# Comparison of the four different methods for reconstruction of electron density profile from vertical-incidence data

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## Abstract

Electron density N(h)-profile – is important geophysical characteristic and is the aim of many radiophysical methods of upper atmosphere investigation. The work is devoted to comparative analysis of the four different methods of electron density reconstruction from vertical sounding (vertical-incidence) data. The digisondes make good use of the Huang-Reinisch method for N(h)-profile reconstruction from measured vertical sounding data. The Guliaeva technique of N(h)-profile reconstruction is also widely distributed in the science environment. But this technique asks for complete height-frequency characteristic. And calculation of the peak height of the F2-layer in critical frequencies region requires the very small frequency step. The Mikhailov method (reducing this disadvantage in hmF2 calculation) was examined too. Among other things, the N(h)-profile reconstruction can be carried out via capability of the International Reference Ionosphere to adapt by parameters which can be received from measured height-frequency characteristic. In the work comparison of the mentioned methods of N(h)-profile reconstruction was carried out on the basis of vertical sounding data obtained by DPS-4 Digisonde in Irkutsk in 2006.

## 1. Introduction

The ionosonde network of stations played a primary role in the ionosphere research during the 20th century. In particular, the empirical electron density profiles of the International Reference Ionosphere (IRI) are fitted to the F2 layer peak electron density and height based on the CCIR maps produced from the ionosonde observations. Adaptation capabilities of IRI and the possibility of its application for calculation of conditions for radiowave propagations over paths by different length (in addition to methods for calculation of propagation characteristics) make this model attractive for calculations as maximum usable frequency (MUF), so angles of arriving and group delays of signals. Ionosphere parameters $f_0E$, $f_0F2$, hmF2 forecasted by model, agree well with median experimental $f_0E$, $f_0F2$, hmF2 values and calculated hmF2 values via vertical sounding (VS) data of digisonde and FMCW–ionosounder with error which is pleasant for semi-empirical ionosphere model (as IRI).

Besides forecasting of different parameters, IRI model also allows to reconstruct the electron density N(h)-profile for any geographical place and any time. However N(h)-profile (as other ionosphere parameters) according to IRI model is enough different from real values of electron density.

The reconstruction of electron density N(h)-profile from experimental VS data allows to get more exactly data about electron density, than IRI model. There are some methods of N(h)-profile reconstruction from experimental height-frequency characteristic (HFC) in the world. In this work we tried to compare three methods (besides IRI) among them (on the base of Irkutsk digisonde data) and with IRI as well.

## 2. Digisondes and Huang-Reinisch Method

One of the main instruments for observing of the atmosphere state are Digisondes, which work in many world locations, and they are manufactured by The University of Massachusetts Lowell's Center for Atmospheric Research (UMLCAR). In Russia Digisondes DPS-4 are set in Irkutsk (since 2002), in Norilsk, Yakutsk and Zhigansk. The main purpose of DPS-4 is the reconstruction of electron density N(h)-profile from VS ionogram and measurements of ionosphere irregularities drift velocities on the basis of Doppler and angle measurements. The DPS-4 system compensates for a low power transmitter (300 W versus 10 kW for previous systems) by employing intrapulse phase coding, digital pulse compression and Doppler integration. The data acquisition, control, signal processing, display, storage and automatic data analysis functions have been condensed into a single multi-tasking, multiple processor computer system, while the analog circuitry has been condensed and simplified by the use of reduced transmitter power, wide bandwidth devices, and commercially available PC expansion boards.

N(h)-profile reconstruction through the software complex of Digisonde is made according to Huang-Reinisch method. For each layer, the N(h)-profile is expressed in terms of shifted Chebyshev polynomials with a logarithmic argument containing the starting plasma frequency and the critical frequency of the layer. The peak height and a set of coefficients specify the electron density distribution of each layer. A valley model derived from incoherent scatter observations at Arecibo describes the E-F transition. The frequent problem of missing h'(f) data points at the beginning of a trace is addressed by analytical expansion in the true height (profile) domain rather than by direct extrapolation of the h'(f) trace. The validity of the Digisonde N(h)-profiles has been verified by comparison with incoherent scatter radar profiles.

## 3. Observations' Situation and Data

For this work, for quiet geomagnetic conditions typical ionograms, obtained by Irkutsk Digisonde DPS-4, with E-, F1, F2-layers of ionosphere (without sporadical layers and F-spread) during twenty-four hours period in winter, equinox and summer time in 2006 without disturbances of ionosphere structure were taken from the database of ISTP SB RAS in Irkutsk (52.4°N, 104°E).

## 4. N(h) analysis

Ionograms provide a record of the apparent or virtual height of reflection of radio waves in the ionosphere as a function of the wave frequency. The inversion of these data to obtain an N(h) profile, giving the electron density as a function of real height, is ambiguous due to an absence of direct information at low frequencies and from any valley regions between the ionospheric layers. Reflections are not obtained from within the valley, so the continuity of the density vs. height input is lost and only indirect information is obtained about any profile at greater heights. To obtain accurate values for the real heights in the F region, information about the overall effect of the valley between the E and F layers is required. Usually a valley model is derived from incoherent scatter observations.

Besides the Huang-Reinisch method for reconstruction of N(h)-profile from ground-based vertical incidence ionograms there are other methods for N(h)-profile reconstruction exist, including the Guliaeva' ITERAN program and the Mikhailov method (they were used in this work).

ITERAN is Fortran program for rapid iterative N(h) analysis of ionograms. It's a second order method with one-parameter model of starting and valley ionization. As a basis of ITERAN program, parabola approximation h vs. $f_N^2$ in intervals of profile dividing was set. This program as methods of the second order is supposed to have piecewise linear changing of the first derivate $dh/df_N^2$. Every unseen region is interpreted as one elementary interval with the same parabolic N(h)-profile approximation in it, that other intervals have. It corresponds to the model with one unknown parameter – a height at the beginning of the profile or minimum plasma frequency in a valley.

However, Guliaeva method (and many others) has a serious defect, as there is no exact definition of the peak height value. For this reason the necessity of step dividing according to frequency with the task of HFC near critical frequency appears, and peak heights are determined by extrapolation formula, what is not correct. This problem cannot be solved by piecewise parabolic approximation of reflection height. The reason of failure is in that giving the task the expression for signal stopping is used, it runs out from ray optics method, which doesn't work near critical frequency region of layer.

In the Mikhailov method of N(h)-profile reconstruction the task of HF-radiowave propagation is solved by method of normal waves in frames of spherical-symmetric isotropic model of ionosphere. It allows finding of correct decision of the task at the critical frequency region of layers.

According to received traces in the result of ionogram processing, N(h)-profile is reconstructed by different methods up to peak height of F2-layer. IRI model was adapted according to critical frequency and peak height (calculated by Huang-Reinisch method) got in the result ionosphere VS sessions of Digisonde in Irkutsk.

For estimation of truth of the reconstructed N(h)-profiles (from the experimental VS ionogram) they made reverse recalculation of N(h)-profile in HFC (according to standard technique of solving the direct task of recalculation of N(h)-profile into HFC). Recalculated by this way HFC was compared with initial trace got by the result of processing of VS ionogram (experimental data).

It is seen that the greatest divergence of profiles is seen in the region of heights from 120 km up to 170 km (the problem of valley at the reconstruction of N(h)-profiles is actual till now). One must mark that Huang-Reinisch method calculates N(h)-profile even with the absence of E-layer in ionogram (in this case the critical frequency $f_0E$ is forecasted according to IRI model automatically).

At the same time values of peak height hmF2 and values of half-peak height h(0.5Nm) were compared, which were got from reconstructed N(h)-profiles by different ways (the difference between values hmF2 и h(0.5Nm) is the analog of F2-layer semi-thickness).

The difference of heights of the reconstructed N(h)-profiles by examined N(h)-profile reconstruction methods according to HFC in some hours reached 50 km (in summer period). It is seen that the smallest difference between heights values is seen in N(h)-profiles reconstructed by Huang-Reinisch and Mikhailov methods.

## 5. Conclusions

In the VS database in Irkutsk there are ionograms (especially summer period) when with the E-layer only the F1-layer (G condition) is seen, or when strong echoing Es-layer is presented. In this case N(h)-profile doesn't be calculated by no one methods (besides IRI model) as there is no information about the F2-layer. For cases of one-layered and two-layered F-layer adaptation capabilities of IRI model according to HFC parameters of Digisonde with N(h)-profile reconstruction give satisfying results.

The work had shown that investigated techniques for electron density reconstruction from VS data have satisfactory fit (by parameters and by profile shape) between them. Mikhailov method for N(h)-profile reconstruction is more correct and thereby recalculated HFCs from reconstructed N(h)-profiles (by direct task estimation) are more closed to original ionograms.

Height values obtained by Huang-Reinisch and Mikhailov methods are more closing to ones between them (except summer day time). Existing disorder with heights values is explained by different investigations of N(h)-profile reconstruction methods, but for many tasks in many cases for calculation of radiowave propagation characteristics one can neglect these differences of heights values. However Huang-Reinisch method of electron density reconstruction has useful advantage above other methods (thanks to integrated interaction with IRI model), because of it gives possibility for reconstruction of N(h)-profile from any HFC (and when track in low part of E-layer is absent). In this case forecasting values of critical frequency and peak height for E-layer are used, which absence make difficult for reconstruction of N(h)-profile by other methods.

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