Study of Ionosphere with the help of Incoherent Scatter Radar during the Magnetic Storm

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Abstract

Specific features of the variations and structure of the ionosphere above northern Europe during the known magnetospheric storm of January 10, 1997, have been analyzed using the oblique-incidence backscatter (OIB) methods. The OIB equipment installed near St. Petersburg, Gor'kovskaya, represent a BIZON small radar, the data of which were compared with the CUTLASS radar data, GPS observations of TEC, and geophysical data of the Sweden, Finnish, and Russian high-latitude observatories. A local substorm that occurred from 14:51 to 16:55 UT has been studied in detail. The types of reflections from the MIT polar wall and the narrow ionization trough have been identified.

1. Introduction

The aim of the present work is to study the specific behavior of the subauroral ionosphere and its parameters during the well-known magnetospheric storm of January 6–11, 1997, which have been extensively analyzed within the scope of different programs [1, 3, 5, 8], using the oblique-incidence backscatter (OIB) equipment. The main problem is to correctly identify OIB ionograms, i.e., to soundly compare traces on ionograms to specific physical processes or phenomena: the main ionospheric trough (MIT), diffuse precipitation boundary (DPB) that forms the trough poleward wall (TPW), narrow ionization trough (NIT) and ring ionospheric trough (RIT) that originate during substorms or storms, diffuse luminosity boundary (DLB) located south of the equatorward boundary of the auroral oval, convective removal of increased-density plasma from the dayside cusp, etc.

2. Description of the experiment

The BIZON OIB equipment, represents a two-channel version of the digital ionosonde for vertical and oblique-incidence sounding of the ionosphere [10]. This instrument operates like a radar and makes it possible to simultaneously determine frequency of a signal reflected from the ionosphere, height of the reflecting ionospheric layer, amplitude and phase of a reflected signal, Doppler frequency shift and spectrum, and wave polarization. The frequency band is 1– 30 MHz. The BIZON ionosonde has been installed at Gor'kovskaya observatory. The receiving and transmitting antennas are oriented toward the north. A wide spectrum of geophysical data from a number of Sweden, Finnish, and Russian observatories (Fig. 1) located in the assumed region of signal backscatter by the BIZON radar were used to describe this disturbance. It was interesting to compare the BIZON OIB data with the data of another radar, CUTLASS, which research instrument represents the HF double radar with two receiving–transmitting centers [9]. CUTLASS antenna patterns cover almost the entire region of BIZON radar sounding. Figure 2 presents its data for January 10, 1997. The panel "a" illustrates the intensity of the energy backscattered from ionospheric irregularities that were formed during the storm. An intense signal scatted by sporadic layers (*Es*) always exists at latitudes of 64°–66°. Scattering from the ionospheric *F* region and from the Earth's surface through the *F* region takes place at latitudes of 70°–75°. The panel "b" illustrates the character of velocities of ionospheric irregularities. It changes insignificantly at latitudes of 64°–66°, and the latitude range 70°–75° is characterized by predominant scattering from the Earth through the ionospheric *F* region. The panel "c" indicates the variations in the signal spectrum width. It characterizes the intensity of irregularities. The measurements of the total electron content during reception of GPS signals [1, 8] were used to monitor the structure and dynamics of the ionosphere.

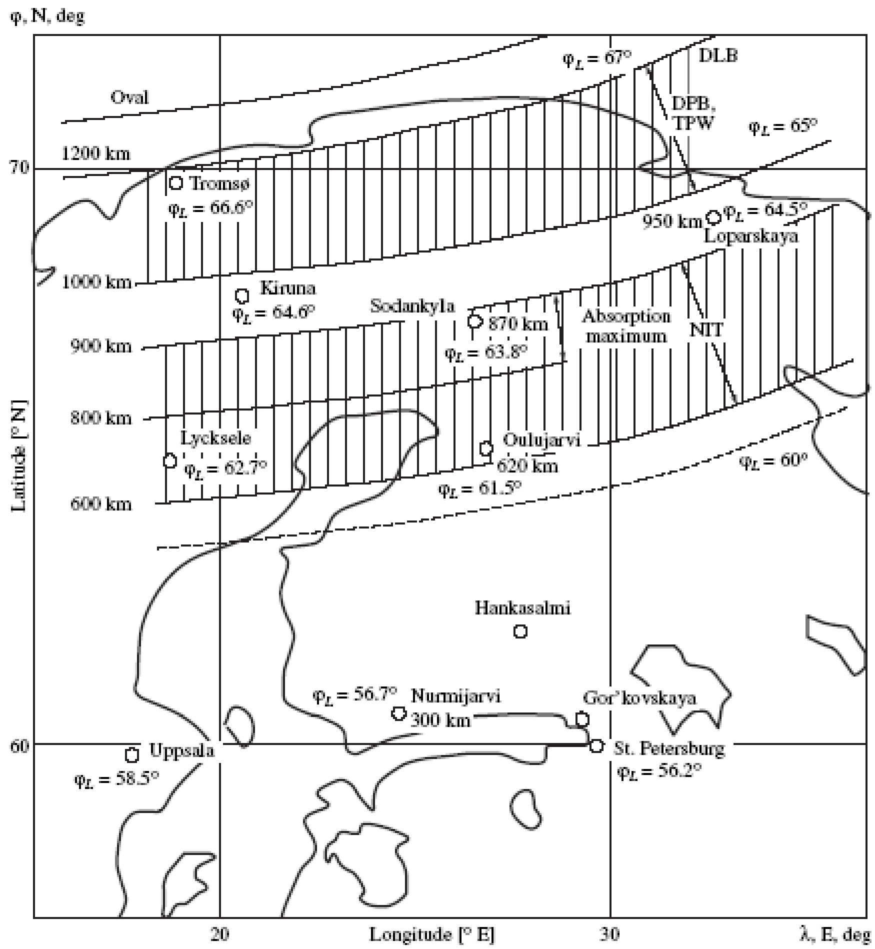

Fig. 1. The scheme of the large-scale ionospheric structure irradiated by the OIB (BIZON) equipment.

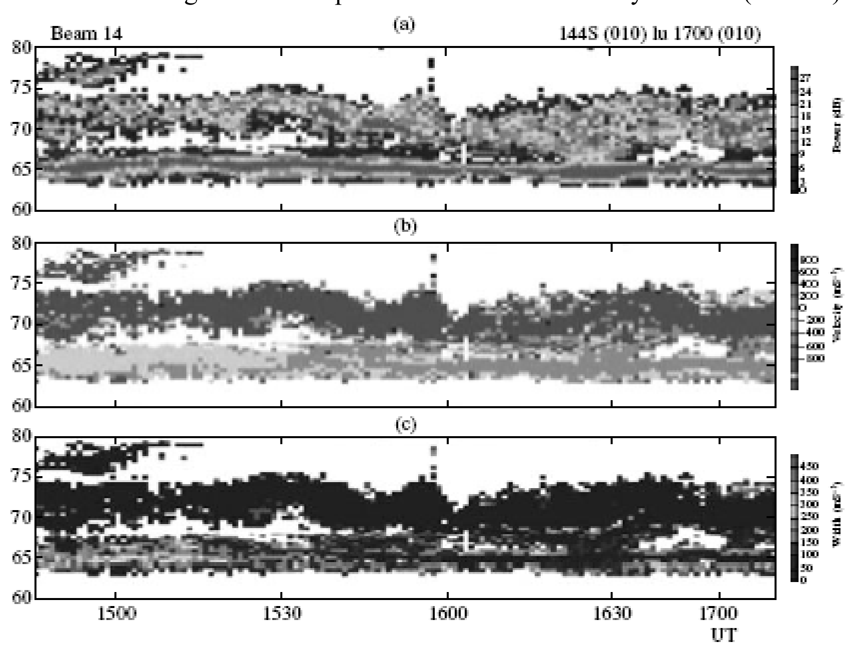

Fig. 2. Data of the CUTLASS radar backscatter during the magnetic storm of January 10, 1997: (a) energy, (b) velocity, (c) spectrum width [11].

3. Discussion

Reflection traces on ionograms should be interpreted based on a complex approach: geophysical data, accumulated experimental materials, data of satellites and other radars, etc. should be taken into account.

1) Ionospheric backscatter in the *F* region is caused by irregularities (blobs) extended along the magnetic field lines, which are generated due to particle precipitation and exist for several minutes and more. Immediate backscatter from such blobs can be realized when an incident radio beam is perpendicular to the magnetic field. In this case the zones of radio backscatter and reflection are considered coincident in the *F* region. Immediate backscatter is also possible from the *F* region at distances independent of frequency. Traces of reflections dude to slant *F* and scatter from the Earth are observed on OIB ionograms in addition to the above traces. Slant *F* correlates well with spread *F*, and the assumption exists that these are two identical phenomena [2]. The similarity between slant *F* and backscatter from the Earth consists in that the inclination of any trace can be used to determine the layer altitude and critical frequency. TPW generates critical reflections in the form of inclined traces with magnetoionic splitting and simultaneous presence of spread *F*. Scattering by TPW ionization irregularities and radio reflection occur from the region where plasma frequency is equal to incident wave frequency. The critical frequencies of extraordinary (f_x) and ordinary (f_o) waves found from the experimental data make it possible to determine the plasma frequency (f_N) [4]:

$$f_x^2 - f_o^2 \approx \frac{f_N^2}{1-(f_N/f_x)^2} \tag{1}$$

Subsequently, the electron density value can be found from the formula

$$Ne = 1.24 \cdot 10^{10} f_N^2 \tag{2}$$

NIT, which is located near TPW and is often observed in the evening during a substorm, has steep gradients of electron density. Therefore, the reflection pattern similar to TPW can be anticipated in this case.

2) In the ionospheric *E* region, precipitating particles and secondary electrons form horizontally oriented clouds or layers with increased electron density. Irregularities extended along the magnetic field (auroral *E*-blobs) are constantly observed here as well as in the *F* region. Ionization of these blobs can reach ionization densities considerably exceeding Ne = 10^6 cm^{-3} [7]. The following traces of reflections are possible on OIB ionograms: immediate *E*-backscatter, slant *E*, and backscatter from the Earth through slant *E*. The latter trace is encountered comparatively rarely. Slant *E* reflection can is intensified during disturbances. Reflections from individual discrete auroral arcs are sometimes observed during substorms. They have the shape of multistage direct traces without a group delay at limiting frequencies [10]. In this case the pattern of radio reflections substantially changes for 1 min. Radio scattering by ionospheric irregularities, originating at gradients of auroral arc drift velocities, is observed here.

3) Thus, it seems possible to distinguish three main types of reflection traces on OIB ionograms:

- traces with a smooth increase in distance with increasing sounding frequency: slant *F*, slant *E*, backscatter from the Earth through the *F* region or slant *F*, and backscatter from the Earth through slant *E*;
- flat reflections: immediate scattering from the *F* and *E* regions and reflection from auroras;
- traces with a group delay: on the polar wall of MIT and NIT and immediate scattering from the *F* region with a mode structure.

Fifty two OIB ionograms, which were divided into six groups so that the ionograms would be of an identical character within each group, were obtained during the studied period from 14:50 to 16:55 UT. Let us consider reflection traces on real ionograms representing each group (Fig. 3).

(i) flat reflections due to scattering from the *F* region at a distance of 1200km, most likely from DPB or TPW;

(ii) reflections with a smooth increase in the distance with increasing frequency for 800–1000 km, most probable from NIT or sporadic *Esr* in the region of Sodankyla;

(iii) reflections with a group delay from DPB or TPW at a distance of 1100km and from NIT at *D* =800km;

(iv) flat reflections due to immediate scattering from the *E* region (*D* = 100–500 km);

(v) flat reflections from auroral at distances of 1200–2000 km;

(vi) reflections with a smooth increase in the distance for backscatter from the Earth by means of the *F* region.

4. Conclusion

The local substorm that occurred during the well-known magnetic storm of January 10, 1997, was studied with the help of BIZON OIB equipment. The obtained ionograms were divided into groups proceeding from the physics of the observed phenomena. Possible types of reflections from ionospheric structures were revealed

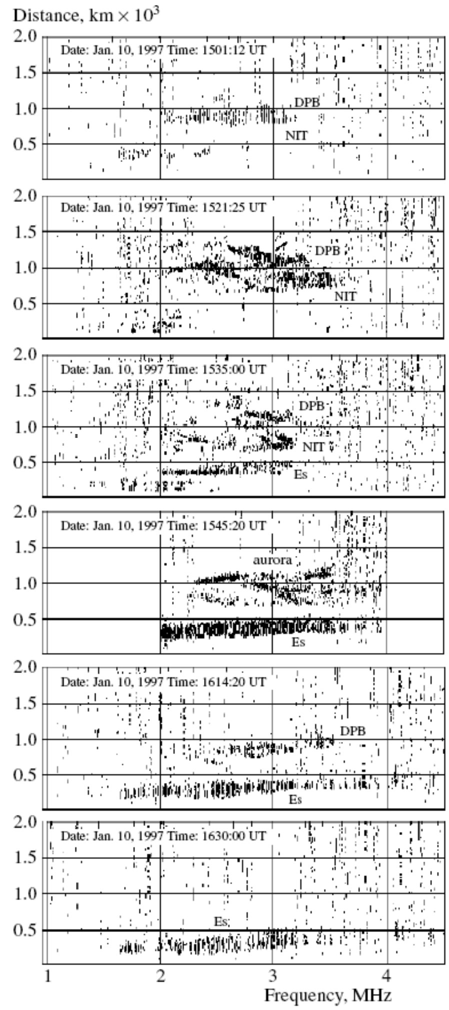

Fig. 3. Real BIZON OIB ionograms. Each ionogram is typical of one of six groups composing all 52 ionograms.

5. References

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