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COMPARISON OF OBSERVED SCHUMANN RESONANCE DATA WITH THE SINGLE DIPOLE SOURCE APPROXIMATION THEORIES

By

Toshio OGAWA and Shigeaki OTSUKA

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Abstract

The vertical electric field component of natural ELF noises observed at Kyoto in the fall of 1971, when the main signal sources were supposed to be in the equatorial region, was analyzed by the automatic tracker of the Schumann resonances, and the diurnal variations of the peak frequencies and the peak amplitudes of the first three modes were obtained. The diurnal patterns of the frequencies are seen to agree qualitatively with the theoretical curves calculated by Jones with a single dipole source in view of the source-receiver distances, while those of the amplitudes are not in agreement with the calculated results by Polk with a small extent of source area. The observed diurnal amplitudes of both frequencies and amplitudes are much smaller than the theoretical results. This suggests that any theory to interprete the Schumann resonance data should use worldwide spreaded source signals.

1. Introduction

The time variations of Schumann resonances depend principally on the following two main factors: the distance between a receiver and the thunderstorm region which is considered the main source, and the height distribution of electric conductivity of the lower ionosphere as an upper boundary of the cavity. Although there is local-time dependence in the effect of the ionospheric conductivity, it will be cancelled out because the resonant waves propagate around the earth several times. Therefore the diurnal variations of resonance frequencies and peak amplitudes depend primarily upon source-receiver separation. From this point of view the experimental data of the apparent resonance frequencies and the peak amplitudes were compared with the theories which concern source-receiver separation by Jones [1969] and Polk [1969].

2. Observations

An automatic tracking system of Schumann resonance frequencies and peak amplitudes was made. The principle of the system is the same as that made at M.I.T. (Nelson [1967]). Details of the system are described in another paper (Ogawa and Murakami [1973]). The vertical electric field component of natural ELF electromagnetic noises were received with the ball antenna set up on the roof of the Geophysical Institute. Using the automatic resonance tracker, it is possible to make the real time recording of the apparent resonance frequencies and the peak amplitudes of the first (5–11 Hz), the second (11–17 Hz), and the third (17–23 Hz) modes of the Schumann resonances on chart paper. In the present paper were analyzed only data in the period from 17 September to 30 October, 1971, when the center of the thunderstorm area that is supposed to be the main source of ELF noises, is considered to be on the equator. The values of frequencies were read from the chart paper every hour, and those of amplitudes every two hours. Few data that were evidently disturbed by the artificial noises were not taken into the analyses. The monthly mean values of the first three mode peak frequencies of Schumann resonances for each hour were calculated

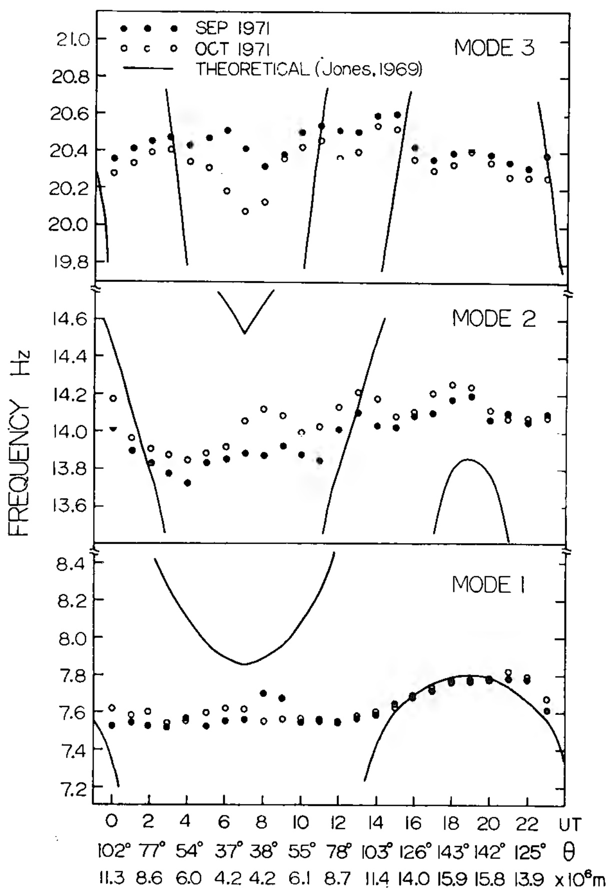

Fig. 1. The diurnal variations of resonance frequencies of the Schumann resonances. θ in the horizontal axis gives the angular separation from Kyoto to the signal source which is assumed to be at the intersecting point of the equator and the longitude 16 h local time.

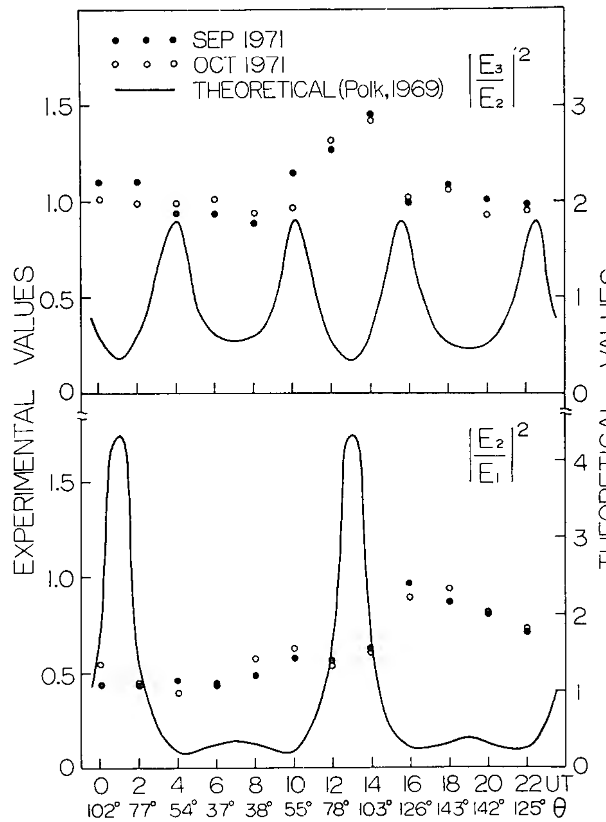

Fig. 2. The diurnal variations of the square ratios of the second to the first, and the third to the second mode amplitudes of the Schumann resonances. θ gives the same as in Fig. 1, and the source is assumed same as in Fig. 1.

and are plotted in Fig. 1 with the universal time (UT).

As regards the peak amplitudes, in order to compare them with the theoretical results calculated by Polk [1969] later on, the ratios of mode 2 to mode 1, and of mode 3 to mode 2 for the square of the values of every two hours each day were calculated, and then the monthly mean values of the ratios were obtained. The diurnal variations are given in Fig. 2.

First as for the frequencies, it is found from Fig. 1 that the diurnal variations of both September and October are similar as a whole except small differences a few hours before and after 7 UT. The variation patterns of the higher modes have higher harmonics than the lower modes. The overall monthly mean values of the first three mode frequencies in September are 7.62 Hz, 14.0 Hz, and 20.4 Hz respectively, and those in October are 7.64 Hz, 14.1 Hz, and 20.3 Hz respectively.

Secondly as for the amplitudes, no clear difference is found between September and October. The discontinuities in both $|E_2/E_1|^2$ and $|E_3/E_2|^2$ occur around 15 UT.

3. Comparison with the theories

The vertical electric field of the resonant modes excited by the vertical electric dipole in the spherical shell cavity with the assumed curved perfect conductor earth and the ionosphere of inhomogeneous, isotropic conductivity, is given by

$$E_r = -i\frac{Idl\nu(\nu+1)}{4\pi a^2 \varepsilon_0 \omega h}\sum_{m=0}^{\infty}\frac{(2m+1)P_m(\cos\theta)}{m(m+1)-\nu(\nu+1)}, \tag{1}$$

where the notation is that of Jones [1969]. Using the Eq. (1) Jones [1969] calculated the field intensity from a single dipole source by more than two hundred terms in the summations, employing the $\nu(\omega)$ data previously derived by himself [Jones, 1967] from the single term approximation in which it is assumed that in the immediate neighborhood of a resonance, i.e., when $m(m+1)\sim\mathrm{Re}[\nu(\nu+1)]$, only one term in the summation contributes significantly to the field. Jones thus obtained the relation between the frequencies at the maximum amplitudes and the source-receiver distances. To compare with the present experimental results, the curves of diurnal variations of the apparent resonance frequencies estimated by Jones are reproduced in Fig. 1, assuming that the dipole source is at the local time 16 h on the equator. From the comparison between the experimental and theoretical results, it is found that the general patterns of diurnal variations may be seen to agree qualitatively, but the theoretical amplitudes of the diurnal variation are much larger than the present experimental amplitudes. This discrepancy comes from the fact that the radio source is assumed of single point in the calculations.

Polk [1969] calculated the square of the ratio of the amplitudes of successive resonant modes on the assumption that both the phase velocity and the attenuation constant are approximately constant for pairs of successive resonance frequencies, and the source has some extent. That is,

$$\left|\frac{E_{r,n+1}}{E_{r,n}}\right|^2_{\mathrm{DIST}} \approx \left|\frac{(2n+3)\omega_{n,0}}{(2n+1)\omega_{n+1,0}}\right|^2 \frac{\int_{\theta_1-\Delta}^{\theta_1+\Delta} P^2_{n+1}(\cos\theta)\sin\theta d\theta}{\int_{\theta_1-\Delta}^{\theta_1+\Delta} P^2_n(\cos\theta)\sin\theta d\theta}. \tag{2}$$

In Eq. (2) is cancelled out the effects of intensity at the source and of the ionospheric conductivity profile. In order to compare with the present experimental results, $|E_2/E_1|^2$ and $|E_3/E_2|^2$ calculated from Eq. (2) are reproduced in Fig. 2. In this case it is assumed that the sources are distributed over the region centering at the intersecting point of the equator and the longitude 16 h local time, and have an extent of $\Delta=20°$. The calculated results, as well as those of frequencies, give the remarkably larger amplitudes of the diurnal variation than the experimental results. Moreover the theoretical and the experimental patterns of diurnal variations do not coincide at all.

4. Conclusion

One of the most important reasons why the amplitudes of the diurnal variations of Schumann resonances with respect to the resonance frequencies and the peak amplitudes calculated by Jones and Polk respectively are much larger than those of the present experimental results is what the area distribution of the thunderstorm region assumed as the radio source in the calculations is none or very small. In view of the diurnal variation of the distribution of worldwide thunderstorm areas, it must not be considered that the thunderstorm occurs only near 16 h local time, but a large per cent of that occurs simultaneously in the regions of the world other than the region of 16 h local time. If the effect of this source distribution is taken into account, the calculated results will come close to the experimental results. Such a calculation of apparent frequencies of the Schumann resonances is being made.

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