Variations of the total electronic concentration in the ionosphere in seismically active region

Valentin Kashkin[1], *Tatyana* Rubleva[1*], *Konstantin* Simonov[2], *Andrey* Zabrodin[1,3], and *Aleksey* Kabanov[1]

[1]Siberian Federal University, 79 Svobodny pr., 660041, Krasnoyarsk, Russia
[2]Institute of Computational Modeling SB RAS, 50/44 Akademgorodok, 660036, Krasnoyarsk,
[3]Russia[3]Federal Research Centre “KSC SB RAS”, 50 Akademgorodok, 660036, Krasnoyarsk, Russia

Abstract. In this work we studied the variations in the total electron concentration (TEC) obtained from measurements of the global navigation system GPS in the preparation zone for the 2010 catastrophic Chilean earthquake (M_w = 8.8) under calm background conditions at a minimum of 24 solar activity (SA) cycles. The analysis of the geodynamic activity and ionospheric TEC disturbances in the seismically active region of this catastrophic earthquake is carried out. A computational technique has been developed that can be used to study TEC variations over seismically active regions.

Introduction

The study of the ionosphere over seismically active regions according to the data of the global navigation systems GPS/GLONASS within the framework of geodynamic monitoring is an urgent task. It is emphasized in [1-3] that movements along a fault in the earth's crust in the region of the earthquake source lead to a significant effect on the atmosphere and emission of gravitational waves along the earth and oceanic surfaces. In [2] it is noted that internal gravitational waves lead to a change in the total electron concentration (TEC) in the ionosphere, which can be recorded by the GLONASS/GPS receiving equipment.

This work is devoted to the study of seismic data in the source zone of the future strong Chilean earthquake of 2010 with a magnitude of M_w = 8.8 and the total electron concentration variations in the ionosphere over these regions under relatively calm background conditions. It should be noted that the preparation of strong earthquakes takes a rather significant time period and requires multidimensional studies over the sources of upcoming seismic events.

The catastrophic earthquake in Chile occurred on February 27, 2010 [4]. The time period of our study is January-March 2009. This period is interesting for two reasons. First, it coincides with the beginning of the 24th solar activity cycle (SA), the formal beginning of which fell on January 2009 [5, 6]. Second, estimates were obtained in [7], from the analysis of which it follows that seismic activity is inversely proportional to solar activity.

* Corresponding author: tvrubleva@mail.ru

The correlation coefficient is R = - 0.8. As a result, in February 2010, Chile [8] experienced one of the most destructive earthquakes in the past 50 years. This earthquake caused a strong tsunami, the height of which reached 3 meters in the coastal zone of the province of Maule (coast of Chile).

The aim of our study is a detailed analysis of seismic data in the source zone of the strong Chilean earthquake of 2010 with M_w = 8.8. At the same time, relatively calm background geophysical conditions were observed. Also, the article refines the total electron concentration variations obtained on the basis of GPS measurements in the preparation area of this natural disaster.

1 Analysis of geomonitoring data

According to the USGS catalog [9] the analysis of geophysical information was carried out in the period from January to March 2009 in the source focal zone of the future Chilean earthquake M_w = 8.8. At the same time, relatively calm background geodynamic conditions were observed. According to updated information from [9] the source size was approximately 600 × 250 km. This zone had an elongated shape parallel to the western coast of Chile in the meridional direction. Its depth according to estimates in [4] reached a value of ≈ 45 km.

In our work according to [9] it was revealed that in January-March 2009, 32 seismic events of weak and medium strength were observed in the studied seismically active region, their magnitudes varied from 3.8 to 5.3.

The distribution of the magnitudes of weak and medium seismic events is shown in Fig. 1. Here, crustal earthquakes occurring at a depth of 70 km are highlighted in blue and intermediate earthquakes with a hypocenter from 70 to 300 km are highlighted in red. The depths of their hypocenters varied from 0.3 to 148 km.

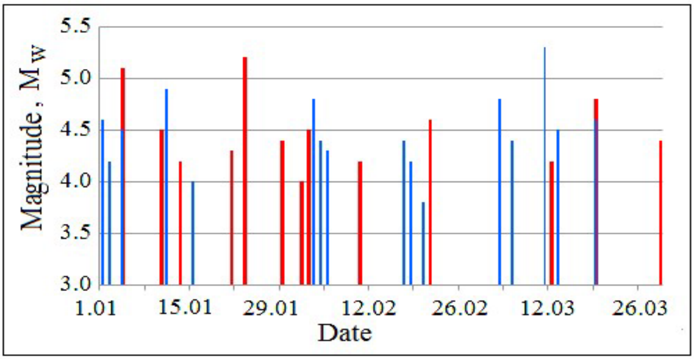

Fig. 1. Distribution of crustal and intermediate earthquakes with $M_w > 3$ from January to March 2009

The analysis of the spatial location of the studied seismic events in January-March 2009, according to [9] showed that twelve occurred underwater earthquakes were in the ocean near the junction of the two tectonic plates of Nazca and the South American one and the remaining twenty were near the Chilean coast in the transition zone land-ocean.

In the investigated seismically active area as can be seen in Fig. 1 during each month of the 2009 time period there was a sequential change of two dynamic modes in the form of seismic calm and geodynamic activity. The duration of these regimens in time varies from 1 day to 2 weeks. Probably, such a rhythm of oscillations in the focal zone of the future Chilean earthquake reflects the alternation of earthquakes differing in magnitude and depth of occurrence. As noted in [10] continuous and different-scale variations in the volume-stress state of the lithosphere at different depths are associated with the processes of interaction of ascending flows of light gases.

The detected oscillatory regime is probably related to the peculiarities of the development of seismicity in the studied region. The results obtained are consistent with the results of work [11] in which the foreshock events of 2000-2010 were considered in the region of the future Chilean earthquake and an increase in the number of earthquakes with a magnitude $M_w > 4$ in 2009 was revealed.

2 Ionospheric precursors of earthquakes

Anomalous disturbances (inhomogeneities) in the ionosphere were repeatedly found above the source zones of strong earthquakes during seismic activity [12, 13]. These atmospheric objects are structural elements of the ionospheric plasma and are recorded in the form of irregular deviations of its electron concentration and other characteristics from the average values [2].

Variations in the total electron concentration are studied as ionospheric precursors of strong earthquakes [12]. According to [14] TEC is the integral number of electrons contained in the vertical column of the atmosphere with a base at the earth's surface and up to the satellite's flight height with a cross section of 1 m^2. The total electron abundance is mainly determined by the electron concentration at the maximum of the ionospheric layer F_2 where the oxygen ion O_+ prevails.

TEC values obtained from GPS measurements are presented in a special IONEX format [15]. We have developed a method for processing this data. An archive of the values of the total electron concentration relative to the focal region of a strong earthquake with $M_w = 8.8$ was formed both for the background conditions in January-March 2009 and for active seismic processes in February 2010.

In Fig. 2 shows the variations in the TEC values from February 13 to March 13, 2010 relative to the focal region of the strong earthquake with $M_w = 8.8$. The TEC unit is: $1\text{TEC} = 10^{16}$ electron/m^2.

This period covers 2 weeks during the period of preparation of the seismic event and 14 days during the period of aftershock activity in the seismically active area. The arrow marks the date of February 27, 2010, when the catastrophic earthquake occurred in the province of Maule (Chile).

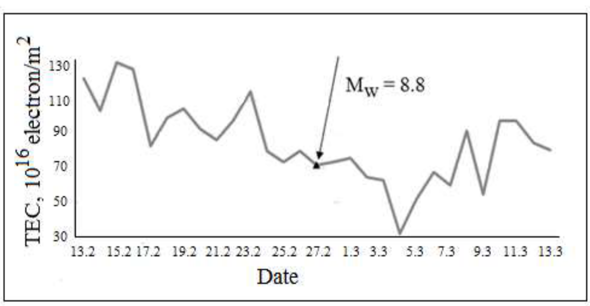

Fig. 2. TEC variations in the ionosphere relative to the epicentral region of the Chilean earthquake

As seen in Fig. 2 within 4 days from 23 to 27 February the total electron concentration values in the ionosphere over the focal area of the strong Chilean earthquake decreased from ($115x10^{16}$ electron/m^2) to ($72x10^{16}$ electron/m^2) by $43x10^{16}$ electron/m^2. In the next 3 days of aftershock activity the values of the total electron concentration over the focal region did not much exceed the value TEC = $72x10^{16}$ electron/m^2 determined for February 27, 2010.

Conclusion

In the course of the research the following results were obtained. A seismic database has been prepared for the source zone of the catastrophic Chilean earthquake of 2010 with $M_w = 8.8$. It was noted that relatively quiet background geodynamic conditions were observed in January-March 2009 at a minimum of 24 solar activity (SA) cycles.

An archive of TEC data obtained on the basis of GPS satellite information for the study periods in 2009 and 2010 has been formed. A method for processing and interpreting TEC data has been developed. A comparative analysis of geophysical and ionospheric data on the source zone of the Chilean earthquake during its preparation in January-March 2009 was performed. A detailed analysis of the total electron concentration values has been carried out which makes it possible to clarify the beginning of the preparation process in the source focal zone of the strong Chilean earthquake.

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