Optics and Radar based Observations

Practical

EISCAT ESR
Incoherent Scatter and Weather in Space

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1. Introduction to the problem

Monitoring of the space weather is not a task that can be carried out by using simple instruments on Earth. In order to study the behaviour of the magnetosphere and the ionosphere and how it is affected by the relationship between the Sun and the Earth; more complex instruments, capable of high altitude measurements of the different physical parameters on this region, are required.

One of these instruments is the incoherent scatter radar system. The use of this system allows the measurement of electron density, ion and electron temperatures, ion composition and plasma velocity. This is achieved by means of scattering off the electrons in the study region creating an echo that later can be analysed. After this, any change in the signal could be related to the ion conditions on this area given that the ions control the behaviour of the electrons. (3)

However, the use of this instrument is not a task as simply as measuring the temperature with a thermometer. The possibility of measuring the space weather interest parameters was given by using the EISCAT Svalbard Radar System (ESR). This is an incoherent scatter radar system operated at 500 MHz located in the Svalbard, Norway. Therefore, it is considered Ultra High Frequency (UHF) Radar with an enabled receiver which will allows us to analyse the received data. (1)

The purpose of this practical is to be able to understand how this radar works, what data can be obtained from it and to compares the obtained results with other sources in order to verify the reliability of this instrument and we can confirm by ourselves how similar or different the data could be.

2. Experiment

The experiment took place at the computer lab of LTU campus Kiruna. LTU shares facilities with EISCAT headquarters and three EISCAT researchers provided us with the required support to perform this practical. In order to run the experiment we used the Eiscat Realtime Operating Software (EROS) software. Under this software we indicated that we wanted to run the following:

- Experiment: Beata
- Duration: May 12th, 2011, from 9:54 AM to 10:04 AM (local time)

Once the experiment started, it was controlled from the EROS console. From this console the start instruction was given, it was programmed to stop in a specific time and the recording of the data was enabled. Among the commands utilized are:

- runexperiment: This was the instruction to start the experiment.

- stopexperiment xxxx: where xxxx was the indicated time in which the experiment should stop.
- enablerecording: it was used to record the data.
- disablerecording: It was used to stop the recording of the data

In addition, the EROS console, gave the opportunity to review the data as it was received. The screen displayed the different values and the real time review was possible. Finally, the storage of the data was automatically and once the experiment was completed, the review of the data for the analysis of it proceeded.

3. Data Analysis

Once performed the experiment and all the required data was acquired, a comparison with other sources of information was necessary in order to corroborate that the acquired data was similar to and within similar limits.
The first comparison consisting on reviewing different internet sources in order to check the space weather conditions. Among the parameters to be reviewed were geomagnetic storms, sunspot number and solar wind parameters. Below the results of this comparison can be found:

Information collect from spaceweather.com (7) consisted on the following:

- Solar Wind
    - Speed: 337.1 km/sec
    - Density: 0.7 protons/cm^3
- Sun
    - Sunspot number: 84
    - 10.7 cm flux: 94 sfu
- Interplanetary Magnetic Field
    - B_{total}: 3.9 nT
    - B_z: 1.1 nT north

Another source of information is spacew.com, (6) the data obtained from them is shown below:

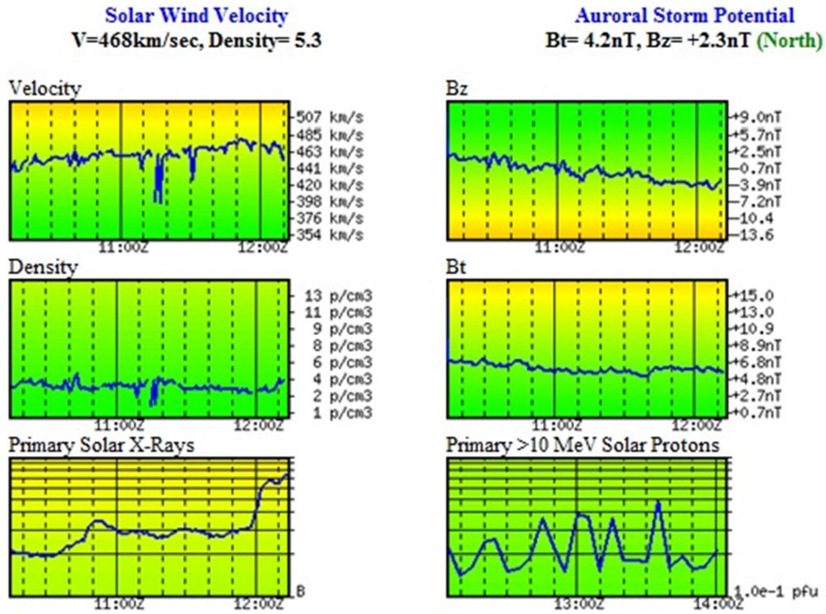

Figure 1 – Solar Wind activity and auroral storm potential according to spacew.com

The following step as part of the obtained comparison was to verify the electron number density from the International Reference Ionosphere (IRI) model at the same time that the experiment was conducted with the EISCAT radar on the location of the radar which was on the coordinates 78º N, 16° E. According to the data obtained from the IRI, the following plot is obtained (4):

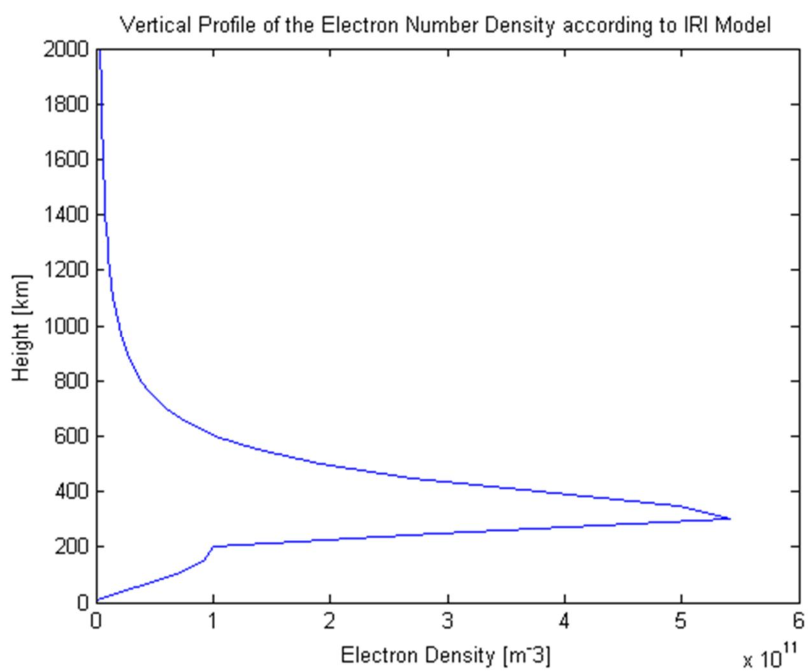

Figure 2 – Electron Number density according to the IRI model.

It can be seen from the data obtained from the IRI model that the highest electron density occurs at an altitude of approximately 300 km with a density of 5.41*10^{11} electrons/m^3. The density decreases beyond this maximum value until it reaches a value on the same order of magnitude than the proton density already found on the different internet sources.

Once having the data of the IRI model, the corresponding step was plot the data retrieved from the EISCAT radar as part of the experiment already performed. The figure below shows the vertical profile of this data.

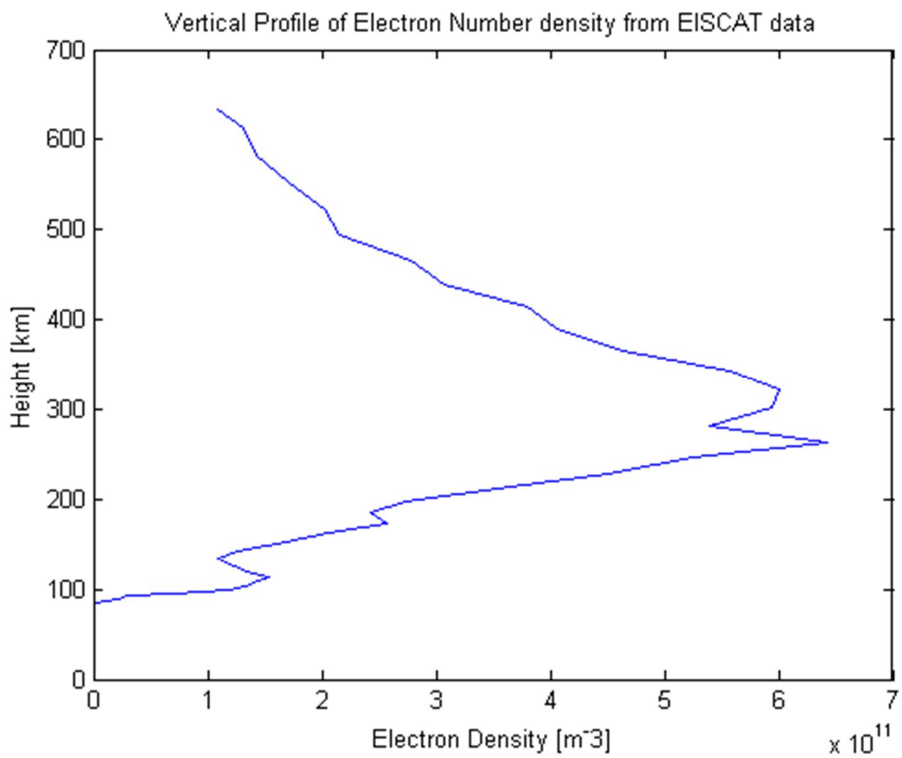

Figure 3 – Electron Number density from the data retrieved from the EISCAT radar.

According to figure 3, it can be seen that the highest electron number density occurs at approximately the same altitude. In the case of the data obtained from the EISCAT radar, the maximum electron density occurs at approximately 270 km with an electron density of 6.42*10^{11} electrons/m^3. It is clearly evident that there is a discrepancy on the data retrieved from the EISCAT radar and the data provided by the IRI model. This discrepancy is valid given that the data retrieved from the EISCAT radar is not calibrated. The data plotted as part of the EISCAT radar is raw data meaning that it is data from which certain considerations have not been taken into account, among these considerations are the effects of the external environment on the transmitted power like snow on the antennas or the amount of clouds on the sky. Therefore a calibration of this data is required in order to have an accurate assessment between both sources of data.

The following step to verify the data obtained from the EISCAT radar consisted on making a comparison of the maximum electron density between the obtained data and the data provided by EISCAT dynasode. (2) Dynasode provides a frequency value which is related to electron density by a given frequency. This term is f_oF2. The value for this term retrieved from dynasode is 6.6496 MHz and the relationship with electron density is given by the following formula:

$$f_oF2 = \frac{\sqrt{\frac{N_e e^2}{\varepsilon_0 m_e}}}{2\pi}$$

Given that the value of f_0F2 is known and the remaining terms are constants, it is possible to find the electron density. The calculated electron density taking the dynasonde data as reference is $5.4858*10^{11}$ electrons/m^3.

Having calculated the electron density from dynansode and estimated the electron density with the raw data obtained from EISCAT radar, the comparison of these values is in order.

- Electron density estimated with uncalibrated data from EISCAT: $6.42*10^{11}$ electrons/m^3.
- Electron density calculated with EISCAT dynasonde data: $5.49*10^{11}$ electrons/m^3.
- Difference on estimations: 16.94 %
- Magic Constant: 0.85514

Given that the difference between the electron density of the uncalibrated data from EISCAT and the electron density calculated with the EISCAT dynasonde data is above 10%, a magic constant number is required. The magic constant is given by the result of the maximum electron density of the dynasonde divided by the maximum electron density taken from the EISCAT radar. This value is a number agreed by EISCAT organization that is used to take into account the effects of the external environment on the transmitted power and it is used to scale the radar constant and be able to obtain calibrated data out of the radar. 5.508

After using the magic constant on the raw data retrieved from the EISCAT radar, a new difference on the estimations was calculated. The results of this new estimation are found below:

- Electron density estimated with calibrated data from EISCAT: $5.51*10^{11}$ electrons/m^3.
- Electron density calculated with EISCAT dynasonde data: $5.49*10^{11}$ electrons/m^3.
- Difference on estimations: 0.36 %

The new calibrated data gives a new opportunity to compare the data against the IRI model. These two sets of data which do not have to be the same should approach more than the previous ones given that the EISCAT radar data is now calibrated.

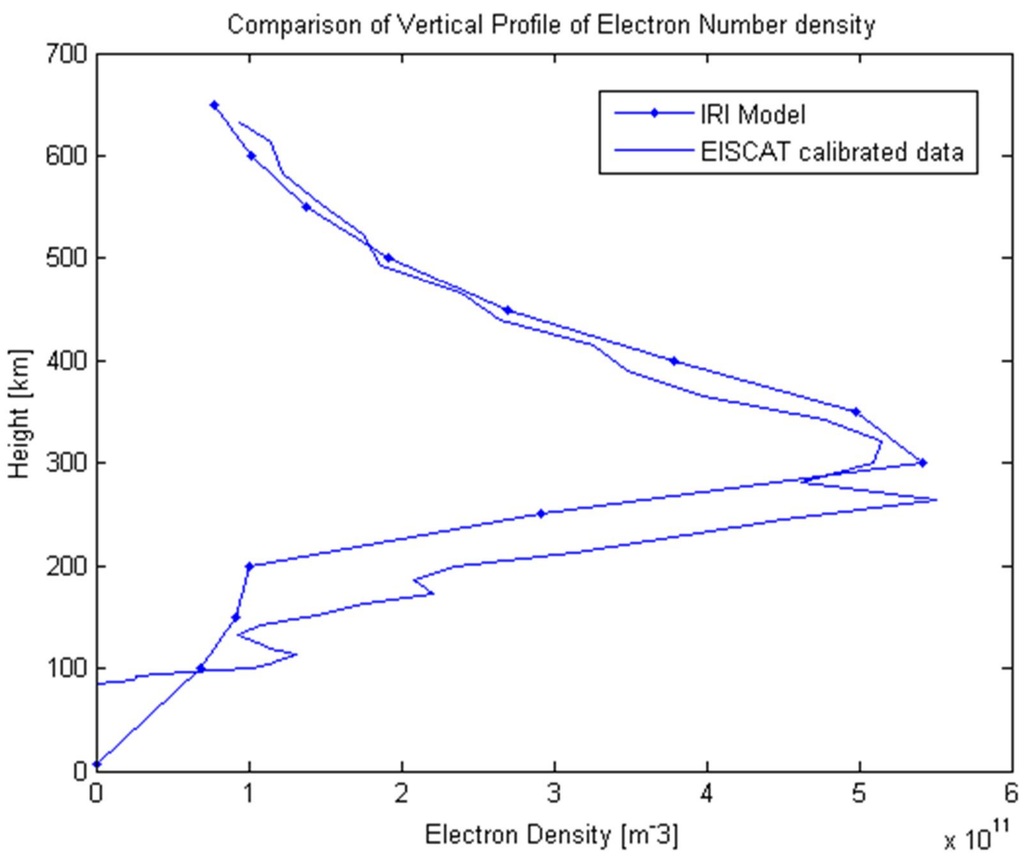

Figure 4 – Electron Number density from calibrated EISCAT radar and IRI model together.

It can be seen by the superimposing of both profiles, EISCAT calibrated data and IRI model, that both of them matches. This suggests that the calibration done by using the magic constant was an accurate one and the data is reliable. However, even though the data matches, both profiles are not exactly the same and this is shown by a pike at a lower altitude present on the EISCAT calibrated data but which is not present at the IRI model. The reason of this difference might be due to a low altitude echo of the signal that might be causing a reflection of it and therefore causing to appear as a second pike on the data. Another reason could be the presence of a wave on the solar wind caused by a solar flare that might be causing the reflection on the of the electron density at a lower altitude. However, this last possibility might not be true given that the monitoring of the solar activity previously explained does not show high solar activity. It is must be taken into consideration that the IRI model it is just a model and therefore it is difficult for it to predict the unexpected changes on the space weather that might lead to have two pikes in the data. Finally, the small downwards shift on the curve could be caused by the presence of an active electrical field which might have caused a drift on the curve.

The next part in the analysis of the data consisted on the comparison of the f_0F2 critical frequencies of the EISCAR radar against two other radars. The results of this comparison are below:

- EISCAT radar on Svalbard: 6.6496 MHz
- Sodankylä Ionosonde: 5.8 MHz
- Tomsk Dynosonde: 6.544 MHz

The selected instruments to perform the comparison were the Sodankylä Ionosonde (5) and Tomsk Dynosonde. The f_0F2 frequency was estimated from the figure below. The figure data is the Ionosonde data compared against time. In order to perform the comparison with Tomsk Dynosonde, a request for data with the dynosonde's administrator was placed given that the webpage with the data has not been updated since March 25th, 2011.

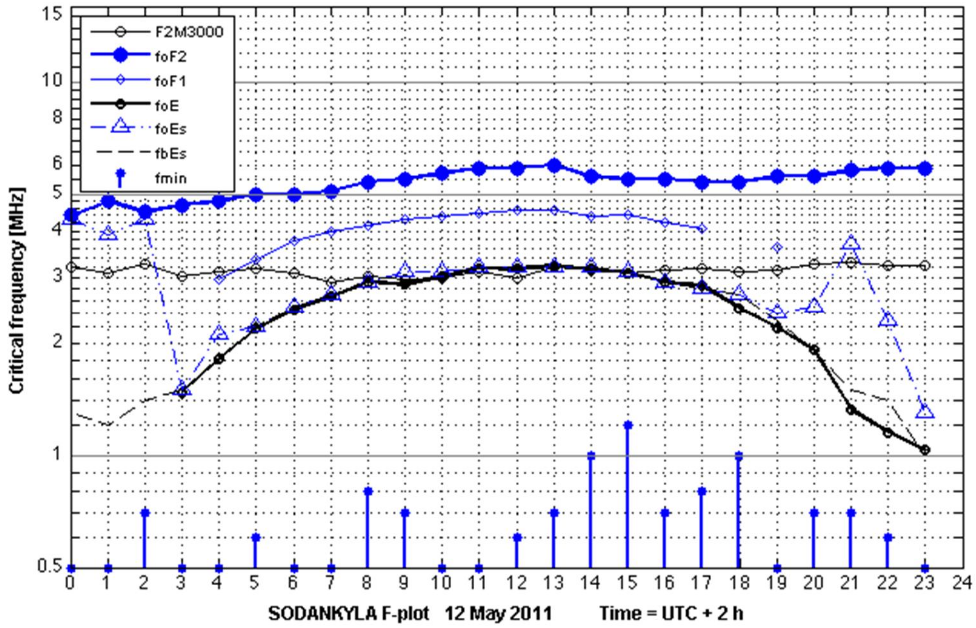

Figure 5 – F_0F2 data taken from Sodankylä Ionosonde.

Looking at the f_oF2 values from the different radars, it is possible to see that these results are not the same. The variation between the values at the different locations could be due to the difference in the geographical location of the radars. Therefore each radar look at a different part in the sky and these values are not the same all over the globe.

Finally, as part of the analysis of the data, the profiles for electron and ion temperatures are discussed.

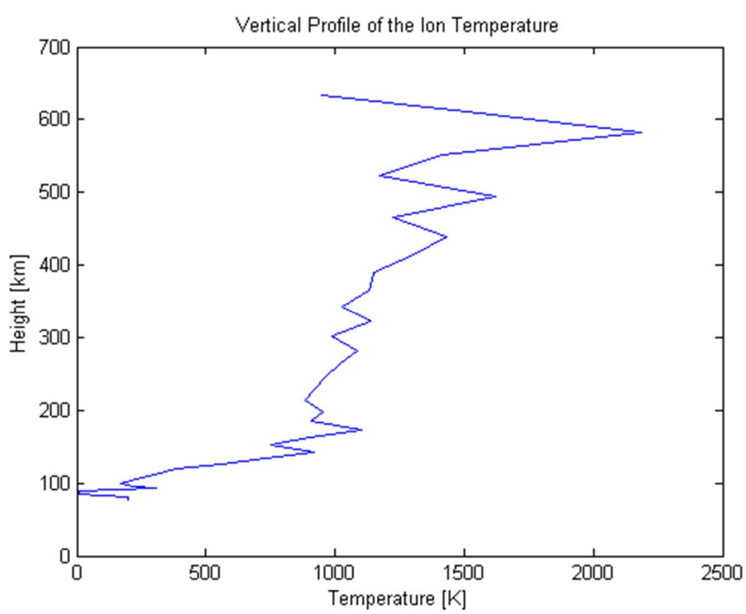

Figure 6 – Ion Temperature.

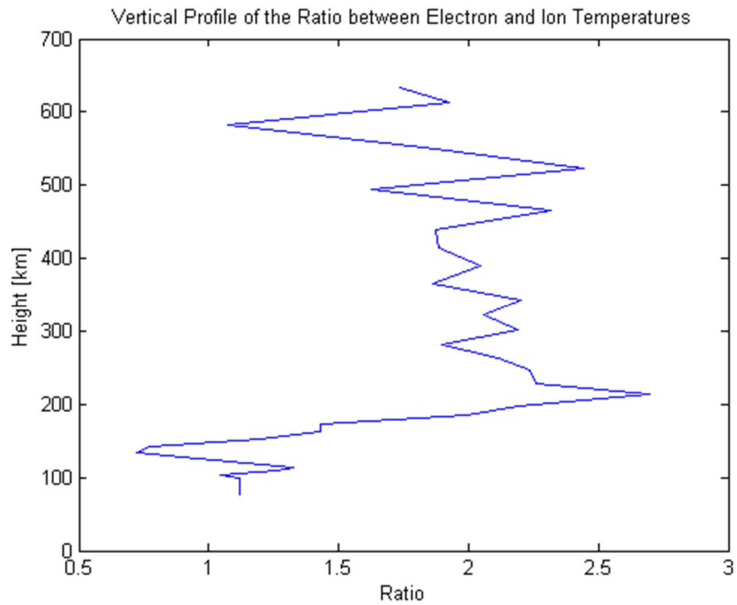

Figure 7 – Ratio between electron and ion temperatures.

It can be seen from the figures above how the ion temperature is increasing with the height. In addition it can be seen that the electron temperature is higher than the ion temperature at most of the heights. The high value of the ratio between ion and electron temperatures is in accordance with regular to low solar activity. It has been discussed previously that during the time of the measurements the proton density was low, below 1 proton/cm^3, and the speed velocity was not particularly high suggesting low solar activity. This is confirmed by the ion and electron temperatures which are not high because if high solar activity existed the ion temperature could have been particularly high.

4. Conclusion

This practical gave the opportunity to review how real radars operate. Previously, it has been learned how radars processed the data however by looking at the actual output of a radar it was possible to have a better idea of their entire operation in general. However, it should be noted that the most difficult part of operating a radar consists on the interpretation of the data. It was possible to see that even after getting the results some special commands and instructions are needed in order to calibrate the radar and be able to interpret adequately what is has been read. Unfortunately, radars does interpret the information been their only responsibility to transmit what they see.

References

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Confirmation of Participation

The purpose of this document is to confirm our participation in the realization of this practical exercise. The members of this team participated on the investigation of the required information, performed the required analyses to interpret the data, performed the required calculations and discussed the results.

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