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GEODETIC RESULTS FROM ISAGEX DATA

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AUGUST 1974

GSFC

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ISAGEX DATA

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ABSTRACT

Laser and camera data taken during the International Satellite Geodesy Experiment (ISAGEX) have been used in dynamical solutions to obtain center-of-mass coordinates for the Astro-Soviet camera sites at Helwan, Egypt and Oulan Bator, Mongolia and East European camera sites at Potsdam, German Democratic Republic and Ondrejov, Czechoslovakia. The results are accurate to about 20m in each coordinate. The orbit of PEOLE ($i = 15°$) has also been determined from ISAGEX data and mean Kepler elements suitable for geodynamic investigations are presented.

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INTRODUCTION

The ISAGEX experiment was initiated by the French Centre National d'Etudes Spatiales (CNES) in the autumn of 1969 through a proposal for an international laser and photographic campaign on satellites equipped with laser reflectors.

The ISAGEX experiment was endorsed by the COSPAR XIIIth General Assembly, Leningrad, 1970. The objective of the program was to collect a set of homogeneous and well distributed precise laser and camera satellite observations for the purposes of dynamic and geometric geodesy. The experiment involved seventeen countries and over fifty tracking stations. The data gathering portion of the experiment extended from December 1970 to September 1971.

The results of a dynamical solution which combined ISAGEX laser data with the optical and laser tracking data recorded during the National Geodetic Satellite Program (NGSP) and the CNES/SAO 1968 Observing Program have been reported previously by Marsh, et al. (1973). This solution provided coordinates for over 70 globally distributed tracking stations. Also very preliminary analyses of Astro-Soviet and East European camera data received as of May 1973 were reported by Marsh, Douglas and Klosko (1973b). The present paper represents a continuation of the analyses of the ISAGEX data using the laser and optical data available as of May 1974 to refine coordinates for the camera stations.

DYNAMICAL SOLUTIONS FOR STATION COORDINATES

The orbital and station coordinate recovery solutions were derived through the use of the GEODYN program (Martin, 1972) on the GSFC IBM 360/95 computer. GEODYN is a multiple arc, multiple satellite orbit and geodetic parameter estimation system based upon Cowell-type numerical integration techniques. Model parameters included luni-solar gravitational perturbations, solar radiation pressure, the Jacchia Model Atmosphere (1965, 1968, 1970, 1971) for drag computation, BIH polar motion and UTI data, and the GEM-1 gravity model (Lerch, et al. 1972) modified by the use of the resonant coefficients from the SAO 1969 S.E. II (Gaposchkin and Lambeck, 1970). This gravity model was used to insure consistency with the GSFC 1973 solution.

In the present effort, we have been primarily concerned with computation of orbital residuals from the Astro-Soviet and Eastern European data and a dynamical adjustment of the coordinates for these sites since data from these stations have not previously been available. The stations are:

ASTRO-SOVIET	EAST EUROPEAN
Oulan Bator, Mongolia	Ondrejov, Czechoslovakia
Helwan, Egypt	Potsdam, German Democratic Republic

The Astro-Soviet instruments were the AFU-75 tracking cameras and the East European stations used the Zeiss SBG camera. Figure 1 shows the locations of these stations, along with the other stations which participated in the ISAGEX. Table 1 presents a summary of the data used from these four stations, along with the RMS values of the residuals in the solutions. Data was contributed by several other Astro-Soviet and East European camera stations but were not analyzed since sufficient numbers of observations were not available for dynamical orbit computations. However, the data could be used in geometric analyses.

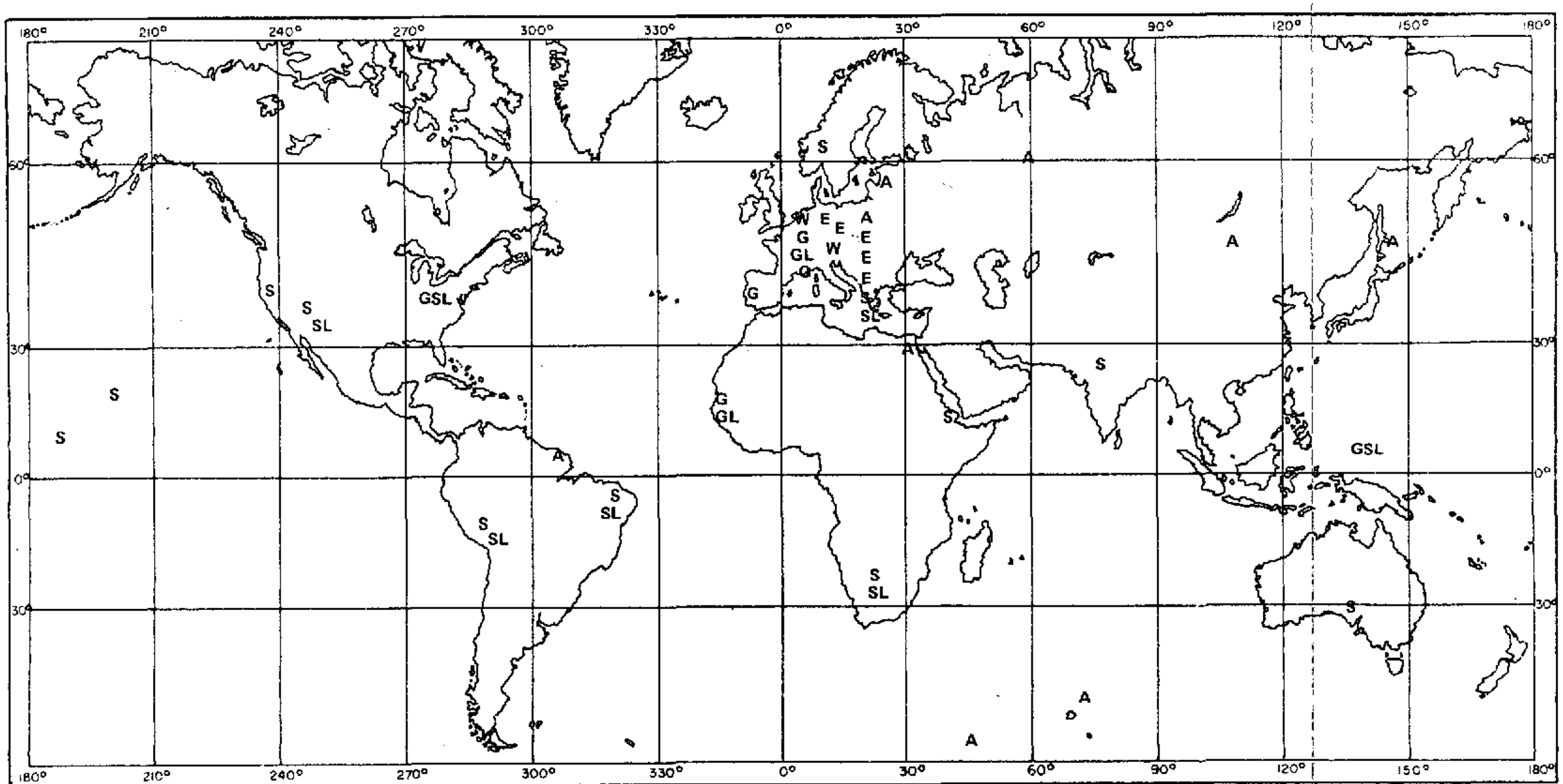
These data were preprocessed with corrections applied in accordance with the information provided in ISAGEX Report No. 16, "Data Handling Booklet" (Brachet 1973). In the case of the Astro-Soviet data, we applied corrections for annual and diurnal aberration and parallactic refraction; precession and nutation were applied to convert from the reference system with a mean equator and

Table 1

Summary of Astro-Soviet and East Europe Camera Data
Used in Dynamical Computations

Station	Right Ascension* (α)		Declination (δ)	
	No.	R.M.S.	No.	R.M.S.
Oulan Bator, Mongolia	27	3.0 arc sec	29	4.2 arc sec
Helwan, Egypt	46	2.9 arc sec	47	2.8 arc sec
Ondrejov, Czechoslovakia	32	3.5 arc sec	32	6.0 arc sec
Potsdam, German Democratic Republic	25	4.0 arc sec	26	4.6 arc sec

*Right Ascension Residuals have been multiplied by cos δ.



A	ASTROSOVIET CAMERA	GSL	GSFC LASER
E	EAST EUROPEAN CAMERA	S	SAO CAMERA
G	GRGS (FRENCH) CAMERA	SL	SAO LASER
GL	GRGS LASER	W	WEST EUROPEAN CAMERA

Figure 1. Locations of Stations Which Collected Data During the International Satellite Geodesy Experiment

equinox of 1950.0 to a true of date system. The passive observation time tags were converted from USSR UT1 time to U.S. Naval Observatory (USNO) UTC time.

Corrections for annual and diurnal aberration were already applied to the data from Potsdam (1181) and Ondrejov (1147). We applied parallactic refraction to the Ondrejov data. The passive observation times for these data were converted from the BIH UTC system to the USNO UTC system.

In this solution, coordinates for the ISAGEX lasers and other cameras were held fixed at the values derived earlier by Marsh, et al., (1973). Thus, these new coordinates were determined from combined laser/optical reference orbits.

In the interest of efficient use of the computer, and since little overlap existed in the data, separate multi-arc solutions were made for each of the 4 site locations. Table 2 presents the arcs used in these solutions. Note that the solution for Helwan consisted of GEOS-1 data alone. GEOS-2 data could not be used because of large inconsistencies. If this problem could be solved, the solution would probably be significantly improved. In contrast, only GEOS-2 data (flashes) could be used for the Ondrejov solution, since there was a problem of timing system fluctuations as large as 7ms for passive satellites at this station.

EVALUATION OF STATION COORDINATES

Table 3 presents the results obtained from this investigation and those provisional values given in ISAGEX Report No. 7 (Brachet, 1970). Differences between the provisionally available coordinates and the new values range from a few tens of meters to a few hundred meters.

The largest error source in this analysis is due to uncertainty in the modeling of the Earth's gravity field. As a means of assessing the magnitude of this error, the solutions were computed using the SAO 1969 (Gaposchkin and Lambeck, 1970) gravity model as well as the GSFC GEM-1 model mentioned earlier. The differences in the adjusted latitude and longitude coordinates were less than 20 meters in every case, while the height coordinate differences were less than 10 meters. Since the GEM-1 model gave a lower (by almost a factor of two) residual rms it is concluded that the GEM-1 solution is more accurate. Thus, the coordinate errors due to gravity model uncertainty are probably less than the differences in the two sets of coordinates and are assessed as less than 20 meters in latitude and longitude and less than 10 meters in height.

An initial height comparison at Oulan Bator indicated a difference on the order of 1400 meters between the dynamically derived value and the value of 175 m provided in the ISAGEX Report No. 7 (Brachet, 1970). Further checking with the

Table 2

Orbital Arcs Used in Dynamic Solutions

	Satellite	Begin					End				
		yr.	mo.	day	hr.	min.	yr.	mo.	day	hr.	min.
					Oulan Bator						
Arc 1	GEOS 1	71	02	23	02	15	71	02	25	22	14
Arc 2	GEOS 1	71	02	26	02	31	71	02	28	22	28
Arc 3	GEOS 2	71	04	13	18	40	71	04	14	21	47
Arc 4	GEOS 2	71	04	16	07	28	71	04	19	04	12
					Potsdam						
Arc 1	GEOS 1	71	03	02	00	40	71	03	06	20	54
Arc 2	GEOS 2	71	04	03	07	00	71	04	05	05	09
Arc 3	GEOS 1	71	07	01	02	29	71	07	03	02	53
					Ondrejov						
Arc 1	GEOS 2	71	04	01	01	48	71	04	04	19	31
Arc 2	GEOS 2	71	04	13	02	14	71	04	15	23	22
Arc 3	GEOS 2	71	04	19	04	05	71	04	21	08	35
Arc 4	GEOS 2	71	04	29	01	51	71	05	02	20	32
Arc 5	GEOS 2	71	08	13	01	11	71	08	16	00	40
					Helwan						
Arc 1	GEOS 1	71	07	05	00	20	71	07	08	01	09
Arc 2	GEOS 1	71	07	11	22	44	71	07	14	03	00
Arc 3	GEOS 1	71	07	20	21	41	71	07	22	22	02
Arc 4	GEOS 1	71	07	23	19	31	71	07	25	23	55
Arc 5	GEOS 1	71	07	26	20	01	71	07	30	20	32

Table 3

Astro-Soviet and East European Station Coordinate Values

Station		Latitude (Deg, Min, Sec)			Longitude (E.) (Deg, Min, Sec)			Height (Meters)
Oulan Bator, Mongolia	New Value	47	51	55.1	107	3	10.7	1540
	Old Value*	47	51	56	107	3	00	1505
	Difference			.9			10.7	35
Helwan, Egypt	New Value	29	51	31.6	31	20	32.5	97
	Old Value*	29	51	31.1	31	20	28.05	120
	Difference			.5			4.45	23
Ondrejov, Czechoslovakia	New Value	49	55	15.8	14	47	55.4	525
	Old Value*	49	55	19.4	14	48	3.9	537
	Difference			3.6			8.5	12
Potsdam, GDR	New Value	52	22	49.7	13	3	54.1	147
	Old Value*	52	22	51.4	13	3	58.8	136
	Difference			1.7			4.7	11
Coordinates are referred to an ellipsoid with: a_e = 6378155 meters, 1/f = 298.255								

*From Brachet, 1970.

Defense Mapping Agency/Topographic Command (Niska, 1974) revealed that the MSL height should be 1550 m. Thus using a geoid height of -45 meters (Marsh and Vincent, 1974) results in an ellipsoidal height of 1505 m or a difference of 35 meters with respect to the dynamic value.

An additional comparison was possible for the height coordinate at Potsdam since a value for the surveyed height above mean sea level (MSL) was provided. To this value of 109 meters, the geoid height of 27 meters from the GEM-6 detailed gravimetric geoid (Marsh and Vincent, 1974) was added resulting in an implied height above the reference ellipsoid of 136 meters, 11 meters less than the value recovered dynamically. This level of agreement is considered good since the 11 meter difference includes errors in the dynamical recovery, MSL survey errors, and errors in the geoid.

The quality of simultaneous data is important to consider. Figures 2 and 3 show the residuals in right ascension times cosine declination ($\alpha \cos \delta$) and declination (δ) for typical simultaneous passes of Helwan with Dionysos, Greece and with Debra Zeit (DEZEIT), Ethiopia. The consistency is generally very good,

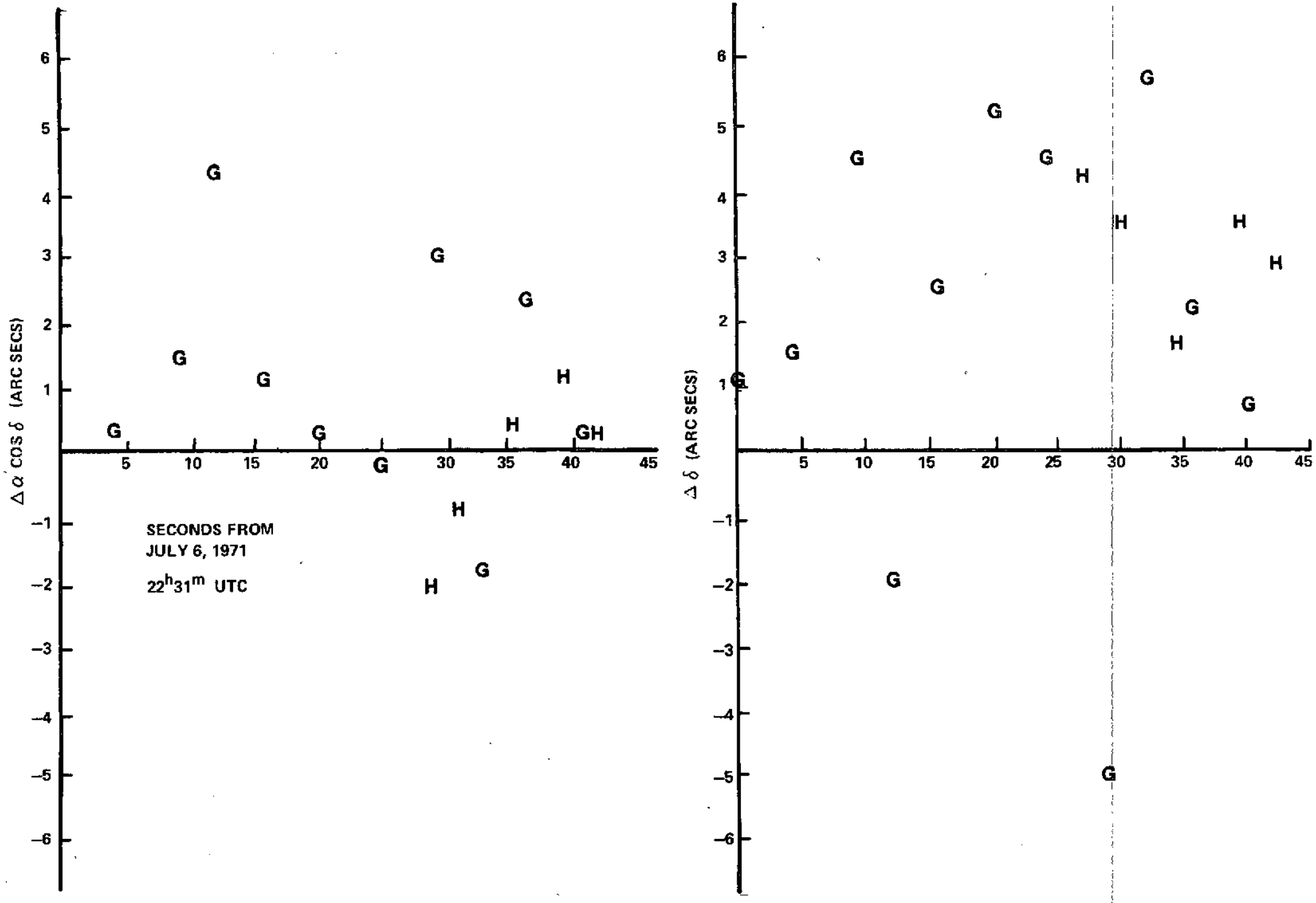


Figure 2. Residuals from Simultaneous Observation of GEOS-1 by Cameras at Dionysos, Greece, (G), and Helwan, Egypt, (H)

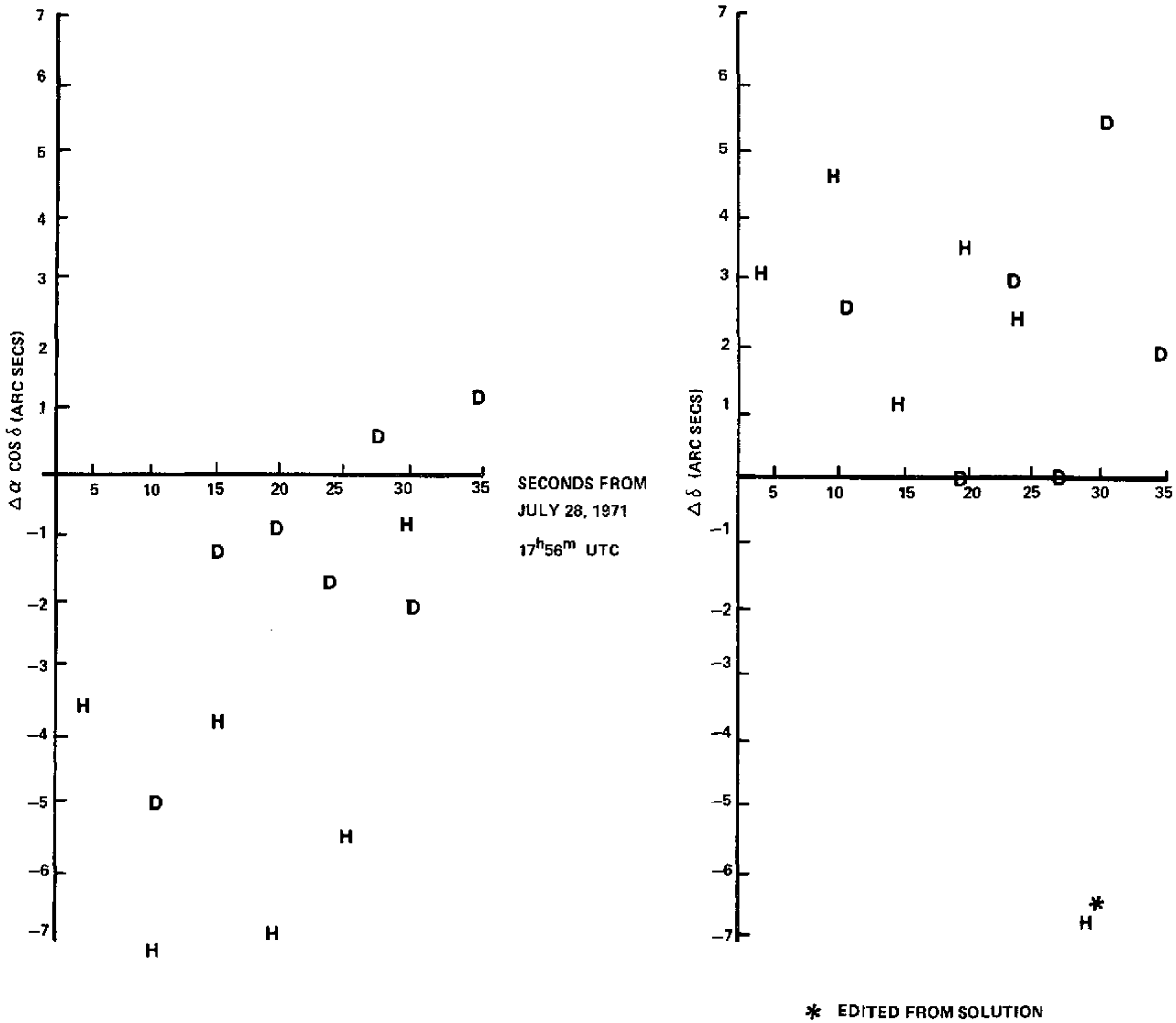


Figure 3. Residuals from Simultaneous Observation of GEOS-1 by Cameras at Helwan, Egypt, (H) and Dezeit, Ethiopia, (D)

except for the $\alpha \cos \delta$ residuals in Figure 3. The inconsistency is about 3 arc seconds between the centroid of the Helwan residuals and the centroid of the DEZEIT residuals.

Figures 4 and 5 show residuals for simultaneous tracking of Ondrejov with Haute Provence and/or Zimmerwald. The consistency is excellent, small average differences of only the order of one arc second appearing.

MEAN ELEMENTS OF PEOLE*

During 1971, osculating orbital elements for PEOLE were determined at 4-6 day intervals to provide prediction data for the GSFC laser at Guam as part of the International Satellite Geodesy Experiment. The orbits were determined almost entirely from CNES and NASA Minitrack data, with occasional passes of GSFC laser data from Guam, CNES laser data from Dakar, Senegal and SAO laser data from Arequipa, Peru and Natal, Brazil also employed. Because of the low inclination of the orbit and resultant diminished geopotential perturbations, the orbits determined from the Minitrack data alone are surprisingly precise. The uncertainty of the elements is much lower than the amplitudes of the orbit variations of interest.

The orbit of PEOLE is especially interesting for atmospheric and geopotential investigations. The mean decay rate of the semi-major axis is about 30m/day, but there is considerable variation over the year. The perturbations due to odd zonal harmonics are also very large. Solar tidal perturbations may also be perceptible in the inclination.

We have prepared mean orbital elements of PEOLE from the osculating elements by the combined analytic-numerical technique developed by Douglas, Marsh, and Mullins (1972). The method involves the analytical removal of all large short periodic perturbations followed by a numerical averaging over 1 day to remove remaining small high frequency effects. Thus all long periodic and secular effects remain in the mean elements.

Figure 6 shows the mean semi-major axes obtained from the orbital fits. The SAO 1969 Standard Earth (Gaposchkin and Lambeck, 1970) gravity model was used in the orbit determinations. To get the most accurate orbits possible, the drag coefficient was adjusted in each orbital arc. When the mean elements were computed, the appropriate drag coefficient was used for each computation. Thus the mean elements given here are an accurate portrayal of the evolution of the orbit.

*Presented to the Symposium on Satellite and Terrestial Triangulation, Graz, Austria, May 1972.

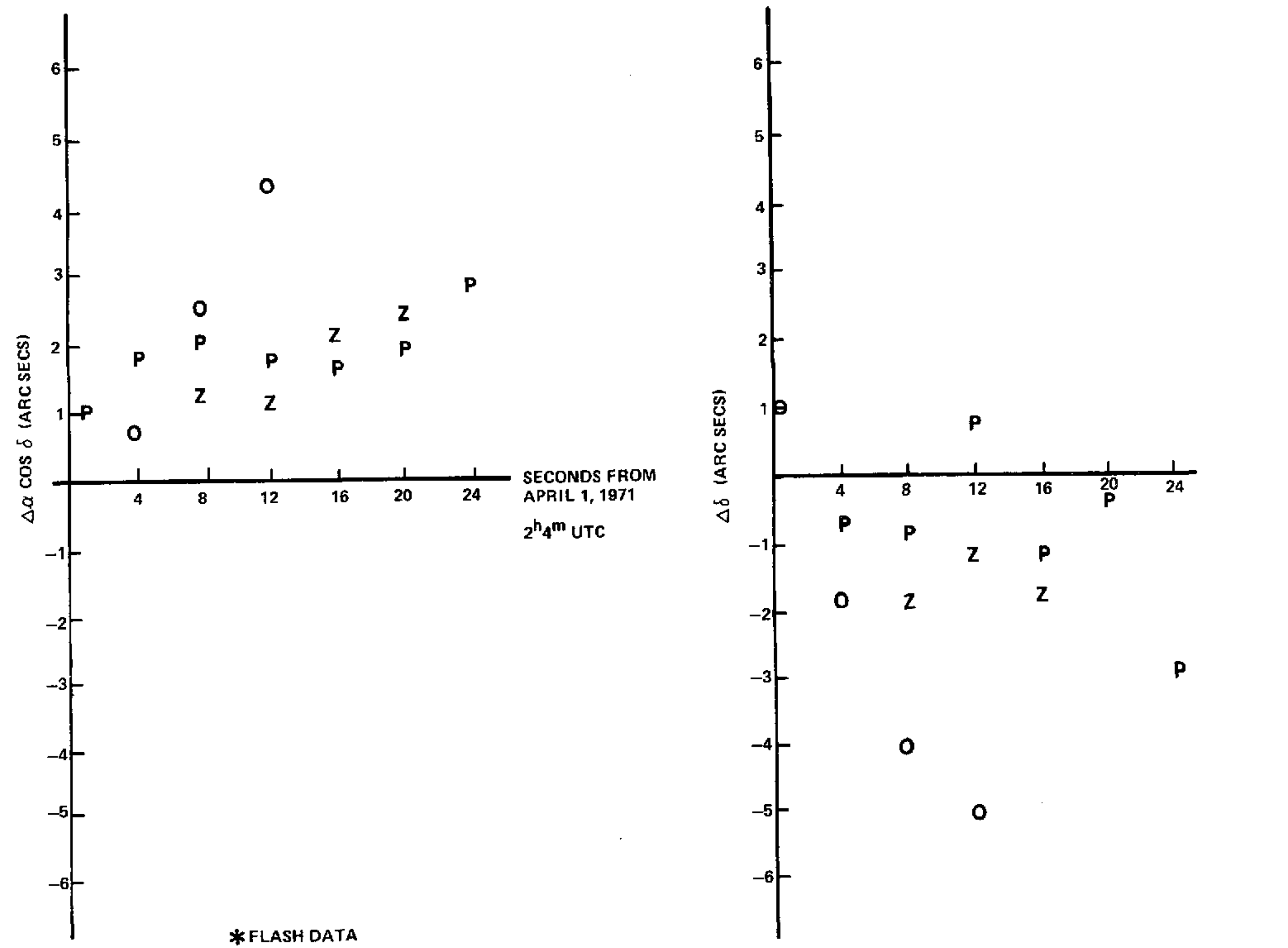


Figure 4. Residuals from Simultaneous Observation* of GEOS-2 by Cameras at Haute Provence, France, (P), Zimmerwald, Switzerland, (Z), and Ondrejov, Czechoslovakia, (O)

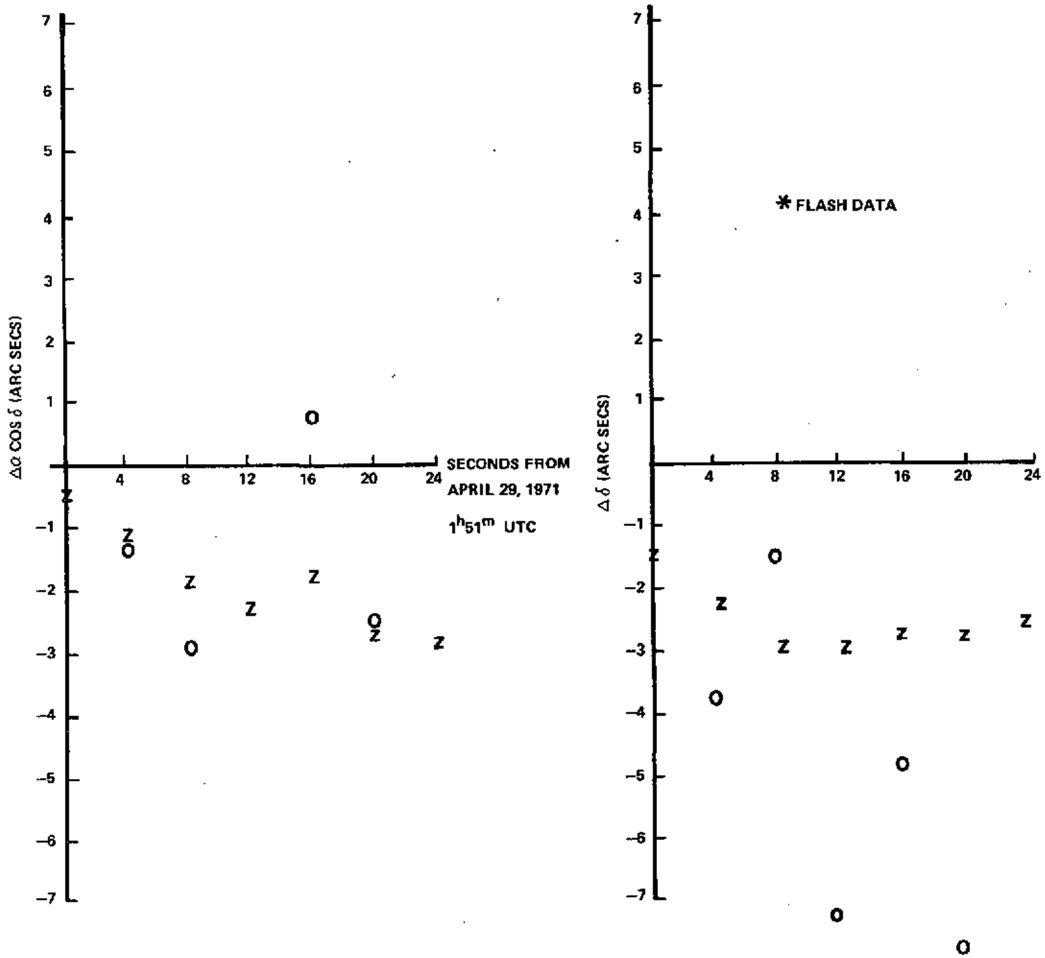


Figure 5. Residuals from Simultaneous Observation* of GEOS-2 by Cameras at Ondrejov, Czechoslovakia, (O) and Zimmerwald, Switzerland, (Z)

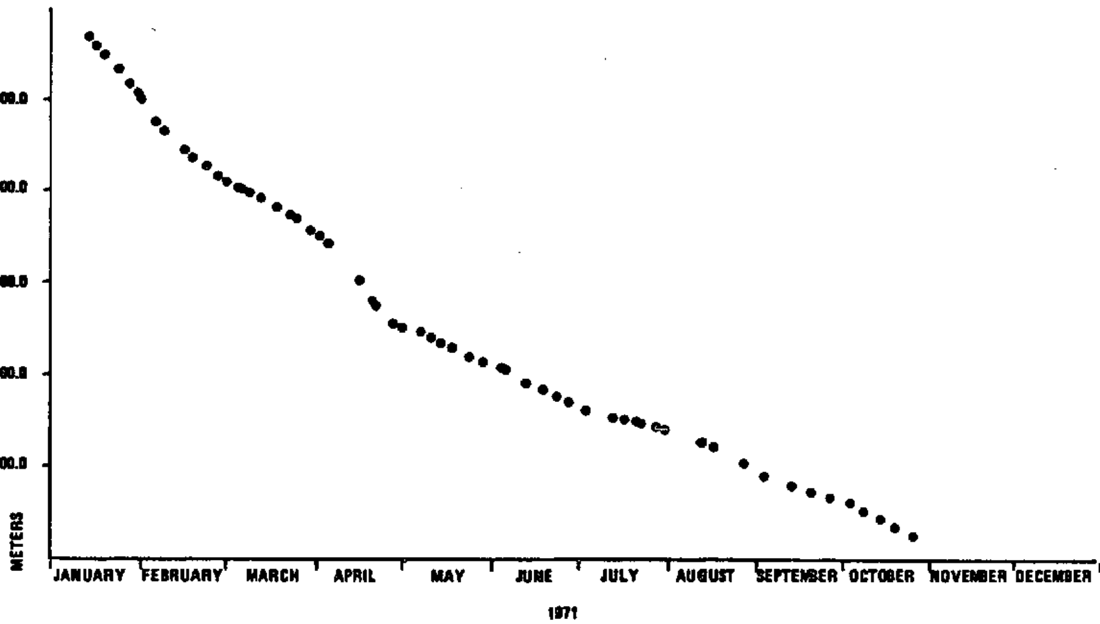


Figure 6. Mean Semi-Major Axis PEOLE-ISAGEX

As is evident in Figure 6, the PEOLE orbit decays rapidly, up to 1 Km per month. This can be a serious matter for geodetic investigations unless the drag perturbation can be accurately modeled. Preliminary results show that if the drag coefficient C_D is allowed to adjust and the atmospheric density is modeled by the Jacchia model atmosphere (Jacchia 1965, 1968), the unmodeled part of the decay is only a few hundred meters out of a total decay of about 12 Km during the year.

Figure 7 shows the mean eccentricities of the PEOLE orbit. Clearly visible are the secular decay due to atmospheric drag and the approximately 28 day oscillation due to the odd zonal harmonics. Figure 8 shows the residual eccentricity for the first six months of 1971 after removal of atmospheric drag effects by the Jacchia model, zonal harmonic effects by the SAO 1969 Standard Earth, and luni-solar perturbations. About 80% of the odd zonal harmonic effects have been accounted for, but a discernable unmodeled 28 day effect remains. The precision of the mean eccentricities is probably better than one part in 10^5, which is consistent with the observed dispersion in the semi-major axis.

Table 4 presents all of the mean elements of PEOLE in tabular form. The time system is UTC. It is hoped that these elements will prove useful to other investigators.

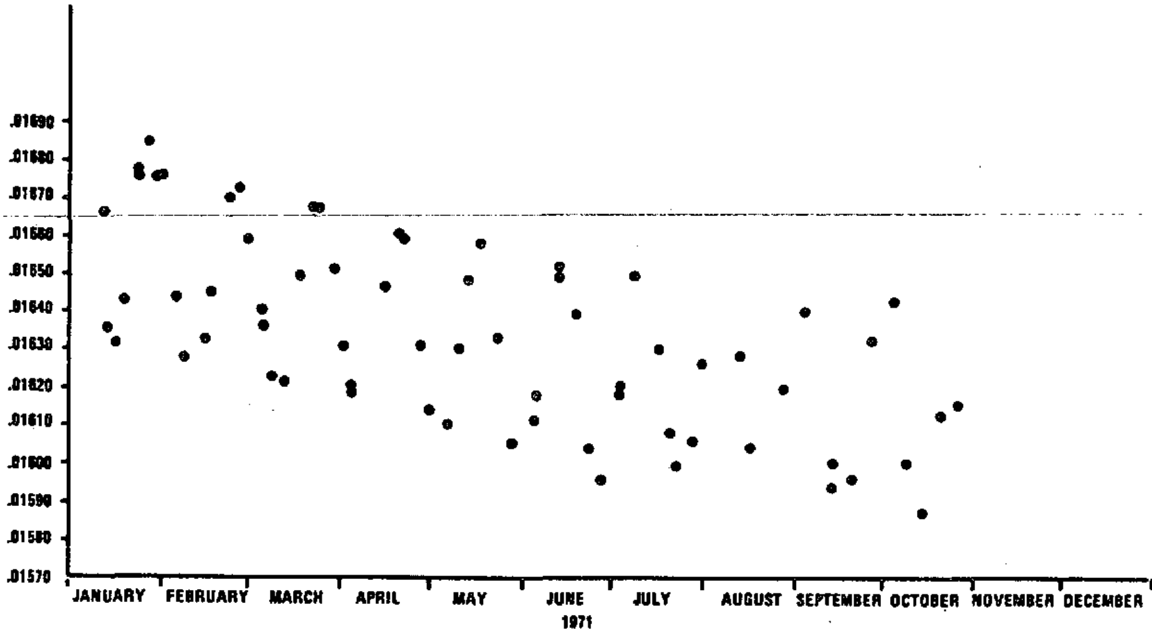


Figure 7. Mean Eccentricity PEOLE-ISAGEX

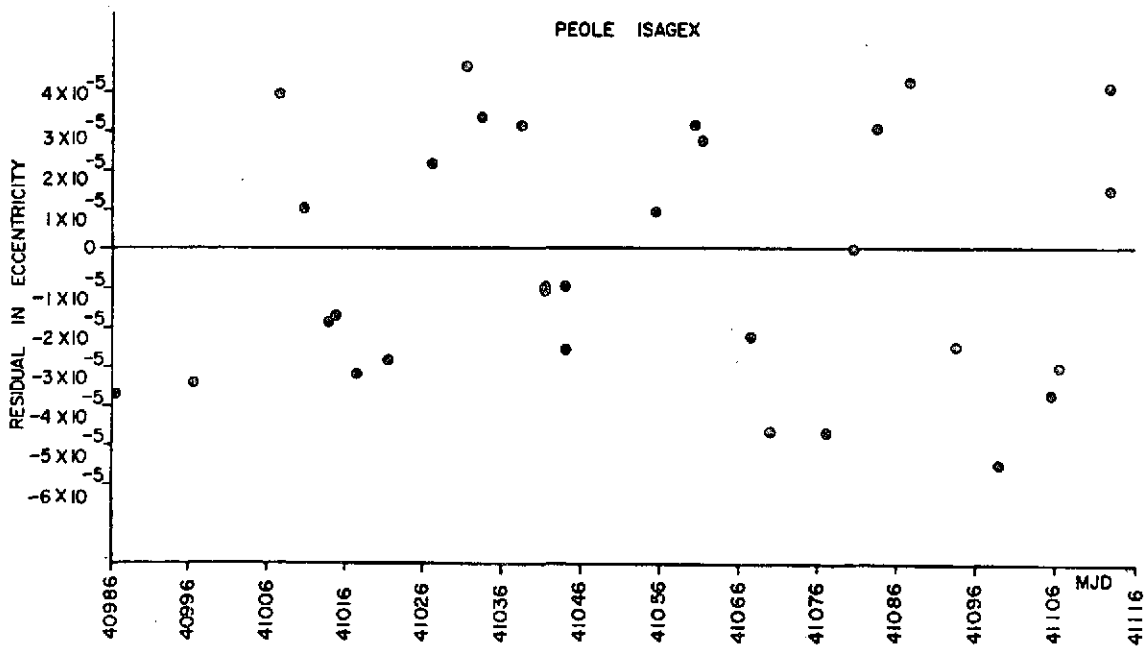


Figure 8. Residual Eccentricity with the SAO 1969 Standard Earth

Table 4

Mean Orbital Elements for PEOLE in 1971

TIME (MJD)	A (METERS)	E	I (DEGREES)	W (DEGREES)	N (DEGREES)	M (DEGREES)
40986.462777718	7009597.65794	.016318072	15.005041	284.502345	329.983986	272.467983
40969.598587931	7009496.24795	.016431391	15.003364	325.512804	308.136896	72.322104
40980.535451358	7009065.18692	.016760687	15.002480	109.920721	231.911210	73.006024
40981.527499936	7008989.37515	.016763530	15.004165	122.806151	224.997559	323.522267
40986.527499936	7008760.49327	.016439371	15.005973	188.881498	190.138038	347.859913
40996.691770807	7008434.12950	.016328953	15.006885	324.957811	119.257080	194.275450
41007.739895800	7008153.84322	.016731696	15.005039	109.975350	42.207647	80.774218
41010.823229133	7008093.98813	.016596132	15.005453	150.325923	20.707355	325.820695
41013.875349697	7008029.01813	.016407595	15.006312	190.634867	359.409315	45.245626
41014.720844875	7008023.29546	.016364875	15.005303	201.825101	353.521845	235.949252
41017.613136546	7007979.37785	.016233129	15.004977	240.499837	333.352564	182.610428
41021.564918947	7007931.57096	.016218049	15.003086	293.677443	305.802825	20.165382
41027.302175889	7007828.91640	.016499448	15.005339	10.045811	265.786622	22.221106
41031.510509222	7007731.82794	.016680768	15.003418	65.226442	236.432323	150.427399
41033.749305556	7007704.26232	.016682622	15.003252	94.608871	220.803376	212.832062
41038.665972223	7007579.79792	.016520497	15.003250	158.651671	186.502305	160.731429
41041.665972223	7007510.57854	.016315559	15.004321	198.360467	165.572664	323.896117
41041.665972223	7007511.13861	.016316788	15.003988	198.348222	165.572256	323.906145
41044.073888858	7007430.93191	.016207604	15.006617	230.469847	148.782859	208.591962
41044.073888858	7007424.36241	.016191831	15.007851	230.531730	148.771502	208.532473
41055.707638889	7007012.27887	.016473809	15.007148	26.056669	67.617400	349.853476
41060.555995330	7006790.47464	.016611171	15.005030	89.416583	33.785076	297.275156
41061.567870335	7006748.11580	.016600013	15.004057	102.517254	26.718476	296.202663
41067.566643483	7006553.07894	.016315249	15.005819	181.265120	344.851391	262.722309
41070.505451365	7006529.29015	.016147889	15.006345	220.426074	324.341752	102.501169
41076.937997651	7006457.96388	.016109947	15.007621	306.899043	279.457015	222.535129
41080.521330984	7006401.82527	.016309650	15.008408	354.695809	254.459198	261.580187
41083.737141183	7006364.99685	.016489700	15.005768	37.046092	232.010882	140.419192
41087.712604132	7006300.71825	.016589230	15.006053	88.985690	204.245469	113.253548
41093.540972223	7006207.76799	.016338391	15.004546	165.198842	163.546331	253.613233
41098.707638889	7006166.71870	.016058260	15.004907	234.026188	127.486426	102.151093
41105.624305556	7006075.61479	.016123877	15.006421	325.944392	79.204999	288.090801
41106.595486081	7006056.40525	.016174233	15.006813	339.906843	72.427259	70.272318
41113.499305556	7005929.86731	.016526877	15.007457	70.742412	24.221344	190.680570
41113.499305556	7005929.71787	.016500672	15.004844	70.683683	24.228347	190.734001
41119.624305556	7005831.39543	.016397185	15.005168	150.857124	341.457969	116.358894
41124.624305556	7005772.62825	.016046345	15.002939	217.156717	306.558098	158.114630
41128.749305556	7005713.31352	.015960138	15.003575	272.469959	277.778438	210.203634
41134.665972223	7005619.61580	.016208890	15.005438	351.795978	236.458749	103.661178
41134.665972223	7005619.47976	.016191483	15.005103	351.826308	236.461812	103.626994
41143.666574022	7005542.42048	.016502691	15.002993	109.867984	173.586867	257.678586
41147.583240689	7005517.31855	.016308187	15.001108	161.163059	146.232117	280.272045
41151.543310151	7005491.63513	.016086811	15.001788	213.816710	118.576584	173.824012
41206.456724507	7004814.71612	.016007896	15.007528	221.425675	95.064661	210.917568
41232.159027881	7004522.15697	.016007106	15.004148	201.475885	275.513842	241.771183
41237.796035231	7004429.07921	.015879833	15.003299	277.554388	236.125368	90.091051
41243.354455969	7004350.33496	.016135797	14.988362	351.952758	197.311994	240.104514
41248.989837927	7004243.73143	.016164420	14.981067	65.708509	157.930468	83.197875

CONCLUSIONS

The new center of mass coordinates presented in this paper in combination with our previous (Marsh, et al., 1973) results give strong ties covering the Eurasian continent and northern and southern Africa. The mean orbital elements of PEOLE, determined from a combination of laser and Minitrack data, have already proven useful in geodynamic investigations (King Hele, 1973; Wagner, et al., 1974). All of these results demonstrate the value of properly coordinated cooperative programs.

ACKNOWLEDGEMENT

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REFERENCES

Brachet, G., "International Satellite Geodesy Experiment Plan," ISAGEX Report No. 7, CNES, November 1970.

Brachet, G., "Data Handling Booklet," ISAGEX Report No. 16, CNES, May 1973.

Douglas, B. C., Marsh, J. G., Mullins, N. E., "Mean Elements of GEOS-1 and GEOS-2," Celestial Mechanics 7, pp. 195-204, 1973.

Gaposchkin, E. M., and Lambeck, K., "1969 Smithsonian Standard Earth (II)," SAO Special Report 315, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, 1970.

Jacchia, L. G., "Static Diffusion Models of the Upper Atmosphere with Empirical Temperature Profiles," SAO Special Report 170, 1965.

Jacchia, L. G., Campbell, I. G., Slowley, J. W., "Semi-Annual Density Variations in the Upper Atmosphere, 1958 to 1966," SAO Special Report 265, 1968.

Jacchia, L. G., "New Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles," SAO Special Report 313, 1970.

Jacchia, L. G., "Revised Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles," SAO Special Report 332, 1971.

King Hele, D. G., Cook, G. E., "Analysis of 27 Satellite Orbits to Determine Odd Zonal Harmonics in the Geopotential," RAE Technical Report 73153, December 1973.

Lerch, F. J., Wagner, C. A., Smith, D. E., Sandson, M. L., Brown, J. E., Richardson, J. A., "Gravitational Field Models for the Earth (GEM 1 and 2)," GSFC Document X-553-72-146, May 1972.

Marsh, J. G., Douglas, B. C., Klosko, S. M., "A Global Station Coordinate Solution Based Upon Camera and Laser Data — GSFC 1973," presented at the First International Symposium on the Use of Artificial Satellites for Geodesy and Geodynamics, Athens, Greece, May 1973, also NASA/GSFC Document X-592-73-171, May 1973.

Marsh, J. G., Douglas, B. C., Klosko, S. M., "Analyses of Precision Reduced Optical Observations from the International Satellite Geodesy Experiment (ISAGEX)," GSFC Document X-590-73-340, November, 1973b.

Marsh, J. G., Vincent, S., "Global Detailed Geoid Computation and Model Analysis," Geophysical Surveys 1, pp. 67-97, 1974.

Martin, T. V., "GEODYN Systems Operation Description," Wolf Research and Development Corporation Final Report on Contract NAS 5-11736-129, February 1972.

Niska, O. R., Defense Mapping Agency/Topographic Center, Department of Geodesy, Private Communication, 1974.

Wagner, C. A., Douglas, B. C., Williamson, R. G., "The Road Program," GSFC Document X-921-74-144, January 1974.