MERENTUTKIMUSLAITOKSEN JULKAISU
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CONTRIBUTION TO THE KNOWLEDGE OF THE RANGE OF SEA LEVEL VARIATIONS IN THE NORTH BALTIC

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STENIJ and HELA have given a comprehensive picture of the frequency of different sea levels along the Finnish coast in their statistical investigation into this phenomenon (6). From the results attained the Institute of Marine Research is able to answer a great number of inquiries, principally of a practical nature. Fairly often, however, the institute receives inquiries on problems that cannot be easily solved with the aid of the data in the publication mentioned above. The greatest velocity at which sea level variations may occur, for instance, is one such question. HELA (1) has certainly in a minor paper paid attention to this problem and illustrated it with some diagrams, but no more detailed study of the phenomenon is yet available. Furthermore, the rather important problem of the annual course of sea level variations also has been investigated relatively little. Statistical inquiries about sea level, however, frequently fail to cover the whole year and are confined to a definite limited time, for instance the navigation or the vegetation period.

The aim of the present investigation is to examine these questions in more detail. For this purpose the statistical adaption of the material has been carried out mainly with regard to the velocity and the annual course of sea level variations.

STENIJ's and HELA's investigations have shown very distinctly that the extreme values of sea level are increasing towards the inner parts of the Gulfs of Bothnia and Finland, and that high and low sea levels are more frequent in the north and the east than in the south-west part of the Finnish sea area. Some local deviations from this general rule may certainly be noted, but on the whole we find an almost linear relationship between sea level and the geographical position of the station on the coast. For this reason it is not always necessary to examine the records of all the automatic sea level stations, but in many cases it may

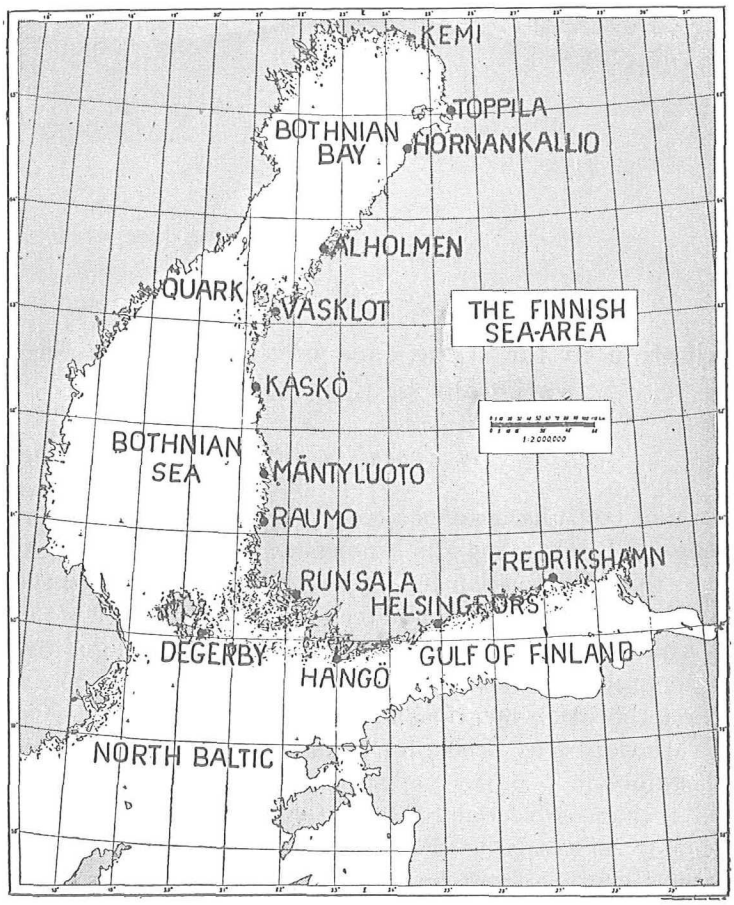

Fig. 1. The positions of the stations.

suffice to choose places characteristic of a larger region and study only them. As such typical stations we have generally used Kemi, Hornankallio, and Mäntyluoto in the Gulf of Bothnia, Degerby in the northern Baltic proper and, finally, Fredrikshamn in the Gulf of Finland. In some cases the selection has been still more limited and only the northernmost station Kemi and the easternmost Fredrikshamn have been used in addition to Degerby. Figure 1 shows the positions of the Finnish automatic sea level stations. The observation material, up to the year 1946, is published in the series of the Institute of Marine Research (5).

The first step was to determine and examine for the three last-named stations the frequency of the cases where the variations in sea level in the course of one hour amounted to at least 5 cm. The material used for this purpose covers the registered data for the 10 year period 1940—1949.

HELA (1) has carried out a similar statistical investigation for the stations Kemi, Degerby, and Helsingfors, using six observations daily; his sea level differences thus correspond to a time of four hours. On the other hand HELA's results are more complete than those of the present paper as he has considered statistically all sea level variations without exception, while we have limited the research to variations of over 5 cm. In this connexion the question arises as to which of the two intervals may be considered the more appropriate. Theoretically a shorter time is doubtless preferable, but for practical purposes a more prolonged period offers considerable advantages. It is fairly obvious that for harbour and other coastal constructions and buildings it is much more important to know the absolute limits for sea level variations than the amount of these variations during one hour. On the other hand it may be borne in mind that rapid sea level variations usually cover a longer period than four hours, although the most pronounced cases of increase and decrease, forming generally a part only of a more prolonged process, are of short duration. The four-hour period is thus by no means sufficient to illustrate the entire phenomenon in every detail, but the results attained in order to give a clear picture must at any rate be completed with other data. An examination of the sea level differences in the course of one hour seems, therefore, to be the most suitable.

The values in question are collected in Tables 1—3. In this connexion it may be pointed out that the observation material comprises some cases where the registered data do not correspond to reality but are more or less influenced by damping and other disturbing factors. Moreover, longer or shorter periods of interruption in the registrations have been noted. This concerns principally Kemi, where damping has been very pronounced during several years. In order to avoid the damped or otherwise disturbed values the decennial period originally used, 1940—1949, has for this station been limited to six years, 1944—1949, during which the observations have been relatively satisfactory. Owing to this fact the values for Kemi are not immediately comparable with those for Degerby and Fredrikshamn, but the differences are certainly not big enough to give an entirely erroneous picture of the local distribution of hourly sea level variations. The figures in Table 1—3 give the average frequencies for a year and they are arranged for each month in sections covering the consecutive groups 5.0—5.9 cm, 6.0—6.9 cm etc. A comparision of the three tables shows very distinctly that a considerable difference exists between Kemi and Fredrikshamn on the one hand and Degerby in the other. We can see that while the total yearly number of differences from 5 cm upwards at both the former stations amounts to about 300, thus corresponding to roughly 3.5 % of all the observations, the frequency at Degerby is 68 cases or 0.77 % only. It may, however, be pointed out that the tables

Table 1. The average annual frequencies of hourly sea level differences greater than 5 cm at Kemi, 1944—1949.

	Differences, cm																												
	5.0— 5.9	6.0— 6.9	7.0— 7.9	8.0— 8.9	9.0— 9.9	10.0—10.9	11.0—11.9	12.0—12.9	13.0—13.9	14.0—14.9	15.0—15.9	16.0—16.9	17.0—17.9	18.0—18.9	19.0—19.9	20.0—20.9	21.0—21.9	22.0—22.9	23.0—23.9	24.0—24.9	25.0—25.9	26.0—26.9	27.0—27.9	28.0—28.9	29.0—29.9	30.0—30.9	31.0—31.9	42.0—42.9	>5.0
J	16.7	10.8	3.2	4.3	1.0	0.8	0.8	0.5	—	0.2	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	38.5
F	6.0	2.7	1.7	0.3	—	0.2	—	—	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	11.1
M	2.7	1.5	—	—	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.4
A	2.7	0.8	—	0.3	—	—	0.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.1
M	7.7	2.5	2.0	0.2	0.8	0.8	0.7	0.3	—	0.3	—	—	0.3	0.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	16.3
J	6.3	3.0	2.0	1.0	0.8	0.7	0.7	0.3	0.3	0.3	0.2	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15.8
J	4.0	1.8	0.8	0.8	0.2	0.7	0.3	0.2	0.2	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9.2
A	7.0	3.5	2.2	1.0	0.7	0.5	0.2	0.2	0.2	—	—	—	—	—	—	—	—	—	—	—	—	0.2[1]	—	—	—	—	—	—	15.7
S	15.3	7.7	5.3	3.5	2.0	2.0	0.5	1.5	0.5	0.3	0.2	0.2	0.3	—	0.3	0.3	0.2	—	—	0.2	—	0.2	—	0.2	—	—	0.2	0.2[2]	41.1
O	21.0	11.3	8.0	4.2	4.0	1.8	1.0	1.2	—	0.5	0.3	—	0.5	—	0.2	0.5	0.2	—	0.3	—	—	—	—	—	0.2	—	—	—	55.2
N	14.7	10.8	5.2	3.0	3.3	2.3	0.5	0.5	0.5	0.3	0.3	—	0.3	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	41.9
D	18.3	9.2	5.7	4.0	1.8	0.8	0.8	0.3	0.2	—	0.5	0.2	0.2	—	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	42.2
Year	122.4	65.6	36.1	22.6	14.8	10.6	5.8	5.0	2.1	2.1	1.7	0.6	1.6	0.9	0.7	0.8	0.4	—	0.3	0.2	—	0.2	0.2	0.2	0.2	—	0.2	0.2	295.5

[1]) Value uncertain. [2]) HELA (1) gives 59 cm as an extreme case of hourly sea level increase at Kemi (1. XI. 1934).

Table 2. The average annual frequencies of hourly sea level differences greater than 5 cm at Degerby, 1940—1949.

	Differences, cm														
	5.0— 5.9	6.0— 6.9	7.0— 7.9	8.0— 8.9	9.0— 9.9	10.0—10.9	11.0—11.9	12.0—12.9	13.0—13.9	14.0—14.9	15.0—15.9	16.0—16.9	17.0—17.9	18.0—18.9	>5.0
J	5.3	2.8	1.3	0.9	0.3	0.3	—	—	0.1	—	—	—	—	—	11.0
F	3.7	1.8	1.1	0.1	0.4	0.2	—	—	0.1	0.1	—	—	—	—	7.5
M	3.5	1.0	0.5	—	0.2	0.4	0.1	0.1	0.1	—	—	0.1	—	—	6.0
A	2.2	0.7	0.3	—	—	—	0.1	—	—	—	0.1	—	0.1	—	3.5
M	1.2	0.7	0.3	0.6	0.3	0.1	—	—	0.1	0.1	—	—	—	—	3.4
J	1.5	0.3	0.2	0.1	—	—	0.1	—	—	—	—	—	—	—	2.2
J	0.1	0.4	0.1	—	—	—	—	—	—	—	—	—	—	—	0.6
A	0.9	0.8	0.4	0.2	0.2	—	—	—	—	—	—	—	—	—	2.5
S	1.5	1.3	0.5	0.2	—	—	—	—	—	0.2	—	—	—	—	3.7
O	4.3	1.7	1.2	0.6	0.2	0.4	0.2	0.2	0.1	0.1	—	—	—	0.1	9.1
N	4.8	2.0	0.4	0.6	0.2	0.2	0.1	—	—	—	—	—	0.1	—	8.4
D	6.1	2.4	0.5	0.6	0.3	0.1	—	—	—	—	—	—	—	—	10.0
Year	35.1	15.9	6.8	3.9	2.1	1.7	0.6	0.3	0.5	0.5	0.1	0.1	0.2	0.1	67.9

Table 3. The average annual frequencies of hourly sea level differences greater than 5 cm at Fredrikshamn, 1940—1949.

	Differences, cm																			
	5.0— 5.9	6.0— 6.9	7.0— 7.9	8.0— 8.9	9.0— 9.9	10.0—10.9	11.0—11.9	12.0—12.9	13.0—13.9	14.0—14.9	15.0—15.9	16.0—16.9	17.0—17.9	18.0—18.9	19.0—19.9	20.0—20.9	21.0—21.9	22.0—22.9	23.0—23.9	>5.0
J	22.4	13.1	8.1	4.3	3.0	2.7	1.1	1.1	1.0	0.5	0.1	0.1	0.1	0.1	0.1	—	0.1	—	0.1	58.0
F	13.5	7.8	4.7	2.9	1.1	0.5	0.5	0.1	0.2	—	—	—	—	—	—	0.1	—	—	—	31.4
M	11.1	3.8	2.6	0.9	0.2	0.3	0.4	0.3	0.1	—	—	—	—	—	—	—	—	—	—	19.7
A	7.4	3.6	1.3	0.6	0.1	0.1	0.2	—	0.1	—	—	—	—	—	—	—	—	—	—	13.4
M	5.8	3.6	1.4	0.4	0.6	0.1	—	0.1	—	—	—	—	—	—	—	—	—	—	—	12.0
J	4.1	2.4	0.8	0.6	0.5	—	0.2	0.1	—	—	0.1	—	—	—	—	—	—	—	—	8.8
J	0.9	0.9	0.2	0.1	0.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.4
A	5.1	2.8	2.3	1.0	0.9	0.3	0.4	0.1	0.1	—	—	—	—	—	—	—	—	—	—	13.0
S	10.0	4.0	2.2	0.9	0.7	0.3	0.3	0.1	0.1	0.1	—	—	—	—	—	—	—	—	—	18.7
O	13.1	7.5	5.4	2.5	1.3	1.3	0.9	0.6	0.8	0.2	0.2	0.2	—	0.1	—	—	—	—	—	34.1
N	16.2	10.0	8.0	4.2	2.6	1.8	0.7	0.4	0.4	0.6	0.2	0.1	0.1	0.2	—	—	—	—	—	45.5
D	24.2	13.0	6.9	3.6	3.0	1.3	0.7	0.3	0.3	0.1	0.1	—	—	0.1	—	0.1	—	0.1	—	53.8
Year	133.8	72.5	43.9	22.0	14.3	8.7	5.4	3.2	3.1	1.5	0.7	0.4	0.2	0.5	0.1	0.2	0.1	0.1	0.1	310.8

also show a distinct dissimilarity obtaining between Kemi and Fredrikshamn. The figures in Table 4, which gives the number of cases with an increase or decrease greater than 5, 10, 15, 20, 25 and 30 cm, are typical of this dissimilarity. It is immediately apparent that for differences greater than 10 cm even, the inequality between Kemi and Fredrikshamn is quite perceptible, and percentually it increases considerably when we pass over to larger differences. The extreme values observed differ widely, too. Thus the greatest hourly difference at Kemi is 42 cm, at Fredrikshamn it is 23 cm only. From Kemi southwards and Fredrikshamn westwards the number of cases in the different groups decreases gradually towards the values for Degerby.

Table 4. Annual frequencies of cases with an hourly sea level difference greater than 5, 10, 15, 20, 25, and 30 cm at Kemi, Degerby and Fredrikshamn.

	>5 cm	> 10 cm	> 15 cm	> 20 cm	> 25 cm	> 30 cm
Kemi	295.5	34.0	8.4	2.9	1.2	0.4
Degerby	67.9	4.1	0.5	—	—	—
Fredrikshamn	310.8	24.3	2.4	0.5	—	—

Passing over to the annual course of the rapid sea level differences we can, with the aid of Tables 1—3, verify a considerable distinction between the autumn and winter months on the one hand and the spring and summer ones in the other. In July we have a minimum for all the three stations; for Kemi, however, it is a secondary one, as the main minimum occurs there in April. This minimum is probably the consequence of the large fast ice cover extending in the Bothnian Bay from the coast far into the open sea. There is no doubt that this ice cover exercises a certain damping influence upon sea level variations. In the narrower Gulf of Finland the edge of the fast ice border usually lies much nearer the coast, large sea lanes occur, moreover, more frequently and the damping influence of the ice cover is therefore not so prominent. In the Bothnian Bay on the contrary this influence may be traced by the late autumn months at least to some degree (3). Table 1 shows that the maximum number of cases with larger variations is observed at Kemi in October, while Fredrikshamn shows a continuous rather rapid increase of these cases throughout the autumn towards the maximum, which is reached first in January. At Degerby too the maximum appears in January, but at this station the increase during the autumn months is not so regular.

As already has been pointed out a statistical examination of rapid sea level variations in the course of one hour is by no means sufficient to provide a general picture of the phenomenon under consideration.

In order to complete it in greater detail we have determined the frequency of days with an absolute sea level difference of 0.1—10.0 cm, 10.1—20.0 cm etc. The stations used are Kemi, Hornankallio, Mäntyluoto, Degerby, and Fredrikshamn, and the research period 1940—1949. Damped or otherwise uncertain observation data have been omitted. The results, expressed as percentages, are given in Table 5.

Table 5. The average frequencies (%) of different daily sea level differences.

	Differences, cm														
	0.1— 10.0	10.1— 20.0	20.1— 30.0	30.1— 40.0	40.1— 50.0	50.1— 60.0	60.1— 70.0	70.1— 80.0	80.1— 90.0	90.1—100.0	100.1—110.0	110.1—120.0	120.1—130.0	130.1—140.0	140.1—150.0
Kemi	25.0	36.0	18.7	9.2	4.8	2.8	1.8	0.7	0.7	0.14	0.14	0.05	0.09	—	—
Hornankallio	28.8	39.3	16.8	8.1	3.5	2.0	0.9	0.2	0.2	0.07	0.03	—	—	—	—
Mäntyluoto .	52.5	34.0	9.3	2.7	1.0	0.2	0.1	0.03	—	—	—	—	—	—	—
Degerby	63.7	30.1	4.8	1.2	0.3	—	—	—	—	—	—	—	—	—	—
Fredrikshamn	22.0	40.7	18.0	8.8	5.1	2.4	1.2	0.9	0.5	0.2	0.2	0.07	0.03	0.07	0.03

This table shows the varying character of the daily sea level variations along the Finnish coast. At Degerby almost two thirds of these variations fall within the limits of 10 cm, and roughly 94 % reach 20 cm at the most. Furthermore we may mention that the daily sea level differences are without exception below 50 cm. At Mäntyluoto already a distinct displacement of the daily sea level differences towards higher values can be noted. This appears, for instance, on the one hand in the number of cases with differences below 10 cm, which shows a more than 10 % decrease, on the other hand in the increased value for all the remaining groups and the occurrence of one case with a daily sea level difference over 70 cm. The same tendency, still more marked, is characteristic of Hornankallio and Kemi. In this connexion it may be mentioned that in order to avoid the influence of damping the years 1944—1949 only have been taken for Kemi. The use of the entire 10-year period should increase the values for the first group by a round 6 % and cause a decrease in the three following groups of about 3, 2, and 1 % respectively. Passing over to Fredrikshamn in the Gulf of Finland we note that this station shows on the whole an amazing similarity with Kemi. The most characteristic features of the values for Fredrikshamn are that the number of days with small differences (< 10 cm) is here at its lowest, the maximum of the daily differences at its highest reaching in one case as high a value as 142 cm.

Table 6 has been computed in order to give a picture of the average annual course of daily sea level differences. This table comprises the mean daily sea level differences during different months for the same

stations and periods as above, and the observed maximum differences are given in Table 7.

Table 6. The annual course of the daily sea level differences in cm.

	J	F	M	A	M	J	J	A	S	O	N	D	Mean
Kemi	28.6	17.0	15.7	15.0	17.3	16.5	13.2	17.7	23.4	29.6	28.6	29.1	21.0
Hornankallio	22.9	17.6	15.8	14.5	14.3	13.0	11.1	15.3	17.8	24.2	25.5	25.5	18.1
Mäntyluoto .	16.1	13.1	12.6	10.9	9.2	8.5	7.1	9.6	11.6	14.8	15.2	16.2	12.1
Degerby	12.7	11.1	11.1	9.4	8.5	8.1	6.8	8.0	9.3	11.2	12.0	12.7	10.1
Fredrikshamn	28.6	22.1	21.5	17.2	16.2	15.4	12.7	17.2	18.2	23.3	29.0	28.0	20.8

Table 6 shows very distinctly the considerable differences between the individual months. At all the stations the minimum is reached in July, and Kemi also has a secondary minimum in April, which must be ascribed to the influence of the ice cover. The appearance of the maximum is not so regular and varies over a period of four months, October—January. It is probable, however, that the early maximum at Kemi is due to a displacement of the extreme values resulting from the later considerable extension of the ice. It may be borne in mind too that the percentages for the four months October to January differ from each other at Kemi within a range of 1 % only, and the possibility can by no means be excluded therefore that in the relatively short research period (6 years) accidental circumstances have influenced the result, at least to some degree. Finally, it may be mentioned that the numerical relationship between the maximum and the minimum for the same station shows a remarkable regularity. Thus for all the stations except Degerby the minimum amounts to about 44 % of the maximum; at the latter station it is roughly 54 %.

Table 7. The maximum daily sea level differences in cm.

	J	F	M	A	M	J	J	A	S	O	N	D
Kemi	103	64	63	65	101	59	86	88	88	123	100	112
Hornankallio	86	70	86	82	102	50	62	69	73	96	71	94
Mäntyluoto .	64	59	70	52	39	32	24	32	38	62	71	56
Degerby	45	48	38	32	28	25	18	25	34	48	47	41
Fredrikshamn	109	86	84	79	70	61	59	107	83	103	133	142

Examining Table 7, which gives the maximum daily sea level differences by individual months during the research period (for Kemi once more 6 years only), we note that in this case too summer (June—July) is characterized by the lowest values, whilst the high sea levels appear generally in autumn and winter. The maximum in May at Hornankallio, however, forms an exception to this rule and indicates the irregular character of this phenomenon and the difficulty of drawing general conclusions in this connexion.

Besides daily sea level variations it may be of interest to examine statistically the variations occurring in the course of a month. For this purpose all the thirteen Finnish registering stations were used and the investigation is based upon the 30 year period 1921—1950, in so far the stations have been in action during this time. For stations which started later the period is of course shorter. Table 8 shows the average values for the monthly sea level differences. This table too is very instructive in many respects. With the exception of Kemi all the stations reached their maxima in January; the minima appeared everywhere in July. Moreover, all the stations except Fredrikshamn show a secondary maximum in November. In order to make Table 8 somewhat more complete

Table 8. The average monthly sea level differences (cm).

Station	Kemi	Toppila	Hornankallio	Alholmen	Vaskiot	Kaskö	Mäntyluoto	Raumo	Runsala	Degerby	Hangö	Helsingfors	Fredrikshamn
Period	1922—50	1922—50	1922—50	1922—50	1922—50	1926—50	1925—50	1933—50	1922—50	1924—50	1921—50	1921—50	1928—50
J	138	129	122	100	88	80	76	73	74	57	70	91	120
F	102	95	96	87	77	70	66	63	64	52	65	79	95
M	84	77	77	68	62	56	54	56	53	47	56	72	91
A	80	74	74	68	60	57	52	50	48	42	50	61	72
M	80	76	69	56	54	48	44	43	44	36	44	55	68
J	77	69	61	52	49	44	40	36	43	35	42	49	59
J	68	59	51	45	42	37	35	34	38	31	39	45	54
A	92	82	68	56	51	46	45	47	47	37	45	56	73
S	114	107	88	73	66	58	53	55	57	44	53	68	96
O	140	124	106	88	76	71	66	66	65	50	60	82	112
N	146	133	119	97	84	79	70	70	69	55	64	88	112
D	131	118	110	85	77	71	67	65	66	53	59	86	117
Year	104	95	87	73	66	60	56	55	56	45	54	70	89
Max.	243	199	203	171	148	142	140	137	136	119	128	153	193
Min.	31	25	27	27	26	21	20	20	21	19	25	26	26

we have added the last two rows, giving the maximum and minimum monthly sea level differences noted at each station. By way of explanation it may be mentioned that the maximum differences occurred in the Bothnian Bay and the Quark in autumn (October and November), at all the remaining stations in January. The minima show a larger dispersion, but for the greatest part (6 cases) appear in July; in June there are 2 cases, in May and April one case each and, finally, in March 3 cases. The three last cases are noted at the northernmost stations Kemi, Toppila and Hornankallio in the year 1923 and they are due to the exceptionally slight air pressure variations and the weak wind force during this month. The difference between the maximum and minimum air pressure in

March 1923 at Vasa amounted to only 16.3 mm, the average value for March during the twenties being almost double this, or 32.0 mm. The deviation is thus considerable. For the mean wind force the corresponding figures are 1.9 m per sec and 4.3 m per sec, respectively.

Table 9—13 have been computed in order to give some idea of the frequency of different sea level differences. These tables represent once

Table 9. The average frequencies (%) of different monthly sea level differences at Kemi.

	Differences, cm																					
	30.1—40.0	40.1—50.0	50.1—60.0	60.1—70.0	70.1—80.0	80.1—90.0	90.1—100.0	100.1—110.0	110.1—120.0	120.1—130.0	130.1—140.0	140.1—150.0	150.1—160.0	160.1—170.0	170.1—180.0	180.1—190.0	190.1—200.0	200.1—210.0	210.1—220.0	220.1—230.0	230.1—240.0	240.1—250.0
J	—	—	—	—	3.6	—	7.1	10.7	7.1	17.9	14.3	10.7	3.6	7.1	3.6	7.1	7.1	—	—	—	—	—
F	—	7.1	3.6	10.7	3.6	14.3	3.6	17.9	10.7	7.1	7.1	10.7	—	3.6	—	—	—	—	—	—	—	—
M	—	11.1	11.1	14.8	7.4	18.5	3.7	11.1	14.8	3.7	—	—	—	3.7	—	—	—	—	—	—	—	—
A	—	14.8	11.1	25.9	3.7	11.1	7.4	14.8	3.7	3.7	—	—	—	3.7	—	—	—	—	—	—	—	—
M	3.7	—	25.9	11.1	14.8	18.5	11.1	3.7	—	—	11.1	—	—	—	—	—	—	—	—	—	—	—
J	—	7.1	25.0	17.9	—	25.0	10.7	7.1	7.1	—	—	—	—	—	—	—	—	—	—	—	—	—
J	3.4	20.7	13.8	27.6	6.9	10.3	3.4	10.3	3.4	—	—	—	—	—	—	—	—	—	—	—	—	—
A	—	—	3.4	10.3	13.8	27.6	13.8	17.2	3.4	6.9	—	3.4	—	—	—	—	—	—	—	—	—	—
S	—	3.4	3.4	—	10.3	—	3.4	24.1	17.2	10.3	6.9	10.3	3.4	—	6.9	—	—	—	—	—	—	—
O	—	—	—	—	—	—	7.1	7.1	14.3	17.9	10.7	10.7	17.9	3.7	3.7	—	—	—	3.7	—	—	3.7
N	—	—	—	—	—	3.4	6.9	—	27.6	—	10.3	10.3	13.8	3.4	3.4	3.4	3.4	10.3	—	—	—	3.4
D	—	—	—	—	6.9	—	10.3	6.9	17.2	13.8	10.3	6.9	10.3	3.4	6.9	3.4	3.4	—	—	—	—	—
Year	0.6	5.3	8.0	9.8	5.9	10.6	7.4	10.9	10.6	6.8	5.9	5.3	4.1	2.4	2.1	1.2	1.2	0.9	0.3	—	—	0.6

Table 10. The average frequencies (%) of different monthly sea level differences at Hornankallio.

	Differences, cm																	
	20.1—30.0	30.1—40.0	40.1—50.0	50.1—60.0	60.1—70.0	70.1—80.0	80.1—90.0	90.1—100.0	100.1—110.0	110.1—120.0	120.1—130.0	130.1—140.0	140.1—150.0	150.1—160.0	160.1—170.0	170.1—180.0	180.1—190.0	190.1—200.0	200.1—210.0
J	—	—	—	—	3.6	—	3.6	10.7	14.3	**25.0**	14.3	3.6	7.1	10.7	3.6	3.6	—	—	—
F	—	3.6	3.6	3.6	14.3	3.6	7.1	14.3	**17.9**	10.7	7.1	10.7	3.6	—	—	—	—	—	—
M	3.6	3.6	10.7	21.4	3.6	**25.0**	3.6	3.6	10.7	10.7	—	—	—	3.6	—	—	—	—	—
A	—	3.6	10.7	14.3	**28.6**	7.1	14.3	7.1	7.1	3.6	—	—	—	3.6	—	—	—	—	—
M	—	7.1	14.3	**25.0**	10.7	**25.0**	7.1	3.6	—	—	7.1	—	—	—	—	—	—	—	—
J	—	7.1	**25.0**	**25.0**	17.9	7.1	7.1	10.7	—	—	—	—	—	—	—	—	—	—	—
J	—	17.2	**37.9**	20.7	17.2	3.4	3.4	—	—	—	—	—	—	—	—	—	—	—	—
A	—	—	3.4	**31.0**	27.6	17.2	6.9	6.9	6.9	—	—	—	—	—	—	—	—	—	—
S	—	—	6.9	10.3	6.9	**17.2**	10.3	**17.2**	13.8	3.4	10.3	—	3.4	—	—	—	—	—	—
O	—	—	—	—	3.4	—	20.7	**27.6**	10.3	20.7	6.9	3.4	—	3.4	—	—	—	3.4	—
N	—	—	—	—	3.4	3.4	6.9	—	**31.0**	17.2	6.9	10.3	6.9	10.3	—	—	—	—	3.4
D	—	—	—	—	—	10.3	**17.2**	17.2	6.9	**17.2**	3.4	13.8	6.9	3.4	3.4	—	—	—	—
Year	0.3	3.5	9.3	**12.6**	11.4	9.9	9.0	9.9	9.9	9.0	4.6	3.5	2.3	2.9	0.6	0.3	—	0.3	0.3

Table 11. The average frequencies (%) of different monthly sea level differences at Mäntyluoto.

	Differences, cm												
	10.1—20.0	20.1—30.0	30.1—40.0	40.1—50.0	50.1—60.0	60.1—70.0	70.1—80.0	80.1—90.0	90.1—100.0	100.1—110.0	110.1—120.0	120.1—130.0	130.1—140.0
J	—	—	—	12.0	**20.0**	16.0	16.0	4.0	16.0	8.0	4.0	—	4.0
F	—	—	7.7	15.4	19.2	11.5	**26.9**	3.8	—	15.4	—	—	—
M	—	—	15.4	**30.8**	**30.8**	11.5	11.5	—	—	—	—	—	—
A	—	3.8	19.2	**34.6**	19.2	15.4	—	7.7	—	—	—	—	—
M	—	7.7	**30.8**	**30.8**	**30.8**	—	—	—	—	—	—	—	—
J	3.8	**38.5**	15.4	23.1	3.8	11.5	3.8	—	—	—	—	—	—
J	—	**34.6**	**34.6**	23.1	7.7	—	—	—	—	—	—	—	—
A	—	7.7	23.1	30.8	**38.5**	—	—	—	—	—	—	—	—
S	—	—	15.4	**34.6**	19.2	19.2	11.5	—	—	—	—	—	—
O	—	—	3.8	19.2	15.4	**34.6**	11.5	3.8	7.7	—	—	3.8	—
N	—	—	3.8	15.4	3.8	**30.8**	26.9	7.7	7.7	—	3.8	—	—
D	—	—	—	11.5	**26.9**	**26.9**	15.4	11.5	3.8	—	3.8	—	—
Year	0.3	7.7	14.1	**23.5**	19.6	14.8	10.3	3.2	2.9	1.9	1.0	0.3	0.3

Table 12. The average frequencies (%) of different monthly sea level differences at Degerby.

	Differences, cm										
	10.1— 20.0	20.1— 30.0	30.1— 40.0	40.1— 50.0	50.1— 60.0	60.1— 70.0	70.1— 80.0	80.1— 90.0	90.1—100.0	100.1—110.0	110.1—120.0
J	—	—	18.5	**25.9**	14.8	**25.9**	7.4	3.7	—	—	3.7
F	—	3.7	**25.9**	**25.9**	22.2	3.7	14.8	3.7	—	—	—
M	—	3.7	25.9	**44.4**	11.1	7.4	3.7	3.7	—	—	—
A	—	18.5	**33.3**	29.6	7.4	3.7	7.4	—	—	—	—
M	7.4	11.1	**48.1**	29.6	3.7	—	—	—	—	—	—
J	7.4	**37.0**	25.9	14.8	11.1	3.7	—	—	—	—	—
J	3.7	**48.1**	37.0	11.1	—	—	—	—	—	—	—
A	—	22.2	**48.1**	18.5	11.1	—	—	—	—	—	—
S	—	11.1	25.9	**44.4**	14.8	—	3.7	—	—	—	—
O	—	11.1	7.4	**29.6**	**29.6**	18.5	—	3.7	—	—	—
N	—	3.7	3.7	**40.7**	25.9	14.8	7.4	3.7	—	—	—
D	—	3.7	14.8	**25.9**	**25.9**	18.5	3.7	3.7	3.7	—	—
Year	1.5	14.5	26.2	**28.4**	14.8	8.0	4.0	1.9	0.3	—	0.3

Table 13. The average frequencies (%) of different monthly sea level differences at Fredrikshamn.

	Differences, cm																	
	20.1— 30.0	30.1— 40.0	40.1— 50.0	50.1— 60.0	60.1— 70.0	70.1— 80.0	80.1— 90.0	90.1—100.0	100.1—110.0	110.1—120.0	120.1—130.0	130.1—140.0	140.1—150.0	150.1—160.0	160.1—170.0	170.1—180.0	180.1—190.0	190.1—200.0
J	—	—	—	—	—	9.1	13.6	**18.2**	9.1	9.1	4.6	9.1	9.1	4.6	—	4.6	4.6	4.6
F	—	—	4.6	4.6	9.1	9.1	18.2	9.1	9.1	**22.7**	4.6	9.1	—	—	—	—	—	—
M	—	—	4.6	—	**31.8**	4.6	13.6	18.2	9.1	—	9.1	—	4.6	—	—	—	—	4.6
A	—	—	9.1	18.2	**31.8**	13.6	4.6	13.6	4.6	4.6	—	—	—	—	—	—	—	—
M	—	—	4.6	27.3	**31.8**	22.7	9.1	—	4.6	—	—	—	—	—	—	—	—	—
J	—	4.6	**31.8**	18.2	27.3	9.1	—	9.1	—	—	—	—	—	—	—	—	—	—
J	4.3	8.7	21.7	**43.5**	8.7	8.7	—	4.3	—	—	—	—	—	—	—	—	—	—
A	—	—	8.7	21.7	**26.1**	17.4	4.3	4.3	13.0	4.3	—	—	—	—	—	—	—	—
S	—	—	—	4.3	17.4	17.4	17.3	13.0	**21.7**	4.3	4.3	—	—	—	—	—	—	—
O	—	—	—	—	—	—	13.0	**39.1**	8.7	8.7	8.7	—	4.3	13.0	—	4.3	—	—
N	—	—	—	4.3	—	13.0	4.3	13.0	8.7	**17.4**	13.0	13.0	8.7	—	4.3	—	—	—
D	—	—	—	4.3	—	—	4.3	13.0	**21.7**	17.4	4.3	21.7	4.3	—	—	8.7	—	—
Year	0.4	1.1	7.0	12.2	**15.2**	10.4	8.5	13.0	9.3	7.4	4.1	4.4	2.6	1.5	0.4	1.5	0.4	0.7

more the stations Kemi, Hornankallio, Mäntyluoto, Degerby, and Fredrikshamn. As the periods of observation according to Table 8 deviate for the separate stations, and sometimes also for different months at the same station, the results are given in percentages. A comparison of the five tables under consideration shows very distinctly not only the considerable dissimilarity of the individual stations but also the large deviations between different months noted at the same station. It may be mentioned that, for instance, at Kemi the most frequent monthly sea level differences fall within the limits 100—110 cm, closely followed by the groups 80—90 cm and 110—120 cm, at Hornankallio we note an annual maximum for the 50—60 cm group, at Mäntyluoto and Degerby we have quite distinct maxima in the 40—50 cm groups, and, finally, at Fredrikshamn we have again, as might be expected, a displacement towards larger differences with the maximum frequency falling in the 60—70 cm group.

The next step was to select as a unit a still more prolonged period, i. e. the year. Here we have limited our researches to the maximum, average and minimum values of sea level differences. The figures in question are given in Table 14. The periods for the individual stations are the same as in Table 8.

Table 14. The maximum, average and minimum values of annual sea level differences (cm).

	Kemi	Toppila	Hornankallio	Alholmen	Vaskiot	Kaskö	Mäntyluoto	Raumo	Runsala	Degerby	Hangö	Helsingfors	Fredrikshamn
Maximum differences	282	258	252	215	192	179	156	142	156	131	146	184	243
Years of appearance	1929	1929	1929	1929	1929	1929	1934	1934	1929	1934	1922	1938	1932
Average differences	214	192	182	153	139	129	117	112	116	96	114	145	184
Minimum differences	144	123	116	99	89	90	84	85	77	64	89	112	144
Years of appearance	1926	1926	1926	1946	1946	1946	1946	1946	1946	1945	1945	1946	1947

The fluctuations in the differences are percentually greatest in the northern part of the Gulf of Bothnia, where at Hornankallio the annual maximum difference is almost 2.2 times greater than the minimum one. Southward the ratio in question diminish amounting, for instance, in Helsingfors to 1.6 only. Table 14 also shows the years in which the extreme annual differences have been reached. A short study of these data may

be very instructive. Thus we can see that within the entire area of the Gulf of Bothnia, including Runsala and Degerby, the appearance of the maximum differences is divided between two years, i. e. the year 1929 for the more northerly stations and Runsala, the year 1934 for Mäntyluoto, Rauma, and Degerby. The minimum differences show a similar feature, in this case the years concerned being 1926 and 1946, and the boundary moves south of Hornankallio. This indicates the frequently observed fact that the variations of sea level in the Gulf of Bothnia have a very regular character, the deviations between adjoining stations lying principally in the amplitudes of the variations and not so much in their form. The result is somewhat different if we consider the stations in the Gulf of Finland. This sea region is represented in our research by three stations only, with the distance between Hangö and Fredrikshamn less than that between Kemi and Alholmen, but according to Table 14 neither the maximum nor the minimum differences show any correlation. It is true on the other hand that for instance the year 1938, which is characteristic of the maximum difference at Helsingfors, occupies second place in this respect at Hangö and Fredrikshamn, and the same is true of the minimum difference in the year 1946. But in spite of these instances it cannot be denied that the sea level variations have a so to say more individual character in the Gulf of Finland than in the Gulf of Bothnia, with its distinctly regional distribution of the extremes.

The above can be verified from Table 15. This table has been added in order to provide a picture of the absolute sea level differences observed at the Finnish automatic stations during the years indicated in Table 8. For the two stations Hangö and Helsingfors, which began their activity considerably earlier than the other stations, a foot-note to this table gives the relevant values for the years 1904—1920. This certainly makes the results for these stations more complete, but these values are on the other hand not immediately comparable with those at the remaining stations. The figures in Table 15 are not identical with the differences between the maximum and minimum values for the sea level given by Stenij and Hela (6). The discrepancy is due to the fact that no account has been taken in our table of the upheaval of the earth's crust. But it must be borne in mind that the appearance of the extremes is a fairly irregular phenomenon; indeed we cannot be certain that the absolute maximum has already been reached. As a rule the deviations between Stenij's and Hela's values and those given here are not large, falling within the limits of 15 cm. A much more striking shortcoming in this connexion is without doubt the dissimilarities that may arise from the deviating lenghts of the observation periods. A study of Table 15 shows however that the greatest part of the extreme values appeared in years when the station net had been complete. Thus at the four northernmost stations

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Table 15. Maximum sea level differences (cm).

	Kemi	Toppila	*Hornankallio*	Alholmen	Vaskłot	Kaskö	*Mäntyluoto*	Raumo	Runsala	Degerby	Haugö	Helsingfors	Fredrikshamn
Amplitude	292	285	273	236	200	184	170	160	175	147	[1] 170	[2] 194	252
Appearance of the maximum	1925 I 1934 XI	1925 I	1925 I	1925 I	1935 X	1935 X	1935 X	1935 X	1922 I	1935 X	1922 I	1944 I	1932 I
Appearance of the minimum	1936 X	1936 X	1936 X	1936 X	1929 I	1947 II	1947 II	1947 II	1947 II	1947 II	1934 IV	1937 I	1945 XI

[1]) In 1917 XI a maximum causing the amplitude 192 cm. [2]) In 1913 III and 1917 XI maxima causing the amplitude 213 cm.

the maximum was reached in the year 1925, the minimum in the year 1936. Farther southward in the Gulf of Bothnia the maximum appeared without exception in the year 1935, while the year 1947 is characterized by the lowest sea levels observed. The station Vasklot in the Quark, with its minimum in the year 1929, is interesting that in spite of the upheaval of the coast the absolute minimum was observed 6 years earlier than the absolute maximum.

Passing over to the Gulf of Finland we note that there is no correlation between the times of appearance of the maxima or those of the minima. Only if the longer period is considered for Hangö and Helsingfors do we find, in the year 1917, a coincidence of the maxima at these stations. The picture would grow still more complicated if we were to add to the table the values for the two automatic stations Viborg and Björkö, ceded to the Soviet Union after the war. These two stations, lying relatively near each other in the eastern reaches of the Gulf of Finland, were in action during the years 1926—1939. At Viborg the maximum was reached in the year 1931, the minimum in the year 1930. At Björkö both the extremes appeared in the year 1932. We thus have a coincidence for the maxima at Fredrikshamn and Björkö, all the remaining values showing complete irregularity. In this connexion it may of course be pointed out that the general tendency of sea level variations in the Gulf of Finland too indicates mutually corresponding values; maximum values at a station are attended by high sea levels at the adjoining stations, minimum values by low sea levels. It is only the extreme values themselves that are dispersed and suggest the more local character of the phenomenon in the Gulf of Finland.

A comparison of the relationship between corresponding amplitudes for different stations may be of considerable interest. As immediately comparable figures were indispensible in this connexion the sea level differences for the separate series at Degerby were denoted with 1.00 and the relative differences for the other stations computed from this value. Table 16 shows these relative values for the average daily, monthly and yearly differences, as well as for the absolute amplitudes of sea level differences. With the exception of the daily differences the amplitudes show a relative decrease as we move from shorter to longer periods. The correlation is smallest for the stations in the inner parts of the gulfs, where the distance to Degerby is at its longest. The relative differences for different periods there reach a value of about 15 %. But these deviations are still not enough to disturb the general character of the phenomenon.

A investigation of the annual variations of sea level cannot be considered complete without a short survey on the average annual course of sea level. This question has already been repeatedly treated in other

Table 16. Sea level differences at different stations relative to Degerby.

	Kemi	Toppila	Hornankallio	Alholmen	Vaskiot	Kaskö	Mäntyluoto	Rauma	Runsala	Degerby	Hangö	Helsingfors	Fredrikshamn
Mean daily differences	2.08	—	1.79	—	—	—	1.20	—	—	1.00	—	—	2.06
Mean monthly differences	2.31	2.11	1.93	1.62	1.47	1.33	1.24	1.22	1.24	1.00	1.20	1.56	1.98
Mean annual differences	2.23	2.00	1.90	1.59	1.45	1.34	1.22	1.17	1.21	1.00	1.19	1.51	1.92
Total differences	1.99	1.93	1.86	1.61	1.36	1.25	1.16	1.09	1.19	1.00	1.16	1.32	1.71

connexions (2, 4), but it may in any case be appropriate to illustrate it with new figures. Table 17 gives the deviations of the monthly means from the yearly averages for Kemi, Hornankallio, Mäntyluoto, Degerby, and Fredrikshamn. The periods employed are the same as in Table 8. We can see that at all the stations May shows the lowest sea level, this minimum being very marked. On the contrary the maximum at the northern stations, coming in December, is not pronounced. Farther southward there is a marked maximum in October. The deviations between the different stations are not on the whole great. The amplitude amounts at Kemi to 29 cm, Degerby 24 cm, and Fredrikshamn 26 cm.

Table 17. The annual course of sea level variations (cm).

	J	F	M	A	M	J	J	A	S	O	N	D
Kemi	7	—3	—13	—12	—17	—5	2	4	6	11	11	12
Hornankallio	7	—2	—12	—11	—17	—4	2	5	6	11	10	11
Mäntyluoto .	4	—4	—10	—8	—16	—4	3	5	5	10	5	6
Degerby	2	—3	—10	—7	—14	—2	6	7	7	10	5	5
Fredrikshamn	0	—6	—10	—8	—15	—3	5	6	6	11	5	6

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