GEOMAGNETIC STORMS AND ASSOCIATED PHASE ANOMALIES OF A VLF RADIO WAVE AT MIDLATITUDES

Tadayoshi Hara and Koji Horiai

International Latitude Observatory of Mizusawa, Japan

ABSTRACT

Sudden phase anomalies (SPA's) were investigated by data obtained from the reception of NLK during 25 months from August 1970 to December 1973 with the point of view of associating SPA's with geomagnetic storms. We will express the amount of SPA by a phase deviation with respect to a monthly mean value and use the horizontal component of geomagnetism observed at Memanbetsu (Japan) together with the Ap-index published regularly in the J. Geophys. Res. as an index of intensity of a geomagnetic storm. The results obtained for nocturnal periods at midlatitudes are:

a) Phase of the NLK wave is advanced by 10 μs in the case of moderately large storms (i.e. around 70 γ).

b) Phase change occurs 2 hours later than the main phase of a geomagnetic storm and continues for about 2 days, but a weak effect continues for about 5 days.

SPA's are observed at noon when the solar zenith angle is about 70° and observed also during extremly large storm periods even with a solar zenith angle of 30°.

INTRODUCTION

Precise time comparisons are attained with a stability of the order of 0.1 microseconds by using the Loran-C system within the ground wave region. But this area is limited to the restricted region of the northern hemisphere. The VLF navigation system and especially Omega is effective for global frequency calibration or for navigation purposes. But VLF signals which are received during nocturnal periods show frequent phase fluctuations by as much as 8 microseconds and those fluctuations correspond to a position error of more than one nautical mile. VLF signals which propagate for a long distance are explained by the wave guide mode theory [1], and the reflection height in daytime may be arouned 70 km (electron density may be 300 cm^{-3}) [2]. A reflection height of 85 km at night can be assumed from the reflection height in daytime and by amounts of diurnal phase variations. This height corresponds to the upper D-region. Electron density in the D-region is strongly disturbed by the radiation of electromagnetic waves and high energy particles from the Sun. In daytime, electron density increase is caused by sudden enhancement of X-ray fluxes whose wave length is less than 8 Angstroms during the solar flare periods. In night time, the flux of Lyman-α which is the main ionization source in the D-region extremly decreases, then the ionization by precipitations of high energy particles is effective. The marked ionization by high energy particles is observed in the polar cap region. Also in the midlatitude region, the possibility of ionization by precipitations of high energy particles has been discussed in association with geomagnetic storms. But there is no association between this phenomena and Polar Cap Absorption (PCA) events. About half of the propagation path (7300 km) from the NLK transmitter (Jim Creek, Washington, USA, geographic coordinates, 121°35'W, 48°05'N, geomagnetic latitude 54°N) to Mizusawa (geographic coordinates, 141°08'E, 39°08'N, geomagnetic latitude 29°N) goes near the polar cap region and SPA's (Sudden Phase Anomalies) are often observed during geomagnetic storms. The association of the SPA's of the NLK (18.6 KHz) radio signal at Mizusawa with geomagnetic storms is examined in this report.

SPA'S DURING NOCTURNAL PERIODS

Cesium frequency standards are equipped at both receiving site and transmitting site but slight frequency differences were observed and a constant frequency off-set was removed by using the daytime data. Twenty four month's data were obtained during the periods of August 1970 to July 1971, September 1971 to October 1971, April 1972 to October 1972, and August 1973 to December 1973. We will express the amount of SPA by deviation of phase with respect to a monthly mean value and will exclude strongly disturbed days. A negative sign means the phase of the received signal is advanced. Phase data were taken with a Tracor Model 599E VLF Tracking Receiver every 15 minutes to a resolution of 0.1 microseconds but there could be an instrument error of 0.5 microseconds. Standard deviations of a single observation are ±0.5 microseconds for the best condition (i.e. in the daytime in summer) and are ±8 microseconds in the night time. Calibrations of the receiving system are made monthly by suppling a synthesized signal to the loop antenna. Data of geomagnetism at the Memanbetsu Magnetic Observatory, Japan were used. Associations of SPA's with geomagnetic disturbances were examined when disturbances of the horizontal component were greater than 100 gammas. Belrose and Thomas [3] called the SID (Sudden Ionospheric Disturbance) which accompanied the main phase of geomagnetic storm, the 'primary storm effect' and the one which begins three or four days after the onset of storms and continues for several days, the 'storm after-effect'.

We designate the SPA which occurs immediately after the main phase, the PSE and the one which occurs after the PSE, the SAE. Correspondences of geomagnetic storms and associated PSE's and SAE's were sumerized in three groups as follows.

Table I - a)

Geomagnetic Storms at Memanbetsu, Japan, and Associated Phase Disturbances of NLK Signal Received at Mizusawa, Japan. 'Primary Storm Effect' was Observed in these SPA's.

Date of onset of SPA's			Time of ssc		Deviation of H-component	Duration of 'storm after effect'
Year	Month	Day	Day	Hour(U.T.)	(γ)	(day)
1970	8	17	16	2204	280	2
	11	7	7	0046	149	1
	11	21	21	0622	132	2
	12	14	14	0154	284	4
1971	1	27	27	0430	117	5 - 8
1972	4	28	27	13.3	132	3
	8	9	9	0037	241	4
1973	10	29	28	7.5	187	3

Table I - b)

'Storm After Effect' was observed but 'Primary Storm Effect' was not observed in these SPA's.

Time of ssc				Deviation of H-component	'Primary storm effect'	Duration of 'storm after effect'
Year	Month	Day	Hour (U.T.)	(γ)		(day)
1970	10	16	0917	138	?	5
1971	4	9	0428	174	?	2
	4	14	1243	184	Day time	4
	5	6	2.0	101	?	3
	9	17	1125	108	Day time	2
1972	6	17	0628	290	Day time	1
	8	4	0119	520	Day time	4
1973	9	22	3.0	162	?	2 - 4
	10	2	4.3	119	?	1 - 3

Table I - c)

Neither 'Primary Storm Effect' nor
'Storm After Effect' was observed
for these Magnetic Storms.

Time of ssc				Deviation of H-component	'Primary storm effect'	'Storm after effect'
Year	Month	Day	Hour (U.T.)	(γ)		
1970	11	18	1225	141	Day time	?
1971	4	3	2139	102	?	No
	5	17	0629	112	?	?
	9	24	1430	119	?	?
1972	5	15	1849	187	No	No
1973	10	16	0520	101	?	?
	11	24	10.7	109	No	?

a) The case of the PSE's and SAE's which are detected in the NLK signal at Mizusawa is tabulated in Table I - a).

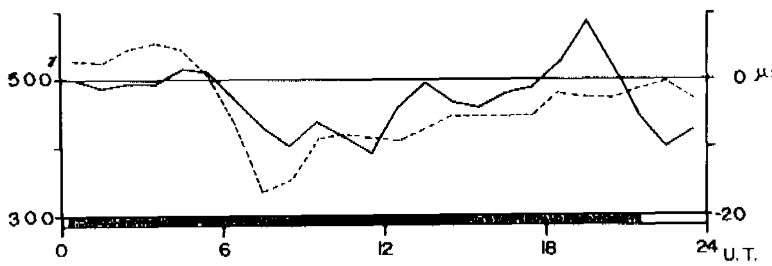

Fig. 1-The solid line shows an anomalous phase change of NLK at Mizusawa on 14 December, 1970. The dotted line shows hourly mean value of the geomagnetic horizontal component. All the propagation path is day time for 22h to 0h U.T. and night time for 10h to 15h U.T.. The remaining periods contain the transition region.

These eight storms are moderately large and bay like patterns are easy to distinguish such as the example shown in Fig. 1. Correspondences of decrease of the horizontal component in advance of the received signal can be clearly seen from Fig. 1. An averaged correspondence is depicted in Fig. 2 for storms of 17 August, 7 November, 21 November, and 14 December, 1970 which are similar in bay like patterns. In this case epochs of each storm were fixed to coincide in the main phase.

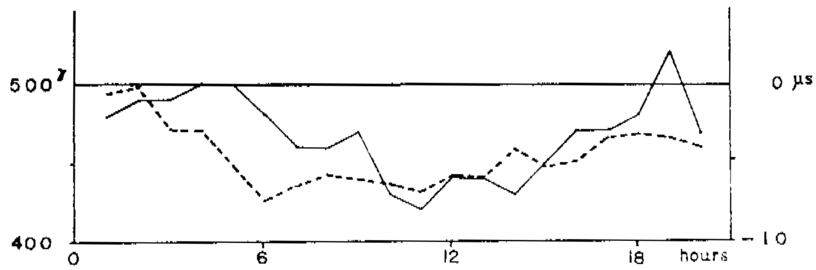

Fig. 2-The dotted line shows the geomagnetic horizontal component averaged for four events in 1970. The solid line shows the corresponding phase change of the NLK signal at Mizusawa.

The feature of PSE of VLF radio waves which propagate in the midlatitude in night time shows us that the phase of VLF signal advances after two hours of a main phase of a storm by the amount of 8 microseconds for a decrease of 70 gammas of the hourly mean horizontal component. An example of SAE is shown in Fig. 3 for the storm of 14 December, 1970.

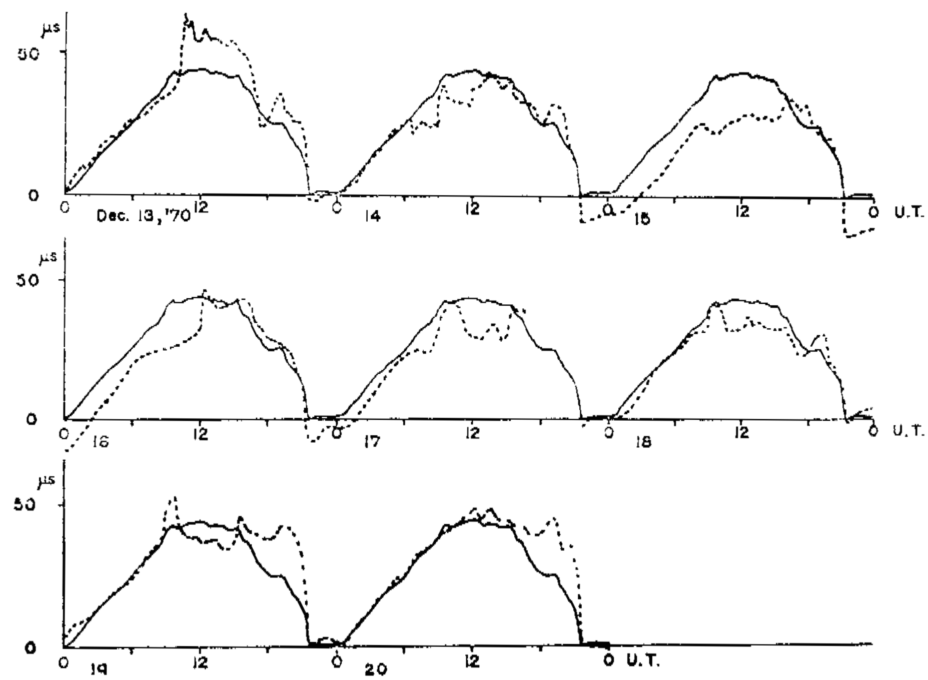

Fig. 3-The solid line shows monthly mean value of the diurnal phase change. The dotted line shows day-to-day phase variation associated with the geomagnetic storm of 14 December, 1970 (main phase is around 6h U.T.). A large phase advance continued for two days and the small effect continued for four days.

The sudden commencement of the magnetic storm (ssc) was at 0154 U.T. on 14 December, 1970 and 4 hours later a main phase began and SAE occured on 15 and 16 December which was greater than PSE. To see how long the SAE persists, the superposed Ap-index and SPA's are shown together in Fig. 4 for the same storms as shown in Fig. 2. It has been said that SAE persists for 10 days or more for large storms [3], but it may be said that a large effect continues for 2 days and a small effect for 5 days in our case.

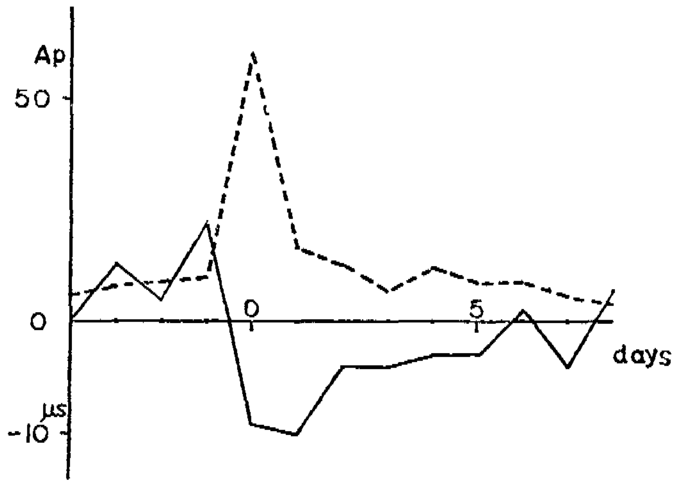

Fig. 4-The solid line shows the day-to-day variations in the mean phase of NLK at Mizusawa and corresponding mean geomagnetic disturbances are represented by the Ap-index (dotted line).

b) SAE's are detected but PSE's are not observed in these cases, which are tabulated in Table I - b). In this table the 9 examples are included as SPA's which can not be distinguished from abnormal ionizations aroused by an X-ray burst. Examples shown are cases of no SPA effect, because the geomagnetic disturbances occured in day time and cases in which we can not say that storms caused obvious SPA's even in nighttime. Berlose and Thomas summarize the subject of the SAE by noting that the greatest increases in ionization occurs 2 - 4 days after the time of maximum magnetic disturbance [3]. In our case, it may be said from Figs. 3 and 4 that the time lag of the SAE is one day.

c) In table I - c) 7 storms are shown which do not cause either PSE or SAE. These storms were not so large except for the one which occured on 15 May 1972.

SPA'S IN DAYTIME

It may be said that the anomalous ionization changes in the D-region associated with geomagnetic storms are not significant in daytime. And storm after effect has been observed only in the m.f. absorption data in daytime. On our NLK - Mizusawa propagation path, SPA's were observed 3 times in daytime. Two SPA's were detected on 14 December and on 21 November in the winter of 1970 where solar zenith angles were between 60° and near 80° and they were pretty large even at noon. An example of anomalous phase advance can be seen in Fig. 3, where daytime mean phase advances were 13 μs and 4 μs for storms of 14 December and 21 November, 1970 respectively. Another SPA was observed on 4 August, 1972 when the solar zenith angle was small but this storm was exceptionally large and caused a phase advance of 8 μs averaged during the daytime period from 1930 U.T. to 0300 U.T.. An X-ray burst was observed on 4 August by the SOLARD10-Explorer44 but the X-ray flux of 1 to 8 Angstroms calmed down by 1800 U.T. of the same day. So the SPA may not include ionization by X-ray radiation.

DISCUSSION

Using l.f. absorption Lauter and Knuth investigated the storm after-effect which is the main feature of the D region at midlatitudes [4]. They made clear that the storm after-effect is observed mainly after storms with Ap>60. In our case, however, the storm after-effect was observed after storms with Ap>30. This fact might be due to the unusual propagation path which follows the precipitation region for about 3000 km and also might be due to the method of phase comparison which is sensitive to ionization changes.

In accordance with the position of the radiation belt over Europe, Lauter and Knuth found that there is a strong decrease in number and intensity of absorption effects with latitude south of 53°N. The storm after-effect might be aroused in the region of geomagnetic latitudes of 55°N in which the NLK - Mizusawa circuit is parallel to the geomagnetic L shell 3 at 100 km altitude. It may be made clear, however, which region affects the SPA by comparing cases where the region in question is either in day time or night time when the main phase of a storm begins.

CONCLUSIONS

Correlations between disturbances of the D-region and geomagnetic storms were examined by the phase data of VLF radio signals which propagate in midlatitude. SPA's were aroused in nighttime by 70% of geomagnetic storms whose disturbances had a horizontal component greater than 100 gammas. SID's caused by X-ray burst persist for a relatively short time and these SPA's are easy to identify but SPA's associated with geomagnetic storms continue for long periods and great care must be taken when using these signals for navigation and frequency comparison purposes. During the moderately large storm of 21 April,1970 a direct measurement of precipitation fluxes was made and showed that this ionization is in competition with the total of all other daytime ionization sources for the midlatitude D-region [5]. It may be expected that extremly large storms will then cause an anomalous phase advance even in the daytime. Actually, in the storm of 4 August, 1972, an 8 μs phase advance was observed. In winter the solar zenith angle has the large value of 70° even in daytime for the NLK - Mizusawa circuit, and SPA's were observed as a SAE in moderately large storm periods. The cause of differnces between predicted and measured diurnal phase was mentioned above and this discrepancy amounts to about 10 microseconds. In addition to SPA's associated with geomagnetic storms, anomalous phase retardations were observed chiefly in September and October and might be due to local disturbances of propagation [6]. These retardations are cancelled out by storms and they then advance and become stable in advanced phase.

ACKNOWLEDGEMENTS

The authers wish to express their hearty thanks to Prof. H. Oya, because this investigation was made according to his suggestion and was evaluated with his advice. We are indebted also to Mr. B. McCune who read through this manuseript and improved some expressions.

REFERENCES

[1] WAIT, J. R. : Electromagnetic Waves in Stratified Media. Pergamon Press, (1962).

[2] NICOLET, M. and AIKIN, A. C. : The Formation of the D Region of the Ionosphere. J. Geophys. Res. 65, 5, (1960), 1469-1483.

[3] BELROSE, J. S. and THOMAS, L. : Ionization changes in the middle latitude D-region associated with geomagnetic storms. J. Atmosph. Terr. Phys., 30, (1968), 1397-1413.

[4] LAUTER, E. A. and KNUTH, R. : Precipitation of high energy particles into the upper atmosphere at medium latitudes after magnetic storms. J. Atmosph. Terr. Phys., 29, (1967), 411-417.

[5] GOUGH, M. P. AND COLLIN, H. L. : Energetic electron precipitation as a source of ionization in the night-time D-region over the midlatitude rocket range, South Uist. J. Atmosph. Terr. Phys., 35, (1973), 835-850.

[6] BATES, H. F. and ALBEE, P. R. : General VLF Phase Variations Observed at College, Alaska. J. Geophys. Res., 70 (1965), 2187-2211.

QUESTION AND ANSWER PERIOD

PAPER NOT PRESENTED ORALLY, THEREFORE, NO QUESTIONS AND ANSWERS.