STATISTICS OF GLOBAL ELF TRANSIENTS DUE TO LIGHTNING

Eran Greenberg and Colin Price

Department of Geophysics and Planetary Sciences, Tel-Aviv University, Tel-Aviv, Israel.

ABSTRACT

Schumann Resonances (SR) are resonant electromagnetic waves in the Earth-ionosphere cavity, induced primarily by lightning discharges, with a fundamental frequency of about 8 Hz and higher-order modes separated by approximately 6 Hz [1]. The SR are made up of the "background" signal resulting from global lightning activity, and ELF "transients" resulting from particularly intense lightning discharged somewhere on the planet (ELF - extremely low frequency range). Since transients within the earth-ionosphere cavity due to lightning propagate globally in the ELF range, we can monitor and study global ELF transients from a single station. Data from our Negev desert (Israel) ELF site has been collected for more than 7 years using two horizontal magnetic components and a vertical electric field ball-antenna. The ELF transients have been monitored in the 5-40Hz range with a sampling frequency of 250Hz. In this paper we present statistics related to the probability distribution of ELF transients, and the spatial and temporal variations in transient statistics as observed at our station. Williams [2] suggested that SR parameters may be used to monitor planetary temperatures (linked to SR through the lightning flash rate, which increases nonlinearly with temperature). More recently, Price [3] suggested to monitor global upper-tropospheric water vapor changes with SR (water vapor and lightning activity are closely linked through thunderstorms). If it is possible to monitor global temperature and water vapor changes through SR records from a single station, SR may be a convenient and a low-cost tool for global climate change observations. Since ELF transients represent the most intense lightning flashes, tracking their statistics may supply additional information regarding thunderstorm variability on all spatial and temporal scales.

INTRODUCTION

The worldwide lightning activity is produced by about 2000 thunderstorms somewhere around the globe [4], generates dozens of lightning discharges per seconds. Many attempts were made over the years to know the globe flash rate- from Brooks in his prior work who estimated that the global flash rate is 100 flashes\second [5] through Christian et al. now days who determined the rate of about 44 flashes\second based on data of the optical transient detector (OTD) as observed from space [6]. A lightning discharge, radiate radio noise all over the frequency spectrum, although the main interest of our research is in the lower ELF band. The advantage of this frequency band is the low attenuation rate signals exhibit while propagating along the earth-ionosphere waveguide, and therefore by observing the electromagnetic signals in time and frequency domains one can deduce the behavior of the global lightning activity [7, 8, 9, 10, and 11].

ELF OBSERVATION SYSTEM

The ELF instruments used in this study are located at Tel Aviv University's astronomical observatory near the town of Mitzpe-Ramon in the Negev Desert. The station has two horizontal magnetic induction coils for receiving the magnetic field in the north-south direction (H_{ns}) and the east-west direction (H_{ew}) and one vertical electrical ball antenna for receiving E_r [12]. The three components of the electromagnetic field are sampled at 250Hz, with a notch filter at 50Hz in use. The raw time series data are saved in 5-minutes files, with all analysis performed during post-processing.

PARAMETRS DIURNAL CHANGES – TIME DOMAIN

Statistical analysis of the signal in time domain reveals that it follows the normal distribution very well, between 1-99%. We can assume that the number of intense events in each file obeys the Poisson distribution, so the parameter of the Poisson distribution λ was estimated for every hour with maximum likelihood. For each 5 minutes file we have estimated the normal distribution parameters μ and σ and calculated the number of intense events due to its excursion above the background noise by 5σ (=15pT). Data was recorded synoptic (one file every hour) from February until October 2004 and a total number of 4320 files were observed → so for every hour some 180 files were analyzed to deduce the diurnal behavior of the global lightning activity. The three global lightning activity centers revealed: south-east Asia, central Africa and the Americans which are dominant at 08, 14 and 20(UT) respectively. Its origin is thunderstorms activity which develops late afternoon local time after a mean delay time of about three hours with respect to the solar.

Each horizontal magnetic field sensor is sensitive to waves arriving from directions normal to its axis. Therefore, due to the observation station in Mitzpe-Ramon global position, the three major regions of thunderstorm activity located at the most sensitive arrival azimuths, i.e. 90° to the sources. Waves from south-east Asia arrive from east and detected by the north-south magnetic induction coil, and the same for waves from the Americans which come from west. Waves from Africa arrive from south and therefore detected by the east-west magnetic induction coil.

To resolve the inverse problem we assume four lightning strokes with amplitude of 1[C·km] from different global locations to represent the most active regions, based on OTD observations: Malaysia (south-east Asia), Rwanda (central Africa), Florida (North America) and Argentina (South America). The normal distribution parameter σ is determined by the variance of the background noise level: increased lightning activity leads to increased values of σ parameter. Based on data from the magnetic north-south coil three maxima observed at 08-09, 12-13 and 17-18(UT) which represent the three major 'hotspots'. The African chimney is decreased since the north-south coil sensitive to the other twos but due to its global position should be decreased even more. The Asian chimney is more powerful than the American chimney, in agreement with theory. The σ parameter is less influenced by the global lightning activity than the number of intense events- while σ at 08-09(UT) is greater in 1-2% from its values at 17-18(UT) the number of intense events above 15pT greater than 30% between those two time durations. Based on data from the magnetic east-west coil one clear maximum observed at 13-

14(UT) due to the sensitivity of the east-west sensor to arriving signals from Africa but also due to most intense lightning activity in this region. The American chimney should be more powerful than the south-east Asia chimney. Again, the σ behavior is more moderate comparing to the number of intense events – while the values of σ at 13-14(UT) is greater in 30% from its values around midnight but the number of intense events respectively is greater than 230%. The changes in the number of intense follows theory with better agreement than changes in σ parameter.

PARAMETRS DIURNAL CHANGES – FREQUENCY DOMAIN

By observing the diurnal changes of the fundamental SR mode at 8Hz for H_{ns}, two peaks are prominent above the background at 08 and 20(UT) contributed by the south-east Asia and the Americans activity centers. The Asian chimney is more powerful than the American one, and the quality factor of the Earth-Ionosphere cavity at 08(UT) is lower than at 20(UT). By observing the diurnal changes of the fundamental SR mode at 8Hz for H_{ew} the most active thunderstorm center in the globe can clearly be seen at 14(UT) and its amplitude in relative to the other centers is in agreement with theory.

THE WAVEGUIDE MODAL STRUCTURE

Although the north-south induction coil is less sensitive to signals arriving from direction closely normal to its axis (Africa), the modal structure of the waveguide attenuated the second SR mode at 14Hz arriving 10,00km from its origin to the observation station. To simulate the waveguide modal structure we assume that a lightning stroked in four global positions: Malaysia (3.25˚N 101.75˚E); Rwanda (1.25˚S 27.75˚E); Florida (28.75˚N 81.75˚W); Argentina (27.75˚S 56.25˚W). Its source-observer distances and the arrival azimuths to our ELF station are 7600km/99˚, 3600km/193˚, 10600km/308˚ and 11600km/246˚. Another assumption is that at ELF frequencies the quasi-transverse electromagnetic mode (TEM) is the only mode effectively radiated, and therefore the propagated waves in the Earth-ionosphere cavity consist of the radial electric field E_r and the horizontal magnetic field H_φ [13]. In geocentric spherical polar coordinates $\{r, \theta, \varphi\}$ the magnetic field may be written in terms of zonal harmonic series:

$$H_\varphi(\omega) = \frac{M_c(\omega)}{4\pi ha} \sum_{n=1}^{\infty} \frac{(2n+1) P_n^1(\cos\theta)}{n(n+1) - \nu(\nu+1)}$$

where ω denotes the angular frequency; θ is the great circle angle from lightning to the observer; ε_0 is vacuum permittivity; a is the radius of the Earth; h is the height of the ionosphere; $P_n^1(\cos\theta)$ is the associated Legendre function of degree n and order 1; υ is the modal eigenvalue related to the propagation constant of the Earth-ionosphere spherical shell cavity; and $M_c(\omega)$ is the vertical charge moment of the lightning ground flash.

CONCLUSIONS AND SUMMARY

In this paper we have demonstrated the effectiveness of single station ELF observations to monitor the global lightning activity centers by remote sensing. Its contribution is essential for a better understanding of the global electric circuit and climate change. The signals in time and frequency domains exhibit pronounced excursion on 8, 14 and 20(UT) correspondingly to the three major lightning activity centers in south-east Asia, central Africa and the Americans respectively. Its origin is thunderstorms activity which develops late afternoon local time after a mean delay time of about three hours with respect to the solar zenith.

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