

DELIVERABLES SUMMARY SHEET

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Deliverable N°: 2 (Sampling strategies for environmental surveying)
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Short Description :

The aim of the project SUMARE is to develop autonomous sensing systems which can be used to survey the distribution of seabed resources, in a manner which is considerable more economic than traditional survey methods. Two applications are being used with this aim in mind: sand bank survey and maerl bed mapping.

Deliverable 2 presents the work achieved under workpackage 2, which concerns the development of sampling strategies for each of these applications. The design of these sampling strategies is based both on existing survey information and new information collected as part of the project. Their analysis provides elements for the development of sampling strategies so that error can be minimised at various stages of the process. This in turn will ensure an optimisation in data gathering and offer a better knowledge of the amount of natural resources available.

Partners owning: ICIT (HWU)

Partners contributed: MUMM
I3S(CNRS)
IST

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Project SUMARE

**(Survey of Marine Resources)
IST Contract IST/1999/10836**

Deliverable 2: Sampling strategies for environmental surveying

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Introduction

1. Background

Project SUMARE (Survey of Marine Resources) concerns the efficient use of autonomous sensors with regard to surveying/mapping seabed resources. Two natural seabed phenomena are being used as case studies in this project:

- Sand banks off the Belgian coast. Naturally occurring sand deposits have been regularly monitored by traditional methods in an effort to regulate the sand extraction industry.
- Maerl beds around the Orkney Islands, Scotland. Maerl is the term given to a group of small calcareous algae which form extensive deposits covering the seabed under certain conditions. Maerl extraction occurs extensively in Brittany, France, and to a lesser extent in the UK.

For more information on sand banks and maerl, see Deliverable 1 “Models of a priori knowledge”.

The aim of Project SUMARE is to develop sensing systems which can be used survey the distribution of these resources on the seabed, in a manner which is considerable more economic than traditional survey methods. The sand application involves the use of MAUVE, a 2m long torpedo autonomous underwater vehicle (AUV), fitted with bathymetric and localisation instrumentation. The maerl application uses the ROV PHANTOM, which is fitted with a video camera, sonar and other data gathering instrumentation.

This document presents the theory and work achieved under workpackage 2. This workpackage relates to the design of the sensing methodology to be employed in each of the separate applications. An outline of the objectives of this workpackage is given below. The following chapters discuss:

- **Traditional marine survey criteria for sand banks**
After repositioning sandbank monitoring in the context of sustainable exploitation of natural resources, a method used to compute volume is proposed. The error budget established from recording, navigation and tidal reduction error contributions is presented and updated for the tidal reduction contribution. From that analysis, a preferred sampling window is introduced. The reviewed error budget is discussed in term of error on the volume calculation and a case study is proposed for the reference track rG21.
- **Sandbank criteria**
As stated in the Technical Annex of the project, the ultimate interest to the end-user for this application is the estimation of the total volume of the sand bank below certain level lines. This chapter discusses the specific criteria relevant for surveys for the sand bank volume. Its major goal is to produce models that relate the quality of the acquired raw data to the final confidence associated to the indexes that can be derived from it, describing the impact of the distinct kinds of errors that affect the collected data series.

- **Chapter 4: Maerl criteria**

This chapter examines the development of the visual sensing method which is being used to gather data on maerl habitats. Information is presented on the differing visual properties that maerl can have on the seabed, using greyscale histograms. The impact of vehicle trajectory on the quality of data is discussed. Observation strategies for estimating the total amount of maerl are also presented.

The final chapter presents a summary of this information and discusses the conclusions which have been reached.

2. Objectives of this workpackage

The objective of this workpackage is to examine the criteria which should be used in the sensing strategies for each application, i.e. sand and maerl. Different criteria demand the use of different survey methods. Consequently, a sensing strategy can be formulated specific to both the sand and maerl applications.

Chapter
2

Discussion of criteria used in traditional marine surveys of sand banks.

1. Introduction and position of the problem

Offshore exploitation of sand on the Belgian Continental shelf began in 1979. This exploitation has grown over the past few years, raising the question of the sustainability of this activity to the authorities, who have to judge what is the maximum amount of exploitation to authorise.

The Kwintebank, one of the Flemish Banks, has been subject of the most intense exploitation as it is located close to the main harbour and its sand is suited to construction purposes.

A monitoring programme was set up by the Belgian Ministry of Economic Affairs to control the effects of the aggregate extraction on the environment. The changes in bank morphology and topography were studied from 1983 to 1994 in the frameworks of different research projects. One of the principal objectives of the monitoring programme was to discover if sand extraction could cause a decrease in the bank volume. The evolution of bank volume was studied with the help of time series of bathymetric records.

The criteria used to evaluate the performance of data acquisition in this case are closely related to the accuracy of the sampled bathymetric data. The discussion is based on the analysis and update of the error budget proposed in SUMARE deliverable D1 "Models of a priori knowledge". Update of the tidal reduction error is proposed conducting to the possibility of sampling optimisation.

1.1 Kwintebank zone and available data

Time series of bathymetric records were obtained along reference tracks across the Kwintebank.

As a general basis, these reference tracks were sailed four times a year and a total of almost 900 profiles exist. Detailed information on these data is provided in the SUMARE deliverable D1 "Models of a priori knowledge".

A subset of 75 profiles has been extracted from the database and a comprehensive statistical analysis is available in Appendix 1.

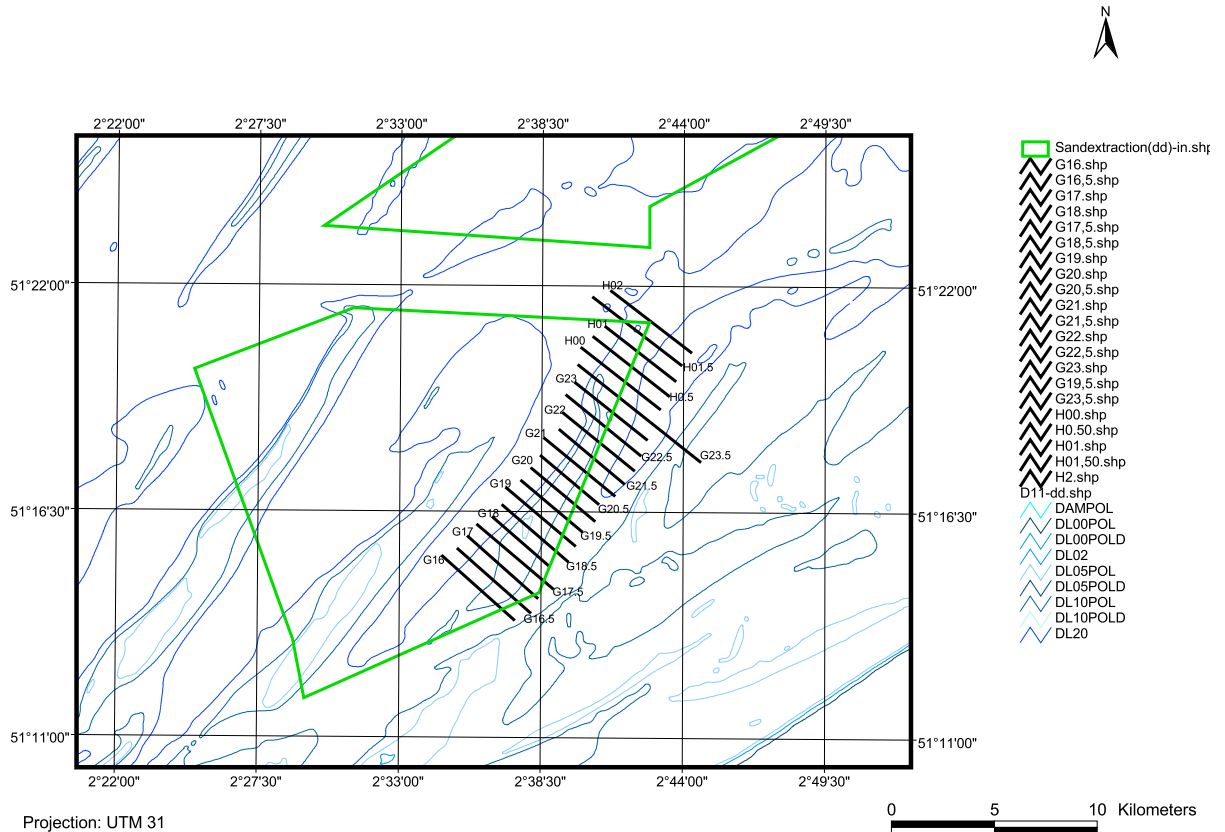


Figure 1 Reference tracks on the Kwintebank . Zones delimited by dotted line are zones reserved for sand extraction.

1.2 Assessment of volumetric changes

The analysis of volumetric evolution was based on single beam echosounding profiles along a number of reference tracks transversal to the bank's axis, see Figure 1.

Processing of the raw bathymetric data included tidal reduction and corrections for variations in the ship's velocity and heading. Net bathymetric profiles were then plotted relatively to a zero level that corresponded to the local MLLWS¹. Unit volumes were defined corresponding to the volumes determined by the surface of a transversal bank cross-section and by a reference plane, situated at intervals of 2.5 m beneath the zero reference level. The principal unit volumes that were used were (i) the total bank volume, corresponding to the volume defined by the lowest reference plane intersecting the bank above the highest base concavity and (ii) the top slice volume, defined at the bottom by the highest reference plane intersecting the bank (Figure 2)

The unit volumes were calculated for each reference track and for each survey period. A regression analysis² was then applied to the time-series of unit volumetric data for each reference track. This analysis provided values for the mean annual change of the unit volume and thus an indication of the zones of the sand bank that are or are not subject to a net erosion due to exploitation.

¹ MLLWS (Mean Low Low Water Spring). Mean of the lowest low spring tide.

² Linear regression or Chebyshev polynomial of degree 2.

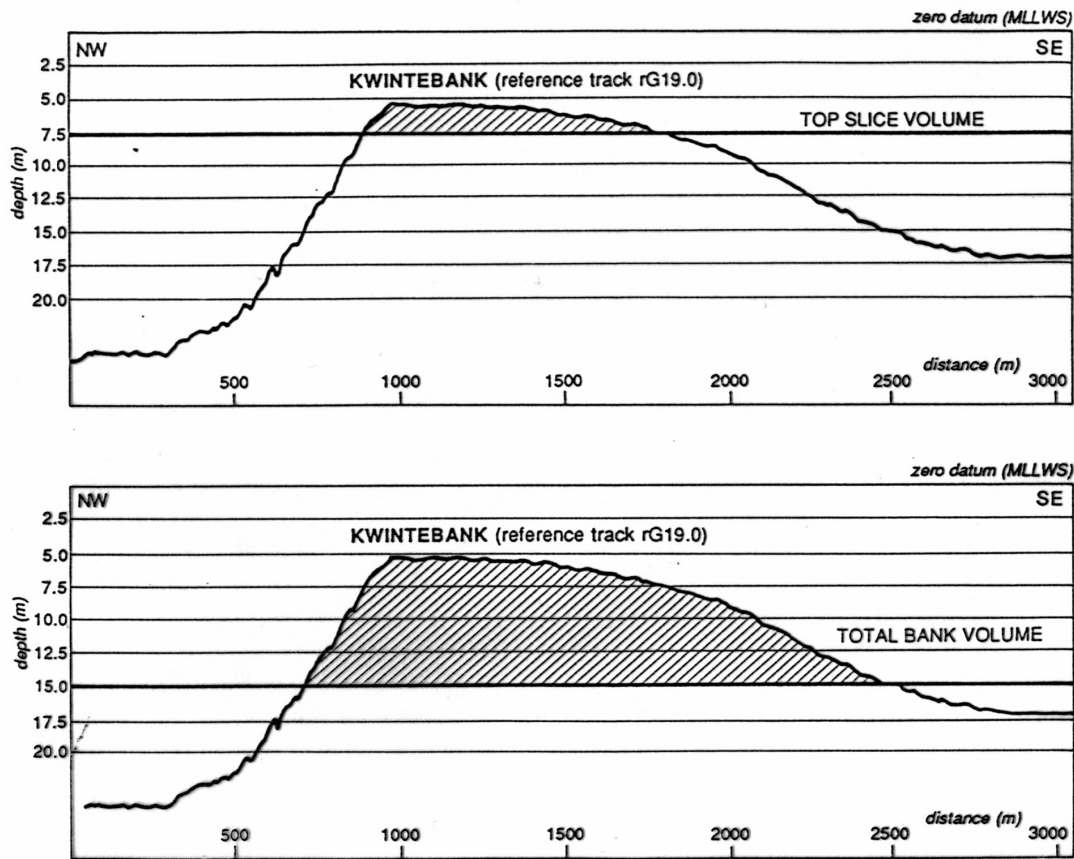


Figure 2 Definition of total bank volume and top slice volume

2. Error budget and analysis

2.1 Summary of the error budget

A thorough investigation of the effects causing possible errors in the depth measurements showed that 29 sorts of errors could be distinguished³. Only the most important one will be treated here. If measurements, calibrations and processing are carried out with sufficient care, most of the errors will not be significant.

Three main types of errors can be distinguished: (i) errors occurring during the recording process, (ii) errors occurring during the processing (including the reduction procedures) and (iii) errors due to navigation errors.

Due to the continuous update of instrumentation we present the error budget for two periods 1988-1993 and after 1993.

³ A complete error budget was provided with the presentation of the data in SUMARE deliverable D1 "Models of a priori knowledge".

Source of error	Precision data 1988-1993	Precision data After 1993
Error in recording		
Echosounder	+4.0 cm/-4.0 cm	+4.0 cm/-4.0 cm
Speed of sound	+2.5 cm/-2.5 cm	+2.5 cm/-2.5 cm
Heave	+10.0 cm/-10.0 cm	+2.5 cm/-2.5 cm
Presence of slopes	+8.0 cm	+8.0 cm
Subtotal	+24.5 cm/-16.5cm	+17.0 cm/-9.0 cm
Error in reduction procedure		
Tidal reduction	+32.0 cm/-32.0 cm	+13 cm/-13 cm
Static draught	+5.0 cm/-5.0 cm	+5.0 cm/-5.0 cm
Var. in stat. draught	+5.0 cm/-5.0 cm	+5.0 cm/-5.0 cm
Subtotal	+42.0 cm/-42.0 cm	+23.0 cm/-23.0 cm
Error in navigation		
Error in navigation	+8.5 cm/-8.5 cm	+8.5 cm/-8.5 cm
Total error	+75.0 cm/-67.0 cm	+48.5 cm/-40.5 cm

Table 1. Total error budget for the measurements carried out in 1988 and 1993 by the Rumacog research team.

Table 1 shows that the total error for survey work decreased from almost 75 cm to less than 50 cm in 1993.

According to the IHO⁴ the various error components are considered to be independent random errors. This means that the errors have an equal probability of being positive or negative. One exception on this rule is the error caused by the presence of slopes in which case the recorded depth will always be smaller than the actual depth.

A factor that has to be considered is that the actual error on the measurements will nearly always be smaller than the values of Table 1. It would be indeed an unfortunate sounding if each potential error component had the same sign what would increase the total error. It is more likely that some components would have opposite signs and be partially self-cancelling.

2.2 Update on the Tidal correction method: Study of the temporal distribution of the tidal reduction error.

Table 1 expresses that the reduction of the tidal signal is responsible for an error of approximately a quarter of the total error budget. Further research has been undertaken in order to study the temporal distribution of that error during a tidal cycle. The outcome of this study could be important in terms of sampling strategy.

Tidal reduction of the bathymetric sounding is achieved by the “classical” Van Cauwenberghe tidal reduction method for the Belgian coast. That method is fully described in the SUMARE deliverable D1 “Models of a priori knowledge”.

⁴ International Hydrographic Organisation

2.2.1 Theoretical consideration

In order to evaluate the temporal distribution of the error made by tidal reduction using the Van Cauwenbergh method, several computational experiments were undertaken. The first one uses a mathematical model and the second one the harmonic method.

The reduction method is applied at the same location as the model or as the harmonic method. Results are compared. Error⁵ distribution and time series are issued.

As an example, the experiment done using the harmonic method is presented. In harmonic method the tidal signal is represented by a periodic function series expansion where periods and amplitudes are known.

At one station, the error due to tidal reduction being a difference between two such series expansions, it can be easily rewritten as follows

$$\Delta(\bar{s}, t) = \sum_k \Delta_k \cos(\omega_k (t - t_0) - \phi_k)$$

Where \bar{s} is the coordinate of the point where the error is calculated, t is the time, t_0 the initial time, ω_k is the angular frequency of the constituent k , Δ_k the amplitude of the error at the frequency ω_k and ϕ_k the phase.

In order to study the distribution in time of the error, we propose the following change of variable.

$$\tilde{t} = (t - t_0) - nT_{M_2}$$

With T_{M_2} the period of the semi-diurnal lunar tide (12.4205 h) and n the number of semi-diurnal cycle occurring between t_0 and t . Using the variable change, the terms of the series read

$$\cos(\omega_k \tilde{t} + \omega_k nT_{M_2} - \phi_k)$$

It is easy to show that for the lunar semi-diurnal frequency (M_2) and its harmonics (M_4, M_6, \dots), the error, if any, will take a single value at all times $\tilde{t} \in [0, T_{M_2}]$. That value is equal to $\Delta_k \cos(\omega_k \tilde{t} - \phi_k)$. For all other frequencies in the tidal signal, the error, if any, can take all values between $-\Delta_k$ and $+\Delta_k$ at all times $\tilde{t} \in [0, T_{M_2}]$. If a sufficiently long time period is considered, the error at all times $\tilde{t} \in [0, T_{M_2}]$ will be equal to a mean value (coming from the error made at the lunar semi-diurnal frequency and its harmonics) plus a random value around that mean. The upper and lower limits of the interval of variation of the error are certainly equal to $-\sum_n \Delta_k$ and $+\sum_n \Delta_k$ where the sum is made over all constituents except the M_2 and its harmonics. Our result for a full year calculation showed that the interval of variation of the error is far from being uniform over the interval $[0, T_{M_2}]$. That may be of interest for the definition of the best sampling strategy.

⁵ Error means difference between the computed value and the value obtained by the reduction method.

2.2.2 Error evaluation

For the following four points of our interest zone, Westhinder, Nieuwpoort, Oostende and Zeebrugge, harmonic constants are available (Mouchet, 1990). Evaluation of the different constituents to the total tidal signal can be obtained by a modified version of Foreman (1984).

Stations closest to the Kwintebank are Westhinder, Nieuwpoort and Oostende. Nieuwpoort is used as reference station for the tidal reduction method. One can easily compute for the three other stations two tidal elevations. One by the use of harmonic constant and the other by the use of the tidal reduction methods applied to the astronomical tide at Nieuwpoort. The difference between the two elevations being the error on the tidal reduction that we want to evaluate.

The total error computed for a period of a year is given for Oostende in Figure 3.

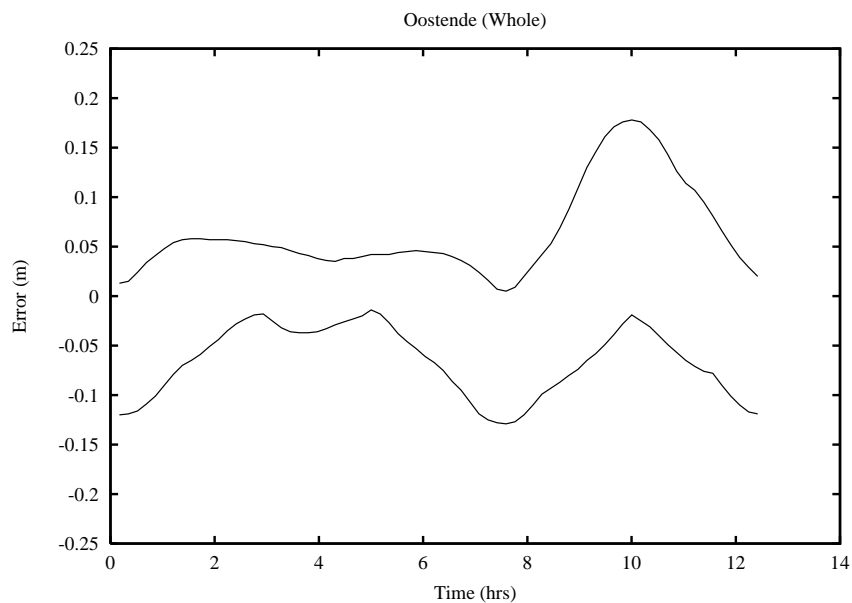


Figure 3 : Domain of variation of the total error due to the tidal reduction during the lunar semi-diurnal tide at Oostende .

Results presented in Figure 3 enhance a window of approximately four hours characterized by an error of ± 5 cm. It is during such a window that bathymetric measurement should be preferably conducted by the AUV. Magnitude of the tidal current during the measuring window needs to be known. There is no advantage in minimizing the tidal reduction error if the horizontal registration error increases. That point shall be discussed later.

The error due to all semi-diurnal harmonic constituents remains small, approximately 2.5 cm as one can observe in Figure 4.

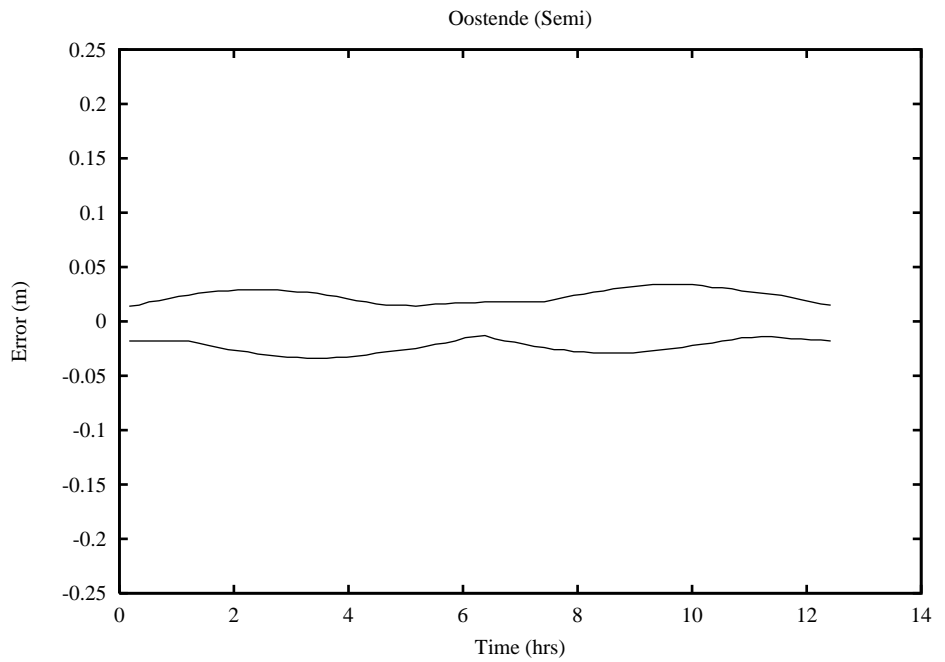


Figure 4: Domain of variation of the error due to the tidal reduction for all harmonic constituents of M2 during the lunar semi-diurnal tide at Oostende

Much of the error can be assigned to constituents at the quarter-diurnal and six-diurnal frequency as shown on Figure 5.

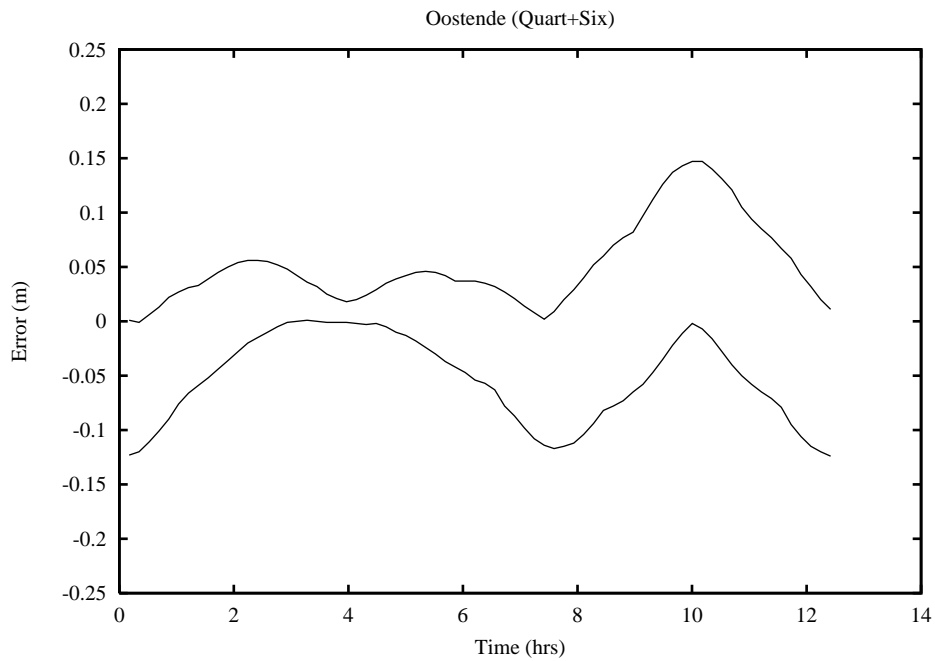


Figure 5 : Contribution to the total error of the quarter-diurnal and six-diurnal components at Oostende

As previously stated, we also made a similar experiment using the MUMM mathematical model OPTOS_CSM, instead of the harmonic method, to compute the tidal elevation. The same behaviour can be observed.

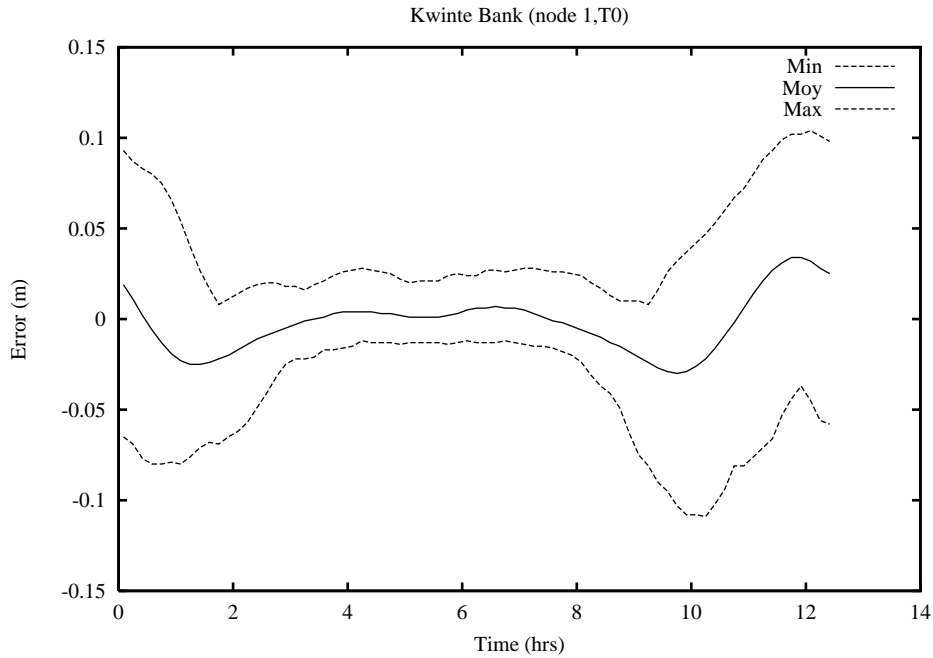


Figure 6: Temporal distribution of the error due to the tidal reduction. Model experiment no wind.

Figure 6 features the error in tidal reduction for a location just south of the Kwintebank. This location is a grid point of the model labelled 1 on Figure 7.

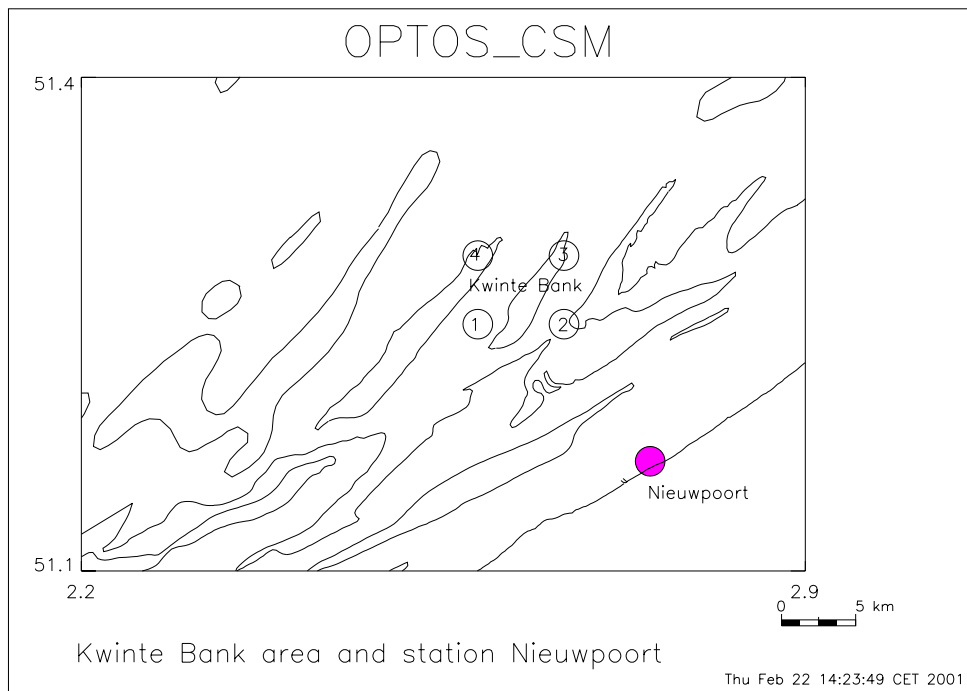


Figure 7 Localisation of reference points for the model experiment

Within the model experiment it is of added value to include a simulation of forcing by the wind⁶.

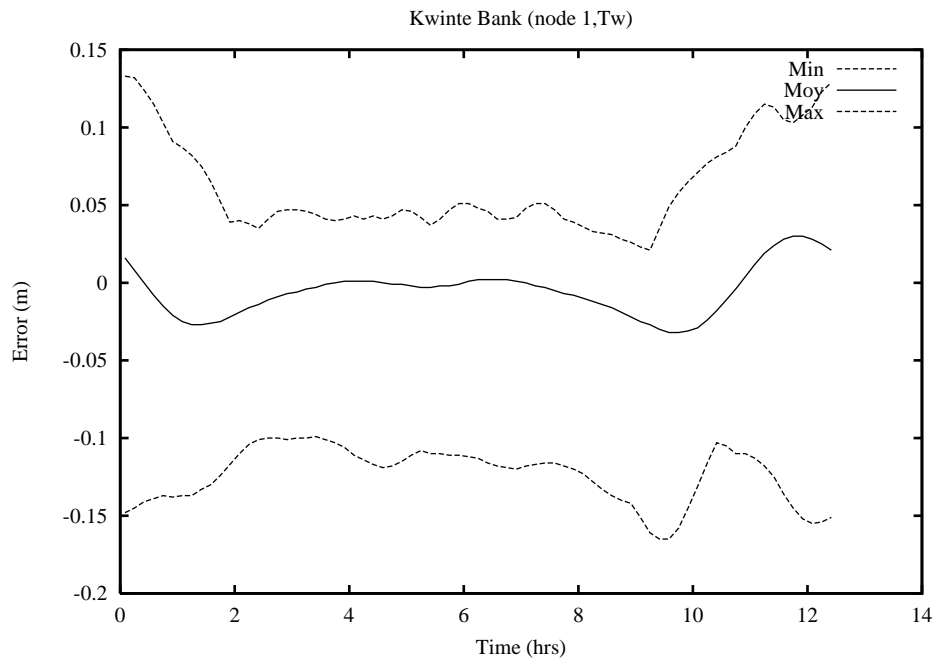


Figure 8 Temporal distribution of the error due to tidal reduction. Model experiment with 1998 real wind forcing

Figure 8 indicates that the form of the temporal distribution is not affected by the wind forcing and if the extreme values are higher than in the run without wind, the absolute value of the error rarely exceeds 0.1m.

2.2.3 Frequency distributions

Frequency distribution of the error for the model experiment without wind forcing is presented in Figure 9 while the experiment with wind forcing is shown in Figure 10. Both distributions are normal and the mean value for the case with no wind is -0.003 m with a standard deviation of 0.026 m. These values increase to a mean of -0.006m with a standard deviation of 0.029 m for the experiment including wind forcing. A comparison of such results with Figure 13 of annex 1 will be conducted later on.

⁶ Observed wind for the year 1998 has been used for that simulation

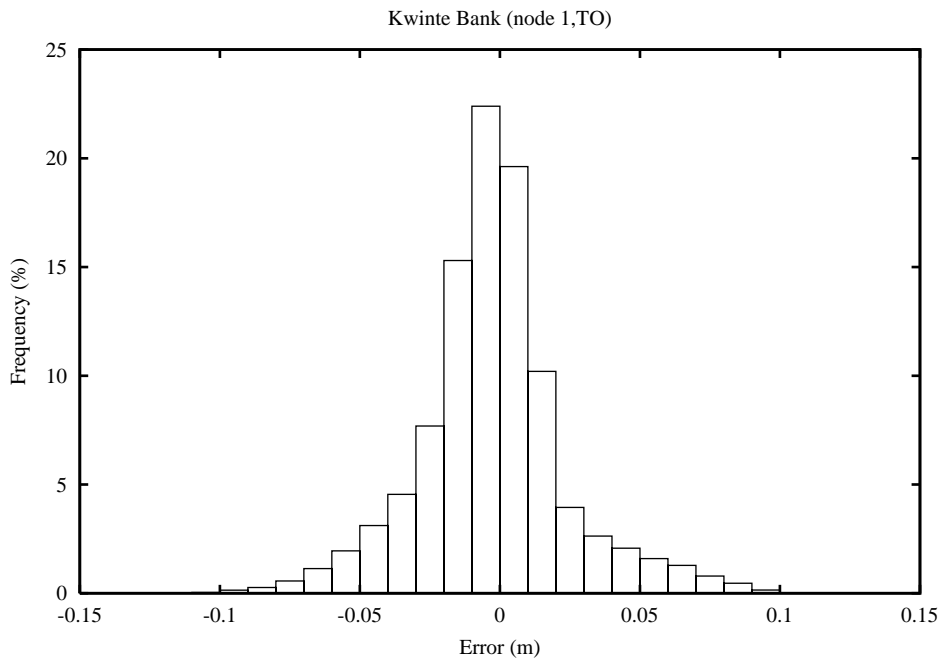


Figure 9 Histogram of the tidal reduction error. Model experiment without wind

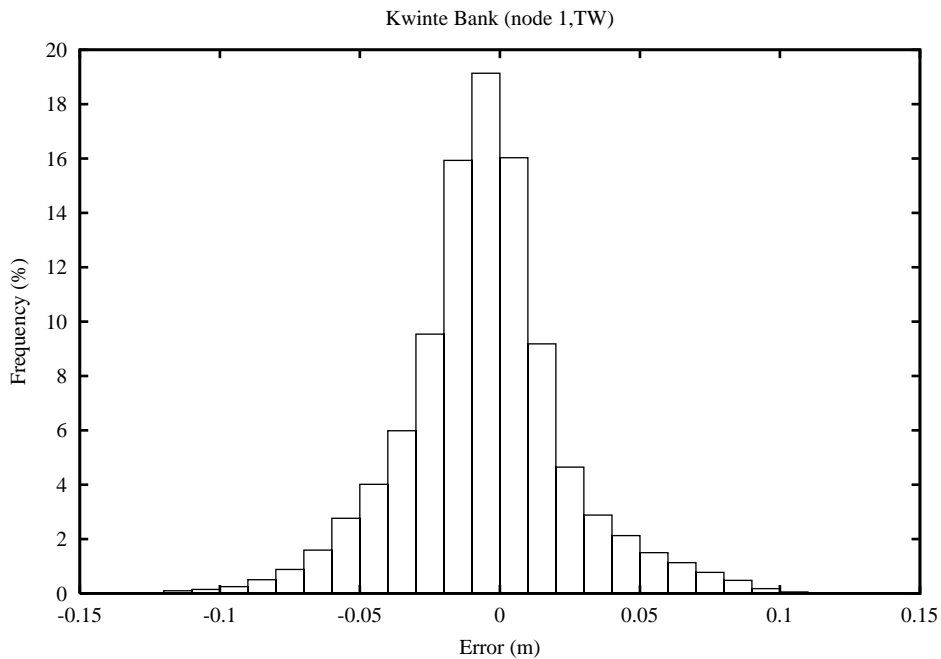


Figure 10 Histogram of the tidal reduction error. Model experiment with wind

2.2.4 Conclusion

From the above analysis, it has been shown that a window exists in the tidal cycle representing a minimum tidal reduction error. Bathymetric measurements should be taken preferably inside that window. It was noted earlier that knowledge of tidal elevation and current were required to demonstrate the operational use of the minimum error window.

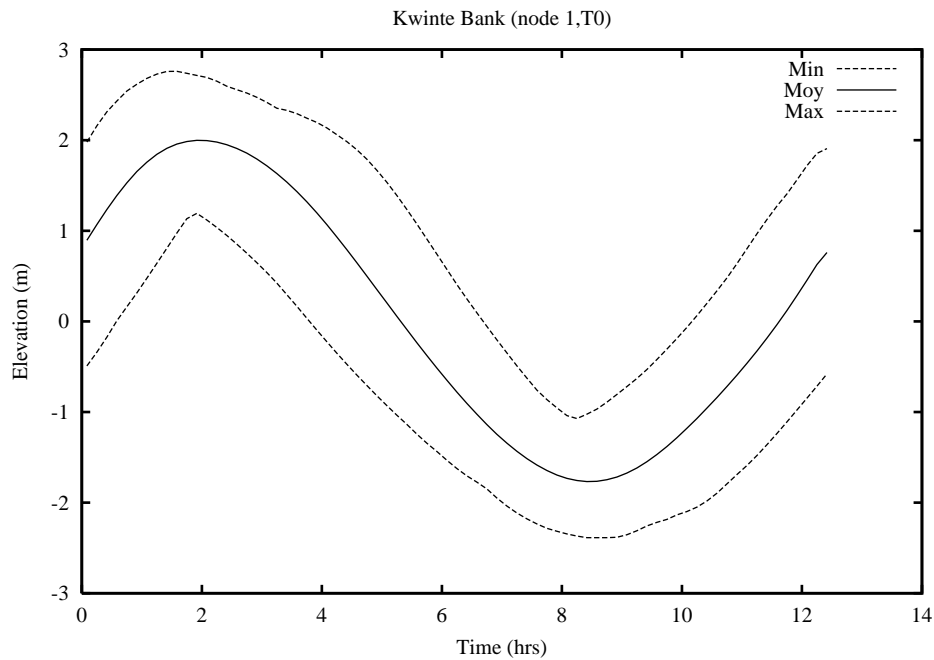


Figure 11 tidal elevations on the Kwintebank given over a tidal cycle. Dotted lines are minimum and maximum tidal elevation.

Figure 11 shows that the minimum error window starts approximately at high tide and stops 1 hour before low tide. That situation leaves the possibility for the research vessel or AUV to cruise over the crest of the Kwintebank safely. During the minimum error window, the tidal current ranges between 0.6 m/s at high tide to 0.2 m/s at the end of the period.

In conclusion, the proposed minimum error window is completely compatible with all aspects of bathymetric measurements. It is foreseen that this concept shall be used for optimising the sampling strategy.

2.3 Transport of the error from bathymetric measurements to volume calculation.

Volume calculation is made for every profile in the form of integration⁷, giving the surface delimited by the profile itself and the reference depth line. If we focus on the error budget of Table 1 at the scale of a single track, it can be observed that the error due to the tidal reduction, the speed of sound and the static & dynamic draught systematically affects the complete profile instead of randomly all soundings of the track. Therefore, the contribution can be seen as a constant depth offset inside the interval +/- 25.5 cm for post 1993 surveys and +/-44.5 cm for pre 1993 surveys.

In addition to this, the 75 profiles proposed for the statistical examination by I3S have been digitised by hand and an error related to the position of the reference point has to be accounted for. If one can accept that a positioning error of one millimetre is possible, then a corresponding error of +/- 25 cm on the depth and of +/-10 m. on the horizontal is possible. The error made during the phase of profile following is considered to be random.

Taking into account a total error of +/-69.5 cm on the bathymetric measurement, one can calculate the error transported to the volume. An example of such calculation is

⁷ Integration method used here is the 5-points Newton-Cotes method

proposed for the reference depth of 15m and for the reference track rG21.

Volume calculation for the rG21 reference track profiles					
Date	15 m	15 m+dH	15 m -dH	dH +	dH-
22/02/88	5962.9	6920.8	5102.3	957.9	860.6
21/03/89	5340.8	6278.3	4485.4	937.6	855.4
01/06/88	5617.2	6589.0	4763.9	971.8	853.3
21/02/89	5335.0	6301.6	4403.4	966.6	931.6
20/06/89	6142.3	6865.7	5265.4	723.4	876.9
17/05/89	6050.5	6984.5	5188.9	934.1	861.6
20/07/90	5671.1	6627.9	4812.1	956.8	859.0
18/06/91	5162.7	6113.1	4322.8	950.4	839.9
01/07/91	5534.6	6532.4	4637.1	997.8	897.5
15/07/91	4842.4	5873.4	4144.9	1031.0	697.5
02/12/91	5534.5	6509.5	4679.3	975.0	855.2
05/05/92	5044.6	5984.9	4203.7	940.3	840.9
10/07/92	5106.1	6074.4	4225.2	968.3	880.9
09/09/92	5103.3	6054.3	4227.3	951.1	876.0
20/10/92	5240.5	6189.4	4380.5	948.9	860.0
22/12/92	4651.8	5500.2	3709.4	848.5	942.4
24/02/93	4668.6	5597.9	3837.4	929.2	831.2
15/07/93	5126.7	6079.0	4284.5	952.3	842.2
09/11/93	6115.8	7159.6	5200.5	1043.8	915.3
01/03/94	4585.9	5532.2	3761.7	946.3	824.2
27/09/94	4163.1	5103.1	3342.6	940.0	820.5
15/12/94	4481.8	5420.2	3633.3	938.4	848.5
08/02/95	4222.4	5151.6	3386.4	929.2	836.0
06/06/95	4104.1	5049.4	3257.5	945.2	846.6

Table 2 Unit volume calculation for the 25 profiles selected for rG21 reference track. Reference depth for the calculation is 15m. Column n° 3 and 4 give the unit volume taking into account the measurement error. The last two columns give the value of the unit volume error.

The results proposed in Table 2 and in Figure 12 have to be contrasted with the study of De Moor and Lanckneus (1994) and with Table 3 issued in SUMARE deliverable D1 "Models of a priori knowledge".

Table 3 features some results of the volume calculation obtained in deliverable D1.

Section N°	09/11/93	WWK 95	BGS 99-00	De Moor Min-Vol	De Moor Max-Vol
rG19-15m	12920	11634	11214	10947	12888
rG19-10m	4192	4194	3678	3650	4997
rG21-19m	12727	10602	8797	9822	11961
rG21-15m	6115	4606	3164	4356	6082
rH01-17.5	1533	1820	-	1193	2551
rH01-15m	-	91.5	-	95	541

Table 3. Section volume calculations (from deliverable D1); results are in m³/m, WWK 95 stands for the section extracted from the gridded bathymetry WWK 1995. BGS 99-00 stands for the section extracted from multi-beam gridded bathymetry based on 1999 and 2000 survey. 09/11/93 is the date of on-site survey. De Moor min-vol and max-vol are extreme values measured by De Moor and Lanckneus (1994).

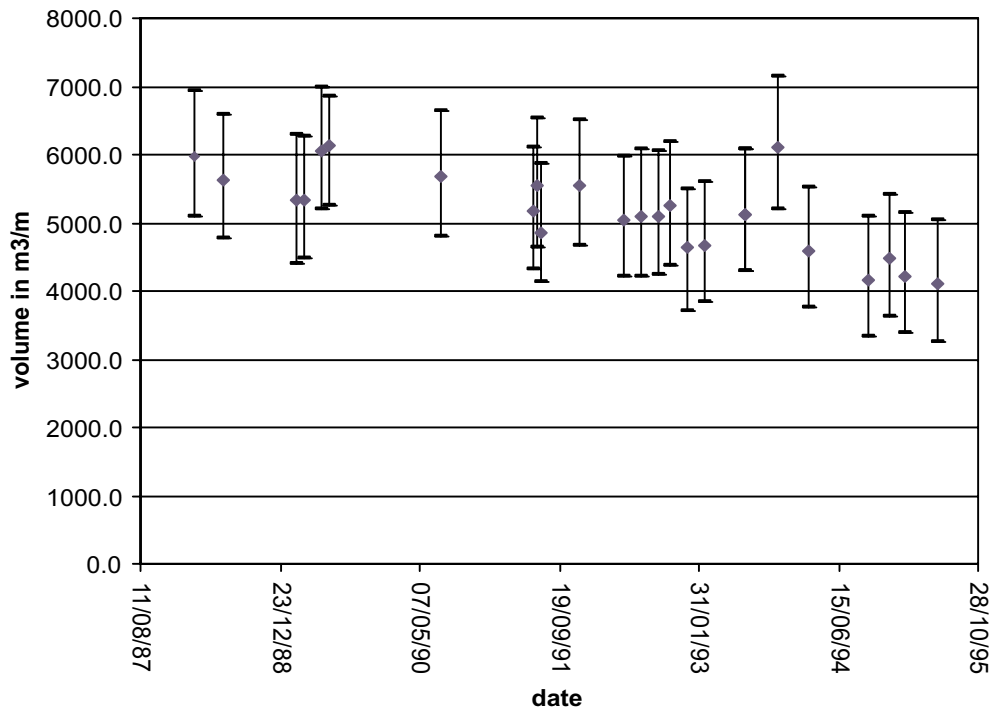


Figure 12 Unit volume calculation for the rG21 reference track. Error bars are proposed based on the analysis of the total error budget. Volume is expressed in m³/m.

According to our calculation, the rG21_15 m mean unit volume ranges from 4519 to 6190 m³/m while observed unit volume ranges from 4356 to 6082 m³/m (Table 3).

It is therefore possible that the earlier proposed decrease in volume for rG21 could not be significant. Nevertheless, statistical study of appendix 1 proposed a possible decrease of sand volume for the rG21 reference track and further data and research is needed to confirm or not that tendency. With that purpose, it could be possible to correlate the present results with the analysis of the so-called 'black-box' data taken by sand exploitation vessels.

2.4 MUMM comments on the conclusion of Appendix 1

The first point of the conclusion concerns automatic alignment and tidal reduction.

Figure 13 of Appendix 1 features a histogram of computed shift and offsets made necessary to align the 75 profiles provided by MUMM. Offset or vertical correction is identified (Rendas and Lourtie, Appendix 1) as error due to tide reduction. Amplitude of the proposed correction is not of the same order of magnitude as what was proposed for tidal reduction (see Table 1, deliverable D1 and the analysis given above).

Moreover, the proposed distribution for the vertical correction is far from normal as should be the tidal reduction error distribution (see Figure 9 & Figure 10).

Nevertheless, we suggest that the vertical correction should be attributed to all "systematic" sources of error⁸ such as the static and the dynamic draught, the speed of the sound calculation error, the digitalisation of the profile error and the tide

⁸ At the profile time scale

reduction. Further classification in pre-1994 and post-1994 profiles could help in identifying error sources.

Finally, information on the mean and standard deviation on the vertical correction will help for further analysis. In order to verify the capability of that stated better method for the tide correction, it is proposed to I3S that they carry out an intercalibration exercise. Methodology is to compare the tidal signal extracted by the I3S method and compare it with measured or calculated tide.

Concerning the horizontal alignment, Figure 13 shows values ranging from -140m to +60m. Possible error in horizontal registration depends mainly on the period of measurement. If an accuracy of +/-100 m characterised pre- 1988 data because of the use of DECCA and TORAN positioning systems, post-1988 data have accuracy better than 5m (Syledis and DGPS systems). The accuracy of post-1988 data has been studied as follows. The precision of Syledis was well controlled during the monitoring programme by sailing one single reference track 22 times in one single day. The position corresponding with the intersection of the sailed track and the crest line of one well known, straight, large sandwave was calculated for each track. From the analysis of the 22 intersection points it could be deduced that the precision in positioning was better than 5 m (mean of deviation values: 1.7 m, standard deviation of deviation values: 1.4 m). DGPS⁹ was only used after 1994 and therefore concerns only very few of the profiles presented here. DGPS has a precision similar to Syledis one (± 5 m).

On the 75 profiles proposed by MUMM only one is dated from the period pre-1988.

The second point of the conclusion concerns the global error distribution presented at Figures 34 to 39 and related information. By global error (Rendas and Lourtie, annex 1 included here), it is considered the total error less tidal correction error. Table 4 is constructed taking extreme values found in the various histograms given in Appendix 1 (figure 34 to 39) as well as information given in Table 1.

Error range comparison			
	From table 1 less tidal error worse case pre-1993	From table 1 less all systematic pre-1993 worse case	From stat. approach figure 34 to 39 annex 1
rG19	+/- 67 cm	+/- 55cm	~ +/- 100 cm
rG21	+/- 67 cm	+/- 55 cm	~ +/- 250 cm
rH01	+/- 67 cm	+/- 55 cm	~ +/- 150 cm

Table 4 Error range comparison between statistical approach and error budget

Comparing values given in Table 4 and taking into account that figures given in Table 1 are worst case, it appears that the statistical approach overestimates approximately by a factor of two the possible error range. That conclusion is worse with a factor 4 for rG21.

Overestimation of the error range is even bigger if one accepts our proposition to explain vertical alignment by all causes of systematic error and not just by tidal reduction.

It is not very clear from an instrumental point of view why the global error should be different from one reference track to another. Appendix 1 proposes to attribute cause of the error to lateral displacement.

⁹ Differential Global Positioning System

A question arises: Why lateral displacement should involve such a difference between reference track rG21 and rH01?

If reference track rG19 is identified as a stable and slowly varying track, that is not the case for tracks rG21 and rH01 featuring big sand waves and sharp bathymetric gradients. Our examination of navigation error permits us to estimate the range of the error to +/- 8.5 cm when horizontal registration precision is 5m. That figure is the worse case, when a constant bathymetric gradient of 2° exists and when the profile is systematically cruised away from the theoretical line. On a practical point of view, it is clear that the sensor trajectory is more like an oscillation centred on the theoretical track and the error at the profile scale should be random. If one can accept horizontal oscillation of +/- 25 m, range of the worst case error is +/- 43 cm. A factor of two remains when comparing with numbers given in Appendix 1.

We could propose two hypotheses to explain the remaining factor of two. One is to be found in the existence of the few strait lines that are observed in bathymetric profile. The answer could be obtained with the reprocessing based on the I3S reconstructed profiles. Our second hypothesis is that probably, the variation of shape of the bank is not negligible invalidating the proposed statistical approach.

From Appendix 1 Figures 34 to 39, conclusions are also given in terms of sand volume decrease for reference tracks rG21 and rH01. When comparing that with SUMARE deliverable D1 Figure 2.2.13, we find that the same hypothesis has been proposed. But we find also that the same behaviour may apply to the rG19 reference track. That is not supported by the statistical analysis.

2.5 References

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