Studying travelling ionospheric disturbances from near-vertical ionosphere sounding with high temporal resolution

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Abstract

In this study, we analyze the near-vertical ionospheric sounding data obtained with a multipurpose digital chirp ionosonde. The ionosonde was recording ionograms once each minute. We analyzed the results of processing the datasets over three observational years from 2010 to 2012. Obtaining ionograms with a high temporal resolution allowed us to trace the dynamics and evolution of additional traces referred to as "cusps", and also to combine ionograms with such traces into sequences. The percentage of ionograms containing cusps proved to be more than 10% of the overall number of ionograms. Thus, during daytime, the rate surpasses 30%, whereas, during nighttime, such ionograms are practically absent. The typical cusp lifetime proved to be 4-15 min, therefore, disturbed ionograms are much more rarely detected with standard vertical sounding ionosondes. The presence of such traces unambiguously evidences significant electron density horizontal gradients caused by travelling ionospheric disturbances (TIDs) with scales up to 50 km.

1. Introduction

The ionosphere dynamics is mostly determined by travelling ionospheric disturbances (TIDs) of different scales. TIDs may be the ionosphere response to the forcing from the underlying atmosphere through infiltration or transformation of internal gravity waves (IGWs) [1]. At that, the estimate of the energy transported within different ranges of wave lengths represents a problem of current importance.

Small scale TIDs (up to 50 km spatial scale) were revealed at near-vertical ionospheric sounding with a high temporal resolution (1 minute) like characteristic additional traces on ionograms (cusp type anomalies) [2-5]. From observations within the frequency range of 1-15 MHz the TID-caused electron density horizontal gradients in the ionosphere were established to be present not only in the F2 region, but also in the F1 region. The averaged data for several years at the fixed frequency in the Southern Hemisphere showed that in the seasonal variation in the manifestation of the TID-caused effects, the maxima are observed in summer and in winter, whereas the minima are observed at the equinoxes [2]. However, investigations into the long-term sequences of ionograms with a high temporal resolution to obtain quantitative results were severely constrained by the capabilities of the equipment applied at that time.

In a number of papers [5, 6], endeavors were made through ray tracing analysis to interpret the simplest particular cases of the cusp occurrence at vertical ionospheric sounding. Thus, in [5], the authors showed that cusps on the ionograms were caused by oblique reflections. Authors in [7] corroborated this conclusion by addressing the parabolic background model of the ionosphere containing the electron density horizontal gradients in the presence of disturbance. In [8], the statistical analysis of the ionograms obtained with the "Cyclone" vertical sounding ionosonde for 30 winter days in 2011 was performed. The authors addressed simple-shape cusps: "Nose" and "U-shaped."

In this paper, we perform an analysis of TID manifestations in the long-term data series with a high temporal resolution. These series were obtained at the path of near-vertical sounding of the ionosphere located in the Northern Hemisphere Asian region.

2. Equipment

At the Institute of Solar-Terrestrial Physics of Siberian Branch of Russian Academy of Sciences (ISTP SB RAS) Geophysical Observatory (51°48' N, 103°5' E), there is a multipurpose ionosonde. This ionosonde is an ISTP SB RAS designed and developed, fully digital, wideband device, applies a frequency modulated, continuous wave (FMCW ionosonde, or chirp ionosonde) within the 1.3-30 MHz range [9]. The ionosonde has a direct sampling receiver with 8 independent channels to receive FMCW. Synchronization of time and frequency at the receiver and transmitter is provided by GPS timing unit. In the ionosonde standard operating mode, vertical sounding is performed once each minute with the frequency swept within 1.3-15 MHz, at a 500 kHz/s rate, and with a 10 W peak radiation power. Also, simultaneously with vertical sounding, the ionosonde receives a signal of near-vertical every-minute sounding from a chirp transmitter located 120 km away, near the town of Usolye (52°53' N, 103°16' E). As a sounding signal source, we use a transmitter equipped with a digital generator of signals and with a 100 W power amplifier. Near-vertical sounding is performed once each minute with the chirp signal within the 1.5-15 MHz range, at a 400 kHz/s rate. The obtained

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quadrature samples from the ionosonde receiver output are processed to derive ionograms with a 1.25-km height resolution and with a 20-kHz frequency resolution. During additional observational campaigns, the ionosonde also receives oblique sounding signals from the ISTP SB RAS chirp transmitters in Norilsk, Khabarovsk, and Magadan.

3. Observational results

In our analysis, we involved the datasets of the ionosphere near-vertical sounding for three observational years, 2010 through 2012. The number of the ionograms recorded every other minute is more than 250.000. Ionograms were recorded once each minute, so it allowed us to study the dynamics of the ionograms and their detailed structure, which is quite difficult to do with the standard 15-min sounding periodicity.

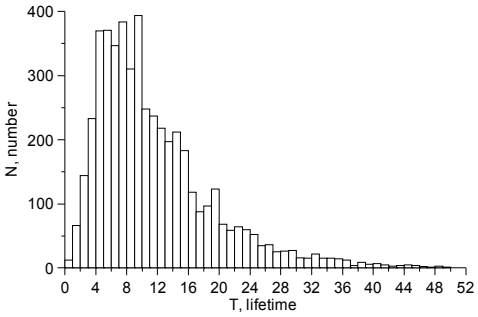

Figure 1. Histogram of cusp observation interval duration

The number of the ionograms with cusps is more than 26.000, which is over 10% of all the recorded ionograms. This fact allows us to state that the presence of the electron density significant horizontal gradients in the ionosphere represents a regular rather than incidental phenomenon. The main difference between the ionograms obtained with a one-minute interval and the ionograms obtained with the standard 15-min interval is that the shape and the location of cusps vary slowly enough from ionogram to ionogram. This allows us to trace the dynamics of cusps on the adjacent ionograms and to combine such ionograms into sequences.

Figure 1 presents the histogram of distribution of the obtained sequence durations for all the observational time over 2010-2012. One can see that there are practically no ionograms with cusps that would be isolated from the remaining ones. With the full number of the detected sequences (about 5.000), there were only 10 non-connected (individual) ionograms with cusps. It is apparent that the bulk of the recorded ionograms with cusps produces the 4-15 min sequences (the share of such sequences is about 70%). This explains the difficulties when integrating the sequences of ionograms with the cusps obtained with the standard 15-min sounding interval. At the same time, automated processing of similar sequences is difficult even at one-minute sounding periodicity. Therefore, yielding their characteristics as a whole requires presently the operator's interactive processing. The presence of sequence of several ionograms for each cusp obviously caused by the same disturbance allows us to tell about the cusp motion direction over the ionogram and about its lifetime.

Cusps are greatly diverse in shape, size, and motion velocity over the ionogram [10]. Nevertheless, in the bulk of cases, cusps have rather a simple shape, and each ionogram involves only one trace of similar kind (so-called simple-shape cusp). The example of such a case is presented in the sequence of ionograms of near-vertical sounding (Fig. 2). Such cusps' mean lifetime is about 7-9 minutes. They usually appear at the high frequency end of the h'(f) trace and the apparent heights of reflection are greater than the normal F-region reflection. Then it displaces into the region of smaller apparent heights and smaller frequencies (down- and leftward along the h'(f) trace). The percentage of such cusps varies from 50% to 95% seasonally. A rarer case is when the cusp moves in the opposite direction (up- and rightward along the trace). Even much rarer occurrence is when cusps first move top to bottom, and then move upward [11].

Another interesting feature of ionograms with cusps is a possibility of cusp appearance left of the main h'(f) trace with a subsequent motion downward along the trace and with possible crossing the latter. Such ionograms are comparatively few, the obtained data show that about 85% cases refer to the situations when the cusp appears right of the main trace.

Except the ionograms with single simple cusps, one can sometimes observe complex-shape cusps. This is mostly a winter and very rare phenomenon (under 5% of the total ionograms with cusps). The complex cusps have a mean lifetime of about 20 minutes. As a rule, in the presence of such cusps, the main trace distorts significantly, which implicitly evidences a large amplitude of the disturbance causing them.

Ionograms with cusps have some well-defined seasonal and diurnal peculiarities. Thus, in November-December and in July-August, the number of ionograms with cusps surpasses 15%. The cusp appearance probability minimum falls on the equinox periods when their number is less than 10%. Also, a seasonal peculiarity is that, during summertime, there are practically no ionograms with complex cusps and much fewer ionograms on which the cusp motion direction differs from the standard down- and leftward direction. During wintertime, the complexity of additional traces and the variability in the cusp motion direction over the ionogram is much higher.

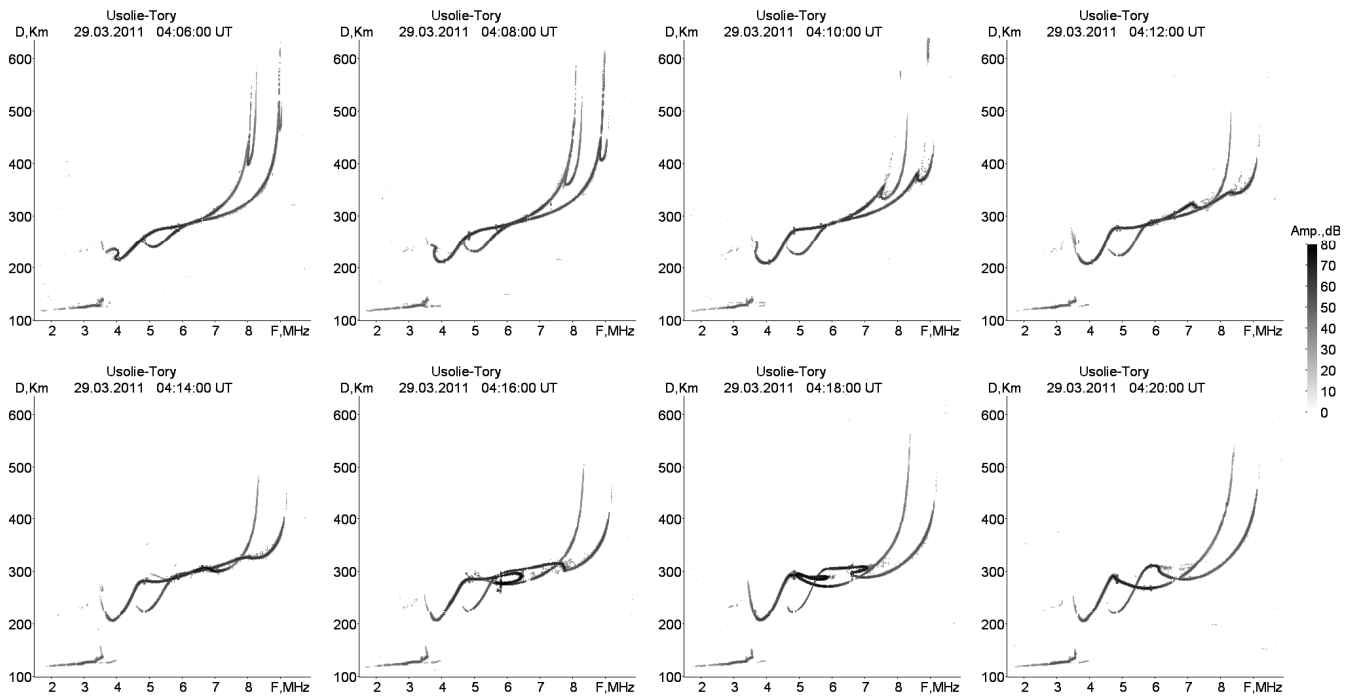

Figure 2. Evolution of a simple-shape cusp on ionograms

Figure 3 demonstrates the diurnal dependences of recording ionograms with cusps. Here, the summary pattern is presented during the 2011 winter and summer seasons for the simple-shape cusps: Fig. 3a shows the number of cusp occurrence inside the hourly interval per one day, and Fig. 3b exhibits their mean lifetime. One can see that the probability for appearance of ionograms with cusps has a non-uniform distribution inside the day. During daylight, the number of ionograms with traces reaches 30% of the total number of the recorded ionograms while they are practically absent during nighttime. The time range when cusps are observed is a little wider for the summer period, than for the winter period. Besides, the cusp occurrence and the mean lifetime of the simple-shape cusps for the summer period are approximately one and a half times more than those for the winter period.

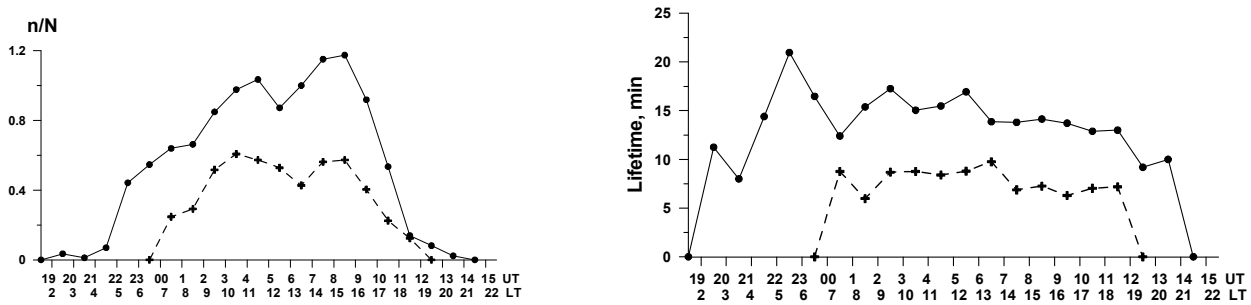

Figure 3. Mean occurrence (a) and mean lifetime of simple-shape cusps inside hourly intervals counting on one day averaged by winter season months (dotted line) and summer season months (solid line)

4. Conclusion

As a result of analyzing the data with a high temporal resolution obtained at the near-vertical sounding path located in the Northern Hemisphere Asian region, we revealed that cusp type anomalies on ionograms are quite a regular phenomenon. Over 2010-2012, more than 10% of the investigated ionograms involved cusps. Also, during daytime, the number of the disturbed ionograms reached 30%, whereas they were practically absent during nighttime. The cusp characteristic lifetime for the most prevalent simple-shape type was 4-15 minutes which explains a small number of cases of recording disturbed ionograms at the vertical sounding ionosonde standard operation. Cusp type anomalies practically never occur on individual ionograms with the one-minute sounding periodicity. Thereby, this sounding mode is quite suitable to record manifestations of TIDs with the characteristic spatial scales up to 50 km.

5. Acknowledgments

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