Measurement of VLF propagation perturbations during the January 4, 2011 Partial Solar Eclipse

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January 2011

Contents

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. Their 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.

1 Contact: http://sidstation.loudet.org/email-en.xhtml

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 (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.

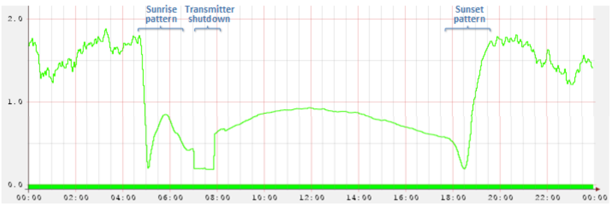


Figure 1: Typical evolution of VLF signal amplitude on a quiet day. The daytime propagation is very stable.

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.

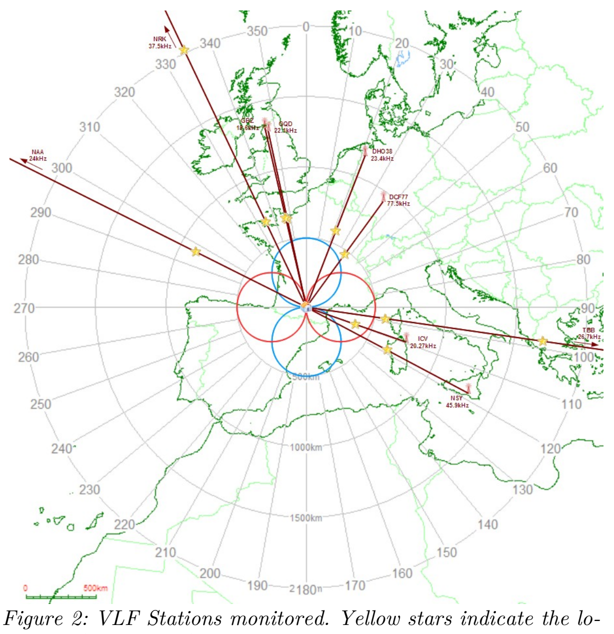


Figure 2: VLF Stations monitored. Yellow stars indicate the location of the sub-reflective point.

Eclipse Characteristics

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

		Sub-reflective point (3)		Sunrise at 75km height (4)	Obscuration (5)	Magnitude at mid eclipse (6)	Partial Eclipse						Delay from sunrise at 75km and 1st contact (9)
							Start (1st contact)		Mid		End (4th contact)		
(1)	Freq (kHz) (2)	Lat	Long				Time (7)	Alt (8)	Time (7)	Alt (8)	Time (7)	Alt (8)	
GBZ	19.58	49°14'33"N	000°48'51"W	06:59:40	63.41%	0.71977	06:56:14.6*	-09.5°	08:07:26.9	+00.4°	09:26:19.6	+09.5°	-00:03:25
ICV	20.27	42°18'28"N	005°31'27"E	06:17:05	57.21%	0.66676	06:48:59.8*	-03.7°	08:02:29.7	+07.5°	09:25:17.4	+17.6°	00:31:55
GQD	22.1	49°08'57"N	000°38'38"W	06:58:44	63.40%	0.71964	06:56:08.8*	-09.4°	08:07:25.8	+00.5°	09:26:25.0	+09.7°	-00:02:35
DHO38	23.4	48°21'01"N	004°04'24"E	06:37:41	65.28%	0.73529	06:56:22.9*	-06.2°	08:10:18.1	+03.8°	09:32:19.0	+12.7°	00:18:42
NAA	24	49°30'41"N	032°42'16"W	09:08:01	NO ECLIPSE								
TBB	26.7	41°13'02"N	014°50'21"E	05:37:25	60.70%	0.69612	06:52:42.7	+03.3°	08:12:43.8	+14.6°	09:42:20.8	+23.2°	01:15:18
NRK	37.5	54°14'18"N	007°44'47"W	07:42:45	N/A	0.73472	07:02:42.8*	-14.4°	08:11:13.1*	05.4°	09:26:04.8	+02.9°	-00:40:02
NSY	45.9	40°31'09"N	008°06'19"E	06:02:50	55.91%	0.65545	06:47:59.7*	-01.3°	08:02:47.8	+10.2°	09:27:20.6	+20.4°	00:45:10
DCF77	77.5	46°50'27"N	004°50'11"E	06:30:40	63.69%	0.72185	06:54:31.5*	-05.3°	08:08:40.6	+05.0°	09:31:16.4	+14.1°	00:23:52

Table 1: Eclipse characteristics at the sub-reflective point of each monitored station

Legend:

(1) VLF station call
(2) VLF station frequency
(3) Latitude and Longitude of the sub-reflective point (mid point of the great circle path between the transmitter and the receiving station.
(4) Universal Time of the sunrise at the sub-reflective point at 75 km height (height of the D-layer).
(5) Obscuration —Percentage of the Sun’s disk surface covered at mid eclipse (N/A if the Sun is below the horizon at mid eclipse).
(6) Magnitude —Fraction of the Sun’s diameter covered by the Moon at mid eclipse.
(7) Universal Time of the event. If the event occurs while the sun is below the horizon, an asterisk (*) will appear after the hour.
(8) Alt —Altitude of the sun, in degrees, above the horizon. Altitude is determined at ground level, and will be more important at the D region height.
(9) Delay between the sunrise at 75 km and the 1st contact. Negative values mean that the eclipse starts before the sunrise.

Appendix 1 shows detailed information from NASA's GSFC eclipse website.

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.

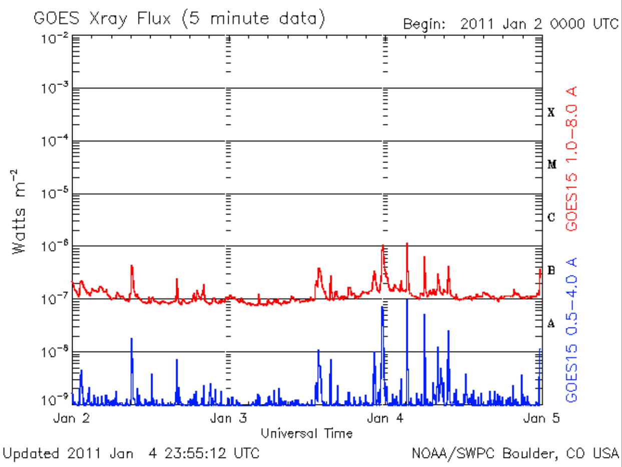


Figure 3: GOES-15 x-ray flux measurements. Source: http://www.swpc.noaa.gov/ftpdir/warehouse/2011/2011_plots/xray/20110104_xray.gif

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

Event	Start	Max	End	Class
#2940	05:57	06:02	06:05	B9.4
#2950	07:56	08:01	08:08	B3.3
#2960	09:35	09:39	09:41	B3.6
#2970	09:43	09:47	09:49	B6.4

Source:
http://www.swpc.noaa.gov/ftpdir/warehouse/2011/2011_events/20110104events.txt

None of them reached the C-class level ($> 10^{-6}\,\mathrm{W/m^2}$) 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.
- DCF77 (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.

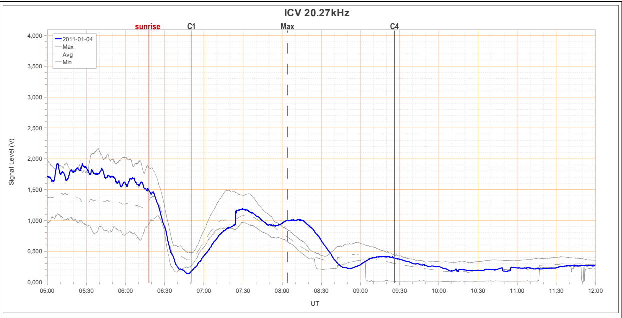


Figure 4: ICV 20.27 kHz

- 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.

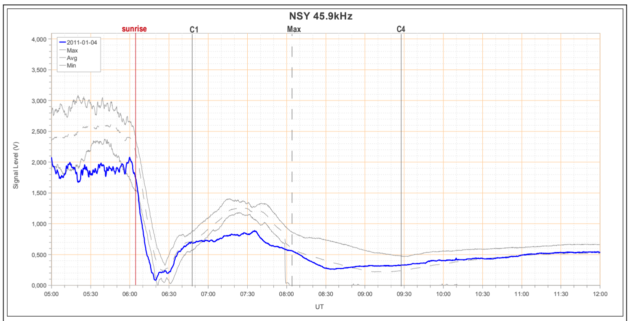


Figure 5: NSY 45.9 kHz

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 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

[1] Eclipse induced ionospheric perturbations derived from VLF-LF propagation experiments, P. Lassudrie-Duchesne, R. Fleury :
http://ursi.org/Proceedings/ProcGA02/papers/p0765.pdf

[2] VLF observation of the Aug 11, 1999 total solar eclipse by Peter Wilhelm Schnoor, DF3LP, from Kiel, Germany :
http://www.df3lp.de/eclipse.png

[3] VLF observation of the Oct 03, 2005 annular solar eclipse by Jean-Louis Rault, F6AGR, from Epinay-sur-Orge, France :
http://fr.groups.yahoo.com/group/fr_LW_group/files/_Eclipse%20de%20soleil%20en%202005/

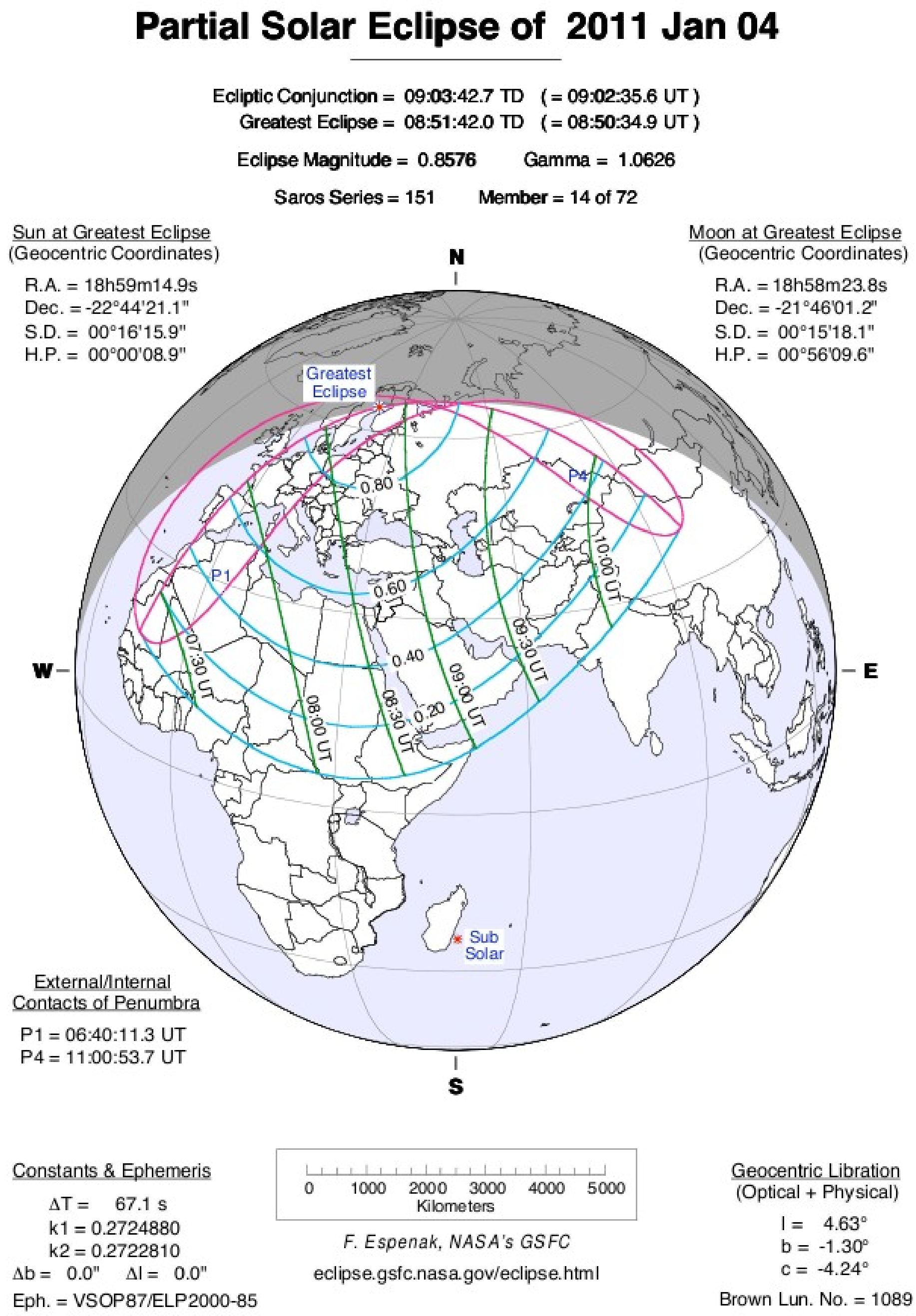
[4] Interactive Eclipse Path using Google Maps —NASA Eclipse website:
http://eclipse.gsfc.nasa.gov/SEsearch/SEsearchmap.php?Ecl=20110104

[5]Archive of solar flares (National Geophysical Data Center) — 2011 data:
ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_FLARES/XRAY_FLARES/xray2011/

[6] AAVSO SID program:
http://www.aavso.org/solar-sids

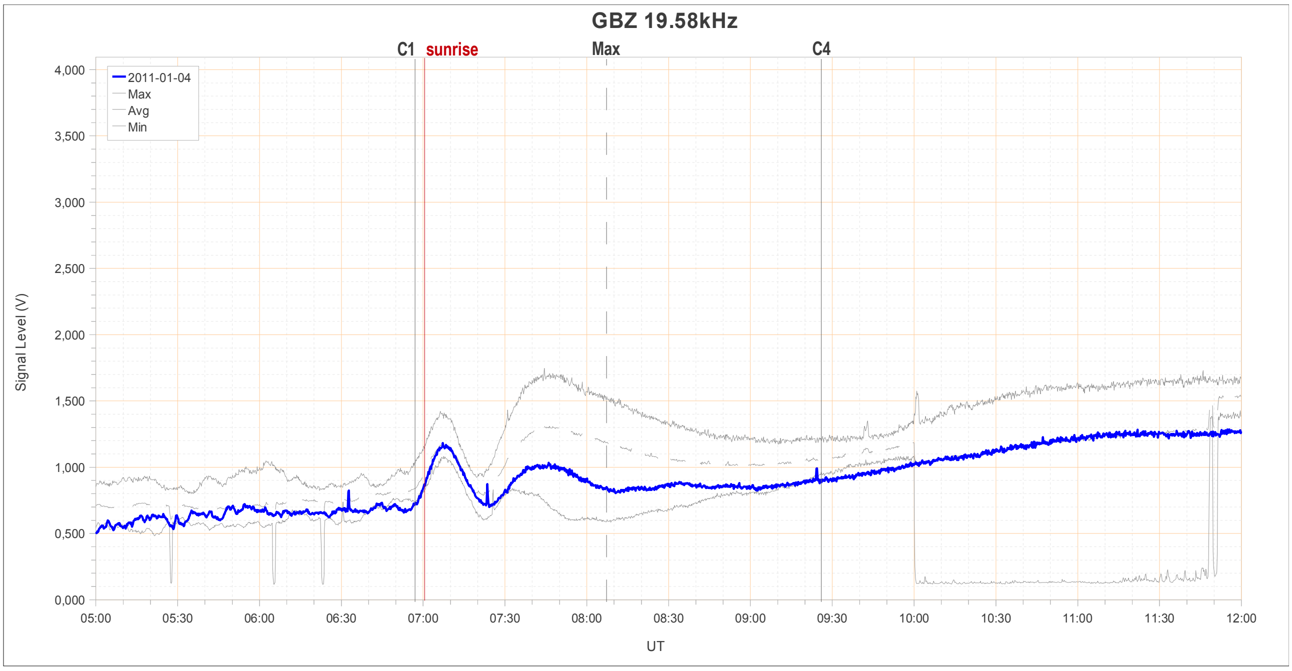
[7] Description of the author's SID monitoring station with access to real-time measurements:
http://sidstation.loudet.org/

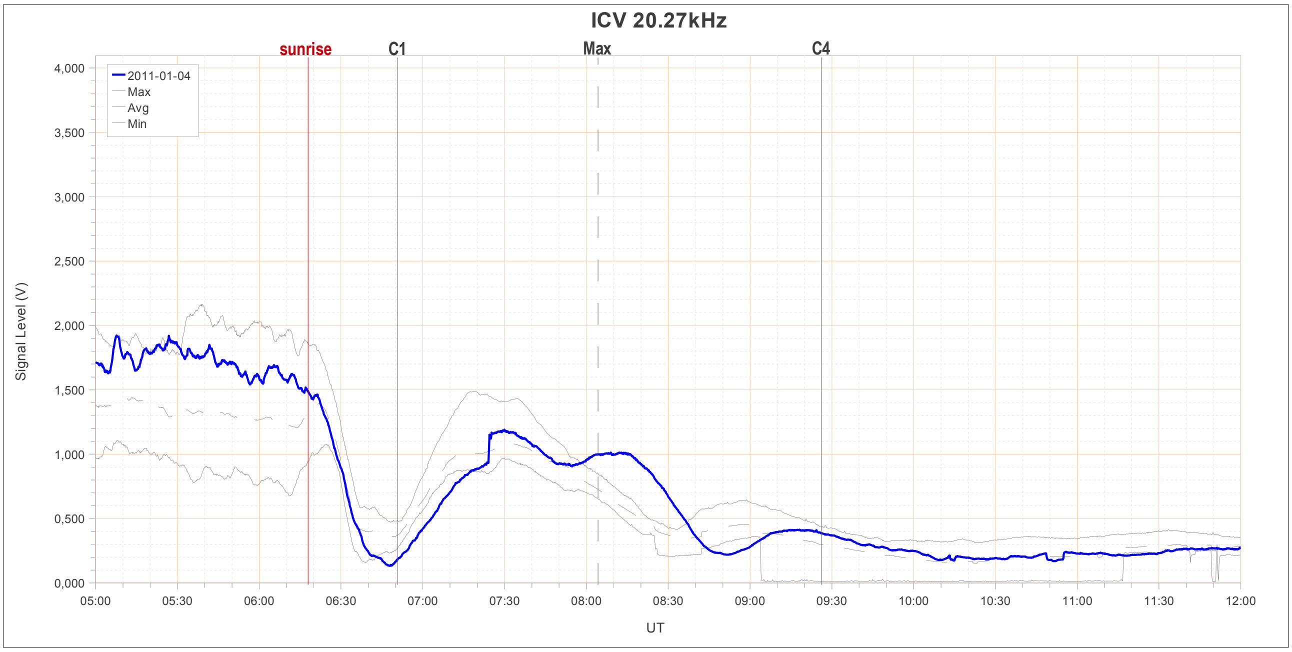
Appendix 1: Eclipse Details

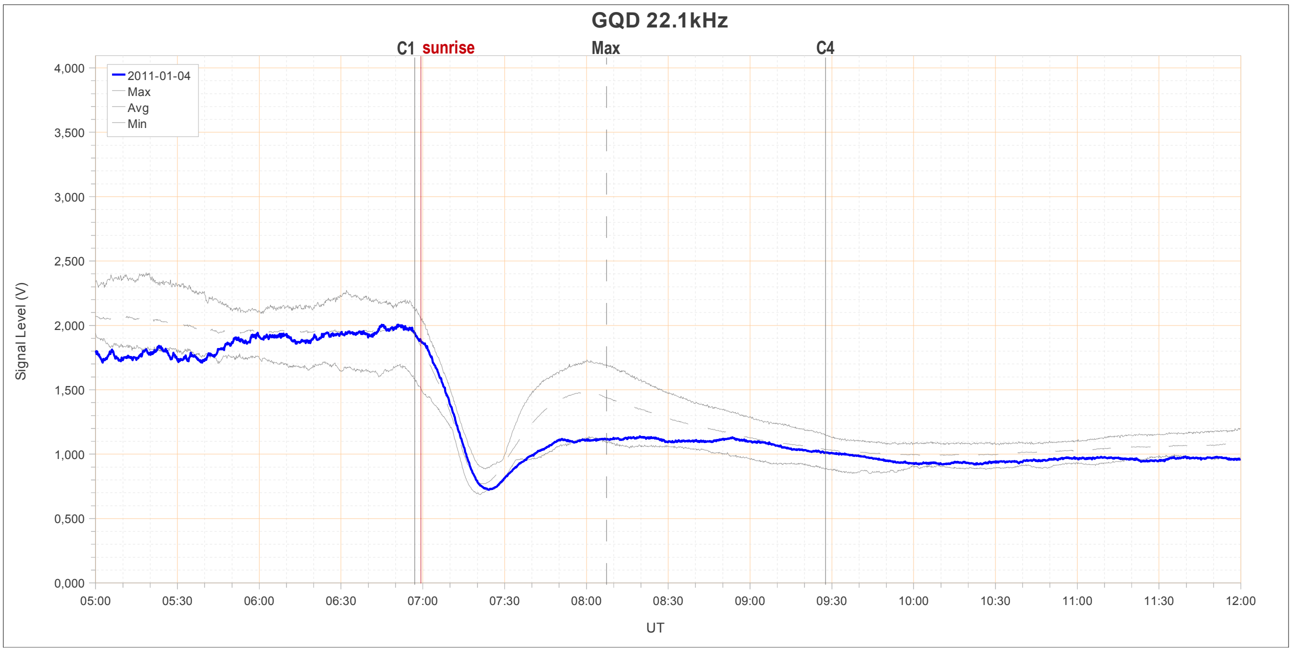


Source: http://eclipse.gsfc.nasa.gov/OH/OHfigures/OH2011-Fig01.pdf

Appendix 2: Detailed Plots






GQD 22.1kHz
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sunrise
Max
C4
2011-01-04
Max
Avg
Min
Signal Level (V)
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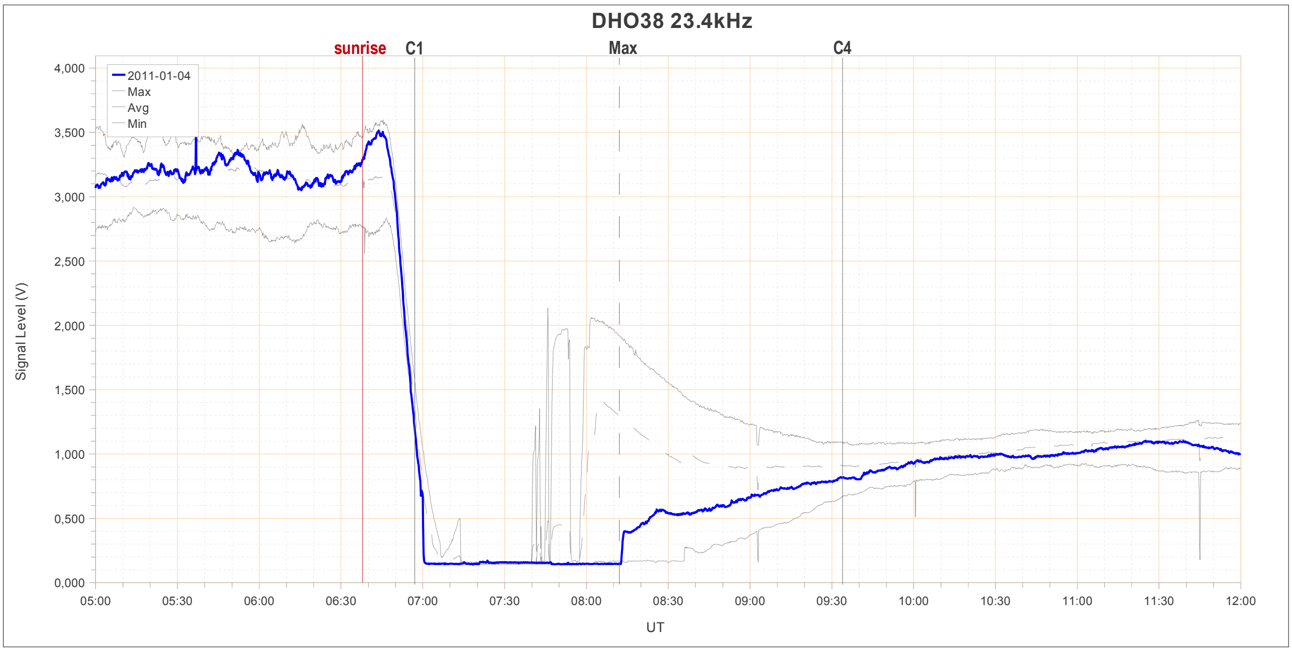
3,500
3,000
2,500
2,000
1,500
1,000
0,500
0,000
05:00
05:30
06:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
UT


DHO38 23.4kHz
sunrise
C1
Max
C4
2011-01-04
Max
Avg
Min
Signal Level (V)
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3,000
2,500
2,000
1,500
1,000
0,500
0,000
05:00
05:30
06:00
06:30
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10:30
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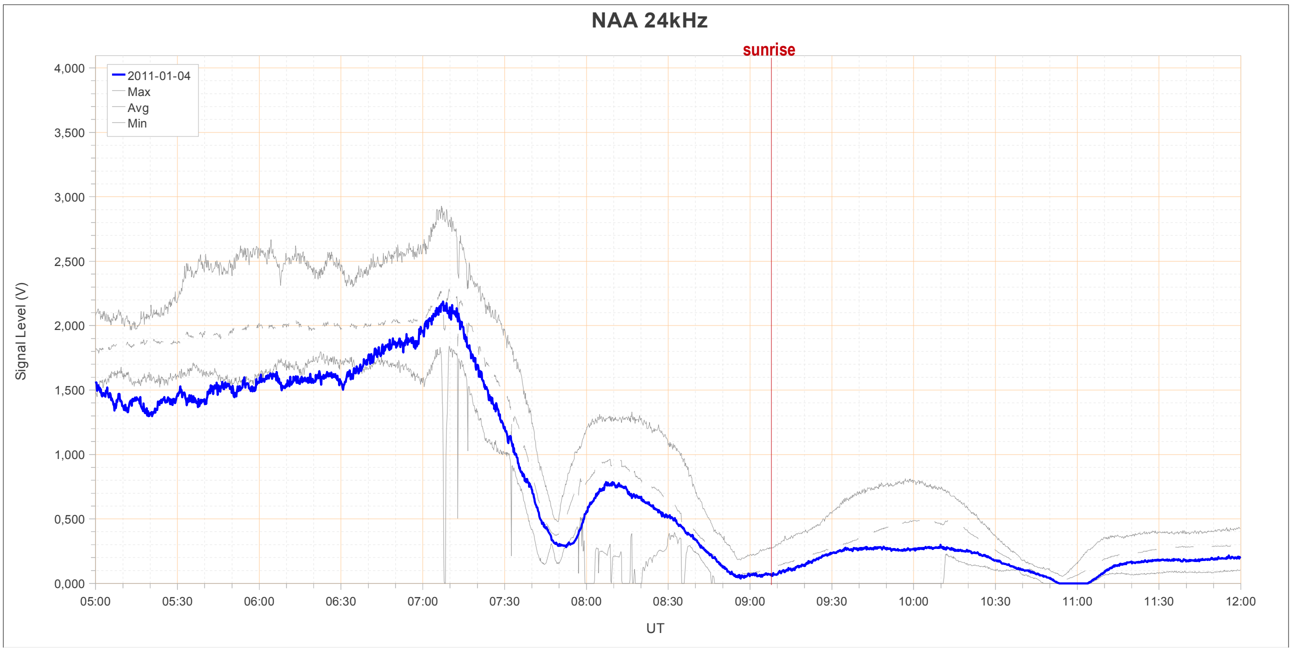
11:30
12:00
UT


NAA 24kHz
sunrise
2011-01-04
Max
Avg
Min
Signal Level (V)
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2,500
2,000
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05:00
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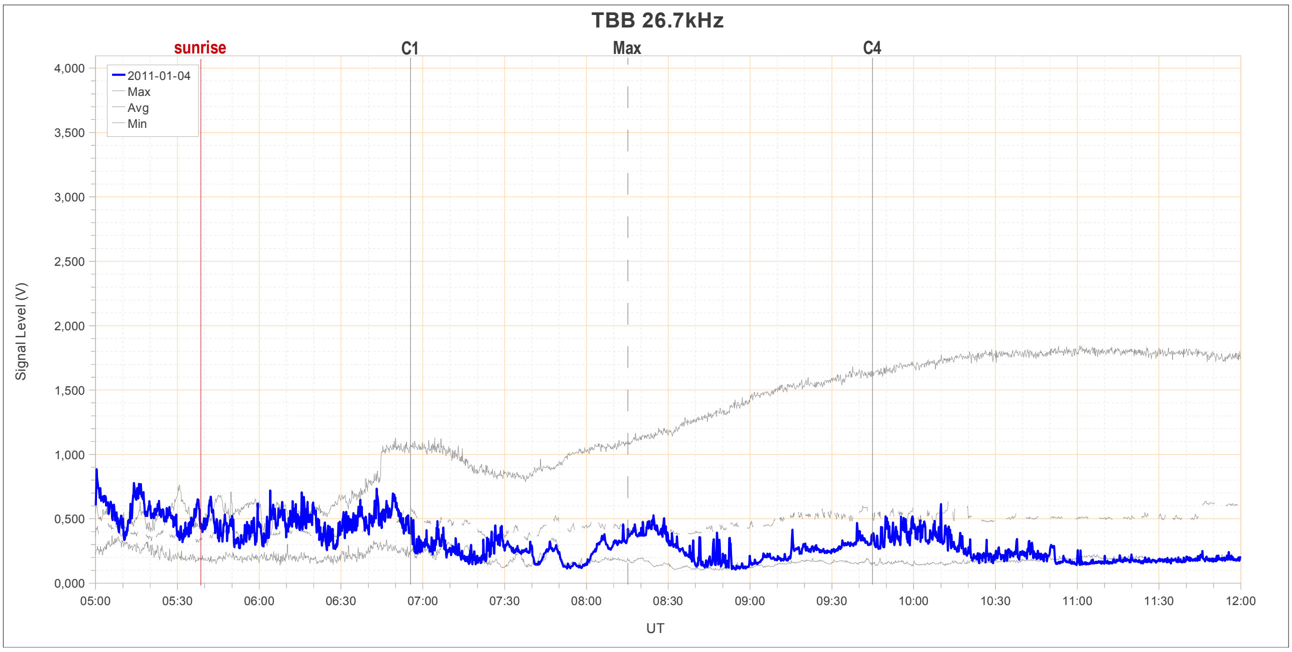
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C1
Max
C4
2011-01-04
Max
Avg
Min
Signal Level (V)
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2,000
1,500
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05:00
05:30
06:00
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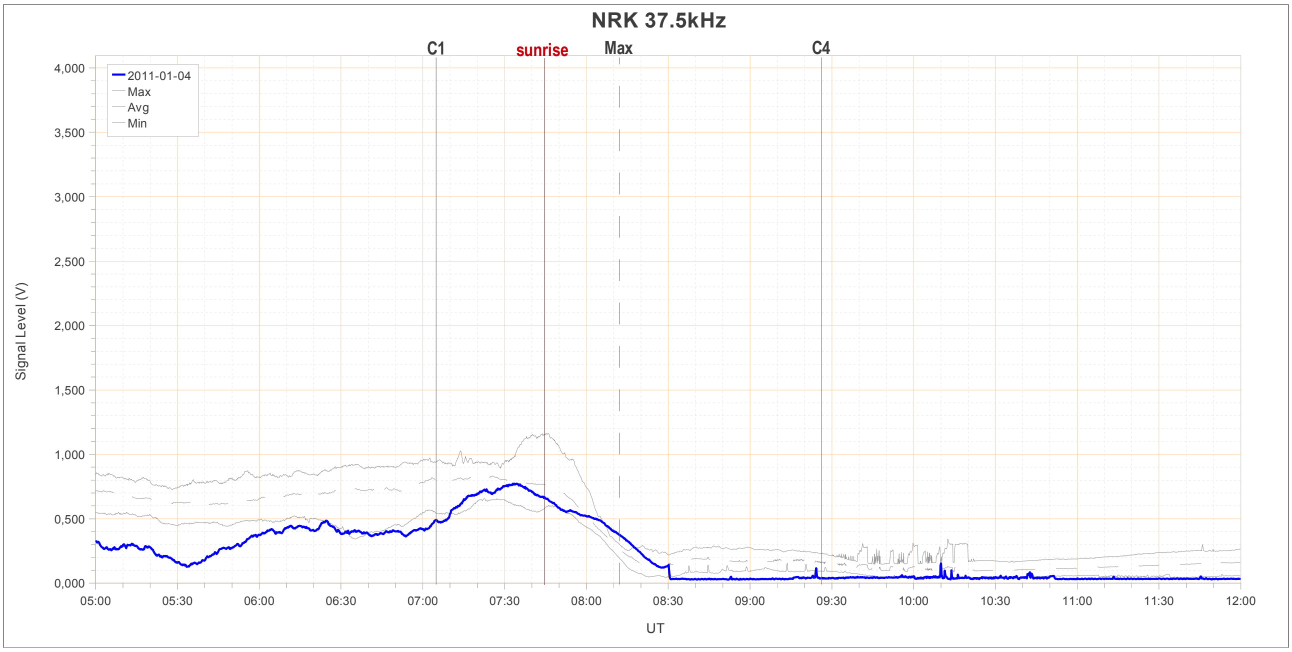
NRK 37.5kHz
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sunrise
Max
C4
2011-01-04
Max
Avg
Min
Signal Level (V)
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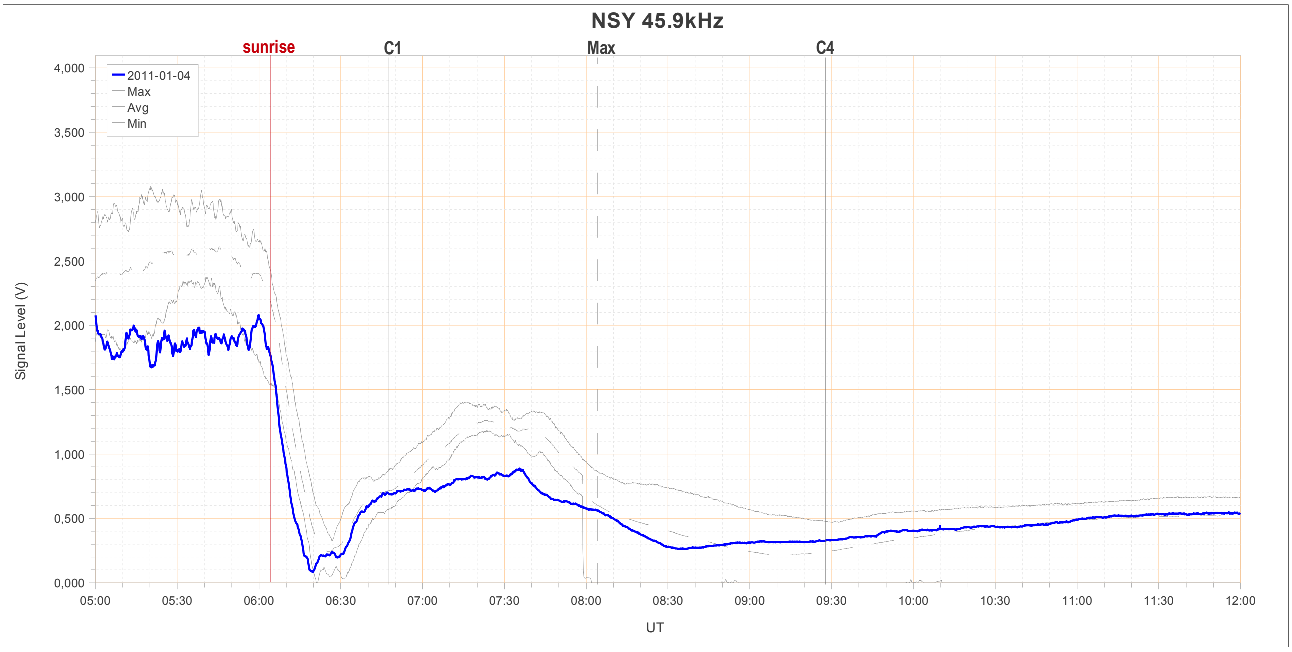
NSY 45.9kHz
sunrise
C1
Max
C4
2011-01-04
Max
Avg
Min
Signal Level (V)
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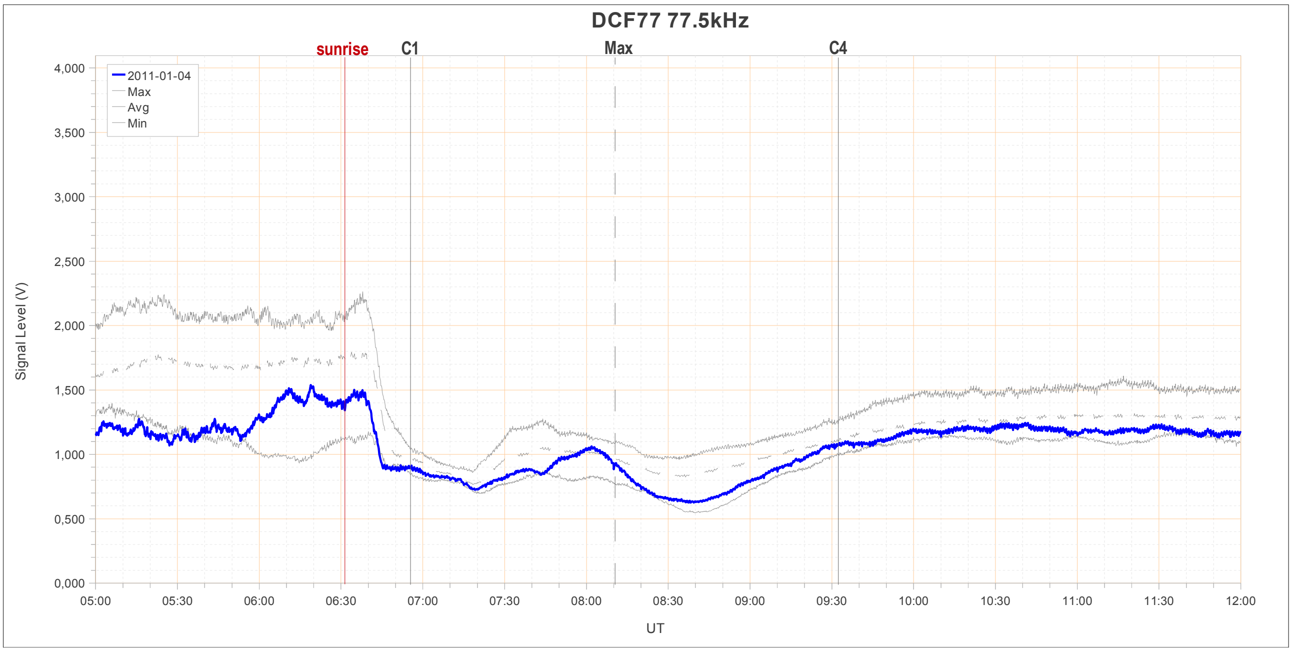
DCF77 77.5kHz
sunrise
C1
Max
C4
2011-01-04
Max
Avg
Min
Signal Level (V)
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3,000
2,500
2,000
1,500
1,000
0,500
0,000
05:00
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06:30
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