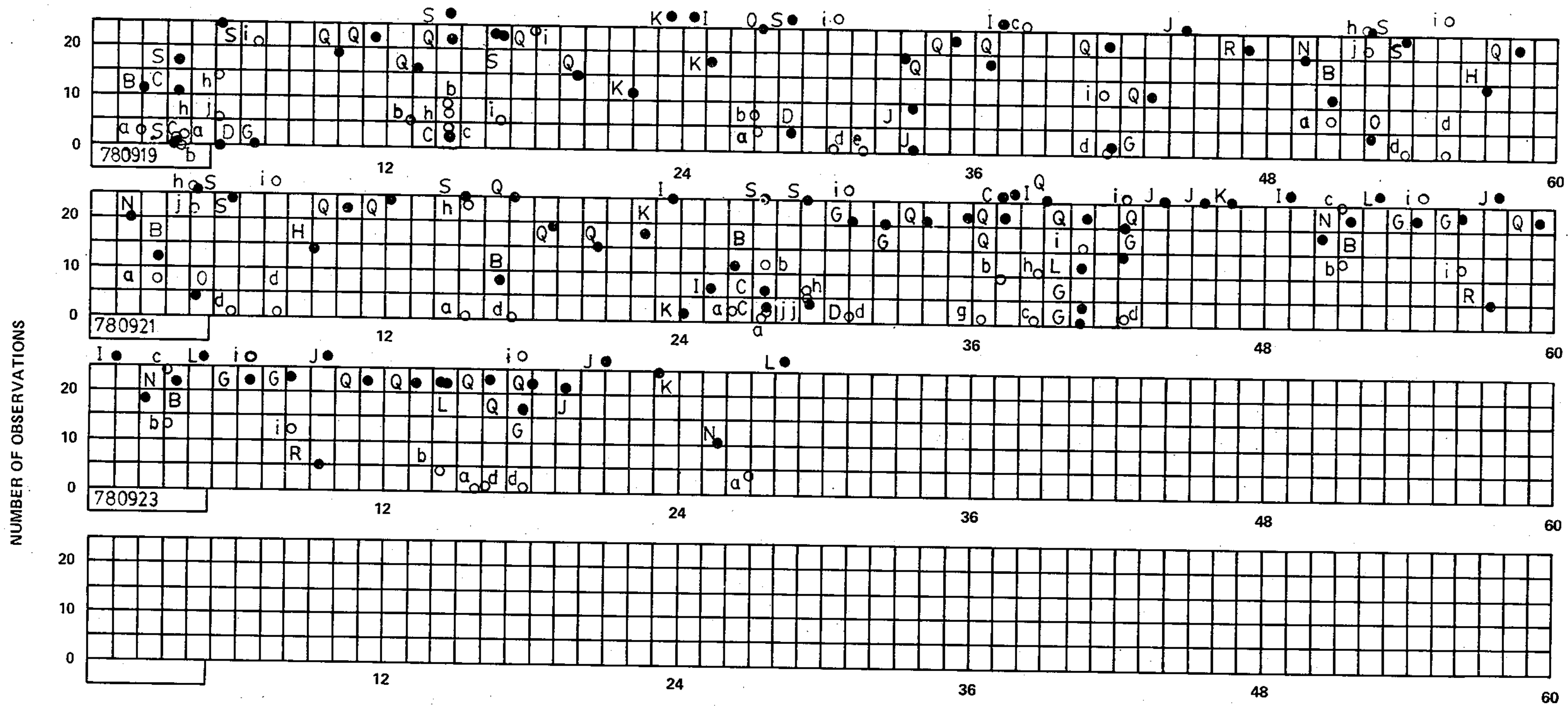
In obtaining the orbital solutions for the Seasat and GEOS-III in the precision orbit computations environment different sets of physical and environmental parameters and station geodetics were used and evaluated. One of the fundamental capabilities that exist in GTDS is its capability to make use of different size gravitational models along with other parameters, which is essential in an operational environment. In this investigation the three earth's gravitational fields which were used and evaluated were the GEM 9, GEM 10B, and the PGS 1040. These three gravitational fields were determined at the GSFC using observational tracking data from both NASA and non-NASA stations and global gravimetric data while making use of the research and development orbit computations system GEODYN. When a specific gravitational field is used for orbit computations then the earth's gravitational constant (GM), the mean equatorial radius of the earth (a_e) and the earth's inverse flattening factor (1/f) must be properly specified. These particular parameters for each of the three gravitational fields are listed in Table 1. The orbital and physical parameters that were used in this investigation are listed in Table 2. It should be understood that in the computations for the nonconservative forces of drag and solar radiation that both spacecrafts were assumed to have a spherical shape, although this is usually an extreme idealization.

Through the analysis and evaluations which have been performed in this investigation for precision orbit computations, it has become apparent that good

(<u>Physical Parameters</u>, etc., continued)

or precise station geodetics are very essential in obtaining specific levels of consistency between orbital solutions. The evaluations which have performed indicates that the quality of station geodetics are not as important at the 20 to 40 meter level of consistency between orbital solutions as they are at the 5 to 15 meter level of consistency between solutions. Therefore, the station geodetics which have been used for the precision orbit computations for both Seasat and GEOS-III are the coordinates which have been derived by J. Marsh of the GSFC which are given in Table 3. It should be pointed out that selected code letters are assigned to specific stations in order to represent that station on the tracking data distribution figures that are presented in Figures 1 through 3.

TRACKING DATA DISTRIBUTION
SATELLITE AND TIME PERIOD SEASAT-1 SEPT 78



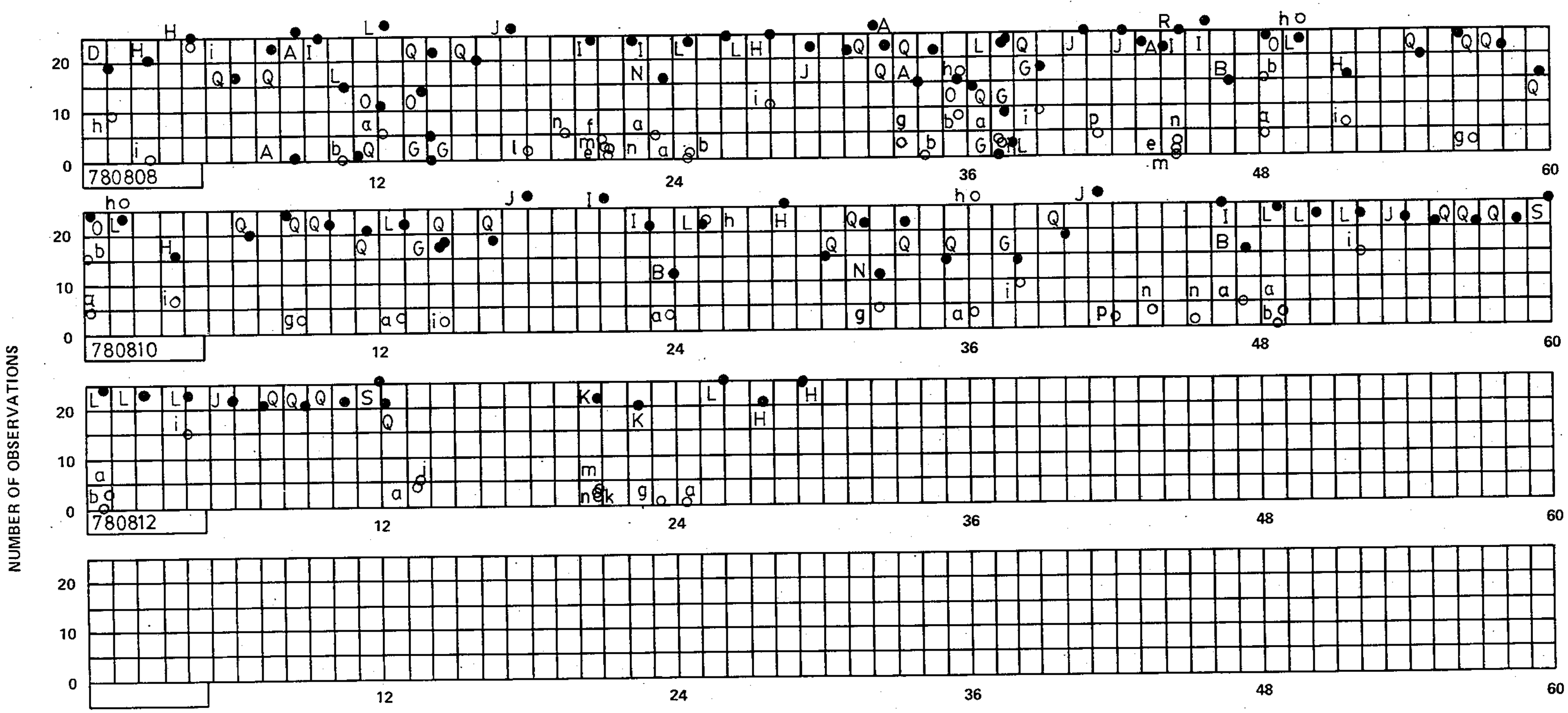
○ RANGE / 10 - LASER
● DOPPLER - USB

B	AGO3	a	AREL
C	BDA3	b	BDAL
D	ETCA	c	GTKL
G	GDS3	d	HOPL
H	GDS8	e	KOOL
I	GWM3	g	ORRL
J	HAW3	h	RAML
K	MAD8	i	SNDL
L	MIL3	j	STAL
N	ORR3		
Q	ULA3		
R	MAD3		
S	MILA		

DATA RATE: 2 PER MINUTE
NOTES: LASER RATE VARIES

Figure 1

TRACKING DATA DISTRIBUTION
SATELLITE AND TIME PERIOD SEASAT-I AUG 78



○ RANGE/10 - LASER
● DOPPLER - USB

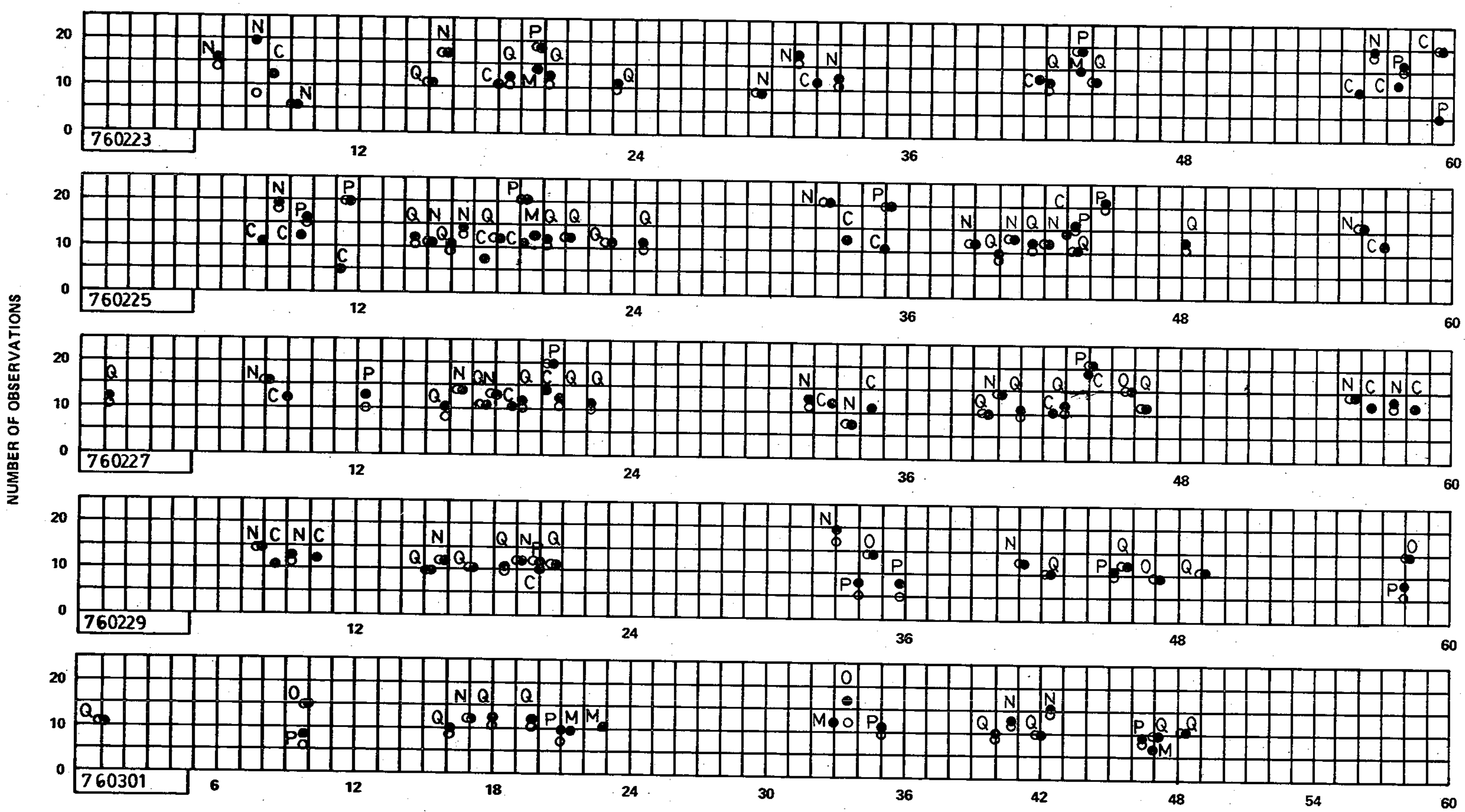
A	ACN3	a	AREL
B	AGO3	b	BDAL
G	GDS3	e	KOOL
H	GDS8	f	NATL
I	GWM3	g	ORRL
J	HAW3	h	RAML
K	MAD8	i	SNDL
L	MIL3	k	WE2L
N	ORR3	m	SAFL
O	QUIS	n	GRAL
Q	ULA3	p	HLWL
R	MAD3		
S	MILA		

ELAPSED TIME (HOURS)

DATA RATE: 2 PER MINUTE
NOTES: LASER RATE VARIES

Figure 2

TRACKING DATA DISTRIBUTION
SATELLITE AND TIME PERIOD GEOS-3 FEB 76



O RANGE
● DOPPLER

C BDA3
M MI23
N ORR3
O QUIS
P ROSS
Q ULA3

DATA RATE: 6 PER MINUTE
NOTES: Used every 3rd obs.

Figure 3

SEASAT PRECISION ORBIT COMPUTATION

Observational Tracking Data for Seasat

The observational tracking data used for precision orbit computations for Seasat were a combination of USB/SRE range rate data from STDN and Laser data from STDN and SAO. The USB/SRE range rate data provided the strong global coverage both in terms of geographical distribution and in time. The Laser observational tracking data provided strength in terms of accuracy for the precision orbit computations.

An analyses of both the USB/SRE range rate data and the Laser data in terms of distribution and time provided two specific time intervals, September 19 through September 26, 1978 and August 8, 1978 through August 15, 1978 over which the precision orbit computations were performed. The amount of observational tracking data during these two particular time intervals contained approximately 20 passes of USB/SRE data and 12 passes of Laser data for each typical twenty-four hour interval. Figures 1 and 2 give the station and data distribution for the September 1978 period and the August 1978 period.

Orbital Analyses for Seasat

In determining the consistency between orbital solutions to the 1 to 5 meter level for the Seasat spacecraft, a number of gravitational field models, station geodetics and integration step size were evaluated. Through these evaluations with the use of GTDS, it has been established that the PGS-1040 gravitational field and the station geodetics, which have been designated Marsh II, have given the best results in terms of consistency between orbital solutions. The PGS-1040 gravitational field and the Marsh II station geodetics have been determined at GSFC through the use of GEODYN. It should be pointed out that in the determination of the PGS-1040 gravity field that both Laser and USB/SRE observational tracking data from the Seasat spacecraft were used.

The length of the observational data arc was thirty hours for the orbital solutions which were determined for this investigation. In order to determine the consistency between successive orbital solutions for the Seasat spacecraft a six-hour interval was established as the time frame over which the consistency was to be determined. The maximum difference in a given six-hour overlap interval between two successive orbital solutions in terms of spacecraft position is the measure of consistency which has been determined by this process.

The orbital solutions for the Seasat spacecraft using only the USB Doppler tracking and the additional techniques for computations in the September and August 1978 time frames are given in Tables 4 and 8. Information pertaining to the individual solutions are given in these tables including the rho one solve-for parameter, which is equivalent to a density correction for each of the Seasat orbital solutions. In addition, the maximum discontinuities between successive solutions for each specific six-hour overlap interval are presented in terms of radial, cross track and along track differences. The results of this analysis indicate that using the Doppler only that an average 10-meter level of consistency for the September 1978 time frame can be obtained while for the August 1978 time frame only a 13-meter level of consistency was obtained. These results indicate that the 5-meter level of consistency between the orbital solutions is difficult to obtain using only USB Doppler data. An assessment of these results would indicate that there should be no problem with the number of tracking passes in the individual solutions although the distribution of passes within the solutions could cause problems. It is felt that the mathematical modeling or the computational procedures should not cause problems in achieving the 5-meter level of consistency.

The next set of orbital solutions for Seasat were computed based on Laser tracking data only and the results of these computations are given in Tables 5 and 9. Information pertaining to these computations for the individual solutions are given in these tables including the rho one solve-for parameters. The maximum discontinuities between successive orbital solutions for each specific six-hour overlap interval are presented. The results of this analysis indicate that using the Laser tracking data by itself that an average 4.4 meter level of consistency can be obtained for the September 1978 time frame while for the August 1978 time frame only an 8.8-meter level of consistency was obtained. These results indicate the 5-meter level of consistency between individual solutions can be obtained when using only Laser tracking data for certain time frames during the Seasat satellite lifetime. Again, an assessment of these results would indicate that since the mathematical modeling and the computational procedures are the same then the differences in the August and September 1978 time frames has to be in another area. The only other area where differences can be attributed has to be in the Laser tracking data, in other words the distribution of the data or the quality of data.

Another set of orbital solutions for Seasat were determined based on Laser and USB Doppler tracking data and the results of these computations are given in Tables 6 and 10. The information pertaining to these computations are given in these tables, including the rho one solve-for parameters. The maximum discontinuities between successive orbital solutions for each specific six-hour overlap interval are also presented in these tables. The results of this analysis indicate that using both the Laser and USB Doppler tracking data that an average 3.6-meter level of consistency was obtained for the September 1978 time frame while for the August 1978 time frame only a 7.4-meter level of consistency was obtained. These results indicate that making use of the combination of Laser and USB Doppler tracking data gives a little better overall consistency between successive solutions than when using the Laser observations only. Since the mathematical modeling and the computational procedures were the same then the slight improvements comes from the strength of more comprehensive distribution of observational tracking data throughout the individual orbital solutions.

Further analysis was performed to determine the affect of having equal number of observations per pass for both the Laser and USB Doppler tracking data in determining each orbital solutions and the level of consistency for the September 1978 time frame. The results of these individual orbit computations are given in Tables 6 and 7 along with the rho one solve-for parameters. The maximum discontinuities between successive orbital solutions for each six-hour overlap interval are also presented in these tables. The results of this analysis indicate that making use of the observational tracking data in this manner and using the same mathematical modeling and computational procedures an average of 4.1 meter level of consistency was obtained. This result of 4.1-meter level of consistency obtained in this process and the other average values of 3.7- and 4.4-meter levels of consistency obtained when using Laser and USB Doppler data in another process of observations selection and using Laser data by itself are basically the same. In other words, at this particular level of consistency it is difficult to indicate in terms of an average value, which are the better results.

GEOS-III PRECISION ORBIT COMPUTATIONS

Observational Tracking Data for GEOS-III

GEOS-III orbital solutions were calculated for a period extending from February 23, 1976, to March 2, 1976. The available unified S-band range and range-rate data is shown in Figure 3. Only the range-rate data were used for the solutions described here. Unlike the tracking data distribution for Seasat, the GEOS-III tracking data distribution is not uniform, having intense tracking about once a day, and very little tracking at other times. On the average, there is available slightly less than one pass of tracking per orbital revolution.

Orbital Analysis for GEOS-III

Orbital solutions for GEOS-III were calculated using GTDS and the Goddard Earth Model 10B (GEM10B) gravity model. This gravity model is based, in part, on GEOS-3 altimetry data. Since the altitude of GEOS-III is about 50 kilometers greater than that of Seasat, the orbital effects of atmosphere drag are significantly smaller. Unlike Seasat, estimation of the drag parameter does not sppear to affect the accuracy of differential correction solutions. The GEOS-III solutions were calculated by solving only for the spacecraft state vector at epoch.

The GEOS-III solutions were 30 hours in length, each solution overlapping neighboring solutions by six hours. Because ephemeris comparisons in the solution overlap intervals are used for orbital accuracy estimates and because of the strongly periodic characteristic of the tracking schedule, it might be expected that the overlap comparisons could be affected by the placement of the overlap interval relative to the periods of intense tracking. If the overlap intervals coincided with the intense tracking periods it might be expected that the ephemeris differences would be lower than if the overlap intervals were located in periods of little tracking.

In order to examine this possible effect, the solution intervals were placed in time two different ways. In the first scheme, the epochs of each 30-hour solution were located at 15^h on successive days. This procedure puts the periods of intense tracking into the six-hour solution overlap intervals, and each soluton has strong tracking at its start and end, but little in between. The second scheme placed the epochs at 0^h on successive days. This placed the intense tracking in the middle of each solution, with very little in the overlap intervals.

GEOS-III orbital solutions, along with the ephemeris overlap comparisons that were calculated using these two approaches are summarized in Tables 11 and 12. In these tables, the tracking observations for each solution are separated into two categories (indicated by the diagonal line) because of slightly different tracker types; this is not relevant for this study. The orbital fits, as indicated by the weighted RMS, (the assigned range-rate standard deviation was 2.0 centimeters per second) were about the same, overall, for the 0^h and 15^h solutions. Similarly, the standard deviations of the solution residuals were about one centimeter per second for each set of solutions.

The ephemeris overlap differences for both sets of solutions are also quite similar. The maximum total differences average about 7 meters for both the 0^h and 15^h solutions. Also the maximum cross-track differences average about 6 meters for both sets of solutions. On the other hand, the radial and along-track differences for the two sets of solutions are distinct. For the 15^h solutions, the maximum radial differences and the maximum along-track differences average to 0.5 and 2.4 meters, respectively. For the 0^h solutions, the corresponding averages are 1.0 and 4.9 meters. Thus, the placement of the intense tracking at the end of the solution intervals, rather than the middles, reduced the along-track and radial differences by about a factor of two.

This reduction in along-track and radial differences, and presumably, a corresponding reduction in along-track and radial orbit error may be explained as follows. It is well known that radial and along-track orbit displacements are coupled together in the equations of motion; thus it is natural that changes in along-track and radial orbit error should be correlated. Placement of the intense tracking at the ends of a solution interval causes the orbit solution to better average out along-track and radial force modeling errors, leading to smaller peak radial and along-track orbit errors than if the tracking data was concentrated in the middle of each solution, leaving both ends of a solution "floating".

COMPARISONS OF VARIOUS SETS OF TRACKING STATION COORDINATES

The GEOS-III solutions described in the previous section were calculated using tracking station coordinates derived by J. Marsh of GSFC. Corresponding GEOS-III orbital solutions were calculated using three other sets of tracking station coordinates. These three sets are NASA Spacecraft Tracking and Data Network coordinates (STDN), GEM9 coordinates, and World Geodetic System (Geoceiver) WGS(G) coordinates.

The STDN coordinates are those used for GSFC operational orbit determination (Reference A). The GEM9 coordinates were derived as a part of the GEM9 and GEM10 gravity models (Reference B). The WGS(G) coordinates for the NASA S-band tracking stations were specially derived for this study. These station coordinates were based upon coordinates of nearby geoceivers.

GEOS-III orbital solutions using the STDN, GEM9, and WGS(G) station coordinates are summarized in Tables 13, 14, and 15 respectively. These solutions were calculated using the same GTDS input parameters, except for station coordinates as the solutions in Table B (15^h epochs). Thus, comparisons among the results in these four tables are a direct comparison of the effect of various sets of tracking station coordinates. (The value of the semi-major axis of the earth, used for evaluation of the gravity force was slightly different for the solutions calculated using Marsh coordinates. Subsequently, tests showed the effect of this change negligible for these comparisons.)

Comparisons of Various Sets of Tracking Station Coordinates (continued)

None of the three additional sets of station coordinates performed as well in these solutions as the Marsh coordinates. In the order of increasing weighted RMS residuals and increasing overlap differences, these three sets of coordinates are ordered as follows: WGS(G), GEM9, and STDN. In the case of the STDN coordinates, the maximum radial differences average to 4.2 meters, while the total differences average to 21 meters. These results are consistent with the position differences of the GEOS-III tracking stations in the Marsh and STDN coordinates, which are typically 15 to 25 meters.

CONCLUSIONS

The results of this study have shown that orbital consistency at the five-meter level can be obtained for Seasat and GEOS-III using the operational Goddard Trajectory Determination System. The attainment of this orbital consistency level requires the use of the most precise gravity models and tracking station coordinates that are currently available. For Seasat, the use of Laser range tracking data was found to increase the level of orbital consistency when used alone or in combination with the unified S-band range-rate tracking data. For GEOS-III, the use of the unified S-band tracking data alone produced orbital consistency of the order of five meters.

Table 1 Physical, Geophysical, and Astronomical Parameters Used

QUANTITY	VALUE
UNIVERSAL CONSTANT OF GRAVITATION (G)	6.673×10^{-23} KM^3 S^{-2}KG^{-1}
ASTRONOMICAL UNIT	1.495978930×10^8 KM
SOLAR MOMENTUM FLUX DENSITY	4.5 N KM^{-2}
EARTH GRAVITATIONAL CONSTANT (GM)	3.9860064×10^5 KM^3 S^{-2} (GEM 9) 3.9860064×10^5 KM^3 S^{-2} (GEM10B) 3.9860062×10^5 KM^3 S^{-2} (PGS 1040)
EARTH MEAN EQUATORIAL RADIUS (a_e)	6378.140 KM (GEM 9) 6378.139 KM (GEM10B) 6378.140 KM (PGS 1040)
EARTH INVERSE FLATTENING FACTOR (1/f)	298.250 (GEM 9) 298.257 (GEM10B) 298.257 (PGS 1040)
SPEED OF LIGHT (c)	2.997925×10^5 KM S^{-1}

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TABLE 2. Orbital and Spacecraft Parameters for the Spacecraft Studied

SPACECRAFT	NOMINAL ORBIT CHARACTERISTICS		SPACECRAFT CHARACTERISTICS	
	ALTITUDE (km)	INCLINATION (deg)	MASS (kg)	CROSS-SECTIONAL AREA (m^2)
GEOS-3	825 to 855	115.0	345.909	1.4365
SEASAT-1	770 to 800	108.0	2220.8	25.31

Table 3. Marsh II Tracking Station Coordinates

STATION	GEODETIC LATITUDE	GEODETIC LONGITUDE	HEIGHT ABOVE SPHEROID (m)	CODE
ACN3	−7°57'17".289	345°40'22".186	534.33	A
AGO3	−33°09'03".946	289°20'00".558	717.59	B
BDA3	32°21'04".533	295°20'31".325	−30.10	C
ETCA	38°59'54".171	283°09'28".749	12.35	D
GDS3	35°20'31".789	243°07'35".311	919.69	G
GDS8	35°20'29".495	243°07'34".792	925.69	H
GWM3	13°18'38".243	144°44'12".465	133.05	I
HAW3	22°07'34".681	200°20'05".231	1148.56	J
MAD8	40°27'19".553	355°49'53".216	819.66	K
MIL3	28°30'29".250	279°18'23".625	−38.24	L
ORR3	−35°37'40".410	148°57'25".169	934.39	N
QUIS	−0°37'18".967	281°25'10".404	3578.86	O
ULA3	64°58'19".233	212°29'13".235	333.90	Q
MAD3	40°27'22".248	355°49'49".163	816.80	R
MILA	28°30'29".318	279°18'25".474	−42.40	S
AREL	−16°27'56".708	288°30'24".533	2475.99	a
BDAL	−32°21'13".767	295°20'37".890	−36.87	b
GTKL	21°27'37".770	288°52'04".972	−32.36	c
HOPL	31°41'03".201	249°07'18".798	2334.76	d
KOOL	52°10'42".215	5° 48'35".055	75.0	e
NATL	−5°55'40".145	324°50'07".165	22.70	f
ORRL	−35°37'29".741	148°57'17".133	932.45	g
RAML	28°13'40".630	279°23'39".244	−37.24	h
SNDL	32°36'02".628	243°09'32".737	975.00	i
STAL	39°01'13".359	283°10'19".751	47.00	j

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[a]REFERENCE SPHEROID: SEMIMAJOR AXIS, 6378.155 km. INVERSE FLATTENING FACTOR, 298.255.

TABLE 4

SATELLITE AND TIME PERIOD SEASAT - September 1978

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for Both Laser and USB Doppler

Geopotential Model PGS-1040**

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.5

Drag Parameters C_D=2.1

Atmospheric Density Model H.P., F#150

Solve-For Parameters State and Rho one

Editing Parameters 3 Sigma

Other USB-Doppler, Earth Tides Polar Motion, Marsh II Geodetics***

Arc Start Time	Arc Length (hrs)	No. of Sta-tions	Observations: Range No. Avail-able	Range No. Used	Range-Rate No. Avail-able	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information: RHO ONE		PASSES		Run ID
780919	30	7*			403	345	.83		1.68					-.65		20*		
										0.94	11.76	4.66	12.28					
780920	30	9			371	325	.99		1.98					-.67		17		
										1.01	11.59	2.15	11.67					
780921	30	9			366	310	.96		1.93					-.53		20		
										2.20	5.04	7.60	8.37					
780922	30	10			513	426	.82		1.64					-.22		25		
										1.54	3.21	7.62	7.70					
780923	30	9			444	392	.82		1.65					-.21		21		
												AVER	10.00					

*Number of Stations and Passes - Laser/USB Doppler

**Computation based on PGS-1040: Gravitational Constant GM = 398600.62 km^3/sec^2, Equatorial Radius R_e=6378.140 km and Inverse Flattening Coefficient = 298.257

***Ellipsoid Parameters for Marsh II Geodetics: Equatorial Radius R_e=6378.155 km and Inverse flattening coefficient=298.255

TABLE 5

SATELLITE AND TIME PERIOD SEASAT - September 1978

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for Both Laser and USB Doppler

Geopotential Model PGS-1040**

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.5

Drag Parameters C_D=2.1

Atmospheric Density Model H.P., F#150

Solve-For Parameters State and Rho one

Editing Parameters 3 Sigma

Other Laser Range, Earth Tides, Polar Motion, Marsh II Geodetics***

Arc Start Time	Arc Length (hrs)	No. of Stations	Observations: Range No. Available	Range No. Used	Range-Rate No. Available	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information: RHO ONE		PASSES		Run ID
780919	30	6*	69	66			0.16	1.48		0.81	0.83	3.41	3.45	-.56		15*		
780920	30	8	79	77			0.17	1.67		0.28	2.16	1.28	2.39	-.63		12		
780921	30	6	89	85			0.17	1.60		1.98	1.52	7.39	7.43	-.49		14		
780922	30	8	79	77			0.12	1.03		0.80	3.73	3.09	4.50	-.55		17		
780923	30	5	64	64			0.12	1.15						-.11		10		
												AVER	4.44					

*Number of Stations and Passes - Laser/USB Doppler

**Computation based on PGS-1040: Gravitational Constant GM = 398600.62 km^3/sec^2, Equatorial Radius R_e=6378.140 km and Inverse Flattening Coefficient = 298.257

***Ellipsoid Parameters for Marsh II Geodetics: Equatorial Radius R_e=6378.155 km and Inverse flattening coefficient=298.255

TABLE 6

SATELLITE AND TIME PERIOD SEASAT - September 1978

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for Both Laser and USB Doppler

Geopotential Model PGS-1040**

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.5

Drag Parameters C_D=2.1

Atmospheric Density Model H.P., F#150

Solve-For Parameters State and Rho one

Editing Parameters 3 Sigma

Other Laser Range and USB-Doppler, Earth Tides, Polar Motion, Marsh II Geodetics***

Arc Start Time	Arc Length (hrs)	No. of Stations	Observations: Range No. Available	Range No. Used	Range-Rate No. Available	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information: RHO ONE		PASSES		Run ID
780919	30	6/7*	69	66	403	345	1.10	1.52	1.92					-0.64		15/20*		
										0.67	0.40	2.22	2.25					
780920	30	8/9	79	75	371	325	1.15	1.50	2.06					-0.71		12/17		
										0.93	2.02	3.25	3.80					
780921	30	6/9	89	83	366	310	1.16	1.34	2.08					-0.49		14/20		
										1.69	0.91	3.95	4.00					
780922	30	8/10	79	77	513	427	0.99	1.10	1.84					-0.14		17/25		
										0.66	2.72	4.18	4.69					
780923	30	5/9	64	63	444	392	0.96	1.11	1.84					-0.20		10/21		
												AVER	3.68					

*Number of Stations and Passes - Laser/USB Doppler

**Computation based on PGS-1040: Gravitational Constant GM = 398600.62 km^3/sec^2, Equatorial Radius R_e=6378.140 km and Inverse Flattening Coefficient = 298.257

***Ellipsoid Parameters for Marsh II Geodetics Equatorial Radius R_e=6378.155 km and Inverse flattening coefficient=298.255

TABLE 7

SATELLITE AND TIME PERIOD SEASAT - September 1978

MAJOR RUN CHARACTERISTICS Approximately Equal Laser and USB Doppler Observations Per Pass

Geopotential Model PGS-1040**

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.5

Drag Parameters C_D=2.1

Atmospheric Density Model H.P., F#150

Solve-For Parameters State and Rho one

Editing Parameters 3 Sigma

Other Laser Range and USB-Doppler, Earth Tides, Polar Motion, Marsh II Geodetics***

Arc Start Time	Arc Length (hrs)	No. of Stations	Observations: Range No. Available	Observations: Range No. Used	Observations: Range-Rate No. Available	Observations: Range-Rate No. Used	Residual Statistics: Wtd. RMS	Residual Statistics: Standard Deviations Range (m)	Residual Statistics: Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information: RHO ONE		PASSES		Run ID
780919	30	6/7*	318	305	403	344	1.02	0.94	2.01	0.43	0.95	1.54	1.59	-.61		15/20*		
780920	30	8/9	230	224	371	324	1.15	1.26	2.05	0.64	2.59	2.57	3.15	-.71		12/17		
780921	30	6/9	305	280	366	310	1.19	1.25	2.10	1.70	0.93	7.10	7.11	-.54		14/20		
780922	30	8/10	360	338	513	427	1.01	0.90	1.90	0.55	3.11	2.70	3.87	-.12		17/25		
780923	30	5/9	200	198	444	392	1.00	1.02	1.91					-.17		10/21		
												AVER	4.05					

*Number of Stations and Passes - Laser/USB Doppler

**Computation based on PGS-1040: Gravitational Constant GM = 398600.62 km^3/sec^2, Equatorial Radius R_e=6378.140 km and Inverse Flattening Coefficient = 298.257

***Ellipsoid Parameters for Marsh II Geodetics: Equatorial Radius R_e=6378.155 km and Inverse flattening coefficient=298.255

TABLE 8

SATELLITE AND TIME PERIOD SEASAT - August 1978

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for USB Doppler

Geopotential Model PGS-1040**

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.5

Drag Parameters C_D=2.1

Atmospheric Density Model H.P., F#150

Solve-For Parameters State and Rho one

Editing Parameters 3 Sigma

Other USB-Doppler, Earth Tides Polar Motion, Marsh II Geodetics***

Arc Start Time	Arc Length (hrs)	No. of Stations	Observations: Range No. Available	Range No. Used	Range-Rate No. Available	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information: RHO ONE		PASSES		Run ID
780808	30	10*			470	400	.88		1.76					-.89		22*		
										0.93	4.89	9.78	10.90					
780809	30	10			538	429	.82		1.65					-.90		26		
										2.88	3.16	9.92	10.20					
780810	30	8			366	317	.55		1.11					-.11		17		
										1.41	6.64	10.20	11.90					
780811	30	8			335	276	.80		1.61					-.10		16		
										4.13	14.20	20.20	21.40					
780812	30	7			317	269	.83		1.66					-.74		14		
												AVER	13.60					

*Number of Stations and Passes - Laser/USB Doppler

**Computation based on PGS-1040: Gravitational Constant GM = 398600.62 km^3/sec^2, Equatorial Radius R_e=6378.140 km and Inverse Flattening Coefficient = 298.257

***Ellipsoid Parameters for Marsh II Geodetics: Equatorial Radius R_e=6378.155 km and Inverse flattening coefficient=298.255

TABLE 9

SATELLITE AND TIME PERIOD SEASAT - August 1978

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for Laser

Geopotential Model PGS-1040**

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.5

Drag Parameters C_D=2.1

Atmospheric Density Model H.P., F#150

Solve-For Parameters State and Rho one

Editing Parameters 3 Sigma

Other Laser Range, Earth Tides, Polar Motion, Marsh II Geodetics***

Arc Start Time	Arc Length (hrs)	No. of Stations	Observations: Range No. Available	Range No. Used	Range-Rate No. Available	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information: RHO ONE		PASSES		Run ID
780808	30	6*	135	87			2.05	1.85		1.33	2.92	6.78	7.19	-.81		11*		
780809	30	6	152	130			2.03	2.03		0.57	3.34	6.58	7.13	-.64		15		
780810	30	5	108	105			1.56	1.56		1.43	3.74	10.20	10.80	-.77		9		
780811	30	5	142	105			2.42	2.40		2.13	3.82	10.30	10.30	-.75		9		
780812	30	4	105	61			1.99	1.95						-.72		7		
												AVER	8.85					

*Number of Stations and Passes - Laser/USB Doppler

**Computation based on PGS-1040: Gravitational Constant GM = 398600.62 km^3/sec^2, Equatorial Radius R_e=6378.140 km and Inverse Flattening Coefficient = 298.257

***Ellipsoid Parameters for Marsh II Geodetics: Equatorial Radius R_e=6378.155 km and Inverse flattening coefficient=298.255

TABLE 10

SATELLITE AND TIME PERIOD SEASAT - August 1978

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data for Both Laser and USB Doppler

Geopotential Model PGS-1040**

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.5

Drag Parameters C_D=2.1

Atmospheric Density Model H.P., F#150

Solve-For Parameters State and Rho one

Editing Parameters 3 Sigma

Other Laser Range and USB-Doppler, Earth Tides, Polar Motion, Marsh II Geodetics***

Arc Start Time	Arc Length (hrs)	No. of Sta-tions	Observations: Range No. Avail-able	Observations: Range No. Used	Observations: Range-Rate No. Avail-able	Observations: Range-Rate No. Used	Residual Statistics: Wtd. RMS	Residual Statistics: Standard Deviations Range (m)	Residual Statistics: Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information: RHO ONE		PASSES		Run ID
780808	30	6/10*	135	83	470	400	1.07	1.40	1.87	1.53	0.91	8.78	8.85	-.82		11/22*		
780809	30	6/10	152	122	538	429	1.02	1.37	1.78	0.66	1.70	2.90	3.36	-.83		15/26		
780810	30	5/8	108	102	366	317	1.01	1.48	1.61	1.36	4.67	3.87	5.93	-.89		9/17		
780811	30	5/8	142	103	335	276	1.45	2.25	1.99	2.30	2.91	11.25	11.26	-.82		9/16		
780812	30	4/7	105	60	317	269	1.15	1.79	1.87					-.74		7/14		
												AVER	7.35					

*Number of Stations and Passes - Laser/USB Doppler

**Computation based on PGS-1040: Gravitational Constant GM = 398600.62 km^3/sec^2, Equatorial Radius R_e=6378.140 km and Inverse Flattening Coefficient = 298.257

***Ellipsoid Parameters for Marsh II Geodetics: Equatorial Radius R_e=6378.155 km and Inverse flattening coefficient=298.255

TABLE 11

SATELLITE AND TIME PERIOD GEOS-III February and March 1976

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for USB Doppler

Geopotential Model GEM 10B **
Lunar/Solar Gravitation YES
Solar Radiation Parameter C_R=1.45

Drag Parameters C_D=3.09
Atmospheric Density Model H.P., F#75
Solve-For Parameters State Vector

Editing Parameters 3 Sigma
Other USB-Doppler, Earth Tides Polar Motion, Marsh II Geodetics***

Arc Start Time	Arc Length (hrs)	No. of Sta-tions	Observations: Range No. Avail-able	Range No. Used	Range-Rate No. Avail-able	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information				Run ID
																PASSES		
760223	30	5*			53/147	40/95	.67	.9/1.5		1.0	1.4	4.7	4.8			15*		
760224	30	5			41/79	34/59	.47	.8/1.0		1.0	8.0	4.5	4.1			9		
760225	30	5			65/181	34/125	.50	1.0/1.0		0.7	2.4	2.2	2.8			19		
760226	30	4			34/172	28/123	.63	1.5/.2		0.6	1.9	2.9	3.2			15		
760227	30	4			51/167	44/132	.69	1.0/.5		0.5	8.5	3.7	8.9			16		
760228	30	5			53/115	44/92	.53	1.3/.9		1.5	10.8	9.8	14.6			13		
760229	30	5			39/109	30/81	.61	1.4/1.2		1.0	6.2	4.4	7.4			12		
760301	30	4			116	85	.45		.9	1.5	8.5	6.9	10.4			10		
760302	30	5			20/88	8/72	.52	.6/1.1								10		
												AVER	7.6					

*Number of Stations and Passes for USB Doppler

**Computation based on GEM 10B: GM = 398600.64 km^3/sec^2, R_e=6378.139 km and 1/f = 1/298.257

***Ellipsoid Parameters for Marsh II Geodetics: R_e=6378.155 km and 1/f = 1/298.255

TABLE 12

SATELLITE AND TIME PERIOD GEOS-III February and March 1976

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for USB Doppler

Geopotential Model GEM 10B **

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.45

Drag Parameters C_D=3.09

Atmospheric Density Model H.P., F#75

Solve-For Parameters State Vector

Editing Parameters 3 Sigma

Other USB-Doppler, Earth Tides Polar Motion, Marsh II Geodetics***

Arc Start Time Epoch at 15 hrs.	Arc Length (hrs)	No. of Stations	Observations: Range No. Available	Range No. Used	Range-Rate No. Available	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information		PASSES		Run ID
760223	30	5*		69/159		55/121	.55		0.8/1.2	1.1	10.8	3.5	11.2			17*		
760224	30	5		94/187		58/138	.51		1.0/1.0	0.4	5.2	1.2	5.4			21		
760225	30	5		67/263		46/193	.60		1.2/1.2	0.3	2.3	1.2	2.5			25		
760226	30	4		65/251		51/200	.65		1.1/1.4	0.1	6.0	1.1	6.0			23		
760227	30	4		79/193		67/163	.63		1.1/1.3	0.3	7.7	3.1	8.2			21		
760228	30	5		69/203		50/158	.65		1.7/1.2	1.5	9.9	6.1	11.4			21		
760229	30	5		13/154		11/110	.61		0.9/1.2	0.3	2.9	2.2	3.5			14		
760301	30	4			134	114	.57		1.1	0.2	5.2	0.9	5.3			12		
760302	30	5		32/134		8/105	.72		0.8/1.5							15		
												AVER	6.7					

*Number of Stations and Passes for USB Doppler

**Computation based on GEM 10B: GM = 398600.64 km^3/sec^2, R_e=6378.139 km and 1/f = 1/298.257

***Ellipsoid Parameters for Marsh II Geodetics: R_e=6378.155 km and 1/f = 1/298.255

TABLE 13

SATELLITE AND TIME PERIOD GEOS-III February and March 1976

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for USB Doppler

Geopotential Model GEM 10B **

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.45

Drag Parameters C_D=3.09

Atmospheric Density Model H.P., F#75

Solve-For Parameters State Vector

Editing Parameters 3 Sigma

Other USB-Doppler, Earth Tides Polar Motion, STDN Geodetics***

Arc Start Time Epoch at 15 hrs.	Arc Length (hrs)	No. of Sta-tions	Observations: Range No. Avail-able	Range No. Used	Range-Rate No. Avail-able	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information		PASSES		Run ID
760223	30	5*			69/159	55/123	1.88		3.1/4.0	5.3	31.9	11.4	33.4			17*		
760224	30	5			94/187	58/123	1.08		2.0/2.2	10.4	21.1	41.9	42.0			21		
760225	30	5			67/263	46/186	1.64		3.2/3.1	1.6	15.0	3.7	15.3			25		
760226	30	4			65/251	51/196	1.90		3.4/3.5	3.0	3.7	7.3	7.5			23		
760227	30	4			79/193	62/157	1.48		3.2/3.6	3.2	3.6	10.9	11.2			21		
760228	30	5			69/203	48/153	1.59		3.7/2.9	3.5	14.5	14.0	17.2			21		
760229	30	5			13/154	11/108	1.50		0.5/3.0	5.2	29.9	16.2	33.2			14		
760301	30	4			134	115	1.21		2.4	1.5	9.2	3.2	9.5			12		
760302	30	5			32/134	8/98	1.08		1.8/2.1							15		
												AVER	21.2					

*Number of Stations and Passes for USB Doppler

**Computation based on GEM 10B: GM = 398600.64 km^3/sec^2, R_e=6378.139 km and 1/f = 1/298.257

***Ellipsoid Parameters for STDN Geodetics: R_e=6378.139 km and 1/f = 1/298.255

TABLE 14

SATELLITE AND TIME PERIOD GEOS-III February and March 1976

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for USB Doppler

Geopotential Model GEM 10B **

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.45

Drag Parameters C_D=3.09

Atmospheric Density Model H.P., F#75

Solve-For Parameters State Vector

Editing Parameters 3 Sigma

Other USB-Doppler, Earth Tides Polar Motion, GEM 9 Geodetics***

Arc Start Time Epoch at 15 hrs.	Arc Length (hrs)	No. of Stations	Observations: Range No. Available	Range No. Used	Range-Rate No. Available	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information		PASSES		Run ID
760223	30	5*		69/	159	55/122	.75	1.	2/1.4	2.4	17.0	9.4	19.0			17*		
760224	30	5		94/	187	58/138	.71	1.	5/1.4	0.6	7.3	2.3	7.6			21		
760225	30	5		67/	263	42/194	.78	1.	4/1.5	0.5	0.5	1.5	1.5			25		
760226	30	4		65/	251	51/202	.94	2.	2/1.7	0.9	3.4	2.8	4.4			23		
760227	30	4		79/	193	63/163	.77	2.	0/1.3	1.2	1.2	5.1	5.2			21		
760228	30	5		69/	203	47/151	.94	2.	6/1.6	2.7	18.8	10.5	21.0			21		
760229	30	5		13/	154	11/103	.74	0.	9/1.3	2.6	12.8	10.3	16.0			14		
760301	30	4			134	105	.84		1.7	1.1	5.2	4.5	6.4			12		
760302	30	5		32/	134	8/104	.89	1.	1/1.8							15		
												AVER	11.8					

*Number of Stations and Passes for USB Doppler

**Computation based on GEM 10B: GM = 398600.64 km^3/sec^2, R_e=6378.139 km and 1/f = 1/298.257

***Ellipsoid Parameters for GEM 9 Geodetics: R_e=6378.139 km and 1/f = 1/298.255

TABLE 15

SATELLITE AND TIME PERIOD GEOS-III February and March 1976

MAJOR RUN CHARACTERISTICS Approximately 30 Second Data Rate for USB Doppler

Geopotential Model GEM 10B **

Lunar/Solar Gravitation YES

Solar Radiation Parameter C_R=1.45

Drag Parameters C_D=3.09

Atmospheric Density Model H.P., F#75

Solve-For Parameters State Vector

Editing Parameters 3 Sigma

Other USB-Doppler, Earth Tides Polar Motion, WGS Geodetics***

Arc Start Time Epoch at 15 hrs.	Arc Length (hrs)	No. of Stations	Observations: Range No. Available	Range No. Used	Range-Rate No. Available	Range-Rate No. Used	Residual Statistics: Wtd. RMS	Standard Deviations Range (m)	Standard Deviations Range-Rate (cm/sec)	Maximum COMPARE Position Differences (m): Radial	Cross-Track	Along-Track	Total	Solve-For Parameters and Other Information				Run ID
																PASSES		
760223	30	5*			69/159	55/117	.43		.8/0.9	1.2	20.8	6.5	21.4			17*		
760224	30	5			94/187	58/138	.75		1.2/1.5	0.4	4.7	1.8	5.0			21		
760225	30	5			67/263	46/194	.85		1.7/1.6	1.2	8.0	3.6	8.2			25		
760226	30	4			65/251	51/199	.77		1.5/1.5	0.7	9.2	2.8	9.5			23		
760227	30	4			79/193	67/163	.78		1.6/1.4	0.5	6.0	3.3	6.7			21		
760228	30	5			69/203	51/158	.76		1.9/1.2	1.7	13.4	7.4	14.8			21		
760229	30	5			13/154	11/110	.84		0.4/1.5	1.7	6.1	5.6	7.7			14		
760301	30	4			134	114	.55		1.1	0.6	12.6	2.0	12.6			12		
760302	30	5			32/134	8/105	.68		0.6/1.4							15		
												AVER	10.7					

*Number of Stations and Passes for USB Doppler

**Computation based on GEM 10B: GM = 398600.64 km^3/sec^2, ~~R_e=6378.139 km and 1/f = 1/298.257~~

***Ellipsoid Parameters for WGS Geodetics: R_e=6378.139 km and 1/f = 1/298.255

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