EISCAT data analysis
From EISCAT data to ionospheric parameters

Carl-Fredrik Enell
✉ carl-fredrik.enell@eiscat.se

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1 Overview and some theory

2 Running GUISDAP

3 Calibration

4 GUISDAP results
Outline

1. Overview and some theory
2. Running GUISDAP
3. Calibration
4. GUISDAP results
Analysis — from data files to ionospheric parameters

Several of these

To one of these

EISCAT Scientific Association

EISCAT UHF RADAR

Several of these
A data dump

Principle:
- All possible 1st lags
- All possible 2nd lags
- ...
EISCAT data files

A data dump

Ion line data  Plasma line data  Calibration and background
EISCAT data storage

- Directory name structure: pulse code, antenna scan, version, affiliate code, @antenna
- Hourly subdirectories
- Compressed Matlab `.mat` compatible files
- Name is seconds since New Year
EISCAT data files

Contents of data files 1

**d_data**  Lag profiles
autocorrelation domain (Level 2) data, complex vectors, sorted:

1. lag
2. range

**d_raw**  
- transmitter samples
- received raw voltage domain (Level 1) data (available only from certain experiments)
EISCAT data files

Contents of data files 2

d_parbl Metadata

- Time
- Transmitter power
- Antenna azimuth and elevation
- and much more
More information about data and metadata

GUISDAP analysis package

- Originally “Grand Unified Incoherent Scatter Design and Analysis Package”, M. Lehtinen et al.
- Maintained by I. Häggström, EISCAT HQ
- Matlab software
- Direct theory of scattering spectrum
  - Electron density
  - Ion temperature
  - Temperature ratio
  - Line of sight velocity
  - etc
- Atmospheric models (IRI, MSIS)
  - Neutral temperature
  - Density / collision frequency
  - Ion composition
- Fitting to lag profiles (following slides)
**Standard parameters found by fitting the Ion-acoustic line**

Ion temperature (Ti) to ion mass (mi) ratio from the width of the spectra

Electron to ion temperature ratio (Te/Ti) from “peak_to_valley” ratio

Electron (= ion) density from total area (corrected for temperatures)

Line-of-sight ion velocity (Vi) from the Doppler shift
Standard parameters found by fitting the Ion-acoustic line

- Ion temperature ($T_i$) to ion mass ($m_i$) ratio from the width of the spectra

- Electron to ion temperature ratio ($T_e/T_i$) from “peak_to_valley” ratio

- Electron (= ion) density from total area (corrected for temperatures)

- Line-of-sight ion velocity ($v_i$) from the Doppler shift
Principle of GUISDAP analysis

- Applying Fourier transform theory, the theoretical spectra can be fitted directly to the lag profiles using precalculated spectral ambiguity functions (Nygrén 1996, p. 78)

\[
LP(t, t') = R \int_{\rho} P_z^0(\rho) \left[ \int_{-\infty}^{+\infty} W_{tt'}(\nu, \rho) \Sigma(\nu, \rho) d\nu \right] d^3 \rho
\]

- \(\Sigma\) = ISR spectrum (parameters \(N_e, T_i, T_r, v_0\) ... not shown)
- \(\nu\) = frequency
- \(W\) = spectral ambiguity function (the Fourier transform of the 2-D pulse ambiguity function)
- \(P\) = single scattering power
- \(R\) = radar coefficient, with calibration

- Calculated by experiment initialization
- Stored with experiment definitions
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Requirements

- Matlab
  - Matlab 2018a must be patched with the most recent upgrade
  - Other releases should be fine
- Unix environment preferred
- Windows needs bzip2 decompression utility
  - Option 1: run in cygwin
  - Option 2: install 7-Zip
Get the distribution

Download

- Download https://www.eiscat.se/scientist/user-documentation/guisdap-9-0/
- Unpack the tar archive where you want it

OS-specific configuration

- Unix: make a link to .../bin/guisdap (e.g. in /usr/local/bin)
- Windows:
  - Edit windows_start.m
  - Edit anal/canon.m and make sure the path to 7-Zip is correct
Starting GUISDAP

- Unix: type ”guisdap” in a console.
- Windows: Make sure windows_start.m has been edited. Right-click on this file and select Run.

Matlab will start with paths set up.
The GUISDAP main window

- Type "analyse" (NB "s" spelling).
- This window will appear
- Click and main window appears
GUISDAP settings

- Path to data
- Time interval
- Experiment definition
- Integration (seconds), 0=antenna dwell
- Save path (Set filename to AUTO)
- Wait for real-time data (do not use)
- Figures to show

Additional parameters

Set and click GO
GUISDAP run example

Note: plot fit parameters only for short tests, it is slow
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Need for calibration?

GUISDAP corrects for

- Measured transmitter power
- Geometry
  - Antenna gain
  - Range
- Receiver chain response
  - Noise source with known power
But...

Difference between calculated and actual antenna gain may be caused by snow or water in the antenna, etc.

**Absolute calibration — Compare electron density**

1. Electron density maximum and ionosonde foF2
2. Plasma lines
Calibration with ionosonde

- Find measured F (or E) layer peak $N_e$
- Get ionosonde critical frequency $f_{oF2}$ ($f_{oE}$)
- Calculate "true" $N_e$ using the relation

$$f_{\text{crit}} = f_p = \frac{\omega_p}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{N_e e^2}{\varepsilon_0 m_e}} \quad (1)$$

Available in Tromsø. Svalbard ionosonde has been discontinued, unfortunately.
Calibration routine

- You can do ionosonde calibration by hand...
- However an automatic routine exists: `calib_ne.m`
Calibration routine

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Calibration routine

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Plasma line calibration

- A direct measure of $N_e$
- Not always detectable by EISCAT
- Only available in certain pulse code experiments, see experiment document

In practice

- Integrate plasma line data with GUISDAP
  - **ESR folke** Separate receiver, data in @32p directories
- Run *calib_pl_ne.m*
- Modify parameters in order to avoid misidentifying interference as plasma line peak
Plasma line calibration

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[Graph showing plasma line calibration data]

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Reanalysis with calibration

- Uncomment and set the “Magic_const” to
- This will scale the measured transmitter power

After this, we have results in physical units
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GUISDAP output

AUTO directory naming structure
Directory name consists of: date, pulse code, integration time @antenna

Contents
- Matlab files
- Name is also time in seconds
Content of GUISDAP output

Experiment metadata

name_ variables e.g.
- site name
- experiment name

Results and instrument parameters

r_ variables
### Important result ($r_-$) variables 1

- Time
- Azimuth
- Elevation
- Magic constant
- Tx power
- gfd structure (GUISDAP config)
## Important result (r_) variables 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>r_pprange</td>
<td>Ranges of raw power</td>
</tr>
<tr>
<td>r_pp</td>
<td>Raw power</td>
</tr>
<tr>
<td>r_ppw</td>
<td>Resolution</td>
</tr>
</tbody>
</table>
The actual analysis results

- **r_range**  Ranges (weighted)
- **r_h**     Heights
- **r_param**  Fitted parameters
  - Fitting is user definable e.g. ranges of fitting vs taken from models, limits
  - Usually 6 of the 8 columns are used
## Contents of `r_param`

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] (default: taken from atmospheric models, not fitted)
5. Ion drift velocity $v_i$ (the component along the line of sight, positive toward the radar) [m/s]. Note: By convention positive is away from the radar, so Vizu plot changes the sign of this parameter.
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$_2^+$ (default: constant at each altitude, not fitted)
### Error estimates

- **r_error**: Errors of fitted parameters
- **r_pperr**: Errors of power profile

### Fit status
Results are also converted to Madrigal format and uploaded regularly (manual operation)
Questions?

https://www.eiscat.se
@ carl-fredrik.enell@eiscat.se