DIURNAL–SEASONAL VARIATIONS IN THE SCHUMANN RESONANCE: TERMINATOR EFFECT OR SOURCE–RECEIVER DISTANCE EFFECT?

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ABSTRACT

The extremely low frequency (ELF) radiation from global lightning produces an electromagnetic phenomenon in the Earth-ionosphere cavity known as the Schumann Resonance (SR). The long term diurnal variations in the SR first three modes (8Hz, 14Hz, 20Hz) of the magnetic and electric components are considered from data collected during many years of observation at a number of stations around the globe. The observations show rapid changes in the SR parameters across the day-night terminator boundary. Changes in amplitude, frequency and damping of the first SR harmonic occur during 30 – 60 minutes at the morning and evening passage of the terminator. However, comparison with a simple uniform-cavity model (no day-night differences) shows good agreement between model prediction and SR observation of the diurnal-seasonal amplitude variations of lightning sources.

INTRODUCTION

The Schumann Resonance (SR) features and basic theory are discussed in [1, 2, 3]. In this report we suggest a new presentation for the diurnal variations of the SR amplitude recorded during a number of years at different stations [Hollister (36.8^0 N, 121.5^0 W, USA), Nagycenk (47.6^0 N, 16.7^0 E, Hungary), Negev (30^0 N, 340^0 E, Israel)] and compare these with the annual dynamics of the day-night terminator. Data include the two horizontal magnetic field components of the first SR mode (~8 Hz) and the vertical electric field for the first three modes (~8 Hz, ~14 Hz, ~20 Hz).

Diurnal and seasonal changes of the SR amplitude are caused by changes in the intensity and position of global lightning activity, which is concentrated within the three major thunderstorm regions: Southeast Asia, Africa, and South America. The maximum of thunderstorm activity migrates from one center to the other during the late afternoon hours, which corresponds to approximately 08, 14, and 20 UT in the different regions. This daily motion of thunderstorms is observed at all stations. On the annual scale, however, the lightning activity migrates northward or southward, and can also change the SR amplitude [4].

Diurnal amplitude variations at a station depend on the median distance from the station occupied by the global thunderstorms and on the current level of the activity itself. The largest SR amplitudes are observed during the day owing to the thunderstorms occurring predominantly at local afternoon hours. The effect of source–observer distance variations results in remarkable similarity of records made at remote stations when the data are plotted in the local time [2, 4, 5 and 6]. An impact of changes in the local height of the ionosphere was also suggested by [6], though unresolved from the pure source distance variations pertinent to the experiment.

The terminator region is also known as a place hardly effecting radio wave propagation. Theory of the influence of lateral ionospheric gradients on ELF was considered in a number of fundamental theoretical works and reviews [7, 8, and 9]. There are claims that the passage of the solar terminator over a station produces distinct effects in the SR characteristics. The terminator is observed twice a day (at the sunrise and the sunset), and the main problem here is that the amplitude of terminator effect is smaller than those from the regular diurnal variations in the lightning activity and its migration. To single out the terminator effect, it is necessary to make the observations during long period (some years) with a sufficient time resolution (~15 min.). We suppose this effect is not simply connected with changes of solar elevation angle during sunrise or sunset but with drastic changes in ionosphere parameters in the terminator region. The effect is more pronounced during sunrise than during sunset as much greater lateral gradients are observed in the ionosphere during the morning hours.

OBSERVATIONS AND RESULTS

We used the SR data of the Stanford STAR Laboratory collected at two stations: Hollister (SAO, USA) and Parkfield (PKF, USA) - the records are available at http://quake.geo.berkeley.edu/ncedc/em.intro.html. Data series started in 1995, and the time resolution is 15 minutes. The record contains the amplitude, the damping and the peak frequency of the first SR resonance evaluated by the software developed by Dr. M. Fullekrug. Since the two stations are placed closely and give the same results, we show only the records of the SAO station: two orthogonal magnetic components, namely, north–south and west–east field. We also use the Nagycenk data containing the vertical electric field data, as well as the records made in the Negev Desert (Israel) where the SR electric and magnetic fields are registered.

We chose the following form for data representation so that we can see together the diurnal and annual variations of SR parameters at a station. All data for a specific year are plotted where the color represents the parameter value. Day of the year is along the X-axis and local time appears along the Y-axis. Diurnal variation of the parameter is represented by the color change in the vertical direction and the annual variations appear in the horizontal direction. Absent points have a value of zero. The data are clipped at an upper value and each point greater then upper value has this value. By choosing upper and lower values and color scales we may optimize data representation. If we have data for a number of years we can produce an average picture. Absent points are excluded from averaging.

Observations at Hollister (USA) and Nagycenk (Hungary)

Fig. 1 shows the diurnal-seasonal picture for the amplitude of the SR first mode in west-east magnetic field. Black lines represent morning and evening terminator passage over the station. Clearly we see greater SR amplitudes during day hours compared to the night hours and changes at the terminator line. Greater contrast is seen at winter months. There are changes in frequency as well, which are more complicated than for amplitude at the terminator line. The damping parameter also decreases at the morning terminator and increases at evening terminator. Observations at other stations Nagycenk (Hungary) and Negev (Israel) confirm that the terminator effect exists. Fig. 2 shows diurnal-seasonal variation in the vertical electric at Nagycenk (UT is on vertical scale, but for this station difference between UT and LT is 1 hr.). The terminator is clearly seen in all three SR modes (A1, A2, A3) as in Hollister data (Fig. 1). Sharper changes along the terminator lines are observed for higher mode (A3~20 Hz). Fig. 3 shows the average changes in SR parameters during morning terminator passage. Averaging was made for years 1997-99 and data was taken in time interval ±2.5 hours from terminator passage (0 time). More pronounced changes are seen in all characteristics of west-east magnetic field: a rapid growth in the amplitude, decrease in the damping and temporary decrease the frequency.

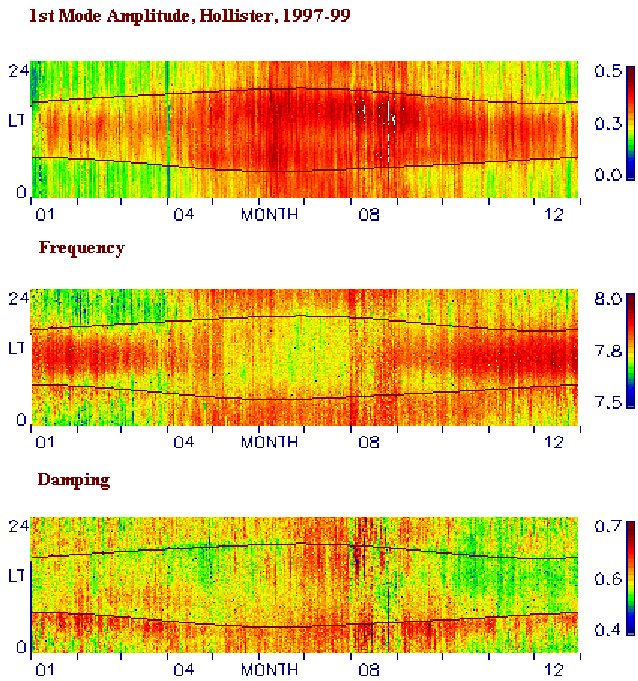

Fig. 1 Diurnal-seasonal variation of SR 1st mode in WE magnetic field amplitude, frequency and damping at Hollister, California.

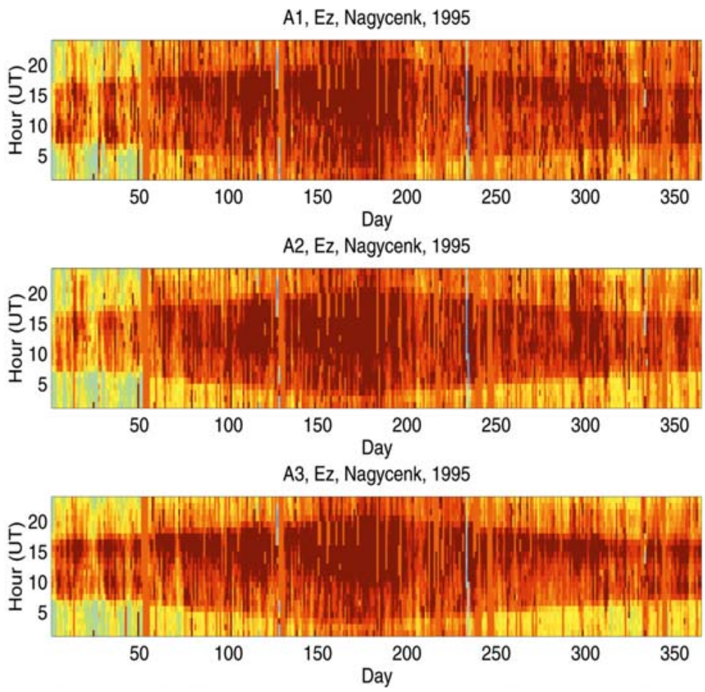

Fig. 2 Diurnal-seasonal variation of the first 3 SR modes in electric field amplitude at Nagycenk, Hungary

The variations occur in approximately half an hour period, and suggesting one of the two possible explanations. The first one implies the influence of the terminator when the following simplistic considerations could be used. Suppose the whole cavity is uniformly filled with the lightning strokes, while the local ionosphere height varies. The amplitude of the vertical electric field will subsequently increase on the dayside of the globe because the ionosphere is lower there (like the field in a capacitor). However, such an interpretation cannot explain the other simultaneous changes (for example decrease in the apparent resonance frequency and damping at morning terminator).

The alternative explanation exploits variations in global thunderstorm activity, which is concentrated in the vicinity of the dusk terminator. The large scale variations are caused by the seasonal drift of the activity. When sources tend to be closer to the observer (during the summer), the amplitude increases and the apparent resonance frequency decreases in the horizontal magnetic field component. The rapid variations shown in Fig. 3 are explained by the onset of the global thunderstorm activity in the Asian centre when the active zone, placed around 15–17 hr LT, crosses the ocean and comes to Indonesia. In this case the 0.5 hr duration of rapid amplitude growth is in accord with the duration of the activity in a standard thunderstorm cell being around 1 hr.

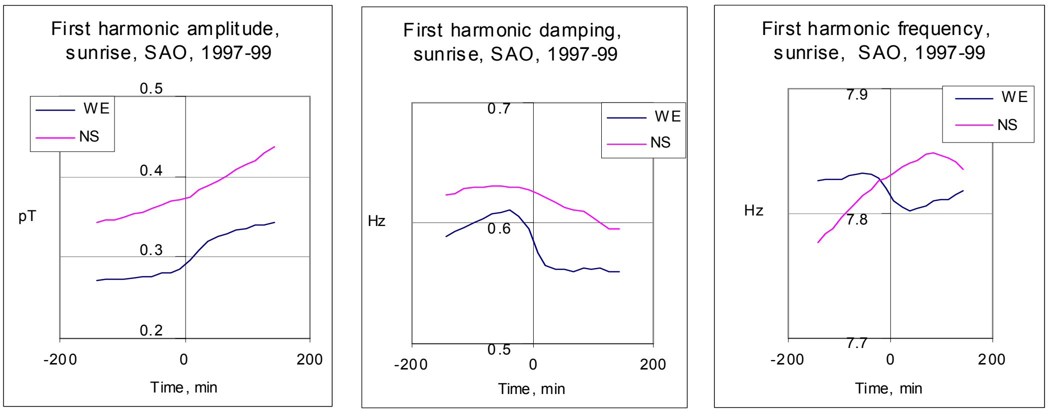

Fig. 3 SR parameters changes at the morning terminator at Holister.

MODEL CALCULATIONS

The data computed in the model of uniform cavity (Fig. 4) are very similar to the experimental results (Fig. 2). The seasonal variations arise in the model from the north–south drift of the global thunderstorms. We show the amplitude of the first Schumann resonance mode in two model distributions of the global thunderstorms.

The first one is the simplest possible model of lightning activity concentrated at the point where the local time is 15 hr. Therefore the source circles the globe during the day. The amplitude of the source equals to 1 between 08 and 22 hr UT, it switches to the 0.02 value between 22 and 08 hr UT. The source drifts from the equator to the north or to the south by $\pm 20^0$ during the year. The observer is placed at Nagycenk (47.6N, 16.7 E, Hungary). The second model implies the three global thunderstorm centres. Diurnal variations of the thunderstorm activity world-wide were picked from the climatological (WMO) data, and choosing of the other characteristics including the annual source drifts was made similarly to [4]. These data show the diurnal annul maps averaged over period of four years from 1994 to 1997 (not shown here). By comparing the patterns measure experimentally with the model data we admit that the 'day-night' patterns are obtained in the regular cavity arising from the seasonal drifts of the global thunderstorm activity. There are obvious deviations of the computed data from the records, which could be attributed to definite drawbacks of the model.

CONCLUSIONS

The new effective form of presentation for the SR data was proposed that allow to clearly displaying the diurnal and seasonal variations in a very compact way. The most rapid changes in the SR parameters occur in the close vicinity of the day-night interface. Changes in the amplitude, frequency, and damping of the first SR mode take place in 30 – 60 minutes intervals around morning and evening terminator times at the observatory. Rapid variations are present in both the vertical electric and horizontal magnetic field components, but they are the most pronounced in the east–west magnetic field. The model results allow (at least in a part) for an interpretation in the framework of the uniform Earth–ionosphere cavity model. Changes in the long–term SR diurnal variations are caused by seasonal meridional drifts in the sources. Resolving between the terminator and the source drift effects is complicated by the thunderstorm activity occurring close to the local sunset and hence close to the evening terminator. Further attempts to extract the effect from the day-night asymmetry should be based on the long–term records in the polar region. The seasonal drift of the sources is still present here, while the passage of day–night interface takes place only during intermediate season. Therefore, impact of asymmetry must produce peculiar patterns in the polar region.

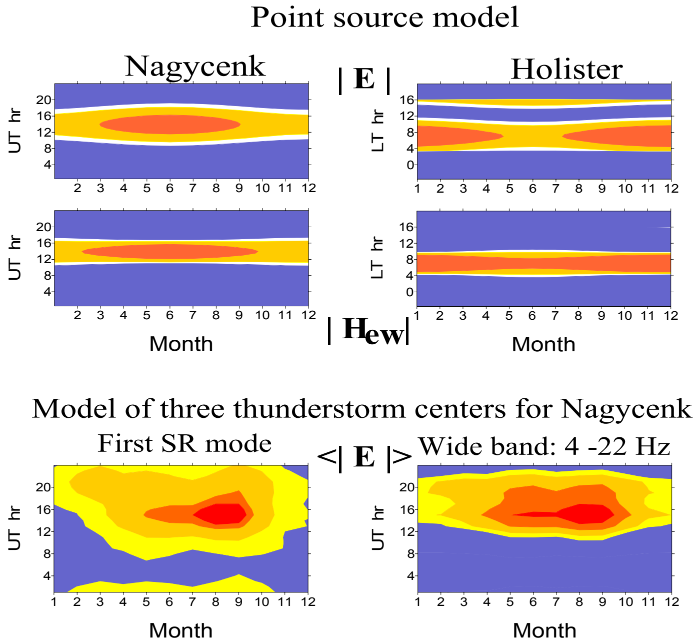

Fig. 4. Model annual–diurnal variation of the SR amplitude caused by the seasonal drift of global thunderstorms in the uniform Earth–ionosphere cavity. A) The single compact centre at 15 hr LT and observer is at Nagycenk (47.6 N and 16.7 E) and at Hollister (36.8 N and 121.5 W). B) Model of three global thunderstorm centres for Nagycenk.

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