THE OBSERVATION OF VLF EMISSIONS AT MOSHIRI

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Abstract

The routine observation of VLF emissions was begun at Moshiri in January last year, using crossed loop antennas of triangle type of 2 turns, 43 meters in height and 60 meters at the base. The observing frequency range is from 4 kc/s to 6 kc/s. The recording system used is the minimum reading pen-recorder, developed by G. R. A. Ellis. The results obtained from the observation during the period from January to November 1963 indicate that the VLF emissions are observable at geomagnetic latitudes as low as 34° and the majority of the VLF emissions are of hiss type, but during severe magnetic storms chorus are also observable and that the correlation between occurrence rate of noise burst and geomagnetic activity, measured by daily k-index and magnetic storm, is very close, however, it does not seem so close with the pt type geomagnetic pulsation, while the peak flux density of noise burst does not appear to depend directly on geomagnetic activity. In order to confirm these results a more detailed investigation with a full data of geomagnetism and considerations on effects of atmospherics may be needed.

1. Introduction

Recently, the mechanism of generation and propagation of VLF emissions has been studied and many interesting results have been reported for high latitudes. But VLF emissions could not be observed at lower latitudes. So far as is known, examples observed at points lower than 40° (geomagnetic latitude) have not yet been obtained in the world. Since IGY, whistlers have been observed at Wakkanai, situated at the northernmost point of Japan, but even here no VLF emissions have yet been observed distinctly, yet in Japan it is only in the northern Hokkaido district that an observatory will have any chance of observing VLF emissions. But at Wakkanai man-made noise has increased considerably and therefore it has become rather unsuitable for their observation.

A survey of noise in north Hokkaido, therefore, carried out to locate a suitable site for observing VLF emissions and it was found that Moshiri, situated in the Experimental Plantation of Hokkaido University would be suitable for this purpose. A new observatory has been built there and a routine observation of whistlers had been carried on since November 1962, and since January 1963 the intensity of VLF emissions ranging from 4 kc/s to 6 kc/s has been observed. Moreover, the directional observation of VLF emissions at 5 kc/s was begun in June 1963. Up to the present, these observations have been continued for about one year. In spite of the approaching quiet sun year, the solar activity was unexpectedly high last autumn. So, some interesting data were obtained. This paper outlines the method of the observation and gives the results obtained in about eleven months.

2. Location of Observing Site

The survey of man-made noise for locating an observing site was carried out at several points in the Experimental Plantation of Hokkaido University. And it was found that most of the noise giving interfering disturbance was due to cross talks from the wired broadcasting networks using the earth-return system directly effected the degree of interfering disturbance.

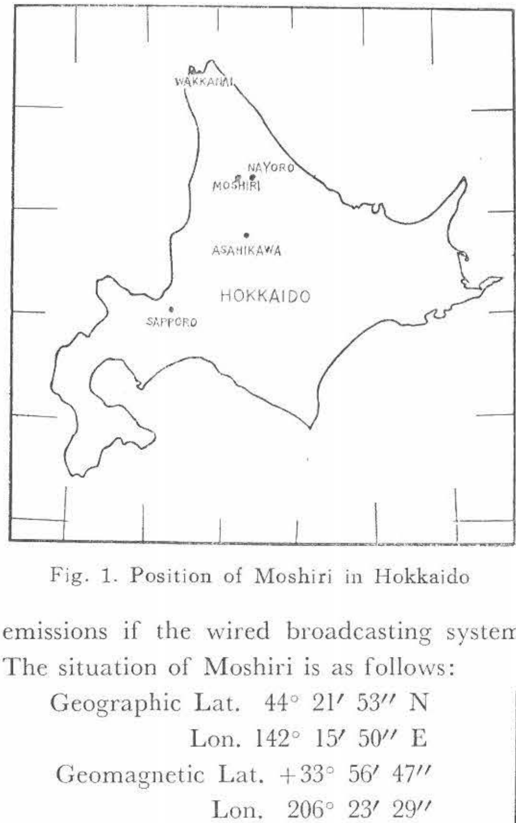

Fig. 1. Position of Moshiri in Hokkaido

Therefore, a small village named Moshiri in the Experimental Plantation area and more than 20 km remote from the nearest town, was picked out and the measurement of interfering noise was made in this village. The noise level of Moshri showed the minimum value among the noises of other points, and the interference from the wired broadcasting was also minimum.

So, it was expected that Moshiri would be suitable for observing VLF emissions if the wired broadcasting system was improved and made non-interfering. The situation of Moshiri is as follows:

Geographic Lat. 44° 21′ 53″ N
Lon. 142° 15′ 50″ E
Geomagnetic Lat. +33° 56′ 47″
Lon. 206° 23′ 29″

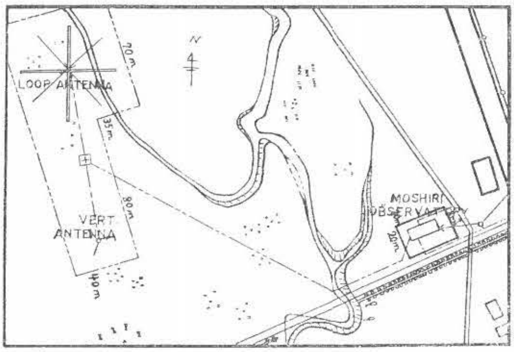

Fig. 2. Moshiri Observatory

3. Elimination of Interference from the Wired Broadcasting

In Hokkaido the earth-return system is used in the wired broadcasting. Therefore, interference for the observing apparatus is very violent for the reason that same operating frequency range is used for both. To investigate a method to eliminate this interference, various kinds of tests were made by the test line of 1 km long constructed in our institute. As a result, the interference vanished when the parallel two-wire-system of NSD cable was used. In this method the steel wire contained in NSD cable was earthed and the two conducting wires were earthed through the hum balancer bridging both wires. Therefore, the wired broadcasting system of this village expanding for 20 km was changed to this two-wire system using NSD cable. By this new system, the observation of VLF emissions free from interfering disturbances by cross talks from wired broadcasting was made possible.

4. Observing Technique

The antenna system consisting of a pair of crossed loops and a vertical, is employed to measure the intensity, arrival direction and polarization of whistlers and VLF emissions. The crossed loop antenna pair used is of the triangle type of two turns of 5 m/m copper weld steel wire and its dimension measures 43 meters in height and 60 meters at the base. The vertical antenna is a pipe of 15 meters long. To reduce the interfering disturbances, the antenna and the pre-amplifiers are installed about 250 meters away from the main apparatus. The signal received by the antenna is stepped up by the input transformer, amplified by a cascode amplifier, transformed into a low impedance by a cathode follower circuit and introduced to the main apparatus

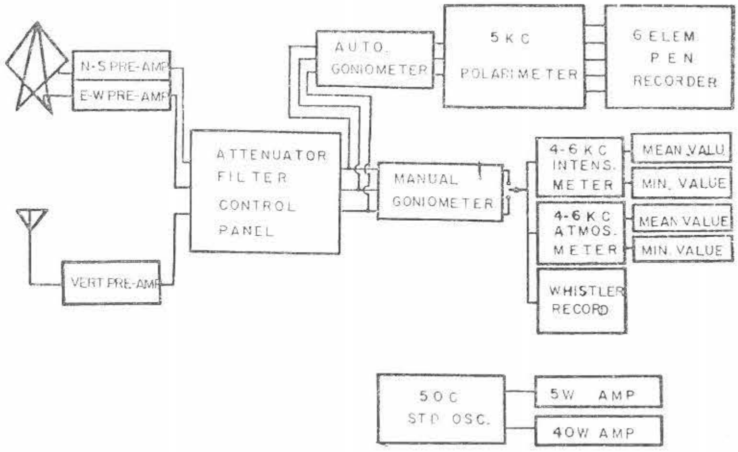

Fig. 3. Block-diagram of Apparatus of VLF Emissions

by a twin-ax cable of 300 meters long through a junction box. The signal from the pre-amplifier is supplied to an attenuator of 30 db, operated automatically by the over-scale incoming signal, and then through band elimination filters for VLF communication waves supplied to the next apparatus. Three outputs from the antenna system of a pair of loops and a vertical, are amplified separately by the same three amplifiers as mentioned above. A goniometer of dual sine-cosine potentio-meter is inserted between the channels of the crossed loops to rotate manually the directivity of the crossed loop antenna system, and the output from the goniometer is supplied to the intensity meter of VLF emissions. The routine observation is usually made by selecting the minimum azimuth of interfering noises. The receiving frequency range of this intensity meter is 4 to 6 kc/s. The output of the intensity meter is rectified to d−c and is averaged for 1 milli-second and then fed to a resistance-capacitance circuit with a charging time constant of 1 minute and a discharging time constant of 2 milli-second.

The d−c output is recorded on chart paper moving at 5 cm/hour.

The sensitivity of the intensity meter for the signal equal to the noise is 0.002 microvolt $(\text{meter})^{-1} \cdot (\text{c/s})^{-1/2}$. The total gain from the input of the pre-amplifier to the output of the intensity meter is 160 db at the maximum, but is usually 120-130 db at operations. Therefore, the full scale of the chart is equal to 0.05-0.015 microvolt $(\text{meter})^{-1} \cdot (\text{c/s})^{-1/2}$.

On the one hand, another goniometer rotating automatically with a period of 30 minutes is inserted in the same position as the former goniometer. The outputs of two channels from the latter goniometer are supplied to phase shifting circuits, in which the signals are led or lagged at right angle and added to the original signals. Then, the incoming signals are divided into the right-handed polarized wave and the left-handed polarized wave. These five signals — two channel outputs from the latter goniometer, vertical antenna output, right-handed and left-handed polarized waves — are supplied separately to five channels of narrow band amplifiers. These outputs are detected, averaged and recorded in the same manner as the intensity meter. The receiving frequency is 5 kc/s and the band-width 80 c/s. The sensitivity for the signal equal to the set noise is of the same value as of the intensity meter. The total gain of this polari-meter is designed 20 db high compared with the intensity meter, for the reason of the narrow band width. But, the full scale of the chart is of the same value in both.

5. Observational Results.

Observational results of intensity variation in VLF emissions at 4—6 kc/s at Moshiri during the period from January to November 1963, are briefly reported here. But the period between May 10 to May 31 are excluded, because the equipment was being re-adjusted then.

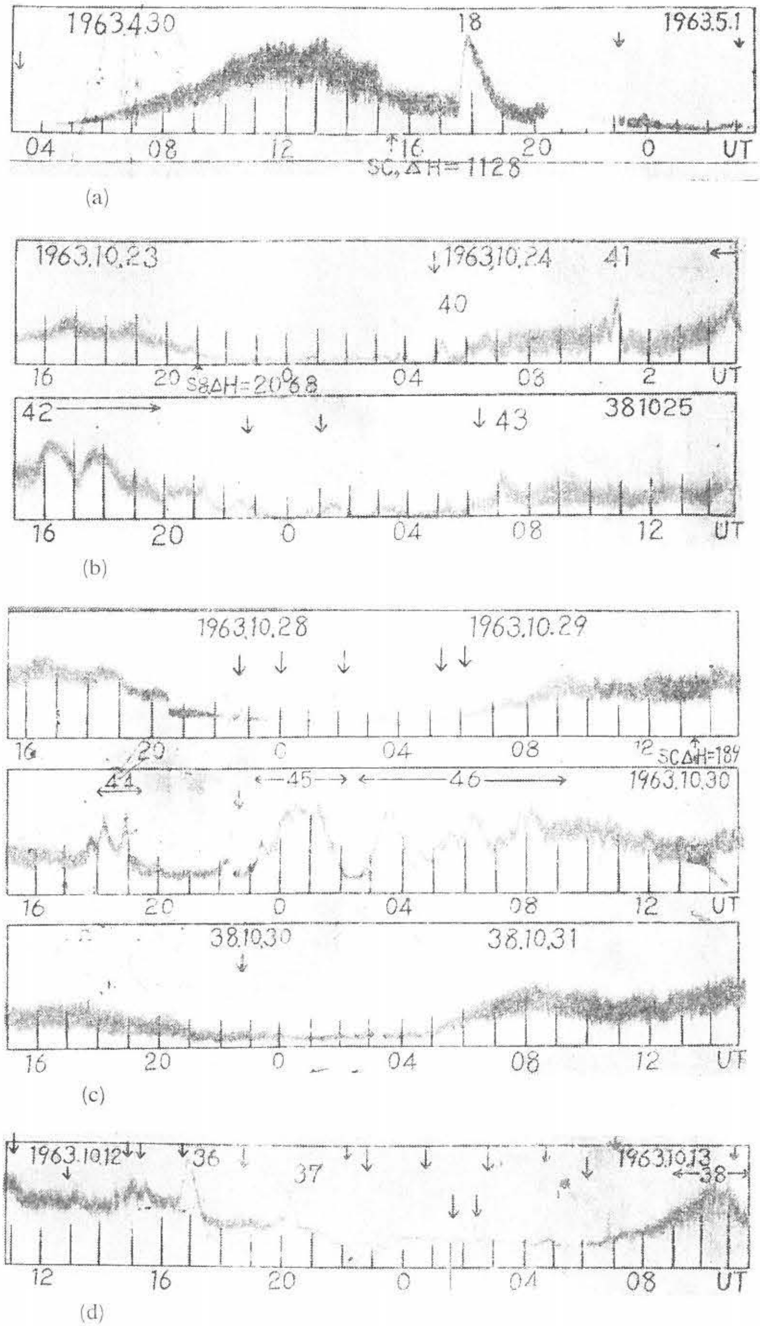

Fig. 4. Recordings of noise bursts

(a) to (c): associated with geomagnetic storm

(d): not associated with magnetic storm

↑ : indicate commencement of magnetic storm

↓ : indicate jammings of radio waves from VLF stations

Table 1 Noise burst Jan.—Nov., 1963 (except 10–31 May)

Date U. T.	Starting time U. T.	Duration	Peak: Flux density $W.m^{-2}(c/s)^{-1}$	Peak: Time U. T.	Sample No.
1963					
Jan. 2	16^h 30^m	2^h 00^m		~17^h 00 17 50	1
7	16 40	1 20		17 20	2
11	18 40	1 20		18 50	3
15 *	11 10	2 50		13 05	4
17	16 00	1 45		17 15	5
18	01 00	3 30		03 40	6
18	23 30	2 15		01 20	7
22	20 15	1 00		20 30	8
24	—	—		21 55	9
30 *	16 00	5 45		16 30	10
31 *	16 50	0 40		17 00	11
Feb. 10 *	10 20	2 10		10 45 12 15	12
12	10 45	1 15		11 30	13
13	09 30	9 30		~10 30 11 30	14
27	07 00	1 10		07 40	15
Apr. 15	03 15	1 45		04 50	16
17	17 45	2 45		18 30	17
30 *	17 40	1 50		17 55	18
May 1 *	16 00	1 00		16 20	19
4	02 30	1 30		03 25	20
Aug. 4	11 00	1 25		11 40	21
19 *	07 30	1 30		08 05 08 35	22
19 *	10 00	2 00		10 20	23
20 *	09 00	4 30		10 40	24
Sep. 5	08 30	1 50		09 50	25
9	08 10	4 35		10 50 12 00	26
16 *	13 20	0 40		13 25	27
17 *	14 40	0 50		15 00	28
18	09 00	1 30		09 35	29
21 *	20 50	0 40		21 05	30
22 *	08 30	11 40	$3.2 \cdot 10^{-19}$	18 30	31
23 *	03 45	6 45	$4.8 \cdot 10^{-19}$	~08 40 09 05	32
25 *	03 00	1 00	$4.4 \cdot 10^{-20}$	~03 20 03 35	33
25 *	08 00	1 00	$6.1 \cdot 10^{-20}$	08 30	34
25 *	14 20	2 20	$1.3 \cdot 10^{-19}$	16 05	35
Oct. 12	17 05	55	$4.9 \cdot 10^{-18}$	17 20	36
12	20 15	45	$2.7 \cdot 10^{-18}$	20 50	37
13	09 00	3 20	$3.8 \cdot 10^{-18}$	10 25	38
15	20 00	25	$1.4 \cdot 10^{-18}$	20 15	39
24 *	05 00	30	$1.3 \cdot 10^{-18}$	05 20	40
24 *	10 30	30	$4.2 \cdot 10^{-18}$	10 55	41
24 *	14 00	5 50	$5.4 \cdot 10^{-18}$	16 40	42
25 *	07 00	1 00	$2.8 \cdot 10^{-18}$	07 15	43
29 *	17 50	1 30	$4.2 \cdot 10^{-18}$	18 35 19 15	44
29 *	23 15	3 00	$5.1 \cdot 10^{-18}$	00 40	45
30 *	02 45	9 15	$4.9 \cdot 10^{-18}$	03 55	46
Nov. 4	17 00	6 00	$5.4 \cdot 10^{-18}$	20 25	47
7 *	18 55	20	$5.1 \cdot 10^{-18}$	19 05	48
9 *	19 00	45	$5.1 \cdot 10^{-18}$	19 15	49
22	18 00	45	$5.0 \cdot 10^{-18}$	18 30	50
24	21 20	1 15	$3.4 \cdot 10^{-18}$	22 05	51
30	12 10	30	$2.8 \cdot 10^{-18}$	12 20	52

* : Geomagnetic storm

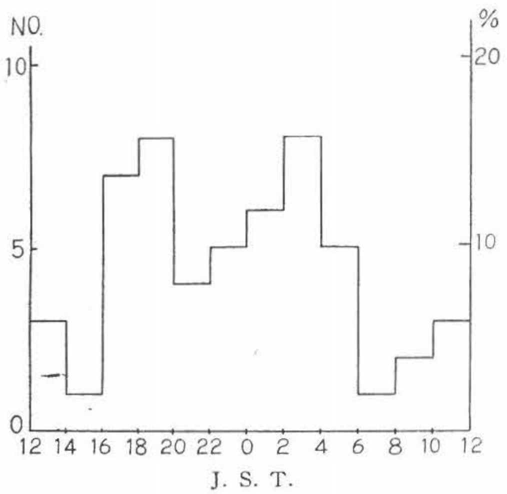

Fig. 5. Diurnal variation of noise burst

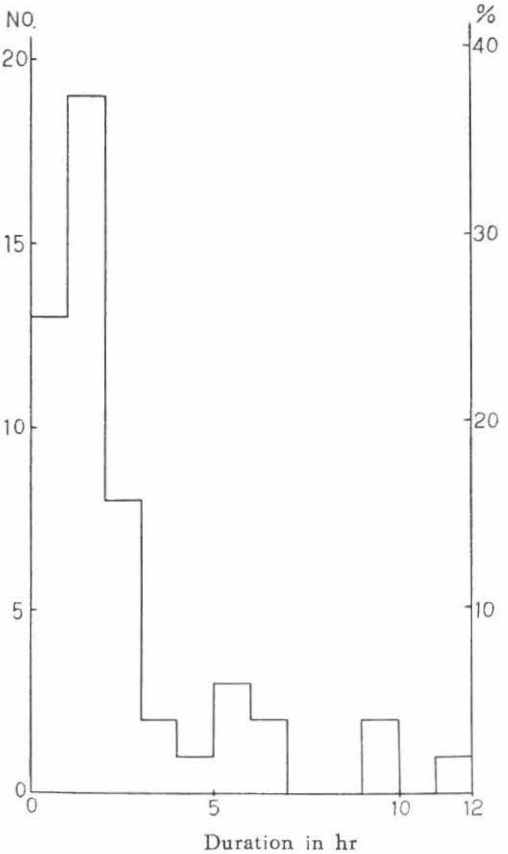

Fig. 6. Occurrence distribution of noise burst with duration time

As at higher latitudes, at Moshiri very sharp and clear VLF emissions of burst type (hereafter they are called noise burst) were frequently detected during geomagnetic storms.

Some examples of noise burst are shown in Figs. 4(a) to 4(d). Recordings of Figs. 4(a) to 4(c) were obtained during magnetic storms and that of Fig. 4(d) was obtained when no magnetic storm occurred. In these Figures the starting time of a magnetic storm is indicated with the mark ↑, and a serial sample number (see Table 1) is given to each noise burst. Jammings by VLF radio waves occurred very frequently, in spite of many efforts to eliminate them, and these are shown with the mark ↓ in the Figures. The abbreviation sc or sg by the side of the mark ↑ means that the magnetic storm commenced suddenly or gradually and ΔH indicates the maximum variation of horizontal component of geomagnetism during the storm.

Through the whole observation period 52 noise bursts were observed. They are listed in Table 1, in which occurrence date, starting time, duration time, peak time, peak flux density and the serial sample number are shown. But, for the noise burst earlier than September 22, the value of peak flux density is not given because the sensitivity of the receiver could not be known accurately. The mark * in the column of dates means that magnetic storms occurred on these days.

The diurnal variation of the starting time of all noise bursts is shown in Fig. 5. It can be seen that the occurrence of noise burst has two peaks, one between near sun-set and 20 JST, another between 02 and 04 JST and in the day

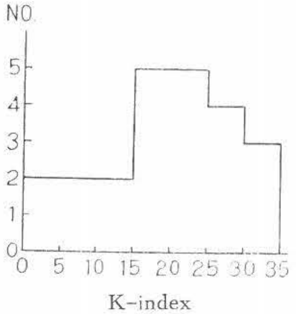

Fig. 7. Occurrence number of noise burst in each range of daily sum of K-index
Jan.—Aug., 1963 (except 10–31 May)

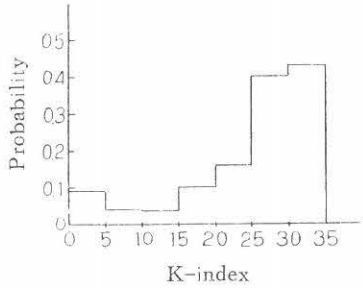

Fig. 8. Occurrence probability of noise burst in each range of daily sum of K-index
Jan.—Aug., 1963 (except 10–31 May)

time it decreases. Similar diurnal variations have been obtained for whistlers observed at Toyokawa and Wakkanai, so the diurnal variation of noise burst seems to be affected by propagation as whistlers are.

The duration time ranged from twenty minutes to eleven hours and forty minutes and the mean value is about two hours and twenty-six minutes. The relation between occurrence number and duration time of noise burst is shown in Fig. 6. This indicates that many of noise bursts ended within three hours and only few noise bursts continued over seven hours.

As far as measured, the peak flux density varied between $4.4 \cdot 10^{-20}$ and $5.4 \cdot 10^{-18} W \cdot m^{-2} . (c/s)^{-1}$ and in average $3.1 \cdot 10^{-18} W \cdot m^{-2} . (c/s)^{-1}$ is obtained. The percentage ratios between these peak values and those measured by G. R. A. Ellis at Camden (geomag. lat. 42°S) during from June to December, 1958 are about 7.3% and 9.0% for minimum and maximum values respectively.

The number of days when noise bursts occurred against each range of daily sum of three-hour range k-index is shown in Fig. 7. The examination period is between January and August and the data of k-index from Memambetsu Geomagnetic Observatory are used. It must be noted that 28.5% of the days on which noise bursts occurred was geomagnetically calm days when the daily sum of k-index did not exceed 15. The maximum number of days of noise burst can be seen in the range 15 to 25 of daily k-index. But, this does not mean that the occurrence probability of noise bursts is highest in such a range of k-index. Fig. 8 shows the rate of number of days when noise bursts occurred to the total number of days in each range of daily k-index. This result indicates that the occurrence probability of noise burst increases as the magnitude of daily k-index increases. But, at present, as the upper value of daily k-index is limited within 34, it is not clear whether the occurrence probability increases over this limit of daily k-index or not.

Results examined on relations between the occurrence of noise bursts and the pt

Table 2 Occurrence correlation between noise burst and Pt and magnetic storm

	Total No. of day or time	No. of day or time associated with noise burst	% (e)/(a)	64%
Noise burst	44 days (a)	——	(f)/(a)	45%
Pt	138 days (b)	28 days (e)	(e)/(b)	20%
Mag. storm	19 times (c)	20 days (f) 13 times (g)	(g)/(c)	68%
Mag. storm $\Delta H > 100\gamma$	13 times (d)	12 times (h)	(h)/(d)	92%

type geomagnetic pulsation** and geomagnetic storm are indicated in Table 2. The examination period is from 1 Jan. to 29 Nov., 1963 and the data of pt are taken from preliminary catalogues of disturbances compiled in Japan and the data of geomagnetic storm are taken from Kakioka Geomagnetic Observatory for the period 1 Jan. to 31 Aug. and on and after 1 Sept. they are taken from the above disturbance catalogues. The percentage of the number of days (e) when both noise burst and pt were observed to the number of days (a) when noise bursts were detected is 64% and in the case of magnetic storm the percentage becomes 45%. From these results, it appears that the correlation of noise burst is closer to pt than to magnetic storm. But, this is not true. This comes from the fact that the number of days (b) on which pt occurred was far more numerous compared with the case of magnetic storm (f). Thus, the percentage of (e) to (b) decreases to 20%, while the percentage of occurrence number of magnetic storm (g) during which a noise burst or bursts occurred to the total number of magnetic storm (c) rises to 68% and when magnetic storms are confined to larger ones, ΔH of which was not less than 100γ, the percentage further increases up to 92%. It can be seen from this result that the correlation between the occurrence of noise bursts and magnetic storm is very high and that the occurrence probability of noise burst seems to increase as the magnetic storm becomes more intense. This agrees with what have been obtained in the previous result in which the daily k-index was used.

All magnetic storms through the whole observing period are listed with noise bursts in Table 3. The starting time of magnetic storms occurred since 1 Oct., 1963 is taken from the Alerts of URSI GRAM when available. A series of noise bursts was frequently observed during a single magnetic storm. Noise bursts of Nos. 40, 41, 42 and 43 in Fig. 4 (b) and Nos. 44, 45 and 46 in Fig. 4 (c) are such examples. A series of noise bursts during a single magnetic storm can be regarded as a noise storm. The duration of noise storms varied from two hours and ten minutes to forty-eight hours and fifty minutes and the average value is twenty-four hours and forty-three minutes. The delay time of noise storms from the commencement of a magnetic storm is two hours and twenty minutes and sixty-eight hours for minimum and maximum cases,

** A new classification of geomagnetic pulsations was decided on at the Assembly of IAGA held at Berkley, 1963. The terminology pt was limited to a special type of pulsation, pi 2 then.

Table 3 List of geomagnetic storm and noise storm, 1 Jan.—29 Nov., 1963

Magnetic storm					Noise storm				
Starting time	Ending time	Duration	Type*	ΔH (γ)	Starting time	Duration	No. of burst	Time delay from sc or sg	Maximum peak flux density $Wm^{-2}(c/s)^{-1}$
Jan. 12^d 15^h 2^m	15^d 23^h 0^m	3^d 7^h 58^m	s g	102	Jan. 15^d 11^h 10^m	2^h 50^m	1	68^h	
29 11 3	31 24 0	2 12 57	s g	131	30 16	25 30	2	19	
Feb. 9 22 31	11 23	2 1	s c	108	Feb. 10 10 26	2 10	1	11 50^m	
Apr. 4 05 46	7 19	3 13	s c	84					
19 03 17	20 18	1 15	s c	44					
30 15 22	May 2 21	2 6	s c	112	Apr. 30 17 40	23 20	2	2 20	
June 6 16 0	7 24 0	1 8 0	s g	117					
Aug. 19	21		s g	129	Aug. 19 07 30	30	3		
Sept. 14 }	16		s c	130 }	Sept. 16 13 20	45 10	2		
16 }	17		s c	80 }					
19	19		s c	45					
21 }	22		s c	214 }	21 20 50	37 40	3		$4.8 \cdot 10^{-19}$
22 }	23		s g	255 }					
24	26		s g	112	25 03 30	13 10	3		$1.3 \cdot 10^{-19}$
27	29		s c	88					
Oct. 23 21	25		s g	206	Oct. 24 05	27	4		$5.4 \cdot 10^{-18}$
29 13 24	31		s c	189	29 17 50	18 10	3	8	$5.1 \cdot 10^{-18}$
Nov. 5	10		s g	102	Nov. 7 18 55	48 50	2	4 25	$5.1 \cdot 10^{-18}$
17	17		s c	76					

*s c : Sudden commencement type magnetic storm

s g : Gradual commencement type magnetic storm

ΔH : Maximum value of variation in horizontal component of geomagnetism respectively.

In the noise bursts associated with magnetic storms (group A noise burst) the average duration time and the average peak flux density become two hours and fourty-one minutes and $3.46 \cdot 10^{-18} W \cdot m^{-2} . (c/s)^{-1}$, respectively, while in those not associated with magnetic storms (group B noise burst) they become two hours and five minutes and $3.67 \cdot 10^{-18} W \cdot m^{-2} . (c/s)^{-1}$, respectively. The duration time of group A is 28.8% longer than that of group B. The difference of duration time between the two groups is not so great as might be expected from the effects of magnetic storms. On the other hand, the result on peak flux density is quite contrary to the expectation that the peak flux density should be greater for group A than for group B. This result seems to mean that the peak flux density does not depend directly on geomagnetic activity.

As for flux density of noise burst, effects of atmospherics seem to be not neglegible, so in order to investigate more exactly the problems involving flux density of noise burst, it is necessary to find some devices to measure net flux density. But, this seems difficult and remains as a future problem.

The geomagnetic data used here are not sufficient for examining one-to-one relation between noise bursts and geomagnetic phenomena, especially for pulsations.

6. Conclusions.

After the preparations for two years, the routine observation was begun in January 1963. It has been proved that the observation of VLF emissions at a point lower than magnetic latitude 40° is possible under the condition free from interfering noises.

The results obtained in this study indicate that the correlation between occurrence rate of noise burst and geomagnetic activity, measured by k-index and magnetic storm, is very close, however, it does not seem so close with the pt type geomagnetic pulsation, while the peak flux density of noise burst does not appear to depend directly on geomagnetic activity.

In order to confirm these results it is clear that a more detailed investigation with a full data of geomagnetism is needed.

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8. References.

(1) Ellis, G. R. A.: J. Atmos. and Terrest. Phys. 10, 302–306, 1957.

(2) Ellis, G. R. A.: Planet. and Space Sci., 1, 4, 1959.

(3) Ellis, G. R. A.: J. G. R., 65, 3, 1960.