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

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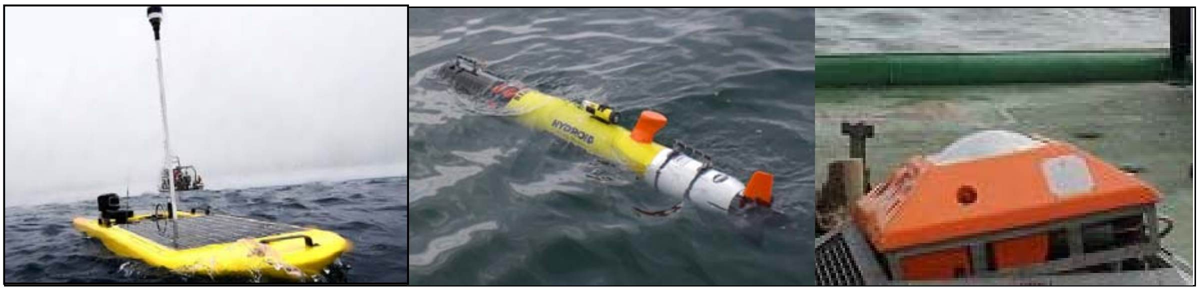

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Van Lancker, V., Baeye, M., Fettweis, M., Francken, F. & Van den Eynde, D. (2014). Monitoring of the impact of the extraction of marine aggregates, in casu sand, in the zone of the Hinder Banks. Brussels, RBINS-OD Nature. Report <MOZ4-ZAGRI/X/VVL/201401/EN/SR01>, 384 pp. (9 Annexes).

Abbreviations

ADCP:	Acoustic Doppler Current Profiler
AUMS	Autonomous Underway Measurement System
BM-ADCP:	Bottom-mounted Acoustic Doppler Current Profiler
C3	Data from a Turner Design fluorometer, proxy for turbidity
DGPS	Differential Global Positioning System
FPS Economy	Federal Public Service Economy, SMEs, Self-Employed and Energy
HM-ADCP	Hull-mounted Acoustic Doppler Current Profiler
Hs	Significant wave height
JD	Julian Day
LISST:	Laser In-Situ Scattering and Transmissometry
Mab:	Meter above bottom
MSFD	European Marine Strategy Framework Directive
NE	Northeast-directed (flood)
OPTOS-BCZ	Hydrodynamic model applied to the Belgian coastal zone
POC:	Particulate Organic Carbon
PON:	Particulate Organic Nitrogen
SPM:	Suspended Particulate Matter
SW	Southwest-directed (ebb)
TASS	Turbidity Assessment Software System (www.ecoshape.nl)
Tidal phase (xx)	Spring/Neap/Mid tide, with indication of the tidal coefficient
UTC	Universal Time Coordinates
WG-ADCP	Wave Glider Acoustic Doppler Current Profiler

Executive summary

The far offshore Hinder Banks are targeted for exploitation of huge quantities of sand, mainly for coastal defence works. Here, up to 2.9 million m^3 can be taken over 3 months, with a maximum of 35 million m^3 over a period of 10 years. Large vessels can be used extracting 12500 m^3 per run. South of the Hinder Banks concession, a Habitat Directive area is present, hosting ecologically valuable gravel beds. For these, it is critical to assess the effect of multiple and frequent depositions of fine material from dredging-induced sediment plumes.

A monitoring strategy was set-up, tailored for assessing the importance and extent of physical perturbations that are created by the extraction activities. The monitoring design focuses on hydrodynamics and sediment transport with feedback loops between both modelling and field studies. Main targets are assessing changes in seafloor integrity and hydrographic conditions, two key descriptors of marine environmental status within Europe's Marine Strategy Framework Directive. Seafloor integrity relates to the functions that the seabed provides to the ecosystem (e.g., structure; oxygen and nutrient supply), whilst hydrographic conditions refer to currents and/or other oceanographic parameters of which changes could adversely impact on benthic ecosystems.

State-of-the-art instrumentation (from RV Belgica) has been used, to measure the 3D current structure, turbidity, depth, backscatter and particle size of the material in the water column, both in-situ and whilst sailing transects over the sandbanks. In the Habitat Directive Area, gravel bed integrity (i.e., epifauna; sand/gravel ratio; patchiness) was measured as well. Most innovatively, an autonomous underwater vehicle was deployed (Wave Glider®, Liquid Robotics Inc.), resulting in quasi 22 days of current, turbidity and other oceanographic data.

From a first data-model integration, and analyses against hydrometeorological databases, main results showed: (1) high spatial and temporal variability of turbidity, both current- and wave-induced; (2) important topography-induced resuspension over the sandbanks, especially under wave agitation; (3) spreading and deposition of dredging-induced sediment plumes; and (4) competitiveness of ebb and flood, meaning that deposition of fine sediments on the gravel beds is realistic. Field data on currents were used for the validation of a three-dimensional hydrodynamic model. Results confirmed good model predictions of current magnitude and current directions in zone 4, critical for future impact assessment.

Data will be integrated with results from the morphological and biological monitoring, respectively carried out by the Continental Shelf Service of FPS Economy and the Institute for Agricultural and Fisheries Research.

Samenvatting

De ver uit de kust gelegen Hinderbanken zijn het doel van exploitatie van enorme hoeveelheden zand, voornamelijk voor kustverdedigingswerken. In deze zone kan maximaal 2.9 miljoen m^3 ontgonnen worden over 3 maanden, met een maximum van 35 miljoen m^3 over een periode van 10 jaar. Grote schepen, die per keer 12.500 m^3 ontginnen, kunnen worden ingezet. Ten zuiden van de concessiezone is een Habitatrichtlijnengebied aanwezig, dat ecologisch waardevolle grindbedden herbergt. Voor deze is het essentieel om het effect van vele en frequente afzettingen van fijn materiaal van bagger-geïnduceerde sedimentpluimen te beoordelen.

Een monitoringstrategie werd opgezet, om het belang en de omvang van fysieke verstoringen die door de extractie-activiteiten worden veroorzaakt, te beoordelen. Het ontwerp van monitoring richt zich op de hydrodynamica en sedimenttransport, met terugkoppelingen tussen modelleringen en veldstudies. Belangrijkste doelen zijn het beoordelen van veranderingen in de zeebodemintegriteit en hydrografische condities, twee belangrijke descriptoren om de mariene milieutoestand binnen Europa's Kaderrichtlijn Mariene Strategie te evalueren. Zeebodemintegriteit heeft betrekking op de functies die de bodem biedt voor het ecosysteem (bv. structuur, zuurstof en toevoer van voedingsstoffen), terwijl hydrografische condities verwijzen naar stromingen en/of andere oceanografische parameters waarvan veranderingen een negatieve invloed kunnen hebben op benthische ecosystemen.

State-of-the-art instrumentatie (aan boord R/V Belgica) werd gebruikt om de 3D-stroomsnelheidstructuur, troebelheid, diepte, backscatter en deeltjesgrootte van het materiaal in de waterkolom te meten, zowel in-situ als tijdens het varen van transecten over de zandbanken. In het Habitatrichtlijnengebied werd ook de grindbedintegriteit (d.w.z. epifauna; zand/grind verhouding; heterogeniteit) gemeten. Als meest innovatieve meetstrategie, werd een autonoom onderwaterrobot ingezet (Wave Glider®, Liquid Robotics Inc.), wat resulteerde in quasi 22 dagen data van stroomsnelheid, troebelheid en andere oceanografische gegevens.

Uit een eerste datamodelintegratie en vergelijking met hydro-meteorologische databases, volgen als belangrijkste resultaten: (1) hoge ruimtelijke en temporele variabiliteit van de troebelheid, zowel stromings- als golfgeïnduceerd; (2) belangrijke topografisch geïnduceerde resuspensie over de zandbanken, vooral onder golfwerking; (3) verspreiding en afzetting van door extractie geïnduceerde sedimentpluimen; en (4) het competitieve karakter van eb en vloed, waardoor afzetting van fijn sediment op de grindbedden in het zuiden reeël is. Velddata van stroomsnelheden werden gebruikt voor de validatie van een 3D hydrodynamisch model. Resultaten bevestigden goede modelvoorspellingen van de grootte van de stroomsnelheid alsook van de richting ervan in zone 4, van cruciaal belang voor toekomstige

effectenbeoordelingen.

De gegevens zullen worden geïntegreerd met de resultaten van de morfologische en biologische monitoring, respectievelijk uitgevoerd door de Dienst Continentaal Plat van de FOD Economie en het Instituut voor Landbouw- en Visserijonderzoek.

Preface

Results presented in this report relate to the monitoring of intensive aggregate extraction in zone 4, Hinder Banks (MOZ4). Since 2013, the monitoring activities are 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 for the measurements that commenced in 2011, as well as for the model development. Additionally, an opportunity was provided to demonstrate the potential of an autonomous underwater robot (Wave Glider®, Liquid Robotics Inc.) for environmental monitoring. To build a knowledge base on the environmental effects in zone 4, all results are reported. In a later phase, data will be integrated with results from the morphological and biological monitoring, respectively carried out by the Continental Shelf Service of FPS Economy (COPCO) and the Institute for Agricultural and Fisheries Research (ILVO).

I. Introduction

A monitoring programme has been designed allowing testing hypotheses on the impact of marine aggregate extraction in the far offshore Hinder Banks. In this report, monitoring is focussed on hydrodynamics and sediment transport with feedback loops between both modelling and field studies. 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). 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; and (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. 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[1]. 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 will

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[1] For descriptor 7 on hydrographic conditions, the monitoring programme should allow evaluating the following specifications (Belgische Staat, 2012):

(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 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).

be compared to datasets recorded under the events of intensive aggregate extraction. The extraction will inherently give rise to sediment plumes and subsequent release of fines in the water column. Insight is needed in the dispersion of the fines and the probability of siltation in the nearby Habitat Directive area. A probability study is needed to which extent siltation, as a result from dredging, would lead to overtopping and hence deteriorate the integrity of the gravel beds. 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[2], another indicator within MSFD (descriptor 6 Seafloor Integrity).

2. Study area

The Hinder Banks form part of a sandbank complex, located 40 km offshore in the Belgian part of the North Sea (BPNS). On the sandbanks, depths range from -8 m to -30 m (Figure 1); 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 et al., 2009 @SediCURVE database). Tidal currents reach more than 1 ms^{-1}; waves are easily more than 1 m in height. These offshore sandbanks are the first wave energy dissipaters in the BPNS.

Over a 10-yrs period intensive extraction of marine aggregates (up to 2.9 million m^3 over 3 months) is allowed in this area, with a maximum of 35 million m^3 over a period of 10 years. Large vessels can be used extracting 12500 m^3 per run. Present-day yearly extraction levels recently surpassed 3 million m^3, the majority of which was extracted with vessels of 1500 m^3. Such intensive extraction is new practice in the BPNS and the environmental impact is yet to be determined. South of the Hinder Banks concession, a Habitat Directive area is present, hosting ecologically valuable gravel beds (Houziaux et al., 2008) (Figure 1). For these, it is critical to assess the effect of multiple and frequent depositions from dredging-induced sediment plumes.

[2] For 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 (test zones to be defined), 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.

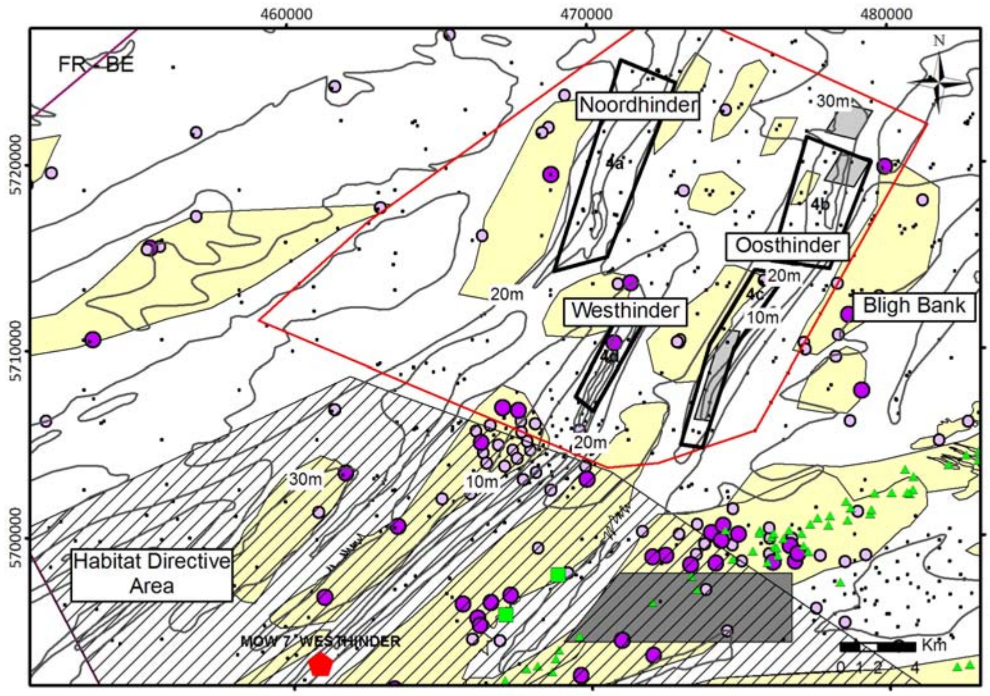

Figure 1. Area of the Hinder Banks, where intensive marine aggregate extraction is allowed in zone 4 (red line) along 4 sectors (black polygons). Within these sectors geomorphological monitoring is carried out by COPCO (light grey polygons). A Habitat Directive Area (hatched) is present at a minimum of 2.5 km from the southernmost sectors. Presence of gravel (purple) and stones (green) 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 rectangles), east of the Oosthinder, ecologically valuable epifauna is present. Indicated also is the position of the Westhinder measuring pole (Flanders Hydrography) (red pentagon) where most of the hydrometeorological data are derived from. Grey polygon in the Habitat Directive Area is an anchorage zone.

3. Materials and methods

3.1. *Measurements and spatial observations*

Measurements and observations started in November 2011, before major extraction activities took place. Since then three 1-week campaigns a year were executed resulting in a total of 7 campaigns in the period 2011-2013, all with RV Belgica. Additional data were acquired with an autonomous underwater vehicle (AUV) 'Wave Glider' from Liquid Robotics, and 4 longer-term deployments were made using a bottom-mounted acoustic Doppler current profiler, for which also RV Simon Stevin was used for the recover. See Figure 2, for an overview of the data.

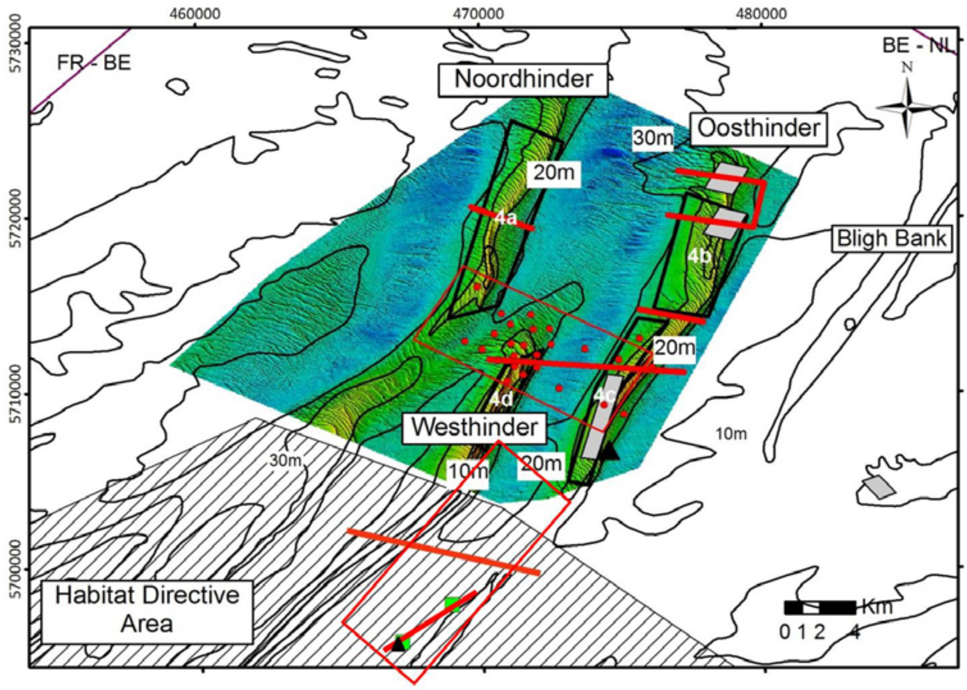

Figure 2. Sandbanks and troughs in the area of the Hinder Banks. Cross-sectional lines show the locations of ADCP profiling. Along the transects, water sampling and vertical profiling were performed. Full-coverage depth measurements were performed in the red delineated zones in the central and southern part of the Hinder Banks, and were validated with sediment samples. The triangle indicates the position of longer-term measurements of currents and turbidity. Small green rectangles in the Habitat Directive area are the locations of ecologically valuable gravel beds. Background bathymetry: FPS Economy, Self-Employed and Energy. This FPS is responsible for the geomorphological monitoring in the area, with focus on the grey zones within Sectors 4b and 4c.

3.1.1. Short-term spatial observations (*RV Belgica*)

In 2011-2013, the following observations were made:

(1) In the 4 sectors, transects (3-7 km) were sailed over the sandbanks throughout a tidal cycle (13-hrs) measuring the full three-dimensional current velocity and direction, together with the turbidity based on the acoustic backscatter. RV Belgica's hull-mounted acoustic Doppler current profiler (HM-ADCP - workhorse RDI, 300 kHz) was used at a preferred ship speed of 8 kt. Bin sizes varied from 0.25, 0.30, 0.50 to 1 m.

(2) At dedicated locations, very-high resolution acoustic measurements were performed with RV Belgica's multibeam system (Kongsberg-Simrad EM3002, 300 kHz), in function of sediment transport estimations and habitat characterizations. Depth, backscatter, and water column data were obtained. Repetitive MBES measurements will allow identifying erosion and/or deposition areas, as well as bedload transport pathways and magnitude, from the asymmetry and rate from the migration of the sand dunes, superimposed on the sand-

banks. Results will be combined and compare with bathymetric data from FPS Economy, SME's, Self-Employed and Energy.

(3) Throughout the measurements, RV Belgica's Autonomous Underway Measurement System (AUMS) recorded a.o. optical backscatter as a proxy of turbidity. The AUMS instrumentation is linked to a seawater pump system taken water, continuously, at the bow of the ship at 3.2 m. Although, the quality of these data is still under evaluation, their relative values aid in the quantification of turbidity variations in the study area.

See Annex D for the periods, location and technical specifications.

3.1.2. Longer-term measurements at a fixed location

Near-bottom processes (currents and turbidity) were studied using a bottom-mounted Acoustic Doppler Current Profiler (BM-ADCP; Teledyne/RD Instruments, 1200 kHz Workhorse Sentinel) at 2 locations:

(1) A location was defined along the eastern steep flank of the Oosthinder sandbank to study the direct impact of the extraction processes. The location was chosen near Sector 4c, outside of main navigation routes and along the steep flank where less beam trawling occurred. In the period 2012-2013, four deployments were realised. One BM-ADCP has not yet been recovered, due to burial of the instrument in the sand. Bin sizes varied from 0.25 to 0.50 m.

(2) In the Habitat Directive Area, a 1200 kHz BM-ADCP was deployed for one week in the trough of a barchan dune where rich gravel beds occur. Aim was to study the relation between the barchan morphology, its fine sediment trapping efficiency (eddies at the lee side?) and the deposition of fines on top of the gravel beds. Bin size was set at 0.25 m.

See Annex C for the periods, location and technical specifications.

3.1.3. Longer-term spatial observations (*Wave Glider*, Liquid Robotics)

Liquid Robotics made available a Wave Glider (HERMES), type SV2. The Wave Glider is composed of two parts: a *float* which is roughly the size and shape of a surfboard and stays at the surface; a *sub* having wings and hanging 6 meters below on an umbilical tether. Because of the separation, the float experiences more wave motion than does the sub. This difference allows wave energy to be harvested to produce forward thrust (www.liquidrobotics.com) (Figure 3). The AUV was deployed and recovered with the oceanographic vessel *RV Belgica*, respectively on April 15th and May 6th (see http://www.youtube.com/watch?v=pjRICKQIrzU for a movie on the deployment from RV Belgica).

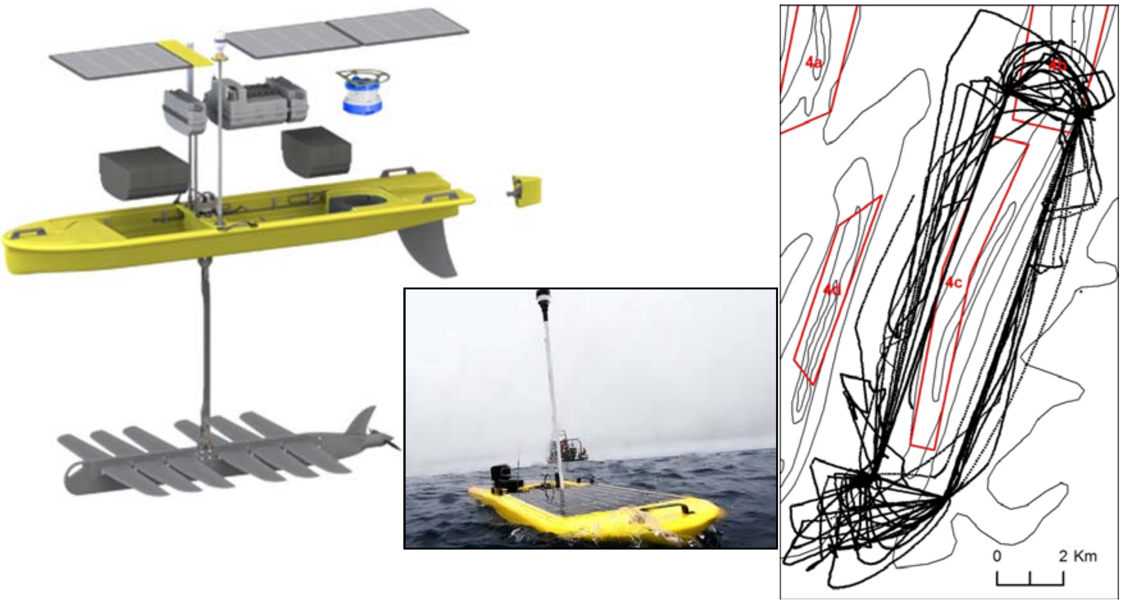

Figure 3. Left: Wave Glider SV2, Liquid Robotics. Float (payload, incl. ADCP) and sub. Right: trajectory during the period 15/4 – 6/5 2013 (see also Annex F).

Apart from navigation and payload control computers and satellite communication systems, the Wave Glider was equipped with a fluorometer (Turner Designs, C3 submersible fluorometer) equipped with sensors measuring chlorophyll-A and crude and refined (poly and mono-aromatic hydrocarbons) oil fluorescence, as well as turbidity and water temperature just below the float of the Wave Glider. The fluorometer incorporated three optical sensors ranging from the deep ultraviolet to the infrared spectrum. The light emitting diode for measuring turbidity from the scattering of light had a wavelength of 850 nm. Values were expressed in relative fluorescence units (RFU) and can report values between 0 and 65535.

Additionally, the float of the Wave Glider housed an Acoustic Doppler Current Profiler (ADCP) (Teledyne/RD Instruments, 300 kHz), which was programmed to resolve current and acoustic backscatter data over vertical bins or cells of 1 to 2 m resolution. The Wave Glider had an average speed of 1.14 kt, with a maximum of 1.69 kt.

See Annex F for the period, location and technical specifications.

3.1.4. In-situ measurements and sampling

Water properties

For calibration of the continuous registrations (HM-ADCP; BM-ADCP; AUMS) water samples were taken using a Niskin bottle of 5 to 10 l, mounted on a Seacat profiler (SBE09 CTD system). The latter allows vertical profiling of oceanographic parameters using CTD for salinity, temperature and depth; and optical backscatter sensor (OBS) for turbidity. Particle size distribution and volume concentration in the water column was measured using a Sequoia type C 100 X Laser In-Situ Scattering and Transmissometry (LISST). Using an annular ring detector, the instrument derives in-situ particle sizes, in the range 2.5 to 500 μm, from the scattering of particles on 32 rings. The size distribution is presented as concentration ($\mu l l^{-1}$) in each of the 32 log-spaced size bins. Date and time, optical transmission, water depth and temperature are recorded as supporting measurements (http://www.sequoiasci.com). Water samples were filtered on board for suspended particulate matter (SPM) every 30'. Standard 0.5 l was filtered, increasing up to 1.5 l in the very low turbidity waters. At the stationary locations extra filtrations were done, once per hour, for particulate organic carbon (POC/PN) (0.250 l), and a bottle of water (0.33 l) was kept for calibration of the conductivity sensor for salinity.

See Annex B for the periods, location and technical specifications.

Seabed properties

On selected locations seabed sediment samples were taken:

(1) To derive additional sediment parameters to refine sediment transport models (e.g. bottom roughness) and habitat characterization. Van Veen grab samples (ST1208, # 26), and reconnaissance Hamon grabs (RV Simon Stevin July 2012, # 6) were taken.

(2) To evaluate sediment changes as a result of the large-scale extraction of marine aggregates, presuming a deposition of fine sediments (e.g. siltation) from the overflow. In July 2013 (ST1319) this was tested in two areas: (i) in the sandy sediments in and out Sector 4c. Shallow boxcores (2-3 replicates at 4 locations) were taken to quantify grain-size variation in the upper sediment layers; and (ii) in the Habitat Directive Area, along the gravel beds with rich epifauna. Here, a Hamon grab (11 replicates) was used to assess sediment and biological variability. Locations were defined on the basis of very detailed imagery, obtained with an autonomous underwater vehicle REMUS Hydroid 100, 900 kHz (Belgian Navy, July 2012, ST1219). It is intended to sample these locations each year allowing studying grain-size variation through time, and potentially changes in bottom structure.

See Annex H, in the respective RV Belgica cruise reports, for the periods, location and technical specifications.

3.2. Data analyses

Most of the acoustic data, acquired in the period 2011-2013, have been processed. Seabed samples have not been treated yet. The methodological approach is still under evaluation.

All data were time-stamped (Universal Time Coordinates, UTC) allowing accurate correlations of various observations. These timestamps were converted to Day of Year (1/1/2013 12h=0.5). In the Annexes Julian Day is mentioned. In this report both are identical.

3.2.1. Water column properties derived from water samples

On board, water samples were filtered, in three replicates, using preweighted Whatmann GFC filters. These were analysed at the Marine Chemistry Lab (OD Nature, MARCHEM). SPM concentrations (Unit gl^{-1}) were obtained after drying of the filters for 48 hours, after which weight differences were calculated. A deviation of 12 % between the replicates is acceptable (MARCHEM Standards). Measuring uncertainty of deriving SPM from filtrations is 17 %. In total 976 samples were obtained. POC/N analyses (Unit gl^{-1}) were carried out in the laboratory using an Interscience FlashEA 1112 Series Element Analyser. Measuring uncertainty is 12 % for POC; 18 % for PN (MARCHEM AK 7.0). For salinity (Unit PSU), a Laboratorium salinometer – Portasal 8410 (Guildline) van Ocean Scientific Int. was used; the measuring uncertainty is 0.15 % (MARCHEM). It needs emphasis that water samples were taken at different levels in the water column (e.g., at 3.2 m under the water surface when water is taken with the seawater pump, against 2-3 meter above the bottom (mab) when using the Seacat profiler). In the latter case, the depth is derived from the CTD profiles (see below). Still, important uncertainties arose on the exact sampling depth, as the Seacat frame was easily carried away by the currents. This complicates the match-ups with ADCP data, a necessary step for calibration towards mass concentrations of SPM.

See Annex B for all results.

3.2.2. Water column properties derived from optical measurements

Conductivity-depth-temperature (CTD) and optical backscatter (OBS)

CTD data from the Seacat profiler were analysed to derive the depth of the vertical profiles (e.g., link with water sampling and ADCP profiles). OBS data are not yet processed; they will be converted later to mass concentrations of SPM.

Fluorescence data (Turner Designs, C3 submersible fluorometer)

Data were used as obtained from the sensor (RFU) and remain relative values. No data were available to calibrate towards Nepheloid Turbidity Units (NTU) and eventually mass concentrations of SPM. Data showed a range in values from around 6 to 650 RFU. For representations, interquartile ranges[3]

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[3] Median values, interquartile ranges and outliers were defined for some data series, with high variability in the values.

Median: For an odd number of data points, this is the middle value. For an even number points, it is the mean of the middle values. First quartile [QL]: Value[(number of points + 1)/4, rounded were calculated, as also outliers to eliminate the high values that occurred throughout the data series. 0-50 RFU was regarded a range of valid data that could be used for further averaging of turbidity against a series of combinations of hydro-meteorological conditions. In the results, only this range is represented.

In-situ particle size variation from LISST

Data from the LISST-100X were processed following the guidelines "Processing LISST-100 and LISST-100X data in MATLAB", posted on the Sequoia Scientific website (Sequoia Sci, 2008). After correction for the background (i.e., instrument and ambient water related) binary data from the rings were converted into volume concentrations ($\mu l l^{-1}$) per ring. This dataset was further analysed in terms of temporal variability (e.g., throughout a 13-hrs tidal cycle) and over the vertical (i.e., from the surface to 2-3 mab).

Underway optical backscatter measurements (AUMS)

These data were used as they are provided by RV Belgica's ODAS system.

3.2.3. Water column properties derived from acoustical measurements (Acoustic Doppler Current Profiler)

ADCPs detect the echoes returned from suspended material (i.e. "sound scatterers") from discrete depths of the water column. Echo intensities, per transmitted pulse, are recorded in counts (also termed the Received Signal Strength Indicator (RSSI), providing indirect information on the currents and density of suspended matter ('backscatter') within each ensonified bin. For the backscatter, the values remain relative as the instrument cannot differentiate the echo intensity from various sources (i.e. suspended sediments, debris, plankton, or air bubbles and high levels of turbulence, e.g. due to waves). This bias complicated interpretation of the datasets, as also quantitative analyses to find correlation with hydro-meteorological datasets.

Currents and turbidity

For recalculation of bin depth to actual depth values, a fixed draught of 4 m was added for RV Belgica; 0.25 m for the Wave Glider. Depending on the blanking distance associated to the type of instrument and the bin size (2 bins are lost), the first depth was around 7 m for the hull-mounted profiles with RV Belgica (for 1 m bins). For the Wave Glider this depth was 12 m, because of contamination of the data in the upper water layers by the submerged part of the Wave Glider. Due to interference with the strong amplitude of the signal near the bottom, 2 bins needed to be removed (i.e., 2 m above the bottom

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off to nearest whole number]; Third quartile [QU]: Value[3 x (number of data points + 1)/4, rounded off to nearest whole number. The interquartile range [IQR] is the difference between the first and third quartiles. An outlier is any point that falls below [(QL – Factor)*IQR] or above [(QU + Factor)*IQR]. A default factor of 1.5 was taken.

are lost for a bin size of 1 m; 4 m for a bin size of 2 m). Pulses were averaged into ensembles at a time interval of 60 seconds per sample. For most of the time series, bottom track pings were available to correct for platform motion. For the Wave Glider data, this averaging process resulted in a horizontal resolution of ± 40 m at an average platform speed of 1.14 kt. The average standard deviation (or accuracy) of current estimates was ± 0.018 ms^{-1} for the 300 kHz ADCP, at 1 m bin size; ± 0.009 ms^{-1} for the 1200 kHz, at 0.05 m bin size ADCP (RDI software). For the HM-ADCP data (RV Belgica), also 60 seconds averaging was applied, resulting in a horizontal resolution of ± 240 m, at an average ship speed of 8 kt. Current errors were around 0.09 ms^{-1}. The horizontal resolution varied with the ship's speed. Errors increased dramatically when using smaller bin sizes for the 300 kHz ADCP.

Algorithms were used to convert the measured RSSI counts to acoustic backscatter in decibels (dB) using the echo intensity scale (dB per RSSI count). This conversion adjusted for beam spreading and acoustic absorption through the water column and provided a quasi-range-independent measure of the relative concentration of sound scatterers in the water column (Kim et al., 2004). Decibel (dB) values were then converted to mass concentrations of suspended particulate matter (SPM in gl^{-1}), by calibration against SPM values derived from water filtrations during several field campaigns. This calibration remained very tedious and is still work in progress given (1) the high spatio-temporal variability of the backscatter in the datasets, (2) the differences in the depth of the water sampling, and (3) variety in the samplers themselves. The ranges of SPM values, obtained from the acoustics, were in similar order of magnitudes as those obtained from water filtrations, though the actual values may still change, when new calibration data become available. For the backscatter, the firmware did not provide error estimates, still it is clear that the larger the bin size the more data are smoother out, and detailed variation will not be detected. Therefore, during some experiments, small bin sizes were used, e.g., to show tide-topography interaction.

In Annexes, C, D and F, the full variation of current magnitude/direction, and backscatter/calculated SPM values are provided, together with localisation maps, wave height and tidal level during the measurements. For further quantitative analyses, time series of currents and SPM were extracted at appropriate levels (e.g., representative for the upper and lower water layers, and depth-averaged). These were visualized separately to distinguish variation more easily and for correlation analyses (Annex E). A running average was applied, mostly over a 20 min window. In some figures, outliers are removed based on statistical analyses[3]. In this report only preliminary correlation analyses are presented. Quantitative analyses on currents and SPM were only performed on the 1 to 2 m bin size data.

Bottom shear stress

Data from the longer-term BM-ADCP deployments were further analysed to calculate bottom shear stresses. For the calculations (e.g., Dyer, 1980), a logarithmic profile was fit to the near bottom velocity data in order to obtain the friction velocity u_* and typify the surface texture by a roughness length, z_0, using the relation

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

where u is the horizontal mean velocity measured at height z above the bottom and κ is the von Karman's constant. The bed shear stress can then be calculated using the friction velocity as

$$\tau_0 = \rho {u_*}^2$$

with ρ the water density.

Here, the first nine cells from the bottom-mounted ADCP were used to fit the logarithmic profile, using a least squares fit. A correlation coefficient (r) was calculated between u and $\ln z$. In addition, an estimation of the errors, associated with the calculation of $u_*$and z_0, was provided using the method of Wilkinson (1983). Error envelopes were calculated and were presented together with the data (Annex C).

3.2.4. Seabed properties derived from acoustical measurements

The very-high resolution multibeam bathymetry and backscatter data that were obtained, in full-coverage, along the central part of the Hinder Banks (RV Belgica ST1208 and ST1309) and along the Oosthinder sandbank in the Habitat Directive Area (RV Belgica ST1319) were processed in grids of a resolution of 1, 2 and 5 m. Tidal reduction (Lowest Astronomical Tide, LAT) was provided by FPS Economy, SMEs, Self-Employed and Energy. Comparison with their bathymetric datasets is underway.

3.2.5. Seabed properties derived from sampling

Seabed samples have not been treated yet. The methodological approach is still under evaluation. See Annex H for photographs of the samples (ST1219; ST1319).

3.2.6. External data

Hydro-meteorological data

Wave information (significant wave height in m, direction of low and high frequency waves in degrees, low frequency (0.03 Hz to 0.1 Hz) wave energy in cm^2) were obtained, at 30 min interval, from a Wavec buoy (Westhinder location, Flanders Hydrography) at 18 km southwest of the study area (Figure 1). Sea surface elevation and 3D currents (10 min interval) were extracted from an operational 3D hydrodynamical model (OPTOS-BCZ, Luyten et al., 2011). Wind velocity and direction (10 min interval) originated from the fixed Westhinder measuring pole (Flanders Hydrography) (for location, Figure 1). A tidal coefficient[4] was calculated to discriminate easily between spring and neap tide and variability in spring tidal levels. In this report, values more than 70 were regarded spring; 50 mid neap tide. During the measurements in the period 2011-2013, a maximum of 87 was calculated.

Topography data

To analyse topography-induced resuspension, the bathymetry and the bathymetric position index (BPI, Lundblad et al., 2006) were derived from very-high resolution multibeam data (Kongsberg Simrad EM3002). Sandbank *vs.* gully was coded, as also the position of the steep and gentle slope, topzone and depression.

Vessel monitoring data (only for the Wave Glider data series)

To detect human-induced variability (e.g., dredging, but also variation induced by wakes of nearby ships) in SPM, ship navigation data were obtained (Schelderadarketen; Van den Branden et al., 2013) and, when relevant, coupled to the time series (e.g., shortest distance to the Wave Glider). To detect dredging-induced sediment plumes, the timing of dredging activities was accounted for. In Annex F, the positions of a dredging vessel are indicated in white dots if during the Wave Glider transect active extraction took place; if not, grey dots were used representing the last dredging cycle. The dredging vessel had a hopper capacity of ~2500 m^3.

MODIS Satellite data

The temporal variation of the C3 turbidity sensor, mounted in the Wave Glider float, was validated using imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) (via MUMM/GRIMAS extraction tool (http://www2.mumm.ac.be/remsem/timeseries/) (Vanhellemont et al., 2011). Main motivation was to have an independent dataset to verify the relative variations in the dataset. For each Wave Glider record a nearest window

[4] For the calculation of the tidal coefficient a methodology was adopted that is commonly used in France, and used by the French Hydrographic Service SHOM (http://fr.wikipedia.org/wiki/Calcul_de_marée). A tidal coefficient represents the amplitude of the tidal level compared to its averaged level and is expressed in hundredths. In France data is used from tidal levels in Brest where a value of 100 is the maximum astronomical tidal level. For this location, regarded as being representative for the Atlantic coast, the values vary between 20 and 120. Values more than 70 are regarded spring tide; those below neap tide. A coefficient of 95 corresponds to average spring tidal levels; 45 average neap tidal levels. For the calculation of the tidal coefficient for Belgian waters an averaged tidal level (TAW) was taken from a 10-yrs elevation data series (2001-2010) from the tidal gauge at Oostende (Vlaamse Hydrografie, 2011). This value (2.339 m TAW) was subtracted from the high water levels at Oostende (Meetnet Vlaamse Banken, HWO) during each campaign. The outcome was first divided by the averaged value of the most elevated tidal levels (i.e., equinox spring tidal levels; for Oostende this equals to 6/2 m TAW, Vlaamse Hydrografie, 2011) and then multiplied with 100 to obtain the value in hundredths. In short the formula is [(HWO-2.339)/3*100].

of 25 pixels (1 km x 1 km) was derived. In the case of no clouds, an SPM value (incl. mean, median and standard deviation) was calculated at each of these pixels. For the correlation with the C3 data, a median MODIS-derived SPM value was retained when measurements could be performed in 13 of the 25 pixels, and when the time span between the Wave Glider and MODIS was less than 2 hours. During the Wave Glider period, the range of the daily image provision of MODIS was between 12h and 13h45 (UTC).

3.3. *Quantitative model validation*

Measurements fed into numerical models (250 m x 250 m grid resolution) for conducting impact assessments under various scenarios of extraction activities. The following models are involved:

3.3.1. Validation of the hydrodynamic model OPTOS-FIN

The three-dimensional current measurements of the hull-mounted ADCP and the current measurements from the longer-term ADCP measurements (BM-ADCP, Wave Glider) were used to validate the OPTOS-FIN model (Luyten 2011). This three-dimensional hydrodynamic model has a grid resolution of 250 m x 250 m and has 10 σ-layers over the vertical. A statistical analysis of the differences between the model results and the observations was executed to determine the accuracy of the model outputs. *See Annex G for a full reporting on the validation, making use of the newly measured current time series.*

3.3.2. Validation of the sand transport models MU-SEDIM

MU-SEDIM model (Van den Eynde et al., 2010) calculates bottom shear stresses and sand transport, using a local total-load transport formula, on a grid with a resolution of 250 m x 250 m. A first task consists of comparing the bottom shear stress, calculated with the numerical model, with the bottom shear stress, derived from the ADCP measurements (see above). The complexity of this task necessitates further data analyses, as well as methodological approaches.

Secondly, foreseen in 2014, the predicted sediment transport magnitude and directions will be compared against sediment transport estimates, derived from sand dune migrations and asymmetries. This work will be carried out in cooperation with FPS Economy, Self-Employed, SMEs and Energy.

3.3.3. Validation of advection-diffusion sediment transport models MU-STM

MU-STM model (Fettweis & Van den Eynde, 2003; Van den Eynde, 2004) calculates advection and dispersion, and erosion and deposition of fine-grained material and (fine) sand in the water column, on a grid with a resolution of 250 m x 250 m. Main validation period is foreseen in 2014-2015.

First simulations were made for the validation of human-induced events, derived from the Wave Glider dataset. Based on Stokes' Law (http://en.wikipedia.org/wiki/Stokes'_law), settling velocities were calculated and used in combination with current information from the measuring pole MOW7 (Location Figure 1) (Figure 4).

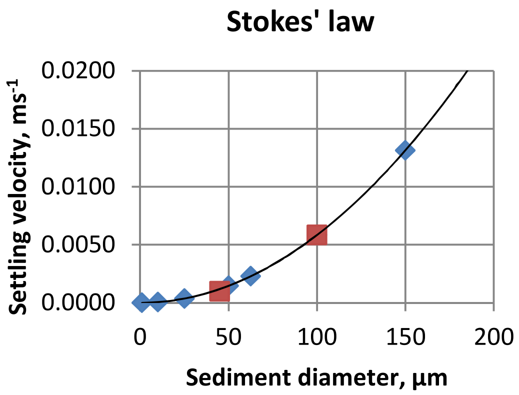

Figure 4. Settling velocities used for particle sizes of 40 µm and 100 µm, based on Stokes' Law.

4. Results

First results are shown for the data collected in the period 2011-2013. All of the data series are shown in Annex A-F, together with relevant hydro-meteorological data, such as tidal level and wave height. Results from a first exploratory data mining are presented. Note that the spatio-temporal nature of the datasets, covering a sandbank-trough topography, and the different depths of the water sampling, complicate the interpretations, and caution is needed when performing time series analyses. In addition, important lag-effects between an event and the detection occur, the latter fully dependent on whether or not its location is within the dispersal radius of a turbidity increase. Moreover, the area is generally deeper, hence imposing a lesser sediment mobility, meaning that additional forcing by waves becomes more important, being less predictable. Hence, hypotheses on the forcing are formulated; these will need further testing when new data become available.

4.1. Natural variation in sediment processes

4.1.1. Tidal variation

From the 13-hrs time series, measured in the period 2011-2013, it was found that surficial currents reached up to 1.2 ms^{-1} during spring tide (Figure 5). In the low water layers (2-3 mab), under spring tidal conditions, currents were measured up to 1 ms^{-1} also. This occurred only over the sandbanks, where currents reached almost similar magnitudes in the upper and lower waters, especially during the ebb tidal phase (Figures E-01 to E-08, Annex E). In the deeper waters of the troughs, the surficial currents were approximately 21 % higher than those in the lower water layers (Wave Glider series, Figure 9).

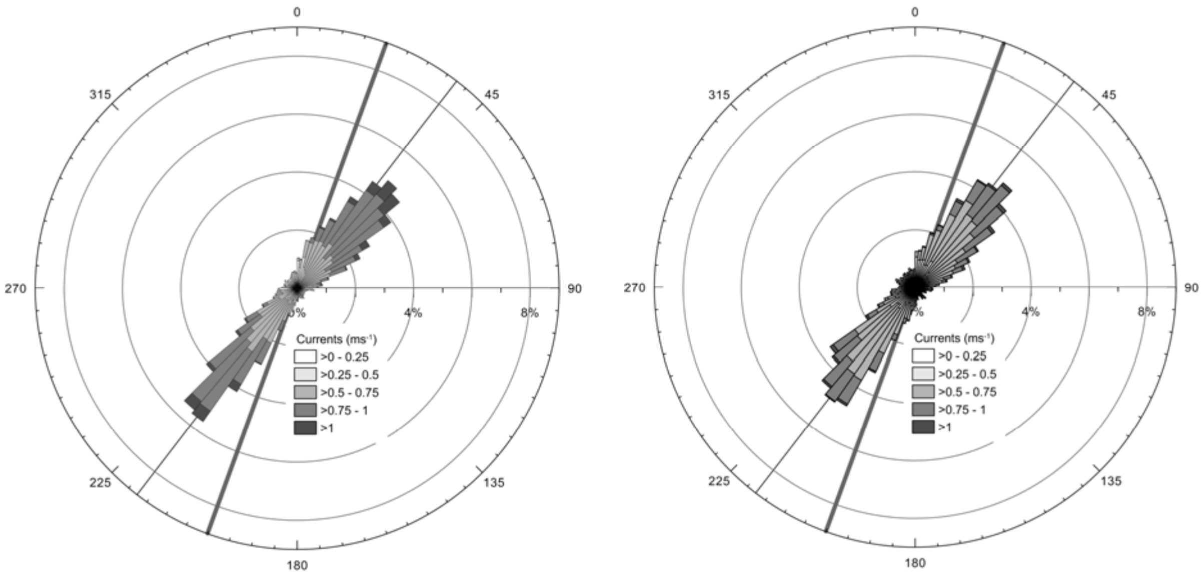

Figure 5. Frequency of occurrence of the currents from all hull-mounted ADCP data series with 1 m bin size. Troughs and sandbanks are covered. Left: Measured currents for the upper water layers (angle of maximum current (--)). Right: for the lower water layers (angle of maximum current (--). Note a clockwise deviation of 17° between the sandbanks' axis (thick line) and the maximum current in the upper water layers (--).

Flood and ebb currents were very competitive for all data series (Figure 5). Generally, the flood tidal phase lasted longer than the ebb tidal phase. This was reflected in the SPM concentration values as well (Figure 7). More fine sediments are transported during flood, though hydro-meteorological conditions and/or human influence may reverse the situation. In the upper water layers, and without influence of events, SPM concentration reached values of approximately 0.003 to 0.005 gl^{-1}; this was fairly consistent in the period 2011-2013, and applied for all data series, and the filtration datasets. SPM concentration in the lower water layers was much more prone to variation, both naturally and sampling-induced. SPM concentration in the lower waters along the Wave Glider trajectory were on average 0.007 to 0.010 gl^{-1} (Figure 6) though with outliers of up to 0.030 gl^{-1} and beyond. The majority of the data were acquired in the troughs, and the sandbanks were mostly crossed under slack water conditions.

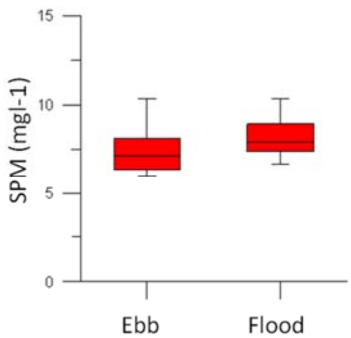

Figure 6. ADCP-derived SPM concentrations throughout the Wave Glider trajectory. Values are mostly representative for SPM concentrations in the troughs. Here, median values and interquartile ranges are shown; outliers were removed.

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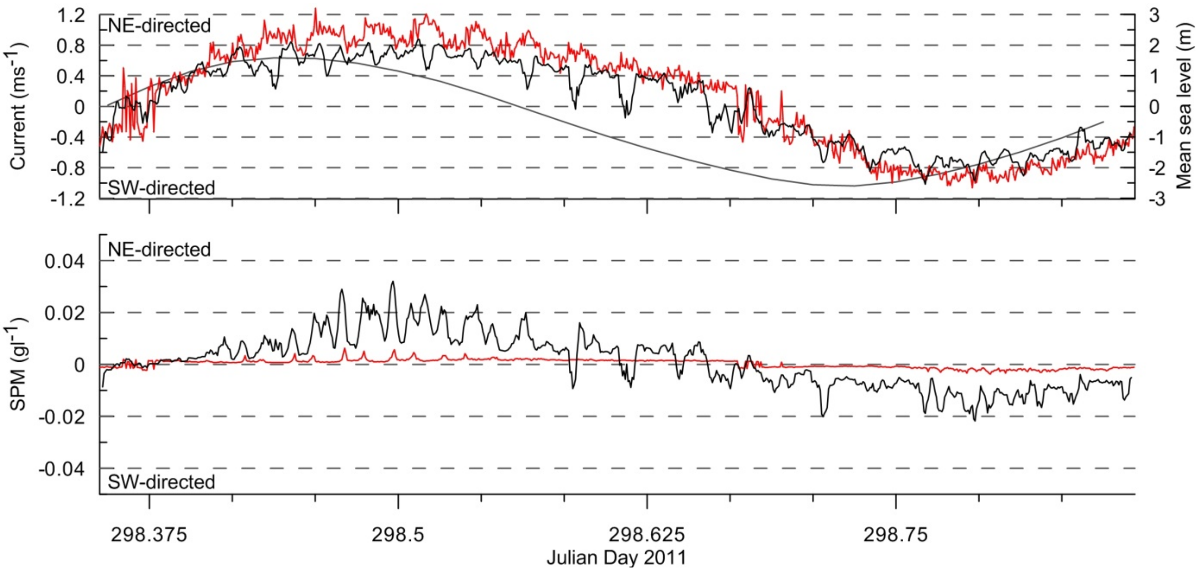


Figure 7. Example of current and SPM variation on a sandbank top and flank, here measured along transects in Sector 4b, north part of the Hinder Banks (Belgica ST1128. 25/10/2011; Spring tide - tidal coefficient 73). Red line related to the upper water layers; black line to the lower water layers. Mean sea level (OPTOS-BCZ) is indicated as well.

Spring-Neap variation

Current velocities clearly increased from neap to spring tidal levels with values up to 1.2 ms^{-1} during the periods with the highest tidal coefficients (up to 87 in the measurement period). Still, hitherto, no quantitative relationship could be derived between current strength and SPM concentrations.

A change of base level (minima of turbidity proxy) from neap to spring could best be observed from the surficial C3 fluorometer sensor data in the Wave Glider (Figure 8) that is a proxy for turbidity. The strong fluctuations in the dataset did hamper deriving a good correlation between the C3 values and the tidal coefficients. The Wave Glider ADCP time series also showed a slight increase in base level for spring, though the increase was less pronounced, probably due to different settings that were used throughout the data series. Neap to mid tidal conditions were measured with 1 m bin settings (part 1 and 3); during spring (part 2), 2 m bins were used for data acquisition (Figure 8).

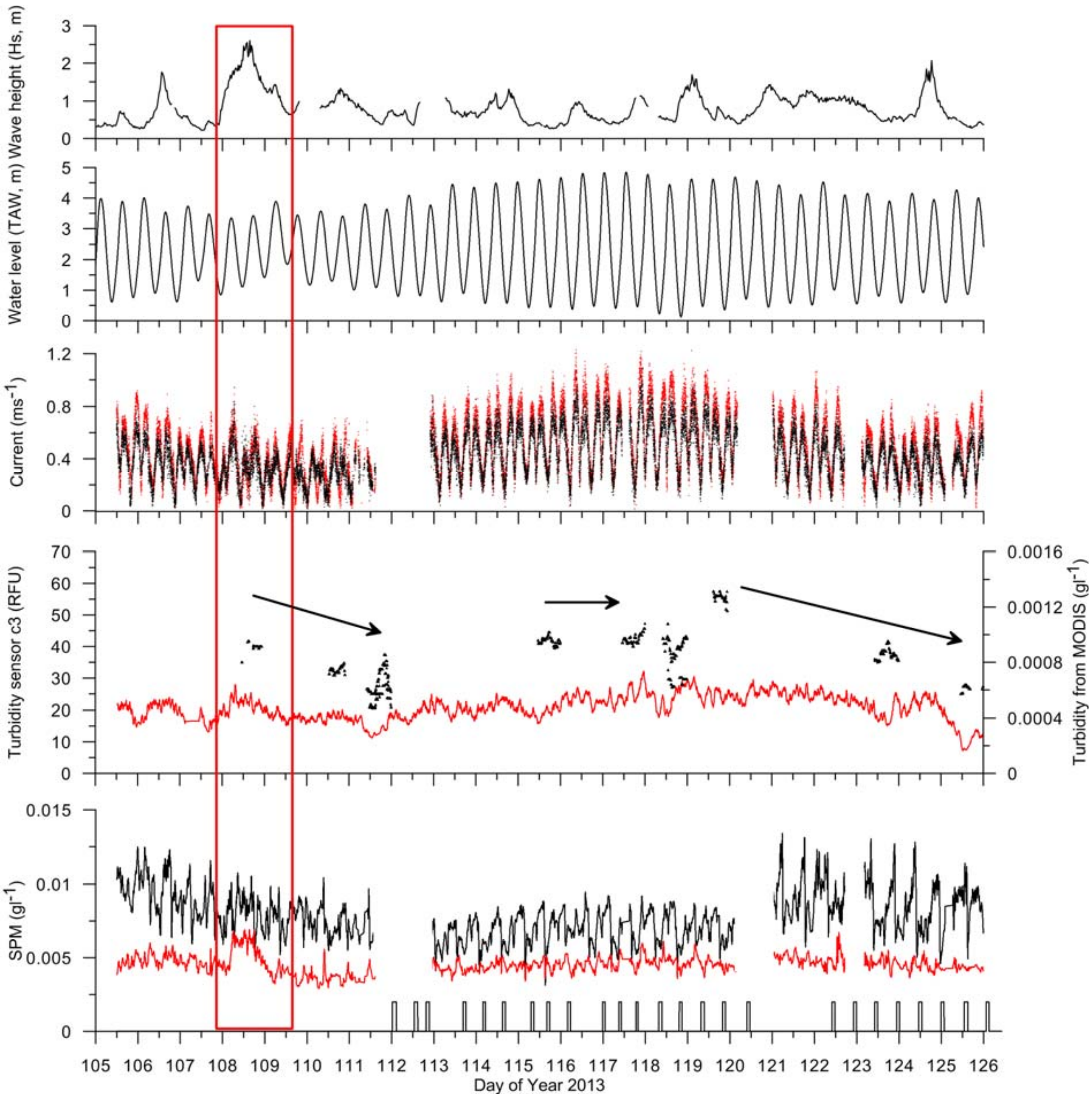


Figure 8. Composite of the Wave Glider data sets, together with the hydro-meteorological conditions. Currents are derived from the Wave Glider ADCP; in red: currents in the upper waters, in black: currents in the lower waters. The C3 sensor provides a proxy for the surface SPM concentration variation. Superimposed are turbidity values derived from cloud-free MODIS satellite imagery data. The multiple values per day represent the closest match-ups along the Wave Glider trajectory. Note similar relative variation (arrows) between the C3 and MODIS data. Lower figure is SPM variation in the upper (red) and lower waters (black), as derived from the Wave Glider ADCP. Note the influence of waves (Day of Year 108-109) in the C3, ADCP and MODIS data, with most variation in the upper waters. Neap to spring variation is most obvious from an increase in the base level, or minimum values, of SPM concentration variation (C3 and ADCP). Markers at the x-axis of the lower figure represent the dates of extraction activities (25 events). C3 and ADCP data are smoothed using a running average of 20'. Red rectangle corresponds with a somewhat rougher period with nearly 3 m high waves.

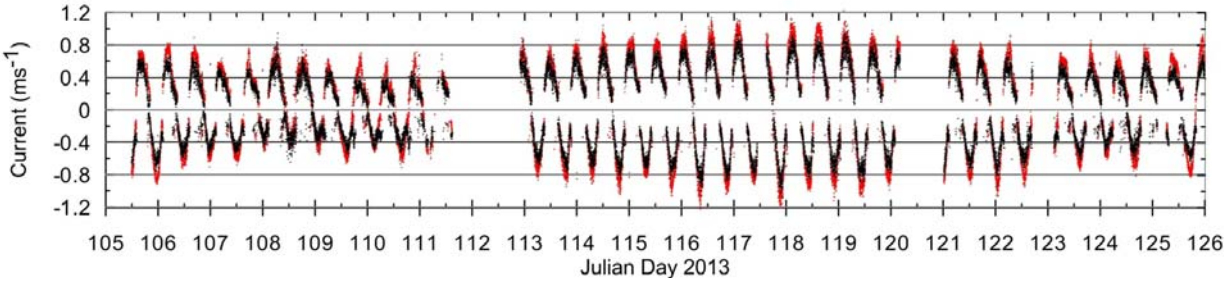


Figure 9. Current variation in the upper (red) and lower (black) waters during a neap - spring (113-120) tidal cycle along the Wave Glider trajectory, covering troughs and sandbanks (15/4 – 6/5 2013). Sandbanks were mostly crossed under slack water conditions. (+) NE-directed (flood); (-) SW-directed (ebb).

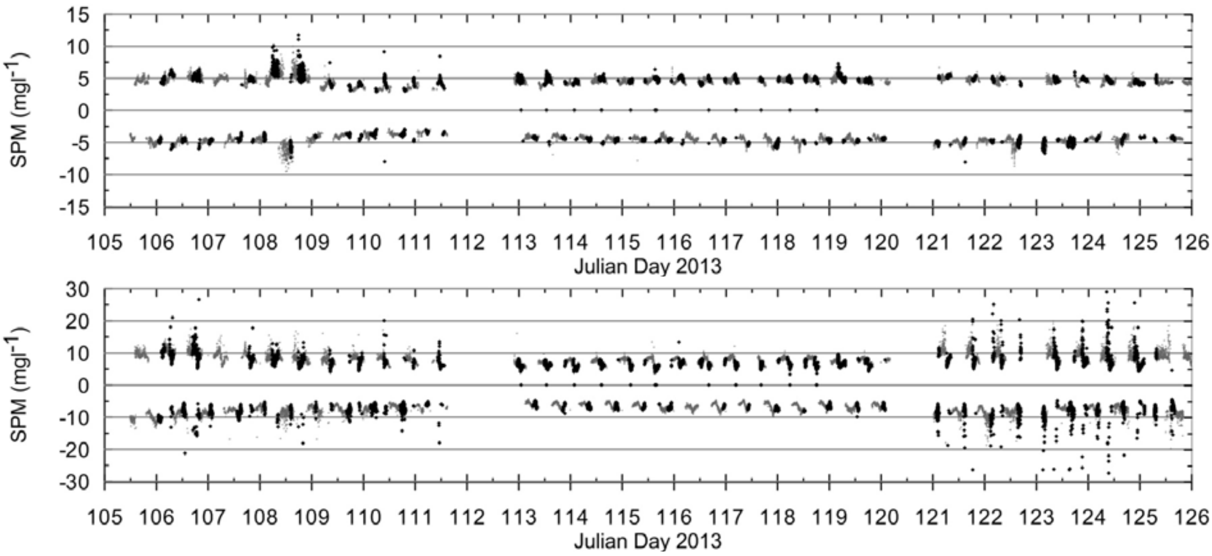


Figure 10. ADCP-derived SPM concentration from the Wave Glider. Top: SPM concentration in the upper waters; Bottom: SPM concentration in the lower waters. Black: data on sandbanks. Julian Days 108-109 correspond with a storm event (wave height ± 3 m, Figure 8), resulting in increased SPM concentration levels; this was mostly visible in the upper waters. (+) NE-directed (flood); (-) SW-directed (ebb).

Topography-induced variation

In the troughs, current ellipses were narrow and elongated, with their southwestern parts to be more narrow and pointed, and their northeastern parts to be more rounded. An increase in current strength was observed over the sandbanks, which is in agreement with previous observations in other areas (e.g., Pattiaratchi and Collins, 1987). Generally, it could be observed that the cross-bank component of the flow increased towards the crest of the sandbanks, because of continuously decreasing depths, together with a decrease in the along-bank component due to friction. Tidal ellipses were more circular than in the troughs. On the western gentle slopes, strongest currents in the upper waters were more or less equally important in the flood and ebb direction, though in the lower waters, the ebb current dominated. On the eastern steep slopes, the ebb tidal current was stronger, over the entire water column.

On the sandbanks, under spring tidal conditions, SPM concentrations in the lower water layers reached 0.020 to 0.040 gl^{-1}, with higher values in the southern part *vs.* the northern part of the Hinder Banks. The topography-induced resuspension was confirmed with data from the water samples: 0.015 gl^{-1} in the northern sectors, up to 0.020 gl^{-1} in the southern Sector 4c. The difference of water-derived values with those from the ADCP might be due to uncertainties in the exact sampling depth that caused difficulties when the ADCP backscatter was calibrated against measured SPM concentrations.

Also, the Wave Glider data series provided clear examples of resuspension above sandbanks, especially along the somewhat shallower north part of Sector 4c (Figure 11; Annex F, e.g., N15, N17, N19 and others). Figure 12 shows rapidly increasing resuspension with increasing wave height.

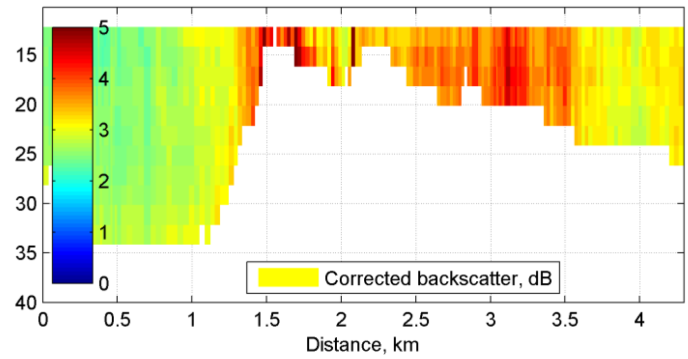


Figure 11. Example of topography-induced resuspension (Hs < 1 m). Here, along the Oosthinder sandbank, north part Sector 4c (Wave Glider data series, Annex F, N15).

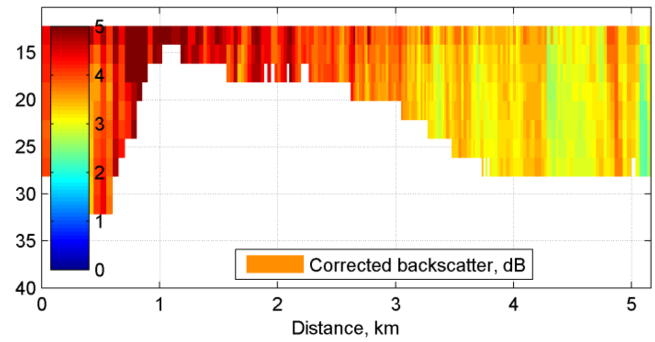


Figure 12. Example of topography-induced resuspension under higher wave conditions (Hs: 1-2 m). Here, along the Oosthinder sandbank, north part Sector 4c (Wave Glider data series, Annex F, N26).

The longer-term in-situ measurements along the eastern steep slope of the Oosthinder sandbank (Annex B, Figures C-01, C-02) showed more in-depth insights. For both time series (June/July 2012 and March/April 2013), having comparable tidal coefficients, the ebb tidal current was clearly stronger than the flood. However, in the water column, higher SPM concentrations were derived during the flooding phase of the tide. This was particularly the case for the 2012 dataset (Figure C-01). Evaluating the bottom shear stresses during the March/April 2013 spring-neap tidal cycle, data showed that bottom shear stresses during ebb are 2 to 3 times higher than during flood (Figure 13). This must have induced a significant resuspension of the sandbank's upper sediments during the ebb. It is hypothesized that these mobilized sediments were subsequently transported away during the flooding phase of the tide. This is an example of a lag effect whereby highest SPM events are lagging behind the forcing that was responsible for the resuspension.

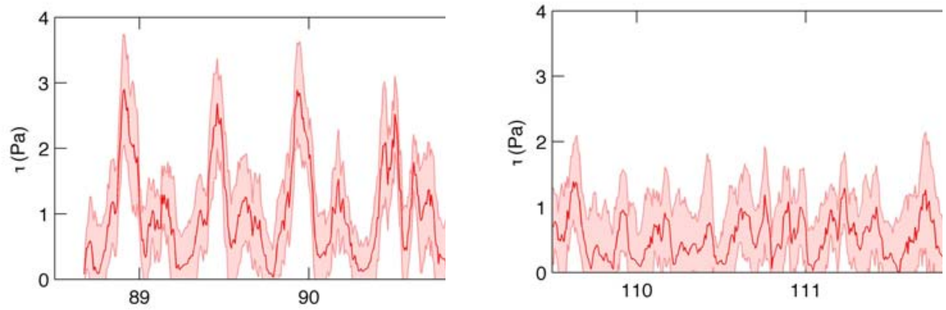


Figure 13. Extract of a 27-days time series on bottom shear stress (with error envelope, based on uncertainties in the calculations), calculated from in-situ BM-ADCP data, acquired along the east flank of the Oosthinder sandbank. Left: Spring tide; Right: Neap. Note the variation in bottom shear stress from 0 to nearly 4 Pa; the significant difference between flood and ebb during spring, fading away during neap tide. Bottom shear stresses during ebb maximum currents are 2 to 3 times higher than during flood. See Annex C for the full time series (30-03-2013 = Day of Year 89; 20-04-2013 = Day of Year 110).

A 13-hrs in-situ data set from July 2012 showed good agreement with this hypothesis (Figure D-07, Figure 14). During the ebbing phase of the tide, resuspension took place of the sandbank's sediment resulting in a local sediment plume that was subsequently carried away by the flood. This explains the SPM concentration values derived from the water samples (Annex A) during this 13-hrs cycle: ebb resuspension resulted in an increase of SPM concentrations from roughly 0.010 gl^{-1} to 0.050 gl^{-1} , then SPM concentration dropped back to 0.005 gl^{-1} and increased again to 0.050 gl^{-1} during maximum flood. Afterwards, background values of 0.005 gl^{-1} were measured again. Such event driven increases in SPM concentrations were measured several times from the water sample filtrations (see Annex B, ST1319, ST1328).

Data series also showed resuspension over large dune structures. Again this was only observed during particular phases of the tide, i.e., mostly during maximum currents. For examples see Figures D-11 to D-16. Due to the particular conditions needed for resuspension, the Wave Glider data series only limitedly showed resuspension over dunes (i.e., mostly crossing of the sandbank during slack waters). The time series over the barchans dunes (July 2013) also showed resuspension in their troughs (Figure D-20). Note that the tidal coefficient during this period was only around 50 (mid tide).

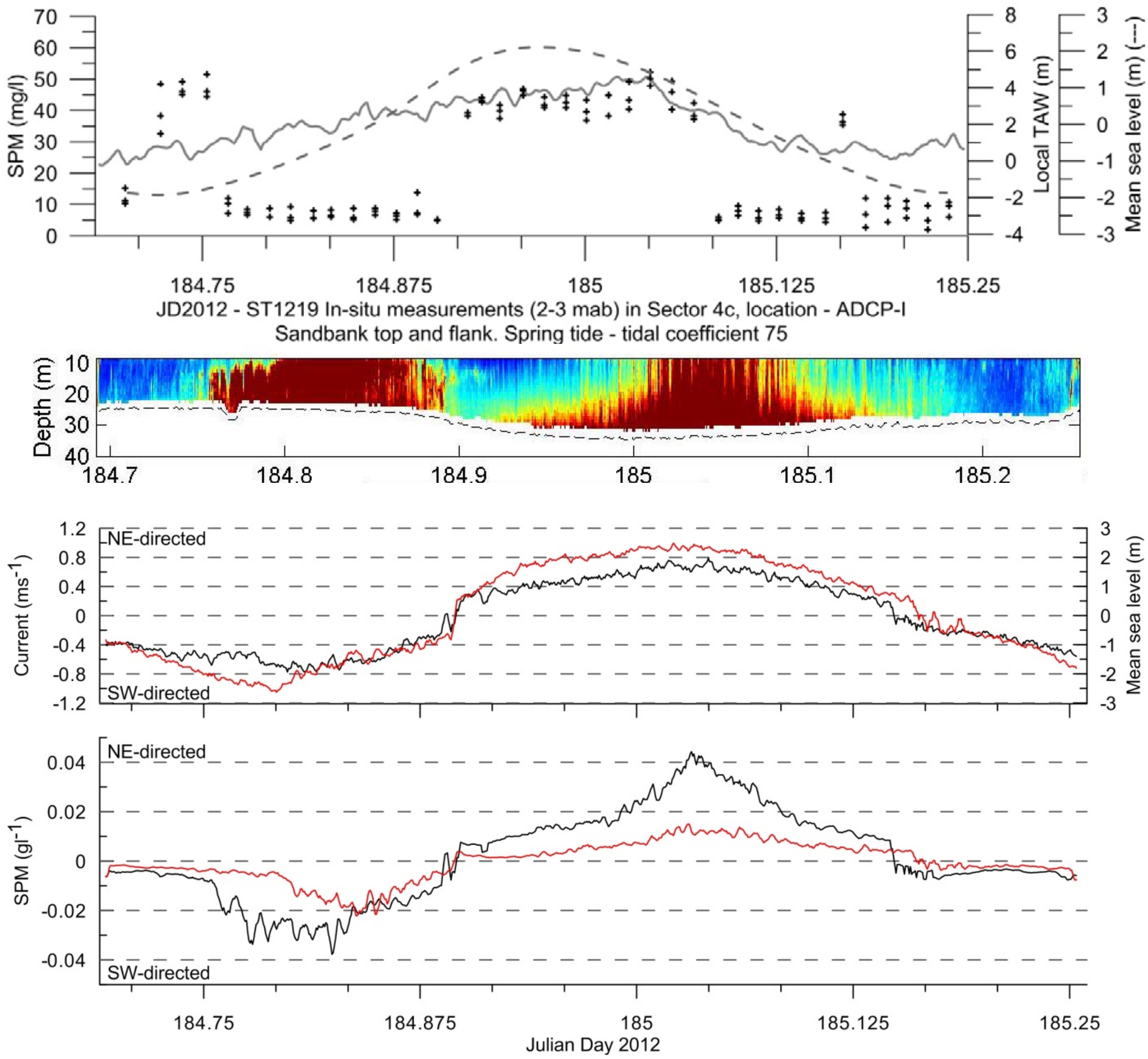


Figure 14. Example of topography-induced variation in SPM concentration, as measured in-situ along the eastern flank of the Oosthinder sandbank. From Upper to Lower figure: (1) SPM concentration derived from water sample filtrations. Dashed line is mean sea level (OPTOS-BCZ); local TAW is the depth variation, calculated from the ships' DGPS; (2) ADCP-derived relative SPM concentrations (blue to red: low to high); with extracted time series of upper (red) and lower (black) currents and SPM values represented in (3). The first SPM concentration increase corresponded with resuspension of the sandbanks' sediments during ebb, giving rise to a sediment plume. This sediment plume is subsequently transported away by the flood current (second turbidity event). Note that the sediment plume is spatially variable, hence can be missed during water sampling.

Data were also available to evaluate the particle sizes of SPM in the water column. For October 2013 (ST1328), Figure 15 shows the vertical variation of the diameter at an average depth of -14 m; Figure 16 and Figure 17 demonstrate the variation during a vertical profile in the water column for flood and ebb respectively. The main modes for the flood were around 10, 75, and 320 μm. For the ebb 10, 80, 190, and 320 μm could be depicted. Modes at 10, 320 μm. For the ebb 10, 80, 190, and 320 μm could be depicted. Modes at 10, 100 and 300 μm were found in the trough of a barchan dune in the Habitat Directive Area (Figure 18). Further research is needed to evaluate whether these sizes correspond with flocs of varying aggregations. As the peaks around 300 μm were present throughout the tide, they likely reflected the presence of plankton. Note that somewhat smaller aggregations were measured during maximum current velocities, with a decrease in volume concentration of the larger aggregations. This pleads for the presence of flocs, next to biogenic particles. However, this was not the case in the trough of the barchan dune in the Habitat Directive Area. Here, larger aggregations also occurred during maximum currents. Further verification is needed on the nature of these aggregations.

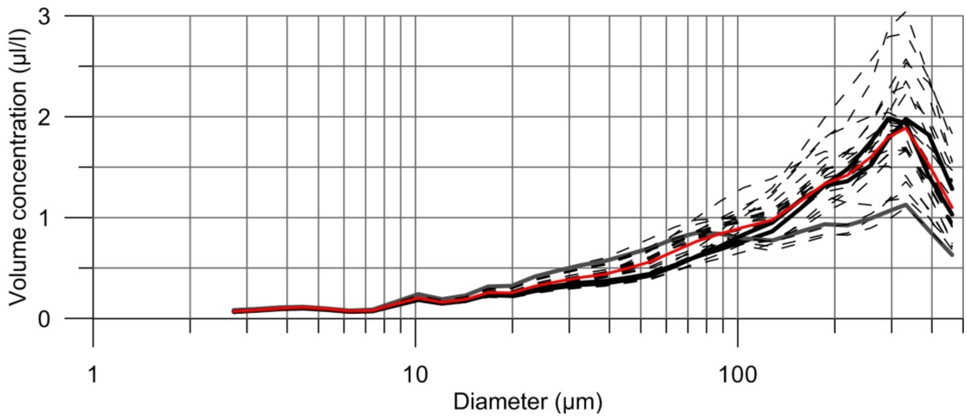


Figure 15. Particle size distribution of LISST measurements during a 13-hrs cycle at an average depth of -14m. RV Belgica ST1328. Sector 4c, eastern steep flank of the Oosthinder sandbank. Thick red line is averaged value of the spectra. Thick grey line is measured during maximum flood; thick black lines during maximum ebb.

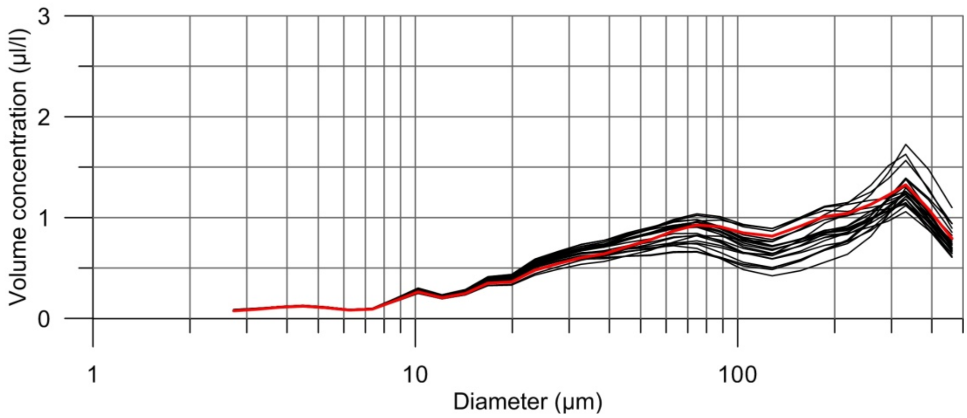


Figure 16. Particle size distribution of LISST measurements during a vertical profile during flood; depth from -11 m to -0.5 m. RV Belgica ST1328. Sector 4c, eastern steep flank of the Oosthinder sandbank. Thick red line is averaged value of the spectra.

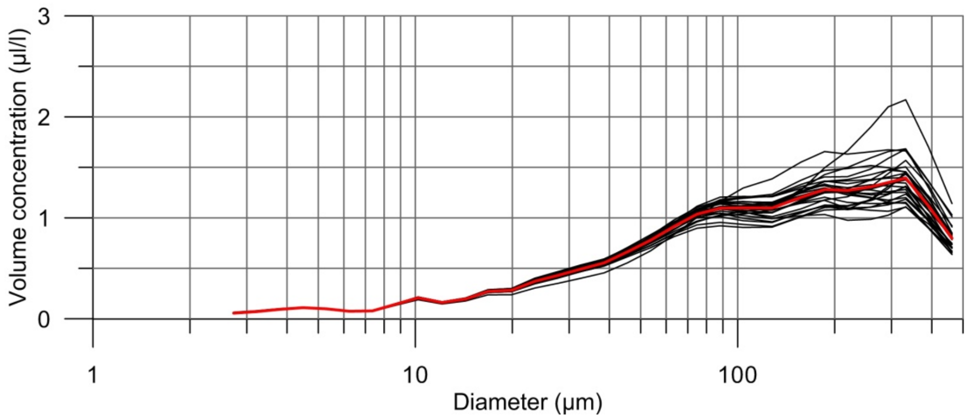


Figure 17. Particle size distribution of LISST measurements during a vertical profile during ebb; depth from -16 m to -0.5 m. RV Belgica ST1328. Sector 4c, eastern steep flank of the Oosthinder sandbank. Thick red line is averaged value of the spectra.

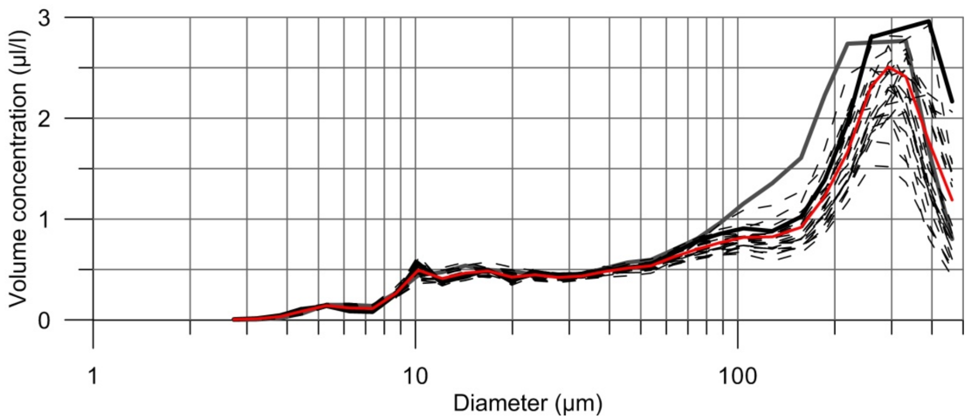


Figure 18. Particle size distribution of LISST measurements during a 13-hrs cycle at an average mid water depth of -18m (seafloor at +/- 33 m). RV Belgica ST1319. Habitat Directive area, trough of a barchan dune. Thick red line is averaged value of the spectra. Thick grey line is measured during maximum flood; thick black lines during maximum ebb.

4.1.2. Wave-induced variation

Deeper lying offshore sandbanks are mainly influenced by tidal currents, though wave resuspension was evidenced from the data, especially over the sandbanks (-8 to -30 m) (Figure 19).

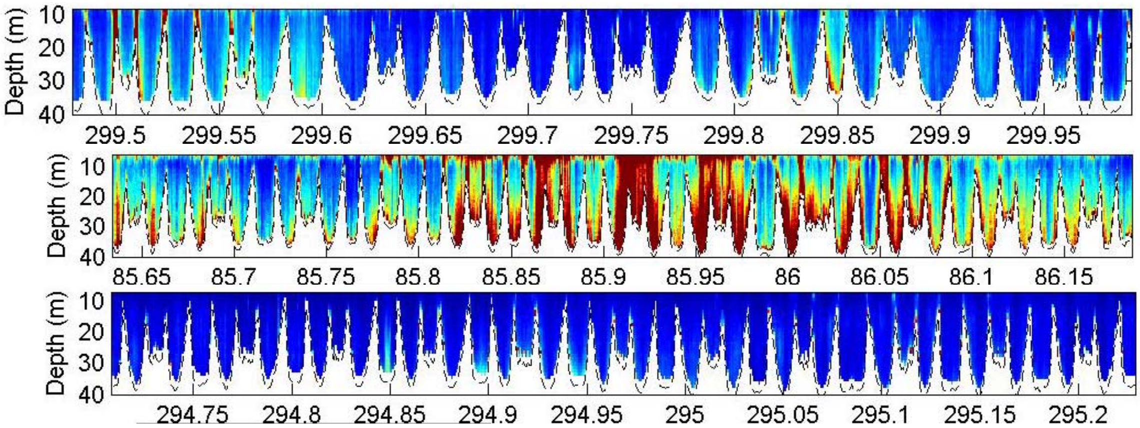


Figure 19. 13-hrs transect over Sector 4c-4d. (1) ST1128. Day of Year 2011 (26/10/2011). Spring tide (86). Wave height around 1 m. (see Figure D-04). Resuspension above the sandbanks during maximum current velocities during flood and ebb; (2) ST1309. Day of Year 2013 (26-27/03/2013). Spring tide (74). Wave height around 2 m. (see Figure D-17). Resuspension above the sandbanks during maximum current velocities during flood and ebb, however overall higher SPM concentration values are derived; and (3) ST1328. Day of Year 2013 (21-22/10/2013). Spring tide (74). Wave height around 0.8 m (see Figure D-21). Limited resuspension above the sandbanks. Blue to red: increasing SPM concentration values.

During ST1309 (26-27/03/2013) only surface water samples could be taken, because of too high waves for vertical profiling and sampling near the bottom. Figure 20 gives the results of the water filtrations. Although the water samples were taken from the seawater pump, prone to more bias, consistent high SPM concentration values were derived.

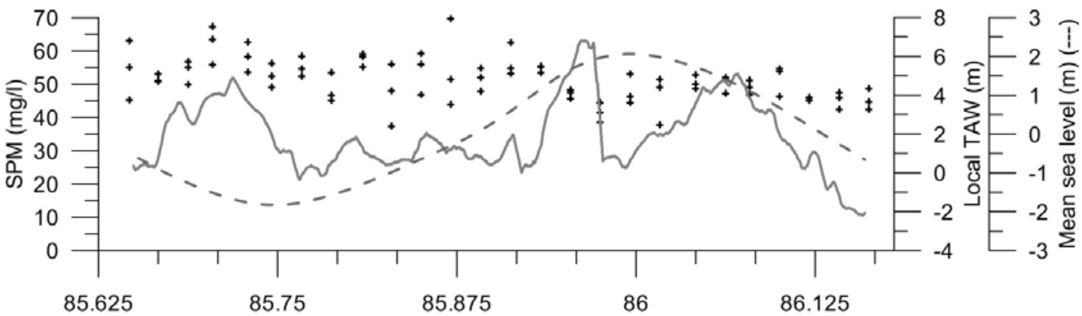


Figure 20. ST1309 (26-27/03/2013). SPM concentration derived from filtrations of water samples taken near the surface (@3.2 m below surface). High SPM concentration values were measured throughout the series. Wave height was around 2 m. Dashed line is mean sea level (OPTOS-BCZ). Local TAW is the depth variation, calculated from the ships' D, and reflects the depth variation throughout the transect.

The Wave Glider data also showed differences induced by wave resuspension. Relative variation of the values of the surface C3 sensor agreed well with variations in wave height (Figure 8). This was also the case for the

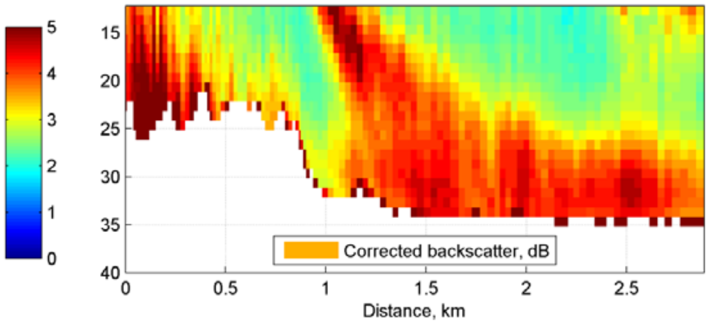
MODIS satellite data (Figure 8), although much less data were available. On a sandbank level (Sector 4c on the Oosthinder sandbank), differences were clearly seen between the shallower northern part (-15 to -20 m) and the deeper southern part (-20 to -25 m). Once sediments are resuspended, SPM concentration increased over a vaster area. It was observed also that under higher wave heights, high backscatter values were recorded at the water surface. It is not clear yet whether this is biased data (e.g., caused by air bubbles) or if it effectively represented high SPM concentration values (e.g., W6, significant wave height Hs: 2-3 m; E6, Hs: 2-3 m; E26, Hs to 2 m; N5-6, Hs: 2 m). Analyses are underway to show the correlation between turbidity and wave parameters.

4.2. *Human-induced variation*

Only the Wave Glider dataset was available to discuss first results on the effects of human-induced variation. During that period, 25 dredging cycles took place using a dredging vessel of ~2500 m^3. Due to natural resuspension of the sandbanks under higher energetic conditions, it proved very hard to quantify natural from human-induced variability from the time series. The Wave Glider did detect, unambiguously, the descending of a dredging-induced sediment plume from the upper waters to the bottom (Figure 21). This detection took place ± 3-hrs after the last extraction event. Extraction took place during the ebbing phase of the tide, hence currents were to the southwest, and also winds blew in this direction.

For this extraction period, all extraction took place during the ebbing phase of the tide. This was related to the need of high water for the disposal operations in the shallow nearshore. This will be the most common situation for all dredging operations in zone 4.

First simulations were done of the pathways of fine sediments after release of a dredging ship, taking into account real hydro-meteorological conditions. Figure 22 and Figure 23 show that particles of 40 µm (silt) can reach easily the Habitat Directive area and that deposition of fines is realistic. Fine sands (63-125 µm) settle in the near-field area. In Year 2, these findings will be further worked out, using the numerical model OPTOS-FIN in combination with MU-STM (see above). Meanwhile, an extensive quantification of the generation and dispersal of dredging-induced sediment plumes is carried out using an independent software package (TASS, Spearman et al., 2011; www.ecoshape.nl).



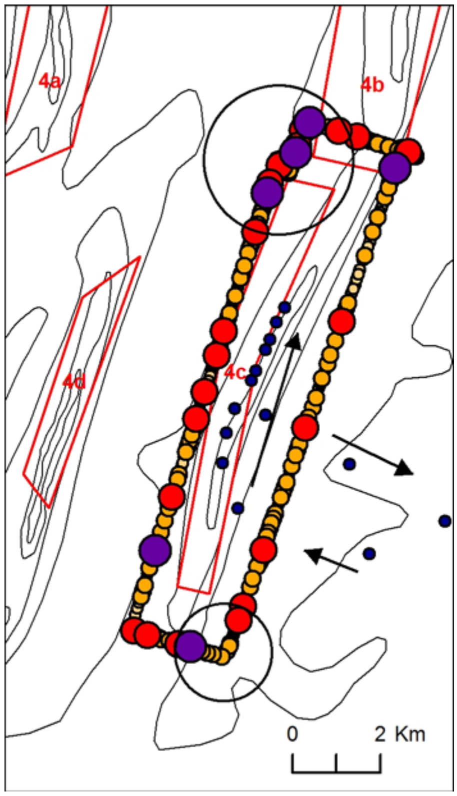


Figure 21. Left: Wave Glider ADCP depth profile showing the deposition of a dredging-induced sediment plume. The plume descended in the southeast corner (lower circle in right figure). Right: C3 sensor data showing relative variation (graduated symbols) in surface SPM after the extraction event (dots in Sector 4c, with indication of the sailing direction of the vessel). Upper circle indicates the C3 variation during the extraction. Extraction took place during the ebbing phase of the tide (to the SW). The descent of the sediment plume took place ± 3-hrs after the last extraction event.

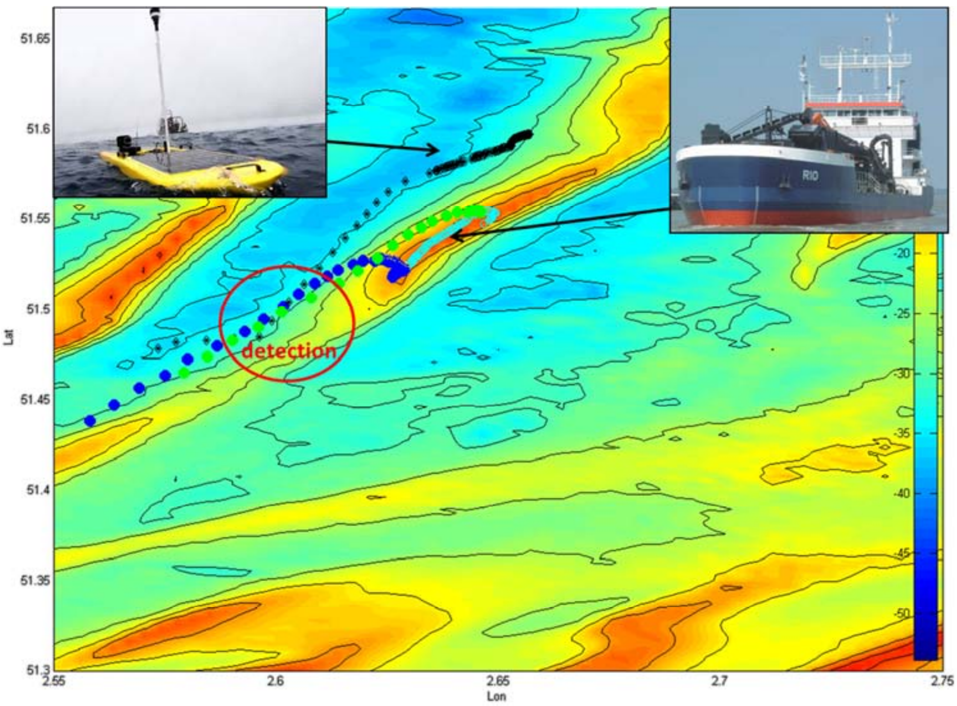


Figure 22. Simulation of the dispersal pathway of silt grains (40 μm; blue: release at the beginning of the dredging; green: particles released at the end of the dredging) after extraction (Sector 4c). For this extraction event, the Wave Glider (black dots) ADCP detected higher SPM concentration values in the water column from the southward end of the western trajectory onwards. Wind, currents and waves were all directed to the SW.

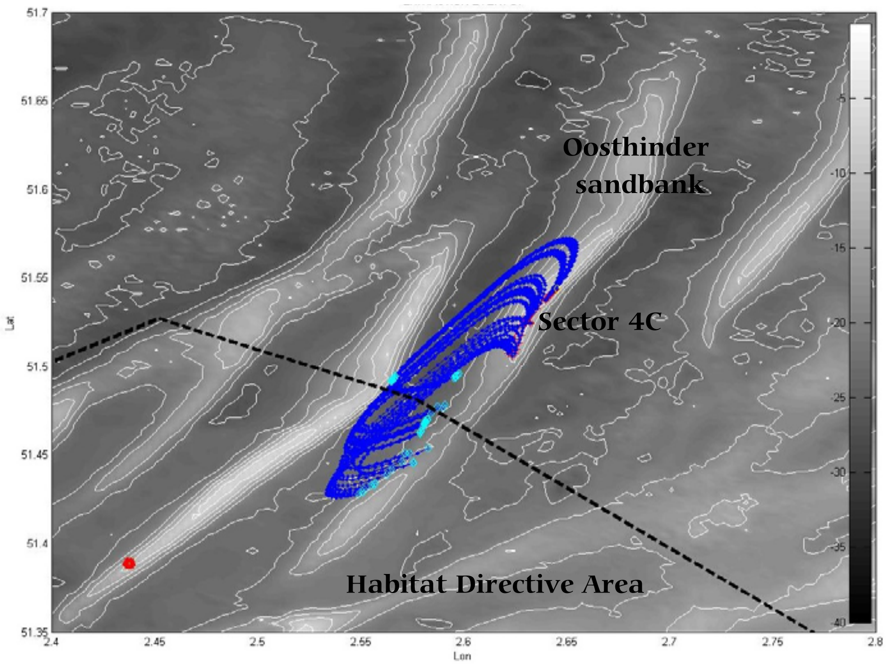


Figure 23. Simulation of the dispersal pathway of silt grains (40 μm) after extraction (Sector 4c) during the ebbing phase of the tide (extraction event 1). Current data were used from the Measuring pole Westhinder, 18 km southwest of Sector 4c (red dot). The simulations show that, in this case, the fine grains would settle in the area of the barchan dunes (cyan dots), where rich gravel beds occur.

Regarding the impact of turbidity increases in the Habitat Directive area, data showed that overall turbidity levels in this area were low (Figures D22-23; E-10). Cross-sectional transects over the Westhinder and Oosthinder sandbank showed lower values than similar transects in zone 4 (Figure 19). Still, the data series in the barchan dune area, west of the Oosthinder sandbank, showed higher ranges in turbidity (Figure D-19, D-20). Sampling along the gravel beds in the barchan dune troughs showed the presence of mud enrichment, both in July 2012 and July 2013 (Figure 24).

Figure 24. Habitat Directive Area. Mud enrichment in the area of gravel beds with rich epifauna. Sample in July 2013 (RV Belgica ST1319).

It is not clear yet whether this mud enrichment is due to the intensive extraction that took place in Spring in 2012 and 2013, or whether it is a natural phenomenon. It is hypothesized that the barchan dunes, due to their pronounced morphologies, are efficient trappers of fine sediments, regardless a natural or human-induced source. Re-investigation of pre-extraction samples and video imagery is needed to validate whether such fine enrichment occurred also historically (Houziaux et al., 2008). It needs stipulating that in the period March-June 2012 intensive extraction took place at a rate of 2 times per day, for 83 days. Main ships had a hopper capacity of ± 4000 to 6000 m³ (Van den Branden et al., 2012). From Autumn 2013 onwards, mainly ships of around 12000 m³ are being used.

Human-induced variation was also clearly visible from the repetitive multibeam depth recordings (RV Belgica, Kongsberg-Simrad 3002D, 300 kHz) along the central part of zone 4 (± 32.25 km²). Data were obtained in March 2012 (ST1208) and 2013 (ST1309). Although these recordings were performed primarily for the identification of larger-scale erosion/deposition areas, the differential map between both campaigns (Figure 25) showed both naturally- and human-induced variation. Dune migration to the northeast was observed for both Westhinder and the Oosthinder, though with overall erosion in Sector 4c where most intensive extraction took place (724.107 m³ in 2012, Van den Branden et al., 2012). The relation with extraction is fully dealt with by COPCO, FPS Economy.

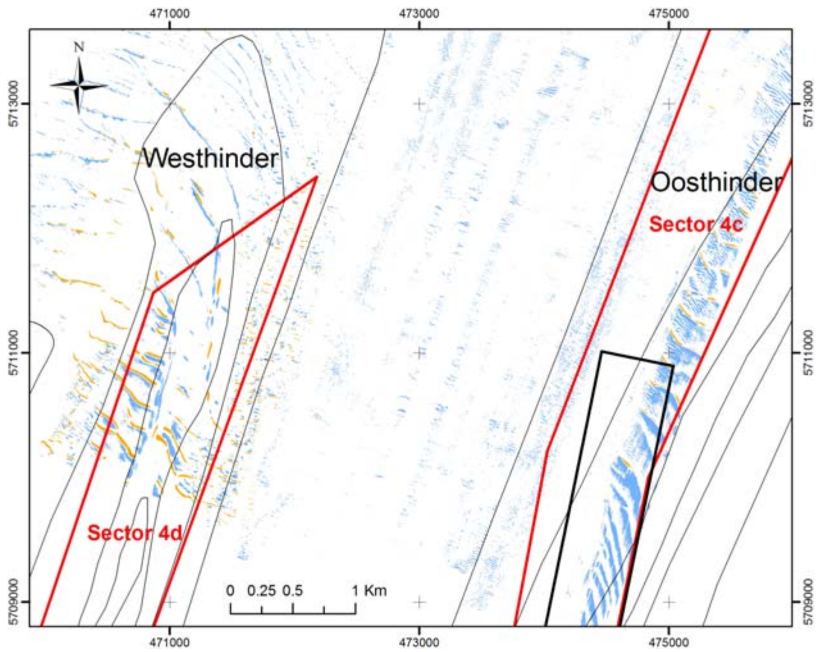


Figure 25. Multibeam bathymetry-derived map of depth differences between March 2013 and March 2012 (UTM-31, WGS84). Blue is erosion (> 1 m); orange: accretion (> 1 m). Red polygons delineate the marine aggregate sectors; black polygon is the extension of the monitoring area of FPS Economy, COPCO. Note the most intensive erosion on the top of the Oosthinder sandbank, partially due to dune migration. Dune migration was also visible on the Westhinder sandbank, though with less overall erosion.

4.3. *Model validation*

Annex G provides an extensive validation of the three-dimensional hydrodynamic model OPTOS-FIN in the new extraction zone 4 in the Hinder Banks region. This validation was important since the model will be used to predict the currents, driving sediment transport models, to assess the impact of the dredging works on the sand transport in the area, and to model sediment plumes.

Previously, the OPTOS-FIN model was validated in the framework of other projects, such as the Belspo MAREBASSE project (Van Lancker et al., 2004), where for the Kwinte Bank region root mean square error (RMSE) values were found between 0.072 and 0.127 ms^{-1}. In the Belspo BOREAS project (Dujardin et al., 2010; Mathys et al., 2012), validation was performed over the entire BPNS. Larger RMSE values were obtained, varying from 0.125 ms^{-1} to 0.218 ms^{-1}, but this could be related to a lower quality of the measurements.

The extensive current measurements, obtained in zone 4, were all used in the validation. This included two longer-term data series from bottom-mounted ADCPs, as also, twelve data series from 13-hrs cycles, acquired with RV Belgica's hull-mounted ADCP. Also the Wave Glider data series along a 22 days trajectory were used.

Comparison between the bottom-mounted ADCP results and the model predictions showed a good agreement. The bias between the measured and the modelled depth-averaged current magnitude was between -0.03 and +0.03 ms^{-1} with a RMSE of less than 0.09 ms^{-1}. Also the directions were well predicted with a RMSE of less than 17°. However, the turning from the ebb to the flood seems to be too late. No big differences were observed when evaluating the currents at the bottom or at the surface separately. The RMSE remained less than 0.12 ms^{-1}. However, surface currents were slightly overpredicted by the model, whilst the bottom currents were slightly underpredicted.

When using the hull-mounted ADCP results, the time step of the time series was much shorter, i.e. 1-minute interval, to take into account the rapidly varying water depths, when crossing the sandbanks and the troughs. When evaluating the depth-averaged currents, the influence of the bin size of the ADCP measurements was clear. For bin sizes, smaller than 1 m, the agreement between the measurements and the model results quickly decreased. The RMSE increased to more than 0.30 ms^{-1} for a bin size of 0.5 m, and to almost 0.60 ms^{-1} for bin sizes of 0.30 or 0.25 m. As was already known, this is due to the bad quality of the measurements of the currents for these small bin sizes. Hence, for the further validation, only the first 7 campaigns were used, where the bin size was set at 1 m. For these campaigns, the bias is between 0 ms^{-1} and 0.015 ms^{-1}, except for one campaign, where the bias was 0.09 ms^{-1}. RMSE varied between 0.062 ms^{-1} and 0.142 ms^{-1}, with a mean

RMSE for all campaigns of 0.106 ms^{-1}. Also the current directions were well reproduced with a RMSE between 8.6° and 23.5°. For one campaign, HM01, there seemed to be a shift in the measurements. Overall, results were highly satisfying, especially taking into account measurements with a moving vessel, hence with changing positions and rapidly varying water depths from the troughs to the sandbanks. Also for the hull-mounted ADCP measurements, a small underprediction was observed for the bottom currents, and a small overprediction for the currents in the different layers. The current directions were well predicted over the entire water column. Finally, it was shown that the RMSE for the current magnitude decreased (slightly) with the total water depth, while the RMSE for the current direction increased with total water depth. Furthermore, the underprediction of the current directions seemed to increase with water depth.

Finally, also the ADCP data obtained with Liquid Robotics' Wave Glider©, were validated against results from the OPTOS-FIN model. The bias for the current magnitude for the three separate periods (with changing parameters for the ADCP) varied between -0.03 ms^{-1} and 0.015 ms^{-1}, with a RMSE around 0.07 ms^{-1}. The RMSE for the current directions remained below 20°. Also in this case, a small overprediction of the surface currents, and a small underprediction of the bottom currents were observed. Overall, the currents at different levels in the water column were very well predicted. It was shown that in shallower water, the current magnitude is slightly overpredicted, whilst in deeper water, the current magnitude is underpredicted. The RMSE of the current magnitude decreased slightly with water depth. Also for these measurements, the underprediction of the current direction was higher for deeper waters, while the RMSE increased with increasing water depths. An overview of the results is given in Table 1.

Table 1. Synthesis of the validation of the current measurements against OPTOS-FIN model predictions (Bias: difference between both; RMSE: root mean square error). BM: bottom-mounted; HM: hull-mounted; WG: Wave Glider.

ADCP Series	**Currents Bias / RMSE (ms^{-1})**	**Direction Bias / RMSE (°)**	**Surface currents RMSE Remarks**	**Bottom currents RMSE Remarks**
BM	-0.03 to +0.03 ms^{-1} / < 0.09 ms^{-1}	/< 17°	< 0.12 ms^{-1} overprediction	< 0.12 ms^{-1} underprediction
HM 1 m bin	0 ms^{-1} to 0.015 ms^{-1} / mean 0.106 ms^{-1}	/8.6° to 23.5° underprediction, highest in deeper waters	overprediction for all layers	underprediction
WG	-0.03 to 0.015 ms^{-1} /< 0.07 ms^{-1}	/<20° underprediction, highest in deeper waters	overprediction	underprediction

Overall, the validation exercise showed that the OPTOS-FIN model had a good performance in extraction zone 4, with good model predictions of current magnitude and current directions.

See Annex G for a full reporting of the results.

5. Discussion and conclusions

Focus of this monitoring programme was the characterization of the hydrodynamic and sediment transport regime in a sandbank area subdued to intensive marine aggregate extraction. Marine aggregate extraction alters the local bathymetry by the direct removal of sediments. However, the duration of the dredging and its magnitude, together with the hydrological regimes (tides, bottom currents, waves) and the sediment grain sizes create significant different responses on the topography of the area. Additionally, fine sediments are released through the overflow during the extraction process. Hydrodynamics and sediment transport, and the interaction with topography, will determine the importance of deposition of fines. This is most critical in the neighbourhood of areas under the Habitat Directive, especially where species, sensitive to siltation, occur. This was of concern in the monitoring programme. To obtain a sound background on the natural conditions, prior to large-scale dredging, and given the variable sandbank – trough topography, a spatio-temporal monitoring design was set-up.

5.1. Results from the spatio-temporal monitoring strategy

Integrated monitoring in the period 2011-2013 provided: (1) 14 data series of water profiling in combination with water sampling, resulting in 976 water filtrations; (2) 23 short-term data series of 13-hrs tidal cycles of currents and turbidity; (3) 5 longer-term measurements of currents and turbidity, including a data series obtained with an autonomous underwater vehicle *Wave Glider*. The latter provided an integrated series of currents, turbidity, chlorophyll-A, and temperature data; (4) 2 full-coverage multibeam bathymetry and backscatter mosaics, recorded centrally in zone 4, and 1 in the Habitat Directive Area; and (5) a series of seabed samples, with 26 Van Veen grabs to characterize seabed texture, 10 boxcores in the surroundings of Sector 4c for vertical grain-size variation in the upper seabed, and 17 Hamon grabs in the gravel area for the follow-up of siltation in the area.

Main aim was to depict the spatial and temporal variations of currents and turbidity in zone 4 of the Hinder Banks. Causes of these variations were discussed distinguishing between natural, hence tidal- and wave-induced, and human-induced variation. Regarding the latter, changes were expected caused by multiple and frequent depositions from dredging-induced sediment plumes.

Evaluation of the results obtained in 2011-2013 leads to the following conclusions on:

(1) Natural variation

- Competitiveness of ebb and flood currents with currents up to 1.2 ms^{-1}. Sandbanks, west of zone 4 (e.g., in Sector 4a) tend to be slightly more ebb dominant than those to the east (e.g., Sector 4b, 4c). Generally, SPM is naturally more transported to the northeast. This is likely due to a natural sediment flux to the northeast, in combination with a somewhat longer duration of the flood current. This was also the case in the Habitat Directive Area.

- In the absence of events, SPM concentrations in the upper water layers varied around 0.003 to 0.005 gl^{-1}. In the lower water layers concentrations increased in the range of 0.007 – 0.010 gl^{-1} in the gullies; and up to 0.020 – 0.040 gl^{-1} over the shallow sandbanks.
- On the sandbanks, an important resuspension by waves was observed. Remobilised sediments are subsequently carried away. Concentrations were measured up to 0.070 gl^{-1} in the upper water layers.
- First calculations of bottom shear stresses resulted in 2-3 times higher values during ebb at Spring tide. This implies that near bottom transport is likely more directed to the southwest. This is especially the case along the eastern steep slopes of the sandbanks.
- First comparison with the geomorphological monitoring carried out by COPCO, and confirmed by the larger scale measurements in 2012 and 2013, showed clear dune migration to the northeast. This might be explained by the availability of sediment, resuspended during ebb, and subsequently transported by the flood current. Compared to the troughs, current ellipses on the sandbanks are more rotary, keeping sediments longer in suspension, hence prone to transport by the upcoming current.

(2) Human-induced variation

- Well-delineated sediment plumes were observed resulting from marine aggregate extraction activities. Sinking and deposition were observed around 8 km off the last dredging activity, in the direction of the ebb current.
- If marine aggregate extraction consistently takes place during the ebbing phase of the tide, fine sediments from dredging-induced overflow deposits will increasingly be transported to the southwest, in the direction of the Habitat Directive Area. It can be expected that the gravel epifauna will be subdued to higher than usual SPM levels.
- First simulations showed that the finest particles (40 μm) can deposit in the gravel bed area after transport during a tidal cycle.
- Gravel beds are most rich in epifauna in the trough of barchan dunes. The pronounced morphologies of these dunes may provide protection from intensive beam trawling, though
- It is hypothesized that the steep gradients of the barchan dunes give rise to eddy formations that trap fine sediment. Data showed rectilinear currents, hence in water depths around 30 m, deposition of fines during slack water is likely. If the fine sediment trapping implies more nutrient supply, this may be beneficial to epi-

fauna development, though if SPM levels increase significantly (e.g., due to human-induced sediment sources), it may have adverse impacts on the long-term. Follow-up is needed to evaluate whether siltation is increasing and whether this can be related to the dredging activities. Simulations are needed that take into account the frequency and intensity of the marine aggregate extraction activities.

5.2. Methodology

On a methodological level, the RV Belgica 13-hrs transect-based monitoring over the sandbanks proved valuable to depict the spatial and temporal variability in the area. However, a 13-hrs cycle remains a snapshot, and valuable data can only be obtained under fair to moderate weather conditions. In addition, it needs emphasis that with the 300 kHz hull-mounted ADCP 2 to 3 m above the seabed are missed out, hence no data are available on near bed sediment processes. A combination with fixed instrumentation (e.g., bottom-mounted frames or benthic landers) remains a necessity to overcome this issue and to obtain longer time series, minimally over a spring-neap tidal cycle. Most importantly, it can provide information under more agitated conditions and storms, the periods when most sediment transport takes place.

Still, calibration of the measurements remains critical and requires in-situ measurements. With the presently used Seacat profiler, water samples and LISST data, could only be retrieved at 2-3 m above the seabed, at best. During stronger tidal currents the profiler was easily carried away and mostly the mid water column was sampled. The uncertain variation in depth complicated the calibration of the acoustic instruments. A heavier frame could lead to more accurate results by reducing bias from frame fluctuations in the water column.

At present, only limited information is available on human-induced variation. Shiptime for monitoring did not synchronize with the timing of dredging activities. So far, only the Wave Glider dataset comprised data that could be related directly to the dredging, e.g., well-delineated sediment plumes, and increased SPM levels. Though, with the moving of the platform an event can be detected only, and no quantification of the extent and evolution of sediment plumes was possible with the chosen survey design. It needs evaluation what kind of information fixed instrumentation can provide. Hitherto, 1 longer-term bottom-mounted frame has been deployed in a period with dredging activities. However, the instrument got buried and is still not recovered. This incident, together with the desire to deploy instruments at more or less protected locations, put important constraints on deployments of benthic landers. In zone 4, there are no fixed measuring poles in the neighbourhood of which instruments could be placed.

The Wave Glider proved being a valuable platform for depicting both naturally and human-induced variation. Events were detected, though these could not be quantified in space and time, as the platform moved away from the event. With the chosen survey design, based on the necessity to sail around the extraction sector on the sandbank, the Wave Glider dataset provided an oversampling of the troughs and an undersampling of the sandbanks. Additionally, sandbanks were mostly crossed during slack water, hence less data were available under maximum currents when sediments are resuspended. From this, the Wave Glider cannot be regarded a substitution for environmental monitoring in sandbank areas, when a large buffer is needed around human activities. Careful consideration of the survey design is needed.

Regarding the use of MODIS satellite data, it should be noted that the derived SPM values are much lower than those measured in the field and/or those derived from acoustic measurements. Still, the relative variations were similar, at least during the Wave Glider period. More in depth-analyses are needed.

5.3. Future monitoring

It remains important to continue the evaluation of natural variability in the area, albeit restricted to selected transects covering the sandbanks. In-situ measurements for calibration remain a necessity. Longer-term deployments are necessary, but are, at present, not possible due to a lack of instruments.

For quantifying the effects of human activities more targeted monitoring efforts are needed: e.g., to derive increases of SPM in the water column and near the seabed. Information is needed on the actual particle sizes in the overflow of the dredging vessel, for which dedicated sampling is needed. To steer the monitoring, it is most critical to have model simulations for different cases of extraction, including the class of vessels, duration and frequency, and their technical specifications (e.g., overflow mechanism). This will determine the magnitude of the potential impacts, both in the near and in the far field. For the monitoring of potential dredging-induced increases in siltation, seabed sampling and visual observations are needed.

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8. Annexes

Annex A-E. Data RV Belgica

Annex F. Wave Glider data series

Annex G. Validation of OPTOS-FIN

Annex H. RV Belgica Campaign Reports

Annex I. Publications

COLOPHON

This report was issued in January 2014

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☒ final version
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☐ confidential

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☒ English
☐ Dutch
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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.

Annexes A-E

A. Overview hydro-meteorological conditions in the measurement periods
B. Overview filtrations 2011-2013
C. Overview longer term measurements 2012-2013
D. Overview short-term measurements 2011-2013
E. Analyses short-term measurements 2011-2013. Time series *Flood vs. Ebb*

These Annexes form part of the report:
Van Lancker, V., Baeye, M., Fettweis, M., Francken, F. & Van den Eynde, D. (2014). Monitoring of the impact of the extraction of marine aggregates, in casu sand, in the zone of the Hinder Banks. Brussels, RBINS-OD Nature. Report <MOZ4-ZAGRI/X/VVL/201401/EN/SR01>.

A. Overview hydro-meteorological conditions in the measurement periods

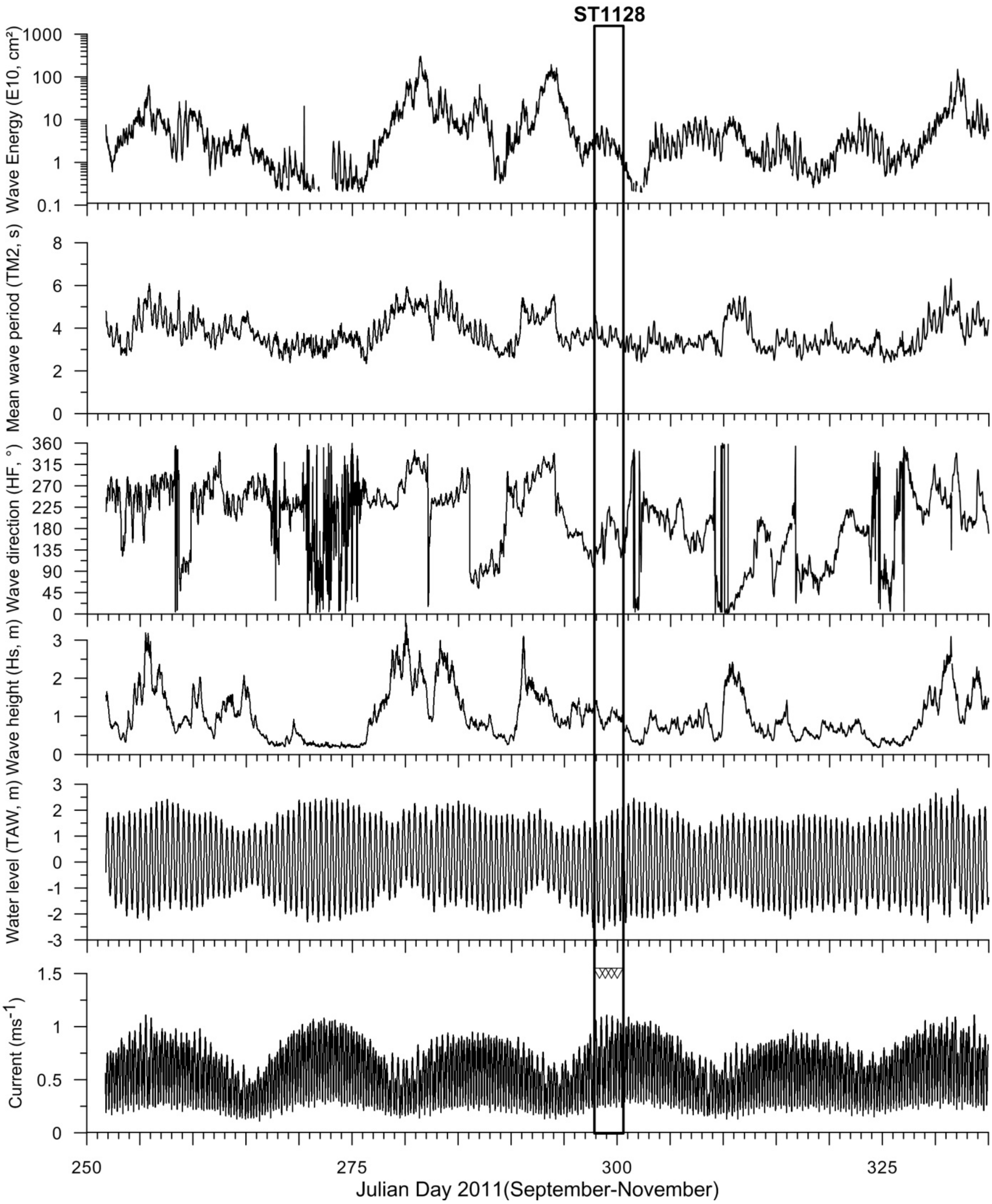


Figure A-01. Hydro-meteorological conditions in the period 1/9 - 30/11 2011. Currents and water levels are modelled values (OPTOS-BCZ). Wave parameters are derived from the Wavec buoy near the Westhinder.

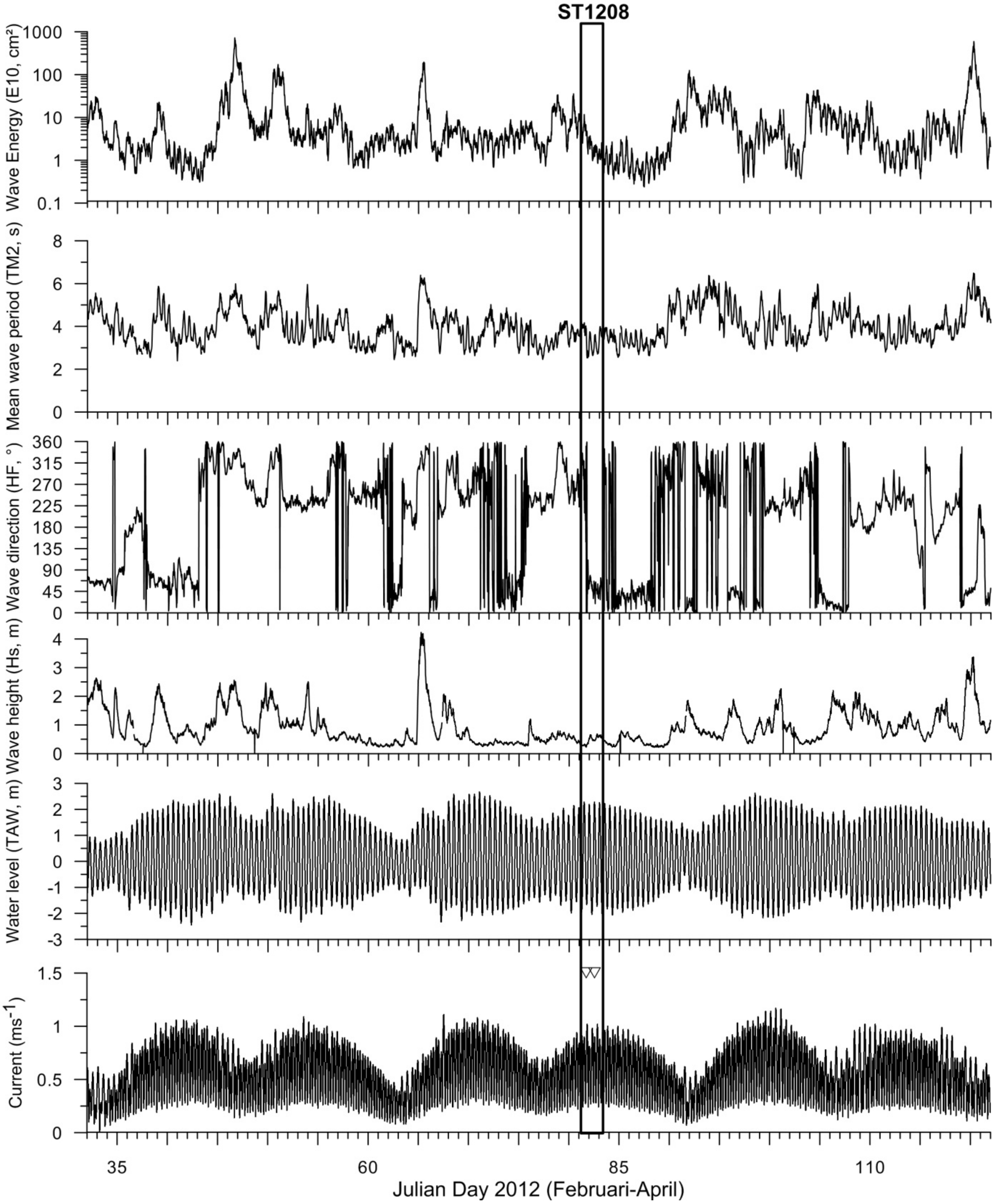


Figure A-02. Hydro-meteorological conditions in the period 1/2 - 30/4 2012. Currents and water levels are modelled values (OPTOS-BCZ). Wave parameters are derived from the wavec buoy near the Westhinder.

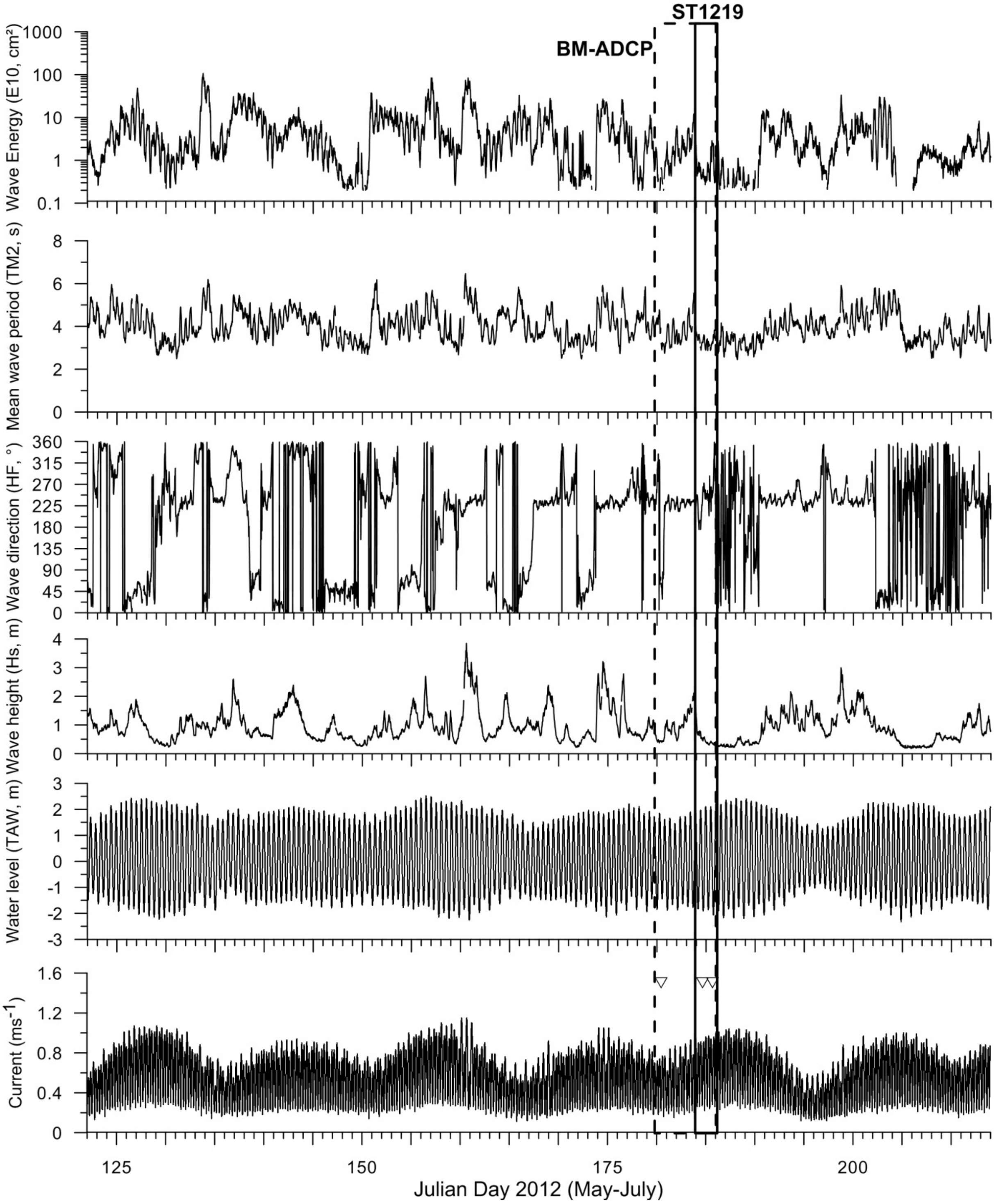


Figure A-03. Hydro-meteorological conditions in the period 1/5 - 31/7 2012. Currents and water levels are modelled values (OPTOS-BCZ). Wave parameters are derived from the wavec buoy near the Westhinder.

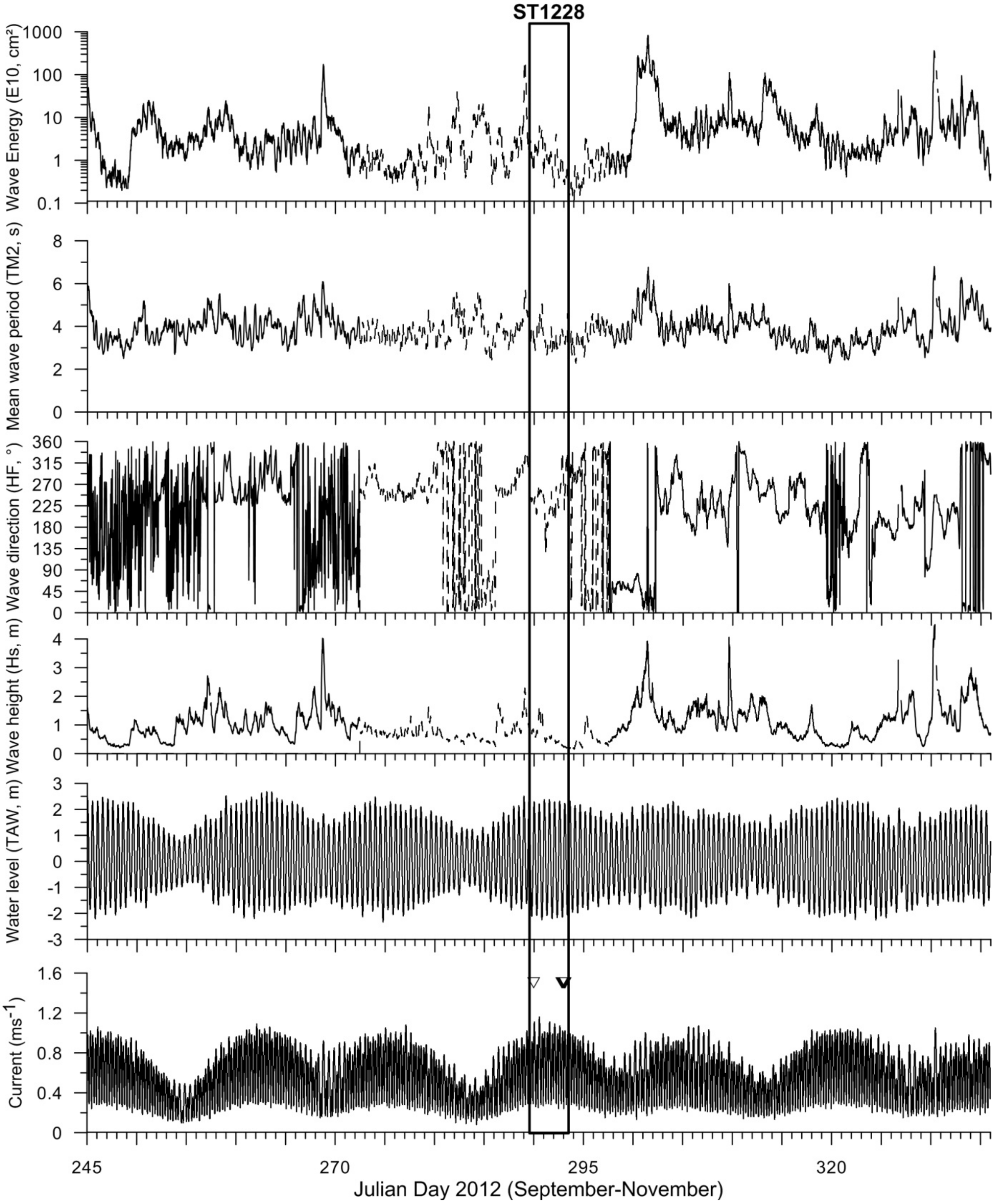


Figure A-04. Hydro-meteorological conditions in the period 1/9 - 30/11 2012. Currents and water levels are modelled values (OPTOS-BCZ). Wave parameters are derived from the wavec buoy near the Westhinder. No wave data were available for the period 28/9-23/10 2012; data were taken from the wavec buoy near Bol van Heist (dashed line).

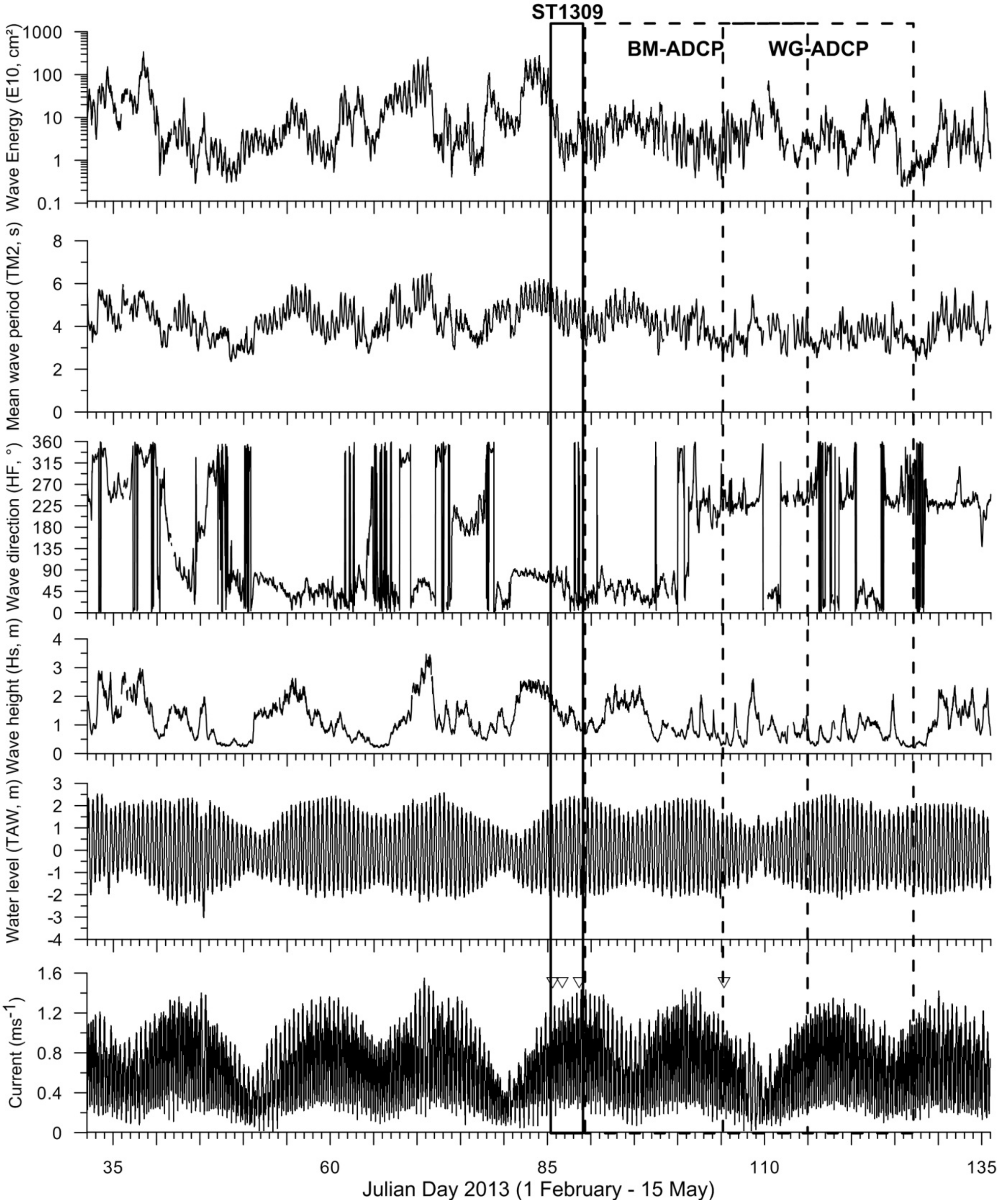


Figure A-05. Hydro-meteorological conditions in the period 1/2 - 15/05 2013. Currents and water levels are modelled values (OPTOS-BCZ). Wave parameters are derived from the wavec buoy near the Westhinder.

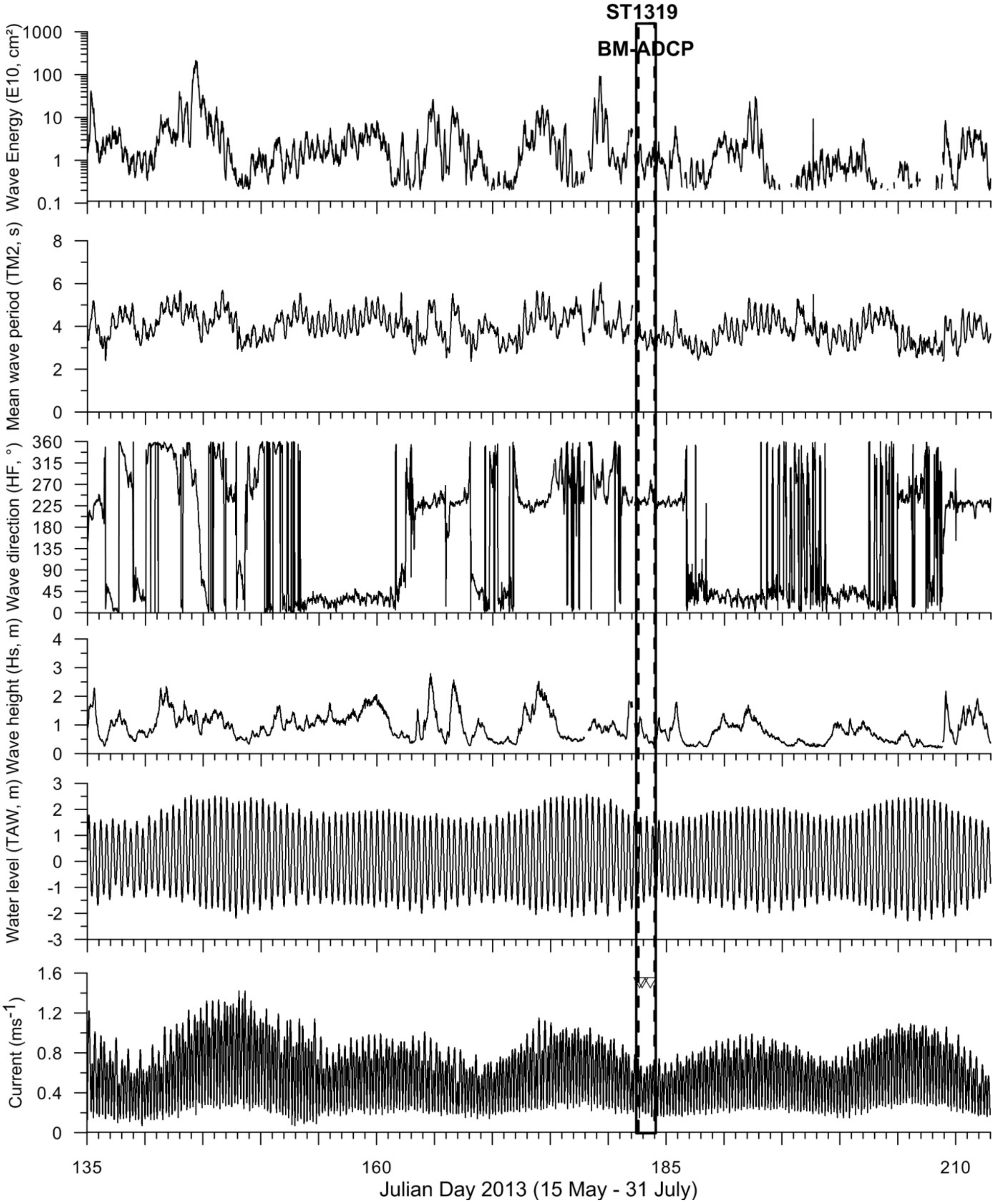


Figure A-06. Hydro-meteorological conditions in the period 15/5 - 31/07 2013. Currents and water levels are modelled values (OPTOS-BCZ). Wave parameters are derived from the wavec buoy near the Westhinder.

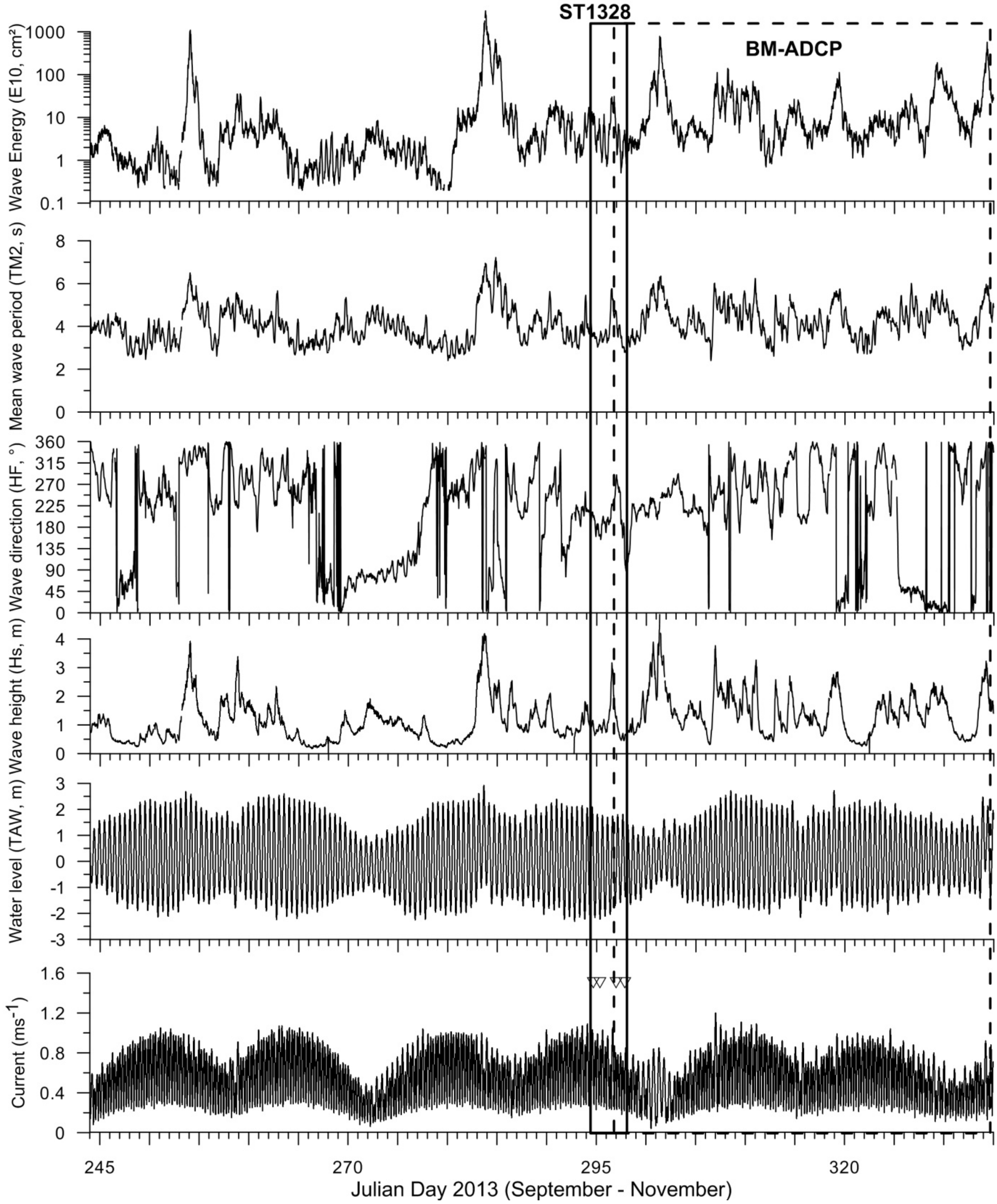


Figure A-07. Hydro-meteorological conditions in the period 1/9 - 30/11 2013. Currents and water levels are modelled values (OPTOS-BCZ). Wave parameters are derived from the wavec buoy near the Westhinder.

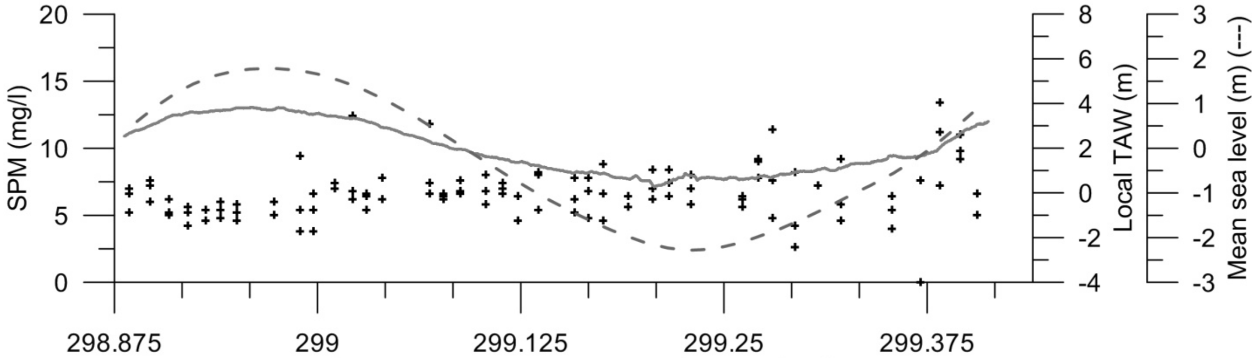
B. Overview filtrations 2011-2013

Tabel B-01. Overview of campaigns (2011-2013) during which water samples were taken during 13-hrs cycles. JD: Julian day, calculated per year.

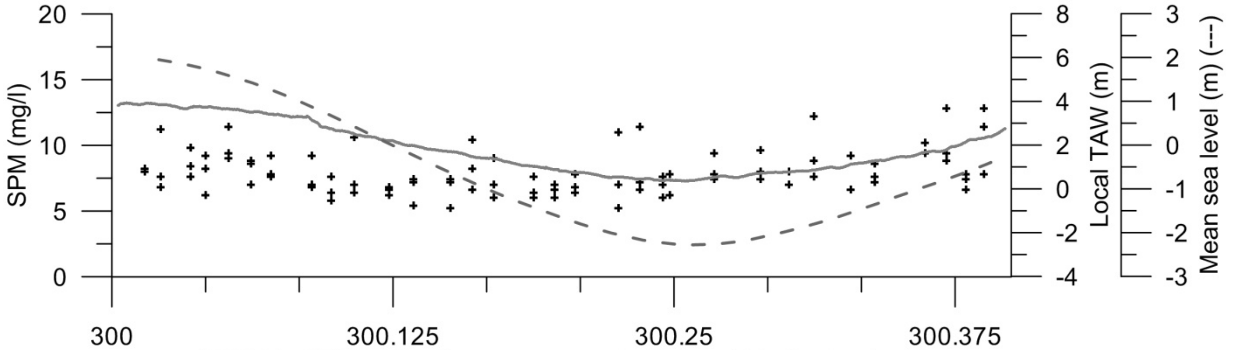
Nr	Campaign	Sector	Time1	Time2	JD1	JD2	Duration
1	ST1128	4b	2011-10-25 21:13	2011-10-26 09:44	298.88	299.41	12.52
2	ST1128	4d-4c	2011-10-27 00:21	2011-10-27 12:26	300.01	300.52	12.08
3	ST1208	4b-4c	2012-03-21 18:06	2012-03-22 05:29	81.75	82.23	11.37
4	ST1208	4a	2012-03-22 14:24	2012-03-23 02:52	82.60	83.12	12.47
5	ST1219	4c	2012-07-02 16:47	2012-07-03 05:42	184.70	185.24	12.91
6	ST1226	4b-4c	2012-10-16 00:15	2012-10-16 04:43	290.01	290.20	4.46
7	ST1226	4b-4c	2012-10-17 23:16	2012-10-18 04:54	291.97	292.20	5.65
8	ST1226	4c-4d	2012-10-18 19:14	2012-10-19 04:10	292.80	293.17	8.93
9	ST1309	4c-4d	2013-03-26 15:31	2013-03-27 03:54	85.65	86.16	12.39
10	ST1319	HD area-Trough barchan dune	2013-07-01 18:00	2013-07-02 07:00	182.75	183.29	13
11	ST1319	HD area - Transect barchan dunes	2013-07-02 15:31	2013-07-03 05:29	183.65	184.23	13.97
12	ST1328	4c-4d	2013-10-21 17:16	2013-10-22 05:15	294.72	295.22	11.99
13	ST1328	4c	2013-10-22 20:00	2013-10-23 08:58	295.83	296.37	12.97
14	ST1328	Buffer Zone 4 - HD area	2013-10-23 23:43	2013-10-25 05:47	296.99	298.24	30.07 *split*

Tabel B-02. Additional information on the filtration series (2011-2013). T_coeff: Tidal coefficient calculated for water levels at Oostende (≥ 70: spring; 50: mid neap tide). Hs: Significant wave height Westhinder measuring pile (*: data Bol van Heist).

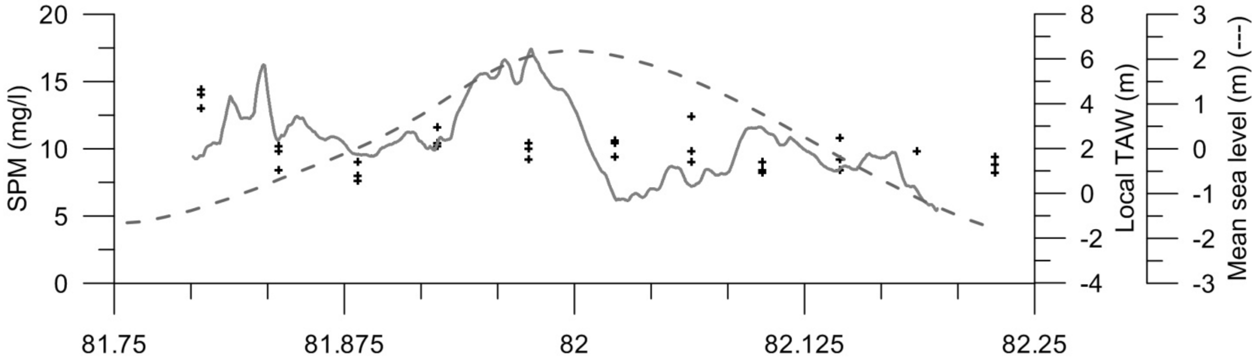
Nr	Sampler	Tidal phase	T_coeff	Hs (m)	Remark
1	SBE19-L-10l; 2-3 mab	Spring	73	0.91	In-situ sampling
2	SBE19-L-10l; 2-3 mab	Spring	86	0.94	In-situ sampling
3	SBE19-L-10l; 2-3 mab	Mid	67	0.49	In-situ sampling
4	SBE19-L-10l; 2-3 mab	Spring	74	0.59	In-situ sampling
5	SBE19-L-10l; 2-3 mab	Spring	75	0.44	In-situ sampling
6	AUMS_SAMPLER@3.2m	Spring	82	0.66*	For calibration AUMS
7	SBE19-L-10l; 2-3 mab	Spring	87	0.43*	
8	AUMS_SAMPLER@3.2m	Spring	85	0.25*	For calibration AUMS
9	GPUMP@3.2m	Spring	74	1.65	Transect sampling, because of too high waves
10	GPUMP@3.2m	Mid	60	0.76	Due to technical problems, sampling of surface waters only
11	GPUMP@3.2m	Mid	50	0.39	Transect sampling
12	GPUMP@3.2m	Spring	74	0.77	Transect sampling
13	SBE19-L-5l; -16 to -20m depth	Spring	78	1.06↑	Due to technical problems, sampling at mid water column
14	GPUMP@3.2m	Spring	77	0.69↓	Transect sampling



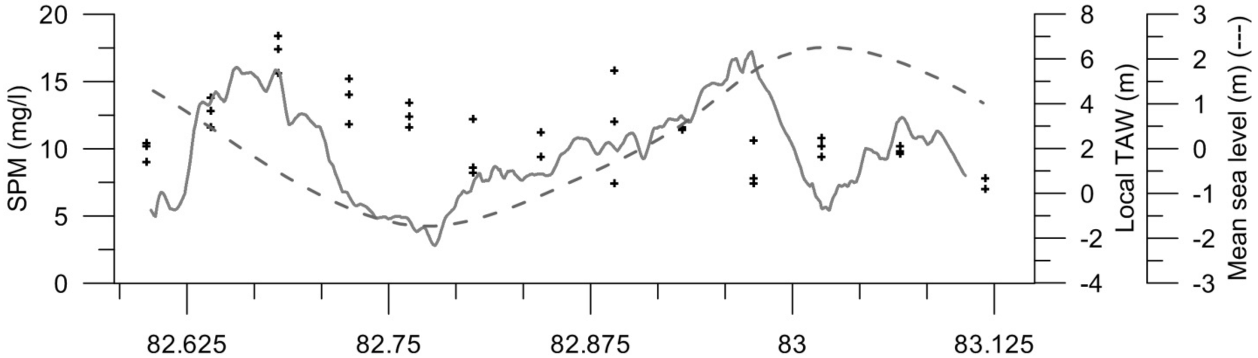
JD2011 - ST1128 In-situ measurements (2-3 mab) in Sector 4b
Sandbank top and flank. Spring tide - tidal coefficient 73



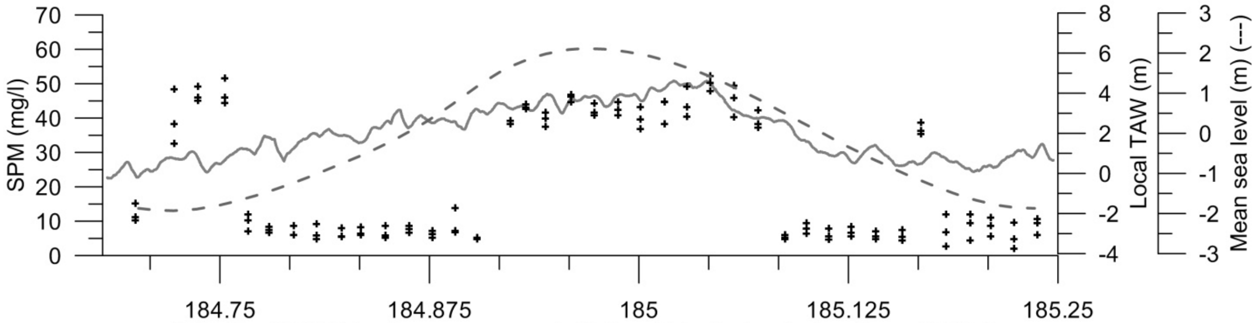
JD2011 - ST1128 In-situ measurements (2-3 mab) in Sector 4c-4d
Sandbank top and flank. Spring tide - tidal coefficient 86



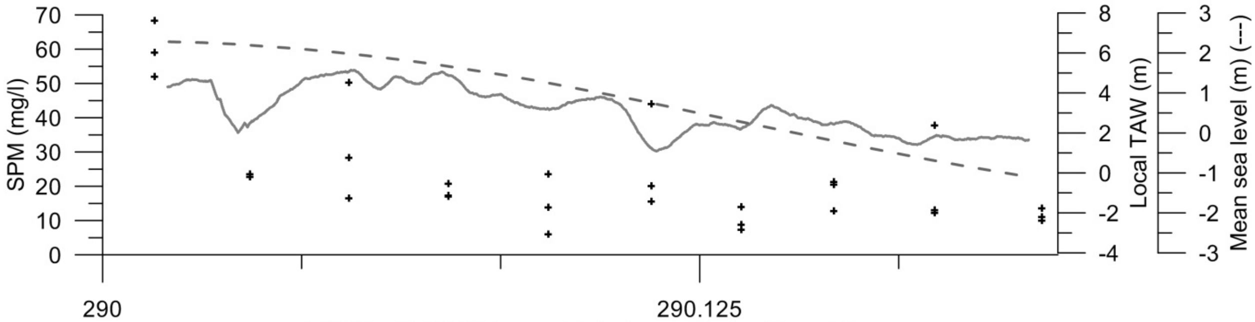
JD2012 - ST1208 In-situ measurements (2-3 mab) in between Sector 4b and 4c
Sandbank top. Spring tide - tidal coefficient 67



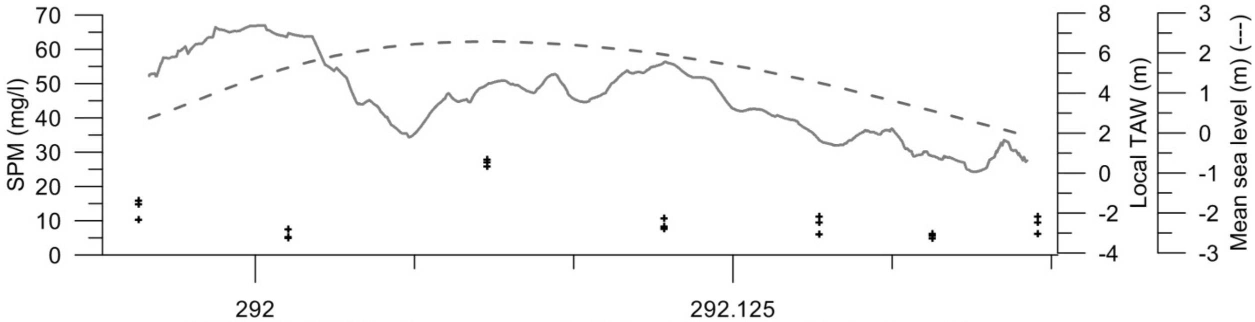
JD2012 - ST1208 In-situ measurements (2-3 mab) in Sector 4a
Sandbank top. Spring tide - tidal coefficient 74



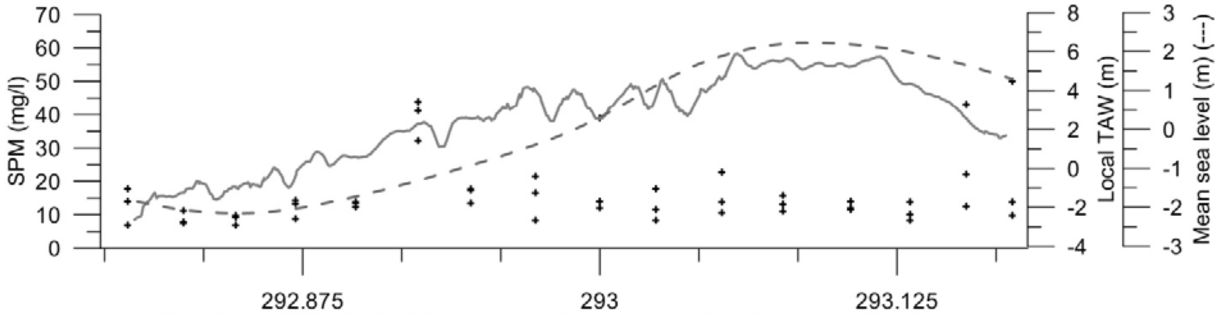
JD2012 - ST1219 In-situ measurements (2-3 mab) in Sector 4c, location - ADCP-I
Sandbank top and flank. Spring tide - tidal coefficient 75



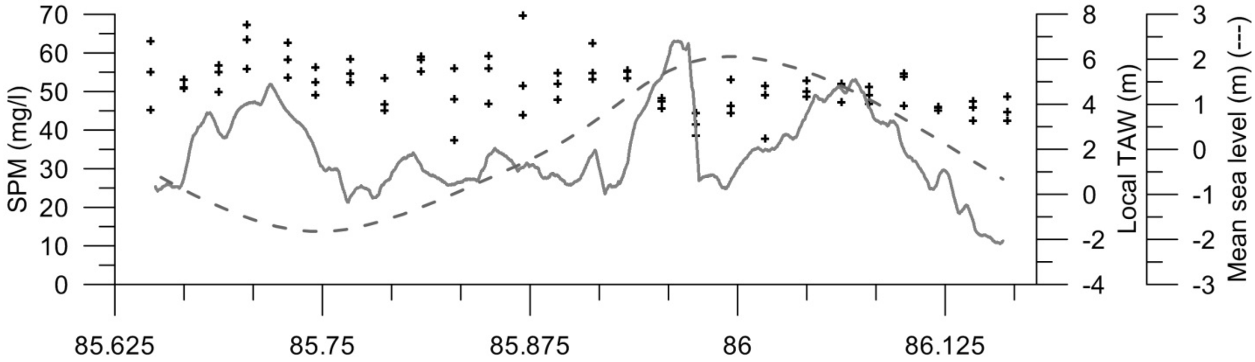
JD2012 - ST1226 Transect in between Sector 4b and 4c
Near surface (@3.2m) AUMS sampling. Spring tide - tidal coefficient 82



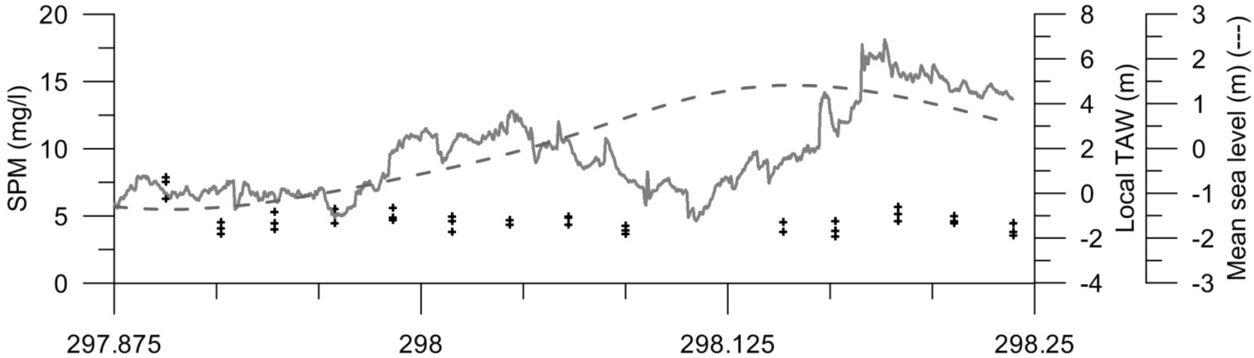
JD2012 - ST1226 In-situ measurements (2-3 mab) in between Sector 4b and 4c
Sandbank flank. Spring tide - tidal coefficient 87



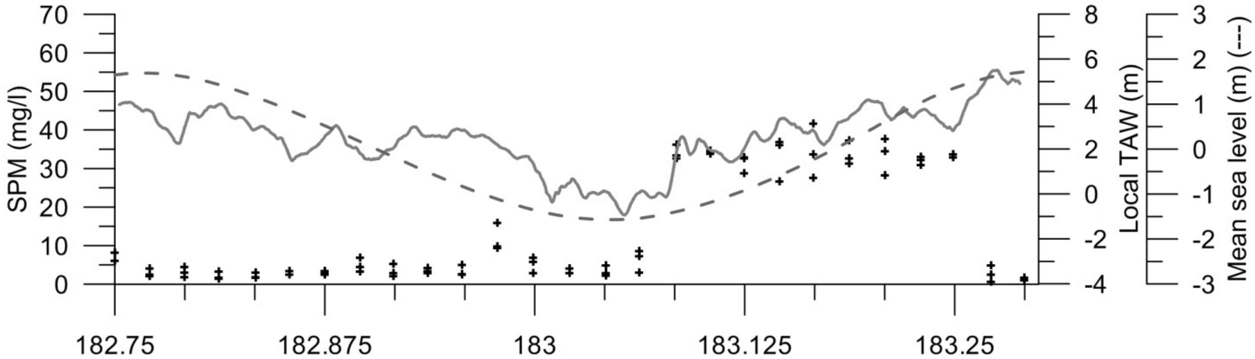
JD2012 - ST1226 Habitat Directive area. Transect over Oosthinder and Westhinder
Near surface (@3.2m) AUMS sampling. Spring tide - tidal coefficient 85



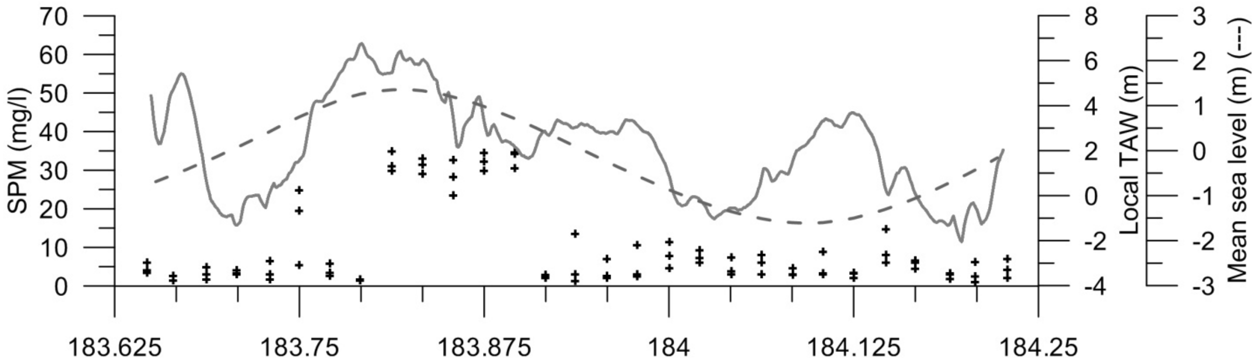
JD2013 - ST1309 Transect over Sector 4c-4d
Near surface (@3.2m) sampling. Spring tide - tidal coefficient 74



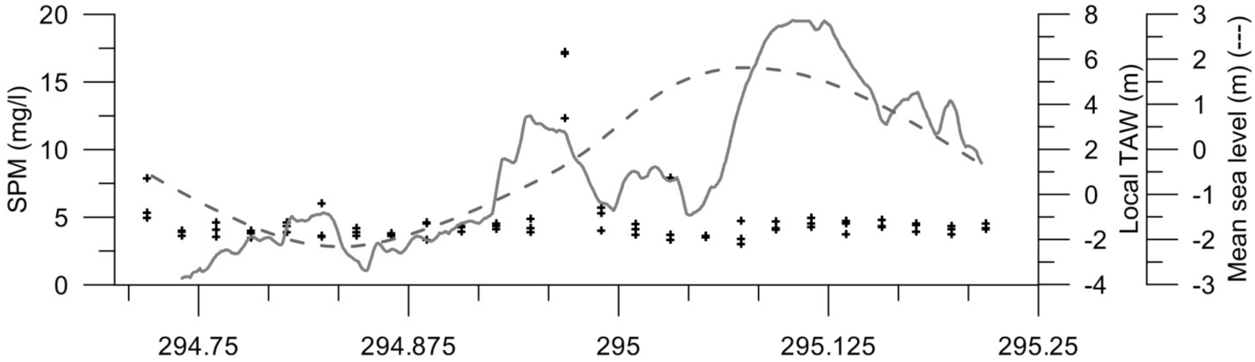
JD2013 - ST1328 Transect along Buffer zone 4 - Habitat Directive area
Near surface (@3.2m) sampling. Spring tide - tidal coefficient 77



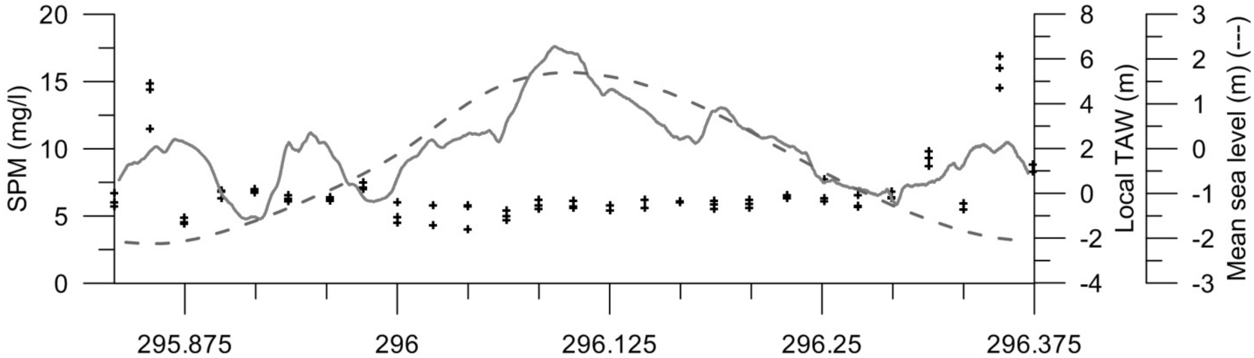
JD2013 - ST1319 In-situ measurements (near surface (@3.2m) sampling), Habitat Directive area
Trough barchan dune. Mid tide - tidal coefficient 60



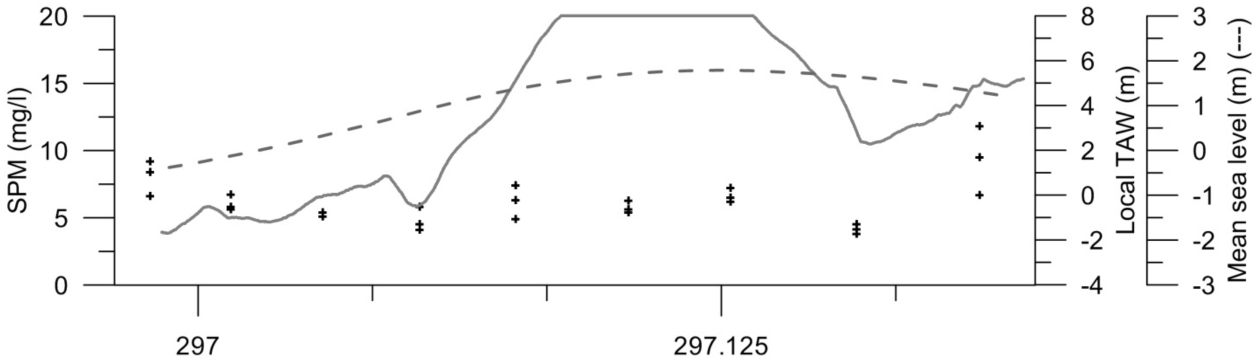
JD2013 - ST1319 Transect over barchan dunes in Habitat Directive area
Near surface (@3.2m) sampling. Mid tide - tidal coefficient 50



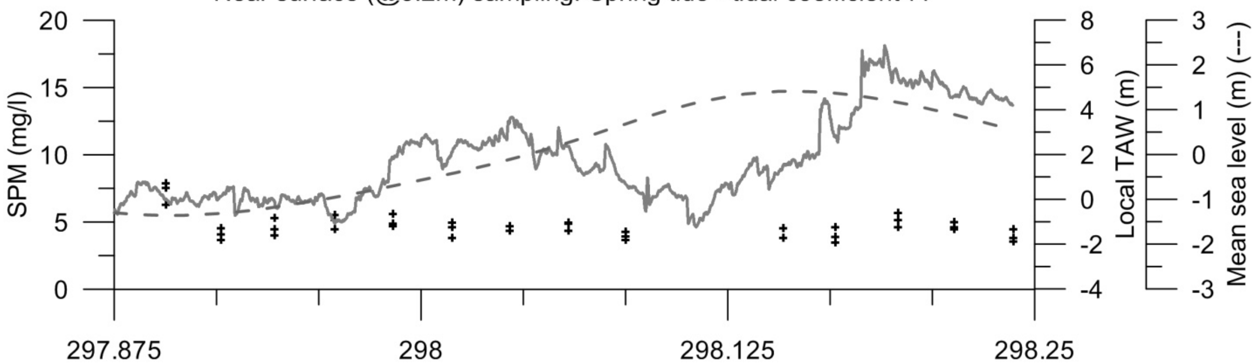
JD2013 - ST1328 Transect over Sector 4c-4d
Near surface (@3.2m) sampling. Spring tide - tidal coefficient 74



JD2013 - ST1328 In-situ measurements (depth -10 to -15m) in Sector 4c. Location ADCP-I
Sandbank flank. Spring tide - tidal coefficient 78



JD2013 - ST1328 Transect along Buffer zone 4 - Habitat Directive area
Near surface (@3.2m) sampling. Spring tide - tidal coefficient 77



JD2013 - ST1328 Transect along Buffer zone 4 - Habitat Directive area
Near surface (@3.2m) sampling. Spring tide - tidal coefficient 77

C. Overview longer-term measurements 2012-2013

Table C-01. Longer term measurements with bottom-mounted broadband ADCP and Wave Glider.
JD: Julian day, calculated per year.

Nr	Time1	Time2	JD1	JD2	#Days	ADCP kHz	Bin size	Start bin
1	2012-06-28 11:06:11	2012-07-04 16:06:11	180.47	186.67	6.21	1228.8	0.25	0.81
2	2013-03-27 16:10:59	2013-04-25 13:50:58	88.67	115.58	26.90	1228.8	0.25	0.81
3	2013-04-15 08:05:15	2013-05-07 07:29:50	105.34	127.31	21.98	300	1-2	
4*	2013-07-01 22:12:00	2013-07-04 10:00:00	182.92	185.42	2.49	1228.8	0.25	0.81
5*	2013-10-22 08:44 local	*Not yet recovered*	295.36	NA	NA	1228.8	0.25	0.81

**not processed*

Table C-02. Location of bottom-mounted ADCP and Wave Glider.

Nr	ID	Location	Position (WGS84)
1	ADCP-I	Oosthinder eastern steep fank	51°30.558'N, 002°37.814'E
2	ADCP-I	Oosthinder eastern steep fank	51°30,577'N, 002°37,800'E
3	WG-ADCP	Around Oosthinder, Sector 4c	*Wave Glider trajectories*
4	ADCP-GRAVEL	Oosthinder, western flank. Trough barchan dune	51°24.781'N; 002°31.603'E
5	ADCP-I	Oosthinder eastern steep fank	51°30.970'N; 002°37.949'E

See Annex F for the full Wave Glider data series.

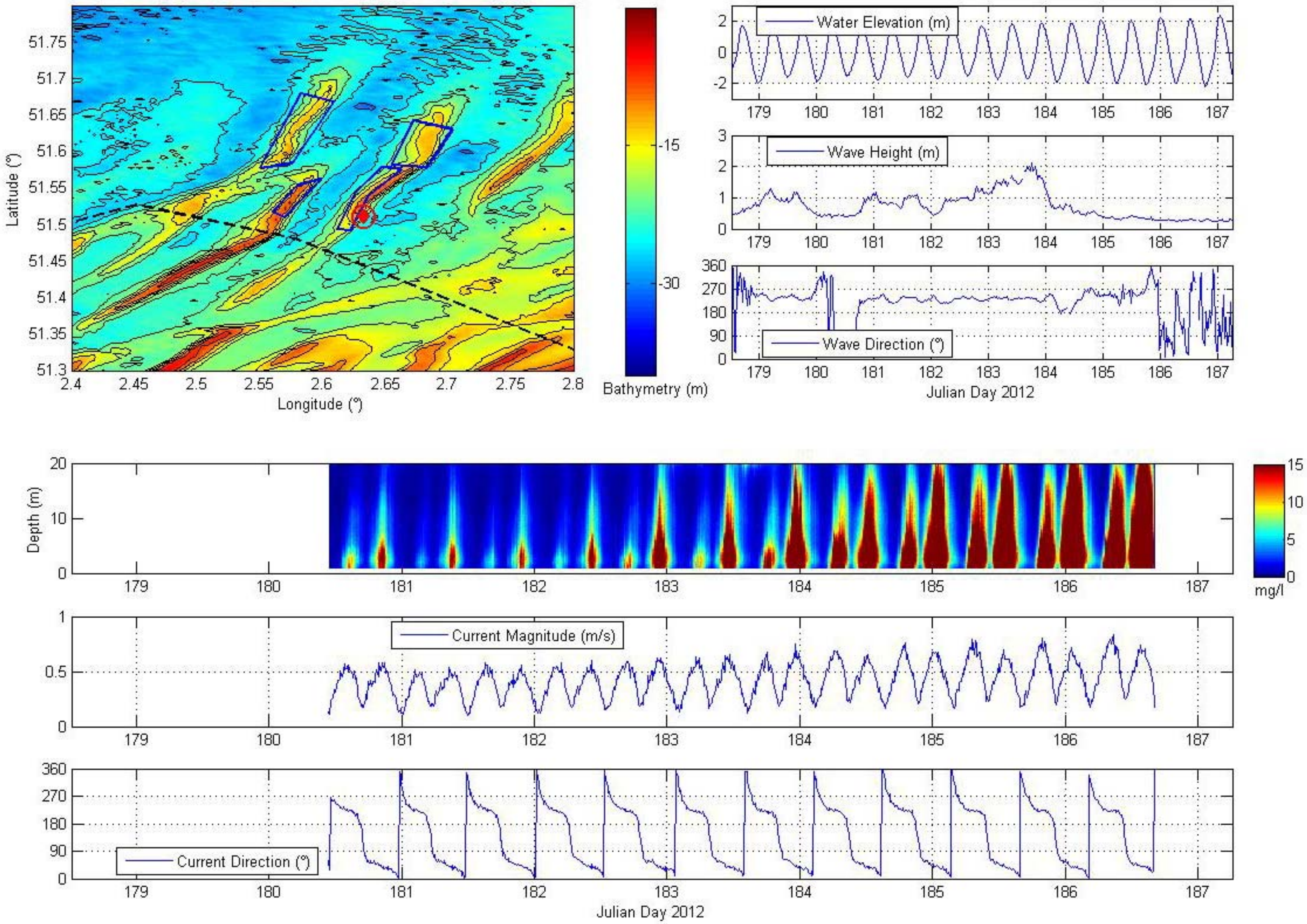


Figure C-01. Long-term measurements (28/6-4/7 2012) with bottom-mounted ADCP at the lower steep flank of the Oosthinder sandbank. Mid to spring tide with tidal coefficient of 63 to 84, respectively at Julian Day 180 and 187.

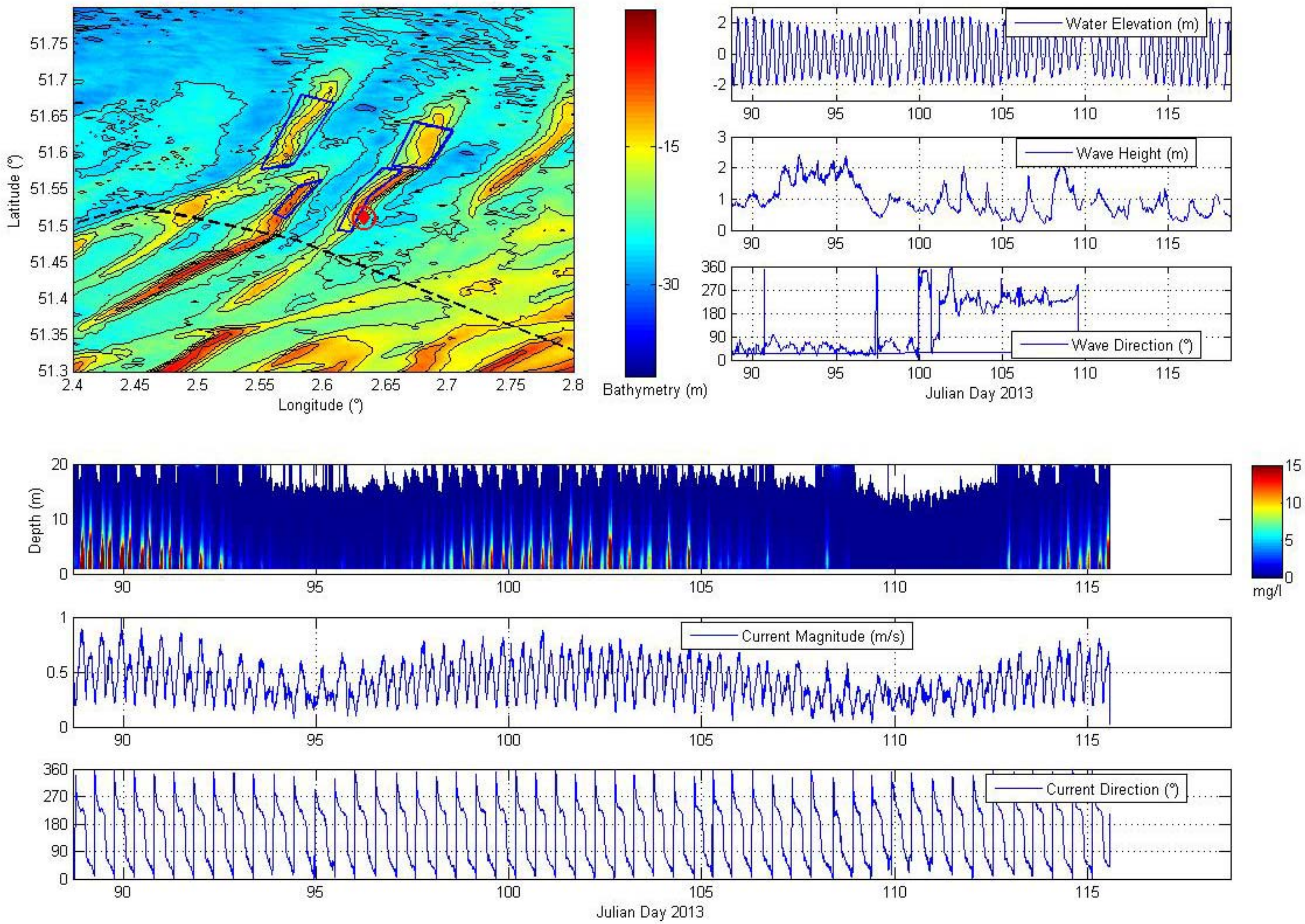


Figure C-02. Long-term measurements (27/3-25/4 2013) with bottom-mounted ADCP at the lower steep flank of the Oosthinder sandbank. Three springtides, with a tidal coefficient of around 83.

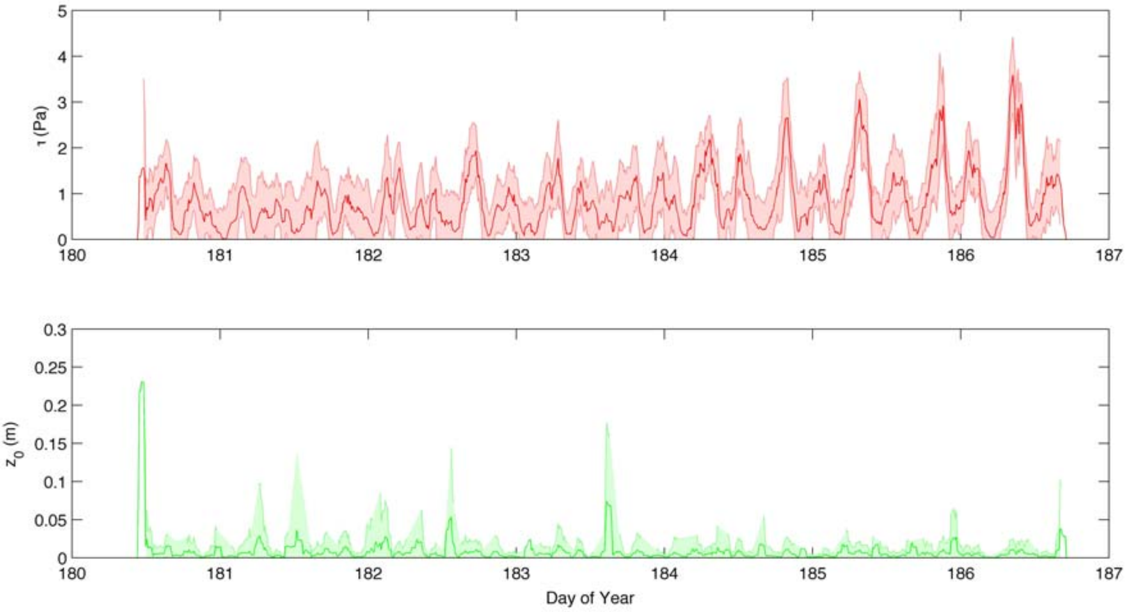


Figure C-03. Bottom shear stresses (Pa) with error envelope, as derived from the long-term measurements (28/6-4/7 2012) with bottom-mounted ADCP at the lower steep flank of the Oosthinder sandbank.
Mid to spring tide with tidal coefficient of 63 to 84, respectively at Day of Year 180 and 187.

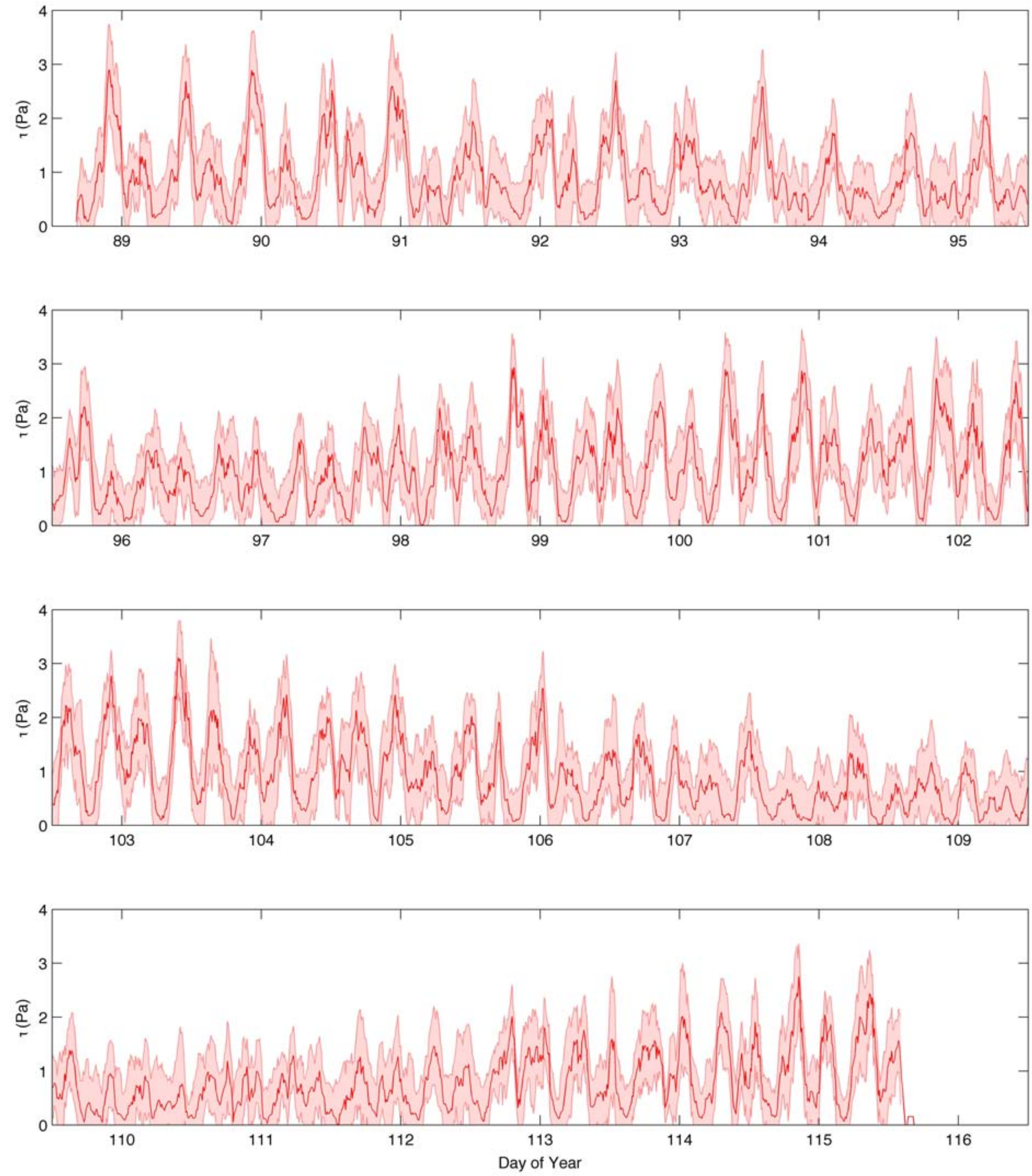


Figure C-04. Bottom shear stresses (Pa) with error envelope, as derived from the long-term measurements (27/3-25/4 2013) with bottom-mounted ADCP. Lower steep flank of the Oosthinder sandbank.
Three springtides, with a tidal coefficient of around 83.

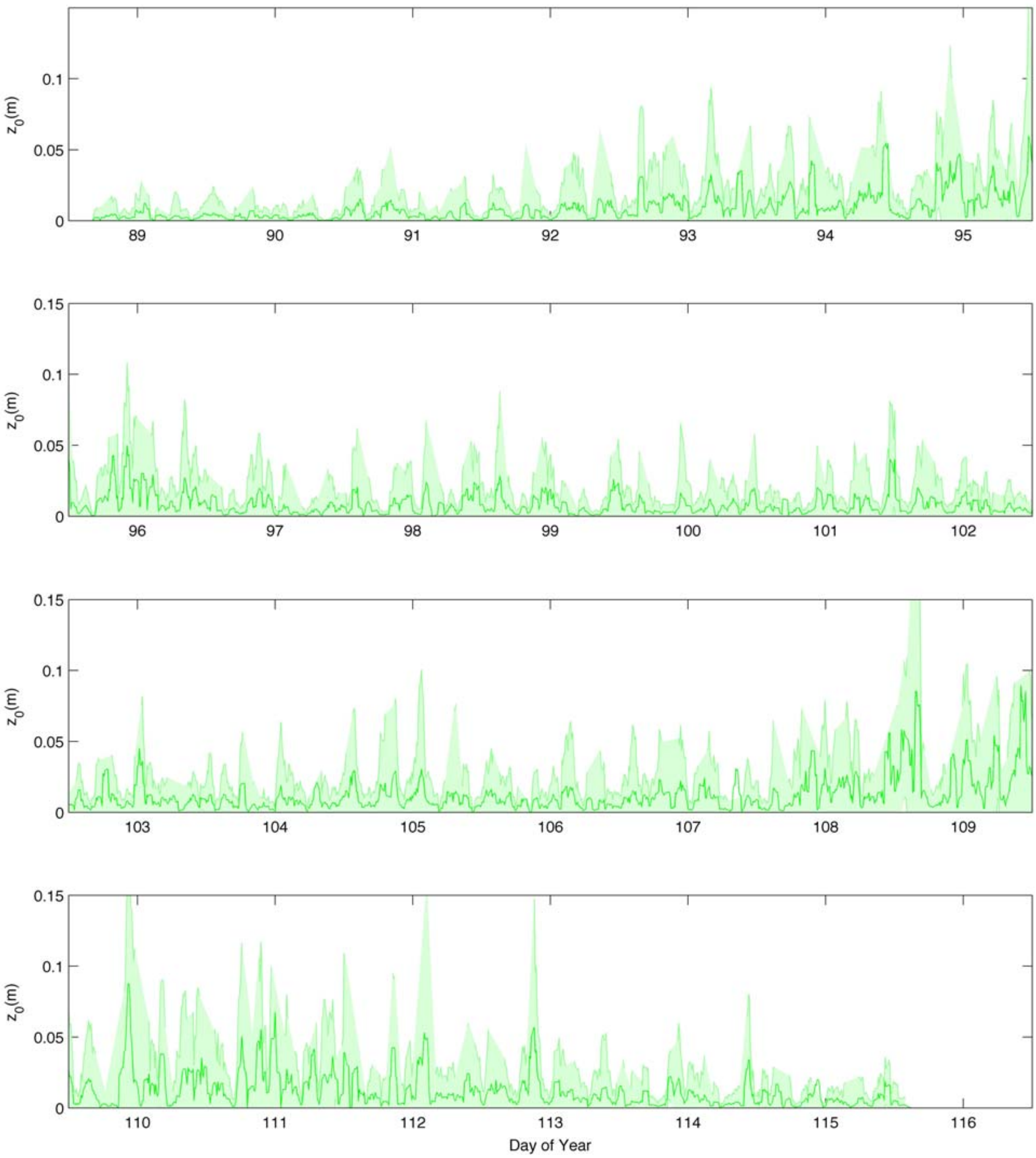


Figure C-05. Time series of the roughness length z0 with error envelope, as derived from the long-term measurements (27/3-25/4 2013) with bottom-mounted ADCP. Lower steep flank of the Oosthinder sandbank. Three springtides, with a tidal coefficient of around 83. Variation in roughness length (proxy of surface texture) determines to a large extent the variation in bottom shear stress (Fig. C-04).

D. Overview short-term measurements 2011-2013

Table D-02. Short-term measurements with hull-mounted broadband ADCP (RV Belgica 300 kHz; average draught sensor 4m) in the period 2011-2013. JD: Julian day, calculated per year. Bin specification in m.

Nr	Campaign	Time1	Time2	JD1	JD2	Duration	Bin size	Start bin
1	st1128	2011-10-25 08:22:12	2011-10-25 20:56:12	298.35	298.87	12.57	1	7.09
2	st1128	2011-10-25 21:16:12	2011-10-26 10:01:12	298.89	299.42	12.75	1	7.09
3	st1128	2011-10-26 11:29:02	2011-10-26 23:49:01	299.48	299.99	12.33	1	7.09
4	st1128	2011-10-26 23:49:01	2011-10-27 12:49:01	299.99	300.53	13.00	1	7.09
5	st1208	2012-03-21 17:24:46	2012-03-22 06:20:47	81.73	82.26	12.93	1	7.08
6	st1208	2012-03-22 13:43:04	2012-03-23 03:11:03	82.57	83.13	13.47	1	7.08
7	st1219	2012-07-02 16:36:38	2012-07-03 06:07:39	184.69	185.26	13.52	1	7.09
8	st1219	2012-07-03 16:09:42	2012-07-04 05:15:42	185.67	186.22	13.10	1	7.09
9	st1226	2012-10-16 00:16:33	2012-10-16 04:58:33	290.01	290.21	4.70	0.5	4.59
10	st1226	2012-10-18 19:35:06	2012-10-18 20:11:08	292.82	292.84	0.60	0.5	4.59
11	st1226	2012-10-18 21:55:30	2012-10-18 22:31:32	292.91	292.94	0.60	0.5	4.59
12	st1226	2012-10-18 23:07:15	2012-10-18 23:44:15	292.96	292.99	0.62	0.5	4.59
13	st1226	2012-10-19 00:21:38	2012-10-19 00:58:38	293.02	293.04	0.62	0.5	4.59
14	st1226	2012-10-19 01:38:24	2012-10-19 02:14:26	293.07	293.09	0.60	0.5	4.59
15	st1226	2012-10-19 02:56:04	2012-10-19 03:28:04	293.12	293.14	0.53	0.5	4.59
16	st1226	2012-10-19 04:01:07	2012-10-19 04:31:10	293.17	293.19	0.50	0.5	4.59
17	st1309	2013-03-26 15:12:26	2013-03-27 04:28:26	85.63	86.19	13.27	0.5	4.58
18	st1309	2013-03-27 16:28:22	2013-03-27 17:19:23	86.69	86.72	0.85	1	7.08
19	st1319	2013-07-01 17:29:36	2013-07-02 07:39:37	182.73	183.32	14.17	0.25	4.47
20	st1319	2013-07-02 15:07:50	2013-07-03 08:33:50	183.63	184.36	17.43	0.3	4.49
21	st1328	2013-10-21 16:59:36	2013-10-22 05:29:36	294.71	295.23	12.50	1	7.09
22	st1328	2013-10-24 00:04:35	2013-10-24 05:02:35	297.00	297.21	4.97	0.5	4.59
23	st1328	2013-10-24 21:20:05	2013-10-25 06:27:05	297.89	298.27	9.12	1	7.09

In Figures D-01 to D-23 current information is represented for the third valid bin under the sensor. The depth is variable depending on the bin size.

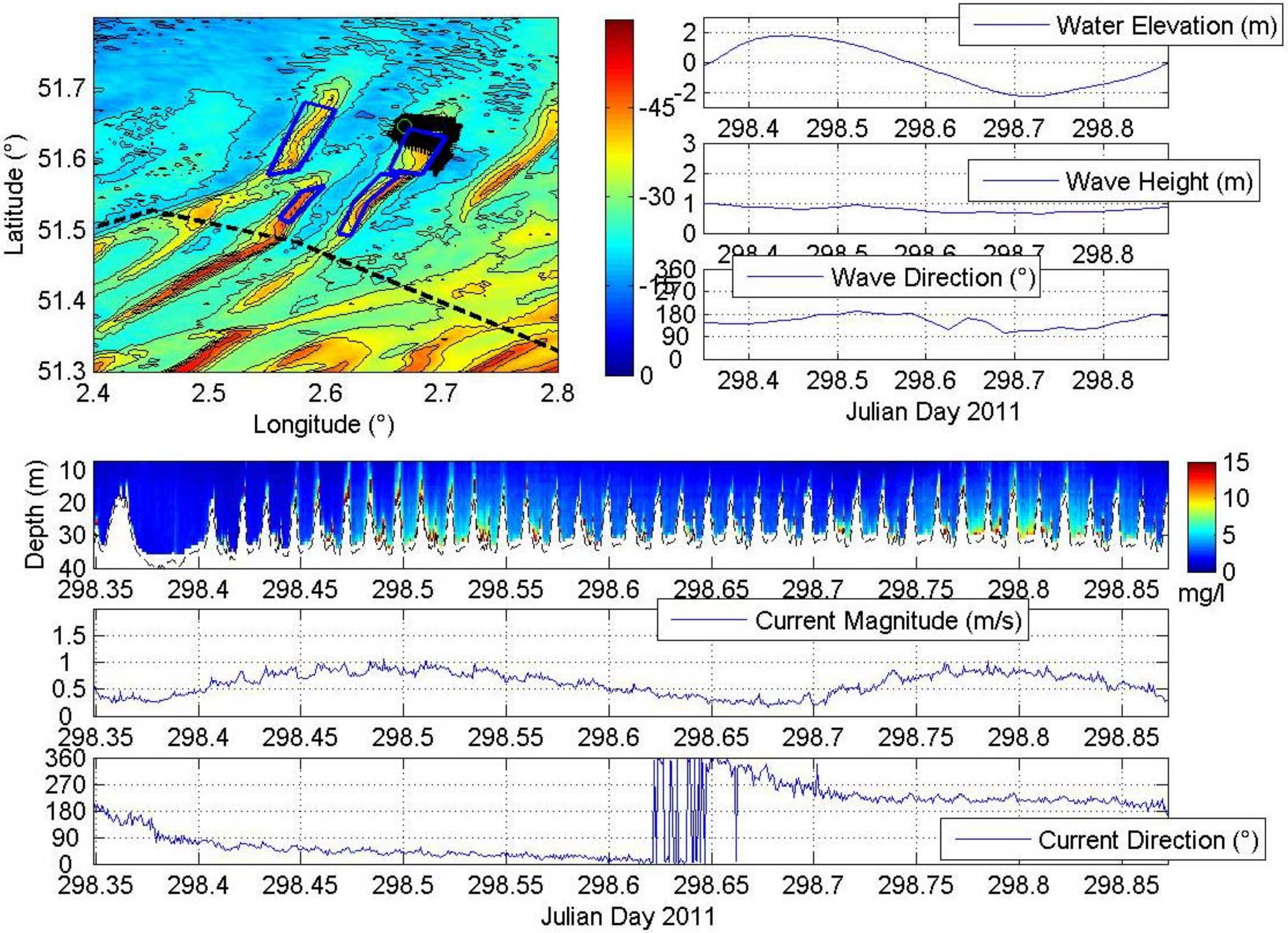


Figure D-01. RV Belgica ST1128. 25/10/2011. Transects in Sector 4b. Sandbank top and flank.
Spring tide - tidal coefficient 73. Currents at +/-9 m water depth.
Surface flood current competitive to surface ebb current, though the flood lasts longer.

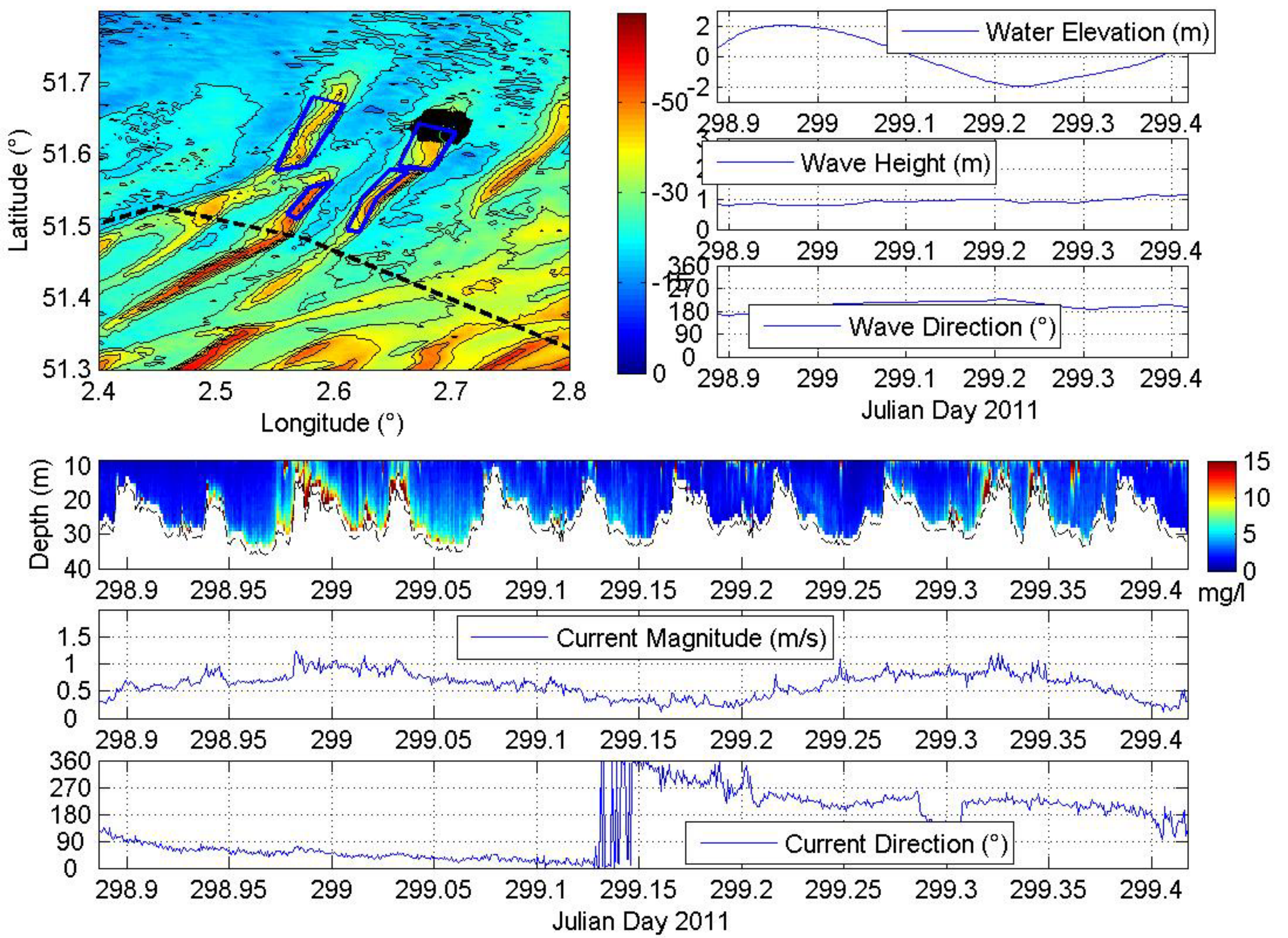


Figure D-02. RV Belgica ST1128. 25-26/10/2011. Transects and in-situ measurements in Sector 4b. Sandbank top and flank.
Spring tide - tidal coefficient 73. Currents at +/-9 m water depth. Surface flood current competitive to surface ebb current, though the flood lasts longer.

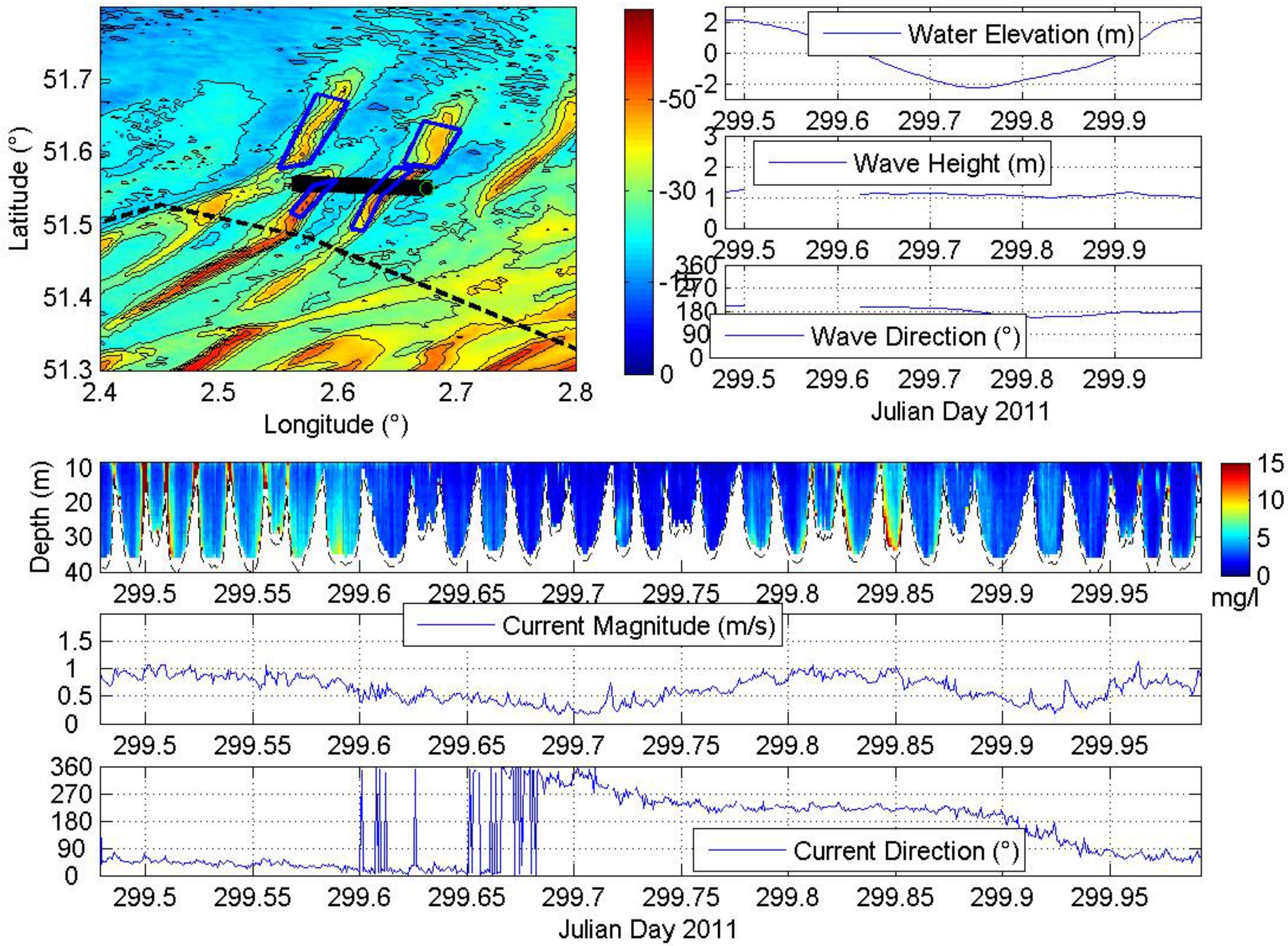


Figure D-03. RV Belgica ST1128. 26/10/2011. Transects covering Sector 4c-4d.
Spring tide - tidal coefficient 86. Currents at +/-9 m water depth. Note resuspension above the sandbanks during maximum current velocities during flood and ebb.

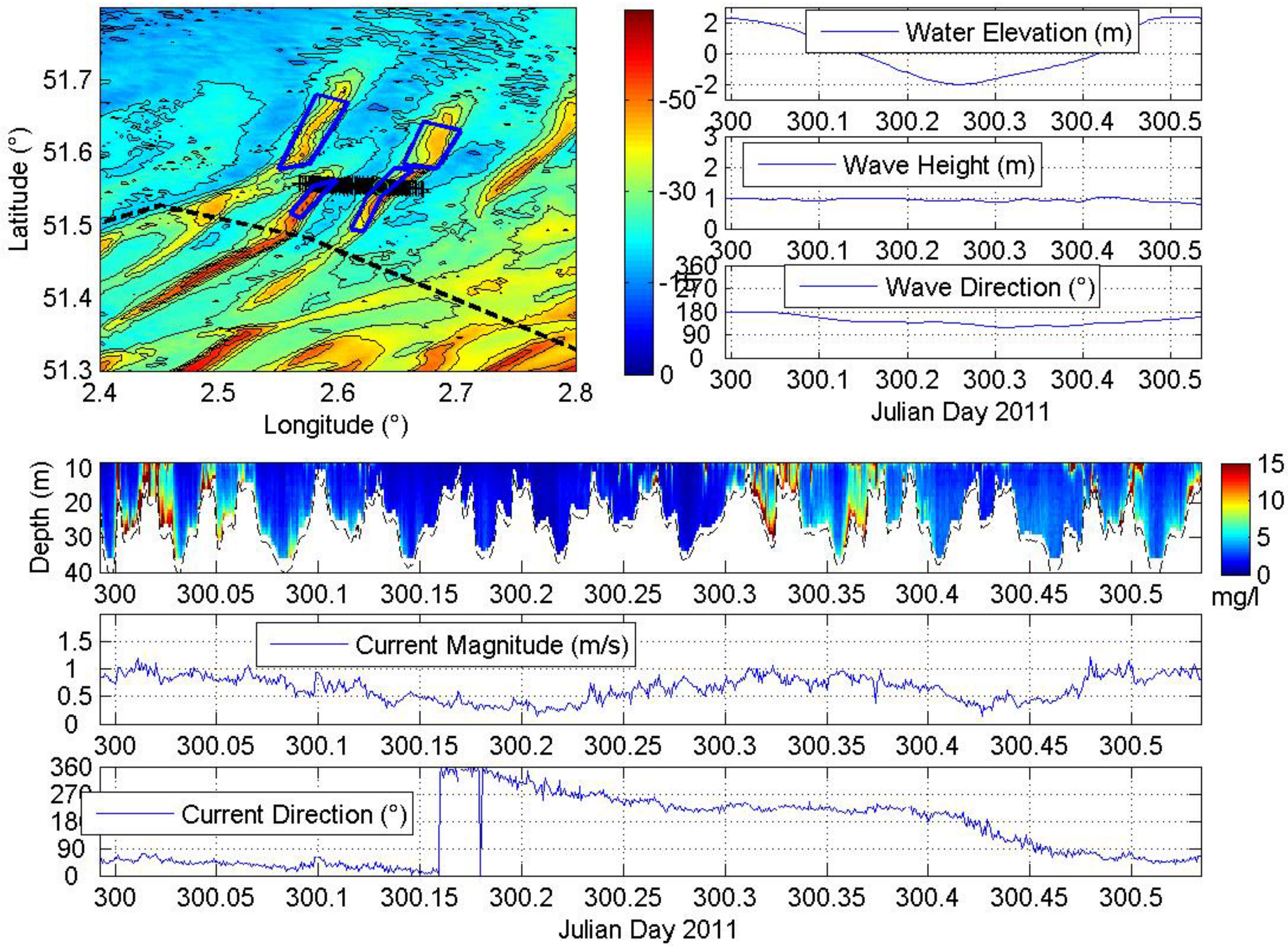


Figure D-04. RV Belgica ST1128. 26-27/10/2011.Transects and in-situ measurements covering Sector 4c-4d.
Spring tide - tidal coefficient 86. Currents at +/-9 m water depth. Note resuspension above the sandbanks during maximum current velocities during flood and ebb.

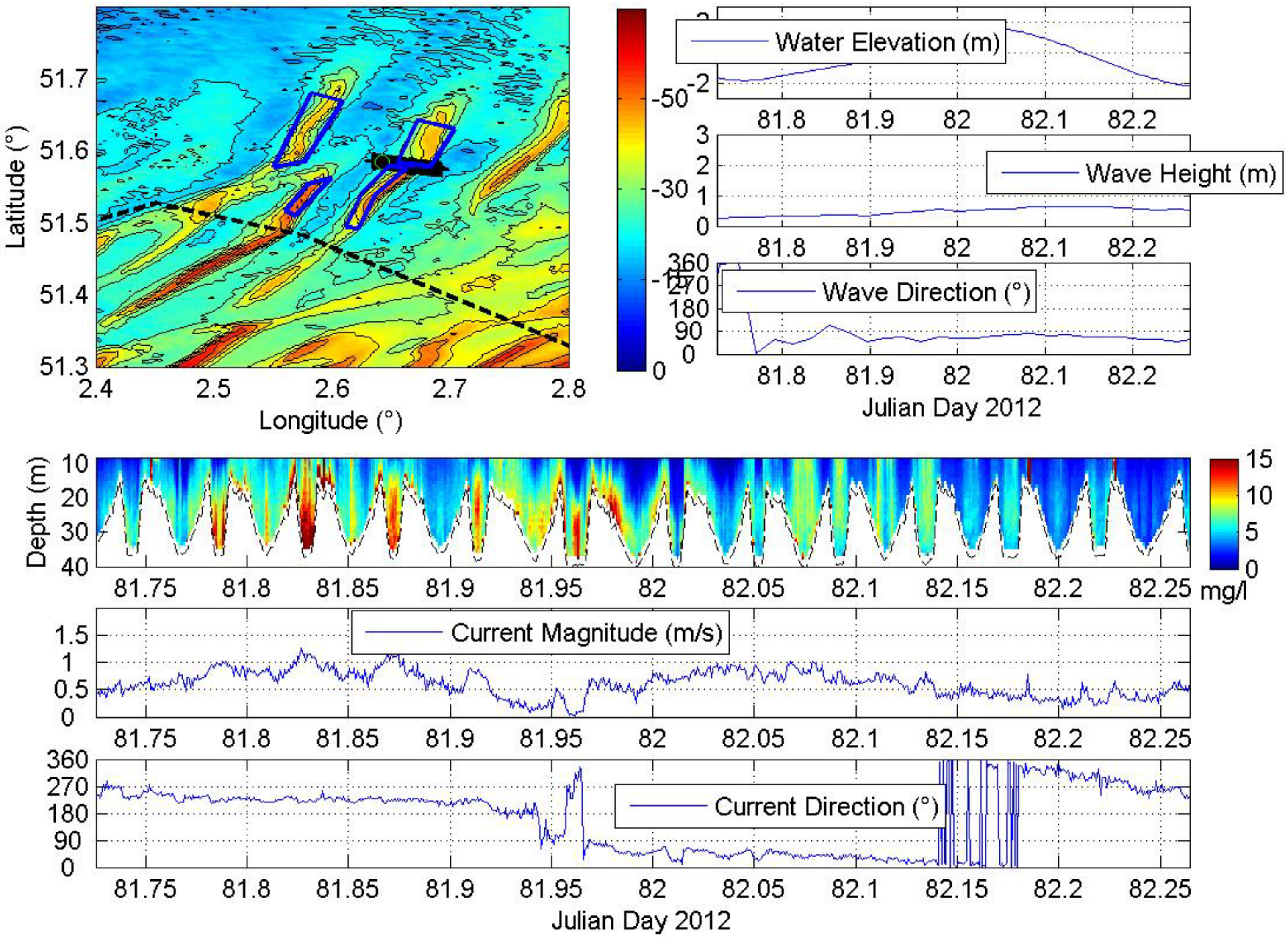


Figure D-05. RV Belgica ST1208. 21-22/03/2012. Transects in between Sector 4b and 4c.
Spring tide - tidal coefficient 67. Surface ebb current stronger than surface flood current. Currents at +/-9 m water depth.
Note resuspension above the sandbanks, especially during maximum ebb current velocities.

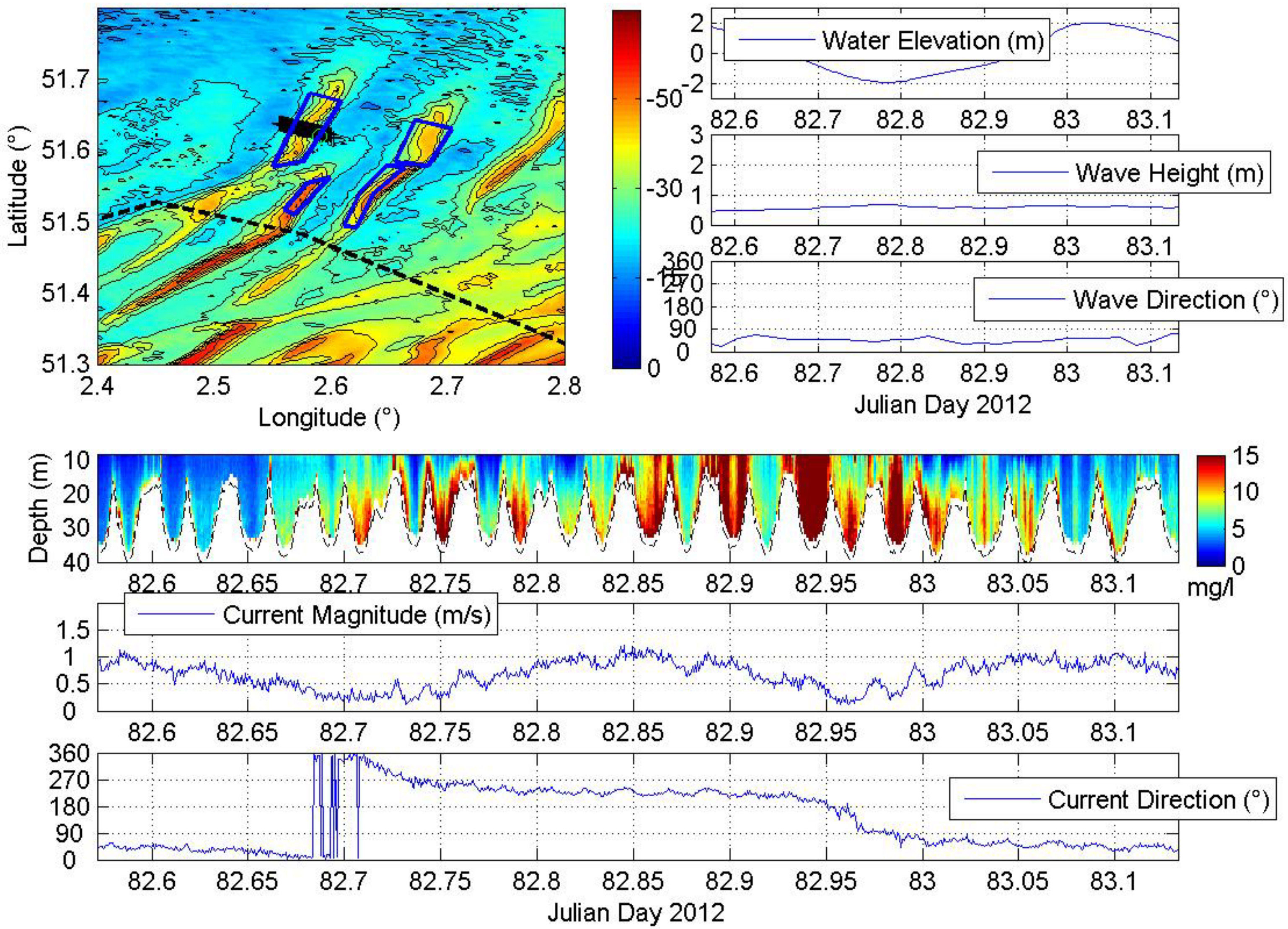


Figure D-06. RV Belgica ST1208. 22-23/03/2012. Transects over Sector 4a.
Spring tide - tidal coefficient 74. Currents at +/-9 m water depth.
Note resuspension above the sandbanks, especially during the ebb tidal phase. Important lag effects of SPM maximum in relation to maximum current velocity.

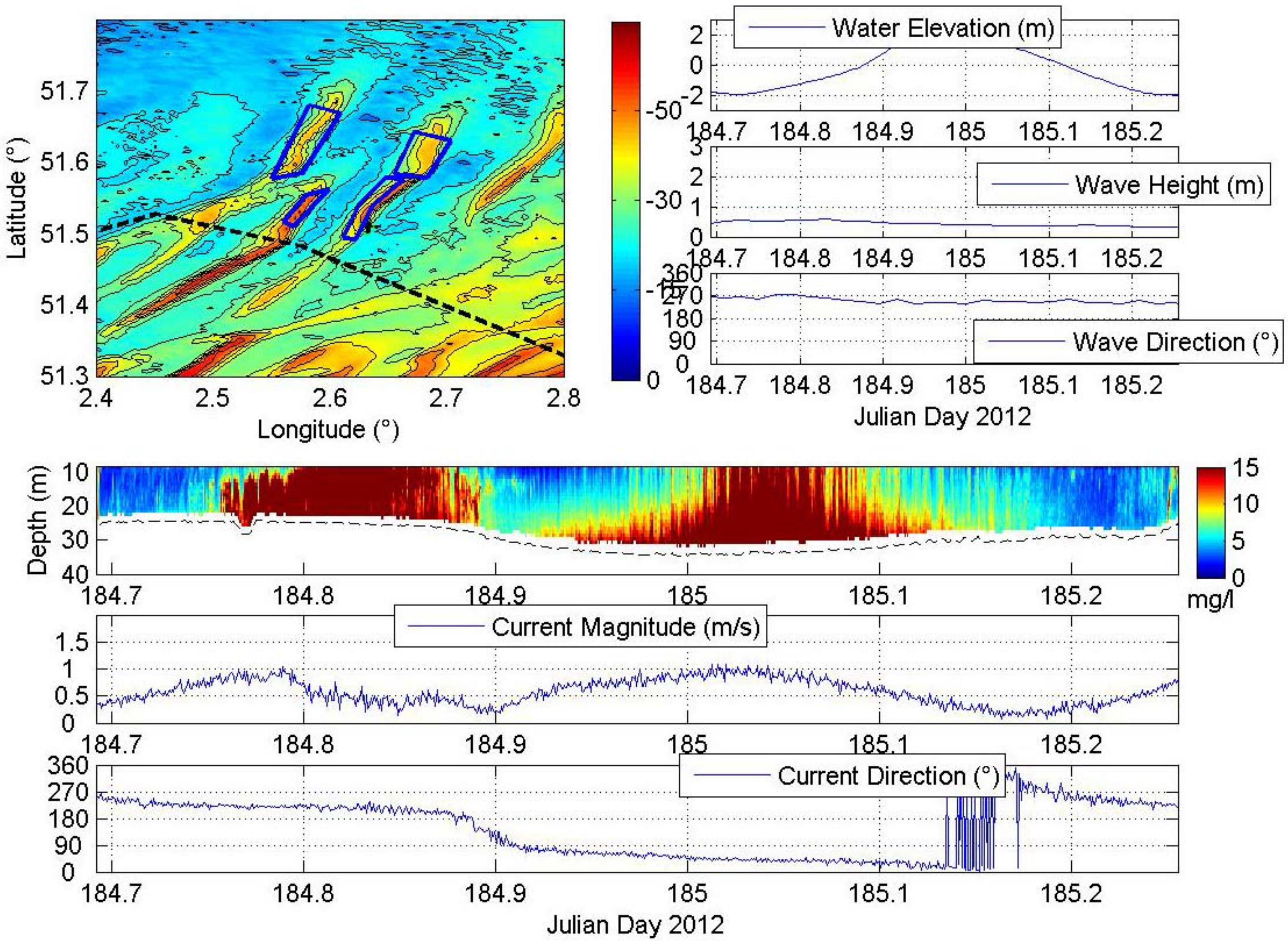


Figure D-07. RV Belgica ST1219. 2-3/7/2012. In-situ measurements in Sector 4c, location - ADCP-I. Sandbank top and flank.
Spring tide - tidal coefficient 75. Currents at +/-9 m water depth. The first turbidity event is a sediment flare, resulting from resuspension during ebb.
Consequently this natural sediment plume is transported away during the flood tidal phase (second turbidity event).

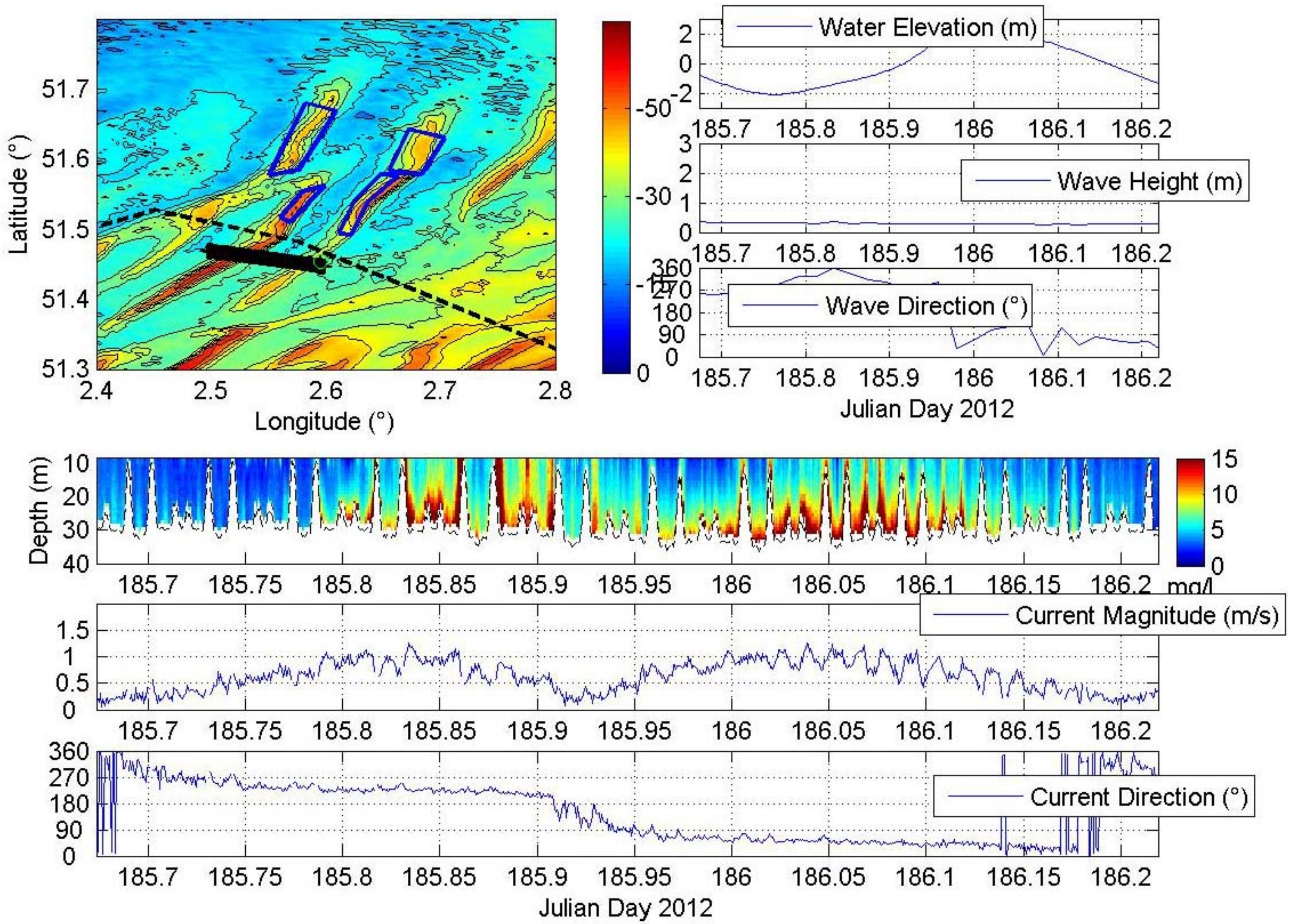


Figure D-08. RV Belgica ST1219. 3-4/7/2012. Habitat Directive Area. Transects covering Westhinder and Oosthinder sandbank.
Spring tide - tidal coefficient 79. Currents at +/-9 m water depth.
Note resuspension above the sandbanks during maximum current velocities during flood and ebb.

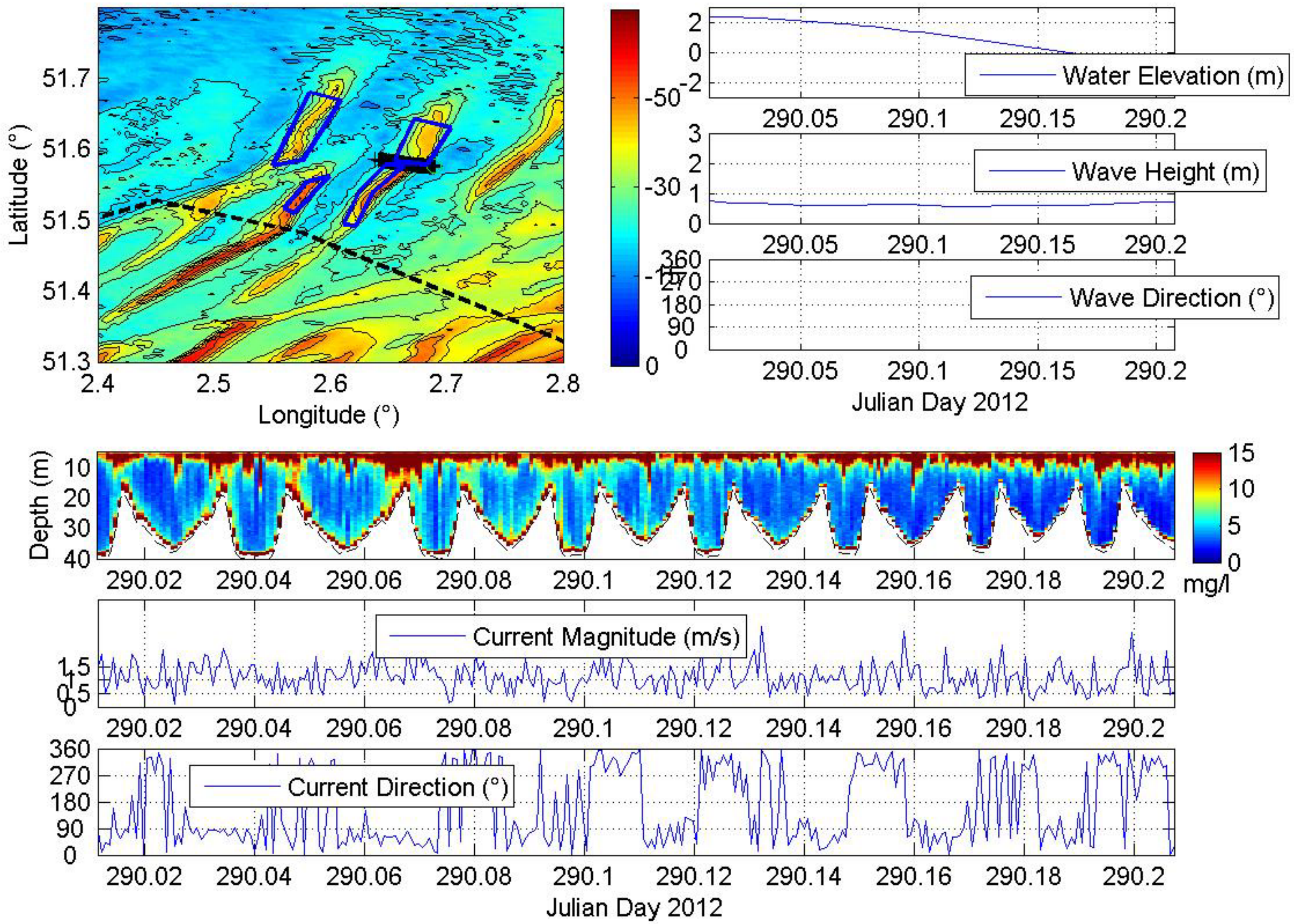


Figure D-09. RV Belgica ST1226. 16/10/2012. Transects in between Sector 4b and 4c.
Spring tide - tidal coefficient 82. Currents at +/- 6 m water depth.

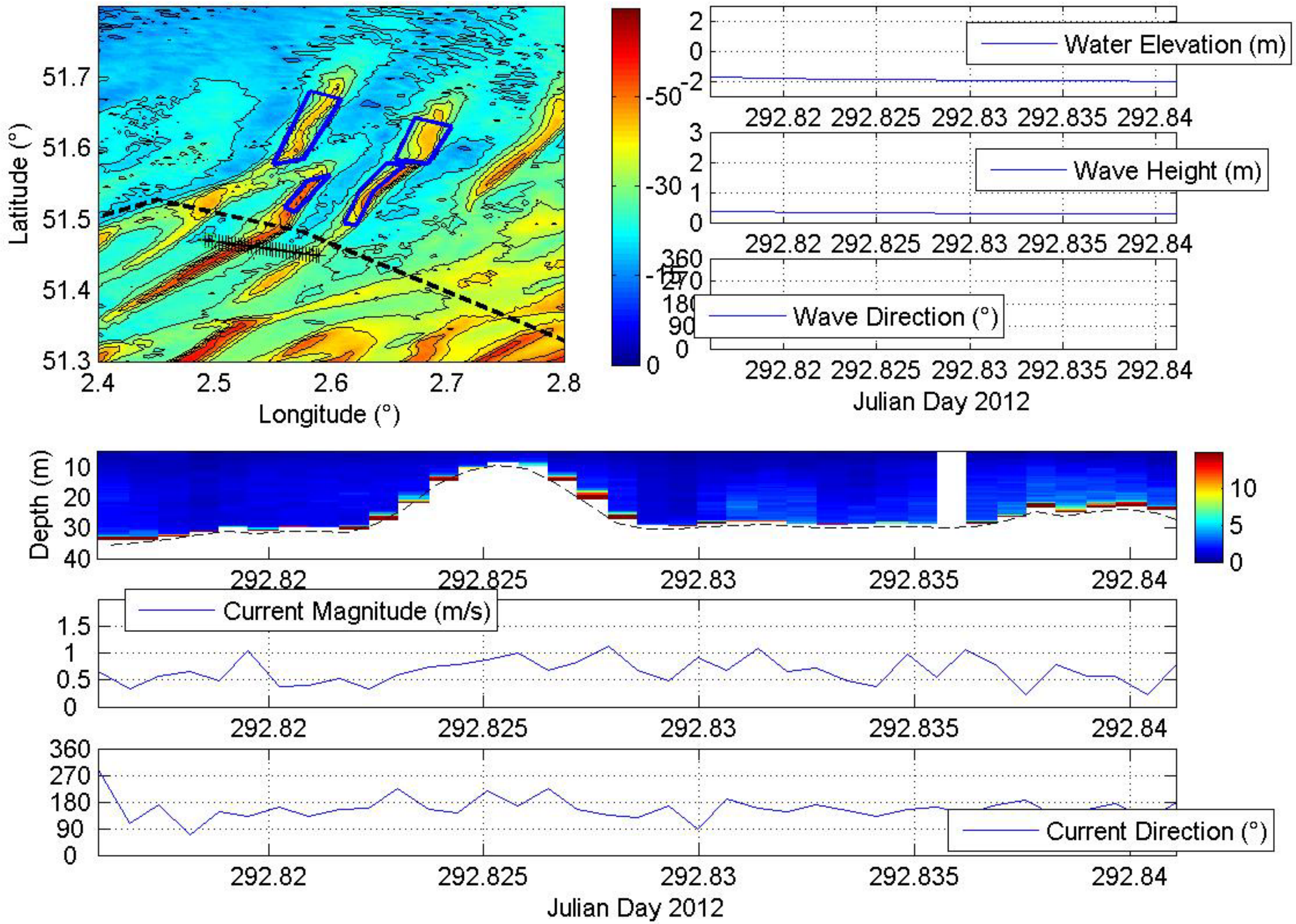


Figure D-10. RV Belgica ST1226. 18/10/2012. Habitat Directive area. Transect over Oosthinder and Westhinder sandbank.

Spring tide - tidal coefficient 78. Currents at +/- 6 m water depth.

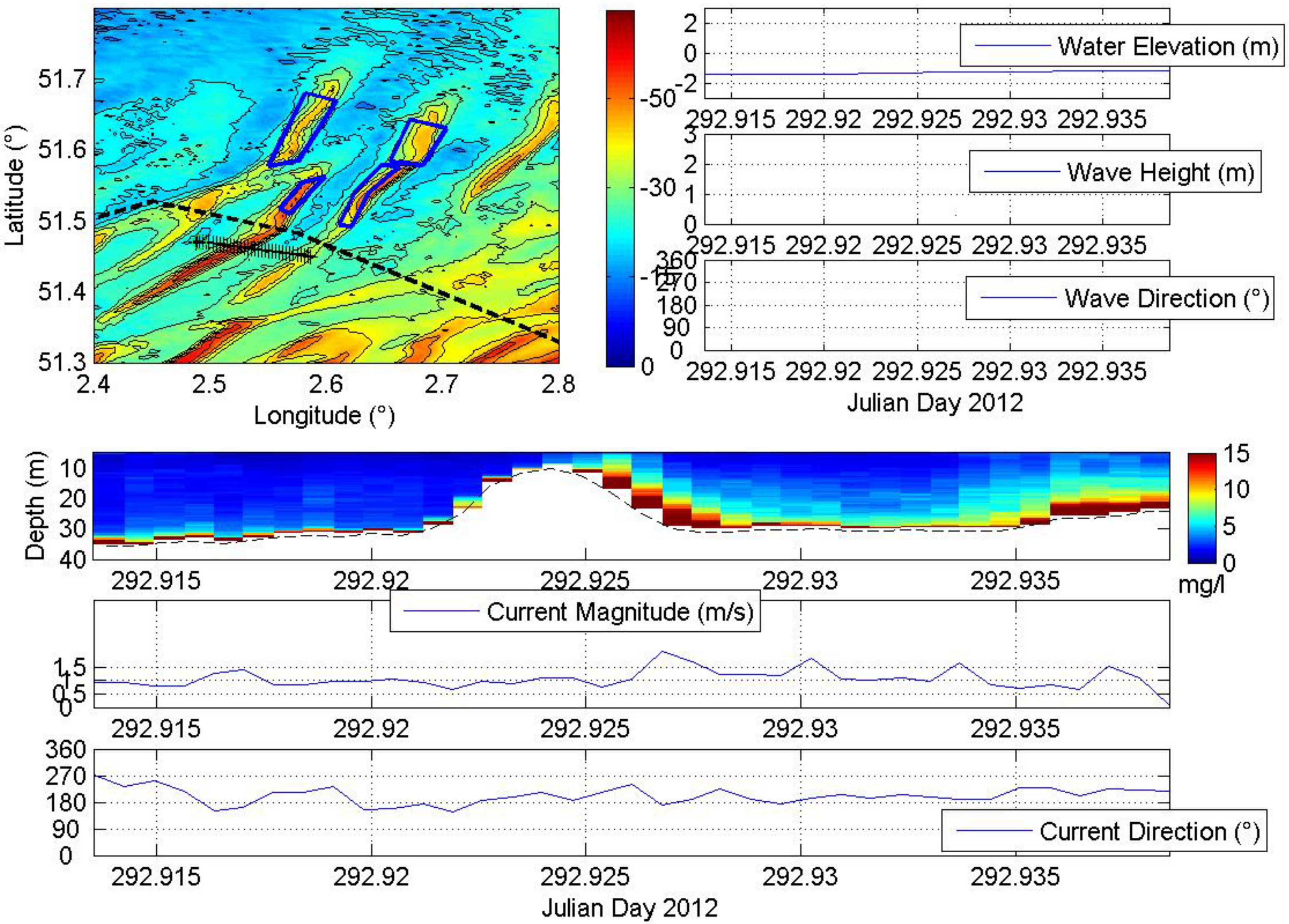


Figure D-11. RV Belgica ST1226. 18/10/2012. Habitat Directive area. Transect over Oosthinder and Westhinder sandbank. Spring tide - tidal coefficient 85. Currents at +/- 6 m water depth.

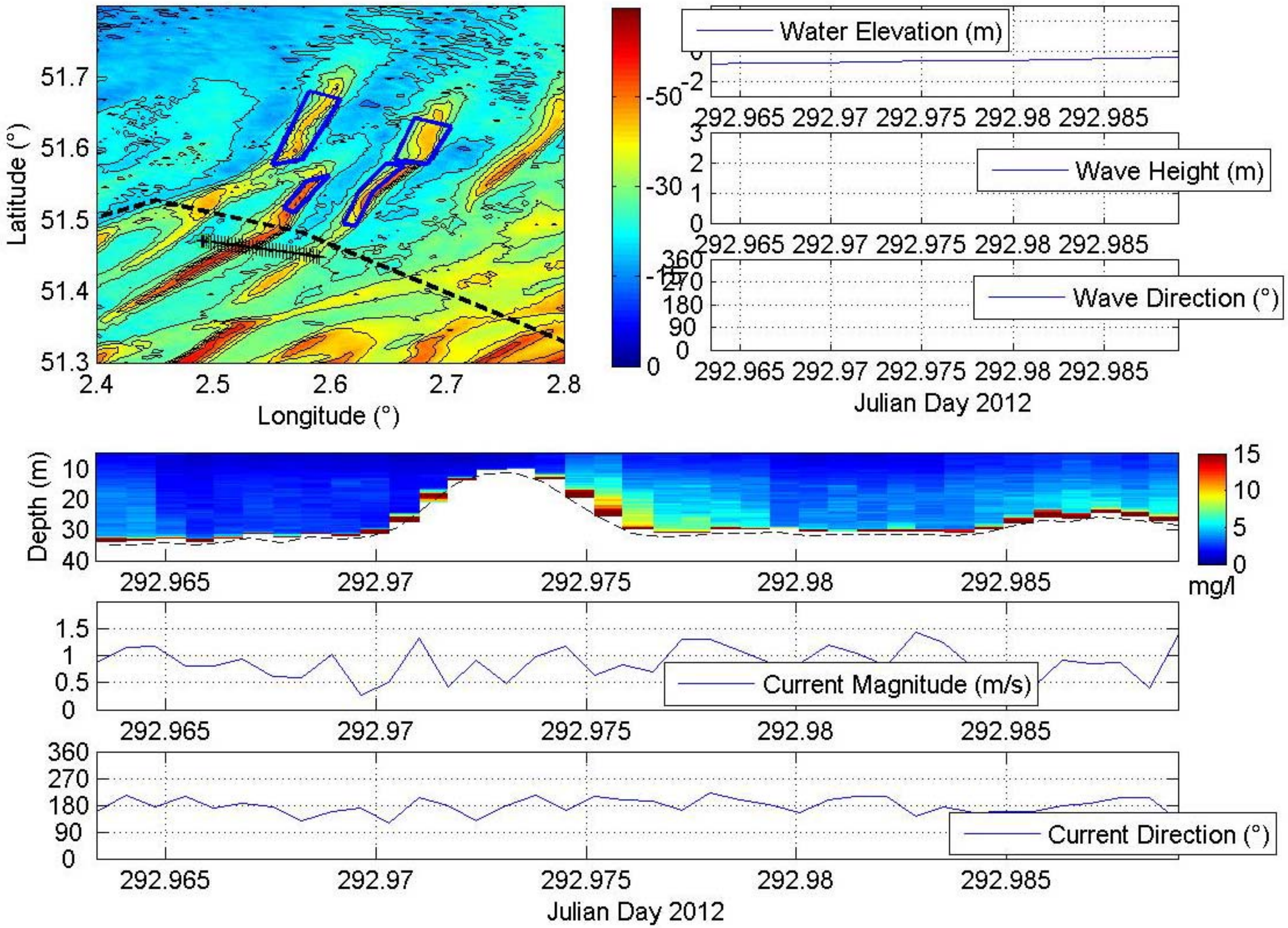


Figure D-12. RV Belgica ST1226. 18/10/2012. Habitat Directive area. Transect over Oosthinder and Westhinder sandbank. Spring tide - tidal coefficient 85. Currents at +/- 6 m water depth.

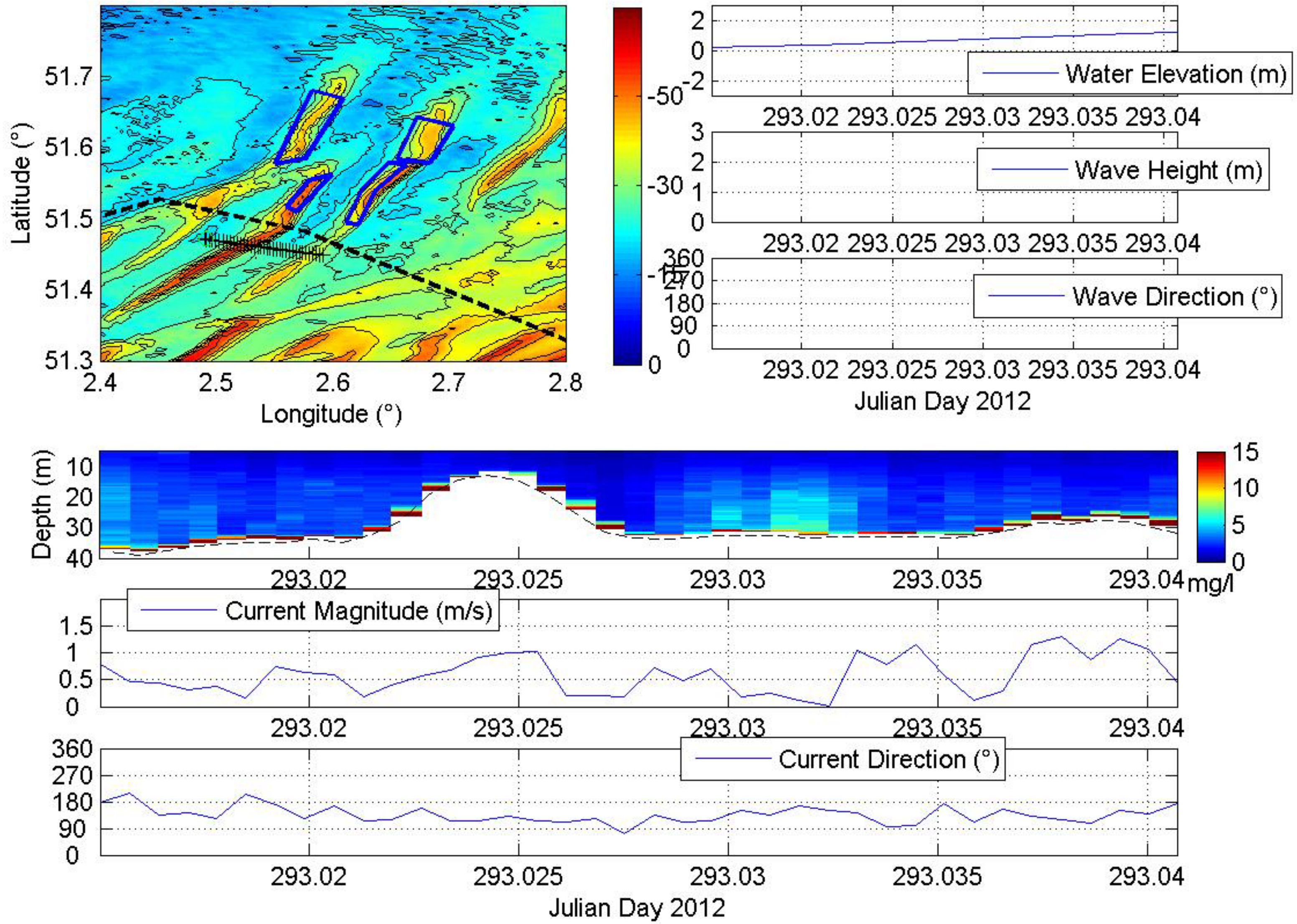


Figure D-13. RV Belgica ST1226. 19/10/2012. Habitat Directive area. Transect over Oosthinder and Westhinder sandbank. Spring tide - tidal coefficient 85. Currents at +/- 6 m water depth.

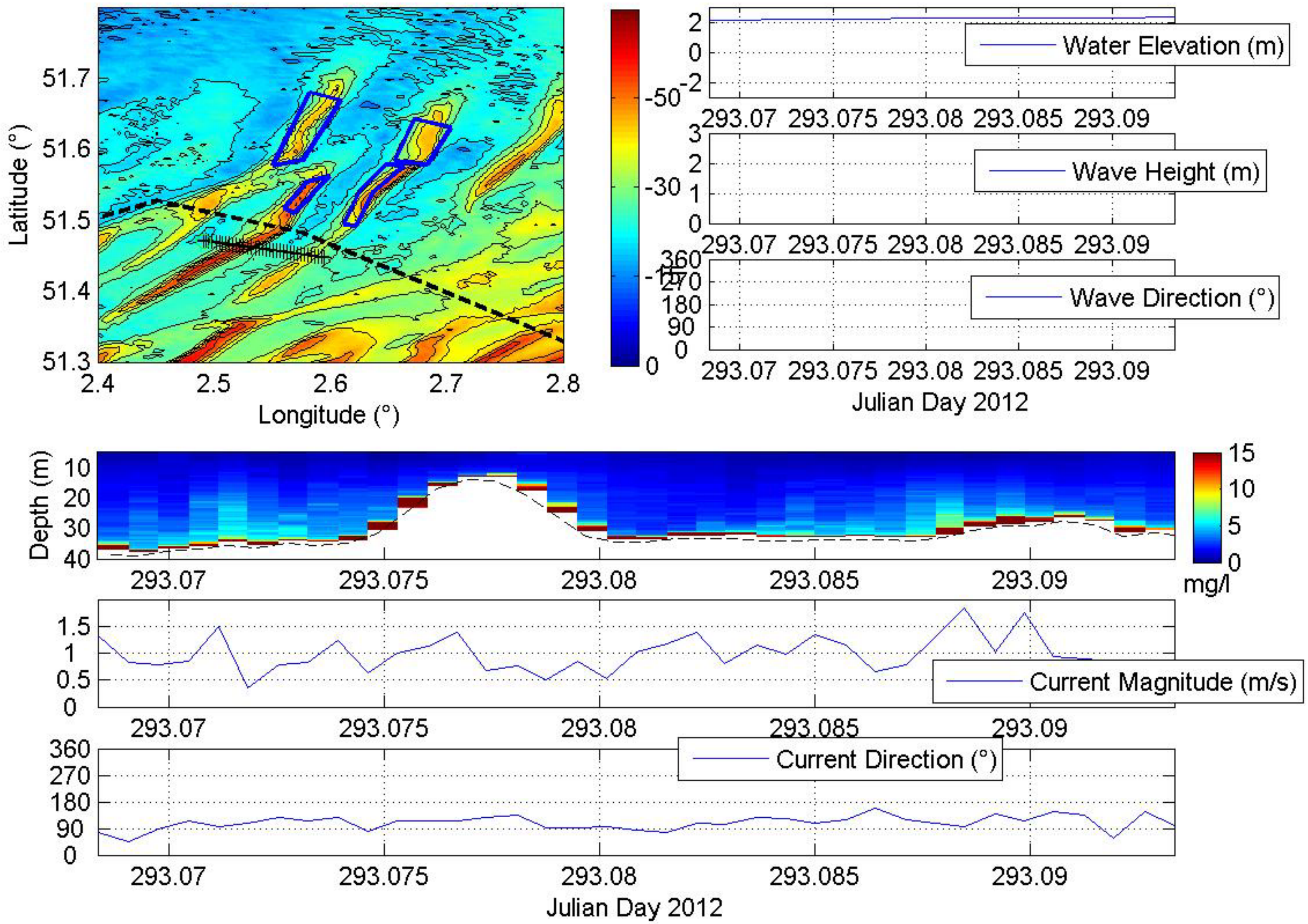


Figure D-14. RV Belgica ST1226. 19/10/2012. Habitat Directive area. Transect over Oosthinder and Westhinder sandbank. Spring tide - tidal coefficient 85. Currents at +/- 6 m water depth.

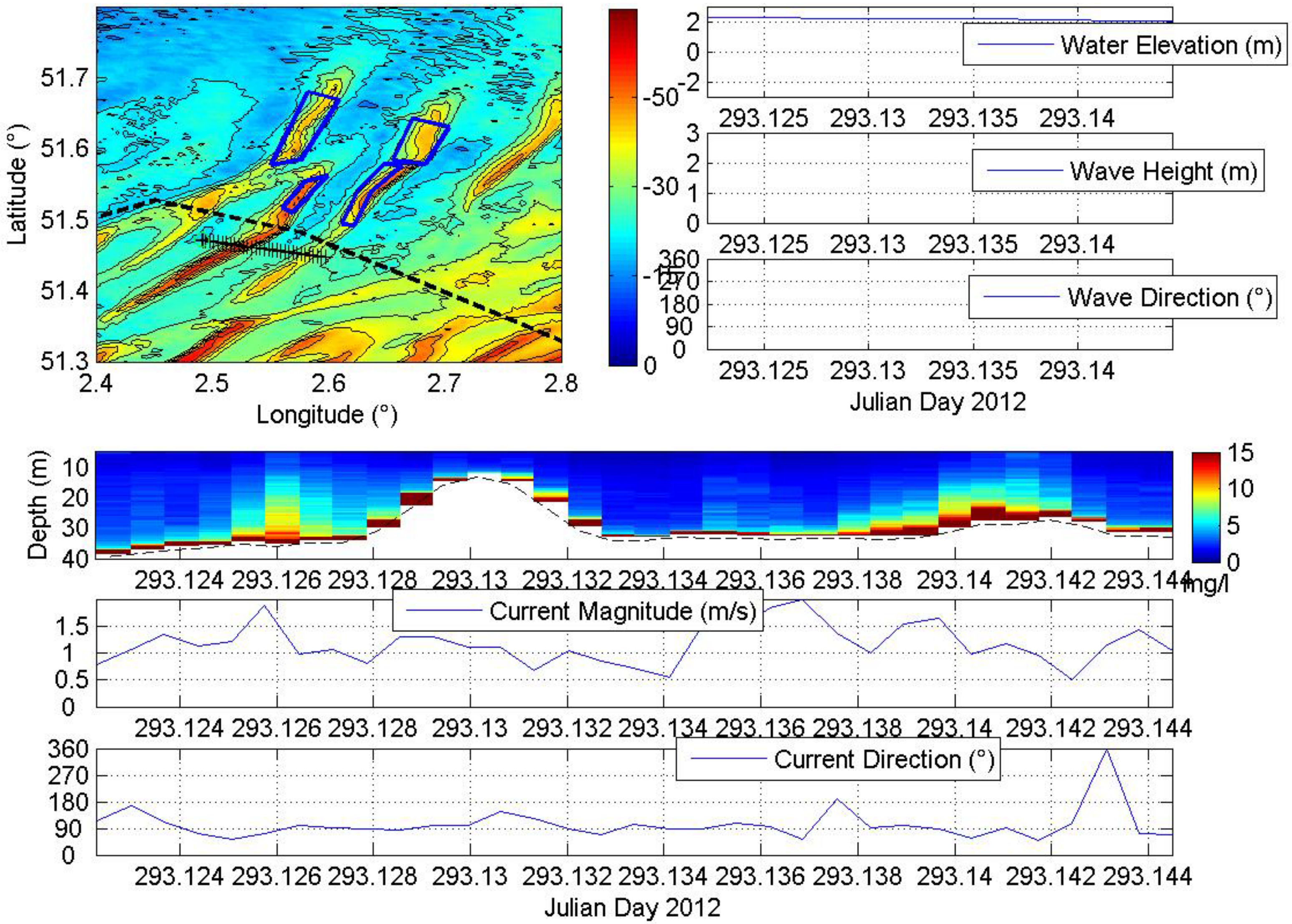


Figure D-15. RV Belgica ST1226. 19/10/2012. Habitat Directive area. Transect over Oosthinder and Westhinder sandbank. Spring tide - tidal coefficient 85. Currents at +/- 6 m water depth.

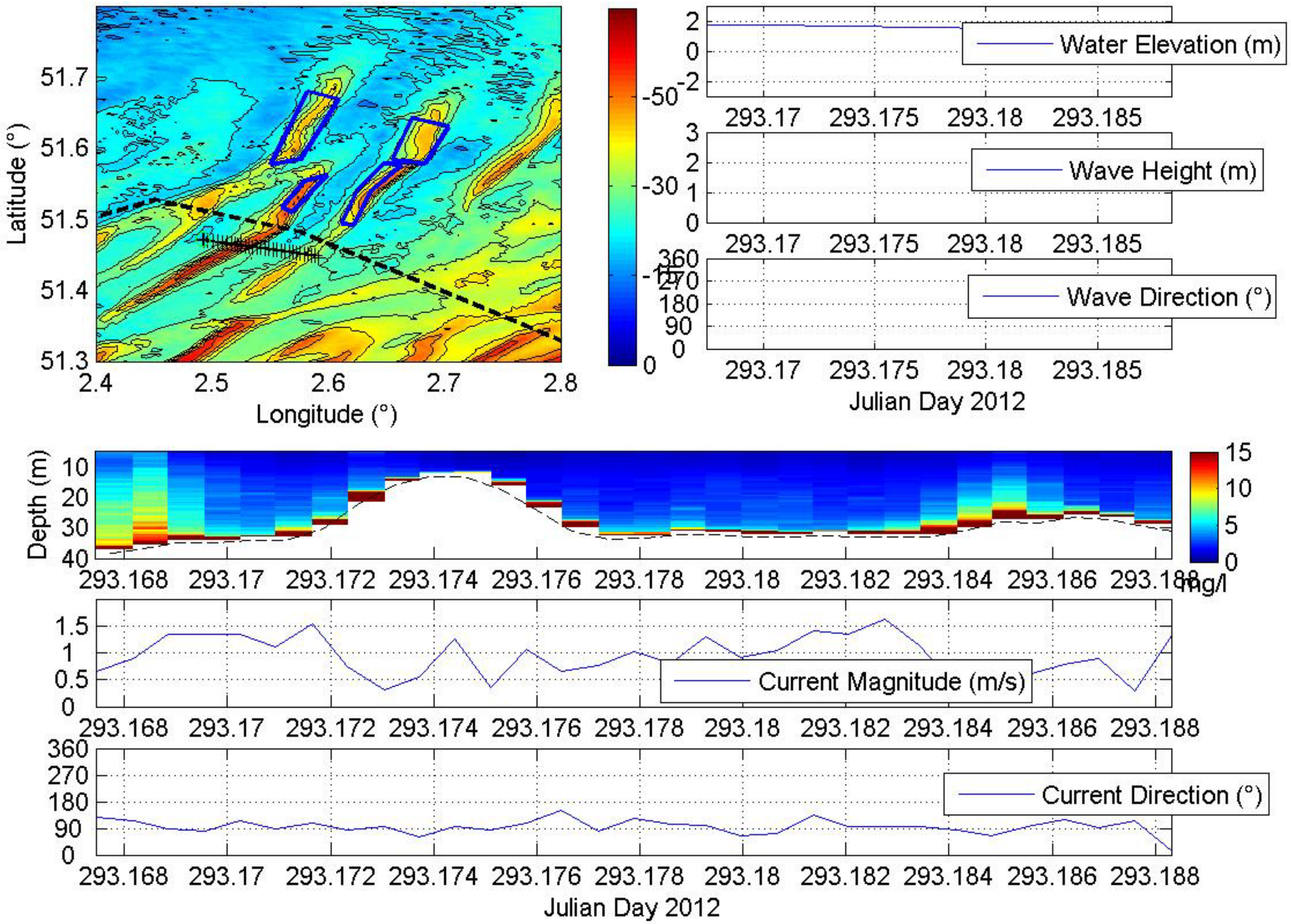


Figure D-16. RV Belgica ST1226. 19/10/2012. Habitat Directive area. Transect over Oosthinder and Westhinder sandbank. Spring tide - tidal coefficient 85. Currents at +/- 6 m water depth.

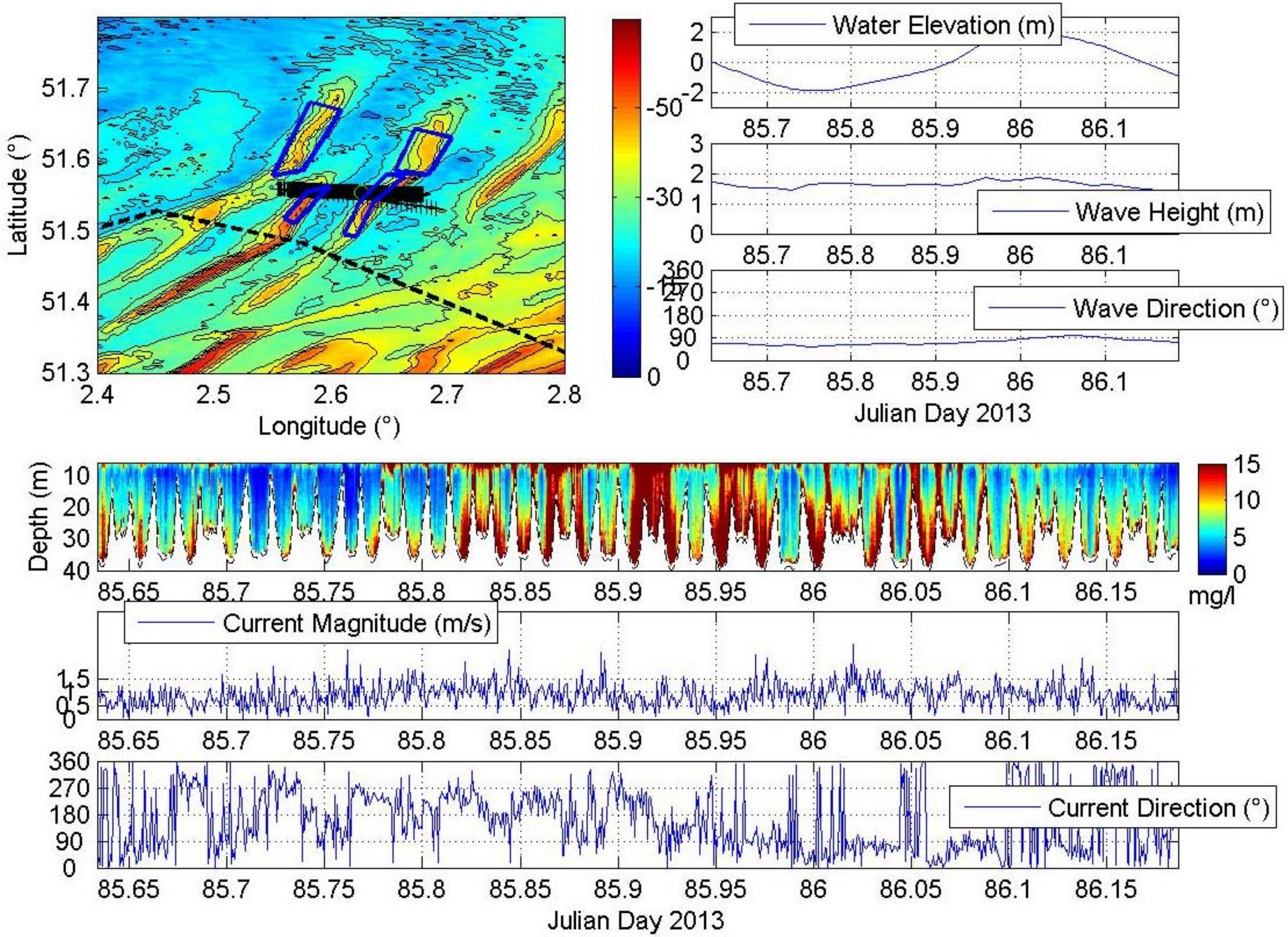


Figure D-17. RV Belgica ST1309. 26-27/03/2013. Transect over Sector 4c-4d.
Spring tide - tidal coefficient 74. Currents at +/- 6 m water depth. Note resuspension above the sandbanks during maximum current velocities during flood and ebb.

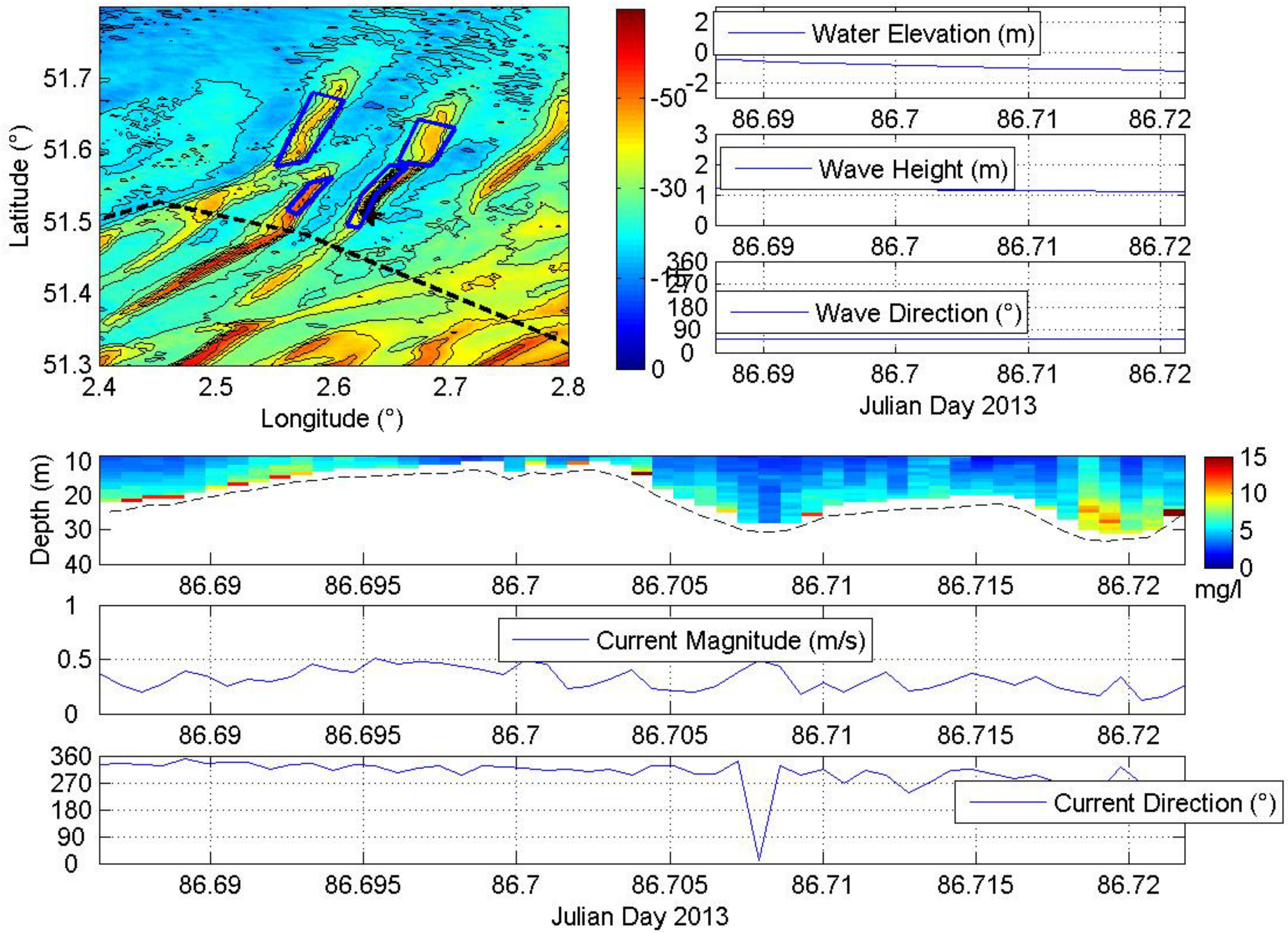


Figure D-18. RV Belgica ST1309. 27/03/2013.
Spring tide - tidal coefficient 74. Currents at +/- 9 m water depth.

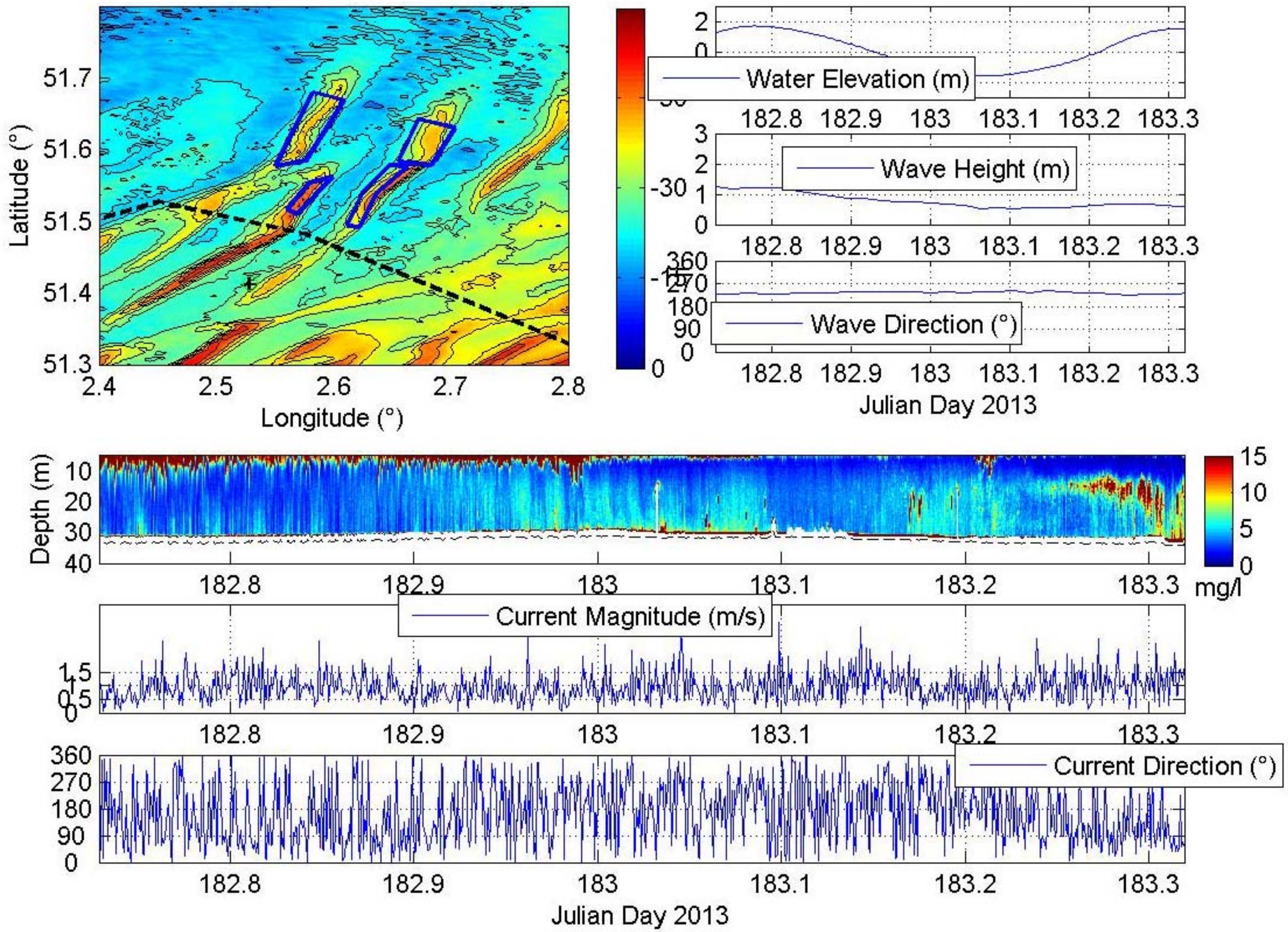


Figure D-19. RV Belgica ST1319. 1-2/7/2013. In-situ measurements, Habitat Directive area. Trough barchan dune.
Mid tide - tidal coefficient 60. Currents at +/- 5 m water depth.
Note higher SPM values around the ebb tidal level. A sediment plume is present around flood tide.

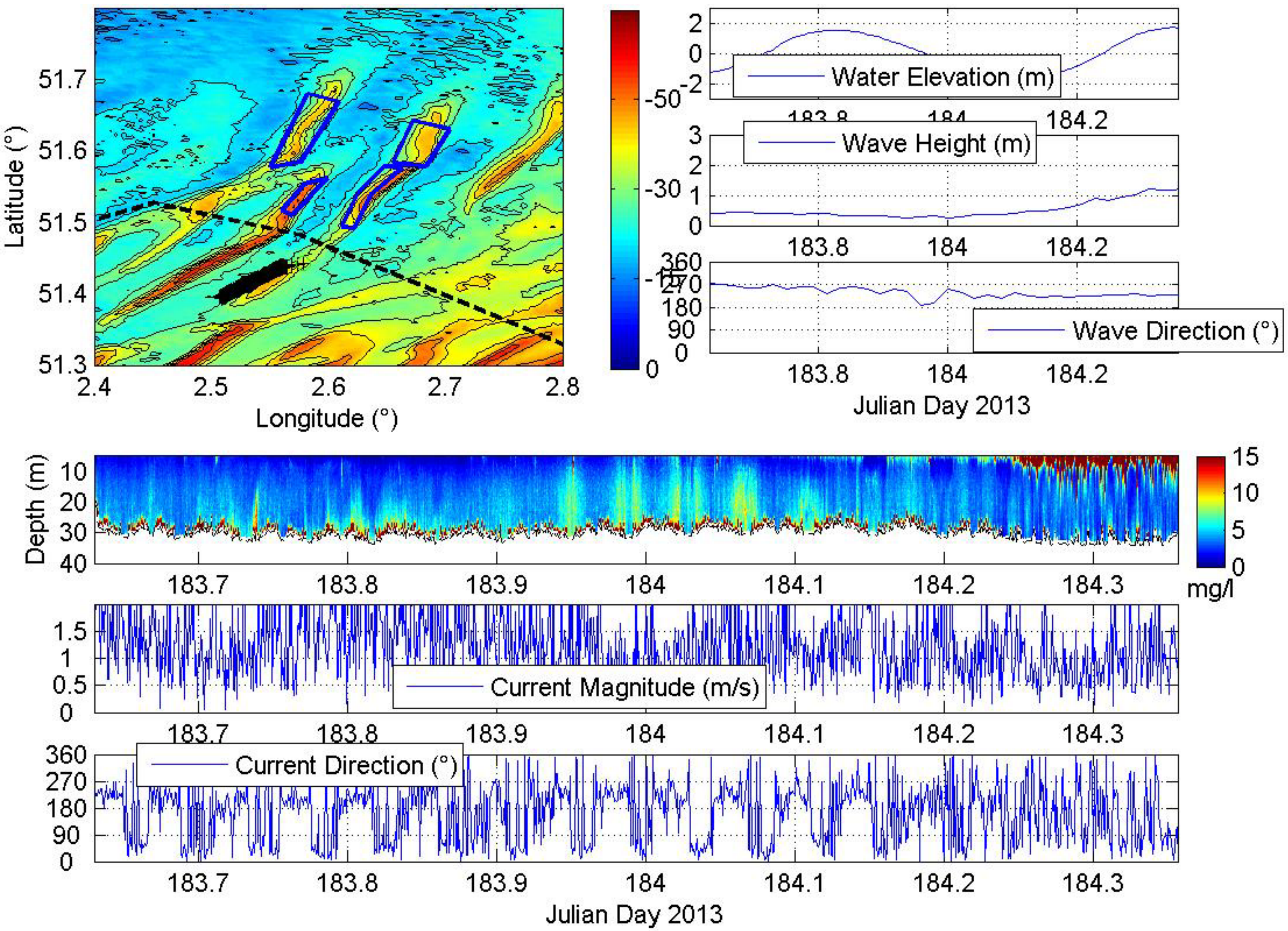


Figure D-20. RV Belgica ST1319. 2-3/7/2013. Transect over a series of barchan dunes in the Habitat Directive area.
Mid tide - tidal coefficient 50. Currents at +/- 5 m water depth.
Note higher SPM values around the ebb tidal level. A sediment plume is present around flood tide.

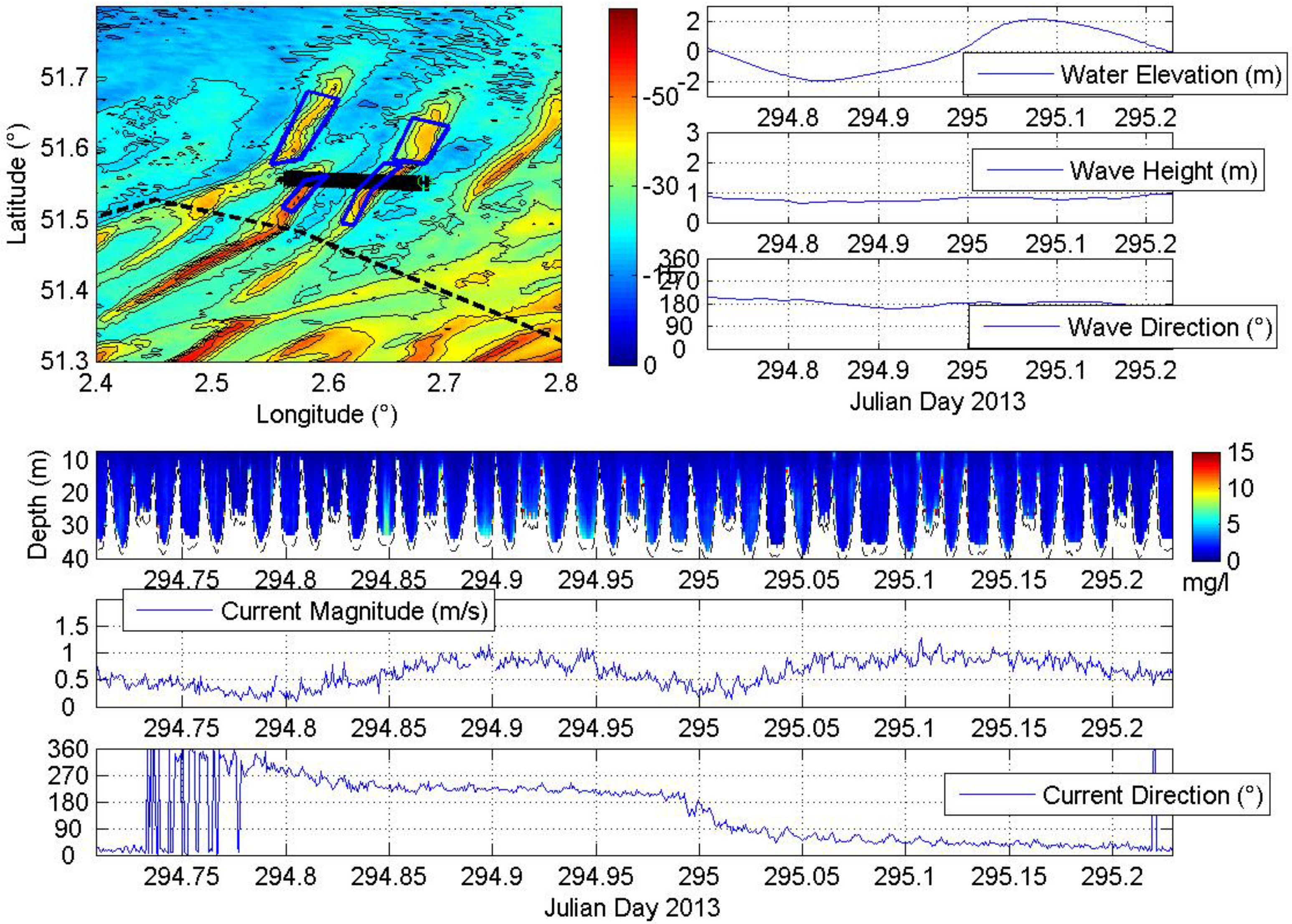


Figure D-21. RV Belgica ST1328. 21-22/10/2013. Transect over Sector 4c-4d.
Spring tide - tidal coefficient 74. Currents at +/- 9 m water depth.
Limited resuspension above the sandbanks, except some during maximum ebb currents.

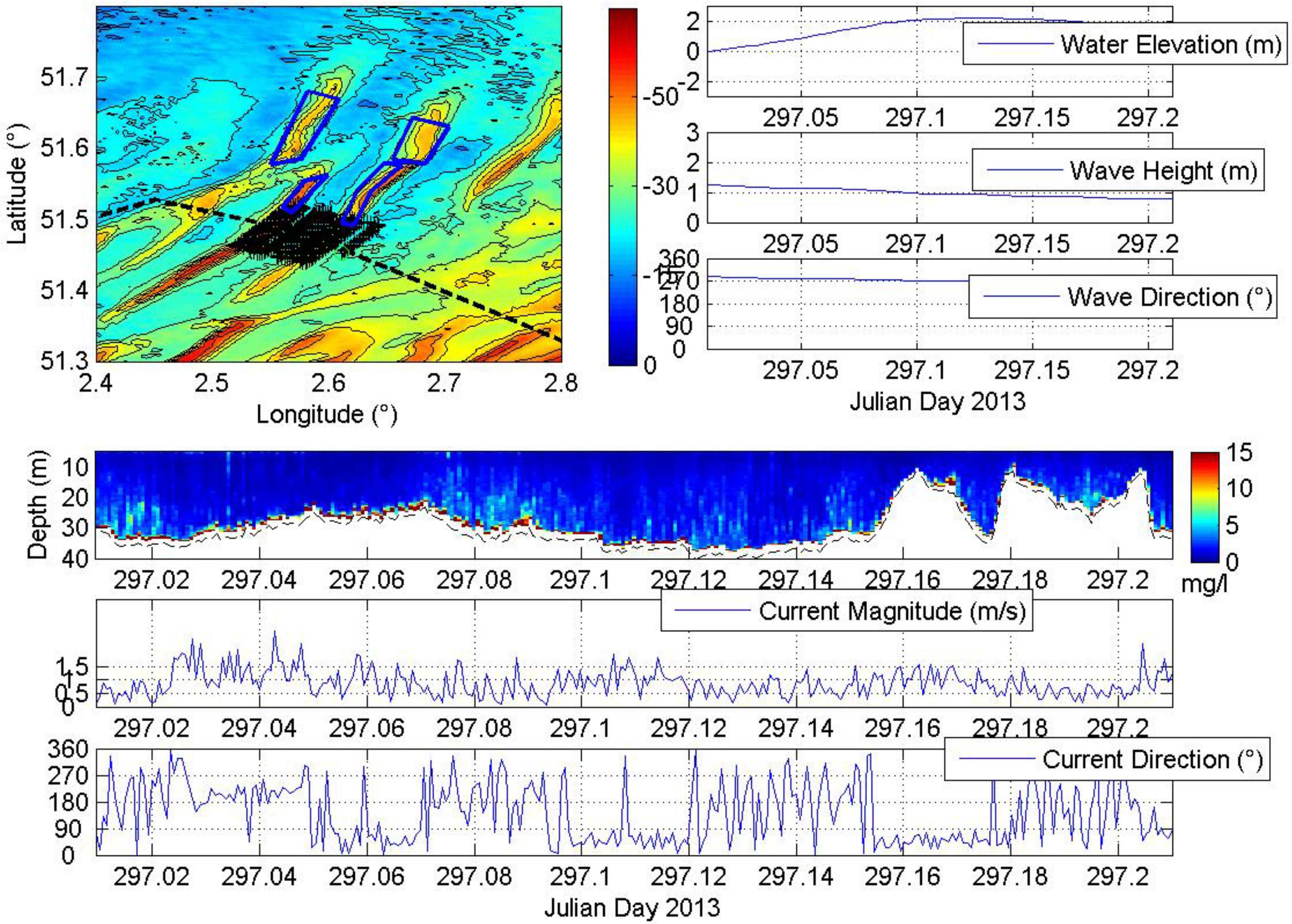


Figure D-22. RV Belgica ST1328. 24/10/2013. Transects (NE-SW) along Buffer zone 4 - Habitat Directive area. Sailing from East to West. Spring tide - tidal coefficient 77. Currents at +/- 6 m water depth.

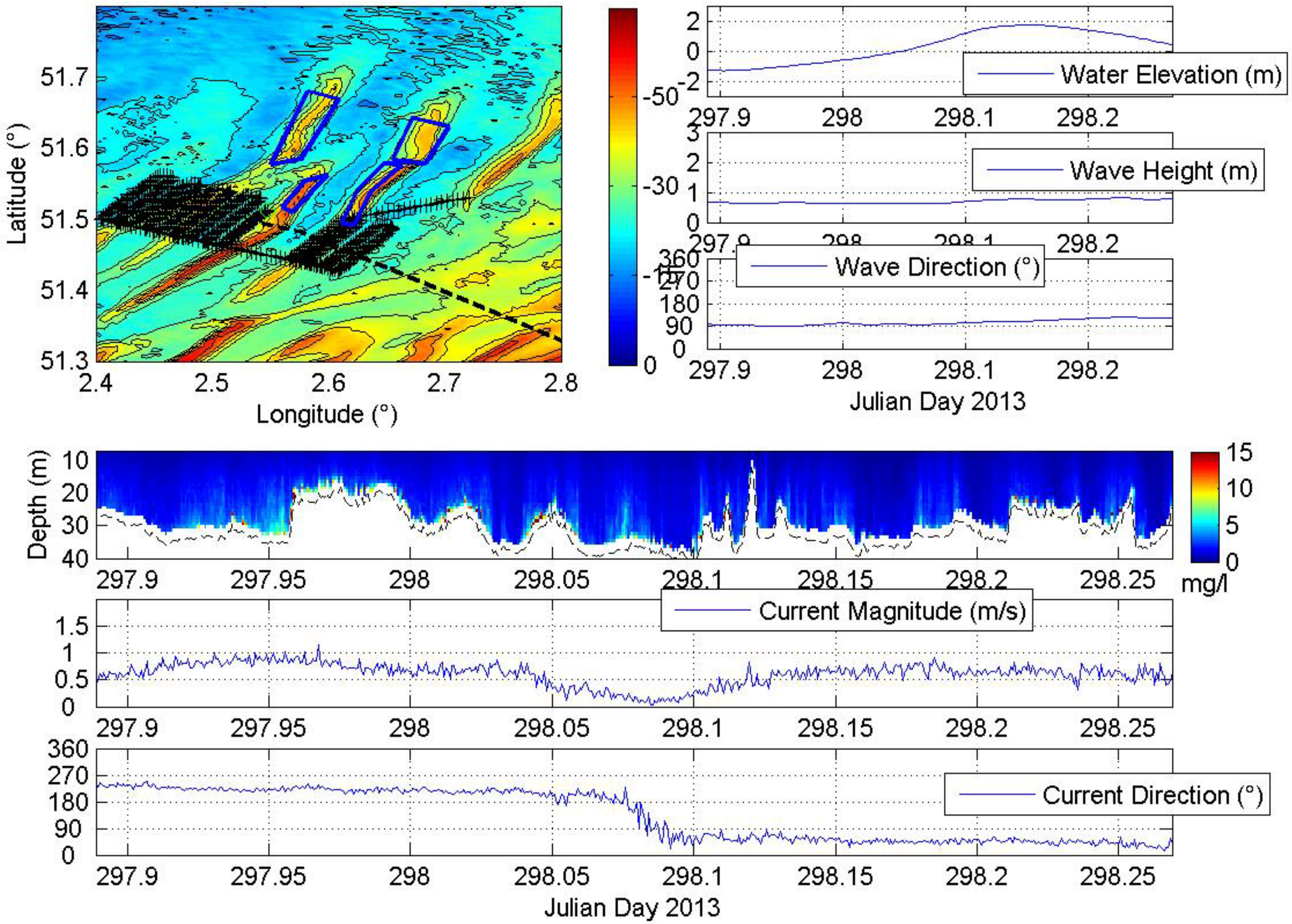


Figure D-23. RV Belgica ST1328. 24-25/10/2013. Transects (NE-SW) along Buffer zone 4 - Habitat Directive area. Spring tide - tidal coefficient 77. Currents at +/- 9 m water depth.

E. Analyses short-term measurements 2011-2013. Time series *Flood vs. Ebb*

Time series (5-min averaged) of the current and SPM variation are represented, respectively for the upper water layers (+/- 7 m (red)) and for the lower water layers, two to three meters above the bottom (black). Data originates from the hull-mounted ADCP (RV Belgica, 300 kHz). Only data, acquired in bin sizes of 1m, are shown, because of most reliable current measurements for these bin sizes. The data was transformed into positive values when the current direction is towards the north-east (0-135°, and >315°); negative when the direction of the current is towards the south-west (135-315°). Mean sea level (m) are modelled values at the Westhinder measuring pole (OPTOS-BCZ). Timestamps are converted to Julian Days per year. Major ticks distance is 3 hrs; minor ticks 1 hr. Generally, 13-hrs cycli are represented.

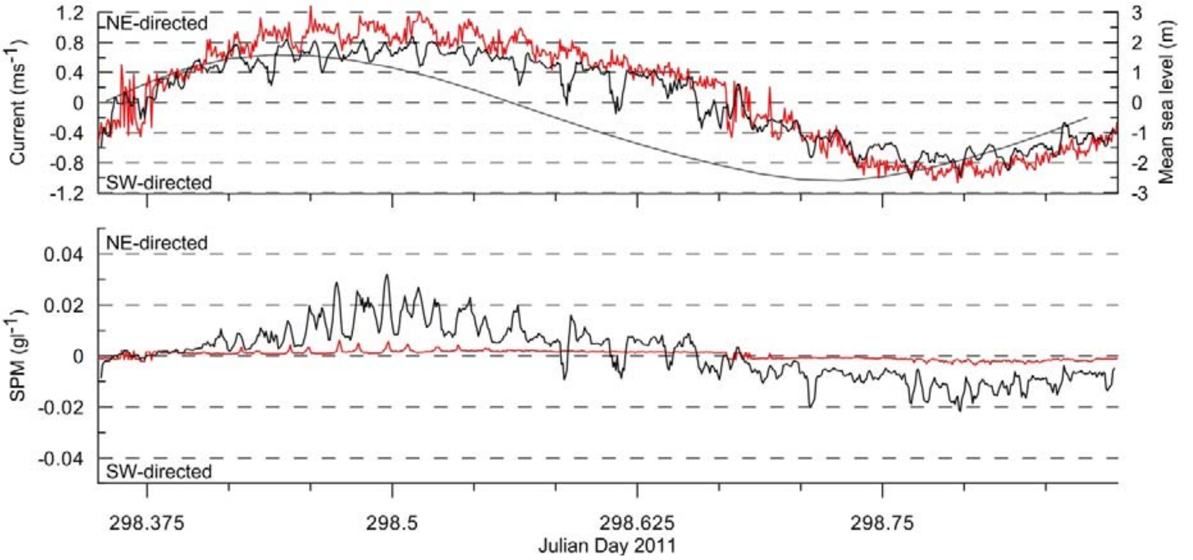


Figure E-01. Belgica ST1128. 25/10/2011. Transects in Sector 4b. Sandbank top and flank. Spring tide - tidal coefficient 73.

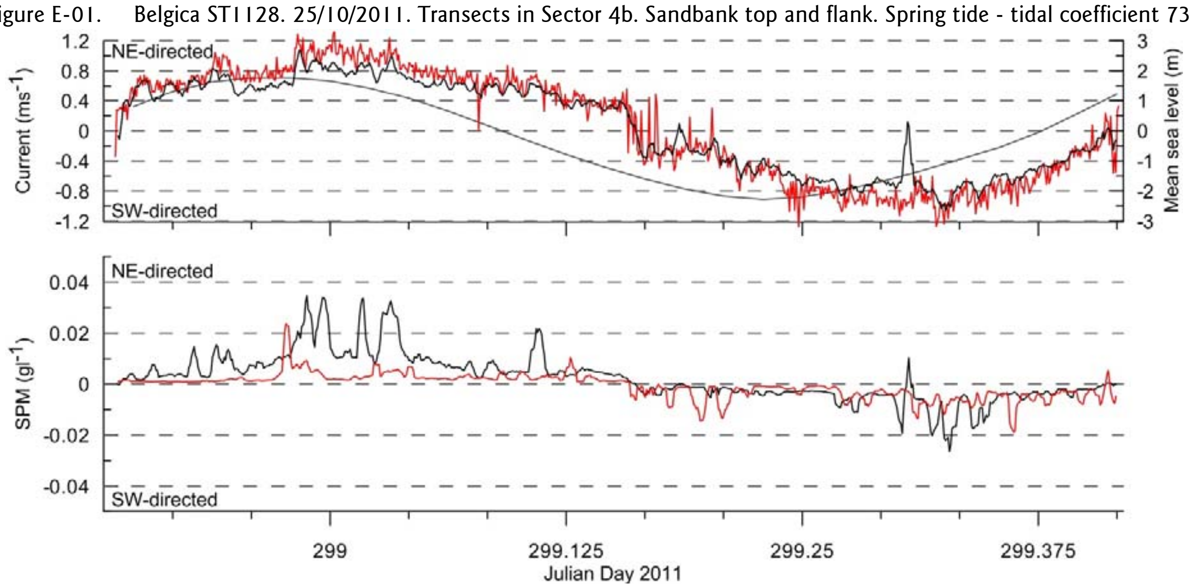


Figure E-02. RV RV Belgica ST1128. 25-26/10/2011. Transects and in-situ measurements in Sector 4b. Sandbank top and flank. Spring tide - tidal coefficient 73. Currents at +/- 7 m water depth and 2-3 mab.

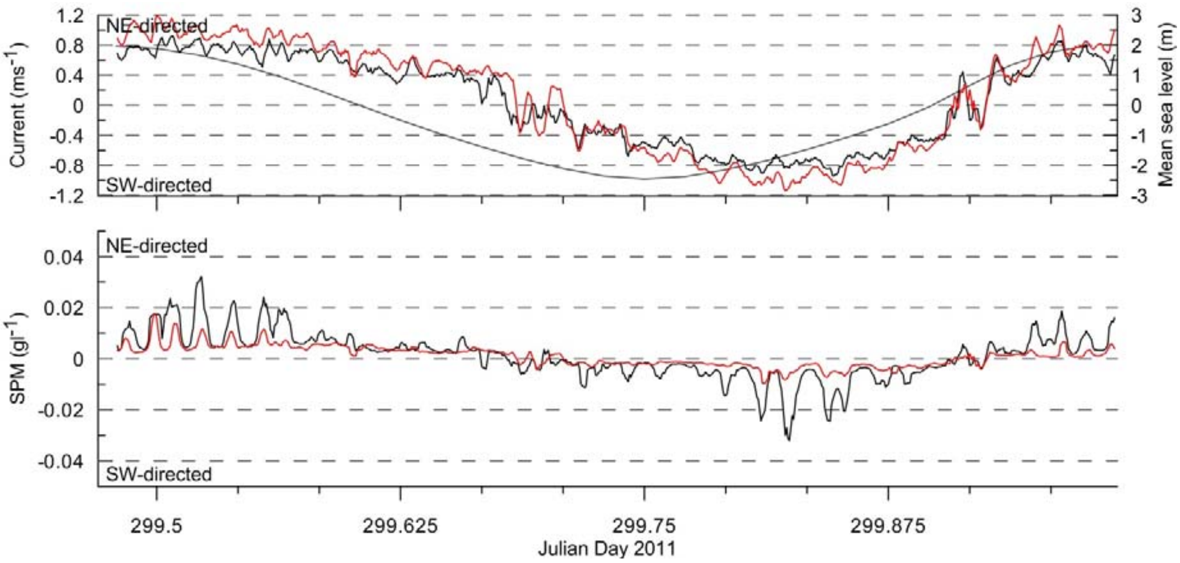


Figure E-03. RV Belgica ST1128. 26/10/2011. Transects covering Sector 4c-4d. Spring tide - tidal coefficient 86.

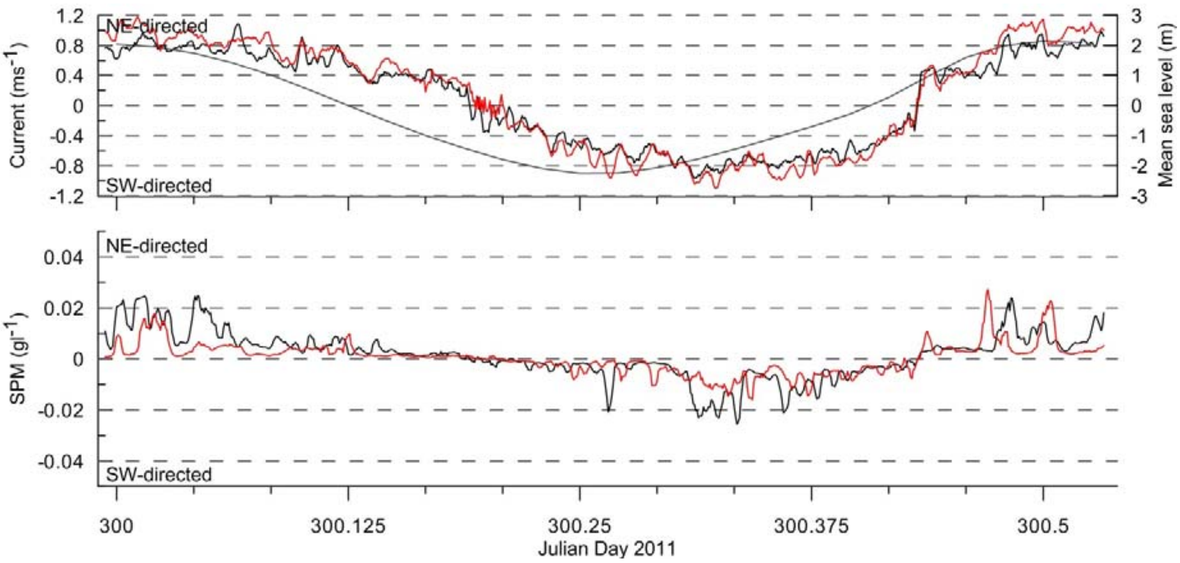


Figure E-04. RV Belgica ST1128. 26-27/10/2011.Transects and in-situ measurements covering Sector 4c-4d. Spring tide - tidal coefficient 86.

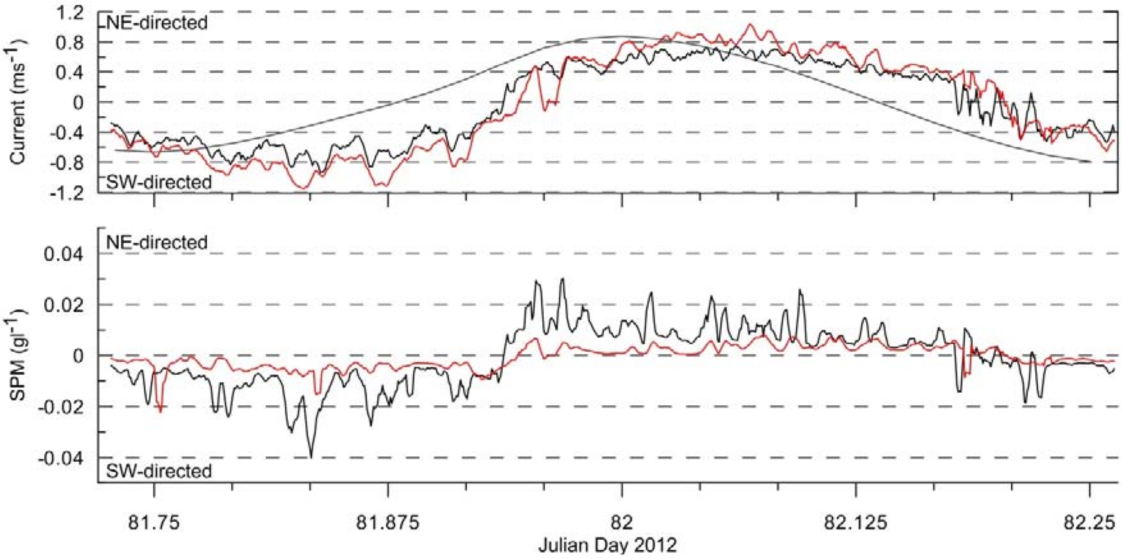


Figure E-05. RV Belgica ST1208. 21-22/03/2012. Transects in between Sector 4b and 4c. Spring tide - tidal coefficient 67.

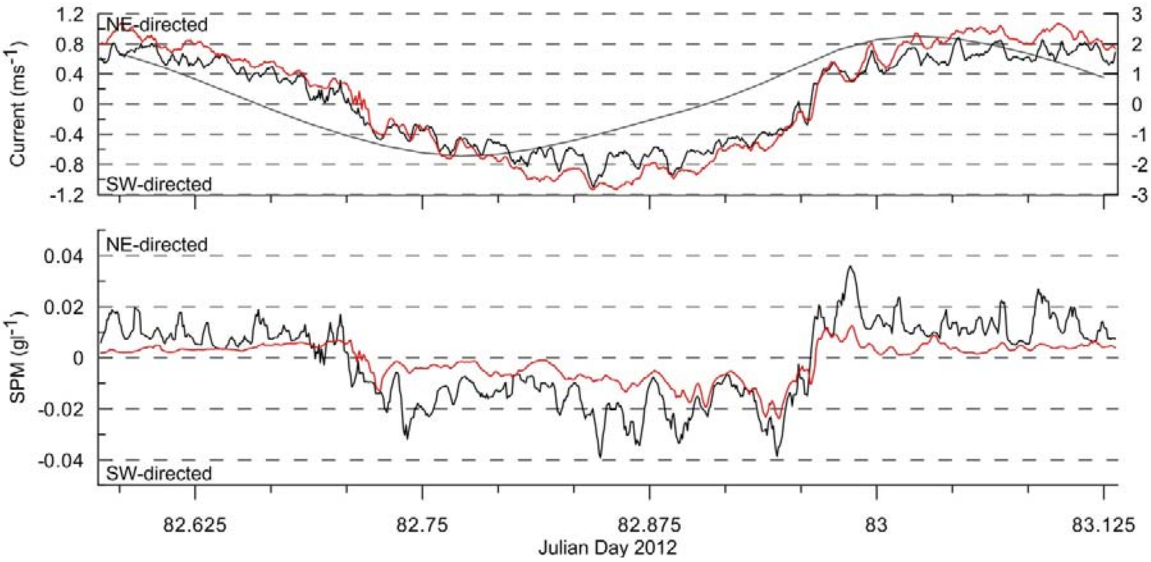


Figure E-06. RV Belgica ST1208. 22-23/03/2012. Transects over Sector 4a. Spring tide - tidal coefficient 74.

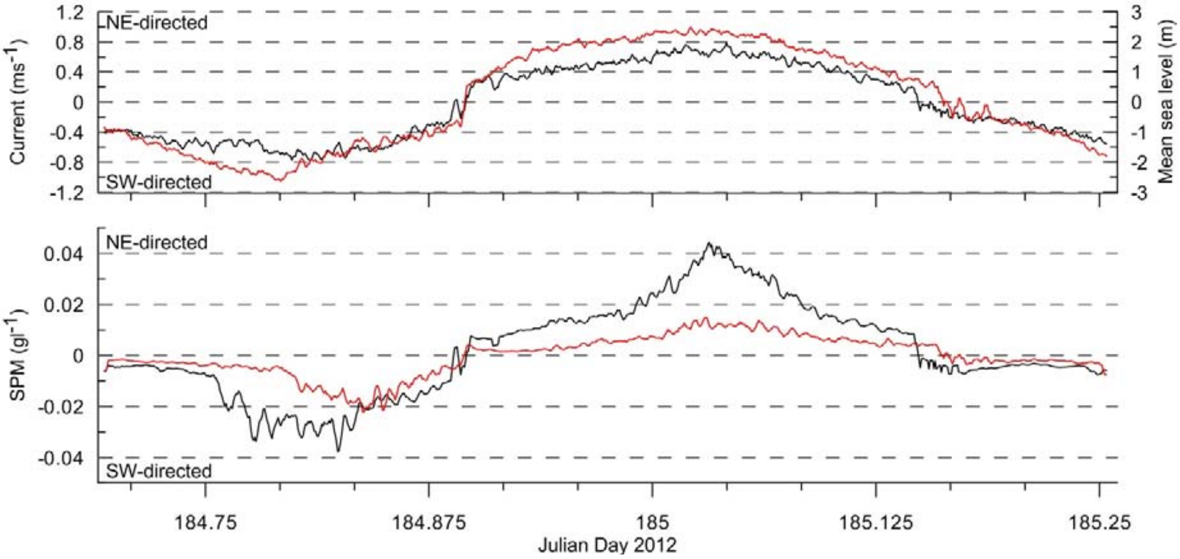


Figure E-07. RV Belgica ST1219. 2-3/7/2012. In-situ measurements in Sector 4c, location - ADCP-I. Sandbank top and flank. Spring tide - tidal coefficient 75. Resuspension during the ebb gave rise to a sediment flare that surfaced and was then transported away during the flooding phase of the tide. Compare with Figure D-07 for SPM ranges in the water column. Interestingly, the water sampling mostly missed the bottom sediment flare, but picked-up the higher SPM values during flood (see Annex A, JD2012 – ST1219)).

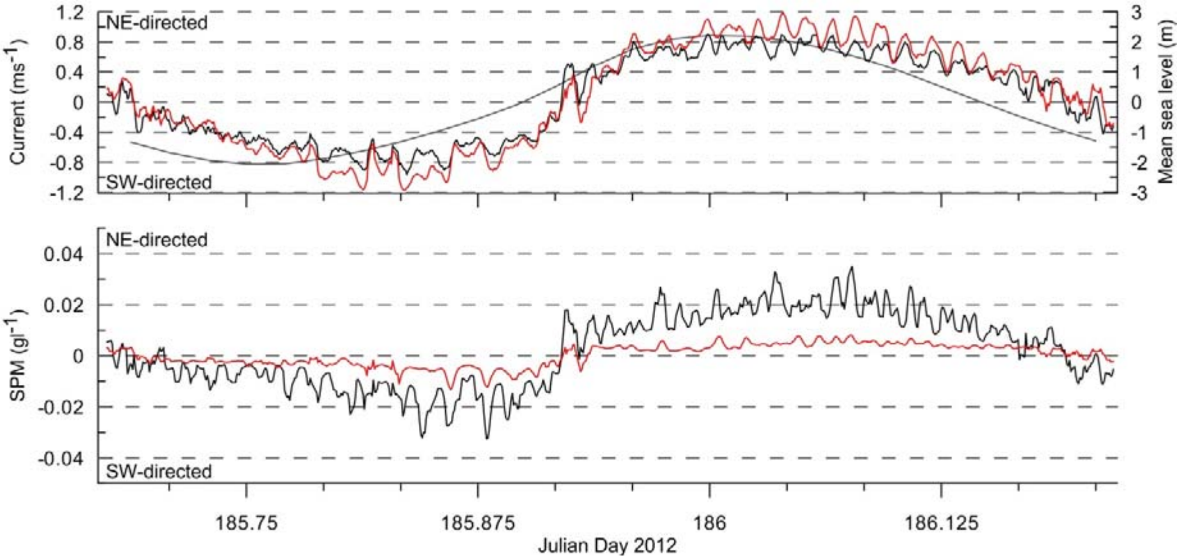


Figure E-08. RV Belgica ST1219. 3-4/7/2012. Habitat Directive Area. Transects covering Westhinder and Oosthinder sandbank. Spring tide - tidal coefficient 79.

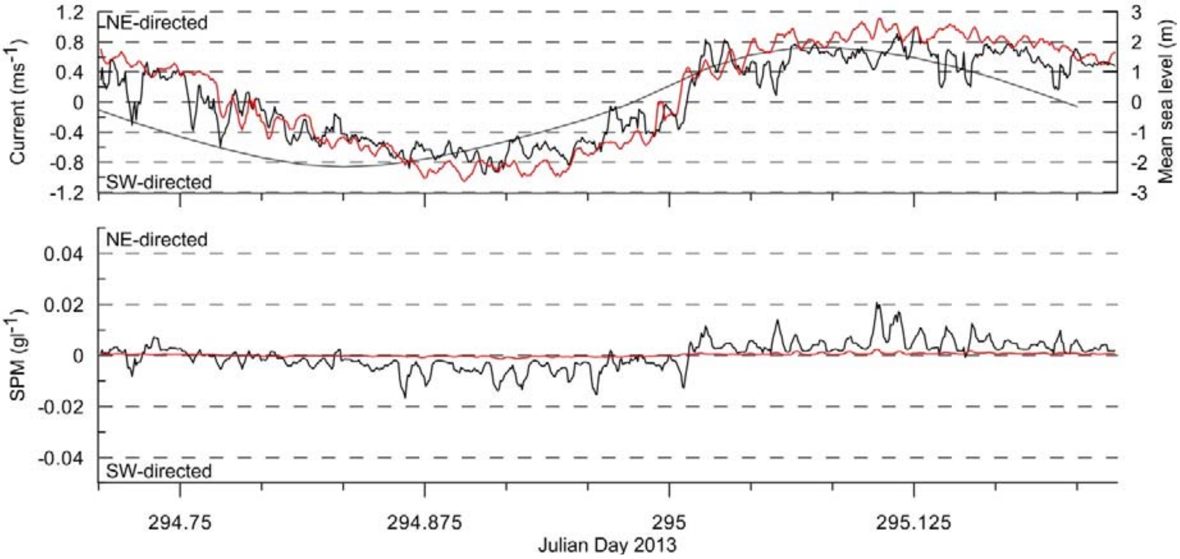


Figure E-09. RV Belgica ST1328. 21-22/10/2013. Transect over Sector 4c-4d. Spring tide - tidal coefficient 74. Currents at +/- 9 m water depth.

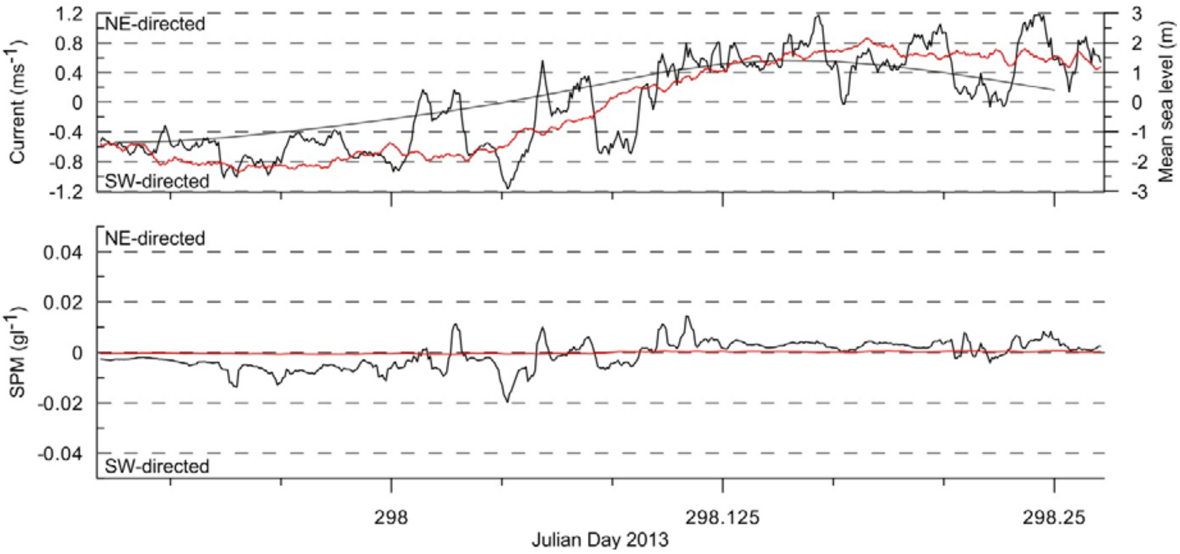


Figure E-10. RV Belgica ST1328. 24-25/10/2013. Transects along Buffer zone 4 - Habitat Directive area. Spring tide - tidal coefficient 77.

Annex F

Wave Glider data series

Wave Glider sv2 (HERMES) (Liquid Robotics)

15/4 – 6/5 2013

This Annex forms part of the report:

Van Lancker, V., Baeye, M., Fettweis, M., Francken, F. & Van den Eynde, D. (2014). Monitoring of the impact of the extraction of marine aggregates, in casu sand, in the zone of the Hinder Banks. Brussels, RBINS-OD Nature. Report <MOZ4-ZAGRI/X/VVL/201401/EN/SR01>.

ROYAL BELGIAN INSTITUTE OF NATURAL SCIENCES

OPERATIONAL DIRECTORATE NATURAL ENVIRONMENT

SECTION ECOSYSTEM DATA ANALYSIS AND MODELLING
SUSPENDED MATTER AND SEABED MODELLING AND MONITORING GROUP

Overview of the Wave Glider data series
Belgian part of the North Sea, 15/4 – 06/05/2013

Vera Van Lancker, Matthias Baeye & Dries Van den Eynde

WAVEGLIDER/X/VVL/201401/EN/TR01

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1. Introduction

From April 15th to May 6th, a pilot monitoring was conducted using the autonomous underwater vehicle (AUV) 'Wave Glider' from Liquid Robotics. For the first time Liquid Robotics' Wave Glider HERMES (type SV2) was deployed in a shallow sandbank area of -8 to -40 m of water depths with currents of up to 1.2 ms^{-1}. Sea-based human activities are widespread in the Belgian part of the North Sea; as such the mission was highly challenging for the Wave Glider and its pilots. Objectives were to identify and address potential logistical challenges, compare data collected using different methods, and determine if AUV technology offers advantages for future environmental monitoring in sandbank areas.

2. Mission

The scientific goal of the mission was to characterize a shallow water sandbank environment subdued to aggregate extraction. On the one hand, background information is needed on the natural variability of sediment processes, on the other hand this activity is known to create sediment plumes. Challenging is to detect the plumes, their dispersal, as also their deposition. As such, the Wave Gliders' trajectory was chosen to detect both natural and human-induced variability. Previous studies showed highly competitive flood and ebb currents (NE- and SW-directed, respectively), as such it was important to assess the dispersion of sediment plumes under both conditions. Based on this, and technical exclusion zones (e.g. water depths less than -10 m, intensive shipping routes, as also the marine aggregate concession zone) a box was defined contouring the extraction site at a safety distance of minimum 1 km (Figure 1). From a navigation technical and energy saving point of view, the Wave Glider was programmed to sail the western and eastern boundary during the ebbing (SW) and flooding (NE) phase of the tide, respectively. The southern and northern profiles, crossing the sandbank, were sailed under most favourable tidal conditions. Pilots adjusted the timing accordingly, meaning that the Wave Glider lengthened or shortened its path. The Wave Glider sailed for 22 days or 39 rounds around the extraction site. 25 extraction events took place during this period.

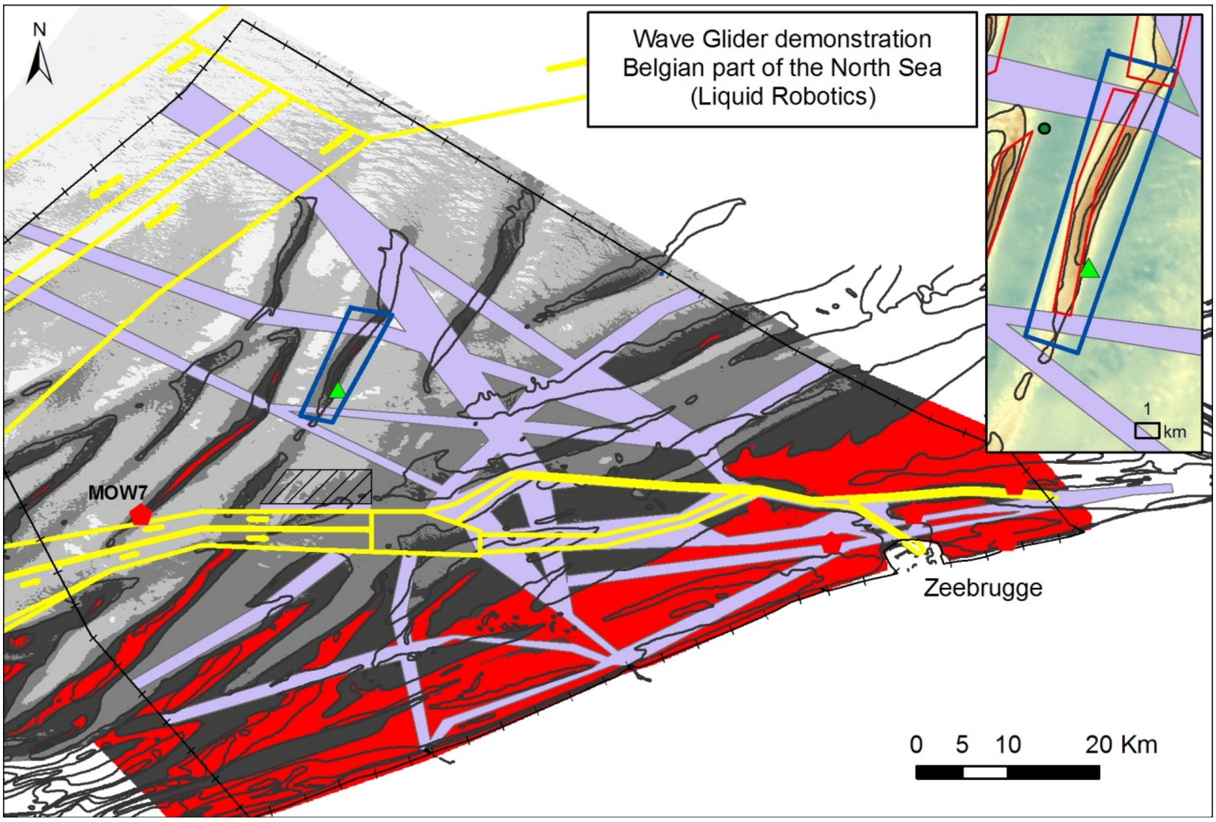


Figure F-01. Belgian part of the North Sea, with indication of the navigation routes (yellow and purple). Wave Glider could only operate in areas deeper than -10 m (non-red) and outside a safety buffer of 1 km around major human activities. A Wave Glider trajectory was defined around the Oosthinder sandbank (blue polygon), where during the demonstration marine aggregate extraction took place in Sector 4c (red polygon in inset). The Wave Glider followed this path for 22 days. During this period data were recorded with a bottom-mounted ADCP (green triangle). Also shown is the hydro-meteo measuring pole at the Westhinder (MOW7), where closeby a Wavec buoy was measuring wave parameters (Flanders Hydrography).

3. Wave Glider platform

The Wave Glider is composed of two parts: a *float* which is roughly the size and shape of a surfboard and stays at the surface; a *sub* having wings and hanging 6 meters below on an umbilical tether. Because of the separation, the float experiences more wave motion than does the sub. This difference allows wave energy to be harvested to produce forward thrust (www.liquidrobotics.com) (Figure F-02). The AUV was deployed and recovered with the oceanographic vessel *RV Belgica*, respectively on April 15th and May 6th (see http://www.youtube.com/watch?v=pjRICKQIrzU for a movie on the deployment from RV Belgica).

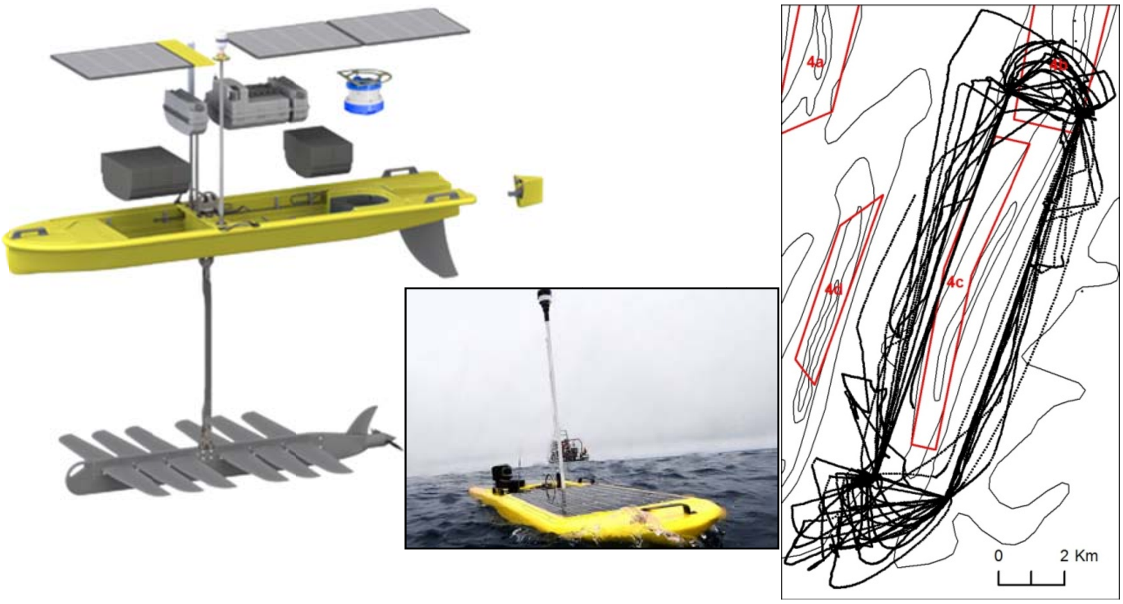


Figure F-02. Left: Wave Glider SV2, Liquid Robotics. Float (payload, incl. ADCP) and sub. Right: trajectory during the period 15/4 – 6/5 2013.

Apart from navigation and payload control computers and satellite communication systems, the Wave Glider was equipped with a fluorometer (Turner Designs, C3 submersible fluorometer) equipped with sensors measuring chlorophyll-A and crude and refined (poly and mono-aromatic hydrocarbons) oil fluorescence, as well as turbidity and water temperature just below the float of the Wave Glider. The fluorometer incorporated three optical sensors ranging from the deep ultraviolet to the infrared spectrum. The light emitting diode for measuring turbidity from the scattering of light had a wavelength of 850 nm. Values were expressed in relative fluorescence units (RFU) and can report values between 0 and 65535 (www.liquidrobotics.com).

Additionally, the float of the Wave Glider housed an Acoustic Doppler Current Profiler (ADCP) (Teledyne/RD Instruments, 300 kHz), which was programmed to resolve current and acoustic backscatter data over vertical bins or cells of 1 to 2 m resolution. The Wave Glider had an average speed of 1.14 kt, with a maximum of 1.69 kt. Figure 3 shows the hydrometeorological conditions during the period of the Wave Glider. Also the conditions of the preceding period are shown to indicate the timing of a deployment of a bottom-mounted ADCP (BM-ADCP), as well as of a measuring campaign with RV Belgica (ST1309) during which water samples were taken.

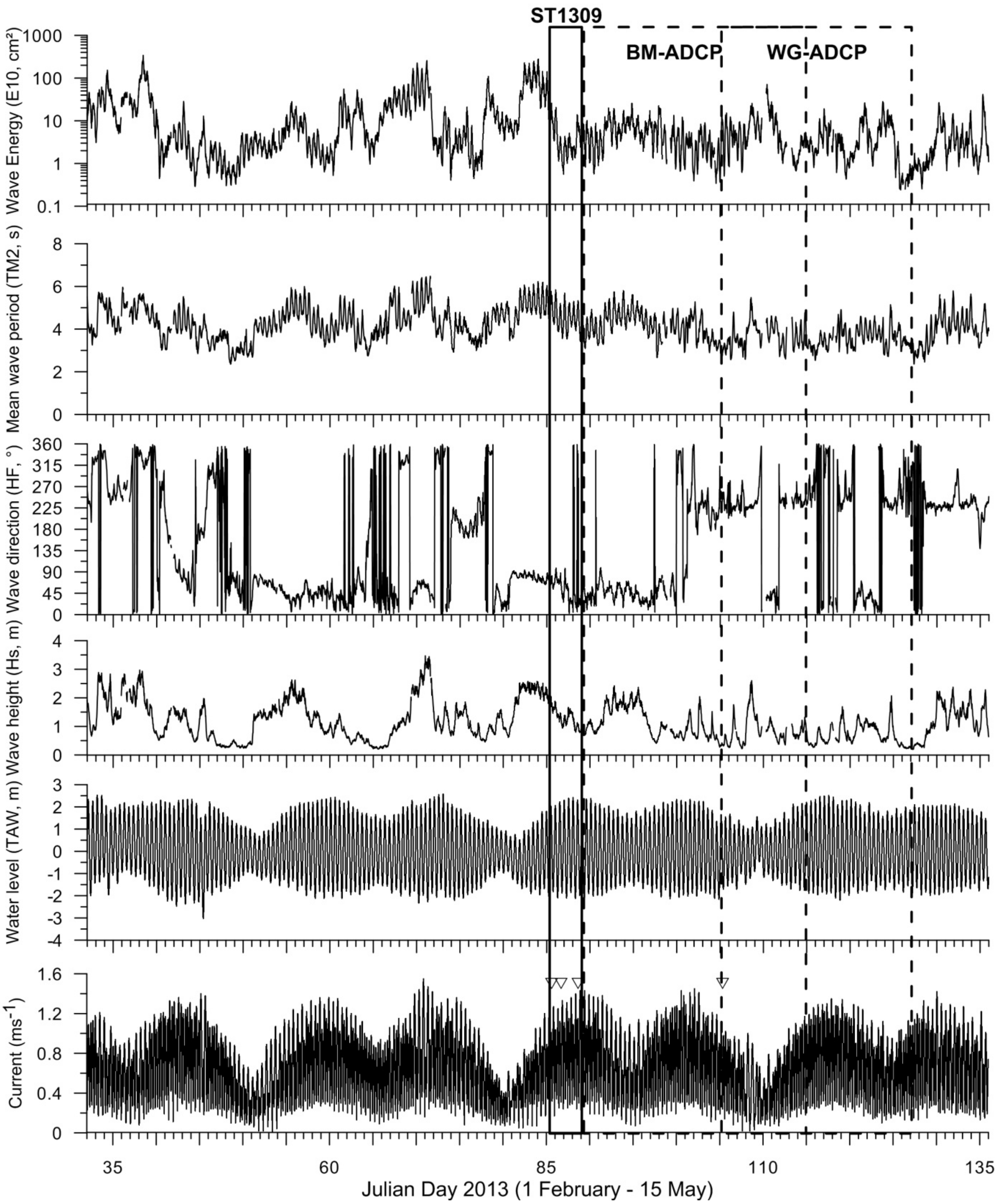


Figure F-03. Hydro-meteorological conditions in the period 1/2 - 15/05 2013. Currents and water levels are modelled values (OPTOS-BCZ). Wave parameters are derived from the Wavec buoy near the Westhinder (Meetnet Vlaamse Banken).

5. Data analysis

5.1. *Fluorescence data (Turner Designs, C3 submersible fluorometer)*

Data were used as obtained from the sensor (RFU) and remain relative values. No data were available to calibrate towards Nepheloid Turbidity Units (NTU) and eventually mass concentrations of SPM. Data showed a range in values from around 6 to 650 RFU. 0-50 RFU was regarded a range of valid data that could be used for further averaging of turbidity against a series of combinations of hydro-meteorological conditions.

5.2. *Acoustic Doppler current profiler*

Currents and turbidity

ADCP data were recorded in three parts, each with different settings (Table 1). For Part 1 and 3, currents were resolved into 1 m bins; part 2 into 2 m bins. OD Nature required this change in settings because initially no bottom-tracking was activated. However, the extra ping for the bottom caused a doubling of the bin size to 2 m, which eventually was too coarse for the purpose of the mission and the initial settings were returned to.

Table F-01. Details Wave Glider data series (JD: Julian day, calculated per year).
For the ADCP data, there are three parts, each with different settings (* with bottom-tracking).

Part	Date1	Date2	JD1	JD2	#Days	ADCP kHz	Bin size
1	2013-04-15	2013-04-21	105.50	111.63	6.13	300	1
2	2013-04-22	2013-04-30	112.92	120.17	7.25	300	2*
3	2013-05-01	2013-05-06	121.02	126.11	5.09	300	1
Total					**18.47 data from 21.98 days at sea**		

For recalculation of bin depth to actual depth values, a draught 0.25 m was applied for the Wave Glider. The first bin that could be used was around 12 m only, because of contamination of the data in the upper water layers by the submerged part of the Wave Glider. Due to interference with the strong amplitude of the signal near the bottom, 2 bins needed to be removed (i.e., 2 m above the bottom are lost for a bin size of 1 m; 4 m for a bin size of 2 m). Pulses were averaged into ensembles at a time interval of 60 seconds per sample. For the Wave Glider data, this averaging process resulted in a horizontal resolution of ± 40 m, at an average platform speed of 1.14 kt.

Algorithms were used to convert the measured RSSI counts to acoustic backscatter in decibels (dB) using the echo intensity scale (dB per RSSI count). This conversion adjusted for beam spreading and acoustic absorption through the water column and provided a quasi-range-independent measure of the relative concentration of sound scatterers in the water column (Kim et al., 2004). Decibel (dB) values were then converted to mass concentrations of suspended particulate matter (SPM in gl^{-1}), by calibration against SPM concentration values derived from water filtrations during previous field campaigns. This calibration remained very tedious and is still work in progress given the high spatio-temporal variability of the backscatter in the datasets (see datasheets). The ranges of SPM concentration values, obtained from the acoustics, were in similar order of magnitudes as those obtained from water filtrations..

5.3. *Hydro-meteorological data*

Wave information (significant wave height in m, direction of low and high frequency waves in degrees, low frequency (0.03 Hz to 0.1 Hz) wave energy in cm^2) were obtained, at 30 min interval, from a Wavec buoy (Westhinder location, Flanders Hydrography) at 18 km southwest of the study area (Figure 1). Water levels, current velocity and direction (10 min interval) were extracted from an operational 3D hydrodynamical model (Luyten et al., 2011). Wind velocity and direction (10 min interval) originated from the fixed Westhinder measuring pile (Flanders Hydrography) (for location, Figure 1).

5.4. *MODIS Satellite data*

The temporal variation of the C3 turbidity sensor, mounted in the Wave Glider float, was validated using imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) (via MUMM/GRIMAS extraction tool (http://www2.mumm.ac.be/remsem/timeseries/) (Vanhellemont et al., 2011). Main motivation was to have an independent dataset to verify the relative variations in the dataset. For each Wave Glider record a nearest window of 25 pixels (1 km x 1 km) was derived. In the case of no clouds, an SPM concentration value (incl. mean, median and standard deviation) was calculated at each of these pixels. For the correlation with the C3 data, a median MODIS-derived SPM value was retained when measurements could be performed in 13 of the 25 pixels, and when the time span between the Wave Glider and MODIS was less than 2 hours. During the Wave Glider period, the range of the daily image provision of MODIS was between 12h and 13h45 (UTC).

5.5. *Bottom-mounted ADCP*

During the Wave Glider period a bottom-mounted ADCP (BM-ADCP; Teledyne/RD Instruments, 1200 kHz Workhorse Sentinel) was located along the eastern steep flank of the Oosthinder sandbank (Figure 1). Current and backscatter analyses followed the same procedure as described above.

6. Results

For a full reporting on the results reference is made to Van Lancker et al. (2014).

6.1. *Natural variation*

Wave Glider data series confirmed the highly competitive nature of flood and ebb currents in the area. Generally, the flood tidal phase lasted longer than the ebb tidal phase. This was reflected in the SPM concentration values as well. More fine sediments were transported during flood, though hydro-meteorological conditions and/or human influence could reverse the situation. In the upper water layers, and without influence of events, SPM concentration reached values of approximately 0.003 to 0.005 gl^{-1}. SPM concentration in the lower waters along the Wave Glider trajectory were on average 0.007 to 0.010 gl^{-1}, though with outliers of up to 0.030 gl^{-1} and beyond. It needs emphasis that the majority of the data were acquired in the troughs, and the sandbanks were mostly crossed under slack water conditions. In the deeper waters of the troughs, the surficial currents were approximately 21 % higher than those in the lower water layers.

An overview of results is given in Figure 4.

Current velocities clearly increased from neap to spring tidal levels with values up to 1.2 ms^{-1}. A change of base level (minima of turbidity proxy) from neap to spring could best be observed from the surficial C3 fluorometer sensor data in the Wave Glider (Figure F-04) that is a proxy for turbidity. The strong fluctuations in the dataset did hamper deriving a good correlation between the C3 values and the tidal currents. The ADCP time series also showed a slight increase in base level for spring, though the increase was less pronounced, probably due to different settings that were used throughout the data series. Neap to mid tidal conditions were measured with 1 m bin settings (part 1 and 3); during spring (part 2), 2 m bins were used for data acquisition (Figure F-04).

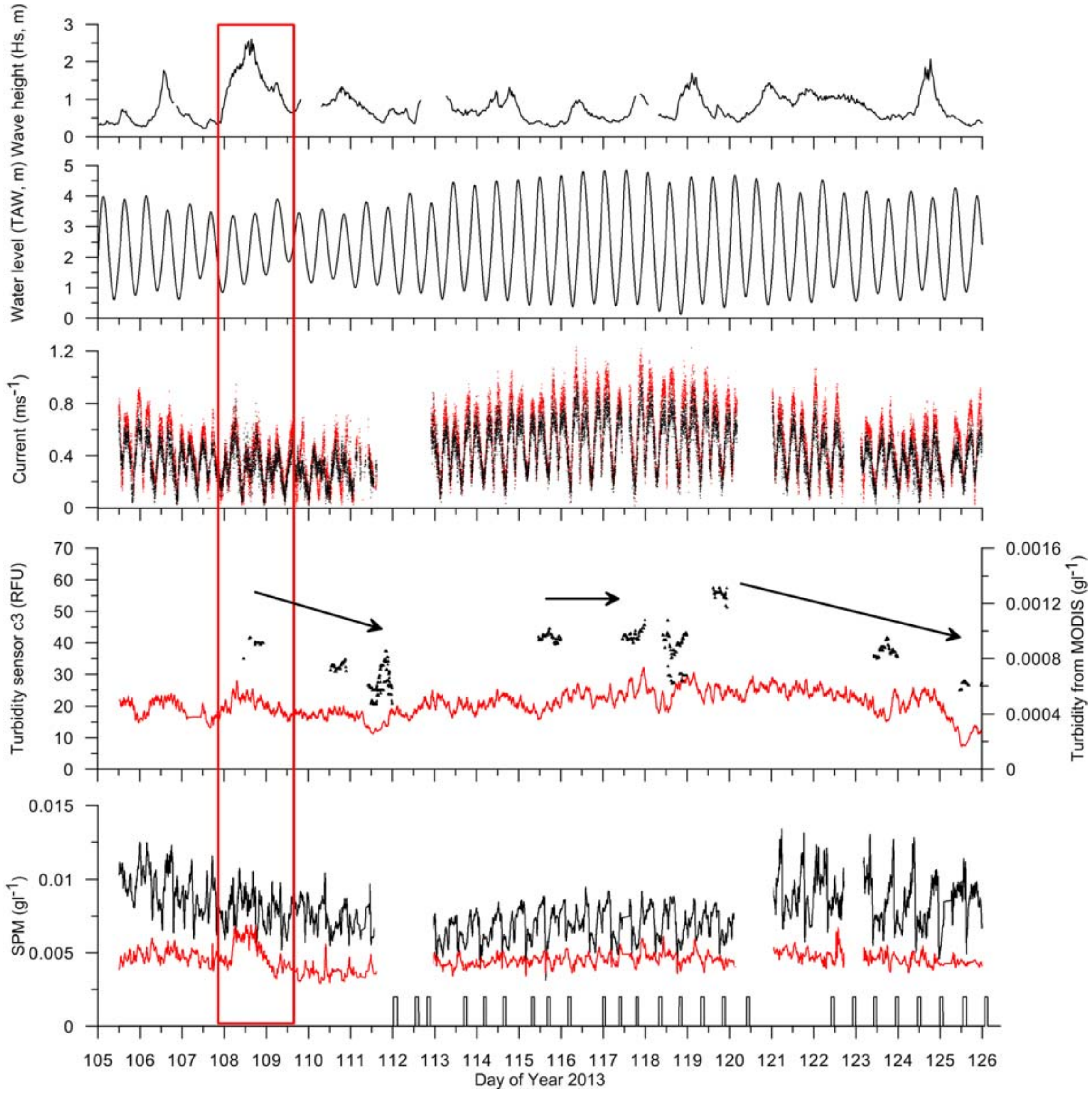
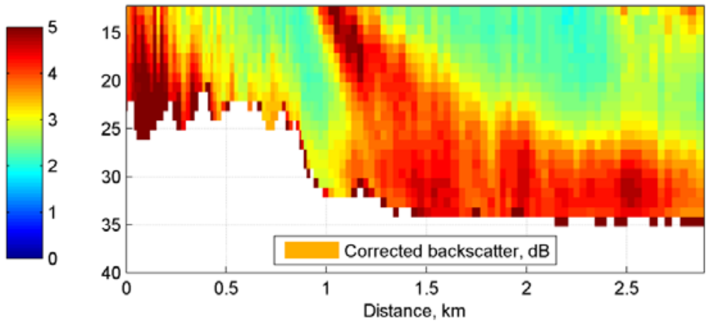


Figure F-04. Composite of the Wave Glider data sets, together with the hydro-meteorological conditions. Currents are derived from the Wave Glider ADCP; in red: currents in the upper waters, in black: currents in the lower waters. The C3 sensor provides a proxy for the surface SPM concentration variation. Superimposed are turbidity values derived from cloud-free MODIS satellite imagery data. The multiple values per day represent the closest match-ups along the Wave Glider trajectory. Note similar relative variation (arrows) between the C3 and MODIS data. Lower figure is SPM concentration variation in the upper (red) and lower waters (black), as derived from the Wave Glider ADCP. Note the influence of waves (Day of Year 108-109) in the C3, ADCP and MODIS data, with most variation in the upper waters. Neap to spring variation is most obvious from an increase in the base level, or minimum values, of SPM concentration variation (C3 and ADCP). Markers at the x-axis of the lower figure represent the dates of extraction activities (25 events). C3 and ADCP data are smoothed using a running average of 20'. Red rectangle corresponds with a somewhat rougher period with nearly 3 m high waves.

6.2. *Human-induced variation*

During the Wave Glider period, 25 dredging cycles took place using a dredging vessel of ~2500 m³. Due to natural resuspension of the sandbanks under higher energetic conditions, it proved very hard to quantify natural from human-induced variability from the time series. The Wave Glider did detect, unambiguously, the descending of a dredging-induced sediment plume from the upper waters to the bottom (Figure F-05). This detection took place ± 3-hrs after the last extraction event. Extraction took place during the ebbing phase of the tide, hence currents were to the southwest, and also winds blew in this direction.



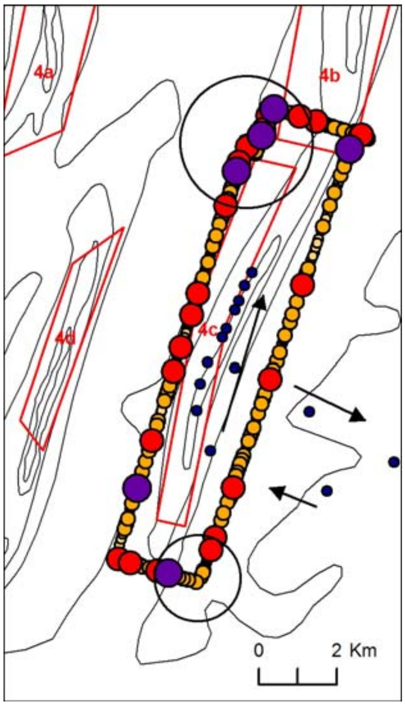


Figure F-05. Left: Wave Glider ADCP depth profile showing the deposition of a dredging-induced sediment plume. The plume descended in the southeast corner (lower circle in right figure). Right: C3 sensor data showing relative variation (graduated symbols) in surface SPM after the extraction event (dots in Sector 4c, with indication of the sailing direction of the vessel). Upper circle indicates the C3 variation during the extraction. Extraction took place during the ebbing phase of the tide (to the SW).

6.3. *Validation of the data against models*

The ADCP data obtained with Liquid Robotics' Wave Glider©, were validated against results from the OPTOS-FIN model (Luyten et al., 2011). The bias for the current magnitude for the three separate periods (with changing parameters for the ADCP) varied between -0.03 ms^{-1} and 0.015 ms^{-1}, with a root mean square error (RMSE) around 0.07 ms^{-1}. The RMSE for the current directions remained below 20°. A small overprediction of the surface currents, and a small underprediction of the bottom currents were observed. Overall, the currents at different levels in the water column were very well predicted. It was shown that in shallower water, the current magnitude is slightly overpredicted, whilst in deeper water, the current magnitude is underpredicted. The RMSE of the current magnitude decreased slightly with water depth. Also for these measurements, the underprediction of the current direction was higher for deeper waters, while the RMSE increased with increasing water depths. For the full validation report reference is made to Van den Eynde et al., (2014). This report includes also the validation of the BM-ADCP data of which the period partly overlapped with the Wave Glider data series.

7. Wave Glider data sheets

The entire data series on the C3 and ADCP data is represented in the following figures, and show consecutively the West, South, East and North profiles. The West and East profiles are sailed in the troughs; the South and North profiles are recorded, whilst crossing the Oosthinder sandbank.

Each Figure shows: (1) location (Lat/Long in WGS84) of the Wave Glider with a magenta dot for the beginning of the transect (W-S-E-N). If during this transect active marine aggregate extraction took place, this trajectory is indicated with white dots with a black dot for the beginning; if not, grey dots were used for the last dredging cycle before the Wave Glider passage. Background bathymetry is in meters Mean Lowest Low Water Spring; (2) Significant wave height (Hs), recorded by the Westhinder Wavec buoy (Flanders Hydrography) (for location see Figure D-02); (3) Pitch and roll of the Wave Glider platform (°); (4) Surface turbidity variation as derived from the C3™ Submersible Fluorometer (RFU units); (5) Depth (m) *vs.* ADCP-derived current magnitude (ms^{-1}); (6) Depth (m) *vs.* ADCP-derived current direction (°); (7) Depth (m) *vs.* ADCP-derived backscatter, corrected for beam spreading and absorption (dB); and (8) Along- and across bank current magnitude (ms^{-1}). Distance in km is calculated from the beginning of the Wave Glider trajectory per W, S, E or N trackline.

Original timestamps in Universal Time Coordinates (UTC) were converted to Day of Year (1/1/2013 12h=0.5).

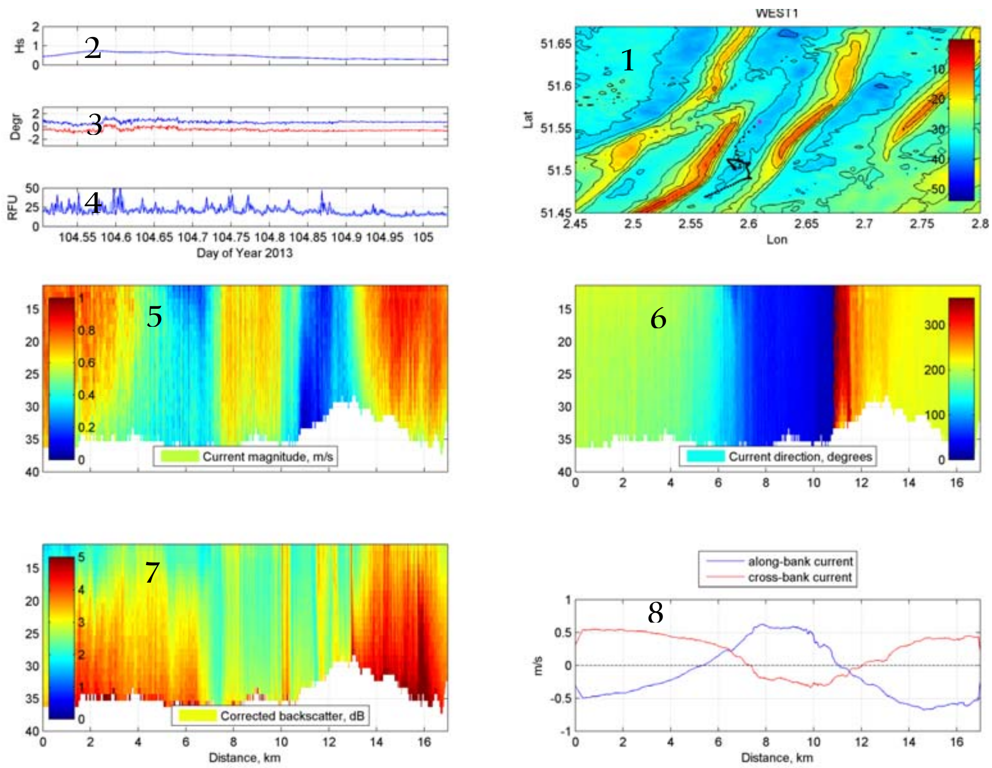


Figure F-06. Example of a Wave Glider datasheet.

8. Discussion and conclusions

The Wave Glider proved being a highly valuable platform for depicting both naturally and human-induced variation. Natural resuspension above sandbanks could be observed clearly, both under tidally- and wave-induced currents. Most importantly, the Wave Glider allowed identifying well-delineated sediment plumes resulting from marine aggregate extraction activities. Sinking and deposition were observed around 8 km off the last dredging activity, in the direction of the ebb current.

Pros and cons are summarized in the following Table 2.

Table F-02. Pros and Cons with respect to the Wave Glider monitoring experience.

Pros	**Cons**
• Stable platform in a dynamic environment; • Integrated spatio-temporal dataset ; • Long-term continuous data series, containing natural variability and human-induced effects; • Event detection, from peak to waning phase; lag effects; • Remote control	• No equal representation of forces; Much more data in the troughs than over the sandbanks. Crossing of sandbanks around slack water, missing out on the highest turbidity events; • Slow speed resulting in trajectories of 10-15 hrs. Only detection of events, no quantification; • Lack of validation/calibration; • Additional datasets needed for balanced evaluations of environmental conditions.

Most of the cons were related to the survey design. The latter was based on the necessity to sail around the extraction sector on the sandbank. As such, the Wave Glider dataset provided an oversampling of the troughs and an undersampling of the sandbanks. The spatial extension of the sector meant that a round had a long duration, in relation to the tide. Shorter tracklines might be more useful with a focus on sandbank dynamics, or with more active intervention of pilots, guided by scientists.

9. Acknowledgements

Ryan Carlon, François Leroy, and Kim Hosaka from Liquid Robotics are thanked for providing OD Nature the opportunity to deploy the Wave Glider© Hermes in the Belgian offshore waters, and for their help and support in the deployment and the recovery of the Wave Glider, together with MSO team members. Their pilots are acknowledged for the control and guidance of the Wave Glider during the operations.

The commander and crew of RV Belgica are acknowledged for their support during the deployment and recovery operations. Lieven Naudts, and other team members of the Measuring Service Ostend (MSO) of the Operational Directorate Natural Environment (OD Nature) are thanked for preparations and logistical support.

Hydro-meteorological data were obtained from IVA MDK - afdeling Kust – 'Meetnet Vlaamse Banken'. Modelled data on currents and water levels were derived from OPTOS-BCZ, with special thanks to Sébastien Legrand.

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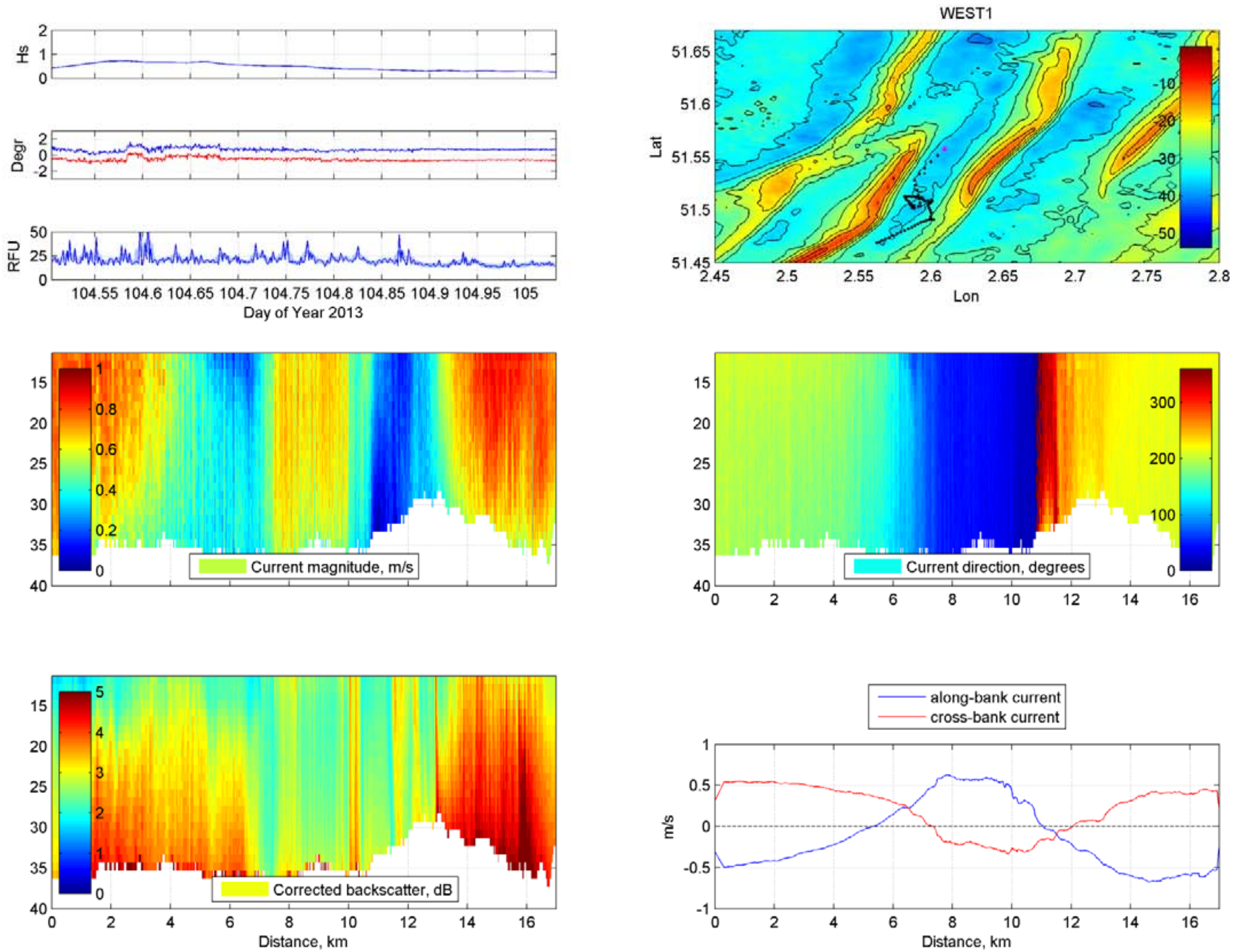

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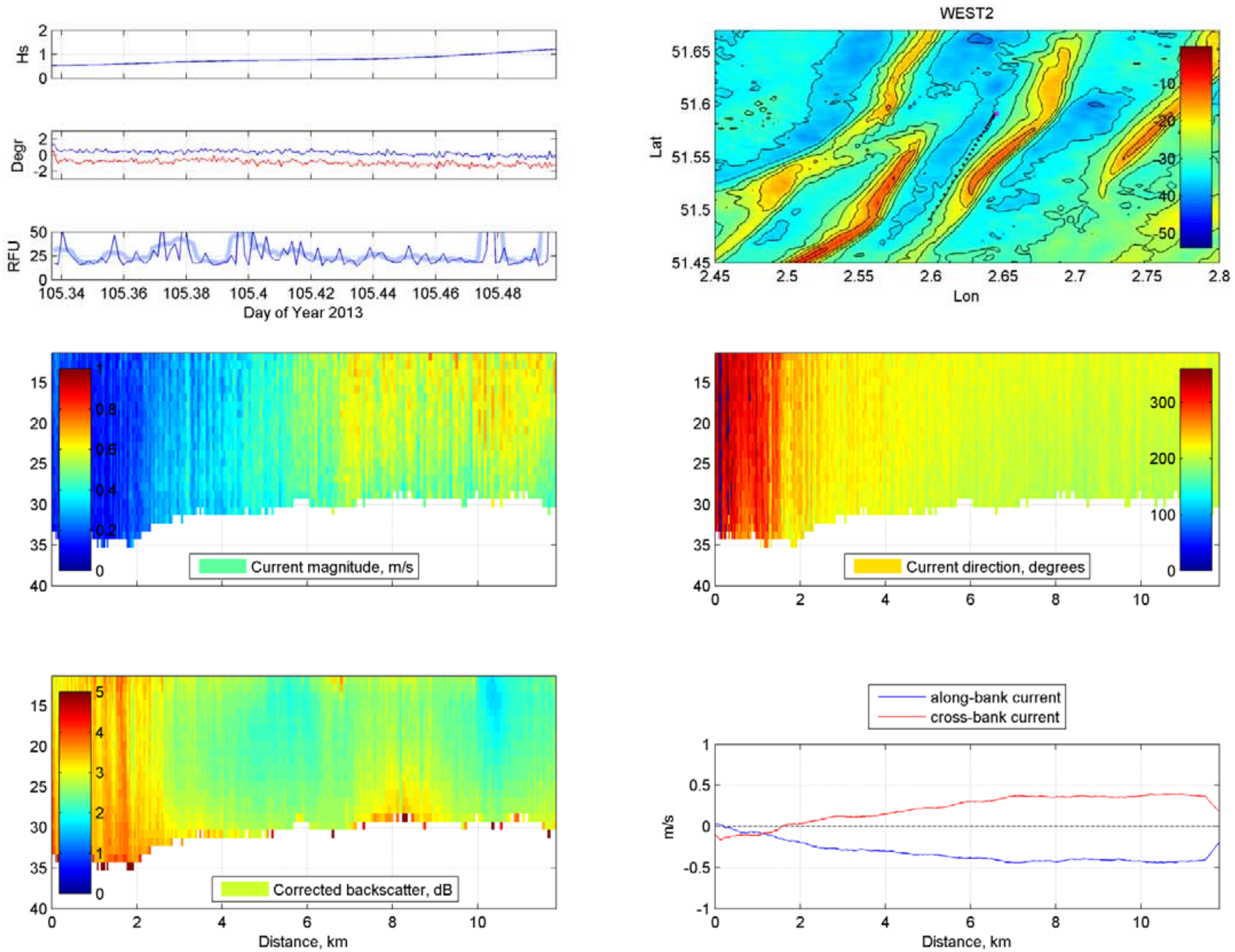

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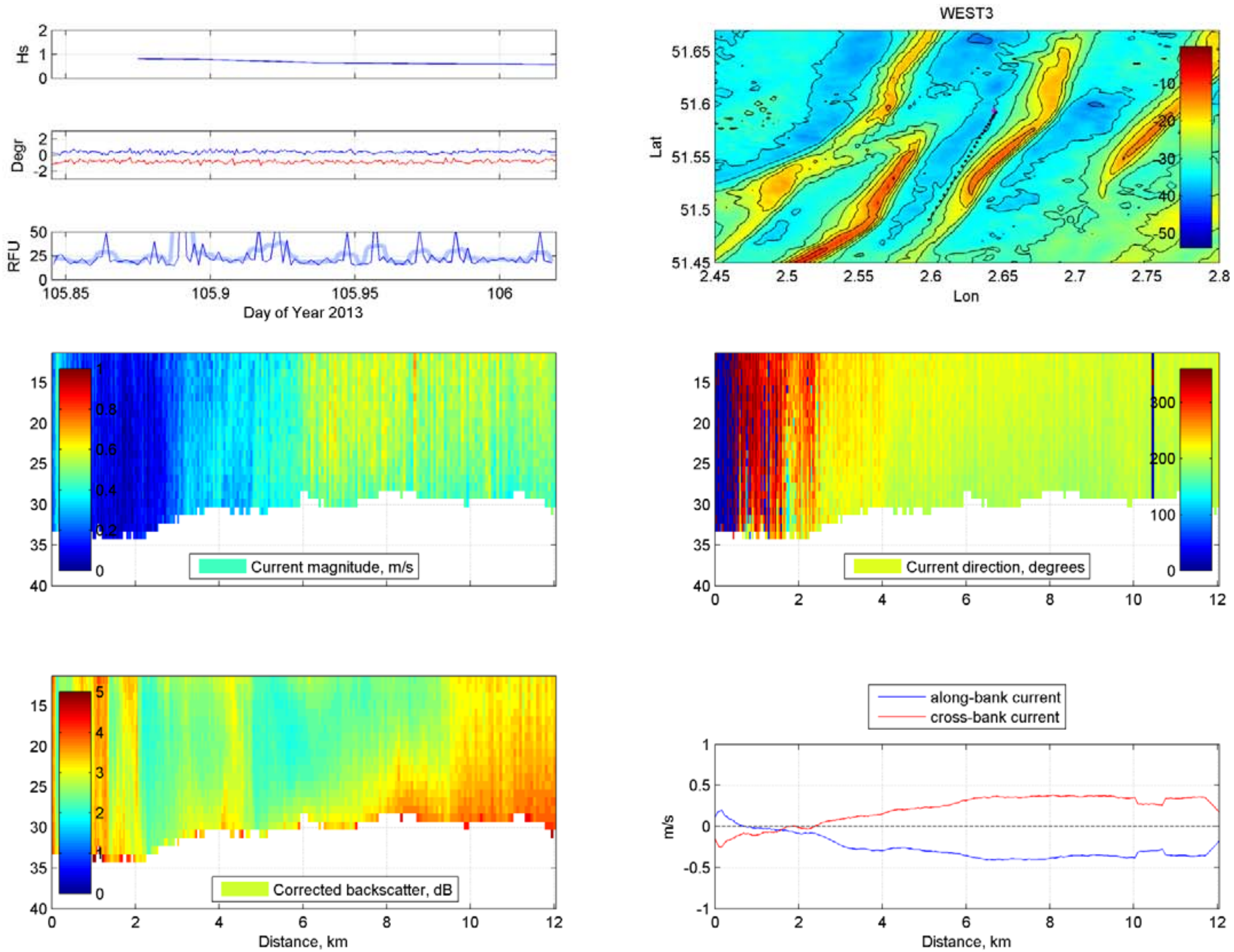
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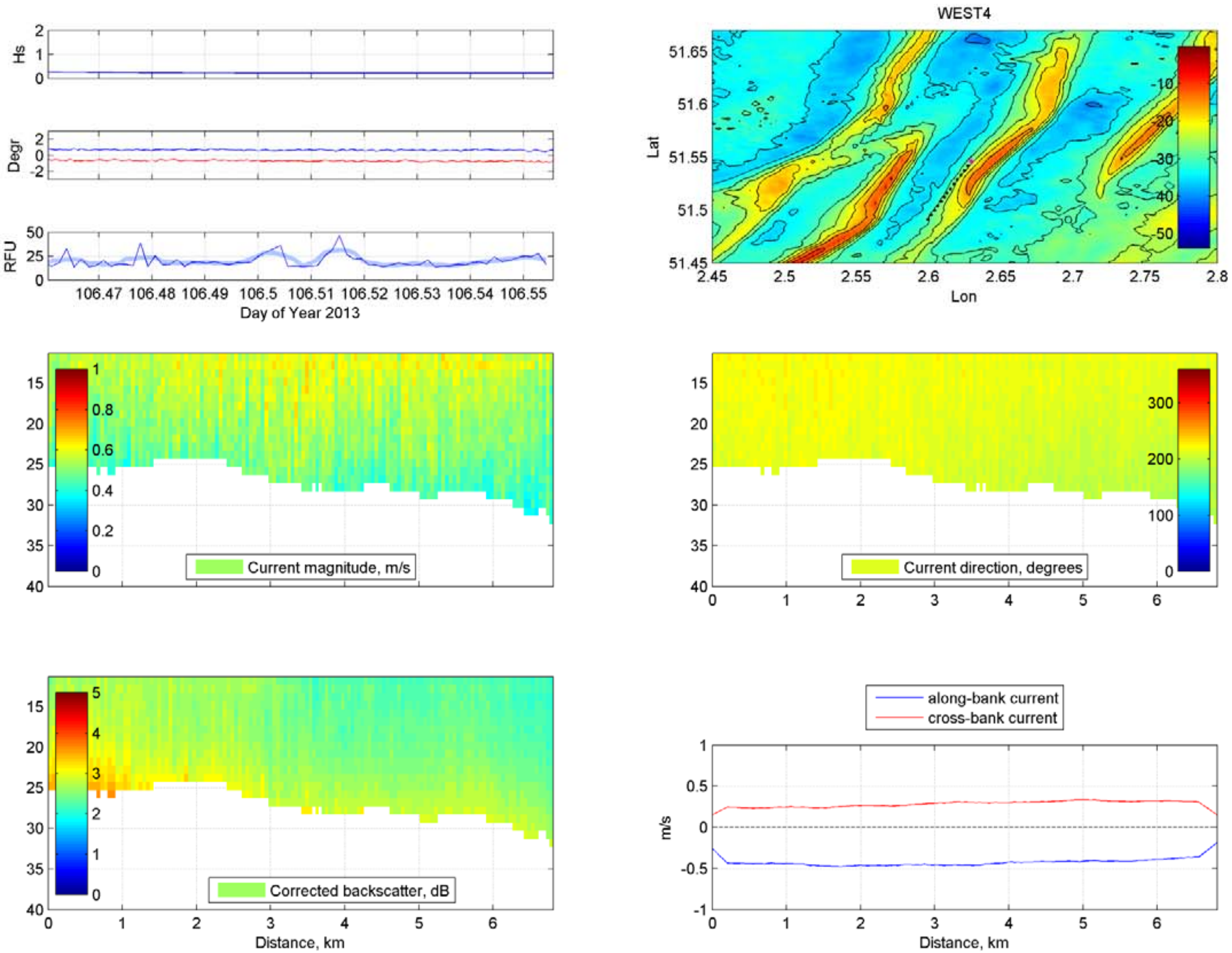

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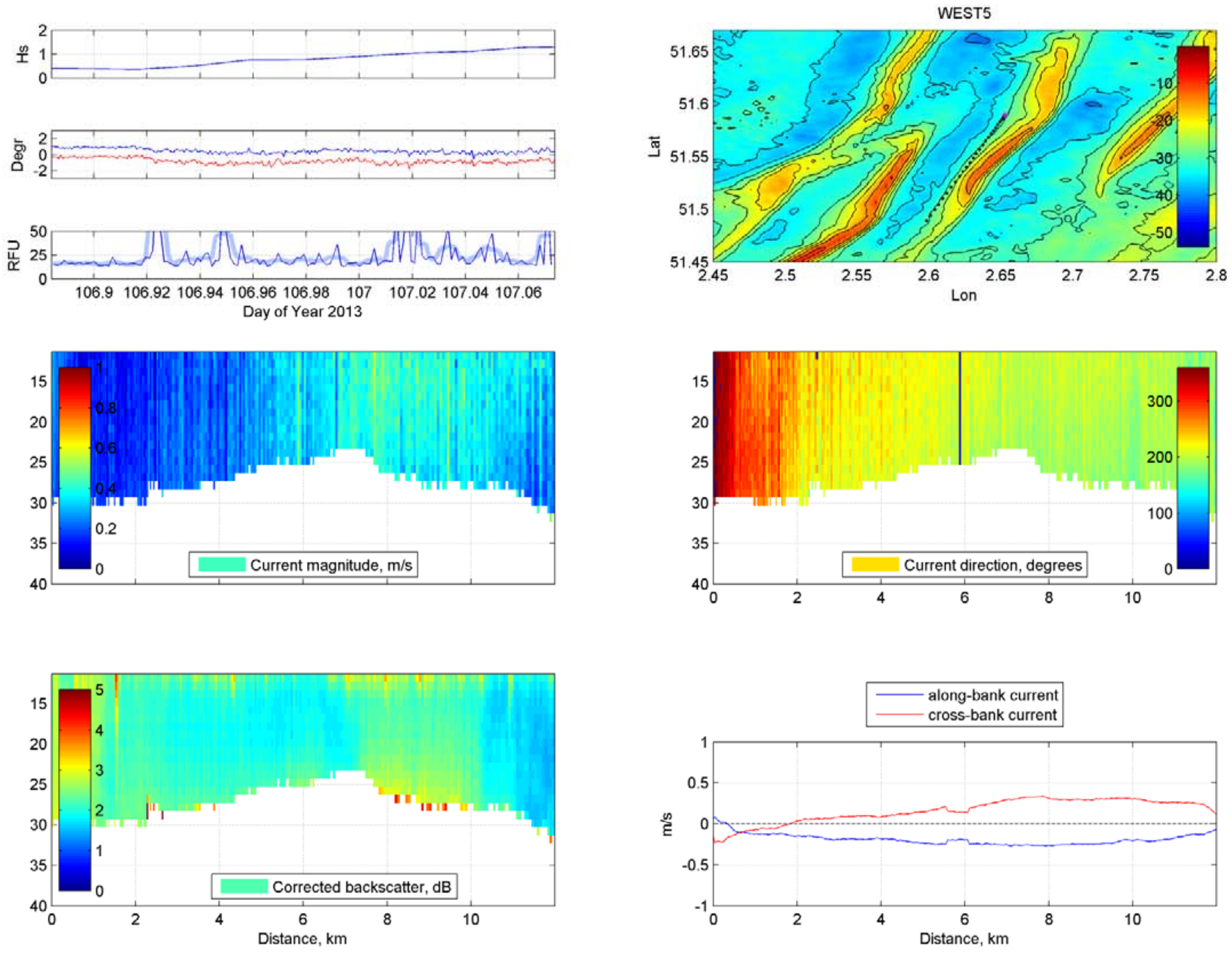

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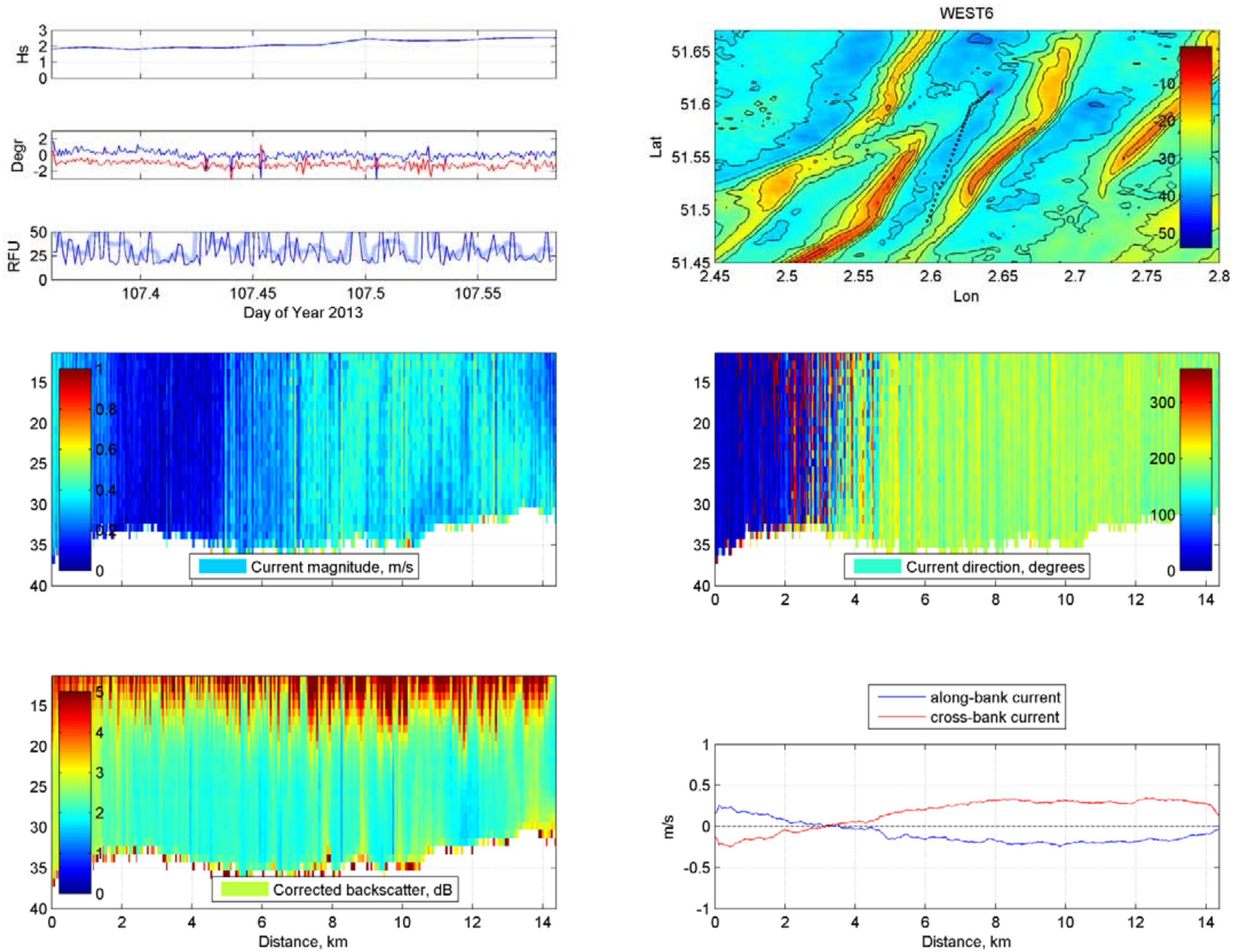

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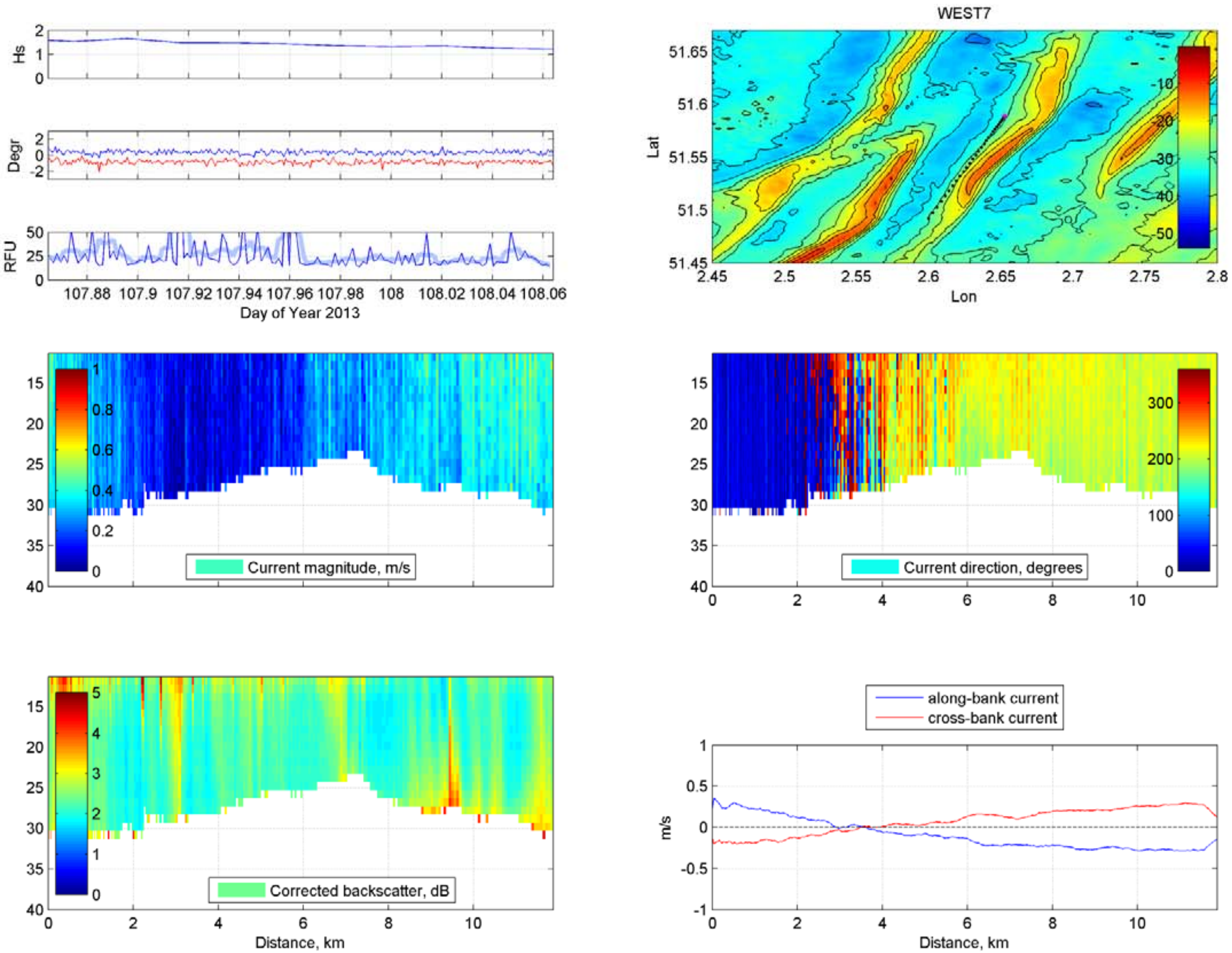
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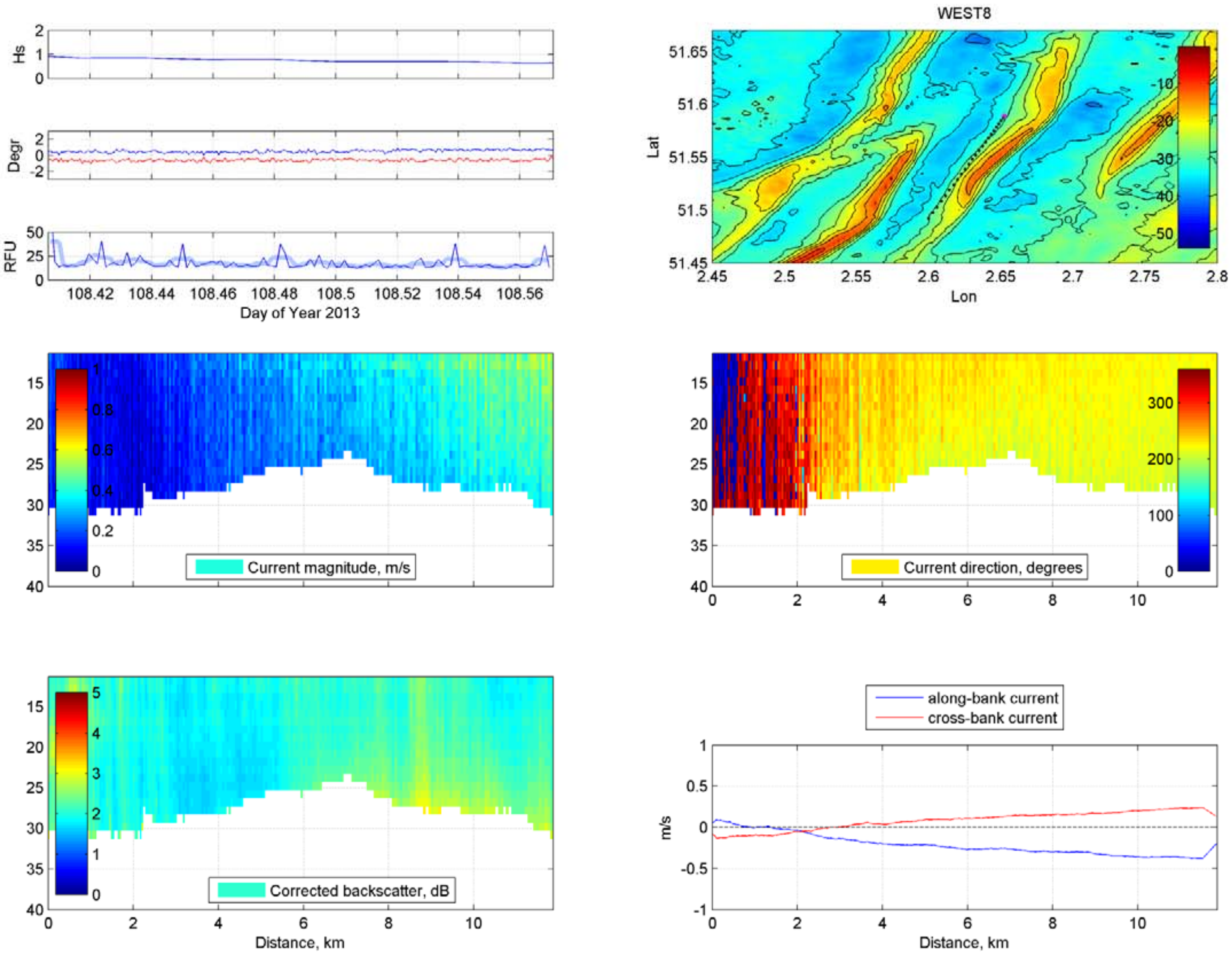
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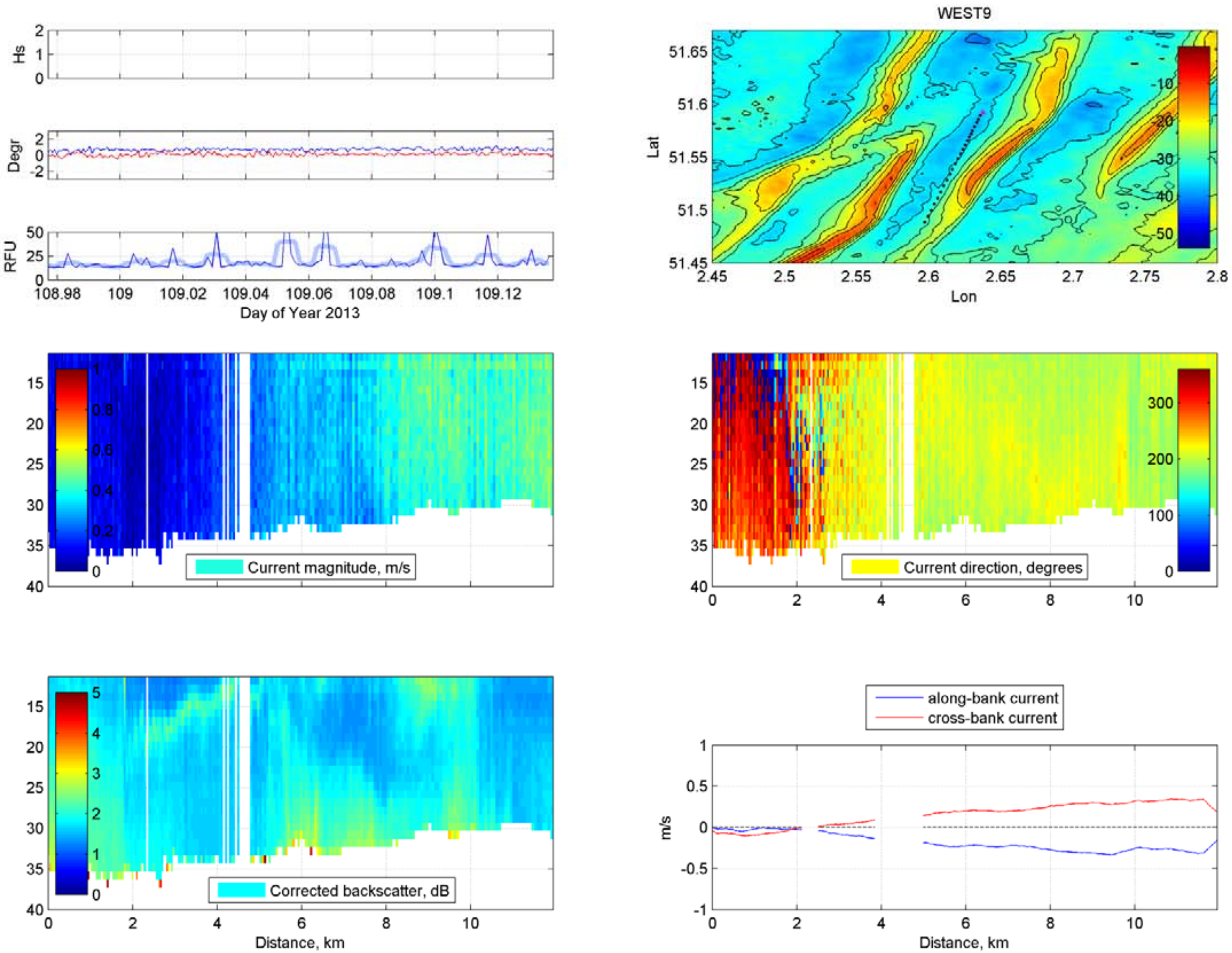

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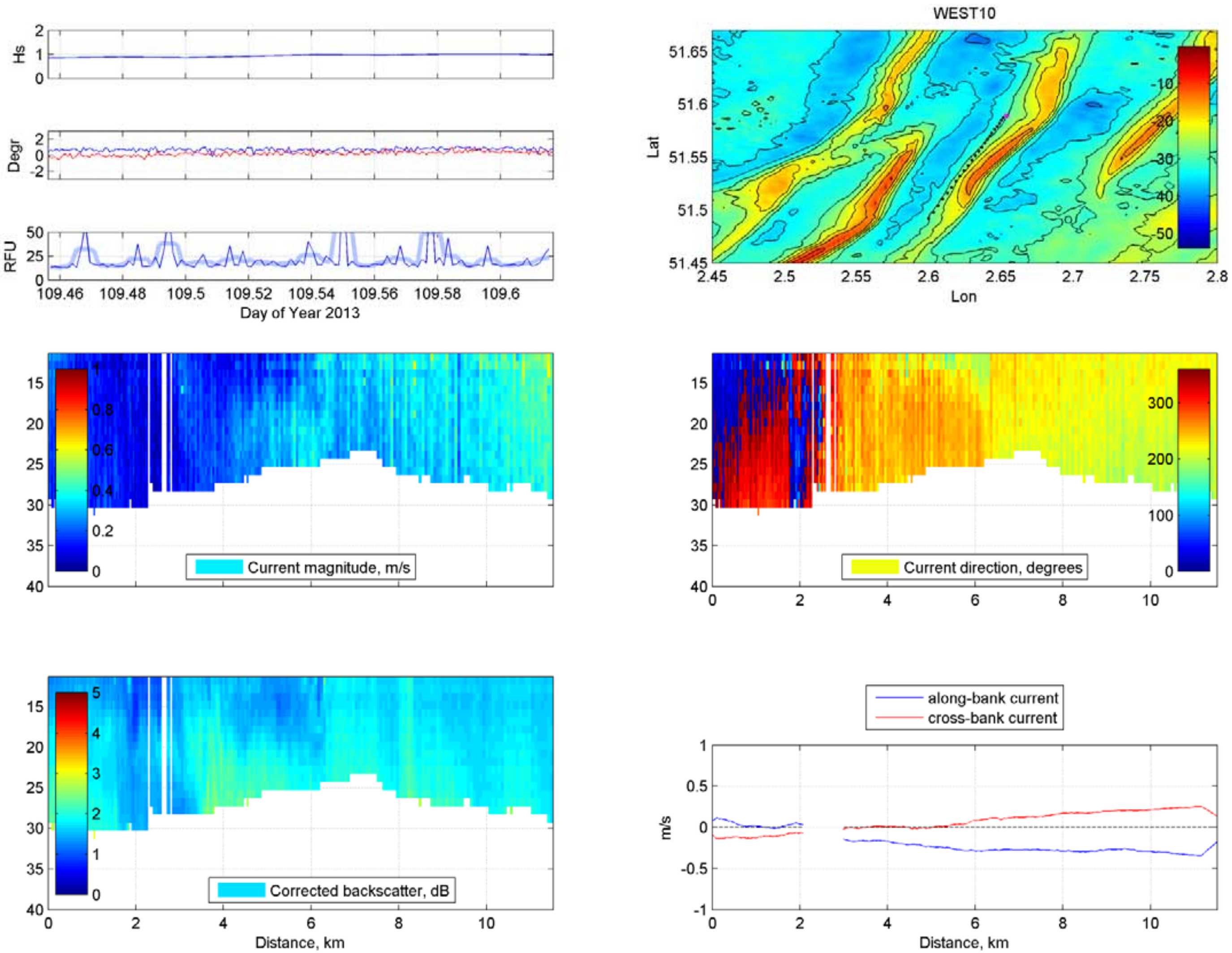

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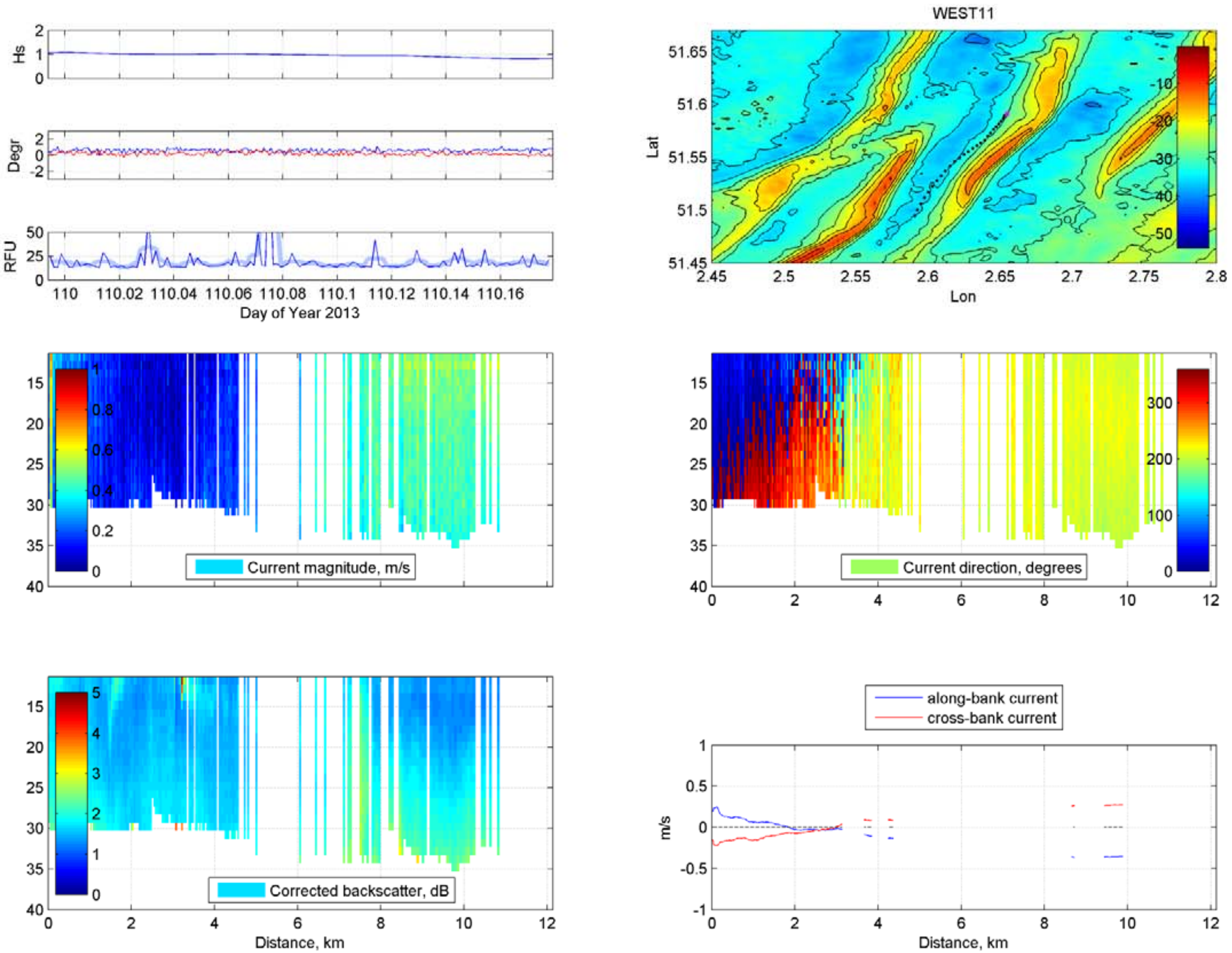

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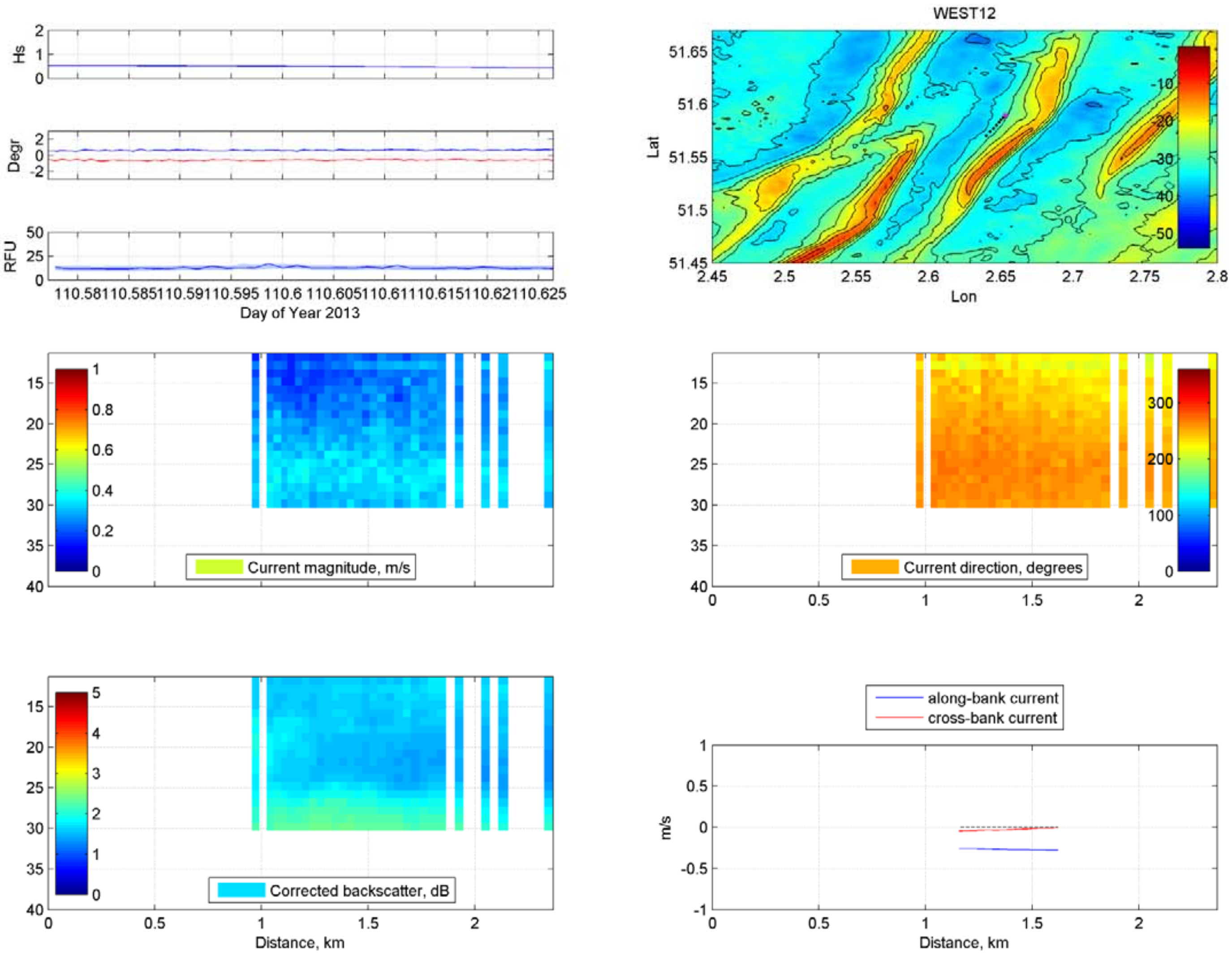
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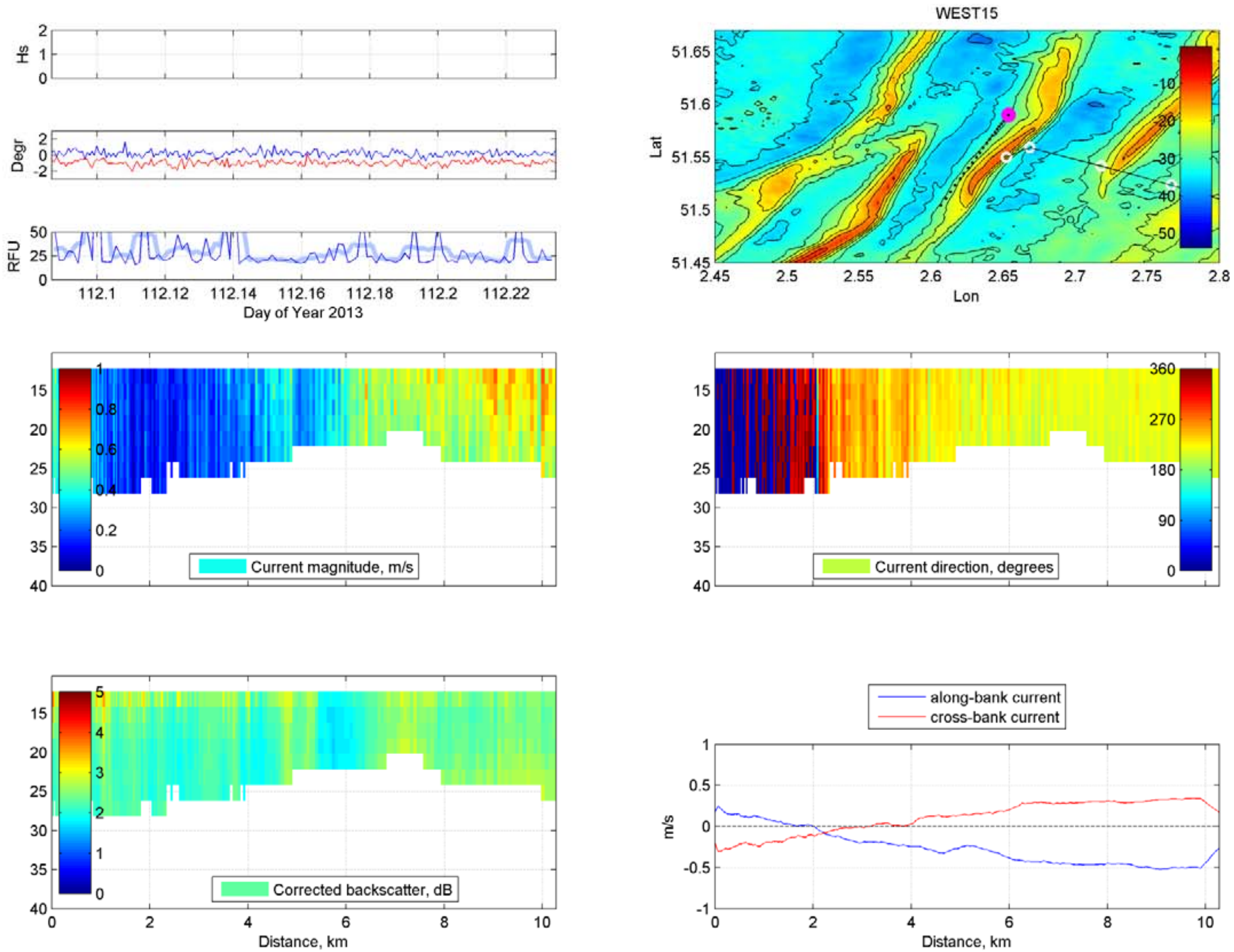

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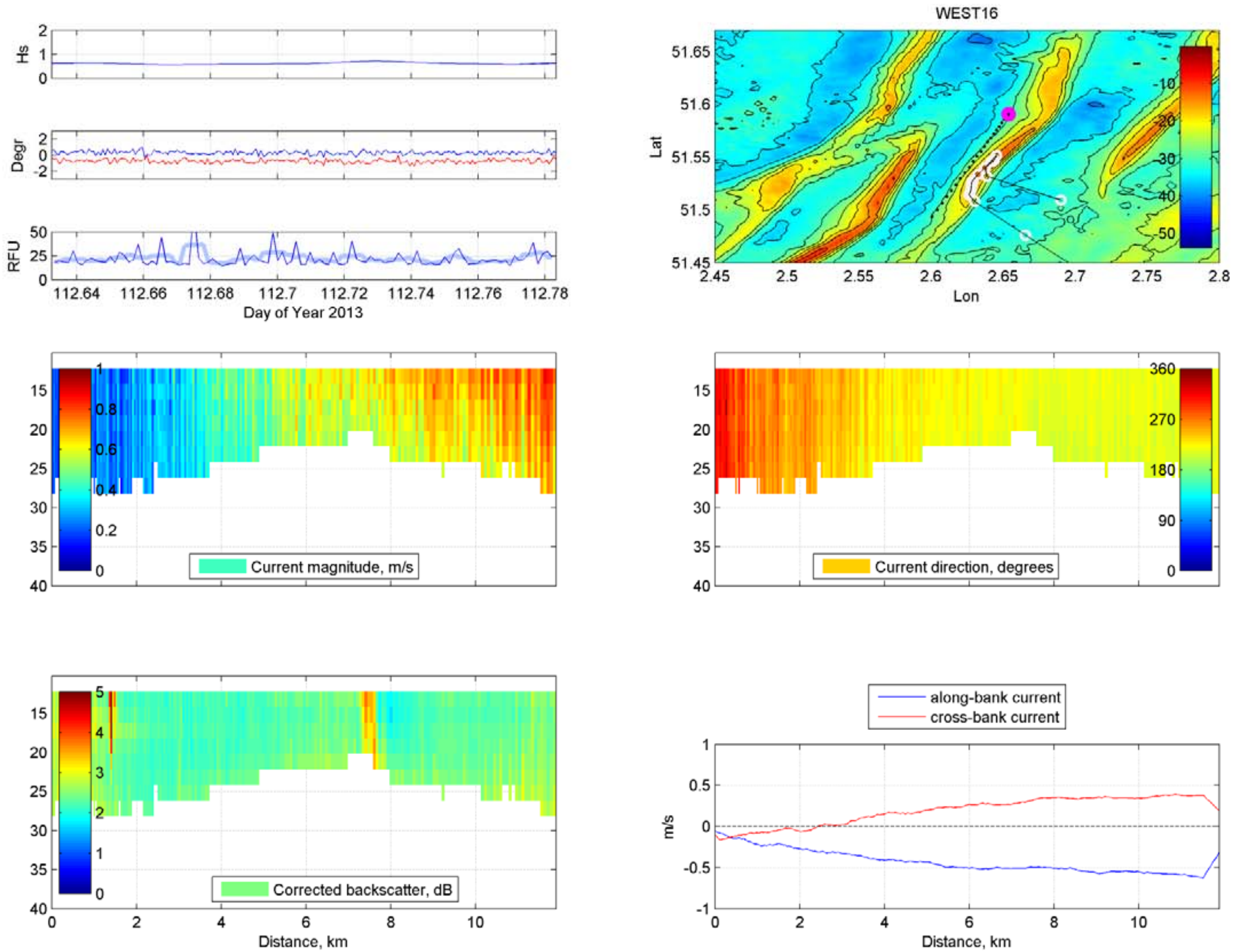

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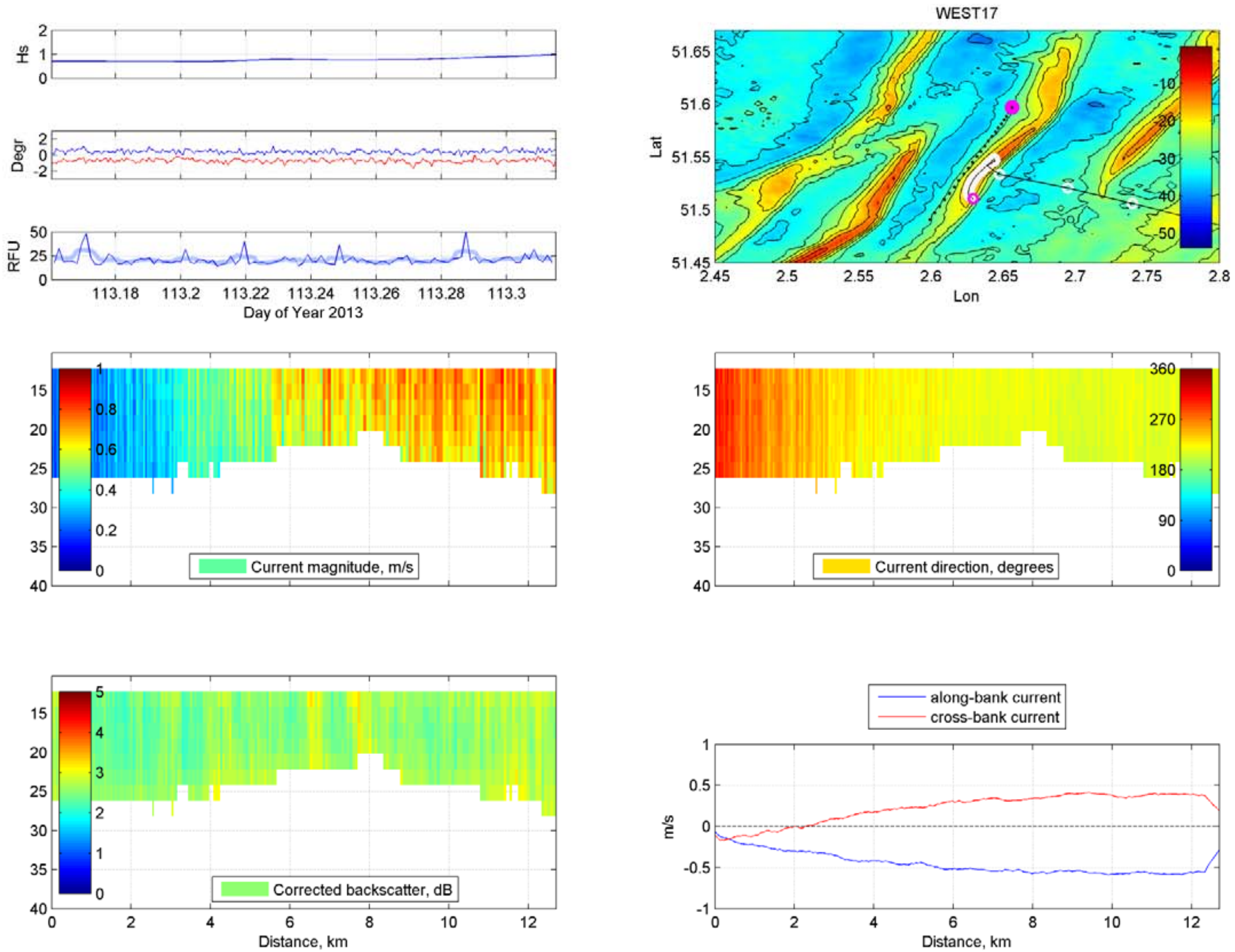

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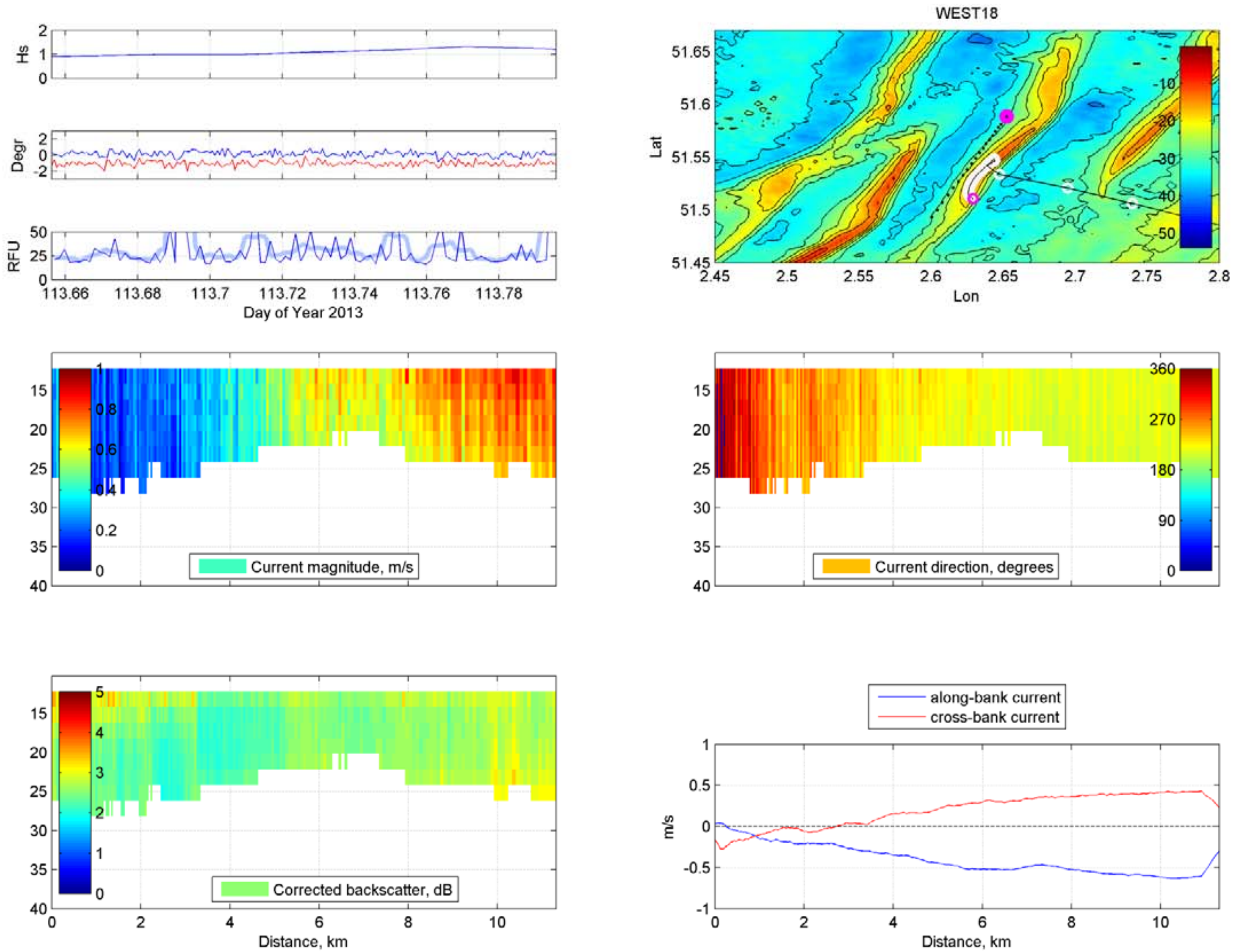

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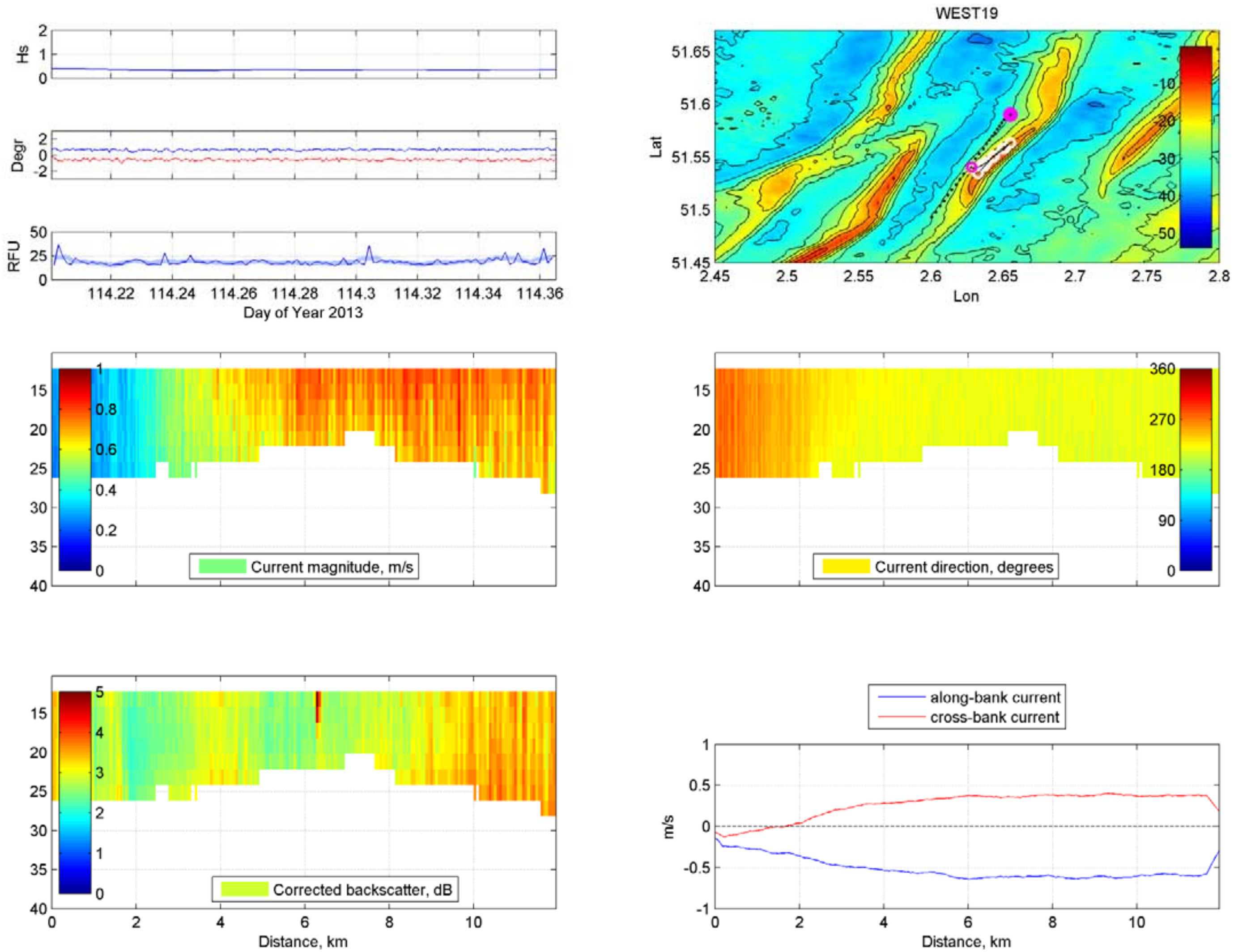

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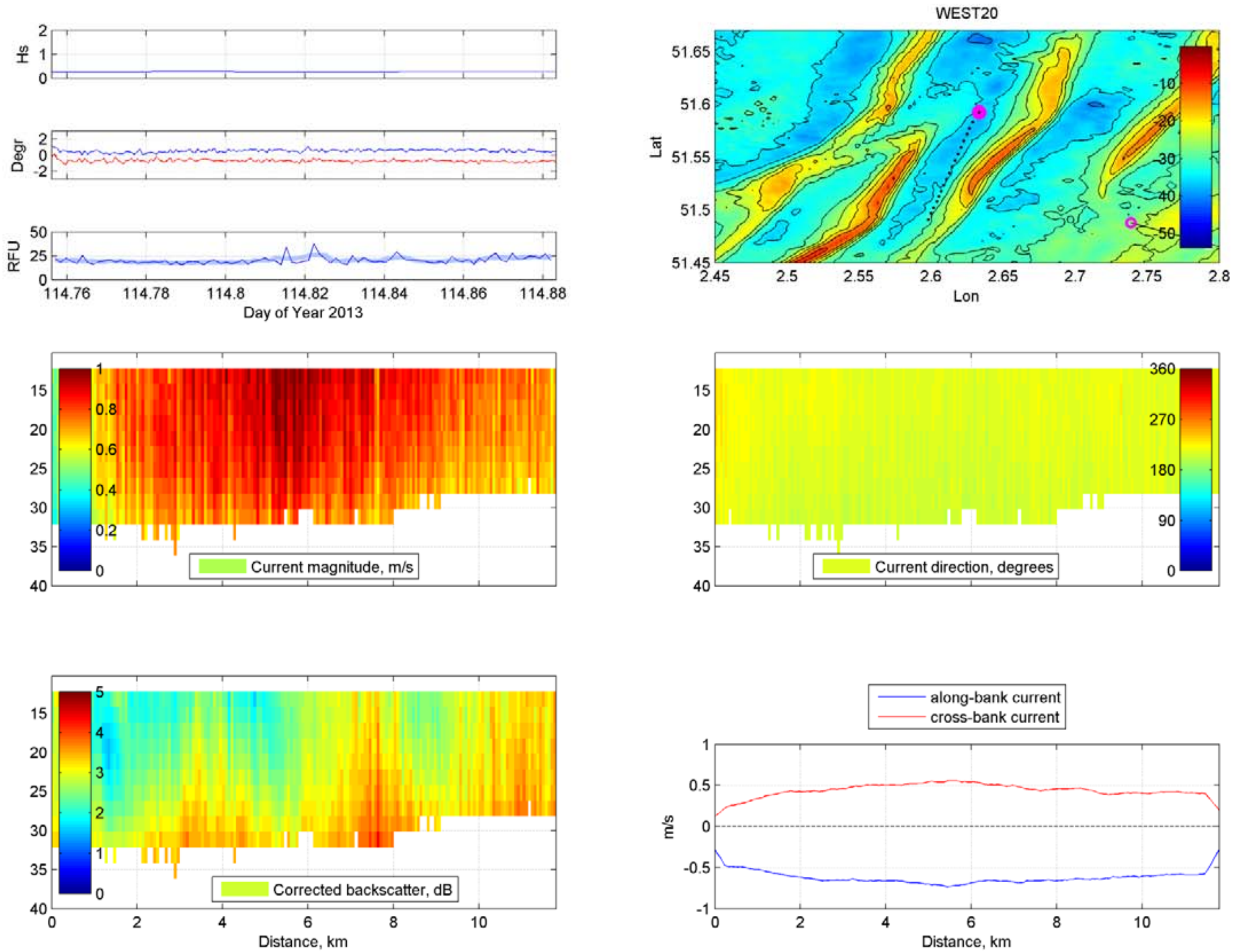
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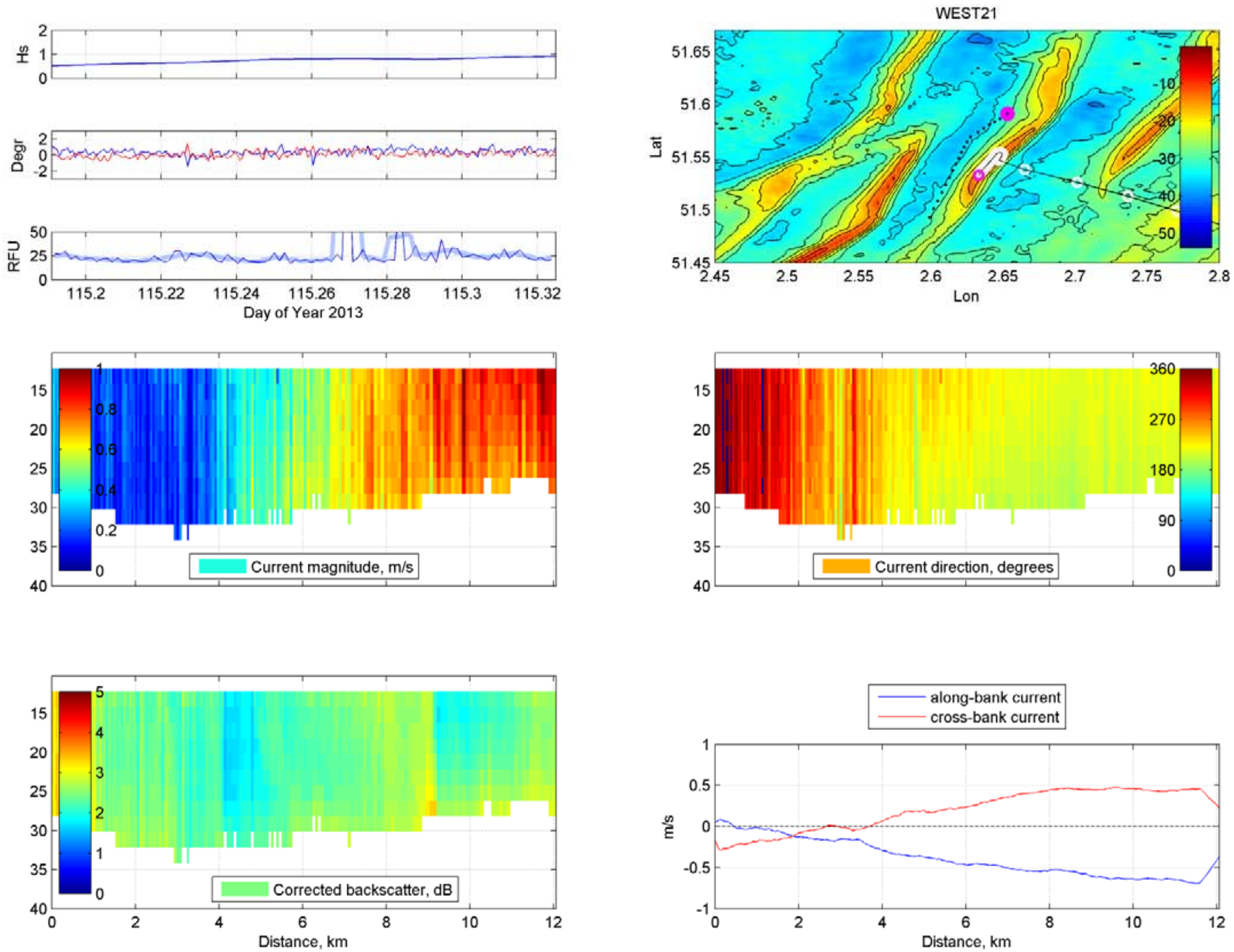

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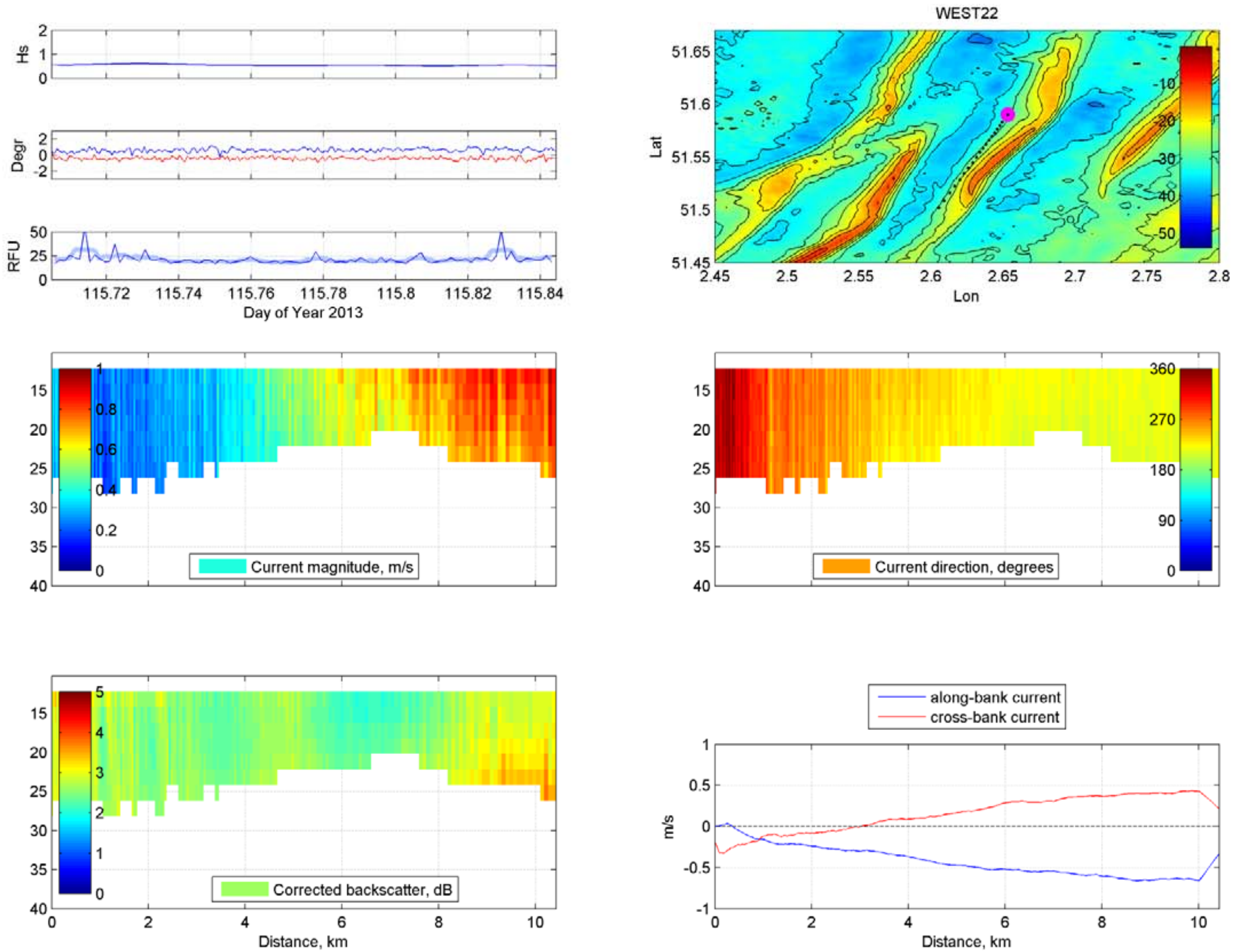

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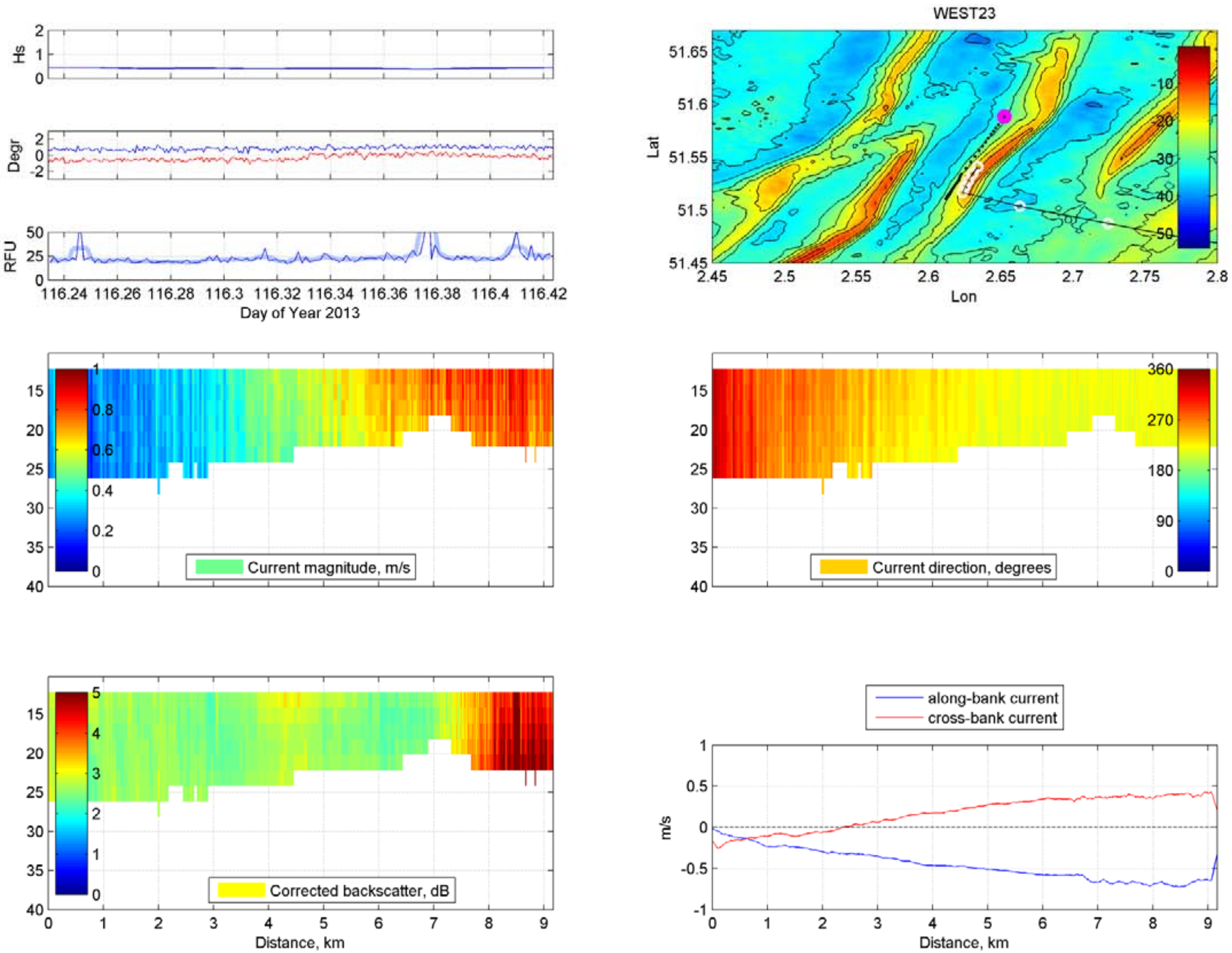

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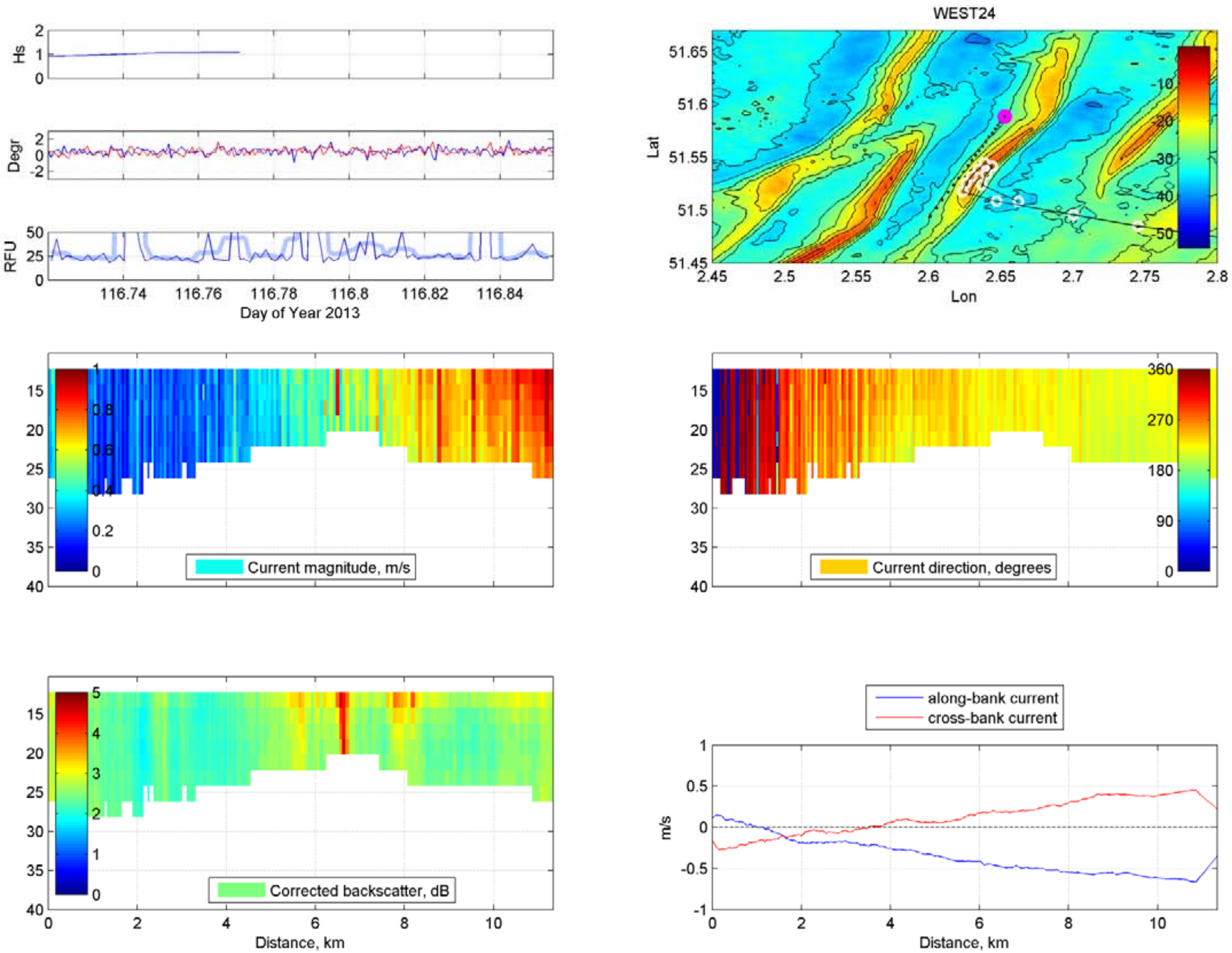
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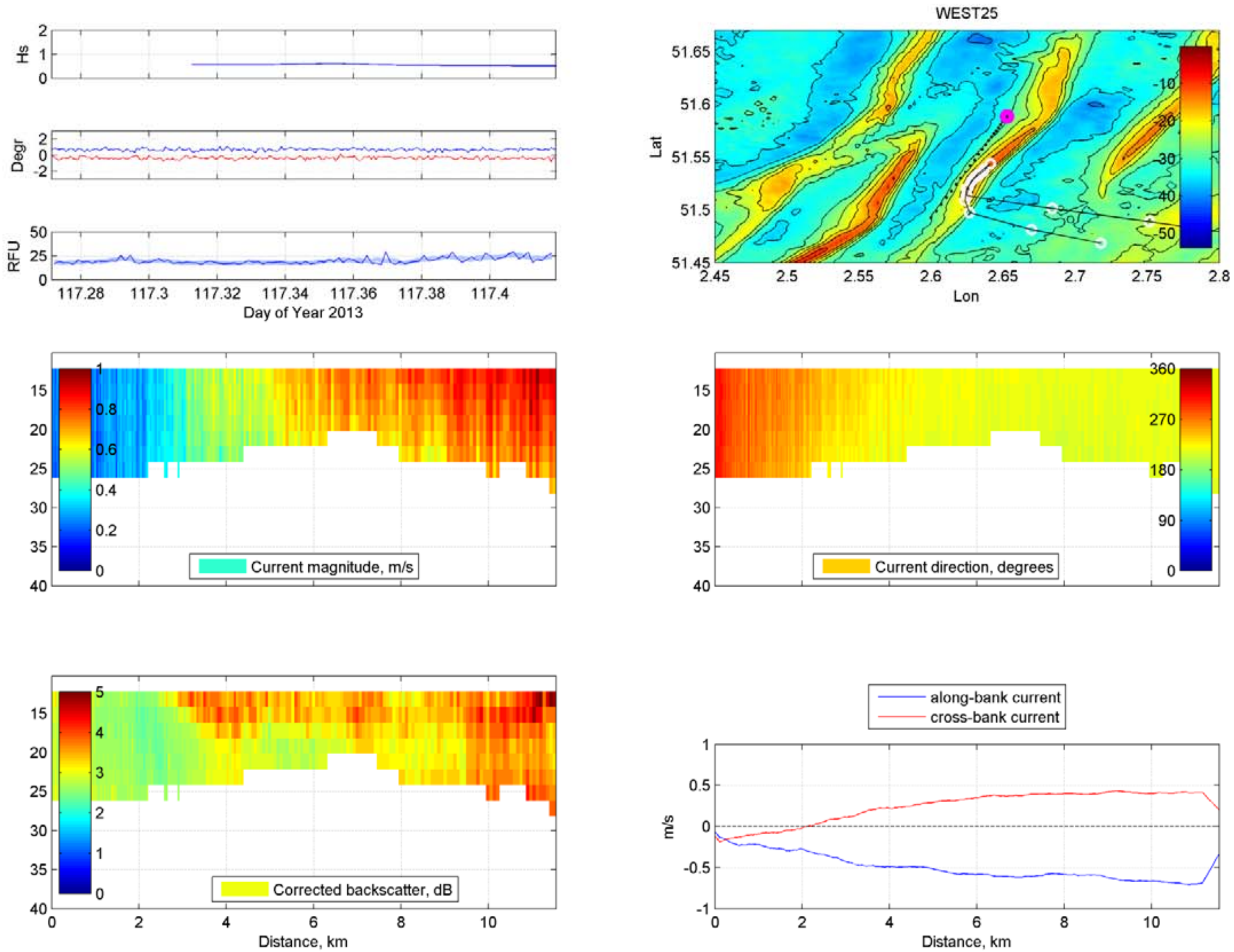
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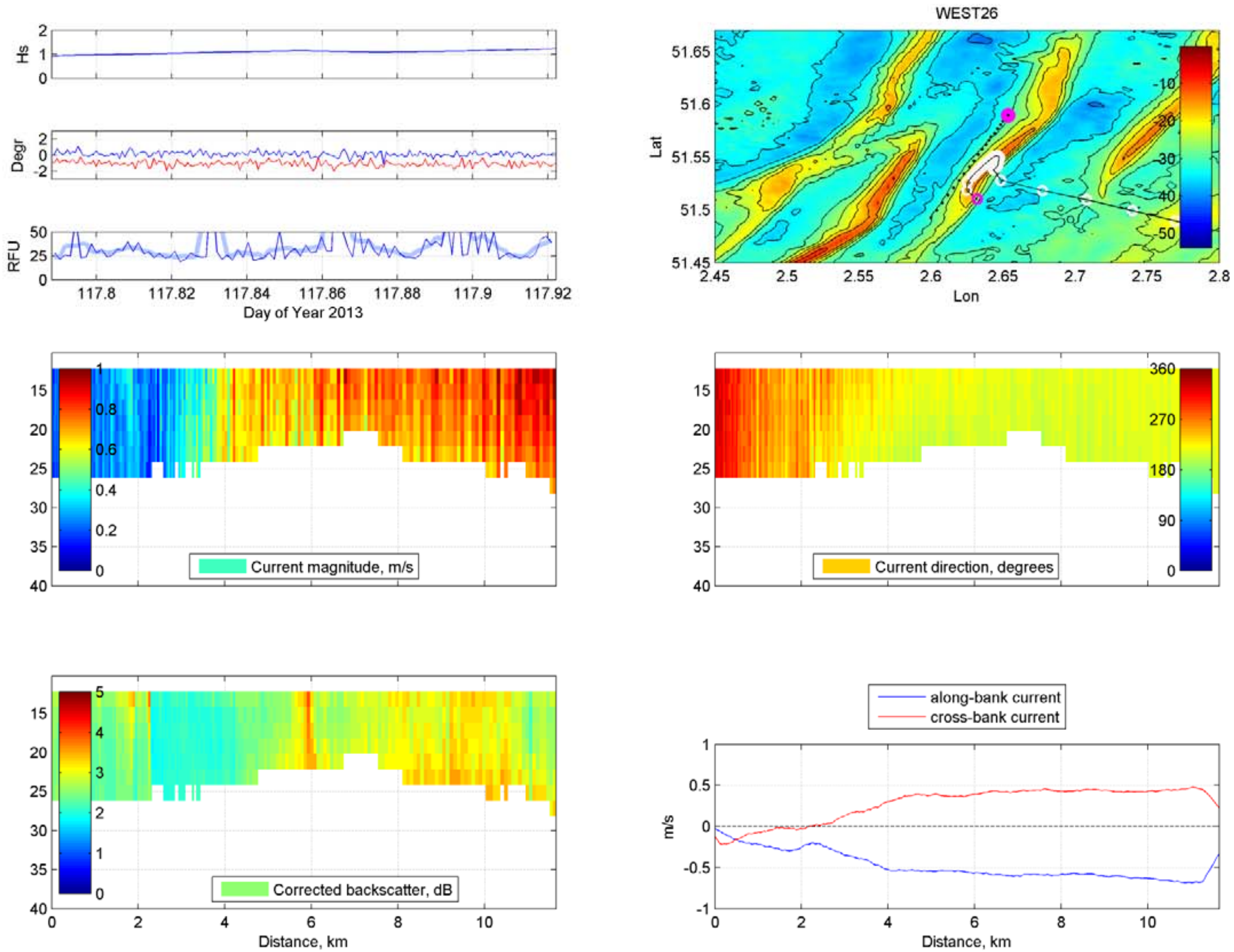
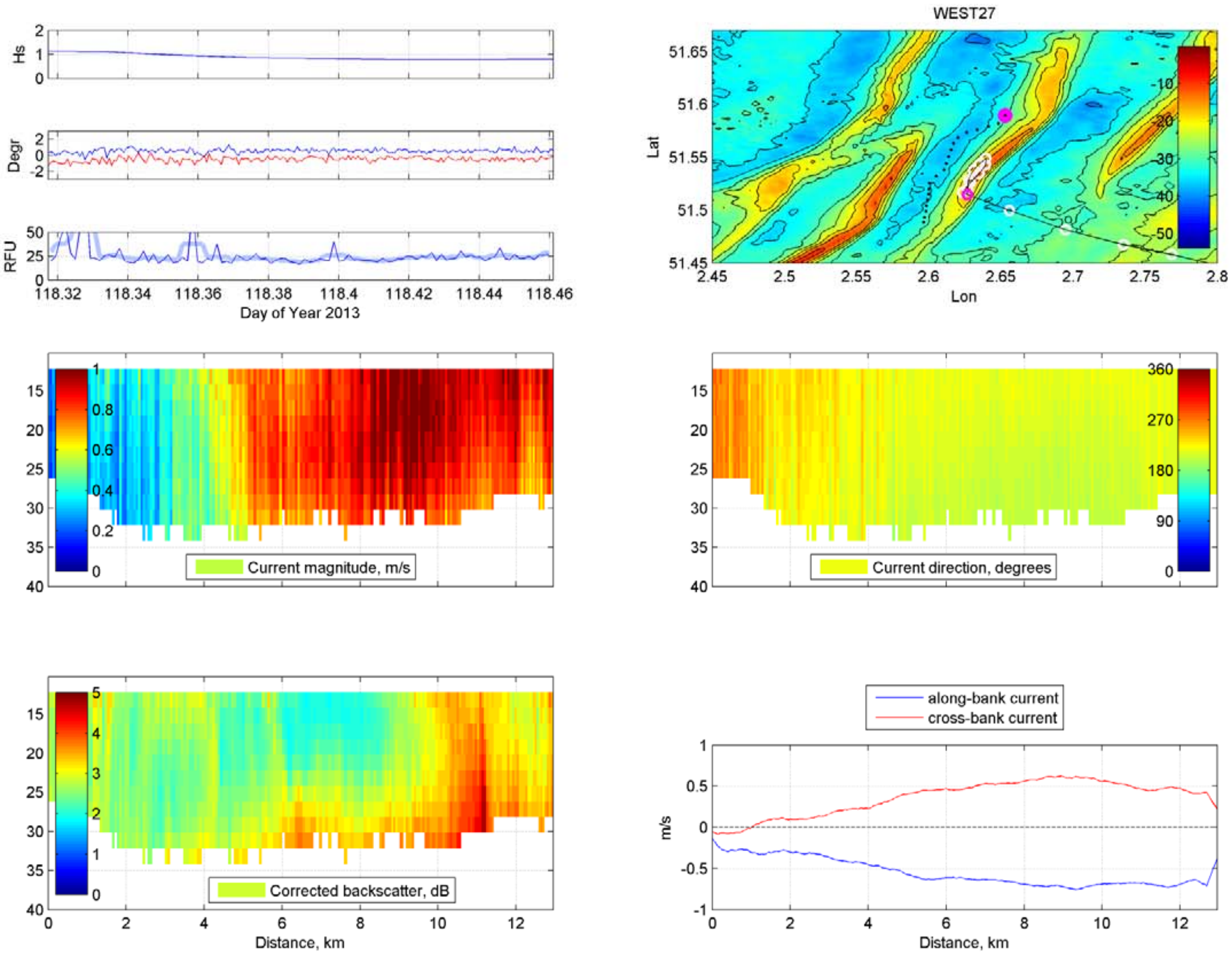
Distance, km
Distance, km

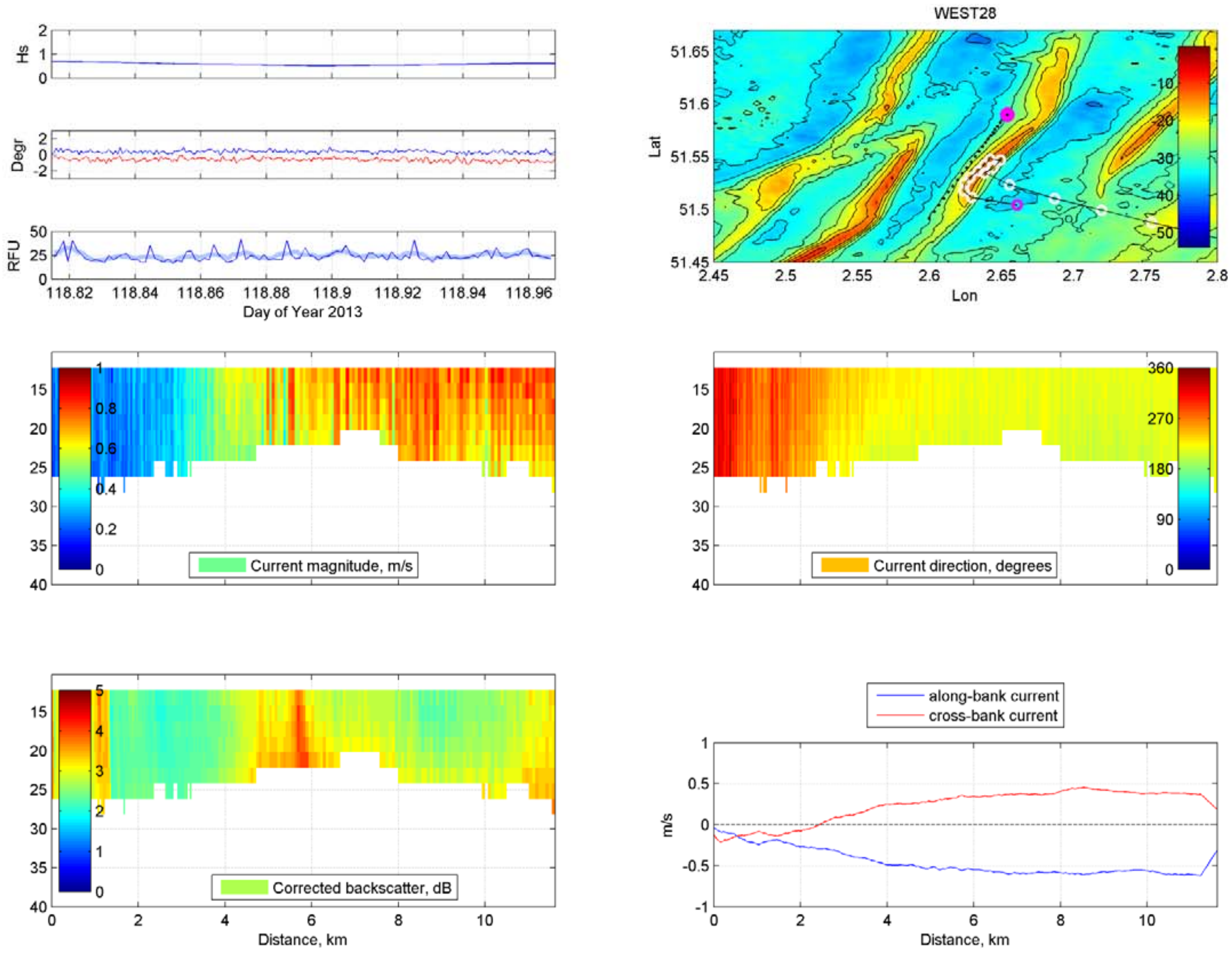
F36


WEST26
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F37


WEST27
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F38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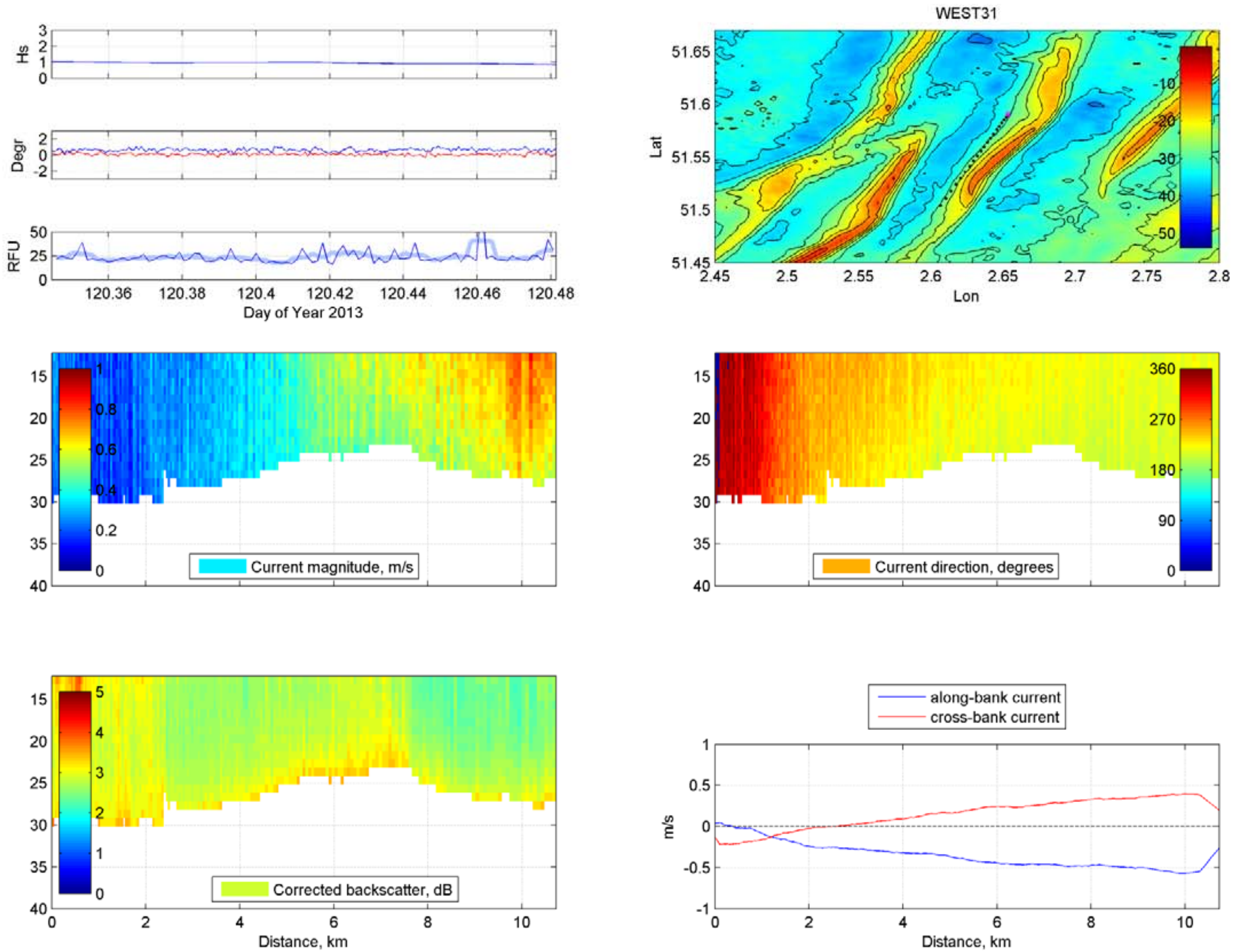
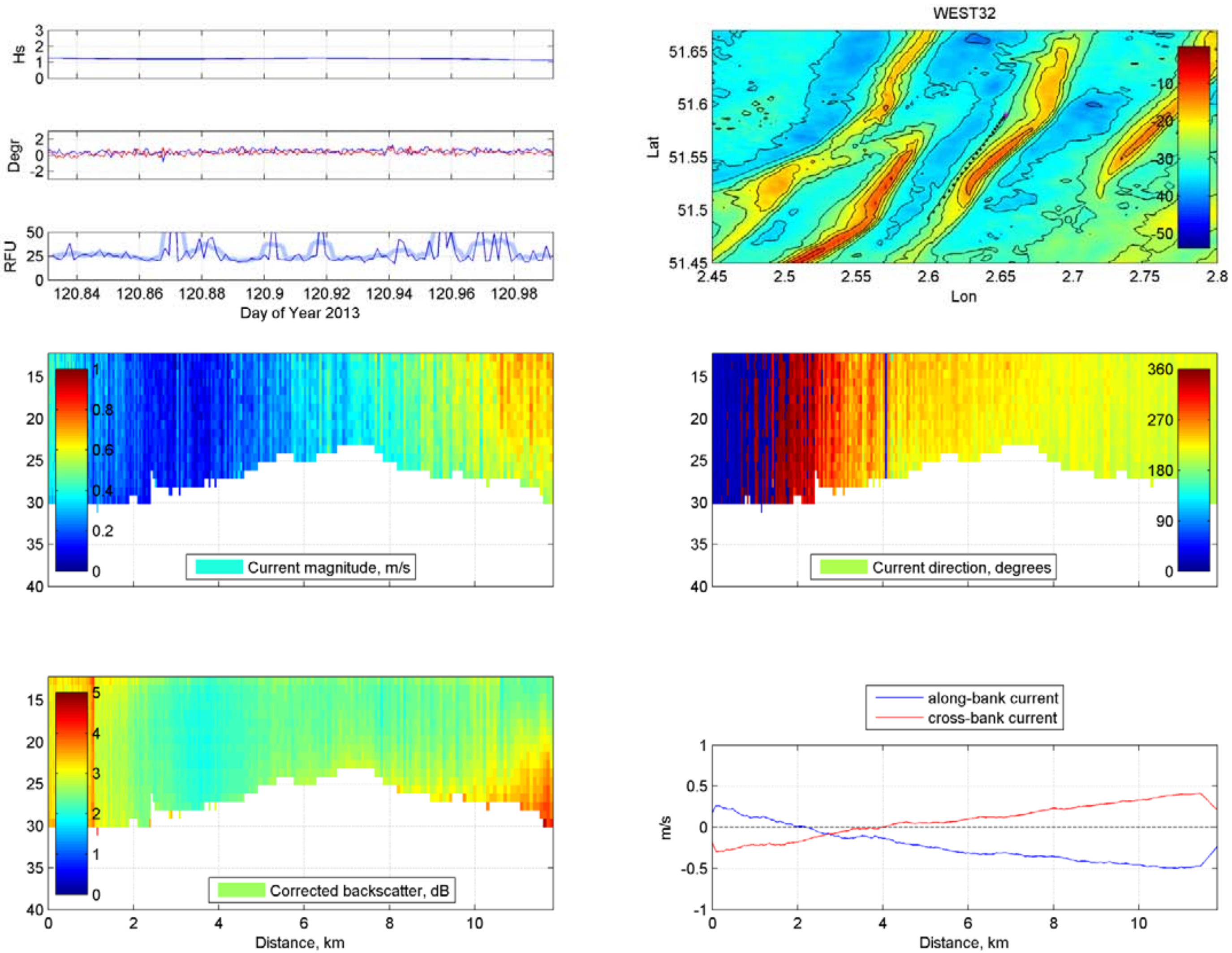
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F39



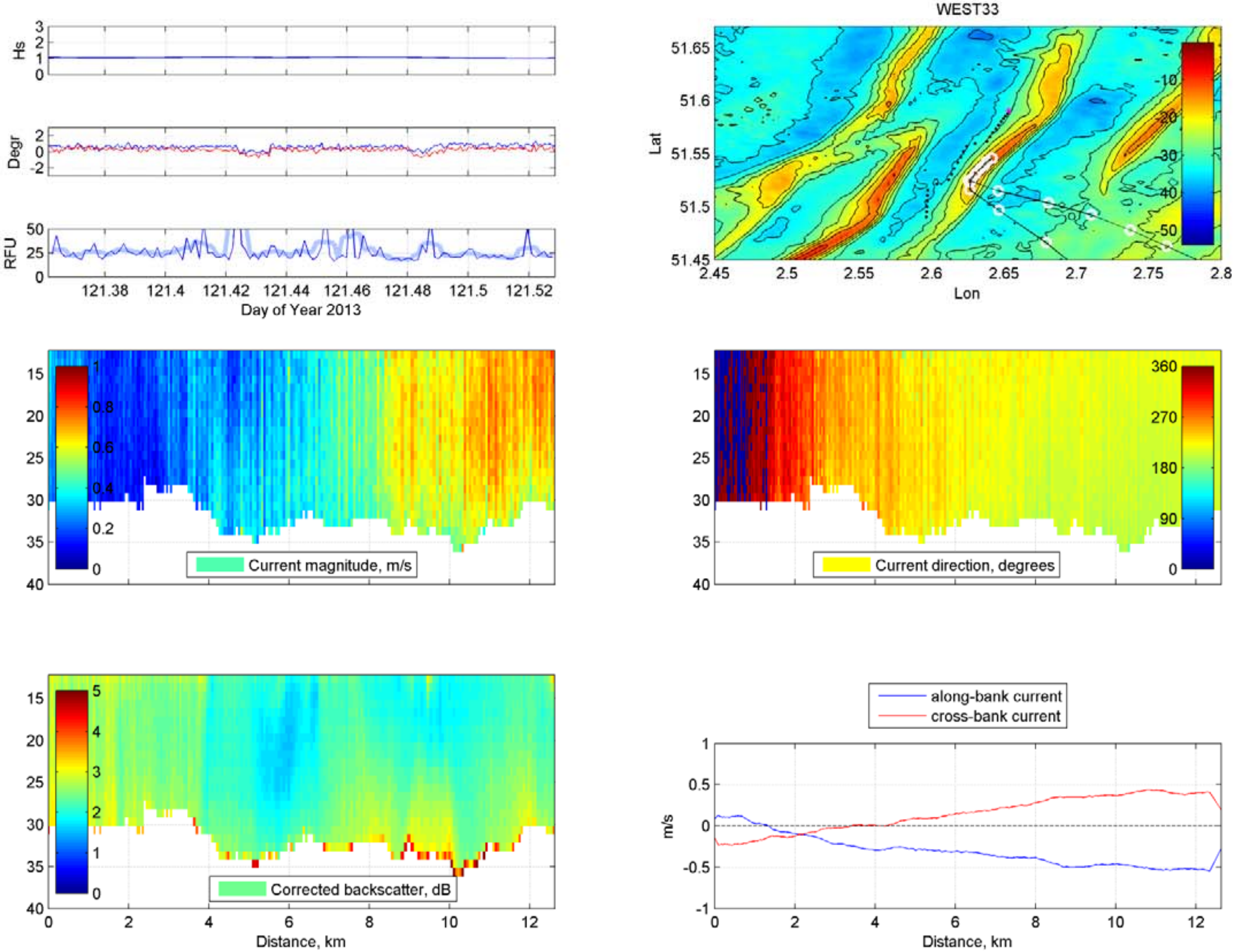
WEST31
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

F40



Hs
Degr
RFU
Day of Year 2013
WEST32
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F41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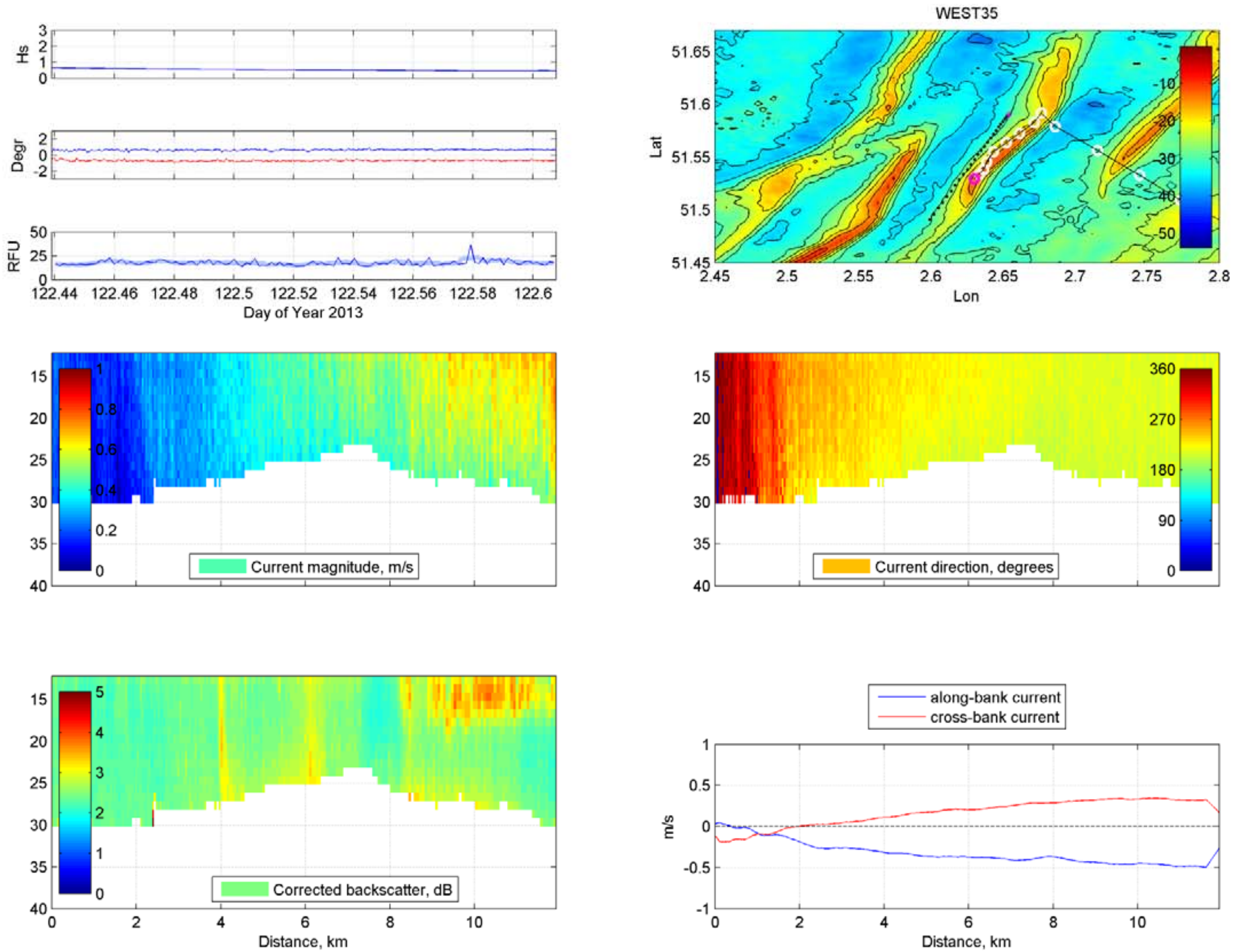
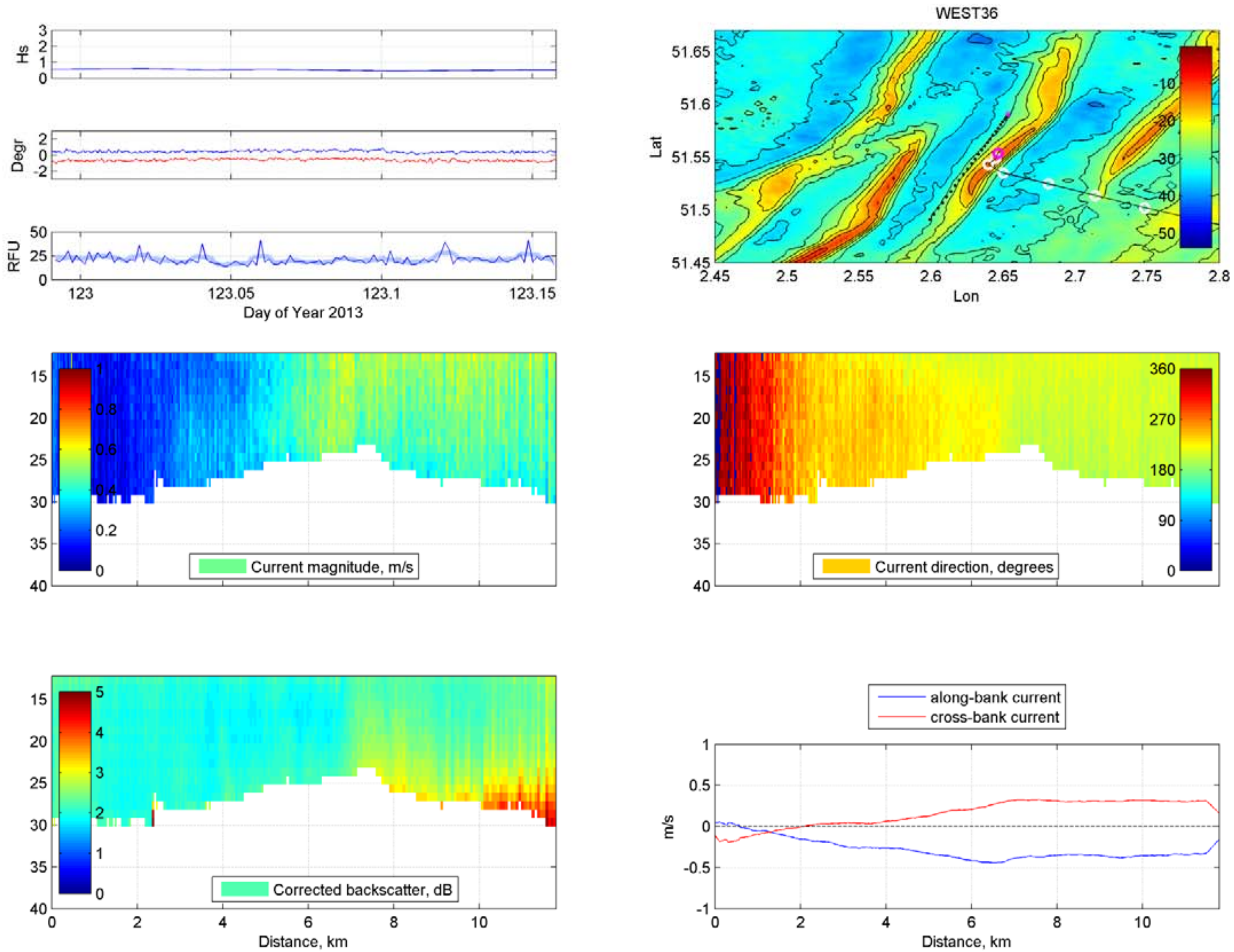
Degr
RFU
Day of Year 2013
WEST33
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F42

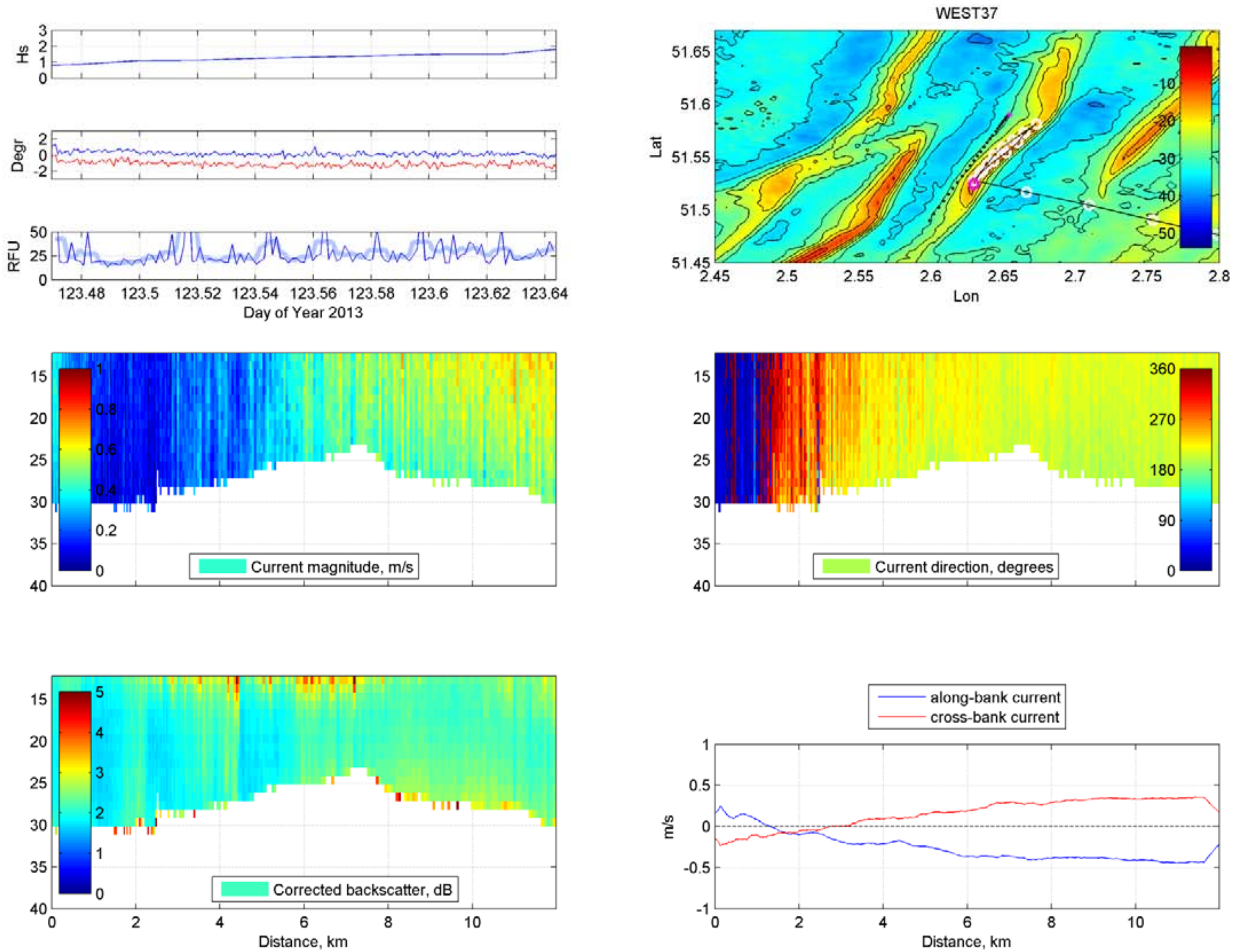


WEST35
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

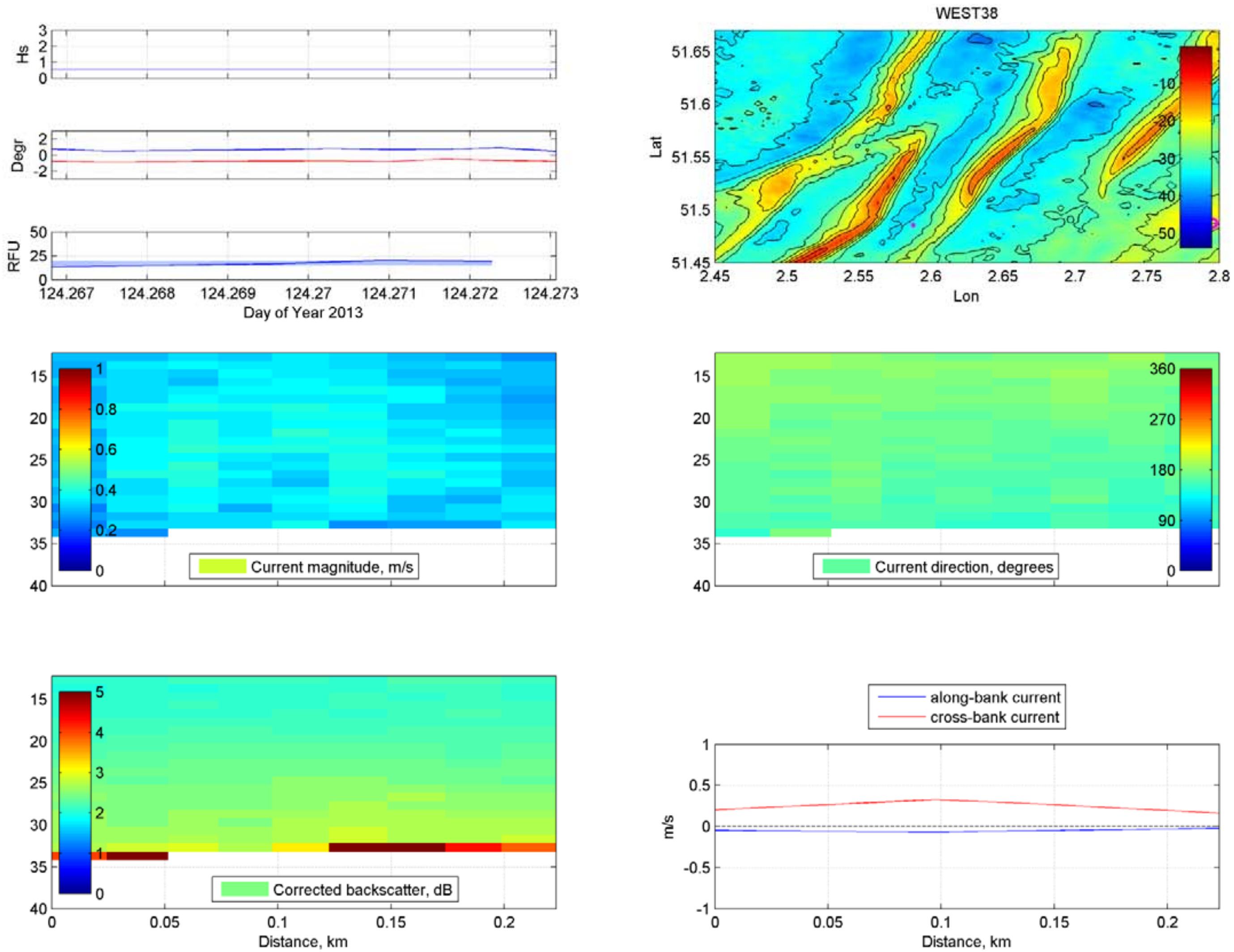
F43


WEST36
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s
Distance, km

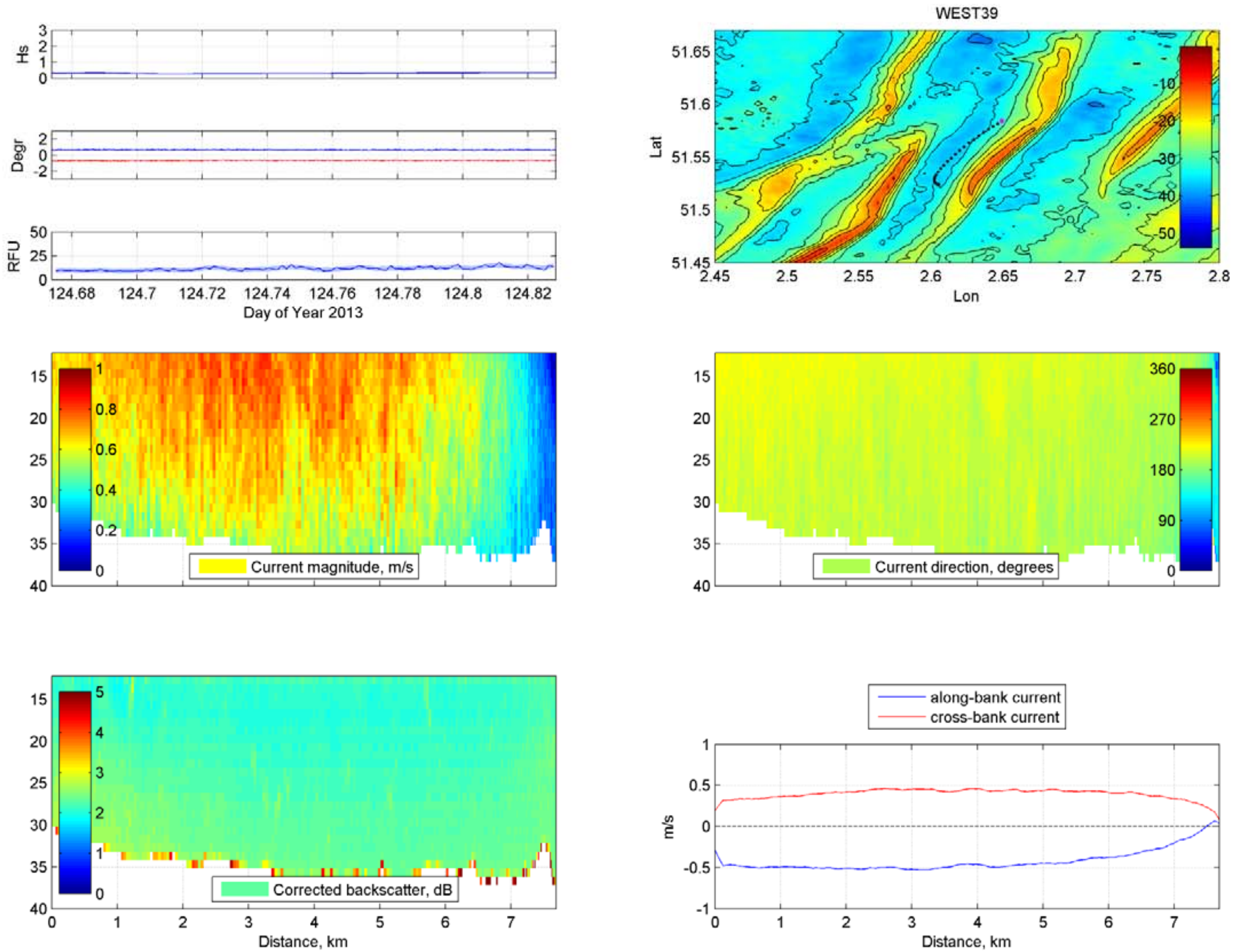
F44



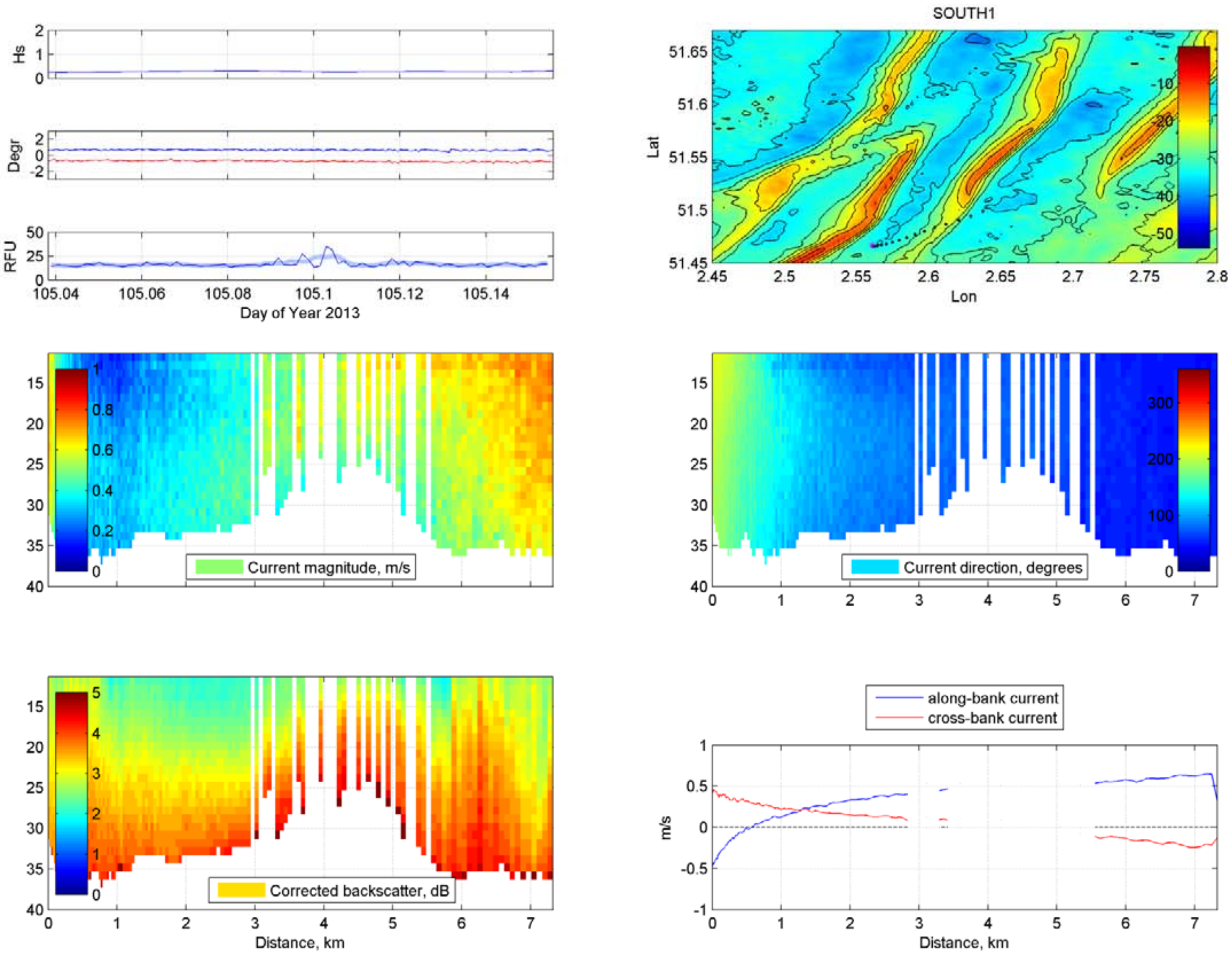
WEST37
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km


WEST38
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

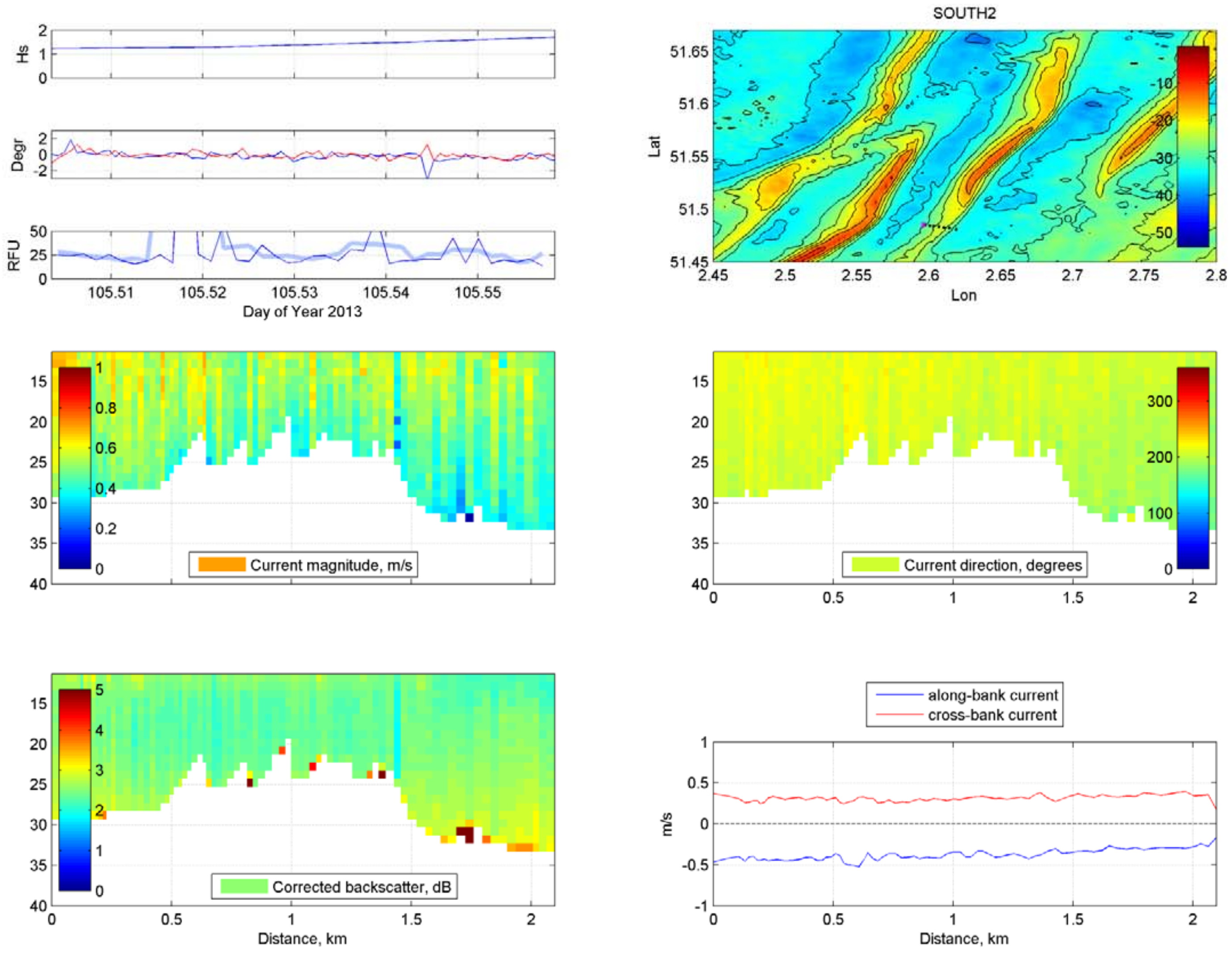
F46



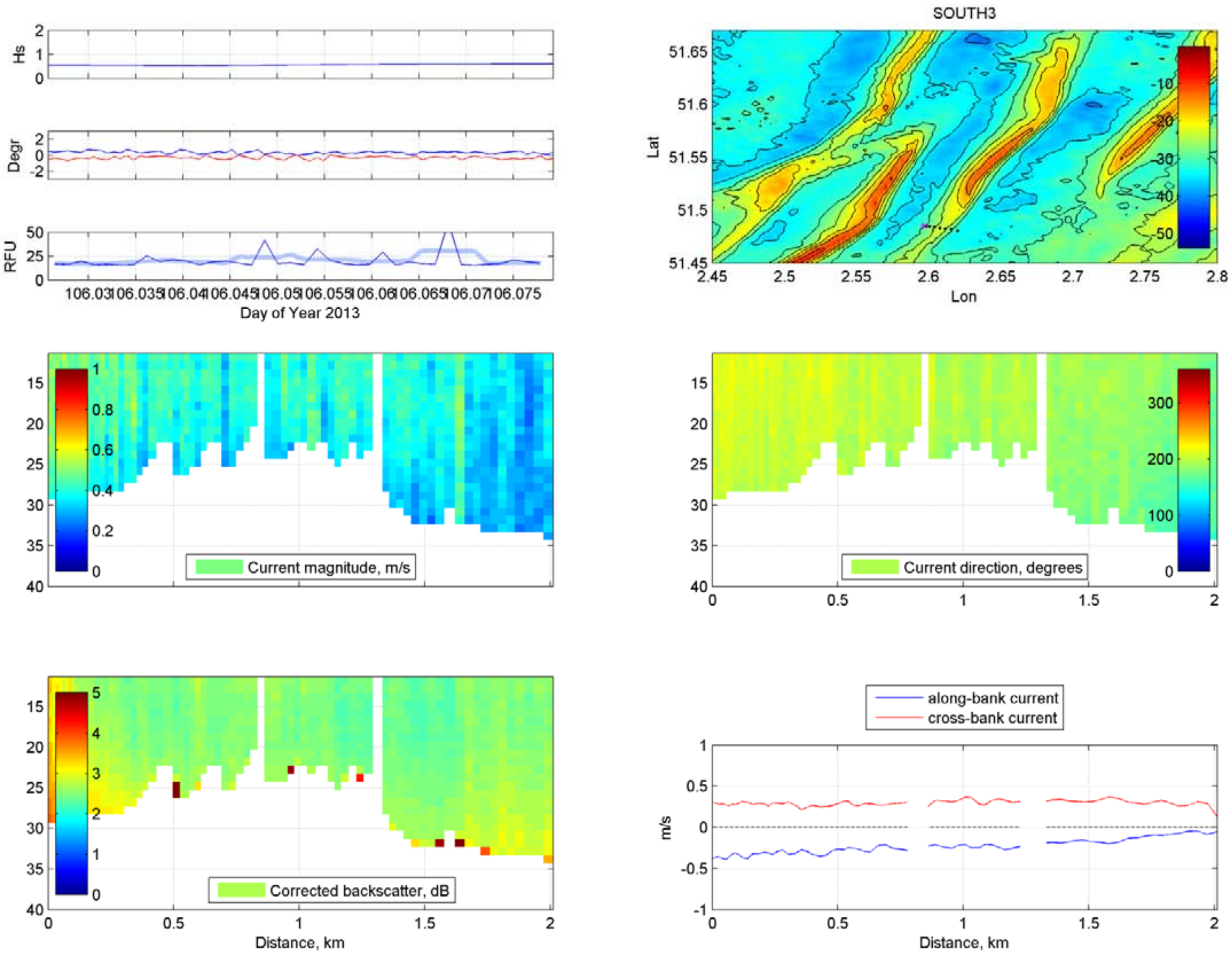
WEST39
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km


SOUTH1
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

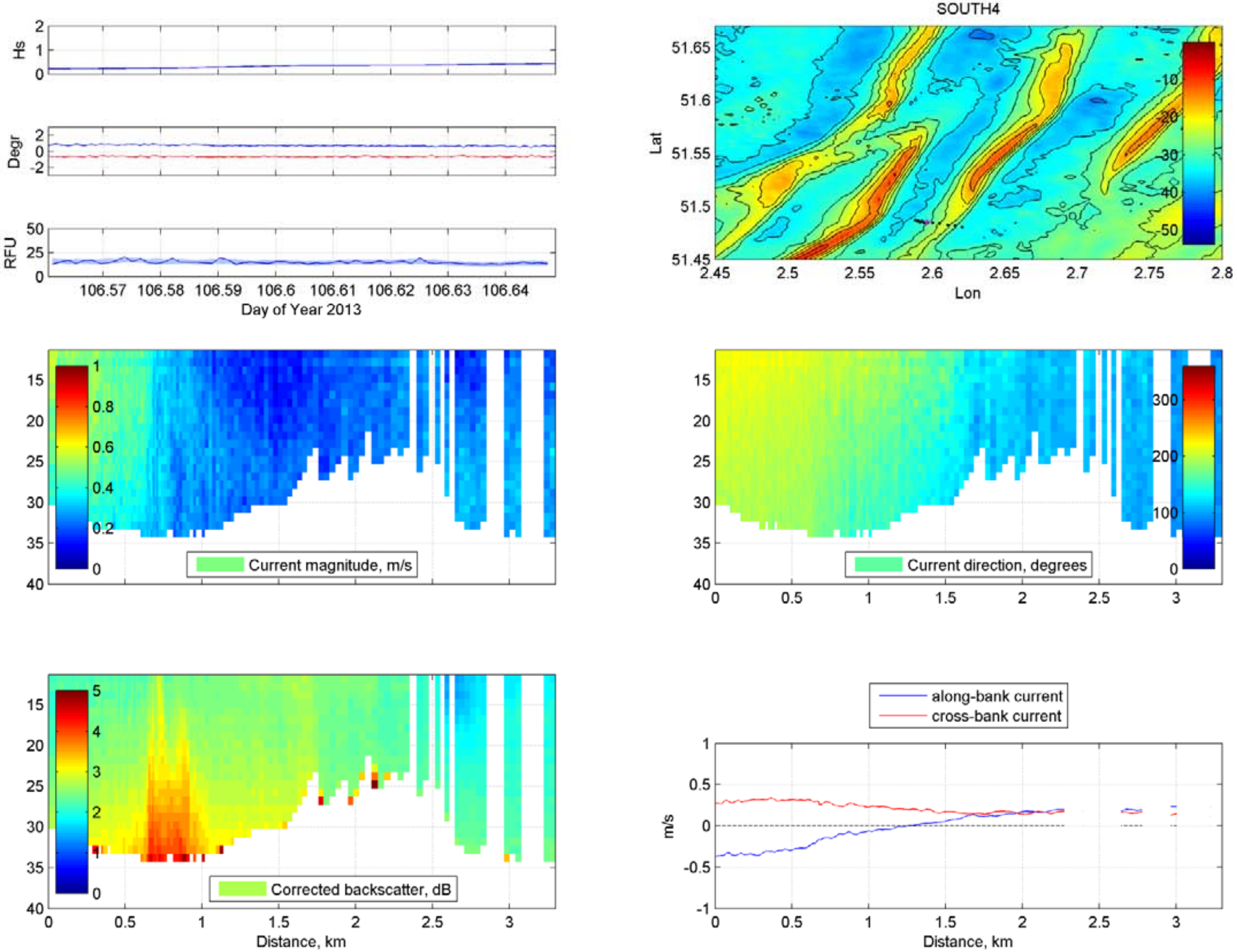
F48



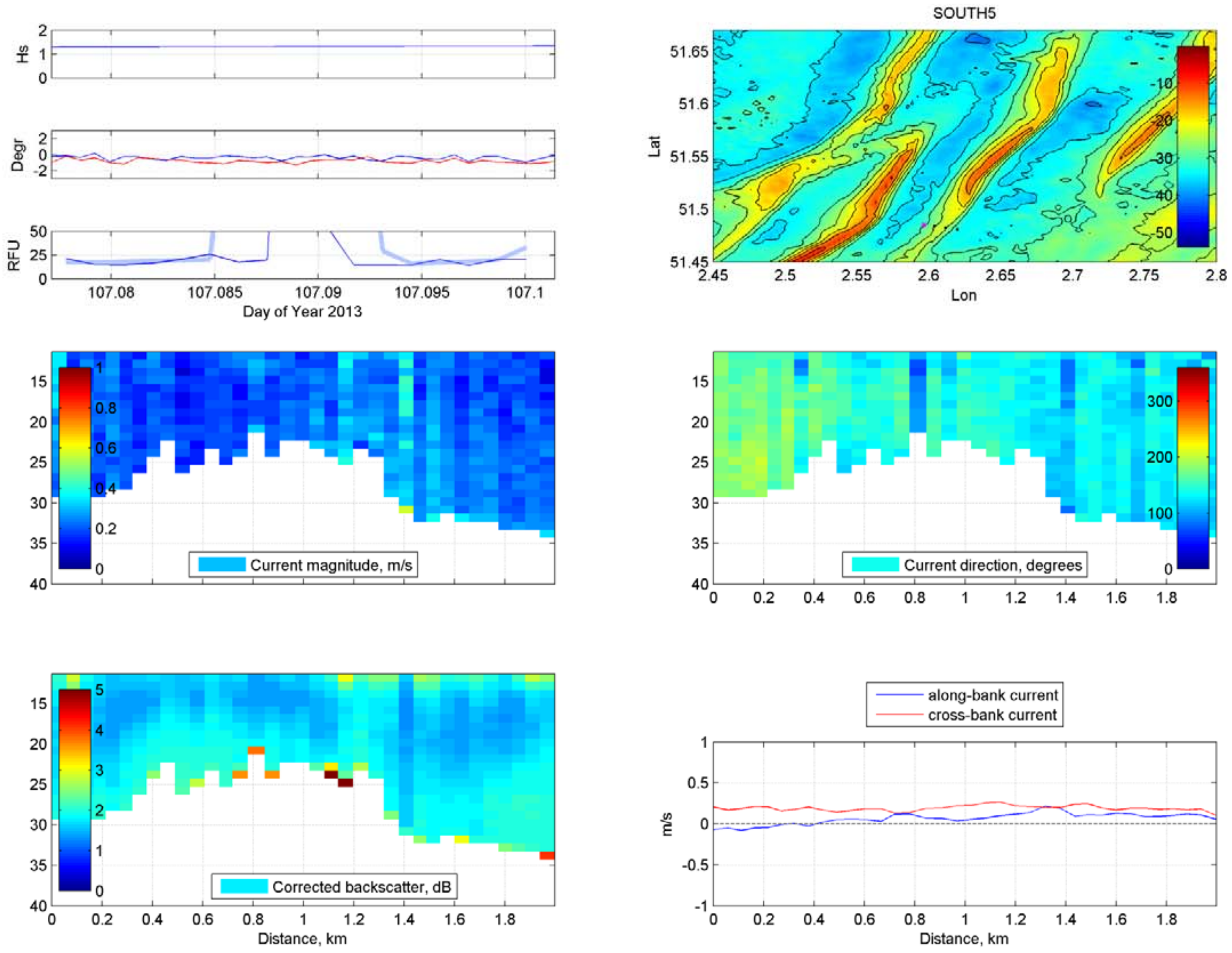
Hs
Degr
RFU
Day of Year 2013
SOUTH2
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s
Distance, km

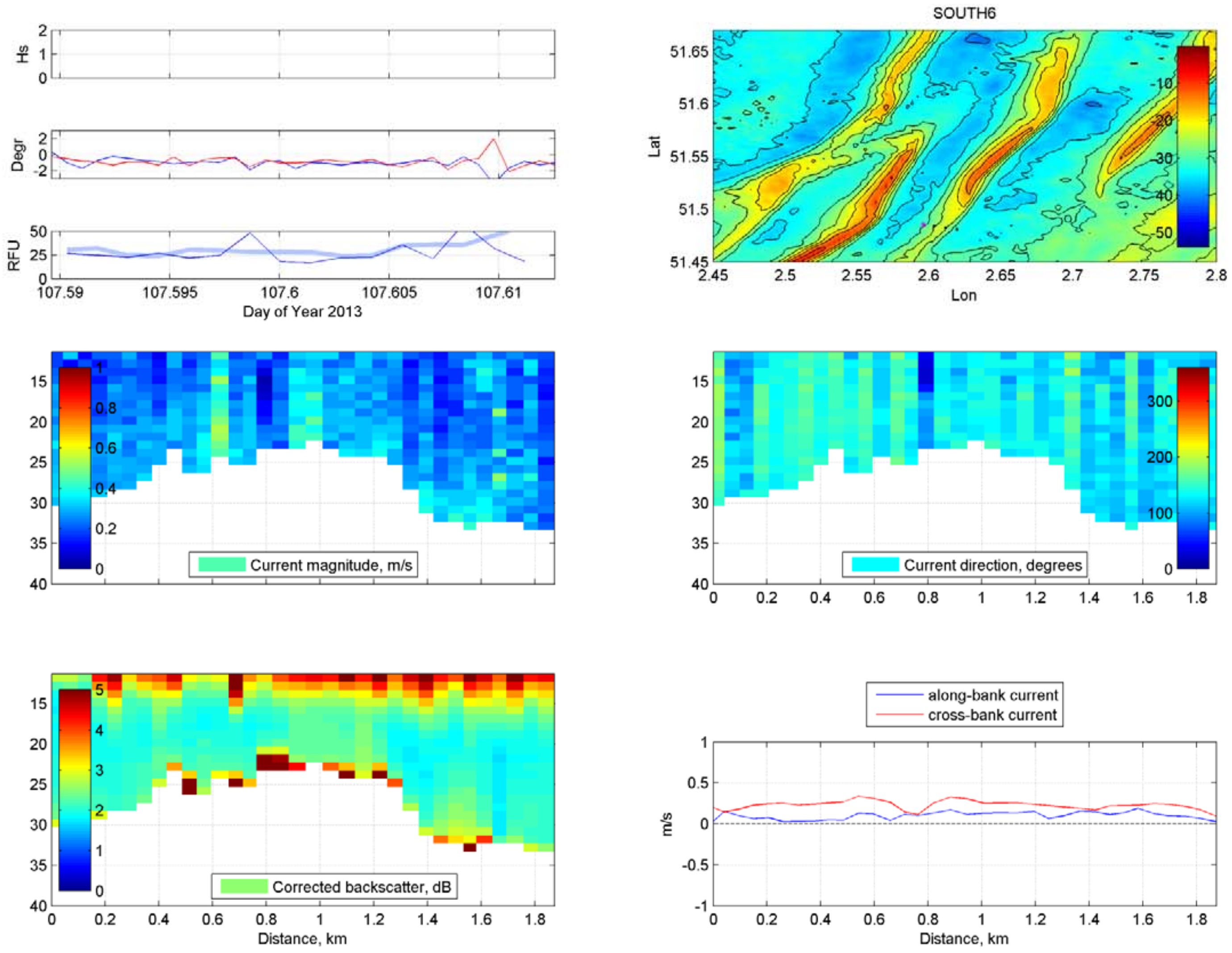


Hs
Degr
RFU
Day of Year 2013
SOUTH3
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km



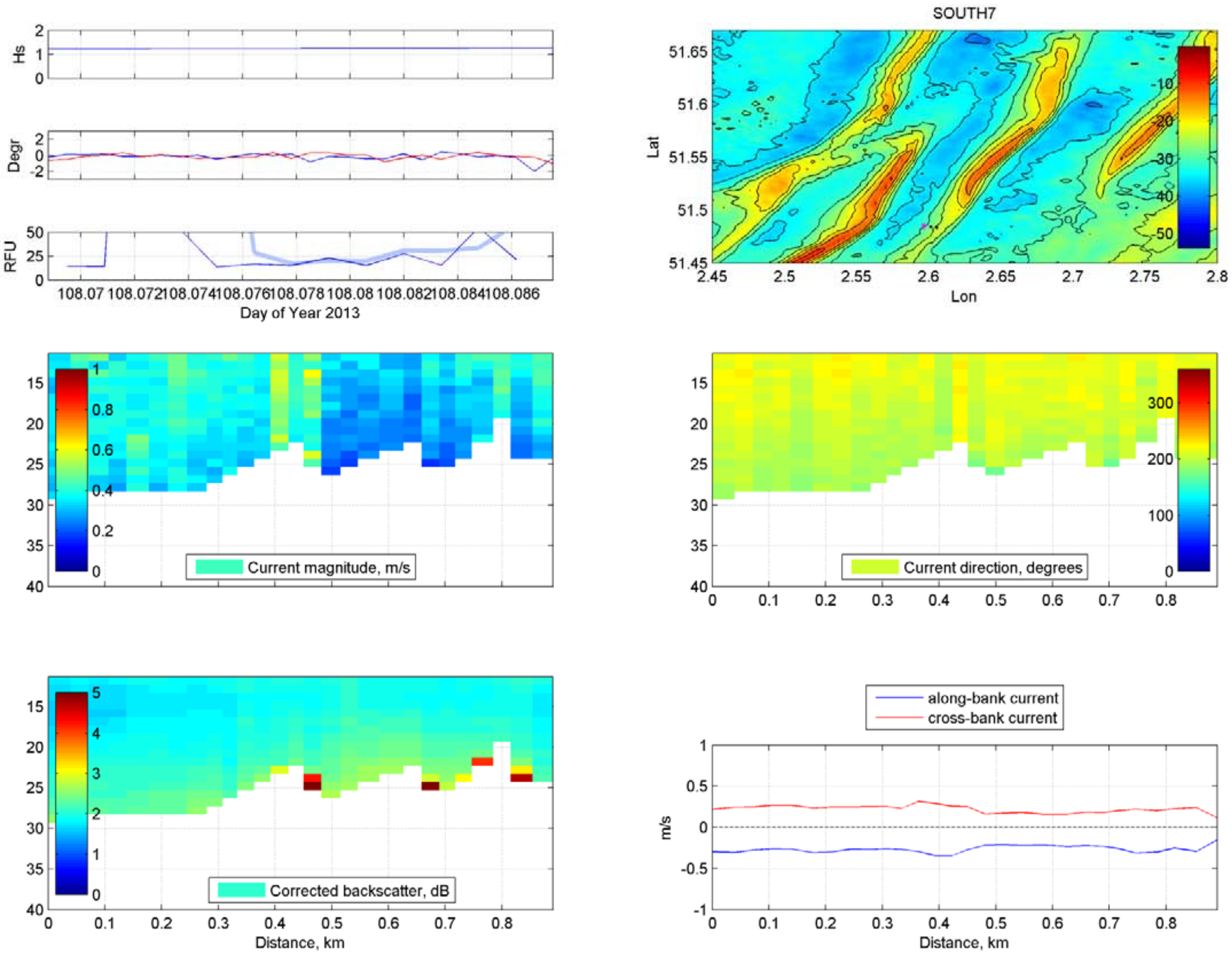
SOUTH4
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

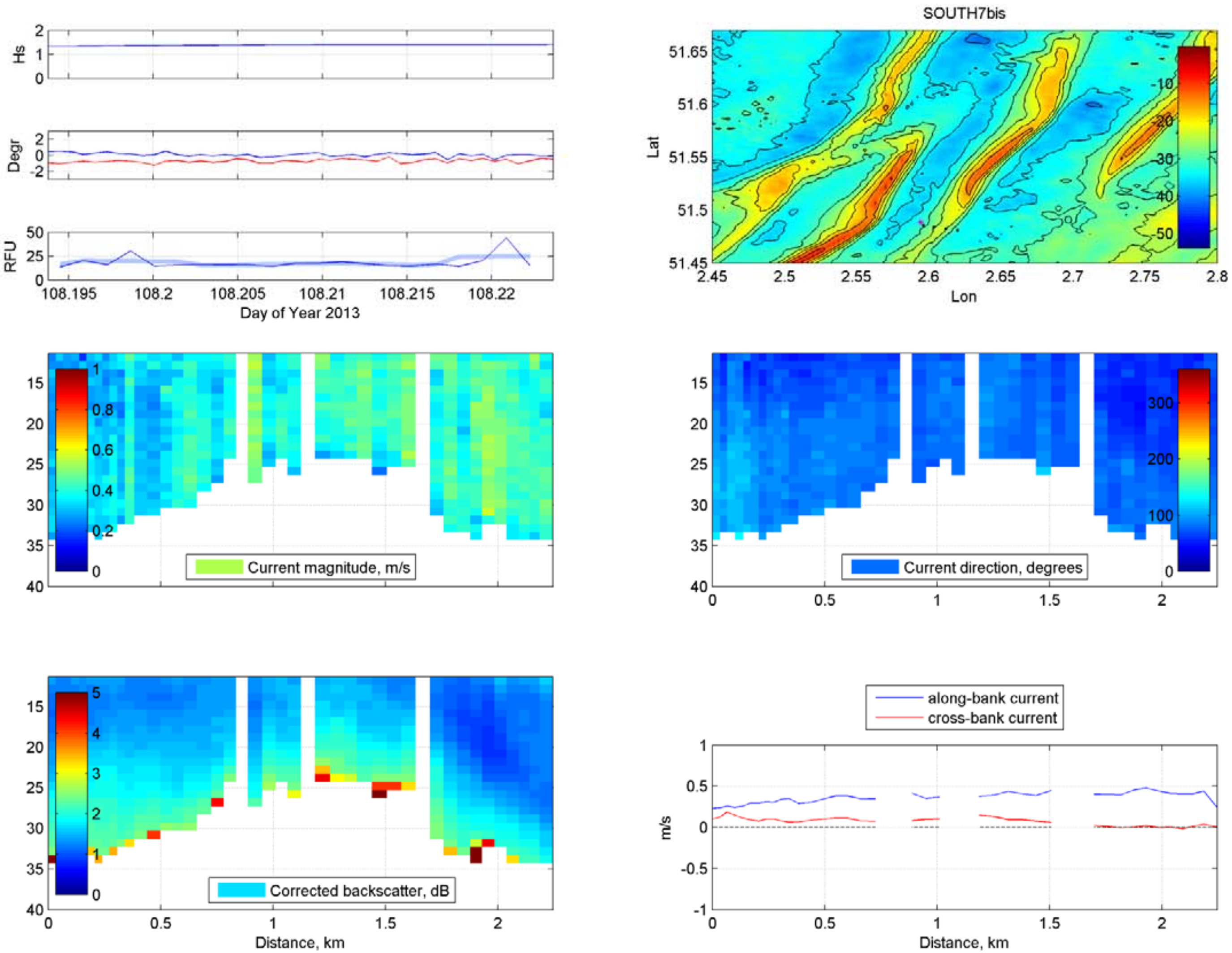

SOUTH5
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

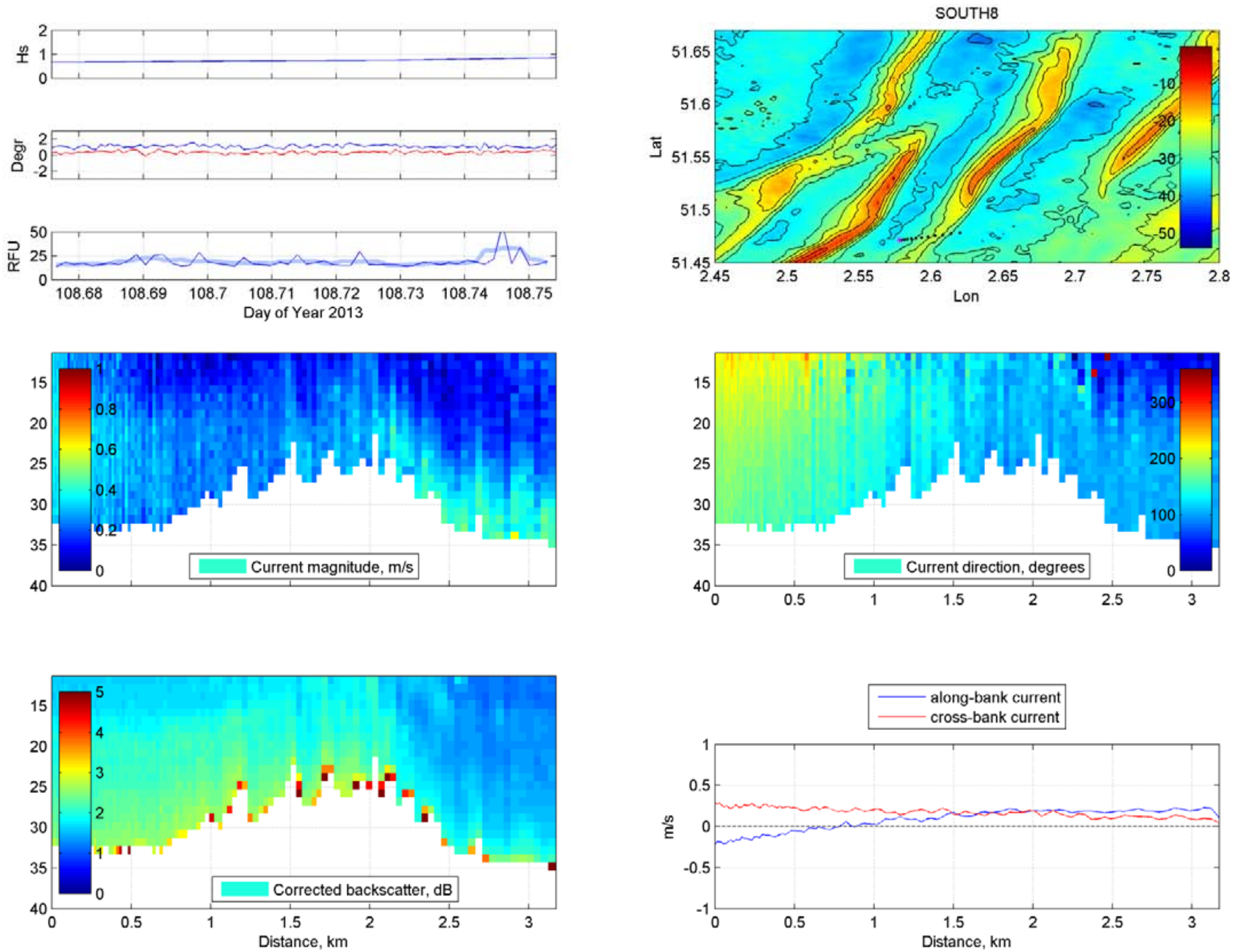


SOUTH6
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

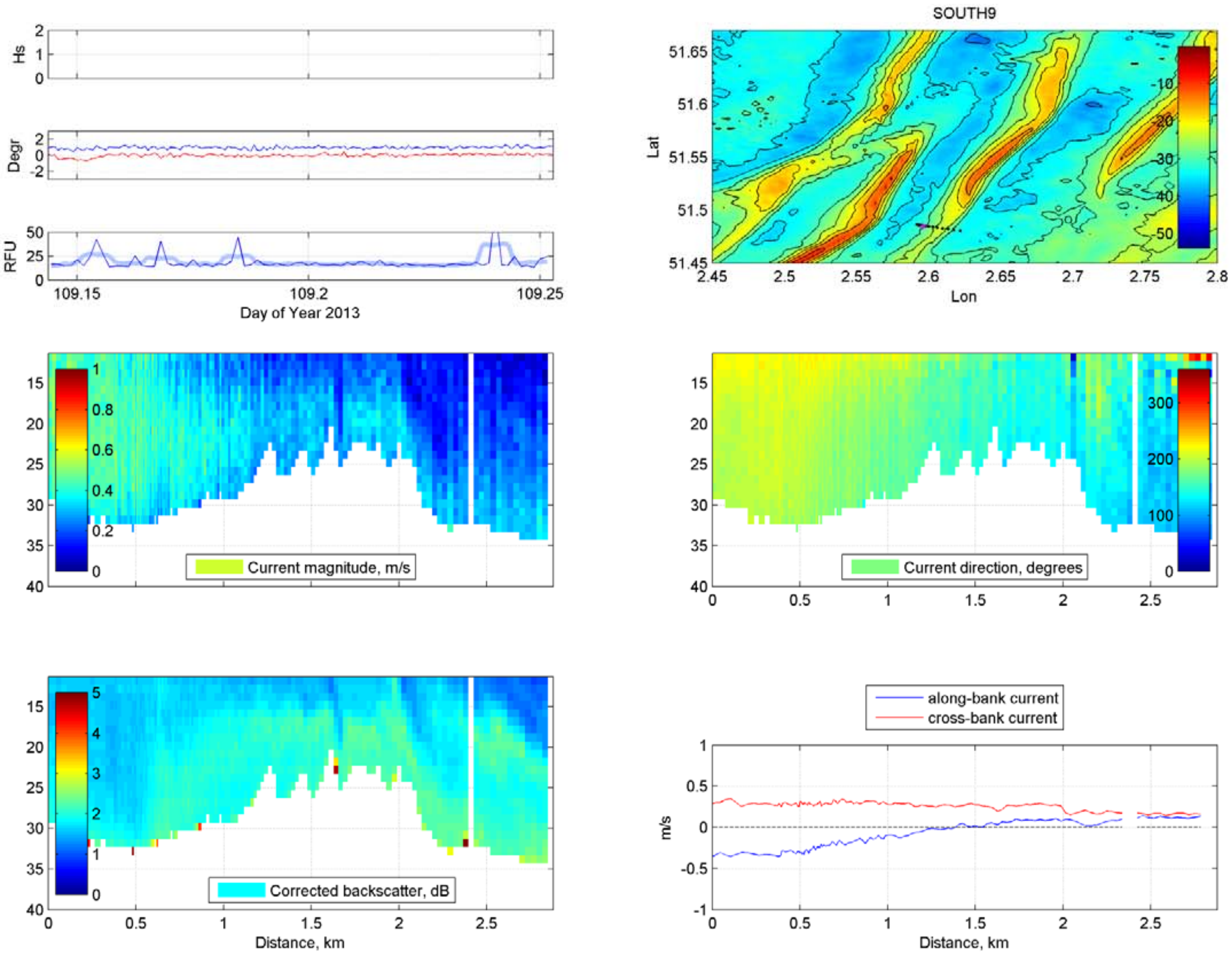
F53


SOUTH7
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

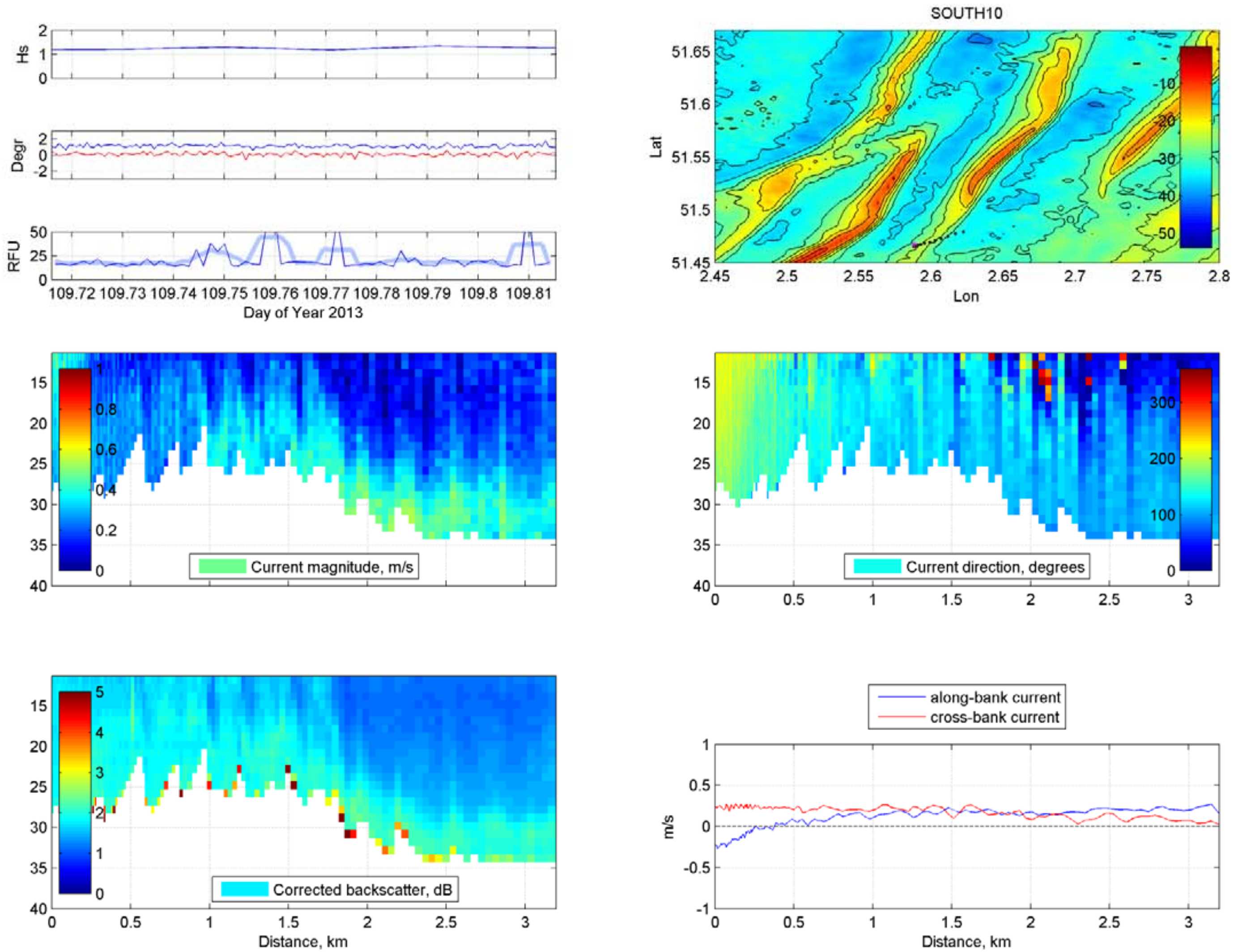

SOUTH7bis
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km



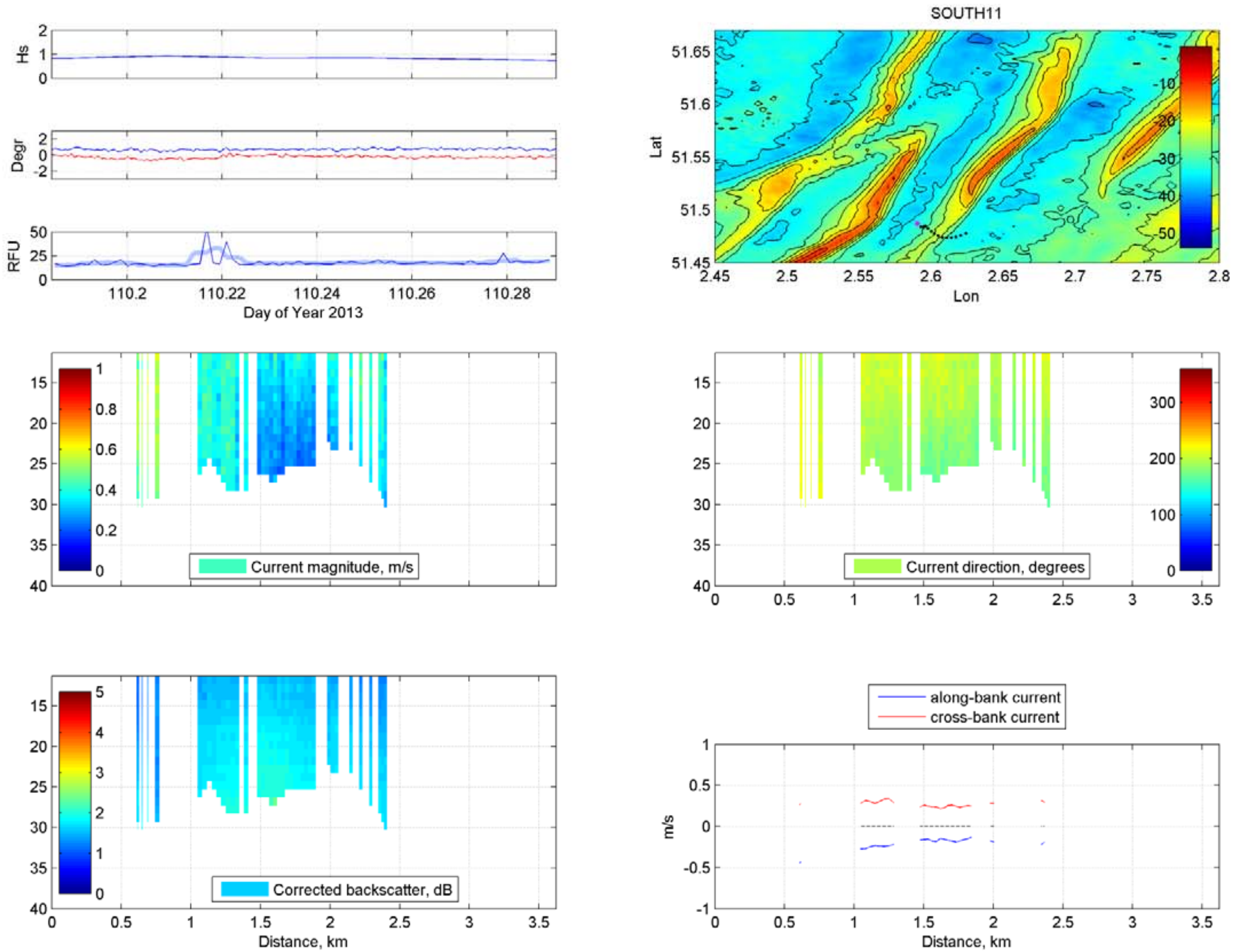
SOUTH8
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km



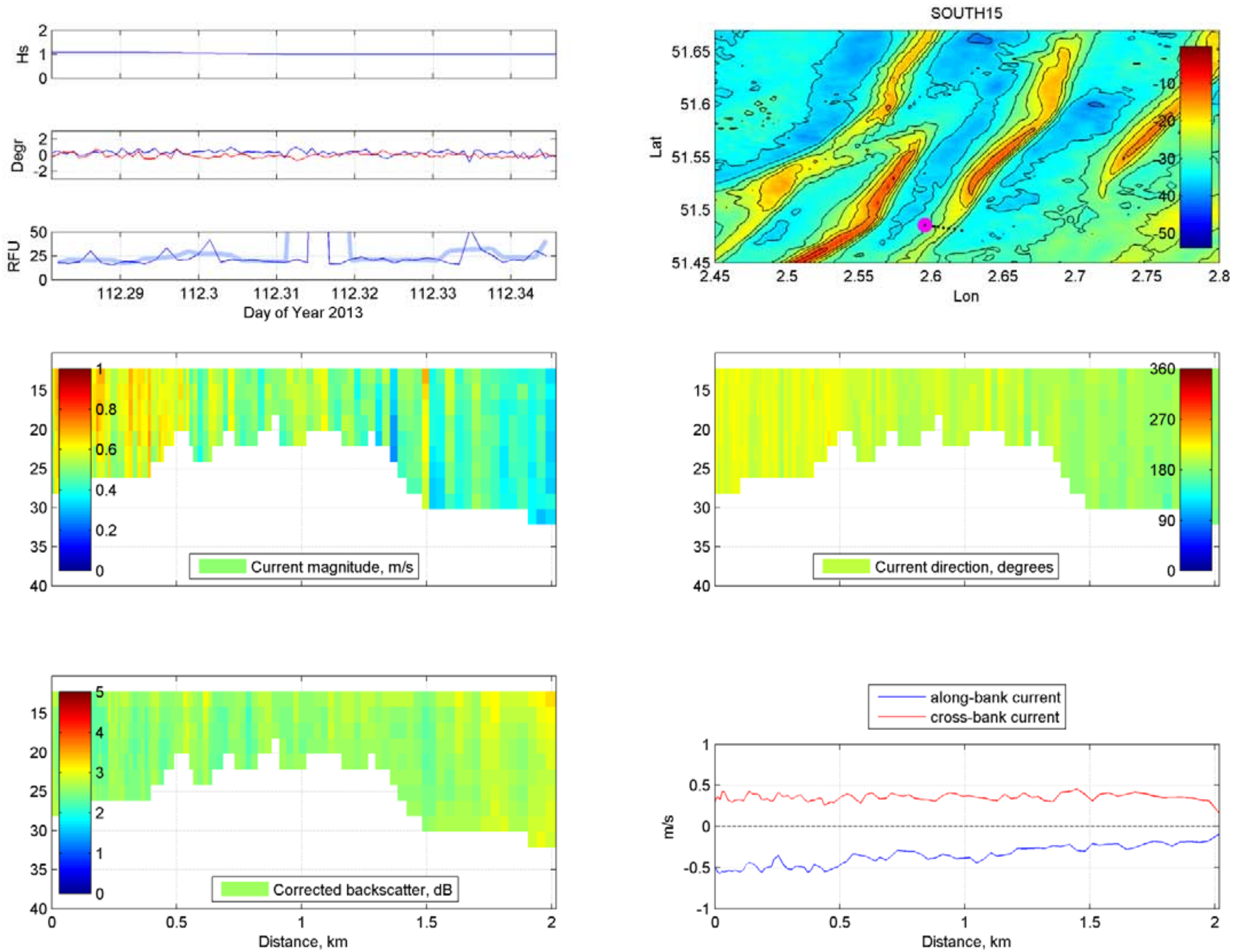
SOUTH9
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km



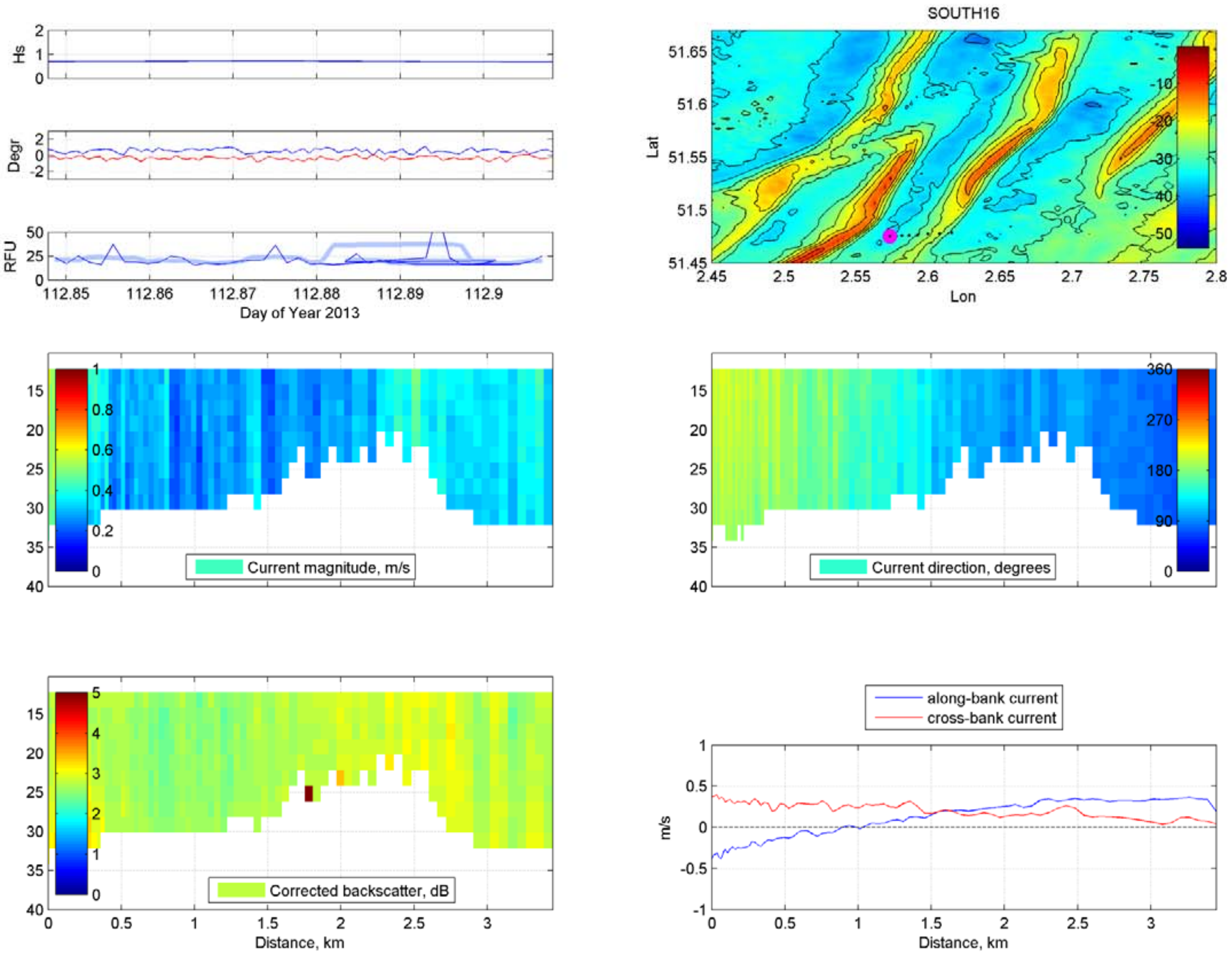
SOUTH10
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

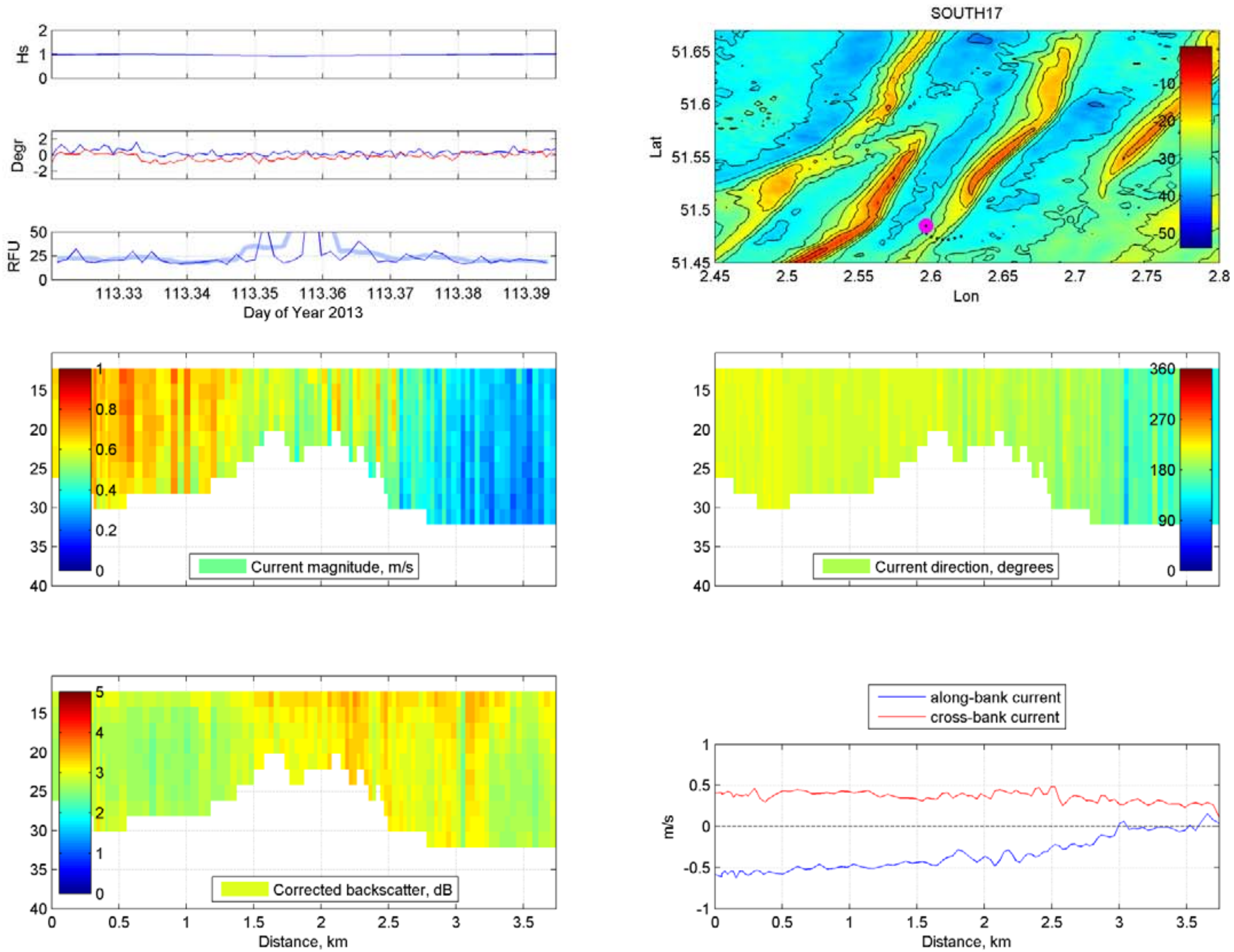

Hs
Degr
RFU
Day of Year 2013
SOUTH11
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

F59

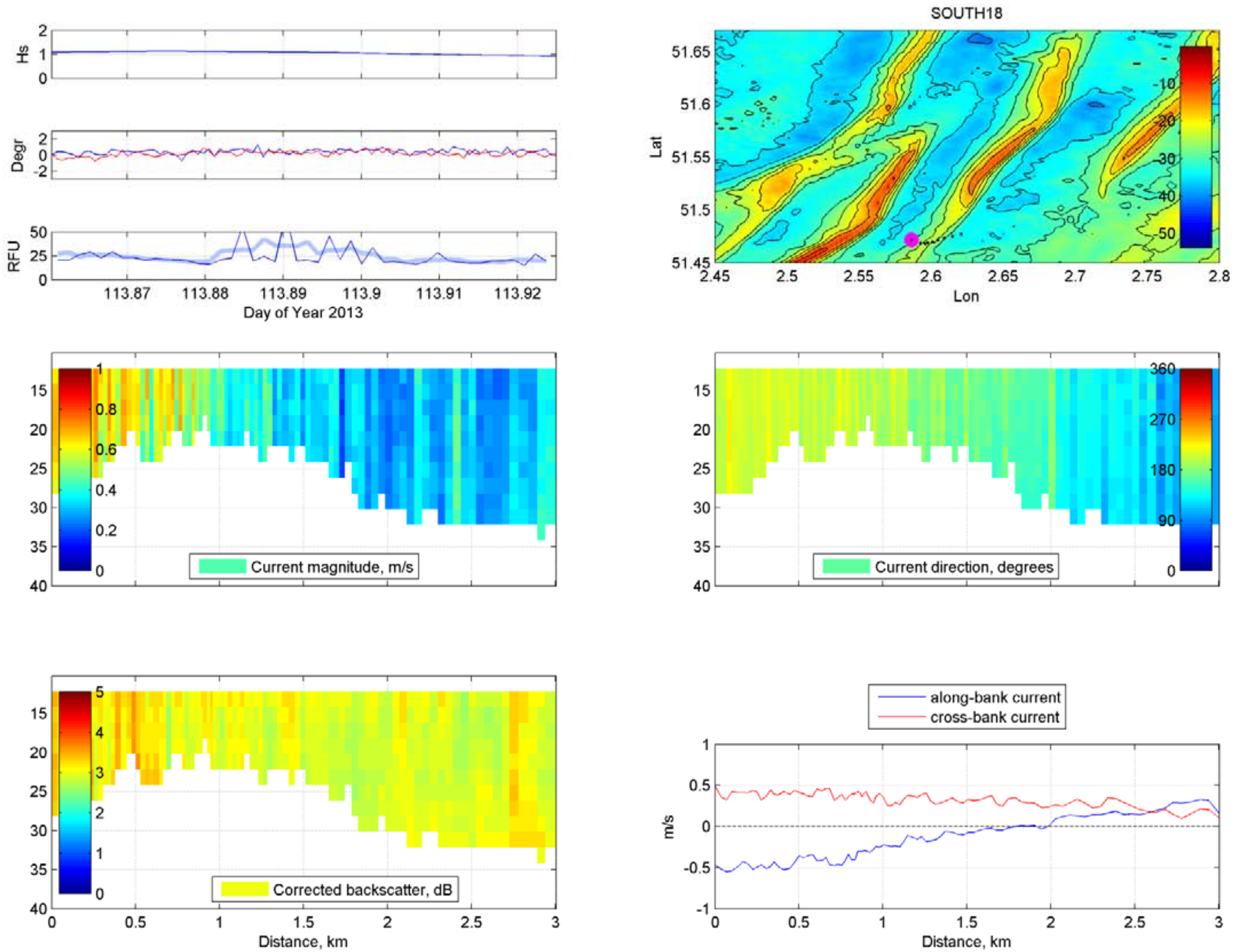


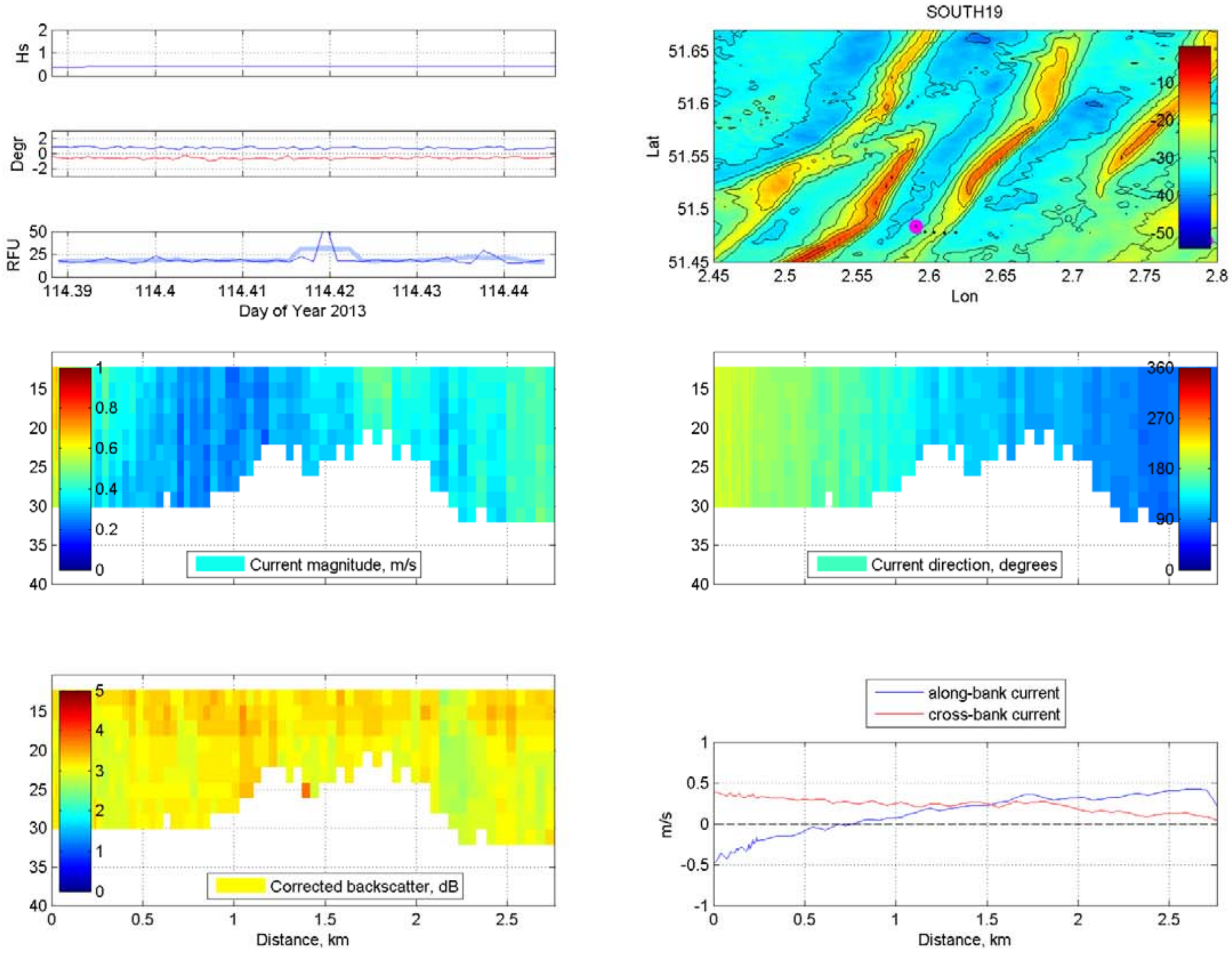
SOUTH15
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km


SOUTH16
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km



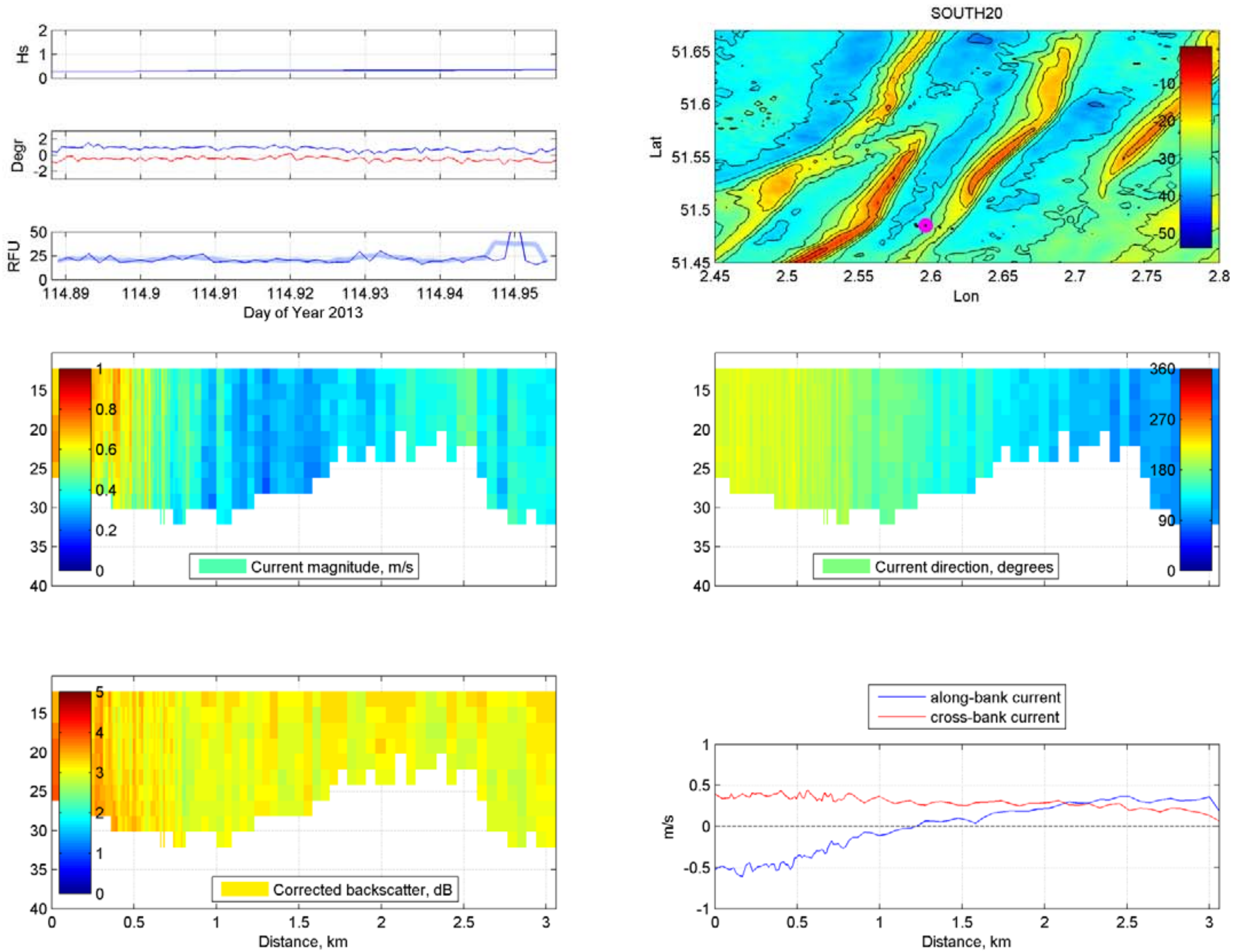
Hs
Degr
RFU
Day of Year 2013
SOUTH17
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km


SOUTH18
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km



Hs
Degr
RFU
Day of Year 2013
SOUTH19
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s
Distance, km

F64



Hs
Degr
RFU
Day of Year 2013
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Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
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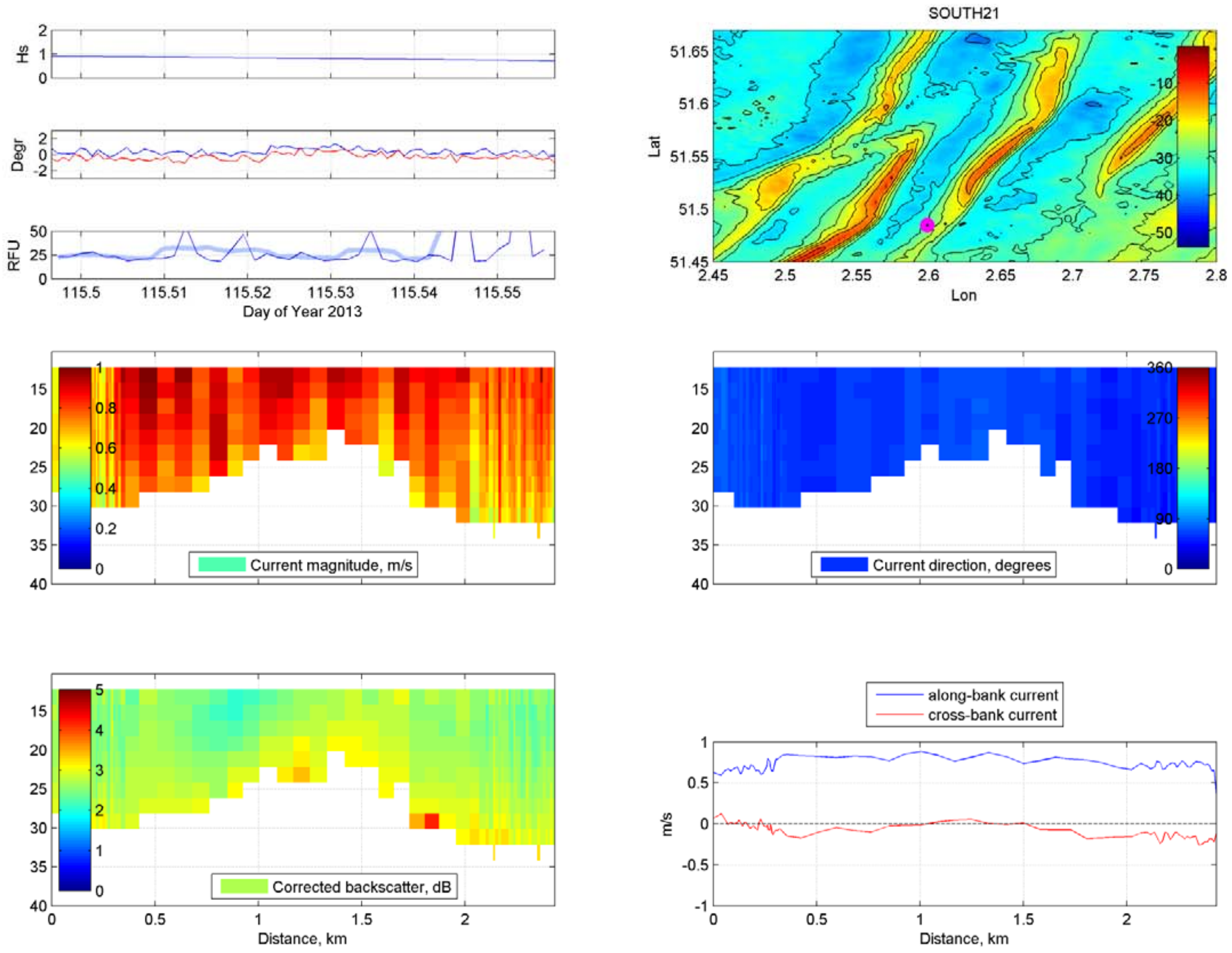
cross-bank current
m/s
Distance, km



Hs
Degr
RFU
Day of Year 2013
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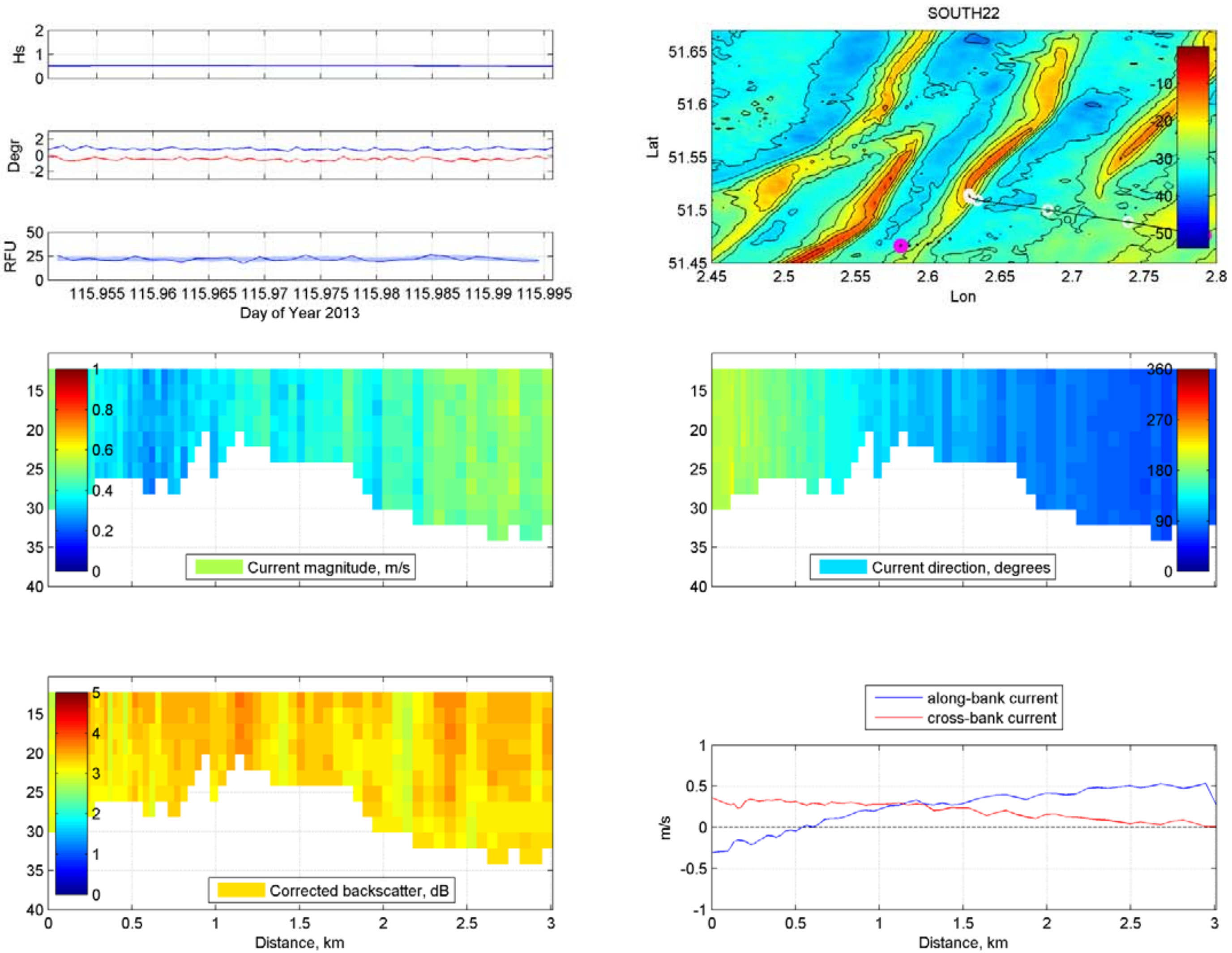
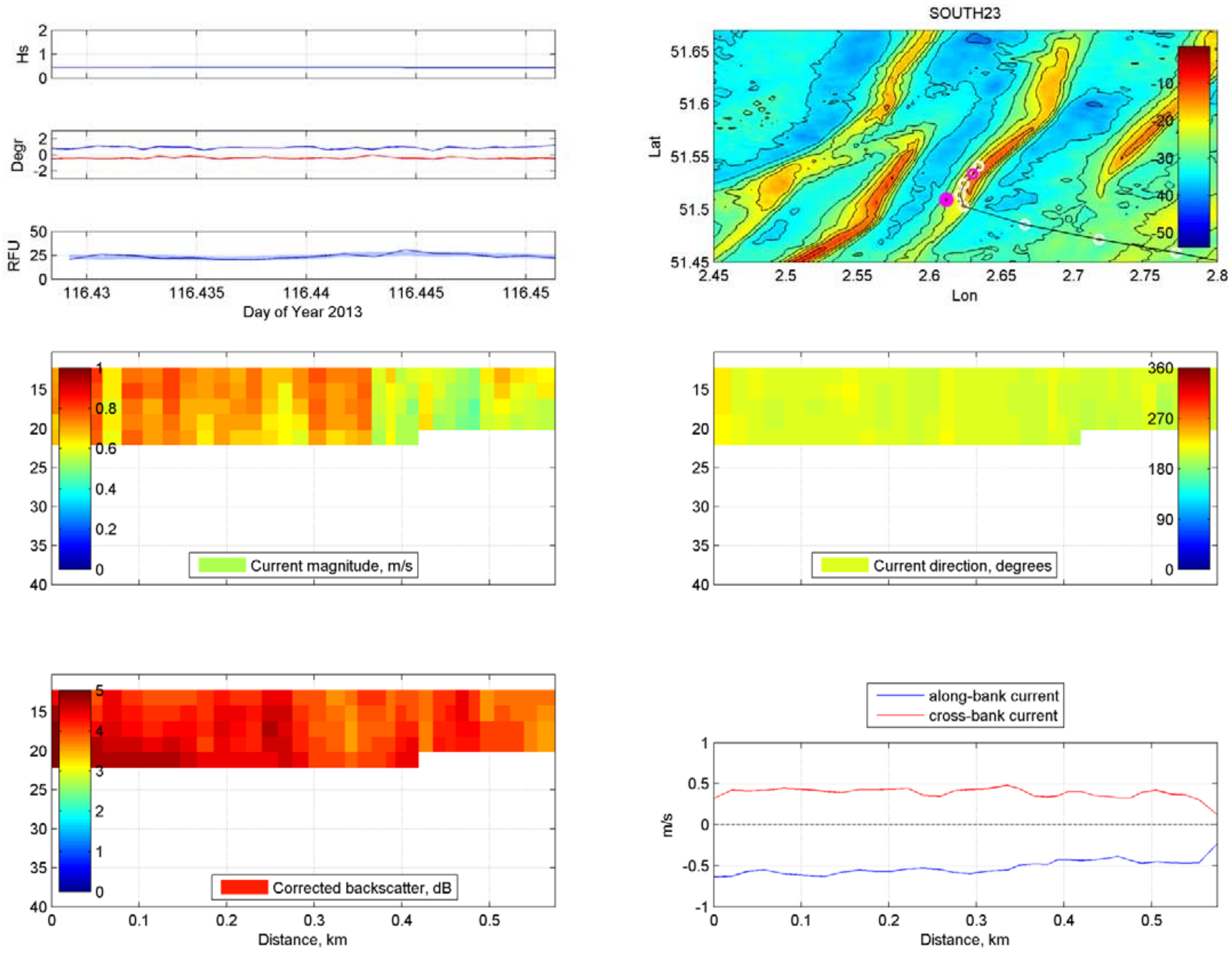
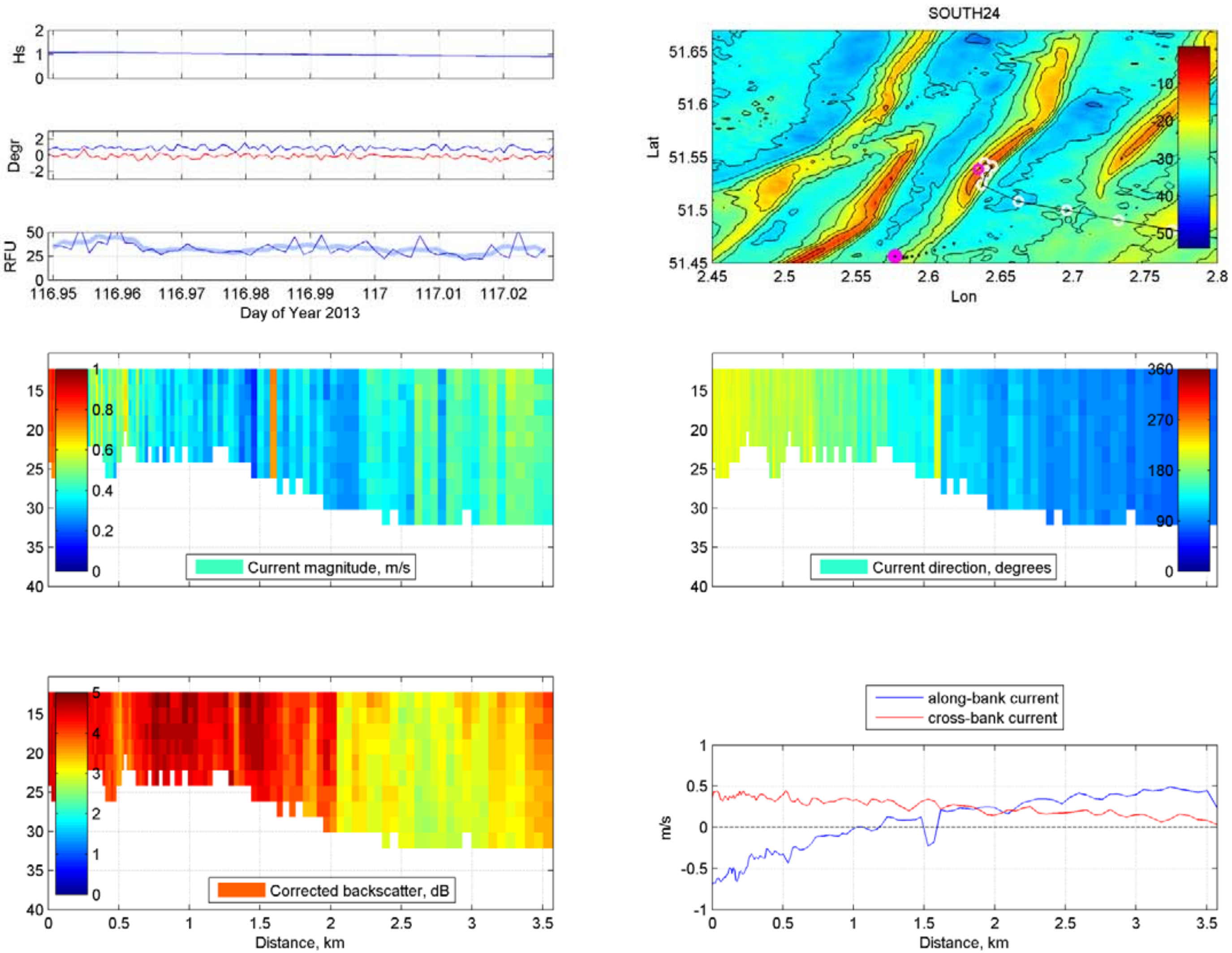
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s
Distance, km


SOUTH22
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km



Hs
Degr
RFU
Day of Year 2013
SOUTH23
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km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Degr
RFU
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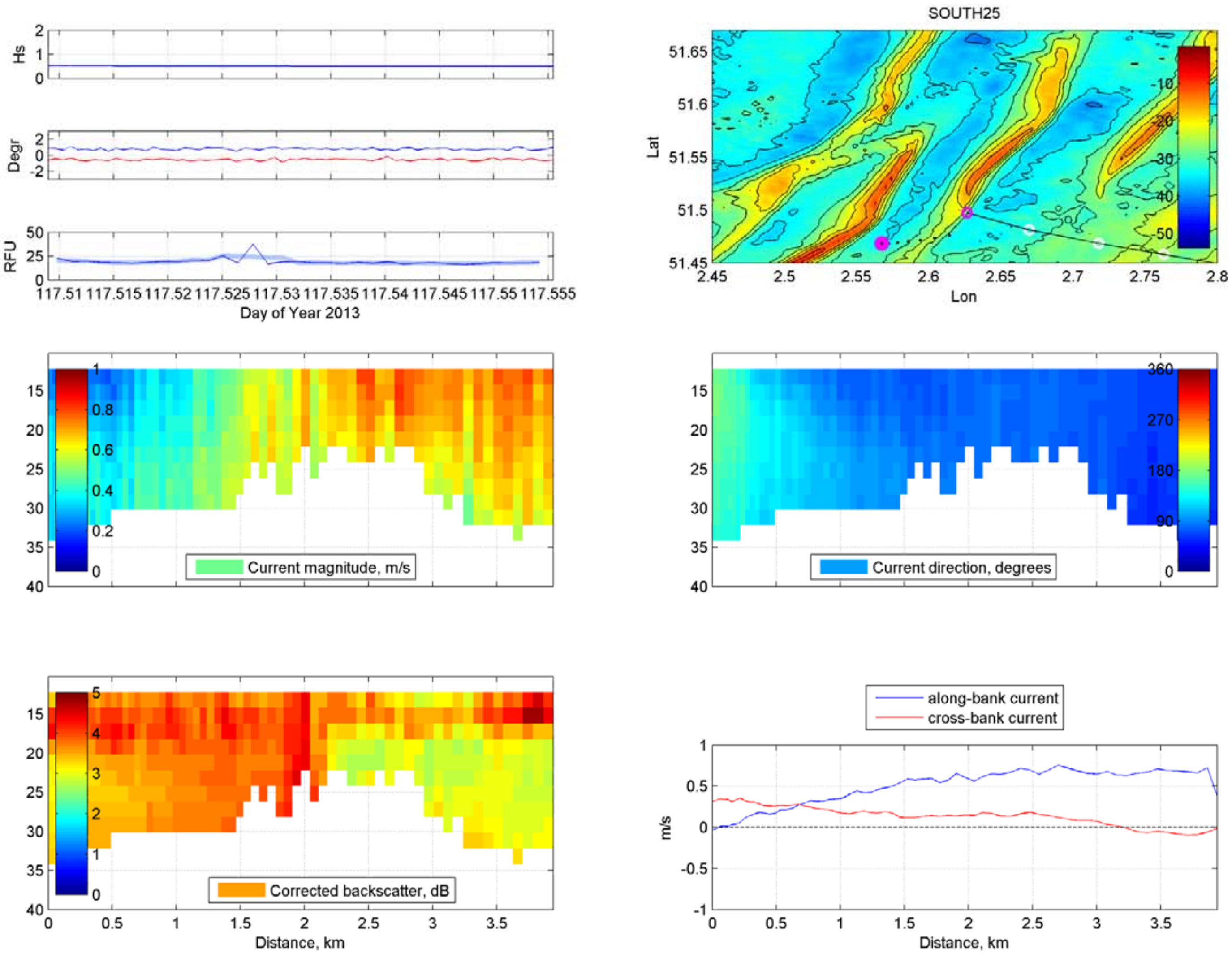
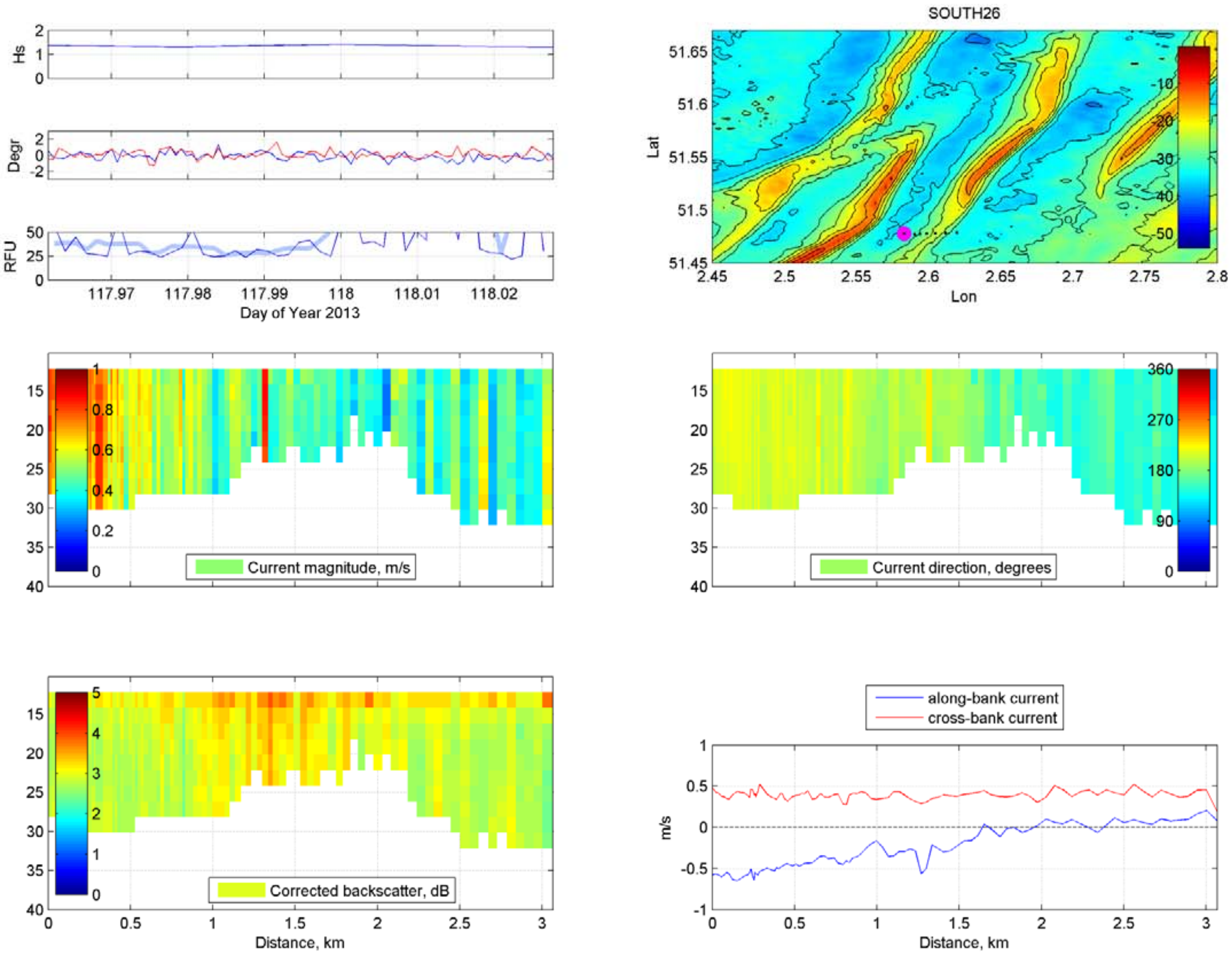
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km


Hs
Degr
RFU
Day of Year 2013
SOUTH25
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F70


SOUTH26
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
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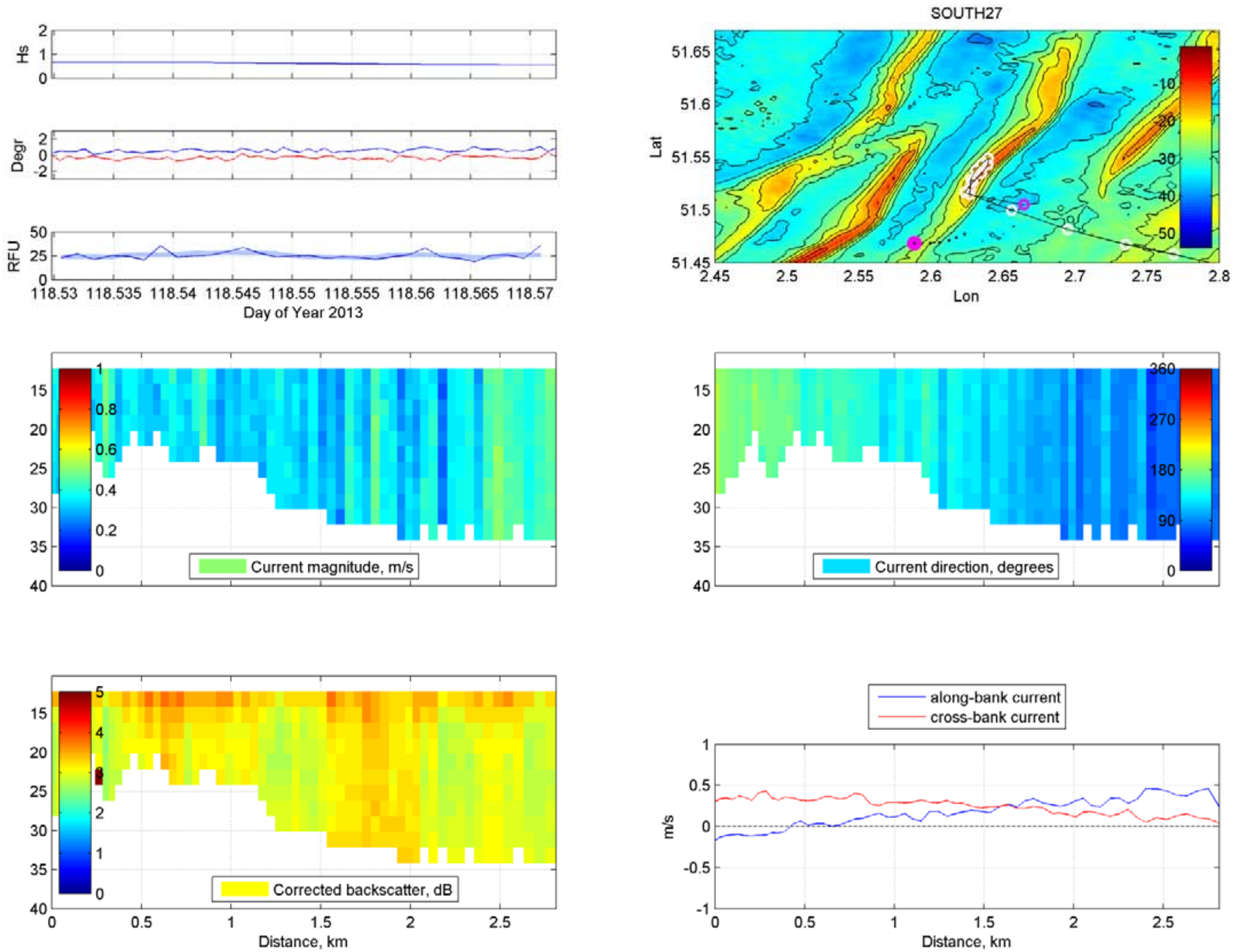
m/s
Distance, km
Distance, km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Degr
RFU
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Lat
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Current direction, degrees
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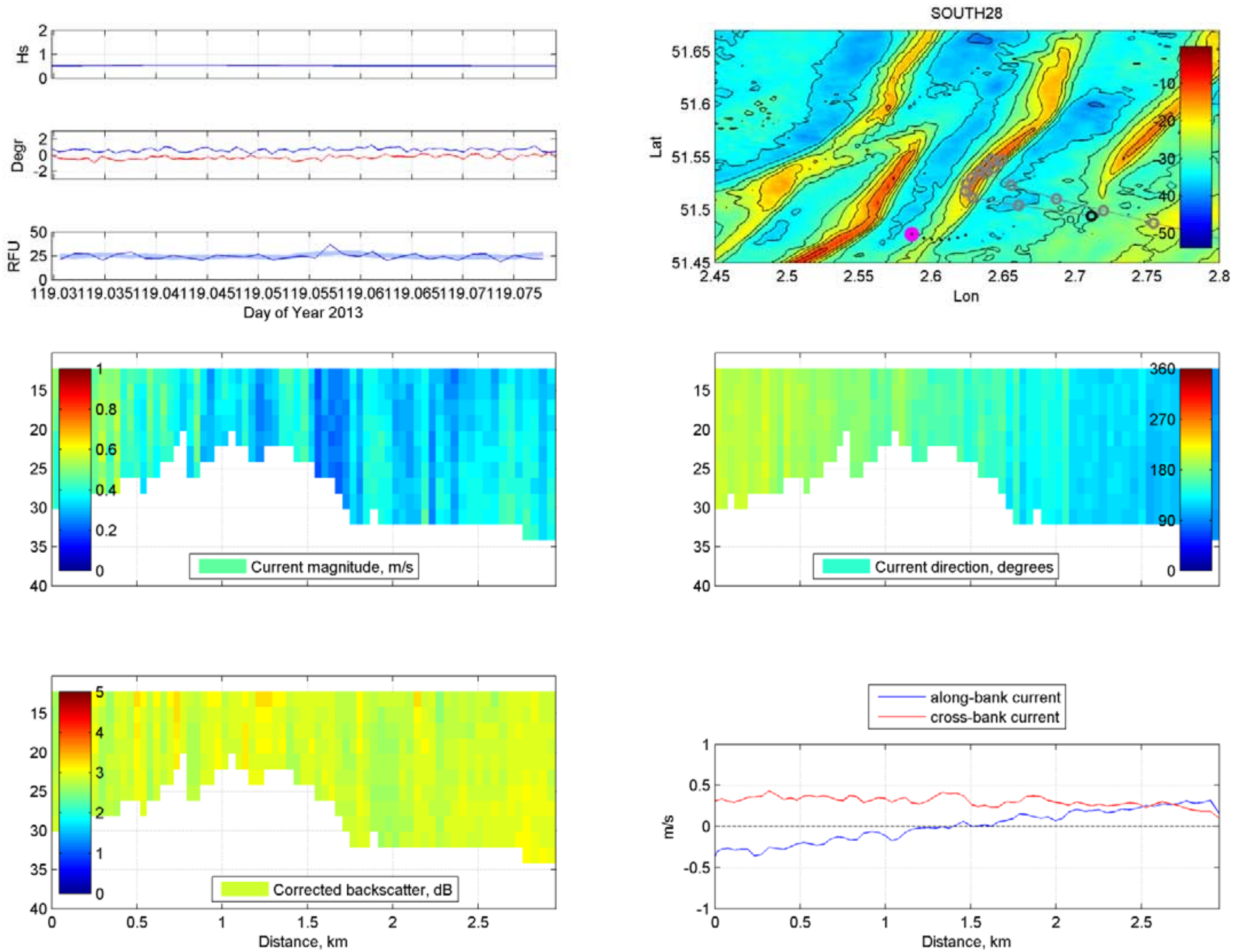
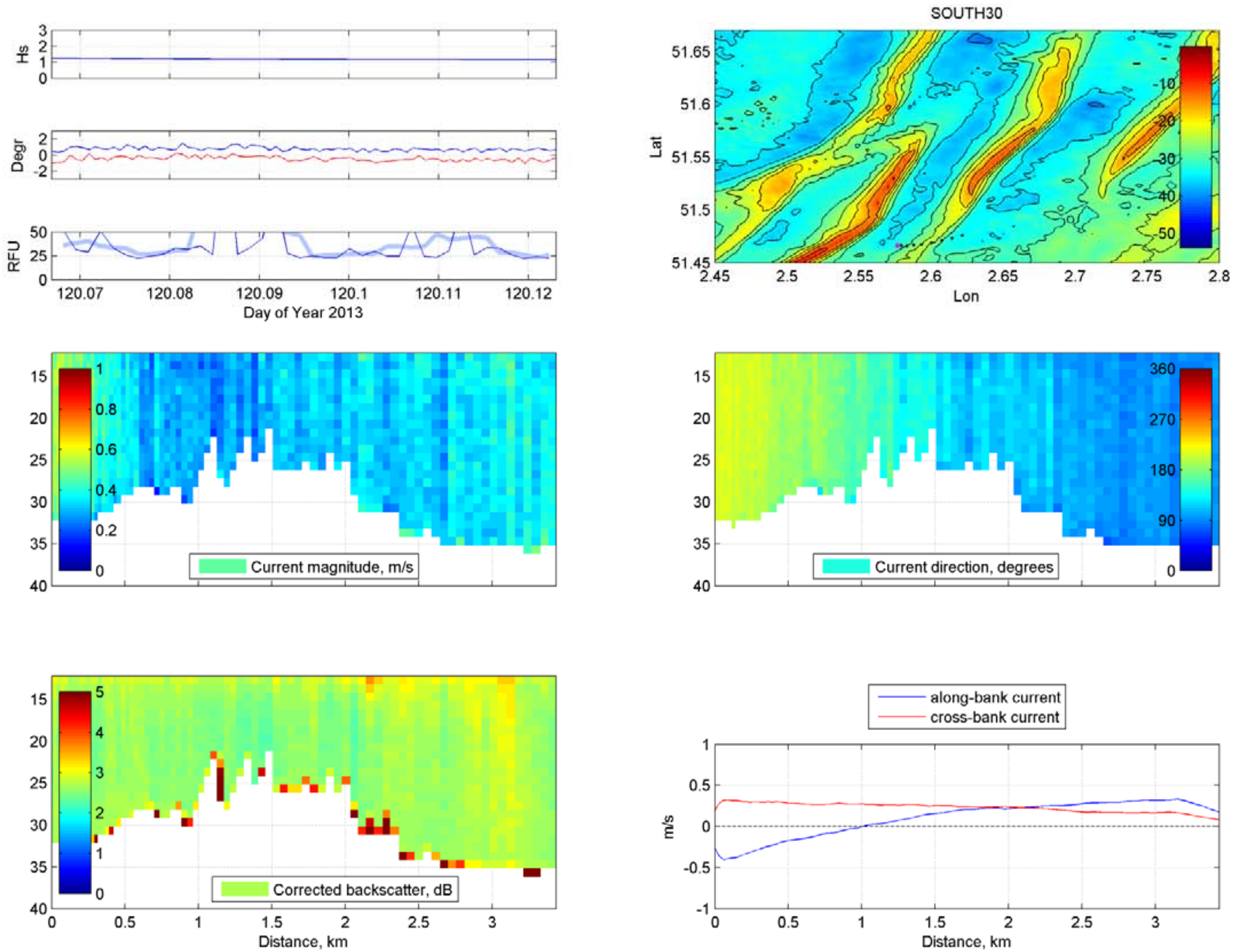
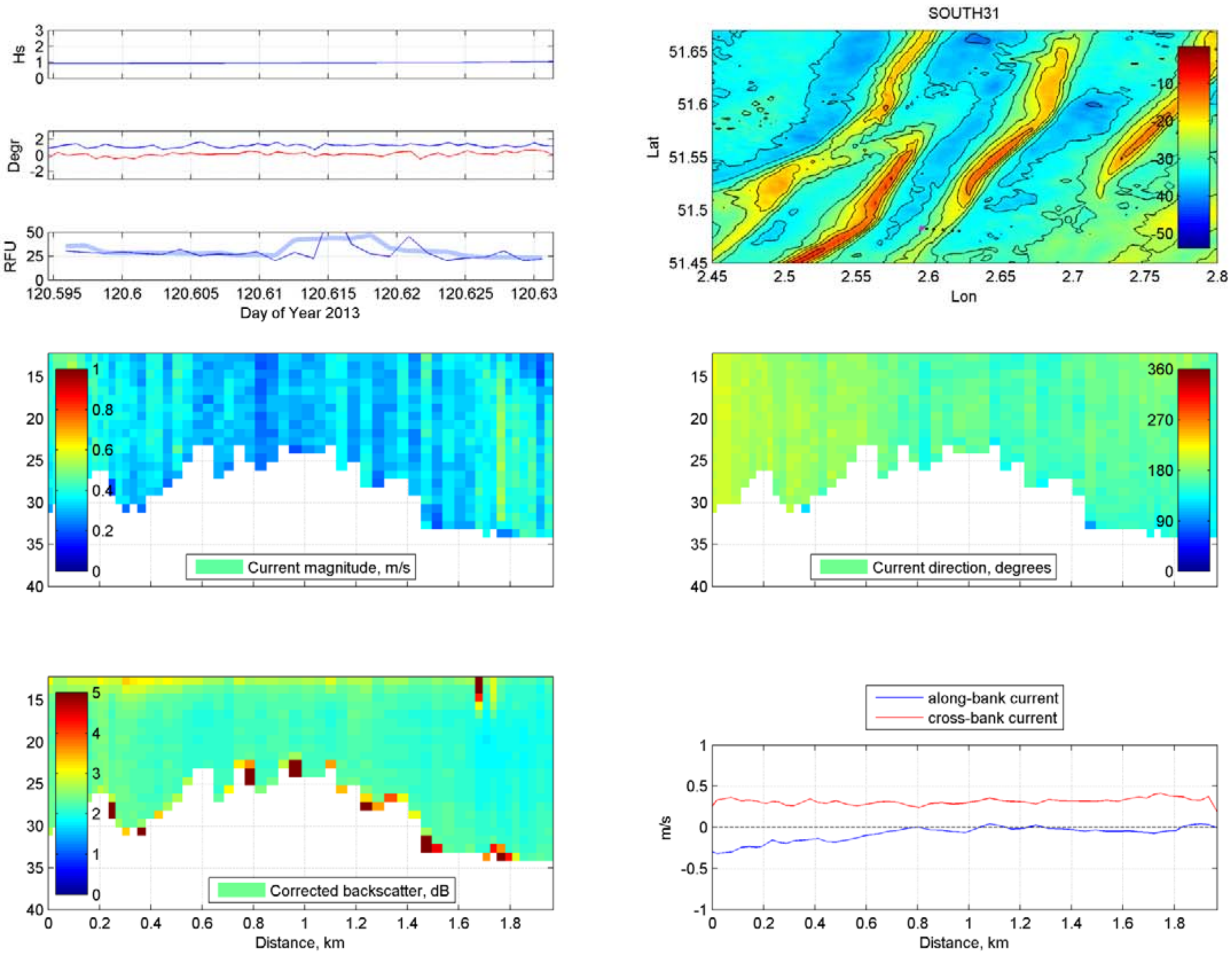
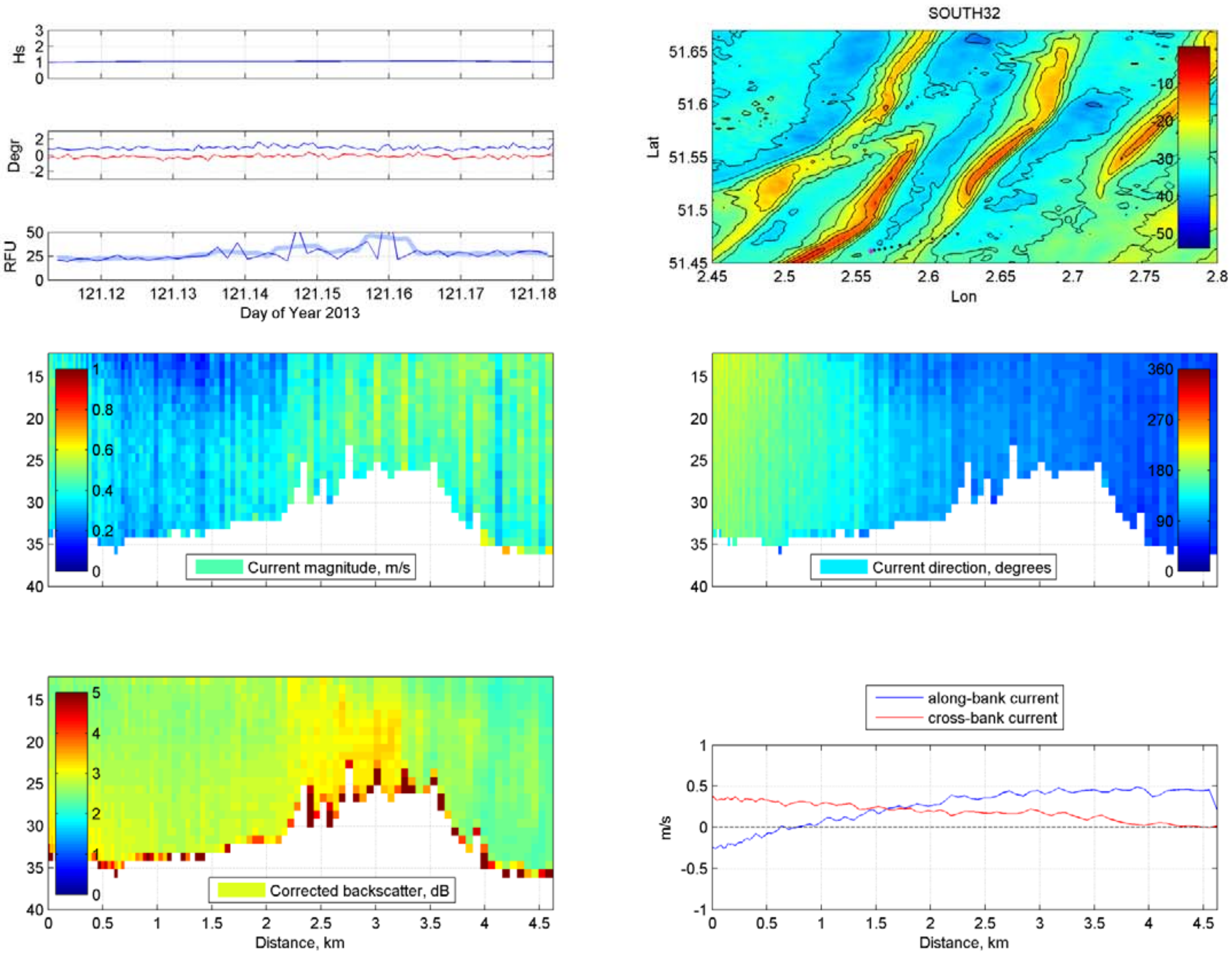
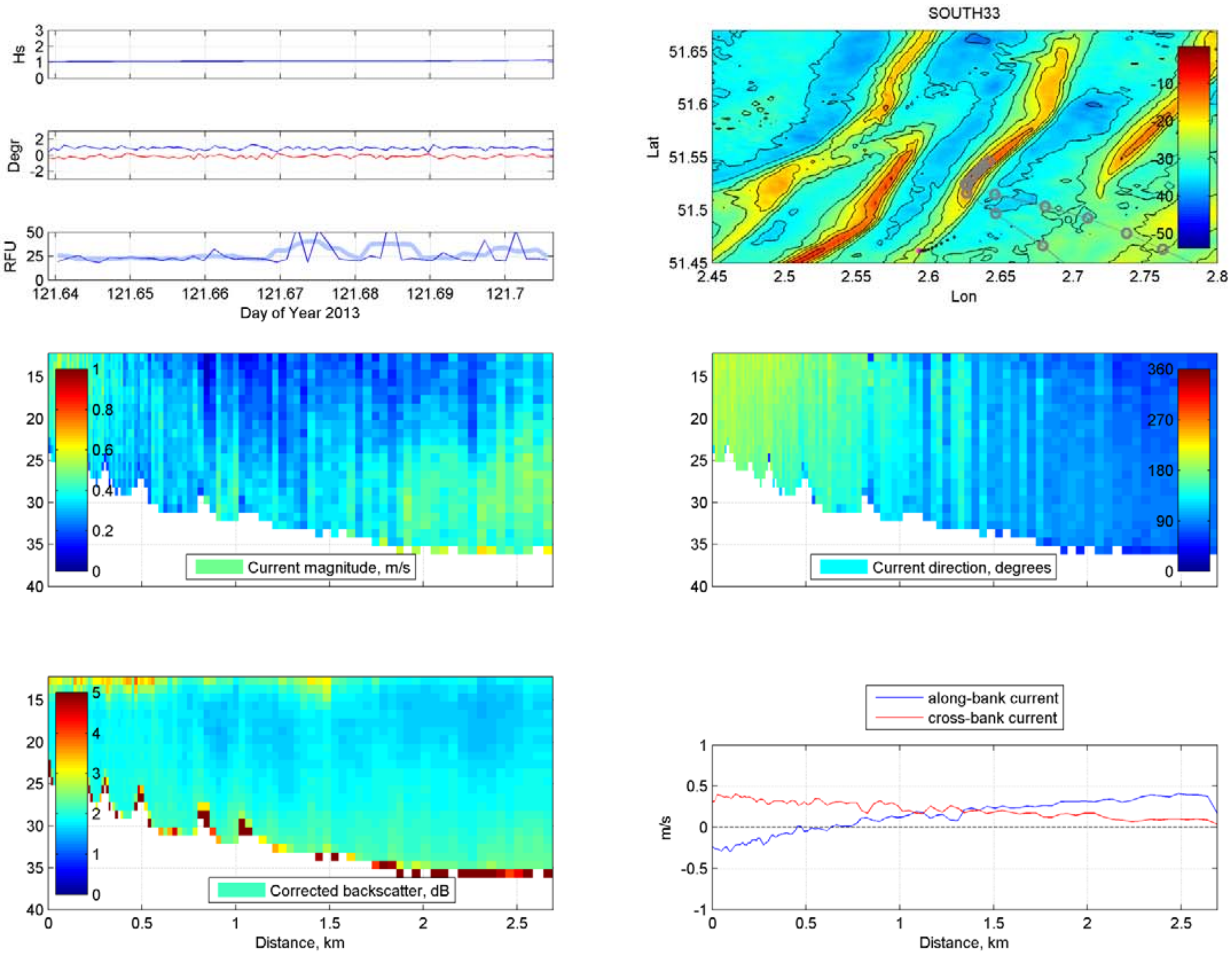
m/s
Distance, km
Distance, km


SOUTH28
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

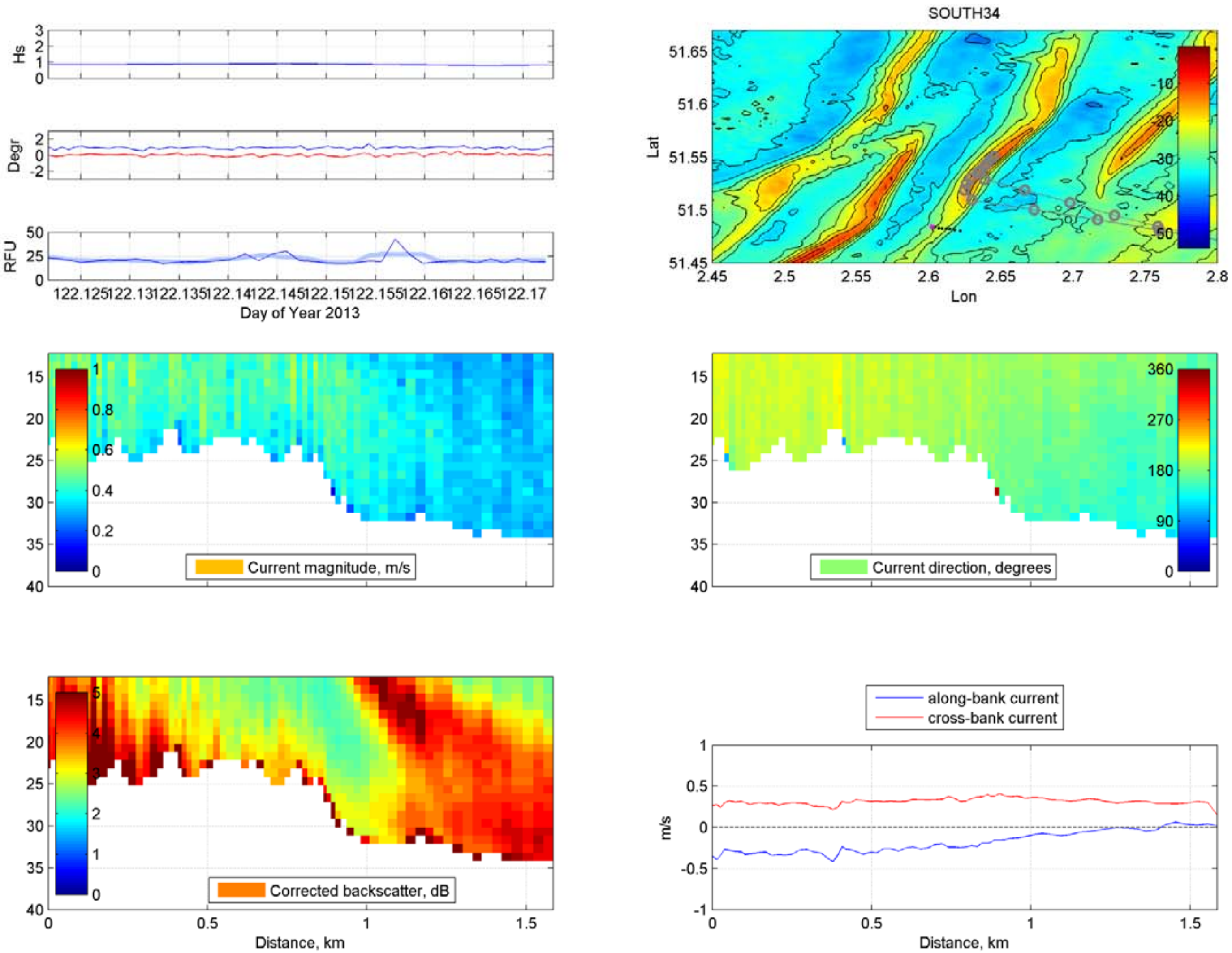

SOUTH30
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km


SOUTH31
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

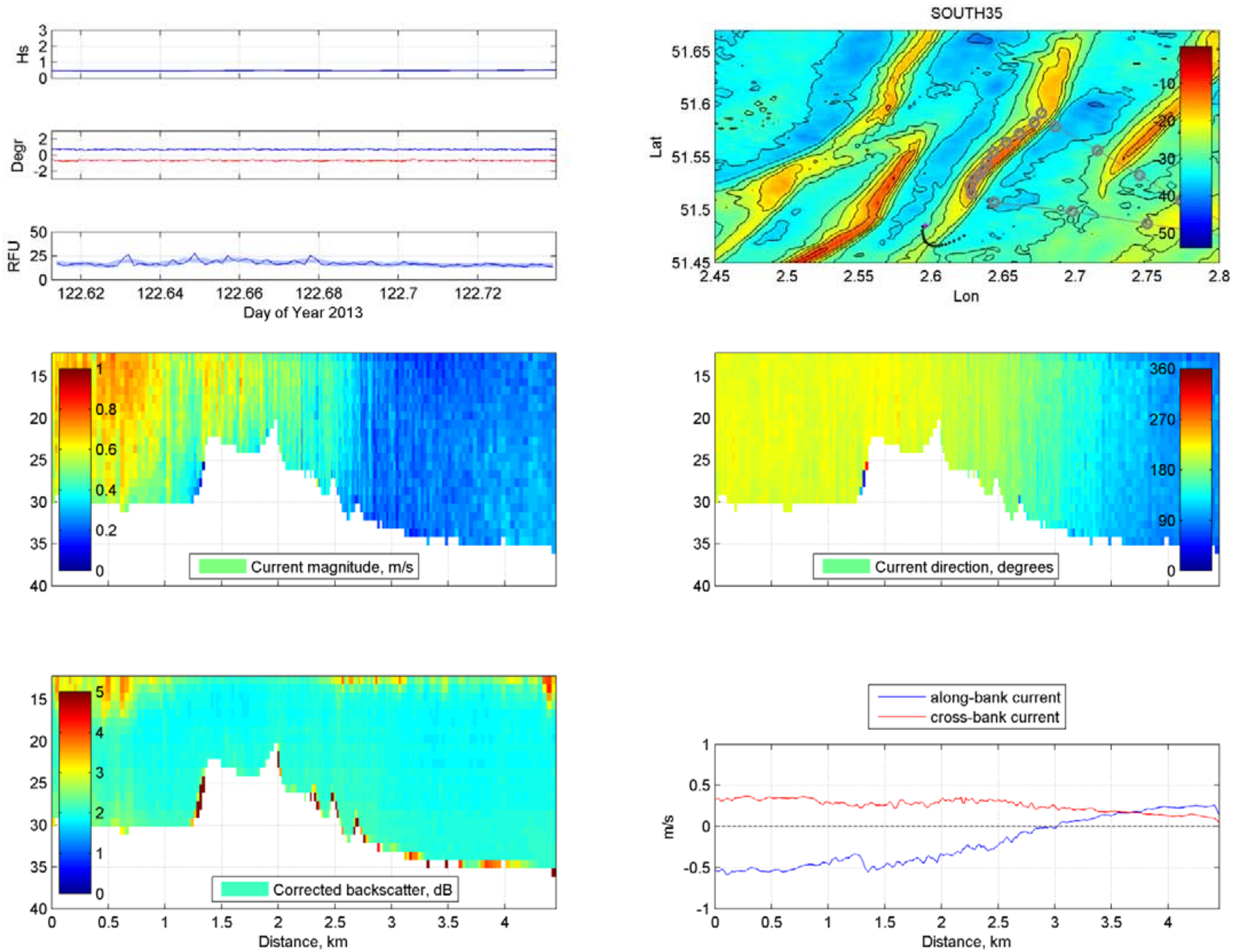

Hs
Degr
RFU
Day of Year 2013
121.12
121.13
121.14
121.15
121.16
121.17
121.18
SOUTH32
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s


SOUTH33
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

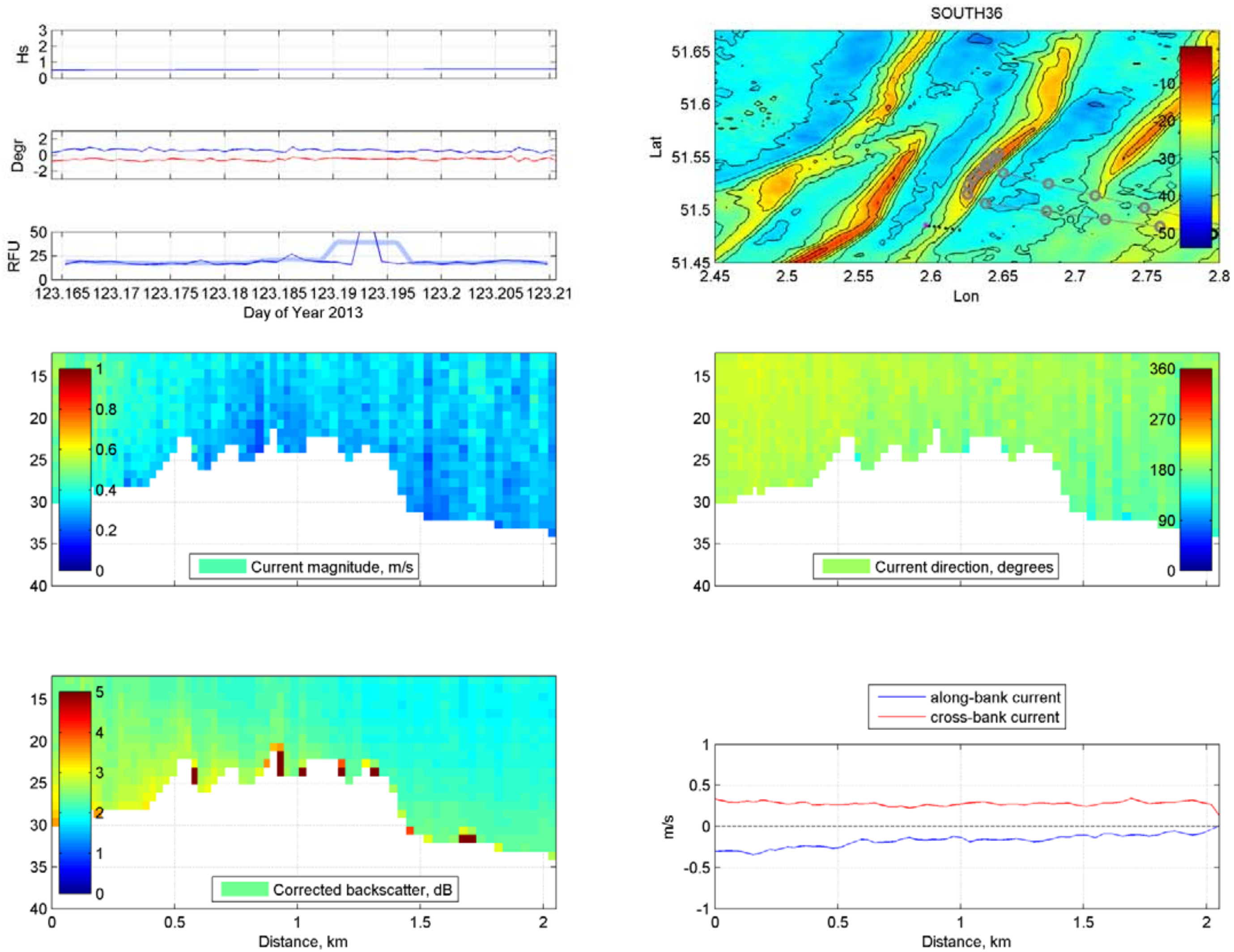
F77


SOUTH34
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F78

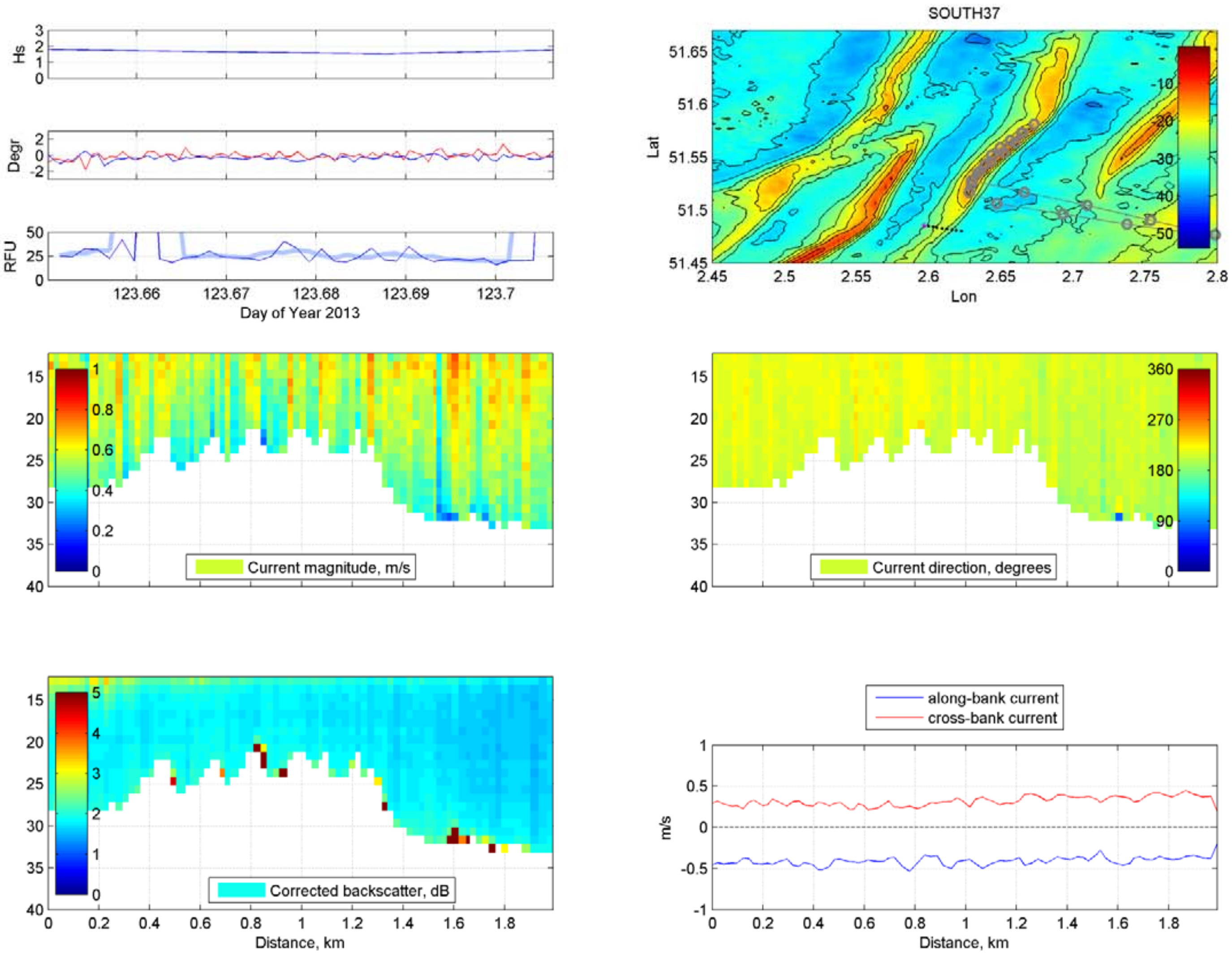


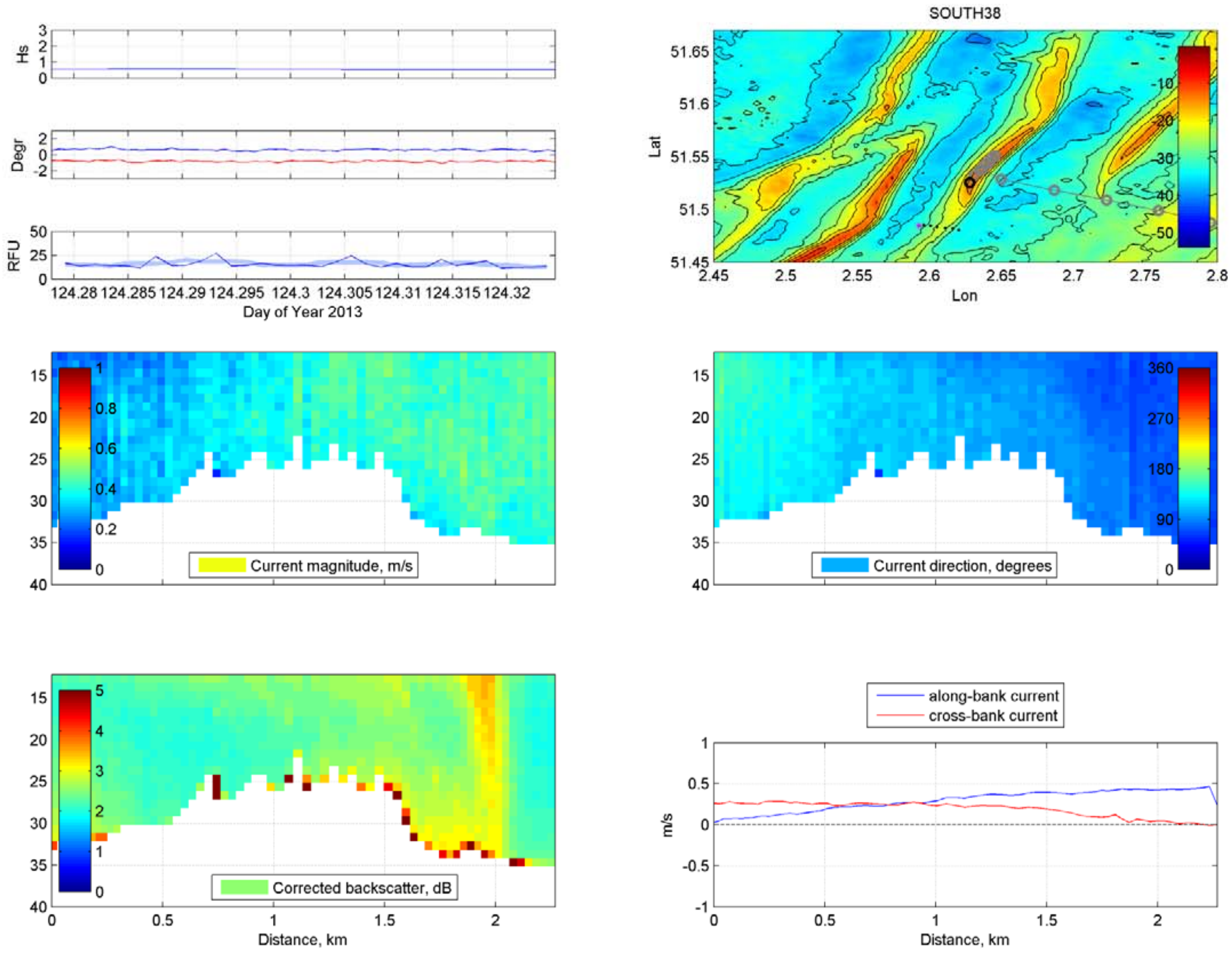
SOUTH35
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km



SOUTH36
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

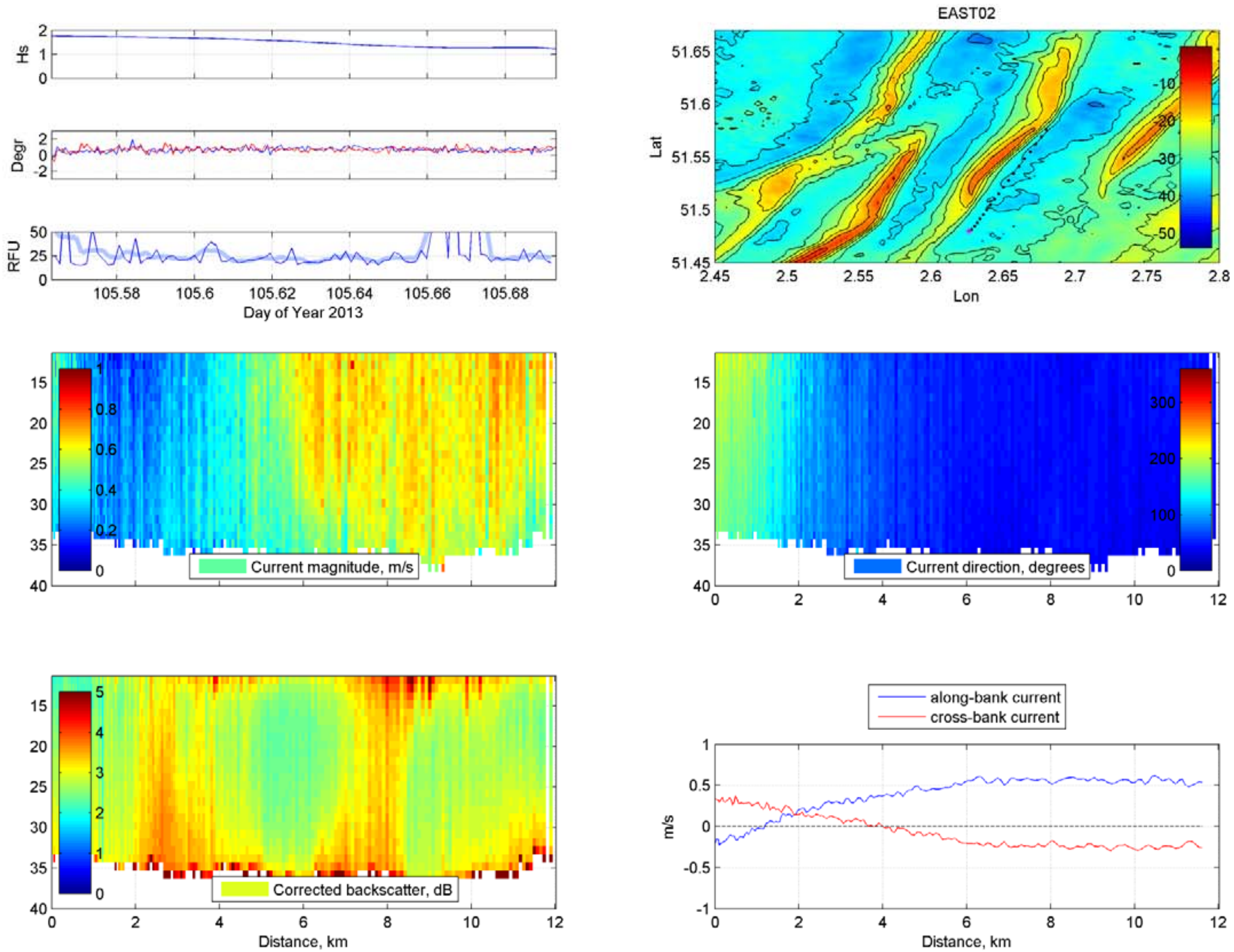
F80

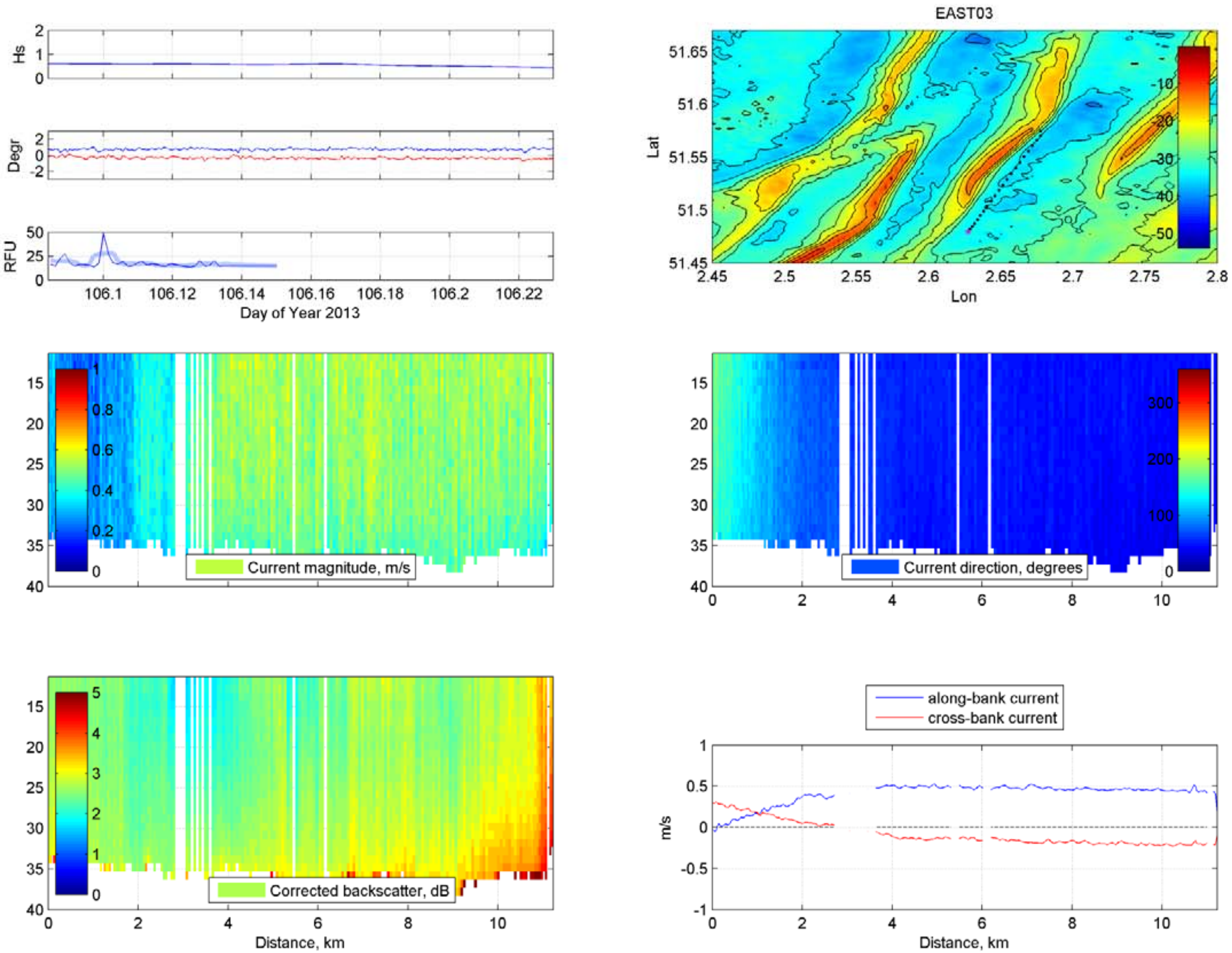

SOUTH37
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

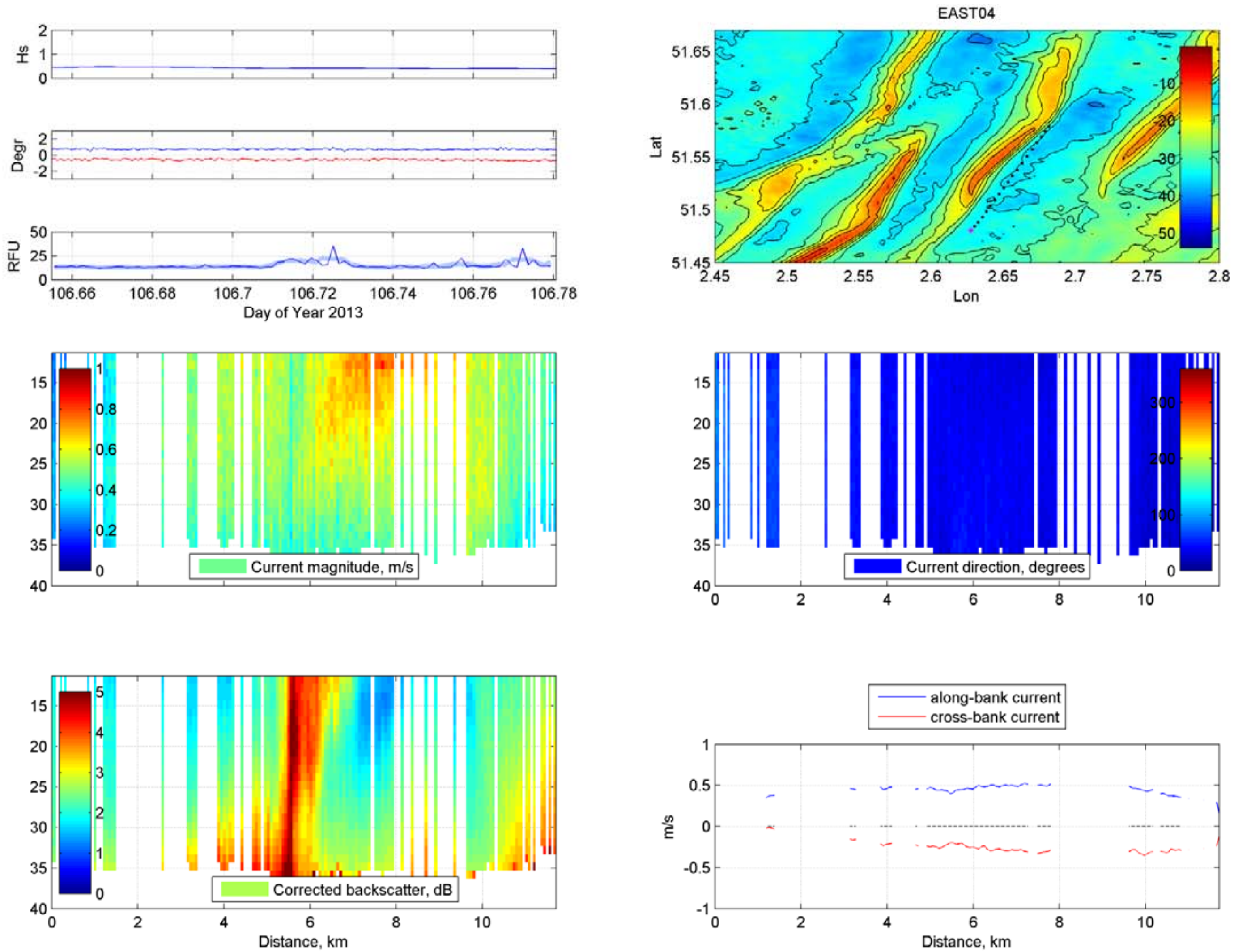


SOUTH38
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F82

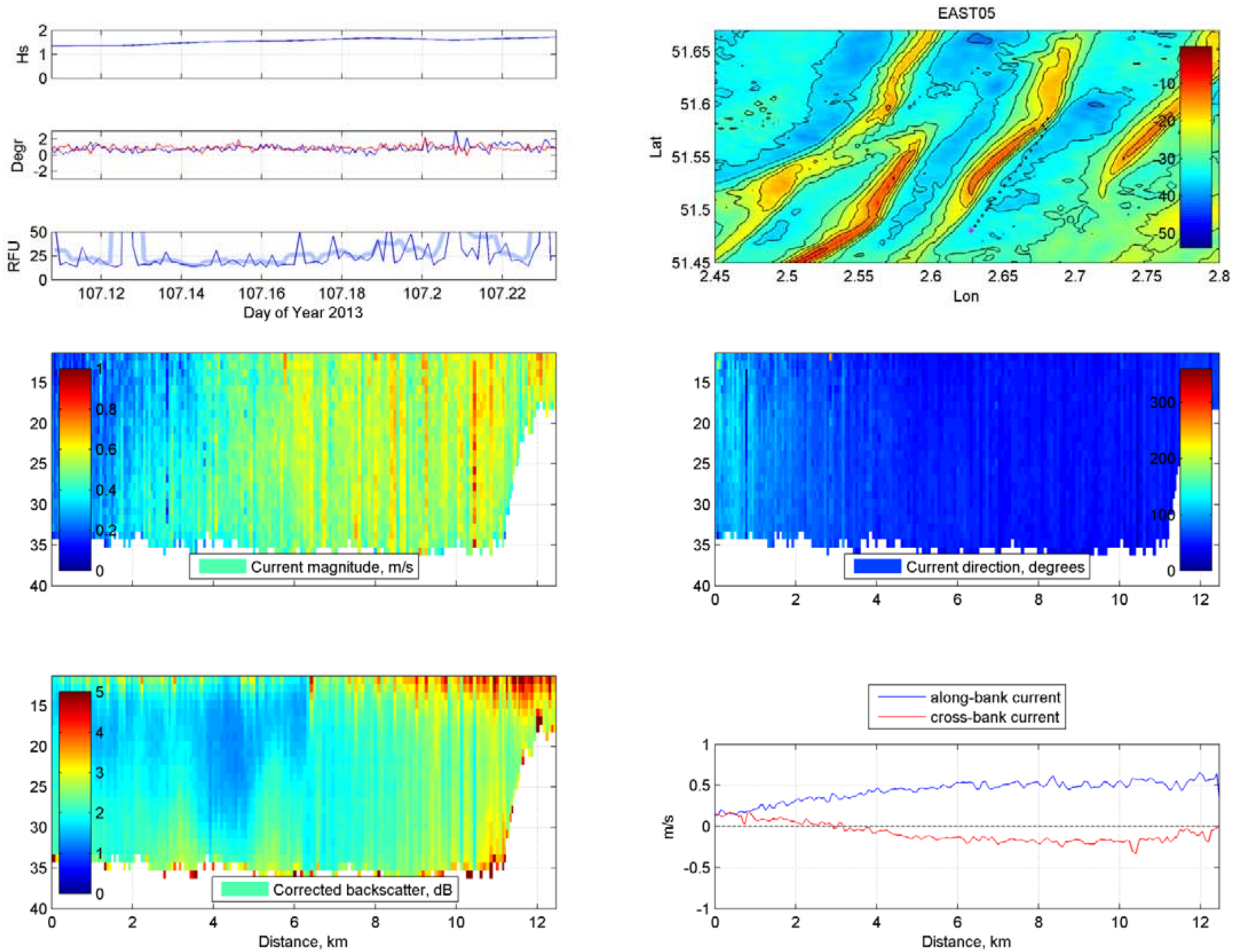

EAST02
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

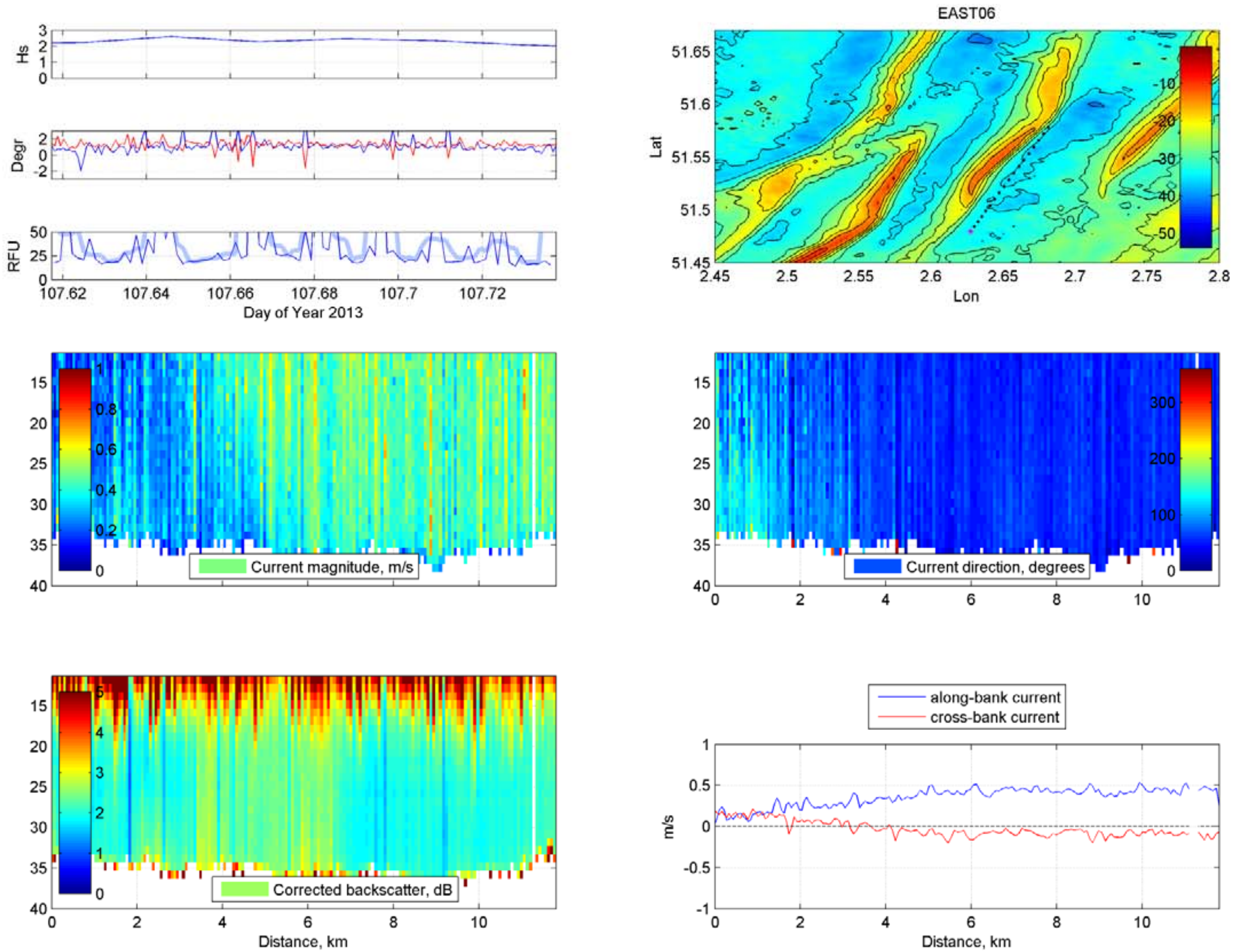

Hs
Degr
RFU
Day of Year 2013
EAST03
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

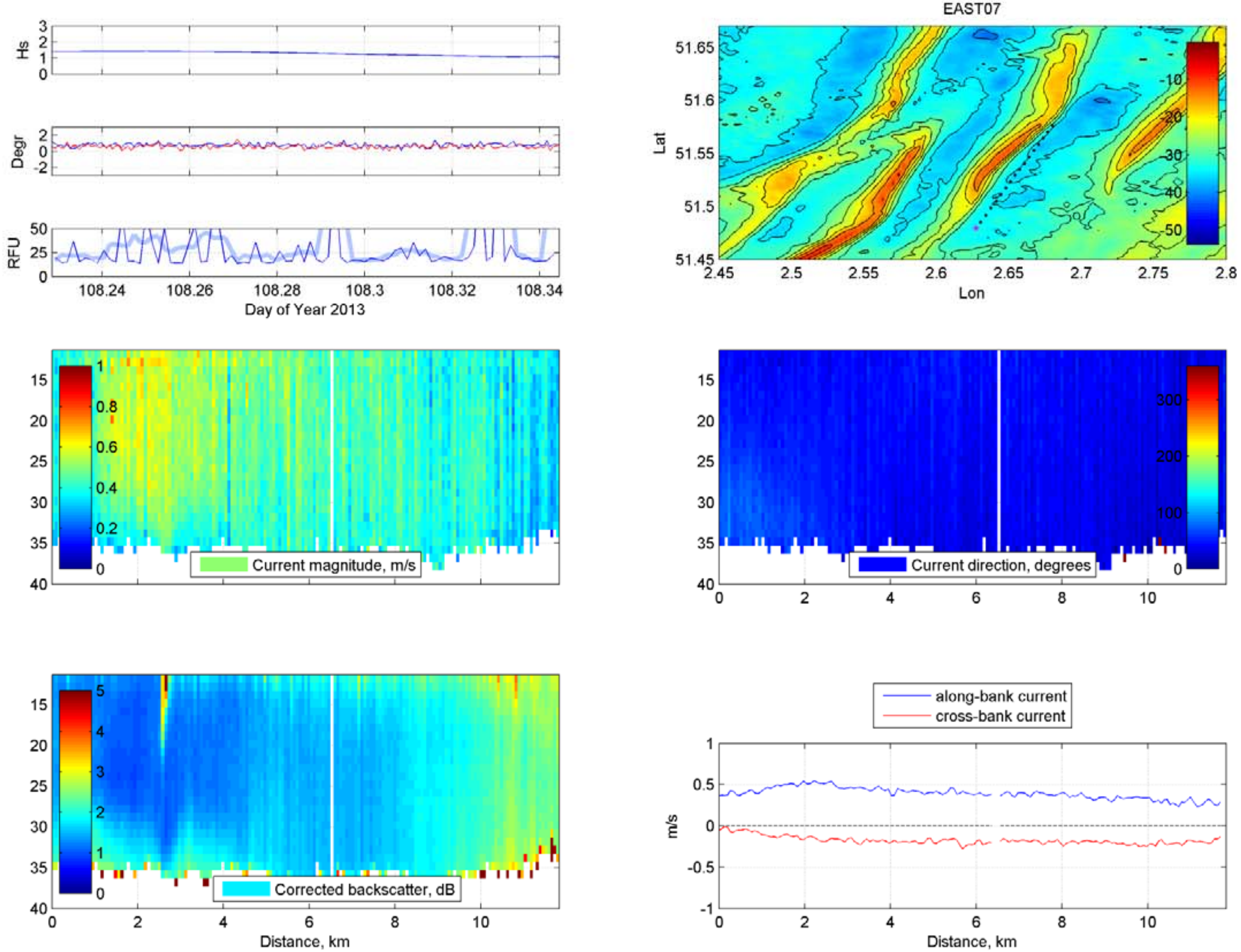


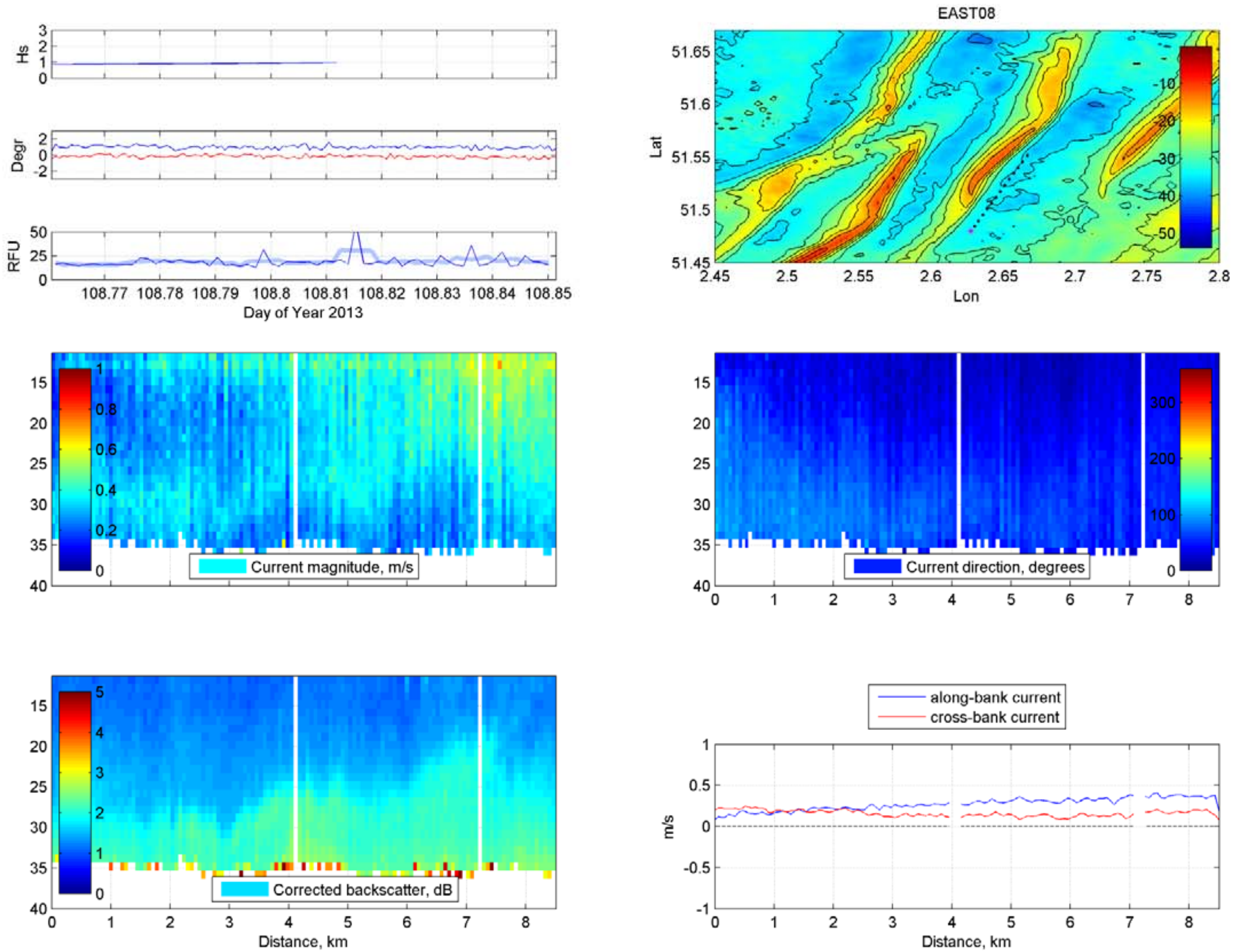
Hs
Degr
RFU
Day of Year 2013
EAST04
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s
Distance, km

F85

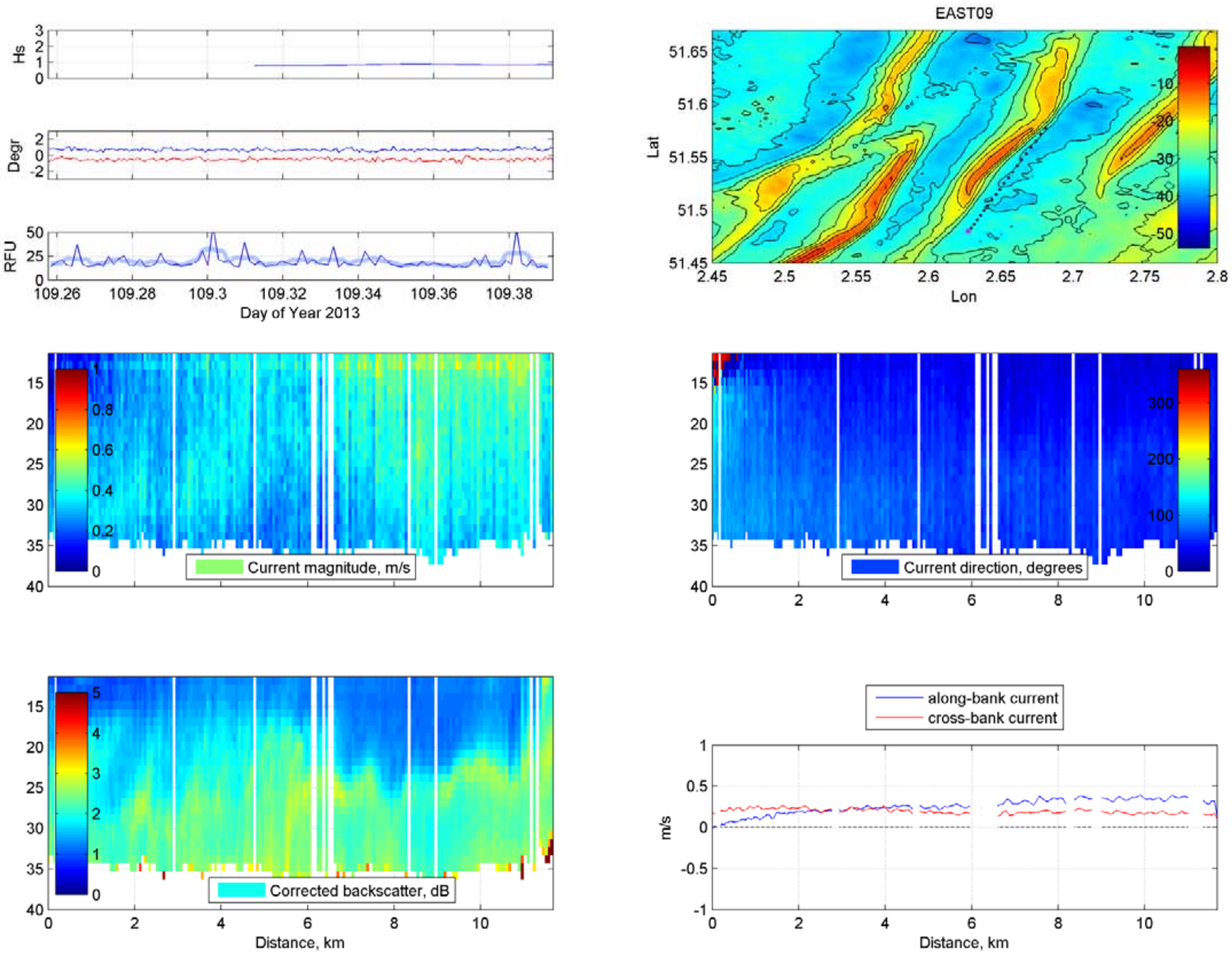

EAST05
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km


EAST06
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km


EAST07
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

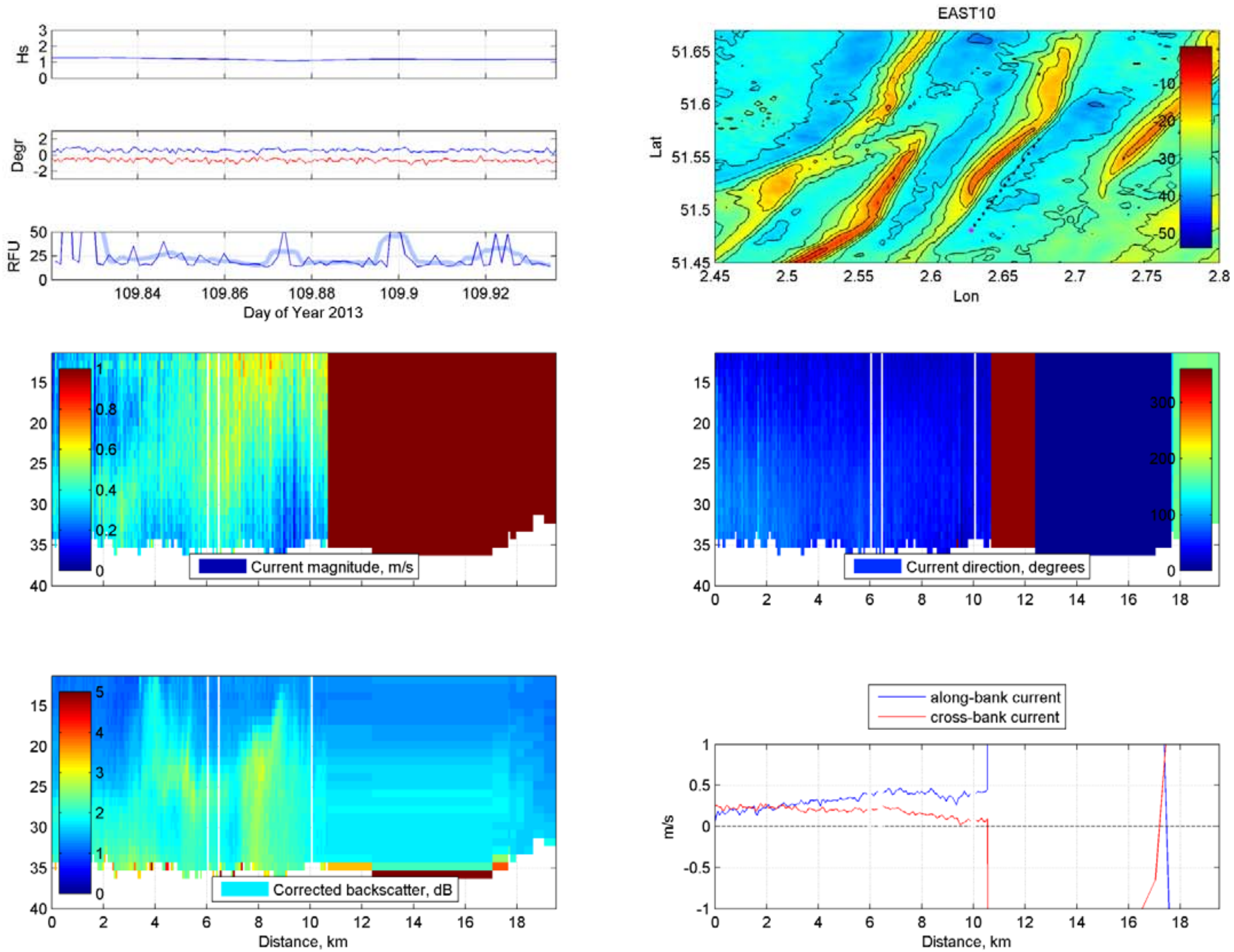


EAST08
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

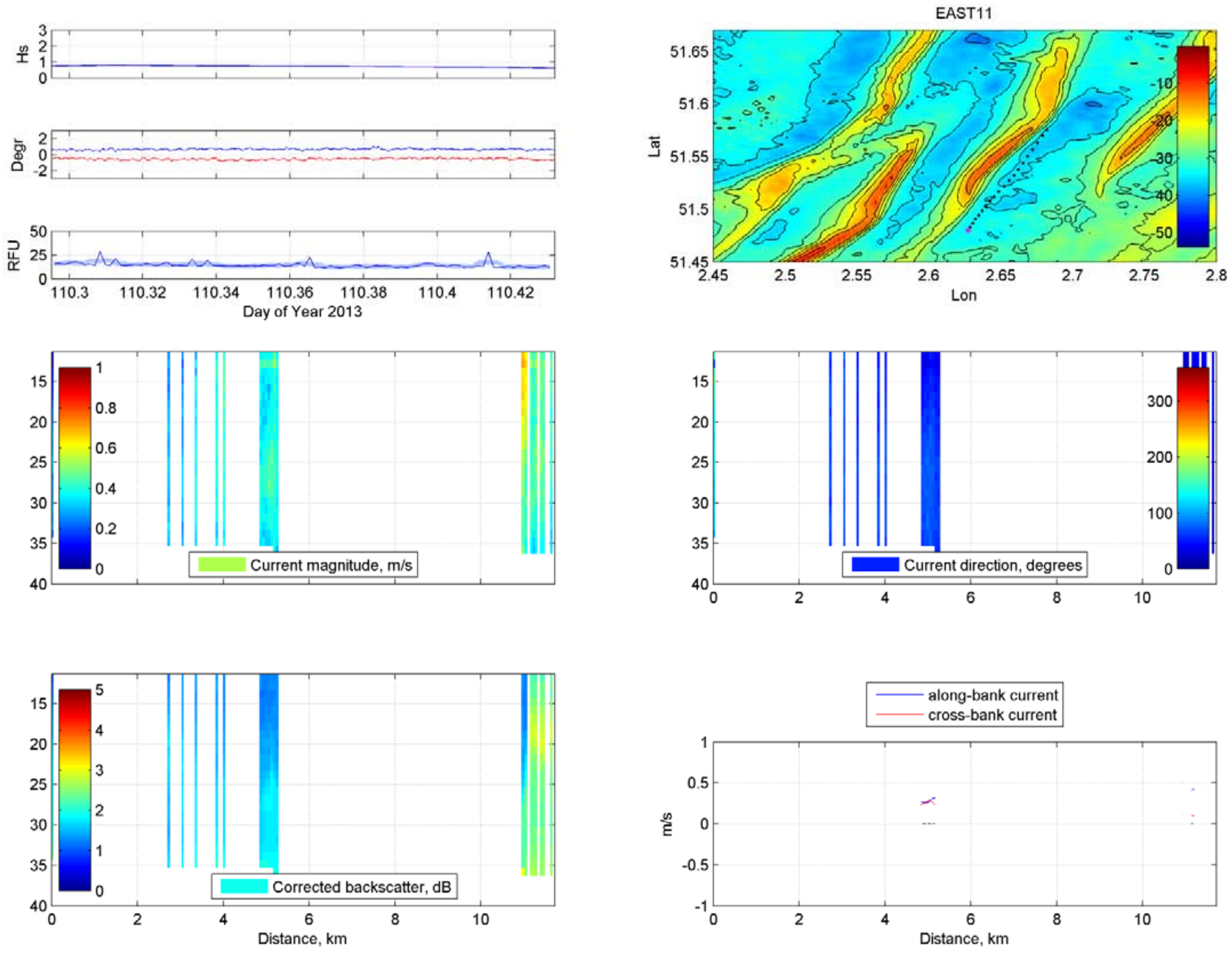


EAST09
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

F90

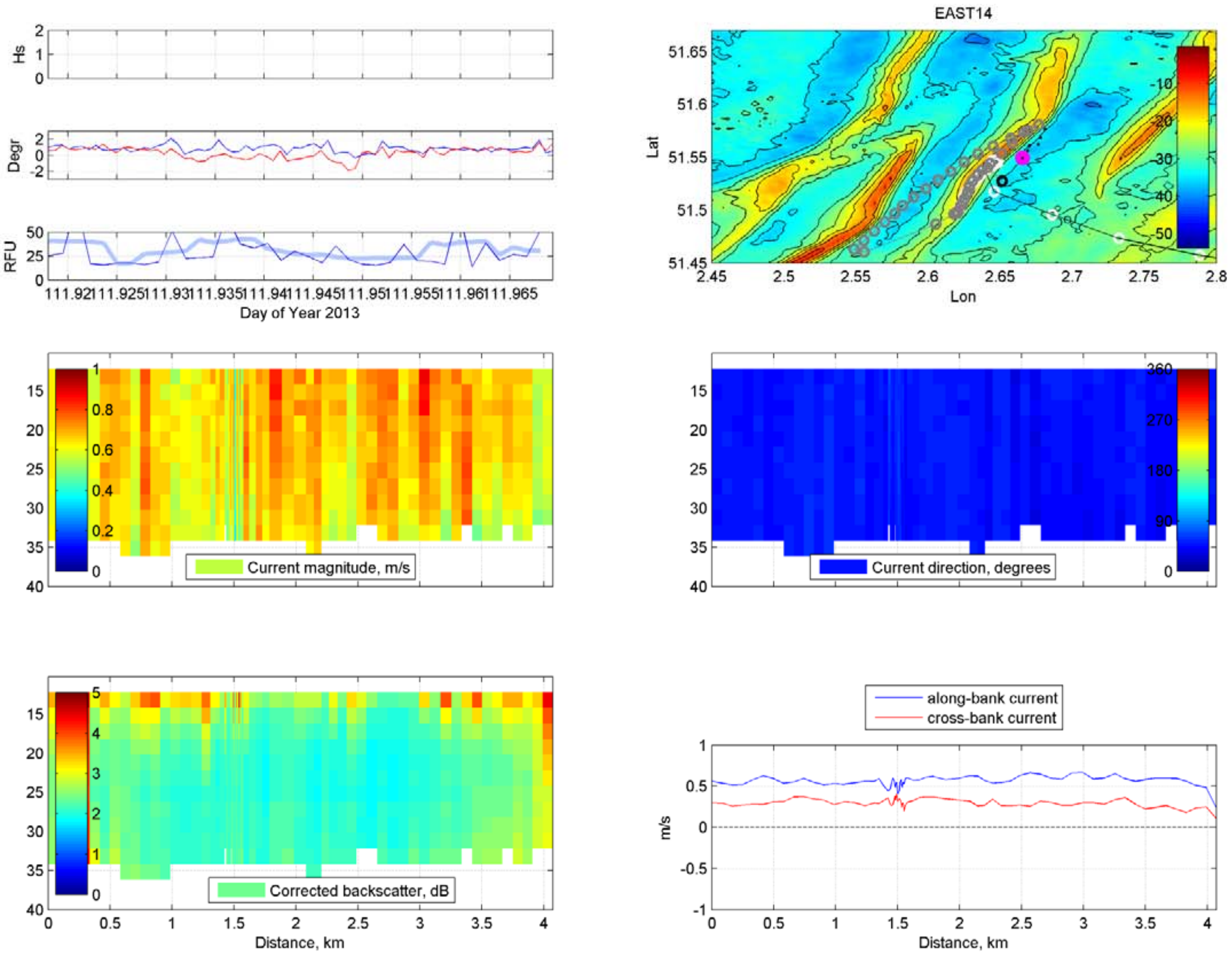

EAST10
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

F91



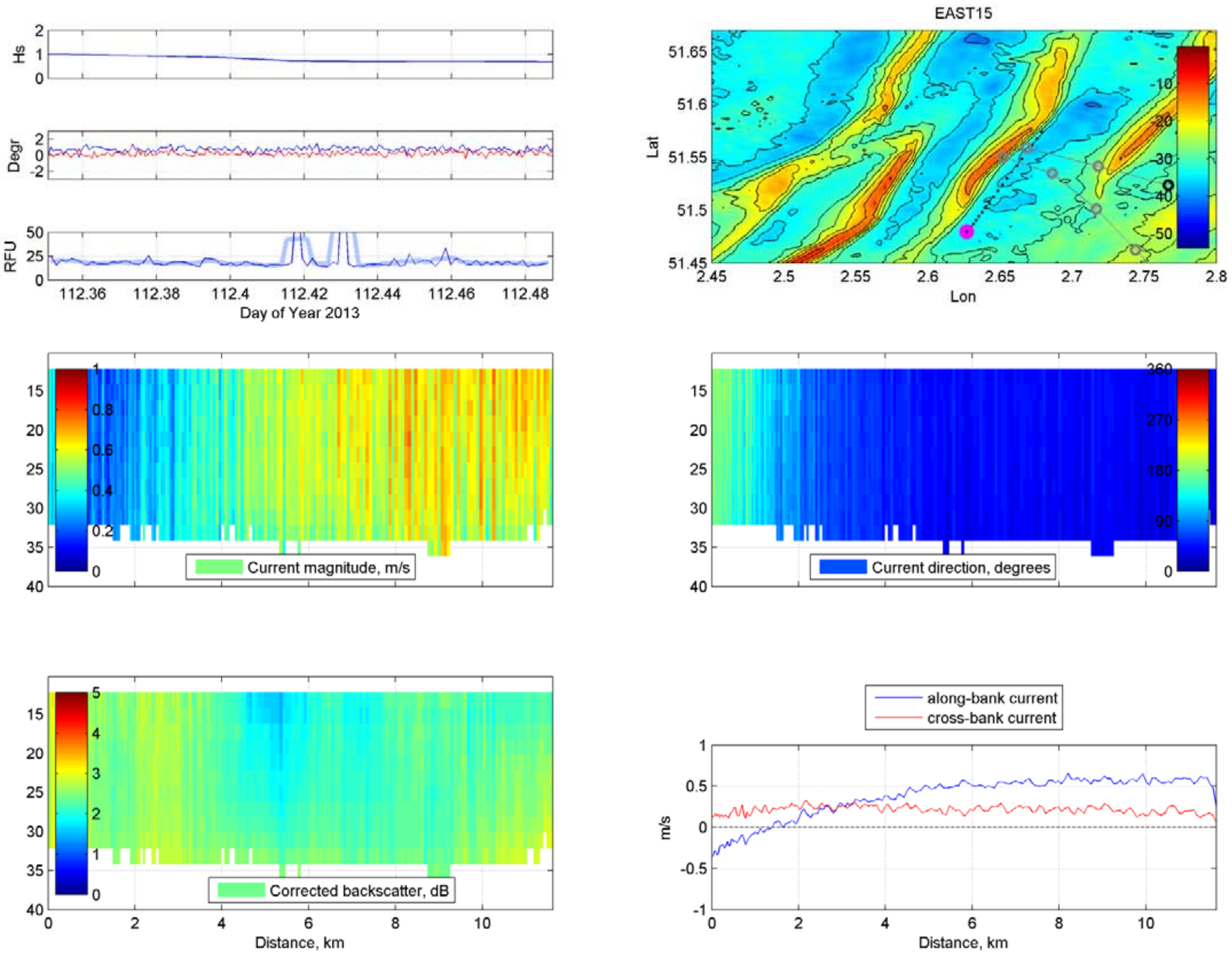
EAST11
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F92

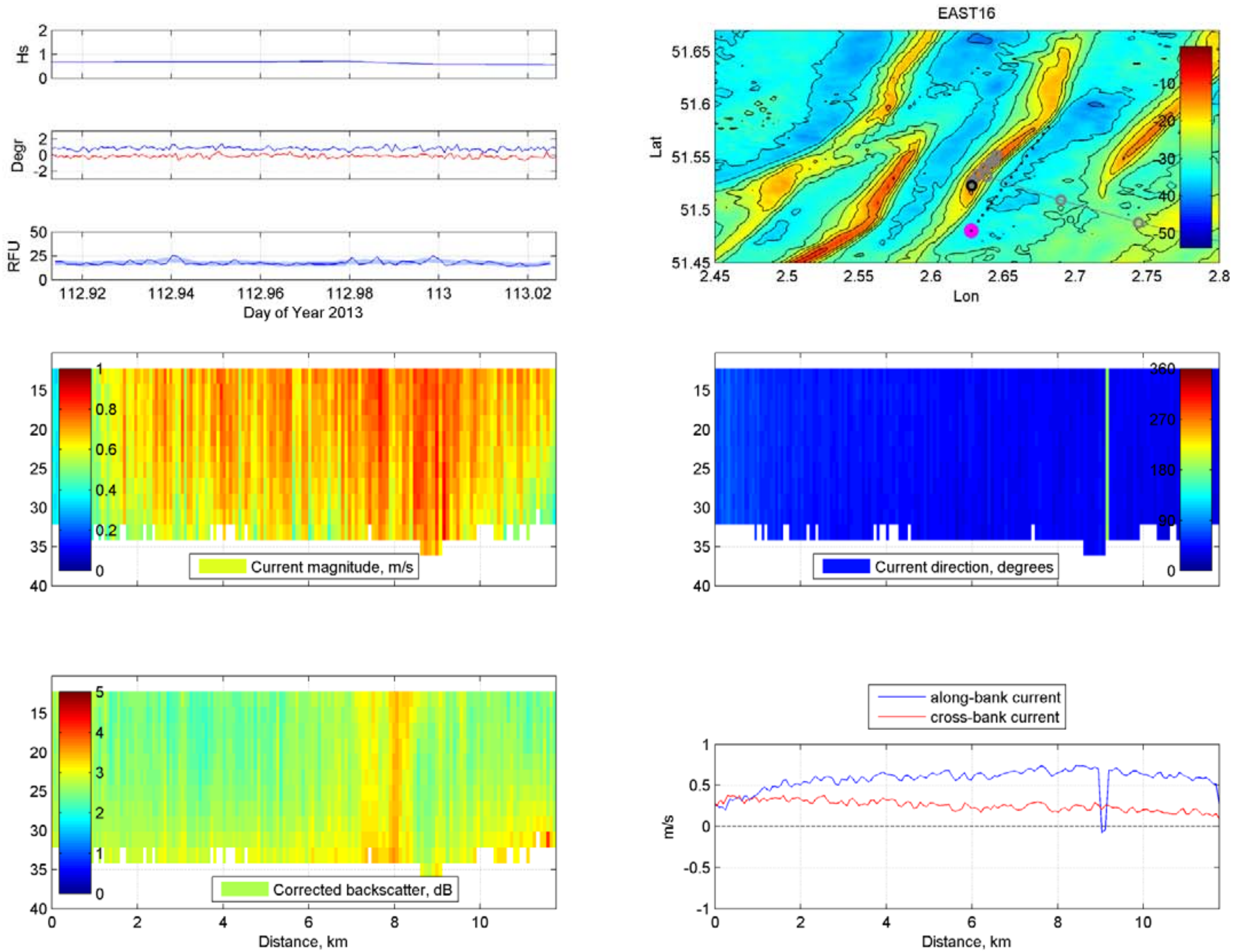


EAST14
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

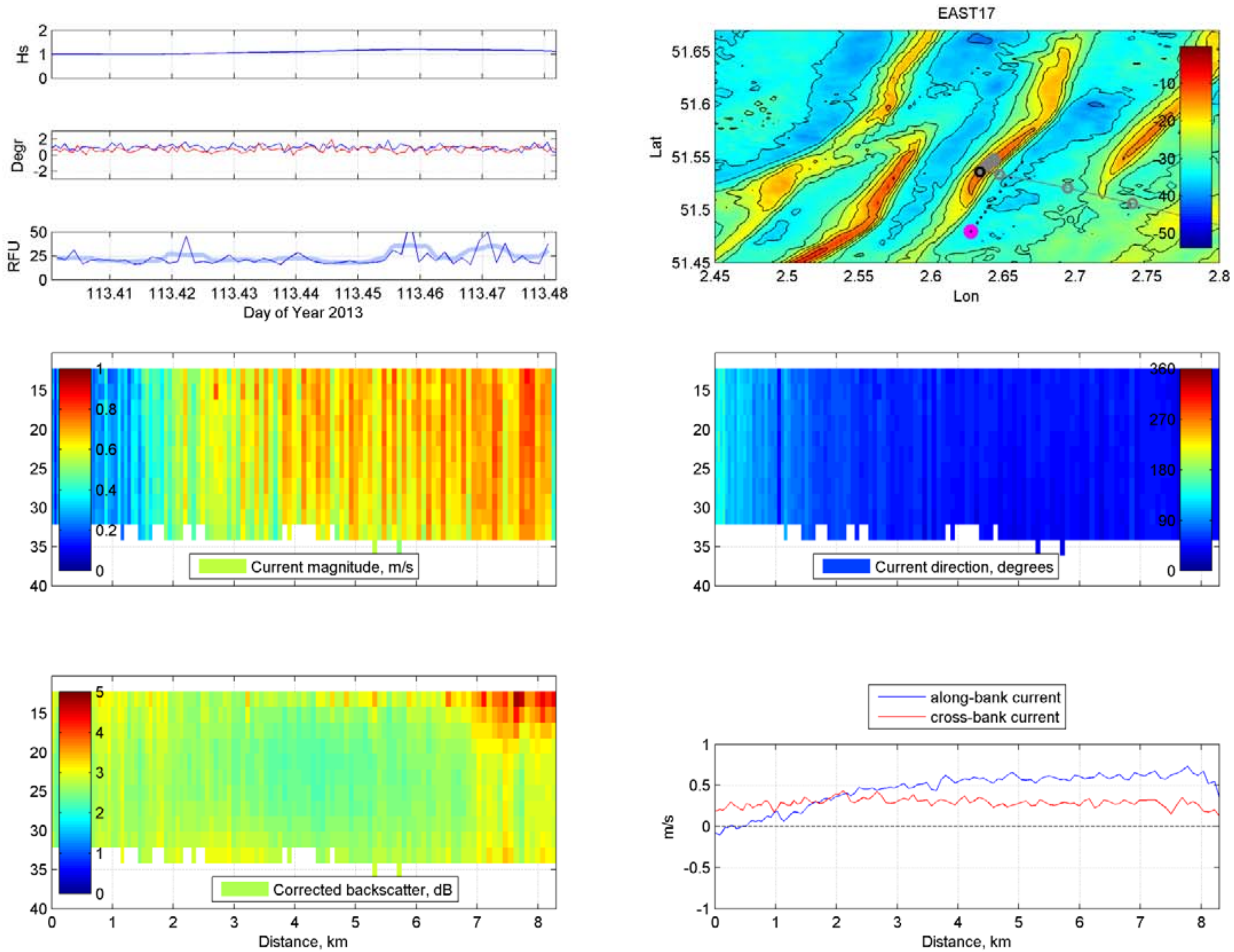
F93



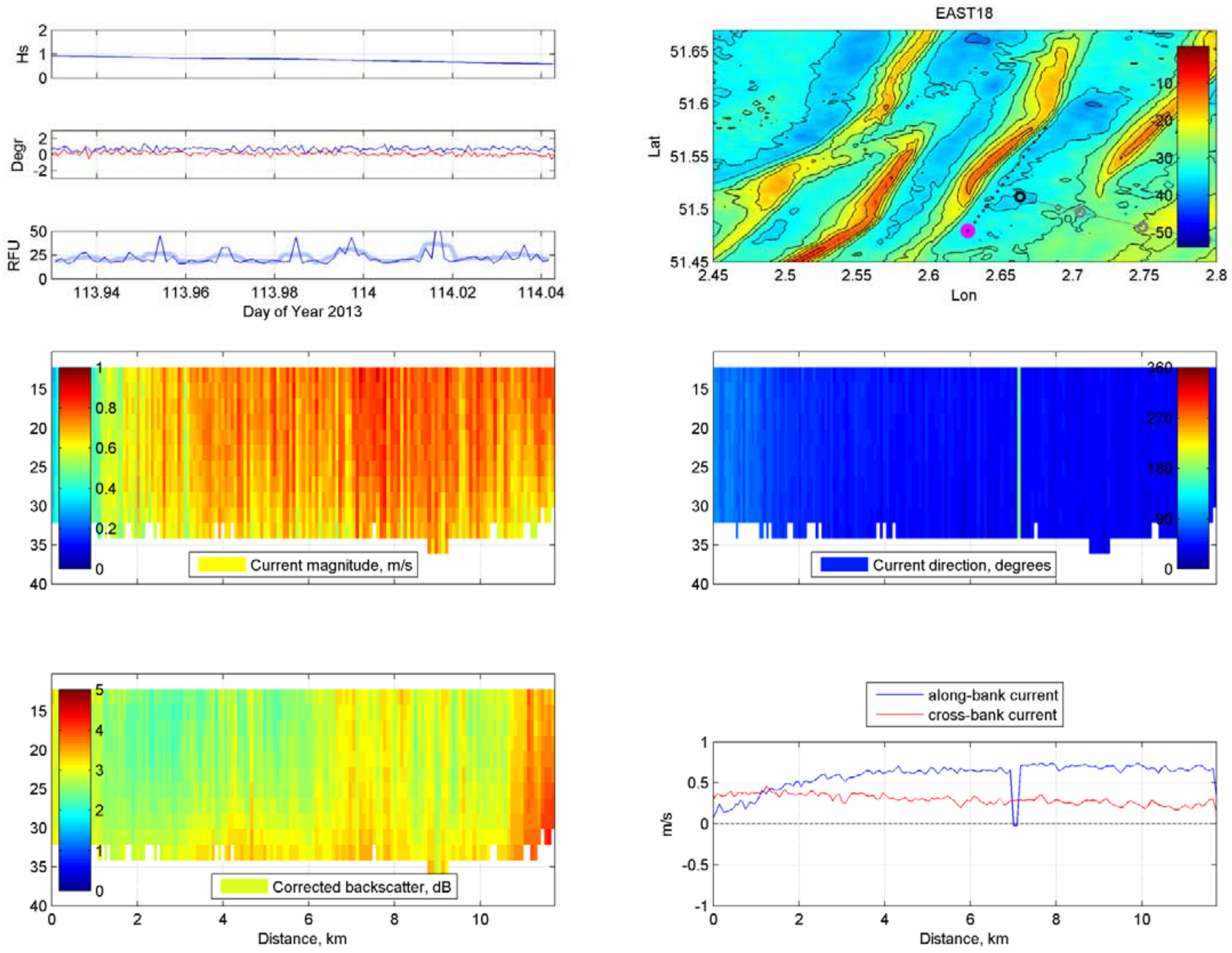
Hs
Degr
RFU
Day of Year 2013
EAST15
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

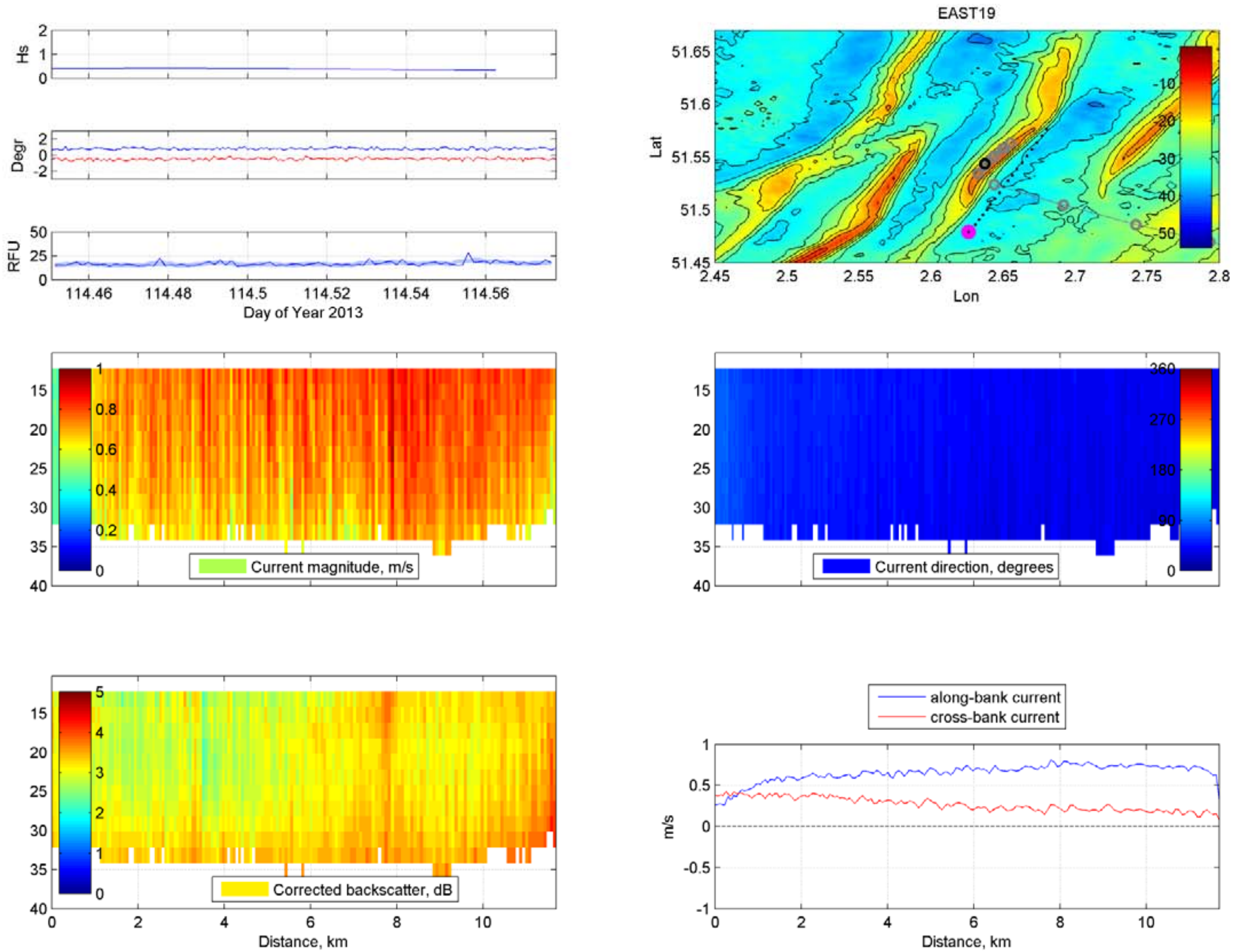


EAST16
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km



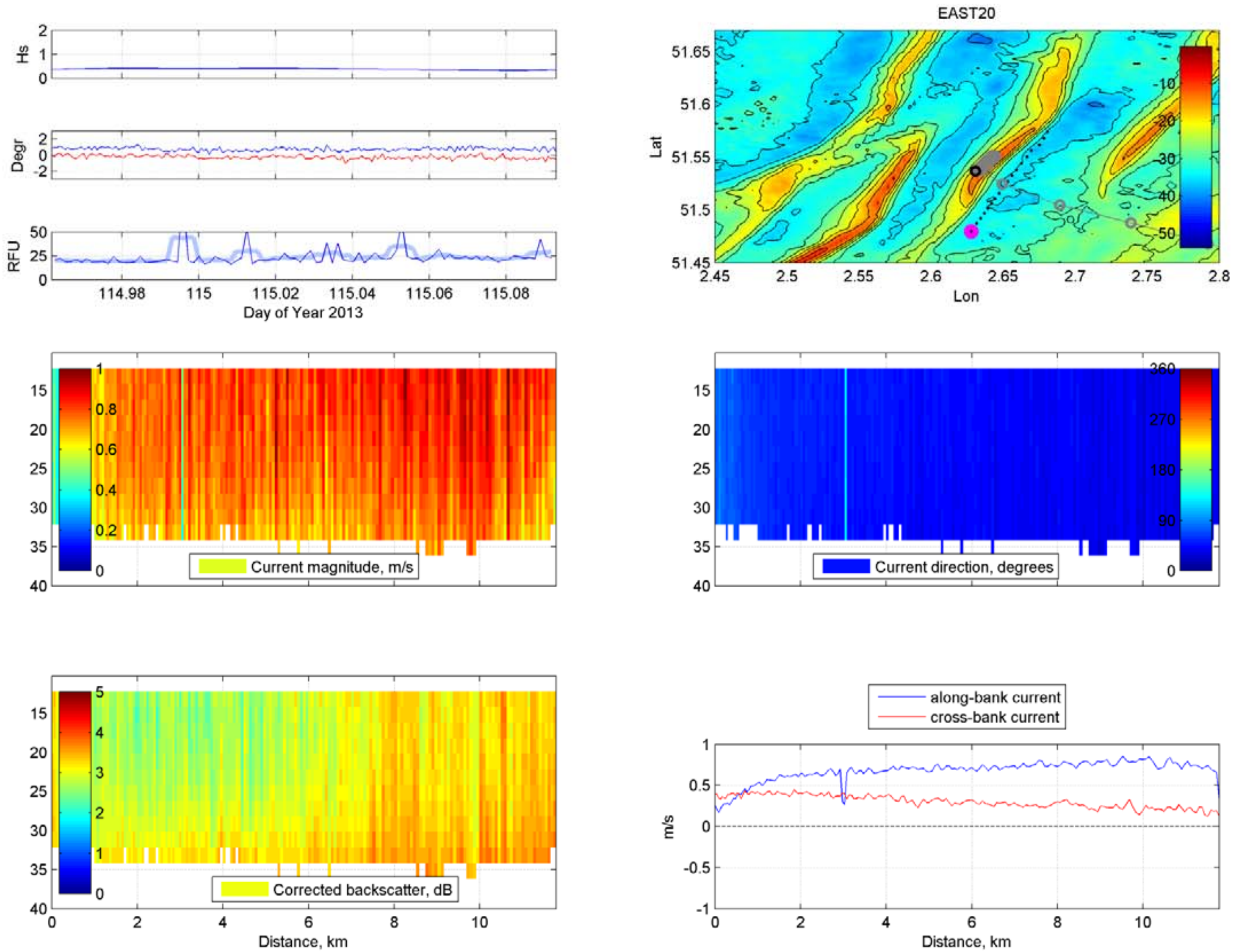
EAST17
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

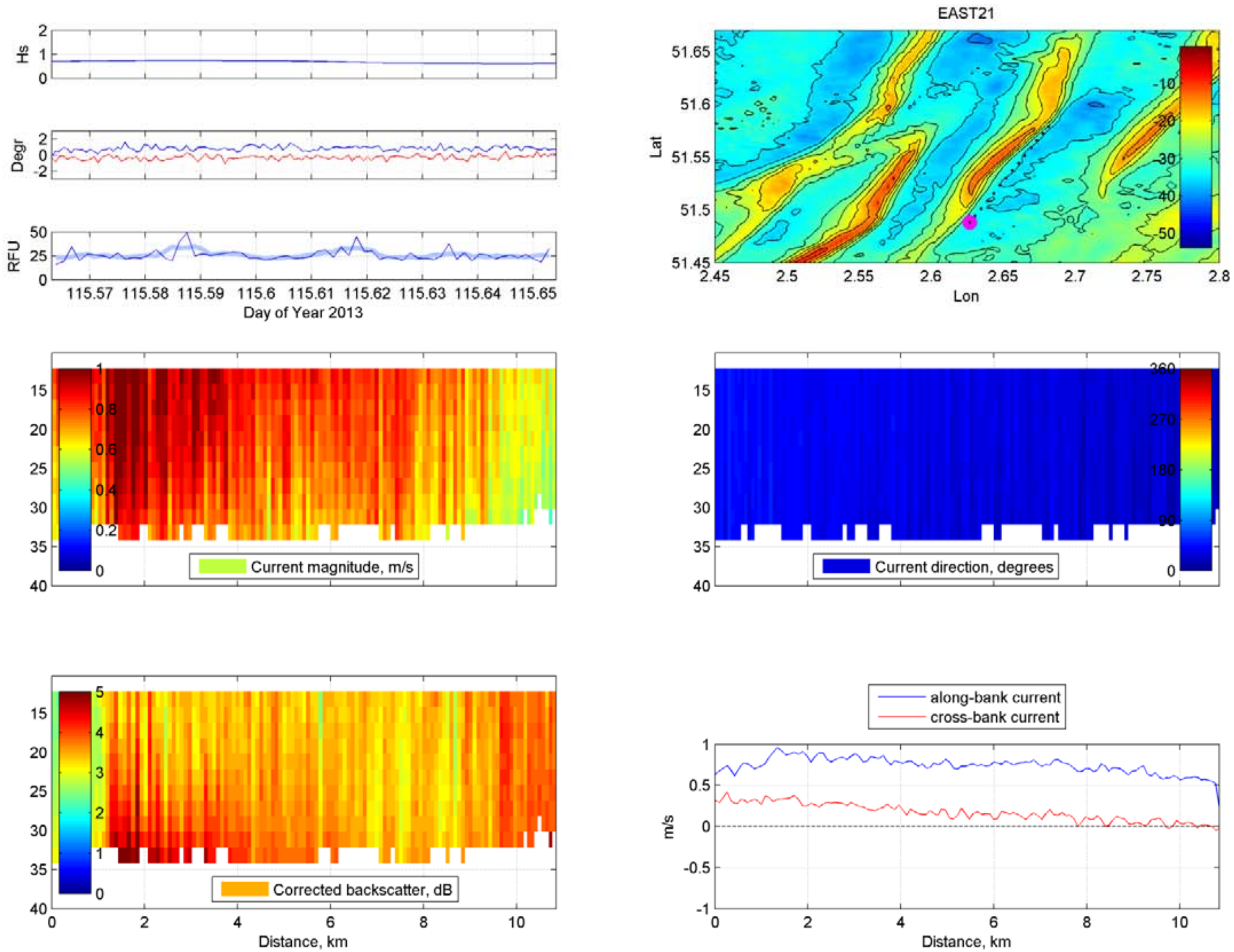

EAST18
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km



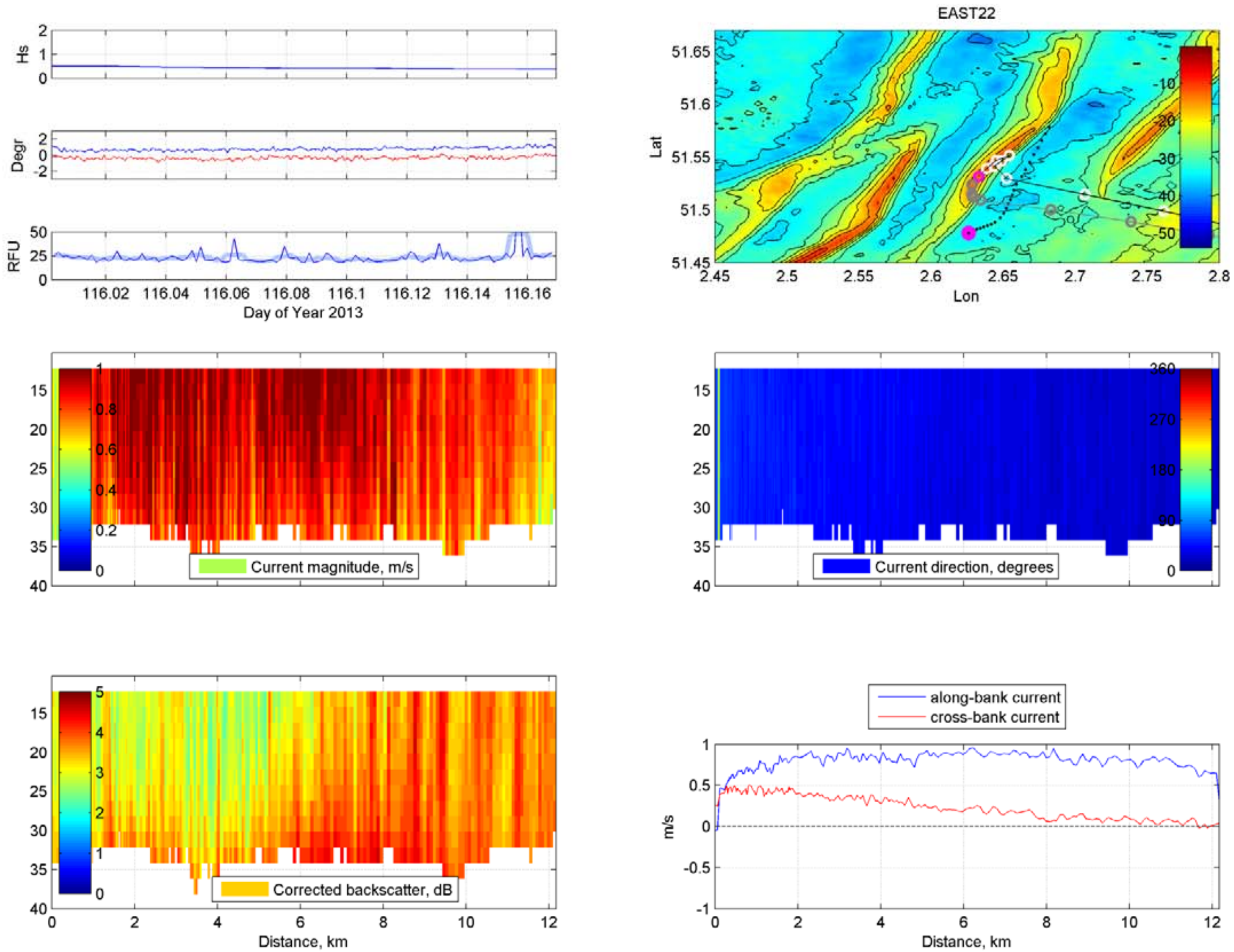
EAST19
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F98

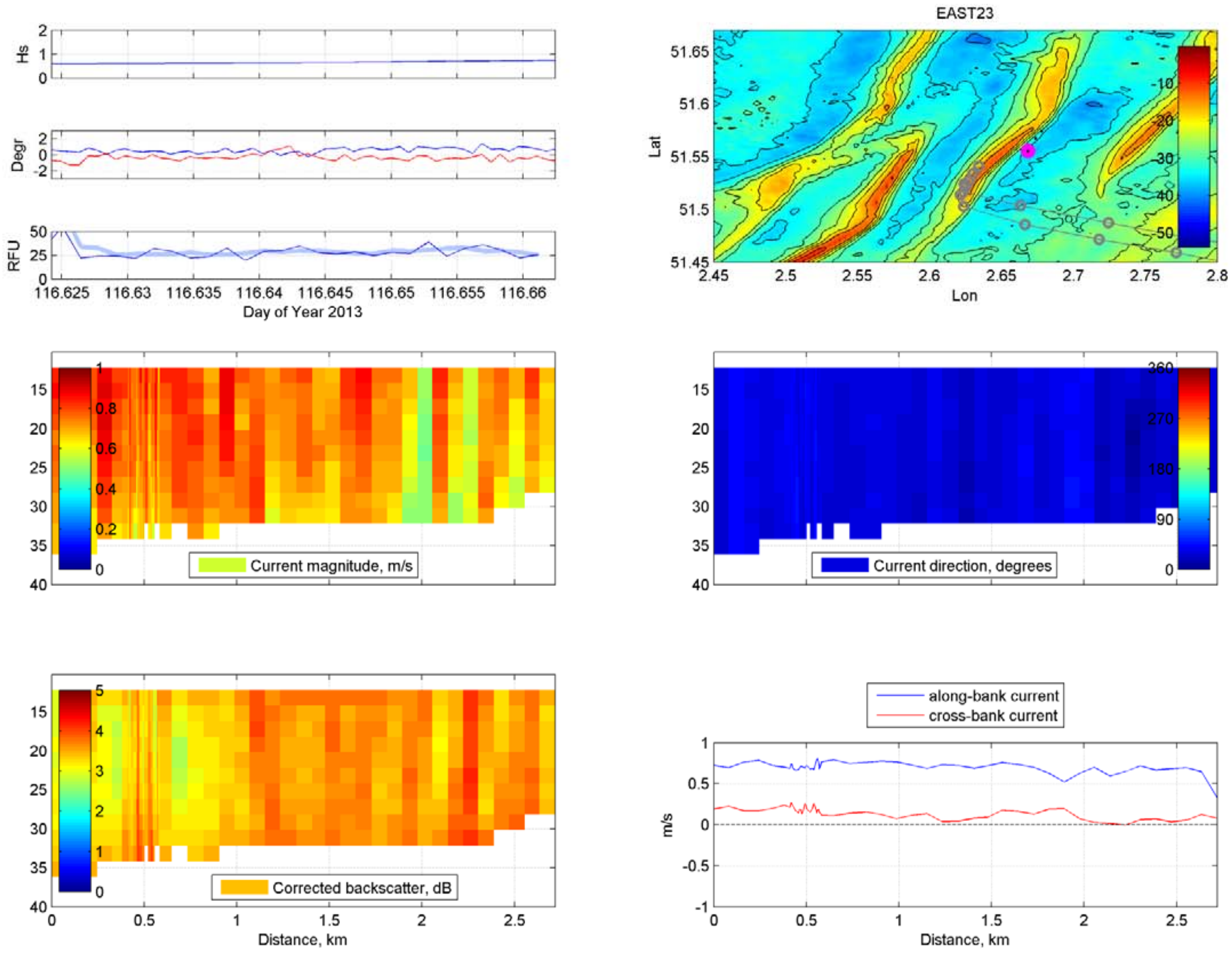

EAST20
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km



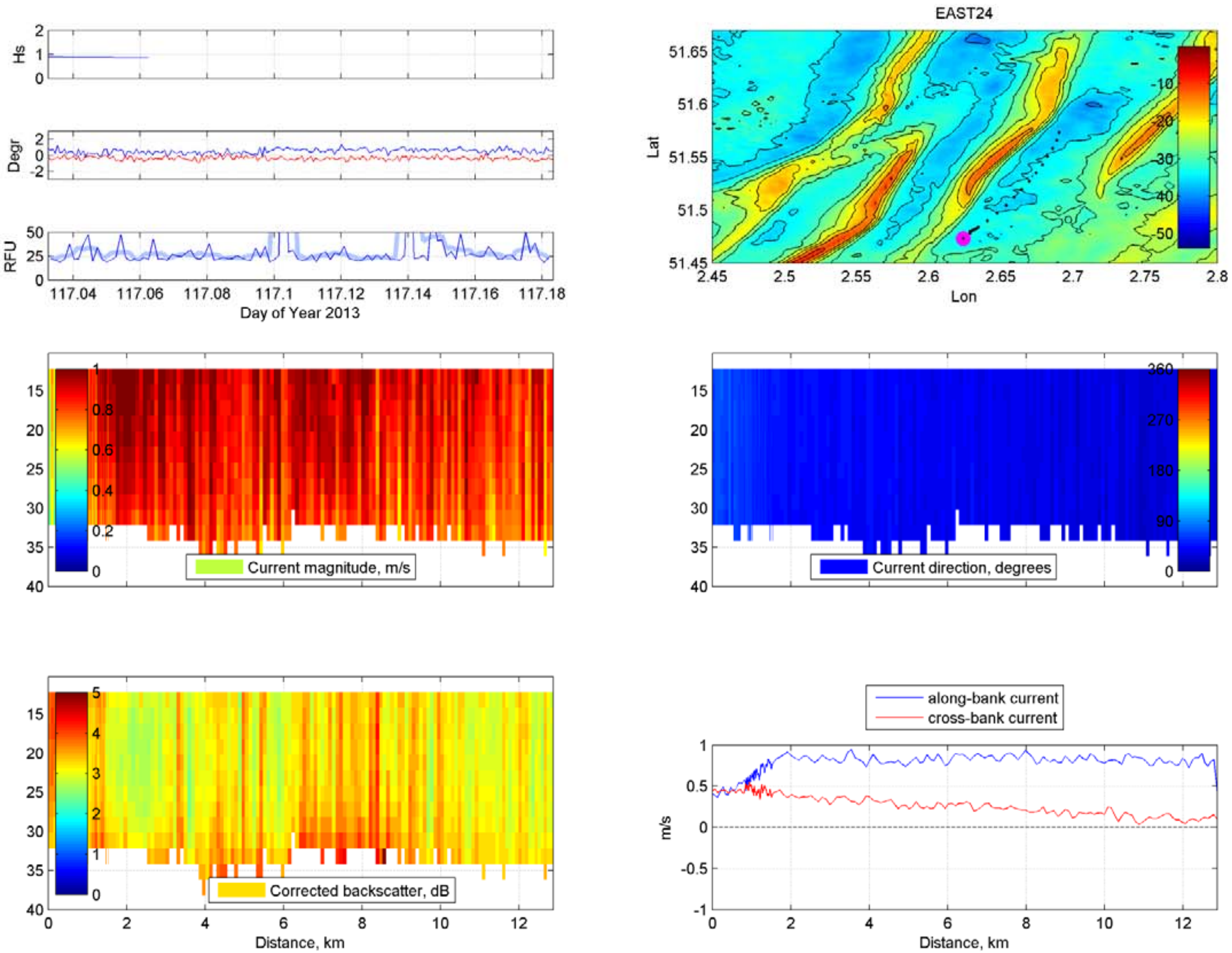
EAST21
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km


EAST22
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

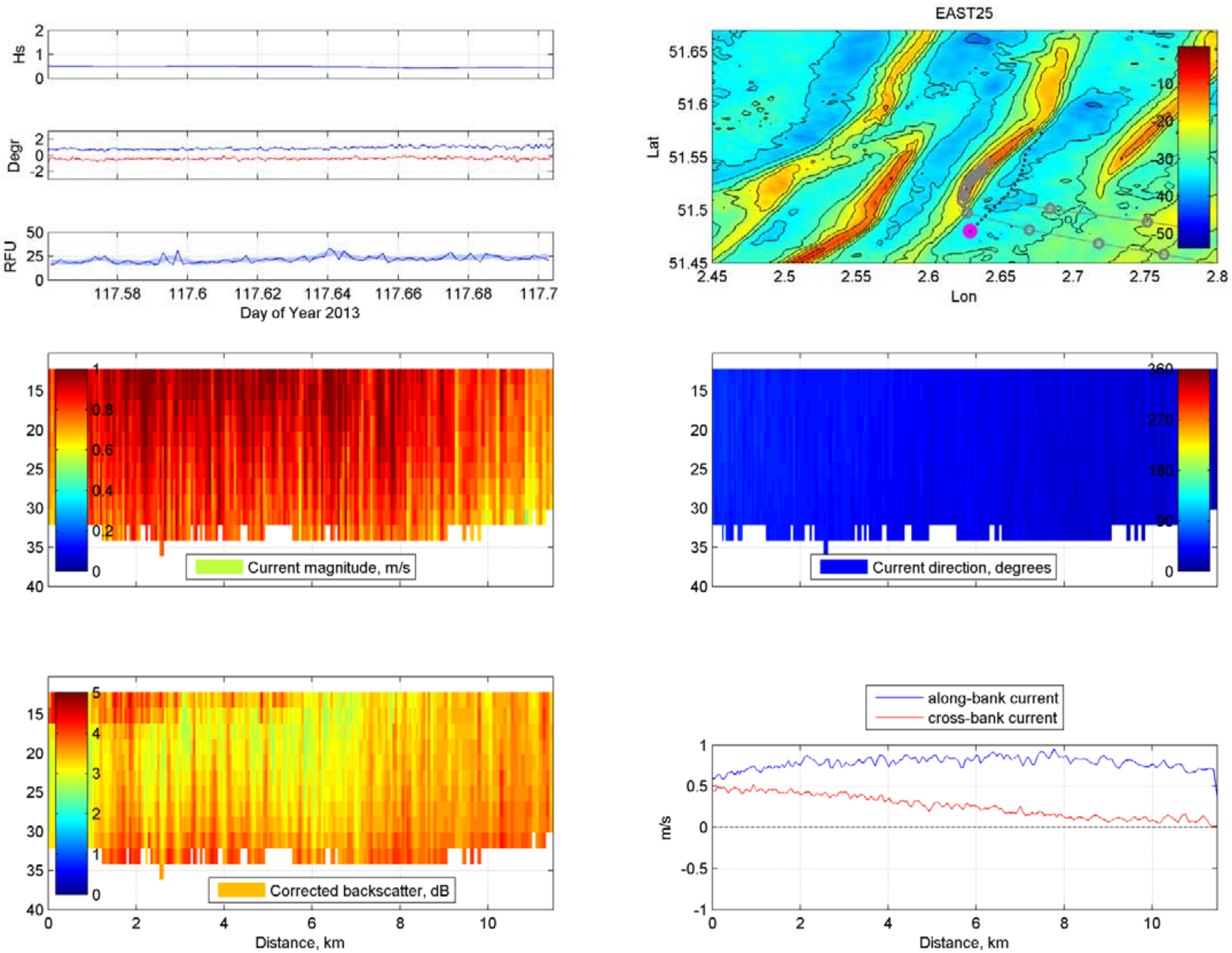
F101



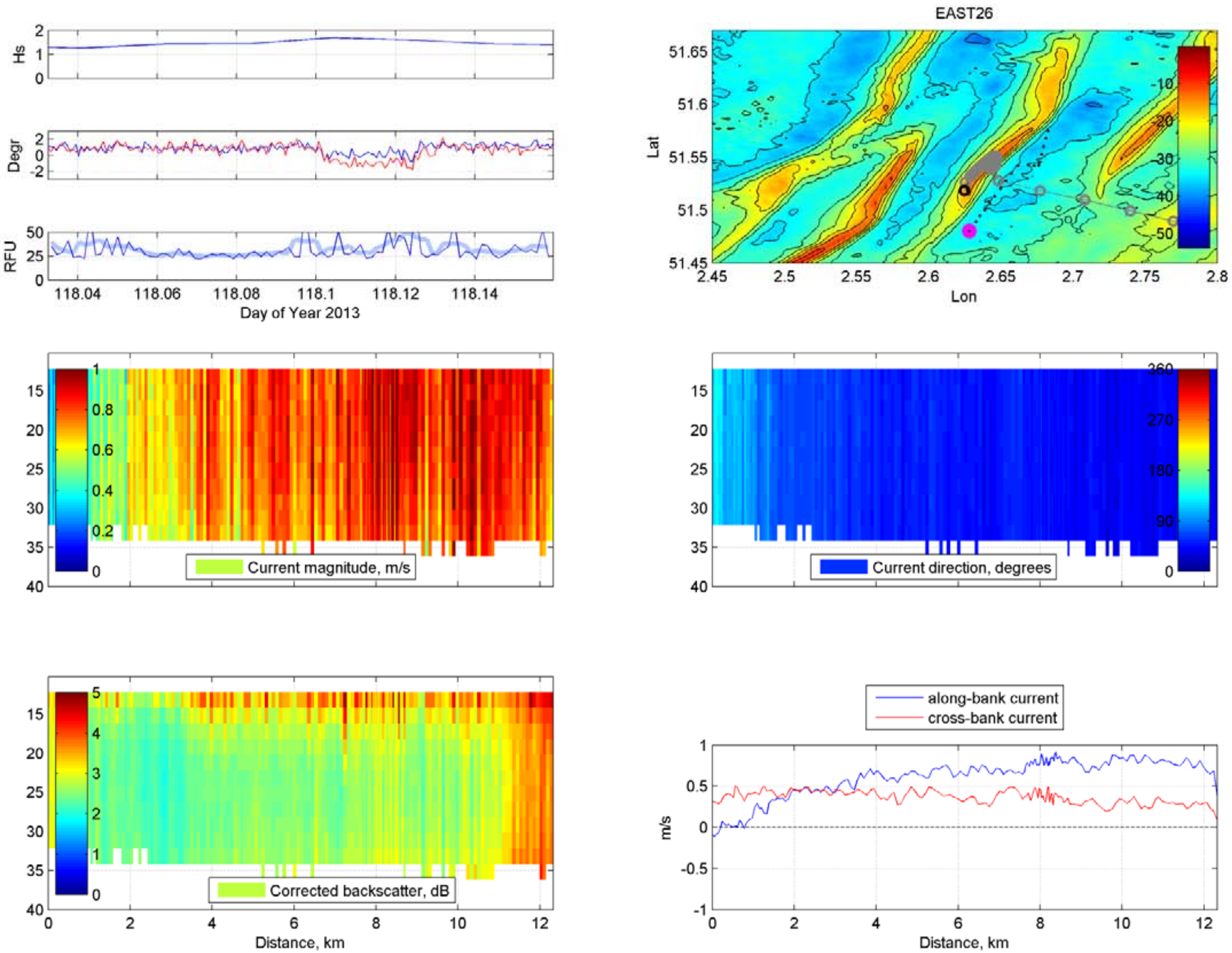
EAST23
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km



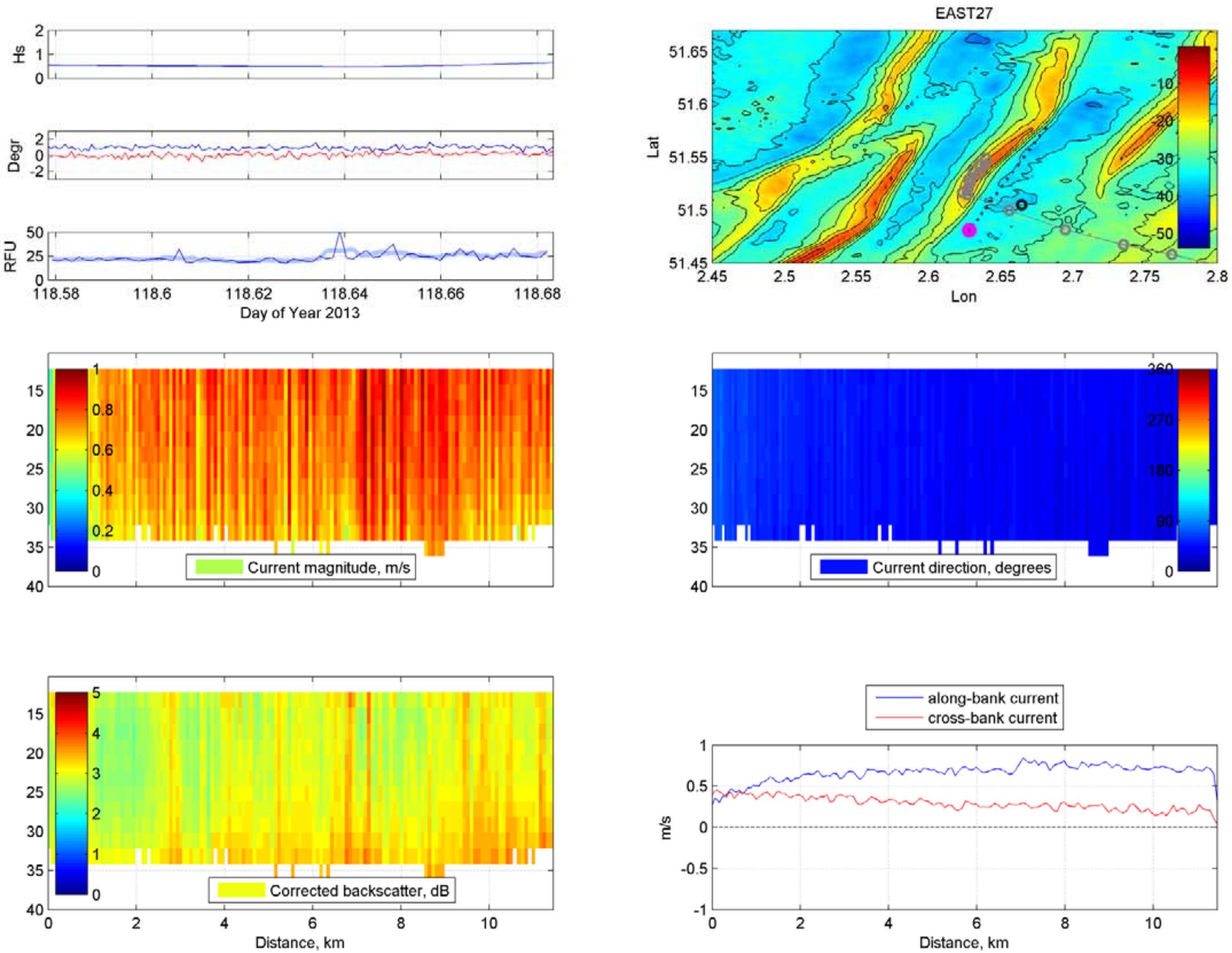
Hs
Degr
RFU
Day of Year 2013
EAST24
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s
Distance, km

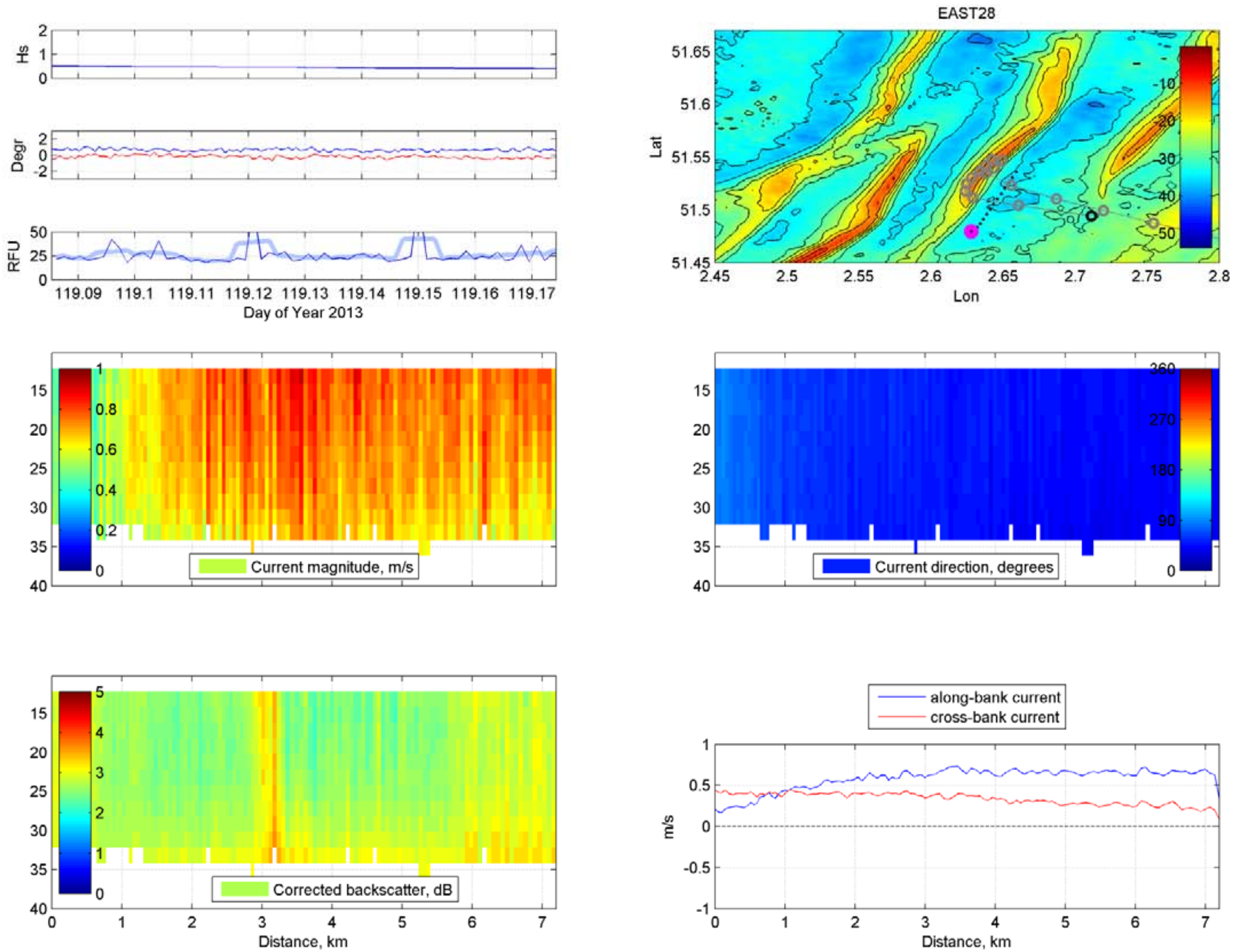

EAST25
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F104

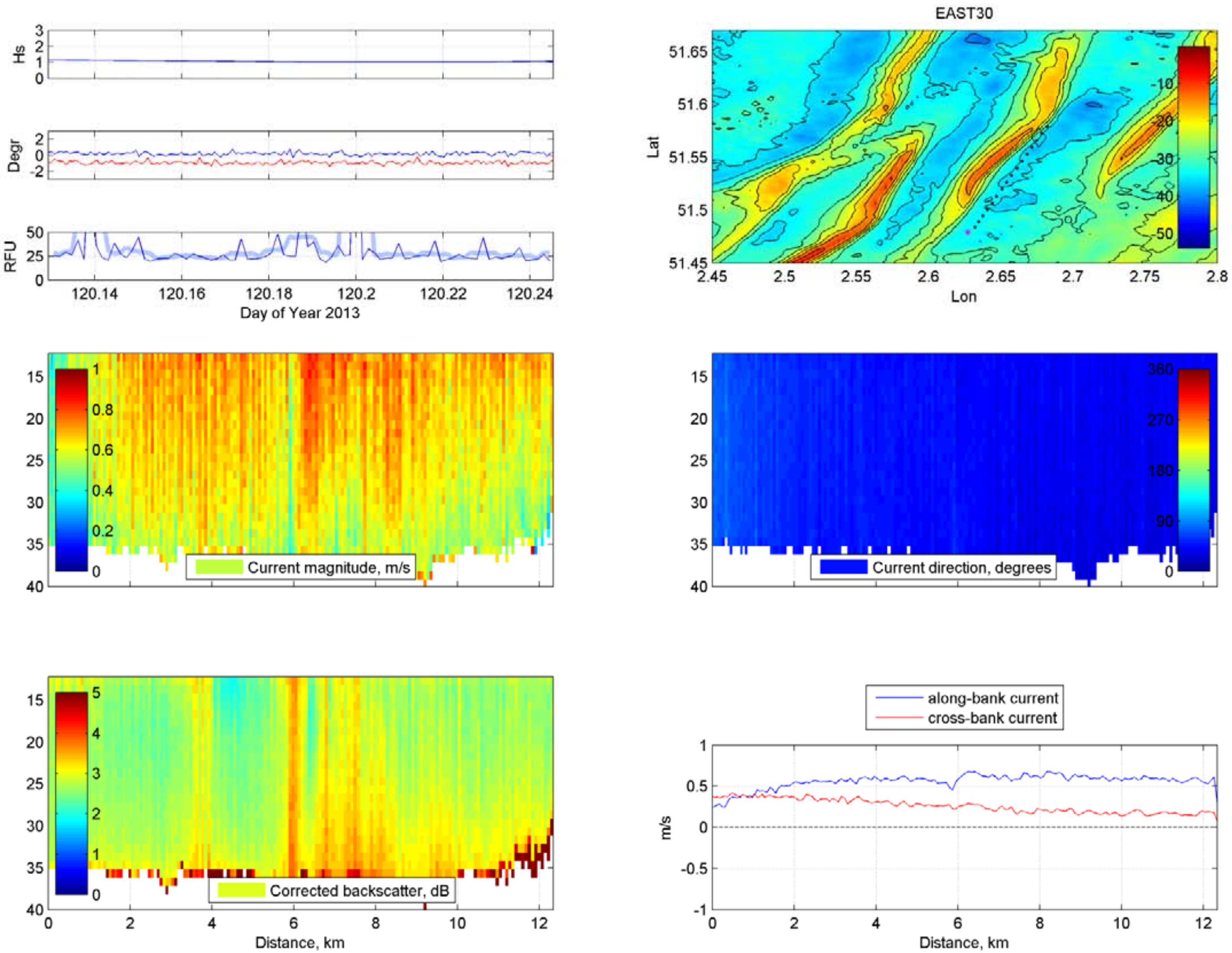


EAST26
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km


EAST27
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

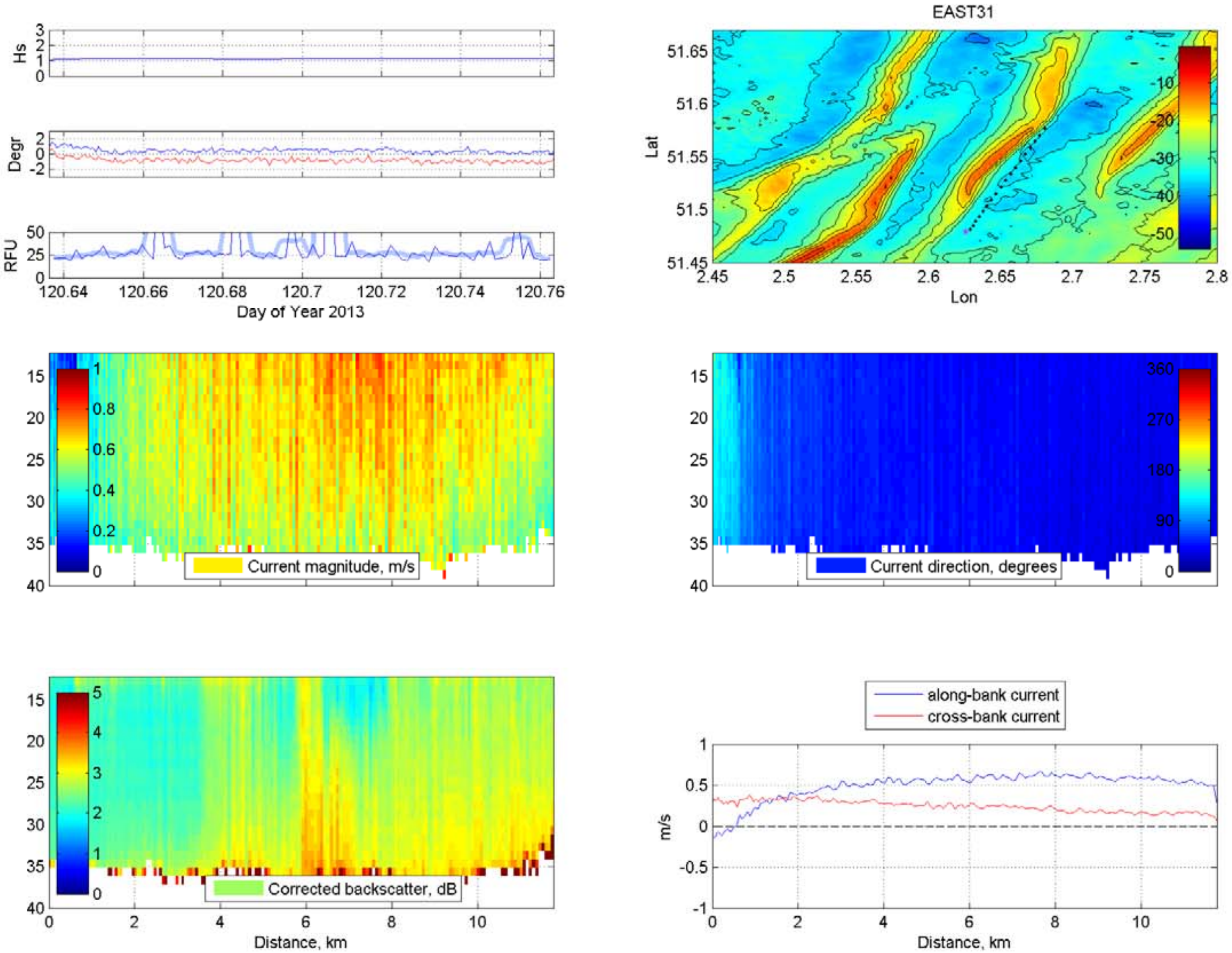


EAST28
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

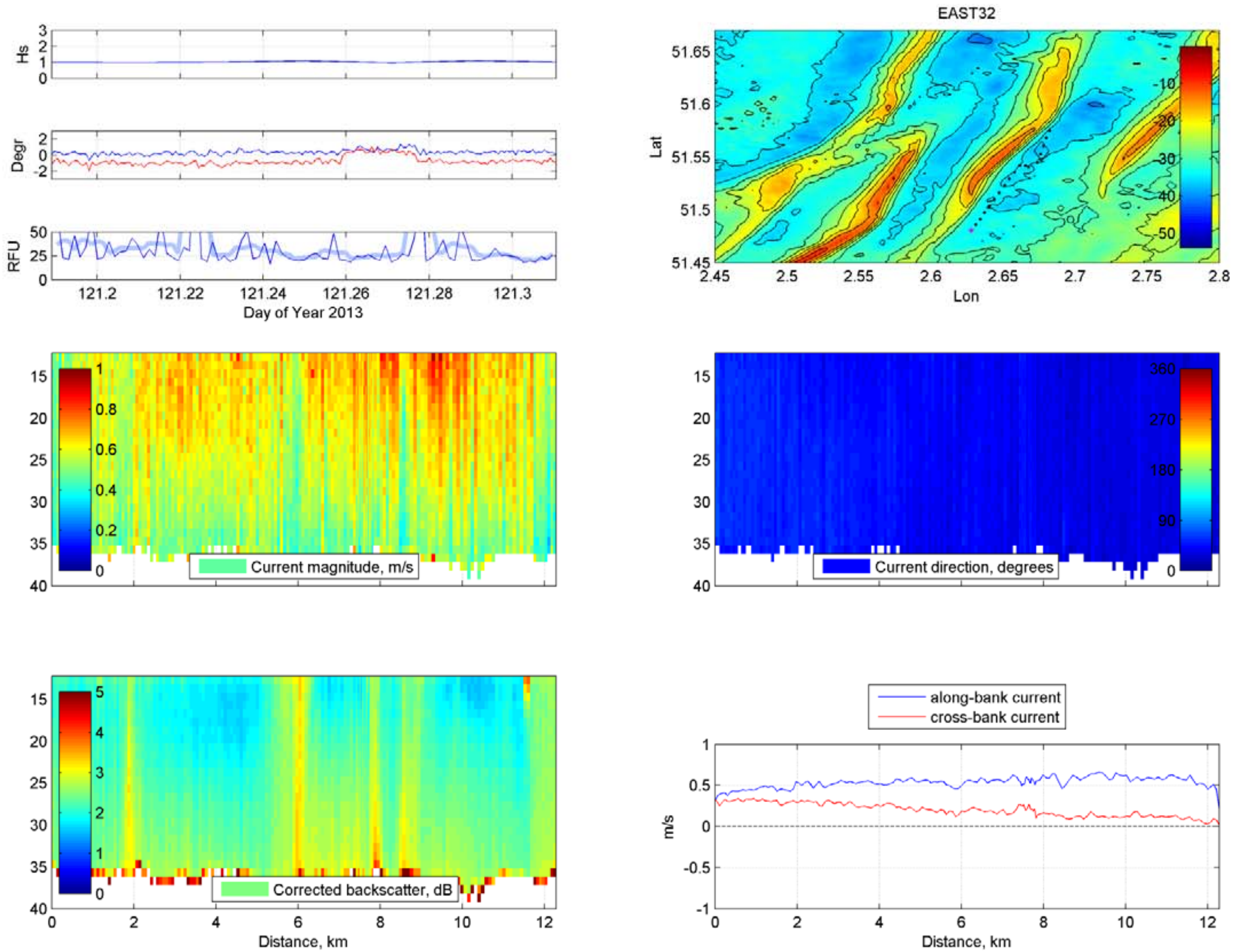


Hs
Degr
RFU
Day of Year 2013
EAST30
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s
Distance, km

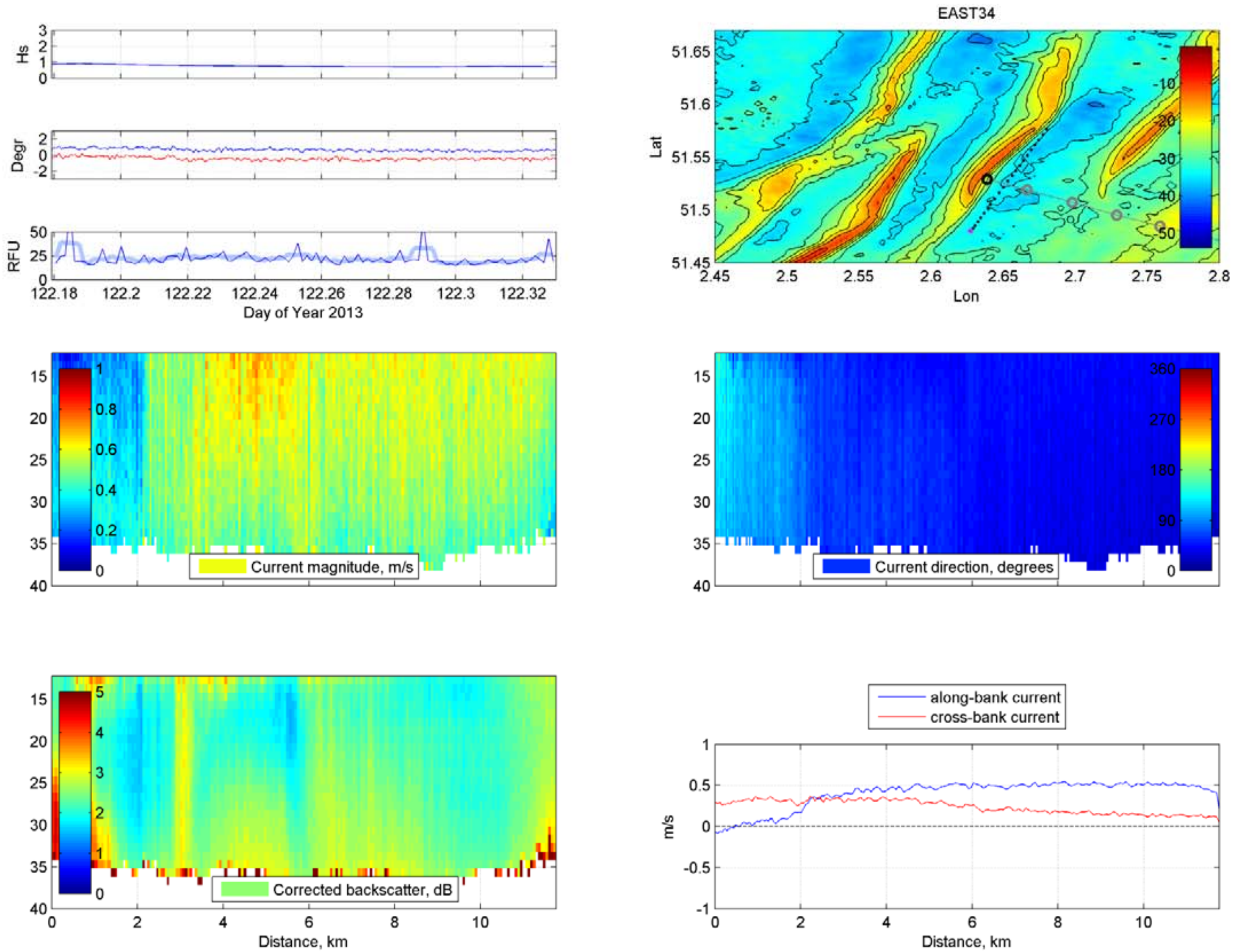
F108


EAST31
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

F109

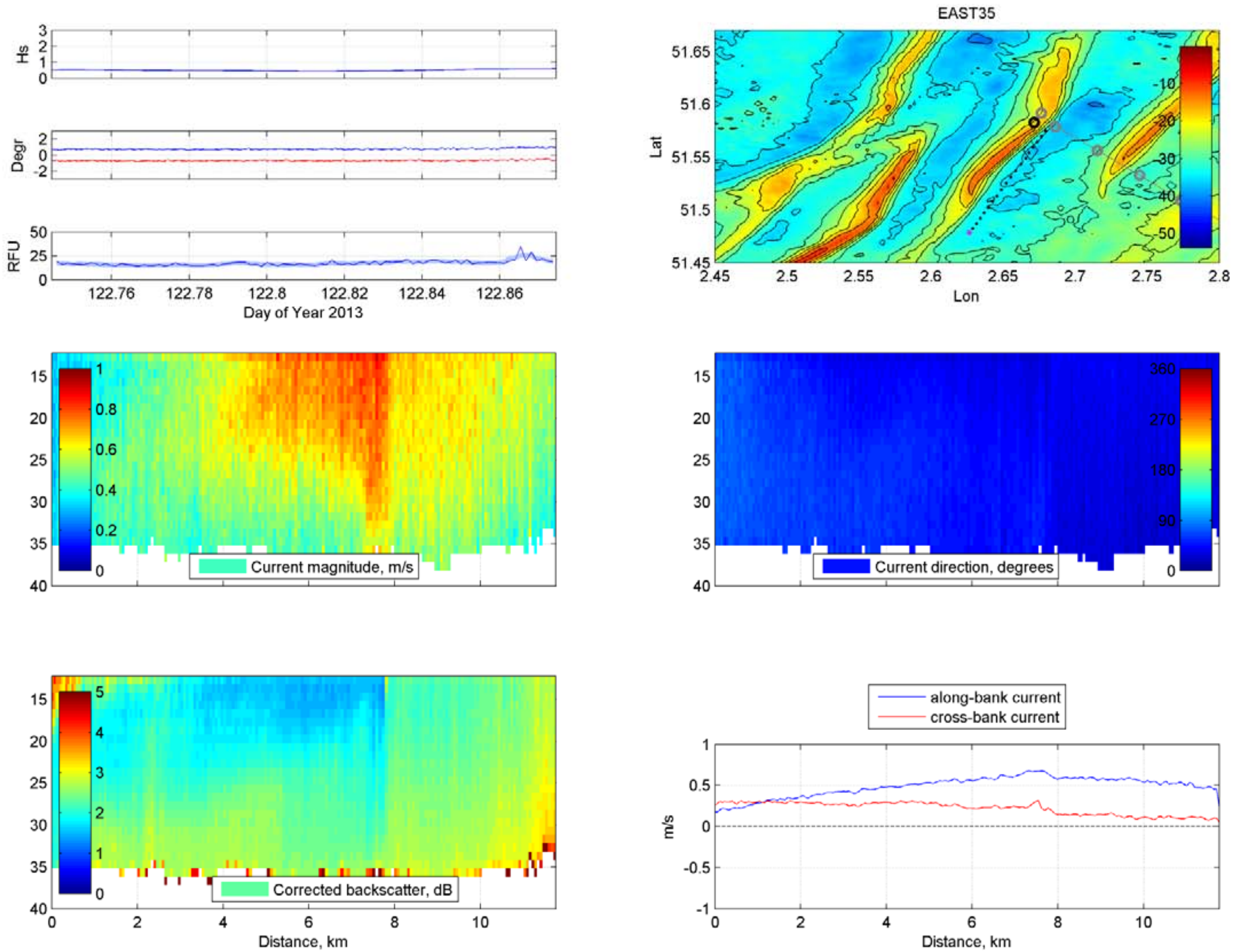


Hs
Degr
RFU
Day of Year 2013
EAST32
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s
Distance, km

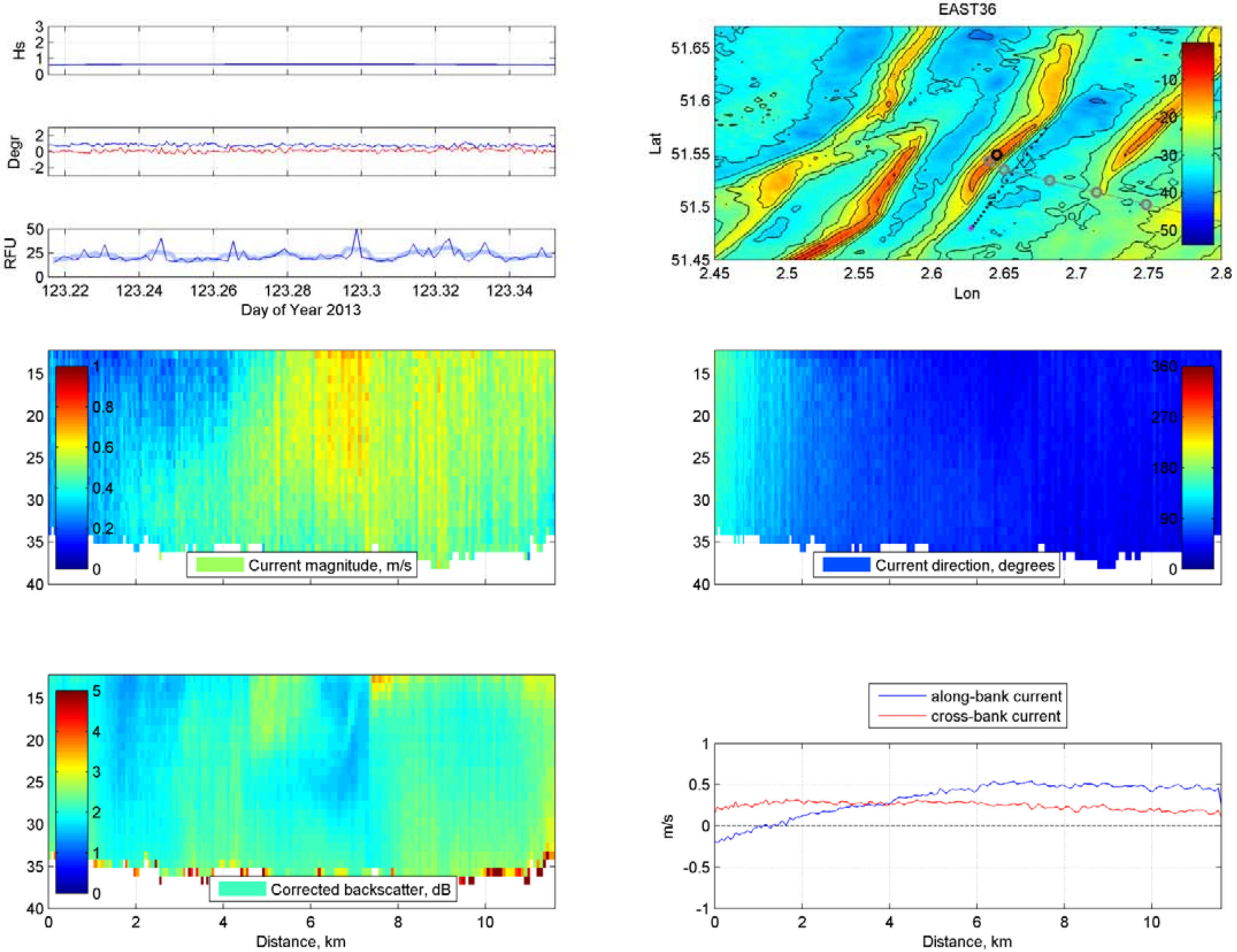


Hs
Degr
RFU
Day of Year 2013
EAST34
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

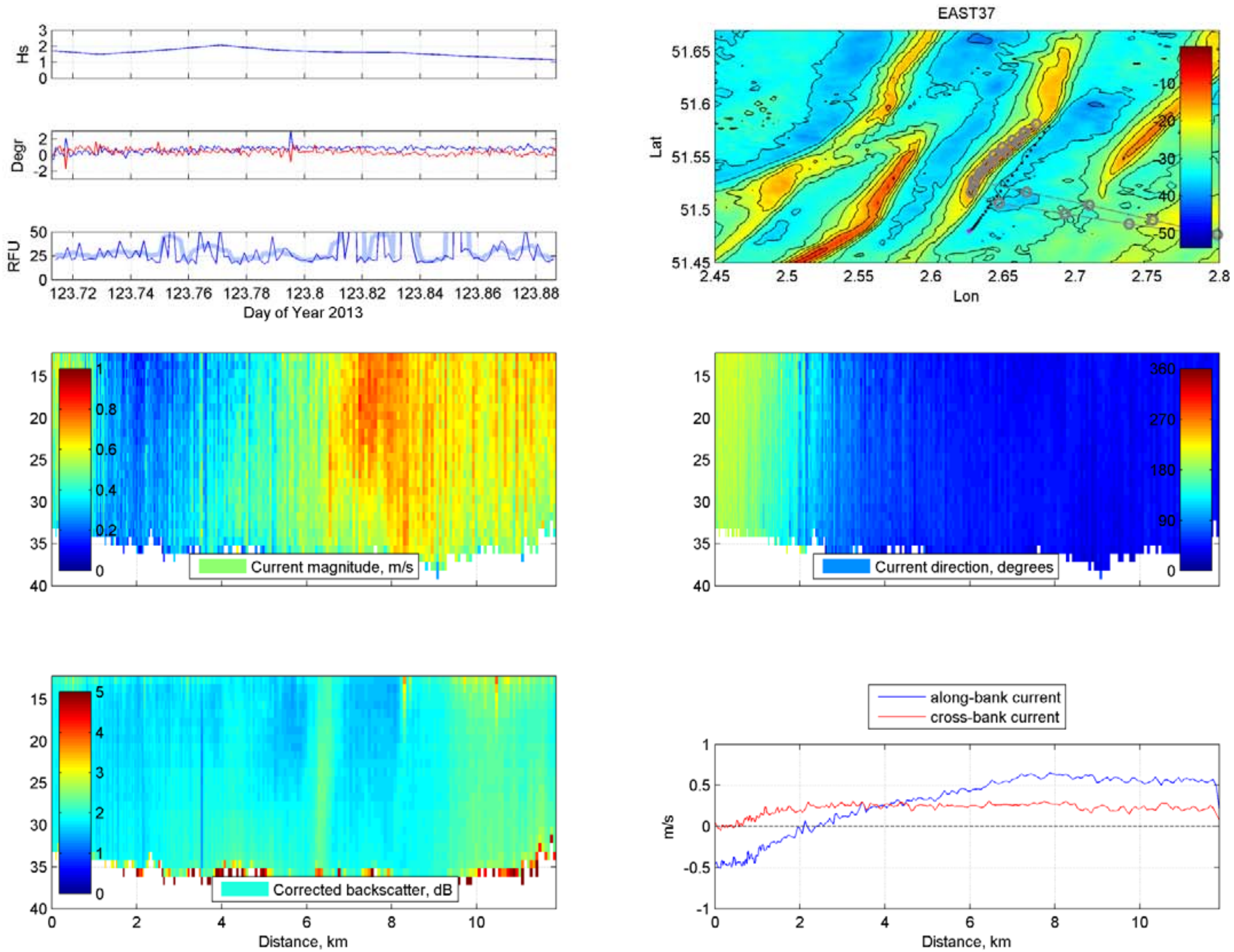
F111

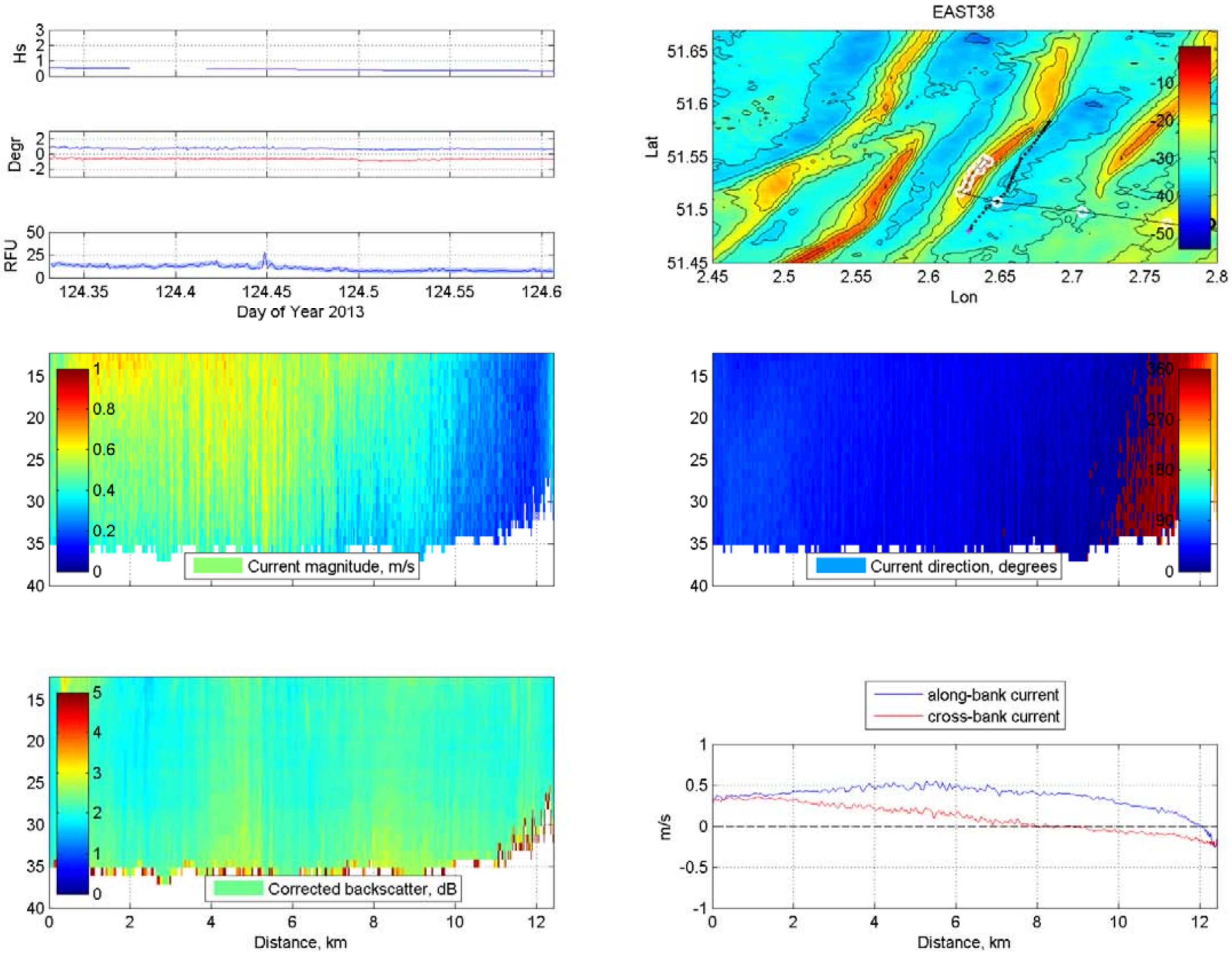


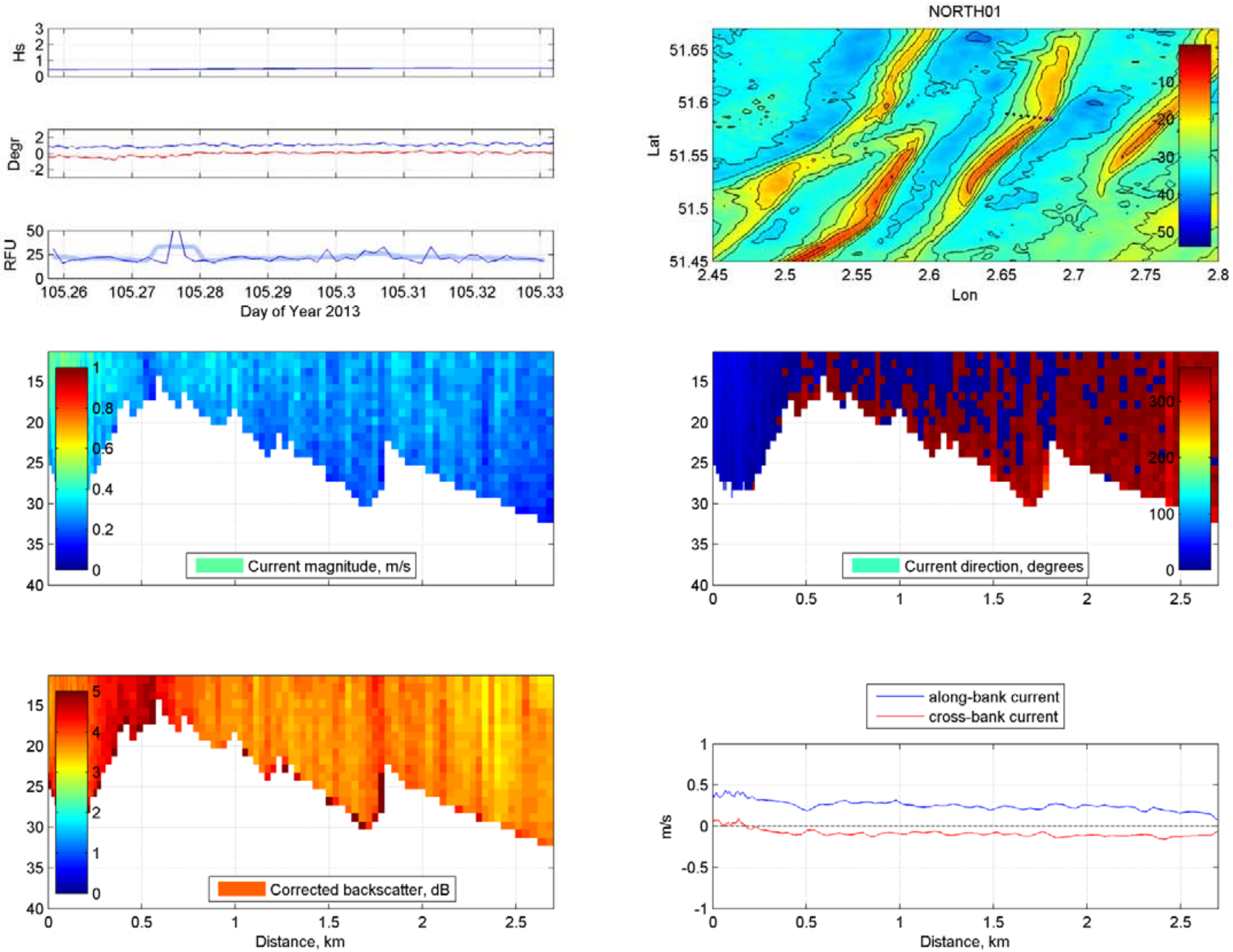
Hs
Degr
RFU
Day of Year 2013
EAST35
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
Distance, km
along-bank current
cross-bank current
m/s
Distance, km

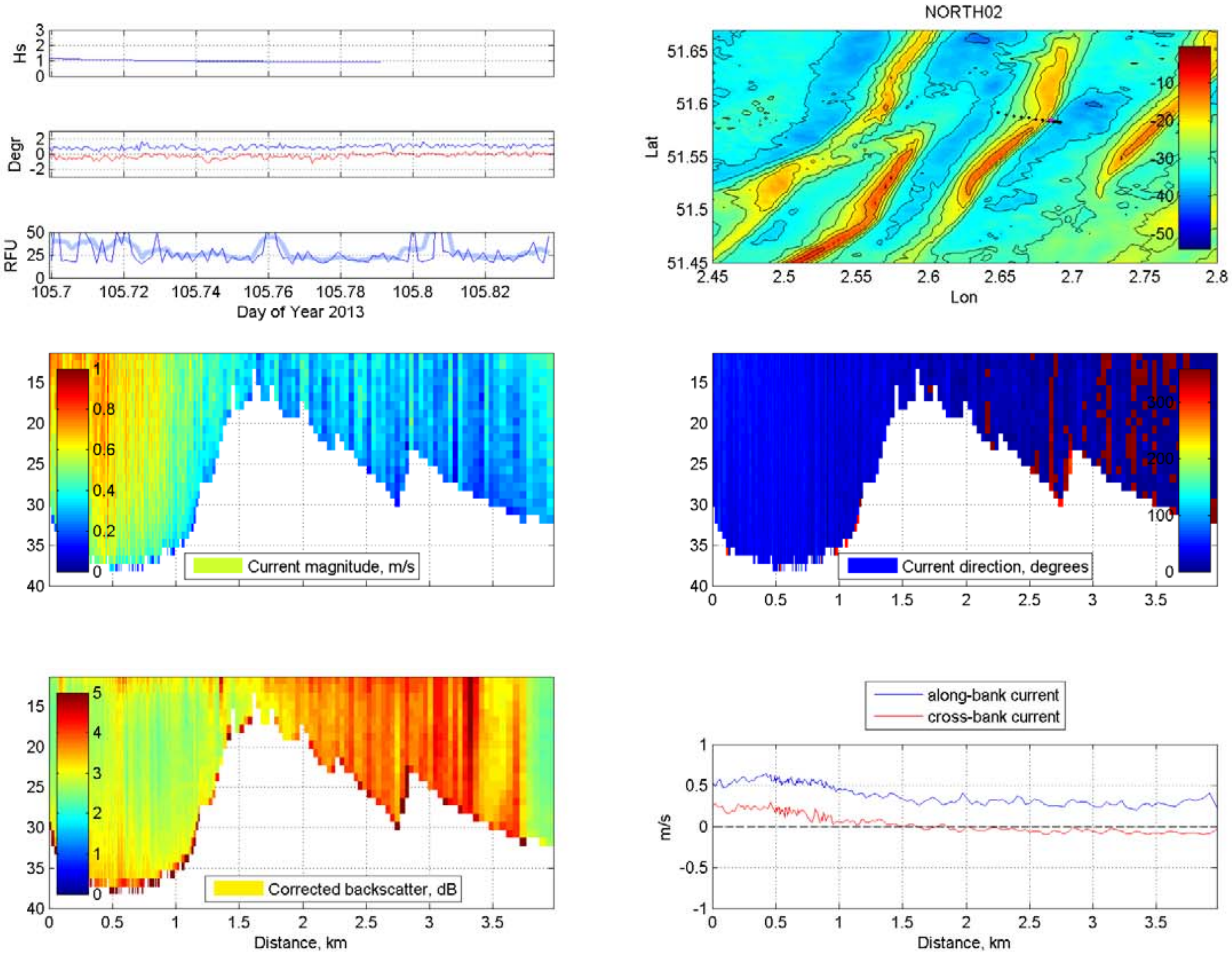

EAST36
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

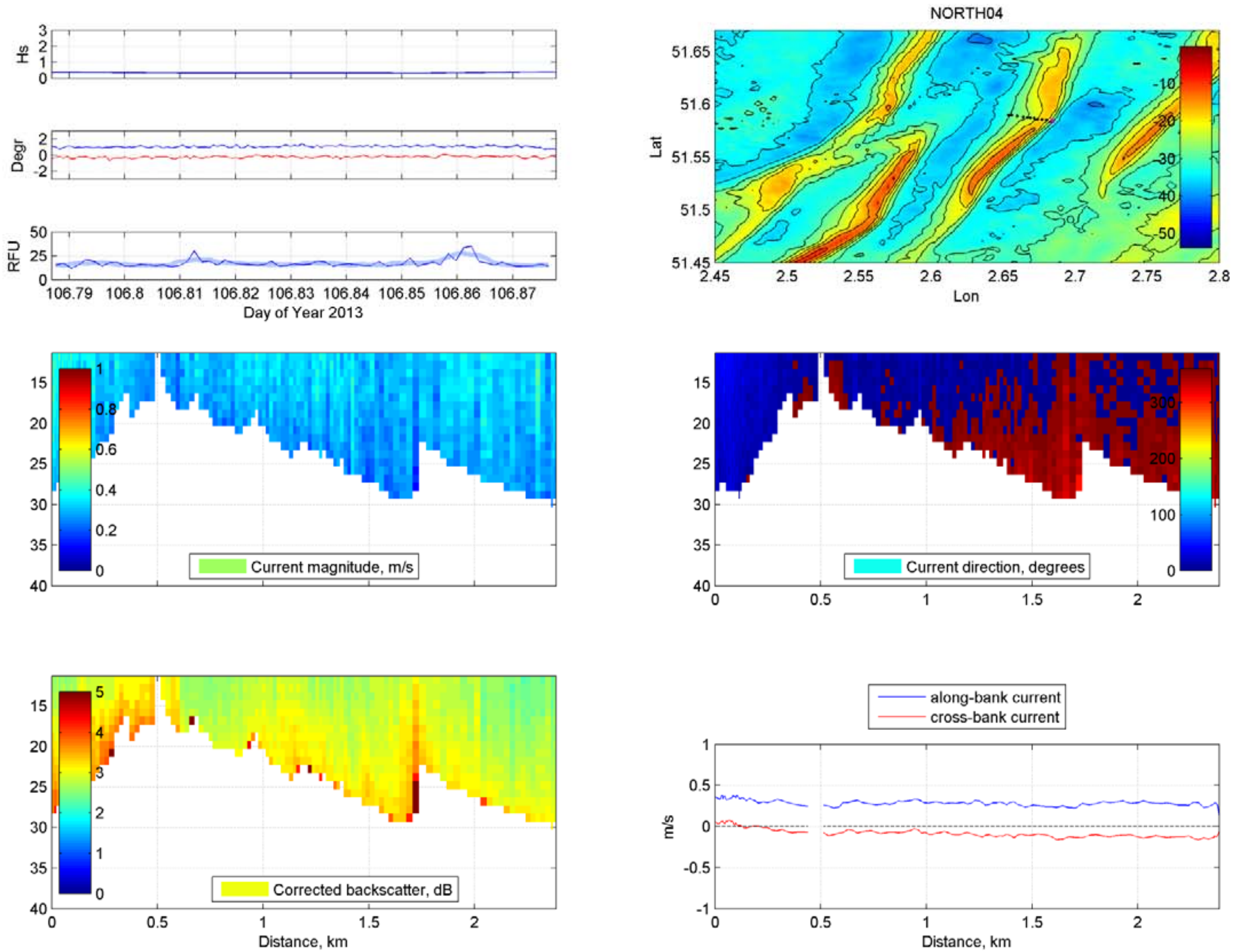
F113

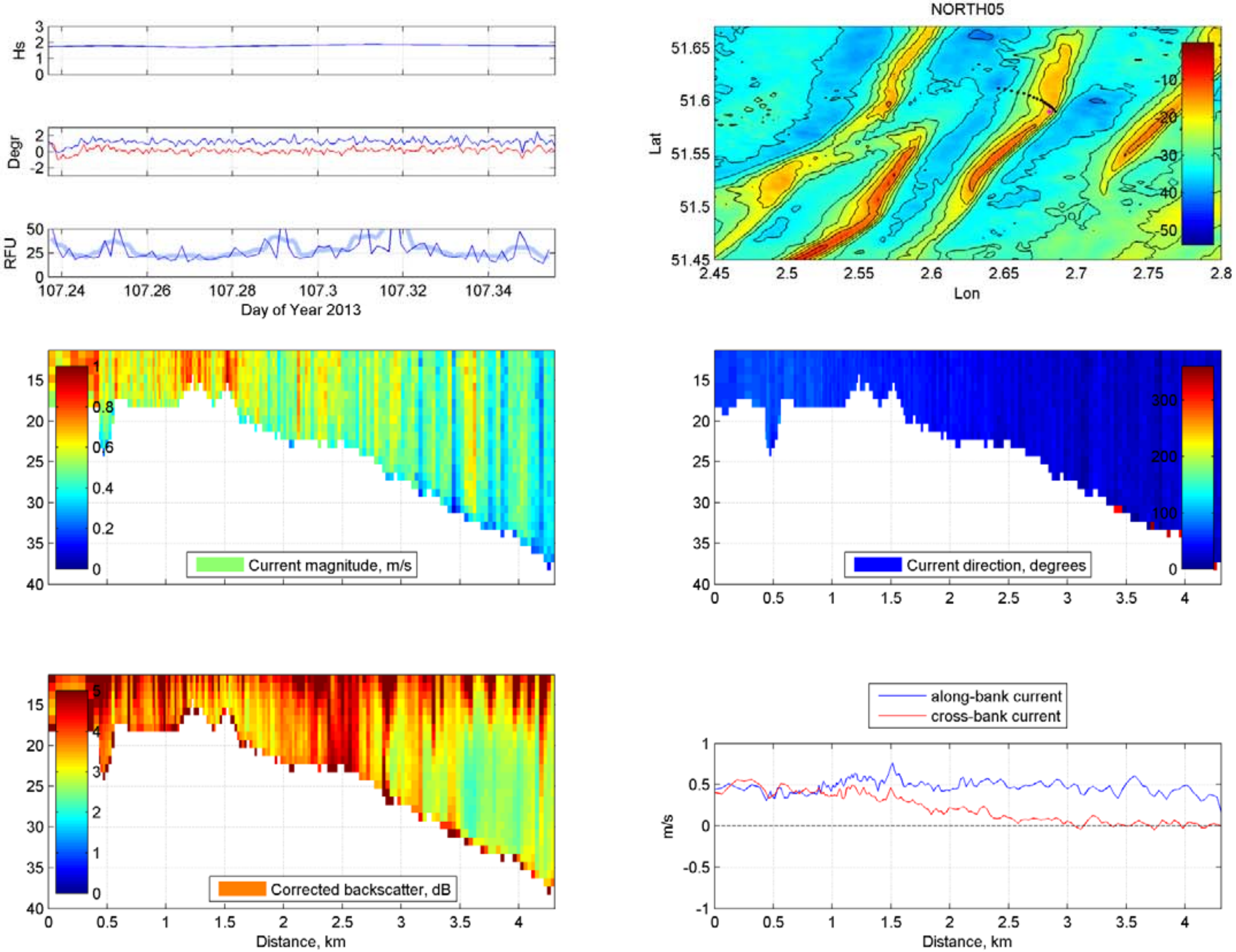

EAST37
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km


EAST38
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

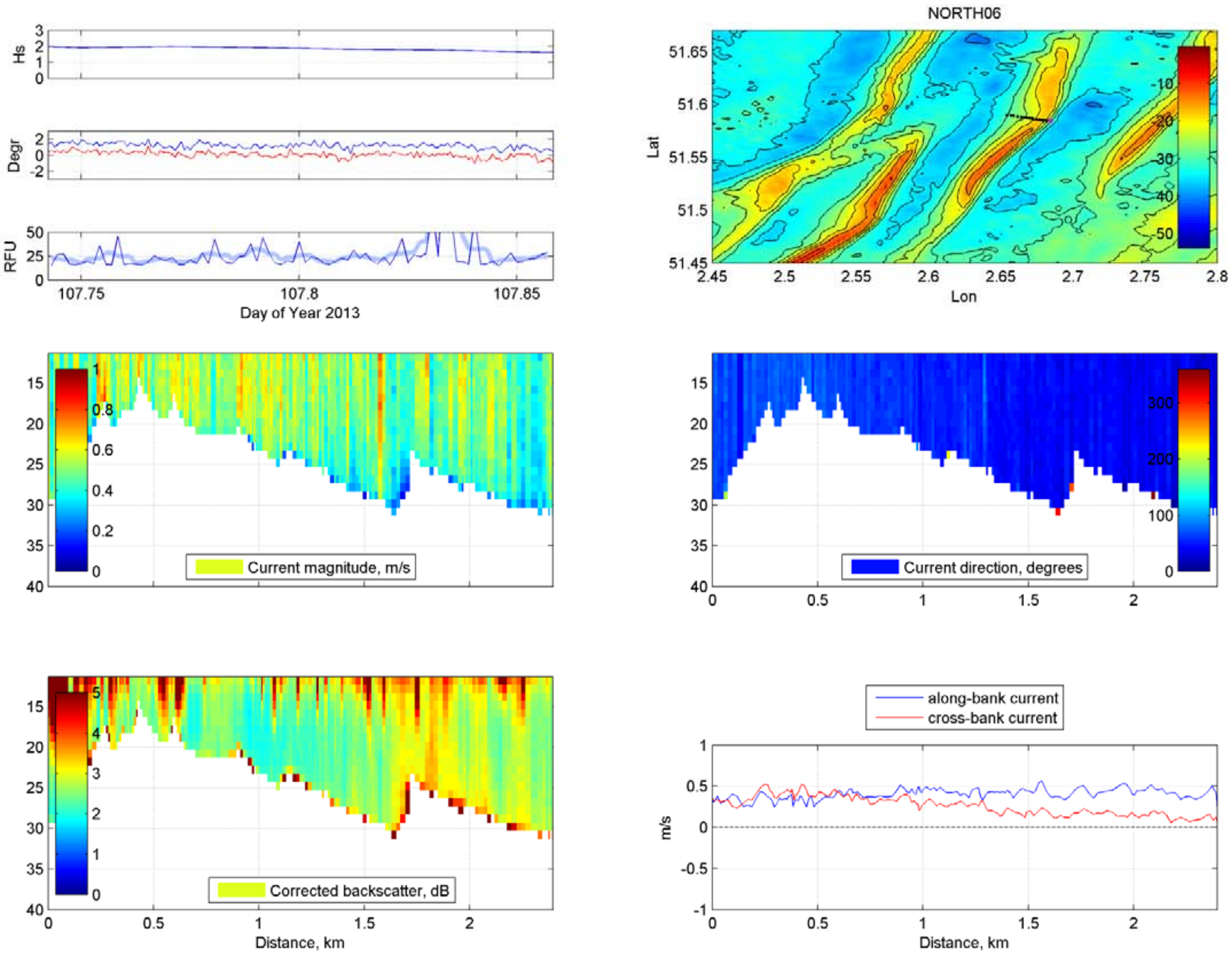

NORTH01
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

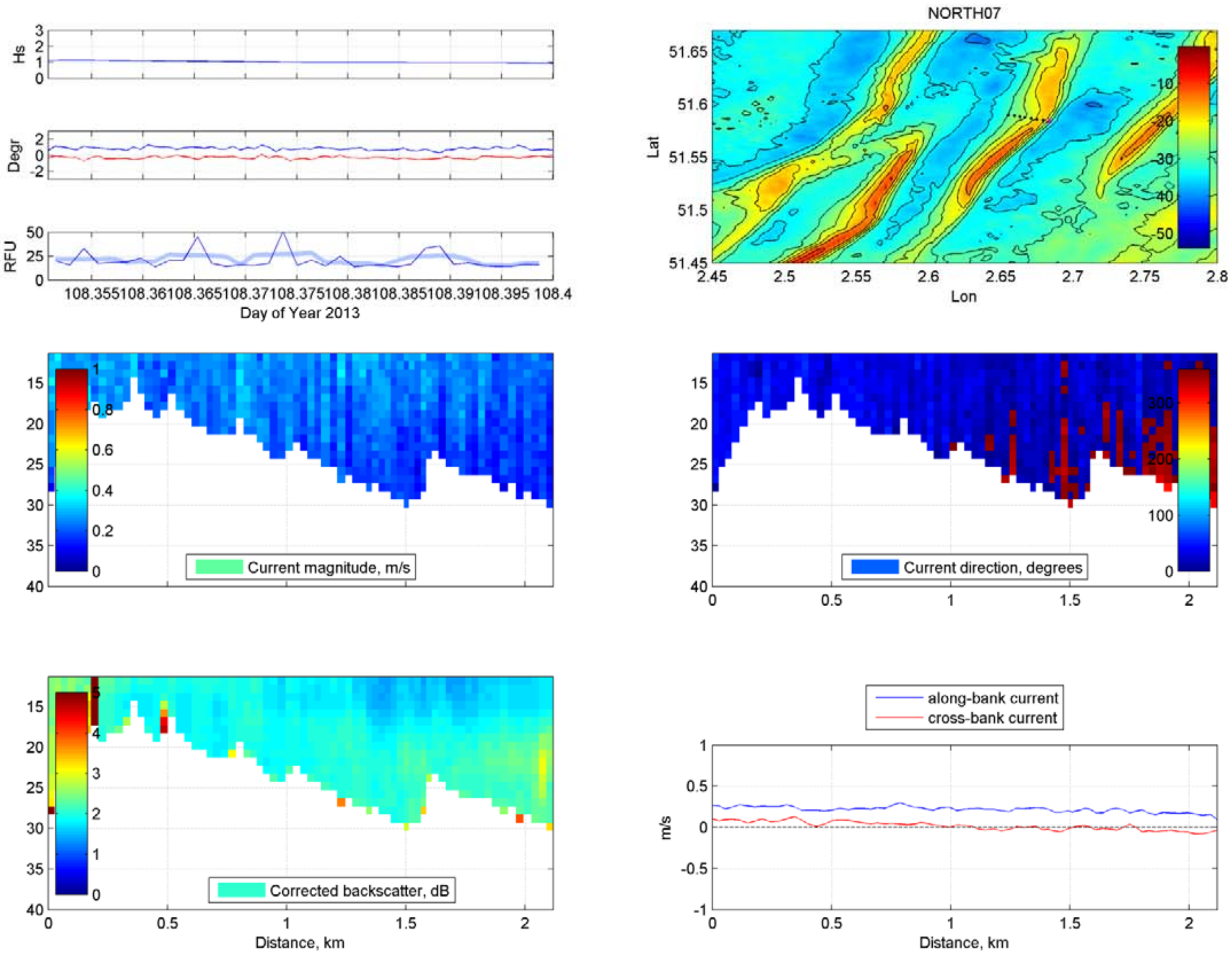

NORTH02
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

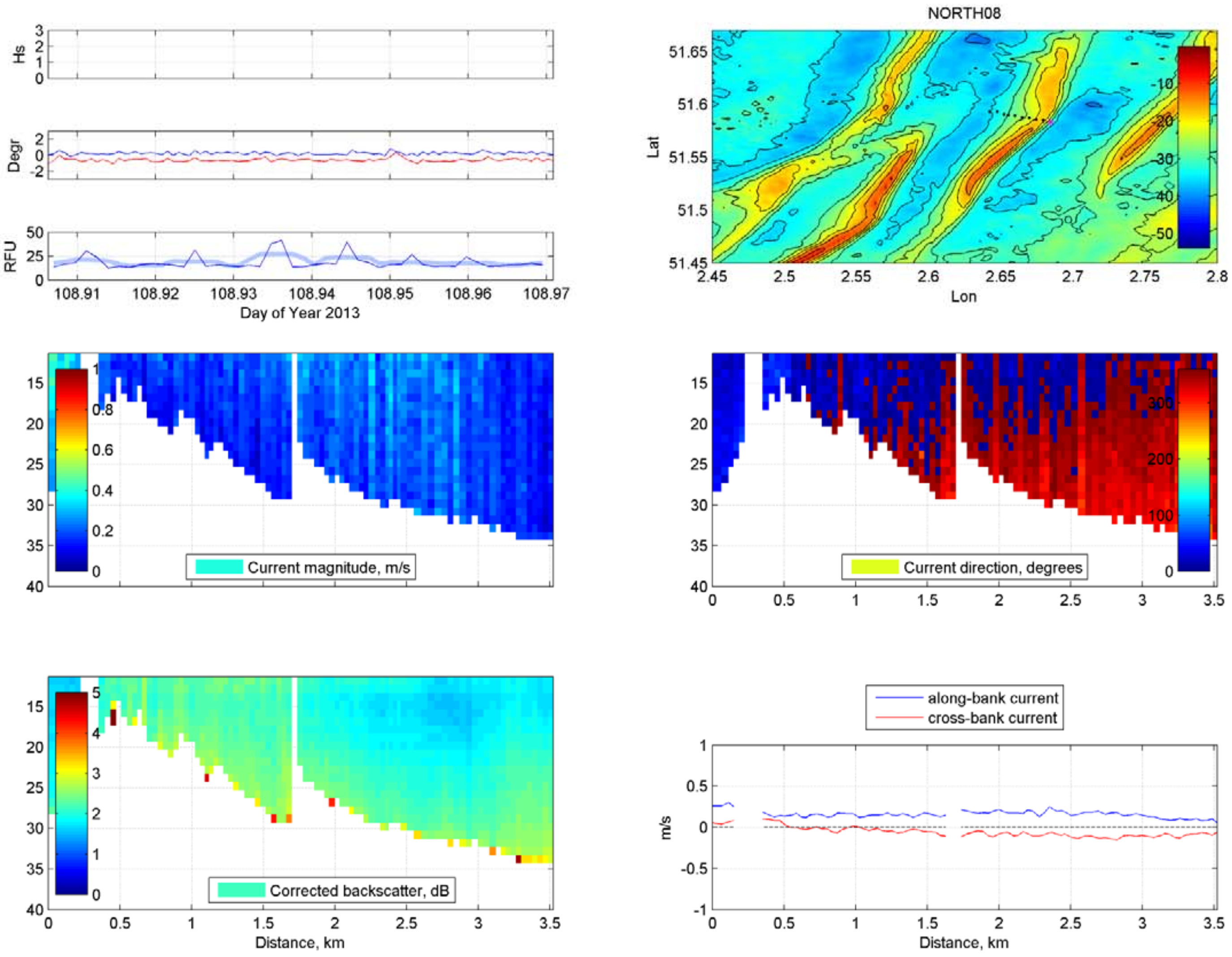

Hs
Degr
RFU
Day of Year 2013
NORTH04
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km



NORTH05
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

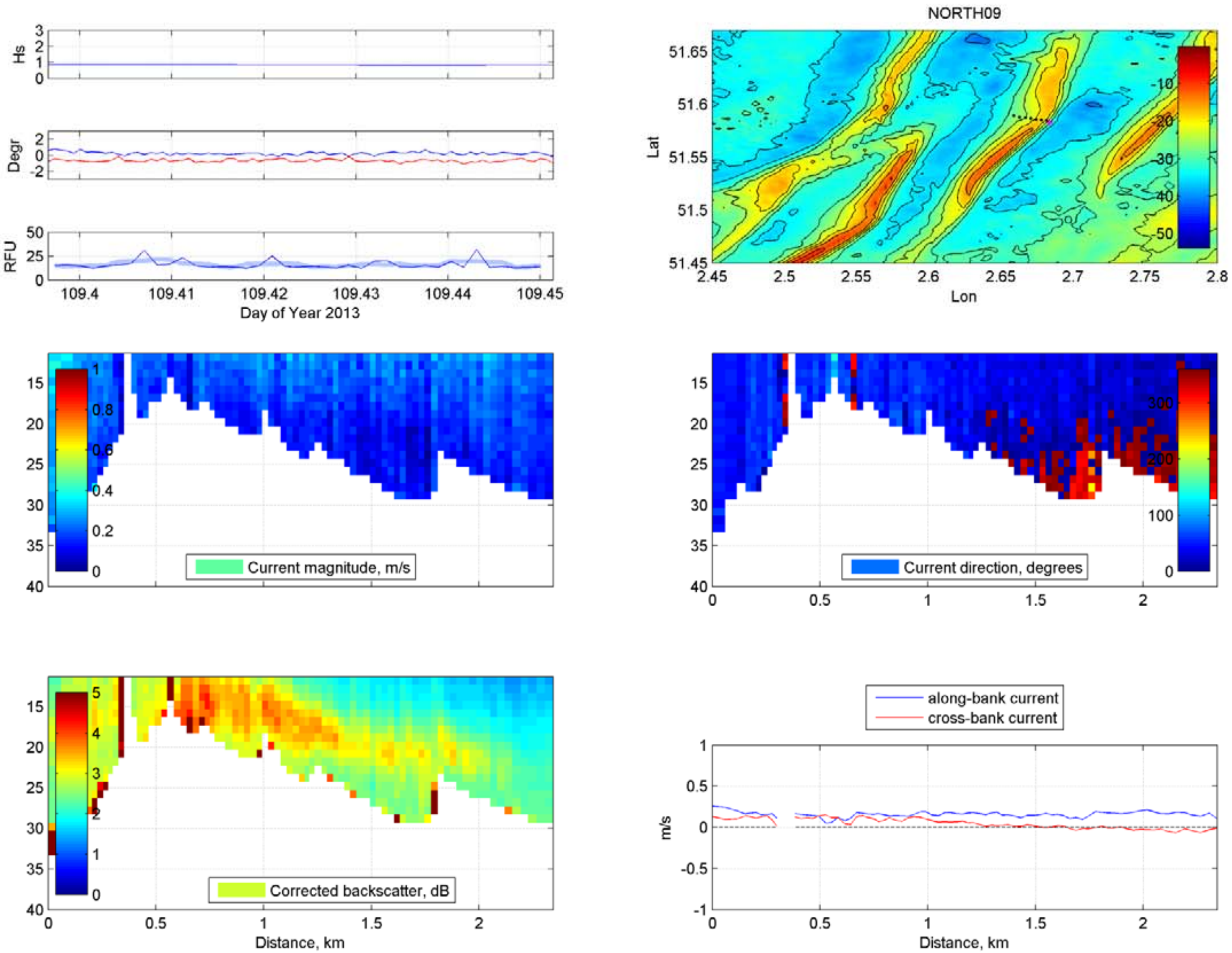

NORTH06
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km


NORTH07
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km

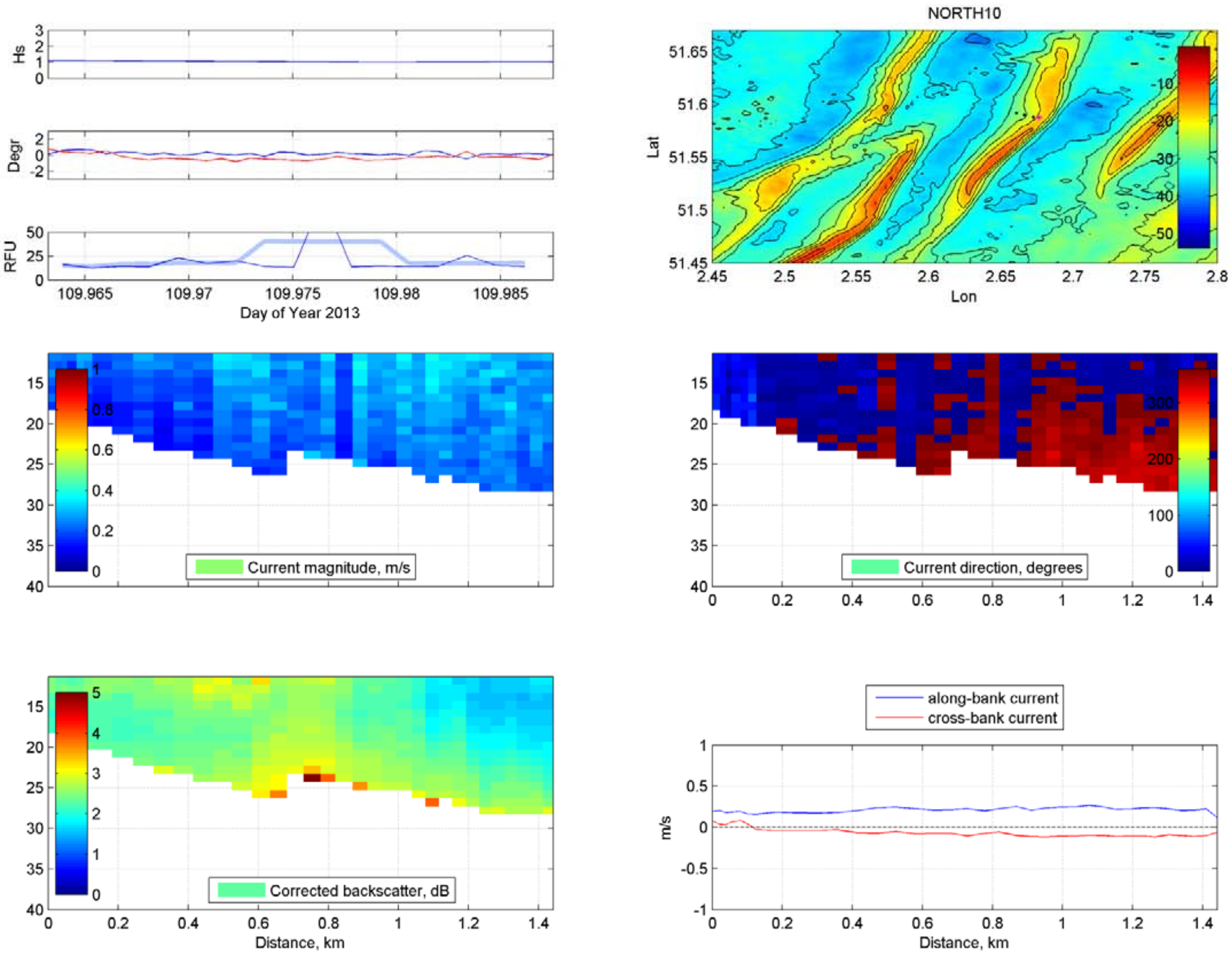


NORTH08
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

F122

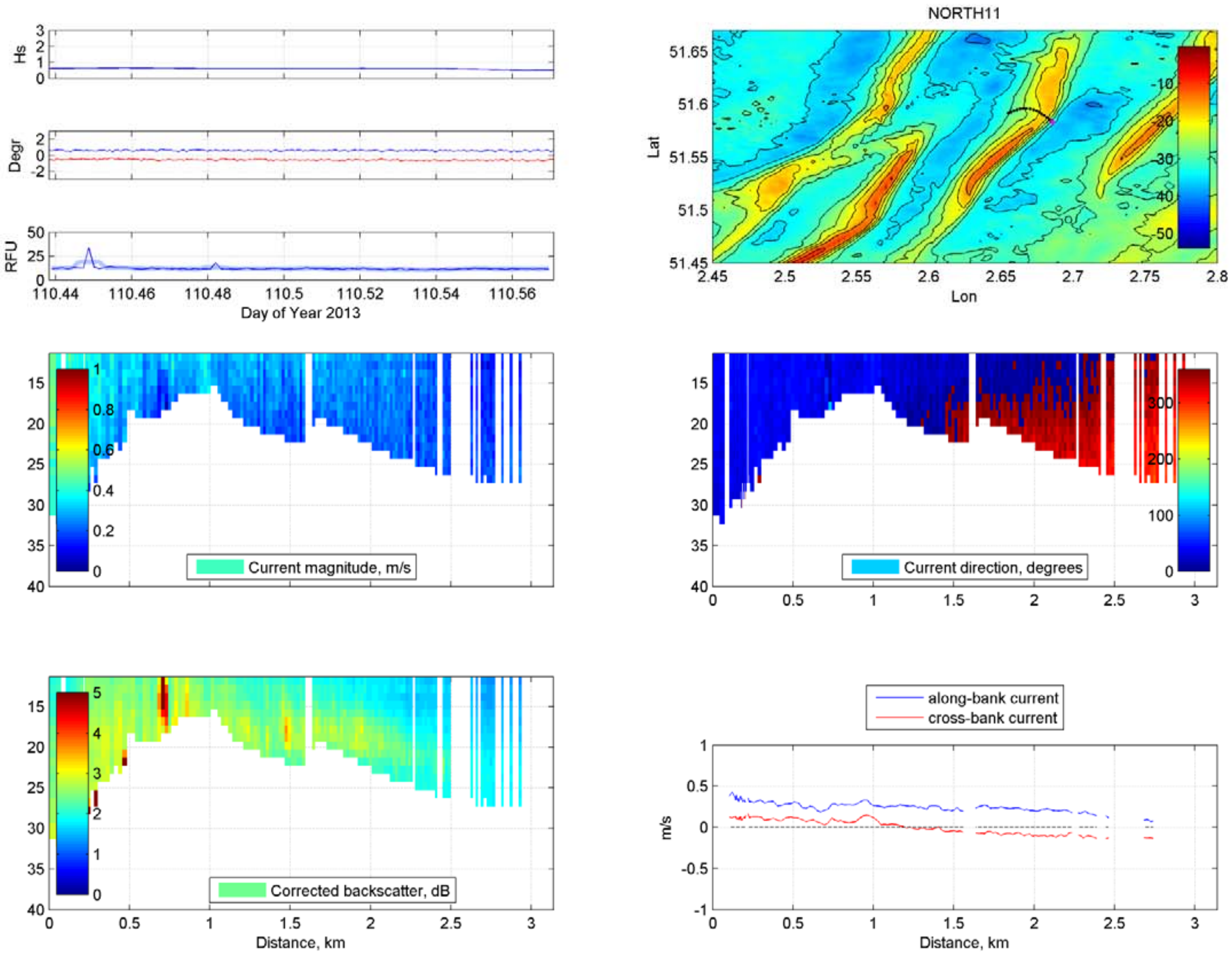


NORTH09
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km
Distance, km



NORTH10
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
Current direction, degrees
Corrected backscatter, dB
along-bank current
cross-bank current
m/s
Distance, km

F124



NORTH11
Hs
Degr
RFU
Day of Year 2013
Lat
Lon
Current magnitude, m/s
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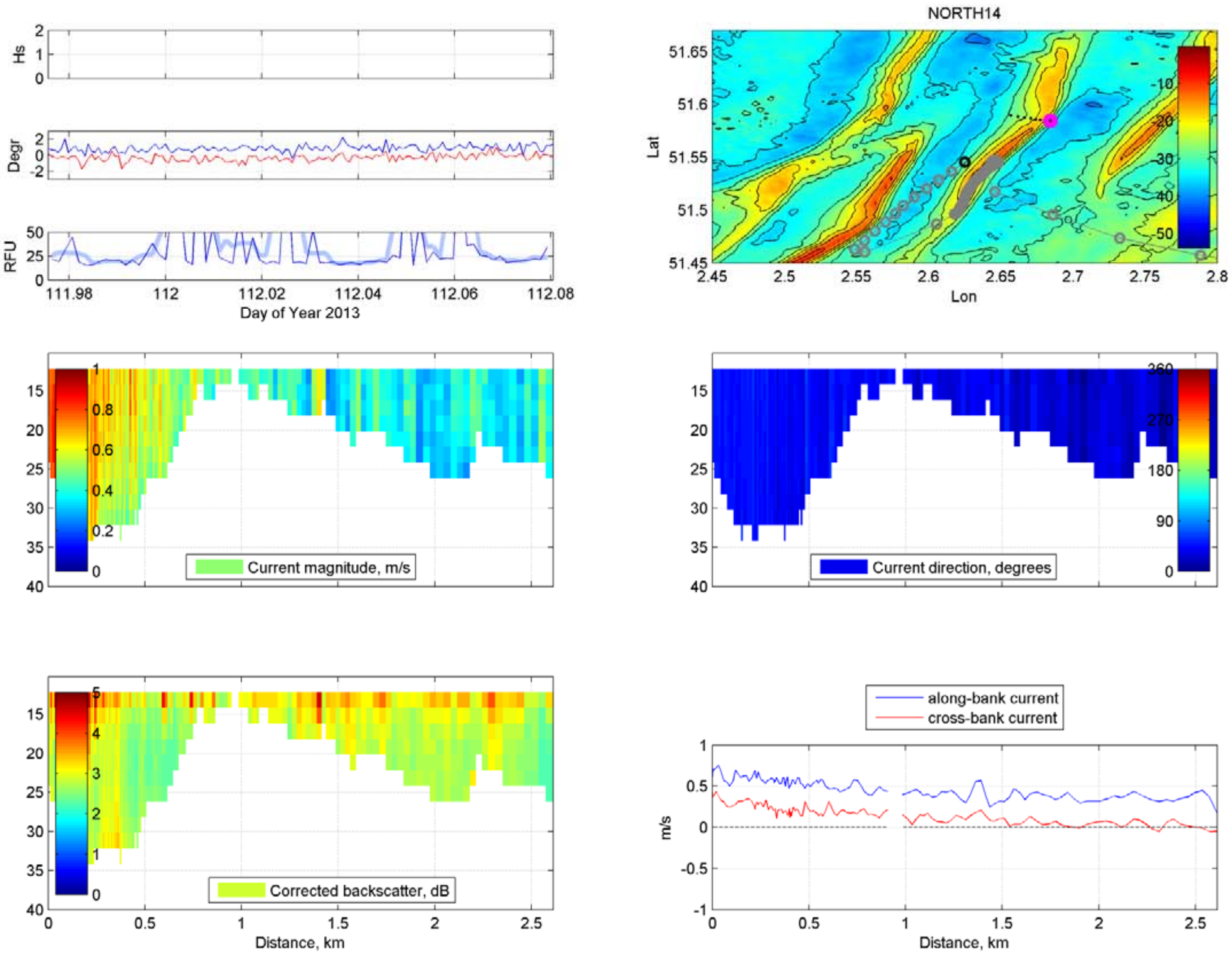
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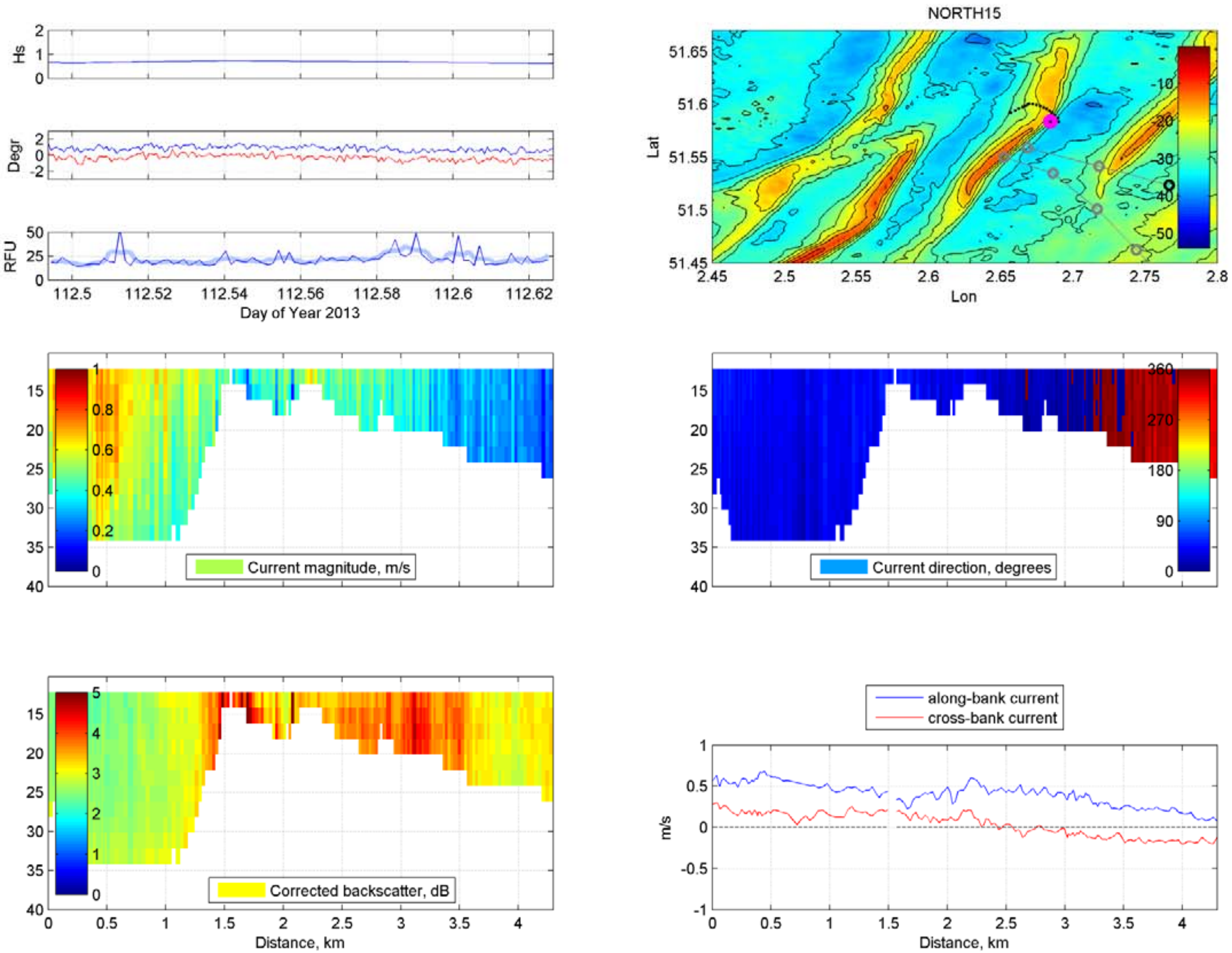
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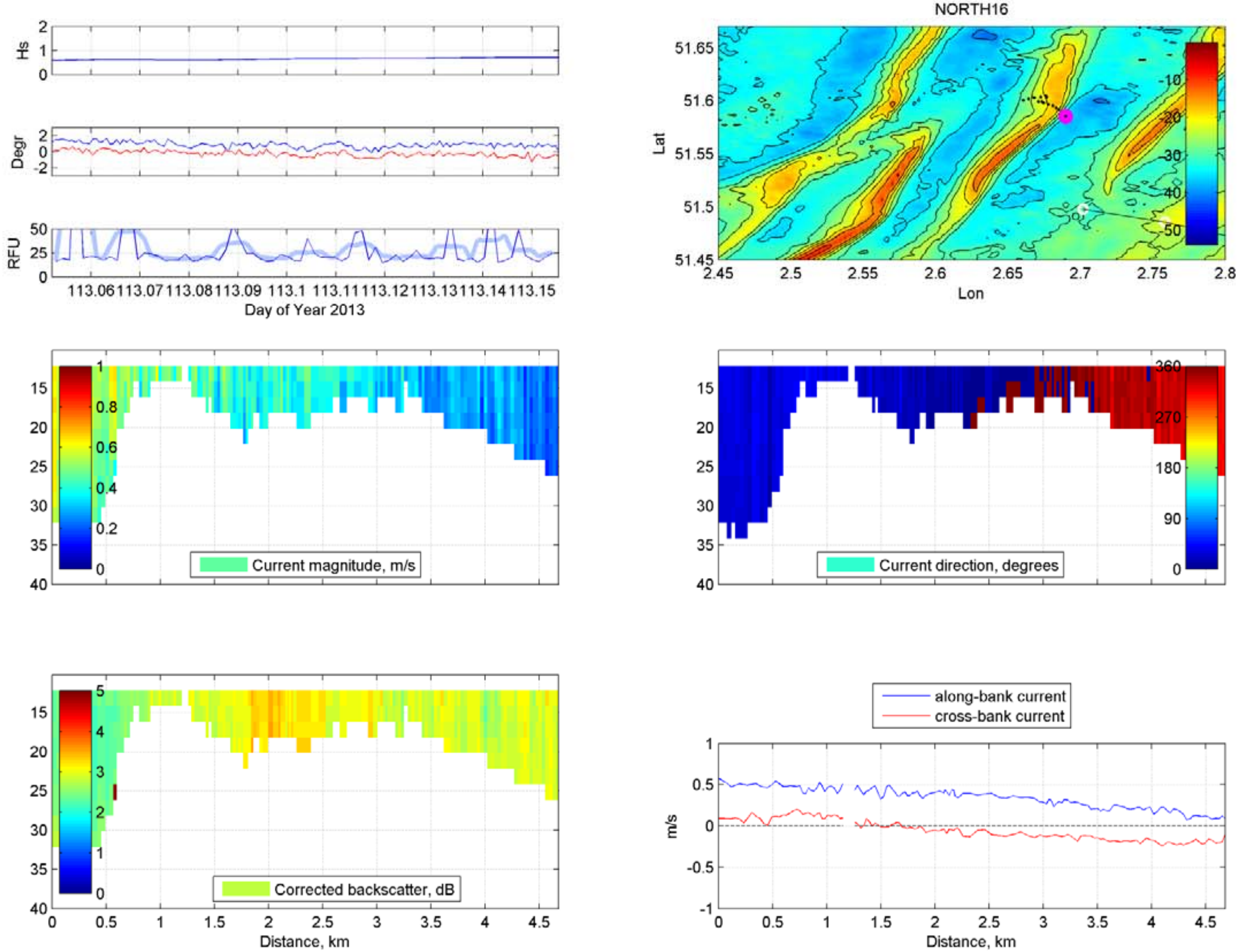
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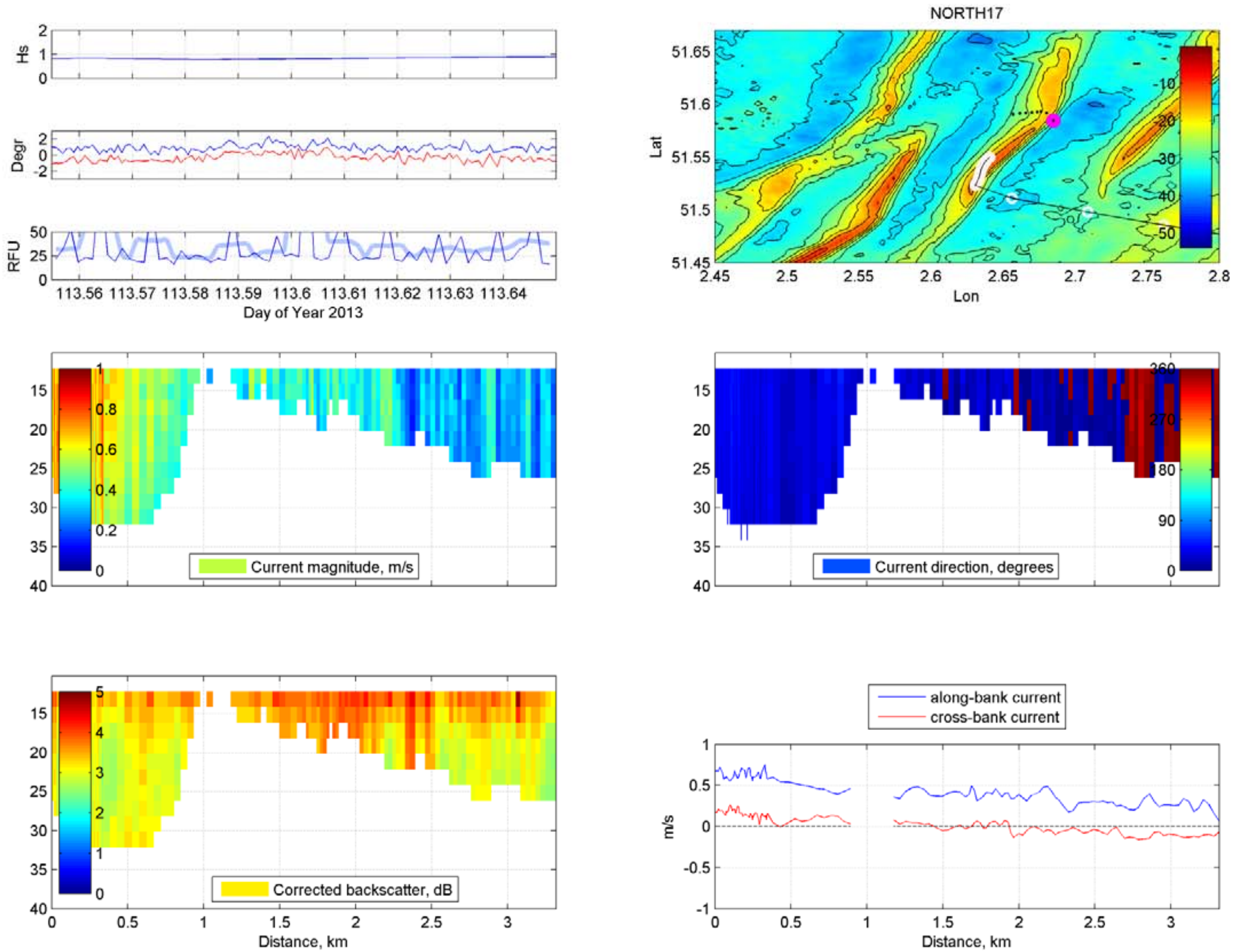

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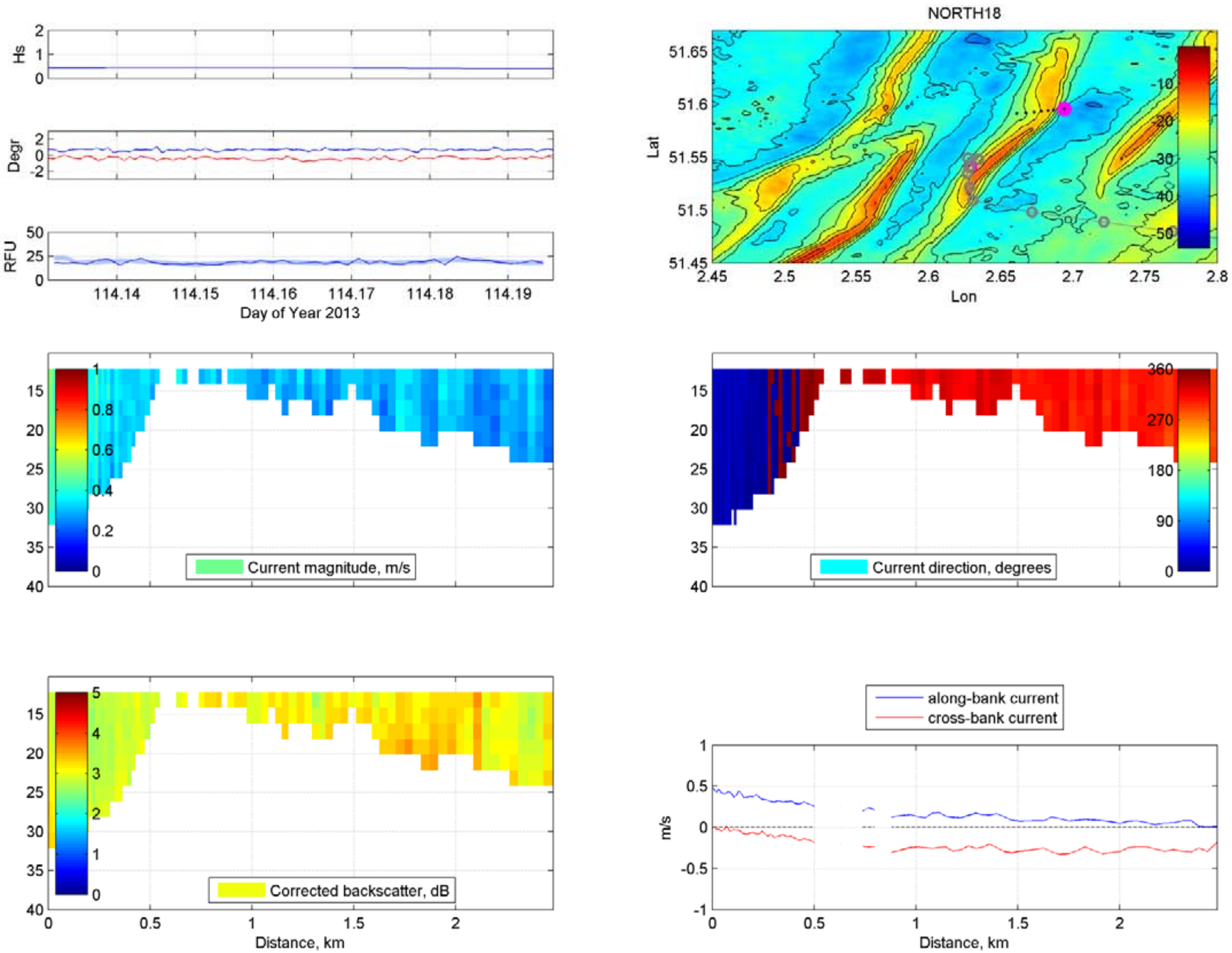
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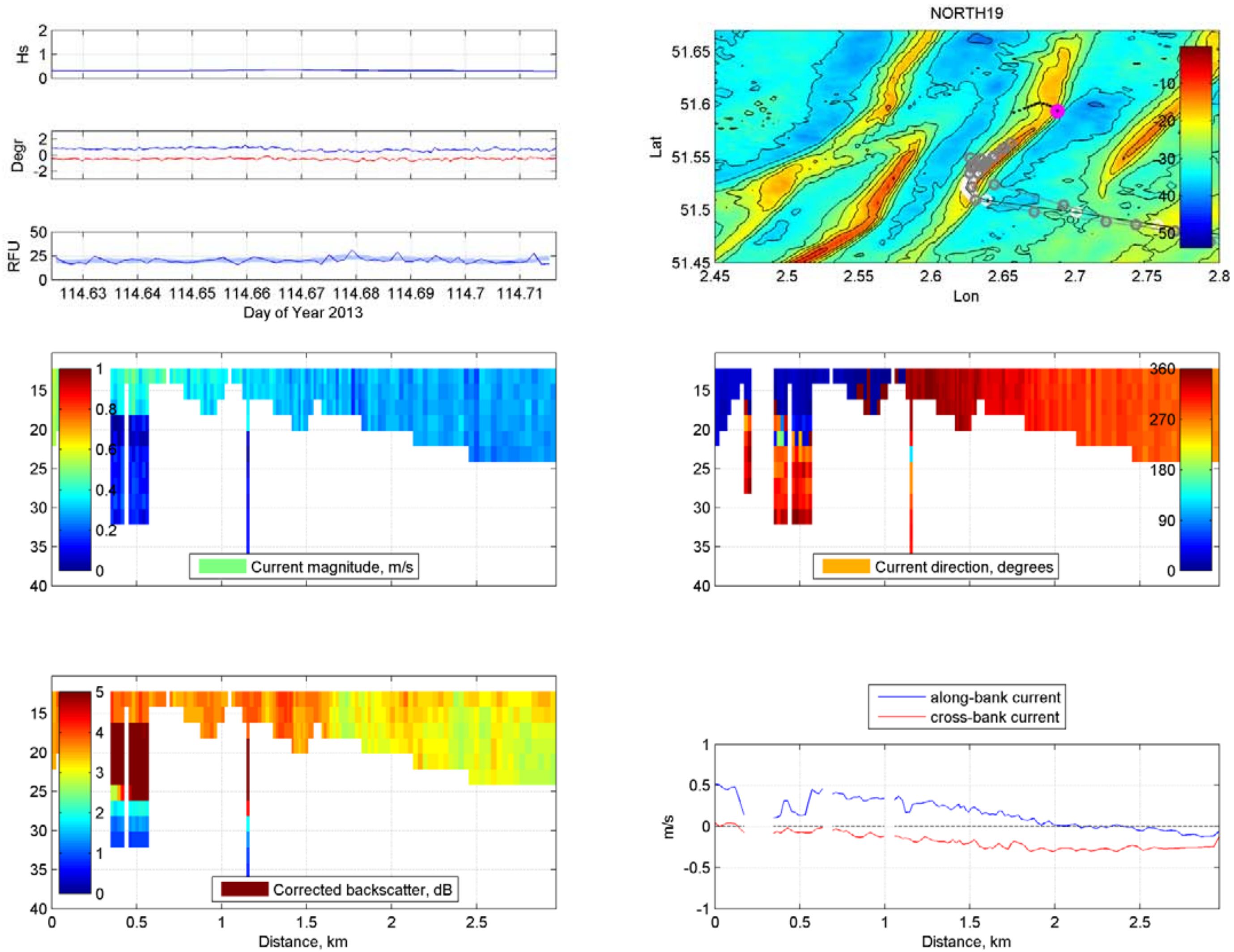

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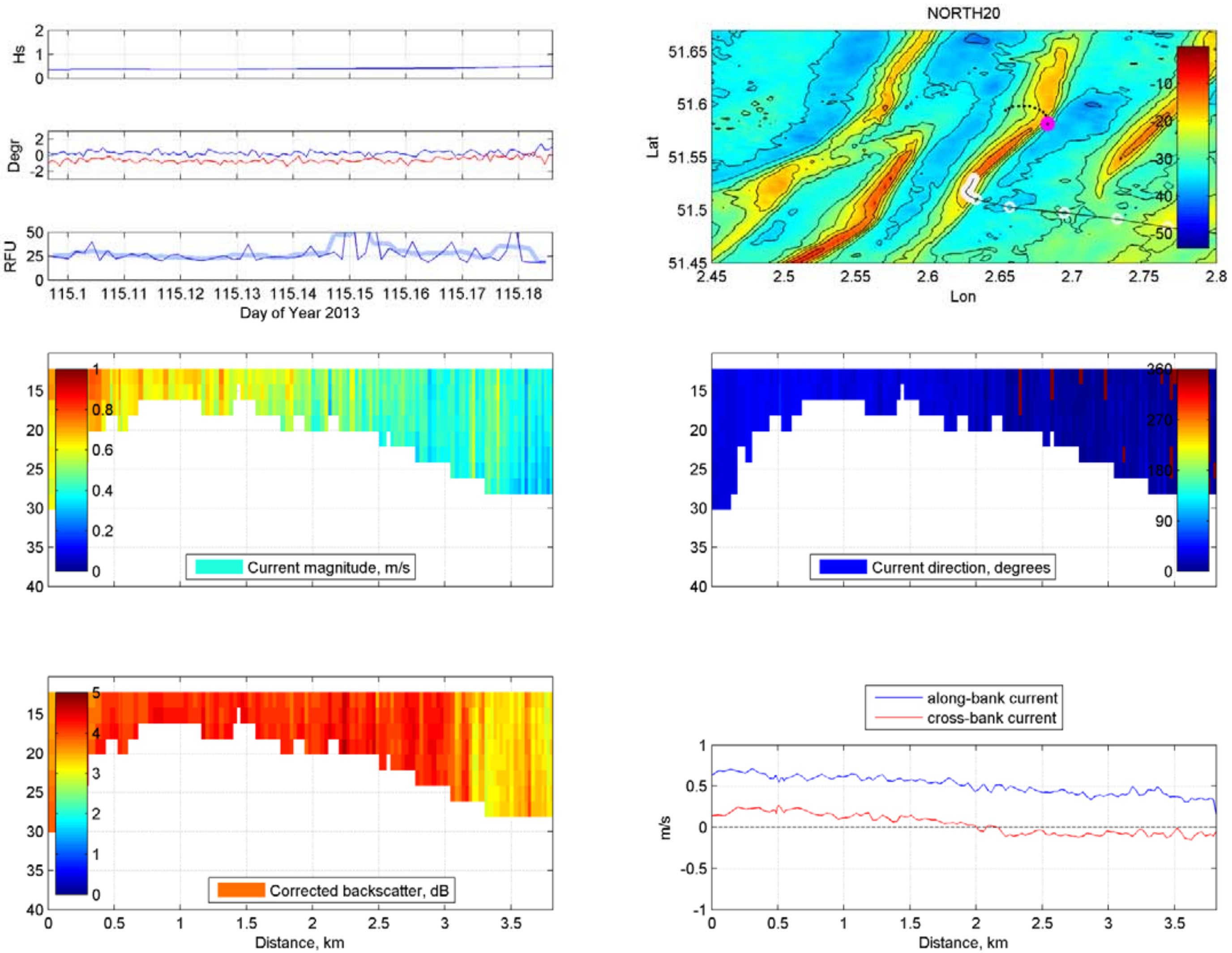

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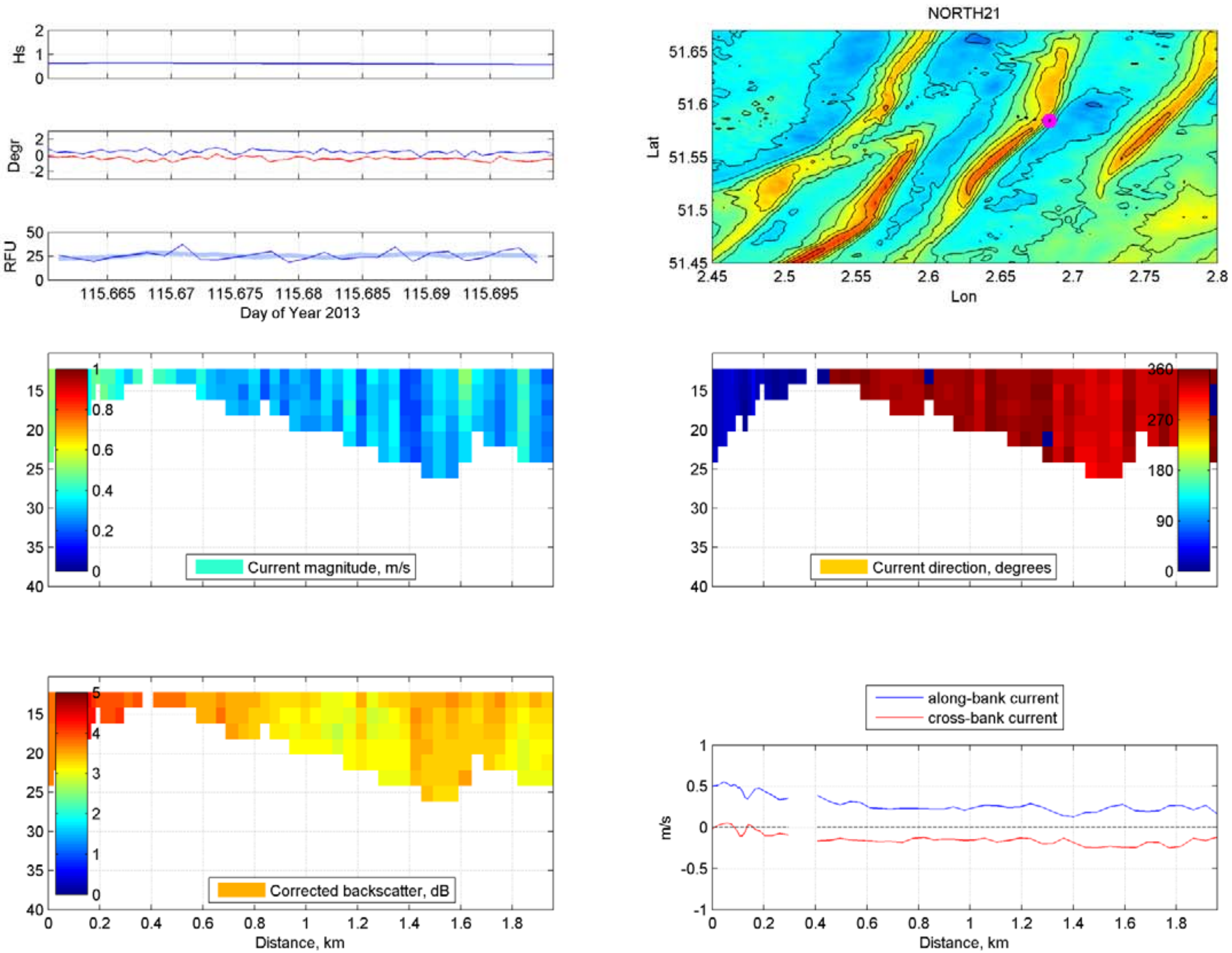

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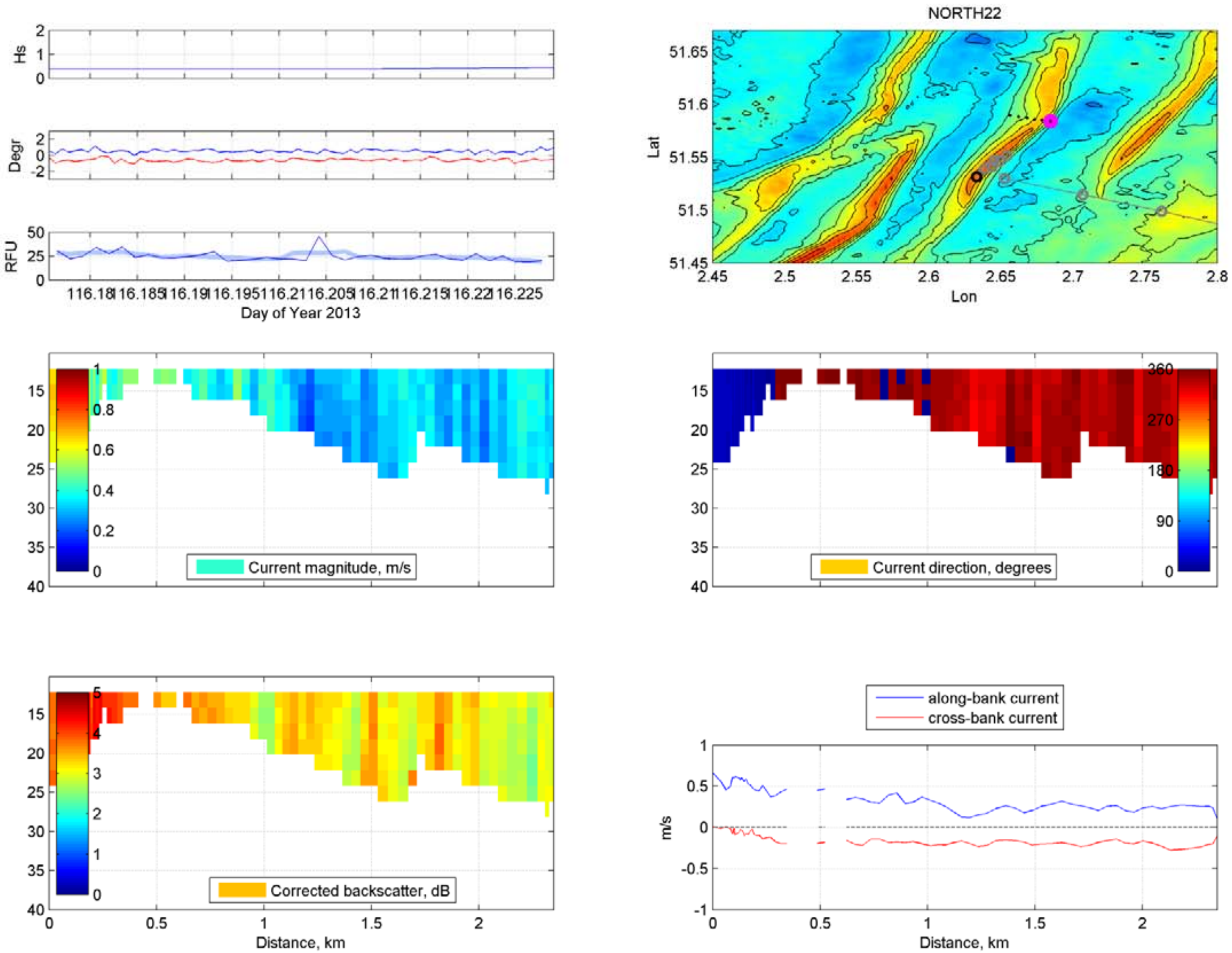

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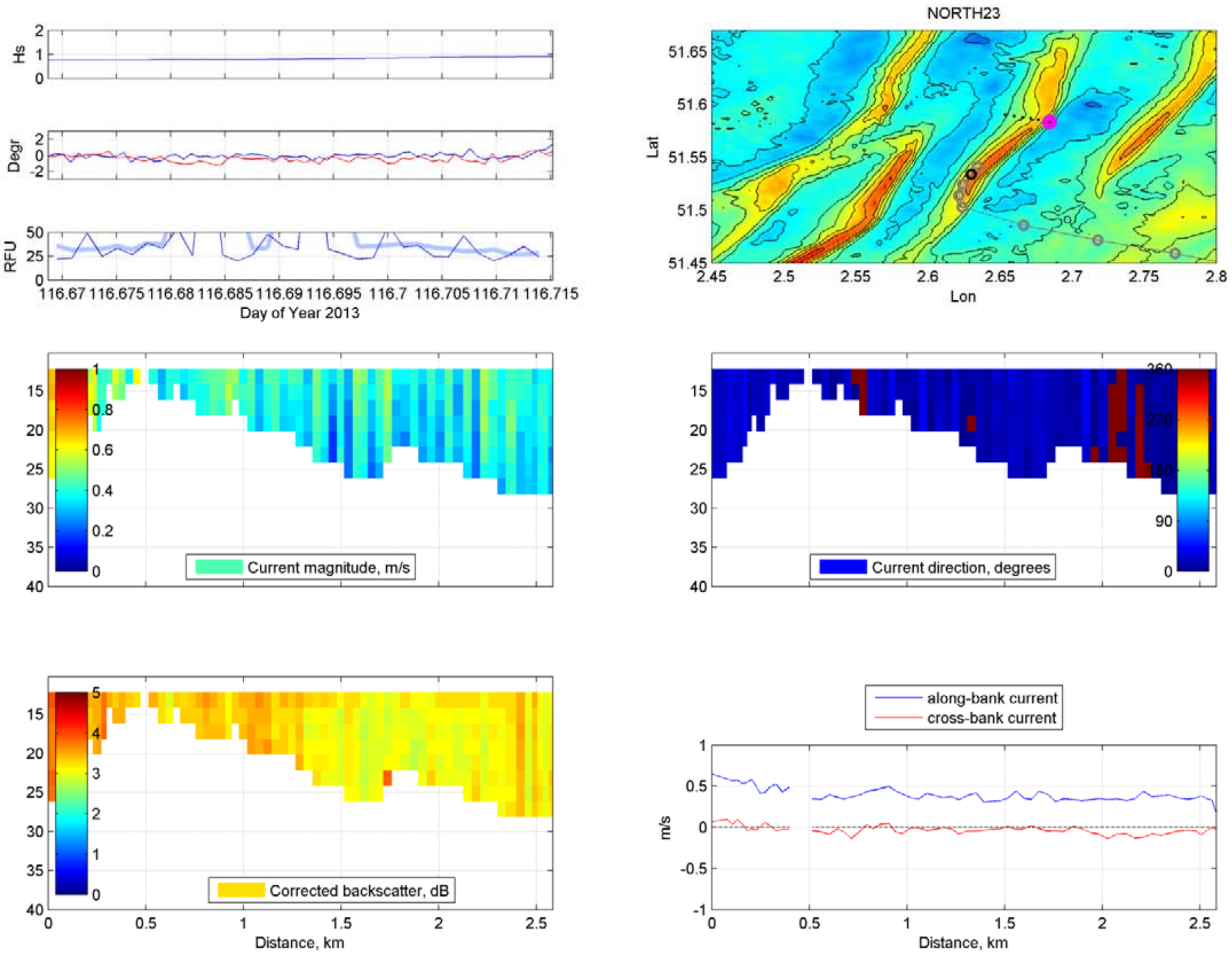
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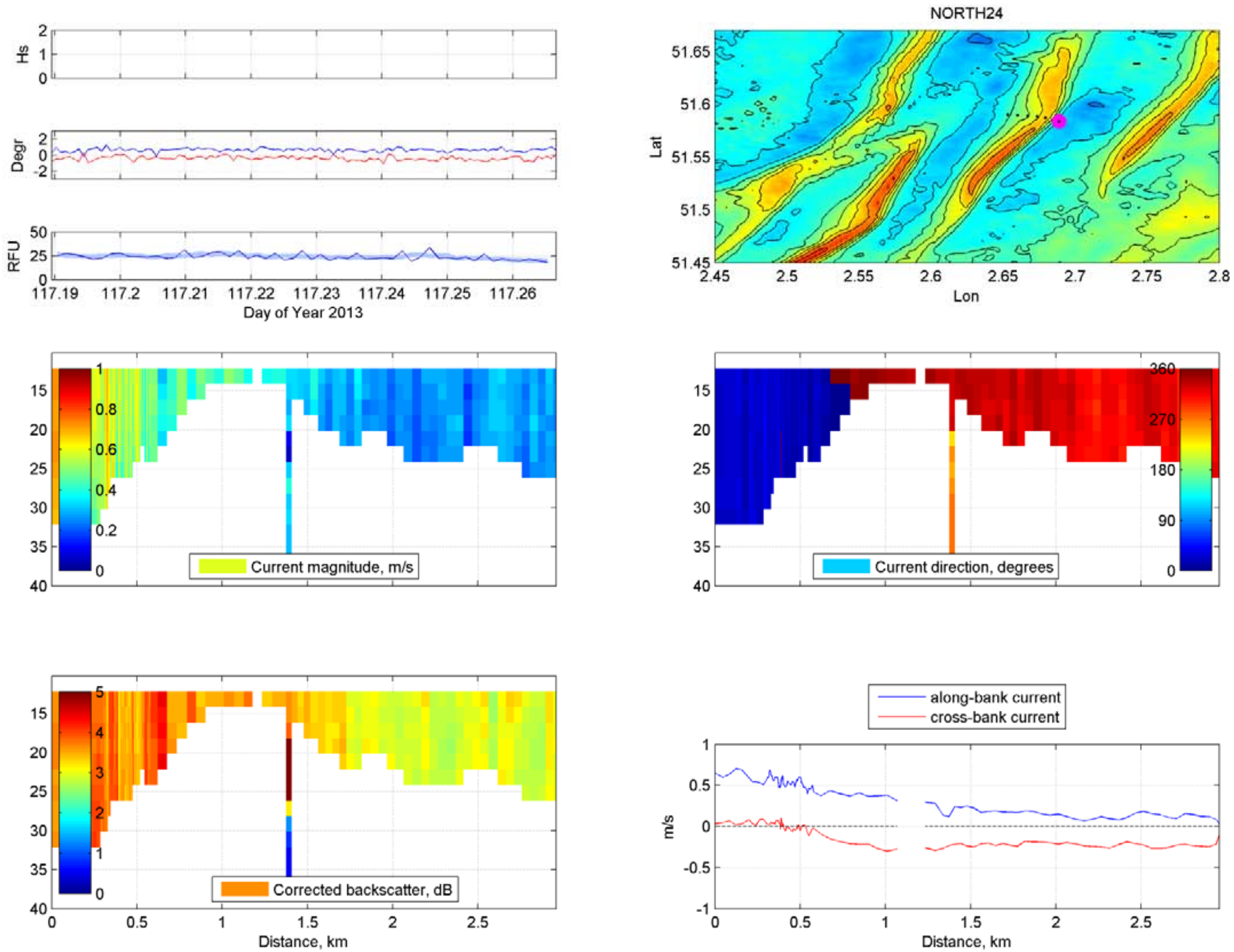
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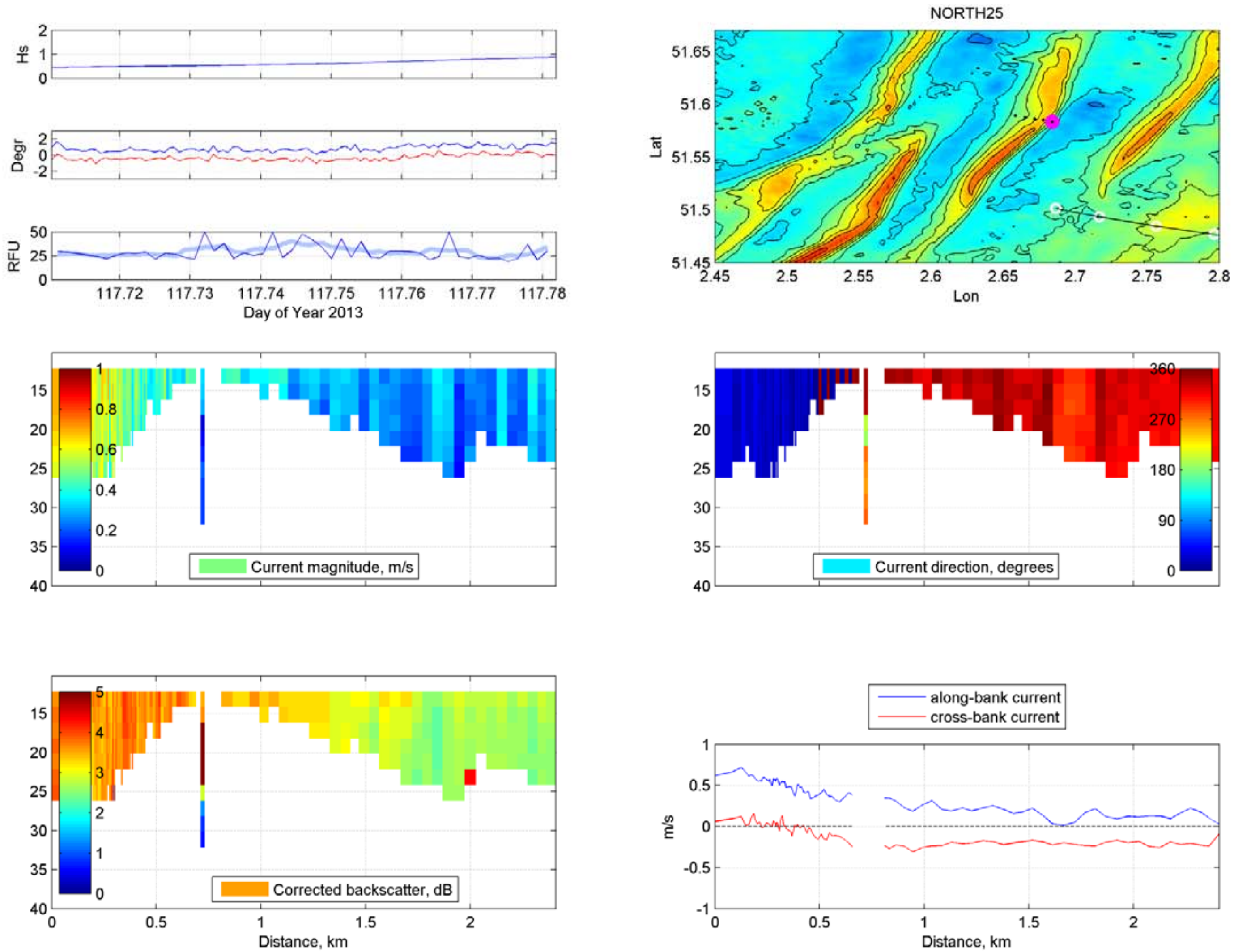

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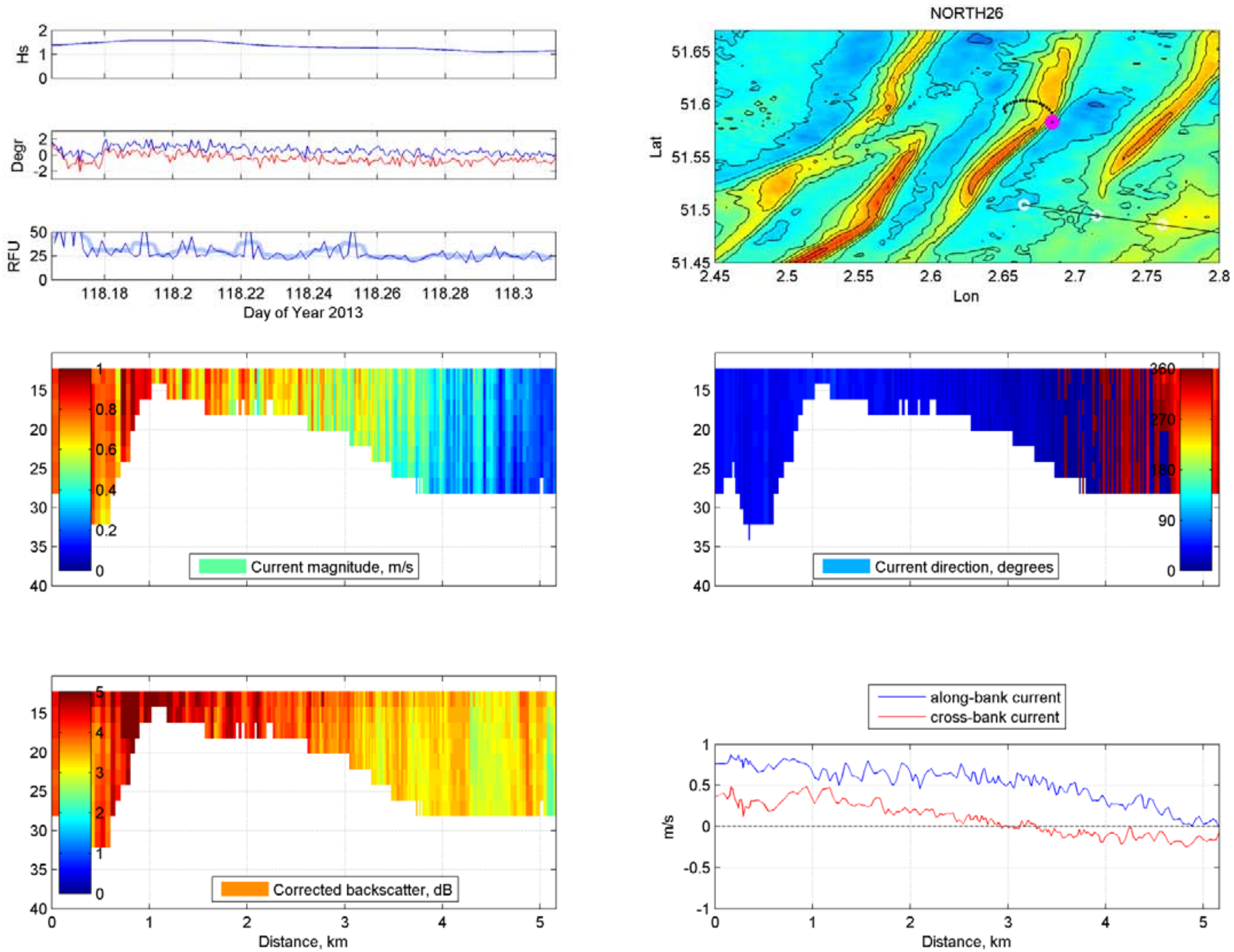

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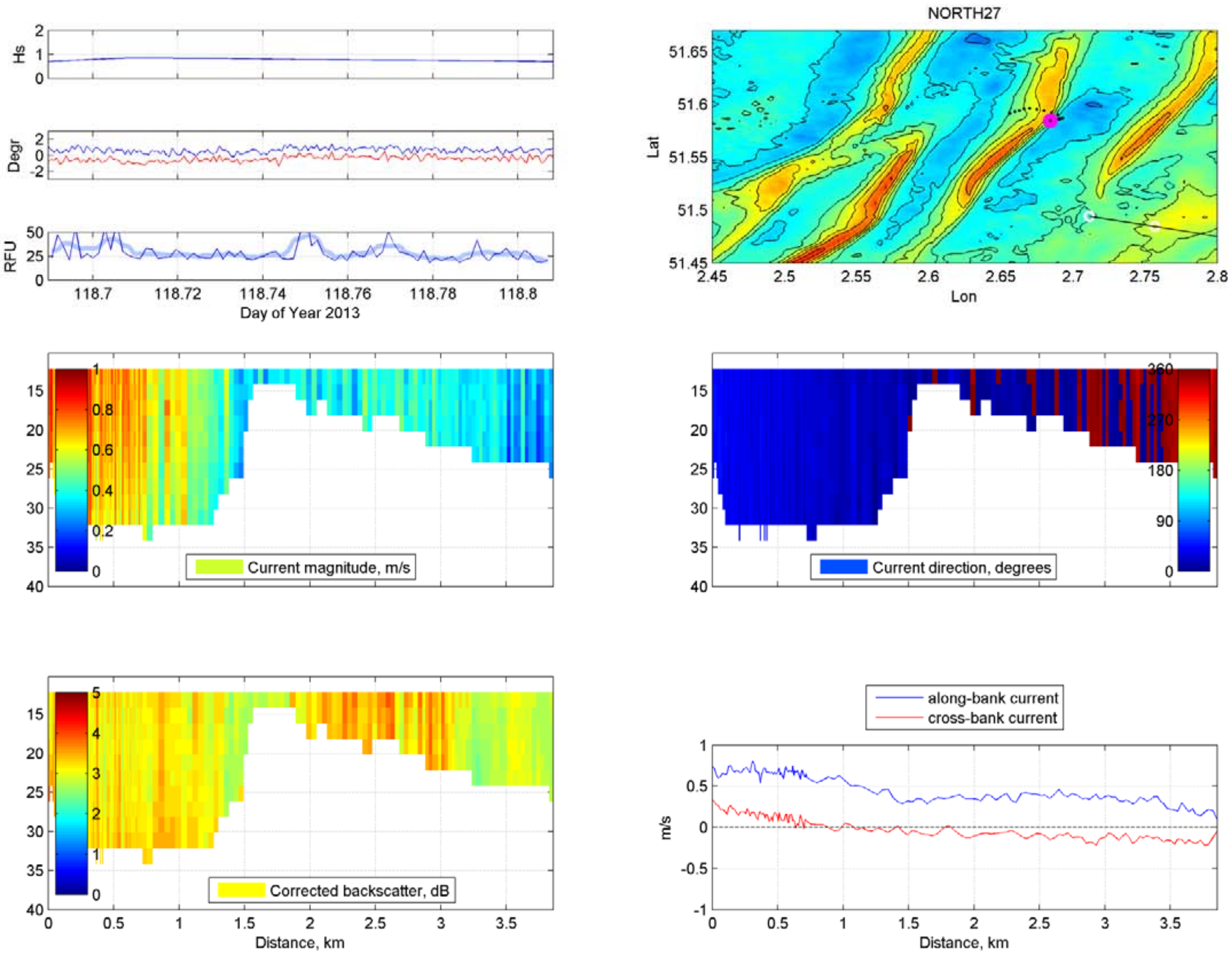
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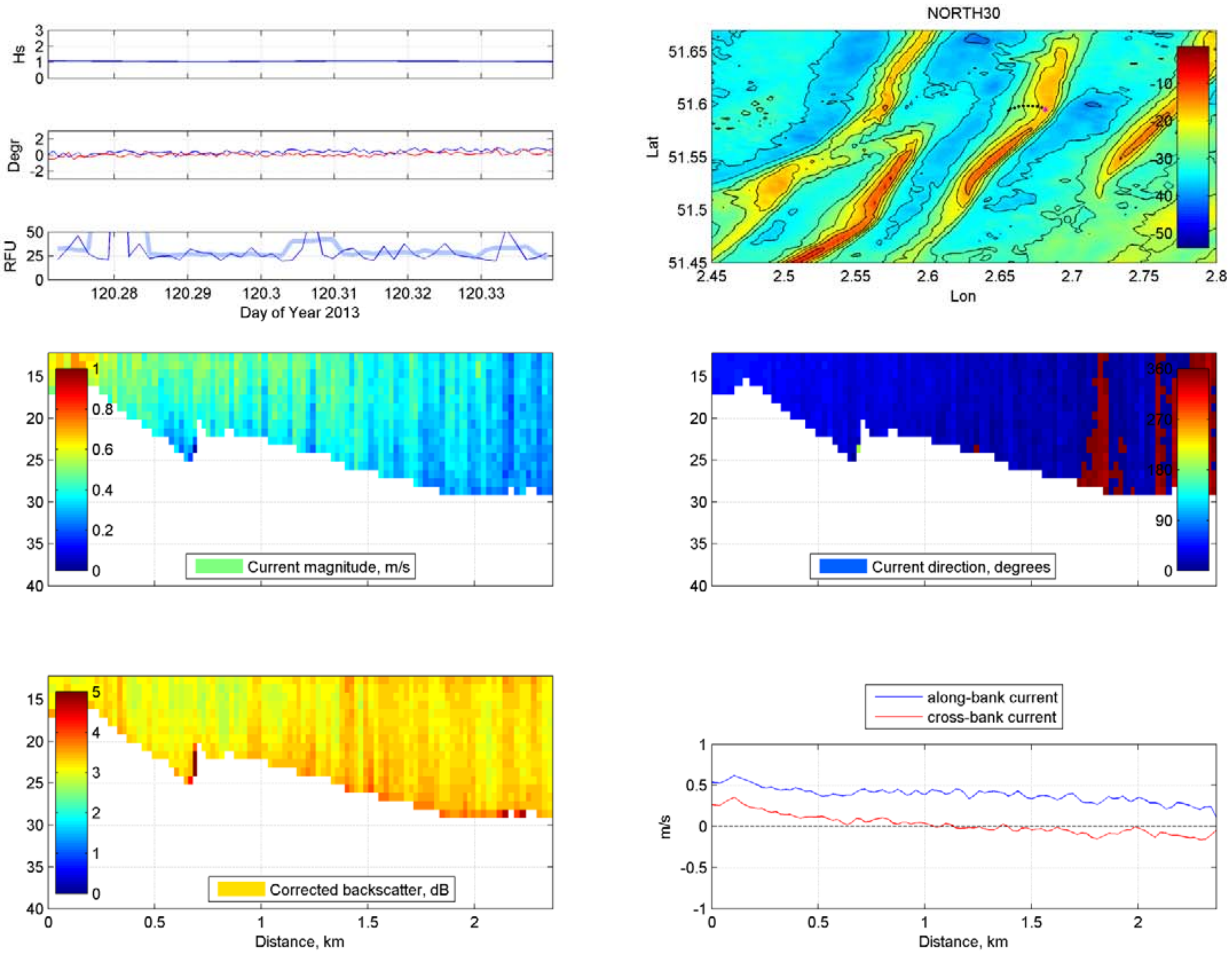
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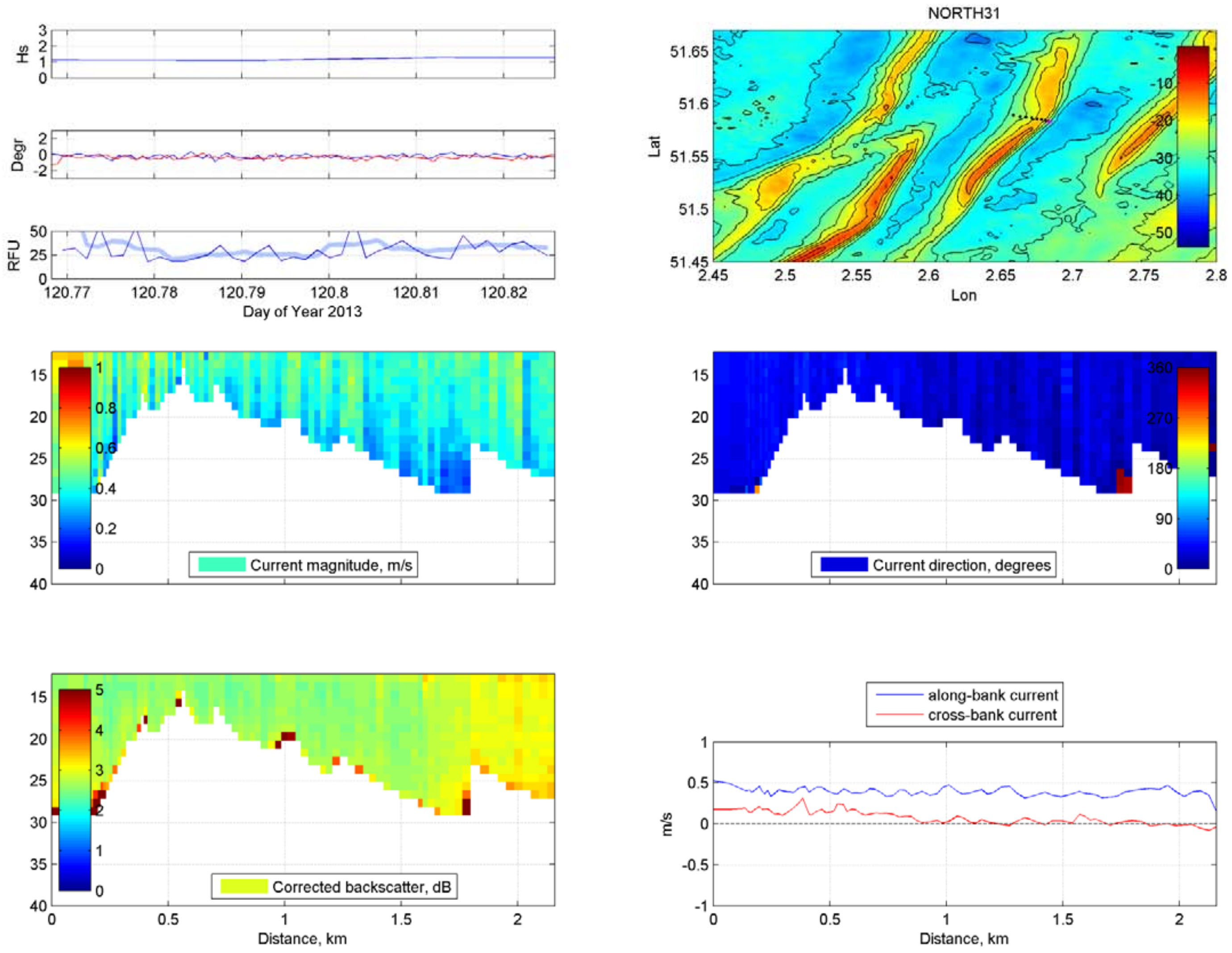

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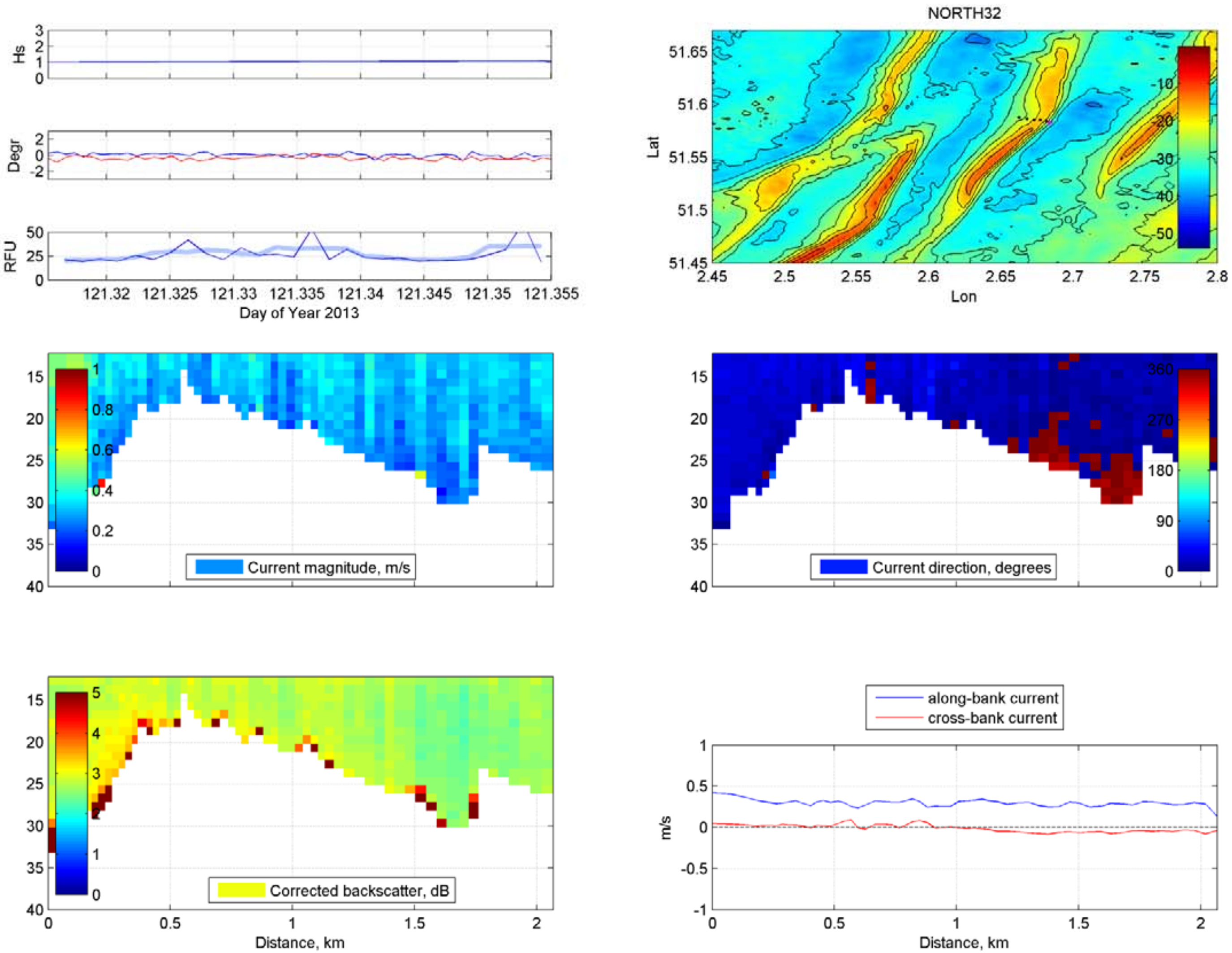

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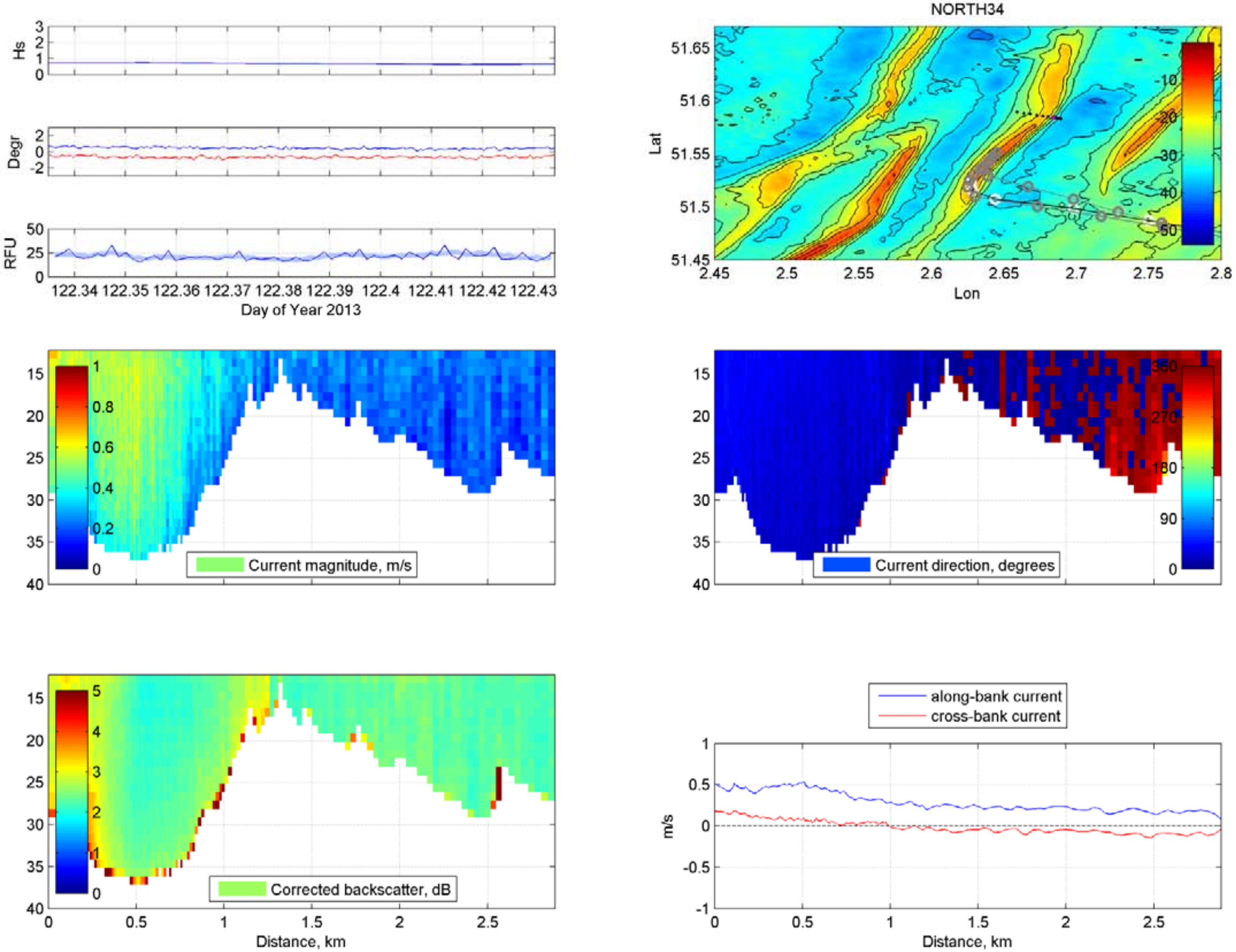
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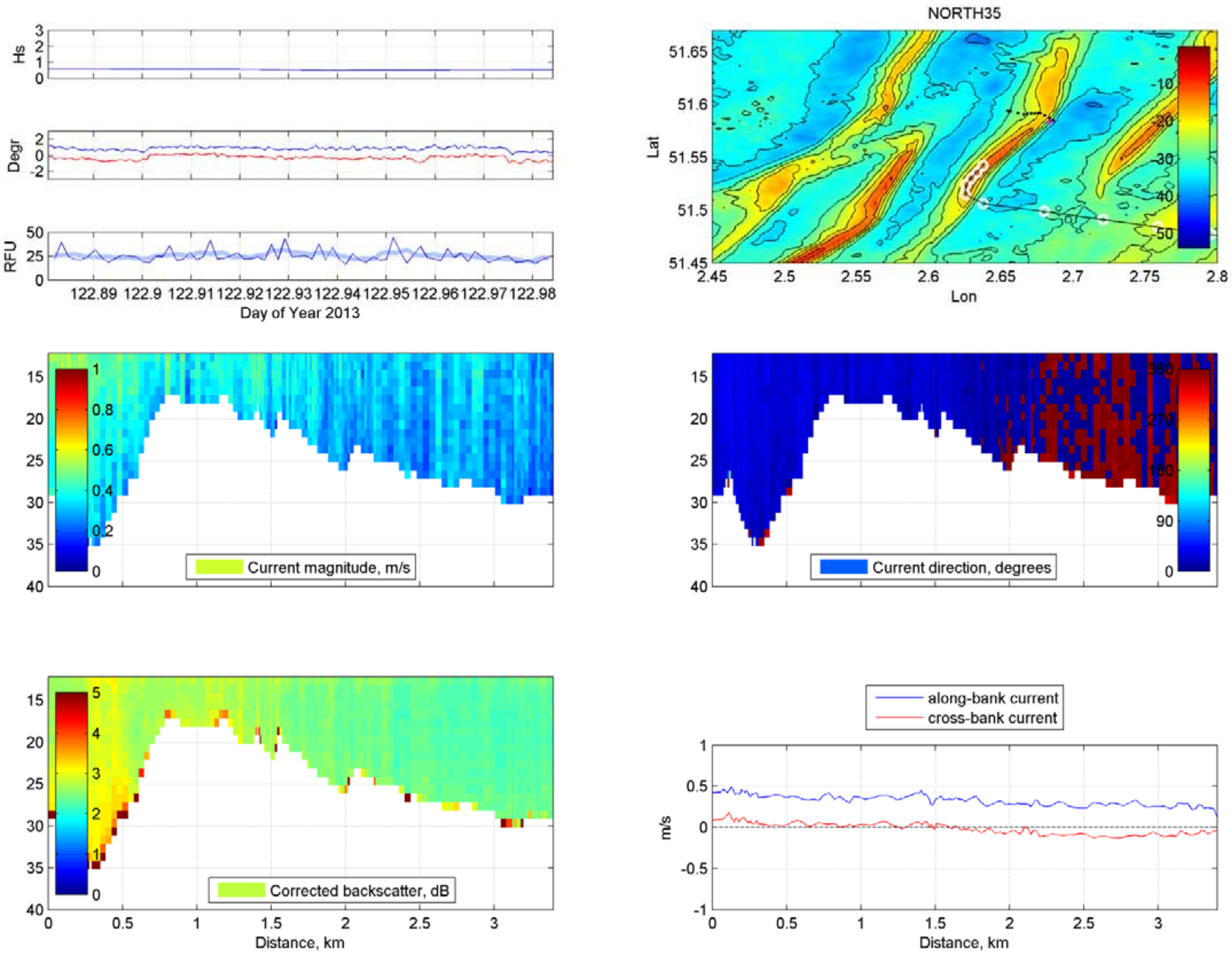
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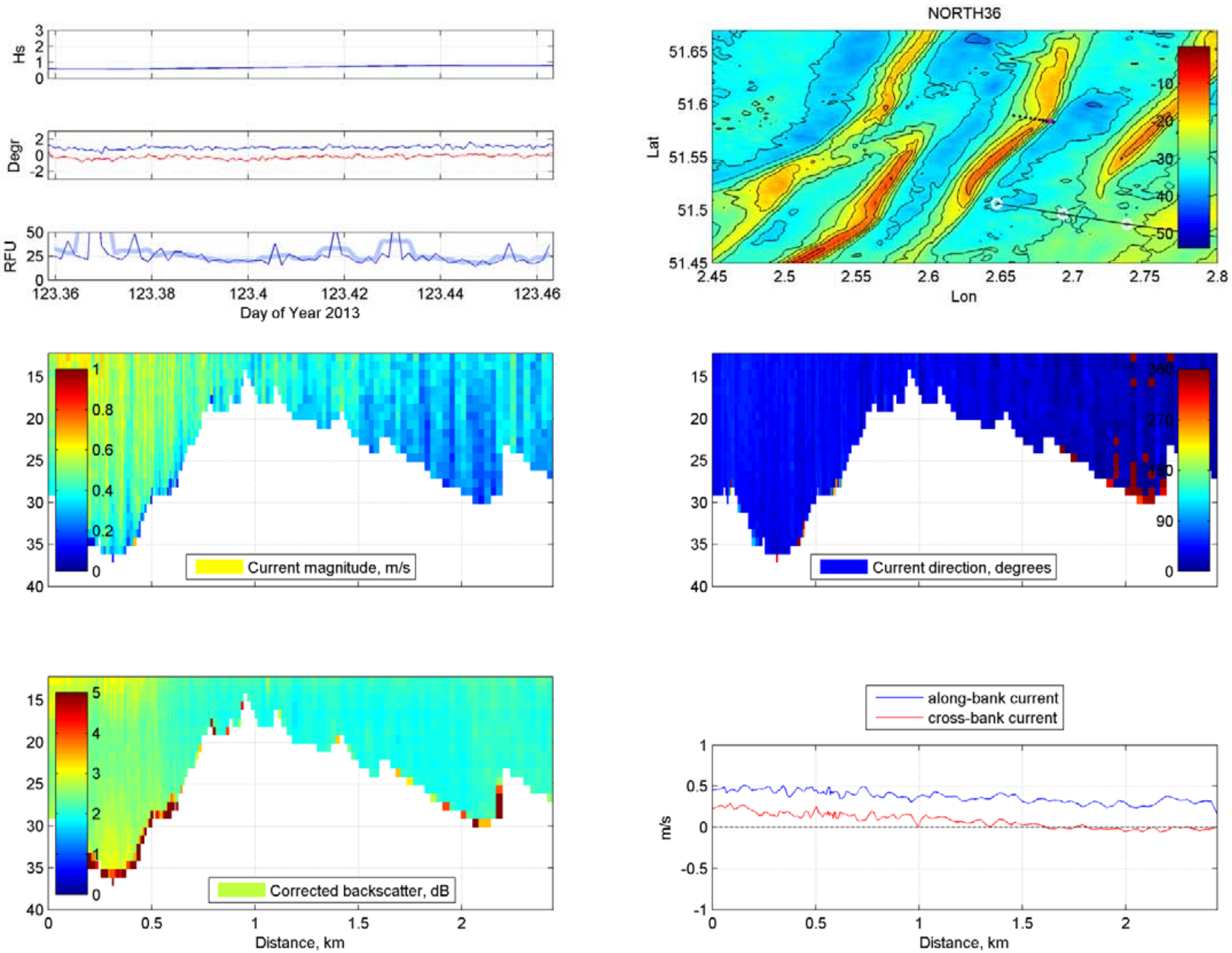
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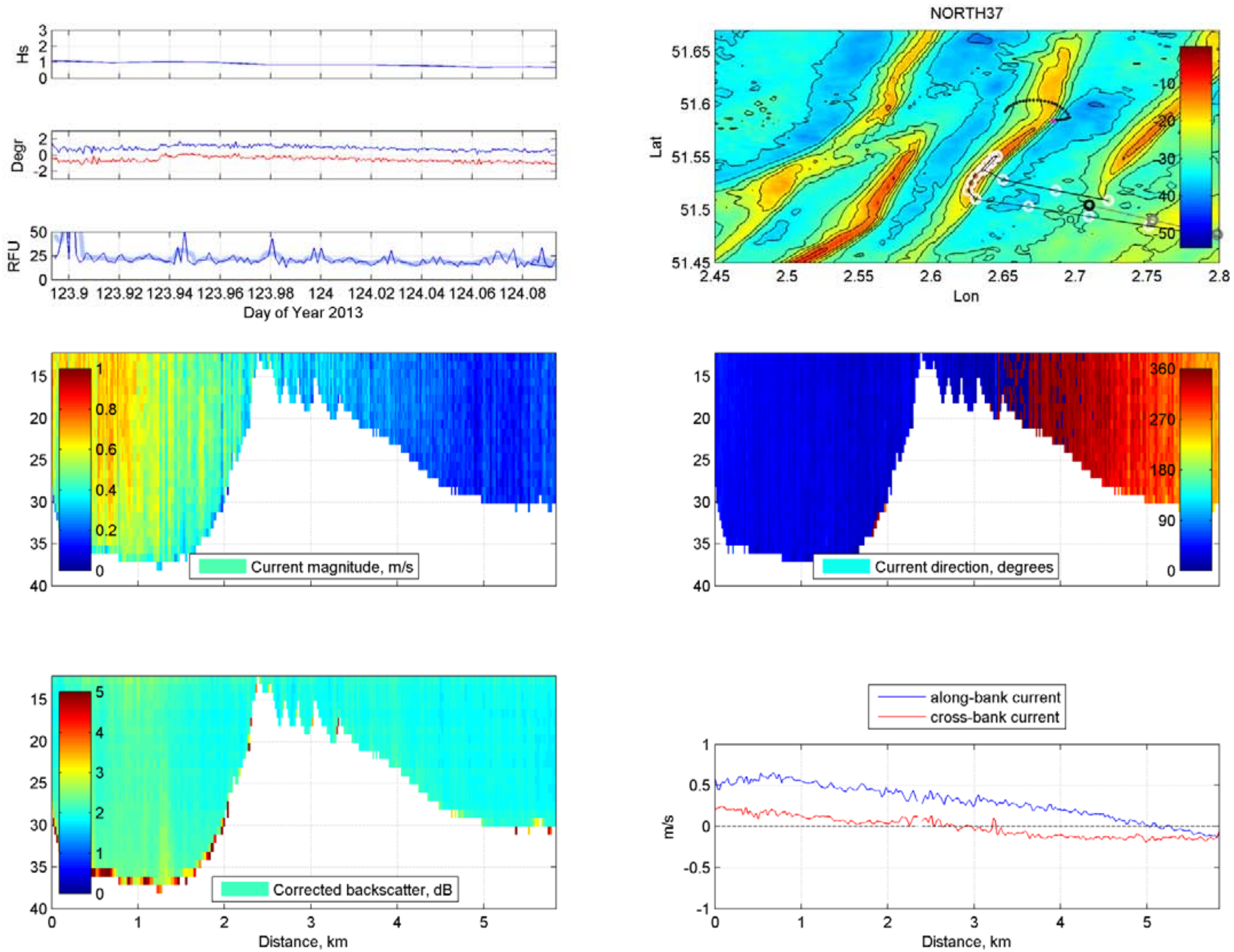
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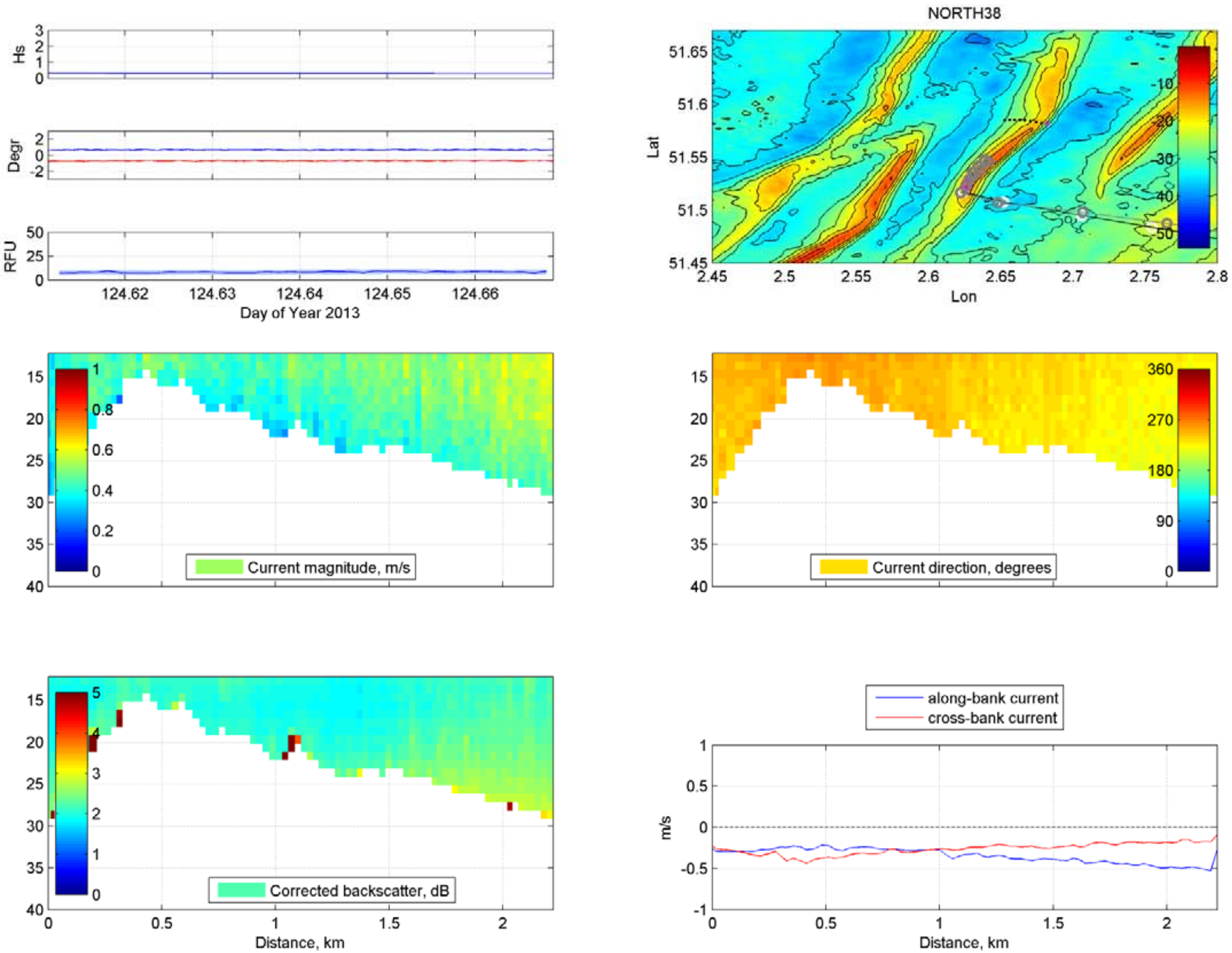

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❍ COLOPHON

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- ☐ revised version of document
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Annex G

Validation of the OPTOS-FIN model in marine aggregate extraction zone 4, Hinder Banks

This Annex forms part of the report:
Van Lancker, V., Baeye, M., Fettweis, M., Francken, F. & Van den Eynde, D. (2014). Monitoring of the impact of the extraction of marine aggregates, in casu sand, in the zone of the Hinder Banks. Brussels, RBINS-OD Nature. Report <MOZ4-ZAGRI/X/VVL/201401/EN/SR01>.

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OPERATIONAL DIRECTORATE NATURAL ENVIRONMENT

SECTION ECOSYSTEM DATA ANALYSIS AND MODELLING
SUSPENDED MATTER AND SEABED MODELLING AND MONITORING GROUP

Validation of the OPTOS-FIN model in marine aggregate extraction zone 4, Hinder Banks

Dries Van den Eynde, Matthias Baeye and Vera Van Lancker

ZAGRI-MOZ4/X/DVDE/201401/EN/TR/1

Prepared for ZAGRI and MOZ4 projects

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1. Introduction

In this report, the validation of the OPTOS-FIN model is discussed, that was performed in the framework of the ZAGRI/MOZ4 projects. This model will be used to model the currents in the MOZ4 zone, for modelling the sand transport and the sediment plumes in the area. The OPTOS-FIN model has already been validated in the framework of the BOREAS project, but has never been validated for the MOZ4 zone specifically. Since in the framework of the ZAGRI/MOZ4 project, different current measurements have been executed with bottom-mounted and hull-mounted Acoustic Doppler Current Profilers (ADCPs), these measurements will be used to validate the results in the area.

In a first section the models are presented, together with the validation exercises that were already performed prior to this study. The measurements are shortly presented and the results of the validation are given in the second section. Some conclusions are put forward in the last section.

2. Numerical models

2.1. *Introduction*

On the Belgian Continental Shelf, two three-dimensional hydrodynamic models are commonly used for the calculation of the water elevations and the currents. The OPTOS-BCZ model is a model with a resolution of about 800 m x 770 m, while the OPTOS-FIN model uses a three times higher resolution of about 270 m x 260 m. While in the framework of the ZAGRI/MOZ4 project, the OPTOS-FIN model will be used for the sediment transport calculations, both models will be discussed here. Indeed, the OPTOS-BCZ model provides the boundary conditions for the OPTOS-FIN model and as such the quality of the results of this model is also of concern.

Both models will be discussed shortly, while also previously obtained validation results will be presented here.

2.2. *OPTOS-BCZ*

2.2.1. Hydrodynamic model

The three-dimensional hydrodynamic modelling software COHERENS (Luyten *et al.*, 1999) 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. Remark that, at present, a new version of the COHERENS software is being developed (Luyten *et al.*, 2011), mainly allowing the model to use parallel computing, while adding also some new features, like improving the numerical scheme and adding a wetting-drying mechanism, but the main (hydrodynamical) physics remain the same.

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 42.86″ in longitude (817 to 833 m) and of 25″ in latitude (772 m). The extent and the bathymetry of the model are presented in Figure 1. The model has 20 σ-layers over the vertical.

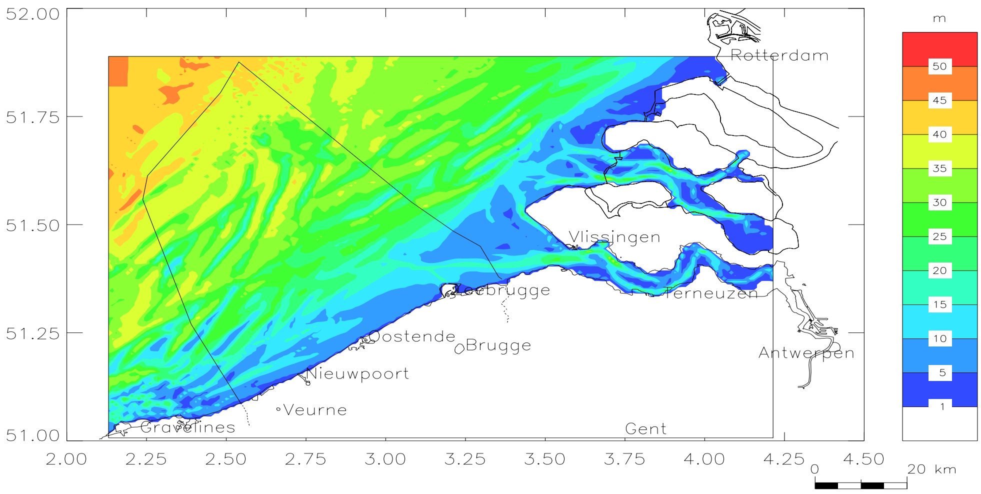


Figure 1: Bathymetry of the OPTOS-BCZ model.

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, which are calculated using four semi-diurnal and four diurnal constituents.

2.2.2. Validation

2.2.2.1. *Marebasse*

The validation of the OPTOS-BCZ model has been executed in, amongst others, the framework of the Marebasse project. In Van Lancker *et al.* (2004), this validation was reported. The main conclusions are reproduced here.

The OPTOS-BCZ model was validated extensively, using 400 hours of current profiles on the Belgian Part of the North Sea, measured with a bottom mounted Acoustic Doppler Current Profiler (ADCP), type Sentinel 1200 kHz Workhouse of RDInstruments. These data were taken over various places on the Belgian Continental Shelf, near the coast (*e.g.*, B&W Zeebrugge Oost), or more offshore (Kwintebank, Vlakte van de Raan, Sierra Ventana).

Some statistical calculations, *i.e.*, Root Mean Square Error (RMSE), bias and correlation (see Appendix A for the definition of these parameters)were calculated in order to apprehend the differences in magnitude and direction of the currents between model simulation results and ADCP measurement data.

The RMSE, which gives a global indication of the error, of the amplitude of the currents is situated between 5 and 15 cm/s (except for campaign 2003/04 where it attains 30 cm/s). The error varies in general relative little with water depth. There exist however significant differences between the campaigns. The currents in the 'deep' water campaigns are particularly well represented by the model, whereas in the less deep areas the results are less good. These areas are usually characterized by highly variable bathymetry on small horizontal scale (sand dunes), which cannot be represented accurately on the model grids. The precision of the model results depends also on the precision of the meteorological data used in the model run.

The relative error gives a view of the error as a function of the magnitude of the variable. Without surprise, one can see that the relative error is more important near the bottom where the currents are smaller, and that it is generally less than 20 % further up in the water column, except for campaign–2003/04 (see figure 2). The error during campaign 2003/04 may be related to the high variability of the wind.

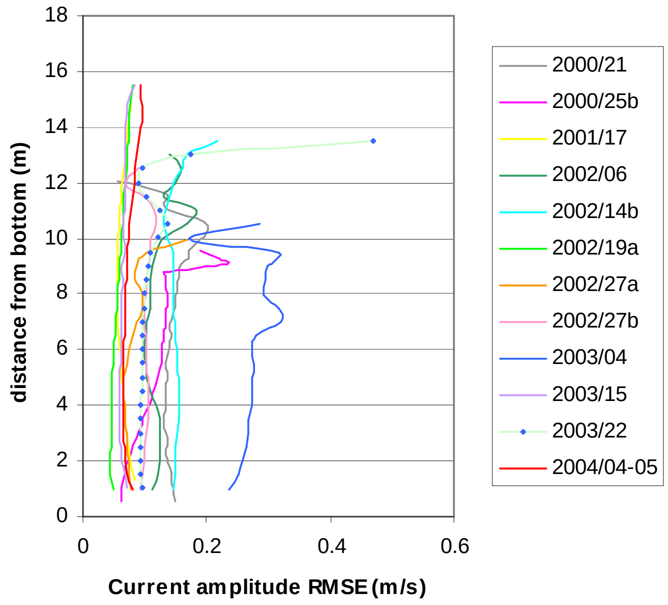


Figure 2: Root mean square error (RMSE) of the current amplitudes between model and ADCP data as a function of the distance from the bottom.

Concerning the current direction, small errors are found in the model results for most of the campaigns. The results of campaign 2000/21 and 2003/04 are less good with a vertical mean error of about 0.4 radians or 25°, which is probably caused by the fact that the wind was strong and variable and that the model cannot take this accurately into account. The model directions for most of the campaigns show also a strong increase in error near the surface. This could be due to a bad representation of the wind direction for the model or just be related to the fact that above a certain level the number of values taken into account is insufficient for a representative statistics.

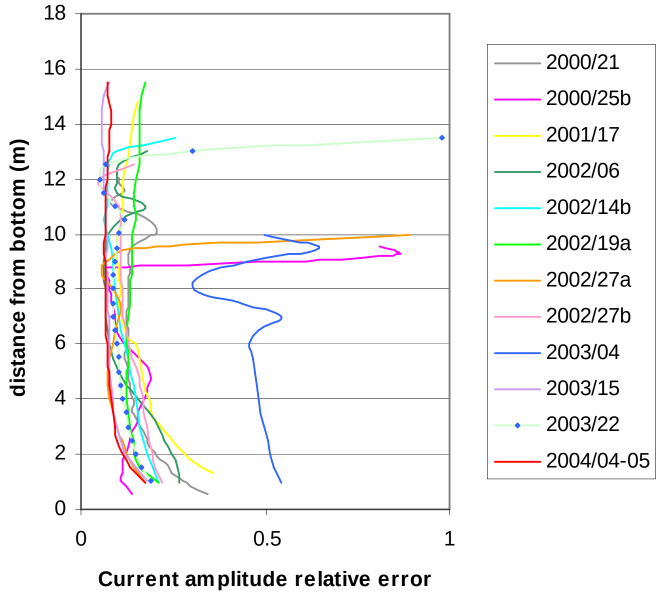


Figure 3: Relative error of the current amplitudes between model and ADCP data as a function of the distance from the bottom.

The validation exercise leads to the conclusion that the magnitude and the direction of the current profiles are satisfactory represented by the three-dimensional hydrodynamic model. The RMSE of the magnitude of the currents is usually less than 15 cm/s and the error of the direction usually is less than 20° except during some of the simulation where specific problems occurred.

More information on this validation can be found in Van Lancker *et al.* (2004).

2.2.2.2. *Boreas*

The BOREAS project (Mathys *et al.*, 2012) aimed at the assessment of the ocean energy, both tidal and wave energy, on the Belgian Continental Shelf. For this reason, the OPTOS-BCZ and the OPTOS-FIN models were applied to calculate the currents and the possible ocean energy, due to currents. The models were validated in the framework of the project first.

To validate the currents (Dujardin *et al.*, 2010), ADCP measurements at three stations near the harbour of Zeebrugge (Wandelaar, A2-buoy and Bol Van Heist) were used for a period of three months (October-December 2006). Unfortunately, some questions on the quality of the measurement data were raised. First of all, the upper bin and the second bin, below the water surface, seemed suspicious and could not be taken into account. Furthermore, a shift in the level of the currents measurements seemed to be existent, which was "corrected" by a shift of the measurement data.

The results of the validation showed that the RMSE values increase with depth at the Wandelaar and the Bol van Heist, and decreased with depth for the A2-buoy. The OPTOS-BCZ shows a bias between 0.034 m/s (bin3, ~3 m below the water surface) and -0.121 m/s (bin6, ~11 m below water surface) at the Wandelaar and Bol van Heist stations, and between -0.075 m/s and -0.118 m/s for the A2-buoy. Overall, the currents are underestimated by the model.

The RMSE varied between 0.130 m/s to 0.145 m/s for station Wandelaar, 0.188 m/s to 0.211 m/s for station Bol van Heist and 0.170 m/s and 0.203 m/s for station A2-buoy.

Overall, one can conclude that the validation with these measurements didn't gave the same results as the results of the Marebasse validation exercise. However, this could be caused by the less good quality of the measurements that were used for the exercise.

Remark that in the framework of the BOREAS project, the model results were also compared with the LTV model, a three-dimensional hydrodynamic model, used by Flanders Hydraulics Research (FHR). The LTV model gave similar results. While the results were less good at the Bol van Heist, with a larger underprediction and a larger RMSE, the results were slightly better at Wandelaar.

2.3. *OPTOS-FIN*

2.3.1. Model

In addition to the OPTOS-BCZ model, a hydrodynamic model with a higher resolution, OPTOS-FIN, is used to calculate the water levels and the currents on the Belgian Continental Shelf. This model is also based on the COHERENS model. The model has a resolution which is three times higher than the resolution of the OPTOS-BCZ model, *i.e.* 14.29" in longitude (272 to 278 m) and 8.33" in latitude (257 m). This model has a 10 σ-layers distribution of the depth. The model is coupled at the open boundaries with the OPTOS-BCZ model. The bathymetry of this model, which is less extended to the east, is shown in Figure 4.

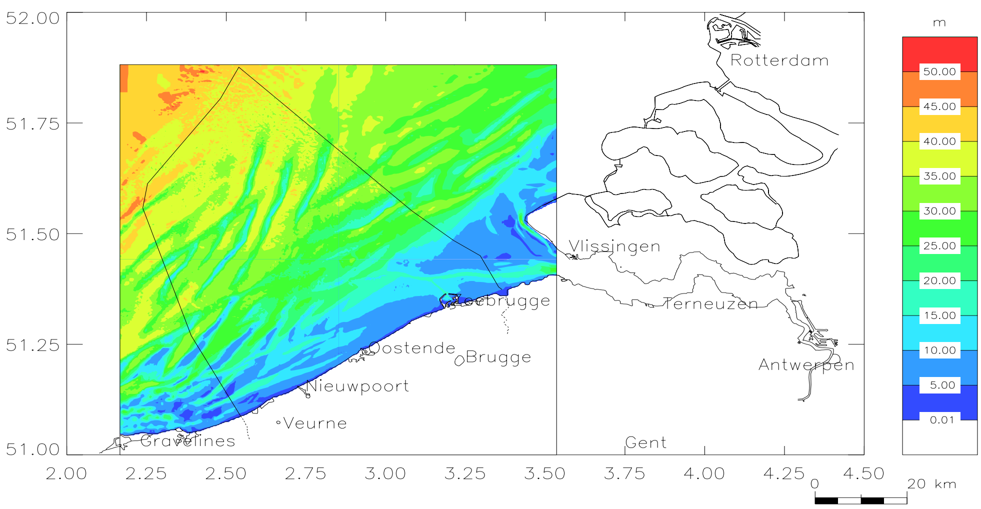


Figure 4: Bathymetry of the OPTOS-FIN model.

2.3.2. Validation

2.3.2.1. *Marebasse*

In the framework of the Marebasse project, also a validation of the OPTOS-FIN model was executed. The model was used for the calculation of the effects of sand extraction on the sediment transport on the Kwinte Bank and a validation was performed. The results are reported in Van den Eynde *et al.* (2010).

For the validation, measurements from a bottom mounted Acoustic Doppler Current Profiler (ADCP) were used, which were executed on the Kwinte Bank, during two measuring campaigns. The RMSE are presented in Table 1. For the longer March 2004 period, the RMSE of the magnitude of the depth-averaged currents calculated by the OPTOS-FIN model is around 0.072m/s, which is clearly satisfying.

Table 1: RMSE of the U-component (RMSE U), RMSE of the V-component (RMSE V) and RMSE of the magnitude of the depth-averaged current (RMSE) for the OPTOS-FIN model.

Start of campaign	Period	RMSE U (m/s)	RMSE V (m/s)	RMSE (m/s)
11/06/2003	25h	0.140	0.119	0.127
02/03/2004	216h	0.069	0.083	0.072

2.3.2.2. *BOREAS*

In the framework of the BOREAS project (Mathys *et al.*, 2012), also the OPTOS-FIN was validated with the same current measurements.

The results of the OPTOS-FIN model are similar as the results of the OPTOS-BCZ model, discussed above in Section 2.2.2.2. Also for the OPTOS-FIN model, the RMSE values increase with depth at the Wandelaar and the Bol van Heist, and decreased with depth for the A2-buoy. The OPTOS-FIN shows a bias between 0.020 m/s (bin3, ~4 m below the water surface) and -0.138 m/s (bin6, ~11 m below the water surface) at the Wandelaar and Bol van Heist stations, and between -0.082 m/s and -0.124 m/s for the A2-buoy. The measured currents are, for this case, even more underestimated by the OPTOS-FIN model than by the OPTOS-BCZ model.

The RMSE varied between 0.125 m/s to 0.158 m/s for station Wandelaar, 0.149 m/s to 0.218 m/s for station Bol van Heist en 0.172 m/s and 0.198 m/s for station A2-buoy. These results are similar as the results of the OPTOS-BCZ model. The RMSE is a little bit smaller higher in the water column, and a little bit lower near the bottom.

One can again conclude that the validation with these measurements didn't gave the same results as the results of the Marebasse validation exercise, but that this probably is caused by the less good quality of the measurements, that were used for the exercise.

3. Validation using ADCP measurements

3.1. *Overview of the ADCP measurements*

For the validation of the currents in the MOZ4 area, different measurement campaigns have been executed. An overview of the different measurements is given in Table 2.

Table 2: ADCP measurements

Code	Pos.	Freq (kHZ)	Start	End	Δt (s)	#bins	First bin (m)	Bin size (m)
BM01	Bottom	1200	28/06/2012	04/07/2012	600	79	0.81	0.25
BM02	Bottom	1200	29/03/2013	25/04/2013	600	119	0.80	0.25
HM01	Hull	300	25/10/2011	26/10/2011	60	30	3.09	1.00
HM02	Hull	300	26/10/2011	27/10/2011	60	30	3.09	1.00
HM03	Hull	300	19/03/2012	20/03/2012	60	40	3.08	1.00
HM04	Hull	300	21/03/2012	22/03/2012	60	40	3.08	1.00
HM05	Hull	300	22/03/2012	23/03/2012	60	40	3.08	1.00
HM06	Hull	300	02/07/2012	03/07/2012	60	40	3.09	1.00
HM07	Hull	300	03/07/2012	04/07/2012	60	40	3.09	1.00
HM08	Hull	300	16/10/2012	16/10/2012	60	100	0.59	0.50
HM09	Hull	300	18/10/2012	19/10/2012	60	100	0.59	0.50
HM10	Hull	300	26/03/2013	27/03/2013	60	100	0.58	0.50
HM11	Hull	300	01/07/2013	02/07/2013	60	128	0.47	0.25
HM12	Hull	300	02/07/2013	03/07/2013	60	128	0.49	0.30
WG01	Wave G	300	15/04/2013	21/04/2013	60	45	2.32	1.00
WG02	Wave G	300	22/04/2013	30/04/2013	60	23	4.18	2.00
WG03	Wave G	300	01/05/2013	06/05/2013	60	46	3.20	1.00

3.2. *Bottom mounted ADCP*

Two measuring campaigns have been executed with a bottom mounted ADCP. The measurements have been executed on the same place at (51° 30.6′ N, 2° 37.94). The ADCP was located east of the southern part of the Oosthinder, see Figure 5. The first measurements took a period of 6 days and used 79 bins of 0.25 m. Given the system frequency (300 kHz), the measurements in this case didn't cover the entire water column. The second campaign lasted for almost 27 days.

The ADCP measurements had a time step of 10 minutes. To compare them with the model results, the measurements were averaged over a time step of 30 minutes.

3.2.1. Total water depth

The total water depth, as calculated by the model, is compared with the water depth, calculated from the bottom mounted ADCP, for the second measuring campaign and is shown in Figure 6. A bias of about 2.0 m is observed between the two mean water depths. This is quite large, but might be due to differences in the bathymetry. Since the bathymetry of the numerical model is supposed to be a mean water depth over the entire grid cell, while the ADCP measures the water depth in the actual point, some differences in total water depth may occur. The unsystematic RMSE (not taking into account the effect of the bias – see Appendix A) is only 0.47 m, while the correlation coefficient between the modelled and the measured total water depth is 0.90.

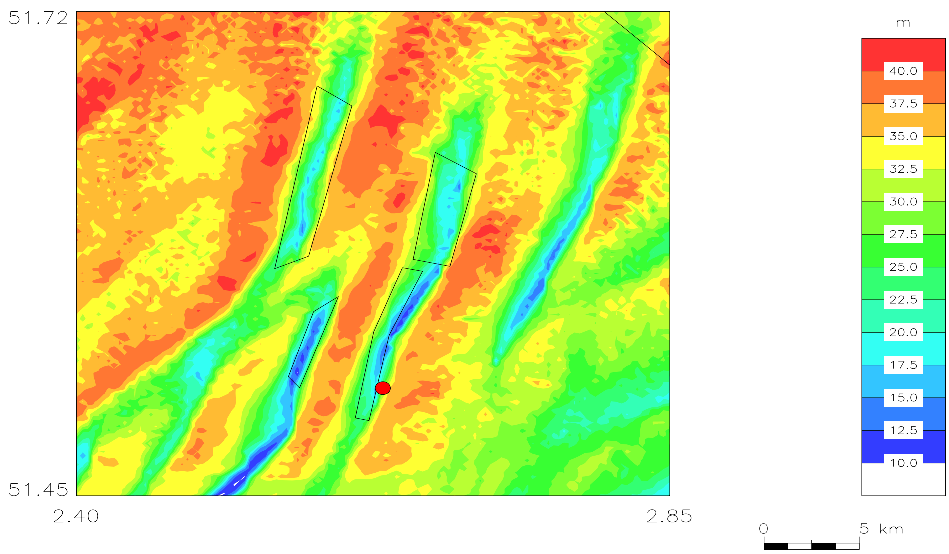


Figure 5: Position of the bottom mounted ADCP.

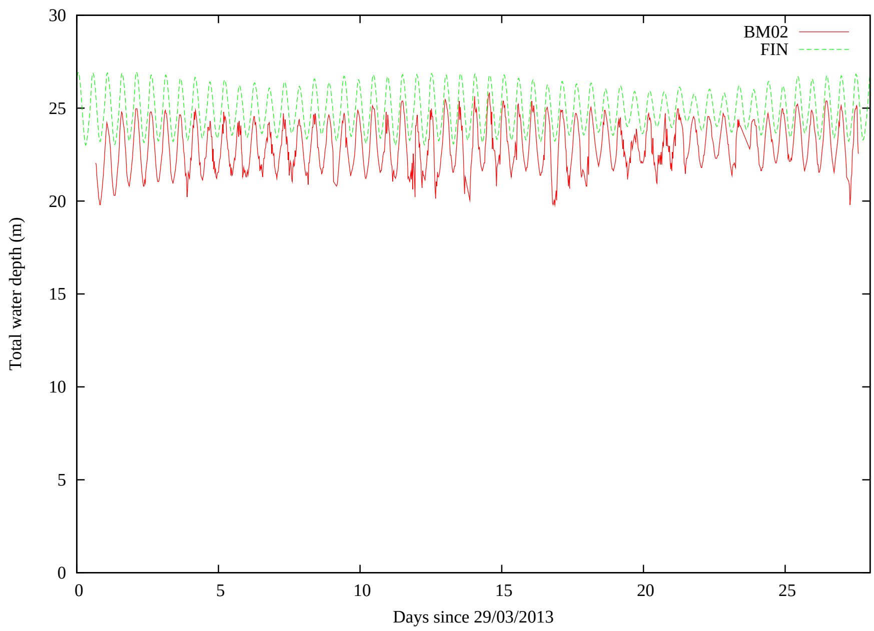


Figure 6: Total water depth from the bottom-mounted ADCP (BM02) and from the OPTOS-FIN model (FIN).

3.2.2. Depth-averaged currents

First of all, the depth-averaged currents from the bottom mounted ADCP are compared with the model results. The measurements are first averaged over depth and further averaged over time, to obtain time series with a time step of 30 minutes. In Figure 7 the depth-averaged currents and current directions are presented for the first measuring campaign.

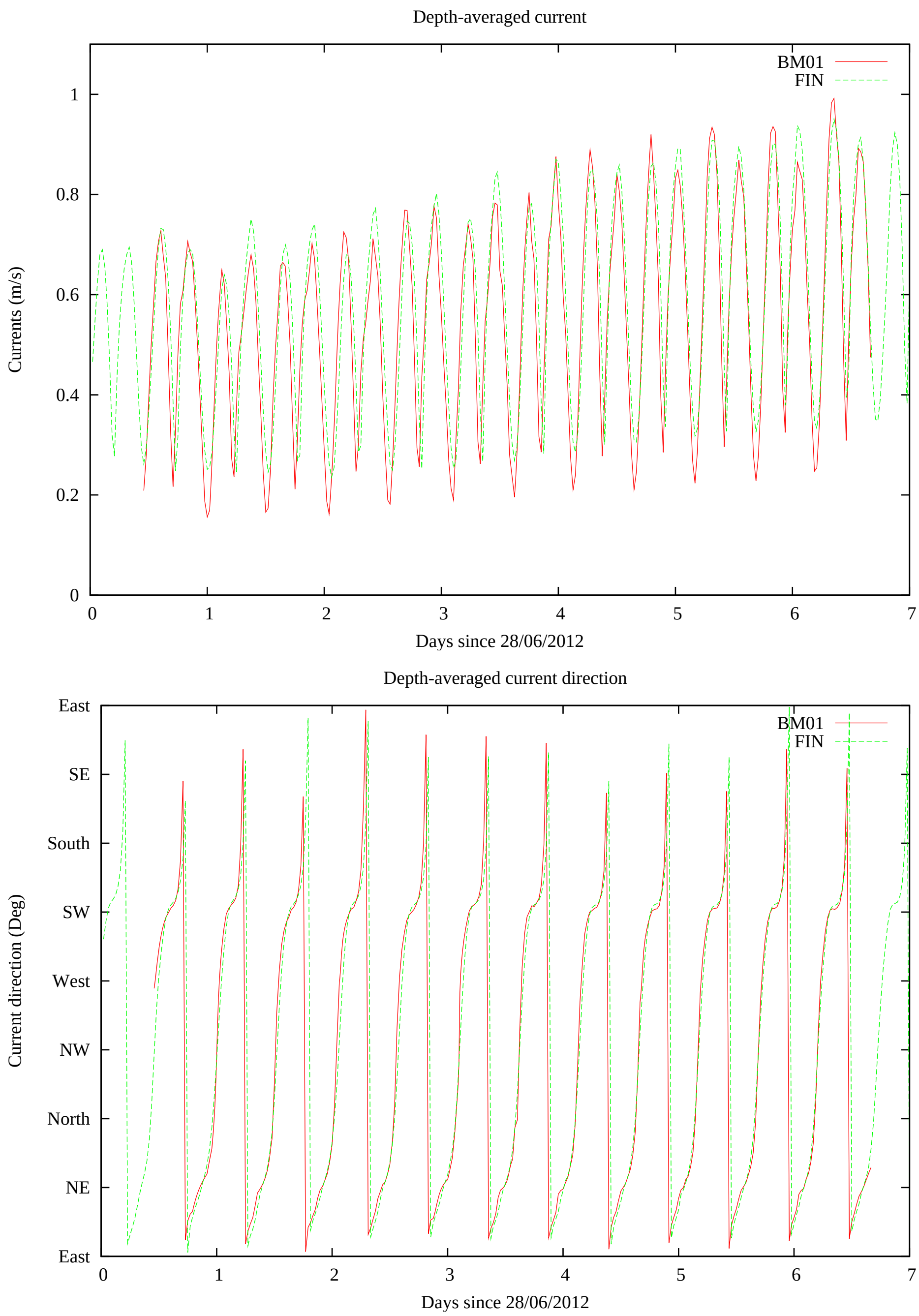


Figure 7: Depth-averaged current magnitude (top) and current direction (bottom) from the bottom-mounted ADCP (BM01) and from the OPTOS-FIN model (FIN).

The current magnitudes and current directions are quite well reproduced by the model, with however some overprediction of the currents, certainly for the slack waters. Some statistical results are presented in Table 3. The scatter plots for the current magnitudes and current directions are shown in Figure 8.

Table 3: Number of comparison points (Numb.), Bias, RMSEand S.I. for the depth-averaged current magnitude and direction.

Campaign		Current magnitude				Current direction		
	Numb.	Bias (m/s)	RMSE (m/s)	Corr	S.I. (%)	Bias (deg.)	RMSE (deg.)	Corr
BM01	299	0.031	0.086	0.922	15.5	-8.2	17.6	0.990
BM02	1293	-0.034	0.090	0.924	15.3	-3.9	14.1	0.992

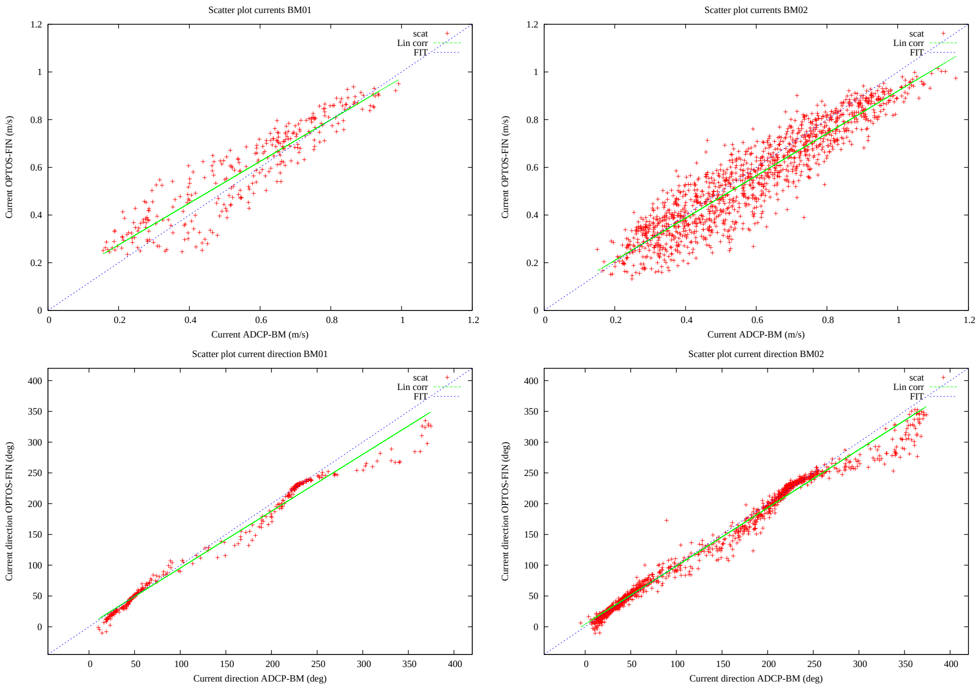


Figure 8: Scatter plots for the depth-averaged current magnitude (upper) and current direction (lower) for the measuring campaigns BM01 (left) and BM02 (right).

The statistical results show a small overprediction of the current magnitude for the first campaign (+3 cm/s) and a small underprediction for the current magnitude during the second campaign (-3 cm/s), while the RMSE is about 9 cm/s for both campaigns. The scatter plot shows, that the main underprediction in the second campaign is due to a underprediction of the higher currents. Also the current direction is very well modelled, with a bias of -8° and -4° for the first and second campaign respectively and a RMSE of 18° or 14°. Also the scatter plots show a good comparison between measured and modelled current directions. Only for directions between 300° and 360°, the model seems to underpredict the directions, meaning that the turning from ebb to flood seems to be too late. Overall, the results of the model are clearly satisfactory.

3.2.3. Currents at the bottom and surface

It is also of interest to see whether the three-dimensional structure of the currents are well reproduced by the hydrodynamic model. Therefore at three levels in the water column, the ADCP-measurements are compared with the model results. Comparisons are performed near the bottom, at ADCP-bin 8 at 2.55 m above the bottom, in the middle of the water column, at ADCP-bin 43, at 11.30 m above the bottom, and near the water surface, at ADCP-bin 78, at 20.05 m above the bottom. In Figure 9, the current magnitude and current directions at the three water levels are shown for measuring campaign BM01. Some statistical results are presented in Table 4.

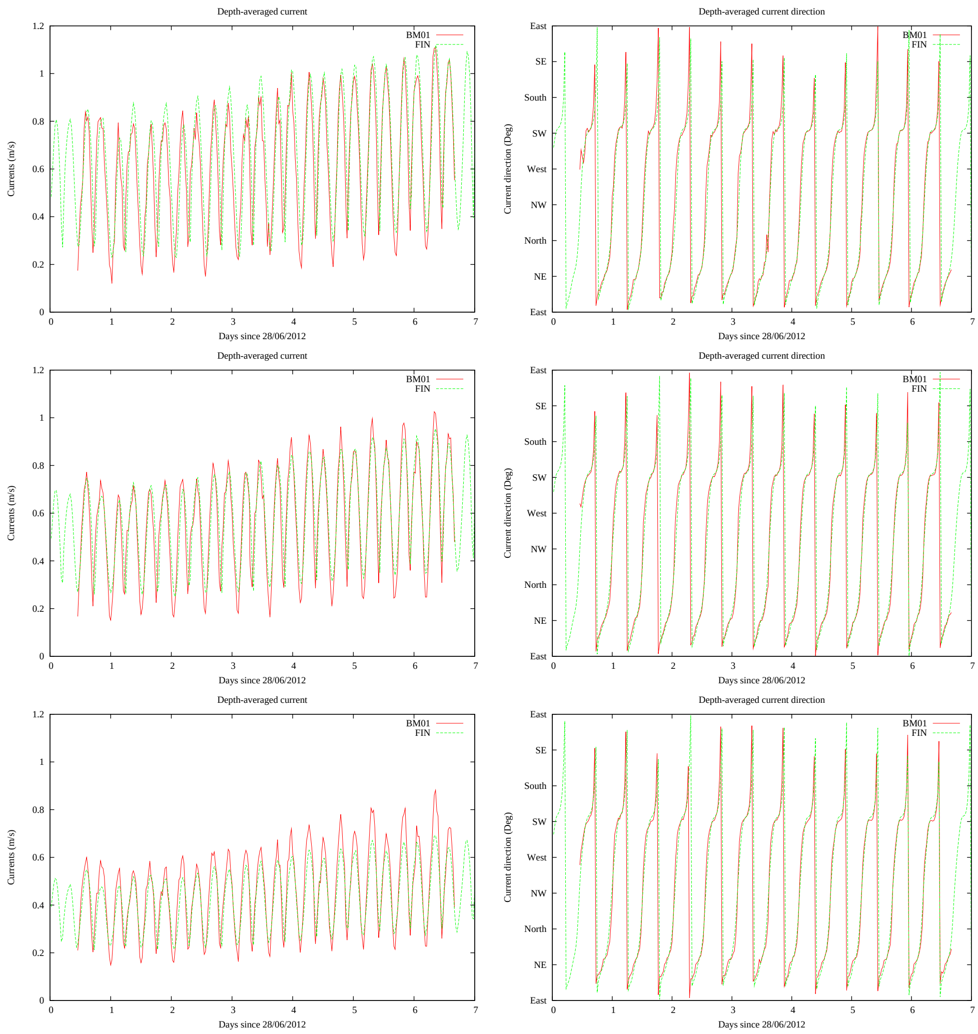


Figure 9: Currents magnitude (left) and current direction (right) for measuring campaign BM01 at the surface (20.06 meter above bottom - upper), middle of the water column (11.31 m above bottom - middle) and near the bottom (2.56 m above bottom – lower).

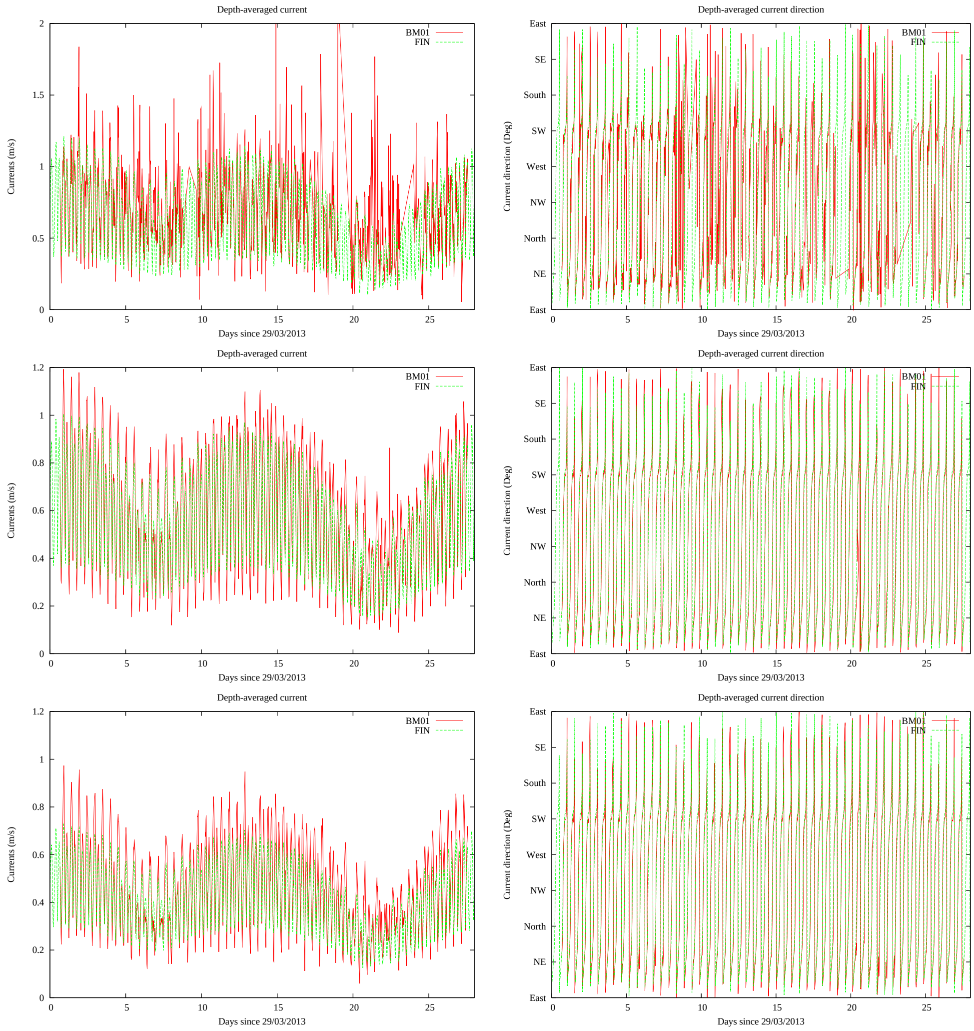


Figure 10: Currents magnitude (left) and current direction (right) for measuring campaign BM02 at the surface (20.05 meter above bottom - upper), middle of the water column (11.30 m above bottom - middle) and near the bottom (2.55 m above bottom – lower).

Table 4: Campaign (Cmp.), height of the measurement above the bottom (Hght.), number of comparison points (Num.), Bias, RMSE and S.I. for the current magnitude and direction.

Cmp.	Hght.	Current magnitude					Current direction		
		Num.	Bias	RMSE	Corr	S.I.	Bias	RMSE	Corr
	(m)		(m/s)	(m/s)		(%)	(deg.)	(deg.)	
BM01	20.06	299	0.039	0.123	0.887	0.197	-9.6	20.1	0.987
	11.31	299	0.013	0.079	0.935	0.138	-6.8	16.9	0.990
	2.56	299	-0.027	0.065	0.956	0.141	-5.6	15.3	0.990
BM02	20.05	1015	-0.054	0.278	0.550	0.396	-1.1	45.5	0.894
	11.30	1293	-0.026	0.095	0.934	0.163	-2.4	13.2	0.993
	2.55	1293	-0.045	0.084	0.943	0.183	-1.9	13.0	0.992

First of all, one remarks that the measurements near the surface during the second campaign BM02 are not of good quality. This can be clearly seen in Figure 10, both for the current magnitude as for the current direction. This is also clearly shown in the statistical results with a RMSE which is more than 2 times larger than the RMSE in the near surface layer, during the campaign BM01.

Furthermore, one can observe, that the model tends to underpredict the currents near the bottom (bias of -2.7 cm/s and -4.5 cm/s for BM01 and BM02 respectively), but overpredict the currents near the surface (bias of 3.9 cm/s for BM01). The RMSE however stays limited and varies between 6.5 m/s and 12.3 cm/s (excluding the measurements near the surface for the second campaign). The directions seem to be well predicted by the model over the entire water column, with no clear differences between the modelled direction near the bottom or near the surface.

3.3. *Hull-mounted ADCP*

A total of 12 measuring campaigns were executed with RV Belgica, during which currents were measured, using the hull-mounted ADCP. These tracks of these campaigns are shown in Figure 11. To look at the position of the different campaigns seperately, the position of the tracks are also plotted with colors and without the bathymetry in Figure 12. Most measurements are executed in the MOZ4 area. Campaign HM02 starts near the harbour of Zeebrugge, while campaign HM03 is executed more in the north, near the Belgian-Dutch border. Campaign 9 and 12 have been executed south of the MOZ4 area, in the Habitat Directive area, near the gravel beds.

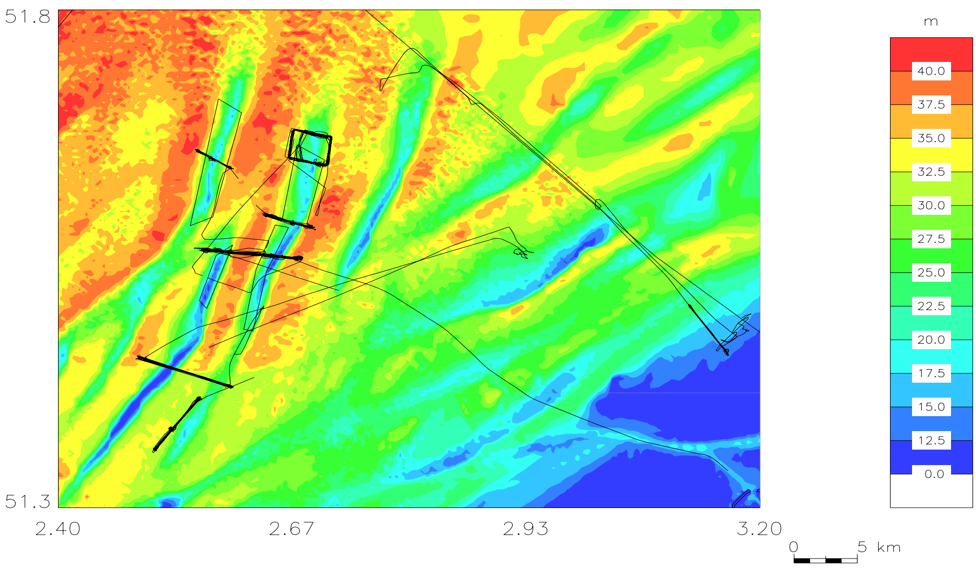


Figure 11: Tracks of the measurements with the hull-mounted ADCP.

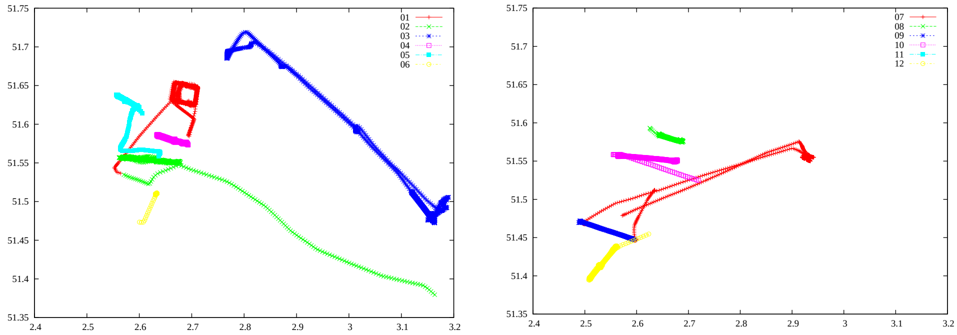


Figure 12: Tracks of the measurements with the hull-mounted ADCP.

In some campaigns, a track is repeated over a sand bank (campaigns HM02, HM04 and HM10), while in other campaigns a rectangular route has been followed (HM01).

As can be seen in Table 2, the number of bins and the bin size is not always the same over the different campaigns. While the number of bins varies between 30 and 128, the bin size varies between 1.00 m and 0.25 m. This will have consequences for the quality of the measurements as will be shown further. The time step of the measurements is 60 seconds. This is necessary to take into account the rapidly varying water depth, and the related variations in the currents.

3.3.1. Total water depth

The total water depth of the water column under the hull-mounted ADCP was compared with the model results. The measured water column is taking into account a draught of 4.5 m under the RV Belgica, and the blanking of the results in the last two layers above the sea bottom. While for the results of the bottom mounted ADCP, the measured results were averaged over 30 minutes, to filter out some noise, this was not possible here, due to the rapidly varying water depths, due to the change of position. A plot of the changing water depths for campaign HM01 is shown, together with the total water depth, as modelled by the OPTOS-FIN model. During the first period, the total water depth is rapidly varying between less than 20 m and more the 35 m. This is well reproduced by the model results. A bias of 1.1 m however is still found for this campaign, which is almost the average value found for all campaigns, see Figure 14, where for the different campaigns the bias is presented. This is possibly due to an underprediction of the draught or due to a larger blanking at the bottom of the water column. The unsystematic RMSE varies between 2 and 3.5 m, which is quite large, but which is acceptable, when taking into account the large variation of water depths and the uncertainty in the water depth measurements.

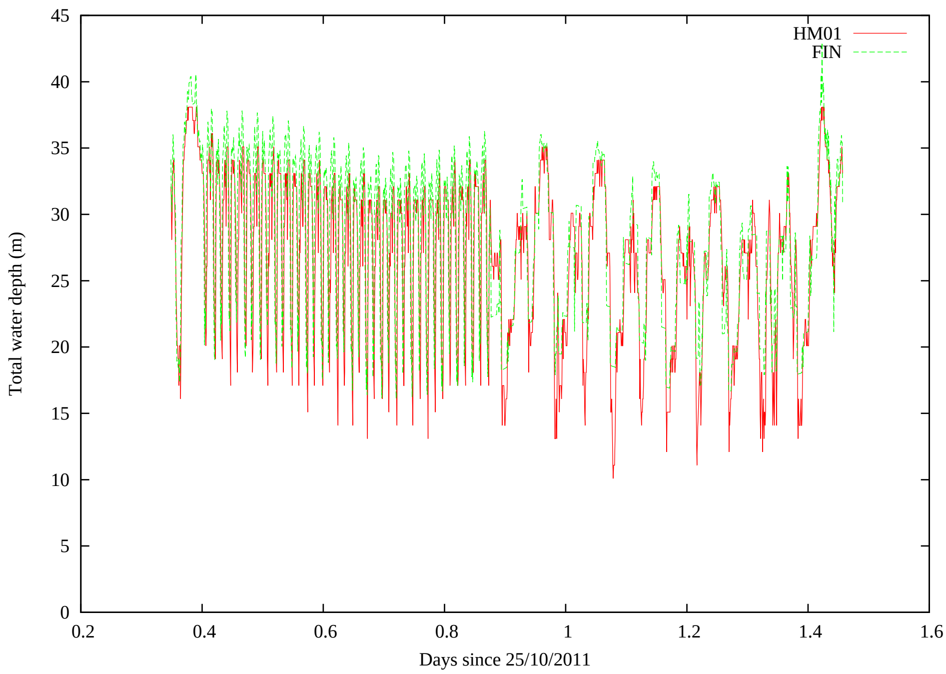


Figure 13: Total water depth during campaign HM01 for the hull-mounted ADCP (HM01) and calculated by the OPTOS-FIN model (FIN).

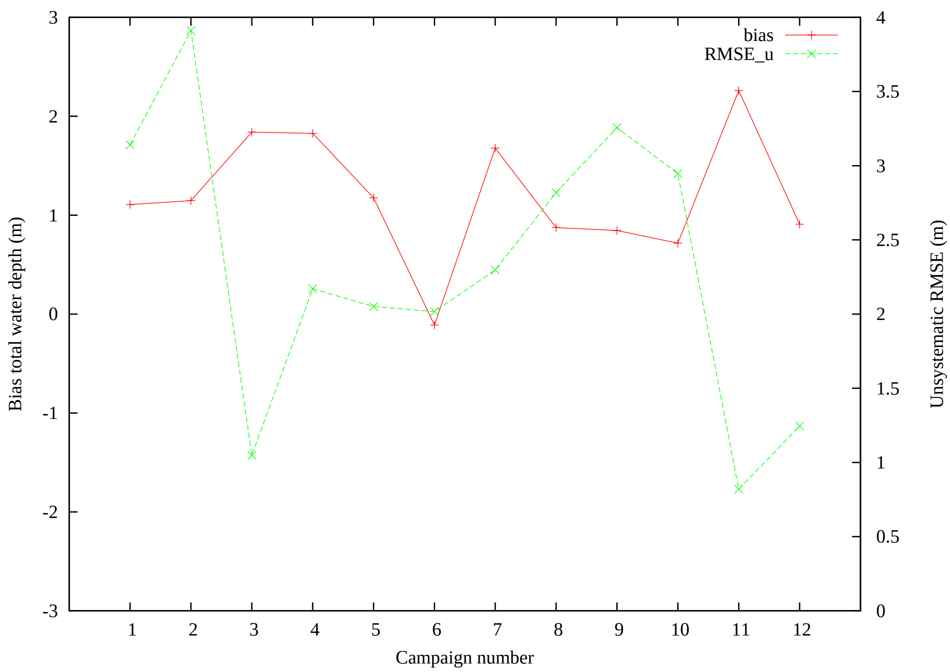


Figure 14: Bias and unsystematic RMSE between the total water depth measured by the hull-mounted ADCP and calculated by the OPTOS-FIN model.

3.3.2. Depth-averaged currents

The depth-averaged currents and directions for the different campaigns were compared again with the model results. The currents were not averaged over a period of 30 minutes, to account for the change of position of the measurements and the rapidly changing of the water depths. In Figure 15 the depth-averaged currents and current directions are presented for the campaign HM04. One can clearly see that the model follows the overall behaviour of the depth-averaged currents, with the tidal variation over a period of hours and with shorter variations, due to the change of position and the change of total water depth. Also the directions of the depth-averaged currents are well reproduced.

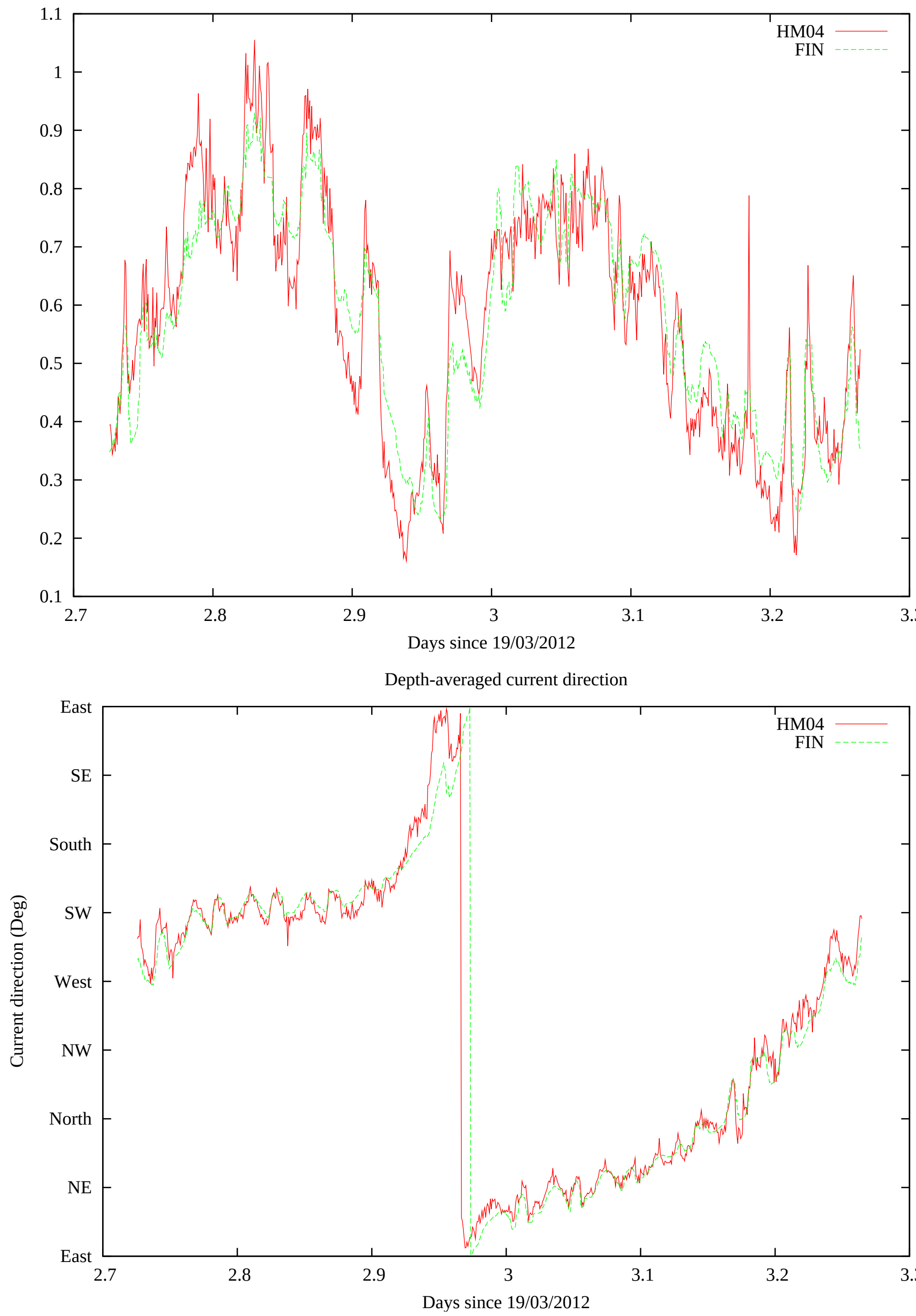
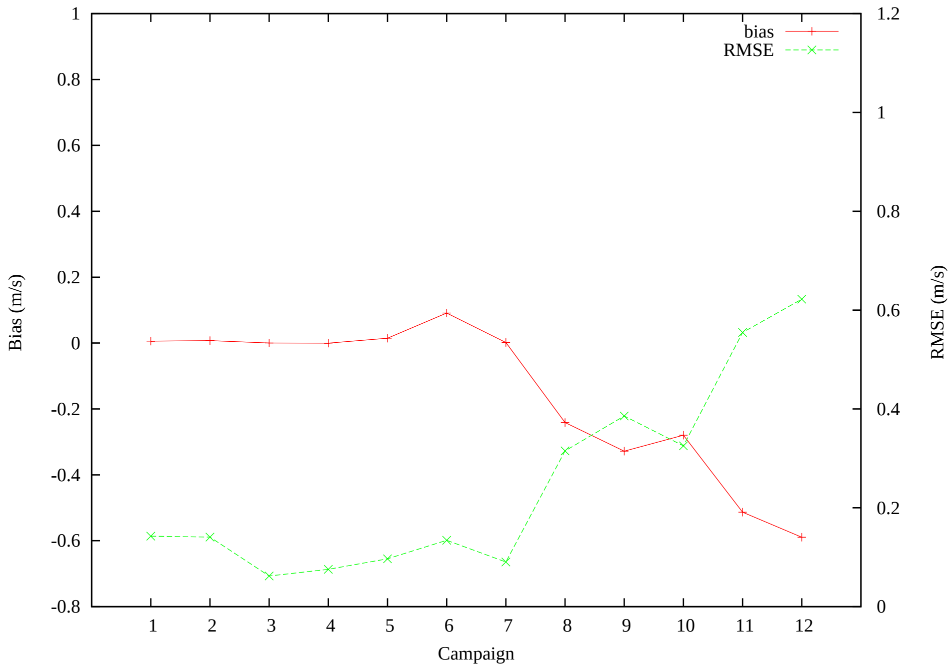


Figure 15: Depth-averaged current magnitude (top) and current direction (bottom) from the hull-mounted ADCP campaign HM04 and from the OPTOS-FIN model (FIN).

It is however clear that the results will vary for the different campaigns. In Figure 16, the bias, RMSE and correlation coefficient are plotted for the different campaigns. For reference, also the bin size of the ADCP is plotted for the different campaigns.



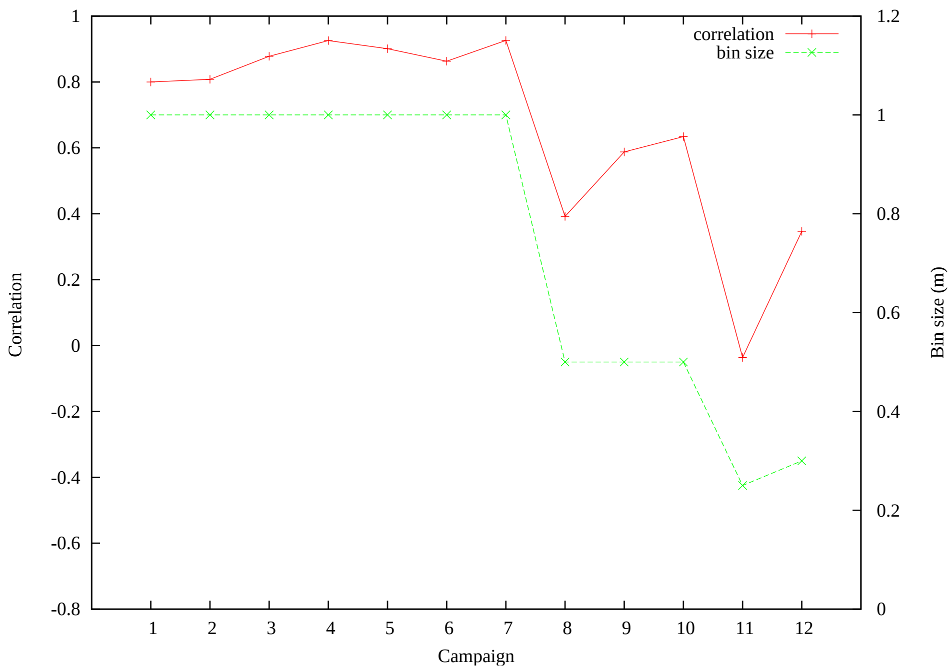


Figure 16: The bias, RMSE (upper) and correlation coefficients (lower) for the different measuring campaigns with hull-mounted ADCP, together with the ADCP bin size (lower).

One clearly observes the obvious influence of the bin size on the results. For the campaigns with a bin size of 1 m, the bias is between 0 m/s and 0.09 m/s, (except for campaign HM06, where the bias is a little bit larger at

0.015 m/s), while the RMSE remains below 0.15 m/s and the correlation is higher than 0.80. For smaller bin sizes, however, the results of the comparison between the measurements and the model results are much worse. This is clearly a results of the decrease in quality of the ADCP current measurements with a decrease in bin size, a characteristic of the ADCP which is well known. One can conclude that for doing good quality current measurements, the bin size of the 300 kHz ADCP must be at least 1 m. The bias, RMSE, correlation and scatter index for the current magnitude and direction for the campaigns with a bin size of 1 m, are given in Table 5.

Table 5: Number of comparison points (Numb.), Bias, RMSE, correlation and S.I. for the depth-averaged current magnitude and direction for the hull-mounted ADCP campaings HM01 to HM07.

Campaign		Current magnitude				Current direction		
	Numb.	Bias (m/s)	RMSE (m/s)	Corr	S.I. (%)	Bias (deg.)	RMSE (deg.)	Corr
HM01	1597	0.006	0.142	0.800	23.1	-13.2	23.5	0.985
HM02	1673	0.007	0.141	0.808	21.2	-6.1	15.6	0.990
HM03	861	0.000	0.062	0.878	11.7	-0.6	8.6	0.996
HM04	777	0.000	0.076	0.926	13.1	-4.5	11.5	0.994
HM05	869	0.015	0.097	0.901	14.9	-3.7	12.9	0.993
HM06	827	0.091	0.134	0.863	25.8	-10.4	17.6	0.990
HM07	1312	0.002	0.090	0.926	14.7	-5.5	13.2	0.993
Mean		0.017	0.106			-6.3	14.7	

The biases for 6 campaigns are even smaller than the results with the bottom-mounted ADCP, where the bias was -0.03 m/s or 0.03 m/s for the two campaigns. Only for campaign HM06, the bias is larger, with a bias of 0.09 m/s. The RMSE for campaigns HM01, HM02 and HM06 are larger than the RMSE using the bottom mounted ADCP, but stays smaller than 0.15 m/s, and are even better for campaigns HM03 and HM04. Also the direction is very well reproduced by the model with a mean bias of -6.3° and a mean RMSE of 14.7°

Remark that, when investigating the results further in detail, it appeared that the results for the campaign HM01 improves considerably after a shift in time of the measurements with a period of -35 minutes. While the bias increases in this case to 0.011 m/s, the RMSE decreases to 0.104 m/s and the correlation coefficient increases to 0.896. Also for the current directions, there is a better agreement in this case with a bias of 5.6° and a RMSE of 18.1°. The reason for this shift is not clear.

From the scatter plots (Figure 17) again, the good comparison between measured and modelled current direction is shown. Also here, the model seems to underpredict the directions between 300° and 360°, meaning that the turning from ebb to flood seems to be too late.

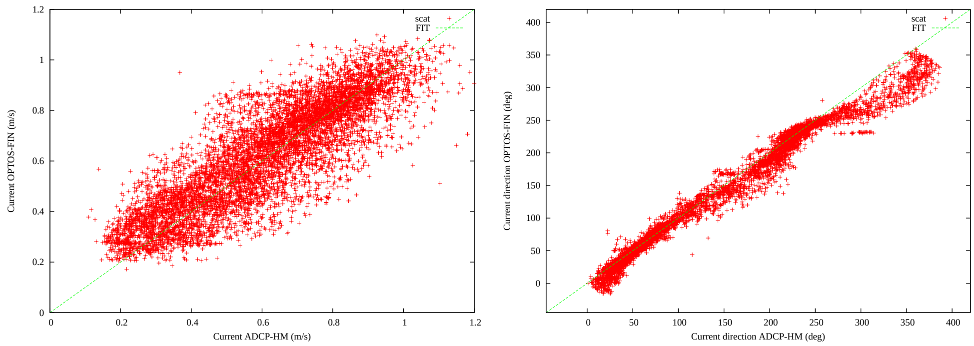


Figure 17: Scatter plots for the depth-averaged current magnitude (left) and current direction (right) for the measuring campaigns HM01 to HM07.

3.3.3. Currents at the bottom and the surface

Also for the measurements with the hull-mounted ADCP, the quality of the modelled currents near the surface, in the middle of the water column and near the bottom are investigated. Due to the fact that the water depth is varying with position, the comparison has been executed in four levels. For the surface currents, the currents at 7.5 m below the water surface are taken. These are the measurements, closest to the surface, taking into account the draught of 4.5 m and the fact that for campaigns HM01 to HM07, the first bin of the ADCP is at 3.08 m below the sensor. The currents in the middle of the water column are taken at 14 m below the water surface. For the currents at the bottom, the currents at 2.5 m above the bottom are taken. This is the last current where ADCP measurements are available, taking into account the blanking of 2 bins above the bottom. Finally also the currents at 10 m above the bottom are evaluated. Due to the fact that the total water depths are not exactly known and estimated, the exact level above the bottom is not certain. Remark that depending on the water depth, the layer of 14 m below the water surface can be lower than the layer at 10 m above the bottom or vice-versa.

As an example, in Figure 18, the current magnitude and current directions at three water levels are shown for measuring campaign HM07. The current magnitude and the current directions are well predicted by the OPTOS-FIN model. One can remark a small underprediction of the currents near the bottom.

The bias and the RMSE for the different campaigns and for the four different water levels are presented in Figure 19. One can observe that for most campaigns, there is an overprediction of the currents near the surface and an underprediction of the currents near the bottom. Not accounting for campaign HM06, which clearly gives less good results, the mean overprediction of the surface currents is 0.026 m/s, while the underprediction of the bottom currents is 0.076 m/s. The RMSE is a little bit higher for the surface and bottom currents than for the currents in the middle of the water column. For most campaigns the RMSE remains below 0.15 m/s, this is clearly satisfying.

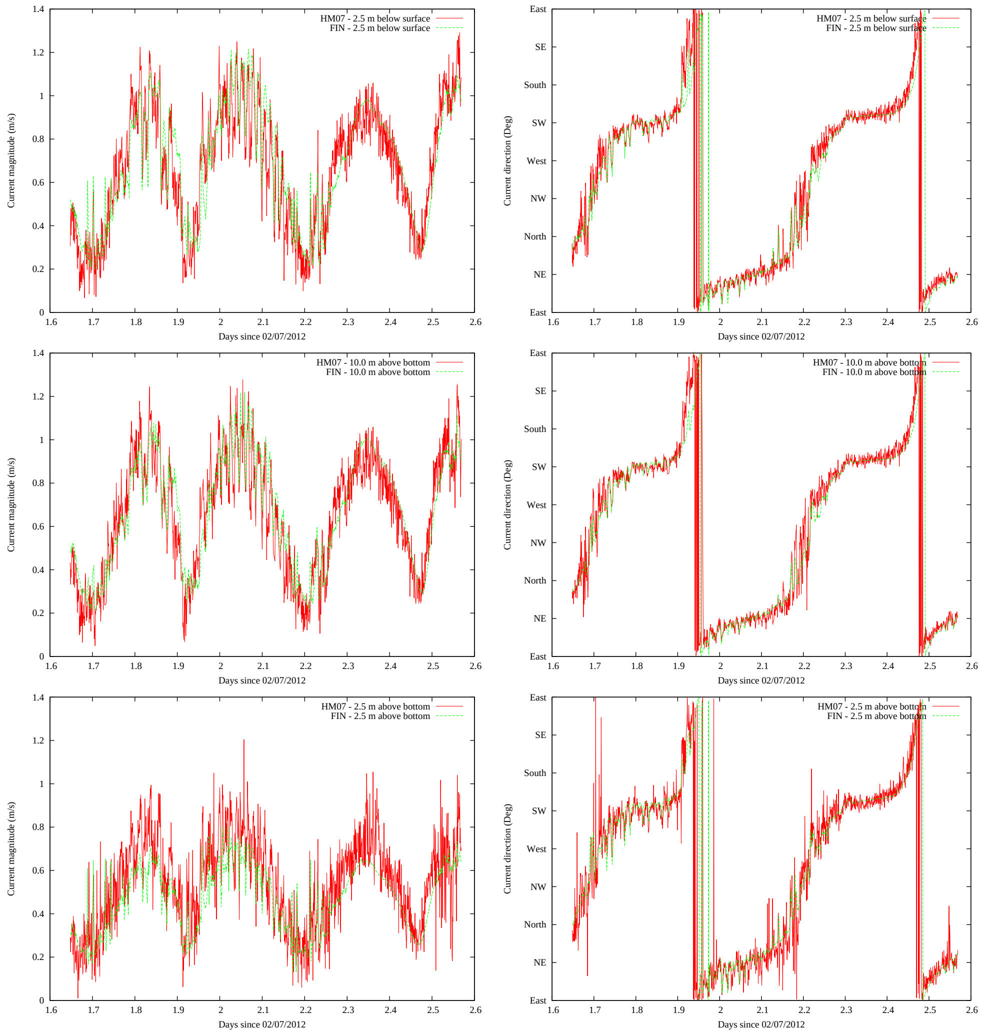


Figure 18: Currents magnitude (left) and current direction (right) for measuring campaign HM07 at the surface (2.5 meter below surface - upper), middle of the water column (10.0 m above bottom - middle) and near the bottom (2.5 m above bottom – lower).

Also for the directions (see Figure 20), the RMSE seems to be smaller for the currents in the middle of the water column, than for the surface and bottom currents. The RMSE remains lower than 22.5° for all campaigns, except for campaign HM01. This probably has caused by the observed time shift that was between the measurements and the model results.

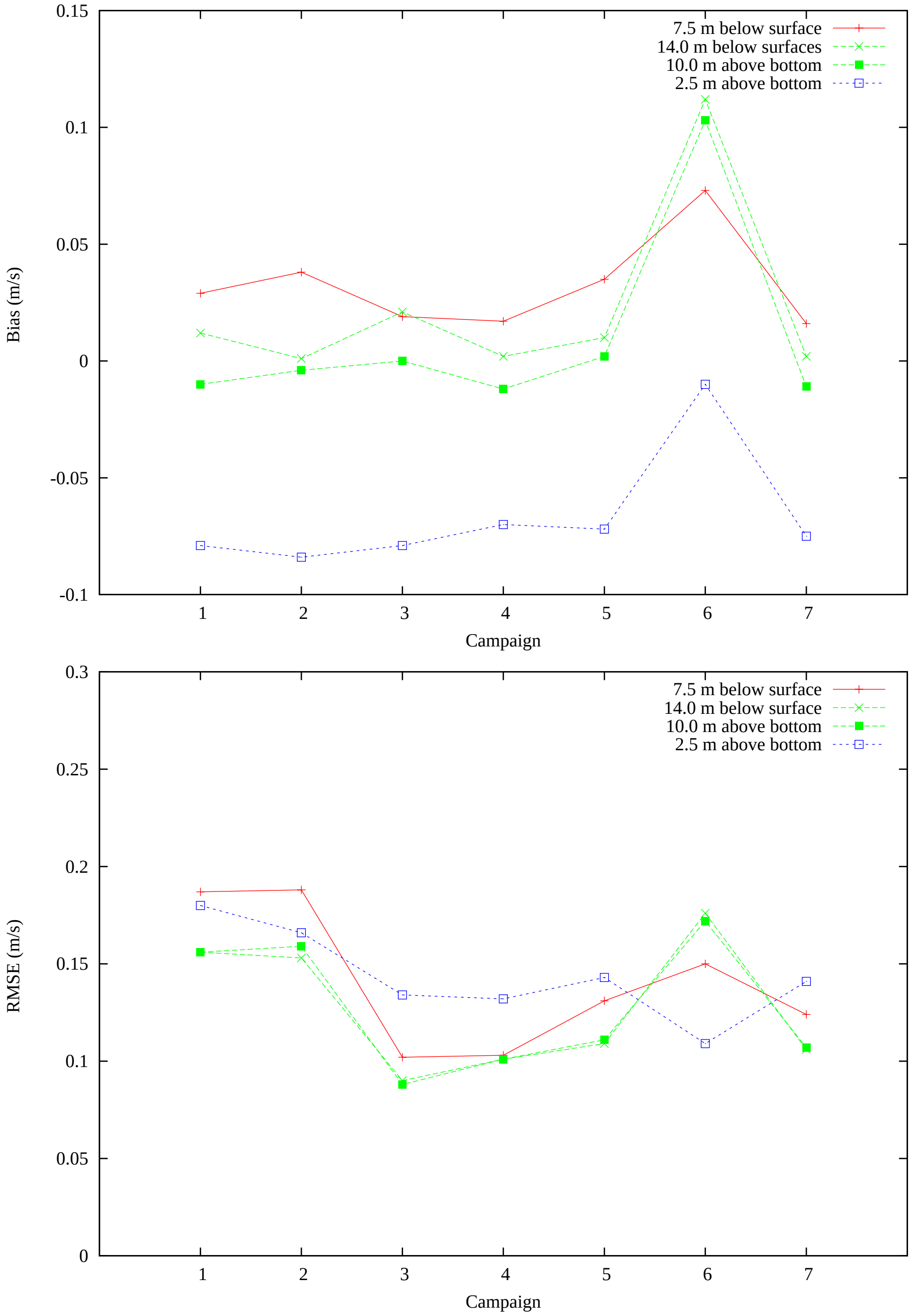


Figure 19: Bias (upper) and RMSE (lower) for measuring campaigns HM01 to HM07 for the current magnitude at the surface (2.5 meter below surface), in the middle of the water column (14.0 m below surface and 10.0 m above bottom) and near the bottom (2.5 m above bottom).

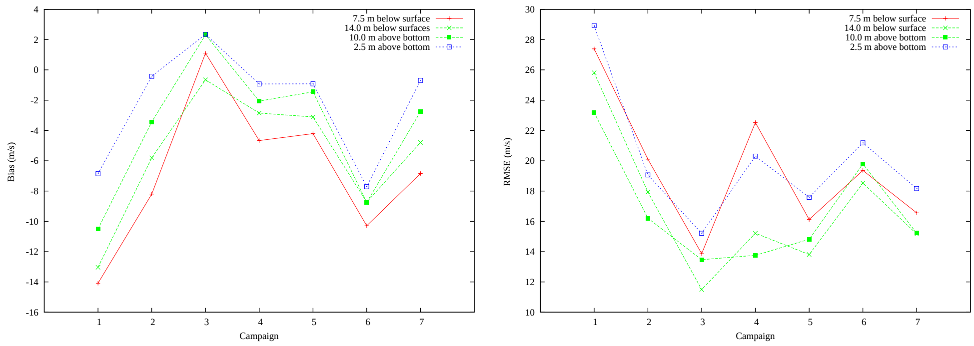


Figure 20: Bias (left) and RMSE (right) for measuring campaigns HM01 to HM07 for the current direction at the surface (2.5 meter below surface), in the middle of the water column (14.0 m below surface and 10.0 m above bottom) and near the bottom (2.5 m above bottom).

3.3.4. Influence of water depth

Since the measurements with the hull-mounted ADCP, the water depth varies over a large range the influence of the water depth on the quality of the model results can be assessed. In Figure 21 the bias and the RMSE are presented for the current magnitude and the current direction as a function of the water depths.

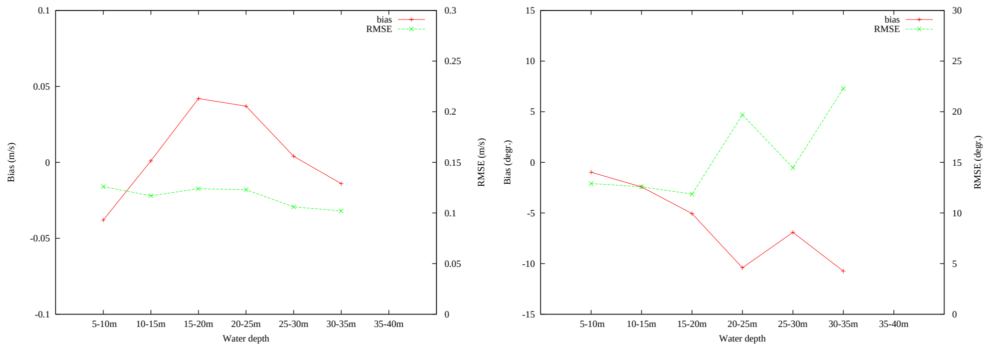


Figure 21: Bias and RMSE for measuring campaigns HM01 to HM07 for the current magnitude (left) and current direction (right) as a function of the total water depth.

For the shallow water (5-10 m) and in very deep water (30-35 m), the model seems to underpredict the current magnitude, while in the medium depth waters (15-25 m), the current magnitude is overpredicted. One can see that the RMSE decreases with increasing depth, indicating that in deeper waters, the current magnitude is better modelled. This was already observed in the validation of the OPTOS-BCZ model in the framework of the Marebasse project (see section 2.2.2.1).

For the current direction, the underprediction of the current direction increases with depth, while the RMSE of the current direction seems to increase with water depth.

3.4. Wave Glider© mounted ADCP

For the period of April 15th 2013 till May 6th 2013, OD NATURE had the opportunity to deploy a Wave Glider©, from Liquid Robotics (see Figure 22). The Wave Glider is an unmanned autonomous marine robot that uses wave energy for its propulsion. The wings on a board, which floats some meters below the Wave Glider, converts the wave energy in mechanical thrust (see Figure 23).

The Wave Glider is programmed to follow a preset course, but is followed from the Operation Centre to correct the course if necessary, *e.g.*, to avoid collision with vessels. The Wave Glider houses different instruments, including an ADCP. More information on the Wave Glider© can be found at the website of Liquid Robotics at http://liquidr.com.

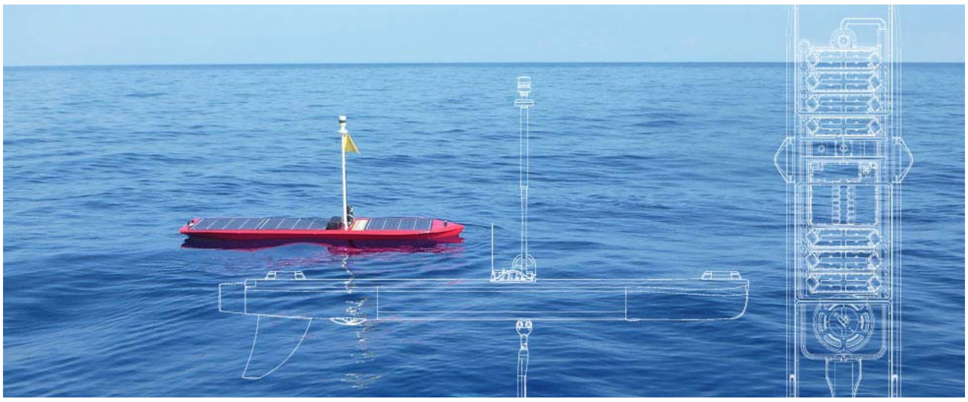


Figure 22: Photo of the Wave Glider© from Liquid Robotics (source: http://liquidr.com).

In the framework of the project, the Wave Glider was deployed in the area for almost 22 days. During the full period, the Wave Glider was programmed to sail a route around Sector 4c, in the south-east area of the Hinder Banks. The tracks sailed are shown in Figure 24. During the full period ADCP measurements were taken, but the characteristics of the ADCP were changed two times during the period, *i.e.*, at April 21st and at April 30th 2013 (see Table 2). Therefore, the full period is split in three periods WG01, WG02 and WG03. Fortunately, the bin size of the ADCP was during the entire period at least 1 m, so that good quality current data were taken.

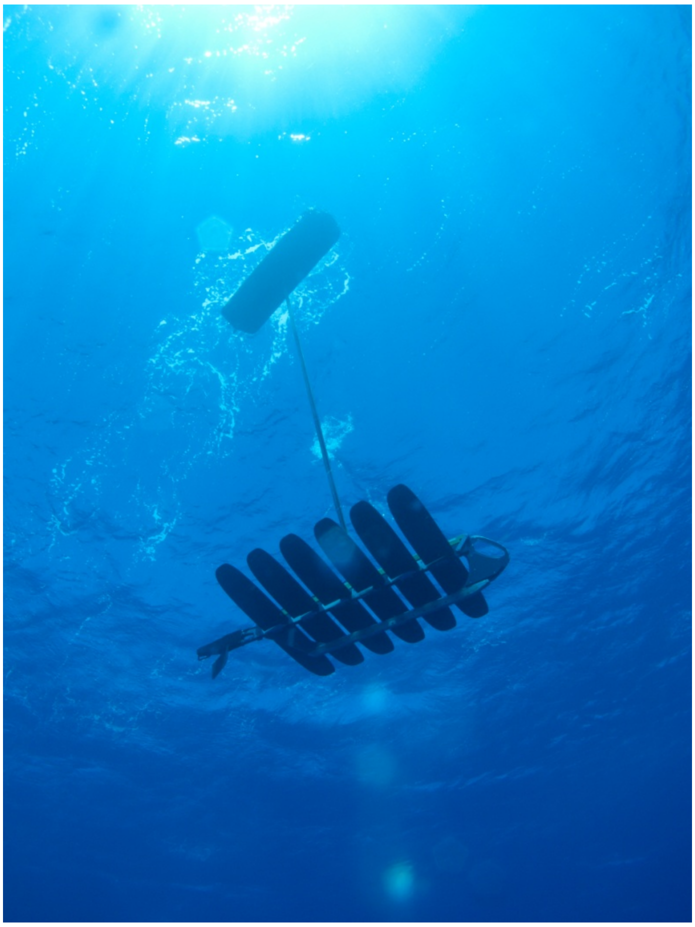


Figure 23: Propulsion system of the Wave Glider© from Liquid Robotics (source: http://liquidr.com).

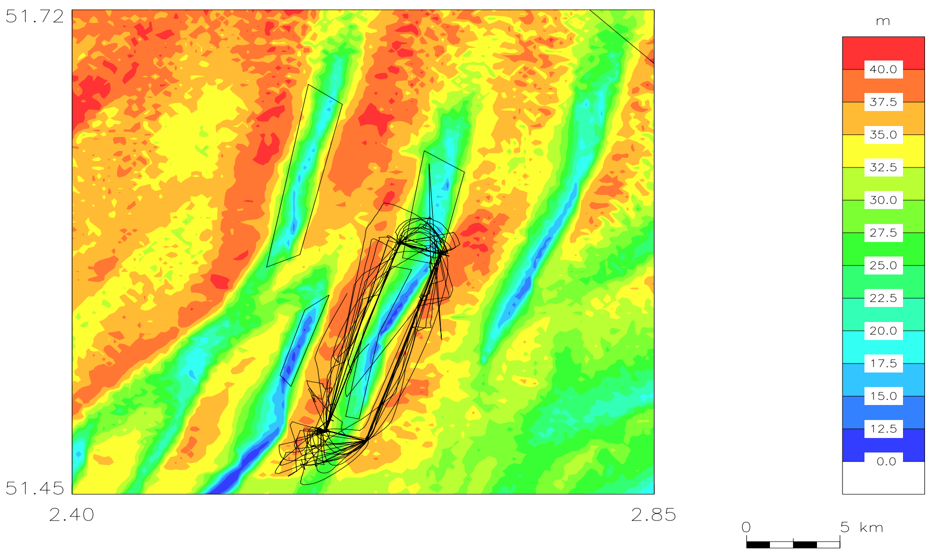


Figure 24: Tracks of the measurements with the Wave Glider© (from Liquid Robotics).

3.4.1. Total water depth

The total water depth of the water column under the hull-mounted ADCP was compared with the model results. In this case, the draught of the ADCP is only 0.25 m below the water surface; the last two bins above the sea bottom are again blanked. Since the Wave Glider moves over the sand bank several times, the water depths varies again over a large range, from almost 15 m to more than 40 m of water depth (see Figure 25). However, the speed of the Wave Glider is much slower than that of the RV Belgica. The variation of the water depth, due to the change of position, therefore is slower, and an averaging of the results, to remove some of the noise in the measuring results, is possible. This is shown in Figure 26, where the original and the averaged time series over a period of 10 minutes, of the measured and modelled total water depth are shown.

The total water depth is quite well reproduced by the model, during the Wave Glider campaign. The bias varies between -0.65 m and 0.46 m, the RMSE is between 1.4 and 1.6 m (see Table 6).

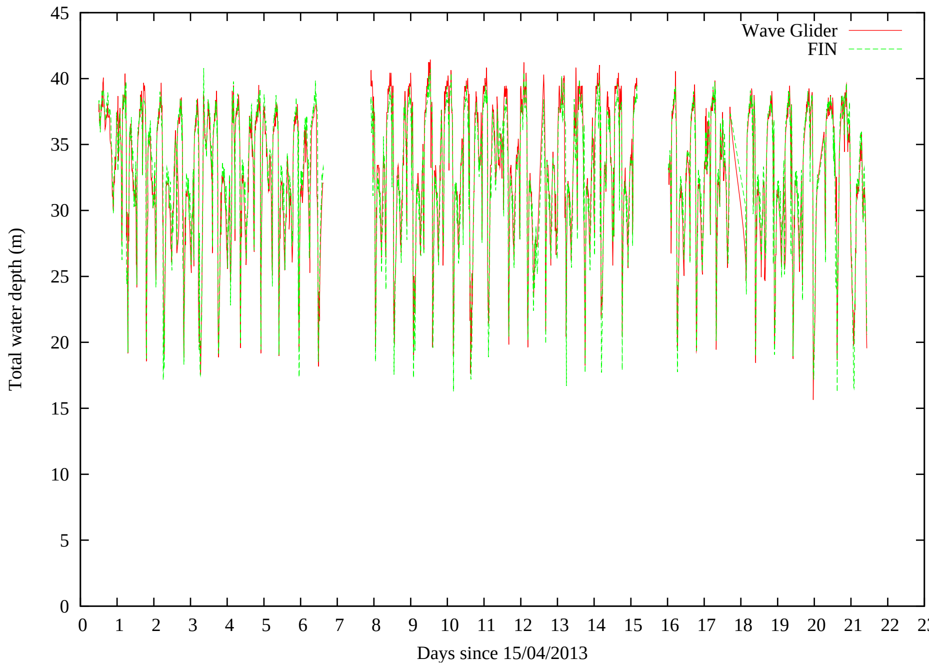


Figure 25: Total water depth during campaign WG01, WG02 and WG03 for the Wave Glider mounted ADCP (Wave Glider) and calculated by the OPTOS-FIN model (FIN).

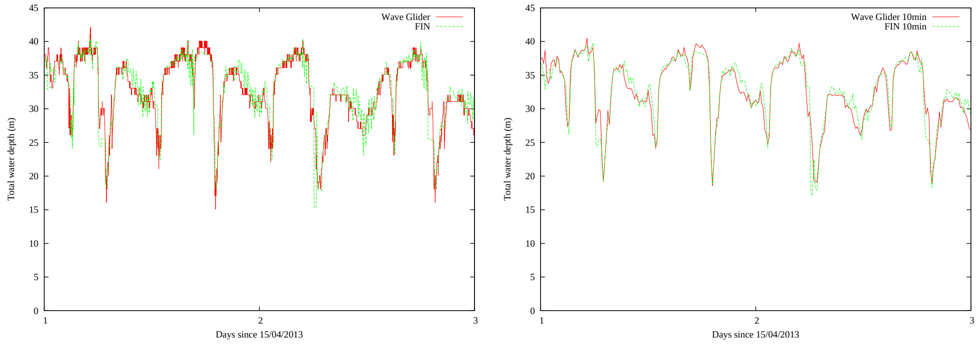


Figure 26: Total water depth during two days of campaign WG01 with a time step of 1 minute (left) and an averaged time step of 10 minutes (right) for the Wave Glider mounted ADCP (Wave Glider) and calculated by the OPTOS-FIN model (FIN).

Table 6: Number of comparison points, bias, RMSE and correlation for the total water depth.

Campaign	Total water depth			
	Number	Bias (m)	RMSE (m)	Corr
WG01	852	0.43	1.43	0.960
WG02	1023	-0.65	1.58	0.961
WG03	698	0.18	1.38	0.965

3.4.2. Depth-averaged currents

Also for the Wave Glider campaigns, the depth-averaged current magnitude and directions were evaluated first. However it has to be remarked that due to the fact that the Wave Glider uses the wave energy for its propulsion from a board, located some meters below the Wave Glider (see Figure 23), this board will influence the currents measurements at one or two bins. The currents at these bins have been interpolated first, before calculating the depth-averaged currents. Further, as explained above, the ADCP measurements were averaged over a period of 10 minutes, to remove some of the noise in the measurements. The current magnitude and current directions are presented for the full period in Figure 27.

Also for the ADCP measurements from the Wave Glider, the OPTOS-FIN model predictions are of a good quality. Both the current magnitude and the current directions are well modelled. The bias (see Table 7) varies between 0.015 m/s and -0.029 m/s, while the RMSE is between 0.056 m/s and 0.072 m/s. This is clearly satisfying. Also the bias for the current directions are very small, while the RMSE remains limited to 19.6° for the first period and to 10.9° for the second and third period.

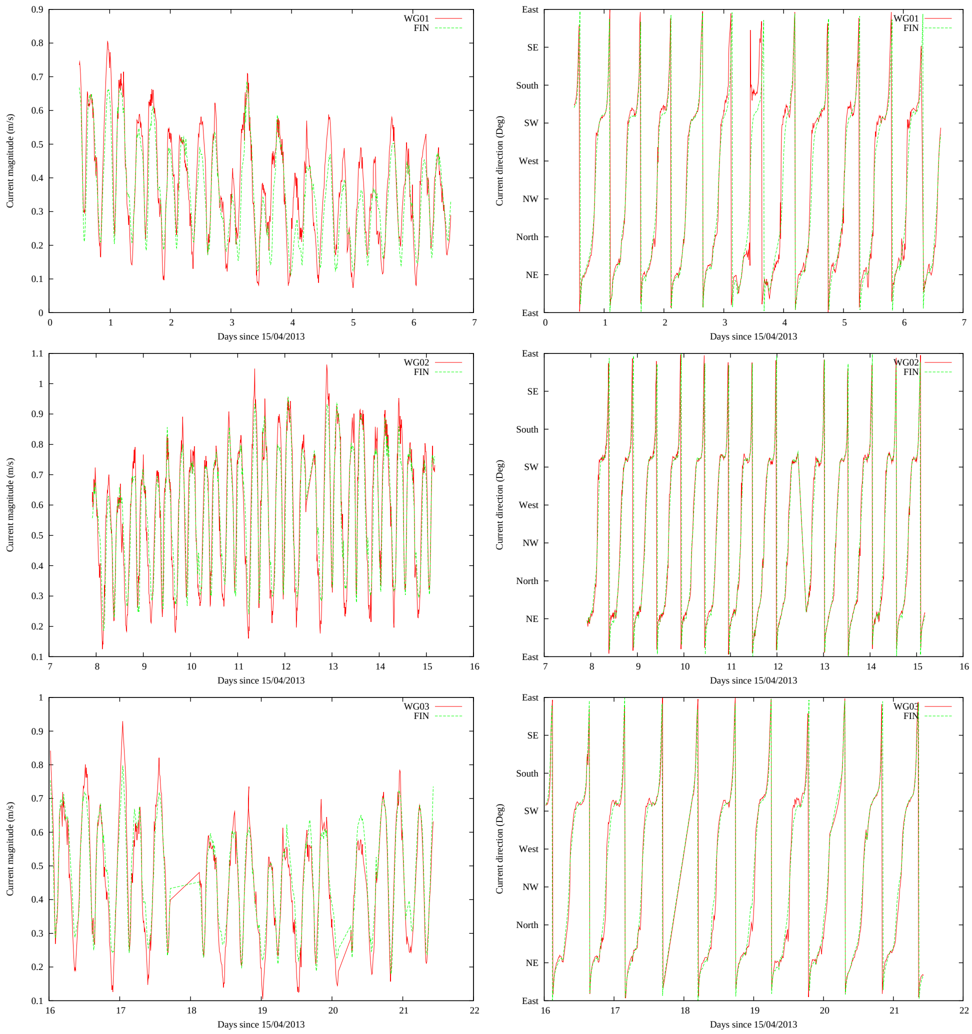


Figure 27: Depth-averaged current magnitude (left) and current direction (right) from the three parts of the Wave Glider mounted ADCP measurements (WG) and from the OPTOS-FIN model (FIN).

Table 7: Number of comparison points (Numb.), Bias, RMSE, correlation and S.I. for the depth-averaged current magnitude and direction for the hull-mounted ADCP campaigns HM01 to HM07.

Campaign		Current magnitude				Current direction		
	Numb.	Bias (m/s)	RMSE (m/s)	Corr	S.I. (%)	Bias (deg.)	RMSE (deg.)	Corr
WG01	852	-0.029	0.072	0.911	18.9	-6.2	19.6	0.985
WG02	1023	-0.009	0.071	0.947	12.3	-3.6	10.9	0.995
WG03	698	0.015	0.056	0.955	12.3	0.5	10.7	0.994
Mean		-0.008	0.066			-2.6	13.7	

Also the scatter plots (Figure 28) show the good comparison between measured and modelled current magnitude and direction. The underprediction of the current direction between 300° and 360° is less clear here.

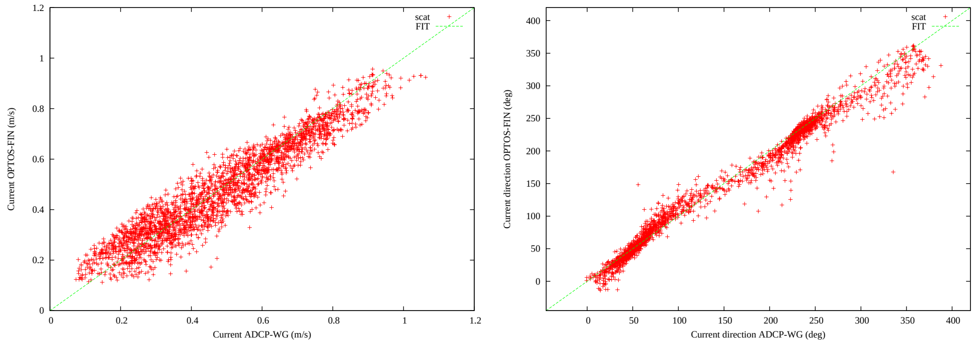


Figure 28: Scatter plots for the depth-averaged current magnitude (left) and current direction (right) for the measuring campaigns WG01 to WG03.

3.4.3. Currents at the bottom and the surface

The quality of the currents at the bottom and the surface are evaluated also for the measurements with the ADCP, mounted on the Wave Glider. Also for the Wave Glider data, the comparison has been executed in four levels. Since the draught for the ADCP mounted on the Wave Glider is less than for the hull-mounted ADCP, the surface currents could be evaluated at 5.0 m below the water surface, instead of at 7.5 m below the water surface. The currents in the middle of the water column are in this case taken also a little bit higher, at 12 m below the water surface. For the currents at the bottom, the currents at 2.5 m above the bottom are taken. This is the last current where ADCP measurements are available, taking into account the blanking of 2 bins above the bottom. However for the second period (WG02), the data at 2.5 m above the bottom, are all corrupted. Therefore, in this case, the currents at 5.0 m above the bottom are used for the comparison. Also, the currents at 10 m above the bottom are evaluated, as a proxy for the currents in the middle of the water column.

As an example, in Figure 29, the current magnitude and current directions at three water levels are shown for first part of the period (WG01). The current magnitude and the current directions are well predicted by the OPTOS-FIN model. Also here, on can remark an underprediction of the currents near the bottom.

When looking at the statistics for the three separate periods (see Table 8), one can observe that the results of the validation during the first period (WG01) are clearly not as good as for the two other periods. The currents in all layers are underpredicted, especially at the bottom (bias of -0.05 m/s). The RMSE stays below 0.10 m/s, but also the correlation is relatively low (correlation of 0.78 for the currents near the bottom).

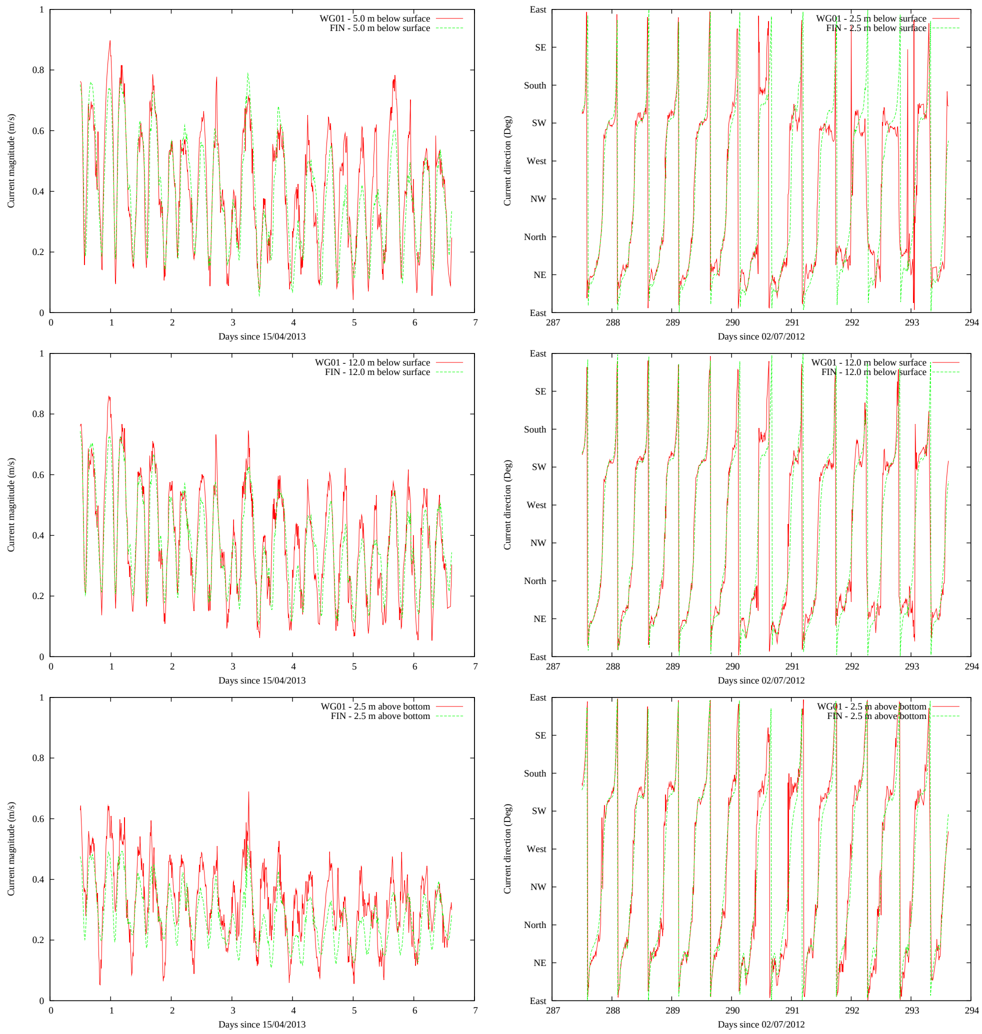


Figure 29: Currents magnitude (left) and current direction (right) for measuring campaign HM07 at the surface (2.5 meter below surface - upper), middle of the water column (10.0 m above bottom - middle) and near the bottom (2.5 m above bottom – lower).

Also the RMSE on the current directions are relatively high with RMSE between 21.3° and 23.5° For the second and the third period, the results of the comparison are much better. Here again, one observes a small overprediction of the currents near the surface and an underprediction of the currents near the bottom. The RMSE for the current magnitude is between 0.06 m/s and 0.08 m/s. Only for the currents near the bottom for the second period, the RMSE is higher, with a value of 0.11 m/s. However, some problems seems to be apparent with the current measurements near the bottom for the second period. The current directions are relatively well predicted with an average RMSE of 13.0°

Table 8: Campaign (Cmp.), height of the measurement above the bottom (Hght.), number of comparison points (Num.), Bias, RMSE and S.I. for the current magnitude and direction.

Cmp.					Current			Curre
	Hght. (m)	Num.	Bias (m/s)	RMSE (m/s)	Corr	Bias (deg.)	RMSE (deg.)	Corr
WG01	2.5 mbs	853	-0.032	0.093	0.877	-6.3	32.5	0.944
	12.0 mbs		-0.020	0.077	0.914	9.6	23.7	0.969
	10.0 mab		-0.023	0.081	0.864	-2.6	21.3	0.983
	2.5 mab		-0.051	0.093	0.781	-4.5	22.1	0.981
WG02	2.5 mbs	1023	0.022	0.085	0.940	-6.6	14.1	0.992
	12.0 mbs		0.001	0.072	0.953	4.8	10.5	0.994
	10.0 mab		-0.011	0.075	0.936	0.0	9.9	0.995
	5.0 mab		-0.080	0.112	0.927	-3.4	11.0	0.994
WG03	2.5 mbs	698	0.032	0.076	0.951	-2.6	18.3	0.982
	12.0 mbs		0.024	0.063	0.960	1.9	12.7	0.991
	10.0 mab		0.011	0.068	0.910	4.7	12.6	0.993
	2.5 mab		-0.025	0.068	0.893	4.8	14.7	0.991

3.4.4. Influence of the water depth

Also during the measurement with the ADCP mounted on the Wave Glider, the water depth varies over a large range. There, the influence of the water depth on the quality of the model results can be assessed for these measurements. In Figure 30, the bias and the RMSE are presented for the current magnitude and the current direction as a function of the water depths.

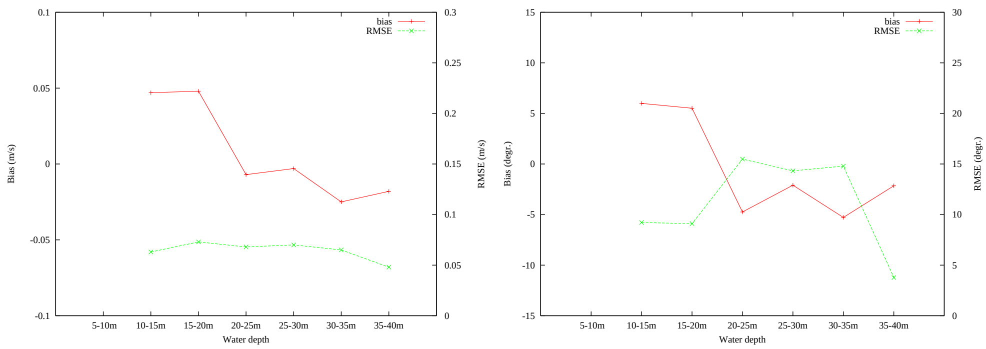


Figure 30: Bias and RMSE for measuring campaigns WG01 to WG03 for the current magnitude (left) and current direction (right) as a function of the total water depth.

In this case, the current magnitude is overpredicted in the shallower waters (5-15 m) and underpredicted in deeper waters (30-40 m). The underprediction of the current magnitude was also found for the ADCP data from the hull-mounted ADCP. Also here, the RMSE decreases slightly with increasing depth.

The current direction is underpredicted in deeper waters (20-40 m) and underpredicted in shallower waters (10-20 m). Also for the Wave Glider data, the RMSE of the current direction seems to increase with water depth, except for the very deep waters (35-40 m). In the latter case, however, only 40 measurements were available.

4. Conclusions

A validation was presented of the results of the three-dimensional hydrodynamic model OPTOS-FIN in the new extraction zone 4 for the extraction of marine aggregates. This model will be used to predict the currents, driving sediment transport models, and to assess the impact of the dredging works on the sand transport in the area, as also to model sediment plumes.

Previously, the OPTOS-FIN model was validated in the framework of other projects, but not specifically in the MOZ4 area. In the framework of the Marebasse project, RMSE values were found between 0.072 and 0.127 m/s at the Kwintebank. In the framework of the Boreas project, larger RMSE values were obtained, varying from 0.125 m/s to 0.218 m/s, but it was shown that this could be related to a lower quality of the measurements.

For zone 4 extensive current measurements were carried out in the period 2011-2013, in the framework of the ZAGRI/MOZ4 projects. Two longer term data series from bottom-mounted ADCPs were available, as also, twelve data series from 13-hrs cycles, acquired with RV Belgica's hull-mounted ADCP. During one period, ADCP data was available from a 22 days trajectory with a Wave Glider©.

Comparison between the bottom-mounted ADCP results and the model predictions showed a good agreement. The bias between the measured and the modelled depth-averaged current magnitude was between -0.03 and +0.03 m/s with a RMSE of less than 0.09 m/s. Also the directions were well predicted with a RMSE of less than 17°. The turning from the ebb to the flood seems to be too late however. No big differences are observed when evaluating the currents at the bottom or at the surface separately. The RMSE remains restricted to less than 0.12 m/s. However, surface currents seem to be slightly over-predicted by the model, while the bottom currents seem to be slightly under-predicted.

When using the hull-mounted ADCP results, the time step of the time series was much shorter, i.e. 1-minute interval, to take into account the rapidly varying water depths, when sailing over the sand banks and the gullies. When evaluating the depth-averaged currents, the influence of the bin size of the ADCP measurements was clear. For bin sizes, larger than 1 m, the agreement between the measurements and the model results quickly decreases. The RMSE increases to more than 0.30 m/s for a bin size of 0.5 m, and to almost 0.60 m/s for bin sizes of 0.30 or 0.25 m. As was already known, this is due to the bad quality of the measurements of the currents for these small bin sizes. Hence, for this validation exercise, only the first 7 campaigns were used, where the bin size was set at 1 m. For these campaigns, the bias is between 0 m/s and 0.015 m/s, except for one campaign, where the bias was 0.09 m/s. The RMSE varied between 0.062 m/s and 0.142 m/s with a mean RMSE for all campaigns of 0.106 m/s. Also the current directions are well reproduced with a RMSE between 8.6° and

23.5°. For one campaign (HM01) there seems to be a shift in the measurements.

Overall, taking into account the changing of the position and the rapidly varying water depth, the results are highly satisfying. Also for the hull-mounted ADCP measurements, a small under-prediction is observed for the bottom currents, and a small over-prediction of the currents near the surface. The RMSE remained below 0.20 m/s for the currents in the different layers. The current directions were well predicted over the entire water column. Finally, it was shown that the RMSE for the current magnitude decreased (slightly) with the total water depth, while the RMSE for the current direction increases with total water depth. Furthermore, the under-prediction of the current directions seems to increase with water depth.

Finally, also the ADCP data obtained with Liquid Robotics' Wave Glider©, were modelled well by the OPTOS-FIN model. The bias for the current magnitude for the three separate periods (with changing parameters for the ADCP) varied between -0.03 m/s and 0.015 m/s, with a RMSE around 0.07 m/s and the RMSE for the current directions remained below 20°. Also in this case, a small over-prediction of the surface currents, and a small under-prediction of the bottom currents were observed. Overall, the currents at different levels in the water column were very well predicted. It was shown that in shallower water, the current magnitude is slightly over-predicted, while in deeper water, the current magnitude is under-predicted. The RMSE of the current magnitude decreased slightly with water depth. Also for these measurements, the under-prediction of the current direction was higher for deeper waters, while the RMSE increased with increasing water depths.

Overall, the validation exercise showed that the OPTOS-FIN model is performing very well in extraction zone 4, and that the current magnitude and current directions are modelled satisfactory.

5. Acknowledgements

The commander and crew of the RV Belgica are acknowledged for their support during the measuring campaigns. Lieven Naudts, Reinhilde Van den Branden and other team members of the Measuring Service Ostend of the Operational Directorate Natural Environment are thanked for their logistical support, especially during the deployment of the bottom-mounted ADCPs and for their help in the deployment and the recovery of the Hermes Wave Glider. Ryan Carlon, François Leroy and Kim Hosaka from Liquid Robotics are thanked for providing OD Nature the opportunity to deploy the Wave Glider© Hermes in the Belgian coastal waters, and for their help and support in the deployment and the recovery of the Wave Glider, as also for the control and guidance of the Wave Glider during the operations.

6. References

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7. Appendix A: 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 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:

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

f COLOPHON

This report was issued by OD Nature in February 2014.

Its reference code is MOD code.

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NORTH SEA MATHEMATICAL MODELS

MODELLING GROUP

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Annex H

Cruise reports RV Belgica 2011 - 2013

Nr	Campaign	Period
1	ST1128	24-27/10/2011
2	ST1208	19-23/03/2012
3	ST1219	02-06/07/2012
4	ST1226	15-19/10/2012
5	ST1309	25-29/03/2013
6	ST1319	01-04/07/2013
7	ST1328	21-25/10/2013

This Annex forms part of the report:
Van Lancker, V., Baeye, M., Fettweis, M., Francken, F. & Van den Eynde, D. (2014). Monitoring of the impact of the extraction of marine aggregates, in casu sand, in the zone of the Hinder Banks. Brussels, RBINS-OD Nature. Report <MOZ4-ZAGRI/X/VVL/201401/EN/SR01>.

RV BELGICA CRUISE 2011/28 - REPORT

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Geology: 24-27/10/2011

Reference to this report:
Van Lancker, V., Van den Branden, R., Janssens, R., Vereecken, E., Coulier, G. (2011). *Cruise report RV Belgica ST1128, 24-27/10/2011*. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, 8p.

1. CRUISE DETAILS

1.	Cruise number		2011-28
2.	Date / hour	Zeebrugge ETD Zeebrugge ETA	24/10, 10h50 27/10, 17h
3.	Responsible scientist Participating institutions		Dr. Vera Van Lancker (MUMM) MUMM
4.	Area of interest		Belgian part of the North Sea

2. LIST OF PARTICIPANTS

Institute	*Participant*	*24-27/10*
MUMM	Vera VAN LANCKER	X
	Reinhilde VANDENBRANDE	X
	Emiel VEREECKEN (UGent)	X
	Rindert JANSSENS (volunteer)	X
	Gijs Coulier	X
TOTAL		**5**

3. SCIENTIFIC OBJECTIVES

MUMM VVL – ZAGRI/MOZ4

Monitoring of hydrodynamics and sediment transport to evaluate the effects of the exploitation of non-living resources of the territorial sea and the continental shelf.

Within this campaign ADCP profiling is attempted along key areas in Zone 4 within the Hinder Banken region. The spatial datasets will later allow planning the location of a dedicated benthic lander, to obtain longer time series of hydrodynamics and sediment transport.

MUMM VVL - MULTIBEAM

Characterization of seabed features and monitoring of seabed dynamics using RV Belgica's multibeam echosounder. Within this campaign the focus is on filling multibeam data gaps in the area north of the Vlakte van de Raan.

MUMM PR - WFD

The project is part of the continuous surveillance and evaluation of the quality of the marine environment in the region of the Belgian continental shelf (BCS) in the framework of the national obligations toward the Joint Assessment en Monitoring Program (JAMP) of the OSPAR commission and the Water Framework Directive of the EC ((2000/60/EC). MUMM 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 Fisheries. Quality assurance and quality control during sampling and in the laboratory receive a high priority within the project.

MUMM - AUMS

The AUMS (Autonomous Underway Measurement System) project 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. 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 MUMM's public web site and following quality control, from the Belgian Marine Data Centre.

4. OPERATIONAL COURSE

All times are given in local time. All coordinates in WGS84.
Throughout the campaign, measurements are made with the AUMS system.
CSD: Continental Shelf Department of FPS Economy, SME's, Self-Employed and Energy, responsible for the multibeam monitoring related to sand and gravel extraction Belgian part of the North Sea.

Monday, 24/10/2011

LW 05:58(0.75); HW 12:05(4.30); LW 18:28 (0.33)

10h50 Sail off from Zeebrugge

Transit to W01 for water sampling

11h32 Sampling W01 (2011-10-24 09:32:50 W01 51°22.5; 3°11.3)

Transit to Thornton Bank for search tripod

13h17 start MBES profiles
2 series of 4 lines were sailed with a spacing of 50m
No objects could be detected in real-time.

14h07 end

Transit to Vlakte van de Raan for multibeam recordings

15h20 Start MBES recording. Depth and backscatter, as also water column data were logged.

Tuesday, 25/10/2011

HW 00:35(4.62); LW 06:50(0.55) ; HW 12:54(4.59) ; LW 19:18(0.16)

03h55 End MBES recording

Transit to W05 for WFD water sampling

05h18 Sampling W05 (2011-10-25 03:18:50 W05 51°24.4 ;2°49.3)

Transit to W06 for WFD water sampling

07h13 Sampling W06 (2011-10-25 05:13:10 W06 51°15.6 ; 2°26.8)

Transit to Hinder Banken – northern area

09h50 Start ADCP profiling

Interruption ADCP profiling

10h26 Navy exercise - Damage control
11h06 End

11h06 continuation ADCP profiling

23h end ADCP profiling

23h13 Start sampling LISST-CTD-NISKIN10L along ADCP profile. Points HBN1, HB2, HBN3, HBN4, HBN5, HBN6, HBN7. Per location, 6 times profiles were taken.

Wednesday, 26/10/2011

HW 01:21(4.82) ; LW 07:39 (0.38); HW 13:40(4.81); LW 20:06(0.05)

Within the sampling scheme, also Van Veen grab samples were taken:
09h59 Van Veen grab sampling HBN4
10h14 Van Veen grab sampling HBN5
10h38 Van Veen grab sampling HBN6
11h02 Van Veen grab sampling HBN1
11h18 Van Veen grab sampling HBN2
11h34 Van Veen grab sampling HBN3
11h51 Van Veen grab sampling HBN7

12h End of sampling LISST-CTD-NISKIN10L along ADCP profile

Transit to southern part Zone 4 Hinder Banken

13h Start ADCP profiling track south of zone 4
ADCP track: 51°33.419 N; 002°34.269 E to 51°33.037 N; 002°40.252 E

Thursday, 27/10/2011

HW 02:06(4.92); LW 08:26(0.26); HW 14:25(4.95); LW 20:52 (0.02)

02h End ADCP profiling

02h07 Start sampling LISST-CTD-NISKIN10L along ADCP profile. Points HBS1, HBS2, HBS3, HBS4, HBS5, HBS6,. Per location, 9 times profiles were taken

Within the sampling scheme, also Van Veen grab samples were taken:
08h01 Van Veen grab sampling HBS6
08h18 Van Veen grab sampling HBS5
08h32 Van Veen grab sampling HBS4
09h03 Van Veen grab sampling HBS3
09h20 Van Veen grab sampling HBS2
09h38 Van Veen grab sampling HBS1

14h50 End of sampling LISST-CTD-NISKIN10L along ADCP profile

Transit to Zeebrugge

17h Arrival at Zeebrugge

- End of campaign ST1128 –

5. TRACK PLOT

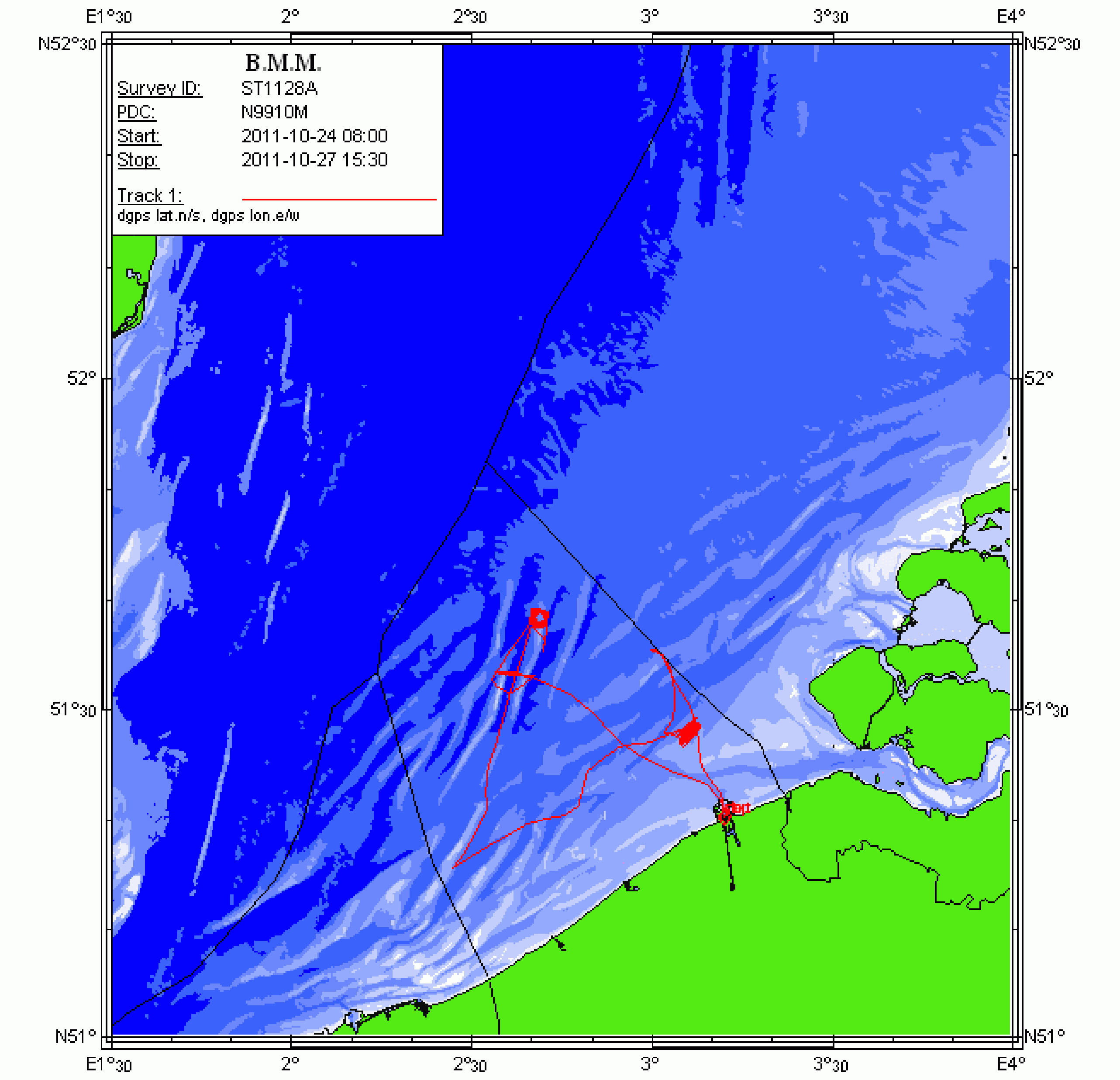

Figure 1: Track plot of campaign 2011/28

6. MEASUREMENTS AND SAMPLING

6.1. MUMM-ZAGRI/MOZ4

1. Hydrodynamic and sediment transport measurements were sailed along a transect crossing the Westhinder and Oosthinder (+/- 7km), respectively along sector 4 and 3 of the exploitation zone 4, Hinder Banken region.
   a. 13 hrs ADCP profiling (RDI 300 kHz),
   b. 13 hrs water column characterization using the Seacat with CTD, OBS, LISST100 instrumentation and 10l Niskin bottles for water sampling (filtration SPM, POC).
   c. Seabed sampling (Van Veen) at selected locations, in function of sediment transport calculations

Table 1

Sailed ADCP track (+/-7km)				
X-Y	51°33.419 N	002°34.269 E	51°33.037 N	002°40.252 E

2. Hydrodynamic and sediment transport measurements crossing alternatively CSD's monitoring zone HBMA and HBMB (sector 2 of zone 4 Hinder Banken)
   a. 13 hrs ADCP profiling (RDI 300 kHz)
   b. 13 hrs water column characterization using the Seacat with CTD, OBS, LISST100 instrumentation and 10l Niskin bottles for water sampling (filtration SPM, POC).
   c. Seabed sampling (Van Veen) at selected locations, in function of sediment transport calculations

Table 2

ADCP track, 1-2-3-4 continuous line					begin points				endpoints			
1-2	477013	5722579	480055	5721893	51	39.224	2	40.063	51	38.861	2	42.704
2-3	480055	5721893	479668	5719369	51	38.861	2	42.704	51	37.498	2	42.377
3-4	479668	5719369	476651	5720055	51	37.498	2	42.377	51	37.862	2	39.759

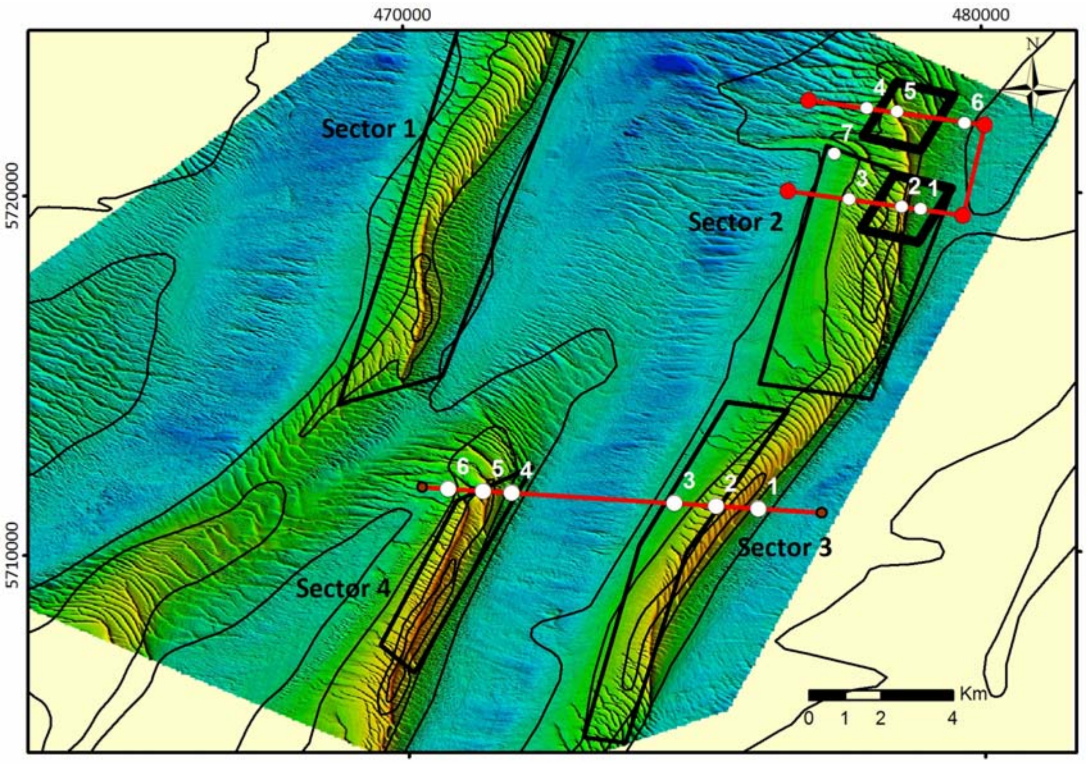

Figure 1: Overview of ADCP profiling in the Hinder Banken area. Along the sampling locations vertical profiling of CTD, OBS, and LISST was performed, together with water sampling and Van Veen grabs.

4.2. MUMM – Multibeam (MBES)

Full-coverage multibeam north of the Vlakte van de Raan (resolving data gaps to obtain full-coverage multibeam data of the entire area)

Multibeam surveying
Tripode search: ~1hr
Vlakte van de Raan: ~12h20
Total: 13h20

4.3. MUMM – PR

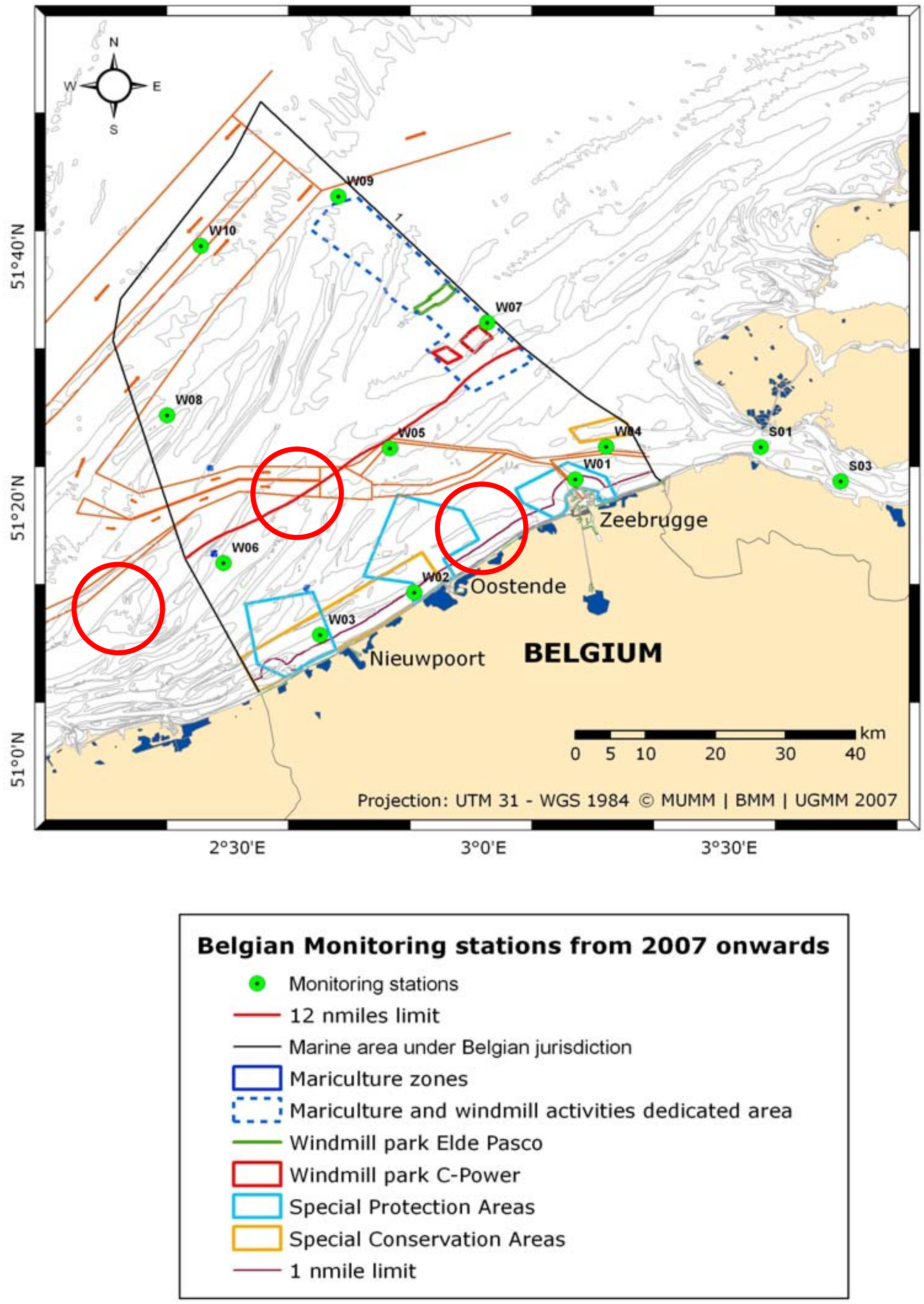

Figure 2: Map with sampling stations WFD

Table 3: Sampling positions

Station	Position	
	N.B.	O.L.
W01	51°22.500’	3°11'.250
W05	51°24.100’	2°48.500’
W06	51°16.250’	2°25.833’

7. REMARKS

Officers and crew are greatly acknowledged for their assistance in the training of the students. The skilful assistance to the various deployments is very much appreciated.

8. DATA STORAGE

- Multibeam echosounding: on hard disk MUMM-BRU; copy will be provided to BMDC. Contact person: Vera Van Lancker
- ADCP: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- LISST: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- Seacat sensor data: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- WFD water sampling MUMM-OST. Contact person: Patrick Roose/Gijs Coulier

RV BELGICA CRUISE 2012/08 – CRUISE REPORT

Subscribers:	Dr. Vera Van Lancker/Prof. Dr. Ann Vanreusel (Delphine Coates) Dr. Michael Fettweis; Jan Haelters
Institutes:	Management Unit of the North Sea Mathematical Models (MUMM) Ghent University, Section Marine Biology (UGent-SMB)
Addresses:	MUMM-Bru: Gulledelle 100, B-1200 Brussels UGent-SMB: Krijgslaan 281, B-9000 Ghent
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Monitoring/Geology-Education: 19/03/2012 - 23/03/2012

Reference to this report:

Van Lancker, V., Coates, D., Fettweis, M., Francken, F., Haelters, J., Hindryckx, K., Kinds, A., Van Campenhout, J., Van den Branden, R., Van den Eynde, D., and Ocean and Lakes students (2012). *Cruise report RV Belgica ST1208, 19-23/03/2012*. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, 12p.

1. CRUISE DETAILS

1.	Cruise number	2012/08
2.	Date/time	Harbor TD: 19/03/2012 at 11h15 *Touch and Go at 17h45 (RHIB)* Harbor TA: 20/03/2012 at 18h06 Harbor TD: 20/03/2012 at 19h03 Harbor TA: 22/03/2012 at 09h56 Harbor TD: 22/03/2012 at 10h55 Harbor TA: 23/03/2012 at 13h
3.	Chief Scientist Participating institutes	Dr. Vera Van Lancker (20-23/03/2012) Delphine Coates (19/03/2012) MUMM, UGent-SMB
4.	Area of interest	Belgian part of the North Sea

2. LIST OF PARTICIPANTS

Institute	NAME	19-20/03/12	20-22/03/12	22-23/03/12
MUMM	Vera Van Lancker	X (embarkation 17h45 RHIB)	X (Ch.sc.)	X (Ch.sc.)
	Reinhilde Van den Branden	X	X	
	Frederic Francken	X (disembarkation 17h45 RHIB)		
	Dries Van den Eynde			X
	Kevin Hindryckx	X		
UG-SMB	Delphine Coates	X (Ch.sc.)		X
	Jelle Van Campenhout		X	X
	Arne Kinds[1]		X	
Oceans & Lakes Students	Amon Kimeli	X		
	Pieter Jan De Nul	Absent		
	Amina Hamza	X		
	Reynald Gimena	X		
	Lizzy Muzungaire	X		
	Benson Kirathe	X		
	Genyffer Troina	X		
	Mirka Laurila		X	
	Pankaj Pant		X	
	Yen Dinh Thi Hai		X	
	Aladin Andrisoa		X	
	Nadine Newmark		X	
	Hendra Silahoho		X	
	Katrien Verlé		X	
	Joana Castro			X
	Nair de Jésus Mendez			X
	Lucia Paiz Medina			X
	Arne Adam			X

	Brecht Vanhove			X
	Iván Pablo Loaiza Alamo			X
	Wanda Bodnar			X
	Total	**10**	**11**	**11**

3. SCIENTIFIC OBJECTIVES

MUMM-VVL - STUDENTS
Students will be trained in the framework of the MSc program Oceans and Lakes, course "In-situ and remote sensing tools in Aquatic Sciences" (Van Lancker & Ruddick). Measurements and observations are performed in function of scientific projects (see below), as also on the Vlakte van de Raan, in continuation of previous educational programs.

MUMM-VVL-ZAGRI/MOZ4
Monitoring of hydrodynamics and sediment transport to evaluate the effects of the exploitation of non-living resources of the territorial sea and the continental shelf.
Within this campaign current and backscatter profiling, together with vertical profiling of water column properties at dedicated locations, is carried out along key areas in Zone 4 within the Hinder Banken region. The spatial datasets will later allow planning the location of a benthic lander, to obtain longer time series of hydrodynamics and sediment transport. Multibeam echosounding, and/or sediment sampling, is carried out in function of sediment transport quantification.

MUMM-MF - MOMO
The measurements are carried out in the framework of the MOMO project. MOMO stands for the monitoring and modeling of cohesive sediment transport and the evaluation of the effects on the marine ecosystem due to dredging and dumping operations. The primary objective of the project is the study of the cohesive sediments on the Belgian Continental Shelf (BCS) using numerical models and field measurements. The combination of monitoring and modeling provides information on the transport processes of the fine fraction and is therefore fundamental to answer questions on composition, origin and residence on the BCS, the change in characteristics of this sediment due to dredging and dumping operations, the effects of the natural variability, the impact on the marine ecosystem especially due to alterations of habitats, the estimation of the net input of hazardous substances in the marine environment and the possibilities to reduce these last two items.

MUMM-BR – MONITORING BELWIND
Monitoring Belwind wind mill farm. Monitoring of hydrodynamics and sediment transport.

MUMM-JH - MONITORING OF OFFSHORE WINDFARMS: MOORING OF PODS
In the framework of the assessments of the effects of the construction and operation of offshore windfarms on small cetaceans, MUMM uses Passive Acoustic Monitoring Devices: porpoise detectors (C-PoDs). A C-PoD consists of a hydrophone, a processor, batteries and a digital timing and logging system, and has an autonomy of up to four months (www.chelonia.co.uk). Data obtained provide an indication of the (relative) abundance of harbor porpoises in the vicinity of the device, up to a distance of approximately 300m. Data obtained from one PoD can give an indication of presence/absence of porpoises, and can be compared to data obtained from PoDs moored at other locations. For mooring PoDs at MOW1 and at the Thorntonbank, a tripod is used; the PoD is attached vertically to the central column.

MUMM-AUMS
The AUMS (Autonomous Underway Measurement System) project 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. 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 MUMM's public web site and following quality control, from the Belgian Marine Data Centre.

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 19/03/2012

Zeebrugge *HW 11h42 (43 dm LAT);*
LW 17h56 (10 dm LAT); HW 23h59 (43 dm LAT)

09h-10h: Embarkation of instruments and personnel

11h15: *Transit to Zeebrugge, area northeast of harbor quay* for sampling operations. Departure was earlier than foreseen, because of incompatibility with other ships leaving the harbor.

11h50-12h23: Sediment samples aMT to characterize locations for a future tripod deployment

Transit to MOW1 for tripod recovery and deployment

13h45 Start recovery tripod, but without success (rope is winded around tripod). Divers are needed.

Transit to Zeebrugge to collect divers with RHIB

13h57-14h15: Pick up of divers to enable tripod recovery
15h25-16h05: Total diving operation

15h45 Recovery tripod
15h55: Deployment MOW1 tripod at position 51°21.561'N; 3°6.910' E (Commandant)

17h39-17h51: Disembarkation F. Francken and divers; pick-up of V. Van Lancker and crew member with RHIB

Transit to Vlakte van de Raan

18h56-19h05: Beam trawling

19h53-00h26: Multibeam echosounding

Tuesday 20/03/2012

Zeebrugge *LW 06h20 (6 dm LAT); HW 12h27 (45 dm LAT); LW 18h40 (9 dm LAT)*

00h34-07h00: ADCP profiling (13hrs cycle), together with water sampling (LISST-CTD-NISKIN10L along ADCP profile)

Ebb phase of the tide.

Water sampling at 01h28; 02h28; 03h20; 04h22; 05h21; 06h28

Transit to Bligh Bank for tripod deployment

08h30 Currents are still too strong for tripod deployment (> 1 kn and Spring equinox).
10h12 Tripod deployment (slack water period) at position 51°42.192N; 2°48.B36' E (Commandant)

Transit to Thornton Bank

11h19-11h32: C-POD deployment Cardinal buoy Thornton Bank

Transit to Vlakte van de Raan

12h26-12h32:	Beam trawling
12h43-14h27:	Van Veen grab sampling (sediment and macrobenthos)
14h39-14h44:	Beam trawling
15h00	Reineck boxcorer
15h23-16h40:	Multibeam operations

Transit to Zeebrugge harbor

18h06-19h03: Touch and go at Zeebrugge. Change of students (Group 2).

Transit to Hinder Banken

21h30- Multibeam echosounding

Wednesday 21/03/12

Zeebrugge *HW 00h42 (45 dm LAT); LW 07h02 (5 dm LAT); HW 13h04 (47 dm LAT); LW 19h16 (8 dm LAT)*

-07h34:	End of multibeam recordings
07h57-11h09	Van Veen grab sampling (sediment and macrobenthos)
11h43-16h09	Multibeam echosounding
16h15-16h42	Beam trawling
17h05-17h56	Multibeam echosounding
18h28	ADCP profiling (13hrs cycle), together with water sampling (LISST-CTD-NISKIN10L along ADCP profile)
	Sampling: 19h06; 20h08; 21h08; 22h10; 23h13; 00h24; 01h31; 02h31; 03h27; 04h27; 05h28; 06h29

Thursday 22/03/12

Zeebrugge *HW 01h17 (46 dm LAT); LW 07h38 (4 dm LAT); HW 13h38 (47 dm LAT); LW 19h50 (7 dm LAT)*

-07h30 End of ADCP profiling in between sector 2 and 3

Transit to Zeebrugge

09h56-10h55: Touch and go at Zeebrugge. Change of students (Group 3)

Transit to Hinder Banken

13h39-14h33	Beam trawling
14h48	ADCP profiling (13hrs cycle), together with water sampling (LISST-CTD-NISKIN10L along ADCP profile)
	Sampling at 15h24; 16h21; 17h21; 18h24; 19h18; 20h15

Friday 23/03/12

Zeebrugge *HW 01h52 (47 dm LAT); LW 08h13 (4 dm LAT); HW 14h13 (48 dm LAT); LW 20h23 (6 dm LAT)*

-04h	End of ADCP profiling
04h28-07h42	Multibeam recordings

08h00-10h30 Van Veen grab sampling (sediment and macrobenthos): 10 stations

Transit to Zeebrugge

13h00 Arrival at Zeebrugge

- End of campaign 2012/08 -

5. TRACK PLOT

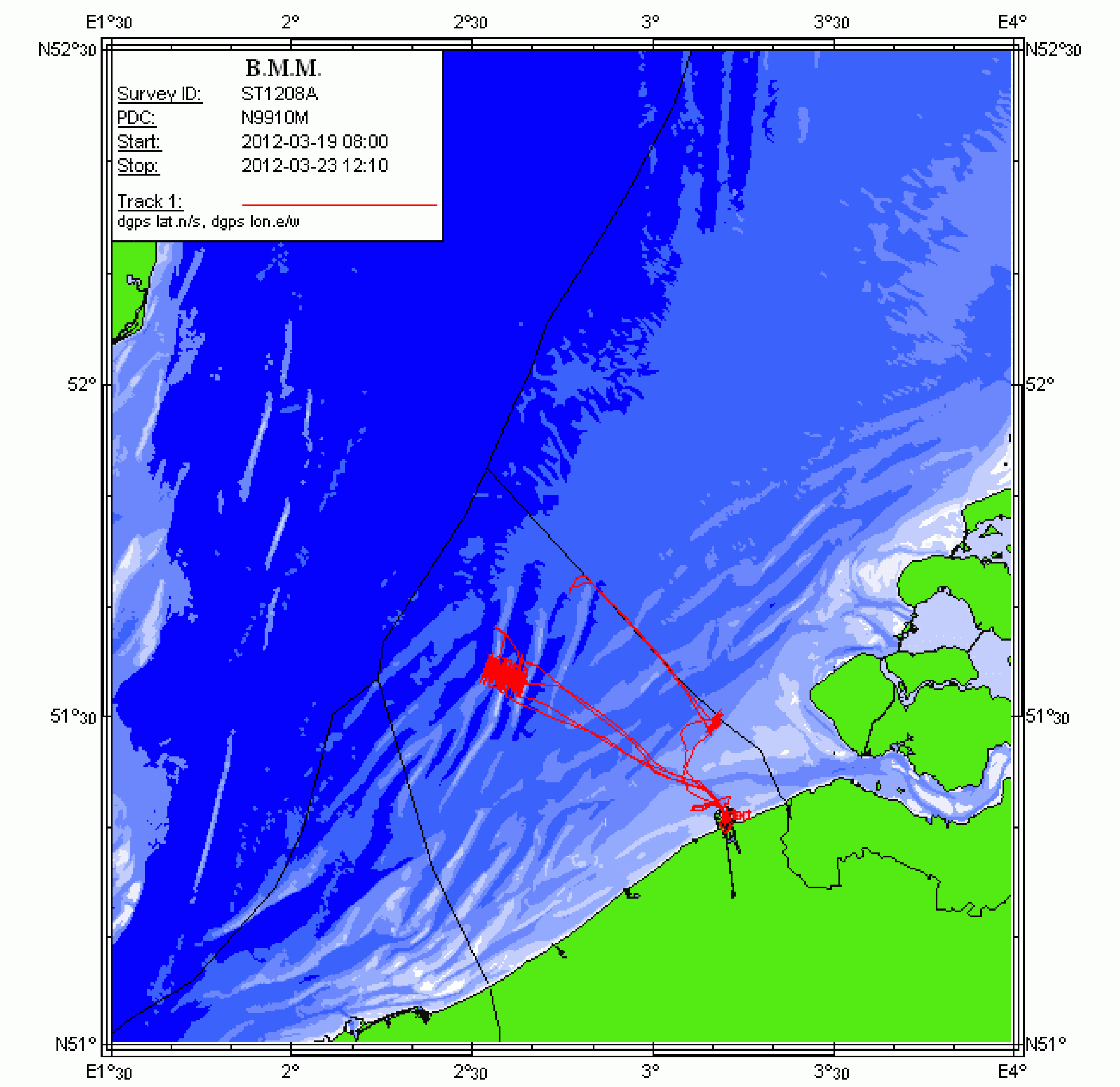

Figure 1: Track plot of campaign 2012/08

6. MEASUREMENTS AND SAMPLING

6.1. MUMM-ZAGRI/MOZ4

Hydrodynamic and sediment transport measurements have been performed along a transect in sector 1 and in-between sector 2 and 3 of the exploitation zone 4, Hinder Banken region.

a. 13 hrs ADCP profiling (RDI 300 kHz),
b. water column characterization using the Seacat with CTD, OBS, LISST100 instrumentation and a 10l Niskin bottle for water sampling (filtration SPM, POC, salinity).
c. Seabed sampling (Van Veen) at selected locations, in function of sediment transport calculations

Table 1

ADCP tracks (WGS84)				
Sector 1	51°38.117N	2°33.710E	51°37.448N	2°35.596E
Sector 2_3	51°34.965N	2°38.886E	51°34.587N	2°40.836E

Table 2. Vertical profiling and water sampling

Sector 1			Sector 2_3	
Top sandbank	51°37.834N	2°34.549E	51°34.726N	2°40.094E

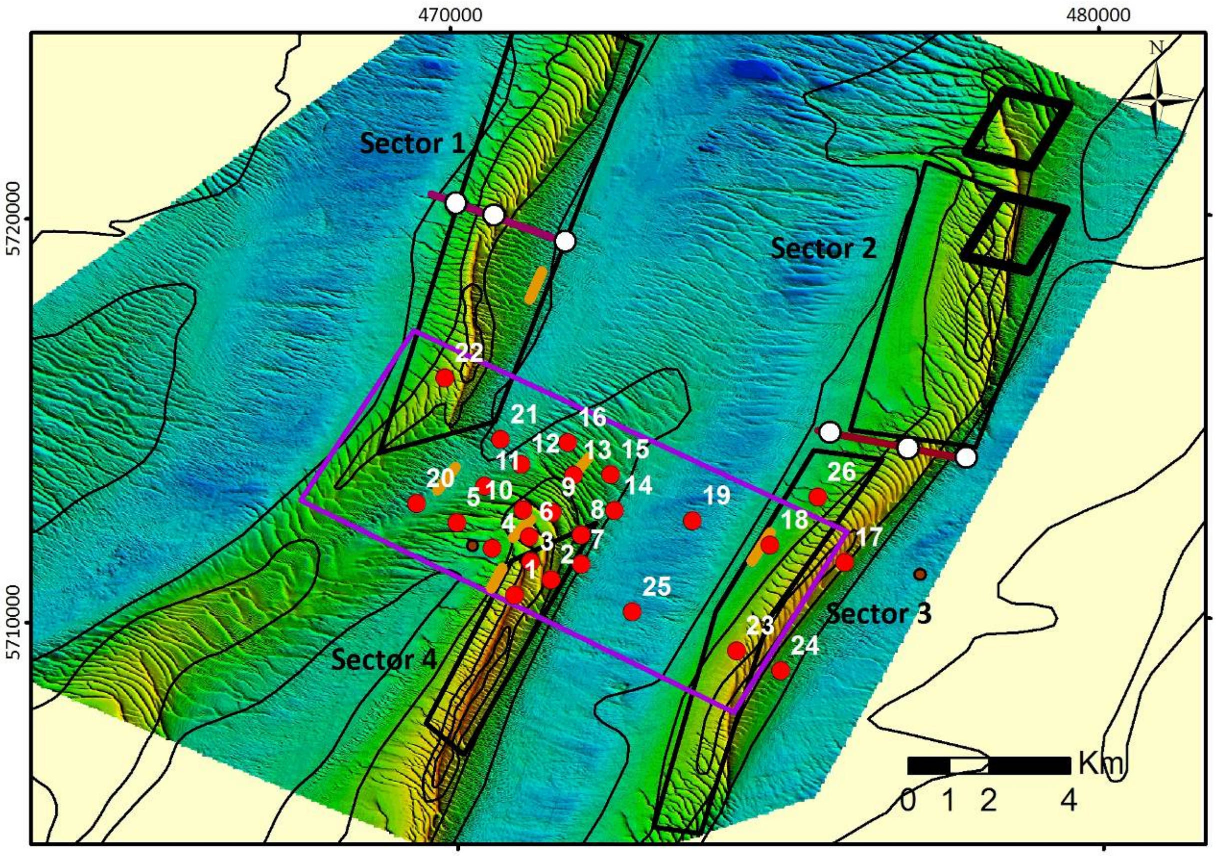

Figure 2: Overview of ADCP profiling in the Hinder Banken area. During campaign ST1208 ADCP profiling has been performed in Sector 1 and in-between Sector 2 and Sector 3. Water sampling and vertical profiling was carried out on the sandbank tops only. Purple polygon shows area of multibeam echosounding and consecutive sediment and macrobenthos sampling (1-24). Thick orange lines are Beam trawl tracks.

Table 3. Water sampling Hinder Banken (HB). Profile in between Sector 2 and 3.

Station Name	Gear	OdasIII Time	WGS84_LAT	WGS84_LONG
S2-3_Niskin 01	SBE19-L-10l	2012-03-21 18:06:50	51° 34.650'	002° 40.006'
S2-3_Niskin 02	SBE19-L-10l	2012-03-21 19:08:10	51° 34.655'	002° 39.915'
S2-3_Niskin 03	SBE19-L-10l	2012-03-21 20:08:40	51° 34.699'	002° 40.009'
S2-3_Niskin 04	SBE19-L-10l	2012-03-21 21:10:30	51° 34.775'	002° 40.069'
S2-3_Niskin 05	SBE19-L-10l	2012-03-21 22:13:00	51° 34.788'	002° 40.086'
S2-3_Niskin 06	SBE19-L-10l	2012-03-21 23:24:20	51° 34.795'	002° 40.080'
S2-3_Niskin 07	SBE19-L-10l	2012-03-22 00:31:50	51° 34.695'	002° 40.068'
S2-3_Niskin 08	SBE19-L-10l	2012-03-22 01:31:30	51° 34.641'	002° 39.928'
S2-3_Niskin 09	SBE19-L-10l	2012-03-22 02:27:10	51° 34.601'	002° 40.128'
S2-3_Niskin 10	SBE19-L-10l	2012-03-22 03:27:50	51° 34.659'	002° 40.082'
S2-3_Niskin 11	SBE19-L-10l	2012-03-22 04:28:00	51° 34.742'	002° 40.105'
S2-3_Niskin 12	SBE19-L-10l	2012-03-22 05:29:00	51° 34.708'	002° 40.186'

Table 4. Water sampling Hinder Banken (HB). Profile in Sector 1.

Station Name	Gear	OdasIII Time	WGS84_LAT	WGS84_LONG
S1_Niskin 01	SBE19-L-10l	2012-03-22 14:24:00	51° 37.763'	002° 34.583'
S1_Niskin 02	SBE19-L-10l	2012-03-22 15:21:20	51° 37.815'	002° 34.521'
S1_Niskin 03	SBE19-L-10l	2012-03-22 16:21:40	51° 37.801'	002° 34.347'
S1_Niskin 04	SBE19-L-10l	2012-03-22 17:24:40	51° 37.815'	002° 34.513'
S1_Niskin 05	SBE19-L-10l	2012-03-22 18:18:20	51° 37.845'	002° 34.465'
S1_Niskin 06	SBE19-L-10l	2012-03-22 19:15:20	51° 37.873'	002° 34.418'
S1_Niskin 07	SBE19-L-10l	2012-03-22 20:15:40	51° 37.821'	002° 34.515'
S1_Niskin 08	SBE19-L-10l	2012-03-22 21:21:10	51° 37.803'	002° 34.599'
S1_Niskin 09	SBE19-L-10l	2012-03-22 22:21:50	51° 37.733'	002° 34.695'
S1_Niskin 10	SBE19-L-10l	2012-03-22 23:25:40	51° 37.780'	002° 34.620'
S1_Niskin 11	SBE19-L-10l	2012-03-23 00:26:10	51° 37.911'	002° 34.511'
S1_Niskin 12	SBE19-L-10l	2012-03-23 01:36:00	51° 37.796'	002° 34.576'
S1_Niskin 13	SBE19-L-10l	2012-03-23 02:52:00	51° 37.784'	002° 34.657'

6.2. MUMM-STUDENTS

A. Vlakte van de Raan

(1) Full coverage multibeam echosounding upper slope north of the Vlakte van de Raan. Previously dense aggregations of macrobenthos were found

(2) ADCP profiling together with water sampling and vertical profiling of CTD, LISST, OBS.

Table 5. ADCP track (3km) over a sandbank-through relief

X-Y	507355	5707755	509008	5705256	51	31.252	3	6.361	51	29.902	3	7.786

Vertical profiling of CTD, LISST, OBS and water sampling at locations:

Table 6. Water sampling Vlakte van de Raan (VVR)

Station Name	Gear	OdasIII Time	WGS84_LAT	WGS84_LONG
VVR_Niskin 1	SBE19-L-10l	2012-03-20 00:28:20	51° 28.621'	003° 9.576'
VVR_Niskin 2	SBE19-L-10l	2012-03-20 01:28:00	51° 28.638'	003° 9.644'
VVR_Niskin 3	SBE19-L-10l	2012-03-20 02:20:50	51° 28.553'	003° 9.572'
VVR_Niskin 4	SBE19-L-10l	2012-03-20 03:22:50	51° 28.541'	003° 9.700'
VVR_Niskin 5	SBE19-L-10l	2012-03-20 04:21:30	51° 28.598'	003° 9.551'
VVR_Niskin 6	SBE19-L-10l	2012-03-20 05:28:10	51° 28.561'	003° 9.533'

(3) Sediment and macrobenthos samples in the multibeam covered area.

Table 7. Van Veen/Reineck sampling Vlakte van de Raan (VVR)

Station Name	Gear	OdasIII Time	WGS84_LAT	WGS84_LONG	EA DEPTH_33
VV_VVR_01	VV	2012-03-20 11:43:40	51° 28.567'	003° 09.039'	-17.3
VV_VVR_06	VV	2012-03-20 12:04:30	51° 30.053'	003° 10.825'	-18.5
VV_VVR_07	VV	2012-03-20 12:12:50	51° 29.899'	003° 10.534'	-18.7
VV_VVR_05	VV	2012-03-20 12:24:10	51° 29.609'	003° 10.815'	-16.8
VV_VVR_04	VV	2012-03-20 12:36:30	51° 29.543'	003° 11.025'	-16.0
VV_VVR_03	VV	2012-03-20 12:47:50	51° 29.292'	003° 10.610'	-16.1
VV_VVR_02	VV	2012-03-20 12:59:10	51° 28.986'	003° 09.859'	-16.8
VV_VVR_14	VV	2012-03-20 13:08:30	51° 29.092'	003° 09.343'	-17.6
VV_VVR_13_1	VV	2012-03-20 13:24:10	51° 29.423'	003° 10.177'	-17.3
VV_VVR_13_2	VV	2012-03-20 13:25:00	51° 29.418'	003° 10.163'	-17.3
VV_VVR_13_3	VV	2012-03-20 13:25:40	51° 29.414'	003° 10.161'	-17.3
VV_VVR_13_4	VV	2012-03-20 13:27:00	51° 29.410'	003° 10.164'	-17.3
R_VVR_07	R	2012-03-20 14:00:00	51° 29.873'	003° 10.517'	-17.5

(4) Beam trawling: tracks on the upper slope of the Vlakte van de Raan (VVR_1; VVR_2) and one track in the gully north of the Vlakte van de Raan (VVR_5).

Table 8. Beam trawling Vlakte van de Raan (VVR)

Station Name	Gear	OdasIII Time	WGS84_LAT	WGS84_LONG	EA DEPTH_33
BMT_VVR_5_start	BMT	2012-03-19 17:56:40	51° 28.615'	003° 04.628'	-19.8
BMT_VVR_5_end	BMT	2012-03-19 18:02:10	51° 28.829'	003° 05.007'	-20.1
BMT_VVR_1_start	BMT	2012-03-20 11:26:40	51° 29.097'	003° 10.181'	-17.1
BMT_VVR_1_end	BMT	2012-03-20 11:31:40	51° 28.919'	003° 09.771'	-17.3
BMT_VVR_2_start	BMT	2012-03-20 13:39:20	51° 30.015'	003° 10.728'	-17.8
BMT_VVR_2_end	BMT	2012-03-20 13:43:50	51° 30.191'	003° 11.045'	-17.6

B. Hinder Banken

(1) Full-coverage multibeam echosounding in the box indicated on Fig. 2.

(2) Sediment and macrobenthos samples in the area covered with multibeam

Table 9. Van Veen sampling Hinder Banken (HB)

Station Name	OdasIII Time	WGS84_LAT	WGS84_LONG	Comment
VV_HB_01	2012-03-21 10:09:40	51° 32.772'	002° 34.824'	
VV_HB_02	2012-03-21 09:59:20	51° 32.936'	002° 35.335'	
VV_HB_03	2012-03-21 09:36:20	51° 33.202'	002° 35.041'	
VV_HB_04	2012-03-21 09:25:40	51° 33.356'	002° 34.524'	
VV_HB_05	2012-03-21 06:57:00	51° 33.717'	002° 34.070'	
VV_HB_06	2012-03-21 09:14:10	51° 33.524'	002° 35.027'	
VV_HB_07	2012-03-21 09:46:30	51° 33.166'	002° 35.696'	
VV_HB_08	2012-03-21 09:01:00	51° 33.544'	002° 35.689'	
VV_HB_09	2012-03-21 08:32:50	51° 33.856'	002° 35.301'	
VV_HB_10	2012-03-21 08:24:10	51° 33.895'	002° 34.927'	
VV_HB_11	2012-03-21 07:14:30	51° 34.203'	002° 34.402'	
VV_HB_12	2012-03-21 07:29:50	51° 34.515'	002° 34.918'	
VV_HB_13	2012-03-21 07:53:50	51° 34.348'	002° 35.605'	
VV_HB_14	2012-03-21 08:46:00	51° 33.857'	002° 36.220'	
VV_HB_15	2012-03-21 08:03:40	51° 34.356'	002° 36.092'	
VV_HB_16	2012-03-21 07:40:30	51° 34.798'	002° 35.508'	
VV_HB_17	2012-03-23 08:37:50	51° 33.181'	002° 39.198'	

VV_HB_18	2012-03-23 08:27:40	51° 33.427'	002° 38.201'	
VV_HB_19	2012-03-23 08:02:30	51° 33.748'	002° 37.256'	
VV_HB_20	2012-03-23 07:40:20	51° 33.964'	002° 33.485'	
VV_HB_21	2012-03-23 07:26:10	51° 34.867'	002° 34.594'	
VV_HB_22	2012-03-23 07:14:40	51° 35.639'	002° 33.853'	
VV_HB_23	2012-03-23 09:16:00	51° 32.037'	002° 37.749'	
VV_HB_25	2012-03-23 08:56:40	51° 32.520'	002° 36.411'	Gravel, no sample taken
VV_HB_25	2012-03-23 08:59:50	51° 32.510'	002° 36.412'	Gravel, no sample taken
VV_HB_25	2012-03-23 09:02:40	51° 32.492'	002° 36.398'	Gravel, no sample taken
VV_HB_26	2012-03-23 08:15:00	51° 34.067'	002° 38.861'	

(3) <u>Beam trawling</u>: 6 tracks (Figure 2)

Table 10. Beam trawling Hinder Banken (HB)

Station Name	OdasIII Time	WGS84_LAT	WGS84_LONG	Comment
BMT_HB_01_end	2012-03-21 15:21:10	51° 34.307'	002° 35.570'	Empty
BMT_HB_01_start	2012-03-21 15:15:20	51° 34.660'	002° 35.887'	Empty
BMT_HB_02_end	2012-03-21 15:33:10	51° 33.672'	002° 34.940'	
BMT_HB_02_start	2012-03-21 15:29:40	51° 33.852'	002° 35.124'	
BMT_HB_03_end	2012-03-21 15:49:10	51° 32.565'	002° 34.360'	
BMT_HB_03_start	2012-03-21 15:42:30	51° 32.949'	002° 34.538'	
BMT_HB_04_end	2012-03-22 12:45:40	51° 33.627'	002° 38.286'	
BMT_HB_04_start	2012-03-22 12:39:40	51° 33.237'	002° 38.014'	
BMT_HB_05_end	2012-03-22 13:16:10	51° 34.536'	002° 34.109'	
BMT_HB_05_start	2012-03-22 13:12:30	51° 34.296'	002° 33.909'	
BMT_HB_06_end	2012-03-22 13:38:30	51° 37.013'	002° 35.210'	
BMT_HB_06_start	2012-03-22 13:33:50	51° 36.722'	002° 35.064'	

6.3. MUMM-MOMO

1. Recovery and deployment of tripod

The tripod deployed at MOW1 has been recovered and replaced on Monday 19/03.

Table 11. Tripod handling MOW1.

ID	Instrument	Date (local time)	Lat_wgs84	Lon_wgs84
MOW1	Tripod recuperation	19/03	51°N 21.516’	3°E 7.126’
“	Tripod deployment	19/03	51°N 21.561’	3°E 6.910’

2. Reconnaissance sampling and survey of future deployment area of a tripod (aMT)

A new location is to be determined for the future deployment of a benthic tripod on behalf of Maritime Entrance (aMT), Flemish Authorities. The deployment is to be located northeast of the quay of Zeebrugge harbor, at a location not hindered by traffic or navigational constraints (Figure below). Preferably the surficial sediments are not composed of loose muds.

Table 12. Sampled Van Veen locations outer Zeebrugge harbor area

ID	Lat_wgs84		Lon_wgs84	
AMT1	51°N	22.038’	3°E	12.538’
AMT2	51°N	22.759’	3°E	12.859’
AMT3	51°N	22.095’	3°E	12.451’
AMT4	51°N	22.476’	3°E	11.260’

6.4. MUMM-BELWIND

Deployment of tripod

Deployment of a tripod on the Bligh Bank on 20/03.

Table 13. Tripod handling Bligh Bank

ID	Instrument	Date (local time)	Lat_wgs84	Lon_wgs84
Bligh Bank	Tripod deployment	20/03 10h12	51°42.192N	2°48.B36’ E

6.5. MUMM-JH

C-POD at Cardinal buoy Thornton Bank was missing, hence no recovery. Another C-POD was deployed around 20/3/12, 11h20.

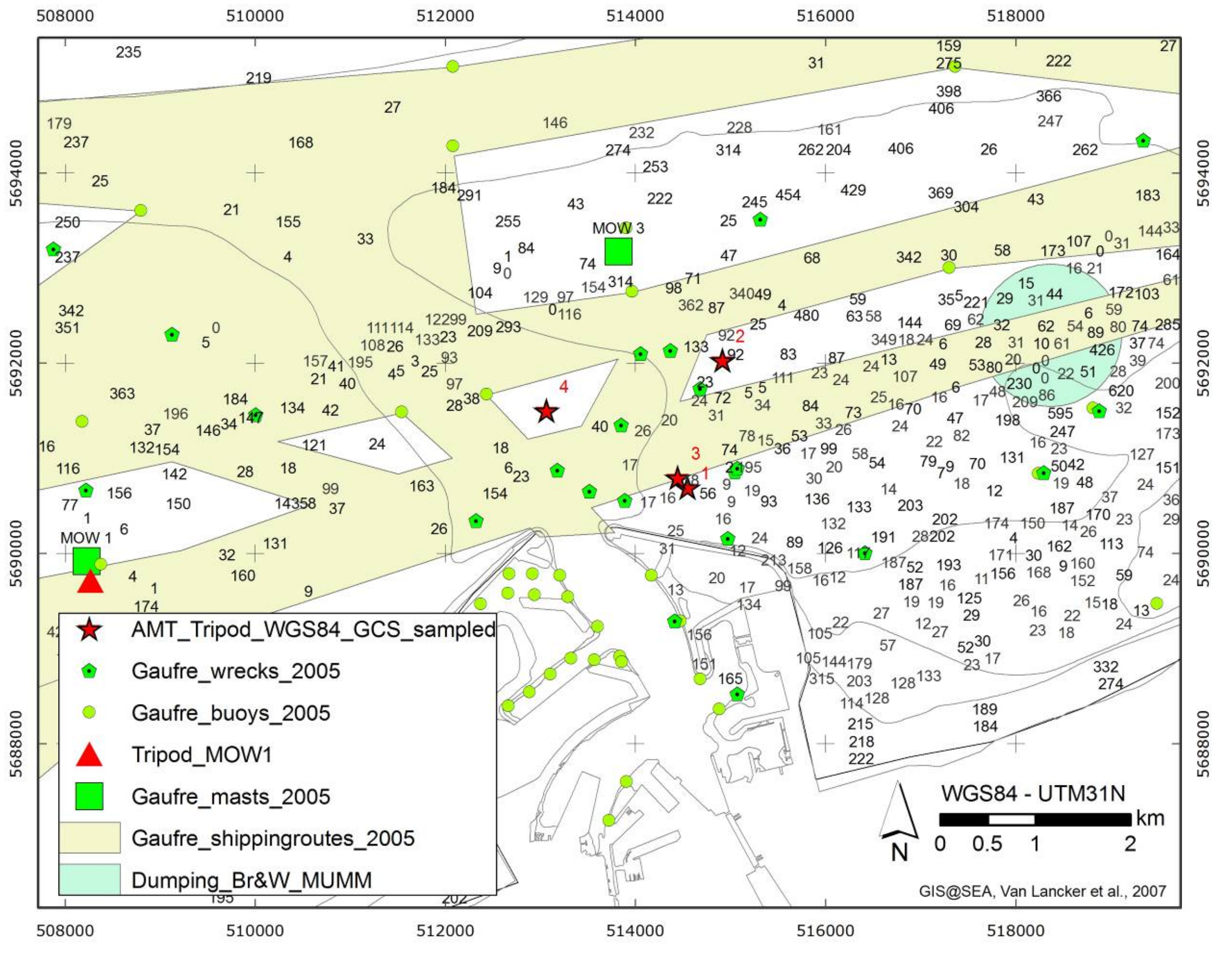

Figure 2: Sampling locations (aMT_Tripod), together with known median grain-sizes in the area.

Figure 3: Pictures of samples taken outside Zeebrugge harbor.

7. REMARKS

- Officers and crew are thanked warmly for the skillful handling of the operations, as also in acquainting the students in sea-going operations.
- Highly favorable weather conditions
- No technical problems were encountered

8. DATA STORAGE

- Multibeam echosounding: on hard disk MUMM-BRU; copy will be provided to BMDC. Contact person: Vera Van Lancker
- ADCP: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- LISST: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- Seacat sensor data: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- Sediment and macrobenthos samples: UG-SMB. Contact person: Delphine Coates
- Beam trawling data: UG-SMB. Contact person: Delphine Coates
- All automatic online acquired data (ODASIII including AUMS) have been provided to BMDC. Contact person: BMDC@mumm.ac.be

RV BELGICA CRUISE 2012/19 – CRUISE REPORT

Subscribers:	Dr. Vera Van Lancker/ Sonia Papili, Olga Lopera /Jan Reubens
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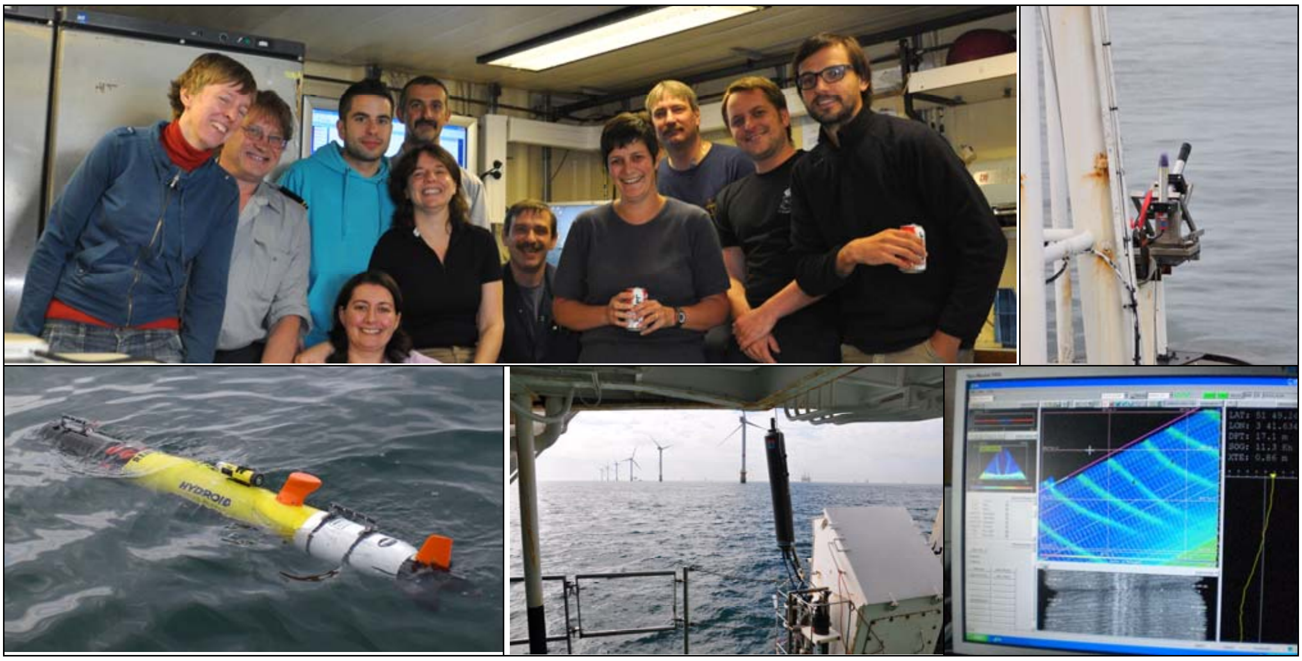
Monitoring/Geology: 2/07/2012 - 6/07/2012



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

Reference to this report:

Van Lancker, V., Baeye, M., Muñiz-Piniella, A., Nechad, B., Van den Branden, R., Papili, S., Coppens, P., Lelong, M., and Regent, Y. (2012). *Cruise report RV Belgica ST1219, 2-6/07/2012*. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, 14p.

1. CRUISE DETAILS

1.	Cruise number	2012/19
2.	Date/time	Harbour TD: 2/7/2012 at 10h45 Harbour TA: 6/7/2012 at 13h05
3.	Chief Scientist Participating institutes	Dr. Vera Van Lancker MUMM / Belgian Navy DGMR / UGent-SMB
4.	Area of interest	Belgian and Dutch part of the North Sea

2. LIST OF PARTICIPANTS

Institute	NAME	2-6/7/2012
MUMM	Vera Van Lancker	X
"	Reinhilde Van den Branden	X
"	Bouchra Nechad	X
	Angel Muñiz-Piniella	X
	Matthias Baeye	X
Belgian Navy - DGMR	Sonia Papili	X
	Marnick Lelong	X
	Ives Regent	X
	Paul Coppens	X
Total number of participants		**9**

3. SCIENTIFIC OBJECTIVES

MUMM-VVL: ZAGRI/MOZ4

Monitoring of hydrodynamics and sediment transport to evaluate the effects of the exploitation of non-living resources of the territorial sea and the continental shelf.
Within this campaign ADCP profiling and 13hrs oceanographic and sediment transport measurements are foreseen in and around Zone 4 within the Hinder Banken region.

MUMM-VVL: MULTIBEAM

Multibeam measurements were performed along the deltafront of the Vlakte van de Raan starting in Belgian waters and continuing in the Dutch coastal zone. Results will be used for a habitat mapping study based on the multibeam data and coupled to benthos data from IMARES (NL). Hypotheses will be tested on the relationship of the distribution of the invasive species *Ensis directus* and abiotic parameters. It adds to system and process knowledge of the Belgian-Dutch coastal zone, relevant within Europe's Marine Strategy Framework Directive.

DGMR-SP: MNR07/MNR09

MRN07 - Study of sand dynamics at small scale to evaluate the risk of mine burial.
MRN09 – Detection and classification of mines using high resolution SAS images.

The project MRN07 aims to evaluate the necessary time for partial or total burial of objects in shallow water (<50m depth) by studying the sand dynamics at a small scale on the BCS in both time and space domain. Several techniques will be used to reach this goal: time series of side scan sonar measurements will be performed, boxcores for validation of acoustic images will be taken and instrumented mines are deployed in strategic site to investigate small-scale variability of sand dynamics over long periods, 3 to 12 months each site. The areas of analysis will be chosen in the first instance by considering scientific criteria and then their economical and social value. In the range of areas with good scientific characteristics, it will be preferred to make measurements in sites densely populated by ships and fishermen. This choice is due to the fact that the research will be used for military and civil application regarding the safety of human life on the North Sea

The project MRN09 aims to determine the limits for the detection and classification of seabed objects, in particular mines. In the frame of the Long Term Critical Requirement 21 (Fast detection and neutralization of a minefield) and following the development of autonomous underwater vehicles (AUV), it is necessary to develop classification procedures. This work will focus on the study of synthetic aperture sonar (SAS) images to validate SAS image processing algorithms, which will be developed. Data (high resolution SAS images) will be collected using the available equipment (modern mine hunters and sensors from the Mine Warfare Data Center) during the measurement campaigns that will be planned in collaboration with the MRN07 study.

UGent/SMB-JR: Monitoring of offshore windfarms: relocation of lost acoustic receivers

The foundations of wind turbines act as secondary artificial reefs, attracting different kind of fish species. Initially, high densities of fishes present at artificial reefs where related to an increased productivity. In 1983 an alternative hypothesis, stating that artificial reefs attract fishes due to behavioural preferences but do not increase productivity, emerged (Bohnsack 1989). This PhD research aims to determine attraction and/or net productions of the ichthyofauna on the artificial hard substrates of the wind turbines placed at the Thorntonbank. A nearby artificial hard substrate (LCT 457ship wreck) and sand bank will act as reference sites. Different techniques will be integrated to understand, quantify and visualize the functional relationships between the ichthyofauna and the artificial reef. Quantification is done using visual (visual census, camera observations) and invasive techniques (gill nets, line fishing). Cod (Gadus morhua) and pouting (Trispoterus luscus) are selected for detailed investigation on habitat and food preferences, condition index and migration patterns using different techniques (e.g. stomach content analysis, fatty acid analysis, telemetry).

During this campaign, the Belgian Navy, DGMR will use its instrumentation to relocate lost acoustic receivers in the windmill farm of the Thornton Bank.

MUMM-REMSEM

Collect a set of turbidity and marine reflectance dataset, in moderate to very turbid waters to study their relationship. The main objectives are: a) to gain experience using the TriOS system for the radiometric measurements aboard the ship, and b) to gather in-situ data of turbidity (TU), Suspended Particulate Matter concentration (SPM), fluorescence (Fluo) and marine reflectance (Rrs) to be added to the REMSEM database, and used for TU and TSM algorithms calibration/validation.

MUMM-AUMS

The AUMS (Autonomous Underway Measurement System) project 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. 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 MUMM's public web site and following quality control, from the Belgian Marine Data Centre.

4. OPERATIONAL COURSE

All times are given in local time (UTC-2). All coordinates in WGS84.
Throughout the campaign, measurements were foreseen with the AUMS system, but the system was not operational.

Monday 2nd July

Zeebrugge HW 13h09 (4.22m TAW); LW 19h31 (0.48m TAW)

09h-10h	Embarkation of instruments and personnel
10h45	Sail off from Zeebrugge (awaiting ship entering the harbour)

Transit to Wandelaar for multibeam recordings DGMR

10h48-16h46	Multibeam recording (22 lines) **(~6h in total)**

Transit to Hinder Banken for 13hrs measurements for MUMM

18h33	Anchoring. *Around 18h30 clear observation of topzone crestline of Oosthinder (drop from 7.2 to 10m). Water masses meet with along the Westside more agitated water; along the east side more calm water masses.*
18h50	Start 13hrs cycle at one location (13hrs cycle). ADCP recordings (from 18h38), together with water sampling (LISST-CTD-NISKIN10L) **every 20'**. Location east flank Oosthinder. **Dataset <ST1219 HB ADCP-I> 13hrs**

Tuesday 3rd July

Zeebrugge HW 1h32 (4.38m TAW); LW 7h54 (0.47m TAW);
HW 13h59 (4.30m TAW); LW: 20h21 (0.34m TAW)

07h50	End 13hrs cycle

Transit to gravel bed fields for REMUS AUV measurements and multibeam recordings, DGMR

8h30-	Start Remus mission (Area G1-G2), Remus alignment
09h35	RIB in water
09h38	Remus in water
11h45	Remus recovered
11h50	Remus on board
11h55	Optical measurements MUMM-REMSEM, ST01
12h10-14h00	Multibeam recordings (Area G1-G2) (10 lines) **(~2h in total)**
14h05	Second Remus Mission (Area G5 "Refugium")
14h25	RIB in water
14h28	Remus in water
15h00	Remus on board
15h05- 15h42	Multibeam recording (Area G5 "Refugium") (5 lines) **(37' in total)**

Transit to east flank Oosthinder to relocate an ADCP deployed during campaign CP2012/18 with REMUS AUV

16h30	Remus mission to locate the ADCP, Remus Alignment
16h50	RIB in water
16h55	Remus in water
17h30	Remus on board

Transit to ADCP transect location in Hinder Banken area, MUMM

18h	ADCP profiling (13hrs cycle) along a transect crossing the Westhinder and Oosthinder

Wednesday 4th July

Zeebrugge HW 2h21 (4.50m TAW); LW 8h41 (0.47m TAW);
HW 14h44 (4.38m TAW); LW 21h07 (0.22m TAW)

07h15 End of ADCP profiling **(13h15 in total)**

Transit to Thornton Bank for relocation of acoustic receivers (UG-SMB) with AUV REMUS, DGMR

09h15 Arrival Thornton Bank
09h40 Start Remus recordings in the windmill park around D5-D6 piles
12h05 End Remus recordings

Transit to Hinder Banken, for continuation multibeam recordings DGMR

13h50 Optical measurements MUMM-REMSEM, ST02

15h45-17h30 Multibeam recordings in-between G1 and G2 area **(1h45 in total)**

Transit to ADCP location, eastern flank of Oosthinder to recover ADCP, MUMM

18h55 Start of operations for recovery bottom-mounted ADCP
19h20 RHIB onboard, ADCP instrument recovered.
Following the ADCP frame is picked-up.

Transit to Dutch coastal zone south of Rotterdam harbour, MUMM

Thursday 5th July

Zeebrugge HW 3h06 (4.58m TAW); LW 9h25 (0.46m TAW);
HW 15h27 (4.44m TAW); LW 21h52 (0.11m TAW)

00h32 Halt in the channel north of the area of interest to measure a sound velocity profile.
From this location onwards, multibeam recordings were performed.

13h30 Temporary halt of multibeam recordings.

It is decided to test the AUV REMUS for the detection of macrobenthic communities. A test area was chosen and an AUV programme was made for a box of +/- 200*200m.

13h10 Optical measurements MUMM-REMSEM, ST03

13h30 – 14h55 Remus mission (Dutch coastal zone). 1800 kHz. N-S and W-E lines are programmed.

14h20 Optical measurements MUMM-REMSEM, ST04

15h09 Continuation multibeam recordings, sailing from the Netherlands towards Belgium.

Friday 6th July

Zeebrugge *HW 3h51 (4.63m TAW); LW 10h09 (0.46m TAW);*
HW 16h11 (4.49m TAW) ***SPRING***

09h20 Optical measurements MUMM-REMSEM, ST05

11h11 End of multibeam recordings **(~20h in total)**

Transit to Zeebrugge

13h05 Arrival at Zeebrugge

-End of campaign-

5. TRACK PLOT

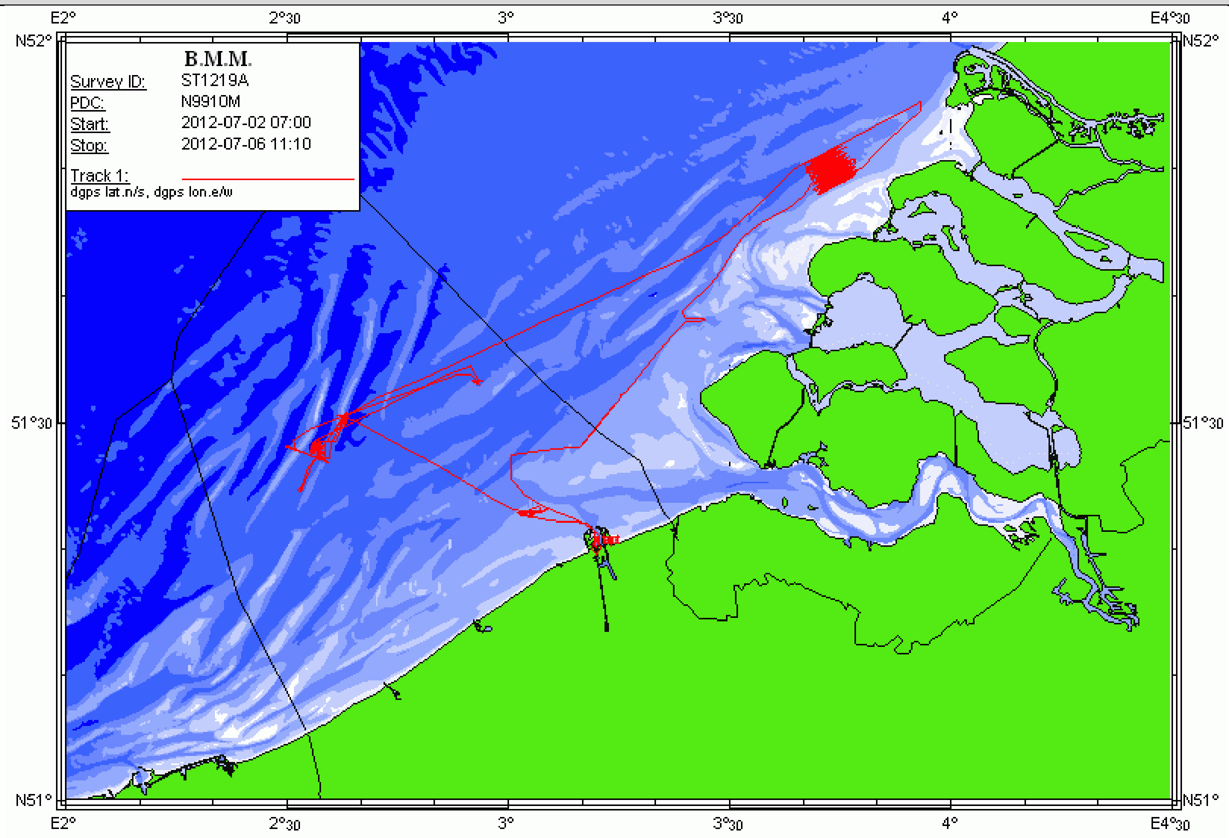


Figure 1: Track plot of campaign 2012/19

6. MEASUREMENTS AND SAMPLING

6.1. MUMM-VVL: ZAGRI/MOZ4

1. Hydrodynamic and sediment transport measurements at a single location

    a. 13 hrs ADCP profiling (RDI 300 kHz) at a single location
    b. Water column characterization through vertical profiling using the Seacat with CTD, OBS, LISST100 instrumentation and a 10l Niskin bottle for water sampling (filtration SPM, POC). **Every 20 min.**

        ⇨ **Dataset <ST1219 HB ADCP-I> 13hrs**

        ⇨

Table 1. Location of the 13hrs vertical profiling and sampling. ADCP-I. Tidal excursion +/- 220m.

	Station location	
ADCP Impact	51°30'.600N	2°37'.939E

Table 2. Vertical profiling and water sampling +/- every 20'. Location: ADCP-I

StationName	Gear	OdasTime	SPM (500ml)	Salinity	POC (120ml)
ADCP-I_Niskin 01	SBE19-L-10l	2012-07-02 16:47:40	x		x
ADCP-I_Niskin 02	SBE19-L-10l	2012-07-02 17:20:50	x	x	
ADCP-I_Niskin 03	SBE19-L-10l	2012-07-02 17:41:20	x	x	
ADCP-I_Niskin 04	SBE19-L-10l	2012-07-02 18:04:10	x	x	x
ADCP-I_Niskin 05	SBE19-L-10l	2012-07-02 18:24:20	x	x	
ADCP-I_Niskin 06	SBE19-L-10l	2012-07-02 18:42:10	x	x	

ADCP-I_Niskin 07	SBE19-L-10l	2012-07-02 19:03:40	x	x	x
ADCP-I_Niskin 08	SBE19-L-10l	2012-07-02 19:23:00	x	x	
ADCP-I_Niskin 09	SBE19-L-10l	2012-07-02 19:44:40	x	x	
ADCP-I_Niskin 10	SBE19-L-10l	2012-07-02 20:01:10	x	x	x
ADCP-I_Niskin 11	SBE19-L-10l	2012-07-02 20:22:10	x	x	
ADCP-I_Niskin 12	SBE19-L-10l	2012-07-02 20:42:50	x	x	
ADCP-I_Niskin 13	SBE19-L-10l	2012-07-02 21:02:40	x	x	x
ADCP-I_Niskin 14	SBE19-L-10l	2012-07-02 21:22:10	x	x	
ADCP-I_Niskin 15	SBE19-L-10l	2012-07-02 21:41:10	x	x	x
ADCP-I_Niskin 16	SBE19-L-10l	2012-07-02 22:09:50	x	x	
ADCP-I_Niskin 17	SBE19-L-10l	2012-07-02 22:22:50	x	x	x
ADCP-I_Niskin 19	SBE19-L-10l	2012-07-02 23:01:50	x	x	
ADCP-I_Niskin 20	SBE19-L-10l	2012-07-02 23:21:50	x	x	x
ADCP-I_Niskin 21	SBE19-L-10l	2012-07-02 23:42:00	x	x	
ADCP-I_Niskin 22	SBE19-L-10l	2012-07-03 00:01:30	x	x	x
ADCP-I_Niskin 23	SBE19-L-10l	2012-07-03 00:22:20	x	x	
ADCP-I_Niskin 24	SBE19-L-10l	2012-07-03 00:41:10	x	x	
ADCP-I_Niskin 25	SBE19-L-10l	2012-07-03 01:01:20	x	x	x
ADCP-I_Niskin 26	SBE19-L-10l	2012-07-03 01:21:50	x	x	
ADCP-I_Niskin 27	SBE19-L-10l	2012-07-03 01:42:20	x	x	
ADCP-I_Niskin 28	SBE19-L-10l	2012-07-03 02:05:40	x	x	x
ADCP-I_Niskin 29	SBE19-L-10l	2012-07-03 02:24:00	x	x	
ADCP-I_Niskin 30	SBE19-L-10l	2012-07-03 02:43:20	x	x	
ADCP-I_Niskin 31	SBE19-L-10l	2012-07-03 03:02:20	x	x	x
ADCP-I_Niskin 32	SBE19-L-10l	2012-07-03 03:23:30	x	x	
ADCP-I_Niskin 33	SBE19-L-10l	2012-07-03 03:46:30	x	x	
ADCP-I_Niskin 34	SBE19-L-10l	2012-07-03 04:02:30	x		x
ADCP-I_Niskin 35	SBE19-L-10l	2012-07-03 04:23:50	x		
ADCP-I_Niskin 36	SBE19-L-10l	2012-07-03 04:44:50	x	x?	
ADCP-I_Niskin 37	SBE19-L-10l	2012-07-03 05:02:20	x		x
ADCP-I_Niskin 38	SBE19-L-10l	2012-07-03 05:22:20	x		
ADCP-I_Niskin 39	SBE19-L-10l	2012-07-03 05:42:20	x	x?	x (250ml!)

2. Hydrodynamic and sediment transport measurements along a transect in a gravel area south of zone 4, Hinder Banken region.
    a. 13 hrs ADCP profiling (RDI 300 kHz) along a transect

Table 3. Coordinates of 13hrs ADCP transect in the Habitat Directive Area.

ADCP tracks (WGS84)				
Gravel area	2°29'.922E	51°28'.157N	2°35'.843E	51°26'.834N

3. Recovery bottom-mounted ADCP along east flank of the Oosthinder sandbank

The ADCP was deployed on Friday 29 June 2012 during campaign ST1218 and was recovered during ST1219 on Wednesday, 4 July 2012. Approximately, 6 days of measurements are obtained. Recovery process went very fluently. Very calm weather conditions.

Table 4. Coordinates of longer term bottom-mounted ADCP deployment.

ADCP longer term measurements (+/- 6 days). Location ADCP-I			Deployment UTC	Recovery UTC
ADCP Impact	51°30'.651N	2°37'.954E	2012-06-29 xx:xx:xx	
REMUS relocation	51° 30'.558N	2° 37'.814E		~2012-07-04 17:00

4. Overview of measurements in the Hinder Banken area

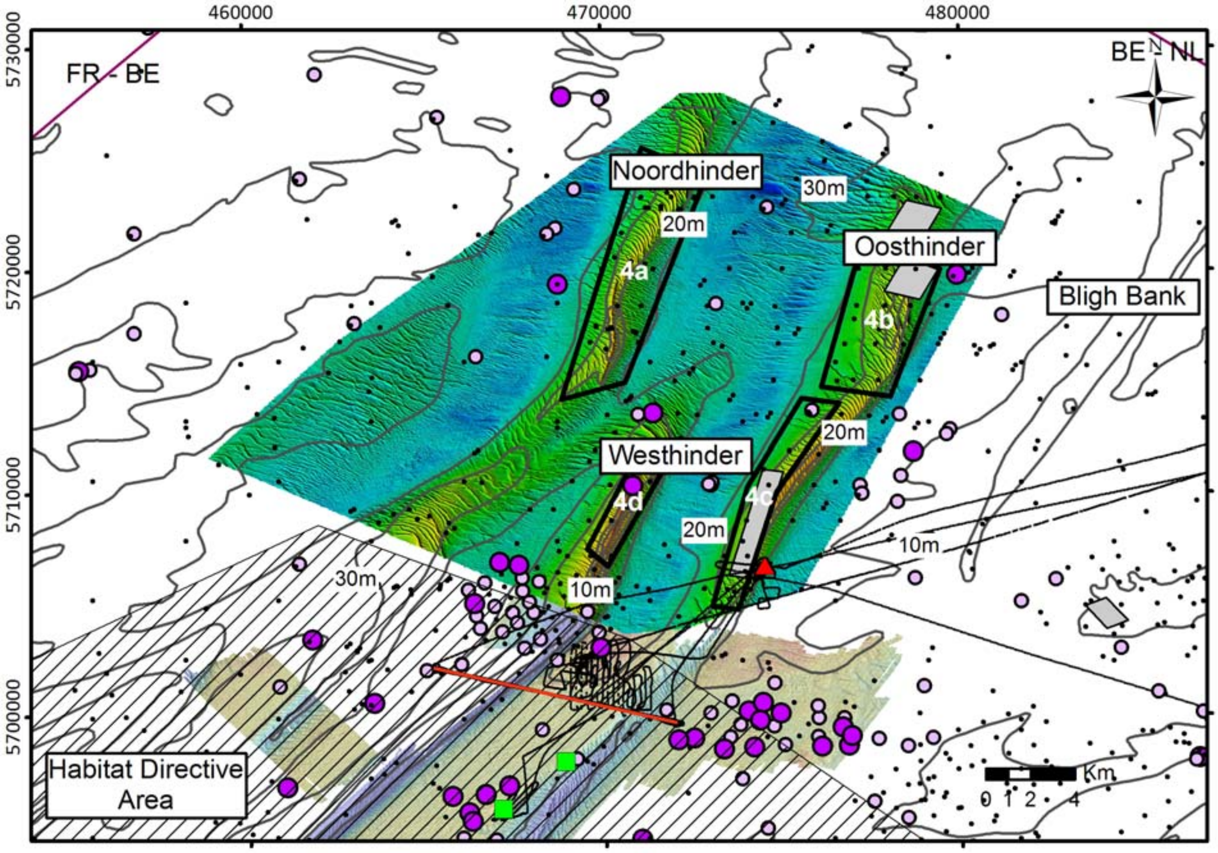


Figure 2: Hinder Banken area with indication of 4 sectors for marine aggregate extraction (4a, 4b, 4c, 4d) (black polygons). Red polyline in the Habitat Directive area represents the trackline of 13hrs ADCP profiling (ST1219). Red triangle is the position of the 13hrs cycle of water samping and vertical profiling of oceanographic parameters (ST1219). Grey shaded polygons represent follow-up areas of multibeam bathymetry (FPS Economy, Self-Employed, SME's and Energy, since May 2011) and benthos (ILVO). The Habitat Directive Area is present at a minimum of 2.5km from the southernmost sectors. In this area valuable gravel beds are occurring, here represented by circles; they represent seabed samples with more than 20 % of gravel. At the smallest dots no gravel was found, at least using a Van Veen grab. The green rectangles represent refugia where the seabed hosts a high biodiversity. The thin black line represents the tracklines of the vessel.

6.2. MUMM-VVL: MULTIBEAM

1. Full-coverage multibeam recordings (Kongsberg-Simrad EM3002)

Table 5: Start line (south) of the box where full-coverage multibeam has been sailed.

Track	Lat_wgs84		Long_wgs84	
Full_end	51	49.608	3	47.163
Full_start	51	48.014	3	42.245

2. Single-track multibeam recordings along pre-defined lines

Table 6: Start and end position of the single line multibeam tracklines.

Track	Lat_wgs84		Long_wgs84	
Track 1_start	51	52.617	3	52.186
Track 1_end	51	55.211	3	57.067
Track 2_start	51	46.520	3	37.181
Track 2_end	51	48.525	3	41.343
Track 3_start	51	38.076	3	22.079

Track 3_end	51	38.076	3	28.178
Track 4_start	51	28.141	3	9.892
Track 4_end	51	31.897	3	15.138

Apart from these lines the transit from the Dutch to Belgian coastal waters was sailed bordering the -10m MLLWS depth contour.

In total 20h of MBES was sailed.

3. 13hrs ADCP transect with water sampling and vertical profiling of oceanographic parameters

These measurements were not carried out. Priority was given to the full-coverage multibeam recordings.

6.3. DGMR-SP: MNR07/MNR09

1. Multibeam data acquisition (Kongsberg-Simrad EM3002)

Table 7: Coordinates of MBES lines in Area: Wandelaar (~6h in total)

Area	ID	Long (DM)	Lat(DM)
Area1	First line A	3° 03,900’ E	51° 23.038’ N
	First line B	3° 02,420’ E	51° 23,038’ N
	Last line A	3° 02.420’ E	51° 22,798’ N
	Last line B	3° 03,900’ E	51° 22,798’ N
Area2	A	3° 1,946’ E	51° 22,611’ N
	I	3° 2,218’ E	51° 22,608’ N
	L	3° 2,218’ E	51° 22,725’ N
	M	3° 1,942’ E	51° 22,722’ N

Table 8: Coordinates of MBES lines in Area: Hinder Banken (~4h15 in total)

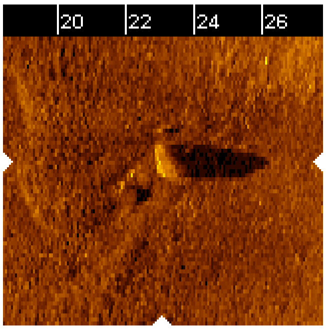
Area	ID	Long (DM)	Lat (DM)
G1	Start line A	2° 33,758’ E	51° 28,458’ N
	Start line B	2° 33,732’ E	51° 28,080’ N
G2	Start line A	2° 34,633’ E	51° 27,754’ N
	Start line B	2° 34,638’ E	51° 27,367’ N
G5 “Refugium”	Start line A	2° 31,478’ E	51° 24,734’ N
	Start line B	2° 31,682’ E	51° 24,945’ N
Area between G1 and G2	Start line A	2° 34,518’ E	51° 28,017’ N
	Start line B	2° 34,515’ E	51° 27,298’ N

2. AUV REMUS surveys:

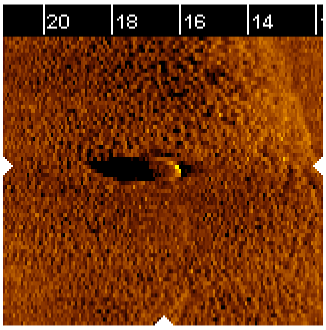
The REMUS Hydroid 100 was used for several mission during campaign ST1219. It hosts a Marine Sonic Technology side-scan sonar with a low and high frequency mode, 900 and 1800 kHz, respectively. Additionally, an RDI ADCP and a YSI CTD is mounted in the instrument.

- **Area G1, G2 Hinder Banken. 3 July 2012 <msn01>**

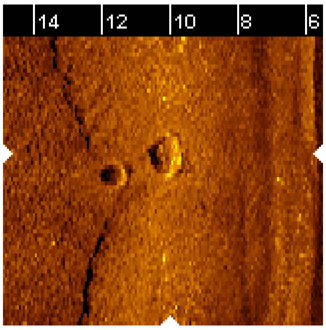
- Frequency used: 900kHz, altitude: 3m, SS range: 30m, track spacing: 15/45m, speed: 4knots.
- Total mission time: 02h03.



Time: July 3,2012 8/08/40
Position: 51N28.208 2E34.062



Time: July 3,2012 8/15/08
Position: 51N28.230 2E34.219

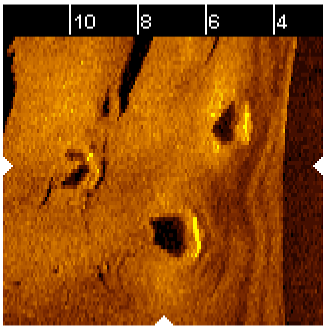


Time: July 3,2012 9/20/51
Position: 51N27.964 2E34.562

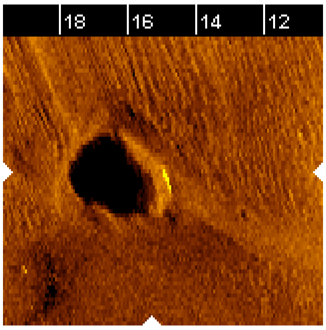
Figure 3. Example of gravel blocks in zone G1, G2. Scale bar in m.

- **Area G5 ‘Refugium’. 3 July 2012 <msn02>**

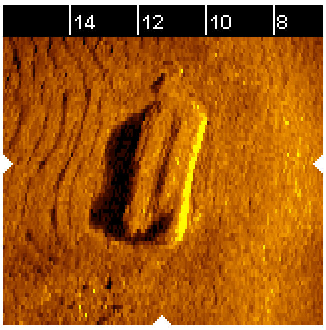
- Frequency used: 900kHz, altitude: 3m, SS range: 30m, track spacing: 15/45m, speed: 4knots.
- Total mission time: 00h23.



Time: July 3,2012 12/29/56
Position: 51N24.741 2E31.534



Time: July 3,2012 12/33/34
Position: 51N24.758 2E31.514

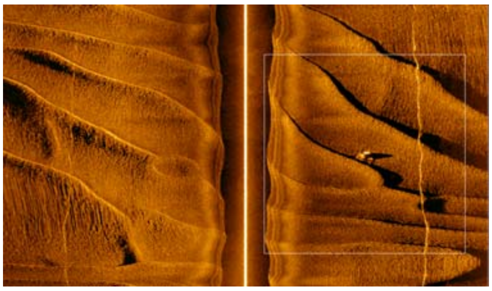


Time: July 3,2012 12/44/00
Position: 51N24.705 2E31.679

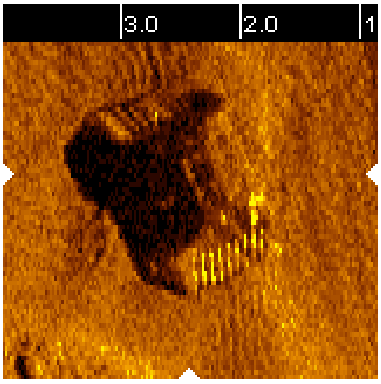
Figure 4. Example of gravel blocks in area G5. Scale bar in m.

- **Relocation ADCP. 3 July 2012 <msn03>**

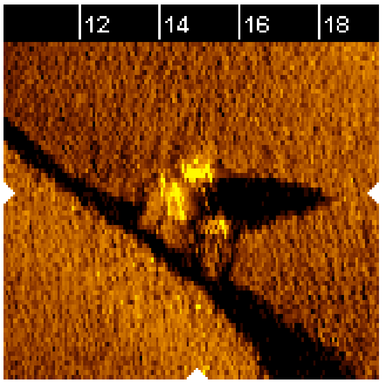
- On request of the Commander, MUMM’s ADCP was relocated with the REMUS because of uncertain position. A box of 100/100m was measured; the ADCP was found at 32m of its position. The mission was carried out in both high (1800 kHz) and low frequency (900 kHz).
- Frequency used: 1800 kHz. Altitude: 3m, SS range: 10m, track spacing: 10/10m, speed: 3knots.
- Frequency used: 900kHz, altitude: 3m, SS range: 30m, track spacing: 15/15m, speed: 3knots.
- Total mission time: 00h30.


The ADCP is located in the lee side of large dunes

Position: 51° 30.5581' N; 2° 37.8136' E



HF image



LF image

bottom frame ADCP housed in bottom frame

Figure 5: Imaging of bottom-mounted ADCP with REMUS and real-life example. Scale bar in m.

- **Relocation acoustic receivers Thornton Bank. 4 July 2012 <msn04>**

- In <reacquire mode>, REMUS transects were programmed at 6 different locations around the windmills D6 and D5 on the Thornton Bank. Four out of six receivers were localized.
- Frequency used: 1800kHz, altitude: 3m, SS range: 10m, track spacing: 10m, speed: 3knots.
- Mission time: 02h21.

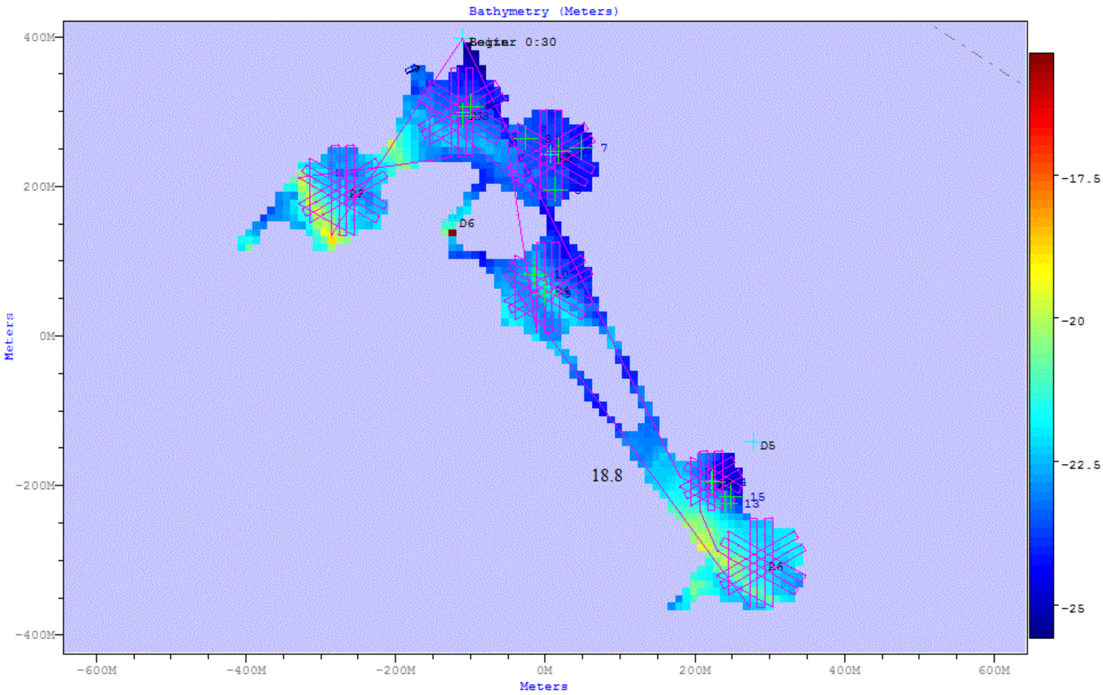


Figure 6: Sailed transects in reacquire mode to relocalize lost acoustic receivers.

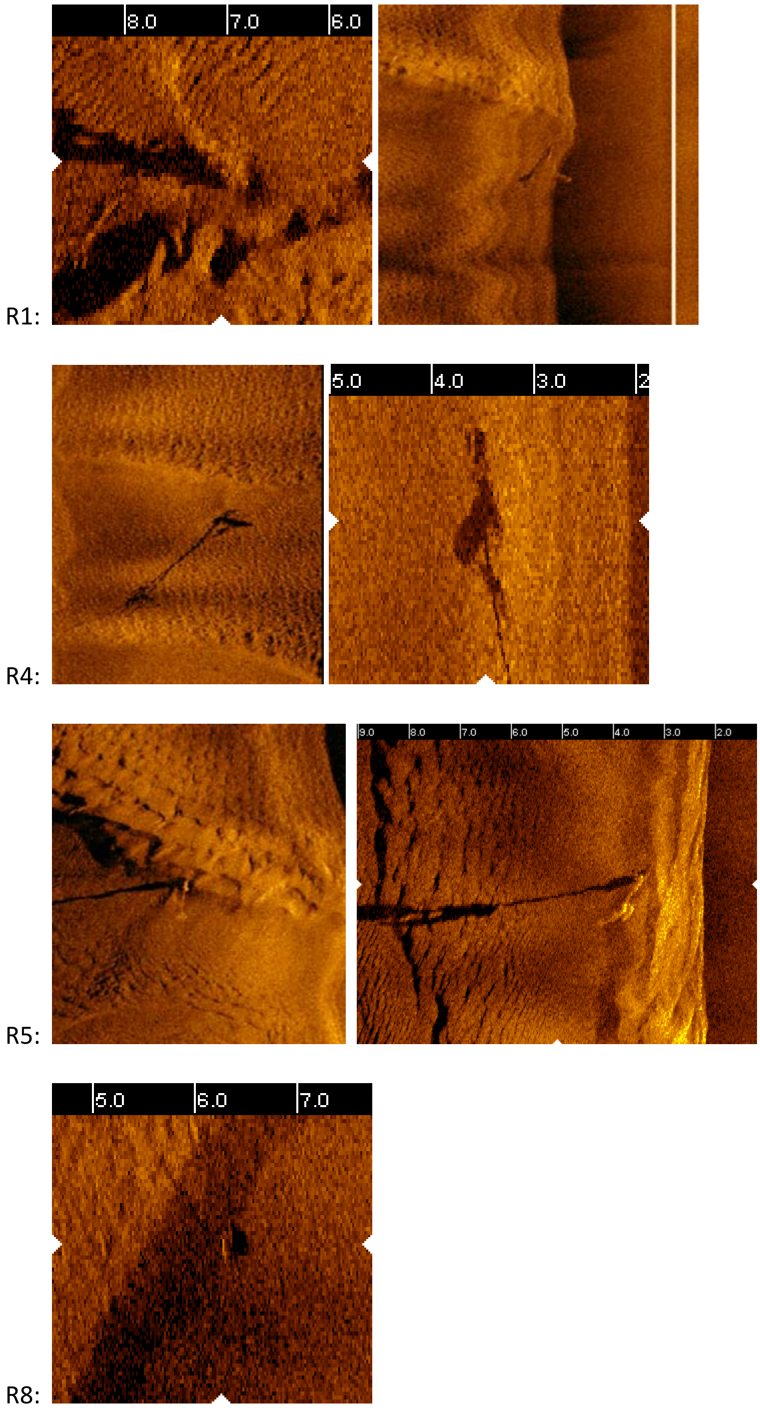


Figure 7: Imaging of acoustic receivers in the windmill farm area (scale bars in m).

- **REMUS survey to verify biologically-induced acoustic facies, derived from multibeam echosounding. Dutch coastal zone, 5 July 2012 <msn05>**

- Based on terrain variability and higher roughness areas on multibeam imagery (EM3002), an area of 150*150m was selected for verification with the REMUS AUV in high frequency mode.
- Frequency used: 1800 kHz. Lines are sailed N-S and W-E. Altitude 3m, SS range: 10m, track spacing: 10m, speed: 3knots.
- Mission time: 01h00.

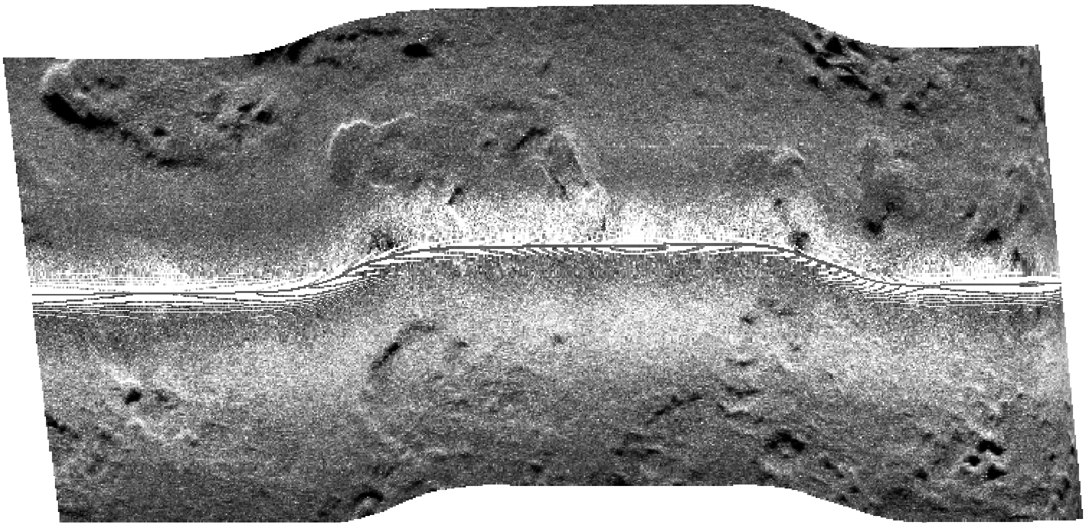


Figure 8. Example of a bioturbated surface. Corrected side-scan sonar image (1800 kHz). Across range 10m.

6.4. UGent SMB-JR: Monitoring of offshore windfarms: relocation of lost acoustic receivers

With its REMUS AUV, DGMR has relocated lost acoustic receivers in the windmill farm of the Thornton Bank (see above) (responsible scientist of the receivers is Jan Reubens, Ghent University, Section Marine Biology).

Table 9. Coordinates of the lost receivers

Receiver	Latitude (WGS84) *Theoretical*		Longitude (WGS84) *Theoretical*		Relocation with REMUS	Latitude (WGS84) REMUS	Longitude (WGS84) REMUS
R1	51	33.1188	2	55.4310	X	51N33.116	2E55.433
R2	51	33.0624	2	55.2924			
R4	51	32.9922	2	55.5312	X	51N33.091	2E55.554
R5	51	33.0882	2	55.5342	X	51N32.987	2E55.530
R6	51	32.7924	2	55.7784			
R8	51	32.8518	2	55.7202	X	51N32.841	2E55.744
R11_a	51	31.6938	2	57.1860			
R11_b	51	31.7058	2	57.2200			

6.5. MUMM-REMSEM: Optical measurements

Simultaneaous optical and water quality measurements could be performed: TU, SPM, Fluo and radiometric fields. The REMSEM measurements are summarised in Table 10.

The water samples were collected at the sea surface (0.5m depth), with a bucket. TU measurements were performed using the 2100 HACH turbidimeter, 3 replicates before and 3 replicates after SPM filtrations; SPM were filtered using GF/F filters. The fluorescence was measured in the bucket during 5 minutes, using the TriOS micro-Fluorometer.

The radiometric field was monitored via three TriOS-RAMSES hyperspectral spectroradiometers, mounted on a steel frame fixed to the prow of the ship. The TriOS system was directed forward, and the ship oriented at 135° with regard to the sun azimuth angle, to avoid any interfering signal from the ship and sunglint.

General notes:
- 2 half days (3rd, 5th July) prevented against measuring the radiometric field.
- The range of turbidity remained quite low (< 9 NTU) during this summer campaign; very calm weather conditions prevailed.

- While the fluorescence did not exceed 7 mg m^{-3} at stations ST01 to ST04, high values were registered at station ST05, varying from 24 up to 44 mg m^{-3}.

Table 10: Summary of REMSEM measurements.

Date	Station ID	Time (UTC)	TriOS	SPM	TU	Fluo
3/7/2012	ST01	09:55	X	X (3 replicates)	X (2x3 replicates)	-
4/7/2012	ST02	11:50	X	X (3 repl.)	X (2x3 replicates)	X
5/7/2012	ST03	11:10	X	X (3 repl.)	X (2x3 replicates)	X
5/7/2012	ST04	12:20	X	X (3 repl.)	X (2x3 replicates)	-
6/7/2012	ST05	07:20	X	X (6 repl.)	X (2x3 replicates)	X

6.6. MUMM-AUMS

No data were recorded; the system was not operational due to technical problems with the seawater pump.

7. REMARKS

- Officers and crew are thanked warmly for the skillful handling of the operations and excellent atmosphere.
- Highly favourable weather condtions

8. DATA STORAGE

MUMM

- Multibeam echosounding: on hard disk MUMM-BRU; copy will be provided to BMDC. Contact person: Vera Van Lancker
- ADCP: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- LISST: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- Seacat sensor data: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- Data on optical measurements and calibration through water sampling. MUMM-REMSEM database: Contact person: Bouchra Nechad.

DGMR

- Multibeam echosounding (EM3002): on hard disk RV Belgica; back-up DGMR where data is stored in Zeebrugge, Stafblok, 1 floor- VSW-MWU. Contact person: Sonia Papili.
- REMUS AUV data measured by Hydroid Remus 100. Data stored in Zeebrugge, Stafblok, 1 floor- VSW-MWU. Contact person: Paul Coppens.

RV BELGICA CRUISE 2012/26

Subscriber:	Dr. Jan Vanaverbeke[1] , Dr. Vera Van Lancker[2], Dr. Michael Fettweis[2]
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Ecosystems: 15-19/10/2012

<u>Reference to this report:</u>
Vanaverbeke, J. and Van Lancker, V. (2012). *Cruise report RV Belgica ST1226, 15-19/10/2012*. Ghent University, Marine Biology Research Group and Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, 13p.

1. CRUISE DETAILS

1.	Cruise number	2012/26
2.	Date/time	Harbour TD: 15/10/2012 at 10h30 Harbour TA: 19/10/2012 at 14h00
3.	Chief Scientist Participating institutes	Dr. Jan Vanaverbeke UGent-SMB / MUMM
4.	Area of interest	Belgian part of the North Sea

2. LIST OF PARTICIPANTS

Institute	Participant	15/10-19/10
UGent	Jan VANAVERBEKE (chief scientist)	X
	Guy DESMET	X
	Bart BEUSELINCK	X
	Annelien RIGAUX	X
	Liesbet COLSON	X
	Sarah Vanden Eede	X
	Yana Deschutter	X
MUMM	Vera VAN LANCKER	X
	Reinhilde VAN DEN BRANDEN	X
	Matthias BAEYE	X
	Joan BACKERS	Only 15/10
	Kevin HINDRYCKX	Only 15/10
	Total	**10 (+2)**

3. SCIENTIFIC OBJECTIVES

This cruise was made for the purpose of the Marine Biology Research Group of Ghent University and the Management Unit North Sea Mathematical Models (MUMM). The cruise collected samples to be used in UGent's FWO project "The functional role of marine macrobenthos for the functioning of the sea floor", and the MONWIND project. The latter project aims at monitoring the effects of the installation of offshore windmill farms on the marine ecosystem. During this cruise, data were collected for the monitoring of the macrobenthos inhabiting soft sediments. MUMM's main activities related to the deployment of a benthic tripod (MOMO) in the coastal zone, and to 13hrs transects along sections of the Hinder Banks (ZAGRI/MOZ4), recording current velocities, direction and backscatter (RDI 300 KHz ADCP) or depth and backscatter from multibeam (Kongsberg Simrad EM3002D). Full-coverage multibeam-derived depth and backscatter data were recorded in a former aquaculture area. Throughout the campaign, measurements were made with (1) AUMS system; and (2) hull-mounted ADCP data, both for studying spatial variation of suspended particulate matter (bin size was set to 0.25m).

UGENT/SMB-JV: The functional role of marine macrobenthos for the functioning of the sea floor
Research within this project aims at (1) investigating the effect of soft sediment inhabiting key organisms on the functioning of the seafloor and the processes related to the benthic-pelagic coupling and (2) understanding the structural and functional link between the distribution of these key species and the ecological features of the seabed.

UGENT/SMB-DC: MONWIND / Benthos of soft substrates
This part of MONWIND aims at assessing the possible effects of the installation of wind mill farms on the macrobenthos from soft sediments, both at a large scale as on a very detailed scale in the immediate vicinity of a wind mill. During this cruise, samples for the large-scale assessment were collected.

MUMM-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 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.

MUMM-VVL: ZAGRI/MOZ4

Monitoring of hydrodynamics and sediment transport to evaluate the effects of the exploitation of non-living resources of the territorial sea and the continental shelf.

MUMM-AQUACULTURE

Surveying of former legal aquaculture zones (MB 7/10/2005) with the possibility of detecting remaining debris (e.g. anchors, concrete blocks). Results are important in the view of securing the future use of the zones by other activities (e.g. fisheries).

MUMM-AUMS

The AUMS (Autonomous Underway Measurement System) project 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. In particular, many new parameters can now be measured continuously including important ecosystem parameters such as nitrate, ammonia, silicate, dissolved oxygen and CO_2, 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 MUMM's public web site and following quality control, from the Belgian Marine Data Centre.

4. OPERATIONAL COURSE

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

Monday 15 October

09.00: arrival and boarding of UGent and MUMM teams

10.30: Departure of RV Belgica

11.00: **Station MOW1 (MUMM):** Tripod recovery at MOW1.

12.30 – 13.15 : T&G Zeebrugge: disembarkation of part of the MUMM team (Backers and Hindryckx).

14.00-16.25: **Station 701**: CTD, Van Veen (5 deployments), Reineck boxcorer (3 deployments), hyperbenthic sledge, beam trawl.

18.20: Arrival at MUMM's fixed ADCP location. After consultation with the master of RV Belgica, it was decided not to deploy the ADCP because of strong currents and no favourable weather conditions for the later recovery of the instrument.

18.20-20.55: **Gootebank:** Samples (5 replicate Van Veen samples) were collected at 4 stations.

21.10-23.50: **Thornton Bank**: Samples (5 replicate Van Veen samples) were collected at 5 stations**.**

Tuesday 16 October

02.15-06.54: MUMM: Recordings of hull-mounted ADCP data along a transect perpendicular to the central part of the Oosthinder sandbank (Sector 2-3). Every half hour a water sample was taken with the AUMS system.

Bad weather prevented sampling for UGent in the Hinderbanken area, and RV Belgica returned to the coast.

11.00-12.15: **Station 115**: CTD (however, not functioning!), Van Veen (5 deployments) , Reineck boxcorer (3 deployments), hyperbenthic sledge. The wind was strengthening close to the coast as well, and it was decided not to deploy the beam trawl anymore.

13.15-12.55: **Station 120**: CTD was still not functioning. Only Van Veen (5 deployments) and Reineck (3 deployments) samples were obtained here.

The weather forecast predicted deteriorating weather circumstances, and RV Belgica returned to the harbour of Zeebrugge, where it arrived at 16.00.

Wednesday 17 October

10.00: departure

12.00-13.15: **Station 790**: CTD, Van Veen (5 deployments), Reineck boxcorer (3 deployments), beam trawl, hyperbenthic sledge

14.40-15.45: **Station 140**: CTD, Van Veen (5 deployments), Reineck boxcorer (3 deployments), beam trawl, hyperbenthic sledge

17.15-24.00: **Thornton Bank**: Van Veen samples (5 deployments per station) were obtained at 19 stations.

Thursday 18 October

01h03-07h20: MUMM: Recording of multibeam bathymetry, backscatter and water column data along a transect perpendicular to the central part of the Oosthinder sandbank (Sector 2-3). Every half hour, vertical profiles of CTD, OBS and LISST were taken, together with water samples.

08.00-19.40: **Bligh Bank**: Van Veen samples (5 deployments per station) were obtained at 23 stations.

21.02- : MUMM: Alternating recordings of hull-mounted ADCP and multibeam bathymetry/backscatter/water column data along a transect perpendicular to the south part of the Oosthinder sandbank and central part of the Westhinder (Habitat Directive Area). Every half hour a water sample was taken with the AUMS system.

Friday 19 October

-06.29: End of measurements

08.03-09.32: MUMM: Multibeam recordings (bathymetry, backscatter, water column data) in the former mussel aquaculture zone D1.

10.00-10.45: **Station 115bis**. Reineck sampling: 14 deployments

14.00: arrival of RV Belgica in Zeebrugge, end of campaign.

5. TRACK PLOT

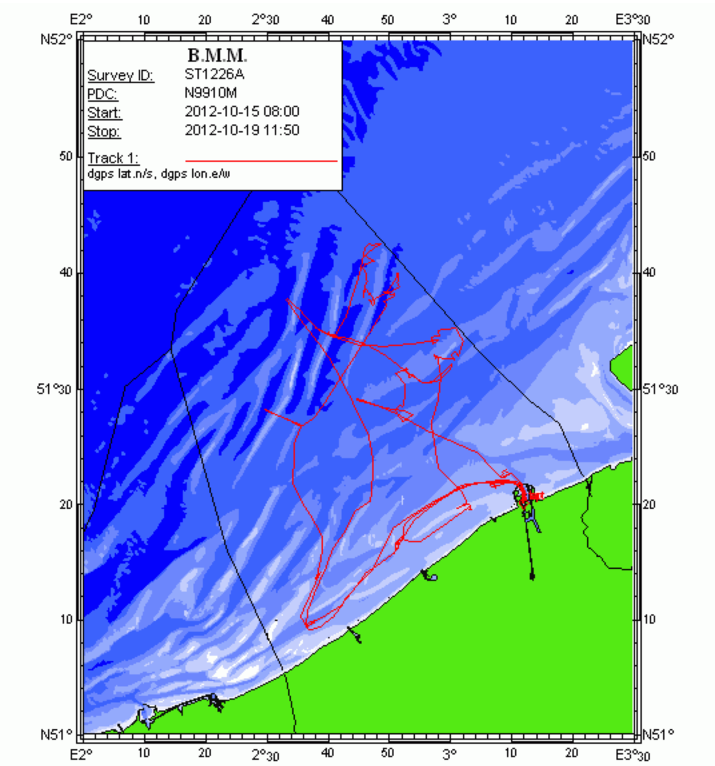

Fig 5.1: Track plot of campaign 2012/26

6. MEASUREMENTS AND SAMPLING

6.1. UGENT-JV: FUNCTIONAL ROLE MACROBENTHOS

Methodology

The operations for the UGent team included sampling of the fixed stations mentioned above and collecting macrobenthos samples at the monitoring stations. All fixed stations on the Belgian Part of the North Sea were sampled for meiobenthos, macrobenthos, hyperbenthos and epibenthos.

Meiobenthos was sampled by means of a Reineck boxcorer.

Every time, the corer was deployed three times in order to get true replicates. At all stations, two perspex cores (10 cm²) were used to subsample the Reineck boxcorer. One core was fixed in a 4% formaldehyde tap water solution and will be used for meiobenthic studies. The sediment from the other core was dried in the oven and will serve to establish sediment characteristics. At Station 115bis, the Reineck boxcorer was deployed 14 times. From each deployment, a subsamples was obtained using a core of 10 cm diameter. These cores were sliced onboard in cm-slices, and homogenized. The homogenized sediment is used in an experiment investigating the effect of bio-irrigation on bacterial and archaeal abundances and diversity.

Macrobenthos was sampled using a Van Veen grab. Out of each grab, some sediment was collected for sediment characterisation. On all stations, five replicates were taken. The sediment was sieved on board of the Belgica over a 1-mm sieve.

Epibenthos was sampled with a three-meter beam trawl with a mesh size of 5 mm (10 mm stretched) in the cod end. All tows were made over a distance of 1000 m in the direction of the current with a towing speed of 1.5 knots per hour.

Hyperbenthos was sampled with a hyperbenthic sledge containing four nets: two nets with 0.5-mm mesh and two with 1.0-mm mesh. The lower nets samples the lower 0.5 m of the water column while the upper nets sample the water column between 0.5 and 1 m above the bottom. All tows were made against the current at a speed of 1.5 knot per hour.

Monitoring stations for soft sediment macrobenthos were only sampled with the Van Veen Grab. Again, 5 replicates per station were collected, and sediment was sieved on board over a 1 mm-sieve

Stations

Samples for the FWO project were planned to be collected at fixed locations on the Belgian Part of the North Sea. Storm prevented a full execution of this programme. Only stations marked with "*" were actually sampled.

Table 6.1.1 Location of planned stations.

Station	Latitude	Longitude
701*	51° 22.63	03° 09.25
702	51° 22.63	03° 18.68
780	51° 27.70	03° 02.60
790*	51° 16.87	02° 51.13
115*	51° 09.350	02° 36.350
215	51° 16.20	02° 36.76
630	51° 37.75	02° 33.24
UG8	51° 28.57	02° 35.01
115bis*	51° 09.11	02° 37.13
330	51° 26.037	02° 48.486
120*	51° 11.10	02° 42.07
140*	51° 19.50	03° 03.00

6.2. UGENT-DC: MONWIND

Methodology
See 6.1

Stations
Samples for the MONWIND project were collected at the Gootebank, Thornton Bank and Bligh Bank.

Table 6.2.2 Sampling locations at Bligh Bank

Bligh Bank - Belwind									
	Samples	Latitude	Longitude	North WGS	East WGS		Latitude	Longitude	
1	BBI02	51.655106	2.7730616	5722703.67	484301.12		51° 39.306	2° 46.384	5xVV
2	BBI05	51.684861	2.791611	5726009.1	485593.75		51° 41.092	2° 47.497	5xVV
3	BBI26	51.639578	2.8187704	5720967.85	487458.83		51° 38.374	2° 49.126	5xVV
4	BBI33	51.666024	2.8512395	5723903.97	489711.69		51° 39.961	2° 51.074	5xVV
5	BBE09	51.653214	2.8545808	5722478.82	489939.94		51° 39.193	2° 51.275	5xVV
6	BBE06	51.639543	2.8371367	5720960.98	488729.77		51° 38.373	2° 50.228	5xVV
7	BBE05	51.625775	2.8180737	5719432.88	487406.79		51° 37.547	2° 49.084	5xVV
8	BBE14	51.706222	2.784802	5728386.07	485130.04		51° 42.373	2° 47.088	5xVV
9	BBE12	51.68862	2.7744012	5726430.67	484405.3		51° 41.317	2° 46.464	5xVV
10	BBE16	51.671145	2.7661829	5724488.92	483830.99		51° 40.269	2° 45.971	5xVV
11	BBC01	51.674729	2.758216	5724889.33	483281.38		51° 40.484	2° 45.493	5xVV
12	BBC02	51.69194	2.767305	5726801.43	483915.95		51° 41.516	2° 46.038	5xVV
13	BBC03	51.709924	2.777361	5728799.39	484617.13		51° 42.595	2° 46.641	5xVV
14	BBC04	51.61909	2.824985	5718688.2	487883.42		51° 37.145	2° 49.499	5xVV
15	BBC05	51.633346	2.844077	5720270.7	489208.57		51° 38.001	2° 50.645	5xVV
16	BBC06	51.646999	2.860551	5721786.83	490351.64		51° 38.820	2° 51.633	5xVV
17	BBE19	51.643853	2.768525	5721453.11	483983.33		51° 38.631	2° 46.111	5xVV
18	BBE20	51.637251	2.781047	5720716.19	484847.58		51° 38.235	2° 46.863	5xVV
19	BBE21	51.629738	2.793114	5719878.19	485680.29		51° 37.784	2° 47.587	5xVV
20	BBC07	51.635429	2.763744	5720517.28	483649.48		51° 38.126	2° 45.825	5xVV
21	BBC08	51.628599	2.775811	5719755.05	484482.27		51° 37.716	2° 46.549	5xVV
22	BBC09	51.621086	2.786739	5718917.22	485236.24		51° 37.265	2° 47.204	5xVV
23	BBE22	51.709344	2.813136	5728727.95	487088.77		51° 42.561	2° 48.788	5xVV
Total numbers of samples									**115**

Table 6.2.3 Sampling locations at Thornton Bank

Thorntonbank – C-Power									
	Samples	Latitude	Longitude	North WGS	East WGS		Latitude	Longitude	
1	TBE05	51.5486204	2.9524304	5710837.5	496701.58		51° 32.917	2° 57.146	5xVV
2	TBE14	51.543939	2.959807	5710316.55	497212.78		51° 32.636	2° 57.588	5xVV
3	TBE15	51.5875910	3.0088560	5715170.56	500613.54		51° 35.255	3° 0.531	5xVV
4	TBE16	51.5779660	3.0244030	5714100.37	501690.99		51° 34.678	3° 1.464	5xVV
5	TBE06	51.5435374	2.9930165	5710271.15	499515.72		51° 32.612	2° 59.581	5xVV
6	TBE07	51.5489043	3.0020033	5710868	500138.91		51° 32.934	3° 0.120	5xVV
7	TBE08	51.5537713	3.0121983	5711409.35	500845.72		51° 33.226	3° 0.732	5xVV
8	TBE10	51.5657709	2.9532999	5712744.84	496763.09		51° 33.946	2° 57.198	5xVV

9	TBE11	51.5713212	2.9644317	5713361.68	497534.96		51° 34.279	2° 57.866	5xVV
10	TBE12	51.5772048	2.9706467	5714015.83	497965.95		51° 34.632	2° 58.239	5xVV
11	TBEC01	51.5365510	3.0022860	5709494.14	500158.55		51° 32.193	3° 0.137	5xVV
12	TBEC02	51.5430130	3.0109010	5710212.86	500755.96		51° 32.581	3° 0.654	5xVV
13	TBEC03	51.5478360	3.0199790	5710749.38	501385.34		51° 32.870	3° 1.199	5xVV
14	TBEC04	51.5710110	2.9469410	5713327.92	496322.76		51° 34.261	2° 56.816	5xVV
15	TBEC05	51.5771790	2.9574920	5714013.41	497054.39		51° 34.631	2° 57.450	5xVV
16	TBEC06	51.5838340	2.9647960	5714753.28	497560.88		51° 35.030	2° 57.888	5xVV
17	TBC01	51.5066849	2.8768615	5706179.8	491453.87		51° 30.401	2° 52.612	5xVV
18	TBC06	51.5199189	2.8965500	5707649.49	492822.38		51° 31.195	2° 53.793	5xVV
19	TBC10	51.5228517	2.8503055	5707981.21	489614.49		51° 31.371	2° 51.018	5xVV
20	TBC12	51.5301357	2.8803159	5708787.46	491697.88		51° 31.808	2° 52.819	5xVV
Total numbers of samples									**100**

Table 6.2.4 Sampling Locations at the Gootebank

Goote Bank – Reference area									
	Samples	Latitude	Longitude	North WGS	East WGS		Latitude	Longitude	
1	GBC06	51.4697949	2.8498133	5702080.66	489568.24		51° 28.188	2° 50.989	5xVV
2	GBC07	51.4754565	2.8698290	5702707.64	490959.62		51° 28.527	2° 52.190	5xVV
3	GBC21	51.4532919	2.8697684	5700242.67	490951.03		51° 27.198	2° 52.186	5xVV
4	GBC24	51.4630499	2.8971875	5701324.85	492857.73		51° 27.783	2° 53.831	5xVV
Total number of samples									**20**

Sampling was planned at the Lodewijcksbank as well, but this was prevented due to stormy weather.

6.3. MUMM-MF: MOMO

Recovery MUMM's benthic tripod at station MOW1.

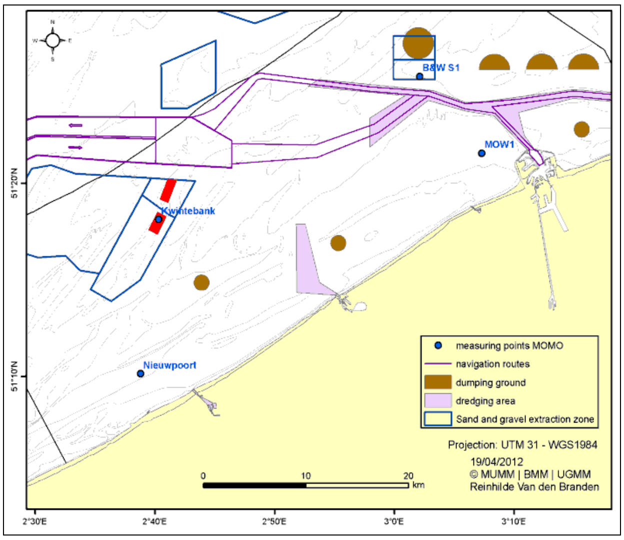

Fig 6.3.1: Location of station MOW1 where MUMM's benthic tripod was recovered.

6.4. MUMM-VVL: ZAGRI/MOZ4

Hydrodynamic and sediment transport measurements in the marine aggregate concession zone 4, Hinder Banken region (Fig 6.4.1):

a. Testing of survey designs (MBES: Multibeam Kongsberg Simrad EM3002, depth, backscatter and water column data) *vs.* hull-mounted ADCP (RDI 300 kHz)) for impact evaluations of marine aggregate extraction;
b. Water column characterization using the Seacat with CTD, OBS, LISST100 instrumentation (VLIZ) and a 10l Niskin bottle for water sampling (filtration SPM, POC).
c. AUMS registrations and water sampling for the calibration of the turbidity sensor.

<u>16/10/2013, 02.15-06.54 (+/- 5hrs)</u>: Recordings of hull-mounted ADCP data along a transect perpendicular to the central part of the Oosthinder sandbank (Sector 2-3). Every half hour a water sample was taken with the AUMS system:

Table 6.4.1: Multibeam echosounding (MBES) profiling.

MBES track (WGS84)				
Sector 2_3	51°34.965N	2°38.886E	51°34.587N	2°40.836E

Table 6.4.2: Water samples for the calibration of the AUMS systems (every 30'). Filtrations for the quantification of suspended particulate matter) were carried out on board.

ID	Timestamp (UTC)
AUMSwat_001	2012-10-16 00:15:40
AUMSwat_002	2012-10-16 00:44:30
AUMSwat_003	2012-10-16 01:14:20
AUMSwat_004	2012-10-16 01:44:20
AUMSwat_005	2012-10-16 02:14:20
AUMSwat_006	2012-10-16 02:45:30
AUMSwat_007	2012-10-16 03:12:30
AUMSwat_008	2012-10-16 03:40:30
AUMSwat_009	2012-10-16 04:10:50
AUMSwat_010	2012-10-16 04:43:10

<u>18/10/2013, 01h03-07h20 (+/- 6h20):</u> Recording of multibeam bathymetry, backscatter and water column data along a transect perpendicular to the central part of the Oosthinder sandbank (Sector 2-3) (see Table 6.4.2). Approximately, every half hour, vertical profiles of CTD, OBS and LISST were taken, together with water samples.

Table 6.4.3: Vertical profiling and water sampling.

Vertical profiling and water sampling		
	Sector 2_3	
1	51°34.726N	2°40.094E

Table 6.4.4: Vertical profiling of CTD, OBS and LISST and water sampling (10L Niskin bottle). Filtrations for the quantification of suspended particulate matter) were carried out on board.

ID	Timestamp (UTC)
SBE19-L-10l	2012-10-17 23:16:00
SBE19-L-10l	2012-10-18 00:12:30
SBE19-L-10l	2012-10-18 01:09:10
SBE19-L-10l	2012-10-18 01:13:10
SBE19-L-10l	2012-10-18 01:27:20
SBE19-L-10l	2012-10-18 02:34:10
SBE19-L-10l	2012-10-18 03:29:40
SBE19-L-10l	2012-10-18 03:32:30

SBE19-L-10l	2012-10-18 04:15:10
SBE19-L-10l	2012-10-18 04:54:50

18-19/10/2013, 21.02-06h29 (+/- 9h30): Alternating recordings of hull-mounted ADCP and multibeam bathymetry/backscatter/water column data along a transect perpendicular to the south part of the Oosthinder sandbank and central part of the Westhinder (Habitat Directive Area). Every half hour a water sample was taken with the AUMS system.

Table 6.4.5: Water samples for the calibration of the AUMS systems. Filtrations for the quantification of suspended particulate matter) were carried out on board.

ID	Timestamp (UTC)
AUMSwat_001	2012-10-18 19:14:10
AUMSwat_002	2012-10-18 19:48:00
AUMSwat_003	2012-10-18 20:19:30
AUMSwat_004	2012-10-18 20:55:40
AUMSwat_005	2012-10-18 21:32:20
AUMSwat_006	+/- 2012-10-18 22:00
AUMSwat_007	+/- 2012-10-18 22:30
AUMSwat_008	+/- 2012-10-18 23:00
AUMSwat_009	+/- 2012-10-18 23:30
AUMSwat_010	+/- 2012-10-19 00:00
AUMSwat_011	+/- 2012-10-19 00:30
AUMSwat_012	+/- 2012-10-19 01:00
AUMSwat_013	+/- 2012-10-19 01:30
AUMSwat_014	+/- 2012-10-19 02:00
AUMSwat_015	+/- 2012-10-19 02:30
AUMSwat_016	+/- 2012-10-19 03:00
AUMSwat_017	+/- 2012-10-19 03:30
AUMSwat_018	+/- 2012-10-19 04:00
AUMSwat_019	+/- 2012-10-19 04:30

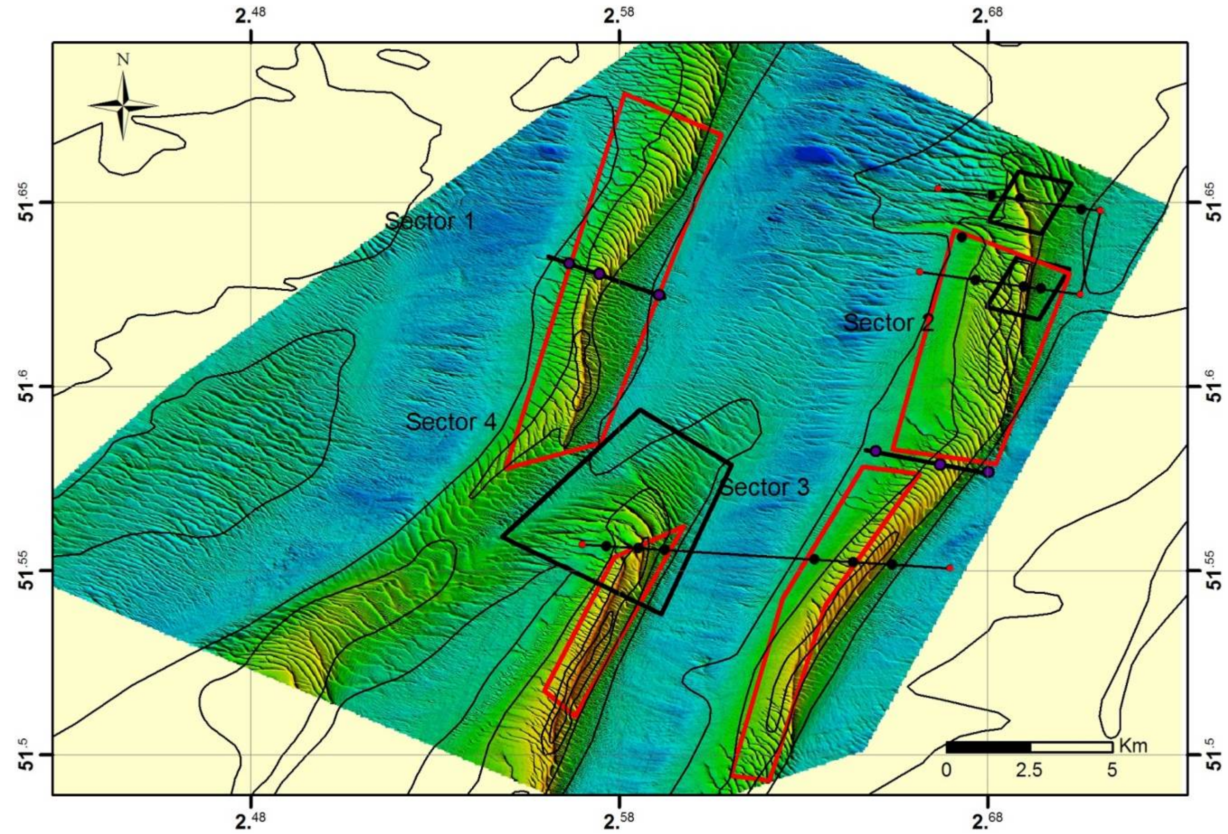

Fig 6.4.1: Marine aggregate extraction concession zone 4 in the Hinder Banken region. Red polygons show the different Sectors where extraction activities are allowed. Black lines show the locations of ADCP profiling during previous campaigns. During this campaign MBES and ADCP profiling has been performed in-between Sector 2 and Sector 3. Along this transect, water sampling and vertical profiling has taken place in the topzone of the sandbank. More to the south (see Fig 5.1) an additional transect was sailed recording multibeam bathymetry/backscatter/water column and ADCP currents/backscatter data, following an alternating survey design scheme.
Background bathymetry: FPS Economy, Self-Employed and Energy.

6.5. MUMM-AQUACULTURE

Surveying of former legal aquaculture zones (MB 7/10/2005) with the possibility of detecting remaining debris (e.g. anchors, concrete blocks). Results are important in the view of securing the future use of the zones by other activities (e.g. fisheries). 3 zones are targeted for further inspection: D1 Smal Bank; D2, Oostdijck; and D3 Westhinder sandbank.

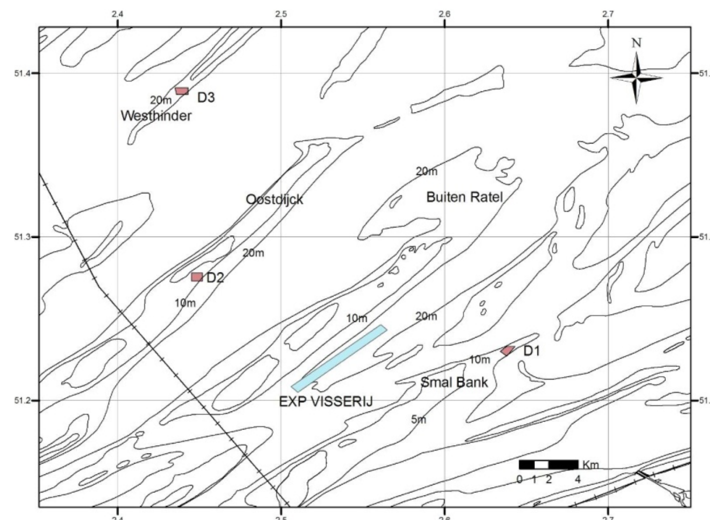

Fig 6.5.1: Locations of former aquaculture zones (red). The blue area is related to former fisheries' experiments.

During the survey only zone D1 was scanned. This was due to:

- D2 and D3 are within the safety buffer zone of respectively the radar tower on the Oostdijck sandbank and of the measuring pile MOW7 on the Westhinder; RV Belgica is too big a ship for navigation too close to these obstacles;
- Small buoys demarcate the areas; day light and a good visibility are crucial during surveying.

During this campaign MUMM was entitled night time only, except for Friday morning 19/10 for a period of 1h30. 11 lines were sailed in zone D1, allowing coverage of the concession zone itself, but not the buffer zone. Especially east of the zone, small buoys hindered efficient surveying. Measuring conditions were favourable.

<u>19/10/2012, 08.03-09.32 (+/- 1h30):</u> MUMM: Multibeam recordings (bathymetry, backscatter, water column data) in zone D1.

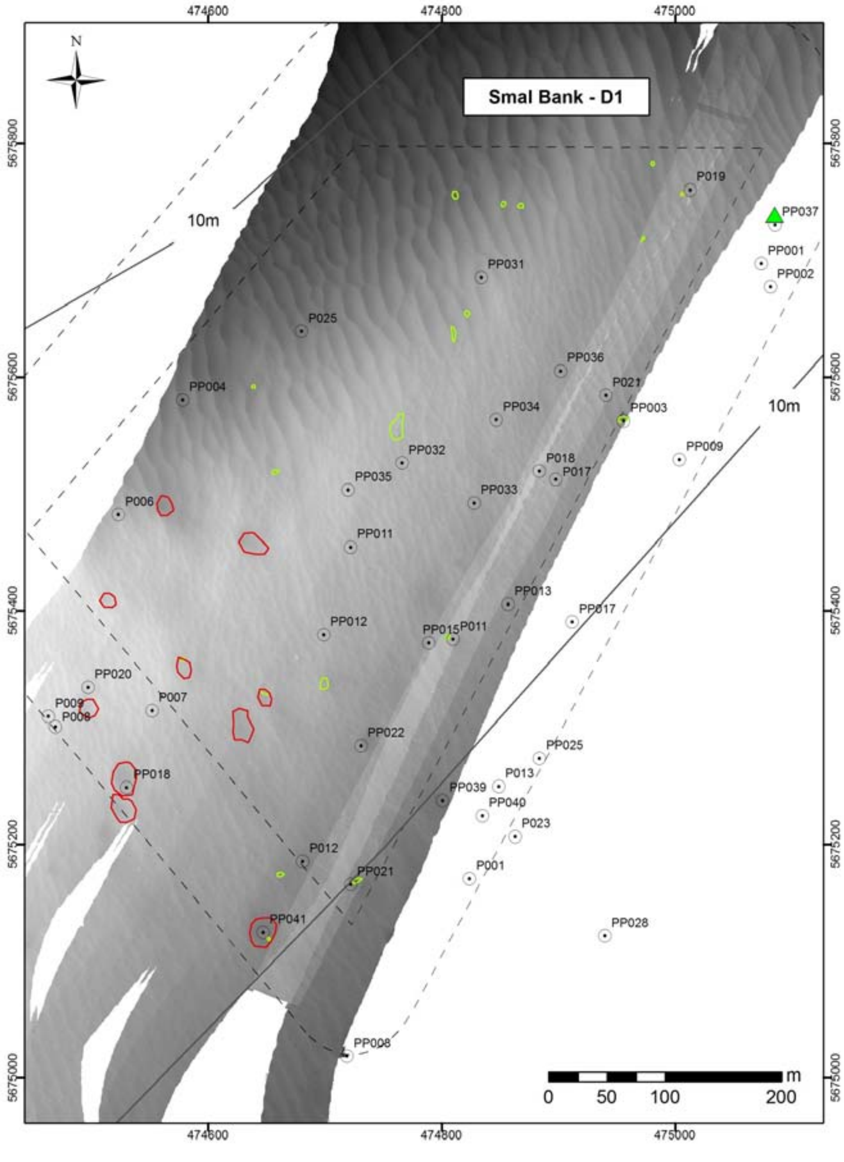

Fig 6.5.2: Digital terrain model of zone D1 on the basis of the new multibeam measurements. D1 is situated on the Smal Bank, a sandbank shallower than 10m (green triangle is the position of a Cardinal buoy). The dashed line demarcates the extent of the former mussel aquaculture concession zone. A buffer zone of 100m is also indicated. Previous contacts that were identified on side-scan sonar imagery are indicated (numbered). On the basis of the present survey, scour zones were indicated (red polygons), as well as new contacts (green polygons).

6.6. MUMM-AUMS

Throughout the campaign measurements were made with the AUMS system. At 2 locations water samples were taken with the in-built AUMS sampler (see above Table 6.4.2; 6.4.5). Water filtrations were carried out for the calibration of the turbidity sensor.

7. REMARKS

We warmly acknowledge the skilful and patient help of the master and crew of the *RV* Belgica. This helped us to collect samples, even in difficult weather circumstances.

8. DATA STORAGE

UGENT

- Seacat sensor data: on hard disk UGent-SMB. Contact person: Jan Vanaverbeke

MUMM-VVL

- Multibeam echosounding: on hard disk MUMM-BRU; copy will be provided to BMDC. Contact person: Vera Van Lancker
- ADCP: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- LISST: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- Seacat sensor data: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker

MUMM-MF

- Only recovery of the benthic tripod at MOW1

RV BELGICA CRUISE REPORT 2013/09

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Monitoring/Geology-Education: 25/03/2013 - 29/03/2013

<u>Reference to this report:</u>

Van Lancker, V., Baeye, M., Van den Branden, R., Coates, D., Van Campenhout, J., Vanermen, N., Verstraete, H. and students party (2013). *Cruise report RV Belgica ST1309, 25-29/3/2013*. Royal Belgian Institute of Natural Sciences, MUMM, 11p.

1. CRUISE DETAILS

1.	Cruise number	2013/09
2.	Date/time	Harbour TD: 25/03/2012 : 11h Touch and Go Zeebrugge : 26/03/2012: 8h30-9h35 Touch and Go Zeebrugge : 27/03/2012: 8h-8h54 Touch and Go Zeebrugge : 28/03/2012: 8h-9h Harbour TA: 29/03/2012: 14h
3.	Chief Scientist Participating institutes	Dr. Vera Van Lancker MUMM / UGent-SMB; INBO
4.	Area of interest	Belgian part of the North Sea

2. LIST OF PARTICIPANTS

Institute	NAME		G	25-26	26-27	27-28	28-29
MUMM	VAN LANCKER Vera		F	X	X	X	X
	VAN DEN BRANDEN Reinhilde		F	X	X	X	
	BAEYE Matthias		M	X			X
	HINDRYCKX Kevin		M				X (day only)
	BACKERS Joan		M				X (day only)
UG-SMB	COATES Delphine		F	X	X	X	X
	VAN CAMPENHOUT Jelle		M	X	X	X	X
INBO	VANERMEN Nicolas		M			X	X
	VERSTRAETE Hilbran		M			X	X
Oceans & Lakes Students[1]	BELLESTEROS REDONDO, Laura		F	X			
	EDEYE, Kennedy Osuka		M	X			
	GARCIA, Christine Jane		F	X			
	HOUTTAVE, Kim		F	X			
	LE CLERCQ, Raphaelle		F	X			
	LORENT, Sophie		F	X			
	MARTINEZ USEROS, Aina		F	X			
	NGUYEN, Thi Thanh Thanh Dung		F	X			
	BASHNIN, Tayebeh		F		X		
	EVANGELINOS, Dimitrios		M		X		
	GONZALEZ GARCIA, Pablo		M		X		
	IGNOUL, Ann		F		X		
	MUSALIZI, Sarah		F		X		
	ANYANWU, Emmanuel		M		X		
	AGUSTO, Laura Elisabeth		F			X	
	ELSEN, Jasper		M			X	
	GARCIA SOLARES, Javier		M			X	
	GRAçA CUNHA, Ana		F			X	
	MATABA, Gordian		M			X	
	MESTDAGH, Sebastiaan		M			X	
	PAUWAERT, Zoë		F			X	
	PINZONE, Marianna		F			X	
	AHMED, Farhana		F				X
	ALFARO CORDOVA, Eliana		F				X

	BAZIL MOSILLE, Julietha		F				X
	DASAN, Antony Franklin		M				X
	NGUVA MBELLA NJAKO, Fritz		M				X
	RASOLONIRIANA, Rindra		M				X
	THANT, Silvy		F				X
	VON WIELLIGH, Lian		M				X
	VOIGT, Maria		F				X
		Total number of participants:		**13**	**10**	**14**	**15+2**

G: Gender

3. SCIENTIFIC OBJECTIVES

MUMM-VVL/UG-SMB - STUDENTS

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 (ZAGRI/MOZ4-SMB-JV, *see below*).

MUMM-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.

MUMM-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 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.

INBO-ES

Based on the results of standardized ship-based seabird counts, the Research Institute for Nature and Forest (INBO) investigates the effects of offshore wind farms on the presence and distribution of seabirds. Following a BACI set-up, the INBO performs monthly surveys along a fixed monitoring route through the impact and control areas at the Blighbank (Belwind wind farm), Thorntonbank (C-Power wind farm), and future wind farm at Lodewijkbank (Northwind).

MUMM-JH Monitoring of offshore windfarms: mooring of PoDs (MONIWIND)

In the framework of the assessments of the effects of the construction and operation of offshore windfarms on small cetaceans, MUMM uses Passive Acoustic Monitoring Devices: porpoise detectors (C-PoDs). A C-PoD consists of a hydrophone, a processor, batteries and a digital timing and logging system, and has autonomy of up to four months (www.chelonia.co.uk). Data obtained provide an indication of the (relative) abundance of harbor porpoises in the vicinity of the device, up to a distance of approximately 300m. Data obtained from one PoD can give an indication of presence/absence of porpoises, and can be compared to data obtained from PoDs moored at other locations. For mooring PoDs at MOW1, a tripod is used; the PoD is attached vertically to the central column. Additional PoDs will be attached to cardinal buoys (e.g. C-Power site, CP-N buoy and at a location to be specified).

SMB-JV: The functional role of marine macrobenthos for the functioning of the sea floor

Research within this project aims at (1) investigating the effect of soft sediment inhabiting key organisms on the functioning of the seafloor and the processes related to the benthic-pelagic coupling and (2) understanding the structural and functional link between the distribution of these key species and the ecological features of the seabed.

MUMM-AUMS

The AUMS (Autonomous Underway Measurement System) project 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. 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 MUMM's public web site and following quality control, from the Belgian Marine Data Centre.

ESA

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 (UTC+1). All coordinates in WGS84.Throughout the campaign, measurements were made with the AUMS system.

Monday 25th March

Zeebrugge LW 06h19 (7 dm LAT); HW 12h24 (45 dm LAT); LW 18h30 (8 dm LAT)

09h-11h Embarkation of instruments and personnel (2 tripods, 1 ADCP; biological sampling material)
Sail off from Zeebrugge

Weather forecasts were not favourable. It is decided to carry out sampling first, in the near coastal zone. The tripod and deployments are postponed to Thursday when weather predictions are best. The ADCP deployment, zone 4 Oosthinder sandbank, was scheduled for Wednesday evening, since there is no deck space for 2 tripods and an ADCP.

Transit to biological sampling points (UG-SMB)

13h15-13h31 Biological sampling at station 130 (1 fish track; 3 Van Veen grabs / Reineck; Niskin; CTD)
15h30-16h01 Biological sampling at station 120 (1 fish track; 3 Van Veen grabs / Reineck; Niskin; CTD)
16h38-16h55 Biological sampling at station 115bis (1 fish track; 3 Van Veen grabs / Reineck; Niskin; CTD)
17h15 Fish net broken

Transit to MOW1, for measurements at anchored position

21h24 Start 13-hrs cycle ADCP profiling at MOW1, together with water sampling (seawater pump) (MUMM-MF)

Tuesday 26th March

Zeebrugge HW 00h39 (45 dm LAT); LW 06h55 (5 dm LAT); HW 12h59 (47 dm LAT); LW 19h08 (6 dm LAT)

07h18 End of ADCP profiling

Transit to Zeebrugge

8h10 Arrival at Zeebrugge
Touch & Go Zeebrugge (Disembarkation Group 1; Embarkation Group 2)

09h35 *Transit to station 700*

10h02-10h28 Biological sampling at station 700 (Van Veen grabs / Reineck; Niskin; CTD)
Fish track not possible, because of technical problems. (UG-SMB)

Transit to station 780

11h48-12h Biological sampling at station 780 (3 Van Veen grabs / Reineck; Niskin; CTD)
Fish track not possible, because of technical problems. (UG-SMB)

12h11-14h30 Calibration multibeam
Multibeam recordings along 4 profiles (time series for the follow-up of bedform dynamics) (MUMM-VVL)

Transit to Hinder Banks

15h56 Start 13-hrs cycle ADCP profiling crossing the Oosthinder and Westhinder sandbank (Sector 4c-4d), together with water sampling (LISST-CTD-NISKIN10L along ADCP profile) (MUMM-VVL)

Wednesday 27th March

Zeebrugge HW 01h14 (47 dm LAT); LW 07h33 (3 dm LAT); HW 13h35 (49 dm LAT); LW 19h48 (5 dm LAT) SPRING

05h22 End of ADCP profiling

Transit to Zeebrugge

8h-8h54 Touch & Go Zeebrugge (Disembarkation Group 2; Embarkation Group 3; Disembarkation MUMM (2); Embarkation INBO)

Transit to bird route (INBO)

09h30-17h50 Bird counting (INBO) (8h20), meanwhile multibeam recordings (MUMM)

Transit Hinder Banks, Oosthinder

18h08 Deployment of a bottom-mounted ADCP at position 51°30,577’ N, 002° 37,800’ E. Recovery foreseen during campaign ST1312. (MUMM-VVL)

18h34 Fish track Oosthinder
18h58 Biological sampling at location OH-H182, Oosthinder
(3 Van Veen grabs / Reineck; Niskin; CTD)

19h30 Multibeam recordings in the central zone of the Hinder Banks (MUMM-VVL)

Thursday 28nd March

Zeebrugge HW 01h50 (49 dm LAT); LW 08h14 (2 dm LAT); HW 14h13 (50 dm LAT); LW 20h30 (4 dm LAT)

-05h30 End of multibeam recordings

Transit to Zeebrugge

08h-09h Touch & Go Zeebrugge (Disembarkation Group 3; Embarkation Group 4)

Transit to station 710

09h30-10h30 Biological sampling at station 710 (1 fish track; 3 Van Veen grabs / Reineck; Niskin; CTD) (UG-SMB)

Transit to Zeebrugge, area northeast of harbor quay

10h45-11h30 Deployment of tripod at TP-aMT (51°N 22.663,' 3°E 10.843') (MUMM-MF)

Transit to Thornton Bank, C-Power North cardinal buoy, NE Thornton Bank

13h-14h30 PoD recovery and deployment (MUMM-JH)

Transit to Zeebrugge, tripod deployment and recovery

16h-18h Recovery of tripod and deployment of tripod at MOW1 (51°N 21.597, 3°E 6.997') (MUMM-MF)

Touch & Go Zeebrugge disembarkment MUMM personnel (2). Embarkment of Matthias Baeye

Transit to Hinder Banks

21h Multibeam recordings central zone (MUMM-VVL)

Friday 29th March

Zeebrugge HW 02h29 (50 dm LAT); LW 08h56 (2 dm LAT); HW 14h53 (50 dm LAT)

05h End of multibeam

Transit to Thornton Bank, bird route

07h-13h Bird counting (INBO) (6h), meanwhile multibeam recordings (MUMM-VVL)

Transit to Zeebrugge

14h00 Arrival at Zeebrugge

End of campaign

5. TRACK PLOT

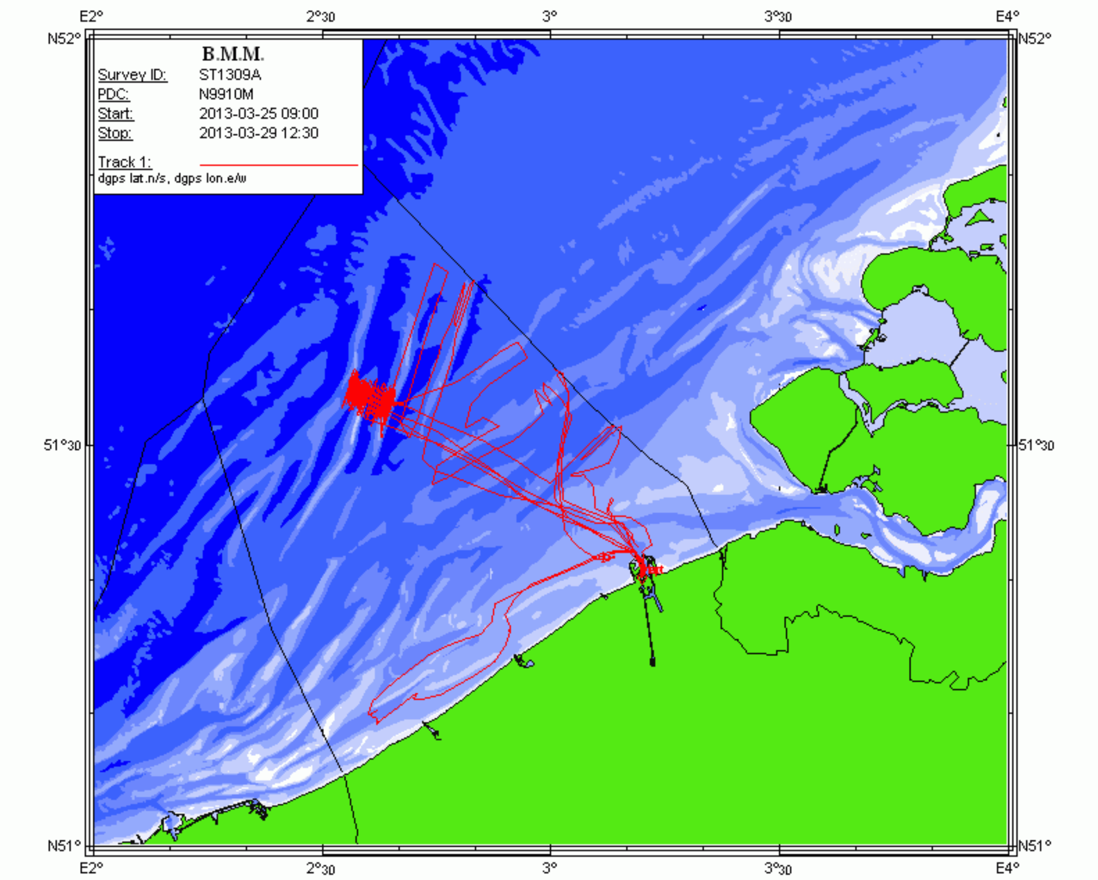


Fig. 1: Track plot ST1309.

6. MEASUREMENTS AND SAMPLING

6.1. MUMM-VVL-ZAGRI/MOZ4-STUDENTS

Hydrodynamic and sediment transport related measurements and observations in marine aggregate concession zone 4, Hinder Banken region.

a) Deployment of **a Bottom-mounted Acoustic Doppler Current Profiler** (BM-ADCP) (RDI 1200 kH) along the eastern flank of the Oosthinder (Table 1 for coordinates);
b) **13-hrs ADCP profiling** (RDI 300 kHz) along a transect crossing Sector 4c (Oosthinder) and 4d (Westhinder) of the marine aggregate concession zone 4 (Table 2), together with **water column characterization** from water samples taken with the seawater pump (GPUMP@3.2m). Filtrations of 0.5 l for suspended particulate matter (Table 3).
c) **Full-coverage multibeam echosounding** (depth and water column data) along the central part of the Hinder Banks (HBC) (+/- 20h)
d) **Follow-up bedform migration with multibeam bathymetry**, north of the Vlakte van de Raan (Time series).
e) **Seabed sampling** (Van Veen) at 1 selected location (OH_H182 (ILVO location); see SMB-JV); also a vertical profile of water column characteristics was taken (CTD, OBS)
f) **AUMS** registrations (continuous)

Table 1: Coordinates of longer term bottom-mounted ADCP deployment

ADCP longer term measurements			Deployment Deployment data	Recovery Recovery date
ADCP Impact	51°30,577'N	002° 37,800'E	2013-03-27 16:10:59	2013-04-25 13:50:58 ST1312)

Table 2: ADCP track crossing the Sectors 4d (Westhinder) and Sector 4c (Oosthinder) (see Fig. 2).

ADCP track (+/-7km)				
X-Y	51°33.419 N	002°34.269 E	51°33.037 N	002°40.252 E

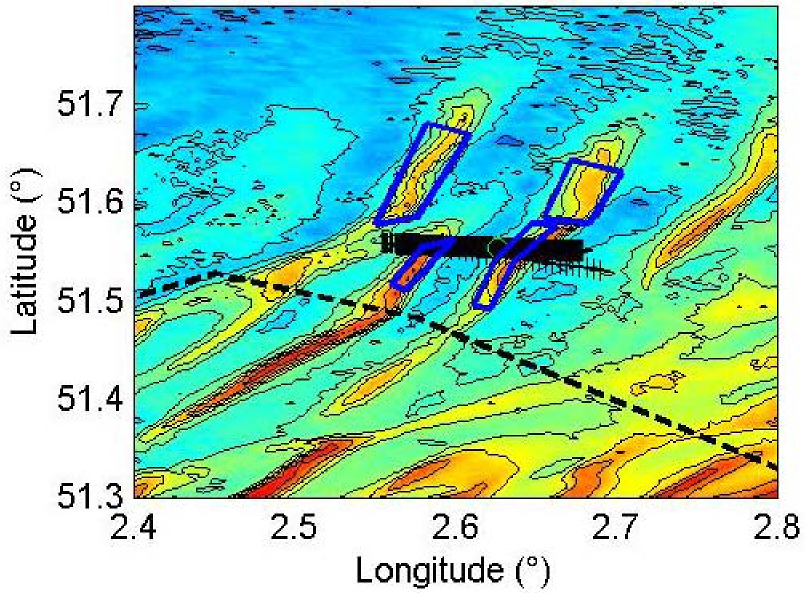


Fig 2: Marine aggregate extraction concession zone 4 in the Hinder Banken region. Blue polygons show the different Sectors where extraction activities are allowed. Black lines show the location of ADCP profiling. Along this transect, water was sampled using the seawater pump. Dashed line is delineation Habitat Directive Area.

Table 3: Positioning water samples during 13-hrs transect Sector 4c-4d.

ID	Timestamp	Lat (WGS84	Long (WGS84)
OH HB01	2013-03-26 15:31:00	51.556943	2.575103
OH HB02	2013-03-26 16:00:00	51.551320	2.676445
OH HB03	2013-03-26 16:30:00	51.556973	2.569908
OH HB04	2013-03-26 16:54:30	51.553053	2.632750
OH HB05	2013-03-26 17:30:10	51.554695	2.605650
OH HB06	2013-03-26 17:54:10	51.555580	2.595347
OH HB07	2013-03-26 18:24:10	51.551823	2.646815
OH HB08	2013-03-26 18:54:10	51.555818	2.581767
OH HB09	2013-03-26 19:25:30	51.550923	2.660985
OH HB10	2013-03-26 19:54:30	51.556635	2.566297
OH HB11	2013-03-26 20:24:10	51.549303	2.670877
OH HB12	2013-03-26 20:54:10	51.556573	2.567168
OH HB13	2013-03-26 21:24:10	51.550297	2.668842
OH HB14	2013-03-26 21:54:10	51.556390	2.584010
OH HB15	2013-03-26 22:24:20	51.552292	2.651207
OH HB16	2013-03-26 22:54:10	51.555670	2.597455
OH HB17	2013-03-26 23:24:10	51.553503	2.628762
OH HB18	2013-03-26 23:54:10	51.552975	2.633845
OH HB19	2013-03-27 00:24:10	51.558500	2.560147
OH HB20	2013-03-27 01:00:00	51.550512	2.673263
OH HB21	2013-03-27 01:30:00	51.555690	2.584495
OH HB22	2013-03-27 01:54:10	51.554117	2.617235
OH HB23	2013-03-27 02:24:10	51.552118	2.649148
OH HB24	2013-03-27 02:54:10	51.556383	2.581338
OH HB25	2013-03-27 03:24:10	51.550723	2.670732
OH HB26	2013-03-27 03:54:10	51.557887	2.563073

6.2. SMB-JV-STUDENTS

The map below shows the stations that were visited during the cruise. One extra sampling point was taken in the area of the Hinder Banks. Location W07 was not sampled.

Table 5: Sampling locations

Station	Latitude	Longitude
115bis	51° 09.11	02° 37.13
120	51° 11.10	02° 42.07
130	51° 16.18	02° 54.30
700	51° 22.60	03° 13.20
710	51° 26.06	03° 08.00
780	51° 27.70	03° 02.60
OH_H182 (ILVO location)	51° 33.06	02° 38.12

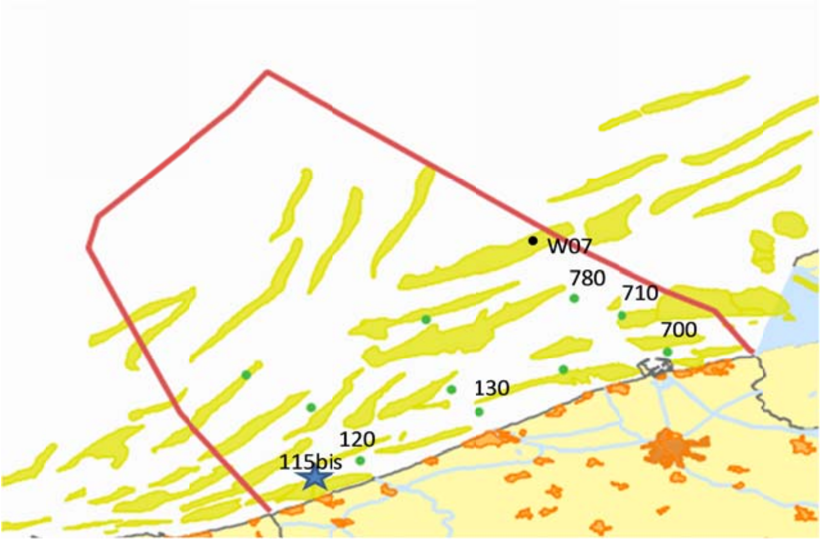


Fig 3: Sampling locations.Location W07 will not be sampled.

Objectives

The BPNS is characterized by gradients in sediment composition (fine – coarse sediments) and primary production. This has an effect on: (1) densities; (2) community composition; and (3) diversity of the benthic communities. In addition, this has an effect on benthic ecosystem functioning. We will sample the water column, macrobenthos and epibenthos, and assess ecosystem functioning rates (as Sediment Community Oxygen Consumption – SCOC along an East-West and inshore-offshore gradient to describe the effects of these gradients. This will allow

- Describing an inshore-offshore gradient in biological communities and ecosystem functioning (via BPc);
- Describing an east-west gradient in biological communities and ecosystem functioning (via BPc);
- Relating possible changes to environmental gradients in surface primary production and sediment composition.

Sampling included:

- 1 CTD profile (vertical profile in the water column);
- 10L water sample with Niskin bottle (SPM and chl *a*) in the water column: filtration on board
- 2 Reineck boxcore deployments with the following subsampling:
  - 1 core (10cm²) for sediment analysis;
  - 1 core for oxygen profiling and SCOC measurements;
  - 1 core for measurement of chl *a* concentrations in the sediment;
- Van Veen grab (3 deployments) : macrofauna sieving on board;
- Beam trawl (2.8m): identification and measurements on board;

6.3. MUMM-MF-MOMO

13-hrs ADCP tidal cycle
Location MOW1, together with water sampling. Water was tapped from the seawater pump, because of bad weather. No vertical profiles could be taken.

Recovering and deployment of tripod
The aMT tripod was deployed at Thursday 28/03 near Zeebrugge location TP-aMT (TerreinProef aMT). At MOW1, aA tripod was recovered on Thursday 28/03 and another tripod was deployed at the same location. See Table and Figure.

Table 6: Position and time of tripod recovery/deployment (MUMM-MF).

ID	Instrument	Date (local time)	Lat_wgs84	Lon_wgs84
MOW1	Tripod recovery	28/03 16h-18h	51°N 21.599'	3°E 6.838'
"	Tripod deployment	28/03 16h-18h	51°N 21.597'	3°E 6.977'
TP-aMT	Tripod deployment	28/03 10h45-11h30	51°N 22.663'	3°E 10.843'

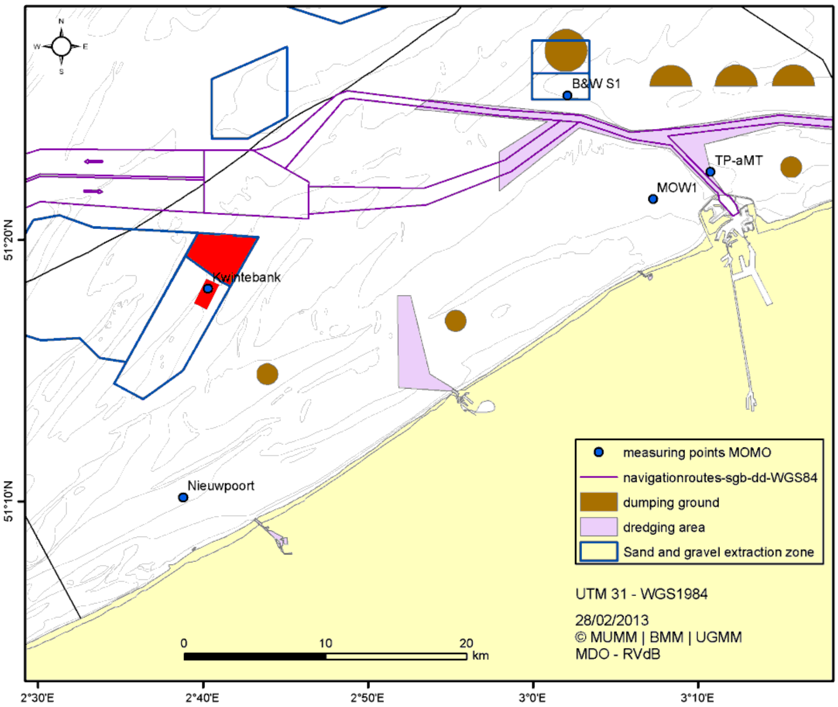
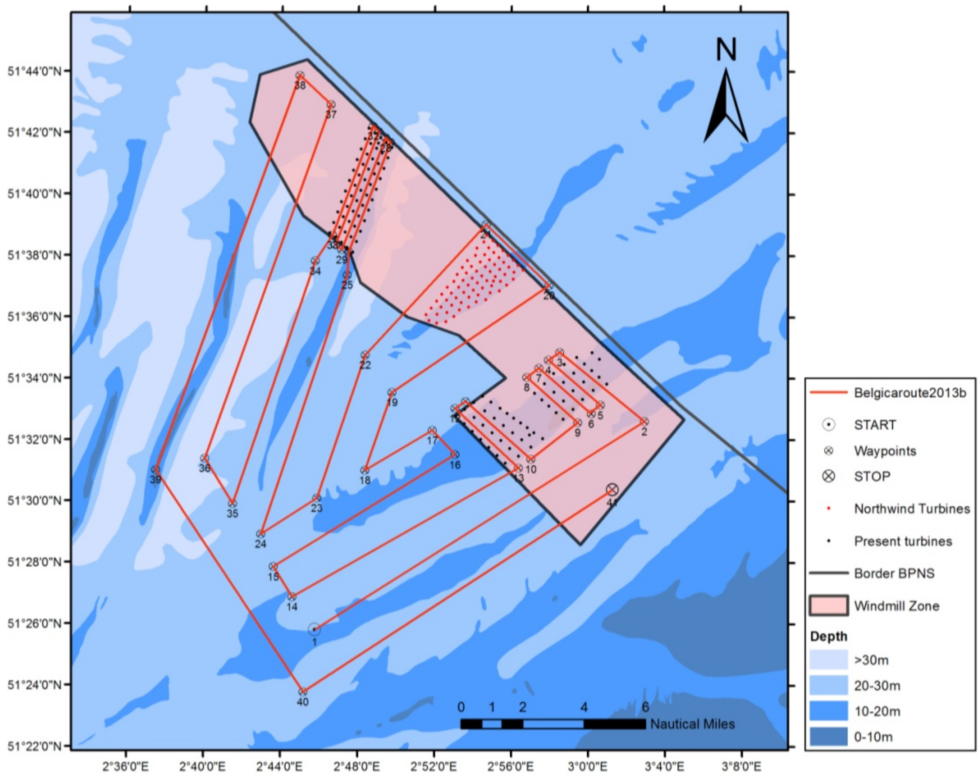


Fig 4: Location of MOW1 and other MOMO measuring points.

6.4. INBO

A monitoring trajectory of about 160 nm was envisaged along which seabirds were counted. Approximately **15hrs** were made available.



WP	X	Y
1	2°45'47"	51°25'49"
2	3°02'57"	51°32'37"
3	2°58'31"	51°34'52"
4	2°57'56"	51°34'37"
5	3°00'40"	51°33'09"
6	3°00'10"	51°32'52"
7	2°57'26"	51°34'22"
8	2°56'48"	51°34'04"
9	2°59'28"	51°32'35"
10	2°57'01"	51°31'23"
11	2°53'37"	51°33'16"
12	2°53'04"	51°33'02"
13	2°56'23"	51°31'06"
14	2°44'36"	51°26'53"
15	2°43'37"	51°27'52"
16	2°53'04"	51°31'32"
17	2°51'53"	51°32'19"
18	2°48'22"	51°31'01"
19	2°49'46"	51°33'34"
20	2°57'58"	51°37'03"
21	2°54'41"	51°39'02"
22	2°48'22"	51°34'46"
23	2°45'53"	51°30'06"
24	2°42'58"	51°28'57"
25	2°47'25"	51°37'23"
26	2°47'30"	51°38'08"
27	2°49'39"	51°41'43"
28	2°49'25"	51°41'51"
29	2°47'08"	51°38'13"
30	2°46'49"	51°38'22"
31	2°49'03"	51°42'04"
32	2°48'45"	51°42'14"
33	2°46'39"	51°38'41"
34	2°45'45"	51°37'50"
35	2°41'28"	51°29'55"
36	2°40'01"	51°31'24"
37	2°46'33"	51°42'56"
38	2°44'55"	51°43'54"
39	2°37'28"	51°31'01"
40	2°45'10"	51°23'47"
41	3°01'17"	51°30'23"

Fig 5: Full monitoring trajectory for seabird counting.

6.4. MUMM-JH-MONIWIND

Recovery and mooring of a PoD at C-Power North cardinal buoy, NE Thornton Bank.

Table 8: Position and time of PoD recovery / deployment.

ID	Instrument	Date (local time)	Lat_wgs84	Lon_wgs84
C-Power North	PoD	28/03 13h-14h30	51°N 35.40’	3°E 0.30’

7. REMARKS

- Officers and crew are thanked warmly for the skillful handling of the operations and student assistance.
- Favourable weather conditions

8. DATA STORAGE

MUMM
- Multibeam echosounding: on hard disk MUMM-BRU; copy will be provided to BMDC. Contact person: Vera Van Lancker
- ADCP: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- Water samples: BMDC
- Seabed samples; integration into BMDC. Contact person: Vera Van Lancker

UG-SMB
- Jan Vanaverbeke

INBO
- Bird counting. Database INBO. Contact person: Nicolas Vanermen

RV BELGICA CRUISE REPORT 2013/19

Subscribers:	Dr. Vera Van Lancker[1]; Nicolas Vanermen[2]
Institutes:	[1]Royal Belgian Institute of Natural Sciences. OD Nature [2]Research Institute for Nature and Forest (INBO)
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Monitoring/Geology: 01/07/2013 - 04/07/2013

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

Reference to this report:
Van Lancker, V., Baeye, M., De Mesel, I., Houttave, K., Pauwaert, Z., Van den Branden, R., and Vanermen, N. (2013). *Cruise report RV Belgica ST1319, 1-4/7/2013*. Royal Belgian Institute of Natural Sciences, OD Nature, 15p.

1. CRUISE DETAILS

1.	Cruise number	2013/19
2.	Date/time	Harbour TD: 01/07/2013 : 13h15 Harbour TA: 04/07/2013: 16h30
3.	Chief Scientist Participating institutes	Dr. Vera Van Lancker MUMM / INBO
4.	Area of interest	Belgian part of the North Sea

2. LIST OF PARTICIPANTS

Institute	NAME	01-04/07
RBINS OD Nature	VAN LANCKER Vera	X
	VAN DEN BRANDEN Reinhilde	X
	BAEYE Matthias	X
	PAUWAERT, Zoë	X
	HOUTTAVE Kim	X
	DE MESEL Ilse	X
INBO	VANERMEN Nicolas	X
	Total number of participants:	**7**

3. SCIENTIFIC OBJECTIVES

OD Nature-VVL: ZAGRI/MOZ4

ZAGRI is a continuous research programme 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 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. 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.

INBO-NV

Based on the results of standardised ship-based seabird counts, the Research Institute for Nature and Forest (INBO) investigates the effects of offshore wind farms on the presence and distribution of seabirds. Following a BACI set-up, the INBO performs monthly surveys along a fixed monitoring route through the impact and control areas at the Blighbank (Belwind wind farm), Thorntonbank (C-Power wind farm), and future wind farm at Bank zonder Naam (Northwind).

MUMM-AUMS

The AUMS (Autonomous Underway Measurement System) project 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. 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 MUMM's public web site and following quality control, from the Belgian Marine Data Centre.

ESA
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 were made with the AUMS system.

Monday 1st July

Oostende LW 14h42 (12 dm LAT); HW 20h45 (46 dm LAT)

09h-10h15 Embarkation of instruments and personnel (1 bottom-mounted ADCP; 1 Hamon Grab (VLIZ); 1 boxcorer
13h15 Sail off from Zeebrugge

13h15-17h30 Bird counting (INBO) (4h15)

Transit to Oosthinder sandbank (Habitat Directive Area 'Flemish Banks')

15h30-18h30 Problems with starting-up the multibeam system (Windows software failure). No solution found. Location ADCP and 13hrs cycle position were determined on the basis of former multibeam measurements and REMUS100 imagery (July 2012) (OD Nature-VVL).

18h30-19h30 Deployment of ADCP (OD Nature-VVL MOZ4) at position 51°24.781; 002°31.603. Within the trough of a barchan dune, where rich epifauna occurred, a flatter area was chosen for safe deployment/recovery (OD Nature-VVL).

20h- Start 13-hrs cycle +/- 150m southwards of the location of the ADCP (LISST100-CTD-OBS) (Anchor position: 51°24.674; 002°31.625 at the stoss side of a barchan dune) (OD Nature-VVL).

Tuesday 2nd July

Oostende LW 03h18 (9 dm LAT); HW 09h23 (46 dm LAT); LW 15h47 (13 dm LAT); HW 21h49 (45 dm LAT)

09h End of 13-hrs cycle

Transit to windmill zone for bird counting

10h30-16h40 Bird counting (INBO) (6h10), meanwhile multibeam recordings were made (OD Nature-VVL).

Transit to Hinder Banken

17h30- Start 13-hrs cycle ADCP profiling in the Habitat Directive Area along a profile transecting the barchan dunes along the west side of the Oosthinder sandbank (Hull-mounted ADCP RDI 300 kHz). Water samples were taken from the seawater pump (GPUMP) every 30' (SPM only) (OD Nature-VVL).

Wednesday 3th July

Oostende LW 04h24 (10 dm LAT); HW 10h30 (45 dm LAT); LW 17h05 (13 dm LAT); HW 22h58 (45 dm LAT)

08h End of ADCP profiling

08h15-10h30 Sediment sampling (Hamon Grab) in the gravel rich trough of the barchans dunes, Habitat Directive area. 11 replicates (OD Nature-VVL)

Transit to windmill zone for bird counting

10h30-18h Bird counting (INBO) (7h30), meanwhile multibeam recordings were made (OD Nature-VVL).

Transit to Hinder Banken

21h30- Multibeam recordings along the Oosthinder sandbank and adjacent gullies in the Habitat Directive Area (OD Nature-VVL).

Thursday 4th July

Oostende LW 05h39 (11 dm LAT); HW 11h39 (45 dm LAT); LW 18h20 (12 dm LAT)

-08h End of multibeam recordings

Transit to ADCP location

09h30-10h30 Recovery bottom-mounted ADCP (OD Nature-VVL).

11h30-13h30 Sediment sampling with boxcorer in marine aggregate concession zone 4, Sector 4c. At 4 locations (2 in / 2 out of the Sector) samples were taken (2-3 replicates).

Transit to Zeebrugge

16h30 Arrival at Zeebrugge

End of campaign

5. TRACK PLOT

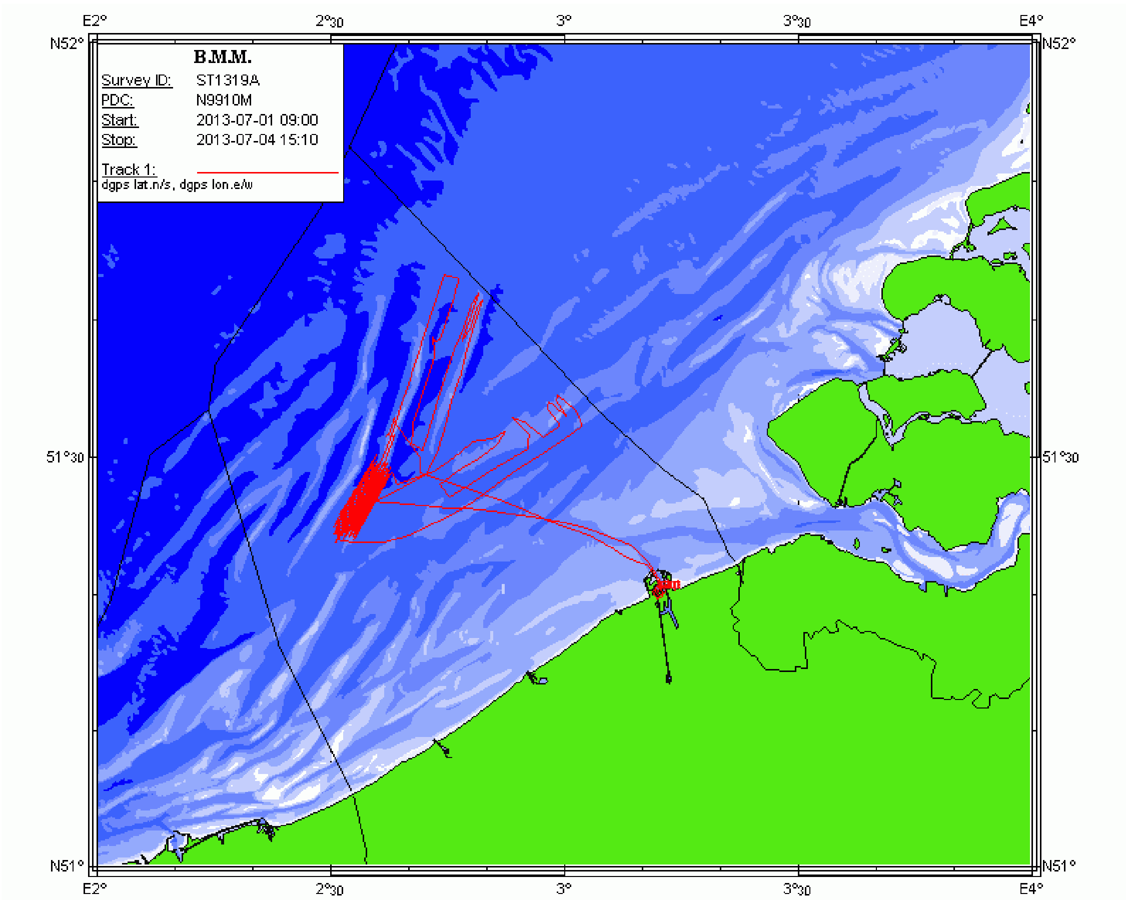


Fig. 1: Track plot ST1319.

6. MEASUREMENTS AND SAMPLING

6.1. OD Nature-ZAGRI/MOZ4

Hydrodynamic and sediment transport related measurements and observations in marine aggregate concession zone 4, Hinder Banks region and adjacent Habitat Directive Area ‘Flemish Banks’.

Measurements and observations:

a. **Full-coverage multibeam echosounding** along the Oosthinder sandbank and adjacent gullies in the Habitat Directive Area (Fig. 2)
b. Deployment of **a Bottom-mounted Acoustic Doppler Current Profiling** (BM-ADCP) (RDI 1200 kHz; shallow water mode; 12 Hz ping rate) in the Habitat Directive Area. The ADCP was deployed in the trough of a barchan dune where rich epifauna occurred. Position was determined from previously acquired very high resolution imagery (REMUS100, July 2012) (Table 1 and Fig. 2, 3 and 6 for location).
c. **13-hrs water column characterization** near the location of the BM-ADCP (Location: 51°24.674; 002°31.625) (every 30’). Due to technical problems with the oceanographic cable the Seacat frame (Conductivity-Temperature-Depth, CTD; Optical Backscatter Sensor, OBS; Laser In-situ scatterometer for particle sizes, LISST100 (VLIZ)) was manipulated with the davit. Due to space constraints, it was not possible to mount a Niskin bottle for water sampling above the Seacat profiler. Instead, water samples were taken from the seawater pump (filtrations of 0.5 l for suspended particulate matter, SPM, every 30 min; Particulate Organic Carbon, POC, 0.25 l; frozen) and salinity (0.25 l) every 1h). The data transmission cable for the Seacat profiler was only 18m; as such the maximum depth of the profiling was limited (total water depth +/- 30m). As such, the Seacat profiler remained at +/- -18m during the 13-hrs cycle and every 30 min a vertical profile was made (up and down) (Table 2, for timestamps and locations).
d. **13-hrs ADCP profiling** in the Habitat Directive Area along a profile transecting the barchan dunes along the west side of the Oosthinder sandbank (Hull-mounted ADCP RDI 300 kHz) (Table 3; Fig. 3). Water sampling was done every 30’ (SPM only; filtration of 0.5 l) (Table 4, for timestamps and locations).
e. **Hamon Grab**, was used for sampling of biological and sediment data in patches of coarse sands and gravel. Positions were determined from previously acquired very high resolution multibeam bathymetry and REMUS100 imagery. Ten samples were taken in the same trough of a barchan dune. An eleventh sample was collected for sediment analyses (Fig. 4, 5, 6: Sample 1 to 11; Table 5). The 10 collected samples were sorted and sieved on board. After collecting the sample from the grab, the residual water was cautiously removed and biggest gravel stones were put in buckets. The bulk of the sample, mainly sand and gravel, was then stored in a second bucket. After the sampling effort, every sample was sieved on a sieve of 1mm mesh size. The previously stored stone also contained a lot of biological activity as is shown in Figure 4.
f. **Boxcores** were taken to assess seafloor integrity in and out Sector 4c. Ten box core sediment samples were taken on four different sites (2 in / 2 out of Sector 4c) (Fig. 2; Table 6). From each core, two subsamples were collected using PVC tubes of about 60 cm long. No on board analyses was done for these samples. Brief lithological descriptions were made (Table 7).
g. AUMS registrations (continuous)

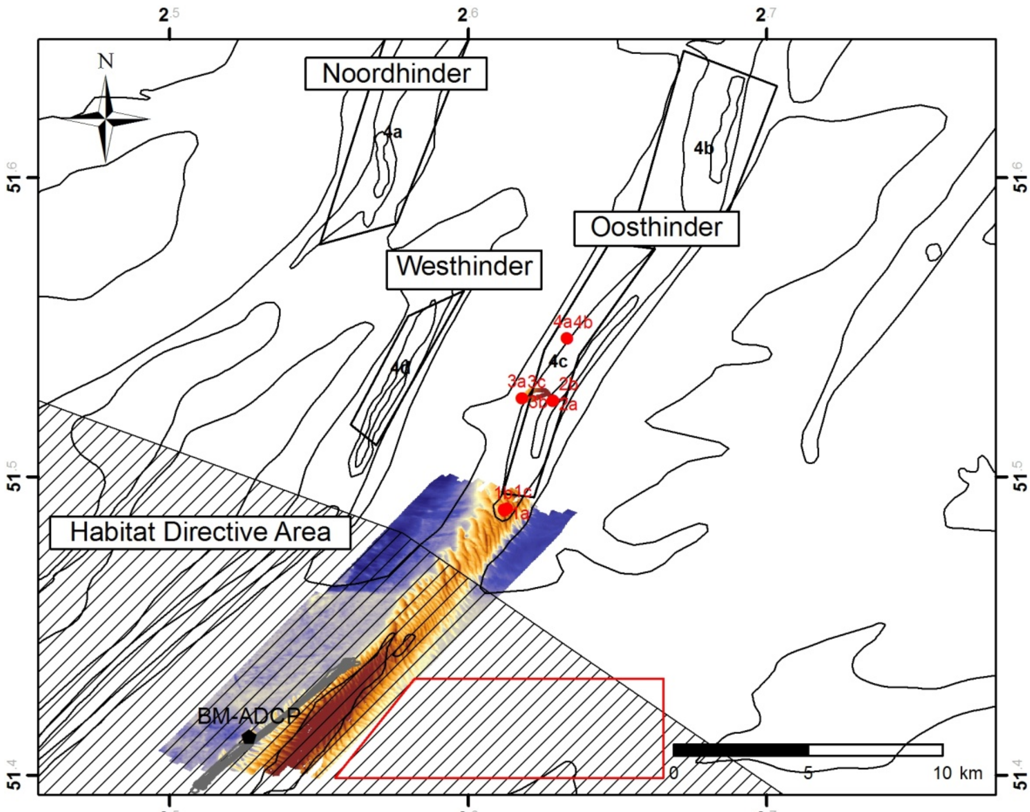


Fig. 2: Hinder Banks region where to the north marine aggregate extraction is allowed in 4 different Sectors (4a-4d) and to the south a Habitat Directive area is defined. During RV Belgica campaign ST1319, the following measurements took place: (1) 4-days deployment of a bottom-mounted ADCP (BM-ADCP), backed-up with 13-hrs water sampling and vertical profiling; (2) 13-hrs cycle hull-mounted ADCP transects along a series of barchans dunes, west of the Oosthinder sandbank, backed-up with water sampling; (3) Multibeam bathymetry in the Habitat Directive area, concentrating on the Oosthinder sandbank and adjacent gullies; (4) Hamon grabs in a trough of a barchans dune where rich epifauna is present; and (5) Boxcores in and around Sector 4c. The series of boxcores is indicated (1a, 1b, 1c; 2a, 2b; 3a, 3b, 3c; and 4a, 4b).

Table 1: Location of bottom-mounted ADCP in the Habitat Directive Area.

ADCP-GRAVEL	51°24.781'N; 002°31.603'E

Table 2: Positioning water samples near bottom-mounted ADCP (Location 51°24.674; 002°31.625).

TIMESTAMP (UTC)	Gear Code	Station	WGS84_NB (°)	WGS84_OL (°)
2013-07-01 18:30:00	GPUMP	2	51,41235	2,528960
2013-07-01 18:59:40	GPUMP	3	51,41242	2,528795
2013-07-01 19:12:20	GPUMP	1	51,41225	2,529037
2013-07-01 19:29:20	GPUMP	4	51,41224	2,529095
2013-07-01 20:01:00	GPUMP	5	51,41233	2,528988
2013-07-01 20:29:40	GPUMP	6	51,41241	2,528862
2013-07-01 21:00:10	GPUMP	7	51,41240	2,528883
2013-07-01 21:30:20	GPUMP	8	51,41239	2,528898
2013-07-01 21:59:00	GPUMP	9	51,41236	2,528948
2013-07-01 22:28:20	GPUMP	10	51,41231	2,52894
2013-07-01 22:57:40	GPUMP	11	51,41224	2,528952
2013-07-01 23:28:10	GPUMP	12	51,41247	2,528613
2013-07-01 23:59:00	GPUMP	13	51,41227	2,528902
2013-07-02 00:30:00	GPUMP	14	51,41225	2,528532
2013-07-02 01:01:00	GPUMP	15	51,41165	2,527927

2013-07-02 01:29:30	GPUMP	16	51,41125	2,528032
2013-07-02 02:01:50	GPUMP	17	51,41123	2,528032
2013-07-02 02:30:50	GPUMP	18	51,41167	2,526995
2013-07-02 02:59:40	GPUMP	19	51,41166	2,527012
2013-07-02 03:30:10	GPUMP	20	51,41181	2,527110
2013-07-02 03:59:00	GPUMP	21	51,41190	2,527230
2013-07-02 04:29:50	GPUMP	22	51,41175	2,527252
2013-07-02 05:00:20	GPUMP	23	51,41230	2,528467
2013-07-02 05:31:10	GPUMP	24	51,41231	2,528655
2013-07-02 05:58:40	GPUMP	25	51,41219	2,528813
2013-07-02 06:31:10	GPUMP	26	51,41218	2,528887
2013-07-02 07:00:00	GPUMP	27	51,41221	2,529012

Table 3: ADCP transect in the Habitat Directive Area

ADCP-T-HD	2°30.445’E	51°23.670’N	2°33.721’E	51°26.296’N

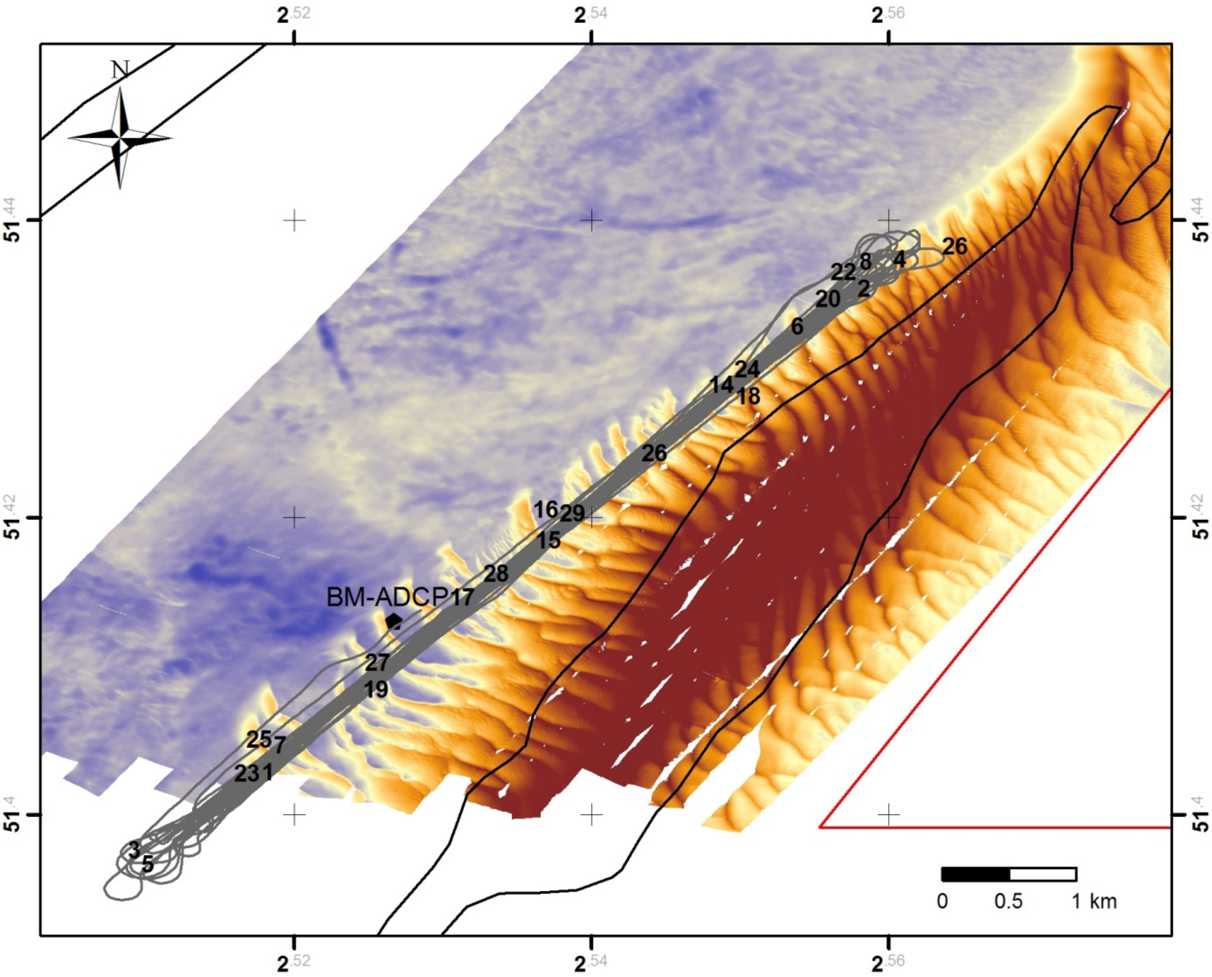


Fig. 3: Location of the 13-hrs hull-mounted ADCP transect along the series of barchans dunes, west of the Oosthinder sandbank. Numbers represent the sequence of water samples (1-29) that were taken. The pentagon is on the position of the bottom-mounted ADCP (BM-ADCP). Background is the multibeam-derived depth digital terrain model (2x2 m), as sailed during this campaign. Red polygon delineates the anchor zone.

Table 4: Positions of water samples along the 13-hrs transect crossing the series of barchan dunes.

TIMESTAMP	Gear Code	Station	WGS84_NB (°)	WGS84_OL (°)
2013-07-02 15:31:30	GPUMP	1	51,40325	2,517753
2013-07-02 15:57:20	GPUMP	2	51,43573	2,557843
2013-07-02 16:29:20	GPUMP	3	51,39665	2,508747

2013-07-02 16:58:50	GPUMP	4	51,43641	2,560260
2013-07-02 17:31:20	GPUMP	5	51,39573	2,509657
2013-07-02 17:59:40	GPUMP	6	51,43190	2,553342
2013-07-02 18:29:40	GPUMP	7	51,40374	2,518573
2013-07-02 18:59:00	GPUMP	8	51,43624	2,557942
2013-07-02 19:30:00	GPUMP	9	51,45972	2,595607
2013-07-02 20:00:00	GPUMP	10	51,44854	2,582695
2013-07-02 20:30:00	GPUMP	11	51,42002	2,552790
2013-07-02 21:00:00	GPUMP	12	51,48406	2,613320
2013-07-02 21:30:00	GPUMP	13	51,41707	2,547710
2013-07-02 22:00:00	GPUMP	14	51,42797	2,547888
2013-07-02 22:28:50	GPUMP	15	51,41784	2,536207
2013-07-02 22:59:50	GPUMP	16	51,41958	2,537695
2013-07-02 23:29:10	GPUMP	17	51,41367	2,530432
2013-07-03 00:00:20	GPUMP	18	51,42799	2,549625
2013-07-03 00:30:10	GPUMP	19	51,40845	2,524592
2013-07-03 01:01:00	GPUMP	20	51,43447	2,556813
2013-07-03 01:30:10	GPUMP	21	51,40379	2,518828
2013-07-03 02:00:40	GPUMP	22	51,43555	2,557642
2013-07-03 02:30:30	GPUMP	23	51,40183	2,516263
2013-07-03 03:00:00	GPUMP	24	51,42901	2,549603
2013-07-03 03:31:30	GPUMP	25	51,40412	2,518503
2013-07-03 04:00:00	GPUMP	26	51,42336	2,543360
2013-07-03 04:11:50	GPUMP	26	51,43727	2,563560
2013-07-03 04:33:50	GPUMP	27	51,40927	2,524743
2013-07-03 04:58:20	GPUMP	28	51,41525	2,532695
2013-07-03 05:29:40	GPUMP	29	51,41933	2,537808

***Table 5: Positioning sampling points Hamon Grab (HG)**. (not corrected for lay-back +/- 32m)*

TIMESTAMP (UTC)	Gear	Station	WGS84_NB (°)	WGS84_OL (°)	WG84_Y	WG84_X
2013-07-03 06:05:50	HG	1	51.41278	2.527286	5695835	467125
2013-07-03 06:16:50	HG	2	51,41247	2,527442	5695800	467136
2013-07-03 06:30:00	HG	3	51,41277	2,527008	5695834	467106
2013-07-03 06:59:30	HG	4	51,41256	2,526883	5695811	467097
2013-07-03 07:10:40	HG	5	51,41264	2,526928	5695819	467100
2013-07-03 07:22:40	HG	6	51,41203	2,527797	5695752	467160
2013-07-03 07:37:30	HG	7	51,41235	2,527033	5695788	467107
2013-07-03 07:48:20	HG	8	51,41284	2,526787	5695842	467090
2013-07-03 07:56:40	HG	9	51,41230	2,527560	5695782	467144
2013-07-03 08:05:50	HG	10	51,41233	2,528008	5695784	467175
2013-07-03 08:18:20	HG	11	51,41222	2,527718	5695772	467155

Fig.4: Epifauna, as sampled at location 1 and 2.
Left: Tubularia and Actiniaria. Right: Alcyonium digitatum.

Sample 1

Sample 2

Sample 3

Sample 4

Sample 5

Sample 6

Sample 7

Sample 8

Sample 9

Sample 10

Sample 11

Fig. 5: Overview of the content of all Hamon Grabs.

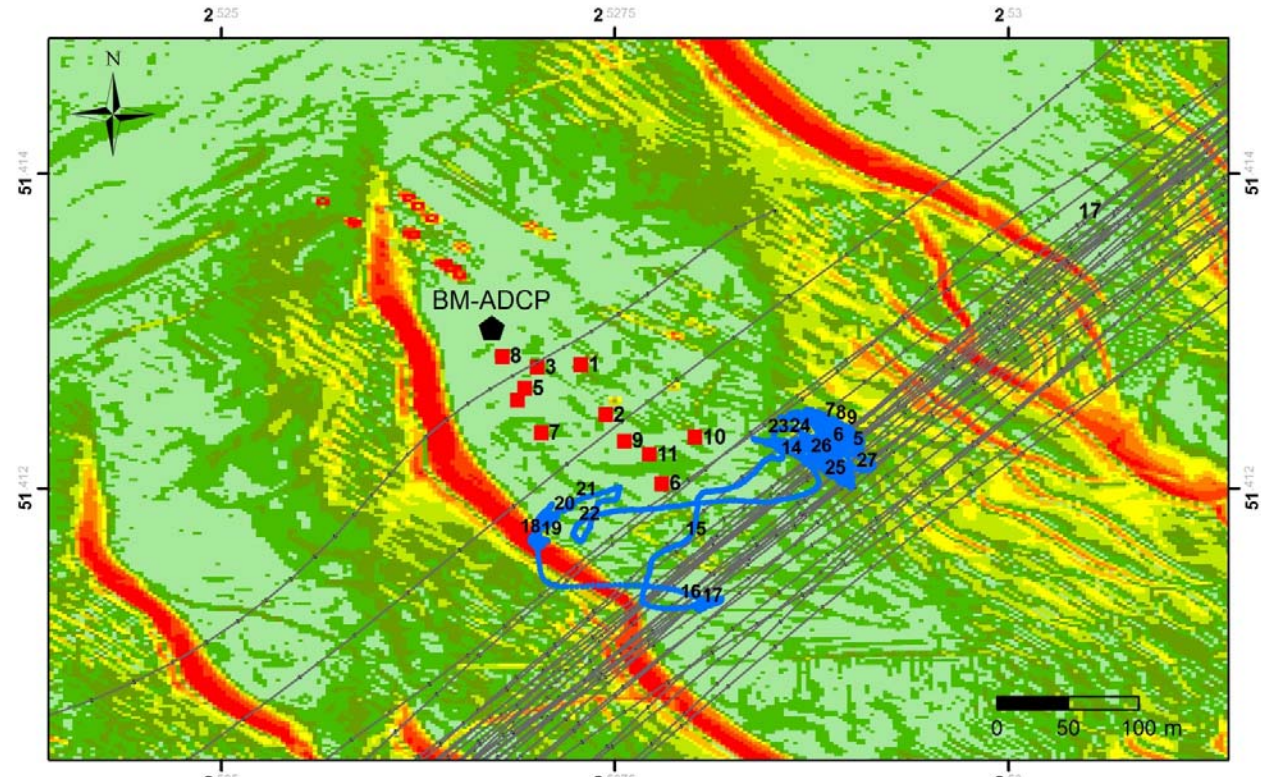


Fig. 6: Overview of Hamon Grab locations (sample 1-11) in the trough of barchan dunes, west of the Oosthinder sandbank. The location of the bottom-mounted ADCP (BM-ADCP) is indicated, as also the ships' trackline (blue) over a 13-hrs tidal cycle during which water samples (5-27) were taken, as also vertical profiles of CTD, OBS, and LISST. Additionally, the tracks of the 13-hrs hull-mounted ADCP transect over the series of barchan dunes are shown, with indication of the position of the water sampling and vertical profiles (e.g. 17 shown in the figure). Background is a slope map of the multibeam-derived depth digital terrain model, as sailed during this campaign. Note the slope variation in the trough, indicative of the presence of gravel patches. The red areas correspond with the steepest parts of the dunes.

Table 6: Positioning of the box core (BC) sampling points. *(not corrected for lay-back +/- 32m)*

TIMESTAMP (UTC)	Gear	Station	WGS84_NB (°)	WGS84_OL (°)
2013-07-04 08:41:00	BC	1a (1)	51,48877	2,61221
2013-07-04 08:56:10	BC	1b (2)	51,48896	2,612077
2013-07-04 09:08:10	BC	1c (3)	51,48949	2,613158
2013-07-04 09:37:50	BC	2a (4)	51,52526	2,628433
2013-07-04 09:48:40	BC	2b (5)	51,52548	2,628522
2013-07-04 10:07:30	BC	3a (6)	51,52633	2,618177
2013-07-04 10:28:10	BC	3b (7)	51,52624	2,618237
2013-07-04 10:45:10	BC	3c (8)	51,52625	2,617988
2013-07-04 11:08:10	BC	4a (9)	51,54639	2,633095
2013-07-04 11:27:00	BC	4b (10)	51,54623	2,633278

Table 7: Boxcore lithological descriptions. Visual estimations.

ID	GS SimpleLitho	main lithology min percentage	main lithology max percentage	Wentworth minimum grain size (µm)	Wentworth maximum grain size (µm)	Shell content min percentage	Shell content max percentage	sand percentage min	sand percentage max	calcium carbonate class percentage	Free text
1A	sand	90	100	400	1000	0	10	90	100	0-10	Coarse sand.
1B	sand	80	100	400	1000	5	25	90	100	0-10	Coarse sand. Black spots throughout the core.
1C	sand	90	100	400	1000	5	15	90	100	10-20	Coarse sand.
2A	sand	90	100	400	1000	10	30	75	95	10-20	Coarse sand, shell hash (more).
2B	sand	90	100	400	2000	15	30	60	100	10-20	Coarse sand, shell hash (more).
3A	sand	90	100	400	2000	10	25	75	100	10-20	Homogeneous coarse sand, shell hash; patchy.
3B	sand	80	100	400	1000	30	60	40	60	20-30	Coarse sand, shell hash patchy, mud in suspension.
3C	sand	90	100	400	1000	10	30	80	95	0-10	Homogeneous coarse sand, shell hash; patchy; skeleton sea urchins.
4A	sand	85	100	400	1000	10	20	80	100	10-20	Coarse sand, darker material on top (in suspension); 15 cm: black band, shell hash and some larger shells.
4B	sand	85	100	400	1000	10	25	75	100	0-10	Homogeneous coarse sand; larger shell pieces in patches, black spots.

Core 1A:

Core 1B:

Core 1C:

Core 2A:

Core 2B:

Core 3A:

Core 3B:

Core 3B:

Core 3C:

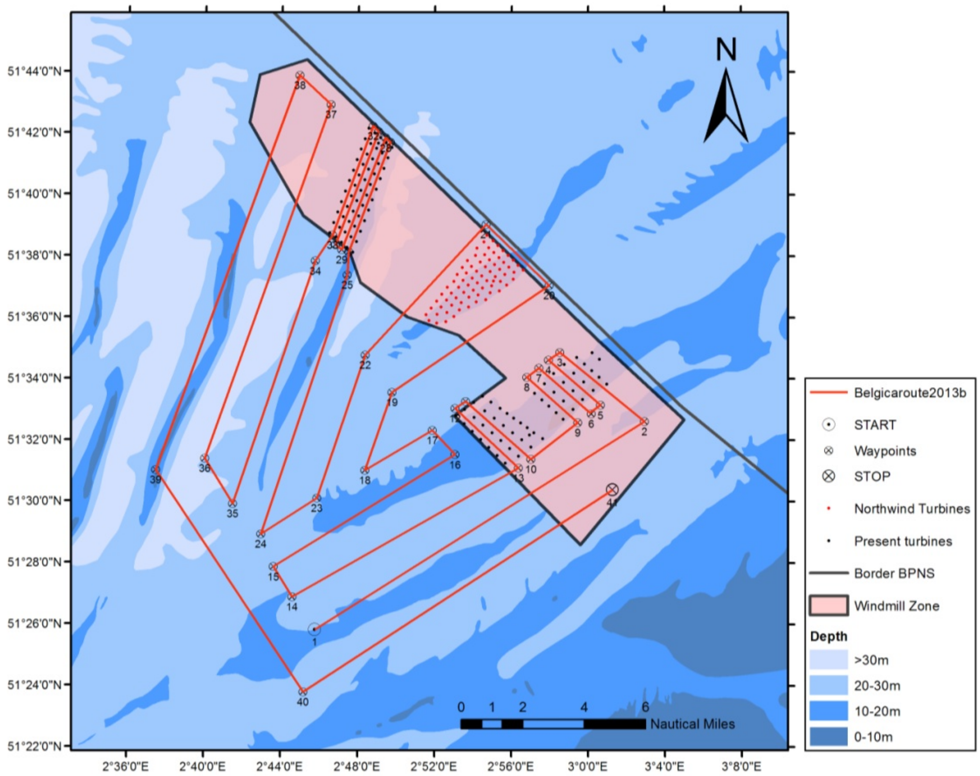
Core 4A:

Core 4B:

Fig. 7: Overview of the content of all boxcores.

6.2. INBO

A monitoring trajectory of about 160 nm was envisaged along which seabirds were counted. Approximately **18hrs** were made available.



WP	X	Y
1	2°45'47"	51°25'49"
2	3°02'57"	51°32'37"
3	2°58'31"	51°34'52"
4	2°57'56"	51°34'37"
5	3°00'40"	51°33'09"
6	3°00'10"	51°32'52"
7	2°57'26"	51°34'22"
8	2°56'48"	51°34'04"
9	2°59'28"	51°32'35"
10	2°57'01"	51°31'23"
11	2°53'37"	51°33'16"
12	2°53'04"	51°33'02"
13	2°56'23"	51°31'06"
14	2°44'36"	51°26'53"
15	2°43'37"	51°27'52"
16	2°53'04"	51°31'32"
17	2°51'53"	51°32'19"
18	2°48'22"	51°31'01"
19	2°49'46"	51°33'34"
20	2°57'58"	51°37'03"
21	2°54'41"	51°39'02"
22	2°48'22"	51°34'46"
23	2°45'53"	51°30'06"
24	2°42'58"	51°28'57"
25	2°47'25"	51°37'23"
26	2°47'30"	51°38'08"
27	2°49'39"	51°41'43"
28	2°49'25"	51°41'51"
29	2°47'08"	51°38'13"
30	2°46'49"	51°38'22"
31	2°49'03"	51°42'04"
32	2°48'45"	51°42'14"
33	2°46'39"	51°38'41"
34	2°45'45"	51°37'50"
35	2°41'28"	51°29'55"
36	2°40'01"	51°31'24"
37	2°46'33"	51°42'56"
38	2°44'55"	51°43'54"
39	2°37'28"	51°31'01"
40	2°45'10"	51°23'47"
41	3°01'17"	51°30'23"

Fig. 8: Full monitoring trajectory for seabird counting.

7. REMARKS

- Officers and crew are thanked warmly for the skillful handling of the operations.
- Favourable weather conditions

8. DATA STORAGE

MUMM

- Multibeam echosounding: on hard disk MUMM-BRU; copy will be provided to BMDC. Contact person: Vera Van Lancker
- ADCP: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- LISST: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- Seacat sensor data: on hard disk MUMM-BRU; copy MUMM-OST. Contact person: Vera Van Lancker
- Seabed samples; integration into BMDC. Contact person: Vera Van Lancker

INBO

- Bird counting. Database INBO. Contact person: Nicolas Vanermen

RV BELGICA CRUISE 2013/28

Subscriber:	Dr. Jan Vanaverbeke[1] , Dr. Vera Van Lancker[2]
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Ecosystems: 21-25/10/2013

Reference to this report:

Vanaverbeke, J. and Van Lancker, V. (2013). *Cruise report RV Belgica ST1328, 21-25/10/2013*. Ghent University, Marine Biology Research Group and Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, 15p.

1. CRUISE DETAILS

1.	Cruise number	2013/28
2.	Date/time	Zeebrugge TD: 21/10/2013 at 10h50 Zeebrugge TA: 25/10/2013 at 13h00
3.	Chief Scientist Participating institutes	Dr. Jan Vanaverbeke UGent-SMB / MUMM
4.	Area of interest	Belgian part of the North Sea

2. LIST OF PARTICIPANTS

Institute	**Participant**	**21/10-25/10**
UGent	Jan VANAVERBEKE (chief scientist)	X
	Guy DESMET	X
	Bart BEUSELINCK	X
	Annelien RIGAUX	X
	Liesbet COLSON	X
	Pieter Blondeel	X
	Yana Deschutter	X
	Pieter BLONDEEL	X
	Niels VIAENE	X
	Lisa MEVENKAMP	X
MUMM	Vera VAN LANCKER	X
	Reinhilde VAN DEN BRANDEN	X
	Frederic FRANCKEN	X
	Total	**13**

3. SCIENTIFIC OBJECTIVES

This cruise was made for the purpose of the Marine Biology Research Group of Ghent University and RBINS OD NATURE. The cruise collected samples to be used in UGent's FWO project "The functional role of marine macrobenthos for the functioning of the sea floor", and the MONWIND project. The latter project aims at monitoring the effects of the installation of offshore windmill farms on the marine ecosystem. During this cruise, data were collected for the monitoring of the macrobenthos inhabiting soft sediments. MUMM's main activities related to the project ZAGRI and MOZ4. ZAGRI aims 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 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

UGENT/SMB-JV: The functional role of marine macrobenthos for the functioning of the sea floor
Research within this project aims at (1) investigating the effect of soft sediment inhabiting key organisms on the functioning of the seafloor and the processes related to the benthic-pelagic coupling and (2) understanding the structural and functional link between the distribution of these key species and the ecological features of the seabed.

UGENT/SMB-DC: MONWIND / Benthos of soft substrates
This part of MONWIND aims at assessing the possible effects of the installation of wind mill farms on the macrobenthos from soft sediments, both at a large scale as on a very detailed scale in the immediate vicinity of a wind mill. During this cruise, samples for the large-scale assessment were collected.

MUMM-VVL: ZAGRI/MOZ4
Monitoring of hydrodynamics and sediment transport to evaluate the effects of the exploitation of non-living resources of the territorial sea and the continental shelf.

MUMM-AUMS
The AUMS (Autonomous Underway Measurement System) project 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. 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 MUMM's public web site and following quality control, from the Belgian Marine Data Centre.

4. OPERATIONAL COURSE

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

Monday 21 October

09.00: arrival and boarding of UGent and RBINS OD Nature teams

10.50: Departure of RV Belgica

12.20-15.00: **Gootebank:** Samples (5 replicate Van Veen samples) were collected at 4 stations. Sampling took longer than expected due to the presence of large stones at the seafloor, and a non optimal functioning of the winch operating the Van Veen grab.

16.00-18.00: **Bligh Bank.** A start was made with the extensive Van Veen sampling at the Bligh Bank: 4 stations were sampled (5 replicates at each station).

19h- Start 13-hrs cycle ADCP profiling along a transect (Sector 4c-4d), together with water sampling from the seawater pump (at 3.2m). Filtration for suspended particulate matter.

Tuesday 22 October

07h30 End of ADCP profiling.

08h44 ADCP deployment at lee side Oosthinder sandbank, position 51°30.970'N – 002°37.949'E

Transit to Bligh Bank

09.45-17.20. **Bligh Bank**. Continuation of Van Veen sampling. Due to suboptimal (slow) functioning of the winch, it was decided to go for 3 replicate drops per station. (Note: the problem with the slow winch was solved later during the cruise, but we sticked to 3 replicate Van Veens for the monitoring stations to guarantee uniformity in the sampling procedure. In addition, other problems with the whinch became apparent. Sticking to 3 replicates allowed to finish the sampling within the time constraints of a 1 week campaign).

18.10-19.20: **Thornton Bank.** A start was made with the Van Veen sampling at the Thornton Bank: 4 stations at the northern site of the sandbank were sampled (3 replicates at each station).

*Transit to **Hinder Banks area***

20.30. Arrival **Oosthinder** sandbank. No connection could be made between the Seacat and the deckunit. An alternative solution was sought delaying the start of the 13-hrs cycle.

21.56- Start 13-hrs cycle near the location of the ADCP (LISST-CTD-NISKIN10L) (OD Nature-VVL)

Wednesday 23 October

11.00: end 13h Cycle OD Nature

Weather conditions were very bad at the planned sampling locations (St.330 – St. 215) and even did not allow sampling near the coast (St. 115). The Belgica remained closed to the coast in sheltered waters. When weather conditions improved, Belgica returned to more offshore waters to continue sampling.

21.00-24.00 **Thornton Bank**. Van Veen samples (3 per station) were collected at 10 stations.

*Transit to **Hinder Banks area***

23.29- Start of transects along which multibeam echosounding and ADCP are recorded simultaneously (OD Nature VVL). Every 30’ a water sample is taken and filtered for suspended particulate matter (sea water pump; 1000-1500 ml). Average ship’s speed 8 kt. Start from transect nr. 1.

Thursday 24 October

-06h52 End of transects (9 were sailed).

08.00-09.20: **Station 330.** Van Veen (8 deployments), Reineck boxcorer (3 deployments), hyperbenthic sledge. The beam trawl was not used due to the presence of large stones in the area.

10.00-11.35: **Station 780.** Van Veen (5 deployments), Reineck boxcorer (3 deployments), hyperbenthic sledge, beam trawl.

13.00-14.15: **Station 790.** Van Veen (5 deployments), Reineck boxcorer (3 deployments), hyperbenthic sledge, beam trawl.
15.15-17.40. **Station 215.** Van Veen (5 deployments), Reineck boxcorer (3 deployments), hyperbenthic sledge, beam trawl.

20.00-21.05. **Thornton Bank**. Van Veen sampling (3 replicates per station). Two stations in the middle of the windmill farm could not be sampled due to darkness.

*Transit to **Hinder Banks Area***

23h11- Continuation of transects along which multibeam echosounding and ADCP are recorded simultaneously (OD Nature-VVL). Every 30’ a water sample is taken and filtered for suspended particulate matter (sea water pump; 1500 ml). Average ship’s speed 8 kt. Start from transect nr. 10.

Friday 25 October

-06.00: End of measurements

09.20-09.45 **Thornton Bank**. Van Veen sampling (3 replicates per station) on the remaining 2 stations.

11.15-12.30: **Station 701**. Van Veen (5 deployments), Reineck boxcorer (3 deployments), hyperbenthic sledge, beam trawl. Due to a heavy shell load, the net of the beam trawl was damaged.

13.00: arrival of RV Belgica in Zeebrugge, end of campaign.

5. TRACK PLOT

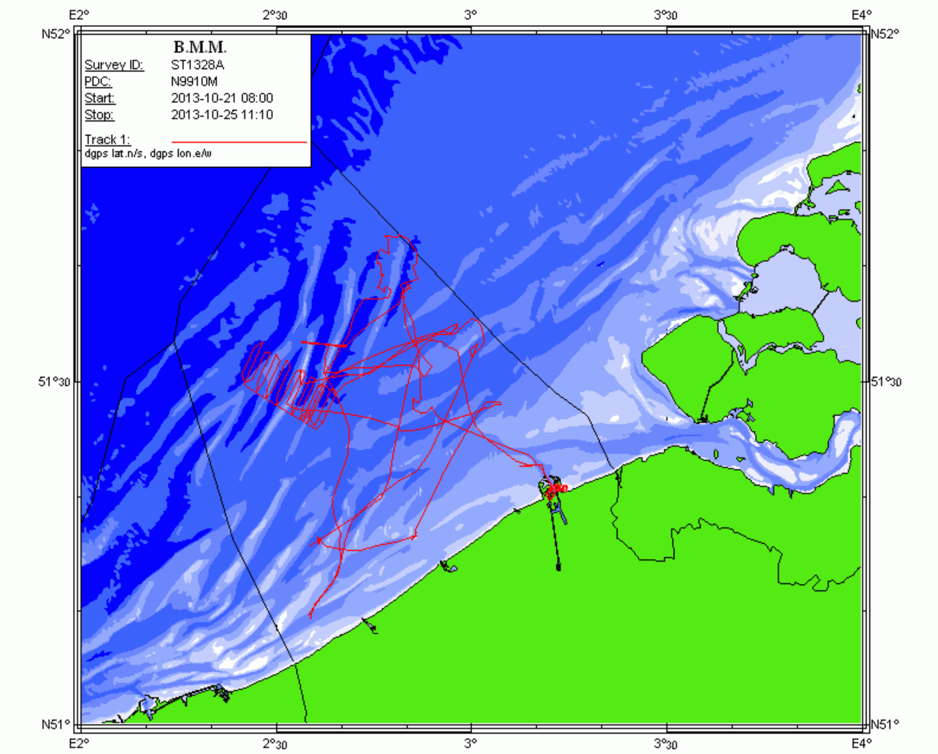

Fig 5.1: Track plot of campaign 2012/26

6. MEASUREMENTS AND SAMPLING

6.1. UGENT-JV: FUNCTIONAL ROLE MACROBENTHOS

Methodology

The operations for the UGent team included sampling of the fixed stations mentioned above and collecting macrobenthos samples at the monitoring stations. All fixed stations on the Belgian Part of the North Sea were sampled for meiobenthos, macrobenthos, hyperbenthos and epibenthos.

Meiobenthos was sampled by means of a Reineck boxcorer.

Every time, the corer was deployed three times in order to get true replicates. At all stations, two perspex cores (10 cm^2) were used to subsample the Reineck boxcorer. One core was fixed in a 4% formaldehyde tap water solution and will be used for meiobenthic studies. The sediment from the other core was dried in the oven and will serve to establish sediment characteristics.

Macrobenthos was sampled using a Van Veen grab. Out of each grab, some sediment was collected for sediment characterisation. On all stations, five replicates were taken. The sediment was sieved on board of the Belgica over a 1-mm sieve. At St. 330, extra Van Veen grabs served a planned experiment in which seawater exchange between the water column and the permeable sediments will be measured over a mimicked tidal cycle.

Epibenthos was sampled with a three-meter beam trawl with a mesh size of 5 mm (10 mm stretched) in the cod end. All tows were made over a distance of 1000 m in the direction of the current with a towing speed of 1.5 knots per hour.

Hyperbenthos was sampled with a hyperbenthic sledge containing four nets: two nets with 0.5-mm mesh and two with 1.0-mm mesh. The lower nets samples the lower 0.5 m of the water column while the upper nets sample the water column between 0.5 and 1 m above the bottom. All tows were made against the current at a speed of 1.5 knot per hour.

Monitoring stations for soft sediment macrobenthos were only sampled with the Van Veen Grab. Again, 5 replicates per station were collected, and sediment was sieved on board over a 1 mm-sieve

Stations

Samples for the FWO project were planned to be collected at fixed locations on the Belgian Part of the North Sea. Storm prevented a full execution of this programme. Only stations marked with “*” were actually sampled.

Table 6.1.1 Location of sampled stations.

Station	Latitude	Longitude
701	51° 22.63	03° 09.25
780	51° 27.70	03° 02.60
790	51° 16.87	02° 51.13
215	51° 16.20	02° 36.76
330	51° 26.037	02° 48.486

6.2. UGENT-DC: MONWIND

Methodology
See 6.1

Stations
Samples for the MONWIND project were collected at the Gootebank, Thornton Bank and Bligh Bank.

Table 6.2.2 Sampling locations at Bligh Bank

Bligh Bank - Belwind									
	Samples	Latitude	Longitude	North WGS	East WGS		Latitude	Longitude	
1	BBI02	51.655106	2.7730616	5722703.67	484301.12		51° 39.306	2° 46.384	5xVV
2	BBI05	51.684861	2.791611	5726009.1	485593.75		51° 41.092	2° 47.497	5xVV
3	BBI26	51.639578	2.8187704	5720967.85	487458.83		51° 38.374	2° 49.126	5xVV
4	BBI33	51.666024	2.8512395	5723903.97	489711.69		51° 39.961	2° 51.074	5xVV
5	BBE09	51.653214	2.8545808	5722478.82	489939.94		51° 39.193	2° 51.275	5xVV
6	BBE06	51.639543	2.8371367	5720960.98	488729.77		51° 38.373	2° 50.228	5xVV
7	BBE05	51.625775	2.8180737	5719432.88	487406.79		51° 37.547	2° 49.084	5xVV
8	BBE14	51.706222	2.784802	5728386.07	485130.04		51° 42.373	2° 47.088	5xVV
9	BBE12	51.68862	2.7744012	5726430.67	484405.3		51° 41.317	2° 46.464	5xVV
10	BBE16	51.671145	2.7661829	5724488.92	483830.99		51° 40.269	2° 45.971	5xVV
11	BBC01	51.674729	2.758216	5724889.33	483281.38		51° 40.484	2° 45.493	5xVV
12	BBC02	51.69194	2.767305	5726801.43	483915.95		51° 41.516	2° 46.038	5xVV
13	BBC03	51.709924	2.777361	5728799.39	484617.13		51° 42.595	2° 46.641	5xVV
14	BBC04	51.61909	2.824985	5718688.2	487883.42		51° 37.145	2° 49.499	5xVV
15	BBC05	51.633346	2.844077	5720270.7	489208.57		51° 38.001	2° 50.645	5xVV
16	BBC06	51.646999	2.860551	5721786.83	490351.64		51° 38.820	2° 51.633	5xVV
17	BBE19	51.643853	2.768525	5721453.11	483983.33		51° 38.631	2° 46.111	5xVV
18	BBE20	51.637251	2.781047	5720716.19	484847.58		51° 38.235	2° 46.863	5xVV
19	BBE21	51.629738	2.793114	5719878.19	485680.29		51° 37.784	2° 47.587	5xVV
20	BBC07	51.635429	2.763744	5720517.28	483649.48		51° 38.126	2° 45.825	5xVV
21	BBC08	51.628599	2.775811	5719755.05	484482.27		51° 37.716	2° 46.549	5xVV
22	BBC09	51.621086	2.786739	5718917.22	485236.24		51° 37.265	2° 47.204	5xVV
23	BBE22	51.709344	2.813136	5728727.95	487088.77		51° 42.561	2° 48.788	5xVV
Total numbers of samples									**115**

Table 6.2.3 Sampling locations at Thornton Bank

Thorntonbank – C-Power									
	Samples	Latitude	Longitude	North WGS	East WGS		Latitude	Longitude	
1	TBE05	51.5486204	2.9524304	5710837.5	496701.58		51° 32.917	2° 57.146	5xVV
2	TBE14	51.543939	2.959807	5710316.55	497212.78		51° 32.636	2° 57.588	5xVV
3	TBE15	51.5875910	3.0088560	5715170.56	500613.54		51° 35.255	3° 0.531	5xVV
4	TBE16	51.5779660	3.0244030	5714100.37	501690.99		51° 34.678	3° 1.464	5xVV
5	TBE06	51.5435374	2.9930165	5710271.15	499515.72		51° 32.612	2° 59.581	5xVV
6	TBE07	51.5489043	3.0020033	5710868	500138.91		51° 32.934	3° 0.120	5xVV
7	TBE08	51.5537713	3.0121983	5711409.35	500845.72		51° 33.226	3° 0.732	5xVV
8	TBE10	51.5657709	2.9532999	5712744.84	496763.09		51° 33.946	2° 57.198	5xVV

9	TBE11	51.5713212	2.9644317	5713361.68	497534.96		51° 34.279	2° 57.866	5xVV
10	TBE12	51.5772048	2.9706467	5714015.83	497965.95		51° 34.632	2° 58.239	5xVV
11	TBEC01	51.5365510	3.0022860	5709494.14	500158.55		51° 32.193	3° 0.137	5xVV
12	TBEC02	51.5430130	3.0109010	5710212.86	500755.96		51° 32.581	3° 0.654	5xVV
13	TBEC03	51.5478360	3.0199790	5710749.38	501385.34		51° 32.870	3° 1.199	5xVV
14	TBEC04	51.5710110	2.9469410	5713327.92	496322.76		51° 34.261	2° 56.816	5xVV
15	TBEC05	51.5771790	2.9574920	5714013.41	497054.39		51° 34.631	2° 57.450	5xVV
16	TBEC06	51.5838340	2.9647960	5714753.28	497560.88		51° 35.030	2° 57.888	5xVV
17	TBC01	51.5066849	2.8768615	5706179.8	491453.87		51° 30.401	2° 52.612	5xVV
18	TBC06	51.5199189	2.8965500	5707649.49	492822.38		51° 31.195	2° 53.793	5xVV
19	TBC10	51.5228517	2.8503055	5707981.21	489614.49		51° 31.371	2° 51.018	5xVV
20	TBC12	51.5301357	2.8803159	5708787.46	491697.88		51° 31.808	2° 52.819	5xVV
Total numbers of samples									**100**

Table 6.2.4 Sampling Locations at the Gootebank

Goote Bank – Reference area									
	Samples	Latitude	Longitude	North WGS	East WGS		Latitude	Longitude	
1	GBC06	51.4697949	2.8498133	5702080.66	489568.24		51° 28.188	2° 50.989	5xVV
2	GBC07	51.4754565	2.8698290	5702707.64	490959.62		51° 28.527	2° 52.190	5xVV
3	GBC21	51.4532919	2.8697684	5700242.67	490951.03		51° 27.198	2° 52.186	5xVV
4	GBC24	51.4630499	2.8971875	5701324.85	492857.73		51° 27.783	2° 53.831	5xVV
Total number of samples									**20**

6.3 OD Nature-VVL: ZAGRI/MOZ4

Hydrodynamic and sediment transport related measurements and observations were made in the marine aggregate concession zone 4, Hinder Banks region and adjacent Habitat Directive Area 'Flemish Banks'.

a. Deployment of a Bottom-mounted Acoustic Doppler Current Profiler (BM-ADCP) (RDI 1200 kHz) along the steep side of the Oosthinder sandbank (see Table);
b. Near the BM-ADCP, 13-hrs water column characterization (every 30') using the Seacat frame mounted with CTD, OBS, LISST100 instrumentation and a 5l Niskin bottle for water sampling (filtration SPM (filtration 1 to 1,5L), POC (250 ml), salinity). Due to technical constraints, the Seacat frame could only measure at about 15 m below the sea surface. Meanwhile, hull-mounted ADCP data were recorded (1m bin size) (see Table).
c. 13-hrs ADCP profiling along a profile transecting the Oosthinder and Westhinder sandbank (Sector 4c-4d) (Hull-mounted ADCP RDI 300 kHz; 1 m bin size). Water sampling is done from the seawater pump every 30' (filtration of 1 to 1,5L) (SPM only) (see Table).
d. Multibeam registrations (Kongsberg-Simrad EM3002), simultaneously with hull-mounted ADCP (0,5 to 1m bin size). Water sampling is done from the seawater pump every 30' (filtration of 1L) (SPM only) (see Table).
e. No sampling of suspended sediments during the 13-hrs cycles using the centrifuge: centrifuge not available.
f. AUMS registrations (continuous)

Throughout the campaign multibeam recordings were made (<ST1328_TRANSIT>) (depth and backscatter).

The following figure shows the areas of interests.

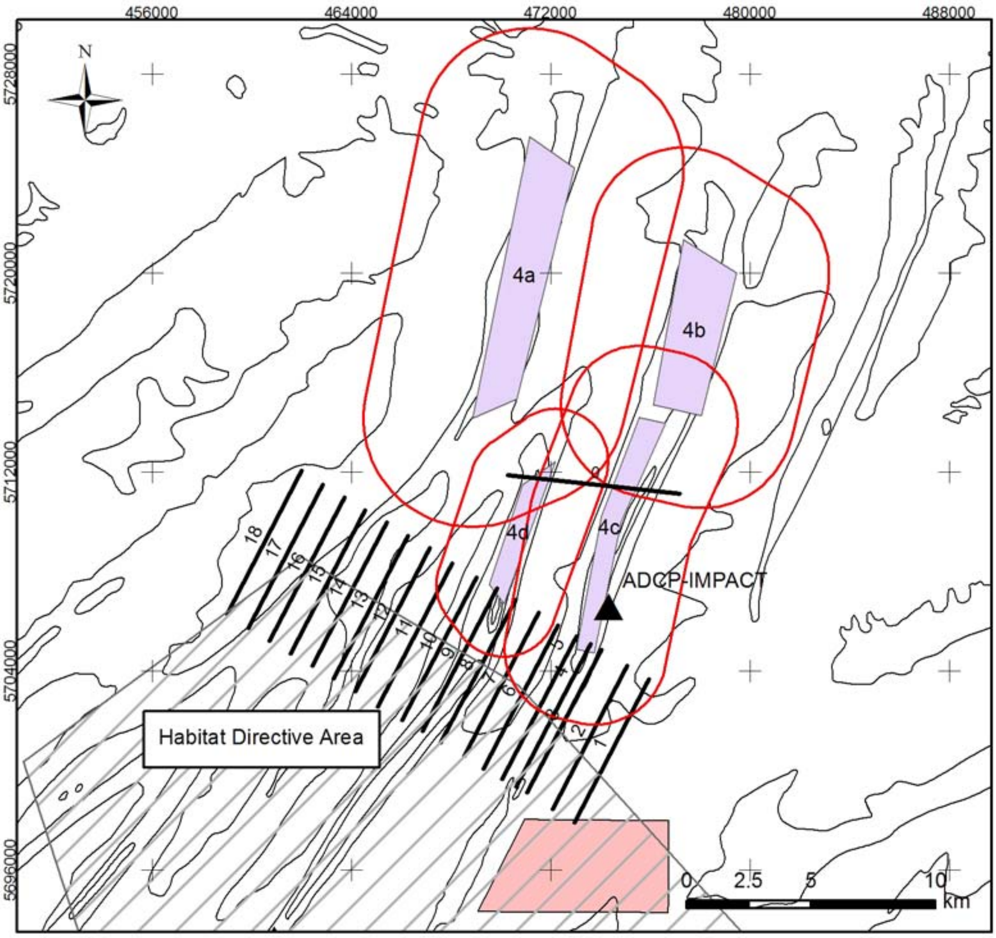

Fig 6.3.1: Hinder Banks area where (1) Marine aggregate extraction sectors are defined (4a-4d); (2) a Habitat Directive area is present (hatched area). Red buffer delineates the area into which effects are allowed according to the Marine Strategy Framework Directive. The anchor zone is also indicated (pink area). Measurements during ST1328 comprised: (1) Deployment of a bottom-mounted ADCP (triangle), together with a 13-hrs water sampling and vertical profiling; (2) 13-hrs hull-mounted ADCP transect (crossing Sector 4c-4d), together with water sampling; and (3) multibeam echosounding, together with ADCP profiling and water sampling along 18 lines, perpendicular to the Habitat Directive Area; line 1-5 were sailed twice (24 and 25/10).

Table 6.3.1: Deployment of a bottom-mounted ADCP

ADCP longer term measurements			Deployment Deployment date	Recovery Recovery date
ADCP Impact	51°30.970'N	002°37.949'E	2013-10-22 08:44 local	Foreseen at 2013-11-28

Table 6.3.2: Vertical profiling and water sampling (Sector 4c). RV Belgica anchored.

Oosthinder topzone	Near ADCP-impact position	51°30.740'N	002°37.534'E

Table 6.3.3: ADCP track crossing the Sectors 4d (Westhinder) and Sector 4c (Oosthinder).

ADCP track (+/-7km)				
X-Y	51°33.419 N	002°34.269 E	51°33.037'N	002°40.252'E

Table 6.3.4: Transects along which multibeam echosounding and ADCP were recorded simultaneously. Water samples were taken and filtered for suspended particulate matter.

Line	WGS84_NB_FROM		WGS84_OL_FROM		WGS84_NB_TO		WGS84_OL_TO	
1	51	29.011	2	39.202	51	25.897	2	36.643
2	51	29.302	2	38.451	51	26.187	2	35.892
3	51	29.648	2	37.557	51	26.533	2	34.999
4	51	29.772	2	37.172	51	26.656	2	34.614
5	51	29.939	2	36.692	51	26.824	2	34.135
6	51	30.163	2	36.036	51	27.048	2	33.479
7	51	30.440	2	35.374	51	27.324	2	32.817
8	51	30.723	2	34.550	51	27.606	2	31.995
9	51	30.969	2	33.912	51	27.853	2	31.357
10	51	31.204	2	33.207	51	28.087	2	30.653
11	51	31.501	2	32.348	51	28.384	2	29.794
12	51	31.829	2	31.577	51	28.712	2	29.024
13	51	32.097	2	30.807	51	28.979	2	28.254
14	51	32.376	2	30.072	51	29.258	2	27.520
15	51	32.644	2	29.319	51	29.526	2	26.768
16	51	32.911	2	28.584	51	29.793	2	26.033
17	51	33.190	2	27.831	51	30.072	2	25.280
18	51	33.491	2	27.095	51	30.372	2	24.545

Table 6.3.5: Positioning water samples during 13-hrs transect Sector 4c-4d.

TIMESTAMP (UTC)	Station	Gear Code	WGS84_NB(°)	WGS84_OL(°)
2013-10-21 17:16:04	1	GPUMP	51,55436	2,62105
2013-10-21 17:45:43	2	GPUMP	51,55486	2,60853
2013-10-21 18:15:06	3	GPUMP	51,55255	2,64520
2013-10-21 18:45:00	4	GPUMP	51,55616	2,57981
2013-10-21 19:15:51	5	GPUMP	51,55086	2,67328
2013-10-21 19:45:26	6	GPUMP	51,55745	2,56715
2013-10-21 20:15:26	7	GPUMP	51,55141	2,65519
2013-10-21 20:45:25	8	GPUMP	51,55552	2,59035
2013-10-21 21:15:39	9	GPUMP	51,55304	2,63086
2013-10-21 21:45:33	10	GPUMP	51,55369	2,62192
2013-10-21 22:15:24	11	GPUMP	51,55473	2,59825
2013-10-21 22:44:35	12	GPUMP	51,54994	2,67026
2013-10-21 23:14:15	13	GPUMP	51,55739	2,56584
2013-10-21 23:45:30	14	GPUMP	51,54960	2,67451
2013-10-22 00:14:55	15	GPUMP	51,55659	2,58183
2013-10-22 00:44:38	16	GPUMP	51,55252	2,64515
2013-10-22 01:14:50	17	GPUMP	51,55490	2,60649
2013-10-22 01:45:18	18	GPUMP	51,55364	2,62839
2013-10-22 02:15:04	19	GPUMP	51,55201	2,64713
2013-10-22 02:45:15	20	GPUMP	51,55819	2,57171
2013-10-22 03:15:07	21	GPUMP	51,55154	2,67886
2013-10-22 03:46:04	22	GPUMP	51,55696	2,57549
2013-10-22 04:15:30	23	GPUMP	51,55123	2,66150
2013-10-22 04:45:27	24	GPUMP	51,55574	2,59321
2013-10-22 05:15:15	25	GPUMP	51,55256	2,63927

Table 6.3.6: Positioning water samples and vertical profiling during 13-hrs cycle near location of bottom-mounted ADCP.

TIMESTAMP (UTC)	Station	Gear Code	WGS84_NB(°)	WGS84_OL(°)
2013-10-22 20:00:16	BM01	SBE19-L-5l	51,51329	2,62448
2013-10-22 20:30:27	BM02	SBE19-L-5l	51,51265	2,62437
2013-10-22 20:59:43	BM03	SBE19-L-5l	51,51219	2,62465
2013-10-22 21:30:56	BM04	SBE19-L-5l	51,51172	2,62452
2013-10-22 21:59:08	BM05	SBE19-L-5l	51,51104	2,62535
2013-10-22 22:27:53	BM06	SBE19-L-5l	51,51104	2,62536
2013-10-22 23:03:04	BM07	SBE19-L-5l	51,51104	2,62540
2013-10-22 23:31:15	BM08	SBE19-L-5l	51,51105	2,62557
2013-10-23 00:00:03	BM09	SBE19-L-5l	51,51116	2,62594
2013-10-23 00:30:32	BM10	SBE19-L-5l	51,51225	2,62580
2013-10-23 00:59:48	BM11	SBE19-L-5l	51,51284	2,62711
2013-10-23 01:32:40	BM12	SBE19-L-5l	51,51288	2,62712
2013-10-23 02:00:06	BM13	SBE19-L-5l	51,51299	2,62744
2013-10-23 02:29:23	BM14	SBE19-L-5l	51,51317	2,62722
2013-10-23 03:00:42	BM15	SBE19-L-5l	51,51322	2,62715
2013-10-23 03:30:02	BM16	SBE19-L-5l	51,51335	2,62696
2013-10-23 03:59:38	BM17	SBE19-L-5l	51,51349	2,62670
2013-10-23 04:28:51	BM18	SBE19-L-5l	51,51357	2,62652
2013-10-23 04:58:23	BM19	SBE19-L-5l	51,51364	2,62616
2013-10-23 05:30:27	BM20	SBE19-L-5l	51,51365	2,62608
2013-10-23 06:02:00	BM21	SBE19-L-5l	51,51368	2,62596
2013-10-23 06:30:23	BM22	SBE19-L-5l	51,51367	2,62617
2013-10-23 06:59:19	BM23	SBE19-L-5l	51,51370	2,62611
2013-10-23 07:30:39	BM24	SBE19-L-5l	51,51372	2,62600
2013-10-23 07:59:53	BM25	SBE19-L-5l	51,51371	2,62608
2013-10-23 08:30:57	BM26	SBE19-L-5l	51,51369	2,62634
2013-10-23 08:58:40	BM27	SBE19-L-5l	51,51367	2,62643

Table 6.3.7: Positioning water samples during transects along which multibeam echosounding and ADCP were recorded simultaneously.

TIMESTAMP (UTC)	Station	Gear Code	WGS84_NB(°)	WGS84_OL(°)
2013-10-23 23:43:30	G1	GPUMP	51,47231	2,64420
2013-10-24 00:11:20	G2	GPUMP	51,44923	2,60870
2013-10-24 00:42:50	G3	GPUMP	51,48954	2,62206
2013-10-24 01:16:20	G4	GPUMP	51,44989	2,58151
2013-10-24 01:49:20	G5	GPUMP	51,49450	2,60790
2013-10-24 02:28:00	G6	GPUMP	51,45939	2,56516
2013-10-24 03:03:10	G7	GPUMP	51,50273	2,58577
2013-10-24 03:46:30	G8	GPUMP	51,46401	2,53655
2013-10-24 04:28:50	G9	GPUMP	51,50478	2,55596
2013-10-24 21:30:30	G10	GPUMP	51,49444	2,53240
2013-10-24 22:02:50	G11	GPUMP	51,48730	2,50818
2013-10-24 22:34:10	G12	GPUMP	51,52292	2,52009
2013-10-24 23:09:20	G13	GPUMP	51,48975	2,47641
2013-10-24 23:43:30	G14	GPUMP	51,53257	2,49470
2013-10-25 00:18:20	G15	GPUMP	51,49848	2,45136
2013-10-25 00:52:10	G16	GPUMP	51,53879	2,46838
2013-10-25 01:26:40	G17	GPUMP	51,51064	2,42908
2013-10-25 02:00:00	G18	GPUMP	51,54894	2,44397
2013-10-25 03:32:30	G19	GPUMP	51,44500	2,62185
2013-10-25 04:03:00	G20	GPUMP	51,48380	2,63706
2013-10-25 04:39:50	G21	GPUMP	51,44598	2,58642
2013-10-25 05:13:00	G22	GPUMP	51,48793	2,61268
2013-10-25 05:47:30	G23	GPUMP	51,45903	2,57868

Table 6.3.8: Timestamps and details of transects along which multibeam echosounding and ADCP were recorded simultaneously.

MBES	Transect	UTC start	UTC stop	ADCP bin size	Water sample	SVP
1	1	2013-10-23 23:29	2013-10-23 23:35	0,25		1508
2	*turn*	2013-10-23 23:35	2013-10-24 00:00	0,50	2013-10-23 23:43:30	1508
3	2	2013-10-24 00:00	2013-10-24 00:30	0,50	2013-10-24 00:11:20	1508
4	*turn*	2013-10-24 00:30	2013-10-24 00:33	0,50		1508
5	3	2013-10-24 00:33	2013-10-24 01:09	0,50	2013-10-24 00:42:50	1508
6	*turn*	2013-10-24 01:09	2013-10-24 01:13	0,50		1508
7	4	2013-10-24 01:13	2013-10-24 01:41	0,50	2013-10-24 01:16:20	1508
8	*turn*	2013-10-24 01:41	2013-10-24 01:44	0,50		1508
9	5	2013-10-24 01:44	2013-10-24 02:16	0,50	2013-10-24 01:49:20	1507,12
10	*turn*	2013-10-24 02:16	2013-10-24 02:24	0,50		1507,12
11	6	2013-10-24 02:24	2013-10-24 02:50	0,50	2013-10-24 02:28:00	1507,12
12	*turn*	2013-10-24 02:50	2013-10-24 02:59	0,50		1507,12
13	7	2013-10-24 02:59	2013-10-24 03:36	0,50	2013-10-24 03:03:10	1507,12
15	*turn*	2013-10-24 03:36	2013-10-24 03:44	0,50		1507,12
16	8	2013-10-24 03:45	2013-10-24 04:12	0,50	2013-10-24 03:46:30	1507,12
17	*turn*	2013-10-24 04:12	2013-10-24 04:21	0,50		1508
18	9	2013-10-24 04:21	2013-10-24 04:52	0,50	2013-10-24 04:28:50	1508
19	*turn*	2013-10-24 04:52	2013-10-24 04:54	0,50		1508
21	10	2013-10-25 21:11	2013-10-25 21:16	1,00		1508
22	*turn*	2013-10-25 21:16	2013-10-25 21:46	1,00	2013-10-24 21:30:30	1508
23	11	2013-10-25 21:46	2013-10-25 21:55	1,00		1508
24	*turn*	2013-10-25 21:55	2013-10-25 22:23	1,00	2013-10-24 22:02:50	1508
25	12	2013-10-25 22:23	2013-10-25 22:30	1,00		1508
26	*turn*	2013-10-25 22:30	2013-10-25 22:56	1,00	2013-10-24 22:34:10	1508
27	13	2013-10-25 22:56	2013-10-25 23:05	1,00		1508
28	*turn*	2013-10-25 23:05	2013-10-25 23:32	1,00	2013-10-24 23:09:20	1508
29	14	2013-10-25 23:32	2013-10-25 23:40	1,00		1508
30	*turn*	2013-10-25 23:40	2013-10-26 00:06	1,00	2013-10-24 23:43:30	1508
31	15	2013-10-26 00:06	2013-10-26 00:15	1,00		1508
32	*turn*	2013-10-26 00:15	2013-10-26 00:43	1,00	2013-10-25 00:18:20	1508
33	16	2013-10-26 00:43	2013-10-26 00:47	1,00		1508
34	*turn*	2013-10-26 00:47	2013-10-26 01:15	1,00	2013-10-25 00:52:10	1508
35	17	2013-10-26 01:15	2013-10-26 01:21	1,00		1508
36	*turn*	2013-10-26 01:21	2013-10-26 01:49	1,00	2013-10-25 01:26:40	1508
37	18	2013-10-26 01:49	2013-10-26 01:55	1,00		1508
38	*turn*	2013-10-26 01:55	2013-10-26 02:24	1,00	2013-10-25 02:00:00	1508
39	transit	2013-10-26 02:24	2013-10-26 03:24	1,00		1508
40	1	2013-10-26 03:24	2013-10-26 03:52	1,00	2013-10-25 03:32:30	1508
42	*turn*	2013-10-26 03:52	2013-10-26 04:00	1,00		1508
43	2	2013-10-26 04:00	2013-10-26 04:31	1,00	2013-10-25 04:03:00	1508
44	*turn*	2013-10-26 04:31	2013-10-26 04:37	1,00		1508
45	3	2013-10-26 04:37	2013-10-26 05:03	1,00	2013-10-25 04:39:50	1508
46	*turn*	2013-10-26 05:03	2013-10-26 05:07	1,00		1508
47	4	2013-10-26 05:07	2013-10-26 05:38	1,00	2013-10-25 05:13:00	1508
48	*turn*	2013-10-26 05:38	2013-10-26 05:42	1,00		1508
49	5	2013-10-26 05:42	2013-10-26 06:00	1,00	2013-10-25 05:47:30	1508

6.4. MUMM-AUMS

Throughout the campaign measurements were made with the AUMS system. At 2 locations water samples were taken with the in-built AUMS sampler (see above Table 6.4.2; 6.4.5). Water filtrations were carried out for the calibration of the turbidity sensor.

7. REMARKS

We warmly acknowledge the skilful and patient help of the master and crew of the *RV* Belgica.

Annex I

<u>Publications</u>

Van Lancker, V., Baeye, M., Francken, F., Legrand, S., Van den Eynde, D., Degrendele, K., De Mol, L., Roche, M. (2013). Impact evaluation of marine aggregate extraction through adaptive monitoring of bottom shear stress in bedform areas, *in*: Van Lancker, V. *et al.* (Ed.) (2013). *MARID 2013: Fourth International Conference on Marine and River Dune Dynamics. Bruges, Belgium, 15-17 April 2013. VLIZ Special Publication*, 65: pp. 271-276.

Van Lancker, V., Baeye, M., Francken, F., Van den Eynde, D., Evangelinos, D., De Mesel, I., Kerckhof, F., Van den Branden, R., & Naudts, L. (2014). Working together on innovative monitoring strategies: adapting to nature, huge demands and grand challenges. VLIZ Young Scientist Days. Brugge, 7/3/2014.

This Annex forms part of the report:
Van Lancker, V., Baeye, M., Fettweis, M., Francken, F. & Van den Eynde, D. (2014). Monitoring of the impact of the extraction of marine aggregates, in casu sand, in the zone of the Hinder Banks. Brussels, RBINS-OD Nature. Report <MOZ4-ZAGRI/X/VVL/201401/EN/SR01>.

Impact evaluation of marine aggregate extraction through adaptive monitoring of bottom shear stress in bedform areas

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Abstract

Dedicated monitoring programmes are needed for the evaluation of the effects of the exploitation of non-living resources on the territorial sea and the continental shelf. Related to physical impacts, hydrodynamics and sediment transport, together with sedimentological and morphological evolution, need investigation. Overall aim is to increase process and system knowledge of both natural and exploited areas, with a particular focus on the compliancy of extraction activities with respect to European Directives (e.g., European Marine Strategy Framework Directive and Habitat Directive). More specifically assessments are needed of changes in seafloor integrity and hydrographic conditions, two descriptors to define Good Environmental Status within Europe's Marine Strategy Framework Directive.

An important parameter is the bottom shear stress, with knowledge needed on both natural and anthropogenically-induced variability. Bottom shear stress measurements are used for the validation of numerical models, necessary for impact quantification in the far field. Extensive data-model integration is critical for adequate assessments of the status of the marine environment, a prerequisite for sustainable use of living, and non-living resources.

1. INTRODUCTION

Mineral and geological resources can be considered to be non-renewable on time-scales relevant for decision-makers. During the last decade, socio-economic demands for marine aggregate resources in the North-East Atlantic or OSPAR region have increased at an unprecedented pace. During the past few years, hundreds of millions m^3 of offshore sand and gravel have been extracted for coastal maintenance, harbour extensions and onshore industrial use. Future aggregate demands will be even higher. Increasing volumes of nourishment sand are needed as accelerating sea-level rise will leave our coastlines ever more vulnerable. In addition, vast quantities of sand and gravel will have to be extracted to realize the large infrastructural works that are the key components of many visions on coastal zone and offshore development.

Sustainable use of marine resources is required and is inevitably linked to good environmental status (GES) of the marine environment. This is the 2020 goal of the Marine Strategy Framework Directive (MSFD, 2008/56/EC). Furthermore, following the Habitat Directive (92/42/EEC), Natura 2000 sites have been implemented in the marine environment. Appropriate assessments are needed of any plan or project that may affect such sites.

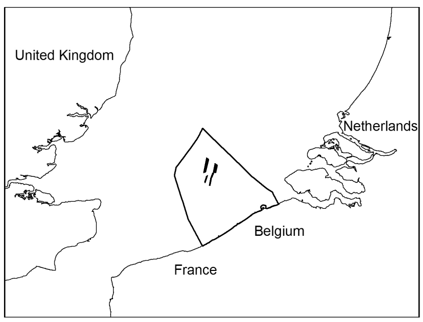
To allow monitoring of the evolution towards GES, a series of descriptors have been defined. Related to physico-chemical seabed attributes, descriptor 6 on seafloor integrity and descriptor 7 on hydrographic conditions are relevant in the context of aggregate extraction. GES for seafloor integrity refers to the structure and functions of the ecosystems that need safeguarding, without adversely affecting benthic ecosystems, whilst GES for hydrographic conditions means that permanent alteration of hydrographical conditions does not adversely affect marine ecosystems. 'Not adversely affected' can be interpreted as meaning that impacts may be occurring, but all impacts are sustainable such that natural levels of diversity, productivity, and ecosystem processes are not degraded (Rice et al. 2012). Hence, there is a clear need for methodologies and tools that allow quantification of natural and man-made changes that, in combination with geological knowledge bases, define sustainable exploitation thresholds. Only then assessments can be made whether or not recovery from perturbations will be rapid and secure, and whether changes will remain within the range of natural variation.

For the first cycle of MSFD (2012-2018), Belgium put forward some physical indicators that should allow monitoring progress towards good environmental status (Belgische Staat 2012).
(1) For seafloor integrity, they are related to particular sediment classes (cf. predominant habitat types), of which the spatial extent and distribution should remain equal, or at least within its margins of uncertainty (Van Lancker & van Heteren 2013, for a discussion). Furthermore, the ecological value of gravel beds is recognized and an indicator is proposed that stipulates that 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. This relates directly to exploitation-induced increases in turbidity that may lead to siltation in areas where those gravel beds occur.
(2) Bottom shear stress is chosen as an indicator to assess changes in hydrographic conditions. Using validated mathematical models, it is calculated over a 14-days spring-neap tidal cycle. 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; (iii) 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.
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 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).

This paper outlines the monitoring programme that should allow quantifying the effects of marine aggregrate extraction and evaluating the compliancy with respect to European Directives. The natural dynamics of the seabed, and of its bedforms in particular, complicate the debate. The monitoring programme has started in 2013 with pre-investigations in 2012.

2. STUDY AREA

Over a 10-yrs period intensive extraction of marine aggregates (up to 2.9 million m³ over 3 months) is allowed on the Hinder Banks, a sandbank complex located 40 km offshore in the Belgian part of the North Sea (BPNS). Depths are from 5 m to 30 m (Fig. 1). The sandbanks 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. Such intensive extraction activities are new practice in the BPNS, for which the environmental impact is yet to be determined. Furthermore, a Habitat Directive Area is present at a minimum of 2.5 km from the southernmost exploitation sectors. In this area, highest biodiversity is found in the troughs of barchans dunes (Houziaux et al. 2008).



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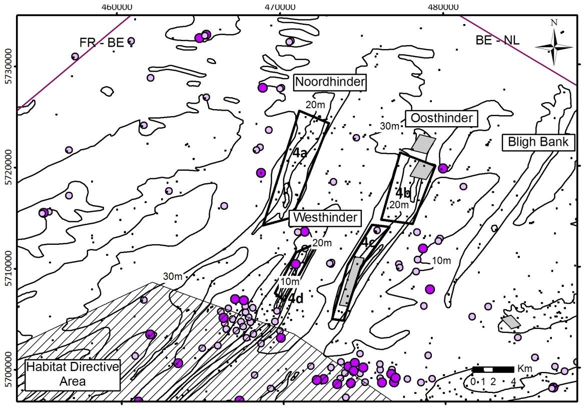

b

Figure 1. The Belgian part of the North Sea (a) and the area of the Hinder Banks (b), where intensive marine aggregate extraction is allowed in 4 sectors (black polygons). A Habitat Directive Area is present at a minimum of 2.5 km from the southernmost sectors. The size of the dots represents relative amounts of gravel with a minimum of 20 %. Borders with France (FR-BE) and the Netherlands (BE-NL) are indicated. In the grey shaded areas repetitive multibeam recordings.

3. MONITORING PROGRAMME

The monitoring programme is steered towards the testing of impact hypotheses, that are based on 30-yrs of extraction practices and its related research on the effects (Van Lancker et al. 2010, for an overview):

(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) (i.e., no change of sediment transport pathways); (6) Cumulative impacts with other sectors (e.g., fisheries) are minimal; and (7) Large-scale extraction does not lead to changes in wave energy dissipation that impact on more coastwards occurring habitats.

A tiered approach is proposed consisting of in-situ measurements and modelling. Critical is to assess potential changes in hydrographic conditions, as a consequence of multiple seabed perturbations (e.g., depressions) and their interactions. In short, current measurements along transects are needed to depict spatial variability over the sandbank areas, in combination with quantification of turbidity to assess changes due to the release of fines throughout the extraction process. Consequently, insight is needed in the dispersion of the fines and the probability of siltation in the nearby Habitat Directive area.

3.1 In-situ measurements

Three campaigns a year are aimed at and include: (1) Transect-based measurements (Fig. 2) of the full three-dimensional current velocity and direction, together with turbidity based on the acoustic backscatter over 13-hrs cycles (hull-mounted acoustic Doppler current profiler). (2) Very-high resolution acoustic measurements (Kongsberg-Simrad EM3002 multibeam, MBES) to obtain depth, backscatter, and water column data. Repetitive MBES measurements allow identifying erosion and/or deposition areas, estimating bedload transport pathways and magnitude from the asymmetry and rate from the migration of sand dunes, and assessing seabed sediment changes. (3) Water column measurements at fixed stations, over 13 hrs windows, to study temporal variations in salinity, temperature and depth (CTD), turbidity (optical backscatter sensor, OBS), and particle size distributions (Sequoia type C 100 X Laser In-Situ Scattering and Transmissometry, LISST). Water samples are taken for calibration of the OBS measurements.

To investigate near-bottom processes, it is envisaged to use a benthic tripod, instrumented with sensors dedicated to the measurement of currents, using ADP (Acoustic Doppler Profiler) and ADV (Acoustic Doppler Velocimeter) instruments, and turbidity (OBS). Bottom shear stress will be calculated (Francken & Van den Eynde 2010). At least, recordings of 14 days spring/neap tidal cycles are aimed at.

Seabed sediment samples are taken in function of increasing the reliability of sediment maps that serve as input to sediment transport models (e.g., bottom roughness). Changes in seabed sediment samples (e.g., siltation) are evaluated.

Optimal positions of the in-situ measurements are based on the results of the acoustic measurements (ADCP and MBES), and model results.

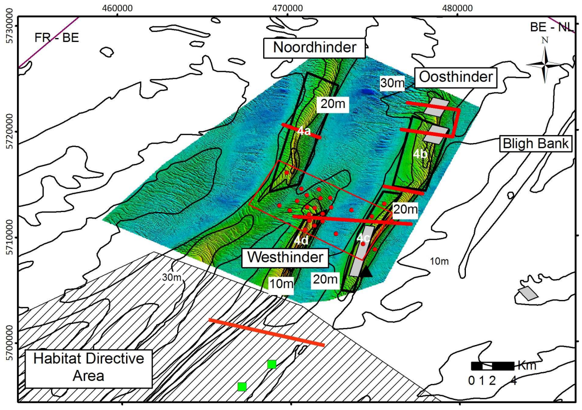

Figure 2. Sandbanks and troughs in the area of the Hinder Banks. Cross-sectional lines show the locations of ADCP profiling. Along the transects, water sampling and vertical profiling is performed. Repetitive MBES measurements are performed in the grey zones and within the rectangle covering the central zone of the Hinder Banks, together with sediment samples. The triangle indicates the position of longer-term measurements of sediment processes. Small rectangles in the Habitat Directive area are the locations of ecologically valuable gravel beds. Background bathymetry: FPS Economy, Self-Employed and Energy.

3.2 Quantitative model validation

Measurements will feed into numerical models (250 m x 250 m grid resolution) for conducting impact assessments under various scenarios of extraction activities.

Hydrodynamic models (OPTOS-BCZ, Luyten 2010), driving sediment transport and advection-diffusion models, need validation to allow quantification of their accuracy, critical to detect changes in time. Statistical analyses of the differences between model results and observations will be executed.

Sediment transport models (MU-SEDIM, Van den Eynde et al. 2010) need refinement: e.g., bottom shear stress calculated with the numerical model, will be compared with the bottom shear stress, derived from the ADV and ADP measurements (see above). An adjustment of the modelled shear stress to the observed shear stresses will be executed, by fitting the bottom roughness. Using all available data, an analysis of the variability of the resulting bottom roughness, as a function, amongst others, of grain-size distribution, will be executed. Furthermore the predicted sediment transport magnitude and directions will be compared to the sediment transport estimates, derived from sand dune migrations and asymmetries.

Advection-diffusion sediment transport models (MU-STM, Fettweis & Van den Eynde 2003; Van den Eynde 2004) will be refined allowing quantifying erosion and deposition of fine-grained material and (fine) sand in the water column. Results will be compared with the measurements and observations along areas where the probability of settling of finer sediments is highest. The significance of increases in turbidity will be determined from statistical analyses of the longer time series of turbidity (from benthic lander).

4. DISCUSSION

As stated in the introduction, the monitoring programme should allow quantifying the impacts of marine aggregate extraction and evaluating its compliancy with European Directives. The latter is relatively new and the monitoring requires extensive testing of the effectiveness and sensitivity of the indicators that should allow assessing progress towards good environmental status. For assessing changes in hydrographic conditions, the ranges in calculated bottom shear stress will identify whether or not an impact should be further evaluated. If this is the case, it is still acceptable as long as the impacted area remains within a certain buffer. For the exploitation in the Hinder Banks region this buffer is indicated in Fig. 3. Clearly, the area of impact can have significant dimensions. Following this concept, no impact is allowed in the Habitat Directive area, just south of the exploitation zone. Whether or not this indicator would be an early warning, preventing adverse effects on the ecosystem, remains to be investigated.

Furthermore, the influence of varying bedform properties and dynamics is not clear yet.

Calculation of bottom shear stresses is far more complicated in bedform areas, and can potentially not be modelled with conventional techniques. The dynamics of large bedforms and the relation with ecological functions they can provide is poorly studied. According to their setting, dimensions and morphology, some of them are more effective in trapping fine sediments (Van Lancker et al. this volume). In many cases such areas host a richer biodiversity. Whether or not exploitation-induced siltation will adversely affect the ecosystem requires further investigation and debate.

Hence, monitoring programmes should be adaptive, with approaches that are adjustable following external input and new insights. It is a learning process with the aim of reducing uncertainties and allowing calculation of risks when certain environmental goals are not reached (Laane et al. 2012). Extensive data-model integration is needed, that should allow showing the societal relevance of the measures that are proposed to monitor progress towards good environmental status of the marine environment.

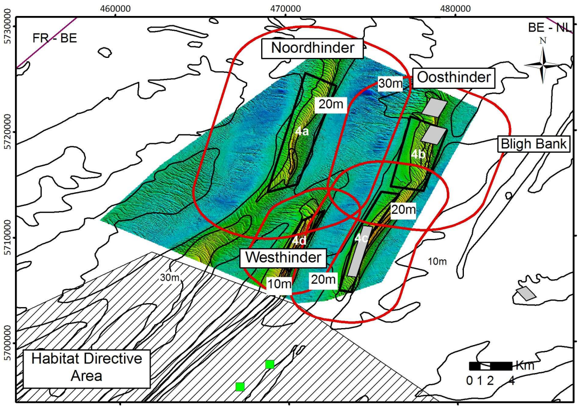

Figure 3. Buffer of acceptable change in bottom shear stress in the Hinder Bank region where marine aggregate extraction is allowed in 4 sectors. Calculations according to Belgische Staat (2012).

5. CONCLUSIONS

A monitoring programme is proposed that should allow quantifying the impacts of marine aggregate extraction and evaluating its compliancy with European Directives. Most importantly, monitoring should allow assessing progress towards good environmental status. This is relatively new and requires extensive testing of effectiveness and sensitivity of indicators. One of the indicators is bottom shear stress and should allow evaluating changes in hydrographic conditions due to human impact. It is stipulated that extensive data-model integration is needed for adequate assessments of the status of the marine environment, a prerequisite for sustainable use of living and non-living resources.

6. ACKNOWLEDGMENT

The evaluation of the effects of marine aggregate extraction forms part of a continuous monitoring programme, paid from the revenues of extraction activities (ZAGRI). The Flemish Authorities, Agency for Maritime Services and Coast fund the dedicated research in the area of the Hinder Banks.

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Working together on innovative monitoring strategies: adapting to nature, huge demands and grand challenges

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Socio-economic demands for marine aggregate resources have increased at an unprecedented pace. For the Atlantic region, hundreds of millions m³ of offshore sand and gravel have been extracted for coastal maintenance, harbour extensions and onshore industrial use. Still, we are facing grand challenges, for which aggregate demands will be even higher. First, increasing volumes of nourishment sand are needed as accelerating sea-level rise will leave our coastlines ever more vulnerable. Secondly, vast quantities of sand and gravel will have to be extracted to realize the large infrastructural works that are the key components of many visions on coastal zone and offshore development. Meanwhile, nature protection is increasing as well, and appropriate assessments are needed of the environmental impacts.

The far offshore Hinder Banks are targeted for exploitation of huge quantities of sand, mainly for coastal defence works. Here, up to to 2.9 million m³ can be taken over 3 months, with a maximum of 35 million m³ over a period of 10 years. Large vessels can be used extracting 12500 m³ per run. Present-day yearly extraction levels recently surpassed 3 million m³, the majority of which was extracted with vessels of 1500 m³. South of the Hinder Banks concession, a Habitat Directive area is present, hosting ecologically valuable gravel beds. For these, it is critical to assess the effect of multiple and frequent depositions from dredging-induced sediment plumes.

How will nature react?
We anticipated with a monitoring strategy, tailored for assessing the importance and extent of perturbations that are created by the extraction activities. Our monitoring design is focussed on hydrodynamics and sediment transport with feedback loops between both modelling and field studies. Main targets are assessing changes in seafloor integrity and hydrographic conditions, two key descriptors of marine environmental status within Europe's Marine Strategy Framework Directive.

State-of-the-art instrumentation (from RV Belgica) is used, to measure the 3D current structure, turbidity, depth, backscatter and particle size of the material in the water column, both in-situ and whilst sailing transects over the sandbanks. In the Habitat Directive Area, gravel bed integrity (i.e., epifauna; sand/gravel ratio; patchiness) is measured as well. Most innovatively, an autonomous underwater vehicle was deployed (Wave Glider, Liquid Robotics), resulting in 24 days of current and turbidity data.

From a first data-model integration, and analyses against hydro-meteorological databases, main results show: (1) high spatial and temporal variability of turbidity, unexpected in the so-called 'clear' waters of the Hinder Banks; (2) important resuspension by waves, regardless the area being considered as 'deep'; (3) spreading and deposition of sediment plumes; and (4) competitiveness of ebb and flood, meaning that the potential for sediment deposition to the south is high. Plume dispersion mechanisms and pathways are now estimated and modelled.

Data will be integrated with results from the morphological and biological monitoring, respectively carried out by the Continental Shelf Service of FPS Economy and the Institute for Agricultural and Fisheries Research. Together, temporal and spatial patterns, scale and processes can be resolved and interlinked with pressures and system vulnerability.

❍ COLOPHON

This report was issued in January 2014

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