Three-dimensional inversion technique for short distance oblique Dynasonde ionograms

Huan Song[1,2], Nikolay Zabotin[2]

[1] Department of Electronics and Information, Wuhan University, Wuhan, China
[2] Department of Electrical, Computer and Energy Engineering, University of Colorado Boulder, USA

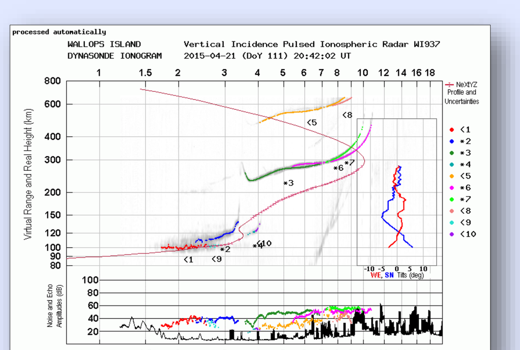
Abstract

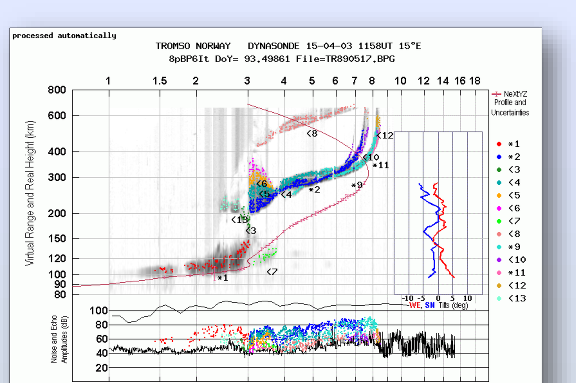
Existing inversion technique for vertical incidence Dynasonde ionograms (NeXtYZ) produces vertical profiles of the electron density and of the two components of the plasma tilts. It has been proved to be a valuable tool for studies of traveling ionospheric disturbances (TIDs) and associated atmospheric gravity waves (GWs). A generalization of this technique for bi- and multi-static sounding configurations is required, to be used for regional interferometric measurements of GWs. Such generalization is proposed here to obtain the plasma density profile and tilts information at the middle point of an oblique sounding path. Numerical ray tracing technique is used to simulate a list of echoes for an oblique Dynasonde ionogram based on a realistic model of disturbed ionospheric plasma density distribution including TIDs and small-scale irregularities. The inversion procedure involves restoration of parameters of the wedge stratified ionosphere model for the middle point of an oblique sounding path, using multiple ray tracing technique and various optimization methods. The inversion procedure can make full use of both extraordinary and ordinary echoes in the simulated oblique ionogram and takes into account the geomagnetic field. To verify the performance of the proposed method, oblique ionograms were simulated with various parameters of the plasma density model, both with small-scale irregularities and without them. The test results show that the calculated plasma density profile fits well with the real plasma density profile. In addition the calculated ionospheric tilts profile reproduces accurately the model characteristics when small-scale irregularities are included. Our results confirm feasibility of expansion of the standard vertical operation of Dynasonde systems to bi- and multi-static sounding modes.

Distinguishing properties of Dynasonde data analysis

- Comprehensive use of phase information in radio echoes.

This is unique to Dynasonde approach to ionospheric radio sounding; in particular this enables processing the list of physical parameters of the echoes instead of traditional amplitude-based image analysis.



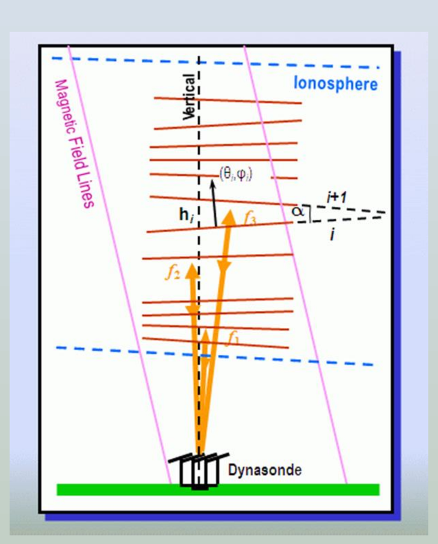


- All echoes are useful.

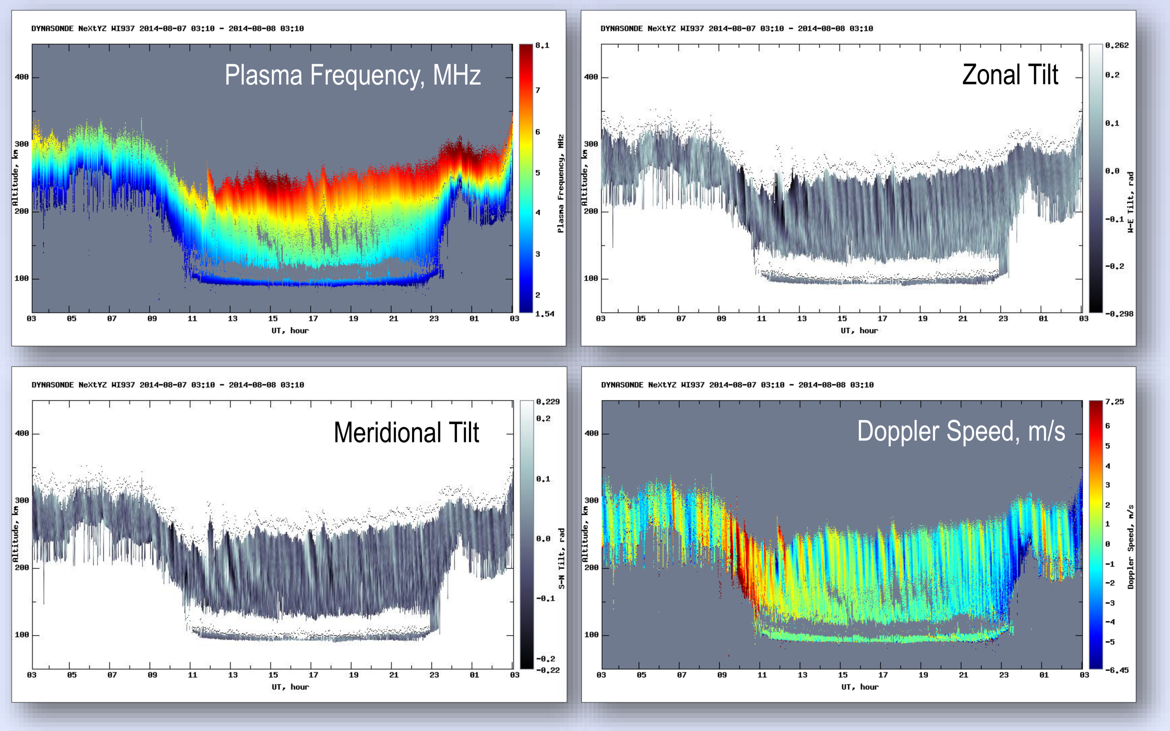
Up to several thousand echoes per ionogram are detected and used. No echo rejection based on range or polarization.

- 3-D structure of ionospheric plasma is accounted for.

No unrealistic assumption of horizontally stratified ionosphere. NeXtYZ ("Next Wise"), plasma density inversion procedure, uses angles of arrival of all echoes and provides parameters of the Wedge Stratified Ionospheric Model instead. [Zabotin et al., Radio Sci., 2006]

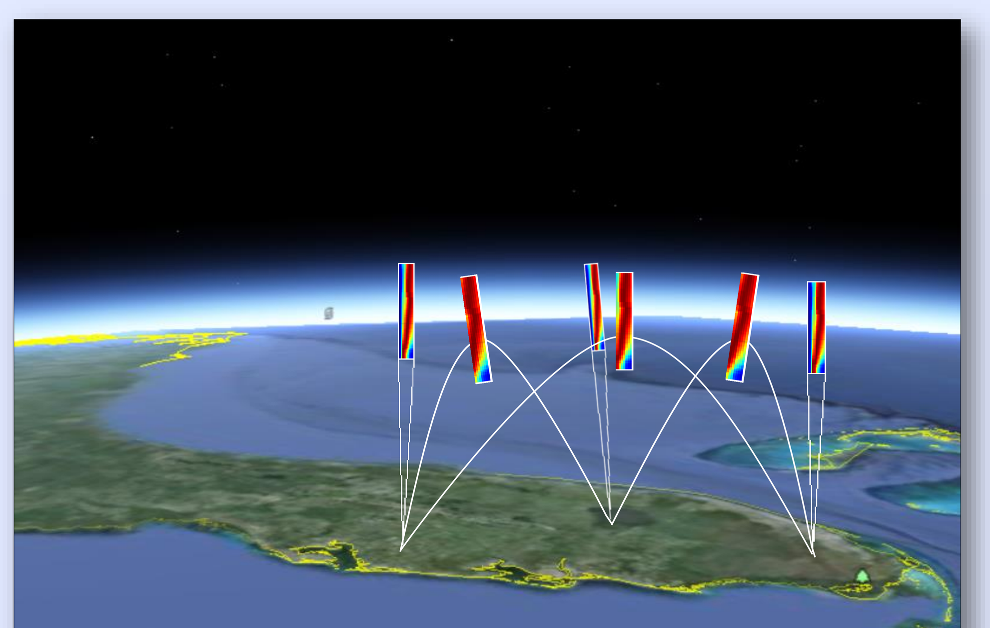


Time series of NeXtYZ results: Wallops Isl., VA, 7-8 August 2014



An example of the standard output of the Dynasonde analysis visualization software: daylong scans of four physical parameters characterizing ionospheric layer (the South-North and West-East tilts, the plasma frequency, and the vertical Doppler speed). The values are shown by color or by shades of gray as functions of the time of the day (in UT hours) and of the real altitude (in km) for Wallops Island, VA on August 7-8, 2014. The slant structures in the images are caused by downward motion of phase fronts of atmospheric waves.

Prospective application: Using AGWs to measure parameters of neutral atmosphere with Dynasonde arrays



- Several Dynasonde locations at the distance of several 10s to few 100s km
- Transportable and/or receive-only systems (cost effectiveness)
- Ability of a long-term monitoring

Input

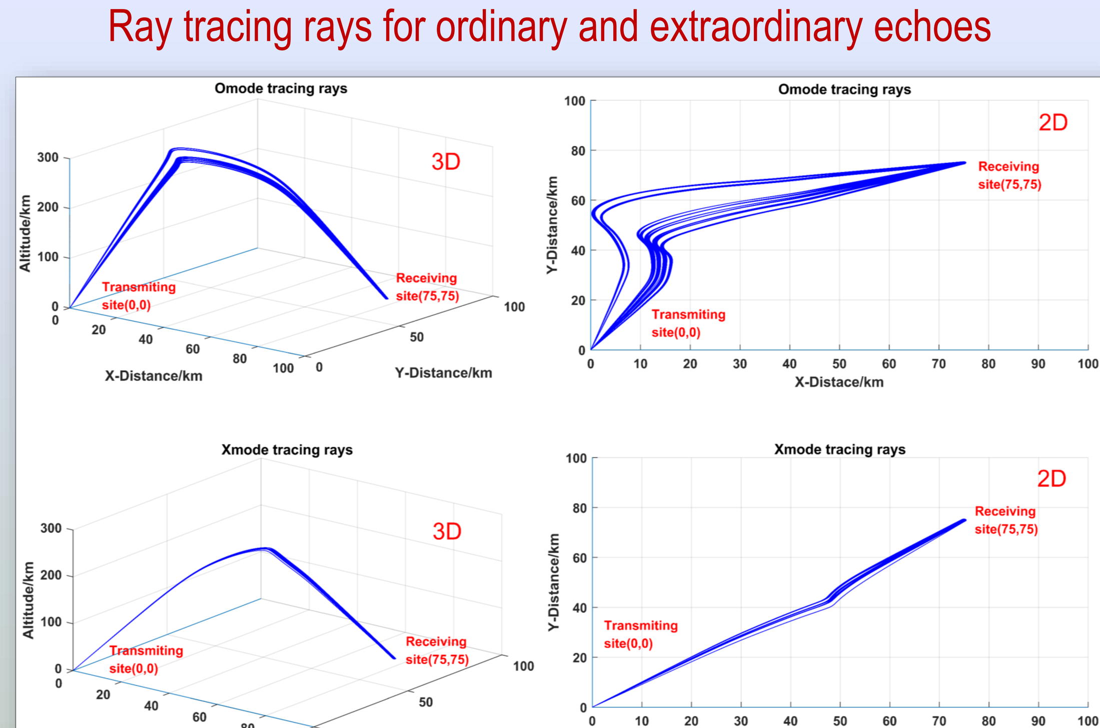
- Altitude range ~100-300 km (bottom side ionosphere)
- Altitude resolution 1 km
- Time resolution 2 min
- Spectral amplitudes and phases for 4 physical parameters

- Several identifiable spectral harmonics
- ω, k_x, k_y, k_z

Output

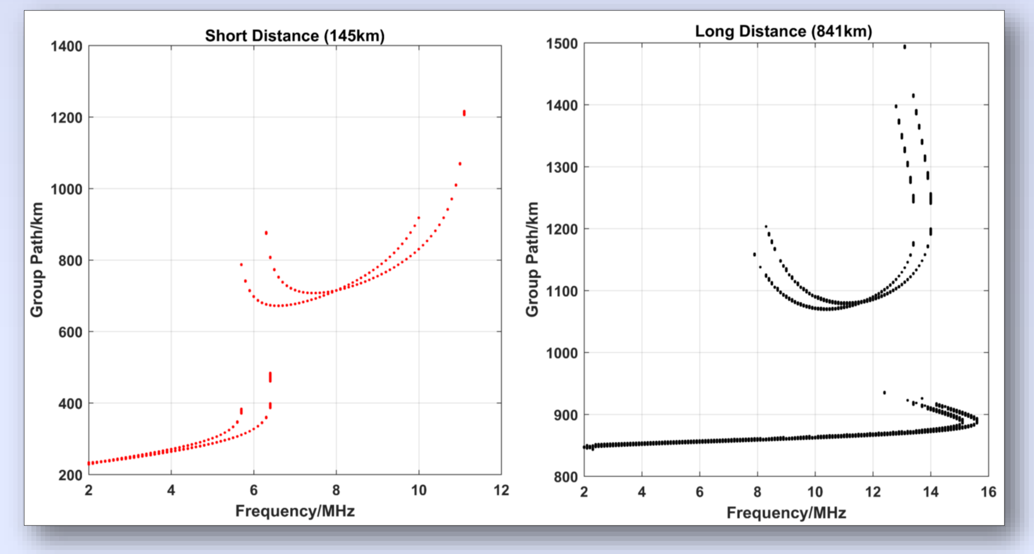
- Vertical profile of u_x, u_y (horizontal components of neutral wind)
- Vertical profile of ρ (neutral density)

Ray tracing rays for ordinary and extraordinary echoes

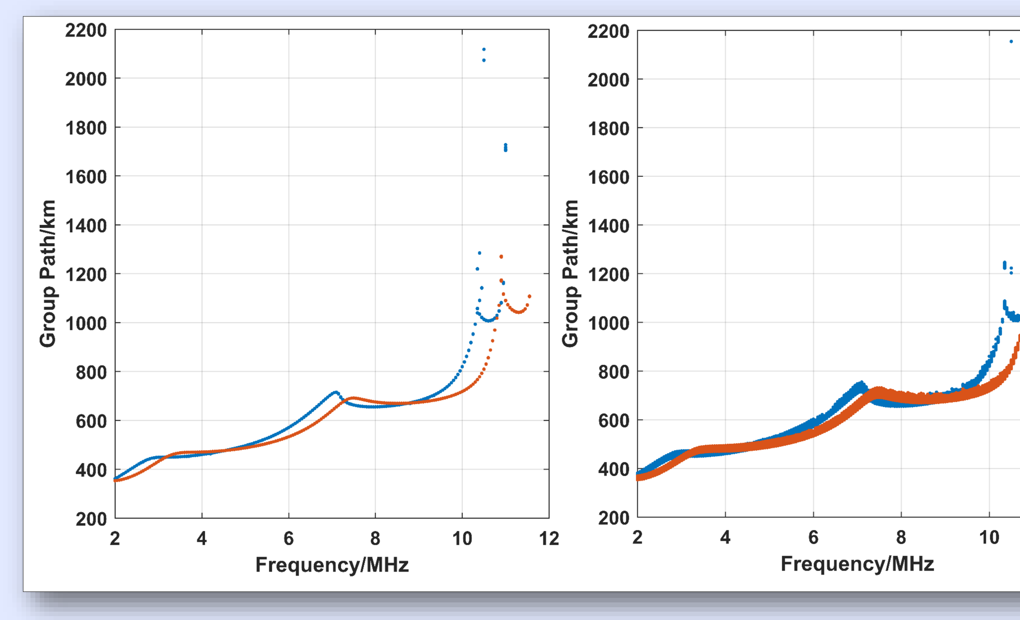


An example of how numerical ray tracing technique works to simulate echoes for an oblique ionogram.

Simulated oblique ionograms for various parameters of the plasma density model



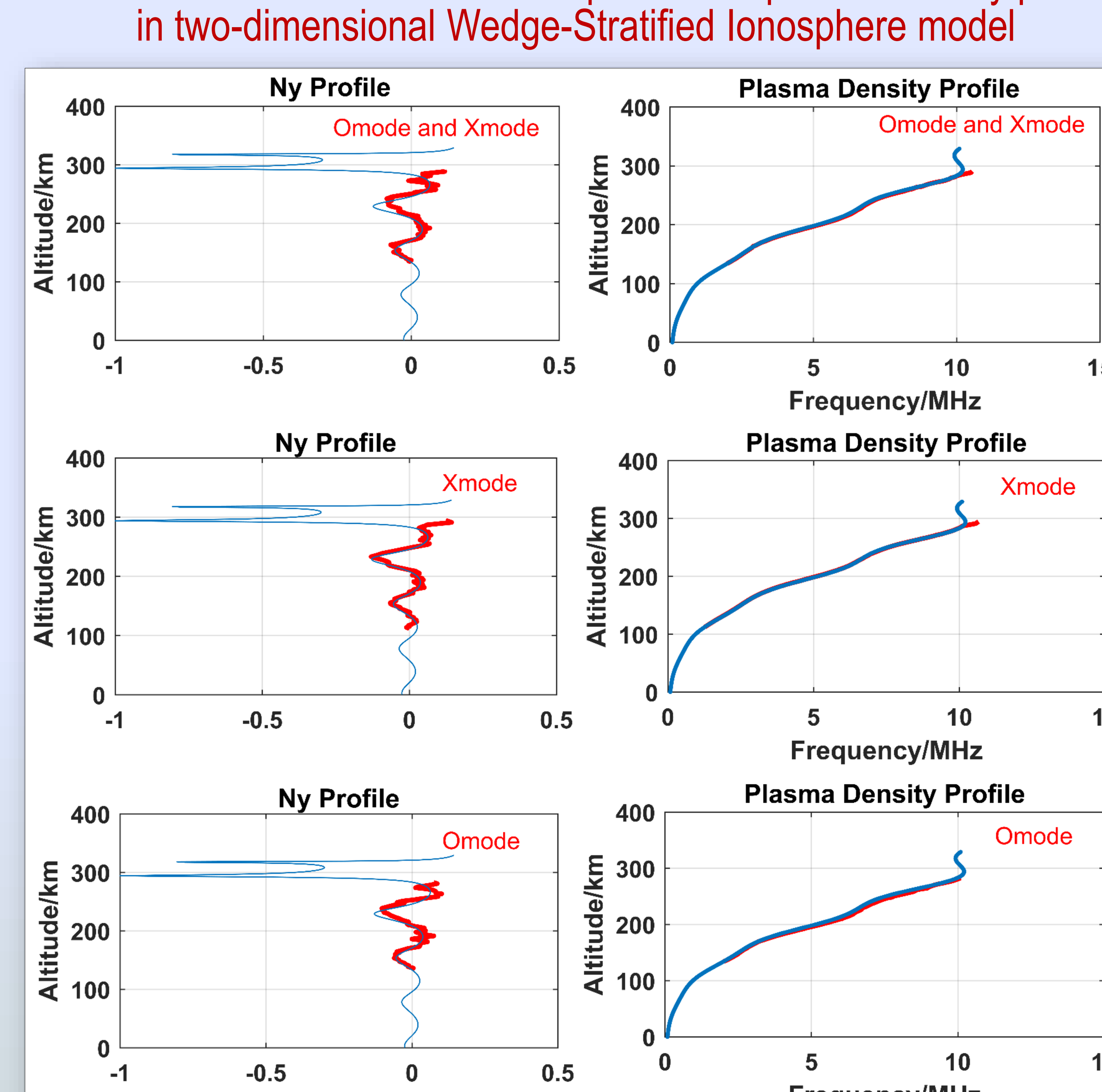
- Without TIDs and small-scale irregularities
  - include E layer and F layer
  - two kinds of oblique sounding distances



- Only with TIDs
  - Amplitude of TIDs is 0.05
  - Characteristic disturbances of the traces

- With TIDs and small-scale irregularities
  - Amplitude of TIDs is 0.05
  - Amplitude of small scale irregularities is 0.0001
  - Small scale irregularities are stretched along the geomagnetic filed
  - Spread of the traces, of the group paths, and of the angles of arrival

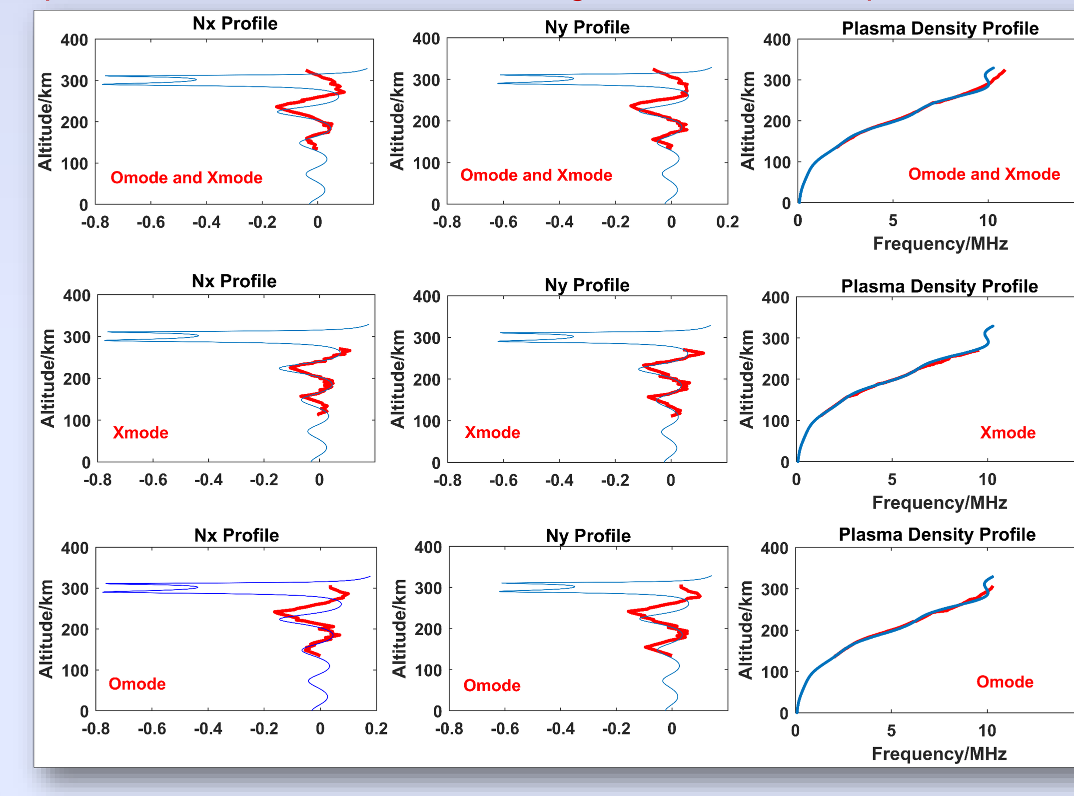
Inversion results for meridional tilt profile and plasma density profile in two-dimensional Wedge-Stratified Ionosphere model



Ny profile is the meridional tilt profile. Two-dimensional simulations and inversions assume that plasma density distribution depends only on two coordinates, Y and Z, in the plane of magnetic meridian.

The blue curves in Ny profiles and plasma density profiles are the model Ny profile and the model plasma density profile. The red curves are the inversion results.

Inversion results for two tilt components and plasma density profile in three-dimensional Wedge-Stratified Ionosphere model



Ny profile is the meridional tilt profile. Nx profile is the zonal tilt profile. The blue curves are model profiles. The red curves are the inversion results.

Inversion Principles

- Inversion is understood as restoration of parameters of the Wedge-Stratified Ionosphere model at the middle point of the bi-static path.
- List of echoes (up to few thousand) serves as input information.
- Echoes are characterized by group ranges, angles of arrival and polarization.
- Also provided are geomagnetic field configuration and coordinates of the transmitter and receiver.
- The inversion is an optimization problem for parameters of the Wedge-Stratified Ionosphere model and is done by minimizing two quantities:
  - the distance between the receiver location and the "ground return point" for oblique rays launched from the transmitter
  - the residual between calculated and real group ranges
- Output of the inversion includes
  - Vertical profiles of the two components of the tilt (directly related to horizontal gradient of the electron density)
  - Vertical profile of the electron density

Summary

- Recent developments in Dynasonde technique [e.g., Negrea et al., 2015; Negrea and Zabotin, 2016; Negrea et al., 2016] enable new efficient approaches in studies of the traveling ionospheric disturbances (TIDs) and underlying gravity waves (GWs).
- The next promising step is using Dynasonde-measured GWs to characterize properties of background thermosphere in a tomography-like approach.
- Regional Dynasonde arrays including both active and receive-only stations and utilizing bi- and multi-static configurations is a cost efficient way to implement this concept.
- A generalization of Dynasonde inversion procedure NeXtYZ for bi-static layout is necessary, and this is the goal of our work.
- Our results confirm feasibility of expansion of the standard Dynasonde vertical sounding operation to bi- and multi-static sounding modes.

References

Zabotin, N.A., J. W. Wright, and G. A. Zhbankov (2006), NeXtYz: Three-dimensional electron density inversion for dynasonde ionograms, *Radio Sci.*, **41**, RS6S32.

Negrea, C., N. Zabotin, T. Bullett, M. Codrescu, and T. Fuller-Rowell (2015), Ionospheric response to tidal waves measured by Dynasonde techniques, *J. Geophys. Res. Space Physics*, **120**, doi: 10.1002/2015JA021574.

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