ECLIPSE INDUCED IONOSPHERIC PERTURBATIONS DERIVED FROM VLF-LF PROPAGATION EXPERIMENTS

P. Lassudrie-Duchesne(1), R. Fleury (2)

(1) *Ecole Nationale Supérieure des Télécommunications de Bretagne*
BP 226, 22303 Lannion Cedex, France. E-mail: Patrick.LassudrieDuchesne@enst-bretagne.fr
(2) *As above, but E-mail: Roland.Fleury@enst-bretagne.fr*

ABSTRACT

Solar eclipses are known to produce disturbances in the lower ionosphere, which result in marked effects on the propagation of VLF-LF radio waves. This paper is concerned with propagation measurements performed during the 11 August 1999 total solar eclipse with a receiver located in the vicinity of the totality region. The main features of the eclipse signatures on various radio paths are interpreted by means of a wave-guide propagation model. A good qualitative agreement with the measurements is obtained by using a simple model for the eclipse induced ionospheric perturbation. Discrepancies exist however which are attributed to the over simplifying assumptions made in the perturbation model.

INTRODUCTION

Solar eclipses are known to produce disturbances in the ionosphere, which result in noticeable effects on low frequency radio wave propagation. This paper is concerned with the effect of the 11 August 1999 total solar eclipse on the propagation VLF-LF radio waves. Such waves are propagated in the Earth-ionosphere wave-guide delimited by the ground and the ionospheric D region.

The 11 August 1999 solar eclipse started at 9:30 UT off the American Eastern coast. The zone of totality swept across the Atlantic Ocean and reached Cornwall at 10:10 UT, then moved on Eastwards over Central Europe. A VLF-LF spectrum monitoring system was operated continuously in Lannion, Northern Brittany (48°45’N,3°27’W). This made it possible to record field strength measurements on a number of radio paths from transmitters located in Western Europe.

EXPERIMENTAL ARRANGEMENT

The VLF-LF spectrum monitoring system located in Lannion comprised an active whip antenna, an anti-aliasing low-pass analogue filter and a 16-bit A/D converter with a sampling rate of 200 kHz. The system was controlled by a PC with a DSP card for real-time data analysis. Acquisitions of 150 ms data sets were Fourier transformed to yield spectra in the frequency range 10-80 kHz with a frequency step of 25 Hz. The repetition period was 1 spectrum/min.

EXPERIMENTAL RESULTS

Peaks relative to various transmitters were observed in the measured spectra. The field strength of the selected transmitters were well above the background noise level (SNR > 20 dB). The peak values relative to each selected transmitter were first integrated over a 200 Hz bandwidth. Values obtained for successive spectra then yielded field strength time series with a resolution of 1 min.

Plots of the measured field strength vs. UT are given in Fig. 2 for each selected transmitter. The time when the eclipse totality reaches the receiver in Lannion is indicated on each graph together with the time of nearest approach of totality to the transmitter. Also shown in Fig. 2 are the measurements performed on the previous day, taken as control day.

Variations in the field strength can be clearly identified on each graph around the time of the eclipse. Although unambiguous, the eclipse signature takes various shapes. It appears as one marked peak in Fig. 2(a) but shows a drop in Fig. 2-(b) and a double peak structure is observed in Fig. 2-(c).

DATA ANALYSIS

In order to interpret these results, the propagation of the VLF-LF waves in the Earth-ionosphere wave-guide was modelled using a propagation software based on the mode theory [1]. In this theory, the waves are considered to propagate between the Earth and the ionosphere as normal modes. The influence of the Earth's magnetic field was taken into account in the propagation model.

The electron density profile in the D region is the most significant input parameters to the propagation model. Following [2], we assumed an exponential profile with gradient parameter b and reference height h'. Values for b and h' have been deduced from measurements by [3] and [4]. For Summer daytime, b and h' were found to take constant values b = 0.5 km^{-1} and h' = 70 km. For Summer night-time, b and h' were found to vary in the range 0.38 - 0.91 km^{-1} and 87 km - 88 km respectively, according to the frequency.

It was assumed that to the main effect of the eclipse was to lift the reflecting height towards its night-time limit of 88 km. For simplicity, the height disturbance was assumed to be uniform along the whole radio path. The height increase $\Delta h'$ was determined by data fit. Since the influence of b is considerably less than that of h', we also assumed for convenience a constant value of b = 0.5 km^{-1} during the eclipse.

In order to interpret the results, some dependence law for $\Delta h'$ with time during the eclipse is required. It was thus assumed that Dh' was proportional to the eclipse obscuration value with a pre-eclipse value of 70 km. In addition it was assumed that the maximum value for Dh' took place at mid-eclipse and was independent of the frequency.

The propagation software was run with h' ranging from 70 to 88 km. An example of results is shown in Fig. 3. As expected, multimode propagation produces signal interference that results in deep fading at particular locations.

The computed signal level was then analysed as a function of h' for the distances corresponding to the selected transmitters. It was found that the maximum value for Dh' that best fitted the data lied around $Dh' \cong 5$ km. This value seems to be in accordance with previous results from [5].

Fig. 4 shows that the simulation results are in good qualitative agreement with the data. It is noted, however, that the agreement for the peak-to-peak amplitudes of the eclipse signatures deteriorates as the frequency increases. In addition, the simulated signatures appear systematically more spread in time than the measured ones. We interpret these discrepancies as the consequence of the over simplified model assumed for the D region disturbance.

CONCLUSION

Field strength VLF-LF measurements conducted during the 11 August 1999 total solar eclipse in Europe have been analysed using the guided wave propagation model. It was found that the data are consistent with a reflection height increase of about 5 km at mid-eclipse. Discrepancies in the amplitude of the eclipse signatures suggest that more realistic variations of $\Delta h'$ with time and position along the radio paths during the eclipse need to be taken into account in the ionospheric disturbance model.

ACKNOWLEDGEMENTS

The development of the spectrum monitoring system used in Lannion was partly supported by the Délégation Générale à l'Armement.

REFERENCES

[1] Morfitt D.G. and Shellman C.H.,1976, MODESRCH, an improved computer program for obtaining ELF/VLF/LF mode constants. Naval Electronics Laboratory Centre Interim Rep. 771, NTIS Accession No. ADA032573. NTIS Springfield, Va. 22161, USA

[2] Wait J.R. and Spies K.P., 1965, Influence of finite ground conductivity on the propagation of VLF radio waves, Radio Sc., 3, 787-791

[3] Morfitt, D.G., 1977, Effective electron density distributions which describe VLF/LF propagation data. Naval Ocean Systems Centre Tech. Rep. TR141, NTIS Accession No. ADA047508. NTIS Springfield, Va. 22161, USA

[4] Ferguson J.A.,1980, Ionospheric profiles for predicting nighttime VLF/LF propagation. NOSC TR 530, NTIS Accession No. ADA 085399. NTIS Springfield, Va. 22161, USA

[5] Meisel D.M., Duke B., Aguglia R.C. and Goldblatt N.R., 1976, Solar eclipse effects on HF and VLF propagation, JATP, 38, 495-502

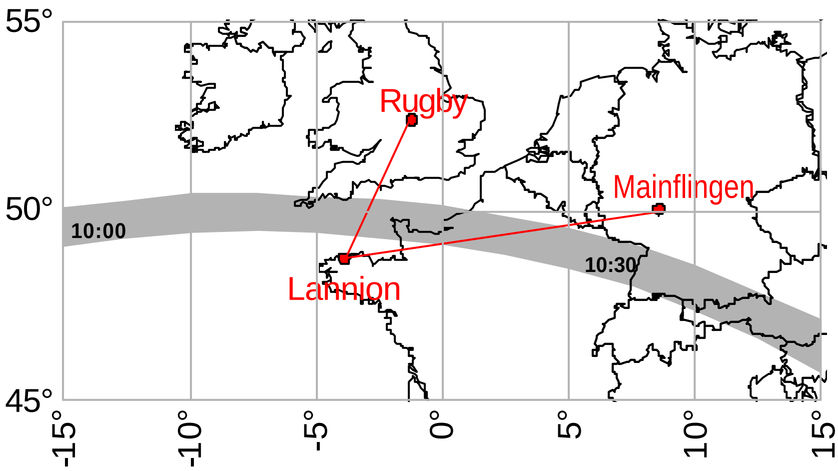

Fig. 1. Path of totality at D region height for the eclipse of 11 August 1999 (grey area) and VLF-LF radio paths used in the analysis. The radio paths have the following characteristics :

Transmitter	Latitude	Longitude	Country	Frequency (kHz)	Path length (km)
Rugby	52°22'N	01°11'W	UK	16.0	433
Rugby	52°22'N	01°11'W	UK	60.0	433
Mainflingen	50°01'N	09°00'E	D	77.5	911

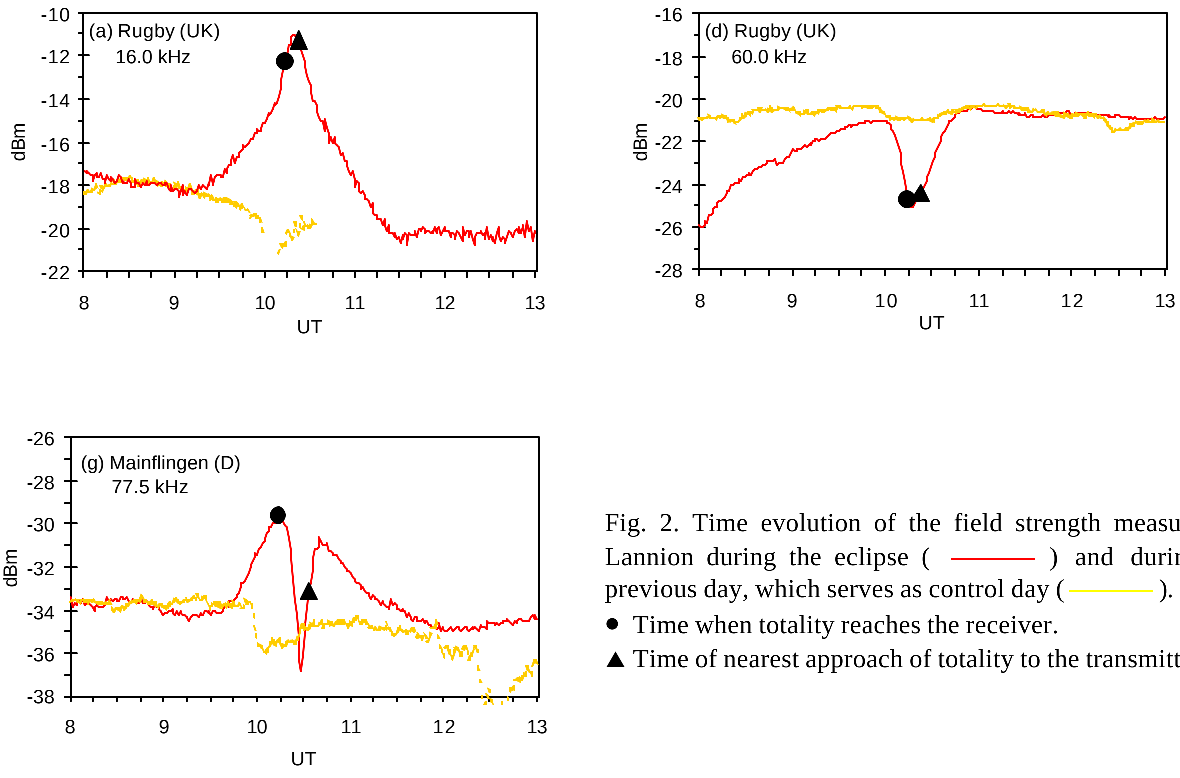

Fig. 2. Time evolution of the field strength measured in Lannion during the eclipse (——) and during the previous day, which serves as control day (——).

● Time when totality reaches the receiver.

▲ Time of nearest approach of totality to the transmitter.

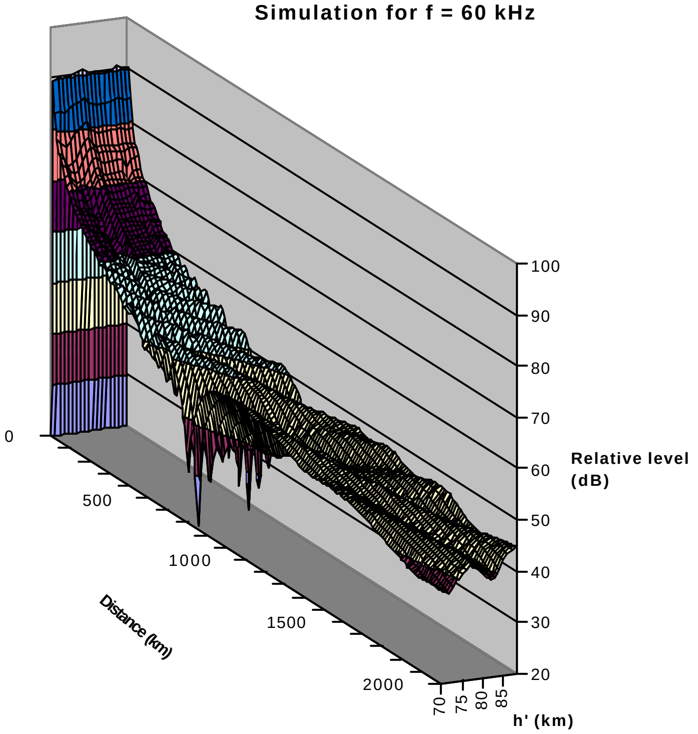

Fig. 3 . Example of simulation results yielded by the wave-guide propagation model at 60 kHz.

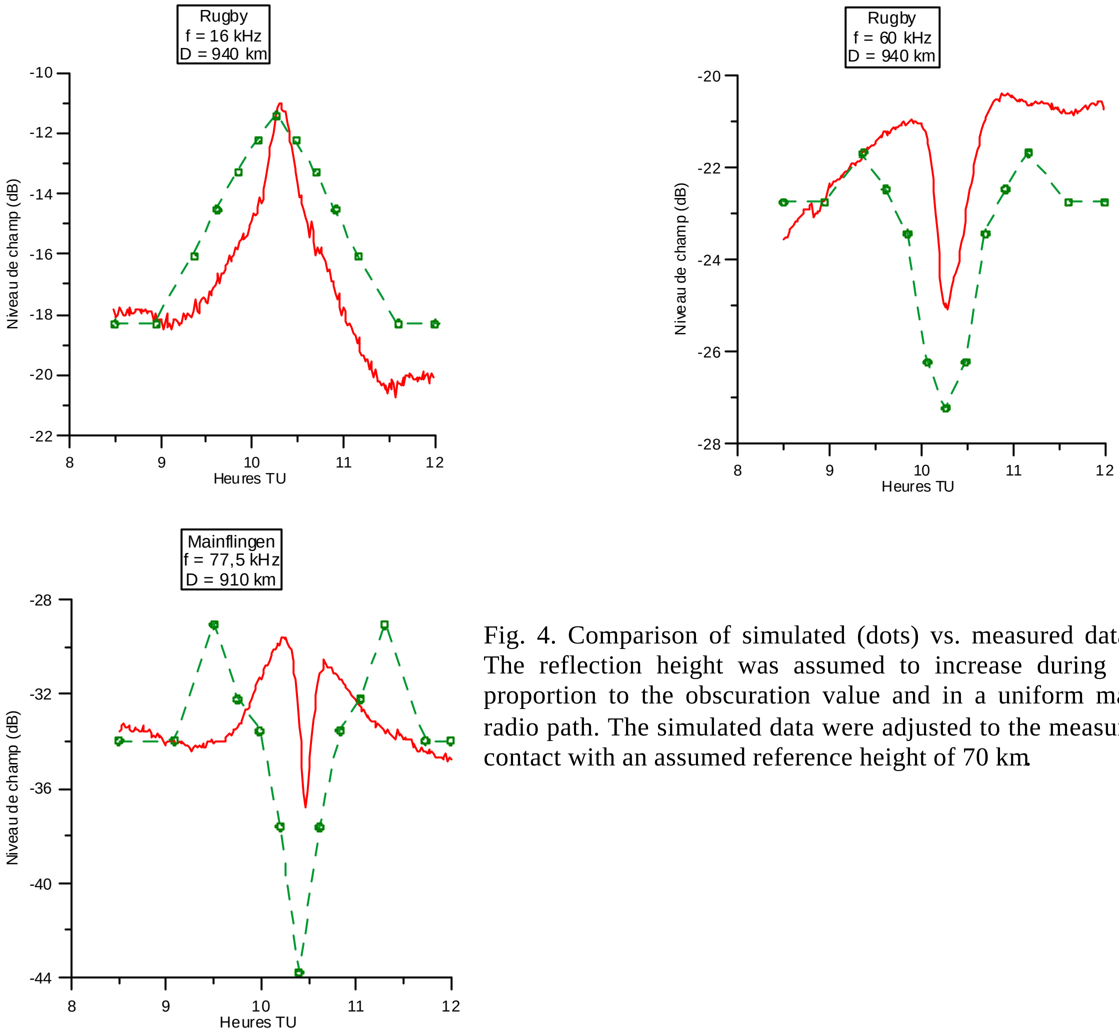

Fig. 4. Comparison of simulated (dots) vs. measured data (red curves). The reflection height was assumed to increase during the eclipse in proportion to the obscuration value and in a uniform manner over the radio path. The simulated data were adjusted to the measurements at first contact with an assumed reference height of 70 km.