B. RESULTS FROM TIDAL OBSERVATIONS MADE IN SOUTH-GREENLAND

BY

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Part I.

Results from observations of the height of the sea level made at Julianehaab ($\varphi = 60° 43'$ N, $\lambda = 46° 02'$ W) in the years 1933 and 1934.

1. The observational data.

The observations consist of readings on a scale (tide staff) of the height of the sea level at high water and low water during the period from June 30th 1933 to October 9th 1933. These observations were made both in the day-hours (7 a.m.—6 p.m.) and in the night-hours (7 p.m.—6 a.m.). During the first two months of the period, observations were made regularly, but for the rest of the period some few observations are missing, mainly on account of bad weather.

From October 10th 1933 to June 30th 1934, the height of the sea level was recorded by means of a Portable Automatic Recording Tide-Gauge, designed by Commander G. T. Rude for the U. S. Coast and Geodetic Survey (See page 16).

The tidal graph is recorded on sheets of special cross-section paper, so that the height of the sea level and the time can be read directly from the sheet. For all solar hours in the period mentioned the recorded height of the sea level has been read from the sheets by Assistant A. Groot Hansen, and entered on lists. The values are given in units of 1/25th foot (1 foot = 30.48 cm.).

In the beginning of January the tide-gauge got out of order on account of frost, but on removing the ice from the float-tube and covering the water in the tube with a layer of petroleum, the tide-gauge worked well in spite of a temperature of so low as —25° (Centigrade). From frost and other reasons, the recorder has been out of function several times for shorter or longer periods, during the winter. During the spring and later, records are only missing for shorter periods.

2. The determinations of the mean sea level.

In order to determine the mean sea level, observations from at least so long a time as the longest period for an important term of the harmonic constituents should be used, in other words, in order to determine the height of the mean sea level, it is necessary to use observations from a whole year, as the annual variation of the height of the sea level may be rather considerable.

On account of the fact that expeditions to Greenland often are of short duration, it has not been possible up to now to determine the mean sea level for any port in Greenland. Mean values of the observed heights of the sea level are given, but these means may on account of the annual variation, differ considerably from mean sea level. Therefore the Chief for the measurements of the height of the sea level of the 7th Thule Expedition has endeavoured to get observations from Julianehaab during a whole year, and in using the tide staff readings of the extremes and the recorded values, observations from a whole year are available.

In order to eliminate the different tidal variations the determination of mean sea level from the readings of the extremes is made in the following manner: Periods equal to a siderial month (27.3 solar days) are considered separately. For each period, the heights observed both at high and at low water are separated according to the solar hour at which they are observed, and for each solar hour, means of the heights at high and at low water are computed, and thereafter the average of these two means is found. From these 24 of the last mentioned averages, the mean for the period is computed. In cases where observations are missing, values calculated by interpolation have been inserted.

The determination of mean sea level for the period during which the height of the sea level has been recorded, is carried out simply in computing the means of all obtained values, treating each month separately. Afterwards small corrections have to be added to these monthly means in order to refer all heights to the true height on the tide staff.

In order to elucidate the question as to whether means obtained from extreme readings and means obtained from recorded values could be used together, for instance for the determination of the annual variations of the height of the sea level, the records obtained in Julianehaab have been used for the determination of the height at high and at low water. From these extreme values, and from the hourly values obtained from the record, means for each of the months from October 1933 to June 1934 have been computed. The means found and their differences, are given in Table 1, expressed in feet.

From Table 1, it will be seen that the difference between the means derived in the two manners is small, but it seems as if the means derived from the hourly values are slightly higher than the means derived from

Table 1. — *Means of the height of the sea level referred to the tide staff.*

Period		From hourly values	From extreme values	Difference
		Feet	Feet	Feet
1933.	October 10th—31st	6.10	6.07	+ 0.03
	November	6.54	6.51	+ 0.03
	December	6.74	6.72	+ 0.02
1934.	January	6.45	6.42	+ 0.03
	February	6.08	6.04	+ 0.04
	March	5.84	5.85	— 0.01
	April	5.30	5.25	+ 0.05
	May	5.79	5.77	+ 0.02
	June	5.84	5.81	+ 0.03
				Mean: + 0.027

extreme values. On account of the smallness of the difference, no error of importance is introduced if means derived from extreme values are used together with means derived from hourly values.

In the following Table 2 therefore, mean values derived according to the two methods have been used together. The table contains mean values for different periods during a whole year, given in feet.

Table 2. — *Mean height of the sea level in Julianehaab referred to the tide staff.*

Period		Feet	
1933.	June 30th—July 26th	5.92	From extreme readings
	July 27th—Aug. 23rd	6.08	
	Aug. 24th—Sept. 19th	6.47	
	Sept. 20th—Oct. 9th	5.96	
	Oct. 10th—Oct. 31st	6.10	From recorded values
	Nov. 1st—Nov. 30th	6.54	
	Dec. 1st—Dec. 31st	6.74	
1934.	Jan. 1st—Jan. 30th	6.45	
	Febr. 10th—Febr. 28th	6.08	
	March 1st—March 31st	5.84	
	April 1st—April 30th	5.30	
	May 1st—May 31st	5.79	
	June 1st—June 30th	5.84	
		Mean: 6.08	

Thus, mean sea level corresponds to the reading 6.08 feet on the tide staff or to a level 12.22 feet (or 3.725 metres) below the bench

Table 3. —
Julianehaab, S = +3.

	A_0	M_2		S_2		N_2	
	Feet	Feet	g	Feet	g	Feet	g
1933. Oct. 11th—Nov. 8th	6.12	2.84	180°	1.09	213°	0.57	157°
Nov. 9th—Dec. 7th	6.69	2.81	180°	1.07	205°	0.58	153°
Dec. 8th—1934, Jan. 5th	6.63	2.92	180°	1.05	217°	0.56	161°
1934. Febr. 23rd—March 23rd	5.99	2.83	179°	1.10	210°	0.61	156°
May 31st—June 28th	5.84	2.79	180°	1.10	214°	0.53	155°
Mean ...	(6.08)	2.84	180°	1.08	212°	0.57	156°
		cm.	ϰ	cm.	ϰ	cm.	ϰ
		86.6	175°	32.9	210°	17.4	149°

	cm.	Feet
Sa	12.5	0.41
Ssa	6.1	0.20

mark: The circular plate with the inscription: "Geodætisk Institut Danmark" placed on the northwestern corner of the storehouse "Nyboder". The point to which levelling has been made is a small hole in the copper bolt in the middle of the plate (See Fig. 10, page 23).

3. Harmonic analysis.

The recorded hourly values for the periods: Oct. 11th 1933—Jan. 5th 1934, Febr. 23rd—March 23rd 1934, and May 31st—June 28th 1934, have been harmonic analysed. Values found by interpolation have been inserted for missing values. Using the method of A. T. Doodson[1]) the terms M_2, S_2, N_2, K_2, K_1, O_1, P_1, M_4 and MS_4 have been computed for the above mentioned periods, having considered periods of 29 days separately. The result of these computations is given in Table 3. In order to elucidate the accuracy with which the amplitudes and phase angles of the different terms have been found, values from each of the considered 5 periods have been given separately. In the table, the quantity A_0, the mean height of the sea level for the period considered, is given for each of the 5 periods, and the value of A_0 given

[1]) Instruction for Analysing Tidal Observations. Published by Order of the Lords Commissioners of the Admiralty, London.

Harmonic constants.

$\varphi = 60°43'$ N, $\lambda = 46°02'$ W.

K_2		K_1		O_1		P_1		M_4		MS_4	
Feet	g	Feet	g	Feet	g	Feet	g	Feet	g	Feet	g
0.30	213°	0.50	115°	0.29	71°	0.16	115°	0.03	98°	0.005	284°
0.29	205°	0.49	112°	0.26	76°	0.16	112°	0.05	123°	0.01	357°
0.28	217°	0.52	114°	0.26	77°	0.17	114°	0.03	126°	0.005	288°
0.30	210°	0.53	113°	0.30	83°	0.17	113°	0.02	97°	0.00	—
0.30	214°	0.52	111°	0.30	76°	0.17	111°	0.04	115°	0.01	265°
0.29	212°	0.51	113°	0.28	77°	0.17	113°	0.03	114°	0.005	299°
cm.	$\varkappa$	cm.	$\varkappa$	cm.	$\varkappa$	cm.	$\varkappa$	cm.	$\varkappa$	cm.	$\varkappa$
8.8	210°	15.5	112°	8.5	73°	5.2	112°	0.9	104°	0.1	292°

$\varkappa$	g
238°	238°
211	211

below in parenthesis, is the mean sea level. All values of A_0 are referred to the tide staff, and not as usual to chart datum. In Table 3 the constants for the annual variations, Sa and Ssa, will also be found.

From the computed harmonic constants, it is possible to determine the height of the sea level for a given moment, but, as stated before, it is necessary to use the first mentioned constants as well as the constants for the annual variations. This has been done for certain moments of the considered periods, that is to say for moments for which the height was known, and the difference between the computed value and the known value in four considered cases, did not exceed 12 cm. It should be added that in order to determine the height of the sea level, the atmospheric pressure and the direction and the force of the wind must also be taken into consideration. These effects have not been fully examined for the observed heights of the sea level in Nanortalik, but it has been stated that a wind of a certain force will cause a smaller variation in the height of the sea level in Nanortalik, than a wind of the same force will cause in Danish waters.

The computation of the harmonic constants has been carried out with the assistance of Miss Ellen Honum in the Geophysical Section of the Danish Meteorological Institute.

In Table 4, the harmonic constants found for different places in Greenland have been compiled for comparison. In the table are given:

Table 4. — *Harmonic tidal constants*

	φ	λ	M_2 H cm.	M_2 $\varkappa$	S_2 H cm.	S_2 $\varkappa$
(1) Cape Bryant	82°21′ N	55°30′ W	12.8	004°	7.0	047°
(2) Cape Morris Jesup	83°40′ N	33°35′ W	4.2	305°	2.4	014°
(3) Little Finsch Island	73°59′ N	21°08′ W	44.9	315°	19.5	000°
(4) Danmark Island	70°27′ N	26°12′ W	35.0	337°	16.2	028°
(5) Finnsbu	63°24′ N	41°17′ W	85.1	127°	36.6	158°
(6) Nanortalik	60°08′ N	45°15′ W	88.5	161°	37.5	203°
(7) Julianehaab	60°43′ N	46°02′ W	86.6	175°	32.9	210°
(8) Godthaab	64°11′ N	51°45′ W	136.0	193°	47.0	229°
(9) Kamarajuk Fjord	71°00′ N	51°00′ W	45.6	298°	17.0	320°
(10) Port Foulke	78°18′ N	72°40′ W	110.9	332°	46.3	005°
(11) Van Rensselaer Harbour	78°38′ N	70°40′ W	102.7	333°	45.4	012°
(12) Thank Good Harbour	81°37′ N	61°40′ W	54.9	352°	25.3	033°

	M_4 H cm.	M_4 $\varkappa$	MS_4 H cm.	MS_4 $\varkappa$	Sa H cm.	Sa $\varkappa$	Ssa H cm.	Ssa $\varkappa$
(1) Cape Bryant	..	..	..	..	..	..	..	..
(2) Cape Morris Jesup	..	..	..	..	..	..	..	..
(3) Little Finsch Island	..	..	..	..	..	..	..	..
(4) Danmark Island	..	..	..	..	..	..	..	..
(5) Finnsbu	..	..	..	..	..	..	..	..
(6) Nanortalik	..	..	..	..	..	..	..	..
(7) Julianehaab	0.9	104°	0.1	292°	12.5	238°	6.1	211°
(8) Godthaab	..	..	..	..	..	..	..	..
(9) Kamarajuk Fjord	..	..	..	..	..	..	..	..
(10) Port Foulke	..	..	..	..	..	..	..	..
(11) Van Rensselaer Harbour	..	..	..	..	..	..	..	..
(12) Thank Good Harbour	..	..	..	..	..	..	..	..

for different places in Greenland.

N_2		K_2		L_2		K_1		O_1		P_1	
H cm.	$\varkappa$	H cm.	$\varkappa$	H cm.	$\varkappa$	H cm.	$\varkappa$	H cm.	$\varkappa$	H cm.	$\varkappa$
2.4	350°	1.9	047°	..	..	9.8	286°	4.3	262°	3.2	286°
..	..	..	..	..	..	7.6	340°	5.7	310°	..	..
11.9	289°	..	..	..	..	11.8	075°	7.6	025°	..	..
7.6	312°	4.4	028°	..	..	8.7	065°	9.2	035°	2.9	065°
15.0	126°	..	..	..	..	13.2	093°	4.4	046°	..	..
..	..	..	..	..	..	19.0	114°	11.0	074°	..	..
17.4	149°	8.8	210°	..	..	15.5	112°	8.5	073°	5.2	112°
26.0	188°	13.0	227°	4	291°	21.0	127°	9.0	081°	7.0	125°
10.6	292°	4.6	322°	1.5	304°	36.5	148°	8.9	139°	12.1	148°
20.4	293°	12.5	005°	..	..	32.0	187°	12.4	145°	10.6	187°
21.3	303°	12.3	012°	..	..	25.9	193°	12.8	150°	8.5	193°
10.7	326°	6.8	033°	..	..	12.2	246°	4.6	209°	4.0	246°

Time and duration of observations		Authority: Observations	Authority: Analysis	Published
1909	28 days	Peary Polar Expedit.	U. S. Coast and Geodetic Surv. Office.	R. A. Harris: Arctic Tides, Wash. 1911.
1909	10 days	Peary Polar Expedit.	J. E. Fjeldstad.	"Maud" Polar Exp. 1918—25, vol. IV, Nr. 4, Bergen 1936.
1933	30 days	Norges Svalbard og Ishavsundersøkelser.	R. Kjaer and J. E. Fjeldstad.	Hydrograph. Review, vol. XI, No. 1, May 1934.
1891—92	86 days	Ryder's Expedition.	C. Crone.	Obs. Mét., Magn. et Hydromét. L'ile de Danemark.
1932	30 days	Norwegian Scientific Expedition.	R. Kjaer and J. E. Fjeldstad.	Hydrograph. Review, vol. XI, No. 1, May 1934.
1883—85	11 months	G. F. Holm's Expedit.	C. Crone	Obs. int. polaires, T. II, livr. II, III, Copenh. 1889
1933—34	145 days	7th Thule Expedition.	J. Egedal.	Medd. om Grønl. Vol. 107, No. II.
1883	47 days	Danish Polar Year Expedition.	C. Crone.	Obs. int. polaires, T. II, livr. I, II, Copenh. 1886.
1930	60 days	A. Wegener's Expedit.	Weiken and H. Rauschelbach.	Erg. d. Deut. Grönl. Exp. A. Wegener 1929, 1930—31, Bd. IV, No. 1, Leipzig.
1860—61	58 days		U. S. Coast and Geodetic Surv. Office.	R. A. Harris: Arctic Tides, Wash. 1911.
1853—54	116 days		U. S. Coast and Geodetic Surv. Office.	R. A. Harris: Arctic Tides, Wash. 1911.
1871—72	174 days	U. S. Polar Expedition.	U. S. Coast and Geodetic Surv. Office.	R. A. Harris: Arctic Tides, Wash. 1911.

the name of the place, the geographic latitude and longitude of the station, the different harmonic constants and other information.

Part II.

Results from observations of the height of the sea level made in Nanortalik ($\varphi = 60°08'$ N, $\lambda = 45°15'$ W) in the years 1932 and 1933.

1. The observational data.

The observations consist of readings, on a scale, of the height of the sea level at high water and low water. The observations were made from July 6th to October 16th 1932, and from May 27th to October 26th 1933. In the year 1932, the heights were observed during day-hours, but in the year 1933 the observations were made both in the day-hours and in the night-hours, so that the height of all high waters and low waters were observed. In 1933 no readings are missing.

2. The determination of mean sea level.

For the determination of the mean sea level, observations from periods of 27 or 28 days have been treated separately. For the observations from 1932, the mean of the mean heights of the solar hours 7 a.m. to 6 p.m. respectively at high and low water are computed, and afterwards the mean of these two means was obtained.

For the observations for the year 1933 where observations were made both in the day-hours and the night-hours, the mean height was found in computing the mean of the mean of the heights observed at high water, and the mean of the heights observed at low water.

In Table 5, the computed mean heights of the sea level for different periods in the years 1932 and 1933 are given. The values are referred to the bench mark consisting of an iron bolt in a hole in the rocks near the old observatory. It is the same bench mark as was used by the G. F. Holm Expedition in the years 1883—86 (See page 22). In 1932 and 1933 the height of the zero point of the scale has been determined in relation to the iron bolt (See page 24).

The determination of the height of mean sea level in Nanortalik from the values of Table 5, will be mentioned below.

Table 5. — *Mean heights of the sea level in Nanortalik for different periods in the years 1932 and 1933.*

Period			Below bench mark
1932.	July 7th—Aug. 3rd	7 a.m.—6 p.m.	6.191 m.
	Aug. 4th—Aug. 31st	„	6.130 m.
	Sept. 1st—Sept. 28th	„	6.044 m.
	Sept. 29th—Oct. 12th	„	6.143 m.
1933.	May 27th—June 22nd	12 p.m.—12 p.m.	6.204 m.
	June 23rd—July 19th	„	6.195 m.
	July 20th—Aug. 16th	„	6.174 m.
	Aug. 17th—Sept. 12th	„	6.127 m.
	Sept. 13th—Oct. 9th	„	6.147 m.
	Oct. 10th—Oct. 23th	„	6.088 m.

Part III.

The relative sinking of the land in the region of South-Greenland surrounding Nanortalik.

1. The determination of the sinking of the land by means of the sea level observations.

In the report[1]) on his expedition to Greenland in 1883—86 Commander G. F. Holm in mentioning the observations of the height of the sea level in Nanortalik has written (in translation): "By means of this it will be possible to ascertain whether the land really sinks as generally maintained, when tidal measurings are again made at a later date."

During the years since 1885, no observations of the height of the sea level had been made until the year 1932, when the observations treated in Part II were commenced, and these observations by the 7th Thule Expedition had just been established in order to examine the question touched on in the mentioned quotation from G. F. Holm's report. The observations made by Holm's expedition and the observations made in 1932 and 1933 are carried out in the same way and in the same place.

The determination of the height at high water and low water was made very carefully by Holm's expedition. The observers, the esquimau

[1]) "Medd. om Grønl." Vol. 9, p. 70, Copenhagen 1889.

interpreters, read the height of the sea level every 10 minutes of an interval beginning three quarters of an hour before the extreme could be expected, and lasting in all, one and a half hours. The observations were afterwards entered in a book from which a page is reproduced in Fig. 12[1]). From the figure it will be seen that the observations have been treated with great care.

For the determination of the variation of mean sea level from 1883—85 to 1932—33, the first difficulty is that neither in the years 1883—85 nor in the years 1932 and 1933, are observations from a whole year available. The observations are made at different periods of the year, the older ones in winter and the new ones in summer, and it is known from the annual variations (the terms Sa and Ssa) for Julianehaab, that the annual variation at the coast of South-Greenland is rather great (range about 30 cm.), thus a difference of several centimetres could be expected between means of winter observations and means of summer observations.

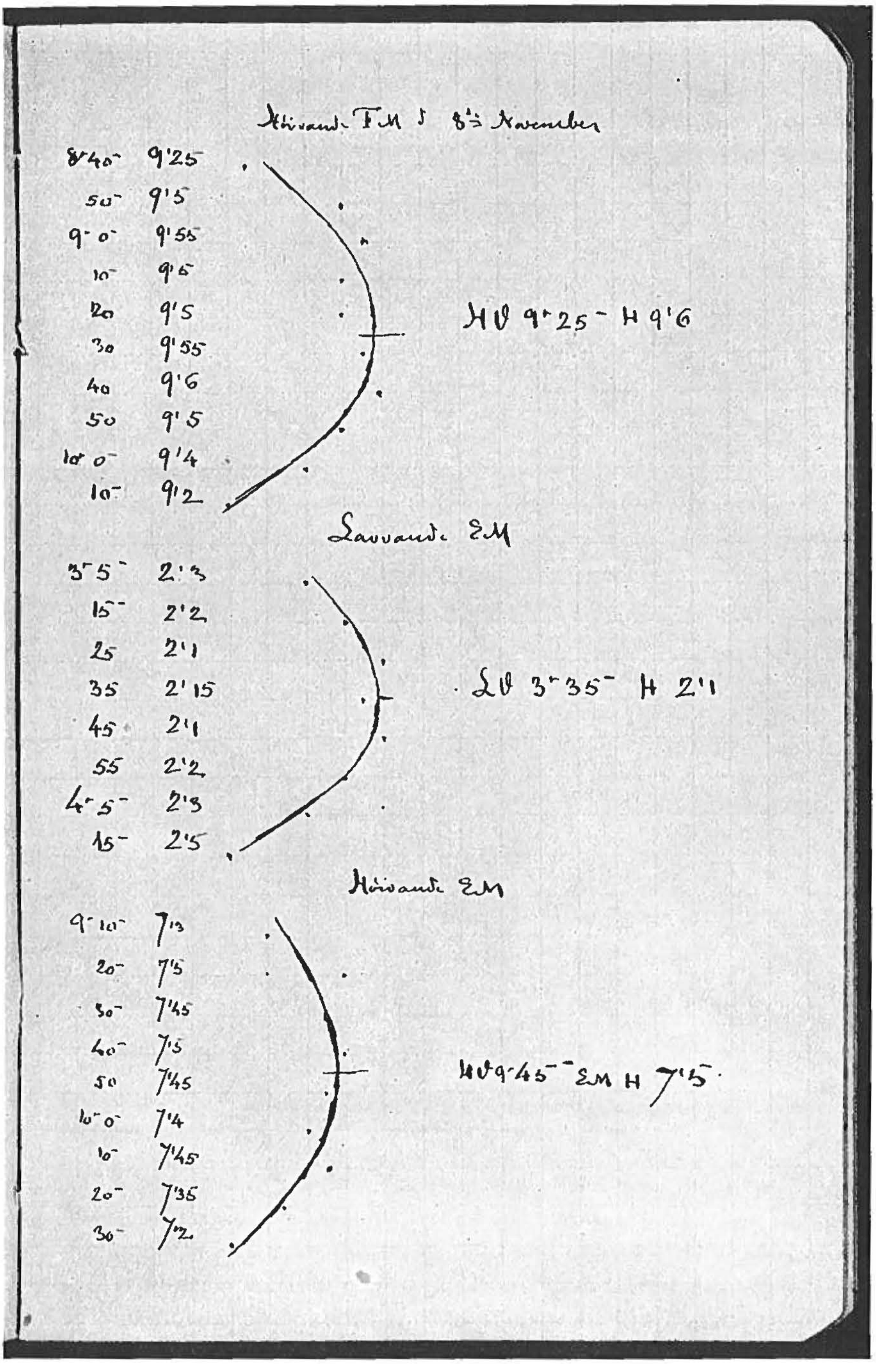
And there is also another difficulty: the observations from the year 1883, and partly from the year 1884, and from the year 1932, are only made in the day-hours, and, as a varying difference exists between the mean height of the sea level for the day-hours and for the night-hours, such values can not be used without correction. The harmonic terms causing this varying difference are the terms K_1 and P_1, but when these terms are known a correction can be computed.

In the present case, consequently, a comparison of mean sea level as determined by the observations from 1883—85 and mean sea level as determined by the observations from 1932 and 1933 cannot be made off hand. It has been found best to make corrections for the annual variations in using the annual variations found for Julianehaab, which is the only place in Greenland for which these variations are known, and further, it may be expected that the annual variations at Julianehaab on account of the relative small distance to Nanortalik ($^3/_4{}^\circ$ of latitude) are not very different from those at Nanortalik.

The corrections for the variations originating from the terms K_1 and P_1 have been found from the values of K_1 and P_1 for Julianehaab. From Table 4 it will be seen that the amplitude of the term K_1 for Nanortalik seems rather high.

In Table 6, all the above-mentioned derived mean heights of the sea level and the necessary corrections are compiled. The table contains:—the periods of one siderial month, the mean sea level for these periods, the corrections for the annual variations and for variations

[1]) The reproduction has been made with the permission of the Director of the Royal Danish Hydrographic Office, where the books for sea level observations from Holm's expedition are preserved.



Højvande FM 8de November

8t40m	9'25
50m	9'5
9t 0m	9'55
10m	9'6
20	9'5
30	9'55
40	9'6
50	9'5
10t 0m	9'4
10m	9'2

HV 9t25m H 9'6

Lavvande EM

3t5m	2'3
15m	2'2
25	2'1
35	2'15
45	2'1
55	2'2
4t5m	2'3
15m	2'5

LV 3t35m H 2'1

Højvande EM

9t10m	7'3
20m	7'5
30m	7'45
40m	7'5
50	7'45
10t0m	7'4
10m	7'45
20m	7'35
30m	7'2

HV 9t45m EM H 7'5

Fig. 12. Reproduction of a page from a book used by G. F. Holm's expedition for sea level observations (1884).

Table 6. — *Mean sea level at Nanortalik referred to the bench mark.*

Period	Interval	Sea level (Below the bench mark)	Correction for annual variations	Correction for K_1 and P_1	Computed mean sea level	Weight
	Hours	m.	m.	m.	m.	
1883. Nov. 1—Nov. 27 ...	$6^1/_2$—$18^1/_2$	6.120	+0.113	+0.062	6.295	1
Nov. 28—Dec. 24...	,,	6.211	+0.155	+0.039	6.405	1
Dec. 25—84, Jan. 20	,,	6.244	+0.141	+0.009	6.394	1
1884. Jan. 21—Febr. 17 ..	,,	6.329	+0.059	—0.024	6.364	1
Febr. 18—March 15.	,,	6.356	—0.054	—0.052	6.250	1
March 16—April 11.	,,	6.447	—0.139	—0.067	6.241	1
April 12—April 25..	,,	6.557	—0.163	—0.071	6.323	$^1/_2$
Oct. 16—Nov. 11...	,,	6.147	+0.076	+0.071	6.294	1
,, ...	$18^1/_2$— $6^1/_2$	6.324	+0.076	—0.071	6.329	1
Nov. 12—Dec. 8 ...	$6^1/_2$—$18^1/_2$	6.218	+0.136	+0.056	6.410	1
,, ...	$18^1/_2$— $6^1/_2$	6.302	+0.136	—0.056	6.382	1
Dec. 9—85, Jan. 5 .	$6^1/_2$—$18^1/_2$	6.224	+0.158	+0.030	6.412	1
,, .	$18^1/_2$— $6^1/_2$	6.313	+0.158	—0.030	6.441	1
1885. Jan. 6—Febr. 1	$6^1/_2$—$18^1/_2$	6.224	+0.110	—0.007	6.327	1
,, ...	$18^1/_2$— $6^1/_2$	6.205	+0.110	+0.007	6.322	1
	Mean 1883—1885: 6.347 ± 0.0160 m.[1])					
1932. July 7—Aug. 3	$6^1/_2$—$18^1/_2$	6.191	—0.006	+0.002	6.187	1
Aug. 4—Aug. 31 ...	,,	6.130	+0.005	+0.033	6.168	1
Sept. 1—Sept. 28...	,,	6.044	+0.011	+0.062	6.117	1
Sept. 29—Oct. 12...	,,	6.143	+0.030	+0.070	6.243	$^1/_2$
1933. May 27—June 22...	0—24	6.204	—0.080	0.000	6.124	2
June 23—July 19...	,,	6.195	—0.023	,,	6.172	2
July 20—Aug. 16...	,,	6.174	+0.003	,,	6.177	2
Aug. 17—Sept. 12 ..	,,	6.127	+0.006	,,	6.133	2
Sept. 13—Oct. 9 ...	,,	6.147	+0.019	,,	6.166	2
Oct. 10—Oct. 23 ...	,,	6.088	+0.051	,,	6.139	1
	Mean 1932—1933: 6.157 ± 0.0093 m.					

[1]) This corresponds to 19.92 feet (Danish). Cfr. Medd. o. Gr. vol. 9, p. 339.

originating from the harmonic terms K_1 and P_1, the computed mean sea level and the weight of the found values. The weights are given in accordance with the number of observations used. The means for the years 1883—85 and the years 1932—33 and their standard deviation are computed. It will be seen that the standard deviation for the older observations is greater than that for the latest observations; in spite of the care with which the older observations seemed to have been made. In this connection, it should be remembered that the computed values for the different siderial months are affected not only by observational errors, but also by effects both from the pressure of the air and from the wind. These effects are greater in winter than in summer, thus the force of the wind in Nanortalik in the years 1884 and 1885 was twice as high in winter as in summer, so that the variations of the height of the sea level caused by wind may be expected to be about three times as great in winter as in summer for the period mentioned. Therefore, the greater standard deviation of the observations from the years 1883—85 is to be ascribed to the fact that during winter, at which time the observations have been made, the deviations from normal sea level are greater than for any other part of the year. For the rest, it is obvious that observations made according to the method used at the observations in 1883—85 should give values having an observational error much smaller than the errors originating from other sources.

As to the reference of the readings of the scale to the bench mark mentioned in this paper (p. 22), all values from 1932 and 1933 have been referred to the bench mark in using the values obtained from the levelling and given on p. 24. For the years 1883—85, it has not been possible to find the result from more than one determination of the difference in height between the bench mark and the scale. A greater part of Holm's observations has been perused without result. It seems rather strange if Holm and his Second-in-Command, Garde, had not made more than one determination, on the other hand, if the determination found is made with the same care as the other observations, and care has been taken that the position of the scale has not been changed in the period considered, then no serious error should arise in this connection.

The found determination is placed on the last page of a book with title (in translation): "V. G.G.U. Sea level observations at Nanortalik 1884—86", and is given in the following form (in translation):

"Levelling
from the 10 feet[1]) point for the observations at the wharf to the deepest thermometer-hole[2]) outside the magnetic house

+ 3.182	— 0.563
+ 2.348	— 0.340
+ 5.530	— 0.903
— 0.903	

4.627 m. = the height of the hole over the 10 feet mark."

[1]) Danish measure: 1 foot = 31.385 cm.

[2]) "The thermometer hole" or "the hole" means the bench mark which is an iron bolt founded in a hole in the rock.

There is still one fact to be mentioned in this connection. G. F. Holm in a communication[1]) has given the height of the hole over the 10 feet mark as 14.75 feet, but this makes 4.629 metres. If more determinations had existed, the mean value of them surely would have been 4.629 metres, therefore, in using the value 4.627 metres, no great error is introduced.

According to the values from Table 6, the total variation of mean sea level from the years 1883—85 to the years 1932 and 1933 is:

$$0.190 \pm 0.0185 \text{ m.},$$

and as the time between the two series of observation is:

48.8 years

the mean variation of mean sea level for the period considered is:

$$3.9 \pm 0.38 \text{ mm. per annum},$$

and this quantity is the value of the relative sinking of the land.

2. Comparison of the found relative sinking of the land in South-Greenland with other results concerning the relative sinking of the land in other parts of Greenland.

Many observations of different kind have been made in different parts of Greenland in order to ascertain the sinking of the land. The position of old buildings and ruins in relation to the present mean sea level, the height in relation to mean sea level of ring-bolts where ships were formerly mooring, and certain geological circumstances have been examined, and hereby it is confirmed that many buildings and ruins are "drowned", and that mooring bolts are found beneath the surface of the sea and so on, every thing telling that the land is sinking.

The first one to call attention to the phenomenon was Dr. C. Pingel. On a visit to Greenland in the years 1828—29, he collected data which proved the sinking of the land, and he communicated in short notes his result to different foreign scientific societies. In a paper[2]) read at the 2nd Scandinavian Naturalist Congress 1840, a more detailed account was given. In this paper Pingel made an interesting comparison between the rising of the land in the Scandinavian Peninsula and the sinking of the land in Greenland.

Later on it has also been tried to determine the extent of the sinking of the land for a certain period.

[1]) Medd. om Grønl. Vol. 9, p. 339, Copenhagen 1889.

[2]) C. Pingel: Om Sænkningen af Grønlands Vestkyst. Forh. 2. skand. Naturforskerm., 1840, pp. 353—363, Copenhagen 1841.

In a paper[1]) by Th. Vogt containing a great many references on this matter, it is stated that Robert Brown estimated the value of the sinking of the land to less than 15 mm. per annum.

From J. A. D. Jensen's expedition in the year 1878, it is reported[2]) that S. Kleinschmidt, teacher at a seminary, had reported that at Lichtenfels ($\varphi = 63°04'$ N, $\lambda = 50°43'$ W) it had been established that three trestles on which a "women's boat" was placed when it had been hauled up from the sea since the year 1789 had to be moved three times in order that the boat should not be taken by the sea, and herefrom it is concluded that the sinking of the land had been 6—8 feet (Danish) in a period of 89 years or 21—28 mm. per annum.

The first real measurements in Greenland of the sinking of the land were made by K. J. V. Steenstrup and Captain F. Froda, R.D.N.

K. J. V. Steenstrup in a paper[3]) read for the Royal Society, Copenhagen, on February 24th, 1905, has discussed the question as to the possibility of determining the sinking of the land in Greenland by means of observations of the position of the sea-weed stripe on the cliffs in relation to some fixed point. Views of other Scandinavian naturalists on the question are mentioned in the paper, and it is finally stated that from two photographs of the sea-weed stripe taken in 1876 and 1904 near Ivigtut, it has been deduced that the sinking of the land amounts to 25 cm. in that period of 28 years or to 8.9 mm. per annum.

In the year 1897 F. Froda (F. Petersen)[4]) in Godhavn determined the vertical distance of 7 balanus-stripes from a fixed mark, and in the year 1923 he repeated the measurements[5]) in measuring the vertical distance of 13 balanus-stripes from the fixed mark, and found that the balanus-stripes were in a position 15 cm. higher on an average than in 1897, and herefrom he deduced the average sinking of the land to be 5.8 mm. per annum.

The method used by Froda is based on the assumption that the balanus-stripes are situated in a rather constant distance below the mean height of high water, but this assumption does not seem to be sufficient. R. Spärck, Professor of Zoology, Copenhagen University, on inquiry has stated that the position in height of the balanus-stripes also depends on the qualities of the substratum, so that only the highest

[1]) Th. Vogt: Bretrykk-teori og Jordskorpe-bevegelser i arktiske trakter i ny tid. Norsk geografisk Tidsskr. Bd. I, pp. 336—386, Oslo 1927.

[2]) Medd. om Grønl. Vol. 1, II, p. 34, Copenhagen 1879.

[3]) K. J. V. Steenstrup: Peut-on conclure de la limite supérieure des herbes marines deposées sur les côtes à la hauteur atteinte par les eaux? Cfr. Medd. om Grønl. Vol. 33, pp. 1—8, Copenhagen 1905.

[4]) Medd. om Grønl. Vol. 14, pp. 343—347, Copenhagen 1898.

[5]) F. Froda: Some observations made in North-Greenland 1923. Medd. om Grønl. Vol. 59, p. 51, Copenhagen 1925.

balanus-stripe may offer some information as to the variation of the height of the sea level. The author therefore concludes that the value for the sinking of the land found by Froda may be affected by the last-mentioned circumstances, and consequently be to some degree uncertain, on the other hand, taking into consideration that the determination from 1897 of the height of the balanus-stripes is based on observations of 7 stripes and that from 1923 on observations of 13 stripes, it is probable that the latter stripes are more dispersed and that these observations result in a value indicating a lower sea level in relation to the value resulting from the first series of observations, and thus indicates a too small sinking of the land. Unfortunately, only the values from the observations in 1923 are known, and not the values obtained in 1897, therefore it can be considered as probable that the sinking of the land at Godhavn exceeds 5.8 mm. per annum.

The value of the sinking of the land found for Godhavn (North-Greenland) is higher than that found for Nanortalik, and in order to further establish that the sinking of the land in North-Greenland is greater than that in South-Greenland, the following results obtained by Dr. Therkel Mathiassen[1]) and placed at disposal for this paper, are to be mentioned.[2]) Th. Mathiassen has examined buildings and ruins which have been inundated in different districts, and he arrives at the following conclusion given in his own words (in translation): "Any actual difference in the subversive forces on the north and south West Coast cannot be proved, although there is a slight excess for North-Greenland. If, for instance, one calculated the percentages of settlements with demolished ruins in proportion to the total number of ruin places visited, 30 °/₀ is obtained for Upernivik District, 38 °/₀ for Diskobugten, 21 °/₀ for Sukkertoppen District and 28 °/₀ for Julianehaab District. If these figures are calculated for the whole North- and South-Greenland, the result is 35 °/₀ and 27 °/₀ respectively. Neither is there any apprecciable difference respecting the subversive forces as regards single ruins." This conclusion by Th. Mathiassen is to be considered in favour of a higher value of the sinking of the land in North- than in South-Greenland.

Th. Vogt in his above-mentioned paper considers the question as to the extent of the sinking of the land in Greenland and in Spitsbergen. Vogt, in estimating the increase in the thickness of the inland ice, finds a value of the increase of the pressure on the earth, and comparing the isostatic effects originating from known variations of pressure on

[1]) Compiled from many of his papers. Cfr. R. Bøgvad's account. Medd. om Grønl. Vol. 107, Nr. III, Copenhagen 1940.

[2]) Later the communication of Th. Mathiassen was embodied in the present paper (p. 8).

the earth in other places, he obtains a value for the sinking of the land in Spitsbergen of 4 mm. per annum. As Greenland is greater than Spitsbergen, he considers the above mentioned values for the sinking of the land in Greenland of 5.8 to 8.9 mm. per annum as reasonable.

The found value for the sinking of the land in South-Greenland, namely 3.9 mm. per annum, is lower than the above mentioned values, and thus lower than the value Vogt would find reasonable. In this connection it should be remembered: that the sinking of the land is not to be expected to be equal in all parts of Greenland.

3. The forces causing the sinking of the land in Greenland.

C. Pingel in his paper, read 100 years ago, compared the sinking of the land in Greenland with the rising of the land in Scandinavia. It is generally agreed that the rising of the land in Scandinavia is caused by isostatic forces acting after the disappearance of the ice of the glacial period, and in the same way it may be concluded that isostatic forces are acting in Greenland, but on account of an increased load (of ice) on the land.

But C. Pingel's comparison can be extended still further. In the regions around the Scandinavian Peninsula, the land is sinking, and in the case of Greenland, Th. Mathiassen[1]) from his investigations in the Hudson Bay district, has made sure that the land there is rising. In Scandinavia, the rising of the land is greatest in northern Sweden, and is decreasing steadily in all directions, until the region where the land is sinking. It is to be expected that the sinking of the land in Greenland in the same way is greatest at some central part of Greenland, and that the extent of the sinking is decreasing in all directions, until a region of rising land is reached.

It is well known that the form of the earth very closely follows the tidal forces which by their action form a tide of $^1/_3$rd of the magnitude corresponding to equilibrium tide. The rising and the sinking of the land are on the contrary taking place very slowly. It is clear that the earth-tides consist in elastic yieldings and that the rising and the sinking of the land is followed by some transport of masses in the interior of the earth. The existence of regions of rising land around a region of sinking land, and regions of sinking land around a region of rising land, supports this assumption.

From the above points of view, it is obvious that the sinking of the land at Godhavn lying near to the central part of Greenland's inland

[1]) Archæology of the Central Eskimos I. Report of the Fifth Thule Expedition IV, 1927.

ice should be greater than the sinking of the land at Nanortalik lying more remote at the utmost end of the narrower part which South-Greenland forms.

As to the question whether the inland ice is growing or not, the best information is received from the report of Wegener's expedition[1]) to Greenland 1930—1931, in which E. Sorge has given the following statement: Jährlich legt sich über das Innere Grönlands eine ein Meter hohe Schneedecke. Das entspricht einer Wasserhöhe von 31.4 Zentimeter. This is the case for the station "Eismitte" ($\varphi = 71^1/_4°$ N, $\lambda = 40°$ W). The augmentation by the snow of the ice in the interior of Greenland is to some degree compensated by the melting of the ice in the coastal regions, and the ice carried away by the glaciers.

F. Loewe in an article[2]) has discussed the question as to the balance of accumulation and dispersion of the ice, and arrives at the following conclusion: "Zuwachs- und Abtrag-Messungen sind räumlich und zeitlich noch viel zu wenig ausgedehnt, um eine Massenbilanz des Inland-Eises aufstellen zu können." But he points out that the inland ice when the Norsemen occupied Greenland 1000 years ago had the same extent as now, that is to say, that the balance nearly exists.

This view agrees well with results obtained by Th. Mathiassen[3]) in examining the position of houses from the period before the 17th century, viz., that the land in Greenland at that time was rising. Comparing again the conditions in Greenland with the Scandinavian Peninsula's conditions where the land is constantly rising, it seems curious that some few hundreds of years back, the land in Greenland (which is now sinking) had been rising.

In this connection it may be mentioned that according to computations carried out by L. Lysgaard[4]) the mean temperature in Jakobshavn from the period 1881—1910 to the period 1901—1930 has risen about $1^1/_3$ degrees C., mainly on account of the rising of the temperature in winter. This may mean more melting of the ice, but may also mean more precipitation, but probably the values found for the sinking of the land in Greenland in the above mentioned period may be affected by this change in the meteorological elements.

At present, many of the problems touched on have to wait for solution till more observations of different kind in a remote future are at hand.

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[1]) Else Wegener: Alfred Wegeners letzte Grönland-Fahrt, Leipzig 1932.

[2]) F. Loewe: Wie ernährt sich Grönlands Inland-Eis? Natur und Volk, Bd. 67, Heft 10, pp. 473—483. Frankfurt a.M. 1937.

[3]) Medd. om Grønl. Vol. 118, Nr. 1, p. 86, Copenhagen 1936—37.

[4]) L. Lysgaard: Ændringer i Danmarks Klima i nyeste Tid. Med en kort Oversigt over Europas og Vestgrønlands Temperaturændringer. Geogr. Tidsskr. Vol. 40, pp. 137—155. Copenhagen 1937.

4. The signification of the found value of the relative sinking of the land.

The above considerations and computations have made it possible to determine the mean yearly variation of mean sea level in relation to a bench mark, and to determine the variation with a so small standard deviation, that the variation must be considered to be a reality. In relation to mean sea level, there is a sinking of the land, and because it is not possible to state whether the land or mean sea level or both of them are changing, the found sinking has been indicated as relative.

From the following two reasons one may conclude that the variation of the land generally is greater than the variation of the mean sea level:

1. In all parts of the world both sinking and rising of the land have been observed.
2. Variations of mean sea level must be variations common for 4/5ths of the surface of the earth.

From a geophysical point of view, the sinking of the land in Greenland is an interesting phenomenon, especially considered as a variation caused by isostatic forces, and therefore efforts ought to be made in order to determine the sinking of the land in different places in Greenland, for instance by the establishment of stations for automatic recording of the sea level and in using old sea level observations[1].

In conclusion, I wish to thank Dr. D. la Cour, Director of the Danish Meteorological Institute, for the permission to obtain assistance in the Geophysical Section of the Institute for computations in connection with the harmonic analysis, Commodore P. Jensen, Director of the Royal Danish Hydrographic Office, for the permission to use and to reproduce parts of the original documents from G. F. Holm's expedition 1883—1886, Professor N. E. Nørlund, Director of the Danish Geodetic Institute, for the permission to use data belonging to the 7th Thule Expedition, Captain Froda, Prof. K. Jessen, Dr. Th. Mathiassen, K. Milthers M. A., Dr. Noe-Nygaard, Prof. R. Spärck, Dr. H. Topsøe-Jensen, Dr. H. Ødum and other persons who have offered their help in connection with the present paper.

[1]) Cfr. Medd. om Grønl. Vol. 107, Nr. III, p. 30, Copenhagen 1940.

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