The 11.08.1999 solar eclipse and the ionosphere: a search for the distant bow-wave

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Abstract

The advantage of studying eclipse disturbances is the perfect predictability of their 4D source geometry, which allows for preparation of adapted systems and schedules. The total solar eclipse period of August 11, 1999 across Europe was notable for exceptionally uniform solar disk, steady solar wind and quiet magnetospheric conditions. Large-scale gravity wave activity prior to the eclipse however disturbed the initial 0900 LT thermosphere weather. This rapid letter is an advance summary about one particular aspect of the West European ionosonde and radar results of the eclipse experiment. It focusses on the possible emergence of a distant eclipse frontal bow-wave. This was expected as a consequence of the supersonic shock of stratospheric Ozone cooling. First-look data of Vertical Incidence Digisonde records are greatly improved by their Real-Time acquisition of inverted true-height profiles. The EBRE (Tortosa, Spain) foF1 and foF2 simultaneous oscillations observed from the second to the fourth hour following maximum solar occultation appear as convincing indicators of the bow-wave signature. Large fluctuations in foF1 and foF2 during some of our control days, of usual gravity wave character, emphasize the importance of meteorologic disturbances on mid-latitude ionosphere variability.

Keywords: F-region eclipse; Mesosphere; Bow wave

1. Introduction

Long-distance dynamics of Solar eclipse wavefronts across the Thermosphere have been observed in various occasions. At sub-tropical magnetic latitudes in Ethiopia, Hanuise et al. (1982) convincingly interpreted their Doppler radar signal as trails of the stratospheric Ozone layer shock pulse in the shape of bow-waves. Fritts and Luo (1993) developed a theoretical model of the phenomenon.

On the other hand the noontime cleft subauroral sources of the Disturbance Dynamo mechanism, shaped like festoons of equatorward convexity are thought to generate the thermospheric travelling atmospheric/ionospheric disturbances (TAD/TID) (Morgan et al., 1978; Kobea and Richmond, 1999). Equatorward propagation of these fronts has been simulated by electric field pulse frontal disturbance computations (e.g. Balthazor and Moffett, 1999).

Because of the great speed (Mach > 2) of the totality umbra, mid-latitude eclipse bow-wave fronts are expected to appear similar to TIDs, except that travelling laterally above the mesospheric forcing source, they must emerge at long distance from the track of totality, and show a closer simultaneity between oscillations at F1 and F2 height levels. The problem of the lateral emergence of the eclipse bow wave remains non-trivial, owing to our limited knowledge of the mesospheric layers (Fritts and Luo, 1993; Mc Landress, 1998).

The purpose of this preliminary note is to present first-look evidence for the bow-wave model from HF radar sightings and from ionosonde records southward of totality.

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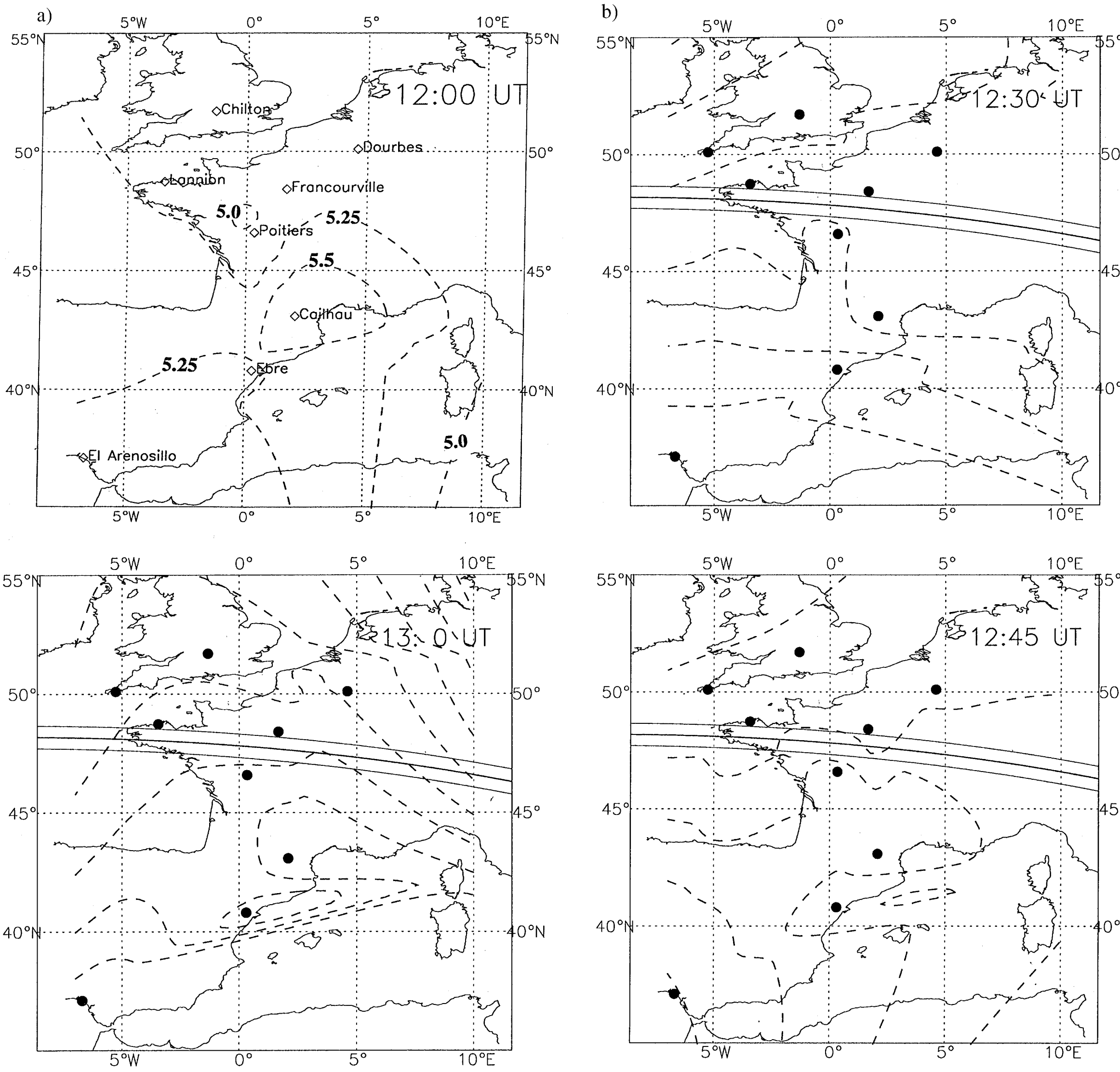

Fig. 1. (a) foF1 and (b) foF2 contour maps over Western Europe for the interval 1200–1300 UT, August 11, 1999.

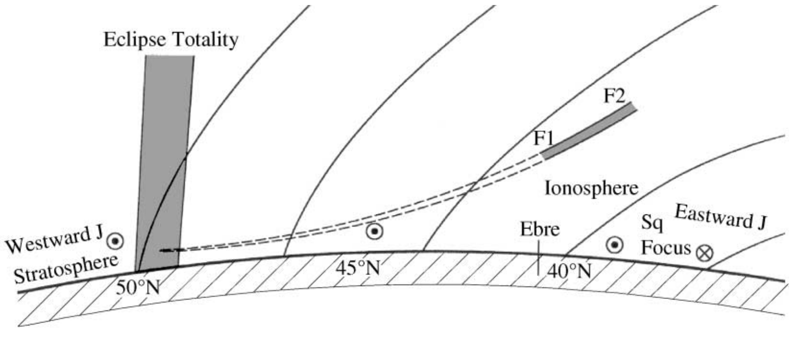

Fig. 2. The Eclipse model derived from Fritts and Luo (1993).

We here use the series presented in Farges et al. (companion paper, this issue), with particular emphasis on the ionogram variations at the two sites Cailhau and Ebre.

In Section 2, we describe the West European latitude chain of instruments and our present virtual height results. The August 10–12, 1999 period was remarkably fortunate for its very quiet Solar flux ($F10.7 = 128$) and its weak-magnetic activity (the K_p indices for August 10–12 were 9, 12+ and 15+). The positive response of European radar and ionosonde communities for measurements during the August 08–15 interval facilitated pooling them in a special database. It allows for a first survey of the F1 and F2 layer responses, with quarter-hourly mapping of F layer critical frequencies (Farges et al., 1999).

In Section 3, we discuss whether the wave fluctuations observed at Ebre between 12 and 14 UT on August 11, 1999 (Fig. 1) can be identified with the eclipse bow-wave front, and if we are justified in considering them as a facsimile for TID perturbation, that could have swept the mid-latitudes towards the magnetic equator (Balthazor and Moffett, 1999).

2. Experimental results

2.1. Ionogram scaling and resolution

Frequency resolution of ionograms (HF group path/frequency records) is much dependent on trace-distortion: careful scaling allows nominally to determine critical (layer maximum) frequencies with 0.01 accuracy. On semi-automatic screen-pointer labeling, the instrumental error can become twice larger. On abnormal oblique group-path frequency near F2 and E layer maxima (often present when gravity waves modify the plasma layering), the error can reach 0.05 to exceptionally 0.20 MHz. For the F1 layer, the critical frequency can be even less precisely measured, imposing error bars of up to 0.5 MHz.

We here present a part of the virtual height series obtained well South of eclipse totality and so far communicated by ionosonde observers (see map Fig. 1). In western Europe, August 10 and 11, 1999 were days of large-scale fluctuations. Ionogram profile distortions and additional strata did not generally exhibit the classical phase descent of gravity wave perturbations. In order to minimize these discontinuous uncertainties, the Cailhau foF2 values were selected at irregular time intervals. The foF1 values remain accurate at better than 0.1 MHz except when an error bar is indicated.

2.2.

At Cailhau (43°0.08′ N, 02°0.08′ E geogr.), a temporary prototype "Very Light Digital Radarsonde" (see the appendix) was set up from August 08–15, 1999. It produced 12 s ionograms (followed by Doppler oscillation records on one auto-selected fixed frequency during 8 s). It operated on two different schedules: regular H12 (every 5 min) or high-speed H120 (every 30 s, which ran on August 09, 11, 13 and 14 from 09 to 21 UT).

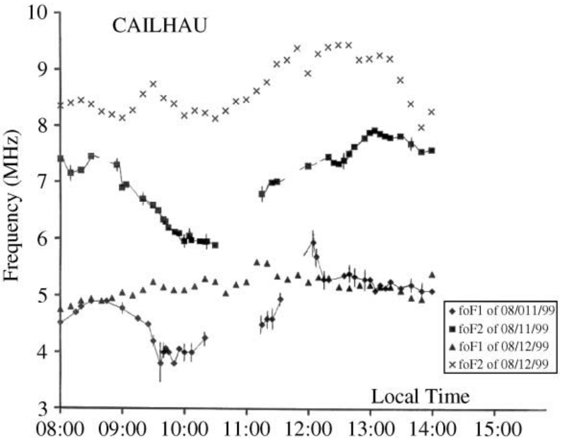

Fig. 3. Eclipse and August 12, 1999 foF1 and foF2 plot, Cailhau.

The f-plot in Fig. 3 shows the main phases of the electron density F1 and F2 layer eclipse depletions closely following the optical eclipse function. Unexpectedly, the F2 layer disturbance is here nearly synchronous with it. But the only possible signs of a bow-wave disturbance are slight (brief high-altitude sporadic E double-layer, non-occulting, at about 1350 UT). Here the shortest distance from centrality, of about 780 km appears too small for full emergence of a frontal bow wave.

2.3.

At Ebre (Tortosa, 40°50′ N, 0°15′ E geogr.), the Digisonde operated on regular H4 schedule for normal periods, and on H12 during 1005–2355 UT intervals on August 10–12. The distinctive foF2 oscillations following local maximum occultation are shown in Fig. 4: from about 1200–1400 UT a train of three successive oscillations nearly simultaneous on foF1 and foF2 are quite clear (the third peak on foF1 being imprecise because of sporadic E occultation).

2.4. HF oblique Radar signatures

The Losquet Island radar (Lannion, Brittanny, 48°8′ N, 03°6′ W geogr.) with rapid panoramic scans of 120-azimuth beams at 30° elevation on 12.4 MHz operated on August 11 and 12. Examples of fixed-azimuth time variations on the eclipse day are given in Fig. 5. Their changes identified various scales of corrugations in fixed-azimuthal scales from a few tens to a few hundreds km bubble-like (group path increases), and blob-type (decreases) gradient enhancements. Two blob-crests consistently came out at 1150 and 12.55 on the sector of sightings from 135 to 175° azimuths which covers the Spanish coast of Catalunya.

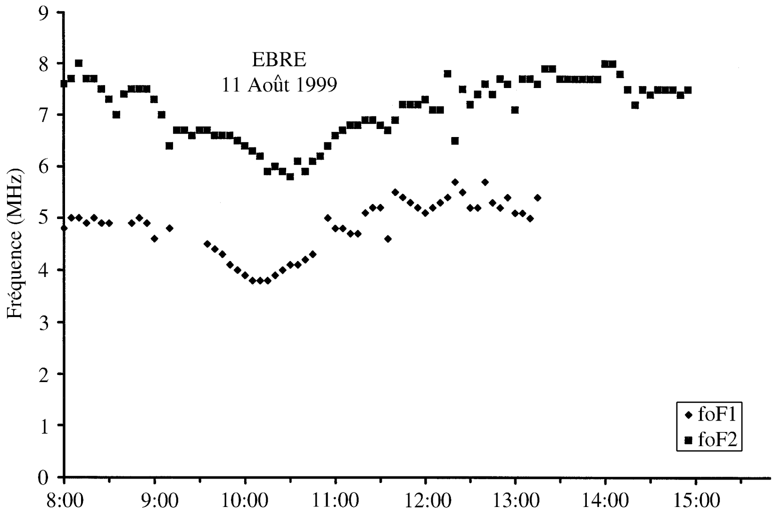

Fig. 4. foF1 and foF2 similar plot to Fig. 3 for Ebre.

2.5. *foF1 and foF2 contour maps*

These emphasize horizontal gradients at physical scales of $< 1°$. The maps for 1230–1300 UT given in Fig. 1 give impressive snapshots of a crest developing before 1200 in the F1 layer around Cailhau, reaching Ebre before 1245 and apparently stagnating out of the North-East coast of Spain later on.

3. Discussion

We need first to discard the ‘bow-wave’ scheme presented for the low-latitude eclipse of September 09, 1987 around Taiwan (Cheng et al., 1992): Our results do not indicate any similar symmetric train of near-totality waves with feather-like wavecrests at 30° from the central line.

3.1. *Various aspects of the bow-wave (Fig. 2)*

First indications of a distant bow-wave emergence sent by a total solar eclipse at ionospheric levels similar to ours were obtained by Hanuise et al. (1982). Spectral analysis of fixed-frequency velocity oscillations above two HF radars (on 7.0 and 8.5 MHz) at distances of 1293 and 1465 km from the totality (which occurred at 1140 on February 16, 1980) yielded 3 periods of 20–30 min after fourth contact. Here the observed distance of emergence was about four times shorter than what can be deduced from Fritts and Luo (1993) velocity contour gradient, but the near-simultaneity of the theoretical emergent strip across the lower thermosphere seems to agree with the Ethiopian 1980 and our 1999 Ebre data.

The present results are bringing out three complementary pieces of evidence:

(i) Vertical-incidence profile series allow to differentiate the distant frontal wave signature (with practically no time phase lag) from those of other internal gravity wave oscillations (semi-oblique and sub-stratification distortions). The latter ones are generally observed to descend in time from F2 down to E, layer levels. Such a signature, observed at Cailhau around 1000 UT in the F2 trace, appears as a solitary perturbation. On the other hand the strong train of 2 1/2 oscillations observed at Ebre, with near- simultaneous phase between 180 and 280 km heights of the F1 and F2 layer’s peaks is a consistent wave signature. Its quasi-periods grew from 30–35 min to 40–45 min from 1200–1400 UT.

(ii) A second evidence comes from the Losquet radar sightings described in our Section 2.4.

(iii) A third evidence arises from the critical frequency contour maps (Fig. 1). It gives an idea of the horizontal shape of the gradient crest that we claim as being formed by the emergent bow-wave.

3.2. *South of Ebre*

No similar wave appears at El Arenosillo (38° N, 05° W geogr.), except a 75 min quasi-sinusoid after 1130 UT. No equatorial fluctuation has been detected at Korhogo (Republic of Ivory Coast, 9°25′ N, 355° E geogr.) on every-5-min ionograms.

3.3. *Meteorologic storm fronts*

These are suspected as potential perturbating sources in the thermosphere. In August 08–15, interval, such tropospheric frontal sources possibly triggered mesospheric

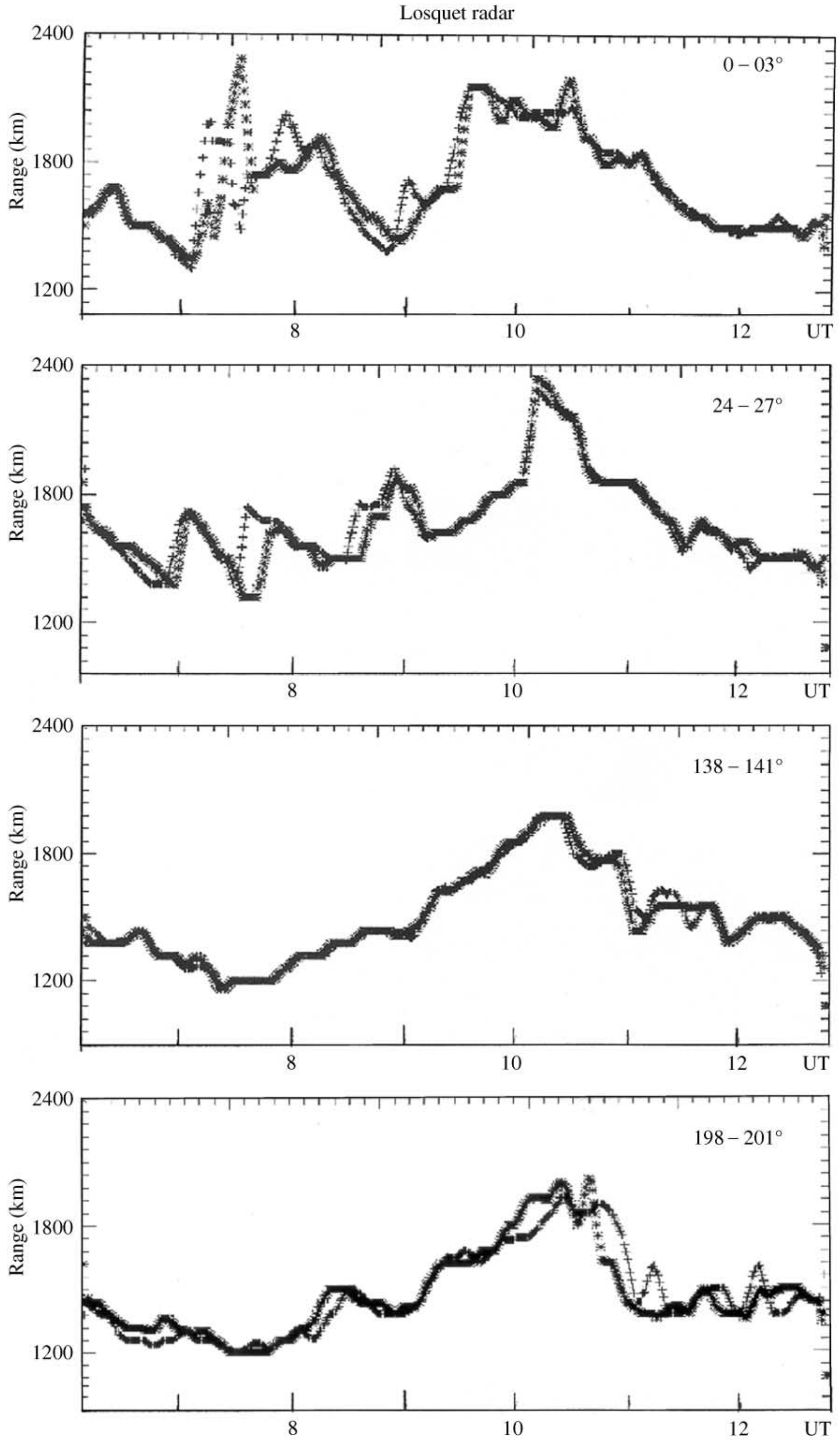

Fig. 5. Losquet Island UT variations 12.4 MHz for North and South-East azimuths; from top to bottom, azimuths 00–03°, 24–27°, 138–141°, 198–201°.

fronts. A careful survey of their higher altitude effects is needed. The massive series of results already collected on the F1 layer peak disturbance — first presented in a companion paper (Farges et al., this issue) — show the impressive variability of ionospheric electron densities across midlatitudes, even during such quiet conditions. From similar, more detailed maps (to be analyzed on the complete database), a geographic comparison with meteorologic data will probably reveal mesosphere–atmosphere flow characteristics.

4. Preliminary conclusion

The existence of a frontal disturbance following the August 11, 1999 solar eclipse is the first observed example of a bow-wave propagating from the totally eclipsed midlatitude stratosphere to the ionosphere at 10° equatorward distance in about 2 h. Further South, this front seems to have been waning before it could reach El Arenosillo (about 1300 km from totality). The further disappearance of this front, and its average velocity, of about 200 m/s are suggesting that its propagation was slowed down by dominant Northward wind flows in the mesosphere. Thus, it seems that our experimental bow-wave as identified from our rough plasma density variations did not propagate without being attenuated, contrary to the one simulated by Balthazor and Moffett (1999) A more complete analysis of the full data is in order to validate these deductions.

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The improved graphics have been graciously produced by Dr. M. Sow, on visit from the Abidjan University (Ivory Coast).

Appendix. The very light ionosonde

This micro-technique homemade instrument (intended to replace the Antarctic RF4 model at Dumont d'Urville) is built around a high-quality frequency-synthetizer and time clock, with fully digital circuits. It is fully automated, PC-controlled and -recorded, with easy remote monitoring of the functions. By using the successive RT frequency point comparisons, ambient noises are recorded on line and rejected from the ionospheric traces (carefully conserving continuous echo signals). Amplitude is colour-coded in 8 dB levels.

At Cailhau it operated on an open-space wineyard area with 250 W power, through a small delta antenna of 50 m diagonal and 9 m effective height.

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