

# Unusual Sunset Terminator behaviour of VLF signals at 17KHz during the Earthquake episode of Dec., 2004

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We have been monitoring VTX station at 17KHz from the Centre for Space Physics VLF receiver. While everyday we receive the so-called classic patterns of sun-rise and sun-set, we started observing irregular behaviour of the local terminators from December 22nd, 2004 onward and it continued till the 30th of December, 2004. It is to be recalled that the devastating Tsunami occurred on the 26th of December, 2004 due to an earthquake 9.0 Richter scale and there were several aftershocks at the level of 6.0 or more in the Richter scale in the next few days which followed. The terminator times shifted towards the night. We suspect that these abnormal behaviours could be due to movements of the ionospheric layer as pointed out by Prof. Hayakawa in his observations in Japan.

## 1 INTRODUCTION

The Centre for Space Physics (CSP) VLF receiving station in Kolkata (22°34'N, 88°24'E) has been monitoring VLF signals almost continuously and the data acquired during the last week of December 2004 showed much anomalous behaviours in the signal amplitude. The VLF receiver was monitoring the VTX station located at Vijayanarayanam (8°26'N, 77°44'E) at 17 KHz which is 1943 km away from the receiver. The receiving antenna was a Gyrator whose description is available elsewhere [1-2]. The signal is automatically recorded through a sound card and is stored at a sampling rate of two per second. This procedure is valid as long as the signal has frequency below 22 KHz. Fig. 1 shows the locations of the receiver and transmitter as well as the epicenter of the earthquake near Sumatra. Though the epicenter does not fall on the great circle path (GCP), given that the earthquake is one of the strongest, and that the Indian plate moved (by about 15 m) underneath the Burma plate along 1200km rupture line, it is possible to assume that the earthquake

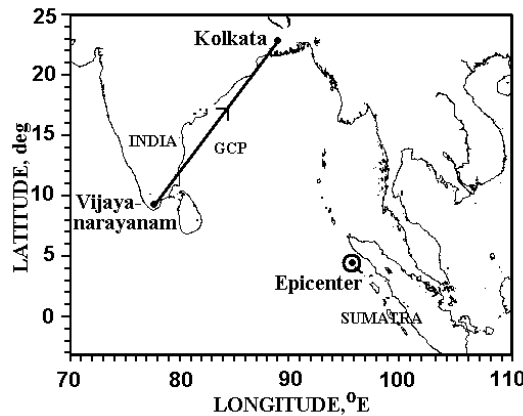


Fig. 1 - Locations of the receiver and transmitter along with the Great Circle Path (GCP). (The epicenter of the earthquake near Sumatran peninsula is also shown.)

preparatory zone is spread out over a large region. On the same day, Andaman and Nicobar islands also had several shocks and aftershocks of magnitude 6.0 or higher. These make one believe that the ionosphere along GCP may have been affected and that is what we detected. The details of the results are presented elsewhere [3].

## 2 RESULTS AND INTERPRETATIONS

Fig. 2 shows the data of the present observation from 20 Dec., 2004 till 2 Jan. 2005, i.e., for a period of two weeks, from 0000hrs to 2400hrs LT (x-axis). The data are shifted in the vertical direction so that the comparison becomes easier. The vertical axis is in decibel (dB) unit. This is the output of the soundcard system in the receiving computer. On 20 and 27 Dec. 2004 and on 1 Jan. 2005, the data are available for the whole day without any interruption. They show the classical pattern – the modulation of the constant VLF signal by the solar radiation in the daytime and atmospheric scintillations in the nighttime. The gradual fall of the VLF signal at around 0600 hrs LT indicates the formation of the D-layer which brings down the ionosphere to a height of around 50 km. The minima that occur right around sunrise and the sunset are known as the *terminators*. Typically, under the normal circumstances, the terminators are very good measures of the sunrise and sunset times. However, in the Kolkata observation of VTX station over the past few years it has always been noticed that the sunrise terminator is delayed by certain amount of the local sunrise time and the sunset terminator is advanced by the similar amount from the local sunset time. This will be dealt with separately. In other days, though the monitoring was interrupted due to power failure, the general features could be identified. Data were received everyday during sunrise, but during the sunset, data of only eight days (out of 14 days reported here) were available. It is long known that earthquakes could be a major cause of the ionospheric perturbations and the consequent disturbances in VLF signals [4-9]. It is believed that the seismic events cause the height of the reflecting layer to lower by as much as 2 km. Thus, the sunrise and sunset terminators, at which the VLF signal shows minimum will show anomalous shifts, as if the

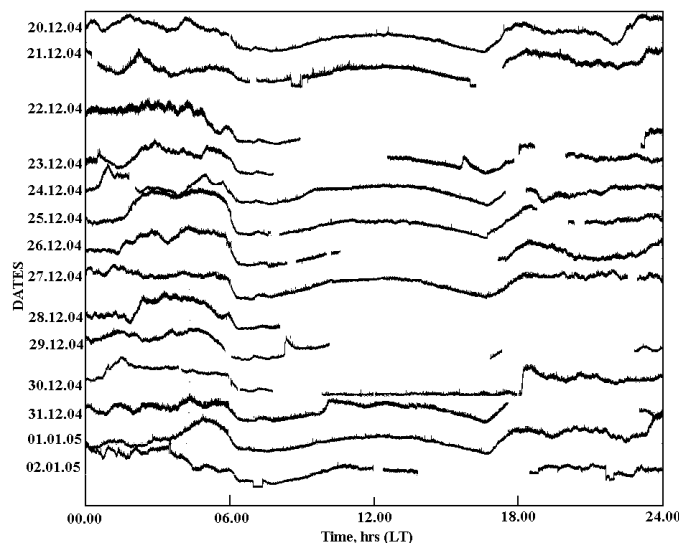


Fig. 2 - Variation of the VLF signal amplitude of the 17 kHz signal at the receiving station from 20 Dec. 2004 to 2 Jan. 2005.

daytime has been extended. It is also known that the radon gas concentration rises anomalously above an earthquake epicentre which may also cause high degree of ionization, thereby affecting the strength of the VLF signals [9] at anomalous times. This also increases electrical conductivity of the layer on the earth surface and lower the ionosphere boundary by ~5 km. We think that the effect of shifting the terminator is expected to be higher at the evening terminator, since the fractional change of the ionospheric height is the largest in the daytime. In Fig. 3, we present the results of only those days of which significant data were available during the evening period. Here, the data of four hours are (from 1600 - 2000 hrs LT) plotted. Vertical arrows mark the terminator locations. Figure 4 shows how the terminator time and the local sunset time vary from day to day. While the sunset time increases monotonically as expected, the evening terminator time shows anomaly in that it shifted towards nighttime by about 9 min on the 24 Dec. 2004. Such a shift, to a larger extent (possibly because of the proximity effect), has been reported earlier for Kobe earthquake [9]. The shift started reducing during 25 - 31 Dec. 2004. After that, it started to rise again. The anomalous behaviour of the evening terminator time that is detected in the present observation could be due to the ionospheric disturbances during major earthquakes. It is to be noted that on 26 Dec. 2004, there were altogether 23 major earthquakes and aftershocks (magnitude 5.0 and above). There were 10 such events on 27, 2 on 28, 7 on 29 and 4 on 30 December. Thus, the anomaly started even on 25 December, when there was no reported earthquake. The data on earthquakes have been taken from the website <http://tsunami.geo.ed.ac.uk/>. Thus, even though the epicenter was more than a thousand kilometre away from GCP between the transmitter and receiver, the general preparatory region was so nig that the effect may be interpreted to be due to the earthquake activities. There were no solar flares, etc. at the terminator times to cause changes.

### **3 CONCLUSIONS**

We report that the ionosphere in the VLF propagation path has behaved anomalously during 22 - 31 Dec. 2004 in that the evening terminator time was shifting towards night. Since a major earthquake occurred on the 26 Dec. 2004 and several tens of earthquakes and aftershocks dotted the Sumatra-Andaman islands region during that period, an attempt was made to co-relate these two phenomena. It was known in the literature that either because of excess ionization due to release of the radon gas or due to movements of the plates, the lower boundary of the ionosphere can be lowered by 2-5 km. This may have caused the signal modulation. Based on the present result, we believe that in future, the VLF observations may be used to issue warning about possible future earthquakes.

### **ACKNOWLEDGEMENTS**

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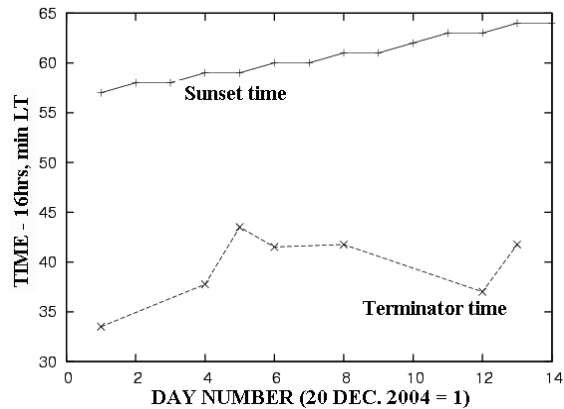
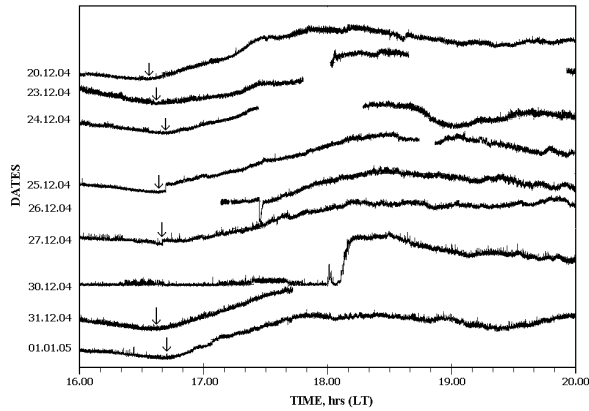


Fig. 3 (left) Four hour data around the evening terminator time. The arrow marks the local minima of the signal before actual sunset.

Fig. 4 (right) Plot of the local sunset time and the terminator time from 20 Dec. 2004 (1<sup>st</sup> day in the plot) till 1 Jan. 2005. The data of 23 December 2004 show shifts by a few minutes, but that of the 24<sup>th</sup> show a shift of about 9 minutes. In subsequent days the shift gradually decreased.

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