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CONTRIBUTION TO THE KNOWLEDGE OF LAND UPLIFT ALONG THE FINNISH COAST

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INTRODUCTION

The consequences of land uplift upon the mean water height along the Finnish coast have been known for centuries, and the first approximate value for the continuous decrease in sea level for the whole Baltic (4.5 foot per 100 years) was computed by Celsius as early as the mid-18th century. It was not, however, until more extensive and reliable tide pole observations were available that a comprehensive study based on data for 15 years and showing the local differences in the secular crustal movements was published by Witting (1918). Years later Witting (1943) took up the problem once again and published his new results based on sea level data over 30 years. Among other more recent papers concerned with the question of land uplift in the Baltic must be mentioned those published by Model (1950), Hela (1953) and Rossiter (1960). In the two latter only tide gauge records were used for the computations. At the present time, therefore, we have at our disposal different series of data on secular variation in sea level along the Finnish coast illustrating, on the one hand, the principal features of the phenomenon, but revealing, on the other, considerable discrepancies in their results for individual stations.

THE PROBLEM

The greatest difficulty in determining the rate of land uplift on the basis of sea level records lies in the fact that the annual averages of the data concerned are affected by a considerable number of different factors. The most significant and easiest surveyable of these factors besides land uplift are:

1. Meteorological: air pressure, wind, precipitation and evaporation.
2. Hydrographic: water density and currents.

3. Hydrological: river discharge.

4. Eustatic: increase in the total water amount in the oceans and seas as a consequence of the melting of inland ice in polar regions.

5. The nodal tide over the period of 18.6 years.

6. The possible effect of occasional subsidence or upheaval in the tide gauge foundation itself or of accidental error in the operation of the apparatus or the readings of the recorded curves. The first of these is, as a rule, eliminated from the records by precise levelling to the closest bench mark made every year, the second by control measurements which are taken at all Finnish tide gauge stations regularly once a week, while errors in the readings are corrected by comparing the results for adjacent stations. These possibilities are not, therefore, greatly disturbing.

Finally, it must be pointed out that since the astronomic tides are weak in the Baltic they do not noticeably influence the annual averages of sea level. These tides and, in addition, a considerable number of other factors summarised by Hela (1964) in his comprehensive paper on the causes of the difference between the geoid and the mean sea level surface, were therefore left out of consideration in this study.

Meteorological factors, especially the wind, have a considerable effect on the sea level fluctuations in a shallow basin like the Baltic. For accurate data it is imperative that this effect be eliminated from sea level records before the determination of the rate of the secular variation. This can be done in two very different ways:

A. The meteorological effect may be removed from tidal records by using air pressure data for stations appropriately situated around the sea basin and deducing a general law for the influence of atmospheric pressure and corresponding winds upon the water surface. Witting was the first to choose this elaborate method, introducing the so-called anemo-baric law as the basis for his computations. Rossiter proceeded in a similar way, although in his study he used quite a different scheme for the elimination of the disturbing effect on the tidal records.

B. The effect of the meteorological and, in addition, of the hydrographic and hydrological factors, may be eliminated on the basis of sea level data themselves. Model followed such a process in his paper, while Hela has developed his own, more accurate, detailed and logical scheme for a similar method.

It may be appropriate here to mention a method used by Dietrich

(1954) for the removal of oceanographic-meteorological effects from sea level records, although this method has not yet been applied to the Baltic. Dietrich based his computations on the records for the Danish tidal station Esbjerg, in the North Sea, and considered separately the influence of atmospheric pressure, water density and wind. The method is extremely elaborate and requires a very great amount of information on water density and wind which is unfortunately not always available; data determined by other means must then be substituted. The results for Esbjerg are interesting, but the method seems to be less reliable for corresponding computations in the Baltic, where the sea level records are greatly influenced by the considerable fluctuations in the total water quantity in the basin.

A study of the different papers giving the rate of the secular variation in sea level along the Finnish coast and a comparison of their results leads to the important question of the choice between the two fundamentally different methods A and B above. Main consideration must obviously be given to the accuracy with which disturbing effects can be eliminated from the original data. Individual results seem to indicate that in a shallow and more or less enclosed sea region like the Baltic, and especially in its large gulfs, where the local meteorological effect of the piling-up of water and the total variation in water quantity are pronounced method B has considerable advantages over method A. This conclusion is based on the following considerations:

First, according to the results of Hela the average error in the calculated decrease in mean sea level for twelve Finnish tidal stations is 0.7 mm per year, while the corresponding value obtained by Rossiter is 1.4 mm per year (comp. Table 2). The reason for these fairly marked deviations in the exactness of the results must not be attributed solely to Hela's use of a longer series of tidal data than Rossiter's. We have probably also to reckon with the fact that the influence of water density was not taken into account by Rossiter and, in addition, with the difficulty of removing, with the aid of a general scheme for air pressure distribution, the local effects, which in some cases may be fairly accentuated, from the sea level records. Local effects are, on the other hand, taken into account, at least to some extent, when elimination is achieved with the aid of the actual sea level data. The greatest disadvange of the method developed by Hela lies in the fact that the results on coastal movements were referred to a selected tidal station which forms the starting point for the rest of the computations. An inaccuracy in the rate of land uplift at this station will therefore be reflected in all the remaining data. In addition, possible secular fluctuation in the meteorological factors will be integrated in the rate of the sinking of the sea level. On the other hand, there exists the possibility that the use of air pressure data may sometimes introduce into the whole mathematical system further inaccuracy owing to a deficiency in the meteorological observations. Moreover, the effect of water density, river discharge, precipitation and evaporation must be evaluated separately. The removal of disturbing meteorological and hydrographic effects from the tidal data themselves allows of far-reaching generalisation on the process of elimination. As Hela has shown in his paper, meteorological and hydrographic factors affect the annual sea level records in two principal ways: in the fluctuations in the total water volume in the Baltic, caused to a more or less pronounced degree by forces outside the basin; and in the slope of the sea surface in the Gulf of Bothnia and the Gulf of Finland, which has to be taken into account as a largely local and regional characteristic. This slope is a feature typical of the two gulfs as a consequence of the predominant distribution of atmospheric pressure and wind over the basin and of the differences in water density (Lisitzin, 1957a and 1958a). Depending on the specific conditions prevailing during individual years the slope may, however, vary considerably in magnitude, the average increase in sea level towards the inner parts of the gulf changing occasionally even into a decrease. To use a term introduced by Miller (1958) the actual slope of the water surface along the coast is, compared with the mean conditions, described hereafter as a positive or negative »set-up» of the sea level. This set-up is, as a rule, characterised by a fairly regular course which makes it easy to eliminate the effect from the tidal data.

It must, furthermore, be kept in mind that the eustatic increase in sea level can hardly be expected to be strictly regular; on the contrary, marked irregularities in its general course are highly probable. We have also to consider the fact that an increase in air temperature is followed not only by an accelerated melting of inland ice, but also by an increase in evaporation counterbalancing the former effect. The final outcome may therefore be fairly complicated. Possible deviations from the average values will, however, be included in the computations as part of the total changes in sea level in the Baltic.

There now arises the significant question of whether the rate of the secular crustal movements is continual or more or less spasmodic.

Unfortunately this question has sofar not been solved by oceanographers. It requires changed methods and a close collaboration between geodesists and seismologists. In spite of the varying results arrived at for different periods of tidal records it seems at present adequate to assume a practically constant course of vertical crustal movement and to aspire only to the determination of average results, attributing the deviations in computed rate of land uplift to the effect of disturbing factors, to their unsatisfactory elimination from the sea level records and possibly, to some degree, to inevitable errors in the original tidal data.

The difficulty in removing completely the different disturbing effects is largely responsible for the fact that the selection of the period of the records used may sometimes be as significant for the final results of the computations as the choice of the method. The length of the period is, of course, of decisive importance, and as many years as possible should be considered in every specific case. It must also be remembered that the meteorological conditions prevailing at the beginning and the end of the chosen span of time may greatly affect the computations. If the average sea level has been relatively low over several years at the beginning of the period, as for instance in the early 1940's, and if the elimination of the disturbing influence has not been satisfactory, the consequence may be an altogether too low computed rate of secular variations. In its most extreme form this fact is demonstrated by the correction of Rossiter's data (1960) amounting to approximately 4 mm per year after the removal of the meteorological effect from the crude sea level data.

COMPUTATIONS

The following results are based on the tidal records of the Finnish tide gauges for the 37 year period 1924—1960. Although most of these sea level stations have been in operation almost uninterruptedly since the beginning of the 1920's an interpolation of the annual averages based on comparison with adjoining stations was necessary for the tide gauge Kaskinen in the years 1924 and 1925, and for the tide gauge Hanko during the period 1940—1942. Since the nodal tide has a duration of 18.6 years its effect is covered by the fact that the period under review was almost double this time.

The location of the Finnish tide gauge stations is shown in Figure 1. Of these stations Rauma and Hamina are not considered in this paper because they did not start recording sea level until 1933 and 1928 respectively.

It may be pointed out that since the average eustatic increase in sea level has not so far been taken into account this chapter gives data on the secular variation in sea level and not the rate of land uplift.

In order to remove the various disturbing effects from the data recorded the general scheme initiated by Hela was followed with,

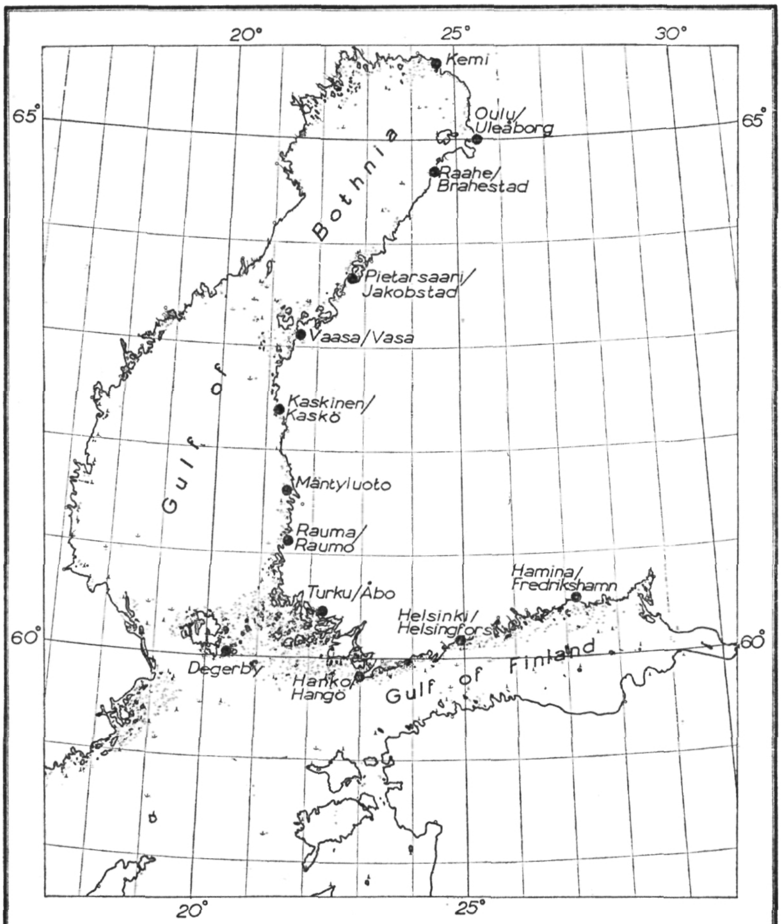

Figure 1. The positions of the Finnish sea level stations.

however, some modifications. In accordance with Hela's study the present work was started with the records for the sea level station Degerby, situated on the Aland Islands relatively close to the centre of the Baltic and its large gulfs, and being thus less subjected to the different disturbing coastal effects, representative of the conditions in this basin. For the computation of the rate of change in sea level the least-squares method was applied to the crude annual averages. This determination resulted in the value —4.77 mm per year, while the value estimated by Witting (1943) and used by Hela (1953) as the starting point of his study was —5.0 mm per year or, more exactly, making allowance for the varying length of the periods on which the results of the individual stations were based, —5.1 mm per year. The divergencies between the recorded annual means and the data computed with the aid of the rate of secular variation in sea level were analysed harmonically concerning the nodal tide. This step was necessary because the nodal tide has a strong effect on the computed rate of secular variation. According to Rossiter (1960) this rate computed with the method of the least squares contains a contribution amounting approximately to 0.1 of the coefficient of the sine-term of the nodal tide. The effect of this tide was eliminated from the data and the least-squares method applied once more, resulting in the positive correction of 0.22 mm per year. The final value for the rate of the decrease in sea level at Degerby was thus 4.55 mm per year.

If we accept the assumption that the recorded data at Degerby are more or less free from various local effects, the residues, which are the consequence of the successive elimination of the primary rate of secular variation, the nodal tide and the correction term, must be ascribed to the variation of the mean sea level in the Baltic caused by meteorological factors, changes in water density, river discharge and possible errors in the recorded data. We have at our disposal an excellent opportunity to check the reliability of these results. Hela (1944) has for a period of ten years 1926—1935 computed the monthly changes in the water quantity in the Baltic, basing his results on the records of twelve stations evenly distributed over all the coasts of the Baltic proper and its large gulfs. Degerby was one of the stations used by Hela in his study, but its contribution to the final results was in this case slight. Nevertheless, the agreement between the annual deviations in mean sea level determined by two completely independent methods is surprisingly good. The data for Degerby in the present study were referred to the average mean sea level for the span of time studied by Hela for the entire Baltic and only the effect of the decrease in sea level, not that of the nodal tide, was eliminated. The results are given in Table 1. The largest deviation between two corresponding figures is that for 1933 which amounts to 1.1 cm, the standart deviation being 0.6 cm. In addition, it may be mentioned that the correlation between the monthly averages of mean sea level in the Baltic computed by Hela and the residues of sea level records at Degerby is as high as 0.991 ± 0.001 (Lisitzin, 1953). This shows that the Degerby data are fairly representative of the whole basin.

Table 1. The annual averages in sea level in cm. in the Baltic during the ten year perioid 1926—1935.

	Degerby	Baltic
1926	-1.8	-1.5
1927	4.1	3.4
1928	0.8	0.1
1929	-0.6	-1.0
1930	-2.5	-2.9
1931	-1.3	-1.2
1932	4.4	4.7
1933	-6.8	-5.7
1934	0.8	1.2
1935	3.1	3.5

Passing on to the remaining tidal stations the first step was to eliminate from the recorded data the residues computed for Degerby. Thereafter the rate for the decrease in sea level was determined by the least-squares method, its influence removed from the data, the harmonic constants for the nodal tide computed and its effect eliminated. Finally, the correction term for the secular variation was determined and the data discharged from its effect. It may be mentioned that the value of the correction term varied from 0.14 to 0.36 mm per year for the different stations.

A brief glance at the residues computed for the individual stations in the way described above already shows considerable regularity in their general pattern along the coast. They may, therefore, in conformity with the scheme given by Hela, be attributed to the slope of the water surface caused by wind, atmospheric pressure and differences in water density. To take as much account as possible of the local meteorological effect upon the slope, its determination for the different years was performed not on a linear basis but in proportion to the average conditions typical of the entire period covering 37 years. After

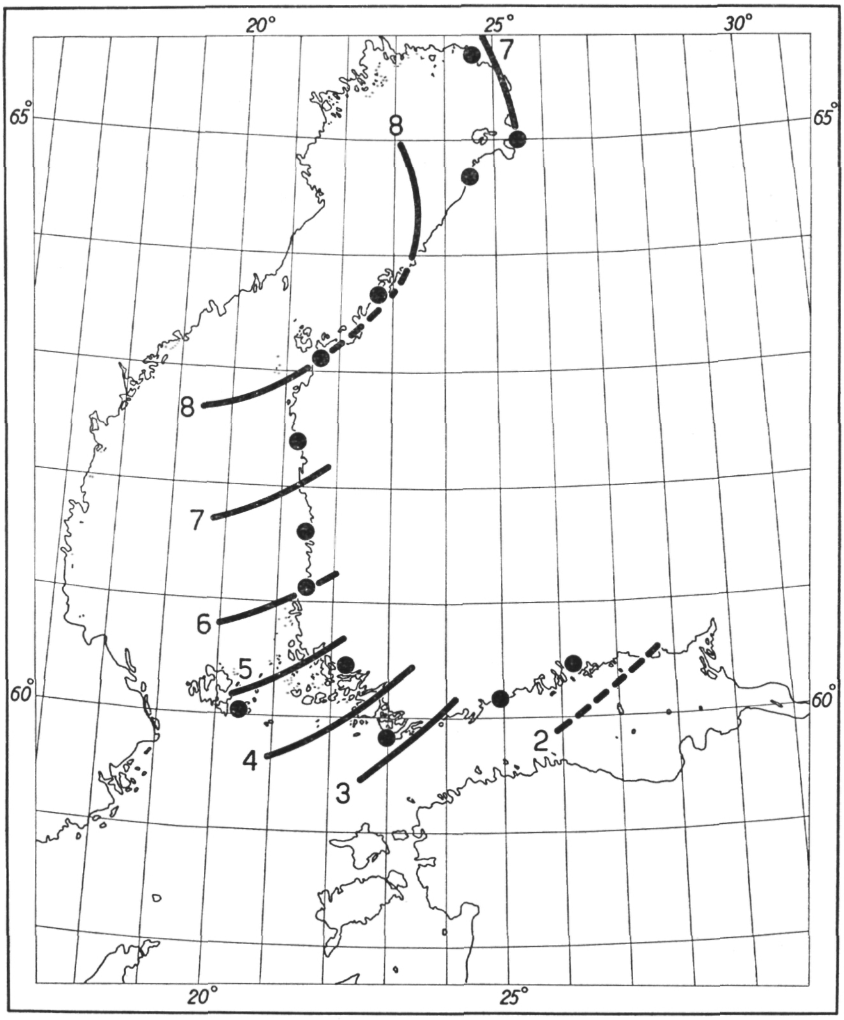

Figure 2. The rate of secular variation in sea level in mm per year.

the elimination of this effect the remaining residues had to be attributable to exceptional local factors prevailing during the separate years, to a deficiency in the method of purifying the data, or to errors in the records themselves. It is these residues which determine the magnitude of the mean error of the rate of secular variation for the particular stations.

The computed results of the rate of secular variation in sea level and the above-mentioned mean errors are given in Table 2. The more pronounced value of the mean errors for Oulu, Vaasa and Turku reflects the location of these stations in areas with an extensive archipelago off the coast and thus more subject to locally accentuated influences. Table 2 also presents a comparison with the values computed by other authors with the aid of sea level records, and with the rate of land uplift determined by Kääriäinen on the basis of two successive precise levellings, and kindly placed at the disposition of the present author. These data are referred to an eustatically invariable mean sea level.

Table 2. The secular variation in sea level in mm per year according to different authors. Eustatic increase in level is not taken into account.*

	Witting 1898—1912	Witting 1898—1927	Model 1904—1937	Hela 1922—1951	Rossiter 1940—1958	Lisitzin 1924—1960	Kääriäinen Presice levelling
Kemi	—	(11.7)	7.2	6.4 ± 1.2	8.5 ± 1.4	7.3 ± 0.9	7.82
Oulu	10.3	10.7	6.3	6.3 ± 1.2	7.0 ± 1.3	7.1 ± 1.0	7.56
Raahe	—	(11.7)	7.5	7.4 ± 0.9	8.0 ± 1.4	7.8 ± 0.7	8.27
Pietarsaari	—	—	8.7	7.6 ± 0.4	9.2 ± 1.4	8.2 ± 0.7	8.13
Vaasa	9.2	8.7	8.0	7.2 ± 0.7	7.6 ± 1.3	8.0 ± 1.1	7.65
Kaskinen	—	—	6.8	7.6 ± 0.7	6.7 ± 1.4	7.4 ± 0.7	7.00
Mäntyluoto	7.4	6.6	6.8	6.5 ± 0,4	5.3 ± 1.4	6.4 ± 0.6	6.35
Rauma	—	—	5.0	5.9 ± 0.4	3.9 ± 1.5	—	6.23
Turku	—	(5.4)	3.3	4.8 ± 0.6	2.5 ± 1.5	4.4 ± 1.2	4.67
Degerby	—	—	3.3	5.1	—	4.6	—
Hanko	4.5	4.0	3.6	3.5 ± 0.6	1.1 ± 1.5	3.1 ± 0.5	2.86
Helsinki	0.8	2.8	2.8	3.1 ± 0.4	-0.4 ± 1.5	2.5 ± 0.5	2.16
Hamina	—	—	3.6	2.2 ± 1.0	-0.4 ± 1.5	—	1.93

* The positive data imply a decrease in mean sea level.

Figure 2 gives the regional distribution of the rate of secular variation in sea level according to the results of this paper.

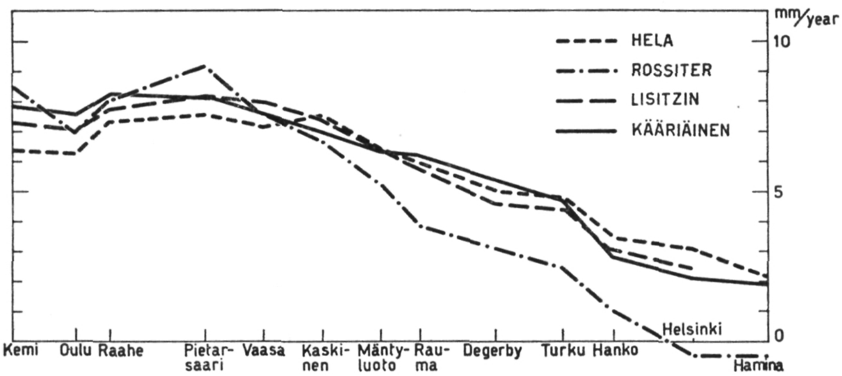

Figure 3. The rate of secular variation in sea level (in mm per year) along the Finnish coast according to different authors.

DISCUSSION OF THE RESULTS

A. Land uplift

It is somewhat surprising to find that the deviations between the results of this study and those given by other authors show a pronounced regularity in their general course. These features appear particularly distinctly from Figure 3, which gives a good picture of the regional distribution of the rate of secular variation in sea level along the Finnish coast, from Kemi in the north to Hamina in the east. The figure includes only the data computed by Hela, Rossiter an the author, and the results on the basis of precise levelling according to Kääriäinen.

Studying the figure we note, for instance, that the values computed by Hela are less pronounced than those determined by the present author in the northern parts of the Gulf of Bothnia (Kemi to Vaasa) and, on the contrary, larger farther south. The maximun negative divergency amounts to 0.9 mm per year for Kemi, the largest positive difference to 0.6 mm per year for Helsinki. These features reveal the general character of the data given by Hela, showing the slightest regional discrepancies; the deviation between the area of the most marked secular variation (around Pietarsaari), and Hamina situated in the eastern part of the Gulf of Finland, is only 5.4 mm per year.

As for Rossiter's results, they show considerable regional differences. The maximum deviation in the rate of secular variation in sea level amounts, according to Rossiter, to 9.6 mm per year, and is reached between Pietarsaari, on the one hand, and Helsinki and Hamina, on the other hand. A comparison of Rossiter's data with the results of this paper shows, therefore, that the former values are higher than the latter, with the exception of that for Oulu, in the northern part of the Gulf of Bothnia, the largest difference amounting to 1.2 mm per year, while farther south and in the Gulf of Finland they are throughout lower, the largest deviation being here as marked as -2.9 mm per year. Turning to the data based on the results of precise levelling, we note that they show a good conformity to the values determined by the present author. The differences at all the stations do not exceed 0.52 mm per year, and they are thus of the magnitude of the average value for the mean error. Since the two sets of data were determined on the basis of two completely different methods the results are fairly encouraging.

Looking for the causes of systematic discrepancy between the separate series of data determined on the basis of sea level observations, one must always bear in mind the fact that though the results given by Hela, Rossiter and the present author refer largely to the same years of recording and certain conformity is therefore evident, a number of differences may, however, be ascribed to the deviations in periods. Rossiter, for instance, in an attempt to choose a span of time with the central year as close as possible to the period, 1950, selected for the levelling network, had the misfortune to start his study with records for a group of years characterised by very low sea level along practically all the European coast. It is probable that this low sea level was the consequence of the extremely cold winters in Europe at the beginning of the 1940's and it may therefore be ascribed to the interruption or even to a regression of the eustatic increase in sea level. This may account for the low values of land uplift computed by Rossiter for the parts of the Finnish coast lying south of Vaasa. The deviations from all other corresponding data are especially pronounced in the Gulf of Finland, where according to Rossiter's results land subsidence would occur, a phenomenon that is contradictory to the data computed by other oceanographers, to the values based on precise levelling and to general experience in these regions. Table 3, which gives the

Table 3. The meteorological anf hydrographic contribution to sea level in mm in comparison with average conditions.

	Kemi	Oulu	Raahe	Pietar-saari	Vaasa	Kaski-nen	Mänty-luoto	Turku	Degerby	Hanko	Hel-sinki
1924	25	20	19	18	16	11	6	7	1	6	8
1925	54	59	60	61	65	68	73	73	79	89	95
1926	—27	—23	—23	—22	—19	—17	—13	—14	—9	—16	—20
1927	9	17	19	20	22	29	37	35	44	43	42
1928	—7	—4	—3	—3	—2	0	3	2	5	9	11
1929	2	—2	—2	—3	—4	—7	—10	—10	—14	—6	—2
1930	—52	—49	—48	—47	—46	—43	—40	—40	—36	—36	—35
1931	—48	—43	—42	—41	—40	—35	—30	—31	—25	—31	—34
1932	40	39	38	38	37	36	35	35	33	42	47
1933	—105	—99	—98	—97	—96	—89	—83	—84	—76	—78	—79
1934	28	23	22	21	20	15	10	11	5	1	3
1935	29	30	31	31	30	31	32	32	34	32	31
1936	—37	—35	—35	—34	—34	—32	—30	—30	—28	—31	—33
1937	—103	—99	—99	—96	—95	—89	—83	—84	—77	—91	—98
1938	154	143	140	138	136	125	114	116	103	102	102
1939	—74	—76	—77	—77	—78	—80	—82	—82	—85	—89	—91
1940	—14	—17	—17	—18	—19	—21	—24	—23	—26	—36	—38
1941	—124	—122	—121	—121	—120	—118	—115	—116	—113	—121	—125
1942	—6	—10	—11	—12	—13	—17	—21	—21	—26	—28	—29
1943	173	159	156	154	151	137	123	126	109	115	131
1944	85	77	75	73	72	64	56	53	48	52	54
1945	10	17	18	20	21	28	35	34	42	44	45
1946	22	17	16	14	13	7	3	2	—5	—7	—8
1947	—125	—126	—126	— 126	—126	—126	—127	—127	—127	—123	—120
1948	73	68	67	66	65	61	55	57	52	56	58
1949	103	98	97	96	95	91	85	88	82	86	87
1950	23	25	25	26	26	27	29	29	30	29	30
1951	—65	—72	—75	—76	—77	—80	—90	—90	—97	—113	—120
1952	19	24	25	26	27	31	35	34	40	33	28
1953	56	47	46	44	42	34	25	26	16	23	26
1954	5	0	—1	—2	—3	—7	—11	—11	—16	—14	—14
1955	14	20	22	22	23	30	36	36	43	54	61
1956	—2	7	9	11	13	22	31	29	40	43	44
1957	59	61	61	61	62	63	65	64	66	80	87
1958	—15	—10	—9	—7	—6	—1	5	4	11	12	12
1959	—49	—47	—47	—46	—46	—44	—42	—43	—40	—41	—42
1960	—124	—115	—113	—112	—110	—101	—92	—94	—83	—95	—103

meteorological and hydrographic contribution, and may, in addition, reflect the irregularities in the general eustatic increase in sea level, according to our results, is very instructive on this point. It can be seen that in the early 1940' s the disturbing factor affecting sea level was uniformly negative, increasing numerically towards the east in the Gulf of Finland. By contrast, in the years 1955—1958 (which correspond to the end of the period chosen by Rossiter) the disturbing factor along the south coast of Finland was positive and numerically higher than at the stations in the Gulf of Bothnia. For the former period we may therefore speak of a negative set-up, in relation to average conditions, in the Gulf of Finland. For the latter period this set-up was positive. There was thus a considerable shift in the slope of the sea surface along the Finnish coast which could hardly be taken into complete account on the basis of a general scheme of air pressure distribution.

One more point must be mentioned in this connexion: the influence of the nodal tide was not eliminated from the data used by Hela. In the next sub-division of this chapter it will be shown that the initial year of Hela's period coincided with a minimum of this tide along the Finnish coast. The end of the period taken by Hela was, on the other hand, characterised by a high value of sea level due to the nodal tide. It can be estimated that the ignoring of this effect resulted in a lowering of the computed rate of land uplift of between 0.7 mm per year (for Kemi) and 0.4 mm per year (for Vaasa, Turku and Degerby). The application of these corrections to Hela's values brings them into close conformity with the results of the present study for the four stations situated north of Vaasa; farther south the deviations from the current data increase when the corrections are made. The question of whether, and to what extent, these considerable discrepancies must be ascribed to the use of different values for the secular variation at Degerby as a starting point for the computations, to the extremely pronounced negative set-up along the coast from Vaasa to Helsinki in the year 1951 (the last year used by Hela in his study), or to other factors must here be left unanswered.

Before turning over to the last item of this study, the nodal tide, attention must be paid to the eustatic increase in sea level caused by the melting of inland ice in polar regions. As pointed out above, this increase can hardly be expected to be either strictly regular or continual.

Not even its average value is known exactly: the particular papers concerned with this question give different figures, and some of the more significant and interesting results are collated in Table 4.

Table 4. The average eustatic increase in sea level in mm per year according to different authors.

Thorarinsson	(1940)	0.5 or more	Cryological aspects
Gutenberg	(1941)	1.1 ± 0.8	Great number of sea level data
Kuenen	(1950)	1.2 to 1.4	Combination of different aspects
Dietrich	(1954)	1.14 ± 0.28	Sea level data for Esbjerg
Lisitzin	(1958b)	1.1 to 1.2	Sea level data for six stations
Wexler	(1961)	1.18	Cryological estimations

The average value of the eustatic increase computed or estimated by different authors amounts to 1.0—1.1 mm per year. In order to get an approximate rate of land uplift this correction must be added to the data representing the secular variation in sea level.

The main purpose of the above comparative study was to give, through numerical examples, an idea of the reliability of the various methods for the computation of land uplift, and of the effect of the period used upon the results. It may also be pointed out that the final solution to the complicated problem of determining land uplift with the aid of sea level records has by no means been found and will require further research.

B. The nodal tide

In order to eliminate the influence of the nodal tide upon the sea level records the relevant harmonic constants were determined. Table 5 gives these results in comparison with the corresponding constants computed by Rossiter (1960). The amplitudes of the equilibrium nodal tide are also included in the table, and have been taken from Rossiter's study.

Table 5. The harmonic constants of the nodal tide.

	Lisitzin		Rossiter		Amplitude of
	Amplitude mm	Years of maximum	Amplitude mm	Years of maximum	the equilibr. nodal tide mm
Kemi	27.7	1931, 1950	9.0	1943	9.2
Oulu	26.4	» »	3.6	1941	9.1
Raahe	26.0	» »	6.4	1943	9.0
Pietarsaari	26.4	» »	6.7	1941	8.7
Vaasa	17.7	» »	5.3	1954	8.5
Kaskinen	20.9	» »	3.5	1952	8.5
Mäntyluoto	20.3	» »	4.9	1952	8.1
Rauma	—	— —	3.6	1952	8.0
Turku	17.7	1931, 1950	5.0	1951	7.8
Degerby	18.1	» »	—	—	—
Hanko	19.9	» »	8.3	1952	7.8
Helsinki	20.8	» »	11.2	1952	7.7
Hamina	—	— —	3.4	1950	7.9

A brief glance at the table suffices to show that the conformity between the data is rather poor. In fact, there is coincidence only in the time of the appearance of the maximum sea level of the tide for the stations situated south of Pietarsaari. For the more northerly stations the phase of oscillation is, indeed, practically the opposite for Rossiter's data and the results of this paper. There is unfortunately no possibility of checking this negative result by additional values. The only data available for the nodal tide on the coast of Finland refer to the island stations of Utö and Rönnskär (Lisitzin 1957 b). For the tide pole station Utö, situated in the skerries between Degerby and Turku, the harmonic constants were based on four complete periods of 18.6 year observations, and resulted, after a levelling of the data, in the years of maximum sea level 1937 and 1956. For Rönnskär, lying in the outer skerries outside Vaasa, the corresponding years computed with the aid of two complete periods around the turn of the century were 1935 and 1954.

A comparison between the amplitudes is still more confusing. The values given by Rossiter show pronounced local variations. Rossiter himself has pointed out in his paper that the »noise level» is high in his data, even after the removal of the meteorological effect. Rossiter's values are, moreover, with the exception of Hanko and Helsinki, less marked than the amplitudes based on the equilibrium theory. The results of the present paper show more conformity. The stations may according to these figures be divided into two groups, one representing the northern part of the Gulf of Bothnia and characterised by an amplitude of 26 to 28 mm, the other covering the entire Finnish coast south of Pietarsaari and the amplitudes varying between 17 and 21 mm. A comparison of these figures with the amplitudes of the equilibrium nodal tide shows that the former are approximately 2.5 to 3 times larger than the latter. Two different points of view may here be cited. Maximov (1960) computed that the amplitudes based on the harmonic analysis of the recorded sea level data transferred to the coast of the Arctic ocean are, on an average, roundly four times more marked than the corresponding amplitudes determined with the aid of the equilibrium theory. A similar tendency can, according to Maximov's results, also be noted for the fortnightly and the monthly tides. The data in the present paper should thus be of the expected magnitude. On the other hand, it appears certain according to a mathematical analysis performed by Proudman (1960), that the 18.6 year tide will follow the equilibrium law. A final conclusion is therefore not at the moment possible.

It may, however, be mentioned that the data in this paper accord better with the results of analysis for the nodal tide performed by Rossiter using crude means of sea level than with those based on corrected data. The harmonic constituents of the nodal tide are in the former case given by Rossiter (1962) only for the four following Finnish tide gauge stations:

	Amplitude mm	Year of maximum
Oulu	31.6	1955
Kaskinen	28.0	1954
Hanko	28.8	1953
Hamina	29.9	1953

According to Rossiter the use of the »smoothing process» on the observed data before analysis for the nodal tide must be viewed with suspicion. While »smoothing» can reduce the scatter of a series of observations, it may also introduce a spurious and undesirable correlation between individual constituents. This may also, of course, apply to the data given in the present paper.

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