Behaviour features of ionosphere F-layer parameters in Irkutsk during the magnetic storm 29-31.10.2003

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ABSTRACT

The powerful magnetic storm 29-31.10 was superposition of two strong magnetic storms from solar flares 28.10 (X17.2) and 29.10 (X10.0). Ionosphere response to the magnetic storm in Irkutsk (52°N, 104°E) was investigated by means of a complex of radiophysical facilities of ISTP SB RAS including digisonde DPS-4, FMCW-ionosonde and incoherent scatter (IS) radar. In the work the main attention is given to the analysis of distinction in the data received on three various facilities.

Keywords: magnetic storm, ionosphere, F-layer, sounding, ionogram

1. DESCRIPTION OF TOOLS

At the end of 2002 ionospheric observatories of the ISTP SB RAS (in Irkutsk and Norilsk) were equipped by digisondes DPS-4, produced by the Lowell's Center for Atmospheric Research (The University of Massachusetts, USA). The main function of DPS-4 is to restore electronic concentration profile from vertical sounding ionograms and to measure drift speed of ionospheric irregularities on basis of Doppler and elevation measurements[1].

Ionosonde transmitting point, using signals with frequency modulated continuous wave (FMCW), is located near Usolye-Sibirskoye ~130 km to the north-west of Irkutsk, receiving point is near village Tory ~130 km to the south-west of Irkutsk. Basic characteristics of the tool are described in the works[2,3]. FMCW-ionosonde serves for oblique and return-oblique ionosphere sounding, registration of round-the-world signals, it can also be used for weak oblique sounding (transmitter in Usolye, receiver in Tory, path length is about 120 km, midpoint of the path is in ~115 km to the west of Irkutsk). Under quiet and weakly disturbed conditions the weak oblique sounding ionograms are not much different from the vertical sounding ionograms, received in Irkutsk[4].

Irkutsk IS radar is a part of the global IS radars network consisting of 9 installations, each of them is a unique scientific tool. The basic function of the radar is measurement of electronic concentration, of electronic and ionic temperatures. Detailed description of the radar can be found in the work 5.

Distinctive feature of the Irkutsk radar is the possibility to measure faraday plane-of-polarization rotation that allows carrying out absolute measurements of electronic concentration in contrast to the majority of IS radars.

Location of tools is shown in Fig.1 (the place of FMCW-ionosonde transmitter coincides with the place of IS radar). One can see from the figure, that the midpoint of the FMCW-ionosonde path is closer to IS radar coverage sector than to Irkutsk. Thus, based on geographical position, a smaller difference between FMCW-ionosonde and IS radar is expected in comparison with Irkutsk digisonde.

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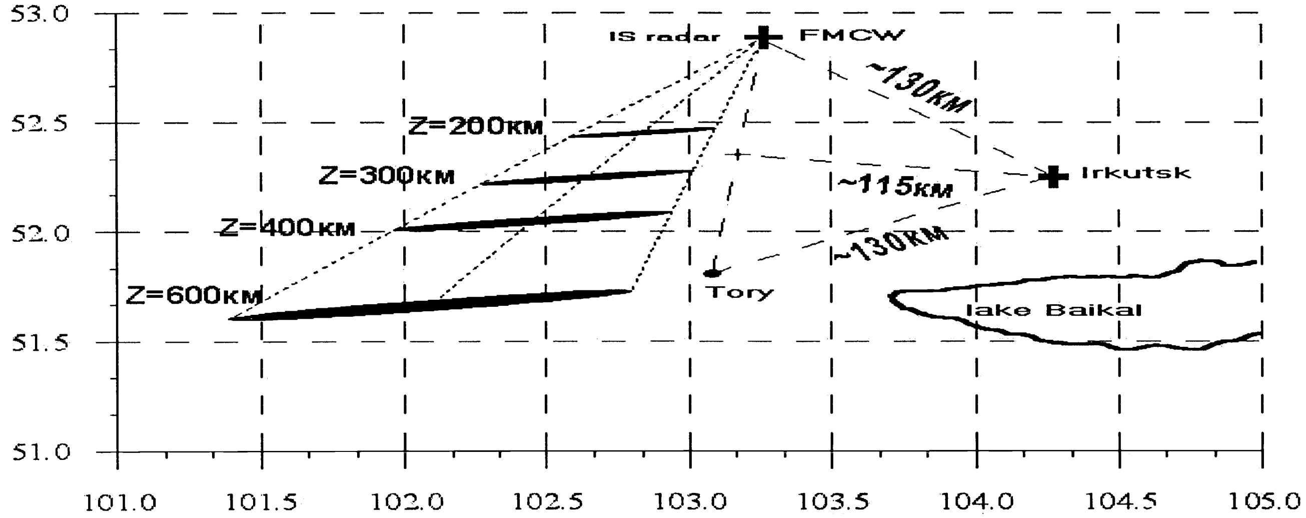

Fig.1. Geographical location of tools.

While comparing results it is necessary to take into account not only location, but also information capabilities of tools during the magnetic storm measurements. The main disadvantage of ionosondes is lack of data during strong absorption in D-region, which as a rule accompanies the main phase of a strong magnetic storm. Occurrence of an intensive sporadic layer also results in the loss of data on F-region. IS radar is insensitive to absorption in D-region and to occurrence of a sporadic layer, but has its own disadvantages. Because of reflection from local objects the minimal height of information reception makes up 150 km. The relation signal-noise deteriorates significantly at small values of electronic concentration during the main phase of a storm. Coherent echoes, frequently observed at the same time [6], introduce additional errors into measurements.

2. RESULTS OF MEASUREMENTS

Fig.2 represents Dst index variations (from the site http://swdcdb.kugi.kyoto-u.ac.jp/dstdir). As can be seen from the picture the storm 29-31.10 is superposition of two storms: the first 12UT 29.10-6UT 30.10 and the second 18UT 30.10-6UT 31.10.

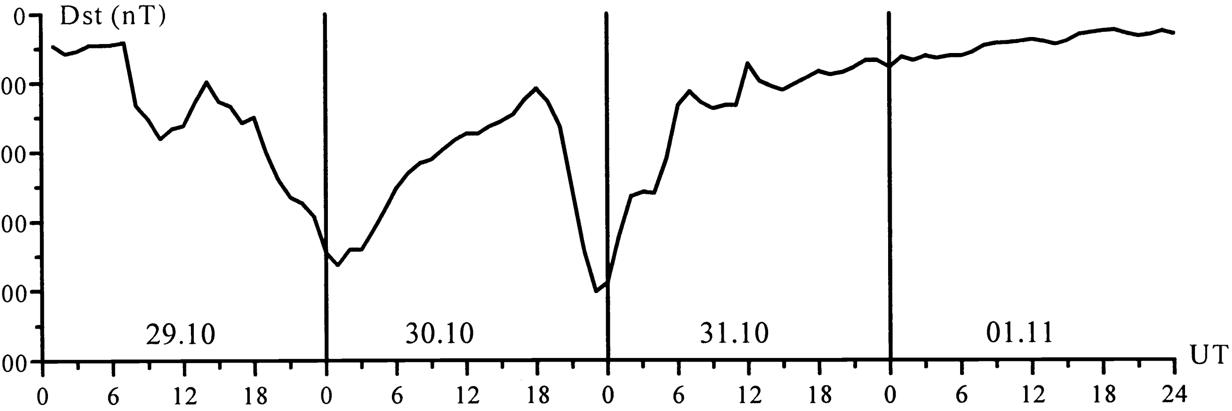

Fig.2. Dst index variations.

Fig.3 shows four-day variation of critical frequency f_0F2 and maximum height h_mF2 of electronic concentration (electronic concentration maximum received on IS radar is recalculated into critical frequency).

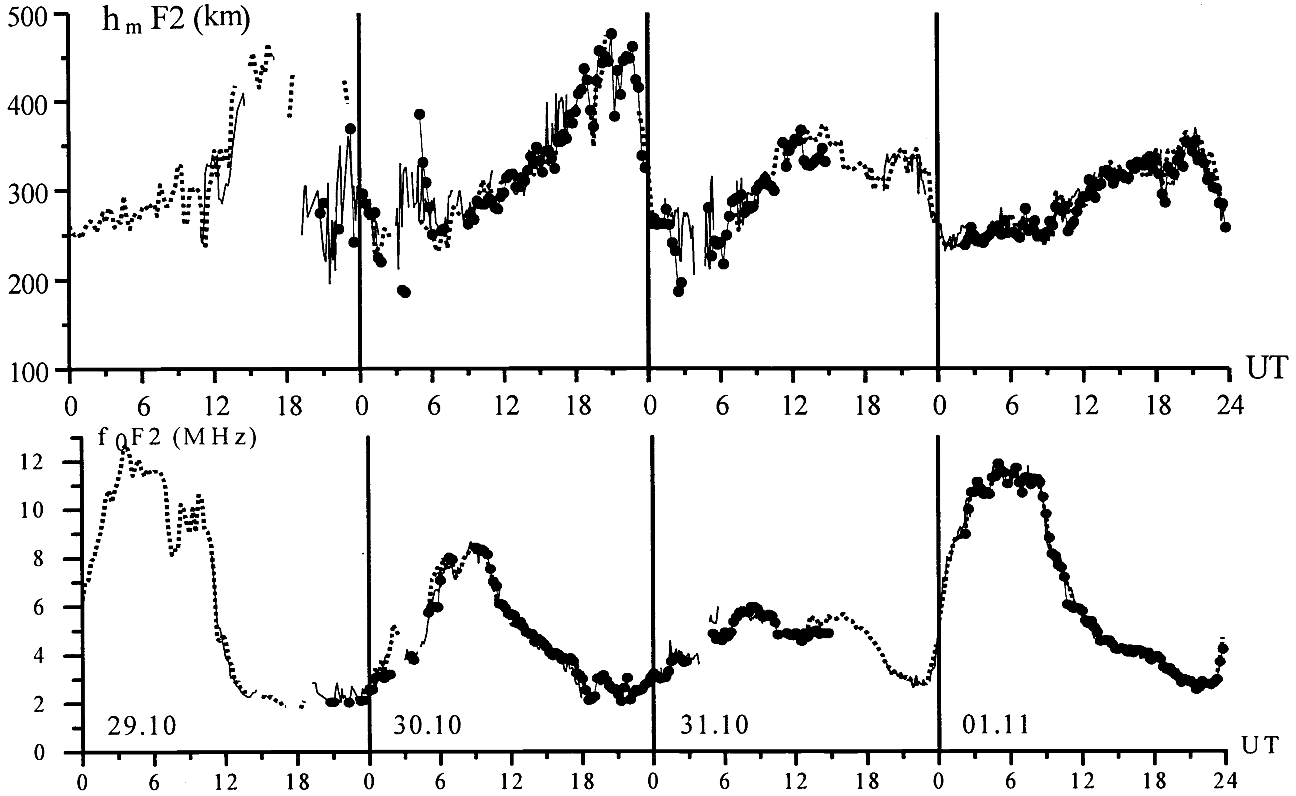

Fig.3. Dynamics of critical frequency f_0F2 and maximum height h_mF2 during magnetic storm 29.10-01.11.2003.

Digisonde DPS-4 data are represented by a dashed line, FMCW-ionosonde data are shown by a line with circles, and IS radar data are denoted by a thin solid line. As indicated in the figure, for all tools there are intervals of null data. Digisonde data are lacking because of the absorption, FMCW-ionosonde data are lacking because of late engaging (29.10, 20:45UT), absorption and technical reasons, IS radar data are lacking because of late engaging (29.10, 10:45UT), technical reasons and powerful coherent echoes, leading to large errors of electronic concentration profile measurement. As a result, full data set was received on 30.10 (1-2 and 5-18UT), 31.10 (7-9UT) and on 01.11. The least distinctions in the data are observed on the quiet day 01.11 and during the period between storms on 30.10 (9-15UT). The greatest differences are registered during recovery phase of the first storm 30.10 (5-6UT), this case will be considered in more detail below.

Analyzing the data on the whole, it should be noted, that differences in maximum height are much more noticeable than differences in critical frequency. These differences become apparent as fast noise-like variations of maximum heights received on IS radar. Intervals of such variations are observed in the main phase of the first storm 29.10 (19-23UT), at restoration phase of the first storm 30.10 (3-6UT), at initial stage of the second storm 30.10 (15-18UT) and at restoration phase of the second storm 31.10 (1-5UT). Possible reason of these variations is residual interaction of coherent echoes. Good agreement between digisonde and IS radar data is observed at initial stage of the first storm 29.10 (11-15UT), as well as between digisonde and FMCW-ionosonde data in the main phase of the second storm 30.10 (18-21UT).

From the point of view of data comparison, the period of phase restoration of the first storm is of interest when the strongest differences in critical frequency between three tools were observed. Fig.4 shows variations f_0F2 and h_mF2 at interval from 0 till 10UT 30.10, designations of curves are the same as in Fig. 3 (digisonde — dashed line, FMCW-ionosonde — line with circles, IS radar — thin solid line).

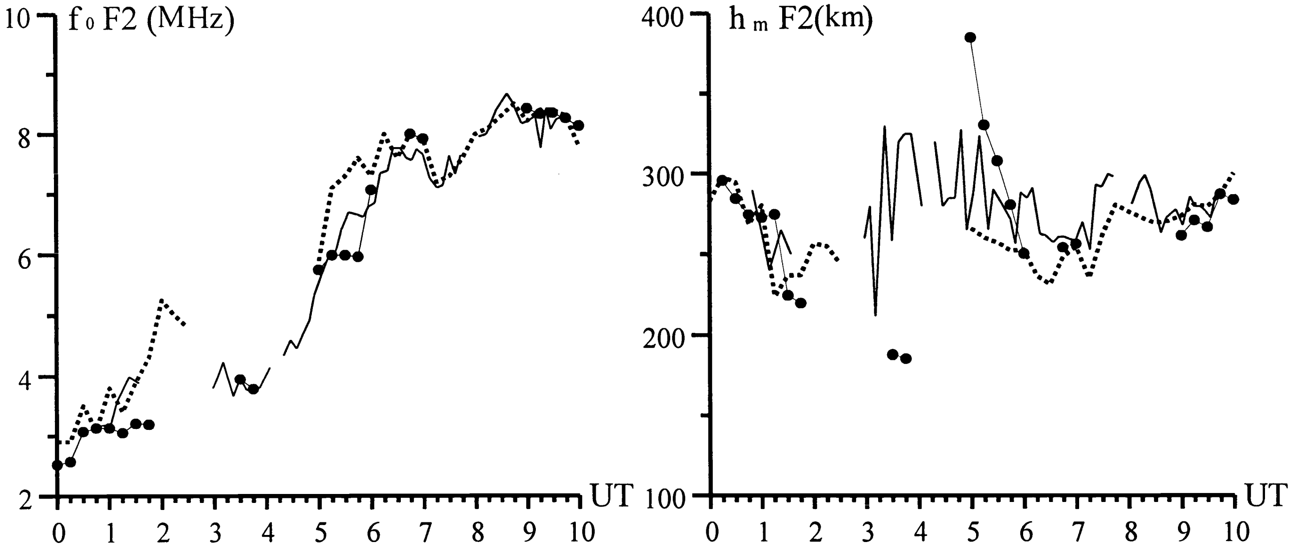

Fig.4. Dynamics of f_0F2 and h_mF2 during 30.10.2003 from 0 till 10UT.

The restoration phase of storm is characterized by no monotonic growth of critical frequency with local maximum about 2UT (according to digisonde data) and local minimum about 4UT (according to FMCW-ionosonde and radar IS data). Monotonous growth of critical frequency begins from 4UT (according to HP radar data). The data of both ionosondes appear from 5UT, in this connection digisonde growth dynamics f_0F2 significantly differs from FMCW-ionosonde dynamics. Starting with 6UT, the tools give close values, and after 9UT practically full data agreement begins. It could be observed, that from 5 till 6UT the least distinctions in FMCW-ionosonde and IS radar data are recorded in the group of three tools. Such character of distinction can be explained by different geographical position of tools (see Fig.1), if one assumes presence of very strong gradients of electronic concentration in the east-west direction. Based on the difference in critical frequency ~1.5 MHz, the gradient of electronic concentration should make up $\sim 2 \cdot 10^5$ cm^{-3} for 100 km. On the interval 5-6UT distinctions become apparent not only in critical frequency, but also in maximum height of electronic concentration. A height values received on FMCW-ionosonde exceed digisonde values significantly, and IS radar data have intermediate values.

Fig.5 represents electronic concentration profiles $N_e(z)$, built according to three tools data (digisonde — dashed line, FMCW-ionosonde — line with circles, IS radar — thin solid line). Comparison of electronic concentration profiles shows, that at 05:00, 05:15, 05:30, 05:45UT three tools give strongly differing results, at 06:00 the results are rather close, at 06:45 digisonde and FMCW-ionosonde profiles practically coincide. At 05:15 and 05:30 IS radar and FMCW-ionosonde show close values of maximal electronic concentration, but N_e values at height ~250 km differ on $\sim 2 \cdot 10^5$ cm^{-3}, the difference between digisonde and IS radar data makes up approximately the same value.

The fact, that all three tools give different electronic concentration profiles, is impossible to explain only by gradients in the east-west direction. Most likely, the non-uniform ionosphere structure had a cloudy character with complex high-altitude dependence. It is possible, that in such complex environment none of the tools gives "true" high-altitude electronic concentration profile. FMCW-ionosonde signal propagation trajectory can deviate from the great circle arc significantly. Occurrence of multi path effect is possible. Powerful lateral reflections can appear along with vertical reflections at vertical sounding. IS radar data are strongly affected by different position of the main directional lobes at different heights (Fig.1) and rather big width (~100 km) of lobes in the east-west direction. In order to estimate characteristics of the non-uniform ionosphere structure it is necessary to perform a rather complex modeling taking into account the above mentioned factors; now we can restrict ourselves only to estimation of maximal value gradient of electronic concentration of the order of $2 \cdot 10^5$ cm^{-3} for 100 km.

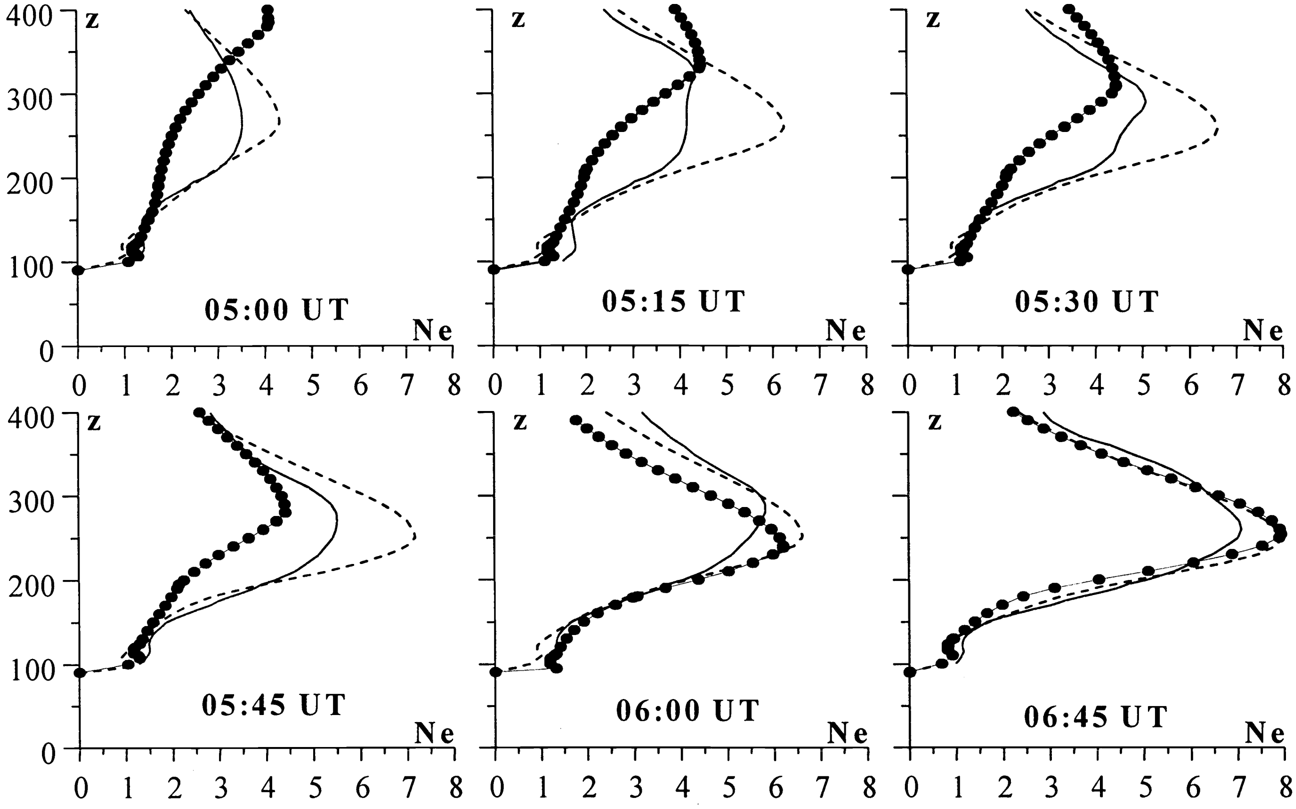

Fig.5. Electronic concentration profiles $N_e(z)$ ($10^{-5} \cdot$ el/cm^3) 30.10.2003.

Fig.6 represents ionograms, received on digisondee and FMCW-ionosonde at 05:00, 05:30 and 06:00UT. If at 06:00UT ionograms are rather close, then at 05:00 and 05:30UT completely different pictures are observed. F1-layer traces observed on FMCW-ionosonde ionograms are not visible on digisonde ionograms and distinctions in h'F2 make up 250 and 200 km for 5:00 and 5:30UT respectively. It is possible, that the more complex FMCW-ionosonde trace results from trajectories realizable at weak oblique propagation and unrealizable at vertical propagation. However, in order to check this hypothesis realization of modeling calculations in ionosphere with complex non-uniform structure is necessary. It should be noted, that observation of the strongest distinctions between three tools from 5 till 6UT 30.10 does not suggest that the presence of complex non-uniform ionosphere structure was typical only of this time interval. It is quite possible, that other cases of strong divergences were not registered because of lack of ionosonde data owing to strong absorption.

3. CONCLUSIONS

The results of research of ionospheric response to superposition of two magnetic storms on the basis of simultaneous measurements on digisonde DPS-4, FMCW-ionosondee and IS radar look as follows. Under quiet conditions (quiet day on 01.11 and between storms on 30.10) all three tools give close results. Digisonde and IS radar data are in good agreement at the initial phase of the first storm; the same holds for digisonde and FMCW-ionosonde data at the main stage of the second storm. The greatest differences are observed at the restoration phase of the first storm. The observed differences are due to strongly developed non-uniform ionosphere structure and to different geographical position of the tools. The estimation of gradient of the maximal value of electronic concentration in the east-west direction makes up value of the order $2 \cdot 10^5$ cm^{-3} for 100 km. To get more detailed estimation of non-uniform structure characteristics the creation of a modeling complex is necessary, taking into account the complex character of radio wave propagation in non-uniform ionosphere.

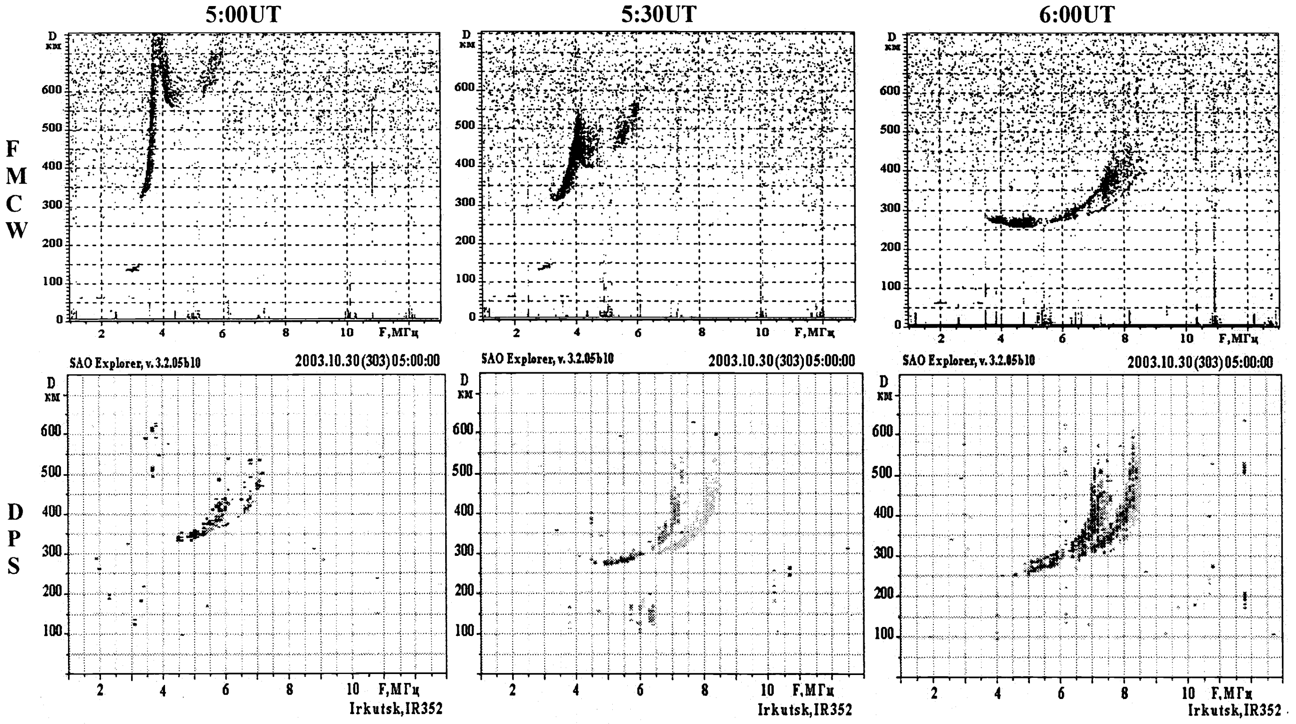

Fig.6. Digisonde DPS-4 (top) and FMCW-ionosonde (bottom) ionograms.

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