Geomagnetic Disturbances and Acceleration of Artificial Earth Satellite.

By

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概　要

人工衛星の週期の変化率の観測結果に見られる不規則な変動は大気の抵抗に依ると考えられる。しかも又，太陽面現象との関係も極めて密接である。本稿では太陽面現象と関係の深い地磁気擾乱との関係及びその可能と思われる説明を述べる。

§ 1. Introduction

Erratic changes in the acceleration of an artificial satellite were first detected by L. G. Jacchia in analysis of the observation of 1957β. [1] Since then, some scientists have made efforts to answer the question "what are main causes of these irregular acceleration?". Main factors examined are as follows ;

1) changes of the air density accompanied with the solar phenomena
2) difference of the air density between night and daylight
3) non-uniform distribution of air density
4) change of effective cross section of satellite
5) solar or lunar tide

Of these factors, the effects of the solar phenomena and the diurnal effects may be survival, after several satellites launching.

The diurnal effect, that is, slow fluctuations connected with the position of the perigee with respect to the sub-solar point was examined by Jacchia and he concluded that the effect is small at the 200km level, but becomes very large at height larger than 350km and reflects a difference in the density profiles of the bright and dark hemispheres of the earth. [1]

Jacchia also examined the correlation between solar flux and the irregularities of the acceleration and concluded that the fluctuations which follow the rythm of the solar flux at 2800 Mc (10.7-cm wave length) increase in amplitude with height and become smaller or disappear when the perigee is in darkness. [1]

This author examined the correlation between the acceleration and the geo-

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[*] Read at the 21st general meeting of the Society of Japanese Geomagnetism and Geoelectricity

magnetic K-index. [*] Nearly the same time, Jacchia reported the transient fluctuations accompanying magnetic storms. [1]

According to L. G. Jacchia, another erratic fluctuations of unexplained origin, such as the perturbation of August and September 1958 is felt that a comparison with conditions in the radiation belts may provide a clue to this effect. [1]

§ 2. Irregularities in the rate of anomalistic period

The satellites which were launched in 1957 and 1958 are tabulated as follows :

Table 1.

Satellite	Launching date	Initial apogee height	Initial perigee	Initial period
1957α_1(Sputnik I)	Oct. 4, 1957	950km (from geoid)	225km(from geoid)	96.2 min.
1957α_2(Sputnik I)	Oct. 4, 1957	950	225	96.2
1957β_1(Sputnik II)	Nov. 3, 1957	1670	240	103.7
1958α (Explorer I)	Feb. 1, 1958	2540	368	114.95
1958β_1(Vanguard)	March 17, 1958	3965	652	134.29
1958β_2(Vanguard)	March 17, 1958	3965	652	134.29
1958γ(Explorer III)	March 26, 1958	2800	188	115.91
1958δ_1(Sputnik III)	May 15, 1958	1880	241	105.9
1958δ_2(Sputnik III)	May 15, 1958	1880	241	105.9
1958ϵ (Explorer IV)	July 26, 1958	2197	257	110.3
1958ζ (Atlas I)	Dec. 18, 1958	?	?	101.4

The anomalistic period and the anomalistic acceleration can be obtained from the observation of the satellite orbit by the numerical differentiation.

The resulted anomalistic acceleration-revolution number (time) curve shows irregularities contrary to the semi-theoretical curve.

For Sputnik I and its rocket (1957α 2 and 1) the data are not precise enough for any conclusions to be drawn. For Sputnik III (1958δ 2), increases in drag occurred about 80, 110 and 140 days after launching, but accurate optical observations, used in the examination, have been rather infrequent and the variations have not been accurately determined. The data of Explorer III (1958 γ) and Atlas I (1958 ζ) are rather insufficient to draw any conclusions.

For Sputnik II (1957β), the rate of decrease of period are given in Fig. 1. (after Jacchia), for Explorer I (1958α) in Fig. 2 (after Jacchia), for Vanguard (1958β_1 and 1958β_2) in Fig. 3, for Sputnik III (1958 δ_1) in Fig. 4 and for 1958ζ, in Fig. 5.

Fig. 1 is obtained from the Smithonian Institution Astrophysical Observatory.

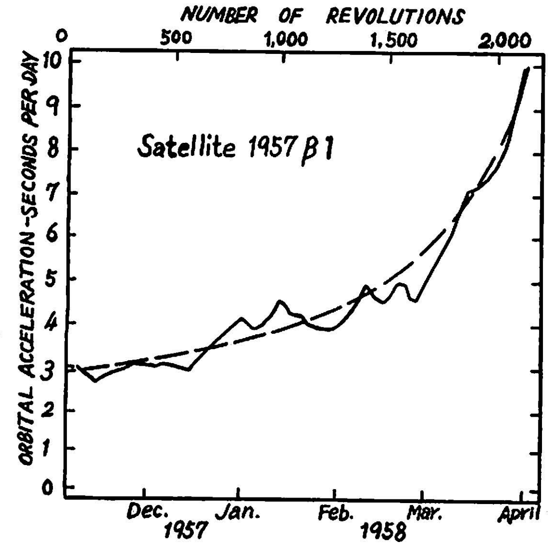

Fig. 1.

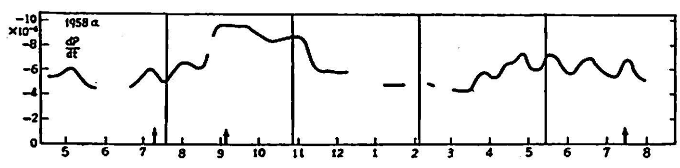

Fig. 2.

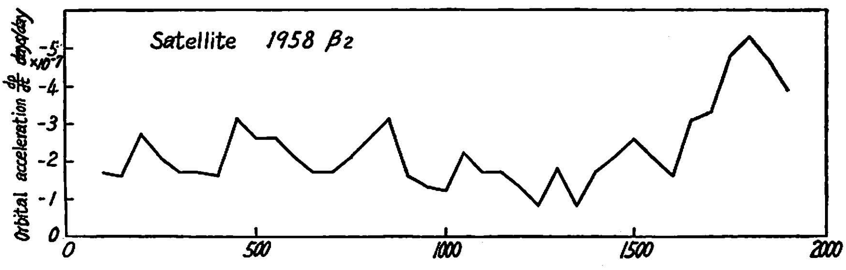

Fig. 3.

Special Report No. 13 (after L. G. Jacchia). The values are the rate of nodal period, but, there is no difference between the accelerations of the nodal and the anomalistic period, owing to the slow motion of the perigee for the particular inclination of this satellite. Fig. 2 is obtained from the Smithonian Institution Astrophysical Observatory Special Report No. 11 and No. 24. Fig. 3, 4 and 5 are

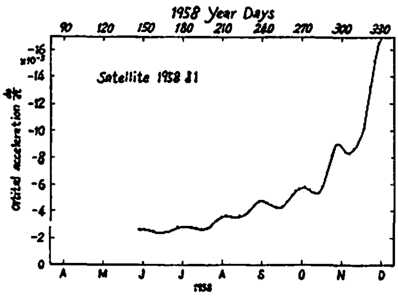

Fig. 4.

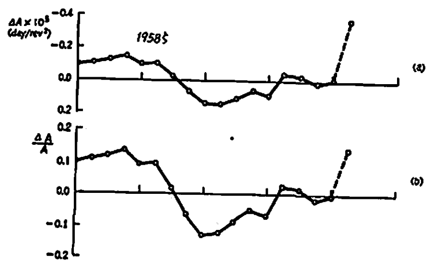

Fig. 5.

reproduced from Nature or Smithonian Institution Astrophysical Observatory Special Report, respectively.

The dotted line in the above mentioned figures, could be obtained semi-theoretically, assuming a model atmosphere, drag coefficients etc. Irregularities of the period can be expressed by the ratios of the observed values to the semi-theoretical values or by the difference between them and both expressions are nearly the same. The results for 1957β are shown in Fig. 6. The curve has some general characteristics. That is semi-periodicity having 28~30 days period, their magnitude amounts to 100% and 10% on an average. In the same period, the fluctuations are in phase on each satellte.

§ 3. Analysis and discussions.

(A) 1957β (Sputnik II)

In this paper, the term "acceleration" will refer to the non-dimensional quantity dp/dt, p is a period of revolution ; t is time.

Thus defined acceleration of artificial satellite 1957β (Sputnik II) are plotted in ordinate in Fig. 1[1] Smoothed curve is drawn for visual aid. And observed value minus smoothed value is shown in Fig. 6[1] During the corresponding period, K-index at Kakioka changes as shown in Fig. 7. Smoothed curve are computed employing the following functions of revolution number n.

1. $=$1957 Nov. $4.41000+0.0720825n-1.19\cdot10^{-6}\,n^2-0.03820(e^{0.0017n}-1)+0.01700\sin(0.237n-128°)$ $(0\leqq n<1800)$
2. $=$1958 March $9.51267+0.066453\,(n-1800)-2.56\cdot10^{-6}\,(n-1800)-0.00125927\,[e^{0.0095(n-1800)}-1]$. $(1800\leqq n<2300)$
3. $=$1958 April $10.95583+0.062547\,(n-2300)-8.78\cdot10^{-6}\,(n-2300)^2-8.316\;10^{-5}\,[e^{0.097(n-2300)}-1]$ $(n\geqq 2300)$

Although K-index at Kakioka is adopted, its variation is nearly the same with

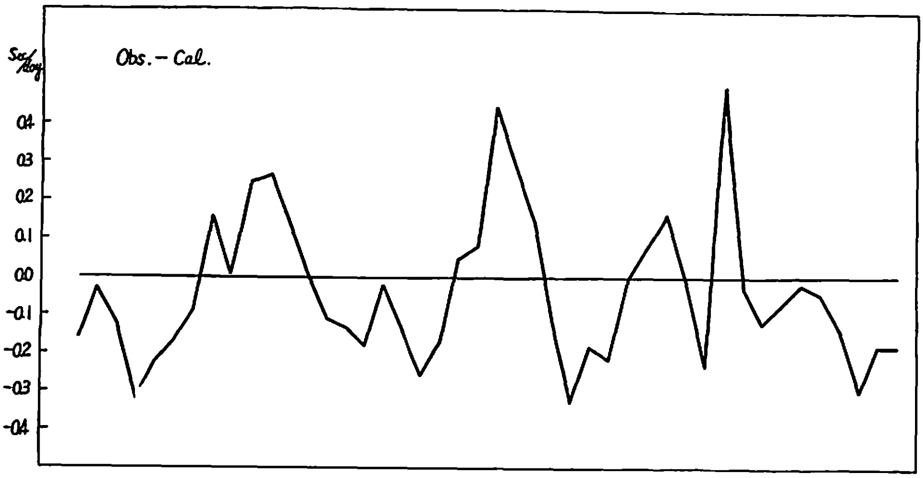

Fig. 6.

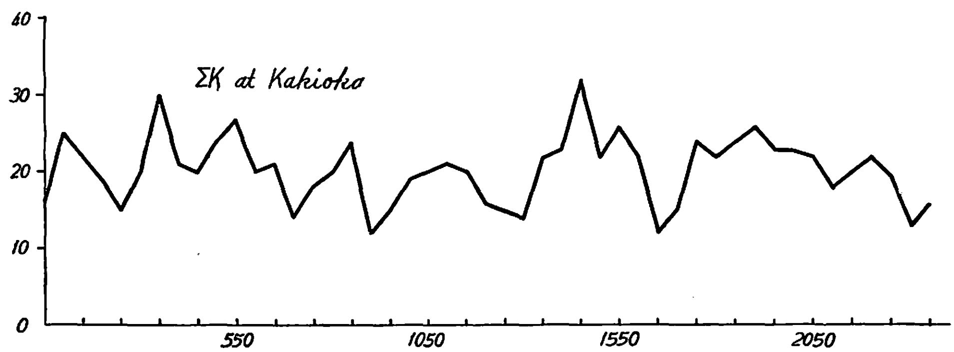

Fig. 7.

that of Kp-index. The one value is a mean of daily sums of K-indices for the period of 50 revolutions of the artificial satellite. The computed correlation coefficient is 0. 38 and is not very good. Testing the significance by the Student's t-distribution, however, both can be said to have some correlation. The time lag between the changes of both is not so clear.

On the other hand, some geomagnetic storms occurred during the period when this artificial satellite was flying and the individual geomagnetic events does not correspond to the distinct increasing or decreasing of the fluctuation of the acceleration. Especially, ssc storm on 11th Feb. 1958 is one of the most energetic storms since last century and other geophysical or astrophysical phenomena have the distinguished events, respectively. However, we cannot easily detect the corresponding event in the fluctuations of the acceleration.

(B) 1958 Alpha (Explorer I) :

The data of 1958α are obtained from "Modified orbital elements for earth satellite 1958 Alpha" in "The predictions, Smithonian Astrophysical Observatory, Cambridge, Massachusets".

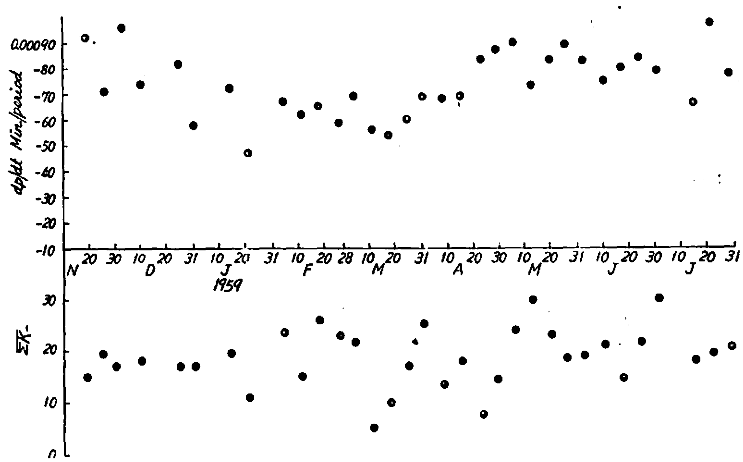

Fig. 8.

The observations for the period from Nov. 1958 to Aug. 1959 give a correlation coefficient, +0.47, with means of ΣK of two days before observation of the artificial satellite. As stated on 1957β, the individual magnetic storms seem to be indifferent to the fluctuations.

(C) 1958 Beta (Vanguard I)

The correlation coefficient with the mean of ΣK for the period of 50 revolutions of the earth satellite are computed, based on the data for the period from Nov. 1957 to Aug. 1958. The computed correlation coefficient is not significant, according to the testing.

(D) 1958 Delta (Sputnik III)

L. G. Jacchia reported that the increasing of the acceleration of this earth satellite in case of magnetic storms on 8~9, July and September, 1958. He computed with a resolution of 10 revolutions around the dates of two great geomagnetic disturbances and compared with the Kp.

This author traited the problem in such a way as that of 1958β and obtained the correlation coefficient +0.23, which is not significant. But the data used in the analysis are not perfect on account of insufficient, accurate optical observations.

(E) 1958 Epsilon (Explorer IV)

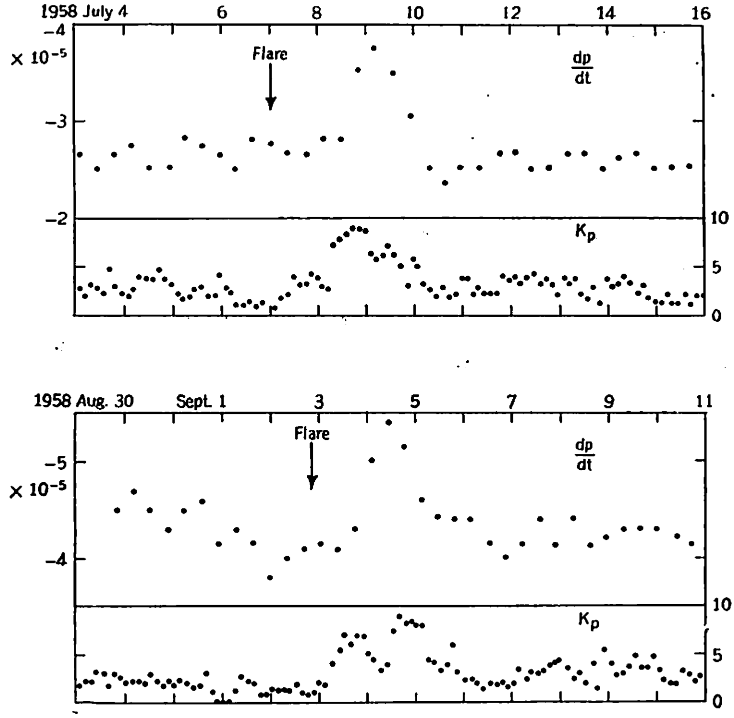

Fig. 9.

From the data of the observations of 1958 Epsilon, which are insufficient, the correlation coefficient, -0.26 is obtained. The value is not significant. In this case, the individual storms also don't correspond to any events of the acceleration.

Statistically, the correlation between the geomagnetic disturbances and the fluctuations of the acceleration is rather poor, in any satellite. Furthermore, the individual events of the geomagnetic conditions don't correspond to the distinguished fluctuations of the acceleration. Only cases of the coincidence of both events are two storms on 8～9, July and 4, September 1958. However, the high correlation of the solar flare or sunspot number are often reported.

As is well known, these phenomena are closely related with the geomagnetic disturbance.

Taking in many factors which affect the fluctuations of the acceleration, the low correlation coefficient may be inevitable.

At any rate, we may be able to say both have some correlation. Furthermore, the correlation may be closest about 200～300 km in height. This fact coincides well with the statement that the transient magnetic storm effects are more predominant in the lower than in the higher, by Jacchia.

The acceleration of the artificial earth satellite can be convincively approximated by :

$$\frac{dp}{dn}=-3p\frac{\overline{F}}{M}\oint\rho(h)ds,$$

where $\overline{F}$ is the mean effective cross-section, M the mass of the satellite and $\rho(h)$, the air density at the height h. The integral represents the air mass, which is hit by the satellite during one revolution. The above equation can be modified in the following form ;

$$\frac{dp}{dn}=-3p\frac{\overline{F}}{M}\rho(h_{re})2\pi(R+h_e)c_{(e)}$$

where h_{re} is the height of the perigee and R the earth's radius. The factor $c_{(e)}$ gives the influence of the eccentricity of the satellite's orbit.

The results of the analysis may give that the increasing of geomagnetic disturbances — not only ssc storm, but the increasing of K-index — make the increase of the air density of the air. From this it may be impossible to attribute to the heating of the air by the inpinging of the solar particle and rather reasonable by the electric drag. Although we have only an insufficient knowledge regarding the electron density in the higher region than the ionosphere, the disturbance of the electron density in the ionosphere in case of geomagnetic storm is well known. [3]

These analysis can not conclude regarding the problem and the analysis in more details will clear up the character of the particle, emitted from the sun in case of geomagnetic storms.

Acknowledgements

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References

[1] Smithonian Institution Astrophysical Observatory Special Report No. 1 - No. 30 and Predictions (1957～1960)

[2] Annals of the International Geophysical Year. Vol. VI, Part I - V.

[3] Jastrow, R. & C. A. Peasse (1957) Atmospheric Drag on the Satellite J. G. R. Vol. 62, No. 3, p. 413.