Charactersitics of midscale ionospheric irregularities caused by the "Chelyabinsk" meteroid impact according to EKB radar and GPS network data

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Abstract

This paper presents the analysis of ionospheric effects in the region close to the "Chelyabinsk" meteoroid explosion at 03:20UT 2013 February 15 from the Institute of Solar-Terrestrial Physics of Siberian Branch of Russian Academy of Sciences (ISTP SB RAS) EKB radar data, from the Institute of Geophysics of Ural Branch of Russian Academy of Sciences (IG UB RAS) PARUS ionosonde data and from GPS network data. According to the data obtained, the ionospheric disturbance caused by the meteoroid did not lead to a variation of the ionospheric mean parameters in the region above the explosion center during the first 15 minutes. The joint analysis shows that the radial ionospheric disturbances with almost similar parameters were observed after meteoroid explosion both by EKB radar and GPS receivers network. These F-layer irregularities have mean drift velocity 320-400m/s and spatial wavelength 150-200km.

1. Introduction

The Chelyabinsk meteoroid impact at 03:20 UT on 2013 February 15, accompanied by a great number of ionospheric, atmospheric and seismic phenomena [1-5]. In this paper, we investigate the ionospheric effects accompanying the meteoroid impact from the EKB radar data (Fig.1A) and GPS network data. The EKB radar is an equivalent to the SuperDARN network CUTLASS radars [6], and is deployed at the IG UB RAS Arti observatory (56º26'N, 58º34'E). The radar was put on a 24-h operation by ISTP SB RAS in mid December, 2012. This allowed to obtain a great number of data on ionospheric conditions at the impact, and also within the period prior to and after the impact with a high spatial-temporal resolution[2]. The EKB radar is located approximately 200 km northward from the explosion point. We also involved the data from vertical ionospheric sounding with the PARUS ionosonde within the Arti Observatory whose location almost coincides with the EKB radar location. Figure 1 shows the observational geometry.

We investigate total electron content (TEC) in the ionosphere after explosion of Chelyabinsk meteoroid based on phase measurement data from dual-frequency GPS receivers. We used data from ARTU, KRTV, NOVM, NVSK, SUMK, SELE, CHUM, TALA, POL2, NRIL stations of International IGS network (http://sopac.ucsd.edu), data from TRIM, ORNB, NNOV, BARN, SIBG stations of Navgeocom company (http://www.navgeocom.ru), CHEL station of "Geosalyut" (Moscow) and "Poleos" (Chelyabinsk) companies.

The meteoroid impact happened at extremely quiet geomagnetic and seismic conditions, as well as the absence of solar flares. To detect effects associated with regular processes in the ionosphere in the scattered signal power dynamics, we analyzed the 2013 February 15 data towards similar quiet (referential) days, 2013 February 9-12, and 18.

As shows the analysis of the Arti observatory data, the maximal electron density at the characteristic 15-min times within the radar vicinity during +/- 1h from the meteoroid explosion differed weakly from that during the referential days.

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2. F-layer effects

As the analysis of EKB radar data shows, the 2013 February 15 day was accompanied by the electron density essential disturbances having the form of oblique tracks with increasing range on the range-time diagram (Fig.1b). Such peculiarities are usually interpreted as several modes of the ionospheric wave disturbances propagating at different velocities. The effect was not observed during similar quiet days 2013 February 9-12(Fig.1c). The qualitative analysis shows that the range to the disturbance weakly depends on the azimuth for the most powerful observed mode, and this peculiarity persists in time. This allows us to assume a radial propagation of the disturbance.

We made appropriate raytracing modeling of radiowaves propagation by using IRI-2007 ionospheric model and Arti ionosonde data. The modeling allows us to explain all the observed tracks at time-range-intensity plot (Fig.1c) by presence of two ionospheric irregularities. The velocities of these ionospheric irregularities are 220m/s and 400m/s and their spatial wavelengths are 150-200km. The irregularities with velocity 200m/s are also observed by EKB radar at E-layer heights near explosion point [2].

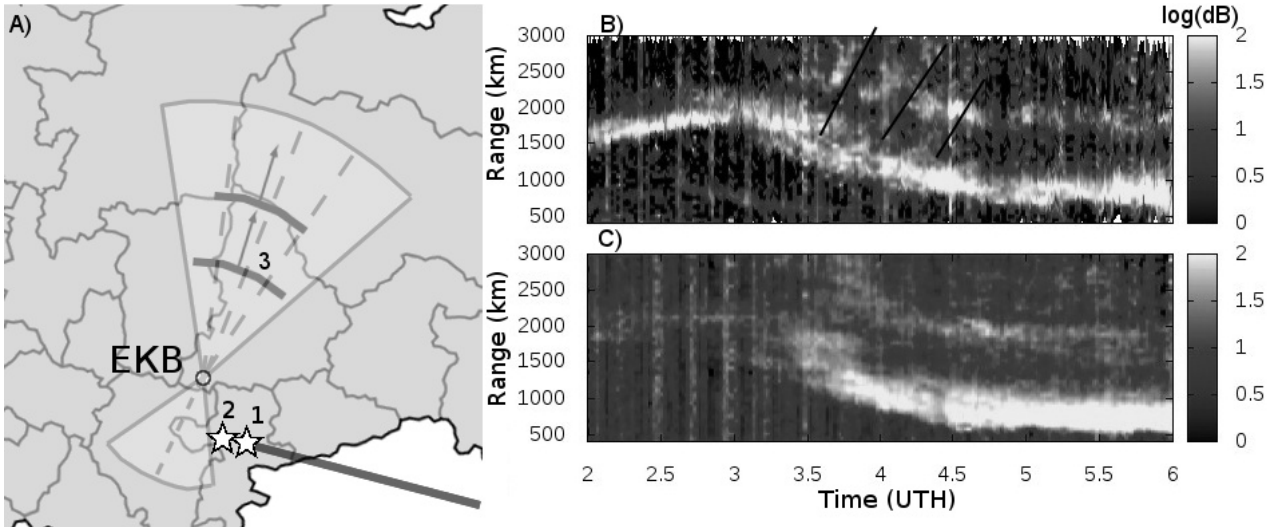

Fig.1. A) - geometry of EKB radar observations. 1-explosion point, 2-meteoroid fall point, 3 – traveling ionospheric disturbances; B) - scattered power averaged over the beams 15/02/2013, black lines mark traveling ionospheric disturbances from the meteoroid; C) - scattered power averaged over the beams and over the similar days 9-12/02/2013

3. GPS-TEC effects

To distinguish ionospheric disturbances caused by meteoroid fall and explosion we filtered out 2-20 min periods from the TEC series. The obtained TEC variations in the day of explosion were compared with TEC variations during the previous and the next day. Detection of the disturbances caused by the meteoroid explosion were difficult because of the fall happened at sunrise, when the ionosphere is characterized by high variability.

Inspite of presence of TEC variations caused by the solar terminator, at stations close to meteoroid explosion point (ARTU, ORNB, CHEL, TRIM) and at some “receiver-satellite” lines of site there were possible to observe the TEC variations typical for shock acoustic wave (Fig.2a)[7]. The TEC oscillations have 15 min periods and 0.1-0.5TECU amplitudes. The disturbances were detected starting from 14 min after meteoroid explosion. The characteristic shape of the oscillations and the absence of the similar oscillations during referential days allows us to conclude that the disturbances were caused by shock wave from the meteoroid explosion.

The TEC variations dynamics is presented at Fig.2b-d. At the figure there is shown the spatial distribution of minima and maxima of TEC oscillations at different time. As one can see the TEC disturbances were propagating almost radially from the explosion point and up to 500-700 km distances. Disturbances wavelengths were about 200km. Propagation velocities of the TEC disturbances reached 320-360m/s, and were close to the acoustic speed in the lower atmosphere.

4. Conclusion

In this paper, we compared characteristics of the midscale ionospheric irregularities within the 100-1500 km ranges from the Chelyabinsk meteoroid explosion point from the ISTP SB RAS EKB radar data, IG UB RAS PARUS ionosonde data and GPS-network data.

According to EKB radar data the main disturbances in the F-layer were nearly radial waves with the center close to the explosion point. The analysis of the experimental data allowed us to determine the equivalent ionospheric velocities for individual irregularities (220 and 400 m/s) with the characteristic horizontal scales of ~200 km. The first disturbance in the F-layer was observed 15 minutes after the explosion, and it propagated away from the radar almost radially.

According to GPS data the analysis of TEC variations during "Chelyabinsk" meteoroid explosion shows that 14 min after explosion there were disturbances observed. They had shapes typical for shock acoustic wave. They had periods ~15 min, wavelengths 200km and amplitudes 0.1-0.5 TECU. The disturbances were propagating radially from explosion point up to 500-700km distances. Their horizontal velocities were 320-360m/s and were close to the lower atmosphere acoustic speed.

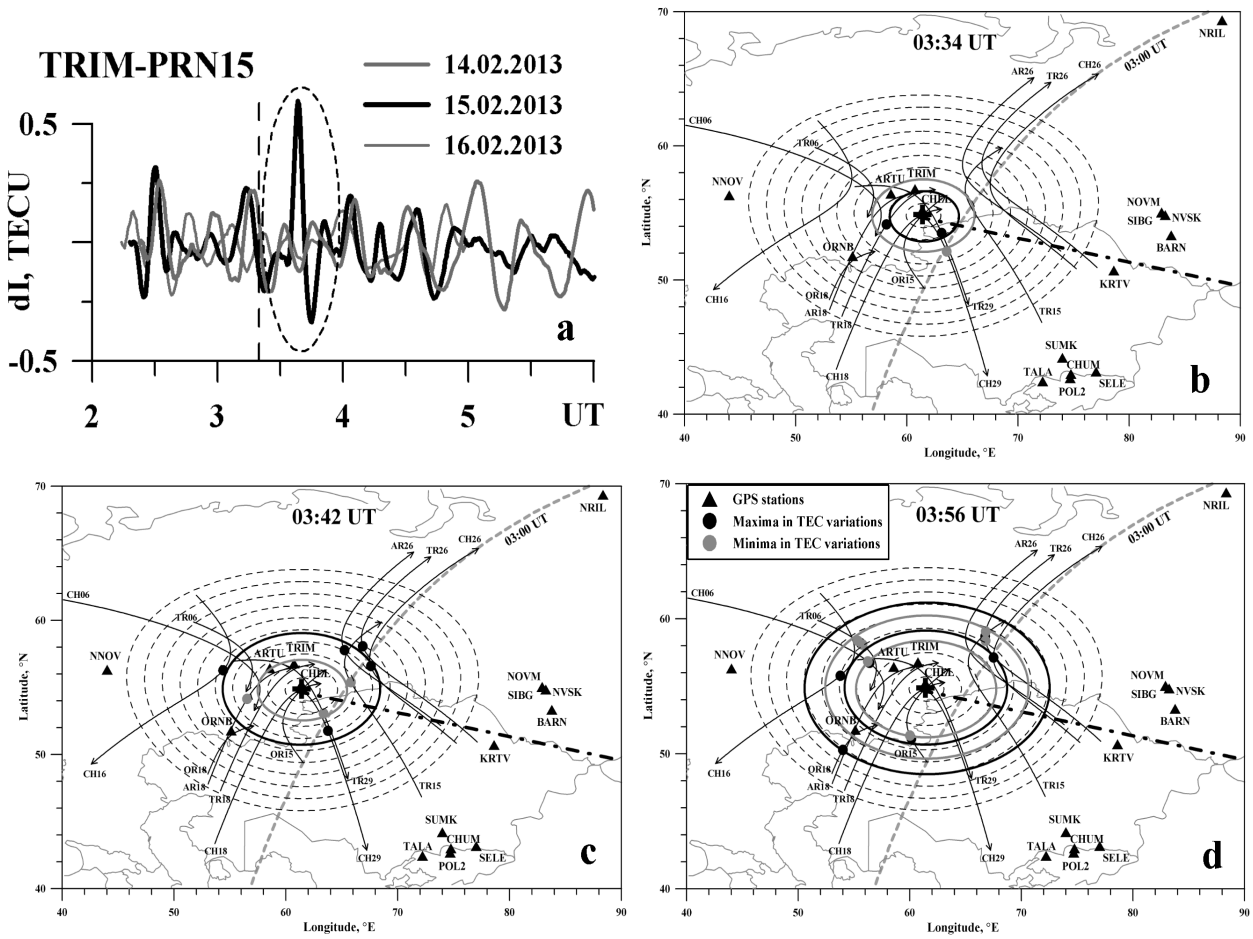

Fig.2. (a) - Wavelike TEC disturbances caused by shockwave from Chelyabinsk meteoroid explosion and measured at TRIM station (PRN15 satellite). Vertical dashed line marks explosion moment. (b-d) - Spatial distribution and propagation of TEC disturbances caused by meteoroid explosion. Thin arrows mark apparent GPS satellites movement. Thick concentric lines mark the position of wave front of the disturbance. To draw it we use the positions of minima (gray dots) and maxima (black dots) in TEC variations for corresponding moment. Gray dashed line marks solar terminator position at 03:00UT. Thick dashed line shows meteoroid trajectory, the cross marks explosion place. Concentric dashed lines show theoretical position of spherical wavefront propagating from the explosion place. The distance between the lines is 100km.

The joint analysis shows that the radial ionospheric disturbances with almost similar parameters were observed after meteoroid explosion both by EKB radar and GPS receivers network.

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