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Investigation of Non-linear effect in ELF/VLF waves observed by the DEMETER satellite over seismic regions

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ABSTRACT: Space plasma is awfully unstable and it disturbed by the geophysical or geomagnetic activities. From last 20 year scientists are study the seismic effect on the space plasma wave in different frequency range. For investigation of seismic effect on the ELF/VLF wave in space plasma a micro-satellite was launched on June 29, 2004, DEMETER is a polar and a circular orbit with an altitude of ~710km.DEMETER space observations provides a very interesting opportunity to investigate and to study earthquake electromagnetic precursors. In this work we have studied disturbances in the ELF/VLF waveform by wavelet higher order spectrum-bispectrum prior to the earthquake with magnitude M=7. 0 on Novmber11, 2004 in the Hokkaido region, Japan. We found that when Kp≥3 (quite geomagnetic condition) in that duration some nonlinear effects are develop and structure turbulence in ELF/VLF waves before few days of earthquakes.

Keywords: Earthquake, ELF/VLF, Bispectrum, Nonlinear

I. INTRODUCTION

A number of research is carried out over the last 20 year has indicated the existence of pre-, co- and post-earthquake ionospheric disturbance at all levels of the ionosphere. On the bases of the observations taken by satellite Intercosmos-19 [1] were first reported Seismo-induced electromagnetic effects in the ionosphere. After this many land-based [2,3,4,5,6,7,8,9,10], space-born[11, 12,13], and joint space-born and land-based studies[14,15] were carried out.

The French microsatellite DEMETER is the first satellite devoted mainly to study electromagnetic effects and it gives opportunity to globally study the electromagnetic pre-seismic emissions using a set of experiments [16].In this paper we are analysis the Extremely Low Frequency/Very Low Frequency (ELF/VLF) signals obtaine through the DEMETER over the Hokkaido region former to the Novmber11, 2004 when geomagnetic state are very quiet(Kp<4) and discuss the response of the ionospheric plasma for the annoyance that instigated with high probability from the lithosphere [16]. It is accepted that there is a lithosphere, atmosphere-ionosphere correlation mechanism that works in the course of the generation of atmospheric gravity waves at acoustic frequencies at the time of the earthquake preparation phase. These begin in the zone of the epicenter, and consequently move upwards, to enhance turbulent content of the ionosphere above the epicenter and to commence gravity waves that transmit in the waveguide of the ionosphere/magnetosphere [2] or by ion exhalation and the subsequent variations in the electric field at the site of the earthquake formation zone, which produces variations in the ionosphere over the epicenter area [16]. According to this concept [18,19,17] recorded turbulence over many seismic zone.

Ionospheric plasma is very unstable and it can be easily disturbed. Development of turbulence in the ionospheric plasma generated when instability is reached at the nonlinear stage. So in geomagnetic quiet conditions if turbulence is build up then its highly possible that the perturbations are produced by some causes having their source at the hypocenter of the earthquakes [16]In this work we have discussed the turbulence over this seismic event. But definition of turbulence is still under conversation although some important features can be noted: many degrees of freedom (diverse scales), every one of which are in nonlinear relations (cross-scale couplings), which creates a flow of energy from manjor (lower frequencies) to minor (higher frequencies) dimensions [15]. Many scientists characterized the turbulence by the shape of the power spectrum [20-22].

On the bases of slope of the power spectrum curve theory of turbulence predicts different type of turbulence Noncompressible isotropic MHD (IK-1965) $k^{-3/2}$ Iroshnikov-Kraichnan, Noncompressible turbulence (K-1941) with $k^{-5/3}$ (Kolmogorow), Noncompressible anisotropic MHD (SG-2000), k^{-2} Sridhar and Goldreich and Whistler turbulence (DB-1997) $k^{-7/3}$.Now a day probability distribution function (PDF) and its parameter such as kurtosis and skewness is used to parameterization of turbulence process[23].

II. EXPERIMENT

DEMETER a microsatellite was launched in 2004 to perform detection of Electro –Magnetic Emission Transmitted from Earthquake Regions which is also the full form of this. The scientific payload of this satellite comprises several instruments that are capable of recording continuous data related to electric and magnetic field variations during its passage over seismically active zones [24]. Measurement of plasma waves and energetic particles is also an asset to the operation of this satellite [25]. Data of ICE (Instrument Champe Electrique) and IMSC (Instrument Magnetometer Search Coil) experiments on-board DEMETER satellite were used to measure the electric and magnetic fields respectively [26] there are two scientific modes one is survey mode where the spectral of one electric and one magnetic component are calculated on-board up to 20kHz and other is the burst mode where in addition to the on-board computed spectra, the waveforms of one electric and one magnetic field component are traced up to 20kHz [15]. In our paper we are using ICE burst mode data which work out from the wave form of one electrical component up to 1.25kHz (Blecki, 2009). The raw data have been taken from the website http://demeter.cnrs-orleans.fr. For analysis and visualization of DEMTER data, a effusive interactive software is accustomed to name SAWN (Software for Wave Analysis) [25].

III. METHODS OF ANALYSIS

A. Wavelet analysis

The first and widely used method for the turbulence analysis is the Fourier transform (FT) but uncertainty time-frequency resolution could not be detected the complicated transient phenomena. Therefore, the FT is quite inefficient for this purpose. Wavelet analysis has developed in the last few years from a somewhat inquisitive technique to offered alternative to Fourier analysis; the mathematical bases of the previous are now as sound as those of the latter [27]. Its discovery was helping to analyze signals that contained rapidly varying frequencies, pulses or short time events (as may occur in ELF/VLF data). At a Fourier transformation signal is decomposed in the form of sine and cosine and computation is an integral over to give time period, it eliminates the temporal information. Wavelet analysis takes as its analyzing basis function wavelets, i.e. oscillating functions that decompose rapidly with time, rather than sine and cosines that have no such decay [28]. When a signal is decomposed in this way it temporal and spatial information does not suppress.

Formal description the wavelet transform-

If x (t) is a signal, then its Fourier transform is given by:

$$X(t) = \int_{-\infty}^{+\infty} x(t)\, e^{-2j\pi ft}\, dt \quad (1)$$

The parameter f is the frequency of the periodic function $e^{-2j\pi ft}$, and therefore *X (t)* is said to represent the frequency content of the function *x (t)*.

The continuous wavelet transform of a signal x (t) is termed as the integral transform:

$$CWT(a,\tau) = \psi(a,\tau) = \int_{-\infty}^{+\infty} x(t)\psi^{*}_{a,\tau}(t)\, dt \quad (2)$$

Where $\psi_{a,\tau}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-\tau}{a}\right)$

Which represent a family functions know as a mother wavelet .The selection of the wavelet $\psi_{a,\tau}(t)$ is neither unique nor random. The function $\psi_{a,\tau}(t)$ is a function with unit energy ($\int_{-\infty}^{+\infty} |\psi_{a,\tau}(t)|^2 dt = 1$) selected in order that it has sufficiently fast decay or compact support, to obtain localization is space. This function must be following the condition of admissibility i.e. zero mean ($\int_{-\infty}^{+\infty} \psi_{a,\tau}(t)\, dt = 0$). In our calculation, we are employing Morlet wavelet, it's given by [29]:

$$\psi_{a,\tau}(t) = e^{-t^2/2} e^{2j\pi f_0 t} = e^{-t^2/2}\left[\cos(2\pi f_0 t) + j\sin(2\pi f_0 t)\right] \quad \ldots(3)$$

Where $f=f_0/a$, f_0 is wavelet central frequency. τ is the transition function.This term regarding to time information in the transform domain. a is scale parameter which characterizes the dilating (to stretch out) (a >1) or contracting (a <1). a (Scale) is inversely proportional to f (frequency) i.e. a=1/f. Farge [30] was studied turbulence in the context of coherent structures by wavelet analysis.

B. Wavelet Bispectrum

The first use of bispectral analysis of space plasma was given in [31].Bispectral analysis belongs to a group of techniques derived from high-order statistics (HOS) that perhaps utilized to analyze non-Gaussian signals, to

Get phase information, to restrain Gaussian noise of unidentified spectral form, and to identify and characterize signal nonlinearities[32]. The bispectrum involves third-order statistics. Spectral evaluation is derived from the conventional Fourier type direct approach through the computation of the third-order moments. In the case of zero-mean signals, third-order moments are analogous to third-order cumulants [32,33].

Let $\{x(t)\}_{t=1}^{\infty}$ be a zero mean, ergodic, discrete time series, with third order moment given by[34]:

$$c_3(\tau_k,\tau_l) = \langle x(t)x(t+\tau_k)x(t+\tau_l)\rangle \ldots(4)$$

where τ is a lag, k and l are integer. The < >brackets put up with an ensemble averaging over various statistically like realizations of the method under scrutiny. The bispectrum is Known as the double discerte Fourier transformation of the higher order moment such as third order moment[35]:

$$B(f_k, f_l) = \frac{1}{(2\pi)^2}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} c_3(\tau_k,\tau_l)e^{-2\pi i(f_k\tau_k - f_l\tau_l)}d\tau_k d\tau_l \ldots(5)$$

Or

$$B(f_k, f_l) = \langle X(f_k)X(f_l)X^*(f_k+f_l)\rangle \ldots(6)$$

where *X*(*f*) symbolizes the Fourier amplitude spectrum of the signal *x*(*t*) at frequency *f* and *X**(*f*) is the complex conjugate. f_k, f_l are the frequencies. The quantities in equation (4) and (5) contain essentially the same information[34].By the analogy definition of the bispectrum in Fourier transform the wavelet bispectrum is given as:

$$B_x(a_1,a_2) = \int_T W_x^*(a,\tau)W_x(a_1,\tau)W_x(a_2,\tau)d\tau \ldots(7)$$

Where $\frac{1}{a} = \frac{1}{a_1} + \frac{1}{a_2}$ or $f=f_1+f_2$ …(8)

The computational procedures for the application of methods of wavelet and bispectral analysis have been build uped in the SWAN package [25]. We used these for the analysis of the data selected for this study.

C. Statistical description of the turbulence

In the selected time interval we have able ot assessment the probability distribution function (PDF) of the electric field intensity due to the sampling rate (2.5Hz). The shape of PDF curve indicates whether the phenomenon has Gaussian for symmetric or non-Gaussian for asymmetry, which is typical for turbulence. Skewness and kurtosis are two parameters which are characterized the PDF.If the value of sknewness and kurtosis is shows deviation from there Gaussian value than the indicated the inttermittecen in electric filed wave form which is obtained by the DEMETER. For the Gaussian distribution the sknewness is zero and the kurtosis value ≤ 3.

IV. OBSERVATIONS

Consider earthquake took place on the November 11, 2004 at18:32:14.1UT in the Japan, in the Hokkaido. It had a hypocenter located at 43.006ºNand 145.119ºE.Its depth was39 km and the magnitude was M=7.0.Two week before the earthquake geomagnetic conditions are very quiet (Kp<4). During this earthquake DEMETER is flying near the epicenter due to that we obtain complete registration of the waveform of the electric field fluctuate in the ELF/VLF data set.

An analysis of ELF/VLF emissions in the environs of the epicenter was achieved in November, 24 (4day) and November, 22 (7day) before the Hokkaido earthquake. We get the increased intensity in these two days the most intensive effect is seen in November, 24. Now we offered a detailed analysis of these day's emissions recorded by DEMETER.

Figure1 (a) reveals the wavelet spectrogram of the Ex signal in ELF/VLF range when the DEMETER is closest to the epicenter on November 24,2004. This day the closest approach of DEMETER to the epicenter was 12:24:34:816 and the distance was 446 km. We found enhancement in the electric field intensity in this time duration, but strong enhancement is found on the 12:24:41 UT(shown Figure1(b)).The enhancement is similar as Abruzzi earthquake reported by Bleck [2011].These strong emissions are well below to the proton gyrofrequeny. Figure1(b) shows the wavelet bispectrum of these disturbance.Wavelet Bispectrum curve is indicates the very strong significant 3-wave interaction in 3kHz-300kHz which is the indication of the turbulence.

To revealing of these turbulence single spectrum is traced in figure 1(d). The slope of the curve is -1.60, which is corresponding to the Kolmogorov model of the turbulence. Statistical calculation of these turbulence such as PDF and its kurtosis and skewness is shown in figure 2(a) and (b). The distribution of PDF curve is asymmetric and the value of Kurtosis and skewness is non-zero at 12:24:41 these are conforming the intermittent in the signal. Weak ELF/VLF emissions are registered by the DEMETER satellite on Novermber 22,2004 ,7 day before the event.

The closest approach to the epicenter was at 1:25:28:415UT and the distance between the satellite and the epicenter 417km.When data of 10 Sec duration analyses by wavelet spectrogram, we recorded enhancement in the wave intensity,but the most intensive emission occurs at the 1:25:29:975UT it is clear from the power evolution (figure3(b)).Figure 3(c) represents the wavelet bispectrum of these emission.The curve indicates the 3-wave weak interaction in the lower frequency range. But the cascade in the energy which is the indication of turbulence. Only these turbulence is weaker than Novermber 22.figure 3 (d) contains a single spectrum and the slope is -1.64 indicates the developed Kolmogorov type of the turbulence. The PDF cure is also asymmetric around there asymmetric mean which is the indication of turbulence (Fig. 4).

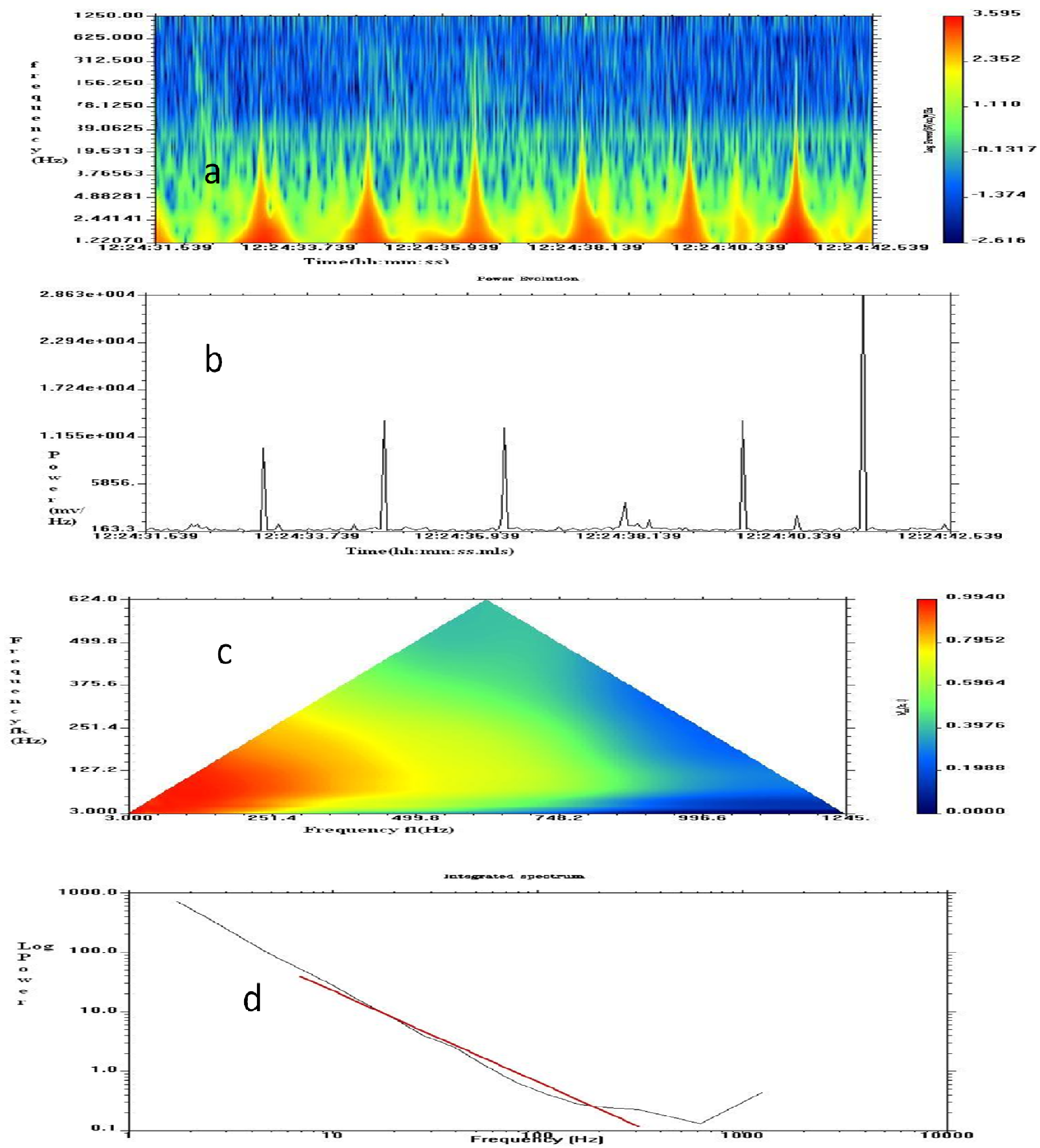

Fig. 1(a) Wavelet spectra up to 1250 Hz of electric field taken by the DEMETER satellite on Novermber 24 ,2004 during burst mode,between 12:24:31 1nd 12:24:42 UT.(b)power elevoulation graph of ELF/VLF signal of same day and time (c)Wavlet bispectrum of Ex signal in the VLF/ELF range.(d) Single spectrum with slope α=-1.60.

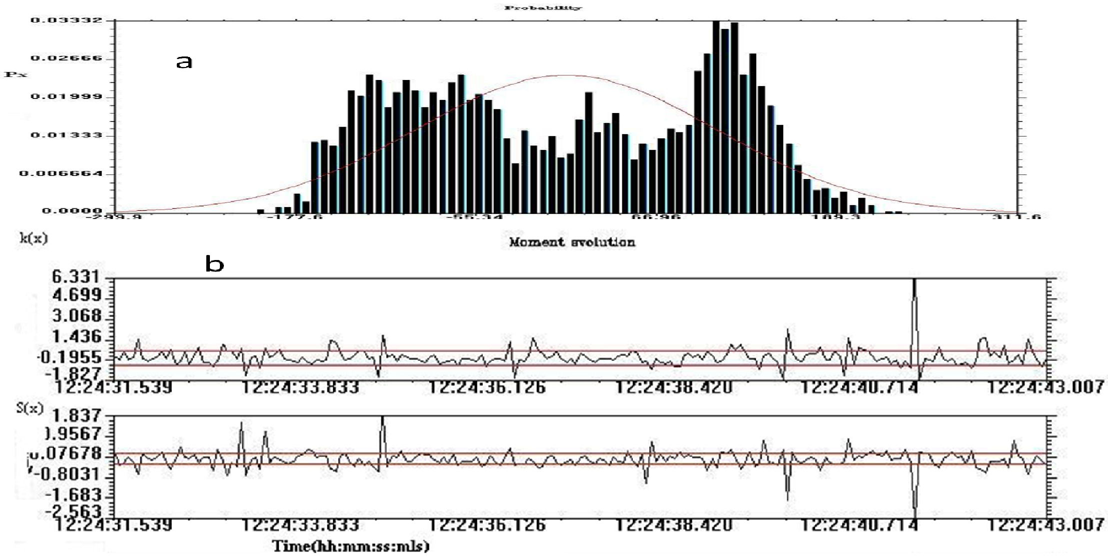

Fig. 2(a) Probability distribution function of electric field intensity variation at the time of strong wave activity .(b) Evolution of the kurtosis and skewness between 12:24:31 and 12:24:43.

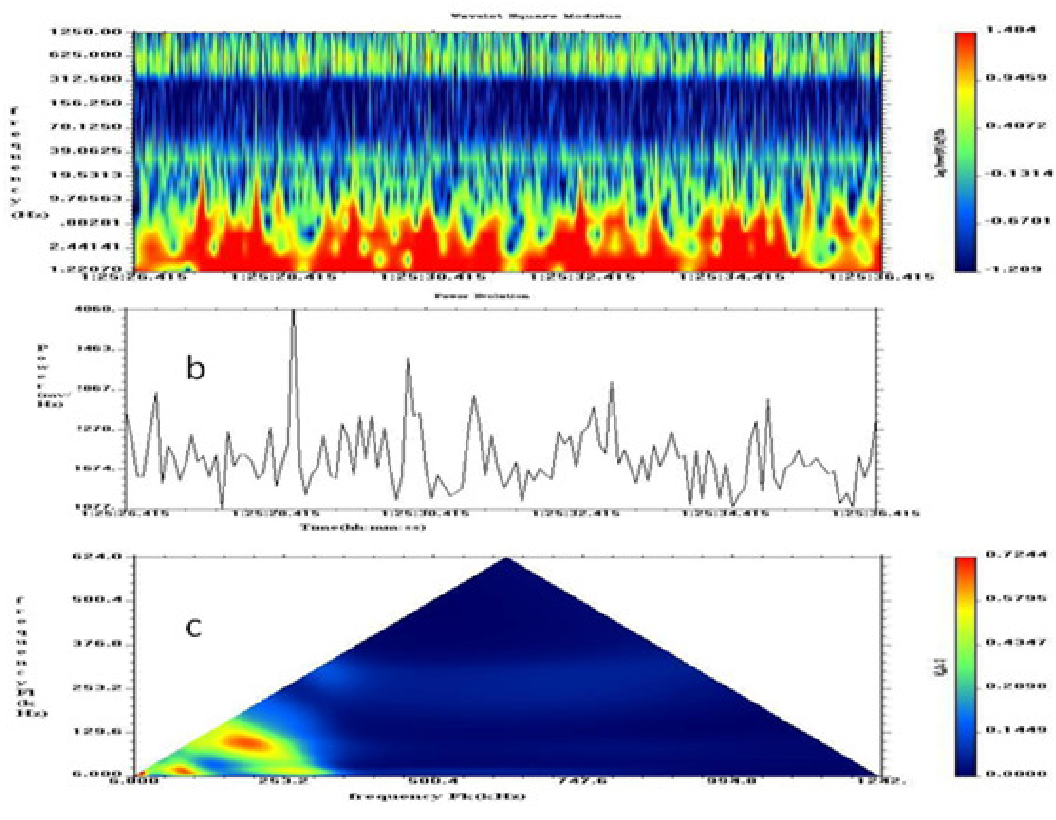

Fig. 3(a) Wavelet spectra up to 1250 Hz of electric field taken by the DEMETER satellite on Novermber 24 ,2004 during burst mode,between 12:25:26 to12:25:36 UT.(b)power Evolution graph of ELF/VLF signal of same day and time (c)Wavlet bispectrum of Ex signal in the VLF/ELF range.(d) Single spectrum with slope α=-1.64.

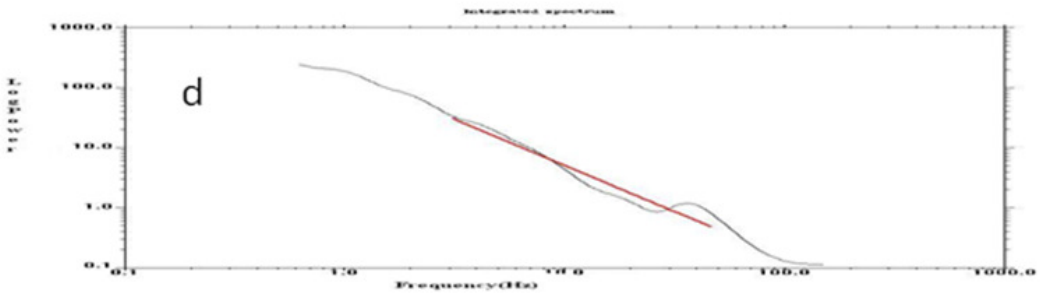

Fig. 3 (d) Single spectrum with slope α=-1.64.

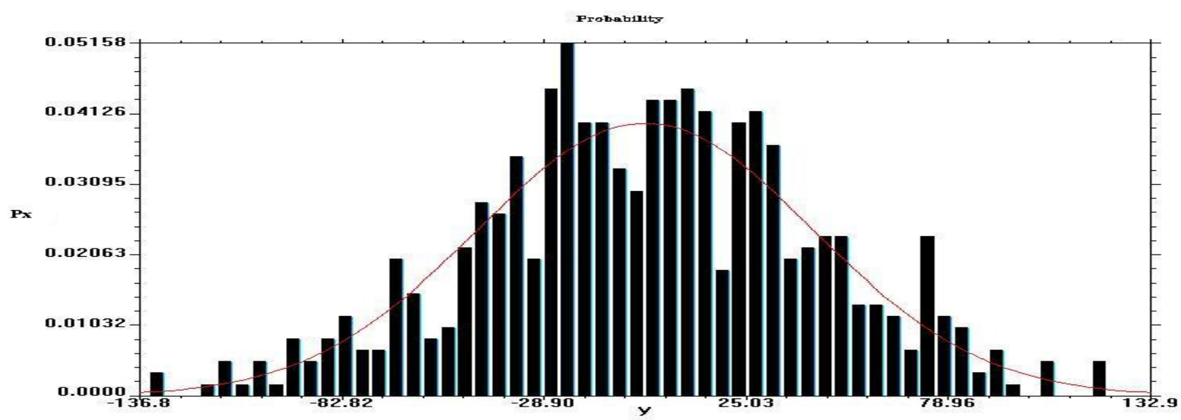

Fig. 4. Probability distribution function of electric field intensity variation at the time of strong wave activity at the time 01:25:28.975UT-01:25:29.215UT.

V. CONCLUSIONS

We have analysis the ELF/VLF emission registered by the DEMETER on the 4day and 7day before the Hokkaido earthquake by the wavelet and higher order statistical tools.The present study shows strong emission prior the event. In this work data is taken at the quite time period and so no ionospheric and magnetospheric sources of perturbation were expected. These turbulence characteristics are not only specifically accours in the time of earthquake its is seen at the high lattitude and equatorial [2,36]. Due to the closest occurrence in time and space of the recorded turbulence with this earthquake, consider that the effects observed in the mid-attitudes are related to a perturbation of the ionosphere that might be related with the preparation for this Hokkaido earthquake.

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