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SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY
Sustainable Management of the North Sea

MANAGEMENT, RESEARCH AND BUDGETING OF AGGREGATES IN SHELF SEAS RELATED TO END-USERS

MAREBASSE

Scientific Report Year 1 (01/04/2002 – 31/03/2003)

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INTRODUCTORY NOTE

This report presents the first scientific results regarding the project Marebasse for which the following partnership was set-up:

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For the specific tasks of the partners and their progress, reference is made to the administrative report.

During the first year of the project, some desk studies were performed related to marine aggregate issues and dredging/dumping operations. The first Marebasse field measurements were made in November 2002. For 2003, Marebasse shiptime was approved in February, June and October. The Belgian oceanographic vessel RV/Belgica is the preferred platform for the field campaigns since it is equipped with state-of-the-art instrumentation. The officers and crew are greatly acknowledged for their cooperation as well as MUMM for approving shiptime.

At this stage, we already wish to acknowledge and thank the end-users associated with the project and for their willingness to provide data and/or instrumentation:

- Federal Public Service Economy, SMEs, Self-employed and Energy – Marine Sand Fund
- Zeegra
- Ministry of the Flemish Community, Administration Waterways, Infrastructure and Nautical Affairs, Waterways and Coastal Section (AWZ-WWK)
- European Dredging Association
- 3E
- Flanders Marine Institute

The Department of Sea Fisheries is thanked for the use of the bottom discriminator software RoxAnn.

On an international level, the project is complementary to the Fifth Framework Research Training Network EUMARSAND (European Marine Sand and Gravel Resources). The project is set-up to address, on a European level, the urgent need for integrated and coherent approaches regarding marine aggregates. However, the main objective of the programme is to train young European researchers, to a high level, in the individual research approaches needed and to provide them with an integrated and balanced view of the diverse and difficult issues involved. The partners involved are Fundacion AZTI (E) (coordination); University of Southampton (UK); Ghent University RCMG (B), National & Kapodistrian University of Athens (G); University of the Aegean (G); Maritime Institute in Gdansk (P); Université du Littoral Côte d'Opale (F); Universiteit Twente (NL) and Christian-Albrechts-Universitaet zu Kiel (D).

The Marebasse project team, April 2003

Reference to this report:
Van Lancker, V., Deleu, S., Le Bot, S., Van Nieuwenhove, B., Fettweis, M., Francken, F., Pison, V., Van den Eynde, D., Monbaliu, J., Lanckneus, J., Moerkerke, G. & Degraer, S. (2003). *Management, research and budgeting of aggregates in shelf seas related to end-users (Marebasse). Scientific Report Year 1*. Federal Office for Scientific, Technical and Cultural Affairs (OSTC), 39 p.

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INTRODUCTION

In recent years, a sustainable management of the Belgian exclusive economic zone (EEZ) becomes increasingly important. This is mainly due to higher exploitation demands towards marine aggregates, but also the dredging industry imposes high stresses on the seafloor. To anticipate on future developments, including the implantation of windmill farms, the Marebasse project aims at developing efficient evaluation tools and strategies (Van Lancker et al. 2002).

For a sustainable management of the whole EEZ, also the broader sediment dynamical framework needs to be studied. This has become feasible as Marebasse can build upon recent investigations and developments including sediment transport models suitable for the evaluation of large-scale sedimentary processes and as a base line for any detailed investigation.

The set-up of evaluation tools and strategies is specifically aimed at on a smaller scale and this within the view of the optimisation and scientifically upgrading of the concepts ‘environmental (impact) assessments’. This calls for a multidisciplinary approach and as such the project integrates knowledge on the physical, geomorphological, sedimentological and biological nature of the seafloor. Moreover, the strength of Marebasse is that different techniques and approaches are applied simultaneously and this mainly with respect to seafloor characterisation and hydrodynamic and sediment transport measurements. Most challenging is the development of acoustical seabed classes to efficiently determine the distribution of the surficial sediments. However, ground-truthing remains important and as such new approaches will be evaluated for the validation of the true nature of the seafloor of the Belgian continental shelf.

Environmental impact assessments are far more difficult to establish. However, towards marine aggregate extraction, present-day investigations provide evidence of longer-term erosion on the sandbank that has been most intensively exploited. In combination with existing monitoring programmes, the Marebasse group will provide complementary expertise and instrumentation to optimally characterise this area of impact. Moreover, state-of-the-art hydrodynamic, sediment transport and wave modelling will be performed to study the extraction-induced changes.

Finally, it needs emphasis that the philosophy of the Marebasse group lies within the concept of a science-based approach to management. Secondary, it is believed that for a sustainable management of the EEZ, other end-users need to be integrated and the better their needs are recognised, the more focused/targeted, the EEZ can be exploited. Therefore, an optimised integration of the research results and its valorisation/exploitation towards end-users’ groups is an inherent component of the project.

RESULTS

1. ENVIRONMENTAL CHARACTERISATION OF THE BELGIAN CONTINENTAL SHELF

Introduction

An appropriate evaluation of a sedimentary system can only be carried out if it can be situated in a larger scale sediment dynamical framework and hence a broad-based approach (WP1), including a review of existing knowledge on marine sediments, is an inherent component of the project (Task 1.1). It remains an approach, since it is difficult to carry out detailed investigations that take into account the whole Belgian continental shelf (BCS). Up till now, the main industry end-user groups are the marine aggregate (MA) and dredging industry and since they impose most stress on the sedimentary system, it is regarded important to get acquainted with their needs and demands, now and in the future (Task 1.1.1; 1.1.2). Still, towards the implantation of windmill farms or, generally, any major anthropogenic impact, there is a need for tools and strategies to prospect and evaluate the state, dynamics and stress of the seabed. Since a variety of issues should be considered, it seems essential to review environmental (impact) assessments on a European level (Task 1.1.3). It should be mentioned that emphasis is put on the characterisation of the sedimentary system; pure biological or fisheries issues are not considered.

The proposed broad-based investigation includes the refinement of a 2D hydrodynamic and sediment transport model (Task 1.2). This consists of the set-up of a new grid (250x250 m²), the coupling of the model with the existing models covering the continental shelf of the North Sea and the calibration and validation of the model (Task 1.2.1). The main goal of the latter is to determine the optimal sediment parameter set and the sensitivity of the model by using available and the within the Marebasse project obtained field data. The newly acquired sediment data will be used to build the initial condition of the sediment transport model and to more accurately quantify the transport, the sedimentation and erosion processes using several size fractions of the sediment (Task 1.2.2). The regional and site-specific scale approaches can make use of the broad-scale model results e.g. help to select relevant sites on a regional scale.

1.1. Review of existing knowledge on marine sediments

1.1.1. Marine aggregate usage, estimated demand and growth against resource type and availability

A first study was performed related to marine aggregate usage. In this context, the grain-size technical needs are firstly discussed.

Resource type - grain-size characteristics

The definition of grain-size characteristics is an important tool in the evaluation of sedimentary systems. During the Marebasse project a large number of samples will be taken with different sampling devices. The samples are normally sieved on 1/4th of phi mesh sizes. When, the silt-clay fraction is higher than 5 %, the fine fraction is measured using a sedigraph (see Annex 2). After standardisation of the data, sedimentological parameters are calculated according to the graphical method of Folk & Ward and the moment statistics.

The aggregate industry shows an interest in the obtained results on the distribution and characteristics of marine sediments. However, their characterisation of the sediments is done in a complete different way. As it is important to produce end products that are of direct use to the end-users, a number of the

Marebasse grain-size results would be preferable produced according to the methodology of the aggregate industry. As such, the method used for the definition of grain-size characteristics in this sector is explained in the following paragraph.

Grain-size parameters in the aggregate industry

The grain-size characteristics in the industry are defined according to official standards. In Belgium, the BIN (Belgisch Instituut voor Normalisatie) which acts under the guardianship of the Federal Public Service Economy, SMEs, Self-employed and Energy, is responsible for the elaboration of all industrial standards. The BIN uses a registered trademark called Benor. The management of the Benor trademark which covers granulates but also a wide range of products including fire extinguishers, electrical appliances, safety glass and furniture is assigned to a number of sectorial certification organisms. The certification organism responsible for the concrete, mortar and the products used in the preparation of concrete (such as sand and gravel) is the OCCN (Nationaal Centrum voor het Wetenschappelijk en Technisch Onderzoek der Cementnijverheid) also named CRIC (Centre National de Recherche Scientifique et Technique pour l'Industrie Cimentière). A manufacturer who carries out a severe internal control of his products can apply for a Benor certificate. In Belgium, the 'Nieuwpoortse Handelsmaatschappij' (NHM) and 'Hanson Aggregates', produce aggregates with a Benor certificate.

The technical regulations determining the classes of natural sand are summarised in the document PTV401 (http://net.reality.be/download/cric/fr/ptv401.pdf). On the Benor certificate, values are attributed to eight parameters. Table 1 gives an example of the parameters mentioned on the certificate (example from a sediment produced by NHM).

Table 1. Parameters on a Benor certificate; definition of the type of sand according to the technical document PTV401.

Rounded sand	0/2	C	0.5	I	a	cc	SB
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*

This definition contains 8 parameters that are:

(1) Origin of sand: three types are distinguished, i.e. round sand (result of the natural erosion processes and found in rivers and seas), broken sand (result of breaking rocks and gravel) and mixed sand (result of mixing round and broken sand).

(2) Nominal grain-size: defined by the indication 0/D in which D is the mesh size in mm of a sieve to be selected from the following series (Table 2):

Table 2. Mesh size (mm) used in the definition of the nominal grain-size. The values between brackets are the reference sieves used to define the class of variability of the grain-size distribution.

0.200	0.250	0.315	0.400	0.500	0.630	0.800
(0.125)	(0.125)	(0.125)	(0.125)	(0.250)	(0.250)	(0.250)
1.00	1.25	1.60	2.00	2.50	3.15	4.00
(0.50–0.250)	(0.50–0.250)	(0.50–0.250)	(0.50–0.250)	(1.00–0.250)	(2.00–0.250)	(2.00–0.250)

The mesh size to be selected is classified by the following rules:

- Rest fraction on sieve with mesh 1.58D ≤ 5%
- Rest fraction on sieve with mesh 2D: 0%
- Rest fraction on sieve with mesh D ≥ 1% and ≤ 15%

(3) Class of variability of grain-size distribution: measured by the deviation of an individual grain-size distribution in relation to the average grain-size distribution. The deviation is measured on 1 or 2 reference sieves of which the meshes are function of the nominal grain-size value (values are given in Table 2). The deviation is expressed in percentage remaining on the sieve in relation to the average remaining fraction. Sand is classified in one of the following classes (Table 3):

Table 3. Classes of sand in function of the variability of the grain-size distribution.

	A	B	C
Max. value of deviation (%)	10	15	20

(4) Average fraction passing through the sieve of 0.080 or 0.063 mm in %.

(5) Class of variability of the content of fine fraction: is measured by the deviation of the individual content of the fine fraction in relation to the average content of the fine fraction. The deviation is expressed in % in relation to the average fraction passing through. Sand is classified in one of the four following classes (Table 4):

Table 4. Classes of sand in function of the variability of the content of the fine fraction.

	I	II	III	IV
Max. value of deviation (%)	1	3	5	7

(6) Purity of sand: defined by the quality of the fine fraction and by the content of organic material.

The quality of the fine fraction is measured by the test of the sand equivalent of sand with 10% fine fraction (ZE) or by the test with methylene blue (BW). Sand is classified in one of the three following classes in relation to the quality of the fine fraction (Table 5):

Table 5. Classes of sand in function of the purity of sand.

	a	b	c
Max. value of ZE or BW	ZE ≥ 60 BW < 1	ZE ≥ 50 BW < 1.5	ZE ≥ 40 BW < 2

The content of organic material must be smaller than 0.5%.

(7) Content of Cl ions: sand of marine origin is classified in one of the three following classes (Table 6) in accordance with the content of chlorine ions expressed in % of the total dry mass of sand.

Table 6. Classes of sand in function of the content of Cl ions.

	CA	CB	CC
Max. content of Cl ions	0.01	0.06	0.10

(8) Content of shells: sand of marine origin is classified in one of the following classes (Table 7) with the maximum allowed content of shell fragments.

Table 7. Classes of sand in function of the content of shells.

	SA	SB	SC
Max. content of shell fragments (%)	≤ 20	≤ 25	≤ 50

Application of the Benor parameters in the Marebasse project

The identification of sand according to the Benor certificate could be carried out for a number of samples taken during the Marebasse project. Most of the parameters can be easily deduced from the grain-size data that are normally produced in the framework of the sedimentological analyses. However the definition of some parameters could be more problematic. Especially the parameters including the factor of variability can only be calculated when time-series of data from particular locations are available. Only then, the deviation of a grain-size distribution in relation to the average distribution can be assessed. As scientific sampling during the project will normally not include multiple samples on particular sites these variability parameters will likely remain unknown.

1.1.2. Dredging location and dumping sites in relation to bottom sediments, hydrodynamic conditions and sedimentation rates

Under the responsibility of the Flemish Region, dredging has to be carried out to maintain the maritime access routes to the Belgian coastal ports as well as the depth of the coastal ports. The large quantities of dredged material resulting from these activities are dumped back in the sea. An overview of the sediment composition (sand/mud) on the bottom in the coastal zone can be found in Van Lancker *et al.* (2001). The dredging areas are situated in a high turbidity zone explaining the very high quantities of fine sediments that are deposited.

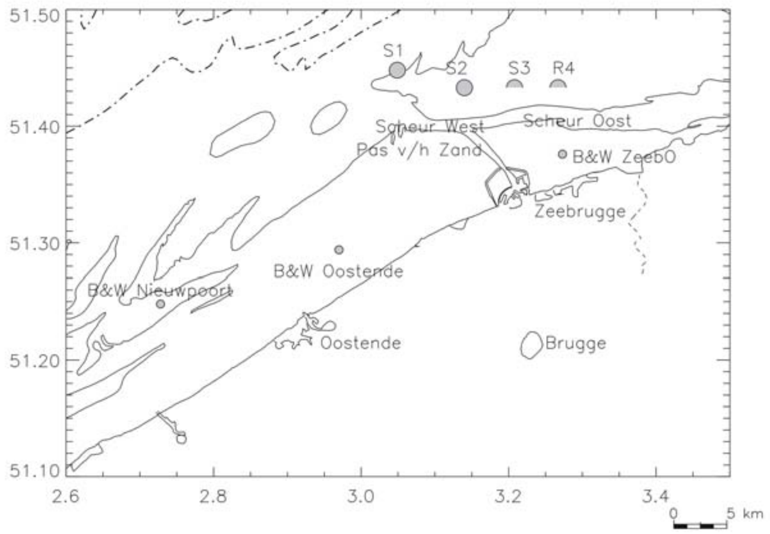


Figure 1: The dumping places and the dredging locations on the Belgian continental shelf

During the dredging years 1997, 1998 and 1999 on average 13.31x10^{6} tonnes dry matter (TDM) have been dredged for maintenance and deepening purposes. From this amount, 7.54x10^{6} TDM where dumped on S1, 0.82x10^{6} TDM on S2, 4.35x10^{6} TDM on Br&W Zeebrugge Oost and 0.60x10^{6} TDM on Br&W Oostende respectively (localisation, see Figure 1). The dumped material consisted of 11% sand and 89% mud, 92% of the sand was dumped on S1. The mud was mainly dumped on S1 (49%) and Br&W Zeebrugge Oost (40%).

Sedimentation in the navigation channel was on average over the three years (see Table 8): 3.78x10^{6} TDM, from which 1.17x10^{6} TDM in the 'Pas van het Zand', 1.08x10^{6} TDM in the 'Scheur Oost', 1.38x10^{6} TDM in the 'Scheur West' and 0.15x10^{6} TDM in the navigation channel of Oostende. The mud content of the sediments is high, and ranges between 83% (Pas van het Zand) to 72% (Scheur West). The dredged matter in the harbours consists of almost 100% mud, on average 7.00x10^{6} TDM is dredged in the harbour of Zeebrugge (Centraal Deel Nieuwe Buitenhaven Zeebrugge (CDNB) and port of Zeebrugge) and 0.45x10^{6} TDM in the port of Oostende. The transported amount of sediment from human operations (maintenance dredging works) during the dredging years 1997-1999 is summarised in the table. Comparison between the estimated natural input of suspended sediment and the quantities dredged and dumped at sea shows that an important part of the suspended matter is involved in the dredging/dumping cycle. The deposition of mud in the dredging areas can be seen as a temporary storage. The effect of dredging and dumping on the sediment balance is of minor importance because dredging and dumping occurs almost continuously and because the major dumping places are situated in the turbidity maximum zone. A more detailed overview is given in Annex 1.

Table 8. Yearly averaged transported amount of sediment from maintenance dredging works (10^{6} TDM/yr) in the dredging areas (1997-1999).

	Total	Sand	Mud
Harbour Zeebrugge	7.00	0.07	6.93
Harbour Oostende	0.45	<0.01	0.45
Total harbours	7.45	0.07	7.38
Pas van het Zand	1.17	0.20	0.97
Scheur Oost	1.08	0.26	0.82
Scheur West	1.38	0.39	0.99
Channel Oostende	0.15	0.02	0.13
Total navigation channels	3.78	0.87	2.91

1.2. Refinement of a 2D sediment transport model and its application

1.2.1. Refinement of the 2D MU-STM model

In order to simulate the sediment transport on the Belgian continental shelf (BCS) it is necessary to have the disposal of a fine-grid numerical model. The BCS has a complicated bathymetry formed by sand banks, the navigation channels and the mouth of the Westerschelde estuary. The boundaries of the BCS model are situated at 51°54′ N and 2°6′E, the grid thus comprises the whole of the BCS. Two versions of the model exist: a coarser one having a grid distance of 5′/7=42.86″ in longitude (817 m - 833 m) and 2.5′/6=25″ in latitude (772 m). The resolution of the fine model is three times better and is 5′/21=14.29″ in longitude (272 m – 278 m) and 2.5′/18 = 8.33″ in latitude (257 m). The BCS model is coupled with the OPTOS model (Pison & Ozer, 2002) that provides the boundary conditions.

<u>Bathymetry of the BCS model</u>

The bathymetrical data are from the Ministry of the Flemish Community, Administration Waterways, Infrastructure and Nautical Affairs, Waterways and Coastal Section (AWZ-WWK), UK Hydrographic Office, POM – Dienst der Hydrografie and RIKZ – Directie Zeeland, Meetinformatiedienst. The French hydrographic Office (SHOM) has been contacted and as soon as data are being made available, they will be used to refine the bathymetry on the grid. The bathymetry corresponds to the average of the most recent data available in every grid cell. The data are arranged per year. The number of data in every grid cell is shown in Figure 2. Remark that the data density is high in the northeast and for the Wester- and Oosterschelde. The data density of the fine model is situated between 5-10 per grid cell on the BCS. The bathymetry in the areas without measurements (the white areas in Figure 2) was interpolated using the OPTOS data. This can be seen clearly in the bathymetry (Figure 3) where the resolution is significantly lower. Areas having a bathymetry lower than 4 m MSL, are deepened up to 4 m. In the BCS model, the reference level is mean sea level (MSL). As the bathymetrical data are referred to MLLWS they had to be transformed to MSL. MLLWS is defined as the lowest of the two low waters during spring tide. The reference surface was calculated for 1999 using the OMNECS model (Fettweis *et al.*, 2002) and the difference added to the depth. The variation of the data in every grid cell is shown in Figure 4 by the scatter index (SI). The SI is defined as the root mean square error (RMSE) divided by the bathymetry of the model. The SI is independent of the water depth and can therefore be used to indicate the relative variance in the data. Figure 4 shows the highest SI in areas with the highest bathymetrical variations such as the Wester- and Oosterschelde and the sandbanks. The fine model has generally a lower SI in these areas and led to the conclusion that the representation of the bathymetry in the fine model is significantly better.

<u>Coupling with the OPTOS-model</u>

The OPTOS modelling system consist of two regional models (CSM and NOS) and of the BCS model. The CSM model comprises the Northwest European continental shelf and calculates the boundary condition for the North Sea model (NOS). The NOS model generates the boundary conditions for the BCS model. The CSM model runs in 2D and is driven by the elevation at the open boundaries, governed by four semi-diurnal (M_2, S_2, N_2, K_2) and four diurnal (0_1, K_1, P_1, Q_1) harmonic constituents. It calculates elevation and currents under the influence of the tides and of wind in 2 or 3D. The OPTOS model is based on the COHERENS code (Luyten *et al.*, 1999). COHERENS has been developed between 1990-1998 in the framework of the EU-MAST projects PROFILE, NOMADS and COHERENS. During this period the COHERENS model was extensively tested and validated. The COHERENS model consists of a hydrodynamic module and modules for biology, resuspension and contaminants. The hydrodynamic module solves - in a Cartesian or spherical co-ordinate system – the momentum equation (using the Boussinesq approximation and the assumption of a vertical hydrostatic equilibrium); the continuity equation and the equations of temperature and salinity. The equations of momentum and continuity are solved using the 'mode-splitting' technique. COHERENS offers a variety of different advection schemes for vector and scalar variables (upwind, TVD, Lax-Wendroff, ...) and for horizontal diffusion. The vertical exchange of physical parameters, biological and suspended matter is controlled by turbulence. COHERENS disposes of different turbulence schemes, such as simple algebraic formulations and 1 or 2 equation turbulence models (Mellor-Yamada and *k*-ε model). A good description of turbulence is important when simulating the vertical current profile.

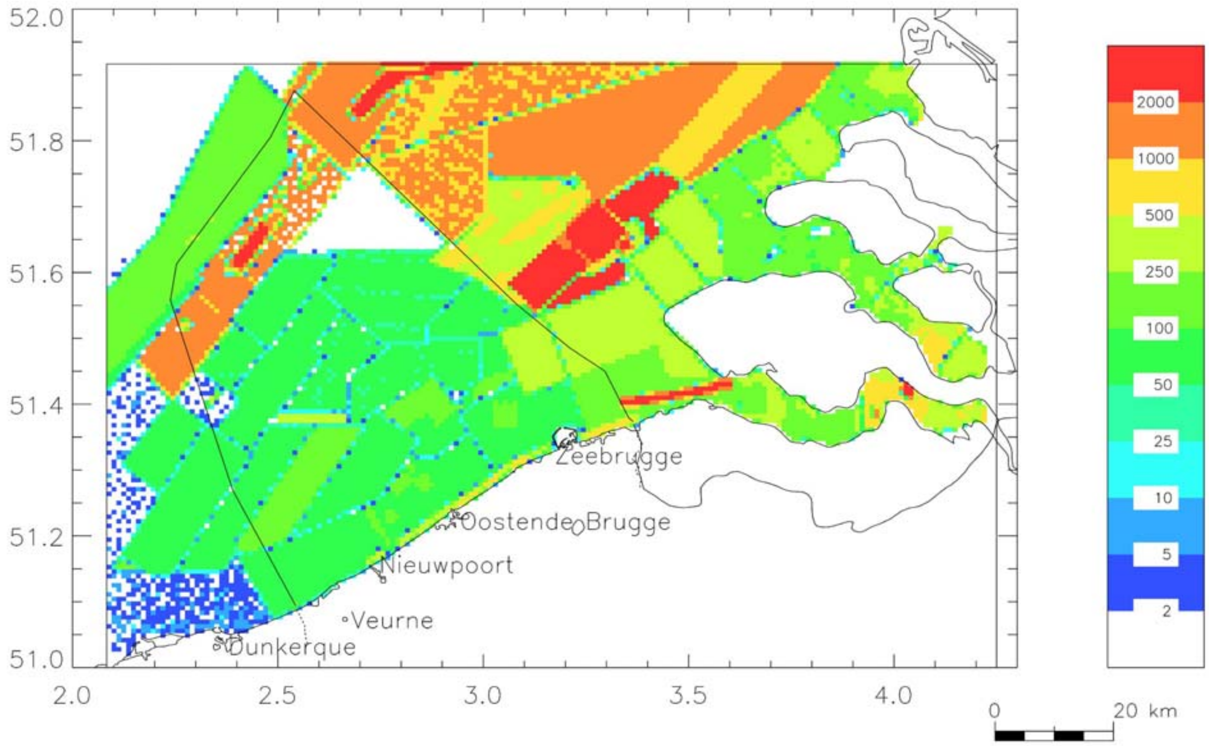
Hydrodynamic results of the BCS model

The hydrodynamics in the considered area are mainly tidally driven. Nevertheless wind and density currents may be important. These forcings are not taken into consideration during the first simulations.

The residual water transport vectors $\vec{U}_{res-trans}$ and the residual current vectors $\vec{U}_{res-cur}$ have been calculated for a period of 6 months without meteorological influences as follows:

$$\vec{U}_{res-trans} = \frac{\sum_{i=1}^{n} h_i \vec{u}_{ci}}{\sum_{i=1}^{n} h_i} \quad ; \quad \vec{U}_{res-cur} = \frac{\sum_{i=1}^{n} \vec{u}_{ci}}{n}$$

with $\vec{u}_{ci}$ the depth averaged current vector on time step *i*, h_i the total water depth on time step *i* and *n* the number of time steps during the period. The results (Figure 5) show clearly that the water transport is high in the coastal zone and directed towards the northeast. The residual current pattern is less uniform and shows clearly the influence of the Flemish Banks and the Wester- and Oosterschelde.



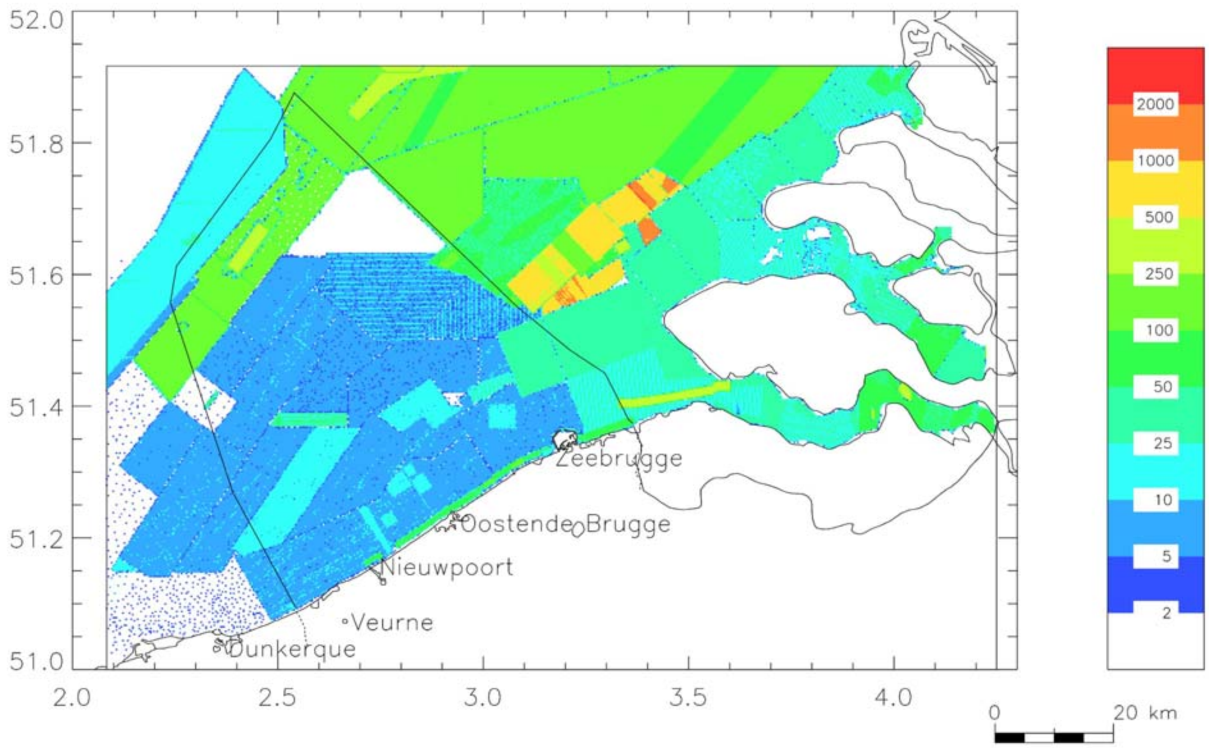


Figure 2. Data density per grid cell of (a) the coarse model (750 m); (b) the fine model (250m).

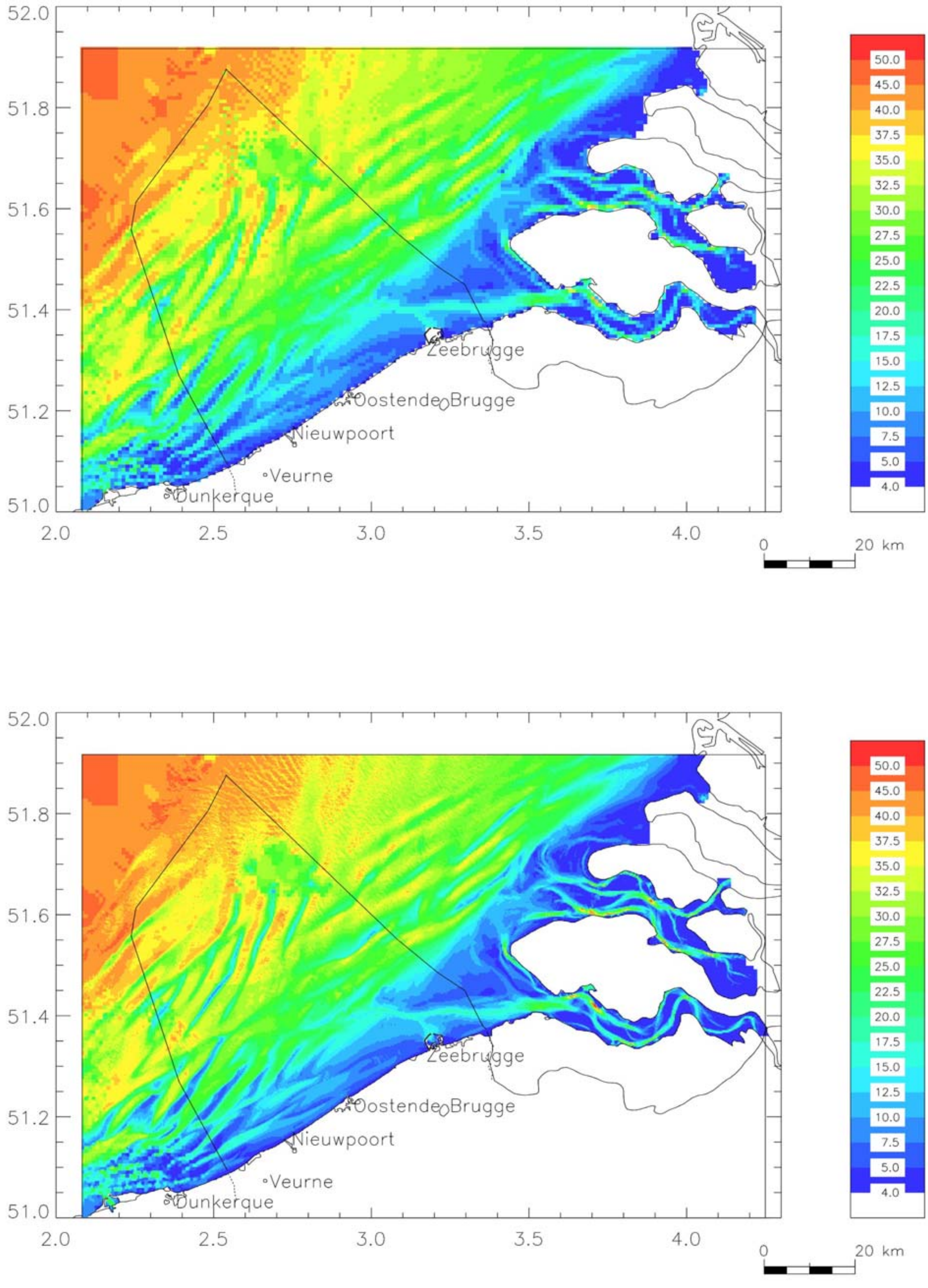


Figure 3. Bathymetry (m MSL) of (a) the coarse model (750 m); (b) the fine model (250 m).

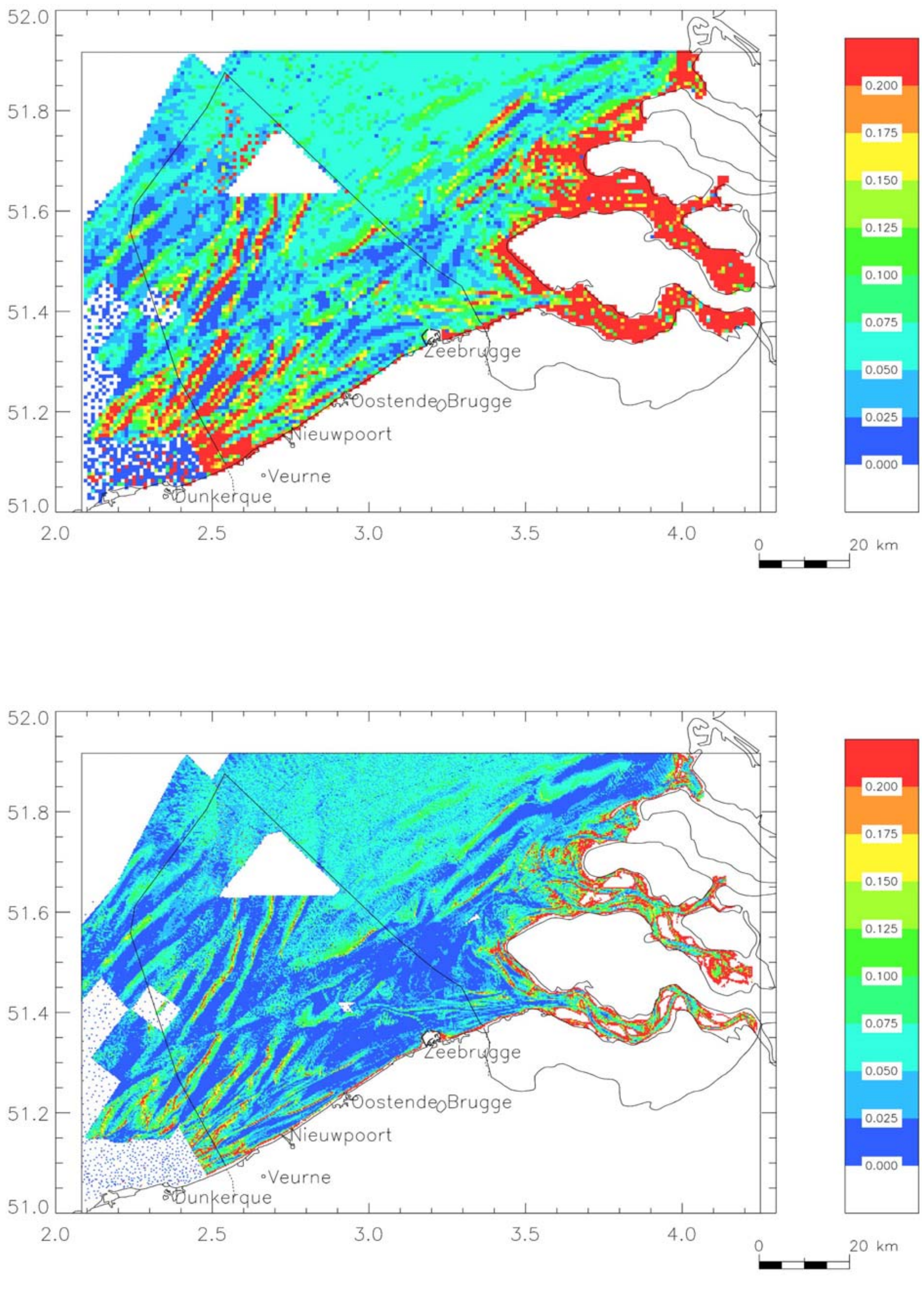


Figure 4. Scatter index of the bathymetry per grid cell for (a) the coarse model (750 m); (b) the fine model (250 m).

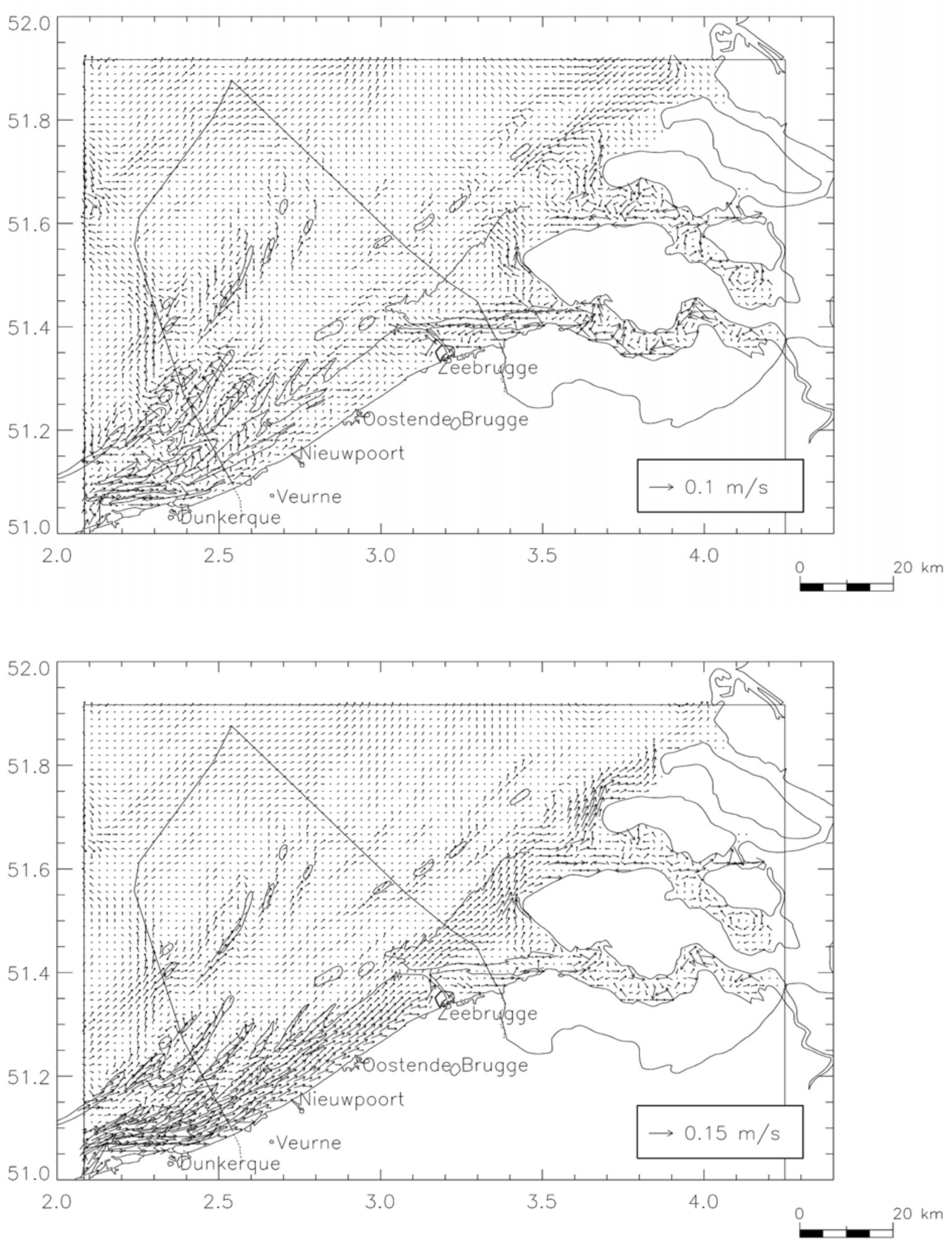


Figure 5. Residual currents (upper) and residual water transport (below) during the first six months of 1999 (no meteo).

2. DEVELOPMENT OF ENVIRONMENTAL ASSESSMENT EVALUATION TOOLS AND STRATEGIES

Introduction

On a regional scale, strategies and evaluation tools are developed for the set-up of optimised *environmental assessments* in view of the sustainable management of the Belgian exclusive economic zone (EEZ) (WP2). To accomplish this aim, fieldwork programmes are designed and sites are selected that are resource, but also issue-driven (Task 2.1.1). On a resource level, it is important to cover the variety of marine sediment types found on the BCS in order to test and tune the best available techniques to the evaluation and prospecting of muddy to gravely sediments. The choice of the sites is biased towards areas that are important within the context of the sustainable exploitation of the EEZ such as areas of interest related to MA extraction, dumping/dredging and to the implantation of windmill farms. The final selection of the sites is done in consult with the advisory committee (see Annex 3). During the first meeting it was decided to start with the sand/mud dominated environments and to centre the measurement boxes around dumping locations (Figure 6). For both the Sierra Ventana as the Oostende region, the old dumping sites had to be abandoned as they reached their maximum capacity. As such, the old areas also become interesting from a MA extraction perspective and in particular S1 might be considered as the site itself is mainly sandy.

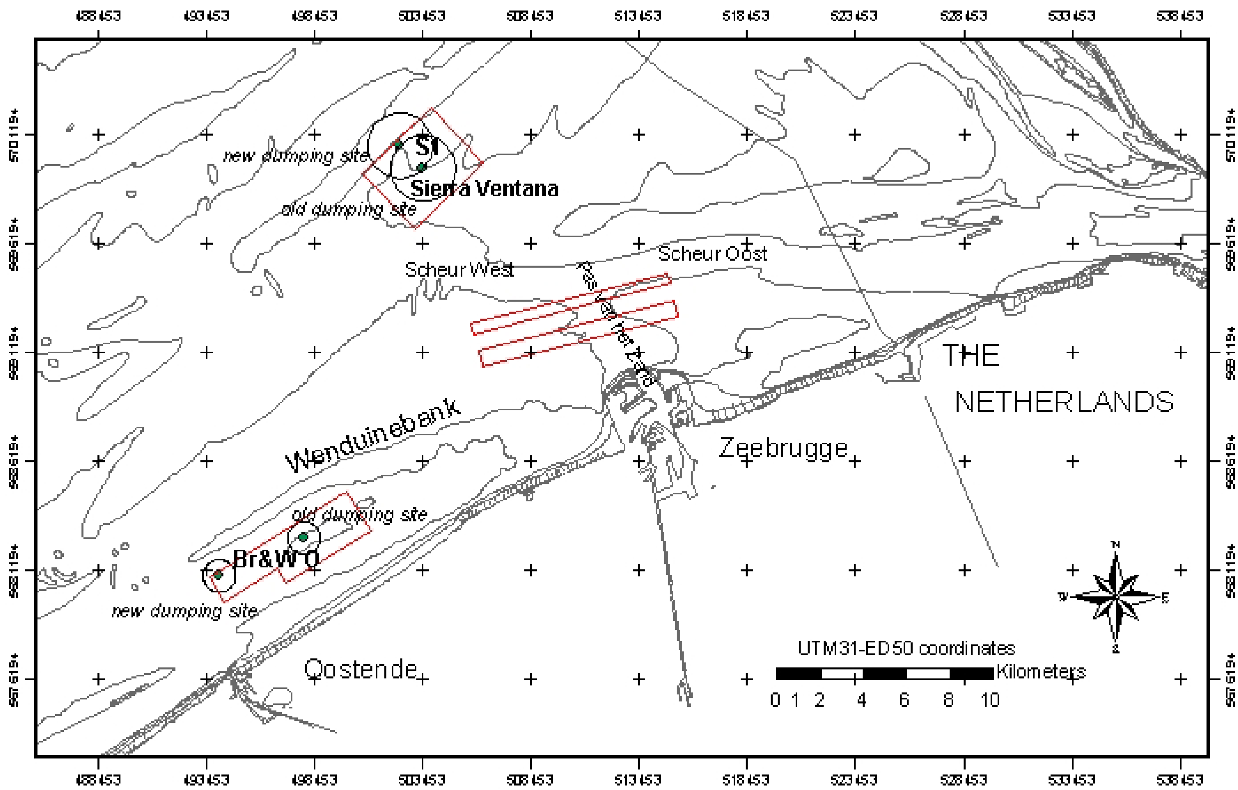


Figure 6. Choice of the sites for the sand/mud dominated environments. They are centred around the old and new dumping site in the Sierra Ventana region (S1); around the 'Pas van het Zand' navigation channel, north of Zeebrugge and around the old and new dumping site near Oostende (Br&W O). The boxes show the present extent of the measurements.

2.1. Field experiments

Table 9 and Figure 7 give a more detailed overview of the field data obtained in the measuring boxes.

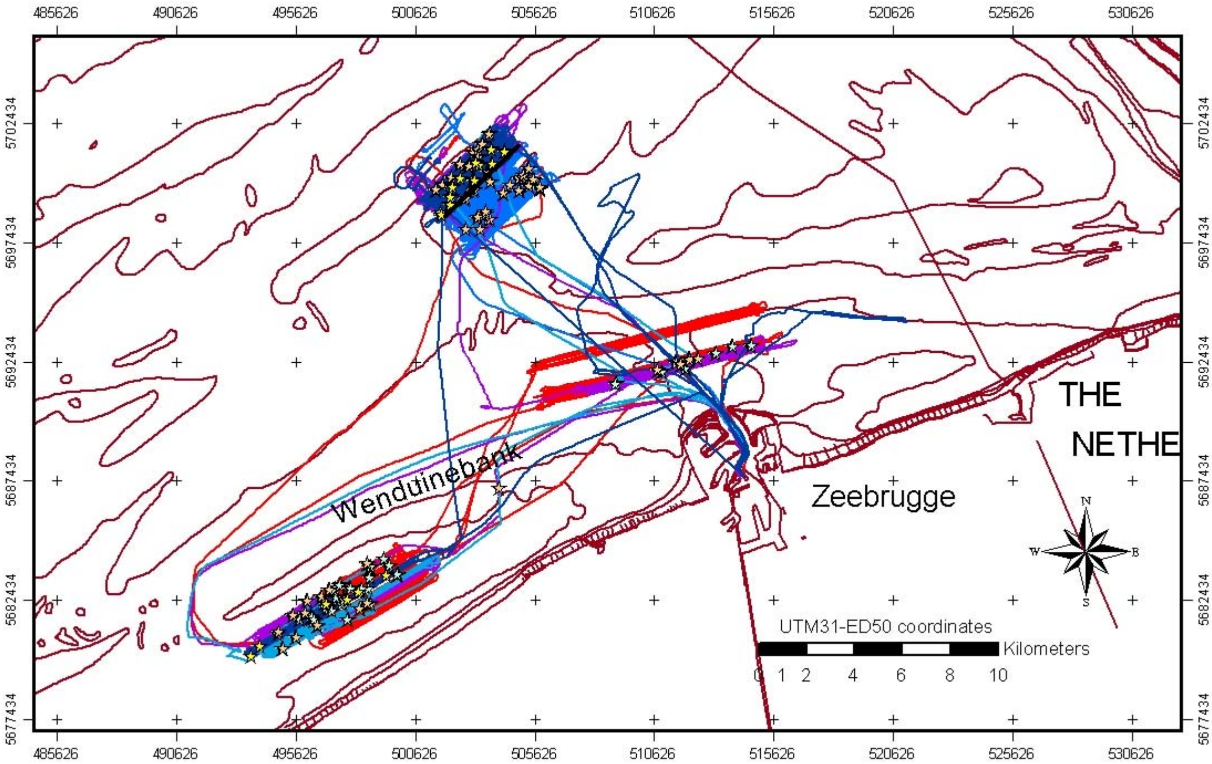


Figure 7. Overview of the data acquired during the Belgica campaigns ST0227 (red polylines; cyan sampling stars), ST0303/04 (light blue and purple polylines; light orange sampling stars) and ST0309 (dark blue polylines; yellow sampling stars).

2.1.1. Geo-acoustical surveying

The areas of interest are firstly surveyed using a variety of instruments of which the acquisition is favourably done simultaneously. This approach enables a more precise intercomparison of the methodologies and the derivatives that can be produced. Moreover, full-coverage surveys are carried out as to obtain a high spatial resolution of the areas of interest. On the basis of these results, a first acoustical seafloor characterisation is done onboard into classes of homogeneous nature. Subsequently, random sampling locations are chosen per homogeneous zone *('Stratified random sampling approach')* (Task 2.1.3). The Belgian oceanographic vessel RV/Belgica is the preferred platform for the field campaigns since it is equipped with state-of-the-art instrumentation.

Generally, data from the following equipment is acquired *simultaneously:*

- Kongsberg-Simrad EM1002S multibeam system for detailed depth and backscatter registrations. The frequencies used are 98 and 93 kHz for the outer beams.
- Single-beam Atlas Deso 20 coupled to the RoxAnn bottom discriminator. Within the project, the use of RoxAnn has been optimised through verification and recalibration of the signal. The frequencies used are 33 and 210 kHz. Presently, only the 210 kHz is recalibrated.
- Very-high resolution digital side-scan sonar registrations (Geoacoustics model 159D; dual frequency). Available frequencies are 100 and 410 kHz; of which the 410 kHz is used during the acquisition.

Table 9. Overview of the data acquired in the sand/mud dominated environments (amount of km is approximate) ; () limited data is available.

Type of measurement	Zeebrugge area			Oostende area			Sierra Ventana		
	ST0227	**ST0303/04**	**ST0309**	**ST0227**	**ST0303/04**	**ST0309**	**ST0227**	**ST0303/04**	**ST0309**
Geo-acoustical									
Multibeam	176 km	50 km		220 km	183 km	54 km		380 km	96 km
Side-scan sonar	63 km			8 km		54 km		*not valid*	96 km
RoxAnn	(176 km)	50 km		(220 km)	183 km	54 km		380 km	96 km
Other									
Medusa		50 km			102 km			40 km	
Ground-truthing									
Van Veen	8	4		29	13	6		30	11
Boxcoring	5	4		14	12			30	11
Reineck	3			11					
Hydrodynamic / sediment transport									
Name of location of 13hrs cycle	TT17	TT18		TT16	TT19				
Bottom-mounted ADCP	13hrs			13hrs	13hrs				
Hull-mounted ADCP	13hrs	13hrs		(13hrs)	(13hrs)				
LISST 100c	13hrs	((13hrs))		13hrs	13hrs				
CTD	13hrs	13hrs		13hrs	13hrs				
OBS	13hrs	13hrs		13hrs	13hrs				
SPM measurements	13hrs	13hrs		13hrs	13hrs				

Additional measurements can be done depending on the available instrumentation and/or opportunities. As such, a feasibility study was carried out using the towed seabed detector (Medusa system) of the company MEDUSA Explorations BV. This instrument was used to provide additional information for the characterisation of seabed sediments and to compare the results with seafloor characterisation from RoxAnn, multibeam and side-scan sonar data. Simultaneously with multibeam registrations, the seabed detector (Medusa) was towed over the seabed (Detector type: Medusa SSU472) measuring the natural radioactivity of the sediments (^{40}K, ^{232}Th and ^{238}U). Moreover, this instrument measures the sound from the shear of the detector with the seabed. The data that has been measured is outlined in de Meijer & Koomans (2003). After calibration of the measurements with in-situ samples of which the radioactive finger printing and the grain-size is determined, the ^{40}K activity concentrations are being translated into grain-sizes (D_{50}) and the ^{232}Th and ^{238}U into % mud fraction. The sound measurements give an indication of the roughness of the sediments (Koomans & de Meijer 2003).

Figure 8 gives an overview of the seabed characterisation and sampling tools. Figure 9 give an example of the results of the Medusa measurements translated into maps related to depth, roughness and the mud fraction. Both Figure 8 and 9 relate to the area north of Zeebrugge.

2.1.2. Ground-truthing

Experience has shown that not all seabed facies detected on the geo-acoustic recordings can be explained by taking surficial Van Veen samples as in many cases they do not give a representative image of the seafloor and therefore a good ground-truthing remains of paramount importance.

Boxcores are now taken to validate the relation of the measurements with the true sediment nature of the seafloor and to get acquainted with the factors controlling the definition of the acoustically derived seabed classes. This technique allows sampling the first 20-50 cm of the subsurface. The boxcore content is firstly described and photographed after which 2 subcores are taken. These are analysed for grain-size and vertical layering. Moreover X-ray analyses and Gamma-densitometry is done (see Annex 2). The treatment of the boxcore samples is clarified in Annex 2.

Preferentially simultaneously with the boxcoring, a Van Veen grab sample is taken for biological purposes. These samples are necessary to further evaluate to what extent acoustic techniques can be used as an indicator of the ecological value of the seafloor. The Van Veen grab (sampling surface 0.12 m^2) was preferred as this tool has been used for many years for biological sampling and as such the samples complement a longer time-series of which the methodology has been standardised (see Annex 2).

If necessary, and if shiptime allows it, additional Van Veen samples are taken to enable the set-up of a sedimentological map per zone of interest. Moreover, this information helps in refining the surficial sediment distribution map on a BCS level (Task 4.1.2).

Although not yet tested but foreseen for the June campaign, different configurations with a video camera (mounted on a corer, sampler, ROV,..) will be tested, specifically as an instrument to understand the small-scale variability and more generally as a tool for environmental assessments. Moreover, the obtained images will be of great help in the development of the reference manual of the acoustic facies (Task 2.3.1.).

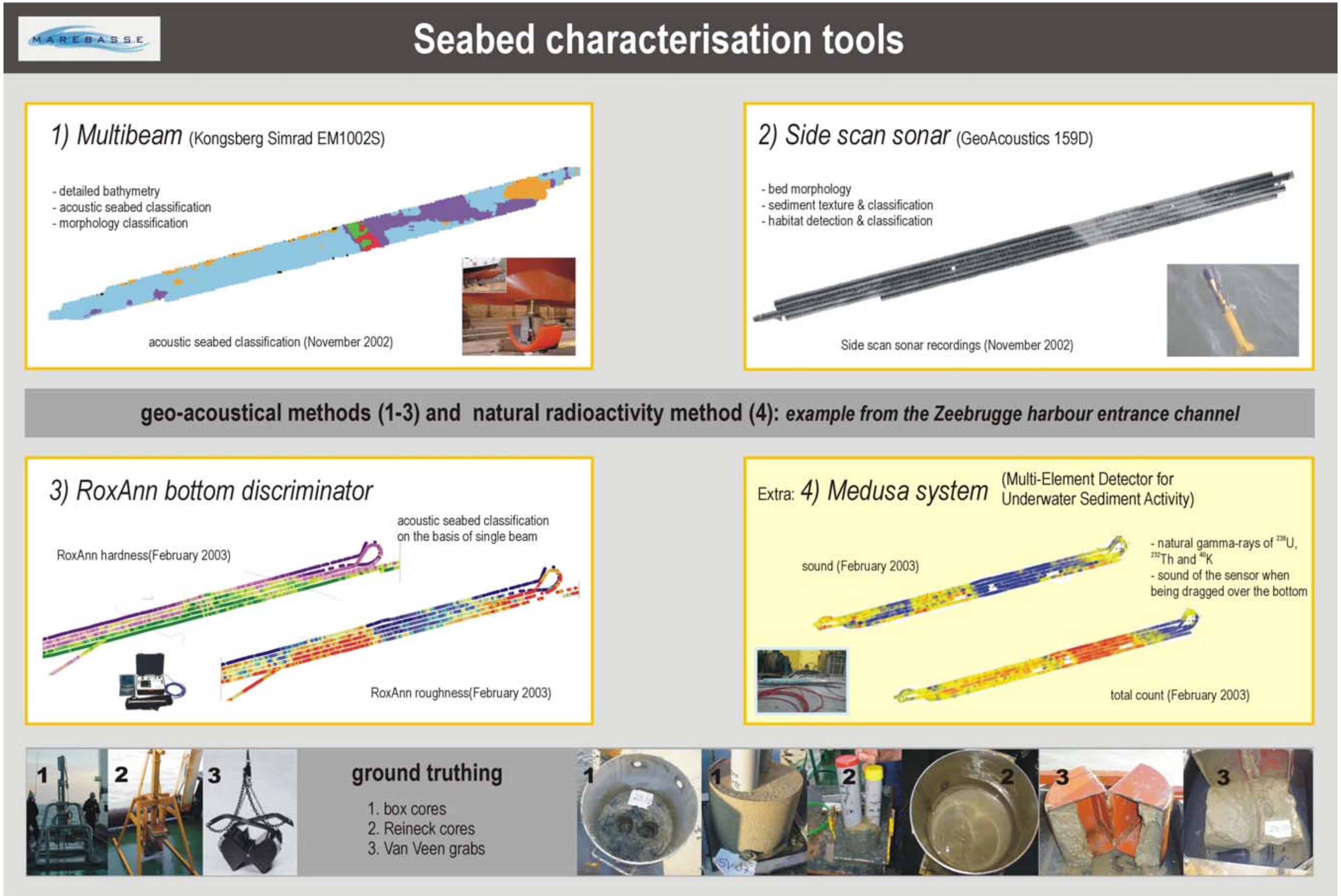


Figure 8. Overview of seabed characterisation tools used in Marebasse.

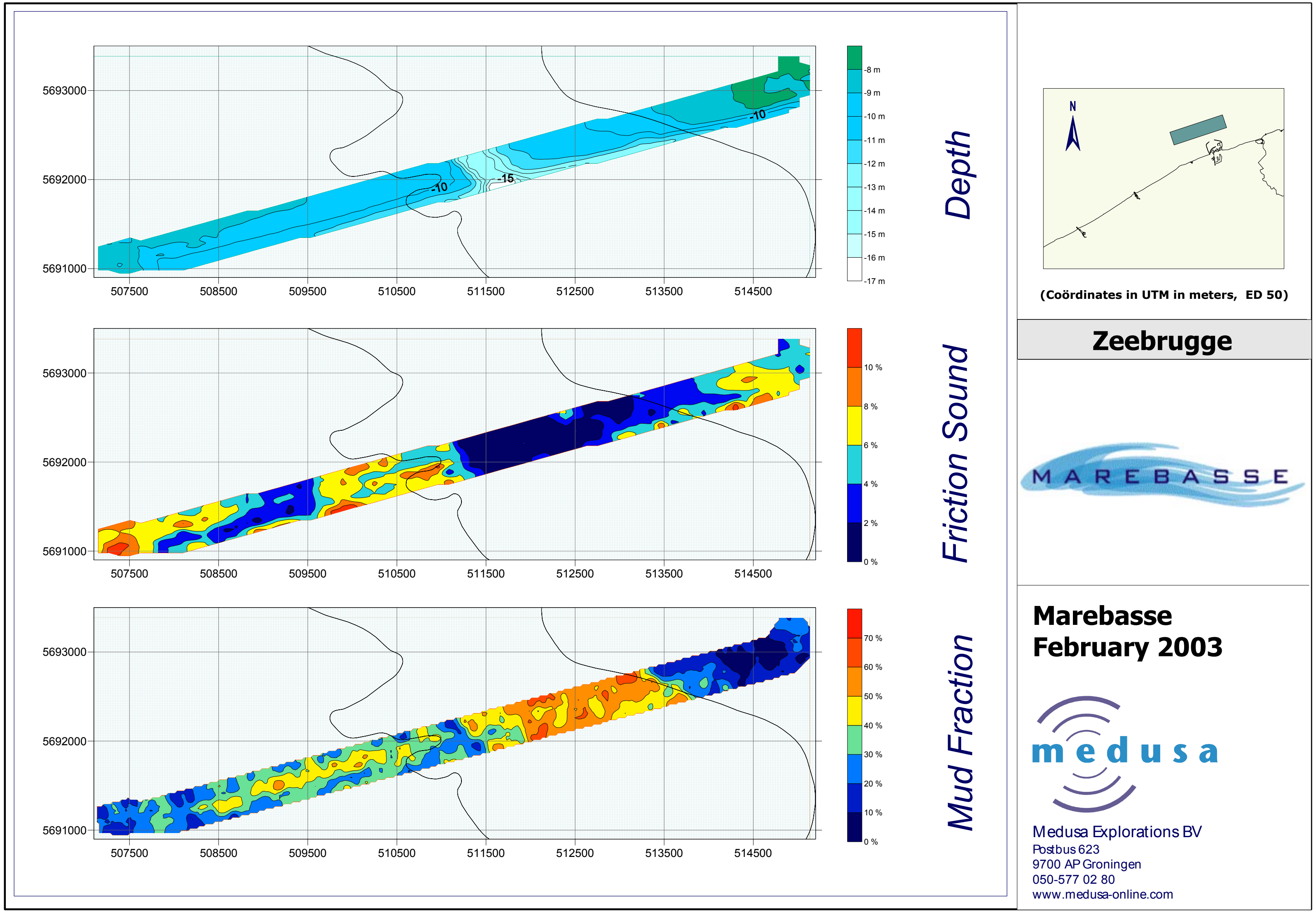


Figure 9. Example of the results of the Medusa measurements. 'Depth' (m) is derived from a pressure meter; 'Friction sound' or roughness (%) represents the sound that the detector makes with the seabed; 'Mud Fraction' (%) based on the amount of the radionuclides ^{238}U, but especially ^{232}Th.

2.1.3. Hydrodynamic and sediment transport measurements

Hydrodynamic and sediment transport measurements are performed using hull- and bottom-mounted acoustic doppler current profilers (AD(C)P), CTD and OBS instrumentation. ADP's are used to determine the vertical current distribution; CTD is a conductivity-temperature-depth meter and optical backscattering sensors (OBS) are used as a measure for suspended sediment concentrations. In-situ suspended particulate matter (SPM) is sampled using Niskin bottles. Through tide measurements (13-hrs cycle) are carried out to characterise the hydrodynamics and sediment transport capacity of the areas under investigation. The hull-mounted (300 kHz, RDI) and bottom-mounted (1200 kHz, RDI) ADCP are normally used. Every 20' a water sample with a 10l Niskin bottle is taken using the Seabird STD/Carousel system (STCD-SBE09, OBS). Every hour, the carousel is hauled on deck and the Niskin bottles are emptied. Additionally, the Seabird SeaCAT system is used in profiling mode (SCTD-SBE19, OBS) to measure the vertical distribution. The water samples are filtered on board for suspended particulate matter and Chl-a. At every station a Reineck and/or Van Veen sample is preferentially taken. Additionally, a laser in-situ scattering and transmissometry (LISST100C) is used (from the *Flanders Marine Institute*). The LISST-100 instrument allows gaining insight into the size-dependent sediment transport processes, the relation between the current stress and the mean sediment size and the settling velocity of the flocculated matter. The instrument is installed as close as possible to the bottom. Every hour a vertical profile is preferentially taken.

2.2. Individual assessment analysis

Throughout the project, an *environmental assessment* (EA) (Task 2.2.3) will be accomplished for 3 sites that are well enough differentiated, encompassing primarily the characterisation of the physical (Task 2.2.1), geomorphological and sedimentological environment and secondary the biological environment (Task 2.2.2). The physical assessment will use the results of the hydrodynamic and sediment transport models and measurements. A geo-environmental assessment will already integrate the geomorphology, sedimentology and biological characteristics; the latter in terms of the species type, abundance and depth occurrence and in view of the ecological evaluation of the acoustic means. Very-high resolution, multi-parameter, three dimensional digital terrain models will be produced providing information on the intrinsic nature of the seafloor (i.e. in terms of sediment type, density, roughness and microrelief) in relation to the deposit morphology.

In consent with the project team, the Oostende area is selected as a case study for a first environmental assessment. This area was chosen, as it is the most constraint area in terms of the position of the dumpsite in relation to the surrounding swale morphology.

2.3. Set-up of environmental assessment tools and strategies

The set-up of environmental assessment tools and strategies (Task 2.3) will be based on all of the data and information gathered throughout the project or related projects. On an acoustical level, three types of tools are aimed at (Task 2.3.1):

2.3.1. Set-up of acoustical seabed classes for the range of sediment types found on the BCS

Quantified acoustical seabed classes are being defined on the basis of the multibeam backscatter data using the software module Triton (Simrad Kongsberg 2001) of which the use is granted through the Federal Public Service Economy, SMEs, Self-employed and Energy (Marine Sand Fund). The programme executes an extraction of 5 statistical features on the backscatter data variation and allows, after training, an automated classification of the seafloor. The advantage is that after correction the backscatter data is regarded standardised and expressed in general applicable decibel values (Simrad Kongsberg 2001). As such, it offers more quantitative results.

As mentioned earlier, a first seabed classification is done onboard to select sampling locations. After processing (mainly clean-up and tide-correction) of the data, the classes are validated and refined taking into account the ground-truth information and the results of the other methodologies used. Presently, experience is being built-up in understanding the true meaning of the acoustic classes. The purpose is to define classes that are applicable for a larger area and ultimately for the whole Belgian shelf. As such, unambiguous seabed classes can only be set-up after revisiting several datasets. This process will be done in consent with the Marine Sand Fund.

2.3.2. Set-up of a reference manual of the acoustic facies on a BCS level

Qualitatively, the acoustic facies itself is characterised from the side-scan sonar imagery of which the resolution is superior to the multibeam imagery derived from the multibeam system EM1002 presently worked with. It is envisaged to also perform backscatter mosaicing from the multibeam data using the software module Poseidon (Simrad Kongsberg 2001; Marine Sand Fund). The main differences in acoustic facies will be well documented and finally presented in a reference manual.

2.3.3. Set-up of an eco-morphological sonar interpretation

Research is also focussed on deriving diverse habitat characteristics of the geo-acoustical data. Within the OSTC/WWK Habitat projects (Degraer *et al.* 2002; Degraer *et al.* 2003), it has been shown that very-high resolution side-scan sonar imagery can be used to study and predict the occurrence of macrobenthic communities (Van Lancker *et al.* 2003a; Van Lancker *et al.* in prep.) and a classification table has been proposed for a standardised interpretation of side-scan sonar data. The set-up scheme of the table is presented in Figure 10.

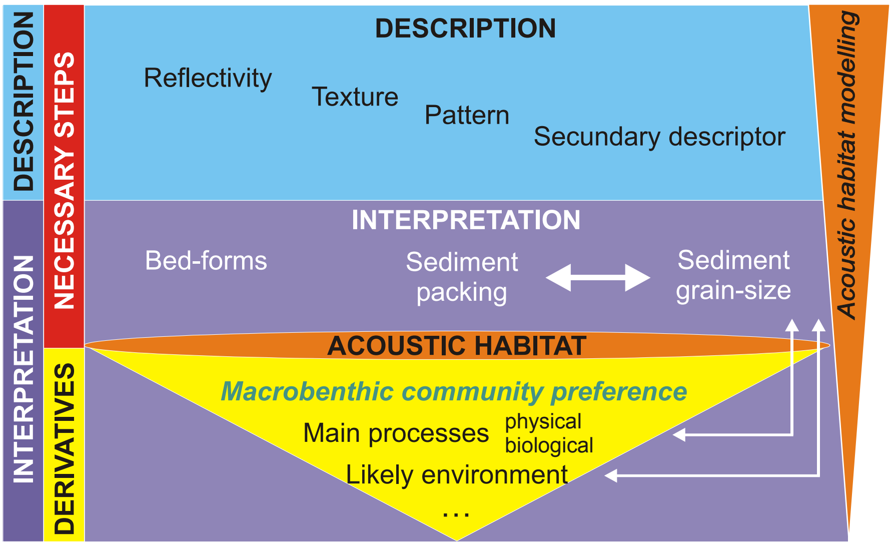


Figure 10. Acoustic habitat modelling scheme (Van Lancker *et al.* 2003a)

Throughout the Marebasse multidisciplinary measurement campaigns, remote sensing techniques in general will be further validated for their ability to detect macrobenthic communities aided by visual ground-truthing (video) and quantitative sampling (i.e. Hamon grab that merely scoops the seabed). This comprises the testing of automated classification systems (a.o. multibeam) for the detection of benthic diversity and community localisation. The datasets will enable to further set-up and validate quantitative relationships between the physical aspects and the occurrence of macrobenthic communities and as such the macrobenthic side-scan sonar interpretation will be validated and fine-tuned at key locations. This is of high importance for the prediction of the ecological value of the seafloor at a larger scale. The Marebasse dataset will anyhow provide more data towards the estuary/dumping site related macrobenthos and gravel bed macrobenthos and hence other acoustic facies/classes and also benthic communities can be detected and described. It is also the purpose to extend the interpretation of at least the side-scan sonar data in terms of other variables such as related to the hydrodynamic regime and sediment transport.

The applicability of the present classification table has been outlined in Van Lancker *et al.* 2003a,b.

3. ASSESSMENT OF AN ENVIRONMENTAL IMPACT (EIA)

An intensive integrated site surveying (WP3) will be focused on the Kwinte Bank, of which the central part was heavily exploited for marine aggregates. The exploitation led to an elongated depression that is presently 5 m below the reference level. As such, aggregate extraction has been stopped since February 15 2003, and the site is closed down for 3 years. Cause and effect research will be carried out to evaluate the true impact of this high level of exploitation and to study regeneration processes.

Detailed integrated fieldwork is foreseen (Task 3.1.1) into which the Federal Public Service Economy, SMEs, Self-employed and Energy, responsible for the follow-up of this area (Marine Sand Fund) plays a crucial role. Moreover, the fieldwork will be complemented with experience and instrumentation related to the Fifth Framework Research Training Network EUMARSAND (European Marine Sand and Gravel Resources).

Basically, the environmental characteristics of the area of impact will be studied using the above mentioned state-of-the-art approach (Task 3.1.2). A very-high resolution seismic investigation is supplementary foreseen to study to what level the exploitation has taken place and to evaluate the resource availability in general. Ground-truthing (Task 3.1.3) will also include video imaging to optimally characterise the area of impact. Hydrodynamic and sediment transport measurements (Task 3.1.4) will will also be derived from an instrumented tripod that can include CTD, OBS, bottom-mounted ADP and a LISST-100 laser diffraction instrument. The tripod is suited to measure intensively the processes on a specific site and is thus complementary to the sediment transport measurements at a larger scale. Given, the importance of the environmental impact study, it will be envisaged whether additional instrumentation will be incorporated into the fieldwork programme. Presently, the planning of the June 2003 campaign is being discussed and optimised.

4. RESEARCH INTEGRATION AND VALORISATION/EXPLOITATION OF RESULTS

Throughout the project, existing and newly acquired data is upgraded through its integration into a *Geographical Information System* (Task 4.1.1). As a start, data from the OSTC project BUDGET (Lanckneus *et al.* 2001) has been translated into GIS. This data is being updated and supplemented with the newly acquired data. The preferred software is AcadMap2000 in combination with ArcGIS(8.3). Spatial analyst tools will later help in unravelling the interrelationships between the diverse datasets.

Towards a sustainable management of the EEZ, an increase in knowledge on the distribution of the surficial sediments is regarded essential. Within Marebasse, existing sedimentological databases will be added with the newly acquired data to be able to map the distribution of the surficial sediments (Task 4.1.2). This process will be refined according to the results of the acoustical seabed characterisation. The set-up of the sedimentological map will largely benefit from the research efforts within the OSTC project GAUFRE (*Towards a spatial structure plan for the sustainable management of the sea,* Maes *et al.* 2003). In this project a zonation into ‘offshore cells’ is foreseen based on zonation maps of the bathymetry/morphology, sedimentology and hydrodynamics. This pleads for a detailed approach into which sediment distribution mapping is crucial as this is the link towards the prediction of macrobenthic communities. This leads to the ultimate goal of setting-up a ‘Habitat structure map with macrobenthic potentials' at the scale of the BCS. This map will then be used as a basis for the evaluation of the impact of the different use-functions on the seafloor environment.

The set-up of an integrated assessment framework (Task 4.1.3) is aimed at and includes a compilation of the knowledge of the different types of sedimentary systems. A cartographic synthesis will be produced; this will build upon the sediment dynamical synthesis map that was produced within the OSTC project BUDGET.

For the valorisation and exploitation of the results, the Marebasse website (Task 4.2.1) serves as the nodal point of information (Figure 11).

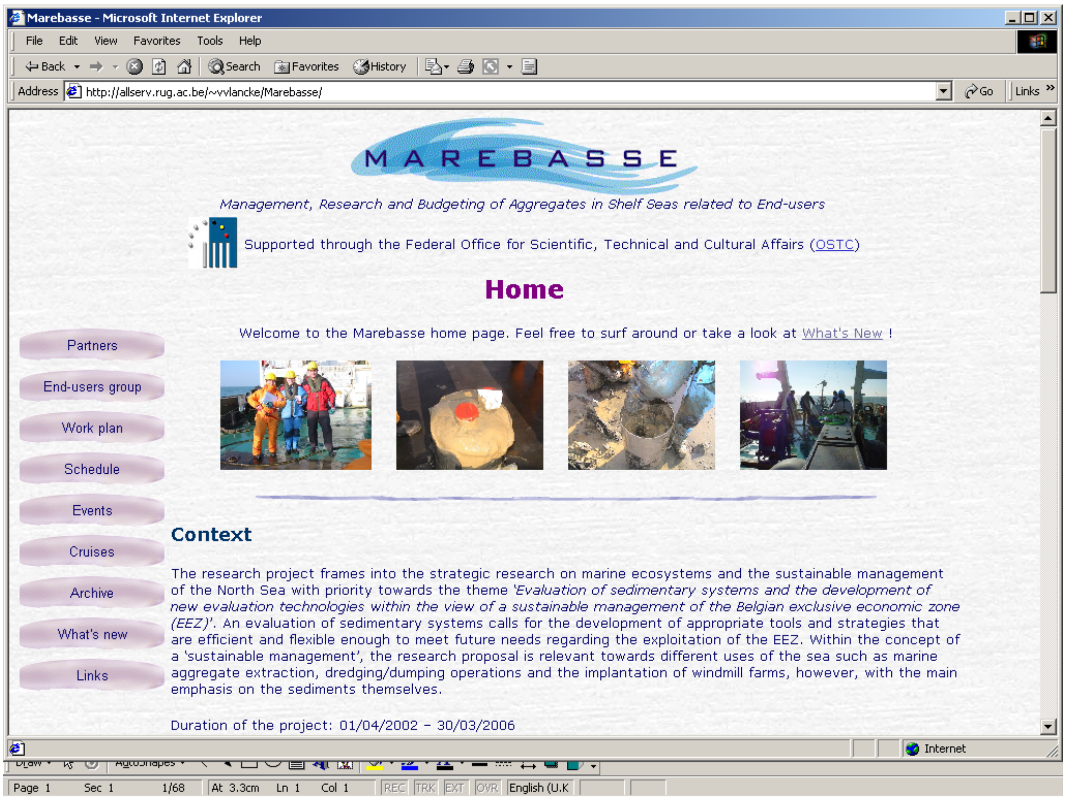


Figure 11. The Marebasse website http://allserv.rug.ac.be/~vvlancke/Marebasse

Within the regulations of the OSTC, an advisory committee has been set up with a meeting schedule of at least 2 times a year (Task 4.2.2). These meetings are also meant to get acquainted with the end-users' needs and as such the Marebasse group will have the opportunity to translate and fine-tune the scientific results towards management or end-users in general. These meetings are important to help in bridging the gap between management and industry end-users. A first discussion meeting took place in October 2002, of which the report can be found in Annex 3.

ANNEX 1. DREDGING LOCATION AND DUMPING SITES IN RELATION TO BOTTOM SEDIMENTS, HYDRODYNAMIC CONDITIONS AND SEDIMENTATION RATES (Fettweis, M., Francken, F., Pison, V. & Van den Eynde, D.)

1. Legal framework of dredging/dumping activities

Dredging has to be carried out to maintain the maritime access routes to the Belgian coastal ports and the depth of the coastal ports and is the responsibility of the Flemish Region. The large quantities of dredged material resulting from these activities are dumped back in the sea. This procedure is the responsibility of the Federal Environment Department. Consequently, managing dredged material is a shared responsibility. In accordance with the law of January 20, 1999, authorisation is required to dump dredging material at sea. The procedure to obtain authorisation for dumping dredged material from activities undertaken by the Flemish Region at sea is laid down in the Royal Decree of March 12, 2000 defining the procedure for authorising the dumping of certain substances and materials in the North Sea. At the moment there are 6 authorisations for dumping dredged material at sea in force. The maximum authorised quantity per year and per dredging area is given in Table A1.1. Maintenance dredging work is understood to mean 'maintaining at the required level' and deepening dredging work is understood to mean 'deepening or broadening ports and channels'.

Table A1.1. Maximum authorised quantities (in 10^6 tonnes of dry matter) per dredging zone per year (validity 01/04/2002-31/03/2004), to be dumped at the dumping sites. (CDNB=Centraal Deel Nieuwe Buitenhaven Zeebrugge, ZBO=Zeebrugge Oost, OE=Oostende, NP= Nieuwpoort), see Figure 1 for the location of the dumping places. $^{(1)}$ In case of necessity maximum 0.5×10^6 TDM of each of the authorised quantities for S1 and S2 may be dumped on S3 and R4.

Dredging areas	Type	S1	S2	S3$^{(1)}$	R4$^{(1)}$	B&W ZBO	B&W OE	B&W NP	TOTAL
Port of Zeebrugge	Maint.					3.00			
	Deep.					1.00			
Pas van het Zand & CDNB	Maint.	5.00	1.70			5.50			
	Deep.	5.00	2.00			0.75			
Scheur Oost	Maint.	2.20	0.40						
	Deep.								
Scheur West	Maint.	2.20	0.40						
	Deep.								
Port of Oostende	Maint.						0.70		
	Deep.								
Access channel Oostende	Maint.						0.90		
	Deep.						1.50		
Access channel and spuikom Blankenberge	Maint.					0.60			
	Deep.								
Access channel & port of Nieuwpoort	Maint.							1.20	
	Deep.								
TOTAL	**Maint.**	**9.40**	**2.50**	**1.00**	**1.00**	**9.10**	**1.60**	**1.20**	**23.80**
	Deep.	**5.00**	**2.00**			**1.75**	**1.50**		**10.25**
GENERAL TOTAL		**14.40**	**4.50**	**1.00**	**1.00**	**10.85**	**3.10**	**1.20**	**34.05**

2. Sediment composition of the dredged matter on the bottom and in the well of the dredger

An overview of the sediment composition (sand/mud) on the bottom in the coastal zone can be found in Van Lancker *et al.* (2001). The dredging areas are situated in a high turbidity zone; this explains the very high quantities of fine sediments that are deposited. The mean sand fraction of the samples (bottom and in the well) from the harbours and the navigation channels are given in Table A1.2 (BMM & AWZ, 1993). Currently the amount of sand in the well is determined using a so-called Hopper Well Densimeter (TVNK, 1998a).

From previously known sediment mixtures, the dredged quantity of sand is estimated using a density of 1.7 t/m^3 in the well; in situ 2.0 t/m^3 is used. The sand fraction in the well is presented that was measured during the period 21/06/1991-25/06/1997. No data exists for the ports of Oostende and Zeebrugge.

The dredged matter from the navigation channels 'Scheur Oost', 'Scheur West' and 'Pas van het Zand' consists of 17-28% sand with a D_{50} of 180-200 μm (Malherbe, 1991). The sand fraction is higher in the 'in situ' samples and situated between 34-82%; see Table A1.2. The difference between in situ and dredged sediments shows that the dredged matter of maintenance dredging works consists of fine sediments that are deposited from suspension. During deepening works 'in situ' sediment is dredged with a higher sand fraction. The high mud content in the navigation channels 'in well' is confirmed by bottom samples in these zones (Fettweis *et al.*, 2003)

The sediment on the dumping site S1 has a D_{50} of 230 μm (TVNK, 1998b), on S2 the D_{50} is situated between 125-250 μm, whereas the sediments on Br&W Zeebrugge Oost mainly consist of fine sand and muddy sand and on Br&W Oostende of fine sand and mud (BMM & AWZ, 1993). The sediment on S1 and S2 consist mainly of sand; the mud is thus suspended by the currents and is transported away.

Table A1.2. Sand fraction (%) in the bottom samples at the dredging and dumping locations (BMM & AWZ, 1993; TVNK, 1998b) and in the well (TVNK, 1998a). (CDNB=Centraal Deel Nieuwe Buitenhaven Zeebrugge, PvhZ=Pas van het Zand, Zeeb=Zeebrugge, Oost=Oostende, ZeebO=Zeebrugge Oost).

	Dredging locations						Dumping places			
	PvhZ	CDNB	Scheur E	Scheur W	Port Zeeb	Port Oost	S1	S2	Zeeb O	Oost.
In situ	34	34	82	51	40	28	>85	85	-	
In well	17	0.4	24	28	-	-	-	-	-	-

3. Quantities dredged and dumped

The quantities of sediment that are dumped in sea are arranged in Table A1.3 per dumping site and in Tables A1.4 and A1.5 per dredging site (maintenance dredging works). The conversion from tonnes dry matter (TDM) towards TDM of sand/mud was done using the values in Table A1.2. It is reasonable to assume that the amount dredged for maintenance purposes is in equilibrium with the sedimentation in these zones. During the dredging year 1999 the 'Scheur Oost' and 'Scheur West' have been deepened, these amounts are not included in the tables and will not be used to calculate sedimentation rates.

During the dredging years 1997, 1998 and 1999, on average 13.31x10^6 TDM have been dredged for maintenance and deepening purposes. From this amount 7.54x10^6 TDM were dumped on S1, 0.82x10^6 TDM on S2, 4.35x10^6 TDM on Br&W Zeebrugge Oost and 0.60x10^6 TDM on Br&W Oostende. The dumped material consisted of 11% sand and 89% mud; 92% of the sand was dumped on S1. The mud was mainly dumped on S1 (49%) and Br&W Zeebrugge Oost (40%). TVNK (1998a) mentions that the growth of S1 is ±0.6x10^6 m^3 of sand that is about 40% of the yearly amount, dumped during the period 1997-1999 (2.28x10^6 TDM or 1.44x10^6 m^3). This could lead to the conclusion that part of the dumped sand has been transported elsewhere.

Table A1.3. Quantity of dumped matter from maintenance and deepening dredging works (10^3 TDM). Avg=average quantity over 3 year. Deepening works were only carried out during 1999 and the matter was only dumped on S1.

	S1			S2			B&W ZeebO			B&W Oostende		
	Tot	Sand	Mud	Tot	Sand	Mud	Tot	Sand	Mud	Tot	Sand	Mud
Dredging year 1997 (April 1997-March 1998)												
Apr	158	3	155	41	1	40	254	2	252	0	0	0
May	293	4	289	65	1	64	1206	12	1194	4	<1	4
Jun	181	2	179	54	1	53	418	4	414	17	<1	17
Jul	194	22	172	110	13	97	227	2	225	18	<1	18
Aug	119	1	118	38	1	37	369	3	366	35	<1	35
Sep	244	30	214	129	16	113	558	6	552	45	<1	45
Oct	535	101	434	154	24	130	233	2	231	28	<1	28
Nov	2159	278	1881	636	68	568	2545	25	2520	235	2	233
Dec	675	83	592	50	4	46	292	3	289	93	1	92
Jan	689	121	568	69	12	57	299	3	296	111	1	110
Feb	661	153	508	208	55	153	263	3	260	121	1	120
Mar	138	12	126	10	<1	10	229	3	226	38	<1	38
Tot	**6046**	**810**	**5236**	**1564**	**196**	**1368**	**6893**	**68**	**6825**	**745**	**5**	**740**
Dredging year 1998 (April 1998-March 1999)												
Apr	89	2	87	22	1	21	210	2	208	43	<1	43
May	110	2	108	21	<1	21	245	3	242	17	<1	17
Jun	145	2	143	27	1	26	374	4	371	47	1	46
Jul	48	1	47	11	<1	11	181	2	179	10	<1	10
Aug	140	7	133	48	6	42	238	3	235	23	<1	23
Sep	182	12	170	50	6	44	337	3	334	29	<1	29
Oct	789	132	657	92	20	72	259	3	256	18	<1	18
Nov	1116	277	839	13	<1	13	263	3	260	42	1	41
Dec	1066	234	832	326	90	236	98	1	97	118	1	117
Jan	1307	210	1097	74	20	54	272	3	269	66	1	65
Feb	813	180	633	24	2	22	221	2	219	18	<1	18
Mar	1651	350	1301	16	1	15	278	3	275	36	<1	36
Tot	**7456**	**1409**	**6047**	**724**	**147**	**577**	**2976**	**32**	**2945**	**467**	**4**	**463**
Dredging year 1999 (April 1999-March 2000)												
Apr	1063	557	506	8	<1	8	295	3	292	31	5	26
May	1254	803	451	3	<1	3	123	1	122	29	5	24
Jun	1328	585	743	0	0	0	369	4	365	110	19	91
Jul	396	198	198	0	0	0	137	1	136	83	14	69
Aug	938	610	328	0	0	0	355	4	351	96	16	80
Sep	1117	584	533	0	0	0	346	4	342	0	0	0
Oct	195	7	188	0	0	0	115	1	114	59	10	49
Nov	141	5	136	0	0	0	187	2	185	29	<1	29
Dec	720	363	357	0	0	0	259	3	256	59	7	52
Jan	147	1	146	34	28	6	265	3	262	25	<1	25
Feb	847	437	410	7	6	1	266	3	263	35	<1	35
Mar	971	460	511	120	35	85	474	5	469	35	<1	35
Tot	**9117**	**4410**	**4507**	**172**	**69**	**103**	**3191**	**34**	**3157**	**591**	**76**	**515**
Average of dredging years 1997-1999												
Avg	**7539**	**2276**	**5263**	**820**	**137**	**683**	**4353**	**45**	**4309**	**600**	**28**	**572**

Table A1.4. Quantity of dumped matter from maintenance dredging works (10^3 TDM) in the navigation channel. Avg=average quantity over 3 year.

	Pas v/h Zand			Scheur Oost			Scheur West			Navig. Oostende		
	Tot	Sand	Mud	Tot	Sand	Mud	Tot	Sand	Mud	Tot	Sand	Mud
Dredging year 1997 (April 1997-March 1998)												
Apr	0	0	0	9	2	7	0	0	0	0	0	0
May	0	0	0	15	4	11	0	0	0	0	0	0
Jun	13	2	11	4	1	3	0	0	0	0	0	0
Jul	205	35	170	2	<1	2	0	0	0	0	0	0
Aug	0	0	0	9	2	7	0	0	0	0	0	0
Sep	207	35	172	5	1	4	31	9	22	0	0	0
Oct	371	63	308	5	1	4	215	60	155	0	0	0
Nov	800	136	664	48	12	36	691	193	497	0	0	0
Dec	473	80	393	22	5	17	0	0	0	0	0	0
Jan	200	34	166	407	98	309	0	0	0	0	0	0
Feb	0	0	0	62	15	47	688	193	495	0	0	0
Mar	0	0	0	46	11	35	0	0	0	0	0	0
Tot	**2269**	**385**	**1884**	**634**	**152**	**482**	**1625**	**455**	**1169**	**0**	**0**	**0**
Dredging year 1998 (April 1998-March 1999)												
Apr	0	0	0	6	1	5	0	0	0	0	0	0
May	0	0	0	7	2	5	0	0	0	0	0	0
Jun	0	0	0	4	1	3	0	0	0	0	0	0
Jul	0	0	0	2	<1	2	0	0	0	0	0	0
Aug	60	10	50	4	1	3	0	0	0	0	0	0
Sep	82	14	68	10	2	8	0	0	0	0	0	0
Oct	566	96	470	24	6	18	175	49	126	0	0	0
Nov	48	8	40	7	1	6	951	266	685	0	0	0
Dec	13	2	11	13	3	10	1132	317	815	0	0	0
Jan	472	80	392	325	78	247	242	68	174	0	0	0
Feb	0	0	0	751	180	571	0	0	0	0	0	0
Mar	0	0	0	1455	349	1106	0	0	0	0	0	0
Tot	**1241**	**210**	**1031**	**2608**	**624**	**1984**	**2500**	**700**	**1800**	**0**	**0**	**0**
Dredging year 1999 (April 1999-March 2000)												
Apr	0	0	0	0	0	0	0	0	0	31	5	26
May	0	0	0	0	0	0	0	0	0	29	5	24
Jun	0	0	0	0	0	0	0	0	0	110	19	92
Jul	0	0	0	0	0	0	0	0	0	83	14	69
Aug	0	0	0	0	0	0	0	0	0	96	16	80
Sep	0	0	0	0	0	0	0	0	0	0	0	0
Oct	0	0	0	0	0	0	0	0	0	59	10	49
Nov	0	0	0	4	1	3	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	41	7	34
Jan	0	0	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0	0	0	0	0
Tot	**0**	**0**	**0**	**4**	**1**	**3**	**0**	**0**	**0**	**449**	**76**	**374**
Average of dredging years 1997-1999												
Avg	**1170**	**198**	**972**	**1082**	**259**	**823**	**1375**	**385**	**990**	**150**	**25**	**125**

Table A1.5. Quantity of dumped matter from maintenance dredging works (10^3 TDM) in harbours. Avg=average quantity over 3 year.

	Pas v/h Zand			Scheur Oost			Scheur West		
	Tot	Sand	Mud	Tot	Sand	Mud	Tot	Sand	Mud
Dredging year 1997 (April 1997-March 1998)									
Apr	211	2	209	232	2	230	0	0	0
May	742	7	735	806	8	798	4	0	4
Jun	469	5	464	168	2	166	17	<1	17
Jul	207	2	205	118	1	116	18	<1	18
Aug	337	3	334	182	2	180	35	<1	35
Sep	358	4	354	329	3	326	45	1	44
Oct	199	2	197	131	1	130	29	<1	28
Nov	2677	27	2650	1125	11	1114	234	2	232
Dec	326	3	323	196	2	194	93	1	92
Jan	327	3	324	123	1	122	111	1	110
Feb	243	2	241	139	1	138	121	1	120
Mar	179	2	177	153	2	151	38	<1	38
Tot	**6275**	**63**	**6212**	**3702**	**37**	**3665**	**745**	**7**	**738**
Dredging year 1998 (April 1998-March 1999)									
Apr	106	1	105	209	2	207	43	<1	43
May	225	2	223	145	1	143	17	<1	17
Jun	342	3	339	200	2	198	47	1	46
Jul	119	1	118	119	1	118	10	<1	10
Aug	247	2	245	109	1	108	23	<1	23
Sep	309	3	306	166	2	164	30	<1	29
Oct	238	2	236	137	1	136	18	<1	18
Nov	259	3	256	128	1	127	42	<1	41
Dec	262	3	259	69	1	68	118	1	117
Jan	474	5	469	140	1	139	66	1	65
Feb	169	2	167	138	1	137	18	<1	18
Mar	348	3	345	142	1	141	36	<1	36
Tot	**3098**	**31**	**3067**	**1702**	**17**	**1685**	**468**	**5**	**463**
Dredging year 1999 (April 1999-March 2000)									
Apr	507	5	502	185	2	183	0	0	0
May	78	1	77	108	1	107	0	0	0
Jun	559	6	553	313	3	310	0	0	0
Jul	219	2	217	59	1	58	0	0	0
Aug	409	4	405	143	1	142	0	0	0
Sep	331	3	328	425	4	421	0	0	0
Oct	238	2	236	66	1	65	0	0	0
Nov	120	1	119	201	2	199	29	<1	29
Dec	392	4	388	144	1	143	18	<1	18
Jan	269	3	266	144	1	143	26	<1	26
Feb	134	1	133	240	2	238	35	<1	35
Mar	548	5	543	376	4	373	35	<1	35
Tot	**3804**	**38**	**3766**	**2404**	**24**	**2380**	**143**	**1**	**142**
Average of dredging years 1997-1999									
Avg	**4392**	**44**	**4348**	**2603**	**26**	**2577**	**452**	**4**	**448**

From Sediment Transport Analysis (STA), HAECON (1994) concluded that the transport direction on S1 is from the northwest towards the southeast, i.e. towards the 'Scheur West' and further towards the 'Pas van het Zand' and 'Scheur Oost'. These STA-results are not confirmed by the sand transport model results in Lanckneus *et al.* (2001) that show a transport direction from W-WSW.

Sedimentation in the navigation channel was over the three years on average (see Table A1.4): 3.78x10^6 TDM, from which 1.17x10^6 TDM in the 'Pas van het Zand', 1.08x10^6 TDM in the 'Scheur Oost', 1.38x10^6 TDM in the 'Scheur West' and 0.15x10^6 TDM in the navigation channel of Oostende. The mud content of the sediments is high, and ranges between 72% (Scheur West) and 83% (Pas van het Zand).

The dredged matter in the harbours consists of almost 100% mud, on average 7.00x10^6 TDM is dredged in the harbour of Zeebrugge (CDNB and port of Zeebrugge) and 0.45x10^6 TDM in the port of Oostende.

4. Beach nourishment

The beach nourishments are mentioned here because they can give an indication of sand erosion along the coastline. Between 1991 and 1999 nourishment works were carried out between Bredene (Hippodroom) and Wenduine (Rotonde), at Blankenberge (Duinse Polders) and at Knokke. The sand was dredged from the Kwinte Bank, the navigation channel of Oostende (Stroombank-West, Poortjes-Oost), the dumping place Br&W Oostende, the navigation channel of Blankenberge and the 'Aanloop A1-A1bis', 'Geul I' and the connection of 'Scheur West – Pas van het Zand'. An overview of the dredged amounts for beach nourishment is given in Table A1.6 (data from AWZ-WWK).

Since the start of the beach nourishments works in February 1991, 10.28x10^6 TDM were dredged (i.e. 1.14x10^6 TDM/yr) (Table A1.6). From this amount 0.12x10^6 TDM originates from a dumping place and 6.76x10^6 TDM from navigation channels.

Table A1.6. Beach nourishment: total dredged amounts of sand in 10^6 TDM per zone (N-Oost=navigation channel Oostende, Br&W O=dumping place Br&W Oostende, N Blank=navigation channel Blankenberge, S-PvhZ=connection Scheur West – Pas v/h Zand, KB= Kwinte Bank).

	Nourishment zone	N-Oost	Br&W O	N Blank	S-PvhZ	KB
Feb 91-May 92	De Haan Centrum	1.13	0	0	1.35	0
Nov 93-Dec 95	De Haan W–Bredene	1.10	0	0	0	0
Nov 94-Nov 95		0	0	0	0.59	0
Feb 98-Aug 99		0.16	0	0	0	1.86
Jan 96 – Feb 98	De Haan E–Wenduine	0.55	0.12	0.13	0	0
Mar 96-Oct 96		0	0	0	0.39	1.31
Oct 98-Apr 99	Blankenberge	0	0	0	0.66	0
Feb 99-May 99	Knokke	0	0	0	0.93	0
Feb91-May99		**2.94**	**0.12**	**0.13**	**3.92**	**3.17**

5. Hydrodynamic conditions on the dredging/dumping sites

A major part of the matter that is dredged and dumped consists of mud; the dredging areas being situated in a turbidity maximum zone. The processes responsible for the high turbidity zone formation are the currents and the import of suspended matter (SPM) through the Strait of Dover/English coast. Mainly because of the decreasing magnitude of residual transport and the shallowness of the area, the SPM is concentrated in the Belgian-Dutch coastal waters and forms a turbidity maximum in front of Zeebrugge. The occurrence of a high turbidity zone can thus best be compared to a kind of congestion in the sediment transport; an open sediment system thus. Mud is continuously deposited and re-suspended. Significant variations occur during tidal cycles and during neap-spring cycles. Also seasons and meteorological conditions have an influence on the mud behaviour. The difference in magnitude between spring and neap tidal currents is partly responsible for the fact that the mud deposits are permanent. During neap tide, the mud has a higher probability to build up a structure, to consolidate and to increase its erosion resistance. More mud is thus found on the bottom and the SPM concentration is relatively low. During spring tide the opposite happens and part of these deposits are again resuspended.

Figure A1.1 shows the tidal current ellipses and the maximum bottom shear stresses during a spring and a neap tide in 1999. The highest maximum bottom shear stresses are situated in the areas with elongated current ellipses: in the western part of the grid and between Zeebrugge and the Westerschelde. In the central part of the grid and along the 'Vlakte van de Raan', the current ellipses are semi-circular and the maximum bottom shear stresses are lower. The Vlakte van de Raan is a shallow area mainly consisting of sand.

6. Synthesis

The transported amount of sediment from human operations (maintenance dredging works) during the dredging years 1997-1999 is summarised in Table A1.7. Comparison between the natural input of suspended sediment and the quantities dredged and dumped at sea shows that an important part of the suspended matter is involved in the dredging/dumping cycle. The deposition of mud in the dredging areas can be seen as a temporary storage of mud. The effect of dredging and dumping on the sediment balance is of minor importance, because dredging and dumping occurs almost continuously and because the major dumping places are situated in the turbidity maximum zone.

Table A1.7. Yearly averaged transported amount of sediment from maintenance dredging works (10^6 TDM/yr) in the dredging areas (1997-1999).

	Total	Sand	Mud
Harbour Zeebrugge	7.00	0.07	6.93
Harbour Oostende	0.45	<0.01	0.45
Pas van het Zand	1.17	0.20	0.97
Scheur Oost	1.08	0.26	0.82
Scheur West	1.38	0.39	0.99
Channel Oostende	0.15	0.02	0.13

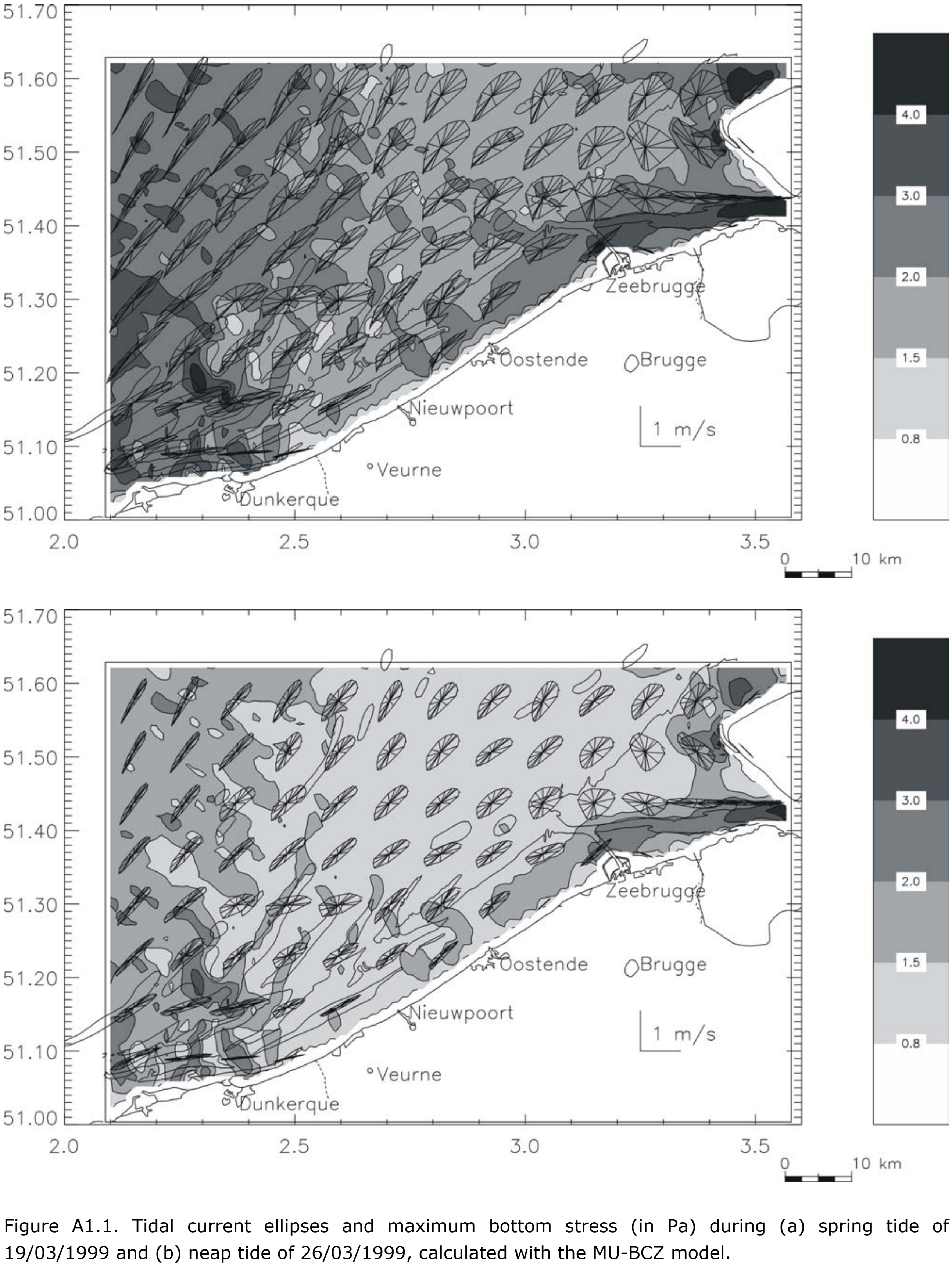


Figure A1.1. Tidal current ellipses and maximum bottom stress (in Pa) during (a) spring tide of 19/03/1999 and (b) neap tide of 26/03/1999, calculated with the MU-BCZ model.

ANNEX 2. SUPPLEMENTARY INFORMATION ON THE ANALYSIS TECHNIQUES

1. Boxcore treatment

Figure A2.1 shows an overview of how the boxcore samples are treated. Supplementary analyses on the subcores that are taken are X-ray radiography and bulk densitometry.

X-ray radiography

X-ray radiography, as used in sedimentology, permits non-destructive analysis of sediment cores. The technique is based on the differential adsorption of X-rays by sediments. Local differences in sediment composition (and thus density) cause differences in X-ray intensity after travelling through the core. The resulting variation in the amount of radiance that reaches the photographic film creates a photographic contrast.

X-rays have a number of interesting properties of which two are of importance to this technique:

1. X-rays can penetrate through every material and are thereby partly absorbed by it. The degree of penetration is a function of the material and the energy of the X-rays.
2. Photographic emulsions are sensitive to X-rays. The degree of blackness is proportional to the amount of X-ray energy of a given wavelength being absorbed by the photographic emulsion. Dark areas represent parts of the sample that are easily penetrable; whereas light areas represent fractions that are more difficult to travel through. This way, a radiograph with light areas will indicate sand (high absorption properties) and dark to black regions will indicate clay (low absorption properties)

The radiographs are typically taken at 100 keV and 120 mA s on 40 cm Agfa Structurix film.

Bulk densitometry

Bulk densitometry can be measured in two ways: by establishing the water content (Bennet & Lambert, 1971) and by gamma densitometry.

1. Analysis of water content
   A sediment sample of 10 to 20 g is taken from the core, weighed and dried for 24 hours at 105 °C. The loss of water is measured by weighing the sample again. The average grain density can be measured by volumetric displacement of distilled water in a calibrated flask (Lambe, 1951) or by taking the density of quartz (ρ = 2650 kg m^{-3})
   The bulk density or unit weight (γ) can be calculated using

   $$\gamma = W_t / ((W_d / D_g) + W_w) = W_t D_g / (W_d + W_w D_g)$$

   Where $W_t = W_w + W_d$; W_w = the weight of the water = approximately the volume of the water; W_d = the weight of the dry matter, salts included; D_g = the average grain density.

2. Gamma densitometry
   The concept is analogous to the X-ray radiography. In this case a source emits gamma rays that travel through the core and are picked up by a receiver. The signal is digitised and logged in a computer. The computer also controls a stepper-motor that shifts the source and receiver with a 1 mm resolution along the core. Regions with high density (sand) attenuate the gamma rays more than low-density areas (mud).

2. Post-treatment of the Van Veen grab samples for macrobenthos

The Van Veen samples are sieved alive using a 1 mm mesh-sized sieve and fixated in an 8% formaldehyde-seawater solution. After staining with Bengal rose, all organisms are sorted out and identified to species level, where possible. Densities are expressed as the number of individuals per square meter (ind./m²). From each Van Veen grab sample, a subsample for grain-size distribution is taken using a plexiglas core (diameter: 3.6 cm). To allow comparison with sediment data available through the MS Access MacroDat database (over 2000 samples), grain-size analysis is performed analogous to the procedure used at the Marine Biology Section (Ugent, Dep. of Biology). After sieving the sediments on a 1 mm mesh-sized sieve, the grain-size distribution of the remaining sediment is analysed by means of a LS Coulter counter with a measuring range from 2 to 850 µm. The sediment fractions of 2-850 µm are expressed as volume percentages, while sediment fractions coarser than 1 mm are expressed as mass percentages. The median grain-size is only calculated on the sediment fraction 2-850 µm.

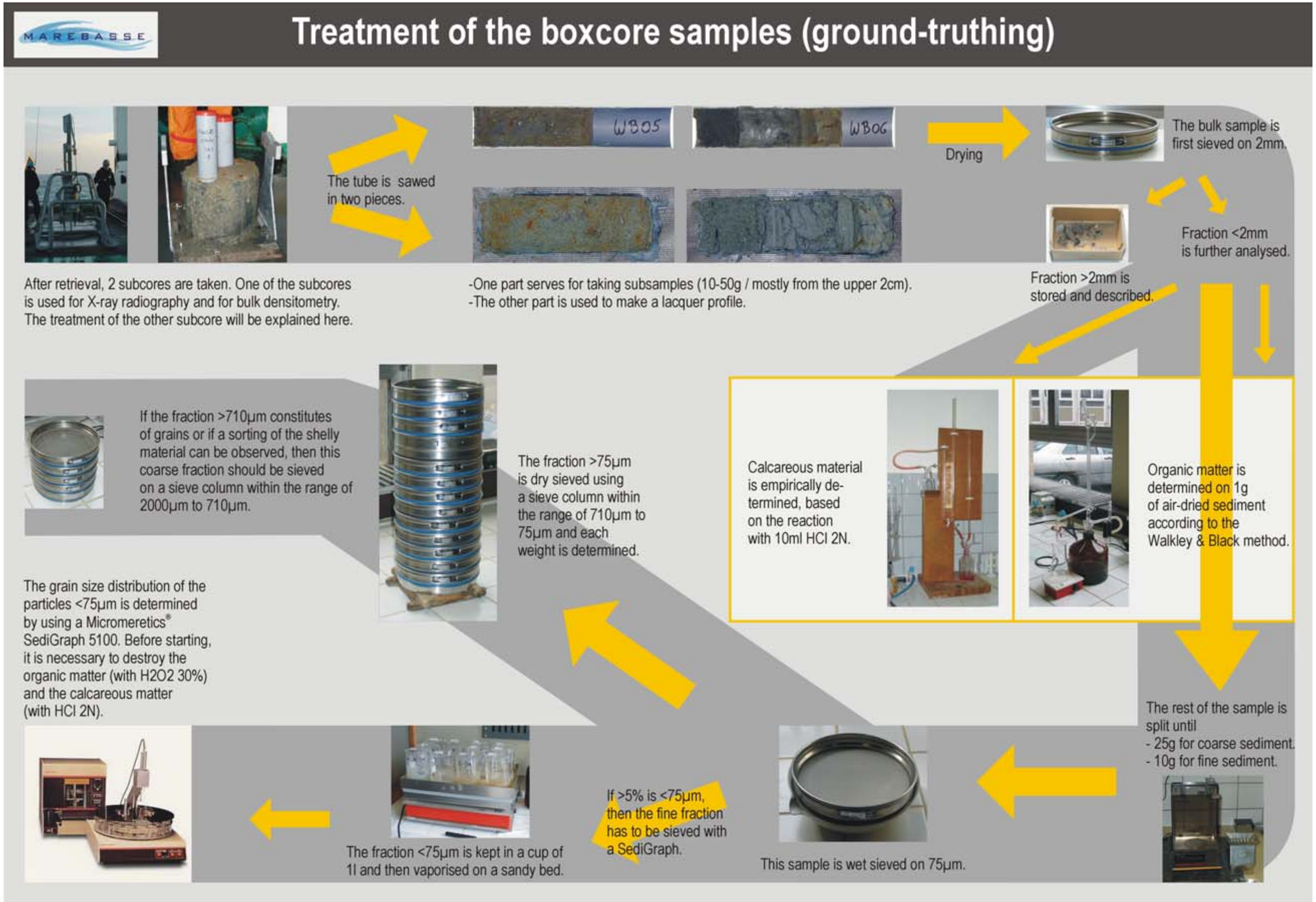


Figure A2.1. Overview of the treatment of the boxcore samples.

ANNEX 3. END-USERS MEETING 1 - OSTC PODOII PROJECT MAREBASSE

Date: Friday, October 4. 14:00 – 17:00

Venue: Ghent University, Geological Institute, Renard Centre of Marine Geology

Agenda:

14:15 Welcome, approval of agenda
Presentation of participants
Outline and objectives of the Marebasse project (Vera Van Lancker, UG-RCMG)
(measurement strategy, instrumentation and localisation of sites)

Short presentation of the different contributions of the individual partners

- Introduction to the sediment transport modelling (Michael Fettweis, MUMM)
- Wave modelling approach (Jaak Monbaliu, KUL)
- The contribution of Marebasse to the knowledge of the occurrence of macrobenthic communities on the level of the Belgian continental shelf (Gert Van Hoey, UG-MARBIO)
- Sampling strategy (Jean Lanckneus, Magelas)

Round table on the needs of the different end-users and how the Marebasse project can contribute (see further)

Conclusion

17:10 Close of meeting

List of participants (16):
Excused: *Bernard de Putter, Bernard Gonsette, Luc Van De Kerckhove, Toon Verwaest, Dries Van den Eynde, Marc De Batist, Geert Moerkerke, Jan Mees, Geert Palmers*

- Federal Office for Scientific, Technical and Cultural Affairs (OSTC), *David Cox*
- Ghent University, Renard Centre of Marine Geology, *Vera Van Lancker (VVL), Sophie Le Bot, Samuel Deleu*
- Management Unit for the Mathematical Modelling of the North Sea and Scheldt Estuary, *Michael Fettweis (MF), Frederic Francken*
- Catholic University of Leuven, Hydraulics Laboratory, *Jaak Monbaliu (JM)*
- Marine Geological Assistance, *Jean Lanckneus*
- Ghent University, Marine Biology Section, *Steven Degraer, Gert Van Hoey*
- Ministry of Economic Affairs, Marine Sand Fund, *Patrik Schotte*
- Zeegra vzw, *René Desaever*
- Ministry of the Flemish Community, Waterways Coast Division, *Dirk De Brauwer*
- European Dredging Association, *Frederik Mink*
- 3E nv., *Frans Van Hulle*
- Flanders Marine Institute, *Jan Seys*

Main outcome of the discussion round on the end-users' needs

Generally, the reaction on the project objectives is positive and the end-users see the link with their interests. It is agreed upon that good reference material (maps) is necessary to support discussions on marine aggregate issues and generally to avoid conflict situations amongst a variety of end-users.

René Desaever, Zeegra vzw, specifically argues the interest of the marine aggregate industry and expresses their need for more detailed information on the occurrence of good quality sand. This demand, especially for construction purposes (+/- 80 % for concrete production), is significantly increasing. However, their concern is being mentioned, as the concessions are restricted through cabling activities, loss of marine aggregate locations for fisheries issues, loss of former Dutch concessions and the possible restrictions if competition would occur with windmill farms. In respect to the latter, the demand for concessions on the Thornton Bank is being retarded. This sandbank was seen as a complementary location to gain coarser sand especially in the view that the central part of the Kwinte Bank would be temporally closed for extraction. It is also put forward that licenses for exploration of the seafloor outside the concession zone cannot be granted (i.e. Hinder Banken for the evaluation of gravel occurrences). Patrik Schotte, Ministry of Economic Affairs explains the procedures of obtaining those licenses and some discussion arises. Regarding the extraction of gravel, it needs mentioning that from present knowledge (DBM report), it seems that the quality of Belgian gravel is not satisfactory for construction purposes (the sand mixture seems to be too high). Except for the burial of sea pipes, all gravel is imported from the UK.

During the outline of the objectives (VVL), it was put forward that the Marebasse group is considering that detailed survey work could be carried out on the dumping locations of dredged material and specifically Br&W Oostende and the Sierra Ventana (S1, 50.10^6 m^3). This directly applies to the management issues regarding the re-use of dredged material. Moreover, these sites are less studied in terms of their seabed characteristics.

From the discussion, it becomes clear that the beneficial use of dredged material is indeed a relevant issue. The marine aggregate industry is interested to use the dredged material for some construction perspectives whilst the Ministry of the Flemish Community sees it as a source for harbour reclamation and levelling works and if the grain-size would be sufficiently coarse, as beach replenishment sand. Frederic Mink points out that this is generally not being done on a European scale, but that it is definitely a positive aspect to consider. He also informs whether Marebasse could provide information on how the hydrodynamic climate could be controlled to minimise the sedimentation in the navigation channel. MF mentions that it is already difficult to simulate the present situation so any prediction would be hard to sustain on a scientific basis.

Frederic Mink informs on the objectives of the European project EUMARSAND. VVL explains that Eumarsand is especially set-up to provide training of young researchers in the diverse issues related to marine aggregate extraction. Moreover, within Eumarsand experience will be shared amongst the countries having a long tradition with marine aggregates, contrary to Mediterranean countries lacking sand and forced to locate sand at larger depths (+/- 100 m). Frederic Mink mentions in particular the European Interreg project Beachmed that addresses these issues.

Jan Seys from the Flemish Marine Institute (VLIZ) outlines how VLIZ can contribute to the Marebasse project. It was mentioned that VLIZ is already active in transferring information to all levels of the community including politicians. It can be evaluated whether it would be useful to set-up an electronic conference on marine aggregate issues. However, this should be well considered and at a stage that the project is mature enough. People from the Marebasse advisory group could act as a steering committee.

René Desaever, Zeegra vzw, offers that it can be considered that the project group carries out additional work directly applicable for the marine aggregate industry. It is mentioned that the group can advise on certain issues and that it can propose further additional work or recommend the purchase of instrumentation. It is agreed that Marebasse is essentially a scientific project; however with a translation of the results towards end-users' needs.

Specific questions/remarks that were put forward:

Zeegra vzw. can provide information on time series of sand quality fluctuations i.e. how much and how long. Information can be provided for the Kwinte Bank, Oost Dijck, (Buiten Ratel) and Thornton Bank.

Interest was shown in how the wave modelling would be done and in that respect how detailed the wind climate will be taken into account ? JM explains that this is based on predictions from the meteorological offices (KMI, Reading…) and that these seem give sufficient detail as well in space as in time. For the prediction of waves, a standard deviation of 25 cm is calculated.

Questions also arose on the difference in grain-sizes amongst the Flemish Banks. VVL outlines that this is dependant on the hydrodynamic climate and the availability of sand; moreover the up building of the sandbanks is not necessarily homogeneous. This addresses the issue where the sand ultimately comes from. VVL points out that the latter is a very interesting, but difficult issue and that it would be worthwhile to try to divide the Belgian continental shelf into sediment transport cells; this might however be beyond the scope of Marebasse.

Finally, René Desaever, Zeegra vzw, invites the group to participate to visit a dredging hopper and to have a look on the sieve installation on land.

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