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Characteristics of Global Thunderstorm Extracted from Schumann Resonance at Agra

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ABSTRACT: Schumann resonance (SR) data obtained by employing a set of 3-component search coil magnetometer at tropical station Agra (geographic lat.27.2°N, long.78°E) are analysed for a period of 12 months between 01 April, 2007 and 31 March, 2008. By giving special attention to the study of first mode SR frequency corresponding to X-component (north-south), various properties of global thunderstorm activities are deduced and interpreted. We show that global thunderstorm activities are concentrated in summer months with peak activity in July, 2007. This result is correlated with optical transient detector (OTD) data and a cross-correlation coefficient of 0.81 is found. The peak activity occurring in the month of July, 2007 is supported by a study of monthly variation of frequency range dF ($dF=f_n^{max}-f_n^{min}$) which shows a significant drop in the month of July. We further show that the general decrease in the first mode SR frequency observed at Agra and other Indian stations is due to minimum solar cycle period of 2008-09 (now increasing).

Keywords: Propagation, Resonance, Electromagnetic Radiation, Cavity Resonator, Matlab.

I. INTRODUCTION

Schumann resonance (SR) is one of the most exciting electromagnetic phenomena occurring in the earth-ionosphere cavity. It shows standing waves at ELF frequencies of 8,14,20,…Hz as a result of resonance between direct and round-the-world ELF waves radiated from lightning discharges. Though, the phenomena of SR was predicted long ago in the year 1952[1] and detected experimentally in 1960 [2], the interest in this field has arisen rather recently due to its various applications in the studies of global thunderstorm activities, surface temperature, lower ionosphere, and forecast of monsoon etc. Some of these studies have been made rather extensively and very valuable results obtained. For example, it has been observed that SR increases with temperature on global tropical scale consistent with the observed sensitivity of lightning to temperature in local measurements [3], [4], the SR intensity records have been used to estimate the level of global thunderstorm activity [5], [6] and studies of SR have provided information on the properties of lower ionosphere and the characteristics of planetary lightning activities [7]. Some recent results on the studies of SR include the reconstruction of the distance profile of global lightning intensity [8], solar terminator effects [9], [10], and anomalies in the characteristics of SR bands related to earthquakes [11].

In the present paper, we analyse the SR data observed at tropical station Agra (geographic lat.27.2°N, long.78°E) for a period of one year from 01 April, 2007 to 31 March, 2008 and extract information on the characteristics of global lightning activity. We study the diurnal variation of the intensity of first mode SR frequency which indicates the variation of intensity of global thunderstorm activity. We find that it is consistent with optical transient detector (OTD) data measured by satellites. Further, the general reduction in the first mode SR frequency observed at Agra and other Indian stations these days is interpreted in the light of solar cycle minimum lying during 2008-09 (now increasing). Efforts are also made to study the diurnal variation in the first mode SR frequency, and size of the thunderstorm zone.

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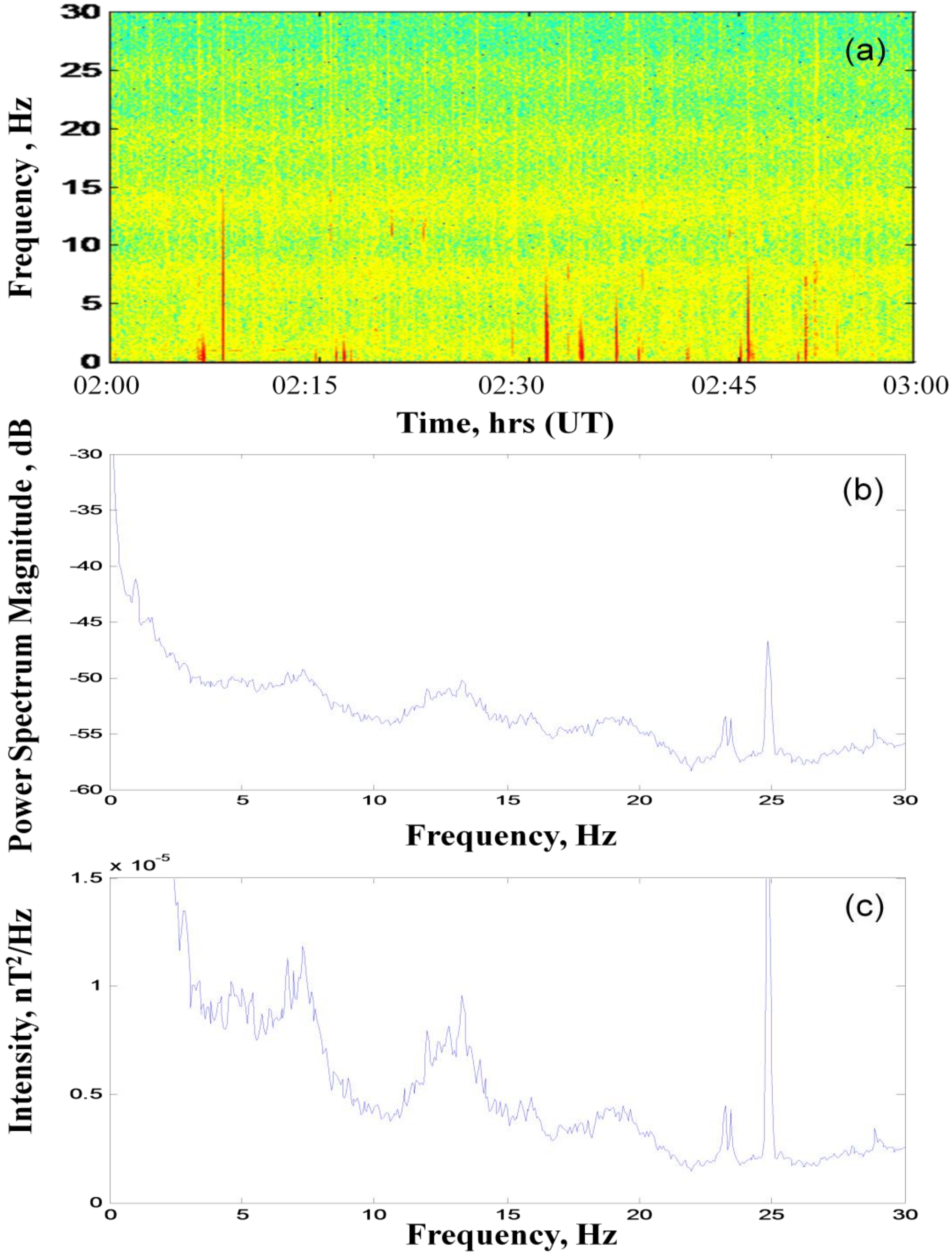

Fig.1: (a) Frequency-time spectrogram of the ULF data recorded at Agra showing four Schumann resonance lines (b) Static spectra of the data in Fig.1a, and (c) corresponding intensity-frequency variation.

II. EXPERIMENTAL SETUP

Schumann resonance data are taken from continuous monitoring of ULF/ELF magnetic field emissions employing a set of 3-component search coil magnetometer that has been imported from Lviv center of Institute of Space Research, Ukraine. The three sensors of the magnetometer are buried 1m underground in orthogonal directions such that X-component is oriented in north-south, Y-component in east-west, and Z-component in vertical directions. The location is chosen in Agriculture field of the Bichpuri campus of R. B. S.College, in rural area, about 12 km west of Agra city where

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electric and electromagnetic disturbances are low. The data from the sensors are brought to the communication unit placed in an observation room about 150 m away from the sensors through specified cables, and digitized at a sampling rate of 64 Hz to be recorded on the hard disc of the computer. Time synchronization is obtained through a GPS system.

III. ANALYSIS PROCEDURE

Offline analysis of the good quality Schumann resonance (SR) data available during the period from 01 April, 2007 to 31 March, 2008 is carried out using FFT available in MATLAB software with 1024 words of data length at a time. The dynamic spectrum of the data showing SR lines on the frequency-time records are converted into static spectra (PSD) from which peak frequencies and corresponding amplitudes are obtained. These are then converted into intensity-frequency graphs for better reproduction of intensity peaks. A running average of 3 points is used for smoothing the intensity data at all frequencies.

IV. RESULTS AND DISCUSSION

In Fig.1 we show an example of the dynamic and static spectra of SR recorded at Agra station. Fig.1a shows the frequency-time spectrogram in which four Schumann resonance lines are clearly seen. The time is shown in UT which is related with local time (LT) as LT = UT + 5.5 hrs. The corresponding static spectrum (PSD) is shown in Fig.1b and the intensity variation is shown in Fig.1c. From Fig.1b,c it may be seen that the maximum power is concentrated in the first mode of the SR which falls gradually at other increasing harmonics. The amplitude of different SR harmonics at a particular observational site depends on the nodal structure of SR standing wave. In some sites the second harmonic may have more power than the first one. However, since the damping increases with frequency, the first mode contains more power than the others [10].

A. Global distribution of thunderstorm activities

In order to extract some useful information from SR data we study the first mode at 8 Hz specifically for the reasons that the intensity of this mode is positively correlated with intensity of thunderstorm activities and surface temperature [3]. For this purpose we process the data through a digital band pass filter for frequency range between 6 and 9 Hz. We select only those filtered data which contain clear SR first mode and then determine the peak frequencies and corresponding intensities. In this way, a time series of the data is formed for 24 hours each day for the period of 12 months from 01 April, 2007 to 31 March, 2008. This time series is used for deducing various properties of SR observed at Agra some of which are described below. It may be noted here that although a best location is chosen in the agriculture fields of the college campus after carrying out extensive surveys, the data are not perfectly free from the disturbances of powerful electric equipment, acoustic noise, movement of trains on railway line (about 300m away), and other man-made noises. However, the best quality data are chosen for the analysis purpose out of the bulk available during the period.

In Fig.2 we show the diurnal variation of the intensity of first mode of SR observed by X components of the sensor. The observed data are divided for the three seasons; summer (May, June, July, and August), winter (November, December, January and February) and two equinoxes combined together (March, April and September, October). It is obvious since the source width (the area covered by maximum thunderstorm activity) moves through the tropical zone around the equator from east to west the radiated ELF waves induce maximum signal intensity in X-component which is orthogonal to propagation direction. The intensities appear in distinct peaks around 07 hrs UT, 11-15 hrs, UT, and 18 hrs UT corresponding to South-East Asian, African and American thunderstorm centers. The intensity is maximum from African source, moderate from Asian, and weakest from American source. There are two peaks in African source indicating movement of source width during broad noon time of Africa. The intensity from the American source is weakest because of large source-observer distance causing significant attenuation of the signals. Since the source width is assumed to be wide, about one fourth of the earth's circumference, it follows the Sun during the day and slightly drifts to the north or to the south in summer and winter in northern hemisphere [12,pp.97]. Our results in Fig.2 are consistent with those of Sinha et al.[10] who have found the three peaks around 7 hrs UT, 10-15 hrs UT, and 20 hrs UT respectively from the measurements at Shillong station in India (geographic lat. 25.34^{o}N, long. 91.53^{o}E).

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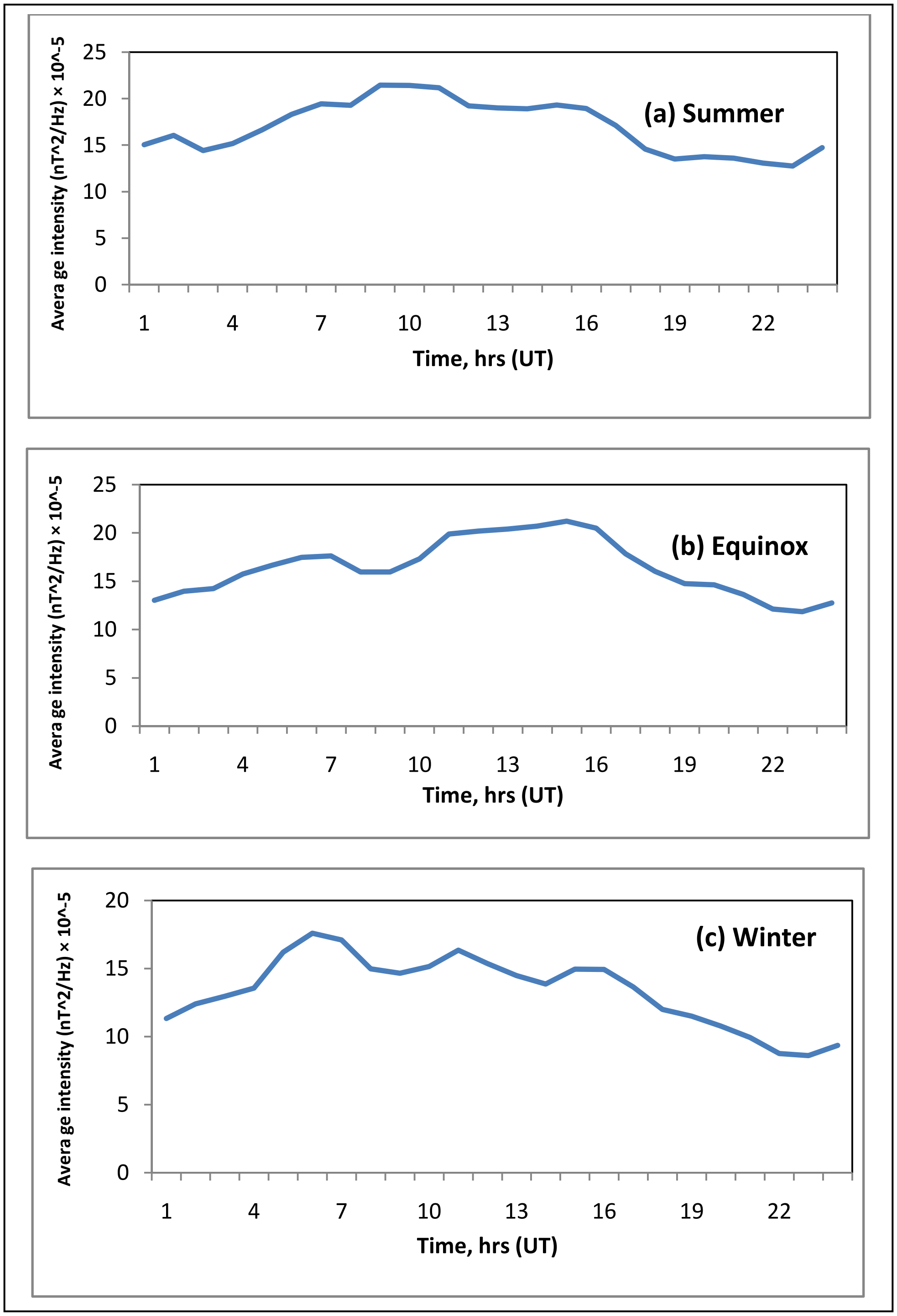

Fig.2: Diurnal variation of intensity of SR of X components during summer, equinox, and winter months deduced from first mode SR data obtained at Agra.

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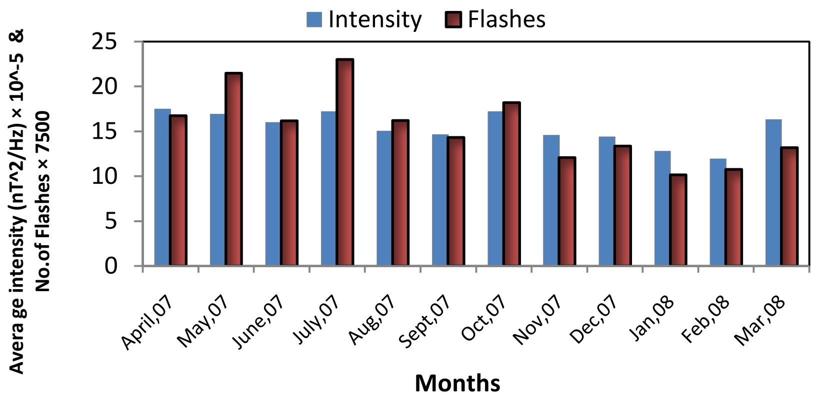

Fig.3: Correlation between the global distribution of thunderstorm activities deduced from SR data at Agra with optical transient detector (OTD) data obtained from Lightning Image Sensor (LIS) on the satellite.

The times of peak thunderstorm activities obtained by us are slightly different than those observed by ELF and optical transient detector (OTD) measurements [13], [14] in which the average data show the corresponding periods as 9-10 hrs UT, 14-15 hrs UT, and 20-22 hrs UT respectively. However, the thunderstorm activity is a function of local time and the diurnal pattern is conditioned by heating of the ground soil by the Sun that provides the atmospheric correction. Since thunderstorms become most active in the afternoon local time, the maximum of global lightning activity is found somewhere between the point of local noon and evening terminator (day-night interface). Seasonal and annual variation in lightning activity are connected with the climate and weather as well. During the year, the thunderstorms drift to the north and to the south following the Sun. As a result the global lightning distribution undergoes modification from month to month. Further, the periods of peak activities may vary depending upon the place of measurement [12,pp.96].

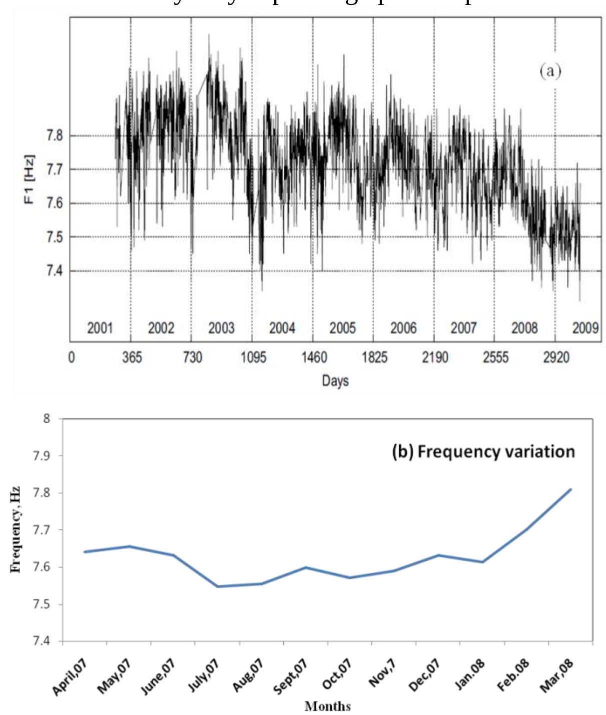

Fig.4: (a) Variation of first mode SR frequency during preceding solar cycle with minimum around 2008-09 [15].
(b) Variation of average first mode SR frequency observed at Agra station during April, 2007 - March, 2008.

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In order to justify that SR data obtained at Agra may show global distribution of thunderstorm activities, we find average intensity of the first mode for each month of the period of analysis and correlate with optical transient detector (OTD) data for the same period. De et al.[6]have compared the SR data obtained at Kolkata, with those obtained at Slovakia, Moshiri and Nagycenk to show theglobal distribution of thunderstorm activities. The OTD data are taken from lightning Image Sensor (LIS) available on the website: http://thunder.nsstc.nasa.gov/data/query/distributions/html. Fig.3 shows a comparison of the two sets of data for the period under study where dark and shaded histograms show the intensities of X-component (North-South direction) and optical flashes given by OTD data. The best correlation is found

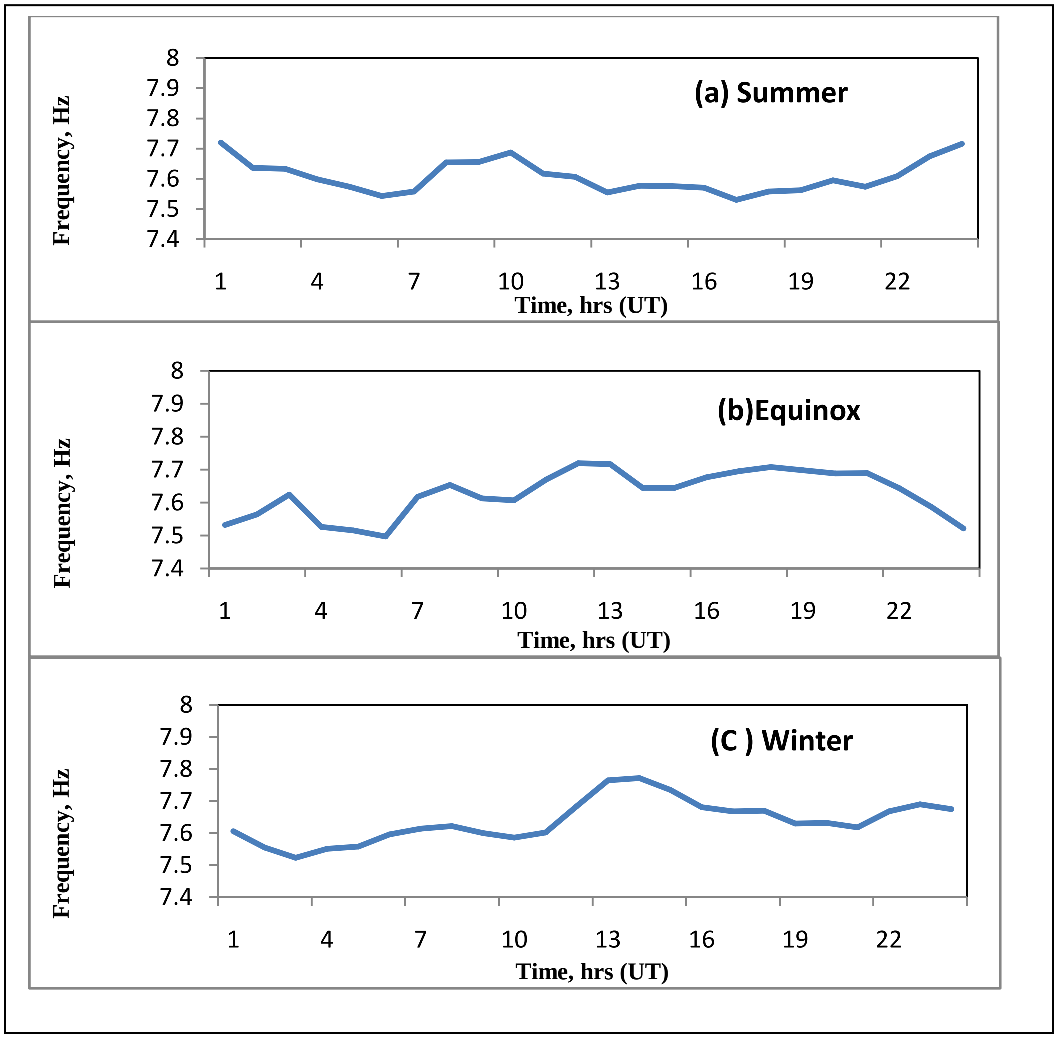

Fig.5: (a) Diurnal variation of average first mode frequency during summer (May-August) (b) equinoxes (March, April, September, October), and (c) during winter (November-February) months.

with X-component data due to the reason that the lightning activities take place in the north-south direction. The correlation is maximum (0.81) as compared to others. This is due the reason that both the SR and OTD measurements suffer due to some drawbacks. The problem with SR lies in a too high global rate of strokes of about 100 events per second. With the basic 8 Hz frequency of SR we have about 12 independent pulses arriving at an observer during the single period of this frequency. It is obvious that signals will overlap severely making impossible their separate processing. The main problem in OTD observations is that an observer does not know what is going on outside the frame of optical device at any particular time. Furthermore, there are 'invisible' strokes, i.e., the discharges whose optical emissions do not reach the top of the cloud [12, pp.94].

B. Decrease in the peak frequency of first mode

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From Fig.1b, c we see that the peak frequency of the first SR mode is about 7.6 Hz, 0.4 Hz less than the real value, and similar reductions occur in other modes as well. Reductions are also seen in peak frequencies of SR data obtained at Shillong for the months of July and August, 2007 and March and May, 2008 (Data obtained with the courtesy of Dr. B.M. Pathan, Indian Institute of Geomagnetism, Mumbai, May, 2010). Recently, Ondraskova et al.[15] have reported a significant decrease of about 0.30 Hz in the fundamental SR frequency from observations at Modra observatory in Slovak Republic during the latest solar cycle having minimum around 2008-09. This extraordinary fall of the fundamental mode frequency is attributed to the unprecedented drop in the ionizing radiation in X-ray frequency band, although the patterns of the daily and seasonal variations remain unchanged. The results of Ondraskova et al.[15] are reproduced here in Fig.4a for ready reference. Similar decreases in the first mode SR frequency have been reported earlier by Satori et al.[16] for the previous 11 year solar cycle.

Although, we do not have long term data with us, we show in Fig.4b monthly variation of the average frequency of the first mode of SR for the period of analysis i.e., from 01 April, 2007 to 31 March, 2008. It may be seen that even though the average frequency is still low, it has an increasing trend with increasing months. This may be interpreted conveniently interms of increasing period of current solar-cycle (2009-2020). Thus the variation in peak frequency of SR first mode isinterpreted in terms of solar cycle variation. According to Satori et al. [16], changes of the X-ray radiation dominates the variations in the conductivity profile within the upper characteristic layer (90-100 km portion of E-region). The decrease of this conductivity by up to one order of magnitude over the solar cycle is responsible for the observed SR frequency decrease by several tenths of Hz.

C. Diurnal variation of first mode SR frequency

It is known that variation in the peak frequency of the first SR mode is due to meriodinal drift of the thunderstorm center. The first mode resonant frequency has a diurnal and seasonal variation. In Figs.5a-c we show the diurnal variation of average peak frequency of the first mode from the data obtained at Agra during summer (May, June, Julyand August), winter (November, December, January and February) and equinoxes (March, April and September, October).The data show a diurnal variation which is similar to that reported by Satori [17] indicating north-south migration of the global thunderstorm activities. However, there are two differences in our data as compared to those of Satori [17]. The first difference is that the average peak frequencies of our data are more (7.4 Hz), and the other is that the winter data do not show a mirror image of the summer data. A possible reason for this may be that our station is located near the Asian source where changes in the intensity of the source in winter may not be significant as in summer. Another possibility is that due to averaging of the data over a period of 4 months the expected dip between 4 to 10 hrs UT is not seen, though for many individual days and even for the month of March, 2008 the expected dip is existing. Finally, there may be a solar cycle effect under which summer-type variation exists for long.

Two possibilities have been suggested for the reduction in frequencies of the first mode; (i)variation in median distance between the source and the observer, and (b) ionospheric modification. Peak frequency changes to the extent of 10-20 percent have been observed which are attributed to the uncertainties arising from spatial distribution of lightning sources exciting the SR modes [18]. De et al.[6] have also observed large diurnal variation in the peak frequency of the first mode and found similar variation in the data obtained at Moshiri in Japan. The peak frequency of the SR first mode varies continuously and it is proportional to the source-observer distance [12, pp.127].

Model calculations have shown that a uniform decrease in the reference ionospheric height reduces the resonant frequencies and Q factors (i.e., it simultaneously increases the wave attenuation). Specifically, it is found that a shift from 8 to 7.6 Hz in the peak frequency of the first mode is caused by a global reduction of ionospheric height by approximately 5 km. However, such reductions will be observed in all the modes, and the effect will be observed globally. Since measurements differ from place to place it is concluded that the deviations observed experimentally are conditioned by the displacement of the global thunderstorms rather than by modification of the global ionospheric profiles [12, pp.268].

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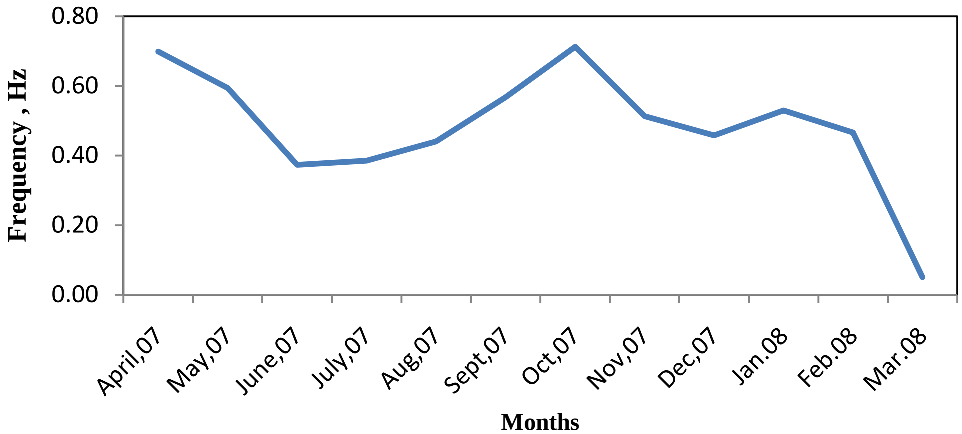

Fig.6: Variation of frequency range dF (=f_n^{max}-f_n^{min}) during the period of analysis. Significant drops in dF in the months of June and March are clearly seen.

D. Size of the thunderstorm region

The dependence of frequency range i.e., the maximum daily value minus the minimum daily value (dF=f_n^{max} - f_n^{min}) has been used for establishing the effective size zone occupied by the worldwide thunderstorm activity (source width) from the Schumann resonance records [19], [4].In fact the frequency range varies inversely with the size of the thunderstorm region [15].

The long term SR monitoring has shown that diurnal variations of resonance parameters may seriously deviate from day to day, thus reflecting the random nature of the sources. Typically, the stable final results are revealed on a month span such as average diurnal variation, which has the daily variations averaged over the month period. In the light of this, we show in Fig.6 diurnal variation of frequency range dF during the 12 months under consideration. This may be interpreted in the light of increasing period of current solar cycle as was seen in the case of peak frequency variation of the first mode (section 4.2). However, there are two distinct drops in the variation of dF, one in the month of June, and other in March. These two drops coincide with the thunderstorm activities in summer and winter months. The summer thunderstorm period is seen to exist for a prolonged period of time from June to September, whereas the winter one is shorter existing between November, 2007 and January, 2008. Hence, the effective thunderstorm zone is much broader in summer than winter.

V. CONCLUSION

The long term SR monitoring has shown that diurnal variations of resonance parameters may seriously deviate from day to day, thus reflecting the random nature of the sources. Typically, the stable final results are revealed on a month span such as average diurnal variation, which has the daily variations averaged over the month period. The effective thunderstorm zone is much broader in summer than winter.

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