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Ionospheric wave signature of the American solar eclipse on 21 August 2017 in Europe

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Abstract

A total solar eclipse occurred on 21 August 2017, with the path of totality starting over the North Pacific Ocean, crossing North-America and ending over the Mid-Atlantic Ocean slightly North of the equator. As a result, a partial solar eclipse was observed as far away as the Western Europe. The ionospheric observatory in Dourbes, Belgium, was right on the edge of the partial eclipse and was exposed for a very short period of only few minutes just before the local sunset. High-resolution ionospheric measurements were carried out at the observatory with collocated digital ionosonde and GNSS receivers. The data analysis revealed a clear wave-like pattern in the ionosphere that can be seen arriving before the local onset of the eclipse. The paper details the analysis and provides a possible explanation of the observed phenomenon.

Keywords: Solar eclipse; Digisonde; Ionospheric waves

1. Introduction

A total solar eclipse occurred on 21 August 2017, with a totality path passing through North America and ending in the Atlantic Ocean. The first contact of the penumbra occurred in the North Pacific Ocean at 15:46:52 UT and the last contact was at 21:04:24 UT in the Mid-Atlantic Ocean, close to the equator. The greatest eclipse occurred at 18:25:32 UT at the location with coordinates 36.97°N, 87.67°W, in the USA, where the width of the total eclipse was 114.7 km. Most of the total eclipse path was above North America, ending above the Atlantic Ocean (see Fig. 1). As a result, a partial solar eclipse was visible even from Belgium, including the RMI Geophysical Centre in Dourbes (50.1°N, 4.6°E). At this location, the eclipse magnitude was 0.11 with a maximum obscuration of 4.3%. The eclipse started at 18:41:03 UT (solar zenith angle of 89.7° and azimuth of 288.4°) and ended at 18:48:00 UT, the end coinciding with the local sunset at ground level. However, the sunset at higher altitudes, e.g., at the height of the ionospheric electron density peak hmF_2, happened significantly later. This is due to the shape of the local altitudinal solar terminator, see Verhulst and Stankov (2017) for a study on the time variations of sunset with altitude.

Rapid changes in the solar electromagnetic flux and in the ionising ultraviolet radiation during solar eclipses induce various effects on both the thermosphere and the ionosphere, including modification of the temperature balance and ionisation in the lower ionosphere, as well as of the transport processes in the upper ionosphere, etc. (Rishbeth, 1968, 1970). Since the local eclipse at low altitudes above Belgium was within a minute of the sunset at ground level, no major effects of the eclipse were expected to be seen in the lower atmosphere. Given the low obscuration level, no major changes in the ionospheric plasma den-

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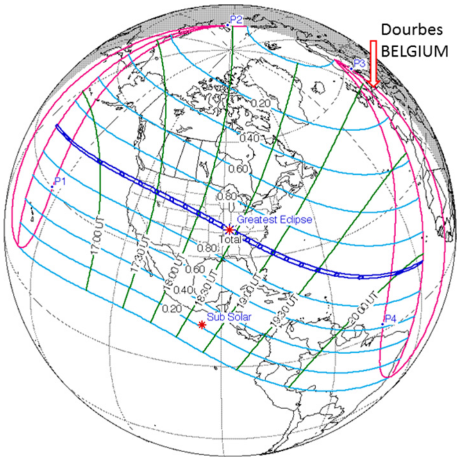

Fig. 1. Schematic (credit: NASA) of the solar eclipse on 21 August 2017 at the Earth' surface. The path of the total solar eclipse is denoted by the strip bounded by dark-blue curves, while paths of the partial (0.80, 0.60, 0.40, and 0.20 magnitude) eclipse are plotted with light-blue curves. The progression of the greatest eclipse is marked by green curves with time stamps (UT). The red arrow points at the location of Dourbes, Belgium. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

sity were expected to be produced in the local ionosphere either. However, well known are the wave phenomena generated by the Moon's shadow passing through the atmosphere (Altadill et al., 2001; Mošna et al., 2017). What interested us in this occasion was whether there would be any signs of wave phenomena present in the ionosphere, especially at such a long distance from the totality path. For this purpose, we have set up a high-cadence measurement campaign during the eclipse with ground-based instruments available to us. First results from the solar eclipse of 21 August 2017 are reported here and discussed in view of our previous experience in eclipse observations (Verhulst et al., 2016; Stankov et al., 2017).

2. Instrumentation and measurements

The instruments used in this study are installed at the RMI Geophysical Centre in Dourbes (Jodogne and Stankov, 2002). The key instrument is a Lowell Digisonde-4D® (Reinisch et al., 2009), a state-of-the-art equipment using HF radar principles of remote sensing to evaluate, with high accuracy and precision, the conditions of the ionospheric plasma above the station. It is capable of simultaneously measuring the following observables using reflected (in vertical incidence) or refracted (in oblique incidence) signals from the ionosphere: frequency, range, amplitude, phase, Doppler shift and spread, angle of arrival, and wave polarisation. Signal transmission is performed with two (NE-SW and NW-SE) crossed delta antennas of 40 m in height and reception is done with an array of four crossed magnetic dipole antennas in a triangular arrangement. The Digisonde is equipped with the latest version of the computer software for automatic ionogram interpretation, ARTIST-5 (Automatic Real-Time Ionogram Scaler with True height) (Galkin et al., 2008), and Digisonde Drift Analysis, DDA (Kozlov and Paznukhov, 2008).

Table 1
Digisonde program parameters for ionogram and skymap soundings during the August 2017 eclipse campaign (see LDI (2009) for more information on Digisonde programming).

	Ionogram	SkyMap
Frequencies	1–10 MHz coarse 25 kHz	5 MHz five 50 kHz steps
Polarity	O only	O only
Integrated reps.	4	128
Wave form	66.$\bar{6}$ µs pulse	16-Chip comp.
Starting seconds	00 & 30	15 & 45
Sounding time	14.470 s	12.830 s

For the purpose of this study, the Digisonde was used to produce ionograms every thirty seconds, the precise settings are listed in Table 1; they are identical to those used during the observation of the 2015 eclipse (Verhulst et al., 2016; Stankov et al., 2017). These settings are optimised to produce, at a high-cadence rate, ionograms of sufficient quality to be scaled easily, but without some less important data. The main differences between the special campaign ionogram configuration and the routine sounding programs are that here only the O-polarised echoes are recorded and not the X-trace, no fine frequency stepping is used, and the 66.7μs pulse wave form is used instead of the 16-chip complementary phase code. This results in shortening the ionogram runtime to less than fourteen seconds, while the skymap program runs in under thirteen second. Thus, both ionograms and skymaps can be produced at a rate of two per minute.

The ionosonde programs are scheduled in 30-min batches. At the half hour mark, the self-test and calibration programs are run (LDI, 2009). This takes one minute, so every half an hour 58 ionograms can be produced with a one-minute data gap at the half hour mark. This special campaign schedule was run on three days, 20–22 August 2017, between 18:00 UT and 21:00 UT. For all the ionograms produced during this campaign the autoscaled parameters were manually verified and corrected.

On the evening of 20 August, strong sporadic *E* layers were observed. This made it difficult to correctly scale the important characteristics from the ionograms. Therefore, the observations on the day after the eclipse, 22 August, are used in this study for comparison to those on the day of the eclipse.

TEC observations were carried out with a high-performance GNSS receiver collocated with the Digisonde. The receiver (NovAtel GPStation-6™) can track all present GNSS constellations and satellite signals with a maximum sampling rate of 50 Hz for each of the 120 available tracking channels (NovAtel, 2011). The vertical *TEC* is automatically calculated from the GNSS measurements at an optimal time resolution of 1 min using the Novatel proprietary software (Shanmugam et al., 2012).