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EXTRAPOLATION OF SHORE-BASED TIDE GAUGE DATA FOR OFFSHORE REDUCTION

An accuracy study

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1. INTRODUCTION

1.1. In Dutch surveying practice, tidal data for reduction of soundings are generally obtained from offshore bottom tide gauges. Because these data are only available after recovery of the instrument, this routine involves considerable delay in the processing of soundings, as well as the inconveniences of preparing, placing and recovering the instrument, worries about possible damage to or loss of the instrument when exposed at sea, and the tedious work of reading and elaborating the results.

1.2. After many years of collecting and analysing offshore tidal data from the North Sea, a wealth of information is available and has been used to compile, and gradually improve, a co-tidal and co-range chart of the North Sea (Reduction Chart North Sea).

It would be interesting to know whether this Reduction Chart has now become sufficiently accurate and reliable to be used for the reduction of soundings entirely by extrapolation of shore-based tide gauge data.

If so, offshore tide gauges need only be used for further systematic research on the tidal movement in the North Sea and the surveyors would be saved quite a lot of trouble.

1.3. This paper describes a method of extrapolating shore-based tide gauge data with the help of the Reduction Chart to produce an offshore tidal curve. An accuracy study is then performed, in which extrapolated tide curves are compared with actually observed offshore tide curves.

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2. PRESENT REDUCTION METHOD

2.1. The method of reduction of soundings in the Netherlands' surveying practice is based on the instructions given in the AHOI (Netherlands abbreviation for General Hydrographic and Oceanographic Instructions). The most relevant points from section 4.02 are paraphrased here :

> 140. – To reduce offshore soundings, recording tide gauges must be used. Alternatively, within 10 nm from the coast, shore-based tide gauges may be used.
>
> 215. – The Reduction Chart North Sea is provided by the NL Hydrographic Office.
>
> 222. – At least two seabed tide gauges must be laid in order to be able to interpolate between two observation series over the survey area (an area that can normally be surveyed by one ship in one month).
>
> 231. – An accuracy of 1 dm shall be aimed for in establishing reduction values.

2.2. In practice, these instructions necessitate the use of bottom tide gauges. Generally, two "Smitt" instruments are launched about 10 nm distance apart to cover the survey area for about one month. In addition, to support and check the registrations of these instruments, a small telemetric bottom tide gauge (WESTI) is laid for shorter periods (about one week) near the centre of the actual sounding area. After recovery of the Smitt tide gauges, the surveyor is able to compute and construct the required part of the tidal curve for every position in the survey area from the registrations and the Reduction Chart by interpolation, from which the value of the reduction to the soundings can be derived.

3. EXTRAPOLATION OF SHORE-BASED TIDE GAUGE DATA

3.1. In the following section an extrapolation method is suggested to obtain an offshore tidal curve from shore-based tidal observations, using the Reduction Chart.

This method has some resemblance to a method used in the British Hydrographic Service, from which it is derived. The main difference is that the Reduction Chart plays a much more important part in our method. This method is also an extension of a method previously used in survey work along the coast, where only a distant standard recording tide gauge was available, or in the vicinity of offshore tide gauges.

3.2. This method is based on a few assumptions :

1. The shape of the tidal curve at the offshore position is about the same as at the shore-based tide gauge.

This assumption only holds at short distances from the shore station, and only in those cases where the shore station was not too much distorted by shallow water effects. Consequently the shore stations of Hook of Holland and Den Helder can only be used as shore stations with great precaution.

2. The Reduction Chart gives reliable information about the tidal wave progress in the North Sea.

This assumption would involve the possibility of constructing the tidal curve at one shore station from data gathered at another.

Unfortunately, however, because of the shallow water effects and the consequent generation of the rather strong M_4 tidal component, it is not easy to describe the tides with simple lines.

Consequently it is hardly possible to demonstrate the double high water at Den Helder and the double low water at Hook of Holland.

3. The meteorological effects will cause the same change in Mean Sea Level (MSL) at a station ashore as they will cause offshore.

This assumption is only true in relatively calm weather where little or no change in MSL occurs, and/or along short distances.

In other situations the assumption is wrong with more or less severe effects.

4. Extrapolation from shore-based tide gauges should only be performed when the tidal range at the shore station is larger than at sea.

This requirement imposes considerable limitations on the choice of shore stations to be used.

Keeping in mind the restrictions imposed by the assumptions it nevertheless must be possible to carry out an experiment.

4. THE EXTRAPOLATION PROCEDURE

4.1. From inspection of the Reduction Chart, the mean lunitidal intervals (MLTI) for high water (HW) and low water (LW) are determined at the shore station and at the position at sea; e.g. :

	HW	LW
Walton-on-the-Naze MLTI	11 h 31	05 h 12
N 50.	12 h 03	05 h 58

The difference at HW is 32 min and at LW 46 min. This causes a change in shape of the shore-curve when it is transformed to the sea-curve, as shown with some exaggeration in figure 1.

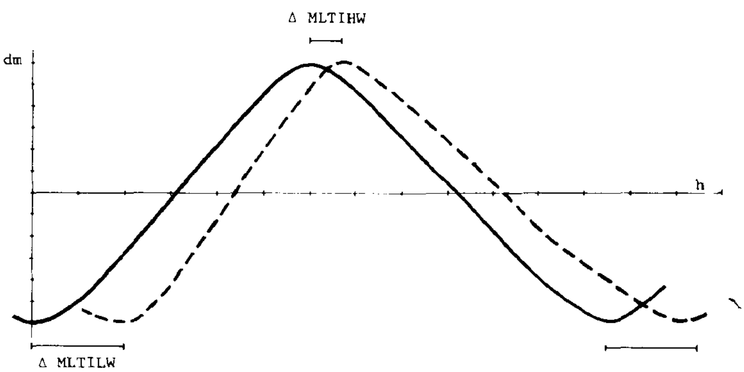


FIG. 1. – Shore-curve and extrapolated curves – Walton-on-the-Naze N 50.

4.2. Attention should be given to the shape of the tidal curves. It is necessary, therefore, to determine which shore station might be representative for which part of the continental shelf. This can be determined only when some knowledge exists of the shapes of tidal curves offshore, e.g. from previous observations.

4.3. Next, the range ratio must be determined from the Reduction Chart by taking the proportion between the Z_0 (height of chart datum below MSL) at the shore station and at the offshore position, e.g. :

	Z_0
Walton-on-the-Naze	3.78 m
N 50	2.76 m

range ratio : 276/378 = 0.730.

Multiplication of the ratio by the tidal level related to MSL at the shore station will yield the offshore level.

As stated before, this range ratio preferably shall be less than 1 in order to prevent enlargement errors. It is realized that this requirement cannot always be fulfilled, and in such cases special caution must be exercised.

5. THE COMPARISON EXPERIMENT

5.1. The above procedure was applied to find the tidal curves at the Netherlands JONSDAP 76 stations N 50, N 52, N 53 and N 54 by extrapolation from Walton on the Naze, Lowestoft, IJmuiden and Den Helder (see fig. 2).

The relevant data on the offshore positions, the shore-based tide gauges, range reductions and time shifts are given in Appendix 1.

During the JONSDAP 76 program, tidal observations were obtained at the stations N 50, N 52 and N 53 for two and three days at spring tide only.

The N 54 series extended for a month.

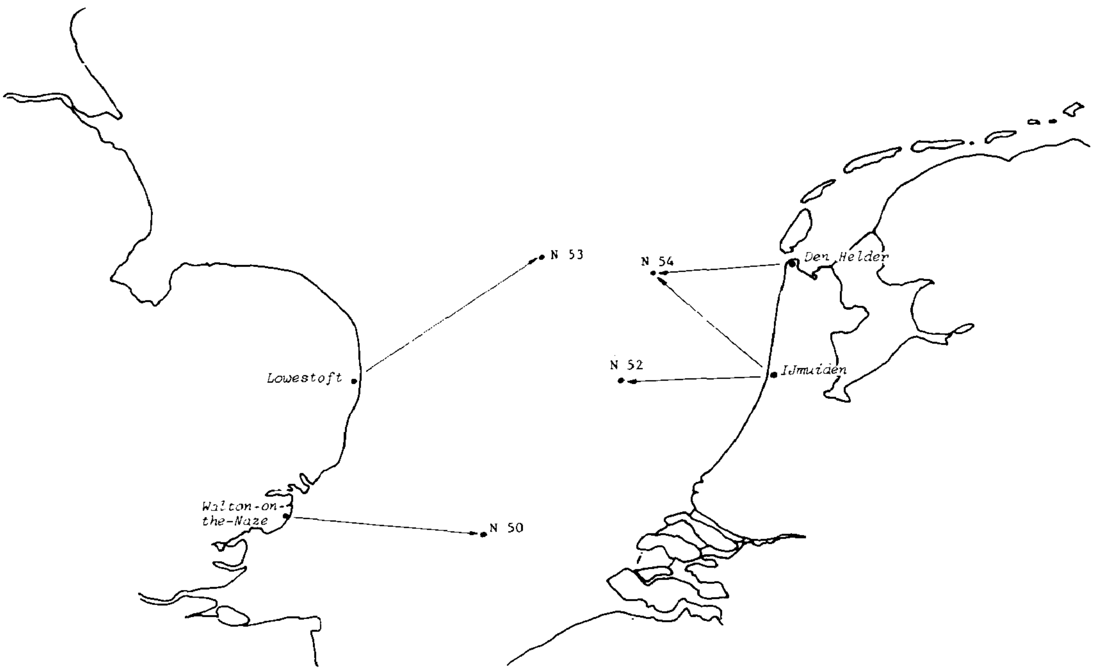


FIG. 2. – Shore and related offshore stations.

5.2. In Appendices 2 and 3 the results of these extrapolations are shown. The manipulated shore curves are plotted together with the observed offshore recordings and can be compared visually.

The results generally are rather disappointing because they hardly show any coincidence.

In particular, the extrapolated Den Helder and IJmuiden curves show considerable differences (up to 6 dm at a tidal range of 12 dm) compared with the observed sea curves.

5.3. In order to quantify the differences accurately and numerically the standard deviations were determined by means of the following formula :

$$\sigma = \frac{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2}}{n-1}$$

in which :

σ = standard deviation
n = number of observations
x_i = value of deviation with serial number i
$\bar{x}$ = mean deviation

This computation of the standard deviation is applicable for any probability distribution.

We may with good reason expect that the distribution of the deviations in our experiment can be described as the Gaussian or normal distribution.

5.4. From the theory of statistics we know that in the case of a Gaussian distribution of deviations, the chance of a deviation exceeding :

0.5 σ is 61.8 %
1.0 σ is 31.74 %
1.5 σ is 13.36 %
2.0 σ is 4.56 %
3.0 σ is 0.26 %

The mean deviation between the extrapolated shore curve and the curve obtained from the bottom tide gauge in the long series Den Helder → N 54 was 0. This was to be expected because we had set the mean levels of both curves to coincide.

The standard deviation, derived from the deviations at hourly intervals, turned out to be 20.8 cm and the maximum deviation 66 cm.

From the above, it follows that we may expect to have deviations exceeding 2 dm in 32 % of the cases and also to have deviations exceeding 4 dm in 4.6 % of the cases.

The same procedure was followed in the shorter observational series :

IJmuiden	→ N 54	σ = 20.8 cm	max. dev. = 72 cm
IJmuiden	→ N 52	σ = 12.0 cm	max. dev. = 25 cm
Lowestoft	→ N 53	σ = 17.9 cm	max. dev. = 42 cm
Walton-o/N	→ N 50	σ = 12.6 cm	max. dev. = 30 cm

A similar British investigation on a half month's series resulted in the same standard deviation (2 dm).

From a statistical point of view, these five results may not be considered as very significant, of course, but they show at least the order of magnitude of the deviations that may be expected when this method is being used.

6. CONCLUSIONS

6.1. The accuracy of the conversion of a shore-based tidal curve to a distant position at sea depends to a large measure on the accuracy and reliability of the Reduction Chart in use, as well as on the extent of resemblance between the shore and the offshore tidal curves. The assumptions underlying the procedure of extrapolation become very debatable when applied over long distances.

The results of the experiments demonstrate very clearly that a standard deviation of 2 dm must be allowed, which means that the Netherlands' accuracy standard for tidal reduction of 1 dm will be exceeded in about 62 % of the cases when working with this method.

6.2. As can be seen from the graphs for IJmuiden, an additional experiment was tried at 3 stations which extrapolated not only the actually observed tidal curve of the shore station, but also the predicted curve from the tide tables. However, this turned out to give very similar discrepancies.

6.3. The procedure described above is not the only alternative to the reduction method presently used in the Netherlands' surveying practice.

One could also think of obtaining an offshore tidal curve from tidal constants derived from previous observational series. This method was not investigated here. It may be suitable for further investigation, although a few of the problems that may arise should be indicated :

In the first place, the tidal constants at offshore positions have been computed from observational series which usually extended over only one or two months. Seasonal errors and other corrections will therefore be included in the results. In the second place, in the "prediction" of the tidal curve of Flushing from tidal constants, discrepancies were found when the results were compared with actually observed curves.

This problem has not been solved yet, but has shown that this method would be inapplicable for producing tide tables. (Rijkswaterstaat uses a different method for the Netherlands Tide Tables, based on the theory of Lubbock, but then only time and height of HW and LW can be predicted).

As yet this method is kept in reserve, in case something has gone wrong for any reason.

7. OPERATIONAL CONCLUSION

7.1. As long as the accuracy requirement for tidal data in the reduction of soundings is maintained at 1 dm, it is quite clear from this study that the chance of exceeding the tolerance by applying the extrapolation method is too large.

Consequently the present method of obtaining reduction data by means of recording offshore tide gauges must be continued, and the inconveniences connected with their use must be accepted.

7.2. In cases where the accuracy requirements can be relaxed to about 3 or 4 dm, the extrapolation method will show great advantages.

APPENDIX 1

Relevant shore and offshore data

Offshore positions :

N 50	51°45' N – 02°33' E
N 52	52°25' N – 03°34' E
N 53	52°58' N – 03°00' E
N 54	52°54' N – 03°48' E

Shore tide gauges' relationship to offshore stations :

Walton-on-the-Naze	→ N 50
IJmuiden	→ N 52 and N 54
Lowestoft	→ N 53
Den Helder	→ N 54

Range reduction :

Amplitudes are derived from the Co-Tidal Chart.
Den Helder → N 54 is derived from the Reduction Chart 1977.

shore		offshore	factor
Walton-on-the-Naze :	3.78	N 50 : 2.76	0.730
IJmuiden :	1.85	N 52 : 0.75	0.405
IJmuiden :	1.85	N 54 : 1.00	0.556
Lowestoft :	2.20	N 53 : 1.03	0.455
Den Helder :	1.20	N 54 : 0.79	0.658

Time difference high water :

shore		offshore	difference
Walton-on-the-Naze :	11.31	N 50 : 12.03	+ 00.32
IJmuiden :	02.20	N 52 : 02.22	+ 00.02
IJmuiden :	02.20	N 54 : 05.45	+ 03.25
Lowestoft :	09.15	N 53 : 06.43	− 02.32
Den Helder :	06.05	N 54 : 05.30	− 00.35

Time difference low water :

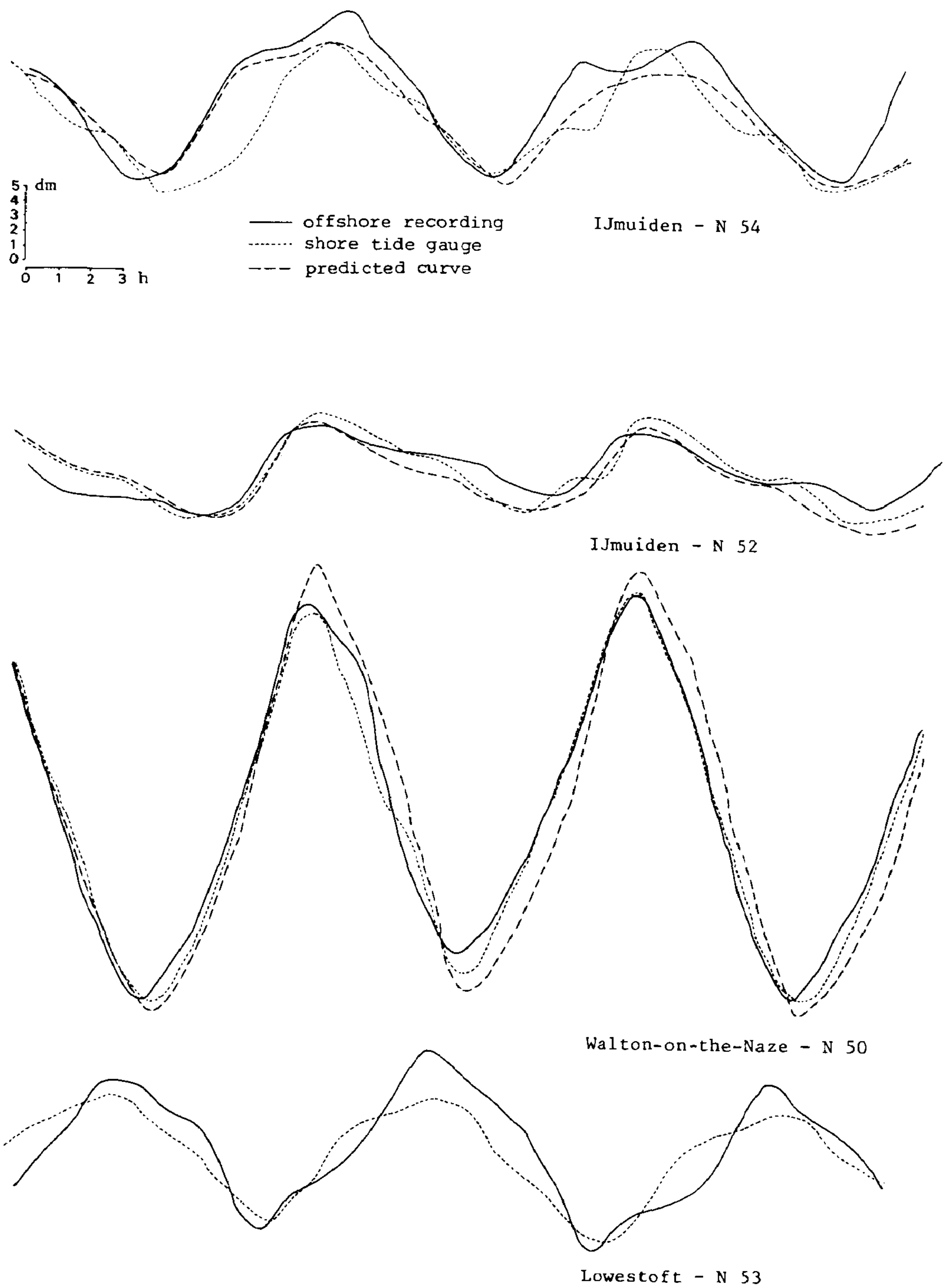
shore		offshore	difference
Walton-on-the-Naze :	05.12	N 50 : 05.58	+ 00.46
IJmuiden :	10.30	N 52 : 09.48	+ 00.42
IJmuiden :	10.30	N 54 : 11.42	+ 01.12
Lowestoft :	03.00	N 53 : 12.18	− 03.07
Den Helder :	00.20	N 54 : 11.51	− 00.54

Relative shift low water with regard to high water :

Walton-on-the-Naze :	N 50 :	+ 00 h 14 min
IJmuiden :	N 52 :	− 00 h 40 min
IJmuiden :	N 54 :	− 02 h 23 min
Lowestoft :	N 53 :	+ 00 h 35 min
Den Helder :	N 54 :	+ 00 h 19 min

APPENDIX 2

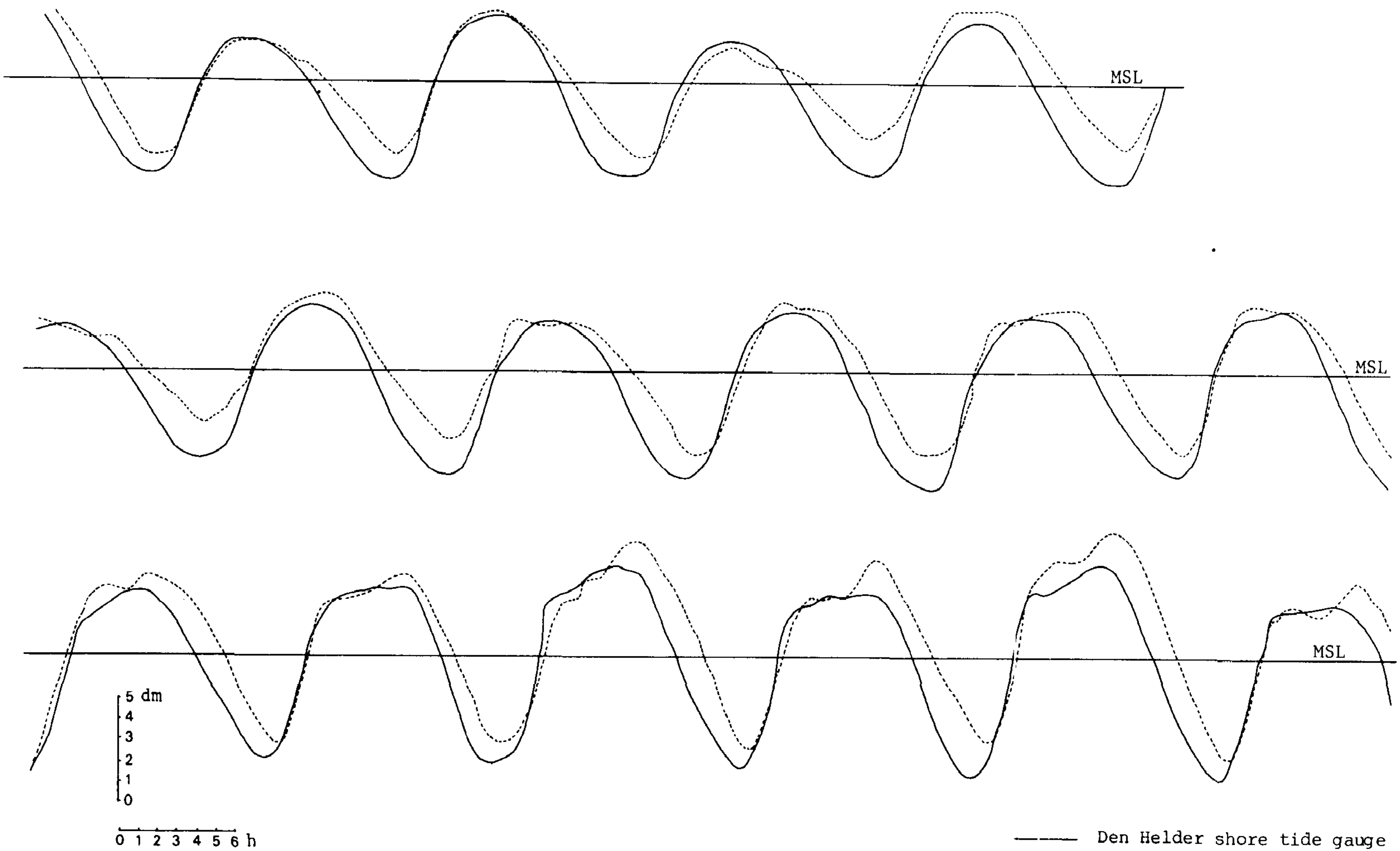
Comparison of short term shore and extrapolated offshore tidal curves



APPENDIX 3

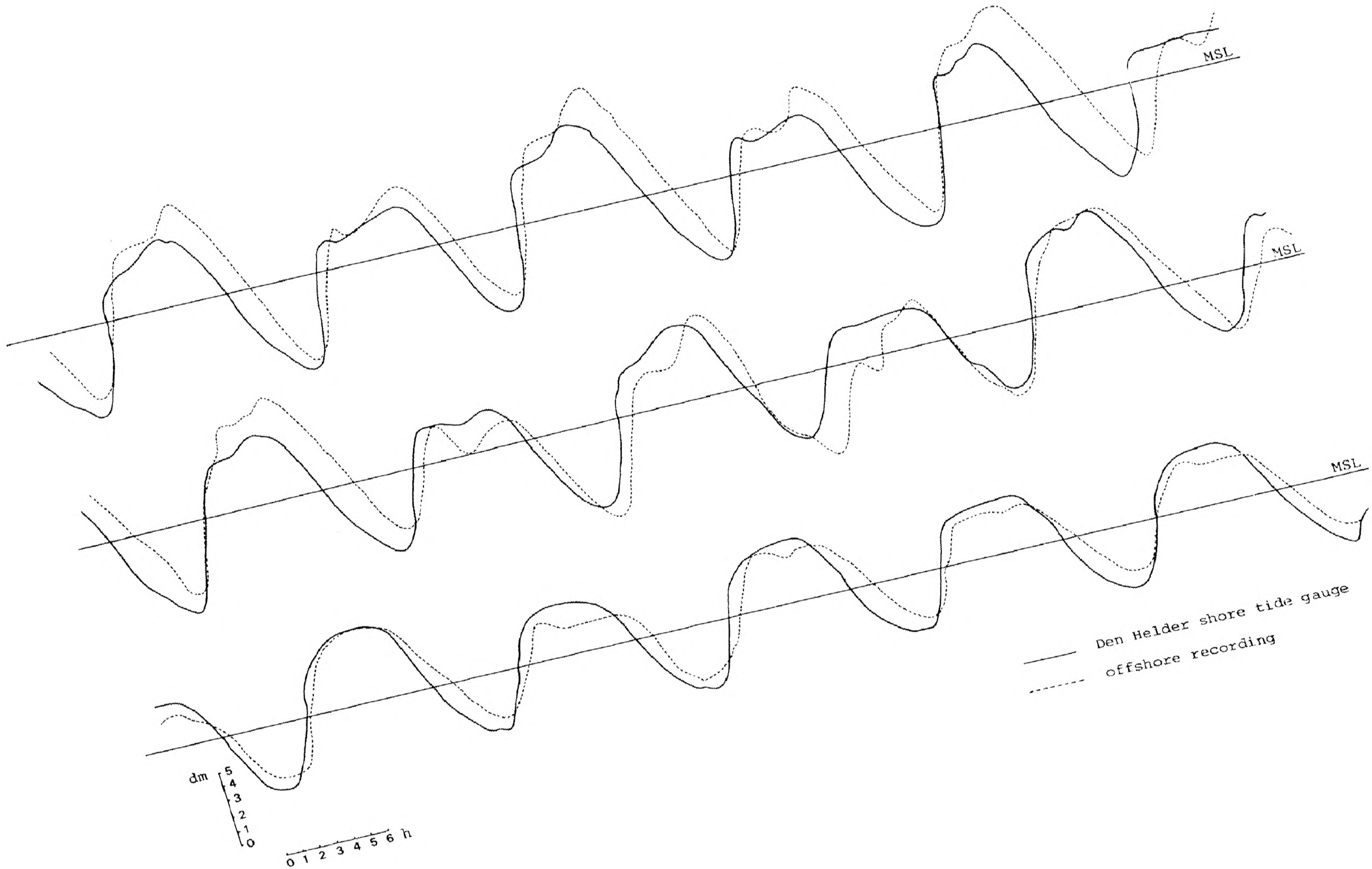
Comparison of sections of long term Den Helder and extrapolated N 54 tidal curves

Den Helder - N 54



——— Den Helder shore tide gauge

------- offshore recording


MSL
MSL
MSL
Den Helder shore tide gauge
offshore recording
dm
5
4
3
2
1
0
0 1 2 3 4 5 6 h

APPENDIX 3
(cont.)