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Termination Time Anomalies Associated with Some Regional Earthquakes

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ABSTRACT:In this paper, we make an attempt to test the termination time technique for prediction of earthquake occurred in and around India. We employ NWC, Australia (Lat. 21.8˚S, Long. 114˚E) transmitter signal (f = 19.8 kHz) and consider the earthquakes occurred on 15 March, 2014 (Magnitude = 5.4) and 21 March, 2014 (Magnitude = 6.3) in Northern Sumatra, Indonesia (Lat. 3.0˚N, Long. 99.0˚E) and Nicobar Island Region (Lat. 7.5˚N, Long. 94.2˚E) respectively. We analyse phase and amplitude of the signals recorded at Agra station (Lat. 27.2˚N, Long. 78˚E), India for the period 20 February, 2014 to 25 March, 2014. Our results show that termination time anomalies do occur but the duration of the anomalies is very small of the order of 16 minutes, which is not significant enough to adopt this technique for earthquake prediction studies and hence it is suggested that the nighttime fluctuation technique should be adopted. The anomalies in the lower ionosphere are found to be caused by atmospheric gravity waves.

KEYWORDS:VLF, Termination time, Earthquake prediction, NWC transmitter signals

I.INTRODUCTION

VLF signals transmitted from fixed frequency transmitters are propagated to long distances through earth-ionosphere space. Since, the earth has large conductivity, the changes in the amplitude and phase of VLF signals are caused mostly by structural and dynamical changes in the lower ionosphere. In recent years, out of many factors causing such changes, earthquake is found to be one of them and hence the monitoring of VLF signals has become a tool for prediction of earthquake. Two methods have been proposed to employ this technique for earthquake prediction studies, which are known as Nighttime Fluctuation and Termination Time method.The first method is based on the analysis of nighttime amplitude and phase anomalies (Gufeld et al., 1992;Gokhberg et al., 1989) and it was further developed as the Fluctuation Method (Shvets et al., 2002, 2004a, b; Hayakawa et al., 2002, 2004a, b). The second method is called the terminator time method, which is based on the determination of the characteristic times of minimums in the amplitude/phase diurnal variations during sunrise and sunset (Hayakawa et al., 1996; Maekawa and Hayakawa, 2006). Hayakawa et al. (1996) presented the first convincing result on ionospheric perturbations for the Kobe earthquake. They found anomalous shifts in the terminator time from a few days before the earthquake until the earthquake date. Hayakawa et al. (1996) and Molchanov et al. (1998) interpreted this terminator time shift in terms of the lowering of the ionosphere by a few kilometers. It was suggested that TT technique was more appropriate for shorter propagation paths. It was further supported by Soloviev and Hayakawa (2002) by the full wave computation. Molchanov and Hayakawa (1998) further found that the ionospheric perturbations appear for a majority of large earthquakes whose magnitude > 6.0, whose epicenter is very close to the great-circle paths and have shallow depth.

The time when the amplitude of the VLF electromagnetic wave in the receiver initially reduces down to the lowest value in morning time defines as sun-rise termination time and sunset termination time is when it secondly reduces down to the lowest value. (Ulas et al., 2012) as shown in Fig.1. Termination times define the lowest level that signals amplitudes reach during the day as shown in Fig.2. Shifting in termination times starting from several days before the earthquake occurs in amplitude characteristic of this signal used as precursor of an earthquake. This shifting may occur backward or onward in time. There might be several reasons of this shifting and earthquakes are one of those reasons. Yamauchi et al. (2007) performed studies which indicate that there is shifting in sunrise termination time (τ_m) and sunset termination time (τ_e) during several days before the earthquake happens.

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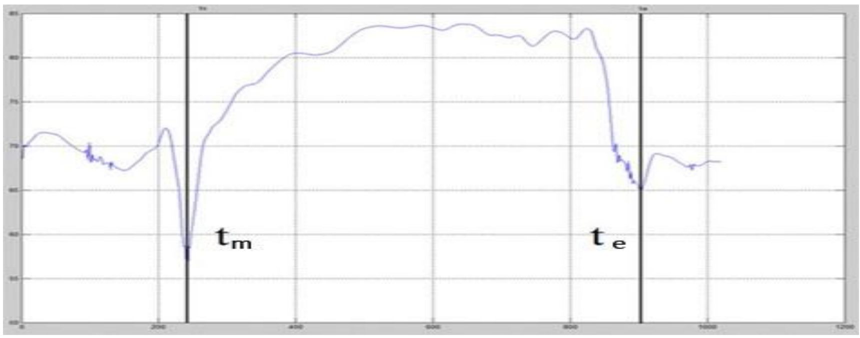

Fig. 1 Detection of termination time on electromagnetic waves (Ulas et al., 2012)

Clilverd et al.(1999) applied the TT technique to long propagation path and concluded that the occurrence rate of successful earthquake predictions using termination time technique could not be distinguished from that of chance and this method was not suitable for prediction. Rodger et al. (1999) applied propagation models such as Omega-Inubo path in Japan and showed that changes in the VLF reflection height associated with earthquakes would be much larger (~4-11 Km) than those suggested earlier (~1-2 Km). But the calculations of Clilverd et al. (1999) and modeling of Rodger et al.(1999) were questioned by Soloviev et al.(2004) on the ground that the perturbed area by the earthquake precursor in the ionosphere is very small as compared to scale of 12 Mm path and TT change cannot be effected by the entire propagation path as considered in the modeling.

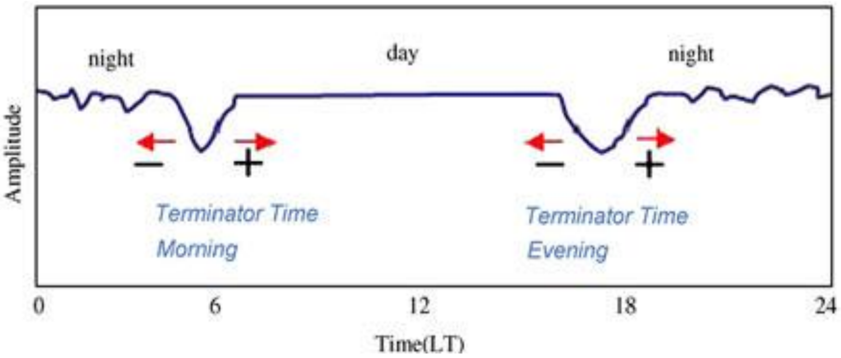

Fig. 2 Sunrise and sunset termination times (Yamauchi et al., 2007)

In the present paper, we consider a medium range propagation path (6.672 Mm) between NWC-VLF transmitter (f=19.8 KHz) located in Australia (Lat. 21.8˚S Long. 114.1˚E) and SoftPAL receiver at Agra, India (Lat. 27.2˚N, Long. 78˚E) and examine the effect of the two earthquakes that occurred on 15 March, 2014 (M=5.4), Northern Sumatra, Indonesia and 21 March, 2014 (M=6.3), Nicobar Island Region close to GCP. Our results show that termination time anomalies do occur but the duration of the anomalies is very small and was not found significant enough to adopt this technique for earthquake prediction studies and hence it is suggested that the nighttime fluctuation technique should be adopted.

II.EXPERIMENTAL SETUP

We have employed SoftPAL (Software Phase and Amplitude Logger) receiver to monitor the phase and amplitude of fixed frequency VLF transmitter signals. We monitor the phase and amplitude of the signal of frequency 19.8 KHz (NWC, Australia). The equipments include electric and GPS antennas, VLF amplifiers, a service unit, DSP card, and necessary software. The sampling rate used is 60 s. Regular monitoring of phase and amplitude variations of the signals has been started since 1 August, 2002 in the Seismo-Electromagnetic and Space Research Laboratory in the R.B.S. Engineering Technical Campus, Bichpuri, Agra. Bichpuri is a rural area, located at about 12 km west of Agra city where local electric and electromagnetics disturbances are low.

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III.RESULTS AND DISCUSSION

We have conducted the observation of the time period 20 February, 2014 to 25 March, 2014 and collected significant amount of data related to amplitude and phase of VLF signals of the frequency 19.8 KHz (NWC signals). In the present study the details of the earthquake data are taken from United States Geological Survey (USGS) website http://earthquake.usgs.gov/earthquakes/. The details of those earthquakes such as date, time, depth, magnitude, location of their occurrences are given in Table 1.

Table 1 Earthquakes which were observed between 20 February, 2014 and 26 March, 2014

	Date	Time (UTC)	Latitude (deg.)	Longitude (deg.)	Depth (km.)	Magnitude	Region
1.	14.3.2014	13:38:08	07.7˚N	94.4˚E	10	5.5	Nicobar Islands Region
2.	**15.3.2014**	10:58:47	03.0˚N	99.0˚E	170	5.4	Northern Sumatra, Indonesia
3.	**21.3.2014**	13:41:06	07.5˚N	94.2˚E	15	6.3	Nicobar Islands Region

The great circle path (distance = 6672 Km) between NWC (Australia) and receiving station at Agra is shown in Fig. 3. This figure is also showing the locations of earthquakes by a solid circle. The earthquakes observed on 15 March, 2014 and 21 March, 2014 were close to the path of the signals coming from the NWC (Australia) to Agra, India. These two earthquakes affected the VLF signals which we have considered for study in this research work and they led to the important effect in the termination time of the recorded signals.

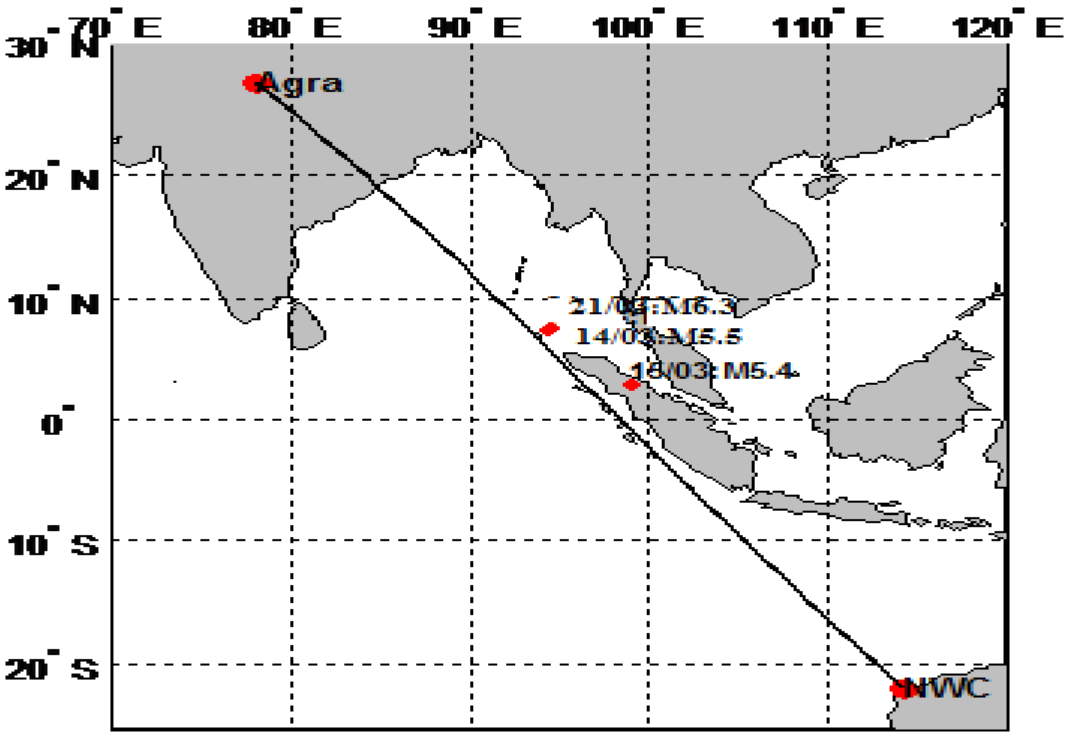

Fig. 3. Location of transmitter (NWC, Australia), receiver (Agra), Great Circle Path (GCP) between NWC (Australia) and Agra (India) and epicenters of earthquakes occurred on 15 March, 2014, 21 March, 2014 and 14 March, 2014

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Fig. 4.shows the variations of the sunrise times during the period of collected data. This figure is showing the variations in the sunrise local time (LT = UT + 5.5 hrs.) and sunrise measured time. The variations in the sunrise time can be seen from the figure before the earthquakes that were observed on 15 March, 2014 and 21 March, 2014.

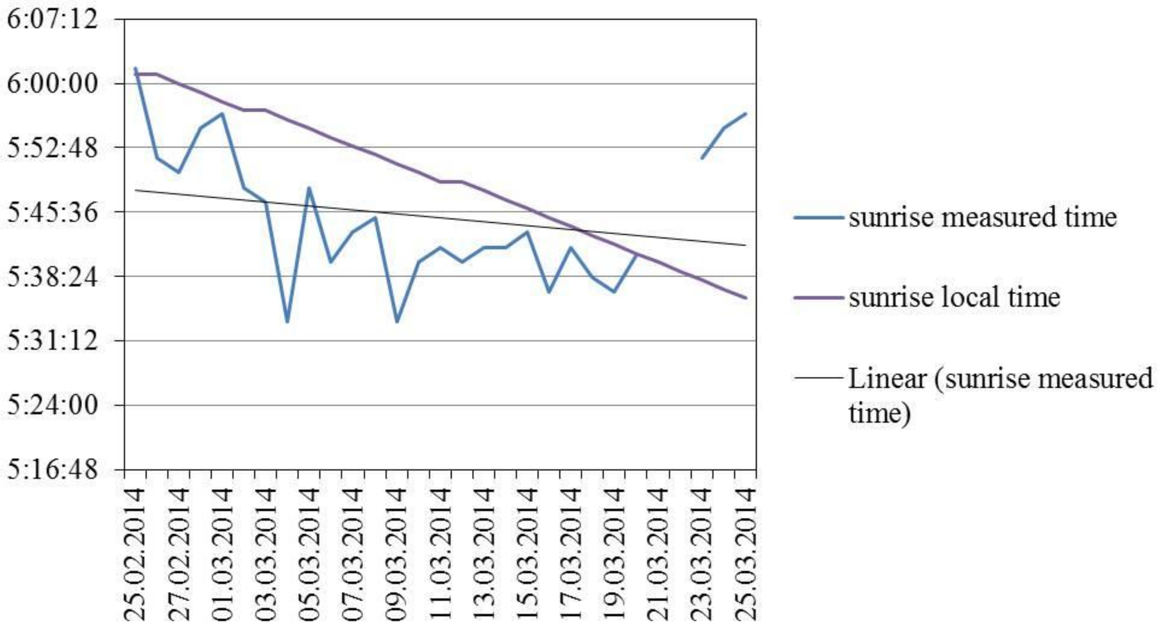

Fig. 4. Variations of sunrise times

The variations in the sunset time are shown in Fig. 5. It shows the variations in the sunset measured time and sunset local time.

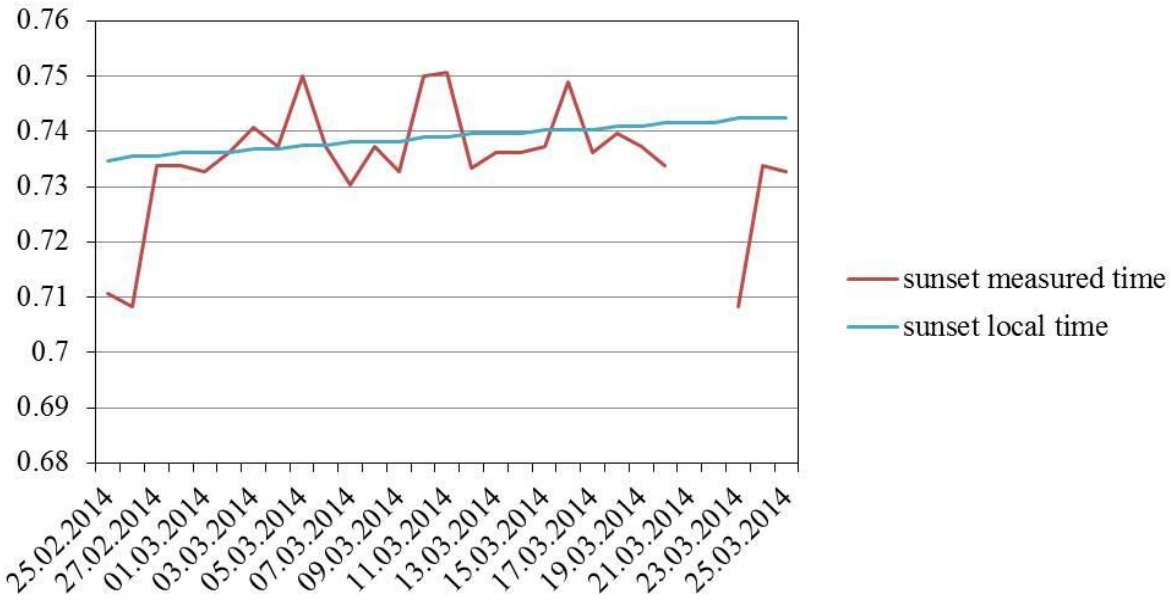

Fig. 5. Variations of sunset times

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Fig. 6.shows the amplitude variation in the VLF signals from 11 March, 2014 to 25 March, 2014. There are variations in the Termination Time before the arrival of earthquake on 15 March, 2014 and 21 March, 2014. These days are marked by arrows. The variations were observed 4 days before the earthquake on 15 March, 2014 and 11 days before the Earthquake on 21 March, 2014. The shift in the sunrise time and sunset time can be seen clearly. Unfortunately, the recorded data of some days was not available, which is mentioned in the figure.

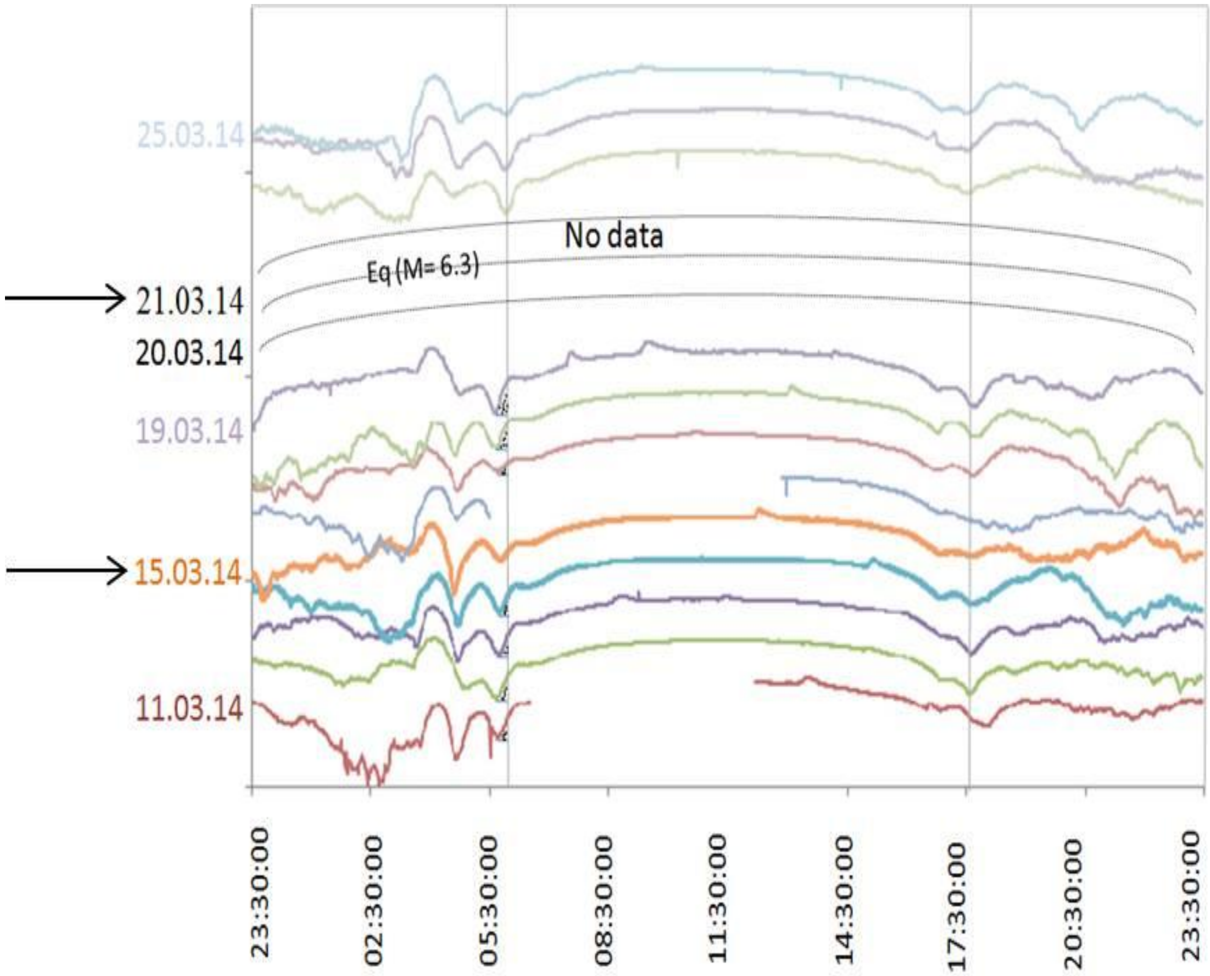

Fig. 6. Variations in the termination time

Fig. 7.is showing the Termination Time variation between 20 February, 2014 and 25 March, 2014. The variations in the termination time are shown in this figure, which are observed before the arrival of earthquakes on 15 March, 2014 and 21 March, 2014. These days are marked by arrows. The maximum variation that is observed is of 16 minutes that was observed on 19 March, 2014 and some variations are obtained in the sunset time before few days of the earthquake. No Data written in the figure shows the unavailability of the data.

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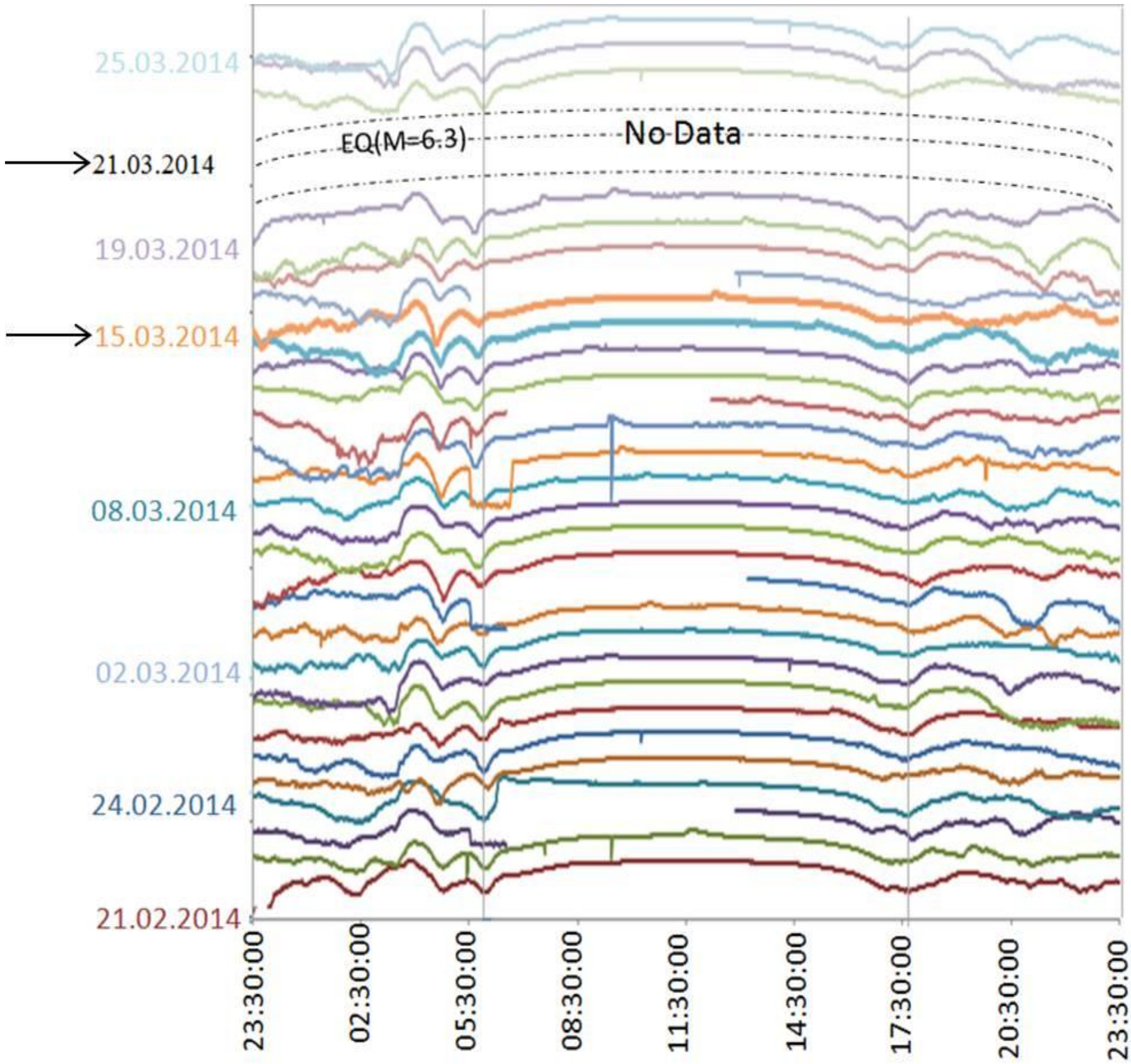

Fig. 7. Variations in the termination time during the time period of 20.2.2014 and 25.3.2014

IV.CONCLUSION

The study of the NWC (Australia) signals (19.8 kHz) received at Agra during the time period 20 February, 2014 to 25 March, 2014 was done. During this time period the three Earthquakes occurred out of which the two Earthquakes, which were close to the GCP of NWC to Agra were considered i.e. on 15 March, 2014, Time (UTC) -10:58:47, Lat. 03.0˚N, Long.99.0˚E, Depth 170 km, Magnitude 5.4, Northern Sumatra, Indonesia and on 21 March, 2014, Time (UTC) -1:41:06, Lat. 07.5˚N, Long.94.2˚E, Depth 15km, Magnitude 6.3, Nicobar Island Region. The continuous recording of the NWC signals was done and it was found that there was the considerable shift in the Termination Time before the arrival of the Earthquakes. The maximum 16 minutes shift was obtained in the sunrise time before few days of the Earthquakes and some variations were obtained in the sunset time also before the arrival of these Earthquakes and the termination time becomes normal after the few days of earthquake. From this research work we conclude that

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the termination time which was proposed by M. Hayakawa and group is suitable for Earthquake prediction. However, the duration of termination time anomaly depends up on many factors and hence considerable trust is given to nighttime fluctuation technique in the present time.

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