POSSIBILITY AND MEASUREMENT OF EARTHQUAKE PREDICTION BASED ON TREND STUDY OF TOTAL ELECTRON CONTENT (TEC) OF EARTH'S IONOSPHERE

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The article discusses a new breakthrough methodology for forecasting events and phenomena that are diverse in their physical nature. The article uses the total electron content trends (TEC) of the ionosphere as initial data for earthquake forecasting. The total electron content of the Earth's ionosphere is a good indicator of its state and its dynamics. It has been found that the most effective for earthquake forecasting are TEC indicators, recorded regularly during the several years preceding the forecasted earthquake.

KEYWORDS

Earthquakes forecasting, trend, electron content of the ionosphere.

1 INTRODUCTION

A significant disadvantage of the existing forecasting methods is the comparison of the monitored parameter (prognostic sign) current value with a certain normative (reference) value, which leads, as a rule, to an erroneous forecast.

This problem is especially acute when forecasting the condition and service life of unique products (nuclear power plants, bridge crossings, hydroelectric dams, large and unique mining equipment, etc.) and, of course, natural disasters [Console 2003, Giovambattista 2000, Faenza 2003, Balara 2018, Krehel 2013]. These forecasting failures are explained by the fact that each controlled object, strictly speaking, is unique, for which there is no standard.

Long-term experience of forecasting showed that as a prognostic sign it is necessary to consider not only the current value of the control parameter, but also take into account its change dynamics during the controlled object observation period.

In other words, the observed phenomenon should not be regarded as a statically frozen picture, but should be presented as a process whose characteristics continuously change throughout the observation period.

Externally, this process manifests itself as trajectory (trend) of a change in time of a controlled parameter. This trend contains information necessary for decision-making, both about the current state criticality degree of the controlled object, and about the moment it reaches its limit state.

So, trend control allows you to determine:

- in engineering – the accident time of man-made products and structures of various design and purpose, including unique and small-scale;
- in medicine - the disease exacerbation time;
- in seismology - the earthquakes time;
- in geomechanics - landslide descent time;
- in glaciology - the glaciers disappearance time, etc.

This problem fully applies to the earthquake forecast. The forecasting methods adopted in seismology, based on a comparison of the monitored parameters current values with their standard, do not lead to the desired result [Geller 1997, Gerstenberger 2005, Harte 2005, Kagan 1997, Keilis-Borok 1988, Keilis-Borok 1990].

The desire to expand the prognostic signs list, amounting to about three hundred, of course, does not solve the problem [King 2003, Kossobokov 1999, Lombardi 2002, Lombardi 2006, Marzocchi 2003, Marzocchi 2008, Krenicky 2012, Lesso 2014, Prislupcak 2014, Jurko 2012, Panda 2017, Straka 2013].

A significant place in these signs list is the Earth's ionosphere parameters, which are sensitive to changes in the seismic situation. The ionized shell of the Earth's atmosphere - the ionosphere - responds significantly to various processes taking place on the Earth's surface and near it in the lower atmosphere, and also, as shown recently, has a significant response to strong mechanical stresses that occur in the Earth's crust before seismic events [Sazhin 2014, Ivanov 2011, Zaborowski 2007]. Therefore, the ionosphere state studies and its change dynamics belong to one of the important Earth sciences directions. A good indicator of the ionosphere state and its variations is the ionosphere's total electron content (TEC) - the electrons number in a vertical column with a 1 m2 cross section and a height from the Earth's surface to the conditional ionosphere's end [Ivanov 2012, Klobuchar 1986, Radicella 2009].

In this regard, the aim of this work was to demonstrate the using trends possibility of total electronic content as prognostic signs of the forecasting earthquake, as well as another effectiveness confirmation of the new forecasting methodology.

The research subject was earthquake retrospective forecasting based on the prognostic signs observation, which were considered as trends in the total electronic content of the Earth's ionosphere.

The object of the research was the parameters characterizing the total electronic content recorded over the territory of Turkey for three years from 2009 to 2011, preceding the earthquake that took place in this country on October 23, 2011.

2 RESEARCH METHODOLOGY

Retrospective forecasting was carried out according to the results of the analysis of prognostic signs, which represented the trends of 12 TEC records. These trends were approximated by a forecast model. The approximation results determined the model parameters, which included the earthquake forecasted time. Mathematically, the approximation process was to minimize the functional *U(f)* (1).

$$U(f)=\left[\sum_{i=1}^{m}\left(P(t_i)-F(T_{PR},\alpha,\beta,\gamma..)\right)^2\right], \qquad (1)$$

where $P(t_i)$ – TEC magnitude; $F(T_{PR},\alpha,\beta,\gamma)$ – forecast model; T_{PR} – earthquake forecast time; α,β,γ – experimental model parameters determined in the approximation process.

The forecast quality was estimated by the forecast deviation degree from the earthquake actual date. The deviation dt was presented as a percentage and was calculated using the following formula:

$$dt = \frac{T_{PR} - T_{ACT}}{T_{ACT}} \cdot 100 \ \%, \qquad (2)$$

where T_{ACT} – the actual earthquake time.

3 RESEARCH RESULTS

The research results are presented in 8 figures. TEC indicators recorded in 2009 are shown in abbreviated form as an example in Fig. 1. Twelve parameters were recorded daily. The same information is graphically shown in Fig. 2.

0U	2U	4U	6U	8U	10U	12U	14U	16U	18U	20U	22U	DAY
5.7	5.8	6.2	7.8	11.3	9	9.1	7.2	6.8	6.1	6.2	5.7	1
5.5	5.5	6	7.6	10.2	9.7	9.5	7.2	6.4	4.9	5.1	5.1	2
4.8	4.9	6.5	8.2	10.7	10.3	12.1	9.3	7.3	7	7.6	6.8	3
6.4	6	6.3	7.8	10.9	10.2	9.4	7.3	6.4	5.9	6	5.6	4
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8.4	8.3	8.6	9.8	12.6	12.1	12.7	8.7	8.3	7.7	7.6	8.1	359
8.5	7.1	8.7	11.6	13.6	13.1	14.5	9.5	10.1	9.5	9.1	9.3	360
9.1	7.4	9.6	10.3	12.1	10.7	12.5	7.8	8.9	7.5	7.5	7.9	361
8	7.2	9.2	9.6	13.1	11.6	12.4	8.6	9.5	8.6	8	7.6	362
7.6	6.3	7.6	8.3	11.5	10.7	10.6	8.3	8.1	7.6	7.7	7.5	363
7.7	5.9	7.1	8.4	10.8	10.2	10.9	7.6	8.2	8.3	7.2	7.1	364
6.1	5.3	7.3	8.7	10.6	9.6	10.6	7.5	8.3	7	6.5	6.5	365

Figure 1. TEC magnitude recorded in 2009 on the eve of the earthquake in 2011

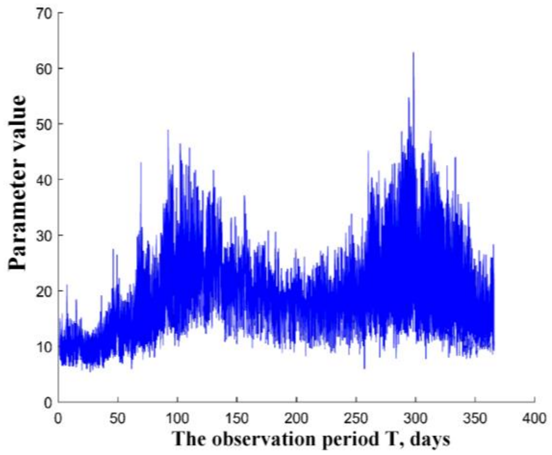

Figure 2. Typical graph of changes in the magnitude of the TEC during the year

The twelve TEC magnitude averaged monthly and observed over 3 years are shown in Fig. 3. Trends clearly show the nature of changes in prognostic signs during the three years preceding an earthquake. The figure also shows the earthquake moment.

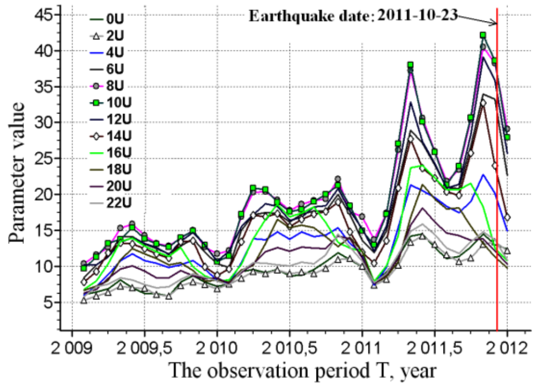

Figure 3. Trends of 12 monthly-averaged values of TEC, recorded over three years (2009 - 2011) on the eve of the earthquake

A typical example of approximating a trend as a prognostic sign by its forecast model is presented in Fig. 4.

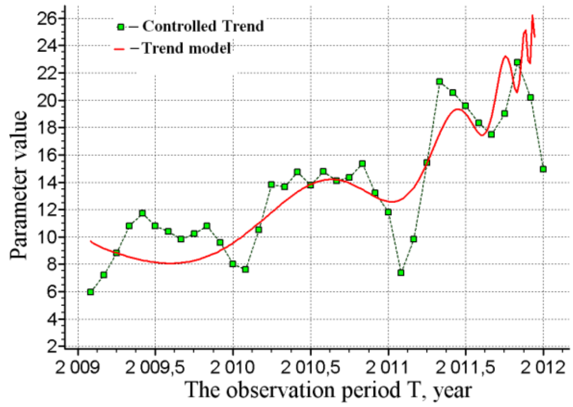

Figure 4. A typical example of the approximation of a trend, as a prognostic sign, its forecast model (parameter 4 U)

The change in forecasts over time obtained from the 12 trends analysis is shown in Fig. 5. The icons indicate the forecasts that have the smallest and greatest deviation from the actual earthquake date.

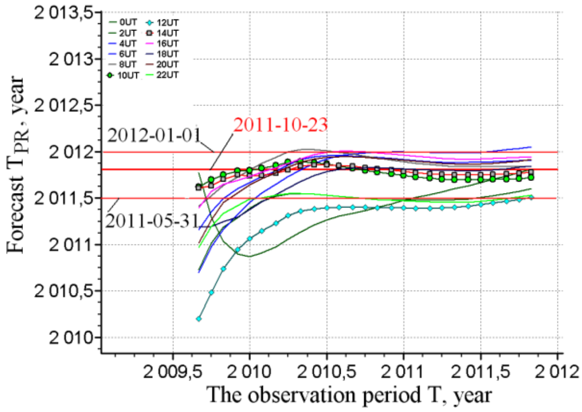

Figure 5. Forecasts of the earthquake moment, based on the analysis of each of the 12 trends recorded in 2009-2011

Deviations of the forecasts from the earthquake actual moment in Fig. 5, are shown in Fig. 6.

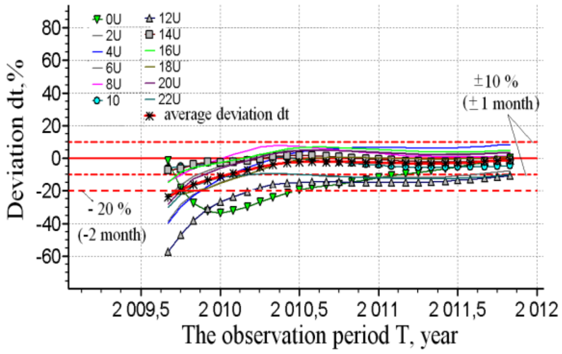

Figure 6. Forecasts deviations from the actual earthquake moment

Forecasts with a minimum deviation from the actual earthquake date (10/23/2011) are shown in Fig. 7 and 8. Forecasts are made based on the trends analysis monthly-averaged values of TEC parameters 10 U and 14 U. The forecast in absolute values is shown in Fig. 7, and the deviation of the forecast from the actual earthquake date is shown in Fig. 8.

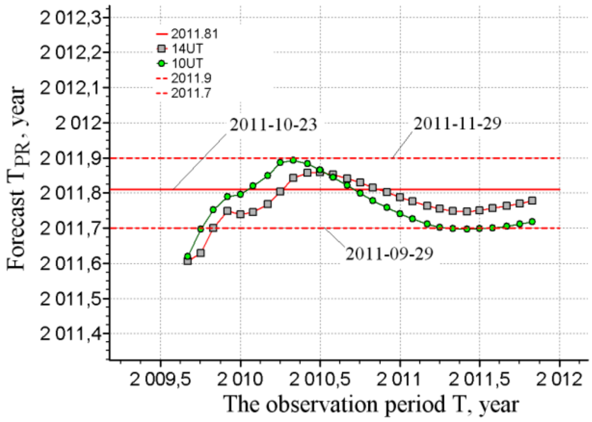

Figure 7. Forecasts based on trend analysis of TEC parameters 10 U and 14 U, which have the smallest deviation from the actual earthquake date

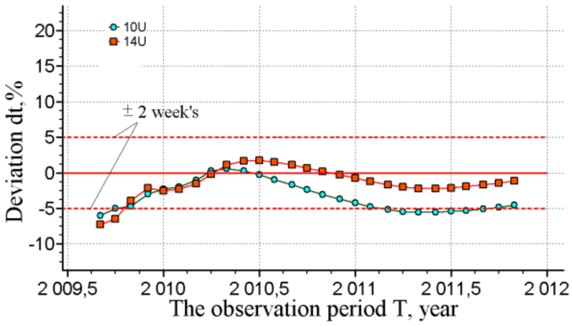

Figure 8. Forecasts deviations from the actual earthquake onset moment obtained based on the trends analysis of TEC parameters 10 U and 14 U

4 THE RESULTS DISCUSSION

The TEC parameters experience spring-autumn seasonal fluctuations in amplitude as follows from Fig. 2. However, this fact has zero information in next earthquake date forecasting.

And, on the contrary, combining in a single time series, three-year control parameters observations, contains information that is very valuable for forecasting, as follows from Fig. 3. So, this information indicates the presence of perceptible trend dynamics of controlled parameters. Moreover, each trend has a different dynamic. Thus, the trends over 10 U, 8 U and 12 U underwent the largest change in three years, and the least 0 U, 2 U and 22 U.

The forecast summary, given in fig. 5, indicates that starting from the middle of 2010, the forecast borders are narrowing and changing in percentage from - 20% to 10%. In months, this corresponds to the deviation of the forecast from the actual date by 1 month up and 2 months down.

Deviations of forecasts obtained by the analysis of trends 10 U and 12 U parameters (Fig. 7, 8) are within ± 5%. When moving to dates, this means that the forecast within two weeks fluctuates relative to the actual date of the earthquake (Fig. 9).

5 CONCLUSIONS

Thus, research, given in this document, indicate, firstly, the forecasting earthquakes possibility based on the trends study in the Earth's TEC parameters and, secondly, the developed methodology effectiveness for forecasting events and phenomena. The forecast made according to this methodology corresponds to the actual earthquake date (Fig. 9) and varies within: ± 5%.

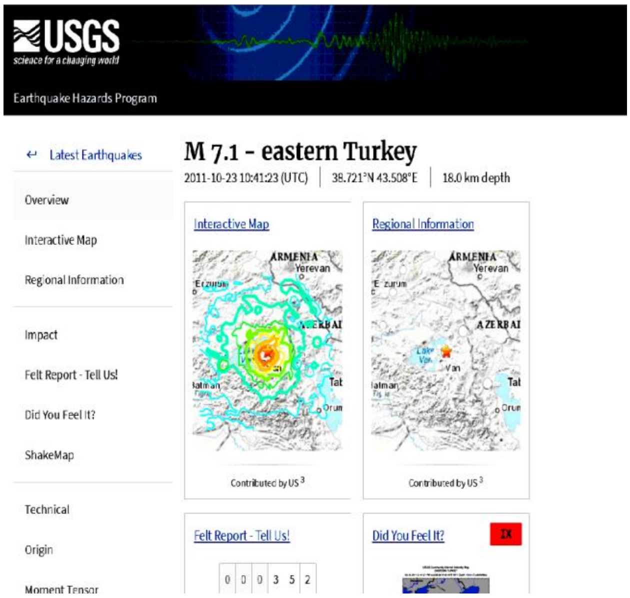

Figure 9. The earthquake parameters that occurred in Turkey on October 23, 2011

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