Radar for Space and Atmospheric Research, F7013R
Space weather and magnetosphere events and the ionosphere — EISCAT radar data analysis

EISCAT Scientific Association*

2017

Read this instruction carefully before the practical sessions on 4–5 May. Also please remember to sign up in advance, so you know what group you belong to!

1 Introduction

This practical session is arranged in collaboration with EISCAT (`https://www.eiscat.se/`). We will analyse **EISCAT incoherent scatter radar** data from several selected events and interpret the results in terms of space weather conditions, magnetospheric events, etc. Staff from EISCAT Headquarters (located in the space campus building close to the LTU department) will supervise your exercises. You will work in small groups in the computer classroom (D2).

Each analysis group will analyse one set of data and shall submit **one report**.

2 Your task

The following assumes that you are familiar with incoherent scatter radar theory (from the lectures by Phil Erickson), and with the EISCAT radars. The details will be presented during the introductory lecture on 2 May — please don't miss this! We will also visit the EISCAT Kiruna site on 3 May, including a short demo of radar operation.

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The purpose of this activity is:

1. to give you an opportunity to get acquainted with EISCAT radar data
2. to learn how to analyse the data with the Matlab software GUISDAP
3. to relate the results to geomagnetic and space weather conditions

Detailed step by step instructions are found below in Section 5. Each group will be provided a selected set of EISCAT data from the archives to analyse. The data have been chosen to represent a number of "interesting" extreme or typical ionospheric or space weather events. Your main task will be to identify what kind(s) of events you can see in the results!

To analyse the EISCAT data, a Matlab software package called GUISDAP has to be used. This software has been developed on Linux and Mac and expects the data files to be compressed with the **bzip2** program. Since the computers in D2 run Windows, additional software is necessary.[1] GUISDAP and a suitable file decompression utility (7zip) have been installed on the course and system disks at LTU and will therefore be available to you in D2. EISCAT HQ staff will assist you.

3 Radar experiments: the necessary background

Common for all EISCAT radar experiments is that there are many things to configure. These include transmission patterns, receiver settings, and antenna motion and the possible configurations differ between the three EISCAT radars. Each configuration will produce data in a different format due to the different time, range and frequency resolutions. Therefore GUISDAP needs to know the type and version of the experiment and on which radar it was running. It can usually guess this from the name of the data directory but you may have to set it manually.

3.1 Pulse code experiments

Pulse codes are designed for different purposes (range resolution, range interval, time resolution) and are named by acronyms such as **beata**, **manda**, **steffe** or **tau0**.

At the Svalbard radar, two different kinds of experiment exist: single-antenna and dual-antenna ones, where the latter (e.g. **folke** and **taro**) switch antennas

[1] Should you want to run GUISDAP on your own laptop, if you have Matlab, OSX and Linux should be straightforward. To run on Windows, you will also need to install **7zip** for the bzip2 decompression.

between pulses, effectively making the single transmitter look like one transmitter for each antenna.

Further descriptions can be found on the EISCAT web page at `https://www.eiscat.se/scientist/user-documentation/`.

3.2 Antenna scan pattern

During each experiment, the antenna is controlled by a scan pattern program. The simplest possible ones will set one direction and then do nothing, whereas others can perform more complicated tasks such as latitude scans or satellite tracking. At the Svalbard radar, the scan program can also switch between the two antennas if not running a dual-antenna experiment. The details of antenna pointing are stored with the data.

3.3 The data

The data you will use are stored in Matlab-compatible files. The file names are generated automatically and consist of eight digits, which are the time in seconds (rounded off to the nearest smaller integer) since new year (1 January 00:00:00 UTC), followed by **.mat.bz2**.

4 Analysing the data

4.1 Starting GUISDAP

GUISDAP[2] is available on your course disk **(K:)**, accessible from the computers in room D2.

In order to set the required paths and global variables for Matlab to find the GUISDAP programs and your data, a startup script has been provided. For this to work you should *not start Matlab in the usual way* but **follow this procedure**:

1. Open the Windows file explorer (Computer *nnnn*)
2. Browse to `K:\SRT\f7013r\radarcourse_2017\eiscat\guisdap8`
3. **Right-click** on `windows_start.m`
4. Select **Run**

[2] Original meaning of the acronym: Grand Unified Incoherent Scatter Design and Analysis Package

This will start Matlab and run a few commands to set the proper search paths and global variables.

To start your analysis, enter the command **analyse** at the Matlab command line. A window called **GUISDAP for Dummies** will appear. After clicking on the GUISDAP logotype the following input fields will be shown:

Data path Path to the data files to analyse (EISCAT will provide one set to each group).

Start time Time in the format **yyyy mm dd HH MM SS**. GUISDAP tries to guess an appropriate start time from the data files, but you may have to set the start time manually if this fails, or in case you want to analyse only part of the contents of the data path.

Stop time GUISDAP tries to guess an appropriate stop time, for manual tuning see above.

Dsp exp GUISDAP tries to guess the correct type of experiment (pulse code and digital receiver settings) from the name of the data directory. Otherwise, select the appropriate experiment path from `exps`.

Vs The version of the experiment (each experiment may exist in different varieties and also differ between the different radars). GUISDAP usually guesses the correct version from the name of the data directory.

Site Radar site abbreviation:

- **K** Remote receiver in Kiruna
- **S** Remote receiver in Sodankylä
- **T** Tromsø UHF radar
- **V** Tromsø VHF radar
- **L** Svalbard radar (Longyearbyen), single antenna or "main" antenna of dual-antenna experiments (this can be either the 32 m or the 42 m depending on experiment configuration).
- **X** Svalbard radar, antenna selection for dual-antenna experiments. Selects the antenna *not* indicated as "main" in the directory name.
- **P,Q** Special parameters related to plasma line data, not used here

Result path Where to save the results. Make sure that this is an **empty** folder, separate for each group of students! End the path name with **AUTO** and GUISDAP will make sure that the results end up in a logical structure of sub-folders.

Real time Wait for data files to appear — only applicable when analysing data in real time during a radar run.

Integration time Select an integration time (in seconds) to add up several data files before fitting. Typical values are **60** s, a multiple of the data dump time, or **0 = antenna dwell time**: for a scanning experiment, select 0 and the integration will be over the times the antenna stood still at each position.

Disp figures Select what plots to show or not to show (1/0) during the analysis: **data dump, power profile, fits, parameter profiles**, and **surface plots of parameter time series**. Suitable values to start with are **[1 1 0 1 1]**.

Special Here you can give Matlab commands to be performed on the data before analysis, for example if parameters have to be corrected and calibrated. Typically used to set "Magic_const" as described below.

GO starts the analysis. Some information will be printed to the Matlab command window and the profile plots selected in **Disp figures** will appear.

The surface plot window will appear when the analysis has finished, if selected. This plot can be reproduced and modified later by calling the Matlab command **vizu**. In order to tell **vizu** that you want to create a new plot and overwrite the first one, it is usually necessary to call it with arguments: **vizu new VERBOSE**.)

4.2 Fit parameters

GUISDAP works by least-squares fitting model data to observed data. The model has six input parameters and out of those, four will be fitted in this analysis. These are: electron density, ion temperature, ion-electron temperature ratio and line-of-sight ion velocity. The parameters are collected in Matlab files containing the result matrix **r_param** which has eight columns and as many rows as ranges. The range/height gates are defined in GUISDAP and the heights can be found in the vector **r_h**.

The six first columns in **r_param** are used and contain values of the six parameters in the following order:

1. Electron density N_e [m^{-3}]
2. Ion temperature T_i [K]
3. Ratio between electron and ion temperature

4. Ion to neutral collision frequency [Hz] (taken from atmospheric models, not fitted)

5. Ion drift velocity v_{i} (the component along the line of sight) [m/s]

6. Composition c = [O^+]/N_{e}[%], under the assumption that the ions are composed to c % of [O^+] and to $(100 - c)$ % of an imaginary ion with a mass of 30.5 u, that is, a typical value for a mixture of NO^+ and O_2^+ (constant at each altitude, not fitted)

4.3 Calibration

At EISCAT, the antenna gains may vary with time (why?) so it may be necessary to calibrate the received power to measure quantitatively correct electron densities. For this purpose we will compare the F2 layer peak electron density with data from *ionosondes*, if available.

1. Determine f_{o}F2 from ionosonde data. There are two options:

   (a) EISCAT dynasonde data (Tromsø; Svalbard until mid-2015)
   `http://dynserv.eiscat.uit.no`. Browse to the **Dynasonde database**, then select site and **SQL Query** and mark **foF2**. The result will appear in MHz if the analysis succeeded in finding an F2 layer.

   (b) TGO digisonde data (Tromsø: use if dynasonde data unavailable)
   `http://www.tgo.uit.no/ionodata/ionosonde.html`
   Select your date and find an ionogram acquired during your experiment. Read out f_{o}F2-

2. Calculate the expected maximum of electron number density N_{e} from f_{o}F2. f_{o}F2 [Hz] is related to the maximum electron density N_{e} [m^{-3}] at the electron density peak of the F region as:

$$f_{\mathrm{o}}F2 = f_{\mathrm{p}}(F2) = \frac{\omega_{\mathrm{p}}}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{N_{\mathrm{e}}e^2}{\varepsilon_0 m_{\mathrm{e}}}} \tag{1}$$

3. Compare ${N_{\mathrm{e}}}^{\max}$ from your GUISDAP analysis with the maximum of N_{e} from f_{o}F2. If the values differ significantly, then set **Magic_const** (in the box Special) to the ratio between the peak electron density calculated from f_{o}F2 and ${N_{\mathrm{e}}}^{\max}$ from your first GUISDAP run. Repeat the GUISDAP run.

5 Analysis task

The practical task is to analyse and interpret EISCAT radar data acquired during selected space weather and ionosphere events. The assistants from EISCAT HQ will prepare the data for you and tell each group what data to analyse. An outline of the procedure follows:

1. Collect information about the conditions when your data were acquired, such as

   - whether any solar flares or coronal mass ejections happened
   - solar proton fluxes (from GOES satellites)
   - solar UV and X-ray emission (from GOES satellite)
   - solar wind parameters including interplanetary magnetic field (from the ACE spacecraft)
   - geomagnetic activity (from magnetic indices or magnetograms)
   - auroral data (from ground-based imagers)
   - ionosphere data (other than your radar data, e.g. from ionosondes)

   A collection of useful links is provided in the folder

   `K:\SRT\f7013r\radarcourse_2017\spaceweather`.

2. Analyse your data with GUISDAP as described above. **Each group** should make sure to save their results (Matlab files and "vizu" overview plots) in a **separate subdirectory**.

3. Plot height profiles of the electron number density N_e [m^{-3}] from your analysis, at least for one "interesting" instant in time. Note the electron density at the F layer peak (or maybe the E layer peak if no F region can be seen).

4. The derived electron density results are not necessarily quantitatively correct, since the received power may have to be calibrated as described above in Section 4.3. The **Magic_const** value, which can be set in the box Special in the "GUISDAP for Dummies" window, is a scale factor that can be applied to the measured transmitter power in order to correct for environmental effects on the transmitted and received power. Can you explain why this may be necessary at the EISCAT stations?

   Hint: GUISDAP assumes the antenna gain to be constant, the transmitted power is measured in the waveguide, and the received power is measured using a known noise source between the antenna and the receiver chain.

You can find a suitable magic constant for example by comparing the peak electron density with the critical F (or E) layer frequency from nearby ionosondes. If you find that the results differ significantly, then re-run the analysis with a suitable magic constant.

5. Plot a height profile of the electron number density from the International Reference Ionosphere (IRI) model. Go to

   `http://iri.gsfc.nasa.gov`.

   Select **RUN ONLINE**. Select the date and time of your experiment, the coordinates of the EISCAT radar (`https://www.eiscat.se/scientist/document/location-of-the-eiscat-facilities/`), and a profile type. Please note that you do not need to run "Optional Input". You will receive an ASCII file of the modelled electron density profile. Please note that the negative values are **NaN**.

6. Compare your calibrated profiles of N_e with the N_e profile you obtained above from the IRI model. Plot the profiles together in the same figure. Do they differ significantly and if so, can you think of a reason why?

7. Look at height profiles of ion and electron temperatures (time development from the "vizu" panel plots or by plotting separate profiles).

8. Look at the line-of-sight velocities measured along the different pointing directions. Does the ionospheric plasma move and in what direction?

9. Discuss the results in terms of the geomagnetic and space weather conditions. Can you identify what kind(s) of space weather event(s) that were going on? Hint: we have selected data from typical "interesting" cases for each group to analyse, each representing one or more types of interaction between the Sun, the magnetosphere and the ionosphere.

6 Report

The structure of the report should be:

1. Title page
2. Introduction to the problem
3. Description of the data you analysed: date, what experiment was run, etc, and what the conditions were like in terms of the space weather, magnetosphere and ionosphere environment
4. Data analysis: method, results and discussion, following the outline in Section 5. References should be given in the text.
5. Conclusions, including a discussion of how the space weather conditions relate to the data.
6. List of references. Web pages are permitted if you clearly state the date and time when the page was accessed (since locations change).
7. Confirmation that you have participated in the work.

The length of the report (excluding the title page) should not exceed 12 pages.

Please note that every use of copy-paste techniques will result in report rejection. Plagiarism will be reported to the LTU lawyer according to Swedish national legislation.

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