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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-2-7. Inter-relations Among Aurora, Sporadic Ionization and Magnetic Disturbance

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In this paper was discussed the numerical relationship among the auroral luminosity, sporadic ionization and geomagnetic disturbance observed in the southern auroral zone, as one of the most fundamental problems on earth storm. Based on one year data at Syowa, the Japanese Antarctic Station, numerical relationship was established as

$J(5577)_{\text{in } KR}=5\times10^{-5}(n_{\max\ Es})^2$ and $J(5577)_{\text{in } KR}=3\times10^{-3}(\Delta H_{\text{in }\gamma})^2$,

in the case of geomagnetic bay disturbance, which may be regarded as quasi-stationary phenomena of basic type in the lower ionosphere.

There were also found in some cases, for example geomagnetic pulsation and severe geomagnetic storm, that the relationship established is appreciably modified. These observational results were examined successfully by a theoretical view point, resulting a conclusion that 1) the bay disturbance and the associated increase in auroral luminoisty and in electron density may be mainly due to electron bombardment of the energy of about 10 kev with flux ranging 10^7 to 10^9, into the upper atmosphere over the auroral zone, that 2) a kind of pulsations is not attributable to the fluctuation of bay disturbance, and that 3) there must exist an additional electric field in the lower ionosphere during severe magnetic storms.

Introduction

In this paper is discussed the mechanism of the inter-relation among aurora, sporadic ionization and magnetic disturbance in the auroral zone. It may be one of the most fundamental problems on the polar storms, as well as the problems on the energy and flux of corpuscles impinging into the upper atmosphere in the polar regions, on the aerial dimension of the corpuscular stream and on the partition of the corpuscular stream into both the southern and the northern polar regions.

In order to study this problem, an upper atmosphere observatory has been set up at the suothern auroral zone, the Japanese Antarctic Base "Syowa" situated at 69°00′S in latitude and 39°35′E in longitude, just under the auroral zone.

Of course, many elements of the polar disturbance phenomena which were observed at the station must be examined in detal in order to get full solution of the present problem. However, in this paper, certain representative elements were selected.

They are

(1) Zenith luminosity of auroral green line J (5577)

(2) Electron density in the sporadic E layer n, and

(3) Horizontal disturbance vector of geomagnetic field ΔH.

Inter-relations among auroral luminosity, sporadic ionization and magnetic disturbance in the case of bay disturbance

Among various kinds of geomagnetic disturbance in high latitudes, geomagnetic bay will be the most simple and fundamental

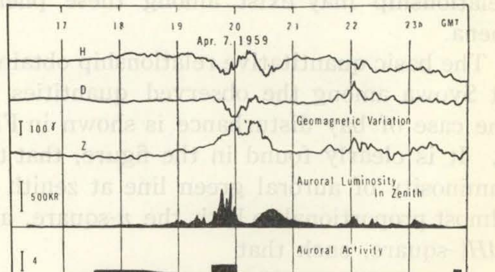

Fig. 1. Typical example of geomagnetic bay disturbance associated with increase in auroral luminosity and in sporadic ionization in the E layer.

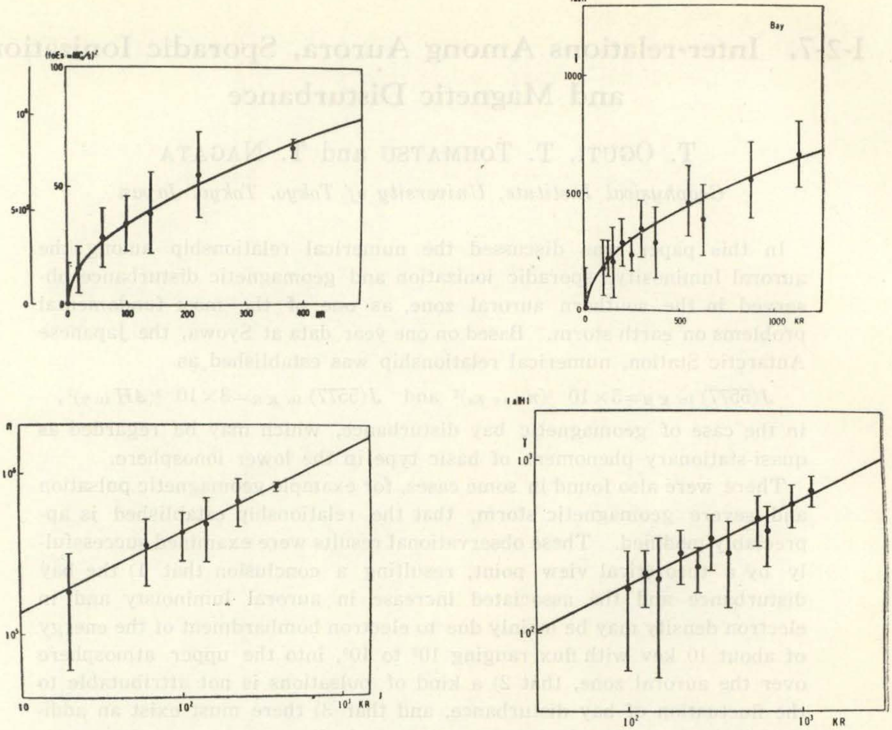

Fig. 2. Numerical relationship among auroral luminosity at zenith, electron density in the E layer and geomagnetic horizontal disturbance. (Upper; in linear scale, Lower; in logarithmic scale)

one.[1] Fig. 1. shows a typical example of bay disturbance associated with increase in auroral luminosity at zenith and in sporadic ionization in the E layer. As seen in the figure, each disturbance begins almost simultaneously, and the maximum deviation of each quantity seems also to occur simultaneously, except the auroral activity in the whole sky. This fact suggests that the mechanism of these disturbance phenomena is of common origin, so that some quantitative relationship may exist among these phenomena.

The basic quantitative relationship obtained at Syowa among the observed quantities in the case of bay disturbance is shown in Fig. 2. It is clearly found in the figure, that the luminosity of auroral green line at zenith is almost proportional to both the n-square, and $|\Delta H|$-square, such that

$$J_{\text{in } KR} = 3\times10^{-3}|\Delta H_{\text{in } \gamma}|^2 \qquad (1)$$

$$J_{\text{in } KR} = 5\times10^{-10}n^2 \qquad (2)$$

The result obtained may be examined from theoretical view point[3] in the case of $J(5577)-n$ relationship. For example, in Fig. 3 is shown the theoretical relationship among incoming electron flux, auroral luminosity and electron density in the E layer. The theoretical relation $J\sim2.5\times10^{-10}n^2$ seems to agree well with the observational one, as seen in the Fig. 2 and Fig. 3 with only a difference in proportionality factor of 2. From this comparison, it may be concluded that the impinging electrons of the energy of

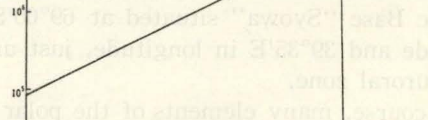

Fig. 3. Numerical relationship between auroral luminosity and electron density in the lower ionosphere, in connexion with incoming electron flux.

about 10 kev, play an important role in the auroral displays, and that the quasi-stationary electron increase and auroral emission in the lower ionoshpere, is reasonably explained by the effect of impinging electron stream of the energy of about 10 kev and with the flux ranging from 10^7 to 10^9. This conclusion seems to be strongly supported by another kind of observational result, namely the results of direct measurements of incoming electron flux by rockets[4),5)] during auroral displays, which have shown that the incoming electron flux during a weak auroral display ($J \sim 10^2 KR$) is about $10^7/\text{cm}^2$ sec, with the energy of about 10 kev, and that during a rather strong display is about $10^9/\text{cm}^2$ sec.

Thus, the quantitative relationship among the auroral luminosity, sporadic ionization and geomagnetic disturbance may be established, in the case of bay disturbances. It must be noted here, that the relationship established holds for the bay disturbance, and the bay disturbance may be ordinarily regarded as a quasi-stationary phonomenon, being representable by an equivalent electric current of simple dipole type[1)] in the lower ionosphere.

Inter-relations between auroral luminosity and geomagnetic disturbance in the case of time varying phenomena

In Fig. 4 are shown some examples of $\Delta H - \Delta J$ relationship in the case of geomagnetic and auroral pulsations. Here in these figures, the relationship is shown to hold between the pulsative fraction of auroral luminosity and also of geomagnetic field. The mean period of the magnetic pulsation named here *Pg* is about 5 min. while that named *Ps* is about 9 sec.

In this relationship, may be pointed out two results of importance. The first one is that the geomagnetic giant pulsation *Pg* is separated into two groups as shown in the figure, *PgI* and *PgII*, with definitely different proportionality factor, namely 1.6 KR/γ and 0.07 KR/γ, and the second point is that the proportionality factor of the short period pulsation is definitely higher than those of giant pulsations. The systematic change in the proportionality factor $|\Delta J/\Delta H|$ with change in the period is tentatively interpreted as follows.

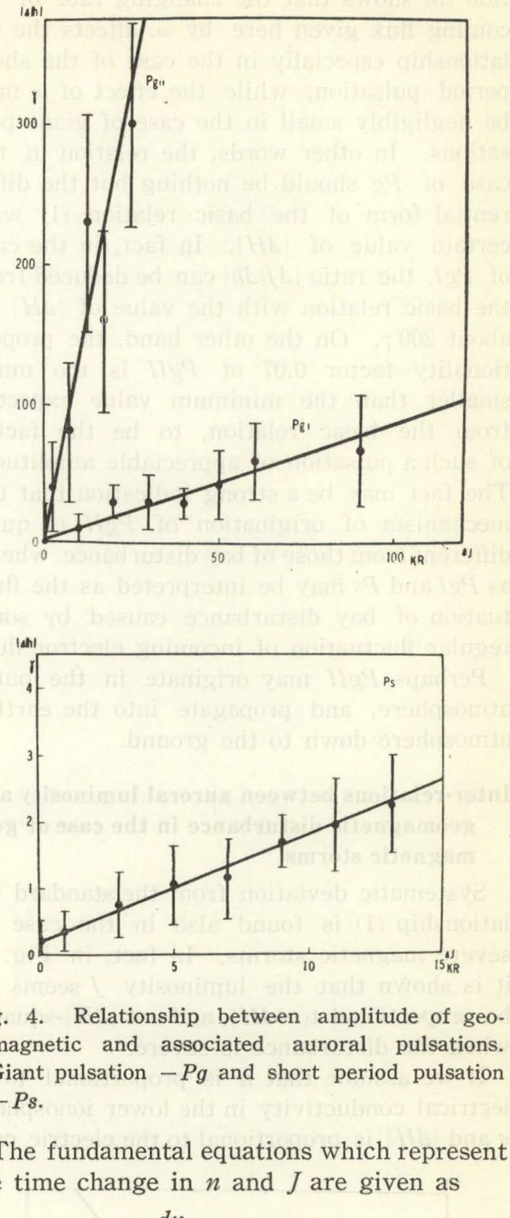

Fig. 4. Relationship between amplitude of geomagnetic and associated auroral pulsations. Giant pulsation $-Pg$ and short period pulsation $-Ps$.

The fundamental equations which represent the time change in n and J are given as

$$\frac{dn}{dt} = Q_1 - \alpha n^2, \tag{3}$$

$$\frac{dJ}{dt} = Q_2 - \lambda J. \tag{4}$$

Postulating a harmonic change in incoming flux of small amplitude with angular frequency ω, and also the simple proportionality between $|\Delta H|$ and n, equations (3) and (4) can be solved by a method of small perturbation resulting

$$\left|\frac{\Delta J}{\Delta H}\right| = \sqrt{1 + \frac{\omega^2}{4\alpha^2 n^2}} \cdot \left|\frac{dJ}{d\Delta H}\right|. \tag{5}$$

Substituted α by a reasonable value, equation (5) shows that the changing rate of incoming flux given here by ω, affects the relationship especially in the case of the short period pulsation, while the effect of ω may be negligibly small in the case of giant pulsations. In other words, the relation in the case of *Pg* should be nothing but the differential form of the basic relation (1) with certain value of $|\Delta H|$. In fact, in the case of *PgI*, the ratio $|\Delta J/\Delta h|$ can be deduced from the basic relation with the value of $|\Delta H|$ of about $200\,\gamma$. On the other hand, the proportionality factor 0.07 of *PgII* is too much smaller than the minimum value expected from the basic relation, to be the factor of such a pulsation of appreciable amplitude. The fact may be a strong indication that the mechanism of origination of *PgII* is quite different from those of bay disturbance, whereas *PgI* and *Ps* may be interpreted as the fluctuation of bay disturbance caused by some regular fluctuation of incoming electron flux.

Perhaps *PgII* may originate in the outer atmosphere, and propagate into the earth's atmosphere down to the ground.

Inter-relations between auroral luminosity and geomagnetic disturbance in the case of geomagnetic storms

Systematic deviation from the standard relationship (1) is found also in the case of severe magnetic storms. In fact, in Fig. 5, it is shown that the luminosity J seems to be proportional to $|\Delta H|$, and not $|\Delta H|$-square, when the disturbance is severe.

If we assume that n is proportional to electrical conductivity in the lower ionosphere σ and $|\Delta H|$ is proportional to the electric current density there i, σ is proportional to i. In other words, the electro-motive force $|E|$ is constant, independent of J and n. In reality, the constant $|E|$ seems to exist in the lower ionosphere in the case of bay disturbance, as well as in the case of weak storms. On the other hand, associated with severe disturbance, there must be some additional electric field which may be proportional to n, since $|\Delta H|$ (i.e. i) is proportional to n^2 (i.e. σ^2) in severe disturbance. It seems to be worthwhile to note here, in connexion with the results mentioned above, that the drift speed of electrons in the lower ionosphere increases abruptly with increase in K_p-index beyond its certain value of about 4[6]. Then, a question arises "What is the original cause of these electro-motive forces?" Many possibilities of emf's have been recently postulated by many investigators but none of them may be complete to be a unique solution being able to interpret synthetically a lot of observational facts. In any case, it is clear enough that there are two kinds of emf's and that therefore the fact must be taken into consideration in any theory of polar magnetic storm.

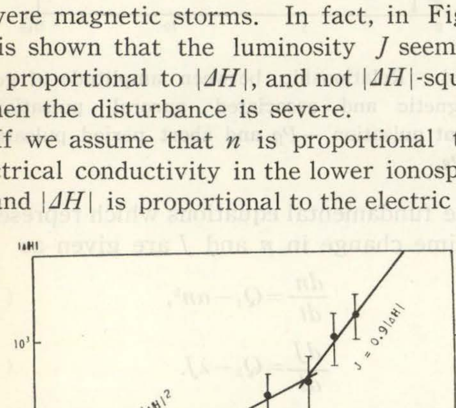

Fig. 5. Relationship between auroral luminosity at zenith and geomagnetic horizontal disturbance in the case of geomagnetic storms.

Conclusion

Through discussion above, it may be concluded that the electron component of the impinging corpuscles, the energy of which ranges from 1 to 100 kev, has roughly sufficient to cause the upper atmosphere disturbance phenomena in the auroral zone. Blackout may be interpreted by an anomalous ionization in the D-region due to the bombardment of high energy electrons and/or due to bremsstrahlung X-ray from incoming electrons. The anomalous ionization in the E-region with simultaneous auroral emission may be due to the electrons of the energy of the order 10 kev.

The excess ionization in the lower ionosphere may be a carrier of overhead electric current along the lower border of auroral arc or band, under the action of the dynamo- or some other electric field. The numerical relationship obtained here between the auroral luminosity, sporadic ionization and geomagnetic disturbance is reasonably acceptable, not only in the case of bay disturbance, but in the cases of some kinds of pulsation and storms.

There remain however, some fundamental problems not yet solved as follows, namely, what is the real cause of electric field which contributes to the production of the overhead electric current? Furthermore we know that $H_\alpha, H_\beta\cdots$ lines of atomic hydrogen is observed in the auroral spectra. This means that protons are also coming. Then, what is the fundamental contribution of protons to the auroral zone disturbance? This is really also an important question. These problems have to be studied in more detail in order to get a full understanding of the whole mechanism of the polar earth storms.

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Discussion

Maeda, K.: Prof. Ellis of Australia found a close coincidence of occurrences of VLF noise, bay disturbance and red aurora. I want to have some idea on the mutual relation between the two findings made by you and Prof. Ellis. Didn't you make any study on a possible relation between ionization, bay disturbance and red aurora instead of green one?

Oguti, T.: No, not yet. We are intending to study them now.

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I-2-8. Polar Blackouts During the International Geophysical Year (A 30 Minute Sound Motion Picture)

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Discussion

Paghis, I.: (a) Would you please amplify what is meant by the statement "PCA event is not necessarily the first stage in the disturbance"?

(b) Are you suggesting that these "impact zone" may last for several hours?

Agy, V.: (a) In those cases we have examined, and in particular those shown in the film, the *entire* polar cap is covered by an absorbing region only after a period of development which may in some cases last for hours and in others only for minutes. Initially, small areas of absorption are evident (often at or near auroral latitudes) which we may interpret as impact zones for solar particles, and as time goes on these areas expand until (as the storagemechanism becomes active) the whole polar cap is covered.

(b) Hours or, in some cases, minutes.
