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Analyses of Schumann resonance spectra from Kolkata and their possible interpretations

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The paper deals with the study of Schumann resonance data set recorded at Kolkata (Latitude 22.56ºN). The results of analyses are confined to a period of one year (January to December 2000). The amplitude and frequency fluctuations along with some aspects of Schumann resonances (SR) during the period are investigated. The variation of global thunderstorm activity as inferred from monthly intensity fluctuations of global SR signals over Kolkata and Modra (Latitude 48.61ºN) is presented and the observed difference has been interpreted.

Keywords: ELF emission, Schumann resonance, Upper atmosphere, Lightning

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1 Introduction

Within the spherical cavity between the Earth's surface and lower ionosphere, standing electromagnetic waves are generated due to excitation energy from lightning. The spherical cavity acts as a resonator. The resonance occurs when the wavelength is of the order of the dimension of the resonator. A subset of such resonances is the Schumann resonance (SR). The observed discrete peak frequencies 8, 14, 20, 26, … Hz in the extremely low frequency (ELF) range are generated by lightning discharges.

Different aspects of SR phenomenon as well as their observation and measurement techniques have been presented by researchers during past five decades[1-11]. Some frequency changes about the peak values and some amplitude changes were found to be present in the observed spectra, which are due to different uncertainties arising from spatial distribution of lightning sources exciting the SR modes.

The power in the first mode has been noted to correlate with global temperature changes[2]. It has been observed that SR increases with temperature on a global tropical scale consistent with the observed sensitivity of the lightning to temperature in local measurements. The relation between SR amplitude and variations in global tropical surface temperature strongly suggest that single station measurements contain globally representable signals and such measurements can, therefore, serve as the diagnostic of temperature and deep convection in the tropical atmosphere. The intensity of SR signals was found to be linked through logical chain to the tropical surface temperature of the Earth[4].

In this paper, the monthly intensity fluctuations of global SR signals over Kolkata during January - December 2000 have been calculated from the recorded data. The results are presented graphically. From the data of the Geophysical Observatory at Slovakia[12], the monthly intensity fluctuations of SR signals are calculated during the same period. The variation of intensity depicts the variation of global thunderstorm activities. Moreover, the frequency fluctuations of the first mode of Schumann resonance is studied from the spectral data recorded from Kolkata.

2 Experimental set up

The antenna system for the experiment has been erected on the ground at a vast bare land in Salt Lake, Kolkata. Square-loop antennas are made for the detection of ELF signals. Two such loops have been mounted on wooden structures connected in series and their effective gain is increased beyond 5 dB with this arrangement.

One square loop has 1 m side with a total of 75 turns and the other square loop with 90 turns has 1.3 m side. A co-axial cable of length 50 m is used to transfer the signal from antenna to the input of receiver where it is pre-amplified. A stereo-preamplifier-integrated circuit with LA3161 chip is chosen whose low frequency response starts below 5 Hz and extends to a few kHz. It is superior to others to handle input voltage in the range of few microvolts to millivolts. The frequency selective stages are designed with active circuit elements. A wide-band amplifier whose output is taken through an active low-pass filter having cut-off frequency nearly 35 Hz further amplifies it. This signal information is then stored in a computer by the data acquisition process in which a 40 Hz generator is used to convert analog signal into digital signal. A wide-band very low input voltage sensitive and low frequency sensitive receiver has been designed, which can detect input signal from 100 to 500 μV.

3 Recording system

The detected ELF signal is recorded by physical technique. The signal is sampled 40,000 times per second and the voltage is then converted to 12-bit digital signal by analog-to-digital converter, i.e. one of the 4096 levels is recorded by the computer. Because of the choice of frequencies, no information is lost in the sampling process except for the quantization error. The loop antennae are vertically mounted in series whose planes are kept parallel to each other along a fixed E-W or N-S direction. The MATLAB software is used for processing raw data which is directly stored from pre-amplifier to the computer via data acquisition system as a DAT file. The necessary band-pass filter designs are included in the program.

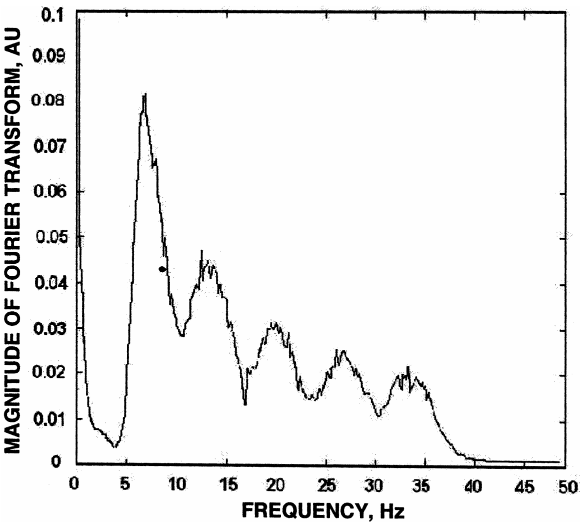

Fig. 1—Frequency response of received signal recorded on 2 April 2000.

4 Analyses of observations

First raw data is plotted in time domain. Then data signals are passed through different filters designed in the program. The outputs of these are stored and discrete Fourier transform (DFT) of the receiver data are performed using fast Fourier algorithm to get the result in frequency domain. Different peaks of Schumann resonance are observed. The frequency response of the received signal recorded on 2 April 2000 is depicted in Fig. 1. The results show resemblance with the earlier studies[13,14].

Observations at different times show amplitude and frequency fluctuations which are obvious due to fluctuations of the causes producing such signal spectra from the middle ionosphere[15-17]. The recorded signal at Kolkata on 12 April 2000 is shown in Fig. 2, which depicts amplitude and frequency changes in all the three modes.

The plane of the antenna system can be rotated about their vertical and for each set up, data could be collected and stored in the computer. During rotation of the antenna, the nature of signal changes slightly but the resonance peaks are found to be nearly equal for different antenna positions. Similar results are found in the earlier experimental studies[2,13,14].

At a particular time, the source intensity is calculated by taking the sum of the power of first three resonance modes. The monthly intensity variations due to global thunderstorm activities obtained from Schumann resonance amplitude are shown by bar graphs in Fig. 3 in the unit of pTHz$^{-1/2}$. Its purpose is to show that intensity fluctuation of SR modes is directly related to the variation of

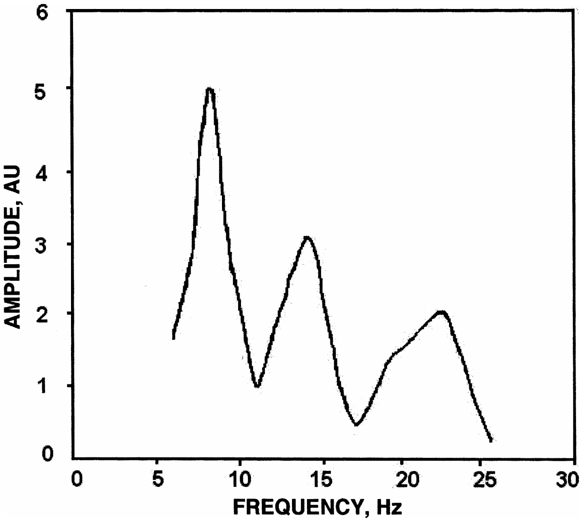

Fig. 2—Recorded Schumann resonance spectra over Kolkata on 12 April 2000

thunderstorm activity. The black coloured bar graphs are drawn from the data for the period January - December 2000 recorded at Kolkata (latitude 22.56ºN). The half-tone bar graphs of Fig. 3 are due to the data from the Geophysical Observatory - Modra, Slovakia (latiude 48.61ºN) for the same period[12]. Intensity reaches maximum value during summer, which agrees with the earlier studies[5,14]. Because of different locations of the two recording centers, the influences of global thunderstorm activity zones for the three modes of SR are also different, for which the annual intensity variations at these two latitudes are different. Satellite observations show the existence of great variability in the longitudinal distribution of thunderstorm activitiy centers along with their temporal and seasonal variations[18]. Observations of global lightning distribution during January 1998 - February 2005 taken from LIS (Lightning Imaging Sensor) NASA, (http://thunder.nsstc.nasa.gov) confirm that the thunderstorm activity in Himalayan region is more prominent than Asia-Australia region. The Asia-Australia has long been thought of as one of the largest thunderstorm producing regions, but recent records confirm that the thunderstorm from Himalayan regions is also strong enough to be one of the distinguished lightning centers all over the world.

The present observations also show seasonal variations, which are to be taken into consideration. Kolkata is nearer to Himalayan and Asia-Australia lightning centers in comparison to Slovakia. This may be the reason for the observed variation of intensity of SR modes.

The global variations of thunderstorm activity centers throughout the year introduce fluctuations in dielectric property and anisotropic conductivity within the cavity. Thus, there will be variations of source-receiver distance as well as the activity of the centers at the receiver which generally introduce seasonal and temporal frequency shifts in the different SR mode particularly in the first mode.

Figure 4 shows the resultant intensity fluctuations of SR modes recorded from four different latitudes during the year 2000. The black coloured and half-tone bar graphs indicate the results recorded from Kolkata and Slovakia, whereas blank bar graphs and bar graphs filled-up by slanting hatched lines are due to Moshiri (latitude 44.29°N) and Nagycenk (latitude 47.6°N), respectively. Because of difference in the distance between location of the source and observational sites, the recorded data exhibited the difference in SR intensity. Moshiri is very close to Asia-Australia violent thunderstorm center than Nagycenk. Because of geographical location of lightning centers, the magnitude of intensity of SR at Nagycenk may be more dependent on African and European sources than American sources. The geographical location of Nagycenk is nearer to African sources of thunderstorm center.

Moreover, there is always existing unequal and anomalous influences because of random distribution of thunderstorm from Alps Mountain located very close to Nagycenk recording center. For these reasons, the fluctuations of resultant intensities of SR at Moshiri and Nagycenk are different. Variation of global thunderstorm activity over these centers during the whole year 2000 can be predicted from Fig. 4.

The difference between maximum and minimum frequency values of the first Schumann resonance frequency recorded during the span of each day has been determined. These diurnal frequency shifts of

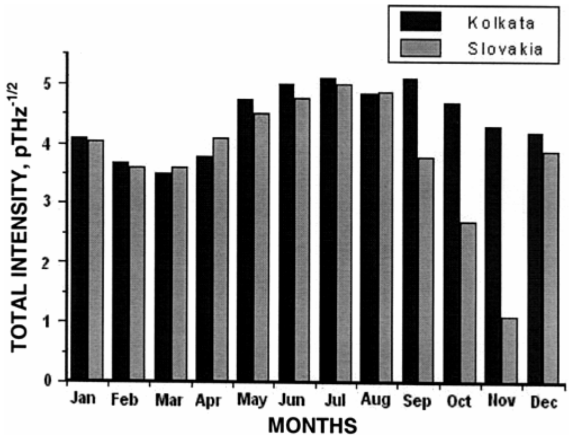

Fig. 3—Variation of resultant intensity of SR modes at Kolkata and Slovakia

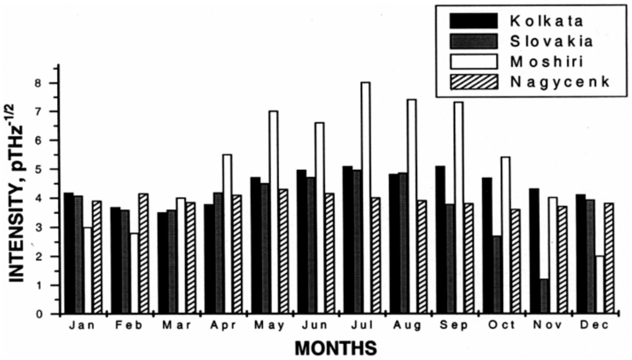

Fig. 4—Resultant intensity fluctuations of SR modes recorded at four different places - at Kolkata; Slovakia; Moshiri (latitude 44.29°N); and Nagycenk (latitude 47.6°N)

the first mode have been averaged over the corresponding month. In this way, the average values are determined for the period January to December 2000 from the recorded data at Kolkata. The results are shown in Fig. 5.

The vertical field component is chosen here to eliminate the antenna directivity. The observed fluctuations of frequency of the first SR mode may be explained by the area covered by the lightning storms and also by the movement of the lightning source with respect to the recording station[4]. It is observed that for severe lightning, there is poor frequency fluctuation. Figure 6 shows the diurnal variation of the peak frequency of first mode for 3-5 May 2000.

The mean diurnal variation of the peak frequency of the first Schumann resonance mode has been presented in Fig. 7 where the different points of the plot are the average value of the mode taken for that hour over all the above three days of observations.

In Fig. 8, the mean diurnal and seasonal variations of the peak frequency of the first SR mode for the spring season (March to May) recorded at Kolkata in the year 2000 are compared with the variations over the same season of the year 2006 at Moshiri, Japan[19]. The curve (a) is drawn with Kolkata data while the curve (b) is due to Japanese work. Figures 6 and 7 deal with the data of three consecutive days in May 2000, so to maintain parity, the spring time data from the Moshiri results have been taken in Fig. 8 for comparison. The difference between the two graphs may be interpreted in terms of variations of the influence of thunderstorm activity centers, namely Asia & Australia; Africa; and Europe & America[20] between Kolkata and Moshiri. The great variability in the longitudinal distribution of thunderstorm activity centers along with their seasonal variations[18] is also to be taken into account in the context of the observed difference.

5 Discussions

The observed variations of both frequency and amplitude in Schumann resonance phenomena are related to changes in global thunderstorm activity as well as due to consequence of complex effects in the earth-ionosphere cavity. The inhomogeneities in the earth-ionosphere cavity and the anisotropy due to geomagnetic field are supposed to introduce conductivity perturbation in the medium which modify the attenuation depending on the location of the source.

The purpose of Fig. 3 is to study the nature of global SR intensity variations due to thunderstorm activities over Kolkata and Slovakia. The influence of Asia lightning activity center is more in these regions than African and American centers. The intensity fluctuation of SR modes due to the main influence of Asian lightning center would be understood from this figure. Thunderstorm occurrences are high during July-August (rainy season) and low during November-December (winter season) for which SR intensity is high in rainy season than in winter season[5]. The thunderstorm center of Asia in the rainy season remains at latitude 15°N, longitude 105°E and it is nearer to both the centers. For this reason, SR

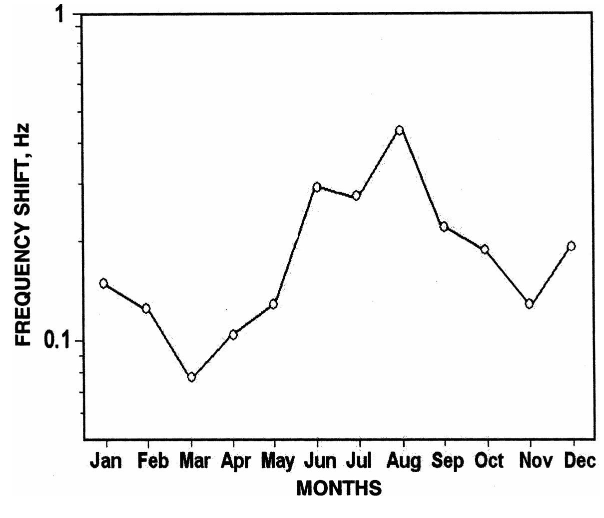

Fig. 5—Annual changes in the averaged values of Schumann resonance frequency variations of the first mode (January to December 2000)

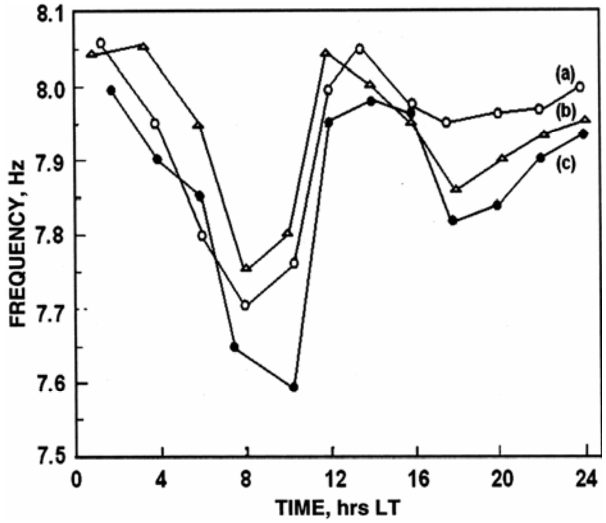

Fig. 6—Variation of peak frequency of the first mode on: (a) 3 May, (b) 4 May, and (c) 5 May 2000

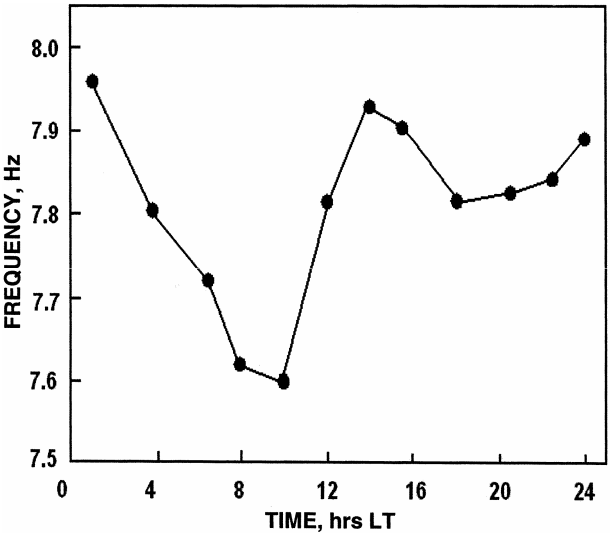

Fig. 7—Mean diurnal variation of peak frequency of the first mode over observations on 3-5 May 2000

intensity bears almost the same value during this season. But the Asian thunderstorm center during winter season remains at latitude 15°S and longitude 130°E and for this, its influence on Slovakia center is less in comparison to Kolkata center. Hence, larger variations of SR intensities at these centers during winter season are found[21]. Moreover, there is extra influence over Kolkata recording center from the Himalayan regions also during winter season. This explains why thunderstorm activities are similar in some part of the year and differ in other part.

Schumann resonance frequencies may be considered as indicator of thunderstorm distribution in global lightning activity level. The growth of global lightning activity is generated by the thunderstorm spreading[22]. The earth-ionosphere cavity acts as resonator of electromagnetic waves generated due to excitation energy from lightning.

The resonance frequency of the earth-ionosphere waveguide is about 8 Hz. The cavity of the waveguide is continuously being excited by lighting strokes all over the globe. The power spectra of the excited modes show peaks with frequencies and Q values corresponding to different resonant modes. Among those, the first resonant mode covers the path very near to the uppermost boundary of the cavity covering maximum path length. Because of the random fluctuation and inhomogeneities of the dielectric property and conductivity of the earth's atmosphere within the cavity, the medium suffers a large-scale perturbation surrounding its uppermost boundary, which mostly influences the first mode of resonance frequency. The other resonant modes which traverse comparatively smaller path would be affected less than the first mode.

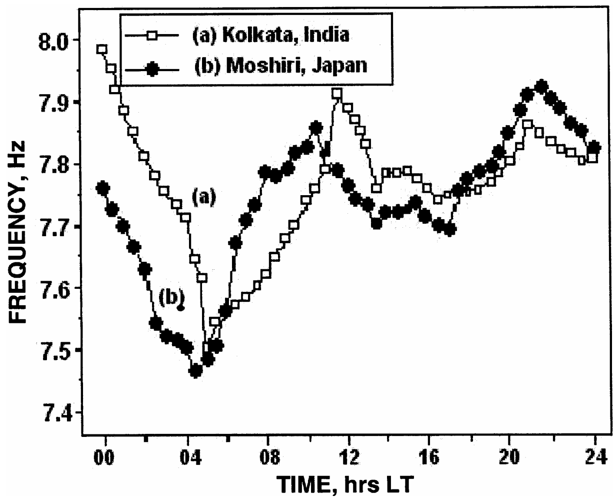

Fig. 8—Diurnal and seasonal variations of the peak frequency of the first mode of SR: (a) for the spring season (March to May) recorded at Kolkata; (b) compared with the results of Moshiri, Japan[19] for the same variations

Specific geographical features of the earth's surface or lack of symmetry of the magnetic field in the ionosphere would cause variable amounts of absorption depending on the location of the source. The varying absorption would be manifested by changes in the peak frequency and Q of the mode and owing to the geometric configuration of each mode, the effect would be different for different modes. The first mode will be more affected than the other modes of SR.

The occurrence of thunderstorm lightning as well as their covered areas at different seasons introduces varying frequency shifts. This rate is much higher during rainy season for which there is more frequency shift. The peak local thunderstorm activity is highest usually in the afternoon due to which the temporal frequency variation is mostly highest during this period.

Frequency shifts are observed in all the modes[23]. The average daily frequency patterns are different for three modes and each mode shows a distinct seasonal variation.

The frequency variation of first SR mode is highly observed during solar proton events, solar X-ray bursts[24], earthquake, traveling ionospheric disturbances[25], intense geomagnetic storm, and heliogeophysical activities[26]. These are generally explained in terms of electron density enhancement without a significant change of ionospheric altitude, changes of ionospheric height, and changes of dielectric permeability of the cavity during the period of occurrence[24].

The observed line-splitting in Schumann spectra has been explained from theoretical background[27,28]. Different records from Kolkata exhibit sub-peaks surrounding three modes. The occurrences of these unequal sub-peaks are due to the uneven influences of global thunderstorm activity centers towards the interaction within earth-ionosphere cavity generating the modes.

There are some attempts to explain such frequency variations[5,29,30]. Those formulations are inadequate on various grounds. More refined theoretical model is contemplated to explain daily and seasonal frequency variations in relation to changes of the source positions as well as to inhomogeneities and anisotropy in the earth-ionosphere cavity. Further studies would cover how changes of SR frequencies could be included in future ELF measurements as an indicator of variations in the global lightning activity level.

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