Luleå University of Technology

F70013R Radar for space and atmosphere research 7.5 ECTS

Practical: EISCAT Space Weather

By

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INTRODUCTION

In this practical we need to analyze the EISCAT radar data for a specific space weather event under the guidance of EISCAT staff.

This practical analysis helped us to conclude that incoherent scatter radar provides an extremely valuable data source for scientific research related to the ionosphere and the magnetosphere. We understood that how the radar systems can be a very useful scientific instrument to measure and evaluate the space weather conditions and its effects.

DATA ANALYSES

We analyzed the EISCAT ESR radar data of selected event 20th March 2015 from 08:00:00 AM to 12:00:00 PM. We interpret the result and total solar eclipse corona is analyzed from the given data.

DESCRIPTION OF THE DATA WE ANALYZED

The observations were made using EISCAT Svalbard Radar (ESR) near Longyearbyen in Spitzbergen, Svalbard.

The EISCAT Svalbard Radar operating specifications:

FREQUENCY BAND: 500 MHz band
TRANSMITTER: Peak signal power of 1000 kW, with 25 % duty cycle and 1 μs – 2 ms pulse length with frequency and phase modulation capability.
ANTENNAS:
(i) 32 meter mechanically fully steerable parabolic dish antenna, and
(ii) 42 meter fixed parabolic antenna aligned along the direction of the local geomagnetic field.
RECEIVERS: Include multiple channels. The data is per-processed in signal processors, displayed and analyzed in real-time and can be recorded to mass storage media both locally and at the main storage facility.
CONTROL: The whole radar system is controlled by computers, and can be remotely commanded from the other radar sites.

Data from the archives of Spaceweather.com for 20th March 2017:

GEOMAGNETIC ACTIVITY: Minor (G1-class) geomagnetic storms are underway around the Arctic Circle. These are, essentially, reverberations from the March 17th CME strike amplified to storm-strength by a newly-arriving solar wind stream. High-latitude sky watchers should remain alert for auroras on March 20th.

TOTAL ECLIPSE OF THE SUN: The first day of northern Spring coincided with a total solar eclipse. The path of totality curved through the Arctic Ocean, making landfall in only two places: Svalbard and the Faroe Islands.

Planetary K-index
Now: Kp= 3 quiet
24-hr max: Kp= 5 storm

Interplanetary Mag. Field
Btotal: 7.0 nT
Bz: 0.1 nT north
Sunspot number: 71

The Radio Sun
10.7 cm flux: 115 sfu

Geomagnetic Storms: Probabilities for significant disturbances in Earth's magnetic field are given for three activity levels: active, minor storm, severe storm.

SPACE WEATHER NOAA Forecasts: Updated at: 2015 Mar 20 2200 UTC

FLARE	**0-24 hr**	**24-48 hr**
CLASS M	01 %	01 %
CLASS X	01 %	01 %

Mid-latitudes

	0-24 hr	**24-48 hr**
ACTIVE	30 %	40 %
MINOR	05 %	20 %
SEVERE	01 %	01 %

High latitudes

	0-24 hr	**24-48 hr**
ACTIVE	15 %	10 %
MINOR	30 %	25 %
SEVERE	35 %	55 %

CONDITIONS OF THE SPACE WEATHER, MAGNETOSPHERE AND IONOSPHERE ENVIRONMENT

1. COLLECTED INFORMATION:

i). There was C-class solar flares which might produce a coronal mass ejection but they are usually slow, weak and rarely cause a significant geomagnetic disturbance here on Earth.

ii). Data from 2015-03-20 shows increase in the differential proton fluxesare increased during solar eclipse which occurred at 09:46:47 [1].

```
:Product: 201503_ace_epam_1h.txt
:Issued: 2015 Apr 01 0510 UT
# Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
# Please send comments and suggestions to SWPC.Webmaster@noaa.gov
#
# Units: Differential Flux particles/cm2-s-ster-MeV
# Units: Anisotropy Index 0.0 - 2.0
# Status(S): 0 = nominal, 4,6,7,8 = bad data, unable to process, 9 = no data
# Missing data values: -1.00e+05, index = -1.00
# Source: ACE Satellite - Electron, Proton, and Alpha Monitor
#
#                      Hourly Averaged Real-time Differential Electron and Proton Flux
#
#                Modified Seconds ---------------------------- Differential Flux --------------------------
# UT Date   Time  Julian  of the  ----- Electron -----   ------------------- Protons keV -------------------  Anis.
# YR MO DA  HHMM    Day     Day   S    38-53   175-315   S    47-68   115-195   310-580   795-1193 1060-1900  Index
#-----------------------------------------------------------------------------------------------------------------

2015 03 19  1700   57100   61200  0  1.09e+03  1.54e+01  0  2.46e+03  2.04e+02  4.44e+01  1.48e+01  3.76e+00  -1.00
2015 03 19  1800   57100   64800  0  1.14e+03  1.73e+01  0  3.43e+03  2.25e+02  4.10e+01  1.32e+01  3.59e+00  -1.00
2015 03 19  1900   57100   68400  0  1.07e+03  1.64e+01  0  3.13e+03  1.93e+02  3.60e+01  1.23e+01  3.10e+00  -1.00
2015 03 19  2000   57100   72000  0  1.10e+03  1.65e+01  0  9.29e+03  3.56e+02  3.53e+01  1.17e+01  2.98e+00  -1.00
2015 03 19  2100   57100   75600  0  1.02e+03  1.65e+01  0  2.53e+03  1.80e+02  3.91e+01  1.16e+01  3.13e+00  -1.00
2015 03 19  2200   57100   79200  0  1.13e+03  1.71e+01  0  3.95e+03  2.22e+02  3.40e+01  1.08e+01  2.82e+00  -1.00
2015 03 19  2300   57100   82800  0  1.03e+03  1.70e+01  0  2.64e+03  1.41e+02  2.79e+01  9.57e+00  2.49e+00  -1.00
2015 03 20  0000   57101       0  0  1.06e+03  1.67e+01  0  2.41e+03  1.34e+02  2.66e+01  8.09e+00  2.48e+00  -1.00
2015 03 20  0100   57101    3600  0  1.04e+03  1.56e+01  0  4.26e+03  1.60e+02  2.42e+01  7.67e+00  2.19e+00  -1.00
2015 03 20  0200   57101    7200  0  1.05e+03  1.66e+01  0  2.35e+04  1.08e+03  3.16e+01  7.80e+00  2.15e+00  -1.00
2015 03 20  0300   57101   10800  0  1.02e+03  1.58e+01  0  2.61e+03  1.27e+02  2.47e+01  7.10e+00  2.13e+00  -1.00
2015 03 20  0400   57101   14400  0  1.05e+03  1.86e+01  0  3.48e+03  1.56e+02  2.40e+01  7.16e+00  2.00e+00  -1.00
2015 03 20  0500   57101   18000  0  1.10e+03  2.16e+01  0  4.28e+03  1.86e+02  2.20e+01  6.53e+00  1.82e+00  -1.00
2015 03 20  0600   57101   21600  0  1.21e+03  2.27e+01  0  2.32e+03  1.01e+02  1.89e+01  6.27e+00  1.64e+00  -1.00
2015 03 20  0700   57101   25200  0  1.20e+03  2.32e+01  0  2.17e+03  8.19e+01  1.72e+01  5.71e+00  1.50e+00  -1.00
2015 03 20  0800   57101   28800  0  1.21e+03  2.21e+01  0  2.18e+03  7.77e+01  1.62e+01  5.05e+00  1.34e+00  -1.00
2015 03 20  0900   57101   32400  0  1.23e+03  2.19e+01  0  2.60e+03  9.12e+01  1.59e+01  5.15e+00  1.34e+00  -1.00
2015 03 20  1000   57101   36000  0  1.28e+03  2.19e+01  0  5.40e+03  2.13e+02  1.71e+01  4.93e+00  1.41e+00  -1.00
2015 03 20  1100   57101   39600  0  1.26e+03  2.11e+01  0  2.74e+03  1.03e+02  1.66e+01  4.79e+00  1.41e+00  -1.00
2015 03 20  1200   57101   43200  0  1.24e+03  2.08e+01  0  2.55e+03  8.16e+01  1.50e+01  4.58e+00  1.34e+00  -1.00
2015 03 20  1300   57101   46800  0  1.22e+03  1.91e+01  0  2.19e+03  6.45e+01  1.27e+01  4.05e+00  1.25e+00  -1.00
2015 03 20  1400   57101   50400  0  1.16e+03  1.81e+01  0  2.13e+03  5.46e+01  1.10e+01  3.66e+00  1.04e+00  -1.00
2015 03 20  1500   57101   54000  0  1.19e+03  1.91e+01  0  2.24e+03  6.78e+01  1.38e+01  4.16e+00  1.23e+00  -1.00
2015 03 20  1600   57101   57600  0  1.20e+03  1.87e+01  0  2.46e+03  8.06e+01  1.56e+01  4.54e+00  1.40e+00  -1.00
2015 03 20  1700   57101   61200  0  1.21e+03  1.86e+01  0  2.72e+03  7.48e+01  1.38e+01  4.50e+00  1.33e+00  -1.00
```

iii). No information about solar UV emission is found. But X-ray emission was of C class geomagnetic disturbance here on Earth.Each X-ray class category is divided into a logarithmic scale from 1 to 9. And we found it was C-1. [2]

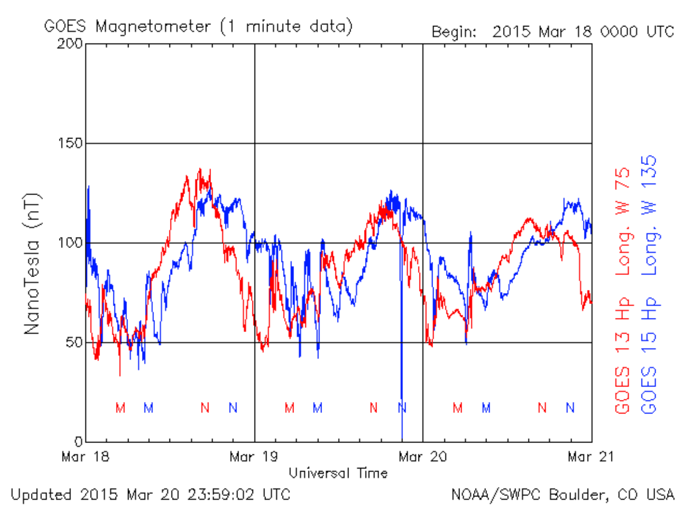
```
:Product: Daily Solar Data          2015_DSD.txt
:Issued: 1800 UT 02 Jan 2016
#
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Cent
#  Please send comments and suggestions to SWPC.Webmaster@noaa.gov
#
#                          2015 Daily Solar Data
#
#                             Sunspot       Stanford GOES15
#           Radio  SESC        Area            Solar  X-Ray  ------ Flares ------
#           Flux  Sunspot    10E-6    New      Mean   Bkgd    X-Ray      Optical
#  Date     10.7cm Number    Hemis. Regions Field  Flux    C  M  X  S  1  2  3
#---------------------------------------------------------------------------------
2015 03 09  123     29       260      0     -999   B5.0   13  2  0 14  6  1  0
2015 03 10  121     42       280      0     -999   B5.4   13  2  0 21  0  1  0
2015 03 11  132     42       360      1     -999   B6.8   14  3  1  8  3  1  0
2015 03 12  127     56       360      1     -999   B9.5   10  5  0  0  0  1  0
2015 03 13  119     87       470      2     -999   B4.8    6  2  0  4  0  0  0
2015 03 14  116     56       350      0     -999   B4.1   12  1  0 13  1  1  0
2015 03 15  114     54       390      0     -999   B4.6    7  2  0 11  2  0  0
2015 03 16  117     57       390      0     -999   B3.6    6  1  0  9  2  1  0
2015 03 17  114     60       810      2     -999   B3.3    2  1  0  4  0  1  0
2015 03 18  115     44       470      0     -999   B6.0   18  0  0 18  1  0  0
2015 03 19  109     71       420      1     -999   B3.5    2  0  0  8  0  0  0
2015 03 20  113     27       120      0     -999   B4.8    1  0  0  0  0  0  0
2015 03 21  114     40       260      2     -999   B4.0    2  0  0  0  0  0  0
2015 03 22  122     88       380      3     -999   B4.0    2  0  0  0  0  0  0
2015 03 23  128    119       540      3     -999   B4.7    3  0  0  2  0  0  0
2015 03 24  133    127       580      1     -999   B4.8    2  0  0  8  0  0  0
```

iv). According to the data there is no change in proton density (1.8 p/cc)

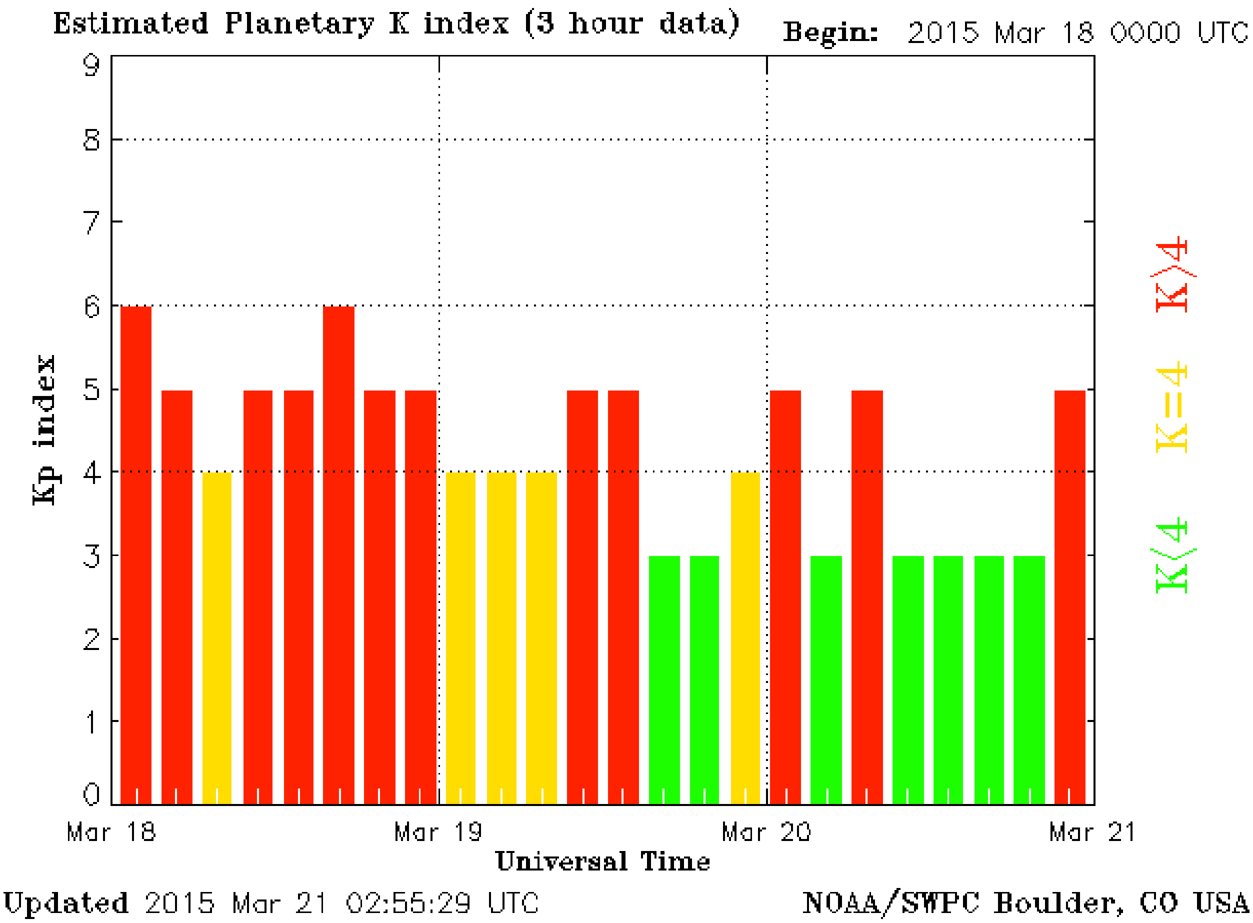
```
:Product: 201503_ace_swepam_1h.txt
:Issued: 2015 Apr 01 0510 UT
# Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
# Please send comments and suggestions to SWPC.Webmaster@noaa.gov
#
# Units: Proton density p/cc
# Units: Bulk speed km/s
# Units: Ion tempeture degrees K
# Status(S): 0 = nominal data, 1 to 8 = bad data record, 9 = no data
# Missing data values: Density and Speed = -9999.9, Temp. = -1.00e+05
# Source: ACE Satellite - Solar Wind Electron Proton Alpha Monitor
#
#   Hourly Averaged Real-time Bulk Parameters of the Solar Wind Plasma
#
#                 Modified Seconds   -------------  Solar Wind  -----------
# UT Date   Time  Julian  of the          Proton      Bulk         Ion
# YR MO DA  HHMM    Day     Day     S    Density     Speed     Temperature
#-------------------------------------------------------------------------
2015 03 19  1900   57100   68400    0        2.1     587.1     2.26e+05
2015 03 19  2000   57100   72000    0        2.4     593.0     2.02e+05
2015 03 19  2100   57100   75600    0        2.6     585.1     2.27e+05
2015 03 19  2200   57100   79200    1        2.2     579.8     1.95e+05
2015 03 19  2300   57100   82800    0        1.8     587.4     1.91e+05
2015 03 20  0000   57101       0    1        2.4     577.6     2.78e+05
2015 03 20  0100   57101    3600    1        1.9     574.2     2.47e+05
2015 03 20  0200   57101    7200    1        1.5     578.6     2.28e+05
2015 03 20  0300   57101   10800    0        1.6     550.6     2.50e+05
2015 03 20  0400   57101   14400    0        1.7     565.7     2.44e+05
2015 03 20  0500   57101   18000    0        1.7     574.1     2.01e+05
2015 03 20  0600   57101   21600    0        1.2     558.9     2.32e+05
2015 03 20  0700   57101   25200    0        1.4     573.3     2.08e+05
2015 03 20  0800   57101   28800    0        1.8     582.4     2.36e+05
2015 03 20  0900   57101   32400    1        1.8     587.7     2.00e+05
2015 03 20  1000   57101   36000    1        1.8     560.3     2.07e+05
2015 03 20  1100   57101   39600    1        1.8     568.8     1.91e+05
2015 03 20  1200   57101   43200    0        1.8     575.1     2.19e+05
2015 03 20  1300   57101   46800    0        1.8     598.6     2.01e+05
2015 03 20  1400   57101   50400    0        2.0     612.8     1.93e+05
2015 03 20  1500   57101   54000    1        1.9     570.9     2.12e+05
2015 03 20  1600   57101   57600    0        1.6     543.3     1.73e+05
2015 03 20  1700   57101   61200    0        1.5     547.0     1.67e+05
2015 03 20  1800   57101   64800    1        1.7     572.4     1.77e+05
2015 03 20  1900   57101   68400    0        2.0     581.7     2.40e+05
```

v). Geomagnetic activity:During the total solar eclipse on March 20, 2015, we found that the geomagnetic field variation of the quiet day decreases due to blocking of the Sun's activity by Moon.

```
# Units: Longitude degrees 0.0 - 360.0
# Status(S): 0 = nominal data, 1 to 8 = bad data record, 9 = no data
# Missing data values: -999.9
# Source: ACE Satellite - Magnetometer
#
#              Hourly Averaged Real-time Interplanetary Magnetic Field Values
#
#                 Modified Seconds
# UT Date   Time  Julian  of the   ----------------  GSM Coordinates --------------
# YR MO DA  HHMM    Day     Day    S     Bx      By      Bz      Bt     Lat.   Long.
#------------------------------------------------------------------------------------
2015 03 19  2200   57100   79200   0     3.9    -2.4    -0.4     4.6    -4.8   328.5
2015 03 19  2300   57100   82800   0     3.2    -2.1    -2.7     4.6   -35.2   326.5
2015 03 20  0000   57101       0   0     5.7    -1.6    -1.5     6.1   -14.0   344.4
2015 03 20  0100   57101    3600   0     5.2    -1.3     1.0     5.4    10.8   346.0
2015 03 20  0200   57101    7200   0     3.9    -1.5    -0.3     4.2    -4.0   338.8
2015 03 20  0300   57101   10800   0     5.3    -1.1    -1.3     5.6   -13.4   347.9
2015 03 20  0400   57101   14400   0     4.6    -1.1    -1.7     5.0   -19.8   346.1
2015 03 20  0500   57101   18000   0     3.1    -1.5    -3.7     5.1   -46.8   334.1
2015 03 20  0600   57101   21600   0     4.1    -2.1     1.5     4.8    17.8   333.6
2015 03 20  0700   57101   25200   0     3.4    -3.7    -1.7     5.3   -18.9   312.5
2015 03 20  0800   57101   28800   0     2.3    -4.0    -3.4     5.8   -36.1   299.9
2015 03 20  0900   57101   32400   0     2.1    -3.3    -3.2     5.0   -39.5   302.6
2015 03 20  1000   57101   36000   0     4.9     1.4     1.7     5.3    18.4    16.4
2015 03 20  1100   57101   39600   0     4.4     3.1     1.1     5.4    11.2    35.4
2015 03 20  1200   57101   43200   0     4.2     3.1     1.9     5.6    19.8    35.9
2015 03 20  1300   57101   46800   0     1.9     4.9     0.7     5.3     7.9    69.1
2015 03 20  1400   57101   50400   0     0.9     5.6     1.6     5.8    15.5    81.0
2015 03 20  1500   57101   54000   0     4.1     1.6    -1.6     4.7   -20.3    21.6
```



vi). Auroral Data: We expect to see a lesser Kp-index during total solar eclipse. That's because during solar eclipse, electron number densities in the ionosphere will decrease and hence auroral activity will also decrease.

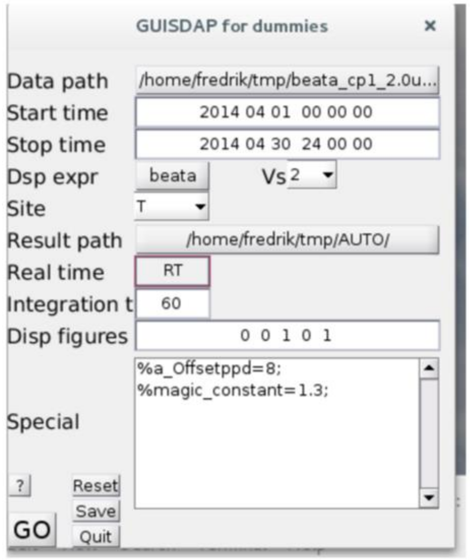


vii). Ionosphere data: Data for Ionosphere is generated from IRI archive [3]. Which is used to plot the relation between maximum electron density & altitude.

2. GUIDAP Configuration

To analyze the data, first we need to configure GUIDAP software package. For our experiment, we used EISCAT ESR radar data.
Start time: 2015 03 20 08 00 00
Stop time: 2015 03 20 12 00 00
Dspexp: IPY (For EISCAT ESR Svalbard radar)
Vs (version of the experiment): for our experiment it was 4.
Site: L (Svalbard radar (Longyearbyen))
Integration t: 60
Disp figures: 1 1 0 1 1
Note: Inputs (1/0) corresponds to data dump, power profile, fits, parameter profiles, and surface plots of parameter time series.

Special: Matlab command to be performed on dataanalysis. [Magic_const = 5.801].



3. Calibration

1. Fof2 was determined from EISCAT Dynasonde data from Svalbard until mid-2015**[]**.

2. Expected maximum of electron number density in the F region was calculated using the following formula.

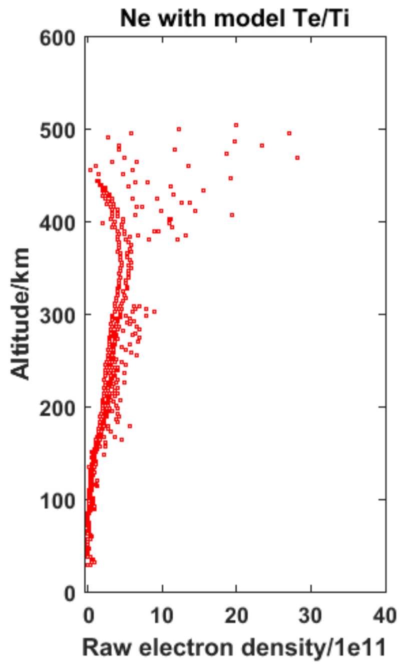
$$f_oF2\;(MHz) = f_P(F2) = \frac{\omega_P}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{N_e e^2}{\varepsilon_o m_e}}$$

   From above equation, we calculated $N_e = 8.16 * 10^{11} m^{-3}$

3. We calculate the Magic constant using equation below:

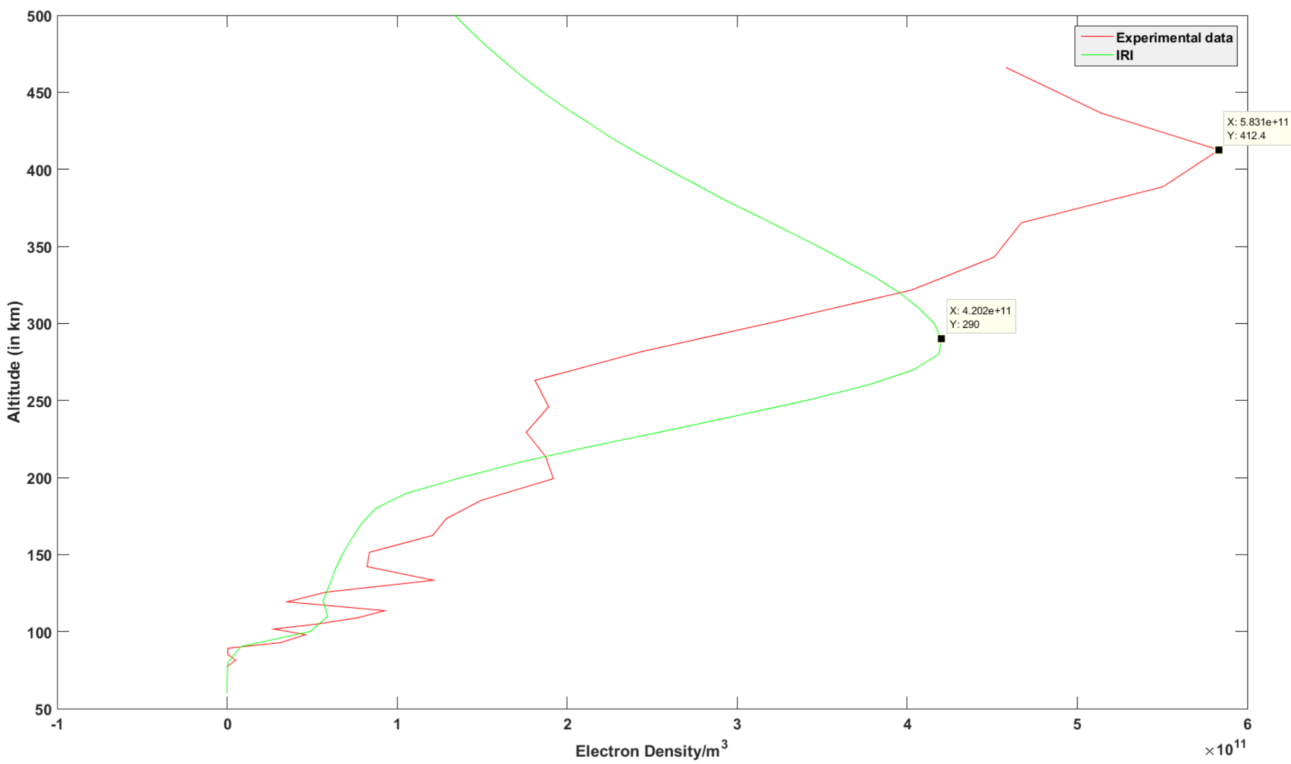
$$Magic\_const = \frac{N_e^{Peak}(Calculated\ from\ f_oF2)}{N_e^{max}(Obtained\ from\ GUIDAP)}$$

   After calculation we got Magic_const = 5.801. We repeated the simulation using Magic_const value and we got

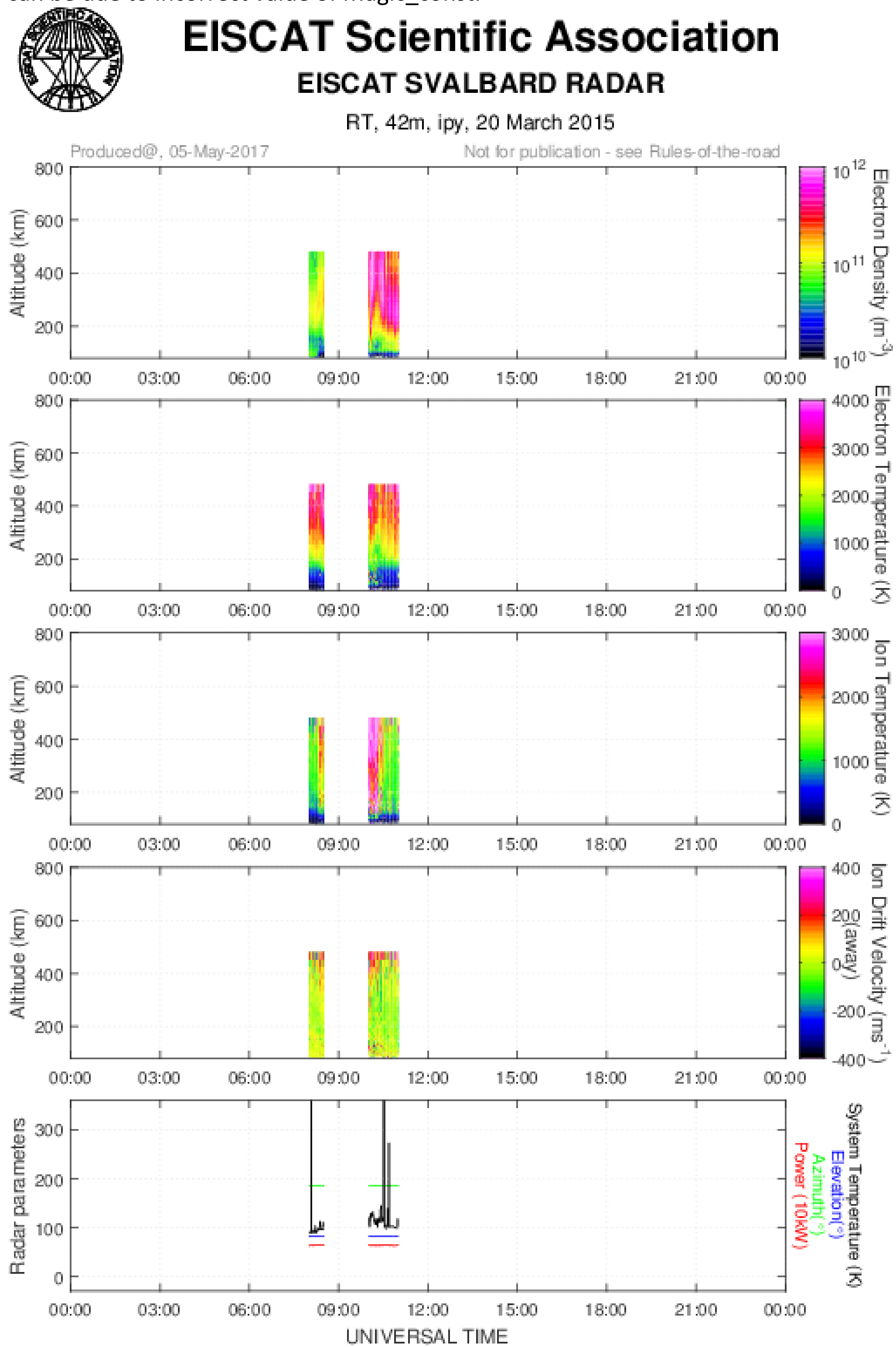


The above plot of electron density is for the time interval 9:46 till 9:47 UTC. The time interval selected is interesting because total solar eclipse on 20 March, 2015 was observed at 9:46:47. E region peak occurs at around 150 km. It can be seen from the above plot that the peak electron density at E layer peak is around 3×1011/m3. The maximum electron density in the F layer occurs at approximately 380 km and has a value approximately 5×1011/m3.

4. Result Analysis



As can be seen from the above plot, there is a considerable difference between the electron densities obtained from IRI and from IPY experiment. Even though the trend is approximately the same, the maximum electron density and the altitude at which it occurs are larger for the IPY experiment. This deviation can be due to incorrect value of Magic_const.



During total solar eclipse, we expect to see minimum electron number density from our radar observations. Svalbard radar measures electron number densities from the power of the returned signal. For the GUISDAP simulation run of the whole experiment, output MATLAB files for the duration 8:31:13 till 10:00:23 UTC were not generated. Since total solar eclipse occurred at 9:46:47 UTC on 20th March, 2015 and lasted for a duration of 2 minutes 47 seconds, we expect the electron number densities to be so low for the duration 8:31:13 till 10:00:23 UTC that the received power was not enough to give any significant results for this duration.
From the vizu plots, it can be observed that electron number densities increased by a factor of 10 after the solar eclipse was over. Also, it can be observed that at high altitudes, electron temperature is around 2000K more than the ion temperature. But for time instants close to the solar eclipse, ion temperature was found to be around 3000 K i.e. of the same order as the electron temperature.
Also, from the vizu plots it can be observed that below 500 km, ionospheric plasma doesn't appear to move at all. But above 500 km, ionospheric plasma appears to be drifting away with a speed of 200 m/s.
The system temperature is always found to be more than 100 K from the vizu plots. It can be observed that elevation is around 98° and azimuth is around 198°. Power is found to be approximately 700 kW.

5.Conclusions

Calibrated Ne and computed Ne seemed similar with a chosen Magic constant
When calibrated profiles of Ne with the Ne profile from the IRI model were compared, they differed significantly. One can see a huge difference when both the profiles were plotted together in the same figure. Quoting 'IRI' webiste: "The major data sources are the worldwide network of ionosondes, the powerful incoherent scatter radars (Jicamarca, Arecibo, Millstone Hill, Malvern, St. Santin), the ISIS and Alouette topside sounders, and in situ instruments on several satellites and rockets."
The data observed from these radars should be completely different from the Svalbard radar as it's placed in the umbra of the eclipse and the IRI radars were part of the penumbra of the eclipse.
We would like to mention that due to some technical errors and server issues, we couldn't extract the whole data from LTU. The single simulation took 3 to 4 hours. The data we got was missing some part of it. We tried to simulate it with several attempts but, failed to acquire whole data. As a result, Height profiles of ion and electron temperatures and line-of-sight velocities plots were partially plotted. As can be seen in above mentioned plots, Ion and electron temperatures, line-of-sight velocities and space weather events were not observed directly in the results. Hence, results as of now are inconclusive for these parameters.

6. Confirmation

We have confirmed that all members of the group Maitreya Ranade, Mini Gupta and Vanshika Kansal have worked on the analysis and report.

7. References

[1]. ftp://sohoftp.nascom.nasa.gov/sdb/goes/ace/daily/20150320_ace_epam_1h.txt
[2]. ftp://ftp.swpc.noaa.gov/pub/warehouse/2015
[3]. https://omniweb.gsfc.nasa.gov/vitmo/iri_vitmo.html
[4]. Spaceweather.com
[5]. www.eiscat.se