SIGNAL STRENGTH RESPONSE TO 11 AUGUST 1999 ECLIPSE EFFECT ON D REGION

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ABSTRACT

The electric field intensity records of six ray paths, from LF to MF range, reflecting in the obscured area of the low ionosphere, have been taken during total eclipse on 11 August 1999. Signals were received near Belgrade (44.85 N, 20.22 E). The maximum of the signal strength occurred with time delay (2'21" - 7'20", respecting to the ray path), after the central line of totality reaches the point of the wave reflection. Considering the time delay as a "time constant" for the electron density variation, the electron density at totality was calculated to be $2.3 \cdot 10^9$ [m^{-3}] - $7.1 \cdot 10^9$ [m^{-3}].

INTRODUCTION

The total solar eclipse on August 11, 1999 was one more opportunity to study the response of the ionosphere to the change of the solar illumination. During eclipse the main source of the electron-ion pairs production is temporally disabled and that affects the ionosphere in two ways: first, the total electron content (TEC) decreases and second, the shape of vertical electron density profile $N_e(h)$, changes. As the eclipse totality path move trough the ionosphere at about 80 km level, the bottom edge of the ionosphere rises and N_e (h) peak in the lower ionosphere almost vanishes. The high ionosphere $N_e(h)$ peak increases and moves upward. The reduction and altitude redistribution of the ionospheric D-region electron density, cause a rise in the effective reflection height of LF and nearer HF radio waves, that can be detected as an increase of signal strenght and increase in phase path. Therefore, by monitoring the signals from transmitters operating at fixed frequency and selected propagation paths, at regular ionospheric conditions and total eclipse, the eclipse effect on D-region electron density can be deduced.

THEORETICAL BACKGROUND

The vertical electron density profile in the ionosphere reflects the equilibrium of numerous electron production and loss processes. In general form, the equation of electron density time variation is:

$$\frac{\mathrm{d}N_e}{\mathrm{d}t} = q - \alpha_{ef} N_e^2 \tag{1}$$

where N_e is the electron density, q is the electron production rate coefficient, α_{ef} is the effective recombination coefficient and t denotes time. By differentiation of the upper equation and assuming the moment of extreme electron production, it follows:

$$\frac{\mathrm{d}^2 N}{\mathrm{d}t^2} = -2\alpha_{ef} N_{qm} \frac{\mathrm{d}N}{\mathrm{d}t} \tag{2}$$

where N_{qm} is the electron density in the moment of extreme q. Equation (2) describes the diurnal changes of the electron density, [1]. It can be also used to describe the electron density oscillation taking place during the solar eclipse, with time constant $\Delta t = 1/(2\alpha_{ef} N_{qm})$. At the moment of total eclipse, the electron production rate coefficient decreases to minimum, but the corresponding electron density continue to decrease, because recombination processes affect the recovery phase. Therefore, there is a time delay from the moment of minimum electron production rate coefficient, to the moment of minimum electron density N_{em}. The time delay represents the “sluggishness” of the ionosphere and it can be regarded as the time constant Δt. Knowing the time delay and effective recombination coefficient, the electron density in the moment of minimum electron production rate coefficient, can be determined. While the time delay can be rather plausibly measured, the value of effective recombination coefficient is still poorly known. Assuming the dissociative recombination as the predominant one in the upper D region, the value $\alpha_{ef} = 5 \cdot 10^{-13}$ m^3/s, can be used.

TIME DELAY MEASUREMENTS

The reflection of the radio wave occurs at the ionospheric height where the plasma frequency is close to the frequency of the signal. The plasma frequency is determined by maximum electron density, [2]. The absorption of the wave energy depends on electron density along the path, being greatest in the vicinity of the reflection point. The moment of minimum electron density at the reflection height, can be detected by occurrence of CW signal strength maximum, (minimum absorption). Monitoring of the CW signal diurnal variation, on the day of solar eclipse as well as during the days preceding the eclipse, was carried out by means of classical A3 technique. The records of electric field strengths over six ray paths, having the reflection points in the obscured area of the lower ionosphere, have been monitored.

Chosen signals are transmitted from Rugby, UK, (52.2 N, 358.9 E) at frequency f = 60 kHz; Germany (50.02 N, 9.00 E), that is the DCF signal for exact time service at f = 77,5 kHz; Brasov, Rumania (45.72 N, 25.6 E), 153 kHz; Topolna, CzechRep, (49.17 N, 17.59 E), 270 kHz; Bratislava, Slovakia (48.52 N, 17.73 E), 1098 kHz and Bacau, Rumania (46.5N, 27.00 E), 1179 kHz. All signals were received in vicinity of Belgrade, Yugoslavia (44.85 N, 20.22 E). Signals were recorded or by long wire antenna, or by loop antenna type HF2-Z2 and receiver type ESH2.

Previously, the signal paths were calculated by raytracing program, using the N_e(h) model which takes in account well known eclipse effects: the decrease of the total electron content (TEC), the rise of the bottom edge of ionosphere and smoothing of the N_e (h) peak in the lower ionosphere, the increase and movement upward of the high ionosphere N_e(h) peak. It enables to make a plan of monitoring, The time interval of continuous recording were planed to be within the times of first and forth contact as given by astronomer's calculation, taking in account the time correction for eclipse totality path on ionospheric altitude. The diurnal records taken in days preceding the eclipse, show the typical dependence of the skywave signal strength on the solar zenith angle. The eclipse effect was detected by continuous recording of the signal strength during 20 minutes interval, around the moment of the totality at the expected wave reflection height. The eclipse effects on each signal was clearly recognized by the maximum of the signal strength during the phase of totality, interrupting the regular diurnal signal strength decrease, due to absorption. The maximum signal strength appears with time delay after the central line of totality reaches the point of the wave reflection. It takes the same time for signal strength to return to the magnitude preceding eclipse. The ray paths of all signals were partially obscured.

Two LF paths are predominantly aligned with totality path. Reflection points at 80 km above the Earth surface, were expected to be inside elliptic spot totally at 103404 UT for signal from Rugby and at 104330 UT for DCF signal, on August 11, 1999. Continuous recording was going on from 102800 UT to 104200 UT, for signal from Rugby. Continuous recording of DCF signal was going on from 103800 UT to 104900 UT. The maximum E field strength for the signal from Rugby was recorded at 103840 UT and for DCF signal, at 104640 UT. So, the measured time delays for Rugby and DCF signals are 4'36" and 3'10", receptively. The records of the these two signals are given in Fig.1.

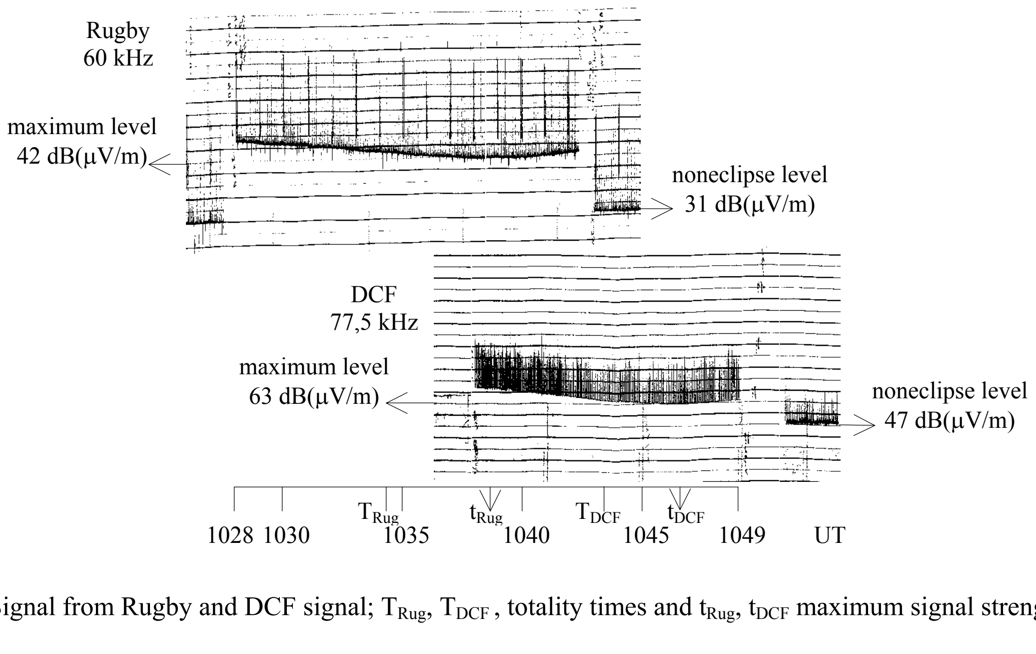

Fig. 1. Signal from Rugby and DCF signal; T_{Rug}, T_{DCF} , totality times and t_{Rug}, t_{DCF} maximum signal strength times.

Four MF to nearer HF paths were rather crossing the totality path. Reflection points at 84.5 km, 88.6 km, 93 km, and 87 km, were expected to be inside elliptic spot totally at 105130 UT (1098 kHz), 105109 UT (270 kHz), 105945 UT (1179 kHz), and 110033 UT (153 kHz), respectively. The E field strength maxima were recorded at 110720 UT (153 kHz), 105330 UT (270 kHz), 105608 UT (1098 kHz), 110705 UT (1179 kHz).

The determined time constants (or time delays) for all six ray paths, assuming the widely accepted value α_{ef} of $5{\cdot}10^{-13}$, yield the values of the electron density in the moment of totality N_{qm}, greater in lower D region, and less in the upper D region, than values given by IRI model for noneclipse conditions, [6]. It can be attributed to complete distortion of electron density profile in D region, during eclipse. Values of the time delays and corresponding N_{qm} values are given in Table 1.

Table 1. Time delays for six ray paths and corresponding

Signal from:	time of totality at reflection height (UT)	time of maximum *E* field strength (UT)	time delay (minutes)	electron density N_{qm} ($\times 10^{-9}$) (m^{-3})
Rugby; 60 kHz	103404	103840	4'36"	3.6
DCF; 77,5 kHz	104330	104640	3'10"	5.3
Bratislava; 1098 kHz	105130	105608	4'38"	3.6
Topolna; 270 kHz	105109	105330	2'21"	7.1
Bakau; 1179 kHz	105945	110705	7'20"	2.3
Brasov; 153 kHz	110033	110800	7'22"	2.3

The reference signal strength was recorded during few minutes after 082800 UT and additionally, few minutes after 120400 UT, (at noneclipse conditions). The overall *E* field strength variation was from about 30 dB(μV/m) at noneclipse period, to 64 dB(μV/m) at eclipse totality, and therefore the scale have been adjusted to the change of conditions. The increase of *E* field strength to the maximum value on some traces is small, but clearly detectable. It was referred by other authors, that the amplitude variation during eclipse was only few percents [4]. The change of relative signal strength up to 25 dB, at 1440 kHz, has been measured during the same event, 11 August 1999, [5]. These results are in agreement with our measurements.

There are two sources of error in determination of electron density in this way. First, the unreliable time delay measurements and second, the lacking knowledge of α_{ef}. It is known that the angle between the path of totality and ray trace vertical projection, influence the measurements of the time delay, [3]. The reliable ionospheric time delay can be measured if the response of *E* field strength is symmetric regarding the moment of electron density minimum. It is the case when the vertical projection of the ray trace intersects the path of totality at the angle 90^0 during entire eclipse event. In our experiment, the spot of totality has been moving from the region of reflection, toward the descending part of W-E directed ray traces. In result, the measured response of *E* field intensity is asymmetric, decreasing more slowly after the moment of electron density minimum, than increasing before that moment. The effect is opposite for E-W directed ray traces. This is shown in Fig. 2, on the record of signal from Brasov, with the ray path in NE-SW direction and having the reflection point very close to the point of maximum totality duration (2'21").

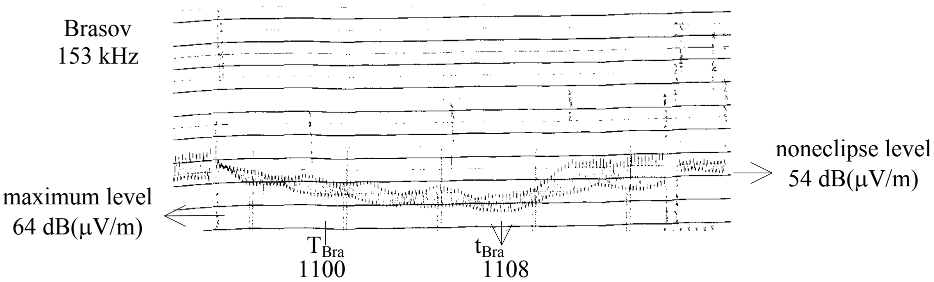

Fig. 2. The signal from Brasov. T_{Bra}, is totality time and t_{Bra}, maximum signal strength time.

CONCLUSION

The results presented in this paper, are in agreement with results obtained during previous eclipses, by other authors. Therefore, these results can contribute to the revision of the D region model, particularly to the estimation of lower ionosphere boundary.

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Reference is also made to the following unpublished material:
Dacic M., The Calculation of totality path at ionospheric height, for 11 August 1999 total eclipse over European region, *Astronomical Observatory, Belgrade*.