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MEAN ELEMENTS OF GEOS-I AND GEOS-II

by

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March 1972

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ABSTRACT

A combined analytical-numerical procedure for determining precise mean orbital elements is presented and applied to the orbits of GEOS-I and GEOS-II. The precision of the mean semi-major axes of these orbits is a few tens of centimeters when optical flash data is used to determine 2 day orbital arcs. Four day Minitrack orbits give mean semi-major axes of a few meters precision. The mean orientation parameters (i, Ω) are obtained to a precision of about $0\overset{''}{.}1$ (~3m) or better from the optical orbits. This precision is adequate for determinations of tidal parameters, particularly in the case of GEOS-II where the tidal perturbation of the inclination is 10".

1. Introduction

The most familiar method for study of the long periodic and secular perturbations of an orbit is to compare the variation of the mean elements of the orbit with the changes predicted by theory . This method has been used with success by many investigators to determine geopotential coefficients, and atmospheric and tidal parameters. It is the purpose of this paper to consider the problem of transforming osculating elements to mean elements with minimum loss of accuracy.

We begin by considering how accurately the osculating elements of an orbit can be determined. This is a complex question depending on the distribution and number of data, orbital arc length, model parameters used, etc., but some generalizations are possible due to recent efforts at Goddard Space Flight Center.

A recent paper by Marsh and Douglas (1971) concerning GEOS-I and GEOS-II shows that for orbital arcs of a few days duration, uncertainty of the geopotential, particularly resonant coefficients, is the most important error source. If resonant coefficients are adjusted the orbital error along-track can be reduced to a few milliseconds in time for a 5-1/2 day orbital arc heavily observed by optical trackers. This is equivalent to about 15 meters. Gaposchkin and Lambeck (1970) report position accuracy of similar magnitude for near-Earth orbits.

Marsh and Douglas (1971) show further that the orbit error tends to be of high frequency. The dominant period of the error is the period of the orbit itself. Thus a least squares fitting procedure will tend to treat this error as "noise" in the sense that the satellite is ahead in its orbit as often as it is behind its "true" position. We should expect the orbital elements to be very precise (if not accurate), indeed much more so than the satellite position itself. One should anticipate obtaining mean elements from relatively short orbital arcs that are precise to a few meters or less.

2. The Definition of the Mean Elements of an Orbit

We wish to remove the high frequency perturbations from a sequence of osculating element sets in order to study the long period and secular variations of the orbit. This will involve removal of the short periodic effects, i.e., those with periods equal to or less than the orbital period, and effects introduced by the rotation of the Earth, the m-daily effects of tesseral harmonics.

The dominant short periodic effects are due to the second zonal harmonic. The amplitude of these effects on satellites such as GEOS-I and GEOS-II is many kilometers. The first order effects are easy to remove by using the equations of Brouwer (1959), or, more generally, by using those of Kaula (1966). The first order short periodic and m-daily effects of tesseral harmonics are also easy to remove analytically, particularly if the previously mentioned development of Kaula (1966) is used. However, short periodic effects of the sun and moon, drag, radiation pressure, second order effects of oblateness, and the interaction of oblateness with other perturbations must also be considered. Obviously, the analytic calculation of all of these small effects is complex, particularly if accuracy at the 1 meter level or better is required. Thus we chose to use analytic techniques to remove only the dominant oblateness and tesseral harmonic perturbations, and to employ a numerical method for removal of the other perturbations. Although a purely numerical method to remove <u>all</u> high frequency perturbations may be theoretically possible, we shall see below that very great efficiency and accuracy is obtained by the combined method.

It is common to think of the mean elements of an orbit as "averages" in some sense. However, examination of the gravitational disturbing function shows that the perturbations do not all average out over the same period. For example, during an orbital revolution, the sun and moon move and the Earth rotates significantly. The time over which the short-periodic perturbations average out is slightly different than a revolution, and most importantly, is different for each perturbing source. Moreover, in satellite theories we usually take into account the motion of the node and perigee in the computation of short-periodic terms, that is, solutions take the form of forced oscillations about a secularly precessing Kepler ellipse. Thus the high frequency perturbations of the geopotential have the frequencies (Kaula, 1966):

$$i\dot{\omega} + j\dot{M} + k(\dot{\Omega} - \dot{\Theta}) \qquad 2.1$$

where i, j and k are integers, $\dot{\Theta}$ is the rotation rate of the Earth and $\dot{\omega}$, $\dot{M}$, $\dot{\Omega}$ are the Kepler element rates. Neither the short-periodic and m-daily geopotential perturbations average out over any common period. In the language of electrical engineering, we really need to <u>filter</u> the osculating elements with an ideal low-pass filter. Removal of high frequency terms by very accurate analytic methods approximates such a filter. A purely numerical averaging filter has relatively poor characteristics because of the lack of any unique period over which all frequencies exactly average. However, by confining the numerical averaging to small (<50m) effects, the error introduced by the averaging is tolerably small.

Considering these remarks, our scheme for determining mean elements takes the following form:

We first generate an ephemeris in terms of osculating elements at one minute intervals for 1 day. From each set of these elements are then subtracted the short periodic oblateness, m-daily, and resonant perturbations. These preliminary mean elements show a variation of 30-50 meters for the GEOS satellites. The preliminary elements are then fitted by least squares to a secularly precessing Kepler ellipse so that the nine parameters $\bar{a}, \bar{e}$, $\bar{I}$, ω_o, $\dot{\omega}$, Ω, $\dot{\Omega}$, M_o, and $\dot{M}$ are determined. The epoch of these elements is taken to be the mid-point of the averaging interval; of course the rates $\dot{\omega}$, $\dot{M}$ and $\dot{\Omega}$ are used to transform ω, M and Ω to this time. In this way long periodic and secular variations are properly represented in the averaged elements.

The necessity for this combined scheme is shown in Figure 1. Mean semi-major axes calculated by purely numerical averaging (X) and the combined method (·) are shown for 2 day GEOS-II optical data arcs. In the elements obtained purely numerically the subtle decay of the semi-major axis is not even detectible.

Figure 2 shows the mean semi-major axes of GEOS-I during 1965-66. Note that the precision is about 25 cm. GEOS-I suffers very large radiation pressure perturbations, as is obvious from the increase of more than 20m in the semi-major axis in early 1966. Figure 2 has been very useful for geodetic investigations involving GEOS-I because inconsistent data arcs are clearly distinguishable (for example, refer to the outlying arcs in April 1966).

Figure 3 shows the mean semi-major axes of GEOS-II for 1968 determined from 2 day optical data arcs. All arcs in this paper were reduced using BIH Polar Motion and UT1 data, the 1969 SAO Standard Earth (Gaposchkin and Lambeck, 1970) gravity model, and a worldwide network of SAO, NASA, and International participants optical tracking stations at coordinates estimated by Marsh, Douglas and Klosko (1971). Note that the orbit of GEOS-II is much more stable than that of GEOS-I against radiation pressure perturbations, although the decay in semi-major axis is highly variable.

Figure 4 presents the mean semi-major axes of GEOS-II where optical data was available in 1969. The precision is poorer than in 1968. No explanation is available.

It would be tempting to conclude from Figures 1-4 that the resonant coefficients for GEOS-I (12th order) and GEOS-II (13th order) must be known to extreme accuracy, because their effects on the mean elements were essentially perfectly removed. However, the beat periods for these orbits are only about 7 days, and the effect of an error in the coefficients tends to be reduced because of the relatively long averaging time. The recent investigation by Marsh and Douglas (1971) shows that the SAO 1969 Standard Earth models about 90% of the resonance effect for GEOS-II. The remaining uncertainty should be detectible in the GEOS-II mean semi-major axes, but the smoothing procedure has obliterated the effect.

Figure 5 shows the semi-major axes for GEOS-II in 1970 obtained from 4 day Minitrack-determined orbits. The scatter is about 2m, a precision sufficiently accurate for studies of atmospheric density. The orientation elements are less well-determined from the Minitrack data (i.e. about 10 arc seconds).

Mean elements for GEOS-I and GEOS-II obtained from optical arcs are given in Tables 1-4. The Minitrack elements are given in Table 5. All mean elements are referred to the true equator and equinox of date.

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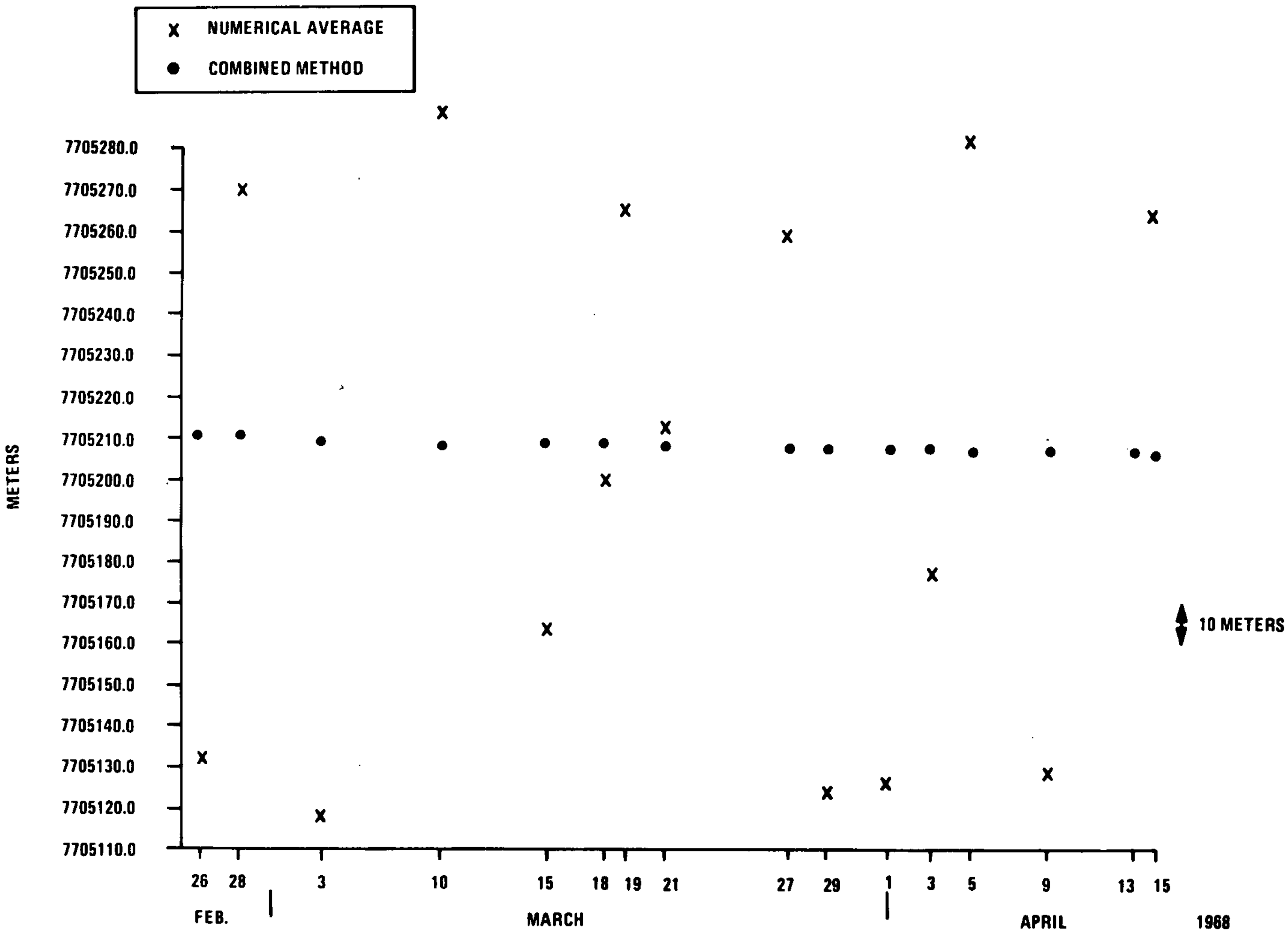

Figure 1. GEOS-II Mean Semi-Major Axis

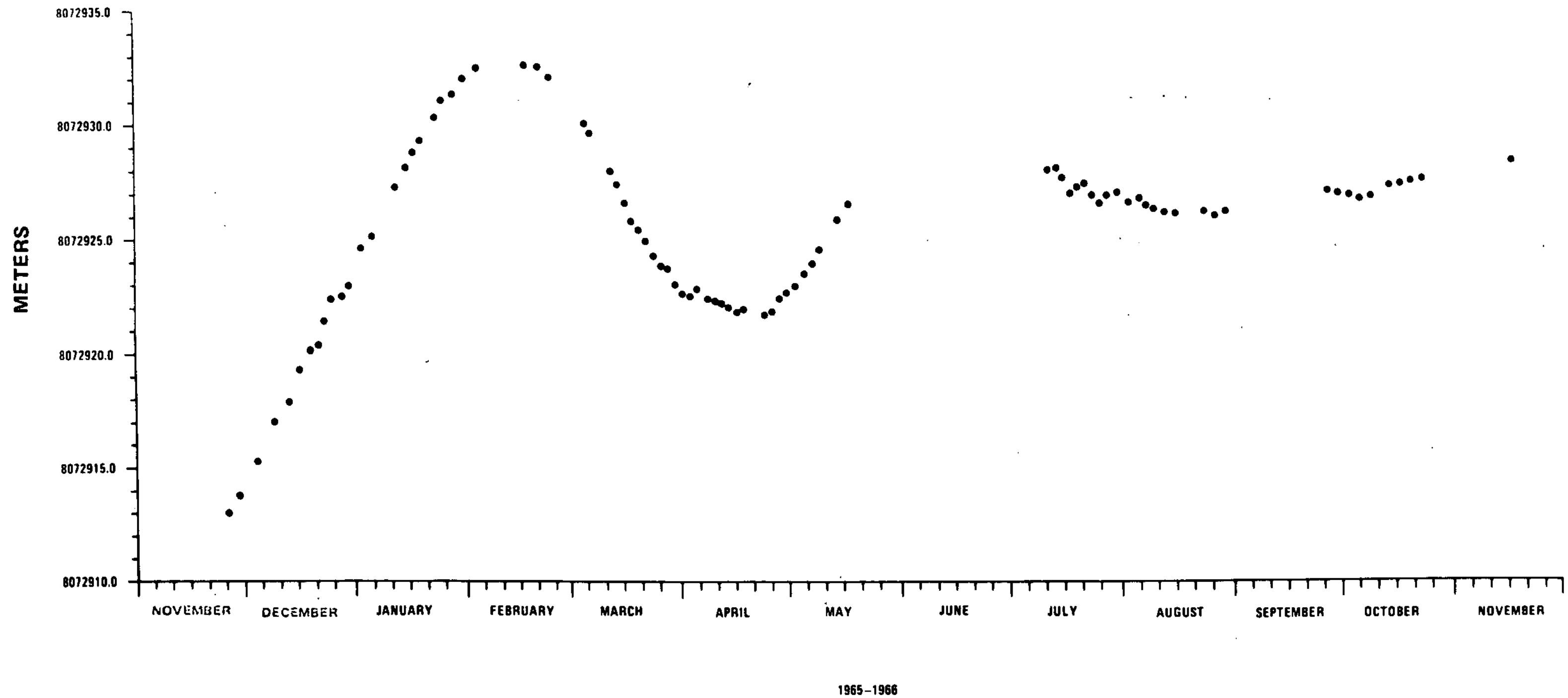

Figure 2. GEOS-I Mean Semi-Major Axis from Two-Day Optical Data

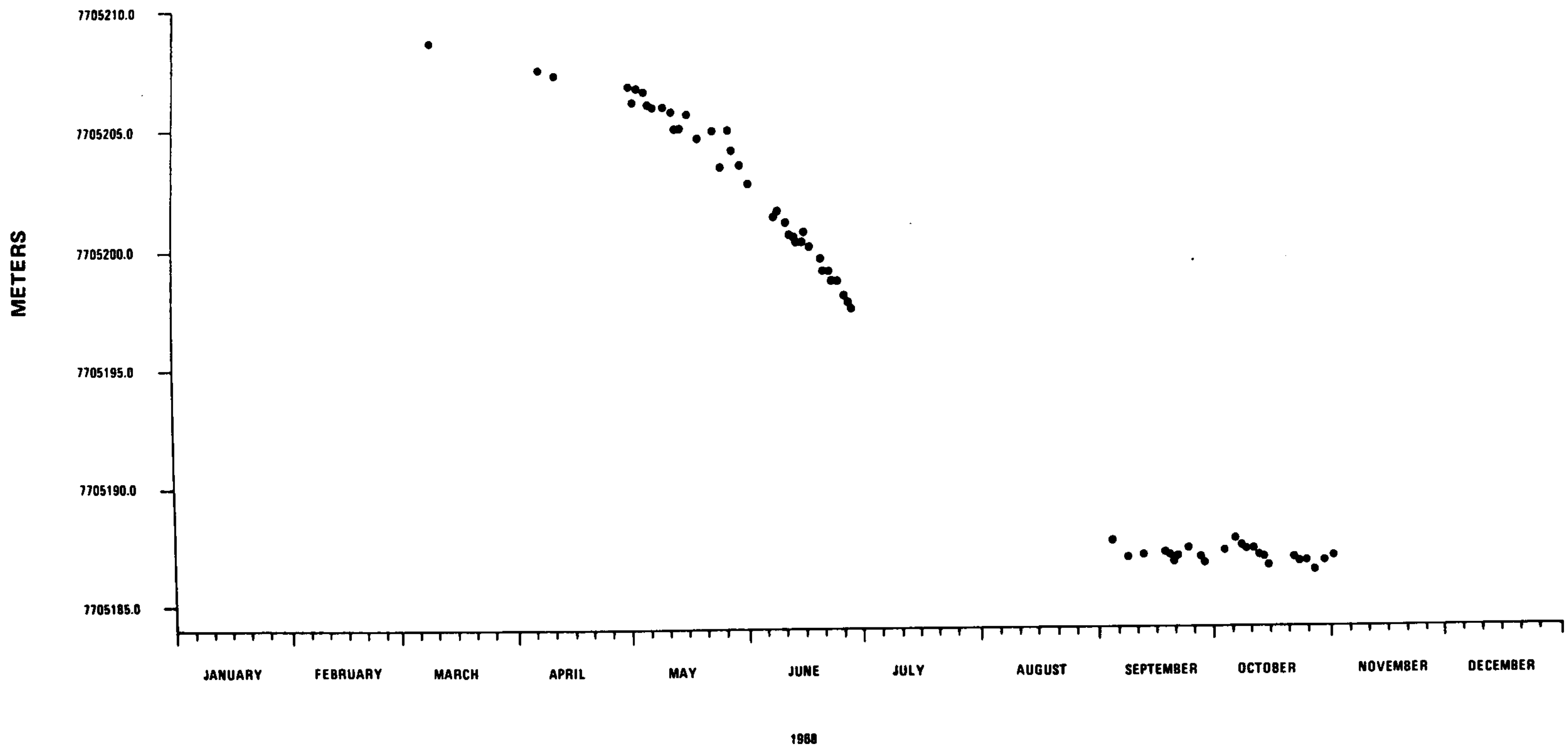

Figure 3. GEOS-II Mean Semi-Major Axis from Two-Day Optical Data

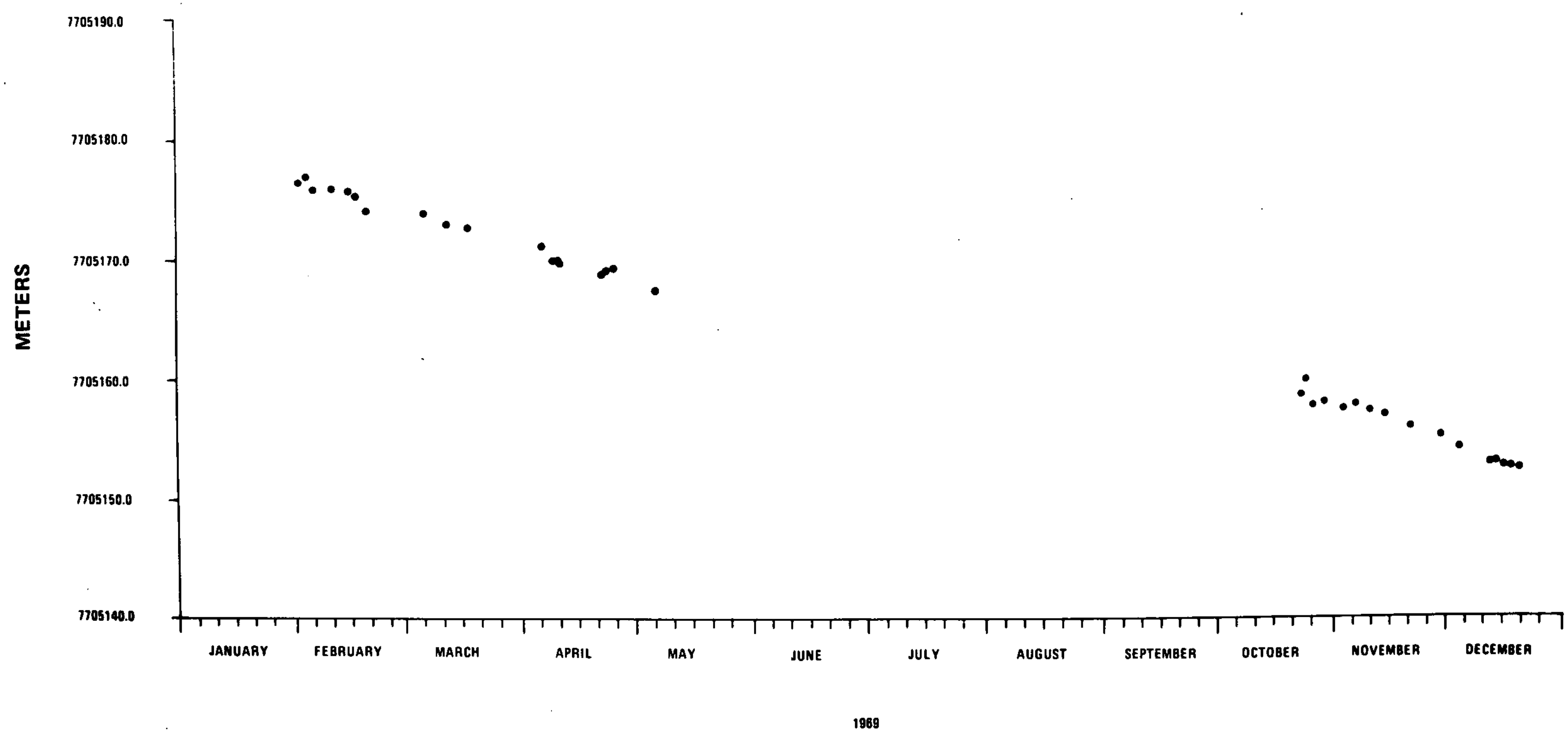

Figure 4. GEOS-II Mean Semi-Major Axis from Two-Day Optical Data

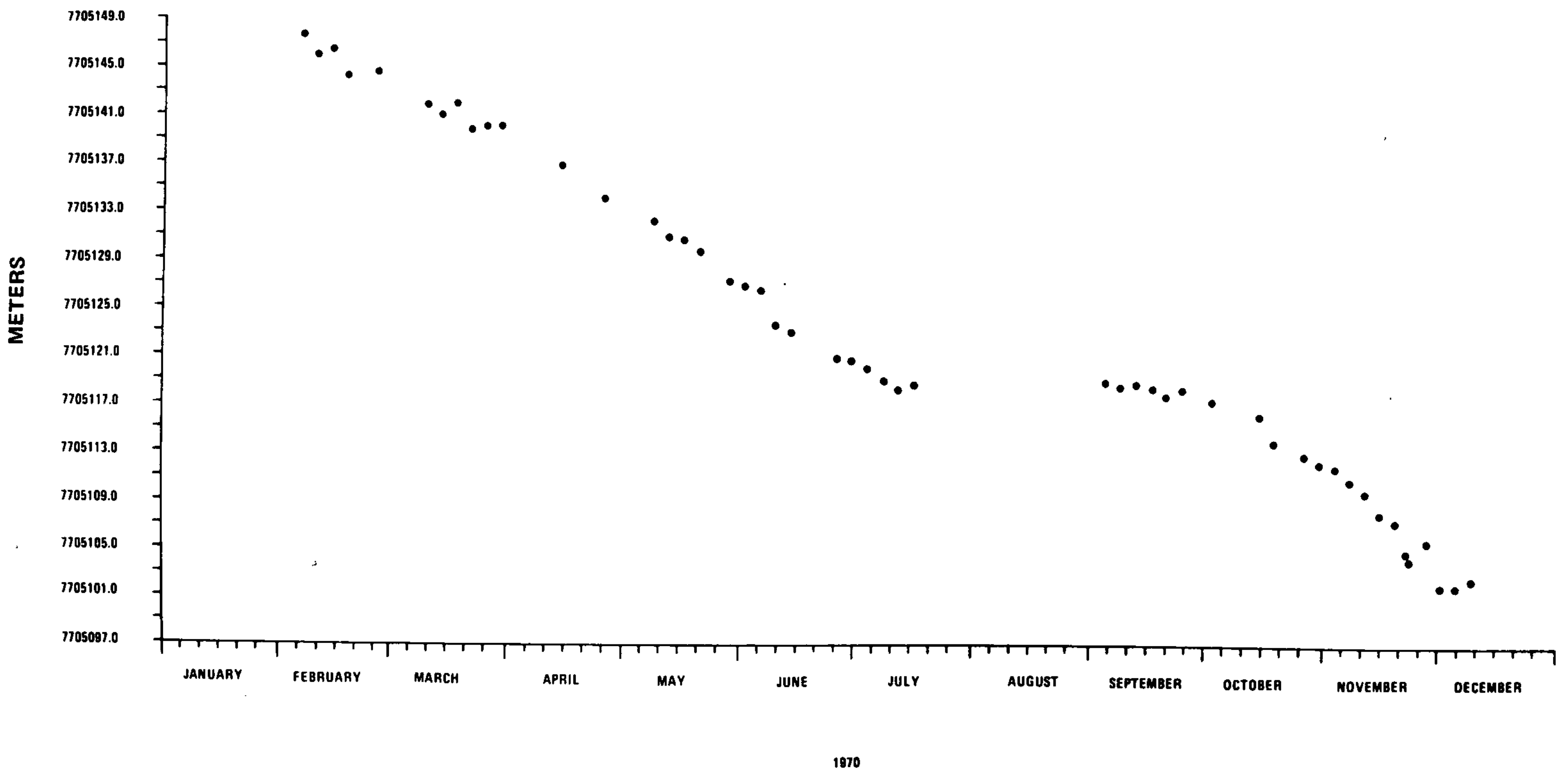

Figure 5. GEOS-II Mean Semi-Major Axis from Four-Day Minitrack Data

Table 1. GEOS-I Mean Elements from 2-Day Optical Data Arcs in 1965-66

TIME[1]	A[2]	E	INCL[3]	OMEGA[3]	NODE[3]	MEAN[3]
39089.5	1.26571290	.072047718	59.384463	161.874716	57.155645	353.944757
39092.5	1.26571302	.072001232	59.384249	163.821604	50.416149	319.022706
39139.5	1.26571527	.071332876	59.384446	194.488521	304.831246	131.461823
39141.5	1.26571537	.071305267	59.384717	195.798105	300.338105	108.146132
39147.5	1.26571562	.071235013	59.384342	199.735009	286.861621	38.182510
39149.5	1.26571572	.071209403	59.383471	201.049472	282.369339	14.858852
39155.5	1.26571588	.071131324	59.382835	204.990792	268.890284	304.890400
39176.5	1.26571596	.070887587	59.380931	218.828981	221.715161	59.952577
39182.5	1.26571588	.070830896	59.382598	222.793104	208.237045	349.558226
39188.5	1.26571556	.070775688	59.383073	226.760209	194.759713	279.968336
39193.5	1.26571982	.070747266	59.387515	230.168032	183.532884	221.523894
39195.5	1.26571523	.070726854	59.384470	231.396769	179.037113	198.308497
39199.5	1.26571502	.070695172	59.384165	234.045554	170.052596	151.655373
39207.5	1.26571466	.070649377	59.384261	239.357778	152.084041	58.339078
39209.5	1.26571459	.070637423	59.383469	240.686895	147.591331	35.012939
39213.5	1.26571447	.070612627	59.383456	243.343200	138.606216	348.366671
39215.5	1.26571443	.070602528	59.383867	244.671442	134.114045	325.043003
39217.5	1.26571438	.070596655	59.383664	246.004459	129.621612	301.713692
39219.5	1.26571444	.070589373	59.382771	247.336538	125.128537	278.366926
39222.5	1.26571437	.070572453	59.382156	249.330856	118.388267	243.404717
39224.5	1.26571435	.070562730	59.382734	250.660109	113.895481	220.083249
39226.5	1.26571434	.070554858	59.383416	251.990322	109.403199	196.755356
39228.5	1.26571431	.070548686	59.383490	253.320493	104.910760	173.434823
39230.5	1.26571427	.070543644	59.383380	254.652176	100.417812	150.109665
39232.5	1.26571429	.070535273	59.383163	255.984872	95.924720	126.783985
39234.5	1.26571426	.070508990	59.385247	259.974564	82.446335	56.815693
39240.5	1.26571428	.070507602	59.385942	261.304021	77.954534	33.490680
39242.5	1.26571436	.070506641	59.386021	262.635175	73.462406	10.163356
39244.5	1.26571440	.070503855	59.385964	263.967855	68.969782	346.835038
39246.5	1.26571444	.070497303	59.386561	265.299136	64.476772	323.507739
39249.5	1.26571454	.070493215	59.388054	267.289720	57.738616	288.520220
39251.5	1.26571460	.070493138	59.388547	268.616533	53.247270	265.192937
39253.5	1.26571470	.070495711	59.388467	269.945461	48.755670	241.862547
39261.5	1.26571501	.070500848	59.389020	275.265847	30.787399	148.531391
39354.5	1.26571491	.071252400	59.382925	336.905344	181.886003	143.652357
39357.5	1.26571387	.070736778	59.397148	338.467910	175.123970	109.186870
39258.5	1.26571490	.070497289	59.388398	273.275085	37.525224	183.527800
39359.5	1.26571495	.071310033	59.382535	340.200568	170.654494	85.352474
39362.5	1.26571491	.071349932	59.382558	342.173370	163.915366	50.379393
39365.5	1.26571495	.071385649	59.383481	344.143339	157.176716	15.407761
39393.5	1.26571509	.071729109	59.381058	2.486512	94.273425	49.025325
39396.5	1.26571508	.071767821	59.380462	4.441854	87.532545	14.072103
39399.5	1.26571506	.071810372	59.380997	6.394963	80.791643	339.118230
39402.5	1.26571503	.071854271	59.382114	8.351121	74.051862	304.158792
39405.5	1.26571506	.071891088	59.382529	10.307432	67.312465	269.197176
39408.5	1.26571511	.071928014	59.382521	12.258539	60.571885	234.241259
39413.5	1.26571514	.072001031	59.384736	15.507838	49.338582	175.581583
39416.5	1.26571515	.072040186	59.384942	17.461324	42.599740	141.017262
39419.5	1.26571518	.072075604	59.384799	19.409982	35.860178	106.059172
39444.5	1.26571528	.072381353	59.382323	35.610492	339.695051	174.765892
39450.5	1.26571513	.072448151	59.381997	39.482851	326.214473	104.878534

[1]MODIFIED JULIAN DAY

[2]EARTH RADII (a_e = 6378155 m).

[3]DEGREES

Table 2. GEOS-II Mean Elements from 2-Day Optical Data Arcs in 1968

TIME	A	E	INCL	OMEGA	NODE	MEAN
39923.5	1.20806230	.032829981	105.789563	76.770108	123.119100	328.975886
39952.5	1.20806211	.032421017	105.782087	30.680489	163.697282	357.158473
39956.5	1.20806208	.032333504	105.782057	24.276055	169.293050	112.816873
39976.5	1.20806199	.031858710	105.778977	351.944182	197.271072	331.419661
39977.5	1.20806190	.031836393	105.778762	350.313934	198.670057	270.363679
39978.5	1.20806199	.031812143	105.778555	348.684076	200.069097	209.307534
39980.5	1.20806196	.031764295	105.778282	345.413643	202.867038	87.206024
39981.5	1.20806189	.031740424	105.778354	343.775901	204.265983	26.157867
39982.5	1.20806187	.031716538	105.778567	342.142993	205.664813	325.105286
39985.5	1.20806187	.031647406	105.779238	337.225322	209.861456	141.965417
39987.5	1.20806183	.031601405	105.779585	333.941722	212.658727	19.877137
39988.5	1.20806172	.031575879	105.779476	332.305494	214.057393	318.828237
39989.5	1.20806173	.031555862	105.779455	330.664268	215.456427	257.783824
39991.5	1.20806182	.031514833	105.778790	327.375911	218.254547	135.701464
39994.5	1.20806166	.031456424	105.778471	322.427169	222.451619	312.596102
39997.5	1.20806172	.031401958	105.779056	317.469534	226.648533	129.500530
39998.5	1.20806170	.031383404	105.779299	315.815085	228.047413	68.470712
40000.5	1.20806148	.031347740	105.779874	312.503600	230.844782	306.413956
40003.5	1.20806158	.031298986	105.780238	307.536836	235.041325	123.329231
40005.5	1.20806149	.031266933	105.780007	304.218632	237.839261	1.280348
40007.5	1.20806136	.031243054	105.779637	300.897278	240.637113	239.235376
40014.5	1.20806115	.031167840	105.780535	289.247518	250.430382	172.112276
40015.5	1.20806118	.031159110	105.780929	287.581317	251.829239	111.057142
40017.5	1.20806112	.031145046	105.781562	284.246896	254.627160	349.068591
40018.5	1.20806103	.031138757	105.781597	282.577493	256.026057	288.056675
40019.5	1.20806102	.031132334	105.781580	280.910807	257.425174	227.042475
40020.5	1.20806099	.031127389	105.781362	279.244988	258.824276	166.027656
40021.5	1.20806099	.031123263	105.781148	277.577346	260.223626	105.015185
40022.5	1.20806105	.031119701	105.780889	275.910026	261.622872	44.002704
40023.5	1.20806096	.031118345	105.780766	274.241973	263.022150	342.991188
40026.5	1.20806087	.031115588	105.781157	269.235588	267.219307	159.960620
40027.5	1.20806080	.031117441	105.781490	267.567695	268.618370	98.949728
40028.5	1.20806080	.031116985	105.781725	265.897043	270.017296	37.941972
40029.5	1.20806074	.031120523	105.782052	264.227949	271.416265	336.932560
40030.5	1.20806073	.031123782	105.782365	262.557346	272.815164	275.924671
40032.5	1.20806064	.031130225	105.782984	259.220161	275.613085	153.905507
40033.5	1.20806059	.031133402	105.783137	257.552237	277.012177	92.895590
40034.5	1.20806055	.031138061	105.783151	255.884186	278.411281	31.885622
40106.5	1.20805890	.032569276	105.791906	138.319133	19.157284	317.149166
40110.5	1.20805892	.032634296	105.792702	131.953476	24.755982	72.848753
40116.5	1.20805894	.032720367	105.792175	122.423970	33.153461	66.383333
40117.5	1.20805892	.032732564	105.792325	120.838506	34.553049	5.303490
40118.5	1.20805888	.032744354	105.792646	119.253257	35.952611	304.223535
40119.5	1.20805891	.032756039	105.793186	117.667782	37.352254	243.143821
40122.5	1.20805856	.032784443	105.794774	112.916703	41.551878	59.897806
40125.5	1.20805890	.032809483	105.795453	108.167497	45.751675	236.649522
40126.5	1.20805889	.032815356	105.795264	106.584508	47.151501	175.566470
40131.5	1.20805895	.032842642	105.794756	98.677890	54.150488	230.146689
40134.5	1.20805903	.032849685	105.795860	93.936460	58.350417	46.852499
40136.5	1.20805896	.032853038	105.796766	90.778075	61.150844	284.720371
40137.5	1.20805894	.032853847	105.797106	89.198984	62.550992	223.634122
40139.5	1.20805895	.032852829	105.797577	86.039879	65.351188	101.461800
40141.5	1.20805890	.032848274	105.797598	82.878992	68.151650	339.291572
40142.5	1.20805891	.032846143	105.797552	81.299892	69.551738	278.205874
40143.5	1.20805884	.032842630	105.797343	79.721352	70.951765	217.119802
40150.5	1.20805889	.032797248	105.797927	68.653859	80.752998	149.536653
40151.5	1.20805887	.032787233	105.798324	67.070595	82.153425	88.455250
40153.5	1.20805887	.032769099	105.799152	63.907490	84.954561	326.288338
40155.5	1.20805881	.032747992	105.799318	60.743530	87.755456	204.122791
40158.5	1.20805888	.032712023	105.798556	55.990713	91.955898	20.882366
40160.5	1.20805891	.032697770	105.798321	52.815944	94.752101	258.933357

Table 3. GEOS-II Mean Elements from 2-Day Optical Data Arcs in 1969

TIME	A	E	INCL	CMEGA	NODE	MEAN
40253.5	1.20805728	.031144348	105.800989	260.913804	225.031050	343.314375
40255.5	1.20805735	.031152447	105.801014	257.585263	227.833454	221.333759
40257.5	1.20805720	.031163520	105.801518	254.258436	230.635504	99.351548
40262.5	1.20805721	.031204049	105.803019	245.943785	237.640264	154.395329
40266.5	1.20805719	.031245901	105.802449	239.299204	243.244824	270.423864
40268.5	1.20805713	.031270617	105.802068	235.982919	246.047632	148.433839
40271.5	1.20805693	.031313189	105.802428	231.013648	250.250814	325.444911
40285.5	1.20805690	.031578077	105.802257	207.915960	269.865302	191.413108
40290.5	1.20805669	.031687462	105.803421	199.716074	276.869434	246.358758
40291.5	1.20805675	.031711432	105.803638	198.081794	278.270281	185.341621
40297.5	1.20805667	.031858321	105.802350	188.295882	286.676158	179.217328
40316.5	1.20805645	.032318523	105.799777	157.602204	313.288659	99.569227
40319.5	1.20805624	.032384677	105.800224	152.790757	317.489653	276.433674
40320.5	1.20805627	.032406058	105.800469	151.192279	318.889961	215.382739
40321.5	1.20805621	.032427096	105.800683	149.595988	320.290233	154.329558
40332.5	1.20805610	.032635068	105.797604	132.059796	335.693350	202.727456
40333.5	1.20805612	.032651466	105.797643	130.470128	337.093263	141.668717
40335.5	1.20805615	.032681444	105.797840	127.294985	339.893341	19.546804
40346.5	1.20805584	.032806800	105.794910	109.862891	355.293239	67.850048
40516.5	1.20805448	.031772242	105.781859	19[illegible].000130	233.141737	135.235435
40517.5	1.20805452	.031796620	105.782362	191.367598	234.540816	74.225669
40519.5	1.20805434	.031845104	105.783441	188.107522	237.338744	312.200632
40522.5	1.20805440	.031919758	105.784515	183.224914	241.535780	129.157343
40527.5	1.20805432	.032046886	105.784595	175.114496	248.532282	184.059779
40530.5	1.20805436	.032121108	105.784980	170.263763	252.730395	0.588299
40534.5	1.20805431	.032217349	105.787029	163.812851	258.327260	116.878565
40538.5	1.20805420	.032310780	105.788661	157.389464	44.678820	232.740412
40546.5	1.20805406	.032485549	105.789122	144.577027	275.121117	104.439743
40553.5	1.20805394	.032611688	105.791992	133.426532	284.917470	37.122657
40559.5	1.20805379	.032689642	105.791863	125.484914	291.916298	91.878122
40565.5	1.20805361	.032783899	105.794699	112.802867	303.113292	323.473841
40568.5	1.20805361	.032800421	105.795222	109.638194	305.913078	201.366766
40570.5	1.20805353	.032813188	105.795028	106.479222	308.712979	79.255759
40572.5	1.20805352	.032826963	105.794676	103.315342	311.512799	317.150629
40574.5	1.20805348	.032833310	105.794631	100.153566	314.312418	195.044478

Table 4. GEOS-II Mean Elements from 4-Day Minitrack Data Arcs in 1970

TIME	A	E	INCL	OMEGA	NODE	MEAN
40622.5	1.20805273	.032330088	105.803069	24.031393	21.524508	144.905319
40626.5	1.20805247	.032237105	105.803973	17.615190	27.129898	260.813351
40630.5	1.20805256	.032132866	105.806208	11.166419	32.731722	16.755234
40634.5	1.20805223	.032039400	105.804752	4.717910	38.333635	132.659568
40642.5	1.20805226	.031848181	105.808746	351.722570	49.542022	4.658630
40654.5	1.20805180	.031560956	105.806043	332.090783	66.356729	352.853117
40658.5	1.20805169	.031465461	105.808168	325.518555	71.961678	108.935934
40662.5	1.20805183	.031393224	105.807551	318.925389	77.566777	225.043674
40666.5	1.20805149	.031326211	105.805020	312.292535	83.170136	341.192204
40670.5	1.20805153	.031257359	105.809066	305.671810	88.776729	97.331558
40674.5	1.20805157	.031219229	105.808912	299.051231	94.381210	213.472452
40690.5	1.20805104	.031115013	105.808490	272.425398	116.804784	318.191139
40702.5	1.20805062	.031163930	105.803610	252.440243	133.619433	306.770053
40714.5	1.20805032	.031311201	105.803131	232.511984	150.433118	295.308295
40718.5	1.20805011	.031369772	105.802505	225.907544	156.037794	51.454571
40722.5	1.20805008	.031439048	105.801356	219.319287	161.642459	167.598017
40726.5	1.20804992	.031531096	105.801882	212.721002	167.245932	283.733815
40734.5	1.20804954	.031692495	105.800213	199.608601	178.454744	155.952111
40738.5	1.20804948	.031795839	105.801966	193.076085	184.057078	272.040862
40742.5	1.20804943	.031896294	105.800241	186.569900	189.660766	28.109005
40746.5	1.20804897	.032000477	105.798525	180.060865	195.264806	144.181443
40750.5	1.20804889	.032103308	105.801036	173.595775	200.867102	260.213297
40762.5	1.20804855	.032400056	105.800031	154.393321	217.675903	248.223540
40766.5	1.20804853	.032479255	105.801323	147.919839	223.278104	4.185032
40770.5	1.20804840	.032555745	105.799797	141.541108	228.881770	120.144159
40774.5	1.20804827	.032634001	105.797933	135.189732	234.483883	236.079251
40778.5	1.20804816	.032695158	105.798660	128.821038	240.086248	352.032374
40782.5	1.20804822	.032750272	105.800255	122.480878	245.686460	107.958420
40832.5	1.20804825	.032581773	105.795792	43.364825	315.700630	296.911512
40836.5	1.20804819	.032496816	105.794409	36.973581	321.298901	52.887887
40840.5	1.20804825	.032417342	105.793667	30.588947	326.899377	168.857519
40844.5	1.20804819	.032336686	105.794896	24.176391	332.497513	284.849364
40848.5	1.20804807	.032251779	105.791738	17.756980	338.098239	40.851677
40852.5	1.20804818	.032156357	105.792660	11.320954	343.697925	156.872219
40860.5	1.20804801	.031953779	105.791364	358.375084	354.894564	28.984253
40872.5	1.20804782	.031685385	105.791626	338.793096	11.691498	17.325988
40876.5	1.20804748	.031583068	105.790467	332.231395	17.288057	133.475353
40884.5	1.20804729	.031430297	105.787678	319.053416	28.486122	5.844201
40888.5	1.20804722	.031358979	105.790446	312.432087	34.084616	122.004118
40892.5	1.20804713	.031315432	105.790658	305.842531	39.684827	238.254308
40896.5	1.20804698	.031248629	105.787919	299.173777	45.284329	354.531777
40900.5	1.20804681	.031205782	105.790209	292.501824	50.881212	110.815660
40904.5	1.20804655	.031163466	105.787647	285.848844	56.481328	227.078892
40908.5	1.20804642	.031147907	105.788407	279.151611	62.077684	343.393237
40910.5	1.20804604	.031138484	105.787697	275.839829	64.871594	200.351828
40912.5	1.20804596	.031140682	105.786241	272.478413	67.679066	99.687940
40916.5	1.20804617	.031145501	105.790085	265.844137	73.277720	215.948012
40920.5	1.20804573	.031162848	105.788235	259.171084	78.876128	332.246748
40924.5	1.20804559	.031198578	105.786853	252.530336	84.476316	88.518011
40928.5	1.20804571	.031235400	105.788810	245.862825	90.075498	204.823027
40932.5	1.20804543	.031279981	105.789355	239.228176	95.673734	321.093979