URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

HF radio channel simulation in the presence of the ionospheric F1 layer

N. Zaalov*, E. Moskaleva
University of Saint Petersburg, Russia, https://spbu.ru

Abstract

Experience has shown that there are many occasions when HF propagation model performance is degraded because of difficulties surrounding the characterization of the Fl region of the ionosphere. This paper presents a brief description of the Fl layer and approach to ionogram simulations with the presence of Fl layer. The data obtained from [http://giro.uml.edu/didbase/scaled.php] GIRO website were used in simulations.

1 Introduction

The F1 layer is the lower part of the daytime F layer. It extends from 140 to 240 km above the Earth and exists only during daylight hours disappearing at night. It is more pronounced during summer and at low sunspot numbers. The maximum electron density of the F1 layer occurs in proximity to local noon when the solar zenith angle is minimum. In general, daytime summer ionograms show a well-developed F1 cusp that make available an accurate automatic scaling of the critical frequency foF1 of the F1 layer. Since the 1960s automatic scaling procedure was developed to scale vertical incident ionograms. The most widely used method is the automatic real-time ionogram scaling with true-height (ARTIST) [1], which was developed by the University of Lowell. Lately, many studies [2, 3, 4] have developed the performance of ARTIST. However on many occasions the ionogram traces do not exhibit sufficiently defined cusp. These cases in which the values of foFl cannot be obtained are described according to URSI standard as L condition. When L condition is observed on ionogram trace, the problem of assessing the frequency of the point of inflection, which defines foF1 in the electron density profile, arises [5].

2 HF wave propagation model

For radio system applications it is important that the outcome of the propagation model be well matched to the electron density specification. A ray-tracing model that can reproduce many of features (including the direction of arrival) observed in measurements especially at high latitudes of the Earth was described in paper [6]. It is noteworthy that the power of the signal is taking into account in these simulations. Lately, it was developed into Northern Ionosphere Model and Ray-Tracing (NIM-RT) model that can simulate another features observed in the experimental measurements including absorption effects [7, 8, 9, 10].

The now-casting and forecasting of HF radio wave absorption are important for the HF communication applications. Absorption of the HF signals in the D region plays a pivotal role in HF propagation. Three primary mechanisms are incorporated into NIM-RT model: diurnal absorption induced by solar UV, absorption associated with X-ray flux, and particle flux generating by solar flares. The modified algorithm for absorption estimation [9] was implemented in NIM-RT software focussing on accounting for short timescale variation of the absorption. NIM-RT model is capable to calculate oblique and vertical sounding ionograms, time dependence of angles of arrival and delay of HF radio waves propagating along specific paths.

The background ionosphere in NIM-RT model comprises E, F1 and F2 layers, the basic parameters of which (critical frequency, height, and vertical-scale of each layer) could be acquired from vertical sounding of the ionosphere. Ionosphere parameters obtained with the International Reference Ionosphere (IRI) have also been employed. In the case of necessity an adaptation of the ionosphere parameters retrieved from IRI model to near real-time condition could be performed according to the method described in [11].

3 Measurements and simulations

The principal goal of this paper is presenting some results of HF channel modelling with the presence of F1 layer based on the data obtained from GIRO network database. Data from GIRO network ionosondes comprising scaling data corresponding to all ionospheric layers are routinely collected from many sites around the world. In this study the digital ionosonde observations in middle latitudes of the Earth (above the Europe) were used. The ionosphere main parameters (peak plasma frequencies, height of peak) of E, Es, F1 and F2 layers are available via Internet. A description of F1 layer was developed and introduced in the IRI model [12]. In this model the F1 layer electron density depends on parameters B1 and D1.

In Figure 1 the daily distributions of the foF1 (left column) and D1 (right column) obtained with MO155 (55.5°N; 37.3°E) ionosonde are depicted. Colour bar at the right side of each panel marks an occurrence rates of foF1 and D1. The data that cover entire 2018 (top row) and March 2018 (bottom row) are exhibited.

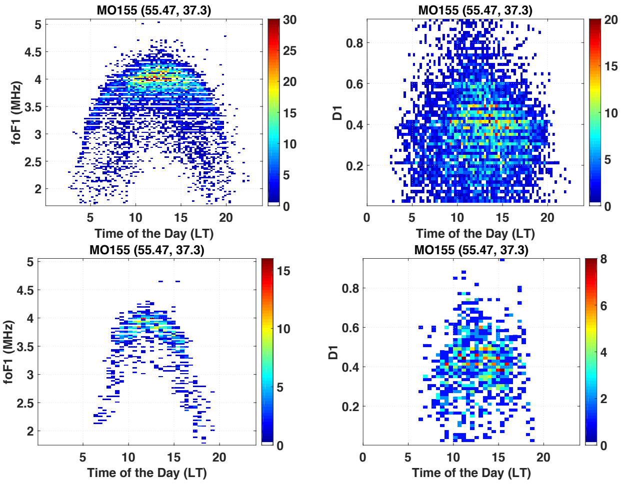

Figure 1. Diurnal distribution of foF1 (left column) and D1 values (right column). The data related to MO155 ionosonde cover entire 2018 year (top row) and March 2018 (bottom row). Colour bar at the right side of each panel marks the number of occurence.

As expected, the diurnal variation of foF1 (left panels) exhibited a systematic behavior corresponding to F1 layer, which arises after sunrise and vanishes at sunset. The foF1 attains the maximum value at local noon. The foF1 occurrence (marked by colour bar at the right of each panel) associated with probability of F1 layer appearance displays not apparent feature. It reaches fairly sharp maximum after noon in time between 12 and 18 LT. The spread of data recorded in one month significantly less then the spread related to entire year data. The diurnal variation of D1 shows very large spread in entire year data and in the single month data. Obviously, the D1 parameters are not available before sunrise and after sunset when F1 layer disappeared.

Vertical profile of the ionosphere based on IRI model [13] is used in NIM-RT model. However, an altitude derivates of IRI electron density profile are not continuous. Some analytic approximation of the ionosphere vertical profile was performed in NIM-RT model. An averaging subroutine was applied to raw data in order to diminish D1 parameter deviation arising as a consequence of F1 layer nature and errors caused by automatic scaling procedure. In addition, an interpolation of raw D1 data was performed to fill short gaps. The D1 data corresponding to 26 March 2018 are exemplified in Figure 2.

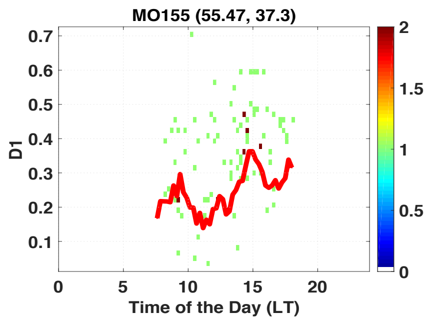

Figure 2. D1 data cover the period from 25 to 27 March 2018. Red line depicted averaged values of D1.

These D1 data with relevant adjustment were used in ionogram simulations presented in Figure 3.

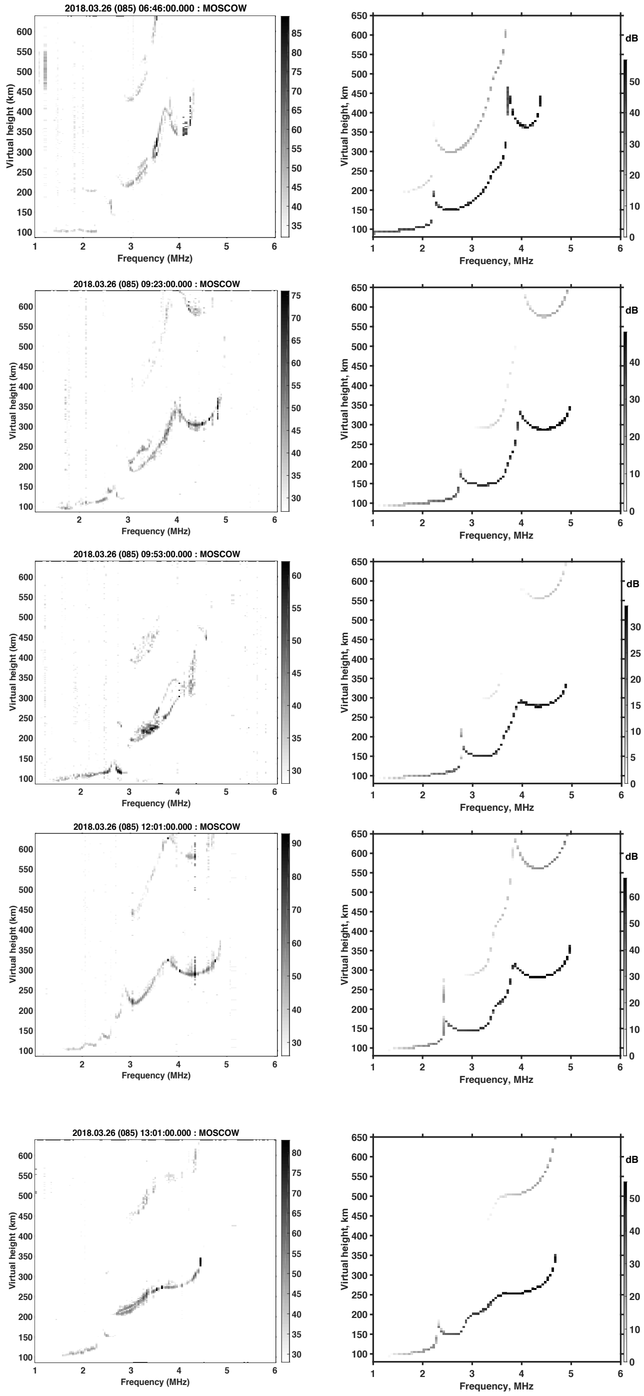

Figure 3. Measured (left column) and simulated vertical ionograms (right column) corresponding to 6:46, 9:23, 9:53, 12:01 and 13:01 UT on 26/03/2018, corresponding to MO155 ionosonde.

Measured (left column) and simulated vertical (right column) ionograms at 6:46 UT (1st row), 9:23 UT (2nd row), 9:53 UT (3rd row), 12:01 UT (4th row) and 13:01 UT (5th row) on 26/03/2018 are exhibited in Figure 3 corresponding to MO155 ionosonde. Note, solely ordinary mode of wave propagation is shown. The power of the signal in dB is indicated with colour-bar at the right. The ionogram trace corresponding to well developed F1 layer is observed at 6:46 UT (top row). The evincing of the cusp structure reveals smooth evolution from 9:23 UT to 12:00 UT when fairly definite cusp is evident. At 13:01 UT (bottom row) L condition occurs and inflection of the traces is observed.

The resemblance between measured (left column) and simulated (right column) ionograms is fairly remarkable. It is noteworthy that the absorption effects due to solar UV illumination were taking into account in simulations.

It is well known that F1 layer is variable in time and space. The example of foF1 value distribution above Europe is shown in Figure 4. Colour bar at the right indicates the foF1 values.

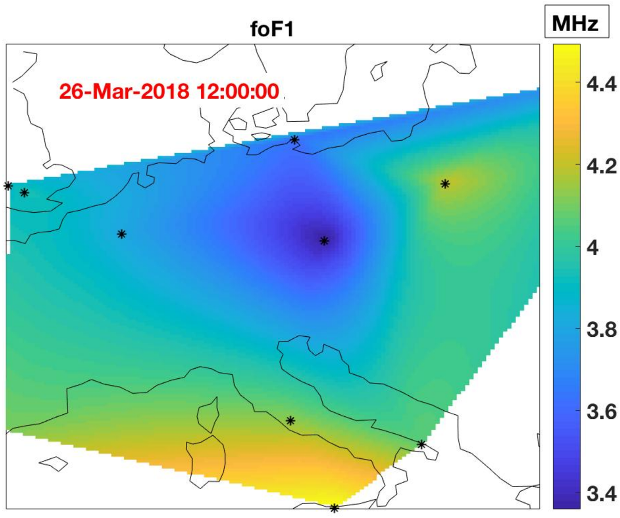

Figure 4. Distributions of the top frequency of F1 layer.

NIM-RT model is capable to calculate oblique sounding ionograms. However, non-monotonic space dependence of foF1 magnitudes leads to the complication relating to oblique ionogram simulation.

4 Acknowledgements

The authors are grateful to the University of Massachusetts Lowell Centre for Atmospheric Research for the Digisonde data and SAO-X program for data processing, NOAA SWPC for the GOES data and IRI Working Group for IRI data.

5 References

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

2. I. A. Galkin, G. M. Khmyrov, A. Kozlov, B.W. Reinisch, X. Huang and D.F. Kitrosser, “Ionosonde networking, databasing, and web serving”, *Radio Science*, **41**, 5, 2006, RS5S33, doi:10.1029/2005RS003384.

3. B.W. Reinisch, X. Huang, I. A. Galkin, V. Paznukhov, A. Kozlov, “Recent advances in real-time analysis of ionograms and ionospheric drift measurements with digisondes”*, J. Atmos. Sol. Terr. Phys.***,** **67**, 2005, pp. 1054–1062, doi:10.1016/j.jastp.2005.01.009.

4. I. A. Galkin, G. M. Khmyrov, A. Kozlov, B.W. Reinisch, X. Huang and V.V. Paznukhov, “The ARTIST 5”, *Radio Sounding and Plasma Physics*, AIP Conf. Proc., 2008, **974**, pp. 150-159.

5. C. Scotto, “Estimation of probability of occurrence of F1 layer or L condition using tables and electron density profile models”, *Advances in Space Research* **48**, 2011, pp. 2053–2056, doi.org/10.1016/j.asr.2011.08.019.

6. N. Y., Zaalov, E. M. Warrington, and A. J. Stocker, “A ray-tracing model to account for off–great circle HF propagation over northerly paths”, *Radio Science*, **40**, 2005, pp.1-14, RS4006, doi:10.1029/2004RS003183.

7. E. V. Moskaleva and N. Y. Zaalov, “Signature of polar cap inhomogeneities in vertical sounding data”, *Radio Science,* **48**, 2013, pp. 547-563, doi: 10.1002/rds.20060.

8. N. Y. Zaalov and E. V. Moskaleva, “A polar cap absorption model optimization based on the vertical ionograms analysis”, *Advances in Space Research*, **58**, 2016, pp. 1763-1777, doi:10.1016/j.asr.2016.07.024.

9. N. Y. Zaalov, E. V. Moskaleva, D. D. Rogov, and N. N. Zernov, “Influence of X-ray and polar cap absorptions on vertical and oblique sounding ionograms on different latitudes”, *Advances in Space Research*, **56**, 2015, pp. 2527-2541, doi:10.1016/j.asr.2015.09.008 .

10. N. Y. Zaalov, E. V. Moskaleva, and F. V. Shekhovtsov, “Method of the HF wave absorption evaluation based on GIRO network data”, *Advances in Space Research*, **63**, 2018, pp. 2075-2087, doi:10.1016/j.asr.2018.12.024.

11. N. Y. Zaalov, E. V. Moskaleva and T. S. Burmakina, “Application of the IRI model to the HF propagation model with optimization of the ionosphere parameters to day-to-day variation”, *Advances in Space Research*, **60**, 10, 2017, DOI: 10.1016/j.asr.2017.08.018.

12. B.W. Reinisch, X. Huang, “Redefining the IRI F1 layer profile”, *Advances in Space Research,* **25**, 2000, pp. 81–88.

13. Huang, X., Reinisch, B.W. “Vertical electron density profiles from the digisonde network”, *Advances in Space Research*, **18,** 6, 1996 a, pp. 121–129.