Dynamics and structure of the vertical ionospheric disturbances caused by Tohoku earthquake according to Irkutsk bistatic CHIRP-sounding

Berngardt O.I.[1], Podlesny A.V.[1], Kotovich G.V.[1]*

[1]Institute of Solar-Terrestrial Physics of Sibirean Branch of Russian Academy of Sciences,
664033, 126a, Lermontova str., Irkutsk, Russia, POBox 291, e-mail:berng@iszf.irk.ru

Abstract

In the work we present results of observation of the mid-scale vertical ionospheric irregularities caused by Tohoku earthquake (11/03/2011, 05:47UT) at distance 3400km from epicenter with 1 minute temporary resolution. Their spatial and temporary dynamics is also investigated. As showed the analysis of the experimental data, the main response of the ionosphere was observed at Irkutsk from 06:10UT to 07:00UT. Short-term variations of the electron density profile were also observed from 06:00UT. This corresponds to the main horizontal speed of disturbances about 4, 2-2.5 and 1.2-1.3 km/s. The vertical scale of the irregularities was 10-20 km. Irregularities practically weren't observed at heights above 180-200km.

1. Introduction

The Tohoku earthquake (11/03/2011, 05:47UT) is considered one of the most destructive earthquakes in XXI century. Mid-scale ionospheric disturbances after Tohoku earthquake have been widely studied by the dense network of GPS-receivers, located in Japan[1-3] and by using Hokkaido SuperDARN radar[4-5]. By using vertical ionospheric sounders, in the vertical profile of electron density there were observed short-lived vertical structures above Japan and Taiwan with a vertical scale 10-20 kilometers[6-7].

In this work we present similar ionospheric effects observed at distance 3400km from epicenter of an earthquake, in Irkutsk, Russia (52N,104E). The main instrument used in the analysis was bistatic CHIRP-sounder of own development of ISTP SB RAS. The CHIRP-sounder provides frequency change speed up to 1000 kHz/sec, and provides 1 minute temporal resolution, comparable with SuperDARN radars and GPS receivers network. The receiver and the transmitter of the sounder are located close to Irkutsk at distance 120 km between each other. Synchronization of time and frequency is provided by GPS.

2. Observations summary

After Tohoku earthquake over the Irkutsk there were observed unusual disturbances in the ionogrames that was corresponded to the presence of mid-scale vertical irregularities (Fig.1a-b). Fig.1b shows earthquake effects at ionograme (06:13UT), Fig.1a shows undisturbed ionosphere (05:59UT). These observations is looking similar to the observations above Japan[7] and Taiwan[6]. In the electron density profile this effect corresponds to the presence of the vertical irregularities with spatial periods 5-20km (Fig.1c).

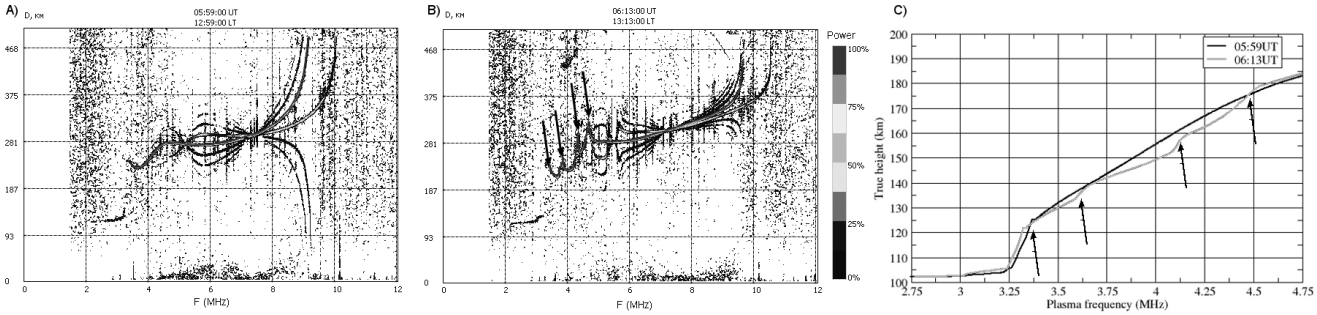

Fig.1. Ionospheric effects caused by Tohoku earthquake near Irkutsk March 11, 2013. A) – undisturbed ionogrames at 05:59UT; B) - disturbed ionogrames at 06:13UT; C) - electron density variations for these ionogrames. Arrows shows positions of the maximal gradients of electron density.

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

At Fig.2 there is shown the dynamics of these spatial irregularities with 1 minute resolution. Fig.2a,c show absence of the irregularities before (March 10, 2011) and after (March 12, 2011) earthquake. As one can see, the irregularities dynamics is too fast and there are almost no correlation between consequent sounding results.

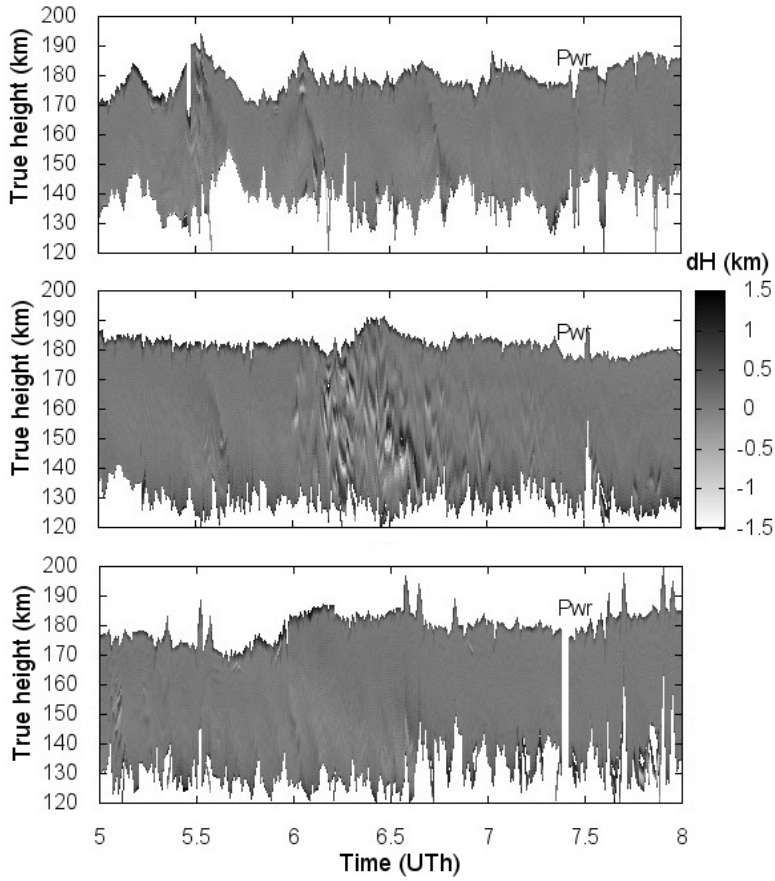

Fig.2. Ionospheric irregularities (variations of true height at fixed plasma frequency) during March 10-12, 2011.

To estimate horizontal velocity of the irregularities we can calculate equivalent velocity as delay between earthquake moment and observation time for each sounding. At Fig.3 we show amplitude of the irregularity as a function of the time (Fig.3A) and as a function of such equivalent horizontal velocity (Fig.3B).

As one can see from Fig.3A the main response of the ionosphere was observed at Irkutsk from 06:10UT to 07:00UT. Weak variations of the electron density profile were observed from 06:00UT. At the days before and after the earthquake such strong and long-lived irregularities were not observed.

As one can see from Fig.3B there are 3 strong modes present in the equivalent velocities distribution: 3.8-4 km/s, 2-2.5 km/s and 1.2-1.3 km/s. The last two modes are the most intensive ones. The obtained velocities corresponds to the seismic waves and don't contradict the data obtained by other researchers at GPS network[3] and Hokkaido SuperDARN radar[5].

3. Conclusion.

In the work we present results of observation of the mid-scale vertical ionospheric irregularities caused by Tohoku earthquake with 1 minute temporary resolution. Their spatial and temporary dynamics is also investigated. As showed the analysis of the experimental data, the main response of the ionosphere was observed at Irkutsk from 06:10UT to 07:00UT. Weak variations of the electron density profile were also observed from 06:00UT. This corresponds to the main horizontal speed of disturbances about 3.8-4, 2-2.5, 1.2-1.3 km/s and below. The average vertical scale of the irregularities was 5-20 km. Irregularities practically weren't observed at heights above 200km. The obtained data don't contradict the data obtained

by other researchers. The one minute time resolution was not enough to estimate vertical velocities of these irregularities.

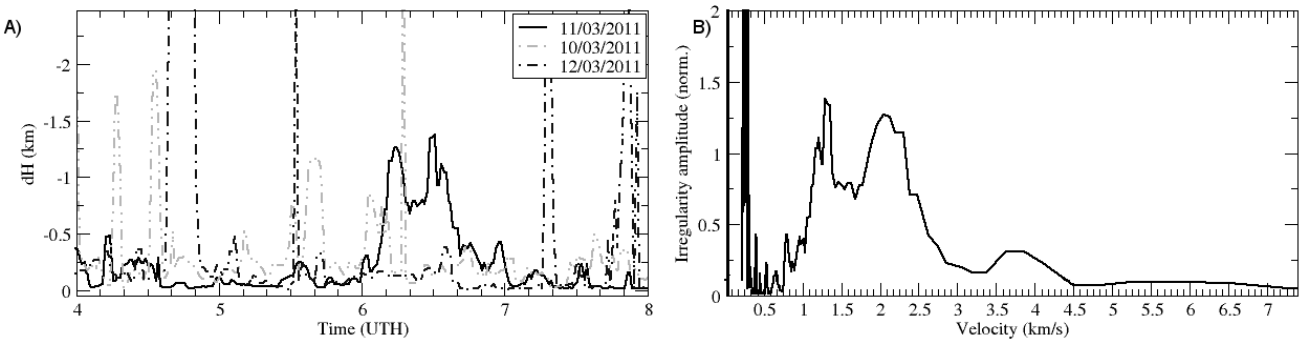

Fig.3. A) - amplitude of the vertical ionospheric irregularities as a function of the time for March 10-12, 2011. B) – amplitude of the vertical ionospheric irregularities as a function of equivalent velocity.

3. Acknowledgments

Work was done under financial support of IV.12.2 OFN RAS program and RFBR grant #14-05-00259-a.

5. References

1. L. M. Rolland, P. Lognonné, E. Astafyeva, E. Alam Kherani, N. Kobayashi, M. Mann, and H. Munekane. «The resonant response of the ionosphere imaged after the 2011 off the Pacific coast of Tohoku Earthquake», *Earth, Planets, and Space* , **63**, 2011, pp.853–857.
2. A. Saito, T. Tsugawa, Y. Otsuka, M. Nishioka, T. Iyemori, M. Matsumura, S. Saito, C. H. Chen, Y. Goi, and N. Choosakul. «Acoustic resonance and plasma depletion detected by gps total electron content observation after the 2011 off the pacific coast of Tohoku earthquake», *Earth, Planets, and Space* , **63**, 2011, pp.863–867.
3. E. Astafyeva, L. Rolland, P. Lognonné, K. Khelfi, and T. Yahagi, «Parameters of seismic source as deduced from 1 hz ionospheric gps data: Case study of the 2011 tohoku-oki event», *Journal of Geophysical Research: Space Physics* , **118(9)**, 2013, pp.5942–5950
4. N. Nishitani, T. Ogawa, Y. Otsuka, K. Hosokawa, and T. Hori, «Propagation of large amplitude ionospheric disturbances with velocity dispersion observed by the SuperDARN Hokkaido radar after the 2011 off the Pacific coast of Tohoku Earthquake», *Earth, Planets, and Space* , **63**, 2011, pp.891–896
5. T. Ogawa, N. Nishitani, T. Tsugawa, and K. Shiokawa, «Giant ionospheric disturbances observed with the superdarn Hokkaido HF radar and GPS network after the 2011 Tohoku earthquake.», *Earth, Planets, and Space* , **64**, 2012, pp.1295–1307
6. J. Y. Liu and Y. Y. Sun. «Seismo-traveling ionospheric disturbances of ionograms observed during the 2011 mw 9.0 Tohoku earthquake», *Earth, Planets, and Space* , **63**, 2011, pp.897–902
7. T. Maruyama, T. Tsugawa, H. Kato, A. Saito, Y. Otsuka, and M. Nishioka, «Ionospheric multiple stratifications and irregularities induced by the 2011 off the pacific coast of Tohoku earthquake», *Earth, Planets, and Space* , **63**, 2011, pp.869–873