NEGATIVE SURGES IN THE SOUTHERN NORTH SEA

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INTRODUCTION

Following a request by the Hydrographer of the Royal Netherlands Navy in connection with the navigation of deep draught vessels in the southern part of the North Sea, a Working Group of the "Raad van Overleg voor fysisch-oceanografisch Onderzoek van de Noordzee" (Consultative Council for Physical Oceanographic Research in the North Sea) has recently made preliminary investigations into the occurrence of negative surges in the southern North Sea. Special attention was given to the Sandettié Bank and the Brown Ridge areas in view of the water depths there.

An abstract of the Group's report has been inserted in the "Zeemansgids van de Nederlandse kust en aangrenzend gebied" (Netherlands Coast Pilot).

The following is a translation of this report. A section dealing with other factors also affecting underkeel clearance has, however, been omitted, as have some suggestions to the above-mentioned Council.

STATISTICAL STUDY OF THE OCCURRENCE OF NEGATIVE SURGES

In addition to the 50 years of data available for the stations of Hook of Holland and Flushing, punched card records of hourly observations of water levels for Dunkerque (about 4.7 years) were obtained from the French Hydrographic Office, and for Dover (about 20.1 years) from the Institute of Coastal Oceanography and Tides at Liverpool. In order to determine these negative surges the observed high and low water levels were compared with the predicted levels given in the Tide Tables. For Dunkerque and Dover, therefore, a polynomial interpolation had first to be made in order to deduce the actual high and low waters from the hourly observations before these could be compared with the tide table values.

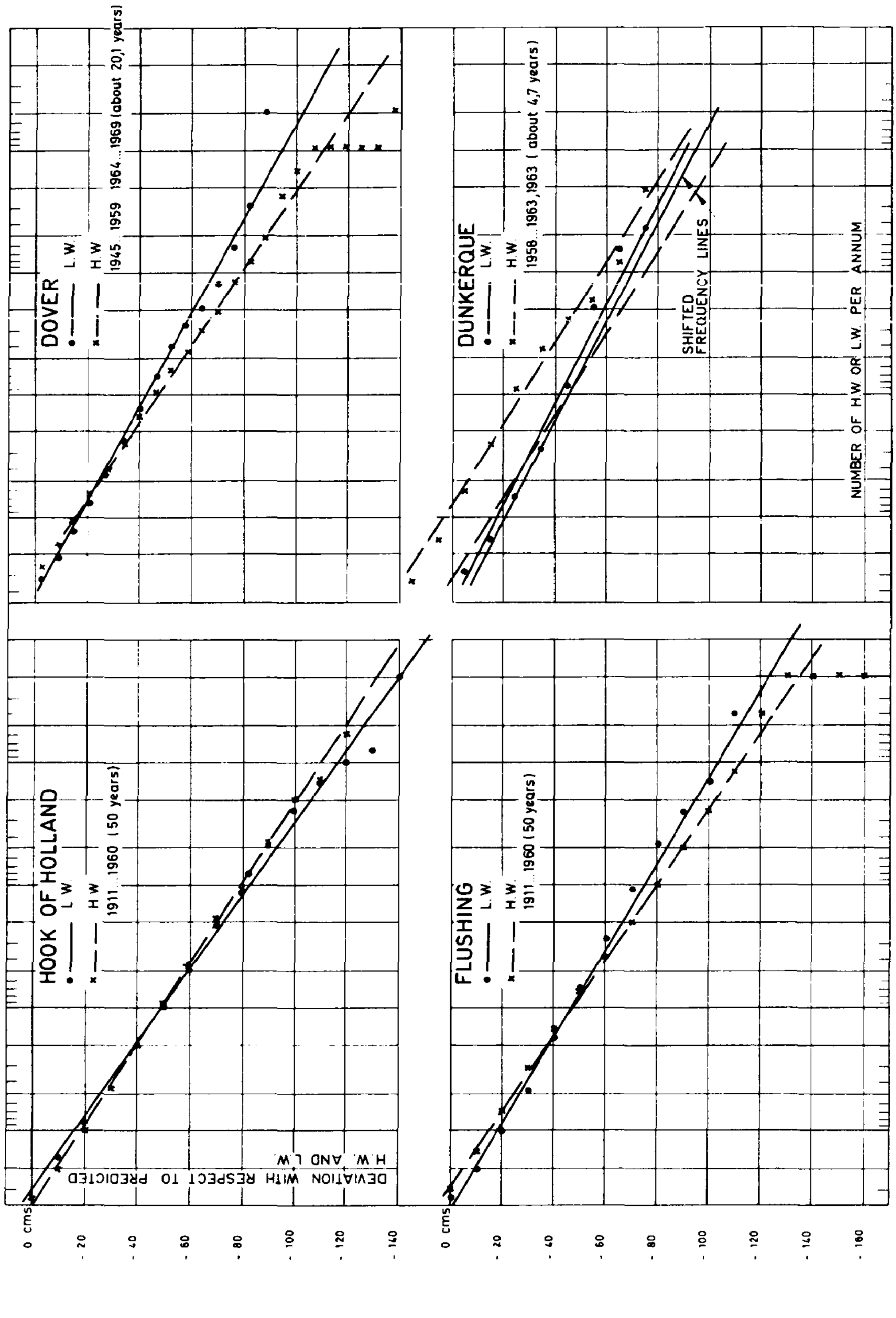
DOVER
L.W.
H.W.
1945...1959 1964...1969 (about 20,1 years)
DUNKERQUE
L.W.
H.W.
1958...1963,1963 (about 4,7 years)
SHIFTED FREQUENCY LINES
HOOK OF HOLLAND
L.W.
H.W.
1911...1960 (50 years)
FLUSHING
L.W.
H.W.
1911...1960 (50 years)
DEVIATION WITH RESPECT TO PREDICTED H.W. AND L.W.
NUMBER OF H.W. OR L.W. PER ANNUM
0 cms
-20
-40
-60
-80
-100
-120
-140
-160
10 2
10
1
10 -1
10 -2

FIGURE 1

The Group firstly attempted to get a general view of the cumulative distribution of the frequencies of negative surges. The excess negative values were therefore plotted in terms of their frequency of occurrence (unit : the number of high or low waters per annum), the excess values being plotted on a linear scale, and the frequency on a logarithmic scale. The results have been assembled in figure 1. It is apparent that if the plotted frequency lines for Dunkerque were shifted 18 cm for High Water and 3 cm for Low Water, better agreement with the other frequency lines would be obtained.

A comparison gave the following results.

TABLE 1

Frequency per annum	At Low Water			At High Water		
	10	1	10^{-1}	10	1	10^{-1}
Hook of Holland	50 cm	83 cm	117 cm	50 cm	80 cm	111 cm
Flushing	46 cm	75 cm	103 cm	47 cm	80 cm	113 cm
Dunkerque	44 cm	68 cm	92 cm	46 cm	75 cm	105 cm
Dover	43 cm	69 cm	96 cm	47 cm	79 cm	111 cm

The differences between the negative surges at low and at high water are not great. The differences for high waters are slightly larger than the differences for low waters, except for the case of negative surges at Hook of Holland. Furthermore, it could not be established that for the southern stations (Dover and Dunkerque) the negative surges were greater than those at the two Netherlands stations. Roughly, therefore, we can say that on an average a negative surge of more than 0.50 m will occur ten times per annum, of more than 0.80 m once per year, and of more than 1.10 m once in ten years.

The similarity of the phenomenon at the four ports is in fact remarkable, particularly as negative surges occur at the two coasts in quite different meteorological conditions. At Dover, the negative surges occur when the winds are southerly to westerly, and in Hook of Holland when they are southerly to easterly. It is well known that the former directions are more frequent than the latter, so that the difference in location apparently neutralizes the difference in meteorological conditions.

Negative surges occur mainly in winter. This is clearly evident in figures 2 to 7 which refer to Hook of Holland, Flushing and Dover. These figures indicate, in percentages and for each month of the year, the probability that the actual Low Water or High Water will be more than a certain arbitrary amount lower, or higher, than the value predicted in the Tide Tables.

It was not possible to establish this kind of graph for the station Dunkerque with sufficient accuracy, due to the relatively short duration of the observational period.

On the basis of 58-60 high and low waters per month, Table 2 converts the percentages of probability as shown in figures 2 to 7 into numbers of high and low waters per period.

TABLE 2

Percentage	Frequency of High or Low Waters
25	15 High or Low Waters per month
5	3 " " " "
1	1 " " Water per 1.7 month
0.1	1 " " " 17 months
0.05	1 " " " 34 months
0.02	1 " " " 85 months

From the graphs a similarity between the phenomena for Hook of Holland, Flushing and Dover can be noted.

Taking the values of the negative surges in summer (June, July, August) and winter (December, January and February) the following table can be established.

TABLE 3

Frequency	At Low Water			At High Water		
	5 %	1 %	0.1 %	5 %	1 %	0.1 %
Summer						
Hook of Holland	2 dm	3 dm	4.5 dm	2 dm	3 dm	4 dm
Flushing	2 dm	3 dm	4.5 dm	2 dm	3 dm	4 dm
Dover	2 dm	3 dm	4.5 dm	1.5 dm	2.5 dm	4 dm
Winter						
Hook of Holland	4.5 dm	7 dm	10.5 dm	5 dm	7 dm	10 dm
Flushing	4.5 dm	6.5 dm	9 dm	4.5 dm	7 dm	10 dm
Dover	4 dm	6 dm	8 dm	4 dm	6.5 dm	9.5 dm

It is noted that especially in winter the negative surges at Dover are slightly smaller than those at Flushing and Hook of Holland. Possibly, this phenomenon is related to the difference of geographical position between Dover and Flushing or Hook of Holland. But the smaller negative surges at Dover in winter rather point to greater coastal effects on the Netherlands side.

We have not yet considered the frequencies of occurrence of negative surges near the Sandettié Bank and Brown Ridge. Unfortunately, no local observations are available. For the present there is no reason to expect a great difference between the frequency lines for offshore stations and those for coastal stations. Since this conclusion is additionally based on the

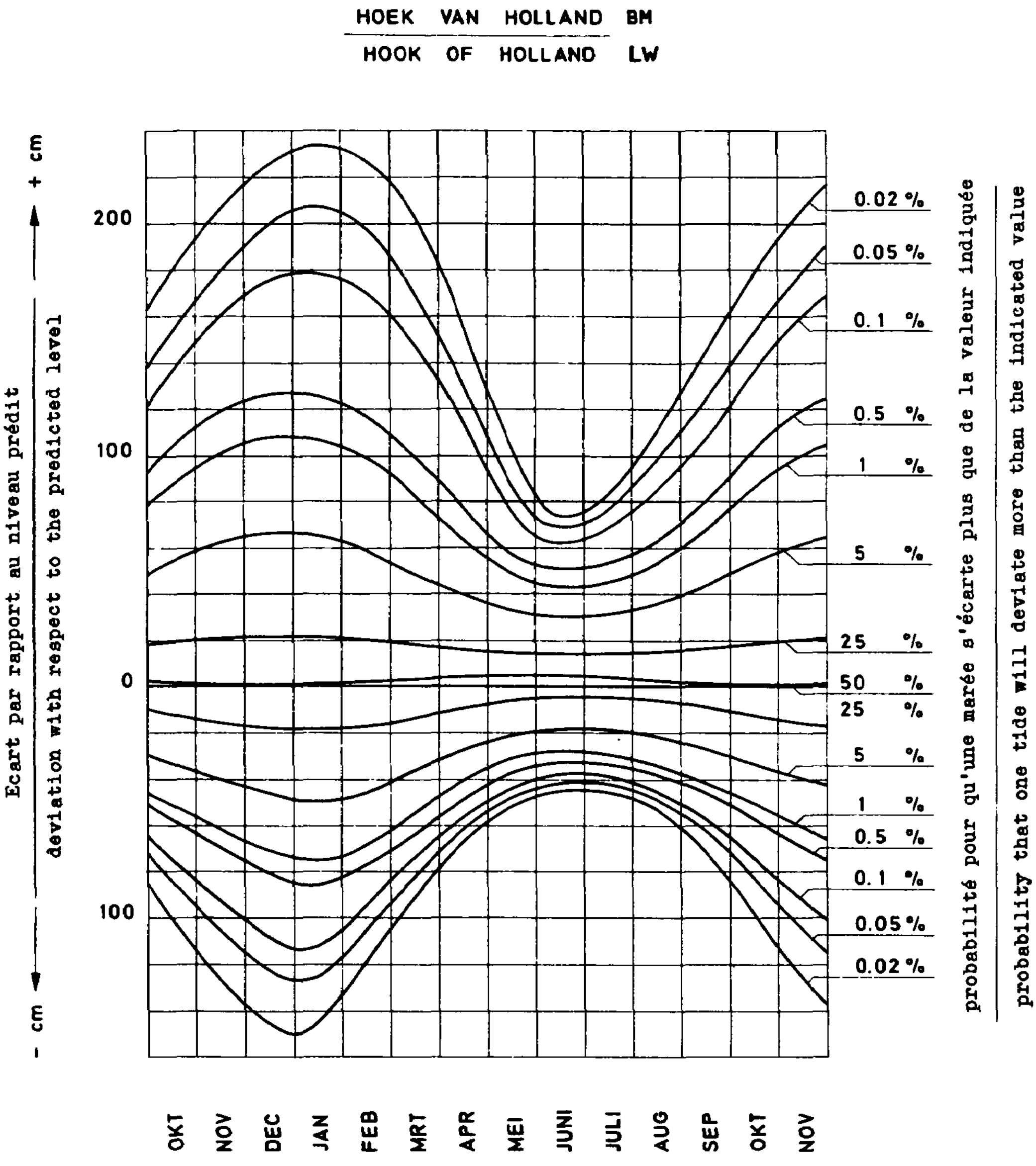

FIGURE 2

results mentioned in the next section it will be better to pass on to these results.

A STUDY OF THE METEOROLOGICAL CONDITIONS DURING NEGATIVE SURGES

For the study of meteorological conditions accompanying negative surges the following data were available :

(a) **From England.**

— A list, covering the period January 1958 to May 1967, of dates on which negative surges of 3 dm or more occurred at the stations : Lowestoft, Harwich, Southend and Tilbury.

— A number of graphs for negative surges at stations on the East coasts of Scotland and England, as well as the Thames Estuary, also covering the period January 1958 to May 1967.

— Hourly water level observations for Dover over the years 1945-1959 and 1964-1969.

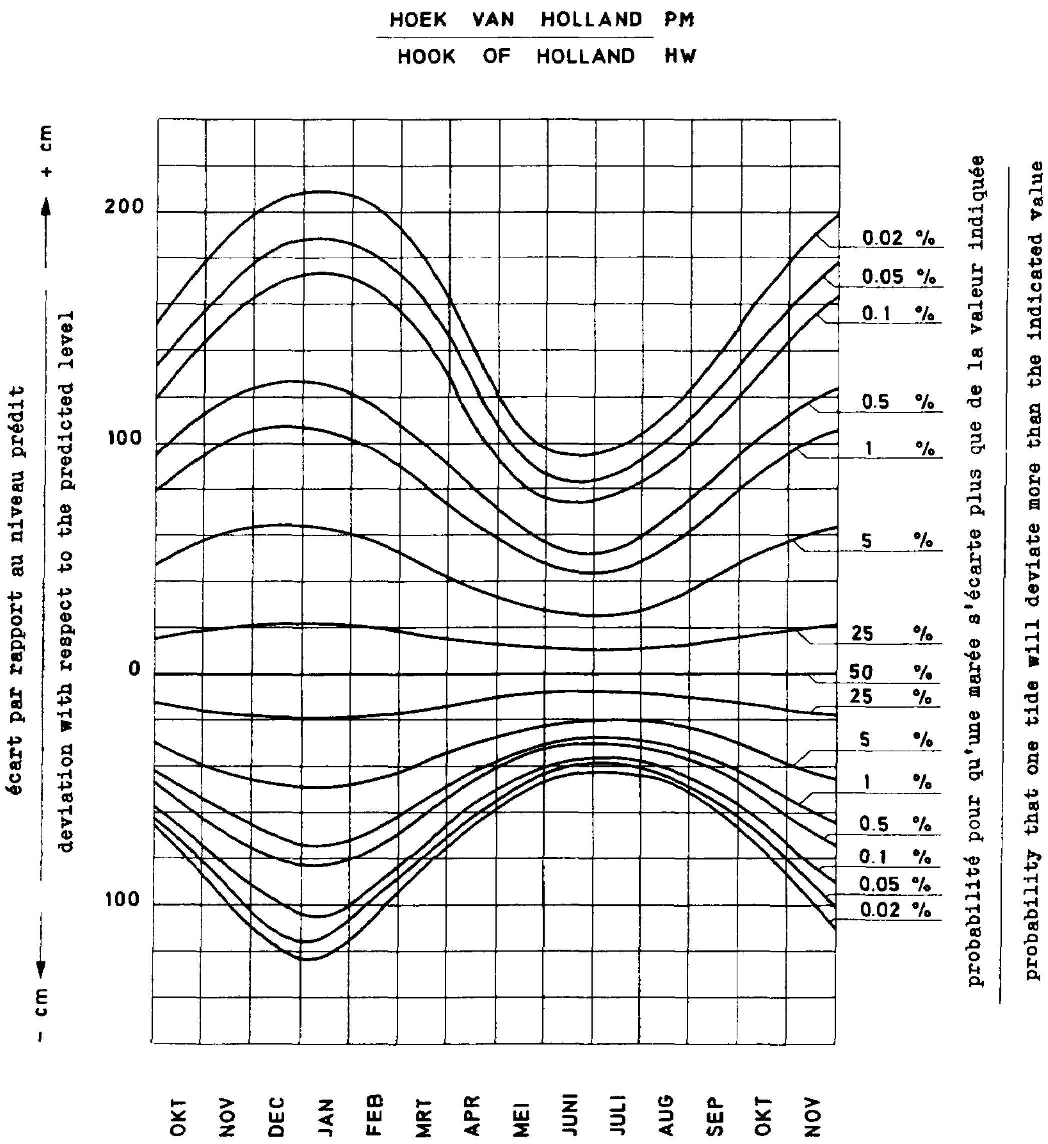

FIGURE 3

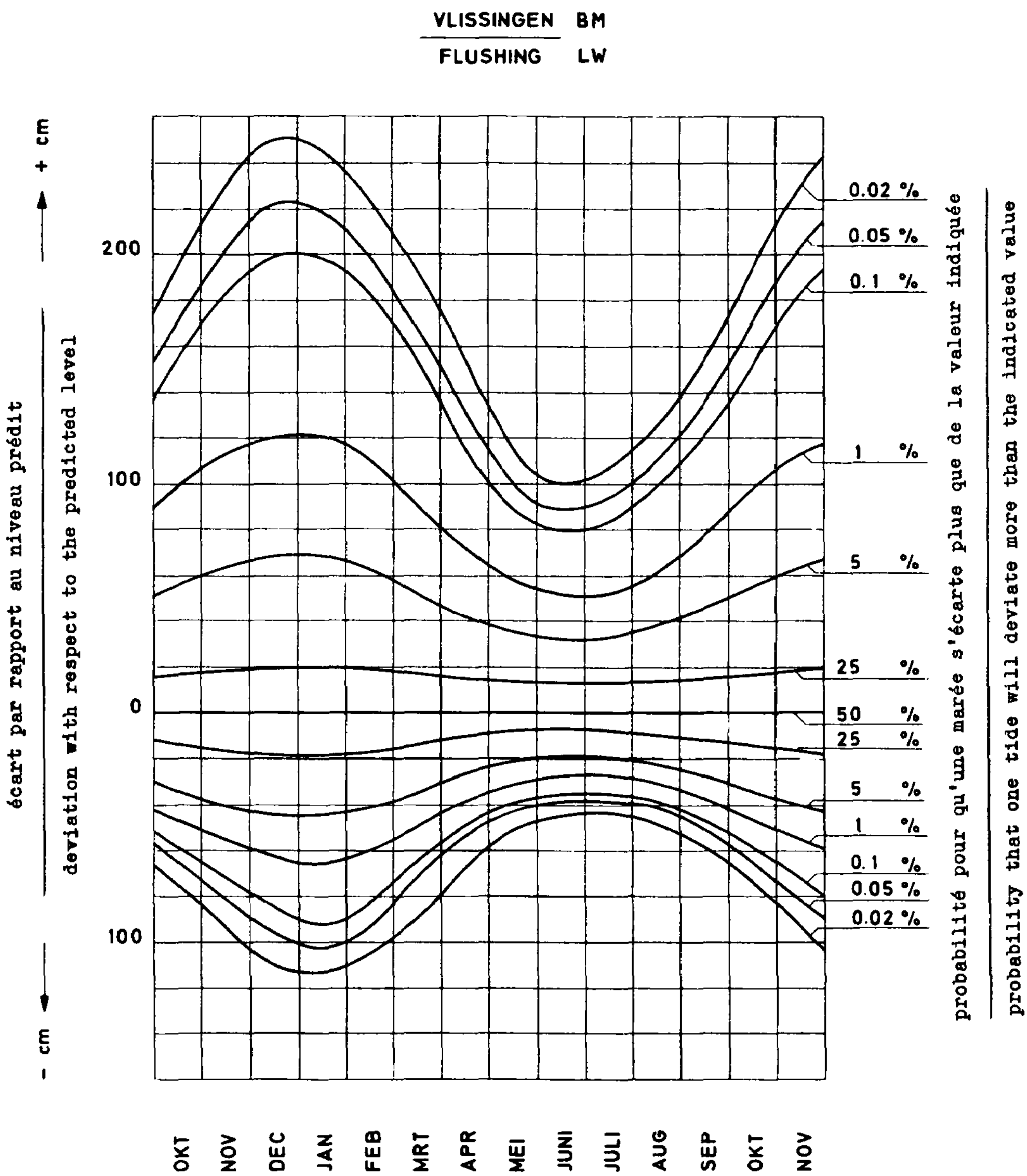

FIGURE 4

(b) **From France.**

— Hourly tidal observations for Dunkerque over the years 1958-1961 and for 1963.

(c) **In the Netherlands.**

— Tables of the difference W-V (i.e. the observed — predicted) values for all the high and low waters at Hook of Holland and Flushing for the

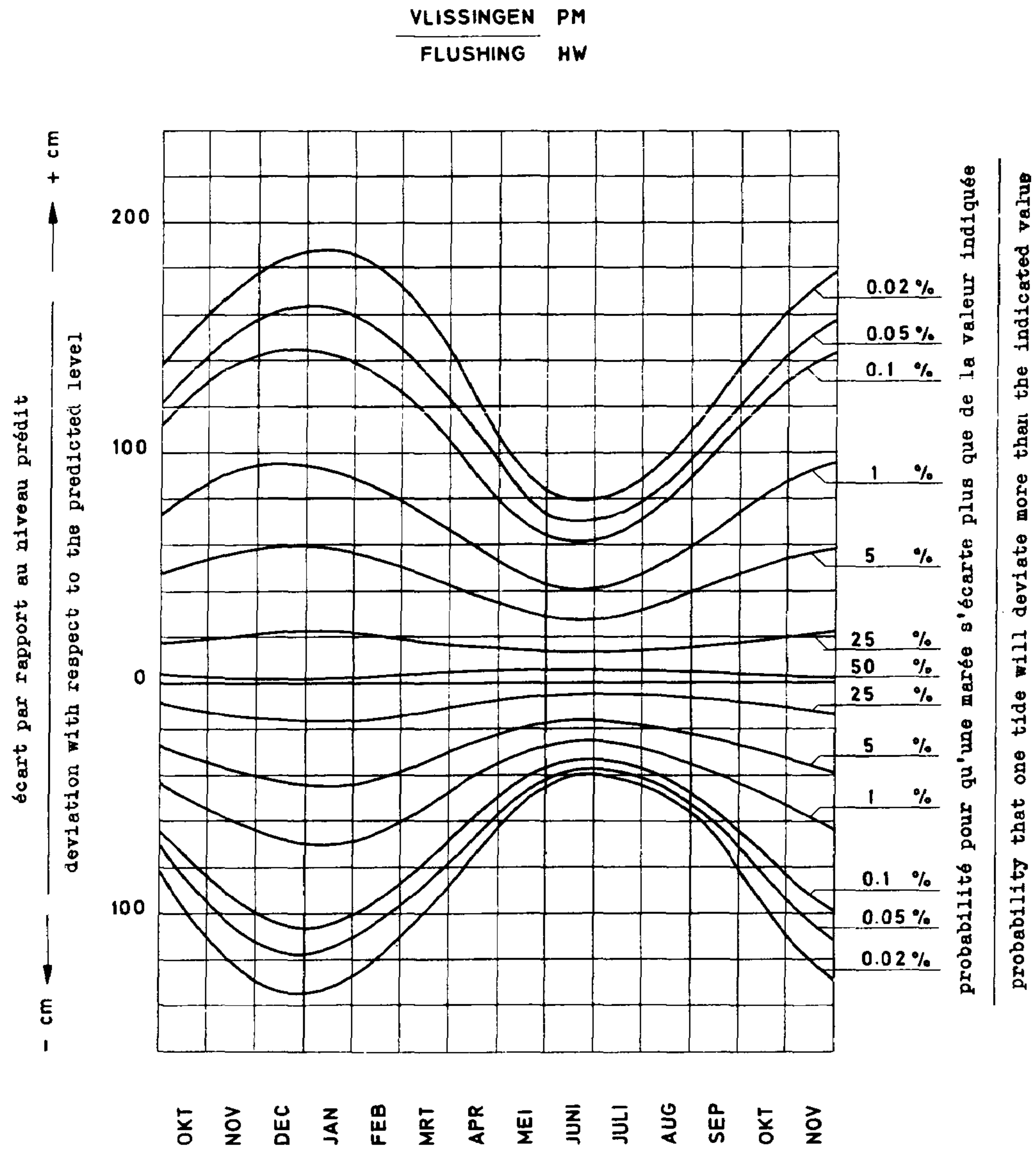

FIGURE 5

years 1911-1960. From these tables the average number of times that a certain lowering — increasing from 0 by steps of 1 dm — will have been exceeded has been calculated. After plotting of the calculations frequency lines have been drawn (figure 1).

— A list of the dates during the period 1911-1967 on which negative surges of more than 1 m occurred at Hook of Holland and Flushing.

— A summary of the periods of low water level, due to meteorological influences, caused simultaneously at Flushing, Hook of Holland, Den Helder, Harlingen and Delfzijl over the period 1932-1964.

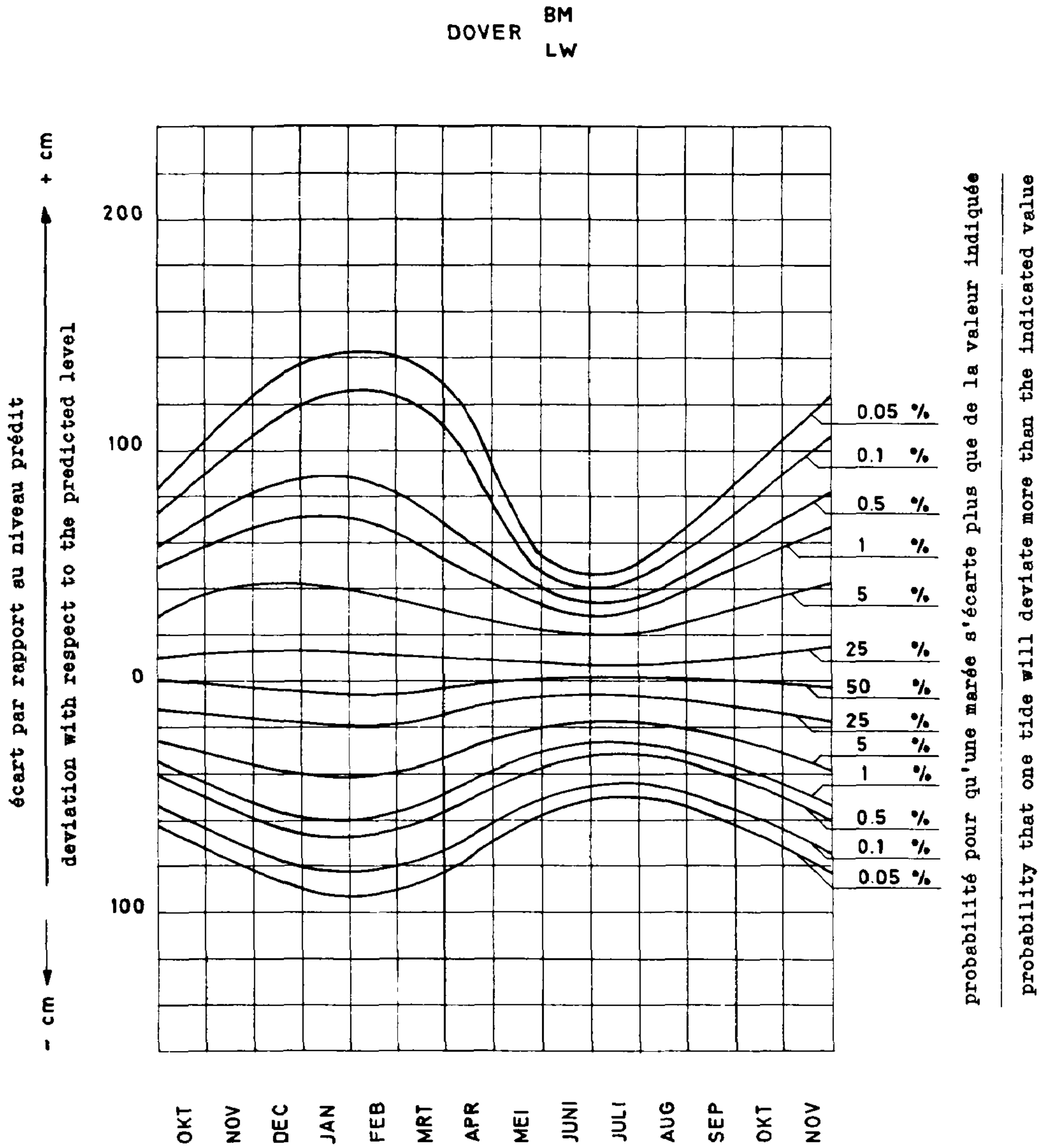

FIGURE 6

With the aid of these data it was possible to obtain some idea about the nature of the phenomenon. The largest negative surges were chiefly at Southend and Tilbury. There were extreme cases of a negative surge at Southend amounting to 23 dm and at Tilbury to even 28 dm. However, considerably smaller negative surges (10-15 dm) were observed simultaneously at other gauge stations. No special meteorological conditions to account for these exceptionally large differences were met so that it is very probable that local topographic conditions have an influence on this phenomenon. This supposition is corroborated by the increase in the negative deviations as soon as the surges enter the Thames Estuary.

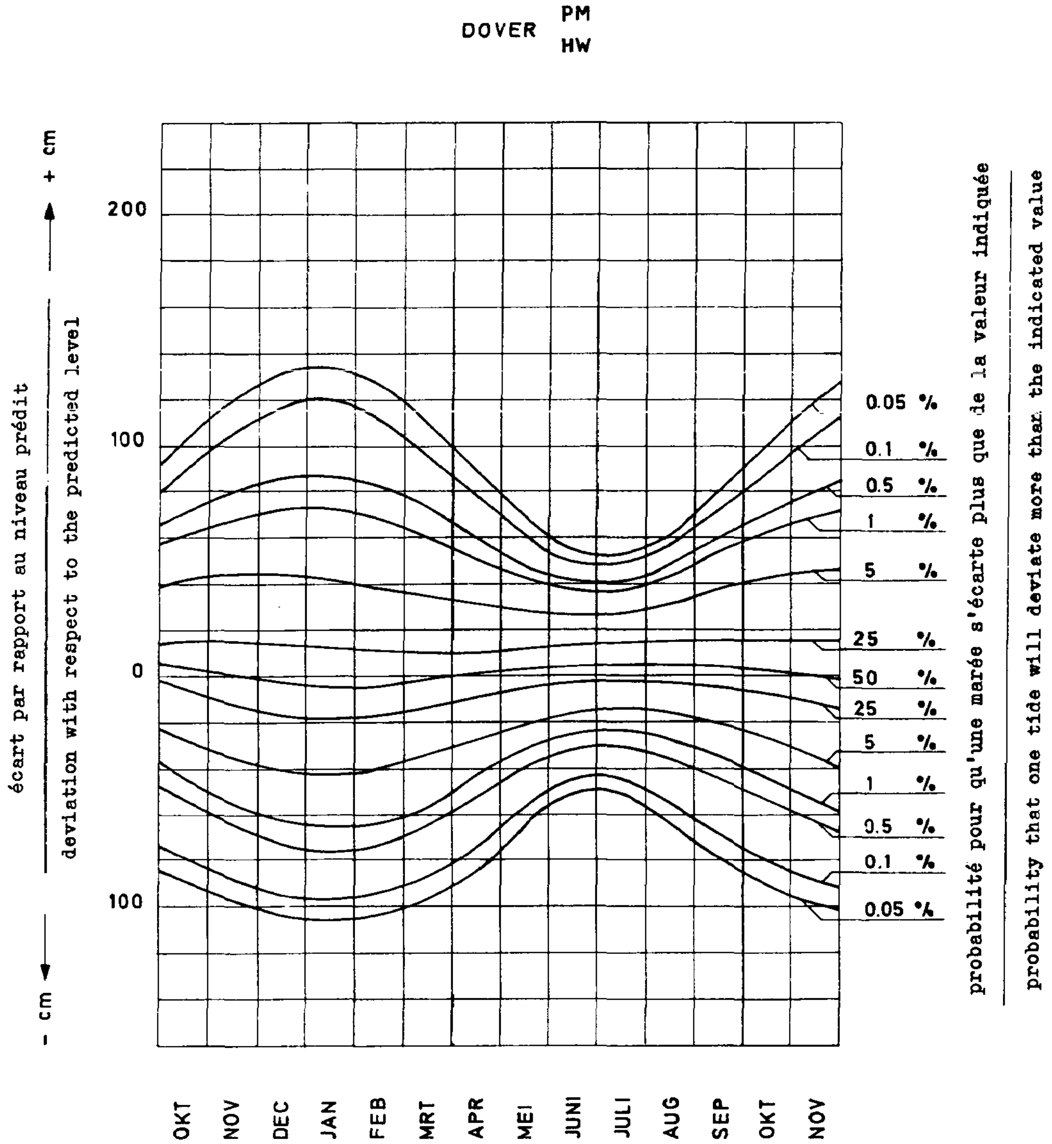

FIG. 7

On studying the negative surges more closely it appeared that there were cases in which the lowerings occurred exclusively along the English coast or else exclusively along the Netherlands coast. However, there were also situations in which lowerings occurred along the two coasts simultaneously. An examination of the weather conditions prevailing at the time made it clear that the lowerings restricted to the English coast were caused by westerly winds, whereas the lowerings occurring exclusively along the Netherlands coast resulted from easterly winds. Southerly winds, on the other hand, led to lowerings along both coasts. The two former types of lowering provoked a W-E inclination of the sea surface. For these cases the mid-sea lowerings are presumed to be small. It would be reasonable to suppose on the other hand that when the weather conditions include southerly winds lowerings are caused over the whole of the southern North Sea, and consequently in the Sandettié Bank and the Brown Ridge areas.

These suppositions find support when the Netherlands tables of wind effects, compiled with a numerical model, are used to compare the effects in the areas of Sandettié, Brown Ridge, and Hook of Holland. For an easterly windfield of 45 kt over the whole of the North Sea and the Channel, the calculated lowerings for Hook of Holland, Sandettié Bank and Brown Ridge amount respectively to 13 dm, 8 dm and 7 dm. A westerly windfield of 45 kt, on the other hand, gives lowerings along the English coast, but elevations of respectively 8 dm and 7 dm for Sandettié Bank and Brown Ridge. For a southerly windfield of 45 kt the calculated lowerings for Hook of Holland, Sandettié Bank and Brown Ridge amount respectively to 21 dm, 19 dm and 18 dm.

These calculated amounts suggest that the mid-sea situation is not less favourable than that for coastal regions, the more so since the coastal effects which are not linear have not been taken into account. Near Sandettié Bank and Brown Ridge, nevertheless, there may also be non-linear effects, whereas the greatest lowerings near Hook of Holland also occur with wind directions less frequently encountered than those causing the greatest lowerings near Sandettié Bank and Brown Ridge.

It seems justifiable to conclude that the frequency lines are unlikely to diverge considerably, and that roughly the same frequency line is probably valid for the whole of the southern North Sea (see the conclusion arrived at in the preceding section).

GUIDANCE FOR NAVIGATING WITH THE HELP OF WATER LEVEL FORECASTS

Accuracy of prediction plays a prominent part where predictions for navigation are concerned. If statistically something is known about the accuracy of the predictions then this accuracy can be envisaged in two ways.

In general we can say that the inaccuracy of the predictions will increase as the instant to which they apply is further away in time. Thus, for a predetermined margin of risk — one in which, for example, the probability that a negative surge of x dm will not exceed y % — there will be an increase in the number of unacceptable situations predicted. The percentage y should be fixed by making a compromise between economy, safety of navigation and environmental preservation.

The second approach is to take this inaccuracy into account when determining the acceptable underkeel clearance. This has the great advantage that the prediction of the negative surge will be more acceptable for the navigator than in the first way. For it will suffice to predict the most probable amount of negative surge. However, if one has to take account of the inaccuracy with respect to each forecast, then these forecasts will have to be made with a large margin of uncertainty or with an extreme value, which will systematically increase safety but will be likely to prejudice confidence in the predictions.

In any case, for establishing any future guidance for navigators it will be necessary to follow continuously the development of weather conditions and the rises and falls of sea surface. On the basis of the insight obtained and of the expected developments, warnings might be given which would guarantee that there was only a small chance of the dangers exceeding a pre-determined risk level.

With regard to the duration of the validity of predictions, the following facts would seem to be relevant. Near the approaches to Hook of Holland vessels have the possibility of anchoring in sufficiently deep water about 40 n.m. offshore. Thus only a few hours after passage is considered safe, the vessel can be in port. These are favourable circumstances. Here the required duration of prediction validity is such that uncertainty about further developments to weather conditions and sea state will be of only very slight importance.

Elsewhere the situation would warrant longer term forecasts. For example, shipping in Dover Strait is so dense that to anchor awaiting safe passage to the southern part of the North Sea is undesirable. Thus, as soon as the vessel passes the Cap de la Hague — that is, a good 12 hours before arrival in the Dover Strait — a decision should be made as to whether to proceed. The predictions should therefore have a duration of validity of longer than 12 hours. It should also be borne in mind that routine predictions are forecast at fixed times, at 6-hour intervals for instance. Thus the duration of the validity period has to be increased by 6 hours, and this would amount to a duration of validity of more than 18 hours.

RELIABILITY OF THE METHOD OF PREDICTION

As has already been remarked in the preceding section, something must be known about the predictions statistically before we can say anything about reliability.

An important data is the difference between mean values for predicted and observed heights and the standard deviation for each of these differences, especially if their distribution is normal. In that case it will be a simple matter to compute the probability that an individual difference will exceed a certain arbitrary value from what is known about normal distribution. The difference between this mean value and the standard deviation has hitherto been determined for positive surges only, but the values are not necessarily applicable for negative surges. Separate investigations had therefore to be made for the case of negative surges.

For this purpose data were gathered on all cases where a negative surge of 5 dm or more occurred in Flushing and/or Hook of Holland during the period January 1965 to July 1970. The cases all occurred between the months of September and March inclusive. The number of cases amounted to about 1% of the total number of ebb and flood tides. Negative surges were then predicted from weather maps and the tables for calculating mean sea level variations. First of all, it was apparent that there was no reason to reject the supposition that the distribution of the difference between the predicted and the actual heights would be normal. Furthermore, no systematic deviations were found for the situations where negative surges of 5 dm and more occurred along the Netherlands coast. The standard deviation was of only 15 cm. This inspires some confidence in the method. For purposes of comparison, on the basis of an 8 dm or more rise the standard deviation calculated was of about 25 cm.

We could surmise that in relation to the coastal effects already mentioned, the standard deviation for the Sandettié Bank and Brown Ridge areas will be still smaller. However, since the non-linear effects can also play a part in this region, we will ignore this fact.

It should be noted, however, that for long term predictions — i.e. those with a validity of 12-18 hours — extrapolation of the weather conditions is a necessity. The inertia of the sea reduces the period of extrapolation to about six hours. This has the effect of reducing the influence of the meteorological uncertainty. Experience so far gained indicates, indeed, that meteorological uncertainty plays a smaller part than one tends to suppose.

It does not seem unreasonable to state that the standard deviation for predictions whose duration of validity is less than 12 hours will range between 25-15 cm for the Sandettié area. However, it will only be possible to verify the correctness of this statement after measurement over a considerable period of time. The speculative element will naturally increase with the length of the period of validity.

Note by the Netherlands Hydrographer :

In December 1972 a pressure tide gauge was established near the Sandettié Light Vessel, and is due to function for a five months' period, in order that further information on negative surges may be gained.