Precursory anomalies in the subionospheric VLF signals for the Kobe earthquake

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1 Abstract

The subionosphric VLF Omega signal transmitted from Tsushima, Japan (geographic coordinates: 34.37N,129.27E) was continuously received at Inubo (35.42N,140.52E).The data were analyzed during 8 months period centered at the great Hyogo-ken Nambu (Kobe) earthquake on Jan. 17, 1995, with its epicenter being located inside the 1st Fresnel zone of the VLF great-circle path. We discovered. with rather high probability, the abnormal behaviour of VLF signal which began a few days before the main shock and probably continued a few weeks after it. To clear up this effect we developed the special (terminator time) method of data processing. which was useful only for our short VLF path (distance ~1000 km). Possible underlying mechanisms of the effect are also discussed.

2 Introduction

A possibility of earthquake prediction is based on the supposition of the existence of precursors. Though a lot of earthquake precursors were observed. it was usually difficult to estimate how many events were fortuitous indeed. Therefore, finding a reliable precursor is an urgent scientific target yet. Recently, in relation with the great earthquake, happened near the Kobe city in Japan on January 17,1995 (5h 46m a.m., L.T., $M_s = 7.2$),whose epicenter was located at 34.6N, 135.0E, we have checked a possibility of making use of radiophysical measurements[1]. First of all we paid attention to VLF signal method, in which phase and amplitude of radio signal of VLF navigational transmitter propagated inside the Earth-ionosphere waveguide is registered. If frequency and reception distance are fixed,then observed VLF signal parameters are mainly related with the reflection height h. That is why VLF signal method became rather popular for recording of short-time electron density variations in the lower ionosphere connected with solar radiation (e.g. Roentgen flares),cosmic rays(Forbusch effect),energetic particle precipitation [2,3] and lightning-induced heating [4,5]. Recently, an idea to use this method for search of earthquake precursory activity was proposed. Gokhberg et al.[6] reported the first abnormal precursory influence of earthquakes on the subionospheric VLF propagation, which was suggested as a possible use for the earthquake prediction. Later, Russian [7] and Japanese [8] colleagues have accumulated more evidence on the abnormal anomalies in the subionospheric propagation associated with earthquakes. This paper presents the experimental results for the Kobe earthquake.

3 Method of data analyses and main effects

We considered the VLF data on reception at Inubo (near Tokyo) (Geographic coordinates:35.42N 140.52E) of VLF signals transmitted from "Omega",Japan(Tsushima,34.37N,129.27E)(see Fig 1). The epicenter of the Kobe earthquake is indicated by a cross and it is about 70 km from the VLF signal path. We used the data on phase and amplitude of signal at the frequency of 10.2kHz and on phase 11.3kHz during the time period from about four months before and four months after the earthquake.

The previous works [6,7,8] mentioned above have dealt with the subionospheric VLF propagation over a long distance (more than a few thousand kilometers), but the distance between Tsushima and Inubo is only about 1000km, which can be considered as a rather short-distance propagation. First of all, we have performed similar kind of analyses as done for the long-distance propagation path. We have analyzed the fluctuation of phase at 10.2kHz at a particular L.T. (L.T.=24h), and we have found that there appeared one peak exceeding 2σ about one week before, a large negative peak exceeding 2σ a few days before the earthquake. Judging from these facts, we can conclude that a tendency of enhanced fluctuation before the earthquake might be a signature of the Kobe earthquake. This analysis is based on the conventional method adopted for the long-distance propagation.[7,8]

Hence,we propose a new way of analysis for subionospheric VLF propagation over short distance ($d \sim 1,000$ km). The terminator points, where the behaviour of phase (and amplitude) has a characteristic minimum,are easily defined two times (t_m, t_e) a day and time accuracy of their determination is about 6 minutes.You can note from specially selected sequence of daily phase variation in Fig.2, that the parameter t_m is decreased and t_e is clearly increased a few days before the earthquake. It seems to us this effect might be connected with the earthquake, but we need to prove it by statistical way.

The temporal variations of terminator times $\langle t_m \rangle, \langle t_e \rangle$ ($\langle\rangle$ means the running mean over ± 15 days around each day) are studied together with local times of sunrise $t_m{}^0$ and sunset $t_e{}^0$ near the end of VLF path (at Tokyo). It is not surprising that the variation of terminator times correlate with astronomical times and "sunrise" in VLF signal behaviour occurs a little later, $\Delta t_m = \langle t_m \rangle - t_m{}^0 > 0$ but VLF "sunset" happens earlier, $\Delta t_e = \langle t_e \rangle - t_e{}^0 < 0$. It is worthwhile to note that $|\Delta t_e| < \Delta t_m$ both for phase and amplitude variations and it is very difficult to find any earthquake signatures in those characteristics. However,they are easy to discover in the TT (terminator time) differences of phase and amplitude $dt_e = t_e - \langle t_e \rangle$, though not shown here. To estimate the statistical importance of these deviations we calculate the seasonal dispersion of data $\sigma = \{(t_e - \langle t_e \rangle)^2\}^{1/2}$ averaging over the whole period of observation,and plot 2σ level. Both TT differences exceed the 2σ level a few days before the day of main shock of earthquake, and it allowed us to suppose that the relation of the spike with the earthquake is not accidental. It seems as rather probable that the event continues after the main shock and looks as a transient wavelet with sharp commencement before the earthquake,especially at the amplitude TT plot.

Trying to prove that coincidence of our VLF event with the Kobe earthquake is not occasional, we have analyzed the behaviour of the all usually supposed changes in VLF transmitter signal. The variations of magnetic storm connected with the precipitated ionization of the ionosphere and variation of solar activity related with photoionization, and variation of rainfall index connected with lightning electric field perturbations are studied and it is evident that all of them are not causative to the abnormal VLF signal phenomena.

4 Discussion

It is not so easy to provide a perfect explanation of the observed effect. We have carried out the simple computation of subionospheric VLF propagation in corresponding with formulation in [2]. The observed VLF electric field E_z is as follow:

$$E_z = WE^0. \quad (1)$$

where E^0 is the field in a free space and W is an attenuation function connected with medium properties and described as a sum of modes:

$$W = B \sum_{n=0}^{\infty} C_n S_n{}^2 H_0{}^{(2)}(kS_n D). \quad (2)$$

where D is distance, k is wave number in a free space depending only on frequency f. B product of excitation and height dependent factor. C_n are constants. Supposing fixed D and f. $H_0^{(2)}$ is Hankel function of second type and finally:

$$S_n = a_n - i\frac{\epsilon_n \tilde{\Delta}}{2kh}/a_n. \qquad a_n = [1 - (n\pi/kh)^2]^{1/2}. \tag{3}$$

where h is height of reflection point. At last $\tilde{\Delta}$ is a function, which is connected with dissipation of VLF energy in the conductive ground and ionosphere medium and which can be estimated from observed values of attenuation of the dominant mode at long distance. We have resonably supposed the followings:(a) five modes of propagation.(b)dissipative attenuation of the first, dominant mode is 3.0 dB/1000 km,(c) the height of VLF wave reflection in the upper atmosphere is 85 km at night and 75 km at day and (d) the characteristic time of the terminator changes is 2 hours. Based on these suppositions, we can comply our theoretical results with the regular diurnal variation in phase and amplitude, observed really. In order to obtain the observed changes in the terminator times during the seismically perturbed period.we need only to assume the total decrease in the reflection height by $\Delta h \sim$ 2km. At present it is difficult to indicate a plausible physical or chemical mechanism of such a conductivity or density perturbation.

The most simple idea for these changes might be connected with intensified radioactive radon exhalation before an earthquake and resultant increase of the electric field at the upper atmosphere like considered in a theoretical scheme developed by [10]. Indeed, there were a lot of papers on intensified radioactive gas appearance before earthquakes[11,12]. There is reported on the radon emanation with an increase of ion density by about 10 times before the Kobe earthquake. Recently the report by [13] appeared where the clear changes in VLF transmitter signals are found just after accidents at powerful atomic station. It could be considered as natural experiment on checking the above-mentioned idea.

We hope that the subionospheric VLF propagation can be considered as a rather promising candidate for the short-term earthquake precursor.

References

[1] Hayakawa,M.,and Y.Fujinawa.Editors, "Electromagnetic Phenomena Related to Earthquake Prediction",Terr Sci.Pub.Comp.,Tokyo,pp.677,1994.

[2] Wait,J.R.. Electromagnetic Waves in Straticfield Media,Pergamon Press,1970.

[3] Galejs,J., Terrestrial propagation of long electromagnetic waves.Pergamon,New York,1972.

[4] Armstrong.W.C.. Recent advances from studies of the Trimpi effect.Antarctic Journal,18,281.1983.

[5] Inan,U.S.,D.C.Shafer,W.J.Yip and R.E.Orville, Subionospheric VLF signatures of night-time D-region perturbations in the vicinity of lightning discharges.J.Geophys.Res.,93.11455.1988.

[6] Gokhberg,M.B.,I.L.Gufeld.A.A.Rozhnoy,V.F.Marenko.V.S.Yampolsky,and E.A.Ponomarev, Study of seismic influence on the ionosphere by super long-wave probing of the Earth-ionospheric waveguide,Phys.Earth Planet.Inter.,57,64,1989.

[7] Gufeld I.L.,G.Gusev and O.Pokhotelov. Is the prediction of earthquake date possible by VLF radio wave monitoring method? in Electromagnetic Phenomena Related to Earthquake Prediction.Hayakawa ,M. and Y.Fujinawa.Editors,Terr.Sci.Pub.Comp.,Tokyo.381-390.1994.

[8] Hayakawa,M.and H.Sato, Ionospheric perturbations associated with earthquakes,as detected by subionospheric VLF propagation.in Electoromagnetic Phenomena Related to Earthquake Prediction,Hayakawa.M. and Y.Fujinawa.Editors,Terr.Sci.Pub.Comp.,Tokyo.391-398.1994.

[9] Rikitake,T., Earthquake prediction,Elseiver,Amsterdam,357 pp,1976.

[10] Pierce,E.T., Atmospheric electricity and earthquake prediction,Geophys.Res.Lett.,3,185-188,1976.

[11] King,C.Ju, Gas geochemistry applied to earthquake prediction: An overview, J.Geophys.Res.,91,12269,1986.

[12] Yamauchi,T., Variation in air radon concentrations in tunnels for observation of crustal movement in the Tokai region of Japan,Res.Let.Tmos.Electr.,12,193-201,1992

[13] Fuks,I.M.,R.S.Shubova, VLF signal anomalies as response on the processes at near-ground atmosphere,Geomagn.Aeronomy,34,130-136,1994(in Russian).

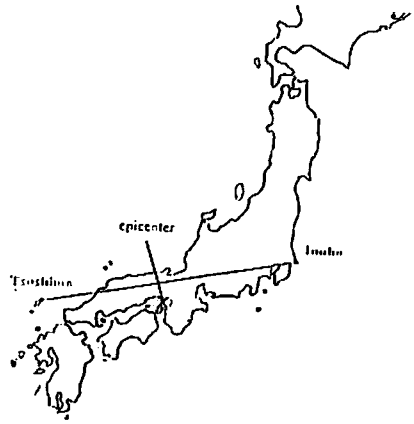

Figure 1: Location of transmitter at Tsushima and receiving station at Inubo is shown. The line connecting these two station is the VLF wave path, and the epicenter of the Kobe earthquake (×) is about 70km from the path.

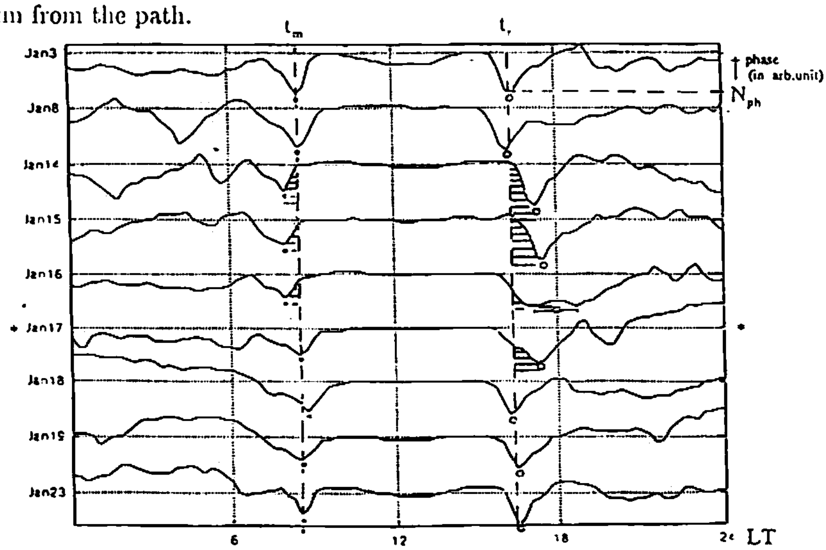

Figure 2: Sequential plots of the diurnal variation VLF signal of phase at Inubo. The definitions of t_m and t_e are given as the times where a minimum in phase takes place around sunrise and sunset, and also the value of phase at minimum is defined as N_{ph}.