Possible Mechanism of the Observed Schuman Resonance Diurnal Amplitude Variations

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Abstract

Schumann resonances (SR) are global electromagnetic resonances excited by lightning discharges between the Earth and the ionosphere. SR serve as a passive global monitoring tool, and as such have numerous applications in lightning, climate and ionosphere research. All of these applications rely on proper interpretation of experimental data. It is vital to understand and correctly interpret the major features of SR records. The best documented and the most debated features of the SR phenomenon are the diurnal variations of the background SR power spectrum. While it is generally realized that these variations are related to the global thunderstorm activity, the structure and timing of the diurnal amplitude variations led to a suggestion that they are strongly influenced by day-night variations in the ionosphere. Here we describe a possible mechanism of the observed SR diurnal amplitude variations, which can explain their structure without invoking the ionosphere day-night asymmetry.

1. Introduction

Schumann resonances (SR) are global electromagnetic resonances in the extremely low frequency (ELF) range. Excited by lightning discharges in the cavity formed by the Earth surface and the ionosphere, SR records reflect the global thunderstorm activity and therefore serve as a passive global lightning activity monitoring tool. Owing to the connection between lightning activity and the Earth's climate, SR may be used to monitor global temperature variations [1] and variations of upper tropospheric water vapor [2, 3]. SR has been used for research and monitoring of the lower ionosphere on Earth and was suggested for exploration of lower ionosphere and lightning activity on celestial bodies [4-6]. SR are used for monitoring transient luminous events – sprites and elves [7-10]. A new field of interest using SR is related to short-term earthquake prediction [11-13]. There are many more SR applications [14], and all rely on understanding and proper interpretation of experimental SR data.

The best documented and the most debated features of the Schumann resonance phenomenon are the diurnal variations of the background SR power spectrum. The first investigators realized that SR field power variations were related to global thunderstorm activity and the observed diurnal variations were explained by the variations in the source-receiver geometry [15-17]. Figure 1a shows 4-year mean diurnal and seasonal amplitude variations in the electric field of the first SR mode for Mitzpe-Ramon station (adapted from figure 4 in [18]). When plotted in this way, a characteristic lens-shape pattern of the diurnal and seasonal variations is revealed, which strongly resembles the shape of the terminator (the day-night transition). While such variations may be explained by the migration of thunderstorms [19], the structure and timing of the diurnal amplitude variations led to a suggestion that they are strongly influenced by day-night variations in the ionosphere [18, 20].

Ionosphere-induced variations are expected to follow accurately sunrise and sunset times from day to day and from season to season. There are records that indeed follow this pattern rather accurately [21]. However such behavior is pertinent to many, but not all daily records. There are numerous days when SR amplitudes do not increase at sunrise or do not decrease at sunset. Two specific examples are shown on Figure 1b which presents two diurnal records of the first SR mode amplitudes at Mitzpe Ramon, Israel made on 5 and 23 January 2000. It is apparent that on these two days amplitude variations are not connected to sunrise/sunset times. Such days are too many to be discarded as “bad records”. The most plausible explanation is that on these days variations caused by lightning activity overwhelmed the ionosphere-induced variations. However, these days do not exhibit higher SR amplitudes, or stronger diurnal amplitude variations. Neither the lightning activity was unusually high or unusually variable. It is also doubtful that ionosphere day-night variations were significantly weaker on these days. This suggests that variations in SR records caused by lightning activity should typically overwhelm the ionosphere-induced variations, which agree with the earlier [22, 23] and more resent theoretical results [24, 25]. This contradicts the ionosphere-dominated explanation of the observed SR behavior and supports the thunderstorm migration hypothesis.

Below we use conventional concepts of lightning climatology and model simulations to describe a possible mechanism that can shape the lens-like pattern in SR amplitude variations presented on a diurnal-seasonal scale, without invoking the ionosphere asymmetry.

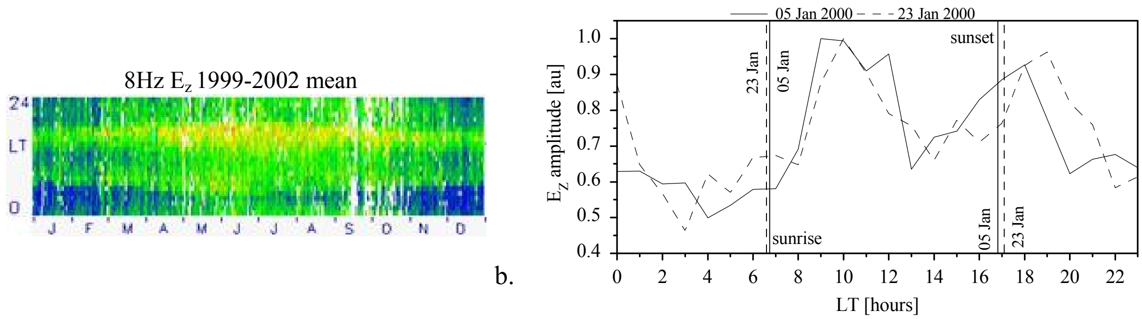

Figure 1: First SR mode E_Z amplitudes recorded at Mitzpe Ramon, Israel. a. 4-year mean (adapted from figure 4 in [18]); b. Diurnal records on 5 and 23 Jan 2000.

3. Model Setup

To calculate SR amplitudes, we use a uniform Two Dimensional Telegraph Equation (TDTE) model, described in great detail in a series of papers [25-30]. As in [6, 25,30], the lower ionosphere conductivity profile is approximated with the "knee" model suggested in [31], which accounts for an important intermediate section of the conductivity profile. Exact model setup and model variables are the same as in [30]. It should be emphasized, that the model used here is a uniform model and as such cannot include lateral height variations of the real cavity. Therefore the diurnal-seasonal amplitude variations calculated with this model depend only on the source-receiver distance, without accounting for the day-night asymmetry, and hence cannot be influenced by the diurnal ionosphere variations – a property unachievable in the real waveguide. By comparing the amplitude variations calculated in a uniform cavity with the ones obtained from experimental data, it is possible to conclude whether diurnal changes of the ionosphere are necessary to explain the major properties of the experimentally observed diurnal SR amplitude variations.

For global lightning activity representation we used 5 years (1995–2000) of Optical Transient Detector (OTD) lightning data, available at http://ghrc.msfc.nasa.gov/. The OTD is a space based optical sensor on an orbit inclined by 70^{o} with respect to the equator [32]. To obtain representation of diurnal lightning activity, OTD orbital data was assembled to monthly diurnal data with hourly time resolution [25,30]. In addition, two simple artificial models were used to check the origin of the lens-like pattern [25]. "Follow the Sun" (FS) model exploits the fact that tropical thunderstorms develop predominantly in the afternoon: in this model there is only a single point source that moves following the sun with 3hr delay. "Follow the Sun Over the Continents" (FSOC) model "corrects" the FS model – here the same source is activated only over the continents, since lightning activity is known to be concentrated over the land.

3. Results

Figure 2 shows simulations with FS, FSOC and OTD inputs for the Mitzpe Ramon station. The diurnal-seasonal variations of SR amplitudes computed with FS model (Figure 2a) have a lens-shaped structure which is created as the FS source moves relative to the station, following the sun. Aside from this lens-shaped maximum, FS model produces another, weaker, maximum around the local midnight. This is the signal from sources at the station antipode, where it is afternoon at this time. The FSOC (Figure 2b) model "turns off" the sources of the FS model, whenever they occur over water. For most stations, including Mitzpe Ramon, this completely wipes-off the midnight maximum, since the station antipode is located in the ocean where there is little lightning activity. Part of the day-side sources are "turned-off" as well, as they fall into the seas. In reality, thunderstorms are not strictly bounded to the continental outlines and extend beyond the land, "re-activating" part of the day sources turned-off in FSOC simulations. Moreover, lightning activity is strongest at local afternoon, but it does not necessarily cease during the rest of the day, adding sources not accounted for in the FS and FSOC models. Hence a wider, but more diffuse lens structure is formed for a global OTD lightning distribution (Figure 2c), which well reproduces the main characteristics of the experimental data (Figure 1a).

Note the pronounced asymmetry between the local morning and evening amplitudes in the FSOC model (Figure 2b). The local evening amplitude records are much higher. This asymmetry is preserved in amplitudes calculated from global lightning distribution (Figure 2c) and is evident in the experimental records (Figure 1a). Such behavior is attributed to the local meteorological asymmetry between the dawn and dusk thunderstorms [21] which is a property of local thunderstorms, while SR records reflect the global lighting activity. There is always dawn and dusk somewhere on the globe. The behavior of local thunderstorm around local sunrise and sunset cannot and should not directly explain the global SR records. It is rather a component that, together with the seasonal thunderstorm drift and the land-ocean distribution, creates the global lightning activity characteristics which, in turn, modified by the nodal structure of the SR fields, define the characteristics of SR records.

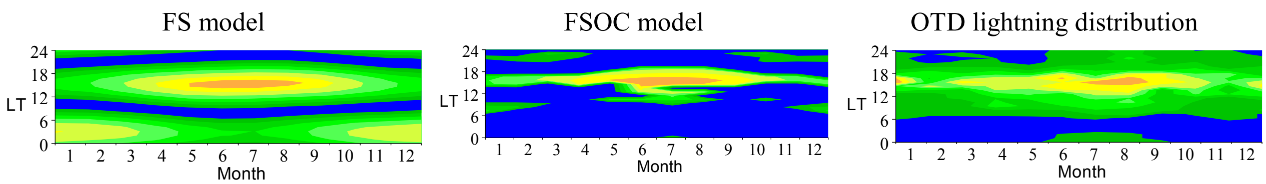

Figure 2: Diurnal-seasonal variations of the electric field amplitude at Mitzpe Ramon station resulting from FS and FSOC models, and OTD lightning distribution (1995-2000 mean) model.

4. Conclusion

The FS and FSOC models help to separate the contribution of different factors to the variations observed in SR records. It appears that the lens-shaped structure of the field variations is crafted primarily by the movement of the sun. As the sun position changes through the day and through the year, and as thunderstorms move relative to the station, the strength of the received signal is altered. The same is true for the antipode of the station. The distribution of the land masses, over which the lightning activity is concentrated, further shapes the outline of the SR records. Peculiarly, for most stations, their antipodes are located in the ocean, producing only weak signals. Consequently, the lens-like pattern in the diurnal-seasonal variations in the SR field amplitudes is crafted by thunderstorm migration, driven by the sun motion and land mass distribution, and the major patterns of the observed SR diurnal amplitude variations can be reproduced without invoking the ionosphere day-night asymmetry.

5. References

1. E.R. Williams, "The Schumann resonance: a global tropical thermometer", *Science, 256*, 1992, pp.1184–1186.
2. C. Price, "Evidence for a link between global lightning activity and upper tropospheric water vapor", *Letters to Nature, 406*, 2000, pp.290–293.
3. C. Price, M. Asfur, "Can lightning observations be used as an indicator of upper-tropospheric water-vapor variability", *Bull. Amer. Meteorol. Soc., 87 (3),* 2006, pp. 291–298, doi:10.1175/BAMS-87-3-291
4. A.P. Nickolaenko, L.M. Rabinowicz, "On the possibility of existence of global electromagnetic resonances on the planets of Solar system", *Space Res., 20*, 1982, pp.82–89.
5. Nickolaenko and Rabinowicz, 1987
6. O. Pechony, C. Price, "Schumann resonance parameters calculated with a partially uniform knee model on Earth, Venus, Mars, and Titan", *Radio Sci., 39(5)*, 2004, doi:10.1029/2004RS003056
7. D.J. Boccippio, E.R. Williams, S.J. Heckman, W.A. Lyons, I.T. Baker, R. Boldi, "Sprites, ELF transients, and positive ground strokes", *Science, 269*, 1995, pp.1088–1091

8. E. Huang, E. Williams, R. Boldi, S. Heckman, W. Lyons, M. Taylor, T. Nelson, C. Wong, “Criteria for sprites and elves based on Schumann resonance observations”, *J.G.R.-Atmospheres, 104(D14)*, 1999, pp. 16943–16964
9. C. Price, M. Asfur, W. Lyons, T. Nelson, “An improved ELF/VLF method for globally geolocating sprite-produced lightning”, *G.R.L., 29(3)*, 2002, doi: 10.1029/2001GL013519
10. M. Sato, H. Fukunishi, “Global sprite occurrence locations and rates derived from triangulation of transient Schumann resonance events”, *G.R.L., 30(16)*, 2003, p.1859, doi:10.1029/2003GL017291
11. M. Hayakawa, Y. Fujinawa, *Electromagnetic Phenomena Related to earthquake Prediction*, Terra Sci. Publ. Comp. Tokyo, 1994, 677p.
12. K. Ohta, K. Ummeda, N. Watanabe, M. Hayakawa, “ULF/ELF emissions observed in Japan, possibly associated with the Chi-Chi earthquakes in Taiwan”, *Natural Hazards and Earth System Sciences, 1*, 2001, pp. 37-42
13. M. Hayakawa, K. Ohta, A.P. Nickolaenko, Y. Ando, “Anomalous effects in Schumann resonance phenomena observed in Japan, possibly associated with the Chi-chi earthquake in Taiwan”, *Atm. Geophysicae, 23,* 2005, pp. 1335–1346
14. C. Price, O. Pechony, E. Greenberg, “Schumann resonances in lightning research”, *Journal of Lightning Research, 1*, 2006, pp. 1–15
15. R.E. Holzer, “World thunderstorm activity and extremely low frequency sferics”, *in Recent Advances in Atmospheric Electricity*, L.G. Smith, ed., Pergamon Press, 1958, pp. 599–602
16. H.R. Raemer, “On the extremely low frequency spectrum of the earth-ionosphere cavity response to electrical storms”, *J.G.R., 66*, 1961, pp.1580–1583
17. M. Balser, C. Wagner, “Diurnal power variations of the earth-ionosphere cavity modes and their relationship to worldwide thunderstorm activity”, *J.G.R., 67*, 1962, pp.619–625
18. A. Melnikov, C. Price, G. Satori, M. Fullekrug, “Influence of solar terminator passages on Schumann resonance parameters”, *J. Atmos. Solar Terr. Phys., 66 (13-14),* 2004, pp.1187–1194
19. A.P. Nickolaenko, M. Hayakawa, *Resonances in the Earth-ionosphere Cavity*, Kluwer Academic Publishers, Dordrecht-Boston-London, 2002
20. D.D. Sentman, B.J. Fraser, “Simultaneous observation of Schumann resonances in California and Australia: evidence for intensity modulation by local height of the D region”, *J.G.R, 96 (9),* 1991, pp.15973–15984
21. G. Sátori, M. Neska, E. Williams, J. Szendrői, “Signatures of the day-night asymmetry of the Earth-ionosphere cavity in high time resolution Schumann resonance records”, *Radio .Sci., 42*, 2006, doi:10.1029/2006RS003483
22. A.P. Nickolaenko, “ELF radio wave scattering by the global non-uniformities of the Earth-ionosphere cavity”, *Izvestia Vuzov, Radiophysica, 29,* 1986, pp.33–40
23. L.M. Rabinowicz, *Global electromagnetic resonances in non-uniform and anisotropic Earth-ionosphere cavity*, Ph.D. thesis, Kharkov State University, Kharkov 1988
24. H. Yang, V. P. Pasko, Three-dimensional finite difference time domain modeling of the diurnal and seasonal variations in Schumann resonance parameters, *Radio Sci., 41*, 2006, doi:10.1029/2005RS003402
25. O. Pechony, C. Price, A.P. Nickolaenko, “Relative importance of the day-night asymmetry in Schumann resonance amplitude records”, *Radio Sci.*, *42*, 2007, doi:10.1029/2006RS003456
26. V.V. Kirillov, “Parameters of the Earth-ionosphere waveguide at ELF”, *The Problems of Diffraction and Wave Propagation, 25*, 1993, pp.35–52
27. V.V. Kirillov, “Two-dimensional theory of electromagnetic wave propagation in the ELF range in the Earth-ionosphere waveguide”, *Izvestiya VUZov Radiophyzika, 39 (9)*, 1996, pp. 1103–1112
28. V.V. Kirillov, V.N. Kopeykin, V.K. Mushtak, “Electromagnetic waves in ELF range in the Earth-ionosphere waveguide”, *Geomagnetizm i Aeronomia, 37 (3)*, 1997, pp.114–120.
29. V.V. Kirillov, V.N. Kopeykin, “Solving a two-dimensional telegraph equation with anisotropic parameters”, *Izvestiya VUZov, Radiophyzika, 45(12)*, 2002, pp.1011–1024
30. O. Pechony, C. Price, “Schumann Resonances: interpretation of local diurnal intensity modulations”, *Radio Sci*., *41*, 2007, doi:10.1029/2006RS003455
31. V.C. Mushtak, E.R. Williams, “ELF propagation parameters for uniform models of the Earth-ionosphere waveguide”, *J. Atmos. Solar Terr. Phys., 64,* 2002, pp.1989–2001
32. H.J. Christian, R.J. Blakeslee, D.J. Boccippio, W.L. Boeck, D.E. Buechler, K.T. Driscoll, S.J. Goodman, J.M. Hall, W.J. Koshak, D.M. Mach, M.F. Stewart, “Global frequency and distribution of lightning as observed from space by the Optical Transient Detector”, *J.G.R.*, *108 (D1)*, 2003, doi:10.1029/2002JD002347
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