VARIATIONS IN HF DOPPLER RADAR SPECTRA MEASURED AT VERTICAL INCIDENCE

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ABSTRACT

The observations of the bottomside ionosphere were performed at 2.8–3.5 MHz during 1995–2001. The Doppler spectra variations were detected to display a great variety of forms, and Doppler spectrum and mean spectrum frequency variation classifications were developed. The rate of appearance of these forms has been estimated, and characteristic diurnal and seasonal Doppler spectrum variations were described. Approximate relations between the Doppler spectrum shapes and ionospheric parameters were derived. The characteristic time scales of evolution of regular and irregular ionospheric structures (electron number densities and their irregularities) during quiet and disturbed conditions were estimated.

INTRODUCTION

The ionosphere can be regarded as a subsystem of the larger system including the earth, the atmosphere, the ionosphere, the magnetosphere, the interplanetary medium, and the sun. Flows of matter, energy, and radiation of different origin enter the ionosphere from below and above. These influences result in non-stationary processes in the bottomside ionosphere (heights of $z \sim 100 - 300$ km) with time scales of seconds to eleven years and more, and this study is concerned with some of these processes captured with the Doppler radar at Kharkiv in Ukraine.

MEASUREMENT TECHNIQUE

The HF Doppler technique at vertical incidence is proved to be convenient to make observations of non-stationary processes in the bottomside ionosphere (see, for example, [1 – 5]). The Doppler radar, considered in detail in [2, 4], consists of two-channel transmitter-receiver system, two transmitting antennas, radar control, signal processing, and data acquisition systems. The system frequency band is $f = 1 - 24$ MHz. In this study, the sounding was made on two close frequencies in the range from 2.8 MHz to 3.5 MHz. The reflected complex-valued signals were recorded on magnetic tape at a sampling rate of 10 samples/sec. A Doppler spectrum was computed every minute by using 512 samples measured over a 51.2-sec interval. To estimate the periods of quasi-periodic processes in the ionosphere, the fast Fourier transform was in addition used over 64-min, 128-min, or 256-min intervals.

OBSERVATIONS

The measurements were made over the solar activity half-cycle from 1995 through 2001. The observations were taken in various seasons including the days close to the summer and winter solstices, the spring and fall equinoxes, over 24 hours, as well as at the dawn and dusk solar terminators. The overall duration of the observations is approximately 6,000 hr.

CONCLUSIONS

1. The 2.8 – 3.5 MHz Doppler radar data have been collected during the 1995 – 2001 year interval. The variations in the Doppler spectra have been revealed to be noted for rich variety (Fig. 1). Two classification schemes have been advanced: in terms of their "width" and in terms of the spectrum mean frequency. According to the first classification,

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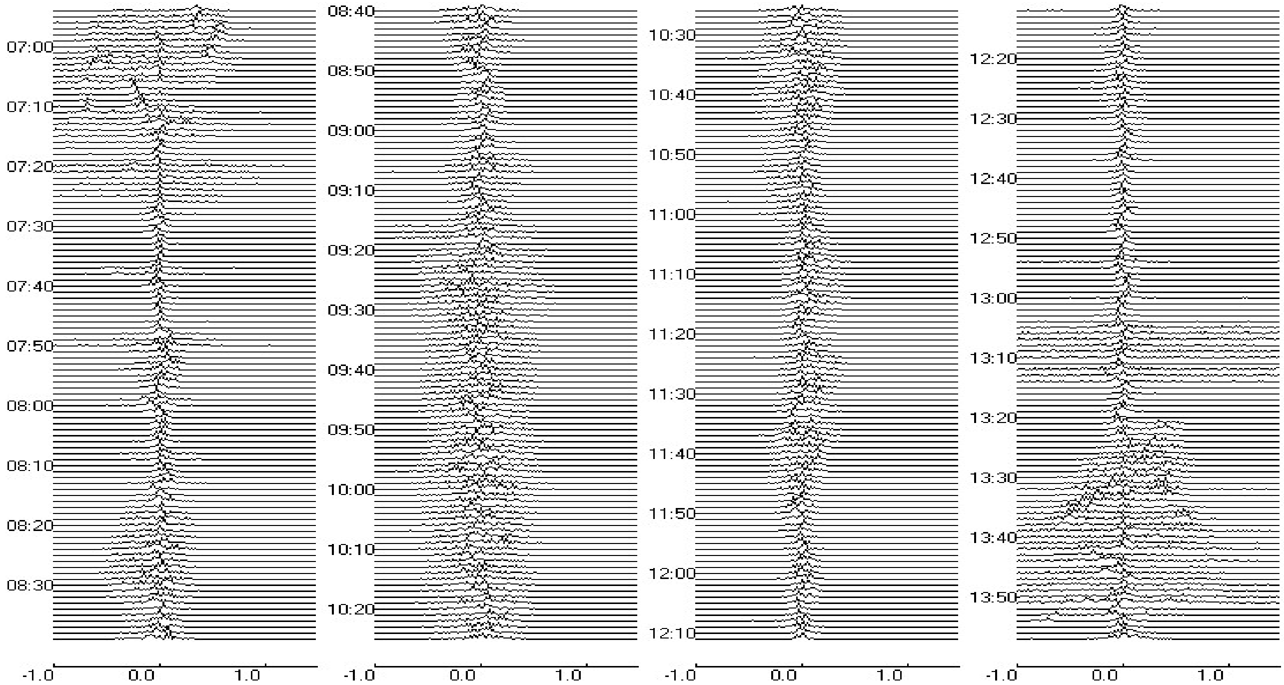

Fig. 1. July 27, 1998, $f \approx 3.0$ MHz. Illustration of appearance and disappearance of multipath propagation in Doppler spectra ("spread" effect), with Doppler shift in Hz as the abscissa and universal time along the ordinate in this and other figures

the spectra are one-mode, two-mode (rarely three- and four-mode) and "spread." According to the second classification, the variations in Doppler spectra are slight, aperiodic, quasi-periodic, and gigantic.

2. In the middle of the day (07:30 − 11:30 UT) and in the middle of the night (19:30 – 23:30 UT) during undisturbed periods (approximately 30% of all the time), Doppler spectra change slightly (Doppler shift is less than 0.1 Hz) and usually remain one-mode. During disturbed periods (approximately 70% of all the time), Doppler spectra most frequently widen, and their mean frequency changes by 0.5 – 1 Hz. Especially strong variations in the medium (20 – 25% of all the time) result in changes in Doppler shift by 1 – 2 Hz (Fig. 2).

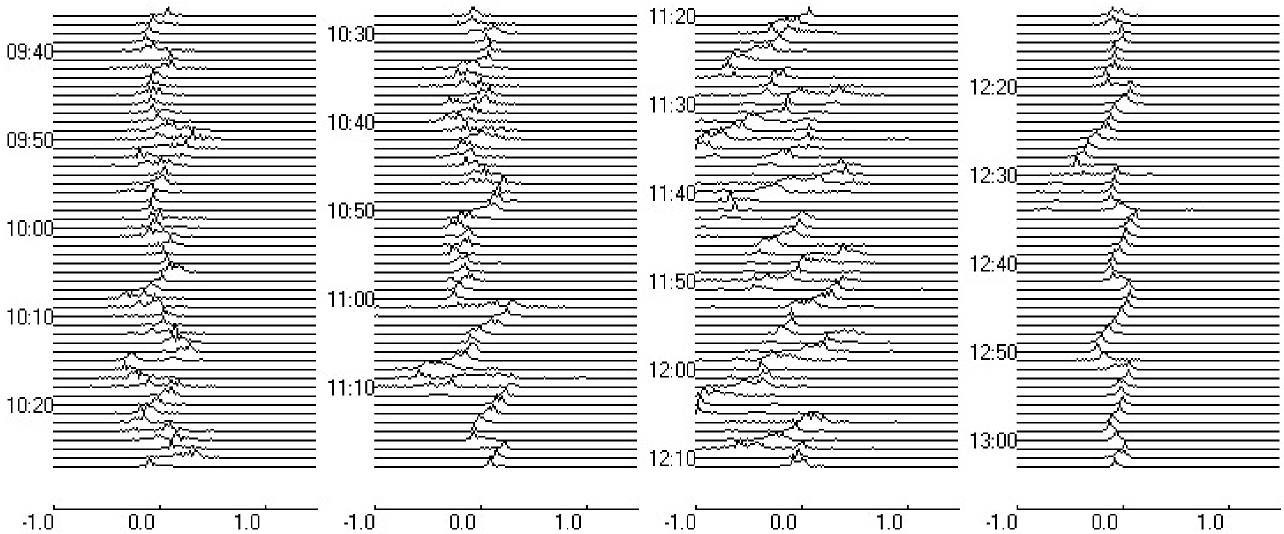

Fig. 2. Illustration of significant variations in both Doppler spectrum and its maximum energy frequency f_{D0} that are characteristic of disturbed conditions, January 15, 1999

3. The moving solar terminator causes ionospheric effects of 50 plus or minus 10 min in duration. They begin ~50 min before sunrise at the ground or at the instant of sunset at the same level. There happen a rich variety of variations in Doppler spectra from the moving solar terminator, and all kinds of spectrum described above occur. The response of the ionosphere is accompanied by both aperiodic and quasi-periodic processes. Sometimes the terminator suppresses the quasi-periodic processes existing before its passage (Fig. 3).
4. A local decrease in Doppler shift in 1 – 2 hr after sunrise and then a local increase of 0.3 – 0.7 Hz for 1 – 2 hr afterwards are observed virtually over all the year. First, an increase in Doppler shift and then a decrease of the same value (approximately 0.3 – 0.7 Hz) occur before sunset at the ground in May through September. The duration of these variations amounts to 1 – 2 hr.
5. The changes in Doppler shift by 0.3 – 0.5 Hz occur in the morning (01:30 – 07:30 UT) and in the evening (11:30 – 17:30 UT).
6. The periods of TIDs from the terminator moving in the ionosphere usually amount to 10 – 40 min, and relative fluctuations in electron density equal to 1 – 3%. Sometimes, the relative fluctuations in electron density attain 10 – 30%. Quasi-periodic processes were recorded over 25 – 30% of all observational time (Fig. 4).

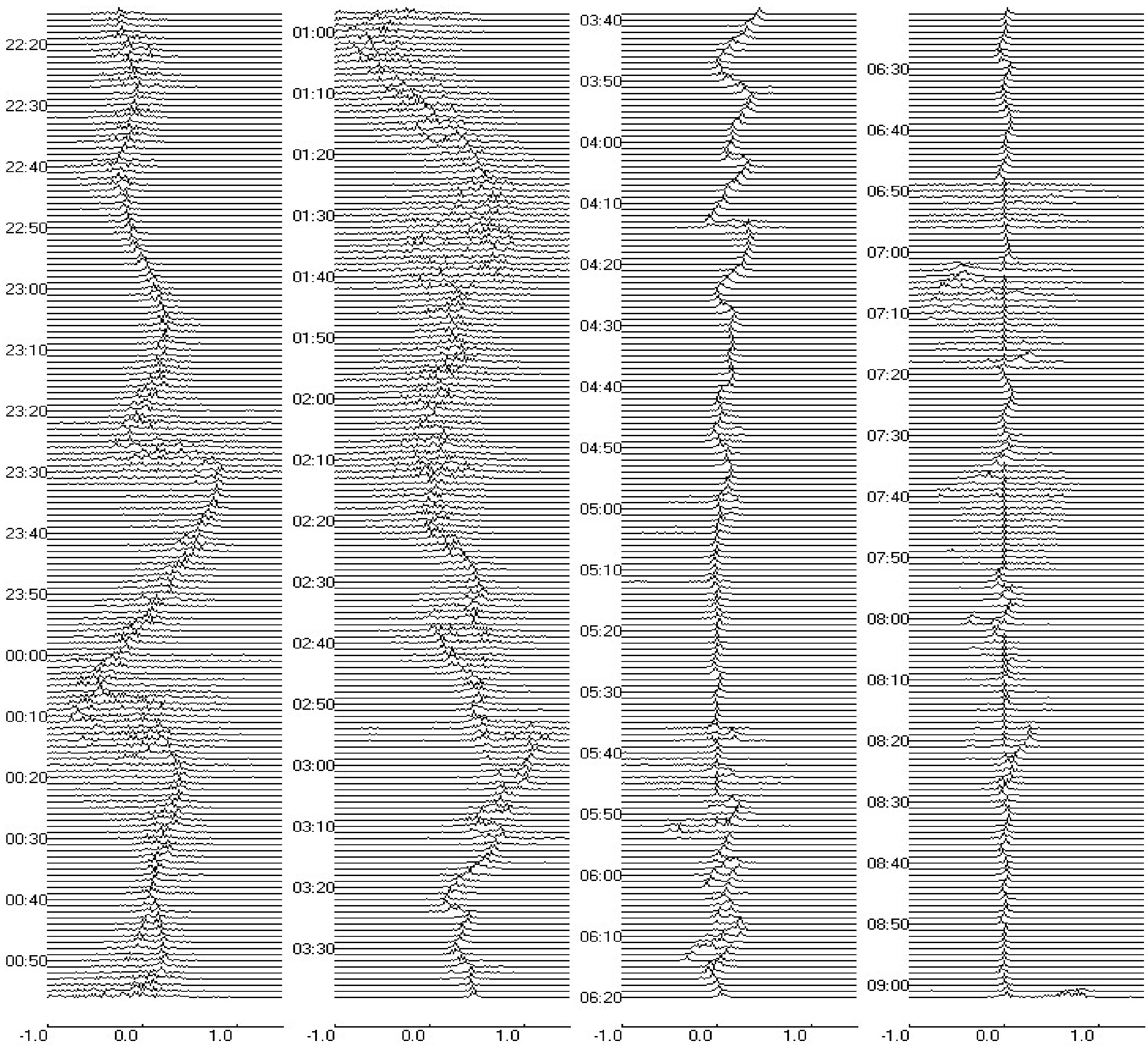

Fig. 3. Illustration of a quasi-periodic process with significant amplitude and varying period in a highly disturbed ionosphere at night and dawn on September 16–17 1999. The dawn terminator caused Doppler spectrum widening, actually Doppler spectrum "spreading," $f \approx 3.5$ MHz

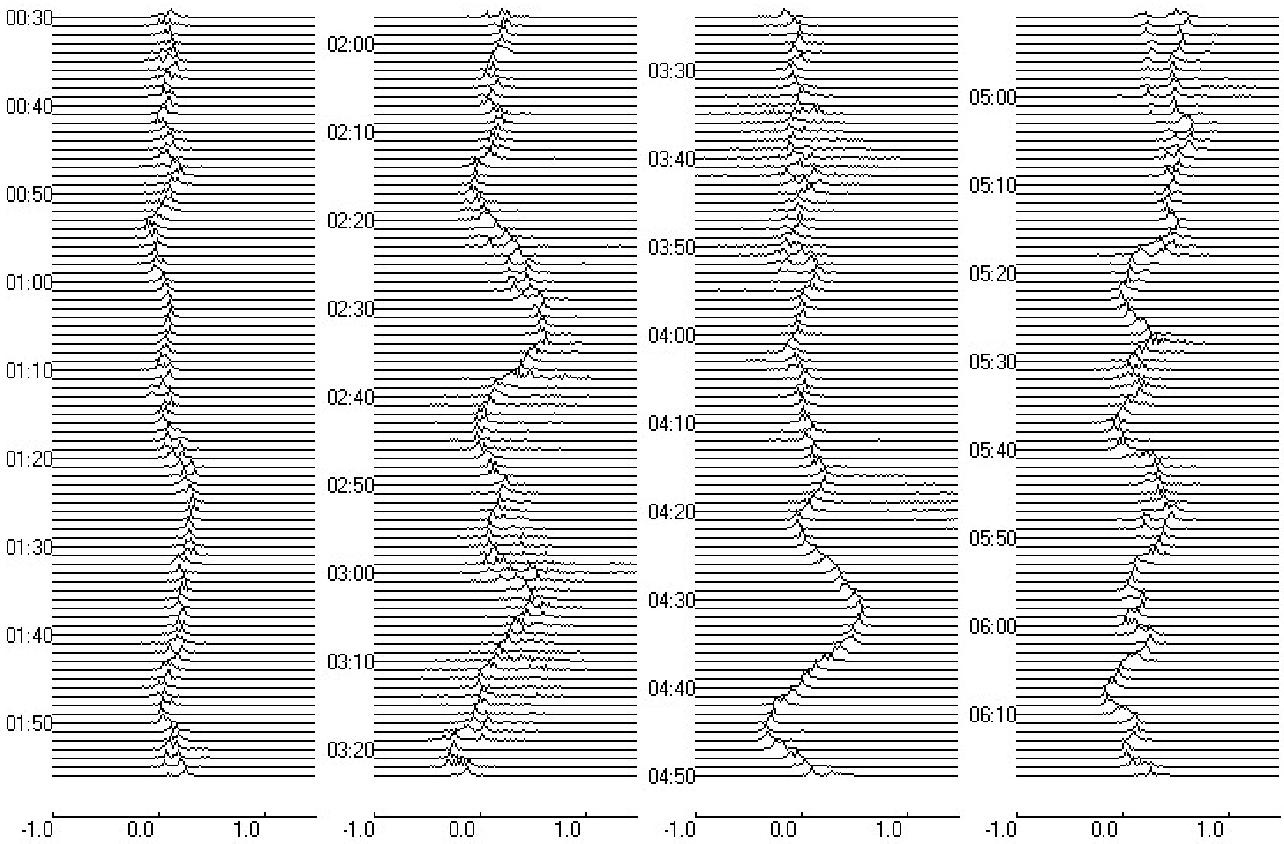

Fig. 4. Illustration of a pronounced quasi-periodic process during a quiet night and significant f_D oscillations caused by the dawn terminator on December 18–19, 1999; f = 3.5 MHz

7. The effect of Doppler spectrum "spreading" was recorded over 35 – 40% of all observational time. It is caused by the scattering of sounding signals by electron density fluctuations with relative fluctuations in electron density of ~ 1% and/or by their reflection from the randomly disturbed layer refracting the radio rays. In both cases, the signal is multimode.

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