Precursor of earthquake using night time VLF amplitude

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Abstract

The results of the analysis of the year-long (2007) monitoring of the night time data of the VLF signal amplitude from the Indian Navy station VTX at 18.2kHz, received at the Indian Centre for Space Physics, Kolkata, are presented. We analyzed this data to find out the correlation, if any, between the night time fluctuation and the seismic events. We found, using individual cases (with magnitudes > 5) as well as statistical analysis (of all the events with effective magnitudes greater then 3.5) that the night time fluctuation of the signal amplitude has the highest probability to be beyond 2σ level about three days prior to the events. Thus the night time fluctuation could be considered as a precursor to the enhanced seismic activities.

1 Introduction

It has been pointed out almost two decades ago that the night time radio signals show anomalous fluctuations several days before the earthquakes (Gokhberg et al., 1989; Gufeld et al., 1992; Rozhnoi et al., 2009; Kasahara et al., 2010). There are several other methods such as the terminator time method (Hayakawa et al., 1996; Molchanov et al., 1998; Hayakawa and Molchanov, 2000; Sasmal et al., 2009) and the D-layer preparation time and the D-layer disappearance time (Chakrabarti et al., 2010) method which can also be used as the precursory effects of earthquakes. Indian Centre for Space Physics has been monitoring the VLF signals from various stations to look for the ionospheric anomalies and to check if any correlations could be found among them. The results of the correlations between the VLF day length (defined as the time difference between the two terminators) and the effective magnitudes of the earthquakes is already reported for VTX-Kolkata propagation path. (Sasmal et al., 2009). Using the data of the same propagation path it is also reported that the anomalous behavior of the DLPT and DLDT are also correlated with the effective magnitudes of the earthquakes. (Chakrabarti et al., 2010). In the present paper we discuss about the anomalous night time VLF amplitude fluctuations before the seismic events. For this we use the data of the year 2007. We find that three days prior to major seismic activities, the night time fluctuation is most significant. This is found to be the case for many individual earthquakes. At the same time, when we compute the effective magnitudes of the collection of earthquakes on each day and correlated with the night time fluctuations, we found that this statistical correlation also peaks three days prior to the event date. This result is consistent with the typical $2-5$ days of precursor time found in other methods (e.g., Kasahara et al., 2010, etc.). Details of our results are in Ray et al. (2011).

2 Methodology of our Analysis

We receive the VLF signals at the several receiving stations of Indian Centre for Space Physics, located all over the India. But for the present paper we analysis the VLF signals received at our Kolkata-station which is located in the south side of Kolkata (Lat. $22°34'$, Long. $88°24'$) city. We use the AWESOME receiver which receives signals from several stations. In particular, we concentrate on the Indian Navy VLF transmitter station VTX, which is located at Vijayanarayanam (Lat. $08°26'$, Long. $77°44'$). This station transmits the VLF signal at 18.2 kHz. In an AWESOME receiver, the antenna has two cross-loops which are capable of detecting fluctuating magnetic field components in the VLF signals. After receiving the data by this antenna, first it is pre-amplified and time stamped by a GPS unit. The data is automatically stored in the computer. For the present purpose, we consider only the data of the local (IST=UT+5:30 hours) night time beginning at 19:30 hours (14:00 UT) and ending at 04:30 hours (23:00 UT) of the (local) next day

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

with a one hour gap just prior to the midnight for data analysis. We picked the data away from sunrise and sunset terminators by at least an hour to avoid contamination from the D-layer formation or disappearance effects. To measure the fluctuation we Use the data set on each day (denoted by i) and compute the mean and the standard deviation (Σ_i). In Fig. 1(a), we plot Σ_i (marked with '+' signs) in dB as a function of i. In order to quantify some fluctuation as anomalous, we need to know what the mean and standard deviation of quiet day fluctuations are. We are assuming that the following is a reasonable procedure to define the mean and the standard deviation of quiet days: we first take the mean and the standard deviation σ out of of all Σ_is and eliminate those fluctuations which are beyond 2σ level. This way we remove 'significantly' anomalous data from our collection of Σ_is to obtain the profile of the mean fluctuation throughout the year, possibly in the absence of seismic events. After this, we compute the mean and compute the standard deviation σ once more. The solid curve in the center represents the mean curve. The solid curves above and below are at $\pm 1\sigma$ and $\pm 2\sigma$ levels respectively. We clearly see many night time fluctuations which are beyond 2σ level. On certain days, there were seismic activities which are shown by open circles in Fig.1(a). This circles are placed right next to the suspected data which may be visually associated with that quake, just for reference, however, true association would automatically be determined from the computation of the correlations (see below). The effective magnitudes (M_{eff_i}) of the activities on each day were computed in the following way. We consider the seismic events which occurred in the neighborhood of the path (GCP) between the transmitter and the receiver. For this purpose, we collect the latitudes and longitudes of the places of the earthquakes, their magnitudes, the depths of the epicenters etc. from the Indian Meteorological Department (http://www.imd.gov.in). We calculate the energy of the earthquake by using the equation $log_{10}E = 4.4 + 1.5M_s$, (for earthquakes $M < 5$) and $log_{10}E = 5.24 + 1.44M_s$, (for earthquakes $M > 5$) fifth magnitude), where, E = energy of the earthquake in Jules and M_s = surface wave magnitude (Lowrie, 2007). We converted this M_s to M by using this formula: $M_s = -3.2 + 1.45M$ (Tobyas & Mittag, 1991). These are empirical relations and thus do not match exactly for $M = 5.0$. However, this does not affect out result. To calculate the effective magnitude M_{eff} of the earthquake on each day, first we obtain the energy of the earthquakes and then we divide this energies by the GCP distance between the mid reflection point and the epicenter of the earthquakes. Here we assumed that the wave is propagating as a Rayleigh wave, though for earthquakes with epicenters deep inside, there may be deviation from this consideration. After adding all the energy contributions on a given day, and using the above formulas backward, we calculate the $M_{eff_i} = M_s$ on each day. Finally we converted this M_s into M. In order to avoid clumsiness, we chose the earthquakes having effective magnitude > 3.5 only. As discussed above, this effective magnitude is a measure of the amount of energy deposition at the mid reflection point and it major contribution comes from the strongest seismic activities. It is to be noted that Fig. 1(a) is for illustration purpose only. While computing the correlation between the standard deviation and the effective magnitude, we used *all* the data and not just those which appear to be anomalous.

3 Correlations of the night time fluctuations and seismic activities

In Fig. 1(b), we present two typical examples of the night time amplitude variation of the VTX signal as a function of time (UT). The 'normal' data (dashed curve) of February 15th, 2007 with fluctuation below 1σ (Fig. 1a) is compared with an 'anomalous' data (solid curve) of February 16th, 2007 with higher night time fluctuation. On 19th February, 2007 there was a moderately strong earthquake ($M = 5.4$) at Southern Sumatra, Indonesia. The anomalous fluctuation of 16/2/2007 could be the precursor of this earthquake.

First we show that when we consider a case by case basis, many of the strong quakes show a correlation with Σ_i. In Fig. 2(a-f), we plot Σ_is for a few days around six prominent earthquakes. (a) 18/1/2007 ($M = 5.8$) at Southern Sumatra, Indonesia; (b) 29/1/2007 ($M = 5.2$) at north of Camorta, Nicobar; (c) 11/2/2007 ($M = 5.6$) at off-coast of Sumatra; (d) 19/2/2007 ($M = 5.4$) at southern Sumatra; (e) 20/4/2007 ($M = 6.2$) at Southwestern Ryukyu Islands, Japan and (f) 24/7/2007 ($M = 5.4$) at northern Sumatra. In all of these cases, we find that three days prior to the earthquake, Σ_i became around 30dB or more. Clearly, this is not the case for all the earthquakes. That is why we carry out the statistical analysis. In Fig. 2(g), we plot the correlation coefficients between the Σ_i and M_{eff_i}. The histograms are drawn at one day interval.

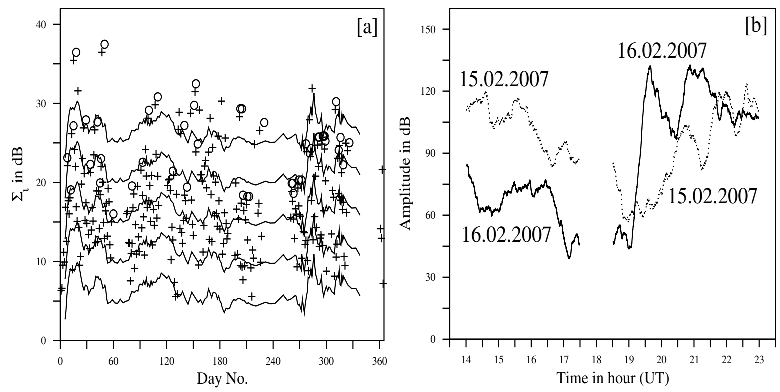

Figure 1: (a) The variation of Σ_i (marked with a '+' sign), the fluctuation on ith day, as a function of day number i for the year 2007. The solid curve in the center is the mean drawn through these Σ_i and the curves above and below are for $\pm\sigma$, $\pm 2\sigma$ variations around the mean. The circles represent the earthquakes having effective magnitudes $M_{eff_i} > 3.5$ on each day (shifted suitably) just to show the association of the earthquake with an observation. (b) An example of a quiet night time (15/2/2007) data as compared with an anomalously fluctuating night time (16/2/2007) data. High fluctuations in the signal amplitude on the the 16th February, 2007 is evident.

Here too, we find that the peak of the correlation is located at three days before the event day. The peak is not unity, since the correlation is not certain. There are significant correlations in other nearby days also. However, we could interpret these coefficients as the un-normalized probability for seismic events. Our prediction of an earthquake within three days is in line with pre-cursors discussed by several workers in 2 to 5 days (e.g. Kasahara et al., 2010, etc.).

4 Concluding Remarks

It has been recognized that the prediction of earthquakes is one of the most difficult tasks faced by the scientific community throughout the world. Any new input, findings or correlations could add to our understanding. While the night time fluctuations were thought to be precursors of an earthquake event, very few studies have been made on this phenomenon (e.g. Kasahara et al., 2010, etc.). In this paper, we presented the analysis of our results. Unlike others, we did not quantify the fluctuations by Fourier analysis, but we simply measured the deviation from the mean signal amplitude. We show both by the case by case analysis of several major earthquakes or by a statistical analysis of all the events in a year, there are hints of significantly large fluctuations in the night time data three days prior to the earthquake activities. There are significant fluctuations before and after, since the correlation coefficient variation with time lag (lead) does not follow a sharp curve. Figure 2(g) can thus be interpreted as un-normalized probability of an earthquake's occurrence within next few days. However, the appearance of the peaks seems to be robust in both the cases by case analysis and in statistical analysis. Because there are always some seismic events after few days, it is difficult to compute the correlations for a very long time since the effect would be due to multiple seismic events. We believe that ours may be treated as the strongest ever evidence of correlations between the ionospheric anomalies and the seismic events. However, pointing to the location of the epicenter is still a distant goal. In future, we will analyze data of other stations and from the fluctuations of amplitudes from several stations at a given time, it may be easier to narrow down the location of the future seismic activities.

S. Ray thanks a RESPOND project of ISRO. Discussions with S. Sasmal and S. K. Mondal are greatly acknowledged.

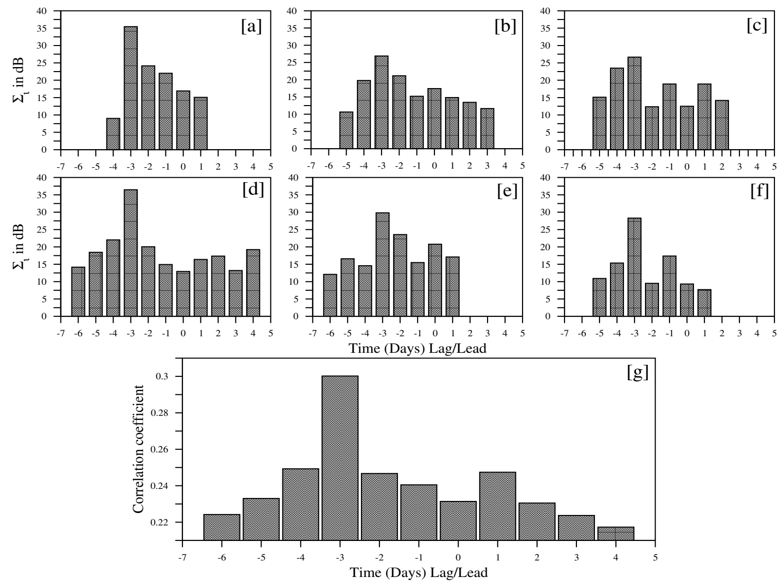

Figure 2: (a-f) Examples of some cases where the fluctuation measure Σ_i became anomalously high three days prior to the seismic activities. (g) Correlation between the effective magnitude M_{eff_i} of the earthquake at the middle point between the transmitter and the receiver, and the standard deviation of the fluctuation measure Σ_i. Note that the correlation peaks three days before the event days.

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