EISCAT Scientific Association

EISCAT User Manual

EISCAT Radar School 2024

Guide originally created for PITHIA – NRF project

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August 2024

Amendment Control

Date	Author	Change
2024/05/27	Mária Miháliková	introduction of amendment system
2024/08/08	Mária Miháliková	update of information

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Introduction

This document was created as part of the PITHIA-NRF project. The intention is that it will be used during training for projects accepted during PITHIA trans-national access (TNA) calls. It will serve as a basic guide of the EISCAT radar systems, experiments, operation, and data analysis.

As an introduction, let us consider the basic working principles of an incoherent scatter radar system:

- A radio signal is produced by a powerful radio transmitter
- The signal encounters free electrons in the ionosphere and experiences Thomson scattering
- The scattered signal is collected by sensitive receivers

The scattered signal from each individual electron has a shift in its frequency due to the motion of the electron. Since the received scattered signal comes from an enormous amount of electrons, it could be considered incoherent (hence the name incoherent scatter radar). However, the electrons are not moving completely independently but are instead partly following the motion of the much heavier ions, whose motion comes both from waves that are inherent in the ionospheric plasma and from the large scale plasma flow. Constructive interference of the scattered signal coming from wave-fronts corresponding to the inherent waves leads to a very specific general shape of the spectrum of the returned signal, and the goal using the incoherent scatter radar method is to determine this spectrum as function of the scattering altitude.

One of the two main inherent wave-modes in the ionospheric plasma is the ion-acoustic mode. The received spectrum from this wave-mode is called the ion line (Fig. 1a), and is typically double-peaked with a width of up to a few tens of kHz. From the shape and frequency shift of the ion line we get information about

- Electron density N_e
- Ion temperature T_i
- Ratio of electron and ion temperatures $\frac{T_e}{T_i}$
- Plasma flow in one direction

The other main inherent wave-mode is the Langmuir wave. This gives rise to sharp peaks in the received spectrum a few MHz in both directions from the centre frequency of the ion line. These are called the plasma lines (Fig. 1b), and their off-set frequencies are very sensitive of the electron density and can thus be used for a good estimate of it.

In the ion line spectrum, the total returned power depends on the number of electrons that have scattered the signal and therefore gives an estimate of the ionospheric electron density. The width of
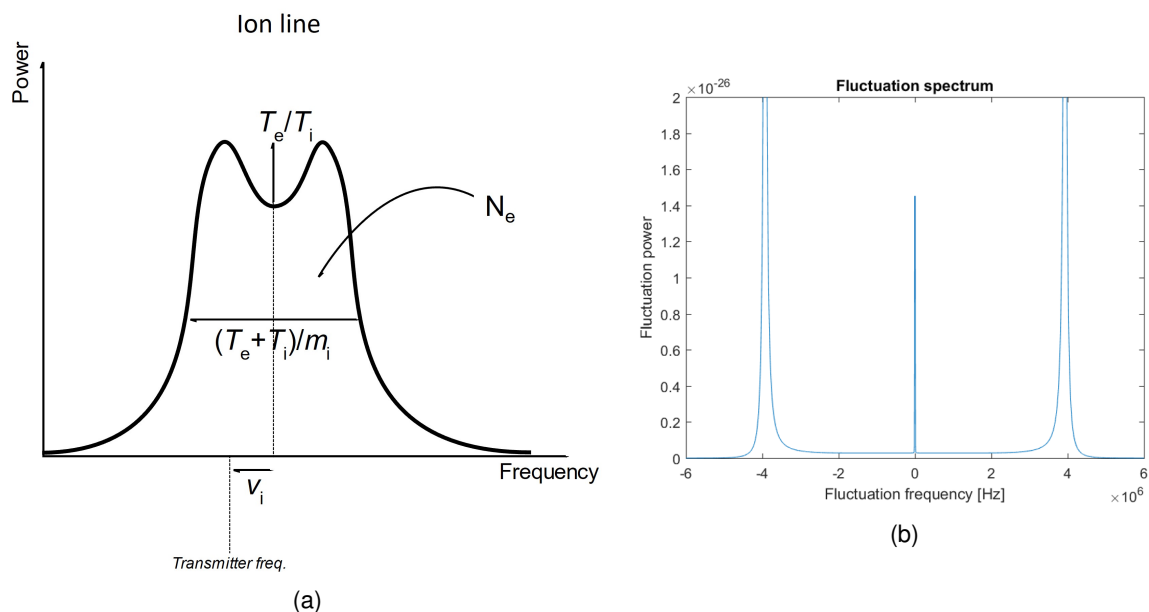

Figure 1: Incoherent scatter spectrum

the spectrum depends on the ion temperature, and the overall shift of the spectrum corresponds to the bulk drift motion of the ions in one direction. The "peakiness" of the ion line spectrum is a sensitive function of the ratio of the electron and ion temperatures.

At altitudes below about 120 km, collisions between the ions and the molecules of the neutral atmosphere affect the ion-acoustic wave mode in the plasma so that the ion line turns into into a single peaked spectrum from which, for instance, the frequency of ion collisions with the molecules of the upper atmosphere can be deduced.

From these basic results, many further ionospheric and upper atmospheric parameters can be derived using different assumptions. These include

- Ion composition
- Electric field strength
- Conductivity
- Joule and particle heating rates
- Neutral air temperature, composition, and wind speed
- Heat and plasma flux along the Earth's magnetic field
- Supra-thermal electron spectra (from the plasma lines)

Not all of these parameters can, however, be determined together nor in all altitude regimes.

Now, knowing the basic incoherent scatter radar principles and what types of data can be obtained from the EISCAT systems, the experimenter has to make some decisions before starting the experiment. These include

- What geographic and/or geomagnetic location (which EISCAT system to use)?
- What time of day and year?
- Which ionospheric region?
- Which resolutions in time and space?
- How should the radar antenna be oriented?

These choices naturally depend on the scientific objectives of the experiment, but for some of them knowledge of the radar systems is also needed.

1   The EISCAT radar systems

EISCAT Scientific Association operates three radar systems (UHF, VHF and ESR) with transmitters on two geographical locations, working in three different radio frequency ranges.

- **The UHF (Ultra High Frequency) system** operates at a frequency range around 929 MHz with a transmitter and receiver on the Ramfjordmoen site near Tromsø (see Table 1). The antenna is a 32 m steerable parabolic dish.

Figure 2: EISCAT UHF Antenna near Tromsø

- **The VHF (Very High Frequency) system** operates at a frequency range around 224 MHz with a transmitter and receiver on the same site as the UHF system (Ramfjordmoen near Tromsø). The antenna consists of four 30 m × 40 m tiltable rectangular dishes, limited to point in the zenith direction or northward. The VHF system also contained two receive-only stations located in Kiruna and Sodankylä (see Table 1) which are already decommissioned. The antennas on these stations were 32 m steerable dishes, and they provided a possibility for tri-static measurements of the plasma flow.

Figure 3: EISCAT VHF Antenna near Tromsø

- **The ESR (EISCAT Svalbard Radar) system** operates at a frequency range around 500 MHz with a transmitter and receiver near Longyearbyen on Svalbard. The system consists of two antennas: one fully steerable 32 m parabolic dish, and one fixed 42 m parabolic dish pointing in the direction of the local magnetic field. This set-up enables simultaneous measurements in two different directions.

Figure 4: EISCAT Svalbard Radar system

Table 1: Geographic location of the EISCAT radar facilities.

Location	Country	Coordinates	
Tromsø	Norway	69°35′ N	19°14′ E
Longyearbyen	Svalbard	78°09′ N	16°01′ E
Kiruna	Sweden	67°52′ N	20°26′ E
Sodankylä	Finland	67°22′ N	26°38′ E

2 EISCAT experiments

The EISCAT radars operate in two basic modes, using approximately half the available observing time for each. In the Special Programme (SP) mode, users conduct individual experiments dedicated to specific experiments and objectives. The resulting data are reserved for the exclusive use of the experimenters for one year from the date of collection. Special programmes often make use of the well developed pulse schemes and observing modes of the Common Programme (CP). EISCAT Common Programmes are conducted for the benefit of the entire user community and the resulting data are immediately available to all.

2.1 Experiment overview

An EISCAT experiment is a set of instructions telling the transmitters, receivers and digital signal processing units what to do at what time. In order to considerably simplify for the users of the radar systems, a set of standard experiments have been created. They differ in range coverage, range resolution, time resolution and spectral resolution so that they are fit for studies of different regions of the ionosphere. Some experiments are usable when the antenna is scanning while others are best used at fixed antenna positions. Some experiments provide plasma line data in addition to the standard ion line data, and some experiments in addition collect raw voltage level data to be analysed by the more experienced user. Expert users can modify the standard experiments, or even create their own ones.

All supported EISCAT experiments are based on alternating codes, but the codes are of different lengths in different experiments.

Some parameters describing the standard experiments used by the EISCAT UHF radar are collected in Table 2. The experiments used when running Common Programmes are beata, bella and manda. The main difference between these experiments lies in the range coverage and resolution, as is illustrated in Figure 5a. Other supported experiments on the UHF radar are arc_dlayer (optimised for D-region measurements), arc1 (good time resolution, for auroral studies) and tau1 (older experiment comparable to bella).

Parameters describing the standard experiments used by the EISCAT VHF radar are collected in Table 3. The experiments used when running Common Programmes are beata, bella, manda and tau7. Similar to the UHF experiments, the main difference between these experiments is in the range coverage and resolution, as is illustrated in Figure 5b. Other supported experiments on the VHF radar are arc_dlayer (optimised for D-region measurements), tau1 (older experiment with similar range span as tau7) and tau8 (older experiment with similar range span as bella). There are three experiments with supported tri-static capabiliy: beata, bella and manda.

Parameters describing the standard experiments used by the EISCAT ESR radar are collected in Table 4. The experiments used when running Common Programmes are ipy, tyko, folke, manda and tau7. Differences include range coverage, as well as power consumption, and is illustrated in Figure 6. The folke experiment is using both the 32 m and the 42 m antennas, and can thus by default make observations in two directions at the same time. Other supported experiments on the ESR radar are arc_slice (good time resolution, for auroral studies), beata (an alternative to ipy or tyko), steffe (different range resolution for different range intervals), tau0 (older experiment with similar range span as tau7), hilde (two antennas, three different range resolutions) and taro (both antennas are used over a large range interval, but with different duty cycles). The experiments using both antennas in coordination are thus folke, hilde and taro. In addition, ipy, tyko, tau7, arc_slice, beata, steffe and taro can switch between the two antennas.

When reading the following tables, we can also get quick estimates of range resolution (from baud length), spectral resolution (from the inversion of the multiplication of code length and baud length) and spectral range (inverse of sampling rate). However, the actual numbers may differ from these estimates depending on what is done during the digital signal processing.

You can find more details about the experiments mentioned here in the User documentation part of the EISCAT website: https://eiscat.se/scientist/document/experiments/.

2.2 Antenna scan patterns

EISCAT has pre-defined a set of antenna scan patterns that should be useful for most scientific measurements. They are named after the Common Programme they are used in. An EISCAT user may
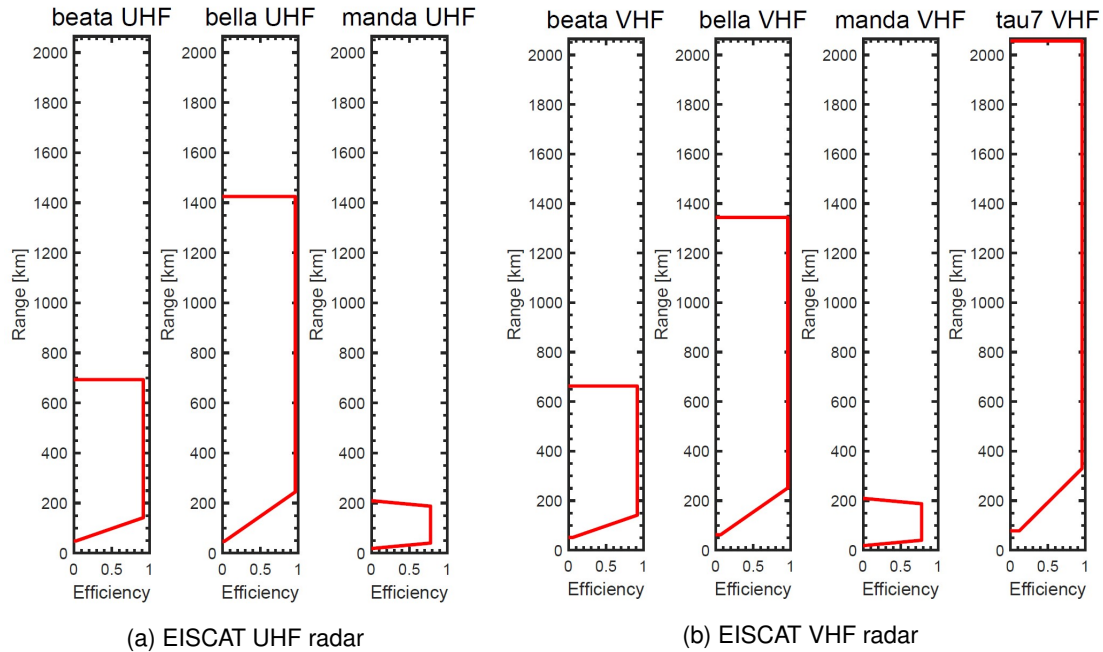
(a) EISCAT UHF radar

(b) EISCAT VHF radar

Figure 5: Overview of the ranges covered by the experiments used in the common programmes.

use one of these scan patterns, but it is also possible to define other patterns to use.

Table 2: EISCAT UHF radar standard experiments.

Name	Code length [bit]	Baud length [µs]	Sampling rate [µs]	Range span [km]	Time resolution [s]	Plasma line	Raw data
beata	32	20	10	49–693	5.0	Yes	-
bella	30	45	15	47–1425	3.6	Yes	-
manda	61	2.4	1.2	19–209	4.8	-	Yes
arc_dlayer	64	2	2	60–139	5.0	-	-
arc1	64	6	6	95–420	0.44	-	-
tau1	16	60	12	48–1353	5.0	-	Yes

Table 3: EISCAT VHF radar standard experiments. The top three experiments have tri-static support.

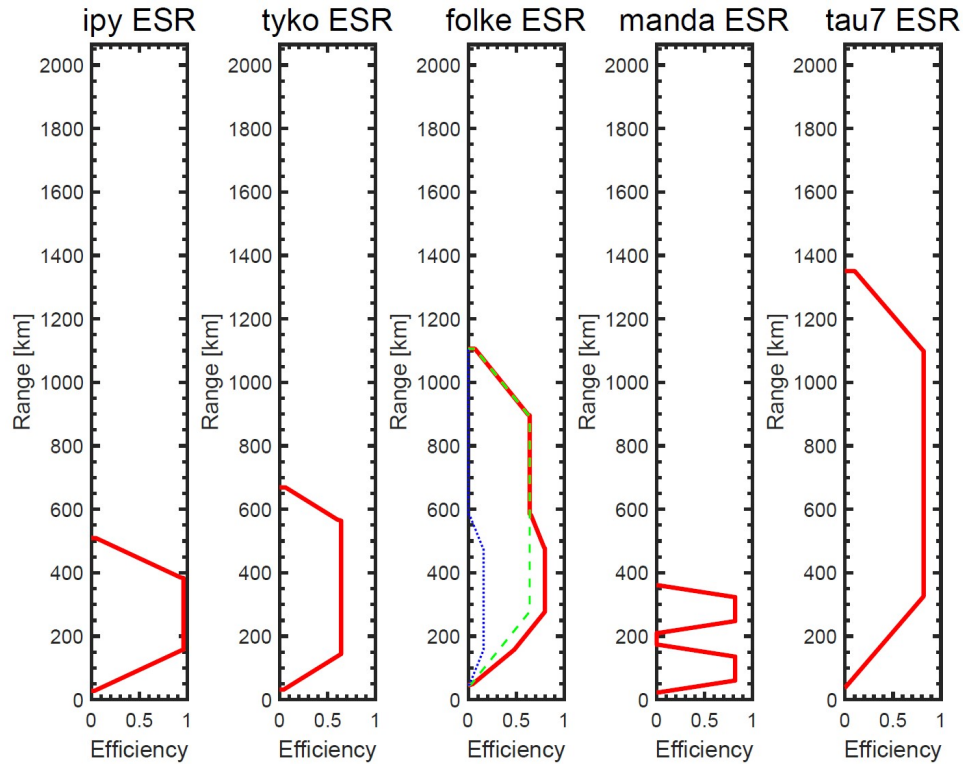| Name	Code length [bit]	Baud length [µs]	Sampling rate [µs]	Range span [km]	Time resolution [s]	Plasma line	Raw data
beata	32	20	20	52–663	5.0	Yes	-
bella	30	45	45	63–1344	3.6	Yes	-
manda	61	2.4	1.2	19–209	4.8	-	Yes
tau7	16	120	15	78–2057	3.6	Yes	-
arc_dlayer	64	2	2	60–139	5.0	-	-
tau1	16	72	24	104–2061	5.0	-	-
tau8	16	84	14	52–1307	5.0	Yes	-

Figure 6: Overview of the ranges covered at the EISCAT ESR radar by the experiments used in the common programmes.

2.2.1 Mainland systems

The UHF and VHF radars are often operated simultaneously during the Common Programme experiments. Such observations offer comprehensive data sets for atmospheric, ionospheric, and magne-

Table 4: EISCAT ESR radar standard experiments.

Name	Code length [bit]	Baud length [µs]	Sampling rate [µs]	Range span [km]	Time resolution [s]	Plasma line	Raw data
ipy	30	30	15	28–509	6.0	Yes	Yes
tyko	16	50	25	32–564	4.0	Yes	Yes
folke	16	100	25	45–1106	6.4	Yes	-
(dual)	16	50	25	45–581	6.4	Yes	-
manda	64	4	2	23–361	4.0	Yes	Yes
tau7	16	120	5	39–1351	6.0	Yes	-
arc_slice	64	6	6	85–481	0.5	-	-
beata	30	50	25	45–645	6.0	Yes	Yes
steffe	16	105	15	34–1021	6.4	Yes	-
	16	30	15	214–1033	6.4	-	-
tau0	16	60	20	53–1297	6.4	-	-
hilde	16	96	16	34–917	5.1	-	-
(dual)	16	32	16	34–963	5.1	-	-
	16	60	20	35–1288	5.1	-	Yes
taro	16	50	25	47–830	6.4	-	-
(dual)	16	50	25	47–830	6.4	-	-

tospheric studies. You can see a representation of the Common Programme experiments in Figure 7.

- **Common Programme One, CP-1**, uses a fixed transmitting antenna, pointing along the geo-magnetic field direction. The three-dimensional velocity and the anisotropy in other parameters can be measured using the VHF receiving stations at Kiruna and Sodankylä. CP-1 is capable of providing results with very good time resolution and is suitable for studies of substorm phenomena, particularly auroral processes where conditions might change rapidly. Continuous electric field measurements can be derived from the tri-static F-region data. On longer time scales, CP-1 mea-surements support studies of diurnal changes, such as atmospheric tides, as well as seasonal and solar-cycle variations.
- **Common Programme Two, CP-2**, is designed to make measurements from a small, rapid trans-mitter antenna scan. One aim is to identify wave-like phenomena with length and time scales comparable with, or larger than, the scan (a few tens of kilometers and about ten minutes). The first three positions form a triangle with vertical, south, and south-east positions, while the fourth is aligned with the geomagnetic field.
- **Common Programme Three, CP-3**, covers a 10° latitudinal range in the F-region with a 17-position scan up to 74°N in a 30 min cycle. The observations are made in a plane defined by the magnetic meridian through Tromsø. The principal aim of CP-3 is the mapping of ionospheric and electrodynamic parameters over a broad latitude range.
- **Common Programme Four, CP-4**, covers geographic latitudes up to almost 80°N (77°N invariant latitude) using a low elevation, split-beam configuration. CP-4 is particularly suitable for studies of high latitude plasma convection and polar cap phenomena. However, with the present one-beam configuration of the VHF radar, CP-4 is run with either both UHF and VHF radars or with UHF only in a two position scan.
- **Common Programme Six, CP-6**, is designed for low altitude studies, providing spectral mea-surements at mesospheric heights. The velocity and electron density are derived from the mea-surements, and the spectra contain information on the aeronomy of the mesosphere. A vertical antenna pointing direction is used.
- **Common Programme Seven, CP-7**, probes high altitudes and is particularly aimed at polar wind studies. The present version, with only one of the VHF klystrons running, is designed to cover altitudes up to 1500 km vertically above Ramfjordmoen.

2.2.2 The EISCAT Svalbard Radar

Equivalent Common Programme modes are available for the EISCAT Svalbard Radar.

- **CP-1** is directed along the geomagnetic field (81.6° inclination).
- **CP-2** uses a four position scan where the 32 m antenna moves between three of the positions, and data is collected by the 42 m antenna while the other one is motion.
- **CP-3** is a 15 position elevation scan using the 32 m antenna with southerly beam swinging positions.
- **CP-4** combines observations in the F-region viewing area with field-aligned and vertical measure-ments.
- **CP-6** is similar to the mainland radar CP-6.
- **CP-7** is similar to the mainland radar CP-7.

The different common programmes are usually run using a specific experiment, as denoted in Table 5.
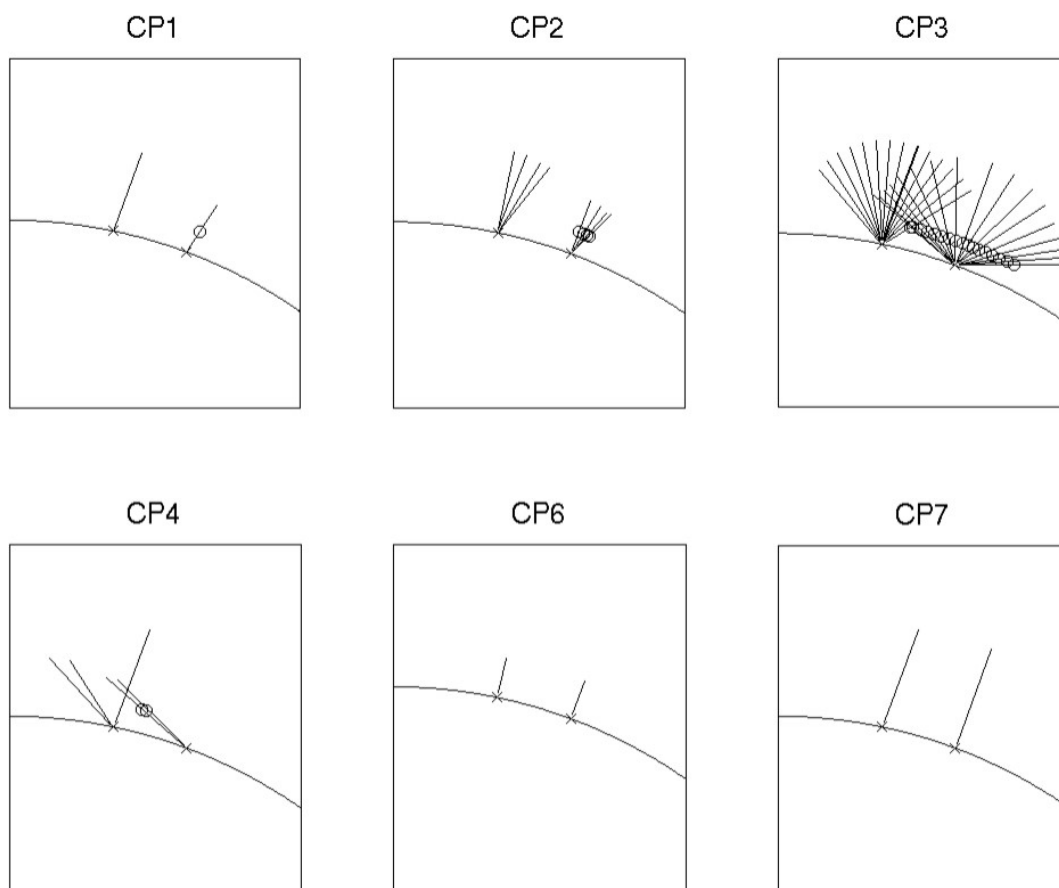
Figure 7: Overview of the common programmes on the EISCAT systems.

Table 5: Common programmes and their connected experiments. Experiment names in italic indicates common programmes that are not normally run.

	UHF	VHF	ESR
CP-1	beata	*beata*	ipy
CP-2	beata	-	tyko
CP-3	bella	-	folke
CP-4	*bella*	bella	folke
CP-6	*manda*	manda	manda
CP-7	-	tau7	tau7

3 EISCAT operation

In the previous chapters we described the EISCAT radar systems and common experiments with which we conduct ionospheric and atmospheric measurements. These systems are taken care of by EISCAT Scientific Association, which is an international non-profit scientific organization with member institutes in several countries. Access to the EISCAT facilities is provided to all the scientist in the Associate countries and to the other Affiliates. Processed data products are made freely available to all. All information about EISCAT's governing rules and procedures can be found in The Bluebook in detail. This chapter will briefly describe the path from acquiring EISCAT observation time to actually running the experiment.

3.1 EISCAT time acquisition

The EISCAT systems are open for researchers who are interested in conducting experiments. How to request time and how to schedule time on the EISCAT radars is divided by membership. If the scientist is working in a country where an institute is a member of EISCAT (Norway, Finland, Japan, South Korea, China, Ukraine, the United Kingdom and Sweden) they can contact point of contact person in given institute/country.

If the scientist works from a non-membership country they can apply for observing time using EISCAT Peer-reviewed Program experiments. Calls for them are published in mailing lists and on the EISCAT website. Except of these possibilities EISCAT is taking part in EU funded projects, presently in PITHIA-NRF project, which offer the possibility to access the facilities through Trans-National Access program.

3.2 Scheduling of an experiment

Once the scientist has acquired EISCAT observation time, they can schedule their observation through EISCAT portal webpage, by selecting Experiment request in the menu and filling in the necessary information. Requests are gathered in the system and the schedule for subsequent month is decided by the EISCAT staff responsible for the scheduling around the beginning of the present month. It is also possible to cancel a scheduled experiment but latest 24 hours before scheduled start time by directly communicating with the responsible person.

3.3 Starting and running an experiment

Scheduled experiments are usually run for the user by EISCAT staff at the given site. Each experiment/common programme is described with the help of .elan file, that includes all the additional commands necessary for the system (e.g. antenna scanning pattern) to perform the given experiment. Very advanced users can create their own scanning patterns or even own experiments but in general the experiments and common programmes designed by EISCAT cover most of the observational needs for phenomena usually observed by EISCAT users.

EISCAT radars are controlled by the EROS System (EISCAT Real-time Operating System). EROS is a tcl/tk software application running on the main process computer at each site. It provides a run-time user interface and handles all macro-scale (longer than seconds) timing in the system. It also loads and configures hardware for micro-scale timing, controls antenna pointing and manages the experiments (i.e. their scheduling, start, stop and changes).

Usually all experiments are run from designated terminal in the control room. In Tromsø it is for VHF radar GOPPI terminal and for UHF radar CULEBRA terminal. Each terminal has similar desktop views. There are several windows that offer the overview of the status of the experiment and the system. There should be visible following windows:

- **EROS console** – This is where the commands are typed. You can start/stop experiment, start recording of data and control radar from this console.

Figure 8: EROS console

- **Messages (site)** – Into this window the messages from EROS system are printed. For example it shows where the data is being written to and if it is successfully written. Error messages will be shown in this window.

Figure 9: Messages window on VHF Tromsø site

- **ELAN (site)** – This window shows messages from the elan file, i.e. what data is being recorded and from which dish.
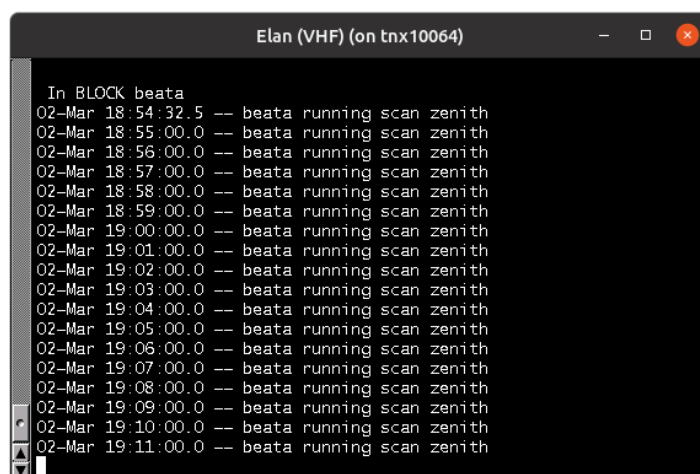

Figure 10: ELAN window on VHF Tromsø site

- **RTG** – RTG (Real Time Graph) window offers a look at the raw data. RTG can be run during the experiment only for the machine on the site, which you are present at. However, RTG from all

the sites that are presently running an experiment can be seen through the web interface on the EISCAT Portal by choosing Realtime graphs and the name of the site in the menu.
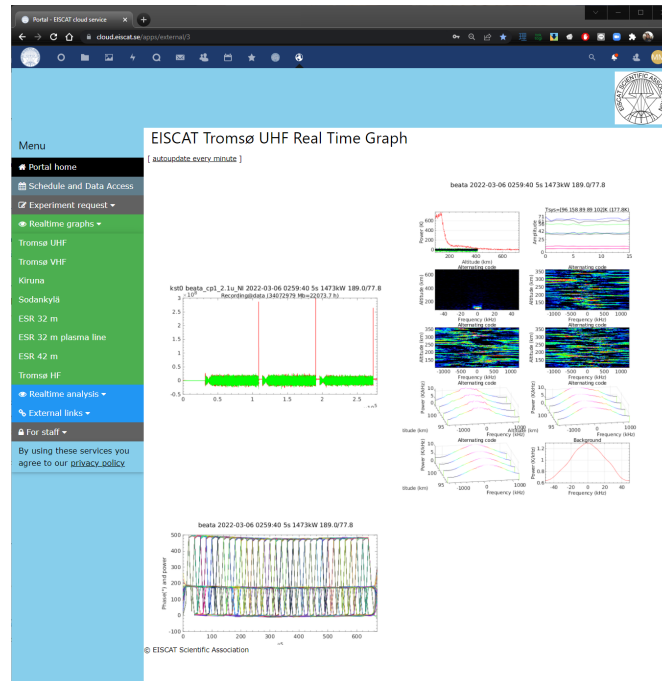

Figure 11: RTG web interface displays the overview of technical status of the system and received raw data.

- **Realtime analysis** – after the experiment is running realtime analysis is started by using EISCAT's Guisdap application. Data is analysed as it is received and overview is offered in several windows. Analysis is again possible to follow through the same web interface of EISCAT Portal by choosing Realtime analysis and the name of the site.
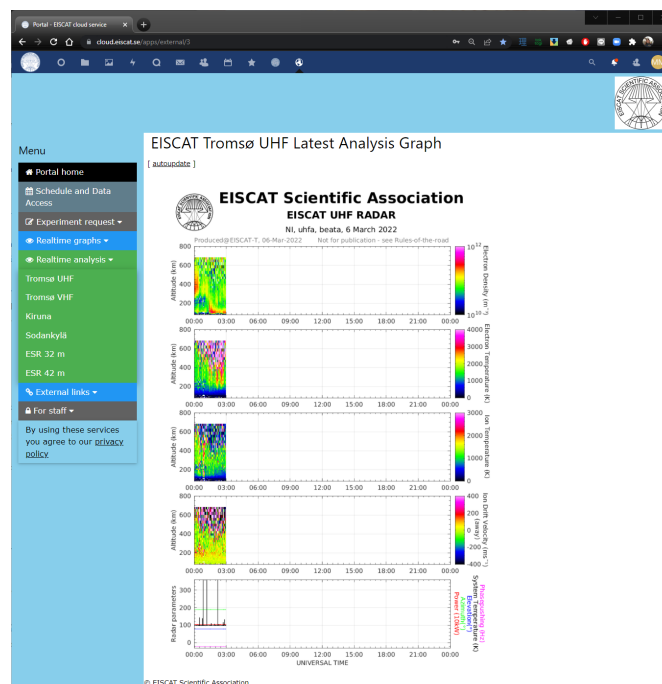

Figure 12: Realtime Analysis web interface displays the overview of the physical parameters gained by analyses (uncalibrated) of the raw data as it is being measured

- **other** – there are other windows that report on various parts of the system. The most important and used are the aforementioned ones.

3.3.1 Step by step overview of running an experiment

    Experiments are usually run for the user by EISCAT staff at the site. Experiment is described with the help of .elan file, that include all the commands necessary for the system and antenna to perform given experiment. All the common programs and experiments described in previous chapter have their directories with all necessary files stored in the /kst/exp/ directory. For special programs there are country directories eg. /kst/exp/UK. To start an experiment follow these steps in the EROS console window:

1. **Check if EROS is running**
   Usually EROS system is already running and you can run your experiment and start recording the data etc in the EROS console window.

2. If you are running an experiment which requires the dish to move then make sure the power to the dish is on. If the dish is not required to move, turn the power off once it is in its position. You can check the status of the antenna dish and power it on with the following commands and <site> flag:

       $ *EROS:*

   <dish/site> printant

       $ *EROS:*

   <dish/site> poweron And eventually turn the power off when the dish is in position with:

       $ *EROS:*

   <dish/site> poweroff

3. Once ready you can start the experiment with the runexp command. The dish/site flag is needed if you are running the experiment remotely and not on the site.

       $ *EROS:*

   <dish/site> runexp <expname> <start time> <scan> <owner> < additional input> For example:

       $ *EROS:*

   runexp /kst/exp/steffe/steffe 12:00 lowelnorth1 UK

       $ *EROS:*

   runexp /kst/exp/tau0/510/tau0 08:00 SP

4. If you are running tri-static system, then you have to start the radars at each of the sites also (KIR - Kiruna, SOD - Sodankylä). You can do this using the <site> flag.

       $ *EROS:*

   KIR runexp /kst/exp/steffe/steffe 12:00 lowelnorth1 UK

       $ *EROS:*

   SOD runexp /kst/exp/steffe/steffe 12:00 lowelnorth1 UK

   The <start time> is always given in UT time. You can also use other commands like now, fullminute (fm), lastminute (lm) to specify the start time relatively to the actual time. If you are running the tri-static system, then always use the same start time in the runexp commands as opposed to fm or lm as this will keep everything synchronized.

   The <scan> and <owner> flags should be specified to label and store the data in appropriate directories.

5. Once the experiment is running, you need to enable the recording:

       $ *EROS:*

   enablerec In case of tri-static system also:

       $ *EROS:*

KIR enablerec

> **$** *EROS:*

SOD enablerec

6. You can check on the experiment anytime by using the printexp command for a given site.

> **$** *EROS:*

printexp

7. Check the data is been written to the data disks:

> **$** *EROS:*

printdata all

To finish an experiment follow these steps:

1. Stop the experiment

> **$** *EROS:*

stopexp <end time>

2. Turn the transmitter into black heat mode.
3. Turn the power off to the dish if the power is still on

> **$** *EROS:*

poweroff

Once the experiment is finished the data acquired during the run will be checked, analysed and calibrated by EISCAT staff and uploaded to the Madrigal database where it is accessible for download. (see Chapter 5)

4   Advanced EISCAT operation - examples

Advanced EISCAT user can create their own scan patterns for experiments and define where, and for how long the antenna should point. The scan pattern is defined in an elan file. In case of a custom scanning pattern, user prepares the elan file and submits it to EISCAT staff ahead of the experiment in timely manner.

Elan files are prepared using the EROS commands and Tcl (tool command language). Links to the reference manuals can be found on the EISCAT website for both the EROS5 User commands and also the Tcl.

The following is an example of elan file describing a scanning pattern in a plane with set azimuth and various elevations.

```
eiscat@goppi:/kst/exp/scans/kst/no$ cat meridianscan_pattern.elan
#------------------------------------------------------------------------------
#
#   At ESR: Magnetic meridian scan N-->Z-->S-->Z-->N
#   At UHF: Magnetic meridian sdan N-->Z-->N-->Z-->N
#
#   One might want to set the dwell time to a multiple of integration time.
#   Ideal scan propagation speed is 0.5 degr/second (= 10 degr / 20 sec).
#
#   It is assumed that the block is entered (like in beata), 4 seconds before exp start time.
#   Then the pointing to the position 1, the lowest elevation north, is given at the start time.
#
#   One should give pointing to the initial position interactively well before
#   the actual experiment start time, as
#
#       ESR: pointdirection -22.07 30
#       UHF: pointdirection 7.03 30
#
#  5-Dec-2015 Jm.
#------------------------------------------------------------------------------

BLOCK meridianscan { args } {

    azellog on

    if [isradar e] {
        SYNC 4
        # azimuth 157.93 - 180  (From lowelsouth2_pattern.elan, version 31-Jan-2014)
        set azim -22.07
        set ELEV [list         30 40 50 60 70 80 90   100 110 120 130 140 150
        140 130 120 110 100 90   80 70 60 50 40]
        esrant Speed-Set 1.2 yes
    } elseif [isradar u] {
        # azimuth 187.03 - 180 (From cp1_pattern.elan, version 2015-01-01)
        set azim 7.03
        set ELEV [list         30 40 50 60 70 80 90   80 70 60 50 40 30
        40 50 60 70 80 90   80 70 60 50 40]
    } else {
        error "[eGet radar] not supported by meridianscan"
    }

    set NPOS [llength $ELEV]

    DO forever {
        for {set posindex 0} { $posindex < $NPOS } { incr posindex } {
            set elev [lindex $ELEV $posindex]
            pointdirection $azim $elev
```

```
            DISP [HMS3] " Pointing to position [format %2d [expr {$posindex+1}]] :
            [format {%6.2f %6.2f} $azim $elev]"
            SYNC 25
        }
    }

}
```

5   EISCAT data

Incoherent scatter radars produce large amounts of data, so the handling of these data is an important part of the EISCAT operations. A number of computer systems have been developed over the years to simplify working with the data. Furthermore, since data are the end product for EISCAT, it is important to have a solid policy in place for the use of EISCAT data.

5.1   EISCAT data collection

The data collected during an EISCAT experiment are initially stored locally and can be accessed from the directory /data in the filesystem used by the computers at the local EISCAT site. This is a temporary storage and the data will be removed after a few months, so it should never be used routinely. Normally, new data will be available within a day from the EISCAT data servers and can then most easily be accessed via the EISCAT schedule website, https://portal.eiscat.se/schedule. Data access from the archive is regulated by the EISCAT data policy, described in Section 5.6.

These data consists of range gate profiles of autocorrelation functions, which can directly be translated to altitude dependence of the spectrum of the returned signal from incoherent scattering.

The data are stored in files compatible with Matlab, and are usually compressed using bzip2. The file names are generated automatically based on the time the data are collected: The number of seconds since new year (1 January 00:00:00 UTC) rounded down, using eight digits. These data are organised in directories named following the pattern of beata_cp1_2.1u_CP@uhf, where beata is the name of the experiment, cp1 is the name of the antenna scan, 2.1 is the experiment version, u is the radar system, CP is the data access type, and uhf is the sensor. Within these directories, the data is sorted in one directory per hour.

Table 6: Codes used for the radar systems in the names of the EISCAT data directories.

Short name	Meaning
l	EISCAT Svalbard radar
r	EISCAT VHF receivers in Kiruna and Sodankylä
u	EISCAT UHF in Tromsø
v	EISCAT VHF in Tromsø

Table 7: Most common codes used for the data access types in the names of the EISCAT data directories.

Short name	Meaning
CP	Common programme
AA	All associates, data immediately available for all member countries
CN	China
FI	Finland
NI	Japan
NO	Norway
SW	Sweden
UK	United Kingdom

Table 8: Codes used for the sensor in the names of the EISCAT data directories.

Short name	Meaning
32m	EISCAT Svalbard radar, the 32 m antenna
32p	EISCAT Svalbard radar, plasma line data
42m	EISCAT Svalbard radar, the 42 m antenna
kir	Kiruna VHF receiver
sod	Sodankylä VHF receiver
uhf	UHF radar in Tromsø
vhf	VHF radar in Tromsø

5.2 Analysis of EISCAT data

In EISCAT terminology, *analysis* means the process of transforming the auto-correlation data collected by the EISCAT systems into physical parameters characterising the ionospheric plasma. This process is conveniently performed using the GUISDAP analysis package. The name stems from "Grand Unified Incoherent Scatter Design and Analysis Package". It consists of Matlab software, applying the direct theory of incoherent scattering spectrum to calculate the parameters.

Guisdap is started by entering **guisdap** in a computer terminal window. This will start Matlab and run a few commands to set the proper search paths and global variables for GUISDAP to function.

To start your analysis, enter the command **analyse** at the Matlab command line. A window called **GUISDAP for Dummies** (Fig. 13) will appear. After clicking on the GUISDAP logotype the following input fields will be shown:
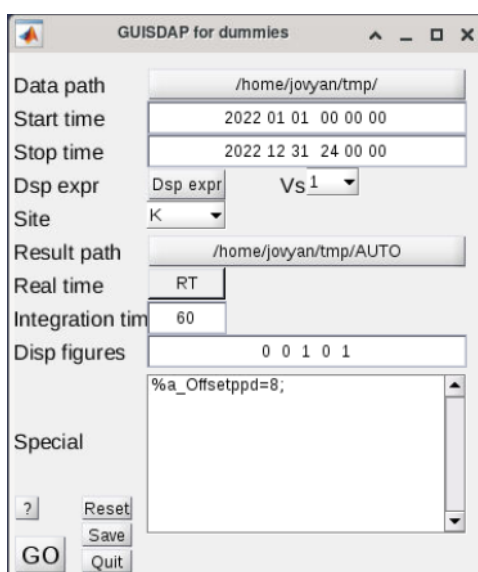
Figure 13: GUISDAP for Dummies main window

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 expr GUISDAP tries to guess the correct type of experiment (pulse code and digital receiver settings) from the name of the data directory. If it is incorrect, select the appropriate experiment name from the list.

Vs The version of the experiment (each experiment may exist in different varieties, and they 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 Special analysis of plasma line data used for some experiments at the EISCAT Svalbard Radar

Q,H Special analysis for non-EISCAT data, so its usage is not covered here

Result path Where to save the results. Make sure that this is an **empty** folder. Use **AUTO** as the final path name to ensure that GUISDAP puts the results 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 to reduce variance. Typical values are 60, a multiple of the data dump time, or 0. For a scanning experiment, if 0 is selected, 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. The five plots are **data dump, power profile, fits, parameter profiles**, and **surface plots of parameter time series**. It takes a considerable time to make some of the plots, so 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" to a non-default value as described below.

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

The surface plot window will only appear after the analysis has finished, if it is selected. This plot can be reproduced and modified later by calling the Matlab command **vizu** (see next section).

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)

The analysed data can be further (re)calibrated, visualised and analysed for advanced physical parameters through other scripts contained in the GUISDAP package, like **calib_ne**, **vizu**, **vel_wrapper**.

5.3 Calibration of EISCAT data

At the EISCAT radar systems the gain of the antennas may vary over time, which is often due to external factors such as wet snow piling up in the antenna dish (see Fig. 14). It may thus be necessary to perform a calibration process to correct the measured received power in order to get correct value for the electron density. Calibration is usually done at the EISCAT headquarters by the EISCAT staff and it is routinely done in two different ways: Using the EISCAT dynasonde data, and using the measured plasma line data. Using the plasma line is beyond the scope of this text, but the dynasonde method is described below.

Figure 14: Snow removal from the EISCAT Svalbard 42 m antenna (photo: Esa Turunen).

For data collected at Tromsø, and at Svalbard until mid-2015, dynasonde data can be used for the calibration. The idea is to compare the dynasonde measurements of the critical frequencies f_{oE} and f_{oF2} in the ionosphere with the results from the GUISDAP analysis (the parameter *P1* in **vizu** described above). This comparison is easiest done by using the command **calib_ne(1)** (for f_{oE}) and **calib_ne(2)** (for f_{oF2}). Some more settings can be used, which can be seen by typing **help calib_ne**. If the disagreement is considered to be too large, a re-analysis of the data can be performed. Using the described process will suggest a new value to use as "Magic_const" in the re-analysis. This is done bye adding the line `Magic_const=xx;` in the **Special** box in the "GUISDAP for dummies" window, where `xx` is the new value to use.
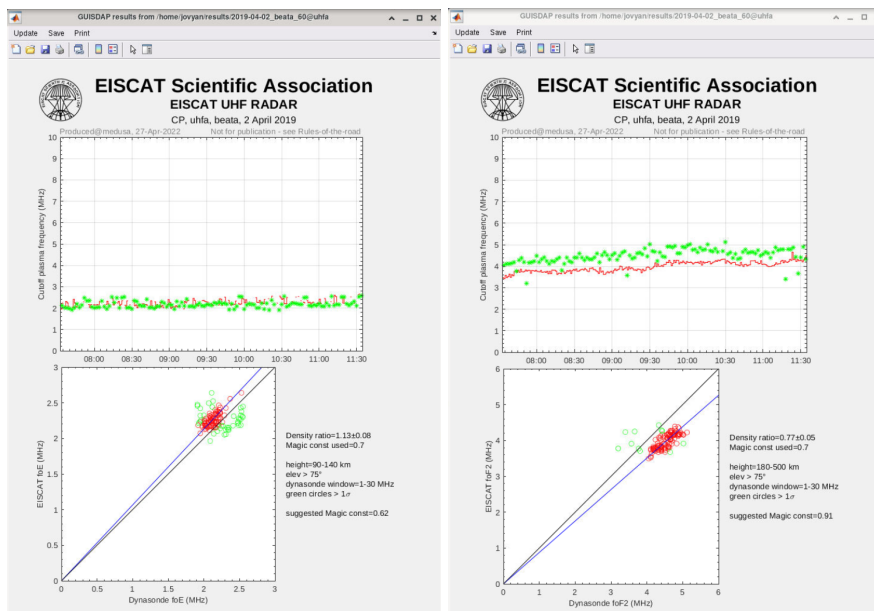
Figure 15: Output figure of **calib_ne(1)** command (left) and **calib_ne(2)** command (right)

There is a possibility for the users to use EISCAT Level 2 data (section 5.6 on page 29) by using the commands **calib_ne**, as described above, and redoing the command **analyse** with appropriate parameters given to the **Special** window in Guisdap interface (Fig. 13). In this case the integration time or other advanced parameters can be changed but this is beyond the scope of this text.

Analysed and calibrated data is what we call EISCAT level 3 data (section 5.6 on page 29). These are the actual physical parameters gained as the result of the **analyse** command (section 5.2) and stored in mat files in your results folder. For archiving purposes these are converted and stored as HDF5 files and made available through the Madrigal database to the scientific community.

5.4   Saving of EISCAT data as HDF5 files

After you finish your analysis matlab files with your data are stored in the results path. You can save these data in EISCAT HDF5 format with the following command:
mat2hdf5('pathtomatfiles','pathtostore')

5.5   Visualisation of EISCAT data

Once the physical parameters are gained through the use of calibration and analysis of the auto-correlation data they can be visualised using the command **vizu** and analysed by the users for their scientific purposes. The gained physical parameters stored in HDF5 files on the Madrigal database can also be visualised the same way using Guisdap. There exist two different HDF5 files for each experiment in the Madrigal database. If you want to visualise the data with help of Guisdap, please make sure to download the file which filename starts with EISCAT and not MAD. If you use the other one the data will fail to load in Guisdap.

Please always check if you are running in the guisdap environment. Your prompt in terminal will have the look of Matlab prompt (») in case you do run it. Vizu and other guisdap commands will not work from standard terminal prompt without running the **guisdap** command first.

To visualise the physical parameters anew or to be able to choose to visualise different data than what was used before, use the command **vizu new VERBOSE**. If you want to just change the data you have already visualised once you can use only parameter VERBOSE with the vizu command: **vizu VERBOSE**

By specifying the **new**, you will be asked for the information denoted by the asterisk (*). By specifying the capital **VERBOSE** you will get to specify the other parameters of the visualisation. Except for the data path, the default values for all parameters are useful, and just pressing enter will use the defaults. Some experiments, and some set-ups, will give you other parameters to select but these are the common ones.

Data path? (*) Default is to your temporary folder. You need to specify the path to your analysed data here.

Status/residual limits? (*) Limit data to be displayed up to the given level of fitting status (0: OK, 1: Max iterations reached, 2: Fitting failed, 3: No fitting performed), and up to the given level of fitting residual. Default is to show all successfully analysed data.

Maximum pp resolution (km)? (*) Limit the shown raw electron density data to those having a maximum size of range resolution. Default is to show all raw electron data.

Your full name? (*) In case you come this far and you get this question, you have made a mistake chosing the path and guisdap doesn't see the data you want it to visualise. If this happens just cancel the matlab process by pressing `CTRL+C` and run the vizu command again

Start time? Choose the time from which you want to start the visualisation as a [year month day hour minute second] vector. Default is the earliest time contained in the data of the chosen file path.

End time? Choose the time at which you want to end the visualisation [year month day hour minute second] vector. Default is the latest time contained in the data of the chosen file path.

Altitude scale? Choose the range of altitudes you want to display. Default is to show all altitudes available for a given experiment.

Parameters: Here you can choose various parameters that you want to display in your figure. The default is [Ne Te Ti Vi AE] which is the standard output surface plot from the guisdap analysis. The possibilities are as follows:

Ne Electron density.

Te Electron temperature.

Ti Ion temperature.

Vi Ion drift velocity in the line-of-sight.

AE Radar system information.

TT Electron and ion temperatures in a combined line-plot (only possible if looking at a single gate, for instance when looking at data from the receive only stations).

LL Radar system information and geographic coordinates of the observed volume (only possible if looking at a single gate, for instance when looking at data from the receive only stations).

Rs The residual from the fitting performed during the analysis.

O+ The ion composition, as described above.

Co Plasma collision frequency, as described above.

Nr Raw electron density. This is the electron density determined only from the power of the return signal, before any fitting of the spectrum.

Lf The plasma line frequency. This is the frequency corresponding to the plasma line for a plasma with the electron density and temperature determined by the analysis.

L1 The maximum plasma line frequency.

Ls Estimate of the plasma line spectrum.

Pf Plasma frequency, calculated from the electron density determined by the analysis.

P1 Maximum of the plasma frequency. This can be compared with the critical frequency measured using a dynasonde.

TC Total electron content. This plot has not yet been implemented so it will produce an error if chosen.

Type of experiment? (*) Default is [CP], which stands for Common Program. Various experiments are run for different countries and users and this string denotes in the header of the figure what kind of experiment it was.

Gates? Choose which gates of the experiment you want to display. Default is all gates that are available for the given experiment.

Y parameter (Ran-1 Alt-2 Lat-3)? Choose the dimension of the Y axis. You can display the data as a function of range (Ran [1]), altitude (Alt [2]), and latitude (Lat [3]). Default is [2] altitude.

Y scale type? Choose if linear or logarithmic scale should be used for the Y axis. The default is [linear] for most experiments.

AzEl screen values? Choose (in case of an experiment with moving antenna) which azimuth elevation levels do you want to plot. The default is to show all data.

Scales (Ran Alt Ne Te Ti Vi coll Comp Res)? You can choose scales to adjust the colourbars/ticks for different parameters in the figure. Depending on the experiment default is [50 900 70 680 1e+10 1e+12 0 4000 0 3000 -200 200 1 100000 0 1 0.1 10]. Please note that two numbers are corresponding to each parameter (lower limit and upper limit of the scale).

Scale (AzEl) The limits on the Y axis for the AE plot.

Strech secs The default of this parameter is 65. It serves only for matlab to be able to better plot the surface plots. Usually it is left at the default value.

Figure 16: The succession of questions when using the command **vizu new VERBOSE**

You may encounter other questions and default parameters depending on the type of experiment you are analysing or your choice. In this guide we were demonstrating the analysis on Beata UHF experiment using cp1 (Common programme one) as antenna scan pattern.

Once you are done with visualising and you achieved the figure you want to preserve, use the command **vizu save**. This saves a pdf and png file with the figure you have last plotted under the default experiment name. If you do not want to overwrite your previous figures, pass another parameter to vizu and use **vizu save nameadd**. The string used as the second parameter will be added to the original name with an underscore (name_nameadd).

To illustrate the work with HDF5 files downloaded from Madrigal please have a look on the set of screenshots on following pages.
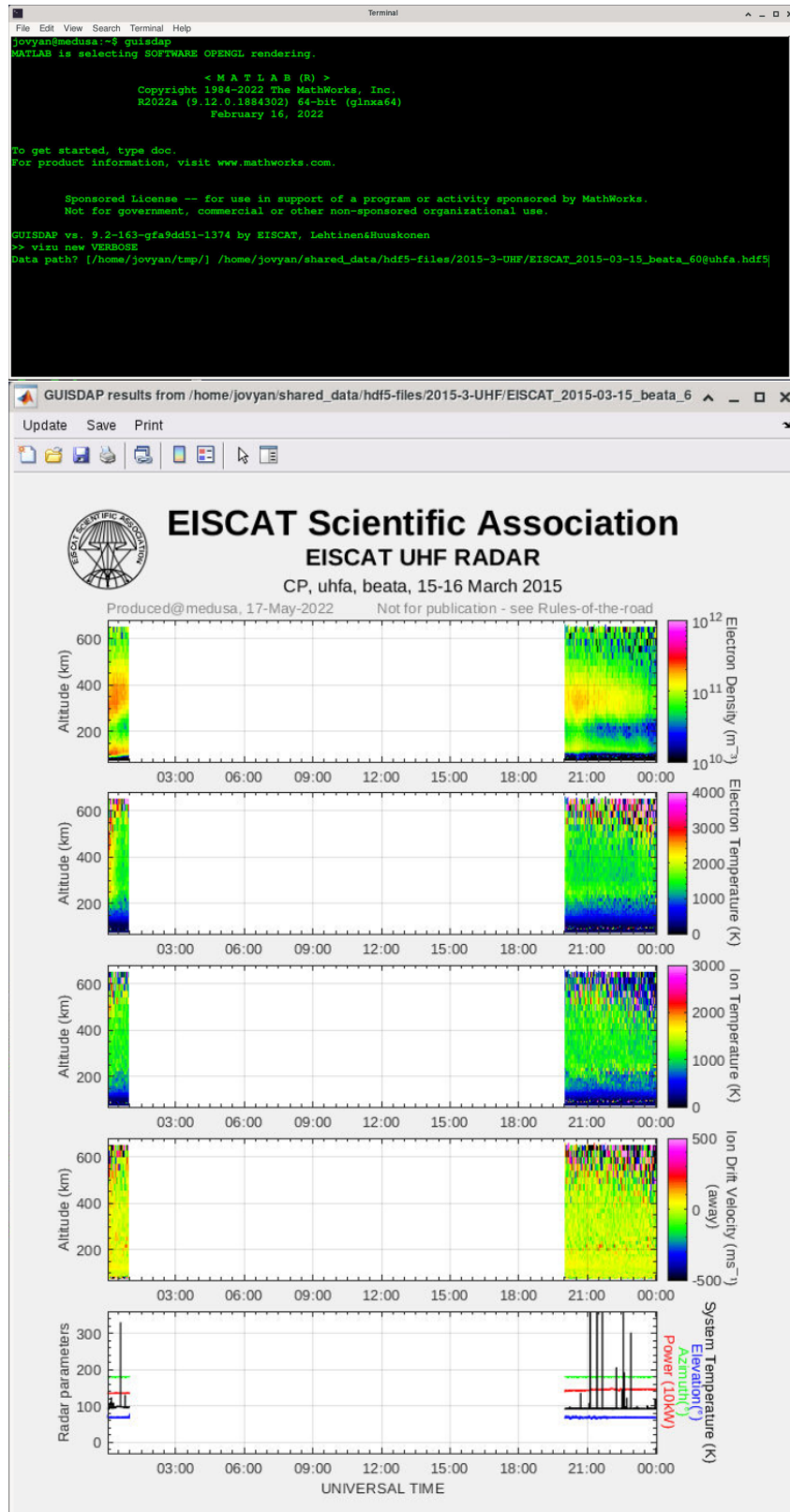
Figure 17: To load the HDF5 file give path to the file stored in shared_folder and not just to the directory. Visualisation with **vizu** and the resulting plot once taking default answers to all following questions would produce the surface plot that is result of the analyse function and that you could see as a quick-look figure in Madrigal.

```
>> vizu VERBOSE
Start time? [ 2015 3 15 0 1 50 ]2015 3 15 20 0 0
  End time? [ 2015 3 16 0 1 1 ]2015 3 15 24 0 0
Altitude scale? [ 70 680 ]
Parameters: Ne Te Ti Vi AE TT LL Rs O+ Co Nr Lf L1 Ls Pf P1 TC
Choose? [Ne Te Ti Vi AE] Ne Te
Gates? [ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 ]
Y parameter (Ran-1 Alt-2 Lat-3)? [ 2 ]
Y scale type? [linear]
AzEl screen values? [ -Inf Inf -Inf Inf ]
Scales (Ran Alt Ne Te Ti Vi Coll Comp Res)? [ 50 900 70 680 1e+10 1e+12 0 4000 0 3000 -500 500 1 100000 0 1 0.1 10 ]
Strech secs? [ 65 ]
>> |
```
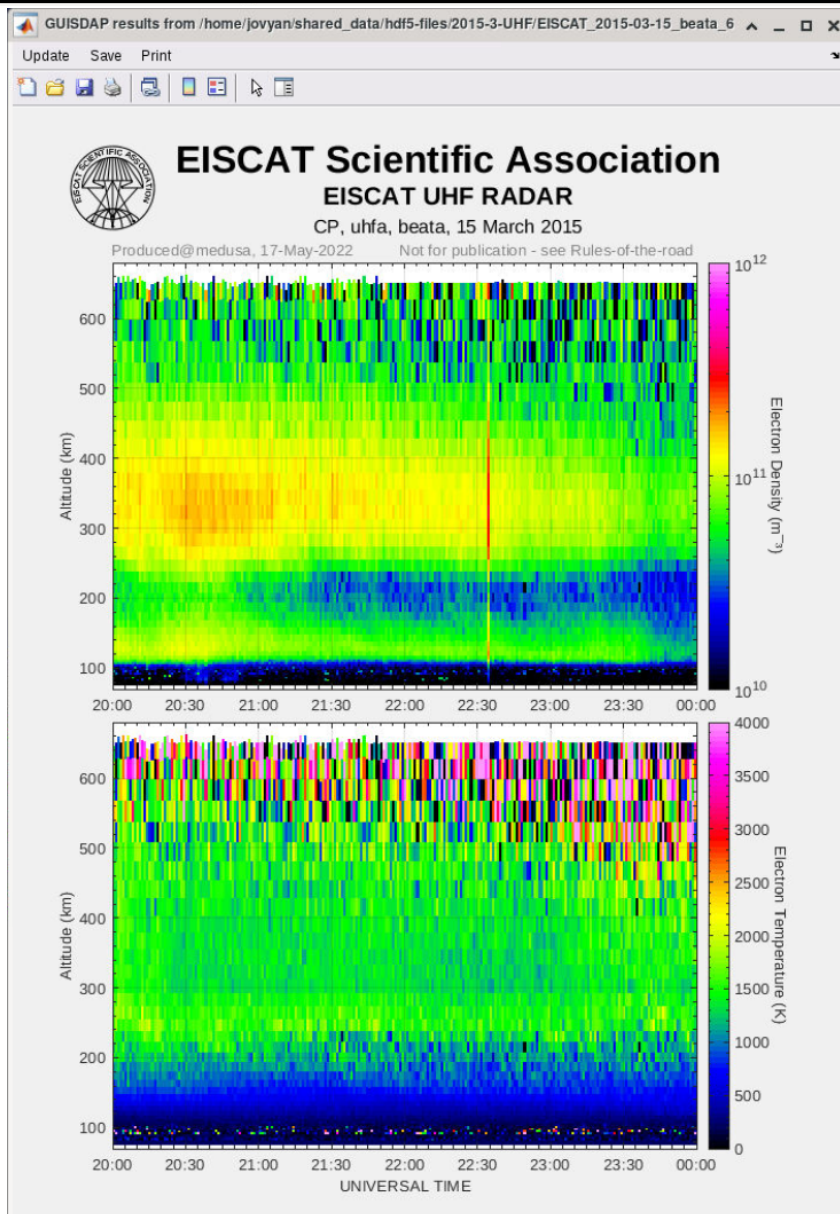

Figure 18: Work with the HDF5 files in guisdap is the same as with mat files gained as a result of runing the **analyse** command on Level 2 data. After going through the questions you can change the parameters for visualisation and gain completely different figure adjusted to your liking.

5.6 EISCAT data policy

The following are the sections about EISCAT data policy coming from the agreement between the EISCAT member countries.

The chain of data levels described here starts from the digital signal processing in the receiver system.

- Level 1. Voltage-level data samples.

- Level 2. The time integrated power spectral data, decoded from the voltage data. The data obtained from passive observations or the data from other EISCAT instruments are also Level 2 data.

- Level 3. The physical parameters that are derived from the level 2 data. At present these are the profiles of physical parameters of the ionospheric plasma (electron density, electron temperature, ion temperature, ion velocity).

- Level 4. External value-added data products. They are normally derived by the users in a process that combines EISCAT data with data from other sources.

- Metadata. The operational parameters accumulated at all sites, like antenna pointing, output power, radar pulses and data processing used are stored and denoted here as metadata.

All data collection, storage, and access is made or arranged by EISCAT through the EISCAT staff.

Level 1 data are not stored at wide bandwidth, though band-limited measurements are stored as resources permit. EISCAT also stores wide-bandwidth Level 1 data for limited time to generate further data products. For well-defined research or development projects users can apply for specific sets of wide-bandwidth Level 1 data to be stored. Such applications will undergo technical and scientific reviews before final consideration. When approved, an agreement must be formulated on the life span of the collected data with a scheme of what data products will be delivered to the EISCAT data archive including a time line for this delivery.

Level 2 data are archived by EISCAT. These data are for exclusive use of the user who carried out the observation during 1 year, and for exclusive use within the EISCAT membership for 2 following years. In the case of newly developed data products that are produced over a time span exceeding 2 years, these are for exclusive use within the EISCAT membership for two years after final production. Users can apply for extended time of exclusive use. Those users carrying out the observations can also reduce the period of exclusive use to open up public access at an earlier time.

Level 3 data are archived by EISCAT. Preliminary, un-validated level 3 data are normally generated in real time and are made available as quick-look plots. These plots are not intended for scientific publication or presentation. Validated level 3 products are made available and archived by EISCAT at a later date as workforce permits. These are for the exclusive use of the user that carried out the observations until 1 year after the observation, at which time they will be made publicly available. Users can reduce the period of exclusive use if they wish.

Level 4 data are normally not archived by EISCAT. When level 4 data are published by the users, it is subject to the same exclusivity as the level 2 or 3 data that was used to create it. Reference to the origin of the data and to the association needs to be given and EISCAT always needs to be informed of the publication. Any usage of data that is not intended for basic research resulting in scientific publications needs to be negotiated with Council in advance.

Operational parameters (metadata) like antenna pointing, output power, radar pulses and data processing used are open to the public at any time.

1. Ownership of all EISCAT Level 1-3 data shall be permanently vested in the EISCAT Scientific Association, for the benefit of all the Associates and Affiliates.

2. Published papers in which data from the EISCAT facility have been used shall always contain an acknowledgment of the support provided by EISCAT , preferably in the standard form available from EISCAT.

3. Authors are required to send reprints of papers in electronic form to the EISCAT Headquarters where a file of EISCAT publications will be kept. Authors are also encouraged to send pre-prints of papers in advance of peer review and publication.

4. A summary of observations shall be published in the EISCAT Annual Reports.

1. EISCAT shall strive to have full transparency in its operations and with respect to the data generated. All observation campaigns shall be clearly documented and the campaign log shall be available for inspection in accordance with the EISCAT Agreement.

2. Generally, data segments containing radar echoes from resident space objects shall be filtered out at a low processing level. When such filtering is not adequate to reach the objectives of the approved observation campaign, special care must be taken to avoid a breach of the Objects and Means of the association as laid down in the EISCAT Agreement.

3. EISCAT raw data containing radar echoes from satellites shall not be distributed to other agencies.

6 First login to EISCAT tools

If you have followed the guide for application to EISCAT VO and were accepted into the EISCAT Radar School group you will have access to the EISCAT tools (jupyter notebook) at both https://jupyter.eiscat.se/ and https://notebooks.egi.eu/. During this school please use the notebooks at https://jupyter.eiscat.se/. You will have access to the notebooks until end of August. If you desire to work with the notebooks later you can find same environment on the EGI notebooks website.
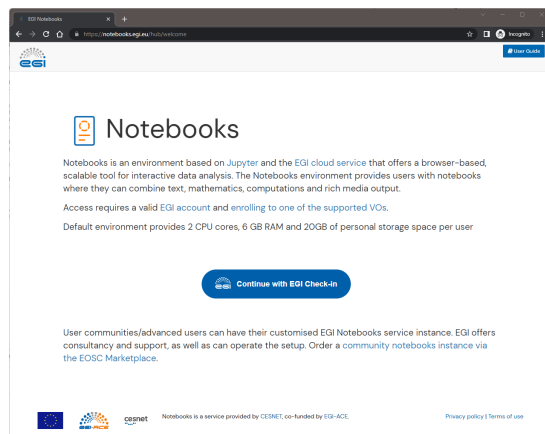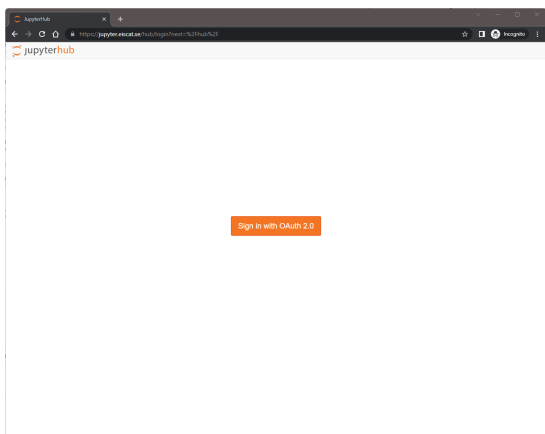
Identify yourself with the account you previously used for your EISCAT VO subscription. Always use the same account for identification as only that one will be able to be checked against the group in EISCAT VO and allows you to access the notebooks. You need to first grant access to EGI notebooks or to EISCAT to access your information.
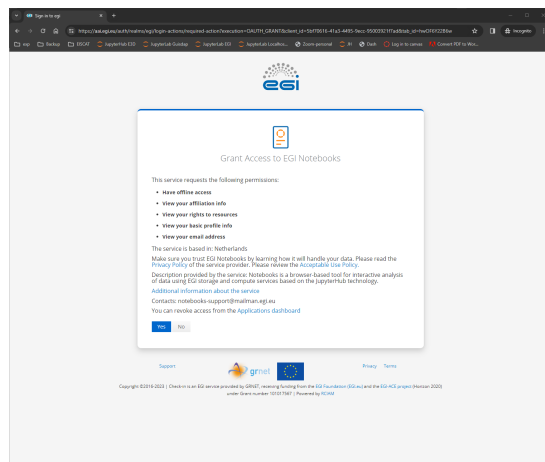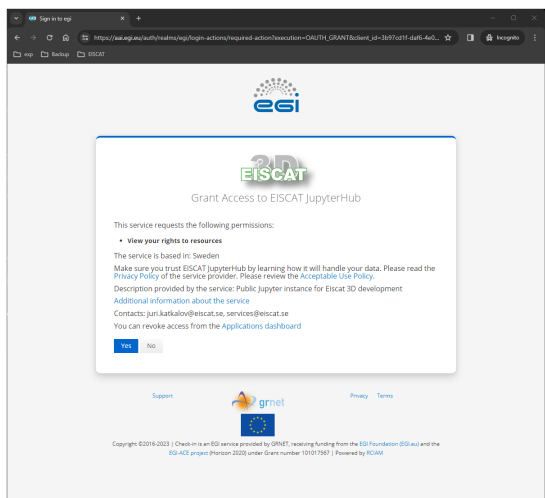
After this step you will either be granted access to the notebooks or the **Unauthorized** webpage loads. If you see a webpage that says that you are not granted access something went wrong and please contact your lecturers.

Finally you will land at the jupyter notebook page with your home directory. You will see the Launcher window with various tools like Python notebooks, Julia, Octave and R integration. But for this course the most important will be the MATLAB integration (**Open MATLAB** icon, third from right in the first row in the following screenshot in the text.)

6.1 Checking necessary folders for GUISDAP

Before you start to look around check if all the necessary directories were created in your home folder. You should see following directories: gup; mydata; results; shared_data (only on EISCAT server); tmp; and user_scripts. On EGI notebooks there will be few more directories unrelated to our notebooks. If you do not see these folders let know your lecturers and they will direct you further.
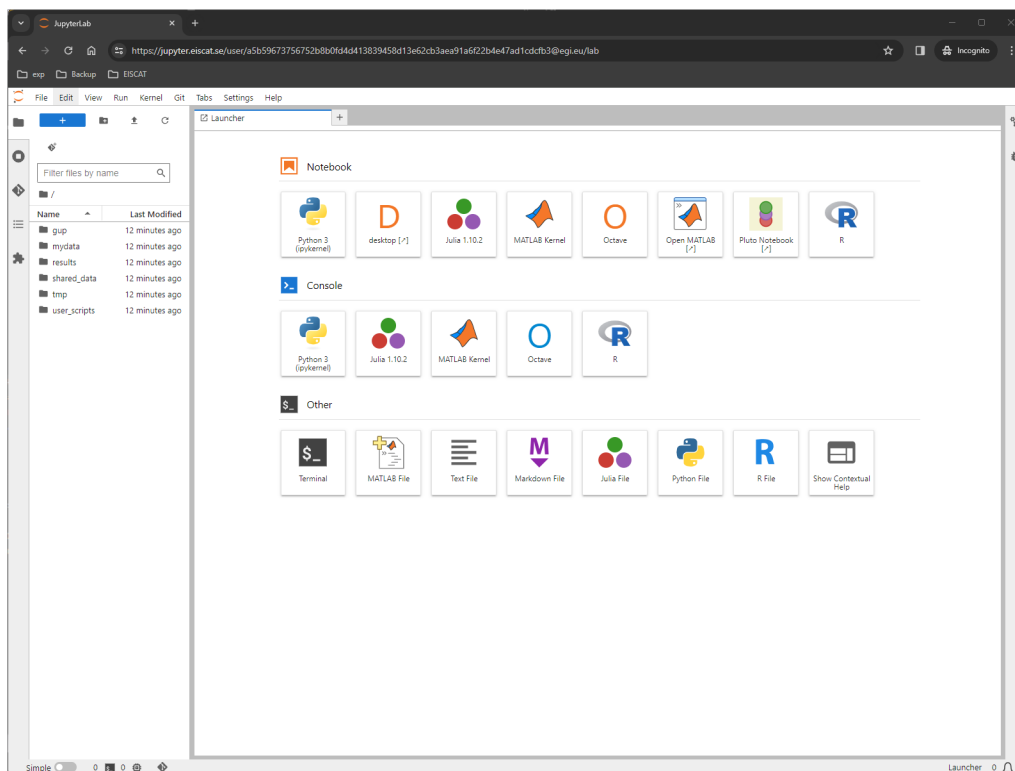

6.2 Trying to run the MATLAB integration for Jupyter notebooks

You can try to click the Open MATLAB icon. A new browser tab will open and MATLAB login screen will come up. On the EISCAT server the licence is provided and it will automatically proceed to load MATLAB. If you want to work later on EGI notebooks you need to put in your MATLAB licence credentials (both Online Licence and Network Licence checkout should work). It can take a while to validate your licence but then the MATLAB integration for jupyter notebook should load as seen in the following screenshots.
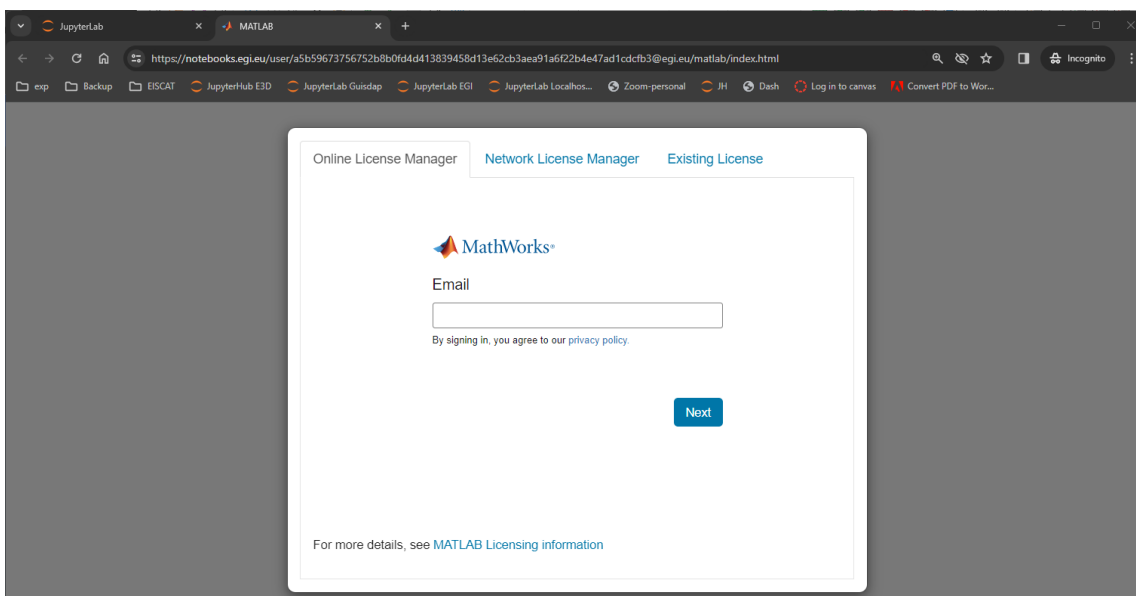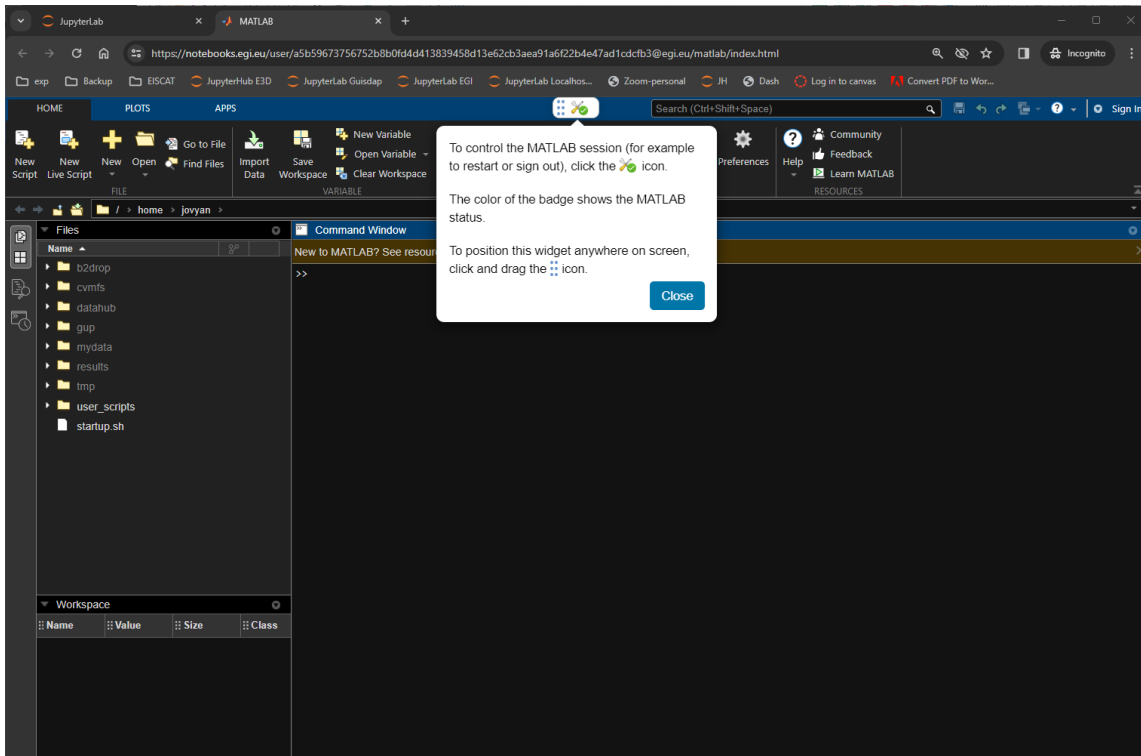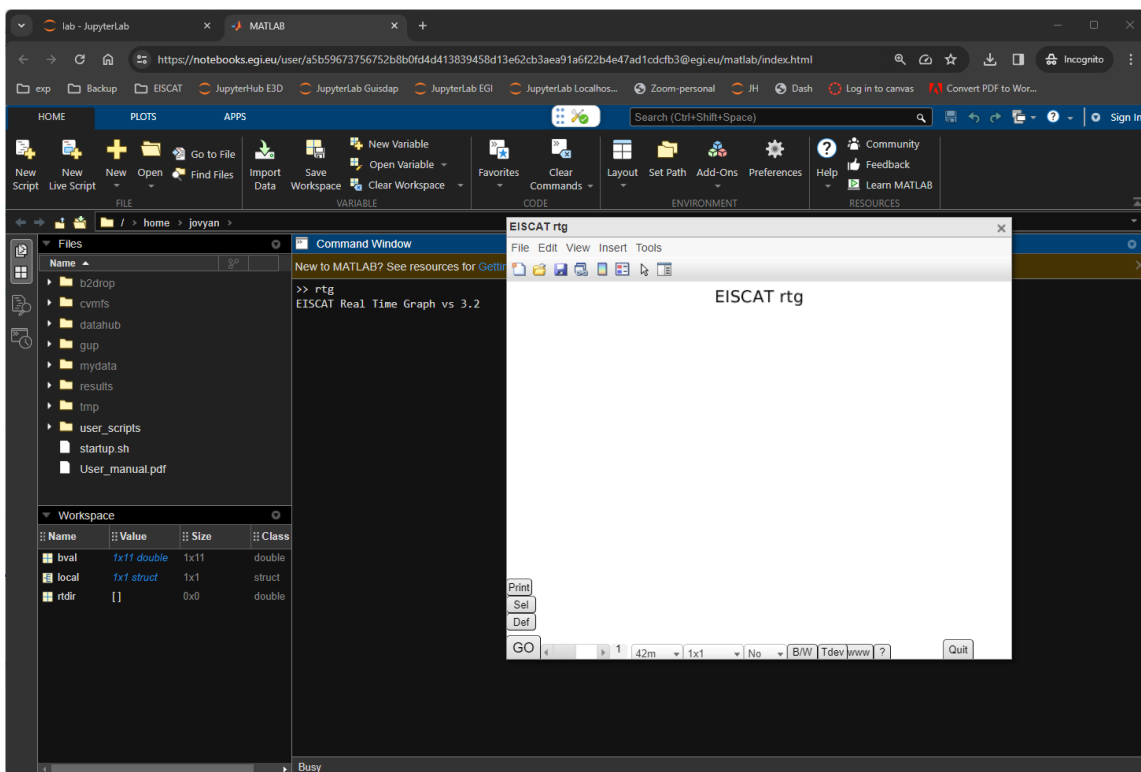
6.3 Starting RTG and GUISDAP

Once your Matlab is loaded you can try to start rtg and guisdap softwares for the first time. You will work with guisdap later in the course. To start up rtg just write **rtg** command in the MATLAB command line as seen in the next screenshot.

Now you can close the rtg window by pressing **Quit** button. Next try to start guisdap by running the commands **guisdap** and **analyse** in the command line. (see the screenshots)
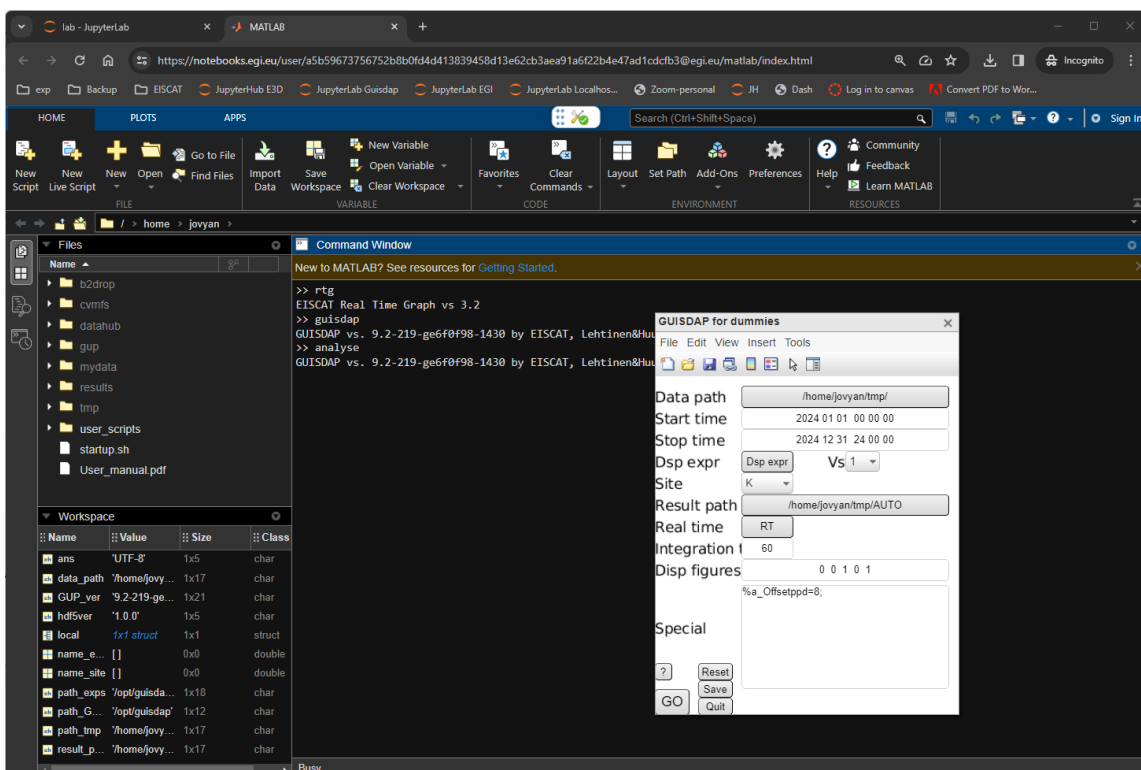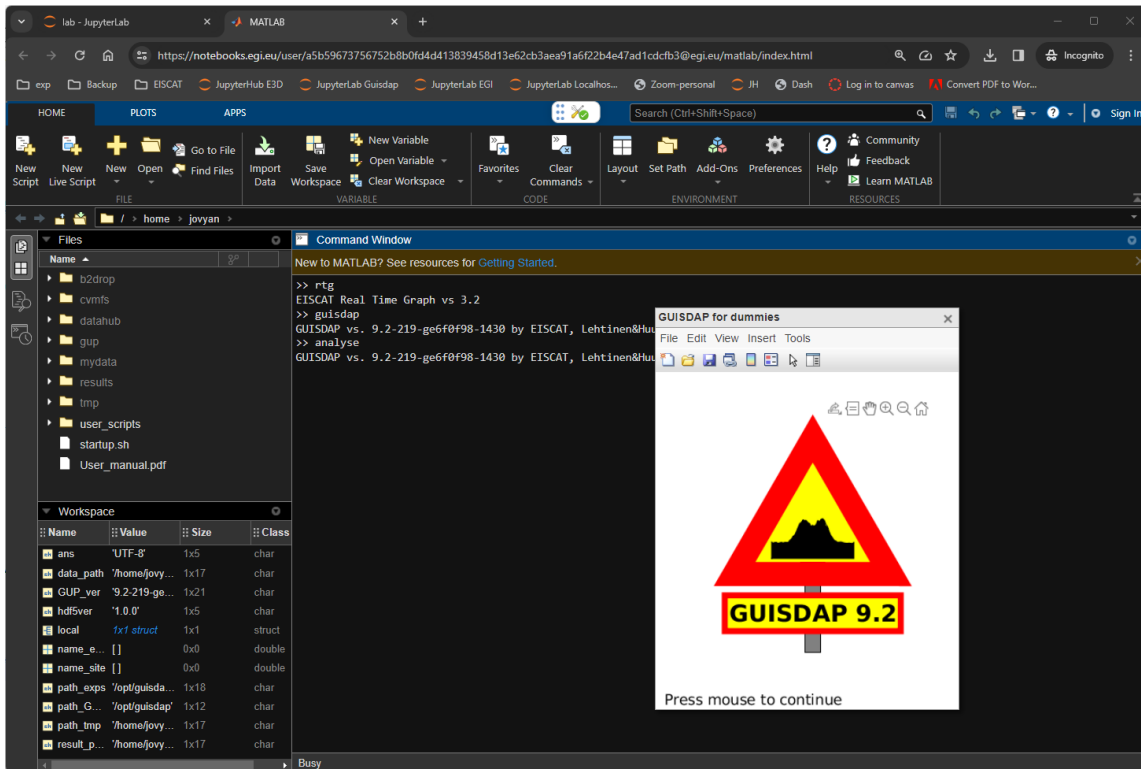

Now you can stop GUISDAP for dummies by pressing the **Quit** button and return to the other browser tab with your jupyter notebook.

6.4 Uploading data to EISCAT environment

The last question we need to answer is how to upload and download data to/from your workspace in the EISCAT environment. For upload you can either use the upload button (orange arrow in the screenshot) or use the wget command (blue arrow in the screenshot) to download data directly into your workspace from a place on internet like the Madrigal database (https://madrigal.eiscat.se/madrigal/) or the EISCAT portal page (https://portal.eiscat.se/schedule/). To demonstrate this command you can try to download the EISCAT User Manual that is stored on EISCAT website directly to your home folder in the EISCAT environment by using the following command in the terminal:

```
wget "https://eiscat.se/wp-content/uploads/2024/01/User_manual.pdf"
```
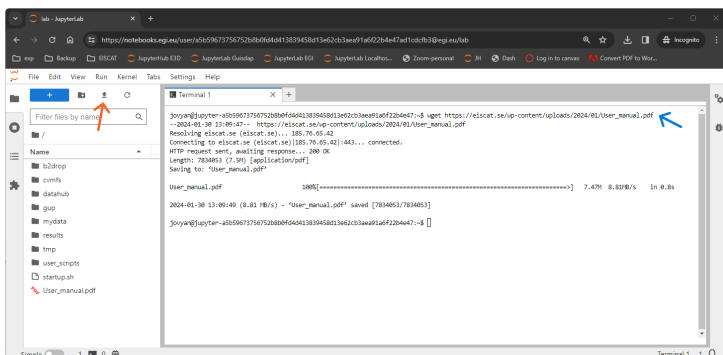

For your course work the data will be provided by your lecturer's and prepared in the shared_data folder.

6.5 Downloading data to local computer

There are also few possibilities how to download data from your home folder in EISCAT environment to your local computer. Jupyter notebooks enable downloading of individual files (by right-clicking on them as seen in the screenshot later) but not whole folders. To download whole folder you can create a zip or tar file first and download this file. You will have to unpack the file in your local computer afterwards.

Let's try to download the **user_scripts** folder to your local computer. First you need to pack the folder for example using the following command in the terminal:

```
zip user_scripts.zip user_scripts/*
```

Once the **user_scripts.zip** file is created you can right-click on it and choose download from the context menu (see the screenshot).