

Precursors of earthquakes in the line-of-sight propagation on VHF band

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Abstract. This paper was intended to find out any relation between anomalous line-of-sight propagations on VHF band and occurrences of earthquakes near the VHF propagation path. The TV broadcasting waves on the VHF band were measured continuously for 504 days, in which we assembled an automatic measurement system. The waves propagated on the line-of-sight from Tokyo Tower to Gunma Univ. in Kiryu were measured on VHF band. In order to distinguish anomalous propagation data from normal data, a statistical process is adopted in such a way that six times deviation from the mean value was adopted as a criterion for distinguishing between the anomalous or normal propagation data. In a time interval between the appearance of anomalous propagation and the occurrence of earthquake was shorter than 48 hours (2 days), the anomalous propagation was additionally recognized as being associated with the earthquake. During the observation period of 504 days, only four anomalous propagations happened and we observed three earthquakes associated with these anomalous propagations. As a result, it is found that anomalous line-of-sight propagations on VHF band might be associated with the earthquakes near the VHF propagation path.

Key words: line-of-sight propagation, precursors of earthquakes, anomalous propagation, VHF band

1. Introduction

Short-time earthquake prediction is one of the most important research tasks for disaster prevention in a country with frequent earthquakes like Japan. There have been reported many geophysical electromagnetic phenomena associated with seismicity, and most reports can be classified into two groups; direct or indirect observations (Hayakawa, 2006). As one of the direct observations, low-frequency magnetic waves from earthquake hypocenter were measured for earthquake predictions (Fraser-Smith et al., 1990). The observations indicate that the background noise had been increased a few weeks prior to

the corresponding earthquake (Hayakawa et al. 1996), and these ULF noises might be resulted from microfracturing progression in the lithosphere. As for indirect observations, abnormal propagation data in VLF or upper bands are suggested as a promising candidate for earthquake prediction, because any disturbance at the bottom of ionosphere causes anomalous propagation of the radio waves. Remarkable data have been reported on VLF Omega propagation signal from Tsushima Japan to Inubo Japan in January 1995 (Hayakawa et al., 1996). The phenomenon was the signal amplitude (and/or phase) variations around sunrise and sunset times and appeared a few days prior to the Kobe Japan earthquake which occurred on January 17, 1995. The anomalous propagation data can be explained in terms of fall of ionospheric bottom (Molchanov and Hayakawa, 1998).

In the meanwhile, some researchers observed FM broadcast stations on VHF band in Japan. They reported that anomalous propagations from over-horizon FM transmitter signals were observed, which seemed to be associated with earthquakes (Kushida and Kushida, 2002). They supposed that the VHF waves were abnormally scattered from the ionosphere, but other researchers inferred that the propagations were influenced by the perturbation in the troposphere. They considered that the perturbed region was within a radius of 100km from the epicenters of earthquakes (Yonaiguchi et al., 2007).

The purpose of this paper is to find out any relation between anomalous propagations on VHF band and occurrences of earthquakes near the VHF propagation path. Waves from broadcast stations on the VHF band had been measured continuously for 504 days. The target transmitting TV stations are placed at Tokyo Tower in Japan. A receiving point (as an observation point) has been set at Kiryu city, 92km northwest of Tokyo, so that the receiving point of Kiryu is located just at the border of the line-of-sight range. The line-of-sight propagation is easily affected by sunlight, winds and atmospheric conditions, especially conductivity near the land surface. On the VHF band, the broadcast waves can be continuously and normally received because the propagation type is mainly ground waves, not over-horizontal propagation. Obviously this is a point essentially different from the previous reports (Fujiwara et al., 2004; Fukumoto et al., 2002; Kushida and Kushida, 2002; Yonaiguchi et al., 2007).

2. Wide band measurement system

Our measurement system is required to capture continuously the strength of waves propagated on VHF TV band. For this purpose an automatic and continuous measurement system consists of multiple antennas, an antenna selector, a spectrum analyzer, a PC for data storage and a web server for open data. Multiple antennas mean that a loop antenna, a discone antenna, a long wire antenna or several Yagi-Uda

antennas are used for the measurement system. Any antenna appropriate for the sensitive reception is automatically selected at each measurement frequency. All antennas of the system are installed on a rooftop of five-story building in a campus of the faculty of Gunma University. The antenna selector has 12 input-ports from various antennas and one output-port connected to the spectrum analyzer, which is controlled by the control PC with data storage. The spectrum analyzer can cover a wide frequency range from 100kHz to 3GHz, so that it can acquire automatically about 50 waves lying in a wide frequency band from LF to UHF band.

A combination of these devices enables us to detect sensitively the wide band waves. The data storage PC can acquire all the measurement data, and also control the antenna selector and the spectrum analyzer. All data as the strength of received signals can be observed every two minutes. Moreover, those data captured by the system are uploaded from the data storage PC to the web server every 30 minutes. They can be always monitored on the Internet at all times (Motojima Lab. H.P.). Schematic diagram of the wide band measurement system is described in Fig.1.

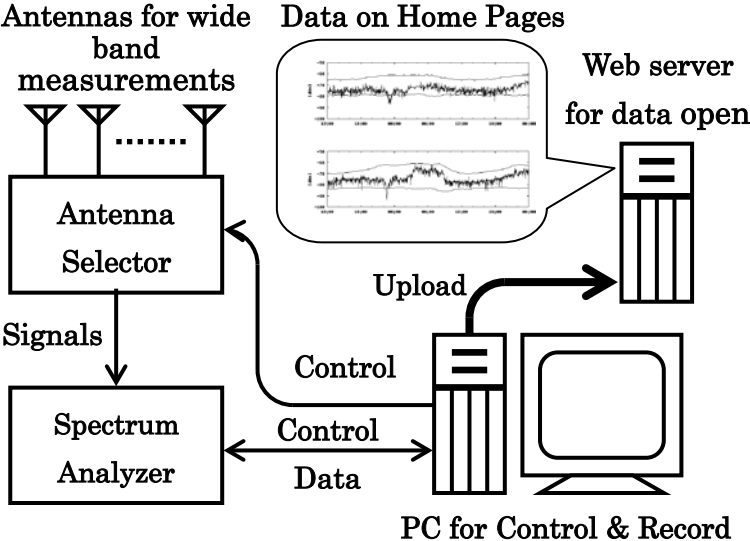


Fig. 1 Schematic diagram of the wide band measurement system.

Table 1 Observation waves.

Station (Analog)	FM Tokyo	NHK General	NHK Education	Nippon TV	TBS	Fuji TV	TV Asahi	TV Tokyo
Frequency in MHz	80.0	91.25	103.25	171.25	183.25	193.25	205.25	217.25

This paper reports definitively on the anomalous propagation on VHF TV-broadcast and FM radio band. Only two Yagi-Uda antennas are adopted for the measurement of VHF band; One is for FM radio wave, and the other for TV-broadcast waves. Both have 5 elements for horizontal polarization and are directed toward the Tokyo Tower. Target waves in this paper are eight waves, which are listed in Table 1.

An observation point is located at Kiryu city, which is 92km away from the Tokyo Tower. In the troposphere the refractive index is known to affect directly the line-of-sight propagation on VHF wave. In order to estimate the line-of-sight range, the following equation is adopted:

$$d = \sqrt{2kR} \left(\sqrt{h_{TX}} + \sqrt{h_{RX}} \right) \quad (1)$$

where d is the distance of line-of-sight from the transmitting point to the receiving point, kR is the effective Earth-radius, h_{TX} and h_{RX} are the height of transmitting and receiving antennas above sea level, respectively. If it is assumed that the transmitting antennas are attached to the Tokyo Tower at 333 meters above sea level ($h_{TX} = 333m$), the receiving antennas are set to 25 meters above ground ($h_{RX} = 25m$) and configuration of the ground is neglected, the distance of line-of-sight boundary d is estimated to be about 95km for the normal atmosphere. The normal atmosphere has the coefficient of effective Earth-radius, $k = 4/3$; and so the receiving point is located near at the boundary of line-of-sight for the normal atmosphere condition.

3. Statistical analysis and discrimination of anomalous data

Waves propagated from Tokyo to Kiryu exhibit short-time fluctuation and include random noise in the signal strength because of the fading due to the atmospheric condition. In order to eliminate these obstructive factors, running averaged values (twenty-minute window) are calculated. Moreover, the wave propagation even in the line-of-sight shows a diurnal variation on VHF band, since signals on the ordinary propagation become weaker in daytime than at night. The reason is that sunlight promotes the atmospheric convection, which decreases the difference in atmospheric refractive index between the surface and the upper air. In order to eliminate the influence of this diurnal variation, a statistical analysis is performed separately for each specific time slot in a day. A day is divided into 72 time slots, each one has twenty-minute period, for example, 0:00-0:20, 0:20-0:40, 0:40-1:00, and so on. Mean values and deviations of signal strength are separately calculated for each time slot through the observation

period.

In this paper we try to find out any relation between anomalous propagations and occurrences of earthquakes on the basis of a distinction between anomalous and normal propagations. In order to distinguish anomalous data from normal ones, a certain statistical process is adopted. Our criterion for this purpose is the standard deviation (σ) for the mean value, and an appropriate criterion is searched. In the statistical process, the deviation for the criterion is varied from 3σ to 6σ while comparing with the occurrences of earthquakes. If the propagation data follow a normal distribution, the probability of exceeding beyond 3σ from the mean value is about 0.27%. It was confirmed through the observation period that the reception data for each wave had the normal distribution approximately. This confirmation is made for each 72 time-slot individually. Besides, even if the nighttime data have the same deviation as daytime, the daytime data may be classified as anomalous but the nighttime data may not, because the nighttime deviation is larger than the daytime deviation. This is the reason why we adopt the criterion by using σ .

The propagating waves on VHF waves had been measured for 504 days from Feb. 1, 2007 to June 15, 2008. When anomalous data have appeared simultaneously on three or more waves among eight waves in Table 1, the anomalous data was recognized as an occurrence of anomalous propagation. In case when the time interval between the appearance of anomalous propagation and occurrence of earthquake was shorter than 48 hours (2 days), the anomalous propagation was regarded as being associated with the earthquake. Furthermore, thoughtful consideration was also given to magnitude and geographical location of each earthquake. As the results of consideration, when the magnitudes of earthquakes were less than M4.5, any relation between the appearance of anomalous propagation and occurrence of earthquake could be hardly found. Besides, when epicenters of earthquakes were farther than 75km from the propagation path from Tokyo Tower to Kiryu, we could not find any significant relation between the two. Therefore, it is assumed that some specific earthquakes could affect the propagation from Tokyo to Kiryu. Those specific earthquakes are such that they have the magnitude greater than M4.5, and their epicenters are located within 75km range from the propagation path. In Fig. 2 the region of the earthquakes' epicenters under the consideration, the transmitting point (Tokyo Tower), the receiving point (Gunma Univ. in Kiryu city), the path of the VHF wave propagation and the epicenters of some earthquakes mentioned later are shown.

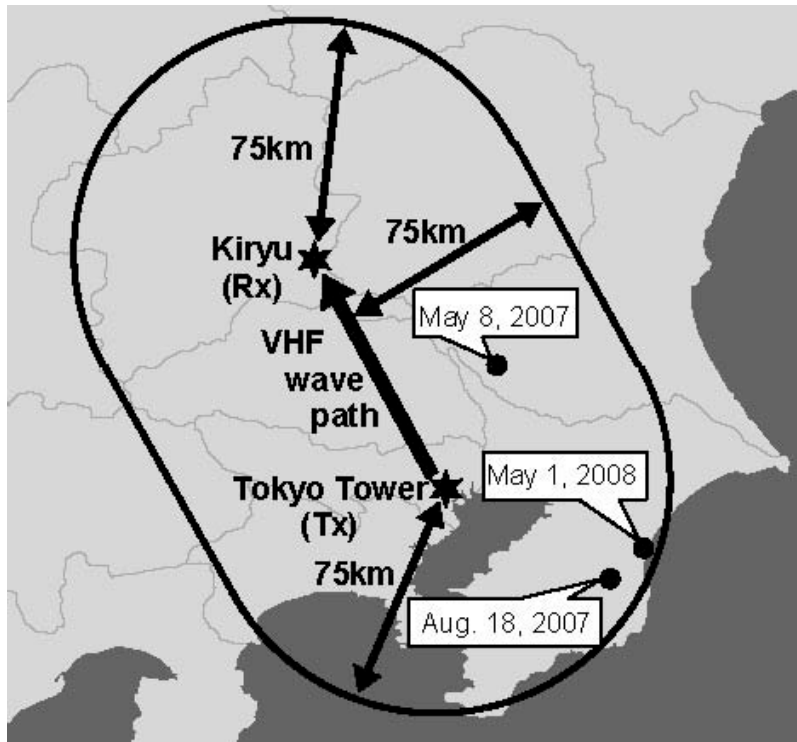


Fig. 2 Region of the earthquakes' epicenters under consideration. Solid circles mean the geographical locations of earthquakes' epicenters that are seemed to be associated with the anomalous propagations.

4. Observation results

The propagated waves had been measured for 504 days from Feb. 1, 2007 to June 15, 2008, and our observation system succeeded in detecting several anomalous propagations in the period. The number of anomalous data depends on the criterion in the statistical analysis. The data acquired are analyzed with varying the deviation from 3σ to 6σ as the criterion, and Table 2 shows the summary on the anomalous propagations associated with earthquakes and all the anomalous propagations, when the deviation as the criterion is varied from 3σ to 6σ .

Table 2 Anomalous propagations associated with earthquakes and all the anomalous propagations.

Criterion	Number of anomalous propagations associated earthquakes (A)	Number of anomalous propagations (B)	Percentage of A to B
3σ	11	181	6.1%
4σ	8	85	9.4%
5σ	6	19	31.6%
6σ	3	4	75.0%

If the deviation 3σ is used as the criterion, we observed 181 anomalous propagations and 11 earthquakes associated with these anomalous propagations. This seems to indicate very small relationship between the two. Table 2 shows that both frequencies of occurrences decrease with deviating the criterion from the mean value. When the 6σ criterion is adopted, only four anomalous propagations happened and we observed three earthquakes associated with anomalous propagations. The ratio of earthquake associated with anomalous propagations is four to three, which is a high probability. So, the highly anomalous propagation data beyond the deviation 6σ are likely to be an precursor of earthquakes.

Anomalous propagation data satisfying the deviation 6σ occurred four times on the following days: April 10, 2007; May 8, 2007; August 16, 2007; and May 1, 2008. The anomalous propagation data on April 10, 2007 were not found to be associated with any earthquake. The other anomalous propagation data were associated with earthquakes with magnitude M4.5 or stronger, whose epicenters were located near the propagation path. The geographical positions of the epicenters are indicated in Fig.2. In this paper two anomalous propagation data are shown in Figs. 3 and 4. Fig. 3 illustrates the anomalous data, which appeared on May 8, 2007. Maximum deviation was -8.95σ from the mean value on TV-Tokyo wave (217.25MHz) at 00:27 LT. About 20 hours later we had the associated earthquake at 21:01 LT, whose epicenter was at southern Ibaraki (geographic coordinates: $36^{\circ}03'N, 139^{\circ}53'E$). The magnitude of the earthquake was 4.5, and the depth of the hypocenter was 46km. The distance between the epicenter and propagation path was about 29km. Fig. 4 shows the anomalous data, which appeared on August 16, 2007. Maximum deviation was -8.08σ from the mean value on TBS wave (183.25MHz) at 21:18 LT. About 40 hours later we observed an earthquake happened at 13:36 LT on

August 18, whose epicenter was at central Chiba ($35^{\circ}21'N, 140^{\circ}21'E$). The magnitude of this earthquake was M4.5, and the hypocenter depth was 24km. The distance between the epicenter and propagation path was found to be about 65km.

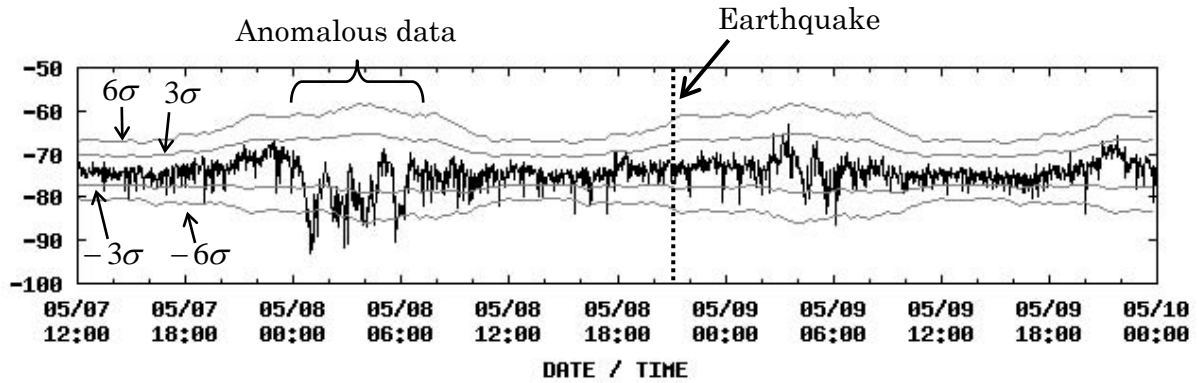


Fig. 3 Anomalous data of TV-Tokyo wave (217.25MHz) on May 7-9, 2007, which may be associated with an earthquake. Maximum deviation was -8.95σ from the mean value at 00:27 LT on May 8, 2007, and the relevant earthquake occurred at 21:01 on May 8, 2007 (dashed vertical line), whose epicenter was at southern Ibaraki ($36^{\circ}03'N, 139^{\circ}53'E$).

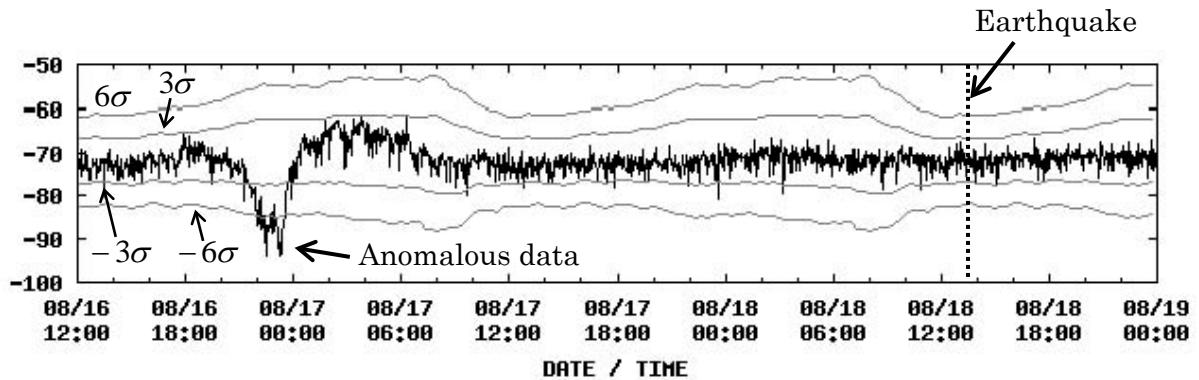


Fig. 4 Anomalous data of TBS wave (183.25MHz) on August 16-18, 2007, which may be associated with an earthquake. Maximum deviation data was -8.08σ from the mean value at 21:18 LT on August 16, 2007, and the corresponding earthquake occurred at 13:36 LT on August 18, 2007 (dashed line), whose epicenter was at central Chiba ($35^{\circ}21'N, 140^{\circ}21'E$).

All of above anomalous data were observed at night, because the signal strength of propagated waves in daytime becomes weaker than in the nighttime. The observation system can hardly capture anomalous data in daytime. In order to make sure of the above relation between the anomalous propagations and earthquakes, the observation should be continued extensively for long time.

5. Conclusions

In this paper line-of-sight propagations of broadcasting waves in the VHF band are analyzed in order to find out a relation between anomalous propagations and earthquakes. In case when the signal strength of propagated wave deviates by six times deviation from the mean value, the data are regarded as an anomalous propagation.

The occurrences of earthquakes whose epicenters were located near the propagation path from Tokyo Tower to Kiryu are considered. As the results of consideration, the relation between the appearance of anomalous propagations and the specific earthquakes is identified. The specific earthquakes were such that they have the magnitude greater than M4.5 and their epicenters were located within 75km range from the propagation path.

The important relationship between the two could be found, but it is not yet ready to be accepted as a fact. Additionally we have to elucidate the mechanism between the anomalous propagations and occurrences of earthquakes. These are considered to be our future works, and so the observation and the analysis should be continued extensively in future as well.

References

- Fraser-Smith A. C., A. Bernardi, P. R. McGill, M. E. Ladd, R. A. Helliwell, and O. G. Villard, Jr., Low-frequency magnetic field measurements near the epicenter of the Ms 7.1 Loma Prieta earthquake, *Geophys. Res. Lett.*, 17, 9, 1465-1468, 1990.
- Fujiwara H., M. Kamogara, M. Ikeda, J.Y. Liu, H. Sakata, Y.I. Chen, H. Ofuruton, S. Muramatsu, Y.J. Chuo, and Y.H. Ohtsuki, Atmospheric anomalies observed during earthquake occurrences, *Geophys. Res. Lett.*, 31, L17110, 2004.
- Fukumoto Y., M. Hayakawa, and H. Yasuda, Reception of over-horizon FM signals associated with earthquakes, in "Seismo Electromagnetics (Lithosphere – Atmosphere – Ionosphere Coupling)", Ed. by M. Hayakawa and O. A. Molchanov, TERRAPUB, 263-266, Tokyo, 2002.

- Hayakawa M., R. Kawate, O. A. Molchanov, and K. Yumoto, Results of ultra-low-frequency magnetic field measurements during the Guam earthquake of 8 August 1993, *Geophys. Res. Lett.*, 23, 3, 241-244, 1996.
- Hayakawa M., O. A. Molchanov, T. Ondoh, and E. Kawai, The precursory signature effect of the Kobe earthquake on VLF subionospheric signals, *J. Commun. Res. Lab.*, 43, 2, 169-180, 1996.
- Hayakawa M., Observation of seismogenic electromagnetic phenomena and recent results, *IEICE-J*, 89-B, 7, 1036-1045, 2006.
- Kushida Y., and R. Kushida, Possibility of earthquake forecast by radio observations in the VHF band, *J. Atmos. Electr.*, 22, 239-255, 2002.
- Molchanov O. A., and M. Hayakawa, Subionospheric VLF signal perturbations possibly related to earthquakes, *J. Geophys. Res.*, 103, A8, 17489-17504, 1998.
- Motojima Lab. H.P. URL (<http://www.el.gunma-u.ac.jp/~motolab/>).
- Yonaiguchi N., Y. Ida, and M. Hayakawa, On the statistical correlation of over-horizon VHF signals with meteorological radio ducting and seismicity, *J. Atmos. Solar-terr. Phys.*, 69, 661-674, 2007.