INVESTIGATION OF SPACE WEATHER EFFECTS

USING THE RUSSIAN CHIRP SOUNDERS NETWORK

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ABSTRACT

This report presents experimental data derived from comparing the HF signal characteristics from different paths of the Russian chirp sounders network for the period from 1989 to 2000. This makes it possible to investigate the influence of high-latitude ionospheric irregularities on signal characteristics along paths in the Asian longitudinal sector as well as to study the response of the mid-latitude ionosphere on geomagnetic storms and substorms. Nowcasting and forecasting techniques for maximum usable frequencies using current chirp-sounding data are discussed. Through the use of current chirp-sounding data it becomes possible to make forecasting with an error of a few percent.

INTRODUCTION

The most powerful disturbances of solar emission (coronal mass ejection, and solar flares) lead to a complicated set of phenomena in the solar wind, the interplanetary magnetic field, and the earth's magnetosphere, ionosphere and neutral atmosphere. The mechanism of solar-terrestrial connections is still poorly understood and is a matter for extensive scientific inquire to date. It is known, however, that the time-variable conditions in space enviroment that are associated with particular solar events have a substantial effect on the HF propagation. For that reason, the practice strongly dictates the need for reliable prediction of the influence of ionospheric disturbances on the HF propagation. With the mean error of long-term predictions of maximum usable frequencies (MUF) of ~20%, the deviations of daily MUF values from the median can far exceed this value. In the case of strong disturbances, especially in high latitudes, radio communication in the HF band can become unfeasible altogether. On the other hand, analysis experimental oblique-incidence sounding (OIS) ionograms from a network of radio paths can serve as a powerful tool for studying the properties of manifestation of space weather depending on solar activity, the season, and on the geographical location of the region. The goal of this report is to summarize the observations of the properties of the HF propagation along the paths of the Russian chirp sounders network for a long period of time.

EXPERIMENT

The structure of the Russian chirp sounders network has been evolving since the end of the 1980s when radio paths were set up in the European and north-east parts of this country which were then combined into a single network. Regular observations have been carried out along oblique-incidence sounding paths with an extent from 220 km to 5700 km over the territory of Russia, as well as along round-the-world paths. Currently there are transmitters in operation at Magadan, Khabarovsk, Irkutsk, and Yoshkar-Ola, as well as receivers at Irkutsk, Yoshkar-Ola, Nizhny Novgorod, and Moscow. Sounding operations are conducted in the frequency band 4-30 MHz. The frequency switching rate was 100 kHz/s. The transmitters were operated on a round-the-clock basis at 15-min intervals. This report presents the experimental data derived from comparing HF signal characteristics for different paths of the Russian chirp sounders network under quiet and disturbed conditions for the period from 1989 to 2000.

The location of the Russian chirp sounders network provides a means of investigating the influence of high-latitude ionospheric irregularities on signal characteristics for radio paths in the Asian longitudinal sector, as well as studying the response of the mid-latitude ionosphere to geomagnetic storms and substorms. In the East-Asian sector the geographic latitudes are in greatest excess of the magnetic latitudes. As a consequence, elements of the large-scale structure, such as the main ionospheric trough, and the zone of auroral ionization, are produced at the background of a low electron ionization. Therefore, a detailed investigation of the manifestation of geomagnetic storms in the ionosphere of this region, as well as the properties of the HF propagation through a disturbed ionosphere is of certain interest. Subauroral (Magadan - Nizhny Novgorod, Magadan - Yoshkar-Ola) and mid-latitude (Magadan-Irkutsk, Irkutsk - Yoshkar-Ola, Khabarovsk - Yoshkar-Ola, Khabarovsk - Nizhny Novgorod) chirp-sounding paths run, respectively, near the northward and southward walls of the main ionospheric trough. This make sit possible to investigate the dynamics of the trough's boundaries under different geophysical conditions and assess the influence of ionization gradients and small-scale turbulence on HF signal characteristics.

Strong geomagnetic disturbances with Kp-index exceeded 5 and with the Dst-index less than -65 units occurred at the time of conducting fifteen experiments. In seven of them, the Kp-index exceeded 7 units, and the values of the Dst-index were less than -100 units. Analysis of the HF propagation in the above experiments received special attention. Additionally, data from a network of vertical-incidence sounding stations, and also data from the Irkutsk incoherent scatter radar and GPS satellites were used.

DISCUSSION

In subauroral and mid-latitudes, the main processes that are responsible for ionospheric disturbances, are believed to include the interaction of ionospheric plasma with equatorward propagating disturbances of the thermospheric wind and neutral atmospheric composition, as well as the expansion effects (toward low latitudes) of areas of energetic electron precipitation and magnetospheric convection [1]. These processes act to displace the boundaries of the main ionospheric trough and to change the ionospheric and thermospheric composition. As a result, the subauroral and mid-latitudes of the north-eastern part of Russia are characterized by long-lasting negative disturbances of ionospheric electron density during the geomagnetic storm development and recovery phases, and a positive disturbance in the evening sector before the negative storm phase. Strong changes of the boundaries of large-scale structures lead to substantial changes in the HF radio wave propagation. There occur strong deviations (by as much as 50-70%) from median values of maximum usable frequencies. As an illustration, Fig. 1a plots the time dependence of the maximum observable frequency for the Magadan - Irkutsk path for quiet and disturbed conditions of October 18 and 19, 1995.
Fig. 1b shows the variation of the index of magnetic disturbance, Kp. It is evident that the magnetic storm in the night-time led to a large negative ionospheric disturbance: the daytime peak of maximum observable oblique-incidence sounding frequencies for the Magadan - Irkutsk path is very poorly pronounced when compared with undisturbed conditions. An analysis of the satellite data from the OVATION project (http://sd-www.jhuapl.edu/Aurora/ovation/ovation_display.html), which were kindly supplied to us for scientific research, showed that the equatorial boundary of the auroral oval during the geomagnetic storm reached 55 degrees N. Furthermore, the Magadan - Irkutsk oblique-incidence sounding path passed though the main ionospheric trough, which explains the extremely low maximum observable frequencies.

The occurrence of sporadic layers of the auroral type and of different-scale irregularities lead to a change in oblique-incidence sounding ionograms and give rise to additional signals scattered from auroral ionospheric irregularities. And signals that are scattered from irregularities, are recorded over a wide frequency range and for long time intervals. Usually, maximum observable frequencies of these signals far exceed the MUF of regular propagation modes along this path in the concerned time interval. As an illustration, Fig.2 presents a typical ionogram, showing signals propagating along the great circle arc in one and two hops (1F2, and 2F2), as well as an additional signal scattered from auroral irregularities. The structure of the scattered signal is quite varied, and its delay with respect to the main propagation modes varies from 100 to 1000 km. This suggests that different formation signal for the scattered signal are at work, and this can be used in future diagnostics of ionospheric irregularities generated during geomagnetic disturbances.

Oblique-incidence sounding and backscatter ionograms represent the occurrence of a so-called "dusk"-effect which is observed in the evening hours of local time and show up as a rapid increase in ionospheric electron density at the beginning of the main phase of the storm, followed by its abrupt decrease. The input of a large amount of energy

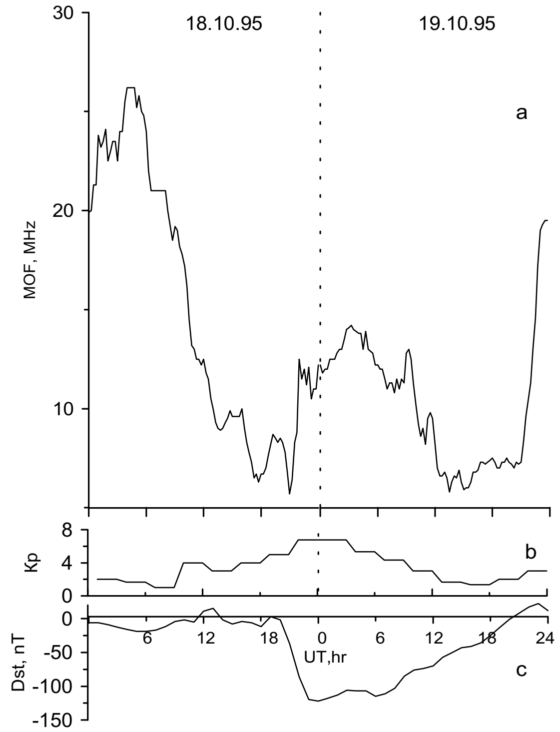

Fig.1. Duirnal variations MOF for path Magadan-Irkutsk (a), Kp (b) and Dst (c) (October 1995).

into the neutral atmosphere through energetic particle precipitation and Joule heating leads to the generation of internal gravity waves (IGW) which propagate from the auroral zone to low latitudes. The oscillatory character of the variations of maximum observable frequencies of OIS ionograms indicates that IGWs propagate through the region of signal reflection in the ionosphere.

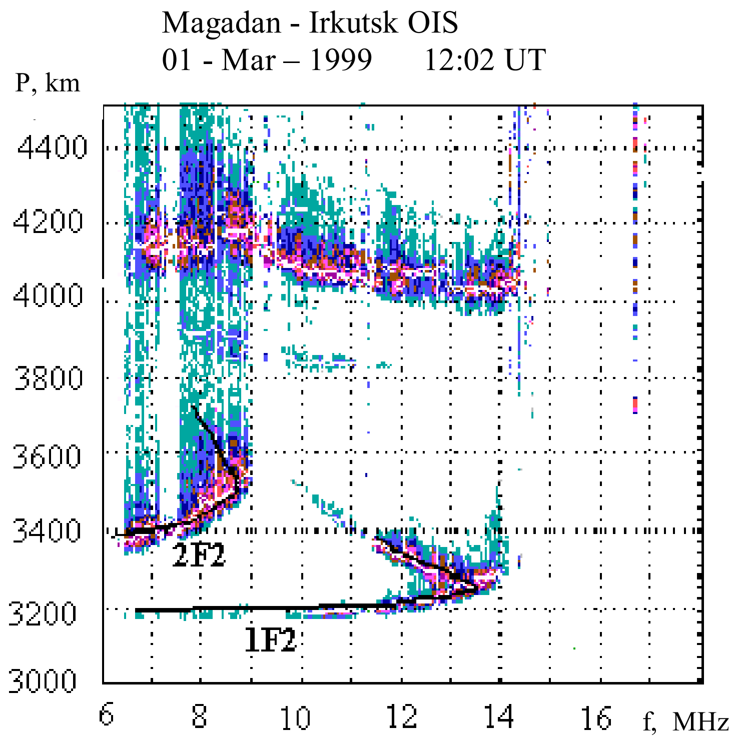

Fig.2 OIS image for the Magadan - Irkutsk path

DIAGNOSTICS AND PREDICTION OF HF RADIO CHANNELS

The modal structure of signals along the oblique-incidence sounding path was modeled on the theory of chirp-signal ionospheric sounding [2]. A technique was developed for direct diagnostics of the radio channel from results of ionospheric soundings by the chirp-signal, based on using adiabatic relationships of the diagnostic signal characteristics and the radio channel under investigation when ionospheric parameters are changing. These relationships were revealed by analyzing experimental data and modeling results on frequency dependencies of group characteristics (DFC) of oblique-incidence and backscatter ionospheric sounding signals under different helio-geophysical conditions. The adiabatic relationships, obtained in this way, provide a means of tackling the following issues related to real-time diagnostics of the HF radio channel:

- determination of the OIS ionograms for a given path from the backscatter ionogram where the azimuths of the oblique-incidence and backscatter sounding paths do not coincide;
- determination of the OIS ionograms for a given path from the oblique-incidence ionogram with a differing azimuth or a different extent.

Digitized ionograms with identified traces can be used in real-time predictions of the signal propagation conditions by extrapolating the time dependence of the MUF. The MUF ratio of different modes is a weakly varying quantity in the case of ionospheric parameter variations. On the other hand, by updating calculated values of the MUF using actual data, it is also possible to determine the group characteristics of signals, i.e. to totally reconstruct the OIS ionogram. The real-time prediction technique is based on the assumption that the ratio of maximum usable frequencies for the same radio path at different times is also weakly dependent on ionospheric parameter variations. Consequently, it is possible to take advantage of additional information about the time dependence of the MUF from, for example, calculations for long-term prediction. Of all short-term prediction configurations, an optimum approach was to use the linear extrapolation method complemented by additional model calculations [3].

This study have given examples of the effectiveness of the proposed real-time prediction technique for quiet and disturbed conditions, as well as at different levels of solar activity. For cases where long-term prediction gave an error in excess of 15-20%, the employment of our technique and current chirp-sounding data reduced the prediction error (with 15-min advance time) up to ~4-5% under quiet conditions, and ~6-7% under disturbed conditions.

CONCLUSION

The experimental investigations that were carried out throughout a total cycle of solar activity have shown that space weather has a substantial influence on the HF propagation even in mid-latitudes. Strong geomagnetic disturbances are accompanied by manifestations of auroral features for the mid-latitude ionosphere of the East-Asian longitudinal sector. Current data from the diagnostic complex on the basis of the chirp sounders can significantly improve accuracy characteristics of long-term prediction of the HF propagation. However, further progress in this direction is possible only with a better diagnostics of the processes occurring in the upper atmosphere, and with the development of an extensive network of chirp sounders operating within a coordinated program.

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