Measurement of VLF propagation perturbations during the January 4, 2011 Partial Solar Eclipse
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Abstract
The January 4, 2011 partial solar eclipse over Europe offered an opportunity to check for perturbations of the D region of the ionosphere affecting the VLF signal propagation. The signal level recordings made during the eclipse were compared to measurements made several days before and after in order to rule out usual daily variations. The author monitored the signal amplitude variation of nine VLF transmitters. Two stations (ICV on 20.27 kHz and NSY on 45.9 kHz) were clearly affected by the eclipse and showed unusual amplitude patterns. The signal paths were the easternmost of the monitored channels. Despite having the lower obscuration (56 and 57%), they had an earlier sunrise. The daytime propagation mode was more established when the eclipse began. This favored the modification of the ionization level of the the D region.

Introduction
The propagation of Very Low Frequency (VLF) radio communications is affected by high-energy solar radiation. Propagation characteristics are different between day and night. Disturbances are triggered by the sudden release of high-energy radiation from x-ray solar flares. Several measurements campaigns during solar eclipses have been conducted in the past (refer for instance to [1], [2] and [3]). They suggest that the D region ionization level is altered during the eclipse, leading to an increase of a few kilometers of the apparent reflection height of the VLF signals and to modifications of the amplitude and the phase of the received signal.

The objective of this paper is to describe the effects of the January 4, 2011 partial solar eclipse on the reception of several VLF transmitters, as observed by the author’s monitoring station. Firstly, this paper presents background information on the specificities of VLF signal propagation. The author’s monitoring station used to record signal strength data is briefly presented. The signal level recordings made during the eclipse are presented and compared to measurements made several days before and after, in order to rule out usual daily variations. This allowed to isolate two channels showing altered amplitude variations during the eclipse. Raw data are available upon request for anyone willing to perform additional processing.
**Background**

**VLF Signal Propagation**

Very Low Frequency (VLF) radio waves are used for military communications with submarines near the surface, for radio-navigation beacons and for time signals. The propagation characteristics in this part of the electromagnetic spectrum are somewhat different from those observed at higher frequencies.

In the daytime, the lowest part of the ionosphere—the D region—is created through a ionization process resulting from the solar radiation: the Lyman-α emission line ($\lambda = 1215.67$ Å) ionizes mainly the nitric oxide (NO). The VLF wavelengths are so long that they are conducted in the Earth-ionosphere waveguide (EIWG) between the Earth’s surface and the D region. The propagation is very stable. Uncommon variations reflect how the ionosphere is affected by x-rays flares from the sun.

At night, the D region disappears and the waves are refracted by the higher E and F layers. The “reflection” coefficient is higher and leads to increased signal strengths.

A typical signal level plot for a quiet day is presented in Figure 1. The sunrise and sunset patterns of the signal amplitude correspond to the transition between the nighttime refraction of the signal and the daytime waveguide propagation mode.

It is important to note that the eclipse timing corresponds to the sunrise pattern. Special care has then to be taken to ensure that the observed amplitude changes are not mistaken with the usual transition pattern.

**Description of the monitoring station**

The author’s station is located in the South of France and monitors nine VLF transmitters (refer to [7]). The signals are received through loop antennas. The receiver contains order-4 active filters centered on the transmitter frequencies and linear detectors (full-wave rectifiers and peak detectors) are used to get the signal amplitude values. These amplitude values are then filtered (the filter time constant is around 1 minute) and converted through 12-bits analog-to-digital converters. The station is referenced under the AAVSO (see [6]) observer ID A-118.

The signal amplitude from the following transmitters is monitored:

- GBZ 19.58 kHz
- ICV 20.27 kHz
- GQD 22.1 kHz
- DHO38 23.4 kHz
- NAA 24 kHz
- TBB 26.7 kHz
- NRK 37.5 kHz
- NSY 45.9 kHz
- DCF77 77.5 kHz

Taking into account the distance between the transmitters and the monitoring station, the sky wave propagation path has only one hop for most transmitting stations. Figure 2 below shows the location of the monitored VLF transmitters and the associated sub-reflective points.

The amplitude levels of the received signals are presented on a linear scale. Each channel has independent scaling and offset to ensure the signal fits in the ADC range between 0 and 4.095V.

![Figure 1: Typical evolution of VLF signal amplitude on a quiet day. The daytime propagation is very stable.](image1)

![Figure 2: VLF Stations monitored. Yellow stars indicate the location of the sub-reflective point.](image2)
## Eclipse Characteristics

The Table 1 below contains the eclipse timing and importance for each monitored VLF station. Data has been obtained from [4].

<table>
<thead>
<tr>
<th>(1)</th>
<th>Freq (kHz)</th>
<th>Sub-reflective point (3)</th>
<th>Sunrise at 75km height (4)</th>
<th>Obscuration (5)</th>
<th>Magnitude at mid eclipse (6)</th>
<th>Partial Eclipse</th>
<th>Delay from sunrise at 75km and 1st contact (9)</th>
</tr>
</thead>
</table>
Background GOES x-ray Flux

The background x-ray flux remained fairly constant during the eclipse period. Figure 3 shows the x-ray flux measured by the GOES-15 satellite.

The only flares listed in the NGDC database ([5]) between 05:00 UTC and 12:00 UTC on January 4, 2011 were:

<table>
<thead>
<tr>
<th>Event</th>
<th>Start</th>
<th>Max</th>
<th>End</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>#2940</td>
<td>05:57</td>
<td>06:02</td>
<td>06:05</td>
<td>B9.4</td>
</tr>
<tr>
<td>#2950</td>
<td>07:56</td>
<td>08:01</td>
<td>08:08</td>
<td>B3.3</td>
</tr>
<tr>
<td>#2960</td>
<td>09:35</td>
<td>09:39</td>
<td>09:41</td>
<td>B3.6</td>
</tr>
<tr>
<td>#2970</td>
<td>09:43</td>
<td>09:47</td>
<td>09:49</td>
<td>B6.4</td>
</tr>
</tbody>
</table>


None of them reached the C-class level (> $10^4$ W/m²) required to raise a sudden ionospheric disturbance on the VLF propagation.

As a consequence, the levels measured during the eclipse were not affected by the solar x-ray flux.

VLF Signal Level Measurements

The VLF propagation has normal day-to-day amplitude fluctuations that can easily span over a ratio of two. In order to detect a potential unusual effect caused by the eclipse, a comparison with measurements made at the same time the three days before and the three days after the eclipse is made.

To that purpose, the plots here below show the minimum, average and maximum values of the daily signal strength on January 1, 2, 3, 5, 6 and 7.

This allows to determine if the amplitude variation observed during the eclipse is within normal daily changes. This point is especially important since the eclipse happened early in the morning, during the sunrise amplitude pattern of the transition between night and day propagation modes.

Among the nine channels monitored, the following were not usable:

- DHO38 (23.4 kHz): the daily transmitter shutdown (from 07:00 UTC to 08:00 UTC) occurred during the eclipse.
- NAA (24 kHz): the eclipse was not visible at the sub-reflective point.
- TBB (26.7 kHz): the transmitter was not active on January 04, 2011.

Several other transmitters did not show unusual patterns:

- GBZ (19.58 kHz): the amplitude does not appear affected by the eclipse.
- GQD (22.1 kHz): the amplitude does not appear affected by the eclipse.
- NRK (37.5 kHz): the transmitter was shutdown at 08:30 UTC on January 04, 2011. Nevertheless, the propagation during the eclipse and before the shutdown does not appear to be significantly affected.
- DCFT7 (77.5 kHz): the amplitude does not appear affected by the eclipse.

The last two stations have more evident effects:

- ICV (20.27 kHz): this channel seems the most affected. The usual sunrise pattern appears distorted and overall shifted by about 15 minutes during the eclipse. Moreover, a significant signal enhancement is visible at about 07:24 UT. This enhancement is not related to any X-ray flare. It lasts till about 07:45 UT. Then, another unusual signal increase peaking at about 08:10 UT appears.

- NSY (45.9 kHz): for this channel, the usual amplitude rebound of the sunrise pattern is less important. The signal increase usually observed appears “stopped” at the beginning of the eclipse. Signal recovers its normal evolution range about half an hour before the 4th contact.

These two stations are the easternmost, and consequently had an earlier sunrise (45 minutes between the sunrise at 75 km height and the 1st contact for NSY 45.9 kHz, and 32 minutes for ICV 20.27 kHz). The daytime transmission mode was then more established than other stations.

Detailed plots are available in Appendix 2.
Conclusion

The January 4, 2011 partial solar eclipse was not really under the most favorable conditions for detecting a disturbance on the VLF propagation. The eclipse happened during the night-to-day transition period that has usually a high variability from day to day. The author monitored the signal amplitude variation of nine VLF transmitters with frequencies ranging between 19.58 kHz and 77.5 kHz. Six of them were usable for this study. Two stations (ICV on 20.27 kHz and NSY on 45.9 kHz) were clearly affected by the eclipse with unusual amplitude patterns. Their sub-reflective points are the easternmost of all usable channels. Despite having the lowest obscuration of the signal path (respectively 56% and 57%), they had an earlier sunrise. The daytime propagation mode was more established when the eclipse began. This favored the modification of the ionization level of the D region leading to more evident effects from the eclipse obscuration. Next solar eclipse of interest for its potential effects on VLF propagation will occur on March 20, 2015. This eclipse will be total over the North Atlantic.

Acronyms

AAVSO American Association of Variable Star Observers
EIWG Earth-Ionosphere Wave Guide
GOES Geostationary Operational Environmental Satellite
GSFC Goddard Space Flight Center
GRB Gamma-Ray Burst
HF High Frequency
LF Low Frequency
NASA National Aeronautics and Space Administration
NGDC National Geophysical Data Center
SID Sudden Ionospheric Disturbance
VLF Very Low Frequency

References


[7] Description of the author’s SID monitoring station with access to real-time measurements: http://sidstation.loudet.org/
Appendix 1: Eclipse Details

Partial Solar Eclipse of 2011 Jan 04

Ecliptic Conjunction = 09:03:42.7 TD (≈ 09:02:35.6 UT)
Greatest Eclipse = 08:51:42.0 TD (≈ 08:50:34.9 UT)
Eclipse Magnitude = 0.6576     Gamma = 1.0528

Sun at Greatest Eclipse
(Geocentric Coordinates)
R.A. = 18h59m14.9s
Dec. = +22°44'21.1"
S.D. = +00°16'15.9"
H.P. = +00°00'08.9"

Moon at Greatest Eclipse
(Geocentric Coordinates)
R.A. = 18h58m23.6s
Dec. = -21°46'01.2"
S.D. = +00°15'18.1"
H.P. = +00°56'09.6"

External/Internal Contacts of Eclipses
P1 = 08:40:11.3 UT
P4 = 11:00:53.7 UT

Constants & Ephemeris
\[ \Delta T = 67.1 \text{ s} \]
\[ k_1 = 0.2734890 \]
\[ k_2 = 0.2722810 \]
\[ \Delta b = 0.0^\circ \quad \Delta l = 0.0^\circ \]
Eph. = VSOP87/ELP2000-85

Geocentric Libration
(Physical)
I = 4.63^\circ
b = -1.30^\circ
c = -4.24^\circ
Brown Lun. No. = 1080

F. Espenak, NASA's GSFC
eclipse.gsfc.nasa.gov/eclipse.html

Source: http://eclipse.gsfc.nasa.gov/OH/OHfigures/OH2011-Fig01.pdf
Appendix 2: Detailed Plots

GBZ 19.58kHz

ICV 20.27kHz