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Peculiar transient phenomena observed by HF Doppler sounding on infrasound time scales

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Abstract

Compared to investigations of the influence of gravity and planetary waves on the ionosphere, the effects of infrasound (periods from about 0.01 s to several minutes) variations have not been studied very much in the last 20 years. Here we present some recent results on peculiar transient phenomena occurring at infrasound timescales, as observed by HF Doppler sounding in the Czech Republic. After a brief description of the measuring equipment for continuous HF Doppler sounding of the ionosphere, we deal with the observations of short-time transient changes that are observed in the Doppler spectrograms in time intervals of a minute or less, and therefore cannot be observed by ionosondes. First, we present examples of S-shaped traces and examine the diurnal and seasonal variation of their occurrence. We show that S-shape phenomena appear to be concentrated near sunset and sunrise. We also discuss the possible source of these disturbances and their relationship to gravity and infrasound waves. Then we show rare patterns with Doppler shifts corresponding to quasi-linear shape (QLS) phenomena in the time–frequency space. Their slope may be positive or negative. We present some of their properties and discuss the possible origin of such a phenomenon. Several potential sources of QLSs were excluded, such as aircrafts, satellites, bolides, meteors, meteorites, thunderstorms or geomagnetic storms. We speculate that QLSs may correspond to the radio waves in the Z-mode reflected at the upper hybrid resonance frequency.

Keywords: Acoustic-gravity waves; Ionospheric effects on radio waves; Ionospheric dynamics; Ionospheric disturbances; Wave propagation

1. Introduction

An HF Doppler technique is a very sensitive method for detecting transient changes in the ionosphere. Davis and Baker (1966) made great progress in the field of frequency variations of ionospherically propagated HF radio signals. Subsequently, many experimental and theoretical studies have followed (e.g., Georges, 1968; Sutcliffe and Poole, 1989; and references therein). The Doppler measurement is usually a part of radar and/or interferometric measurements, which also makes it possible to measure the angle of wave arrival (e.g., Reinisch et al., 1998).

The Doppler technique measures a frequency shift between the transmitted and received signal after its reflection from the ionosphere. This Doppler shift is proportional to the time rate of change of the signal phase path in the ionosphere. This change of the phase path is mainly proportional to the vertical

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movement of the reflection layer. It can also partially depend on the compression or rarefaction of the electron gas frozen onto the field lines. The Doppler shift then arises from a nonzero divergence of electron movement. The compression or rarefaction of electrons can be caused by the field-aligned component of the pulsating magnetic field (see e.g., Sutcliffe and Poole, 1989, for more detail).

In the ionosphere, collisions between neutral particles and ions and electrons couple the dynamics of neutral and ionized components of the atmosphere. The "strength" of this coupling decreases with increasing height; different processes are significant in different height ranges as well. The nature of the coupling depends mainly on the ratio of the neutral-charged particle collision frequency v to the gyrofrequency ω_c, for both electrons (ω_{ce}) and ions (ω_{ci}), and the direction of neutral wind with respect to magnetic field. A detailed description of the coupling between the neutral and ionized gases is available in e.g., Rishbeth (1997), Heelis (2004) and Laštovička (2006).

Because of this coupling, the HF Doppler technique makes it possible to study the atmospheric gravity waves (AGWs), the pioneering study of which was made by Hines (1960). The HF Doppler technique is also an important observational tool used for studying the effects of infrasonic waves on the ionosphere. These effects have been reviewed by Blanc (1985), Pokhotelov et al. (1995) and Krasnov et al. (2006). There are many mechanisms and sources of infrasound excitation in the atmosphere such as various strong meteorological phenomena (Hedlin et al., 2002), bolides, meteors, solar eclipses, auroral activity, earthquakes, nuclear and strong chemical explosions, rocket and shuttle launches, aircrafts, etc. Some of them contribute to ionospheric variability, as excited atmospheric waves propagate to ionospheric heights and modulate the atmospheric medium including its ionized part.

The HF Doppler sounding of the ionosphere at a frequency of 3.5945 MHz has been in operation at the Institute of Atmospheric Physics (IAP), Prague since January 2004. A relatively low transmitted power (~1 W) and experimental setup makes it possible to operate the system in the common volume with the digisonde DPS-4 located at Průhonice. Thus, we have the continuous Doppler spectrograms in association with ionograms observed once every 15 min. Burešová et al. (2006) used these common volume measurements to develop a method of improving ionogram evaluation and interpretation. A short description of the continuous Doppler sounding system is given in Section 2.

Sections 3 and 4 deal with two types of phenomena: peculiar Doppler shift pattern, S-shapes and quasi-linear shape (QLS) patterns, which cannot be observed by digisondes. Brief conclusions close the paper.

2. HF Doppler system of the IAP and primary data processing

The continuous HF Doppler sounder including special software has been developed at the Institute of Atmospheric Physics (IAP), Prague, Czech Republic. The transmitted frequency 3.5945 MHz is derived from the 10 MHz oven-controlled crystal oscillator (OCXO) by means of direct digital synthesis (DDS). The short time stability of the oscillator is 2×10^{-10}. An OCXO of the same stability and spectral characteristics is also used at the receiving site. The desired frequency is again tuned by means of DDS, but it is shifted 80 Hz away from the transmitted frequency in order to get the signal-to-noise ratio as high as possible. After conversion to lower frequencies, the received signal is digitized by the precise Sigma Delta analogue to digital converter. The sampling frequency is 610.35 Hz. Finally, the data are transmitted via a network to a PC station, where they are stored. The precise time synchronization is ensured by GPS.

The transmitter was placed at the Průhonice observatory (49°59′N, 14°33′E), which is located about 7 km from the receiver, in Prague at the main building of the IAP (50°02′N, 14°28′E). A great advantage of this topological arrangement is the common volume measurement with a digisonde DPS-4 located at Průhonice. The drawback of this arrangement is the strong ground wave that makes the detection of small Doppler shifts (~less than 0.04 Hz) impossible. When necessary, we remove the ground wave in the frequency domain. Of course the reflected wave is removed in that case as well, when its Doppler shift is near zero. On the other hand, the ground wave provides us with a direct verification of the stability of the oscillators and a zero drift line. At the beginning of April 2005, another transmitter was installed at the Panská Ves observatory (50°32′N, 14°34′E) of the IAP located about 60 km north of the IAP in Prague. Thus, the ionospheric reflections points (regions) are about 30 km apart.