The behavior features of main ionospheric parameters along a weakly oblique path

V. P. Grozov*, V. E. Nosov, G.V .Kotovich, A.G. Kim, S. M. Matyushonok and
G.K.Ratovsky
Institute of Solar-Terrestrial Physics P.O.Box 4026; Irkutsk 33, 664033, Russia

ABSTRACT

Analysis of the behavior of main ionospheric parameters allows us to study the physical processes in the ionosphere and develop empirical and semi-empirical the ionosphere models (IRI) with applications to the various geo- and radiophysical problems. Vertical-incidence sounding ionosondes provide the key source of information about ionospheric parameters. The worldwide network of ionosondes includes over 120 stations. On the other hand, sounding techniques using chirp-signals (linear-frequency-modulated signals) are also under development mainly for oblique-incidence sounding paths. With a small receiver-transmitter separation on the order of 100 km, weakly oblique-incidence sounding is very similar in its information capabilities to vertical-incidence sounding. Furthermore, the constraint imposed on maximum duration is removed in the case of weakly oblique sounding thus making it possible to use chirp-signals with a long baseline and to significantly improve the signal/noise ratio. It is therefore of interest to estimate the matching weakly oblique-incidence sounding data with vertical-incidence sounding (VS) data acquired by sounders, such as digisonde DPS-4.This paper presents the results derived from comparing the weakly oblique-incidence sounding data with the main vertical-incidence ionospheric parameters obtained with digital ionosonde DPS-4. The comparisons are made for the ionospheric E- and F-regions, for both quiet and disturbed ionospheric conditions. Our study reported in this paper has shown that the recorded ionospheric parameters for the ionosondes of both types are similar in their values for both quiet and disturbed days.

Keywords: ionosphere, ionosonde, ionospheric parameters

1. INTRODUCTION

Information about ionospheric parameters is provided primarily by vertical-incidence sounding ionosondes, the worldwide network of which includes over 120 stations. Ionosondes operating in the continuous mode for oblique paths are used in addition to pulsed ionosondes. Currently the Institute of Solar-Terrestrial Physics SB RAS uses two kinds of ionosondes in the analysis of the behavior of the main ionospheric parameters: the ionosonde based on using chirp-signals[1] (signals with linear frequency modulation), and pulsed ionosonde DPS-4[2].

The receiving system of the chirp-sonde is designed for receiving oblique signals in the weakly oblique sounding mode for paths of about 100 km long (an analog of vertical-incidence sounding (VS)), the oblique sounding mode, as well as in the modes of backscatter sounding and recording round-the-world signals. The facility is located in the ISTP research area near the settlement of Tory (Tunkinsky district, Republic of Buryatia) at about 100 km to the south-west of Irkutsk and forms part of the network of Russian chirp-ionosondes. The key elements of the receiving system are: the antenna-feed devices, the antenna switch, the radio receiver, the chirp-synthesizer, the device for time synchronization and referencing to universal time, and the control computer with interface boards: CFF, ADC, and timer. Currently the antenna-feed devices include three antennas: BS-2 - A=302°/122° (Moscow/Khabarovsk), BS-2 - A=55°/235° (Magadan/Alma-Ata), and VR, the vertical rhombic antenna for weakly oblique-incidence sounding.

The main operating mode is LFM1 in which the receiving system ensures the following reception parameters:

- working frequency range	1.-..35 MHz
- range of scanning rates	10.-.1000 kHz/s
- discreteness of initial frequency adjustment	10^{-6} Hz
- discreteness of scanning rate adjustment	0.001 Hz/s
- band of analysis	100, 200, 500, 1000, 2000, 4000 Hz
- number of counts from delay	512

*E-mail: grozov@iszf.irk.ru

Tenth Joint Int. Symp. on Atmospheric and Ocean Optics/Atmospheric Physics II: Laser Sensing
and Atmospheric Physics, G. G. Matvienko, G. M. Krekov, eds., Proc. of SPIE Vol. 5397
(SPIE, Bellingham, WA, 2004) · 0277-786X/04/$15 · doi: 10.1117/12.548657

- max. number of counts from sounding frequency 600

The upgrades made to the facility in 2001-2002 provides better reliability of the new equipment, an improvement of the signal/noise ratio, and a significant improvement of acquired data, including the delay and sounding frequency resolution. The improved resolution makes it possible to separate the individual echo traces, evaluate the amplitudes, and to carry out a more detailed count of delays of the signal components. An important feature is the absence of noise even in the operating range of powerful broadcasting stations.

Ionosonde DPS-4 is designed to receive signals in the vertical-incidence sounding mode; it was developed by Center for Atmospheric Research (University of Massachusetts Lowell, USA). DPS-4 consists of the main unit and the monitor; two transmit antennas; four receive antennas with polarization switches; the GPS-receiver, and standby power supply batteries. The main unit includes two computers, the transmitter, four receivers, and the signal processor. The main computer controls the reception and transmission processes, reads data from the output buffer of the signal processor, converts data to the necessary format, and stores data on the hard disk of the auxiliary computer. The auxiliary is used for postprocessing of data, stores data on the hard disk and on the CD-disk, and sends the data to the server via the FTP-server.

Ionosonde DPS-4 provides the following reception parameters:

- frequency range:	
operating	1 - 15 MHz
total	1 - 40 MHz
- frequency steps:	
operating	70 kHz
minimum	5 kHz
- number of frequency counts	- 200
number of pulses at one frequency	- 8, 16, 32, 64, 128
interval between pulses	- 0.01 s
number of measured polarizations	- 1 or 2
- number of counts in height	- 128, 256, 512
steps in height	- 2.5, 5, 10 km

2. DESCRIPTION AND ANALYSIS OF THE EXPERIMENT

Irkutsk is a typical mid-latitude ionospheric station (52.5 N, 104.3 E - geographic coordinates; 41.1 and 174.5 - magnetic coordinates of the station). The operation of two ionosonde types made it possible to compare vertical and weakly oblique-incidence sounding results in conditions of the mid-latitude ionosphere of the Eastern hemisphere. The comparison was made for the main characteristics of ionograms: F2-layer maximum (critical) frequency, foF2; E-layer maximum (critical) frequency, foE; and minimum height of reflection from the F-layer, h'F.

For verifying the data agreement degree on recorded ionospheric parameters, joint experiments were conducted in the winter and summer seasons: from 4 to 8 December 2002, and from 23 to 28 March 2003. The level of solar radiation changed little during the aforementioned period in December, while in March the observations were made at the time of a rise of the solar activity index F10.7. This is clearly seen from the variation of the F10.7 index (Fig. 1).

The observing period was characterized by a quiet and weakly disturbed geomagnetic situation.

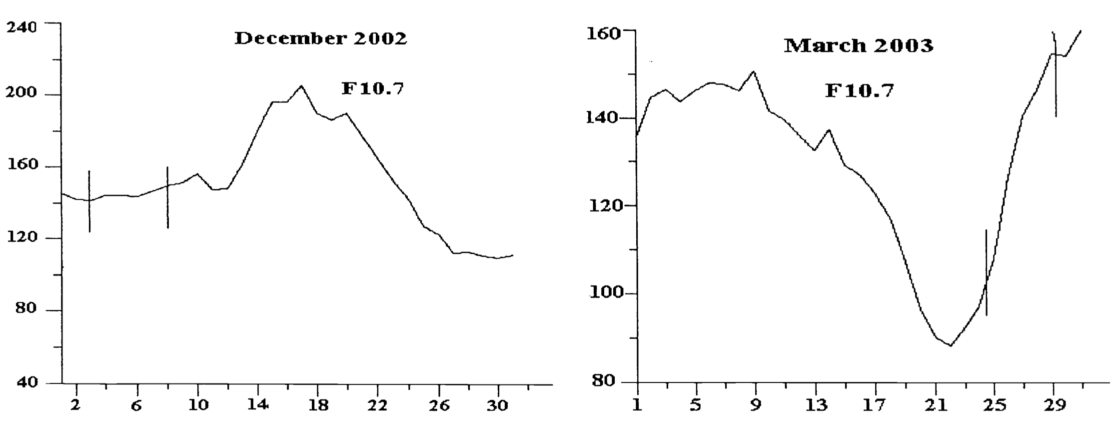


Fig. 1. F10.7 variation. a) December 2002; b) March 2003.

In December 2002, the geomagnetic conditions were quiet, with a weak geomagnetic disturbance on 7 December (total ΣKp = 25, and maximum Ap = 16). Results of FoF2 measurements from the two instruments are presented in Fig. 2a,b.

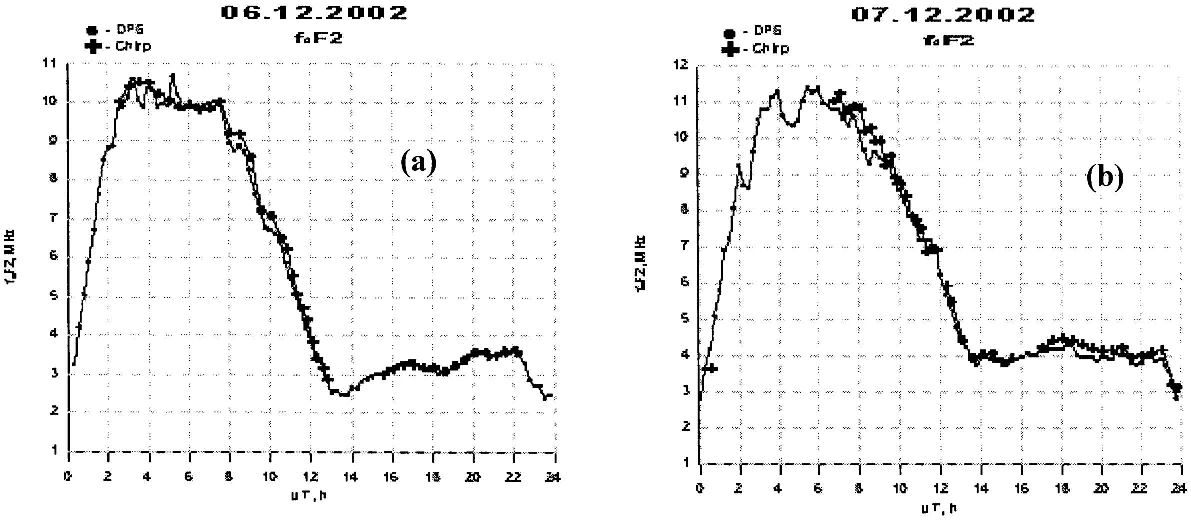


Fig. 2. Diurnal foF2 variation for 6 and 7 December 2002.

The two instruments show a good agreement with regards to the description of the foF2 parameters large-scale diurnal fluctuations and correspond to natural background variations. On the other hand, the time interval from 3 to 5 UT on 6 December exhibits pronounced differences in foF2 fast variations for the ionosondes used in the comparison (a maximum difference as high as 0.7 MHz). Such differences are caused by a number of factors: infrequent measurements with the chirp-sonde for such fast variations; spatial separation of the instruments (130 km); and uncertainties in the determination of foF2 in the presence of traveling ionospheric disturbances (TIDs). An uncertainty in determining foF2 is illustrated by Fig. 3a, showing the ionogram with split traces taken with the chirp-sonde (on 6 December at 12-05 UT). It should be noted that this splitting was absent on the DPS-4 ionogram (Fig. 3 b).

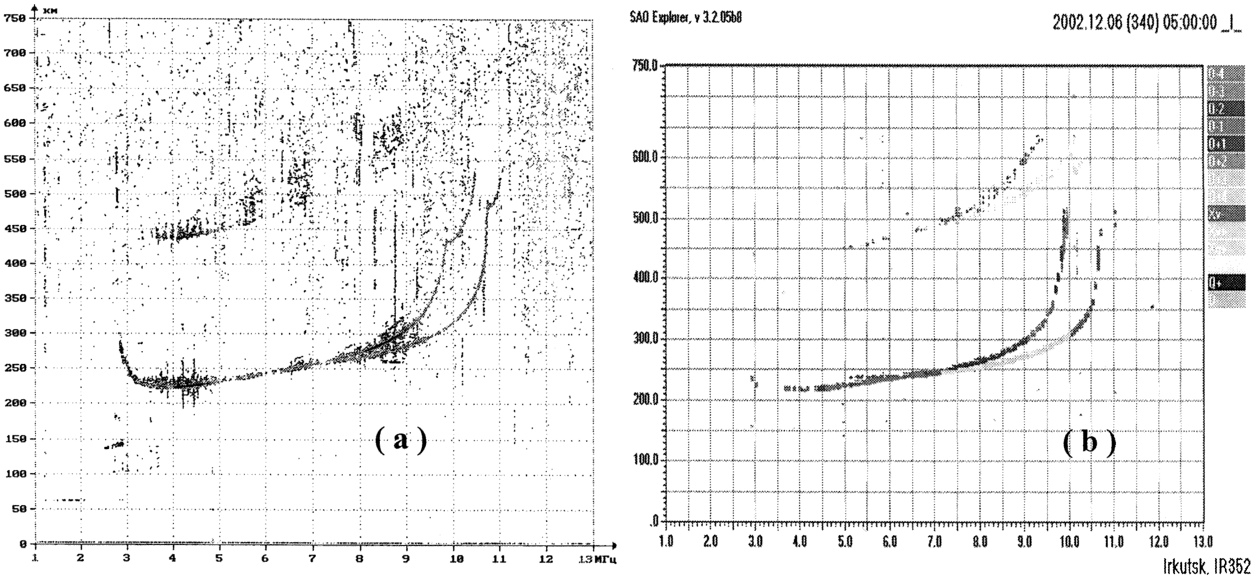


Fig. 3. Ionograms taken with the chirp-sonde (a) and with DPS-4 (b).

Interestingly, the geomagnetic situation was quieter on 6 December when compared with 7 December, although the expected result was an increase in the differences in the presence of stronger geomagnetic disturbances.

In March 2003, several magnetic storms were recorded, one of which corresponded to the interval of joint observations with the chirp-sonde and DPS-4. The diurnal variation of foF2 for 26 March (quiet day) and 27 March (disturbed day, $\Sigma Kp = 31$, $Ap = 27$) is plotted in Fig. 4a and Fig. 4b, respectively.

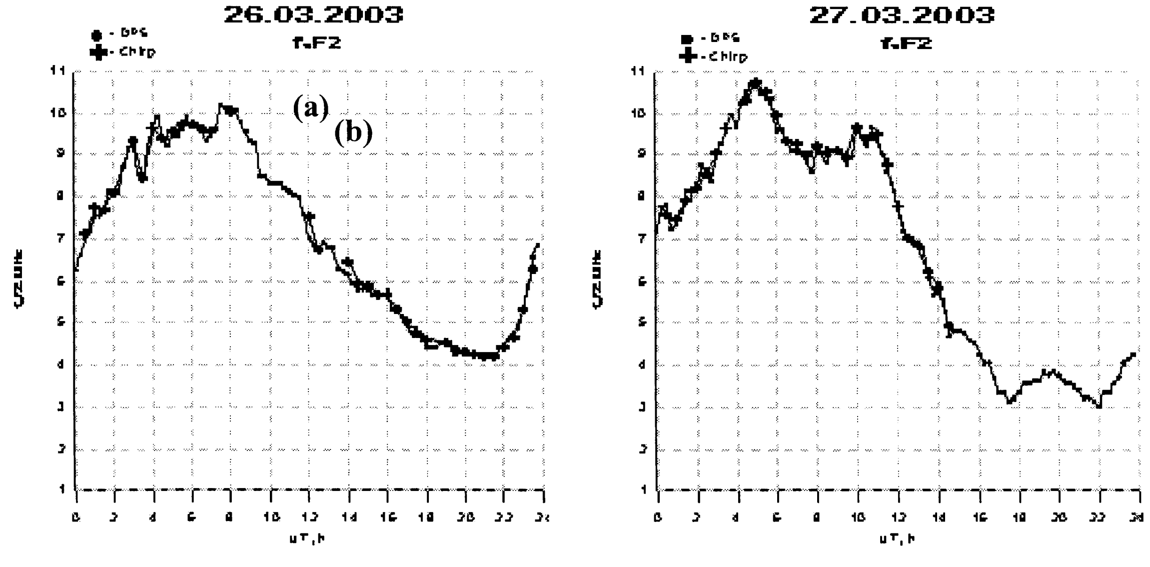
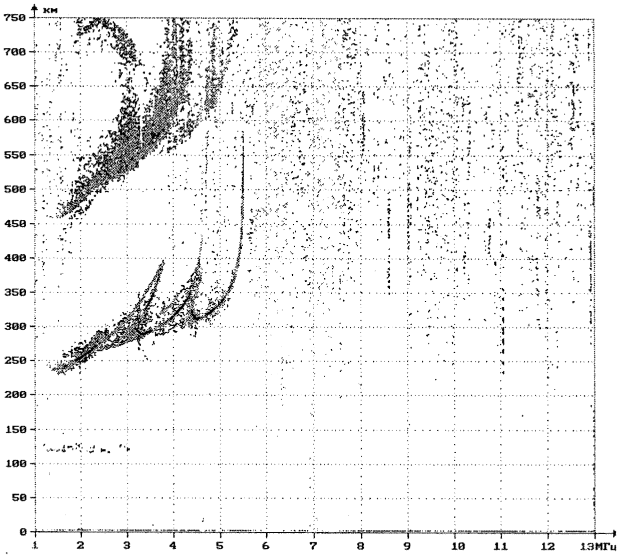


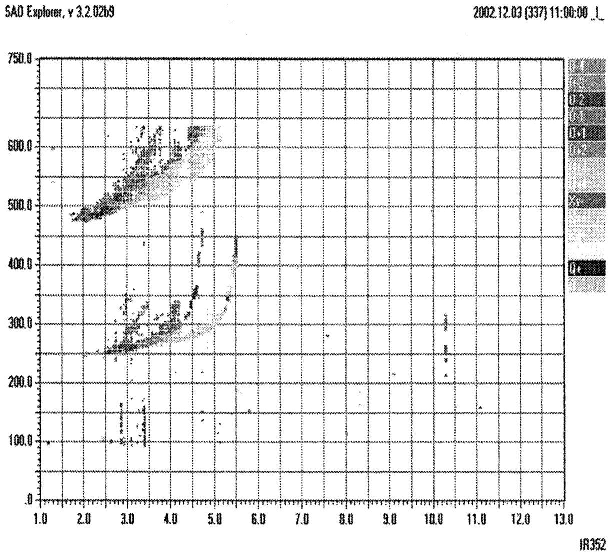
Fig. 4. Diurnal variation of foF2 for 26 and 27 March 2003.

It is evident from the figure that the maximum difference of foF2 does not exceed 0.3 MHz irrespective of the geomagnetic disturbance degree. Thus, in the case of small geomagnetic disturbances with a total Kp <= 31, no correlation was revealed between the foF2 difference degree and the geomagnetic disturbance level.

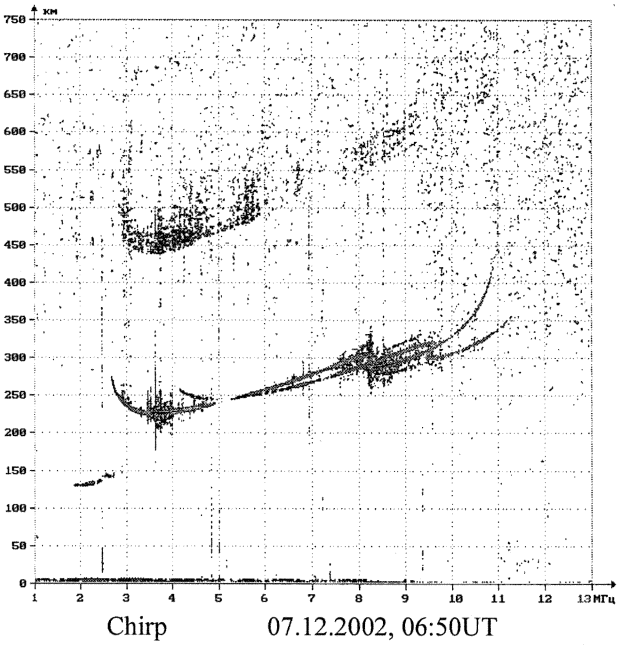
Our analysis has shown that the differences in the foF2 measurement with the two instruments can be caused by TIDs. The differences are more pronounced in the ionogram structure rather than in the diurnal variation of the parameter. This is clearly seen in Fig. 5, showing examples of ionograms: from the chirp-sonde (left), and from DPS-4 (right).



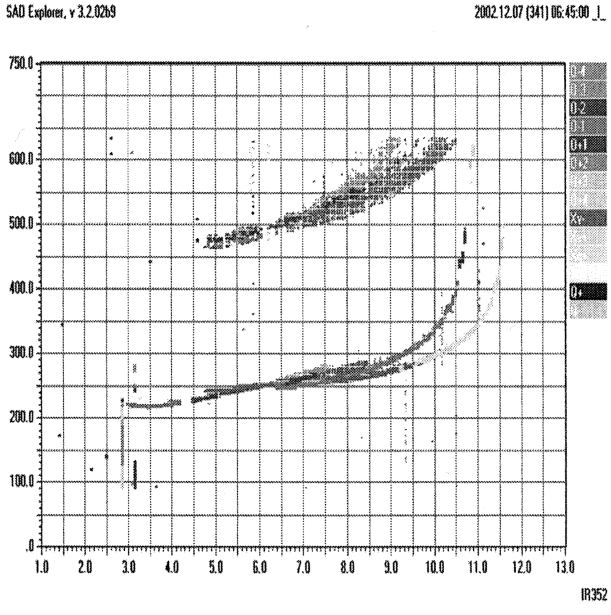
Chirp 03.12.2002, 11:05UT



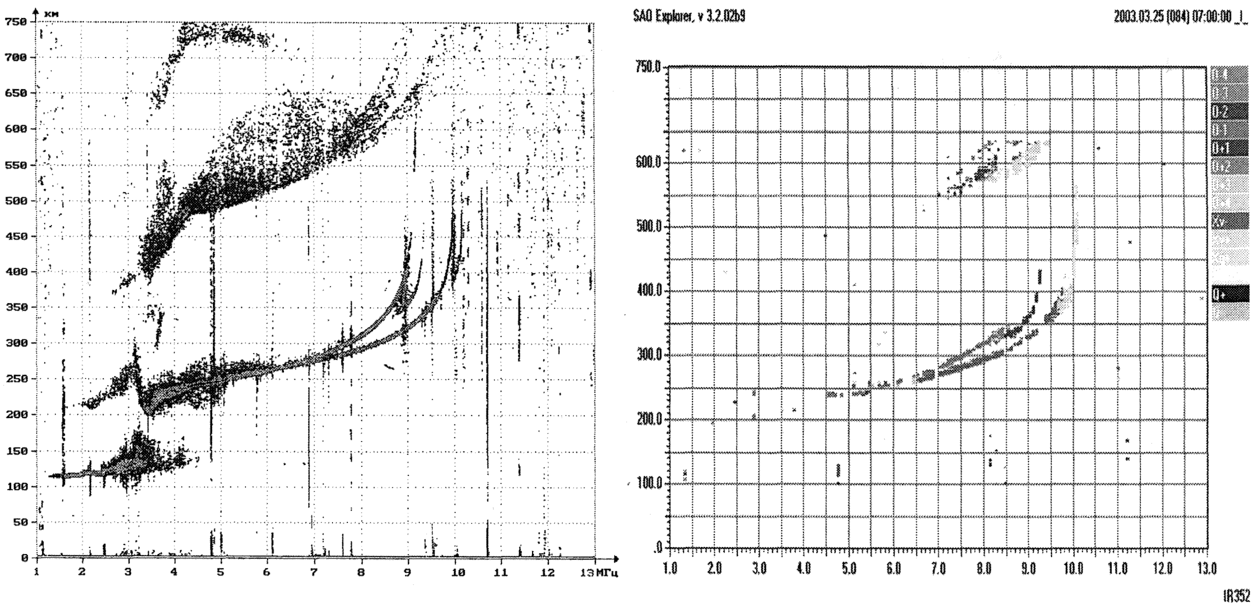
DPS-4 03.12.2002, 11:00UT



Chirp 07.12.2002, 06:50UT



DPS-4 07.12.2002, 06:45UT



Chirp 25.03.2003, 07:00UT DPS-4 25.03.2003, 07:00UT

Fig. 5. Examples of ionograms: from the chirp-sonde (left), and from DPS-4 (right).

It is evident that the fine trace structure on ionograms from the chirp-sonde is more pronounced when compared with DPS-4 ionograms.

The character of the differences in the measurement of the F-layer minimum frequency, h'F, differs from the results of foF2 comparison. The diurnal variation of h'F shows a systematic height excess obtained with the chirp-sonde when compared with the height obtained with DPS-4 (Fig. 6).

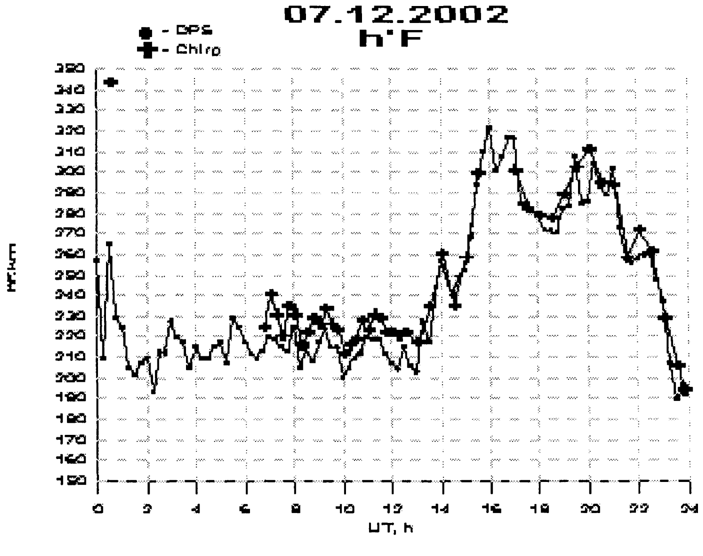


Fig. 6. Diurnal variation of h'F.

Such a difference in h'F is due to the fact that the transmitter and receiver are separated by 130 km in the chirp-sonde. Thus we have a weakly oblique path where the properties of chirp-sounding do manifest themselves. That is, the chirp-sonde measures the group path for a weakly oblique-incidence sounding. This path will be larger than h'F in the vertical-incidence sounding case. A scaling of the DPS-sounder's height-frequency characteristic (HFC) to an oblique-incidence ionogram with the range of 130 km using the method of «transfer curves»[3] shows that the HFC at D = 130 km virtually coincides with the vertical sounding HFC (Fig. 7) with the height difference about 20 km in the region of minimum frequencies of the layers.

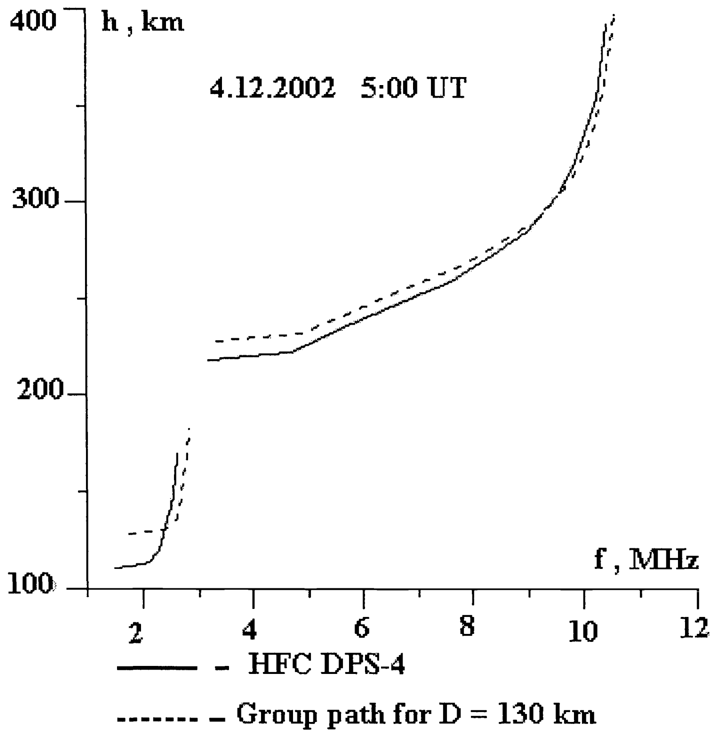


Fig. 7. Group path for D = 130 km, and HFC constructed using DPS-4 data.

Fig. 8 presents the diurnal variation of the E-layer critical frequency, foE, for 4 December obtained with the two ionosondes. It is evident that the critical frequency foE, obtained with DPS-4, is lower than that from the chirp-sonde by 0.2-0.3 MHz and can be taken into account when processing the data from the chirp-sonde. As in the case with the h'F height, the resulting differences are associated with the difference between vertical and weakly oblique-incidence soundings.

For the F2-layer, the correction for the layer critical frequency is less than 0.2 MHz and it is unimportant for the layer, because the density in the F2-layer is higher than that in the E-layer.

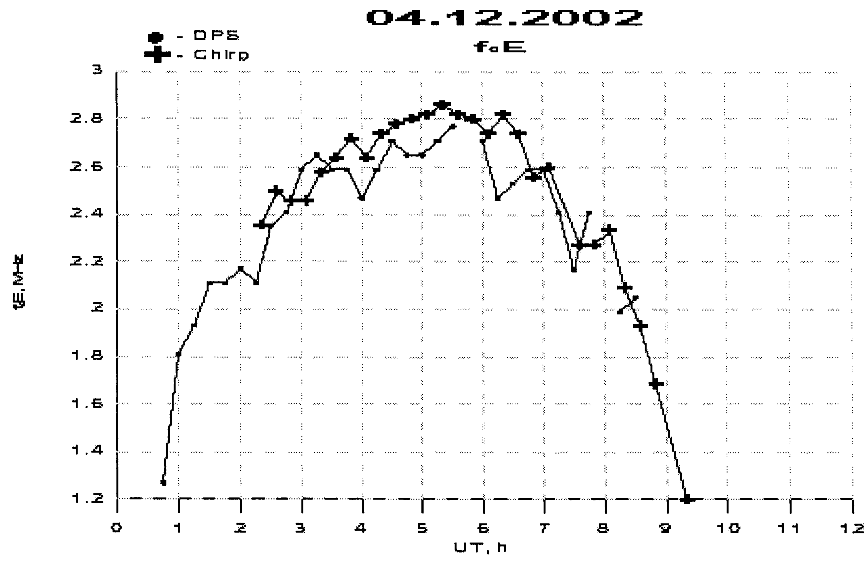


Fig. 8. Diurnal variation of foE for 4 December 2002.

3. CONCLUSION

Our study reported in this paper has shown that the recorded ionospheric parameters for the ionosondes of both types are similar in their values for both quiet and disturbed days. The differences in the E-layer maximum frequency, foE, and in the minimum height of reflection from the F-layer, h'F, are mainly determined by the difference of vertical and weakly oblique-incidence soundings. On the other hand, the differences of the F-layer critical frequency are mainly determined by the propagation of TIDs, i.e. by the character of variation of the ionosphere. Furthermore, the differences are distinguished mainly in the fine structure of ionograms. Thus the combined use of the two ionosondes is the most useful for investigating traveling ionospheric irregularities.

ACKNOWLEDGEMENTS

This work was done with support from the RFBR (grants No. 02-05-64570 and 03-05-64527) and with the use of the data from the shared data center of VSTSIIZ.

REFERENCES

1. Brynko I.G., Galkin I.A., Grozov V.P. et.al.,. "An automatically controlled data gathering and processing system using an FMCV ionosonde", *Advanced in Space Research* **8** (4), pp. 12 1- 124, 1998.
2. Reinisch, B.W., Haines, D.M., Bibl, K., Galkin, I., Huang, X., Kitrosser, D.F., Sales, G.S., and Scali, J.L., "Ionospheric sounding support of OTH radar", Radio Sci. **32**, pp. 168 1- 1694, 1997.
3. Kiyanovsky. M.P., "The computational program on a computer using the modified method of transfer curves". *In: Kiyanovsky. M.P., (Ed.), The ray Approximation and Radio Wave Propagation Questions.* Nauka, Moscows, pp. 287 – 298, 1971.