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Section Ecosystem Data Analysis and Modelling
Suspended Matter and Sea Bottom Modelling and Monitoring Group (SUMO)
and
Management Unit of the North Sea Mathematical Models (MUMM)

Monitoring of the impact of extraction of marine aggregates, in casu sand, in the zone of the Hinderbanks

Scientific Report – January–December 2018

Dries Van den Eynde, Matthias Baeye, Frederic Francken, Giacomo Montereale Gavazzi, Nathan Terseleer & Vera Van Lancker

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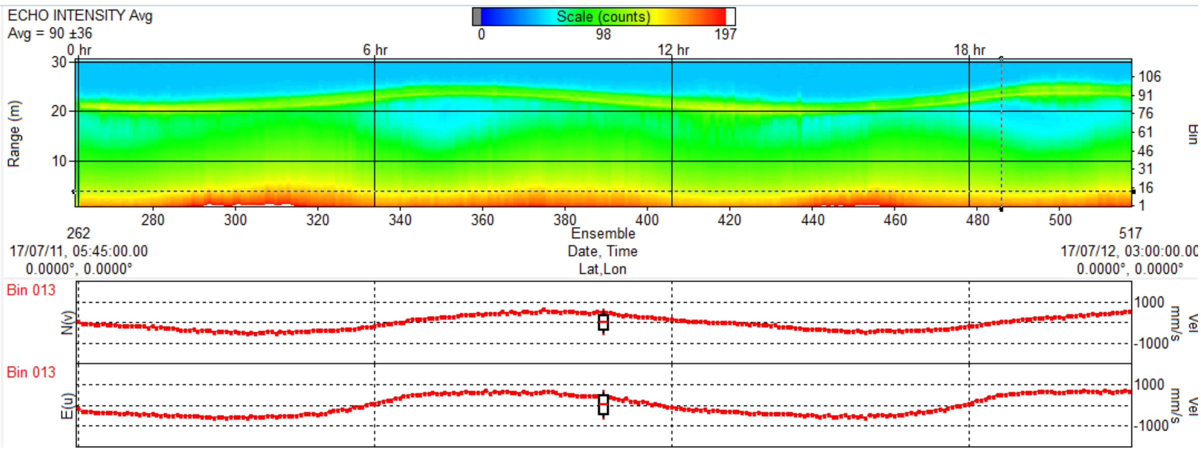

RBINS-OD Nature
100 Gulledelle
B–1200 Brussels
Belgium

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Abbreviations

ADCP	Acoustic Doppler Current Profiler
ADP	Acoustic Doppler Profiler
ADV	Acoustic Doppler Velocimeter
AUMS	Autonomous Underway Measurement System
BM-ADCP	Bottom-mounted Acoustic Doppler Current Profiler
BPNS	Belgian Part of the North Sea
COPCO	Continental Shelf Service of FPS Economy
CTD	Conductivity-Depth-Temperature
DGPS	Differential Global Positioning System
DoY	Day of Year
FPS Economy	Federal Public Service Economy, SMEs, Self-Employed and Energy
GES	Good Environmental Status
HM-ADCP	Hull-mounted Acoustic Doppler Current Profiler
Hs	Significant wave height
ILVO	Institute for Agricultural and Fisheries Research
LISST	Laser In-Situ Scattering and Transmissometry
MSFD	European Marine Strategy Framework Directive
NE	Northeast-directed (flood)
OBS	Optical Back Scatter
POC	Particulate Organic Carbon
PON	Particulate Organic Nitrogen
PSD	Particle-size distribution
RHIB	Rigid Hull Inflatable Boat
ROV	Remotely operated vehicle
RV	Research Vessel
SPM(C)	Suspended Particulate Matter (Concentration)
SW	Southwest-directed (ebb)
TC	Tidal coefficient
Tidal phase (xx)	Spring/Neap/Mid tide, with indication of the tidal coefficient
TSHD	trailing suction hopper dredgers
UGent-RCMG	Ghent University, Renard Centre of Marine Geology
UTC	Universal Time Coordinates
VLIZ	Flanders Marine Institute

Preface

Results presented in this report relate to the monitoring of aggregate extraction in zone 4, Hinder Banks (MOZ4), for the year 2018. It is a follow-up of the reporting with respect to the monitoring in 2013 (Van Lancker et al., 2014), monitoring in 2014 (Van Lancker et al., 2015), monitoring in 2015 as well as to the synthesis report on the period 2011-2015 (Van Lancker et al., 2016) and monitoring in 2016-2017 (Van Lancker et al., 2018).

Since 2013, the monitoring activities were financially supported by the Flemish Authorities, Agency Maritime Services and Coast, Coast. The monitoring programme ZAGRI, funded by the revenues of the private sector, and covering all concession zones in the Belgian part of the North Sea, provides a continuous support to MOZ4, as well as for the measurements that commenced in 2011, as for the model development. Since 2015, monitoring is also supported by the Belspo INDI67 research project. In this project, the MSFD indicators on the physical properties of the water-column and seabed interface and related to the descriptors of Good Environmental Status (GES) 'Seafloor Integrity' and 'Hydrographic Conditions', are investigated in detail. Particularly, the research on quantifying changes in bottom shear stress and benthic habitats (from multibeam backscatter) benefits from this additional funding.

1. Introduction

Over a 10 years period, extraction of marine aggregates (up to 2.9 million m³ over 3 months) is allowed in the region of the offshore Hinder Banks (concession zone 4), with a maximum of 35 million m³. Concessions were granted in four sectors of extraction (4a-b-c-d). Large trailing suction hopper dredgers (TSHD) can be used, extracting up to 12500 m³ per run. These practices contrast strongly with previous extraction activities: up to 3 million m³ per year, in 2011, and mostly using vessels with a capacity of 1500 m³ only. Since 2012, extraction is allowed in zone 4. Up to now extraction was concentrated in Sector 4c, with a peak extraction of nearly 2.5 10^6 m³ in 2014 (Van den Branden et al., 2017) In Figure 1, the extracted volumes of marine aggregates (m³) in the period 2003-2016 are presented. Note a peak extraction of nearly 2.5 10^6 m³ on Sector 4c in 2014, and the absence of extraction in 2015 and 2016 in these sectors. Such intensive extraction is new practice in the Belgian Part of the North Sea (BPNS) and the environmental impact is yet to be determined. The volumes are mostly needed in response to the needs of the Coastal Safety Plan bringing the level of protection against extreme storm events at a 1:1000 years return period, including a +30 cm sea level rise by 2050 (www.kustveiligheid.be).

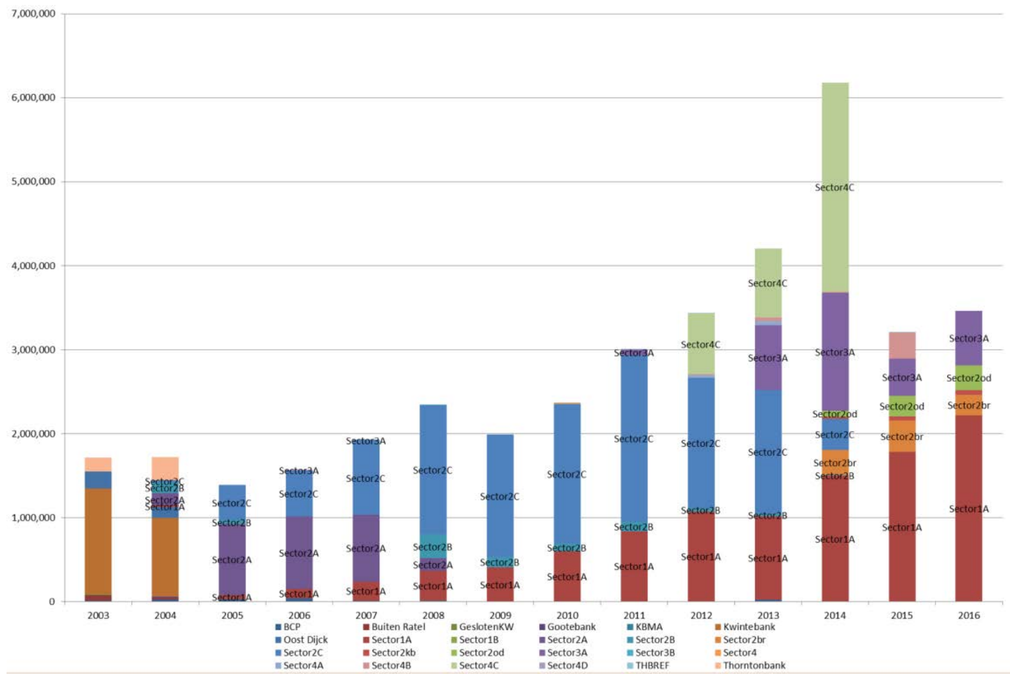

Figure 1: Extracted volumes of marine aggregates (m³) in the period 2003-2016 (Van den Branden et al., 2017). Labels 4, 4a-b-c-d relate to the extraction on the Hinder Banks.

The Hinder Banks form part of a sandbank complex, located 40 km offshore in the BPNS. On the sandbanks, depths range from -8 m to -30 m (Figure 2). They are superimposed with a hierarchy of dune forms, often more than 6 m in height. The channels in-between the sandbanks reach 40 m of water depth. At present, extraction of aggregates takes place mainly on the Oosthinder sandbank. Sediments are medium- to coarse sands, including shell hash, with less than 1 % of silt-clay enrichment (Van Lancker, 2009, @SediCURVE database). Tidal currents reach more than 1 ms^{-1}; waves are easily more than 1 m in height (44 % of the time). These offshore sandbanks are the first wave energy dissipaters in the BPNS.

The extraction sectors on the Hinder Banks are near an area protected under the Habitat Directive (92/43/EEC; see box below), called the "Vlaamse Banken". The northern limit of this area was drawn to include ecologically valuable gravel beds (Houziaux et al., 2008) (Figure 2). These beds have the status of "reefs" (Habitat type code 1170). At present, and in contrast to 100 yrs ago (Houziaux et al., 2008, and references therein), the extent of the reefs has become very marginal because of intensive fisheries. With the extraction activities being a new stressor in the area, it is critical to closely monitor the status of these reefs. Particularly, the areas, where in 2006 still hotspots of biodiversity were found, the so-called *refugia* or protected gravel beds, *sensu* Houziaux et al. (2008), were targeted. These occur in the troughs of morphologically steep sand dunes ('barchan' dunes), and as such considered more protected from trawling activities.

<u>Habitat Directive</u>

http://www.health.belgium.be/en/habitats-directive-areas-belgian-part-north-sea.

In implementation of the Habitats Directive (92/43/EEC), the Belgian State designated a Habitat Directive Area "Vlaamse Banken" (Royal Decree of October 16, 2012). The area is 1099.39 km^2 and located in the southwest of the Belgian part of the North Sea. It borders the French Birds and Habitats area "Bancs de Flandres" and extends to about 45 km offshore. The "Vlaamse Banken" were designated for the protection of the "sandbanks permanently covered with seawater" (Habitat type code 1110) and the "Reefs" (Habitat type code 1170). These sandbanks and reefs are ecologically the most valuable habitats of our North Sea. Two biotopes were characterized as "reefs": (1) reefs formed by the sand mason worms (*Lanice conchilega*), located in shallow water closer to the coast; and (2) the gravel beds occurring more offshore, especially and to a large extent at the level of the Hinder Banks. The gravel beds are a very rare and endangered habitat of gravel and boulders that may or may not be clumped together in the sandy or clayey subsoil and host a unique and rich diversity of species of fauna and flora. They once constituted the biotope of the European oyster which along with the stones were heavily colonised by a very peculiar fauna. Gravel beds fulfil an important function as spawning chamber and nursery of the fish species. Through the use of trawl nets, including the beam trawl their extent has become very marginal.
(http://www.health.belgium.be/en/habitat-types-be-protected).

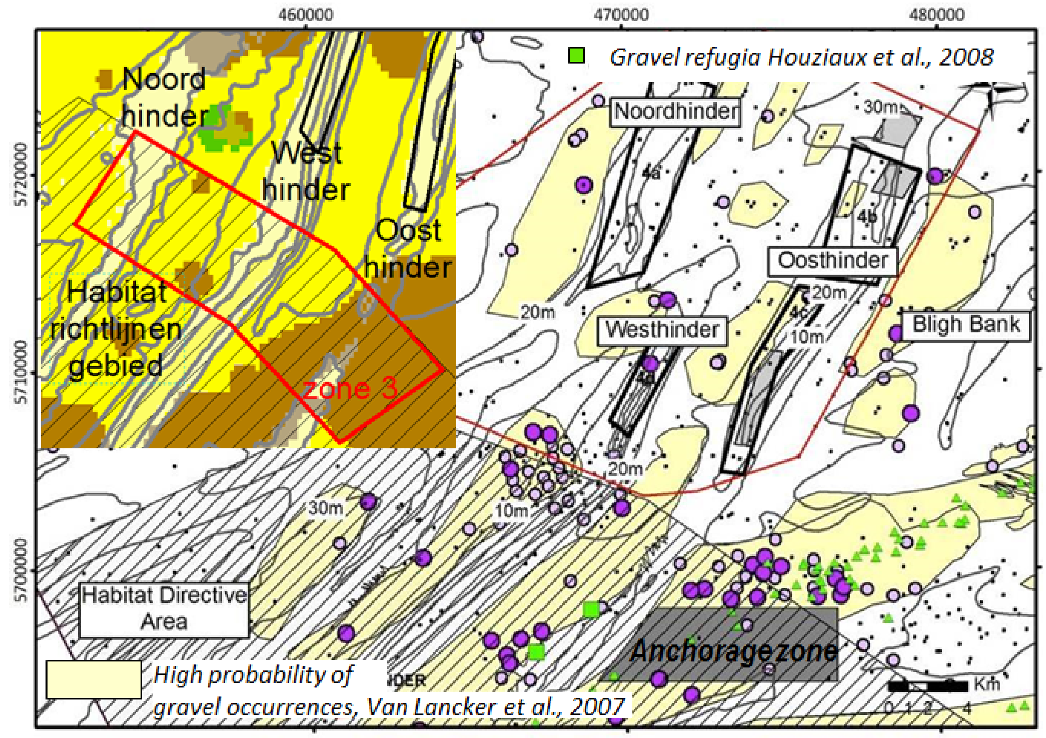

Figure 2. Left: Area of the Hinder Banks, where intensive marine aggregate extraction is allowed in zone 4 (red line in the main figure) along 4 sectors (black polygons). Within and outside these sectors geomorphological monitoring is carried out by COPCO (light grey polygons). A Habitat Directive (HD) area (hatched) is present at a minimum of 2.5 km from the southernmost sectors. Presence of gravel (purple dots) and stones (green triangles) is indicated (size of the dots represents relative amounts of gravel with a minimum of 20 %). In the light-yellow areas, the probability of finding gravel is high (based on samples, in combination with acoustic imagery). In the gravel refugia (green squares), west of the Oosthinder, ecologically valuable epifauna is present. Inset: Delineation of Fisheries Management Zone 3 (FMZ3), as defined in the Marine Spatial Plan. In this area, fisheries will be prohibited in the future allowing for recovery of the gravel beds. Coarse substrates are in brown; sands in yellow, as mapped from sample data.

2. Monitoring design

A monitoring programme, with focus on hydrodynamics and sediment transport, has been designed allowing testing hypotheses on the impact of marine aggregate extraction in the far offshore Hinder Banks. Impact hypotheses were based on findings in the Flemish Banks area where 30-yrs of extraction practices, and related research on the effects, were available (Van Lancker et al., 2010, for an overview). They have been adapted to incorporate descriptors of good environmental status, as stipulated within the European Marine Strategy Framework Directive (MSFD) (Belgische Staat, 2012; 2018). In the context of the present monitoring, main targets are assessing changes in seafloor integrity (descriptor 6) and hydrographic conditions (descriptor 7), two key descriptors of good environmental status, to be reached in 2020.

Summarized, main hypotheses are:

1) Seabed recovery processes are very slow;
2) Large-scale extraction leads to seafloor depressions; these do not impact on the spatial connectedness of habitats (MSFD descriptor 6);
3) Impacts are local, no far field effects are expected;
4) Resuspension, and/or turbidity from overflow during the extraction process, will not lead to an important fining of sediments (e.g., siltation);
5) Marine aggregate extraction has no significant impact on seafloor integrity, nor it will significantly lead to permanent alterations of the hydrographical conditions (MSFD descriptor 7);
6) Cumulative impacts with other sectors (e.g., fisheries) are minimal;
7) Large-scale extraction does not lead to changes in wave energy dissipation that impact on more coastwards occurring habitats.

The monitoring follows a tiered approach, consisting of in-situ measurements and modelling (Figure 3). Critical is to assess potential changes in hydrographic conditions (MSFD, descriptor 7), as a consequence of multiple seabed perturbations (e.g., depressions in the seabed) and their interactions. This could lead to changes in bottom shear stresses, a MSFD indicator that should remain within defined boundaries, as defined by the Belgian State (Belgische Staat, 2012).

For descriptor 7 on hydrographic conditions, the monitoring programme should allow evaluating the following specifications:

(1) Based upon calculated bottom shear stresses over a 14-days spring-neap tidal cycle, using validated mathematical models, an impact should be evaluated when one of the following conditions is met:
   i. There is an increase of more than 10% of the mean bottom shear stress;

ii. The variation of the ratio between the duration of sedimentation and the duration of erosion is beyond the "-5%, +5%" range.

(2) The impact under consideration should remain within a distance equal to the square root of the area occupied by this activity and calculated from the inherent outermost border.

(3) All developments need compliance with existing regulations (e.g., EIA, SEA, and Habitat Directive Guidelines) and legislative evaluations are necessary in such a way that an eventual potential impact of of permanent changes in hydrographic conditions is accounted for, including cumulative effects. This should be evaluated with relevance to the most suitable spatial scale (ref. OSPAR common language).

Therefore, considerable effort went to current and turbidity measurements along transects crossing the sandbanks, as also on point locations for longer periods. These data serve as a reference and are compared to datasets recorded under the events of intensive aggregate extraction. The extraction gives rise to sediment plumes and subsequent release of fine material in the water column. As such, dispersion of the fines and the probability of siltation in the nearby Habitat Directive area is studied, since this may cause deterioration of the integrity of gravel beds present in this area. This relates directly to Belgium's commitments within the MSFD stating that the ratio of the hard substrata surface area versus the soft sediment surface area should increase in time (Belgische Staat, 2012). Furthermore, abrasion of the sandbank and/or enrichment of finer material, could lead to habitat changes, another indicator within MSFD (descriptor 6 Seafloor Integrity).

For this descriptor 6 this monitoring programme contributes to the evaluation of the following environmental targets and associated indicators (Belgische Staat, 2012):

(1) The areal extent and distribution of EUNIS level 3 Habitats (sandy mud to mud; muddy sand to sand and coarse sediments), as well as of the gravel beds, remain within the margin of uncertainty of the sediment distribution, with reference to the Initial Assessment.

(2) Within the gravel beds (selected test zones), the ratio of the surface of hard substrate (i.e., surface colonized by hard substrata epifauna) against the ratio of soft sediment (i.e., surface on top of the hard substrate that prevents the development of hard substrata fauna), does not show a negative trend.

Remark that recently an update of the MSFD report was made by the Belgian State (2018). This could have some implications on the monitoring targets in the future.

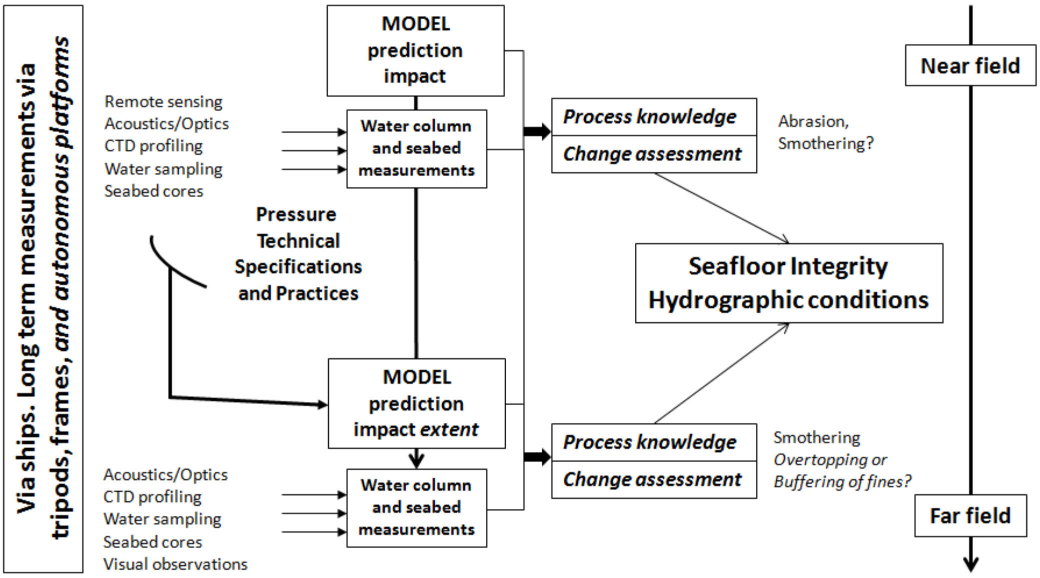

Figure 3. Overview of the research strategy aiming at quantifying both near- and far-field impacts of marine aggregate extraction.

3. Materials and methods

3.1. Measurements and spatial observations

3.1.1. Overview

In 2017, 4 measuring campaigns were planned with the RV Belgica, see Table 1. However, the first two campaigns were cancelled, due to technical problems with the RV Belgica. During campaign 2017/34, no results were obtained in the framework of the project, due to problems with the RV Belgica (generator).

To compensate for the RV Belgica campaigns that were cancelled, three campaigns were organized with the RV Simon Stevin of the Flanders Marine Institute (VLIZ), also these campaigns are indicated in Table 1.

Further, a visit was brought at the Trailing Suction Hopper Dredger (TSHD) Breughel, where some samples from the overflow could be taken (see Table 1).

For the year 2018, 3 measuring campaigns were planned, see Table 1. The operational plans of the different campaigns and the cruise reports are given in Annex 4.

Table 1: Overview of the oceanographic campaigns in 2017 and 2018.

Campaign	Starting date	Ending date	Vessel	Remarks
2017/09	20/03/2017	24/03/2017	RV Belgica	Cancelled
	11/04/2017	13/04/2017	RV Simon Stevin	
	19/04/2017	19/04/2017	TSHD Breughel	
	23/05/2017	24/05/2017	RV Simon Stevin	
	01/06/2017	02/06/2017	RV Simon Stevin	
2017/21b	29/06/2017	30/06/2017	RV Belgica	Cancelled
2017/23	10/07/2017	14/07/2017	RV Belgica	
2017/34	20/11/2017	24/11/2017	RV Belgica	No results
2018/07	19/03/2018	23/03/2018	RV Belgica	
2018/17	09/07/2018	13/07/2018	RV Belgica	
2018/24	22/10/2018	26/10/2018	RV Belgica	

A short overview of the measurements that were taken is given below.

3.1.2. Bottom samples

Van Veen grabs and Hamon grabs were conducted in the Oosthinder sector 4c during campaign 2017/23, to execute a comparative study between the two bottom sampling methods. Van Veens grabs were taken during campaign 2018/17 and 2018/24.

Reineck boxcorers were taken in the HBMC area during campaign 2018/07, to detect changes in grain-size distribution in the upper vertical sediment column.

3.1.3. ADCP measurements

The bottom mounted ADCP was deployed for 27 days from 13/04/2017 to 10/05/2017. The deployment and the recovery were done by the RV Simon Stevin. Furthermore, a BM-ADCP was deployed for 2 days in the trough of a barchan dune in MRPZ3-W during campaign 2017/23.

ADCP profiles using the hull-mounted ADCP (RDI 600 kHz) were taken over a series of dunes during campaign 2017/23.

3.1.4. Water samples

Water samples and vertical profiles of oceanographic parameters were taken in the trough of a barchan dune in MSPZ3-W, including measurements with a LISST during campaign 2017/23.

3.1.5. Video frames

Video was taken at the Hinder Bank South during campaign 2017/23 and during campaign 2018/17 and 2018/28. The visual equipment was made available through the VLIZ. The video frame was equipped with a Bowtech Inspector colour zoom camera (Sony ¼" SuperHD CCD; 18:1 automatic zoom range) and a lightning element. Imagery was recorded in .AVI format and had a standard definition (SD) of 640x480 pixels. Video footage were exported as snapshots from the video.

3.1.6. Multibeam measurements

MBES data acquisition was carried out in het Hinder banks study area, during campaigns 2017/23, 2018/07, 2018/17 and 2018/24. Since the system was used to monitor morphological and sediment changes, depth and backscatter data were obtained.

3.1.7. Centrifuge

Samples of the centrifuged water were collected during campaigns with the RV Belgica.

3.1.8. Satellite measurements

Satellite measurements with the Sentinel-2 satellite were obtained, during a sand extraction event inside sector 4c, with the TSHD Breughel.

3.2. *Modelling*

3.2.1. Modelling of bottom shear stress

The effect of the extraction of sand on the bottom shear stress, using a validated numerical model (see Belgian State, 2012) has been evaluated in Van den Eynde (2016).

A first evaluation of the accuracy of bottom shear measurements and models was executed in Van den Eynde (2015). In Van den Eynde (2016), a further validation of the numerical model was done, based on bottom-mounted ADCP measurements in the Hinderbank area.

In Van den Eynde (2016), three scenarios were modelled to investigate the influence of a large-scale extraction of marine aggregates on the bottom shear stress in zone 4, i.e. a scenario using a maximal extraction depth, a scenario with extraction to the same final water depth and a scenario with all extraction in sector 4c. The simulations showed the for the three scenarios, the change in bottom shear stress in the area, where the impact should remain limited, was limited to less than 6%.

In the framework of the proposal of a new extraction limit for extraction, based on scientific and economic criteria (Degrendele, 2016; Degrendele et al., 2017), some tests have been executed to test that the new extraction limits were in line with the Belgian implementation of the Marine Strategy Framework Directive (MSFD) (Belgian State, 2012). In this Directive, it was stated that human impacts need consideration when the bottom shear stress, calculated with a validated numerical model, changes with more than 10 % at a specified distance of the activity. In Van den Eynde (2017) these tests were presented and some adaptations to the new proposed extraction limits were proposed to assure that no too high bottom shear stress changes occurred, outside the buffer zone of the extraction sector 2c.

Since in the MSFD, it was explicitly stated that the bottom shear stress should be evaluated with a validated numerical model, some more work has been executed to evaluate the accuracy of the measurements of bottom shear stress that are used to validate the numerical models. Measurements of one campaign at MOW1 were used, so that these could be used in more detail.

3.2.2. Modelling of wave propagation on the BPNS

The extraction of sand and gravel on the top of the sand banks in the extraction zones, also has an effect on the breaking of the waves and the propagation of the waves towards the Belgian coast. As such, the extraction of sand could have effect on the coastal protection and finally on the beach profiles. This has been tested using the SWAN model, for the newly proposed extraction limit.

4. Results

For detailed results on the three main topics that form the part of this report, see the following three annexes:

Annex 1
Baeye, M., D. Van den Eynde, V. Van Lancker and F. Francken, 2019. Monitoring of the impact of the extraction of marine aggregates, in casu sand, in the zone of the Hinder Banks. Data report 2017. Report ZAGRI-MOZ4/X/MB/201905/EN/TR01, Brussels, RBINS-OD Nature, 23 pp.

Annex 2
Van den Eynde, D., 2018. Measuring, using ADV and ADP sensors, and modelling bottom shear stresses at the MOW1 site (Belgian continental shelf). Brussels, RBINS-OD Nature. Report MOMO-ZAGRI-MOZ4-INDI67/1/DVDE/201801/EN/ TR01 (Revised version of Report MOMO-INDI67/1/DVDE/201608/EN/TR01), 47 pp.

Annex 3
Van den Eynde, D., T. Verwaest and K. Trouw, 2019. The impact of sand extraction on the wave height near the Belgian coast. Report MOZ4-ZAGRI/X/DVDE/201906/EN/TR03, RBINS-OD Nature and MUMM, Brussels, 44 pp.

5. Conclusions

Due to technical and weather constraints, the number of campaigns in 2017 with RV Belgica were limited. Fortunately, some campaigns were replaced with campaigns with the RV Simon Stevin. Furthermore, a visit on the TSHD Breughel has taken place. In 2018, the three planned campaigns were executed.

ADCP bottom mounted measurement were taken over a longer period of almost a month and a shorter period of 2 days. Furthermore, hull-mounted ADCP measurements were taken. The echo intensity of the ADCP is a proxy for the turbidity and is typically a function of the current magnitude to the power 2. The first analysis of the data shows quite some dB variation as a function of the hydrodynamics, implying in situ resuspension. Further variation could be due to spring-neap tide variations and/or advection. Although the overflow due to the extraction of sand was captured by a satellite, the sediment plume was not seen by the bottom-mounted ADCP.

Measurements in the overflow of the TSHD Breughel showed that around 85% of the overflow was silt or fine-grained material, with a median diameter of 25 µm, that could be advected to the south in the direction of the gravel beds in the Habitat Directive Area. Using two different methods an estimation was made of the amount of overflow, based on the weight data of the hopper load and on the density profiles inside the hopper. Both methods resulted in an overflow of mainly fine-grained material of about 4 kg per second, resulting in an overflow of about 16 ton of sediment during one single extraction event.

On the other hand, grain-size analysis of samples taken in the hopper after the extraction showed overall sand-size material, with no sign of finer fractions. This could be the results of washing out during overflow or during sampling.

The fact that so much fine-grained material is found in the overflow is likely due to the fact that the TSHD vessels were combining both sand mining and harbor access maintenance operations. As a result, dredged matter having a much higher silt content is likely to remain inside the hopper, enriching the fine particles in the overflow. This should be further studied and confirmed in the future.

Some laboratory tests were done to compare the results of the Malvern grain-size analyzer with results from the LISST and the ABS. The results of the LISST and the ABS confirmed that there is no sign of fine-grained material in the hopper samples. The results of the three instruments matched reasonably.

A second study was done on the validation of the bottom shear stress, which is used in the Marine Strategy Framework Directive (MSFD) to evaluate human impacts. The bottom shear stress models were used in Van den Eynde (2017) to evaluate the newly proposed extraction limits with respect to the Belgian implementation of the MSFD. In the framework of this second study, these bottom shear stress models are validated. Measurements of ADV current meters, and ADP current profiles at the MOW1 stations, near the harbor of Zeebrugge were analyzed. It was shown that there is a very low correlation between the different estimates of the bottom shear stresses from high-frequency current measurements or current profiles. It was concluded that the bottom shear stress from the turbulent kinetic energy probably was the most accurate estimate of the bottom shear stress. Moreover, both an estimate of the mean (over a wave cycle) and maximum bottom shear stress could be provided.

The validation of the numerical models of bottom shear stress showed that using a constant bottom roughness of about 0.01 m gave the best results. The Root-Mean-Square-Error (RMSE) for the mean bottom stress was in the order of 0.26 Pa, with a high correlation coefficient. The RMSE for the maximum bottom shear stress was around 0.62 Pa.

A last study was executed on the influence of the newly proposed extraction limits on the propagation of waves towards the coast. The sand banks were thought to be important for the breaking of the waves and are therefore important for the coastal protection. In the study the SWAN wave model was used to simulate the propagation of the waves towards the coast for different wave heights, wave periods, wave and wind directions and water levels. The results showed that the extraction of the sand on the extraction zones does not affect the wave height at the coast significantly.

6. Outreach 2017-2018

6.1. Chapter in books

Van Lancker, V., H. Vandenreyken, B. Lauwaert, A. De Backer en L. Devriese, 2018. Zand- en grindwinning, in: Devriese, L., Dauwe, S., Verleye, T., Pirlet, H., Mees, J. (Ed.) Kennisgids Gebruik Kust en Zee 2018 - Compendium voor Kust en Zee, 79-90.

Van Lancker, V., H. Vandenreyken, B. Lauwaert, A. De Backer and L. Devriese, 2018. Sand and gravel extraction, in: Devriese, L., Dauwe, S., Verleye, T., Pirlet, H., Mees, J. (Ed.) Knowledge Guide Coast and Sea 2018 - Compendium for Coast and Sea.79-89.

6.2. Abstracts & Posters

Baeye, M., F. Francken, V. Van Lancker and D. Van den Eynde, 2017. Marine aggregate mining in the Hinder Banks: on-board sampling of the turbid dredging overflow. Proceedings Studiedag Zand en Grind – Belgisch zeezand – een schaars goed? Oostende, 9/6/2017, 1 pp. + Poster.

Francken, F., D. Van den Eynde and V. Van Lancker, 2017. Application of a large dataset of sediment transport parameters: variability in sediment transport in the HBMC area. Proceedings Studiedag Zand en Grind – Belgisch zeezand – een schaars goed? Oostende, 9/6/2017, 10 pp. + Poster.

Roche, M., K. Degrendele, A. De Backer, D. Van den Eynde and V. Van Lancker, 2018. Monitoring the direct impact of sand extraction on the bathy-morphology and the seabed sediment in the Belgian part of the North Sea. Lessons of ten years of measurements. GeoHab 2018, Marine Geological and Biological Habitat Mapping, Santa Barbara, U.S.

Van den Eynde, D., F. Francken and V. Van Lancker, 2017. Effects of extraction of sand on the bottom shear stress on the Belgian Continental Shelf. Proceedings Studiedag Zand en Grind – Belgisch zeezand – een schaars goed? Oostende, 9/6/2017, 20 pp.

Van Lancker, V., M. Baeye, D. Evagelinos, F. Francken, G. Montereale Gavazzi and D. Van den Eynde, 2017. MSFD-compliant assessment of the physical effects of marine aggregate extraction in the Hinder Banks, synthesis of the first 5 years. Proceedings Studiedag Zand en Grind – Belgisch zeezand – een schaars goed? Oostende, 9/6/2017, 18 pp.

Van Lancker, V., F. Francken, M. Kapel, L. Kint, N. Terseleer, D. Van den Eynde, K. Degrendele, M. Roche, G. De Tré, R. De Mol, T. Missiaen, V. Hademenos, J. Stafleu, S. van Heteren, P.-P. van Maanden and J. van Schendel, 2017. Flexible querying of geological resource quantities and qualities, a sustainability perspective. Proceedings Studiedag Zand en Grind – Belgisch zeezand – een schaars goed? Oostende, 9/6/2017, 13 pp.

6.3. Presentations

20170407 – Baeye. Further Work. MOZ4 Meeting, Agentschap Maritieme Dienstverlening en Kust, Oostende.

20170407 – Francken, F., D. Van den Eynde and V. Van Lancker. Temporal and spatial variability of sediment transport parameters. Case study: the HBMC arera. MOZ4 Meeting, Agentschap Maritieme Dienstverlening en Kust, Oostende.

20170407 – Van den Eynde, D., M. Baeye, F. Francken, P. Luyten, N. Terseleer and V. Van Lancker. Modelling in the framework of the ZAGRI/MOZ4 projects. MOZ4 Meeting, Agentschap Maritieme Dienstverlening en Kust, Oostende.

20170407 – Van Lancker, V., G. Montereale Gavazzi and D. Van den Eynde. Monitoring Hinder Banks. MOZ4 Meeting, Agentschap Maritieme Dienstverlening en Kust, Oostende.

20170508 – Francken, F., D. Van den Eynde and V. Van Lancker. Application of a large dataset of sediment parameters. ECODAM presentation.

20170609 – Roche, M., A. De Backer and D. Van den Eynde. How sustainable is the Belgian sand extraction? Monitoring results and perspectives. Studiedag Zand en Grind – Belgisch zeezand – een schaars goed? Oostende.

7. Acknowledgments

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Royal Belgian Institute of Natural Sciences
Operational Directorate Natural Environment
100 Gulledelle
B–1200 Brussels
Belgium
Phone: +32 2 773 2111
Fax: +32 2 770 6972
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Annex I

Baeye, M., D. Van den Eynde, V. Van Lancker and F. Francken, 2019. Monitoring of the impact of the extraction of marine aggregates, in casu sand, in the zone of the Hinder Banks. Data report 2017. Report ZAGRI-MOZ4/X/MB/201905/EN/TR01, Brussels, RBINS-OD Nature, 23 pp.

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OPERATIONAL DIRECTORATE NATURAL ENVIRONMENT

Section Ecosystem Data Analysis and Modelling
Suspended Matter and Sea Bottom Modelling and Monitoring Group (SUMO)
and
Management Unit of the North Sea Mathematical Models (MUMM)

Monitoring of the impact of the extraction of marine aggregates, in casu sand, in the zone of the Hinder Banks Data report year 2017

Matthias Baeye, Dries Van den Eynde, Vera Van Lancker & Frederic Francken

ZAGRI-MOZ4/X/MB/201905/EN/TR01

Prepared
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RBINS-OD Nature
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Table of Contents

1. Factual part

1.1. Overview of campaigns

11-13/04/2017	RV Simon Stevin
19/04/2017	TSHD Breughel
23-24/05/2017	RV Simon Stevin
1-2/06/2017	RV Simon Stevin
10-14/07/2017	RV Belgica
21-23/08/2017	RV Belgica

1.2. Short overview of the acquired in situ data

- The bottom-mounted ADCP (BM-ADCP) was deployed and recuperated on two different occasions. Both BM-ADCP recordings spanned over a period of 27 + 2 days together. Short-term shipborne ADCP profiles were acquired during different campaigns with RV Belgica.
- Sediment grab samples were taken in the vicinity of the ADCP measurements.
- Samples of centrifuged water were collected during RV Belgica campaigns.
- TSHD Breughel hopper sediment samples (56) were kindly transferred from Maritieme Toegang to RBINS for more advanced analysis (particle size characteristics and organic matter).
- Seawater sampling with Niskin bottles was conducted with RV Belgica and filtrations were analysed for particle concentration and organic matter.
- CTD+LISST profiles were acquired during RV Belgica campaigns.
- A sand extraction event (TSHD Breughel) inside sector 4C was captured by the Sentinel-2 satellite.

2. Visualization of data

2.1. Collection of data

In Figure 1, the campaigns are visualised in the 2017 calendar showing the quite intense campaign programme for spring and summer. RV Belgica campaigns in March and November were unfortunately cancelled due to RV Belgica's technical problems and unfavourable weather conditions respectively.

Figure 1: Calendar with successful field campaigns in 2017 (light blue).

2.2. *Data plots*

Table 1: BM-ADCP settings

frame	frequency	Start		Stop	
		date time	vessel	date time	vessel
bottom-mount	1228.2 kHz	2017/04/13, 08:56:21	RV Simon Stevin	2017/05/10, 21:41:21	RV Simon Stevin
1st bin	**bin size**	**no bins**	**pings/ens**	**time/ping**	**avg ens interval**
0.81 m	0.25 m	119	50	00:06.0	5 min

frame	frequency	Start		Stop	
		date time	vessel	date time	vessel
bottom-mount	1228.2 kHz	2017/07/11, 05:45:00	RV Belgica	2017/07/13, 06:20:00	RV Belgica
1st bin	**bin size**	**no bins**	**pings/ens**	**time/ping**	**avg ens interval**
0.82 m	0.25 m	119	50	00:06.0	5 min

Figures 2 and 3 (lower panel) illustrate the hydrodynamic conditions at 4 meters above the seabed during the two BM-ADCP deployments (Table 1). The echo intensity (in counts) in the upper panel is a proxy for turbidity illustrating the small ebb-flood maxima and the lower values during the slack tides.

Figures 4 and 5 give the current ellipses at 4 meter above the bottom for the two campaigns.

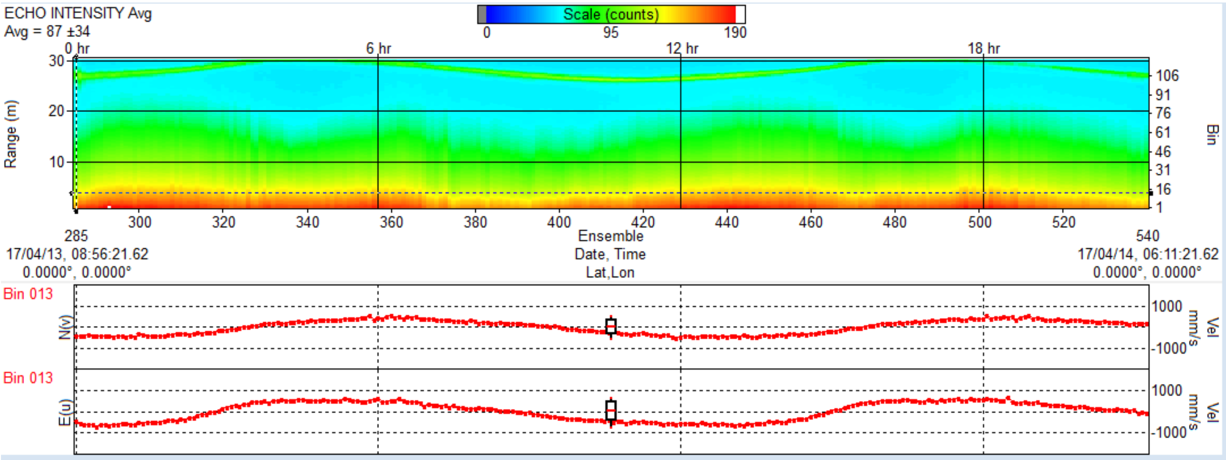

Figure 2: First 256 data points during deployment in April-May (upper panel: echo intensity, and the lower panel: east and north component of the current).

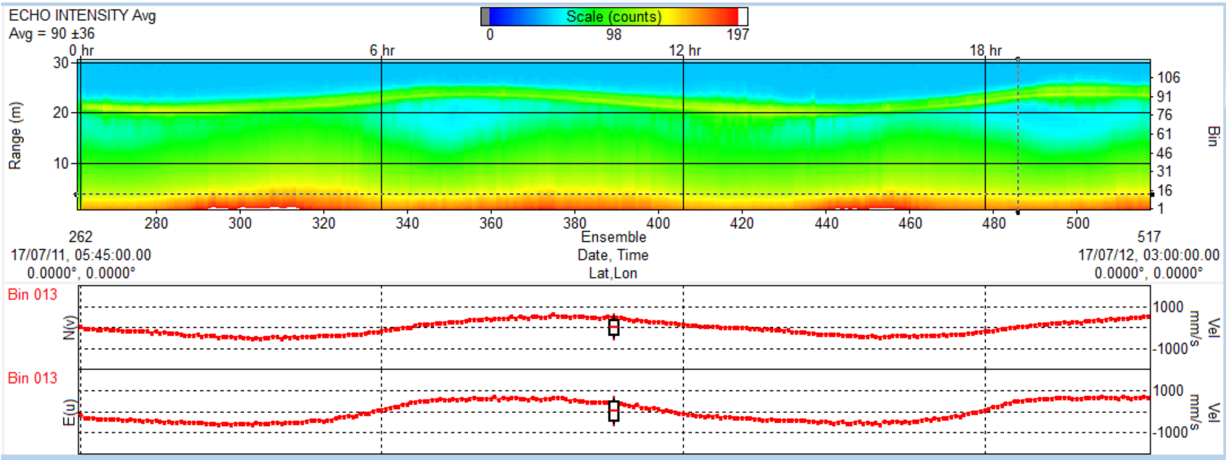

Figure 3: First 256 data points during deployment in July (upper panel: echo intensity, and the lower panel: east and north component of the current).

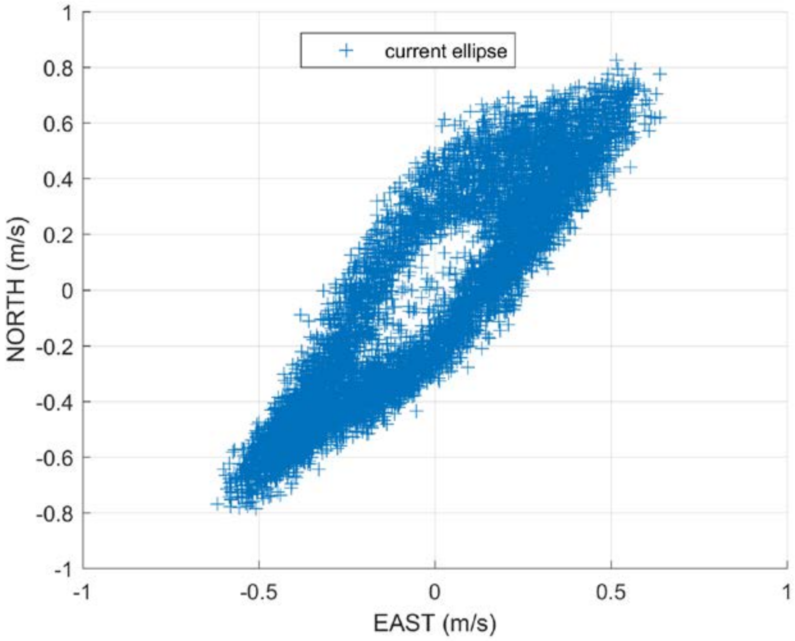

Figure 4: Current ellipse of the long-term BM-ADCP deployment in April-May. Bin number 13 (or 4 mab) was considered here.

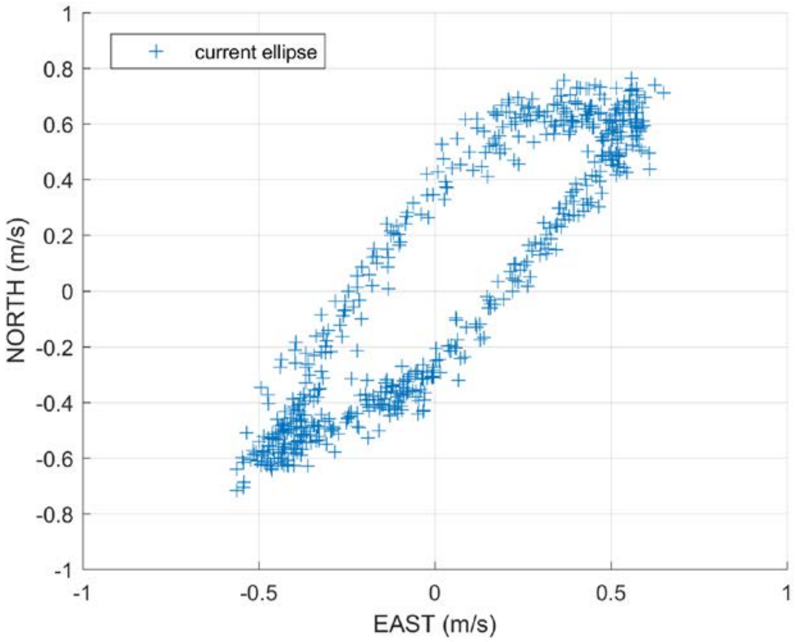

Figure 5: Current ellipse of the 2-days BM-ADCP deployment in July. Bin number 13 (or 4 mab) was considered here.

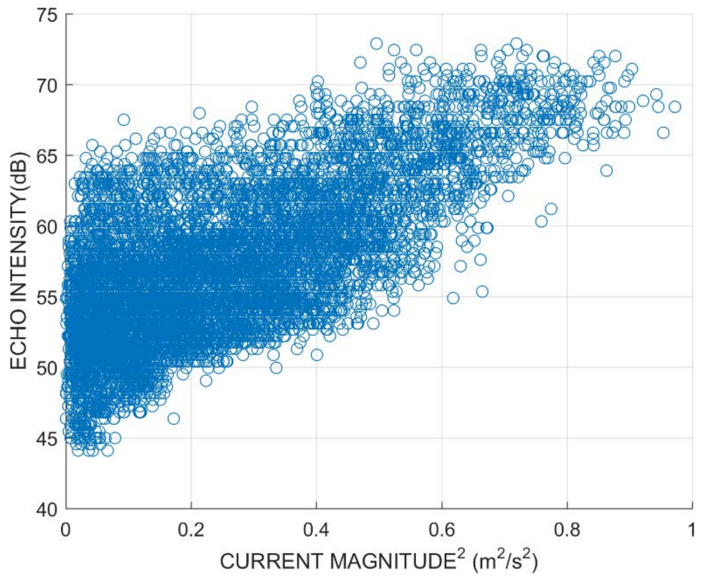

Figure 6: Echo intensity as a function of current magnitude^2 of the long-term BM-ADCP deployment in April-May.

The echo intensity is a proxy for turbidity and is typically a function of the current magnitude to the power 2 (U^2) in a sandy seabed environment (Figure 6 and 7). The long-term deployment captured quite some dB variation (values between 44 and 73) as a function of the hydrodynamics implying an in situ resuspension controlled environment (at 4 mab). Thus this figure illustrates how one can examine this linear relationship with anomalous points that might indicate an advective process playing an additional role. For example, for the lower U^2 values there is a large dB range (45-65) likely explained by the spring-tide and neap-tide variation and/or advection.

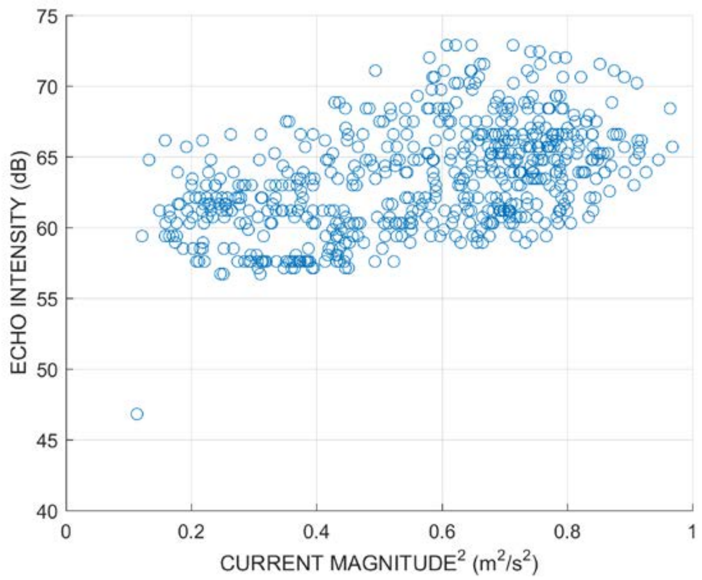

Figure 7: Echo intensity as a function of U^2 of the 2-days BM-ADCP deployment in July. This short-term deployment logically captured much less dB variation.

Table 2 gives the average SPM characteristics of the water measured during the RV Belgica campaign in July.

Table 2: SPM, POC and PON values

SPM	POC	PON
4.0 mg/L	0.44 mg/L	0.065 mg/L

Table 3 and Figures 8 and 9 are the information and data respectively of the hull-mounted ADCP profiler measurements. The echo intensity remains quite constant over the measurement period.

Table 3: ADCP settings for the HM-ADCP deployments

frame	frequency	Start		Stop	
		date time	vessel	date time	Vessel
hull-mount	614.4 kHz	2017/07/13, 20:20:15	RV Belgica	2017/07/13, 22:59:17	RV Belgica
1st bin	bin size	no bins	pings/ens	time/ping	avg ens interval
1.55 m	0.50 m	100	20	00:06.0	1 min

frame	frequency	start		Stop	
		date time	vessel	date time	vessel
hull-mount	614.4 kHz	2017/07/12, 13:18:18	RV Belgica	2017/07/13, 02:07:21	RV Belgica
1st bin	bin size	no bins	pings/ens	time/ping	avg ens interval
1.55 m	0.50 m	100	19	00:06.0	1 min

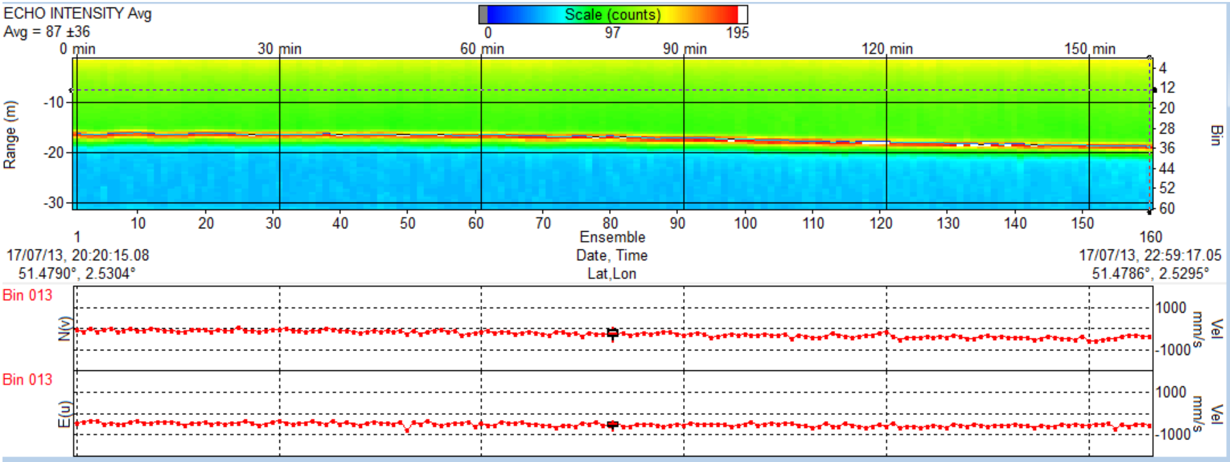

Figure 8: Snapshot of the echo intensity and hydrodynamic conditions (160 mins in total) at the location of the BM-ADCP deployment in July.

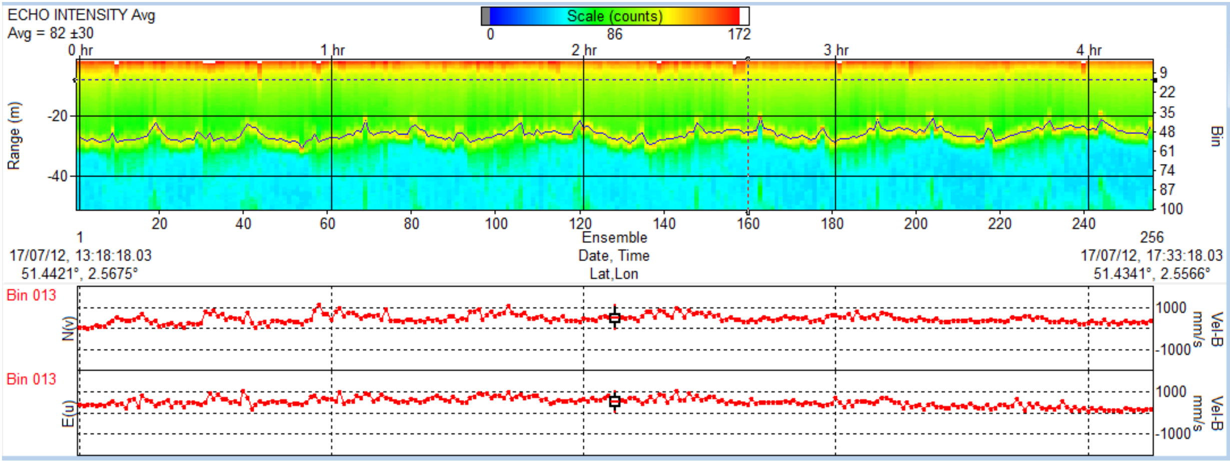

Figure 9: Snapshot of the echo intensity and hydrodynamic conditions (of the 13 hours in total) when sailing transects.

3. Analysis of data of the TSHD Breughel case study

3.1. *Introduction*

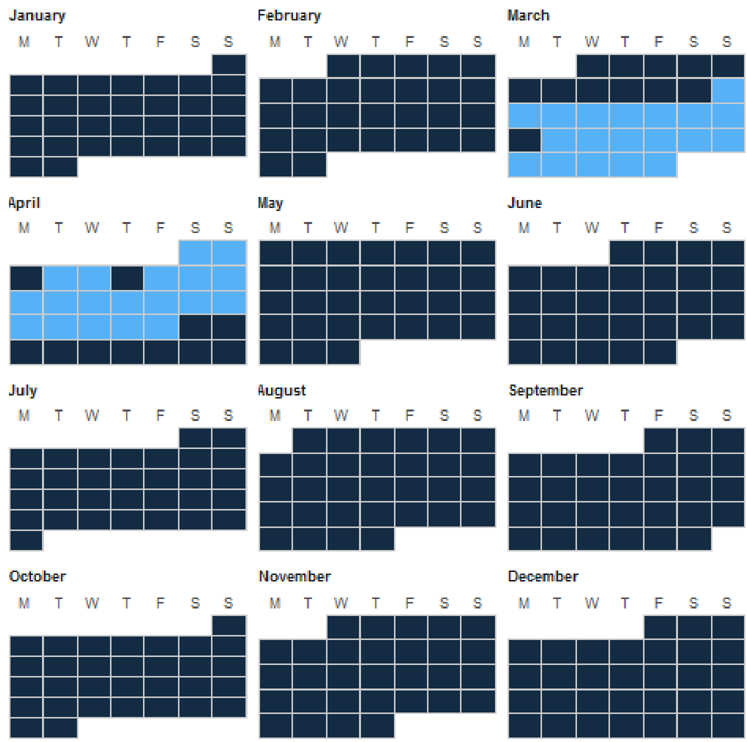

Figure 10: Calendar with TSDH Breughel sand extraction events in sector 4C (light blue)

Sand extraction events systematically started somewhere around LW (+- 2 hours) and last for about 65 to 75 minutes. Overflow roughly starts after 20 minutes.

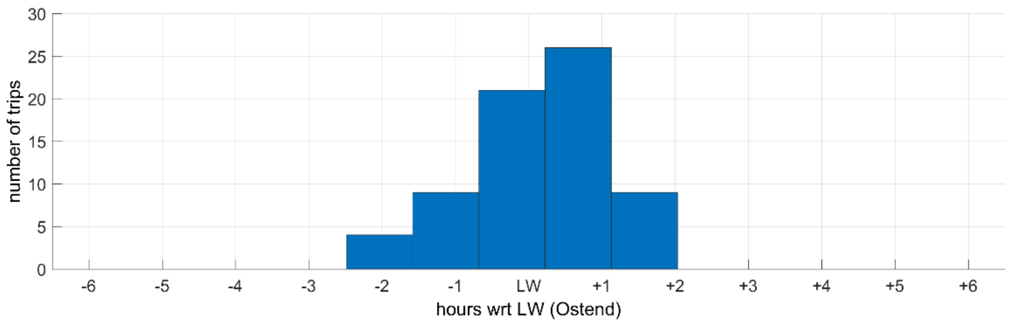

Figure 11: Timing of the sand extraction events with regards to the low water (LW)

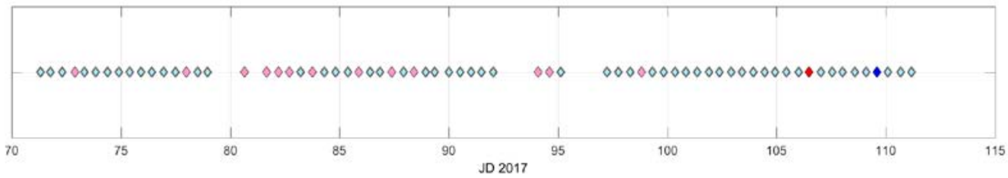

Figure 12: Date/time of sand samples taken inside the hopper after each sand extraction event; light blue, samples with label stored @ rbins-mso; pink, unreadable sample label; red, satellite image (Sentinel 2); blue, on-board monitoring of overflow water

3.2. *Characteristics of overflow particles*

Part of the effort in the monitoring programme intends to examine the characteristics of these overflow particles, such as concentration and size distribution. On-board of the TSHD, 1 L sampling of the sediment-laden overflow was executed in intervals of about 10 minutes for total overflow duration of 47 minutes. The collected overflow water was analysed with a turbidimeter and laser diffraction instrument. These revealed an overflow concentration of up to 1 g/l and a size distribution with d50 diameter of 24.3μm. Some photos taken during this sampling are presented in Annex 1.

Table 4: Particle size monitoring

particle size Distribution Metrics	
d10	7.8 µm
d50	24.3 µm
d90	83.2 µm
mean	24.9 µm
std	44.2 µm
% silt	85
% sand	15

These fine-grained overflow plumes likely remain in suspension for many hours and are systematically transported in a more southwest-ward direction, due to the consistently low tide conditions of these extractions. In an attempt to estimate the amount of water (and these fine-grained particles) flushing back to sea, 2 methods were considered:

Method 1: based on the 10-sec weight data of the hopper load

By means of tracking the weight inside the hopper during sand extraction, the slope of the "time vs. weight" plot changes at the onset (after 23 minutes) of overflow (Figure 13). If we now continue this line until the end of the extraction event is reached after 70 minutes, then a final (and thus fictive) weight of about 33250 ton is obtained. The latter is then subtracted by the measured final (or real) weight of the hopper (17250 ton) after 70 minutes:

- 16000 tons of overflow sediment-laden water during a time window of 70 minutes
- debit of 229 ton overflow water per minute or ~4 ton per second

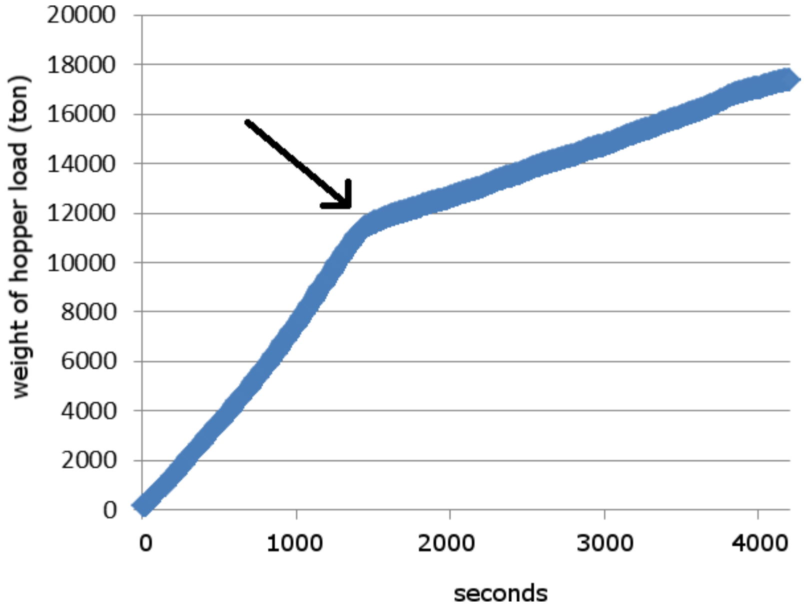

Figure 13: The weight of the hopper load linearly increases until the overflow starts (see black arrow), the slope now is less steep.

The particle concentration of the overflow water is about 1 g per liter implying that 16 ton sediment is brought into the water column via the overflow pipe during one single sand extraction event. This is a debit of 229 kg sediment per minute or ~4 kg sediment per second.

Method 2: based on 8 density profile measurements inside the hopper

By means of density measurements inside the hopper, one can track the raising character of the sand – water interface. When overflow started (after 23 minutes), the interface is located at about 4 m. At the end (after 70 minutes) of the sand extraction event, the sand-air interface (when all water has gone) was located at 10 m. Thus, after 23 minutes the ratio between sand and water is 3/5 (4 m of sand and 6 m of water). This is a ratio that can be used to estimate the volume of water that is being pumped to the hopper. The final hopper volume is 9290 m^3 of which 3716 m^3 (2/5) is sand and 5574 m^3 is water at the onset of overflow. By adding 2 times this volume of water, the total volume of water being pumped inside the hopper is 16722 m^3 resulting in following numbers:

- 239 ton water per minute or ~4 ton water per second
- 16.722 ton sediment
- 239 kg per minute or ~4 kg sediment per second

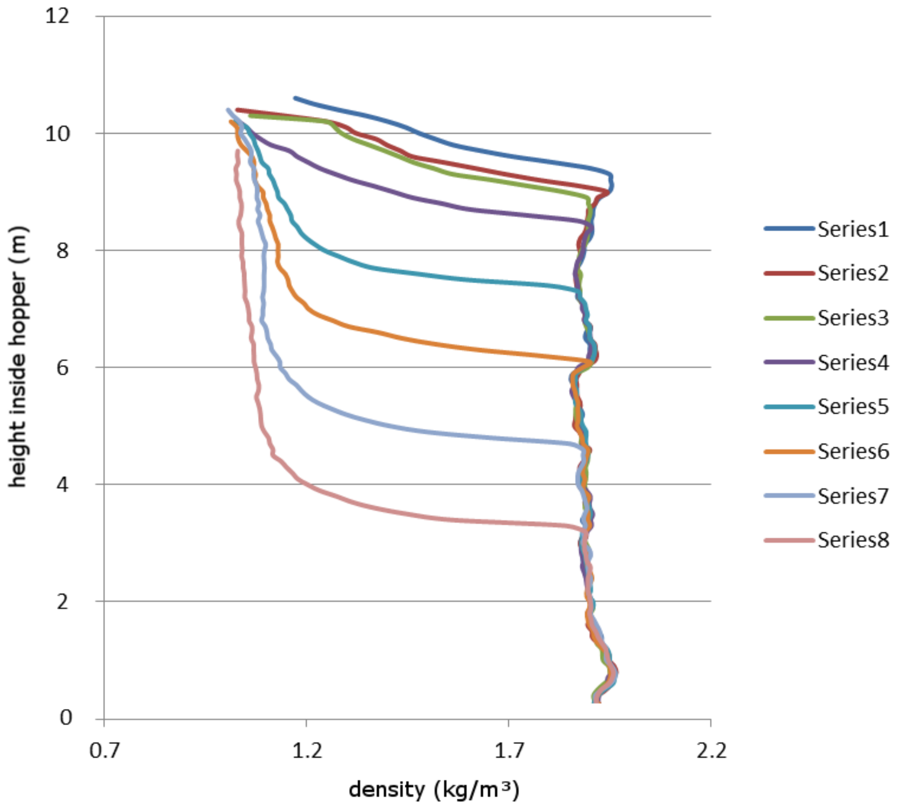

Figure 14: Density profiles inside the hopper load reveal raising sand-water interface. Water has a density close to 1.0 g/cm³; sand is 1.9 g/cm³.

Importantly and for the first time, two TSHD vessels (Breughel and Von Humboldt) were commissioned to combine both sand mining and harbour (access) maintenance operations. As a result, dredged matter having much higher silt-clay content is likely to remain inside the hopper enriching the fine particles in the overflow plumes during sand mining. Typically, the 2 TSHD vessels operated twice a day resulting in an amount of overflow particles equivalent to 4 heavy trucks. This accounts for 1 heavy truck per sand extraction event.

3.3. *Satellite imagery*

These plumes are being observed in satellite imagery with deriving sea surface plume concentrations of 0.01 g/l. In the period February to April 2017, intensive sand mining took place within sector 4c with a frequency of up to 4 trips per day as two hopper dredgers were simultaneously in operation, just before low tide. On 16/04/2017 (10h50 UTC), a Sentinel 2 satellite picture was taken during sand extraction by the TSHD Breughel (busy for 61 minutes, thus close to the end of that particular trip). The associated overflow plume is clearly seen from space. When correcting for atmosphere, concentrations up to 10 mg/L are estimated. Note that the plume is possibly sub-water surface, since the overflow pipe exit is at the hull of the TSHD - in the case of TSHD Breughel this is 10 m.

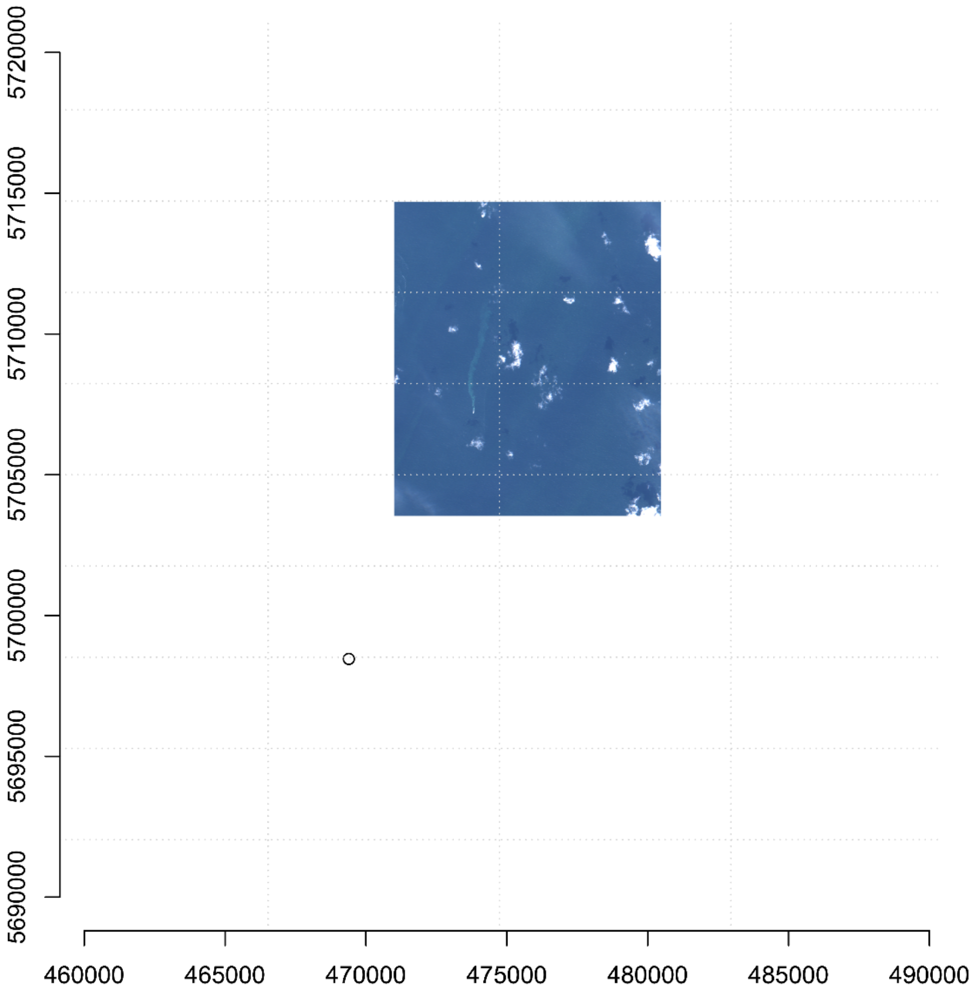

Figure 15: Distance between Breughel and BM-ADCP (circle) is about 8 km

Are overflow particles being "seen" by the BM-ADCP? The ADCP measures over a range of 15 m (as mentioned before), however, this is mainly true for current direction and speed data. Concerning the echo intensity, the range goes up to 30 m (full water column). When generally looking at the echo intensity data, there is no signal of overflow plume particles at first sight. When doing quick calculation to track the particles, an estimation of the time that the particles may reach the ADCP profile gives more direction to the data portions to look at more carefully. Still, no real signal evidencing the overflow is observed. Either, the particle pathways are not passing the ADCP location or the overflow particles are diluted to a strong degree.

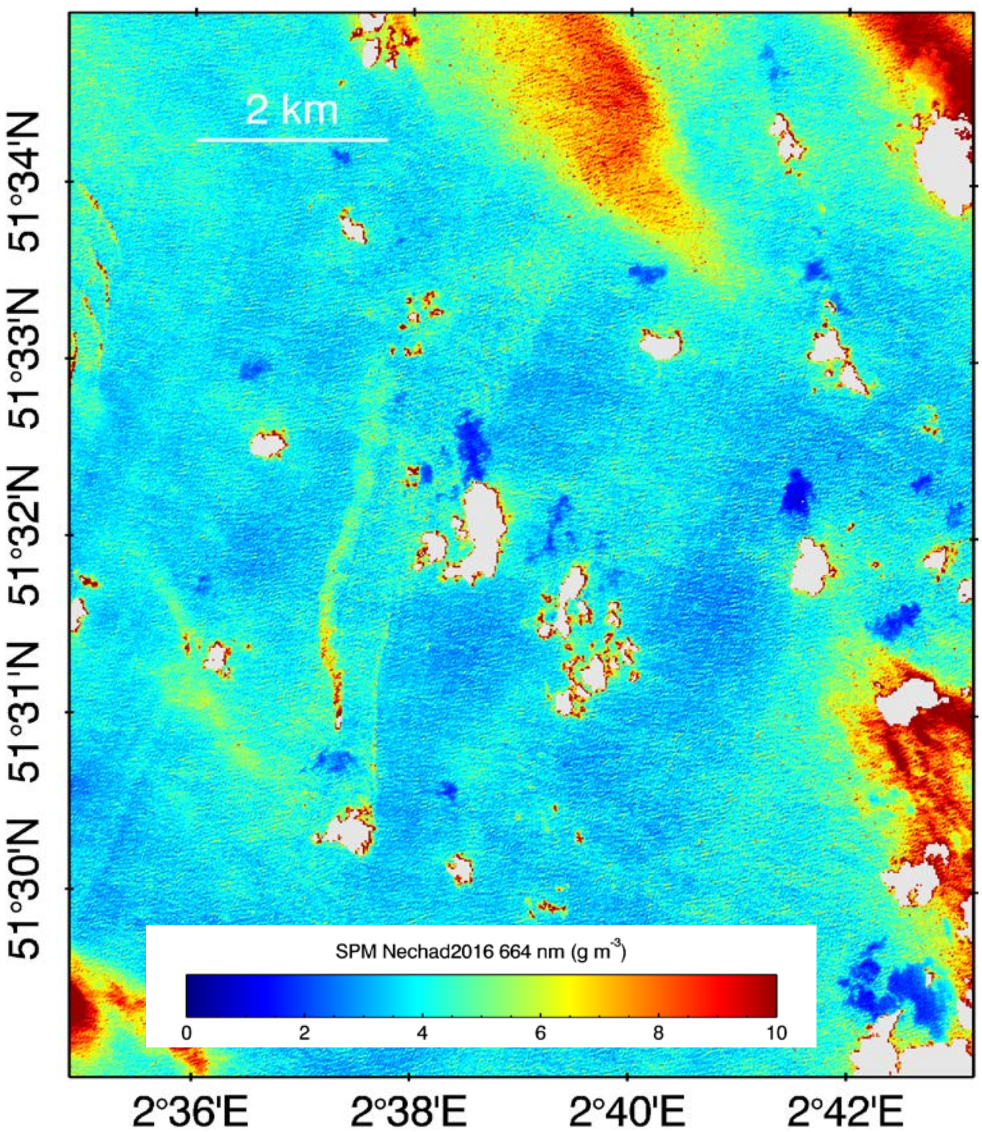

Figure 16: SPM concentration (mg/L or g/m^-3) derived from S2 satellite.

3.4. *Grain size analysis*

Dredger hopper sand was systematically sampled at the end of each extraction event (in the case of the Breughel hopper dredger, this timing also corresponds to the end of overflow). A total of 55 sand samples were analysed with MALVERN in order to understand the possible evolution of the fine fraction (~25 µm mode).

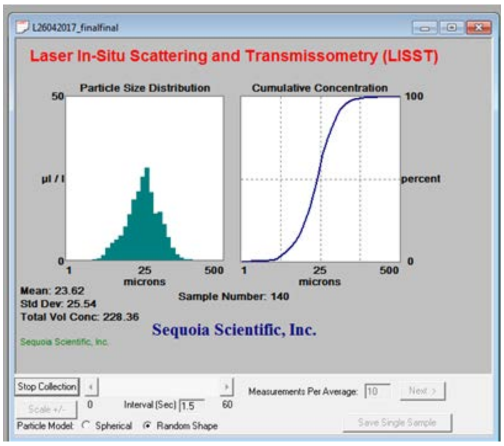

Figure 17: Overflow (trip 278 – on-board overflow water sampling) LISST analysis showing a fine fraction presence centred around ~25 µm, as summarized in Table 4. This fraction only seems to be measured during the overflow events, hence completely absent in the load sand sample when overflow was sand extraction activities were completed.

The latter measured in the overflow water directly on-board trip no 278 (19/04/2017) was the incentive for this grainsize analysis. The period of monitored sand extraction was between 12/03/2017 and 21/04/2017. However, the sand sample (from trip no 278, see Figure 17) surprisingly did not contain any particles associated to the overflow fine fraction. When looking at the 54 other sand samples (Figure 18), there was no presence of this fine fraction neither. The samples show overall medium-sized (Wentworth-scale) sand with main mode around 320 µm. Is this a result of the washing out during overflow or during sampling?

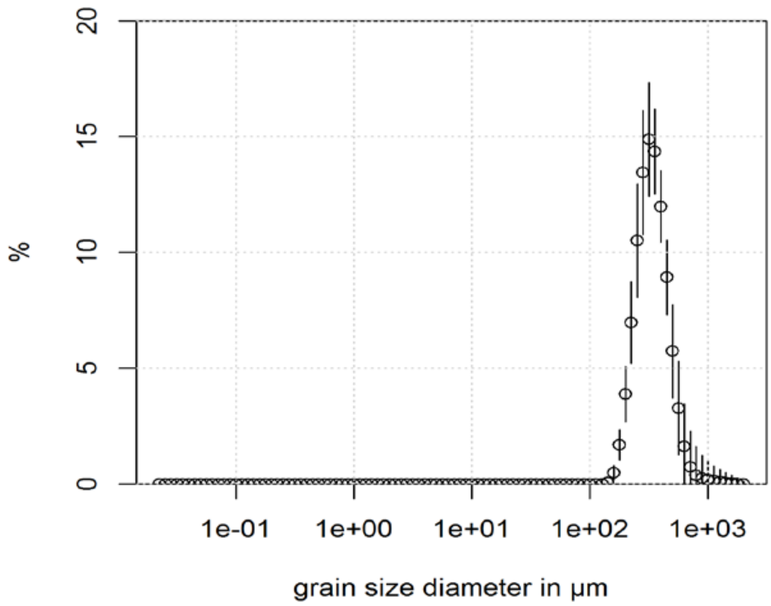

Figure 18: A summary of the MALVERN particle size distribution of all 55 sand samples collected when sand extraction activities were finished per trip (i.e. when overflow stopped). Fine fraction (~25 μm) was absent. Vertical bars are the standard deviation.

3.5. *Labo tests*

In the labo, tests have been executed to calibrate the grain size analysis, measured by different instruments. The results of the MALVERN were compared with results, obtained by the LISST, and by the ABS. Both the LISST and the ABS were installed in a cylindrical tank (see Figure 19). In Figure 20, the particle range for the different instruments is illustrated.

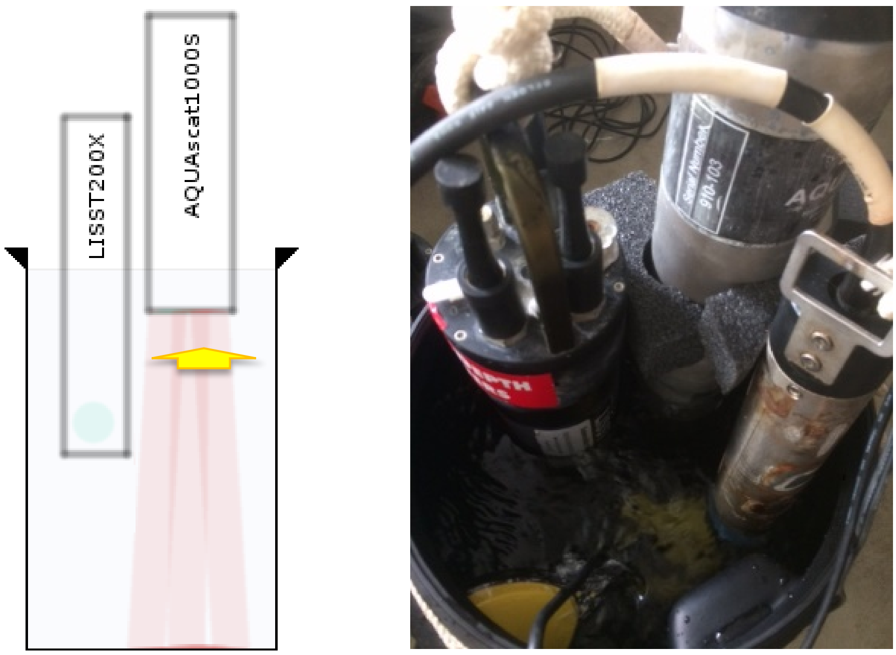

Figure 19: Left, sketch showing the cylindrical tank (height of 60 cm and diameter of 35 cm) with LISST and ABS. LISST measuring volume (blue spot) corresponds to ABS cell no 16 from which the mean particle size was considered here. Yellow arrow refers to continuous bottom-up mixing with submersible water pump. Right, top view photo of the instrumentation inside cylindrical tank.

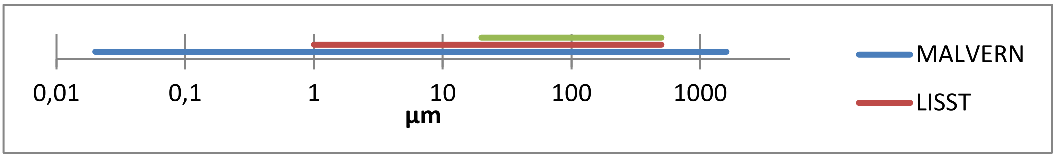

Figure 20: This overview gives the ranges in which the different particle size instruments measure.

The MALVERN particle size range is the largest followed by the LISST and ABS (smallest range). All instrumentation will theoretically measure the same particle size when ranging between 20 and 500 μm.

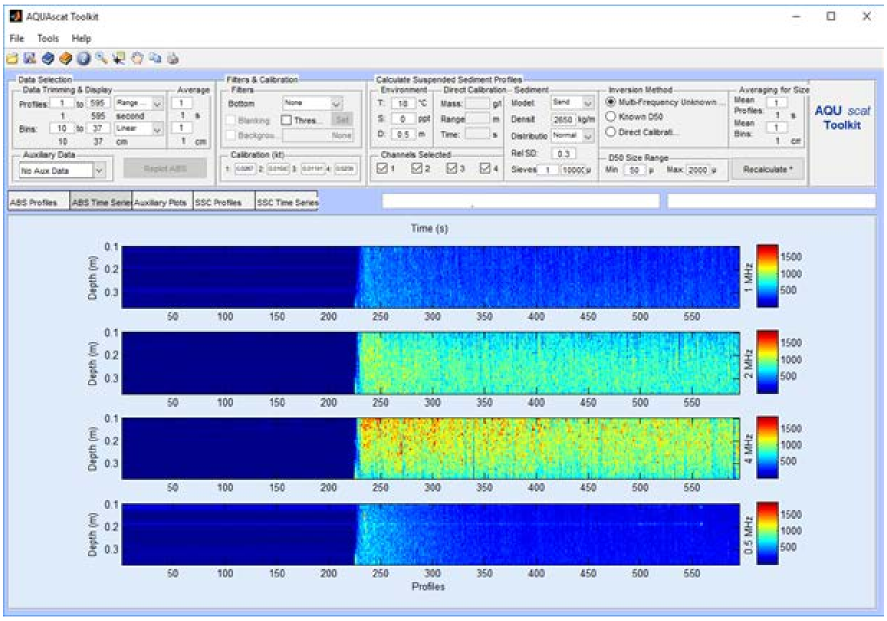

Figure 21: Visualization of the 4 ABS frequencies (1, 2, 4 and 0.5 MHz) is shown in this screenshot (y-axis is depth and x-axis is profile number at 1Hz). From profile 225 onwards sediment was added for particle size comparison tests.

Table 5 is a summary of the particle size distribution (PSD) as measured by the ABS, LISST and MALVERN. The latter two uses laser diffraction technology, the ABS use backscatter multi-frequency acoustics. LISST and MALVERN produce several PSD metrics (mean and percentiles or D-values), whereas the ABS only gives mean particle sizes. The 24 μm centred fine fraction is completely absent. Both LISST and MALVERN full particle size distributions are shown in Figure 22 and 23. Note that the instrumentation range subtly influences the PSD metrics. For example the LISST mean is smaller than the MALVERN mean since the MALVERN measured particles with diameters larger than the LISST upper range limit.

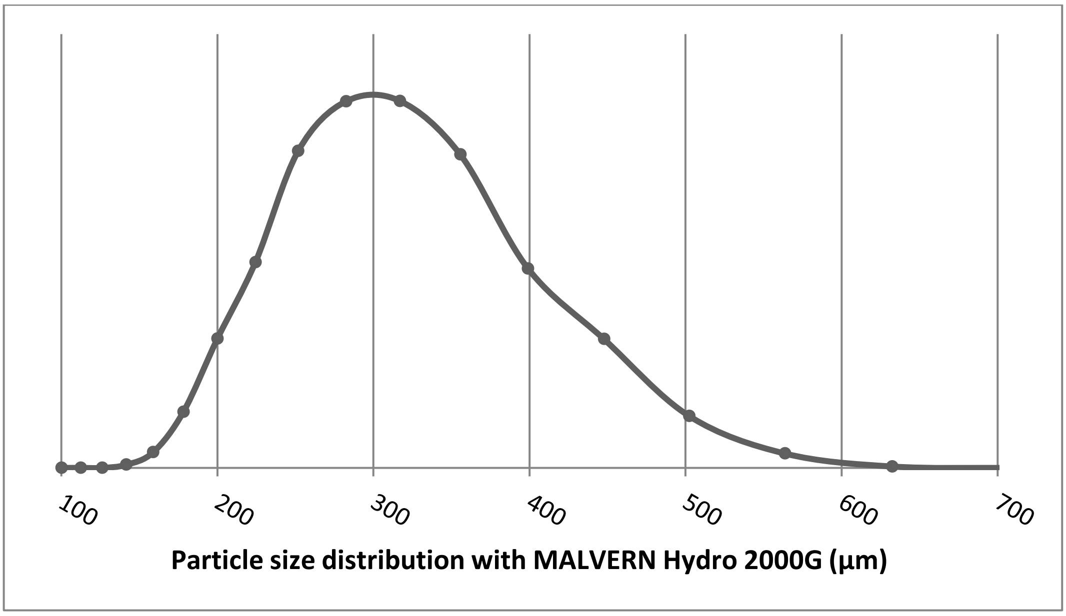

Figure 22: Particle size distribution with MALVERN Hydro 2000G (µm)

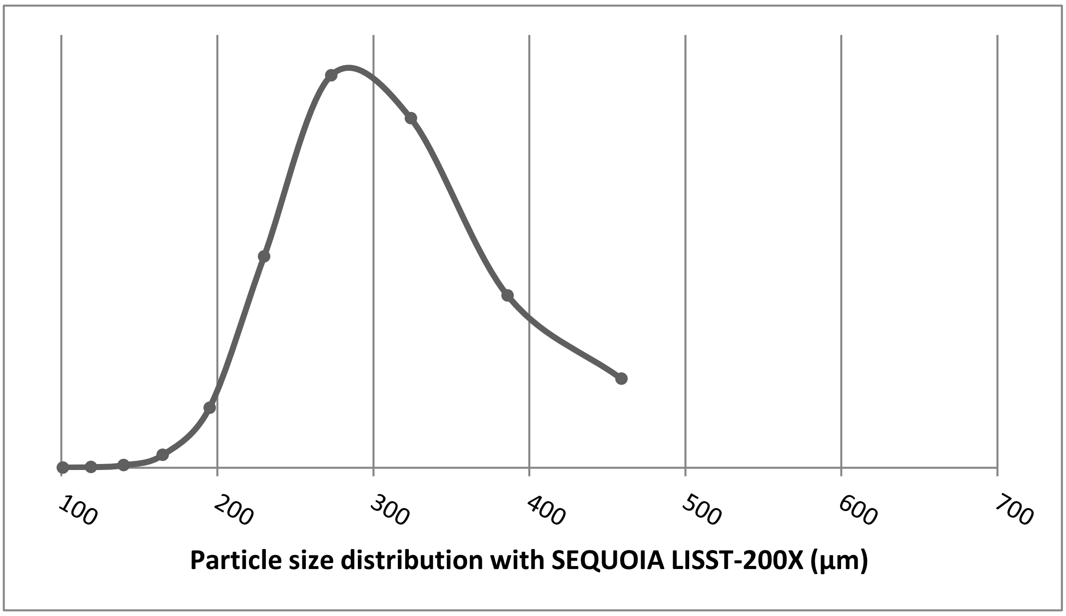

Figure 23: Particle size distribution with SEQUOIA LISST-200X (µm)

Table 5: Mean and percentiles (D-values) in μm result from different particle sizer instruments. Note the varying particle size measuring range for each instrument.

Method	Range	d10	d50	mean	d90
ABS	20 - 500	--	--	305	--
LISST	1 - 500	220	291	291	395
MALVERN	0.02 - 2000	202	282	308	393

COLOPHON

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Royal Belgian Institute of Natural Sciences
Operational Directorate Natural Environment
100 Gulledelle
B–1200 Brussels
Belgium
Phone: +32 2 627 41 91
http://www.naturalsciences.be/
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Suspended Matter and Seabed Monitoring and Modelling Group
and
Management Unit of the North Sea Mathematical Models

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Annex 1: Photos taken during the visit on the TSHD Brueghel

Annex 2

Van den Eynde, D., 2018. Measuring, using ADV and ADP sensors, and modelling bottom shear stresses at the MOW1 site (Belgian continental shelf). Brussels, RBINS-OD Nature. Report MOMO-ZAGRI-MOZ4-INDI67/1/DVDE/201801/EN/TR01 (Revised version of Report MOMO-INDI67/1/DVDE/201608/EN/TR01), 47 pp.

ROYAL BELGIAN INSTITUTE FOR NATURAL SCIENCES
OPERATIONAL DIRECTORATE NATURAL ENVIRONMENT

Section Ecosystem Data Analysis and Modelling
Suspended Matter and Sea Bottom Modelling and Monitoring Group (SUMO)
and
Management Unit of the North Sea Mathematical Models (MUMM)

Measuring, using ADV and ADP sensors, and modelling bottom shear stresses at the MOW1 site (Belgian continental shelf)

Dries Van den Eynde

MOMO-ZAGRI-MOZ4-INDI67/1/DVDE/201801/EN/TR01

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RBINS-OD Nature
100 Gulledelle
B–1200 Brussels
Belgium

Table of Contents

1. Introduction

The bottom shear stress is an important factor for the calculation of sediment transport. The bottom shear stress determines the erosion and resuspension of the material. Furthermore, different total load and bottom load formulae take into account the bottom shear stress (or a related parameter). The calculation of the bottom shear stress, under the combined influence of currents and waves, is however not a trivial task. Different methods and techniques are available in literature, sometimes using many parameters, which are not well known. The methods can vary from very simple models to very complex and time-consuming models. Also for the bottom roughness length, one of the main parameters determining the bottom shear stress, different models are available in literature. All these different models can give results that can vary over a large range.

Furthermore the measuring of the bottom shear stress is very complex and reliable bottom shear stress measurements, that could be used to validate the model predictions, are at the moment not available. Different methods are available to "measure" the bottom shear stress. In Francken and Van den Eynde (2010) a method was described, to calculate the bottom shear stress from the measurements from a high frequency point velocity meter (Acoustic Doppler Velocimeter ADV), where the bottom shear stress can be calculated, using the decay in the turbulent velocity spectrum in the high frequency range, the. Also the turbulent kinetic energy or the Reynolds stresses, which can be calculated from the high frequency velocity variations, can be used to calculate the bottom shear stress. Finally, the bottom shear stress can be calculated from the logarithmic profile of the water currents in the lower water column. These current profiles can be measured using an Acoustic Doppler Profiler (ADP).

In Van den Eynde (2015) measurements from 70 deployments with ADP and ADV sensors installed on bottom landers between 2005 and 2013 were analysed. The results of different numerical models for bottom shear stress and bottom roughness lengths (as a function of bottom ripples) were presented and their results were validated, using the measured bottom shear stresses. These first results showed that the bottom shear stress calculated using different methods do not correlate very well with each other and it is not straightforward to obtain reliable measurements of the bottom shear stress. The turbulent kinetic energy method seems to give the most reliable estimates of the bottom shear stress. Two deployments, one offshore and one nearshore, were analysed in more detail to validate the results. The results showed that the bottom shear stress could be modelled with a sufficient accuracy but that the value of the bottom roughness length could vary over different order of magnitudes. Overall, reasonable results for all deployments were obtained with the Soulsby model and with a bottom roughness length of 0.01 m.

In the present report, measurements of the bottom shear stress from one deployment at the MOW1 site are analysed in more detail. A new method to derive the bottom shear stress from high frequency measurements of current velocity, i.e. the eddy correlation method, was used additionally. Some more pre-processing of the data was included to try to increase the quality of the measurements.

The measurements and the numerical models are discussed in the first two sections. Hereafter the analysis of the bottom stress measurements is presented. In the next section, the validation of the numerical models is discussed. Finally some overall conclusions from the comparison of the model results with the measurements and plans for further work are given at the end.

2. Description of the measurements

To measure the bottom shear stress, measurements were executed with bottom landers that are deployed at the bottom of the sea (see **Error! Reference source not found.**). The frame is, amongst others, equipped with a SonTek ADV Ocean point velocity meter, at 36 cm above the bottom (measuring at 18 cm above the bottom) and a downward looking SonTek 3 MHz ADP current profiler, at 228 cm above the bottom. Measurements of the ADP could be used to calculate the bottom stress from the current profile, while the measurements of the ADV could be used to calculate the bottom stress, using the inertial dissipation method, the eddy correlation method or the turbulent kinetic energy method.

The deployment 071 was executed at station MOW1 (51.360668 °N, 3.114650 °E), near the harbour of Zeebrugge in a water depth of about 10 m. The deployment was executed from 21/08/2013 till 23/09/2013. The position of the stations is presented in Figure 2.

The period comprises more than two spring-neap tidal cycles, with spring-times around days 4, 17 and 31 (Figure 3Figure 19). The significant wave height is below 1 m during the first 20 days of the deployment (Figure 4Figure 22). From day 20 till day 30, higher waves occur, with a peak in significant wave height above 3.0 m at day 21.

Figure 1: Tripod bottom lander.

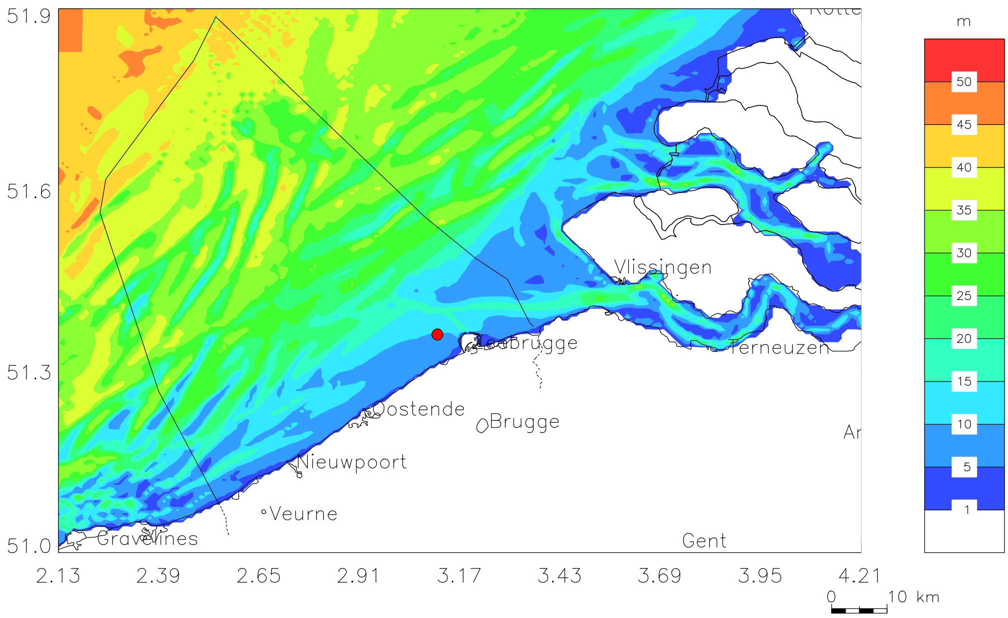

Figure 2: Position of the measuring station. Bathymetry of the OPTOS-BCZ model.

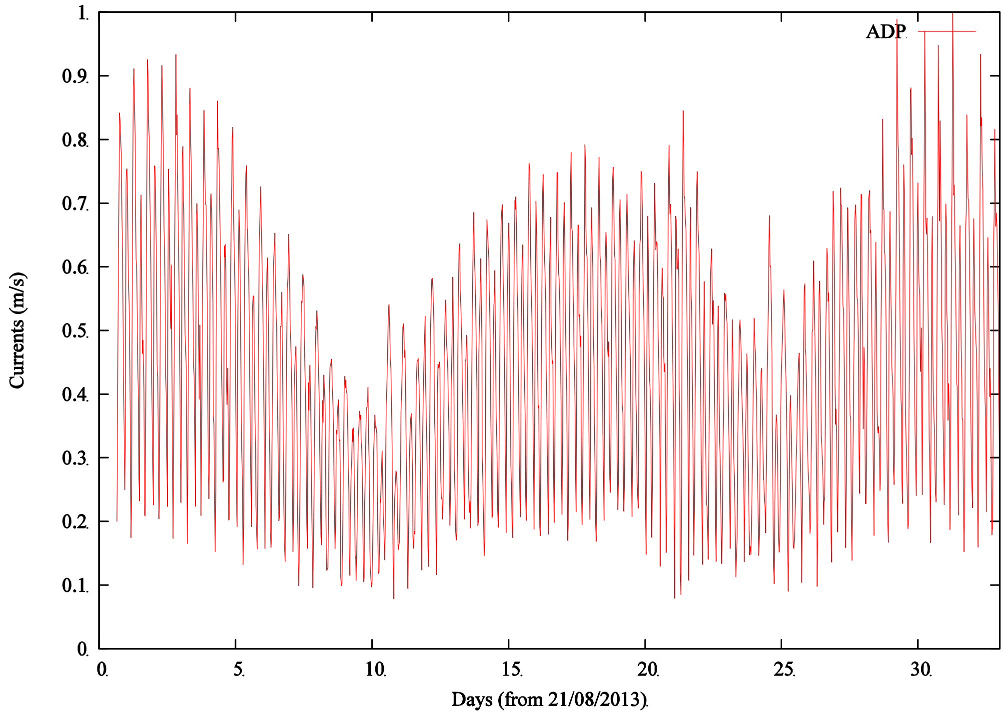

Figure 3: Currents, measured with the ADP during deployment 071.

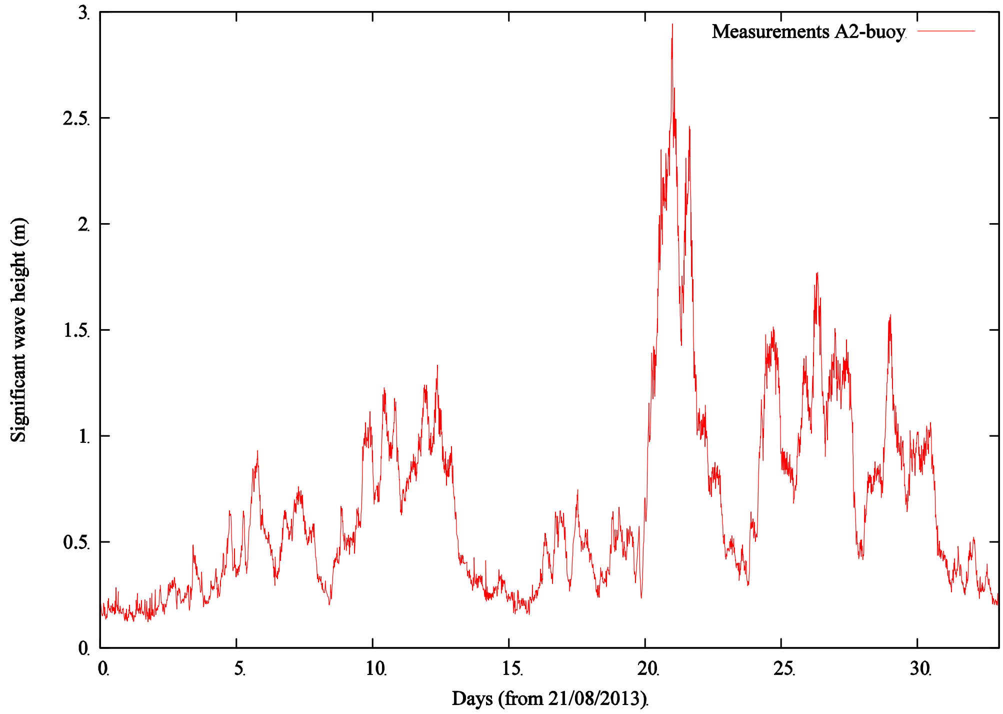

Figure 4: Waves measured at the A2-buoy (data from Vlaamse Gemeenschap, Meetnet Vlaamse Banken).

3. Numerical models

3.1. Introduction

To calculate the bottom shear stress under the influence of the currents and the waves, numerical models are used. A three-dimensional hydrodynamic model is used for the calculation of the water elevations and the currents. A third generation wave model is used to calculate the waves. Both models will be discussed shortly.

Furthermore, different methods and models are available in literature to calculate the bottom shear stress from the currents and waves. The different models that are used in this study, together with the models to calculate the bottom roughness under the influence of bottom ripples and bed load, are discussed in the next section.

3.2. Hydrodynamic model OPTOS-BCZ

The three-dimensional hydrodynamic modelling software COHERENS calculates the currents and the water elevation under the influence of the tides and the atmospheric conditions. The model was developed between 1990 and 1998 in the framework of the EU-MAST projects PROFILE, NOMADS and COHERENS. The hydrodynamic model solves the momentum equations and the continuity equation with, if necessary, equations for the sea water temperature and salinity. The momentum and continuity equations are solved using the 'mode splitting' technique. COHERENS disposes over different turbulent closures. A good description of the turbulence is necessary for a good simulation of the vertical profile of the currents. A new version of the COHERENS software has been developed recently (Luyten *et al.*, 2014), mainly allowing the model to use parallel computing, while adding also some new features, such as improving the numerical scheme and adding a wetting-drying mechanism.

The model OPTOS-BCZ is based on this COHERENS code and is implemented on the Belgian Continental Shelf with a grid with a resolution of 42.8″ in longitude (816 to 834 m) and 25″ in latitude (771 m). This model has a 10 σ-layers distributed over the total water depth. Along the open boundaries, the OPTOS-BCZ model is coupled with two regional models. The OPTOS-CSM model comprises the entire Northwest European Continental Shelf and calculates the boundary conditions of the North Sea model OPTOS-NOS. The latter model calculates the boundary conditions of the OPTOS-BCZ model. The OPTOS-CSM model calculates the depth-averaged currents and is driven by the water elevations at the open sea boundaries, using four semi-diurnal and four diurnal constituents. The bathymetry of OPTOS-BCZ model is shown in Figure 2.

The OPTOS-BCZ model was validated, amongst others, in the framework of the Marebasse project (Van Lancker *et al.*, 2004) and the BOREAS project (Dujardin *et al.*, 2010; Mathys *et al.*, 2011).

3.3. Wave model WAM

The WAM model is a third generation wave model, developed by the WAMDI Group (1988) and described by Günther *et al.* (1992). The WAM model is used both for research and for operational wave forecasting. It includes 'state-of-the-art' formulations for the description of the physical processes involved in the wave evolution. In comparison with the 2nd generation model, the wave spectrum has no restrictions and the wind sea and the swell spectrum are not treated separately.

At the Operational Directorate Natural Environment, the model is running on three coupled model grids. A coarse model grid comprises the entire North Sea, the Fine model models the central North Sea and the Local model calculates the waves in the Southern Bight. The local model has a grid resolution of 0.033° in latitude and 0.022° in longitude. The bathymetry of this local model grid is presented in Figure 5.

The WAM model was recently validated by Van den Eynde (2013).

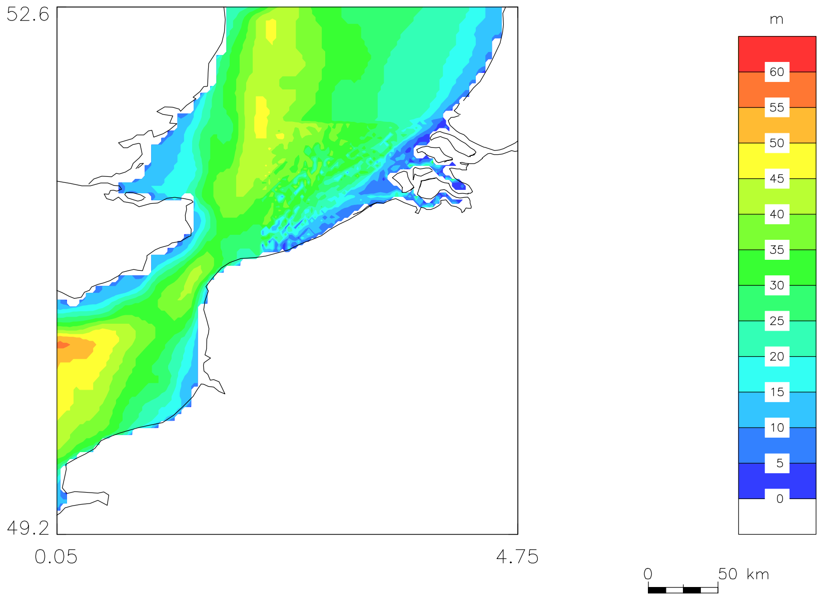

Figure 5: Model grids of the local grid WAM model.

3.4. *Calculation of the bottom shear stress*

3.4.1. Introduction

The calculation of the bottom shear stress is the topic of much research. The bottom shear stresses under the influence of currents alone and under the influence of waves alone over a flat bottom are quite well known. However, the calculation of the bottom shear stress under the combined influence of currents and waves, over a rippled sea bed is complex. First of all, the calculation of the bottom shear stress under the influence of currents and waves is not the simple vector addition of the bottom stress vectors for the currents and the waves alone. Non-linear interactions increase the mean bottom shear stress.

Furthermore, the bottom roughness length, which is an important factor for the calculation of the bottom shear stress, is influenced by different factors. At the bottom itself, the roughness is a function of the grain size. This bottom shear stress, felt by the sediments is called the skin friction. However, at a distance more than a tenth of the length of the bottom ripples, the bottom roughness is also influenced by the bed load and by the height and the length of the bottom ripples. Further away from the bottom, a new logarithmic profile is followed with an apparently increased bottom roughness. The ratio between the skin bottom roughness and the total bottom roughness varies between 1.5 and 20.

In the next sections the bottom shear stress under the influence of the currents, under the influence of the waves and under the influence of the combined effect of currents and waves are discussed separately. Furthermore, also the calculation of the bottom roughness length is discussed in a following section.

3.4.2. Bottom shear stress under the influence of currents

The bottom shear stress under the influence of currents can be written as:

$$\tau_c = \rho C_D \bar{u}^2 = \rho \left(\frac{\kappa}{ln \frac{h}{e z_0}} \right)^2 \bar{u}^2 = \rho u_*^2 \tag{1}$$

with	τ_c	bottom shear stress under the influence of currents
	ρ	water density
	C_D	drag coefficient
	$\bar{u}$	depth-averaged current
	κ	Von Karman constant=0.4
	h	water depth
	e	2.7182
	z_0	bottom roughness length
	u_*	shear velocity

As stated above, for the bottom roughness length, a difference has to be made between the skin bottom roughness felt by the grains itself at the bottom, and the total bottom roughness that is felt by the currents and that is also influenced by the bottom load and by the bottom ripples.

3.4.3. Bottom shear stress under the influence of waves

The bottom shear stress under the influence of waves is calculated using the (maximum) orbital velocity at the bottom. Using linear wave theory, the maximal orbital velocity of a monochromatic wave can be calculated as:

$$u_w = \frac{\pi h_s}{T \sinh(kh)} \tag{2}$$

with	h_s	significant wave height
	T	wave period
	k	wave number

When calculating the wave orbital velocity of a wave spectrum, most of the time the significant wave height and the mean water period are taken as characteristics, although some other recommendations can be found in literature. The wave orbital excursion A can be calculated as:

$$A = \frac{u_w T}{2\pi} \tag{3}$$

The (maximum) bottom shear stress under the influence of waves is then calculated as:

$$\tau_w = \frac{1}{2}\rho f_w u_w^{\,2} \tag{4}$$

with τ_w bottom shear stress under the influence of waves
f_w wave factor

Also for the wave factor, different theories or models are available, however, with relative small differences.

3.4.4. Bottom shear stress under the influence of currents and waves

For the calculation of the bottom shear stress under the influence of currents and waves, a distinction must be made between the mean bottom stress, averaged over a wave cycle and the maximum bottom stress, during a wave cycle. First of all, the mean bottom stress over a wave cycle is augmented by non-linear interactions between the currents and the waves. The maximum bottom stress is the maximum bottom stress during a wave cycle and therefore is not a simple addition of the bottom stress under the influence of the currents and the waves.

Many different models can be found in literature, varying from simple models to very complex iterative models, resolving the stresses in the wave boundary layer and during a complete wave cycle. These very complex models are however very time consuming and not really useful to be used in sediment transport models. In Van den Eynde and Ozer (1993), different simple models were compared with each other and with the results of more complex models, as they were presented in Dyer and Soulsby (1988). The Bijker (1966) model was selected as a good model, giving realistic model results. This model however does not give realistic results for the bottom shear stress under the influence of waves with very small currents. Additionally, no formulation was given for the mean bottom shear stress over a wave cycle. Therefore, this model is not used in this study.

Recently, more realistic and simple models for the combined bottom shear stress were proposed in literature. Therefore, three new formulations were implemented and tested.

First of all, the Soulsby (1995) formulae were implemented which were the results of a two-coefficient optimisation of a simple model to 131 data points, from more complex theoretical models.

More recently, Soulsby and Clarke (2005) developed a new model, assuming an eddy viscosity varying over the water column, but constant in time. The eddy viscosity varies linearly above the bottom in the thin wave boundary layer and has a parabolic function outside the wave boundary layer. Remark that the eddy viscosity is much higher in the thin wave boundary layer than outside. Furthermore, the eddy viscosity in the wave boundary layer is only a function of waves and currents, so that no iterative calculations are needed.

In the wave boundary layer, the shear stress is constant, outside the wave boundary layer, the shear stress varies linearly, to zero at the water surface. A current profile can be calculated by integration of the current profile over the water depth, giving a quadratic equation that can be used to solve the bottom shear stress. The model of Soulsby and Clarke (2005) gives both a formulation for the maximal bottom shear stress during a wave cycle, and the mean bottom shear stress, averaged over a wave cycle. Furthermore, the theory was developed, both for flow over rough and over smooth bottom.

Finally, Malarkey and Davies (2012) developed the theory of Soulsby and Clarke further to include additional non-linearity in the model, which is present in the more complex theoretical models, but is not found in the Soulsby-Clarke model.

More information and some comparison of the results of the different models can be found in Van den Eynde (2015).

3.4.5. Calculation of the bottom roughness

As indicated above, the bottom shear stress under the influence of currents and waves is a function of the bottom roughness length z_0 (for turbulent flow with a rough bottom). A division has to be made between the bottom roughness length at the bottom itself, the skin bottom roughness, caused by the bottom material itself, and the total roughness, felt by the currents and the waves, which are also influenced by the bottom load and the bottom ripples. The skin and the total bottom roughness can be specified by the user itself, or can be calculated by a model. The bottom roughness length, the height above the bottom where the logarithmic current profiles becomes zero, is normally written as a function of the Nikuradse bottom roughness k_s, of the viscosity of the water ν and the friction velocity:

$$z_0 = \frac{k_s}{30} + \frac{\nu}{9u_*} \quad (5)$$

For hydrodynamic rough flows (as is the case for flows over a sandy bed), the second part of the bottom roughness length can be neglected.

The skin bottom roughness is mostly written as a function of the grain-size distribution. A much used formulation is:

$$k_{ss} = 2.5 d_{50} \quad (6)$$

with d_{50} the grain size for which 50% is smaller.

Values for the total bottom roughness can be found in tables. Typical values, found in literature, are k_s=0.2 mm for a mud bottom or k_s=6 mm for a rippled sand bottom. Wang et al. (2000) uses a bottom roughness z_0 of 0.1 cm, thus a bottom roughness k_s of 0.03 m. Drake *et al.* (1992) measured a bottom roughness z_0 over a rippled bed in the order of 1-2 cm.

For the roughness as a function of the bottom load, a division is made between current-domination and wave-domination. For current-domination, the formula, proposed by Wilson (in Soulsby, 1997) is used. For wave-domination, five different possibilities were implemented, which are: 1) the Grant and Madsen (1982) model; 2) the Soulsby model; 3) the Grant and Madsen (1982) model, assuming wave-domination; 4) the Nielsen model and 5) the Raudkivi formulation (all in Soulsby, 1997). For the exact formulations, the reader is referred to Soulsby (1997).

Finally, the bottom roughness length is a function of the bottom ripples. Normally the bottom roughness, due to bottom ripples is written as:

$$k_{sv} = 27.7\frac{\eta^2}{\lambda} \qquad (7)$$

with η the ripple height
λ the ripple length

The ripple geometry itself can be calculated by the model again. Also here, a distinction is made between current-dominated ripples and wave-dominated ripples. Two models to calculate the ripple geometry were implemented. The first model uses the ripple geometry, proposed by Soulsby (1997) for the current-dominated ripples and the ripple geometry, proposed by Grant and Madsen (1982) for the wave-dominated ripples. More recently, a new ripple predictor was proposed by Soulsby and Whitehouse (2005). The model was validated against many laboratory and field experiment results and has the advantage that the time evolution of the ripples can be accounted for. Furthermore, for the current-dominated ripples, sheet flow and ripples that are washed out under larger currents are taken into account.

Again more information and some comparison of the results of the different models can be found in Van den Eynde (2015).

4. Analysis of the measurements

4.1. *Bottom stress from ADP data*

The ADP measured over 12 bins, with a bin size of 0.15 m. The highest bin was at 1.90 m above the bottom (mab), the lowest bin at 0.25 mab. The bottom shear stress can be calculated from the assumed logarithmic profile of the current near the bottom:

$$u = \frac{u_*}{\kappa} \ln \frac{z}{z_0} \tag{8}$$

with u the horizontal current velocity at z m above the bottom, κ the von Kármán constant, equal to 0.4, u_* the shear velocity and z_0 the bottom roughness length. This relation should be valid in the lowest 20% of the water column, below an outer turbulent region (Wilcock, 1996).

The shear velocity is related to the bottom shear stress, using the relation:

$$\tau = \rho u_*^2 \tag{9}$$

When the equation is rewritten as:

$$u = \frac{u_*}{\kappa} \ln z - \frac{u_*}{\kappa} \ln z_0 \tag{10}$$

the measured profile can be fitted to this logarithmic profile, using a least squares method (Wilkinson, 1984).

In Figure 6, current profiles, averaged over all current profiles in a certain direction, are shown. It can be seen that the current profiles in East and East-East-north (EEN) direction are showing a logarithmic profile neat the bottom, but are disturbed higher in the water column. This is probably due to the acoustic transponder that was installed on the tripod. This is also visible to a lesser extent in the profiles in East-north-north, in North, in South-East-East and South-South-East directions. Furthermore, it can be observed that the lowest current (at 0.25 mab) is often a little bit higher than the currents in the second lowest bin, see e.g. the profile in the West and the West-West-South directions. This lowest bin is possible disturbed by the bottom and/or by high concentrations of sediments near the bottom. Finally, one has to observe that during most of the profiles, not disturbed by the transponder, are more or less constant and don't show a clear logarithmic profile. Remark however, that it is expected that the actual profiles can differ significantly from the averaged profiles (Gross et al., 1992).

Taking into account the disturbance of the current profile in the region above 0.8 m, and the disturbance of the lowest current measurements, the bottom shear stress is calculated for the current profile over the region 0.30 mab to 0.90 mab, taking into account 4 current measurements at 0.40 mab, 0.55 mab, 0.70 mab and 0.85 mab. Drake et al. (1992) used the logarithmic profile to calculate the bottom shear stress, using measurements at three levels above the bottom. The only used the profiles (4 % of the profiles) with a correlation coefficient (see Appendix 1 for the definition of the statistical parameters, used in this report) higher than 0.997, since for lower correlation coefficients, the errors on the bottom stress estimates becomes too high. If only data with a coefficient of determination R^2 higher than 0.99 would be used, only 59 data points would be used. Therefore, this criterium is lowered for this study, so that all bottom stresses are used, with a R^2 higher than 0.95. In this case, 1478 profiles (6 %) can be used, to calculate the bottom shear stress. Remark that, due to the disturbance of the current profiles, the distribution of the good profiles over the different directions is not uniform (see Figure 7). For the current going to East, almost 10 % of the data are used to calculate the bottom shear stress. For currents going to the North, West or South, only about 2 % of the data can be used. Remark that these values do not change significantly, when only the first 20 days, with moderate waves, are taken into account.

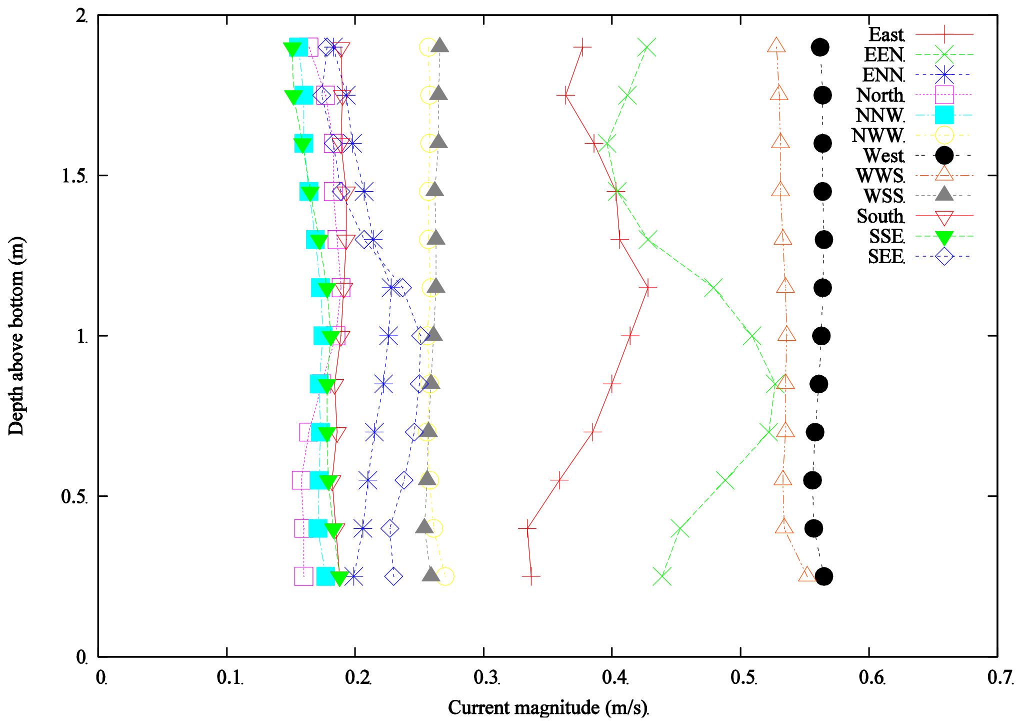

Figure 6: Current profile above the bottom, averaged over the entire deployment 071, for the different current directions.

The calculated bottom shear stresses are shown in Figure 8. Remark that the data from the altimeter on the ADV is used to follow the evolution of the bottom below the tripode. The data from the altimeter is used to correct the level above the bottom where the currents measurements were performed. The correction of the altimeter data is shown in Figure 9.

The bottom shear stress clearly shows a tidal and a spring-neap tidal cycle. Data after day 26 start to get much higher and could not be reliable. Overall, the calculated bottom shear stresses seem high. Remark that when the current nearest the bottom (at 0.15 mab) is taken into account for calculating the bottom shear stresses, the calculated bottom shear stress is much lower. The correlation coefficient however decreases and a minimum correlation coefficient of 90% must be used (instead of a minimum correlation coefficient of 95%) to obtain sufficient results. The fact that the bottom stress calculation from the current profile gives large estimates could be due to effects of stable stratification, associated with suspended sediments (Kim *et al.*, 2000; Fugate and Chant, 2005).

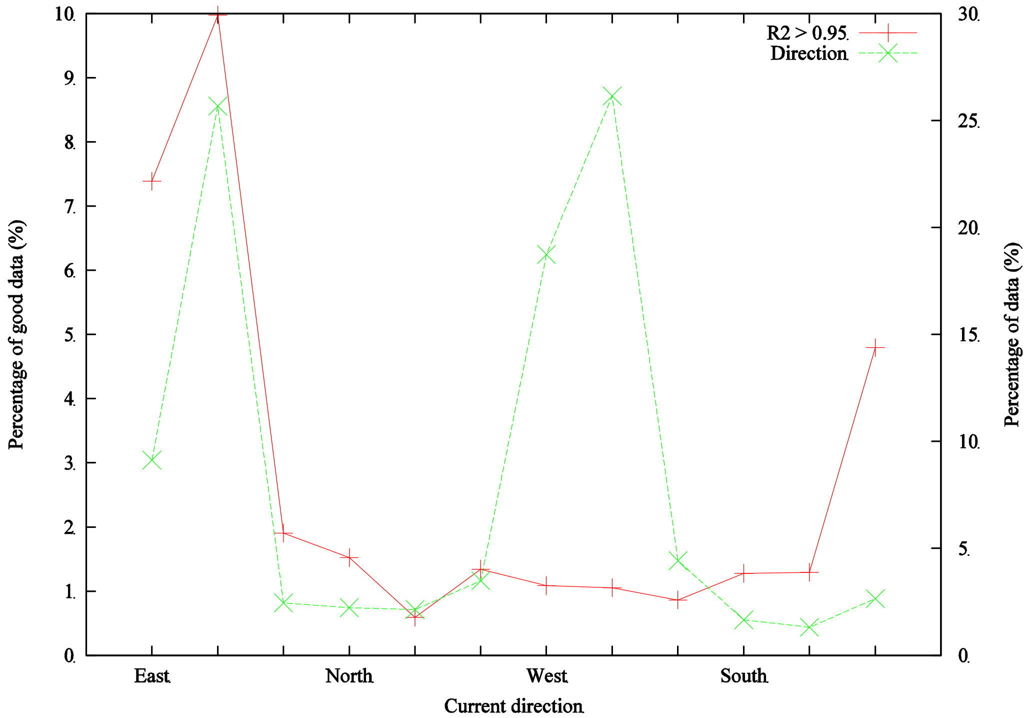

Figure 7: Percentage of good data, as a function of the current direction (red) and the distribution of the current direction of the full deployment.

4.2. *Bottom stress from ADV data*

4.2.1. Preprocessing of the data

The ADV data contain of burst of 7500 samples with a sampling frequency of 25 Hz. The burst interval is 15 minutes. The high frequency data contain, the three dimensional currents, measured at 18 cm above the bottom (when no bottom evolution is present). Also the "correlation" between the three beams of the ADV is recorded. This correlation factor is a measure for the quality of the data, which can be disturbed, e.g. by bubbles or suspended sediments (Elgar et al., 2005). According to the manual of the instrument, the data are suspicious when the correlation falls below 70 %.

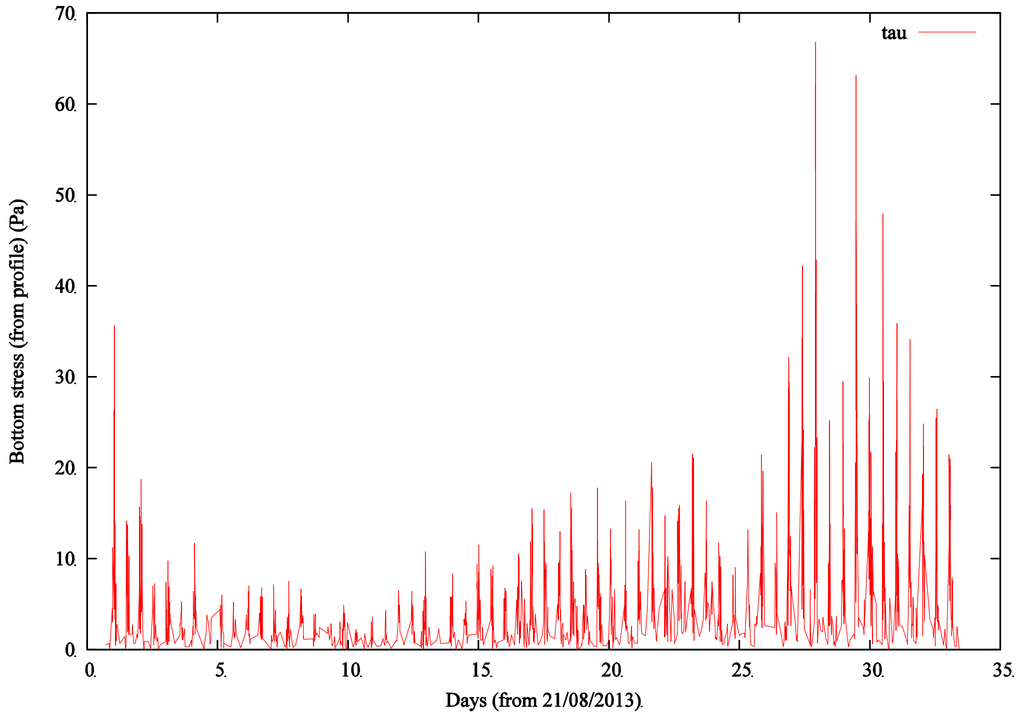

Figure 8: Bottom shear stress, calculated from the current profiles.

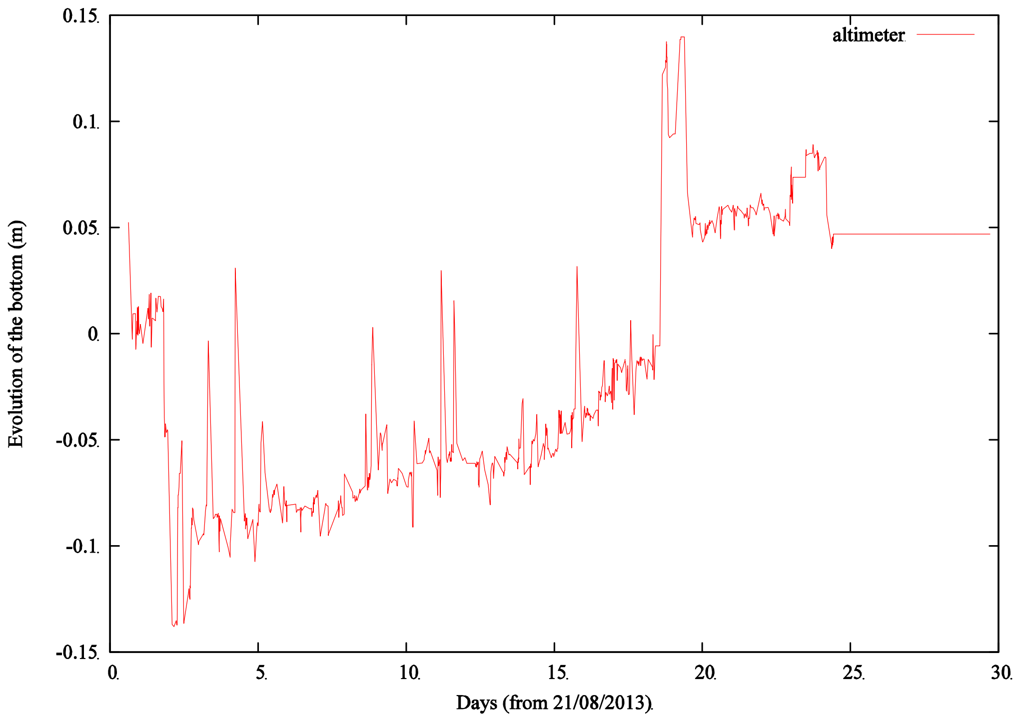

Figure 9: Altimeter data, used to correct the level above the bottom from the current measurements.

The data analysis starts with removing the bad or suspicious bursts. If more than 5 % of the burst data have a correlation (one of the three) that falls below 70 % (or

80 %), the burst data is considered bad and these data are skipped. In total, 220 (490) data burst (8.5 % (19.0 %) of the data) are removed this way. One must remark that the most data were removed in the period with higher waves (after day 21). For the bursts, where less than 5 % of the data have a correlation below 70 %, the bad data, with a correlation below 70 %, were replaced by the mean values at the borders, or were (linearly) interpolated. Also here the most interpolations were executed during the period with higher waves. Finally, the first 17 samples in the burst were removed, during which the compass was not working correctly.

A second step was to remove the spikes from the data. This despiking is executed following the method of Goring and Nikora (2002). In this method the original data, the first and the second derivatives are plotted against each other in a space-phase plot. The points outside the ellipsoid, defined by the Universal criterion are designated as spikes. These spikes are replaced by a third order polynomial using 6 points on either side of the spike. The method iterates until all spikes are removed. An example of the phase-space plots for the first burst is shown in Figure 10.

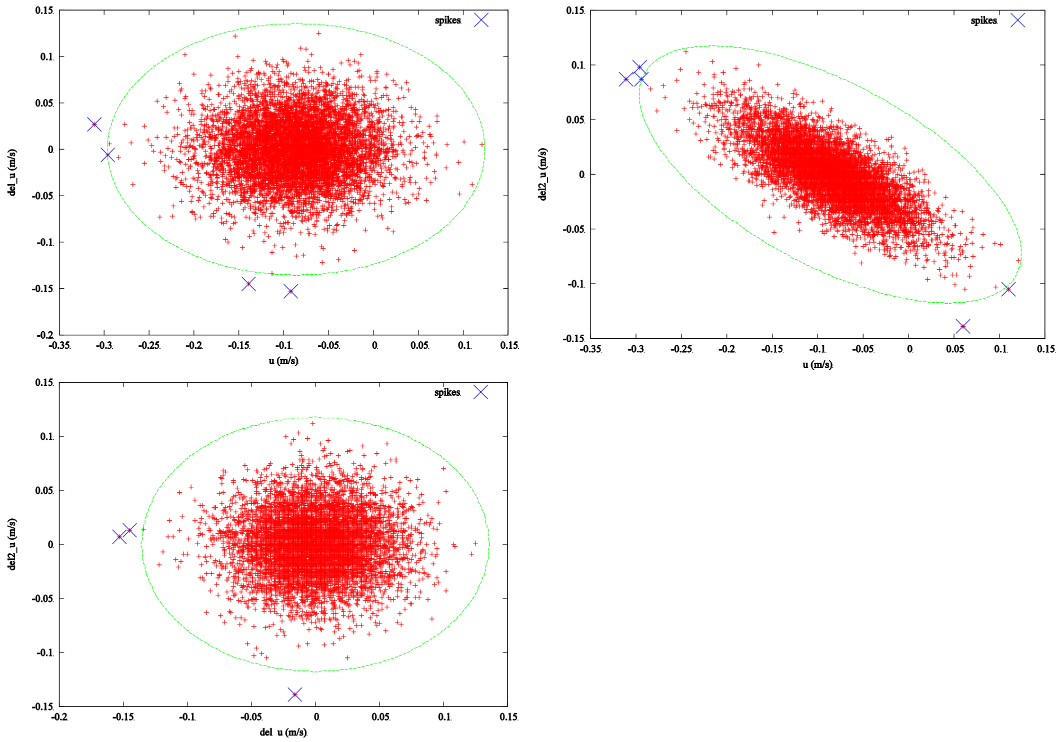

Figure 10: Phase-space plots for the u-velocity of the first burst of the deployment with the ellipsoid defined by the Universal criterion. Left-upper: u-velocity plotted against derivative of u-velocity; right-upper: u-velocity against second derivative of the u-velocity; left-lower: derivative of u-velocity against second derivative of u-velocity.

The total number of spikes, removed in u-velocity, v-velocity and w-velocity is shown in Figure 11. A tidal signal is visible and more spikes are occuring during the period with higher waves. Overall only 206 spikes has to be replaced during one burst, which is less than 1 %.

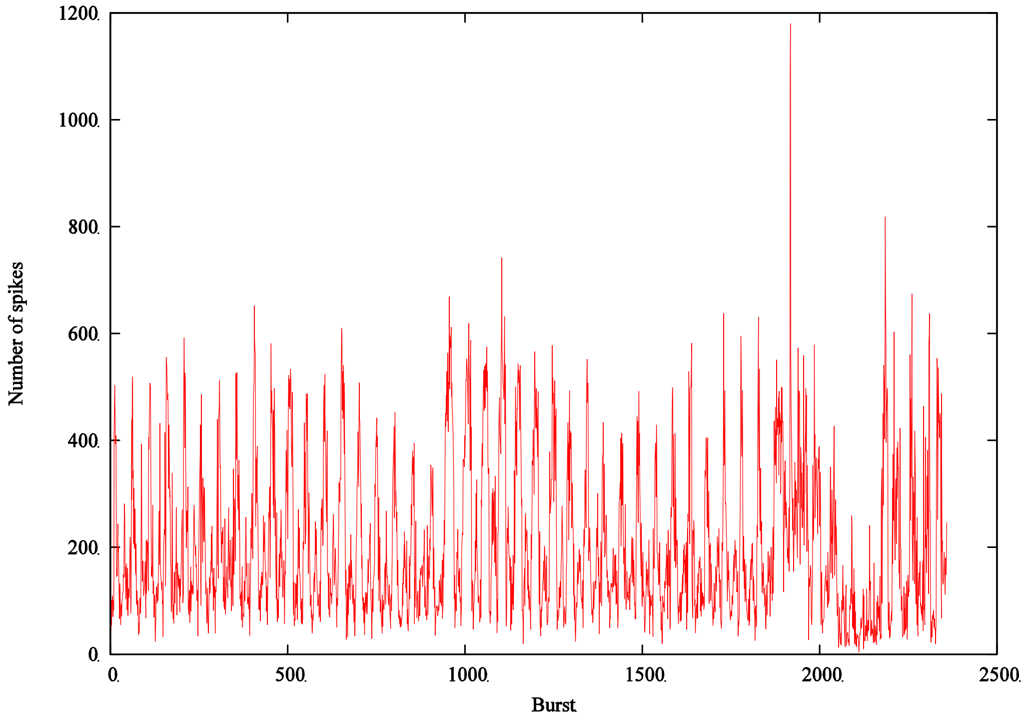

Figure 11: Number of total spikes (u,v,w) over the bursts.

Three methods can be used to calculate the bottom shear stress (e.g. Lecouturier, 2000; Williams *et al.*, 2003), which are discussed shortly hereafter.

4.2.2. Reynold stresses of Eddy Correlation Method

A first method to calculate the bottom shear stress is to calculate the bottom shear stress from the total Reynold stresses (e.g. Huthnance *et al.*, 2002; Williams *et al.*, 2003):

$$\tau = \rho\left(\overline{u'w'}^2 + \overline{v'w'}^2\right)^{1/2} \qquad (11)$$

This method is easy to apply, but the calculations are very sensitive to the correct vertical alignment of the velocimeter (Dyer *et al.*, 2004; Inoue *et al.*, 2011, Huntley, 1988). In theory, waves do not contribute to Reynolds stresses because the horizontal and vertical components of the wave-currents are 90° out of phase. However, if the vertical alignment is not correct, horizontal velocities can 'leak' into estimates of vertical verlocity and vice versa. Different methods are used to correct for this vertical misalignment (e.g., Elgar *et al.*, 2005). In Kim *et al.* (2000) and Lohrman *et al.* (1995) is is suggested to rotate the coordinate system first around the vertical axis until the mean flow is zero along one horizontal axis and afterwards rotating around the the horizontal axis where the mean velocity is zero, until the mean vertical velocity is zero. The rotation was calculated for the data within each tide and for the data within 4 successive tides. The calculated rotations are shown in Figure 12 and Figure 13. One can see that the rotation angles when calculated during each single tide can change considerable. The rotation angle around the vertical axis is around -20°. Indeed, the residual currents at the station is in the direction WSW (at angle 200°). Rotation around the vertical axis over 20° in clock-wise direction results in a mean velocity in West-direction. The rotation over the vertical axis between 10° and 20°, which is relatively high.

The calculated Reynolds-stresses before and after rotation (calculated over 4 tidal cycles) are shown in Figure 14. While it is expected that during the periods with high waves, the Reynolds-stresses would decrease after rotation of the ADV currents, this is not the case. On the contrary, the Reynolds-stresses increase considerable during the periods with high waves.

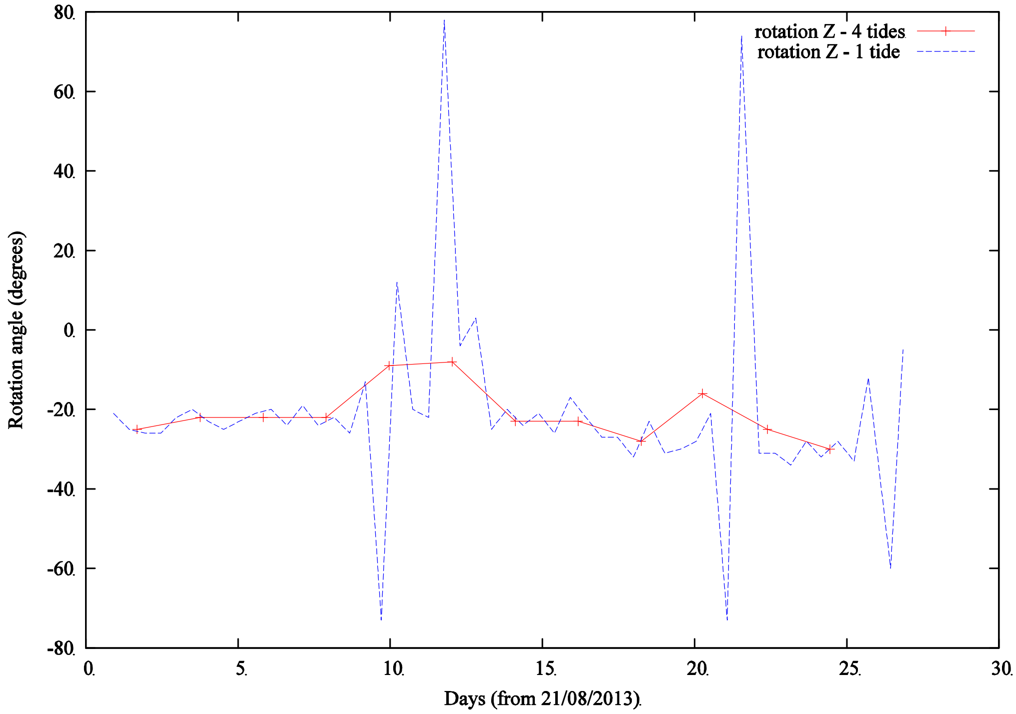

Figure 12: Rotation angle over the Z-axis to correct the vertical alignment of the ADV data.

Therefore another method to rotate the currents, to remove the effect of the waves on the calculation of the Reynolds-stresses was tested. In Lohrman *et al.*, 1995, it was suggested to rotate the currents around the x-axis and y-axis until both the mean vertical velocity is zero and the mean variance of the vertical velocity fluctuations $\overline{w'w'}$ is minimal. Since in this case, the mean vertical velocity and the variance of the vertical velocity fluctuations are calculated for all combinations of rotations over the x- and the y-axis, this method however takes much more computer power. Tests however showed that no better results were obtained using this method.

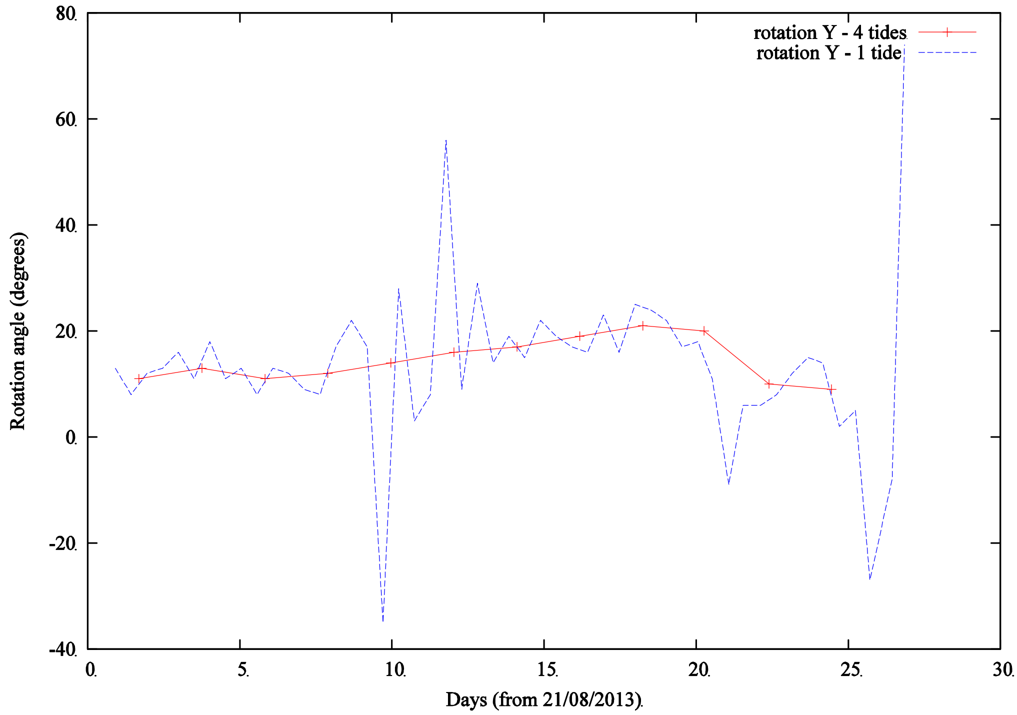

Figure 13: Rotation angle over the Y-axis to correct the vertical alignment of the ADV data.

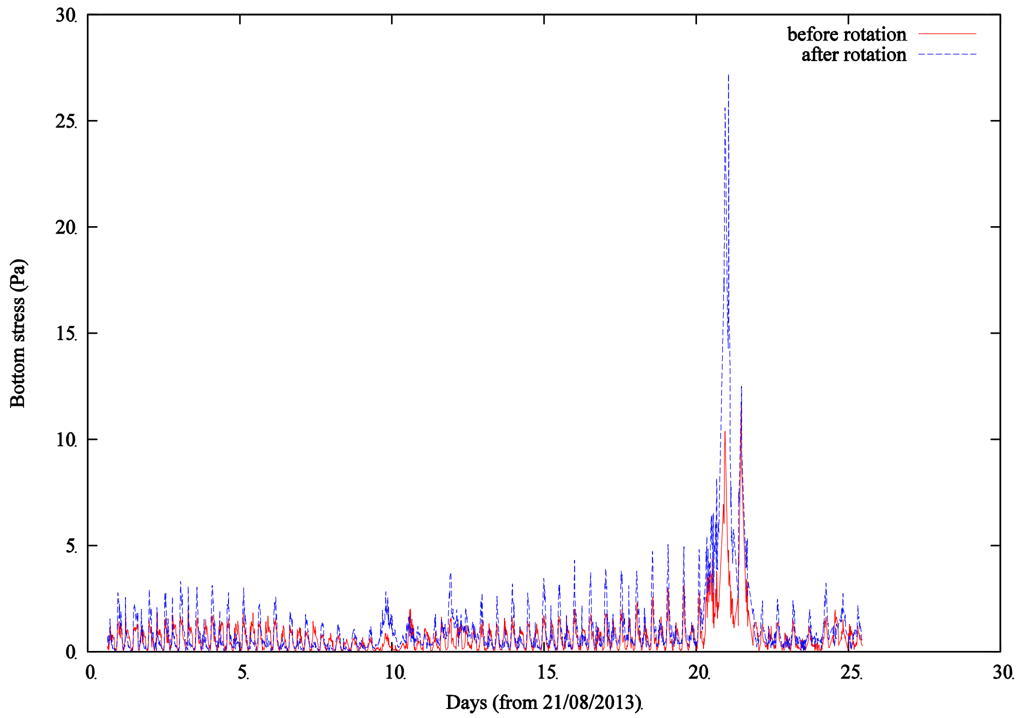

Figure 14: Reynolds-stresses before and after rotation of the ADV velocities.

Remark that in literature, not always good results were obtained using the rotation of the currents. Better estimates of the Reynolds stresses could be obtained by using two ADV sensors near each other (Trowbridge, 1998; Trowbridge and Elgar, 2001).

This technique should be used in the future. Reynolds stresses could also be calculated from the different along-beam velocities from the ADV (Fugate and Chant, 2005; Lohrman *et al.*, 1990; Stacey *et al.*, 1999, Nystrom *et al.*, 2007). Walter *et al.* (2014) uses a spectral phasee decomposition method to separate the turbulent and the wave part in the Reynolds stresses. Also these methods could be explored in the future.

Taking into account the bad results after rotation of the currents, in this study the Reynolds-stresses are used, without rotation.

4.2.3. Intertial dissipation method

In the second method, the intertial dissipation method, the shear velocity if related to the energy dissipation, which is calculated from the velocity spectrum (Huntley, 1988; Sherwood et al., 2006). In the wave spectrum a region exists, the intertial subrange, where three-dimensional spectrum of turbulent motions *E(k)* is scaled by the turbulent dissipation rate ε and decreases with the three-dimenional wave number *k* at the characteristic -5/3 slope, according to:

$$E(k) = \alpha\varepsilon^{2/3}k^{-5/3} \tag{12}$$

The turbulent dissipation is calculated from a transformed spectrum in a frequency range (typically between 1 Hz And 2.5 Hz) not disturbed by the instrument noise, at higher frequencies. Furthermore the spectrum is further corrected with a correction factor to account for the presence of waves (Trowbridge and Elgar, 2001). In the present model, the turbulent dissipation is calculated from the frequency region, where the slope of the transferred spectrum is closest to zero, i.e., the frequency region where the -5/3 decay rate is the closest followed. Using the turbulent dissipation, the bottom shear stress is then calculated from the following relation:

$$\tau = \rho[\varepsilon\kappa z]^{2/3} \tag{13}$$

An disadvantage of this method is that the bottom shear stress is a function of the height above the bottom. To calculate this height, the measured height above the bottom, using the altimeter of the ADV, is used. Remark that the normalised power density spectrum of the vertical velocity is used, since this normally is less disturbed by noise. More information on this method and the implementation can be found in Francken and Van den Eynde (2010).

A typical power density spectrum for the vertical velocity is shown in Figure 15, with a characteristic -5/3 decay in the higher frequencies. The power density spectrum is calculated, using the despiked data and after detrenting the data. The power density spectrum was calculated with 4096 points (i.e., for 2048 frequencies) and with overlap.

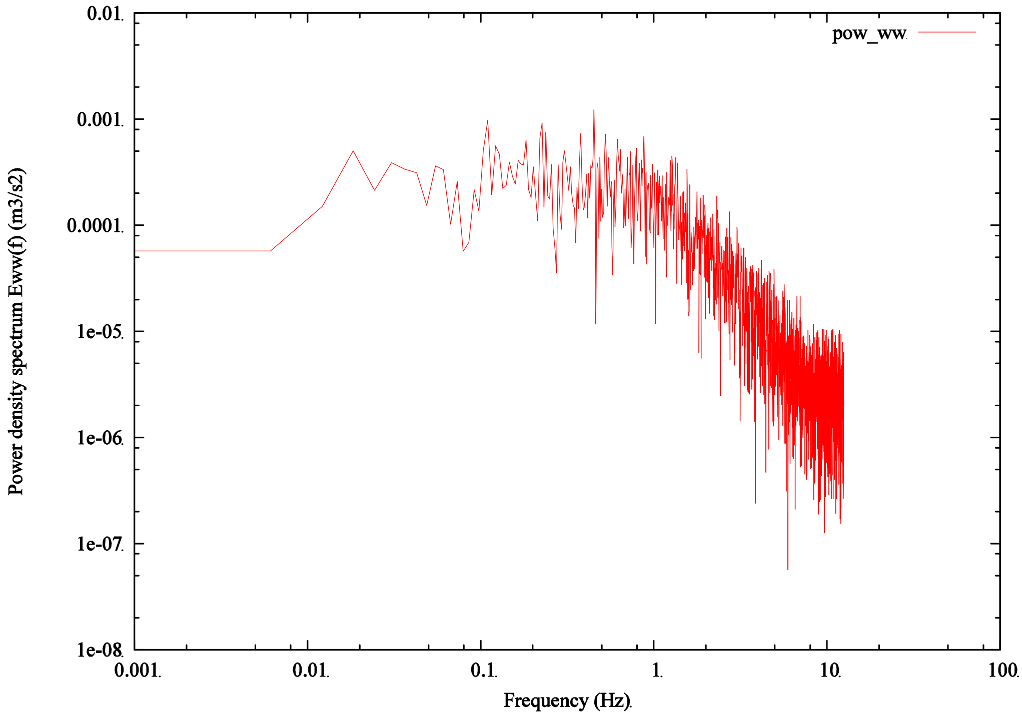

Figure 15: Power density spectrum for the vertical velocity (burst 3).

Remark that the detrenting of the data, before calculating the power density spectrum, results in a slightly higher bottom stress, using the inertial dissipation method, due to the normalisation of the power density spectrum, to the variance of the data.

4.2.4. Turbulent kinetic energy method

A second method to calculate the bottom shear as a function of the total turbulent kinetic energy, which is calculated from the variance of the velocity fluctuations u', v' and w':

$$\tau = C.TKE = C.\rho\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right) \tag{14}$$

with the factor C equal to 0.19, as proposed by Stapleton and Huntley (1995) and Thompson *et al.* (2003). The advantage of the method is that this method is quite straightforward. However, the turbulent kinetic energy, mainly the variance of the horizontal velocity fluctuations, is not only influenced by the turbulence but also by the prevailing waves. This is clearly seen in Figure 16, where the power spectral density for the U-velocity is shown for a period with high waves. Between the frequencies 1/6 Hz and 1/25 Hz a increase in the spectrum can be observed with a characteristic well-known -5 power decay, typically for wave spectra. Different methods are available in literature to split the two spectral densities, but in the present study, the method, proposed by Soulsby and Humphery (1990) is used. To calculate the power in the turbulence, the power spectral density in interpolated across the base of the wave peak, as shown in Figure 16. In the same figure, also the effect on the spectral density is shown of detrenting the burst data first. This detrenting is mainly removing very slow variations, which are not due to turbulence.

As Verney *et al.* (2007) and Verney (2008) suggests the bottom stress, calculated using the total turbulent kinetic energy could be compared to the maximal bottom shear stress under the influence of currents and waves, while the bottom stress, using the turbulent kinetic energy, after removement of the wave and long-period variations, should be a measure of the mean bottom stress under the influence of the waves and the currents. This last bottom stress should be comparable with the bottom shear stress, calculated with the intertial dissipation method, from the Reynolds stresses or from the velocity profile.

4.3. *Analysis of the bottom stress measurements*

Different techniques were discussed to measure the bottom shear stress, i.e., 1) bottom shear stress, measured from the current profile, 2) bottom shear stress calculated from the inertial dissipation method (with correction for waves) 3) bottom shear stress from the Reynolds stresses and 4) bottom shear stress from the turbulent kinetic energy. Using the last method, a separation can be made between the mean bottom shear stress and the maximum bottom shear stress, during a wave cycle. Unfortunately, not all bottom shear stresses, calculated using the different methods, correlate very well with each other. In Figure 17, the bottom stresses, derived from measurement, using different methods, are shown for the entire deployment. In Figure 18, the results during the first 3.5 days are shown. Remark that for the bottom stresses, derived from the current profiles, the profile from 0.15 to 0.90 mab is used (giving lower bottom stresses than when using the profile from 0.30 to 0.90 mab, see section 4.1).

It can be seen that the bottom stresses, derived from the current profiles and the inertial dissipation method are clearly higher than the bottom stresses, derived using the Reynolds stresses or the turbulent kinetic energy. As mentioned in 4.2.2, the influence of the waves on the bottom stress, derived from the Reynolds stresses is clear, and is mainly a results of the misalignment of the ADV. The (Pearson's) correlation factor r between the different results is given in Table 1. Only the correlation between the bottom shear stress, derived from the turbulent kinetic energy and the intertiall dissipation method is higher than 0.70. For the period with lower waves (days 1 to 19), the correlation factor is a little bit higher and also the correlation factor between the bottom shear stress, derived from turbulent kinetic energy and derived from the Reynolds stresses, is higher than 0.85. During the period with higher waves, the correlation between the different results decrease further.

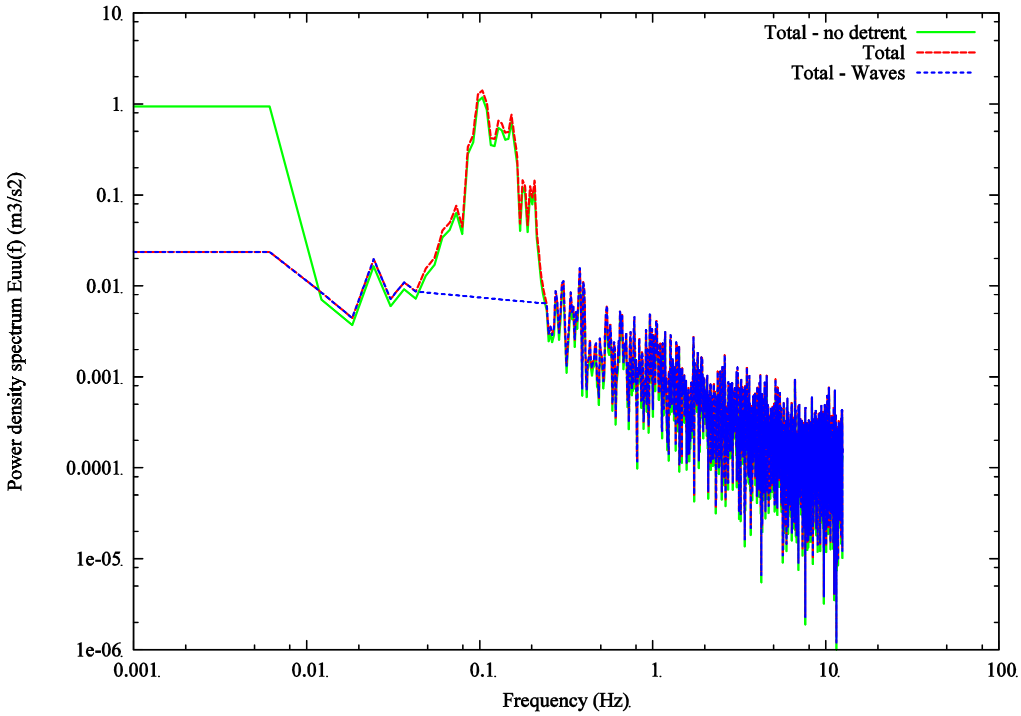

Figure 16: Power density spectrum for the horizontal velocity U during a period with waves (burst 1958). Total power spectrum without detrenting the data (yellow), total power spectrum with detreting the data (red) and power spectrum with waves removed (blue).

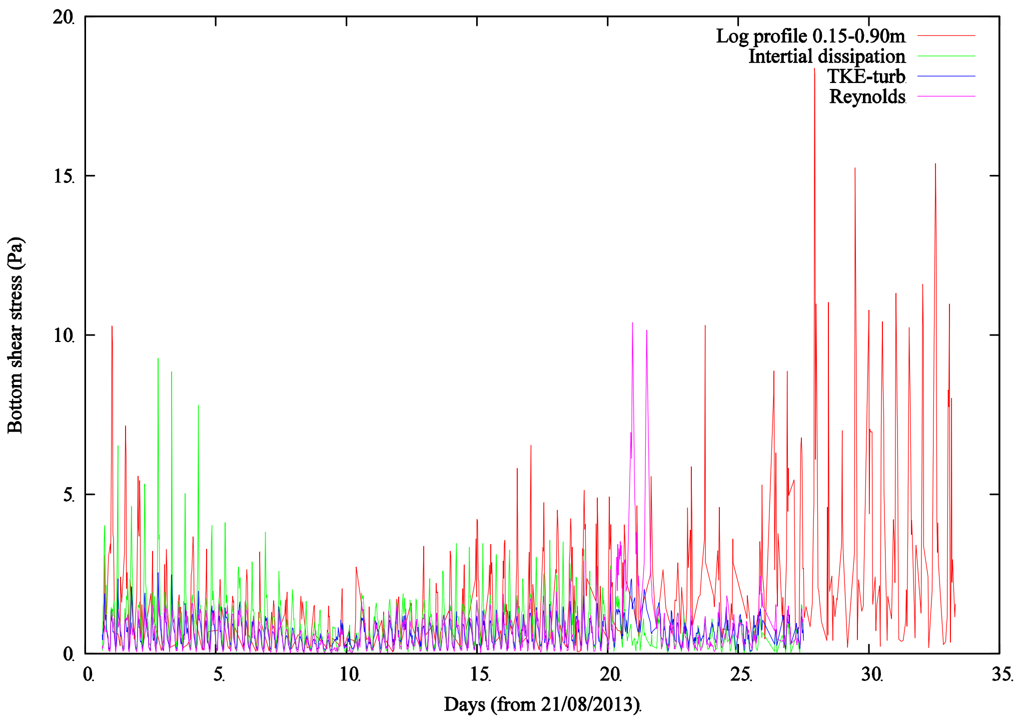

Figure 17: Time series of the different measured bottom stresses.

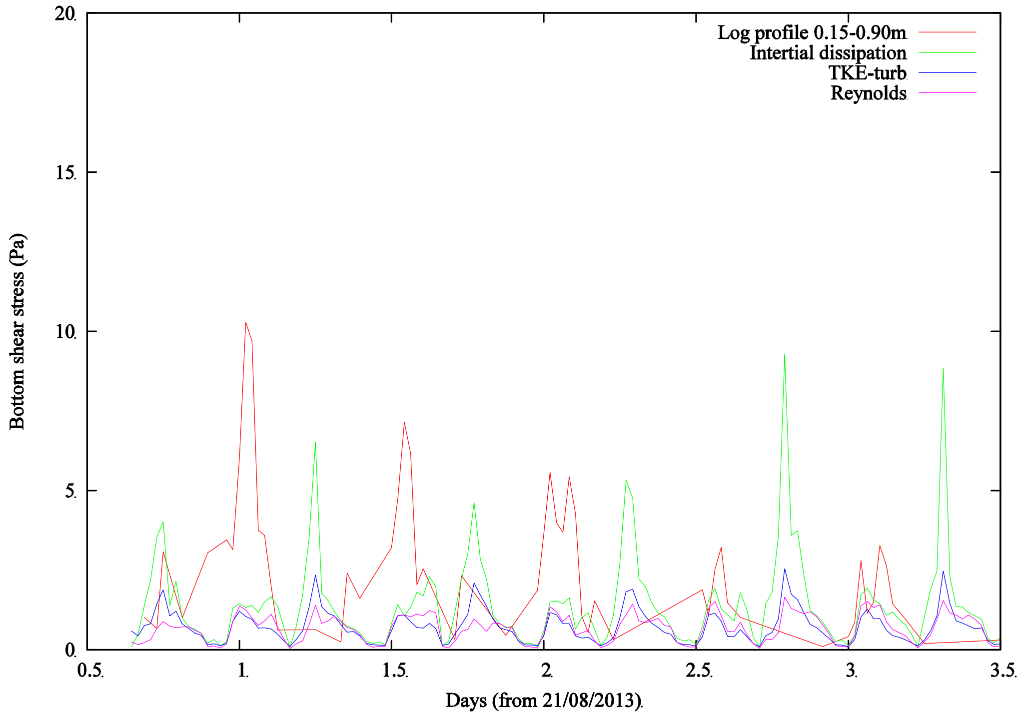

Figure 18: Time series of first 3.5 days of the different measured bottom stresses.

Table 1: Correlation factor between the bottom stresses, derived from measurements with different methods. Inter/I: intertial dissipation method; TKE/T: turbulent kinetic energy method (without waves); Reyn/R: Reynolds stresses; Profile/P: from logarithmic profile. Full: full deployment; No waves: period with lower waves (day 1 – 19); Waves: period with higher waves (day 19 – 27).

	Full				No waves				Waves			
	I	T	R	P	I	T	R	P	I	T	R	P
Inert	1.00	0.74	0.31	0.28	1.00	0.87	0.66	0.35	1.00	0.62	0.26	0.33
TKE	0.74	1.00	0.66	0.46	0.87	1.0	0.85	0.47	0.62	1.00	0.62	0.35
Reyn	0.31	0.66	1.00	0.49	0.66	0.85	1.0	0.57	0.26	0.62	1.00	0.31
Profile	0.28	0.46	0.49	1.00	0.35	0.47	0.57	1.00	0.33	0.35	0.31	1.0

It is clear that the different methods could give quite different results. Given the difficulties with the bottom shear stress derived from the logarithmic profile and with the Reynolds stresses, it is expected that these bottom shear stress estimates are less reliable. Furthermore the intertial dissipation method seems to results in quite high calculated bottom shear stresses. Therefore, it is expected that the best results for the validation will be obtained using the bottom shear stresses, derived from the turbulent kinetic energy. Furthermore, using these bottom shear stresses has the advantage that both the validation of the mean bottom shear stress and of the maximum bottom shear stress can be executed.

5. Validation of the model results

5.1. *Currents and the waves*

In a first section, the validation of the currents and the waves are discussed. For the entire deployment period, the currents were calculated with the OPTOS-BCZ model, while the waves were simulated using the WAM model.

In Figure 19 the model currents results are given for the entire deployment period. One can see that the model results show the same spring-neap tidal cycle as the ADV measurements (see Figure 3). In Figure 20, a comparison is given between the modelled currents and the measurements with the ADP and the ADV for the day 1 to day 4 of the deployment.

For the ADP, the mean over the measured profile is given. The correlation coefficient with the model results is 0.766, with a small bias of -0.013 m/s. The ADP measurements are a slightly smaller than the model results, due to the fact that the measurements are closer to the bottom. It can be seen while in the model results the flood currents are significantly higher than the ebb currents, this is not the case for the ADP measurements, where the ebb currents are higher than the flood currents. It is not clear what is the origin of these differences.

The ADV measurements are similar as the ADP measurement but are a factor 1.66 lower than the ADP measurements. This is again due to the fact that the ADV measurements are taken much more near the bottom at about 0.18 mab. The differences between the ebb and the flood currents are much less for the ADV currents than for the ADP currents. The correlation coefficient between the ADP and the ADV measurements is 0.907.

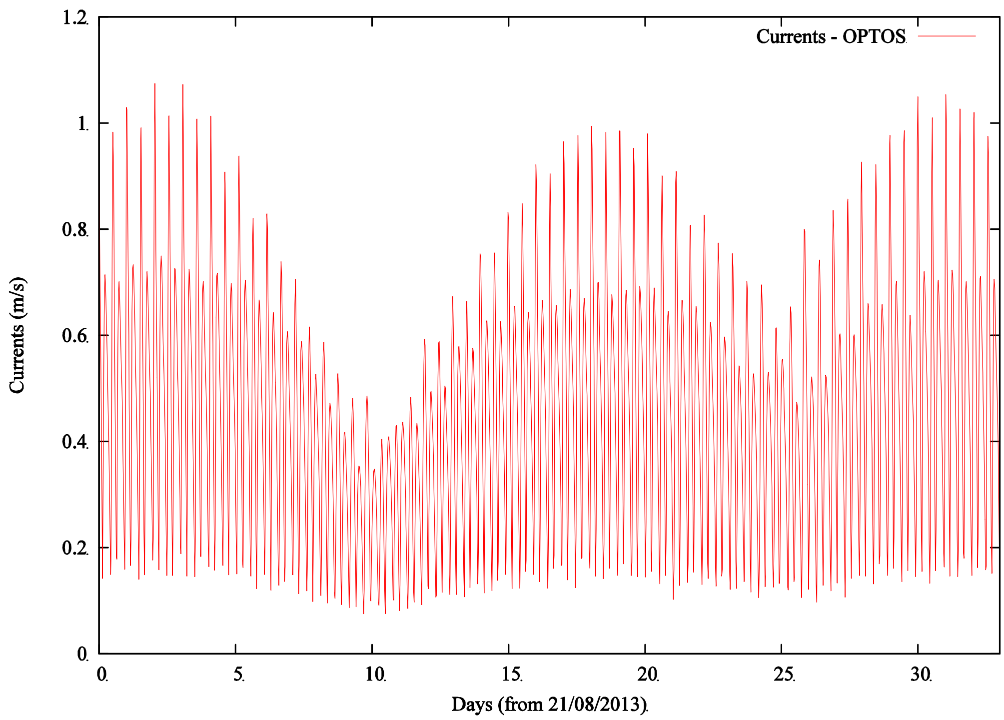

Figure 19: Currents, calculated with the OPTOS-BCZ model during deployment 071.

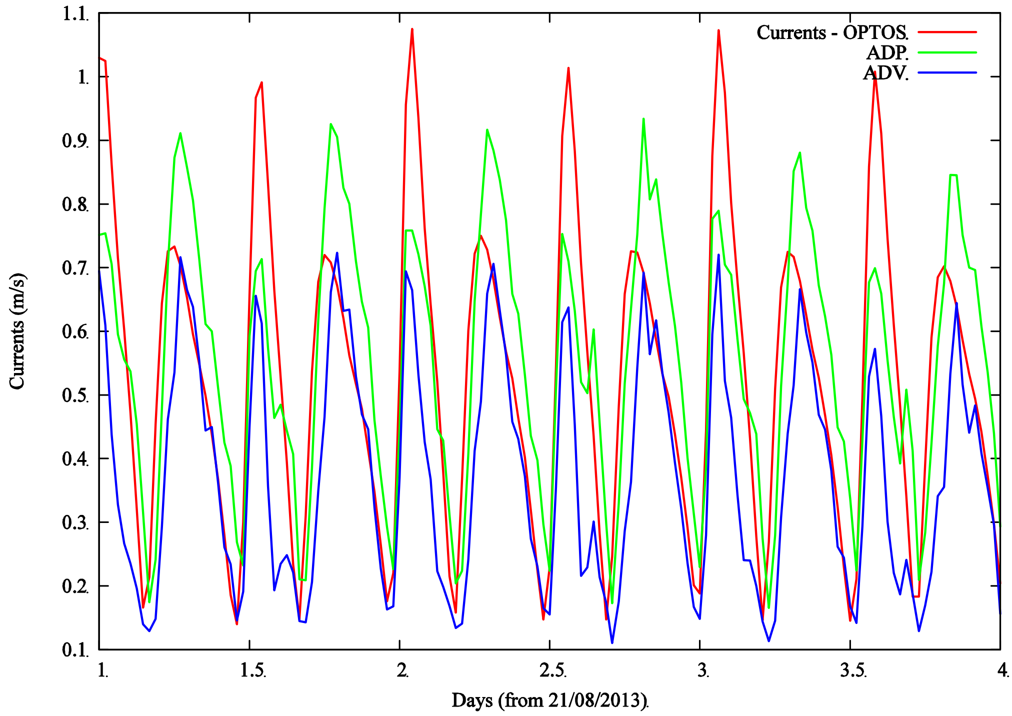

Figure 20: Currents, calculated with the OPTOS-BCZ model, measured currents from the ADP and the ADV for day 1 to day 4.

The current direction is well reproduced by the model, as can be seen in Figure 21.

There is a good agreement between the waves, modelled by the WAM model and the waves measured at the A2-buoy (measurements from Vlaamse Gemeenschap, Afdeling Waterwegen Kust, Meetnet Vlaamse Banken). The correlation between the model results and the measurements is 0.962, the Scatter Index is 22.8 %.

5.2. *Bottom stress with constant bottom roughness*

During the first test, a constant bottom roughness was used to calculate the bottom shear stress. The four different bottom shear stress models were applied. For the mean bottom stress, the model results were compared with the bottom shear stress from the logarithmic profile, the bottom shear stressed, calculated using the intertial dissipation or the eddy correlation method, and the bottom shear stresses, derived from the turbulent kinetic energy, without the influence of the waves. The maximum bottom shear stress is compared with the bottom shear stress, derived from the total turbulent kinetic energy. To be able to compare the model results and the measurements, the measurements were averaged over a period of 30 minutes first.

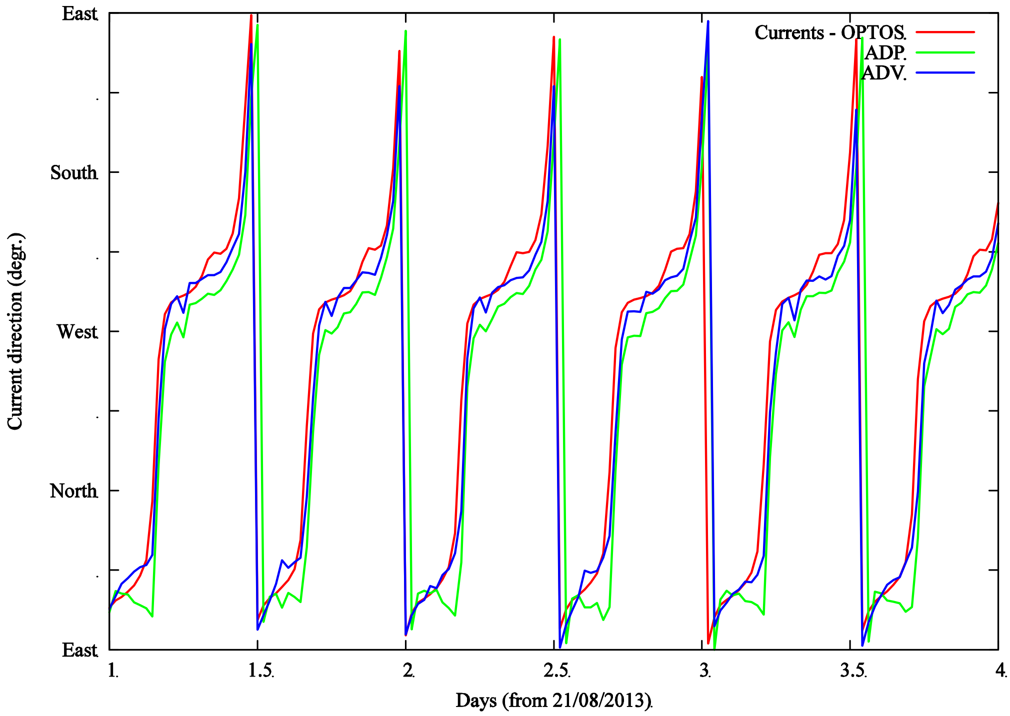

Figure 21: Currents direction, calculated with the OPTOS-BCZ model, measured currents from the ADP and the ADV for day 1 to day 4.

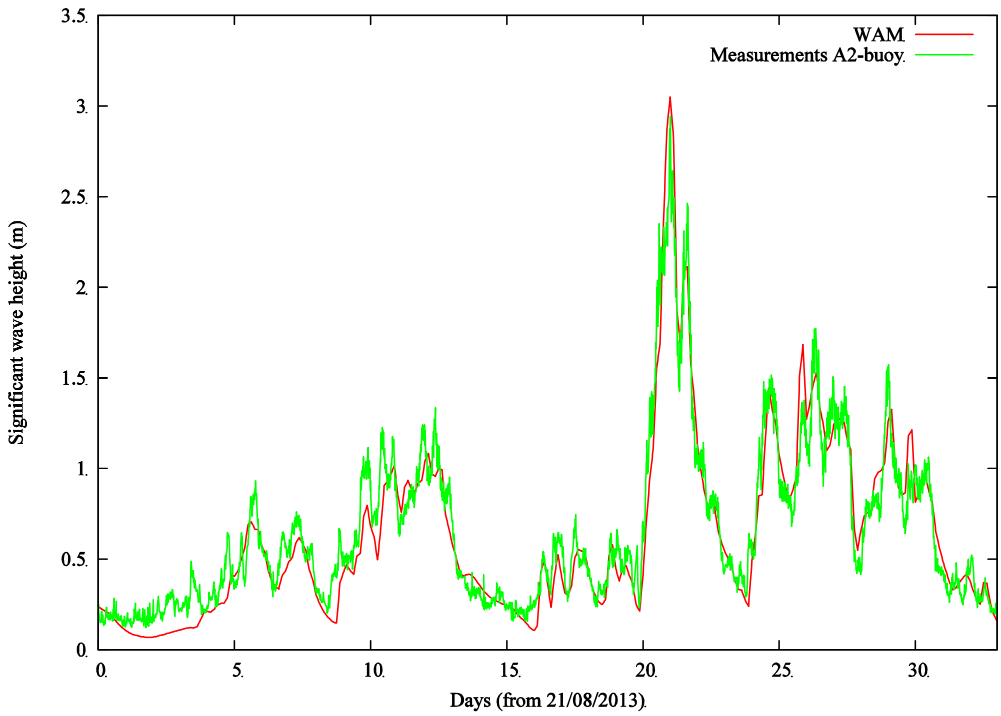

Figure 22: Waves calculated with the WAM model and measurements from the A2-buoy (data from Vlaamse Gemeenschap, Meetnet Vlaamse Banken).

In Table 2, the "best" results for each of the bottom stress measurements are given. The best results are hereby defined as the results with the lowest Root-Mean-Square-Error (RMSE). It is clear that the best results are obtained when using the bottom shear stress, derived from the turbulent kinetic energy, removing the wave influence. In this case, the RMSE remains limited to 0.260 Pa, with a bias of -0.14 Pa. The mean (measured) bottom shear stress is 0.62 Pa. The best result is obtained with the Soulsby model, with a (constant) bottom roughness of 0.01 m.

Table 2: Statistical parameters for the validation of the mean bottom shear stress calculations, using constant bottom roughness.

Measurements	Mean (Pa)	RMSE (Pa)	Bias (Pa)	Corr	Model	Roughn. (m)
TKE-tur	0.624	0.260	-0.136	0.832	Soulsby	0.010
Intertial Dissipation	0.922	0.675	-0.106	0.631	Malarkey-Davies	0.100
Reynolds	0.711	0.618	-0.063	0.628	Soulsby	0.030
Logarithmic Profile	2.429	1.600	-0.392	0.423	Soulsby	0.600

When the model results are compared with the bottom shear stress, derived with the intertial dissipation method or from the Reynolds stresses, the RMSE is around 0.61 Pa. When the bottom stress from the logarithmic profile is used, the RMSE is even much higher, at 1.60 Pa. It is clear that the best results are obtained using the bottom shear stress, derived from the turbulent kinetic energy. Therefore, only the bottom shear stress, derived from the turbulent kinetic energy will be used, further in the report. When comparing the results of the different numerical models, the Soulsby, Soulsby-Clarke and Malarkey-Davies model gives very similar results. The best results for the different models are given in Table 3. While the RMSE are very similar for the different models, the bias is lower for the Soulsby-Clarke model. In this case however, the roughness length is higher (0.03m). Remark however that previous studies showed that the shear stress computation was relatively insensitive to the value of the bottom roughness (Drake and Cacchione, 1986).

Table 3: Statistical parameters for the validation of the mean bottom shear stress calculations, using constant bottom roughness, using the bottom shear stress from the turbulent kinetic energy.

Model	Mean (Pa)	RMSE (Pa)	Bias (Pa)	Corr	Measurements	Roughness (m)
Soulsby	0.624	0.260	-0.136	0.832	TKE-tur	0.010
Soulsby-Clarke	0.624	0.262	-0.024	0.829	TKE-tur	0.030
Malarkey-Davies	0.624	0.265	-0.143	0.831	TKE-tur	0.010

Remark finally that the results during the first period, with lower waves (21/8/2013 till 9/9/2013), the results are slightly better than during the period with higher waves (9/9/2013-27/9/2013). For the Soulsby model, with a bottom roughness of 0.010 m, the RMSE for the first period is 0.220 Pa, while for the second period, the RMSE increases to 0.344 Pa. The modelled results with the Soulsby and the Soulsby-Clarke model are shown in Figure 23 to Figure 25. The results are clearly satisfactory.

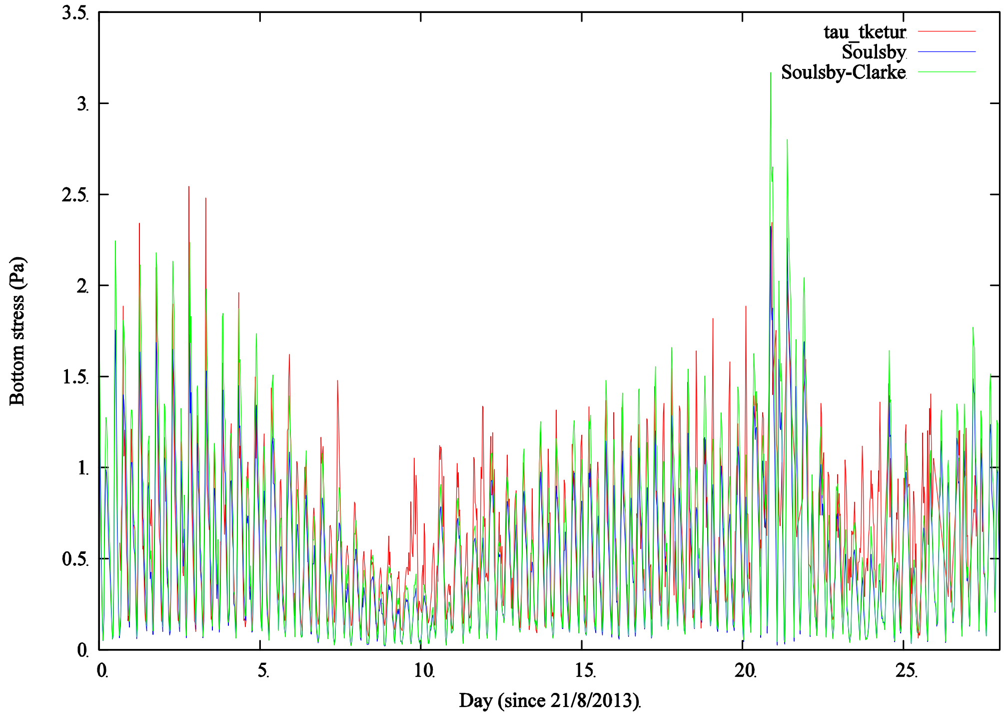

Figure 23: Time series of the mean bottom shear stress, derived from the turbulent kinetic energy and modelled using the Soulsby and the Soulsby-Clarke method.

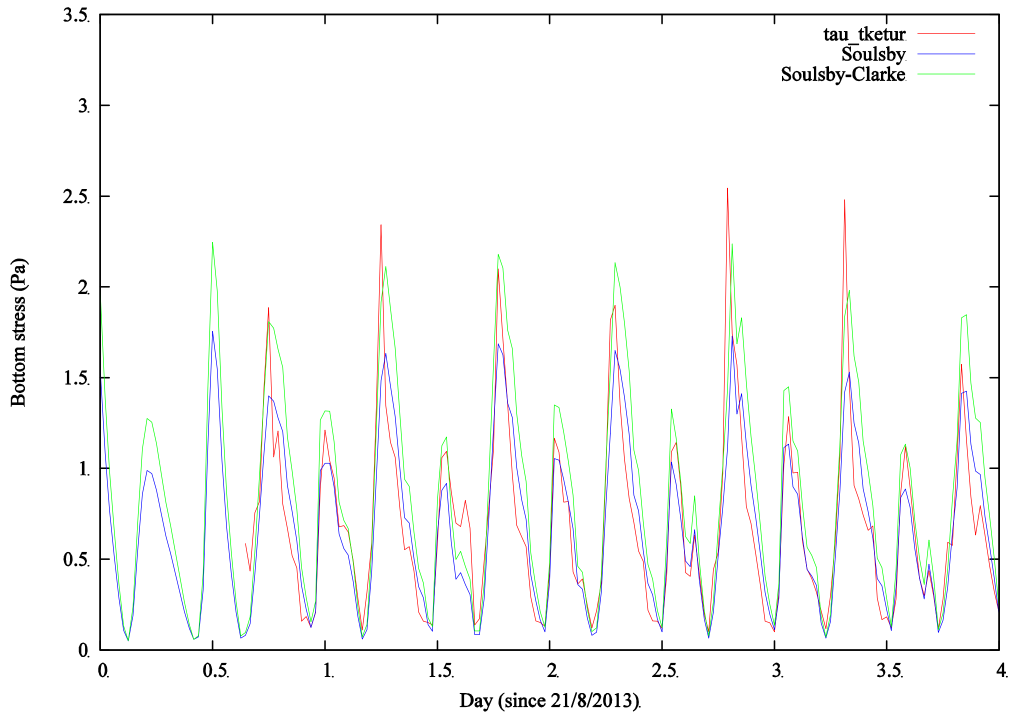

Figure 24: Time series of the mean bottom shear stress, derived from the turbulent kinetic energy and modelled using the Soulsby and the Soulsby-Clarke method for day 0 to day 4.

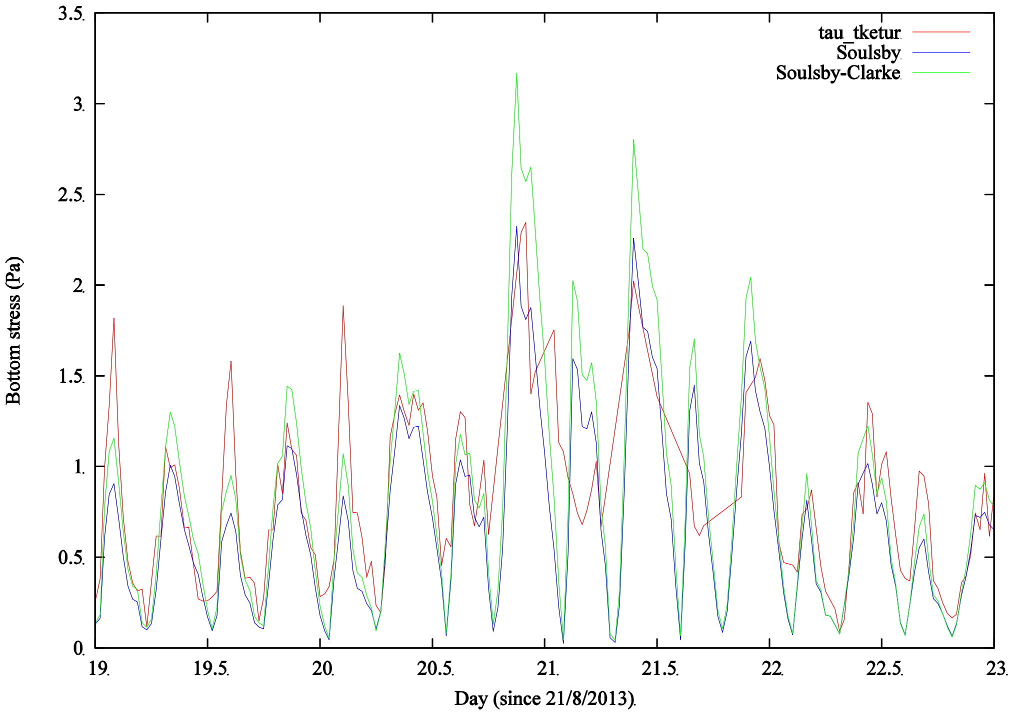

Figure 25: Time series of the mean bottom shear stress, derived from the turbulent kinetic energy and modelled using the Soulsby and the Soulsby-Clarke method for day 19 to day 23.

Using the bottom shear stress from the total turbulent kinetic energy, also the modelled maximum bottom shear stress can be validated (Verney *et al.*, 2007; Verney, 2008). The results of the different models are presented in Table 4.The results for the different model are again very similar. Best results are obtained by the Soulsby-Clarke model, with a bottom roughness of 0.010 m. In this case the RMSE is 0.62 Pa (compared to a mean of the measurements of 1.16 Pa). Also the Soulsby model obtains the best results with a bottom roughness of 0.010 m. Again, the bias is a little bit lower for the Soulsby-Clarke model.

Table 4: Statistical parameters for the validation of the maximum bottom shear stress calculations, using constant bottom roughness.

Model	Mean (Pa)	RMSE (Pa)	Bias (Pa)	Corr	Measurements	Roughness (m)
Soulsby	1.164	0.624	-0.103	0.939	TKE-tot	0.010
Soulsby-Clarke	1.164	0.616	-0.070	0.940	TKE-tot	0.010
Malarkey-Davies	1.164	0.698	0.060	0.920	TKE-tot	0.007

In Figure 26 to Figure 28, the time series for the maximum bottom shear stress are shown, together with the Soulsby and the Soulsby-Clarke model results, both with a bottom roughness of 0.01 m. One can see that during the period with high waves (Figure 28) the Soulsby-Clarke model underestimates the measurements, while the Soulsby model overestimates them. Overall the results are certainly satisfactory.

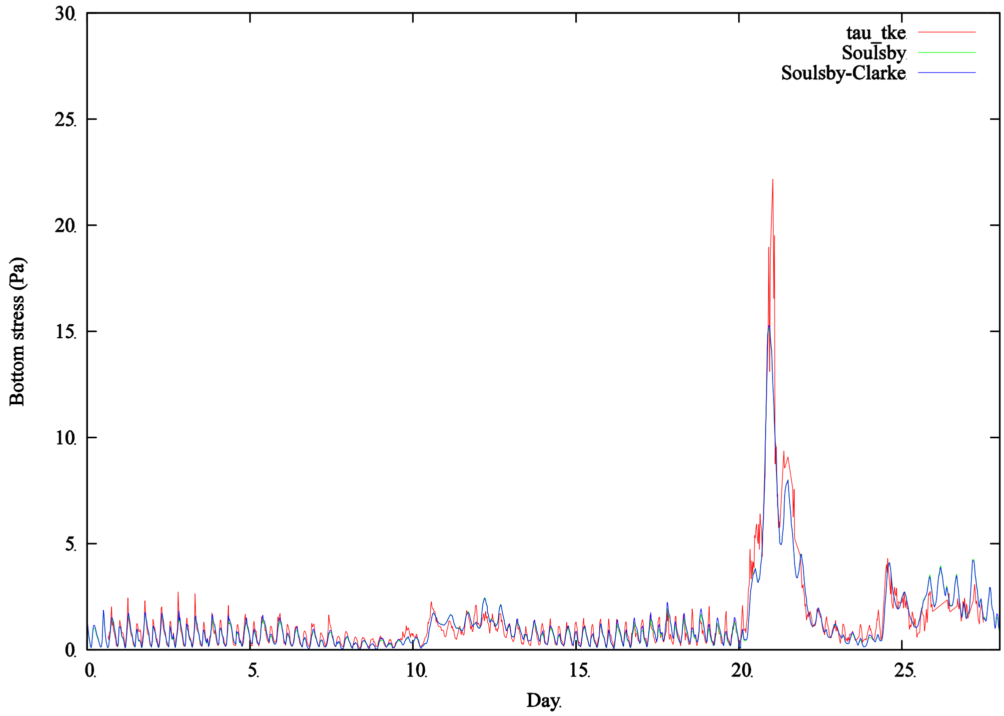

Figure 26: Time series of the maximum bottom shear stress, derived from the turbulent kinetic energy and modelled using the Soulsby and the Soulsby-Clarke method.

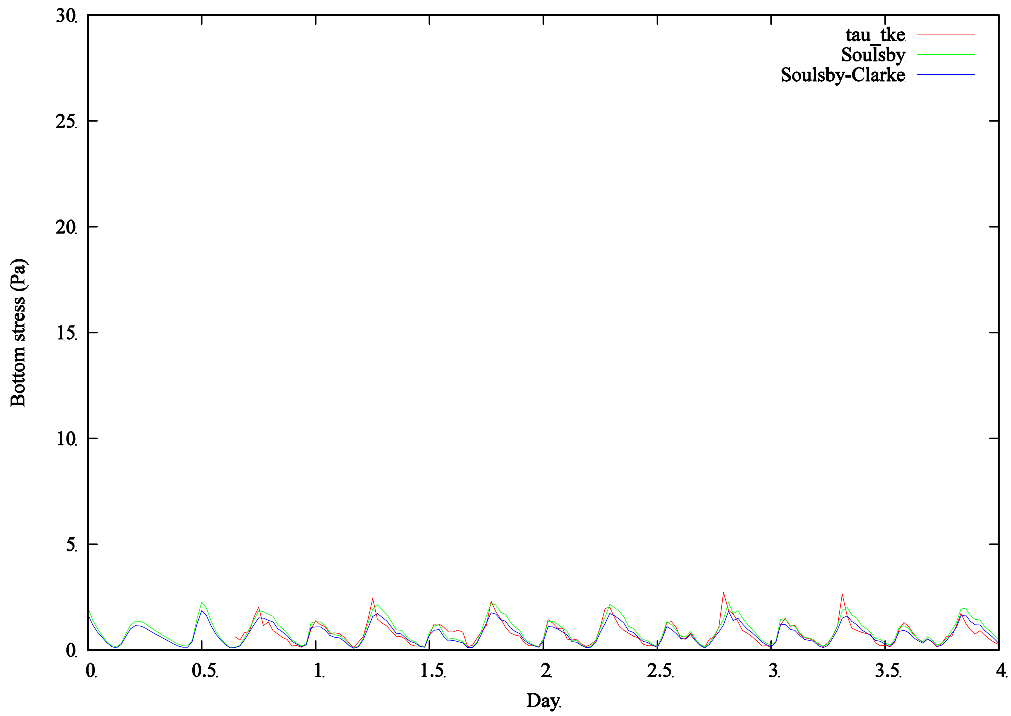

Figure 27: Time series of the maximum bottom shear stress, derived from the turbulent kinetic energy and modelled using the Soulsby and the Soulsby-Clarke method for day 0 to day 4.

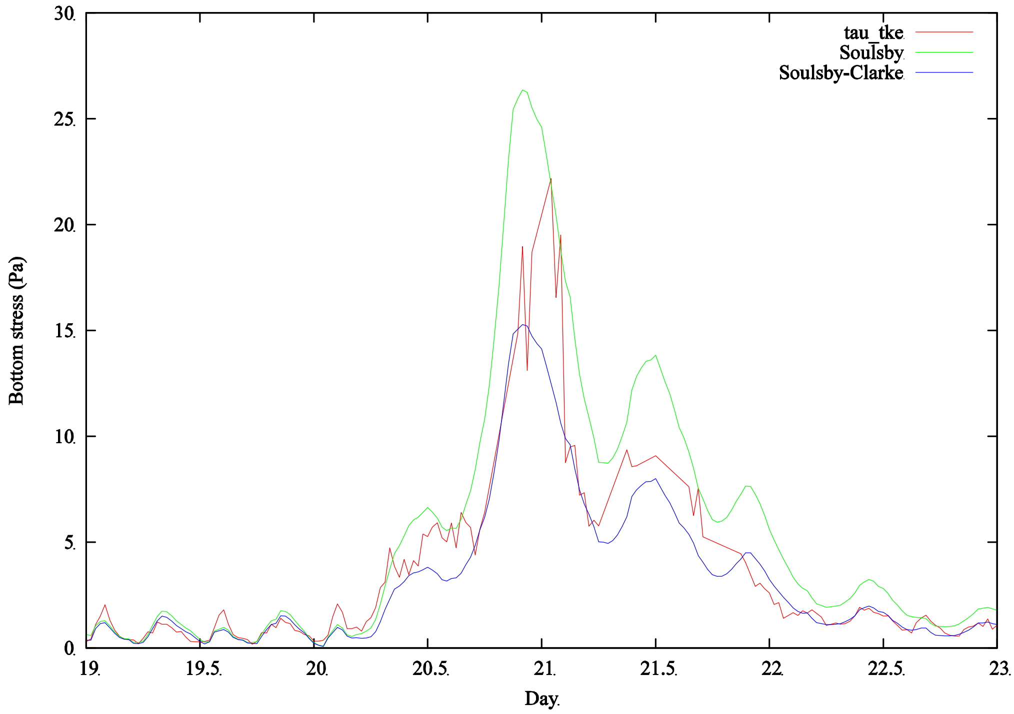

Figure 28: Time series of the maximum bottom shear stress, derived from the turbulent kinetic energy and modelled using the Soulsby and the Soulsby-Clarke method for day 19 to day 23.

5.3. *Bottom shear stress with calculated bottom roughness*

Instead of applying a chosen constant bottom roughness, the bottom roughness can be calculated by the model, using empirical formulations for the form bottom roughness and the roughness, due to bed load, and using empirical formulations for the height and the length of the bottom ripples (see section 3.4.5). In this way, the bottom roughness can vary of the deployment period, which could improve the model results.

In Table 5, the best results for the different numerical models are given. It can be seen that the results are less good than the results with a constant (chosen) bottom roughness. In this case the Soulsby-Clarke model gives the best results, but the RMSE is increased to 0.35 Pa, with a bias of 0.11 Pa. The Malarkey-Davies and certainly the Soulsby model given even worse results. The best results were obtained with the Nielsen model, for the calculation of the bottom roughness due to bedload and the Soulsby-Whitehouse model for the prediction of the ripple geometry. However, the predicted bottom roughness is too high.

Table 5: Statistical parameters for the validation of the mean bottom shear stress calculations, using calculated bottom roughness.

Model	Mean (Pa)	RMSE (Pa)	Bias (Pa)	Corr	Bedload	Ripple	Fac
Soulsby	0.624	0.462	0.199	0.786	Nielsen	Soulsby-W	1.00
Soulsby-Clarke	0.624	0.351	0.106	0.817	Nielsen	Soulsby-W	1.00
Malarkey-Davies	0.624	0.363	0.118	0.816	Nielsen	Soulsby-W	1.00

Tests were executed with a correction factor, with which the calculated bottom roughness was multiplied. This would allow the bottom roughness to vary over the period, due to the changing currents and waves, but would scale them to the correct order of magnitude to predict the bottom shear stress as good as possible. The results are given in Table 6.

Table 6: Statistical parameters for the validation of the mean bottom shear stress calculations, using calculated bottom roughness and using a correction factor.

Model	Mean (Pa)	RMSE (Pa)	Bias (Pa)	Corr	Bedload	Ripple	Fac
Soulsby	0.624	0.252	-0.123	0.836	Soulsby	Soulsby-GM	0.10
Soulsby-Clarke	0.624	0.255	-0.015	0.832	Nielsen	Soulsby-GM	0.30
Malarkey-Davies	0.624	0.259	-0.060	0.818	Nielsen	Soulsby-W	0.30

The results are slightly better than the results obtained with a constant bottom roughness. The best result is obtained by the Soulsby model, using the Soulsby model for the bed roughness, due to bedload and the Soulsby-Grant-Madsen model for calculating the bottom ripple geometry, using a correction factor of 0.10. A RMSE of 0.25 Pa and a bias of -0.12 Pa is obtained. Remark that the correction factor is dependent on the models, used for the calculation of the bottom roughness. Overall the correction factor varies between 0.10 and 0.30, which means that the bed roughness is overpredicted by the models. The results for the bottom shear stress, with and without a correction factor are shown in Figure 29 to Figure 31.

Also the maximum bottom shear stress can be modelled using a calculated bottom roughness. The results without a correction factor are however not good, with a large overprediction of the bottom shear stress (see Table 7). The RMSE is more than 2.7 Pa, with a bias of more than 1.5 Pa. Using a correction factor of 0.10 again, the results are much improved and a RMSE of 0.65 Pa is obtained, with a bias of -0.01 Pa, when the Soulsby-Clarke model is used. This is however still larger than the results obtained with a constant bottom roughness.

Table 7: Statistical parameters for the validation of the maximum bottom shear stress calculations, using calculated bottom roughness, with and without a correction factor.

Model	Mean (Pa)	RMSE (Pa)	Bias (Pa)	Corr	Bedload	Ripple	Fac
Soulsby	1.164	2.856	1.601	0.871	Nielsen	Soulsby-GM	1.00
Soulsby-Clarke	1.164	2.763	1.500	0.873	Nielsen	Soulsby-GM	1.00
Malarkey-Davies	1.164	2.913	1.866	0.885	Nielsen	Soulsby-GM	1.00
Soulsby	1.164	0.659	-0.043	0.925	Soulsby	Soulsby-GM	0.10
Soulsby-Clarke	1.164	0.650	-0.008	0.928	Soulsby	Soulsby-GM	0.10
Malarkey-Davies	1.164	0.728	0.257	0.921	Soulsby	Soulsby-GM	0.10

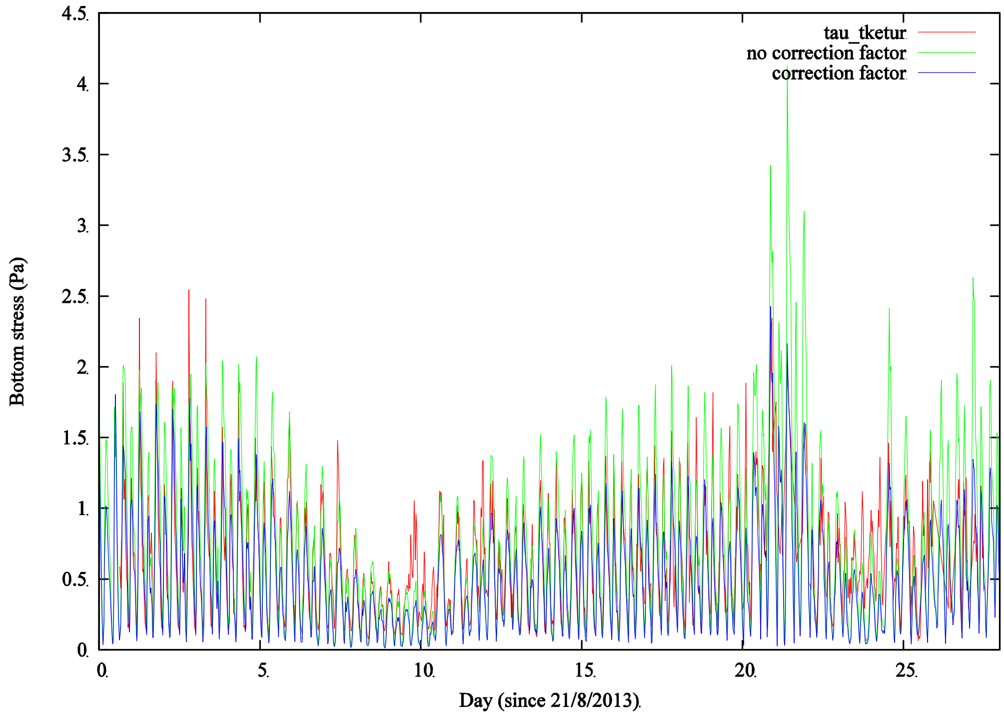

Figure 29: Time series of the mean bottom shear stress, derived from the turbulent kinetic energy and model results. The model uses a predicted bottom roughness, with and without correction factor.

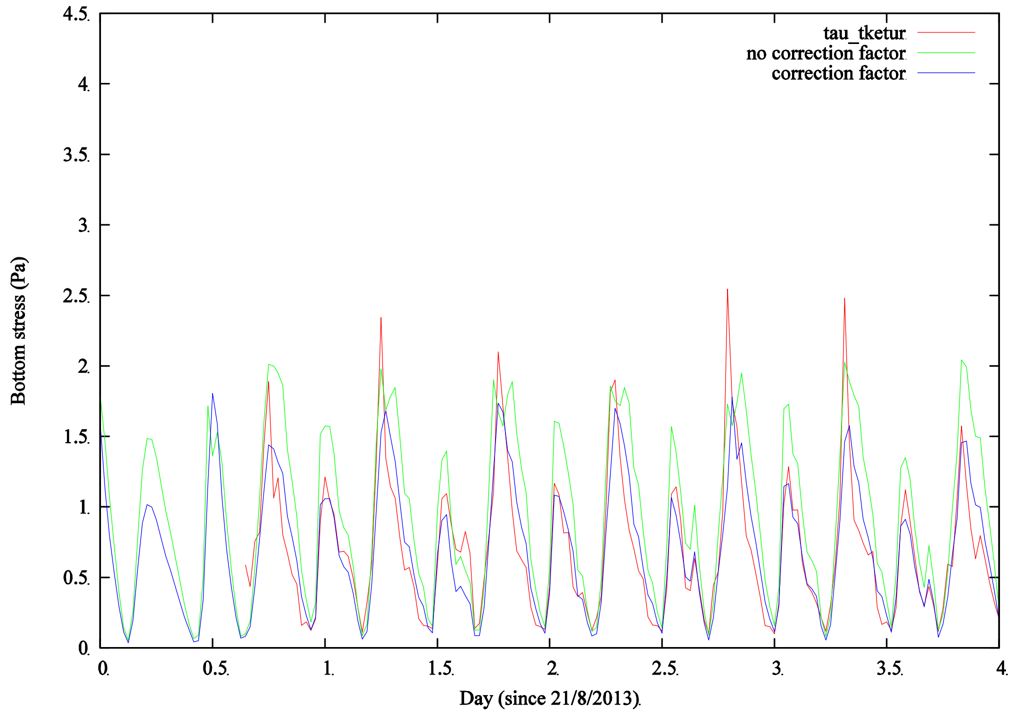

Figure 30: Time series for day 0 to day 4 of the mean bottom shear stress, derived from the turbulent kinetic energy and model results. The model uses a predicted bottom roughness, with and without correction factor.

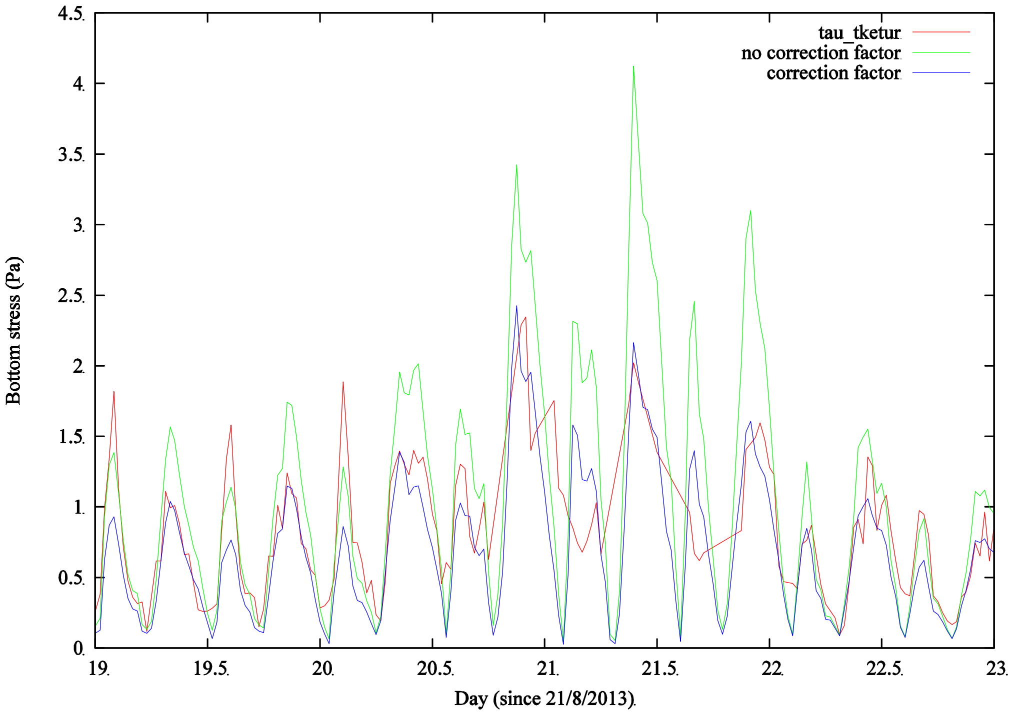

Figure 31: Time series for day 19 to 23 of the mean bottom shear stress, derived from the turbulent kinetic energy and model results. The model uses a predicted bottom roughness, with and without correction factor.

5.4. *Conclusions*

The validation of the currents and the waves showed that the hydrodynamic and wave models provide satisfying results. However, some difficulties in the ebb and flood currents seem to occur, for which no good explanation is available for now.

The validation of the bottom shear stress made it clear that the most reliable method for calculating the bottom shear stress from current measurements is the turbulent kinetic energy method. Furthermore, when this method is used, both the mean bottom shear stress and the maximum bottom shear stress can be derived from the high frequency current measurements.

During the validation of the numerical models for the bottom shear stress, similar results were obtained with the different models. The best results were obtained with a bottom roughness of 0.01 m. Using that value, a RMSE for the mean bottom shear stress in the order of 0.26 Pa was obtained, with a high correlation coefficient. The RMSE for the maximum bottom shear stress was around 0.62 Pa.

When the bottom shear stress was calculated by empirical models, the obtained bottom roughness was too high. Using a correction factor of 0.10, results were much improved. Although the results for the mean bottom shear stress were slightly better than using a constant bottom shear stress, the maximum bottom shear stress was less well modelled. Therefore it is not recommended to use the predicted bottom roughness, but to use a constant bottom roughness of 0.10 m.

6. Conclusions

In the present report, current data from a deployment at the MOW1 station, near the sea harbour of Zeebrugge, were analysed to derive the bottom shear stresses and to validate numerical modesl of bottom shear stresses.

The deployment was executed from August, 21, 2013 to September 27 2013. The instruments included a high frequency (25 Hz) ADV current meter, and a ADP, measuring the current profile over the lowest part of the water column. During the first 20 days, weather was calm and the waves remain limited to less than 1.2 m. After that, waves were higher, with a peak of 3 m wave height at day 21.

The numerical models were discussed first. Three models for the bottom shear stress calculation under the influence of currents and waves were presented, that will be used in the validation exercise.

Further, four methods were described to derive the bottom shear stress from the current measurements: using the logarithmic profile, using the Reynolds stresses, using the inertial dissipation method or using the turbulent kinetic energy. Pre-processing of the data, including despiking the data, was executed first. To improve the quality of the bottom shear stress from the Reynolds stress, the ADV currents were rotated to remove the influence of the waves. These attempts however were not successful. Analysis showed very low correlation between the different estimates of the bottom shear stresses. While the bottom shear stresses from the Reynolds stresses were clearly polluted by the waves, the bottom shear stresses from the logarithmic profiles and from the inertial dissipation method seemed rather high. It was concluded that the bottom shear stress from the turbulent kinetic energy probably was the most accurate estimate of the bottom shear stress. Furthermore, using the turbulent kinetic energy, both an estimate could be made of the mean (averaged over a wave cycle) bottom shear stress and the maximum bottom shear stress.

The validation of the currents and the waves showed that the hydrodynamic and wave models provide satisfying results. However, some difficulties in the ebb and flood currents seem to occur, for which no good explanation is available for now.

The validation of the bottom shear stress made it clear that the most reliable method for calculating the bottom shear stress from current measurements is the turbulent kinetic energy method. Furthermore, when this method is used, both the mean bottom shear stress and the maximum bottom shear stress can be derived from the high frequency current measurements.

During the validation of the numerical models for the bottom shear stress, similar results were obtained with the different models. The best results were obtained with a bottom roughness of 0.01 m, which is still relatively high. Using that value, a RMSE for the mean bottom shear stress in the order of 0.26 Pa was obtained, with a high correlation coefficient. The RMSE for the maximum bottom shear stress was around 0.62 Pa.

When the bottom shear stress was calculated by empirical models, the obtained bottom roughness was too high. Using a correction factor of 0.10, results were much improved. Although the results for the mean bottom shear stress were slightly better than using a constant bottom shear stress, the maximum bottom shear stress was less well modelled. Therefore it is not recommended to use the predicted bottom roughness, but to use a constant bottom roughness of 0.10 m.

Overall, one can conclude that using a constant bottom roughness of 0.1 m, satisfying results can be obtained when modelling the bottom shear stress. However, the fact that the measured bottom shear stress, using different techniques doesn't correlate very well with each other, makes the results of this study still uncertain. It is clear that more research has to be done to evaluate the measurements and to obtain in the future high quality measurements of the bottom shear stress. Only in this way, a solid validation of the model results can be achieved.

In the future, an analysis will be made on the dependency of the bottom roughness length to be used on the water depth, the maximum current or the significant wave height, based on different deployment. Furthermore, it could be useful to obtain new, high quality, measurements of the bottom shear stress. Using two ADV sensors near each other could improve the estimate of the Reynolds stresses, which could provide a second good estimate of the bottom shear stress, apart from the bottom shear stress, derived from the turbulent kinetic energy.

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8. Appendix: Statistical parameters

For the validation, the statistical parameters bias, root mean square error (RMSE), the systematical and unsystematical RMSE and the correlation coefficient can be be calculated.

Hereafter, the measurements series will be presented as x and the model results (that is subject to the test) as y.

The mean values of the time series are represented by $\bar{x}$ (reference) and $\bar{y}$ (subject to test):

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$$

where N is the length of the time series.

The bias is the difference between the mean of the modelled and the measured time series:

$$bias = \bar{y} - \bar{x}$$

The closer the bias is to zero, the better both time series correspond. A positive bias value means that the modelled time series are an overestimation of the observed time series. A negative bias value means that the modelled time series are an underestimation of the observed time series.

The root mean square error (RMSE) is a measure for the absolute error and is defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(y_i - x_i\right)^2}{N}}$$

Corresponding time series will result in RMSE values close to zero.

Furthermore, a systematical RMSE ($RMSE_s$) and an unsystematical RMSE ($RMSE_u$) can be defined, that evaluate respectively, the (absolute) error, which is generated by the deviation from the linear regression of the modelled time series from the measurements, and the error that is generated by the deviation from the individual model results from the linear regression itself. While the systematical RMSE could be reduced by applying a correction, using the linear regression, the unsystemical RMSE is the error which is inherent from the variation from the results themselves. These parameters can be calculated as:

$$RMSE_s = \sqrt{\frac{\sum_{i=1}^{N}\left(\hat{y}_i - x_i\right)^2}{N}}$$

$$RMSE_u = \sqrt{\frac{\sum_{i=1}^{N}\left(y_i - \hat{y}_i\right)^2}{N}}$$

with $\hat{y}_i$ is defined from the linear regression

$$\hat{y}_i = mx_i + b$$

with slope m and intercept b calculated from:

$$m = \frac{N\sum x_i y_i - \sum x_i \sum y_i}{N\sum x_i^{\ 2} - \left(\sum x_i\right)^2}$$

$$b = \overline{y} - m\overline{x}$$

The correlation between both signals is given by Pearson's correlation coefficient, defined as:

$$r = \frac{\sum_{i=1}^{N}\left(x_i - \overline{x}\right)\left(y_i - \overline{y}\right)}{\sqrt{\sum_{i=1}^{N}\left(x_i - \overline{x}\right)^2}\sqrt{\sum_{i=1}^{N}\left(y_i - \overline{y}\right)^2}}$$

The scatter index is a measure for the relative error and is defined by:

$$S.I. = \frac{RMSE}{\overline{x}}$$

COLOPHON

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Royal Belgian Institute of Natural Sciences
Operational Directorate Natural Environment
100 Gulledelle
B–1200 Brussels
Belgium
Phone: +32 2 773 2111
Fax: +32 2 770 6972
http://www.mumm.ac.be/

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Operational Directorate Natural Environment
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Annex 3

Van den Eynde, D., T. Verwaest and K. Trouw, 2019. The impact of sand extraction on the wave height near the Belgian coast. Report MOZ4-ZAGRI/X/DVDE/201906/EN/TR03, RBINS-OD Nature and MUMM, Brussels, 44 pp.

ROYAL BELGIAN INSTITUTE FOR NATURAL SCIENCES
OPERATIONAL DIRECTORATE NATURAL ENVIRONMENT

Section Ecosystem Data Analysis and Modelling
Suspended Matter and Sea Bottom Modelling and Monitoring Group (SUMO)
and
Management Unit of the North Sea Mathematical Models (MUMM)

The impact of sand extraction on the wave height near the Belgian coast

Dries Van den Eynde[1], Toon Verwaest[2] and Koen Trouw[3]

1: RBINS, Operational Directorate Natural Environment, Gulledelle 100, B-1200 Brussels
2: Flanders Hydraulics Research, Department of Mobility and Public Works, Berchemlei 115, B-2140 Antwerp
3: Fides Engineering, Unitaslaan 11, B-2100 Antwerp

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RBINS-OD Nature
100 Gulledelle
B–1200 Brussels
Belgium

Table of Contents

I. Introduction

Over the last years, the extraction of marine aggregates is increasing considerable. While in the period 2003-2010, the total volume of extracted marine aggregates on the Belgian Continental Shelf stayed below 2.5 Mm^3, since 2011 the extraction increased, with peaks at 2013, with an extraction of more than 4.0 Mm^3, and 2014, with an extraction of even more than 6.0 Mm^3 (Van den Branden et al., 2016). Furthermore, since 2012, concessions were granted in the region of the offshore Hinderbanks. The volumes are mostly needed in response to the needs of the Coastal Safety Plan bringing the level of protection against extreme storm events at a 1:1000 years return period (www.kustveiligheid. be).

The limits of the extraction in the Belgian Law is set at 5 m below the reference level, that was defined by the Service Continental Shelf of the Federal Public Service Economy (COPCO) (Law of 13 June 1969 on the exploration and the exploitation of non-living resources of the territorial sea and the continental shelf, changed by the law of January 20th, 1999 and April 22th, 1999). This reference model is based on a detailed terrain model of the sea bottom in the extraction zones, measured during multi-beam surveys in the first half of the previous decennium. Based on this limit, three areas in the extraction Sector 2 (KBMA, KBMB and BRMC), where extraction led to a deepening of more than 5 m, were closed (see Figure 1). In other areas in Sector 1 (TBMAB) and Sector 4 (HBMC), this limit is approached as well, which will lead to the closure of these areas, based on the current legislation.

This method however doesn't take the structure of the sea bottom and the differences in impact into account. Furthermore, the sustainable character of the marine aggregate extraction becomes at risk. The areas with the best quality sands (median size to coarse sands) are being closed while zones with economically less interesting quality (fine sands) remain open. Therefore, COPCO started with a new project to define a new extraction limit levels, which were based on scientific and economic criteria (Degrendele, 2016; Degrendele et al., 2017). The goal of these new extraction limit levels is to limit the impact of the extraction in the most sensitive areas for sediment and habitat and to increase the economic sustainability, by accounting for the available volumes and the quality of the sands. Three scenarios were proposed: a maximum, minimum and medium scenario. Remark that in the new scenarios, the total volume of the reserves, i.e., the total volume that could be extracted, decreases from about 1050 Mm^3 to 927 Mm^3, 538 Mm^3 or 599 Mm^3 respectively. At the moment, the scenario 3 is the preferred one.

In Van den Eynde (2016; 2017), the effect of these new proposed extraction limit levels on the changes in the bottom stress were evaluated, according to the Belgian implementation of the European Marine Strategy Framework Directive (Belgian State, 2012; 2018). In this Directive, it was stated that human impacts need consideration when the bottom shear stress, calculated with a validated numerical model, changes with more than 10 % at a specified distance of the activity. The impact of extraction of marine aggregates, up to the new proposed extraction limit levels, was evaluated with this respect. Simulations were executed with numerical models to test whether the three newly proposed extraction limit levels were within these constraints.

Results showed that for the medium scenario 3, no problems occurred for most sectors and that only for an area of 4.90 km² remained, west of Sector 2c, the bottom stress changes with more than 10 % outside the buffer zone. A solution was proposed to increase the extraction limit level to such a level, that no bottom stress changes higher than 10 % are still present, outside the buffer zone.

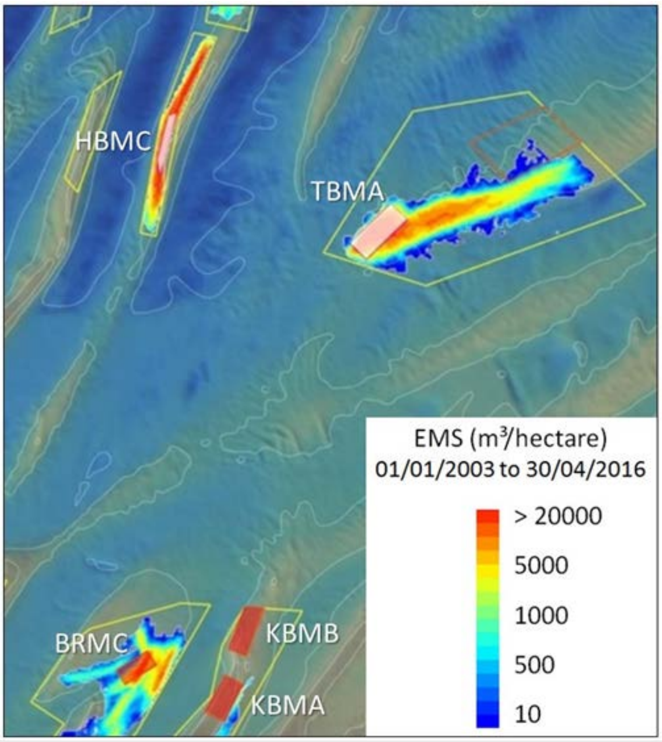

Figure 1: Areas, closed for extraction (red) and areas where the limit is almost reached (rose) (from: Degrendele, 2016).

In this report, the effect of the change of the extraction level limit on the wave propagation on the Belgian continental shelf is investigated. This is done using the SWAN wave model. From these results the effect of the extraction on coastal protection is evaluated.

Remark however that in the current report the Sector 4a is not considered anymore and a new extraction Sector 5 is being defined. The simulations are executed for these extraction sectors. Remark also that in the current report Sector 3 (Sierra Ventana) is out of scope.

In the first section the model is shortly presented. The second section discusses the setup op the model grid. In the third section, the simulations are presented, while a discussion is presented in the next section. A conclusion in formulated in the last section.

2. Numerical model

For the propagation of the waves over the shallow Belgian coastal waters, different models can be used. For the operational forecasts of the waves on the Belgian coast, the third generation WAM model is used (WAMDI Group, 1988; Günther et al., 1992). The local grid however only a resolution of 0.033° in latitude and 0.022° in longitude, which is more than 1.5 km.

Therefore, for this study the SWAN model (e.g., Ris, 1997; Booij et al., 1999; Holthuijsen et al., 1989, 1993, 2003) is used. The SWAN model is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. The model calculates in time and space, the generation of waves, their propagation and shoaling, non-linear wave-wave interaction, white-capping, bottom friction and depth-induced breaking. In comparison with the WAM model, the model is more suited to calculate the propagation of the waves in the nearshore area. The main disadvantage is that the models is preferably used in stationary mode. The SWAN model is implemented (see next session) on a grid of 250 m x 250 m, better representing the sand banks. This is needed to evaluate the effect of sand extraction on the wave propagation.

In the current project, the SWAN cycle III version 40.51 is used (SWAN, 2006a, 2006b).

3. Development of the bathymetries

3.1. New SWAN bathymetry

In the framework of the CLIMAR project (Van den Eynde, 2011; Van den Eynde et al., 2011), the SWAN model was used to simulate the propagation of the waves from offshore to the Belgian coast and to investigate the effect of sea level rise on the wave propagation. For that application, the model was implemented on a Cartesian grid, rotated over 25.5° anti-clockwise, along the Belgian coast, with a resolution of 250 m x 250 m, a grid that was prepared by KULeuven & FHR (2004). The rotation is needed to assure that the distance from the coast to the offshore boundaries are similar. This assures that the time of the waves, travelling from the offshore conditions to the shore takes the same time, which is useful, using the model in stationary mode. The lower left point of the grid had the co-ordinates (50°54'00", 2°07'12"). This grid was 125 km long (along the coast) and 39 km wide (offshore). The model bathymetry is shown in Figure 2.

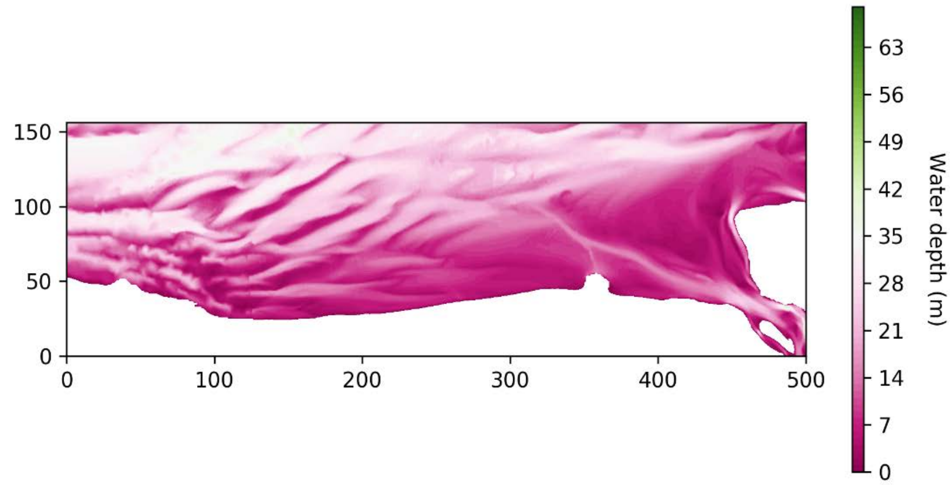

Figure 2: Bathymetry and extension of the SWAN model grid, used in the CLIMAR project (Van den Eynde et al., 2011).

Unfortunately, this model grid is not extended enough to the north (offshore) to include the extraction sectors in the Hinderbank area. Therefore, it was decided to construct a new bathymetry in the framework of this project that uses the same characteristics but is extended more offshore.

The new model grid is based on the new bathymetries that were developed for the new hydrodynamic model train, based on the COHERENS software, that is being installed at the RBINS-OD Nature (Dulière, 2017). The BeC grid has a resolution of 250 m x 250 m and covers the entire Belgian Continental Shelf. Since the SWAN model is rotated, not all points in the new SWAN grid are covered by the BeC grid. In the northwest corner, data from the SoB grid were used, which has a resolution of 750 m x 750 m, and covers the Southwestern part of the North Sea (Dulière, 2017). More than 90% of the new grid points were interpolated from the BeC grid, while less than 10% is interpolated from the SoB grid.

Some differences between the new grid and the old grid can be found. Since for the old grid, the TAW reference was used, while for the new grid, Mean Sea Level was used as reference (for the hydrodynamic models), an overall difference between the two bathymetries was expected. When comparing the points that are sea points in both grids, a difference of 2.61 m was calculated. This is some 0.28 m higher than the expected difference between TAW and MSL for Ostend (Vlaamse Hydrografie, 2011).

Furthermore, the coastline of the two models do not perfectly match. In 120 points, points were land in the original grid, while they are sea in the new grid. This is mainly around or in the harbours of Dunkerque or Zeebrugge, or in the Westerschelde. On the other hand, 1437 land points in the new grid, were sea points in the old grid. These are mainly grid points near the coast, with very low or negative bathymetries in the old grid, where in the grid from Dulière (2017), the grid points were put to land, to avoid stability problem in the hydrodynamical model. These grid points were put to sea in the new grid, taking into account the difference between the reference level of the old and the new grid.

In Figure 3, the new bathymetry is shown, while in Figure 4 the differences between the old and the new bathymetry is shown, corrected for the overall difference of 2.61 m.

Large differences can be seen in the western part of the grid, at the French Continental Shelf. Although there is no reason to expect that the grid from Dulière (2017) has less quality in that part of the grid, the results are however striking. De Maerschalck (FHR, pers. comm.) pointed out that that part of the grid is not well represented in the new bathymetry. Therefore, in that part of the grid, the old bathymetry was kept.

The final bathymetry is shown in Figure 5. In the figure, also 10 possible output points before the Belgian coast are show where the output could be used by coastal models such as the XBeach model (Roelvink et al., 2009; 2015) and the UNIBEST-CL+ model (https://www.deltares.nl/en/software/unibest-cl/). The XBeach model is operated by Flanders Hydraulics Research (FHR) to evaluate the changes of the beach profiles during storms (De Roo et al., 2015; Kolokythas et al., 2016). The UNIBEST-CL+ model is operated to simulate larger scale coastline dynamics. These points were taken from IMDC (2009) to represent the wave climate for the 10 coastal municipalities. The information on these 10 points is given in Table 1.

For the Belgian coast, 260 section are defined (De Roo et al., 2014) that could be used for output and for evaluation of the beach profiles. The points are normally defined at the -5 TAW level, or at a distance of 1500 m out of the coast. Output at all these section points could be provided if necessary.

Table 1: Output points at the coastal municipalities and at Westhinder. Depth is model depth.

Output point	Abbreviation	Easting (m)	Northing (m)	Depth (m MSL)
De Panne	Dpa	470931	5662065	7.4
Koksijde-Oostduinkerke	Kok	473498	5664586	5.3
Nieuwpoort	Nwp	479850	5667537	7.6
Middelkerke-Westende	Mid	486455	5671160	6.9
Oostende	Oos	492895	5675867	7.7
Bredene	Brd	495981	5679099	7.0
De Haan-Wenduine	DHn	501611	5681711	7.3
Blankenberge	Bla	508487	5686226	7.5
Zeebrugge	Zbr	511637	5691881	16.4
Knokke-Heist	Knk	519616	5689721	8.1
Westhinder	Whi	461338	5692842	25.8

In Figure 6 and Figure 7, the differences between the old and the new bathymetry are shown. Since in the French part of the bathymetry, the old bathymetry was kept, no differences are found in that part of the grid. Figure 7 zooms in on the differences between -4 m and +4 m. Larger differences can be found in the North of the area, near the fair channels and in the Westerschelde. Since no output points are defined in the Westerschelde, the larger differences in the new grid are not important in this case.

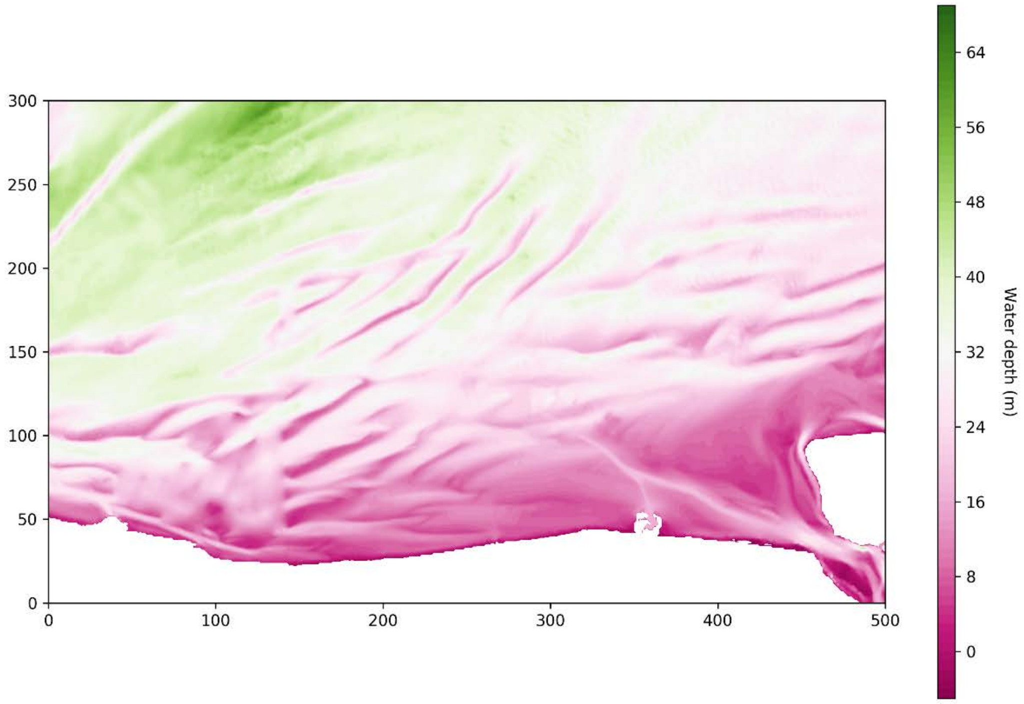

Figure 3: New extended SWAN grid, based on the old SWAN grid and the BeC and SoB hydrodynamical grids. Reference levels is MSL.

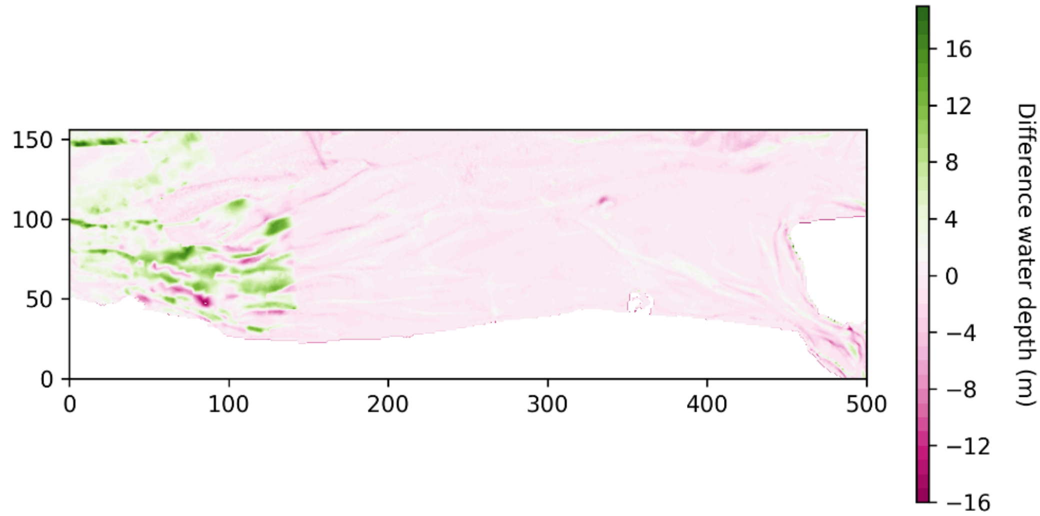

Figure 4: Differences between old and new extended SWAN grid.

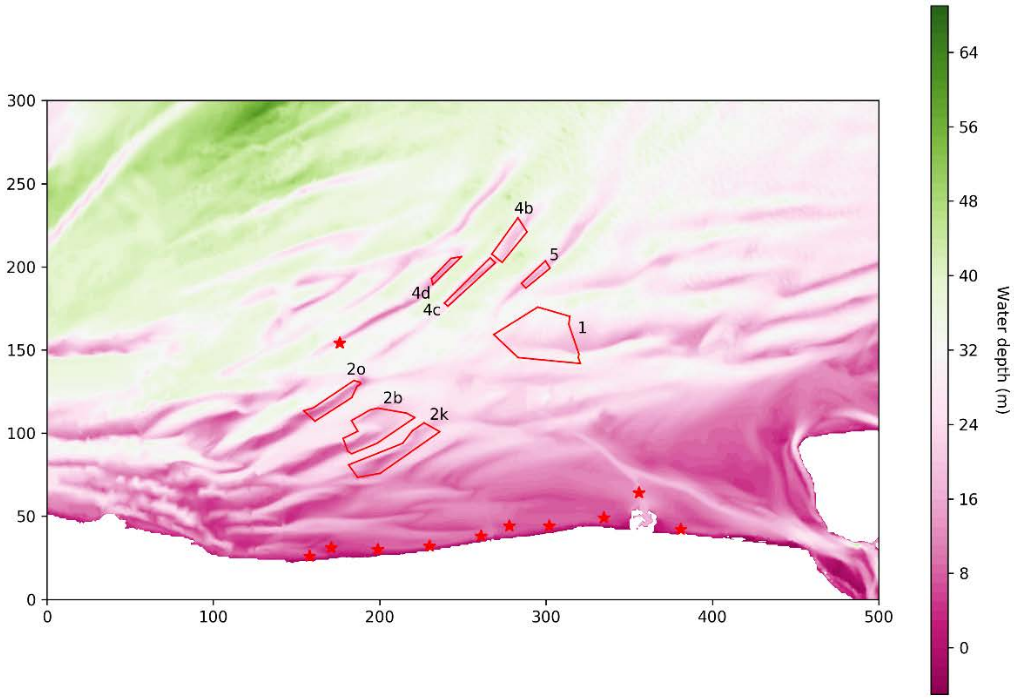

Figure 5: New extended SWAN grid, based on the old SWAN grid and the BeC and SoB hydrodynamical grids. Reference levels is MSL. Points are output points at the coastal municipalities and the wave buoy at Westhinder (offshore). The extraction zones are indicated.

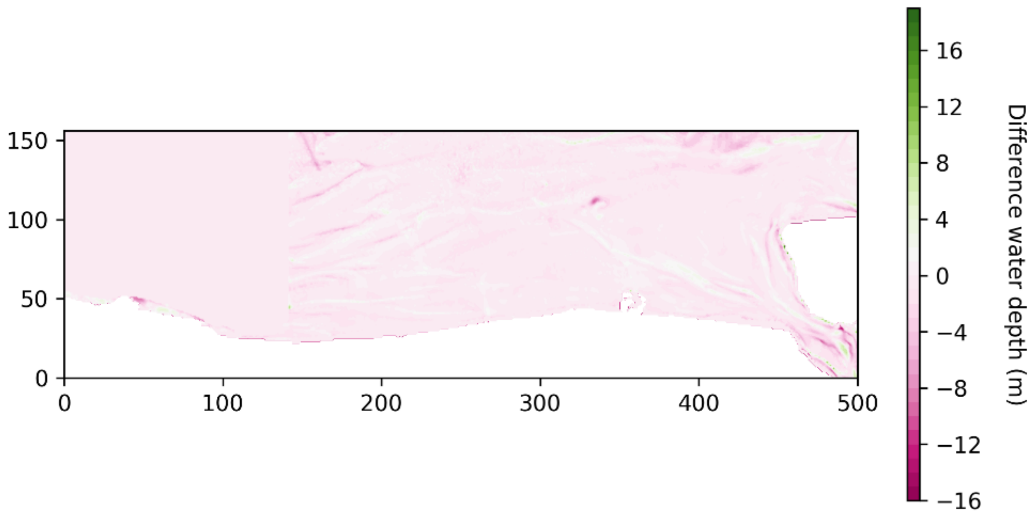

Figure 6: Differences between old and new extended SWAN grid, with original French part.

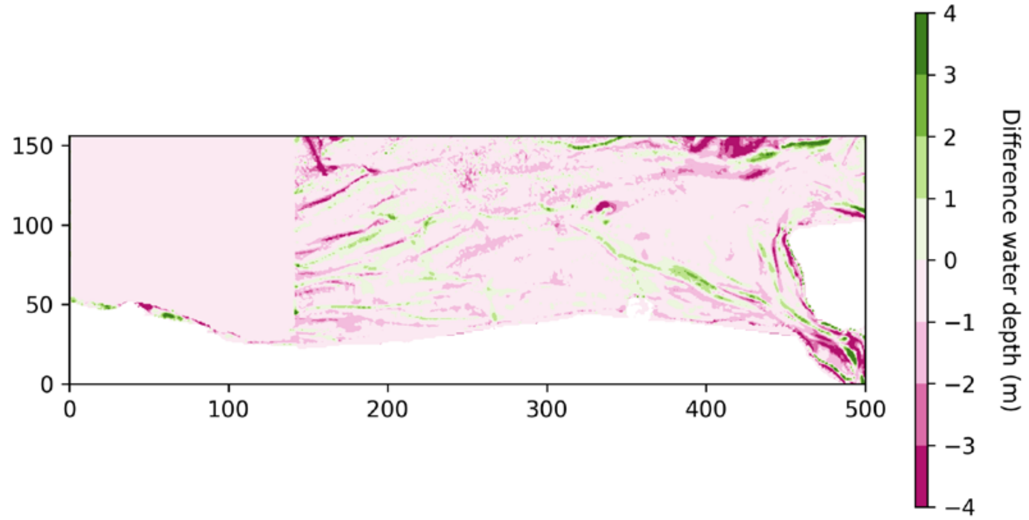

Figure 7: Differences between old and new extended SWAN grid, with original French part, zoomed in between -4 m and +4 m.

3.2. *Inclusion of the new reference level at the extraction Sectors*

To check the influence of the sand and gravel extraction, the bathymetry of the SWAN grid is adapted in the extraction zones to the newly proposed extraction levels. The position of the extraction sectors in the SWAN grid is shown in Figure 8.

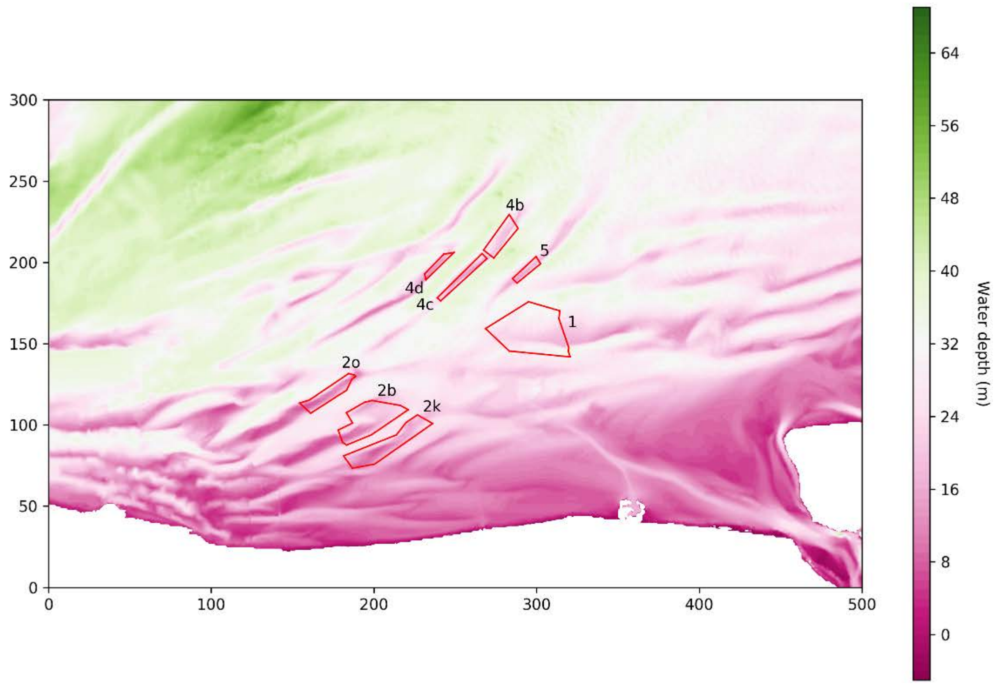

Figure 8: Position of the different extraction sectors in the SWAN grid.

For the present bathymetry and for the newly proposed extraction limit level, bathymetrical files were received on a grid of 5 m x 5 m for the different sectors from COPCO. To make the inclusion of these data consistent, both data sets were included in the SWAN bathymetry. A similar procedure is used, as was used in Van den Eynde (2016; 2017).

First, a new reference bathymetry was prepared based on the COPCO data. By averaging, the bathymetry for the grid cells of the model grid were derived. An average was only taken when at least 500 points could be used.

It can be noted that the differences between the reference bathymetry provided by COPCO and the bathymetry of the new SWAN grid vary between +0.17 m and -0.75 m, with the COPCO reference bathymetry being deeper for all sectors, except for sector 4c. These values are similar than the differences that were observed in Van den Eynde (2017). The fact that the COPCO reference bathymetry is less deep in the sector 4c than the SWAN grid is however surprising and is caused by the differences in the hydrodynamic grids that were used to construct the SWAN grid (Dulière, 2017). To make the introduction of the COPCO data in the SWAN bathymetry more consistent, the COPCO bathymetries were shifted over the difference for the different zones.

Since tests in Van den Eynde (2017) showed that adapting the borders to ensure a more smooth transition between the grids didn't improve the results, this was not done in this report.

In Figure 9, the difference between the (shifted) reference COPCO bathymetry and the bathymetry of SWAN is shown, for the sector 1. Some differences between the bathymetries are clear. Mainly at the southwestern part of the zone, some larger differences are visible.

Table 2: Difference between depth in the COPCO reference bathymetry and the SWAN bathymetry for the different sectors.

Sector	Difference (m)
1	-0.74
2b	-0.26
2k	-0.75
2o	-0.60
4b	-0.63
4c	0.17
4d	-0.29
5	-0.57

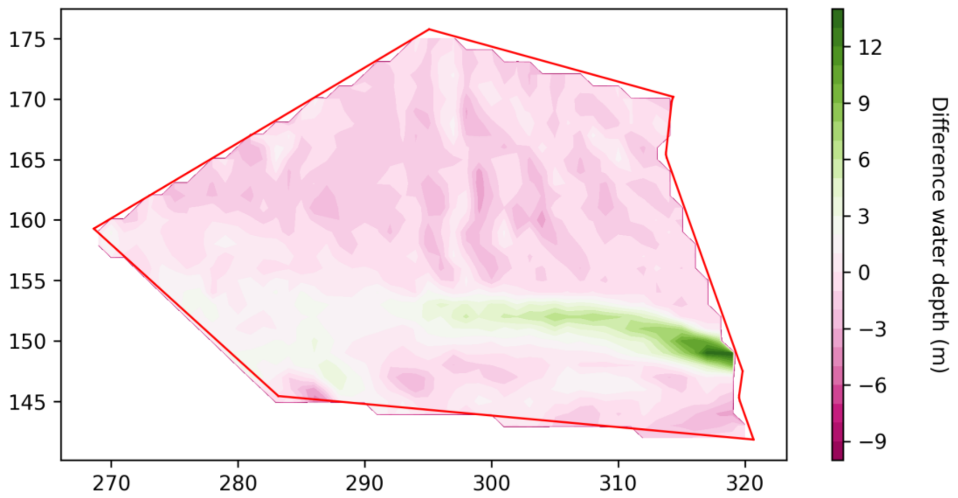

Figure 9: Difference between the (shifted) COPCO reference bathymetry and the SWAN bathymetry for the sector 1.

In Figure 10, the final bathymetry with the included COPCO bathymetry is shown for the sector 1.

After the preparation of the new reference bathymetry, the same procedure was followed to prepare the new bathymetry, where the bathymetry in the extraction zones was lowered to the new (proposed) extraction limit. The bathymetries were again first averaged over the model grid cells and were shifted over the same difference, that was found between the reference bathymetry and the SWAN model bathymetry. The bathymetry for the new extraction limit for sector 1 is shown as an example in Figure 11. In Figure 12, the difference between the reference bathymetry and the extraction limit bathymetry is shown for the same zone. In Figure 13, the difference between the reference bathymetry is shown for a cross-section of the bathymetry at Y=195, where the sectors 4c, 4d and 5 are cut.

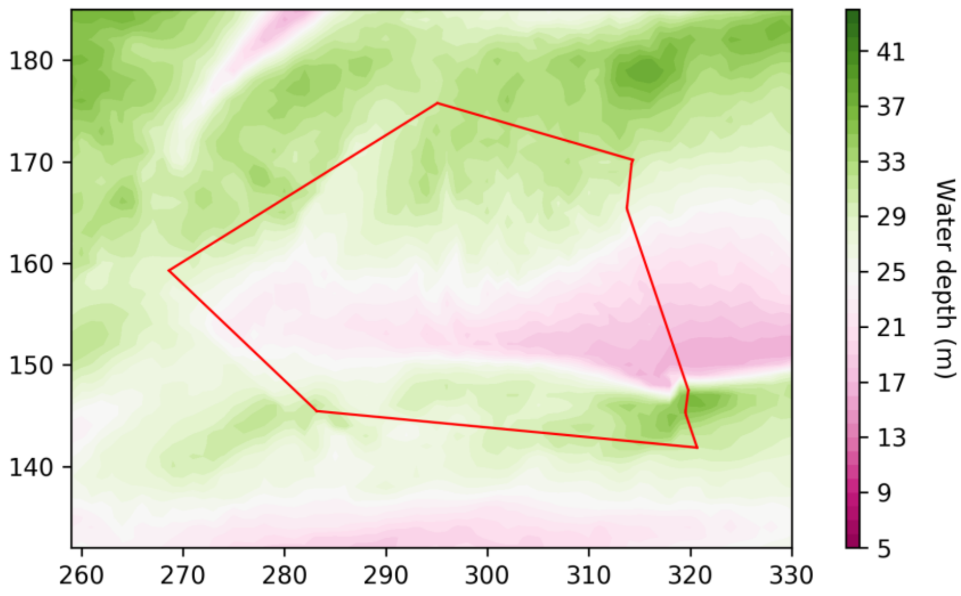

Figure 10: New bathymetry for the sector 1, based on the COPCO bathymetry.

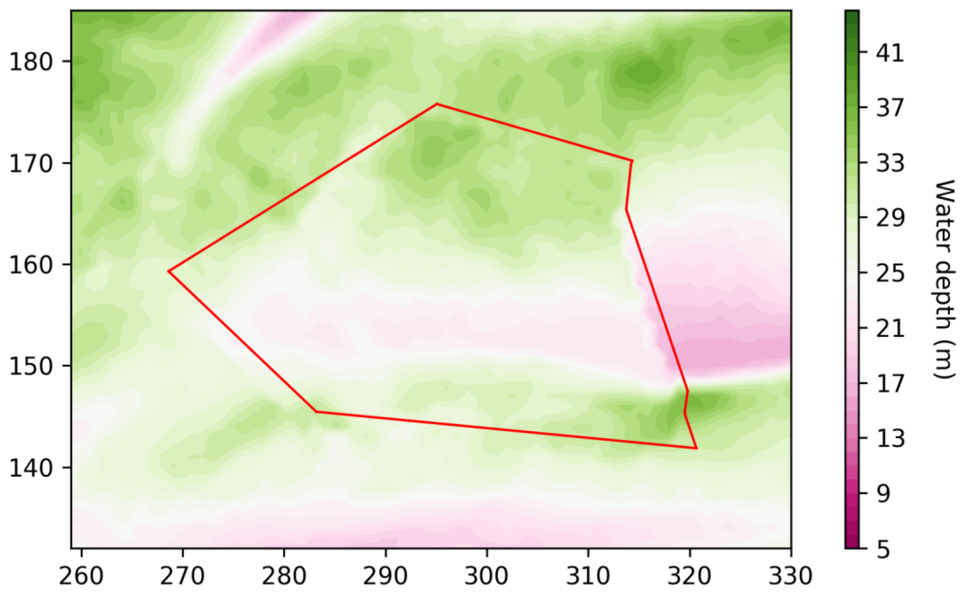

Figure 11: New extraction limit bathymetry for the sector 1, based on the COPCO bathymetry.

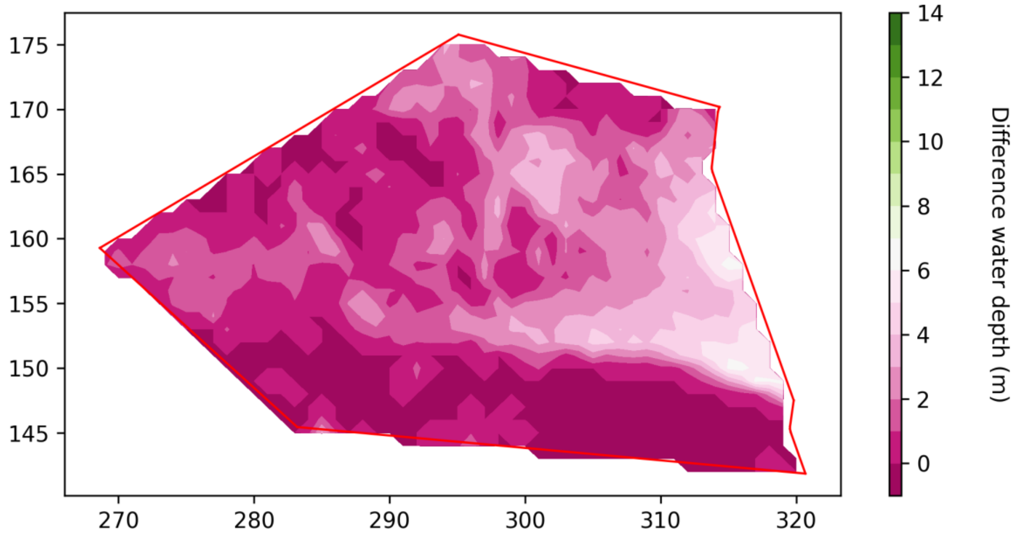

Figure 12: Difference between the reference bathymetry and the extraction limit bathymetry for the sector 1.

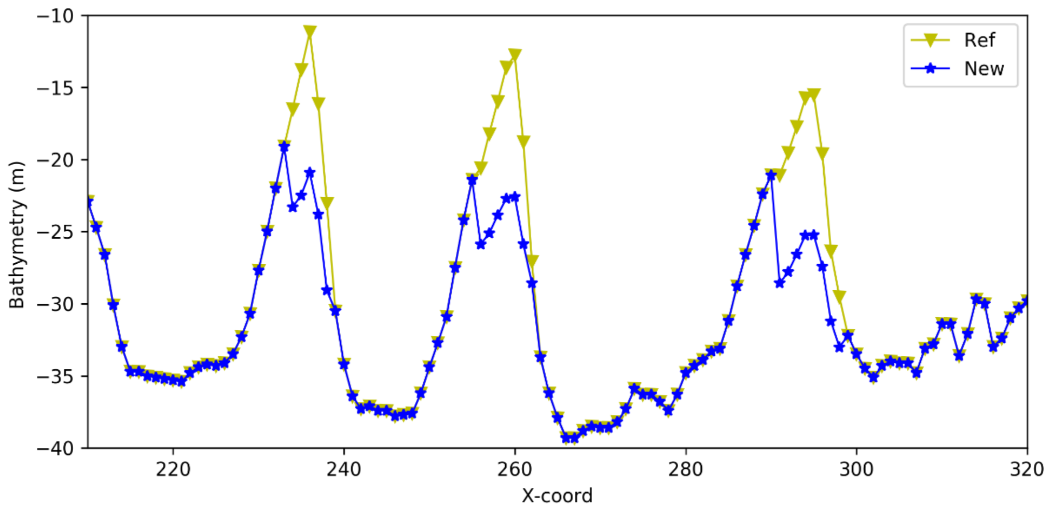

Figure 13: Difference between the reference bathymetry and the extraction limit bathymetry at Y=195.

Some information on the area of the different sectors for the different sectors can be found in Table 3. Sector 1 is clearly the largest zone, with a size of 73 km², while sector 4d and the new sector 5 are the smallest ones, with a size of only 5.2 km² and 6.2 km² respectively. In the Table 3, also the volume is given of the marine aggregates that could be extracted. The largest amount can be extracted in sector 1, namely about 93 Mm³. In the other sectors, the extractable amount varies between 35.7 Mm³ (sector 4d) and 85.4 Mm³ (sector 2b). Remark that in the sector 1 only 1.28 m can be extracted on average over the entire sector, while in sector 5, more than 7 m can be extracted on average over the zone. In total a volume of 508 Mm³ can be extracted in the different sectors.

Table 3: Area and the volume extracted for the different extraction sectors.

Sector	Area (km^2)	Extraction (Mm^3)	Extraction/Area (m)
1	73.1	93.23	1.28
2b	39.4	85.37	2.16
2k	34.7	66.03	1.90
2o	17.2	52.10	3.03
4b	14.9	63.98	4.30
4c	10.5	66.53	6.34
4d	5.2	35.68	6.80
5	6.2	44.94	7.26
TOT	201.2	507.86	2.52

4. Modelling the effect of extraction on wave propagation

4.1. *Introduction*

In a first section, some small tests with the boundary conditions will be presented and some parameters in the SWAN model will be explained. In the main part, simulations with the reference and the extraction limit bathymetry will be presented for different wave heights and wave directions. Simulations of the 1000 yearly storm for the Belgian coast, including possible sea level rise will be discussed in the next section.

4.2. *SWAN model and boundary conditions*

4.2.1. General information

The SWAN model, version 40.51, is used with most of the default values. The model grid was already discussed in the previous sections. The wave spectra in the model are described for 37 frequencies within the frequency range of 0.025 Hz to 0.85 Hz. The frequencies are logarithmic distributed. The full directional range is covered with a resolution of 10°.

The model uses the 3th generation source files, including linear and exponential wind growth, white capping, non-linear 4-wave interactions (so-called quadruplets), depth-induced wave breaking, bottom friction and non-linear shallow water 3-wave interactions (so-called triads). The triads and bottom friction, non-active by default, were activated.

The model was run in stationary mode, with default accuracy parameters and with maximum 40 iterations. Normally around 7 iterations are used in the current calculations.

While recent research by Zijlema et al. (2012) showed that in older versions of SWAN (like the 40.51 version) wave growth by wind was overestimated, which was compensated by larger bottom friction for wind sea, the lower bottom friction was not included here, because the new wave growth formulations were not included in the 40.51 version of the model

Simulations were only executed for winds to the shore, covering the wind directions from South-West (SW) over North (N) to North-East (NE) with a resolution of 22.5°. Remark that the winds from NNW is almost a wind perpendicular to the shore. At the boundaries a Jonswap spectrum is applied with a peak enhancement parameters γ of 3.3, representing a (fully developed) wind sea spectrum. The directional width is set to 30°, in agreement with the results of the tests by IMDC (2009). The waves are characterised by a significant wave height *Hs*, a peak period *Tp* and a wave direction *Dir*. A constant wind was applied with a wind speed *Ws*. The wave direction at the boundary was assumed to be the same as the wind direction.

4.2.2. Boundary conditions

In IMDC (2009) some tests have been executed to check the influence of applying boundaries at the northern boundary alone or at the northern and western boundary of the model grid. It was stated that applying waves at the eastern boundary was not important, due to the limited effect of these boundaries at the Belgian coast, as they used the model grid, set up by KULeuven and FHR (2004), which was limited offshore to Westhinder. The results showed that for the Belgian coast, the effect of the boundaries was not too important. Since the model grid has been extended considerable to the North in this project, some initial test to check the influence of the boundary conditions on the results at the Belgian coastal stations were carried out.

To check the influence of the boundary conditions, six simulations were executed: three simulations with waves applied at the northern, western and eastern boundary, and three simulations with waves, only applied at the northern boundary. The waves at the boundaries had a significant wave height of 2 m and a peak frequency of 7 s. The water level was set at 0 m TAW, i.e. at -2.33 m below MSL. Wind speed was set at 14 m/s, with wind and wave directions from SW, NNW and NW. In Figure 14 and Figure 15, the significant wave height is shown with respectively boundaries at the N, E and W and with boundaries from the N only and for waves and wind from the NNW (perpendicular to the coast). The difference between the two maps is shown in Figure 16.

The difference in the points near the coast are shown in Figure 17. The Belgian zone is shaded. One can see that the differences in this case are mainly at the western and eastern boundaries and that the difference at the Belgian coast is limited.

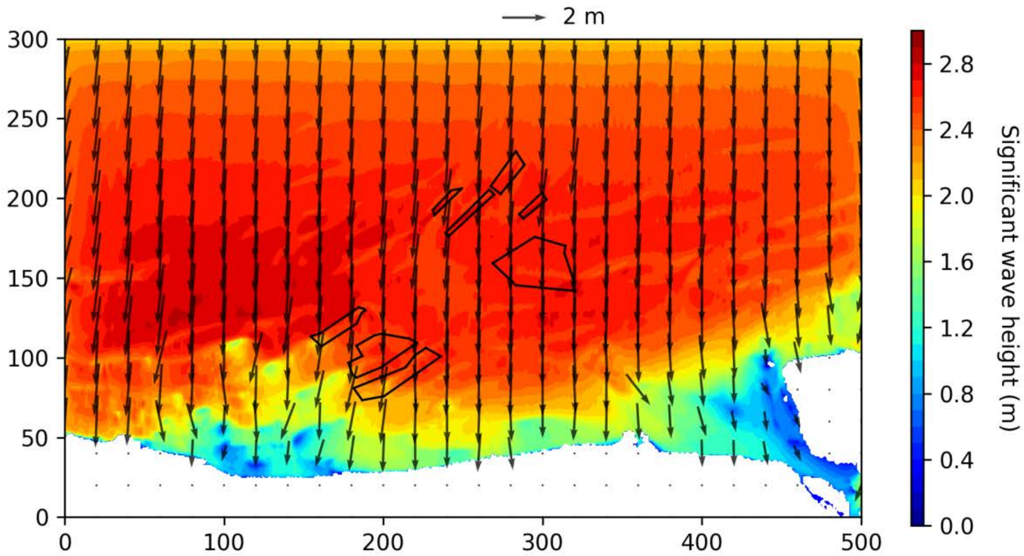

Figure 14: Significant wave height with boundaries at N, E and W. Waves at boundaries: Hs=2.0m, Tp=7s, Dir=NNW; wind speed Ws=14 m/s.

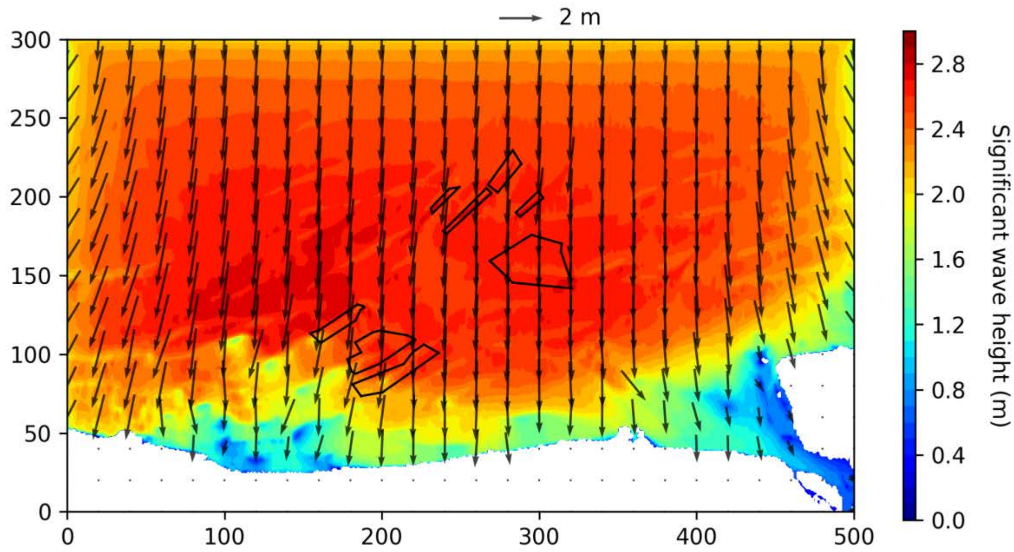

Figure 15: Significant wave height with boundaries at N. Waves at boundaries: Hs=2.0m, Tp=7s, Dir=NNW; wind speed Ws=14 m/s.

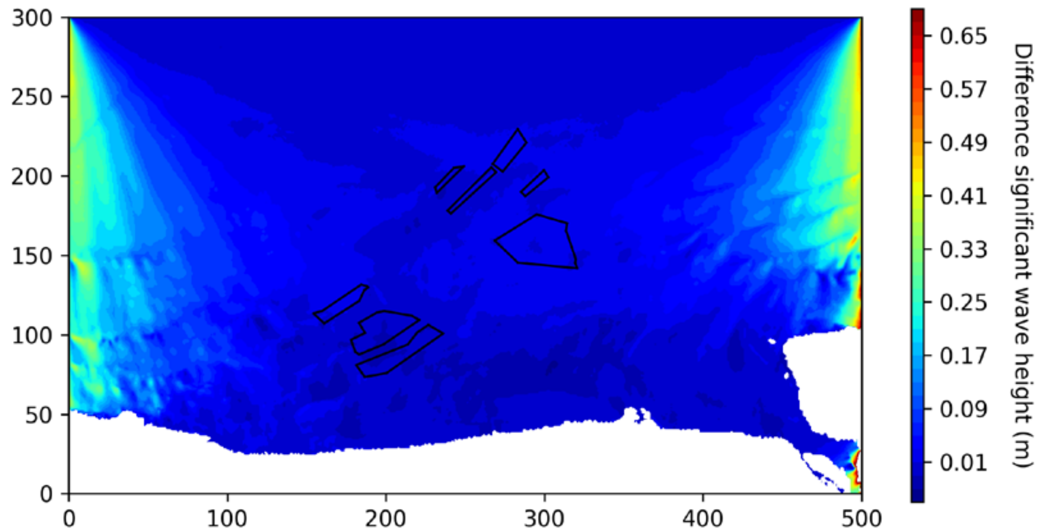

Figure 16: Difference in significant wave height between simulation with boundaries at N, E and W and simulation with boundaries at N. Waves at boundaries: Hs=2.0m, Tp=7s, Dir=NNW; wind speed Ws=14 m/s.

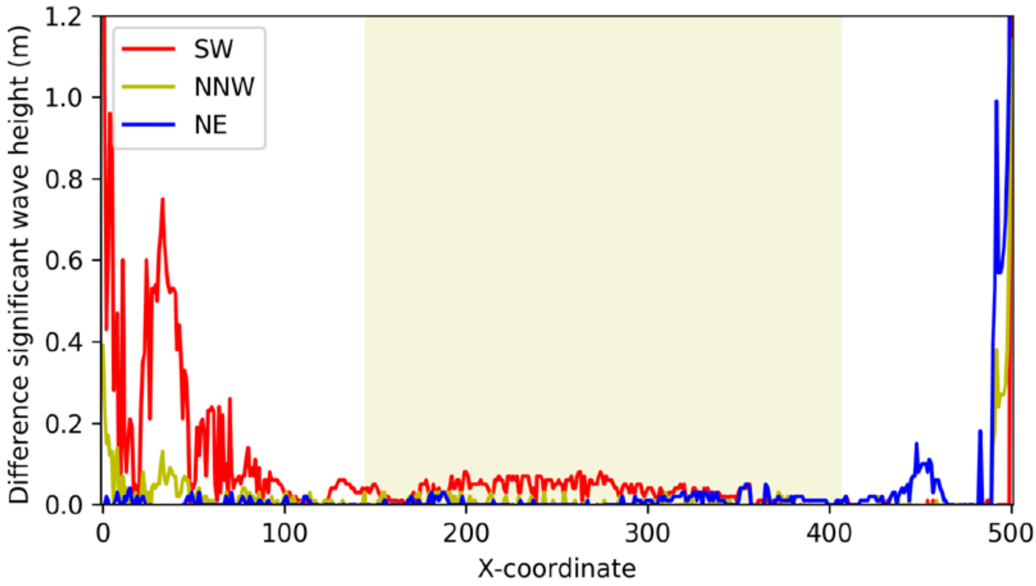

Figure 17: Difference in significant wave height between simulation with boundaries at N, E and W and simulation with boundaries at N at the points near the coast. Waves at boundaries: Hs=2.0m, Tp=7s, wind speed Ws=14 m/s. Different wind directions. Belgian zone is shaded.

The same differences maps are shown for waves and winds coming from the SW and NE respectively in Figure 18 and Figure 19. One can see that for these other wave and wind directions, the differences at the border itself are much larger, but that the influence at the Belgian coasts itself remains limited. This can also be seen again in Figure 17.

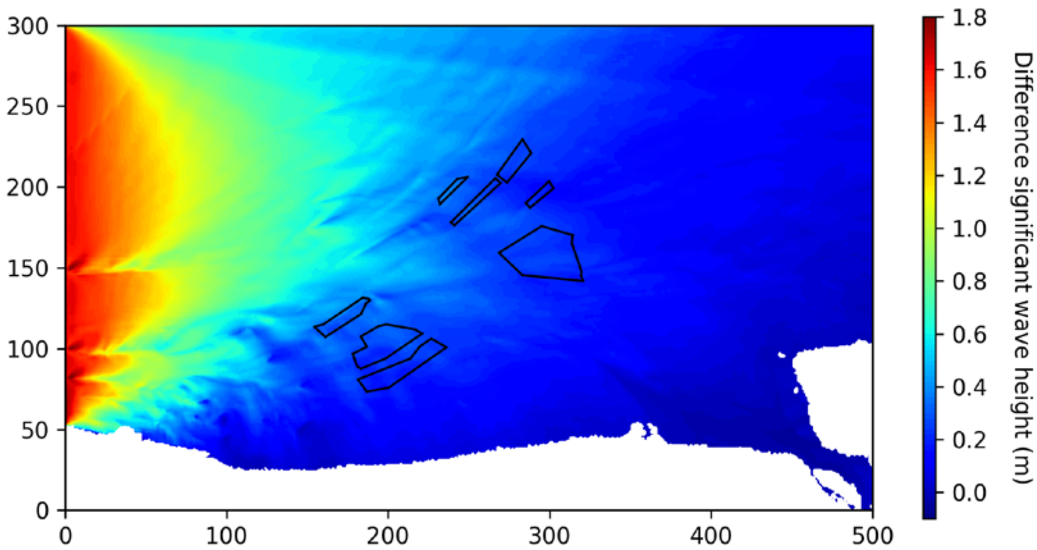

Figure 18: Difference in significant wave height between simulation with boundaries at N, E and W and simulation with boundaries at N. Waves at boundaries: Hs=2.0m, Tp=7s, Dir=SW; wind speed Ws=14 m/s.

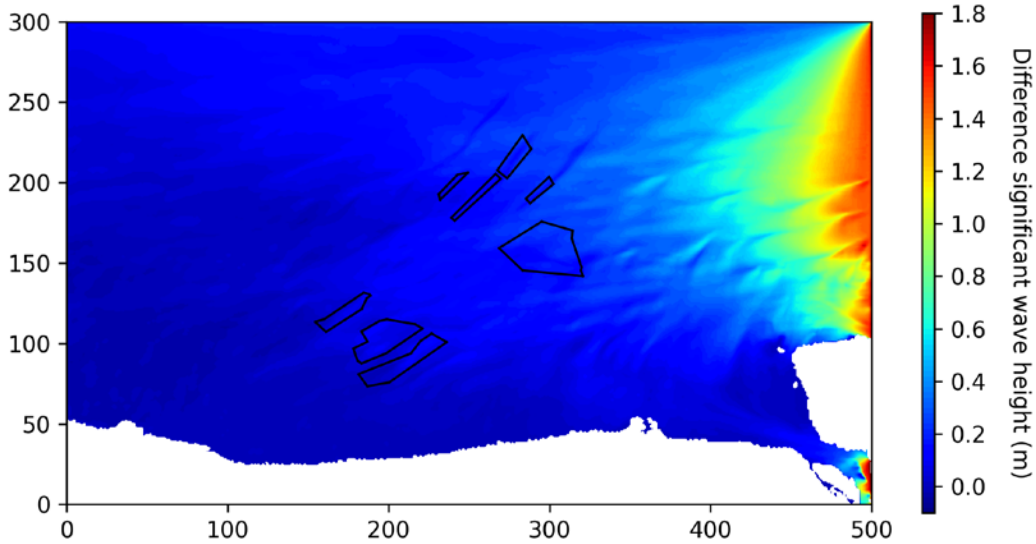

Figure 19: Difference in significant wave height between simulation with boundaries at N, E and W and simulation with boundaries at N. Waves at boundaries: Hs=2.0m, Tp=7s, Dir=NE; wind speed Ws=14 m/s.

In Figure 22, the difference in significant wave height is shown between the two simulations for the three wave and wind directions for the coastal stations defined above and for Westhinder. The maximum differences occur for the waves coming from SW. In stations Nieuwpoort and Oostende an increase of 0.07 m is found when applying boundary conditions at the N, E and W boundary compared to applying only boundaries at the N boundary. Since Westhinder is closer to the western boundary, the increase in significant wave height is considerable in this case, i.e. 0.62 m (from 2.49 m for boundaries at N, E and W boundary to 1.87 m for boundaries at N only). For the simulation with winds coming from NE, a small increase in significant wave height is found at the stations at the eastern coast, up to 0.07 m at station Zeebrugge. For winds coming from the NNW, the difference in significant wave height at the Belgian coast remains limited to less -0.02 m (decrease at Oostende).

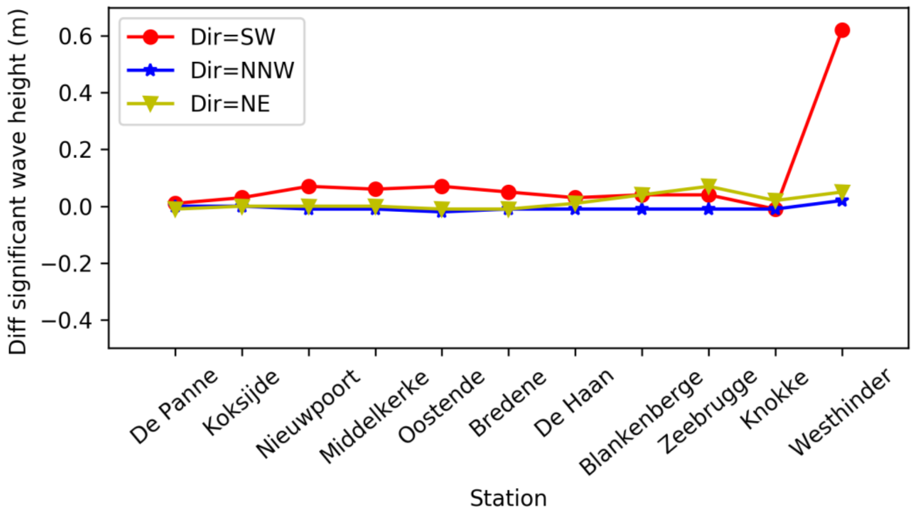

Figure 20: Difference in significant wave height between simulation with boundaries at N, E and W and simulation with boundaries at N. Waves at boundaries: Hs=2.0m, Tp=6s, Dir=NE; wind speed Ws=14 m/s.

The differences in mean period are presented in Figure 21. The largest difference is again for winds coming from the SW, with an increase of 0.31 s for station Nieuwpoort (and 0.89 s for Westhinder). The increase for winds coming from NE and N remains limited to 0.15 s at Blankenberge and Zeebrugge and to 0.05 s at De Panne and Middelkerke respectively.

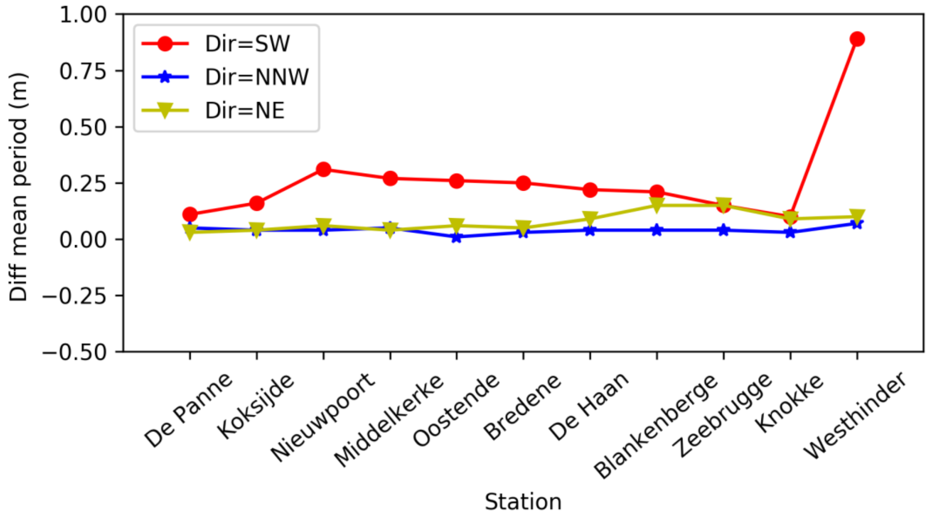

Figure 21: Difference in mean period between simulation with boundaries at N, E and W and simulation with boundaries at N. Waves at boundaries: Hs=2.0m, Tp=6s, Dir=NE; wind speed Ws=14 m/s.

It is important to realise that these differences as such are not important. In the report the effect of the extraction of sand on the propagation of waves to the Belgian coast is investigated. However, these simulations give an indication on the differences one can expect from changing the boundary conditions. In the rest of the report the waves will be applied at the three boundaries, i.e., N, E and W, since these seem to give the most realistic results.

4.3. Simulations for normal climate

For the effect of the extraction of sand at the propagation of the waves to the Belgian coast, a total of 108 simulations have been executed. Three different wave heights were applied at the boundaries of the model, i.e., Hs = 2 m, 3 m and 4 m. In Verwaest et al. (2008), a wave climate for the Belgian coast, based on measurements at station Westhinder was derived. They estimated that around 9.4 % of the time, wave heights of 2 m or higher were encountered at Westhinder with wind/wave direction between SW, N and NE. Waves with significant wave height of 3 m and 4 m are already more extreme cases.

Furthermore, in Verwaest et al. (2008) a relation was proposed between the wave height and the peak period and between the wave height and the wind speed for the waves with significant wave height of 2 m, which are peak period Tp= 7 s and wind speed Ws = 14 m/s. Based on these relationships, values were proposed for significant wave heights of 3 m and 4 m as well, see Table 4. Simulations were performed for 9 different wave and wind directions, going from SW to NE, with a resolution of 22.5°. Furthermore, simulations were executed for low waters and high waters. Low water was set at 0 m TAW, i.e. at -2.33 m below MSL, while high water was set at +2.33 m MSL. To test the effect of the extraction of sand, simulations were of course executed for the reference bathymetry and for the bathymetry with the new proposed extraction limit level. As such, a total of 108 simulations have been executed.

Table 4: Significant wave height, peak period and wind speed for the simulations

Significant wave height (m)	Peak period (s)	Wind speed (m/s)
2	7	14
3	8	18
4	9	22

Some results are first presented for the coastal stations (and Westhinder) in a first section, since this is the main objective of this report. Some more general results are presented in a second section.

4.3.1. Results at the coastal stations

In Figure 22 to Figure 27 for the different coastal stations (and for station Westhinder) and for the different wave and wind directions, the difference in significant wave height is given for the different significant wave heights at the boundaries (and the corresponding wind speed) and for the HW and LW water levels. As a reference in Figure 28, also the significant wave heights are given for boundary conditions with significant wave height of 4 m and for the wind and wave directions of SW, NNW and NE.

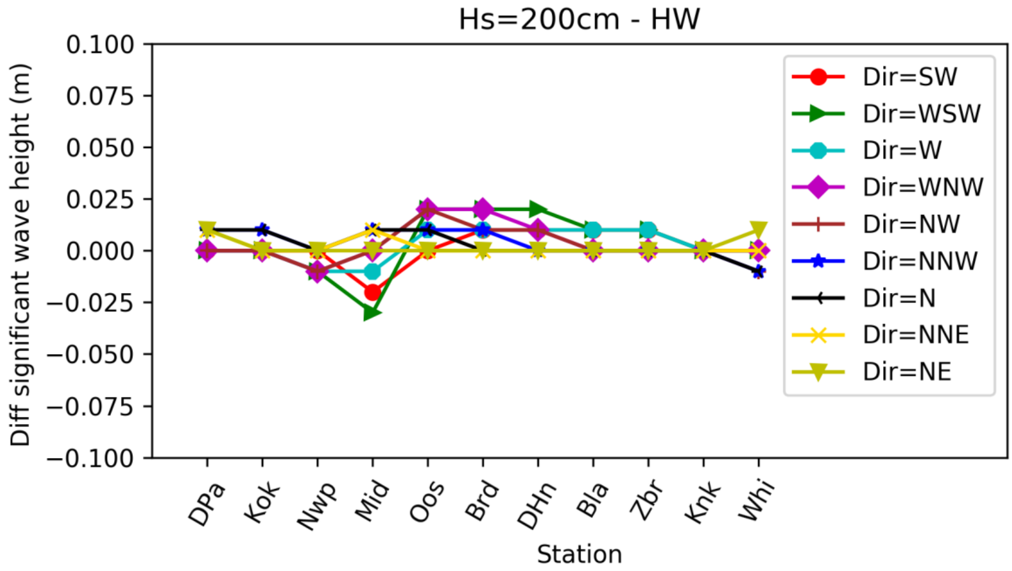

Figure 22: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 2.0 m, wind speed = 14 m/s, different wave and wind directions. HW situation (MSL +2.33 m).

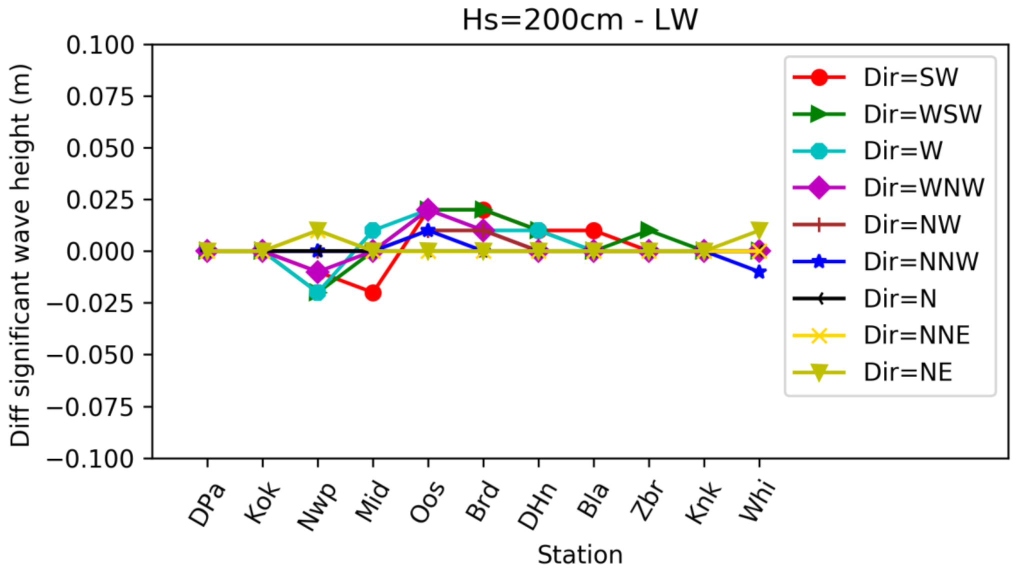

Figure 23: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 2.0 m, wind speed = 14 m/s, different wave and wind directions. LW situation (MSL -2.33 m).

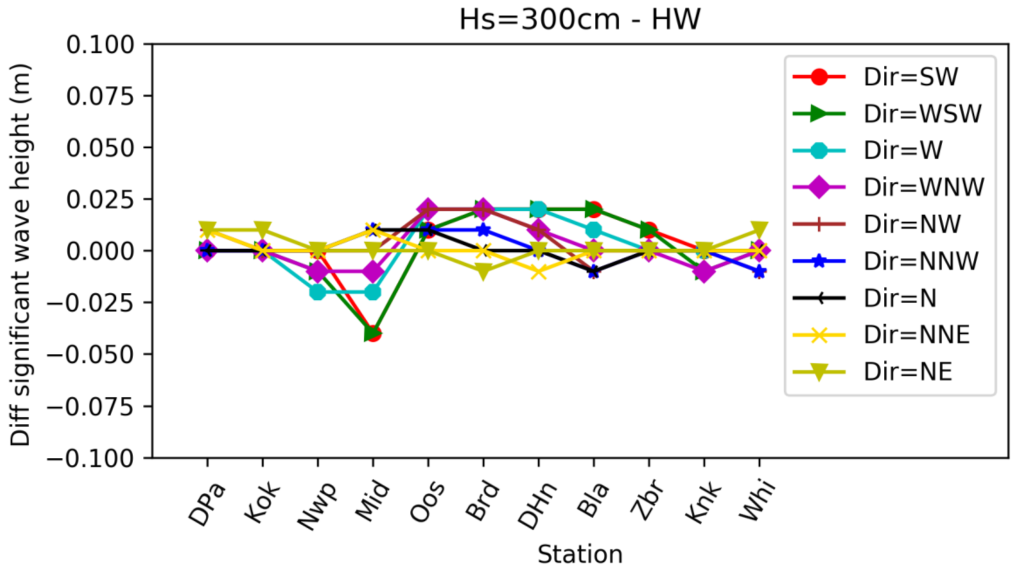

Figure 24: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 3.0 m, wind speed = 18 m/s, different wave and wind directions. HW situation (MSL +2.33 m).

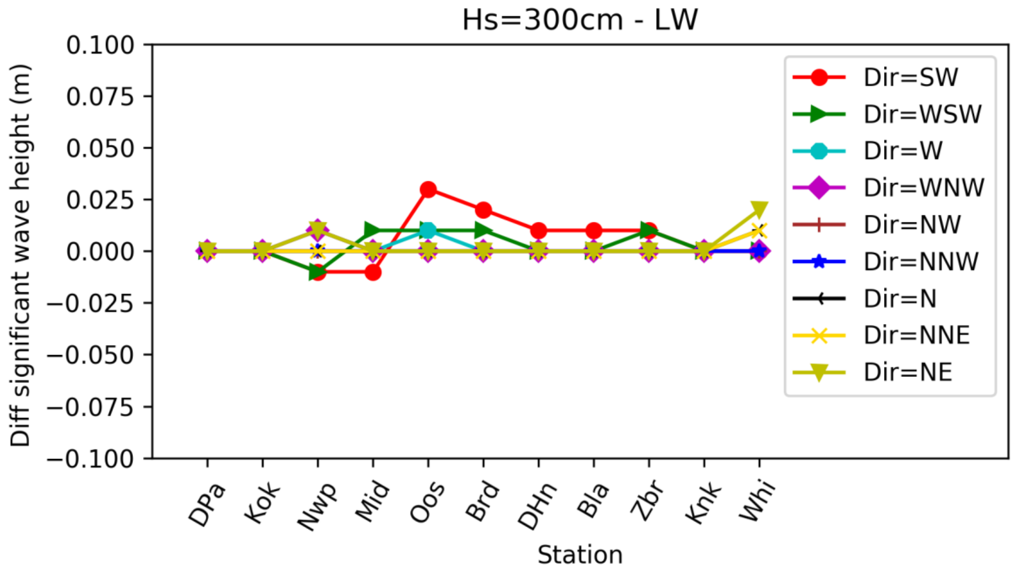

Figure 25: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 3.0 m, wind speed = 18 m/s, different wave and wind directions. LW situation (MSL -2.33 m).

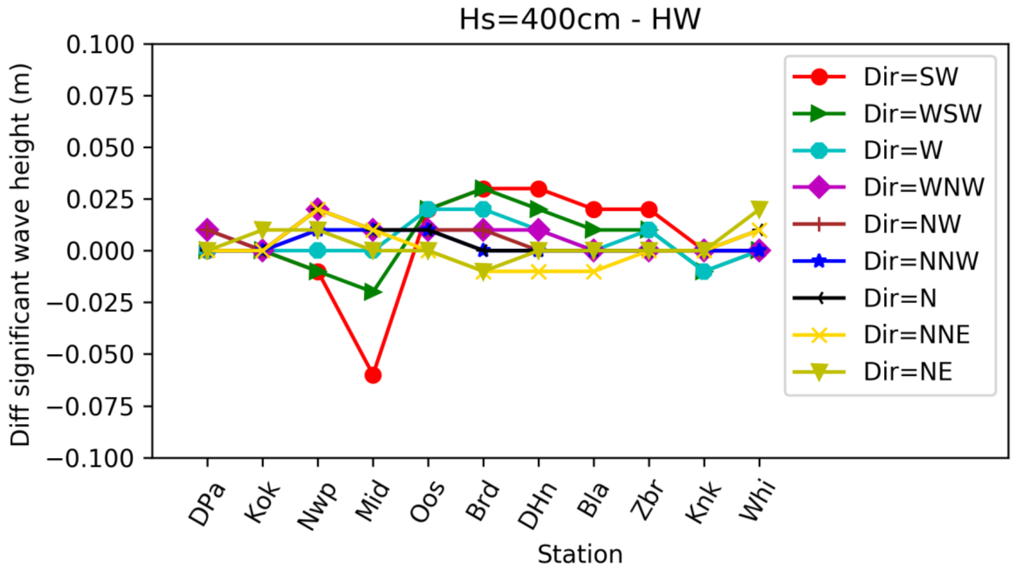

Figure 26: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 4.0 m, wind speed = 22 m/s, different wave and wind directions. HW situation (MSL +2.33 m).

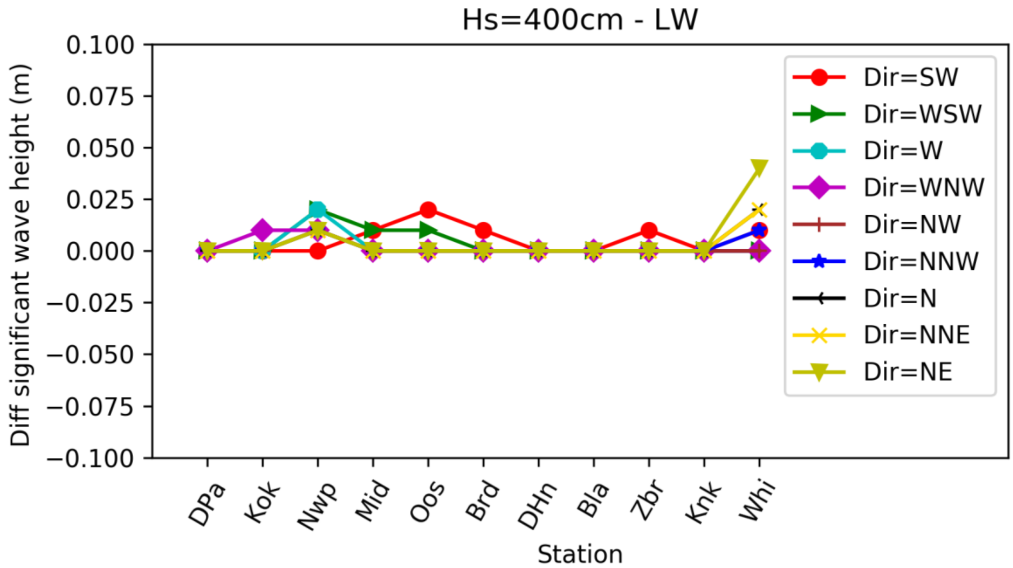

Figure 27: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 4.0 m, wind speed = 22 m/s, different wave and wind directions. LW situation (MSL -2.33 m).

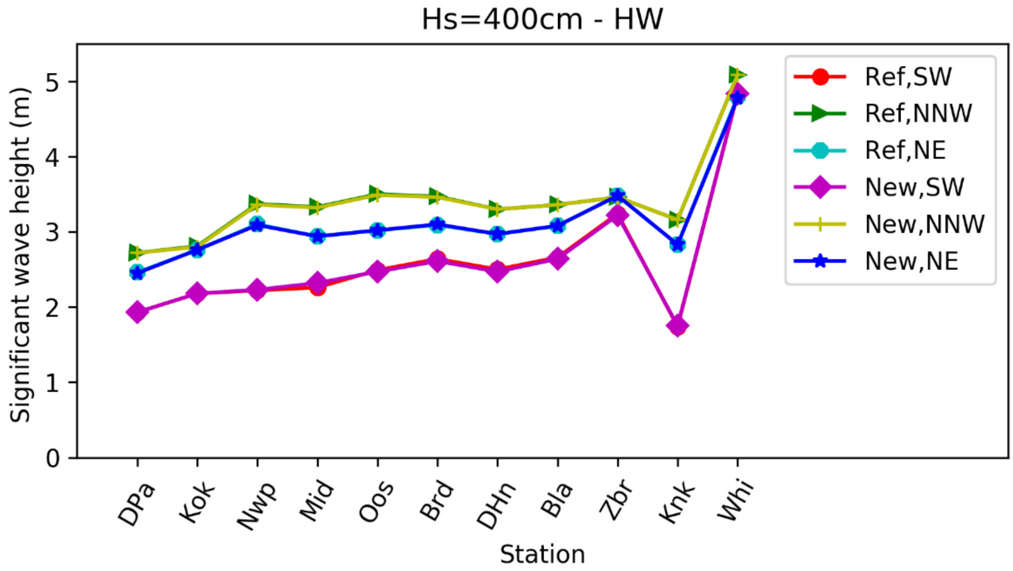

Figure 28: Significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit (NEW) compared to without extraction (REF). Waves at boundary with significant wave height of 4.0 m, wind speed = 22 m/s, different wave and wind directions. HW situation (MSL +2.33 m).

For the significant wave height of 2 m at the boundaries, the difference at the coastal stations is limited to 0.02 m or less, both for the HW and the LW water levels, except for station Middelkerke, where a decrease in wave height is expected for HW water level and for waves from WSW of -0.03 m. The effects at the coast are therefore limited. Overall, a small decrease in significant wave height could be expected for some western stations (Nieuwpoort, Middelkerke), while a small increase is expected for some central stations (Oostende, Bredene, De Haan). The effects are slightly larger for the HW water level than for the LW water level.

Similar results are found for a significant wave height of 3 m at the boundaries. At stations Middelkerke, a decrease is found of significant wave height of -0.04 m for winds coming from WSW and SW and for HW. On the other hand, an increase of +0.03 m is found for station Oostende for wind from SW. Also here, for the rest, the differences remain limited to 0.02 m.

For significant wave heights of 4 m at the boundaries and wind speeds of 22 m/s, the changes remain limited. The decrease at station Middelkerke for HW and winds from SW is -0.06 m now, while for the same wind direction, the increase in significant wave height at stations Bredene and De Haan is +0.03 m now. For the rest the results are limited to 0.02 m. To illustrate the limited influence of the sand extraction, the significant wave height for the two simulations is shown for the coastal stations in Figure 28. Although there are differences for the difference coastal stations and for the wind direction, the influence of the sand extraction is limited.

Remark that also at station Westhinder, the changes remain very limited. Only for winds from NE and wave height of 4 m at the boundaries, an increase in wave height is found of +0.04 m.

One can conclude that the highest effects are to be expected at HW water levels, and that in the area Nieuwpoort-Middelkerke a small decrease is expected and in the area Oostende-Bredene-De Haan a small increase is expected. This is illustrated in Figure 29. Furthermore, the highest changes are expected for the largest waves and for the winds from SW and WSW. Overall, however, the effects remain very limited.

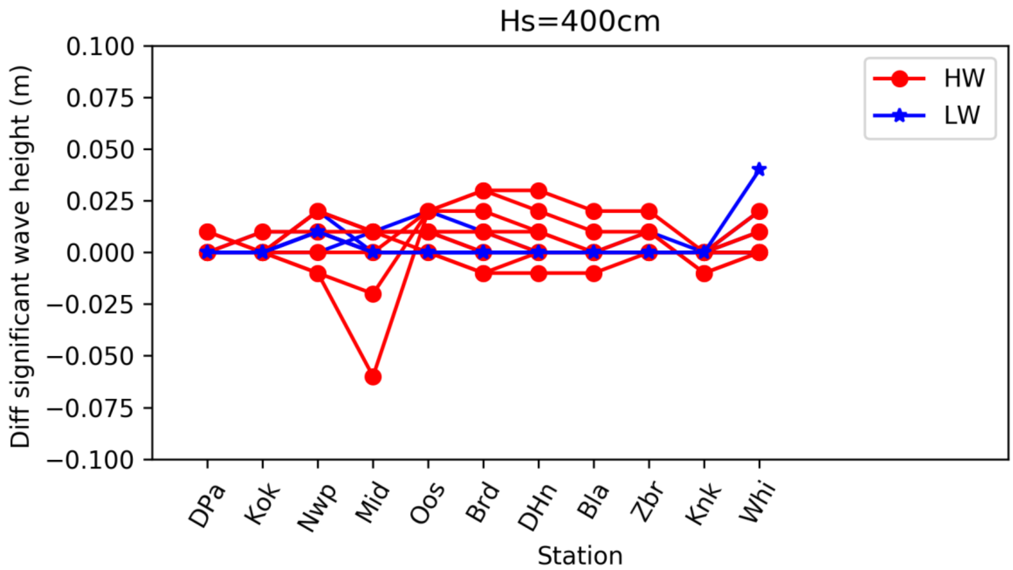

Figure 29: Difference in significant wave height at coastal stations and Westhinder for simulation without extraction and with the new proposed extraction limit. Waves at boundary with significant wave height of 4.0 m, wind speed = 22 m/s.

The changes to the mean period near the coast remain limited to less than -0.09 s or +0.07 s, and are the largest for winds coming from SW. Also the changes in wave direction remain limited to less than +1.7 degrees or -1.4 degrees.

4.3.2. Overall results

In the previous section, it was shown that the results of the new limit for sand extraction has limited effects on the significant wave height at the coastal stations. However, the effect on the Belgian continental shelf itself, more offshore, closer to the extraction zones itself, can be much larger. Some information on this is presented in this section.

In Figure 30 the maximum and the minimum differences are shown in the model grid for the different simulations. One can see that the maximum decrease in wave heights is limited to -0.43 m. The maximum decrease is larger for the waves coming from N to NE. For the maximum increase in wave height, more differences can be observed. First of all, it is clear that for the difference are larger for higher significant wave heights at the boundaries. However, also the water level is of great importance.

The maximum increase for low water (MSL -2.33 m) and for wave heights of 3 m at the boundaries is much larger than the maximum increase for high water (MSL +2.33 m) and for wave heights of 4 m at the boundaries. The maximum differences are for waves coming from NNW (perpendicular to the coast) to NE. The maximum increase during HW is +1.0 m for waves coming from NE, while the maximum increase during LW is +1.85 m for winds coming from N.

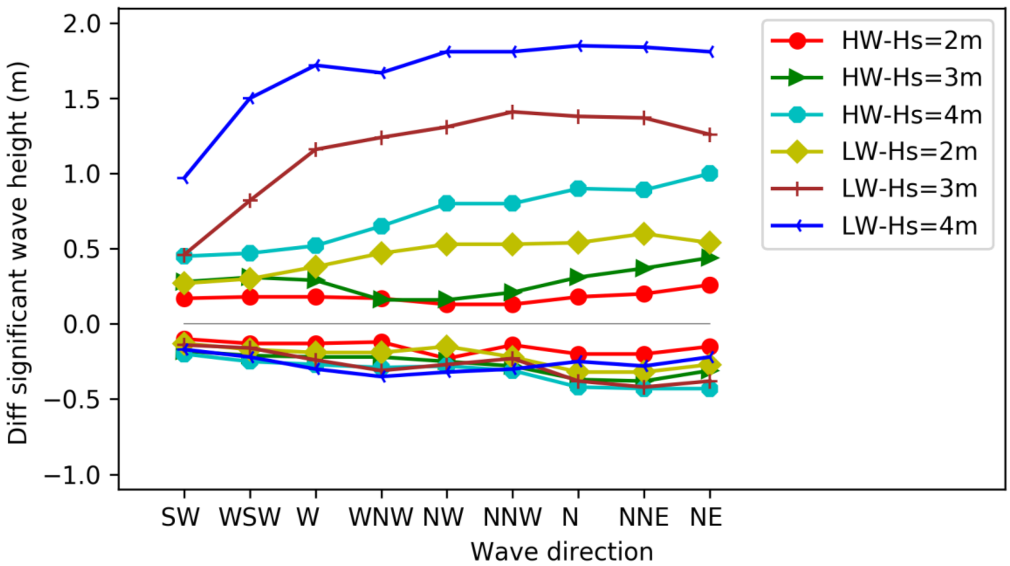

Figure 30: Maximum and minimum difference in significant wave height at the model grid for simulation without extraction and with the new proposed extraction limit as a function of the wind direction, for three different wave heights at the boundaries (*Hs*=2 m – *Ws*=14 m/s; *Hs*=3 m – *Ws*=18 m/s; *Hs*=4 m – *Ws*=22 m/s) and for HW and LW water levels.

In Figure 31, the position of the points where the maximum and the minimum differences in significant wave height are found for all simulations. The maximum differences are mostly found southwest (or south) of the extraction zones 3, mostly around the extraction zone Oostdyck. The minimum differences are found near south of east of the extraction zones 1, 4 and 5, while also two points are found near the coast.

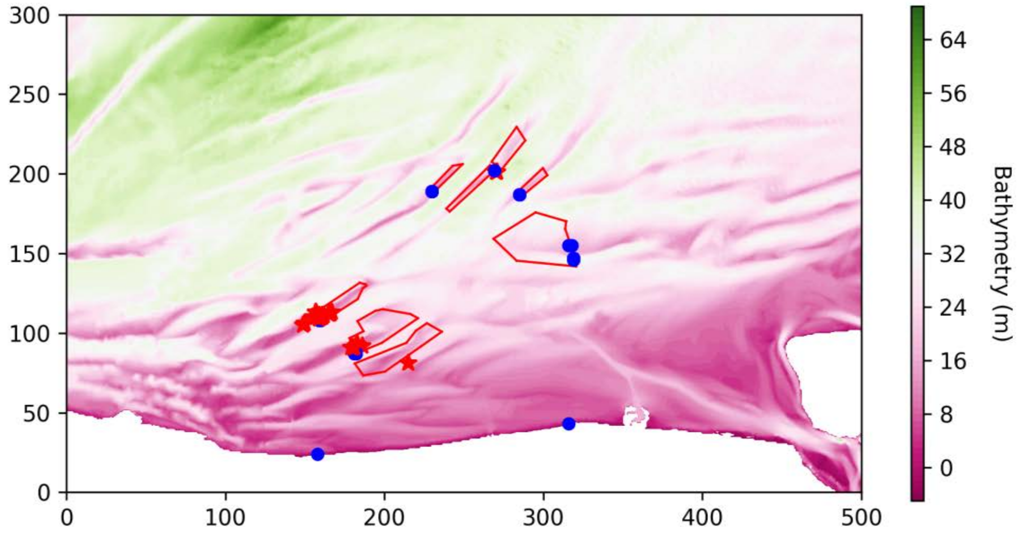

Figure 31: Position of the points were highest increase (red stars) and highest decrease (blue dots) in significant wave height are found for all simulations.

As an example, the significant wave heights for the LW water level, and for significant wave height of 4 m coming from the N, for the simulations with original bathymetry and with the bathymetry, for the new extraction limit are given in Figure 32 and Figure 33. The differences between the two significant wave heights is given in Figure 34.

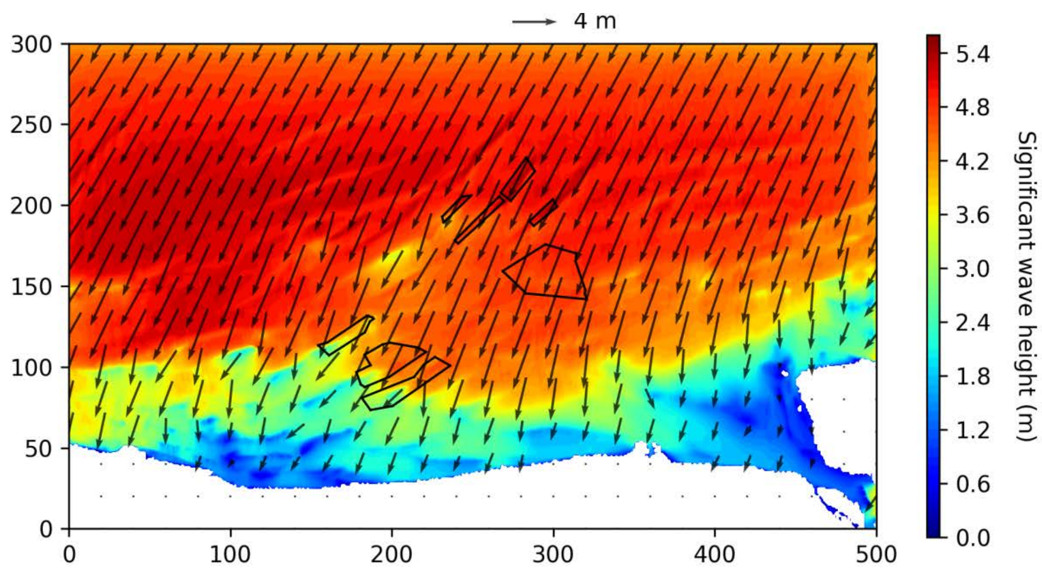

Figure 32: Significant wave height with original bathymetry. Waves at boundaries: Hs=4.0m, Dir=N; wind speed Ws=22 m/s.

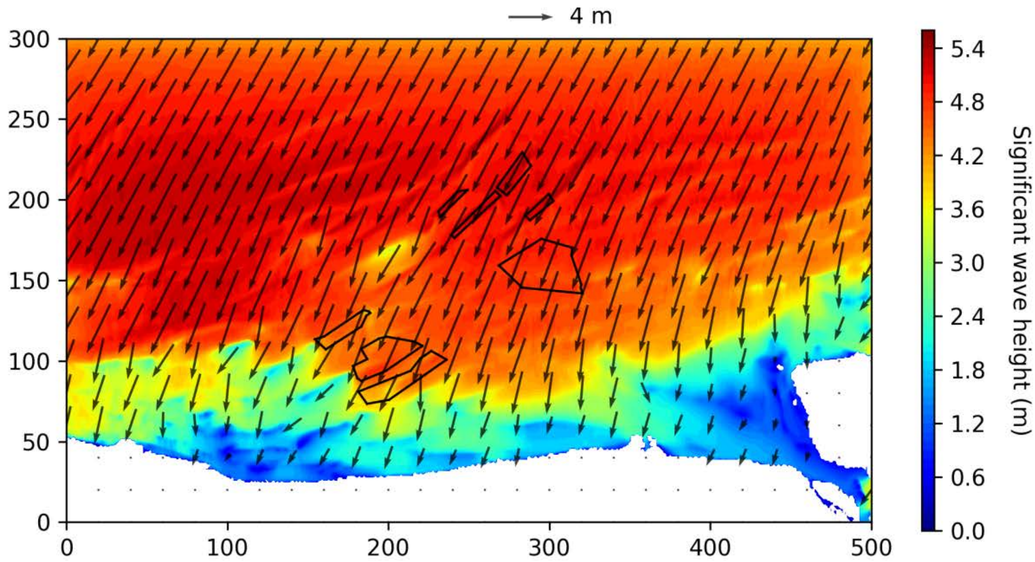

Figure 33: Significant wave height with extraction limit bathymetry. Waves at boundaries: Hs=4.0m, Dir=N; wind speed Ws=22 m/s.

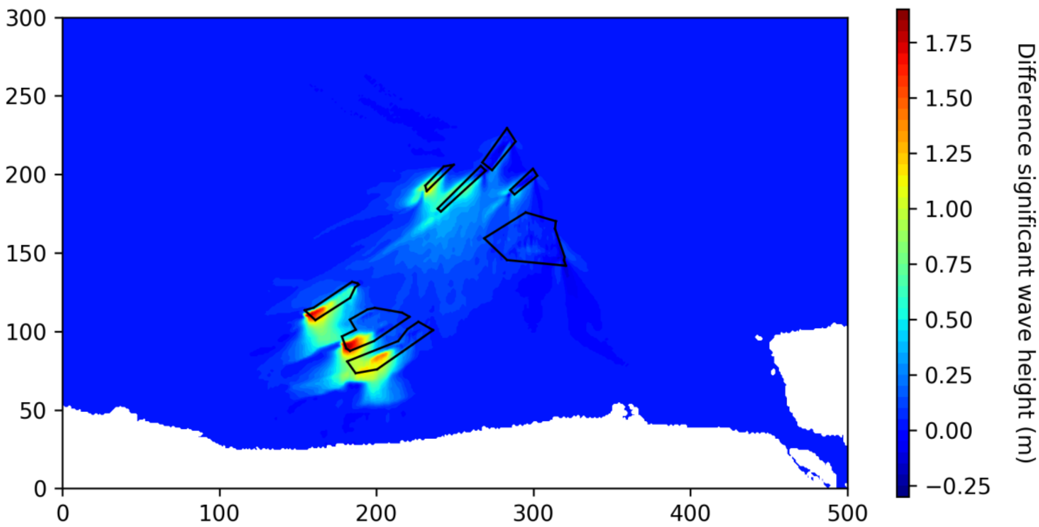

Figure 34: Difference in significant wave height between simulation with extraction limit bathymetry and simulation with original bathymetry. Waves at boundaries: Hs=4.0m, Dir=N; wind speed Ws=22 m/s.

One can see that the effect in the neighbourhood of the extraction zones can be quite considerable, with an increase in significant wave height south of the extraction zone 3 at the Buitenratel of +1.85 m, but that the effect at the Belgian coast is negligible.

4.4. Simulations for 1000 yearly storm

4.4.1. Introduction

Finally, also some simulations were executed for the so-called 1000 yearly storm. In this case waves of 6 m are applied at the boundaries, the water level is set at 7 m above TAW (i.e., at 4.67 m above MSL). The peak frequency is set at 10.5 s and the wind velocity is put at 30 m/s. These parameters are based on de Roo et al. (2014). Normally these boundary conditions are taken at station Westhinder. In this case the same boundary conditions were taken at the boundary of the new grid, which is extended more to the North. The simulations were done for 4 wind directions, which are N, NNW, NW and WNW since these directions contribute to the resulting extreme wave height near the coast and depending on the location, one direction can have more impact due to sand mining than the other.

To take into account possible sea level rise on a longer term, reference was taken to the recent report of CREST and Coastal Project Coastal Vision (2019), were common climate change scenarios for the Belgian coast were proposed. For the current study, the values for the IPCC (2013) RCP4.5 and RCP8.5 were taken, using a sea level rise of +0.60 m and +0.85 m respectively for the year 2100.

Although it is very unlikely that a 1000 yearly storm with waves with significant wave height up to 6 m at the boundary occur with no storm surge, the simulations were also done with low water situation, thus with water level at MSL -2.33 m as reference.

The simulations were executed for the reference bathymetry and for the bathymetry with the new proposed extraction limit for extraction.

4.4.2. Results at the coastal stations

As for the normal climate, the results at the coastal stations are presented first. In Figure 35, the significant wave heights at the coastal stations and at Westhinder are shown for the 1000 yearly storm with boundaries of significant wave height of 6 m and wind speed of 30 m/s. One can see that the significant wave height at De Panne and Koksijde remains below 4 m, while at the coastal stations from Nieuwpoort to Blankenberge, the significant wave height varies around 4.5 m. At Zeebrugge, the station a little bit more offshore, a significant wave height of more than 5 m is reached. At Westhinder, a significant wave height of more than 7.5 m is reached for winds from the WNW. Overall the highest wave heights are obtained for winds from the NW. Since the wave height is clearly higher than 6 m at Westhinder, the simulations represent an even extremer case than the 1000 yearly storm, with significant wave height of 6 m at Westhinder.

In Figure 36 to Figure 39, the differences in significant wave height at the coastal stations (and Westhinder) are shown for the different simulation and for the different water levels, due to the sand extraction.

One can see that the effects at the coastal stations also in these cases remain limited. Most effects are seen for waves and winds coming from NW and especially WNW. Only in these cases changes of more than 0.02 m are expected. The largest increase in significant wave height is for a sea level rise of +0.85 cm, where the increase in significant wave height is +0.05 m at station Nieuwpoort. For the current sea level, at station Zeebrugge and Knokke a decrease of significant wave heights is found of -0.04 m and -0.03 m respectively. Overall the effects are negligible.

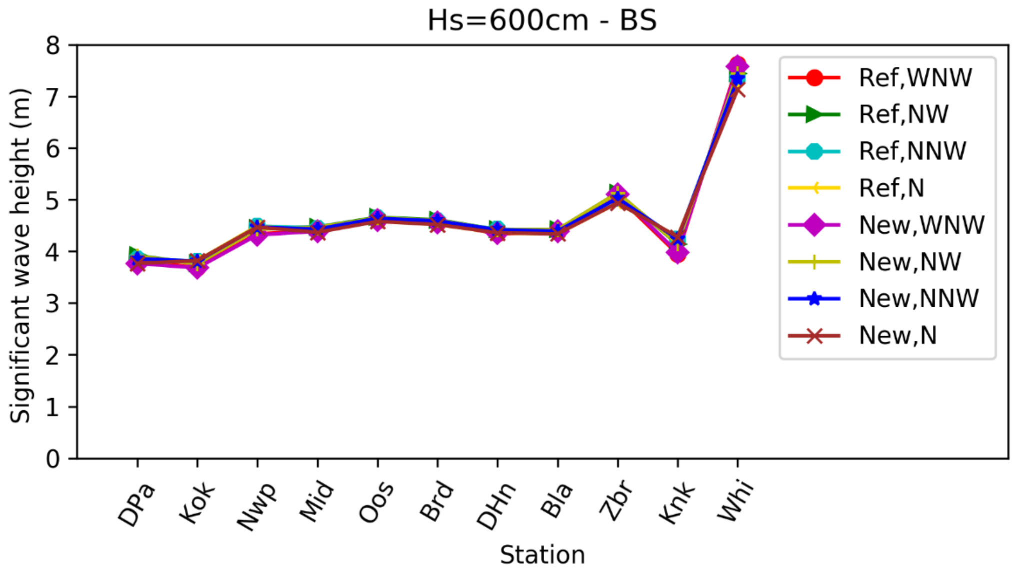

Figure 35: Significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit (New) compared to without extraction (Ref). Waves at boundary with significant wave height of 6.0 m, wind speed = 30 m/s, water level at 4.67 m MSL (1000 yearly storm). Results for different wave and wind directions.

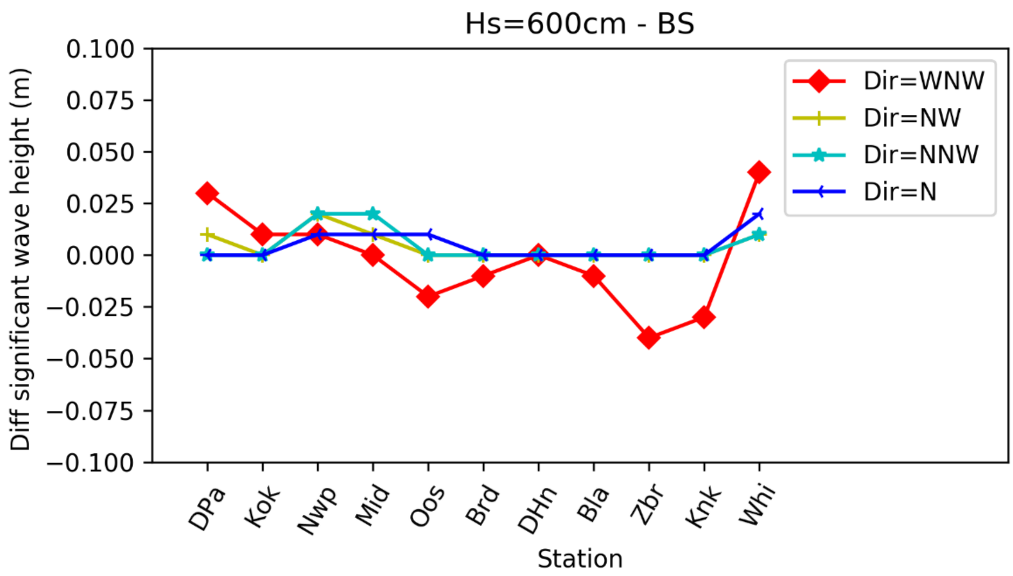

Figure 36: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 6.0 m, wind speed = 30 m/s, water level at 4.67 m MSL (1000 yearly storm). Results for different wave and wind directions.

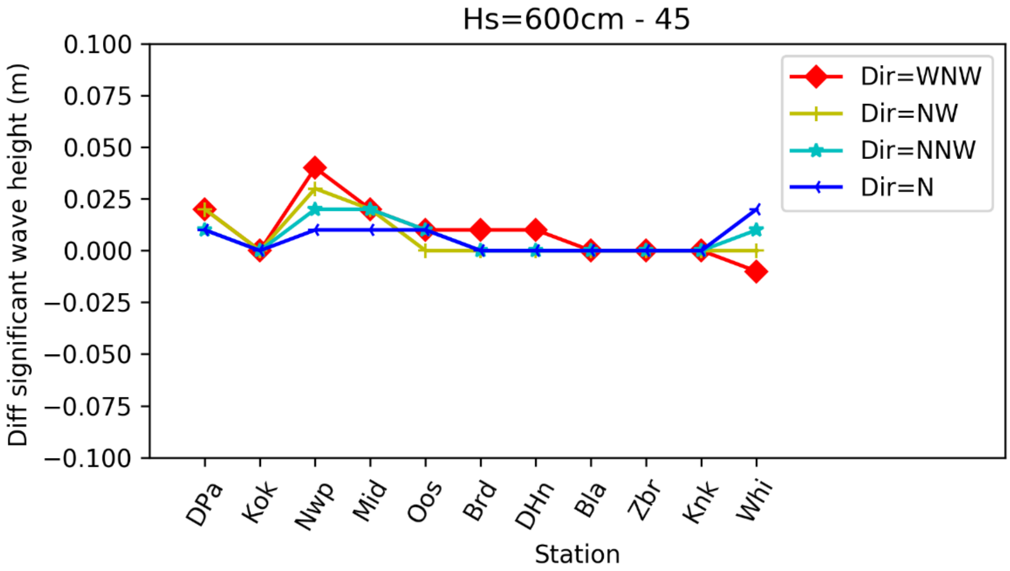

Figure 37: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 6.0 m, wind speed = 30 m/s, water level at 5.27 m MSL (1000 yearly storm + sea level rise RCP 4.5). Results for different wave and wind directions.

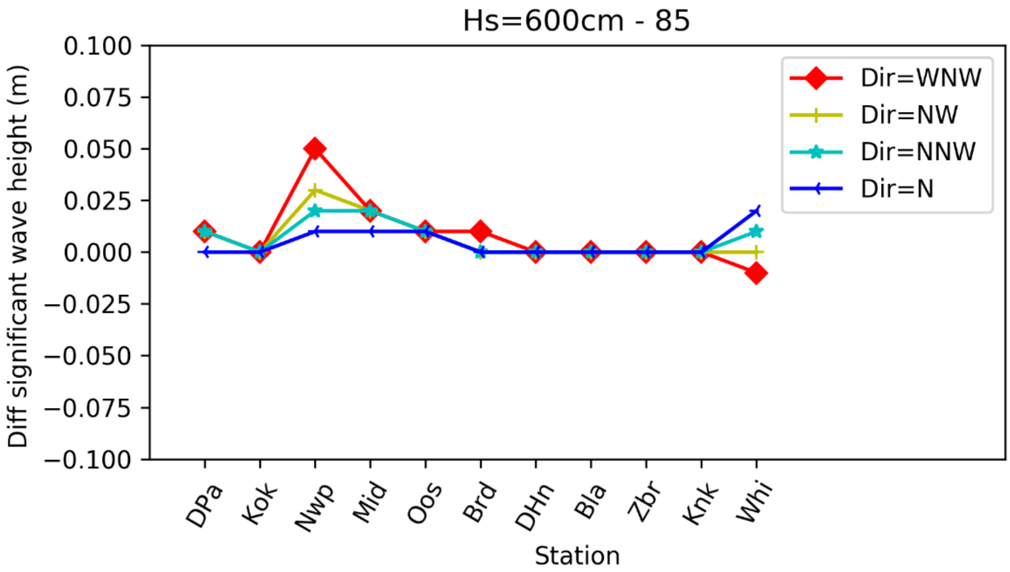

Figure 38: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 6.0 m, wind speed = 30 m/s, water level at 5.52 m MSL (1000 yearly storm + sea level rise RCP 8.5). Results for different wave and wind directions.

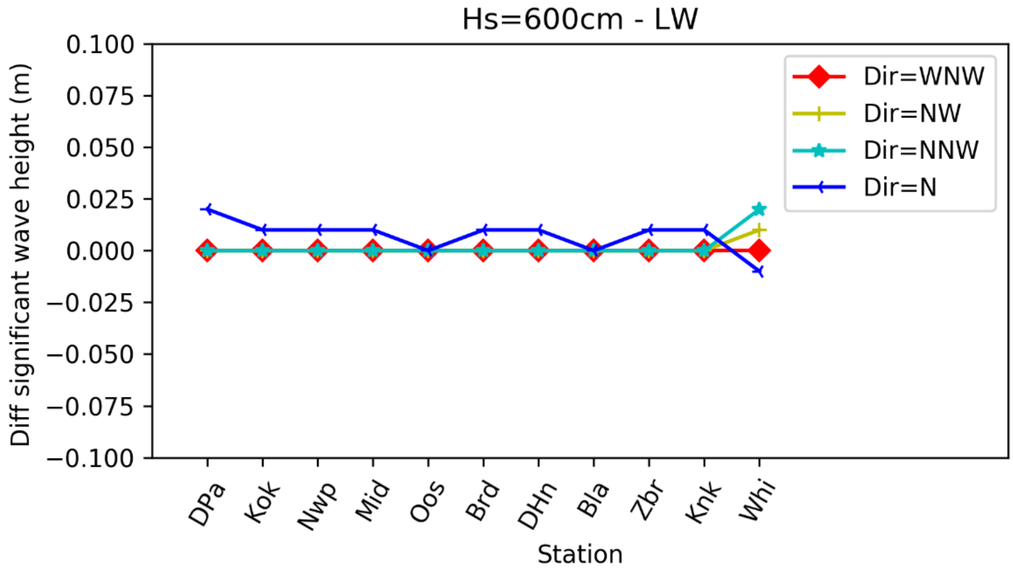

Figure 39: Increase of significant wave height at coastal stations and Westhinder for simulation with the new proposed extraction limit compared to without extraction. Waves at boundary with significant wave height of 6.0 m, wind speed = 30 m/s, water level at -2.33 m MSL (1000 yearly storm – low water). Results for different wave and wind directions.

For the situation with the 1000 yearly storm during low water level, the changes at the coastal stations are even less and are always below 0.02 m. Only for winds from N, an increase in significant wave height of +0.02 m is found for station De Panne. The differences are less than 1% of the obtained wave height in the considered points.

4.4.3. Overall results

The results at the Belgian Continental Shelf, more offshore, near the extraction zones are again much higher, as expected.

In Figure 40, again the maximum and the minimum differences are shown in the model grid for the different simulations. One can see that the maximum decrease in wave heights is again limited to -0.53 m, in this case for RCP 4.5 and for waves from NW. The maximum increase in wave heights for the 1000 yearly storm is +1.52 m for the waves coming from the North. This maximum increase is slightly lower when sea level rises of +0.60 m or +0.85 m are taken into account. For the 1000 yearly storm during low water (MSL -2.33 m) the maximum increase in significant wave height is much higher, up to +2.72 m, in this case from waves coming from the WNW.

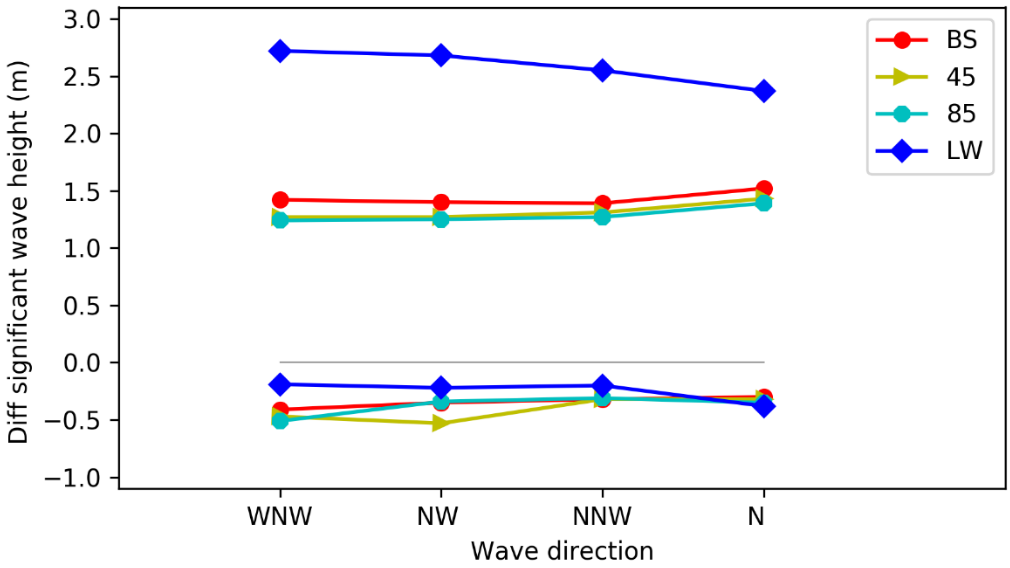

Figure 40: Maximum and minimum difference in significant wave height at the model grid for simulation without extraction and with the new proposed extraction limit as a function of the wind direction, for the 1000 yearly storm (at the boundaries *Hs*=6 m – *Ws*=30 m/s) and for different water levels: BS=+4.67 m MSL, 45=5.27 m MSL, 85=5.52 m MSL, LW=-2.33 m MSL.

The significant wave height for the 1000 yearly storm, for the two bathymetries are shown in Figure 41 and Figure 42. The differences between the two significant wave heights is given in Figure 43.

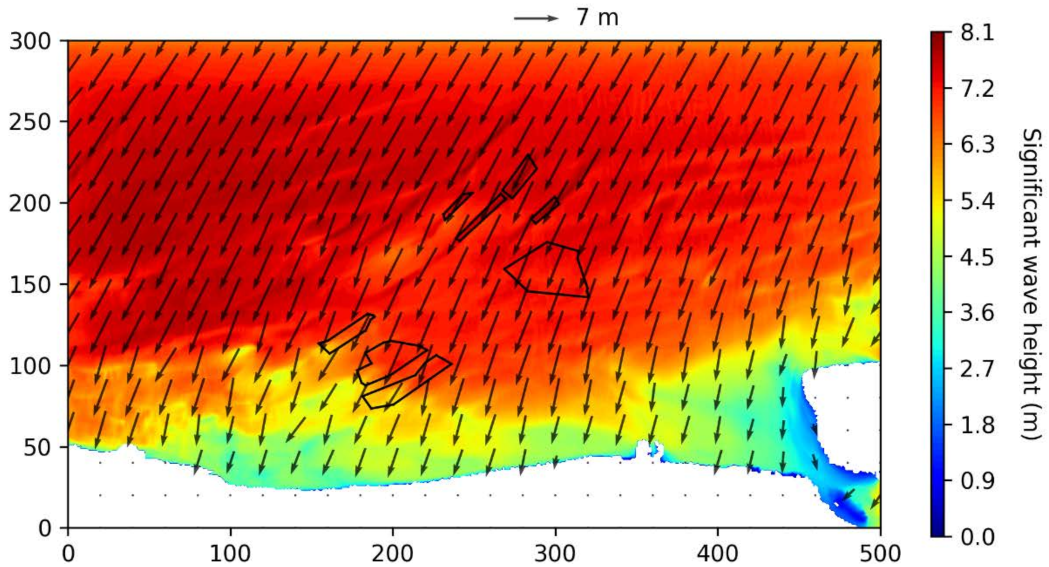

Figure 41: Significant wave height with original bathymetry for 1000 yearly storm. Waves at boundaries: Hs=6.0m, Dir=N; wind speed Ws=30 m/s, water level=4.67 m MSL.

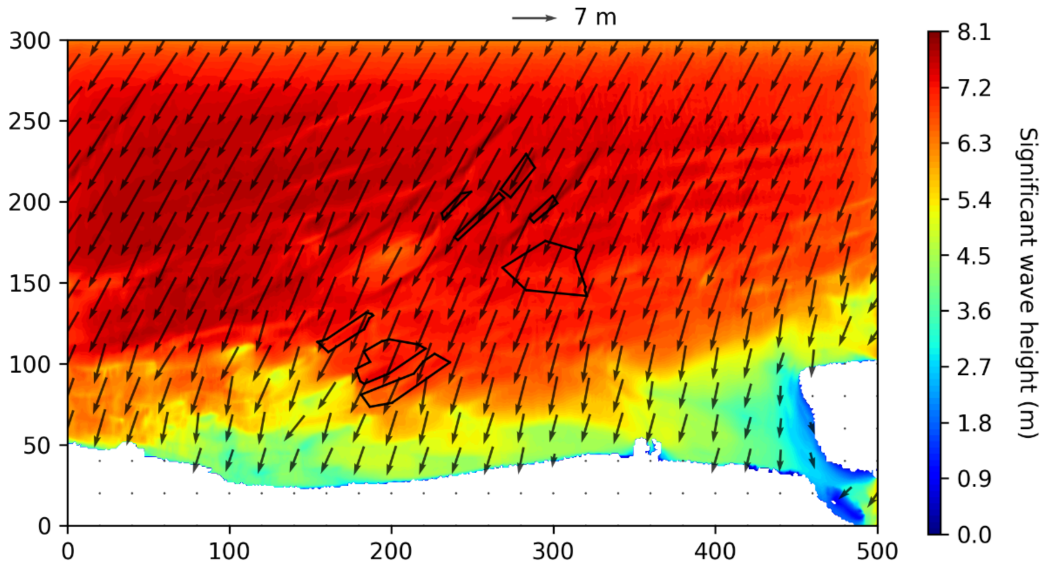

Figure 42: Significant wave height with extraction limit bathymetry for 1000 yearly storm. Waves at boundaries: Hs=6.0m, Dir=N; wind speed Ws=30 m/s, water level=4.67 m MSL.

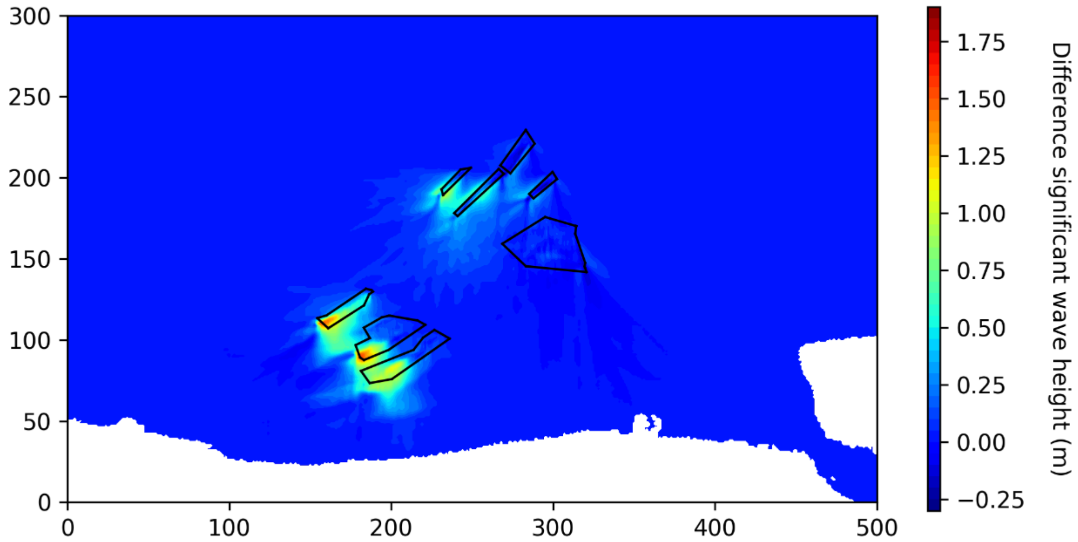

Figure 43: Difference in significant wave height between simulation with extraction limit bathymetry and simulation with original bathymetry for 1000 yearly storm. Waves at boundaries: Hs=6.0m, Dir=N; wind speed Ws=30 m/s, water level=4.67 m MSL.

5. Discussion on the effect of sand extraction on coastal protection

To evaluate the effects on coastal protection one considers the normal wave climate as well as the wave conditions during 1000 yearly storm conditions. The water levels can be assumed to be unaltered by the extraction scenarios due to the small size of the extraction zones compared to the southern North Sea area at which scale tides and storm surges are generated.

The normal wave climate drives changes in the coastline position. Positive gradients in alongshore transport and net cross-shore transport which is off-shore directed induce erosion of the coastline. The intensities of these transports are proportional with the significant wave height. From the SWAN model results, one observes very small changes of the significant wave heights along the coast, less than ±1 % on average. The impact of these changes on coastline erosion can be considered negligible.

The conditions during a 1000 yearly extreme storm determine the coastal safety level. Higher wave heights will result in larger erosion of dunes and dry beaches and in more overtopping of sea dikes and structures in the harbours. From the SWAN model results, one observes a very small increase of the wave height, 0.05 m maximum. However, this increase is so small that it can be considered negligible for the evaluation of the coastal safety level. This is confirmed by results of an earlier evaluation of sand extraction at the Kwintebank from coastal safety perspective (Verwaest and Verelst, 2006).

It can be concluded that the effect on coastal protection of the sand extraction scenarios considered is negligible. This conclusion is attributed to the large distance from the extraction sectors to the coastline, namely more than 10 km.

6. Conclusions

In the present report, the effect of extraction of marine aggregates on wave propagation to the Belgian coast was studied. More especially, the impact of a newly proposed extraction limit levels, as proposed by Degrendele (2016) and Degrendele et al. (2017), on the wave propagation was investigated.

In a first section, a new bathymetry for the SWAN model was constructed, which extended more to the North, to include in the model the different extraction zones. The bathymetries, which were provided by COPCO were inserted in the bathymetry, to simulate the propagation of the waves to the Belgian coast for the two bathymetries and to estimate the increase or decrease of the significant wave height at the coast. Ten coastal stations were defined for the coastal municipalities to compare the results.

First, the effect of the boundaries was tested. It was concluded that using bathymetries at the northern boundary only or using boundaries at the northern, eastern and western boundaries didn't influence the result at the Belgian coast significantly.

For the current climate 108 different simulations were executed with different significant wave heights at the boundaries (2 m, 3 m and 4 m), for different water levels (high water and low water) and for different wind and wave directions from SW to NE with an increment of 22.5°. The results showed that the effect of the extraction on the significant wave height at the coastal stations is very limited. Although in the neighbourhood of the extraction zones, an increase of significant wave height is possible up to +1.85 m, the effect at the coastline is negligible. Therefore, it can be concluded that the impact of the extraction scenarios on coastline erosion can be considered negligible.

For 1000 yearly storm conditions, some simulations were executed, including the effect of possible sea level rise (up to +0.85 m) until 2100. It was clear that large effects on the wave heights can be expected near the extraction zones, especially during low water situations, but that the effect at the coastline remains very limited to an increase of +0.05 m maximum (less than 1% increase). It can be concluded that the impact of the extraction scenarios on the coastal safety level is negligible.

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COLOPHON

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☐ Dutch
☐ French

If you have any questions or wish to receive additional copies of this document, please send an e-mail to *DVandenEynde@naturalsciences.be*, quoting the reference, or write to:

Royal Belgian Institute of Natural Sciences
Operational Directorate Natural Environment
100 Gulledelle
B–1200 Brussels
Belgium
Phone: +32 2 773 2111
Fax: +32 2 770 6972
http://www.mumm.ac.be/

Royal Belgian Institute of Natural Sciences
Operational Directorate Natural Environment
Suspended Matter and Seabed Monitoring and Modelling Group

museum

The typefaces used in this document are Gudrun Zapf-von Hesse's *Carmina Medium* at 10/14 for body text, and Frederic Goudy's *Goudy Sans Medium* for headings and captions.

Annex 4

RV Belgica campaign planning and reports.

RV BELGICA CRUISE 2017/21B - PROGRAM

Subscribers:	Vera Van Lancker[1a], Ilse De Mesel[1b], Alain Norro[1a]
Institutes:	[1] Operational Directorate Natural Environment (OD Nature) – RBINS
Addresses:	[1a] OD Nature, Gulledelle 100, 1200 Brussels [1b] OD Nature, 3de en 23ste linieregimentsplein, Oostende
Telephones:	+32(0)2 7732129 (VVL); +32(0)2 773214041 (AN); +32 59 24 20 51 (IDM)
E-mails:	vvanlancker@naturalsciences.be, idemesel@naturalsciences.be, anorro@naturalsciences.be

Monitoring: 29/06/2017 - 30/06/2017

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1. General form RV Belgica 2017
2. List of participants
3. Scientific objectives
4. Research area – Sampling stations
5. Operational course
6. Occupation of laboratories
7. Use of Infrastructure and instrumentation
8. Sampling – On board analysis
9. Automatic data acquisition: ODASIII continuous measurements
10. Chemicals

1. GENERAL FORM RV BELGICA 2017

1.	Cruise number	2017/21b
2.	Date/time Zeebrugge ETD Zeebrugge ETA	29/06/2017: 12h00* **All scientists present at <u>11h00</u>** 30/06/2017: 14h00
3.	Chief Scientist Participating institutes	Ilse De Mesel OD Nature
4.	Geographical area DIPCLEAR necessary	Belgian part of the North Sea NO
5.	Scientific personnel	9
6.	Intervention required of: - Marine scuba team - Marine medical assistance - Pilot	 NO NO NO
7.	Necessary infrastructure onboard or on the quay to embark or disembark equipment.	RV Belgica ship's crane
8.	Logistic assistance OD Nature for SCTD, AUMS, data acquisition (ODASIII) or other.	Start-up ODASIII, AUMS
9.	Remarks: - For the diving, four tanks of oxygen (20 L each) should be available (now at OD Nature Ostend) - High pressure compressor (verification of functioning needed) - A film crew (Diplodokus) will embark on this cruise and will film the activities	

General remarks c/o OD Nature - Measurement Services Ostend:

i) There are only basic blankets, sheets and a pillow slips available on board, no towels. Every scientist/student can bring his/her bed linen when desired.

ii) All scientists involved in deck operations are to wear appropriate safety clothing such as safety shoes/boots, gloves etc. Only safety helmets are available on board.

iii) Please note that scientists are invited to bring their own GSM. The RV Belgica GSM shall be made available only in exceptional circumstances such as communications related to operational aspects of the ongoing cruise (e.g. calls to OD Nature concerning ODASIII) and in case of an emergency.

iv) All participants are requested to settle their account (daily meal fee, drinks) aboard in Euro (small bills please). Checks are no longer accepted, and neither credit cards nor proton facilities are available.

v) Following governmental regulations, as from January 1st 2006 smoking inside the ship is entirely prohibited. Please refer to the information posted on the message board inside the ship for the dedicated smoking areas on the outer decks.

vi) It is prohibited to bring and use any kind of illegal drugs onboard. In case of violation, criminal prosecution will be initiated and any further access to the ship will be denied.

vii) It is not allowed to bring your own alcoholic drinks onboard. There is a possibility to purchase limited amounts of alcoholic drinks onboard. It is also not allowed to bring your own food onboard unless agreed upon by the CO and crew (cfr. special dietary requirements).

viii) It is no longer allowed to park on the quays of the Naval Base in Zeebrugge. Any violation will lead to a fine of 120 €. Please use the dedicated parking lots on the base. The crew and the guards can give information on the correct locations. For long stays (> 3 days/3 nights) a document needs to be filled in and needs to be left visible in the car and the car keys need to be given to the guards of the base (see document sent with this program).

ix) Each scientist has an email account aboard. This should mainly be used for work related to the campaign.

x) The AUMS screen in the wet lab can only be used for visualization of the AUMS parameters and can't be used for any other purpose! Please report abuse to Coordinator RV Belgica.

xi) All participants embarking on RV Belgica should be in good health allowing them to perform their activities at sea without being an extra safety risk and/or possibly causing a loss of ship time. When in doubt of a participant's medical situation the Chief Scientist or person in question should contact the Coordinator RV Belgica prior to the cruise. The Coordinator RV Belgica will consult and decide with the CO RV Belgica if the person in question can embark on the RV Belgica cruise.

For approval OD Nature: 19/06/2017
Update: 22/06/2017

L. NAUDTS, Dr.-Adviseur
OD Nature Coordinator RV BELGICA

2. LIST OF PARTICIPANTS

Institute	NAME	Gender	29-30/6
RBINS OD NATURE	Ilse De Mesel	*F*	X
	Lars Kint[1]	*M*	X
	Kelle Moreau	*M*	X
Scientific Diving Team	Alain Norro	*M*	X
	Patrick Hendricks[1]	*M*	X
	Valerie Woit[1]	*F*	X
Production House Diplodokus	Kwinten Van Laethem[1]	*M*	X
	Liesbeth De Ceulaer[1]	*F*	X
	Jonathan Wannyn[1]	*M*	X
			9

[1]*Permission for embarkation on RV BELGICA is requested for this person.*
Assignment of the cabins by the Chief-Scientist at the start of the campaign.

3. SCIENTIFIC OBJECTIVES

OD Nature-VVL (ZAGRI/MOZ4)
ZAGRI is a continuous research program on the evaluation of the effects of the exploitation of non-living resources of the territorial sea and the continental shelf. MOZ4 research focuses on the hydrodynamics and sediment transport in a marine aggregate extraction zone, far offshore, and its impact on an adjacent Habitat Directive Area. Overall aim is to increase process and system knowledge of both areas, with particular focus on the compliancy of the extraction activities with respect to the European Marine Strategy Framework Directive. More specifically changes in seafloor integrity and hydrographic conditions need assessment.

OD Nature-IDM (MSFD monitoring gravel beds)
Within the framework of the EU Directive MSFD a monitoring program was developed for the biological communities on the gravel beds. The gravel beds have been under a lot of pressure due to human activities, mainly fisheries, which caused a severe decline or virtual extinction of typical hard substrate species. This monitoring program, with sampling of the gravel beds with a Gilson Dredge, has been specifically developed to follow up the MSFD indicators that have been reported to the EC.

OD Nature-LN (ICOS)
The AUMS (Autonomous Underway Measurement System) system is inspired by the success of similar systems deployed on various ships of opportunity in the framework of the European Union FerryBox project (www.ferrybox.org). The instrumentation will greatly enhance the continuous oceanographic measurements made by RV Belgica by taking advantage of the significant technological improvements since the design of the existing (salinity, temperature, fluorescence) systems (cfr. ICOS Standards). In particular, many new parameters can now be measured continuously including important ecosystem parameters such as nitrate, ammonia, silicate, dissolved oxygen and CO2, turbidity, alkalinity and phytoplankton pigments. In addition, the new equipment allows automatic acquisition and preservation of water samples, rendering RV Belgica operations significantly more efficient by reducing onboard human resources. Data will be available in near real-time via OD Nature's public website (http://odnature.naturalsciences.be/belgica/en/odas) and following quality control, from the Belgian Marine Data Centre. Since 2015, the AUMS data are also delivered to the EC ESFRI project ICOS.

ESA-MC (GNSS)
For the European Space Agency continuous GNSS (Global Navigation Satellite system) data is autonomously acquired in the maritime environment for performance evaluation under different conditions.

4. RESEARCH AREA - SAMPLING STATIONS

4.1. OD Nature-MOZ4/ZAGRI

Seabed nature is investigated in detail in the zone of the Hinder Banks in relation to marine aggregate extraction activities on the Oosthinder sandbank (Sector 4c, Fig. 1).

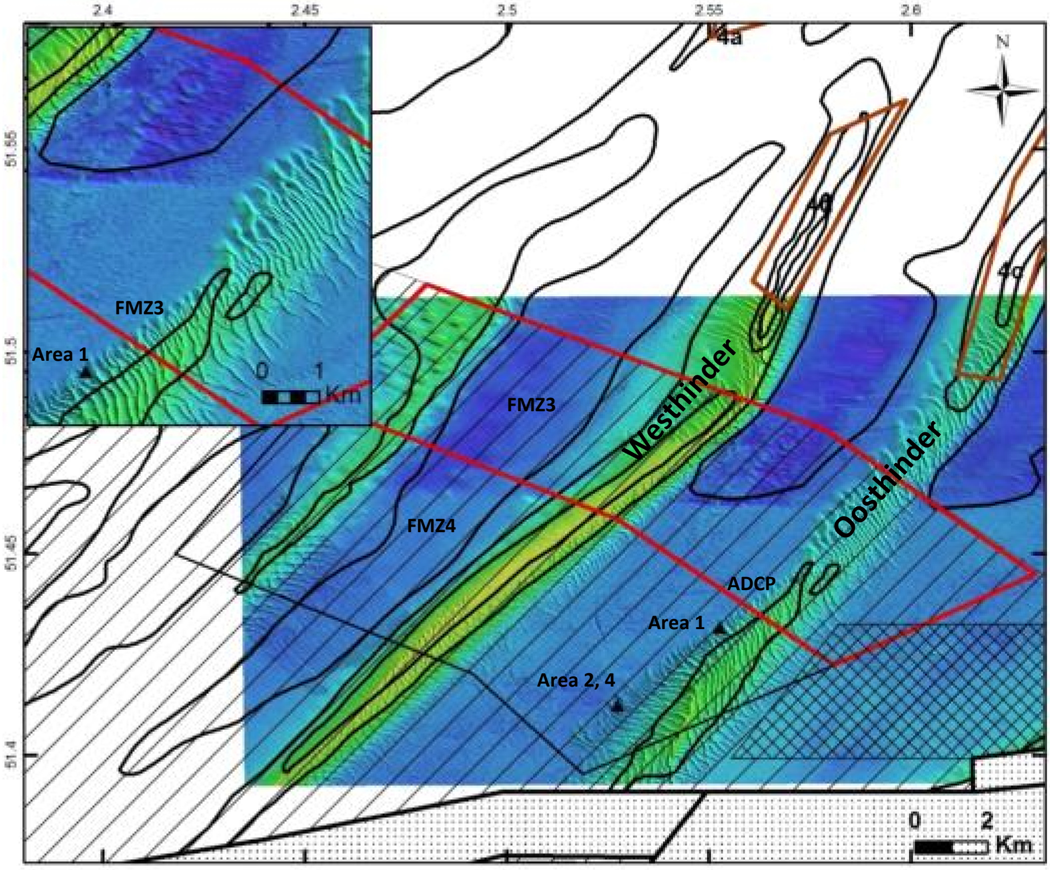

Figure 1: Hinder Banks with indication of Fisheries Management Zone 3 (FMZ3, red polygon) and Zone 4 (FMZ4, black polygon). Area 1, 2, 4 were previously defined hotspots of biodiversity in Zone 4 (see Fig. 2 for detail). In Zone 3 higher biodiversity is expected at the ADCP location (see Fig. 3 for detail).

<u>Main aims of this campaign are:</u>

(1) **Sand thickness estimations on gravel beds**. From recent monitoring of gravel beds, we observed that most of the natural gravel fields were overtopped with sand. Previously acquired time series of very-high resolution multibeam bathymetric mapping showed sedimentation in the gravel fields, though the depth differences fell within the error envelope of the bathymetric measurements. Therefore, to validate the environmental status of the gravel beds diving operations are needed.

Main aims of the diving:

- To determine the sand thickness on the gravel fields (measuring pole or alternative)
- To obtain high quality imagery of the gravel fields (High-definition video)
- To obtain shallow cores (push core) allowing analysing the sand cover

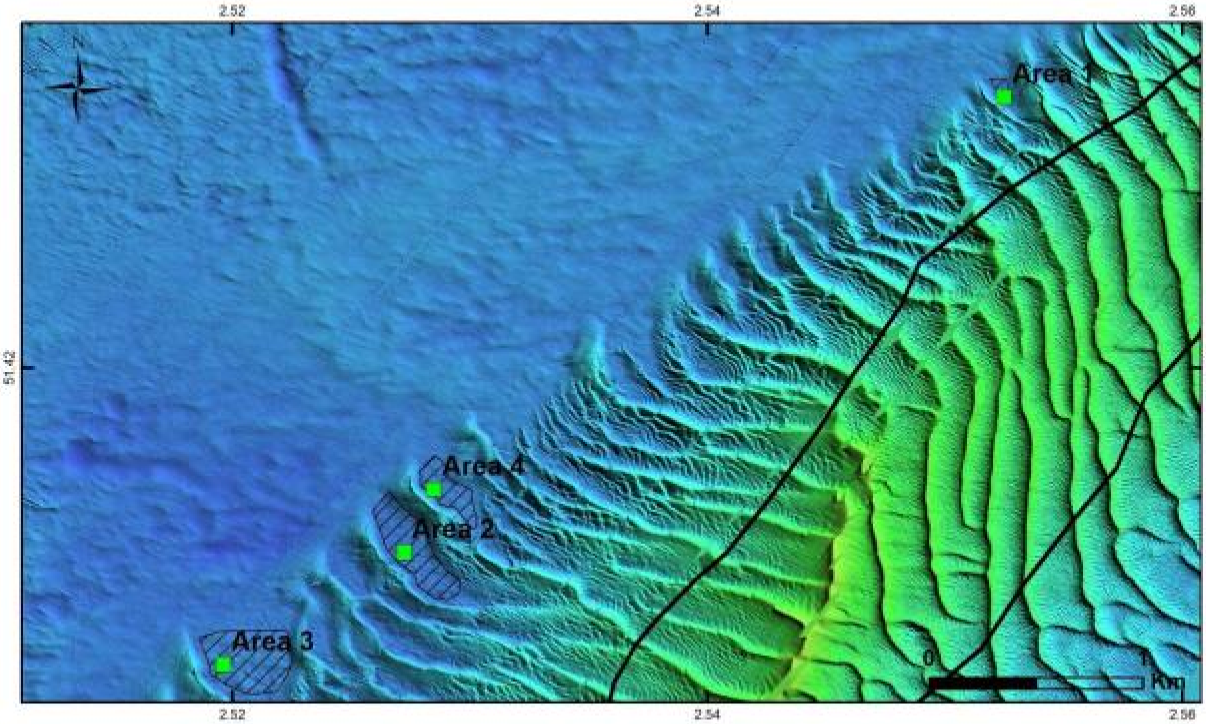

Figure 2. South part of the Oosthinder sandbank where a series of barchan dunes are attached to the main sandbank. In their trough position gravel beds were found. In Area 2, 3 and 4 hotspots of biodiversity were found in the period 2012-2015. In this campaign, priority goes to diving in Area 4 since historic diving data exist in this area.

Table 1: Locations for diving observations (in order of priority)

Sample id	WGS84_NB	WGS84_OL	Remar5
Area 4_Dives 2007, 2014	**51°24.8322'**	**2°31.6590'**	**Start position dive**
Area 2_Refugium South	51°24.7333'	2°31.6333'	Location refugium
FMZ3_Dive near ADCP	51°26.193'	2°33.579	ADCP location 2017

The diving observations are also valuable in the framework of the OD Nature-IDM programme on MSFD monitoring of gravel beds.

(2) **Sediment transport along sand dunes**. The gravel fields hosting richest biodiversity occur in the trough of steep sand dunes. If the dunes are steep enough, tide-topography interactions deflect the currents, potentially trapping fine-grained material in the trough of the dunes. This process will be studied using the newly acquired 600 kHz Acoustic Doppler Current Profiler (ADCP, RDI Instruments) mounted in the hull of RV Belgica. During the transect, suspended particulate matter (SPM) in the water column will be sampled with RV Belgica's centrifuge purifier.

Table 2. Position of the transect over dunes in Fisheries Management Zone 3

ID	Lat_from	Long_from	Lat_to	Long_to
FMZ3_BDTransect	51°26.101'	002°33.446'	51°26.503'	002°34.027'

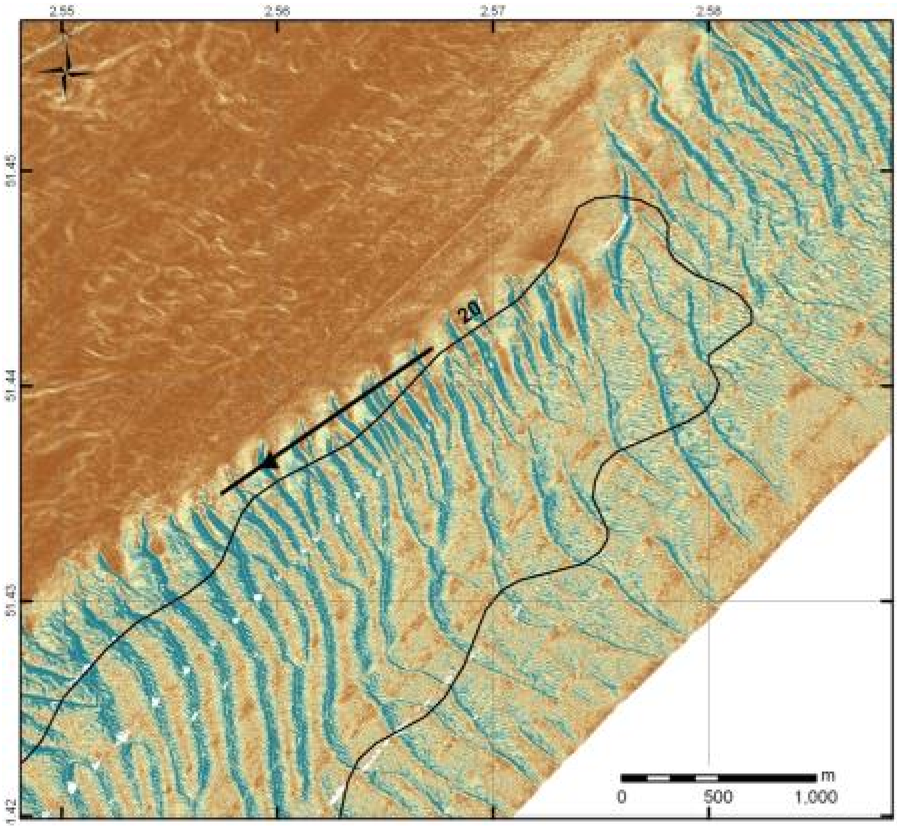

Figure 3. Slope map of the Oosthinder sandbank. Location ADCP (triangle) and transect over sand dunes (see Fig. 1).

5. OPERATIONAL COURSE

All times are given in local time (UTC+2). All coordinates in WGS84.Throughout the campaign, measurements will be made with the AUMS system.

During both days, the Diplodokus team will film the activities.

Thursday 29 June

High Tide Oostende 18h06
Spring tide NM 24/6

09h00-12h00	Embarkation of equipment and scientific personnel. **Scientist should be aboard the latest at 11h00.**
12h00	Transit from Zeebrugge to Hinder Banks south
15h00	On-site
15h10	RHIB with divers leaving
15h30-16h30	Diving (video, sand thickness estimation and cores; the cores need to be kept vertical during transport)
17h00	Transit to hull-mounted ADCP transect location
17h30	Through-tide hull-mounted ADCP transect (measuring currents and turbidity over sand dunes) Meanwhile, sampling with the centrifuge purifier

Friday 30 June

High Tide Oostende 06h41

08h45	End of ADCP recordings Transit to dive site Hinder Banks south

09h40	RHIB with divers leaving
10h00-11h00	Diving (video, sand thickness estimation and cores; the cores need to be kept vertical during transport)
11h00-14h00	Transit to Zeebrugge

End of campaign

6. OCCUPATION OF LABORATORIES

Bridge:	ESA
Wet lab:	AUMS visualization
Microbiology Lab:	
Chemistry Lab:	
Fish Lab:	Diving equipment
Biology Lab:	AUMS
Rear Deck:	

(*) Necessary alterations specified on board.

7. USE OF INFRASTRUCTURE AND INSTRUMENTATION

Ship's crane

ODASIII data acquisition and presentation system

Laboratory equipment
- Freezer and refrigerator for sample preservation **(in wet lab)**
- Milli RO/ Milli Q system

Underway measurements
- Sea-Bird SBE21 thermosalinograph
- AUMS (Autonomous Underway Measurement System)
- Sub-surface seawater pump
- Centrifuge purifier

Navigation/Meteorology
- Standard meteorological instruments (wind, atmospheric pressure, PAR, air temperature)
- Septentrio AsteRx2eH RTK – EGNOS DGPS system
- Furuno GP-170 EGNOS DGPS system
- Ship heading and speed
- Kongsberg EA400 echosounder with 33, 38 and 210 kHz transducer

Hull-mounted ADCP
- RDI Workhorse Mariner 600 kHz ADCP

Multibeam
- Kongsberg Simrad EM3002D multibeam echosounder

Diving
- For the diving, four tanks of oxygen (20 L each)
- High pressure compressor

8. SAMPLING - ON BOARD ANALYSIS

Core subsampling

9. AUTOMATIC DATA ACQUISITION: ODASIII continuous measurements

Instrument	ODASNr	Parameter	Data acquisition rate			
	ID		ODASIII standard		extra	
			10 sec.	10 min.	1 sec.	0.5 sec.
SEPTENTRIO AsteRx2eH RTK EGNOS receiver	573	Sept LAT.N/S	X	X	X	
	574	Sept LON.E/W	X	X	X	
	575	Sept CA_TAW	X	X	X	
	576	Sept UTCTIME	X	X	X	
	577	Sept SPEED	X	X	X	
	578	Sept COURSE	X	X	X	
	579	Sept QUALITY	X	X	X	
	580	Sept DSTA	X	X	X	
	581	Sept DRMS	X	X	X	
	582	Sept HEADING	X	X	X	
FURUNO GP-170 EGNOS DGPS receiver	560	Fur LAT.N/S	X	X		
	561	Fur LON.E/W	X	X		
	562	Fur HG_MSL	X	X		
	563	Fur UTCTIME	X	X		
	564	Fur SPEED	X	X		
	565	Fur COURSE	X	X		
	566	Fur QUALITY	X	X		
	567	Fur DSTA	X	X		
	568	Fur DRMS	X	X		
ANSHUTZ GYRO STD20 compass	36	SHIP HEADING	X	X		
CONSILIUM SAL 860T doppler log	387	PT/ST SPEED	X	X		
	388	DEPTH SAL860	X	X		
	389	FO/AF SPEED	X	X		
Kongsberg EA400 echosounder	465	EA DEPTH_38	X	X	X	
	466	EA DEPTH_210	X	X	X	
	467	EA DEPTH_33	X	X	X	
FRIEDRICHS meteostation	243	R. WINDDIR SB	X	X		
	244	R. WINDSPD SB	X	X		
	245	ATM PRESSURE	X	X		
	246	AIRTEMP. DRY	X	X		
	247	AIRTEMP. WET	X	X		
	266	SOL RAD [WINDSP PB	X	X		
	375	R. WINDSPPB	X	X		
	376	R. WINDDIR PB	X	X		
	487	SOL RAD	X	X		
	488	ATM PRESSURE 2	X	x		
SEA-BIRD SBE21 thermosalinograph	191	SBE21 TEMP.	X	X		
	192	SBE21 SALIN.	X	X		
	193	SBE21 SIGTH.	X	X		
	194	SBE21 S.VEL.	X	X		
	216	SBE21 I-TEMP	X	X		
	217	SBE21 COND	X	X		
	570	SBE21 FREQ 0	X	X		
	571	SBE21 FREQ 1	X	X		
	572	SBE21 FREQ 2	X	X		
SEA-BIRD SBE38 temperature	242	SBE38 TEMP.	X	X		
VALEPORT HM SVP	559	VALEPORT SV	X	X		
VALEPORT 106 CM currentmeter	382	CURR. I-VEL				
	383	CURR. I-DIR				
	384	CM DEPTH				
MARELEC small A-frame	206	LENGTH_W1	X	X		
	207	SPEED_W1				
	208	MEANTRAC_W1	X	X		
	209	PEAKTRAC_W2				
MARELEC oceanographic winch	210	LENGTH_W2	X	X		
	211	SPEED_W2				
	212	MEANTRAC_W2	X	X		
	213	PEAKTRAC_W2				

pump status	377	SEAWATERPUMP	X	X		
	378	SEWAGE PUMP	X	X		
	489	SW PUMP VOL.	X	X		
	569	SW PUMP FLOW	X	X		
AUMS OceanPack						
Endress+Hauser	506	EH TURBIDITY L	X	X		
	508	EH TURBIDITY H	X	X		
Campbell Scientific OBS3+	510	OBS LOW	X	X		
	511	OBS HIGH	X	X		
SEA-BIRD SBE45	500	SBE45 SALINITY	X	X		
Trios Microflu	512	CHLOROPHYLL	X	X		
	513	BLUE ALGAE	X	X		
	514	CDOM	X	X		
Aanderaa optode	501	OPTODE O2	X	X		
Meinsberg	504	pH	X	X		
Turner Designs	515	FLUORESCENCE	X	X		
OceanPack MK2	518	pCO2	X	X		
Li-Cor LI-190SA	530	PAR	X	X		
Calculated parameters						
F: Absolute wind	120	IN-WIND DIR.	X	X		
	121	IN-WINDSPD.	X	X		
	122	IN-WINDSP.BF	X	X		
	379	IN-WINDIR PB	X	X		
	380	IN-WINDSP PB	X	X		
	381	IN-WINDBF PB	X	X		
F:Humidity	182	HUMIDITY DW	X	X		
F: Improved position	479	LAT AFRAME	X	X		
	480	LON AFRAME	X	X		
	481	LAT BENTHOS	X	X		
	482	LON BENTHOS	X	X		
	483	LAT VV FRAME	X	X		
	484	LON VV FRAME	X	X		
	485	LAT OCEANO	X	X		
	486	LON OCEANO	X	X		

Note that 1 sec data acquisition is asked for, to obtain high resolution single-beam bathymetry over the sand dunes.

10. CHEMICALS

N/A

RV BELGICA CRUISE 2017/23 – CRUISE REPORT

Subscribers:	Dr. Ilse De Mesel[1a], Dr. Vera Van Lancker[1b], Mr. Giacomo Montereale Gavazzi[1b], Dr. Alain Norro[1b], Dr. Michael Fettweis[1b]
Institutes:	[1] Operational Directorate Natural Environment (OD Nature) – RBINS
Addresses:	[1a] OD Nature, 3^{e} en 23^{e} linieregimentsplein, Ostend [1b] OD Nature, Gulledelle 100, 1200 Brussels
Telephones:	+32 59 24 20 51 (IDM)
E-mails:	Idemesel@naturalsciences.be, vvanlancker@naturalsciences.be , goa.montereale.gavazzi@gmail.com, anorro@naturalsciences.be , mfettweis@naturalsciences.be

Monitoring: 10/07/2017 – 14/07/2017

RV BELGICA CRUISE 2017/34 – CRUISE REPORT

Subscribers:	Koen Degrendele (KD)[1] Dr. Vera Van Lancker (VVL)[2], Giacomo Montereale Gavazzi (GMG)[2]
Institutes:	[1]FPS Economy - Continental Shelf (FPS Economy-CSS) [2]Operational Directorate Natural Environment (OD Nature)
Addresses:	[1]FPS-CSS: Koning Albert II-laan 16, B-1000 Brussels [2]OD Nature-BRU: Gulledelle 100, B-1200 Brussels
Telephones:	+32(0)2 2778411 (KD); +32(0)2 773 21 29 (VVL) ; +32(0)2 773 21 11 (GMG)
E-mails:	koen.degrendele@economie.fgov.be; vvanlancker@naturalsciences.be; giacomo.monterealegavazzi@naturalsciences.be

Monitoring: 20/11/2017 - 24/11/2017

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1. Cruise details
2. List of participants
3. Scientific objectives
4. Operational course
5. Track plot
6. Measurements and sampling
7. Remarks
8. Data storage

1. CRUISE DETAILS

1.	Cruise number	2017/34
2.	Date/time	Zeebrugge TD: 21/11/2017 at 13h00 Zeebrugge TA: 22/11/2017 at 18h00
3.	Chief Scientist Participating institutes	Koen Degrendele FPS Economy – CSS OD Nature
4.	Area of interest	Belgian part of the North Sea

2. LIST OF PARTICIPANTS

INSTITUTE	NAME	21-22/11/2017	22-23/11/2017
FPS Economy - CSS	Koen Degrendele	X	X
	Marc Roche	X	X
OD Nature	Michael Fettweis	X	
	Matthias Baeye	X	
	Joan Backers	X	
	Reinhilde Van den Branden	X	
Total number of participants:		6	2

3. SCIENTIFIC OBJECTIVES

CSS-KD

Implementation of the continuous investigation laid down in section 3, §2, subsection 3, of the law of June 13th 1969, concerning the exploration and exploitation of non-living resources on the Belgian Continental Shelf, and the concession decisions.

The follow up of the repercussions of the sand extraction on the stability of the sand banks and surrounding area in the exploitation zones, in order to formulate policies concerning the exploitation in the concession zones on a scientific base. The sediments of the Belgian continental shelf will be investigated in order to:

1. Establish the impact of sand extraction on the sand budget and seabed sediments.
2. Survey the sand winning sites to detect significant changes of the seabed sediments and the morphology of the seabed and sand banks in order to guarantee the availability of sand to extract in the future.

OD Nature-GM (INDI67/MONIT.BE)

Within Europe's Marine Strategy Framework Directive (MSFD), progress towards Good Environmental Status (GES) needs monitoring in a most time- and cost-effective way. For the GES descriptors 6 and 7, on seafloor integrity and hydrographic conditions, respectively, new integrative indicators (i.e. bottom shear stress, turbidity and seabed/habitat type) need developing. To advance the mapping of seabed/habitat types, a Community of Practice (CoP) on seabed mapping will be established, investigating the main issues preventing joint mapping of the seabed. Within SEACoP (CoP on 'Surveying for Environmental Assessments') the following objectives are targeted: a) estimation of the precision, sensitivities and repeatability of the acoustic devices to detect changes in seabed/habitat types; b) quantification of the external sources of variance in the acoustic signature, including the influence of near-bed and water column suspensions on backscatter data; c) definition of best practice in ground-truthing the acoustic signal, with emphasis on visual techniques; and d) innovation in collaborative seabed mapping.

OD Nature-MF (MOMO)
The project "MOMO" is part of the general and permanent duties of monitoring and evaluation of the effects of all human activities on the marine ecosystem to which Belgium is committed following the OSPAR-convention (1992). The goal of the project is to study the cohesive sediments in the Belgian part of the North Sea 'BPNS' using numerical models as well as by carrying out of measurements. Through this, data will be provided on the transport processes which are essential in order to answer questions on the composition, origin and residence of these sediments on the BPNS, the alterations of sediment characteristics due to dredging and dumping operations, the effects of the natural variability, the impact on the marine ecosystem, the estimation of the net input of hazardous substances and the possibilities to decrease this impact as well as this in-put.

OD NATURE-VVL (ZAGRI/MOZ4)
ZAGRI is a continuous research program on the evaluation of the effects of the exploitation of non-living resources of the territorial sea and the continental shelf. MOZ4 focuses on the monitoring of hydrodynamics and sediment transport in relation to marine aggregate extraction in a far offshore zone. Overall aim is to increase process and system knowledge of this area, with a particular focus on the compliancy of the extraction activities with respect to the European Marine Strategy Framework Directive. More specifically changes in seafloor integrity and hydrographic conditions will be assessed. An important parameter is the bottom shear stress, with knowledge needed on both natural and anthropogenically-induced variability. Results will be used for the validation of mathematical models, necessary for impact quantification.

OD Nature-LN (ICOS)
The AUMS (Autonomous Underway Measurement System) system is inspired by the success of similar systems deployed on various ships of opportunity in the framework of the European Union FerryBox project (www.ferrybox.org). The instrumentation will greatly enhance the continuous oceanographic measurements made by RV Belgica by taking advantage of the significant technological improvements since the design of the existing (salinity, temperature, fluorescence) systems (cfr. ICOS Standards). In particular, many new parameters can now be measured continuously including important ecosystem parameters such as nitrate, ammonia, silicate, dissolved oxygen and CO2, turbidity, alkalinity and phytoplankton pigments. In addition, the new equipment allows automatic acquisition and preservation of water samples, rendering RV Belgica operations significantly more efficient by reducing onboard human resources. Data will be available in near real-time via OD Nature's public website (http://odnature.naturalsciences.be/belgica/en/odas) and following quality control, from the Belgian Marine Data Centre. Since 2015, the AUMS data are also delivered to the EC ESFRI project ICOS.

ESA-MC (GNSS)
For the European Space Agency continuous GNSS (Global Navigation Satellite system) data is autonomously acquired in the maritime environment for performance evaluation under different conditions.

4. OPERATIONAL COURSE

All times are given in local time. All coordinates in WGS84.
Throughout the campaign, measurements are made with the AUMS system.

Tuesday 21/11/2017

LW 09:09 – 21:25; HW 03:02 - 15:16;

09h00-11h00 Embarkation of instruments and personnel.

13h00: Departure from Zeebrugge.
Problems with PU of EM3002D.
MBES measurements are postponed.

15h00: Start of 13h cycle near MOW1.

15h15	Van Veen sample
15h25	Start of 13h cycle
15h27, 15h43, 15h00	Niskin bottles 1, 2, 3
16h20, 16h40, 17h00	Niskin bottles 4, 5, 6
17h20, 17h40, 18h00	Niskin bottles 7, 8, 9
18h20, 18h40, 19h00	Niskin bottles 10, 11, 12
19h20, 19h40, 20h00	Niskin bottles 13, 14, 15
20h20, 20h40, 21h00	Niskin bottles 16, 17, 18
21h20, 21h40, 22h00	Niskin bottles 19, 20, 21
22h20, 22h40, 23h00	Niskin bottles 22, 23, 24
23h20, 23h40, 24h00	Niskin bottles 25, 26, 27

Wednesday 22/11/2017

LW 09:41 – 21:54; HW 03:33 - 15:47;

00h20, 00h40, 01h00	Niskin bottles 28, 29, 30
01h20, 01h40, 02h00	Niskin bottles 31, 32, 33
02h20, 02h40, 03h00	Niskin bottles 34, 35, 36
03h20, 03h40	Niskin bottles 34, 35 (Chl, POC, TEP on sample 35)

04h00: End of 13h cycle.

09h00: Pick-up of divers in Zeebrugge.

11h00-11h30 EM3002D test survey near MOW1.

12h00-14h00 Attempts at recuperation of tripod near MOW1 with divers: no success.

15h00: Disembarkation of divers and OD Nature team in Zeebrugge.

15h30-17h00 EM3002D test survey near MOW1.
Further MBES measurements are postponed due to worsening weather conditions.
Technical problem with generator.

18h00: Arrival in Zeebrugge.

20h00: Campaign is cancelled due to technical problems with generator.

Thursday 23/11/2017

LW 10:11 – 22:24; HW 04:02 - 16:18;

09h00: Disembarkation of FPS Economy team.

End of campaign 2017/34

5. TRACK PLOT

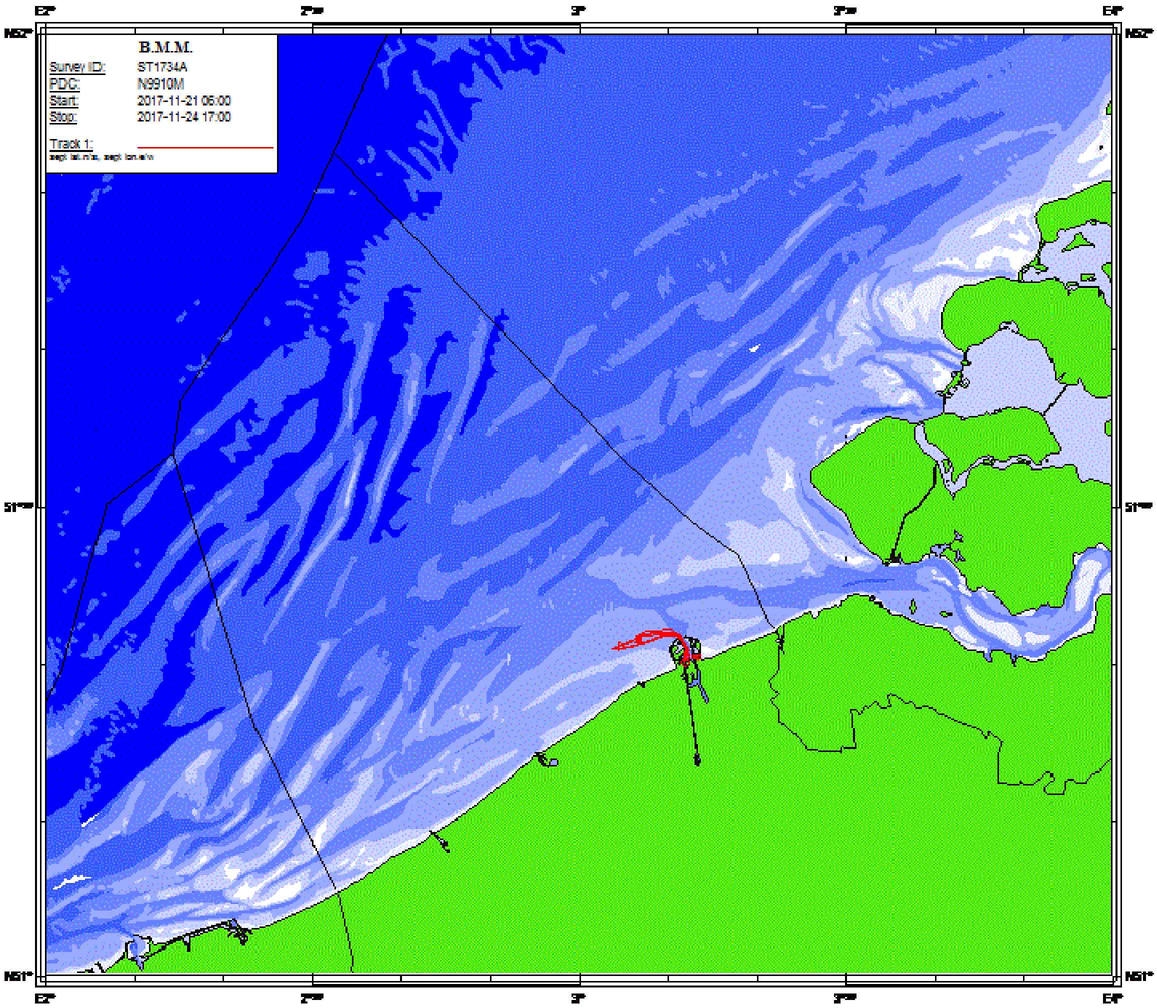

Figure 1: Track plot of campaign 2017/34

6. MEASUREMENTS AND SAMPLING

6.1. CSS-KD

No results

6.2. OD Nature-GMG (PhD/INDI67) and MF (MOMO

1) Recuperation and deployment of tripod

Divers were necessary to attach a buoy at the tripod, the tripod itself could not been recuperated due to too strong winds.

2) Through tide measurement (13h) and bed sampling

A through tide cycle was carried out at MOW1 (21-22/11), see table 2. On the Rosette was also attached a LISST 200X (SN2043). The SBE09(792) was not working, and at the SBE09(206) was attached the OBS3+ T8706 and T8729.

Water samples were taken for turbidity measurements and filtrations of suspended particulate matter concentration each 20 min, and chlorophyll, POC/PON and TEP concentration each hour; bottle samples were collected hourly for salinity measurements. A Van Veen grab was taken, see Table 3 and Photo 1.

Table 2: Position of 13h measurements.

ID	Start (Date + time GMT)	End (Date + time GMT)	Lat_wgs84	Lon_wgs84
MOW1	21/11/2017 14h25	22/11/2017 03h00	51°N 21.5540’	3°E 7.8492’

Table 3: Position of the Van Veen grab sample.

ID	Lat/Lon WGS 84	Date (GMT)	Description
MOW1	51°N 21.554, 3°E 7.8492’	22/06/2017 14h35	top: about 10cm fine sand with some lenses of greenish fluid mud on top.

Photo 1: Van Veen grab sample taken at MOW1

6.3. OD NATURE-VVL (MOZ4-ZAGRI)

No results

7. REMARKS

- Weather conditions were not suitable for the planned multibeam measurements.
- Technical issue with the EM3002D PU:
  After consultation with Kongsberg, the problem was identified as a failure of the battery on the BIOS. The BIOS parameters were introduced manually and the system started correctly.
- Technical issue with one of the generators on the RV Belgica caused the campaign to commence later (Tuesday noon) and finish early (Wednesday evening).
- The crew of the RV Belgica is acknowledged for the valuable and greatly appreciated cooperation.

8. DATA STORAGE

All raw multibeam data from the RV Belgica EM3002D is stored by FPS Economy – Continental Shelf Department. For all information contact Koen Degrendele (koen.degrendele@economie.fgov.be)

1. CRUISE DETAILS

1.	Cruise number	2017/23
2.	Date/time	Zeebrugge, 10/07/2017 : 10h38 Zeebrugge, 14/07/2017: 14h30
3.	Chief Scientist Participating institutes	Dr. Ilse De Mesel OD NATURE
4.	Area of interest	Belgian part of the North Sea – Hinder Bank area

2. LIST OF PARTICIPANTS

Institute	NAME	Gender	10/07/17	10/07 – 14/10/17	14/07/17
OD NATURE	Ilse De Mesel	*F*	X	X	X
	Francis Kerckhof	*M*	X	X	X
	Danae Kapasakali	*F*	X	X	X
	Lars Kint	*M*	X	X	X
	Giacomo Montereale Gavazzi	*M*	X	X	X
	Nathan Terseleer Lillo	*M*	X	X	X
	Frederic Francken	*M*	X	X	X
	Reinhilde Van den Brande	*F*	X	X	X
	Joan Backers	*M*			X
	Kevin Hindryckx	*M*			X
FPS Economie	Marc Roche	*M*	X		
	Koen Degrendele	*M*	X		
Diplodokus	Bram Conjaerts	*M*	X	X	X
	Kwinten Van Laethem	*M*	X	X	X
	Liesbeth De Ceulaer	*F*	X	X	X
	Jonathan Wannijn	*M*	X	X	X
	Georges Pichot	*M*	X	X	X
Total number of participants:			15	13	15

3. SCIENTIFIC OBJECTIVES

<u>OD Nature-MOMO</u>

The project "MOMO" is part of the general and permanent duties of monitoring and evaluation of the effects of all human activities on the marine ecosystem to which Belgium is committed following the OSPAR-convention (1992). The goal of the project is to study the cohesive sediments on the Belgian continental shelf 'BCS' using numerical models as well as by carrying out of measurements. Through this, data will be provided on the transport processes which are essential in order to answer questions on the composition, origin and residence of these sediments on the BCS, the alterations of sediment characteristics due to dredging and dumping operations, the effects of the natural variability, the impact on the marine ecosystem, the estimation of the net input of hazardous substances and the possibilities to decrease this impact as well as this in-put.

OD Nature – MSFD monitoring gravel beds

Within the framework of the EU Directive MSFD a monitoring program was developed for the biological communities on the gravel beds. The gravel beds have been under a lot of pressure due to human activities, mainly fisheries, which caused a severe decline or virtual extinction of typical hard substrate species. This monitoring program, with sampling of the gravel beds with a Gilson Dredge, has been specifically developed to follow up the MSFD indicators that have been reported to the EC.

OD Nature-AN - MONWIN Underwater noise

Environmental monitoring of underwater noise in a wind park located inside the Belgian zone of the North Sea. An underwater sound recorder will be moored in the Rentel zone in order to monitor the construction emitted sound.

OD Nature-VVL (ZAGRI/MOZ4)

ZAGRI is a continuous research program on the evaluation of the effects of the exploitation of non-living resources of the territorial sea and the continental shelf. MOZ4 research focuses on the hydrodynamics and sediment transport in a marine aggregate extraction zone, far offshore, and its impact on an adjacent Habitat Directive Area. Overall aim is to increase process and system knowledge of both areas, with particular focus on the compliancy of the extraction activities with respect to the European Marine Strategy Framework Directive. More specifically changes in seafloor integrity and hydrographic conditions need assessment.

OD Nature-GMG (INDI67/MONIT.BE)

Within Europe's Marine Strategy Framework Directive (MSFD), progress towards Good Environmental Status (GES) needs monitoring in a most time- and cost-effective way. For the GES descriptors 6 and 7, on seafloor integrity and hydrographic conditions, respectively, new integrative indicators (i.e. bottom shear stress, turbidity and seabed/habitat type) need developing. To advance the mapping of seabed/habitat types, a Community of Practice (CoP) on seabed mapping will be established, investigating the main issues preventing joint mapping of the seabed. Within SEACoP (CoP on *'Surveying for Environmental Assessments'*) the following objectives are targeted: a) estimation of the precision, sensitivities and repeatability of the acoustic devices to detect changes in seabed/habitat types; b) quantification of the external sources of variance in the acoustic signature, including the influence of near-bed and water column suspensions on backscatter data; c) definition of best practice in ground-truthing the acoustic signal, with emphasis on visual techniques; and d) innovation in collaborative seabed mapping.

OD Nature-LN (ICOS)

The AUMS (Autonomous Underway Measurement System) system is inspired by the success of similar systems deployed on various ships of opportunity in the framework of the European Union FerryBox project (www.ferrybox.org). The instrumentation will greatly enhance the continuous oceanographic measurements made by RV Belgica by taking advantage of the significant technological improvements since the design of the existing (salinity, temperature, fluorescence) systems (cfr. ICOS Standards). In particular, many new parameters can now be measured continuously including important ecosystem parameters such as nitrate, ammonia, silicate, dissolved oxygen and CO2, turbidity, alkalinity and phytoplankton pigments. In addition, the new equipment allows automatic acquisition and preservation of water samples, rendering RV Belgica operations significantly more efficient by reducing onboard human resources. Data will be available in near real-time via OD Nature's public website (http://odnature.naturalsciences.be/belgica/en/odas) and following quality control, from the Belgian Marine Data Centre. Since 2015, the AUMS data are also delivered to the EC ESFRI project ICOS.

ESA-MC (GNSS)

For the European Space Agency continuous GNSS (Global Navigation Satellite system) data is autonomously acquired in the maritime environment for performance evaluation under different conditions.

4. OPERATIONAL COURSE

All times are given in local time. All coordinates in WGS84.
Throughout the campaign, measurements are made with the AUMS system.

Monday 10th July
High Tide Zeebrugge 15h28
10:38 – 12:40: Transit to the Thorntonbank
12:40 – 16:05: Multibeam Throntonbank
16:05 – 18:00: transit to Zeebrugge
18:00 – 18:20: Rhib tranfer FOD Economie
18:20 – 20:25: Transit to Thornton Bank area
20:25 – 22:40: Multibeam transect 11-15

Tuesday 11th July
High Tide Zeebrugge 03h43 ,15h57
0030 – 05:45: multibeam HB South
05:45 – 07:00: transit to MSPZ3
07:00 – 07:15: videoframe on location HBSouth
07:15 – 07:40: transit
07:40 – 07:50: deployment of the ADCP at location 51°28.7N-002°31.796^E
07:50 – 08:30: transit to MSPZ4
08:30 – 09:40: Gilson tracks 1-4 in MSPZ4
10:00 – 11:30: Hamon Grabs 1 - 6 in MSPZ4
11:45 – 13:15: Videoframe on location BV6 (MSPZ4)
13:15 – 14:20: Gilson tracks 5-8 in MSPZ4
14:20 – 14:45: transit to MSPZ3
14:45 – 15:30: Van Veen samples in MSPZ3
15:30 – 15:50: transit to MBES line 2
15:50 - … : start multibeam MBES line 2

Wednesday 12th July
High Tide Zeebrugge 04h15 ,16h30
05:05: end of multibeam Kwintebank
05:05 - 06:50: transit to the Westhinder
07:54 – 08:50: Van Veen samples on the Westhinder
08:50 – 10:15: transit to MFSD 13
Opmerking: Wind N-8Bft
10:15 – 14:00: Van Veen samples on MSFD track
14:00 – 15:30: transit to Westhinder
15:35: start 13hrs cycle ADCP on the Westhider

Thursday 13th July
High Tide Zeebrugge 04h51 ,17h07
04:05: End of 13hrs cycle Westhinder
04:35 – 7:20: multibeam on the Westhinder
07:20 – 08:20: transit to MSPZ3 – ADCP location
08:20 – 08:30: ADCP recovery
08:30 – 09:00: transit within MSPZ3
09:00 – 09:20: Gilson tracks GD10a/b
09:30 – 09:50: Hamon Grabs HG10a/b
09:50 – 10:40: transit to zone RC4c
10:40 – 11:45: Hamon grabs &Van Veen samples in zone RC4c
11:45 – 12:30: transit to MSFD4
12:30 - 12:40: Hamon grab on MSFD4
12:45 – 13:05: Gilson dredge on MSFD4

13:50 – 14:05: video frame on MSFD4
14:30 – 15:00: Gilson dredge along MSFD transect
15:40 – 16:50: Hamon grab in on MSFD transect
16:50 – 17:15: transit to Westhinder
17:15 – 21:00: Multibeam Westhinder
21:25 start 13hrs cyclus (short version)

Friday 13th July

High Tide Zeebrugge 05h32

01:00 einde 13-uur cyclus
01:25 – 03:50: multibeam
03:50 – 07:00: transit to Zeebrugge
07:00 – 07:30: Rhib transfer MDO
07:30 – 08:05: transit to MOW1
08:05 – 09:20: replacement tripode at MOW1
09:20 – 12:00: transit to RENTEL area
12:00: deployment sound recorder in RENTEL area
12:00 – 14:30: transit to Zeebrugge
14:30: disembarkment

- End of campaign 2017/23 -

5. TRACK PLOT

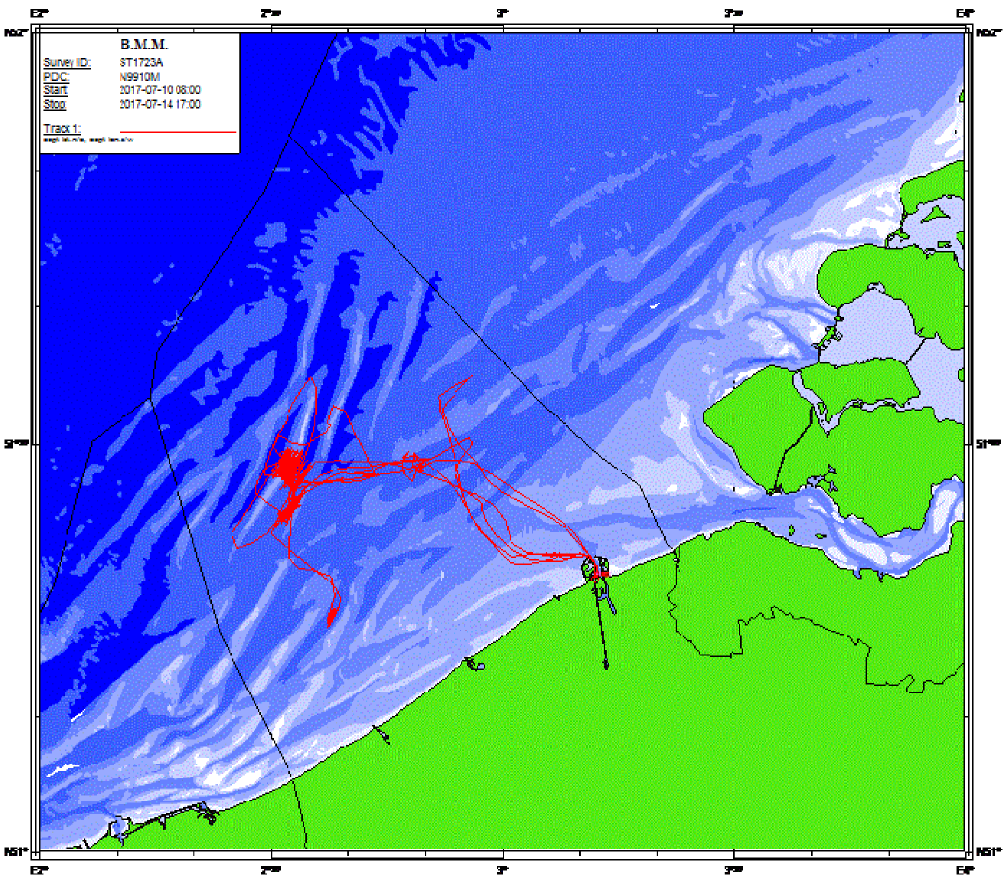

Figure 1: Track plot of campaign 2017/23

6. MEASUREMENTS AND SAMPLING

6.1. OD NATURE-MOMO (MF)

The tripod at MOW1 was successfully replaced.

6.2. OD NATURE-Monitoring gravel beds (IDM)

Gilson Samples

Samples were collected with the Gilson dredge at 7 locations. At each site, two tracks of 250m were collected. An overview of the sampling sites and the samples are given in table 1.

Table 1: Overview of the Gilson track samples

	Start		End		
Sample	N	E	N	E	Picture
GD1 MSPZ4	51.4141	2.526825	51.41071	2.523131	
GD2 MSPZ4	51.40579	2.517569	51.40178	2.512833	
GD3 MSPZ4	51.40083	2.50796	51.40505	2.514326	
GD4 MSPZ4	51.41154	2.523528	51.41543	2.528568	

GD5 MSPZ4	51.44704	2.46565	51.44938	2.467647	
GD6 MSPZ4	51.45344	2.470926	51.45806	2.474333	
GD7 MSPZ4	51.46081	2.477052	51.46512	2.480919	
GD8 MSPZ4	51.46533	2.480182	51.47	2.484269	
GD10A MSPZ3	51.49631	2.502905	51.50122	2.506564	
GD10B MSPZ3	51.50587	2.510229	51.51101	2.514134	

GD11 MSFD track	51.46286	2.724103	51.46312	2.730805	
GD12 MSFD Track	51.46101	2.73154	51.45975	2.725134	
GD13 MSFD Track	51.45465	2.648071	51.45759	2.651672	
GD14 MSFD Track	51.45921	2.652992	51.45327	2.647104	

Video frames

Video footage was collected at three sites. At site VF4 the first attempt was not successful because of the high currents, and was repeated when currents had dropped. However, also the quality of this track is rather poor. An overview of the locations of the different tracks is given in table 2.

Table 2: overview of the coordinates of the start and end points of the video tracks

Sample	Start		End	
	N	E	N	E
HBSouth	51° 26.21648	2° 33.00377	51° 26.34635	2° 33.11927
MRPZ4 relict	51° 24.96149	2° 31.74900	51° 24.93996	2° 31.73083
MSFD VF4	51° 27.79939	2° 43.57950	51° 27.77065	2° 43.50795
MSFD VF4b	51° 27.84945	2° 43.60113	51° 27.74028	2° 4347146

Hamon Grab

Four Hamon Grab samples were collected respectively on Gilson trajectory 10, 11 en 14. An overview of the locations and the samples is given in Table 3.

Table 3: overview of the locations and samples collected with the Hamon Grab for biological analysis

sample	N	E	Picture
HG10A MSPZ3	51.496890	2.502612	
HG10B MSPZ3			
HG11 MSFD Track	51.524015	2.6235853	
HG14 MSFD Track	51.455744	2.649455	No picture

6.3. OD NATURE- MONWIN Underwater noise (AN)

A measuring chain for underwater noise was deployed inside the Rentel concession zone (51°35’129 N -002°56’037E) on the 13th July at 12:00. The recovery of the mooring is foreseen for cruise 2017-25 at the end of August 2017**.**

6.4. OD NATURE- ZAGRI/MOZ4 (VVL)

A comparative study between Van Veen grab and Hammon Grab samplers was conducted in the Oosthinder sector 4c (samples ID: ST1273-4c001 etc… in Table 4 under the INDI67/MONIT.BE paragraph of this report). The experiment comprised the acquisition of a substrate sample using both sampling gears at the same location. Samples have been frozen in order to analyze the organic content (samples in freezer at Oostende).
ADCP measurements (both stationary using the bottom mounted ADCP and transecting using the hull-mounted system) were also conducted in the MSPZ3 area and combined with water column sampling with Niskin bottles and the recently acquired LISST instrument. Locations reported in Table 1 and Figure 2.

1. Deployment and recovery of a bottom-mounted ADCP in the trough of a barchan dune in MRPZ3-W
ID: ADCPZ3-W
Settings:

Beam frequency: 1200Hz
Profiling mode: 1
Cells: 119
Cell size: 0.25m
Pings/ensemble: 50
Ensemble interval: 300s
Blanking distance: 0.45m
1st bin dist: 0.82m

Deployment: 11-07-2017 05:47 (UTC) 51° 28.7N 2° 31.806E
Recovery: 13-07-2017 6:24 (UTC) 51° 28.7N 2° 31.787E

2. ADCP profiling along a transect over a series of dunes (Hull-mounted ADCP RDI 600 kHz). Aim was to characterize vortex structures in the lee side of the dunes.
Water sampling and vertical profiling of oceanographic parameters was conducted at 2017-07-12 22:26:20, 2017-07-12 23:40:30, and 2017-07-13 00:24:20 (Seacat frame SBE19 housing CTD, Seapoint turbidity meter, oxygen sensor, and Frame with a LISST (200x) to measure in-situ particle size).

3. Water sampling and vertical profiling of oceanographic parameters at a fixed location (Table 2: Fig. 3) in the trough of a barchan dune in MSPZ3-W (Seacat frame SBE19 housing CTD, Seapoint turbidity meter, oxygen sensor, and Frame with a LISST (200x) to measure in-situ particle size).
See Table 1 (below) for the timestamps.

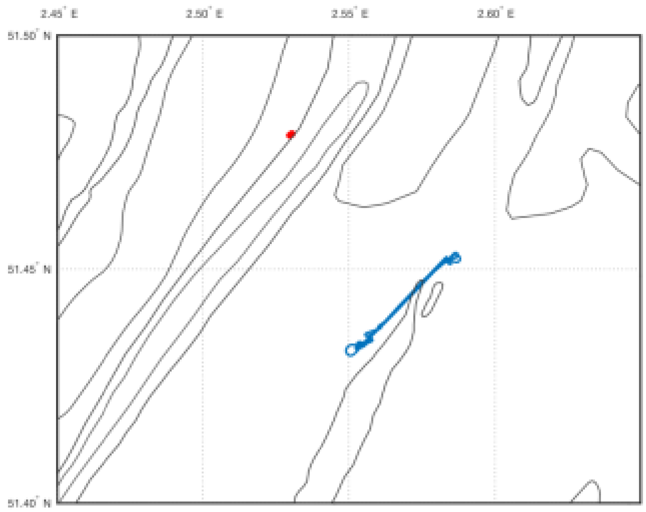

Figure 2 – Map reporting the locations of the ADCP operations carried out during the ST1723 campaign. In red: location of the bottom mounted ADCP (Table 2, Fig. 2) and in blue: location of the 13h cycle transects using the hull-mounted ADCP.

Table 1 – water sampling and profiling stations timestamps

ID	Timestamp (UTC)	SPM filtration (ml)	Salinity	POC/PON
MSPZ3E-TRANSECT 1	2017-07-12 22:26:20	1500	x	250
MSPZ3E-TRANSECT 2	2017-07-12 23:40:30	1500		
MSPZ3E-TRANSECT 3	2017-07-13 00:24:20	1500	x	250
BM-ADCP 1	2017-07-13 19:29:03	1500		
BM-ADCP 2	2017-07-13 20:03:39	1500	x	250
BM-ADCP 3	2017-07-13 20:33:27	1500		
BM-ADCP 4	2017-07-13 21:02:12	1500	x	250
BM-ADCP 5	2017-07-13 21:32:21	1500		
BM-ADCP 6	2017-07-13 22:01:28	1500	x	250
BM-ADCP 7	2017-07-13 22:30:51	1500		
BM-ADCP 8	2017-07-13 22:57:06	1500	x	250

Table 2 – Bottom mounted ADCP location from ODAS

StationName	Gear	SampleRef	SampleStartTime	N	E
position BM ADCP	HM ADCP	001	13/07/2017	51.47858683	2.534582774

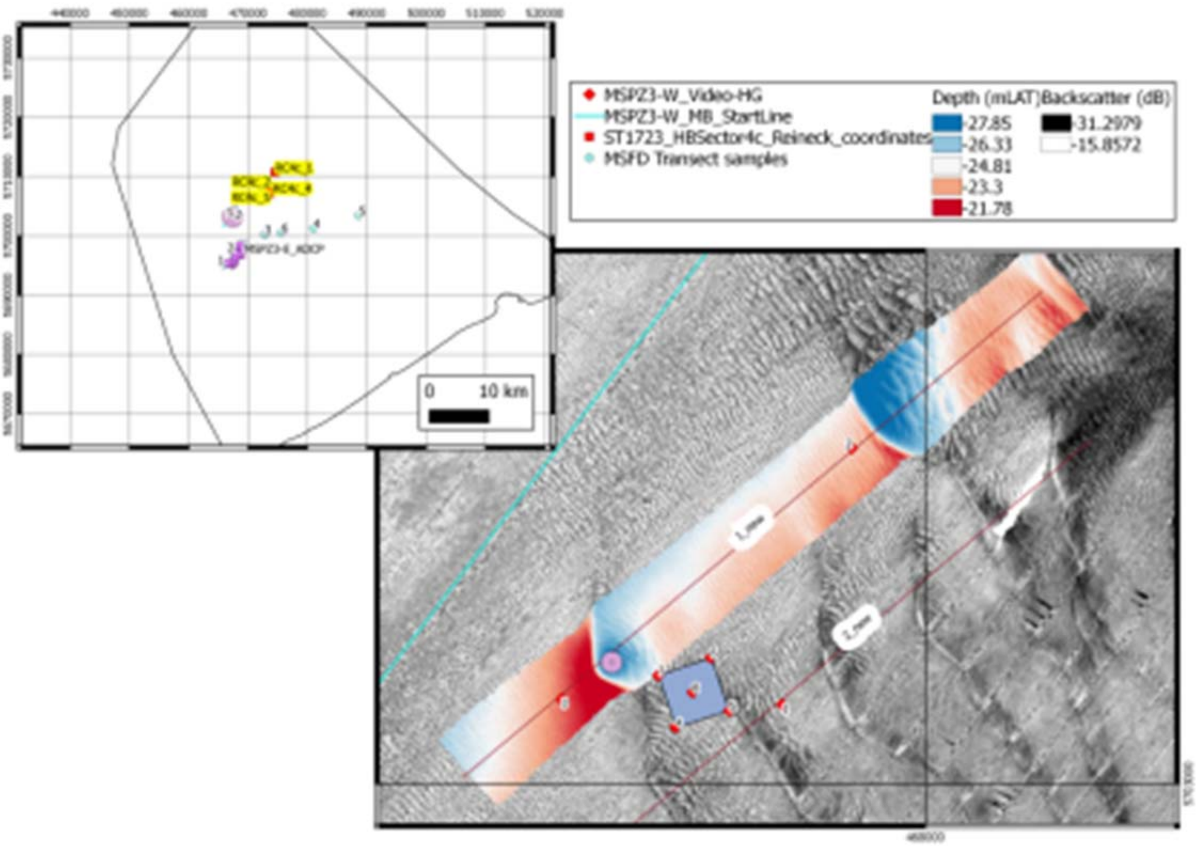

Figure 3 – map representation of the location of the stationary, bottom-mounted ADCP

6.5. OD NATURE - INDI67/MONIT.BE (GMG)

A series of actions where brought forward under the umbrella of this project:

1) MBES data acquisition was carried out for the planned MSFD offshore transect as well as for the Fisheries Zone 3 and 4 within the Hinder banks study area and the Kwintebank reference calibration area (extent of MBES data is reported in Figure 4 in green)

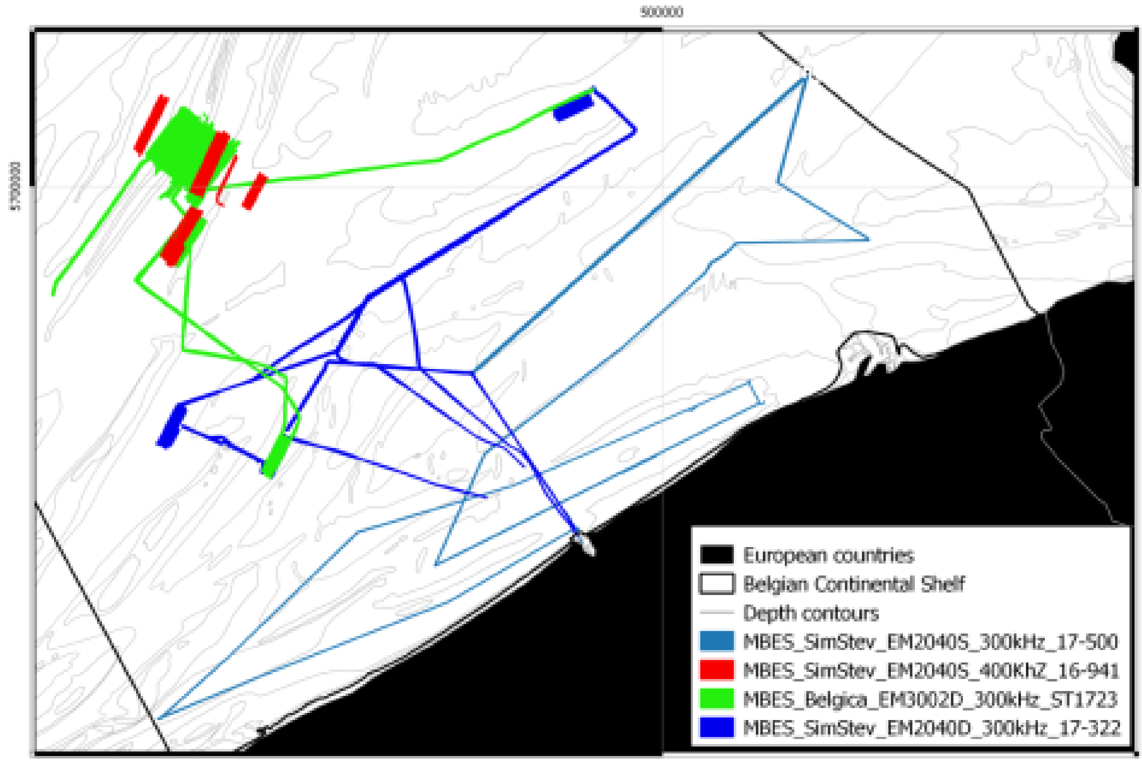

Figure 4: Overview of the collected MBES data

2) A set of sediment and video samples were acquired in order to validate the acoustics: In total, 2 Video tracks (Table 6) and 37 sediment samples were collected with Hamon and Van Veen grab samplers (Table 7).

Table 3 – overview of the coordinates of the videoframes deployed in MSPZ3

StationName	Gear	SampleRef	SampleStartTime	N	E
Hbsouth	Video frame	001	11/07/2017	51.43647385	2.549170939

Table 4 – Coordinates of the samples collected with Van Veen and Hammon Grab in the MSPZ3 study area

X	Y	Team	Time	Cruise	Gear	MBES	Malvern	kHz	ID
2.530282	51.40568	RBINS-ODN	11/07/2017 10:03:14	ST1723	HG	EM3002D	y	300	HB001
2.536079	51.41063	RBINS-ODN	11/07/2017 10:17:06	ST1723	HG	EM3002D	y	300	HB002
2.537758	51.41676	RBINS-ODN	11/07/2017 10:30:31	ST1723	HG	EM3002D	y	300	HB003
2.544903	51.42244	RBINS-ODN	11/07/2017 10:50:07	ST1723	HG	EM3002D	y	300	HB004
2.552305	51.42171	RBINS-ODN	11/07/2017 11:07:48	ST1723	HG	EM3002D	y	300	HB005
2.55739	51.42728	RBINS-ODN	11/07/2017 11:27:52	ST1723	HG	EM3002D	y	300	HB006
2.51244	51.51149	RBINS-ODN	12/07/2017 07:53:55	ST1723	VV	EM3002D	y	300	MSFD-T001
2.513284	51.5118	RBINS-ODN	12/07/2017 07:56:18	ST1723	VV	EM3002D	y	300	MSFD-T001
2.510549	51.40675	RBINS-ODN	12/07/2017 10:14:18	ST1723	VV	EM3002D	y	300	MSFD-T001
2.533217	51.5332	RBINS-ODN	12/07/2017 08:20:10	ST1723	VV	EM3002D	y	300	MSFD-T002

2.533369	51.42519	RBINS-ODN	12/07/2017 10:36:00	ST1723	VV	EM3002D	y	300	MSFD-T002
2.608832	51.4525	RBINS-ODN	12/07/2017 11:17:44	ST1723	VV	EM3002D	y	300	MSFD-T003
2.72745	51.46274	RBINS-ODN	12/07/2017 12:08:14	ST1723	VV	EM3002D	y	300	MSFD-T004
2.727506	51.46294	RBINS-ODN	12/07/2017 12:10:50	ST1723	VV	EM3002D	y	300	MSFD-T004
2.838031	51.4824	RBINS-ODN	12/07/2017 13:42:50	ST1723	VV	EM3002D	y	300	MSFD-T005
2.838362	51.48214	RBINS-ODN	12/07/2017 13:45:28	ST1723	VV	EM3002D	y	300	MSFD-T005
2.512892	51.46517	RBINS-ODN	13/07/2017 15:46:54	ST1723	HG	EM3002D	y	300	MSPZ3001
2.514895	51.46439	RBINS-ODN	13/07/2017 15:41:42	ST1723	HG	EM3002D	y	300	MSPZ3002
2.525894	51.48063	RBINS-ODN	13/07/2017 16:03:49	ST1723	HG	EM3002D	y	300	MSPZ3003
2.527468	51.48228	RBINS-ODN	13/07/2017 16:12:42	ST1723	HG	EM3002D	y	300	MSPZ3004
2.538521	51.48726	RBINS-ODN	13/07/2017 16:29:24	ST1723	HG	EM3002D	y	300	MSPZ3005
2.530561	51.49136	RBINS-ODN	13/07/2017 16:44:10	ST1723	HG	EM3002D	y	300	MSPZ3006
2.53579	51.47839	RBINS-ODN	11/07/2017 15:02:56	ST1723	VV	EM3002D	y	300	MSPZ3-W001
2.537394	51.48262	RBINS-ODN	11/07/2017 14:46:16	ST1723	VV	EM3002D	y	300	MSPZ3-W002
2.532544	51.47801	RBINS-ODN	11/07/2017 15:25:47	ST1723	VV	EM3002D	y	300	MSPZ3-W004
2.534362	51.47843	RBINS-ODN	11/07/2017 15:11:34	ST1723	VV	EM3002D	y	300	MSPZ3-W005
2.53421	51.47977	RBINS-ODN	11/07/2017 14:55:52	ST1723	VV	EM3002D	y	300	MSPZ3-W006
2.532273	51.47885	RBINS-ODN	11/07/2017 15:20:44	ST1723	VV	EM3002D	y	300	MSPZ3-W007
2.533121	51.47867	RBINS-ODN	11/07/2017 15:16:11	ST1723	VV	EM3002D	y	300	MSPZ3-W008
2.633267	51.54771	RBINS-ODN	13/07/2017 11:39:56	ST1723	HG	EM3002D	y	300	ST1273-4c001
2.620804	51.52526	RBINS-ODN	13/07/2017 11:19:34	ST1723	HG	EM3002D	y	300	ST1273-4c002
2.623426	51.52414	RBINS-ODN	13/07/2017 11:07:16	ST1723	HG	EM3002D	y	300	ST1273-4c003
2.633407	51.5475	RBINS-ODN	13/07/2017 11:42:58	ST1723	VV	EM3002D	y	300	ST1273-4c001
2.621419	51.52489	RBINS-ODN	13/07/2017 11:22:22	ST1723	VV	EM3002D	y	300	ST1273-4c002
2.623857	51.5238	RBINS-ODN	13/07/2017 11:09:43	ST1723	VV	EM3002D	y	300	ST1273-4c003
2.61957	51.51549	RBINS-ODN	13/07/2017 10:37:51	ST1723	HG	EM3002D	y	300	ST1723-4c001
2.629076	51.52241	RBINS-ODN	13/07/2017 10:53:05	ST1723	HG	EM3002D	y	300	ST1723-4c004
2.628875	51.52164	RBINS-ODN	13/07/2017 10:55:19	ST1723	VV	EM3002D	y	300	ST1723-4c004
2.619199	51.51567	RBINS-ODN	13/07/2017 10:40:46	ST1723	VV	EM3002D	y	300	ST1723-4c005

7. REMARKS

- Weather

The program was altered on board due to bad weather conditions on Wednesday. Because of these changes, one 13hrs cycle could not be fit in and was reduced to 6hrs. The other planned activities have not been jeopardized.

- Technical issues that have affected the cruise plan and/or scientific operations

The MBES needed to be calibrated before measurements could be made during the cruise. The calibration was done on the Thornton Bank and went well. No issues with the system have been encountered during the campaign and high quality data were obtained.

8. DATA STORAGE

- What data is stored?
  Video from the Videoframe, MBES logged data, ODAS data, Sediment samples and biological data
- Where is the data stored?
  OD Nature (contact: Ilse De Mesel, Giacomo Montereale Gavazzi, Vera Van Lancker)
- Who is the contact person?
  Ilse De Mesel (biological data), Giacomo Montereale Gavazzi and Vera Van Lancker (sediment and water column related data)

All data will be provided to OD NATURE-BMDC in accordance to the RV Belgica ship time request.

RV BELGICA CRUISE 2018/07 - CRUISE REPORT

Subscribers:	Prof. Dr. Vera Van Lancker (VVL); Prof. Dr. Ann Vanreusel (AV); Mr. Giacomo Montereale Gavazzi (GMG)
Institutes:	Operational Directorate Natural Environment (OD Nature)
Addresses:	OD Nature-BRU: Gulledelle 100, B-1200 Brussels
Telephones:	+32(0)2 773 21 29 (VVL); +32 (0)9 264 85 21 (AV); +32(0)2 773 21 29 (GMG)
E-mails:	vera.vanlancker@naturalsciences.be; ann.vanreusel@ugent.be; giacomo.monterealegavazzi@naturalsciences.be

Monitoring / Education: 19/03/2018 - 23/03/2018

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1. Cruise details
2. List of participants
3. Scientific objectives
4. Operational course
5. Track plot
6. Measurements and sampling
7. Remarks
8. Data storage

1. CRUISE DETAILS

1.	Cruise number	2018/07
2.	Date/time Zeebrugge departure	19/03/2018: no departure because of technical issues 19/03/2018: 18h05 20/03/2018: 09h55; and 21h01 (delayed) 22/03/2018: 9h41; and 17h52 23/03/2018: 14h arrival
3.	Chief Scientist Participating institutes	Vera Van Lancker RBINS-OD Nature
4.	Area of interest	Belgian part of the North Sea

2. LIST OF PARTICIPANTS

Institute	Family name	Given name	Gender	19/3	20/3	21/3	22/3	23/3
RBINS-ODN	VAN LANCKER	Vera	F	SC1	SC1	SC1	SC1	SC1
	MONTEREALE GAVAZZI	Giacomo	M	SC3	SC3	SC3	SC3	SC3
	KINT	Lars	M	SC4	SC4	SC4	T&G AM	
	SCHOLDIS	Tom	M				SC5 T&G PM	SC5
	BAEYE	Matthias	M	X				
	VAN DEN BRANDEN	Reinhilde	F				X	
ODN-MSc Stud	VISSENAEKENS[1]	Elise	F				X	
Students Oceans and Lakes Group 1	JIMÉNEZ ALCÁNTARA	Juana	F	SC7				
	BYNS	Cara	F	X				
	CHTOURIS	Nikolaos-Kimon	M	SC5				
	FAUZIYAH	Arida	F	X				
	HAILEYESUS	Girma	M	SC6				
	MOREAUX	Benoît	M	X				
	STRAUSS	Sylvia	F	SC2				
	VAN DER AA	Pierrot	M	SC9				
	VAN WERVEN	Bernike	F	SC8				
	KNOPS	Laura	F	X				
	KUMBAGOWDANA SATISH	Sidanth	M	X				
	MOODLEY	Kylene	F	X				
	PHAN	Nhat Truong	M	X				
Students Oceans and Lakes Group 2	ABREU	Bruno	M		ABSENT			
	CLAES	Jolien	F		X			
	DIERKENS	Morgane	F		X			
	NANSUMBI	Florence	F		X			
	NGUYEN	Nhut	M		X			
	NGUYEN	Thuy Dung	F		X			
	PANTÒ	Gabriella	F		X			
	PLEVOETS	Tim	M		X			
	RUNDT	Christine	F		X			
	EIJKELHOF	Yoeri	M		X			
	WOUTERS	Bram	M		X			
	MUTETI	Jane	F		X			
	VAN LOOCK	Stephanie	F		X			

Students Oceans and Lakes Group 3	GOAD	Devonne	F				SC7	SC7
	IQRAM	Muhammad	M				SC12	SC12
	LOUIS	Victoria	F				SC8	SC8
	NGUU	Josphat	M				SC13	SC13
	SAID	Hashim	M				SC14	SC14
	OUDE LUTTIKHUIS	Dorien	F				SC9	SC9
	PAOLETTI	Silvia	F				SC10	SC10
	SUELLO	Rey Harvey	M				SC15	SC15
	VAN ROOZENDAEL	Benjamin	M				SC4	SC4
	VERHAEGEN	Coralie	F				SC2	SC2
	BUYDENS	Marius	M				X	
	KORDENI	Maria	F				X	
		Scientists:		Day: 4 Night: 3	Day: 3 Night: 4	Day: 3 Night: 3	Day: 3 Night: 3	Day: 3
		Students:		Day: 13 Night: 6	Day: 13 Night: 0		Day: 13 Night: 10	Day: 10
		Overall total		**Day: 17 Night: 9**	**Day: 16 Night: 4**	**Day: 3 Night: 3**	**Day: 16 Night 13**	**Day: 13**

3. SCIENTIFIC OBJECTIVES

<u>OD NATURE-VVL/UG-SMB - STUDENTS</u>

Students will be trained in the framework of the MSc program Oceans and Lakes, course “In-situ and remote sensing tools in Aquatic Sciences”. They will learn to: (1) conduct most of the stages of a scientific expedition at sea (from sample collection to reporting); (2) apply a multidisciplinary approach in marine research; (3) get acquainted with different techniques of data and sample collection at sea; (4) collaborate in a scientific team including the vessel crew in order to achieve common objectives; and (5) gain insight in some important patterns of temporal variation and spatial gradients present on the Belgian Part of the North Sea (BPNS). Measurements and observations are performed in function of scientific projects (e.g., ZAGRI/MOZ4; INDI67, *see below*).

<u>OD NATURE-VVL (ZAGRI/MOZ4)</u>

ZAGRI is a continuous research program on the evaluation of the effects of the exploitation of non-living resources of the territorial sea and the continental shelf. MOZ4 focuses on the monitoring of hydrodynamics and sediment transport in relation to marine aggregate extraction in a far offshore zone. Overall aim is to increase process and system knowledge of this area, with a particular focus on the compliancy of the extraction activities with respect to the European Marine Strategy Framework Directive. More specifically changes in seafloor integrity and hydrographic conditions will be assessed. An important parameter is the bottom shear stress, with knowledge needed on both natural and anthropogenically-induced variability. Results will be used for the validation of mathematical models, necessary for impact quantification.

<u>OD Nature-GM (INDI67/MONIT.BE)</u>

Within Europe’s Marine Strategy Framework Directive (MSFD), progress towards Good Environmental Status (GES) needs monitoring in a most time- and cost-effective way. For the GES descriptors 6 and 7, on seafloor integrity and hydrographic conditions, respectively, new integrative indicators (i.e. bottom shear stress, turbidity and seabed/habitat type) need developing. To advance the mapping of seabed/habitat types, a Community of Practice (CoP) on seabed mapping will be established, investigating the main issues preventing joint mapping of the seabed. Within SEACoP (CoP on ‘Surveying for Environmental Assessments’) the following objectives are targeted: a) estimation of the precision, sensitivities and repeatability of the acoustic devices to detect changes in seabed/habitat types; b) quantification of the external sources of variance in the acoustic signature, including the influence of near-bed and water column suspensions on backscatter data; c) definition of best practice in ground-truthing the acoustic signal, with emphasis on visual techniques; and d) innovation in collaborative seabed mapping.

<u>OD Nature-GL (JELLYMOD)</u>

In the framework of the JELLYMOD (Modelling jellyfish in the North Sea) project, we are developing a jellyfish drift model with the aim to better understand the origin and the mechanisms that trigger the jellyfish blooms in the North Sea. The model calibration/validation processes request many observations of jellyfish. In addition to records of beaching events that are available for instance on waarnemingen.be, there is a need for observations at sea (surface and under water). In particular, it is necessary to know the species (different species have different life traits), the size (to estimate the time they drift), the position and depth of observed jellyfish. The jellyfish monitoring program, which helps to further develop the jellyfish drift model, is made thanks to the in-kind contribution of scientists on a voluntary basis.

OD Nature-LN (ICOS)

The AUMS (Autonomous Underway Measurement System) system is inspired by the success of similar systems deployed on various ships of opportunity in the framework of the European Union FerryBox project (www.ferrybox.org). The instrumentation will greatly enhance the continuous oceanographic measurements made by RV Belgica by taking advantage of the significant technological improvements since the design of the existing (salinity, temperature, fluorescence) systems (cfr. ICOS Standards). In particular, many new parameters can now be measured continuously including important ecosystem parameters such as nitrate, ammonia, silicate, dissolved oxygen and CO2, turbidity, alkalinity and phytoplankton pigments. In addition, the new equipment allows automatic acquisition and preservation of water samples, rendering RV Belgica operations significantly more efficient by reducing onboard human resources. Data will be available in near real-time via OD Nature's public website (http://odnature.naturalsciences.be/belgica/en/odas) and following quality control, from the Belgian Marine Data Centre. Since 2015, the AUMS data are also delivered to the EC ESFRI project ICOS.

4. OPERATIONAL COURSE

All times are given in local time. All coordinates in WGS84.
Throughout the campaign, measurements were made with the AUMS system.

Jellyfish observations were made throughout the cruise.

Monday 19/03/2018

Zeebrugge *LW 08:56 – 21:09; HW 14:55;*
Spring tide, from 50 dm LAT to 45 dm LAT during the week

09h00-10h00 Embarkation of instruments and personnel.
Counting of jellyfish in harbor

Due to technical issues with the crane (fixed around 17h) departure was delayed until 18h
Regarding multibeam echosounding (MBES), the motion reference unit (MRU) did not work, hence planning was adapted.
For the first group of students all demonstrations were given in the harbor. Six students stayed overnight.

18h05 *Sail to disposal ground Br&W Oostende for 13 hr cycle (south of Wenduine Bank)*

20h35 Tidal cycle sampling (planned location BM-ADCP)
Centrifuge sampling
HM-ADCP Profiling

Tuesday 20/03/2018

LW 09:35 – 21:49; HW 03:10 - 15:33;

07h End of measurements

07h25: Transit to Zeebrugge

09h55 Touch & Go at Zeebrugge. Embarkation Student Group 2. Disembarkation overnight students
Counting of jellyfish in harbor

MRU MBES still not working; technical assistance was asked to Kongsberg. Intervention was set at 17h.

11h22 *Sail off from Zeebrugge to Br&W Oostende for seabed sampling*

13h28-14h44 Seabed sample (Van Veen grab: VV01 > VV05; 130)

14h48 Sail towards Zeebrugge

16h53 Arrival at Zeebrugge

Intervention Kongsberg for MRU problems MBES (17h-21h)

21h01: Transit to Hinder Banks

Wednesday 21/03/2018

LW 10:15 – 22:29; HW 03:48 – 16:12;

00h39 MBES recording MBES Fisheries Management Zone 3-W (FMZ3-W)

06h52-07h55 Video FMZ3 during slack water (NW1-NW2-NW3), alternating with Van Veen grab samples at three locations

08h14 Multibeam echosounding FMZ3
16h26

Transit to Oosthinder sandbank, HBMC for Reineck boxcoring

17h10 Reineck sampling HBMC (8 locations)
18h50

Transit to FMZ3-SE Oosthinder south for 3 video point locations

19h49-20h28 Video imaging at three locations (FMZ3-SE1, SE2, SE3)

20h45 MBES FMZ3-SE starting from 800 m East of line 51°26.031, 2°33.808; 51°28.084, 2°35.835

Thursday 22/03/2018

LW 10:56 – 23:11; HW 04:29 - 16:55;

03h55 End of observations

Transit to Zeebrugge

06h57 Arrival at Zeebrugge. Disembarkation Lars Kint.
Counting of jellyfish in harbor

Embarkation third group of students.

09h41 Departure from Zeebrugge.

Transit to disposal ground Br&W Oostende, south of Wenduine Bank

11h22 MBES around Br&W Oostende

14h02 Deployment of BM-ADCP in the vicinity of Br&W Oostende location
ADCP deployment at position 51°16.374; 002°54.944

14h23-15h17 Reineck boxcoring at locations S5-S4-S3-S2-S1 and at ADCP location

16h05 MBES towards harbour

17h28 Touch & Go at Zeebrugge. Disembarkation Student Group 3 (10 students stay overnight)

17h52: Transit to Br&W Oostende

20h17 Anchored

20h30 Tidal cycle sampling at Br&W Oostende (51°16.455’; 002°55.058’)
Centrifuge sampling
HM-ADCP Profiling

Friday 23/03/2018

LW 11:40; HW 05:14 – 17:41;

08h05	End of measurements Centrifuge: 4290980-4304625 (20h-08h30; 0.3 l/s)
09h45-09h57	Recovery of BM-ADCP
10h16	Van Veen grab ADCP
10h39	MBES (extremely difficult to stay on the line)
11h51	Sail off to Zeebrugge
14h00	Arrival at Zeebrugge

5. TRACK PLOT

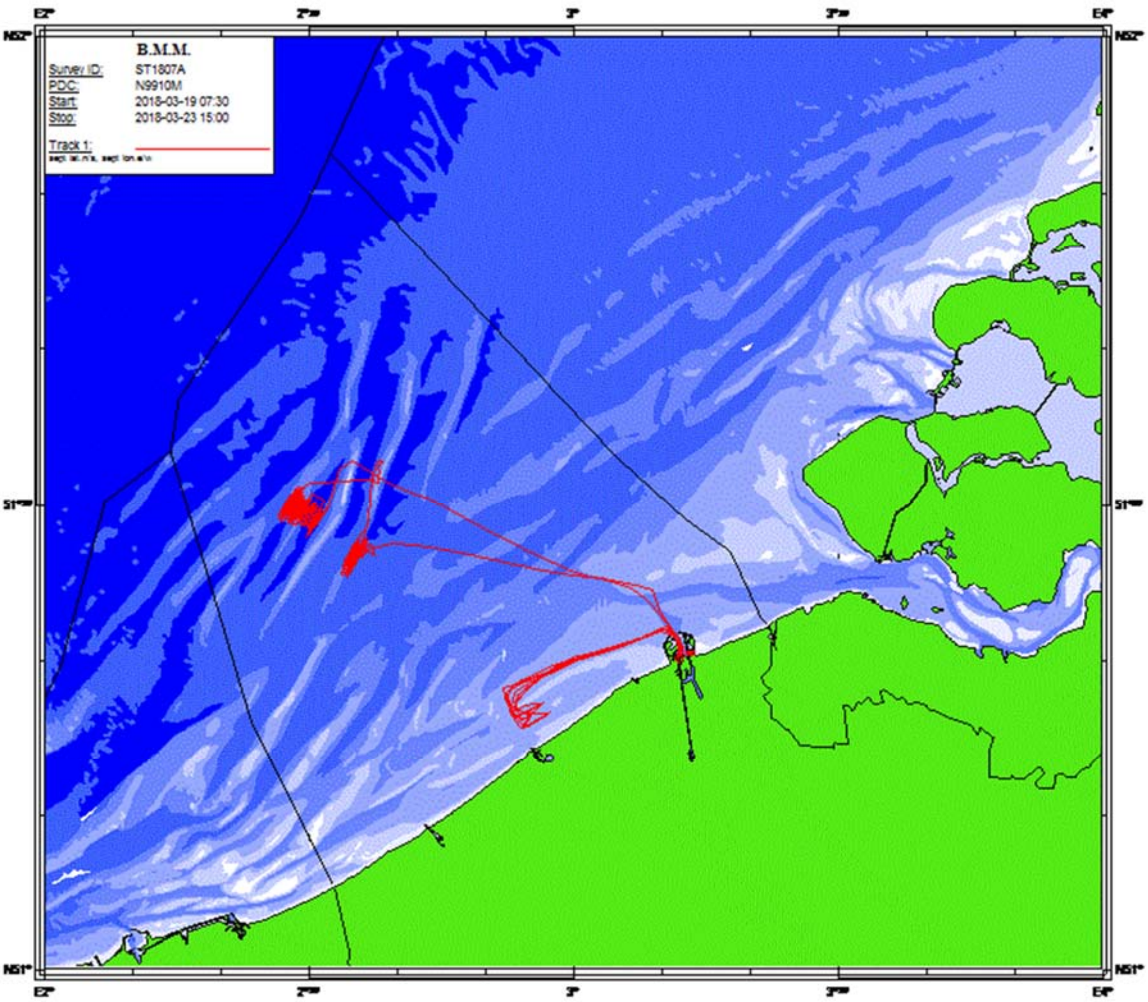

Figure 1: Track plot of campaign 2018/07

6. MEASUREMENTS AND SAMPLING

6.1. OD Nature MONIT.BE/INDI67 and MOZ4

(1) In the framework of Europe's Marine Strategy Framework Directive (MSFD), good environmental status (GES) of marine waters need monitoring. One of the GES descriptors is related to seafloor integrity, and therefore the Belgian State defined fixed trajectories, in combination with areas, along which multibeam depth and backscatter data are acquired on a repetitive basis.
(2) Monitoring of the effects of marine aggregate extraction (MOZ4)

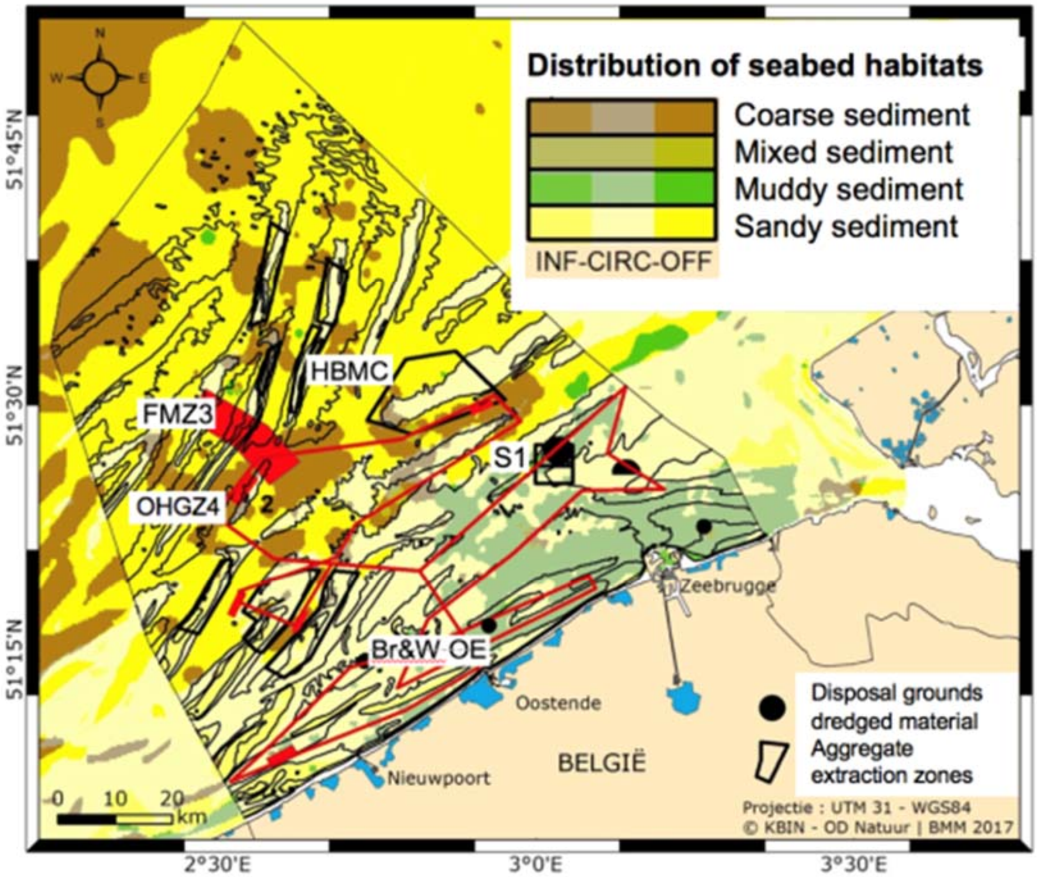

Figure 2: Distribution of broad-scale infralittoral (INF), circalittoral (CIRC) and offshore (OFF) habitat types in the Belgian part of the North Sea, together with the trajectories and monitoring areas to study seabed changes through time. The sites for detailed investigation during this campaign are indicated.

6.1.1 Extending the MSFD monitoring areas along disposal grounds of dredged material (Fig. 2, Br&W OE)

Measurements were carried out along disposal ground of dredged material Br&W Oostende, south of the Wenduine Bank.

Table 1: Central position of the disposal ground

Location	Lat (DD MM.MMM)	Long (DD MM.MMM)	Buffer Distance (m)
Br&W Oostende	51° 22.896 N	2° 15.835 E	750

(a) Deployment of a bottom-mounted Acoustic Doppler Current Profiler (BM-ADCP) (1200 kHz).

Table 2: Position and time of BM-ADCP deployment and recovery.

ID	Instrument	Date (local time)	Lat_wgs84	Lon_wgs84
Br&W Oostende	BM-ADCP deployment	22/3 14h02	51°16.374	002°54.944
Br&W Oostende	BM-ADCP recovery	23/3 09h45-09h57		

(b) Multibeam data acquisition (depth and backscatter) using RV Belgica's Kongsberg EM3002D (300 kHz) echosounder along selected lines.

(c) Seabed sampling:

- Reineck boxcorer. Locations were derived from the newly acquired multibeam data. Subcores were taken from the Reineck boxcorer and sliced on board (1-cm interval).
- Van Veen grab sampling at five locations in preparation of a future vibrocoring campaign.

(d) Tidal cycle measurements

Throughout the tidal cycle, a frame with oceanographic sensors and a water sampler (10L Niskin bottle) was lowered to the seabed every 30'. The Seacat frame (SBE 09 STD-system) was used, a.o. equipped with a CTD to measure conductivity, temperature and depth, and a Seapoint turbidity meter. An additional frame was attached to the Seacat frame in which a Laser in-situ Scatterometer and Transmissometer (LISST200x, Sequoia) was mounted.

The vertical profiling was carried out as slow as possible with every 2 m a break of about 30s. During the measurements suspended sediments were collected with the centrifuge. Data was also recorded from RV Belgica's hull-mounted acoustic Doppler current profiler (HM-ADCP, 600 kHz).

Table 3: Position and time of tidal cycle measurements, Br&W Oostende.

ID	Timestamp UTC	Lat_wgs84 (degrees)	Lon_wgs84 (degrees)
Br&W Oostende T1	2018-03-19 19:35:00	51.26897493	2.901586667
Br&W Oostende T2	2018-03-22 19:00:00	51.2867817	2.8750707

Table 4: Overview of 1st tidal cycle, Br&W Oostende near location BM-ADCP

Station	Timestamp (UTC)	Parameters	SPM	POC	POC	Sample	PSU bottles	Remark	HACH
			ml	filternr	ml	position			NTU AVG
T1-ST1	no bottle					-6 m from surface	na	start file	
T1-ST2	2018-03-19 20:05	SPM+salinity+POC	250	415	90	-6 m from surface	y	closing bottle and start file	228
T1-ST3	2018-03-19 20:30	SPM+POC	250	420	90	-3 m from surface	n	closing bottle and start file	285
T1-ST4	2018-03-19 21:00	SPM+salinity	250			-3 m from surface	y	closing bottle and start file	317
T1-ST5	2018-03-19 21:30	SPM+POC	250	416	90	-3 m from surface	n	closing bottle and start file	295
T1-ST6	2018-03-19 22:00	SPM+salinity	250			-3 m from surface	y	closing bottle and start file	269
T1-ST7	2018-03-19 22:30	SPM	250			-3 m from surface	n	closing bottle and start file	227
T1-ST8	2018-03-19 23:00	SPM+salinity+POC	250	417	90	-3 m from surface	y	closing bottle and start file	259
T1-ST9	2018-03-19 23:30	SPM	250			-3 m from surface	n	closing bottle and start file	316
T1-ST10	2018-03-19 00:00	SPM+salinity+POC	250	418	90	-3 m from surface	y	closing bottle and start file	220
T1-ST11	2018-03-19 00:30	SPM	250			-3 m from surface	n	closing bottle and start file	168
T1-ST12	2018-03-19 01:00	SPM+salinity+POC	250	419	90	-3 m from surface	y	closing bottle and start file	149
T1-ST13	2018-03-19 01:30	SPM	250			-3 m from surface	n	closing bottle and start file	138
T1-ST14	2018-03-19 02:00	SPM+salinity+POC	500	421	160	-3 m from surface	y	closing bottle and start file	99
T1-ST15	2018-03-19 02:30	SPM	500			-3 m from surface	n	closing bottle and start file	99
T1-ST16	2018-03-19 03:00	SPM+salinity+POC	500	422	**166**	-3 m from surface	y	closing bottle and start file	84
T1-ST17	2018-03-19 03:30	SPM	500			-3 m from surface	n	closing bottle and start file	88
T1-ST18	2018-03-19 04:00	SPM+salinity+POC	250	423	**83**	-3 m from surface	y	closing bottle and start file	154
T1-ST19	2018-03-19 04:30	SPM	250			-3 m from surface	n	closing bottle and start file	106
T1-ST20	2018-03-19 05:00	SPM+salinity+POC	500	424	160	-3 m from surface	y	closing bottle and start file	100
T1-ST21	2018-03-19 05:30	SPM	500			-3 m from surface	n	closing bottle and start file	80
T1-ST22	2018-03-19 06:00	SPM+salinity+POC	500			-3 m from surface	y	closing bottle and start file	85
T1-ST23						-3 m from surface	n	no time, 2 hour travel to harbor	
T1-ST24						-3 m from surface	y	no time, 2 hour travel to harbor	

Remarks
one salinity bottle not labelled: st8 or st10?
centrifuge sample from 21h onwards

Table 5: Overview of 2nd tidal cycle at Br&W Oostende.

Station	Timestamp (UTC)	Parameters	SPM	POC	POC	HACH
			ml	filternr	ml	NTU AVG
T2-st1	2018-03-22 19:35	SPM	250			126
T2-st2	2018-03-22 20:00	SPM+salinity+POC	250	500	70	84
T2-st3	2018-03-22 20:30	SPM	250			70
T2-st4	2018-03-22 21:00	SPM+salinity+POC	250	501	70	83
T2-st5	2018-03-22 21:30	SPM	250			74
T2-st6	2018-03-22 22:00	SPM+salinity+POC	250	502	70	80
T2-st7	2018-03-22 22:30	SPM	250			110
T2-st8	2018-03-22 23:00	SPM+salinity+POC	250	503	70	97
T2-st9	2018-03-22 23:30	SPM	250			128
T2-st10	2018-03-23 00:00	SPM+salinity+POC	250	504	70	131
T2-st11	2018-03-23 00:30	SPM	250			105
T2-st12	2018-03-23 01:00	SPM+salinity+POC	250	505	70	112
T2-st13	2018-03-23 01:30	SPM	250			95
T2-st14	2018-03-23 02:00	SPM+salinity+POC	250	506	70	95
T2-st15	2018-03-23 02:30	SPM	250			115
T2-st16	2018-03-23 03:00	SPM+salinity+POC	250	507	70	63
T2-st17	2018-03-23 03:30	SPM	250			51
T2-st18	2018-03-23 04:00	SPM+salinity+POC	250	508	70	64
T2-st19	2018-03-23 04:30	SPM	250			79
T2-st20	2018-03-23 05:00	SPM+salinity+POC	250	509	70	98
T2-st21	2018-03-23 05:30	SPM	250			64
T2-st22	2018-03-23 06:00	SPM+salinity+POC	250	510	70	88
T2-st23	2018-03-23 06:30	SPM	250			97
T2-st24	2018-03-23 07:00	SPM+salinity+POC	250	511	70	81
Centrifuge sample from 20h local time onwards until 23/3 08h30: 4290980-4304625 (20h-08h30; 0.3 l/s)						
Sample position: 5 m lowered from frame position in surface waters (due to high currents)						

6.1.2 Seabed mapping in Fisheries management zone 3, Hinder Banks (Fig. 1, FMZ3)

To improve on the good environmental status of marine waters, and to mitigate on the effects of fisheries-related bottom trawling, the Belgian State defined four zones in its Marine Spatial Plan where fisheries will be controlled. In Fisheries Management Zone 3, in the Hinder Banks region, it is targeted to halt fisheries in the future. To monitor the effect of this measure on seabed habitats it is critical to have a good baseline on both its physical and biological environmental state.

Table 6: Coordinates of Fisheries Management Zone 3, Marine Spatial Plan

Lat/Long DD MM.MMM	
51° 26.691' N	2° 37.841' E
51° 25.334' N	2° 34.852' E
51° 27.500' N	2° 31.625' E
51° 29.301' N	2° 27.055' E
51° 30.998' N	2° 28.804' E
51° 28.860' N	2° 34.680' E

During this campaign the mapping of this zone was finished.

Based on the newly acquired multibeam data, locations were defined for sampling and video observations.

Table 7: Timestamp of grab samples taken in Fisheries Management Zone 3, Marine Spatial Plan

ID	Timestamp	Gear	Remark
FMZ3-1	2018-03-21 06:04:00	Van Veen grab sampler	
FMZ3-2	2018-03-21 06:28:07	Van Veen grab sampler	failed, stones

FMZ3-2b	2018-03-21 06:30:50	Van Veen grab sampler	
FMZ3-3	2018-03-21 06:55:13	Van Veen grab sampler	

Table 8: Video imaging in Fisheries Management Zone 3, Marine Spatial Plan

FMZ3-SE1	Video frame	2018-03-21 18:49:00	2018-03-21 18:55:00
FMZ3-SE2	Video frame	2018-03-21 19:05:00	2018-03-21 19:09:00
FMZ3-SE3	Video frame	2018-03-21 19:23:00	2018-03-21 19:28:00

6.1.3 Mapping of marine aggregate extraction zone 4c, Oosthinder sandbank (Fig. 1, HBMC)

(a) Multibeam data acquisition along monitoring area HBMC (FPS Economy, Continental Shelf Service, COPCO): was already completed before the campaign (ST1806).
(b) Collection of shallow cores (Reineck boxcorer) in the HBMC area. Aim is to detect changes in the grain-size distribution in the upper vertical sediment column.

Table 9: Timestamps of shallow cores taken in HBMC

ID	Gear	Timestamp	Remark
A05	Reineck boxcorer	2018-03-21 16:10:30	
A04	Reineck boxcorer	2018-03-21 16:23:55	
B04	Reineck boxcorer	2018-03-21 16:42:52	
D02	Reineck boxcorer	2018-03-21 17:00:00	
D03	Reineck boxcorer	2018-03-21 17:09:07	important loss of sediment; Reineck not closing properly
D01	Reineck boxcorer	2018-03-21 17:27:18	
A07	Reineck boxcorer	2018-03-21 17:38:59	
A08	Reineck boxcorer	2018-03-21 17:50:36	
+GoPro camera. Settings 2.7k; 30 FPS; wide view			

6.1.3 Mapping and ground-truthing of a gravel bed, Oosthinder sandbank (south) (Fig. 1, OHGZ4)

This target was cancelled, because of the time lost at the beginning of the campaign.

6.2. OD Nature JELLYFISH

Jellyfish was counted in the harbor and at sea following the Jellyfish observation protocol.

7. REMARKS

Officers and crew are warmly thanked for their flexibility and assistance during all operations and demonstrations to students.

8. DATA STORAGE

OD NATURE

- Multibeam data, Video data, Seabed samples, Centrifuge sample. Contact person: RBINS: Vera Van Lancker
- ADCP and 13-hrs cycle data: RBINS MDO Ostend. Contact person: Joan Backers

RV BELGICA CRUISE 2018/17 – CRUISE REPORT

Subscribers:	Dr. Ilse De Mesel[1b], Dr. Vera Van Lancker[1a], Dr. Koen Parmentier[1b], Dr. Michael Fettweis[1a], Mr. Giacomo Montereale Gavazzi[1a]
Institutes:	Operational Directorate Natural Environment (OD Nature)
Addresses:	[1a]OD Nature-BRU: Gulledelle 100, B-1200 Brussels [1b]OD Nature –OST: 3[e] en 23[e] Linieregimentsplein, B-8400 Oostende
Telephones:	+32 (0)59 242051 (IDM) ; +32(0)2 773 21 29 (VVL) ; +32(0)59 55 22 41 (KP) ; +32(0)2 773 21 32 (MF)
E-mails:	idemesel@naturalsciences.be; vvanlancker@naturalsciences.be; kparmentier@naturalsciences.be; mfettweis@naturalsciences.be; gmonterealegavazzi@naturalsciences.be

Monitoring: 09/07/2018 - 13/07/2018

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1. CRUISE DETAILS

1.	Cruise number	2018/17
2.	Date/time	Zeebrugge TD: 09/07/2018 at 11h39 Zeebrugge TA: 13/07/2018 at 12h04
3.	Chief Scientist Participating institutes	Dr. Ilse De Mesel OD NATURE
4.	Area of interest	Belgian part of the North Sea

2. LIST OF PARTICIPANTS

Institute	NAME	Gender	09/07 (am-pm)	09/07 pm-13/07
OD NATURE	Ilse De Mesel	*F*		X
	Vera Van Lancker*	*F*	X	X
	Danae Kapasakali	*F*	X	X
	Francis Kerckhof	*M*	X	X
	Marina Yemelyanova	*F*	X	X
	Giacomo Montereale Gavazzi	*M*	X	X
	Lars Kint	*M*	X	X
	Reinhilde Van den Brande	*F*	X	X
	Nathan Terseleer Lillo	*M*	X	X
	Benjamin Van Roozendael	*M*	X	X
	Tom Scholdis	*M*	X	X
	Kevin Hindryckx	*M*	X	
		Total participants:	11	11

**chief scientist on 09/07*

3. SCIENTIFIC OBJECTIVES

OD Nature-MOMO

The project "MOMO" is part of the general and permanent duties of monitoring and evaluation of the effects of all human activities on the marine ecosystem to which Belgium is committed following the OSPAR-convention (1992). The goal of the project is to study the cohesive sediments on the Belgian continental shelf 'BCS' using numerical models as well as by carrying out of measurements. Through this, data will be provided on the transport processes which are essential in order to answer questions on the composition, origin and residence of these sediments on the BCS, the alterations of sediment characteristics due to dredging and dumping operations, the effects of the natural variability, the impact on the marine ecosystem, the estimation of the net input of hazardous substances and the possibilities to decrease this impact as well as this in-put.

OD Nature – IDM (MSFD monitoring gravel beds)

Within the framework of the EU Directive MSFD a monitoring program was developed for the biological communities on the gravel beds. The gravel beds have been under a lot of pressure due to human activities, mainly fisheries, which caused a severe decline or virtual extinction of typical hard substrate species. This monitoring program, with sampling of the gravel beds with a Gilson Dredge, has been specifically developed to follow up the MSFD indicators that have been reported to the EC.

OD Nature-VVL (ZAGRI/MOZ4)
ZAGRI is a continuous research program on the evaluation of the effects of the exploitation of non-living resources of the territorial sea and the continental shelf. MOZ4 research focuses on the hydrodynamics and sediment transport in a marine aggregate extraction zone, far offshore, and its impact on an adjacent Habitat Directive Area. Overall aim is to increase process and system knowledge of both areas, with particular focus on the compliancy of the extraction activities with respect to the European Marine Strategy Framework Directive. More specifically changes in seafloor integrity and hydrographic conditions need assessment.

OD Nature-GMG (INDI67/MONIT.BE)
Within Europe's Marine Strategy Framework Directive (MSFD), progress towards Good Environmental Status (GES) needs monitoring in a most time- and cost-effective way. For the GES descriptors 6 and 7, on seafloor integrity and hydrographic conditions, respectively, new integrative indicators (i.e. bottom shear stress, turbidity and seabed/habitat type) need developing. To advance the mapping of seabed/habitat types, a Community of Practice (CoP) on seabed mapping will be established, investigating the main issues preventing joint mapping of the seabed. Within SEACoP (CoP on 'Surveying for Environmental Assessments') the following objectives are targeted: a) estimation of the precision, sensitivities and repeatability of the acoustic devices to detect changes in seabed/habitat types; b) quantification of the external sources of variance in the acoustic signature, including the influence of near-bed and water column suspensions on backscatter data; c) definition of best practice in ground-truthing the acoustic signal, with emphasis on visual techniques; and d) innovation in collaborative seabed mapping.

OD Nature-KP
The project is part of the continuous surveillance and evaluation of the quality of the marine environment in the region of the Belgian part of the North Sea 'BPNS' in the framework of the national obligations toward the Joint Assessment and Monitoring Programme (JAMP) of the OSPAR commission and the Water Framework Directive of the EC (2000/60/EC). OD Nature determines nutrients, salinity, suspended matter, dissolved oxygen, TOC and POC, chlorophyll a, phaeophytine, optical parameters and organic contaminants in the water column. Phytoplankton biomass and species composition as well as benthos species composition and biomass are also determined as part of the monitoring program. The other determinants (e.g. heavy metals and organic contaminants) in sediment and biota are determined in collaboration with ILVO-Fishery (ecological monitoring). Quality assurance and quality control during sampling and in the laboratory receive a high priority within the project.

OD Nature-LN (ICOS)
The AUMS (Autonomous Underway Measurement System) system is inspired by the success of similar systems deployed on various ships of opportunity in the framework of the European Union FerryBox project (www.ferrybox.org). The instrumentation will greatly enhance the continuous oceanographic measurements made by RV Belgica by taking advantage of the significant technological improvements since the design of the existing (salinity, temperature, fluorescence) systems (cfr. ICOS Standards). In particular, many new parameters can now be measured continuously including important ecosystem parameters such as nitrate, ammonia, silicate, dissolved oxygen and CO2, turbidity, alkalinity and phytoplankton pigments. In addition, the new equipment allows automatic acquisition and preservation of water samples, rendering RV Belgica operations significantly more efficient by reducing onboard human resources. Data will be available in near real-time via OD Nature's public website (http://odnature.naturalsciences.be/belgica/en/odas) and following quality control, from the Belgian Marine Data Centre. Since 2015, the AUMS data are also delivered to the EC ESFRI project ICOS.

4. OPERATIONAL COURSE

All times are given in local time. All coordinates in WGS84.
Throughout the campaign, measurements are made with the AUMS system.

Monday 09 JUL 18

11h39: Sail off from Zeebrugge
12h14: Position WO for water sampling
12h18: Water sampling + CTD
12h30: Van Veen grab sampling WO1
14h00: Start tripod operations at MOW1
14h28: Tripod recovered

14h59: New tripod deployed, at position 51°21.662'; 003°06.893'
15h08: Van Veen grab sample and three water samples at MOW1

RHIB transfer

16h04: Disembarkment Kevin Hindryckx and embarkment Ilse De Mesel

In consent with the Commander and in-line with gradually more adverse weather conditions from Monday evening onwards, it was decided to change the program. As such, measurements were first conducted in the Flemish Banks region and then heading towards the coastal zone on Tuesday.

Transit to Flemish Banks, gully in-between Oostdyck and Buiten Ratel sandbank

18h21-19h50: MBES Rocky Zone
20h16-21h21: Video imaging in the same zone
21h55: MBES gully in-between Buiten Ratel and Kwinte Bank (KWGS)

Tuesday 10 JUL 18

05h30: End of MBES, transit Zone 4 Westhinder
08h01-08h08: Deployment Gilson Dredge at Zone 4 Station 8
08h53-08h59 Deployment Gilson Dredge at Zone 3 Station 7
09h30-09h36: Deployment Gilson Dredge at Zone 3 Station 6
10h21-10h30: Deployment Gilson Dredge at Zone 4 Station 14
11h02-11h10: Deployment Gilson Dredge at Zone 4 Station 13
11h40-11h46: Deployment Gilson Dredge at Zone 4 Station 11
10h19-11h41: MBES sampling points
12h00-13h25: Transit to Kwintebank
13h25-17h01: MBES KWGS
18h35: Water sampling at W03
18h42: Van Veen grab sample W03
19h29: Because of bad weather, anchoring at position 51°09.28'; 2°37.77', Westdiep gully

Wednesday 11 JUL 18

06h12: Transit to Hinder Banks
08h55: Van Veen sample at position 1a (3x)
09h13: Van Veen sample at position 2a (3x)
09h31: Van Veen sample at position 3a (3x)
10h00-11h07: Video imaging OHZ4G (3-4-8(BV4)-4(drift))
11h35: Van Veen at position 5a
11h47: Van Veen at position 4a
12h15: Van Veen at position 6a
13h28-13h40: Deployment Gilson Dredge at 09 SA HB
14h15: MBES 09 SA HB
15h01-15h06: Deployment Gilson Dredge at station 10 SA HB and simultaneous MBES
15h28-15h33: Deployment Gilson Dredge at station 12 SA HB and simultaneous MBES
16h50-17h02: Hamon grab (3X) at Station 08 Zone 4 (BV4)
17h45-17h52: Hamon grab (3X) at Station 07 Zone 3 (punt verzet door schip ten anker)
18h14-18h20: Hamon Grab (3X) at Station 06 Zone 3
18h53-19h02: Hamon Grab (3X) at Station 14 Zone 4
19h39: MBES Zone 4 starting with OHZ4G

Thursday 12 JUL 18

01h30: end of MBES OHZ4G
01h55-04h22: MBES SA Zone 4
04h22-05h03: Video imaging HB Zone 4
05h49-05h59: water sampling and Van Veen grab sample in positon WO8

05h59-07h14: transit to SA N close to the B-FR-UK border
07h22-08h35: MBES SA N
08h35: Hamon Grab at Station18 REP 1 (!Station 17 for biological samples!)
08h43: Hamon Grab at Station18 REP 2 (!Station 17 for biological samples!)
08h51: Hamon Grab at Station18 REP 3 (!Station 17 for biological samples!)
09h07: Hamon Grab at Station17 REP 1 (!Station 18 for biological samples!)
09h10: Hamon Grab at Station 17 REP 2 (!Station 18 for biological samples!)
09h19: Hamon Grab at Station 17 REP 2 (!Station 18 for biological samples!)
09h30: Hamon Grab at Station17 REP 3 (!Station 18 for biological samples!)
09h42-09h49: Deployment Gilson Dredge at Station 17 (Station 18 for biological samples!)
10h10-10h15: Deployment Gilson Dredge at Station 18 (Station 17 for biological samples!)
10h33 – 11h09: MBES in SA N near the border between BE en UK
11h08-13h23: Video imaging northern area (Channel, BIO17, BIO18)
14h00-17h29: MBES SA N
17h41-19h23: Video imaging northern area (20, 21, drift2 to drift1), BIO18(2)
19h37: Hamon grab at Vera 1/HG DRIFT 2
19h47: Hamon grab at Vera 2/HG12 2 DRIFT
21h40: MBES Zone 4

Friday 13 JUL 18

07h51: End of MBES Zone 4
09h18-09h29: Water sampling and Van Veen grab sample at position W05
09h29: transit to Zeebrugge
|12h04 Arrival to Zeebrugge

- End of campaign 2018/17 -

5. TRACK PLOT

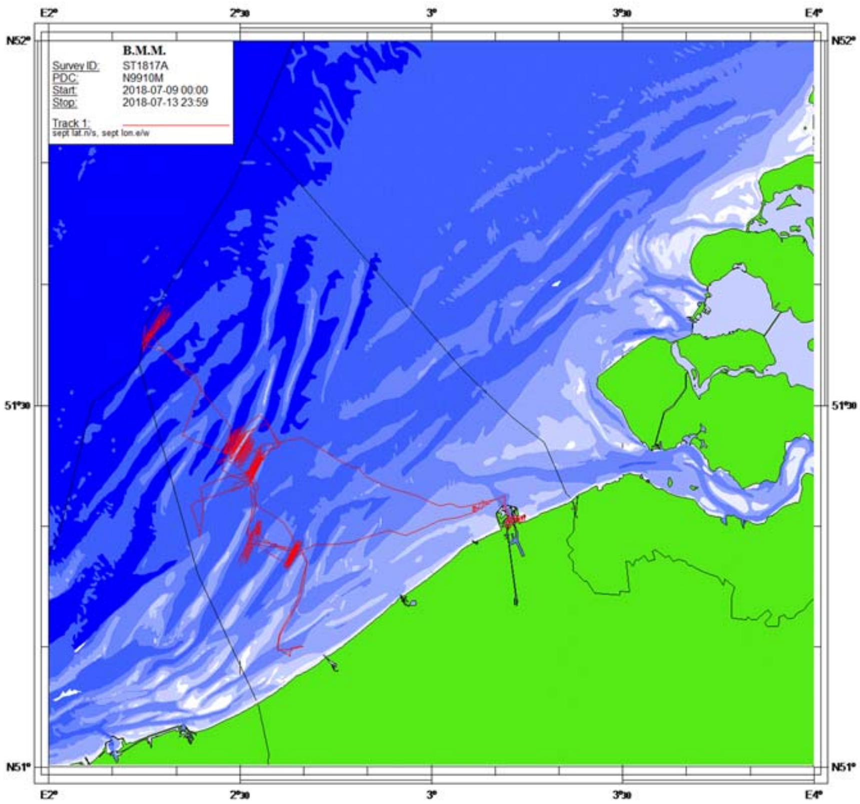

Figure 1: Track plot of campaign 2018/17

6. MEASUREMENTS AND SAMPLING

6.1. OD NATURE-MOMO

The tripod at MOW 1 was successfully replaced (position 51°21.662'; 003°06.893').

6.2. OD NATURE-MSFD MONITORING GRAVEL BEDS

Gilson Dreg

Samples were collected with a Gilson Dreg at 11 locations. At each location, one track of 250 m was collected, except for station 9 where a 700m sample was taken.

Station	Date	N start	E start	N end	E end
Station 8 (Zone 4)	10/07/18	51.40712052	2.517759	51.41034267	2.519233
Station 7 (Zone 3)	10/07/18	51.44245072	2.604234333	51.44541918	2.6046975
Station 6 (Zone 3)	10/07/18	51.47449557	2.573623833	51.47715593	2.569998667
Station 14 (Zone 4)	10/07/18	51.45374438	2.473402333	51.45798175	2.479786667
Station 13 (Zone 4)	10/07/18	51.43541222	2.459968833	51.43901888	2.465047667
Station 11 (SA HB)	10/07/18	51.42033222	2.4397535	51.42389247	2.446051
Station 9 (SA HB)	11/07/18	51.38658727	2.498107333	51.3816962	2.477601667
Station 10 (SA HB)	11/07/18	51.36721802	2.384912667	51.36549327	2.376874833
Station 12 (SA HB)	11/07/18	51.32313462	2.394128667	51.3179985	2.396747833
Station 18 (SA N)*	12/07/18	51.59990807	2.266003167	51.60350113	2.270831833
Station 17 (SA N)*	12/07/18	51.59068565	2.254023167	51.59336955	2.257951667

* numbering is switched for the biological samples!

Hamon grab

Hamon grab samples were collected in triplicate at 5 locations, 4 replicates at one location and single replicates were collected at 2 locations

Station	Replicates	Date	N	E
Station 8 (Zone 4)	1	11/07/18	51.40772	2.518188
Station 8 (Zone 4)	2	11/07/18	51.40772	2.517398
Station 8 (Zone 4)	3	11/07/18	51.40775	2.516925
Station 7 (Zone 3)	1	11/07/18	51.44655	2.606665
Station 7 (Zone 3)	2	11/07/18	51.4467	2.606326
Station 7 (Zone 3)	3	11/07/18	51.44644	2.607017
Station 6 (Zone 3)	1	11/07/18	51.47405	2.567302
Station 6 (Zone 3)	2	11/07/18	51.47405	2.56661
Station 6 (Zone 3)	3	11/07/18	51.47419	2.564219
Station 14 (Zone 4)	1	11/07/18	51.45349	2.471015
Station 14 (Zone 4)	2	11/07/18	51.45379	2.470819
Station 14 (Zone 4)	3	11/07/18	51.45369	2.470134
Station 17 (SA N)	1	12/07/18	51.59041	2.253393
Station 17 (SA N)	2	12/07/18	51.5905	2.253999
Station 17 (SA N)	3	12/07/18	51.59082	2.25433
Station 18 (SA N)	1	12/07/18	51.60043	2.266474
Station 18 (SA N)	2	12/07/18	51.6007	2.26605
Station 18 (SA N)	3	12/07/18	51.60027	2.265792
Station 18 (SA N)	4	12/07/18	51.59969	2.264536

Vera 1/HG DRIFT 2	1	12/07/18	51.59621	2.271308
Vera 2/HG 12 2 DRIFT	1	12/07/18	51.59579	2.268743

6.3 OD NATURE-SEABED MONITORING

(1) In the framework of Europe's Marine Strategy Framework Directive (MSFD), good environmental status (GES) of marine waters need monitoring. One of the GES descriptors is related to seafloor integrity, and therefore the Belgian State defined fixed trajectories, in combination with areas, along which multibeam depth and backscatter data are acquired on a repetitive basis (see Fig. 4.2.1). During this campaign areas were targeted with a higher probability of occurrence of gravel. The locations were determined in mutual consent with program 4.2; they are listed there.
(2) Monitoring of the effects of marine aggregate extraction in the Hinder Banks (MOZ4). The measurements in the gravel bed areas also frame in the objectives of the MOZ4 program since aggregate extraction on the Hinder Banks may impact these coarse-grained habitats.

In addition to the sampling and observations mentioned in section 4.2, the following measurements were conducted.

6.3.1. Seabed mapping in-between Oostdijck sandbank and Buiten Ratel and in-between Buiten Ratel and Kwinte Bank (KWGS)

(a) Multibeam bathymetry and backscatter (Kongsberg Simrad EM3002D multibeam echosounder).
(b) Video imaging based on MBES recordings

Table 6.3.1. Time stamp video imaging Flemish Banks

ID	Area	File	Begin (UTC)	End (UTC)
FB01	Flemish Banks	CAM1_20180709_192411_148	2018-07-09 18:16:00	2018-07-09 18:35:00
FB01(ctd)	Flemish Banks	CAM1_20180709_193315_310	2018-07-09 18:35:00	2018-07-09 18:38:00
FB02	Flemish Banks	CAM1_20180709_194459_875	2018-07-09 18:47:03	2018-07-09 18:56:03
FB03	Flemish Banks	CAM1_20180709_201100_772	2018-07-09 19:13:00	2018-07-09 9:21:0 0

6.3.2. Seabed mapping Hinder Banks south – time series area OHGZ4

(a) Multibeam data acquisition along MSFD monitoring area **OHGZ4**, a gravel bed monitored through time (last survey ST1533, 15-18 December 2015).

Table 6.3.2. Coordinates of RBINS MSFD MONIT OHGZ4 area

Lat/Long DD MM.MMMM	
51º 24.367' N	2º 30.925' E
51º 26.373' N	2º 32.911' E
51º 25.675' N	2º 33.620' E
51º 23.665' N	2º 31.634' E

(c) Collection of ground-truth samples and observations.

Table 6.3.3. Coordinates of the ground-truthing locations in the OHGZ4 area. Three replicates per location were requested.

ID	Gear	Timestamp
VV1a	Van Veen grab	2018-07-11 06:55:26
VV1b	Van Veen grab	2018-07-11 06:59:09
VV1c	Van Veen grab	2018-07-11 07:03:23

VV2a	Van Veen grab	2018-07-11 07:14:05
VV2b	Van Veen grab	2018-07-11 07:17:15
VV2c	Van Veen grab	2018-07-11 07:20:52
VV3a	Van Veen grab	2018-07-11 07:32:13
VV3b	Van Veen grab	2018-07-11 07:35:37
VV3c	Van Veen grab	2018-07-11 07:38:59
VV5a	Van Veen grab	2018-07-11 09:32:08
VV5b	Van Veen grab	2018-07-11 09:35:16
VV5c	Van Veen grab	2018-07-11 09:38:09
VV4a	Van Veen grab	2018-07-11 09:47:53
VV4b	Van Veen grab	2018-07-11 09:52:22
VV4c	Van Veen grab	2018-07-11 09:57:20
VV6a	Van Veen grab	2018-07-11 10:13:36
VV6b	Van Veen grab	2018-07-11 10:17:09
VV6c	Van Veen grab	2018-07-11 10:20:30

Table 6.3.4. Time stamp video imaging OHGZ4

ID	Area	File	Begin (UTC)	End (UTC)
HB03	Hinder Banks	CAM1_20180711_085846_836	2018-07-11 08:00:00	2018-07-11 08:04:00
HB04	Hinder Banks	CAM1_20180711_091739_859	2018-07-11 08:19:00	2018-07-11 08:25:00

6.3.3. Seabed mapping in Fisheries management zone 3 and 4, Hinder Banks (Fig. 4.2.2, FMZ3, FMZ4)

To improve on the good environmental status of marine waters, and to mitigate on the effects of fisheries-related bottom trawling, the Belgian State defined four zones in its Marine Spatial Plan where fisheries will be controlled. To monitor the effect of this measure on seabed habitats it is critical to have a good baseline on both its physical and biological environmental state.

(a) Zone 3: subareas along sampling locations were mapped, aligning with the Gilson and Hamon grab samples as described in Section 4.2.

(b) Zone 4: aim was to map the entire zone, continuing on the time series area of 4.3.2.

Table 6.3.5. Coordinates of Fisheries Management Zone 3 and 4, Marine Spatial Plan

FMZ3 - Zone 3
Lat/Long DD MM.MMM

51° 26.691' N	2° 37.841' E
51° 25.334' N	2° 34.852' E
51° 27.500' N	2° 31.625' E
51° 29.301' N	2° 27.055' E
51° 30.998' N	2° 28.804' E
51° 28.860' N	2° 34.680' E

FMZ4 - Zone 4
Lat/Long DD MM.MMM

51° 29.301' N	2° 27.055' E
51° 27.500' N	2° 31.625' E
51° 25.334' N	2° 34.852' E
51° 23.724' N	2° 31.117' E
51° 25.203' N	2° 29.492' E
51° 26.984' N	2° 25.068' E

6.3.4. Additional seabed mapping in support of the Gilson and Hamon grab sampling (see Section 4.2). Aim was to map the seabed of each sampling or observation location.

6.3.5. Seabed mapping in the northern area, near the Belgium-UK border

Table 6.3.6. Coordinates of the northern area

Lat/Long DD MM.MMMM

51º 36.576' N	2º 14.516' E
51º 38.416' N	2º 17.061' E
51º 37.634' N	2º 18.774' E
51º 33.986' N	2º 13.746' E

6.3.6. Tidal cycle measurements at two locations

This part of the program was cancelled because of time lost due to adverse weather conditions.

6.3.7. Overview of timestamps of the video observations

Table 6.3.7. Overview of timestamps of the video observations

ID	Area	File	Begin (UTC)	End (UTC)
HB08(BV4)	Hinder Banks	CAM1_20180711_094152_202	2018-07-11 08:43:00	2018-07-11 08:51:00
HBDrift	Hinder Banks	CAM1_20180711_095709_627	2018-07-11 08:59:00	2018-07-11 09:07:00
HB14	Hinder Banks	CAM1_20180712_032022_067	2018-07-12 02:22:00	2018-07-12 02:31:00
HB14(ctd)	Hinder Banks	CAM1_20180712_033022_087	2018-07-12 02:31:00	2018-07-12 02:32:00
HB14(2)	Hinder Banks	CAM1_20180712_035912_355	2018-07-12 02:50:00	2018-07-12 03:00:00
North_Channel	Northern area	CAM1_20180712_100711_416	2018-07-12 09:08:00	2018-07-12 09:18:00
North_Channel(ctd)	Northern area	CAM1_20180712_101711_437	2018-07-12 09:18:00	2018-07-12 09:24:00
North_BIO17	Northern area	CAM1_20180712_110027_771	2018-07-12 10:01:00	2018-07-12 10:10:00
North_BIO17(2)	Northern area	CAM1_20180712_111720_458	2018-07-12 10:18:00	2018-07-12 10:28:00
North_BIO17(2)(ctd)	Northern area	CAM1_20180712_112720_485	2018-07-12 10:28:00	2018-07-12 10:38:00
North_BIO17(2)(ctd)	Northern area	CAM1_20180712_113720_496	2018-07-12 10:38:00	2018-07-12 10:47:00
North_BIO18	Northern area	CAM1_20180712_120945_597	2018-07-12 11:11:00	2018-07-12 11:21:00
North_BIO18(ctd)	Northern area	CAM1_20180712_121945_620	2018-07-12 11:21:00	2018-07-12 11:23:00
North_20	Northern area	CAM1_20180712_164019_410	2018-07-12 15:41:00	2018-07-12 15:51:00
North_20(ctd)	Northern area	CAM1_20180712_165019_428	2018-07-12 15:51:00	2018-07-12 15:52:00
North_21	Northern area	CAM1_20180712_170029_290	2018-07-12 16:01:00	2018-07-12 16:10:00
North_Drift2-Drift1	Northern area	CAM1_20180712_174143_717	2018-07-12 16:43:00	2018-07-12 16:52:00
North_Drift2-Drift1(ctd)	Northern area	CAM1_20180712_175143_735	2018-07-12 16:53:00	2018-07-12 16:59:00
North_BIO18(2)	Northern area	CAM1_20180712_181140_511	2018-07-12 17:13:00	2018-07-12 17:23:00
North_BIO18(2)(ctd)	Northern area	CAM1_20180712_182140_537	2018-07-12 17:23:00	2018-07-12 17:23:00

6.4. OD NATURE-KP

Water samples and Van Veen grab samples were collected at locations W01, MOW1, W03, W05 and W08 (table 6.4.1.).

Table 6.4.1. Coordinates of sampling locations

Station	Date	Time (GMT)	N	E	Remark
W01	9/07/2018	10:20:50	N 51 22.4630	E 3 11.4353	
MOW1	9/07/2018	13:45:50	N 51 22.5870	E 3 6.7190	
W03	10/07/2018	16:56:00	N 51 10.0070	E 2 38.8517	
W08	12/07/2018	3:49:40	N 51 27.4970	E 2 20.9892	
W05	13/07/2018	7:23:20	N 51 24.9690	E 2 48.3957	No profile, no communication between CTD and PC

Weather conditions were not favorable for random sampling within the framework of calibration of satellite images.

7. REMARKS

- The planning had to be adjusted on board because of the weather conditions

8. DATA STORAGE

- What data is stored?
  Video from the Video frame, MBES logged data, ODAS data, water quality data, sediment samples and biological data, data on sediment transport
- Where is the data stored?
  OD Nature
- Who is the contact person?
  Ilse De Mesel (biological data), Giacomo Montereale Gavazzi and Vera Van Lancker (sediment a related data), Koen Parmentier (water quality data), Michael Fettweis (sediment transport)

All data will be provided to OD NATURE-BMDC in accordance to the RV Belgica ship time request.

RV BELGICA CRUISE 2018/24 – CRUISE REPORT

Subscribers:	Dr. Vera Van Lancker[1] (VVL), Giacomo Montereale Gavazzi[1](GMG), Nene Lefaible[2] (NL)
Institutes:	[1]Operational Directorate Natural Environment (OD Nature) [2]Marine Biology research Group, Ghent University
Addresses:	[1]OD Nature-BRU: Gulledelle 100, B-1200 Brussels [2]Krijgslaan 281/S8, 9000 Gent
Telephones:	+32(0)2 773 21 29 (VVL) +32(0)9 264 85 34 (NL)
E-mails:	Vera.VanLancker@naturalsciences.be Nene.Lefaible@UGent.be

Monitoring/Geology/Biology: 22/10/2018 - 26/10/2018

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1. Cruise details
2. List of participants
3. Scientific objectives
4. Operational course
5. Track plot
6. Measurements and sampling
7. Remarks
8. Data storage

1. GENERAL FORM RV BELGICA 2018

1.	Cruise number	2018/24
2.	Date/time Zeebrugge departure	22/10/2018 : departure @13h35 23/10/2018: arrival at Zeebrugge @09h04 24/10/2018: departure @08h28 26/10/2018: 13h06 arrival
3.	Chief Scientist Participating institutes	Vera Van Lancker UGent-Marbiol, OD Nature
4.	Area of interest	Belgian part of the North Sea

2. LIST OF PARTICIPANTS

Institute	NAME	Gender	22/10 - 26/10/18
OD NATURE	Vera Van Lancker	F	X
	Giacomo Montereale Gavazzi	M	X
	Lars Kint	M	X
	Frederic Francken	M	X
	Benjamin Van Roozendael	M	X
UGent - SMB	Nene Lefaible	F	X
	Tania Campinas	F	X
	Bart Beuselinck	M	X
	Annelien Rigaux	F	X
	Bruno Vlaeminck	M	X
	Marius Buydens	M	X
	Anouk Ollevier	F	X
		Total participants:	12

3. SCIENTIFIC OBJECTIVES

OD Nature-VVL (ZAGRI/MOZ4)

ZAGRI is a continuous research program on the evaluation of the effects of the exploitation of non-living resources of the territorial sea and the continental shelf. MOZ4 research focuses on the hydrodynamics and sediment transport in a marine aggregate extraction zone, far offshore, and its impact on an adjacent Habitat Directive Area. Overall aim is to increase process and system knowledge of both areas, with particular focus on the compliancy of the extraction activities with respect to the European Marine Strategy Framework Directive. More specifically changes in seafloor integrity and hydrographic conditions need assessment.

OD Nature-GMG (INDI67/MONIT.BE)

Within Europe's Marine Strategy Framework Directive (MSFD), progress towards Good Environmental Status (GES) needs monitoring in a most time- and cost-effective way. For the GES descriptors 6 and 7, on seafloor integrity and hydrographic conditions, respectively, new integrative indicators (i.e. bottom shear stress, turbidity and seabed/habitat type) need developing. To advance the mapping of seabed/habitat types, a Community of Practice (CoP) on seabed mapping will be established, investigating the main issues preventing joint mapping of the seabed. Within SEACoP (CoP on 'Surveying for Environmental Assessments') the following objectives are targeted: a) estimation of the precision, sensitivities and repeatability of the acoustic devices to detect changes in seabed/habitat types; b) quantification of the external sources of variance in the acoustic signature, including the influence of near-bed and water column suspensions on backscatter data; c) definition of best practice in ground-truthing the acoustic signal, with emphasis on visual techniques; and d) innovation in collaborative seabed mapping.

UGent-SMB-NL (Winmon)

In the framework of the offshore wind farm permit, the large scale monitoring of the soft substrate macrobenthos will be carried out on the Bligh Bank, Thorntonbank and the Goote Bank. The baseline studies were carried out during 2005 (for C-Power) and 2008 (for Belwind). Next to that, hyperbenthos will be sampled for the first time on the Bligh Bank, Thorntonbank, and Goote Bank.

UGent-SMB-NL (Marbiol monitoring)

The Marine Biology Research Group organizes a large-scale monitoring campaign in the Belgian part of the North Sea on a yearly basis. This is done in the framework of a long-term project to evaluate the environmental status of the BPNS. During the campaign water samples, sediment samples and benthos samples are gathered.

4. OPERATIONAL COURSE

All times are given in local time. All coordinates in WGS84.

Monday 22/10/2018

HW 00h54/13h10; LW 07h01/19h23

09h00-10h30: Embarkation of instruments and personnel.

13h35 Departure and transit to station **140**
14h55-16h32: Samples at 140 (beam trawl, hyperbenthic sledge, VV's, reineck boxcorer)
*Transit to station **701***
17h31-18h56: Samples at 701 (beam trawl, hyperbenthic sledge, VV's, reineck boxcorer)
*Transit to station **790***
20h26-20h48: Samples at 790 (VV's, reineck boxcorer)

Transit to KWGS calibration area for MBES recordings (between Buiten Ratel and Kwinte Bank)

21h50-00h05: MBES KWGS area

Transit to Thornton Bank south for MBES recordings

Tuesday 23/10/2018

HW 01h19/13h43; LW 07h35/19h57

02h00-05h40: MBES Thornton Bank south

Transit to Zeebrugge to shelter for adverse weather conditions

09h04 Zeebrugge harbour

Wednesday 24/10/2018

HW 02h03/14h16; LW 08h10/20h33

08h28: Sail off from Zeebrugge

Transit to Belwind windmill park for biological sampling

13h27-16h51: Van Veen sampling at Belwind
17h13-18h25: Hyperbenthos at Belwind (WBB06a), track was done twice.
18h45-19h07: Van Veen sampling at Belwind (last 3 samples)

Transit to area between Oosthinder sandbank and Bligh Bank for MBES recordings

19h40: MBES recordings at decca line spacing

Thursday 25/10/2018

HW 02h37/14h51; LW 08h47/21h11

00h33-01h16: Video recordings at locations selected from the newly acquired MBES data

01h30-07h38: Continuation MBES recordings

Transit to C-Power wind mill park for biological sampling

08h28-08h51: Hyperbenthos at C-Power (ftWT2triss)
09h18-11h38: Van Veen sampling at C-Power (part A)
12h28-12h50: Hyperbenthos at Ref C-Power (ftTrack2)
13h21-15h09: Continuation Van Veen sampling (part B)

15h45-18h50: Multibeam data acquisition (@ 8kt) in and around the C-Power wind farm. Strategy discussed with Commander. Two partially overlapping lines were sailed in-between the windmills to ensure covering the UG-Marine Biology sampling locations.

19h12-19h40: Video recordings in Thornton Bank south area (2 locations)
Too strong currents. Operation aborted.
19h46-20h14 Van Veen grab sampling Thornton Bank south (TBS 2-3-4-5-1)

Transit to survey area between Oosthinder and Bligh Bank

20h58: Continuation MBES recordings area between Oosthinder and Bligh Bank

Friday 26/10/2018

HW 03h12/15h27; LW 09h27/21h50

00h57-05h17: Van Veen sampling between Oosthinder and Bligh Bank (DECCA 4-2-3-1)

05h34 End of MBES

Transit to Gootebank

06h41-09h18: Van Veen sampling Gootebank

*Transit to station **330** for biological sampling*

09h55-10h40: Samples at 330 (VV's, Reineck boxcorer (10 drops in total for Marbiol and PLASTOX project))

13h06: Arrival at Zeebrugge

End of campaign

5. TRACK PLOT

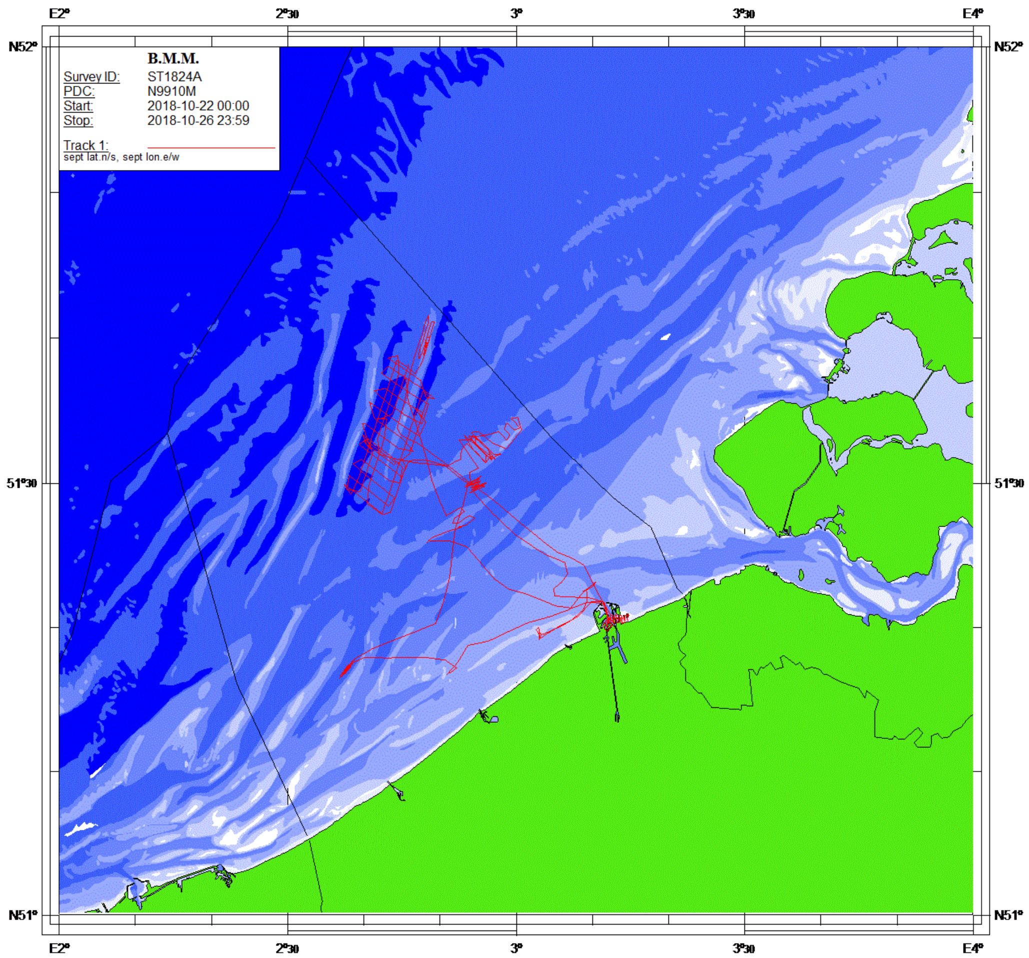

Figure 1: Track plot of campaign 2018/24

6. MEASUREMENTS AND SAMPLING

6.1 RBINS ODN ZAGRI/MOZ4 and INDI67/MONIT.BE

Overall objectives

(1) Monitoring of the effects of marine aggregate extraction in the Hinder Banks (MOZ4). During this campaign research is focused on an area where far-field effects from marine aggregate extraction might cumulate with long-term far field effects from the implementation and operationalization of windmill farms.
(2) In the framework of Europe’s Marine Strategy Framework Directive (MSFD), good environmental status (GES) of marine waters need monitoring. One of the GES descriptors is related to seafloor integrity, and therefore the Belgian State defined fixed trajectories, in combination with areas, along which multibeam depth and backscatter data are acquired on a repetitive basis. During this campaign the mapping of substrates will be enlarged making use of multibeam and ground truthing by sampling and visual observations. As a trial substrate mapping will also be conducted in a windmill farms area.
(3) Testing of substrate mapping strategies.

Water column measurements near the Belwind windmill farm
This target was cancelled, because of the time lost due to adverse weather conditions.

Seabed mapping in the gully east of Oosthinder to gully east of Bligh Bank
Multibeam bathymetry and backscatter (Kongsberg Simrad EM3002D multibeam echosounder) along different decca line configurations (Table 1).

Table 1. Coordinates of the decca lines covering the area between gully east of Oosthinder sandbank and gully east of Bligh Bank. (D01 etc. main decca line; D00.05 start of the 0.5 decca line; DP: lines quasi perpendicular to decca lines)

ID_text	LAT DD MM.mmm (from)	LON DD MM.mmm (from)	LAT DD MM.mmm (to)	LON DD MM.mmm (to)
D00.5	51° 36.670' N	2° 48.910' E	51° 38.601' N	2° 43.181' E
D01	51° 38.165' N	2° 42.908' E	51° 36.201' N	2° 48.616' E
D02	51° 37.473' N	2° 42.475' E	51° 35.476' N	2° 48.163' E
D03	51° 36.806' N	2° 42.058' E	51° 34.785' N	2° 47.731' E
D04	51° 36.082' N	2° 41.606' E	51° 34.028' N	2° 47.257' E
D05	51° 33.334' N	2° 46.823' E	51° 35.416' N	2° 41.189' E
D06	51° 34.705' N	2° 40.744' E	51° 32.586' N	2° 46.356' E
D07	51° 31.880' N	2° 45.914' E	51° 34.026' N	2° 40.319' E
D08	51° 31.137' N	2° 45.449' E	51° 33.316' N	2° 39.875' E
D09	51° 30.431' N	2° 45.008' E	51° 32.637' N	2° 39.451' E
D10	51° 29.692' N	2° 44.545' E	51° 31.931' N	2° 39.009' E
D11	51° 28.982' N	2° 44.102' E	51° 31.250' N	2° 38.583' E
D12	51° 30.544' N	2° 38.141' E	51° 28.243' N	2° 43.639' E
D13	51° 29.842' N	2° 37.703' E	51° 27.525' N	2° 43.239' E
DP1	51° 40.269' N	2° 44.224' E	51° 29.842' N	2° 37.703' E
DP3	51° 29.157' N	2° 39.337' E	51° 38.862' N	2° 45.406' E
DP4	51° 28.851' N	2° 40.031' E	51° 38.536' N	2° 46.088' E
DP5	51° 28.701' N	2° 40.450' E	51° 38.347' N	2° 46.482' E
DP6	51° 27.864' N	2° 42.429' E	51° 36.786' N	2° 48.009' E
DP7	51° 27.541' N	2° 43.201' E	51° 36.670' N	2° 48.910' E

Table 2. Video recordings in area between gully east of Oosthinder sandbank and gully east of Bligh Bank.

ID	Gear	Timestamp (UTC)	Lat (DD)	Long (DD)
Decca area	Video	2018-10-24 22:33- 2018-10-24 23:16	51.54286703 51.54326820	2.680644983 2.680046083

Table 3. Van Veen grab samples in the area between gully east of Oosthinder sandbank and gully east of Bligh Bank. Coordinates corrected for position of the sampling gear.

ID	Gear	Timestamp (UTC)	Lat (DD)	Long (DD)
Decca VV_04	Van Veen grab	2018-10-25 22:58:40	51.52199185	2.73838933
Decca VV_02	Van Veen grab	2018-10-25 23:38:45	51.58557397	2.77983322
Decca VV_03	Van Veen grab	2018-10-26 00:24:18	51.57580897	2.77666117
Decca VV_01	Van Veen grab	2018-10-26 03:17:28	51.62302793	2.75467478

Monitoring Marine Strategy Framework Directive

Table 4. Coordinates of the KWGS calibration area.

KWGS - DD MM.MMMM	
51° 16.8643'	2° 37.1317'
51° 17.9707'	2° 37.9929'
51° 17.8276'	2° 38.4920'
51° 16.7093'	2° 37.5889'

Table 5. Coordinates of the Thornton Bank THBS monitoring area. (box shifted because of shadow antenne)

Gully south of Thornton Bank DD MM.MMM	
51° 29.905'	2° 53.611'
51° 30.525'	2° 55.592'
51° 30.021'	2° 56.059'
51° 29.410'	2° 54.035'

Table 6. Video recordings in the Thornton Bank THBS monitoring area.

ID	Gear	Timestamp (UTC)	Lat (DD)	Lon (DD)
Thornton 1	Video Frame	2018-10-25 17:22:40	51.49812787	2.90137608
Thornton 2	Video Frame	2018-10-25 17:25:34	51.49796435	2.90090103

Table 7. Van Veen grab samples in the Thornton Bank THBS monitoring area. Coordinates corrected for position of the sampling gear.

ID	Gear	Timestamp (UTC)	Lat (DD)	Long (DD)
VV_02	Van Veen grab	2018-10-25 17:47:53	51.49991150	2.90197372
VV_03	Van Veen grab	2018-10-25 17:55:20	51.50011418	2.90783488
VV_04	Van Veen grab	2018-10-25 18:02:52	51.49853795	2.91139195
VV_05	Van Veen grab	2018-10-25 18:06:55	51.49951172	2.91216965
VV_01_A	Van Veen grab	2018-10-25 18:15:06	51.49854902	2.90195795
VV_01_B	Van Veen grab	2018-10-25 18:17:02	51.49853172	2.90142237

Investigative seabed substrate mapping in a windmill farm

With the UGent biological monitoring being conducted in the windmill farms, an opportunity arose to use these samples for the training and validation of multibeam backscatter data. The C-Power windmill park was chosen because of the larger interval between windmills. Aim was to sail full-coverage over the sample locations, as such two overlapping lines were covered to ensure enough overlap for future mapping comparison, i.e., for detecting changes in substrate types.

Table 8. Coordinates of the transects in and out of the C-Power windmill park. Transects CP_01 to CP_05 will be sailed as a trial for substrate mapping inside of the windmill park. The transects cover the sampling locations of UGent Marine Biology.

ID	Location	LAT DD MM.mmm (from)	LON DD MM.mmm (from)	LAT DD MM.mmm (from)	LON DD MM.mmm (from)
CP_01	500 m west from park A	51° 30.572' N	2° 56.049' E	51° 32.860' N	2° 52.409' E
CP_02	Transect 1 in C-Power A	51° 33.110' N	2° 52.991' E	51° 31.092' N	2° 56.528' E
CP_03	Transect 2 in C-Power A	51° 31.383' N	2° 57.110' E	51° 33.318' N	2° 53.428' E
CP_04	Transect 3 in C-Power A	51° 33.547' N	2° 53.927' E	51° 32.040' N	2° 57.121' E
CP_05	500 m east from park A	51° 32.403' N	2° 57.713' E	51° 33.151' N	2° 56.008' E

Synthesis

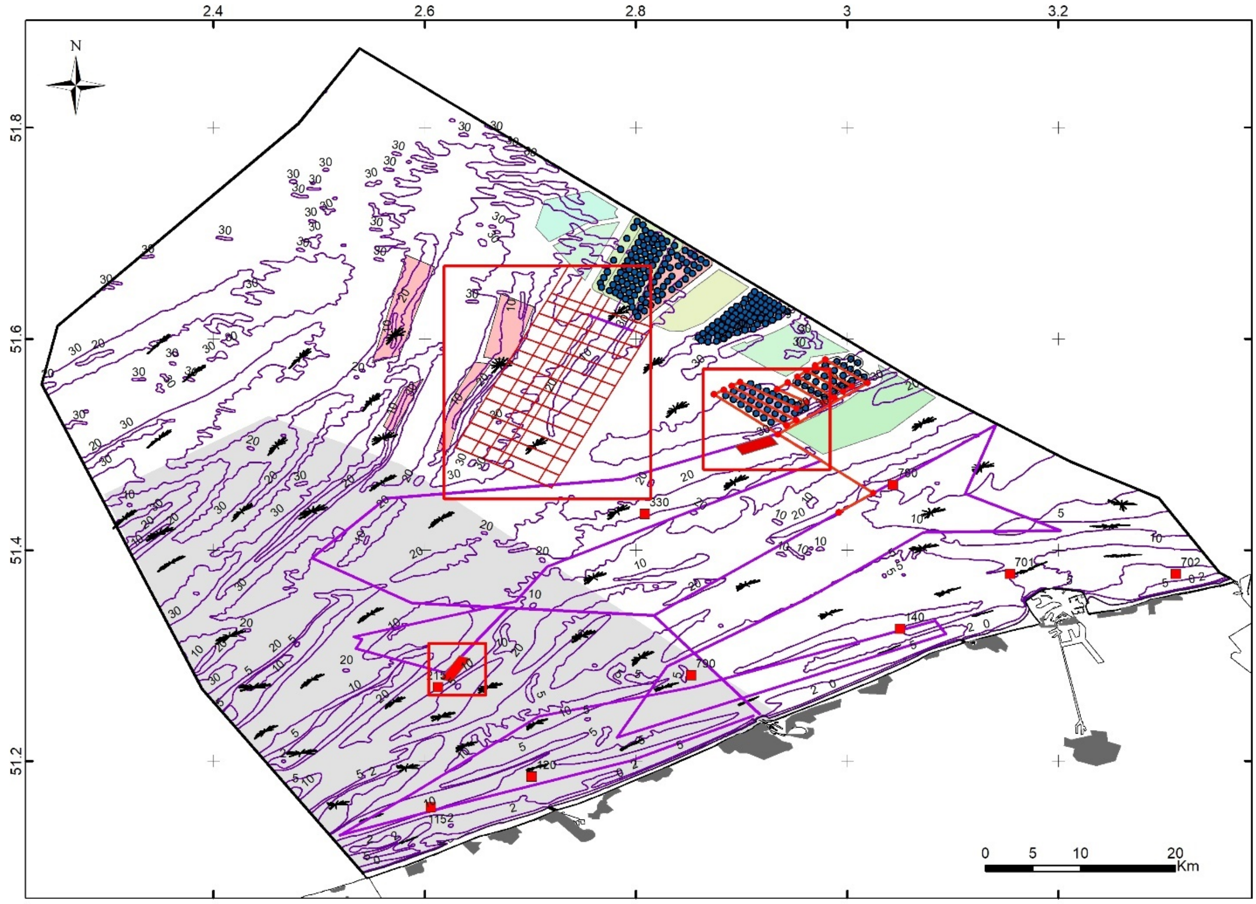

Figure 1. Overview of the locations, programmes ZAGRI/MOZ4, INDI67/MONIT.B.

6.2 UGent-Marbiol: WINMON

1) MACROBENTHOS

Working area for macrobenthos sampling is the Goote Bank (16 stations; reference area), Bligh Bank (36 stations) and Thornton Bank (32 stations). At each station, one Van Veen drop is required. From every grab, one subsample (10 cm^2 core) will be obtained for physico-chemical analysis.
Due to time limitations, 5 Van veen drops were cancelled within Bligh Bank resulting in a total of 31 stations being covered. All stations within Thornton Bank and Goote Bank were sampled.

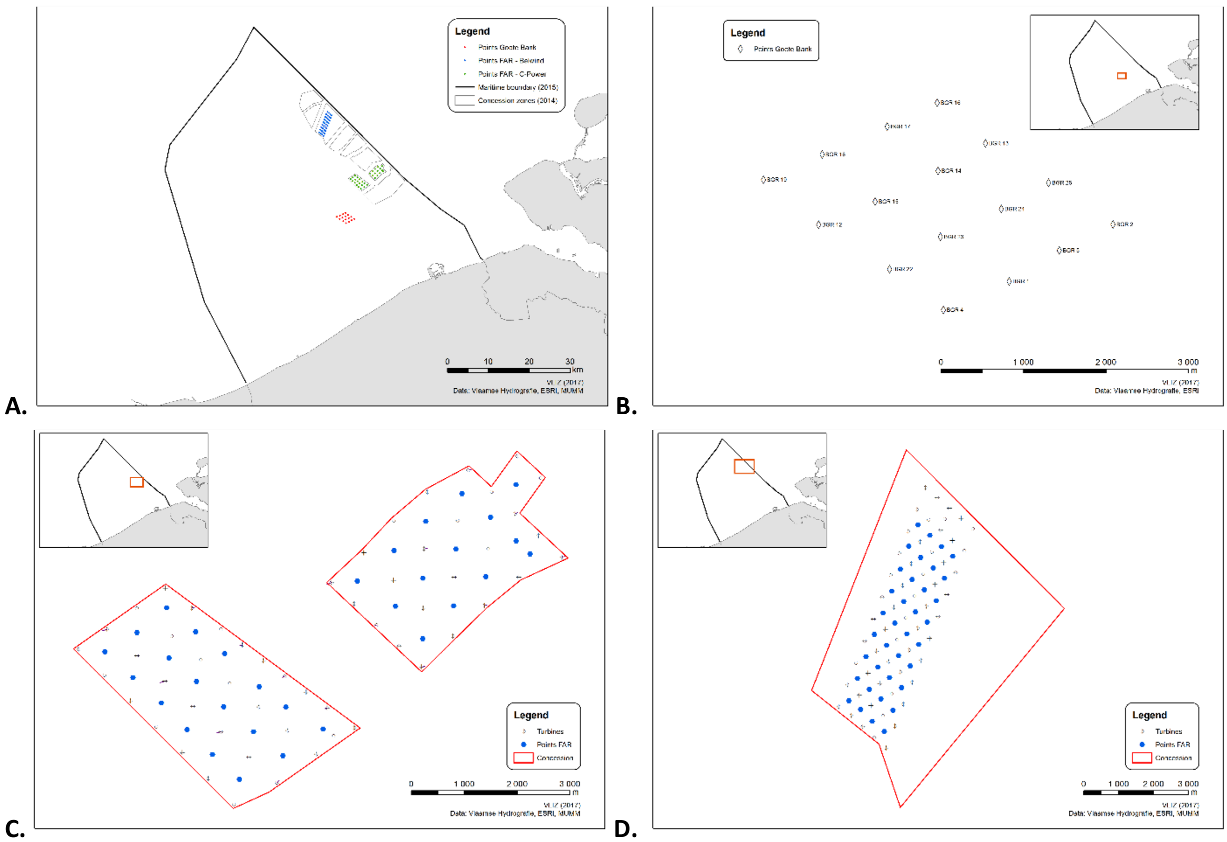

Figure 2. Overview of all sampling points (A.) and sampling points at the Goote Bank (B.), Thornton Bank (C.) and Bligh Bank (D.)(Nathalie De Hauwere, VLIZ).

Table 9. Planned coordinates of sampling stations *(stations highlighted were not sampled).*

code	Latitude	Longitude
BB1_VER	51°41.5821'	2°48.3710'
BB2_VER	51°41.4262'	2°48.6737'
BB3_VER	51°41.2576'	2°48.9664'
BB4_VER	51°41.1100'	2°49.2522'
BB5_VER	51°41.2501'	2°48.1542'
BB6_VER	51°41.0816'	2°48.4570'

BB7_VER	51°40.9215'	2°48.7731'
BB8_VER	51°40.7697'	2°49.059''
BB9_VER	51°40.8931'	2°47.9578'
BB10_VER	51°40.7371'	2°48.2571'
BB11_VER	51°40.5832'	2°48.5631'
BB12_VER	51°40.419''	2°48.8658'
BB13_VER	51°40.5527'	2°47.7580'
BB14_VER	51°40.3947'	2°48.0573'
BB15_VER	51°40.2387'	2°48.3566'
BB16_VER	51°40.0848'	2°48.6525'
BB17_VER	51°40.2123'	2°47.5549'
BB18_VER	51°40.0585'	2°47.8508'
BB19_VER	51°39.8983'	2°48.1534'
BB20_VER	51°39.7383'	2°48.4527'
BB21_VER	51°39.8761'	2°47.3485'
BB22_VER	51°39.714''	2°47.6578'
BB23_VER	51°39.5580'	2°47.9570'
BB24_VER	51°39.4021'	2°48.2528'
BB25_VER	51°39.5314'	2°47.1508'
BB26_VER	51°39.3745'	2°47.4523'
BB27_VER	51°39.2153'	2°47.7466'
BB28_VER	51°39.0652'	2°48.0481'
BB29_VER	51°39.1933'	2°46.9506'
BB30_VER	51°39.0299'	2°47.2514'
BB31_VER	51°38.8840'	2°47.5426'
BB32_VER	51°38.7134'	2°47.8479'
BB33_VER	51°38.8461'	2°46.7505'
BB34_VER	51°38.7142'	2°47.0446'
BB35_VER	51°38.5345'	2°47.3388'
BB36_VER	51°38.3821'	2°47.6440'
TB1_VER	51°34.5670'	3°0.19854'
TB2_VER	51°34.4658'	2°59.3195'
TB3_VER	51°34.2310'	2°59.7922'
TB4_VER	51°33.9917'	3°0.22062'
TB5_VER	51°33.8628'	3°0.44958'
TB6_VER	51°34.1757'	2°58.7361'
TB7_VER	51°33.8996'	2°59.2384'
TB8_VER	51°33.6235'	2°59.7332'
TB9_VER	51°33.8718'	2°58.2267'
TB10_VER	51°33.5958'	2°58.7068'
TB11_VER	51°33.3197'	2°59.2164'
TB12_VER	51°33.5541'	2°57.6361'
TB13_VER	51°33.3057'	2°58.2639'
TB14_VER	51°32.9790'	2°58.7219'
TB15_VER	51°33.2440'	2°54.5281'
TB16_VER	51°33.0050'	2°55.0084'

TB17_VER	51°32.7890'	2°55.4887'
TB18_VER	51°32.4579'	2°56.0649'
TB19_VER	51°32.2557'	2°56.5080'
TB20_VER	51°32.0396'	2°57.1209'
TB21_VER	51°32.9858'	2°54.0487'
TB22_VER	51°32.7331'	2°54.5808'
TB23_VER	51°32.4987'	2°55.0389'
TB24_VER	51°32.2459'	2°55.4895'
TB25_VER	51°31.9976'	2°55.9844'
TB26_VER	51°31.7586'	2°56.4718'
TB27_VER	51°32.7828'	2°53.5324'
TB28_VER	51°32.5255'	2°53.9980'
TB29_VER	51°32.2728'	2°54.471''
TB30_VER	51°32.0061'	2°54.8995'
TB31_VER	51°31.7578'	2°55.3206'
TB32_VER	51°31.5096'	2°55.7712'
BGR 1	51°27.1339'	2°53.4396'
BGR 2	51°27.5194'	2°54.5142'
BGR 4	51°26.9386'	2°52.7578'
BGR 5	51°27.3429'	2°53.9583'
BGR 12	51°27.4792'	2°51.4361'
BGR 13	51°28.0325'	2°53.1630'
BGR 14	51°27.8467'	2°52.6738'
BGR 15	51°27.6375'	2°52.0216'
BGR 16	51°28.2915'	2°52.6504'
BGR 17	51°28.1288'	2°52.1315'
BGR 18	51°27.9380'	2°51.4569'
BGR 19	51°27.7658'	2°50.8492'
BGR 22	51°27.1975'	2°52.1861'
BGR 23	51°27.4158'	2°52.7120'
BGR 24	51°27.6064'	2°53.3420'
BGR 25	51°27.7829'	2°53.8312'

2) HYPERBENTHOS

Hyperbenthos sampling consists of one track at Thornton Bank, one at Bligh Bank, with a reference sample for each concession area (so four tracks in total). The tracks are based on the epifauna tracks from ILVO.
Due to adverse weather conditions, the reference sample in Bligh Bank (WBB02) was cancelled.

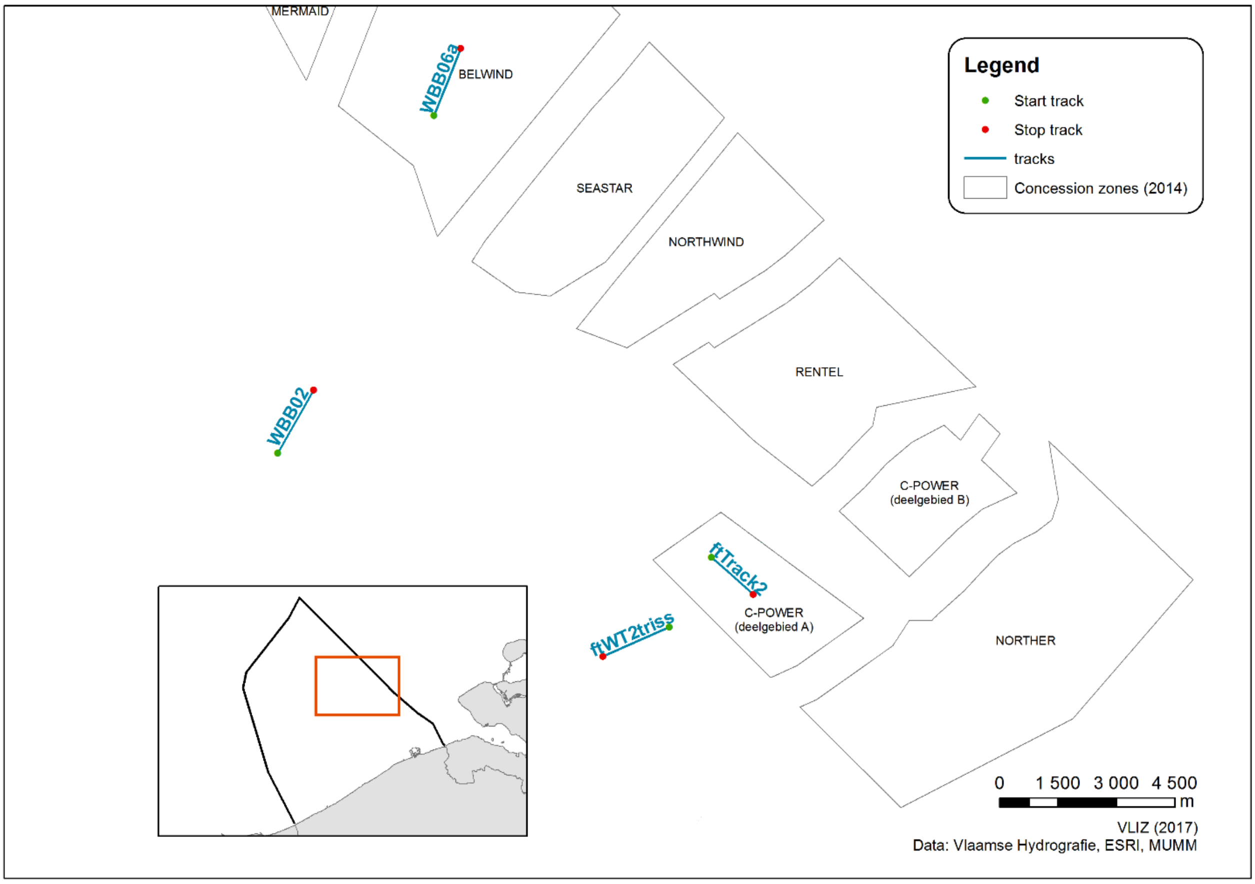

Figure 3. Sampling points for Hyperbenthos (Nathalie De Hauwere, VLIZ).

Table 10. Planned coordinates of sampling stations. Tracks are sailed over a distance of 1 km against the currents and at a speed of 1.5 kt.

		IMPACT		REFERENCE	
		Lat (WGS84)	**Long (WGS84)**	**Lat (WGS84)**	**Long (WGS84)**
BlighBank		WBB06a		WBB02	
	START	N51°38.8870'	E002°47.9545'	N51°34.1771'	E002°44.6422'
	STOP	N51°39.8245'	E002°48.5150'	N51°35.0572'	E002°45.4063'
ThorntonBank		ftTrack2		ftWT2triss	
	START	N51°32.8586'	E002°54.3160'	N51°31.8827'	E002°53.4112'
	STOP	N51°32.3579'	E002°55.2667'	N51°31.4570'	E002°51.9567'

6.3 UGent-Marbiol: LONG TERM MONITORING

The working area consists of the entire Belgian Part of the North Sea. Samples will be collected using Van Veen Grab (5 drops), Reineck boxcorer (3 drops), beam trawl and hyperbenthic sledge. When large stones are present, the Reineck boxcorer and beam trawl will not be deployed.
Due to technical problems, no CTD measurements were taken on the monitoring stations. Because of the time lost and adverse weather conditions only 4 monitoring stations were sampled. At stations 140 and 701 all actions (Van Veen grab, Reineck boxcorer, beam trawl and hyperbenthic sledge) were performed. At stations 790 and 330 only Van Veen grabs and Reineck boxcores were collected.

Table 11. Planned coordinates of monitoring stations *(stations and actions highlighted were not performed).*

Station	Latitude	Longitude	Van Veen	Reineck	Hyperbenthos	Beamtrawl	CTD
701	51° 22.63	03° 09.25	x	x	x	x	x
702	51° 22.63	03° 18.68	x	x	x	x	x
780	51° 27.70	03° 02.60	x	x	x	x	x
790	51° 16.87	02° 51.13	x	x	x	x	x
330	51° 26.04	02° 48.49	x	x	x	x	x
115	51° 09.35	02° 36.35	x	x	x	x	x
215	51° 16.20	02° 36.76	x	x	x	x	x
120	51° 11.10	02° 42.07	x	x	x	x	x
140	51° 19.50	03° 03.00	x	x	x	x	x

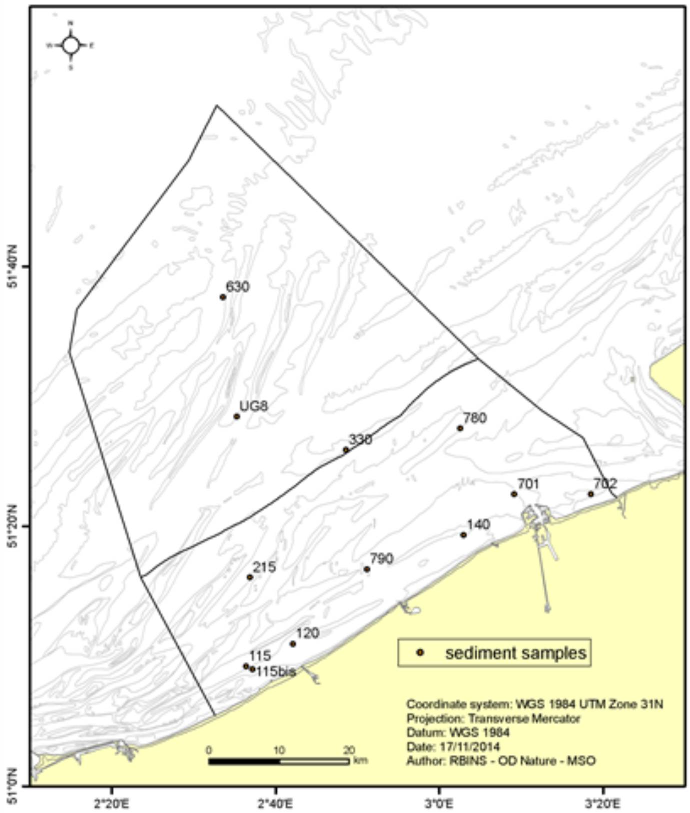

Figure 4. Location of the long-term monitoring stations.

Table 12. List with effective timestamp (UTC) and coordinates of all biological samples. Coordinates corrected for position of the sampling gear.

ID	Gear	Timestamp (UTC)	Lat (DD)	Long (DD)
Reineck_701_1	Reineck box corer	2018-10-22 15:31:12	51.37750473	3.15326385
Reineck_701_2	Reineck box corer	2018-10-22 15:35:01	51.37741280	3.15278142
Reineck_701_3	Reineck box corer	2018-10-22 15:39:08	51.37714055	3.15342585
701_1	Van Veen grab	2018-10-22 15:43:13	51.37722905	3.15322597
701_2	Van Veen grab	2018-10-22 15:46:05	51.37731755	3.15333938
701_3	Van Veen grab	2018-10-22 15:49:15	51.37719892	3.15341898
701_4	Van Veen grab	2018-10-22 15:51:43	51.37720007	3.15350698
701_5	Van Veen grab	2018-10-22 15:54:11	51.37720705	3.15373612
start	Hyperbenthic sledge	2018-10-22 16:04:48	51.37414552	3.14487915
end	Hyperbenthic sledge	2018-10-22 16:24:27	51.37885043	3.15938492
start	Beam trawl	2018-10-22 16:44:30	51.38071505	3.16218313
end	Beam trawl	2018-10-22 16:56:36	51.37339515	3.14499080
790_1	Van Veen grab	2018-10-22 18:26:10	51.28157235	2.85354945

790_2	Van Veen grab	2018-10-22 18:28:28	51.28166415	2.85413335
790_3	Van Veen grab	2018-10-22 18:30:58	51.28158557	2.85457205
790_4	Van Veen grab	2018-10-22 18:33:33	51.28138503	2.85452932
790_5	Van Veen grab	2018-10-22 18:35:44	51.28119787	2.85436122
Reineck_790_1	Reineck box corer	2018-10-22 18:40:45	51.28065262	2.85413818
Reineck_790_2	Reineck box corer	2018-10-22 18:44:06	51.28054275	2.85413843
Reineck_790_3	Reineck box corer	2018-10-22 18:48:30	51.28067703	2.85431595
BB33_VER	Van Veen grab	2018-10-24 11:27:03	51.64689547	2.77831040
BB29_VER	Van Veen grab	2018-10-24 11:35:07	51.65242398	2.78178100
BB25_VER	Van Veen grab	2018-10-24 11:43:35	51.65845375	2.78597132
BB21_VER	Van Veen grab	2018-10-24 11:51:56	51.66481692	2.79039332
BB17_VER	Van Veen grab	2018-10-24 11:59:01	51.66994210	2.79370600
BB13_VER	Van Veen grab	2018-10-24 12:05:50	51.67623240	2.79584987
BB09_VER	Van Veen grab	2018-10-24 12:12:29	51.68216210	2.79920400
BB05_VER	Van Veen grab	2018-10-24 12:19:31	51.68801613	2.80313898
BB01_VER	Van Veen grab	2018-10-24 12:26:19	51.69341253	2.80664342
BB02_VER	Van Veen grab	2018-10-24 12:35:05	51.68978387	2.81118723
BB06_VER	Van Veen grab	2018-10-24 12:42:58	51.68450725	2.80721690
BB10_VER	Van Veen grab	2018-10-24 12:50:04	51.67946257	2.80478515
BB14_VER	Van Veen grab	2018-10-24 12:58:29	51.67309113	2.80067748
BB18_VER	Van Veen grab	2018-10-24 13:05:32	51.66800792	2.79737167
BB22_VER	Van Veen grab	2018-10-24 13:13:15	51.66226730	2.79414825
BB26_VER	Van Veen grab	2018-10-24 13:21:16	51.65615947	2.79086685
BB30_VER	Van Veen grab	2018-10-24 13:28:54	51.65026143	2.78694127
BB34_VER	Van Veen grab	2018-10-24 13:36:12	51.64507078	2.78401642
BB35_VER	Van Veen grab	2018-10-24 13:42:53	51.64196535	2.78929545
BB31_VER	Van Veen grab	2018-10-24 13:51:22	51.64946428	2.79362233
BB27_VER	Van Veen grab	2018-10-24 13:58:00	51.65450567	2.79704233
BB23_VER	Van Veen grab	2018-10-24 14:06:01	51.65938263	2.80114670
BB19_VER	Van Veen grab	2018-10-24 14:13:06	51.66482925	2.80356547
BB15_VER	Van Veen grab	2018-10-24 14:20:47	51.67075183	2.80642343
BB11_VER	Van Veen grab	2018-10-24 14:28:24	51.67658615	2.80881500
BB07_VER	Van Veen grab	2018-10-24 14:36:07	51.68231037	2.81266963
BB03_VER	Van Veen grab	2018-10-24 14:43:27	51.68782387	2.81611048
BB04_VER	Van Veen grab	2018-10-24 14:51:55	51.68524450	2.82101212
failed	Hyperbenthic sledge	2018-10-24 15:13:50	51.66371828	2.80858180
failed	Hyperbenthic sledge	2018-10-24 15:31:07	51.65556475	2.80365015
failed	Hyperbenthic sledge	2018-10-24 16:04:21	51.66394628	2.80846608
failed	Hyperbenthic sledge	2018-10-24 16:25:09	51.65555267	2.80337322
BB20_VER	Van Veen grab	2018-10-24 16:45:22	51.66230380	2.80786310
BB28_VER	Van Veen grab	2018-10-24 16:57:01	51.65084928	2.80043488
BB36_VER	Van Veen grab	2018-10-24 17:07:13	51.63938637	2.79307963
Track_REF_start	Hyperbenthic sledge	2018-10-25 06:28:41	51.52453143	2.86599757
Track_REF_end	Hyperbenthic sledge	2018-10-25 06:51:37	51.52822800	2.87970632
TB27_VER	Van Veen grab	2018-10-25 07:18:49	51.54598237	2.89221013
TB28_VER	Van Veen grab	2018-10-25 07:26:41	51.54183427	2.90059585
TB29_VER	Van Veen grab	2018-10-25 07:34:32	51.53675740	2.90725428
TB30_VER	Van Veen grab	2018-10-25 07:42:06	51.53353818	2.91631750
TB31_VER	Van Veen grab	2018-10-25 07:49:51	51.52941895	2.92339427
TB32_VER	Van Veen grab	2018-10-25 07:57:17	51.52483902	2.93055802
TB26_VER	Van Veen grab	2018-10-25 08:10:01	51.52946815	2.94128723
TB25_VER	Van Veen grab	2018-10-25 08:17:52	51.53299763	2.93257625
TB24_VER	Van Veen grab	2018-10-25 08:25:42	51.53739612	2.92464015
TB23_VER	Van Veen grab	2018-10-25 08:33:02	51.54167887	2.91689300
TB22_VER	Van Veen grab	2018-10-25 08:40:45	51.54520557	2.90849482

TB21_VER	Van Veen grab	2018-10-25 08:48:46	51.54964232	2.89944280
TB15_VER	Van Veen grab	2018-10-25 09:03:21	51.55449143	2.90948995
TB16_VER	Van Veen grab	2018-10-25 09:10:39	51.54940173	2.91599960
TB17_VER	Van Veen grab	2018-10-25 09:18:22	51.54612388	2.92547735
TB18_VER	Van Veen grab	2018-10-25 09:26:00	51.54078802	2.93580170
TB19_VER	Van Veen grab	2018-10-25 09:31:57	51.53737628	2.94293162
TB220_VER	Van Veen grab	2018-10-25 09:38:54	51.53362058	2.95153528
Track_Impact_start	Hyperbenthic sledge	2018-10-25 10:28:03	51.53820050	2.92232055
Track_Impact_end	Hyperbenthic sledge	2018-10-25 10:50:53	51.54492532	2.91032283
TB12_VER	Van Veen grab	2018-10-25 11:21:41	51.55957590	2.96114248
TB13_VER	Van Veen grab	2018-10-25 11:31:53	51.55510343	2.97221070
TB14_VER	Van Veen grab	2018-10-25 11:40:22	51.54910647	2.97871857
TB11_VER	Van Veen grab	2018-10-25 11:48:23	51.55548668	2.98654887
TB10_VER	Van Veen grab	2018-10-25 11:56:18	51.56000315	2.97807998
TB09_VER	Van Veen grab	2018-10-25 12:03:50	51.56474750	2.97094625
TB06_VER	Van Veen grab	2018-10-25 12:11:56	51.57058538	2.97949397
TB07_VER	Van Veen grab	2018-10-25 12:19:28	51.56622467	2.98610713
TB08_VER	Van Veen grab	2018-10-25 12:29:02	51.56110167	2.99666723
TB05_VER	Van Veen grab	2018-10-25 12:38:38	51.56373850	3.00792212
TB04_VER	Van Veen grab	2018-10-25 12:43:56	51.56653620	3.00356192
TB03_VER	Van Veen grab	2018-10-25 12:51:16	51.57048518	2.99682643
TB02_VER	Van Veen grab	2018-10-25 12:59:39	51.57456945	2.98834025
TB01_VER	Van Veen grab	2018-10-25 13:09:41	51.57596385	3.00305252
BGR19_1	Van Veen grab	2018-10-26 04:41:03	51.46277327	2.84698613
BGR19_2	Van Veen grab	2018-10-26 04:43:40	51.46302363	2.84798660
BGR18	Van Veen grab	2018-10-26 04:52:31	51.46647072	2.85788880
BGR17	Van Veen grab	2018-10-26 05:01:32	51.46930250	2.86891887
BGR16	Van Veen grab	2018-10-26 05:08:52	51.47147815	2.87799708
BGR13	Van Veen grab	2018-10-26 05:21:35	51.46744448	2.88615037
BGR14	Van Veen grab	2018-10-26 05:29:21	51.46390457	2.87759552
BGR15	Van Veen grab	2018-10-26 05:37:12	51.46084265	2.86696345
BGR12	Van Veen grab	2018-10-26 05:45:05	51.45799548	2.85797068
BGR22	Van Veen grab	2018-10-26 05:55:05	51.45313708	2.86930923
BGR23	Van Veen grab	2018-10-26 06:03:43	51.45688565	2.87845230
BGR24	Van Veen grab	2018-10-26 06:12:55	51.45984878	2.88936717
BGR25	Van Veen grab	2018-10-26 06:21:24	51.46300227	2.89763158
BGR02	Van Veen grab	2018-10-26 06:36:23	51.45876478	2.90835292
BGR05_1	Van Veen grab	2018-10-26 06:46:01	51.45533232	2.89887008
BGR05_2	Van Veen grab	2018-10-26 06:47:40	51.45528463	2.89866512
BGR01	Van Veen grab	2018-10-26 06:58:53	51.45204200	2.89063517
BGR04	Van Veen grab	2018-10-26 07:18:04	51.44913483	2.88041458
330_1	Van Veen grab	2018-10-26 07:55:19	51.43408267	2.80824813
330_2	Van Veen grab	2018-10-26 07:57:48	51.43399925	2.80813217
330_3	Van Veen grab	2018-10-26 08:00:12	51.43387528	2.80811843
330_4	Van Veen grab	2018-10-26 08:02:30	51.43405597	2.80850347
330_5	Van Veen grab	2018-10-26 08:04:50	51.43397000	2.80839563
Reineck_330_1	Reineck box corer	2018-10-26 08:09:30	51.43414625	2.80844752
Reineck_330_2	Reineck box corer	2018-10-26 08:13:06	51.43392232	2.80824458
Reineck_330_2	Reineck box corer	2018-10-26 08:16:28	51.43377278	2.80795033
Reineck_330_3	Reineck box corer	2018-10-26 08:19:52	51.43398920	2.80788702
Brecht_1	Reineck box corer	2018-10-26 08:23:26	51.43406563	2.80792212
Brecht_2	Reineck box corer	2018-10-26 08:26:28	51.43418452	2.80804698
Brecht_3	Reineck box corer	2018-10-26 08:29:43	51.43431422	2.80837962
Brecht_4	Reineck box corer	2018-10-26 08:32:41	51.43417002	2.80806122
Brecht_5	Reineck box corer	2018-10-26 08:35:59	51.43431015	2.80807165

Brecht_6	Reineck box corer	2018-10-26 08:40:28	51.43399073	2.80780995

7. REMARKS

Officers and crew are warmly thanked for their flexibility and assistance during all operations.

8. DATA STORAGE

OD NATURE

- Multibeam data, Video data, Seabed samples. Contact person: RBINS: Vera Van Lancker
- ADCP data: RBINS MDO Ostend. Contact person: Joan Backers

UGent-Marbiol

- Marbiol (LT-monitoring): Van Veen grab (macrobenthos), Reineck boxcores (meiofauna), Beam trawl (epibenthos, samples were processed on board) and hyperbenthos samples. Contact person: Carl Van Colen (Carl.VanColen@UGent.be)
- Winmon: Van Veen grab (macrobenthos) and hyperbenthos samples. Contact persons: Liesbet Colson and Tom Moens (Liesbet.Colson@UGent.be, Tom.Moens@UGent.be)

All the samples will be processed and stored at the Marine Biology research group, Ghent University.