# The technique of calculation of electron density profile from initial distribution using vertical sounding ionograms

A.M. Vesnin, K.G. Ratovsky

Institute of Solar-Terrestrial Physics SB RAS
Russia, 664033, Irkutsk, Lermontov st., 126a
Fax number: +7-3952-425557
Telephone number: +7-3952-428265, +7-9148-953698
e-mail: art-irk@inbox.ru

## Abstract

The technique of vertical sounding ionogram processing is presented. Our approach is based on modifying initial electron density profile. Initial profile can be obtained from IRI model prediction or from the previous sounding of ionosphere. The method of profile fitting to the ionogram does not require echo traces extraction. The results of practical application of the technique are presented. Technique is applied to processing of nighttime ionograms, as well as to processing of an “apparent F1 layer” phenomenon.

## 1. Introduction

Nowadays there are a number of ionograms processing systems [1], [2]. The problem of ionograms processing is usually divided into two sub problems: a) O and X echoes trace points are extracted from an ionograms; b) the electron density profile is calculated from the extracted traces [1]. In our approach we try to avoid the problem of echo traces extraction. We suppose it can make processing more reliable to different effects in the ionogram such as noise, missing the one-hop reflection with presence of two-hop reflection and so on. It might be very difficult to extract echo traces because of low signal-to-noise ratio in the ionograms as a result of ionosphere inhomogeneity, anthropogenic activity and other factors. There are many algorithms, which have a goal to remove noises and define valuable signal, but none of them can guarantee the result. By the way, the quality of realization of that particular step defines the reliability of final results. In our approach searching through different profiles we select such one which has the best correlation with observed ionogram. The full procedure of ionogram processing is in detail described below.

## 2. Description of the technique

The main idea of our technique is that: iteratively modifying initial electron density profile we choose one which have best correlation with ionogram. Our approach does not assume any final model of electron distribution in ionosphere. Different problems require different data as input. So the way we can obtain initial profiles may be different. For routine processing of ionograms without anomalies initial profile can be obtained from IRI model prediction. By modeling short-period ionospheric disturbance it is possible to use profile, obtained by previous sounding of ionosphere. It is well known, that in some cases the distribution of electron density can be described by simple model. For example, the parabolic approximation is well suited for the night F region. That's why in a number of cases we can use model layers [3] as an initial profile. It is also possible to use profile obtained on such instruments as ionosonde DPS-4. The electron density profile is used as input for our technique. Profile is modified by varying some parameters, which can be initial profile parameters (critical frequency $f_0$, peak height $h_m$) or parameters of disturbance of the initial profile.

Our technique handle electron density profile as array *(Ne(z), z) or (fp(z), z)* if we use plasma frequency. We can associate profile with set of parameter if we use some model. But first of all it is array of dots. There are advantages as well as disadvantages of such a representation. The concrete model is commonly used in the most of ionogram processing system. Thus electron density profile is described by the set of some function, e.g. Chebyshev polynomials, parabola exponential function and so on. [1], [2]. On the one hand, it gives benefit in the amount of data needed for full profile description. Moreover, the layers boundaries, for example, are simply determined from the function parameters. On the other hand, some feature in ionograms can not be described by profile model due to its limitation. We suppose the representation of profile as an array can give more information about electron distribution in ionosphere.

The procedure of fitting profile to experimental data is of special interest. Speaking of fitting profile to ionogram it is necessary to have the criterion of correlation between profile and ionogram. Every profile has

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corresponding virtual height function *h'(f)*. This function determines dependence of virtual height on sounding frequency. In our approach *h'(f)* was calculated using well-known formula [3]:

$$h'(f) = \int_0^{z_0(f)} \mu'(z,f)dz = \int_0^{z_0(f)} \frac{dz}{\sqrt{\varepsilon(z,f)}} \tag{1}$$

where $z_0(f)$ - the height of reflection, $\mu'$ - group index of refraction, corresponding to O component, X component or isotropic case (without magnetic field). In our technique we use calculated *h'(f)* to estimate correlation between profile and ionogram. Ionogram is an amplitude matrix of a signals reflected by ionosphere. Another word, ionogram is two-dimensional amplitude distribution $A(f_i,h_k)$ of frequencies $f_i$ and virtual heights $h_k$. As it was said above *h'(f)* is virtual height *h'* dependence on sounding frequency *f*. Calculating *h'* we can use the same set of frequencies as in ionogram $f_i$, $i=1..I$ and obtain set $h'(f_i)$. Since ionogram is two-dimensional distribution of amplitude in frequency-height coordinates and virtual height function is a curve in the same coordinates, it is possible to display them on the same plot. We assume that maximal amplitude in $A(f_i,h_k)$ on each $f_i$ in most cases correspond to valuable signal. So now we can enter the criterion of correlation between profile and ionogram: the closer *h'(f)* passes to maximal amplitude area of ionogram $A(f_i,h_k)$, better correlation profile has with ionogram. Mathematical expression for this criterion is:

$$As = \sum_{i=1}^{I} \overline{A}_i\,,\; \overline{A}_i = \sum_{k=-1}^{2} A_{ik+n} \cdot W_{ik}\,,\; W_{ik} = 1 - \left|(h_i' - h_{k+n})/2\Delta h\right|,\; n = \left[h_i'/\Delta h\right], \tag{2}$$

The profile corresponds with maximal *As* is considered the best solution. For illustration of the fitting method see Fig. 1

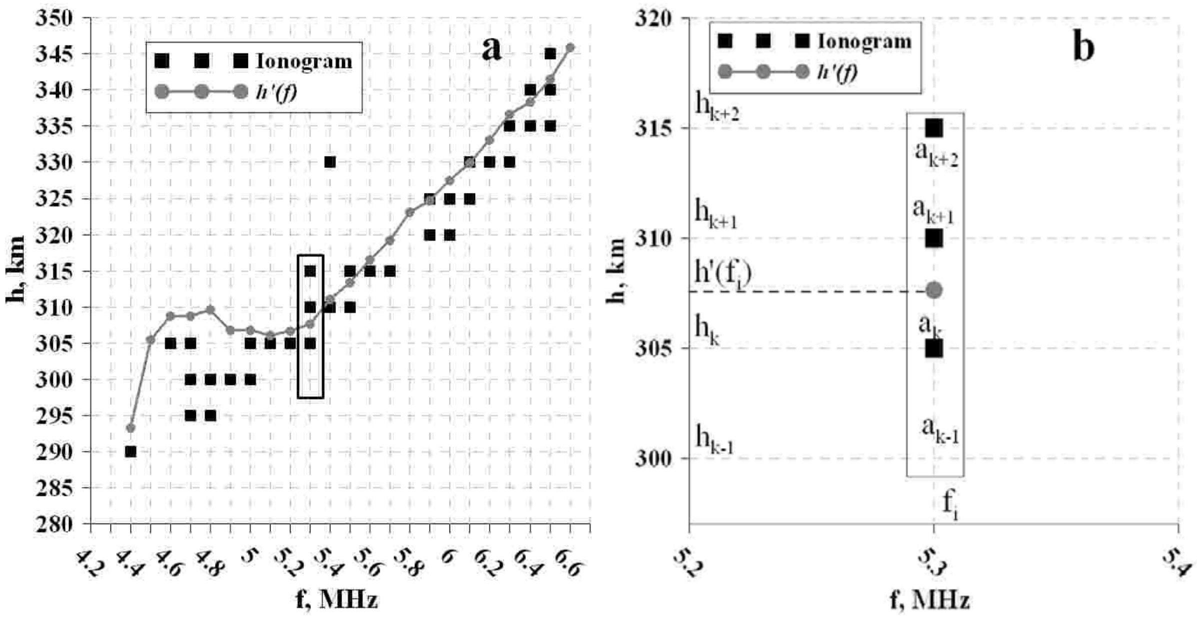


Fig. 1. The illustration of fitting method. a) Ionogram and virtual height function displayed on the same plot; b) part of figure a), highlighted with rectangle.

So the finding of profile, corresponding with the ionogram the best, comes to the following algorithm:

1. Defining a initial electron density (plasma frequency) profile
2. Varying of the parameters, which conduct changing of the initial profile
3. Calculation of *h'(f)* based on modified profile
4. Calculation of summarized amplitude *As* in the vicinity of calculated *h'(f)*
5. Finding maximal *As* in a cycle, including steps 2, 3, 4 and fixation of the parameters, corresponding with the maximal *As*.

## 3. Testing and practical application of the technique

For testing our technique the processing of synthesized ionograms was performed. Virtual height function *h'(f)* was calculated using model parabolic profile. Amplitude of dots in synthesized ionograms, corresponded calculated *h'(f)*, i.e. dots in synthesized ionograms with coordinates (*h'(f)*,*f*), considered $a_c$. After it noise is superimposed on ionogram (see Fig. 2). The processing was based on varying of model profile parameters with defined discrete step. The range of the parameters includes the parameters of source profile (that was used for creation of synthesized ionograms). The error between best-fit parameters and source profile parameters was not greater than discrete step.

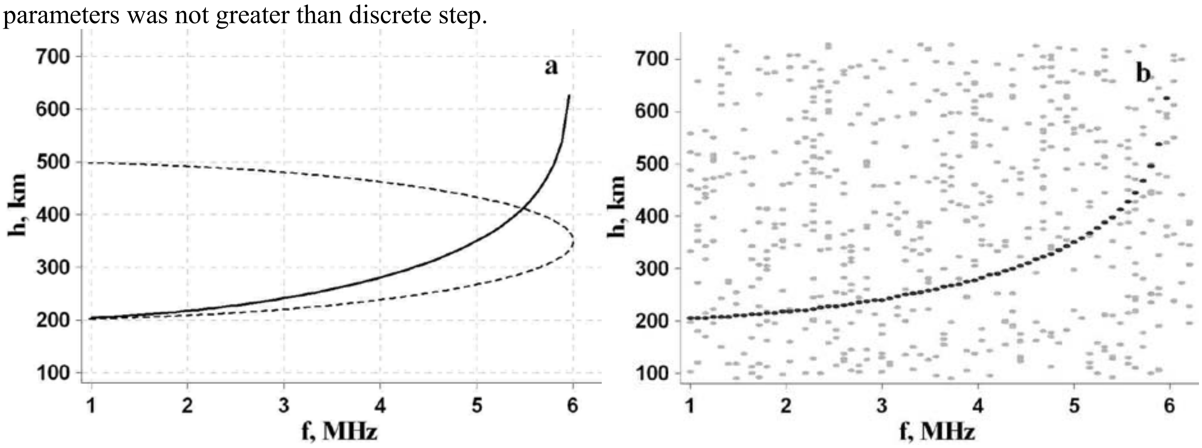


Fig. 2. a) Dashed line – model parabolic profile, solid line – corresponded virtual height function; b) synthesized ionogram, black dots – valuable dots, grey dots – noise.

Using the technique, we processed nighttime ionograms, obtained by ionosonde DPS-4, Irkutsk. At night time F1 layer is absent and F region can be described with simple analytic form such as parabola. Processing was carried out using model parabolic profile. Parameters of profile such as critical frequency, peak height and half thickness [3], were automatically varying. Number of different sets of parameters (number of different profiles) was equal approximately $1{,}2*10^5$. The range of parameters included reasonable values of ionospheric characteristics, and steps were 2 km for peak height, 2 km for half thickness and 0,1 MHz for critical frequency. So we can use the same ranges for all ionograms belong to at least one night. Processing of one ionogram took about 1 min. The technique shows good results and the most fitted profiles represent real electron density distribution. But for some ionograms fitted critical frequency was a bit differ from a real critical frequency. We will try to solve this problem in the future by more accurately accounting echo points. The results of processing are presented on Fig. 3.

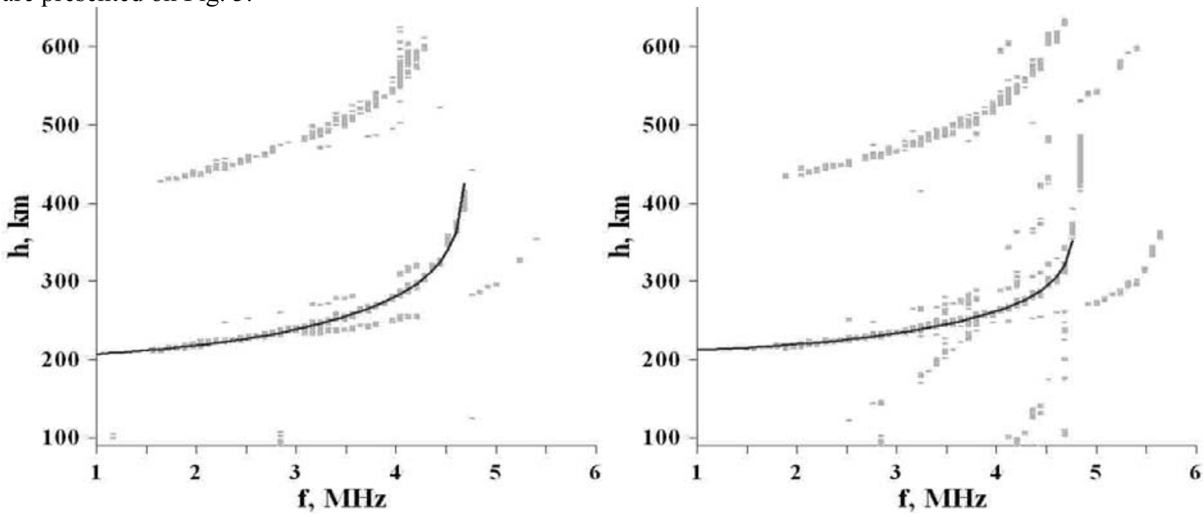


Fig. 3. The results of processing. Dark line – *h'(f)*, calculated from the best profile; grey dots – O component of echo in ionogram.

These results are given here to show that our fitting method and technique in general suit to process real ionograms rather then to give full information of electron density. However, one can obtain critical frequency, peak height and half thickness of F region quite accurately using this algorithm. There is way to reduce time of the processing. As it was said above, all ionograms were processed with using same set of parameters (profiles). So we can save calculated *h'(f)* for each profile once it was calculated and use it again and again.

Also the technique was applied for interpretation of the specific perturbation, which observed in ionograms as "apparent F1 layer". This effect is observed in ionograms as additional bend of the echo traces (see Fig. 4). This phenomenon looks like regular F1 layer, but meaning of critical frequency of "apparent F1 layer" was absolutely untypical for that time of a day, season and level of solar activity. Sometimes "apparent F1 layer" was observed together with regular F1 layer. Described above phenomenon was observed at mid-latitude Irkutsk station in quiet geomagnetic conditions.

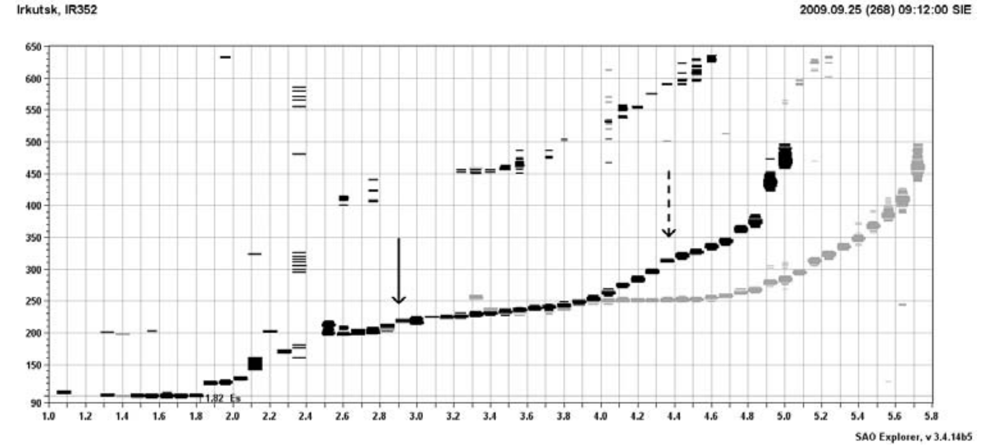


Fig. 4. The "apparent F1 layer" phenomenon at Irkutsk station 09:12 UT, 25.09.09. Black dots – O echo, grey dots – X echo. Dashed pointer shows "apparent F1 layer", solid pointer – regular F1 layer.

Investigation of the "apparent F1 layer" is well depicted in following study [4]. The phenomenon was observed within 25 min period (ionograms were registered every 3 minutes) and accompanied by monotone decreasing of critical frequency as well as virtual height of "apparent F1 layer". The phenomenon was simulated in term of travelling ionospheric disturbance, caused by atmospheric gravity wave (AGW). In that case the initial profile was obtained on ionosonde before appearance of disturbance. We chose sine wave with a Gaussian envelope as a model of disturbance. The disturbance model was imposed on initial electron density profile. The parameters of the model were varied in definite range. Disturbance characteristic were estimated as the result of processing.

## 4. Conclusion

The technique of the vertical sounding ionograms processing are depicted. Vertical sounding ionogram and initial electron density profile are the input data. Application of the technique to the real experimental data has shown feasibility of our profile fitting method, as well as the technique in general. Application of the technique has allowed the interpretation of the apparent F1 layer phenomenon. The technique was realized with the use of amplitude information of only O component, hereafter we are planning to use X component, which will increase the reliability of the algorithm.

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## References

1. B. W. Reinisch and X. Huang "Automatic calculation of electron density profiles from digital ionograms 3. Processing of bottomside ionograms," *Radio Science, Volume 18, N 3,* 1983, pp. 477-492.

2. C. Scotto "Electron density profile calculation technique for Autoscala ionogram analysis," *Advances in Space Research, Volume 44, N 6,* 2009, pp. 756-766.

3. Ya.L. Alpert "Propagation of electromagnetic waves and ionosphere," *M.:Science*, 1972, 563 pp. (in Russian)

4. A.M. Vesnin and K.G. Ratovsky "Modeling "apparent F1 layer" phenomenon observed in the experiment "Radar-Progress" with the software of automatic processing of vertical sounding ionograms," *Solar-Terrestrial Physics, N 16,* 2010, pp. 136-142. (in Russian)