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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-5-4. Some Aspects of Ionosphere Storms

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This paper is concerned with ionosphere storms in middle latitudes, as revealed by observations of radio waves. The purpose is to stress the importance of three experimental results and to raise some questions of theoretical interpretation.

§ 1. Storm phenomena in the low *D* region in middle latitudes

It is well known that, although an ionosphere storm is accompanied by strong absorption of H.F. radio waves at high latitudes there is usually no increase of absorption at middle latitudes. It might, therefore, be concluded that the *D* region was uneffected at middle latitudes. If, however, this region is studied by means of low, or very low, frequency waves it is found that a storm can often be accompanied by profound changes. These have been studied by Lauter and sprenger (1952) in Germany, and Belrose (1956) in England.

The phenomenon will be illustrated by an example taken from Belrose (1956). It occurred during the storm of April 27, 1956. Fig. 1 shows the Abinger magnetogram for a series of relevant days. It will be noticed that there was a magnetic "sudden commencement" at about 22 hrs on April 26 and that the main phase of the magnetic storm started about 02 hrs on April 27 and lasted about four days. It was practically over by May 1.

Fig. 2 shows the variation of the ionospheric index f_0F2 throughout the whole of 1956, in a form made available by the Max-Plank-Institut in Liudau. Days are represented in sequence in such a way as to show up any 27-day recurrence frequency, but that does not concern us here. April 27 is labelled 27 in the tenth column and the fifth row of the table, and it is clear that f_0F2 was less than normal on this day and for about the three following days. On May 1 it had recovered its normal value.

These phenomena in magnetism, and in the *F* layer, are of a well-known type. Now let us turn, however, to consider phenomena in the *D* region. Fig. 3 shows records of the field strength of the sky wave received at Cambridge, England, from a sender distant about 150 km emitting a wave of frequency 200 kc/s. (Note that the sender ceased emitting each night between 2330 and 0015 hrs). The behaviour on April 26 was similar to that usually observed and is considered to be "normal". The amplitude during the day was small. Near sunset, about 1800 hrs, (off the scale of the figure) the amplitude gradually increased and fading occurred with an approximate period of two minutes. The sudden commencement, at 22 hrs was not accompanied by any recognisable effect.

On April 27, however, when the main phase of the storm was well established, the increase of sky-wave amplitude did not occur until about 21 hrs, and when it did the rate of fading was much more rapid than usual. On the next three days, while the main phase of the magnetic storm still persisted, the evening increase of amplitude was still delayed, but the rate of fading gradually became smaller and more like the "normal" rate. During the period May 1, 2, 3, 4, 5, 6 after the storm (as judged by magnetic, and *F* region, phenomena) appeared to be over, the amplitude of the wave recorded in Fig. 3 remained very small during the whole period of observation. On May 7 and 8 the amplitude was again more nomal, but the evening increase did not occur until 2030 hr, considerably later than normal. The occurrence of these phenomena after the magnetic, and *F* region, storms were over might be called the "*D* region after effect." The phenomena of Fig. 3 are similar to those described by Lauter (1952).

Fig. 4 shows the phenomena observed during this same period when waves of frequency 16 kc/s were received at Cambridge from a sender 90 km away. The figure is a record of the changes in phase of the received sky wave, the phase change being

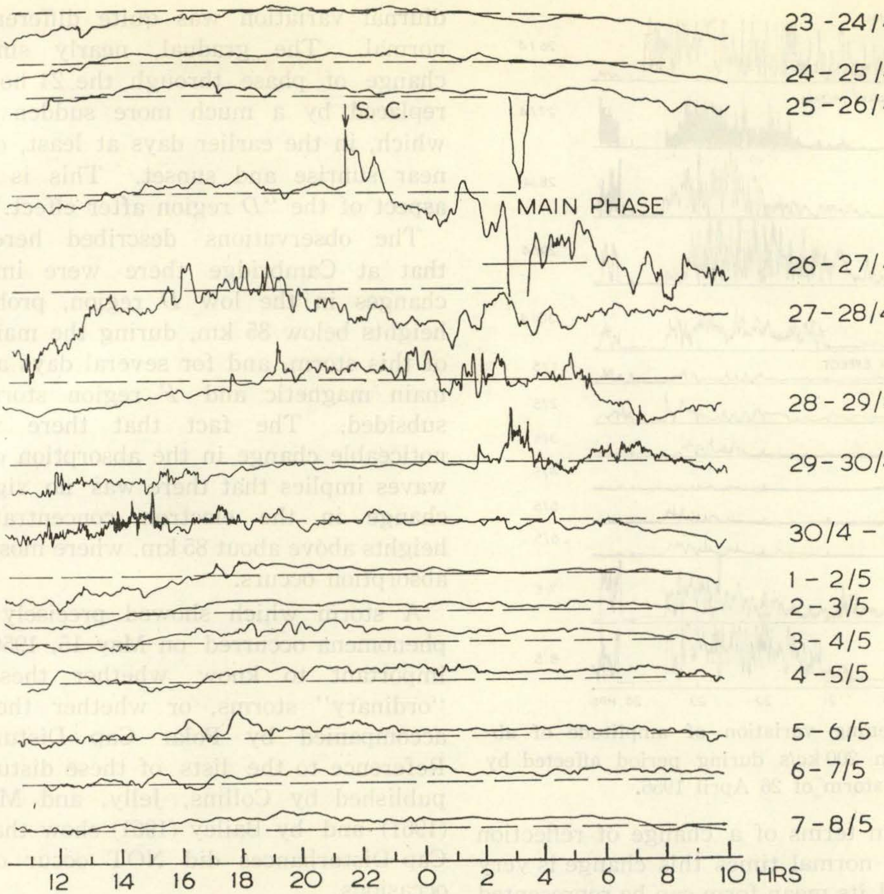

Fig. 1. Magnetic data (the horizontal component of the earth's magnetic field) during the period of the great magnetic storm of 26 April 1956.

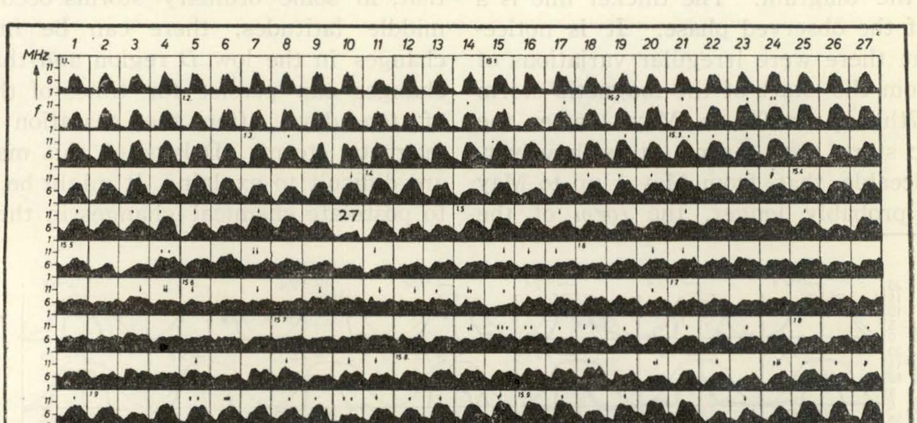

Fig. 2. Diurnal variation of f_0F2 throughout 1956 (By courtesy of Max-Planck Institut für Ionosphären-Physik).

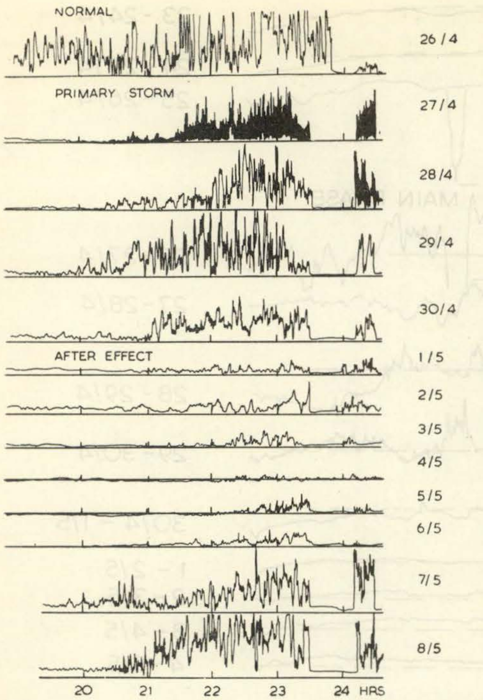

Fig. 3. Evening variation of amplitude of abnormal on 200 kc/s during period affected by magnetic storm of 26 April 1956.

expressed in terms of a change of reflection height. In normal times this change is very regular and its mean form can be represented by the narrow line repeating from day to day in the diagram. The thicker line is a record of the observed phase. It is noticeable that there were irregular variations of phase from the start of the magnetic storm (02 on 27th) up to 00 on May 1 when the magnetic storm was over. It is, however, also noticeable that from May 1 up to May 10, and probably longer, the *form* of the diurnal variation was quite different from normal. The gradual, nearly sinusoidal, change of phase through the 24 hours was replaced by a much more sudden change, which, in the earlier days at least, occurred near sunrise and sunset. This is another aspect of the "*D* region after effect."

The observations described here show that at Cambridge there were important changes in the low *D* region, probably at heights below 85 km, during the main phase of this storm, and for several days after the main magnetic and *F* region storms had subsided. The fact that there was no noticeable change in the absorption of H. F. waves implies that there was no significant change in the electron concentration at heights above about 85 km, where most of this absorption occurs.

A storm which showed precisely similar phenomena occurred on May 15, 1956. It is important to know whether these were "ordinary" storms, or whether they were accompanied by Polar Cap Disturbances. Reference to the lists of these disturbances published by Collins, Jelly, and Matthews (1961) and by Bailey (1961) show that Polar Cap Disturbances did NOT occur on these occasions.

It therefore seems necessary to conclude that, in some ordinary storms occurring in middle latitudes, there can be important changes in the low *D* region and that these changes can persist for times of the order of ten days after the cessation of the magnetic storm. Delays of this magnitude are difficult to explain. It might be possible to postulate chemical changes in the atmos-

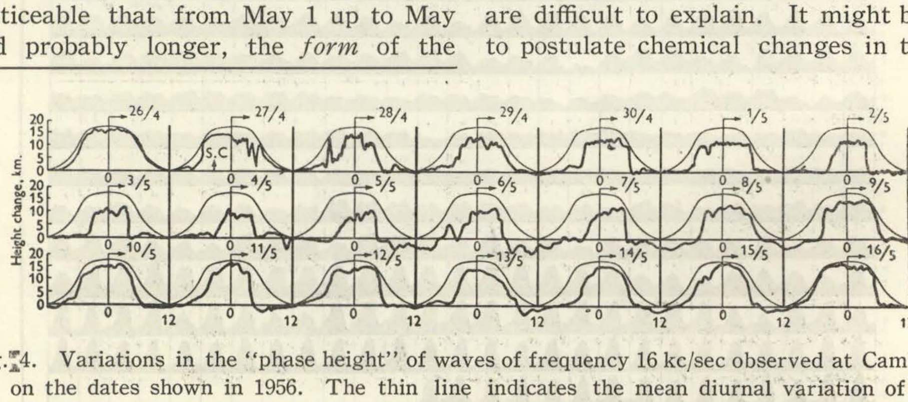

Fig. 4. Variations in the "phase height" of waves of frequency 16 kc/sec observed at Cambridge on the dates shown in 1956. The thin line indicates the mean diurnal variation of phase for all the days of the month. A magnetic storm started with a "sudden commencement" at the time marked SC on 26/4. From 0300 on 27/4 to about 1200 on 28/4 the phase was violently disturbed. During the nights from 30/4 to 9/5 the shape of the curve is unusual; after that it regains its normal shape slowly. This is the "storm after-effect.

phere, or the "dumping" of particles from the outer radiation belt, which is known to become over-full after a storm and to remain so for a time of this order. Neither of these postulates can, however, be dignified by the name of a theory.

§ 2. The total electron content of the ionosphere

It is known that the peak electron concentration in the *F* layer decreases in middle latitudes during a storm (see Fig. 2) and that, at low latitudes it either does not decrease, or even increases. Studies of electron distributions [$N(h)$ curves] have shown that the sub-peak electron content varies in the same way as the concentration at the peak. It is important to know whether the total number of electrons in a unit column counted from top to bottom of the ionosphere varies in the same way. Recent measurements made by Garriott (1960) and others on the waves received from satellites, and by Taylor (1961) on waves reflected from the moon, have shown, without much doubt, that the total number of electrons is reduced during a storm when the peak concentration is reduced. This fact needs explanation.

It is important to know what happens to the total electron content at low geomagnetic latitudes, when the peak concentration either does not change, or increases. Some preliminary results, obtained at the D.S.I.R.

Radio Research Station at Singapore from observations of waves from satellites, appear to show that there the total electron content does not decrease, but usually increases. This result, however, is tentative and needs confirmation.

§ 3 The atmospheric density in the *F* region

It is now well established, from observations of satellite drag, that the atmospheric density in the *F* region increases considerably during an ionosphere storm. This fact must be taken into account in theoretical treatments.

§ 4 Theoretical considerations of *F* layer phenomena

4.1 *Temperature change*

The observed changes of density presumably arise from a change of temperature. It is therefore necessary to consider the result of changing the temperature of the atmosphere in which the *F* layer is formed. The layer is now thought to be the result of

(a) an ionising radiation which produced its maximum effect near the *F1* peak, at 180 km, and which ionises N_2 and O;

(b) the N_2^+ ions rapidly recombine with electrons by a process which dissociates them, and the corresponding electrons are not observed;

(c) the O^+ ions finally lead to a loss of electrons by way of a complicated change-exchange process which simulates attachment with an attachment coefficient which decreases upwards: its magnitude depends on the concentration of N_2 and O_2;

(d) the peak of the *F2* layer results from a balance between diffusion of the electron-ion plasma through the neutral air, and the processes of production and loss.

A change of temperature alters all these processes. It may also alter the ratio of N_2 to O, and hence the proportion of incident radiation "wasted" in producing unobservable ionisation. There are many possibilities to be examined.

4.2 *Movements of the F layer under electromagnetic forces*

Several workers, including particularly Martyn and the Japanese theoreticians, have used the observed magnetic variations to deduce the movements to be expected in the F layer during storm. From the magnetic field changes they deduce the overhead currents, they then assume reasonable (tensor) conductivities, deduced from ionosphere observations, and deduce the corresponding electric fields, and finally they deduce the vertical velocities which these electric fields would produce in the F region.

To make a calculation of this kind it is necessary to know what part of the disturbance magnetic field flows in the ionosphere, and what flows outside the ionosphere, in the ring current. Can a separation of this kind be made by the geomagneticians? If not, can the ionospheric physicists help by stating some range within which the ionospheric currents must lie if they are not to result in absurd movements of the *F* layer?

My colleagues and I are busy considering these, and other, possibilities. I am much indebted to them, and particularly to Drs. Belrose, Garriott, and Rishbeth for the benefit of several valuable discussions.

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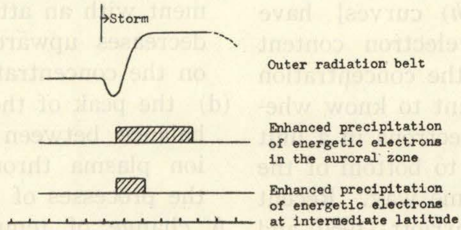
Discussion

Winckler, J. R.: The next picture of energetic ionizing radiation in the *D*-region shows that at intermediate latitudes no long persistence of precipitation is observed.



Dungey, J.W.: How hard are Prof. Winckler's X-rays? *D* layer needs about 1 kev.

Winckler, J. R.: They have the order of 3 to 50 kev.

Martyn, D. F.: I think there are good grounds for believing that $\Delta H(Dst)$ is produced by currents above the ionosphere; it would be almost impossible to produce the westward circular currents in the ionosphere by any possible electric field distribution.

On the other hand there is strong reason to believe that $\Delta H(DS)$ is produced by ionospheric currents. The ionospheric layer movements agree with this interpretation as worked out by Martyn, Maeda, Sato and others.

Ratcliffe, J.A.: That division is useful for *average* magnetic storm, but it would be interesting to make a division into effects from distant currents, and from ionospheric currents, for *individual* storms.

Leonard, R. S.: Is the 16 kc phase shift that occurred before the S. C. a storm effect that occurs before all or most storms?

Ratcliffe: I have not examined other records, from more normal days, sufficiently to decide whether the small phase deviation before the S. C. is, or is not, significant. I agree that this point should be investigated.

Hines, C. O.: With respect to the division between *Dst* and *DS* systems, I believe it possible to say quite clearly how much electric field must be associated with the *DS* system near the auroral zone, simply from the drifts observed there. If conductivites were well known, this would remove the ambiguity completely, but of course they are not well known and the ambiguity may persist at lower latitudes.

I should like to add to Dr. Ratcliffe's list of theories concerning Dr. Belrose's observations yet another. It is to be expected, and there is ground-level evidence to support this, that atmospheric gravity waves are generated during auroral disturbances. The waves of importance to Belrose's measurements would probably be travelling at few meters/sec. After 3 or 4 days they would have progressed about 1000 km from the auroral zone, and therefore would be in the appropriate latitude. Their amplitude would not be seriously damped, because they would be ducted between the thermal inclines at, say, 40 and 90 km. Finally, with a dispersion of velocities over a range of 2 or 3, it would account for the spread of days observed by Belrose. The effect would presumably act by distorting the layer that normally returns the signal, although this part of the problem requires further thought.

Ratcliffe: We have tried to use the observed horizontal drifts of the F layer irregularities to estimate the electric field at middle latitudes, but find some inconsistencies and difficulties.

Piggott, W.R.: (a) If the low level D region effects are due to particle bombardment, considerations of the mass absorption laws show that the energy of the particles must be absorbed in the lower D region, otherwise strong absorption effects will be observed on f_{min}. If very penetrating radiation is present there are simultaneous, HF absorption and low D region effects.

(b) At high latitudes the local current circulation set up near the auroral zone must cause a net horizontal movement of ionization into or out of the current vortex. This will make serious changes in the $F2$ parameters which severely will be dependent on local magnetic activity. These can greatly confuse the general zonal phenomena and need special consideration.

Hultqvist, B. K. G.: I would like to mention a phenomenon which has similar properties to the storm effect described by Dr. Ratcliffe, namely the effects of PCA ionization on the propagation of VLF radio waves. We have had up to 8 days duration for such effects. During the 4 last days the disturbance could be observed only from this effect. There was no absorption, no magnetic disturbance etc. We know fairly certainly that the long duration of PCA effect on VLF waves is produced by high energy particles, which penetrate deep into the atmosphere. This seems to support the possibility mentioned by Dr. Ratcliffe namely that the long duration storm effect associated with non-PCA storm has something to do with a slow precipitation of fairly high energy particles from the outer Van Allen belt.

Ratcliffe: I am sorry, I had meant to mention the work of Dr. Hultqvist. However, my main point is that I am pretty certain that you also get similar phenomena in ordinary storms (not polar cap disturbances) in middle latitudes.