Study of Vertical Movements of the European Crust Using Tide Gauge and GNSS Observations

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Abstract – This research is devoted to the study of vertical movements of the European crust on the basis of two independent methods, namely tide gauge and GNSS observations results. The precision with which the movement of the earth's crust according to the results of tide gauge observations can be explored has been calculated. A methodology to identify the duration of tide gauge observations required for studies of vertical movements of the earth's crust has been presented. Approximation of tide gauge time series with the help of Fourier series has been implemented, the need for long-term observations in certain areas has been explained. The diagram of the velocities of the vertical movements of the European crust on the basis of the tide gauge data and GNSS observations has been built and the anomalous areas where the observations do not coincide have been identified.

Key words – vertical land movement, tide gauge, GNSS observations, sea level change.

I. Introduction

Information about slow movements of the earth's crust (especially in tectonically unstable areas) is becoming more and more necessary when creating the reference geodetic networks, the design of large long-term facilities - ports, canals, hydroelectric power stations.

Today there are different methods of observation of the movements of the earth's crust; in particular, it is explored by the use of geodetic, geophysical, oceanographic and geomorphological methods.

II. The influence of the duration of tide gauge observations on the precision of determination of the vertical movements of the earth's crust

It is clear that the longer observations are the more valuable they are for the analysis. For short periods of observations, the value of the RMS errors is higher, highlighting thereby the influence of interannual variations.

For each countdown on the tide gauge we made an equation (1):

$$h_i = -Vt_i + a\,, \qquad (1)$$

where a - unknown coefficient; V - unknown velocity; h_i - countdown on the tide gauge to the epoch t_i.

Solution of the system of equations by the least squares method allows to determine the earth crust velocity V and coefficient a. Precision m of the velocity determination V from time series was calculated from equation (2):

$$m = \frac{\sum_{i=1}^{n}\left[h_i + Vt_i - a\right]^2}{n-1}\,, \qquad (2)$$

where n - number of countdowns.

Graphic image of the desired duration of observations on the European tide gauges to achieve a precision of 0.3 mm/yr is presented in Figure 1.

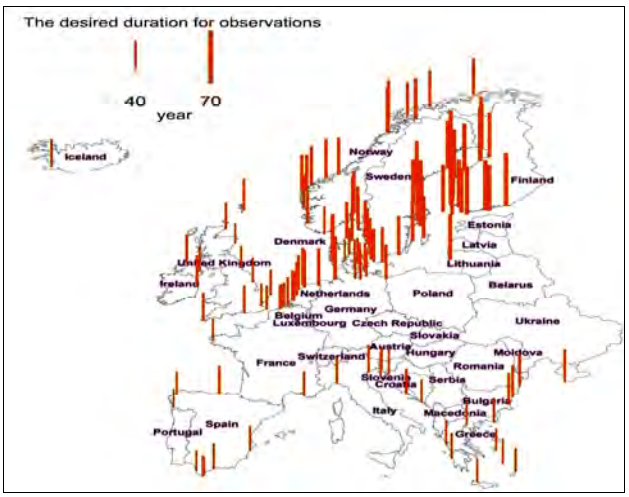

Fig. 1. Graphic image of the desired duration of observations on the European tide gauges to achieve a given precision 0.3 mm/yr

III. Comparison of the results from tide gauge observations with the corresponding GNSS observations

For each countdown on the GNSS receiver we made an equation (3):

$$h_i = Vt_i + a\,, \qquad (3)$$

where a - unknown coefficient; V - unknown velocity; h_i - height, measured by GNSS reciever on the epoch t_i.

Solution of the system of equations by the least squares method allows to determine the earth crust velocity V and coefficient a. Precision m of velocity determaination V from time series was calculated from equation (4):

$$m = \frac{\sum_{i=1}^{n}\left[h_i - Vt_i - a\right]^2}{n-1}\,, \qquad (4)$$

where n - number of countdowns.

The value of the precision m of the linear velocity V is within $0.03 \le m \le 0.30$ mm/yr.

After this the diagram (Fig. 2) of velocity (mm/yr) of vertical movements of the European crust was built on the basis of the results tide gauge and GNSS observations.

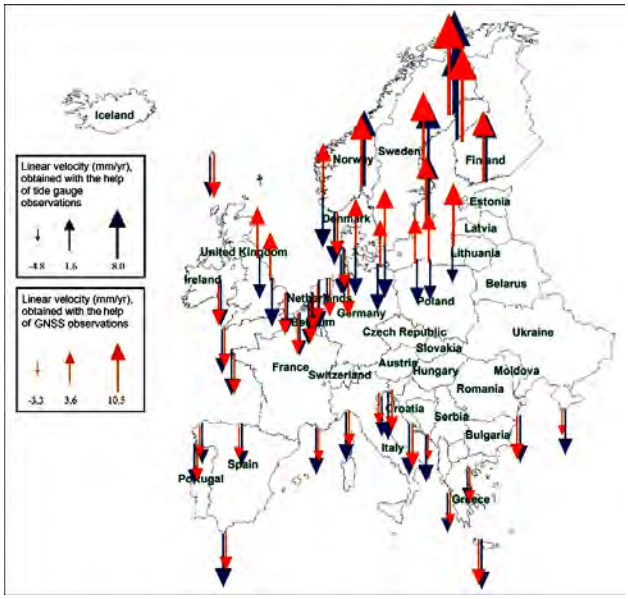

Fig. 2. Diagram of velocity (mm/yr) of vertical movements of the earth's crust, based on the results of tide gauge and GNSS observations

List of tide gauges and GNSS stations, which show differences in the results of determining the vertical movements of the crust, are shown in Table 1.

TABLE 1

LIST OF TIDE GAUGES AND GNSS STATIONS, WHICH SHOW DIFFERENCES IN THE DEFINITIONS OF THE VERTICAL MOVEMENTS OF THE EARTH'S CRUST

Country	Station name	Time of data	B,°N	L,°E	V, mm/yr	D, km
Norway	Stavanger	1919 - 2012	58.97	5.73	-0.45±0.11	8.94
	STAS	2001 - 2014	59.02	5.60	1.62±0.21	
Lithuania	Klaipeda	1949 - 2011	55.70	21.13	-3.11±0.35	1.89
	KLPD	2005 – 2009	55.72	21.12	3.42±0.13	
Poland	Wladyslawowo	1951 - 1999	54.80	18.42	-2.48±0.46	0.37
	WLAD	2003 – 2010	54.80	18.42	0.83±0.06	
	Ustka	1951 - 1999	54.58	16.87	-1.75±0.43	20.40
	REDZ	2008 – 2014	54.47	17.12	0.38±0.09	
Denmark	Hornbaek	1898 - 2012	56.09	12.46	-0.41±0.10	39.24
	BUDP	2005 - 2014	55.74	12.50	2.15±0.21	
	Fredericia	1890 - 2012	55.56	9.75	-1.10±0.05	15.17
	SMID	2003 - 2014	55.64	9.56	1.04±0.16	
Germany	Warnemunde 2	1855 - 2011	54.17	12.10	-1.25±0.05	0.16
	WARN	2003 - 2014	54.17	12.10	0.58±0.15	
UK	North Shields	1895 - 2012	55.01	-1.44	-2.24±0.20	0.07
	NSTG	2003 - 2010	55.01	-1.44	1.28±0.07	
	Immingham	1960 - 2011	53.63	-0.19	-1.03±0.19	20.11
	EASN	2005 - 2010	53.65	-0.12	0.79±0.09	

The land on which differences in the results are observed extends within 55-60°N and 5°W-25°E. The reasons for these differences require further investigation. At these stations the average RMS errors are within the definition of the values of the linear velocities. Perhaps the dominant contribution to the sea level in this region makes the oceanographic component or gravitational anomalies.

Conclusion

The precision with which the crustal movements of the European coastline according to the results of tide gauge observations was substantiated. Its value is 0.3 mm/yr.

The necessary duration of tide gauge observations in order to achieve this precision is not the same throughout Europe. It varies depending on geographical location and oscillates between 30-69 years. For the territory Fennoscandia this duration is 40-69 years, for tide gauges, which are located in Belgium, the Netherlands, and Germany the duration is 37-58 years. The tide gauge located on the territory of Spain, needs 30-41 years of observations to achieve a precision of vertical offset determination of 0.3 mm/yr. The calculated values of the linear velocities obtained from tide gauge and GNSS observations, in most cases, coincide with each other. This may indicate that the cause of changes in sea level is rising or sinking of the earth's crust in this region.

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