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DETERMINATION OF THE SLOPE OF THE WATER SURFACE IN THE GULF OF FINLAND

by

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Abstract

The annual variation of the slope of the water surface in the Gulf of Finland is determined on the one hand using meteorological and hydrographic data, on the other hand on the basis of sea level records.

The annual variations in sea level in the Baltic are caused by three principal factors: changes in the direction and velocity of the wind, fluctuations in atmospheric pressure, and changing density of the sea water. However, the whole is a very complicated problem and it is generally not easy to separate the influence of the different factors. When studying the conditions in a more or less limited sea region the best way is therefore to simplify the problem and select the sea level at a fixed station as a reference level for the variations. A comparison of the sea heights at other stations with this level then gives, of course, not the actual annual sea level variations, but the fluctuations of the slope of the water surface.

In a recent study [2] the author computed the annual variations of the slope of the water surface in the Gulf of Bothnia. The results were reached in two independent ways: on the one hand they were based exclusively on the above-mentioned meteorological and hydrographic data; on the other hand, only sea level records were used. The correspondence between the two series was very satisfactory, the mean error of the deviations amounting, as a rule, to 10% only of the total amplitude of the annual variations. The Gulf of Bothnia, being separated from the

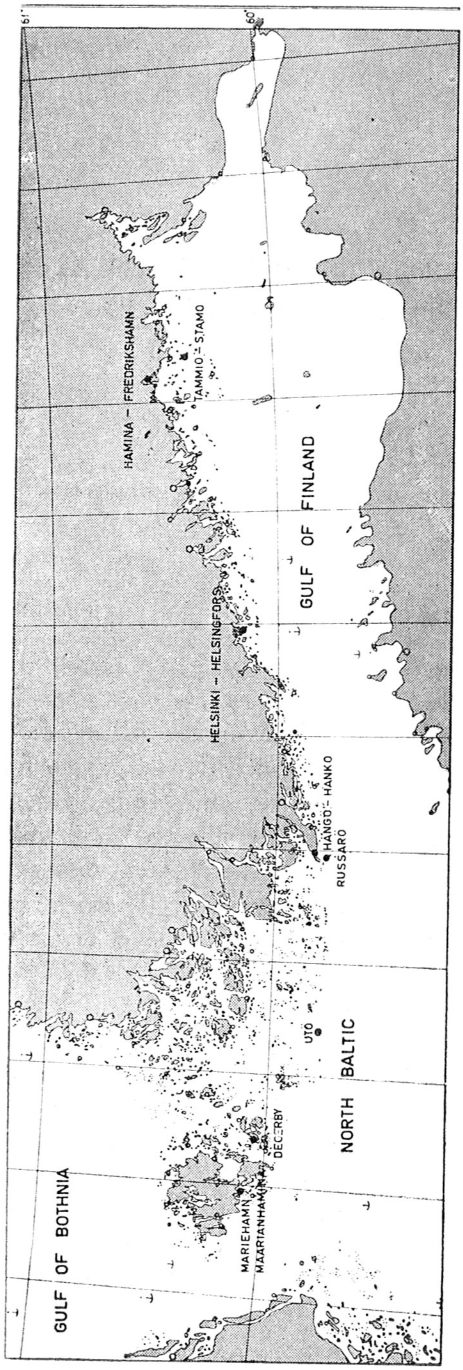

Figure 1. The location of the stations.

Baltic proper by sills and numerous islands, is, without doubt, especially suitable for a study of the slope of the water surface. In the Gulf of Finland the conditions are in many respects less favourable for this purpose, the Gulf being an immediate continuation of the northern part of the Baltic proper and thus not forming a comparatively separated sea area. Moreover, the annual variation in density in the Gulf of Finland has a considerably larger amplitude than in the Gulf of Bothnia, and the increase in density with depth, owing to the marked increase in salinity, is much more pronounced in the former basin than in the latter. This makes the determination of a level at which pressure differences may be considered practically negligable more difficult. The consequence is that all the data based on density are more or less uncertain.

Nevertheless, in order to get results comparable with those for the Gulf of Bothnia, the depth of 20 m was used as a reference level for the determination of the annual variation in density. Indeed, this was a necessity insofar, as Tammio (Stamö), the easternmost station at which continual observations on temperature and salinity are made in the Gulf of Finland by the Finnish Institute of Marine Research, reaches this depth. Besides the temperature and salinity data for Tammio, we have used for the determination of the annual course of density the corresponding mean values for Russarö and Utö, all computed by GRANQVIST [1]. The annual variations in the height of sea level caused by decreasing density in different parts of the Gulf of Finland and adjoining regions of the Baltic proper are given in Table 1.

The average values for the whole year show that the increase in the height of the sea level and thus the decrease in density is considerable in the Gulf of Finland. In fact, in round figures it is double that in the Gulf of Bothnia. In this connexion, it may also be pointed out that the data in Table 1 correspond fairly close with the distribution of the steric sea levels computed by WITTING [5] for the Gulf of Finland.

The amplitude of the annual variations in sea level caused by decreasing

Table 1. Annual variations of sea level differences (cm) caused by decreasing density in the Gulf of Finland and adjacent region.

Area	J	F	M	A	M	J	J	A	S	O	N	D	Year
Tammio—Utö	4.0	3.7	4.0	4.1	4.1	3.4	3.2	3.2	3.4	3.4	3.8	4.0	3.7
Tammio—Russarö	3.3	3.2	3.1	3.2	3.1	2.3	2.6	3.0	3.3	3.0	3.0	3.0	3.0

Table 2. Monthly air presure differences (mb) between Mariehamn and Helsinki.

J	F	M	A	M	J	J	A	S	O	N	D	Year
—1.1	—0.1	0.7	0.3	0.1	0.7	0.4	0.1	0.4	—0.1	—0.4	—0.4	0.0

density is thus, according to Table 1, relatively slight. The effect of the differences in atmospheric pressure on the water heights is somewhat more pronounced. For the determination of this influence the monthly averages of observations on air pressure made in Helsinki (Helsingfors) and Mariehamn (Maarianhamina) during the 20 year period 1921—1940 were used. Table 2 gives these values. On an average for the whole year, there is no pressure difference between Mariehamn and Helsinki, but there exists nevertheless a distinct annual course, the atmospheric pressure at the former station in comparison with the latter being at its lowest in January and at its highest in June. The amplitude amounts to 1.8 mb.

The most important factor influencing the annual variations of the slope of the water surface is, of course, the wind. In computing the effect of the wind upon the sea level we have followed the same method as for the Gulf of Bothnia [2], using a formula given by PALMÉN [4]. This formula had to be modified to some degree, as it was originally worked out for an actual case and not for the evaluation of the monthly averages. The formula used was

$$\Delta H = \frac{3.2\,\alpha L v^2}{d} \qquad (1)$$

where ΔH is the difference in sea level heights in cm for a horizontal distance L, given in 100 km, d the average depth in m of the sea area concerned, and v the average monthly wind velocity in m per sec. α is a factor indicating the relative frequency of different wind directions. When the problem concerns the computation of the piling-up of water caused by wind in the Gulf of Finland, where the main axis lies approximately in the direction WSW—ENE, the most important wind directions are, on the one hand W and SW, on the other hand E and NE. If the relative number of winds covering the former group is denoted by n_W, the corresponding number for the latter group being n_E, the relation

$$\alpha = \frac{n_W - n_E}{n_W + n_E}$$

computed for every month indicates the annual course of the wind effect upon the sea level. In this connexion it may be stressed that the use of formula (1) for monthly averages doubtless involves certain sources of error, but they hardly influence the results so much as to alter the general picture of the phenomenon.

The numerical determination of the effect of the wind upon the sea level was based on the data given by NURMINEN [3]. These data, covering the area of the Northern Baltic and the region of Hangö (Hanko), refer to the 15 year period 1921—1935. The average monthly values for wind velocity and the factor α, used in the following, are collected in Table 3.

Table 3. The annual course of average wind velocities (m per sec) and the factor α in the area of the Northern Baltic and the region of Hangö.

	J	F	M	A	M	J	J	A	S	O	N	D
Average wind velocity	4.9	4.0	3.5	3.4	3.3	3.5	3.3	3.4	3.9	4.5	4.2	4.4
Factor α	0.46	0.10	0.33	0.01	0.16	0.49	0.39	0.47	0.43	0.50	0.30	0.37

Passing from meteorological data to the sea level records, the first step was to determine for the tide gauge stations Hamina (Fredrikshamn), Helsinki, Hangö and Degerby the annual variations for each station referring to the corresponding mean sea level. The period used was 1926—1955. For the stations Hamina and Hangö observations were missing for a few years; they were computed by means of interpolation. The results are given in Table 4.

Although the deviations between the annual course for different stations are not marked, they are quite distinct. It may, for instance, be mentioned that in February the mean sea level at Degerby is 1.0 cm

Table 4. The annual variations of sea level (cm) in the Gulf of Finland and adjoining area.

Station	J	F	M	A	M	J	J	A	S	O	N	D
Hamina	2.0	—6.8	—11.3	—8.2	—14.5	—3.7	4.7	6.1	8.0	11.2	4.8	7.7
Helsinki	1.7	—6.9	—10.8	—7.6	—13.7	—3.2	5.1	6.1	7.3	10.3	4.3	7.1
Hangö	2.2	—6.5	—11.0	—7.6	—13.7	—3.6	5.2	6.4	6.9	10.1	4.6	7.1
Degerby	2.5	—5.8	—11.2	—8.0	—14.0	—3.4	5.4	6.6	6.7	9.6	4.8	7.3

higher than at Hamina, in October 1.6 cm lower. There is thus a relative height alteration of 2.6 cm. In order to obtain a complete picture of the relative sea levels in the course of the year these heights were computed with regard to Degerby and to Hangö. In the former case the deviations are somewhat more pronounced, owing to the longer distance between the stations; in the latter case the data are restricted to the Gulf of Finland proper which in many respects may be of considerable advantage. Table 5 gives these values.

Table 5. Relative sea level heights (cm) with the data for Degerby and Hangö as reference level.

	J	F	M	A	M	J	J	A	S	O	N	D
					Degerby as reference level							
Hamina	—0.5	—1.0	—0.1	—0.2	—0.5	—0.3	—0.7	—0.5	1.3	1.6	0.0	0.4
Helsinki	—0.8	—1.1	0.4	0.4	0.3	0.2	0.3	—0.5	0.6	0.7	—0.5	—0.2
					Hangö as reference level							
Hamina	—0.2	—0.3	—0.3	—0.6	—0.8	—0.1	—0.5	—0.3	1.1	1.1	0.2	0.6
Helsinki	—0.5	—0.4	0.2	0.0	0.0	0.4	—0.1	—0.3	0.4	0.2	—0.3	0.0

A more close study of the data in Table 5 reveals a relatively complicated picture. For instance, the slope of the water surface between Hamina and Degerby shows four maxima and four minima in the course of the year. We shall return to this question later in this study.

These preliminary computations completed, the determination of the annual variations of sea level differences on the basis of two independent series of observational data involved no difficulty. Tables 6—9 reproduce the results. The first line of these tables gives the water height differences caused by decreasing density and based on the values collected in Table 1.

Table 6. Sea level differences (cm) between Hamina and Degerby.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Density effect	4.0	3.7	4.0	4.1	4.1	3.4	3.2	3.2	3.4	3.4	3.8	4.0	3.7
Air pressure effect	—1.4	—0.1	0.9	0.4	0.1	0.9	0.5	0.1	0.5	—0.1	—0.5	—0.5	0.0
Wind effect	2.7	0.4	1.0	0.0	0.4	1.5	1.1	1.3	1.6	2.5	1.3	1.7	1.3
Total	5.3	4.0	5.9	4.5	4.6	5.8	4.8	4.6	5.5	5.8	4.6	5.2	5.0
Sea level	4.5	4.0	4.9	4.8	4.5	4.7	4.3	4.5	6.3	6.6	5.0	5.4	5.0
Difference	0.8	0.0	1.0	—0.3	0.1	1.1	0.5	0.1	—0.8	—0.8	—0.4	—0.2	—

Table 7. Sea level differences (cm) between Helsinki and Degerby.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Density effect	2.4	2.2	2.6	2.7	2.7	2.3	1.9	1.8	1.8	2.0	2.3	2.4	2.3
Air pressure effect	—1.1	—0.1	0.7	0.3	0.1	0.7	0.4	0.1	0.4	—0.1	—0.4	—0.4	0.0
Wind effect	1.4	0.2	0.5	0.0	0.2	0.8	0.6	0.7	0.8	1.3	0.7	0.9	0.7
Total	2.7	2.3	3.8	3.0	3.0	3.8	2.9	2.6	3.0	3.2	2.6	2.9	3.0
Sea level	2.2	1.9	3.4	3.4	3.3	3.2	2.7	2.5	3.6	3.7	2.5	2.8	3.0
Difference	0.5	0.4	0.4	—0.4	—0.3	0.6	0.2	0.1	—0.6	—0.5	0.1	0.1	—

Table 8. Sea level differences (cm) between Hamina and Hangö.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Density effect	3.3	3.2	3.1	3.2	3.1	2.3	2.6	3.0	3.3	3.0	3.0	3.3	3.0
Air pressure effect	—0.8	0.0	0.5	0.2	0.0	0.5	0.3	0.0	0.3	0.0	—0.3	—0.3	0.0
Wind effect	1.8	0.3	0.6	0.0	0.3	1.0	0.8	0.9	1.0	1.6	0.8	1.2	0.9
Total	4.3	3.5	4.2	3.4	3.4	3.8	3.7	3.9	4.6	4.6	3.5	4.2	3.9
Sea level	3.7	3.6	3.6	3.3	3.1	3.8	3.4	3.6	5.0	5.0	4.1	4.5	3.9
Difference	0.6	—0.1	0.6	0.1	0.3	0.0	0.3	0.3	—0.4	—0.4	—0.6	—0.3	—

Table 9. Sea level differences (cm) between Helsinki and Hangö.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Density effect	1.6	1.5	1.5	1.5	1.5	1.1	1.3	1.4	1.6	1.4	1.4	1.6	1.4
Air pressure effect	—0.4	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.0	—0.1	—0.1	0.0
Wind effect	0.8	0.1	0.3	0.0	0.1	0.4	0.3	0.4	0.5	0.7	0.4	0.5	0.4
Total	2.0	1.6	2.0	1.6	1.6	1.7	1.7	1.8	2.2	2.1	1.7	2.0	1.8
Sea level	1.3	1.4	2.0	1.8	1.8	2.2	1.7	1.5	2.2	2.0	1.5	1.8	1.8
Difference	0.7	0.2	0.0	—0.2	—0.2	—0.5	0.0	0.3	0.0	0.1	0.2	0.2	—

The second line indicates the relative effect of the atmospheric pressure interpolated or extrapolated for the different distances with the aid of Table 2. The third line gives the influence of the wind, computed for the particular stations from formula (1) using the data for the average wind velocity and for the factor α given in Table 3. The fourth line shows the total effect of the above-mentioned hydrographic and meteorological factors. In the fifth line are reproduced the sea level data from Table 5

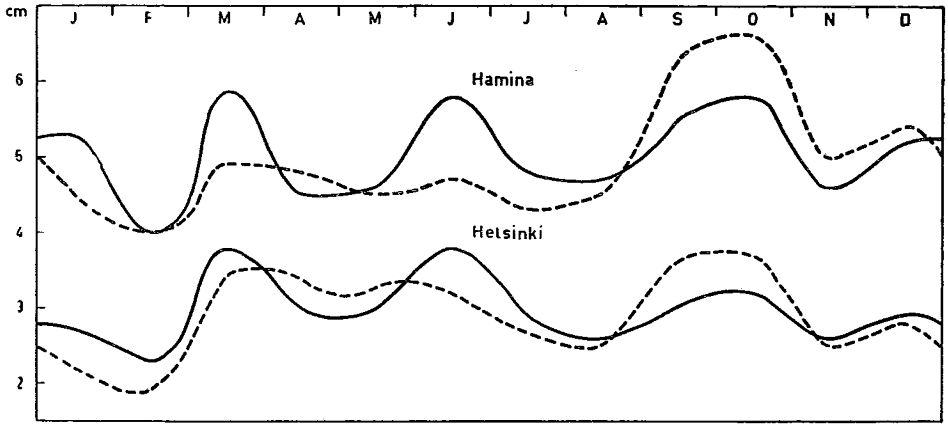

Figure 2. Height differences between Hamina and Helsinki, on the one hand, and Degerby on the other hand. The solid curves are determined with the aid of hydrographic and meteorological data, the dashed curves on the basis of sea level records.

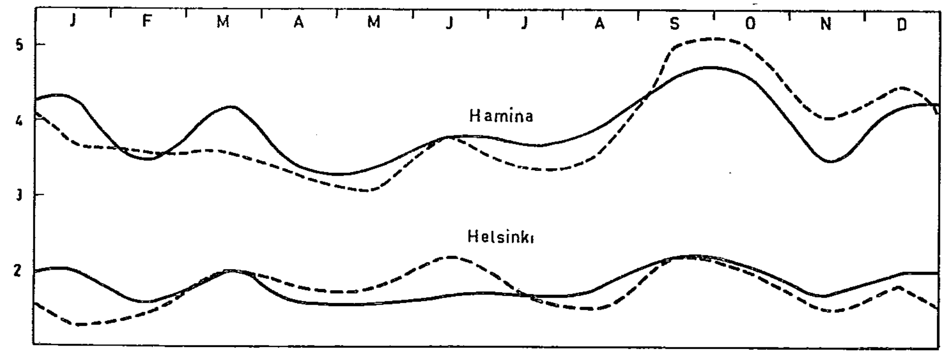

Figure 3. Height differences between Hamina and Helsinki, on the one hand, and Hangö on the other hand. The solid curves are determined with the aid of hydrographic and meteorological data, the dashed curves on the basis of sea level records.

to which are added the average yearly effect of density, atmospheric pressure and wind. The last line, finally, gives the deviations between the fourth and the fifth lines. These deviations and the graphical presentation in Figures 2 and 3 show that there exist between the two series of data considerable deviations which become more accentuated owing to the slight amplitude of the annual variations. On the other hand the two figures indicate very distinctly that the general rhythm shows a considerable conformity for the two series. In all the cases with the exception of the hydrographic-meteorological curve for the distance Helsinki—Hangö and the sea level curve representing the height differences between Helsinki and Degerby four more or less pronounced and coincident maxima and minima occur. The total amplitudes are of the same magnitude for the corresponding series, but for the height data based on Degerby as the reference level the oscillations show relatively marked deviations during the first part of the year. This is probably due to the position of the tide gauge station outside the region of the Gulf of Finland, the variations in the sea level concerned thus being subject to different effects which are not considered in this study. A possible cause for the less satisfactory correspondence between the data of the two series may be sought also in the fact that all the sea level observations employed refer to tide gauge stations which are situated on the north coast of the Gulf of Finland. Owing to the influence of Coriolis' force, drift currents provoked by W and SW winds, which are the most important for the present purpose, deviate to the right and move towards the south coast of the Gulf. Unfortunately the sea level observations available for this coast are too limited to be used in this regard. In this connexion it may be mentioned that also for the Gulf of Bothnia it was noted that the conformity between two corresponding series is smaller for the tide gauge stations lying on the Swedish coast than for those situated on the Finnish coast.

For the comparison of the amplitudes of the height deviations of the recorded sea level with the mean errors of the deviations of heights computed according to the two different methods, Table 10 has been worked out. This table shows that the mean errors correspond in round figures to 20—30% of the amplitude; numerically, however, they are relatively slight.

Table 10. The amplitudes of the height deviations (cm) of the recorded sea level and the meen errors of the differences.

Region	Amplitude	Mean error
Hamina—Degerby	2.6	0.6
Helsinki—Degerby	1.8	0.4
Hamina—Hangö	1.9	0.4
Helsinki—Hangö	0.9	0.3

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