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Diurnal seismicity and temperature

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ABSTRACT

Global earthquake catalog data are systematically examined to see the seismicity variation with local time over 24 hours basis. It is observed that the occurrences of earthquakes are more during the night than during the day. The earthuake counts go down during the day and it is minimum in the afternoon at 15 – 16 hours and then steadily goes up till midnight. This typical signature of the diurnal seismicity seems to be consistent for the global earthquake data for different periods, seasons, longitudes and depths. The sagging of the earthquake counts during the day, reduces for latitudes away from the equators. It is seen that this diurnal seismicity plot obtained for large number of earthquakes is modulated by the inverse of diurnal temperature plot applicable for any place close to the equator.

INTRODUCTION

Electro-magnetic (EM) emissions are reported during Sunrise and Sunset (Kolvankar 2007). The Sun induces semidiurnal stresses on the Earth surface, which results in EM emissions in a very wide frequency band from VLF to microwave (KHz-GHz range) (Kolvankar 2008). Several authors reported earthquakes and volcanic eruptions during anomalous EM emissions (Yoshino & Tomizawa 1989, Warwick, Stoker & Meyer 1982, Gokhberg, Morgounov & Pokhotelov 1995, Kolvankar 2007). EM emissions are also reported on the Moon surface at Sunrise and Sunset timings (Bulow, Johnson & Shearer 2005) The signal propagation characteristics, the phase in particular, of the sub-ionospheric VLF Omega that transmit from Tsushima to Inubu, exhibit abnormal behavior at the time of local Sunrise and Sunset (Haykawa et al.,1996). Significant earthquakes in the longitude regions that include California, occur more often in the morning hours than any other time of the day (Goldman, Parkar & Chu YEAR MISSING) Out of 7 great earthquakes (M>7.8) in the Indian region during the last 200 years, five (1819, 1897, 1905, 1941 and 1950) have occurred during the evening or early morning hours. It is found that in general the percentage of earthquakes occurri ng during evening/early mornings are larger than that during the daytime (Srivastava & Gupta 2004). Many of these phenomena, which were observed locally and reported by different workers, have many things in common which induced us to study them on a global scale. The local timings of the earthquakes from standard catalog for very large period are utilized to see the cumulative effects of such phenomena and their effect on the occurrences of earthquakes during the different time of the day.

DATA ANALYSIS

Most earthquake catalogs provide the earthquake data with universal time (UT). The local time (LT) of any earthquake is obtained simply by adding/subtracting the factor of (+/- Longitude (epicenter) /15) to the UT provided in the earthquake catalog. We have used the NEIC-USGS earthquake catalog data, magnitude >4.0 for the period 1973-2006 (up to June) and magnitude >3.0 for the period 2006 (from July) to 2008, longitude -180° to +180°, latitude -90° to +90° and depth 00 to 700 km. About 2,86,474 events were available in the catalogs for the present study.

To see the seismicity pattern for different periods, number of earthquakes (EQ counts) of five–year window for the period 1973-2008, are plotted with time, in 15-minute slots with total 96 slots representing 24 hours. In order to find the basic pattern of these graphs 3/5/7 moving point average (MPA) method is adopted. The top of each 15-minute EQ-count bars is joined to visualize a line graph (Fig.1). These plots do not show any definite pattern when plotted with UT. However, when the same data are plotted with LT, it indicates that the number of earthquakes during the morning, evening and night hours are more. These graphs provide higher EQ counts from 0000 - 0430 hours (LT), and the EQ counts decrease steadily till around 1530 hours, again rise steadily and reach to a maximum level at around 2400 hours. Each of these plot, which can be termed as diurnal seismicity plot (DSP) are very consistent in their pattern. Fig 2 provides DSP for the world earthquakes (1973-2008), which represents average of all DSP plots in Fig 1, distinctly show low EQ counts at around 1530 hours.

DSPs with different MPA values are drawn in Fig 3. Three different sections of this figure provide DSP for 3, 5 and 7 MPA. The higher MPA values provide smoother DSP where as the lower MAP = 3, provides more details with a bit of noisy waveform.

Fig. 4 provides DSPs for different variables; like periods (1973-1984, 1985-1996, 1997-2008), longitudes (-180º-90º, -90º-00º, 00º-90º, 90º-180º), seasons (for the months May-June-July-August

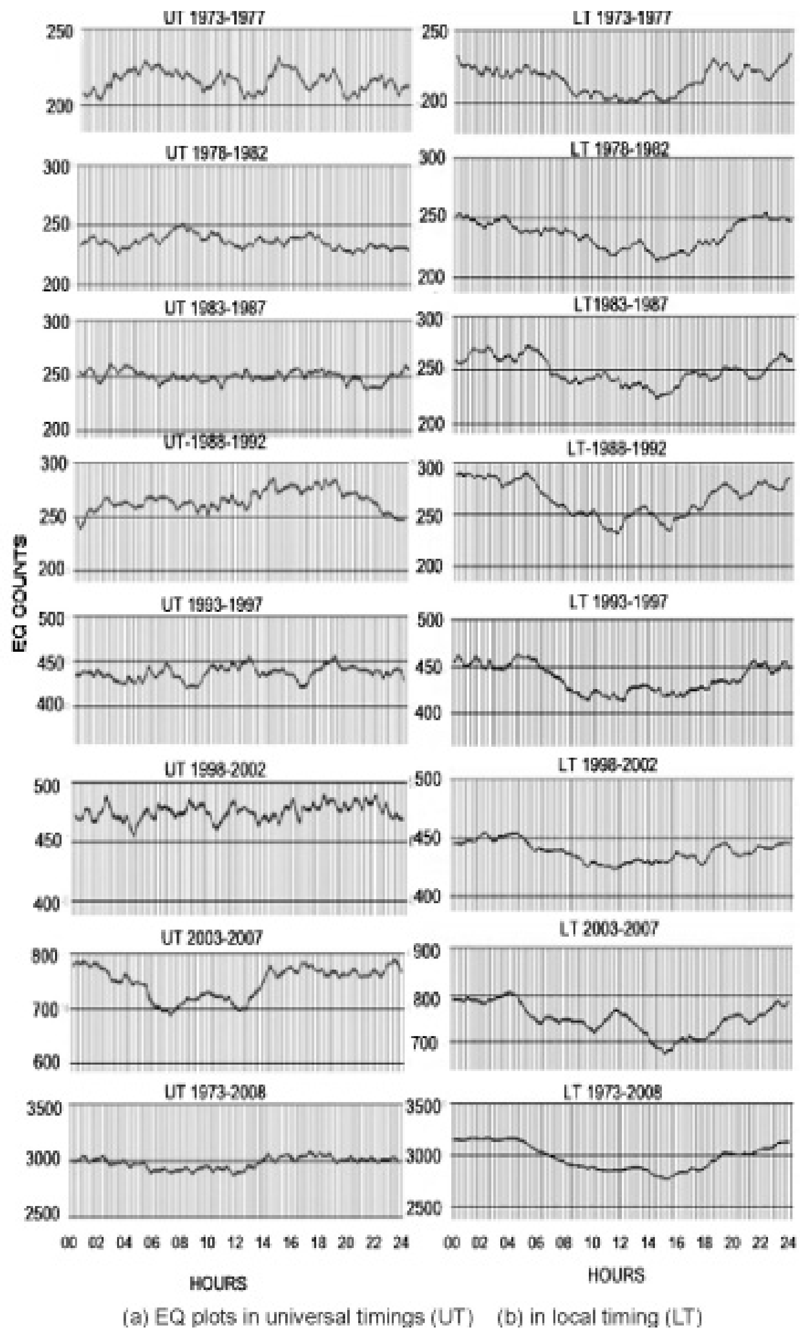


Figure 1. (a) EQ plots in universal timings (UT) and (b) in local timing (LT) for five years blocks during 1973-2008.

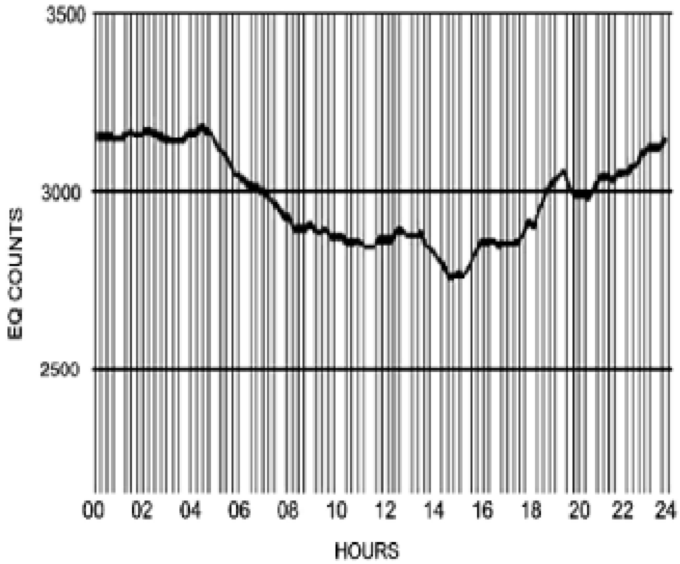


Figure 2. The line-graph shows low EQ-counts during the local daytime for the world earthquakes (1973-2008) for total 2,86,474 events.

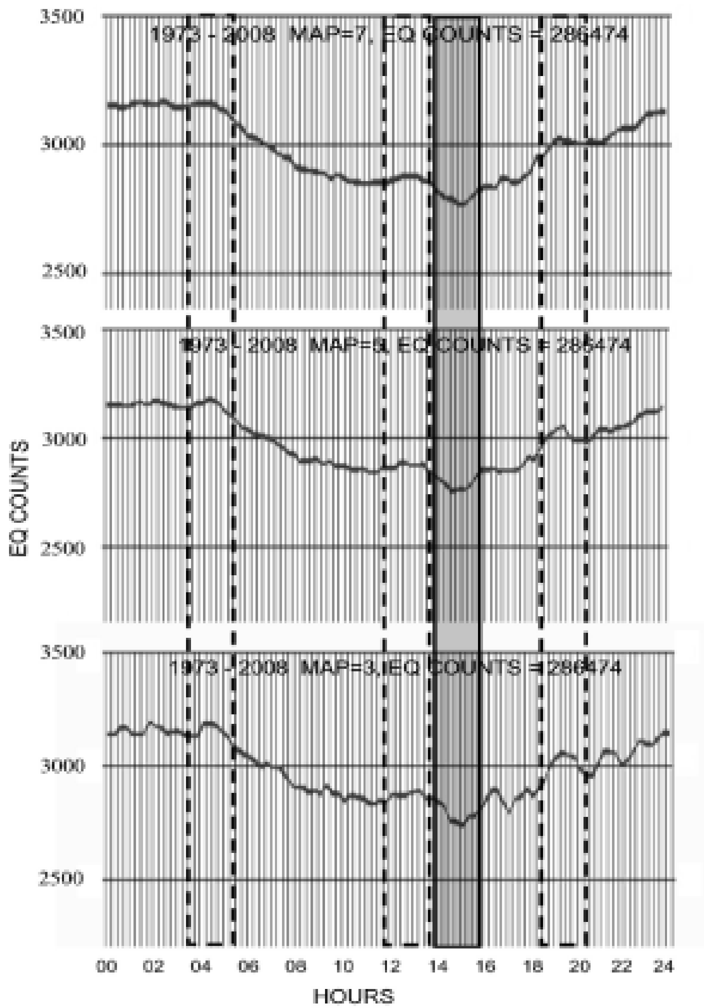


Figure 3. DSPs are drawn with different numbers (3,5,7) of moving averages points *AP).*

(MJJA) when Sun stays above equator, March-April-September-October (MASO) when it stays along the equator and November-December-January-February (NDJF) when it stays below the equator) and EQ depths (0-12 km, 13-40 km, 41-100 km, 101-250 km, 251-1000 km). In all these figures, DSPs are showing almost identical pattern as indicated in Fig.2. However, there are some undulations as marked by four elongated rectangle areas. Three of them provide positive undulations at around 0430 hours, 1300 hours and at 1930 hours (marked with rectangle with dashed lines), where as the one at 1530 hours provides negative undulation marked with semitransparent rectangle. This area indicates that the EQ counts register a minimum counts at around 1530 hours. This basic pattern is similar to that of the inverse diurnal temperature plot (DTP) for locations close to equator. The diurnal temperature plot indicates a maximum temperature at around the same time, which gradually goes down till around 0600 hours in the morning and then steadily rises to a maximum level at 1530 hours. This observation suggests that the diurnal seismicity has a good correlation with the inverse of DTP.

The two undulations at 0430 hours and at 1930 hours could be the effect of the gravitational force from the Sun acting tangential to the edges of the Earth. Actually RF noise is observed at Sunrise (0600) and Sunset (1800) and the EQ counts are expected to be higher. The locations for these undulations at 0430 and 1930 hours lay behind the tangential points (0600 and 1800 hours) on earth with respect to Sun position. Similarly major undulations are also seen during the midday at about 1200-1300 hours and these could have been induced by semidiurnal stresses which triggers earthquakes (Kolvankar, 2008).

Fig 4B provides DEP for different set of longitudes. The quadrant 90^o to 180^o has the highest EQ counts, and it contributes to over 55 % of the total world earthquakes. Due to high EQ counts, the DEP for this region is much smoother than the other three quadrants.

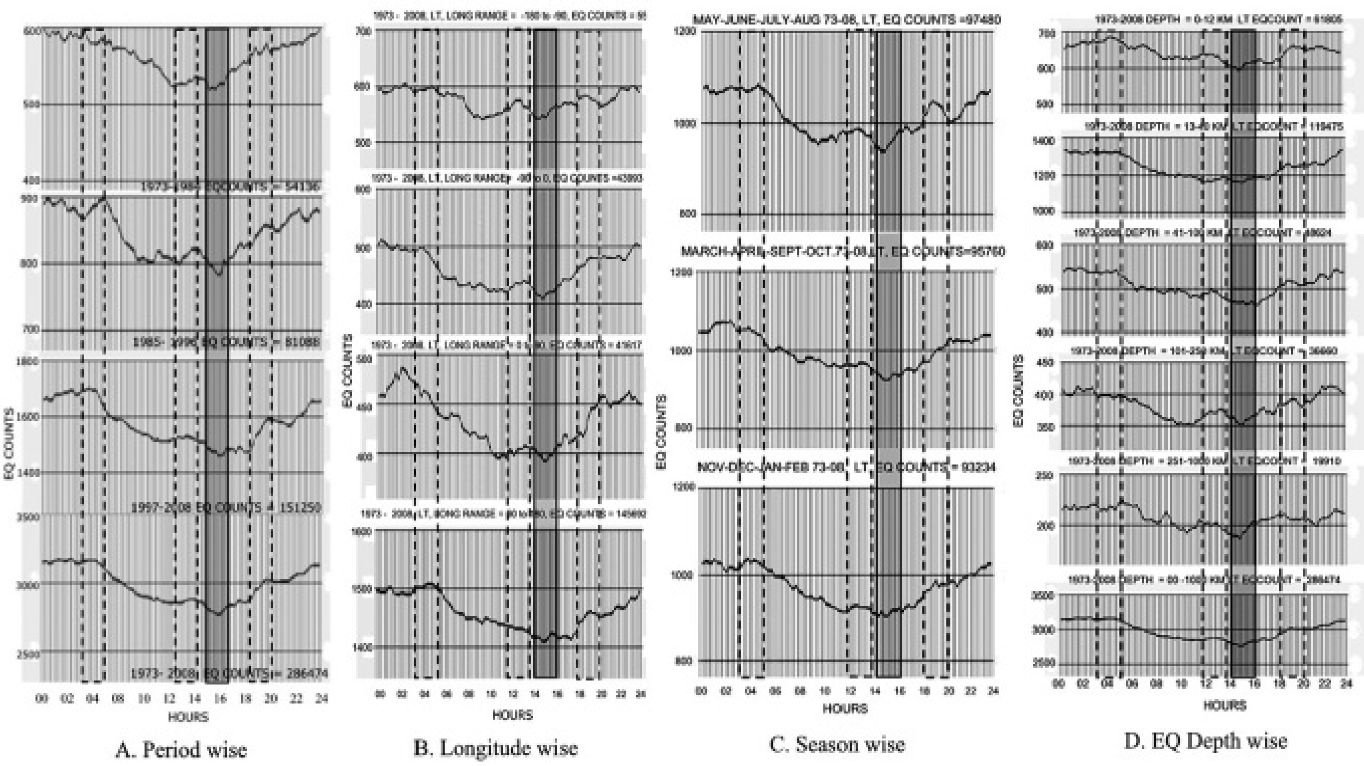


Figure 4. Four DSPs for different parameters A. Periods (1973-1984, 1985-1996, 1997-2008) B. Longitudes (-180^o-90^o, -90^o-00^o, 00^o-90^o, 90^o-180^o) C. Seasons, for months May-June-July-August (MJJA), March-April-September-October (MASO) and November-December-January-February (NDJF) and D. EQ depths (0-12 km, 13-40 km, 41-100 km, 101-250 km, 251-1000 km), period 1073-2008.

VARIATION IN LT INDICES

In order to account for an amount of sagging seen during the daytime in the diurnal seismicity plot (DSP), two indices are defined. The first one is defined as LT Index A and the second one as LT Index B. These indices are defined below:

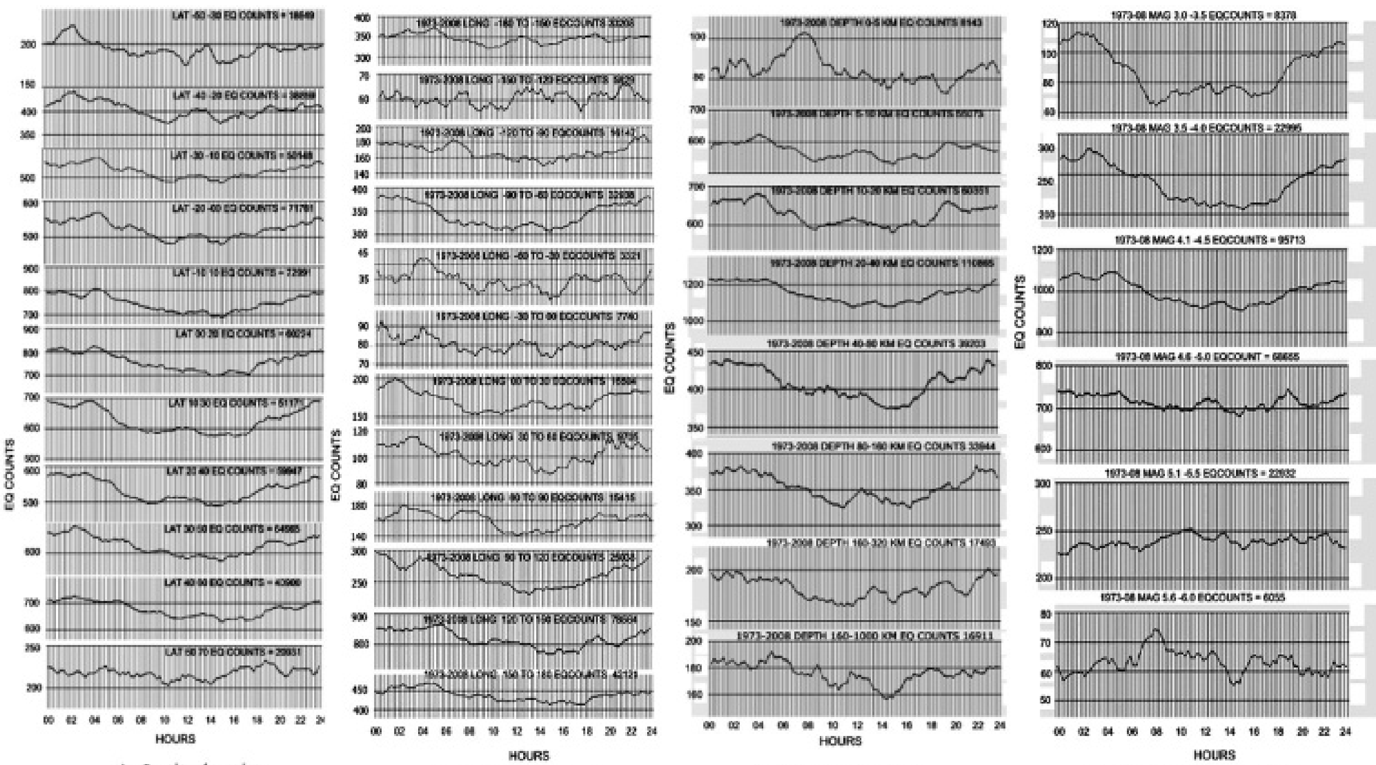
LT Index A = ((EQ counts during the night period, 20 – 04 hours) / (EQ counts during the day period, 08 – 16 hours)) -1) * 100.

LT Index B = ((EQ counts during the night period, 00 – 04 hours) / (EQ counts during the day period, 13 – 17 hours)) -1) * 100. During 00-04 hours the EQ counts are maximum and between 13 - 17 hours they are seen to be minimum.

Fig. 5A provides DSPs for world earthquakes for different sets of latitude ranges. Most DSPs in this figure provide typical sagging in the central area of the plot and the effect proportionately diminishes for latitude ranges away from the equator. Fig. 6A provides plot for LT indices verses sets of latitude ranges. This graph peaks for latitudes at around 10^{o}. As expected LT index B values are higher than the LT index value A, for most sets of latitude ranges. However for the extreme latitude ranges both indices provide negative values as indicated in this figure.

Fig. 5B provides DSPs for the twelve vertical segments of the globe each with a width of 30^{o}. Fig. 6B provides plot of LT indices verses longitude ranges. This figure provides wide variations in the LT index values. The longitude segment of -150^{o} to -120^{o} belongs to the high seismicity area of Alaska and North America. Pacific Ocean occupies the central area of this segment. Since these seismicity areas are located much away from equator, the corresponding LT indices are low. The seismicity area within longitudes 120^{o} to 180^{o} belongs to the east and central of pacific plate and again majority of seismically active areas are much away from equator and hence the LT indices are comparatively lower. The area under the longitudes -30^{o} to 0^{o} belongs to Atlantic ridge which runs from north to south and majority of this area is again away from equator, resulting in lower LT indices value.

Fig. 5C provides DEPs for different depth ranges. It is evident from these plots that all the earthquakes in different depth segments provided this sagging effect during the daytime indicating that the effect is deep rooted. Fig. 6C, which provides plot of LT



A. Latitude wise B. Longitude wise C. EQ Depth wise D. EQ Magnitude wise

Figure 5. DSPs for different sets of parameters A. Latitudes, B. Longitudes, C. EQ depths and D. EQ magnitudes. All these parameters are varied in smaller steps to display minute changes in the signatures of their DSPs.

indices verses depth range, indicates that the LT indices are low for very shallow focus as well as very deep focused earthquakes. In the middle range (5 km to 320 km) the LT indices values are consistently in the higher range.

Fig.5D provides DEPs for different magnitude range. For earthquakes with lower magnitude range (Magnitude range = 3-4), the sagging effect during the daytime is the largest, which tapers down for higher magnitude ranges. DEPs for magnitude range 3-4 also provide saturation effect during the day interval. Fig. 6D provides plot of LT indices verses magnitude ranges. The LT indices show very high value in the range of 42-44 for earthquakes in the magnitude range of 3 to 3.5. Values of these indices reduce with higher earthquake magnitudes and turn negatives for earthquakes magnitude above 5.0. This is also evident from the last two DEPs of Fig. 5D, which indicate higher EQ counts during the day time (middle portion) than during the night period.

Seasonal effect on DSPs is demonstrated in Fig 7. Two sets of waveforms for the latitude ranges (- 60° to - 40°) and (40° to 60°) are illustrated separately to demonstrate the sagging effects in DSPs for the months NDJF (Latitude range of - 60° to - 40°) and for months of MJJA (Latitude range of 40° to 60°), which is absent in other two DSPs of the respective sets. This demonstrates how Sun affects the pattern of DSPs for opposite latitude ranges when it stays away from equator.

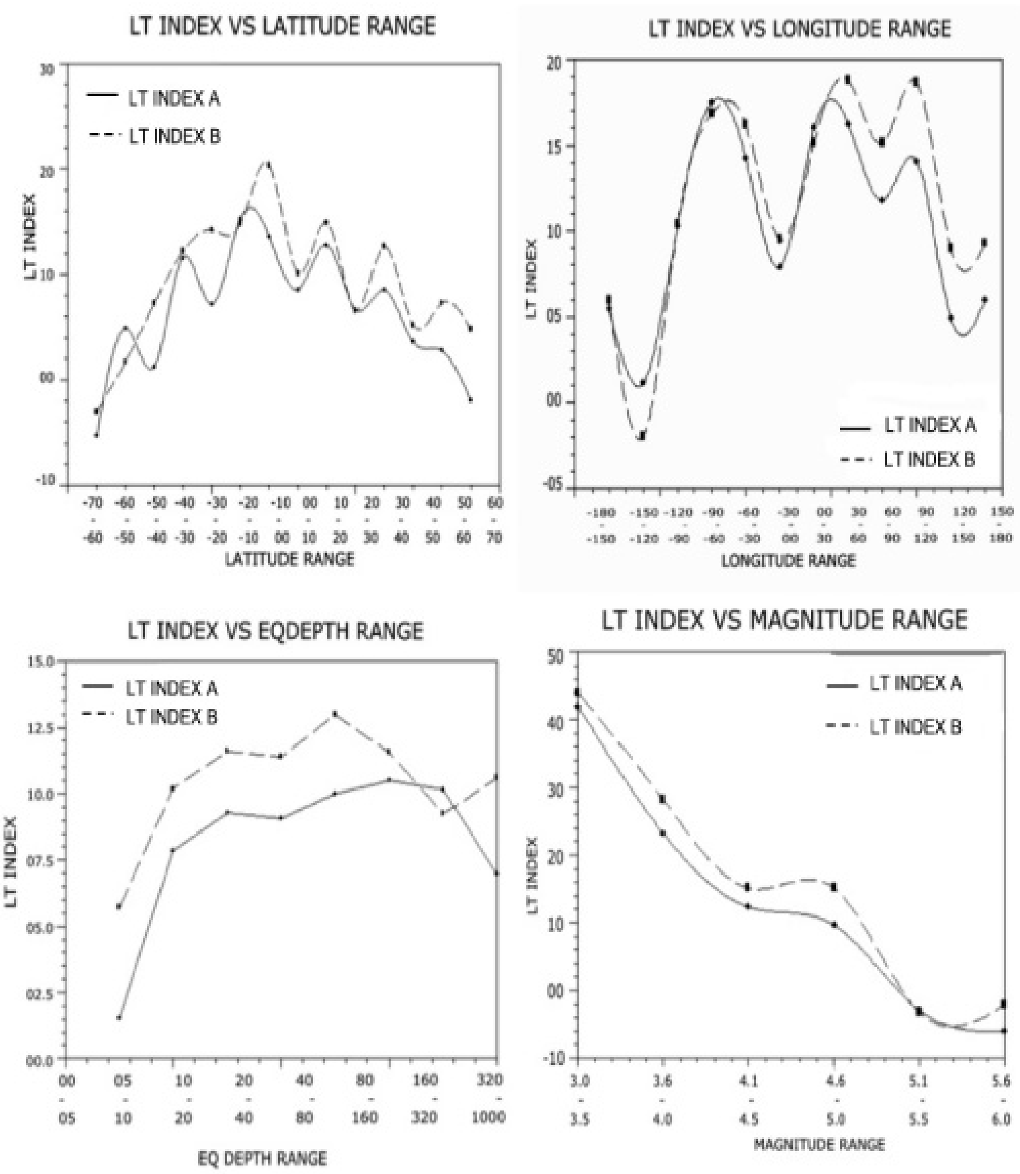


Figure 6. Plot of LT indices verses A. Latitude range, B. Longitude range, C EQ depths and D. EQ magnitudes.

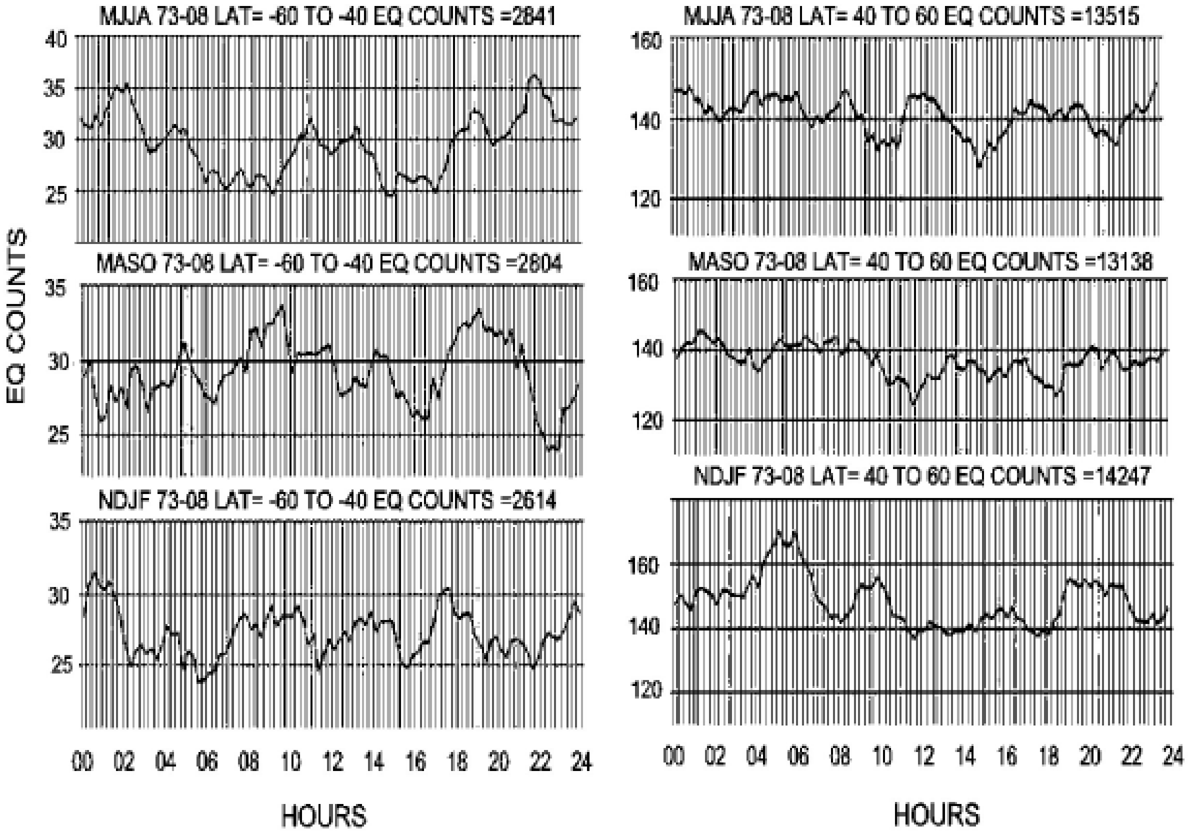


Figure 7. Set of DSPs for three different seasons for latitude ranges of (-60º to -40º) and (40º to 60º).

POSSIBLE CAUSES FOR THE FORMATION OF A TYPICAL SIGNATURE OF DSP

So far the study has been carried out with the data sets utilizing the local time, which in turn provide data sets with respect to the Sun position. These datasets indicate that the primary cause for formation of the typical signature of DSPs, is the Sun itself. Earth receives light and heat energies from the Sun. Apart from these two inputs, there is gravitational force which binds earth to revolve around the Sun. The typical signature of the DSP suggests that it could be because of the light or heat energy or due to both of these energies. However, if the gravitational force or the tidal stresses due to Sun has any part to play in the formation of diurnal seismicity pattern then since the gravitational force of the Moon on earth is over 2.1 times that of the Sun, and corresponding tidal stresses from the moon are much stronger and the data set aligned to the Moon position would provide more pronounced effect.

In recent times there are good numbers of publications that established clear correlation with shallow focused and smaller magnitude earthquakes with the earth tide. (Metivier et al., 2008, Cochran, Vidale & Tanaka 2004). The earthquakes possibly triggered by the earth tide show higher counts aligned to Moon position. In the diurnal seismicity plot we have exactly different situation where the earthquake counts are lower when the Sun is up in the sky. So it is evident that the tidal force of the Sun does not contribute to the formation of diurnal seismicity plot.

SIMILARITY IN DSP AND THE INVERSE OF THE TEMPERATURE PLOT

Fig.8 provides DSP for world earthquakes (1973-2008). The dashed line trace plot, which is superimposed on this graph, approximately represents reciprocal of the DTP (diurnal temperature plot) for any location close to the equator. The EQ counts in this DSP are at minimum, at around 1530 hours in LT. This is the highest temperature point for any place close to the equator (physical geography.net). The corresponding LT indices values are lowest for such locations. For different seasons when Sun goes

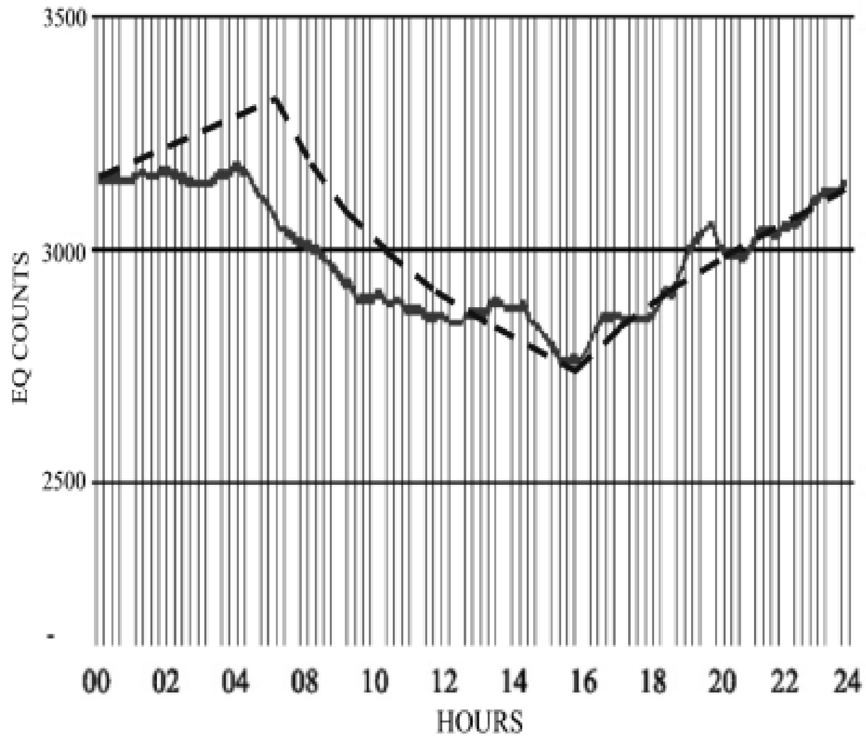


Figure 8. Comparison of diurnal seismicity plot (DSP- red trace) for world earthquake with the inverse diurnal temperature plot (DTP- dashed line).

to north or to south by around 23°, this point may vary +/- 30 minutes around 1530 hours mark (Shimshoni 1971). Although DSP is seen proportional to the inverse of light and heat energies received from the Sun on 24 hours basis, it is the heat energy, which contributes heavily for the formation of DSP.

UPPER AND LOWER SATURATIONS IN DSPS

Fig.9 provides examples of upper and lower saturations in DSPs. The top figure illustrates Fig.2, which provides DSP for the world earthquakes (1973-2008). The portion for 0000 to 0430 hours provides almost constant level although the inverse of DTP shows lowering of temperature during this interval as indicated in Fig.8. The bottom figure provides another DSP for world earthquakes for magnitude range of 3.1 to 4.0 with LT index A = 33. This figure indicates saturation at lower level between hours 1000 to 1800 hours.

DISCUSSION

Few workers studied diurnal seismicity for some localized data. US NOAA (United states National Oceanic and Atmospheric Administration) carried out analysis of 15,325 events for duration 1968-1970 and found larger activity during the night time than during other hours of the day and it is conjectured that the position of the Sun is the cause of the increased seismicity during the night (Shimshoni 1971). The authors (Finn, Blandford & Mach 1972) felt that the detection capability of the week signals diminishes during the daytime on account of greater cultural seismic noise, which results in more events during the night. Similar thinking was provided by Rydelek & Selwyn Sacks (1989), who felt that smaller events should be logged at night than during the day and use day-to-night noise modulation to develop a completeness test of the earthquake catalogs. However, proper instrumentation and selections of good remote site for the sensor housing, has resulted in acquiring good quality data for micro-earthquakes in the magnitude range of -.0.5 and above. The local quarry blasts can also be filtered out with identifications of dominant Rg phase in the coda (Kolvankar 2001). The earthquakes with magnitude 3.0 and above are chosen for the present study and hence can considered as genuine cases.

The phenomenon of low earthquake counts during the day and higher counts during the night period is also not a tidal effect. Among the principal body tide constitutes, M2 (period of 12.421hours)

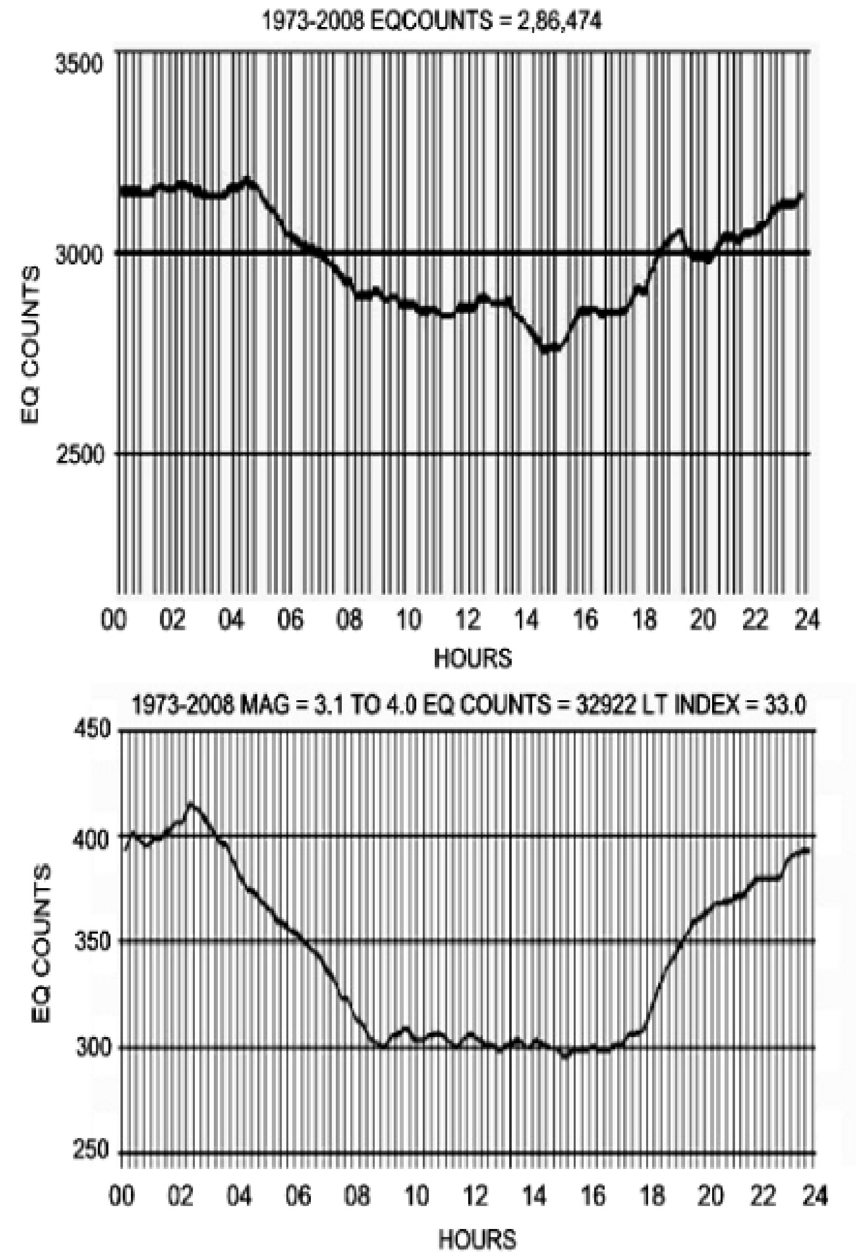


Figure 9. Examples of upper and lower saturations of DSPs. The top figure provides DSP for world earthquakes 1973-2008. Portion of this DSP for 0000 to 0430 hours provides almost constant level although the inverse of DTP shows lowering of temperature during this interval (as indicated in Fig.8). The bottom figure provides DSP for earthquakes (magnitude range of 3.1 to 4.0) with LT index A = 33. This figure indicates saturation at lower level during 1000 to 1800 hours.

has the largest amplitude (typically 384.83 mm) and all other semi-diurnal and diurnal types of tides produces amplitudes of few percentage (up to 50%) of this. The effect of M2 was observed by few workers as stated earlier but the corresponding plots peaks in the centre position when Moon is well above the earthquake locations. However the Diurnal seismicity plot indicate exactly opposite trend which support that there no tidal effect due to tide constitutes S2 (due to Sun) in these plots.

Few workers also provided the direct relationship between diurnal magnetic field and ground temperature. Study of seismic activity in the Mt. Vesuvius area indicated that the variation of solar activity and the earth magnetic field are in close relation to this earthquake activity. The diurnal variation of the earth's magnetic field are caused by the ionosphere currents system generated by solar radiation and even modulates the seismic activity of the local regions. This was observed for various earthquake sequences (Duma & Vilardo 1998), (Duma & Ruzhin 2003). The magnetic field variation caused by the electric current in the upper atmosphere or the ionosphere, which are driven by solar activity, is supported by many other workers (Rastogi 1998). So primarily it is the solar activity, which modulates the H component of the earth magnetic field (Sq variation), which in turns modulates the seismic activity. This effect is seen for earthquakes at all depths and could possibly be caused by the induced magnetic moment (Duma & Ruzhin 2003) due to variation in the earth magnetic field at deeper level as well.

SUMMARY AND CONCLUSIONS

The diurnal seismicity patterns (DSPs) for the world earthquake data (source NEIC – USGS) are very consistent for different periods, longitudes, seasons and EQ depths. The sagging effect of the diurnal seismicity can be measured by two LT indices A & B. Two LT indices decreases for earthquakes away from the equators and their values even turn negative for earthquakes beyond +/- 50^{o} latitudes. Similar effect is seen for earthquakes with different magnitudes. Both LT indices are the highest for low magnitude range and their values goes dow7n for higher magnitudes and as in the earlier case, these values turn negatives for magnitudes over 5.0. However for world earthquakes in different longitude range, these indices show some variations due to various earthquake regions situated much away from the equator. These LT indices for world earthquakes for different depths indicate small variations. The seasonal effect is also seen for earthquakes at +40^{o} to +60^{o} and - 60^{o} to -40^{o} latitude ranges when Sun stays in the south and north respectively.

The four undulations seen in all these DSPs is a very important feature of this study. Out of four undulations, the one at 1530 hours provide negative type and undoubtedly this can be linked to the highest temperature observed for all places close to the equator. The other three provides positive undulations. Of which two are possibly caused at early morning and late evening due to gravitational forces acting tangentially and one between 1200 to 1300 hours is possibly caused by semidiurnal stresses which also triggers earthquakes.

The heat energy received by from Sun inversely modulates the H component of the earth magnetic field, which in turn modulates diurnal seismicity pattern.

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REFERENCES

Bulow, R.C., Johnson, C.L. & Shearer, P.M., 2005. New events discovered in the Apollo Lunar Seismic Data, J.Geophys.Res., 110, E10003,doi:10.1029/2005 5JE002414.

Finn,E.A., Blandford, R.R.& Mack, H., 1972. Comments on "Evidence for higher seismic activity during the night by M Shimshoni "Geophysics. J. R. Astr. Soc., 28, 307- 309.

Cochran, E.S., Vidale, J.E. & Tanaka, S., 2004. Earth tides can trigger shallow thrust fault earthquakes, Science, 306, 1164– 1166. 132.

Data base USGS/NEIC (PDE) 1973 – Present. http://neic.usgs.gov/neis/epic/epic_global.html

Duma, G. & Vilardo., G, 1998. Seismicity Cycle in the Mt. Vesuvius Area and their relation to solar flux and the variation of the Earth Magnetic Field Phys. Chem. Earth, 23 (9-10), 927-931.

Duma, G. & Ruzhin, Y., 2003. Diurnal change of earthquake activity and geomagnetic Sq-variation, Natural Hazard and Earth system Sciences, 3, 171-177.

Haykawa, M., Molchanov, O.A., Tondoh & Kawai, E., 1996. The precursory signature effect of the Kobe earthquake of VLF sub-ionospheric signals. *J. Commun. Res. Lab.*, 43, 169–180.

Gokhberg,M.B., Morgounov,V.A. & Pokhotelov, O.A., 1995.

Earthquake Prediction Seismo-electromagnetic Phenomena. Gorden and Breach Science Publication, 112-113.

Goldman, J.A., Parkar, D.S. & Chu, W.W., 1997. Knowledge Discovery in an Earthquake text database: Correlation between significant earthquakes and the time of the day. http://www.cs.ucla/goldman.

Kolvankar, V.G., 2001. Earthquake Sequence of 1991 from Valsad Region, Guajrat. BARC-2001/E/006.

Kolvankar, V.G., 2007. RF emissions, types of earthquake precursors: possibly caused by the planetary alignments, J. Indi.Geophys. Uni.,11 (3), 157-170.

Kolvankar, V.G., 2007. Earthquake patterns based on diurnal and semidiurnal RF emission related to earthquakes/ Volcanoes observed with 24 hours periodicity, Current Science, 93 (5), 710 -717.

Kolvankar, V.G., 2008. Sun induces semi-diurnal stresses on earth's surface, which trigger earthquakes and volcanic eruptions. New concept in global tectonic newsletter no 47.

Metivier, L., De Viron, O., Clinton, P., Renault, S., Diament, M. & Patau, G., 2009. Evidence of earthquake triggering by the solid earth tides, Earth and Planetary Sci. Letts., 278, 370-375.

Rastogi, R.G., 1998. Distrubance diurnal electric field in Indian and American Equatorial Electrozet Regions, J.of Atmosphieric and Solar Derrestrial Physics, 60, 1471-1476.

Physical Geography.net Fundamentals eBook Chapter 7: Introduction to the Atmosphere (1) Daily and Annual cycles of Temperature.

Rydelek Paul, A. & Selwyn Sacks, I., 1989. Testing the completeness of earthquake catalogs and the hypothesis of self–similarity" Nature 337, 251-253,

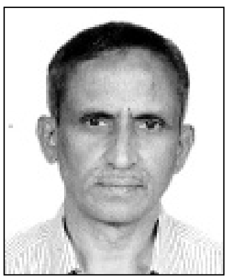
Shimshoni, M., 1971. Evidence for higher seismic activity during the night, Geophysics. J. R. Astr. Soc.,24, 97-99.

Srivastava, H.N. & Gupta, G.D., 2004. Disaster mitigation vis-avis time of occurrence and magnitude of earthquakes in India, Natural Hazards, 31 (2), 343-356.

Yoshino, T. & Tomizawa, I., 1989. Observation of low frequency electromagnetic emissions at precursors to the volcanic eruptions at Mt. Mihara during November 1986, Physics of the Earth and Planetary Interiors, 57, 32-39.

XY plot software developed by Steven Folkman, Mechanical & Aerospace Eng. Dept. Utah State University Logan, UT 84322-4130. http://www.neng.usu.edu/mae/faculty/stevef/prg/ESPlot/index.html

Warwick, J.W., Stoker, C. & Meyer, T.R., 1982. Radio emission associated with rock fracture: Possible application to the Great Chilean earthquake of May 22, 1960. J. Geophys. Res., 87, 2851-2859.



Mr. Vinayak G. Kolvankar retired as scientific officer [H] and Head, seismic instrumentation section, Seismology Division of Bhabha Atomic Research Centre, Trombay, Mumbai. He has mainly worked in seismic instrumentation and has developed various seismic data acquisition systems for different applications, such as for short periods and long period seismic network, rock burst data acquisition etc. He developed reliable trigger mechanism for online event data acquisition, which resulted in reduction in the acquired data considerably. Besides he developed various sub-systems in the form of multi-channel waveform display system, time code generation and extraction, multi-channel analog and digital telemetry, etc. He has also worked for UNESCO's project in Southeast Asia as a consultant on Seismic Instrumentation. He was instrumental in leading a team, which successfully developed a radio telemetered seismic network [RTSN] at Bhatsa to monitor reservoir induced seismicity of the local region, a first of it's kind developed within the country with indigenous know-how. The observations of RF emissions with the remote field stations of this network related to the Valsad earthquake sequence of 1991 led him to study these types of phenomena in details. This paper is one such study conducted to find similar phenomenon which govern the seismicity pattern.