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OF THE INJUN III SATELLITE[1]

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Luigi G. Jacchia[2] and Jack Slowey[3]

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Summary.--Injun III is a near-spherical object in an orbit with eccentricity 0.16, inclination 70°.4 and a mean perigee height of 250 km. An analysis of the drag during the first half-year after launching has revealed:

a) that on geomagnetically quiet drags the upper-atmosphere temperature in the auroral zones is essentially the same as at the equator;

b) that the heating that accompanies geomagnetic perturbations in the auroral zones is four or five times greater than the heating experienced during these perturbations in low latitudes.

In addition, the present analysis gives a calibration of atmospheric models at the critical height of 250 km. The amplitude of the diurnal temperature oscillation is found to be smaller than expected, but the cause of the discrepancy may lie in part with the atmospheric model.

AUTHOR

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1. General

Injun III (Satellite 1962 βτ2) was launched on December 13, 1962, in a rather eccentric ($e = 0.16$) orbit inclined $70^{\circ}.4$ to the equator, with a mean perigee height of about 250 km. During the second half of January and most of February 1963 the perigee of the satellite was located in latitudes between 65° and 70° north, providing an opportunity for study of the effect of atmospheric heating in the auroral zones. The satellite was put on the observing list of the Baker-Nunn cameras. Luckily, two geomagnetic perturbations of moderate intensity (maximum $K_p = 6^-$ in both cases) occurred on January 31 and February 10, respectively, and revealed an atmospheric heating effect several times greater than during comparable events at low latitudes. During the half-year covered by the observations that are analyzed in this paper, the perigee of the satellite explored practically the whole allowed range of latitudes and underwent twice the day-and-night cycle, permitting a good separation of the diurnal effect from a possible latitude effect--which was found to be undetectably small. Furthermore, it was possible to compare the densities with those of atmospheric models, providing a needed correction for the critical height of 250 km, where there has always been a chronic scarcity of observations.

2. Atmospheric densities and temperatures

Atmospheric densities were computed with the method and the formulae described in S.A.O. Special Report No. 100 (Jacchia and Slowey, 1962b), except for the night density profile $\rho_0(z)$ in equation (7), which in its original version would have given a nighttime density scale height $H_\rho = 41$ km at $z = 250$ km, instead of the value $H_\rho \approx 30$ km, which can be expected to prevail today on the basis of more recent models (Nicolet, 1961; Harris and Priester, 1962) and from the determinations by King-Hele and Rees (1962). For the present paper we have used

$$\log_{10} \rho_0(z) = \text{const.} - 0.0014863z + 8.835 \exp(-0.0032z);$$

which gives $H_\rho = 30.6$ at $z = 250$ km. According to equation (7) of Special Report No. 100, the maximum daytime density should be 1.4 times the maximum nighttime density. This ratio may be a little too small; 1.8 seems to be a better value according to the data contained in this paper. In any case, the amplitude of the diurnal variations of the model atmosphere is more than sufficiently close to reality for the purpose of determining atmospheric densities.

The presentation area of the satellite, computed from drawings kindly provided by the National Aeronautics and Space Administration, was taken to be 3629 cm^2; the shape is close enough to the spherical to ensure reliable atmospheric-density determinations. The mass of the satellite, according to the launching agency, is 5194 grams, so the area-to-mass ratio is $A/m = 0.0699\ g/cm^2$. The drag coefficient, as usual, was taken to be 2.2.

Both Minitrack observations and field-reduced positions from Baker-Nunn cameras were used in the present paper. Photographs with the Baker-Nunn cameras were started on January 16, 1963. The drag data before that date must be considered somewhat less reliable concerning details, although averages over 2 or 3 days should be quite correct. In particular, one should be cautious about the data covering the magnetic disturbances of December 16, 1962, and January 14, 1963, which were derived from few observations only. The gap in the drag data between April 22 and May 4, 1963, is also caused by scarcity of observations. The results of the reduction are shown in table 1, in the same format as in S.A.O. Special Reports No. 100 and 125. As usual, we have given both the density at perigee height and the density reduced to a standard height above the geoid--which in this case is 250 km. The reduction to the standard height was done using the same atmospheric-density equations as were used for the determination of the densities themselves.

The temperature T_π (from Nicolet II; see below) is the exospheric temperature above the satellite perigee computed on the basis of Nicolet's model. A detailed tabulation of atmospheric densities as a function of exospheric temperature and height was kindly supplied to us by Dr. Nicolet. These new tables are an improved version of those published in S.A.O. Special Report No. 75 (Nicolet, 1961); they show some systematic differences with respect to them. The runs of log ρ as a function of the exospheric temperature for the old version (Nicolet I) and the new version (Nicolet II) are illustrated in figure 2, which also shows the curve of nighttime log ρ from Harris and Priester (1962).

3. Temperature calibration

As Priester (1963) has shown, for heights above 350 km there is near-perfect agreement in the minimum nighttime temperatures determined from King-Hele's (1963) densities using the Harris-Priester model and from Jacchia and Slowey's (1962b) densities using the Nicolet I model. We can thus assume with great confidence that the relation between the 10.7-cm solar flux and the nighttime exospheric temperature as determined by Jacchia (1963a, b; see figure 1) is essentially correct (for the daytime temperatures, there is a systematic difference between the models).

During the last part of May 1963 the perigee of the Injun III satellite was located nearly opposite the sun and in low latitudes; moreover, geomagnetic activity was reduced to a minimum. This provided a good opportunity for checking on the temperatures of table 1. Around May 23, 1963, the atmospheric density at z = 250 km, as determined from the Injun III satellite, was 2.8 g/cm^3 (log ρ = 13.55). The 10.7-cm flux $F_{10.7}$ was then 85, and the average for a one-month period around that date was also 85. For $\bar{F}_{10.7}$ = 85 figure 1 gives us a nighttime temperature of 750°K; the contribution of the semiannual temperature oscillation should be just about 0 on May 23. The point corresponding to T = 750° and log ρ = -13.55 is shown on figure 2; it obviously falls below the curves corresponding to both Nicolet's and the Harris-Priester models. The observed density is only 0.59 times that given by Nicolet II, and 0.80 times the Harris-Priester density for an exosphere night temperature of 750°. For log ρ = -13.55 Nicolet II gives an exospheric temperature of 625°, i.e., a value 125° lower than the one we have assumed to be correct. Therefore we conclude that the temperatures given in table 1 are all to be augmented by some 125°; this we have done in figure 4, where a plot of the exospheric temperatures appears below that of the densities reduced to z = 250 km.

4. Auroral-zone heating during magnetic storms

All the data on upper-atmosphere perturbations related to geomagnetic disturbances have so far been derived from the drag analysis of satellites with perigees located in low or moderate latitudes (Jacchia, 1959, 1961a, b, 1963a; Groves, 1961; Jacchia and Slowey, 1962a, b, 1963). The amplitudes of these perturbations can be accounted for by assuming that the heating of the atmosphere above the height of 350 km is proportional to the 3-hourly geomagnetic index a_p. A study (Jacchia and Slowey, 1963) of 46 atmospheric-drag perturbations of Explorer IX (Satellite 1961 δ1, inclination 38°.8) during a 283-day interval in the year 1961 has yielded for the atmospheric heating the relation $c = \Delta T/\Delta a_p = 1^\circ.0$ (temperature T in $^\circ$K). A plot of the observed data is given in figure 3. If allowance is made for the limited resolution of the drag determinations, the value of the coefficient c must be increased to 1°.2.

The temperature variations during geomagnetic perturbations shown in figure 4 must be taken in a relative sense. The amplitude of the temperature variations can be counted correct only if

a) the height at which the heating occurs is the same as that assumed for the heat source in Nicolet's model;

b) the values of dp/dt derived from Nicolet's model are correct at z = 250 km on geomagnetically quiet days.

Although there is good indication that both conditions are roughly satisfied, one should be cautious when using these amplitudes quantitatively. No matter, however, how far the conditions are from being satisfied, an intercomparison of the amplitudes during different geomagnetic perturbations should be quite safe.

In addition to density and temperature as a function of time, figure 4 gives the three-hourly geomagnetic index a_p (in the original form on perturbed days; averaged over 24 hours on quiet days), the 10.7-cm solar flux, the latitude of perigee and the angular distance of the perigee from the diurnal bulge (assumed to center 2 hours east of the subsolar point). Even a cursory glance at the density and temperature plots reveals that the atmospheric heating during the geomagnetic disturbances of January 31 and February 10, when the latitude of perigee was 70°, was much greater than during comparable geomagnetic disturbances when the perigee was at lower latitudes. The temperature rise was about 350° during the first disturbance, and about 250° during the second. The a_p range was about 60 in both cases; this gives for c an average value of 5°. On the other hand, the atmospheric perturbations that accompanied the geomagnetic disturbances when the satellite perigee was at low latitudes give a value of c close to the normal $1^\circ.0$ or $1^\circ.2$.

If we assume that for the auroral zones we also have a near-linear relation between a_p and T, as in figure 3, a value of c of 5° would lead us to temperature increases of the order of 2000° during first-rate magnetic storms, when a_p reaches 400. Such temperatures are of the order of magnitude predicted by Cole (1962) on the basis of Joule heating; Cole also predicts a fivefold increase in heating in the auroral zones, which is just about what is observed.

5. The diurnal effect and a search for latitude effect

The perigee of Injun III was close to the center of the dark hemisphere twice. The first time, in February, the latitude of perigee was near 70° north; the second time, in May, it was between 20° and 30° south. On both occasions the temperature reached just about the same minimum value on quiet days (750° after correction). Since also the 10.7-cm solar flux was not appreciably different on the two dates (80 in February, 85 in May), we must conclude that on quiet days there is no appreciable difference in upper-atmosphere temperature between the auroral zones and the equatorial zone. The difference in temperature manifests itself only during magnetically disturbed days.

From drag material for satellites with perigee heights above 350 km and dating mainly from the interval 1958-1961 Jacchia and Slowey (1962b) found that the temperature at the center of the diurnal bulge is 1.35 times higher than at the opposite point in the dark hemisphere. The data used for figure 1, which also include some 1962 data, give the best fit with a factor of 1.33. If we take 750°K for the nighttime minimum that occurred toward the end of May in the temperature curve of Injun III, we would expect to find a temperature of about 1000°K at the beginning of April, when the perigee came within 20° of the diurnal bulge. Although the temperature curve shows a maximum around that time, it reached only about 900°K--and that was at a time when the contribution of the semi-annual temperature oscillation must have been at its maximum (some 20°-30° above mean level, if we extrapolate the amplitude of the oscillations from previous years). This smaller amplitude of the diurnal variation may result in part from a locally wrong value of dp/dT in Nicolet's model for heights around 250 km, although there is some indication from other satellites that the diurnal variation may have really decreased as sunspot minimum approached.

All we can say with confidence is that the diurnal density maximum was about 5.2×10^{-14} g/cm^3, higher by a factor of 1.85 with respect to the nighttime minimum. If the semiannual effect was present, the factor should be decreased a little--perhaps to 1.7 or 1.8.

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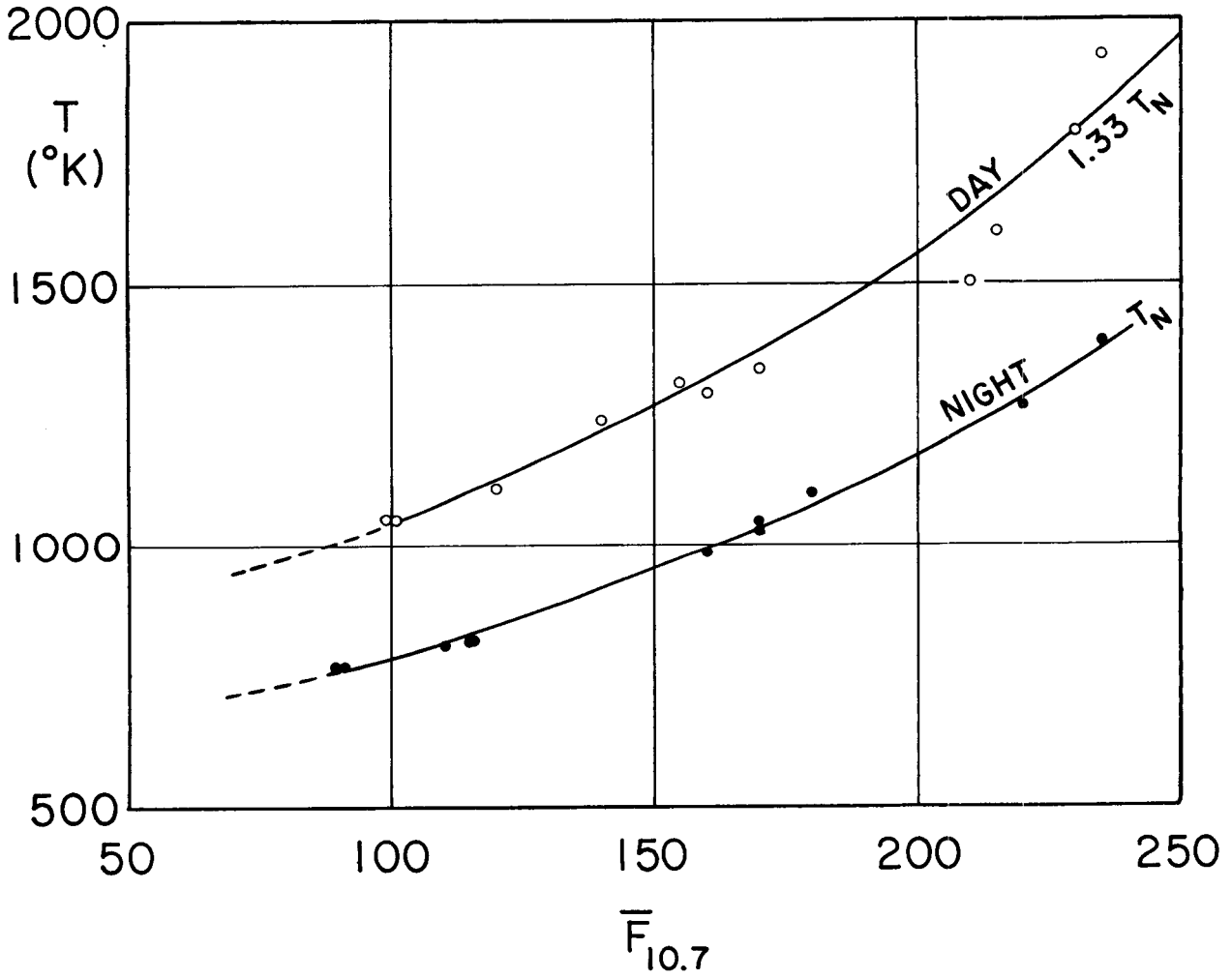

Figure 1.-- Day and night exospheric temperatures as a function of the 10.7-cm flux. Temperatures and fluxes are mean values, from which the effect of the "27-day" oscillations has been removed by smoothing. The temperatures were computed from the densities derived from satellite drag by use of Nicolet's (1961) multi-temperature model. Satellites with perigee heights from 350 to 750 km were used for this diagram. (from Jacchia, 1963b)

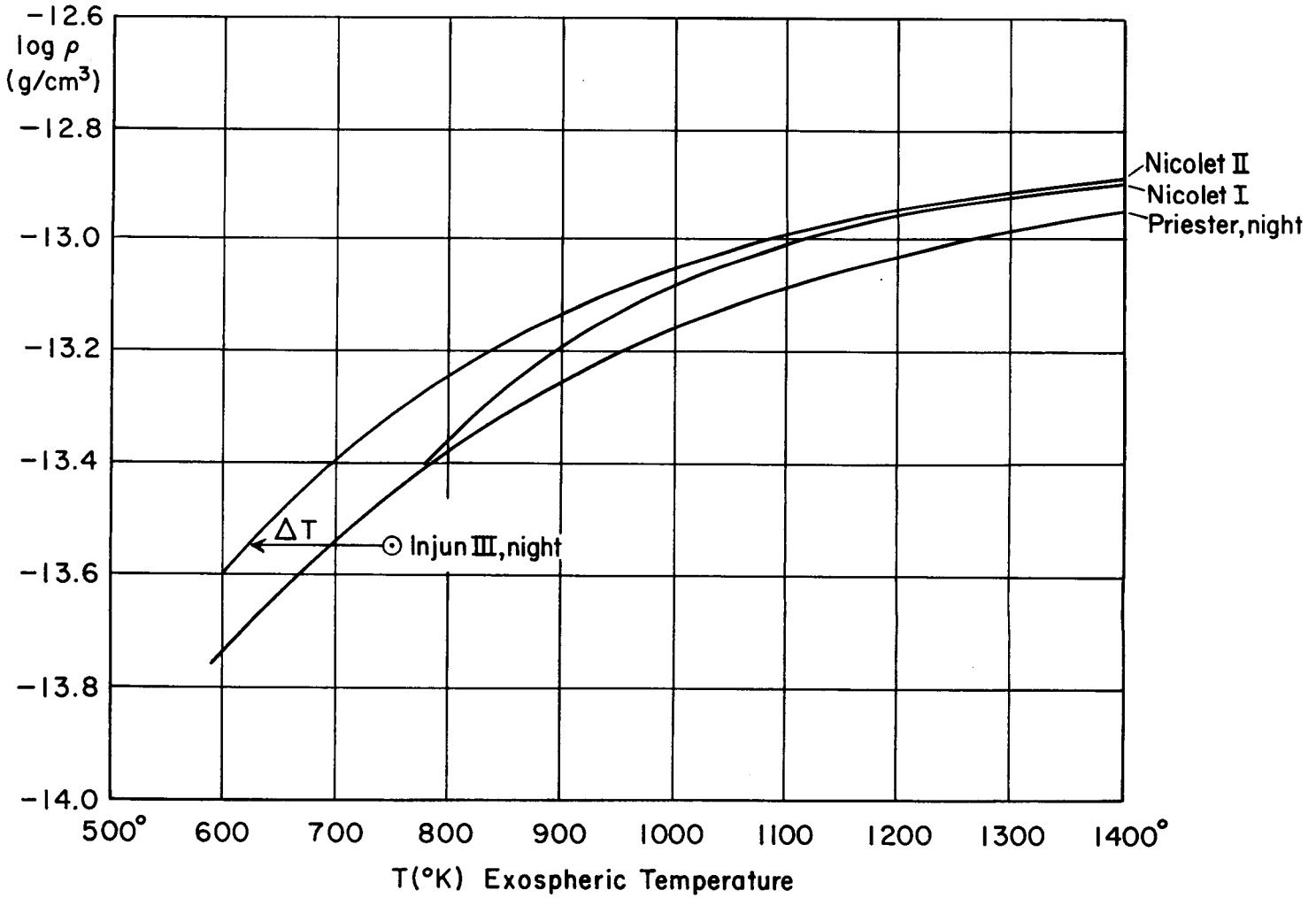

Figure 2.-- Atmospheric densities as a function of exospheric temperature for a height of 250 km. The curves shown are those of Nicolet's original and improved model (Nicolet I and II), and of the Harris-Priester model for the nighttime minimum. The circled dot is the result of the Injun III analysis in the present paper. Δ T represents the correction to be applied to the temperatures of table 1.

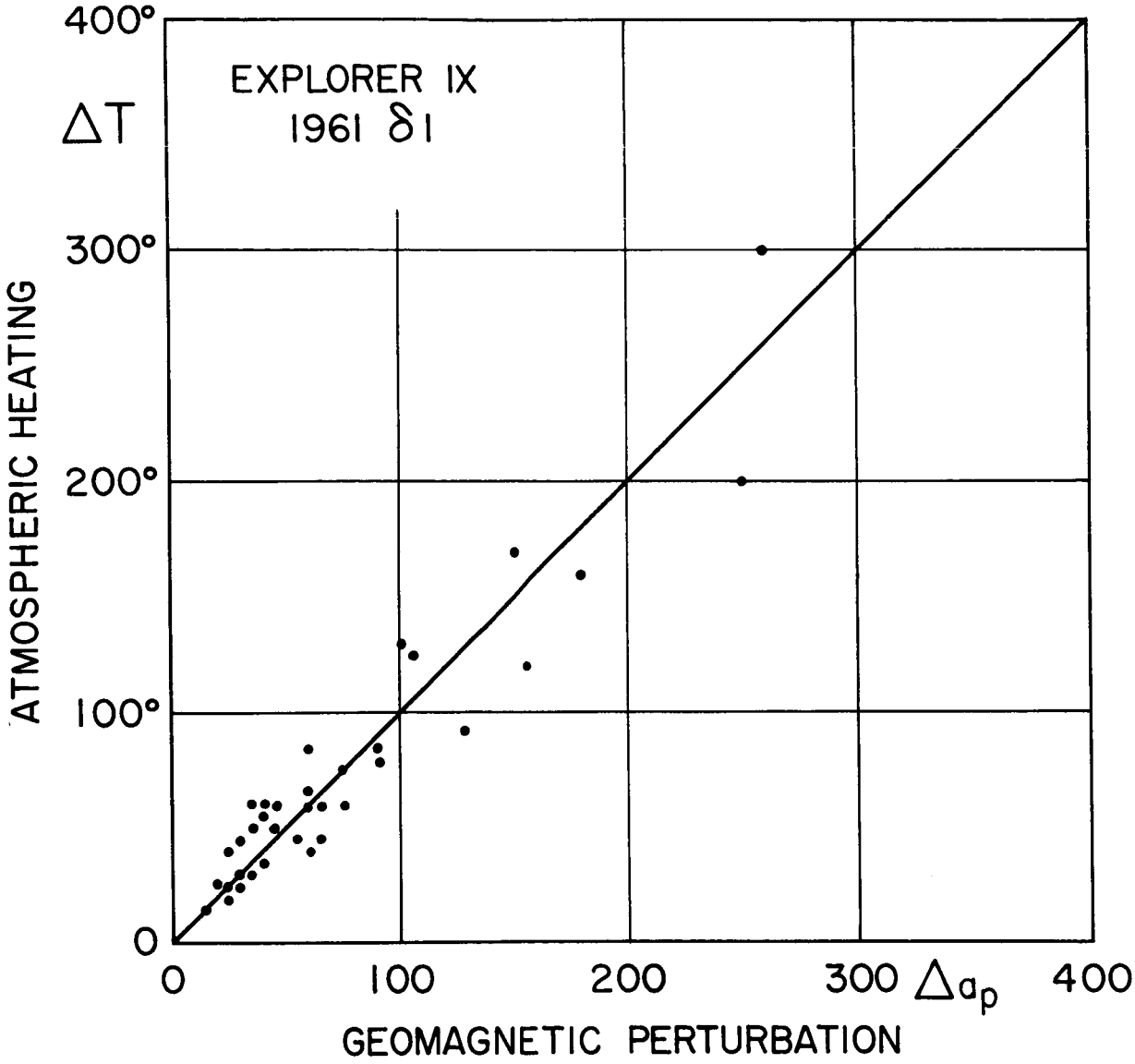

Figure 3.-- Atmospheric heating (in °K) as a function of the amplitude of the 3-hour geomagnetic index a_p from Explorer IX data. Although the straight line $\Delta T = 1.0\ \Delta a_p$ fits the observations best, the most probable value of $\Delta T/\ \Delta a_p$ is 1.2, if allowance is made for the limited resolution of the accelerations from which the temperatures are derived. Since the inclination of the Explorer IX satellite is 38.8, these data refer to low geomagnetic latitudes (from Jacchia and Slowey, 1963).

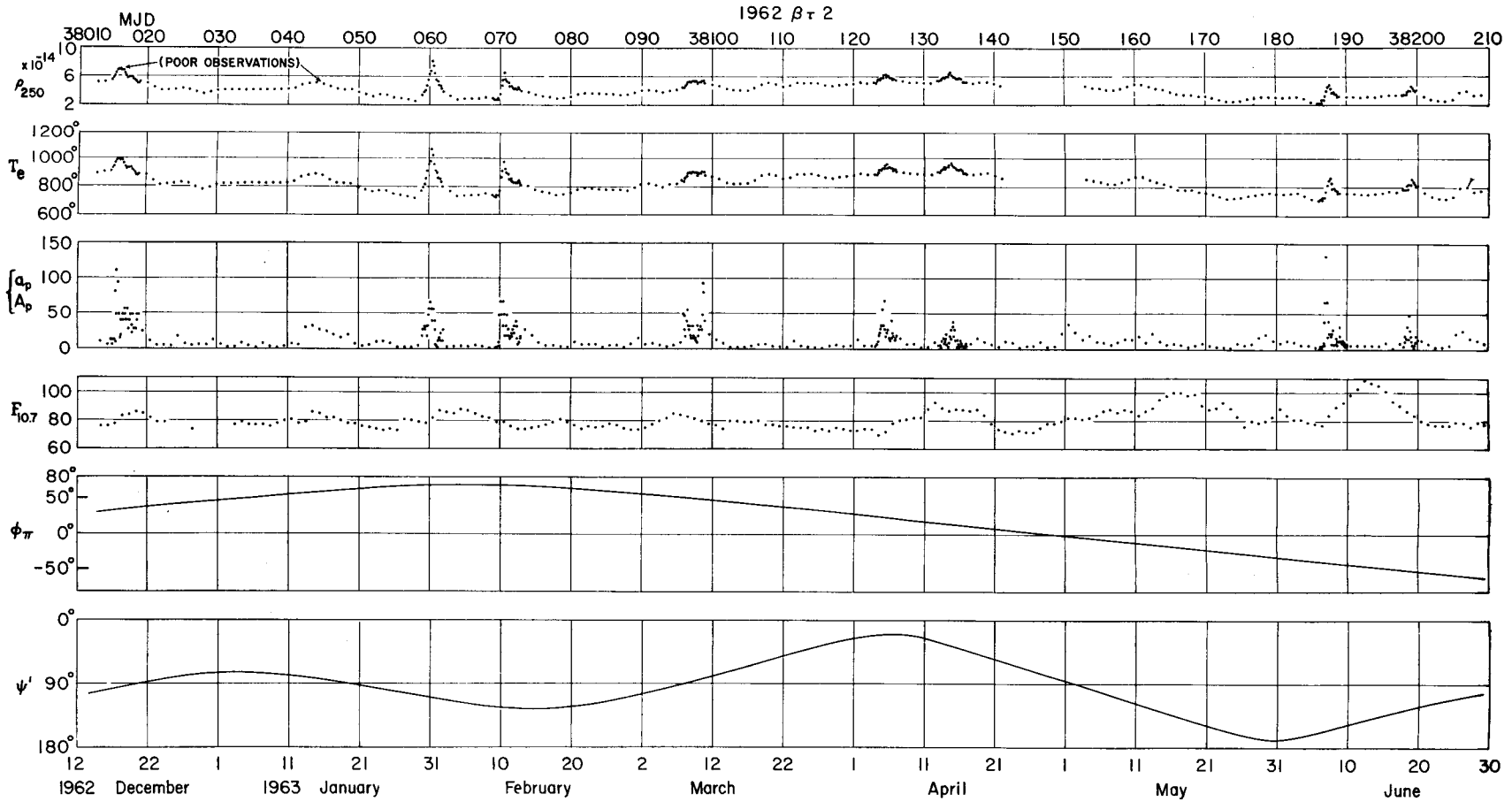

Figure 4.-- Atmospheric densities reduced to a standard height of 250 km (first strip) and corrected temperatures (second strip, see text) from the drag of the Injun III satellite. For comparison the diagram also shows the geomagnetic a_p index, the 10.7-cm solar flux, the latitude of perigee and the angular distance of the perigee from the diurnal bulge (taken as 30° east of the subsolar point).

Table 1.--Acceleration, drag, atmospheric densities, atmospheric temperature, and geometric parameters

SATELLITE 1962 βτ2

MJD	$-10^6\dot{P}$	$\dot{P}_R$ *	$-10^6\dot{P}_A$	$\log \rho_\pi$	$\log \rho_s$	T_π (°K)	z (km)	$\alpha_\pi-\alpha_\odot$ (deg.)	ψ_0' (deg.)	ψ_{30}' (deg.)
38013.00	6.04		6.04	-13.20	-13.28	775	244.1	120.0	126.6	101.6
14.00	6.23		6.23	.19	.27	784	244.1	116.7	124.0	99.3
38015.00	6.37		6.4	-13.18	-13.26	792	244.1	113.4	121.4	97.2
15.20	6.84		6.8	.15	.23	812	244.1	112.8	120.9	96.7
15.40	6.99		7.0	.14	.22	822	244.1	112.1	120.4	96.3
15.60	7.63		7.6	.10	.19	852	244.1	111.4	119.9	95.9
15.80	7.94		7.9	.09	.17	867	244.1	110.8	119.3	95.5
16.00	8.09		8.1	.08	.16	878	244.1	110.1	118.8	95.0
16.20	8.08		8.1	.08	.16	878	244.1	109.5	118.3	94.6
16.40	7.90		7.9	.09	.17	867	244.2	108.8	117.8	94.2
16.60	7.88		7.9	.09	.17	867	244.2	108.1	117.3	93.8
16.80	7.54		7.5	.11	.19	847	244.2	107.5	116.8	93.4
17.00	7.04		7.0	.14	.22	822	244.2	106.8	116.3	93.0
17.20	6.70		6.7	.16	.24	807	244.2	106.1	115.9	92.6
17.40	6.85		6.8	.15	.23	812	244.3	105.5	115.4	92.2
17.60	6.83		6.8	.15	.23	813	244.3	104.8	114.9	91.8
17.80	6.82		6.8	.15	.23	813	244.3	104.2	114.4	91.5
18.00	6.48		6.5	.17	.25	798	244.3	103.5	113.9	91.1
18.20	6.30		6.3	.19	.27	788	244.3	102.8	113.4	90.7
18.40	6.12		6.1	.20	.28	778	244.4	102.2	112.9	90.3
18.60	5.78		5.8	.22	.30	763	244.4	101.5	112.5	89.9
18.80	5.77		5.8	.22	.30	763	244.4	100.8	112.0	89.6
19.00	5.92		5.9	.22	.29	769	244.5	100.1	111.5	89.2
38020.00	5.79		5.79	-13.22	-13.30	764	244.6	96.8	109.2	87.4
21.00	5.11		5.11	.28	.35	729	244.8	93.4	106.9	85.8
22.00	4.51		4.51	.34	.40	697	245.0	90.0	104.7	84.2
23.00	4.58		4.58	.33	.40	702	245.2	86.6	102.5	82.7
24.00	4.66		4.66	.32	.39	708	245.4	83.2	100.4	81.4
25.00	4.73		4.73	.32	.38	714	245.7	79.8	98.4	80.2
26.00	4.55		4.55	.34	.39	705	246.0	76.3	96.5	79.1
27.00	4.16		4.16	.38	.43	684	246.2	72.8	94.7	78.1
28.00	3.89		3.89	.41	.45	669	246.5	69.3	92.9	77.2
29.00	4.10		4.10	.38	.43	684	246.8	65.8	91.3	76.5
30.00	4.31		4.31	.36	.40	698	247.1	62.2	89.8	76.0
31.00	4.38		4.38	.36	.39	705	247.4	58.6	88.3	75.6
32.00	4.34		4.34	.36	.39	704	247.7	55.0	87.0	75.3
33.00	4.30		4.30	.37	.39	704	248.0	51.4	85.8	75.2
34.00	4.30		4.30	.37	.39	706	248.4	47.7	84.7	75.2
35.00	4.28		4.28	.37	.39	707	248.7	44.0	83.8	75.4
36.00	4.22		4.22	.38	.39	706	249.0	40.2	82.9	75.7
37.00	4.18		4.18	.38	.39	705	249.3	36.4	82.2	76.2
38.00	4.20		4.20	.38	.39	709	249.6	32.6	81.7	76.8
39.00	4.17		4.17	.38	.38	709	249.9	28.7	81.3	77.5
40.00	4.15		4.15	.39	.38	710	250.2	24.8	81.0	78.3
41.00	4.32		4.32	.37	.36	723	250.5	20.8	80.8	79.3
42.00	4.67		4.67	.34	.32	747	250.8	16.8	80.8	80.4
43.00	4.86		4.86	.32	.30	761	251.1	12.7	81.0	81.5
44.00	4.94		4.94	.31	.29	768	251.3	8.6	81.2	82.8
45.00	4.73		4.73	.33	.31	758	251.6	4.3	81.6	84.2
46.00	4.27		4.27	.37	.35	731	251.8	0.0	82.1	85.6
47.00	3.90		3.90	.41	.39	709	252.1	355.7	82.8	87.1
48.00	3.84		3.84	.42	.39	707	252.3	351.2	83.6	88.7
49.00	3.77		3.77	.43	.39	704	252.5	346.7	84.4	90.3
50.00	3.41		3.41	.47	.43	680	252.7	342.1	85.4	92.0
51.00	3.22		3.22	.50	.46	667	252.9	337.3	86.5	93.8
52.00	2.94		2.94	.54	.49	647	253.0	332.5	87.7	95.5
53.00	3.08		3.08	.52	.47	659	253.2	327.6	89.0	97.3
54.00	3.03		3.03	.52	.48	657	253.3	322.6	90.3	99.1

*This column is included for the contribution to the acceleration resulting from solar radiation pressure which, for this satellite, is not significant.

Table 1.--Continued

SATELLITE 1962 βτ2

MJD	$-10^6\dot{P}$	$\dot{P}_R$	$-10^6\dot{P}_A$	log ρ_π	log ρ_s	T_π (°K)	z (km)	$\alpha_\pi-\alpha_\odot$ (deg.)	ψ'_0 (deg.)	ψ'_{30} (deg.)
38055.00	2.72		2.72	-13.57	-13.52	634	253.4	317.5	91.7	100.9
56.00	2.62		2.62	.58	.53	627	253.6	312.2	93.2	102.8
57.00	2.44		2.44	.61	.56	615	253.7	306.9	94.8	104.6
58.00	2.29		2.29	.64	.59	605	253.8	301.4	96.4	106.4
38059.00	3.01		3.0	-13.52	-13.47	660	253.9	295.9	98.0	108.2
59.20	3.34		3.3	.48	.43	684	253.9	294.8	98.3	108.5
59.40	3.50		3.5	.46	.40	699	253.9	293.6	98.7	108.9
59.60	4.15		4.1	.39	.33	742	253.9	292.5	99.0	109.2
59.80	4.80		4.8	.32	.26	789	253.9	291.4	99.3	109.6
60.00	5.61		5.6	.25	.20	842	254.0	290.3	99.7	109.9
60.20	5.93		5.9	.23	.17	862	254.0	289.1	100.0	110.2
60.40	7.23		7.2	.14	.09	955	254.0	288.0	100.3	110.6
60.60	6.58		6.6	.18	.12	911	254.0	286.8	100.7	110.9
60.80	5.61		5.6	.25	.20	842	254.0	285.7	101.0	111.3
61.00	4.79		4.8	.32	.26	790	254.0	284.5	101.4	111.6
61.20	4.63		4.6	.34	.28	777	254.0	283.4	101.7	111.9
61.40	4.14		4.1	.39	.33	743	254.0	282.2	102.0	112.3
61.60	3.98		4.0	.40	.34	736	254.0	281.1	102.4	112.6
61.80	3.66		3.7	.43	.38	715	254.0	279.9	102.7	112.9
62.00	3.33		3.3	.48	.42	685	254.0	278.7	103.1	113.2
38063.00	2.88		2.88	-13.54	-13.48	652	254.0	272.9	104.8	114.8
64.00	2.43		2.43	.61	.56	617	254.0	267.0	106.5	116.3
65.00	2.52		2.52	.60	.54	624	254.0	261.1	108.2	117.8
66.00	2.53		2.53	.60	.54	625	254.0	255.1	109.9	119.1
67.00	2.58		2.58	.59	.53	628	253.9	249.2	111.6	120.3
68.00	2.71		2.71	.57	.51	638	253.8	243.3	113.2	121.4
69.00	2.53		2.53	.59	.54	624	253.8	237.5	114.8	122.4
38069.20	2.36		2.4	-13.62	-13.56	614	253.8	236.3	115.2	122.5
69.40	2.36		2.4	.62	.56	614	253.7	235.1	115.5	122.7
69.60	2.52		2.5	.60	.55	621	253.7	234.0	115.8	122.9
69.80	2.52		2.5	.60	.55	621	253.7	232.8	116.1	123.0
70.00	3.00		3.0	.52	.47	661	253.7	231.7	116.4	123.2
70.20	4.14		4.1	.38	.33	742	253.7	230.5	116.7	123.3
70.40	4.79		4.8	.32	.26	789	253.6	229.4	117.0	123.5
70.60	5.76		5.8	.23	.18	854	253.6	228.2	117.3	123.6
70.80	4.95		5.0	.30	.25	801	253.6	227.1	117.6	123.7
71.00	4.63		4.6	.33	.28	775	253.6	226.0	117.8	123.9
71.20	4.47		4.5	.34	.29	768	253.5	224.8	118.1	124.0
71.40	3.98		4.0	.39	.35	734	253.5	223.7	118.4	124.1
71.60	3.98		4.0	.39	.35	734	253.5	222.6	118.7	124.2
71.80	3.82		3.8	.42	.37	719	253.5	221.5	119.0	124.3
72.00	3.66		3.7	.43	.38	712	253.4	220.3	119.2	124.4
72.20	3.66		3.7	.43	.38	712	253.4	219.2	119.5	124.5
72.40	3.66		3.7	.43	.38	712	253.4	218.1	119.8	124.5
72.60	3.82		3.8	.42	.37	719	253.4	217.0	120.0	124.6
72.80	3.66		3.7	.43	.38	711	253.3	215.9	120.3	124.7
73.00	3.49		3.5	.45	.41	697	253.3	214.8	120.5	124.7
38074.00	3.37		3.37	-13.47	-13.42	686	253.2	209.4	121.7	124.9
75.00	3.12		3.12	.50	.46	666	253.0	204.0	122.8	124.9
76.00	2.94		2.94	.53	.49	651	252.9	198.8	123.8	124.7
77.00	2.83		2.83	.54	.51	641	252.7	193.7	124.6	124.3
78.00	2.64		2.64	.57	.54	625	252.5	188.8	125.3	123.7
79.00	2.70		2.70	.56	.53	629	252.4	183.9	125.8	123.0
80.00	2.90		2.90	.53	.50	643	252.2	179.1	126.1	122.1
81.00	3.25		3.25	.48	.45	668	252.0	174.5	126.3	121.0
82.00	3.41		3.41	.46	.44	678	251.8	169.9	126.3	119.8

Table 1.--Continued

SATELLITE 1962 βτ2

MJD	$-10^6\dot{P}$	$\dot{P}_R$	$-10^6\dot{P}_A$	log ρ_π	log ρ_s	T_π (°K)	z (km)	$\alpha_\pi-\alpha_\odot$ (deg.)	ψ_0' (deg.)	ψ_{30}' (deg.)
38083.00	3.38		3.38	-13.47	-13.44	675	251.6	165.5	126.1	118.4
84.00	3.34		3.34	.47	.45	670	251.5	161.1	125.7	116.9
85.00	3.33		3.33	.47	.45	668	251.3	156.8	125.2	115.2
86.00	3.35		3.35	.47	.46	667	251.0	152.6	124.5	113.4
87.00	3.38		3.38	.47	.46	668	250.7	148.5	123.6	111.5
88.00	3.33		3.33	.47	.47	662	250.5	144.4	122.5	109.5
89.00	3.65		3.65	.43	.43	683	250.3	140.4	121.2	107.4
90.00	3.96		3.96	.40	.40	702	250.0	136.5	119.9	105.2
91.00	4.08		4.08	.38	.39	708	249.8	132.7	118.3	102.9
92.00	3.95		3.95	.40	.40	697	249.6	128.8	116.6	100.6
93.00	3.80		3.80	.42	.43	685	249.4	125.1	114.9	98.2
94.00	4.07		4.07	.39	.40	700	249.1	121.4	112.9	95.7
95.00	4.24		4.24	.37	.39	709	248.9	117.8	110.9	93.2
38095.80	4.58		4.6	-13.33	-13.35	729	248.7	114.9	109.2	91.1
96.00	4.60		4.6	.33	.35	729	248.6	114.1	108.8	90.6
96.20	4.95		4.9	.31	.33	746	248.6	113.4	108.4	90.0
96.40	5.13		5.1	.29	.31	757	248.5	112.7	107.9	89.5
96.60	5.47		5.5	.26	.28	779	248.5	112.0	107.5	89.0
96.80	5.53		5.5	.26	.28	778	248.4	111.3	107.0	88.5
97.00	5.54		5.5	.26	.28	778	248.4	110.6	106.6	87.9
97.20	5.56		5.6	.25	.27	783	248.3	109.9	106.1	87.4
97.40	5.58		5.6	.25	.27	782	248.3	109.2	105.7	86.9
97.60	5.57		5.6	.25	.27	782	248.2	108.5	105.2	86.3
97.80	5.59		5.6	.25	.28	781	248.2	107.8	104.7	85.8
98.00	5.28		5.3	.27	.30	764	248.1	107.1	104.3	85.3
98.20	5.46		5.5	.26	.28	774	248.1	106.4	103.8	84.7
98.40	5.64		5.6	.25	.28	779	248.0	105.7	103.3	84.2
98.60	5.66		5.7	.24	.27	784	248.0	105.0	102.9	83.6
98.80	5.68		5.7	.24	.27	784	247.9	104.3	102.4	83.1
99.00	5.37		5.4	.27	.30	766	247.9	103.6	101.9	82.5
38100.00	5.27		5.27	-13.28	-13.31	756	247.6	100.1	99.5	79.8
01.00	5.04		5.04	.30	.33	741	247.3	96.7	96.9	77.0
02.00	4.68		4.68	.33	.37	718	247.0	93.3	94.4	74.2
03.00	4.50		4.50	.35	.39	705	246.7	89.9	91.7	71.4
04.00	4.55		4.55	.34	.39	705	246.4	86.6	89.0	68.5
05.00	4.68		4.68	.33	.38	710	246.1	83.3	86.3	65.7
06.00	5.14		5.14	.29	.35	733	245.8	80.0	83.5	62.8
07.00	5.77		5.77	.24	.30	763	245.5	76.7	80.7	59.9
08.00	6.00		6.00	.22	.29	772	245.2	73.4	77.9	57.0
09.00	5.83		5.83	.24	.31	760	244.9	70.2	75.0	54.1
10.00	5.45		5.45	.27	.34	738	244.6	67.0	72.1	51.3
11.00	5.69		5.69	.25	.32	748	244.2	63.8	69.1	48.4
12.00	6.25		6.25	.21	.29	772	243.9	60.6	66.2	45.6
13.00	6.31		6.31	.20	.29	772	243.6	57.5	63.2	42.7
14.00	6.30		6.30	.20	.29	769	243.2	54.3	60.2	40.0
15.00	6.21		6.21	.21	.30	762	242.9	51.2	57.1	37.2
16.00	6.01		6.01	.22	.32	750	242.5	48.0	54.1	34.6
17.00	5.97		5.97	.23	.33	746	242.2	44.9	51.0	32.0
18.00	6.20		6.20	.21	.31	754	241.9	41.8	48.0	29.5
19.00	6.33		6.33	.20	.31	758	241.5	38.7	44.9	27.2
20.00	6.57		6.57	.18	.30	767	241.2	35.6	41.8	25.1
21.00	6.81		6.81	.17	.28	775	240.9	32.6	38.7	23.3
22.00	6.70		6.70	.17	.29	768	240.6	29.5	35.6	21.8
23.00	6.79		6.79	.17	.29	770	240.3	26.4	32.5	20.6
38123.20	6.79		6.8	-13.17	-13.29	771	240.3	25.8	31.8	20.5
23.40	7.13		7.1	.15	.27	783	240.2	25.2	31.2	20.3
23.60	7.47		7.5	.12	.25	800	240.2	24.6	30.6	20.2

Table 1.--Continued

SATELLITE 1962 $\beta\tau 2$

MJD	$-10^6\dot{P}$	$\dot{P}_R$	$-10^6\dot{P}_A$	$\log \rho_\pi$	$\log \rho_s$	T_π (°K)	z (km)	$\alpha_\pi-\alpha_\odot$ (deg.)	ψ_0' (deg.)	ψ_{30}' (deg.)
38123.80	7.49		7.5	-13.12	-13.25	800	240.1	24.0	30.0	20.1
24.00	7.66		7.7	.11	.24	808	240.1	23.4	29.4	20.0
24.20	7.84		7.8	.11	.23	812	240.0	22.8	28.7	19.9
24.40	8.34		8.3	.08	.21	834	240.0	22.2	28.1	19.9
24.60	8.36		8.4	.07	.20	838	239.9	21.5	27.5	19.8
24.80	8.05		8.0	.09	.22	820	239.9	20.9	26.9	19.8
25.00	8.07		8.1	.09	.22	824	239.8	20.3	26.3	19.9
25.20	7.92		7.9	.10	.23	815	239.8	19.7	25.6	19.9
25.40	7.77		7.8	.11	.24	810	239.7	19.1	25.0	20.0
25.60	7.47		7.5	.12	.25	797	239.7	18.5	24.4	20.0
25.80	7.48		7.5	.12	.25	797	239.7	17.9	23.8	20.2
38126.00	7.43		7.43	-13.13	-13.26	793	239.6	17.3	23.2	20.3
27.00	7.24		7.24	.14	.27	784	239.4	14.2	20.2	21.2
28.00	7.12		7.12	.14	.28	778	239.3	11.2	17.2	22.6
29.00	7.08		7.08	.14	.28	775	239.1	8.2	14.3	24.3
30.00	6.93		6.93	.15	.29	768	239.0	5.1	11.7	26.3
31.00	7.02		7.02	.15	.29	772	239.0	2.1	9.4	28.6
32.00	7.39		7.39	.12	.26	788	239.0	359.1	7.8	31.1
38132.20	7.43		7.4	-13.12	-13.27	788	238.9	358.5	7.6	31.6
32.40	7.58		7.6	.11	.25	796	238.9	357.9	7.5	32.1
32.60	7.90		7.9	.09	.24	809	238.9	357.3	7.4	32.6
32.80	8.05		8.1	.08	.23	817	238.9	356.7	7.4	33.2
33.00	8.04		8.0	.09	.23	813	238.9	356.1	7.4	33.7
33.20	8.19		8.2	.08	.22	821	238.8	355.5	7.5	34.2
33.40	8.35		8.3	.07	.22	825	238.8	354.9	7.7	34.8
33.60	8.66		8.7	.05	.20	842	238.8	354.3	7.9	35.3
33.80	8.97		9.0	.04	.18	855	238.8	353.7	8.1	35.9
34.00	8.47		8.5	.06	.21	833	238.8	353.1	8.4	36.4
34.20	8.30		8.3	.07	.22	825	238.7	352.5	8.7	37.0
34.40	8.12		8.1	.08	.23	816	238.7	351.9	9.1	37.5
34.60	7.95		7.9	.09	.24	808	238.7	351.3	9.5	38.1
34.80	7.77		7.8	.10	.24	803	238.7	350.7	9.9	38.7
35.00	7.75		7.8	.10	.24	803	238.7	350.1	10.4	39.2
35.20	7.90		7.9	.09	.24	807	238.7	349.5	10.8	39.8
35.40	7.72		7.7	.10	.25	799	238.7	348.9	11.3	40.4
35.60	7.22		7.2	.13	.28	778	238.6	348.3	11.8	41.0
35.80	7.20		7.2	.13	.28	778	238.6	347.7	12.3	41.5
38136.00	7.21		7.20	-13.13	-13.28	778	238.6	347.1	12.9	42.1
37.00	7.05		7.05	.14	.29	771	238.6	344.1	15.7	45.1
38.00	7.24		7.24	.13	.28	779	238.6	341.0	18.6	48.1
39.00	7.25		7.25	.13	.28	780	238.6	338.0	21.7	51.1
40.00	6.85		6.85	.15	.30	763	238.6	335.0	24.8	54.2
41.00	6.46		6.46	.17	.33	746	238.6	332.0	28.0	57.3
38153.00	5.94		5.94	-13.20	-13.33	741	240.6	295.8	66.9	95.4
54.00	5.69		5.69	.22	.35	731	240.8	292.8	70.1	98.6
55.00	5.54		5.54	.23	.36	725	241.0	289.7	73.4	101.9
56.00	5.19		5.19	.26	.38	710	241.2	286.7	76.7	105.1
57.00	5.09		5.09	.27	.39	706	241.4	283.6	79.9	108.3
58.00	5.37		5.37	.25	.36	722	241.6	280.6	83.2	111.5
59.00	5.75		5.75	.22	.33	743	241.8	277.5	86.4	114.7
60.00	5.98		5.98	.20	.31	756	242.0	274.5	89.6	117.8
61.00	5.99		5.99	.20	.31	758	242.2	271.4	92.9	121.0
62.00	5.50		5.50	.23	.34	735	242.4	268.3	96.1	124.2
63.00	5.20		5.20	.26	.36	721	242.6	265.2	99.3	127.3
64.00	4.95		4.95	.28	.38	710	242.7	262.1	102.5	130.5

Table 1.--Continued

SATELLITE 1962 βτ2

MJD	$-10^6\dot{P}$	$\dot{P}_R$	$-10^6\dot{P}_A$	log ρ_π	log ρ_s	T_π (°K)	z (km)	$\alpha_\pi-\alpha_\odot$ (deg.)	ψ_0' (deg.)	ψ_{30}' (deg.)
38165.00	4.60		4.60	-13.31	-13.41	692	242.9	259.0	105.7	133.6
66.00	4.21		4.21	.35	.45	670	243.0	255.9	108.9	136.7
67.00	4.13		4.13	.36	.46	667	243.2	252.8	112.0	139.8
68.00	4.05		4.05	.37	.46	664	243.5	249.7	115.2	142.9
69.00	3.82		3.82	.40	.48	653	243.8	246.5	118.3	145.9
70.00	3.69		3.69	.41	.49	647	244.1	243.4	121.4	148.9
71.00	3.46		3.46	.44	.52	635	244.5	240.2	124.5	151.8
72.00	3.13		3.13	.48	.56	617	244.8	237.1	127.5	154.6
73.00	2.78		2.78	.54	.60	600	245.1	233.9	130.5	157.4
74.00	2.78		2.78	.54	.60	601	245.5	230.7	133.5	160.1
75.00	2.93		2.93	.51	.57	611	245.8	227.6	136.4	162.6
76.00	3.11		3.11	.49	.54	623	246.2	224.4	139.3	164.8
77.00	3.21		3.21	.48	.52	632	246.6	221.1	142.1	166.7
78.00	3.31		3.31	.46	.51	641	247.0	217.9	144.9	168.0
79.00	3.35		3.35	.46	.50	646	247.4	214.7	147.5	168.7
80.00	3.21		3.21	.48	.51	639	247.8	211.4	150.0	168.6
81.00	3.13		3.13	.49	.51	636	248.2	208.2	152.4	167.6
82.00	3.19		3.19	.48	.50	643	248.6	204.9	154.6	166.1
83.00	3.23		3.23	.48	.49	649	249.0	201.6	156.6	164.2
84.00	2.86		2.86	.53	.54	625	249.4	198.3	158.3	162.0
85.00	2.37		2.37	.61	.61	597	249.9	194.9	159.7	159.6
38186.00	2.27		2.3	-13.63	-13.63	594	250.3	191.6	160.6	157.1
86.20	2.26		2.3	.63	.62	595	250.4	190.9	160.8	156.6
86.40	2.26		2.3	.63	.62	596	250.5	190.2	160.9	156.1
86.60	2.57		2.6	.57	.57	614	250.6	189.6	161.0	155.6
86.80	2.57		2.6	.57	.56	614	250.7	188.9	161.1	155.1
87.00	3.20		3.2	.48	.47	658	250.8	188.2	161.1	154.6
87.20	3.84		3.8	.41	.40	702	250.9	187.5	161.2	154.0
87.40	4.31		4.3	.36	.34	736	250.9	186.9	161.2	153.5
87.60	4.46		4.5	.34	.32	749	251.0	186.2	161.2	153.0
87.80	3.98		4.0	.39	.37	717	251.1	185.5	161.1	152.5
88.00	3.50		3.5	.45	.43	683	251.2	184.8	161.1	152.0
88.20	3.49		3.5	.45	.43	684	251.3	184.1	161.0	151.4
88.40	3.33		3.3	.47	.45	670	251.4	183.5	161.0	150.9
88.60	3.16		3.2	.48	.46	663	251.5	182.8	160.9	150.4
88.80	3.00		3.0	.51	.49	649	251.6	182.1	160.7	149.9
89.00	2.99		3.0	.51	.49	649	251.7	181.4	160.6	149.3
38190.00	2.90		2.90	-13.53	-13.50	645	252.2	178.0	159.7	146.7
91.00	2.85		2.85	.54	.50	644	252.6	174.5	158.4	144.1
92.00	2.74		2.74	.55	.51	638	253.1	171.0	156.7	141.5
93.00	2.71		2.71	.56	.51	639	253.6	167.5	154.9	138.9
94.00	2.67		2.67	.57	.51	639	254.1	164.0	152.9	136.3
95.00	2.78		2.78	.55	.49	651	254.6	160.4	150.7	133.8
96.00	2.89		2.89	.53	.46	664	255.1	156.8	148.4	131.3
97.00	2.77		2.77	.55	.47	658	255.7	153.2	146.1	128.8
38198.00	2.87		2.9	-13.54	-13.45	670	256.2	149.5	143.8	126.4
98.20	2.87		2.9	.53	.45	673	256.3	148.7	143.3	125.9
98.40	2.87		2.9	.54	.44	674	256.4	148.0	142.8	125.4
98.60	3.18		3.2	.49	.40	700	256.5	147.3	142.3	124.9
98.80	3.34		3.3	.48	.39	709	256.6	146.5	141.8	124.5
99.00	3.34		3.3	.48	.38	710	256.8	145.8	141.4	124.0
99.20	3.66		3.7	.43	.33	742	256.9	145.0	140.9	123.5
99.40	3.50		3.5	.45	.36	727	257.0	144.3	140.4	123.0
99.60	3.34		3.3	.48	.38	712	257.1	143.5	139.9	122.6
99.80	3.18		3.2	.49	.39	705	257.2	142.8	139.4	122.1
38200.00	3.18		3.2	.49	.39	706	257.3	142.0	138.9	121.7

Table 1.--Continued

SATELLITE 1962 βτ2

MJD	$-10^6\dot{P}$	$\dot{P}_R$	$-10^6\dot{P}_A$	$\log \rho_\pi$	$\log \rho_s$	T_π (°K)	z (km)	$\alpha_\pi-\alpha_\odot$ (deg.)	ψ'_0 (deg.)	ψ'_{30} (deg.)
38201.00	2.52		2.52	-13.60	-13.49	651	257.9	138.2	136.5	119.4
02.00	2.17		2.17	.66	.54	623	258.5	134.4	134.1	117.2
03.00	1.97		1.97	.71	.58	609	259.1	130.5	131.7	115.0
04.00	1.89		1.89	.73	.59	605	259.7	126.5	129.3	112.9
05.00	2.02		2.02	.70	.55	619	260.3	122.5	126.9	110.9
06.00	2.66		2.66	.58	.42	686	261.0	118.5	124.6	108.9
07.00	2.71		2.71	.57	.41	695	261.7	114.4	122.3	107.1
08.00	2.32		2.32	.64	.47	662	262.4	110.2	120.1	105.3
09.00	2.35		2.35	.64	.45	670	263.1	105.9	117.9	103.6

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 catalogues of satellite observations, orbital information, and preliminary results of data analyses prior to formal publication in the appropriate journals.

Edited and produced under the supervision of Mr. E. N. Hayes and Mrs. Barbara J. Mello, the reports are indexed by the Science and Technology Division of the Library of Congress, and are regularly distributed to all institutions participating in the U. S. space research program and to individual scientists who request them from the Administrative Officer, Technical Information, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts 02138.