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Characteristics of VHF over-horizon signals possibly related to impending earthquakes and a mechanism of seismo-atmospheric perturbations

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Abstract

There have been evidences of the presence of atmospheric disturbances associated with earthquakes, as based on the reception of over-horizon VHF signals. In this paper we propose a generation mechanism of such atmospheric perturbation based on the changes in geochemical quantities associated with earthquakes.

Keywords: Electromagnetics; Scattering and diffraction; Wave propagation; Exploration geophysics; Atmospheric processes

1. Introduction

There have been recently observed a lot of convincing evidences on the electromagnetic effects associated with earthquakes (e.g., Hayakawa and Molchanov, 2002). The propagation of over-horizon FM signals probably associated with impending earthquakes has been observed by Kushida and Kushida (1998). They detected the signals from an over-horizon transmitter in Central Japan several days or weeks prior to the Kobe earthquake. Though we do not receive any signal from a VHF transmitter out of the light-of-sight, we sometime receive the signals from the transmitter and we define this as being abnormal. Some correlation was found between the abnormal VHF wave propagation and the earthquakes which happened at certain sensitive regions. This phenomenon has been studied intensively for a number of earthquakes in Central Japan from February 1 till June 30, 2000 by Fukumoto et al. (2001, 2002). The FM transmitter is located in Sendai, 312 km far from the receiver in Chofu, whereas the distance of line-of-sight was 80 km. Though the FM signals (77.1 MHz) from Sendai have not been detected in Chofu on normal days because it is out of the line-of-sight, over-horizon FM signals have been occasionally received in Chofu with small incident angle smaller than 20°. The direction findings of the signal bearing have shown that there are sometimes a lot of differences with regards to the bearing of the future epicentre. Fukumoto et al. (2001, 2002) have found that the

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cross-correlation between the abnormal over-horizon FM signals and earthquakes exhibits a significant peak around 7 days before the earthquake. Recently, an experimental evidence for the same phenomena has been confirmed by Fujiwara et al. (2004).

There are few papers on seismo-atmospheric perturbations on the basis of studies on over-horizon VHF signals (Kushida and Kushida, 1998, 2002; Fukumoto et al., 2001, 2002; Fujiwara et al., 2004). We can summarize the important informations from these earlier works as follows, which would be essential for the following theoretical considerations.

(1) Over-horizon VHF FM transmitter signals are not detected on normal conditions (Kushida and Kushida, 1998; Fukumoto et al., 2002), but they are received on some occasions.
(2) Such abnormal over-horizon VHF signals are found to be received at a station out of the line-of-sight with small incident angle (incident angle $\leqslant 20^{\circ}$) (Fukumoto et al., 2001, 2002).
(3) The cross-correlation between over-horizon VHF signals and earthquakes indicates that such an anomaly takes place about one week before the earthquake (Fukumoto et al., 2002; Fujiwara et al., 2004).
(4) The direction finding of the bearing of observed over-horizon signal shows that there is sometimes a lot of difference with regards to the bearing of a future earthquake. Always, the region or the atmospheric perturbation seems to be close to the land area for oceanic earthquakes (Fukumoto et al., 2002).

Unlike the initial hypothesis by Kushida and Kushida (1998); Fukumoto et al. (2002) have found that this VHF anomaly is attributed not to the ionosphere, but to the atmospheric perturbation (Point(2)). This atmospheric perturbation tends to take place about one week before the earthquake (Point (3)). Point (4) is indicative of the suggestion that the atmospheric scatterer for over-horizon VHF signal seems to take place close to the land (not over the sea).

2. Proposal of a generation mechanism of seismo-atmospheric perturbations

Kushida and Kushida (1998) and Pilipenko et al. (2001) have assumed without any convincing results that the abnormal over-horizon VHF wave propagation is due to the back-scattered radiation from the meter-scale plasma irregularities in the ionosphere above the seismo-active region. The plasma irregularities can be resulted from the propagation of internal/acoustic gravity waves (IGW) in the ionosphere. It was hypothesized that there may be three possible mechanisms of IGW generation in the seismo-active region: (1) seismo-gravitational vibrations of the ground surface, (2) periodic heating and (3) non-stationary gas emanation through the rock.

It should be noted that the seismo-gravitational vibrations can be hardly applied to our phenomenon because of weak amplitude of the IGW caused by such vibrations. Indeed, the pressure variations in the near-surface layer of the atmosphere (ΔP) can be estimated as follows:

$$\Delta P = \rho v \frac{\partial \xi}{\partial t} \sim \rho v \frac{\xi}{\tau}, \tag{1}$$

where ρ is the air mass density, v is the acoustic wave velocity, and $\partial\xi/\partial t$ denotes the time-derivative of the ground surface displacement. Considering the typical microseism measurement with displacement amplitude of about 10^{-4} cm and with the period $\tau = 6\,\mathrm{s}$ and taking $\rho = 1.2\,\mathrm{kg/m^3}$ and $v = 340\,\mathrm{m/s}$ brings the pressure variation in the atmosphere $\Delta P \sim 0.1\,\mathrm{mPa}$, which is found to be 2–3 order-of-magnitude smaller than the level of the atmospheric acoustic noise at the ground surface.

We recall that the weak over-horizon signals detected at Chofu were identified by audio monitoring done by the FM Sendai broadcasting, which operates at the frequency 77.1 MHz. It is common knowledge that the effect of long-range VHF wave propagation is usually due to tropospheric ducting via the wave reflection below the tropopause (Turman, 1955; Hall et al., 1996). Yonaiguchi et al. (2007) have actually found this ducting effect in particular seasons (summer). In this case the VHF waves are guided in the same way as in a metallic waveguide. The ducting in the troposphere followed by the ray distortion builds up as a result of refraction index changes with altitude. In the geometric optics approach the curvature radius, R, of the ray can be expressed via the refraction index n as follows (e.g., see Landau and Lifshitz, 1982):

$$\frac{1}{R} = \mathbf{N} \cdot \frac{\nabla n}{n}, \tag{2}$$

where $\mathbf{N}$ denotes the unit vector of a principal normal to the curve/ray.