Analysis of Schumann Resonances based on the International Reference Ionosphere

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***Abstract*—Schumann Resonances (SRs) are simulated and analyzed in this work using the geodesic finite-difference time-domain (GFDTD) method coupled with the international reference ionosphere (IRI). Through simulations, global lightning activities are considered as excitations and real environmental parameters of the Earth-ionosphere system are introduced. Simulation results obtained with analytic ionosphere models are also included in order to compare with our simulation results.**

I. Introduction

Schumann Resonances (SRs) are the resonant electromagnetic (EM) waves in the Earth-ionosphere system, which are mainly caused by global lightning discharges. Because SRs are easily effected by local environment and global properties (such as lightning distribution), they are considered to be effective indicators of global phenomena such as EM distribution, thunderstorm activities and temperature variations [1], [2], [3], [4]. However the lack of efficient simulation tools and experimental data before 2000s slows the application study of SRs. In the recent years, with the development of modern computation/experiment techniques the study of SRs are again valued.

The study of SRs can trace back to 1950s [5], since then researchers had studied this phenomena using mainly the analytic method [6], [7]. It is not until recent years numerical methods have been applied to such study. With the help of modern measurement techniques, the study of SRs applications are becoming possible, such as global lightning triangulations and global climate variation detections.

Although numeric EM simulation techniques such as the finite-difference time domain (FDTD) method can provide enough accuracy for most EM application studies [8], the uncertainty of parameters of the whole Earth-ionosphere system makes SRs simulations difficult. Nowadays, the accurate simulation of global parameters, especially global ionosphere conductivity distributions play a key role in most present SRs application studies, as they vary with many parameters such as time, location and temperature [9]. Many recent SRs simulations relies on the analytic ionosphere models such as the ”Knee” model or ”two-exponential” model [10], [1], however such models can only reveal approximate average ionosphere conductivity distributions, thus cannot provide enough accuracy for further SRs application studies. The development of the international reference ionosphere (IRI) [9] provides a good tool for such problem.

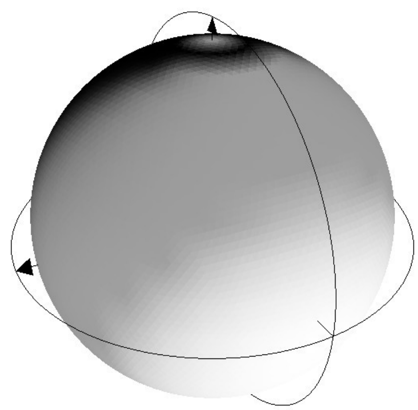

Fig. 1. Ionosphere conductivity distribution at height 80km. Generated at UT=0.0 from the international reference ionosphere (IRI).

In this work we apply the geodesic FDTD (GFDTD) method to simulate extremely low frequency (ELF) EM wave propagation in the Earth-ionosphere system, to study the SRs based on the ionospehre conductivity data from IRI, because the geodesic FDTD model has many advantages over other time domain EM solutions such as the optimized stability property of the FDTD algorithm [11]. Global parameters such as lightning discharges, lossy Earth's crust and geodesic information are also included in the simulations. We have also compared the results simulated with IRI and with different analytical ionosphere models.

II. Method

A. Ionosphere Conductivity Model

The data of IRI are generated from the worldwide network of ionosondes, which can provide an empirical standard model of the ionosphere. Because conductivity profiles are not directly provided by IRI, calculations have to be made to obtain these data [1]. Fig. 1 presents typical global conductivity distributions generated from IRI. The observation height is 80km and at UT=0.0 on Jan. 1st, 2010. From this figure the diurnal variations and polar anomalies of the ionosphere are clearly presented.

The comparison of ionosphere conductivity generated from IRI and from analytic ”Knee” ionosphere models are presently

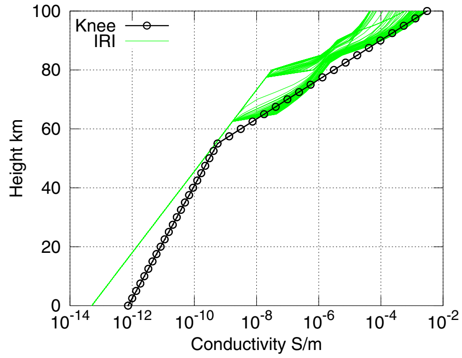

Fig. 2. Conductivity profiles of different ionosphere models. Knee: the "Knee" model. IRI: global conductivity profile variations obtained on Jan. 1st, 2010.

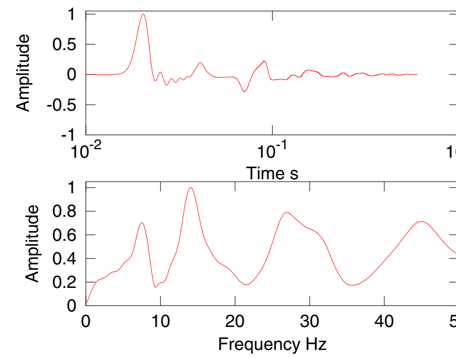

Fig. 3. Time domain and frequency domain waveforms obtained at $UT = 0$, 32°N,118°E (Nanjing).

in Fig. 2, in which the vertical conductivity profiles are generated. In this figure, global conductivity profile variations are presented to compare with the "Knee" conductivity model, which was proposed in [10] and widely adopted in many ionosphere studies. Through comparison the advantage of using IRI data is clearly presented as the inhomogeneity of global conductivity distributions can be fully considered.

B. Excitations

Global lightning activities are believed to be the common reason of SRs as they are continuous and possess tremendous power. In this work artificial lightning currents from global lightning centers (Southeast Asia, Africa, and South America [1]) are modeled to be excitations of SRs. The form of the lightning currents is described in [1].

C. Simulation Model and Method

The GFDTD method is applied to study SRs in this work. In this method the Earth-ionosphere system model is constructed by the alternating planes of transverse-magnetic (TM) and transverse-electric (TE) field components, which are composed of triangular cells and hexagonal cells (including 12 pentagonal cells), respectively. Then integral form of the Maxwell's equation is introduced to the model to complete the FDTD process. In this work, the horizontal direction (tangential direction of the Earths surface) resolution is about 250 km and the radial (vertical) direction resolution is 5km. This mesh can provide enough accuracy for the frequency band 0.0150 Hz, to calculate the SRs.

The calculation region of this work extends to a depth of 50 km into the lithosphere (to account for the lossy ground) and to an altitude of 100 km above sea level (the top of the ionosphere D region). To accurately describe the EM environments of the lossy Earth-ionosphere system, topographic data from the NOAA-NGDC [12] are used. In the crust, the permittivity and conductivity are set according to reference models [13], [14].

III. Results and Discussion

The waveforms presented in Fig. 1 are excited using global lightning currents and obtained at $UT = 0$, 32°N,118°E (Nanjing). The result is simulated using the conductivities from IRI. From this figure, the attenuation of waveforms with time are clearly shown (up sub figure). Because the Earth-ionosphere system is a lossy cavity, the SRs can not be accurately obtained using just the Fourier transform (as shown in Fig. 1, down sub figure). In this work, Prony's method is applied to obtain the resonant frequencies and quality factor.

TABLE I
Comparison of resonant frequencies and qualify factors obtained using different ionosphere conductivity models.

	Analytic	IRI		Knee	
	f_n Hz	f_n Hz	Q	f_n Hz	Q
1	7.7	7.81	5.45	7.77	3.80
2	14.0	13.97	6.09	14.16	4.59
3	20.2	20.13	6.52	20.50	5.55
4	26.5	26.24	6.54	26.77	6.46
5	32.8	32.80	7.78	32.99	7.23

Table 1 summarizes the resonant frequencies and qualify factors obtained using different ionosphere conductivity models, compared against analytical results [10]. From this table we can see the frequencies obtained with different models are very similar (the errors are within 1%). Although the differences are slight, they contain information about the local environment and ionosphere properties for further study. It is noted that the average experimental value of the first SR is about 7.8Hz, which means the FDTD results are more accurate than analytic one. The comparison of qualify factors shows differences at the first two resonant frequencies, in which the qualify factor obtained using IRI data is higher than using "Knee" model. Because the simulation results using IRI consider more details of the ionosphere conductivity, we believe these value are more accurate in describing local environment.

A study of global distribution of SRs are presented in Fig. 4. In this simulation, EM waves are observed along the equator at 0°N0°E, 0°N10°E, ..., 0°N350°E (0°N10°W), respectively. Frequency domain waveforms are obtained in 0.01-50Hz, $\triangle f = 0.06$Hz. Similarly, conductivity data from IRI are used to study SR variations. In this figure, several

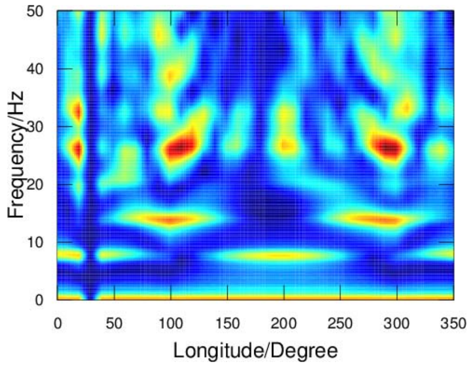

Fig. 4. Global distribution of SRs, $\triangle f = 0.06$Hz.

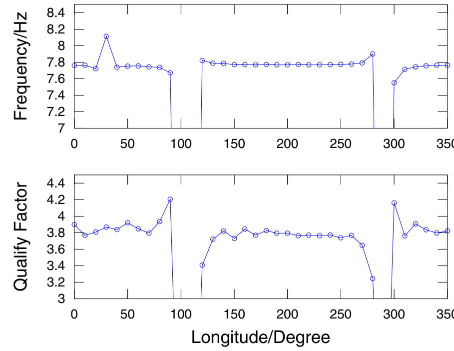

Fig. 5. Global distribution of SRs, $\triangle f = 0.06$Hz.

phenomena are worth noticing: 1, the resonant phenomena are clearly shown with asymmetry, which is obviously caused by the inhomogenous ionosphere conductivities (unlike analytic models such as the "Knee" model); 2, the regular distribution of resonant frequencies (especially the first two ones) is because of the property of ELF waves and the source locations (see previous introduction) and the discontinuity appears at 30°E is also because of the lightning source; 3, the resonances frequencies above 20Hz are not very obvious and vary a lot at specific regions as a result of the mixture of different resonant modes.

Finally, a quantitatively description of the SR variation along the equator are presented in Fig. 5, in which only the first resonant frequency is considered. This figure clearly shows that the first SR and its qualify factor slightly varies with longitude, except for the lightning source region where the first SR can not be obtained. The results of Fig. 4 and Fig. 5 can be good references for further study of SRs applications.

IV. Conclusion

In this work we have applied the GFDTD method to simulate SRs of the Earth-ionosphere system. Conductivity values from the IRI are introduced to study the variation of SR frequencies and qualify factors. Analytic model of "Knee" profile and analytic SR values are also presented to compare with our simulation results. Through simulations, SR frequency variations and global SR distributions are obtained for further study of the Earth's environment and the ionosphere.

The introduction of IRI into the GFDTD method provides a more rigorous model of the Earth-ionosphere system, thus improves the accuracy of EM wave propagation study. In ongoing works the applications of SRs as global indicators are to be studied using the GFDTD coupled with IRI.

Acknowledgment

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