JOURNAL OF GEOPHYSICAL RESEARCH VOL. 68, NO. 10 MAY 15, 1963

Hydromagnetic Waves Generated by the July 9, 1962, Nuclear Weapons Test As Observed at College, Alaska

CHARLES R. WILSON

Geophysical Institute, University of Alaska
College, Alaska

MASAHISA SUGIURA[1]

Goddard Space Flight Center, Greenbelt, Maryland

Abstract. Magnetic effects of the July 9, 1962, high-altitude nuclear weapons test near Johnston Island are studied by means of the record obtained with a rubidium vapor magnetometer at College, Alaska, and the records taken by the U. S. Coast and Geodetic Survey at College and Sitka, Alaska. The first event recorded by the rubidium magnetometer was a sudden increase in the total field 2.1 sec after the detonation; this was followed by a large-amplitude oscillation of period 2.5 to 3 sec, which drove the recorder off scale for several cycles. The first impulse is interpreted as a predominantly longitudinal hydromagnetic wave generated by the detonation. The second event, which commenced 52 sec after the detonation, was recorded by the rubidium magnetometer as a 3 γ negative impulse lasting about 8 sec. The third phase of the bomb effect was a large-amplitude magnetic perturbation of much longer period than the first event, beginning 66 sec after the detonation. This event is interpreted as the arrival of a transverse hydromagnetic wave generated in the magnetosphere at several earth radii and transmitted along the lines of magnetic force to the earth; the transverse wave was generated in the magnetosphere by coupling with the compressional hydromagnetic wave that propagated outward near the equatorial plane from the detonation point.

Magnetic effects of the United States July 9, 1962, high-altitude nuclear weapons test at Johnston Island were observed in Alaska by the U. S. Coast and Geodetic Survey magnetic observatories at College and Sitka with their Ruska rapid-run component magnetometers and by the Geophysical Institute at College with a Varian rubidium vapor total field magnetometer.

The sensitivities and chart speeds of the two instruments at College are: 0.0195 γ/mm and 2032 mm/min (8 inches/min) for the rubidium vapor magnetometer; and for the Ruska component magnetometers 4.6 γ/mm for H, 0.92 min (of arc)/mm for D, 5.0 γ/mm for Z, with a uniform chart speed of 4 mm/min for all three components. Time signals with 1-minute intervals received from the Minitrack Satellite Tracking Station at College were recorded on the rubidium vapor magnetometer record so that the absolute time of sharp magnetic impulses could be determined to within ± 0.06 sec.

Although the magnetic field was moderately disturbed during the night of the test, three distinct groups of hydromagnetic waves were identified as bomb effects at College.

The first event, as recorded by the rubidium vapor magnetometer at College, was a sudden increase in the total field at 0900 11.11 $\pm$ 0.06 sec UT; this was followed by a large-amplitude oscillation, of period 2.5 to 3 sec, which drove the recorder off scale for several cycles. Since the fluctuations were too rapid to be resolved in the records of the Coast and Geodetic Survey magnetometers, the polarization of these waves could not be determined. Because of its very large total field variations, this first event is interpreted as the arrival of a predominantly longitudinal hydromagnetic wave generated by the explosion; in general, longitudinal waves are expected to arrive earlier than transverse waves [*Dungey*, 1958].

The arrival of the second event at 09h 01m 01s $\pm$ 0.5 sec UT was recorded by the rubidium magnetometer as a 3 γ negative impulse lasting about 8 seconds. On the basis of the characteristics of the H, D, and Z rapid-run records, this pulse is interpreted as a predominantly transverse hydromagnetic wave.

Bomke et al. [1960] investigated the magnetic

[1] National Academy of Sciences–National Research Council fellow on leave of absence from the Geophysical Institute, College, Alaska.

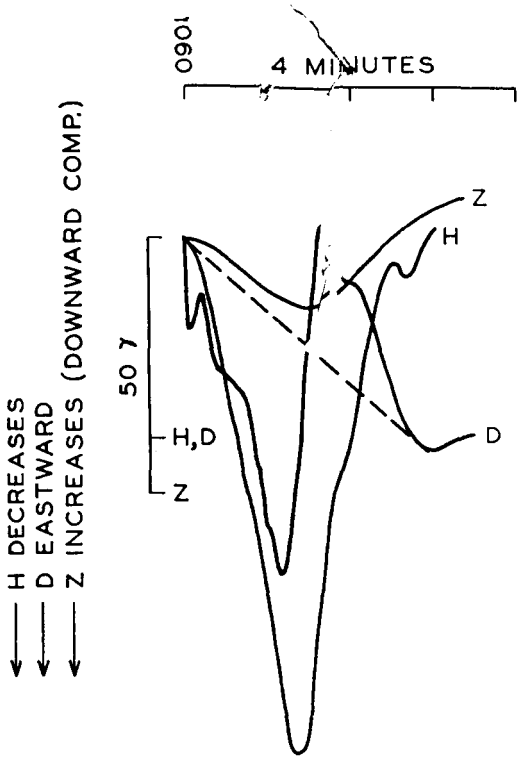

Fig. 1. Rapid-run magnetograms of H, D, and Z superimposed to show the phase relationships for the elliptically polarized transverse wave at College caused by the July 9, 1962, nuclear bomb test. The dashed line shows the eastward background drift in D.

effects from the Argus nuclear bomb tests and proposed that the two signals observed were the longitudinal and transverse hydromagnetic waves generated by the detonations and that these waves were transmitted essentially in ducts concentric with the earth. The travel time for the fast mode along the duct proposed by Bomke et al. from the point directly above Johnston Island to the point directly above College becomes 1.5 sec if values adopted by these authors are used for the height of the duct and the ion density in the duct. The observed travel time was 2.08 ± 0.06 sec. However, there is considerable uncertainty in the ion density at the altitude of the duct, namely 2500 km for the fast mode. Also, the surface distance along the great circle from Johnston Island to College is 5000 km, and the height of the duct is 2500 km; thus it is questionable whether the travel time computed in the above manner for the ducted propagation is meaningful.

The observed travel time can be accounted for at least in order of magnitude as follows: the sudden expansion of the hot plasma created by the detonation generated a longitudinal hydromagnetic wave that subsequently propagated in all directions. Part of the wave energy that was transmitted to a direction obliquely upward was reflected back to the earth's surface by continuous bending downward due to the increasing Alfvén wave velocity with height below the level at which this velocity is a maximum.

Since the wavelength of the longitudinal wave in question is of the same order of magnitude as the dimensions concerned, the straightforward application of ray path theory is probably not valid; hence the propagation path is not analyzed in detail here.

If the second duct for the transverse mode is assumed to be at the height of 1750 km, as in the model proposed by Bomke et al., the travel time for this mode along the duct from the point directly above Johnston Island to the point directly above College is about 8 sec. There was no

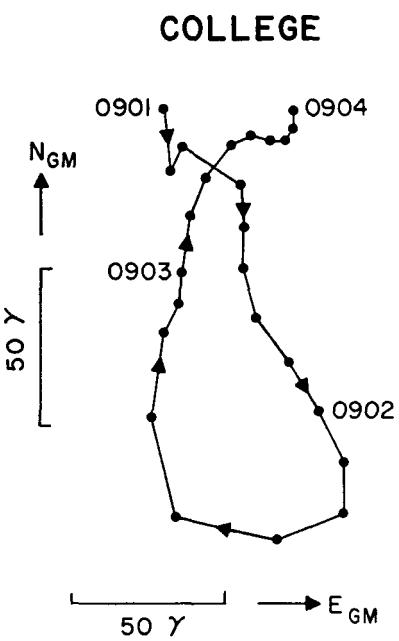

Fig. 2. Vector diagram of the transverse wave showing the locus of the end point of the total horizontal disturbance vector ΔH as a function of time.

CASE FILE COPY

distinct pulse corresponding to the arrival of this mode.

The third phase of the bomb effect is of considerable interest. This third event was a magnetic perturbation of large amplitude, but the variation was much slower than the first event. Whereas the first event consisted of several oscillations with periods of a few seconds, the time scale involved in the third event was about three minutes. The variations in the three components for the third event are shown in Figure 1.

The horizontal projection of the locus of the end point of the total magnetic perturbation vector is shown in Figure 2. This vector diagram resembles those constructed in a similar manner for the magnetic perturbation at College in the sudden commencement of magnetic storms [*Wilson and Sugiura*, 1961]. Figure 2 indicates a clockwise rotation of the magnetic perturbation vector.

The variation in declination appears to consist of a quasi-sinusoidal variation and a slow eastward drift. If we assume that this latter change was a slow variation of the field on which the former was superimposed, and if we subtract the slow variation which is represented by broken lines in Figure 1, the vector diagram for the resultant variation becomes more elliptical (Figure 3).

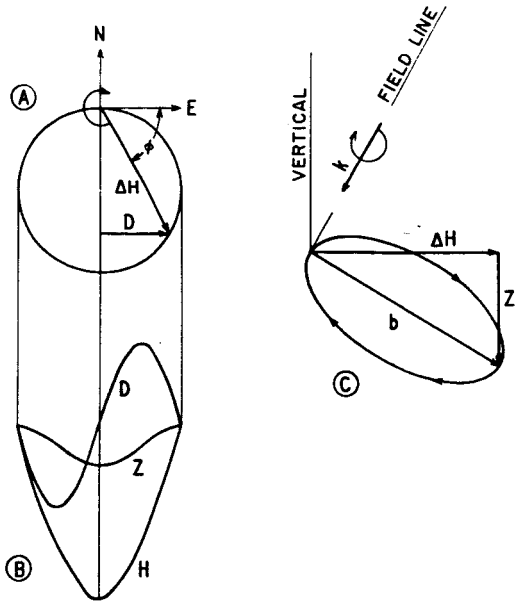

Fig. 4. *A:* Vector diagram for the idealized case in which the disturbance vector **b** increases as $b_0 \sin \phi$, where $\phi = \omega t$. *B:* The corresponding variations in H, D, and Z when the dip is 77°. *C:* Oblique view of the locus of **b** showing the relation between **ΔH** and Z. When **ΔH** is south, Z is downward and in phase with H. **K** is the propagation vector of the incoming wave.

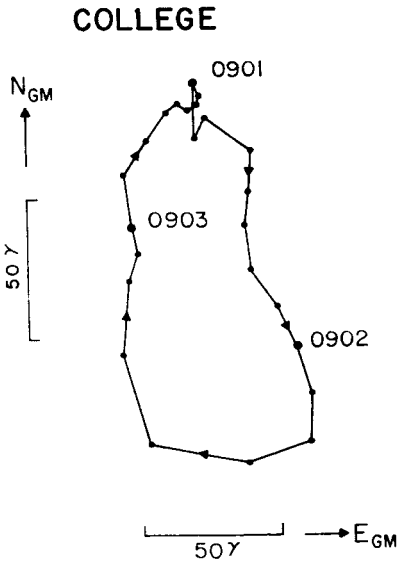

Fig. 3. Vector diagram of the transverse wave in Figure 2 with the background variation in D subtracted to show the clockwise elliptical polarization more clearly.

It is of some interest to examine the Z component. If the earth were a perfect conductor, an electromagnetic signal propagating downward from the ionosphere to the earth would be completely reflected at ground so that the Z component of the signal would be zero. Such complete reflection at ground has been assumed by various authors. However, there is some evidence indicating that the ground reflection is not so complete as is usually supposed. (This subject will be discussed in a separate paper.) Even for waves of periods of a few seconds, ground reflection appears to be very incomplete (Dawson and Sugiura, private communication).

Consider an idealized case of an elliptically polarized transverse wave propagating down a field line with a perturbation vector **b** that varies in magnitude as $b_0 \sin \omega t$. The arrival of such a wave at College where the dip is 77° would produce the variations in H, D, and Z shown in Figure 4*B* and a polarization diagram as in

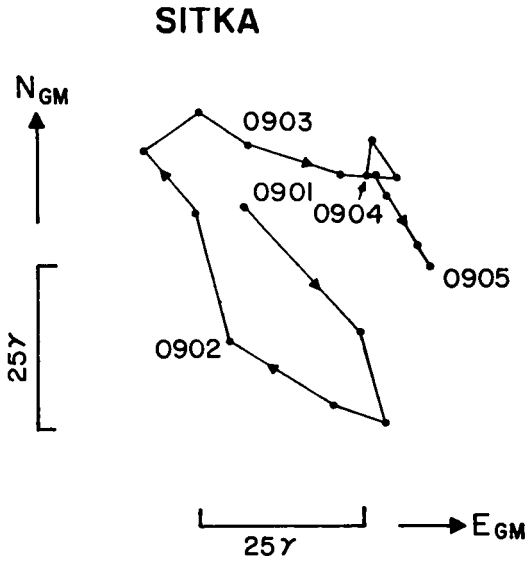

Fig. 5. Vector diagram for the transverse wave at Sitka showing clockwise polarization.

Figure 4*A*. Referring to the oblique view of the polarization diagram in Figure 4*C*, we can see that when **b** is directed southward, producing a decrease in H, the change in Z will be an increase. The change in Z with time will be in phase with that of H as shown in Figure 4*B*. The shapes of the H, D, and Z traces in Figure 1 resemble those in Figure 4*B*, which are drawn on the basis that the wave is polarized in the plane perpendicular to the magnetic field line. Thus it appears that the wave observed was indeed an elliptically polarized transverse hydromagnetic wave transmitted along the field line.

We are thus led to speculate that the third event may have been produced in the following way. The longitudinal hydromagnetic wave created by the explosion propagated radially outward away from the earth, and as the wave went out to regions of distances of several earth radii from the earth, it blew out the magnetic field lines sufficiently to generate transverse hydromagnetic waves, which then propagated along the field lines; these transverse waves should bear the characteristics of circular polarization. The circumstance is quite similar to the mechanism which we have proposed for the sudden commencement of a magnetic storm [*Wilson and Sugiura*, 1961]. In the storm commencement, longitudinal hydromagnetic waves are generated by the encounter of a solar gas cloud with the earth's magnetic field at the outer surface of the magnetosphere and travel toward the earth, whereas in the present case longitudinal hydromagnetic waves were created by the nuclear bomb and propagated outward.

The third phase began about 66 sec after the detonation. We now estimate the transit time of the hydromagnetic perturbation according to our model. We first estimate the time for a hydromagnetic wave to travel from the altitude of the bomb detonation, which is taken to be 400 km, to the point at which the magnetic field line crossing the earth's surface at College intersects the equatorial plane. Since the latitude of Johnston Island is low (19°), we take a path on the equatorial plane out to 5.4 earth radii, and then follow the field line to the earth's surface.

The travel time from 400-km height to 5.4 earth radii was estimated by a numerical integration using the Alfvén wave velocity distribution given by *Dessler et al.* [1960]; this gives 45 sec.

According to our observation of the oscillation of the magnetic field lines at College, the period of oscillation for the fundamental mode is about 114 sec. Taking one quarter of this period to be the travel time of a hydromagnetic wave from the equatorial plane at 5.4 earth radii to College along the field line, this travel time becomes 28.5 sec.

Thus the total travel time for the propagation proposed here is about 74 sec. Considering uncertainties in the distribution of Alfvén velocity in the magnetosphere and the crudeness of our estimate, the time of arrival of the third phase can be regarded as being in agreement, in order of magnitude, with the expectation.

If our hypothesis is correct, we might expect to see a similar transverse wave at Sitka where the storm sudden commencement field often shows circular polarization. Figure 5 shows the vector diagram for Sitka, which can be taken to indicate some tendency for the magnetic vector to rotate clockwise.

Acknowledgments. This project was supported by the Office of Naval Research through contract Nonr 3010(02). We are indebted to the Coast and Geodetic Survey for providing their magnetic records taken at College and Sitka. We wish to thank Dr. R. E. Simpson and Dr. J. P. Heppner for valuable discussions.

REFERENCES

Bomke, H. A., W. J. Ramm, S. Goldblatt, and V. Klemas, Global hydromagnetic wave ducts in the exosphere, *Nature, 185,* 1960.

Dessler, A. J., W. E. Francis, and E. N. Parker, Geomagnetic storm sudden-commencement rise times, *J. Geophys. Res., 65,* 2715, 1960.

Dungey, J. W., *Cosmic Electrodynamics,* p. 75, Cambridge University Press, London, 1958.

Wilson, C. R., and M. Sugiura, Hydromagnetic interpretation of sudden commencements of magnetic storms, *J. Geophys. Res., 66,* 4097, 1961.

(Received February 8, 1963.)