

Department of Physics and Technology

# System upgrade and data evaluation of the AIRIS riometer

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## **0.1 Abstract**

The focus of this thesis has been to investigate how to improve the AIRIS data. This has been done by first of all giving the riometer system an overhaul, checking the wiring and receivers as well as upgrading the riometer computer harddisk. As there has been a lot of issues occurring along the way, the focus finally went to pinpointing exactly what is causing the data quality to be poor and coming up with solutions to fix this. It was found that the temperature control system has a severe effect on the data quality, causing huge fluctuations in the data, and actions needs to be taken in order to solve this.

## 0.2 Acknowledgments

This Master thesis is a result of one-year work made possible through a collaboration between UiT, ALOMAR Observatory and Lancaster University. The topic of research was initially proposed by Sandra Blindheim (ALOMAR) and Björn Gustavsson (UiT). A lot of help was received from Professor Farideh Honary of Lancaster University and Michael Gausa (ALOMAR). ALOMAR has also helped with funding a week of training at Lancaster University in the use of the riometer including data handling, where Farideh was supervising the training. Steve Marple of Lancaster University has also helped me with understanding the riometer data, how to create it, and all the laptop issues I encountered. I would also like to mention Mat Beharrell for helping me with writing the necessary code. Thank you.

Martin Friedrich at Technische Universitet Graz has also been extremely helpful in providing me with information regarding the riometer, its use throughout the history and he has provided me with many helpful papers. I would like to thank you for your setting of some time to talk during your stays at Andøya.

I would like to thank Kolbjørn Blix Dahle for the help in maintaining the riometer instrument and Michael Gausa for helping me with the theoretical aspect of the thesis. Both have been invaluable upon completion of this thesis, and very patient with my many queries and occasionally silly questions.

I big thank you is also in place for Marina Petrozzi. Alongside working on my thesis, I also worked on a project at ASC, and she has been very flexible, patient and accommodating upon completion of this thesis. I am very grateful for this.

Finally, I would like to thank my family for always supporting me, helping out when I needed it and always believing in me. This is for you.

## 0.3 List of Abbreviations

**QDC** Quiet day curve

**LIDAR** LIght Detection And Ranging

**ALOMAR** Arctic Lidar Observatory for Middle Atmosphere Research

**ASC** Andøya Space Center

**TGO** Tromsø Geophysical Observatory

**AIRIS** Andøya Imaging Riometer for Ionospheric Studies

**IRIS** Imaging Riometer for Ionospheric Studies

**Riometer** Relative Ionospheric Opacity Meter

**FPGA** Field-Programmable Gate Array

**MIA** Multi-Instrument Analysis

**CRN** Cosmic Radio Noise

**NLC** Noctilucent Cloud

**SID** Sudden Ionospheric Disturbance

**UPS** Uninterruptible Power Supply

**NaN** Not a Number

## 0.4 Nomenclature

### Atmospheric Theory

$A$  Molecule in Ionosphere

$hf$  Photon

$e^-$  Electron

### Absorption Theory

$A(dB)$  Absorption in Decibels

$f$  Frequency

$P$  Received Signal Power

$P_0$  Received Signal Power when no Ionosphere

$E^*$  Amplitude of Incident Wave

$E$  Amplitude of Received Wave

$\kappa$  Absorption Coefficient

$ds$  Path Length

$q$  Charge of Electron

$N$  Electron Number Density

$m_e$  Mass of an Electron

$c$  Speed of Light

$\epsilon_0$  Permittivity of Free Space

$\mu$  Refractive Index of a Medium

$\nu$  Electron Collision Frequency

$\omega$  Radio Wave Angular Frequency

$\omega_L$  Gyro Frequency

$\alpha$  Ratio

$C_{5/2}$  Integral Convention from Semi-Conductor Theory

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# Chapter 1

## Introduction

### 1.1 Introduction

The Arctic Lidar Observatory for Middle-Atmospheric Research (ALOMAR) is an observatory located at Andøya, in northern Norway. The observatory has many instruments used to study phenomena that occur in the middle atmosphere, including LIDARs, radars, cameras and the riometer. This thesis will focus on the riometer, a versatile instrument used to study cosmic ray absorption in the atmosphere, at around 90 km altitude.

ALOMAR was built in 1994, as a cooperative facility between Andøya Space Center (then Andøya Rocket Range) and several research institutions around the world. Since the facility opened, ALOMAR has obtained several important instruments to study the atmosphere, however it is notably most known for the many Lidars located here. Especially the RMR (Raman - Mie - Rayleigh) Lidar and Na Lidar are used to study the atmospheric condition during rocket launches, as well as providing data regarding observations of atmospheric gravity waves and Noctilucent Clouds. The riometer is an instrument that has a great potential in terms of its capabilities for processing realtime data to be used in rocket launch campaigns.

### 1.2 Research questions

The following research questions is the topic of this thesis;

- How is AIRIS data quality compared to previous years?
- Is the AIRIS system fully operational?

- Is AIRIS data reliable enough to be used in research after upgrades?

These questions were provided by ALOMAR observatory, as their riometer system was in need of an upgrade. Therefore, throughout the year the riometer system has undergone upgrades, and I have undergone training at Lancaster University in order to learn how to process riometer data and answer these questions.

### 1.3 Topic and Motivation

AIRIS is an instrument that was built in collaboration with Lancaster University, at Saura in Andøya. Although the instrument has been operational for several years, a significant upgrade was needed to ensure the continuation of reliable data from the instrument. In this upgrade, the antennas have undergone maintenance, parts have been replaced and the computer system has been updated. In addition, the riometer system hardware is highly sensitive to temperature changes, therefore an upgrade to the house that contains the receivers has also been performed. This includes instalment of a new climate control system, as the previous temperature control system malfunctioned which severely affected the data quality. I have contributed in all these maintenance and upgrade tasks. We now need to know if the data received is reliable, and that will be the focus of this thesis. A comprehensive study has been performed to investigate the data quality after the upgrade, and it will be compared to data from 2009, which is a period when AIRIS data was considered to be ideal.

Since the riometer database is maintained by Lancaster University, I have undergone one week of training in how to process and use riometer data at Lancaster University. ALOMAR observatory previously obtained data upon request from Lancaster University. Now however, ALOMAR can process data as well, which was an additional objective for this thesis project.

It is worth noting that AIRIS is still capable of seeing ionospheric events, however there are remaining issues considering quiet days which makes all the data somewhat unreliable. This will also be demonstrated in the results section. It is also worth mentioning that the riometer data saw a sudden deterioration in quality, which is demonstrated clearly in the results section. The cause of this deterioration has become the main focus of this thesis, due to its severity and unexpectedly occurrence.

## 1.4 Expectations and limitations of the research

Upon completion of this thesis, it was expected that the AIRIS system should be fully operational and the data should be of a quality such that it may be used in research. However, in order to achieve this, there has been a few obstacles and unforeseen events that has effected the progress of this thesis work. Certain AIRIS upgrades had to be done by contractors, for example the installation of the new climate system, which unexpectedly suffered a 5-month delay. When the climate system was installed, another issue occurred with all the parts not fitting properly and so the AIRIS receivers were still affected by unstable temperature conditions until late April 2016, when the issue was fixed. Additionally, there has been some obstacles relating to the production of data due to unforeseen computer issues. Furthermore, as the climate control system was installed in week 14 of 2016 with additional time required to get the parts fitting properly, this severely affected the amount of data available for analysis.

## 1.5 Thesis Structure

This thesis will present Riometer theory and give a detailed insight into the reliability and quality check of the riometer system, as well as the processing of riometer data.

In chapter 2, a detailed description of the instruments included is presented. In chapter 3, theory regarding riometers and its principles are presented, along with atmospheric theory related the function of riometers is presented. In chapter 4, the method is presented along with how to process data and how to analyse data. Chapter 5 provides the results of the investigation. In chapter 6 the results are discussed in terms of the observations made. Chapter 7 provides the conclusion and necessary future actions required.

## 1.6 Unforeseen Events and Obstacles

Although it may be unconventional to include a section about unforeseen events, it is beneficial for future users of AIRIS to document the refurbishment process in some detail. The original topic was to investigate sodium in the atmosphere and its effect upon auroral activity. However, the sodium Lidar at ALOMAR stopped functioning in October of 2015, and is to this date yet to be fully operational. A back-up plan

was to use data from a similar Sodium Lidar in Tromsø, however establishing a relationship with the operators of this Lidar proved fruitless. Therefore, the focus eventually went entirely to the Riometer, and the new plan was to analyse auroral events once the system had been upgraded and the data was deemed reliable. Again, this appeared to be difficult as one of the crucial parts of the riometer upgrades, the installation of a new temperature control system, was delayed by 5 months. When the temperature system was installed, it turned out that some of the components were not fitting properly, and so it took another 3 weeks before this was fixed. Therefore, on the 25<sup>th</sup> of April 2016, the temperature control system was deemed fully operational. In order to create QDC's, the system needs 14 days to collect data (preferably 16 for good measure). However, when the data after the temperature control system installation was created, it turned out to be worse than before the upgrades. Therefore, we have had to troubleshoot why this is so, and the results along with recommended future action is presented in this thesis.



# Chapter 2

## Instrumentation

This chapter will provide technical information regarding the instruments involved. This is important also in relation to the riometer theory, for example, one must consider why the riometers operate at a 38.2 MHz frequency, the area it covers and why the riometers are located where they are. Furthermore, it is important to know the technical aspect of AIRIS in order to understand why it has not been functioning properly, and what can be done to mitigate these issues. Along with AIRIS data, magnetometerdata has also been obtained from Tromsø Geophysical Observatory. Magnetometerdata is used to investigate whether there are any events occurring that may affect the data, but also to check whether these events are observed in the riometer data.

## 2.1 ALOMAR Observatory

The Arctic Lidar Observatory for Middle Atmospheric Research (ALOMAR), is a research facility located 69 degrees north and 16 degrees East, at the island of Andøy 2.1. It was constructed on top of the mountain Ramnan, 376 meters above sea-level. It is a remote sensing facility, with several LIDARs, radars and cameras installed both at the facility and around the island of Andøy. ALOMAR was built in 1994, and is a collaboration between many universities and research institutions such as Leibniz-Institute of Atmospheric Physics (Germany), Colorado State University (USA) and Lancaster University (UK). ALOMAR owns and runs the AIRIS riometer used in this thesis, but Lancaster University operates, process and maintains the database of the riometer observatories.



Figure 2.1: Figures showing location of ALOMAR, and a picture of ALOMAR during Lidar operation, respectively (Photo by: I. M. Larsen)

## 2.2 Riometer

The Relative Ionospheric Opacity meter, or Riometer for short, is a passive instrument that was invented during the 1950s in order to study auroral effects on radio wave propagation. As a significant amount of collisions between electrons and ions, neutral atoms and molecules occur, radio wave absorption will take place. The intensity of this absorption will be greatly affected by the density of electrons and the frequency of collisions. Additionally, this will provide information about various processes in the ionosphere, such as ionisation, electron temperature and collision frequencies. It has also been proposed that the riometer may be utilised as a means

of studying electron densities [1].

There are two basic principles for absorption measurements when using a riometer. AIRIS usually measures absorption that occurs at about 90km altitude, and the reason for this is that absorption occurs for the main part in the D-region (about 60 - 100 km altitude) of the ionosphere [11]. Additionally, in this region there is a large concentration of gas molecules. This effects present free electrons such that their motion will be influenced by collisions that lead to absorption of energy from propagating radio waves. The free electrons collide with molecules or neutral atoms, the heavier particle will receive this energy and absorption of the wave has thus occurred.

In general, riometers can be divided into two types; wide beam riometers and imaging (narrow beam) riometers. Wide beam riometers, as the name implies, have a wide beam. However, that makes it hard to distinguish fine structures in the atmosphere. They produce a large field-of-view, and they are much more cost effective compared to imaging riometers. Andøya Imaging Riometer for Ionospheric Studies (AIRIS) is an example of an imaging riometer. It consists of several small antennas each with a narrow field-of-view of approximately 12 degrees, making it possible to distinguish the finer structures in the D-region. This type of riometers are much more expensive to build, and they are also prone to harsh weather conditions, hence maintenance of the system is very important.

A general overview of riometer systems can be seen in Figure 2.2.

## 2.3 Instruments

### 2.3.1 AIRIS

AIRIS has been operational since 2006, and consists of a number of antennas organised in an array, used to measure the amount of electromagnetic wave ionospheric absorption along with other applications. AIRIS is located at Saura in Andøya, and contains a phased array antenna, producing 49 narrow beams with a 12-degree width of each beam. This allows for investigation of a wide variety of lower ionospheric phenomena such as ionospheric scintillations, auroral absorption, absorption and scintillations induced artificially and structure and dynamics of energetic particle precipitation.

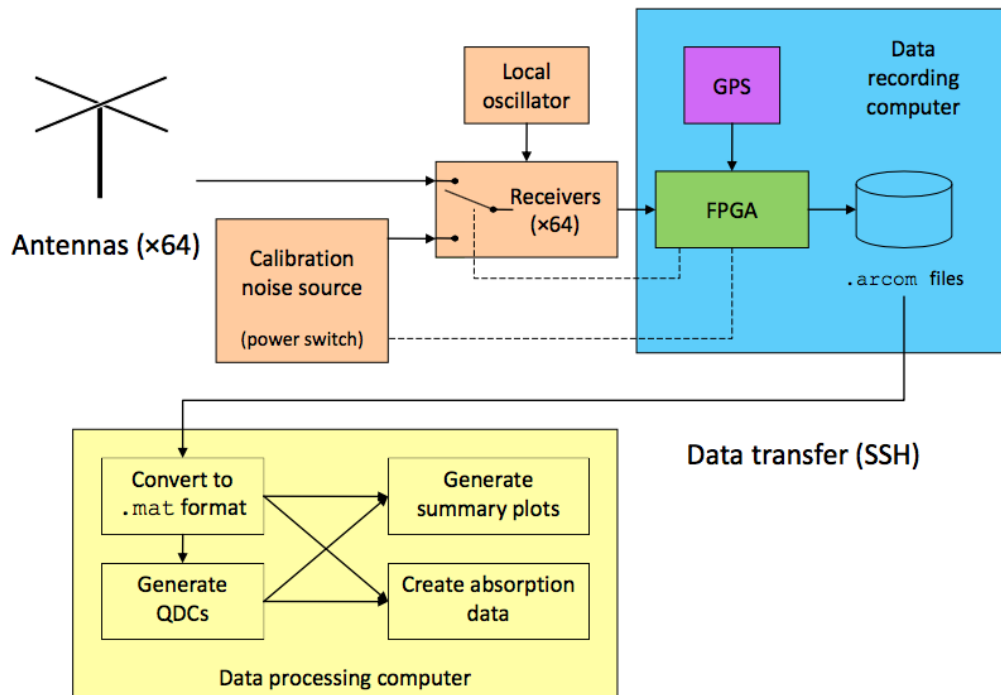


Figure 2.2: Riometer Overview (Photo by: Steve Marple)

Specifications of the AIRIS system are provided here following:

- 38.2 MHz, BW: 250 kHz, Sens: 0.05 dB
- 64 (8x8) crossed dipoles, filled array
- 49 narrow beams, 12 degrees Band Width
- Spatial resolution: 20 km at 90 km altitude
- Sampling rate: 1 second
- Digital Rx and beam Shaping FPGA
- Fixed circular polarization
- 45 degrees antenna angle to minimize mutual coupling

The field covered by AIRIS is shown in figure 2.3

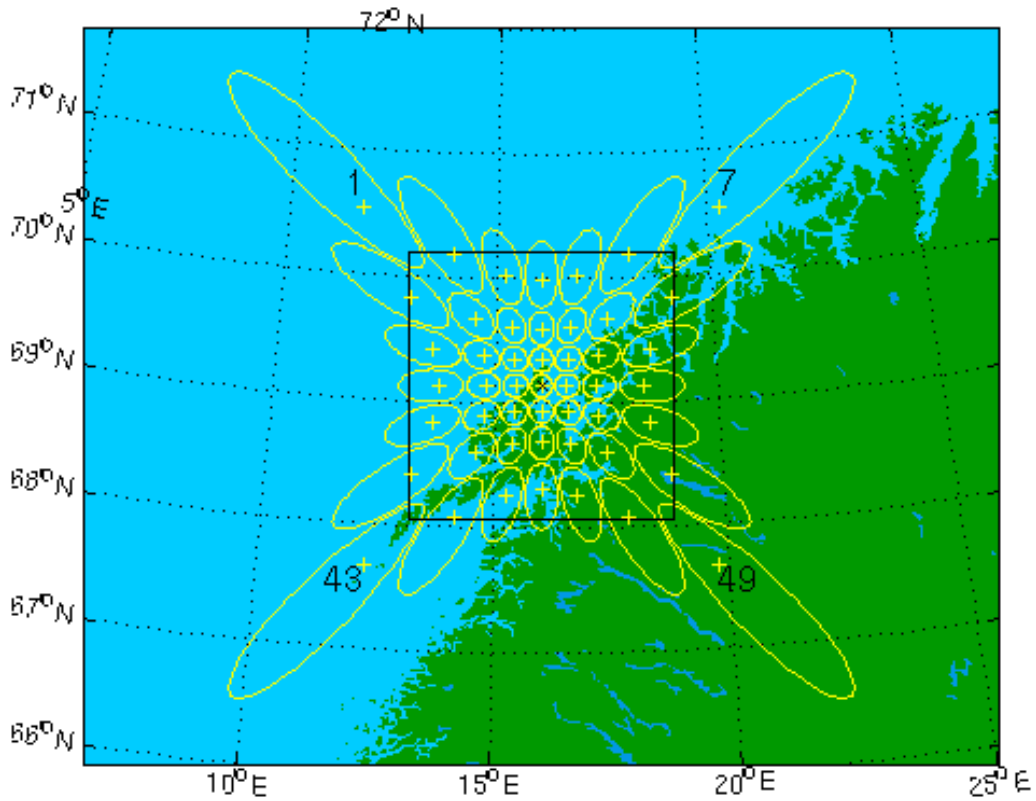


Figure 2.3: Figure showing the area which AIRIS covers (Photo by: Steve Marple)

AIRIS operates in the 38.2 MHz frequency band. The 64 crossed dipoles make it possible to use Butler matrices<sup>1</sup> in order to form the 49 independent beams, and it allows for achieving phasing. Furthermore, the riometer electronic hardware has 64 receiver modules, a source for calibration of noise and an oscillator. Additionally, there are 12 power supplies for the riometer electronics, a computer which records data, and a power supply that cannot be interrupted. All this is located in a small hut next to the riometer antennas at Saura, as demonstrated in Figure 2.4.

### 2.3.2 Riometer Software

The software used to obtain data from AIRIS is based on MatLab. A toolbox specific for riometer systems has been developed [2] by Dr. Steve Marple, allowing for manipulations of, and creation of, Quiet-Day curves (QDCs). Additionally, it is possible to create absorption data, power output, keograms and even short movies that shows events occurring in the ionosphere. In this thesis, the focus will be on

<sup>1</sup>A type of beam-forming network, capable of implementing a set of  $n \times n$  beams [9]

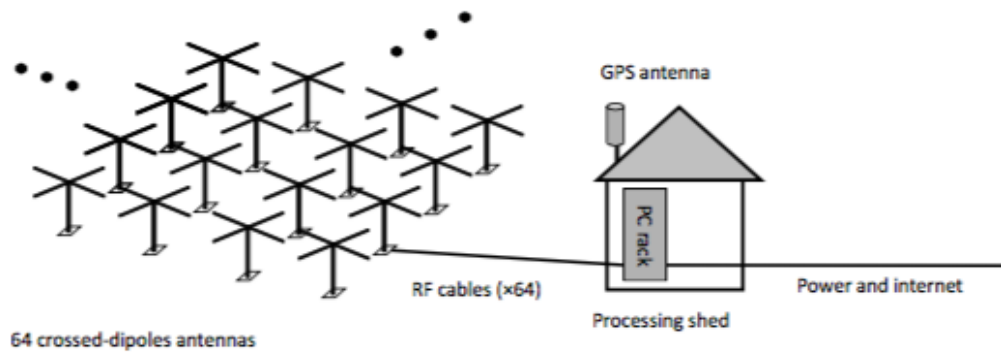


Figure 2.4: AIRIS installation overview (Photo by: Steve Marple)

absorption data, however in order to create absorption data one must first create a QDC for the period of interest. Some specifications of the software I have used are provided here following;

- Matlab version 6.5.1
- Toolbox name: MIA
- Operative system: Ubuntu

MIA (Multi-Instrument Analysis) is a Matlab toolbox written specifically for the analysis of riometer data.

## 2.4 Magnetometer

A magnetometer is an instrument that can measure variations in the Earth magnetic field, and was invented in 1833 by Carl Fredrich Gauss. The Earth magnetic field may be considered in terms of vector quantities both for strength and direction, which the magnetometer is capable of measuring. Through measuring the strength and direction of the Earth magnetic field, it is possible to detect auroral events, but it is also useful in identifying other events such as Coronal Mass Ejections (CME's), substorms and other anomalies.

The Andenes magnetometer is located at  $69.3^\circ$  N and  $16.03^\circ$  E. It has a resolution of 1 second, and measures the Z (vertical component), H (magnetic meridian component) and D (declination, perpendicular to H) components [15].

In this thesis, the Andenes magnetometer will be used as a reference for solar activity, and magnetometer data is obtained from the Tromsø Geophysical Obser-



vatory (TGO) webpage [18]. This is an open source page where it is possible for anyone to investigate magnetometer data for any period of interest, but also for numerous magnetometers around the world.



# Chapter 3

## Theory

In this chapter I will present relevant theory regarding the riometer, absorption and the atmosphere. To understand the principles of riometry, it is important to know what in the atmosphere it is measuring, and where the absorption comes from. In many cases, the riometer is based on fairly straight forward equations, however in order to get there, absorption processes must also be understood. Additionally, ionospheric processes are involved, which must also be considered, along with cosmic ray absorption and a CNA's effect on the ionosphere. Therefore, this chapter will present the necessary theory that provides the basis for absorption and riometry.

## 3.1 Riometer Theory

### 3.1.1 The Riometer Principle

As mentioned in the previous section, riometer absorption is the signal loss relative to the quiet diurnal variation of the received extra-terrestrial radio noise.

In short, what the riometer investigates is the excess absorption at a given time in the ionosphere. The excess absorption ( $L_r$ ) is a result of absorption of cosmic radio noise (CRN), where sources of CRN may include distant stars, which is then compared to a calibration curve (QDC), relative to a quiet ionosphere. The term "quiet" may be somewhat misleading in this context, as it actually refers to the baseline level of radio noise. The riometer is used to measure the absorption of sudden variations from this baseline level of radio noise. Since the invention of riometers, the most common frequencies that riometers measure in, varies from 20 to 50MHz. The advantage of measuring in this range is that the frequency will never be completely reflected by the ionosphere. AIRIS are measuring at a frequency of 38.2MHz. Furthermore, it is worth noting that radio wave absorption is approximately proportional to electron density  $N_e$  and electron-neutral collision frequency  $\mu$  (as demonstrated in equation 3.5). This in turn is proportional to pressure  $p$ .

### 3.1.2 Uncertainties and effects of snow

One of the most common uses of the riometer is in the production of quiet-day curves (QDCs). Each riometer has its own specific QDC, dependent on its location and latitude. However, even though the production of QDC is well established, it is important to note that it has an associated uncertainty of about 0.1 dB. If there are absorption measurements in the atmosphere smaller than this threshold value, it may lead to missing measurements in the data. It is also commonly agreed that one should dismiss data below 0.07 dB, as they may be misrepresentative of the true absorption.

According to Mike C. Rose et al. [14] snow affects a riometer system. They found that as antennas get buried by snow, their signal level will increase about 1/64 (the number of antennas buried in snow, in this case 1 of the total 64 antennas) of approximately 9 dB. However, this effect will depend on the location of the system and the amount of annual snowfall. AIRIS is located above the arctic circle, and so will experience snowfall in the winter season. However, AIRIS is constructed to

minimise these effects, and the antennas are using a technology that may mitigate this effect drastically. Rather than having the traditional solid antenna structure like IRIS, AIRIS antennas are based on an array of connected wires that also work as antennas, which are drastically less susceptible to harsh weather condition (see figure 3.1). This is not to say that AIRIS feels no effect of the climate, but rather that considerations were taken during the construction of AIRIS in order to avoid such problems. It is also worth mentioning that although these types of antennas may reduce effects of snow and wind, it still introduces a need for maintenance. The wires needs to be tightened on a regular basis, and failure to do so may result in data quality being reduced.



Figure 3.1: Figure showing AIRIS antenna technology (Photo by: I. M. Larsen)

### 3.1.3 Cosmic Noise Absorption and Power

The riometer measures absorption, and the goal of the following section is to obtain equations that a practical system uses to measure absorption. However, the process in which to obtain such equations is long and requires a lot of background information. Although the principal riometer equation may be fairly straight forward, measuring and understanding absorption contains a lot of factors that needs to be evaluated. Part of the mathematical aspects included here are outside of the scope

of this thesis, hence it relies on previously obtained and documented results (in particular Equation 3.6).

Neglecting any effects due to the Earth's magnetic field, auroral absorption yield a result depending on frequency as;

$$A(\text{dB}) = \frac{1}{f^2} \quad (3.1)$$

When a radio wave is travelling through the ionosphere, the absorption effects may be found by the following expression (in units of dB);

$$A(\text{dB}) = 10 \log_{10}\left(\frac{P_0}{P}\right) \quad (3.2)$$

Here,  $P$  is the signal power received and  $P_0$  is the power received if no ionosphere is present. It is expected that if there is no absorption, the receiver noise power should stay constant over successive days, therefore, if there is any variation in received power, this may be attributed to absorption. This concept is also the basis for the creation of QDCs.

It is worth noting that the amplitude of radio waves propagating through the ionosphere can be found by the following relation, which also introduces the absorption coefficient  $\kappa$ ;

$$E = E^* \exp\left(-\int \kappa ds\right) \quad (3.3)$$

$E^*$  is the amplitude of the incident wave,  $E$  is the amplitude of received wave, and  $ds$  is the path length. The integration is taken for the distance between the source and the receiver. The absorption coefficient is defined as

$$\kappa(\text{m}^{-1}) = \frac{q^2}{2\epsilon_0 m_e c} \frac{1}{\mu} \frac{N_e \nu}{\nu^2 + (\omega \pm \omega_L)^2} \quad (3.4)$$

For simplicity, the different symbols are listed here following



- $N_e$  is the electron number density
- $q$  is the electron charge
- $m_e$  is the electron mass
- $c$  is the speed of light
- $\epsilon_0$  is the permittivity of free space
- $\mu$  is the refractive index of the medium
- $\nu$  is the electron collision frequency
- $\omega$  is the radio wave angular frequency
- $\omega_L$  is the component of the gyro frequency vector, in the direction of propagation

If we now combine equations 3.2, 3.3 and 3.4, it is possible to rewrite the equation for absorption 3.2, which yields the following result;

$$\frac{A}{dB} = 4.58x10^{-5} \int \frac{1}{\mu} \frac{N}{m^3} \frac{\nu/s}{\nu^2 + (\omega \pm \omega_L)^2} \frac{ds}{m} \quad (3.5)$$

From this results it is possible to draw a few conclusions. In the case where frequencies penetrating the ionosphere are greatly above the critical frequency (see 3.4),  $\mu$  may be set to unity due to absorption being non-deviative. Additionally, riometers usually operate in frequency range between 20-50 MHz, therefore it is possible to neglect  $\omega_L$ , especially when it is compared to  $\omega$ .

Equation 3.5 shows that absorption is dependent on both the electron number density  $N$  and the electron collision frequency  $\nu$ . However, to improve the absorption calculations when it comes to the effects of collision frequency with velocity, one must consider the generalised magneto-electron theory [12]. This is considered for the lower ionosphere, where absorption may be non-deviative and  $\omega \gg \omega_L$ , leading to a rewritten absorption coefficient  $\kappa$ ;

$$\kappa = \frac{5q^2 N_e}{4\epsilon_0 m_e c \omega} \alpha C_{5/2}(\alpha) \quad (3.6)$$

- $\alpha$  is representing the ratio  $(\omega/\hat{\mu})$
- $C_{5/2}(\alpha)$  is a type of integral from semi-conductor theory [13]

$\hat{\nu}$  is associated with the Maxwell-Boltzmann distribution, and is the collision frequency for electrons at the peak of this distribution. Keep in mind that the energy  $kT$  is associated with Maxwell-Boltzmann distribution. It is now possible to again rewrite the equation for absorption;

$$A(dB) = \frac{1.149 \times 10^5}{\omega/s^{-3}} \int \frac{N_e}{m^{-3}} \alpha C_{5/2}(\alpha) \frac{ds}{m} \quad (3.7)$$

Based on these results, we now have 3 equations that measures absorption, namely Equation 3.2, 3.5 and 3.7. These equations for the important theoretical basis for measuring absorption in the atmosphere.

## 3.2 The Atmosphere

Around planets of sufficient mass, one may find an atmosphere. An atmosphere consists of various gases that surrounds the planet, and it is held in place by gravitation. The atmosphere around Earth is divided into several layers, usually based on temperature and composition. The main two constituents of the atmosphere is nitrogen (approximately 78%) and oxygen (approximately 21%) [16]. Some of the other components are carbon dioxide, argon, methane and water vapour. Through use of rocket technology, it has been discovered that the amount of the different types of gases in the atmosphere remain more or less constant up until 100 km. This is a result of turbulence in the atmosphere below 100 km, mixing large volumes in a bulk motion, causing the composition to remain approximately constant [17]. As seen in Figure 3.2, the atmosphere can be divided into several layers. The Troposphere is in 0-10 km altitude, Stratosphere in the 10-50km altitude, Mesosphere in the 50-100km altitude and Thermosphere in the 100-1000km altitude. Above this, we find the exosphere.

The mesosphere is of particular interest for riometer work, as the lower ionosphere exist in this region and the riometer measures in this region as well. The mesopause is a boundary layer that tends to vary with season, being as low as 85 km altitude in summer to approximately 100 km during winter. An interesting feature of the mesosphere is the temperature. Temperature decreases with height as a

result of decreased heating, but also due to cooling by the  $CO_2$  radiative emission. The mesopause at the top of the mesosphere is also the coldest region of the atmosphere, and temperatures here may reach as low as 173 K, however this may vary depending on season and latitude. The riometer measures at 90km altitude, which means that it measures at the top of the mesosphere and in the lower ionosphere, also known as the ionospheric D-region.

### 3.3 The Ionosphere

A rather ambiguous definition of the ionosphere is that it is the part of the atmosphere where propagation of radio waves is affected. However, going into more detail it is easily found that it is a highly complex region of the atmosphere, consisting of several regions each with many variable parameters. The layers have been divided according to the difference in electron density and altitude (D-, E and F-layer) as well as the composition and the physical properties of the recombination. Furthermore, it may also be understood by considering the ionisation of molecules, with the simple equation (1) displayed, where A is any molecule and  $hf$  is a photon. Generally, the further down into the atmosphere you enter, the more particles exists, however there are fewer photons with high enough energy to cause ionisation.



This thesis will focus on the lowest region of the ionosphere, namely the D-region, located in the mesosphere. It is in the altitude range of about 50-90 km, and it is possibly the least monitored ionospheric layer (together with the  $F_2$  region). Additionally, at night it almost disappears in the lower regions (even though incident galactic rays are always present), but during the day it has an average electron density of about  $10^8 - 10^{11} e/m^3$ . The D-layer is also highly correlated with extremely energetic radiation, X-ray photons from the sun and cosmic-ray particles. The reason why the D-region is of particular interest, is due to its use in commercial communication. The D-region governs many parameters that reflects the radio-waves, and makes cross Atlantic communication possible. Despite this, the D-region is poorly understood because the processes involved are extremely complex (Kivelson et. al. 1995 [4]).

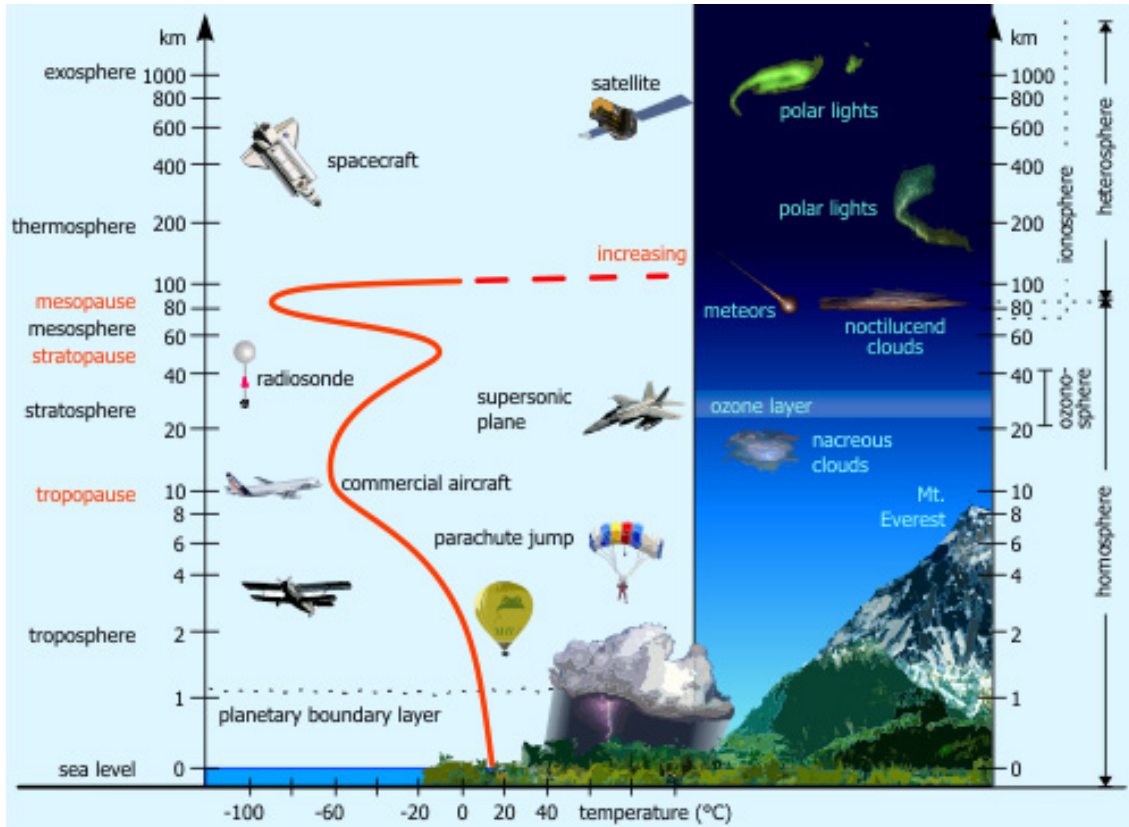


Figure 3.2: The atmospheric structure (Photo by: The ozone hole [19])

The D-region is located in the mesosphere, as seen in Figure 3.2. Some important properties to note about this region, is the change in temperature, it is part of the homosphere and continuity equation (Equation (2)) is the basic equation that governs the energy transfer processes occurring. First of all, the temperature has a drastic decrease from  $\approx 0 - (-90)^\circ\text{C}$  with altitude, until it starts increasing again at the mesopause. Secondly, the mesosphere is part of the homosphere, and this means that particle motion and turbulence mix the atmosphere, and the composition is more or less constant up until the turbo-pause. In other words, the hydrostatic equilibrium is defined by the molecular mass. Finally, the continuity equation governs the processes that occur. The continuity equation consists of a production term, loss term and a transport term, however the transport term is usually neglected in the lower ionosphere as it is not vitally dependent on the photochemical regime but rather described by Chapman layers.

Another important aspect of the D-region is the occurrence of NLCs (about 50-80 km altitude), auroras and meteors entering the atmosphere (above 80 km). This thesis will focus on the aurora, hence the upper D-region will be the main interest area. Auroras may be monitored through utilising the riometer, therefore

this thesis will investigate auroral effects upon absorption.

$$\frac{\delta N}{\delta t} = q - l(n) - \nabla \cdot (\vec{N} \vec{V}) \quad (3.9)$$

### 3.4 Cosmic Radio Noise

The Riometer measures radio noise which has extraterrestrial origin. Cosmic radio noise (CRN) is constantly incident upon the atmosphere and on the ionosphere, and it covers a wide range of frequencies. However, ground based instruments are not always detecting this radio noise, as the radio noise need to have frquencies above the F-region ionospheric critical frequency before entering the ionosphere [10]. If the radio noise frequency is lower than the critical frequency, the radio noise is reflected back into space.

Sources of CRN are both galactic and intergalactic. A big contributor of noise is our galaxy, however other sources of radio noise also encompasses the sun, distant stars and planets. It is worth mentioning however, that some of these sources may only be detected by using high-resolution radio telescopes. The sun is a contributor in that during major solar events, it may dominate the radio noise source, and this is utilised with the riometer. The riometer is able to detect major solar events such as auroral absorption, which is why it is important to make sure that the AIRIS is fully operational, due to its location in the auroral zone. It is important to monitor these absorption events as it may effect High Frequency (HF) and Very High Frequency (VHF) systems, causing "blackouts", but also as it may interrupt communication systems that operates in the 2-10 MHz frequency range [11].

The cosmic radio noise power measured with a fixed receiving system at any sidereal time, would yield a constant result when no absorption is present in the atmosphere. This means that as an instrument is measuring the absorption, the strength of the absorption measured should be a good indicator of the absorption produced by the ionosphere [12]. It is worth noting, however, that absorption of ionospheric origin, is small compared to extra-terrestrial sources. Therefore, it is usually neglected.





# Chapter 4

## Method, data and processing

The absorption data provided in this thesis is processed and analysed by the author. Included is riometer data from before, during and after the AIRIS upgrade. Additionally, temperature and power data is included, which was provided by Kolbjørn Blix Dahle. Magnetometer data was obtained from Tromsø Geophysical Observatory (TGO), by using their open source magnetometer data base.

The program used in this thesis for processing the data is written by Dr. Steven Marple of Lancaster University and myself, with help from Dr. Mat Beharrell of Lancaster University. The program is used for creating QDC data, which is a requirement for processing absorption data. Even though QDC data is not directly used in this thesis, a section which describes QDC data is included along with example absorption data.

In the method section, a brief walkthrough of the upgrades performed is included.

## 4.1 Method

Figure 3.1 shows the riometer antennas. Each antenna is attached to a box in which wiring from the antenna is connected to a coaxial cable, as displayed in the left Figure 4.1. The coaxial cable from each antenna then leads to the receiver rack (right Figure 4.1), and then to the hardware hut where the data is eventually sent to the riometer computer. The first step in the riometer maintenance was to go over each single antenna box and check the wiring. Each wire has been oiled and tightened, as well as the box being checked for any points that may cause water leakage into the wiring. It is worth mentioning that the wiring used in the riometer is adapted for harsh weather conditions, but the connections still need to be protected from rain and snow.



Figure 4.1: Figures showing the antenna box attached to each riometer antenna and the receiver rack in the riometer hut (Photo by: I. M. Larsen)

Once the wiring in the 64 antenna boxes had been checked, the riometer computer received a hard-disk upgrade. This was required as the riometer computer is of an older version that require more space for storage of data. The old temperature system was turned off in October of 2015, yet the installation of the new temperature system suffered an unexpected delay. Figure 4.2 shows the old temperature control system (bottom white box) and the new air-condition system (top white box). The temperature systems are connected to a temperature sensor which monitors the temperature in the riometer hut. Based on the temperature measured by this sensor, the new air-condition unit is set-up to maintain a constant temperature



Figure 4.2: The old and the new temperature systems in the riometer hut (Photo by: I. M. Larsen)

in the hut of around  $20^{\circ}\text{C}$ , and several tests has later been performed in orther to investigate the effect of the new air-condition upon the riometer data and the results are presented in the reulsts section

After the installation of the new temperature control system, it became evident that testing with a UPS was required. The UPS works as a small back-up generator that may provide electricity to a system even if there are a surge in electricity or a black-out. Both the riometer and the riometer computer is now connected to the UPS to prevent future surges or black-outs having any effect on the riometer. Additional tests has also been performed regarding various temperature settings in the riometer hut.

## 4.2 Processing the data

In this section I will focus on how to process riometer data, and how to obtain absorption data from a QDC. Although the file-format in which imaging riometers record and operate in is ARCOM (Advanced Riometer Components), the riometer data is stored in a streaming format, which comprises of packets that also potentially includes descriptors.

The data may then be processed by using a special toolbox in Matlab called MIA (Multi-Instrument Analysis). In MIA, there are two options for processing. The GUI (Graphical User Interface) can be used when processing smaller datasets, however, it also requires that the data desired is already pre-processed. This is a drawback that may interfere with creating more recent QDC's and Absorption spectra. The second option is to use scripts and program directly in Matlab. This is the approach used in this thesis, as it allows for large datasets to be analysed, as well as actually creating QDC's manually without needing authorisation from the Spears-Joule group in Lancaster. Furthermore, processing data directly in Matlab also allows more more freedom regarding desired parameters such as resolutions, start- and end-time, beam selection, and even exclusion of specific time periods.

I have created data by using MIA and running the script written for creating QDC's. Provided below are some code snippets taken into specific consideration, showing how I have used it in processing the data. Note that it is also possible to process data by entering these codes directly into MIA, however, MIA will then assume certain parameters such as only considering one particular beam or automatically exclude certain data such as NaNs (when no data is available). Note that in order to create absorption data, one must first create QDC's from raw data in the riometer database.

First of all, it is important to select which date the QDC (and successively absorption data) should be available for. An example is provided here following, and the entire script may be seen in Appendices .1.

```
% Nominal start time for which QDC is valid
t = timestamp([2015 08 07 0 0 0]);
% Starttime of data used to make QDC
st = t - timespan(2, 'd')
% End of data used to make QDC
et = t + timespan(16, 'd');
```

It is also important to select which riometer to use. MIA is global tool, and can thus create data for several riometers from across the world. The riometer under consideration is AIRIS, which has the associated name *rio\_and\_2*. In comparison, it would for example also be possible to select the riometer in Kilpisjarvi by instead using the code *rio\_kil\_1*. It is possible to select a specific instrument by implementing the following code, as the riometers has specific names associated with their location, and then assigning it to *rio* as demonstrated.

```
% Select riometer; "rio_and_2" for AIRIS
% "rio_kil_1" for IRIS
rio = rio_and_2;
```

As the antennas are arranged in an  $n \times n$  array and each beam is directed at a slightly different point in the atmosphere, it is desirable to select specific beams to find the absorption at that point. Due to the angle at which the beams are pointing, beam 1, 7, 43 and 49 are usually ignored owing to the high spatial uncertainties associated with these beams (see Figure 2.3). The following code options are used to either choose all beams, or just a single beam;

```
% beams to make QDC for (all beams)
beams = info(rio, 'allbeams');
beamsatonce = numel(beams); % All at once

% beams to make QDC for (specific beams)
% beams = info(rio, [1, 25, 30]);
% beamsatonce = numel(beams);
```

It is also possible to select output rows. This means that it is possible to select values to use, for example selecting the mean of the 3rd and 4th highest value at any given sidereal time, for the upper envelope of the QDC. This may be changed by entering other numbers in the following code snippet (for example, set [1 2] instead of [4 5]).

```
outputrows = [4 5];
```

Before it is possible to create the absorption data, it is desirable to check the QDC's for each beam to make sure that the data looks reliable. This is done directly

in Matlab, once the script has finished processing. This is done by simply running the code *checkqdc*, and include parameters such as the riometer desired, the time period specified in the script and finally the location of this data. It is highly beneficial to include a human inspection rather than just an automated numerical test, since Matlab will not provide any automated information regarding the quality of the QDC.

```
checkqdc('init', 'instrument', rio, 'time', t, 'loadfilename',
'/home/spears-joule/larseni/%Y%m%d_b%Q.mat')
```

The QDC's are now created, but before it is possible to create the associated absorption data, the QDC for each antenna must be loaded into the correct function in Matlab. This is done by defining the new QDC, using the *rio\_qdc* function, and again specifying the desired parameters as follows;

```
qdc = rio_qdc('instrument', rio_and_2, 'time', t, 'filename',
'/home/spears-joule/larseni/%Y%m%d_b%Q.mat')
```

The QDC for each antenna in the time period of interest is now ready to be used for processing absorption data. Now simply call the *rio\_abs* function and use the parameters of interest. It is also possible to define specific beams, however the default beam is beam 25 which for the purpose of this thesis is sufficient. Additionally, it is possible to select any start- and endtime within the period for which the QDC is created (for example, define starttime by using *st = timestamp([2009 06 01 0 0 0])*), and one can change the resolution of the absorption spectra.

```
abs = rio_abs('instrument', rio_and_2, 'starttime',
st, 'endtime', et, 'qdc', qdc)
```

## 4.3 How to interpret the data

### 4.3.1 Interpreting QDC data

Here following is an example of a QDC for the period 14.10.2015 - 01.11.2015. It has 1s resolution, and is for beam 26 in the riometer system. The units for the QDC Power is given in dBm, or decibels relative to one millwatt (mW).

For simplicity, a list describing the meaning of the coloured lines are provided here following;

- The green lines are the calculated uncertainty in which the QDC should lie within. Any deviation from these lines may be attributed to absorption events or the system malfunctioning
- The blue line is the calculated standard QDC for a 14 day period
- The red line is the particular variation in the QDC power for this particular period (for which the time is also provided at the top)

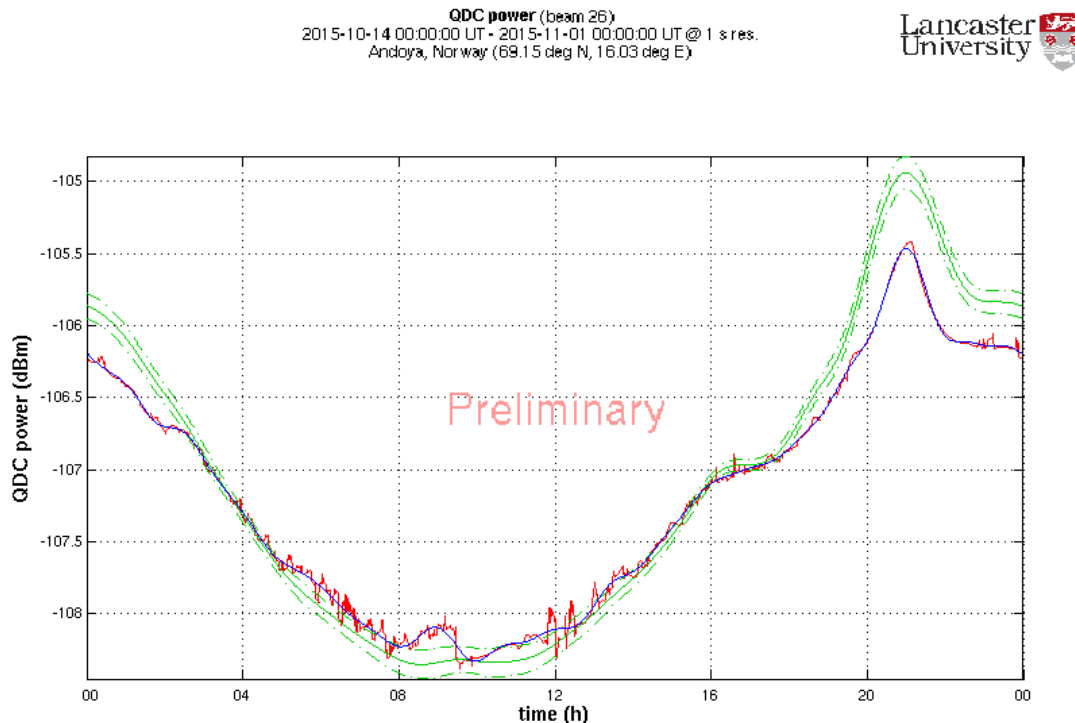


Figure 4.3: Example of QDC-Power output

### 4.3.2 Interpreting Absorption data

An example of an absorption spectra is given in Figure 4.4. The data is for 01.11.2015, with 30s resolution and for beam 18. As the name indicates, absorption spectra is a relative measure of the ionospheric absorption of signal in the atmosphere. The absorption spectra may display the respons to many different events, however it is displayed differently depending on what type of event it is. Looking at this absorption data, it has the potential of being 3 different types of event, however by for example analysing the accompanying QDC, it is possible to identify the particular event.

The event seen (in the small highlighted box) is potentially a Sudden Ionospheric Disturbance, lightning or Solar Radio Emission.

**Sudden Ionospheric Disturbance** is intense ionisation caused by hard X-rays that enters the atmosphere, and the absorption plot will usually display an event of sudden drop in absorption immediately followed by high absorption.

**Lightning** looks very similar to Solar Radio Emission, and is seen as a very short, sharp spike in the data. It can be compared to a QDC plot in order to confirm this (also seen as a small sharp spike), and also weather forecast history.

**Solar Radio Emission** is a result of powerful radio emissions from the Sun. In absorption data, it is seen as largely negative spikes, due to the received power in solar radio emission. This can be compared to a keogram in order to confirm this, where it will be seen as dark blue stripes. Furthermore, solar radio emissions are only seen during the day on absorption spectra. Therefore, in the example absorption spectra provided, what we see is most likely a solar radio emission event in the large yellow highlighted event. The small yellow highlighted box is likely a sudden ionospheric disturbance, however this can be further confirmed by checking the American Association of Variable Star Observers database, which has an overview of all SIDs.

Figure 4.5 shows an example of a keogram. An important difference between absorption spectra and keogram is the fact that keograms display absorption events that spans over several beams, whereas absorption spectra only shows data for a particular beam. In the keogram, one can easily distinguish regions of enhanced absorption. Blue signifies that there are little or no absorption, whereas green towards red signifies that there is an absorption event occurring.



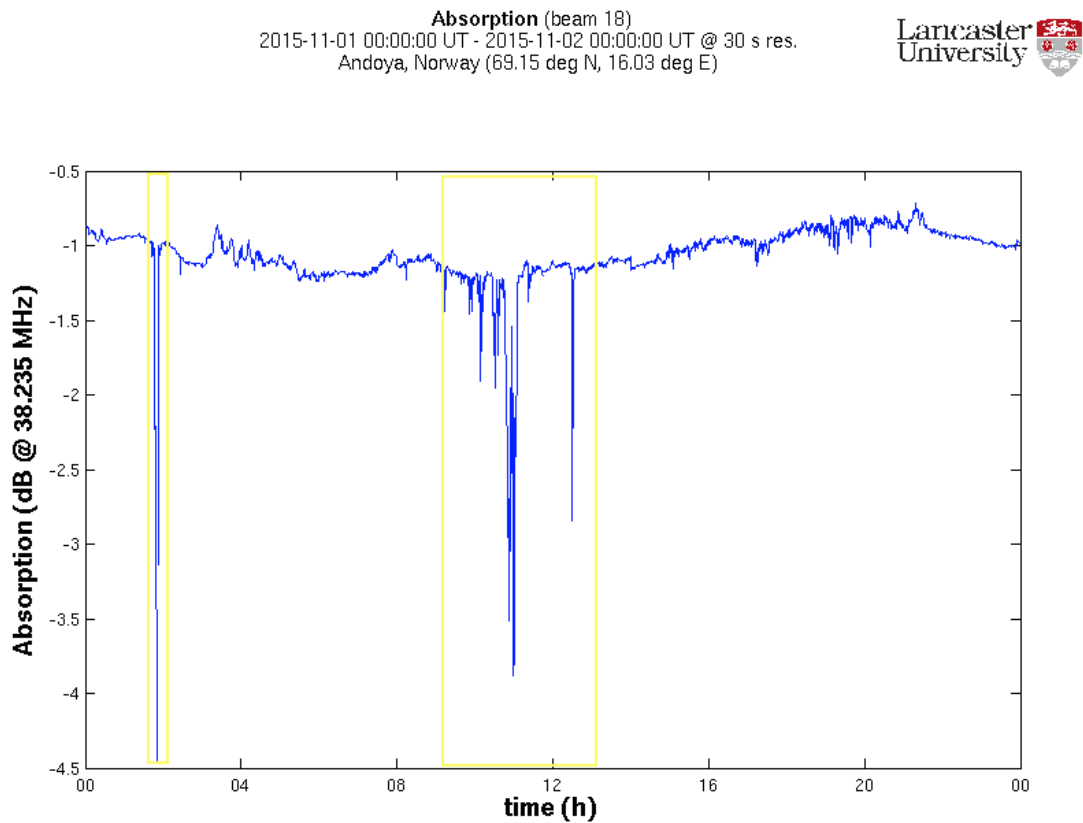


Figure 4.4: Example of Absorption spectra with highlighted events

### 4.3.3 Magnetometer data

Figure 4.6 shows an example of magnetometer data. Magnetometer data is used to detect variations in the Earth magnetic field as a result of incoming solar wind. For the purpose of this thesis, magnetometer data is used as a reference to see if there are any auroral events that may cause absorption in the atmosphere, and subsequently should be detected by the riometer. The green line in Figure 4.6 represents the Andøya riometer.

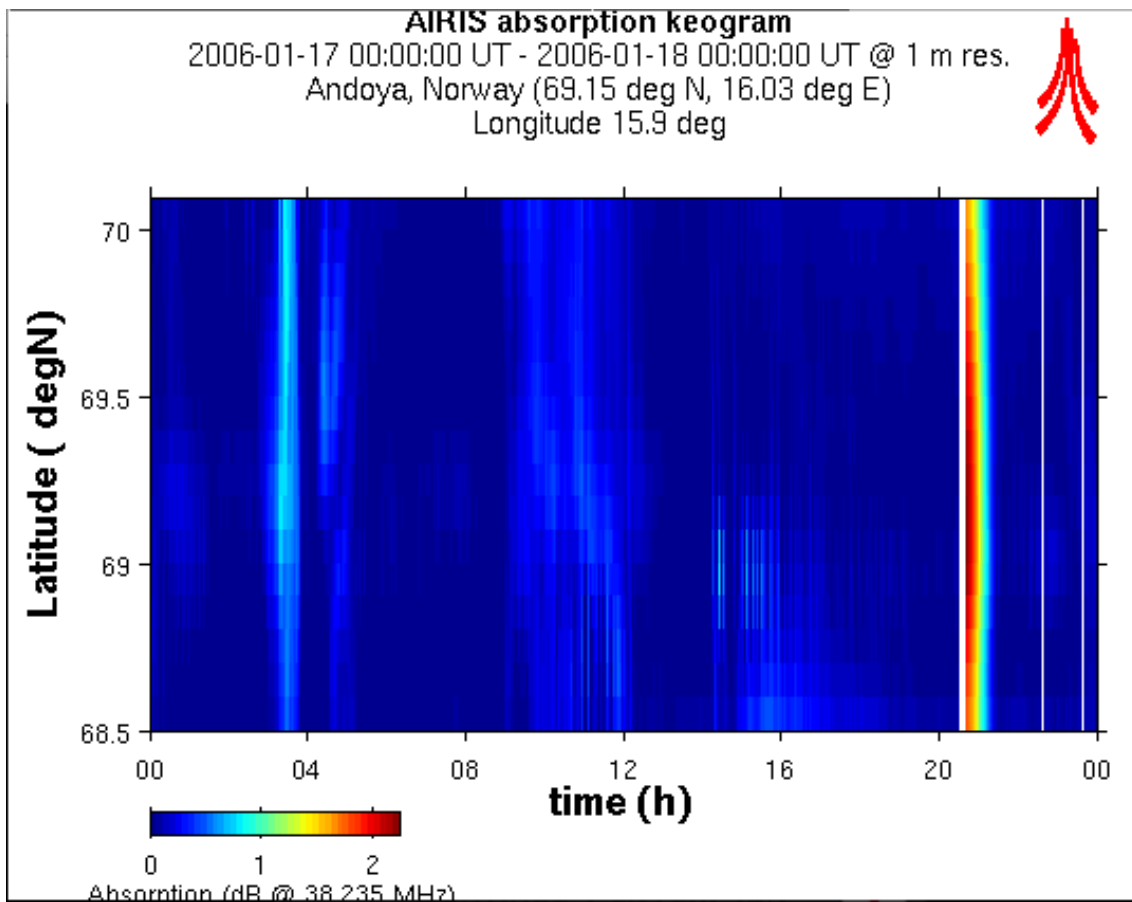


Figure 4.5: Example of keogram data

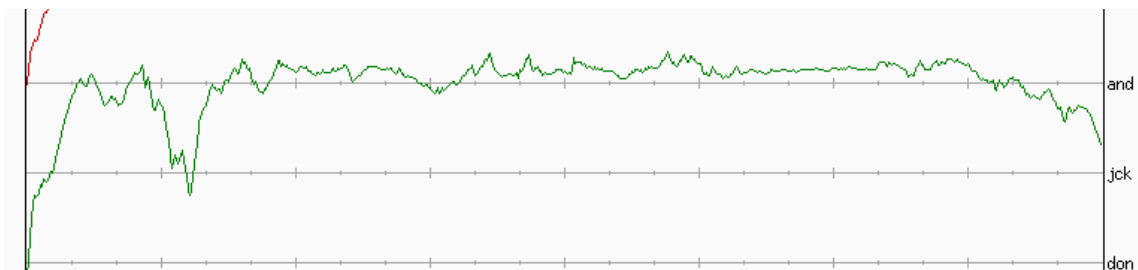


Figure 4.6: Example of magnetometer data

# Chapter 5

## Results

Presented in this section are the results of the tests performed. Data included is absorption spectra, temperature data, power data and magnetometer data.

I have not included all the data made in this thesis, but rather a few selected dates in order to illustrate how the AIRIS data used to be, how the data had deteriorated, and what it looks like now after the maintenance and upgrade.

## 5.1 Data from 01.06.2009

The year 2009 is by many considered a good year for riometer data, especially for AIRIS, as it was a year close to solar minimum. For this reason, this will be used as the ideal period for AIRIS, and also be the level of quality that is desired for AIRIS after the upgrade. It will also be used as a standard for comparison. This choice of data for comparison is not random, as through investigation this is discovered to be a quiet period and so one can infer the QDC levels that are optimal and with small associated uncertainties. The summer period is known to see less auroral activity, which is beneficial when comparing optimal noise level. Although there are some diurnal variation in riometer absorption data, for the purpose of comparison they are so small that they may be neglected.

Even though there are some absorption events occurring in the afternoon, and an auroral event occurring at about 21.00, this is a very good example of how absorption data should look (Figure 5.1). The absorption line should lie more or less constantly around 0 dB, but some minor changes are to be expected due to the sun heating the house where the hardware is located. However, this should not be more than 0.1 dB and also it should be barely noticeable. Furthermore, any absorption events, auroral events, scintillations or other events occurring, should be easily detectable, as displayed in Figure 5.1. The events occurring are easily distinguishable.

Associated temperature data for this date was not possible to obtain, as temperature measurements had not started at this point. However, it will be included for the remaining datasets. Associated power data can be seen in Figure 5.2a, and coincides well with the 2009 data, further confirming the auroral and absorption events.

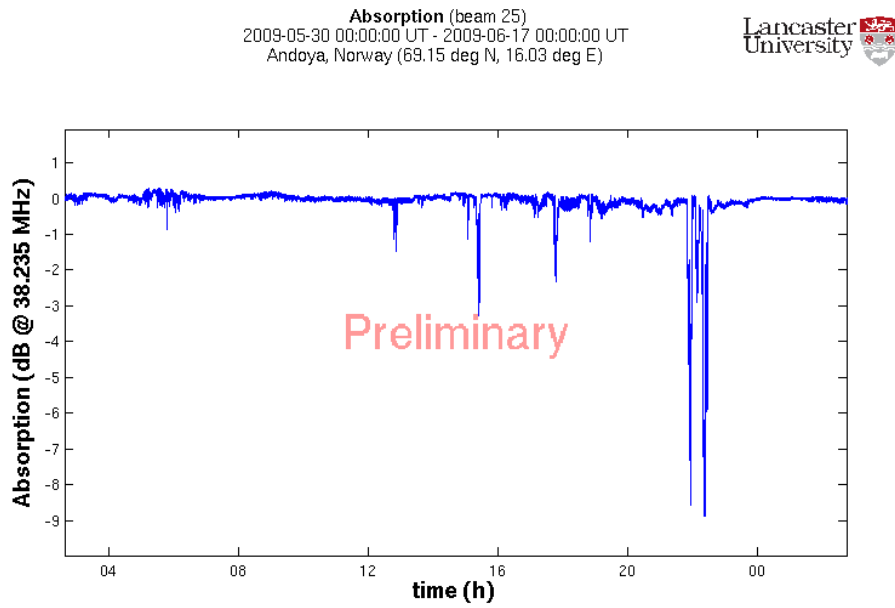
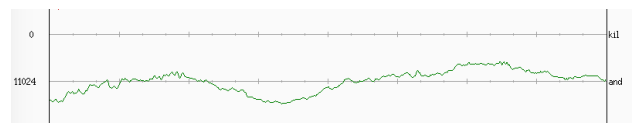
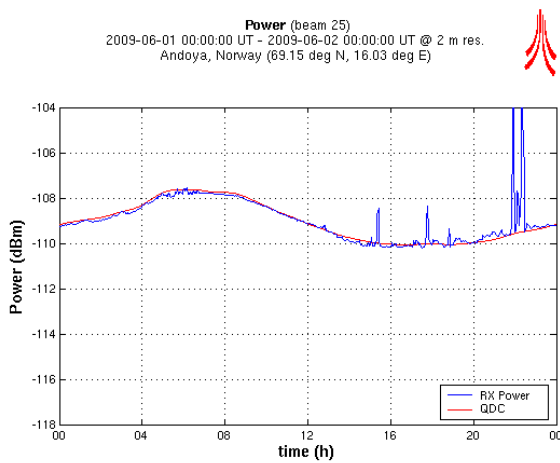


Figure 5.1: AIRIS absorption data from 01.06.2009 for beam 25



(b) Magnetometer data from 01.06.2009

(a) AIRIS power data from 01.06.2009 for beam 25

Figure 5.2

## 5.2 Data from 17.12.2015

This set of data is included to see how the system is performing after initial maintenance. At this point, every single coaxial cable in the antennas has been oiled, checked and fastened. The receiver bench has also been checked to tighten any potentially loose parts, and the riometer computer that receives and sends ARCOM data to the database has received a new hard-drive.

Contrary to the data from 2009, the data from 17<sup>th</sup> of December 2015 is looking quite variable as displayed in Figure 5.3a. There is a large absorption event occurring at 16.00 and lasting up until 22.00. This is also coinciding with magnetometer data (see Figure 5.4b in appendices), indicating that this is an auroral event. Looking at the absorption line, which should lie at about 0 dB on average when there are no events, it is clearly displayed that from 00.00 up until the absorption event starts, something is affecting the data. At this point, the old temperature control system was malfunctioning and hence may be the culprit for the variability. Especially the drop of about 0.3 dB at about 06.00, and the sudden skip at around 11.00 is of concern. When looking at the power data (Figure 5.4a), the same variability is not observed. The power data is looking smooth, and the absorption event is observed between 16.00 to 20.00.

The temperature sensor monitoring the temperature in the hut that the riometer hardware is located is also showing some variability throughout the day, seen in Figure 5.3b. Additionally, there is a major drop in temperature just before midnight, and the source of this is challenging to identify. However, there is a drop in temperature starting at 04.00 in the morning that could potentially be the cause for the drop in the absorption data at 06.00 (it takes some time for the hardware temperature to be affected by the temperature in the hut). However, it appears that the change in temperature from 00.00 to 04.00 does not affect the absorption data to any great extent, thus it is uncertain whether this is the reason for the variable absorption data. The temperature data is seen to vary with about 0.3 degrees celcius, which is an acceptable amount (excluding the sudden drop at midnight).

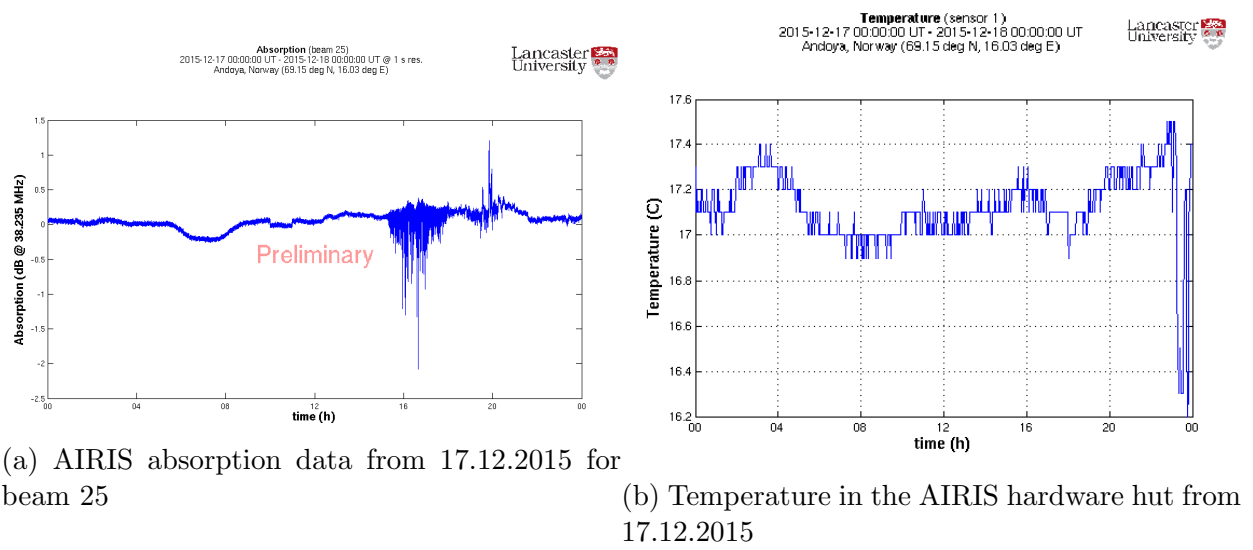


Figure 5.3

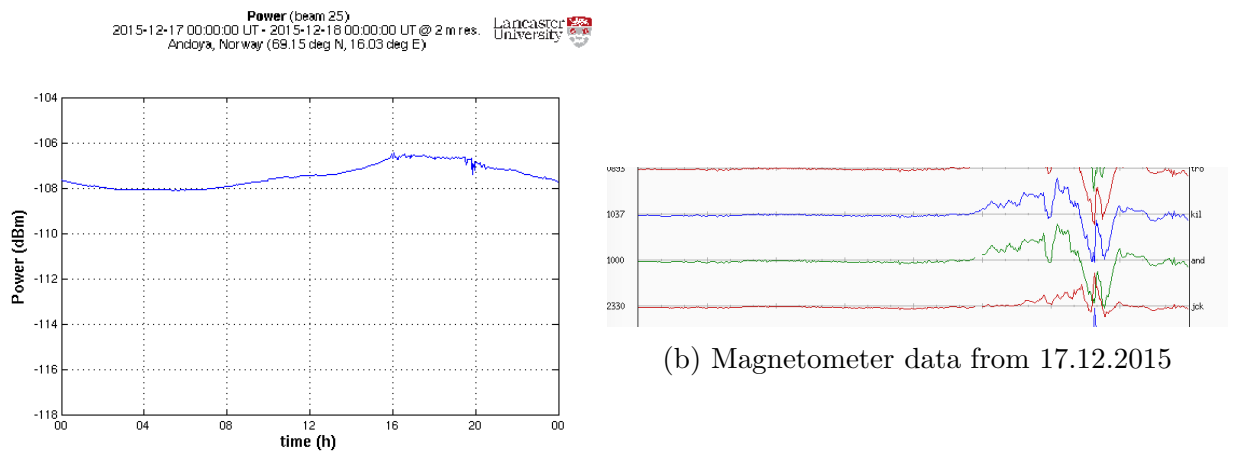


Figure 5.4

### 5.3 Data from 27.04.2016

Figure 5.5a shows absorption data shortly after the temperature system was installed and functioning. As it is very clearly demonstrating, something is affecting the riometer, and it varies with 1 dB, rendering the data useless. It is difficult to pinpoint exactly what is causing this extreme variability. One suggestion is fluctuation electricity to the system, another suggestion is noise from the new temperature control system, however it may also be temperature changes in the riometer hut. In order to understand where this is coming from, a number of tests have been performed. A demonstration of the poor quality of this data can be seen by looking at magnetometer data (see Figure 5.6b). In the afternoon continuing throughout the evening there is an auroral event that affects the magnetic field, which should also be seen in the riometer data. However, when looking at the absorption data, it is impossible to see if there is any absorption occurring at all. The same applies for the associated power data (see Figure 5.6a) which has spike events throughout most of the day. These spikes increases with close to 1 dB, which is a lot when there are no events occurring.

Looking at the temperature data 5.5b, it is evident that there is an issue with the temperature control system. A difference of 7 degrees celcius between maximum and minimum temperature in the hut is quite significant, and when comparing this to the power data 5.6a it is actually observed that the two overlap perfectly. Although the response seen in power data is delayed by a few minutes, this may be explained by the fact that the hardware components needs time to adjust to the air temperature, and it takes more time to cool down.

Furthermore, this is a very good indicator that the riometer system is extremely sensitive to temperature changes, and possibly even more sensitive than originally believed. However, a few tests to ensure this has to be performed, also to exclude (or include) the the fact that noise from the engines in the temperature system may also affect the data. Additionally, fluctuations in the main voltage may also affect the system, which can be mitigated by inserting an UPS.



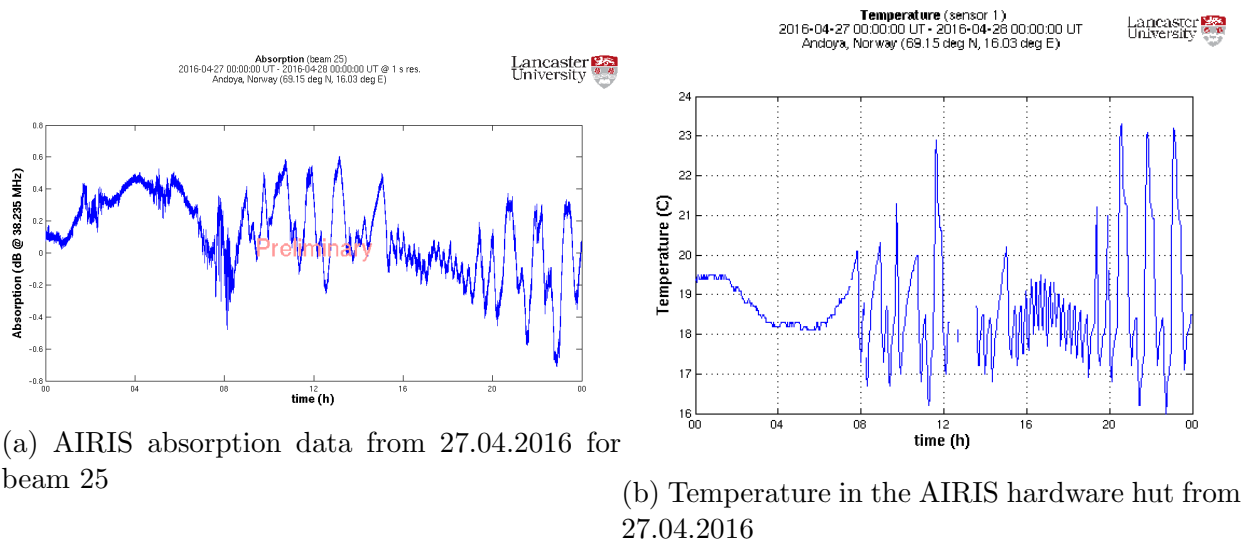


Figure 5.5

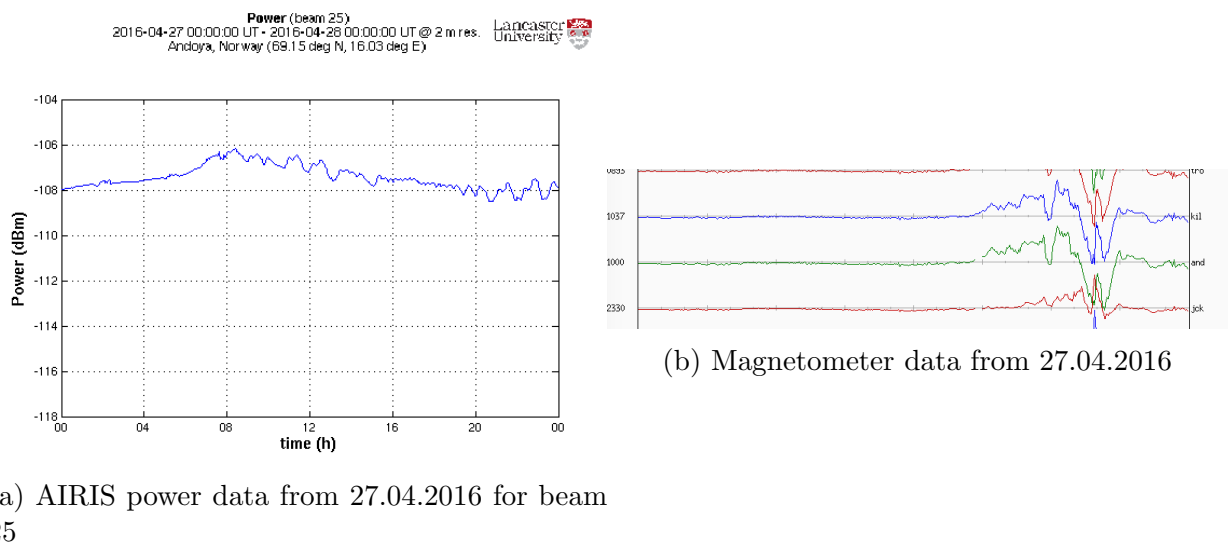


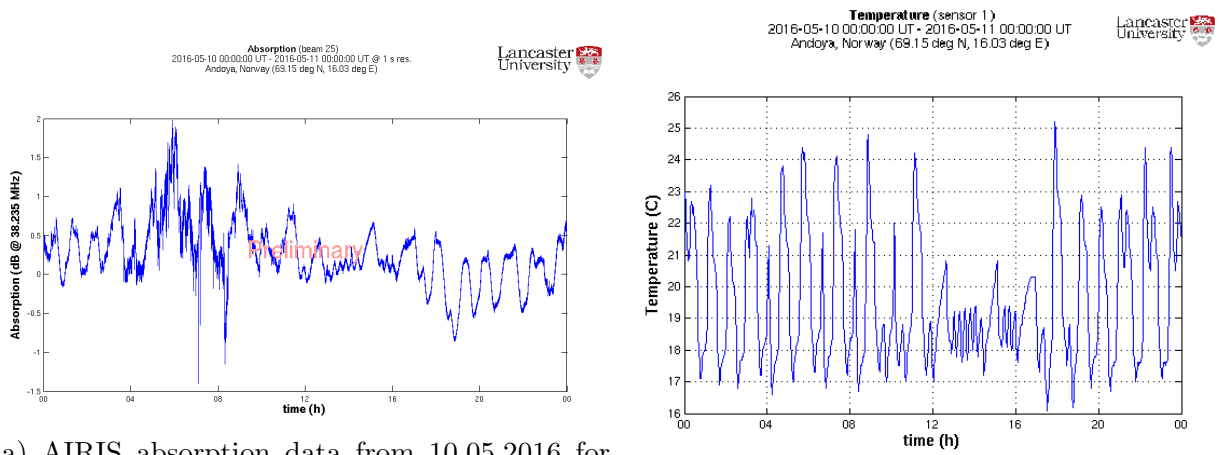
Figure 5.6

## 5.4 Data from 10.05.2016

Upon discovering that the riometer data was being worsened to such a great extent, a few means of action had to be taken. As the source of these fluctuations has to be decided, it is required to perform a few tests. The first test is to try and connect the riometer electricity to a UPS, in case it may be affected by any variations of the mains voltage when connected directly to a socket. On the 10<sup>th</sup> of May 2016, at 17.30 local time, both the riometer computer and the entire riometer system was connected to a UPS. A UPS is an uninterruptible power supply, which means that any disruption, short blackouts or variations in the national power grid will no longer have any effect upon the riometer system. The UPS also works like a small backup generator, so if there is a power cut, the riometer will still be able to run for a short while. Additionally, it was argued that the temperature control system turns itself on and off in order to try and keep a stable temperature in the hut, and due to the amount of power consumption it has this may affect the power in the hut too, which may result in fluctuations on the riometer data.

Looking at the absorption data in Figure 5.7a, it appears that the insertion of the UPS has very little, or no effect, on the variability. This excludes any fluctuations on the national power grid as a source for the variations seen in the data. However, having the system connected to a UPS is still beneficial, as the power to the riometer is now more stable and any short black outs will not affect the system.

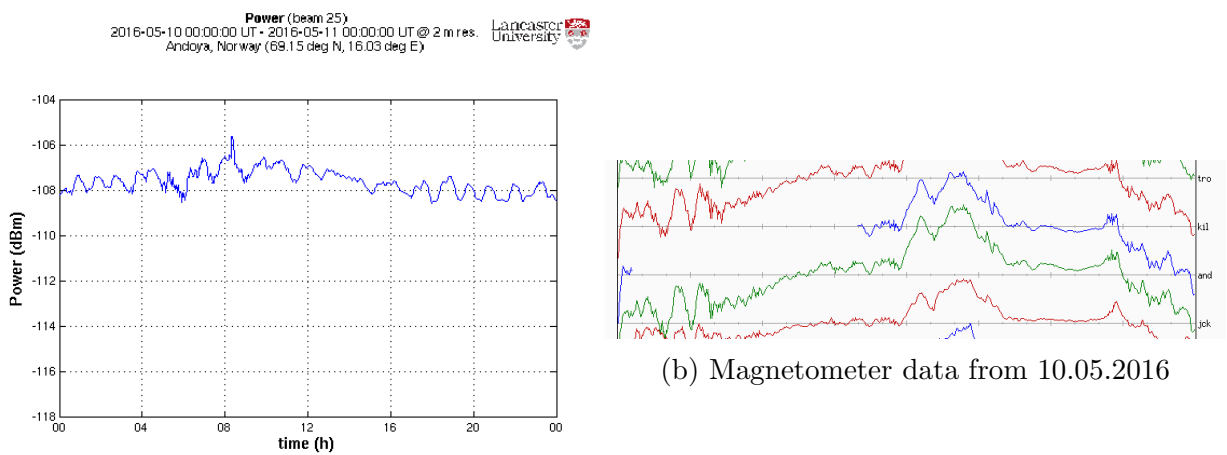
Also the temperature in Figure 5.7b shows no effect on the connection to the UPS. Between 12.00 to 16.00 there is a period with smaller variations in temperature, and this may be attributed to sun naturally warming the hut and the temperature control system therefore may work less. Still, it appears that it also go back a variation of close to 8 degrees celsius at 17.30, which coincides with the time of installation of the UPS.



(a) AIRIS absorption data from 10.05.2016 for beam 25

(b) Temperature in the AIRIS hardware hut from 10.05.2016

Figure 5.7



(a) AIRIS power data from 10.05.2016 for beam 25

(b) Magnetometer data from 10.05.2016

Figure 5.8

## 5.5 Data from 13.05.2016

Figure 5.9a shows absorption data from 12.00 on the 13<sup>th</sup> of May until 12.00 on the 14<sup>th</sup> of May. The reason for this choice of time is due to the fact that changes were made on the temperature control system on the 13<sup>th</sup> of May at 16.20, and it is beneficial to have data for a long period of time. In this case, 24 hours are enough to see the effect of turning the temperature system down to the minimum temperature possible, which is 17 degrees celsius. Additionally, it is beneficial to include data from before the temperature setting change, therefore an additional 4 hours pre temperature change is included. Furthermore, this test is a test of what happens if adjustments is made to the temperature control settings in the hut. Average temperature in the hut was set to be 21 degrees celsius, but it is desired to set the temperature to its minimum value (in this case 17 degrees celsius), hoping that the temperature control will perform more constantly and not causing such huge variations of 7 degrees celsius as observed previously.

As observed in Figure 5.9a, the absorption dropped to about -1.25 dB around 22.00, before eventually stabilising just below 0 dB in the morning of the 14<sup>th</sup>. The data is still fluctuating greatly, but it appears that it takes a few hours of adjustment before it eventually begins to stabilise after midnight. This may be due to the various hardware components being sensitive to temperature changes, and thus require time to adapt. Still, despite the data being somewhat stabilised, it is still rendered useless. This is also seen by comparing with the magnetometer data (see Figure 5.6b) which shows major activity close to midnight on the 13<sup>th</sup>, however there is no trace of this in the absorption data.

The temperature data is only obtainable on a day-by-day basis, which is slightly inconvenient for the purpose of this analysis. Still, temperature for the riometer hut up until midnight is provided in Figure 5.9b, and from midnight until 16.15 for the following day is provided in 5.11b. It appears that adjusting the temperature system to 17 degrees celsius (the minimum value for this system) causes temperature fluctuations on a smaller scale than compared to temperatures seen in 27.04.2016 5.5b. The reason why the temperature was adjusted to the minimum value, was to see if it was possible to create a cooler and more stable temperature in the hut. To some extent, this has been obtained and the fluctuations are now only 2 degrees celsius rather than 7 degrees celsius. Nevertheless, it is observed that riometer is still greatly affected by this, therefore a solution for providing stable operating temperatures is required.

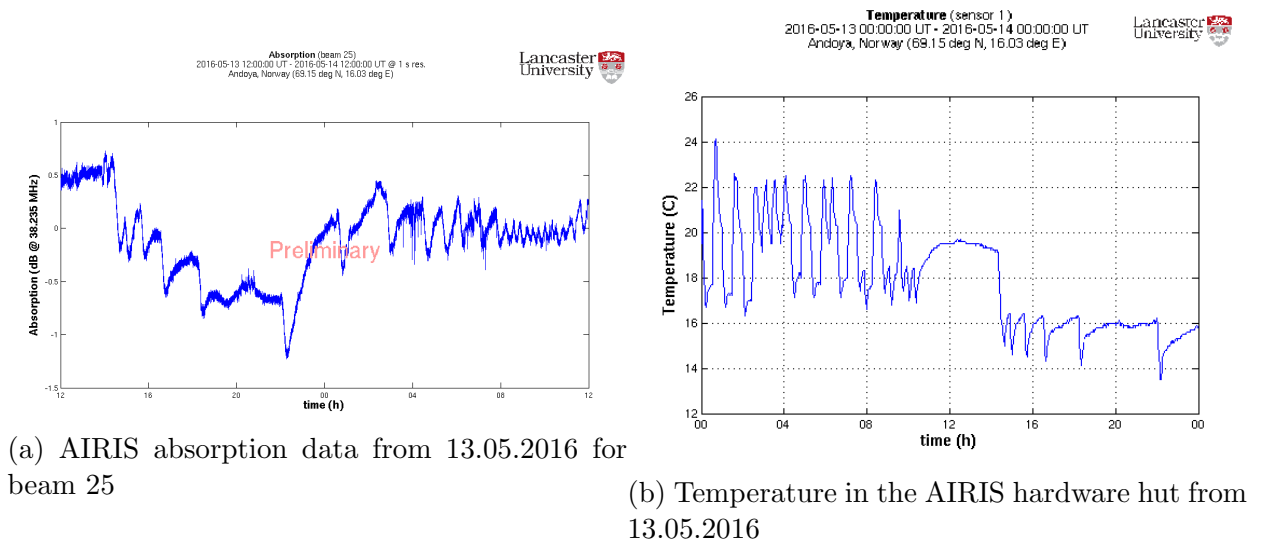


Figure 5.9

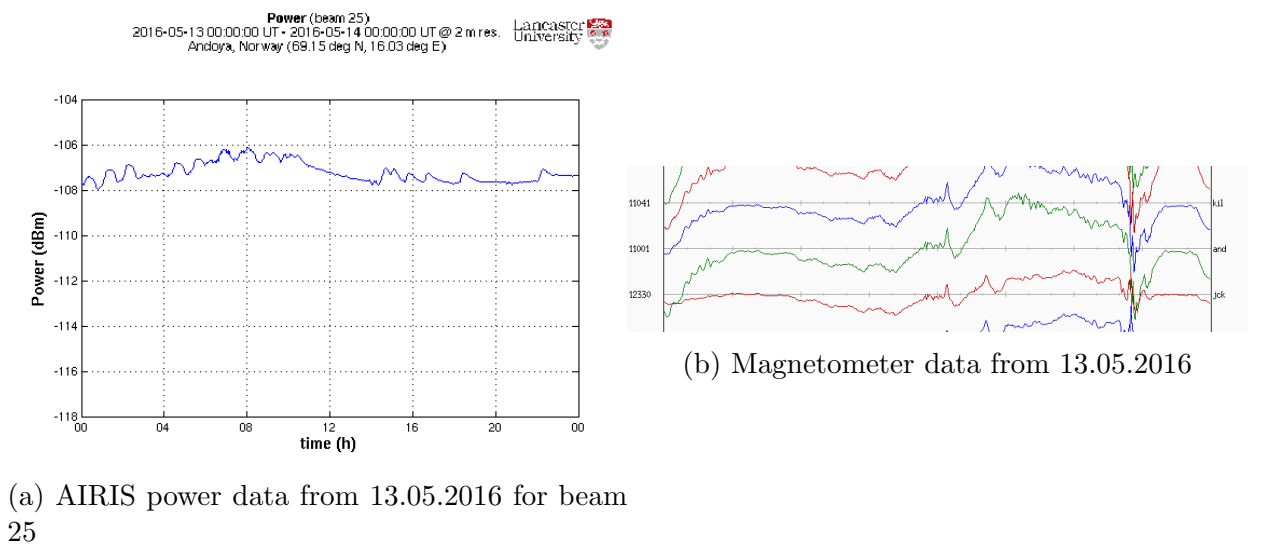


Figure 5.10

## 5.6 Data from 14.05.2016

After having tested with the UPS and operating AIRIS at a lower temperature, it would be beneficial to see what will happen if the temperature control system is turned completely off. It is evident that the temperature control is affecting the data, however the question is whether it is noise from the engines or the temperature itself. Clearly, if it is the temperature, the system receivers and hardware is a lot more susceptible to temperature changes than initially thought. This would also pose an additional challenge in how to install a temperature control system that keeps the temperature in the hut completely stable, without the starting and stopping of the temperature system causing any variations in temperature as indicated by the previous data.

Looking at Figure 5.11a, it is immediately observed that the data appears a significantly less variable than in the observations described in the previous sections. The temperature control system was turned off at 16.15, and the effects of this is both observed in the absorption data but also in the power data (see Figure 5.12a). In the absorption data, starting from about 16.00, the data stops having the drastic fluctuations as observed earlier. It still does have some variations, but this may be attributed to the natural changing temperature in the hut depending on day/night, climate/weather and heating of the sun. From about midnight, the absorption data is rather stable with smaller and less frequent variations. There is also an absorption event occurring in the early hours of the 15<sup>th</sup> of May, indicating that the riometer system is more efficient when there is no temperature control. However, there has been a skip in the absorption data. Normally the base absorption line (no absorption events) should lie at about 0 dB, but the data shows that the absorption line is increasing to close to 1 dB, even after the absorption event.

The temperature sensor also shows the effect of turning off the temperature control system, Figure 5.11b. Although the average temperature in the hut starts increasing slightly before the temperature control is turned off at 16.15, it keeps increasing to 19 degrees after 16.15. However, this is a more steady increase than compared to the drastic variability observed previously. The benefit of this is that it gives the riometer hardware time to adjust, thus not being as severely affected by the temperature variability. However, this also emphasises the fact that the riometer hardware requires a temperature control system that keeps a constant level of temperature. In other words, it needs a temperature control system that does not cool or warm the hut by several degrees over a short period, but rather is

able to keep the temperature completely stable. If the hardware hut were to have no temperature control system, this would potentially be a short term solution, yet this means that future data would have to correct for day/night variations and seasonal variations. Not only that, but also day-to-day variations since the climate at Andøya is extremely irregular and there are drastic changes in whether conditions throughout the day.

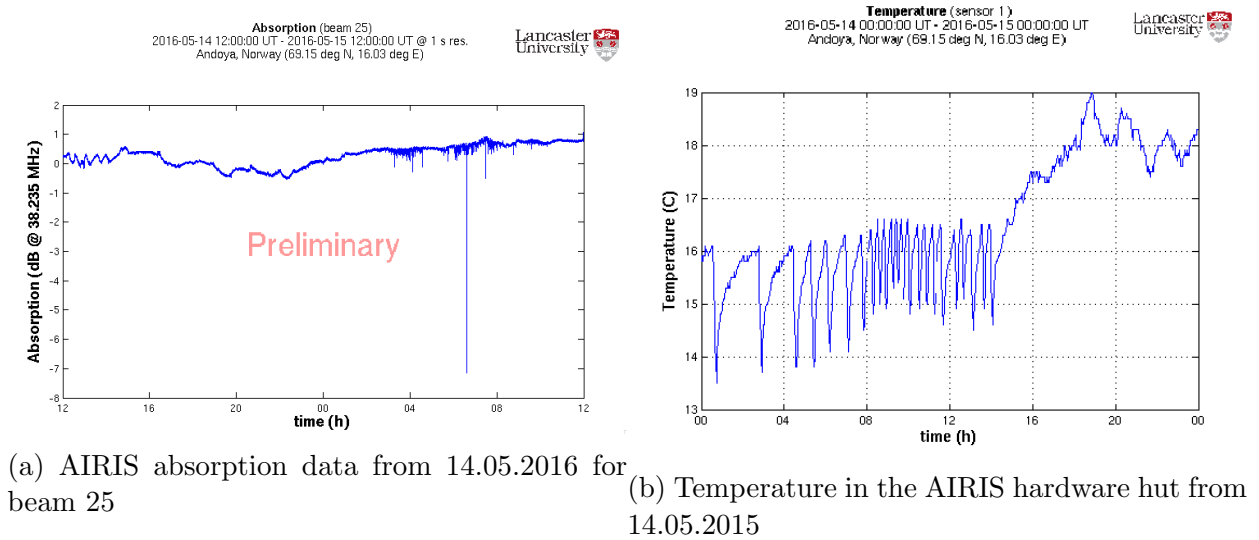


Figure 5.11

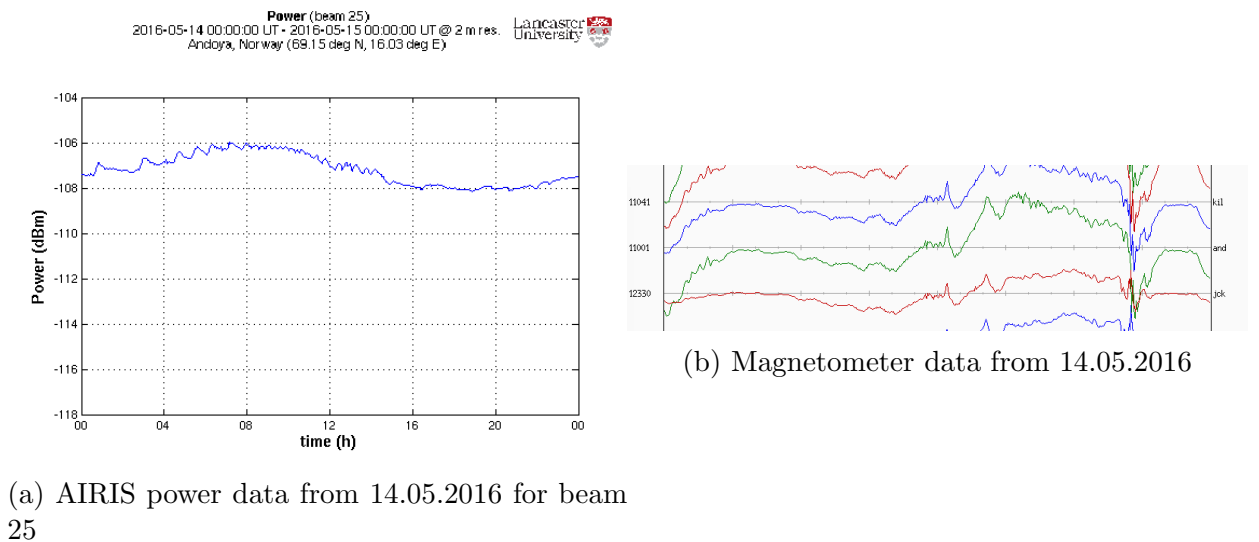


Figure 5.12

## 5.7 Data from 18.05.2016 - 22.05.2016

To emphasise the fact that the riometer is dependent on keeping a constant temperature in the hardware hut, a longer period of absorption data, for several days, is included. Figure 5.13 shows absorption data for 4 days. It is observed that a periodic drop in absorption level is seen around midnight, occurring every day. Due to the periodicity of this 1 dB drop, it is concluded that this may be attributed to the difference between day and night temperatures. Looking at the QDC data in Figure 5.14, it is observed that the QDC is not within the accepted uncertainty for this period. Furthermore, the QDC for this 14-day period is extremely variable (the red line), which may be attributed to the fluctuating temperatures observed in the riometer hut throughout this period.

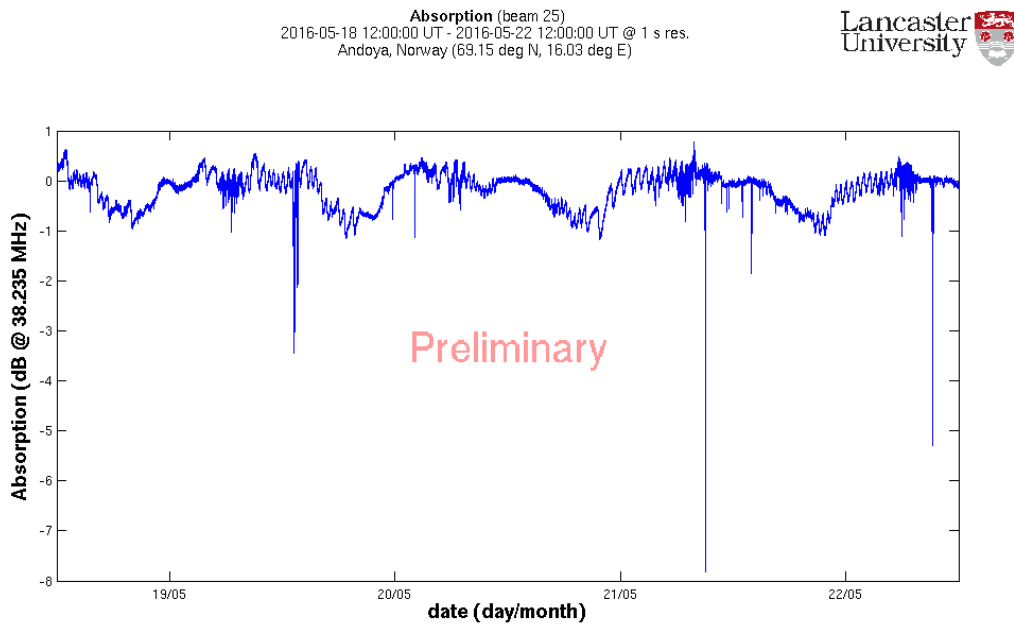


Figure 5.13: AIRIS absorption data from 18.05.2016 - 22.05.2016 for beam 25



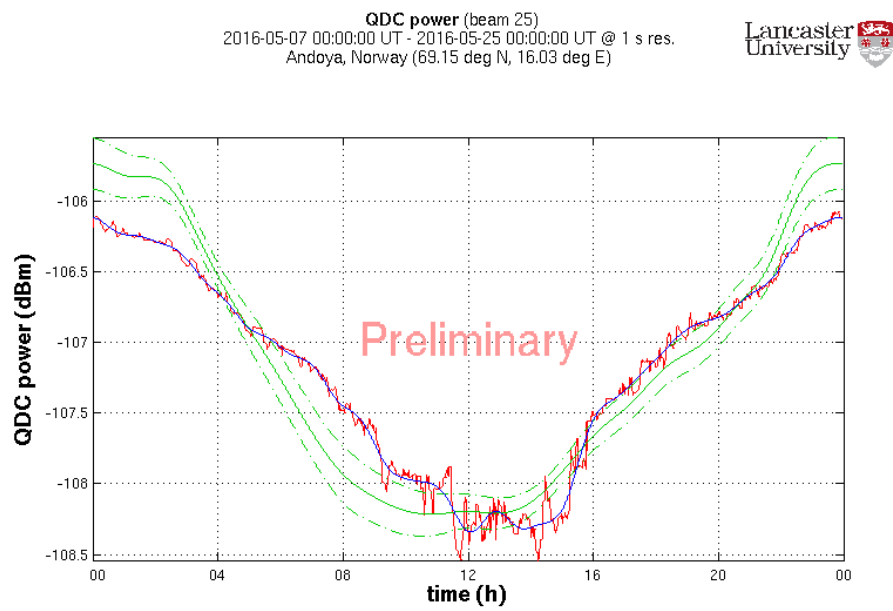


Figure 5.14: AIRIS QDC power data from 07.05.2016 - 25.05.2016 for beam 25



# Chapter 6

## Discussion

In this chapter the results will be discussed based on the observations and analyses made after each step of the upgrades. It is beneficial to discuss how each step of the upgrade has affected the data, as it will be vital for the future completion of the AIRIS upgrades, and in understanding required prospective actions to obtain the ideal quality of riometer data.

## 6.1 Discussion of observations

Before the upgrades were implemented, the riometer system was very affected by a faulty temperature control system and in need for an overhaul. The last time anyone had checked the receivers and the wiring of the antennas and associated coaxial cables, was when the riometer was built in 2006. This is the basis for this thesis-project, and throughout the year as the riometer has received attention, more obstacles has appeared. Therefore, it is now evident that the system will require further attention after the completion of this thesis.

The data from 2009 (see Figure 5.1) reflects how AIRIS was performing when data was considered to be optimal. The absorption line is constant and any absorption events are easily distinguishable from the base line. Although the temperature measurement was not running at this point in time which could be used for comparison, the associated power plot (which should be inversely proportional to the temperature) shows clearly distinguished atmospheric absorption events. Both these plots defines the level at which it is desired that AIRIS has reached after the upgrades and temperature control installation.

Data from 17.12.2015 is included to observe how the riometer was performing when the temperature control system was turned off, and after the initial maintenance of the antennas. All the data included, absorption 5.3a, temperature 5.3b and power 5.4a, shows that there is something affecting the data, however not to such a great extent as observed in the later data. The absorption line is not constant at 0 dB, but absorption events are observed. Although the variation is small and absorption events are observed, the variation is not ideal and therefore the data is of poor quality. At this point, it was challenging to attribute the observed variation to anything specific, however it was believed that it was due to the temperature control system being turned off. The temperature data however, only displays fluctuations of about 0.5 degrees celsius, and the power data appears to be fairly reliable up until the absorption event. Comparing the power during the absorption on 17.12.2015 event to that observed in 2009 (Appendices 5.2a), the system seem to respond completely differently. Rather than having sudden sharp peaks expanding over several decibels, it just stays at about -106.5 dB. Now, the absorption event in 2009 was large, so it may be attributed to the fact that the event on 17.12.2015 is a much smaller event. Yet, when comparing magnetometer data for the two days, it

is seen that the magnetometer data variations from 2009 are smaller than the event from 17.12.2015. Therefore, this poses a question regarding the sensitivity of the system, and requires further investigation.

Data from 27.04.2016 shows the first results after installing the new temperature control system in the riometer hut. The initial data shows an extreme amount of fluctuation which cannot be attributed to any atmospheric absorption event, meaning that something is happening to the riometer system. The exact source of these fluctuations need to be found in order to determine how to mitigate it. Several suggestions were provided in order to figure out what is causing this, and solution for eliminating it. Both the temperature data (Figure 5.5b) and power data (Appendices 5.6a) suggests that the environment in which the riometer hardware is located, may play a substantial part. For example, the riometer hut is located on a field where the only electricity source is through one wire from a different house, meaning that there may be regular fluctuations in the mains voltage that may be the culprit. The newly installed temperature control system draws electricity from the same local electricity grid as the riometer, inferring that as the temperature control system turns itself on and off, this may cause a surge in the electricity that affects the riometer. Additionally, the temperature control engines may produce noise (and vibrations) that affects the riometer, as the hut is very small and there are currently nothing that may mitigate this noise (and vibration). Finally, it may actually be the temperature in the environment itself that causes this, however it was initially deemed unlikely due to this meaning that the receivers and hardware has a very significant susceptibility to temperature changes. Furthermore, it is a susceptibility that was not observed with the previous temperature control system.

Data from the 10<sup>th</sup>, 13<sup>th</sup> and 14<sup>th</sup> of May 2016 shows the results of the tests performed on the system. On the 10<sup>th</sup> up until 16.20 on the 13<sup>th</sup> of May, an UPS was installed in order to investigate whether a variation in the mains voltage may be the cause of the observed fluctuations. The result of this shows that while the instrument may have been affected by some electricity surge, it was not to such a great extent that it caused the drastic fluctuations observed in the absorption data. Still, it is beneficial to keep the riometer connected to the UPS as this will prevent any future electricity fluctuations or short electricity black outs to have any effect on the system.

The next step for the tests is to turn the temperature control system down to its minimum value. The idea is that through doing so, it is hopefully possible to keep a more even temperature in the hut whilst the temperature system also works more constantly rather than turning itself on and off. The result of doing so is observed from 16.20 on the 13<sup>th</sup> to 16.15 on the 14<sup>th</sup> of May. The temperature was turned down to 17 degrees (which was the minimum possible value), and the result initially seemed positive. Throughout the evening of the 13<sup>th</sup>, the temperature sensor shows a drastic decrease in the frequency of fluctuations (Figure 5.9b) and so does the power (Appendices 5.10a). The absorption appears to have a drop in the signal throughout the evening, up until midnight where it appears that it tries to stabilise at just below 0 dB. Frequent fluctuations are still observed, however they are on a much smaller scale. This therefore indicates that the temperature in the hut does, in fact, affect the hardware much more severely than initially believed.

Turning the temperature control system entirely off greatly improves the data, as seen in the data for the 14<sup>th</sup> of May (Figure 5.11a). Even though the temperature in the hut still varies (Figure 5.11b), it does not have the sharp and frequent fluctuations observed previously. The power data (Appendices 5.12a) also show no fluctuations either, but rather very small variations over a longer period of time. From this, it is evident that the temperature of the environment in which riometer hardware is stored, plays a crucial part on the data quality. The environment temperature only need to vary by a few degrees before it affects the power of the riometer. However, these fluctuations need to be rapid and over a short period of time for this to affect the system as drastically as observed. If the typical time-scale of temperature variations are one hour, then the hardware has time to adjust and hence will not be seen in the absorption data as clearly.

An additional set of data has been included, which looks at absorption continuously over several days (Figure 5.13). This was included out of curiosity for how the data looks when considering several days, but it should be noted that this is not the conventional way in which to present absorption data. What is seen in this set of data however, poses new questions regarding the system. Observed is a periodic decrease in the absorption base line, of about 1 dB, and it occurs from about mid-day and lasts until 21.00 in the evening. The initial belief is that this may be caused by heating of the hut from the sun, which emphasise the need for a fully operational climate control system that does not interfere with the data quality. Yet, it should

also be remarked that the temperature control system is actually set to maintain 17 degrees in the hut, but still this absorption baseline variation is observed.





# Chapter 7

## Conclusion

This chapter presents the conclusion drawn based on the results and discussion. First, a general conclusion is presented, and then the focus questions are answered.

## 7.1 Conclusion

Throughout the year and upon completion of this thesis, many sudden obstacles and challenges has occurred. After the sudden deterioration of the riometer data due to the installation of the new temperature control system, it was decided that pinpointing the cause of this deterioration would be the topic of the thesis along with how to mitigate this.

Looking at the data presented, it is clear that the temperature of the environment in which the hardware is stored, does affect the system dramatically. It is therefore required to come up with a solution where the temperature fluctuations are reduced, and a constant temperature is maintained. How to do this however, is another challenge. The riometer hut is small, and at present time, the temperature control system is blowing the air with changing temperature directly at the hardware. An attempt at placing the temperature sensor inside the riometer hardware has been made, but the results of this is yet to be seen.

### 7.1.1 How is AIRIS data compared to before?

The AIRIS data has improved in the final part of the testing, but the quality of the data is poor. Compared to the data from 2009, there is still a lot of work that needs to be done in order to reach that standard, the first step being to figure out how to keep a constant temperature in the riometer hut. Once this is done, calibrations of the antennas should be undertaken, with the expectation of this resolving most of the issues that currently affects the riometer. Although the data quality currently is rather poor, it is possible to see some absorption events. However, when calibration of the antennas has been performed, it is expected that this will increase the sensitivity of the antennas making any atmospheric events easier to detect.

### 7.1.2 Is AIRIS fully operational?

AIRIS is at present time not fully operational. Although it may to some extent be used to detect absorption events, the quality is poor and thus not entirely reliable. By reliable, the amount of absorption observed is considered. The riometer is able to detect an absorption event, however the amount of absorption seen is unreliable. The system itself is currently operational, but there are some improvements yet to be made, along with a full calibration of each antenna.

### 7.1.3 Is AIRIS data reliable for use in research?

At present time, it is not advisable to use AIRIS data for research. Although the data is capable of detecting absorption events, the riometer is at this point difficult to calibrate, as it is suspected that it may be off by several decibels. In other words, the associated uncertainty of the absorption data is at present time higher than desired, making it challenging to estimate the amount of absorption actually occurring. This is a result of the fluctuations seen in the data, and even though turning the temperature control system entirely off has had some positive effect on the data, the riometer system still sees variation due to daily temperature changes.

### 7.1.4 What actions need to be done in order to get it fully operational?

First of all, it is required to find a solution in which the temperature control system does not fluctuate to the extent that it does, or to find a solution where the wind from the system is not aimed directly at the riometer hardware. A possible short term solution could be to build a small wall separating the temperature system from the hardware, however the hut is very small and this would cause problems when manouvering inside the hut. Another solution is to redirect the wind away from the hardware and have it aimed at the floor or the roof of the hut, but again, this require a construction to be built inside the hut. Therefore, ideally, a way of re-directing the wind that does not interfere with the manouverability inside the hut is required.

Following finding a solution for the temperature control system, calibrating the antennas is a necessary step. This would be beneficial in order to check that each balun in each antenna is working properly, and if not, it would show which balun is not working correctly. This is a step that will take a few weeks if it turns out that one of the baluns are malfunctioning, as a new balun must be ordered from Lancaster University.

Since the antennas are based on a wiring technology, another step that could benefit the data quality is checking the wiring (see Figure 3.1). In order words, it could prove beneficial to tighten the wiring that is connected to the ground, in order to stabilise the antennas.

## 7.2 Proposed Future work

Due to the many obstacles that was faced during this thesis, it is proposed that further analysis is undertaken where more data is considered. Upon completion of this thesis, about 3 weeks of data was available for analysis and verification of the AIRIS system quality, after AIRIS upgrades. Therefore, a further investigation of data quality where a longer time period is considered, approximately 6 months, is proposed as this will provide enough time to confirm that the antenna maintenance and exchange of parts, as well as the installation of temperature control system, has been successful. Furthermore, calibration of the antennas should be undertaken once a solution to the temperature control system has been fully accomplished.

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# Appendices





## **.1 QDC power plot script**

Provided is the program used in which to create the QDC power output.

```
TIMESTART = timestamp('now')
tempdir
rio = rio_and_2

% nominal start time (ie beginning of period
% for which QDC is valid
t = timestamp([2015 08 07 0 0 0]);

% start time of data used to make QDC
% st = timestamp([2012 10 31 00 0 0]);
st = t - timespan(2, 'd')

% end time of data used to make QDC
et = t + timespan(16, 'd');
% et = timestamp([2012 11 12 00 0 0]);
et

mia = [];

% example of how to exclude certain periods
exclude = ...
    [timestamp([2011 01 11 04 0 0])
    timestamp([2011 01 12 00 0 0]);  ];

exclude = [];

exclude

% beams to make QDC for
beams = info(rio, 'allbeams');
beamsatonce = numel(beams); % All at once

disp(sprintf('Creating for beam(s) %s, with %d beams at once', ...
```

```

        printseries(beams), beamsatonce));

pause(5);

prefilter = {};
postfilter = {};
postfilter{1} = mia_filter_replace_nans('interpmethod', 'cubic');

prefilter{1} = mia_filter_sliding_average('method', 'median', ...
        'windowsize', timespan(599, 's'));

if 1
    stddev = 4;
    prefilter{2} = mia_filter_qdc_mean_sd('upperlim', stddev, ...
        'lowerlim', -stddev, ...
        'dcadjustmethod', 'minimisesigndiff');

    % Using mean/std deviation filtering can lead to NaNs in the
    % final QDC, replace them with interpolated values before
    % attempting to use the truncated Fourier series fit

    postfilter{1} = mia_filter_replace_nans('interpmethod', 'cubic');
end

% Don't set the fitorder for the Fourier transform,
% compute automatically considering the beamwidth,
% latitude, zenith etc
fitorder = [];

% The method used to create the QDC, either a CHAR or a
% CELL matrix containg the name of the function and any
% optianl parameters to pass to that function.
%
% UPPERENVELOPETOQDC accepts a name/value pair "outputrows"

```

```

% which selects which sorted rows should be output for the QDC
% data. [3 4] means use the mean of 3rd and 4th highest values at
% any given sidereal time.
outputrows = [4 5];

% Give the user a chance to see the outputrows setting
display(outputrows);
pause(2);

createmethod = {'upperenvelopetoqdc', ...
                'outputrows', outputrows};
%createmethod = {'inflectionpointtoqdc', ...
%               'windowsize', timespan(599, 's')};

createmethod

% Now call the makeqdc function with the appropriate parameters
makeqdc(rio, ...
        'mia', mia, ...
        'time', t, ...
        'starttime', st, ...
        'endtime', et, ...
        'beams', beams, ...
        'beamsatonce', beamsatonce, ...
        'exclude', exclude, ...
        'prefilter', prefilter, ...
        'postfilter', postfilter, ...
        'fitorder', fitorder, ...
        'createmethod', createmethod, ...
        'savefilename', '/home/spears-joule/larseni/%Y%m%d_b%Q.mat',
        'savepathsuffix', '.new');

TIME_END = timestamp('now')
TIME_TAKEN = TIME_END - TIME_START
disp('DONE');

```

