SCHUMANN RESONANCES: IMPORTANCE OF THE DAY-NIGHT CAVITY ASYMMETRY

Olga Pechony[(1)], Colin Price[(2)]

[(1)]Tel Aviv University, Geophysics and Planetary Sciences, Ramat Aviv, 69978, Israel, (pechony@gmail.com)

[(2)]As in (1), but e-mail: cprice@flash.tau.ac.il

ABSTRACT

One of the important and long debated questions in Schumann Resonances (SR) modeling and data analysis is the significance of changes in the lower ionosphere on the day and night side of the globe that create an asymmetry in the Earth-ionosphere waveguide, influencing ELF wave propagation. Variations in the SR parameters are observed as the terminator passes over stations at sunrise and sunset[1]. In order to simulate the observed fields, a TDTE-based PUK model[2] was used. The PUK model allows simulating SR parameters in the day/night, or in the uniform mode. Monthly observations from the OTD satellite were used to calculate the SR fields generated by global lightning. Comparisons between observed and simulated SR parameters are presented.

INTRODUCTION

Schumann Resonances (SR) are resonant electromagnetic waves in the Earth-ionosphere cavity, induced mainly by lightning discharges, with a fundamental frequency of about 8 Hz and higher-order modes separated by approximately 6 Hz (extremely low frequency range - ELF). The prediction of SR in 1952 by [3] and their subsequent discovery in 1960 by [4] led to a possibility of monitoring global climate – thunderstorm activity, temperature [5] and atmospheric water vapor [6] from a single station. In order to correctly interpret SR data it is crucial to understand the major features present in the records from stations around the globe. Measurements worldwide show systematic changes in SR parameters throughout the day and through the year. One of the proposed explanations is that this effect is caused by the day-night asymmetry – changes in the ionosphere parameters between day and night [7,1]. Another suggestion is that these changes are caused by diurnal-seasonal drift in global lightning distribution [8].

The data used as the model input were the Optical Transient Detector (OTD) lightning data [9]. OTD records are available from April 1995 through March 2000 and can be ordered at no charge at http://ghrc.msfc.nasa.gov/. OTD is a space based optical sensor on an orbit inclined by 70^{o} with respect to the equator. The satellite orbits the Earth once every 100 minutes and has a 100^{o} field of view. The sensor detects lightning flashes during both daytime and nighttime conditions with a detection efficiency ranging from 40% to 65%, depending upon external conditions. Further information can be found at the official OTD web-site: http://thunder.nsstc.nasa.gov/otd/.

METHODOLOGY

The PUK model is a combination of two Two Dimensional Telegraph Equation (TDTE)-based techniques – the “knee” model developed by [10], which addresses the problem of approximating the knee-like conductivity profile (on a semi-logarithmic scale) of the Earth’s ionosphere, and the global partially-uniform day-night model by [11] which allows a convenient treatment of the day-night asymmetry. The TDTE technique was suggested by [12], and developed by [13]. The TDTE technique is thoroughly described in a series of papers [11,13, 14,15]. The PUK model is described in [2]. The model is very flexible, allowing incorporation of structured conductivity profiles and a convenient treatment of the day-night asymmetry with an easy switch from “uniform” to “day-night” model.

Ionospheric conductivity profile is different on the day and on the night side of the globe (Fig. 1). Since the ionosphere serves as an upper boundary of the earth-ionosphere waveguide, ionospheric conductivity profile has a substantial influence on ELF wave propagation. In order to check the dependence of SR field amplitudes on the day/night changes in ionospheric parameters, simulations were performed in two modes. In the uniform (UN) mode ionosphere was regarded uniform and no day-night variations were taken into considerations. In the day-night (DN) mode these variations were accounted for. The ionospheric conductivity profile parameters for the UN and DN modes are the same as in [2].

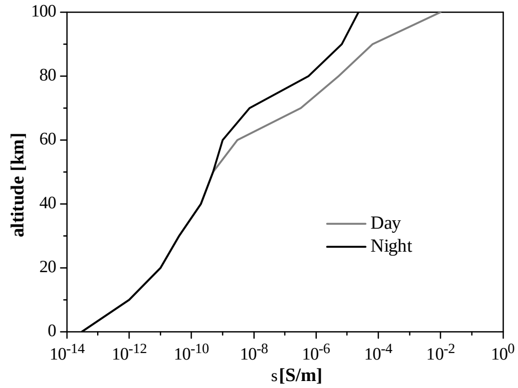

Figure 1: Earth conductivity profile [16].

As input for the simulations OTD data was used. For the current study hourly data is required. Since OTD data is scarce (being most suitable for large time-scale studies), OTD orbital data (from 1995 through 2000) was recalculated as a monthly diurnal mean (MD): monthly mean lightning activity for each hour of the day.

RESULTS

To illustrate the influence of day/night ionospheric conductivity variations on SR fields a simulation with a single source was performed. The source is stationary throughout the day, through the year, and is activated once per hour. Fig. 2 shows electric field calculations (first mode) for a receiver located in Mitzpe Ramon from an African source. Obviously, the UN model should result in no diurnal field variations. On the other hand, the DN model shows distinct variations throughout the day which are caused by the variations in the ionosphere, since this is the only difference between the DN and UN models. Note that these changes occur not on the terminator, but as the sun moves relative to the source-receiver pair. A pair of night-side source (NS) and night-side receiver (NR) result in minimum field intensity, while day-side source (DS) and day-side receive (DR) give maximum.

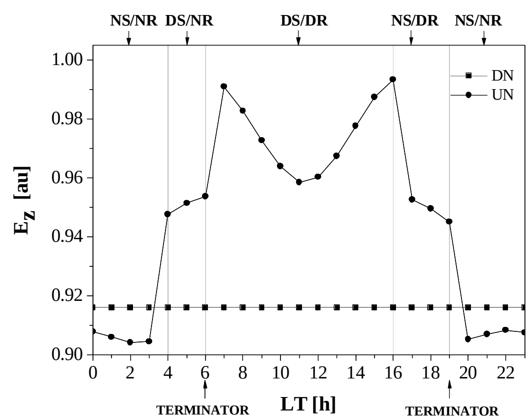

Figure 2: Single source simulation: source located at (20N, 10W), receiver – at (32N, 34E).

Although the variations caused by diurnal changes in the lower ionosphere are clearly seen when considering a single stationary source (~10%), the picture is less clear when calculating fields from a large number of dynamic sources simultaneously. When multiple OTD sources around the globe have all possible configurations around the terminator (NS/NR, DS/NR, DS/DR, NS/DR and NS/NR) the picture is blurred.

Fig. 3 shows experimental data and simulation results for UN and DN models for Mitzpe Ramon (32N, 34E). By comparing the results of DN and UN models we see only small variations caused by day/night conductivity changes, compared to the large variations caused by the changes in the daily lightning activity around the globe. The model simulations (both UN and DN) reproduce fairly well the experimental data, reflecting the major trends in diurnal variations.

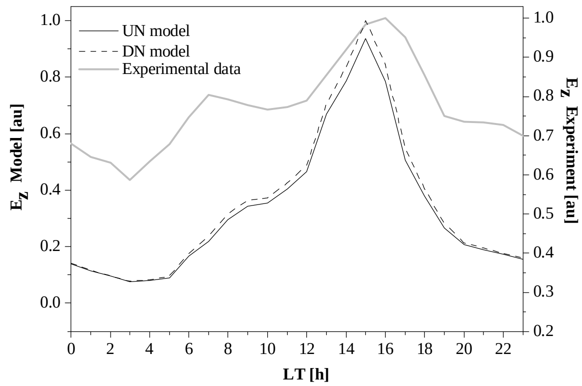

Figure 3: Dec-Jan-Jun-Jul mean simulation results for OTD MD lightning distribution (UN and DN) and experimental data (1999-2002 mean) for Mitzpe Ramon station.

It should be noted that no full agreement can be expected between the field data and the model simulations. OTD records only a fraction of lightning occurring worldwide, giving a qualitative representation of global thunderstorm activity. The missing lightning activity, not recorded by OTD, results in a high background level seen in the SR records, but absent in the model simulations. Variability of lightning activity through the years results in additional differences between the model and the observed data, which are taken for different year span (taking only two overlapping years would be insufficient due to the scarcity of OTD data).

Fig. 4 and Fig.5 offer a close-up of the amplitude variations at sunrise and sunset in Mitzpe Ramon. Results of uniform model simulations and experimental data are shown. Observed field amplitude variations at the terminator crossings are rather well recreated by a uniform model. This implies that diurnal variations in the ionosphere height are not the primary cause of the observed SR field variations. Results for the DN model show little difference.

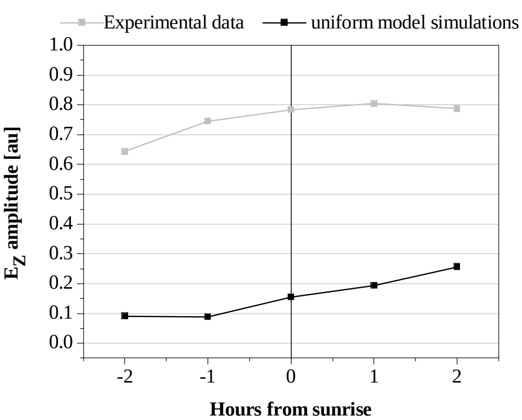

Figure 4: Experimental E_Z amplitude variations at sunrise in MR, Dec-Jan-Jun-Jul mean together with the PUK uniform model simulations.

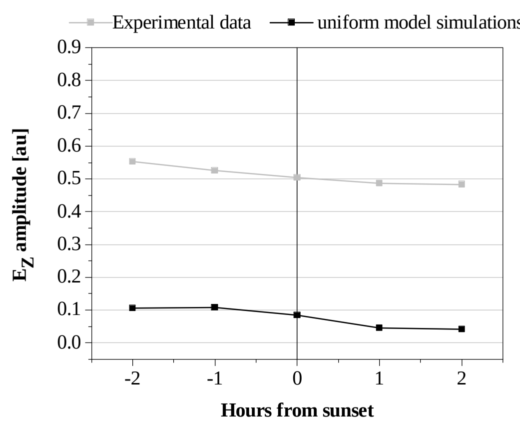

Figure 5: Experimental E_Z amplitude variations at sunset in MR, Dec-Jan-Jun-Jul mean together with the PUK uniform model simulations.

CONCLUSIONS

From the results presented above, it is apparent that the uniform model that does not account for the day/night variations in the ionospheric conductivity profile is sufficient to explain the field variations observed in the experimental data. While changes in the ionosphere cause notable variations in the fields resulting from a single stationary source, their significance is lost when considering world-wide thunderstorm activity. Therefore, the observed field variations appear to be primarily caused by the movement of thunderstorms relative to the measuring station, and not by the changes of the ionosphere conductivity at the station. This conclusion is consistent with the earlier theoretical estimations [8, 12, 17, 18, 19, 20].

REFERENCES

[1] Melnikov, C. Price, G. Satori, M. Fullekrug, 2004: “Influence of solar terminator passages on Schumann resonance parameters”, *J.A.S.T.P.*, 66, 1187-1194.

[2] Pechony, O., C. Price, 2004: "Schumann resonance parameters calculated with a partially uniform knee model on Earth, Venus, Mars, and Titan", *Radio Sci.*, 39(5).

[3] Schumann W.O., 1952: “On the radiation free self-oscillations of a conducting sphere which is surrounded by an air layer and an ionospheric shell” (in German), *Zeitschrift und Naturfirschung*, 7a, 149-154.

[4] Balser M., C.A. Wagner, 1960: “Observations of Earth-ionosphere cavity resonances”, *Nature*, 188, 638-641.

[5] Williams, E.R., 1992: “The Schumann resonance: a global tropical thermometer”, *Science*, 256, 1184-1186.

[6] Price, C., 2000: “Evidence for a link between global lightning activity and upper tropospheric water vapor”, *Letters to Nature*, 406, 290-293.

[7] Sentman D.D., B.J. Fraser (1991), Simultaneous observation of Schumann resonances in California and Australia: evidence for intensity modulation by local height of the D region, JGR, 96(9), 15973-15984.

[8] Nickolaenko, A.P. and M. Hayakawa, 2002: “*Resonances in the Earth-ionosphere cavity*”, Kluwer Academic Publishers, Dordrecht – Boston – London.

[9] Christian H. J., 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, 2003: “Global frequency and distribution of lightning as observed from space by the Optical Transient Detector”, *J. G. R.*, 108(D1), 4005.

[10] Mushtak V.C., E.R. Williams, 2002: “ELF propagation parameters for uniform models of the Earth-ionosphere waveguide”, *J. Atmos. Sol. Terr. Phys.*, 64, 1989-2001.

[11] Kirillov V.V., V.N. Kopeykin, V.K. Mushtak, 1997: “Electromagnetic waves in ELF range in the Earth-ionosphere waveguide”, (in Russian), *Geomagnetizm i Aeronomia*, 37(3), 114-120.

[12] Madden T., W. Thompson, 1965: “Low-frequency electromagnetic oscillations of the Earth-ionosphere cavity”, *Rev. Geophys.*, 3(2), 211.

[13] Kirillov V.V., 1993: “Parameters of the Earth-ionosphere waveguide at ELF”, (in Russian), *The Problems of Diffraction and Wave Propagation*, 25, 35-52.

[14] Kirillov V.V., 1996: “Two-dimensional theory of electromagnetic wave propagation in the ELF range in the Earth-ionosphere waveguide”, (in Russian), *Izvestia VUZov Radiophysica*, 39(9), 1103-1112.

[15] Kirillov V.V., V.N. Kopeykin, 2002: “Solving a two-dimensional telegraph equation with anisotropic parameters”, *Radiophysics and Quantum Electronics*, 45(12), 929-941 (Translated from *Izvestia Visshih Uchebnih Zavedenii, Radiophysica*, 45(12), 1011-1024).

[16] Cole Jr R.K., 1965: “The Schumann Resonances”, *J. Res. Nat. Bur. Stand.*, 69D, 1345-1349.

[17] Large, D.B., J.R. Wait (1968), Theory of electromagnetic coupling phenomena in the earth-ionosphere cavity, J.G.R., 73(13), 4335.

[18] Bliokh, P.V., A.P. Nickolaenko, Yu.F. Filippov (1968), Diurnal variations of the eigen-frequencies of the Earth-ionosphere cavity in connection with the eccentricity of the geomagnetic field, Geomagnetism i Aeronomia, 8(2), 250–260. English translation is published in Geomagnetism and Aeronomy.

[19] Nickolaenko, A.P. (1986), ELF radio wave scattering by the global non-uniformities of the Earth-ionosphere cavity, Izvestia Vuzov, Radiophysica, 29, 33-40. English translation is published in Radiophysics and Quantum Electronics.

[20] Rabinowicz, L.M. (1988), Global electromagnetic resonances in non-uniform and anisotropic Earth-ionosphere cavity, Ph.D. thesis, Kharkov, 1988.