Stochastic relation between the line-of-sight VHF propagation and earthquakes

Kuniyuki Motojima
Faculty of Science and Technology
Gunma University
Kiryu, Gunma, JAPAN
motojima@el.gunma-u.ac.jp

Nozomi Haga
Faculty of Science and Technology
Gunma University
Kiryu, Gunma, JAPAN
haga@el.gunma-u.ac.jp

***Abstract*—This paper was intended to find out any relation between anomalous line-of-sight propagation on VHF radio band and occurrences of earthquakes near the radio propagation path. For that purpose, we established a multidirectional VHF band monitoring system and monitored the waves continuously over the long time. After stochastic consideration of fluctuation in the monitored waves, it was found out that the anomalies on the propagation were monitored on the VHF band a few days prior to occurrences of earthquakes which were characterized by magnitude of them and distance from epicenters. Moreover, the anomaly appeared on multidirectional propagation paths simultaneously.**

Keywords— earthquake precursor; line-of-sight propagation; anomalous propagation; VHF band; statistical analysis

I. Introduction

Short-term earthquake prediction is one of the most important research tasks for disaster prevention. There have been reported many geophysical electromagnetic phenomena associated with seismic activity [1]-[4]. In the meanwhile, some researchers observed the FM radio waves on the VHF band. They reported that anomalous propagation from over-horizon FM transmitter signals were observed. The anomalies seemed to be associated with earthquakes [5]. Other researchers inferred that the anomalous propagation was influenced by the perturbation in the troposphere [6]. They considered that the perturbed region was within a radius of 100km from the earthquakes [7].

The purpose of this paper is to find our any relation between anomalous line-of-sight propagation on the VHF band and occurrences of earthquakes. Waves from FM broadcasting stations within the line-of-sight region had been observed continuously over the long term. An observation point has been set at Kiryu, which is located about 100km north from Tokyo JAPAN. Therefore, the observation point is placed near the outer edge of the line-of-sight range, not over-the-horizon. To monitor the waves over long term, we have established the automatic monitoring system. In order to find anomalous propagation from normal one, statistical analysis was adopted. As the result of it, we found out that the anomalies associated with earthquakes were occurred during the preceding a few days.

II. VHF BAND MONITORING SYSTEM

In order to explore any relation between anomalous line-of-sight propagation on the VHF band and occurrences of earthquakes near the propagation paths, a multidirectional VHF band monitoring system has established. The original feature of the monitoring system is a line-of-sight observation method in which the VHF radio band propagation from multidirectional line-of-sight broadcasting stations has been monitored. The monitoring system was set up in Kiryu JAPAN (36°25'N, 139°20'E), which is located about 100km north from Tokyo.

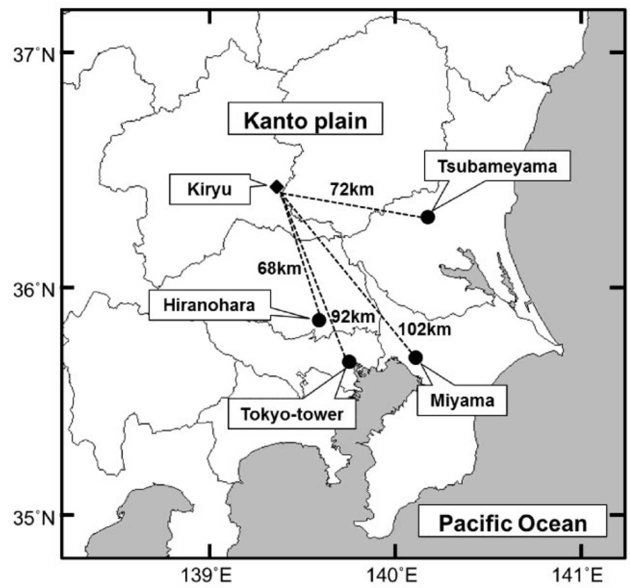

Fig. 1. Monitoring point (Kiryu: solid diamond), locations of transmitter stations (FM radio stations: solid circles) and propagation paths (dashed lines).

TABLE I. MONITORED STATIONS

Transmitter Station	Name of Broadcasting station (frequency)	Propagation path-length
Tokyo-tower	Tokyo FM (80.0MHz)	92km
Miyama	Bay FM (78.0MHz)	102km
Hiranohara	NHK FM Saitama (85.1MHz)	68km
Tsubameyama	NHK FM Ibaraki (83.2MHz)	72km

Map position of the monitoring point (Kiryu: solid diamond), transmitter stations (Tokyo-tower, Miyama, Hiranohara and Tsubameyama: solid circles) and propagation paths (dashed lines) are described in Fig. 1.

Transmitter stations, the names of broadcasting stations, broadcasting frequencies and propagation path-lengths are listed as Table I. They all are within the line-of-sight region from monitoring point.

For long-term observation an automatic and around-the-clock monitoring system consists of multiple antennas, an automatic antenna selector, a spectrum analyzer, a PC for monitoring data storage and a web server for data release. Each antenna is horizontally orientated to each direction, north, south, east and west, they were installed on the roof of a five-story building. Each raw data of the received broadcasting wave is graphed and uploaded onto the web server every half hour, therefore, graphed data can be always visited on the internet.

III. ANOMALOUS LINE-OF-SIGHT PROPAGATION

In other studies the VHF radio waves from over-the-horizon stations were monitored, reception itself means occurrences of anomalous propagation. On the other hand we monitored the line-of-sight propagation wave on the VHF band. Transmitted wave can reach normally into the line-of-sight coverage, so discrimination rule for detection of anomalous propagation was required. For the purpose we adopted a certain statistical process and a criterion as described next: (1) moving averaged values (twenty-minute window) were calculated from monitored wave signal strength, (2) a statistical analysis was performed separately for each specific time slot (five-minute) in a day, because even the line-of-sight propagation was affected by a diurnal variation, then mean values m and standard deviations σ of observed data were separately calculated for each time slot through the observing period, (3) the data exceeded beyond $m+3\sigma$ or $m-3\sigma$ were regarded as the anomalous data, (4) the anomalous data which lasted 30 minutes or more were considered to occur the anomalous propagation. Using above process for the received wave, we could distinguish the anomalous propagation from normal ones in the line-of-sight propagation on the VHF band.

A temporal evolution which was included an anomaly is shown as Fig. 2. Black solid lines indicate the received signal strengths. Three gray dotted lines mean an upper limit of ordinary propagation ($m+3\sigma$), mean value (m) and a lower limit of it (m-3σ) in order from top. They were statistically derived from the long term observational data.

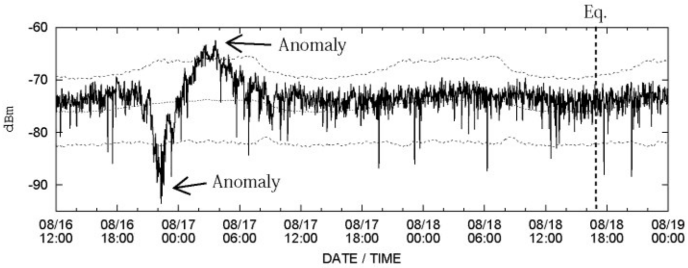

Fig. 2. Temporal evolution of the anomalous propagation on the VHF band, earthquake associated with the anomaly occurred at 16:55 LT on Aug. 18th, 2007, magnitude 5.2, epicenter was (35° 02'N, 140° 02'E).

The anomaly appeared at evening on Aug. 16th, 2007, maximum dip below the -93dBm level occurred at 22:17 LT. Such low signal strength remained a rare event. After that, the signal strength increased 3 o'clock beyond $m+3\sigma$. About 38 hours later the associated earthquake occurred at 16:55 LT on Aug. 18th, magnitude 5.2, the epicenter was (35° 02'N, 140° 02'E) within 75km from the propagation path which is from Tokyo-tower to Kiryu (L=74km), time of occurrence is indicated in dashed line.

IV. RELATIONSHIP BETWEEN ANOMALOUS PROPAGATION AND OCCURRENCE OF EARTHQUAKE

For initial term of VHF band monitoring only Tokyo FM broadcasting had monitored since Feb. 1st, 2007. Then, other broadcasting stations, listed Table I, were included in the monitoring. All monitoring have gone on. Consequently, the Tokyo FM monitoring is the longest period. In this paper, therefore, the Tokyo FM broadcasting monitored data is mainly analyzed for 1155 days, from Feb. 1st, 2007 to Oct. 8th, 2010.

In order to make clear the relation of both phenomena, we defined the successive occurrence of anomalous propagation and earthquake generation within a short period of time as "occurrence of anomalous propagation associated with earthquake." However, even if there were no relation between the anomalous propagation and earthquake, both just happened to occur in a short term. Therefore, we have to estimate the coincidental occurrence probability $P_{unrel}(t_{per})$ under no relation between both phenomena. The probability can be calculated by using the following equation:

$$P_{unrel}(t_{per}) = 1 - ((T_{all} - t_{per}) / T_{all})^{Neq} \quad (1)$$

where t_{per} is the defined length of time period associated anomalous propagation with earthquake, T_{all} is the amount of observing time (T_{all} = 1155 days), and N_{eq} is the number of earthquake occurrences during the whole observation period.

On the other hand, the observational occurrence probability $P_{obs}(t_{per})$ can be obtained from the observation result. It is based on real events and is calculated by the following equation:

$$P_{obs}(t_{per}) = N_{obs}(t_{per}) \; / \; N_{anom} \qquad (2)$$

where $N_{obs}(t_{per})$ is the number of occurrences of anomalous propagation associated with earthquakes in the length of time period t_{per}, N_{anom} is the number of occurrences of anomalous propagation during the whole observation period T_{all} (N_{anom} = 33 on the Tokyo FM wave). If the observational occurrence probability $P_{obs}(t_{per})$ shows comparable to the coincidental occurrence probability $P_{unrel}(t_{per})$, it means that there may be no relation between the anomalous propagation and earthquake.

The number of occurrences of anomalous propagation associated with earthquakes $N_{obs}(t_{per})$ depends on the length of time period t_{per}, because the longer time period t_{per} makes the more anomalous propagation identified as "occurrence of anomalous propagation associated with earthquake." Therefore, both the coincidental occurrence probability $P_{unrel}(t_{per})$ and the observational occurrence probability $P_{obs}(t_{per})$ depends on the defined length of time t_{per}, which is the length of time period associated anomalous propagation with earthquake.

And now, we propose a new concept of the probability gain $PG(t_{per})$ for estimating the relationship between the anomalous propagation and earthquake. The probability gain $PG(t_{per})$ is the ratio of the observational occurrence probability $P_{obs}(t_{per})$ to the coincidental occurrence probability $P_{unrel}(t_{per})$, it can be obtained as follows:

$$PG(t_{per}) = P_{obs}(t_{per}) \; / \; P_{unrel}(t_{per}) \qquad (3)$$

If the $PG(t_{per})$ closes to one, it means that there may be no relation between the anomalous propagation and earthquake.

We estimated the $PG(t_{per})$ carefully for the varied time period t_{per}. As the result of it, we reached a conclusion that the probability gain $PG(t_{per})$ represented the maximum value at the length of time period t_{per} = 2 days. In the following subsections the probability gains $PG(t_{per}$ = 2 days) are shown with respect to magnitude of earthquakes and distances between epicenters and propagation path from Tokyo-tower to Kiryu.

A. Probability Gain with respect to the magnitude of earthquakes

Table II shows the relation between magnitude of earthquakes and the probability gain $PG(t_{per}$ = 2 days). The result indicates that the larger magnitude of earthquake had the more associated with the anomalous propagation. Especially, when the magnitude of earthquakes were larger than 4.5, they had strong relation with anomalous propagation.

B. Probability Gain with respect to distance of epicenters to the propagation path

We considered the positional relation between the epicenter location and the propagation path. Perpendicular distance from epicenters to the propagation path was defined as a distance L. Equidistant curve from the propagation path from Tokyo-tower to Kiryu is shown as an example of L = 75km in Fig. 3.

TABLE II. PROBABILITY GAIN WITH RESPECT TO MAGNITUDE

$\alpha + \beta = \chi.$ (1) (1)

Magnitude (*M*)	Number of Eq. (*Neq*)	Number of Eq. with Anom. (*Nobs*)	Probability Gain
$M > 3.0$	109	8	1.41
$M > 3.5$	50	6	2.19
$M > 4.0$	35	6	3.09
$M > 4.5$	10	4	7.03
$M > 5.0$	2	1	8.76

TABLE III. PROBABILITY GAIN WITH RESPECT TO EPICENTERS

Distance (*L*)	Number of Eq. (*Neq*)	Number of Eq. with Anom. (*Nobs*)	Probability Gain
L < 200km	54	7	2.37
L < 150km	43	5	2.12
L < 100km	22	5	4.06
L < 75km	10	4	7.03

Table III shows the relation between the distance L and probability gain $PG(t_{per}$ = 2 days). The result indicates that the closer epicenters to the propagation path had the more associated with the anomalous propagation. Earthquakes about 150km away from the propagation path had little relation to the anomalous propagation.

$\alpha + \beta = \chi.$ (1) (1)

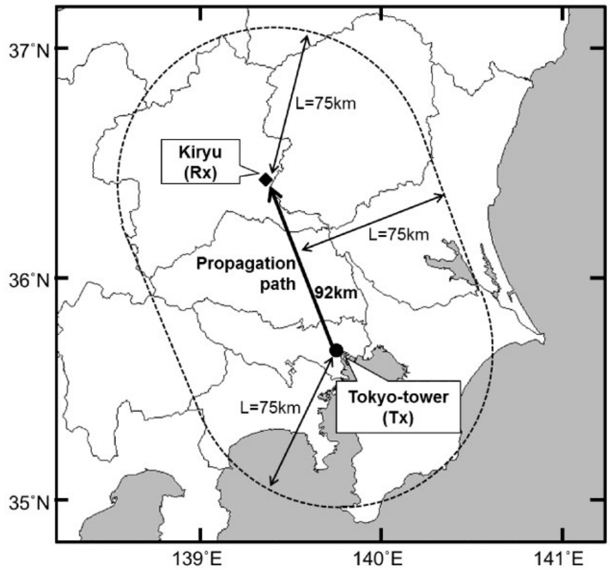

Fig. 3. Equidistant curve (dashed curve, L = 75km) from the propagation path of Tokyo-tower to Kiryu (black arrow). Solid circle and diamond indicate the locations of transmitter stations (Tokyo-tower) and the observational point (Kiryu), respectively.

V. SYNCHRONISTIC ANOMALY IN THE MULTIDIRECTIONAL FM BROADCASTING WAVES

Fig. 4 is the observational result in the multidirectional FM waves, which were incoming from four different transmitting stations, Tokyo-tower, Miyama, Hiranohara and Tsubameyama stations, as shown in Fig. 1. Black solid lines indicate the received signal strengths. Three dotted gray lines mean an upper limit of ordinary propagation ($m+3\sigma$), mean value (m) and a lower limit of it ($m-3\sigma$) in order from top. They were statistically derived from the long term observational data.

Fig. 4 shows the temporal evolutions of the received signal strengths from April 28th to 30th, 2012. First synchronistic anomaly appeared from 2 p.m. on 28th to around noon on 29th, and second synchronistic anomaly occurred from 6 p.m. on 29th to 8 a.m. on 30th. In first synchronistic anomaly the most anomalous propagation occurred round 11 p.m. on 28th from Tokyo-tower (Tokyo-tower). The signal strength fell much below $m-3\sigma$. Other two waves from Hiranohara (NHK Saitama) and Tsubameyama (NHK Ibaraki) had short time anomalies about 23:30 LT on 28th. The anomaly on the wave from Miyama station (Bay FM) had been lasted over the first synchronistic anomaly period.

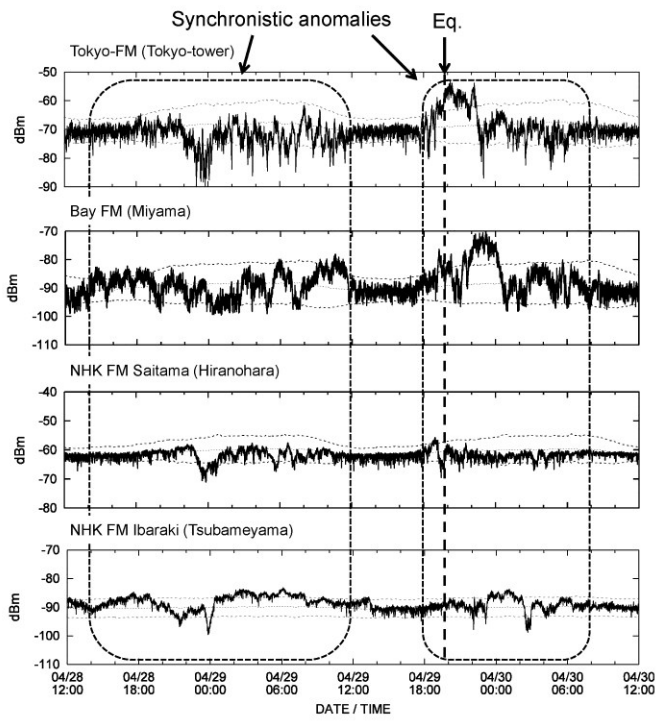

Fig. 4. Temporal evolution of the received signal strengths on April 28th to 30th, 2012. From the top panel, Tokyo-FM (Tokyo-tower), Bay FM (Miyama), NHK FM Saitama (Hiranohara) and NHK FM Ibaraki (Tsubameyama) are drawn. The dashed line indicates the earthquake associated with the anomalies, occurred at 19:28 LT on April 29th, 2012, 5.8 magnitude, its epicenter was (35°42'N, 140°36'E).

During the second synchronistic anomaly an earthquake occurred at 19:28 LT on April 29th, 2012, 5.8 magnitude, epicenter location (35°42'N, 140°36'E), which indicates a black dashed line in Fig. 4. The anomalous propagation seemed to be a precursor of the earthquake.

VI. CONCLUSIONS

In this paper, the relation between anomalous line-of-sight propagation on the VHF band and occurrences of earthquakes was investigated by using the statistical analysis. For that purpose, the multidirectional VHF band monitoring system was established, and the line-of-sight VHF waves have been monitored for a long term. In order to estimate the relation between the two, the new conception of the probability gain was introduced. As the results of observation for over three years and stochastic consideration, we found out the relation between anomalous line-of-sight propagation and earthquakes. Especially, earthquakes associated with anomalous propagation were characterized by magnitude of earthquakes $M>4.5$, and distances from epicenters to the propagation path $L<75$km. The event probability of the line-of-sight propagation increased just a few days prior to earthquakes categorized by the above. Moreover, synchronism detection of anomalous propagation in the multidirectional FM broadcasting waves was observed. The anomalies associated with earthquakes sometimes occurred almost at the same time on the plural radio waves via different pathways. These phenomena have the possibility of narrow focusing the area of epicenter of earthquake.

The important relation 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 propagation 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.

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