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COMPARISON OF IONOSPHERE PARAMETERS f_0F2, $hmF2$ OBTAINED FROM VERTICAL SOUNDING, OBLIQUE SOUNDING, AND IRI DATA

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Abstract
The paper is dedicated to experimental check of operative technique for calculation of F2-layer parameters at the path's midpoint (critical frequency and peak height) using oblique sounding data. In the paper experimental data obtained during 2003-2006 by FMCW-ionosounder in Irkutsk (over different paths with different length and orientation) were used. The IRI data and experimental vertical sounding data (nearest to the path's midpoint) were used for verifying of calculated values. Experimental oblique sounding data recalculation in the path's midpoint parameters was performed on the basis of the modified Smith method without consideration of Earth's magnetic field.

Introduction

For in-line diagnostics we should be experienced in obtaining information about environment at various points of investigated region and as well as at the points where vertical sounding (VS) stations are not installed. The study of the relation between oblique sounding (OS) and VS data plays an important part in the solution of this problem.

A lot of papers were dedicated to questions of diagnostics and forecasting of HF parameters according to OS data. However, an experimental check-up of methods of HF parameters obtaining according to OS data is complicated by the absence of experimental VS data along OS path. At best the real information about environment during the OS session can be obtained in transmitter or receiver points.

In papers [1-2] a simple approach for determination of critical frequency in midpoint of OS path on the basis of Smith method was proposed. This technique can be applied to distance-frequency characteristic (DFC) measured on single-hop path for height-frequency characteristic (HFC) calculation. Previously the technique was checked by simulation over OS path with distance 2300 km and applied to experimental OS data obtained during March-April of 2004 (calculated f_0F2 values have been compared with IRI model f_0F2 values).

This paper devoted to complex experimental checking of operative technique for f_0F2 and $hmF2$ calculation. The checking bases on the ISTP SB RAS FMCW-ionosounder [3] observations during 2003-2006 in Irkutsk (52°N, 104°E) over different (by distance and orientation) OS paths (Norilsk—Tory, Usolie—Tory, Magadan—Tory). IRI data and experimental VS stations (nearest to path's midpoint) data were used for f_0F2 and $hmF2$ values verifying. Experimental VS data of ionospheric station in Podkamennaya Tunguska were used for checking calculated data derived from Norilsk—Tory path, Yakutsk station VS data were used for checking calculated data derived from Magadan—Tory path (Fig. 1), digisonde DPS-4 in Irkutsk data were used for verifying calculated f_0F2 and $hmF2$ values derived from

weakly OS Usolie—Tory path data.

Figure 1. Map of the long distance paths.

Checking on the Usolie—Tory path

Ionosounder transmitting point working with frequency modulated continuous wave (FMCW) signals is located near Usolie-Sibirskoye to the north-west of Irkutsk (Fig. 2), receiving point is near village Tory ~98 km to the south-west of Irkutsk (path length is about ~126 km). Under quiet and weakly disturbed conditions weakly OS ionograms (DFC) are not much different from VS ionograms (HFC) received in Irkutsk [4].

For peak height value (in path's midpoint) determination $f_p(h)$-profile was reconstructed by Huang-Reinisch method which is integrated in digisonde DPS-4 (working in Irkutsk since 2002) software «SAO-Explorer»; it helps to process VS ionograms of digisonde. DFC of FMCW-ionosounder obtained over weakly OS Usolie—Tory path was recalculated into HFC which was used for $f_p(h)$-profile reconstruction.

Calculated values of parameters f_0F2, $hmF2$ (by using of weakly OS data) in Usolie—Tory path's mid-

point were compared with experimental f_0F2, $hmF2$ values obtained by digisonde in Irkutsk and with f_0F2, $hmF2$ values obtained from IRI model. The comparison had shown that there is a good agreement between calculated values and experimental ones (Fig. 3).
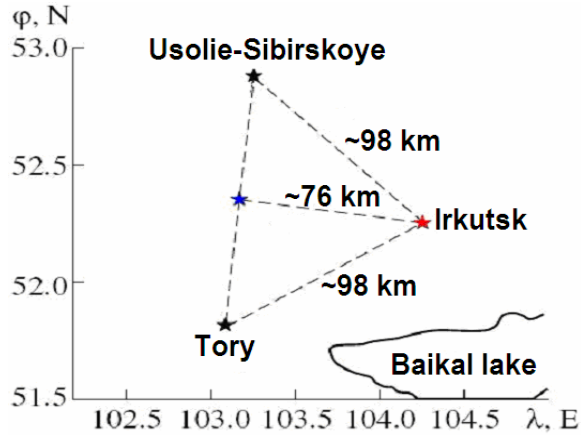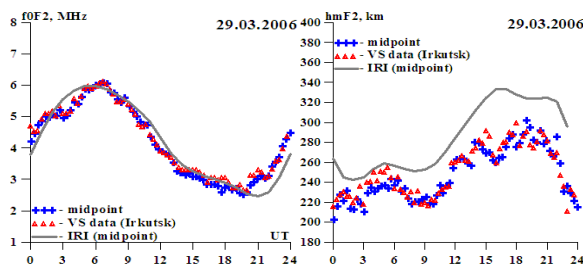

Figure 2. Map of the Usolie—Tory path.

Figure 3. Diurnal variation of f_0F2 and $hmF2$ near midpoint of Usolie—Tory path and in Irkutsk.

Checking on the Norilsk—Tory path

Observations over Norilsk—Tory path (Tory: 51.8°N, 103°E; Norilsk: 69.2°N, 88°E) were organized by separate series since 2003. The path has meridian direction (Fig. 1). The path length is ~2088 km. Coordinates of the path' midpoint: $\varphi = 60.7°$N, $\lambda = 97.5°$E. The closest VS station is located in Podkamennaya Tunguska (61.6°N, 90°E). Unfortunately, there is no total coincidence of this point and the path' midpoint coordinates (distance between them ~416 km).

Hourly values of critical frequencies F2- and E-layers and also of the coefficient M(3000)F2 of the station Podkamennaya Tunguska in a type of table data were presented by station employees. Comparison of more than 250 hourly values of f_0F2 obtained at the station Podkamennaya Tunguska with the values of f_0F2 calculated according to the OS data and characterizing ionosphere in the path' midpoint was carried out. In the Fig. 4 daily run f_0F2 is shown during one day for each season in 2003-2004.

Compared sets of calculation and experimental values of f_0F2 were brought to Universal Time (UT)

format taking into account a longitudinal effect. Podkamennaya Tunguska data when transferring into UT faced the shift of half an hour because of the difference of longitudes of path' midpoint and Podkamennaya Tunguska. It is seen from the Fig. 4 that values obtained from recalculation are agreed well with experimental values.
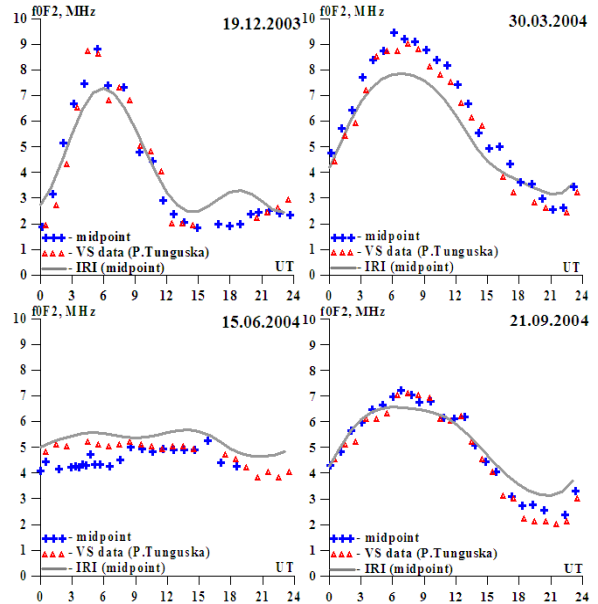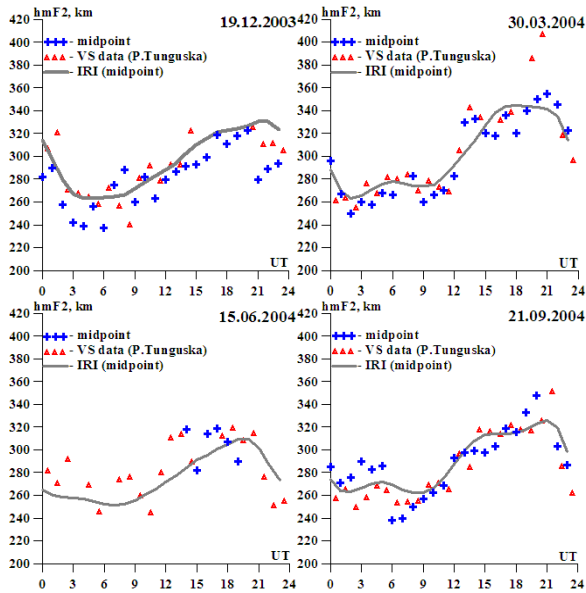

Figure 4. Diurnal variation of f_0F2 near midpoint of Norilsk—Tory path and in Podkamennaya Tunguska.

Experimental check-up of f_0F2 values calculating technique in the OS path' midpoint and in Podkamennaya Tunguska VS station (close to the path' midpoint) showed that absolute deviation of f_0F2 values in Podkamennaya Tunguska from those according to OS data was 0,34 MHz. Average relative deviation ~ 8 % (maximal value ~25 % in separate hours), and a correlation coefficient was 0,96. The largest error is observed at the day time in summer, and this can be explained by the Smith method peculiarity where effects related to wave delay in the lower layers are not taken into consideration. Deviations of f_0F2 values can be explained by medium gradients because of coordinate's differences of investigated points.

In the Fig. 5 daily variations of hourly $hmF2$ values obtained by various ways is shown for the same days as in the Fig. 4. The solid line represents the values according to the IRI model, triangles — according to the simplified Dudeney formula [5] (on the bass of data from Podkamennaya Tunguska), crosses — from N(h)-profile reconstructed according to Guliaeva method [6] from HFC calculated according to the experimental DFC. For June 15, 2004 according to OS data we can calculate HFC only during night hours (in LT) because of total DFC absence during the day. Almost in all DFC of this period only upper rays and screening sporadic Es layer are represented and that allowed calculating only f_0F2 in the path'

midpoint and *hmF2* value are impossible to obtain according to this method. It is seen from Fig. 5 that *hmF2* values are well-agreed between each other. The procedure of *hmF2* value obtaining according to the proposed algorithm via *N(h)*-profile is quite bulky but it can be realized. Thus, in operative goals and in cases when according to OS data it is impossible to calculate *hmF2* value we can use *hmF2* value from the IRI model.
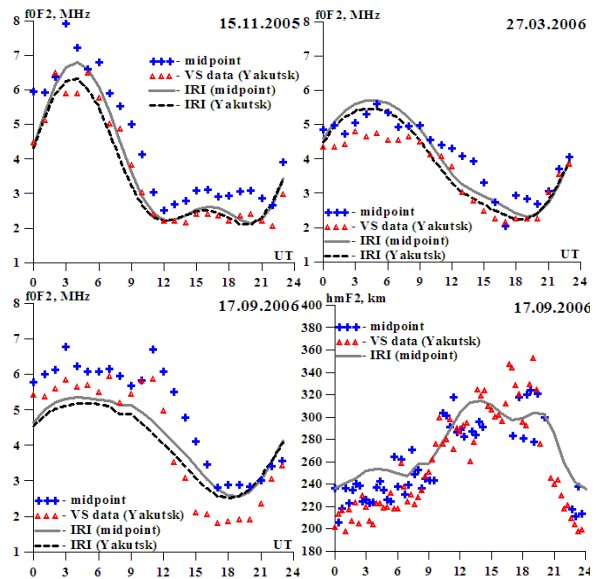

Figure 5. Diurnal variation of *hmF2* near midpoint of Norilsk—Tory path (derived from OS data) and in Podkamennaya Tunguska (experimental data).

Checking on the Magadan—Tory path

Some experimental testing of ionosphere parameters calculation according to VS data was performed earlier [2] for Magadan—Tory path (path length ~3034 km). At that time, in 1989, in the path' middle point (58.2°N, 124.2°E) the ionospheric VS station in Aldan (58.48°N, 125.24°E) was specially installed. But, unfortunately, during the epoch of solar activity maximum (F10.7 ≈ 217) the OS working frequencies range limit (up to 29 MHz) did not allow to obtain total DFC (up to maximum usable frequency (MUF)). Maximum observed frequency (MOF) limited by 29 MHz was lower than calculated MUF. Also because of technical failures there were no data obtained during complete 24-hour period. Nevertheless, limited set of DFCs during those hours (night and transitive period) when we could determine MOF (as crossing frequency of upper and lower rays) allowed us to conclude on significant influence of VS parameters in the path' midpoint when determining MUF by the calculative approach. Errors in comparing MUF as well as the calculated critical frequency according to DFC were ~5 % in average.

Experimental checking using the data obtained in 2005-2006 data (Fig. 6) showed that data of ionospheric VS station in Yakutsk (62°N, 129.6°E), near-

est VS station to Magadan—Tory path's midpoint (distance between them ~516 km or ~4° of latitude), cannot be used for comparison with the data calculated for path's midpoint (spatial gradient is too large). It was proved by comparison VS data obtained during February and March of 1989 in Yakutsk and in Aldan, which was situated very close to the Magadan—Tory path's midpoint. For this purpose experimental VS data obtained in Aldan in 1989 and storing on films were scanned and processed again. VS data obtained in Yakutsk were kindly provided to us by the ionospheric station employers. Also we used the data from IRI-2001 model.

**Figure 6.** Diurnal variation of *f₀F2* and *hmF2* near midpoint of Magadan—Tory path and in Yakutsk.

This did not allow us to use Yakutsk VS station data for reliant testing of technique for media parameters derivation from OS data, like it was done in 1989 when VS station operated near Magadan—Tory path's midpoint (in Aldan, Yakutiya region). In order to demonstrate differences of ionospheric parameters for coordinates of Yakutsk and Magadan—Tory path's midpoint in Fig. 7 daily run of MOF values (from OS experiment over Magadan—Tory path) and MUF values obtained through the use of Yakutsk data with the help *M(3000)F2* coefficient is shown. It is seen that although the experimental OS data correlate with calculated values the quantitive analysis shows deviation value more than 20 %.

Fig. 8 represents diurnal variation of absolute deviation and ratio error between calculated *f₀F2* value in Magadan—Tory path' midpoint and experimental *f₀F2* value in Yakutsk during few days of different months in 2005-2006.

Conclusions

Experimental checking of operative technique for calculation of *f₀F2* and *hmF2* values in OS path's midpoint (carried out on the base of experimental data obtained during 2003-2006 over different length

and orientation of paths) shows satisfying approbation between experimental and calculated values.

Also the checking showed that Yakutsk station VS data correlate with estimated Magadan—Tory values in path's midpoint, but deviation can be more than 20 % that accords to the theory [7].
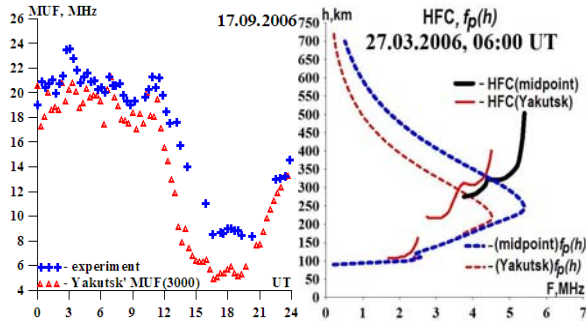
Figure 7. Diurnal variation of experimental MOF and MUF values derived from VS station data in Yakutsk (on the left). HFC and $f_p(h)$-profiles reconstructed from HFC in Yakutsk and recalculated for midpoint from experimental DFC (on the right).
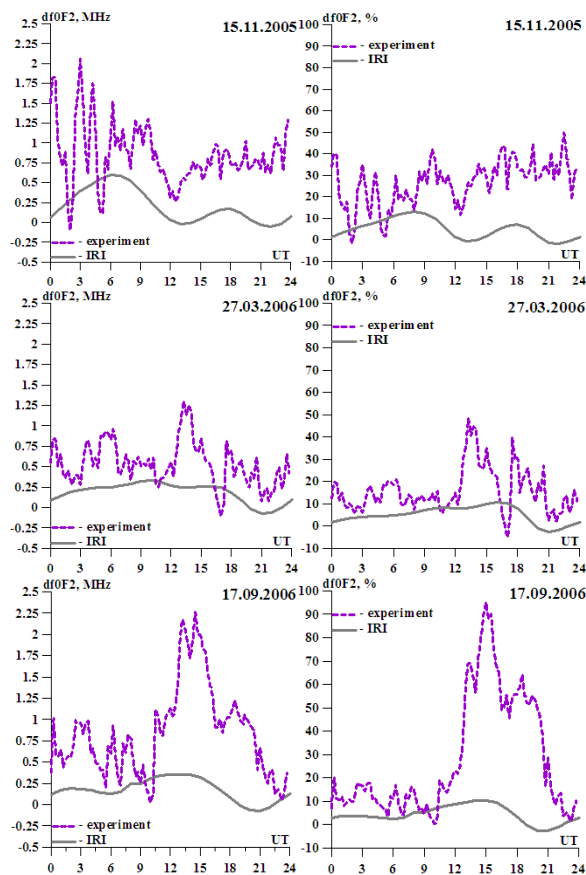
Figure 8. Diurnal variation of absolute deviation (on the left) and ratio error (on the right) between calculated f_0F2 value in Magadan—Tory path' midpoint and experimental f_0F2 value in Yakutsk.

Comparison with IRI model shows that latitude gradients between critical frequencies in Magadan—

Tory path's midpoint and Yakutsk larger than IRI model predicts. Differences mean that IRI insufficiently correctly describes ionosphere in this region (East Siberian high and middle latitudes).

The operative technique of f_0F2 definition (also HFC which can be used for $hmF2$ definition) have satisfying accuracy, and its simple algorithm opens good perspectives for using the technique in real-time for operative diagnostics.

The OS data recalculation into the HF parameters in the path' midpoint can be useful as an opportunity to obtain additional information on the environment in regions where the VS stations are absent. We need only the presence of true experimental OS data and a possibility of the 1F2 mode upper ray parameters obtaining. Also, it can be useful for operational prediction and diagnosis, for development of regional environment models, for adapting of different environment models to real conditions.

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