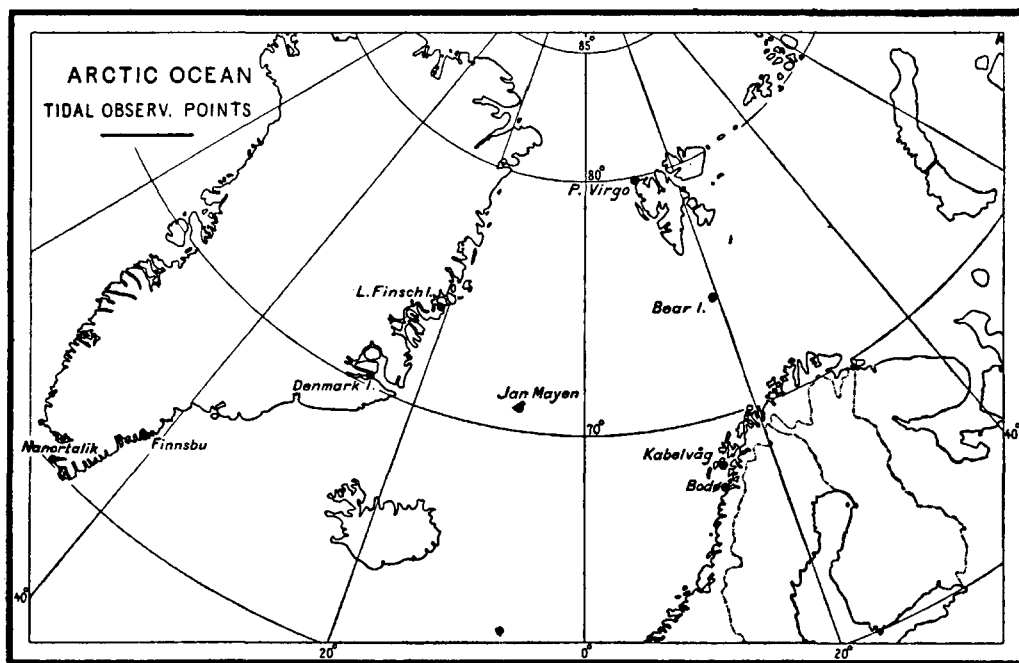# TIDAL OBSERVATIONS IN THE ARCTIC

by

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The tidal observations dealt with in this article were carried out on the Norwegian Arctic expeditions sent out in the years 1930-1933 by the NORGES SVALBARD- OG ISHAVS-UNDERSÖKELSER of Oslo.

The observations in Bear Island in 1930 and in East Greenland in 1933 were made by means of an automatic tide-gauge of American type (Julien P. FRIEZ & Sons, Baltimore, Md., U.S.A.) whereas the observations in Southeast Greenland in 1932 consisted of staff readings only.

The results of the observations were worked up shortly after the return of the expeditions, hence the different methods used.

The time of the observations is always Mean European Time (M.E.T.).



OBSERVATIONS.

*Bear Island* 1930.

The tidal observations on the coast of Bear Island were carried out in connection with a hydrographic expedition to the Svalbard waters on board the fishery inspection vessel of the Navy, the *Michael Sars*. On June 4th the expedition reached Bear Island where the ice conditions that year were very favourable.

With some difficulty the expedition succeeded in erecting the tide-gauge on the steep cliff-coast in Austervaag (N.E. side of the island), where it worked satisfactorily for 30 complete days from June 6th.

That the tidal observations could be successfully carried out throughout such a long period on the open Bear Island coast is in the first instance due to most favourable weather conditions with prevailing westerly winds of moderate force, without a heavy sea or swell. Nor did drift-ice hamper the work of the tide-gauge.

The geographical co-ordinates of the observation point in Austervaag are :

$$74^{o}\ 29'.4\ \text{Lat. N.} \qquad 19^{o}\ 12'.4\ \text{Long. E. Gr.}$$

*South-east Greenland, Finnsbu 1932.*

The tidal observations at the Norwegian Meteorological Station at Finnsbu, in the district of Skjoldungen in South-east Greenland, were carried out in 1932 by the scientific expedition on board the sealer *Veslemari*.

The expedition had no automatic tide-gauge at its disposal, but obtained information about the tide conditions by taking ordinary staff readings through a longer period. It was arranged that the men at Finnsbu should take the readings, but for various reasons these could not always be taken every hour.

The staff readings started on Aug. 17th and were continued until Sept. 15th when the expedition left for Norway.

Fine weather conditions prevailed during the observation period.

The geographical co-ordinates of the observation point are :

$$63^{o}\ 24'\ \text{Lat. N.} \qquad 41^{o}\ 17'\ \text{Long. W. Gr.}$$

*East Greenland, Vesle Finschöya (Little Finsch Island) 1933.*

The extensive programme of the scientific expedition to the East Greenland coast between $71^{o}$ and $76^{o}$ Lat. N. in 1933 also included tidal observations.

The expedition on board the sealer *Polarbjörn* reached the Claveringfjord in East Greenland on July 18th, finding the fjord almost ice-free. On Vesle Finschöya the tide-gauge was put up in a small bay, well sheltered from drift-ice, and was in continuous operation for 30 days.

On Aug. 18th the *Polarbjörn* called at Vesle Finschöya, the tidal observations were discontinued, and a few days later the expedition left East Greenland.

During the observation period the weather and ice conditions in the Claveringfjord were very favourable.

The geographical co-ordinates of the observation point are :

$$73^{o}\ 59'.4\ \text{Lat. N.} \qquad 21^{o}\ 08'.2\ \text{Long. W. Gr.}$$

RESULTS.

*Bear Island 1930.*

The harmonic analysis of the tidal observations from Bear Island has been performed according to the methods described by R. A. HARRIS in *Manual of Tides* (U. S. Coast & Geodetic Survey).

Fig. 1

*Putting up the tide-gauge on Bear Island coast.*

*Montage du marégraphe sur la côte de Bear Island.*



Fig. 2

Finnsbu, S. E. Greenland.



Fig. 3

*"The Tide-gauge Creek".*

*"La Crique du Marégraphe".*

Little Finsch I., E. Greenland.

The grouping of the hourly values to component hours has been done by means of table 42 in *Manual of Tides*. In this way the components $M_2$, $N_2$ and $O_1$ have been computed. The components $K_1$ and $S_2$ were found by the method described by G. H. DARWIN. (*)

This method gives some uncertainty in the determination of the components in question, as it is based on the assumption that the ratio of the components $K_1$ and $P_1$, and $K_2$ and $S_2$ have their theoretical values, and also that the differences of phases are the same as in the equilibrium theory. Therefore, the amplitude and the phase of $S_2$ may be slightly erroneous. The component $M_2$, however, is nearly correct, as may be seen from a curve showing the means of the hourly ordinates.

The component $O$, on the other hand, is rather uncertain, as is also $N$. The results are :

$$A_0 \qquad 54.9 \; \text{\%}_{m}$$

|  | Amplitude | Phase |
|---|---|---|
| $M_2$ | 34.2 $\text{\%}_{m}$ | $50°.5$ |
| $S_2$ | 13.0 ” | $83°$ |
| $N_2$ | 6.7 ” | $35°$ |
| $K_1$ | 5.4 ” | $230°$ |
| $O_1$ | 4.4 ” | $66°$ |

From the harmonic constants we find tidal hour $M_2 = 0$ h. 40, and regarding the quality of the tide we obtain $\dfrac{S_2}{M_2} = 0.38$, while the theoretical value is 0.46 ; $S°_2 - M°_2 = 32°.5$, and the "age of tide" 32 hours.

*South-east Greenland, Finnsbu 1932.*

Since the readings in Finnsbu were made at irregular intervals, one has to interpolate the hourly heights of the sea-level. In order to do this, a continuous curve was drawn by means of the observed values. The drawing of this curve was facilitated by frequent readings near the times of H.W. and L.W. The tide seems to be but little disturbed by meteorological causes, and therefore the shape of the tidal curve could be determined without difficulties.

The hourly heights were read off the completed curve, and submitted to harmonic analysis according to the methods described by HARRIS. The results for the principal components of the tide are :

|  | Amplitude |  | Phase |
|---|---|---|---|
| $M_2$ | 85.1 $\text{\%}_{m}$ | $M°_2$ | $127°$ |
| $S_2$ | 36.6 ” | $S°_2$ | $158°$ |
| $N_2$ | 15.– ” | $N°_2$ | $126°$ |
| $K_1$ | 13.2 ” | $K°_1$ | $93°$ |
| $O_1$ | 4.4 ” | $O°_1$ | $46°$ |

(*) *On an Apparatus for Facilitating the Reduction of Tidal Observations* (Proc. of Royal Soc. of London, Vol. LII, p. 365).

For the sake of comparison the first 15 days were also analysed by the method of Dr. DOODSON (*), Tidal Institute of Liverpool, with the following results :

|        | Amplitude |        |          | Phase |
|--------|-----------|--------|----------|-------|
| $M_2$  | 91.2 $^c\!/_m$ | | $M^o_2$  | 127° |
| $S_2$  | 35.6 ”    |        | $S^o_2$  | 163° |
| $N_2$  | 18.4 ”    |        | $N^o_2$  | 123° |
| $K_1$  | 11.7 ”    |        | $K^o_1$  | 93°  |
| $O_1$  | 5.5 ”     |        | $O^o_1$  | 49°  |

The accordance between the results of the two analyses is satisfactory and gives a check on the values of $N_2$ and $O_1$, whose determination from so short and incomplete a series of observations is difficult.

*East Greenland, Vesle Finschöya (Little Finsch Island) 1933.*

The analysis is made by the method of DOODSON.

The tidal observations cover an interval of 30 complete days, of which the last day has been omitted because this method requires observations from 29 days.

It should be noted that the angles given as $M^o_2$, $S^o_2$, etc., mean the angle usually designated by κ, and not the angle which by DOODSON is designated by g.

As the weather conditions during the period of observations were favourable, and the records, therefore, are very regular, the results should be reliable. The harmonic constants which have been calculated are :

|        | Amplitude |        | Phase   |
|--------|-----------|--------|---------|
| $M_2$  | 44.9 $^c\!/_m$ | | 315°.3 |
| $S_2$  | 19.5 ”    |        | 0°      |
| $N_2$  | 11.9 ”    |        | 289°    |
| $K_1$  | 11.8 ”    |        | 75°     |
| $O_1$  | 7.6 ”     |        | 25°     |

*Comparison with results from other stations.*

It may be of interest to compare the harmonic constants for *Bear Island*, *Finnsbu* and *Vesle Finschöya* with the known harmonic constants from adjacent places. For this prupose we shall make use of the harmonic constants for *Nanortalik* (west of Cap Farvel), *Denmark Island* (in Scoresby Sound) and *Jan Mayen* on the western side ; *Bodö* and *Kabelvaag* (Norway), and *Port Virgo* (West Spitsbergen) on the eastern side, of the Norwegian Sea. In the following table we have compiled the harmonic constants for the principal components at these places together with some other quantities giving the quality of the tide. Most of these are found in HARRIS' *Arctic Tides*.

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(*) *Instructions for Analysing Tidal Observations,* published by the Lords Commissioners of the Admiralty.

| STATION. | Lat. N. | Long. Gr. | $M_2$ | $M_2$ | $S_2$ | $S_2$ | $N_2$ | $N_2$ | $K_1$ | $K_1$ | $O_1$ | $O°_1$ | $\frac{T.H.}{M_2}$ | $S°_2-M°_2$ | $M_2-N_2$ | $K_1-O_1$ | $\frac{S_2}{M_2}$ | $\frac{N_2}{M_2}$ | $\frac{O_1}{K_1}$ | $\frac{T.H.}{K_1}$ | $\frac{T.H.}{O_1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nanortalik | 60°08' | West 45°16' | 88.0 | 161° | 37.5 | 203° | — | — | 18.9 | 114° | 11.0 | 74° | 8.39 | 42° | — | 40° | 0.43 | — | 0.58 | 10.62 | 7.95 |
| FINNSBU | 63°24' | 41°17' | 85.1 | 127° | 36.6 | 158° | 15.0 | 126° | 13.2 | 93° | 4.4 | 46° | 6.98 | 31° | 1° | 47° | 0.43 | 0.18 | 0.33 | 8.95 | 5.82 |
| Denmark Island | 70°27' | 26°12' | 35.0 | 337° | 16.0 | 28° | 7.6 | 312° | 8.7 | 65° | 9.3 | 35° | 0.98 | 51° | 25° | 30° | 0.44 | 0.22 | 1.07 | 6.08 | 4.08 |
| VESLE FINSCHOYA | 73°59' | 21°08' | 44.9 | 315° | 19.5 | 0° | 11.9 | 289° | 11.8 | 75° | 7.6 | 25° | 11.92 | 45° | 27° | 50° | 0.44 | 0.27 | 0.66 | 6.41 | 3.10 |
| Jan Mayen | 71°00' | 8°28' | 40.2 | 328° | 13.1 | 18° | 8.5 | 300° | 3.4 | 97° | 6.1 | 49° | 11.51 | 50° | 29° | 47° | 0.33 | 0.21 | 1.86 | 7.00 | 3.85 |
| Bodo | East 67°17' | 14°23' | 86.6 | 356°5 | 29.9 | 35° | 17.4 | 334° | 10.4 | 208° | 4.0 | 32° | 10.91 | 39° | 22° | 176° | 0.35 | 0.20 | 0.38 | 12.00 | 1.16 |
| Kabetvåg | 68°13' | 14°30' | 90.8 | 39°5 | 32.9 | 44° | 18.6 | 340° | 10.4 | 212° | 4.0 | 54° | 11.15 | 40° | 24° | 158° | 0.36 | 0.20 | 0.38 | 13.16 | 2.63 |
| BEAR ISLAND | 74°29' | 19°12' | 34.2 | 50°5 | 13.0 | 83° | 6.7 | 35° | 5.4 | 230° | 4.4 | 66° | 0.40 | 33° | 16° | 164° | 0.38 | 0.20 | 0.82 | 14.05 | 3.12 |
| Port Virgo | 79°43' | 10°44' | 41.4 | 38°2 | 14.3 | 70° | 7.6 | 13° | 2.7 | 225° | 1.2 | 12° | 0.55 | 32° | 25° | 203° | 0.35 | 0.18 | 0.44 | 13.62 | 0.08 |

It should be noted that HARRIS gives the result of two different analyses for Port Virgo, one contained in the original memoire of *Mission Scientifique pour la mesure d'un Arc de Méridien au Spitzberg, Mission Suèdoise,* Tome I, p. 25, and the other the result of an analysis by the U. S. Coast & Geodetic Survey. The results differ widely on several points, but it seems that the American analysis is erroneous as far as regards the solar component $S_2$, which is found to be 7.9 $\%_m$, and the ratio $\dfrac{S_2}{M_2} = 0.19$. The Swedish analysis gives $S_2 = 14.3$ $\%_m$ and the ratio $\dfrac{S_2}{M_2} = 0.35$, which is nearly equal to the ratio found at all other stations in the northern part of the Norwegian Sea. We therefore adopt this value as the most probable.

A comparison of the harmonic constants shows the great resemblance of the tide at these places. The ratio $\dfrac{S_2}{M_2}$ varies between 0.33 and 0.44, and the ratio $\dfrac{N_2}{M_2}$ between 0.18 and 0.27.

The comparison of the diurnal tides reveals an interesting fact. While the diurnal component $O_1$ has nearly the same phase at the eastern and western sides of the Norwegian Sea, we see that the component $K_1$ is quite different. Thus we find the cotidal hours 6.08 at Denmark Island, 6.41 at Vesle Finschoya and 7.00 at Jan Mayen. At the Norwegian side we find 12.90 at Bodö, 13.16 at Kabelvaag, 14.05 at Bear Island and 13.62 at Port Virgo. The time difference is about 6 hours, or a quarter of a period.

Furthermore, we draw attention to the tidal hours for $M_2$, which give a picture of the propagation of the semidiurnal tide in the northern part of the Norwegian Sea. The cotidal line for 12 h. seems to run almost parallel to the shelf from Norway to Spitsbergen and also parallel to the northern part of East Greenland.

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