

# Whistlers Detected by the Belgian VLF Antenna of Humain

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## 1. ABSTRACT

Whistlers are **electromagnetic VLF** (very low frequency, 3-30 kHz) emissions **initiated by lightning**, propagating along magnetic field lines, observed on ground and in space. Whistler wave analysis is an effective tool for **studying the plasmasphere**. Whistlers acquire particular frequency-time characteristics while they propagate through the magnetospheric plasma, and in particular through the plasmasphere. Their propagation time depends on the plasma density along their propagation paths. It is possible to **derive the plasmaspheric electron density distribution** from these propagation times. We therefore have started a **project to detect whistlers with VLF measurements**. A VLF antenna has been installed in early 2011 in **Humain, Belgium** (50.11°N, 5.15°E). The VLF antenna is made of **two perpendicular magnetic loops, oriented North-South and East-West**, and with an area of approximately 50 m<sup>2</sup> each. This antenna is part of **AWDAnet, the Automatic Whistler Detector and Analyzer system's network**. This network covers low, mid and high magnetic latitudes, including conjugate locations. We use the AWDAnet system to retrieve automatically **electron density profiles from whistler measurements** made in Belgium. In this poster, the first results of **whistler occurrence** are shown.

## 2. INTRODUCTION

### A. Magnetosphere

The terrestrial **magnetosphere** is a large volume of space around the Earth, extending ~65000 km (~10 Earth radii, R<sub>E</sub>) in the Sun direction and more than 2 millions of km in the opposite direction [FIG. 1]. The **solar wind** compresses the magnetosphere on the front side and shapes it into a long tail in the anti-sunward direction. The **plasmasphere** is a toroidal region located in the Earth's magnetosphere, above the ionosphere (~1000 km), extending up to equatorial distances of **4-8 R<sub>E</sub>**. It consists primarily of cool (~1 eV) **electrons and H<sup>+</sup> ions**, and some other ions (He<sup>+</sup> and O<sup>+</sup> mainly).

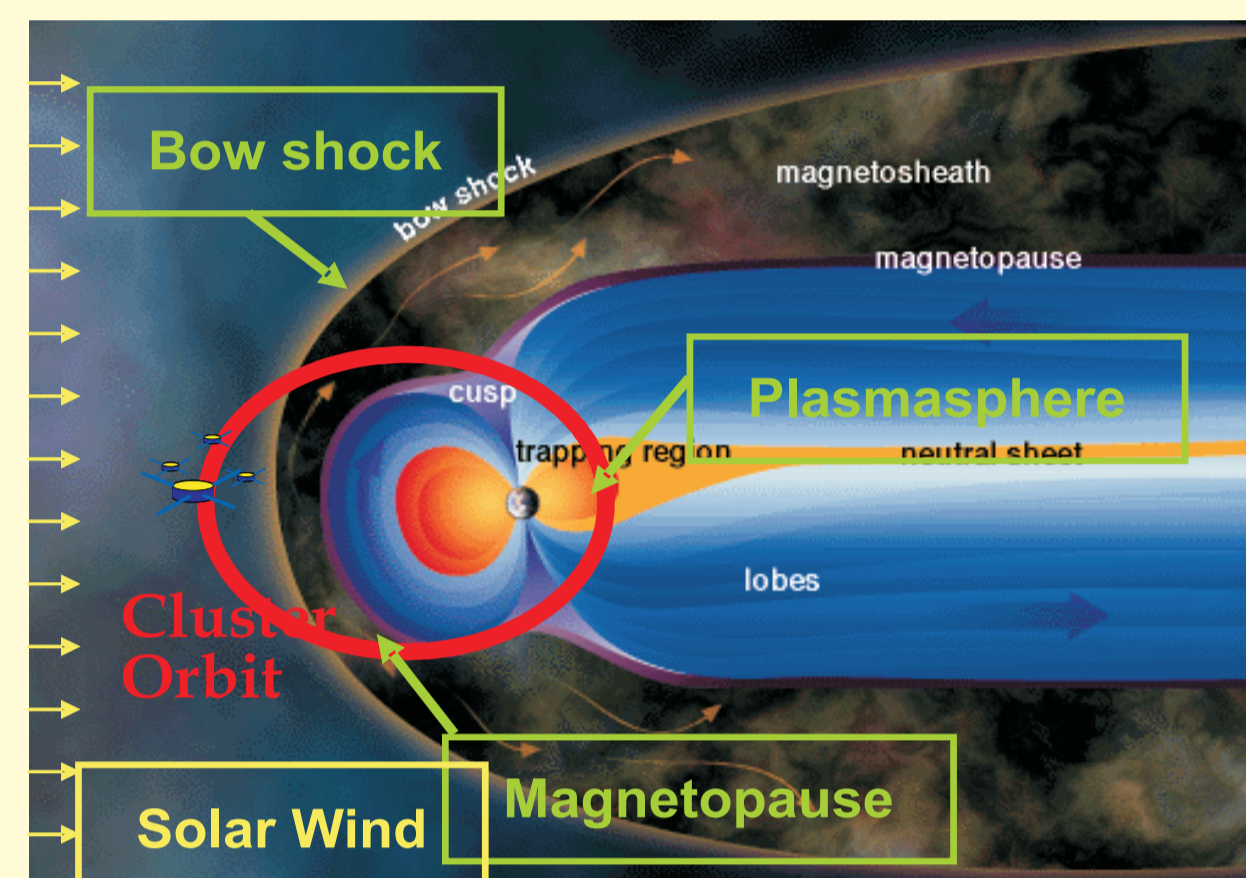


FIG. 1: Sketch of the magnetosphere with the CLUSTER orbit and the regions crossed by the spacecraft (from ESA).

### B. Whistlers

Whistlers are **VLF** (3-30 kHz) **emissions initiated by lightning**, propagating along magnetic field lines, observed on ground and in space [FIG. 2]. The name comes from the fact that the **transposition of the signal into the audio frequency gives the impression of a whistle**.

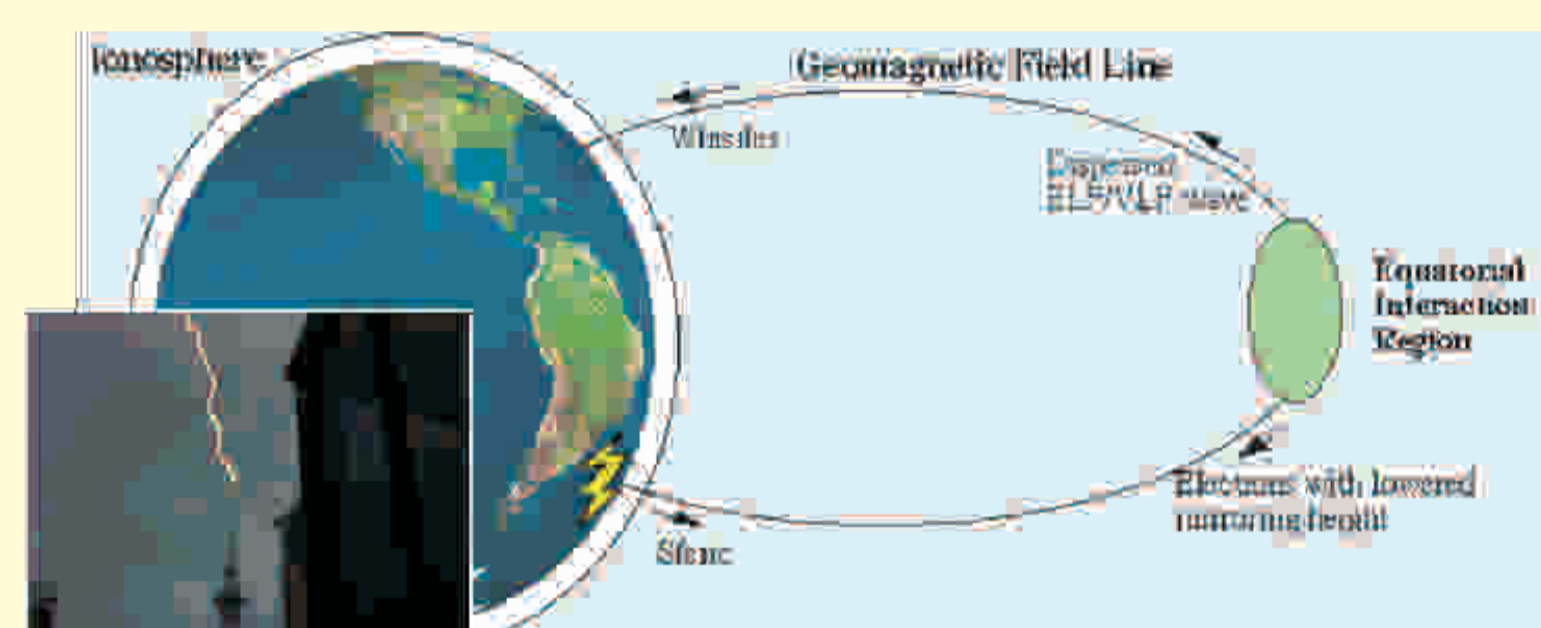


FIG. 2: Sketch of a whistler generation and propagation.

The propagation time of whistlers depends on the plasma density along their propagation paths. It is possible to derive the plasmaspheric electron density distribution from these propagation times [REF. 1].

### C. VLF Antenna

Evolution of the project:

- \* **November 2009**: Meeting with the responsible of the AWDAnet project
- \* **January-October 2010**: Selection of material, decision about the size of the antenna, search of the location
- \* **November 2010**: Installation of the 12 meters mast in Humain, Belgium (50.11°N - 5.15°E)
- \* **January-March 2011**: Installation of hardware / software
- \* **8 April 2011**: First measurements made by the Belgian VLF measurement system

The VLF antenna is made of **two perpendicular magnetic loops**, oriented **North-South and East-West**, and with an area of approximately 50 m<sup>2</sup> each [FIG. 3].

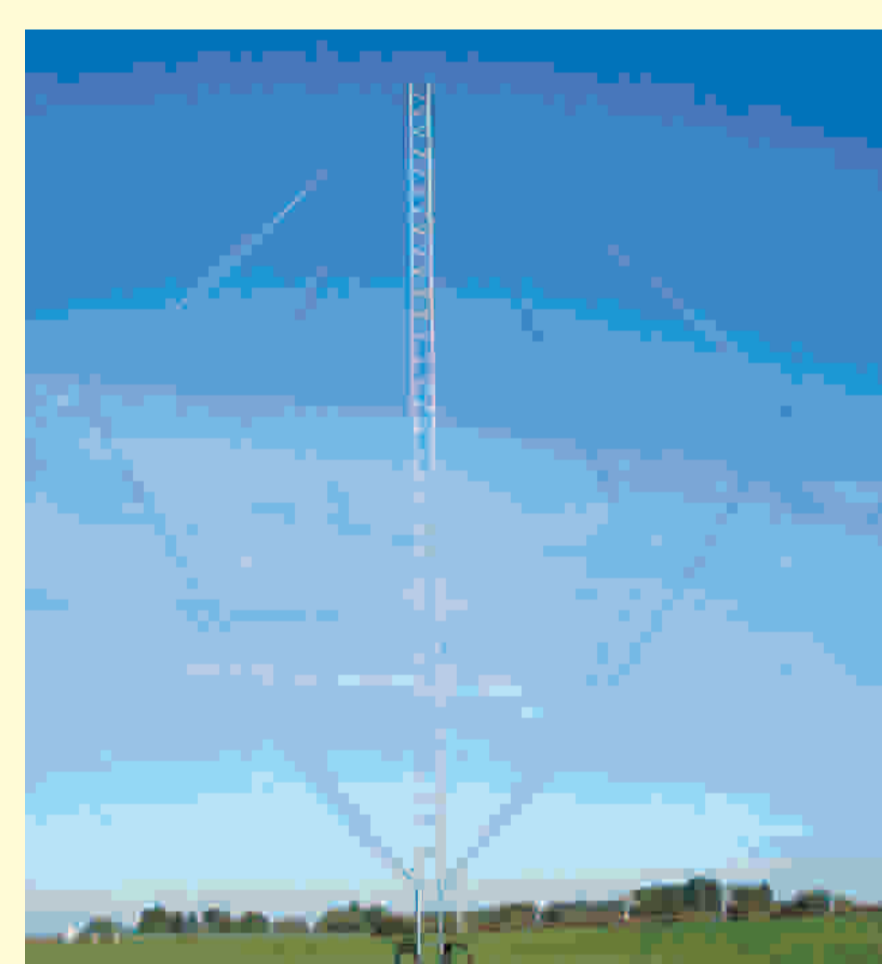


FIG. 3: Picture of the VLF antenna located in Humain, Belgium.

### D. AWDAnet

This antenna is part of **AWDAnet, the Automatic Whistler Detector and Analyzer system's network** [REF. 2]. This network covers low, mid and high magnetic latitudes, including conjugate magnetic locations [FIGs. 4 and 5]. It consists of **same type of antennas with same data analysis software**.

In Europe, 8 antennas are in operations (in red), including Humain and 3 antennas are in preparation (in blue).



FIG. 4: Location of the VLF antennas part of the AWDAnet in Europe.

In the world outside Europe, 12 antennas are in operations (in red) and 6 antennas are planned or in preparation (in blue).

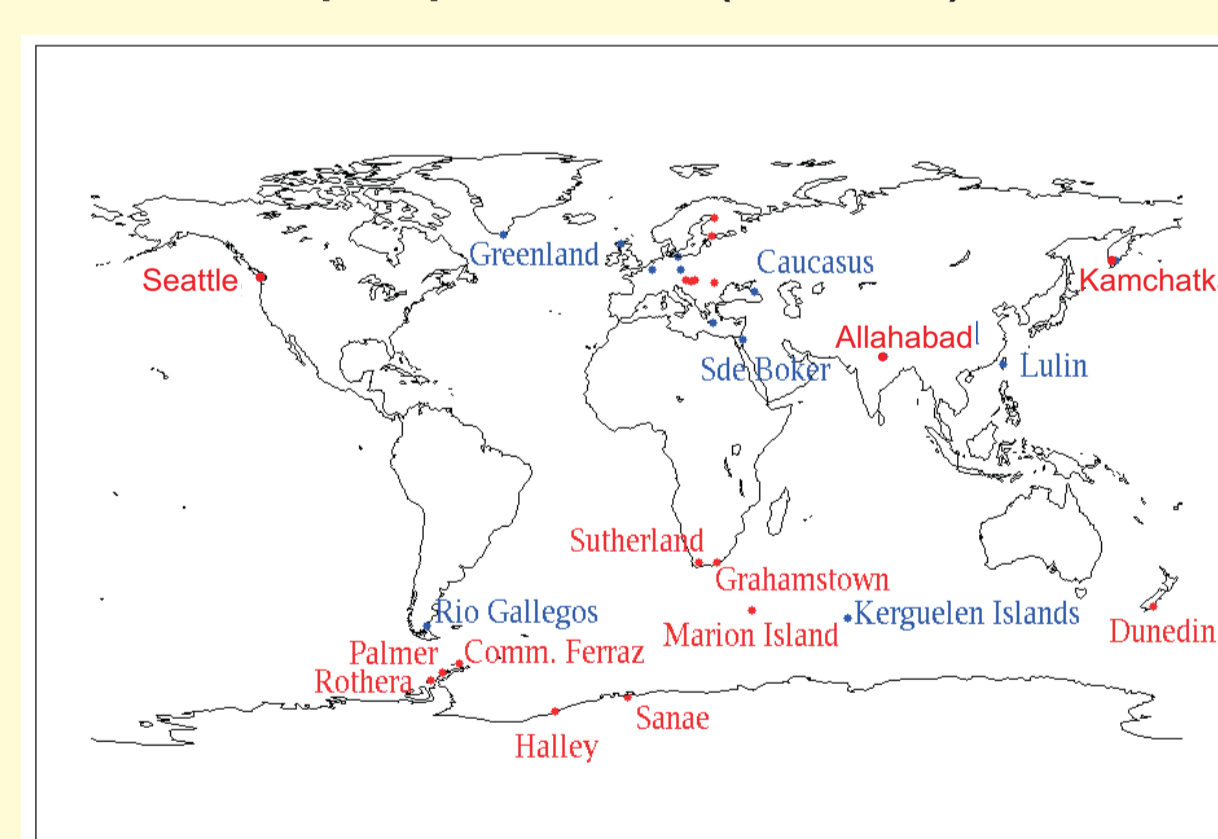


FIG. 5: Location of the VLF antennas part of the AWDAnet in the world outside Europe.

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## 3. FIRST OBSERVATIONS AND ANALYSIS

### A. Dataset

With the antenna recently installed in Humain, Belgium (50.11°N - 5.15°E), we **started the measurements in early April 2011**. There are some data gaps in 2011 due to software/hardware problems:

- \* 15 April - 4 May 2011
- \* 16 June - 31 July 2011
- \* 24 September - 4 October 2011
- \* 9-22 November 2011
- \* 1-6 December 2011

There is full data coverage since January 2012. Total duration of measurements is until now **17.5 months**. As output of the antennas we get time-frequency magnetic field spectrograms (0-20 kHz), in two directions (North-South and East-West).

There is at the station an **automatic software for the detection of whistlers or signals similar to whistlers** [REF. 2], to reduce the quantity of data to be stored. Then a manual selection of the whistlers is done.

### B. Examples

Frequency-time magnetic field spectrograms (0-20 kHz; 5 s; Top: North-South ; Bottom: East-West), but with perturbations [FIG. 6]:

- \* **At fixed frequency**: e.g. 16, 18, 20 kHz (military transmitters or parasitic sources)
- \* **During fixed duration** (~ 0.5 s): regular, at high frequency (e.g. 12, 15 KHz)
- \* **During very short duration** (~ 0,01 s): wide frequency band (several kHz), most of the time

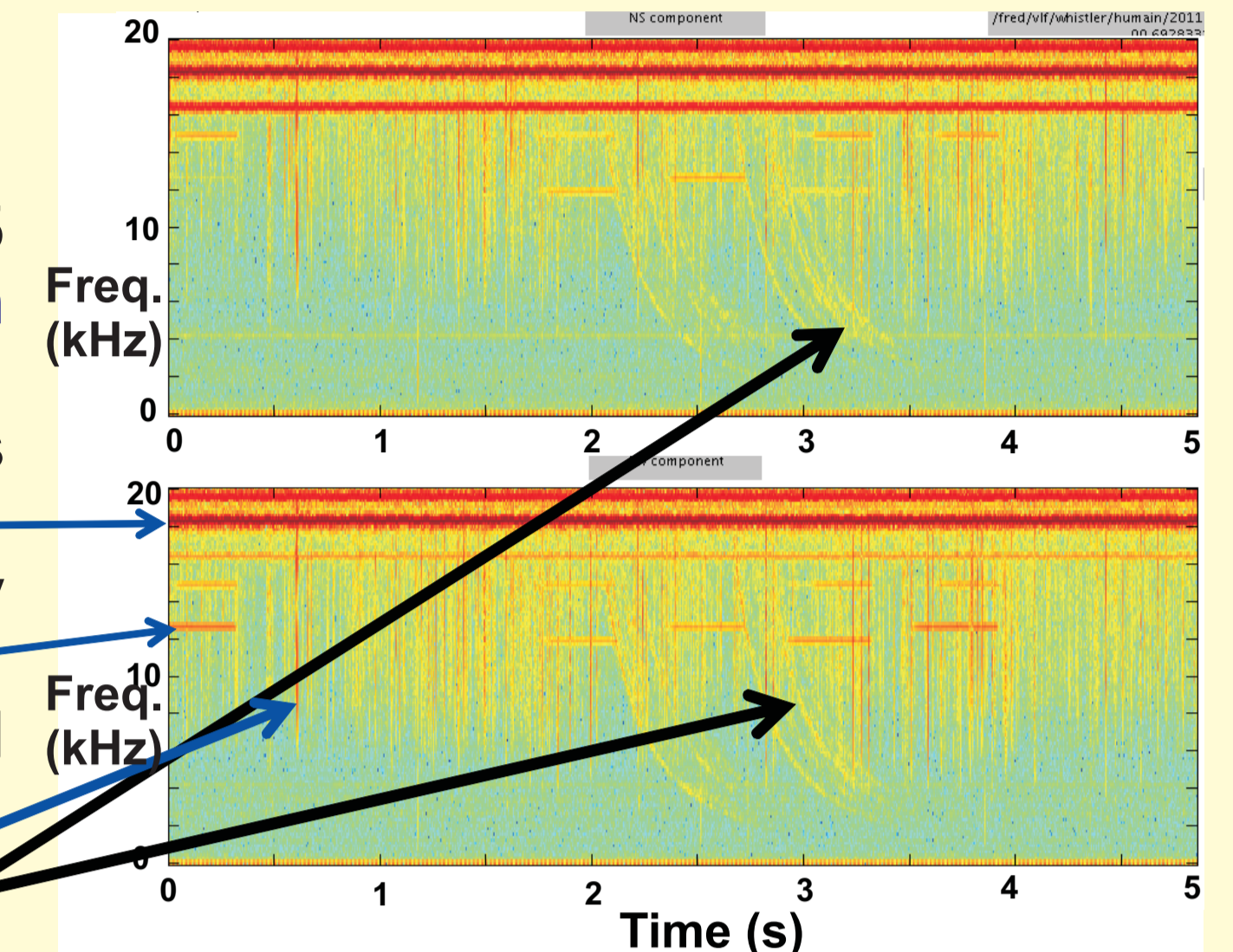


FIG. 6: Frequency-time spectrograms measured at Humain, Belgium, showing whistler signatures.

Whistlers detected and clearly observed in both loops.

### C. Statistical analysis

Overall less whistlers detected than at other AWDAnet stations nearby (e.g. Tihany in Hungary) [REF. 3], several possible reasons:

- \* Missing data
- \* **Antenna area (smaller than at Tihany)** / preamplifier gain
- \* Thunderstorm activity at conjugate point

Statistical analysis during the time period August 2011 – July 2012 [FIG. 7]:

\* UT distribution [FIG. 7b]:

- \* **Whistlers detected mainly during night**, especially between 23-01 and 03-04 UT
- \* Almost no whistlers detected during morning and mid-day (06-14 UT)

\* Seasonal distribution [FIG. 7c]:

- \* **1<sup>st</sup> maximum in spring** (similar proportions as in spring 2011): high thunderstorm activity at conjugate point in southern hemisphere
- \* **2<sup>nd</sup> maximum in August**: half of whistlers recorded during 1 single day (19 Aug 2011) [FIG. 7a]; requires further investigations...

### Global minimum in Winter

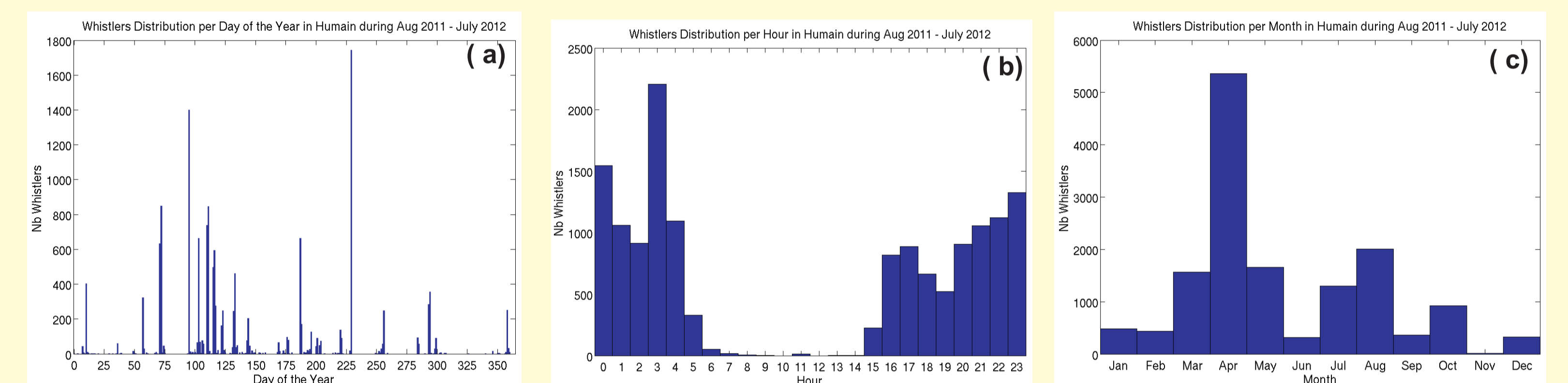


FIG. 7: Statistical analysis of the whistlers observed at Humain, Belgium from 1 August 2011 to 31 July 2012. (a) Daily variation of the whistlers; (b) hourly occurrence of the whistlers; (c) monthly variation of the whistlers.

### D. Single trace analysis

**One event is analyzed in details** to derive some properties of whistlers and of the region crossed by the whistlers [REF. 1]: Whistler observed in Humain on 13 September 2011 at 03:59 UT (strong intensity, both directions, duration ~0.6 s) [FIG. 8]. **The density is determined from inversion with field-aligned density model:**

- \* Denton model [REF. 4]:  $L = 2.31 \pm 0.02 R_E$  and  $N_{eq} = 1646 \pm 80 \text{ cm}^{-3}$
- \* Angerami model [REF. 5]:  $L = 2.35 \pm 0.04 R_E$  and  $N_{eq} = 1466 \pm 97 \text{ cm}^{-3}$

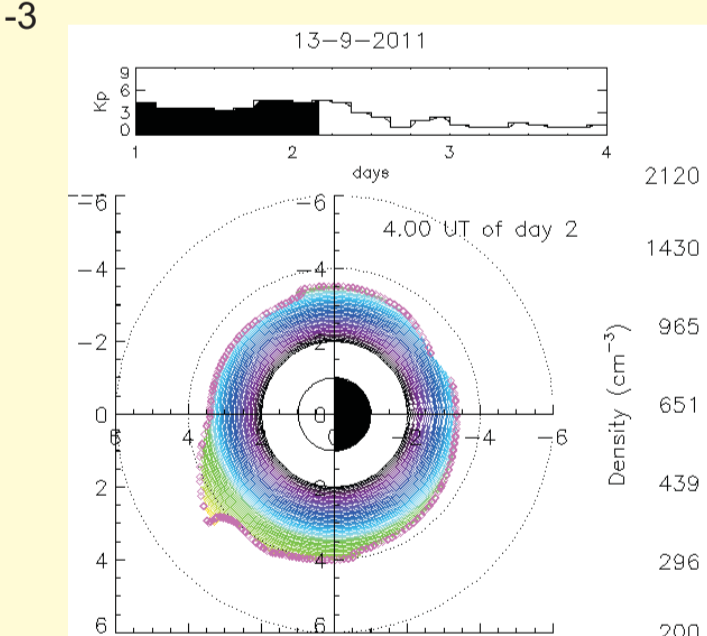


FIG. 9: Plasmaspheric density and plasmopause location in the equatorial plane.

**Comparison with plasmasphere kinetic model of Pierrard (Kp dependent)** [REF. 6]: Plasmaspheric density and plasmopause location (in pink) in the equatorial plane on 13 September 2011 at 04:00 UT [FIG. 9]

- \*  $L = 2.31 R_E - N_{eq} = 1657 \text{ cm}^{-3}$
- \*  $L = 2.35 R_E - N_{eq} = 1606 \text{ cm}^{-3}$

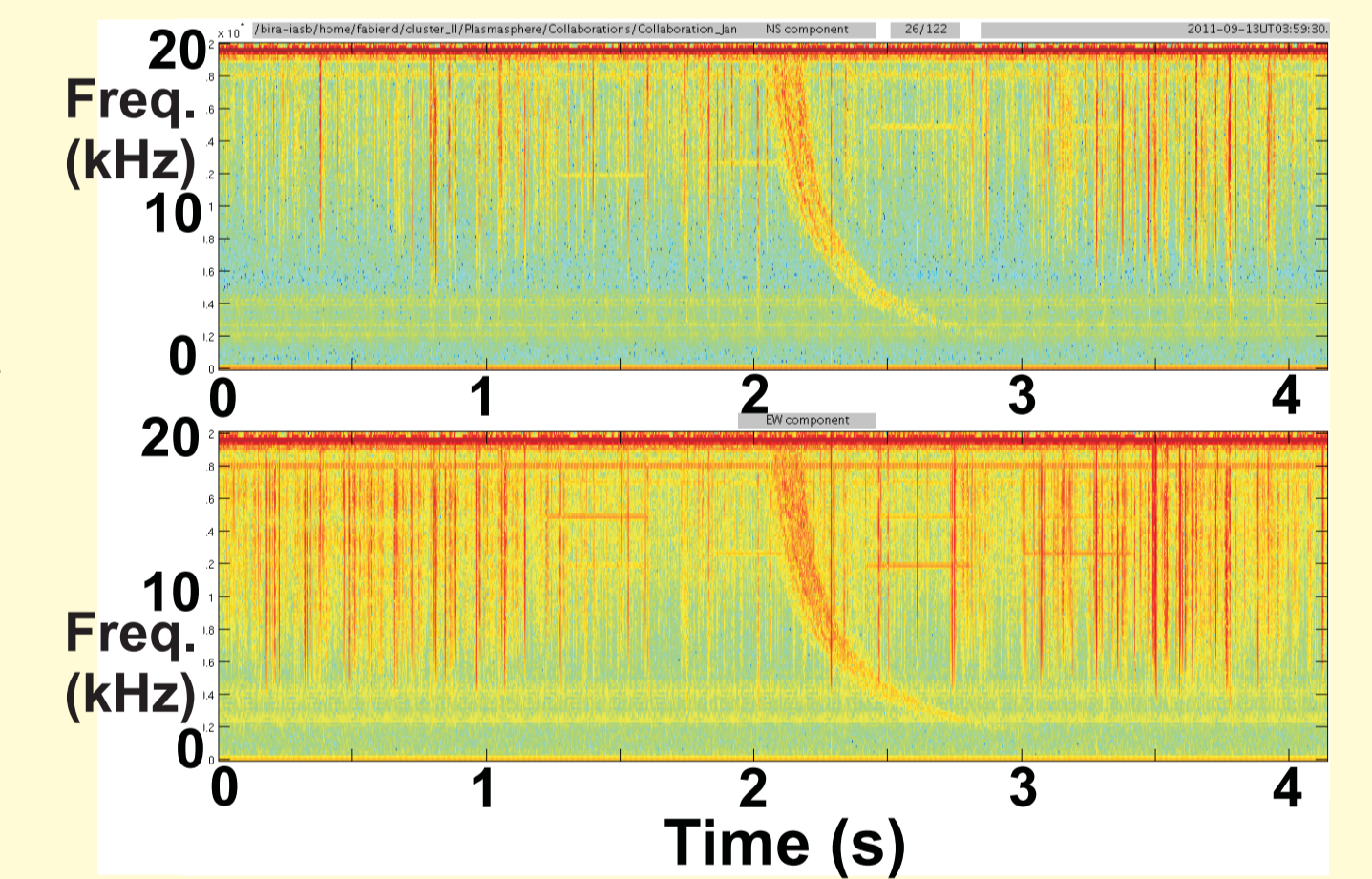


FIG. 8: Frequency-time spectrograms measured at Humain, Belgium.

## 4. CONCLUSIONS

The **VLF measurement system** recently installed in Humain is working well and provides **good quality and useful whistler wave observations** at this location in Belgium (50.11°N - 5.15°E) [REF. 7]. The antenna is **working since early April 2011**. First statistical results:

- \* **Less whistlers** than at other AWDAnet stations nearby (e.g. Tihany in Hungary)
- \* Whistlers detected **mainly during night**, especially between 23-01 and 03-04 UT
- \* **Maximum in spring**: thunderstorm activity at conjugate point in southern hemisphere
- \* Density determined from whistler (tool works well with clear and strong whistler; **good comparison with density obtained from a kinetic model of the plasmasphere**)

Plans for the future:

- \* Continue **automatic whistlers observation and detection**
- \* Derive plasma density from whistlers observations
- \* Continue statistical analysis of whistlers
- \* Compare studies with other AWDAnet stations
- \* **Perform conjugated analysis with in-situ measurements** of density in plasmasphere (with the Cluster mission) [REF. 8]
- \* Develop **comparison with density data obtained from numerical simulations**
- \* Study the **VLF waves that could be generated by meteors**