Principles of Dynasonde Navigator

Michael Rietveld [1], Nikolay Zabotin [2]

[1] EISCAT Scientific Association, Ramfjordmoen, N-9027 Ramfjordbotn, Norway, Mike.Rietveld@eiscat.uit.no

[2] University of Colorado at Boulder, 425 UCB, Boulder, Colorado, 80309 USA, Nikolay.Zabotin@colorado.edu

Abstract

Dynasonde is an ideology of precision ionospheric radio sounding based on rigorously taking into account phase characteristics of a radio echo. Unique products of phase ionosondes intended for various Space Weather-related applications include: echo recognition and noise discrimination, echo classification into traces, scaling of standard ionospheric parameters, 3-D plasma density inversion (NeXtYZ) including true vertical profile with error bars, small-scale irregularity diagnostics, and vector velocities, all obtained directly and autonomously from ionogram data. Our report describes details of implementation of Dynasonde principles in operation of the web portal Dynasonde Navigator (http://dynserv.eiscat.uit.no) hosted by EISCAT.

1. Introduction

The Dynasonde database is a part of the Dynasonde Navigator web portal hosted by EISCAT Scientific Association. This internet resource allows one to explore the current state of the ionosphere over several participating observatories. Interactive graphics give detailed information for the present time and for the preceding 48 hours, from the most advanced ionospheric sounding instrumentation and data processing methods. The three participating dynasonde systems are at high-latitude (EISCAT Tromsø), at very high-latitude (EISCAT Svalbard) and at mid-latitude (Tomsk, Russia) locations. All three are now continuously providing results of their measurements.

2. Dynasonde Essentials

Distinctive Features of Dynasonde Sounding Principles and Data Processing are:

- In Dynasonde data analysis, the radio echo is considered a basic physical object. An echo is defined by 6 precisely determined parameters, each with its individual error estimate. There is no use of an artificial notion of "frequency-range bins".

- Group ranges of high precision are determined through the stationary phase principle. In carefully designed pulse sets the radio frequencies are slightly offset (by 1-4 kHz) from the base frequency to enable precision range measurements (to within a few tens of meters).

- Direct attention is paid to physical properties of the echo. No Fourier transforms; no pulse coding; no coherent summations are applied nor needed. The phase and amplitude of received signals (from raw I&Q) are used directly. In consequence excellent statistics of recognized echoes (up to several thousand per ionogram recording) is obtained. The same echo recognition and characterization process rejects false echoes and noise very efficiently.

- Diverse and sophisticated methods of higher-level data processing are applied. An autonomous classification of the echoes into traces and subsequent inversion procedures are accomplished based on physics-based criteria rather than using indirect and subjective procedures (such as image analysis).

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- There is limited impact to other uses of the radio spectrum. Instead of long sequences of pulses at the same base frequency, only short sequences (3 to 8) of narrowband (30 kHz) pulses are used.

3. Precision

Dynasonde data processing is the only precision technique available for total reflection ionospheric measurements. High resolution of raw I & Q data provided by the hardware is carried over to echo physical parameters; only ionospheric roughness determines their actual uncertainties. Average practical values (not theoretical limits) of resolution provided by Dynasonde data processing at the long-running high-latitude EISCAT Tromsø station are: group range ~100 m, horizontal echolocations ~1 km, Doppler velocity ~3 m/sec, polarization ~1 deg.

4. Products

In the Dynasonde ionogram scaling high precision of physical parameters and rich statistics of recognized echoes yield excellent quality and dependability of higher-level processing results. Echo classification into traces and trace selection are based on physical criteria (not merely upon approximate positions of the echoes in the ionogram image). This process is objectively verifiable. Dynasonde analysis includes many unique, autonomously operating inversion routines. The following represents a list of ionospheric characteristics available through Dynasonde Navigator and Dynasonde Database:

- Standard E, F region parameters.
- 3-D plasma density inversion, 'NeXtYZ', provides, for the first time in ionospheric radio sounding practice, the true vertical profile of plasma density and the vertical profile of horizontal gradients; the 3-D display of reflected echoes replaces the obsolete "sky maps"; NeXtYZ implements the only available algorithm for profile uncertainty calculations that satisfies the requirements of Kalman-filter-based assimilative ionospheric models. Horizontal gradients carry information about atmospheric gravity waves, a ubiquitous feature of ionospheric weather that is becoming an important objective of ionospheric modelling.
- Vector velocities for plasma-contour movement for each structural element of the ionospheric plasma.
- Quantitative parameters of the km-scale irregularity spectrum are produced by the phase structure function method which is uniquely affiliated with other Dynasonde inversion routines.
- Quantification of the ionogram spread F effect is provided.
- Ambient noise level for the entire frequency band used in a sounding session.

All of these products are obtained in standard ionogram mode.

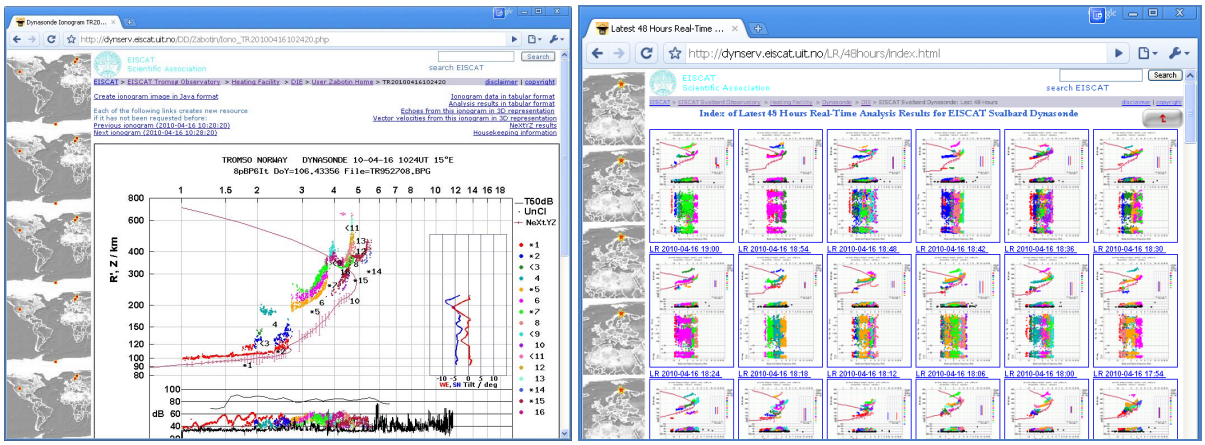

Figure 1. An ionogram display in the database interface (left) and the index of the latest 48-hour analysis results (right) in Dynasonde Navigator.

5. Dynasonde Database

The Dynasonde Database provides innovative solution for centralized data storage and transmission to remote users, and for convenient interactive methods of data mining and visualization. EISCAT's Dynasonde Database currently contains results of data analysis for EISCAT Tromsø station since June 2009, for EISCAT Svalbard station since September 2009, and also contains results of earlier data processing for three stations (Bear Lake Obs., Utah from February 2003 to June 2006, EISCAT Tromsø from June 2003 to December 2006, and Lycksele, Sweden from March 2004 to August 2005).

Access to Tomsk database is provided through a separate link to a server at Tomsk State University. The database currently has 68 subscribers. The subscription is provided through a self-registration procedure. The database core uses MySQL, the industry standard for open relational database servers. It therefore provides the whole set of application programming interfaces allowing various interactions with user's research software. The Dynasonde Database uses SAO format to share in real-time its data and products with the SPIDR and MIRRION systems at the National Oceanic and Atmospheric Administration (NOAA, USA).

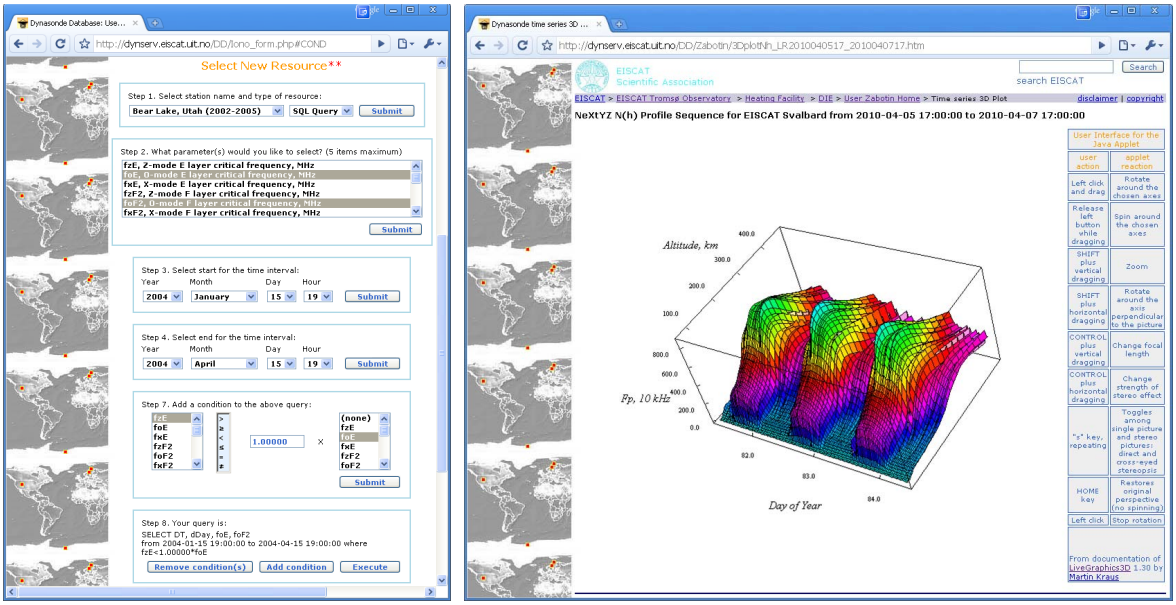

Figure 2. An interactive form for requesting information from the Dynasonde Database (left) and an example of graphical representation of a query result (right).

6. Reprocessing Capability

Dynasonde Navigator provides two level tools for reprocessing of the original data. The first one is a possibility to manually reprocess ionograms through the database interface using only a list of previously recognized echoes stored in the database (not the raw data files). This tool may be particularly useful for accurate re-analysis of the data taken during various campaigns. Most of the processing errors produced by the autonomous analysis are due to wrong selection of the traces. This selection can be corrected by an operator through a specially designed web-based interface. Optionally the analysis system may be directed to also use for reprocessing a different set of critical frequencies (determined by the operator). The results of the reprocessing complement the original analysis results in the database and become accessible for general use. The "operator" privilege is assigned to skilled individuals selected by the system administrator by setting a special flag in the database user registry.

Another level of reprocessing is aimed at a more complete use of the original I&Q data. Frequently (if not always) the ionospheric structures represented by raw signal-to-noise images are more graphical, containing more details than the echo-based images, even using the advanced Dynasonde techniques for the echo recognition. This means that future improvements of the phase-based echo recognition techniques may yield echoes in the parts of the ionograms where the current methods fail. In addition, the raw signal-to-noise information may be effectively used by an operator (whose functions are described above). That is why after the autonomous processing of raw recordings (which are not reasonable to keep because of their large size) the database accommodates a small subset of the original I&Q data the selection of which is based on the signal-to-noise ratio. A special binary format recognized by the analysis program has been designed for that. The subset of the selected I&Q data is also used for plotting the raw signal-to-noise images in the Dynasonde ionograms, together with the traces composed of the recognized echoes. The traces are shown by the color dots and the raw S/N data is shown in the background using a pale gray scale. This technique allows the autonomous processing system to produce usable ionogram images in many occasions where no or few echoes are recognized.