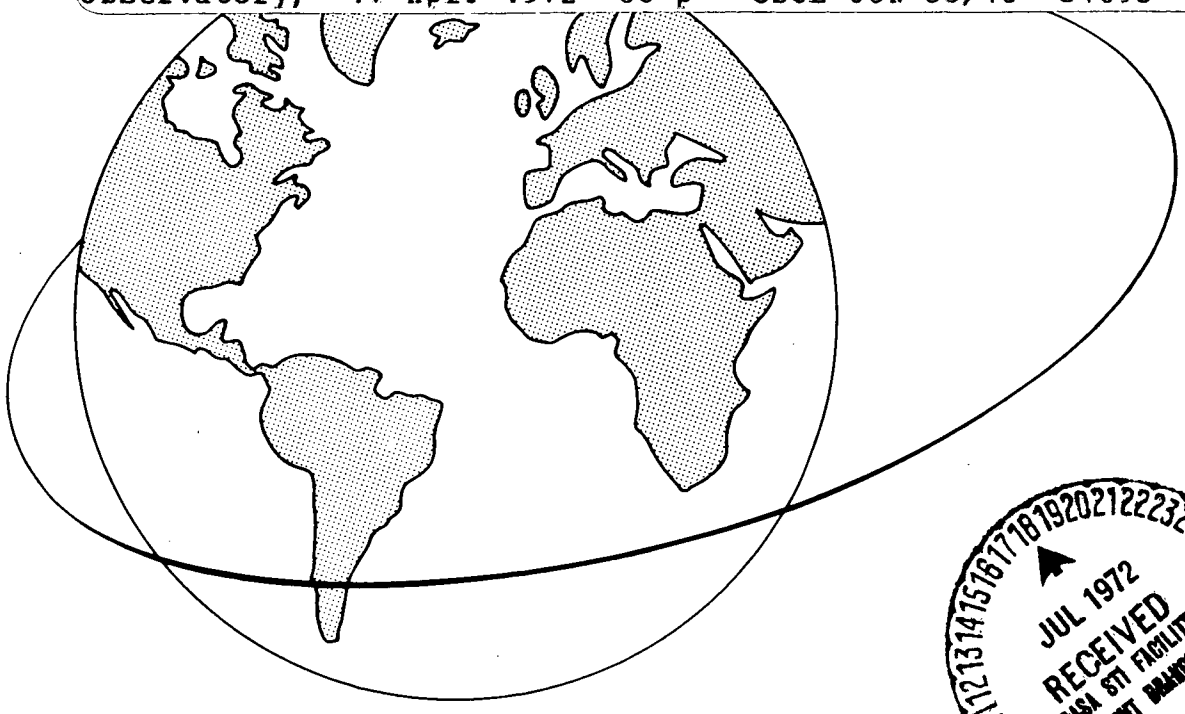
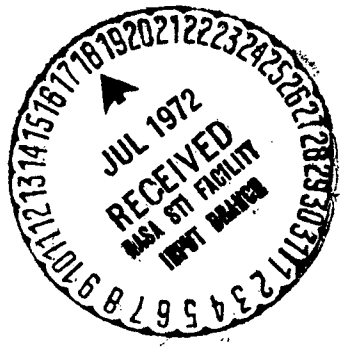
EMPIRICAL DATA AND THE VARIANCE-COVARIANCE MATRIX FOR THE 1969 SMITHSONIAN STANDARD EARTH (II)

E. M. GAPOSCHKIN





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ABSTRACT

Empirical data used in the Standard Earth (II) are described. The variance-covariance matrix is available, and the format of this matrix on a standard magnetic tape is described.

RÉSUMÉ

On présente les données empiriques employées dans la Standard Earth (II). La matrice variance-covariance est disponible et l'on décrit le format de cette matrice sur une bande magnétique standarde.

КОНСПЕКТ

Описываются эмпирические данные которые употреблялись для Стандартной Земли (II). Имеется в распоряжении матрица дисперсии-ковариации, и описывается формат этой матрицы на стандартной магнитной ленте.

EMPIRICAL DATA AND THE VARIANCE-COVARIANCE MATRIX FOR THE 1969 SMITHSONIAN STANDARD EARTH (II)

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1. INTRODUCTION

This note details the empirical data used in the 1969 Smithsonian Standard Earth (II) (Gaposchkin and Lambeck, 1970, 1971). Further, the variance-covariance matrix, or the normal equations, are of use for correlative analysis. This matrix is available on request to interested individuals supplying a magnetic tape. The format and contents of the tape are described here, together with a sample printout. We provide this information so that complete interpretation of the Standard Earth results will be possible.

This work was supported in part by grant NGR 09-015-002 from the National Aeronautics and Space Administration.

2. DEFINITION OF THE REFERENCE SYSTEM

The reduction of astronomical direction observations, such as Baker-Nunn observations, in right ascension and declination requires several straightforward computations. The observations are given with respect to a particular equinox and equator, typically but not always the mean equinox of 1950.0 and the equator of date. The transformation of given observational directions to this system is defined by the expressions (definitions) of precession and nutation, taken from the Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac (1961). The nutation terms were selected such that the total neglected contribution was less than 0.5 m. Corrections for diurnal aberration were applied to the simultaneous observations. Application of parallactic refraction and the numerical values used are given in Section 3.

The relation between the reference system defined above and the terrestrial system is given by the tabular values of UT1 and the pole position (Veis, 1963). The numerical values for UT1 are taken from the Bureau International de l'Heure (BIH); and the polar-motion data, from the International Polar Motion Service (IPMS). Further, SAO maintains a uniform time system (A.S) to which all data are referred. We list the values of A.S - UTC used for this conversion. A thorough documentation of the definition of A.S and its relation to other atomic time systems is being prepared by J. Rolff.

3. PARALLACTIC REFRACTION

The basis of this discussion is from Veis (1966). The parallactic-refraction correction depends primarily on the zenith distance and on the height of the object; but it is also dependent on the atmospheric pressure and the temperature (and, to a minor extent, the humidity) at the observing station.

The following formula gives the parallactic refraction to an accuracy of about 10%:

$$\Delta R = \frac{n-1}{a} \frac{\tan Z}{r \cos Z} \left[1 - e^{a(\cos Z)r}\right] .$$

Under normal conditions (T = 0°0 C, P = 760 mm), this becomes

$$\Delta R = -435''.0 \frac{\tan Z}{r \cos Z} \left(1 - e^{-0.1385\, r \cos Z}\right) \qquad (r \text{ is in km}) . \qquad (1)$$

The temperature and pressure effects on the parallactic refraction correspond to a factor K, by which equation (1) must be multiplied:

$$K = \frac{B}{760} \frac{273}{273 + \theta} = \frac{15.35\, P}{460 + T} ,$$

where B is the pressure in mm Hg, P is the pressure in inches, and θ is the temperature in degrees F. From this, it follows that K, which is 1 for "normal conditions," will change by 3% for a variation of 1 inch in pressure and 2% for a variation of 10°F in temperature.

Correcting each observation for the actual temperature and pressure at the time of the observation is complicated and useless. Therefore, for every station, the mean night temperature and pressure are determined, and the coefficient K is then calculated with these values. Every station will have a different numerical value for

the parallactic refraction, but the value will be the same for all observations from that station. If we consider that the parallactic-refraction correction itself hardly ever exceeds 2" and that variations in night pressure and temperature from their mean values are not appreciable, then we can estimate that this method is sufficient to provide a correction to better than 0."1 in all cases. Table 1 gives the mean night temperature and pressure and the corresponding coefficient K for each camera station. It should be noted that the mean night temperature and pressure and their ranges were obtained from sampling evening and morning data both in winter and in summer. For stations designated with an asterisk, no weather data were available at SAO. In these cases, we used atlas values reduced for temperature and pressure gradiants. The data were compiled by Mr. J. Latimer, Mr. A. Girnius, and Dr. K. Lambeck.

Table 1. Mean temperature, pressure, and parallactic-refraction coefficient K.

Station	T (°F)		P (inches)		K	
	Mean	Range	Mean	Range	Mean	±
9001	56	38	28.61	0.70	0.94	6%
9002	52	30	25.30	0.52	0.84	6%
9003	65	45	29.48	0.79	0.94	8%
9004	63	26	30.06	0.96	0.94	5%
9005	55	42	29.89	0.62	0.95	7%
9006	57	20	23.86	0.48	0.78	4%
9007	49	9	28.38	0.10	0.94	2%
9008	59	51	29.70	0.41	0.95	9%
9009	79	5	29.41	0.18	0.91	2%
9010	66	20	30.03	0.50	0.93	4%
9011	61	16	27.70	0.55	0.91	3%
9012	44	12	20.96	0.42	0.69	3%
9021	48	32	22.78	0.24	0.76	7%
9023	65	45	29.48	0.79	0.94	8%
9025	51	34	26.77	0.34	0.89	8%
9028	66	26	24.04	0.11	0.78	3%
9029	81	20	29.94	0.21	0.94	2%
9030	59	49	30.05	0.40	0.98	5%
9031	53	46	28.89	0.48	0.96	4%
9049	66	20	30.03	0.50	0.93	4%
9050*	49	40	29.50	0.10	0.99	6%
9051	64	52	29.33	0.43	0.95	5%
9066*	34	50	27.20	0.10	0.94	9%
9074*	45	40	29.97	0.05	1.01	7%
9076*	40	40	29.67	0.05	1.01	7%
9077*	44	35	29.40	0.10	0.99	4%
9080*	49	30	29.55	0.02	0.99	3%
9091	59	49	30.05	0.40	0.98	5%
9113*	55	30	27.30	0.10	0.90	3%
9114*	30	55	27.65	0.30	0.96	11%
9115*	38	45	27.87	0.05	0.95	9%
9116*	56	23	27.10	0.20	0.89	4%
9117*	77	6	29.90	0.01	0.95	1%
9118*	83	5	29.90	0.01	0.94	1%

*No weather data available at SAO.

4. TIME-SYSTEM DATA

SAO has maintained a uniform time system called AS, which we use as the independent variable in orbit computation. Data from other agencies are referred to UTC or A3. The time systems A.S and A3 differ by a constant amount during the period of joint observation, and we have adopted the value

$$A.S - A3 = 35.3 \text{ msec.}$$

Whereas A.S and A3 are uniform time systems, UTC has discontinuities. Table 2 gives the time interval, the offset, the rate, and the epoch for the difference A.S - UTC. Therefore, for the interval between T_1 and T_2, the difference is given by the formula

$$A.S - UTC = a + b\,(t - T_3) \quad .$$

There data were compiled by Mr. J. Rolff, and the complete documentation will soon be published.

The relation between a terrestrial system and a celestial system has been documented by Veis (1963), Lundquist and Veis (1966), and Gaposchkin and Lambeck (1970); the definition of sidereal time used is also given therein. We therefore give here only the values of UT1 and pole position used in the analysis.

The UT1 values are taken from the BIH. A quadratic polynomial is fitted to A.S - UT1 for intervals of 25 to 50 days. These polynomials are then used to evaluate A.S - UT1 for each observation time. Table 3 lists the intervals (T_1, T_2) and the three coefficients a, b, and c. The polynomial epoch is T_1, and

$$A.S - UT1 = a + b(T - T_1) + c(T - T_1)^2 \quad .$$

The polar-motion data, taken from IPMS, are presented in Table 4. Linear interpolation is used to compute the pole position.

Table 2. Offset (a), rate (b), and epoch (T_3) of A.S - UTC (in seconds).

T_1	T_2	a	b	T_3
37178.0	37300.0	1.300500	0.001275935	37178.0
37300.0	37481.0	1.458858	0.001296000	37300.0
37481.0	37493.0	1.693434	0.001292000	37480.0
37493.0	37512.0	1.694215	0.001245000	37480.0
37512.0	37563.0	1.643160	0.001280000	37480.0
37563.0	37573.0	1.641500	0.001300000	37480.0
37573.0	37604.0	1.642184	0.001290764	37480.0
37604.0	37665.0	1.643272	0.001289444	37480.0
37665.0	37755.0	1.865000	0.001123200	37650.0
37755.0	37846.0	1.864620	0.001126800	37650.0
37846.0	38030.0	1.864704	0.001126370	37650.0
38030.0	38334.0	2.292725	0.001118458	38030.0
38334.0	38395.0	2.392725	0.001118458	38030.0
38395.0	38486.0	2.800962	0.001293560	38395.0
38486.0	38577.0	2.900766	0.001295716	38395.0
38577.0	38639.0	2.901518	0.001292659	38395.0
38639.0	38669.0	3.001518	0.001292659	38395.0
38669.0	38761.0	3.001589	0.001296048	38395.0
38761.0	38820.0	3.575732	0.001296000	38761.0
38820.0	38942.0	3.675732	0.001296000	38761.0
38942.0	39004.0	3.775732	0.001296000	38761.0
39004.0	39126.0	3.875732	0.001296000	38761.0
39126.0	39491.0	4.348772	0.002592000	39126.0
39491.0	39753.0	5.294852	0.002592000	39491.0
39753.0	39856.0	5.294688	0.002592000	39491.0
39856.0	39887.0	6.240768	0.002592000	39856.0
39887.0	40222.0	6.140768	0.002592000	39856.0

Table 3. Interval and polynomial coefficients of A. S - UT1.

T_1	T_2	a (sec)	b (sec/day)	c (sec/day^2)
36204.0	36254.0	3.3419436E-02	1.7413966E-03	-1.9653803E-06
36254.0	36304.0	1.1579783E-01	1.6564313E-03	2.3026866E-06
36304.0	36354.0	2.0376647E-01	1.9724053E-03	-6.4075849E-06
36354.0	36404.0	2.8634967E-01	1.1769024E-03	-6.7556608E-06
36404.0	36454.0	3.2915559E-01	4.7403947E-04	3.9854468E-06
36454.0	36504.0	3.6300644E-01	9.8815046E-04	7.5413763E-06
36504.0	36554.0	4.3150837E-01	1.6881441E-03	-7.0276712E-07
36554.0	36604.0	5.1412208E-01	1.6352886E-03	-1.4187507E-06
36604.0	36654.0	5.9269873E-01	1.3369852E-03	5.3305095E-07
36654.0	36704.0	6.6077901E-01	1.4851055E-03	-1.4231052E-06
36704.0	36754.0	7.3101019E-01	1.2950031E-03	-5.4199867E-06
36754.0	36804.0	7.8254341E-01	6.5357649E-04	9.7018371E-07
36804.0	36854.0	8.1781323E-01	8.9608601E-04	7.8326401E-06
36854.0	36904.0	8.8181973E-01	1.7266513E-03	5.4035308E-07
36904.0	36954.0	9.6965913E-01	1.6164842E-03	-4.2088497E-06
36954.0	37004.0	1.0403734E+00	1.2334624E-03	3.6669612E-06
37004.0	37054.0	1.1111673E+00	1.6275209E-03	-2.2991768E-07
37054.0	37104.0	1.1915729E+00	1.5900046E-03	-7.8592544E-06
37104.0	37129.0	1.2514738E+00	7.5151427E-04	-9.0206712E-06
37129.0	37154.0	1.2647636E+00	3.1729027E-04	1.7171124E-06
37154.0	37204.0	1.2739287E+00	3.9334216E-04	8.8466494E-06
37204.0	37254.0	1.3157101E+00	1.2979207E-03	2.2318567E-06
37254.0	37304.0	1.3859456E+00	1.5040488E-03	-2.3808790E-06
37304.0	37329.0	1.4545978E+00	1.3634637E-03	-1.1360556E-05
37329.0	37354.0	1.4816626E+00	7.1469680E-04	8.6378757E-06
37354.0	37379.0	1.5049539E+00	1.2979237E-03	1.1227052E-05
37379.0	37404.0	1.5441614E+00	1.8519622E-03	-1.2927014E-05
37404.0	37454.0	1.5811533E+00	1.2896141E-03	-2.5516547E-06
37454.0	37504.0	1.6391211E+00	1.0192945E-03	-5.1144989E-06
37504.0	37554.0	1.6766858E+00	4.0909512E-04	4.7788142E-06

Table 3 (Cont.)

T_1	T_2	a (sec)	b (sec/day)	c (sec/day^2)
37554.0	37604.0	1.7091307E+00	9.7682976E-04	5.6015027E-06
37604.0	37654.0	1.7717014E+00	1.5238953E-03	-1.9881058E-06
37654.0	37704.0	1.8430139E+00	1.2295078E-03	-2.8505878E-07
37669.0	37750.0	1.8500976E+00	1.3292950E-03	1.0572267E-06
37750.0	37775.0	1.9652177E+00	1.6274733E-03	-4.4116246E-06
37775.0	37800.0	2.0033666E+00	1.4431638E-03	5.1982365E-06
37800.0	37850.0	2.0423311E+00	1.9275447E-03	-1.6740674E-05
37850.0	37900.0	2.0972209E+00	5.4773604E-04	2.5860084E-06
37900.0	37925.0	2.1312004E+00	4.2942526E-04	1.7848075E-05
37925.0	37950.0	2.1530614E+00	1.2679157E-03	5.0758782E-06
37950.0	37975.0	2.1876855E+00	1.5673552E-03	6.0104121E-06
37975.0	38000.0	2.2303881E+00	1.7596795E-03	-2.3929621E-06
38000.0	38050.0	2.2723629E+00	1.8061216E-03	-7.3442412E-06
38050.0	38075.0	2.3443713E+00	1.4166823E-03	-7.4459472E-06
38075.0	38100.0	2.3751813E+00	1.1117456E-03	3.8885637E-06
38100.0	38125.0	2.4052685E+00	1.5098997E-03	5.5244772E-06
38125.0	38150.0	2.4460904E+00	1.9001544E-03	-2.2016307E-06
38150.0	38175.0	2.4922992E+00	1.5261783E-03	2.1500173E-06
38175.0	38200.0	2.5320002E+00	1.6969016E-03	-8.5063549E-06
38200.0	38225.0	2.5692042E+00	1.1204620E-03	-4.2270871E-06
38225.0	38250.0	2.5945872E+00	7.3951908E-04	3.6907772E-06
38250.0	38275.0	2.6157014E+00	1.2187016E-03	-2.0808608E-06
38275.0	38300.0	2.6452398E+00	1.1840496E-03	1.1822798E-05
38300.0	38325.0	2.6823862E+00	1.6515924E-03	1.0307286E-05
38325.0	38350.0	2.7299791E+00	2.3000308E-03	-1.3993061E-06
38350.0	38375.0	2.7866262E+00	1.7452761E-03	5.6865353E-06
38375.0	38400.0	2.8345847E+00	2.2618146E-03	2.3151346E-06
38400.0	38450.0	2.8929652E+00	2.1222980E-03	-1.7827515E-07
38450.0	38500.0	2.9985366E+00	2.2489269E-03	-2.2181149E-06
38500.0	38525.0	3.1055364E+00	2.1059601E-03	5.9261142E-06

Table 3 (Cont.)

T_1	T_2	a (sec)	b (sec/day)	c (sec/day^2)
38525.0	38550.0	3.1618240E+00	2.2828237E-03	-6.5076614E-06
38550.0	38575.0	3.2149545E+00	1.7826983E-03	-1.2858835E-05
38575.0	38600.0	3.2515922E+00	1.1229081E-03	1.1779195E-06
38600.0	38650.0	3.2806813E+00	1.0271218E-03	5.1621630E-06
38650.0	38700.0	3.3447122E+00	1.7349050E-03	6.9223856E-06
38700.0	38750.0	3.4478359E+00	2.4947280E-03	-3.1127859E-06
38750.0	38800.0	3.5650003E+00	2.0191565E-03	2.0353551E-06
38800.0	38850.0	3.6710863E+00	2.1398252E-03	5.3738004E-06
38850.0	38900.0	3.7914048E+00	2.6041256E-03	-2.8877087E-06
38900.0	38950.0	3.9148390E+00	2.3167749E-03	-7.9054852E-06
38950.0	39000.0	4.0112048E+00	1.6182636E-03	3.2012126E-08
39000.0	39025.0	4.0927703E+00	1.6264604E-03	1.4563306E-05
39025.0	39050.0	4.1423194E+00	2.4312273E-03	5.0880162E-07
39050.0	39075.0	4.2034270E+00	2.6216789E-03	1.8064693E-06
39075.0	39100.0	4.2699228E+00	2.7719089E-03	-8.9198504E-06
39100.0	39125.0	4.3334899E+00	2.4275809E-03	-4.9610981E-06
39125.0	39150.0	4.3907709E+00	2.2177139E-03	7.5050888E-06
39150.0	39200.0	4.4506128E+00	2.5286991E-03	-6.1648847E-07
39200.0	39250.0	4.5755501E+00	2.7000075E-03	1.8439813E-06
39250.0	39300.0	4.7145492E+00	2.8875033E-03	-1.0885252E-05
39300.0	39350.0	4.8319309E+00	1.6082037E-03	2.0814629E-06
39350.0	39400.0	4.9176891E+00	2.0640510E-03	5.8070299E-06
39400.0	39450.0	5.0350729E+00	2.8196254E-03	-9.3495064E-08
39450.0	39500.0	5.1761499E+00	2.6445467E-03	-2.6977534E-06
39500.0	39550.0	5.3023754E+00	2.3171519E-03	1.9589086E-06
39550.0	39600.0	5.4234892E+00	2.5731920E-03	2.9925984E-06
39600.0	39625.0	5.5596940E+00	2.9268489E-03	-3.1788781E-06
39625.0	39650.0	5.6305129E+00	2.8886166E-03	-1.9757578E-05
39650.0	39700.0	5.6901042E+00	1.8612022E-03	-3.0326599E-06
39700.0	39750.0	5.7756799E+00	1.7452402E-03	3.6480565E-06

Table 3 (Cont.)

T_1	T_2	a (sec)	b (sec/day)	c (sec/day^2)
39750.0	39800.0	5.8717612E+00	2.1564043E-03	6.3961686E-06
39800.0	39850.0	5.9954964E+00	2.8623267E-03	-4.6929630E-06
39850.0	39900.0	6.1270687E+00	2.5043322E-03	1.5646243E-06
39900.0	39925.0	6.2560192E+00	2.7039238E-03	2.0537761E-07
39925.0	39950.0	6.3235243E+00	2.4955302E-03	-2.8520212E-06
39950.0	39975.0	6.3836121E+00	3.4455413E-03	-1.6231575E-05
39975.0	40000.0	6.4593955E+00	2.4756578E-03	-1.6887416E-07
40000.0	40050.0	6.5211865E+00	2.6401475E-03	-1.0707590E-05
40050.0	40100.0	6.6276017E+00	1.8369700E-03	5.4185294E-06
40100.0	40150.0	6.7330783E+00	2.4313746E-03	2.7533980E-06
40150.0	40200.0	6.8608866E+00	2.6823980E-03	1.6945720E-06
40200.0	40250.0	6.9992317E+00	2.5587021E-03	-1.2562317E-06
40250.0	40275.0	7.1245087E+00	2.5201212E-03	9.2045398E-06

Table 4. Pole position.

Epoch	x	y	Epoch	x	y
36387.0	0.188	0.447	36934.0	0.135	0.043
36405.0	0.237	0.411	36952.0	0.073	0.007
36423.0	0.348	0.365	36971.0	0.046	-0.012
36441.0	0.398	0.307	36989.0	0.035	-0.007
36460.0	0.398	0.235	37007.0	0.013	0.025
36478.0	0.368	0.165	37025.0	-0.027	0.059
36496.0	0.330	0.097	37044.0	-0.074	0.094
36514.0	0.280	0.043	37062.0	-0.097	0.124
36533.0	0.218	-0.007	37080.0	-0.107	0.153
36551.0	0.144	-0.038	37098.0	-0.104	0.183
36569.0	0.069	-0.057	37117.0	-0.088	0.209
36587.0	0.000	-0.064	37135.0	-0.040	0.238
36606.0	-0.062	-0.057	37153.0	0.003	0.263
36624.0	-0.112	-0.025	37171.0	0.041	0.288
36642.0	-0.140	0.032	37190.0	0.070	0.300
36660.0	-0.153	0.120	37208.0	0.091	0.305
36679.0	-0.151	0.211	37226.0	0.107	0.301
36697.0	-0.126	0.285	37244.0	0.116	0.288
36715.0	-0.086	0.340	37263.0	0.116	0.270
36733.0	-0.037	0.372	37281.0	0.109	0.248
36752.0	0.026	0.393	37300.0	0.092	0.220
36770.0	0.092	0.406	37318.0	0.074	0.188
36788.0	0.161	0.410	37337.0	0.065	0.161
36806.0	0.223	0.401	37355.0	0.064	0.149
36825.0	0.272	0.370	37373.0	0.063	0.150
36843.0	0.299	0.320	37391.0	0.056	0.157
36861.0	0.308	0.260	37410.0	0.045	0.161
36879.0	0.296	0.201	37428.0	0.035	0.159
36898.0	0.261	0.143	37446.0	0.030	0.154
36916.0	0.202	0.090	37464.0	0.032	0.151

Table 4 (Cont.)

Epoch	x	y	Epoch	x	y
37483.0	0.040	0.149	38030.0	-0.121	0.248
37501.0	0.044	0.150	38048.0	-0.119	0.295
37519.0	0.044	0.152	38067.0	-0.105	0.329
37537.0	0.042	0.157	38085.0	-0.076	0.356
37556.0	0.038	0.165	38103.0	-0.038	0.376
37574.0	0.028	0.173	38121.0	0.009	0.388
37592.0	0.019	0.191	38140.0	0.070	0.387
37610.0	-0.011	0.212	38158.0	0.134	0.375
37629.0	-0.028	0.243	38176.0	0.191	0.349
37647.0	-0.023	0.275	38194.0	0.239	0.307
37665.0	-0.009	0.297	38213.0	0.274	0.251
37683.0	0.008	0.309	38231.0	0.301	0.193
37702.0	0.027	0.314	38249.0	0.281	0.139
37720.0	0.047	0.312	38267.0	0.237	0.091
37738.0	0.071	0.304	38286.0	0.176	0.046
37756.0	0.095	0.290	38304.0	0.112	0.008
37775.0	0.120	0.271	38322.0	0.048	-0.020
37793.0	0.142	0.246	38340.0	-0.011	0.005
37811.0	0.162	0.214	38359.0	-0.069	0.041
37829.0	0.173	0.175	38377.0	-0.122	0.078
37848.0	0.171	0.132	38395.0	-0.171	0.120
37866.0	0.157	0.092	38413.0	-0.206	0.168
37884.0	0.128	0.068	38432.0	-0.194	0.230
37902.0	0.094	0.060	38450.0	-0.169	0.294
37921.0	0.056	0.067	38468.0	-0.139	0.353
37939.0	0.017	0.083	38486.0	-0.101	0.412
37957.0	-0.019	0.104	38505.0	-0.055	0.455
37975.0	-0.054	0.128	38523.0	0.004	0.467
37994.0	-0.086	0.160	38541.0	0.074	0.459
38012.0	-0.110	0.200	38559.0	0.164	0.436

Table 4 (Cont.)

Epoch	x	y	Epoch	x	y
38578.0	0.214	0.394	39126.0	0.071	0.115
38596.0	0.240	0.339	39144.0	0.030	0.103
38614.0	0.241	0.275	39163.0	-0.005	0.098
38632.0	0.239	0.219	39181.0	-0.037	0.098
38651.0	0.255	0.168	39199.0	-0.064	0.105
38669.0	0.250	0.123	39217.0	-0.088	0.120
38687.0	0.219	0.085	39236.0	-0.106	0.145
38705.0	0.161	0.060	39254.0	-0.117	0.178
38724.0	0.099	0.046	39272.0	-0.120	0.214
38742.0	0.042	0.043	39290.0	-0.115	0.254
38761.0	-0.012	0.049	39309.0	-0.103	0.295
38779.0	-0.067	0.069	39327.0	-0.083	0.329
38798.0	-0.120	0.103	39345.0	-0.056	0.346
38816.0	-0.160	0.153	39363.0	-0.011	0.347
38834.0	-0.185	0.226	39382.0	0.052	0.338
38852.0	-0.196	0.286	39400.0	0.097	0.323
38871.0	-0.194	0.334	39418.0	0.118	0.306
38889.0	-0.174	0.374	39436.0	0.124	0.290
38907.0	-0.130	0.408	39455.0	0.122	0.272
38925.0	-0.072	0.434	39473.0	0.113	0.254
38944.0	-0.003	0.444	39491.0	0.098	0.234
38962.0	0.071	0.433	39509.0	0.079	0.214
38980.0	0.127	0.399	39528.0	0.056	0.194
38998.0	0.168	0.349	39546.0	0.033	0.177
39017.0	0.201	0.303	39564.0	0.013	0.164
39035.0	0.221	0.259	39582.0	-0.001	0.157
39053.0	0.227	0.221	39601.0	-0.006	0.155
39071.0	0.220	0.186	39619.0	-0.008	0.154
39090.0	0.194	0.156	39637.0	-0.003	0.153
39108.0	0.138	0.131	39655.0	0.012	0.156

Table 4 (Cont.)

Epoch	x	y	Epoch	x	y
39674.0	0.035	0.163	39984.0	0.067	0.245
39692.0	0.055	0.172	40002.0	0.064	0.231
39710.0	0.046	0.183	40020.0	0.062	0.218
39728.0	0.027	0.195	40039.0	0.071	0.205
39747.0	0.008	0.208	40057.0	0.106	0.193
39765.0	-0.010	0.220	40093.0	0.054	0.157
39783.0	-0.029	0.234	40112.0	0.008	0.156
39801.0	-0.049	0.249	40130.0	-0.027	0.161
39820.0	-0.063	0.269	40148.0	-0.056	0.172
39838.0	-0.066	0.289	40166.0	-0.084	0.197
39856.0	-0.056	0.302	40185.0	-0.109	0.233
39874.0	-0.037	0.308	40203.0	-0.123	0.265
39893.0	-0.014	0.308	40222.0	-0.127	0.289
39911.0	0.008	0.302	40240.0	-0.120	0.310
39929.0	0.031	0.290	40259.0	-0.102	0.330
39947.0	0.051	0.276	40277.0	-0.073	0.349
39966.0	0.064	0.260	40295.0	-0.033	0.365

5. VARIANCE-COVARIANCE MATRIX

The variance-covariance matrix of a 428-dimension system is too lengthy to print here. For those interested, two magnetic tapes with the coefficients are available. The matrix computed from the combined set of normal equations is described by Gaposchkin and Lambeck (1970, 1971) and consists of dynamical, geometrical, gravimetric, and deep-space data.

This matrix is written in BCD (binary coded decimal) in either 7-track or 9-track mode on two tapes. The data on these tapes are divided into five parts:

1. An identification used within SAO; this can be read with

   FORMAT (A10, 4I10)

2. The variance-covariance matrix (the structure of the unknowns is described in part 5). This matrix can be read with

   FORMAT (4 E20. 12)

3. The normal residual; this can be read with

   FORMAT (/(E20. 12))

4. The solution vector; it can be read with

   FORMAT (/(E20. 12))

5. A description of the unknowns.

The station coordinates are designated by the station number, with an X, Y, or Z as appropriate. The stations treated as a net are implied (see Gaposchkin and Lambeck, 1970). The gravity-field coefficients are denoted by C21 for $C_{2,1}$, etc. A certain number of unknowns relating to scale and origin differences between the Deep Space Network and the SAO solution are designated by an asterisk. The station designations, appearing first, are read with

FORMAT (/(I10, A1/10X, A1/10X, A1)).

The scale and origin parameters are read with

FORMAT (A1).

The tesseral-harmonic designations are read with

FORMAT (A1, 2I3).

Appendix A is a sample program that reads this tape and prints part of the matrix and parts 2 through 5 above.

The tape produced as described probably cannot be read by another computer because the SAO operating system has adopted some unique tape-blocking and physical record-size conventions. Therefore, the tape has been specially blocked and written as a nonstandard tape by the program detailed in Appendix B. The format of information on this tape is given in Appendix C.

6. REFERENCES

AMERICAN EPHEMERIS AND NAUTICAL ALMANAC

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1971. Earth's gravity field to the sixteenth degree and station coordinates from satellite and terrestrial data. Journ. Geophys. Res., vol. 76, pp. 4855-4883.

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1966. Geodetic parameters for a 1966 Smithsonian Institution Standard Earth. Smithsonian Astrophys. Obs. Spec. Rep. No. 200, 3 vols., 686 pp.

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APPENDIX A

PARTIAL VARIANCE-COVARIANCE MATRIX

```
                PROGRAM RDCOMR(INPUT,OUTPUT,TAPE9 ,TAPE1=OUTPUT)
000003          REAL A(23,424),SOLVE(500)
000003          REAL ANS(500)
000003           INTEGER KSTA(100)
000003          M=23
000004          N=424
000005          I=0
000006          READ (9,500) Q,NSTA,NROW,NGMDUM,NTESSD
000024      500 FORMAT (A10,4I10)
000024          WRITE(1,500) Q,NSTA,NROW,NGMDUM,NTESSD
000042        1 DO 25 L=1,M
000044          I=I+1
000046          IF (I.GT.N) GO TO 30
000051          PRINT 101,I
000056      101 FORMAT (* ROW*,I10)
000056          READ (9,303) (A(L,J),J=1,N)
000073          WRITE(1,303) (A(L,J),J=1,4)
000107      303 FORMAT (4E20.8)
000107       25 CONTINUE
000112          IF (I.NE.N) GO TO 1
000114       30 CONTINUE
000114           READ(9,300) (SOLVE(K),K=1,N)
000127          WRITE(1,300) (SOLVE(K),K=1,N)
000142      300 FORMAT(         /(  F20.8))
000142           READ(9,300)                (ANS(K),K=1,N)
000155          WRITE(1,300)                (ANS(K),K=1,N)
            C  SKIP BLANK LINE
000170          READ(9,701)IA
000176          WRITE(1,701)IA
000204      701 FORMAT (4A10)
000204          DO 60 I=1,NSTA
000206          READ(9,700)KSTA(I),X,Y,Z
000221          WRITE(1,700)KSTA(I),X,Y,Z
000235       60 CONTINUE
000240      700 FORMAT (I10,A1,10X,A1,10X,A1)
000240          KROW=NROW-NTESSD
000242          DO 85 I=1,KROW
000243          READ (9,701) IA
000250          WRITE(1,702) IA
000256      702 FORMAT (1X,A10)
000256       85 CONTINUE
000261          DO 100 II=1,NTESSD
000262          READ (9,400) IA,L,M
000273          WRITE(1,401) IA,L,M
000305      100 CONTINUE
000310      400 FORMAT(    A1,2I3)
000310      401 FORMAT (1X,A1,2I3)
000310          PRINT 88
000313       88 FORMAT (* END OF COPY*)
000313          END
```

----UNSATISFIED EXTERNALS----- REFERENCES

CC0000001 39 307 218 296

ROW 1
1.33567698F+01 9.37457968F-01 -6.05712508F-01 3.97058130F+00

ROW 2
9.37457968F-01 6.56958007F+00 5.35445446F+00 -2.42779160F-01

ROW 3
-6.05712508F-01 5.35445446F+00 1.55333789F+01 -1.00134302F+00

ROW 4
3.97058130F+00 -2.42779160F-01 -1.00134302F+00 1.79005806F+01

ROW 5
1.81128465E+00 2.69491808E+00 2.62639274E+00 -1.03648805E+00

ROW 6
2.20697815E+00 3.29593253F+00 7.72568561F+00 -2.32969939F+00

ROW 7
6.03681544F+00 4.01484381F-01 -1.25888918F-01 7.18989007F+00

ROW 8
-4.35110333E-01 2.49719651E+00 2.14018587E+00 -6.97750649E-01

ROW 9
3.67601001E-01 2.57005864F+00 7.09132147F+00 -2.18621590E-01

ROW 10
3.34059441E+00 -5.78381933E-01 -1.82588780F+00 8.22891918E+00

ROW 11
-7.55540341E-01 1.08008229F+00 2.32661336F-01 -7.93508025F-02

ROW 12
-1.07137403E+00 1.66786618E+00 5.16703665E+00 -1.33086269E-01

ROW 13
4.56147479E+00 -3.25368566E-01 -1.27109668E+00 9.74928634E+00

ROW 14
2.90983582E-01 2.11514015E+00 1.68435567F+00 -1.06386842E+00

ROW 15
5.75814747E-01 2.92998673F+00 7.55562727F+00 -9.91271592F-01

ROW 16
8.42560988F+00 3.41420713F+00 5.09041871F+00 3.92857150F+00

ROW 17
7.74302275F-01 4.19026544F+00 4.36589015F+00 -1.98016016F+00

ROW 18
2.19281730E-01 1.99491055F+00 5.81191086F+00 -7.94239219F-02

ROW 19
9.08325400E+00 3.93536879E+00 5.74873377E+00 3.02560578E+00

ROW 20
-1.89797314E-01 2.39739339F+00 2.11351114F+00 -1.04645052F+00

ROW 21
-2.69046671E+00 -5.63154293F-01 1.19294220F+00 1.56006032F+00

ROW 22
2.52995510E+00 -8.26988188F-01 -1.89595234F+00 1.11325738F+01

ROW 23
7.19483170E-01 1.86363913E+00 1.53433251E+00 -2.88763343E-01

ROW 24
8.53901430E-01 2.52452773E+00 6.47211618E+00 -2.30613182E+00

ROW 25
6.32303663E+00 6.07415892E-01 1.87631647E-01 8.01063516E+00

ROW 26
1.73037660E+00 3.49749518E+00 3.46649296F+00 -2.47890985E+00

ROW 27
1.71393401E+00 3.49535798E+00 8.47087891E+00 -1.70420264E+00

ROW 28
7.20659234E+00 1.98661211F+00 2.32833373F+00 3.96688042E+00

ROW 29
-1.22430397E+00 1.19217934F+00 3.93813800F-01 3.53133877F-01

ROW 30			
-2.93760168E+00	-3.49977951F-01	1.45711134F+00	1.59173041F+00
ROW 31			
5.56000794E-01	2.27760496F-01	3.47385320F-01	2.70427839F-01
ROW 32			
-2.23025814E-01	1.21391237E-01	1.91232870F-01	-1.11497736E-01
ROW 33			
-4.89164089F-01	-1.29401142F-01	-2.55170455F-01	-2.24003806F-01
ROW 34			
5.38058459E-02	3.22983400E-01	4.36710122E-01	-4.01019335E-01
ROW 35			
-4.79818821E-03	1.02912761F-02	8.75063450F-02	3.50753729E-01
ROW 36			
-4.43174792E-02	-4.56135996F-02	-1.93642260E-01	-7.12989414E-02
ROW 37			
1.75177359E+00	-1.16533013F-01	-4.51175463F-01	1.72103918F+00
ROW 38			
-3.93308957E-01	4.47304892F-01	1.05481135F+00	-2.73834580F-01
ROW 39			
1.56667895E-01	4.00710431F-01	8.56920301F-01	-1.55096430F-02
ROW 40			
-5.81838170E-02	-8.79255130F-02	1.69193706F-01	-4.04044010F-02
ROW 41			
1.71604054E-01	1.90254059E-01	-1.71853745F-01	9.76429730E-02
ROW 42			
1.79291567E-03	-3.25945553E-02	9.39533891E-02	-9.37346432E-03
ROW 43			
3.07323327E-01	1.62166753F-01	1.77857240F-01	-2.81483692F-01
ROW 44			
1.40484072F-01	1.23002057F-01	4.13104805F-01	-4.12738962F-01
ROW 45			
-2.38486518E-01	2.85755459F-02	7.77056453F-02	-1.63283772E-01
ROW 46			
1.77262305E-01	1.63688656F-01	1.66524325F-01	-4.35654097F-02
ROW 47			
-1.73845813E-01	-6.01515925F-03	-2.80190431F-02	4.75583243E-01
ROW 48			
-2.19469813E-01	-6.07614664E-04	-8.41537520E-02	-2.02775586E-01
ROW 49			
4.18356139E-01	-6.31340958F-02	-3.30118366F-02	9.66449225E-02
ROW 50			
2.95108486E-03	-4.07032343E-01	-3.17664473F-01	6.97290921E-01
ROW 51			
2.39818886E-01	2.39666267F-02	9.75106696F-02	-6.60340667F-02
ROW 52			
7.81279078E-01	-5.94680964F-02	-1.70001969F-01	8.05436882F-01
ROW 53			
-1.50378080E-01	-1.12056381F-01	-8.09012007F-02	1.88537338F-01
ROW 54			
2.04750347F-02	7.85086568F-02	-6.52120041F-02	-7.96899080F-02
ROW 55			
1.01820891E+00	4.05578431F-01	5.40615700F-01	5.88951853F-01
ROW 56			
-2.47242292E-02	1.58331697E-01	3.01017420E-01	8.77518774E-02
ROW 57			
1.50433670E-01	4.00692691F-02	-1.13849712F-01	2.66878736F-01
ROW 58			
3.63576880E-01	-1.25785166F-01	-2.64072197F-01	7.69033098F-01
ROW 59			
-1.53470022F-01	1.98684756F-01	3.81603423F-01	-6.01927138F-01
ROW 60			
-6.39747304E-02	1.03885071F-01	-1.09314141F-01	-1.89091326F-01

ROW	61			
	2.24045653E+00	6.46635332E-01	9.17156026E-01	1.48543382E+00
ROW	62			
	-8.98122633E-01	6.86709273E-01	8.91346467E-01	-7.66408720E-01
ROW	63			
	3.43445476E-01	3.45006933E-01	1.01813869E+00	1.11933307E+00
ROW	64			
	4.75663519E+00	6.83351507E-01	4.17484816E-01	4.19182506E+00
ROW	65			
	-5.62533553E-01	1.36257070E+00	1.11600533E+00	6.04730111E-02
ROW	66			
	-7.08246886E-01	9.11622965E-01	3.11216702E+00	3.53799373E-01
ROW	67			
	8.19360639E-01	1.17584782E-01	1.60371043E-01	8.51167310E-01
ROW	68			
	4.44811319E-03	5.31812419E-02	3.64196655E-01	6.78439293E-02
ROW	69			
	-1.33673040E-02	1.20694306E-01	-2.27510145E-01	-6.86298455E-02
ROW	70			
	1.00715456E-01	-1.81760024E-01	-1.62366751E-02	2.80651623E-01
ROW	71			
	4.17822602E-01	3.76391209E-01	-9.61219711E-02	7.69783057E-01
ROW	72			
	1.52218979E-01	-1.53146793E-01	-6.67377798E-03	2.87029451E-01
ROW	73			
	3.01594607E-01	2.33735013E-01	5.04684476E-01	2.03739112E+00
ROW	74			
	6.09132463E-01	-7.17975080E-02	-1.02253133E+00	1.56811471E+00
ROW	75			
	3.00352992E-01	6.16649406E-01	1.80305598E+00	-2.25558532E-01
ROW	76			
	1.76555334E-01	-6.66426586E-02	-1.52802973E-01	3.76123810E-01
ROW	77			
	-9.00746902E-02	1.46062060E-01	2.41805813E-01	-3.44386680E-01
ROW	78			
	1.86572381E-01	-1.99333899E-01	-3.04090630E-01	2.89369616E-01
ROW	79			
	3.76270801E-01	5.93564774E-02	9.46724286E-02	2.45672190E-01
ROW	80			
	1.83203996E-02	4.44673229E-01	4.85499760E-01	-7.23176163E-01
ROW	81			
	1.25553597E-01	8.33625693E-04	-8.18837710E-02	2.31327999E-01
ROW	82			
	5.62459374E-01	-1.11698378E-02	3.46249400E-01	4.99941127E-01
ROW	83			
	-1.17801843E-01	-1.15297134E-01	-2.85833994E-01	1.04561291E-01
ROW	84			
	3.61205459E-01	1.24494411E-01	5.12732797E-01	1.11189987E-01
ROW	85			
	7.50337246E+00	1.18160754E+00	1.31521448E+00	5.47539332E+00
ROW	86			
	3.90566131E-01	2.96667869E+00	3.19307059E+00	-1.98766422E+00
ROW	87			
	1.47791025E+00	3.43309274E+00	8.17242170E+00	-8.41723204E-01
ROW	88			
	-5.40485531E-02	2.99647816E-01	3.83448451E-01	-3.98901801E-01
ROW	89			
	9.96230025E-03	-1.85480156E-01	-1.78360117E-01	8.48909461E-01
ROW	90			
	1.04801695E-02	3.83478629E-02	-4.54101540E-02	-2.93550776E-01
ROW	91			
	3.25820496E-02	2.65480492E-01	3.46387846E-01	-2.53381412E-01

ROW 92			
8.57310370E-03	-4.72603989E-02	1.30787675E-02	4.99924092E-01
ROW 93			
-2.74314708E-02	-8.27953338E-03	-1.27123633E-01	-1.77107451E-01
ROW 94			
-8.83555461E-02	-6.05721281E-02	-8.90003527E-02	4.10345606E-01
ROW 95			
2.09444797E-01	-2.63307486E-01	-2.55664475E-01	1.19010297E+00
ROW 96			
6.18670657E-02	7.40632563E-02	-4.14548962E-04	-3.15098141E-01
ROW 97			
-4.76797784E-03	-6.93132522E-04	3.31864253E-02	2.70060779E-01
ROW 98			
1.85352833E-01	-5.48332571E-02	1.64649596E-02	6.77368961E-01
ROW 99			
-2.76531532E-02	2.76604058E-02	-6.85176843E-02	-2.78603636E-01
ROW 100			
-6.81178653E-02	3.99584441E-01	4.96141876E-01	-6.03552754E-01
ROW 101			
-4.17850176E-02	-2.47005577E-01	-2.98526368E-01	1.04890679E+00
ROW 102			
1.47058184E-02	3.37612069E-02	-4.60926951E-02	-2.93751232E-01
ROW 103			
8.68770154E-02	-2.85969589E-03	9.29394337E-02	2.68804306E-01
ROW 104			
1.91775138E-01	1.83840268E-01	3.47668762E-01	1.02527606E-01
ROW 105			
-1.62084890E-01	-5.17699957E-02	-2.18234052E-01	-1.53003398E-01
ROW 106			
5.63865115E-01	-1.04180976E+00	-2.17426584E+00	6.83503563E+00
ROW 107			
7.05928586E-01	9.87120404E-01	8.68145796E-01	9.24627344E-01
ROW 108			
2.66023417E-01	1.65561680E+00	4.18047610E+00	-1.65976562E+00
ROW 109			
2.34018997E+00	-4.42880445E-01	-1.01122011E+00	6.44337579E+00
ROW 110			
1.23176470E+00	1.21268790E+00	1.53652361E+00	6.73388778E-01
ROW 111			
1.85574309E+00	1.63077995E+00	3.57937382E+00	5.05632651E-01
ROW 112			
1.11574011E-01	3.08349083E-01	3.23534181E-01	-3.92362649E-01
ROW 113			
3.86328027E-02	-3.91863602E-01	-4.49921879E-01	1.40543873E+00
ROW 114			
-1.14690559E-01	-6.38341569E-02	-1.69131480E-01	2.68649928E-02
ROW 115			
1.12587026E-01	-3.63447949E-01	-4.44847968E-01	9.11256043E-01
ROW 116			
5.43765866E-01	-9.17125335E-02	-2.73420725E-01	1.49980887E+00
ROW 117			
2.17922083E-01	4.86549712E-03	6.89956513E-02	2.53135491E-01
ROW 118			
4.09585675E+00	-1.06922011E+00	-1.89263393E+00	8.23652555E+00
ROW 119			
4.99488540E+00	2.67988776E+00	3.05412764E+00	-1.04033825E+00
ROW 120			
-3.53022521E+00	7.13521964E-02	1.87911505E+00	1.22134721E+00
ROW 121			
2.11917974E-01	3.37193126E-01	4.30973637E-01	-2.03561587E-01
ROW 122			
6.13475233E-01	-1.09915429E+00	-1.36168356E+00	3.61310260E+00

ROW 123				
	5.91786288E-02	-2.13922214E-01	-5.10350611E-01	6.13549107E-01
ROW 124				
	9.82752508E-01	2.83981662E-01	4.08102366E-01	-3.11114737E-01
ROW 125				
	-5.61164620E-02	4.10874257E-02	7.47722345E-02	-1.94723587E-01
ROW 126				
	6.67915641E-02	-2.60893954E-01	-3.38864627E-01	6.78019295E-01
ROW 127				
	-4.04492647E-02	9.55236945E-03	5.39263700E-02	-2.43398485E-01
ROW 128				
	-5.54662931E-04	-2.30104622E-02	-9.62718599E-02	1.82946055E-01
ROW 129				
	3.49331014E-04	1.05553471E-03	1.65569570E-03	1.68733899E-04
ROW 130				
	-3.11013442E-03	-8.50979637E-04	-2.87248431E-03	-2.57524143E-03
ROW 131				
	-3.04653291E-03	-2.58973464E-04	1.38225510E-03	-2.69970408E-03
ROW 132				
	1.33824862E-03	-5.27190948E-04	-7.57622250E-03	2.26571336E-04
ROW 133				
	-3.70203673E-03	-7.69761435E-03	-6.82130400E-04	-5.94102927E-04
ROW 134				
	6.31759002E-03	2.46396710E-04	-7.31806585E-04	3.72442875E-03
ROW 135				
	-7.51564510E-04	1.77636682E-03	1.20939198E-03	3.98393427E-04
ROW 136				
	-2.60008527E-03	-2.23753367E-04	2.31057300E-03	-3.20662899E-03
ROW 137				
	4.12239262E-04	-7.76563212E-05	3.18692838E-04	9.28831277E-04
ROW 138				
	6.91523938E-04	1.47535024E-03	1.59902219E-04	1.04005120E-03
ROW 139				
	-1.05079371E-03	-4.47826188E-04	9.09631861E-04	-3.04189417E-04
ROW 140				
	-2.14019617E-03	-1.66745194E-05	-1.19713346E-04	-6.47975014E-04
ROW 141				
	-1.96850666E-03	-1.19025276E-03	2.70247067E-04	-1.19022302E-03
ROW 142				
	3.40852537E-05	-2.89575018E-03	-9.64494824E-04	6.80375000E-04
ROW 143				
	-4.02582869E-03	-9.56088099E-04	-3.16767132E-03	-1.12663089E-03
ROW 144				
	6.72352495E-04	-4.27549326E-04	2.98887826E-03	4.30110479E-04
ROW 145				
	5.48123361E-03	-5.44181337E-04	-1.46591558E-04	3.87006118E-03
ROW 146				
	1.46561667E-03	9.12507772E-04	1.96591069E-03	8.48828362E-04
ROW 147				
	1.26484448E-03	-1.69506043E-03	-9.47540979E-03	6.48247437E-04
ROW 148				
	-2.51516678E-03	2.46209864E-03	5.71664975E-04	-1.77549287E-03
ROW 149				
	6.04797526E-03	4.44142986E-03	8.48991718E-04	1.85683919E-03
ROW 150				
	-1.71369226E-03	-5.40595485E-04	4.75547923E-04	-2.77510823E-03
ROW 151				
	-3.50180341E-03	-4.56817685E-03	7.38829333E-03	-1.25404384E-03
ROW 152				
	3.38538307E-03	-4.01114861E-03	8.60603944E-03	8.46394252E-05
ROW 153				
	1.61677051E-03	-8.00791181E-03	1.71055385E-03	1.58653455E-03

ROW	154			
	1.38179951E-03	1.21112748E-03	-2.53749726E-04	-1.23973617E-03
ROW	155			
	-3.62689046E-03	-6.64577150E-04	3.36498436E-04	-2.81894948E-03
ROW	156			
	6.49912926E-04	-2.16100128E-04	2.18503490E-03	-9.74106584E-04
ROW	157			
	1.55211140E-03	-6.41664777E-04	-6.76876982E-04	1.27165702E-04
ROW	158			
	6.61654253E-04	-1.95959890E-03	-7.46890473E-04	1.67829095E-03
ROW	159			
	1.35601848E-03	2.77209082E-03	4.65078384E-03	-1.91478796E-04
ROW	160			
	6.94126315E-04	-1.35769135E-03	-2.76968761E-03	-3.06387203E-04
ROW	161			
	-2.02904129E-03	-1.30710109E-03	-9.01995327E-05	-7.27544890E-04
ROW	162			
	2.24362842E-03	1.68804964E-03	5.90167759E-03	-1.70927221E-05
ROW	163			
	-1.43650192E-03	-3.67244116E-03	-3.18981249E-03	9.12103659E-04
ROW	164			
	-5.37719091E-04	8.99607622E-04	2.39622404E-03	-8.90138233E-05
ROW	165			
	4.55941750E-04	-1.23521308E-03	3.72486898E-03	-3.63778446E-04
ROW	166			
	2.14213331E-03	-2.19111092E-03	2.86755786E-04	-4.48198294E-04
ROW	167			
	-2.09980448E-03	-4.65670124E-06	-8.91731951E-04	-1.22491151E-03
ROW	168			
	1.07804963E-03	-5.91252801E-04	-1.00671273E-03	4.70343642E-04
ROW	169			
	2.35107576E-04	1.23741368E-03	2.71946049E-03	-1.67148160E-03
ROW	170			
	-3.60930756E-03	-1.14704549E-03	1.51989596E-03	-9.14025283E-04
ROW	171			
	-2.65060448E-03	-2.53373192E-03	-1.25137289E-03	-3.11916364E-03
ROW	172			
	-3.64288449E-03	2.88586378E-03	3.86802969E-03	-1.87736543E-03
ROW	173			
	-1.16647585E-03	-1.25818933E-03	1.11814004E-03	-1.15035926E-04
ROW	174			
	-3.19087727E-03	-2.38639864E-03	2.37807842E-03	-4.53540978E-04
ROW	175			
	2.76684850E-03	7.66027258E-04	2.01860867E-04	1.23627124E-04
ROW	176			
	-5.31045793E-03	-2.38127363E-03	-2.41981926E-03	-1.88296052E-03
ROW	177			
	6.28312686E-04	1.69516244E-03	-2.85279495E-03	-8.48422029E-04
ROW	178			
	-3.20038973E-03	2.36530084E-05	-2.88386838E-03	-1.46299039E-03
ROW	179			
	-2.71255040E-03	-4.74707645E-04	5.21160337E-03	-2.64800270E-03
ROW	180			
	-9.26308674E-04	2.57751023E-03	5.00834480E-03	-9.40145267E-04
ROW	181			
	3.92132452E-03	-3.99916966E-04	-2.04330515E-03	3.33972699E-03
ROW	182			
	-5.81033984E-05	1.52693938E-03	2.97695767E-04	1.59226164E-03
ROW	183			
	1.30954632E-03	1.40344089E-03	1.83247536E-03	7.23854575E-04
ROW	184			
	-5.49417988E-04	1.05930283E-03	-7.78646130E-04	-4.04333063E-04

ROW	185			
	2.48664476E-03	2.39128700E-04	2.49506992F-03	3.13205169E-04
ROW	186			
	-1.60981304E-03	1.86196852F-03	-5.25813354F-04	-1.59712926E-03
ROW	187			
	8.88871645E-04	-3.27645887F-03	-1.93866061F-03	3.61107060F-04
ROW	188			
	-5.42327422E-04	-1.35684758F-03	5.82885537F-04	-5.54782085E-04
ROW	189			
	-6.67487598E-04	1.82436028F-03	-5.10405240F-03	5.06776895F-05
ROW	190			
	1.60998146E-03	-2.62048549F-03	-1.32455429F-03	2.42346810E-04
ROW	191			
	1.81673050E-03	1.60883732F-03	3.21977876F-03	8.35685718E-04
ROW	192			
	-3.63800199E-04	2.20798476F-03	6.12138701F-04	3.49465732E-04
ROW	193			
	1.27328551E-03	1.40002281F-03	5.36322005E-03	6.51777749F-04
ROW	194			
	-4.89669574E-04	-5.20872704F-04	-5.10591280F-04	-3.32479892F-04
ROW	195			
	-3.57249667E-03	-1.06081976E-03	-5.71125961E-03	-2.76220417E-04
ROW	196			
	-2.54262320E-03	3.18173215E-04	-8.34903803F-04	-4.61000189E-05
ROW	197			
	-2.51338673E-03	9.77896712F-04	2.57432625F-03	-5.76532769E-04
ROW	198			
	-1.19082792E-03	-3.05171354E-03	1.67798495F-03	3.35885921E-04
ROW	199			
	-2.73078122E-03	-1.62285559F-03	-8.47257747F-04	-1.02201365F-03
ROW	200			
	1.49997849E-03	1.71786283E-03	8.70066027F-04	1.22738199E-03
ROW	201			
	-4.36212989E-03	-1.94464439F-03	-1.04727667F-03	-1.59935366E-03
ROW	202			
	-6.59507238E-04	-3.73907804F-03	-1.67977316F-03	1.53508398F-03
ROW	203			
	-2.72810000E-03	4.56312900E-03	1.45888254F-03	-2.13284059E-03
ROW	204			
	1.29516957E-04	-2.92067471F-04	1.32603588F-03	6.97850372E-04
ROW	205			
	7.09504899E-04	8.08814254F-05	2.90825511F-03	-9.30165446E-05
ROW	206			
	4.11326734E-04	3.40984456E-03	9.67546820F-04	-1.26304283E-04
ROW	207			
	-3.67579790E-03	-2.17992813F-03	1.62427578F-03	-1.13261386E-03
ROW	208			
	1.62000642E-03	1.87435479F-03	8.31035211F-04	3.14682835F-04
ROW	209			
	-3.12546270E-03	-5.53089091F-03	-5.64181172F-03	-8.62584013E-04
ROW	210			
	-1.63311376E-03	1.62777253E-03	3.35489347E-03	-1.70597277E-05
ROW	211			
	2.41359138E-03	2.75678117F-04	6.77905075F-04	1.98153116F-03
ROW	212			
	7.35165914E-04	-4.60335683F-04	3.12328884F-03	2.10249999F-04
ROW	213			
	3.76024118E-04	2.98270788F-04	6.88347943F-05	3.91800632F-05
ROW	214			
	1.67741570E-03	3.29049593F-05	6.90139039F-04	3.58802336F-04
ROW	215			
	-2.52762589E-03	8.13760000F-04	6.54765874F-04	-2.76876566F-03

ROW 216			
6.17938988E-04	-1.01896151F-03	2.42033911F-03	-1.39201197F-03
ROW 217			
-5.78617431E-04	-1.23771445E-04	-4.00572646E-04	-3.48806327E-04
ROW 218			
-1.88910630E-04	8.82242575E-05	1.84941524E-03	6.20956130E-04
ROW 219			
3.35726488E-03	1.77896784E-04	3.41749611E-03	-4.29012546E-04
ROW 220			
-4.33601502E-03	-2.81002011F-03	-3.04765115F-03	-2.59862690E-03
ROW 221			
1.18906252E-03	1.29939745E-03	5.30070550E-04	1.49825559E-03
ROW 222			
1.15111033E-03	-1.84759420E-03	-1.16278899E-03	4.80360269E-04
ROW 223			
-1.12068199E-03	-1.16963354F-03	-5.72275410F-03	4.48952993E-04
ROW 224			
1.98172524E-03	2.28393755F-03	1.21015448F-03	3.50341562F-04
ROW 225			
1.70836015E-03	-1.91585007E-03	1.47908074E-03	1.04236989E-03
ROW 226			
-1.30963604E-03	7.18437138F-04	-2.84396651F-04	2.26052552E-04
ROW 227			
4.21121203E-03	5.24391957F-03	4.33541530F-03	6.24514639F-04
ROW 228			
3.02877326E-03	-2.42453749E-03	-6.35527256E-03	8.54727047E-04
ROW 229			
-1.55654959E-03	-9.60147163F-04	-1.05849599F-03	-1.29504842E-03
ROW 230			
-6.35238904E-04	9.21891000E-04	1.80906664E-03	-7.14278076E-04
ROW 231			
4.44864155E-04	-1.55492186F-03	-4.70947460F-03	4.91355907F-04
ROW 232			
-2.52995500E-03	6.64489568F-04	7.42084919E-05	-8.35541749F-04
ROW 233			
3.20843646E-03	4.05724548F-04	8.72643595F-03	1.83613440F-04
ROW 234			
3.40094323E-03	1.10548210F-03	3.66745808F-04	8.23960560F-04
ROW 235			
1.24683016F-03	1.17170001F-03	-3.21290490F-04	-1.52832260F-05
ROW 236			
1.39937357E-03	2.45934394E-03	-1.53753618E-03	3.79108528E-04
ROW 237			
2.31203483E-04	-2.19252140F-03	-8.66469221F-04	7.06013673F-04
ROW 238			
4.13299635E-03	-1.32233285F-03	-8.43569778F-04	2.30751464F-03
ROW 239			
-1.26632895E-03	-7.67032835E-04	-3.15574699E-03	-2.61111446E-05
ROW 240			
-6.80162017E-05	1.37837318F-03	3.67787715F-04	-5.11273914E-04
ROW 241			
-8.15928784E-03	3.41009352E-03	1.19670580F-03	-3.17294247F-03
ROW 242			
-1.69964230E-03	7.39750955F-05	-7.21058674F-04	-5.56030718F-04
ROW 243			
-2.54328309E-03	7.77609704F-04	7.77674519F-03	-2.33051219E-03
ROW 244			
-4.67405312E-03	-1.62591921F-03	9.63168201F-05	-2.60214060E-04
ROW 245			
-1.02647233E-03	-6.69630089F-04	-4.73141380F-04	-3.71438370E-04
ROW 246			
-1.19931859E-03	-3.58879367F-03	1.92163921F-03	-4.05480993F-04

ROW 247
-2.78400243E-03 -2.94042946E-03 -3.88330613E-03 -1.02655829E-03
ROW 248
-1.06355414E-03 1.69149645E-03 2.89116091E-03 4.74027166E-04
ROW 249
-2.34454076E-03 2.54021523E-03 2.19231856E-03 -6.33490835E-05
ROW 250
1.05003035E-03 -6.90920071E-04 -2.64232482E-03 1.08221946E-04
ROW 251
8.75619043E-04 2.15907772E-03 4.06651535E-03 -7.16981003E-05
ROW 252
-9.18549252E-04 3.03640376E-04 -9.41028438E-04 5.44340840E-04
ROW 253
-2.88142605E-03 -9.74592976E-04 -2.72807487E-03 -1.27933369E-03
ROW 254
5.26983475E-04 -3.18315509E-04 1.49433768E-03 7.28828720E-04
ROW 255
-2.61476314E-03 1.38768813E-04 -1.54563491E-03 -1.84948067E-03
ROW 256
-1.66930241E-03 -2.53526807E-04 -1.21653298E-03 -4.49522496E-04
ROW 257
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ROW 258
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C 18 14
S 18 14
C 19 12
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C 19 13
S 19 13
C 19 14
S 19 14
C 20 13
S 20 13
C 20 14
S 20 14
C 21 13
S 21 13
C 21 14
S 21 14
C 22 14
S 22 14
END OF COPY
```

APPENDIX B

TAPE-BLOCKING PROGRAM

```
                      PROGRAM XTAPE(INPUT,OUTPUT,TAPE1,TAPE9)
                C     DIMENSION   IA(8,N)
000003                DIMENSION IA(8,30)
000003                K=0
000004                N=30
000005              1 DO 10 I=1,N
000007                K=K+1
000011                READ (9,500) (IA(J,I),J=1,8)
000023                IF (EOF,9) 19,10
000026             10 CONTINUE
000031            500 FORMAT (8A10)
000031             19 BUFFER OUT (1,0) (IA(1,1),IA(8,I ))
000040                IF (UNIT,1)  19,20,99,99
000045             20 IF (I.EQ.N ) GO TO 1
000047             99 CONTINUE
000047                END
```

APPENDIX C

7-TRACK TAPE FORMAT

Each physical record of data contains 2408 characters coded in external BCD, at a density of 556 BPI. The first 2400 characters represent 30 card images of 80 characters each. The last 8 characters are blanks and should be ignored. The last physical record is padded with a variable number of blank-card images.

The file ends with the following sequence of physical records:

CDC SCOPE end-of-file – 8 characters, where the first seven are blanks and the eighth is 17B

tape mark

trailer label – 80 characters in external BCD, beginning
EOF1----------

tape mark

tape mark

BIOGRAPHICAL NOTE

E. M. GAPOSCHKIN graduated in Electrical Engineering from Tufts University in 1957. He received a Degree of Numerical Analysis in 1959 from Cambridge University in England and a Ph. D. in geophysics from Harvard University in 1969.

Since joining the staff at Smithsonian in 1959, he has been programer and Division Chief of the Computations Division and mathematician in the Research and Analysis Department. He has helped develop the basic computer program used in all analyses of satellite motion.

Since 1968, Dr. Gaposchkin has been principal scientist of the satellite geophysics group. His main interests include satellite geodesy and geophysics and applied mathematics.

NOTICE

This series of Special Reports was instituted under the supervision of Dr. F. L. Whipple, Director of the Astrophysical Observatory of the Smithsonian Institution, shortly after the launching of the first artificial earth satellite on October 4, 1957. Contributions come from the Staff of the Observatory.

First issued to ensure the immediate dissemination of data for satellite tracking, the reports have continued to provide a rapid distribution of catalogs of satellite observations, orbital information, and preliminary results of data analyses prior to formal publication in the appropriate journals. The Reports are also used extensively for the rapid publication of preliminary or special results in other fields of astrophysics.

The Reports are regularly distributed to all institutions participating in the U. S. space research program and to individual scientists who request them from the Publications Division, Distribution Section, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts 02138.