Rapid Geomagnetic Fluctuations

By STIG HARALDSON, Uppsala[1]

(Manuscript received June 4, 1960, revised version April 19, 1961.)

Abstract

The article presents an investigation of VLF-oscillations (0.2—200 c/s) in the earth's magnetic field. The measurements were made in the archipelago of Stockholm (59° N) during the period July 1957—June 1959. The oscillations were recorded by two different instruments: a high-speed Heiland oscillograph and a low-speed Esterline-Angus recorder. In the Esterline-Angus diagrams a morning minimum at about 8 o'clock local time was found. In the Heiland oscillograms three different features were found: 1. Frequent occurrence of sinusoidal fluctuations presenting a few very narrow bands; 2. Oscillations in the H- and Z-component are sometimes simultaneous, sometimes not; 3. The amplitudes in the Z-component are smaller than in the H-component. It has not been possible to find a correlation between the fluctuations investigated here and other geophysical phenomena. A possible mechanism for generation of the sinusoidal oscillations is discussed.

1. Introduction

Common geomagnetic variometers have an upper frequency limit about 0.2—0.5 c/s and more rapid fluctuations in the earth's magnetic field have not been recorded until recently, WILLIS (1948), AARONS (1951) etc. The investigation to be described here was started in the spring of 1957, its purpose being to measure the amplitudes in the frequency range 0.2—200 c/s.

2. The apparatus

Two coils were used in recording the fluctuations, one with 1,080 turns and a total area of 9,100 m^2 for the Z-component and another with 3,000 turns and an area of 7,100 m^2 for the H-component.

The resonance frequency of the coils appeared at about 170 and 25 c/s respectively and it was therefore not possible to calculate the field amplitudes directly from the voltages appearing across the terminals. However, it did prove possible to calibrate the apparatus directly in mγ/mm (mγ = milligamma = 10^{-8} gauss) through introducing a known alternating current into a calibration winding surrounding each coil.

During a first period only one amplifier (two cascade connected, battery operated Tektronix Preamplifiers) was used. The H- and Z-components were recorded alternatively on a battery operated Heiland oscillograph. Because of the high paperspeed (7 cm/sec) recordings were made only during intervals of 1—2 minutes every hour.

[1] This investigation has been sponsored by the Swedish Research Institute of National Defence.

In order to eliminate the peak at about 25 c/s in the sensitivity of the H coil, damping was arranged for by applying a resistance of 2.2 kΩ across the coil and by using in the oscillograph a galvanometer with a resonance frequency of 150 c/s. The calibration curves for the apparatus are shown in fig. 1.

During the summer and autumn of 1958 the instrumentation was completed by addition of a modified Tektronix Preamplifier with an extra final stage. This made it possible to make records of both components simultaneously. At about the same time an Esterline-Angus recorder with low paperspeed, about 90 cm/hour, became available. It was then possible to make continuous recordings. As this instrument had only one channel, the Z-component was chosen.

Fig. 2 shows a block diagram of the equipment.

3. Sites

The first measurements were made in the neighbourhood of Uppsala (60° N) during the spring 1957. All that was recorded was a 50 c/s hum from the AC power lines and a $16^2/_3$ c/s hum from the railroads. These disturbances did not decrease appreciably when the local transformer stations in the neighbourhood were disconnected even though the distance to the nearest main AC power transmission line was 2.5 km., the distance to the city of Uppsala 10 km and the distance to the nearest railroad 4 km. In order to eliminate sources of this type, the site had to be moved far away from inhabited regions, but for practical reasons could not be too far away from Uppsala and Stockholm. In July 1957 a test was made on a small island in the outer parts of the archipelago of Stockholm (59° N), about 15 km from the nearest small AC power line and 55 km from the nearest railroad. As no traces of 50 c/s or $16^2/_3$ c/s hum could be discovered, the island was chosen as site for the recordings.

The site had some great disadvantages, as the island was difficult of access, and the instruments were often badly treated in transit, each time recordings were to be made. In order to distribute the days of measurement as evenly as possible over the year, we decided to make recordings 2—4 days per month, but various misadventures during transportation to and from the site made it impossible to keep this programme and the information obtained is therefore rather imperfect from a statistical point of view. During the period 1. 7. 1958—30. 6. 1959, when the equipment was complete, there are only 14 days with recordings, that permit calculation of a fairly certain daily mean value.

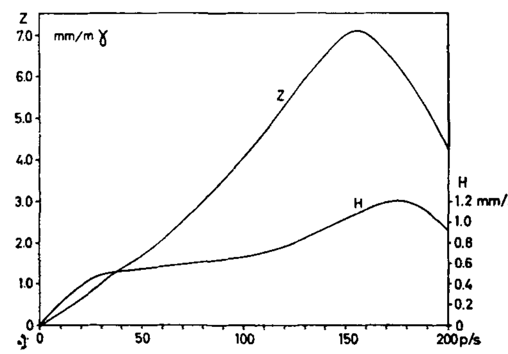

Fig. 1. Calibration curves. The sensitivity in mm mγ (millimeter per milligamma) as a function of the frequency.

The calibration also became a labourious procedure as the capacitance of the coils changed, due to condensation of moisture between the turns. The calibration had to be checked frequently. The noise level from the apparatus, which had to be very low, was controlled by connecting a resistance and a capacitance of the same order as the capacitance of the coils to the amplifier.

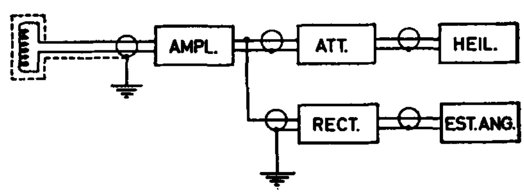

Fig. 2. Block diagram of the apparatus.

4. The Heiland oscillograms

A statistical analysis of the Heiland oscillograms has not yet been made and only some general and interesting features will be discussed. The most striking thing to be observed is that in addition to the noise there are not seldom variations similar to the giant pulsa-

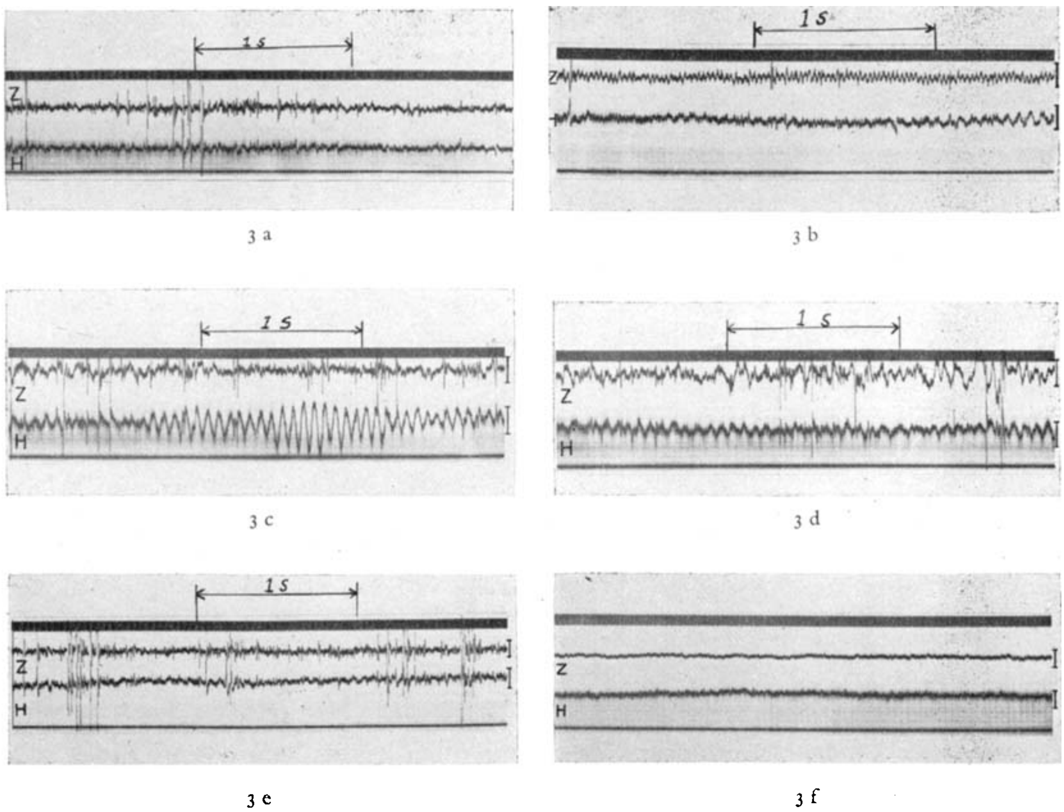

Fig. 3. Heiland oscillograms; a) 1.6. 1959 about 2119 o'clock GMT; b) 2. 6. 1959 about 0855 o'clock GMT; c) 2. 6. 1959 about 1228 GMT; d) 2.6. 1959 about 1229 GMT; e) 11. 6. 1959 about 1924 GMT; f) noise. The lines to the right of the curves give a measure of 10 mγ for the *Z*-component and 20 mγ for the *H*-component at 30 c/s.

tions, i.e. sinusoidal fluctuations with a very definite frequency, see fig. 3 a—e. Fig. 3 f shows the noise from the apparatus.

It is also remarkable that these fluctuations present only a few narrow bands, about 15 c/s, 20 c/s, 30 c/s, 40—50 c/s and 140—160 c/s. Sometimes, oscillations of a very low frequency, < 1 c/s can be found, but on account of the relatively low sensitivity for these frequencies they are rare.

Another very astonishing feature is that the fluctuations in the H- and the Z-component are sometimes simultaneous, sometimes not, as is seen in the figures.

This was observed already before we could make simultaneous records of the H- and Z-component. In every record of H during one day 20 c/s fluctuations could e.g. be found, but no such oscillations appeared in Z. As the total recording time was rather short, the possibility of pure coincidence could not be left out. The simultaneous recordings made later on verified, however, this observation.

The third general feature is that the amplitudes in the Z-component on the whole are much smaller than in the H-component.

Examples of amplitudes:

about 150 c/s:	H	10—20 mγ	up to 100—120 mγ
	Z	1—2 mγ	up to 10 mγ
30 c/s:	H	10—20 mγ	up to 150 mγ
	Z	1—3 mγ	up to 10 mγ
20 c/s:	H	15—20 mγ	up to 150 mγ
	Z	5 mγ	up to 30 mγ
< 1 c/s:	H		up to 30 γ
	Z		up to 2 γ

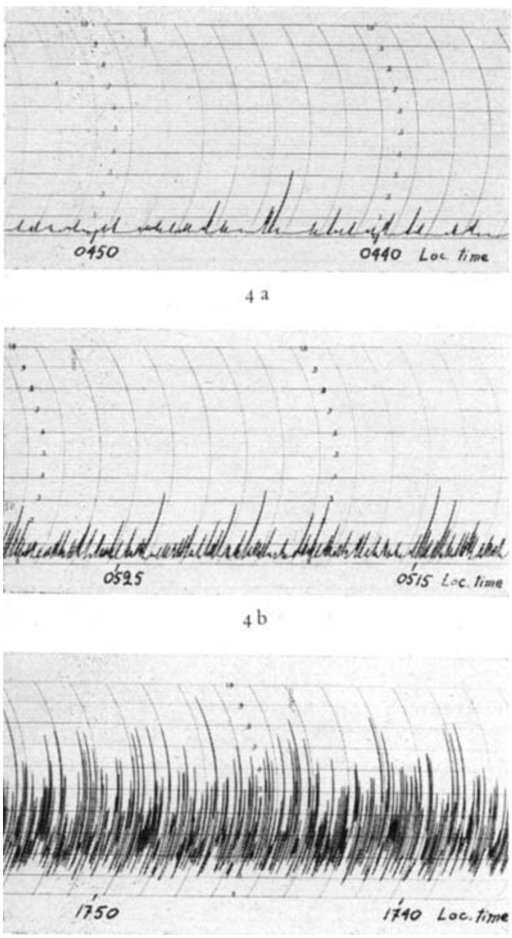

Fig. 4. Esterline—Angus diagrams: a) 9. 1. 1959, a quiet day; b) 21. 10. 1958, a moderately disturbed day; c) 11. 6. 1959, a very disturbed day.

5. Esterline-Angus diagram

Figs. 4 a—c show examples of Esterline-Angus diagrams for quiet days, moderately disturbed days and very disturbed days. As is seen in 4a and 4b, it is not so much the basic level nor the amplitude of the individual "spikes" that are affected, but the "spikes" are more frequent on a disturbed day. The diagrams were divided in half-hour intervals for purpose of analysis. For each half-hour the number of spikes ranging up to between 2.5—5 scale-divisions, 5—10 divisions, 10—15 divisions etc. was counted and the numbers multiplied by the lower limit-value for the interval. The disturbance figure for each half-hour was then defined as the sum of the products.

In order to find an eventual daily variation, the disturbance figure was then expressed in per cent of its daily mean value and the relative disturbance figures for the same half hour of all days were added. This calculation has been confined to the half day 0000—1200 local time, since the sequence of observation was more complete during this interval, gaps during 1200—2400 being due mostly to calibration checks.

As seen in fig. 5 there is a marked minimum about 0800 local time. This confirms what can be directly observed on the diagrams. It is also in agreement with almost all earlier investigation of VLF-noise in middle latitudes. The results reported by Egeland (1959) and Egeland et al (1960) indicate that conditions in the auroral zone (68° N, 70° N and 75° N) may be different.

The geomagnetic K-index for the near-by Lovö Geomagnetic Observatory and the disturbance figures reported here show the same average daily variation but it has not been possible to find a correlation between actual values. The same is true for the K_p-index. On this point earlier investigations have given different results. A correlation has been noted by Aarons (1951), Egeland (1959), Egeland et al (1960) and Maple (1960), but not by Aaron's in two papers from 1953 and 1954. It is here interesting to note that in almost all cases where a correlation has been reported, the measurements have been made in the auroral zone, the exception being Aarons (1951) and (1956). Thus the validity of this correlation and the extent of its latitude dependency are still uncertain.

It should also be noticed that the noise figures, as calculated above, represent a kind of mean value over the interval 0.2—200 c/s, with more weight attached to the higher frequencies and that at least some of the investigations mentioned indicate that the correlation may exist for frequencies below, say, 50 c/s, but not for higher frequencies. In further investigations one should therefore use an apparatus with several channels in order that the amplitudes could be examined over smaller frequency intervals.

We have also tried to correlate the disturbance figures with variations in the cosmic

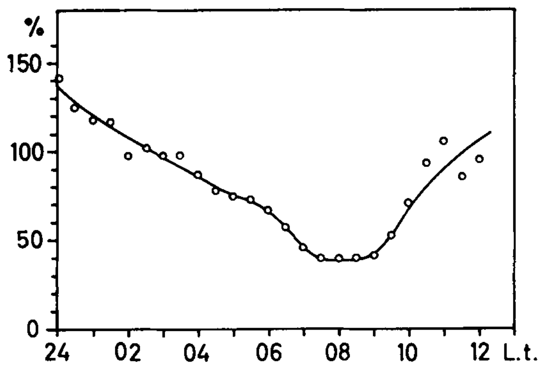

Fig. 5. Relative disturbance figures in per cent of the daily mean v. local time.

ray intensity. At first it seemed as if there was a connection of some kind between these two phenomena, perhaps with a phase shift of one day. Further investigation, however, showed that this connection was very obscure and it is impossible to deduce a correlation between our disturbance figures and the variations in the cosmic ray intensity, recorded at Uppsala.

Similarly, all efforts to find a correlation with ionospheric characteristics, such as the critical frequency for various ionospheric layers a.s.f., have failed.

Now these failures, of course, do not necessarily mean that there is no connection between our disturbance figures and the other geophysical phenomena mentioned. It is more reasonable to think that there is a very complex connection between a great many factors, which makes it very hard to put the things together. It must also be remembered that from a statistical point of view our material is rather small.

6. Origin of the fluctuations

Many of the fluctuations are very similar in form to the giant pulsations, although of much higher frequency. LEHNERT (1956) and (1959) has tried to explain the giant pulsations with magnetohydrodynamic waves in the ionosphere. His calculations show that for the frequencies investigated here, the damping will certainly be too great, so it seems impossible to explain these fluctuations in that way.

Aarons has suggested that ions spiralling in the earth's magnetic field could give rise to fluctuations with the gyrofrequency. It can be worth while considering this possibility. The process must take place at an altitude of 200 – 300 km in order that the mean free path be large enough for the ions to complete several rounds between the collisions.

According to the law of Biot-Savart, a charged particle with a velocity v in the near zone ($r \ll \lambda$) gives a magnetic field with a flux density

$$B = \frac{\mu_0}{4\pi} \cdot \frac{e\, v \times r}{r^3}$$

If we, as Aarons does, let v be the thermal velocity at 300 km altitude, we have $v \sim 6{,}000$ m/s. This can give an amplitude for $B \sim 10^{-33}$ Vs/m². To obtain a total amplitude of 10 mγ $= 10^{-11}$ Vs/m², we thus need totally 10^{22} ions revolving in a coherent manner. This does not seem very likely. On the other hand, if there is a much greater number spiralling at random, it is not quite impossible that there could occasionally exist a net vector sum ot a detectable size. It is also possible, as Aarons has pointed out, that the energy of the ions is suddenly increased by e.g. meteor impacts.

The gyrofrequency is given by the formula

$$f = \frac{B \cdot e}{2\pi\, \mathrm{m}}$$

where B is the total geomagnetic flux density, in Stockholm 0.49 gs, say 0.45 gs and 0.44 gs at an altitude of 200 resp. 300 km.

Table 1 below gives the gyrofrequencies for some of the ions in the ionosphere.

These figures are very suggestive because the frequencies of the sinusoidal fluctuations seen in the Heiland oscillograms almost always

Table 1

	f in c/s at height	
ion	200 km	300 km
H^+	690	680 km
He^+	170	170
N^+	49	48
N_2^+	25	24
O^+	43	42
O_2^+	22	21
O_3^+	14	14
Na^+	30	30

lie around 20 c/s, 30 c/s, 40—50 c/s. The theory is also consistent with the fact that the fluctuations are more frequent in the H- than in the Z-component. Of course, ions rotating over our heads are nearer and therefore easier to detect than ions on a great angular distance from our zenith-direction. But the field from the ions overhead has no or only a small component in the Z-direction, which will be parallel to *r*.

It would be very interesting to record simultaneously fluctuations in two rectangular horizontal directions to see if the fluctuations have a phase shift of 90° in these two components.

This theory, however, is still only guesswork and we are far from a true knowledge about these fluctuations and their origin.

Acknowledgement

The author is deeply indepted to Laborator Sigfrid Wennerberg, Research Institute of National Defence, for support and encouragement during the whole progress of the work. Thanks are also due to Professor Per Ohlin and Docent Einar Lyttkens, Uppsala and Laborator Nicolai Herlofsson, Stockholm, for valuable advice and criticism.

REFERENCES

AARONS, J., 1951: Low-Frequency Noise Disturbance, *Proc. Am. Acad. Arts and Sc.*, **79**, p. 266.

AARONS, J. and HENISSART, M., 1953: Low Frequency Noise in the Range 0.5—20 c/s, *Nature*, **172**, p. 682.

AARONS, J., 1954: *Doctoral Thesis*, University of Paris.

— 1956: Low-frequency Electromagnetic Radiation 10—900 c/s, *J. Geophys. Res.* **61**, p. 647.

AARONS, J., GUSTAFSSON, G. and EGELAND, A., 1960: Correlation of Audio-Frequency Electro-magnetic Radiation with Auroral Zone Micropulsations, *Nature*, **185**, p. 148.

— 1960: Audio-Frequency Electromagnetic Radiation in the Auroral Zone, *J. Geophys. Res.* **65**, p. 2749.

EGELAND, A., 1959: Report No. 6. Inst. of Theoret. Astrophysics, Blindern, Oslo.

LEHNERT, B., 1956: Magneto-hydrodynamic Waves in the Ionosphere and their Application to Giant Pulsations, *Tellus*, **8**, p. 241.

— 1959: Plasma Physics on Cosmical and Laboratory Scale, *Nuovo Cimento*, Suppl. XIII, Ser. X.

MAPLE, E., 1960: *Sub-audio-frequency (1 to 50 c/s) Geomagnetic Fluctuations*, presented at the Geophysical Conference, Helsinki, July—August 1960.

MENZEL and SALISBURY, 1948: Audio Frequency Radio Waves from the Sun, *Nature*, **161**, p. 91.

WILLIS, H., 1948: Audio Frequency Magnetic Fluctuations, *Nature*, **161**, p. 887.