An attempt to correlate first mode Schumann resonance intensity with ground surface temperature at low latitudes*

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Abstract. Employing a system of 3-component search coil magnetometer installed in a remote area in the out skirt of Agra (Geographic lat.27.2°N, long.78°E), India, Schumann resonance (SR) observations have been in progress since 01 April, 2007. In this paper we analyze the first mode intensity data for a period of one year between 01 March, 2011 and 29 February, 2012 and correlate with ground surface temperature (GST) for low latitude region between ± 30°latitude. The GST data are taken from the website: http://www.tutiempo.net. Our results show that the variation curves of the two sets of data match satisfactorily with cross-correlation coefficient of 0.522 which is consistent with earlier workers for low latitude region. We also carry out linear regression analysis and regression equation is utilized to verify the calculated and measured GST which are found to be matching satisfactorily also.

Key worlds: Schumann resonance, ground surface temperature, correlation, regression analysis.

1. Introduction

First predicted by Schumann in 1950 (Schumann, 1952), the Schumann Resonance is one of the most exciting electromagnetic phenomena occurring in the Earth-Ionosphere cavity caused by interaction between direct and round the globe propagation of extremely low frequency (ELF) waves radiated from lightning discharges. The resonances appear as standing waves at different frequency bands of 8, 14, 21 -- Hz. The importance of Schumann resonance phenomenon has been identified rather recently as they found wide ranging applications in the studies of global thunderstorm activities, lower ionosphere, and effects of various geophysical events like solar flares, solar cycle, and earthquake etc. (De, 2007).

Williams (1992) demonstrated for the first time a connection between Schumann resonance intensity and the planetary tropical temperature anomaly. The inherent concept is that the heated ground surface causes the air convection, which transports the warm humid air upward and triggers the cloud formation. The convection increases with temperature and lifts greater amount of vapor, so that immense clouds are developed. Any vertical motion of particles in a cloud causes its electrification; hence, the lightning activity ought to be proportional to the ground temperature (Hayakawa et al., 2006). Though, the earlier work by Williams correlated the SR intensity with temperature anomaly, the recent works have exploited the temperature itself rather than temperature anomaly. For example, works by Satori (2003) and Satori et al. (2003) have inferred the seasonal migration of tropical thunderstorms along the meridian triggered by tropical temperature changes, Sekiguchi et al. (2004, 2006) have studied SR intensity data obtained in Japan for the period of 1999-2002 and compared with ground surface temperature (GST) data for different latitude

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intervals. Hayakawa et al. (2006) have made a quantitative comparison of temperature and electromagnetic data for 43 months long and used cross-correlation coefficient to evaluate their linear connection. Nickolaenko and Hayakawa (2007) have provided an overview of results of SR studies done in the interval from 27th (Maastricht) to 28th (New Delhi) URSI general assemblies including the ELF intensity and global land temperature and Schumann resonance on other planets.

In the present paper we make an attempt to compare the Schumann resonance intensity data obtained at Agra (geographic lat.27.2°N, long.78°E) with the ground surface temperature data for the low latitude region and carry out cross-correlation analysis to find out a linear regression relationship between the two. The results show that the cross-correlation coefficients are positive and the variations of calculated and observed temperature match satisfactorily.

2. Experimental Setup and method of data processing

A set of modified 3-component search coil magnetometer (LEMI-30), imported from Lviv centre of Institute of Space Research, Ukraine, was installed on Bichpuri campus of our college (R. B. S. College, Agra) in April, 2010 and routine observations for ULF/ELF magnetic field emissions started. The three sensors of the magnetometer are buried one meter underground in North-South (X-component), East-West (Y-component), and vertical (Z-component) directions separated from each other. The complete set up is similar to the one used by us earlier (Kushwah et al., 2005, 2009) but with some modification in CAM (communication) unit and software. Also the locations of the sensor and recording system are changed after extensive surveys for better result. The location of the sensors is chosen in the agriculture fields of the campus in rural area about 12 Km West of Agra city, to avoid intense electric and electromagnetic disturbances. The data from the sensors are brought to the CAM unit placed in an observation room about 150 m away through specified cables, and digitized at a sampling rate of 64 Hz to be recorded on the hard disc of the computer. Round the clock observations are taken where time synchronization is obtained through a GPS system.

The three sensors of the magnetometer are induction coils of dimension 870×85 mm each having the following specifications;

- Frequency range of measurement : 0.001-30 Hz
- Measuring range : ± 200 nT
- Transformation factor 0.001- 1 Hz : 20μV/mT
- 1 -30 Hz : 20 mV/nT
- Auxiliary output gain : 20 dB
- Magnetic noise level at 0.01-10 Hz : ≤ 20 pT Hz-1/2 ~ ≤ 0.04 pT Hz-1/2
- Mains interference rejection : > 60 dB

The LEMI-30 system has sampling rate of 256 Hz always. The CAM unit sends these samples to the dedicated PC permanently. The LEMI-30i software in the PC averages these samples at the frequency of 64 Hz simply by summing and dividing, and then forms binary file which is stored in the PC. The recorded data on PC in amplitude-time as stored by the program date wise with starting and end times may be seen in frequency-time (dynamic spectra) by performing spectral analysis using FFT available in MATLAB software with 1024 words of data length (temporal resolution = 16 sec, frequency resolution = 0.06 Hz) at a time. The sampling rate of 64 Hz and flat frequency response of the equipment between 1 and 30 Hz facilitates the way for SR to be observed up to fourth harmonic in the computed power spectra. The power spectral density (PSD) of the input signal shows the relative dominance of frequencies in the whole data set i.e. it gives variation of power spectral magnitudes with frequencies present in the signal. The PSD of the input signal is estimated using Welch spectral technique which uses averaged modified periodogram. The method consists of dividing the time series data into (possibly overlapping) segments, computing a modified periodogram of each segment, and then averaging the PSD estimates. The PSD were prepared for each 1 hour data (230400 data points), and a Hamming window of 1024 data points with sliding of half the window.
is used to compute the modified periodogram of each segment which windows the time-domain signal prior to computing the FFT in order to smooth the edges of the signal. In this method each spectrum is the average of 512 spectra each of 8 sec. The final spectrum is smoothed by taking the running average of 5 points. An example of dynamic spectrum and corresponding PSD obtained from the X-component data recorded on 18 February, 2012 is presented in Fig.1a and b. The PSD shows the variation of amplitude in dB which has the reference level of magnetic noise levels of the sensor at different frequencies. The program may also yield intensity variation over the SR frequency range. An example of such variation is shown in Fig.1c corresponding to the data in Fig.1a and b.

Fig. 1. (a) Frequency-time spectrogram of the ULF/ELF magnetic field emissions recorded on 18 February, 2012 at Agra showing four Schumann resonance lines (b) Static spectra (PSD) of the data shown in Fig. 1a and, (c) Corresponding intensity-frequency variation.

It may be mentioned here that, although we have chosen best possible location for putting the sensors in the Agriculture fields of the college after extensive surveys, the data still pick up some noises because of large sensitivities of the sensors. These noises arise from powerful electric equipments, acoustic noise, and movement of trains on railway line (in East-West direction about 300 m away from the sensors). We have
tried to examine the effect of movement of trains on the quality of data produced by the sensors. For this purpose, we have gone through the time table of trains movement and corresponding frequency-time spectrograms of the data. We have found that there are four regular trains, one weekly train, and occasional movement of goods trains on the line. The regular trains pass through the area between two time slots only i.e. between 0600-0900 hrs and 1800-2100 hrs besides the weekly train movement between 1230 and 1305 hrs. The examination of the data during such periods show that although there are noises picked up by the sensors due to train movements, the SR data are not affected. This may be seen from an example of the SR data (X-component) presented in Fig.1a recorded on 18 February, 2012 during 0200-0300 UT (0730-0830 hrs local time, LT = UT+5.50hrs). The noises appear in the form of vertical lines due to passage of trains during this period. Normally, the PSD of such data indicate the presence of noise, but as seen from Fig.1b, the effect of the noises is very insignificant. The noises due to train movement appear in the Y component of the dynamic spectra also similar to that in the X component, but the Z component is very noisy as usual and extraction of SR parameters is difficult from the spectra. In general, the X components contain more power than the Y components due to the reason that in the Indian zone, ELF waves generated from the thunderstorm activities in the south-East Asian region dominate more as compared to African and American sectors. The raw temporal data show sporadic spikes in amplitude due to passage of trains but no saturation effect is observed. The noises arising from other sources are sometimes serious and do affect the quality of data. However, they are occasional and due precaution is taken while processing the data.

3. Analysis procedure for Schumann resonance data

Offline analysis of the ULF/ELF data is carried out for a period of one year from 01 March, 2011 to 29 February, 2012 using FFT available in MATLAB software with 1024 words of data length at a time. The dynamic spectra (Frequency-time spectrograms) for each day are examined for good quality Schumann resonance bands. In doing so, some data gaps are found which are filled by taking 5 days running averages so that a continuity of data may be maintained. The dynamic spectra are converted in to static spectra (PSD) which are then converted into intensity-frequency graphs. A running average of 5 points is used for smoothing the intensity data at all frequencies.

In order to examine the connection between SR intensity and GST in the low latitude region we consider the first mode SR only as done by Williams (1992) keeping in view the fact that the maximum intensity is concentrated in the first mode normally. Then we 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 March, 2011 to 29 February, 2012. The intensity data are then averaged for each day, and then for 30 days to find average intensity for a month.

4. Ground surface temperature (GST) data

The ground surface temperature (GST) data are taken from the website http://www.tuttiempo.net/en/climate/Agra/07-2012/422.htm. Since SR is a global phenomenon, the regional temperature variation may have profound influence on its characteristics. Keeping this in view, we consider temperature variation for different stations lying in the low latitude region between ± 30° latitude. The stations are so chosen that they may lie on different latitudes but within 3° of longitude. These stations are Agra.
Fig. 2 shows the locations of these stations in India and Sri Lanka. The southern part in this latitude range beyond Sri Lanka lies in ocean where air temperature is not expected to differ much from that over Sri Lanka. Hence an average monthly variation of temperature over the above stations may well represent the GST between ±30° latitude. From an examination of the temperature variations over Agra and that over other stations, we find that the two do not differ much in summer but differ significantly in winter months (see Fig. 3).

![Map of India showing four different stations in the latitude range ±30° N and 3° wide longitude. (geographic lat.27.2°N, long.77.96°E), Nagpur (geographic lat.21.1°N, long.79.05°E), Thiruvananthapuram (geographic lat.8.46°N, long.76.95°E) and Colombo (geographic lat.6.9°N, long.79.86°E).](image)

5. Results and discussion

The variation of SR intensity (daily averages) over the period of one year from March, 2011 to February, 2012 is shown in Fig. 4 by thin line curve. Also shown in the figure is the variation of GST over ±30° latitude by thick dark curve. In order to represent the same ordinate for both the data, the intensity is multiplied by $5 \times 10^5$. In Fig. 5 we show the seasonal variation of the SR intensity and GST. The top panel shows the variation for summer months (May-August), the middle panel for average of the two equinoxes (March-April and September-October), and the bottom panel for winter months (November-February).

From Fig. 4 and Fig. 5 it may be seen that average pattern of variation of these two sets of data are almost similar. To ascertain the level of correlation between the two sets of data, we compute the correlation coefficients. It is seen that the cross-correlation coefficient for the whole year is 0.5212 and the best for the three seasons is 0.5644 for winter months.
Fig. 3. A comparison of measured global surface temperature variation at low latitudes within $\pm 30^\circ$ with those at Agra during March, 2011 - February, 2012.

The result of cross-correlation coefficient of 0.5 for the two sets of data for low latitude within $\pm 30^\circ$ is consistent with Hayakawa et al. (2006) who have found similar result for low latitude but higher values for middle and higher latitudes.

Fig. 4. Average SR first mode intensity variation over the period March, 2011 - February, 2012 (thin line curve). The superimposed curve (thick dark line curve) shows the average measured GST variation over the period.

We now find the link of the annual variation of the SR intensity (dB) with the GST by using the linear regression. The procedure may be illustrated for the low latitude region $\pm 30$ by computing the coefficients of regression A and B in the relation (Hayakawa et al., 2006)

$$I_{[dB]} = A + B \times T_{30}$$

Where $I_{[dB]}$ is the SR intensity and $T_{30}$ is the monthly average GST measured for latitude range $\pm 30$. The regression coefficients are computed from the formulas;
In our case $N=12$ months. The calculated values for the coefficients are:

$A = -45.71147951$

$B = 0.1083257$

So that the final linear regression relation is given as:

$$I_{dB} = -45.71147951 + 0.1083257 \times T_{30}$$  (4)

Fig. 5. The same as Fig. 4 but for three seasons of summer, equinoxes, and winter.

The linear equation (4) can be used to deduce SR intensity or GST in low latitude region if one of them is known. Here, we use this equation to calculate GST by substituting measured values of SR intensity and compare the results with the measured GST. The result is shown in Fig. 6. It may be seen here that the calculated and measured values of GST match satisfactorily with minor deviations in few months.

From the results presented in Figs (4-6) it is seen that cross-correlation coefficients between the SR intensity and GST are positive but small compared to those at middle and high latitudes obtained by Hayakawa et al. (2006). Further, the calculated temperature deviates from the actual observed temperature in few months. Although, the exact reasons for these problems are still not known, we expect that the low
Correlation coefficient may be due to varying seasons and irregular ionization distribution in the ionosphere at low latitudes due to equatorial anomaly.

**Fig. 6.** Variation of measured and calculated GST over the period.

However, the result may be expected to improve by the consideration of long data set for at least 4-5 years as have been done by Williams (1992) and Sekiguchi *et al.* (2004, 2006).

Further, the intensity of an individual SR mode is a function of source–observer distance. The role of diurnal motion of thunderstorms should be reduced by incorporating cumulative intensity of SR modes in the analysis (Sentman *et al.*, 1991, Nickolaenko *et al.*, 1999, Nickolaenko and Hayakawa, 2002). In addition, simultaneous SR intensity data should be taken at least at two antipodal observing stations to eliminate the distance factor. The motion of thunderstorm activity will be of opposite sign with respect to these observing points, and the distance factor will be eliminated in the sum of resonance intensities because the source motion will increase the intensity at one point and decrease at the other by the same amount so that the sum becomes independent of the source position. We propose to carry out an extensive study of SR intensity relation with GST in our future work by taking care of these modifications.

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