# VARIATIONS OF SEA LEVEL IN THE BALTIC

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Translated from *Bulletin d'Information* of the « Comité Central d'Océanographie et d'Etudes des Côtes » (C.O.E.C.), Vth Year, No. 1, Paris, January, 1953.

Variations of sea level in the Baltic, so far as they can be observed from curves recorded by tide gauge, are usually such a complex phenomenon that it is often extremely difficult to detect the origin of the variations. Contrarily to conditions prevailing in the oceans, tides play only a minor part as compared with other disturbance factors. There are nevertheless definitely preceptible tides in the Baltic, and the determination of harmonic constants for the various constituents can be effected by the usual method without trouble. During the summertime, on calm days marked only by slight fluctuations of atmospheric pressure, the curves indicating sea level variation show a surprisingly regular periodic wave, revealing the tide. During these periods there is an extremely satisfactory degree of agreement between curves observed and those computed by means of harmonic constants.

The type of tide varies in different parts of Finnish waters. In the inner and central areas of the Gulf of Bothnia and Gulf of Finland the tide is definitely of the diurnal type, while along the southwest coast of Finland and around the Åland Islands a mixed type of oscillation is observed. This fact enables the conclusion to be reached that the specific tide in the Baltic is of the diurnal type, but that in the southern and central parts of the sea, the semi-diurnal waves entering the Baltic through the Belts and Sund may be superimposed on this wave. The influence of these waves abates as they advance into the larger gulfs and finally becomes negligible as compared with the effect of the diurnal components. With reference to the range of the Baltic tide, it may be of interest to quote a few figures.

Under the most favourable circumstances, the difference between HW and LW is about 15 cm., in the interior of the Gulf of Finland, for instance, while at the mouth of the gulf, this difference does not even reach 5 cm. (3). The tide in the Gulf of Bothnia is even less marked than in the Gulf of Finland. This may be explained by the fact that the Gulf of Bothnia, unlike the Gulf of Finland, is not directly connected with the Baltic, but constitutes an area that is more or less separated from the central basin by the Åland Islands and the shallow sea in the archipelago. The greatest variations that can be caused by the tide amount to less than 7 cm. at the far end of the Gulf of Bothnia, and they decrease to 3 cm. in the southern part of the gulf (2).

These figures suffice to show that even the widest variations caused by the tide in the Baltic and its gulfs cannot be compared with the effect of the tide on

(*) Bracketed figures refer to the bibliography at the end of this article.

other sea coasts, where the difference between HW and LW often reaches several meters. In order that at least approximately equivalent differences may be attained in the Baltic, variations in sea level that are caused by meteorological factors must be considered, especially wind and atmospheric pressure. The effect of precipitation and evaporation must also be mentioned, but these two factors cannot be held responsible for large variations. The flow of rivers into the sea, especially in the spring, as well as the amount of water coming through the Belts and the Sund are likewise factors to be considered.

Wind and atmospheric pressure usually operate jointly in much the same way, so that it is often difficult to assess the influence of either of these factors on fluctuations in sea level. According to Witting (11), the effect of atmospheric pressure is not always easy to evaluate, especially in view of the continual change in the barometric situation, to which the sea level has not the time to adapt itself completely. Hence, when he theoretical coefficient of -13.6 for atmospheric pressure is retained, quite unacceptable wind-effect values are obtained. However, in cases where atmospherical formations are more or less stationary, results may be altogether satisfactory. I have estimated under such conditions that the effect of atmospheric pressure was responsible for approximately 25 % of the total variations in sea level (4). Stenij (10) while investigating an extreme case causing a destructive flood at the end of the Gulf of Finland, calculated that the atmospheric pressure effect induced a rise in sea level of about 25 cm., or slightly more than 10 % of the total rise. Account must also be taken of the fact that the influence of meteorological factors may take very different forms: at times there may be free oscillations, and at others forced oscillations. Moreover, in many cases the wind causes a rise in the sea surface that is sometimes characterized by considerable slope (Windstau). Very often these various factors are observed to operate jointly. Palmen (7 - 9), in various thorough surveys, has dicussed the question of elevation of the sea surface due to wind action. The seiche in the Baltic has been investigated by Neumann (6), among others. In general, however, a thorough and successful analysis has only been possible in strongly marked instances. Usually the total result composed of various factors can only be observed.

The question then arises as to what constitutes the extreme ranges of fluctuations of sea level in the Baltic. They naturally mainly depend on the position of the locality where observations have been carried out, continually progressing towards the interior areas of the Gulfs of Bothnia and Finland. As an approximate norm, it can be stated that the range or variation at Kemin, at the bottom of the Gulf of Bothnia, is about twice as large as at Degerby, located south of the Åland Islands. A few figures supporting this fact may be given (5). The difference between absolute maximum and minimum observed at Kemi during the entire period the tide gauge has been in operation at that station amounts to 292 cm., while the corresponding difference at Degerby only reaches 147 cm. Absolute fluctuations at Kemi are therefore 2.0 times as large as at Degerby. The mean annual difference at Kemi is 214 cm. and 96 cm. at Debergy ; the ratio between these two figures is therefore 2.2. For mean monthly differences, we get 104 cm. and 45 cm. respectively, making a ratio of 2.3. As regards diurnal differences, the corresponding means are approximately 21 cm. at Kemi and 10 cm. at Degerby, which means that the ratio in this case is 2.1. This series of four figures, 2.0, 2.2, 2.3 and 2.1 shows that remarkable consistency prevails between variations in sea level at Kemi and Degerby over different periods. Similar regularity may be noted as prevailing at all other tidal stations along the coasts of Finland.

Certain very interesting conclusions may be drawn from this fact. At Degerby, which is a station already mentioned as being located on an island in the central area of the Baltic itself and its larger gulfs, variations of sea level reflect, at least in first approximation, the mean fluctuations of the sea in question. It may be pointed out, for instance, that correlation between the monthly means of sea level for the entire Baltic (determined by Hela (1) for the ten-year period 1926-1935) and for Degerby supplies a coefficient of 0.991. As might be expected, there is good correlation as regards the Baltic as a whole and Kemi, but in this case the coefficient only amounts to 0.875. The number of oscillations that are characteristic of the station is therefore incomparably larger at Kemi than at Degerby, although there is likewise evidence of them at Degerby. Thus the maximum difference in sea level for the Baltic as a whole during the period described amounts to 111 cm., according to Hela, while the corresponding difference at Degerby is 146 cm. These figures prove that at least 25 % of the variations observed at Degerby must be attributed to local oscillations, while the remainder, or 75 %, depends upon the amount of water existing throughout the Baltic. These variations in turn are mainly due to the amount of water flowing through the Belts and the Sund. If conditions at Kemi are similarly examined, it may be observed that at this station the picture changes completely. Here, slightly more than 60 % of the variations are to be attributed to the local influence of meteorological factors, or at least to factors prevailing in the Gulf of Bothnia area ; and about 40 % to fluctuations in the amount of water in the Baltic. The reasons for this considerable dissimilarity are not easily found. A rise in the height of the sea surface due to wind action is a strongly marked phenomenon in the interior of the gulf, but is of slight importance at Degerby. Oscillations of the seiche in the « Baltic proper-Gulf of Bothnia » system have a nodal line in the area of the Åland Islands. Consequently the effect of the seiche, which may be made evident by a range of over a meter at Kemi, is practically negligible at Degerby. Similar analyses carried out in the case of other stations may enable a rough estimate to be made of the part played by the various factors in total variation of sea level.

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