New Method for Detection of Global Lightning Activity Using Schumann Resonance

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Abstract: We discuss a new method for a global lightning activity mapping using measurements of extremely low frequency (ELF) electromagnetic waves (EW) propagating in the Earth-ionosphere resonance cavity. With the data collected by the Hylaty ELF station, located in Poland (49.19 N, 22.55 E), we analyze the Schumann Resonances (SR) spectra with seven resonance peaks. The measurements are done quasi-continuously, using successive 10 minutes data intervals.

Kułak et al. [2006] found that the interaction of the standing and traveling waves leads to asymmetric shape of observed SR curves. Following this approach, we introduce a numerical model of the ELF electromagnetic waves propagation in the spherical Earth-ionosphere cavity and using this model we compute the asymmetric SR spectral templates for selected distances between the source and the observer. We fit the asymmetric curves describing seven SR maxima to the observational data and we calculate the distances to the thunderstorm centers by solving the inverse problem. As an example we investigate the lightning activity originating from the most intensive thunderstorm center in Africa. We use the observational radio data recorded in January and August 2011 and we construct the monthly lighting activity 1D maps using these data to study the differences in the location of the African storms centers during different seasons.

Schumann Resonance Spectra Decomposition: Asymmetric spectral lines are observed in many resonant systems in Nature. Nevertheless, it is widely assumed that the damped oscillators spectra are described by symmetric Lorentz curves.

Superposition of the standing wave field in the Earth-ionosphere cavity with the field of traveling waves, that transmit energy form the sources (lightning discharges) to the global resonator, is the reason for an asymmetric shape of the observed resonance components. One can remove a part of the signal resulting from traveling field component by using the spectrum decomposition method proposed by Kulak et al. [2006]. The general form of spectrum at any point within a distance θ from a single source is given by equation [Kułak et al. 2006]:

$$W(f,\theta) = s + \frac{z}{f^m} + \sum_{k=1}^{N} \frac{a_k[1+e_k(f-f_k)]}{(f-f_k)^2+(\frac{g_k}{2})^2} \qquad (1)$$

where: W(f,θ) – wave power spectrum, *s* – white noise term, a_k – power of kth peak from the observed N=7 resonance peaks, e_k – introduced asymmetry parameter, f_k – peak frequency and g_k – peak width. For a lack of asymmetry, e_k = 0, the shape of each peak becomes a respective Lorentzian curve and all parameters have their classical meanings.

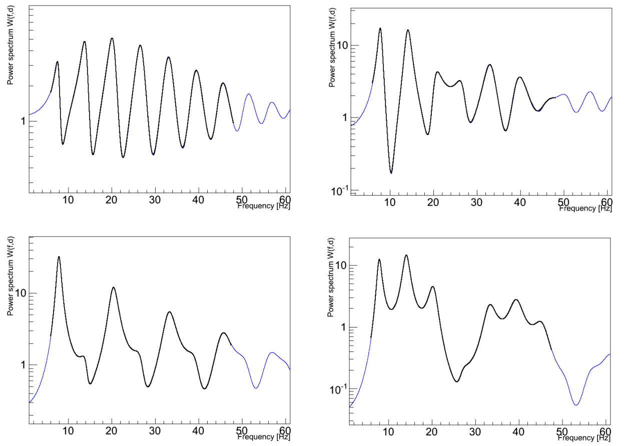

Fig. 1: Numerical model data (in blue) and fitted asymmetric decomposition function (in black), given by equation (1) for selected source-observer separations: 2620 (23.6), 6672 (60), 10008 (90), 13344 (120) km (deg).

Numerical Model SQ0005: We construct physical and realistic model of the Earth-ionosphere cavity, which will be used in the computation of storms activity maps. This model is an extension of the model describing only three SR peaks, used in the paper by Kułak et al. [2006], to the model, that characterize seven SR modes. The physical parameters, used in the numerical solution of TDTE equation, i.e. damping coefficient, are taken form the above mentioned paper and our modeling is limited only to the magnetic field component since this component is measured by Hylaty ELF station. In this numerical model the resonance bands are suppressed in accordance with the theory of Legendre polynomials.

The numerical solution of TDTE equation is obtained for a simple current impulse and for 23 distances ranging from 23.6 degrees up to 156.4 degrees with the mean distance step around 5 degrees. Transforming this distances from degrees to kilometers, which is a more useful units for the readers, give the distances range from 2620 km to 17 394 km with a mean distance step about 550 km. The decomposition function, given by equation (1) (with subtracted color term: z/f^m) is fitted to the numerical model data using the non-linear multiple least square algorithm in the frequency range: 4 – 48 Hz. The example of the numerical modeling, for four different source-observer separations, and the fitted decomposition function is shown in figure 1. Figure 2 shows the values of the peak frequencies for seven SR modes as a function of the source-observer separations. The frequencies do not depend on the distance to the source. Independence on the distance makes the frequencies f_k global values, which describe the physical state of resonant cavity in contrast to the Lorentzian (symmetric) frequencies, which are distance dependent.

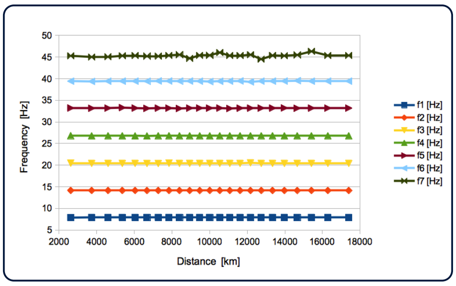

Fig. 2: The frequencies of the seven SR mode as a function of the source-observer distance.

The parameters a_k obtained from the decomposition of the numerical model SQ0005, as a function of the source-observer separations, for the first two SR mode are shown in figure 3.

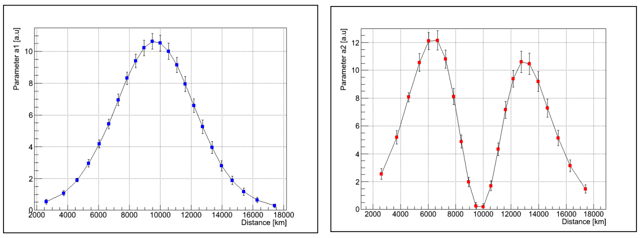

Fig. 3: Amplitude of the first (left panel) and second (right panel) SR mode versus source-observer distance.

Asymmetry parameters e_k are related with the traveling wave field. The absolute values of asymmetry parameter e_1 are large near the sources and as a source-observer separation grows parameter e_1 tends toward zero. Figure 4 shows the dependence of the asymmetry parameters e_1 and e_2 on a distance between source and observer.

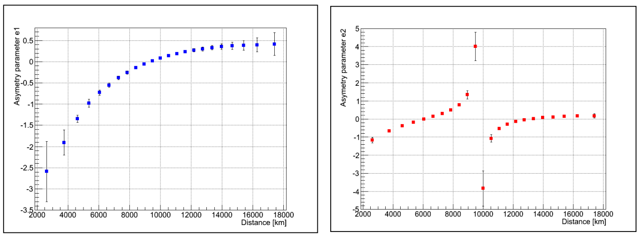

Fig. 4: Distance dependencies of asymmetry parameters e_k for the first two SR modes. Please note that in some case the fitting (statistical only) error bars are smaller then the point size

Comparison Between Observed And Modeled SR Power Spectra: The recorded ELF data were binned in 10 minute intervals and power spectrum was derived from the observational data using the FFT algorithm. For each time interval the asymmetric function (1), which describes the real data, was fitted and such function is denoted by $W_{obs}(f)$. In order to evaluate the distance from the source we look for a numerical model solution, which best fits the observations. For each distance the chi-square test between the appropriate function $W_{th}(f,\theta)$, and real data parameters for $W_{obs}(f)$ is performed to find the minimum. The smallest chi-square value yields the evaluated distance from the source.

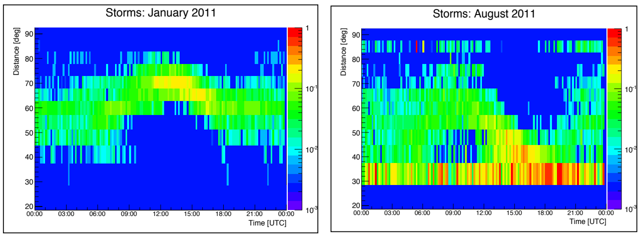

Fig. 5: Cumulative daily storm intensities projected on the distance vs. the UTC time plane. The distances to the storm centers were calculated using the numerical model SQ0005 .

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