10-3-2016

HACORD 2015

Report

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Preface

For our school subject research & development we did this ASGARD-project about cosmic radiation. The goal of the ASGARD project is to give scholars, mainly from secondary school and higher education, the chance to do their own research in ionizing radiation in the earth's atmosphere. The University of Antwerp has participated in this project since 2012. They also developed the HACORD, which is a device that uses Geiger-Müller counters to measure the radiation intensity.

Our goal was to search for relationships between last year's data and this year's data. To accomplish this goal, we would attach HACORD to a weather balloon and send it to an altitude of 34 kilometers and measure the cosmic radiation at different altitudes. After this data had been gathered, we processed the data to be able to draw a conclusion.

This project was worked on in collaboration with the University Of Antwerp (UA) and the KNMI (Royal Netherlands Meteorological Institution). That is why we would like to thank prof. Dr. Van Remortel (UA), Andy Martinez Nieto (UA), Mr. Allaart (KNMI) and of course our teachers: Ms. Robyn and Mr. Groot for their guidance during this project.

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1. Introduction

1.1 Introductory word

Since the beginning of the 20th century people have begun researching our Earth's atmosphere through the use of weather balloons. Only decades later researchers got the idea that ionizing radiation could come from outer space, which was partly thanks to the findings of Hess. In the meantime, a lot of academic research has been conducted in the field of atmospheric radiation. Due to the regular use of weather balloons and the recording of the intensity of the ionizing radiation, one is able to, for example, determine our sun's activity. Another interesting aspect of our Earth's atmosphere is that it functions as a natural particle accelerator.

This means that there is the possibility to do research on elementary particles. We will mainly focus our research on the determination of the sun's solar cycle through the use of yearly experiments measuring the intensity of the cosmic radiation. We will also be helping in the processing of the data of previous years, which the University of Antwerp will provide us with. The processing of this data will help them in continuing their research on cosmic radiation.

To be able to study the information, the data must be processed in a clear and accurate way. That is why it is important that our graphs of the data must be constructed very carefully, in a way that they are easy to read. For this particular goal we use the program gnuplot. Our graphs will be reviewed by Professor Van Remortel.

To test the HACORD we have exposed it to extreme circumstances such as high air pressure, low temperatures and large amount of radiation.

1.1.1 Hypothesis

The hypothesis is that the amount of cosmic radiation will follow the solar cycle, but that this will not be the only factor. It could also be possible that there is not enough data yet because the solar cycle is 11 years long and we will only be the fourth year to measure this data.

1.2 Pre-investigations

1.2.1 Background information

Back in 1785 Coulomb discovered that the charge of an isolated electroscope (a device to measure electrical charge) decreased over time. That is quite interesting, since the charge theoretically should not escape from an isolated electroscope. It was not until 1896 this phenomenon was explained by Becquerel, who said this decrease was the consequence of ionizing radiation. At first they thought this ionizing radiation originated from radioactive sources in the Earth's crust, but in 1910 Wulf proved this theory wrong. He proved this by climbing on the Eiffel tower and measuring how long it took for his electroscope to lose its charge. This took less time compared with an electroscope on the surface of the Earth, thus it proved that it was improbable that the radiation came from the Earth itself. This theory was confirmed by Hess, who did his measurements at an altitude of 5 km and concluded that the radiation had to be coming from outside the atmosphere.

The ASGARD project is an initiative of the Sint-Niklaas institute in cooperation with the KMI and the ESERO-Belgium. The aim of this project to give high school students a chance to do their own research into radiation in the atmosphere. The University of Antwerp joined this research in 2011. They developed the HACORD, a device that measures intensity of radiation by Geiger counters. More information about this device can be found in chapter 1.2.4. The HACORD was further developed in the following years. While at first only the amount of radiation was measured, the improved version allowed for measurements of the angle at which radiation entered the device.

In collaboration with the Royal Netherlands Meteorological Institute (KNMI) in De Bilt, HACORD would be sent up with a weather balloon the KNMI uses to measure ozone density in the atmosphere. That was how the cooperation of Het Goese Lyceum, the University of Antwerp and the Royal Netherlands Meteorological Institute started.

1.2.2 Analysis air shower and particles

The basic model of quantum physics

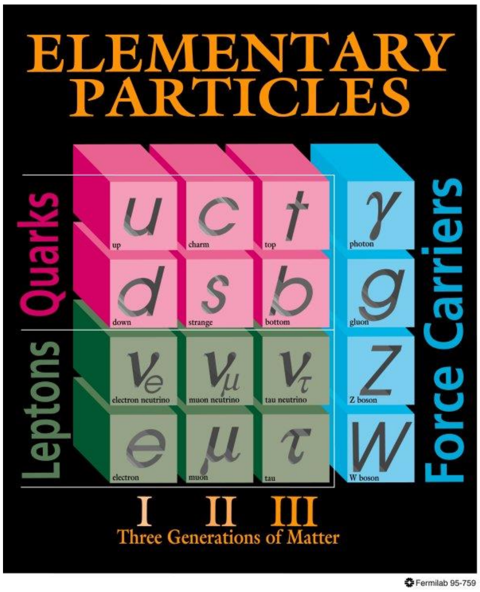

Figure 1

The standard model of the elementary physics uses twelve 'building blocks' (the quarks and leptons) and four force carriers (the bosons). With these building blocks and force carriers, all particles can be made. Figure 1 shows a clear overview of the standard model.

There are four kinds of forces. These are the strong nuclear force, the nuclear weak force, the electromagnetic force and the gravitational force. Every force has its own force carrier, called a boson. These bosons carry discrete amounts of energy, called quanta, from one particle to another

Each force has its own characteristic bosons:

- The gluon mediates the strong force; it "glues" quarks together.
- The photon carries the electromagnetic force; it also transmits light.
- The W and Z bosons represent the weak force; they introduce different types of decays.
- The graviton transports the gravitational force. However, this boson is still a hypothetical boson, since it has not been discovered yet. Proving the existence of this boson is very hard, since, at the subatomic level, the gravitational force is many orders of magnitude weaker than the other three elementary forces.

This basis of quantum physics is important in distinguishing the different particles. The standard model is still a model, even though it has already proven many predictions and it has (mostly) been proven itself as well.

Primary particles

A primary particle is a particle that causes an extended air shower. This particle is of extraterrestrial origin, origination from, for example, the sun. This particle is the first particle of the air shower and is therefore called a primary particle.

There is a lot of uncertainty about the heavy cores. This radiation consists of:

- Approximately 2% of electrons
- Approximately 98% of light and heavy cores. These cores consist of:
- Approximately 85% of protons
- Approximately 12% of alpha particles
- Approximately 3% of heavier cores

Energy primary particles

The energy of the primary particles varies between 0 to $10^{22}\ eV$ ($1\ eV = 1{,}6 \cdot 10^{-19}\ J$).

For comparison:

- Heating 1L of water 1°C $= 4{,}2\ kJ = 2{,}6 \cdot 10^{22}\ eV$
- Energy per proton-proton collision in the LHC (Large Hadron Collider) = approximately $10^{13}\ eV$
- Energy required to ionize an atom = 10-50 eV
- Energy to excite one atom = <10 eV
- Energy to make a conduction electron in a semiconductor = approximately 3 eV

Secondary particles

A secondary particle is a particles that comes into existence in an extended air shower. It is the product of the reaction.

These particles are dependent on height. This radiation consists of:

- Gamma radiation (photons)
- Leptons: electrons, positrons, (anti)muons, neutrinos
- Hadrons: mostly pions, neutrons, (anti)protons, light cores

What particles/radiation

Alpha radiation: Alpha radiation originates from an atomic core. The alpha particle consists of two protons and two neutrons. Therefore, it has atomic number 2 and mass number 4, practically a helium core.

Beta radiation: Beta radiation also originates from an atomic core, even though the beta particle is an electron. This is because a neutron in the core breaks up into a proton and an electron. The proton stays in the core, while the electron is emitted.

Gamma radiation: Gamma radiation originates from the atomic core as well. The gamma particle is a photon, which is a package of energy. A photon is a secondary particle.

Positron radiation: Positron radiation also originates from the atomic core. A positron is a positively charged electron. It is the antiparticle of an electron. A positron comes into existence once a proton breaks up into a neutron and a positron.

Proton and neutron radiation: If an atomic core is bombarded by, for example, an alpha particle, proton and neutron radiation can come into existence, because a proton or a neutron will leave the core.

(Anti) muons: (Anti) muons are seen as leptons. A muon is an unstable, subatomic particle with a half-life of approximately 2.2 μs.

Neutrinos: A neutrino is an electrically neutral, weakly reactive, subatomic particle. It is thought that neutrinos have very little mass, even for a subatomic particle. However, this has not been officially proven yet.

Pions: A pion is also a subatomic particle. There are three types of pions: a positive, neutral and a negative pion. Pions are unstable. The charged particles have a longer half-life than the neutral pions, namely 26 ns and 8.4*10-17 s respectively. Charged pions usually break up into muons and muon neutrinos, while neutral neutrinos break up into photons.

Leptons: Leptons are secondary particles. Electrons, positrons, (anti)muons and neutrinos are all leptons.

Hadrons: Hadrons are secondary particles as well. Pions, neutrons, (anti)protons and light cores are all hadrons

Type of radiation	**Symbol**	**Mas (u)**	**Charge**	**Speed**	**Ionizing ability**	**Penetrating ability**	**Stopped by**	**Penetrating ability in air**	**Deflected by magnetic field**
Alpha	α or He2+	4	2+	Slow	Large	Small	Paper	8cm	Yes, less than beta
Beta	β	1/2000	1-	Fast	Moderate	Moderate	Aluminum	1m	Yes, in the opposite direction of alpha particles
Gamma	γ	0	0	Extremely fast (speed of light)	Small	Large	Lead	∞	No

Origin of cosmic radiation

- Sun (Solar flames and wind): <10^9 eV
- Supernova: <10^{14} eV
- Pulses, binaries: <10^{19} eV
- Ultra-high energetic radiation: >10^{19} eV
  - Burst of gamma radiation
  - Active galactic nucleus

Direction cannot be determined easily because of the magnetic fields in space. Therefore, the position of the source is unknown.

Move in an almost straight line, which means the position of the source is mostly known, but little is known. This radiation is primarily gamma radiation.

Intensity cosmic radiation

- Primary cosmic particles in the top of the atmosphere (100 km): approximately $20/cm^2/s$
- Secondary cosmic particles on sea level: approximately $1/cm^2/s$ (factor 1200)
- For comparison: 1g of Radium: $10^9/cm^2/s$
- The intensity varies with the solar cycle and the climate

Extended air showers

An extended air shower is a very large cascade of secondary particles and electromagnetic radiation. An extended air shower comes into existence when cosmic radiation enters the earth.

When a primary particle enters the atmosphere, it interacts with a nitrogen or oxygen molecule in the atmosphere. This interaction causes the cascade of secondary particles and electromagnetic radiation; the extended air shower.

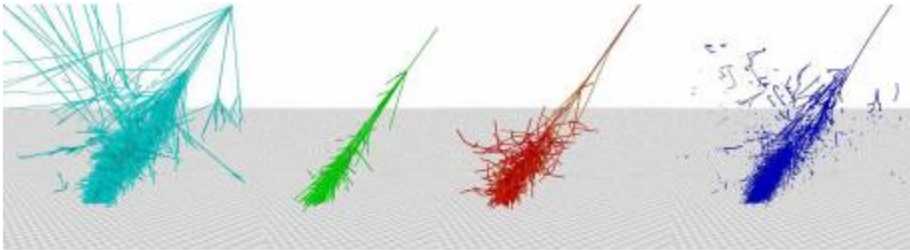

Figure 2 Shower decomposed into various types of secondary particles: photons (cyan), muons (green), neutrons (red) and electron/positron pairs (blue)

An extended air shower can be used as a measurement of the energy of the incoming primary particle. The bigger the extended air shower, the higher the amount of energy of the incoming particle. The following is also true: the more secondary particles come into existence, the higher the amount of energy of the incoming particle is.

The flux of the cosmic radiation in the atmosphere is dependent on the energy, angle of incidence and the kind of particle.

1.2.3 Analysis atmosphere

The atmosphere of our planet is one of the more important aspects that allow life on our planet. It is a layer of gasses that not only provides oxygen to most of the organisms on earth but also protects us from ultraviolet radiation. This analysis describes this special layer around the earth.

Physical properties atmosphere

The atmosphere begins from the earth's surface and at a certain point fades completely into outer space. Scientists are still in discussion about the exact point at which this occurs. However, the Karman line is used as the defining border between atmosphere and space. It is an imaginary border that lies at an altitude of 100 km above the surface of the earth. At this height one would be able to see outer space with her stars during the day as well as the night. This is due to decreasing influence of the atmosphere on the incoming sunlight, so that it loses its characteristic blue color.

The atmosphere is very dynamic, due to different layers that each have their own air composition and specific characteristics. Our atmosphere consists of 5 layers:

- the troposphere 0 - 6/20 km
- the stratosphere to 50 km
- the mesosphere to 85 km
- the thermosphere to 690 km
- the exosphere to 10,000 km

Further on in this analysis the different layers will be described more in detail.

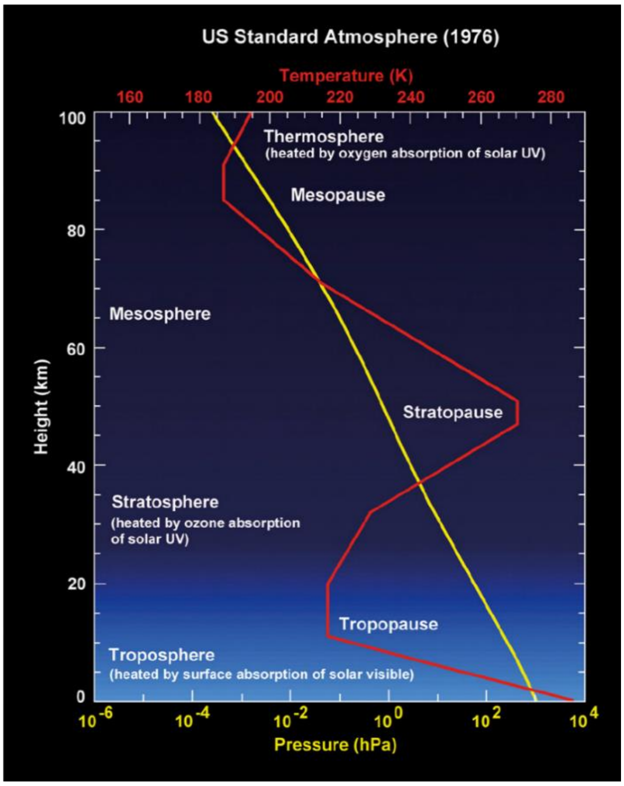

Figure 3

Chemical properties atmosphere

Our Earth's atmosphere consists mostly of a diversity of gases, with a high concentration of nitrogen and oxygen. Down below there is a detailed chart which visualizes the air composition in detail. Important to note is the high concentration of nitrogen (~78%) and oxygen (~21%). Oxygen derives primarily from cyanobacteria and plants. The cyanobacteria were the first to convert carbon dioxide to oxygen. This oxygen was then responsible for the oxidation of rock, this way oxygen disappeared from the earth's atmosphere. All the while the concentration of nitrogen remained the same and thus we are left with our atmosphere that mainly consists of nitrogen.

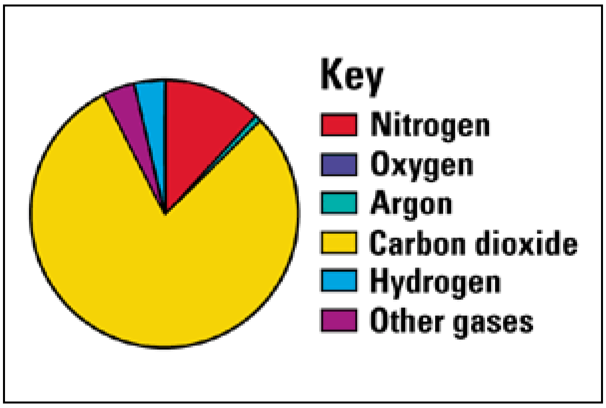

Figure 5 The distribution of molecules that appear in the atmosphere, 4500 million years ago

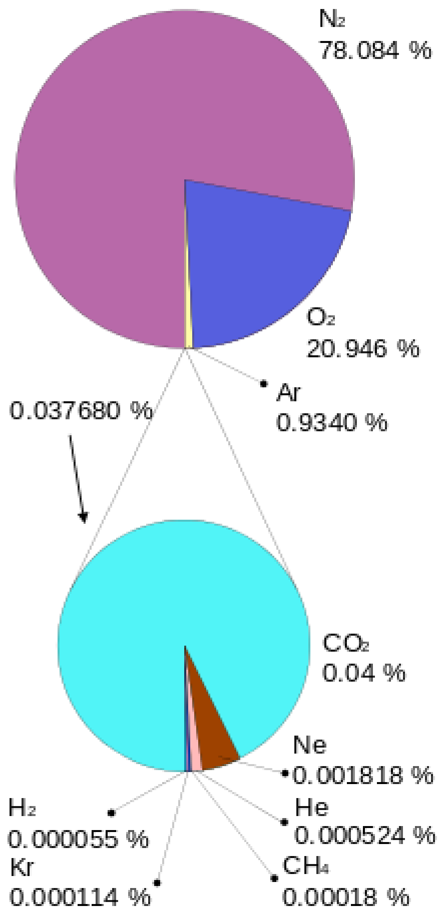

Figure 4 The distribution of molecules that appear in the atmosphere, now

The temperature in the stratosphere increases in relation to the troposphere, even though the pressure still decreases. The next two images show the different layers in the atmosphere, with the corresponding pressure, temperature and altitude.

The troposphere

The troposphere is the lowest layer of the earth's atmosphere. It begins from the surface and stretches to roughly 12 km high, 6-7 km near the poles and 17-20 km around the equator. The tropopause, the border between the troposphere and the stratosphere, is designated by an increasing temperature. Before the tropopause the temperature just decreases in relation to altitude. This can be seen in both figures 3 and 7. One can also note that the pressure is inversely proportional to the altitude. The troposphere, despite it being the smallest layer of the atmosphere in volume, contains almost 75% of all the mass of the total atmosphere and 99% of all water vapor. The troposphere is also the layer where most weather phenomena occur.

The stratosphere

The stratosphere is the second layer of the atmosphere and is characterized by an increasing temperature as the altitude increases. This means that the higher layers of the stratosphere are warmer than the lower layers. The increasing temperature is caused by the high concentration of Ozone that absorbs a lot of energy from the sun and is able to retain that energy. The stratosphere starts from the tropopause, which has already been explained in the previous paragraph. The stratosphere stretches out to about 50 km above the surface. It is also the layer in which most commercial flights occur. This is due to the low air density, and the ability to avoid extreme turbulence this way. The stratosphere contains almost 90% of all the ozone in our atmosphere. Most of the ozone can be found at an altitude of 20-30 km, this specific area is called the ozone layer. Around 97%-99% of potentially dangerous UV-radiation is absorbed by the ozone layer. This makes it our primary defense mechanism against UV-radiation. The high concentration of ozone is a result of the oxygen-ozone cycle. This is the name of the chemical reactions that are required to make ozone. Furthermore, the ozone layer is the layer where weather balloons are send to do measurements.

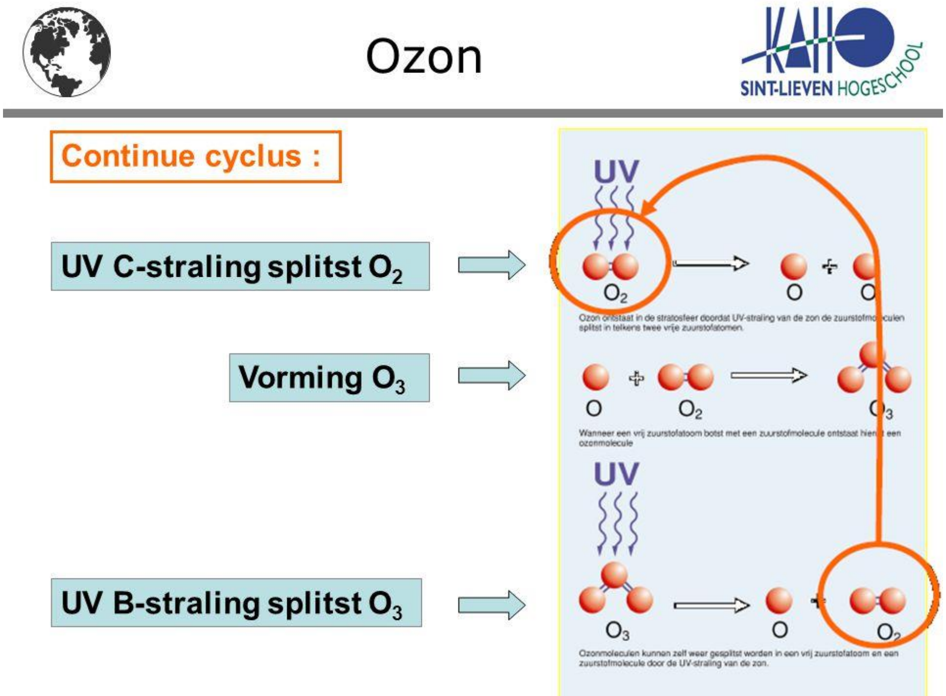

Figure 6

The mesosphere

Around 50 to 60 km above the surface one can find the stratopause and the start of the mesosphere. The mesosphere continues to an altitude of around 80-85 km. The mesosphere is designated by the decline in temperature relative to the stratosphere. The upper layer of the mesosphere is the coldest part of the atmosphere, with temperature often reaching around -100°C. It should also be noted that it is still very hard to conduct measurements in the mesosphere. This is due to the mesosphere being too high for aircrafts and weather balloons, but too low for spacecraft. An interesting aspect of the mesosphere is its responsibility for the aurora borealis.

The thermosphere

Around 85 km above the earth's surface begins the thermosphere, which stretches out to around 690 km. The temperature of the thermosphere increases relative to the mesosphere. This is caused by the ionization of ultraviolet radiation from the sun, which releases a lot of energy in the form of warmth. The temperature in the thermosphere is very dependable on the sun. Under the right circumstances temperatures can rise from 2000°C to even 2500°C. However, these temperatures are very misleading, because the thermosphere is a near-vacuum. Because of extremely low concentration of atoms, one would not be able to feel this temperature at all. Normal thermometers measuring at this kind of altitude would normally indicate a temperature of around 0°C. The thermosphere is the layer where one can find the most satellites and spacecraft, including the International Space Station at a height of 320-380 km.

The exosphere

The exosphere is the layer that directly follows the thermosphere. The concentration of molecules is so low, that particles rarely interact with each other. Because the border between the exosphere and outer space is so vague, the exosphere is often accounted for as a part of outer space.

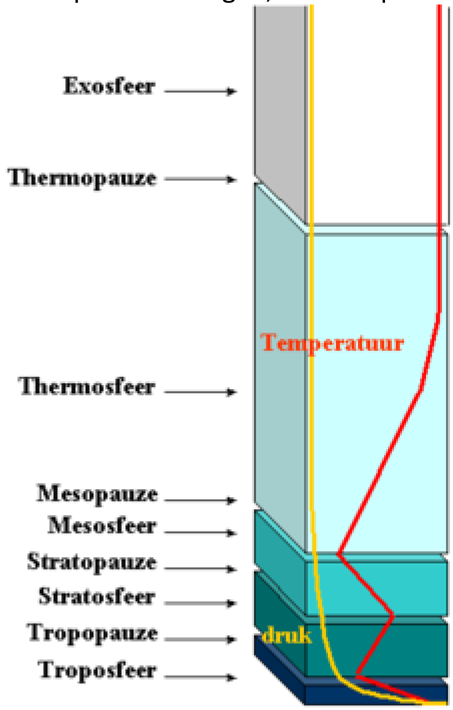

Figure 7

1.2.4 Analysis GM-counter

The analysis of the atmosphere in relation to the radiation is researched using the HACORD-IV setup. This is a measurement device that consists of, among others, multiple Geiger-Müllers counters and an mbed-microcontroller to process measured data.

The functioning

The Geiger-counter only works for detecting particles with an ionizing capability. A high voltage is applied to a tube filled with a diluted gas a high voltage. This voltage is chosen is such a way that a single ionizing particle causes a lot of ion pairs. The number of caused ion pairs is equal to the doubling number $\times 10^8$. When radiation passes through the tube, it will ionize the gas for a moment and a small electric current will run. This will then be amplified and can be heard through a speaker as a tick.

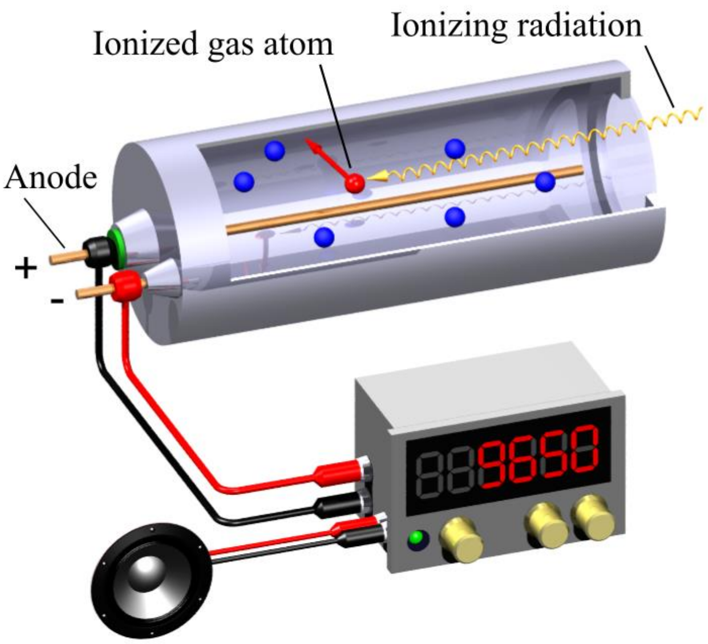

Figure 8 A schematic representation of a Geiger-Müller counter – source: http://nl.wikipedia.org/wiki/Geigerteller

Advantages

- No expensive power supply is necessary with the chosen voltage

Disadvantages

- The 'dead time' of the tube is relatively long for this kind of measuring equipment. This can lead to less accurate measurements.
- The chosen voltage of the measuring equipment has the side effect that a weak β-particle or γ-ray for a very short gives the highest possible ionization. In this short period of time, it is not possible to deduct which different kinds of radiation entered the device.

1.2.5 Analysis solar cycle

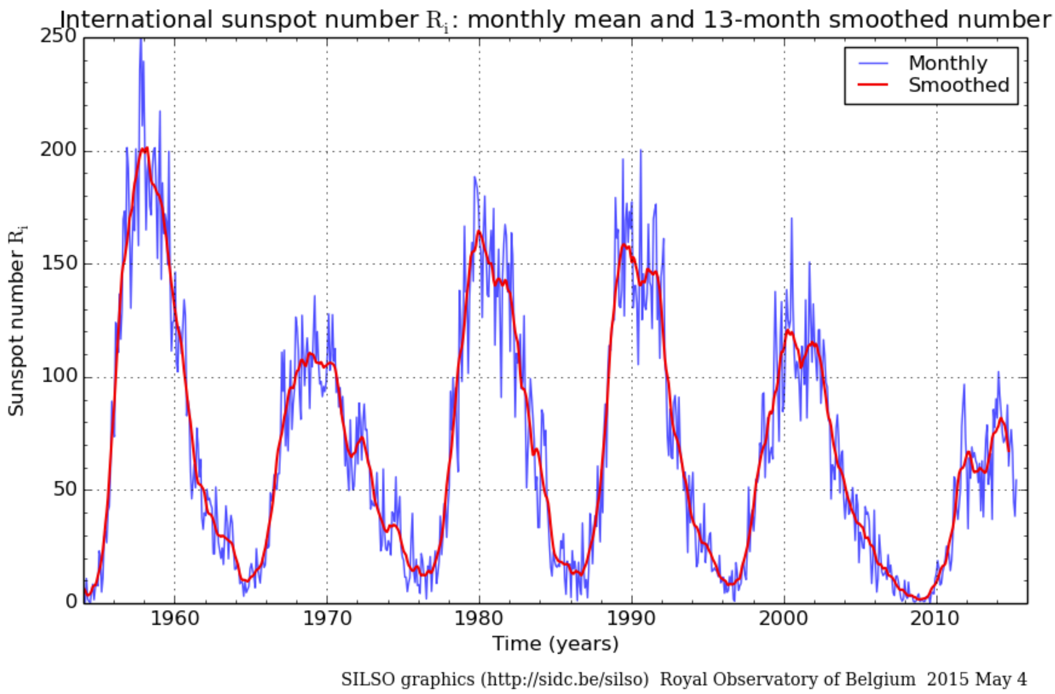

Figure 9

This graph shows the number of sunspots that have been counted during the years. It clearly shows there is an 11-year cycle.

Source: WDC-SILSO, Royal Observatory of Belgium, Brussels

1.2.6 Analysis batteries

In this analysis we will lay down the different pros and cons for the use of several sorts of batteries.

The deep cycle battery is designed to discharge 45 to 75 % of the total capacity at once and to supply a constant power.

The starter battery is designed to provide a huge power surge at once.

Lead batteries

Pros	• Inexpensive and simple to manufacture; low cost per watt-hour • Low self-discharge; lowest among rechargeable batteries • High specific power, capable of high discharge currents • Good low and high temperature performance
Cons	• Low specific energy; poor weight-to-energy ratio • Slow charge; fully saturated charge takes 14-16 hours • Must be stored in charged condition to prevent sulfation • Limited cycle life; repeated deep-cycling reduces battery life • Flooded version requires watering • Transportation restrictions on the flooded type • Not environmentally friendly

Absorbent Glass Mat (AGM)

Pros	• Spill-proof through acid encapsulation in matting technology • High specific power, low internal resistance, responsive to load • Up to 5 times faster charge than with flooded technology • Better cycle life than with flooded systems • Water retention (oxygen and hydrogen combine to produce water) • Vibration resistance due to sandwich construction • Stands up well to cold temperature • Less prone to sulfation if not regularly topping charged
Cons	• Higher manufacturing cost than flooded (but cheaper than gel) • Sensitive to overcharging (gel has tighter tolerances than AGM) • Capacity has gradual decline (gel has a performance dome) • Low specific energy • Must be stored in charged condition (less critical than flooded) • Not environmentally friendly (has less electrolyte, lead that flooded)

Nickel-cadmium batteries

Pros	• Rugged, high cycle count with proper maintenance • Only battery that can be ultra-fast charged with little stress • Good load performance; forgiving if abused • Long shelf life; can be stored in a discharged state, needs priming before use • Simple storage and transportation; not subject to regulatory control • Good low-temperature performance • Economically priced; NiCd is the lowest in terms of cost per cycle • Available in a wide range of sizes and performance options

Cons	• Relatively low specific energy compared with newer systems • Memory effect; needs periodic full discharges and can be rejuvenated • Cadmium is a toxic metal. Cannot be disposed of in landfills • High self-discharge; needs recharging after storage • Low cell voltage of 1.20V requires many cells to achieve high voltage

Nickel-metal-hydride batteries

Pros	• 30–40 percent higher capacity than a standard NiCd • Less prone to memory than NiCd, can be rejuvenated • Simple storage and transportation; not subject to regulatory control • Environmentally friendly; contains only mild toxins • Nickel content makes recycling profitable • Wide temperature range
Cons	• Limited service life; deep discharge reduces service life • Requires complex recharge-algorithm • Does not deal with overcharge very well • Generates heat during fast charge and high-load discharge • High self-discharge; although this can be countered at the cost of capacity. • Performance decreases when stored at high temperatures; must be stored in a cold place at 40% of the total charge

Lithium batteries

Pros	• High specific energy and high load capabilities with Power Cells • Long cycle and extend shelf-life; maintenance-free • High capacity, low internal resistance, good coulombic efficiency • Simple charge algorithm and reasonably short charge times • Low self-discharge
Cons	• Requires protection circuit to prevent thermal runaway if stressed • Degrades at high temperature and when stored at high voltage • No rapid charge possible at freezing temperatures • Transportation regulations required when shipping in larger quantities

1.2.7 Formulas

Barometric formula

The upper formula is the barometric formula, which is retrieved from BiNaS. To get the formula of altitude, we derived the formula:

$$P = P_0 * e^{\frac{-M_r*g*h}{R*T}}$$

$$P_0 = \frac{P}{e^{\frac{-M_r*g*h}{R*T}}}$$

$$e^{\frac{-M_r*g*h}{R*T}} = \frac{P}{P_0}$$

$$\frac{-M_r * g * h}{R * T} = \ln\left(\frac{P}{P_0}\right)$$

$$-M_r * g * h = R * T * \ln\left(\frac{P}{P_0}\right)$$

$$h = -\frac{R * T * \ln\left(\frac{P}{P_0}\right)}{M_r * g}$$

Symbol	**Description**	**Unit**	**Value**
h	Altitude above sea level	m	
R	Gas constant	$J \cdot mol^{-1} \cdot K^{-1}$	8.3144621
T	Temperature	$K(=T_C + 273.15)$	
P	Pressure	Pa	
P_0	Pressure at 0m	Pa	1 atmosphere = 101325.00
M_r	Molecular mass of air on Earth	$kg \cdot mol^{-1}$	0.0289644
g	Gravitational constant	$m \cdot s^{-2}$	9.8127534

Gauss-formula

The Gauss-formula is used for calculating the possibility of getting a certain value, in a given experiment. In this case, the Gauss-formula gives the possibility of measuring, for example, 10 counts/s. The Gauss-formula is a continuous function, which means that x can be every value.

$$gauss(x) = \frac{a}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Symbol	Description
Gauss(x)	The possibility
a	Amplitude
σ	Standard deviation
μ	Average

All values are different depending on the histogram. Therefore, only the standard formula is given.

Poisson-formula

The Poisson-formula is also about the possibility of measuring a certain value, but the Poisson curve is discrete instead of the continuous Gauss curve. This means that x can only be an integer.

$$poisson(x) = \frac{\lambda^x}{int(x)!} \quad e^{-\lambda}$$

Symbol	Description
Poisson(x)	The possibility
λ	λ is a positive real number, equal to the number of occurrences in the time interval. For example, if the expectation is one occurrence every two minutes and the time interval is ten minutes, then $\lambda = 5$.
!	Factorial. 5! Equivalent to $5 \cdot 4 \cdot 3 \cdot 2 \cdot 1$.
Int(x)	Makes sure that x becomes a discrete variable. This means that, for example, 5.2 becomes 5.

Polynomial

The formula of a polynomial can be written as follows: $a_0 + a_1x + a_2x^2 + \cdots + a_nx^n$. This formula can be as long as necessary and is used for the temperature graph. The formula that was used was: $a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gx^6$. Because all letters do not have a useful meaning, there is no description given in this instance.

Standard formula

The following formula was used to make a near straight line.

$$\frac{a}{b + x^2} + c$$

Because all letters do not have a useful meaning, there is no description for this formula either.

1.3 Investigation plan

1.3.1 Sub question 1

What: Analysis air shower and particles

Why: The research done in this project is about cosmic radiation. To be able to research this radiation, it is necessary to know how these processes work and what kind of particles you can encounter.

Who: Marijn and Joey will make this analysis and Koen will check it. Everyone will read the result to get this necessary knowledge as well.

Due: This analysis will be finished on 13 February 2015.

1.3.2 Sub question 2

What: Analysis atmosphere

Why: The research takes place in the stratosphere. It is important to know under which circumstances the research device has to operate.

Who: Arie will work on this analysis and it will be checked by Marijn. The other group members will look into this data after the analysis is finished.

Due: This analysis will be finished on 27 February 2015.

1.3.3 Sub question 3

What: Analysis GM-counter

Why: The measuring device, HACORD IV, consists of four GM-tubes. To understand how the data is collected, we have to know how this GM-tubes work.

Who: Marijn will make this analysis and Arie will check it. Everyone will read the result to get this necessary knowledge as well.

Due: This analysis will be finished on 27 February 2015.

1.3.4 Sub question 4

What: Analysis batteries

Why: The electricity for the measuring device is provided by a battery. Because the devices will encounter various extreme circumstances, the battery has to be able to withstand these circumstances as well. That is why the choice of battery is important.

Who: Marijn and Joey will make this analysis and Arie will check it. Everyone will read the result to get this necessary knowledge as well.

Due: This analysis will be finished on 3 March 2015.

1.3.5 Sub question 5

What: Analysis solar cycle

Why: To compare the radiation intensity to intensity of the solar cycle, we have to know how the intensity of the sun changes.

Who: Koen and Joey will make this analysis and Marijn will check it. Everyone will read the result to get this necessary knowledge as well.

Due: This analysis will be finished on 13 March 2015.

1.3.6 Sub question 6

What: Masterclass at University of Antwerp

Why: In this short lecture Prof. Dr. N. van Remortel of the University of Antwerp will give a short introduction on particle physics and the workings of Batteries and GM-tubes. We will need knowledge on all of these subjects to enable us to work on this project.

Who: Everyone and Prof. Dr. N. van Remortel

Due: 5 March 2015

1.3.7 Sub question 7

What: Calibration and testing of the HACORD IV

Why: To make sure our research device works.

Who: Everyone in cooperation with the UA

Due: 5 March 2015

1.3.8 Sub question 8

What: Making graphs of the test results of the previous sub question.

Why: To practice processing information we gather from the HACORD.

Who: Everyone

Due: End of March

1.3.9 Sub question 9

What: Conducting measurements

Why: To gather data for our research.

Who: Everyone, cooperating with the KNMI and the UA

Due: Start of April

1.3.10 Sub question 10

What: Data Analysis

Why: To try to correlate the data of this year and the preceding years.

Who: Everyone

Due: 29 May 2015

2. Preliminary measurements

These are all graphs we plotted using the data we obtained from the measurements we did on the 5th of March.

Graph 1

The first graph in the series of 10 measurements with a Sr-source (Strontium) at different distances from the Geiger-counters. The data of the experiment with the Sr-source at a distance of 1 cm can be seen in the graph below. The graphs shows the measurements of HACORD IV. Of the HACORD IV, only the third tube is used and not all four tubes. This is a true for all graphs that were produced with the data of the first experiment.

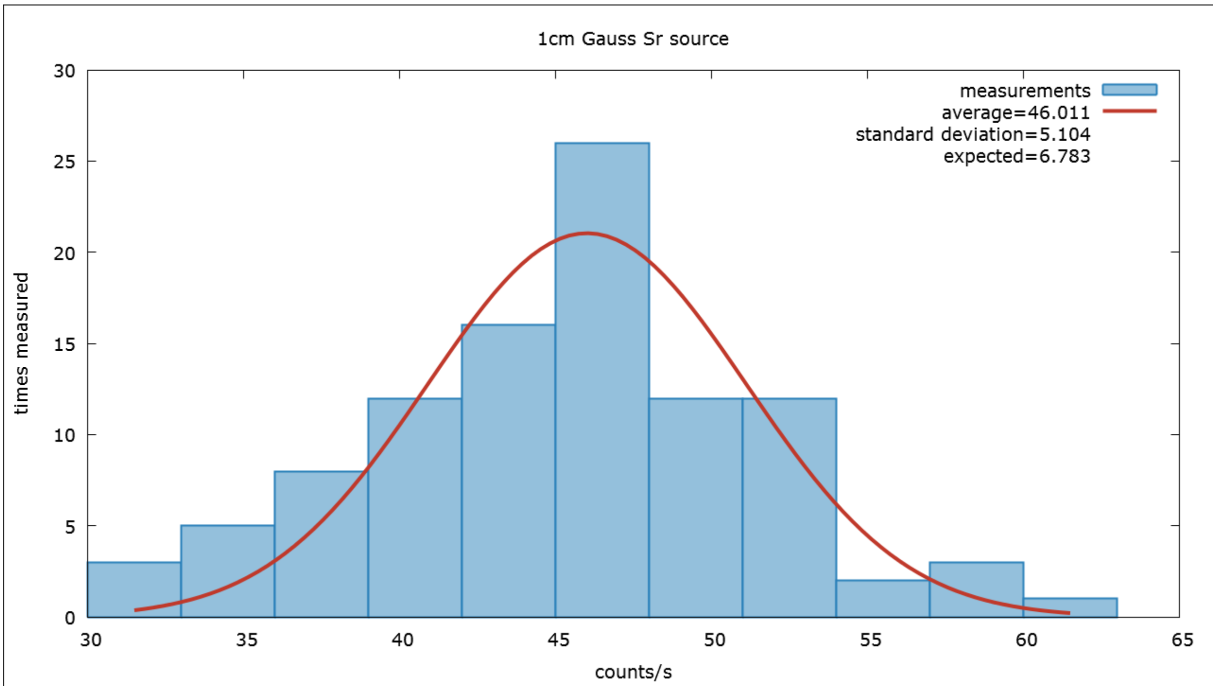

Figure 10

Graph 2

The second graph in the series of 10 measurements with a Sr-source at different distances from the Geiger-counters. The data of the experiment with the Sr-source at a distance of 2 cm can be seen in the graph below.

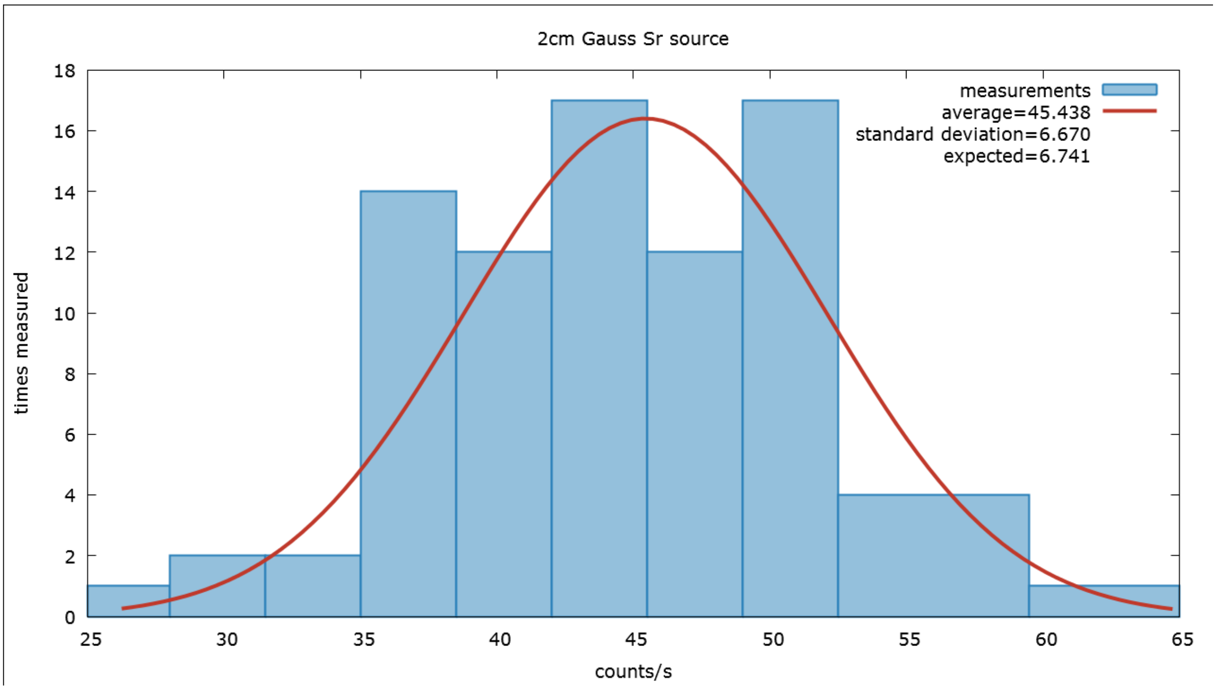

Figure 11

Graph 3

The third graph in the series of 10 measurements with a Sr-source at different distances from the Geiger-counters. The data of the experiment with the Sr-source at a distance of 4 cm can be seen in the graph below.

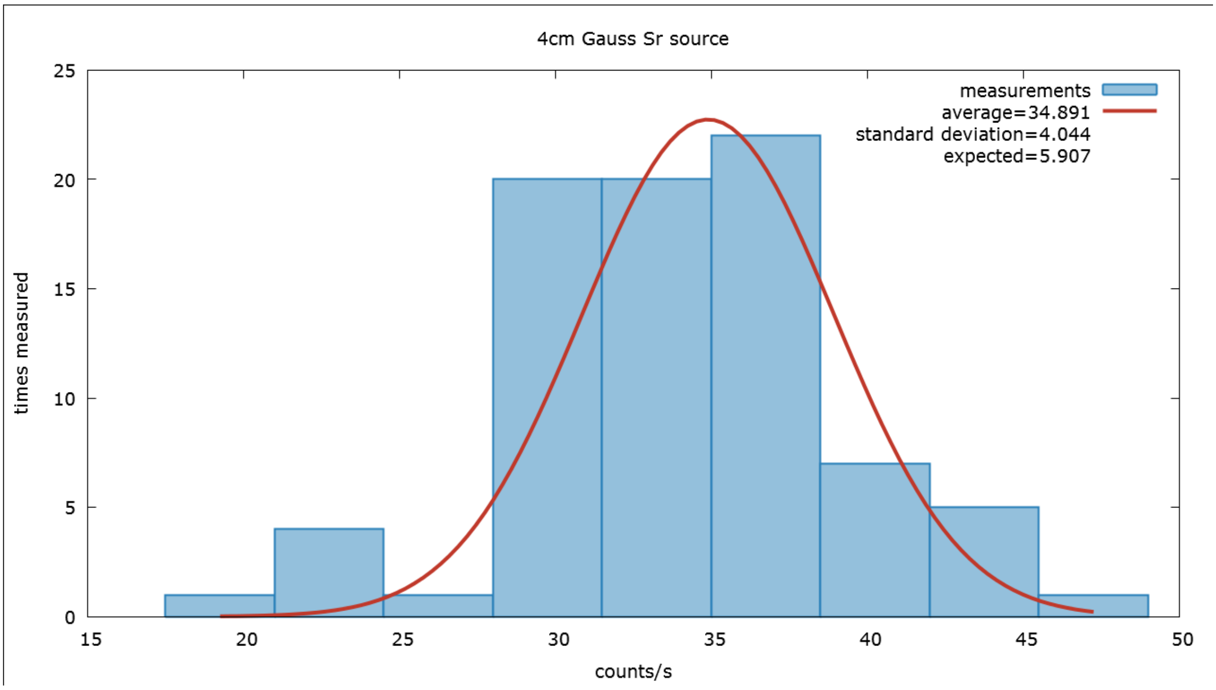

Figure 12

Graph 4

The fourth graph in the series of 10 measurements with a Sr-source at different distances from the Geiger-counters. The data of the experiment with the Sr-source at a distance of 6 cm can be seen in the graph below.

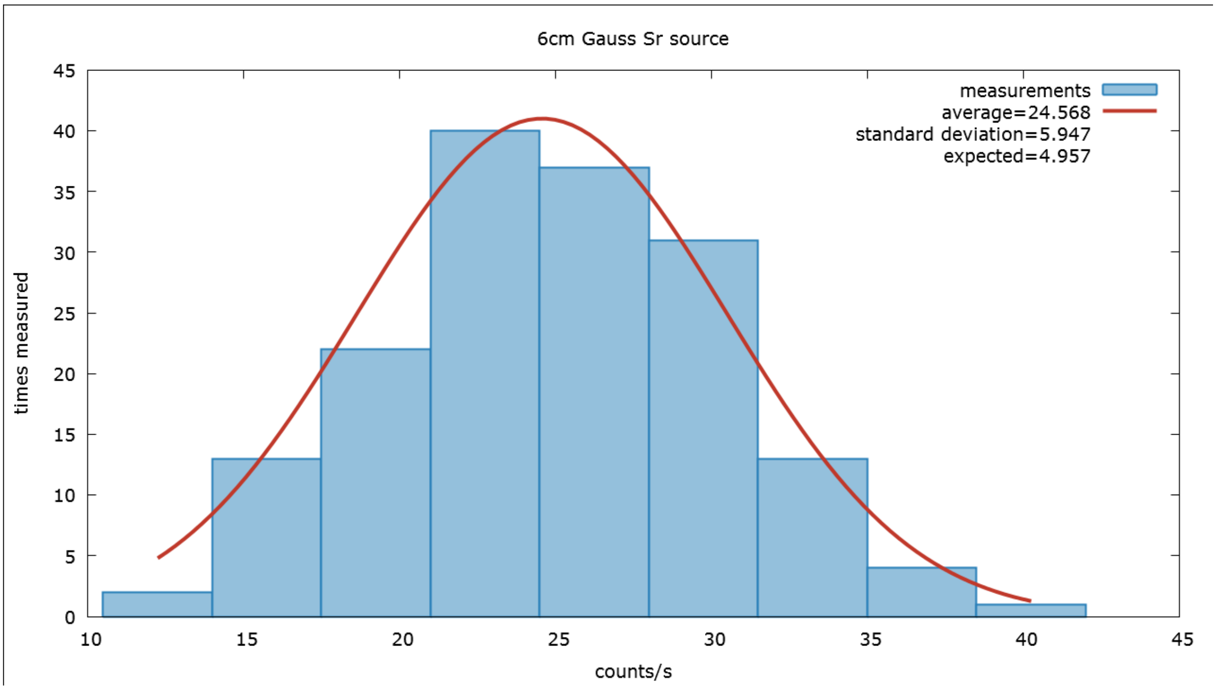

Figure 13

Graph 5

The fifth graph in the series of 10 measurements with a Sr-source at different distances from the Geiger-counters. The data of the experiment with the Sr-source at a distance of 8 cm can be seen in the graph below.

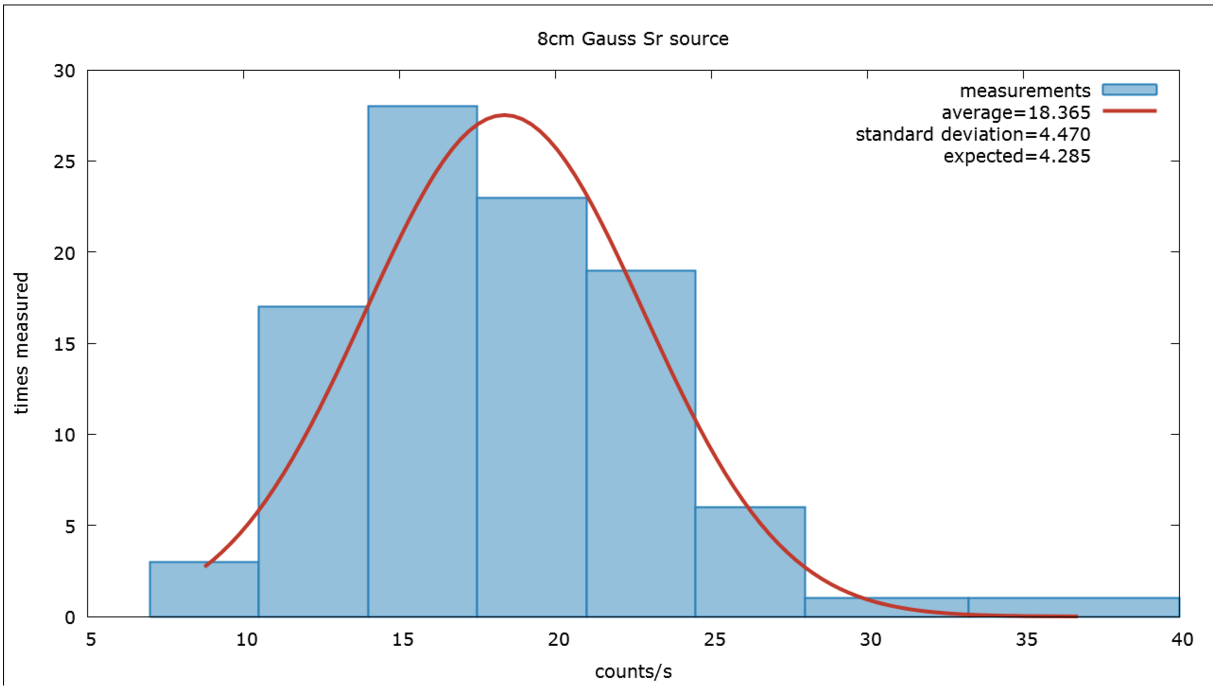

Figure 14

Graph 6

The sixth graph in the series of 10 measurements with a Sr-source at different distances from the Geiger-counters. The data of the experiment with the Sr-source at a distance of 9 cm can be seen in the graph below.

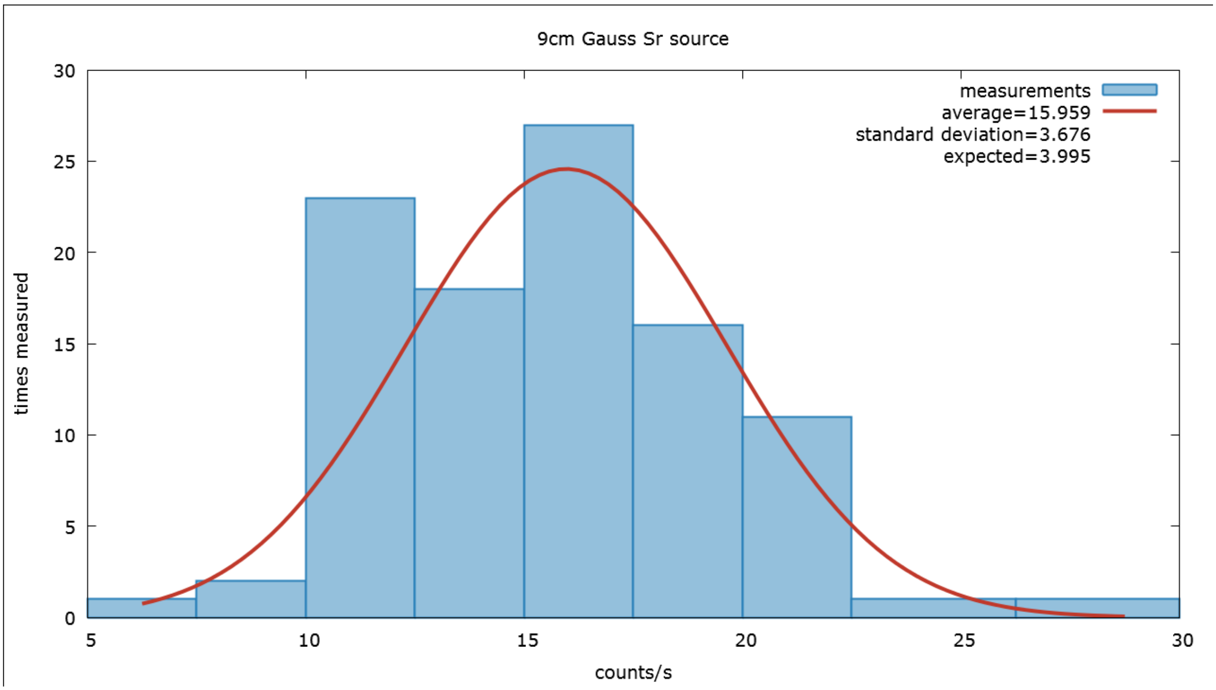

Figure 15

Graph 7

The seventh graph in the series of 10 measurements with a Sr-source at different distances from the Geiger-counters. The data of the experiment with the Sr-source at a distance of 10 cm can be seen in the graph below.

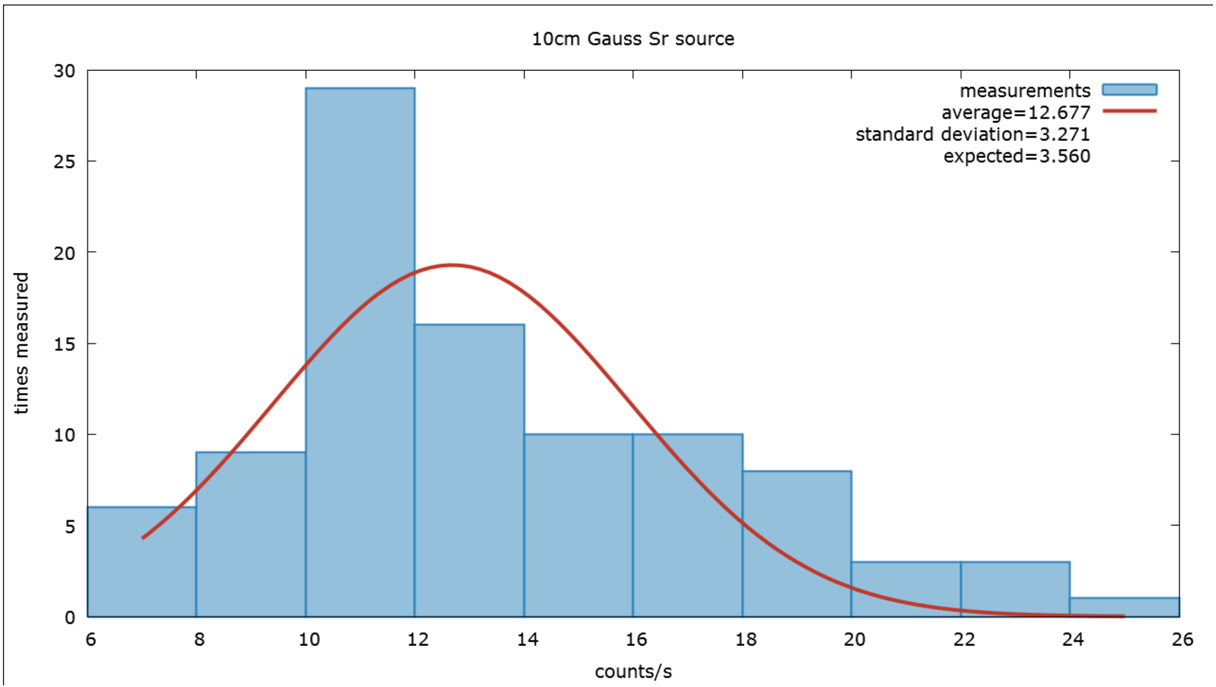

Figure 16

Graph 8

The eighth graph in the series of 10 measurements with a Sr-source at different distances from the Geiger-counters. The data of the experiment with the Sr-source at a distance of 12 cm can be seen in the graph below.

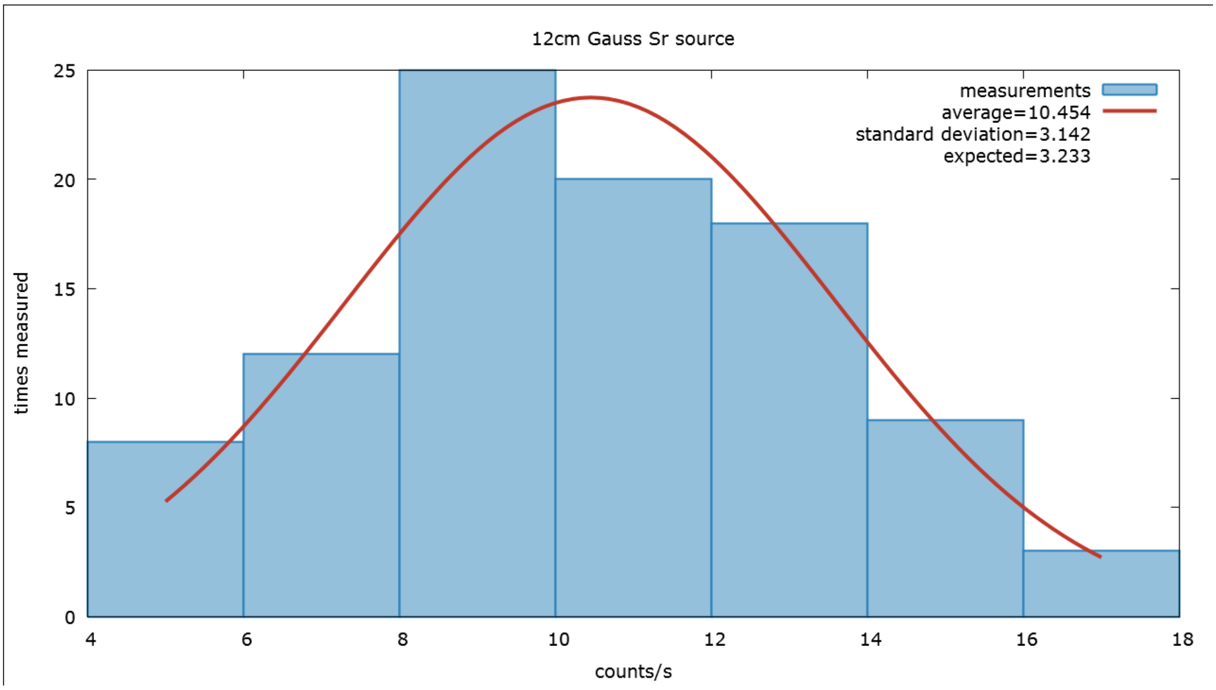

Figure 17

Graph 9

The ninth graph in the series of 10 measurements with a Sr-source at different distances from the Geiger-counters. The data of the experiment with the Sr-source at a distance of 14 cm can be seen in the graph below.

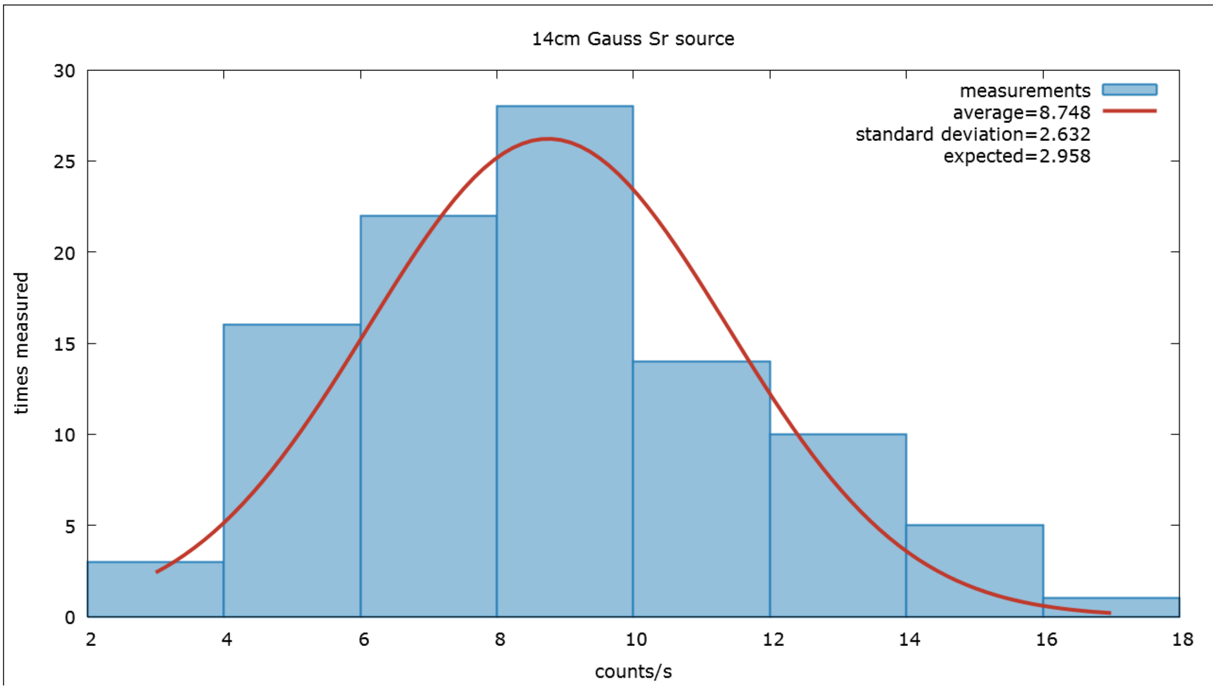

Figure 18

Graph 10

The tenth and last graph in the series of 10 measurements with a Sr-source at different distances from the Geiger-counters. The data of the experiment without a Sr-source can be seen in the graph below. In this case, the background radiation is measured. In graph 20, the Poisson distribution of this graph can be found.

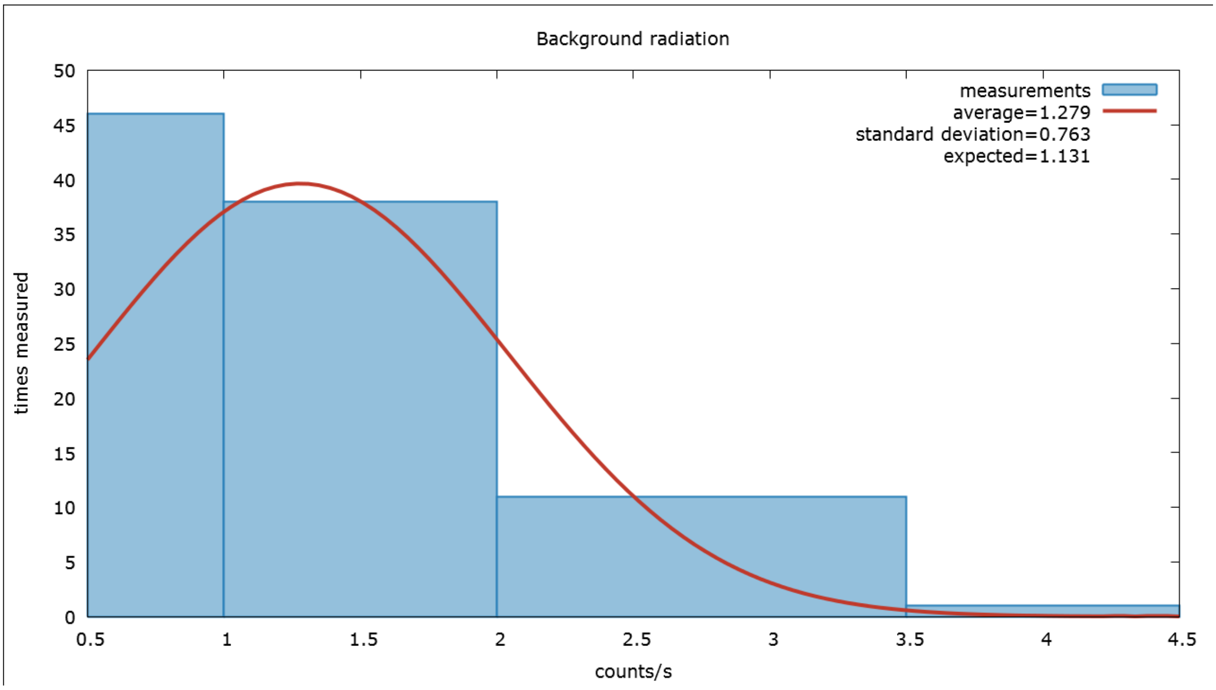

Figure 19

Graph 11

In the graph below, the deviation of HACORD IV relative to a commercial Geiger-counter can be seen. The HACORD teller probably has a maximum measurable intensity of about 50 counts/s. As a consequence, the relationship smooths at approximately 50 counts/s. Furthermore, the HACORD-tube is longer and thinner than the commercial counter, causing the HACORD-tube to receive more radiation at a larger distance. At the start of the experiment, the Sr-source was more directly focused to the commercial tube than to the HACORD-tube. As a cause, the commercial counter will measure more at the start than the HACORD-counter. These three properties of the experiment setup have influenced the results. As a consequence, the final relationship is very different from the expected relationship.

Margin of error: $\sqrt{y}$

An alternative fit can be found in graph 19.

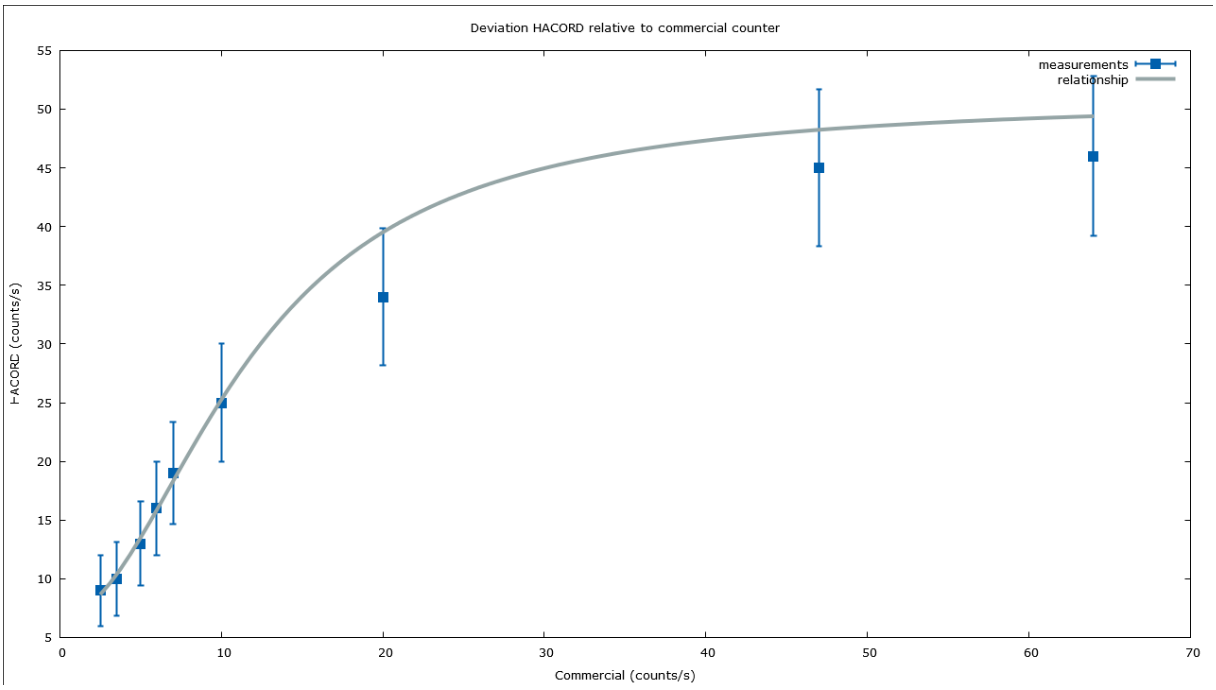

Figure 20

Graph 12

The commercial counter was better aligned to the source than the HACORD GM-counter.

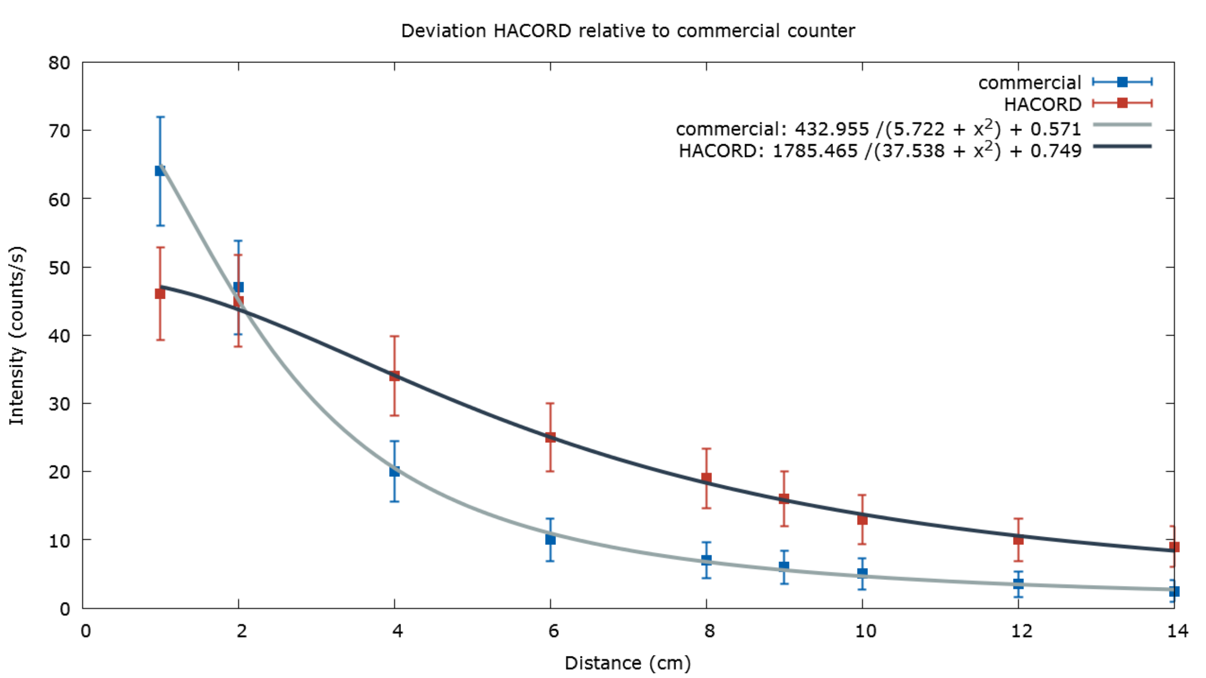

Figure 21

Graph 13

Data averaged over a longer period of time.

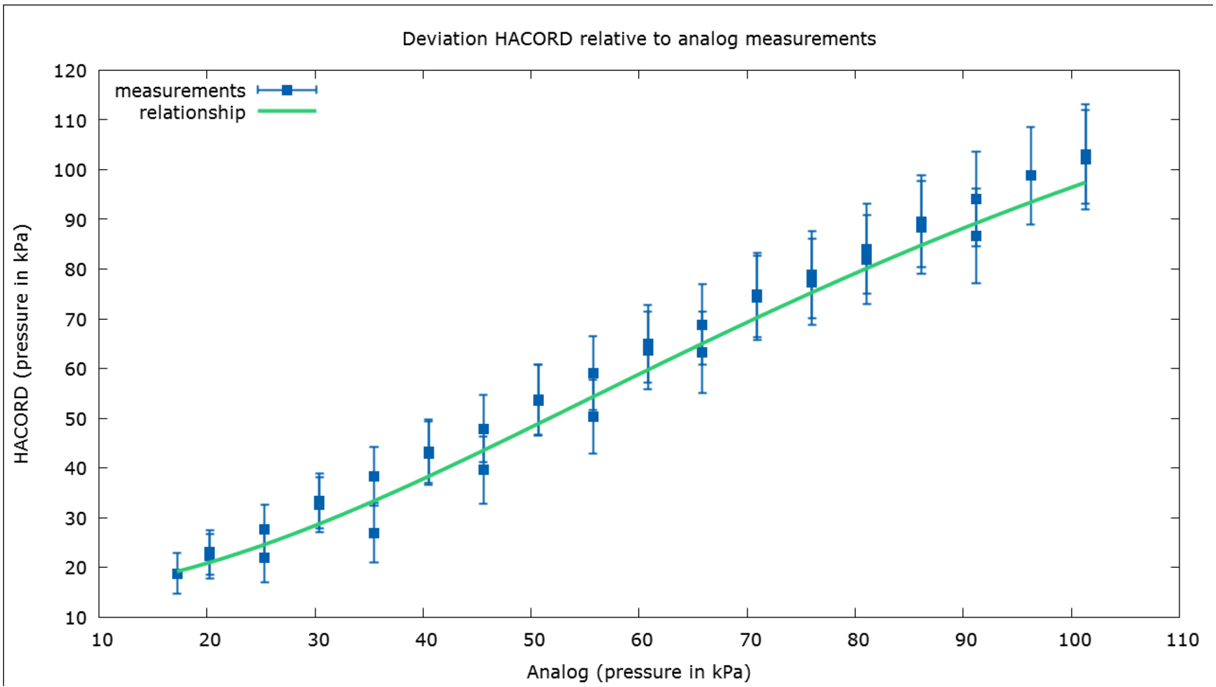

Figure 22

Graph 14

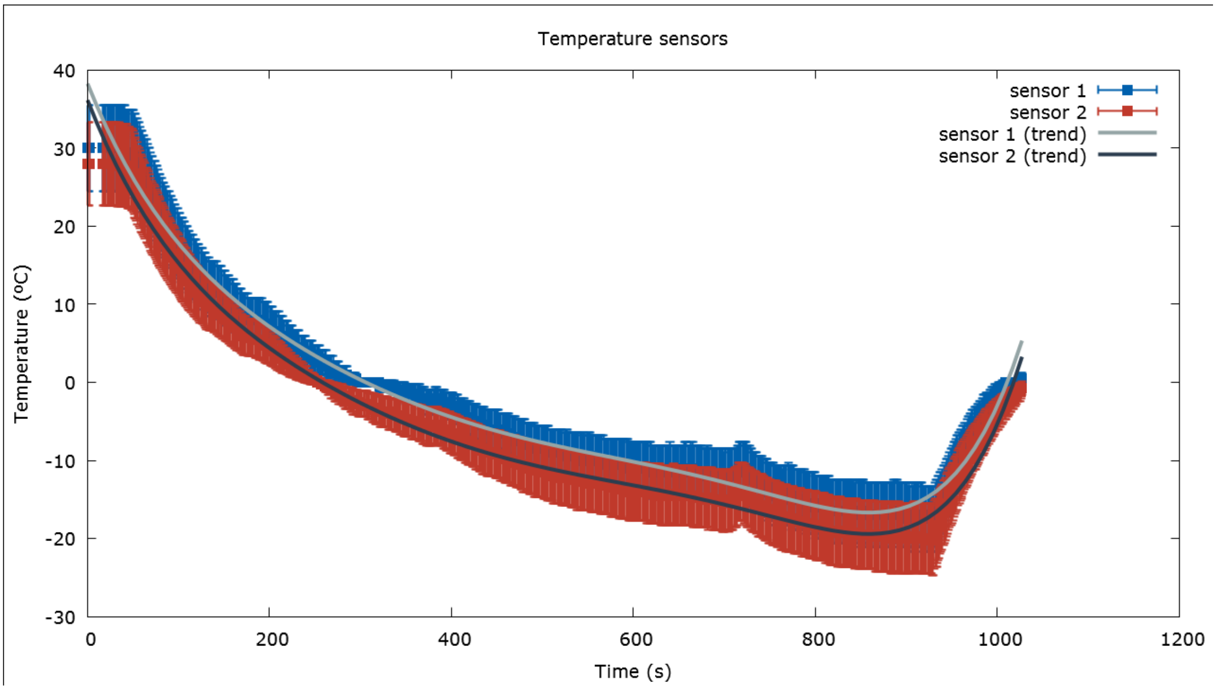

Figure 23

Graph 15

Margin of error: $\sqrt{|y|}$

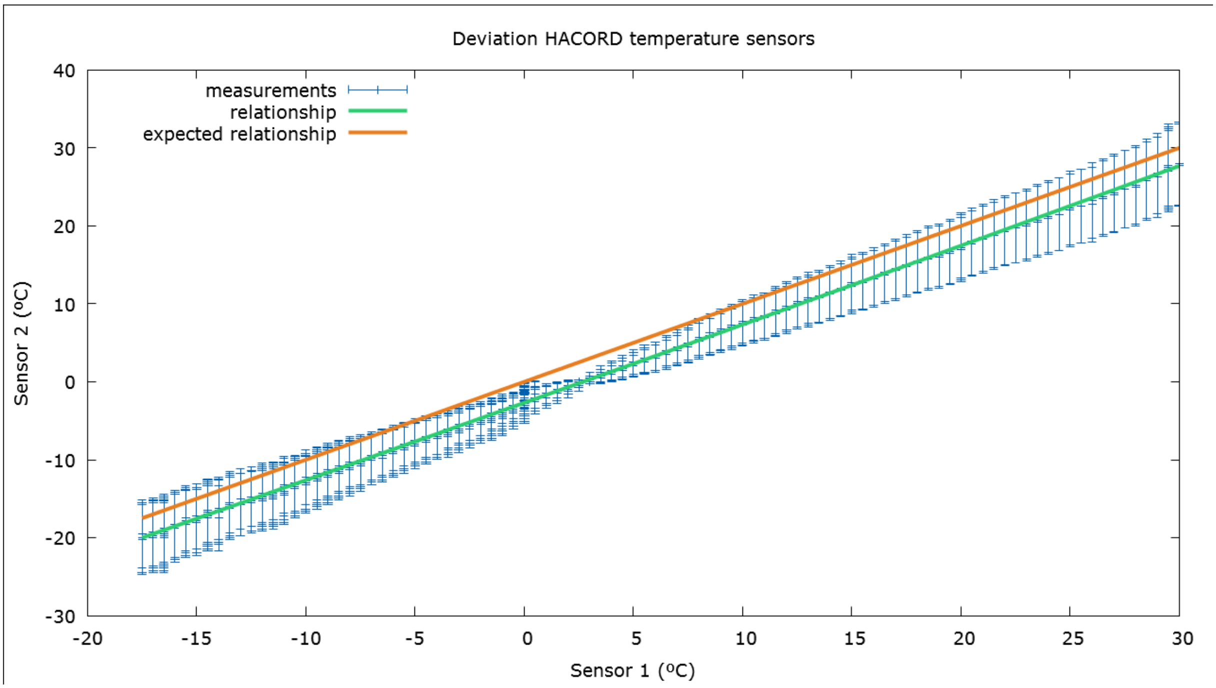

Figure 24

Graph 16

This data corresponds with the data in graph 17. The data is not correct, because we have not measured at an altitude, but this was mainly used to learn how to use the barometric formula, which can be found in chapter 1.2.7. More information can be found at graph 17.

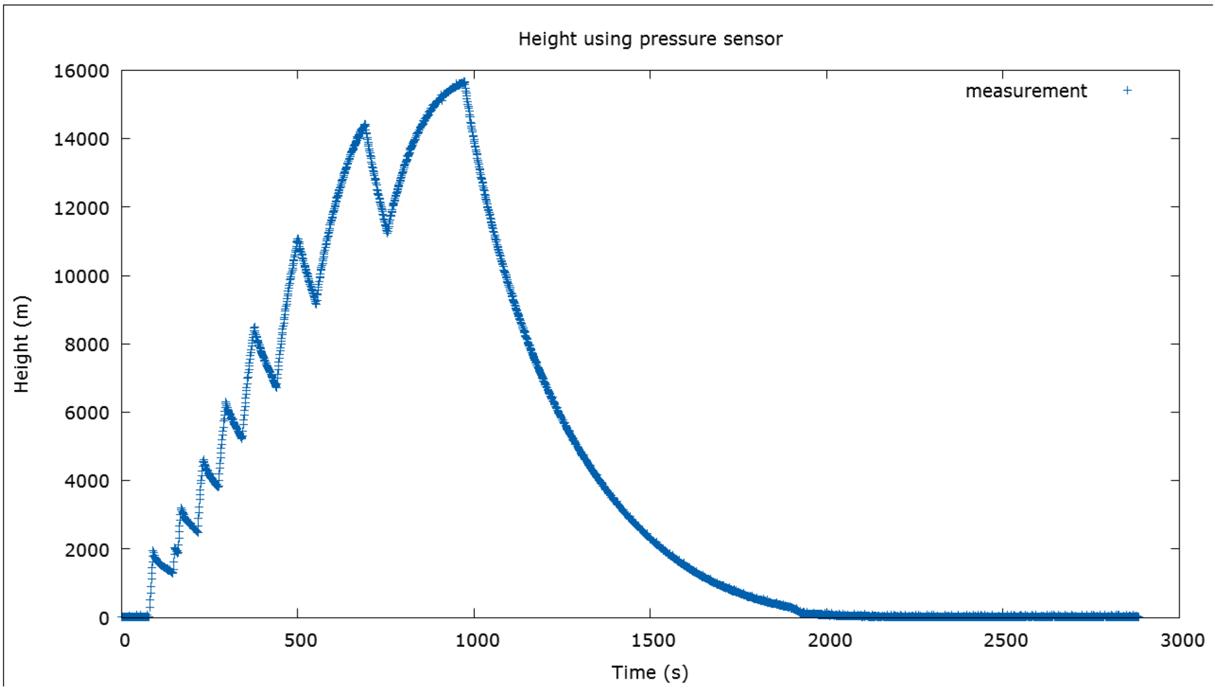

Figure 25

Graph 17

The pressure we have measured under the vacuum pump. There is a zigzag pattern in the graph because we turned off the pump and let the pressure stabilize, causing a recoil.

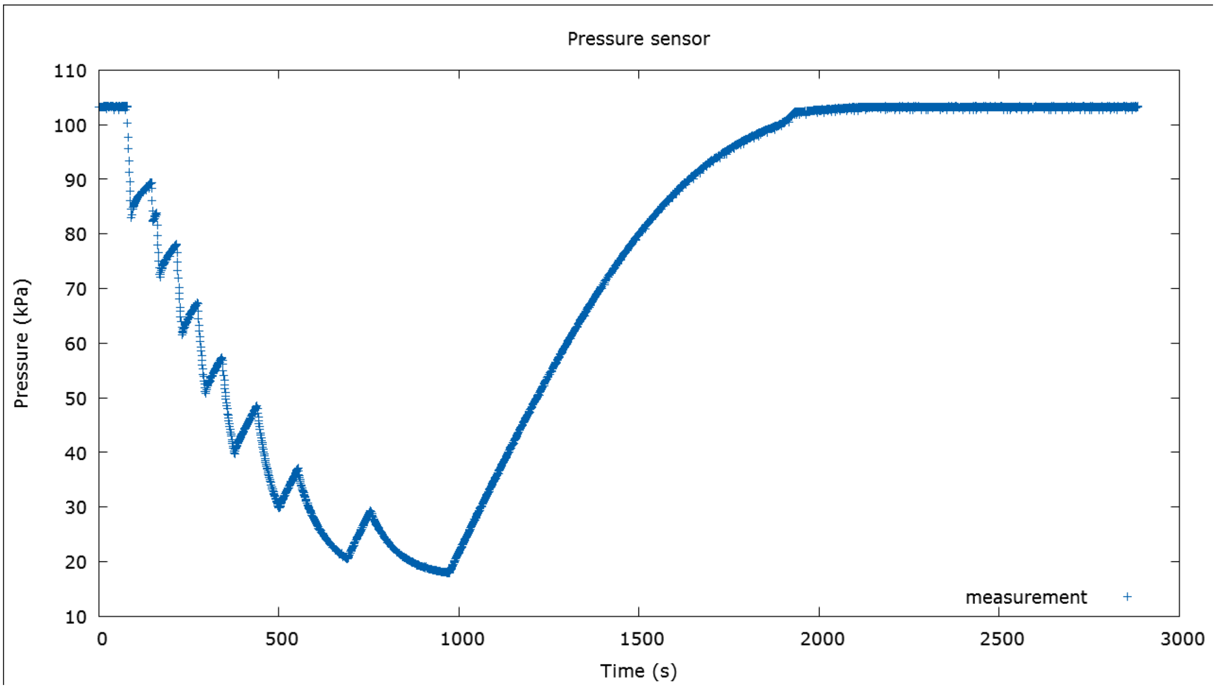

Figure 26

Graph 18

Source: WDC-SILSO, Royal Observatory of Belgium, Brussels

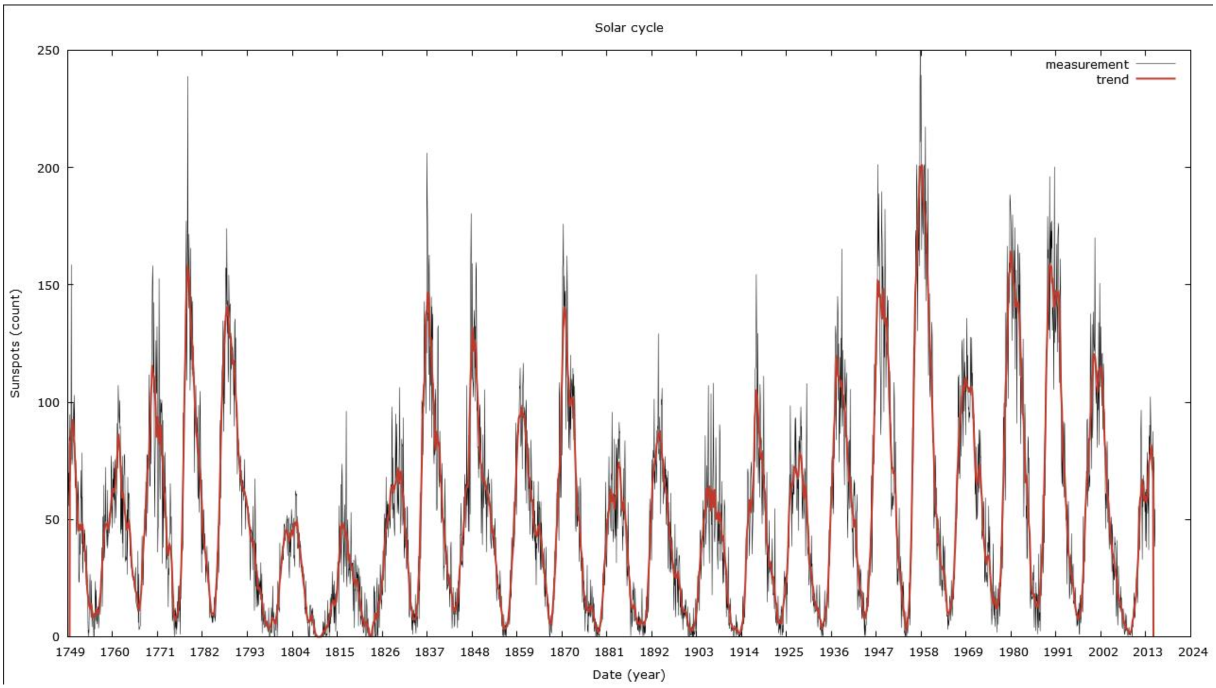

Figure 27

Graph 19

First 6 data points of graph 11.

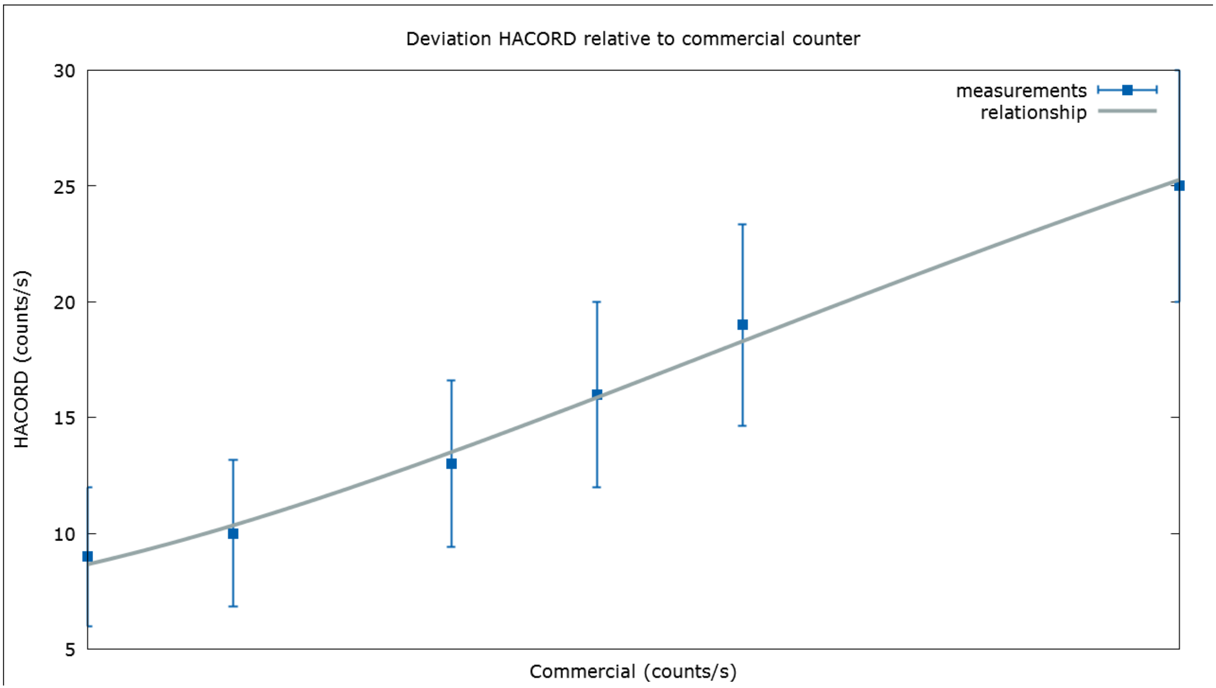

Figure 28

Graph 20

This is a Poisson distribution made of graph 10.

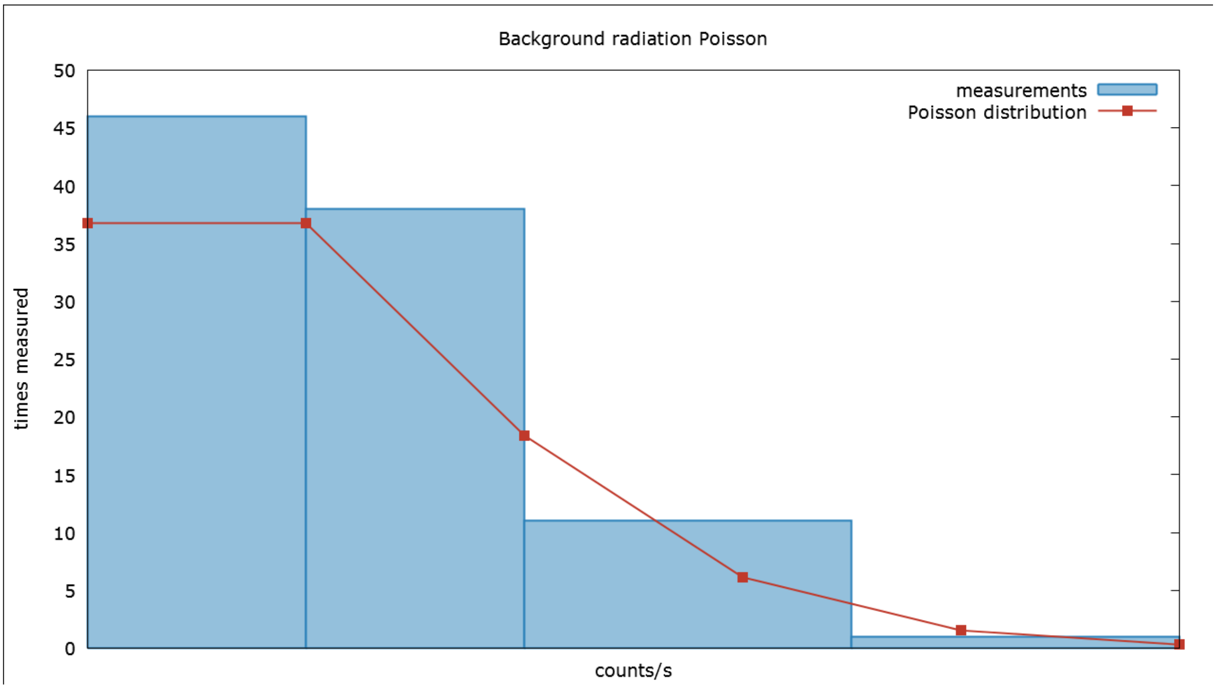

Figure 29

3. Methods and materials

During the experiments the HACORD IV device was attached to an existing ozone-probe of the KNMI. These probes are used weakly in their measurements. During its flight the following data was logged: counts per second, pressure, temperature, time and humidity. The pressure could be used to calculate the height. The counts per second, measured by HACORD's Geiger counters, are the most important to the project.

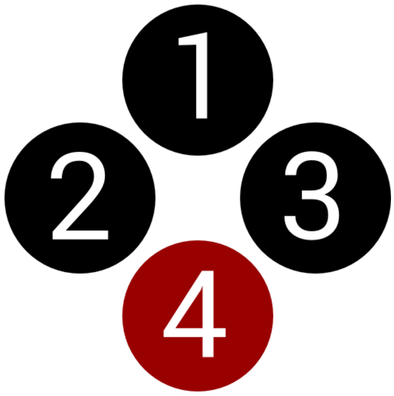

Figure 30 Schematic representation of the tubes

3.1 Experiment setup

Materials

- Radio-probe RS92SGPD, op 403.90 MHz
- Sensors: pressure, temperature, humidity, GPS (position + wind)
- Ozone-sensor (ECC6A)
- Radioactivity-sensor (HACORD)
- Balloon (TOTEX TX1200)
- 2 parachutes
- Line (woven cotton, 20-25 meter)

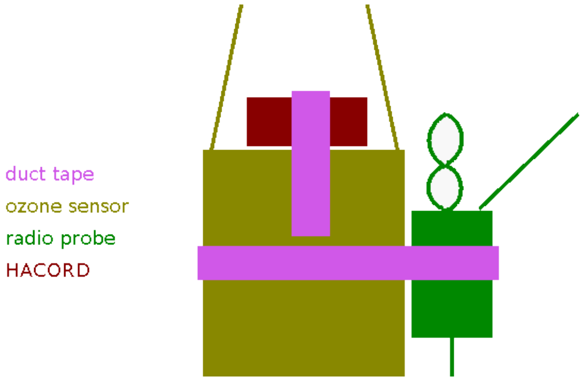

Figure 31 A schematic representation of the experiment setup

Method

- Test and gauge all equipment.
- Tie the equipment together as shown in figure 31.
- Attach the tied devices to the balloon.
- Release the balloon .
- Retrieve the probe where it landed.
- Read and process the data.

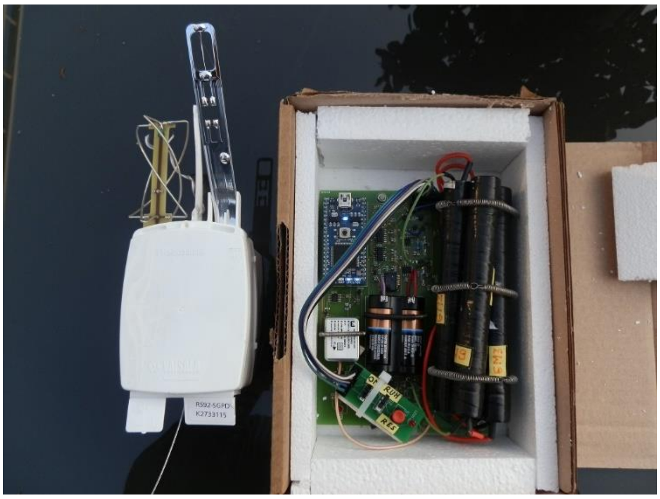

Figure 32 The experiment after it had landed

4. Results

After the probe was retrieved and the data was received the processing of the data could begin. Prof. Van Remortel added, when he transferred the data, that there were a few things that needed extra attention. Tube 4 of the HACORD device had not functioned during the experiment and the measurements are only usable until a height of 20 km. Shortly after that the device completely stopped working.

The first graph shows the height (figures 33). For this graph the barometric formula was used to make the HACORD and the green KNMI graphs. The other KNMI graphs did not need the formula. The graph shows that both the pressure sensor and clock of the HACORD were not very accurate. Both devices get less and less accurate as the height increases. The graph also shows that HACORD stops working after a certain time.

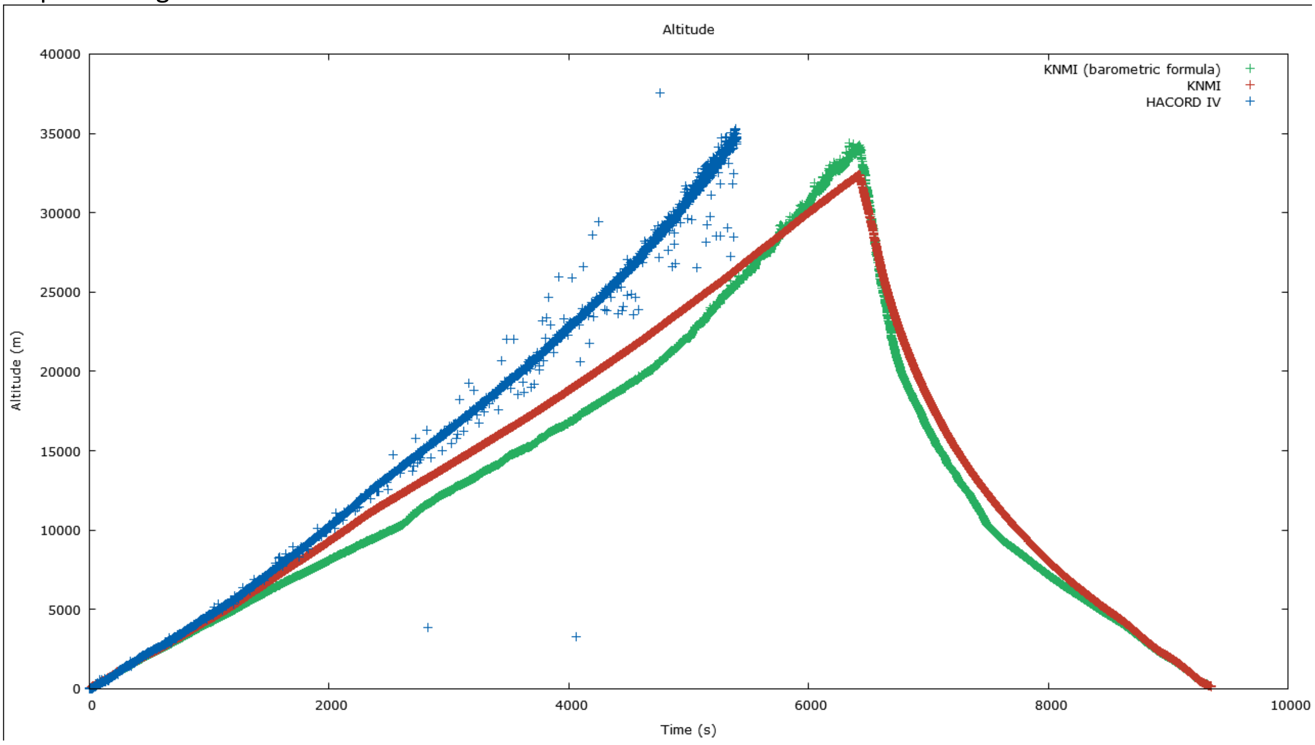

Figure 33 Graph of the altitude using the measurements of HACORD and of the KNMI

Figures 34, 35 and 36 are the most interesting graphs. They show all radiation data from past years in one graph. Figure 34 shows all data relative to the time, like figure 35. The difference between them is the Bezier option used in figure 35, which shows the data more clearly. Figure 36 shows the data of the radiation relative to the height. Here only the data form 2014 and 2015 are shown, as the 2012 and 2013 devices did not have a pressure sensor on board. This also made it impossible to derive the height from the 2012 and 2013 data.

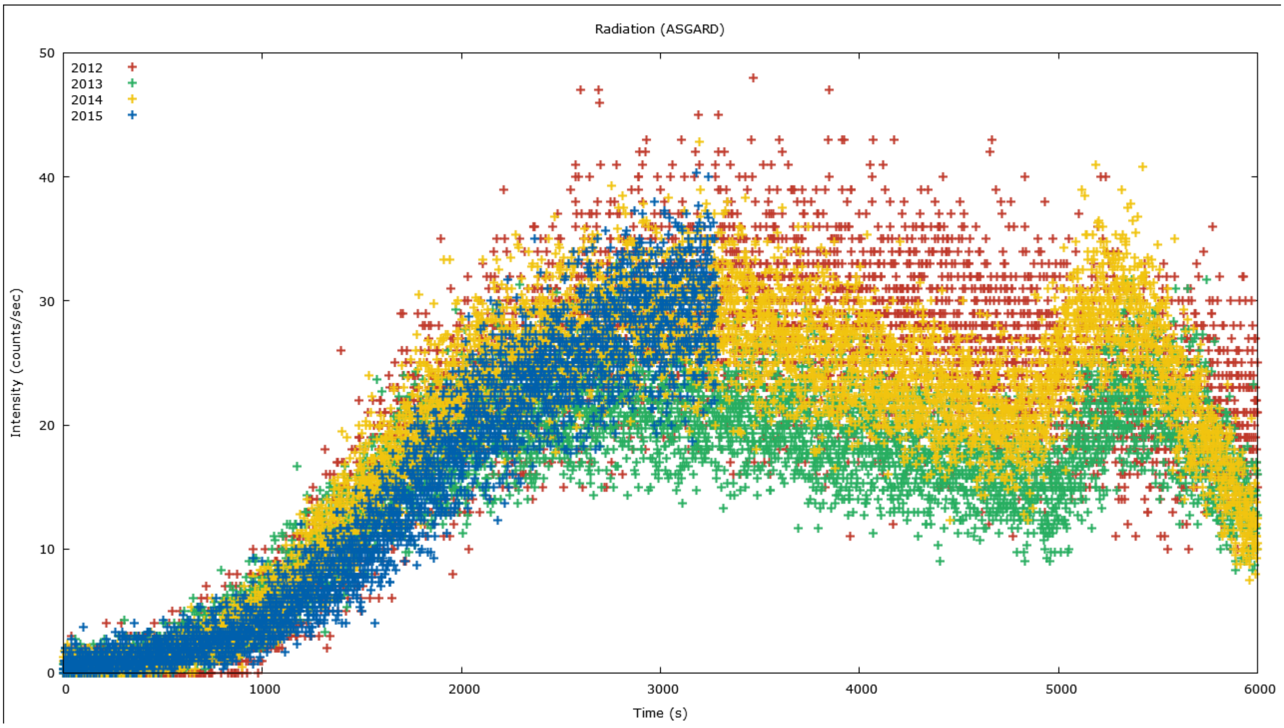

Figure 34

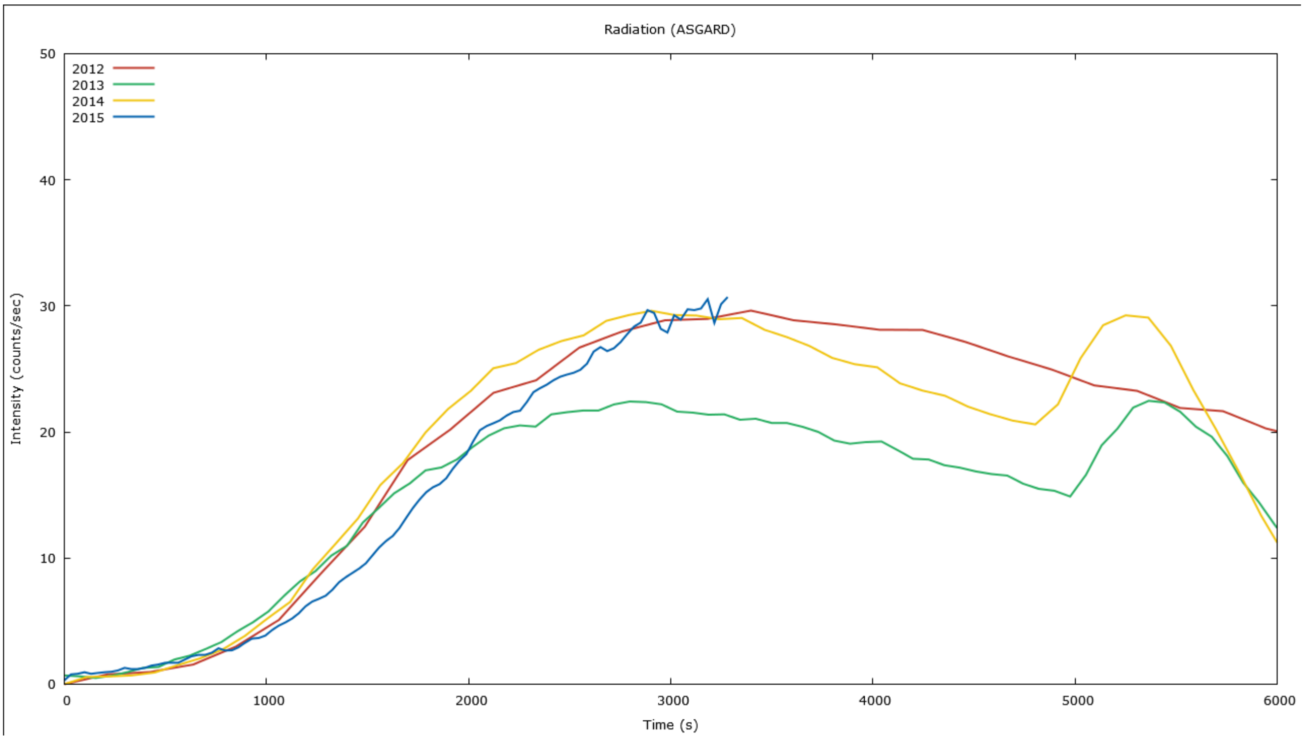

Figure 35

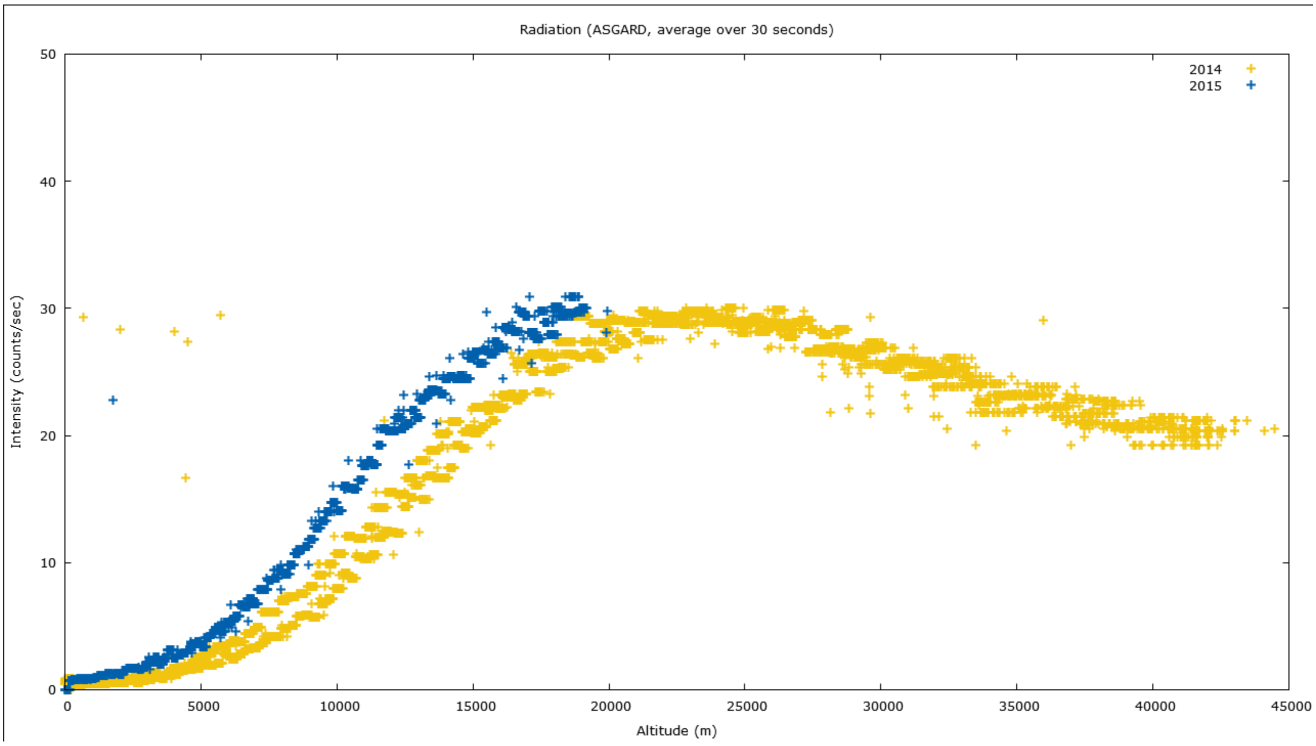

Figure 36

Figure 37 shows the amount of radiation for each tube, relative to the height. Only 2014 and 2015 data was used. This graph shows the angle of incidence. Since tube 4 did not function in the 2015 experiment, it could not be used to determine the angles. Tube 4 was the bottom tube in the 2015 experiment. In order to make a comparison with the 2014 experiment data, the bottom tube from that experiment (tube 1), was also left out.

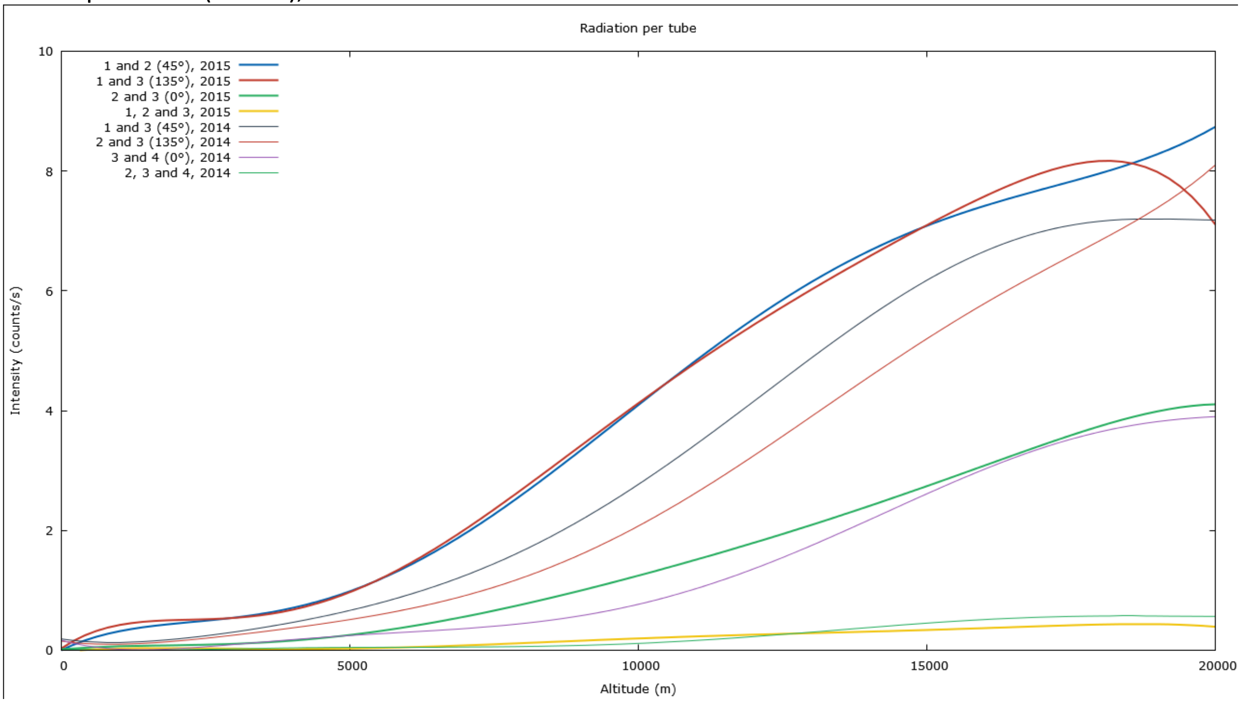

Figure 37

Figures 38 and 39 show the connection between the solar cycle and the average radiation intensity per year. Seeing as the research has only been going for four years, a clear connection could not yet be proved.

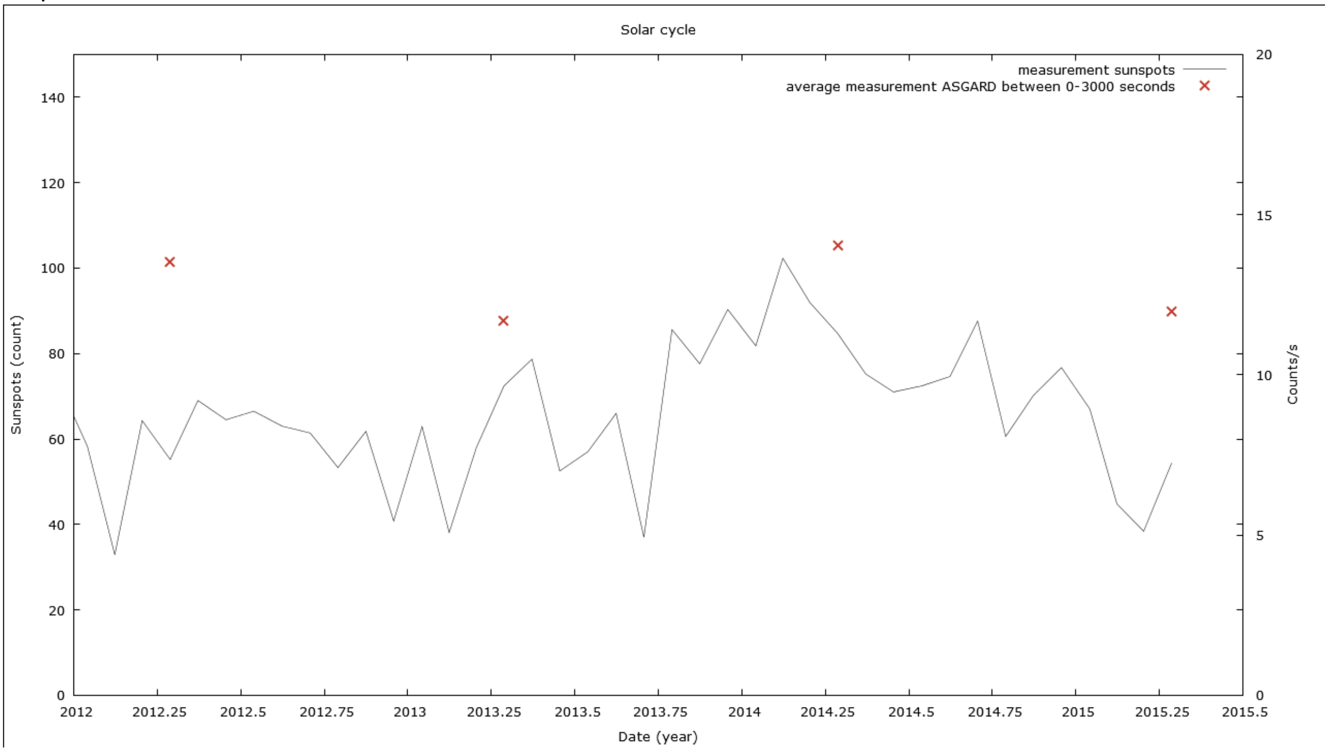

Figure 38

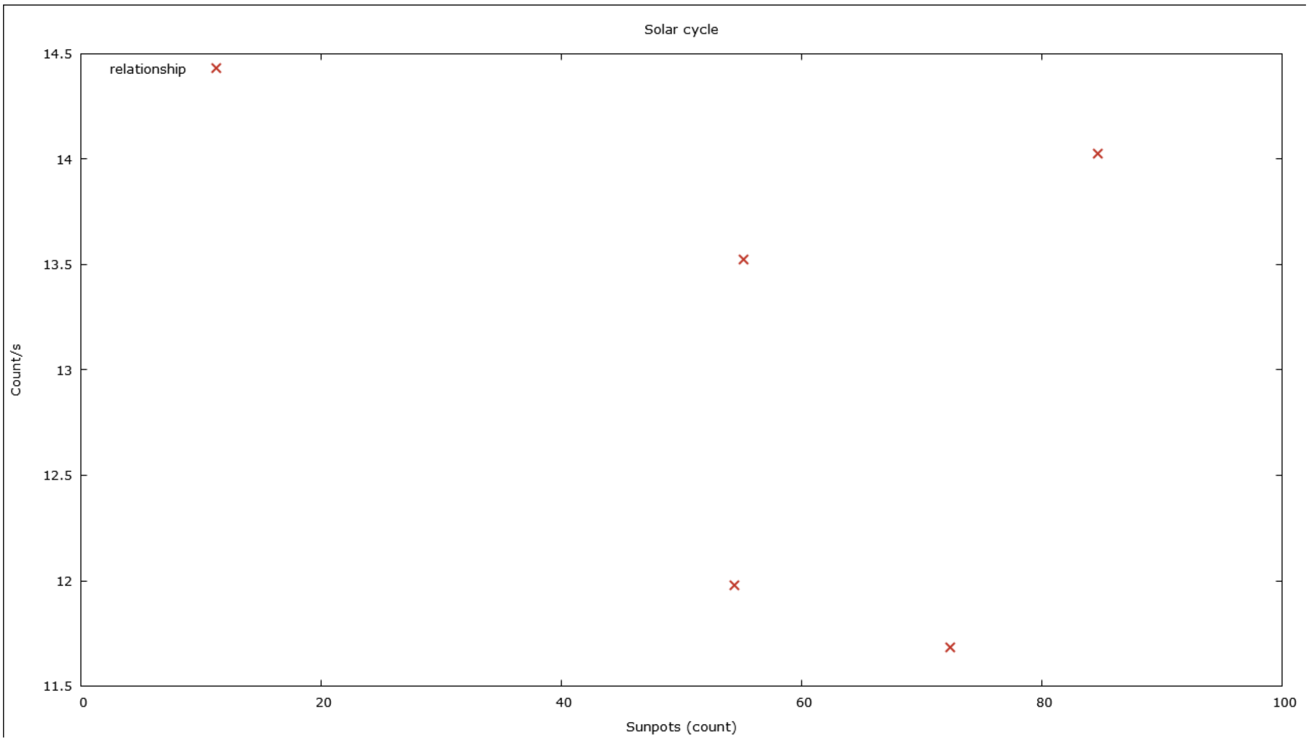

Figure 39

5. Conclusion and discussion

5.1 Main question

Is there a relationship between the data of 2015, the previous years and the 11-year solar cycle?

A relationship can be found between the different years. The data measured during the ascend of the HACORD equipment is quite the same. Unfortunately, there is no data available for the full flight in 2015. When the data is compared with the intensity of the solar cycle, no link can be made. To be able to see this link, data over a larger period of time is necessary.

5.2 Sub questions

What is the distribution with regards to the movement directions of the particles and is there a variation of this as a function of the altitude? With the HACORD II, the first steps towards answering this question were made, but with only two Geiger-Müller-tubes, the resolution was limited. By using four Geiger-Müller-tubes, the resolution was significantly increased.

Figure 37 clearly shows the relationship between the movement direction of the particles and the altitude. This can be seen for both the data of 2014 and the data of 2015. In this graph, it can clearly be seen that for both years, the radiation at an angle of 45° and 135° produces the most counts per second. This can be explained easily because the radiation comes in at a small angle, but still from the top. Radiation at an angle of 0° is still fairly common, certainly at higher altitudes. This is radiation that passes through HACORD horizontally. The lower lines show the radiation going through three tubes at the same time. This is quite rare and this can therefore also be seen by the height of the graph.

6. Completion

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6.2 Task division

What	Who	Checked by
Analysis particles and air shower	Joey, Marijn	Koen
Analysis atmosphere	Arie	Marijn
Analysis Geiger-Muller tube	Marijn	Arie
Analysis batteries	Joey, Marijn	Arie
List of questions	Everyone	Everyone
Masterclass University of Antwerp	Everyone	-
Gauging and testing of HACORD IV	Everyone	-
Research proposal:	-	-
Title page	Koen	Marijn
Table of contents	Koen	Joey
Introduction	Marijn	Arie
Chapter 1: Company profile	Arie	Marijn
Chapter 2: Goal of the assignment	Koen	Joey
Chapter 3: Investigation plan	Joey	Koen
Chapter 4: Theoretical exploration	Everyone	Arie
Chapter 5: Schedule	Koen	Marijn
Writing report visit UA	Koen	Marijn
Analysis solar cycle	Joey, Koen	Marijn
Interpretation of the formulas	Koen and Joey	Arie and Marijn
Creating graphs of the test results using gnuplot	Joey and Koen	Arie
Taking measurements	Everyone	-
Analyzing and processing data	Everyone, especially Koen and Joey	Arie and Marijn
Theoretical exploration	Everyone	Everyone
Contact	Koen	Joey
Technical information	Marijn	Joey
Background information	Arie	Koen
Title page	Koen	Marijn
Preface	Joey	Koen
Chapter 1: Table of contents	Koen	Joey
Chapter 2: Introduction	Arie	Marijn
Chapter 3: Methods and materials	Marijn	Arie
Chapter 4: Results	Joey	Koen
Chapter 5: Discussion	Koen	Arie
Chapter 6: Completion	Joey	Arie
Chapter 5: Task division	Marijn	Joey
Chapter 6: Attachments	Arie	Koen
Chapter 6: Epilogue	Arie	Joey
Chapter 7: Summary	Arie	Marijn

6.3 Attachments

6.3.1 Schematic of the experiment

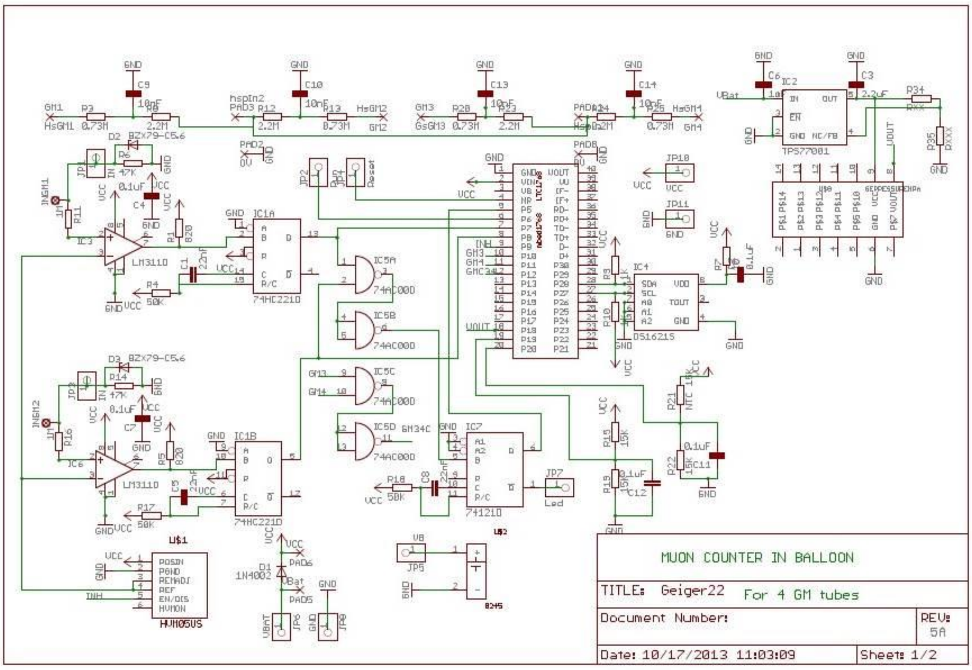

Figure 40

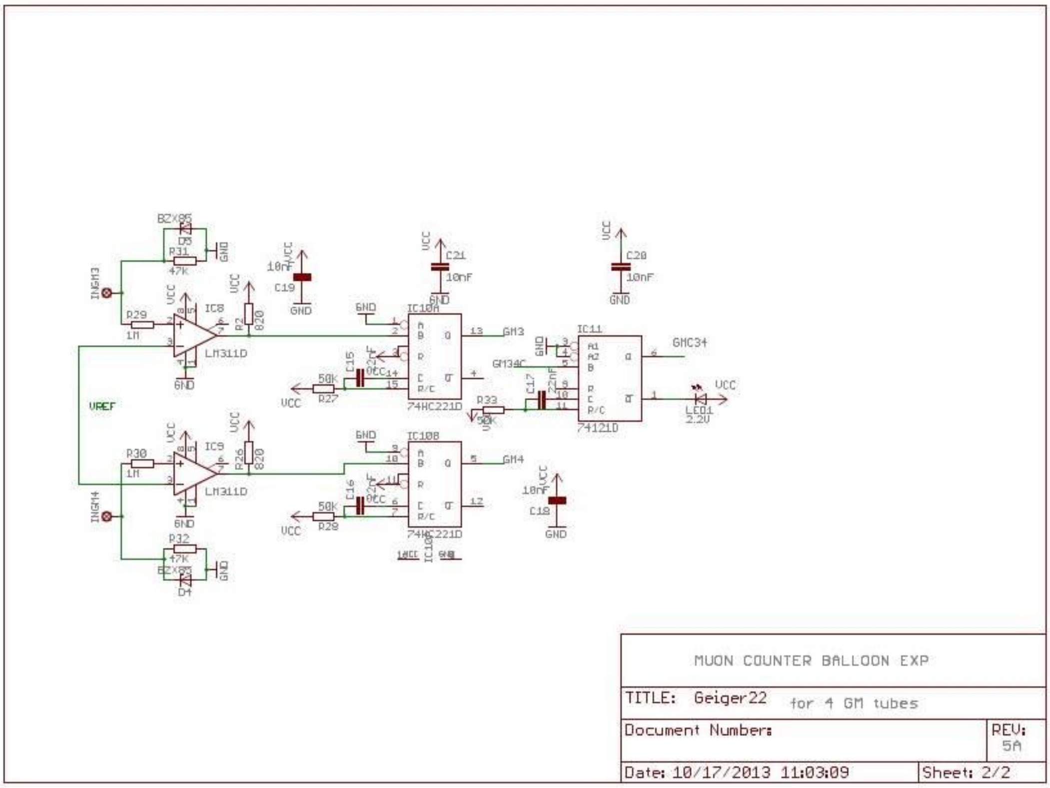

Figure 41

6.3.2 Report University of Antwerp

On the 5th of March 2015, we visited the University of Antwerp, where we received a masterclass physics from prof. Van Remortel. This was necessary so we could understand the definitions and processes that we would encounter in this project.

We started the day with a lesson in particle physics. During this lesson, prof. Van Remortel explained the project itself and among other things, particles, air showers, Geiger-Müller tubes. We made notes during the lessons and learned a whole lot more. Besides, prof. Van Remortel explained what he does at CERN. He basically told us everything, from the construction to the operation of the research.

After the break, we executed various experiments using HACORD. First of all, we tested the device by placing a radioactive source at different distances from the detectors and judging the results. Afterwards, we tested HACORD in a vacuum environment and at low temperatures by using nitrogen. In both extreme circumstances, the measurement equipment did not stop functioning.

6.3.3 Report De Bilt

On the 9th of April 2015, we visited the KNMI to release a weather balloon. At the KNMI, we sent the radiation counter of the University of Antwerp on an ozone flight. At the KNMI, Mr. Allaart also showed us various rooms and divisions of the KNMI, such as the 'weather room', the 'gouge room' and even the lunch room.

The flight started at 13:34 at a field of the KNMI. The balloon snapped after approximately 2 hours at an altitude of 23 kilometers. Half an hour later, the balloon landed in the Achterhoek.

6.4 Epilogue

The past weeks have been busy, challenging and interesting. We started this project without any knowledge of cosmic radiation and in the end we were able to do our own research into it. This would not have been possible without the help of the University of Antwerp, especially professor Van Remortel. Using the masterclass in particle physics we got in Antwerp, we received the knowledge necessary for doing the project. The cooperation was good fun, because Professor Van Remortel was very involved with the project.

It was also quite a challenge get the cooperation between the KNMI and the University of Antwerp going. After a few emails and phone calls we finally managed to do it. By doing this we created our own chance to get the HACORD aboard the KNMI weather balloon.

Our visit to the KNMI was one of the highlights of the project. After the measurements a report had to be written and graphs had to be made. This took some time and energy but was well worth it.

All in all we found this a very fun and interesting project. This was most likely due to the fact that we had a fun, hard-working team and were very well supervised by our teachers as well as the University of Antwerp and the Royal Netherlands Meteorological Institute.

7. Summary

Please note: This is not our abstract, it has been attached separately.

Cosmic radiation started being researched in the beginning of the 20th century. The earth's atmosphere proved to be a promising instrument in the investigation of fundamental particles. Nowadays, weather balloons equipped with Geiger counters and other instruments are sent to the stratosphere all around the world, nearly every day. Due to the increased interest in particle physics, the research of particles in the atmosphere has augmented immensely.

Since it was a hot topic in the scientific world again, the University of Antwerp had, in collaboration with the KMI and the St. Niklaas institution, started an investigation on the connection of the solar cycle and the amount of cosmic radiation. This also leads to our research question: "Is there a correlation between the intensity of cosmic radiation and the solar cycle?"

Together with the KNMI we have released a weather balloon, equipped with instruments provided by the University of Antwerp, this being the HACORD (high altitude cosmic ray detector). The data gathered by the HACORD was sent to us, which we filtered, progressed and visualized. The program used to make graphs and figures is gnuplot, a program that is very good at averaging out data. Our mentor from the University of Antwerp guided us during the project, giving feedback on our findings and plans for the coming weeks. All of the information gathered from this year was compared to results from earlier investigations in 2012, 2013 and 2014.

What we found was not all that astonishing, the data gathered was almost identical to that of previous years. This means that the intensity of cosmic radiation has not increased or decreased. From our data, we can therefore not conclude that the solar cycle influences the intensity of cosmic radiation in our atmosphere. However, a solar cycle lasts 11 years and we have only gathered data on four consecutive years, for a better conclusion to be drawn, more information needs to be gathered in the following years.