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DETERMINATION OF MEAN SEA LEVEL CHANGE OF THE BALTIC SEA ACCORDING TO TIDE-GAUGE OBSERVATIONS

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Formulation of the problem. Today, due to global climate changes in the world, evaluation of levels of seas and oceans is a question of urgent importance because this process affects a large number of spheres of the countries washed by seas and oceans. Therefore maritime countries are interested in the study and research of these tendencies and changes. Determination of sea level change is an important part of climate research because increasing sea level is one of the most tangible effects of climate change. Measurements of sea level changes of the Baltic Sea began in 1707 when the service that gave rise to the Baltic metres above sea level began working in Kronstadt. The Baltic Sea is interesting to study because it is an inland sea located in Northern Europe, and is of interest to many European countries. For example, in Poland mean sea level has been determined for the longest period of time in Swinoujscie for about 200 years. During that period, mean sea level rose by 22 cm. This means that the area of land is decreasing. Now flooding along the coast line is recorded not only in Poland but also in the north of Germany, Lithuania and Latvia. In general, due to global warming, mean water level increases in all the seas surrounding our continent. Nearly 240,000 people living at the Polish coast faced the threat of flooding.

To investigate mean sea level change there is the most frequently used method of satellite altimetry, because in 20 years data of satellite altimetry have become a very important tool in building the geoid parallel to water levels, calculating mean sea level and zero levels. Also for these calculations data of tide-gauge observations are used. The topicality of this theme lies in the need to respond to actual and potential sea level changes of the Baltic Sea.

Analysis of recent researches and publications. In 2015 at Copenhagen conference dedicated to adaptation to climate changes, the report "The second evaluation of climate changes at the Baltic Sea basin" was presented. In its preparation the results of studies of 141 researchers (meteorologists, hydrologists, oceanographers and biologists) from the countries surrounding the Baltic Sea have been used. The work was coordinated by the International scientific research project of the Baltic Sea “Baltic Earth Center” named after Helmholtz in Geesthacht. The report has presented the results of climate change, observed in the last 200 years, and given the projection made by computer simulation that will have taken place by the end of the XXI century.

The studies of mean sea level changes of the Black and Baltic Seas are described in the papers [2,3,4,5]. The mean sea level changes of Black and Baltic Seas were defined according to satellite altimetry missions ERS-1, ERS-2, TOPEX-POSEIDON from 1992 to 2001.

Objectives setting. We are to determine mean sea level change of the Baltic Sea according to tide-gauge observations from 1994 to 2012 and also analyze the results.

Research methodology. Permanent Service for Mean Sea Level (PSMSL) deals with collection, publication, analysis and interpretation of data on sea level [6,7].

PSMSL was founded in 1933 in Liverpool by the National Oceanography Centre (NOC) which is an integral part of the Natural Environment Research Council of the UK. NOC undertakes integrated ocean research and technology development from the coast to the deep ocean. It provides long-term marine science capability including: major facilities; sustained ocean observing, mapping and survey; data management, and scientific advice. PSMSL is a member of Federation of Astronomical and Geophysical Data Analysis Services (International Council for Science). In addition to its primary role of functioning global database of sea level, PSMSL advises operators and analysts of tide generating force. It occupies a central role in the management and development of the Global Sea Level Observing System (GLOSS) and organizes important international study groups to study and analyze important topics. A set of interactive maps allows users to explore sea level change worldwide, using data from tide-gauge entering the global sea level database PSMSL system. PSMSL database is forming through results of tide-gauge observations. A set of data is freely available. PSMSL database is available to the scientific community at the Internet site of PSMSL [6].

Figure 1 shows the location of PSMSL-stations along the coastline of the World Ocean.

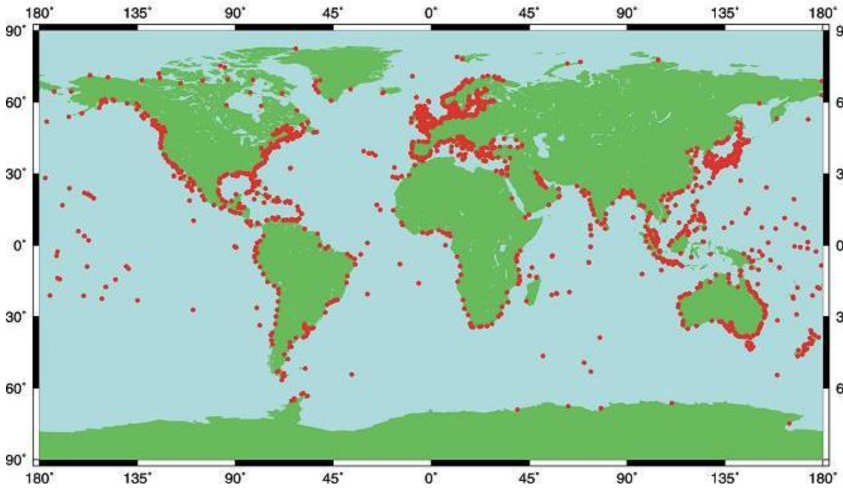

Fig.1. Location of tide-gauges along the coastline of the World Ocean

On the Website of PSMSL there is some information about each PSMSL-station on a separate page. There is a separate section «Data», where a table describes the main characteristics and tide-gauge data measurements over particular period of time. Figure 2 shows an example of information on tide-gauge KOBENHAVN (Denmark). Features of PSMSL-station include station latitude and longitude, coastline code, station code, country, percentage of completeness observations, observation code, observation period, the date of the last update, and the tide-gauge location on the map. Green indicates the PSMSL-station and yellow shows neighboring stations.

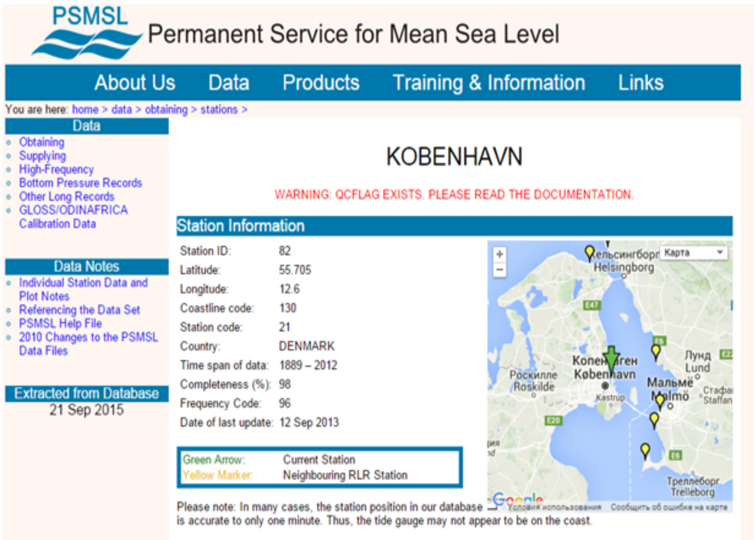

Fig.2. Example of information about PSMSL-station

Tide-gauge measurements are carried out constantly, therefore to simplify the process of search, the information was composed into monthly and yearly units. Tide-gauge measurements make it possible to display sea and ocean level changes and fluctuations graphically. Data of PSMSL-service as a source material were used, namely the average data of sea level changes in monthly values. 42 tide-gauges were chosen to determine sea level changes in the Baltic Sea.

They are located in the following countries: Finland, Lithuania, Germany, Denmark, and Sweden. Fig. 3 shows the location of PSMSL-stations along the coastline of the Baltic Sea. Consequently we may see judging by Fig. 3 that not the whole coastline of the Baltic Sea provided with data, mainly data are absent on southeastern coast of the Baltic Sea.

Fig. 3. Layout of tide-gauges along the coastline of the Baltic Sea

To determine sea level change in the Baltic Sea from 1994 to 2012 you need to conduct a linear trend evaluation according to tide-gauge observations. This evaluation was made at each station in particular. Figure 4 illustrates the linear trend evaluation of mean sea level change of the Baltic Sea on a monthly basis at stations KOBENHAVN (Denmark) and RATAN (Sweden).

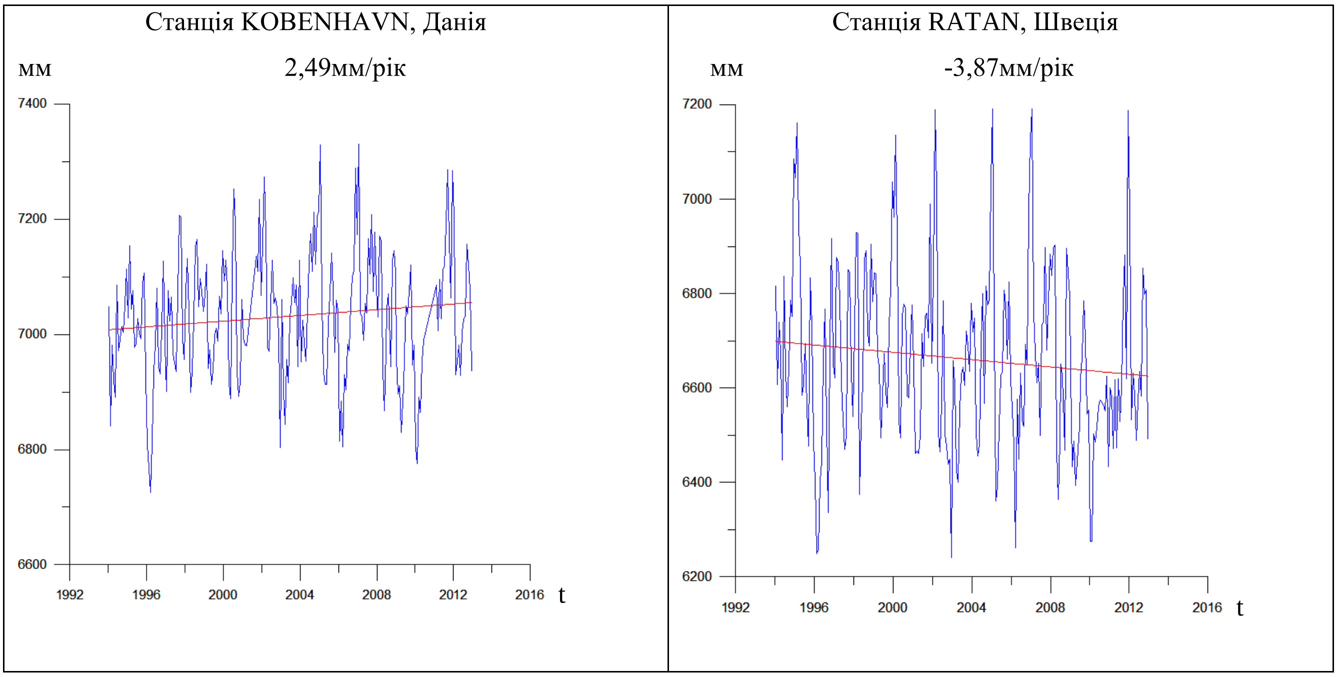

Fig.4. Linear trend evaluation of mean sea level change of the Baltic Sea on a monthly basis at stations KOBENHAVN (Denmark) (on the left hand) and RATAN (Sweden) (on the right hand).

Table 1 presents information that includes information on tide-gauges, namely: ID number, country name, station name, latitude and longitude, where tide-gauge is located, and mean sea level change.

Table 1

Calculated changes in the Baltic Sea at PSMSL-stations (1992-2012)

№	id	country	Name of the station	B	L	Level change (мм)
1	14	Finland	HELSINKI	60,154	24,956	1,18
2	57	Finland	VASA	63,082	21,571	-3,94
3	71	Finland	HANGO	59,823	22,977	1,38
4	79	Finland	ULEABORG	65,04	25,418	-2,66
5	172	Finland	MANTYLUOTO	61,594	21,463	-2,1
6	194	Finland	JAKOBSTAD	63,709	22,69	-3,47
7	229	Finland	KEMI	65,673	24,515	-2,96
8	239	Finland	ABO	60,428	22,101	-0,27
9	240	Finland	BRAHESTAD	64,666	24,407	-4,02
10	249	Finland	DEGERBY	60,032	20,385	-0,71
11	285	Finland	KASKO	62,344	21,215	-2,86
12	315	Finland	HAMINA	60,563	27,179	2,46
13	376	Finland	RAUMO	61,134	21,426	-1,45
14	118	Lithuania	KLAIPEDA	55,7	21,133	4,44
15	8	Germany	WISMAR 2	53,899	11,458	3,65
16	11	Germany	WARNEMUNDE 2	54,17	12,103	4,26
17	13	Germany	TRAVEMUNDE	53,958	10,872	3,72
18	397	Germany	SASSNITZ	54,511	13,643	5,67
19	789	Germany	KIEL-HOLTENAU	54,372	10,157	3,37
20	1448	Germany	KOSEROW	54,06	14,001	2,37
21	82	Denmark	KOBENHAVN	55,705	12,6	2,49
22	98	Denmark	SLIPSHAVN	55,288	10,828	2,72
23	113	Denmark	KORSOR	55,332	11,142	1,51
24	120	Denmark	GEDSER	54,573	11,926	4,48
25	762	Denmark	RODBYHAVN	54,656	11,349	2,02
26	1197	Denmark	FYNSHAV	54,995	9,987	3,32
27	1812	Denmark	TEJN	55,25	14,838	2,6
28	69	Швеція	OLANDS NORRA UDDE	57,366	17,097	0,98
29	70	Sweden	KUNGSHOLMSFORT	56,105	15,589	2,89
30	78	Sweden	STOCKHOLM	59,324	18,082	0,4
31	88	Sweden	RATAN	63,986	20,895	-3,87
32	203	Sweden	FURUOGRUND	64,916	21,231	-2,56
33	330	Sweden	KLAGSHAMN	55,522	12,894	1,46
34	1211	Sweden	SPIKARNA	62,363	17,531	-2,68
35	2101	Sweden	KALIX	65,697	23,096	-2,98
36	2102	Sweden	SKAGSUDDE	63,191	19,013	-3,78
37	2103	Sweden	FORSMARK	60,409	18,211	-0,73
38	2104	Sweden	MARVIKEN	58,554	16,837	0,18
39	2105	Sweden	VISBY	57,639	18,284	1,14
40	2106	Sweden	OSKARSHAMN	57,275	16,478	3,41
41	2108	Sweden	SKANOR	55,417	12,829	5,25
42	2109	Sweden	BARSEBACK	55,756	12,903	3,73

After receiving the results we build the map of mean sea level changes of the Baltic Sea, using the method of interpolation spline functions [1]. Fig. 5 shows mean sea level change of the Baltic Sea, according to tide-gauge observations.

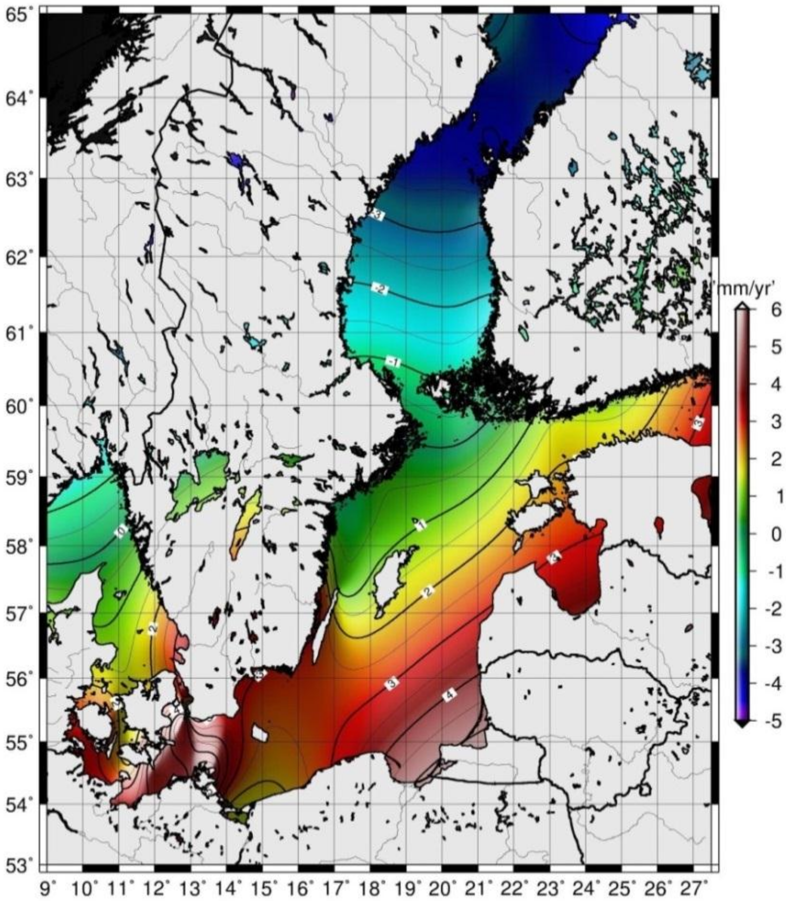

Fig.5. Sea level change of the Baltic Sea, according to tide-gauge observations

Summary. Firstly, we have made linear trend evaluation of mean sea level changes of the Baltic Sea for each tide-gauge based on the measured values for the sea level. Secondly, we have built the map of sea level change of the Baltic Sea after processing the data. Consequently, on analyzing the results we may conclude that the level of the Baltic Sea is rising along the coastlines of Denmark, Germany, Poland, Lithuania, and lowering along the coastlines of Finland and Sweden. Therefore, we see that the sea level is decreasing the northern part of the Baltic Sea. This can be explained by the fact that Scandinavia continues rising, thus the Baltic Sea floods coastlines of the countries that are located in the south of the Baltic Sea.

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