GEOMAGNETIC AND IONOSPHERIC EFFECTS AT BRISBANE FOLLOWING THE NUCLEAR EXPLOSION ON JULY 9, 1962

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Summary

Ionospheric data and geomagnetic micropulsation records from Brisbane have revealed both short-term and delayed effects associated with the U.S. nuclear explosion on July 9, 1962 above Johnston I. The initial ionospheric effects, lasting about 30 s, appeared to be due to severe low-level (D-region) blanketing, probably arising from the dumping of neutron decay products. The micropulsations initiated by the explosion were detected for about 5 min; after an initial transient, they became suppressed during the time when the low-level blanketing ionization was present.

The delayed ionospheric effects were seen most clearly in the F region. Three pressure-wave disturbances with speeds of 840, 330, and 220 m/s produced pronounced decreases in Δf_0F_2, the departure from the monthly mean. It would seem also that the explosion gave rise to a substantial hydromagnetic wave which spread around the world with a speed of 1420 m/s. This wave produced impulsive micropulsation bursts and significant increases in Δf_0F_2 as it passed over Brisbane, probably due to precipitation from the artificial radiation belt. The periodical bursts of micropulsations persisted for at least 24 hr.

I. Introduction

Vertical incidence records from pulsed transmitters (2·28 and 3·84 Mc/s) were made at Brisbane (geomagnetic latitude 35° S.) on July 9, 1962 before and after the nuclear explosion which was detonated at about 400 km above Johnston I. at $09^h\,00^m\,09^s$ U.T., i.e. $19^h\,00^m\,09^s$ Eastern Australian Standard Time (E.A.S.T.). Local ionograms taken at 2-min intervals were available for analysis.

In addition, micropulsations of the geomagnetic field in the range 0·01–2·0 c/s were recorded at Esk (50 km from Brisbane) at this time, both on charts and magnetic tape, using the equipment described by Mainstone and McNicol (1962).

II. Short-term Effects

Records (virtual height of reflection against time) for both fixed frequencies show a sudden disappearance of the first-hop F_2-layer trace 3·4(±0·3) s after the explosion. Portion of the 2·28 Mc/s record is shown in Plate 1, Figure 1. This disappearance of traces is quite different from the normal fading, which can be seen prior to explosion time. The 2·28 Mc/s record indicates a slow signal recovery of about 40 s, while recovery at 3·84 Mc/s takes about 15 s.

A record of the micropulsations produced by the blast, made from a slow-speed tape recording of the north-south component of the field variations in the frequency range 0·01–2·0 c/s, is shown in Plate 1, Figure 2. A frequency-spectrum analysis of

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this tape is shown in Plate 1, Figure 3. At explosion time ($\pm 1\cdot 0$ s) the magnetic record shows the commencement of micropulsations which stop several seconds later. After remaining suppressed for about 30 s the micropulsations continue and last until 5 min after explosion time. It will be noted that the time interval for blanketing of the $2\cdot 28$ Mc/s first-hop F_2-layer trace is approximately the same as that found for the suppression of micropulsations.

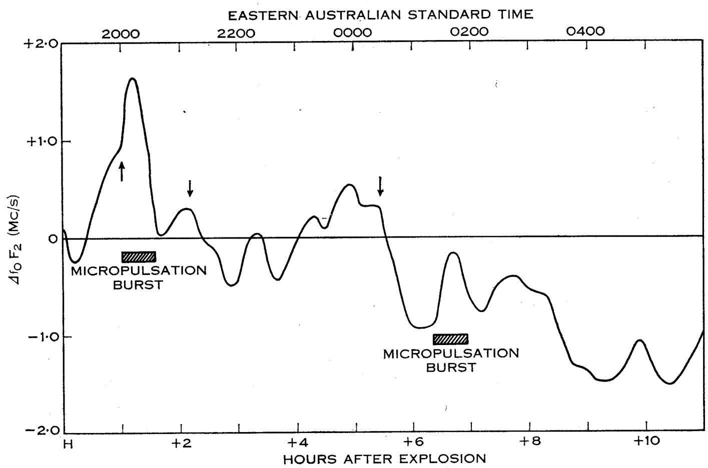

Fig. 1.—Plot of $\Delta f_0 F_2$ for Brisbane for the hours following the explosion. Times of two important micropulsation bursts are also indicated.

III. Delayed Effects

Spread-F conditions, somewhat more pronounced than on other nights in the period, prevailed in the hours following the explosion. The departure from the monthly mean of the minimum f_0F_2 value for signals reflected from near-vertical directions, is shown in Figure 1 for a period of 11 hr following the explosion. The increase and two subsequent decreases in $\Delta f_0 F_2$, which are indicated by arrows in the diagram, agree roughly with similar variations found at Brisbane after previous high-level nuclear explosions. They correspond to disturbances propagating at speeds of 1800, 840, and 340 m/s, assuming for the present that the times indicated by the arrows do in fact represent the times of arrival of each disturbance at Brisbane.

The micropulsation records for the period following the time of the explosion show a strong burst of noise, extending from about $0\cdot 2$ to $0\cdot 8$ c/s, beginning at 2000 E.A.S.T. This burst lasted for 35 min and stopped almost as abruptly as it had started. At 0120 E.A.S.T. on July 10 a remarkably similar disturbance, again lasting for 35 min, was recorded. Then about an hour later, at 0215 E.A.S.T., there began a series of bursts which gave rise to an almost continuous band of noise throughout the remainder of this day, July 10 (Plate 2, Fig. 2). Similar bursts occurred during the following day, July 11, but with decreasing intensity, until by July 12 the bursts had disappeared completely (Plate 2, Fig. 1).

The two micropulsation noise bursts which commenced 1 hr and 6 hr 20 min, respectively, after the explosion time and which were very similar in appearance on the records, coincided with two features of the Δf_0F_2 variation shown in Figure 1, which, in turn, were also markedly similar to one another in detail. In each case there was a marked increase in Δf_0F_2.

IV. Discussion

(a) *Short-term Effects*

The blanketing effects on the ionospheric signals most probably result from an increase in the electron density in the lower regions of the ionosphere. The short-period delay of about half a second between cut-offs of the one-hop trace and the two-hop trace (Plate 1, Fig. 1) suggests that the F_2 layer has a slight tilt and that the paths from the signals of these traces are slightly different. It further suggests that the disturbance has some horizontal velocity.

The most likely mechanism for the blanketing phenomenon seems to be that proposed by Crain and Tamarkin (1961). They envisaged the dumping in the D region of trapped electrons (with the appropriate pitch angles) created by the decay of fast moving neutrons which are produced by the nuclear explosion. The time required for a neutron to reach regions of the exosphere and place electrons in trapped orbits terminating near Brisbane, would be about 1 s. The mirror period for these electrons is about 0·5 s. The 3·4 s delay interval found here is too long to fit this mechanism precisely. However, the protons of this decay process would have energies which would give them mirror periods of several seconds. A 0·5 MeV proton has a mirror period of about 4 s (Zmuda, Shaw, and Haave 1963). If these protons produce the blanketing ionization in the lower E region, the calculated time interval is more consistent with that observed. The other possibility (mentioned by Zmuda, Shaw, and Haave 1963) is that the trapped electrons come from the decay of other fission products which would take a longer time to reach the required decay positions.

It is probable (see, for example, Kato and Takei 1963) that the initial magnetic disturbance propagated electromagnetically to distant points. The subsequent suppression of the micropulsations for about 30 s followed by a fairly sharp recovery, is not easy to explain. The effect was at first attributed to overloading and consequent saturation of the recording instruments but this does not seem likely in view of further evidence, particularly that from the form of the disturbance, shown in Figure 2, registered by the single component (horizontal north-south) fluxgate magnetometer at the radio research station at Moggill, near Brisbane.

The magnetometer record, considerably magnified to show detailed structure, indicates that there was an initial transient disturbance which caused rapid excursions of amplitude $\sim 15\ \gamma$ in both the positive and negative directions. Signals of this magnitude are, of course, far below the saturation level of the magnetometer. After the sharp transient there is a definite time delay before the slower rise from the zero level to the peak amplitude of about $+5\ \gamma$; this delay appears to be of the same order as the time during which the micropulsation activity was suppressed.

In addition, chart recordings of the longer-period micropulsation oscillations in the north–south, east–west, and vertical components were available. Although considerable overloading of these channels did occur, a careful check has disclosed that during the interval between the initial transient and about 30 s later the signal amplitude was substantially smaller than for the oscillations during the succeeding minute or so.

Assuming, in the light of this evidence, that the suppression of micropulsation activity was real, it is possible that the bulk of the shorter-period activity following the explosion may be explained as arising from trapped particles. If the initial transient disturbance was in fact sufficiently severe to cause immediate high-level dumping of virtually all of the trapped particles (in the inner radiation belt) along

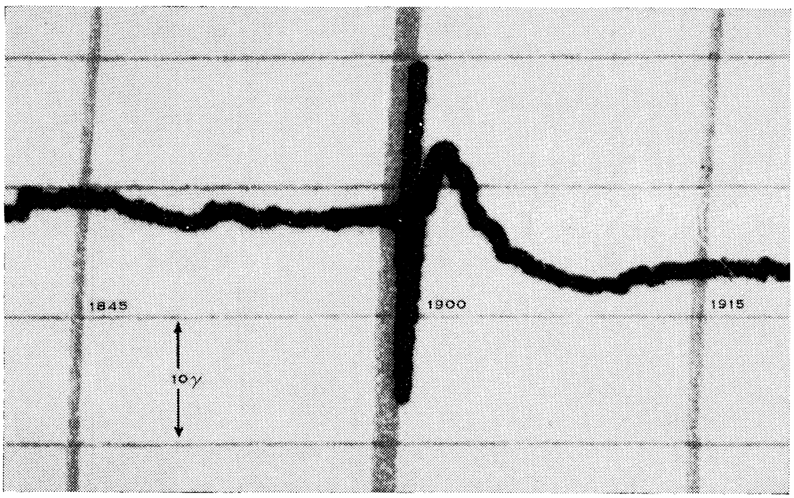

Fig. 2.—Geomagnetic field variation (horizontal north–south component) recorded at Moggill, near Brisbane by fluxgate magnetometer, around the time of nuclear explosion.

its path, then in effect a large impulsive current flow, aligned along the magnetic field, should have existed in the ionosphere for several seconds. Such a current would give rise to transient magnetic effects at the Earth's surface. Several seconds later the tremendous surge of particles from neutron decay processes would have arrived, leading to copious dumping in the lower ionosphere and consequent blanketing effects. After approximately 30 s the trapping region in the vicinity of Brisbane was probably replenished with particles from the decay of fission products. By this time the mirror points should have returned once again to greater heights, giving the particles a rather better chance of remaining trapped. The impulsive nature of the micropulsation signal during this period suggests that considerable dumping probably occurred, but this time well above the *D* and *E* regions. Within about 5 min the micropulsation activity returned to approximately the normal background level (perhaps a little lower). However, as shown below, during the succeeding hours this background level gradually gained in intensity, presumably as larger numbers of particles became trapped in the geomagnetic field in invariant shells corresponding to the geomagnetic coordinates of Brisbane.

(*b*) *Delayed Effects*

(i) *Pressure Wave Disturbances.*—Bowman (1962) has shown that changes in Δf_0F_2 following the U.S. nuclear explosions at Johnston I. in August 1958, suggest that three disturbances propagated from the explosion site with average speeds of 1666, 647, and 333 m/s respectively. For the July 1962 explosion the lowest speed, 330 m/s, is in very good agreement with that deduced from the results of the previous explosions and is probably associated with a pressure wave travelling in the sound channel provided by the temperature inversion at the 80 km level (Bowman, loc. cit.). A disturbance which travelled at about the same speed (322 m/s) was also detected at Brisbane after the Russian nuclear explosion above Novaya Zemlya on October 30, 1961.

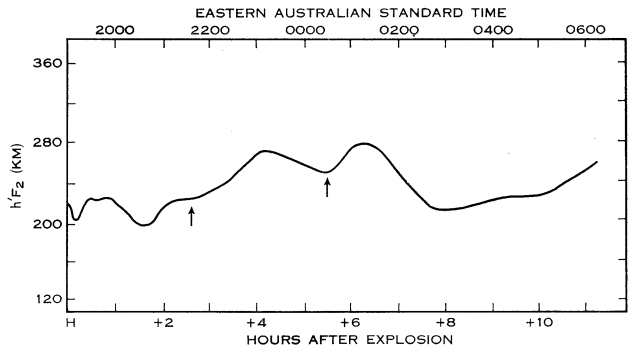

Fig. 3.—Plot of $h'F_2$ variation for Brisbane for the hours following the explosion.

The disturbance which propagated at a speed of 840 m/s corresponds only approximately to those travelling at an average speed of 647 m/s for the earlier Johnston I. explosions and at 630 m/s for the Russian explosions. Since the present explosion took place at a height of 400 km, this disturbance may be due to sound wave propagation above the maximum of the *F* region. If we take the specific heat ratio γ as $1 \cdot 5$ and the molecular weight M as 20, a sound wave having a speed of 840 m/s corresponds to a temperature of about 1200°K. This is consistent with the measured temperature of 1200°K between 300 and 400 km at night (Harris and Priester 1962).

Figure 3 shows that the two disturbances discussed above appear to be associated with height rises in the *F* region. The other disturbance is associated with a height fall in the *F* region; it is thought to be hydromagnetic in nature and is discussed at some length below.

(ii) *Hydromagnetic Disturbances.*—The speed of 1800 m/s for the first of the disturbances mentioned in the previous section is somewhat higher than the average speed of 1666 m/s deduced for the 1958 explosions from records taken at 10 stations in the Pacific area, although it is in good agreement with the speed indicated by the actual times of arrival at Brisbane of the first disturbances due to these explosions.

This disturbance is most probably hydromagnetic. This is borne out by the fact that a disturbance begins on the micropulsation records at the same time (2000 E.A.S.T.). Since this and the very similar magnetic disturbance seen later at 0120 E.A.S.T. on the following day, July 10, 6 hr 20 min after the explosion time, both last for 35 min, it seems likely that they represent the disturbances which propagate in effectively opposite directions around the world as the circular wave-front spreads out radially from Johnston I. As each disturbance passes through the region covered by the enhanced radiation belt due to the bomb in any magnetic meridian plane, it would appear to give rise to local precipitation from the belt. (The basis for this is discussed later.) Van Allen, Frank, and O'Brien (1963) report that the radiation belt intensity fell away from its maximum value at $L = 1 \cdot 2$ to the 10% level at $L = 1 \cdot 8$ and to the 1% level at $L = 2 \cdot 2$, where L is McIlwain's geomagnetic field configuration parameter; Brisbane (geographic latitude 27·5° S.) is thus virtually situated under the belt (Fig. 4). If now we take the time of the peak of the $\Delta f_0 F_2$ increase as the time when the disturbance first passed over Brisbane, i.e. 2015 E.A.S.T., the speed over the surface of the Earth becomes 5100 km/hr or 1420 m/s (the actual speed would of course be higher than this, depending on the height at which the disturbance travelled). Using this speed, the disturbance travelling around the world in the opposite direction would be expected to pass over Brisbane 6 hr 35 min after the time of the explosion, i.e. at 0135 E.A.S.T. on July 10. It will be seen from Figure 1 that the peak of the $\Delta f_0 F_2$ increase recorded during this period does in fact occur at 0140 E.A.S.T. (No such agreement can be obtained if the beginning of the $\Delta f_0 F_2$ increase is taken as the time of transit of the disturbance.)

Clearly this disturbance corresponds to those detected for the earlier nuclear explosions, the discrepancy in the calculated speeds being apparent rather than real. For this type of disturbance the time of arrival at a particular locality is evidently represented by the *peak* of the $\Delta f_0 F_2$ variation, a fact which was not recognized when the 1958 explosion records were analysed. When re-examined in the light of the information provided for the 1962 explosion by the micropulsation records, the 1958 results are generally in accord with the present data.

The projection along the Brisbane magnetic meridian of the motion of a sharp circular wave-front as it passes through the radiation belt at a speed of 1420 m/s, seems to account satisfactorily for the 35 min period during which the magnetic effect is recorded by the north–south micropulsation antenna for each passage of the disturbance. This is indicated in Figure 4 where the positions of a circular wave-front, spreading out around the world from Johnston I. with a speed of 1420 m/s, are plotted for the times at which the magnetic disturbances began and ended. The intersections of these wave-fronts with the magnetic meridian through Brisbane lie quite close to the $L = 1 \cdot 2$ and $L = 2 \cdot 2$ contours representing the confines of the enhanced radiation belt.

The micropulsation bursts possess a fine structure of an impulsive nature and in the case of the first passage of the disturbance the "impulse rate" reaches a maximum between 2005 and 2015 E.A.S.T., whilst for the second passage the time of maximum rate, though not so well marked, appears to be about 0135–0140 E.A.S.T. on July 10. In each case these times are just a little earlier than the times of the peak Δf_0F_2 associated with the burst. It is interesting also that there appears to be some similarity between the impulse rates for the trailing portions of the disturbances—this may indicate a fine structure within the disturbing wave itself.

From Plate 2, Figure 2, it can be seen that the micropulsation bursts are in fact impulsive increases in the intensity of a background noise band. This noise band is a feature of the Brisbane records, and is thought to be associated with the inner radiation belt; it becomes more pronounced during the hours following the nuclear explosion. The fact that the bursts are accompanied by considerable increases

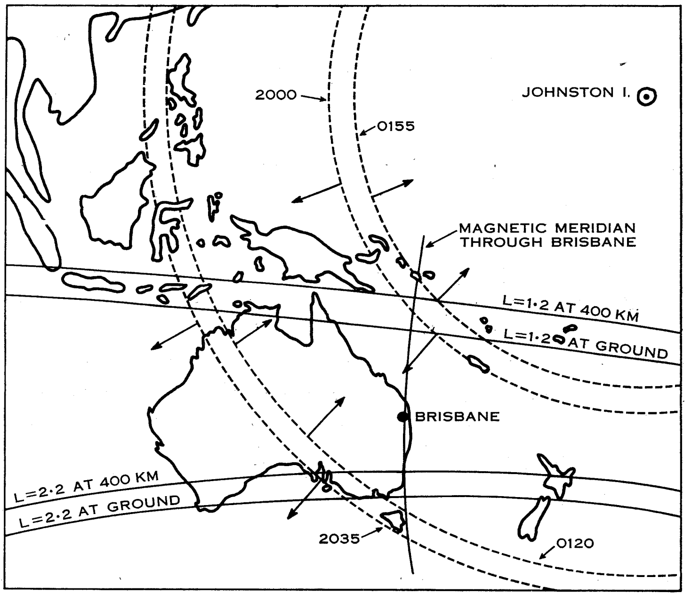

Fig. 4.—Map showing positions of wave-fronts of proposed disturbance (speed 1420 m/s) at times of commencement and times of termination of micropulsation bursts. The confines of the artificial radiation belt ($L = 1\cdot2$ to $2\cdot2$) are indicated.

in Δf_0F_2, points very strongly to the idea that electrons are precipitated into the ionosphere in large numbers as the disturbance wave-front passes through the radiation belt. Naturally occurring disturbances of this type, associated with the noise band, are seen on the Brisbane records from time to time, presumably arising from a similar mechanism; in this case the precipitated particles are assumed to come from the natural inner radiation belt. Rarely, however, does a series of natural disturbances persist for as long as the explosion disturbances shown in Plate 2, Figure 1, in which the decay of the effect can be seen quite clearly.

Although not detectable on the ionospheric records for reasons given below, the return of the disturbance traversing from north-east to south-west, i.e. that originally recorded at 2000 E.A.S.T. on July 9, after a complete circuit of the Earth in about 7·8 hr, can just be discerned on the micropulsation record (Plate 2, Fig. 2). This return disturbance begins at about 0345 E.A.S.T. on July 10. More clearly visible is a disturbance starting at 0215 E.A.S.T., the time when the original wave-front, having spread around the world, would have been in such a position that its northernmost extremity was, at that time, lying approximately parallel to the lines of geomagnetic latitude and was passing through the northern side of the radiation belt as the disturbance converged once more on Johnston I. It is actually after this event that the micropulsation bursts become more or less continuous, although there is some indication that after about 0900 E.A.S.T. on July 10 an approximately 8-hr periodicity may be present once more.

The first two passages of the magnetic disturbance are associated with a fall in the height of the F region (see Fig. 3). The rate at which the height decreases is the same in each case.

(iii) *An Additional Pressure Wave Disturbance.*—The expected ionospheric effects due to the return of the magnetic disturbance beginning at 0345 E.A.S.T. on July 10 are apparently masked by a pronounced drop in $\Delta f_0 F_2$ which occurs at about 0320 E.A.S.T. and which is accompanied by an F-region height rise similar to that caused by the first pressure wave of speed 840 m/s. It seems reasonable to suppose that these effects are due to a travelling disturbance propagating from Johnston I. with a speed of about 220 m/s.

Re-examination of the records for the two 1958 explosions show that a small disturbance having a speed of about 210 m/s was detected on each occasion. Speeds of this order are not much different from the maximum observed speeds for ionospheric travelling disturbances (Heisler 1958). On the other hand, it is perhaps possible that these disturbances propagate in the sound channel at the tropopause level with a speed $\sim$ 280 m/s; the discrepancy between this and the observed speeds could arise from the time taken for the low-level disturbances to reach the F region of the ionosphere.

V. Conclusions

The nuclear explosion on July 9, 1962 has been shown to have produced both short-term and delayed effects in the ionosphere, some of which are associated with magnetic disturbances. The initial ionospheric disturbances appear to be due to low-level (D-region) effects whereas the delayed disturbances are seen most clearly in the F region.

The explosion appears to have initiated a substantial hydromagnetic wave which spread out around the world and converged once more on Johnston I. after almost 8 hr. As the wave passed through the artificial radiation belt it seems likely to have caused precipitation of trapped electrons. The resultant increase in the electron density of the upper ionosphere produced a significant increase in $\Delta f_0 F_2$. The hydromagnetic wave (or whatever disturbance was responsible for the phenomena) travelled more than once around the world.

Three slower-speed disturbances of the pressure-wave type with speeds of 840, 330, and 220 m/s, produced pronounced decreases in $\Delta f_0 F_2$ and corresponding height rises in the F region as they passed over Brisbane.

EFFECTS OF NUCLEAR EXPLOSION

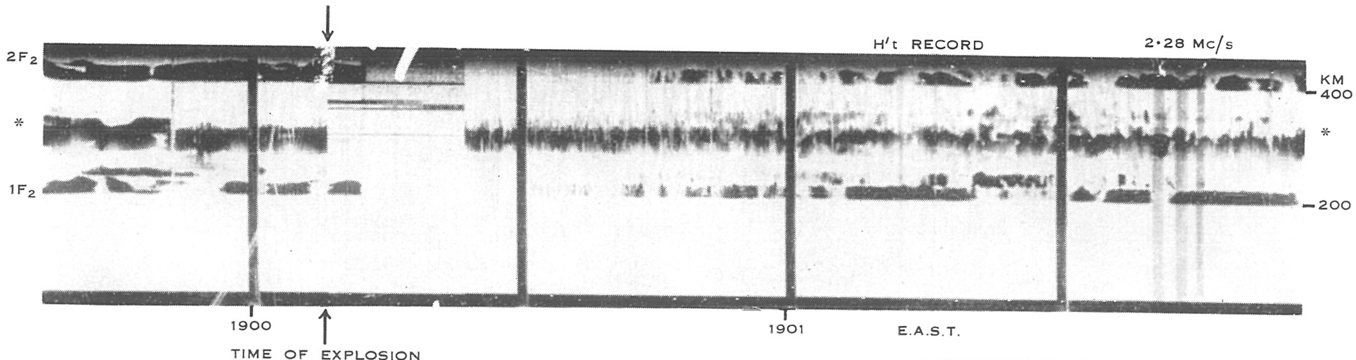

FIG. 1

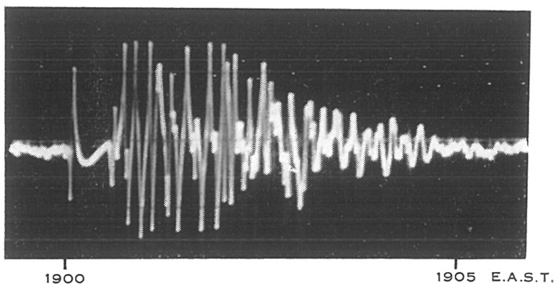

FIG. 2

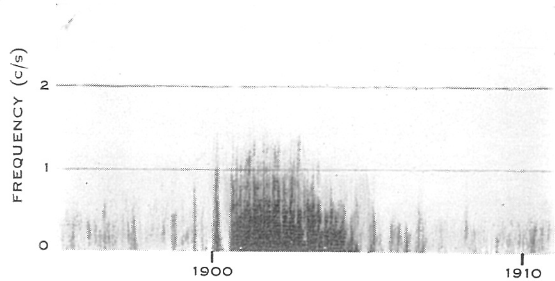

FIG. 3

Fig. 1.—Fixed frequency (2·28 Mc/s) $h't$ record showing F_2-layer absorption events soon after the explosion.

Fig. 2.—Geomagnetic micropulsations (north–south component) produced at Esk in the frequency range 0·01–2·0 c/s immediately after the explosion.

Fig. 3.—Sonagram showing frequency spectrum of the micropulsations shown in Figure 2 of this Plate.

EFFECTS OF NUCLEAR EXPLOSION

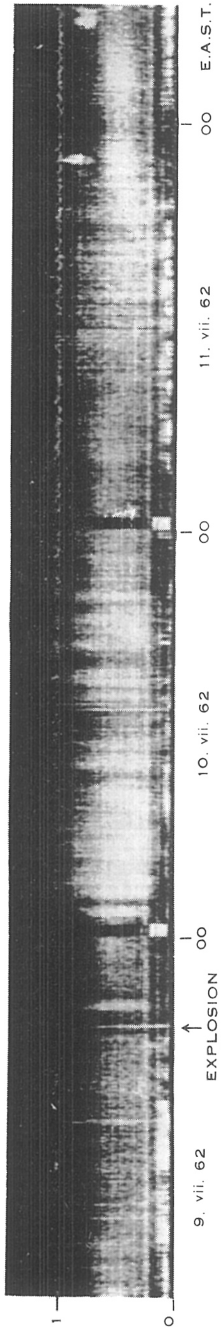

FIG. 1

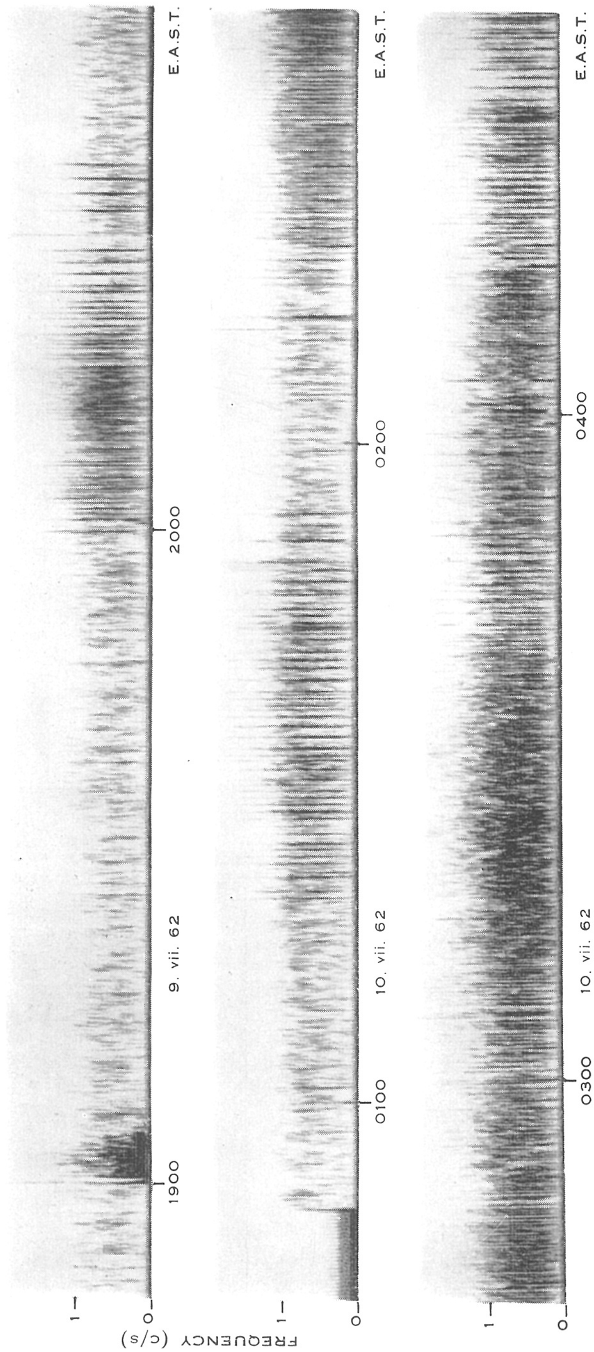

FIG. 2

Fig. 1.—Continuous Rayspan (Raytheon Company spectrum analyser) record showing frequency spectrum of micropulsations at Esk, July 9 to July 12, 1962. The normal low-frequency pc activity can be seen at the bottom of the record during daylight hours.

Fig. 2.—Sonagram showing frequency spectrum of micropulsations at Esk during selected intervals in the hours following the explosion.

The results presented here for the hydromagnetic disturbance may well be of significance in the understanding of magnetic storm effects in the ionosphere.

VI. Acknowledgments

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