radiation from the interior of the sun. The flux at the sun which could explain geomagnetic disturbance (assuming an earth capture cross section of 10 diameters) is of order $10\text{-}10^2$ ergs cm^{-2} sec^{-1}. This is a small (10^{-4}–10^{-3}) of the flux invoked by various authors to explain coronal heating.

Davis: Comment made after the meeting: It seems useful to supplement the discussion following the paper with some comments of a type that could not be supplied extemporaneously. The key issues are whether the energy flux due to thermally generated waves is increased enormously above that for black body radiation if hydromagnetic or acoustic waves are present and if the resultant waves can have major astronomical or geophysical effects. In order to produce such effects, the wave must be reasonably long, hence consider only waves longer than $\lambda_m=1$ cm. Thus we can work in the Rayleigh-Jeans limit. Then the flux for all waves longer than λ_m is

$$B(\geqq\lambda_m)=vkT/3\lambda^3_m \text{ erg cm}^{-2}\text{ sec}^{-1}\text{ sterad}^{-1}.$$

Numerically, if $T=10^6$ °K and $V=10^7$ cm/sec, the minimum possible velocity of an acoustic or hydromagnetic wave in a medium at 10^6 °K, the energy flux is

$$B(\geq 1\text{ cm})=4\times10^{-3}\text{ erg cm}^{-2}\text{ sec}^{-1}\text{ sterad}^{-1}.$$

The black body flux in the solar photosphere ($T=5800°K$) is 2×10^{10} erg cm^{-2} sec^{-1} sterad^{-1}. Thus there can be no astronomical or geophysical consequences of importance due to thermally generated, reasonably long hydromagnetic waves. It is not possible to get greater energy in these waves by allowing shorter waves in a region of lower velocity to propagate to a region with high velocity since refraction will limit the intensity to the thermodynamic limit. Much greater fluxes are obtained if $\nu_m(=v/\lambda_m)$ is increased, but these correspond to thermal conductivity, not to mass motions on a geophysical scale.

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II-1A-3. Infrasonic Pressure Waves Associated with Magnetic Storms

P. CHRZANOWSKI, J. M. YOUNG, G. GREENE
and K. T. LEMMON

National Bureau of Standards, Washington 25, D.C., U.S.A.

Pressure waves with predominant periods between 20 and 80 seconds and amplitudes up to 8 dyne/cm^2 have been recorded with a quadrilateral microphone array near Washington, D. C. during intervals of high magnetic activity. These waves have a trace velocity along the earth's surface higher than the local speed of sound and show diurnal-directional properties consistent with a source on the night side of the earth. A high degree of association with large values of the planetary magnetic index K_p has been established.

Pressure fluctuations in the atmosphere were detected by condenser microphones placed on the surface of the earth so as to form a quadrilateral averaging 7.5 km on a side (Fig. 1). The output of each microphone was amplified and recorded on translucent paper tapes. A visual cross-

* A more complete description of this work has been submitted to the Journal of Geophysical Research.

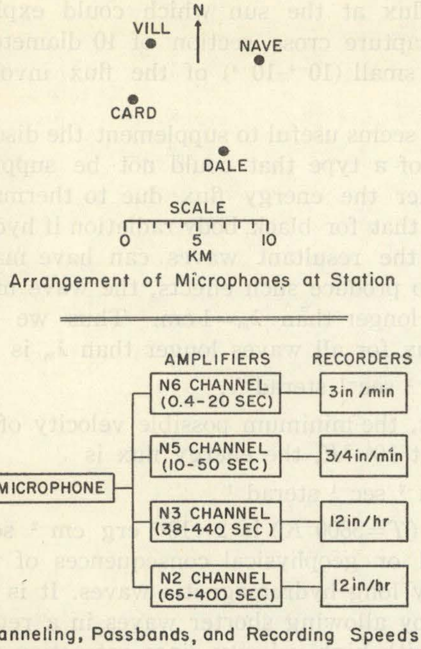

Fig. 1. Schematic diagram of recording equipment showing the relative positions of the microphones and the different frequency ranges used.

correlation technique was used to distinguish passage of a coherent plane wave of sound from more random pressure fluctuations due to wind turbulence and other causes.

A portion of the records from the four microphones during the great magnetic storm of 11 February 1958 is reproduced on Fig 2. The second strip from the bottom shows superposed records aligned to show the sound waves. Time differences between the different microphones obtained from such alignments were used to compute the direction of arrival of the waves and the trace velocity or horizontal phase velocity over the surface of the earth. At 0642 UT sound waves arrived from 340° at 775 m/sec. The waves decreased in amplitude until 0840 when a second burst arrived from 318° with a trace velocity of 550 m/sec. At 0905 waves similar to those at 0642 arrived from 332° at 750 m/sec. The waves decreased in amplitude and disappeared into the background fluctuations between 1100 and 1200 UT. There may be a close connection between

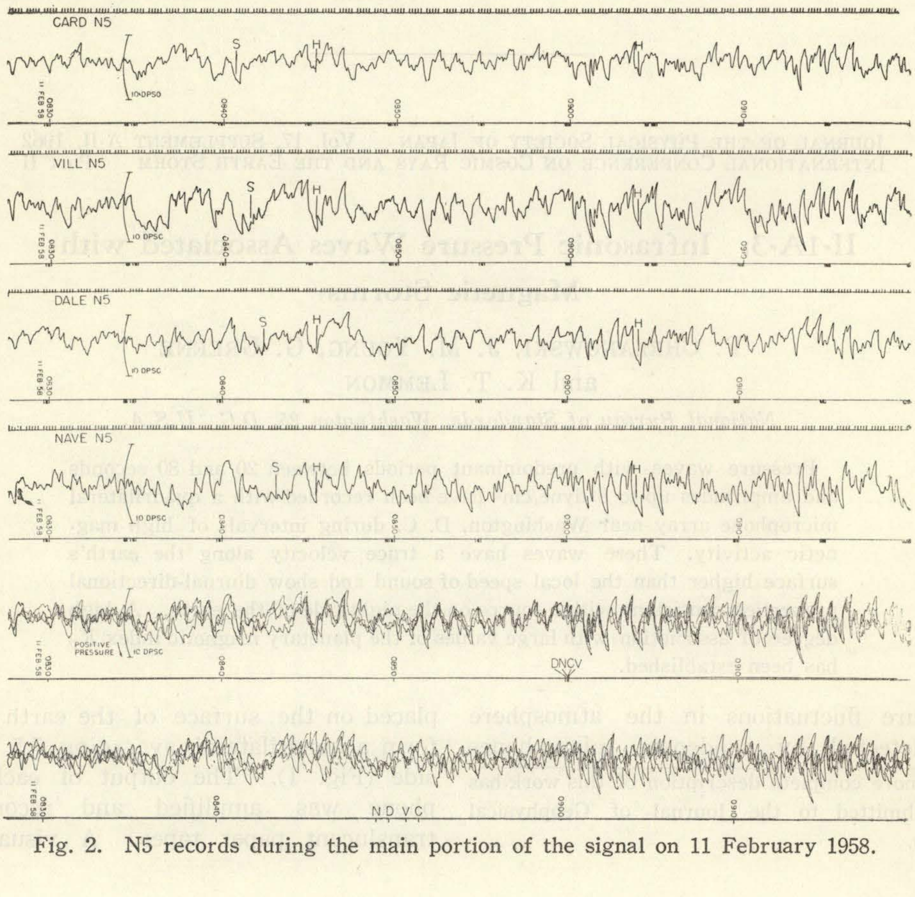

Fig. 2. N5 records during the main portion of the signal on 11 February 1958.

Table I. Sound associated with geomagnetic activity period from June 1958 to December 1959

Planetary Magntic Index	Number of Disturbances	Sound Present	Sound Absent	Station Noisy	Percentage Association
9	4	4	0	0	100
8 or higher	13	10	0	3	100
7 〃	28	20	1	7	95
6 〃	62	36	10	16	78

the almost simultaneous onset of the pressure waves, the bursts of auroral x-rays measured at Minneapolis during the storm [Winckler 1959],[1] the two large magnetic bays that show on the Fredricksburg magnetogram, and the irregular micropulsations reported by Troitskaya [1961].[2]

The planetary magnetic index K_p was chosen as a measure of the degree of disturbance of the environment of the earth by solar corpuscular streams. The degree of association between appearance of sound waves and 62 magnetic disturbances during which K_p rose to 6 or higher is shown in Table 1. During 16 of the disturbances the high random background fluctuations precluded finding a correlatable signal. Sound waves were found during 36 of the remaining 46 magnetic storms. The degree of association was higher for the higher K_p indices.

Fig. 3. Elapsed time between sharp rise in K_p and onset of sound waves.

The histogram in Fig. 3 relates the number of signals to delay in onset time after a change in K_p by at least 2 to a value of 6 or higher within two adjacent 3 hour intervals. They show a tendency to appear 3 to 6 hours after a sharp rise in magnetic activity.

Fig. 4 shows the diurnal variation of the direction from which the sound waves arrive. Individual storms tend to show irregular fluctuations of direction about the trend shown in the figure. The behavior can be qualitatively explained by a source moving around in the Auroral Zone near magnetic midnight. Two other unusual phenomena, the two examples of 5 kc/s radio noise storms during which amplitude fluctuations correlate with a time difference approximately equal to the local time difference between stations reported by Ellis [1961],[3] and the time distribution of neutron intensity increases at different stations during the July 17-18, 1959 storm reported by Ghielmetti [1961],[4] are consistent with night-side sources. Observations simultaneously from several locations should aid in location of the source of these sound pressure waves.

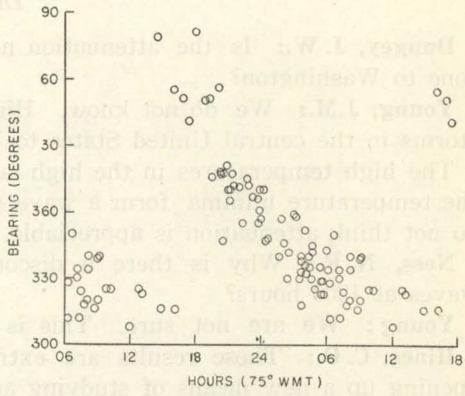

Fig. 4. Diurnal variation of direction of arrival of sound waves during magnetic storms.

The high trace velocity of these signals, usually between 400 and 500 m/sec, make it appear likely that the waves are generated in the upper atmosphere and approach the surface at a high angle.

A study of the relation between these pressure effects and satellite drag effects, charged particle phenomena such as auroral x-rays, auroral light intensity fluctuations, magnetic micropulsations, magnetic bays, apparent ionospheric motions, and low frequency radio noise storms, should be helpful in explaining the behavior of the earth's atmosphere during magnetic storms.

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1) J. R. Winckler, L. Peterson, R. Hoffman and R. Arnoldy: J. Geophys. Res. **64** (1959) 597.
2) V. A. Troitskaya: J. Geophys. Res. **66** (1961) 5.
3) G. R. A. Ellis: J. Geophys. Res. **66** (1961) 19.
4) H. S. Ghielmetti: J. Geophys. Res. **66** (1961) 1611.

Discussion

Dungey, J. W.: Is the attenuation not important in transmission from the auroral zone to Washington?

Young, J.M.: We do not know. Higher frequencies are propagated from tornadic storms in the central United States to Washington.

The high temperatures in the high atmosphere tend to refract sound waves and the temperature minima form a wave guide. For the long wavelengths involved we do not think attenuation is appreciable.

Ness, N. F.: Why is there a discontinuity in the direction of arrival of sound waves at 1200 hours?

Young: We are not sure. This is one of the questions that need further study.

Hines, C. O.: These results are extremely interesting and I think it important in opening up a new means of studying auroral events. The high-frequency cut-off could be extremely sensitive to the atmospheric viscosity at the height of origin, and the low-frequency cut-off to the local temperature. Fourier analysis of the spectrum therefore may give information concerning the height of transfer of the energy from incoming particles or hydromagnetic waves into the acoustic waves. The change in azimuth of sources through the night, rapid before midnight and slow after, would be consistent with sources in a region of turbulence that is spiral-shaped, depending in latitude in the pre-midnight hours and terminating along the auroral zone in the post-midnight hours, such as is observed for intense Es ionization and other manifestations of high-latitude ionospheric and auroral irregularities.

Maeda, K.: Concerning the bearing you showed by slide, I would like to make a comment on the influence of the wind motion along the propagation path of the sound. The bearing you measured is the direction limited in the ground surface, and will not be the true bearing of the place where the wave is generated.

Young: It is true that both the wind and the temperature structure of the atmosphere affects sound propagation. No attempt has been made to correct for this in the data presented. Wind velocities in the ozonosphere do reach values appreciable compared to the velocity of sound.

Dungey: After Hines··· Would experiments with grenades fired from rockets be relevant?

Young: Grenade experiments are valuable in determining winds and tempratures but I think the frequencies involved are usually higher than those discussed here.

Smith, E. J.: 1. How do you distinguish against wind or acoustic pulses?

2. Are your detectors directional? Could a bias be introduced from your selection overlay of records?

3. Neglecting attenuation, there must still be a geometrical drop-off with distance. Extraporating these pulses to the auroral zone, are tornadoes implied?

Young: 1. We require that the transit times across the microphones correspond to a plane wave with trace velocity acoustic or higher, and that the same waveshapes be recognizable on all four records.

2. Not at the frequencies involved. The overlay is done by matching waveshapes

and the results should be self-consistent. At high signal to noise ratio azimuths are quite consistent from different tripartites.

3. Of course we are not sure of the exact distance to the source but the intensity probably is of the same order of magnitude as that from tornadic storms.

Sonett, C. P.: Unless an auroral sound wave has a scale comparable to the earth, is there not an attenuation in ducted propagation?

Young: We do not think attenuation is very important, however the propagation constants and structure of the thin spherical shell of atmosphere surrounding the earth should be taken into account.

Ness: Is the instrument sensitive to earthquake generated sound disturbances? Does this affect the correlation of activity with magnetic field activity?

Young: Radiation from surface waves of very large earthquakes are occasionally recorded but this represents only a very very small proportion of the time.

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II-1A-P1. Hydromagnetic Picture of Earth Storms

A. J. DESSLER*
Physical Research Laboratory, Ahmedabad 9, India

A description of the principal features of magnetic storms has been given in other papers in this proceedings. Therefore, rather than duplicating these other presentations, I will restrict my remarks to subsidiary topics not previously covered.

§1. Stability of the Interface between the Geomagnetic Field and the Solar Wind.

The sudden commencement and initial phase of a magnetic storm are usually attributed to the impact and pressure of solar plasma on the geomagnetic field. It is this period of time during which we can be relatively certain that an enhanced solar plasma is flowing past the earth. It is found, from an inspection of standard magnetometer records and ELF records, that the geomagnetic field at the earth's surface often is not particularly disturbed during the initial phase. On the basis of these observations it may be argued that the boundary between the geomagnetic field and solar wind is inherently stable since any large scale turbulence at the boundary would lead to the generation of hydromagnetic waves that could be detected at the earth's surface. If one wishes to contend that the surface is actually unstable but that the h.m. waves are attenuated before they reach the earth's surface, then a time dependent attenuation mechanism must be envoked, for sometimes the h.m. waves are seen at the earth's surface and sometimes they are not. In light of our present knowledge of the exosphere, such a time dependent attenuation seems quite improbable. Hydromagnetic waves may be generated by energy density fluctuations in the solar wind; the surface magnetometer records may be interpreted as indicating that the initial flow of solar plasma past the earth is smooth and several hours later becomes irregular and turbulent.

(The subject of the stability of the interface is discussed in more detail in a recent letter to the Editor: Dessler, 1961[1] and in a rebuttal to this analysis by Coleman and

* Permanent Address: Lockhead Missile and Space Co., Palo Alto, California.