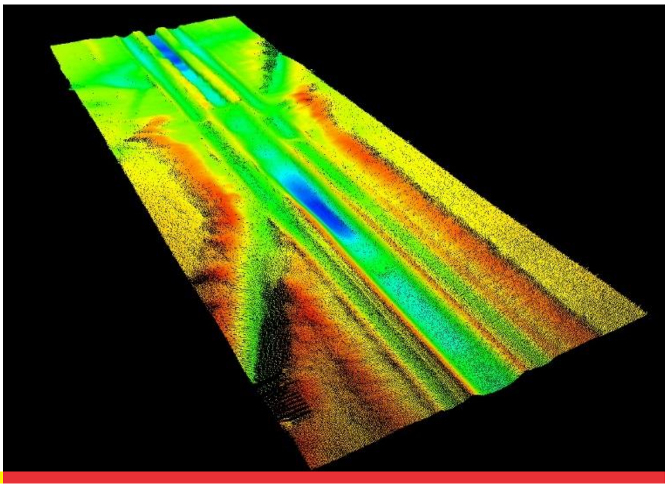
HYDROGRAPHIC SURVEY REPORT

103628-ENN-MMT-SUR-REP-SURVECR
REVISION 02 | CLIENT REVIEW
OCTOBER 2020

ENERGINET



THOR OFFSHORE WIND FARM EXPORT CABLE ROUTE

DANISH NORTH SEA
AUGUST-SEPTEMBER 2020

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MMT

EXECUTIVE SUMMARY

THOR OFFSHORE WIND FARM AND EXPORT CABLE ROUTES OVERVIEW

Energinet are developing the proposed Thor Offshore Wind Farm in the Danish sector of the North Sea (Figure 2). MMT have been contracted to provide hydrographical surveys covering the Offshore Wind Farm and two export cable route options to the landfall location in Jutland, Denmark. The OWF survey area is referred to as OWF, while the export cable route surveys are referred to as ECR. This report covers the results of the surface difference comparison for the two export cable route survey corridors.

An overview image of routes R2 and R3 are presented in Figure 1.

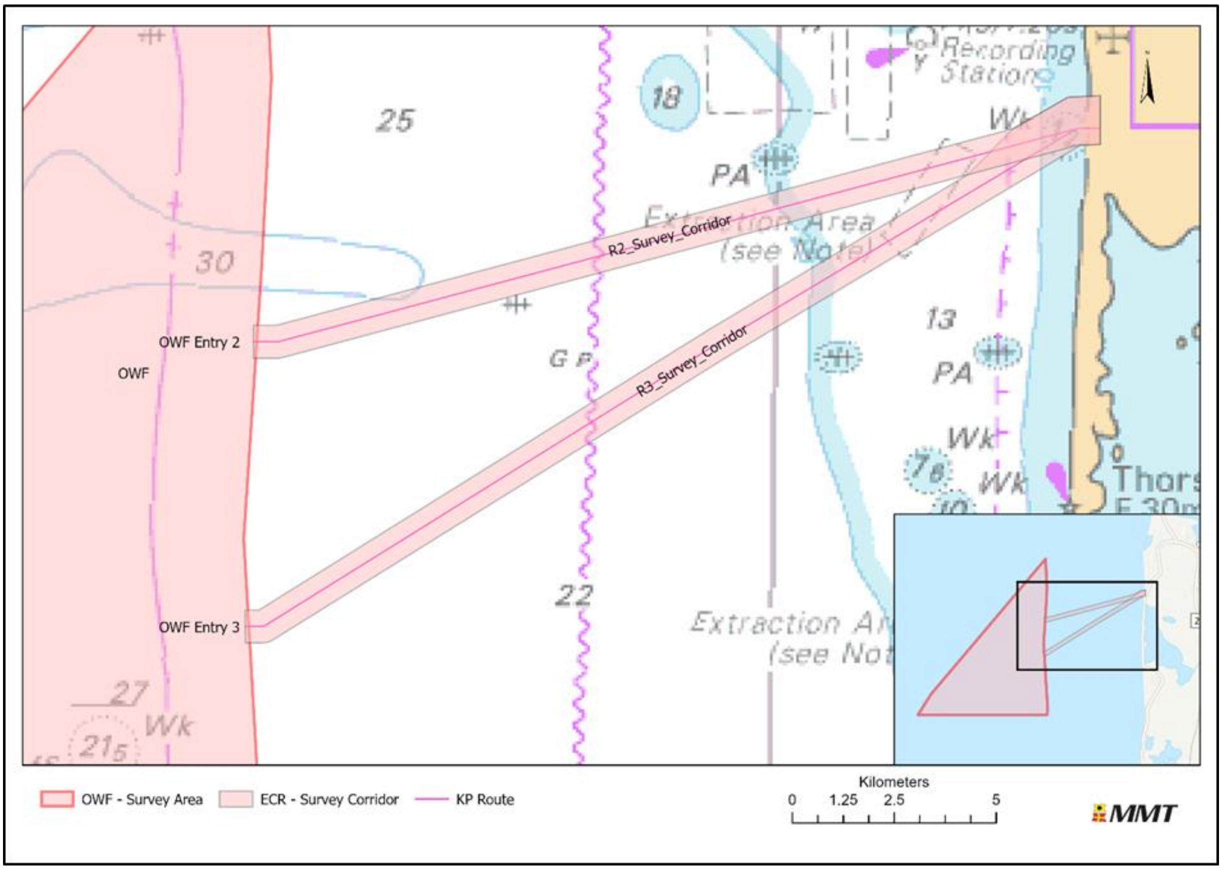

Figure 1 Overview of Export Cable Routes R2 and R3.

PRINCIPAL ROUTE POINTS – ROUTE 2					
Geodetic Datum & Projection: ETRS89 UTM Zone 32N (EPSG 25832)					
Point	KP	Latitude (dd.dddd)	Longitude (dd.dddd)	Easting (m)	Northing (m)
Start: Landfall 1	0.000	56.4571	8.1281	446263	6257296
End: OWF Entry 2	21.444	56.4072	7.7928	425504	6252058

PRINCIPAL ROUTE POINTS – ROUTE 3					
Geodetic Datum & Projection: ETRS89 UTM Zone 32N (EPSG 25832)					
Point	KP	Latitude (dd.dddd)	Longitude (dd.dddd)	Easting (m)	Northing (m)
Start: Landfall 1	0.000	56.4549	8.1129	446263	6257296
End: OWF Entry 3	24.400	56.3444	7.7915	425304	6245071

SURFACE DIFFERENCE RESULTS

In the nearshore zone where the R2 and R3 survey corridors overlap the seabed was found to be highly dynamic. The maximum positive (depositional) and negative (erosional) depth changes for the entire ECR survey area were found here, +2.22 m and -2.71 m.

These depth changes relate to the increase in depth of a channel that runs parallel to the shoreline between KP 0.485 and KP 0.680 (relative to the R2 route) and a shoreward shift in position of a bar feature between KP 0.680 and KP 0.790 (relative to the R2 route). The scoured channel in the nearshore area exposed a wreck that had only been partially observed in the 2019 bathymetry data.

The surface difference results showed that areas of mobile seabed were present along the offshore parts of both R2 and R3 with changes in depth typically within +/-0.5 m according to depth profiles extracted from the cable route positions. Measurements of bedform migration suggested that transport was generally in a north-northeasterly direction with orientations ranging between 007° and 025°. Measurements of horizontal displacement range between 15 m and 50 m since the 2019 survey was conducted and the range of depth change in the offshore parts of the survey corridors was typically within +/-1.0 m.

The direction of movement is derived from the displacement of features that can be correlated between profiles, such as crests and troughs that have similar forms, rather than interpreted from the morphology of the bedform itself.

A qualitative comparison of both routes suggested that R2 exhibited a greater degree of mobility. There are extensive sections of R3 where depth changes were within the vertical uncertainty of the MBES data (+/-0.15 m). This is offset however by an extensive area of mobile seabed between KP 4.0 and KP 8.0 of R3. This mobile zone extends into R2 but only intersects the route in two sections between KP 3.25 and KP 3.80 and KP 4.80 and KP 5.50.

REVISION HISTORY

REVISION	DATE	STATUS	CHECK	APPROVAL	CLIENT APPROVAL
02	2020-10-13	Issue for Client Review	DJO	KG	
01	2020-10-11	Issue for Internal Review	DJO	KG	

REVISION LOG

DATE	SECTION	CHANGE

DOCUMENT CONTROL

RESPONSIBILITY	POSITION	NAME
Content	Senior Data Processor	Andrew Stanley/Chris Bulford
Content, Check	Project Report Coordinator	David Oakley/Darryl Pickworth
Check	Document Controller	Anders Eriksson
Approval	Project Manager	Karin Gunnesson

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ABBREVIATIONS AND DEFINITIONS

CAD	Computer Aided Design
DPR	Daily Progress Report
DTM	Digital Terrain Model
DTU	Technical University of Denmark
EEZ	Exclusive Economic Zone
EPSG	European Petroleum Survey Group
ETRS	European Terrestrial Reference System
GIS	Geographic Information System
GNSS	Global Navigation Satellite Systems
GRS	Geodetic Reference System
IHO	International Hydrographic Organization
INS	Inertial Navigation System
ISO	International Organization for Standardization
ITRF	International Terrestrial Reference Frame
KP	Kilometre Post
M/V	Motorised Vessel
MBES	Multibeam Echo Sounder
MSL	Mean Sea Level
OWF	Offshore Wind Farm
PPS	Pulse Per Second
QC	Quality Control
RPL	Route Position List
RTK	Real-time Kinematic
SOW	Scope of Work
SVS	Sound Velocity Sensor
TPU	Total Propagated Uncertainty
TVU	Total Vertical Uncertainty
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator

1 | INTRODUCTION

1.1 | PROJECT INFORMATION

Energinet are developing the proposed Thor Offshore Wind Farm in the Danish sector of the North Sea. MMT have been contracted to provide a comparative hydrographic survey covering the Offshore Wind Farm (OWF) and two export cable route (ECR) options connecting the OWF to the landfall location near Søndeby Gårde in Jutland, Denmark.

This report covers two export cable route survey corridors including the common nearshore area at the landfall location. A summary of project details is presented in Table 1.

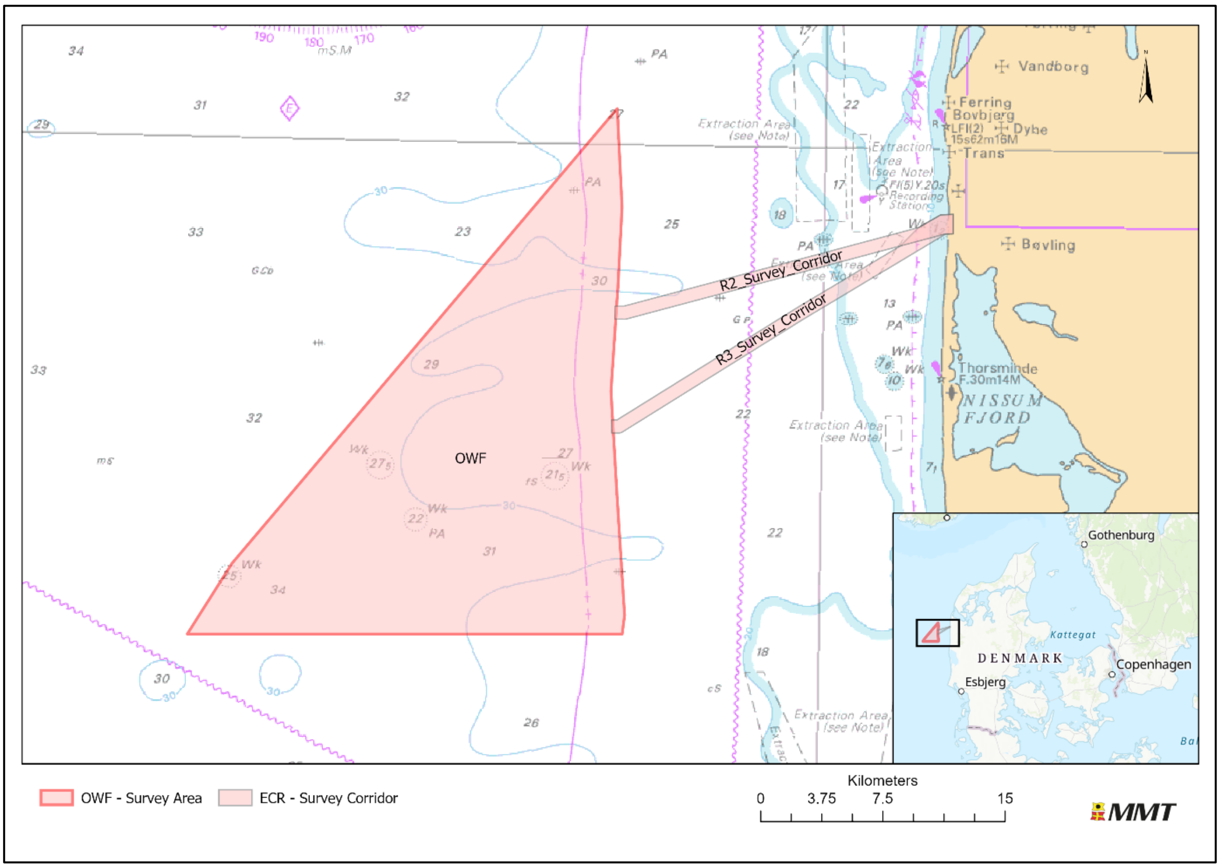

Figure 2 Thor Offshore Wind Farm and Export Cable Routes area overview.

Table 1 Project details.

CLIENT:	Energinet
PROJECT:	Thor Hydrographic Survey
MMT SWEDEN AB (MMT) PROJECT NUMBER:	103628
SURVEY TYPE:	Hydrographic export cable route survey
AREA:	Danish North Sea
SURVEY PERIOD:	July – September 2020
SURVEY VESSELS:	M/V Guardian / M/V Plasticbeam
MMT PROJECT MANAGER:	Karin Gunnesson
CLIENT PROJECT MANAGER:	Jens Colberg-Larsen

1.2| SURVEY INFORMATION – ECR

The ECR work scope comprises two tasks including:

- Project Management and Administration
- Bathymetric surveys

The export cable route surveys cover two export routes, numbered 2 and 3, from Jutland, Denmark to the proposed Thor Offshore Wind Farm location in the Danish sector of the North Sea. This also consists of a nearshore survey where both export cable route options make landfall north of the coastal town of Thorsminde (Figure 2). Export route 2 runs from the Landfall 1 location to the OWF Entry 2 point. Export route 3 runs from the Landfall 1 location to the OWF Entry 3 point. Route extents are shown in Table 2.

The nearshore (<-10 m water depth) bathymetric survey was conducted by the M/V Plasticbeam and the offshore bathymetric survey was completed by the M/V Guardian. M/V Plasticbeam assisted with additional coverage in the offshore part of the ECR. Both survey operations comprised solely of multibeam echo sounder (MBES) data.

This report covers the nearshore and export cable route survey works acquired by MMT.

Table 2 Export cable route extents.

Number	Start KP	End KP
Route 2	0.000	21.444
Route 3	0.000	24.401

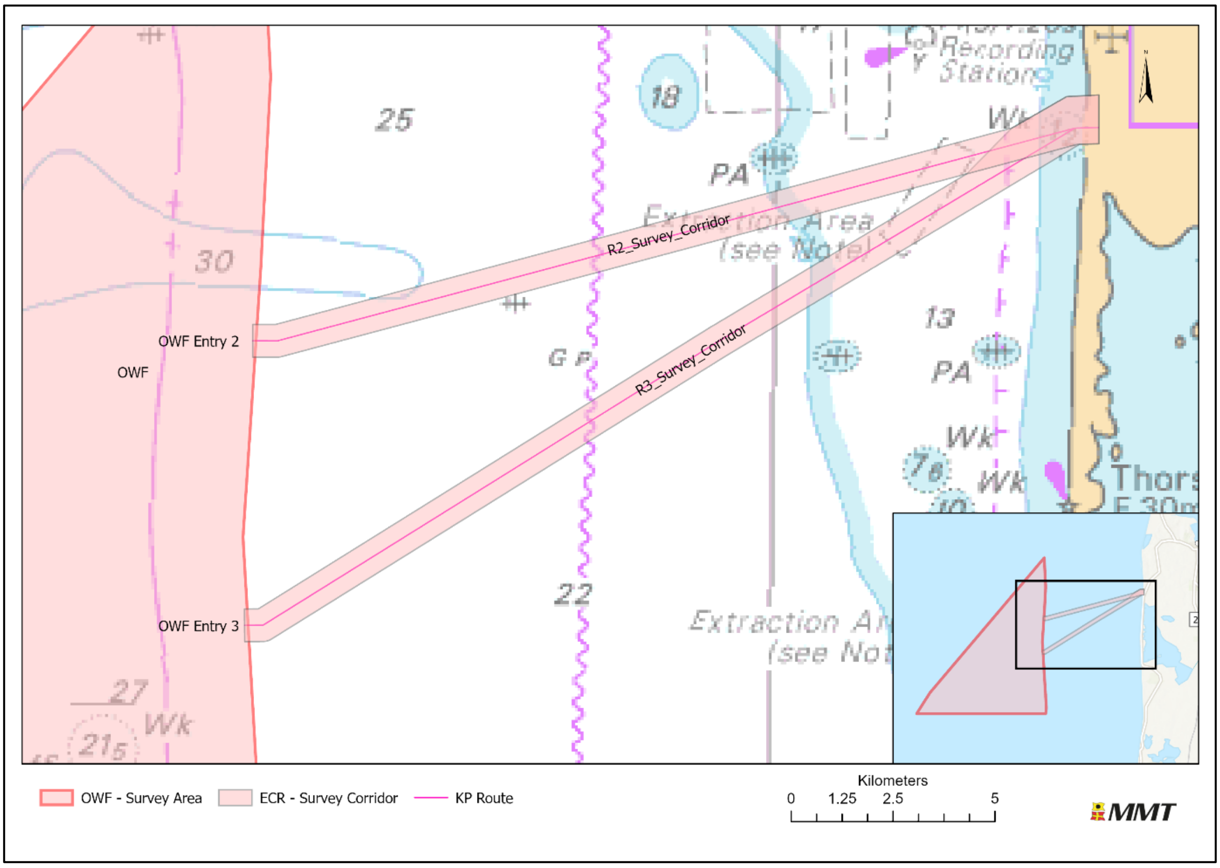

Figure 3 Overview of the Export Cable Routes.

1.3| SURVEY OBJECTIVES

The survey encompassed a bathymetric mapping through hull-mounted Multi-Beam Echo-Sounding with coverage of the OWF area (OWF) and the proposed export cable routes R2 and R3 (ECR). A spatial resolution of 4 (four) soundings per square meter was achieved.

The results of the bathymetric mapping are to be processed, interpreted and compared with the bathymetric datasets from 2019 with the purpose of investigating the dynamic nature of the seabed. This is in the form of this report as well as charts and digital deliverables.

1.4| SCOPE OF WORK

For the ECR the following work packages are included in the scope of work (SOW):

- Work Package A – Offshore Cable Route Survey > 10 m Water Depth
  A full hydrographic seabed survey of the entire cable route corridor to the 10 m water-line to map bathymetry.

- Work Package B – Nearshore and Landfall Survey < 10 m Water Depth
  A full hydrographic seabed survey of the entire cable route corridor from the 10 m water-line to landfall to map bathymetry.

- Work Package C – Reporting and data delivery
  The results of the investigations shall be processed, interpreted and supplied as a number of reports, charts and a set of digital deliverables.

1.5| PURPOSE OF DOCUMENT

This report details the interpretation of the hydrographic survey results from the landfall and offshore wind farm export cable route surveys.

The report summarises the results of the surface difference analysis that was performed on the 2020 and 2019 bathymetry data.

A separate report includes the results of the Offshore Wind Farm survey. A full list of reports is given in Table 3 (Reference Documents).

1.6| REPORT STRUCTURE

The results from the ECR survey campaign are presented in two separate reports.

- Operations Report (single report for OWF and ECR operations)
- Hydrographic Survey Report (this report)

The Hydrographic Survey Report, includes an alignment chart series and north up charts. A full chart list is provided within Appendix B|

1.6.1| HYDROGRAPHIC SURVEY REPORT

This report presents the ECR Hydrographic Survey results.

Attached to the report are the following appendices:

- Appendix A| Route Position List (RPL)
- Appendix B| Chart List
- Appendix C| Profile Graphs

1.6.2| CHARTS

The MMT Charts describe and illustrate the results from the survey. The charts include two sets of North Up chart with a scale of 1:10 000.

The charts contain background data (existing infrastructure, EEZ, 12 nautical mile zone and wreck database) alongside survey results.

A list of all produced charts is presented in Appendix B|.

NORTH UP CHARTS

The two sets of North up charts, in A3 Pdf booklet format, show the following:

- **Bathymetry** presented as a shaded relief colour image, overlaid with contour lines (1 m (minor) and 5 m (major, with depth labels));
- **Surface difference results** presented as a colour image with variable colour intervals (step increasing with increasing displacement either side of 0.0 m).

1.7| REFERENCE DOCUMENTS

The documents used as references to this report are presented in Table 3.

Table 3 Reference documents

Document Number	Title	Author
103628-ENN-MMT-MAC-REP-PLASTICB	Mobilisation and Calibration Report – Plasticbeam	MMT
103628-ENN-MMT-MAC-REP-GUARDIAN	Mobilisation and Calibration Report – Guardian	MMT
103628-ENN-MMT-SUR-REP-OPEREP	Operations Report (OWF & ECR)	MMT
103628-ENN-MMT-SUR-REP-SURVOWF	Hydrographic Survey Report Thor Offshore Wind Farm	MMT
103628-ENN-MMT-SUR-REP-SURVECR	Hydrographic Survey Report Export Cable Route	MMT

1.8| CORRIDOR LINE PLAN

The ECR survey line spacing and minimum parameters are detailed in Table 4.

A breakdown of the survey lines is provided in Table 5.

Table 4 Survey line parameters.

Geophysical Survey Settings	Scope
Route 2	Length 21.444 km
Route 3	Length 24.401 km
Line spacing offshore geophysical Main Lines	50 m
Line spacing nearshore geophysical Main Lines	15 m

Table 5 Survey line breakdown.

Survey Line Breakdown	Scope
Offshore geophysical Main Lines	760.5 km/1162 Lines
Nearshore geophysical Main Lines	95.5 km/212 Lines

2| SURVEY PARAMETERS

2.1| GEODETIC DATUM AND GRID COORDINATE SYSTEM

2.1.1| ACQUISITION

The geodetic datum used for survey equipment during acquisition is presented in Table 6.

Table 6 Geodetic parameters used during acquisition.

HORIZONTAL DATUM: ITRF2014	
Datum	ITRF2014
ESPG Datum code	1165
Spheroid	GRS80
Semi-major axis	6 378 137.000m
Semi-minor axis	6 356 752.314m
Inverse Flattening (1/f)	298.257222101

2.1.2| PROCESSING

The geodetic datum used during processing and reporting is presented in Table 7.

Table 7 Geodetic parameters used during processing.

HORIZONTAL DATUM: ETRS89	
Datum	ETRS89
ESPG Datum Code	4936
Spheroid	GRS80
Semi-major axis	6 378 137.000m
Semi-minor axis	6 356 752.314m
Inverse Flattening (1/f)	298.257222101

2.1.3 | TRANSFORMATION PARAMETERS

The transformation parameters used to convert from acquisition datum (ITRF2014) to processing/reporting datum (ETRS89) are presented in Table 8.

Table 8 Transformation parameters.

DATUM SHIFT FROM ITRF2014 TO ETRS89 (RIGHT-HANDED CONVENTION FOR ROTATION - COORDINATE FRAME ROTATION)	
PARAMETERS	**EPOCH 2019.5**
Shift dX (m)	+0.099440
Shift dY (m)	+0.064160
Shift dZ (m)	-0.120400
Rotation rX (“)	-0.00313900
Rotation rY (“)	-0.01334000
Rotation rZ (“)	+0.02369500
Scale Factor (ppm)	+0.0030100000

Table 9 Test coordinate for datum shift.

UTM Zone	Datum	Easting (m)	Northing (m)	Latitude	Longitude	Location
32	ITRF 2014	399264.77	6232328.08	56° 13' 30,608" N	7° 22' 31,004" E	Point 1
	ETRS 89	399264.28	6232327.54	56° 13' 30.590" N	7° 22' 30.975" E	
32	ITRF 2014	425649.00	6264590.00	56° 31' 11.332" N	7° 47' 29.609" E	Point 2
	ETRS 89	425648.51	6264589.4654	56° 31' 11.314" N	7° 47' 29.581" E	
32	ITRF 2014	446353.50	6233387.15	56° 14' 32.370" N	8° 8' 3.841" E	Point 3
	ETRS 89	446353.01	6233386.6169	56° 14' 32.352" N	8° 8' 3.813" E	

2.1.4 | PROJECTION PARAMETERS

The projection parameters used for processing and reporting are presented in Table 10.

Table 10 Projection parameters.

PROJECTION PARAMETERS	
Projection	UTM
Zone	32 N
Central Meridian	09° 00’ 00’’ E
Latitude origin	0
False Northing	0 m
False Easting	500 000 m
Central Scale Factor	0.9996
Units	metres

2.1.5| VERTICAL REFERENCE

The vertical reference parameters used for processing and reporting are presented in Table 11.

Table 11 Vertical reference.

VERTICAL REFERENCE PARAMETERS	
Vertical reference	MSL
Height model	DTU15

2.2| VERTICAL DATUM

Global navigation satellite system (GNSS) tide was used to reduce the bathymetry data to Mean Sea Level (MSL) the defined vertical reference level (Figure 4). The vertical datum for all depth and/or height measurements was MSL via DTU15 MSL Reduction from WGS84-based ellipsoid heights.

This tidal reduction methodology encompasses all vertical movement of the vessel, including tidal effect and vessel movement due to waves and currents. The short variations in height are identified as heave and the long variations as tide.

This methodology is very robust since it is not limited by the filter settings defined online and provides very good results in complicated mixed wave and swell patterns. The use of high-accuracy RTK positioning online means that there is no need to post-process the vessel navigation before it is applied onto the multibeam echo sounder (MBES) data.

The GNSS tide methodology has proven to be very accurate as it accounts for any changes in height caused by changes in atmospheric pressure, storm surge, squat, loading or any other effect not accounted for in a tidal prediction.

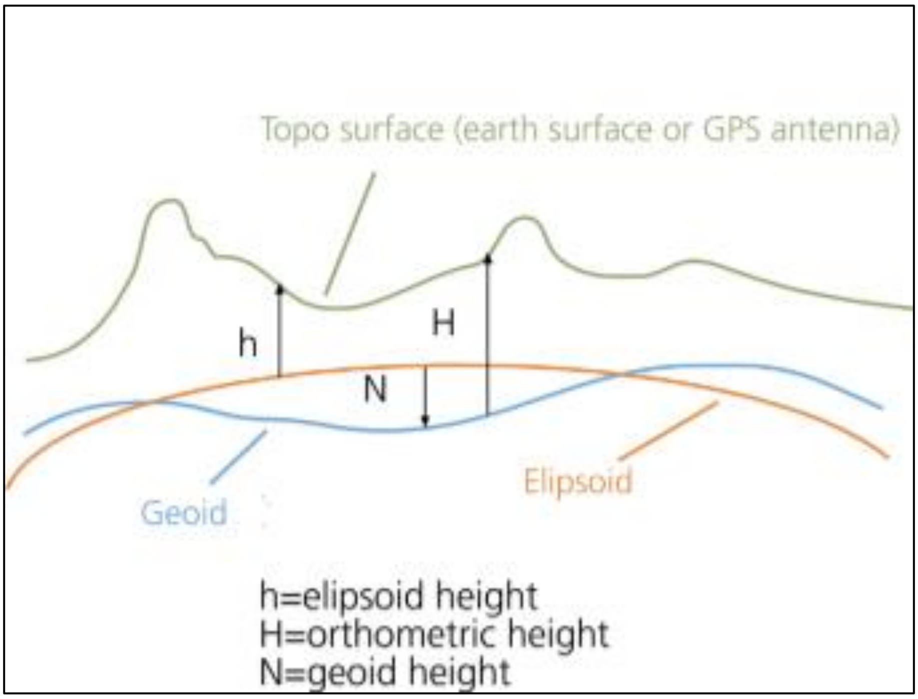

Figure 4 Overview of the relation between different vertical references.

2.3| TIME DATUM

Coordinated universal time (UTC) is used on all survey systems on board the vessel. The synchronisation of the vessels on board system is governed by the pulse per second (PPS) issued by the primary positioning system. All displays, overlays and logbooks are annotated in UTC as well as the daily progress report (DPR) that is referred to UTC.

2.4| KP PROTOCOL

For the export cable routes, the routes are based off the client supplied RPL REV04.

KP 0.000 is located at landfall and KP values increase towards the OWF survey area entry points.

KPs were calculated based upon the relevant UTM mapping projection zone and were at all times related to the selected route. The KP databases used, provided by the client were:

- REV04_LF1-ENTRY2_20190603_JCO – Route 2
- REV04_LF1-ENTRY3_20190603_JCO – Route 3

3| SURVEY VESSELS

3.1| M/V GUARDIAN

The M/V Guardian is a multipurpose vessel that is operated by MMT. All of the survey equipment is regularly calibrated, references to which are made within the MAC report where appropriate. The proposed project development area, offshore wind farm block and two proposed cable routes, off the coast of Jutland for Energinet was surveyed by M/V Guardian in water depths between -4 m and -35 m.

Figure 5 M/V Guardian

Table 12 Vessel-mounted equipment

INSTRUMENT	NAME
Primary Positioning System	Septentrio AsteRx-U Marine
Secondary Positioning System	C&C Technologies C-Nav3050 (C1/C2 corrections)
Primary Gyro and INS System	IxBlue Hydrins III
Survey Navigation System	QPS QINSy
Multibeam Echo Sounder (Medium to Shallow Water)	Reason Seabat T50-R
Sound velocity	MVP30 / AML Base X2 / Valeport MiniSVS

3.2| M/V PLASTICBEAM

The M/V Plasticbeam is a temporarily fitted hydrographical survey vessel, owned and operated by MMT. It operated in 0 m to -8 m water depth to undertake the near shore survey where the export cable route makes landfall near Søndeby Gårde on the west coast of Denmark.

Figure 6 M/V Plasticbeam

Table 13 Vessel-mounted equipment

INSTRUMENT	NAME
Primary Positioning and INS System	Applanix POS MV 320 with MarineStar G2 corrections
Sound Velocity Sensor	Valeport MiniSVS deck cast (S/N 35227)
Multibeam Echosounder	Norbit iWBMS
GPS positioning	Hemisphere GNSS S321 smart antenna kit

4| DATA PROCESSING AND INTERPRETATION METHODS

4.1| BATHYMETRY

The objective of the processing workflow is to create a Digital Terrain Model (DTM) that provides the most realistic representation of the seabed with the highest possible detail. The processing scheme for MBES data comprised two main scopes: horizontal and vertical levelling in order to homogenise the dataset and data cleaning in order to remove outliers.

The MBES data is initially brought into QPS Qimera to check that it has met the coverage and density requirements. The quality of the online RTK positioning solution (from the C-NAV system) was checked by examining the standard deviation of the sounding data and checking the gridded surfaces for tidal busts. Since the vessel used a high-accuracy online position the vertical reduction of the bathymetry data to the specified DTU15 MSL survey datum was performed in real-time.

In addition to the checking the standard deviation of the soundings, the quality of the position solution can be assessed by calculating the Total Horizontal Uncertainty (THU) and Total Vertical Uncertainty (TVU) within the dataset. These surfaces are generated in Qimera and are checked for deviations from the THU and TVU thresholds as specified by the client. This is discussed in further detail in Section 5.1|.

Due to shallow seabed in the nearshore zone of the ECR both Guardian and Plasticbeam were utilised to collect MBES data where the cable routes make landfall. The data from both vessels went through the same QC and cleaning processes upon arrival at the office. They were then combined in Qimera with additional checks to assure vertical alignment between the datasets.

Once the data has passed these checks it is ready to start the process of removing outlying soundings which can be undertaken within Qimera.

In the Qimera workflow an average surface is derived from the sounding data and from this it is possible to remove outliers that lie at a specified numerical distance from the surface, or by setting a standard deviation threshold. Manual cleaning can also be performed using 3D point editor tool to clean areas around features that would be liable to being removed by the automatic cleaning processes.

The work flow diagram for MBES processing is shown in Figure 7.

If the dataset then passes the QC check to project specifications the DTM is exported in ASCII XYZ format for delivery to the client and for further internal use. MMT use EIVA’s NaviModel software to generate products for charting, such as contours and shaded relief images. Bathymetric contours were generated from the 1 m DTM in combination with scaling factors applied to generalise the contours to ensure the charting legibility. The contour parameters used are shown in Figure 8 and an example of the exported contours presented over the DTM is shown in Figure 9. FME was also used to clip the higher resolution ASCII XYZ files into 1 km x 1 km tiles using the 2019 tile schema (Figure 10).

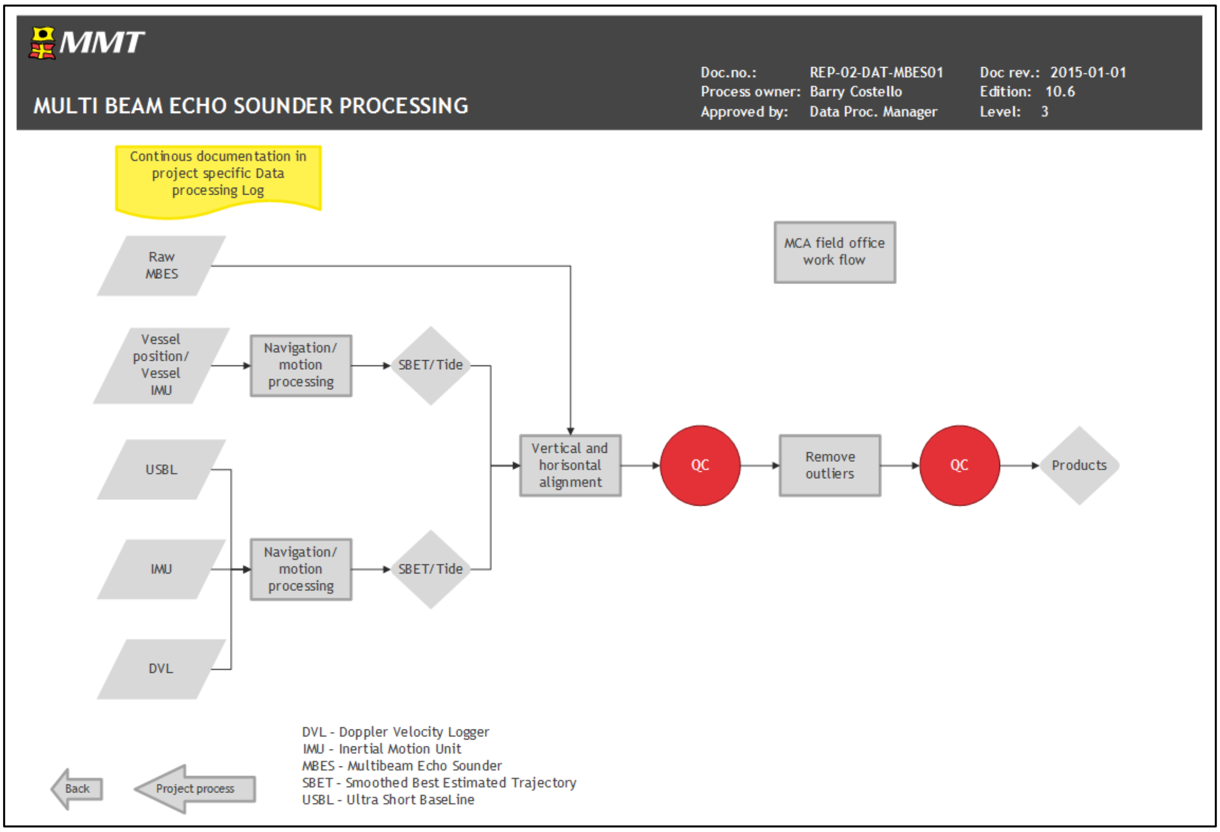

Figure 7 Workflow MBES processing.

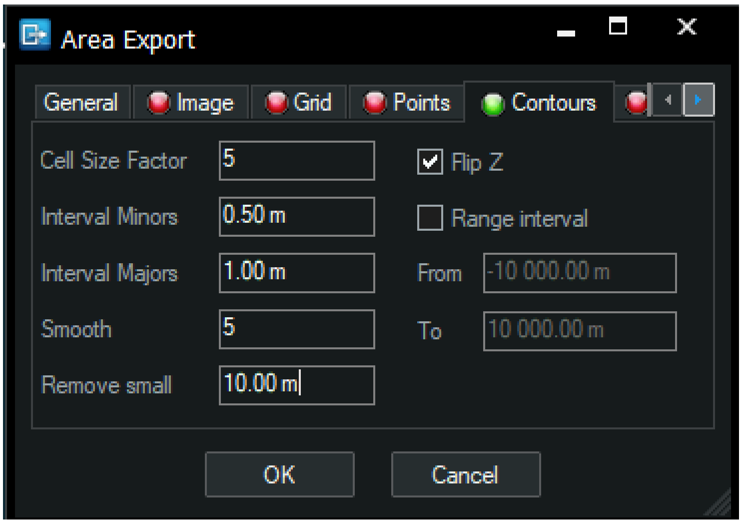

Figure 8 Contour export parameters for the ECR and OWF.

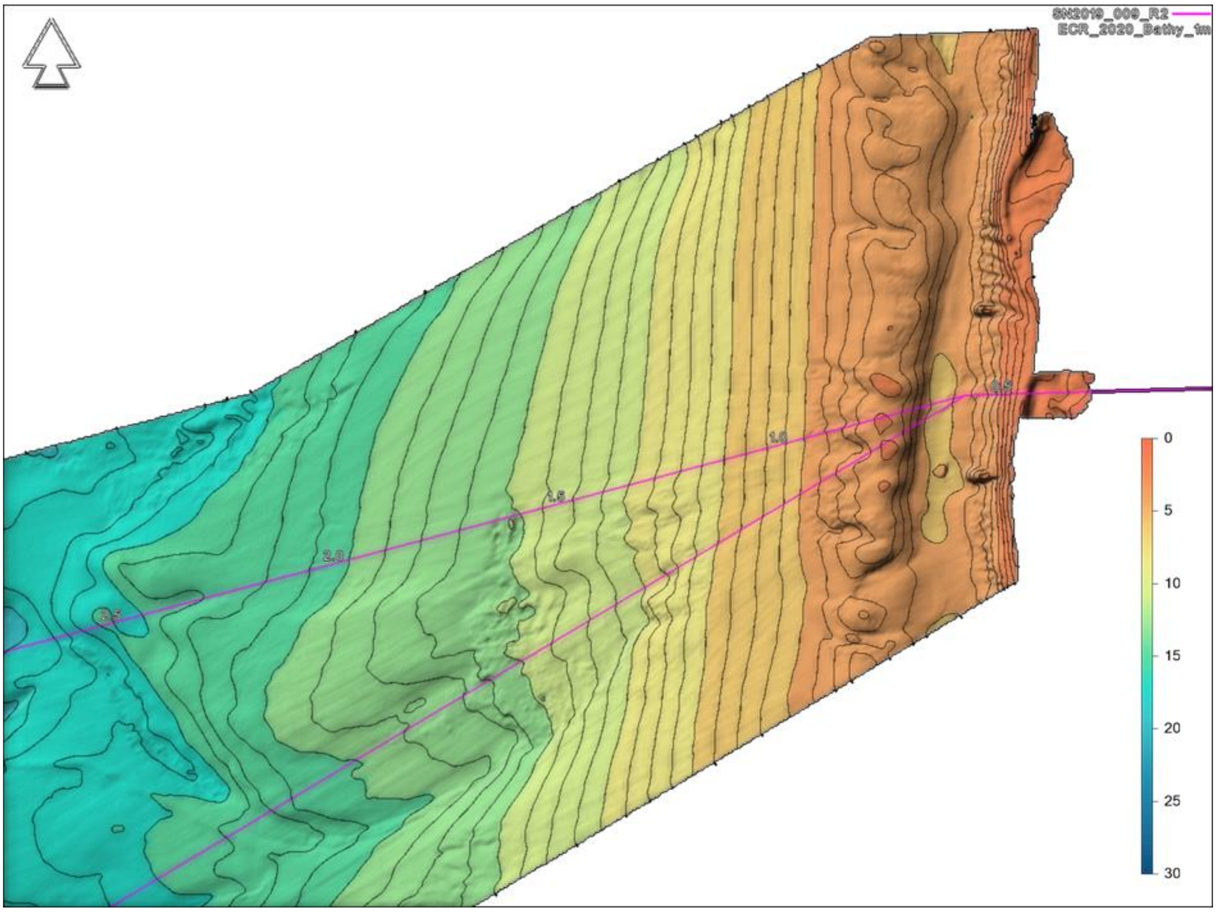

Figure 9 Example of exported contours with 50 cm interval in the nearshore zone of the ECR. Navimodel depth convention is positive down.

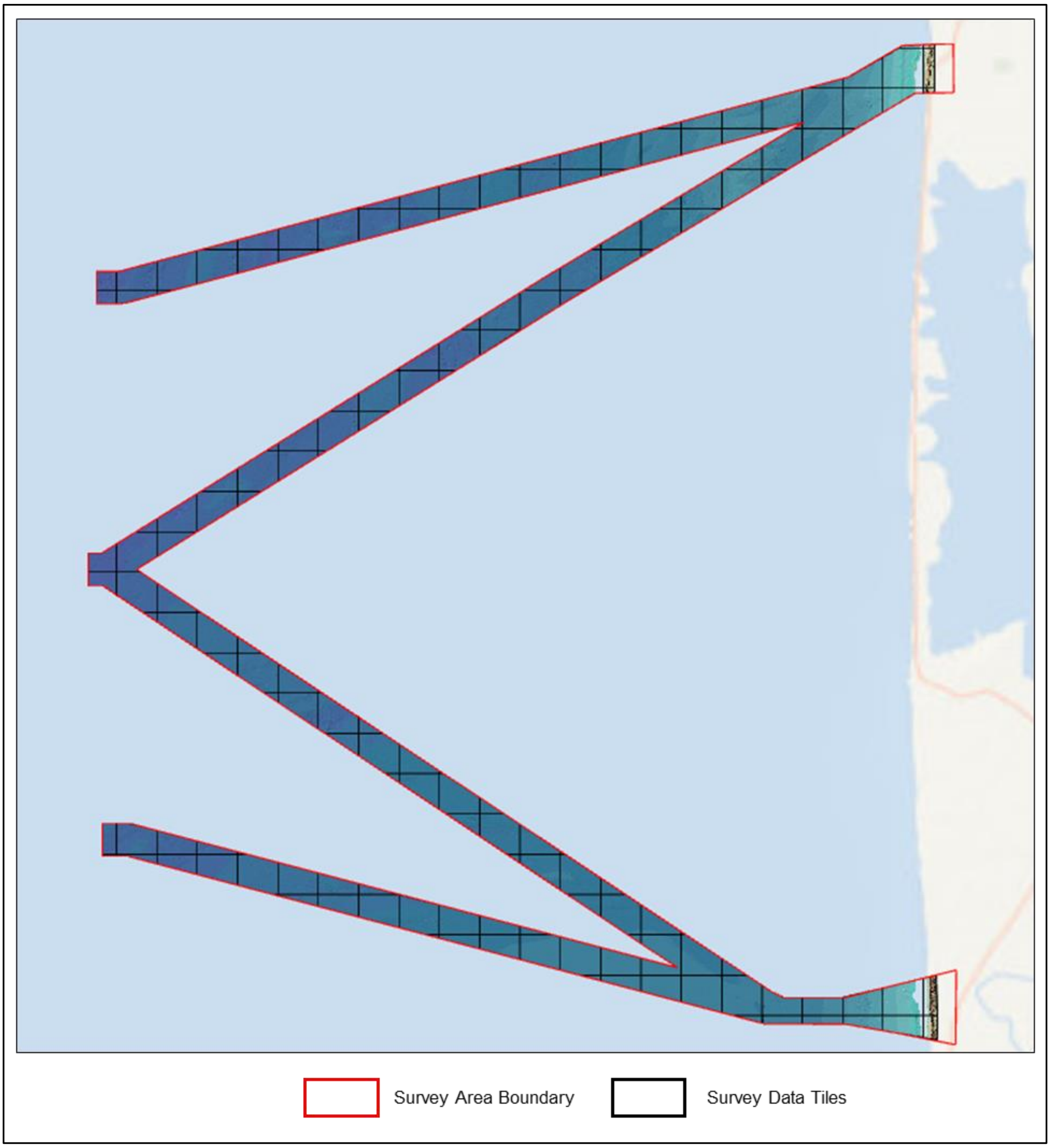

Figure 10 Overview of bathymetry data tile schema used for the ECR.
This image shows the tile schema overlying the full survey coverage achieved in 2019.

5| PROCESSED DATA QUALITY

5.1| BATHYMETRY DATA

The processed MBES bathymetry data meets the required specifications. The horizontal and vertical uncertainty of the soundings data were, for the vast majority of the survey area, within the 0.5 m threshold as specified by the client. Checks were made during acquisition and to ensure that sounding density conformed to the 4 soundings per 1 m cell criteria (Figure 11). Full coverage of the ECR survey area was a key priority and checks were made as the data was delivered to the office team to ensure data gaps were identified and infilled by the vessel.

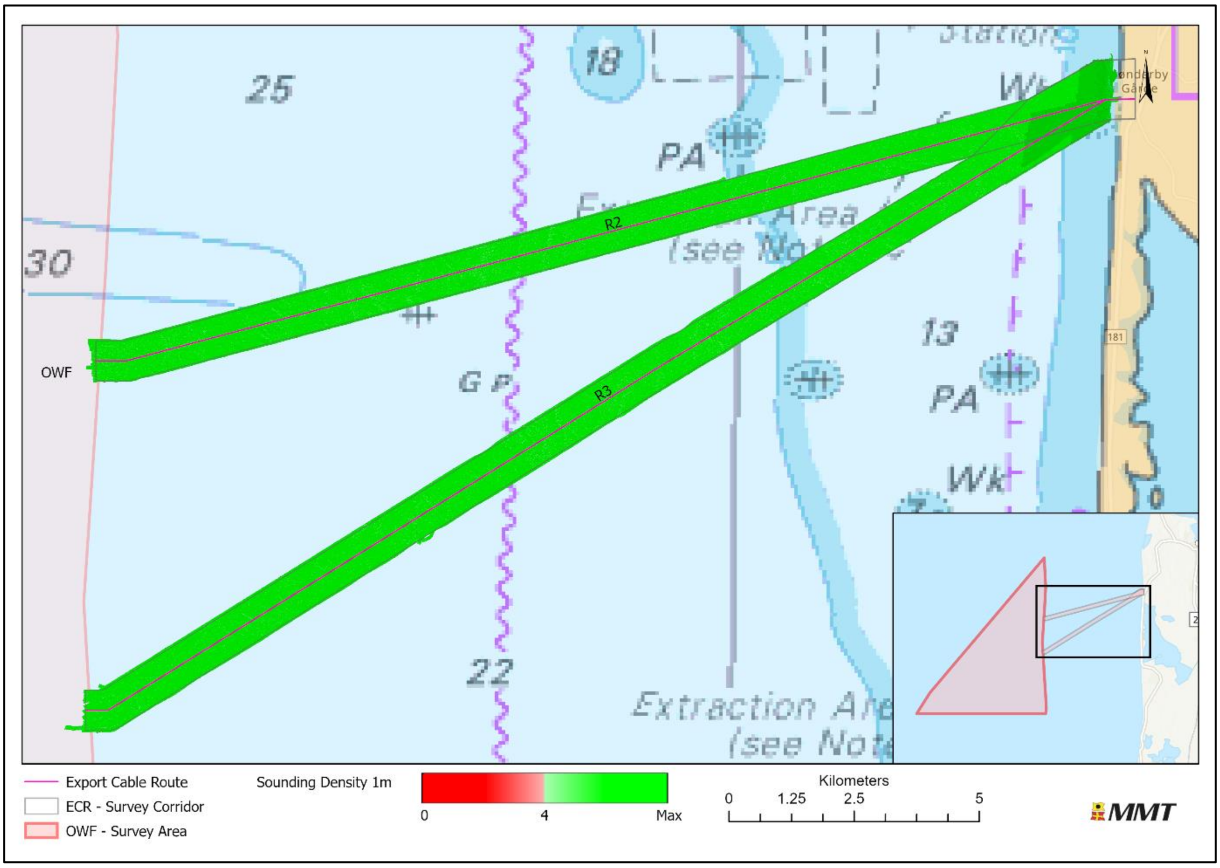

Figure 11 Overview of the sounding density surface for ECR.

The MBES data from Guardian and Plasticbeam were fully combined in the office after survey operations were completed. The principal QC check that was required was to ensure data from both vessels was vertically aligned. To do this the same methodology for checking vertical alignment within a single dataset was followed. Figure 12 shows the areas surveyed by M/V Plasticbeam and M/V Guardian in the nearshore zone of the ECR from the tracklines of each vessel.

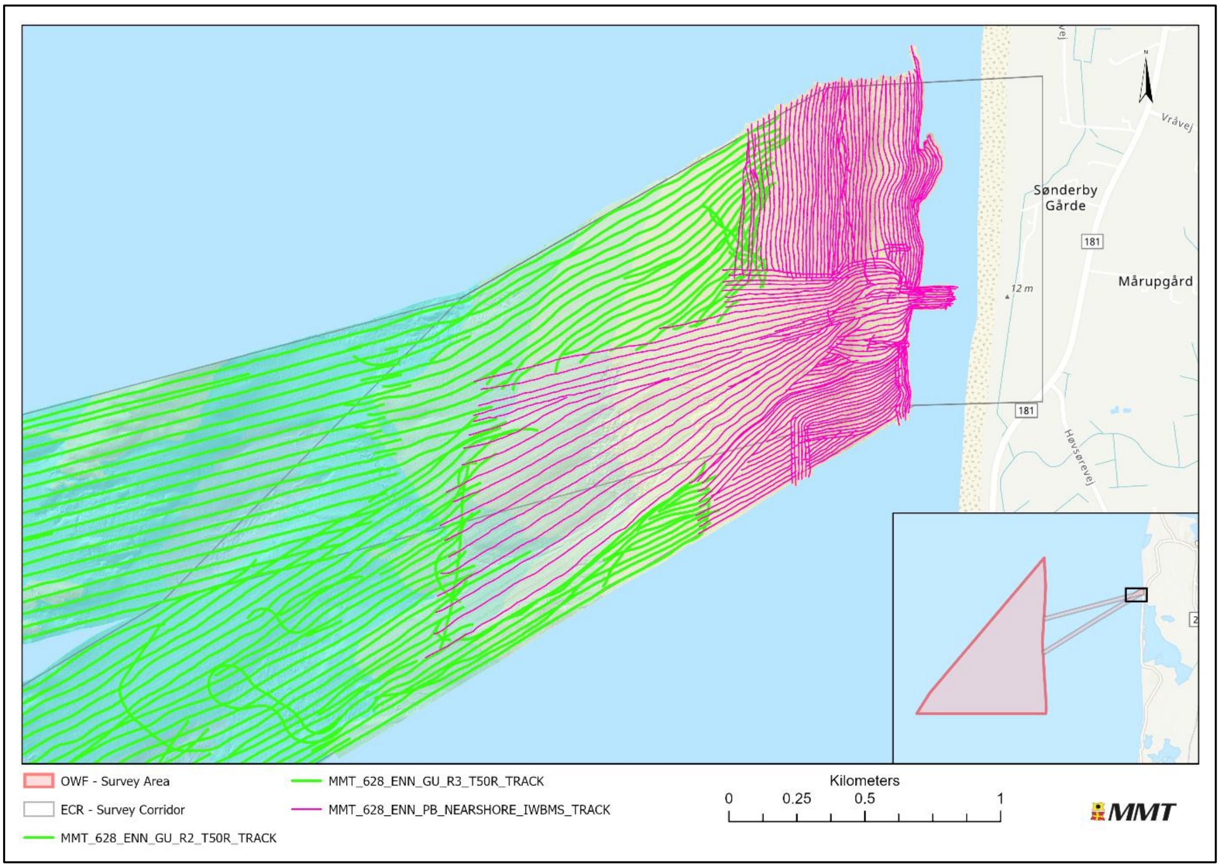

Figure 12 Map of survey lines by M/V Plasticbeam (pink) and M/V Guardian (green) in the nearshore zone of the ECR.

The vertical alignment is checked by generating Qimera surfaces from all MBES data within a survey block. A range of properties are computed for each surface and these are checked systematically to ensure the data falls within specification. The Standard Deviation at 95% confidence interval is checked in order to highlight areas where the vertical spread of soundings within a DTM grid node is high and checks can be made to determine the cause. If necessary, action can be taken to bring the soundings into closer alignment. Regions that have high standard deviations can occur where there are sound velocity errors, errors in the post-processed navigation, acquiring data in heavy weather and where there are steep slopes such as boulder fields.

6| RESULTS

One of the key aims for the 2020 hydrographical survey was to achieve 100% coverage of the ECRs. This area was prioritised during and the offshore survey vessel began survey operations in the OWF once the ECR acquisition was completed. An overview of the coverage achieved in 2019 and 2020 is shown in Figure 13.

As a result of prioritising the ECR the R2 and R3 ECRs have 100% coverage in the offshore areas with differences in coverage arising only in the nearshore zone. These differences result from M/V Plasticbeam encountering bathymetric changes in depth on the landward side that restricted the areas that could be accessed in 2020. A comparison of the coverage in the nearshore zone is shown in Figure 14. Most noticeable in Figure 14 is the lack of coverage that was achieved by the aerial survey in 2019 which, was not a requirement of the 2020 survey. Another noticeable difference results from the attempt to survey along the export cable route as far as was safely navigable. This achieved an additional 175 m compared to 2019 but coverage was restricted to an area 40 m to 50 m either side of the export cable route. This extra coverage was only 30 m short of overlapping the 2019 aerial survey coverage.

Noticeable differences between the 2019 and 2020 surveys arise from the changes in depth, which will be presented in the following section of the report. However, of particular note is the exposure of a charted wreck in the nearshore zone that was not clearly identifiable in the 2019 DTM (Figure 15). This is located at 445639 m E, 6257117 m N. It appears that beach sediments may have been scoured from this area, exposing the wreck and the adjacent dumped blocks, and deposited further offshore. A sediment bar encroaches the western side of the lower frame in Figure 15 and is possibly where the material scoured from the beach has been deposited. The depth changes observed in the nearshore zone are discussed further and quantified in the following section of the report.

Another notable change is the texture of the seabed in some parts of the ECR area. In the 2019 survey the bathymetry exhibits broad areas where the seabed has numerous, closely spaced depressions. These depressions measure between 0.1 m and 0.2 m deep, have diameters of 5.0 m to 10.0 m and with centre positions typically spaced 5.0 m to 15 m apart (although the spacing increases towards the peripheries of these zones).

In the 2020 bathymetry the morphology of the seabed has changed, becoming smoother with the depressions becoming larger in diameter (20.0 m to 40 .0 m) and more widely spaced (centre positions 20.0 m to 40.0 m apart). Examples of these in R2 and R3 are shown in Figure 16 and Figure 17, respectively.

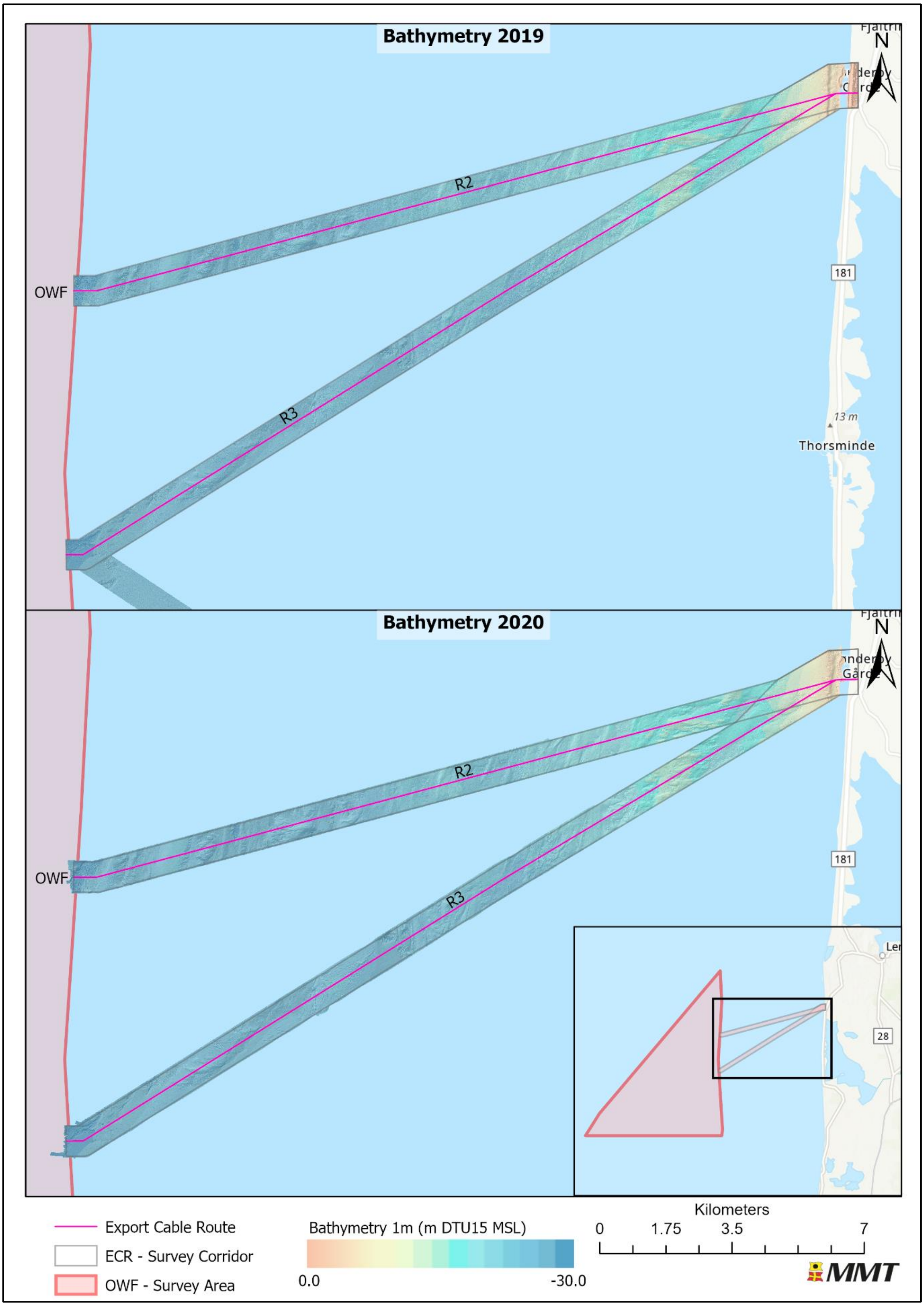

Figure 13 Overview of ECR coverage achieved in 2019 (top) and 2020 (bottom).

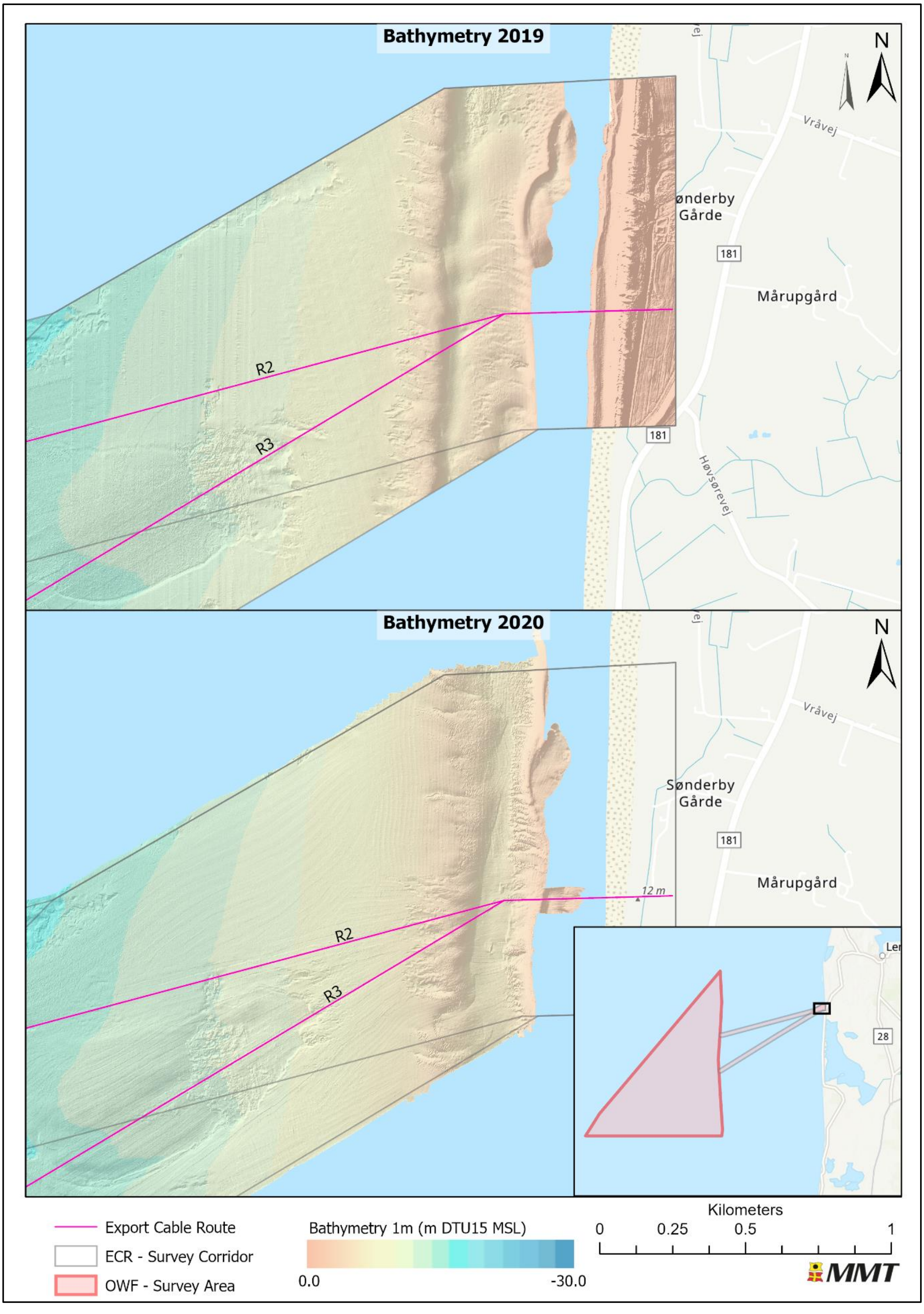

Figure 14 Overview of ECR nearshore coverage achieved in 2019 (top) and 2020 (bottom).

Figure 15 Exposure of charted wreck in 2020 survey (bottom) compared with 2019 (top).

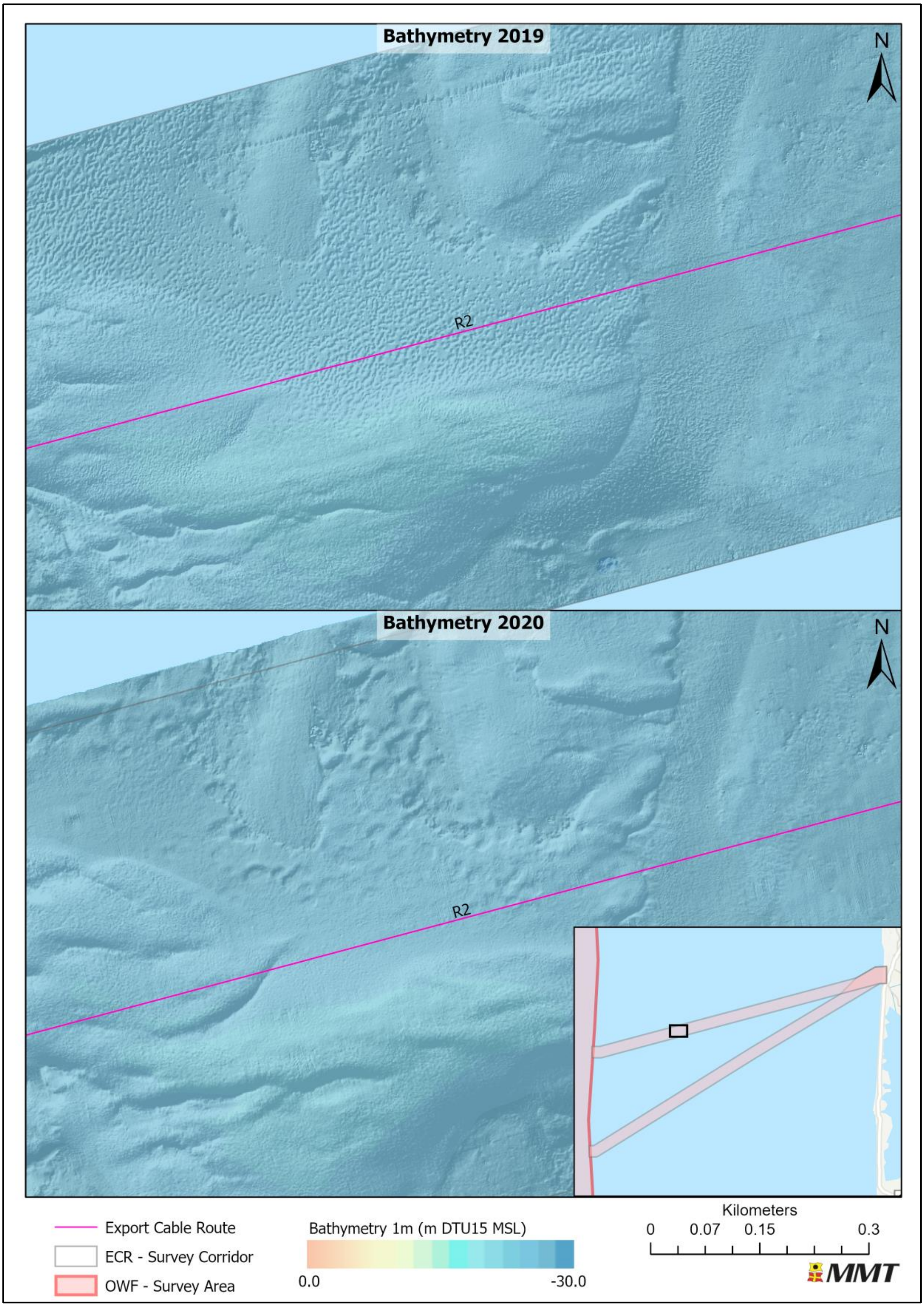

Figure 16 Change in R2 seabed texture between 2019 and 2020.

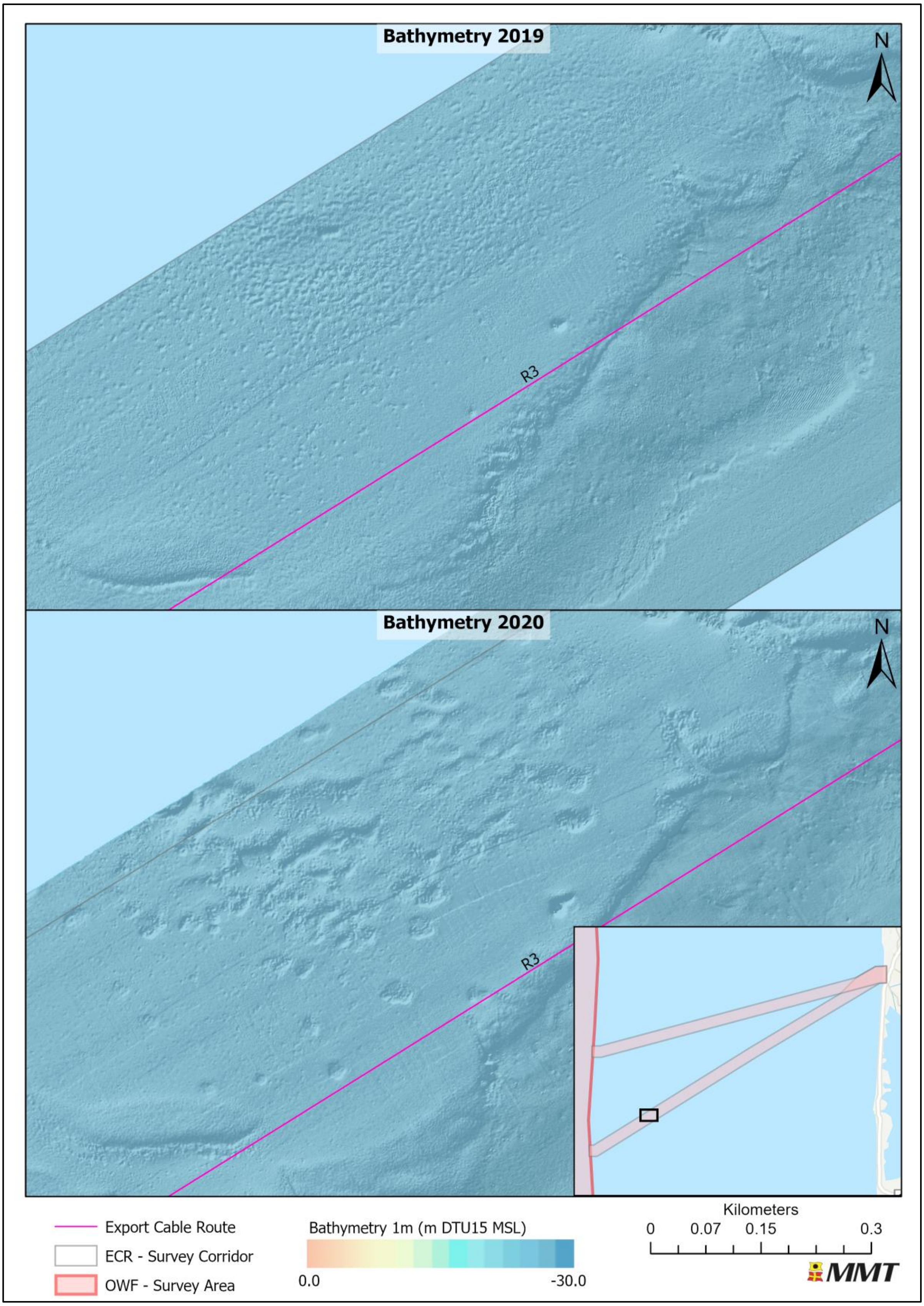

Figure 17 Change in R3 seabed texture between 2019 and 2020.

7| SURFACE DIFFERENCE RESULTS

The surface difference results were calculated in ArcGIS Pro by using the Minus function to calculate the vertical differences between the two rasters. The operation was performed using the following equation:

ECR 2020 Bathymetry – ECR 2019 Bathymetry = ECR Surface difference

The results of this calculation were checked by creating profiles across the bathymetry and surface difference surfaces. This showed that positive difference values corresponded to areas where the 2020 bathymetry was shallower than in 2019. Positive values therefore correspond to accumulations of sediment and negative values where sediment has been eroded. A colourmap was created which highlighted these changes with large increases in depth appearing blue and purple and large reductions in depth coloured orange and red.

To present clear imagery in the report small depth changes have been excluded from the colourmap. This is because small changes in vertical position of the two survey vessels can impose distracting artefacts in the surface difference results. These differences in depth are within the permitted vertical uncertainty for the bathymetry data and means that small changes in depth between the two surveys cannot be clearly associated with seabed movement alone. Assessment was made over the ECR and OWF survey areas and it was found that this exclusion zone would span +/-0.15 m. The exclusion was made by making the cell values within this range appear transparent. For context and interest the shaded relief surface from the 2020 bathymetry is shown in these transparent areas. The same colourmap has been used for both sets of results.

An overview of the surface difference results for the entire ECR area is shown in

Figure 18. The colourmap here has been forced to highlight the positive and negative depth changes at a scale that can be observed in the report.

The range of surface difference values was found to be +2.22 m to -2.71 m. The maximum and minimum values are located in the nearshore zone.

The results show that there are areas of mobile seabed throughout ECRs R2 and R3 however there are large areas which fall within the +/-0.15 m zone where depth changes cannot be separated from the vertical uncertainty of the data. The most prominent zone where mobility has been observed is in the nearshore intertidal zone where large positive and negative changes in depth have occurred. In the overlapping zone between R2 and R3 there is a sinuous line which runs from east to west where the depth has increased since 2019. In the region where the the two ECRs divide is a large expanse of mobile seabed where positive and negative changes in depth indicate the migration of bedforms. This pattern of bedform migration is observed along the length of the ECRs until they reach the OWF, however the areas where these occur are separated by localised areas where little or no sediment mobility was observed. As expected the zones which display mobility are associated with areas where bedforms are present and those areas where mobility is absent, or at least below the limit of reliable detection, correspond to areas of smooth seabed or where the underlying bedrock/consolidated seabed is exposed.

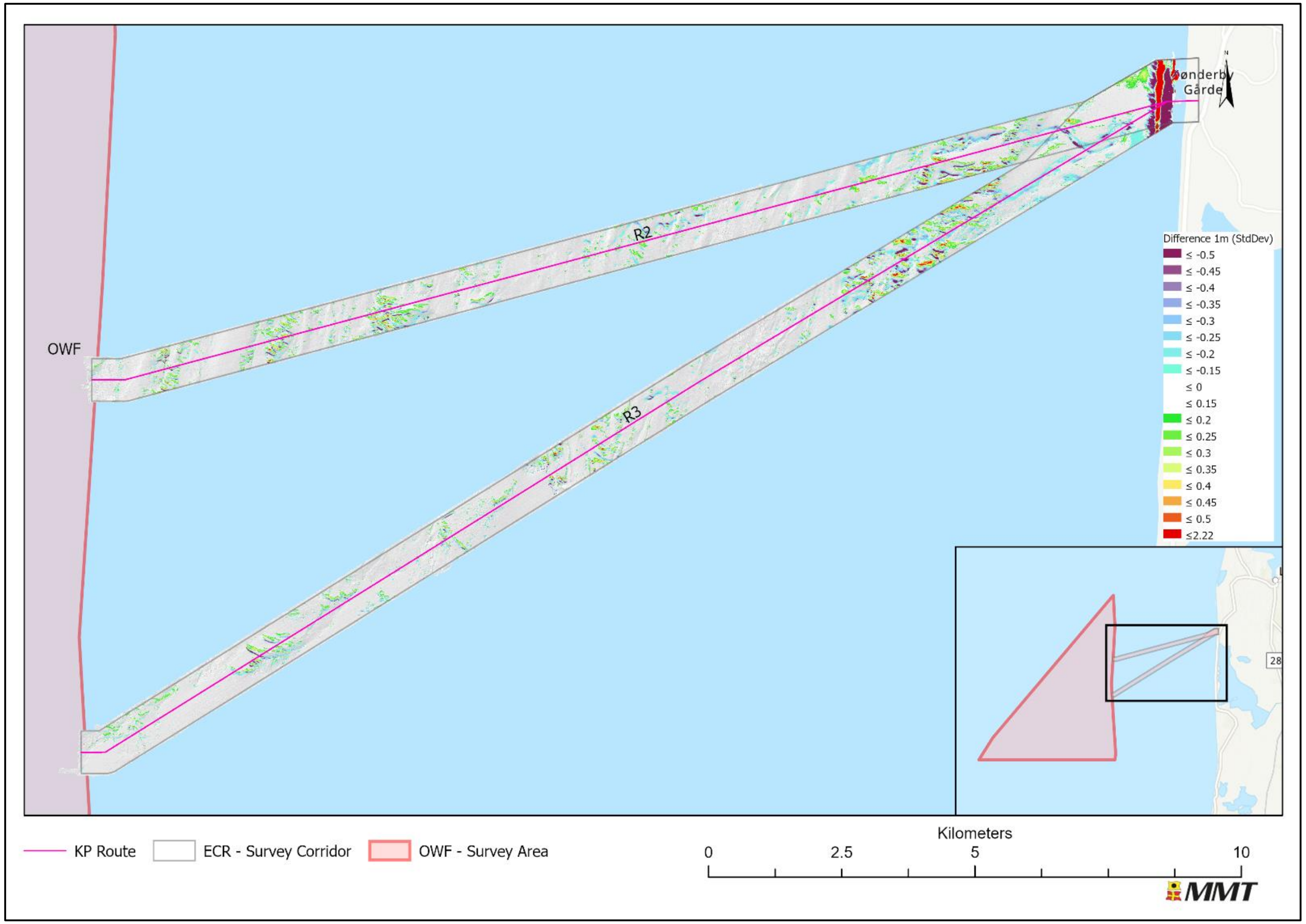

Figure 18 Overview of the ECR surface difference results.
The colourmap is forced to emphasize positive and negative depth changes when viewed at this scale.

7.1| NEARSHORE ZONE

The surface difference results showed that the nearshore zone of the ECR has experienced significant changes in depth since the 2019 survey was conducted. The maximum positive and negative depth changes, +2.22 m and -2.71 m are located in this area. The maximum positive change is located at 445525 m E, 6257167 m N and the maximum negative change at 445742 m E, 6257644 m N.

The shaded relief bathymetry images in Figure 19 show the steep slope that serves as the flank of the deeper channel that runs parallel to the shoreline has moved east, towards the shore by approximately 100 m. The surface difference results show that the channel has increased in depth with changes in excess of -1.0 m covering a large portion of this zone. This increase in depth has exposed the wreck located at 445639 m E, 6257117 m N with changes in depth of -1.3 m to -2.0 m in the sediments around the wreck.

It is not possible to determine from these results whether these large changes occurred gradually during the period between the two surveys. It is possible that these changes relate to the effects of a single storm event that scoured material from the shallower parts of the beach and deposited them along the bar running parallel to the shore.

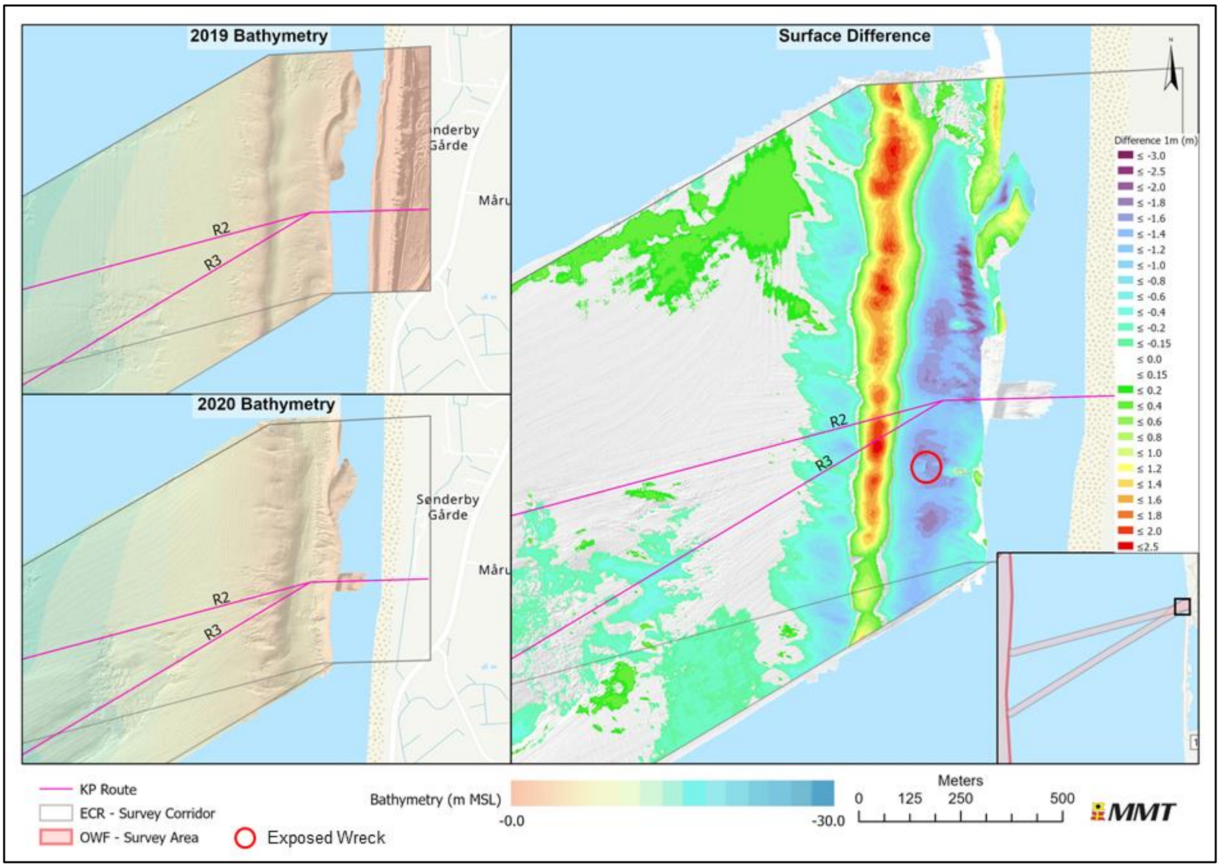

Figure 19 Surface difference results in the nearshore zone of the ECR.

Three profiles showing the variations in depth in the nearshore zone are shown in Figure 20 to Figure 22.

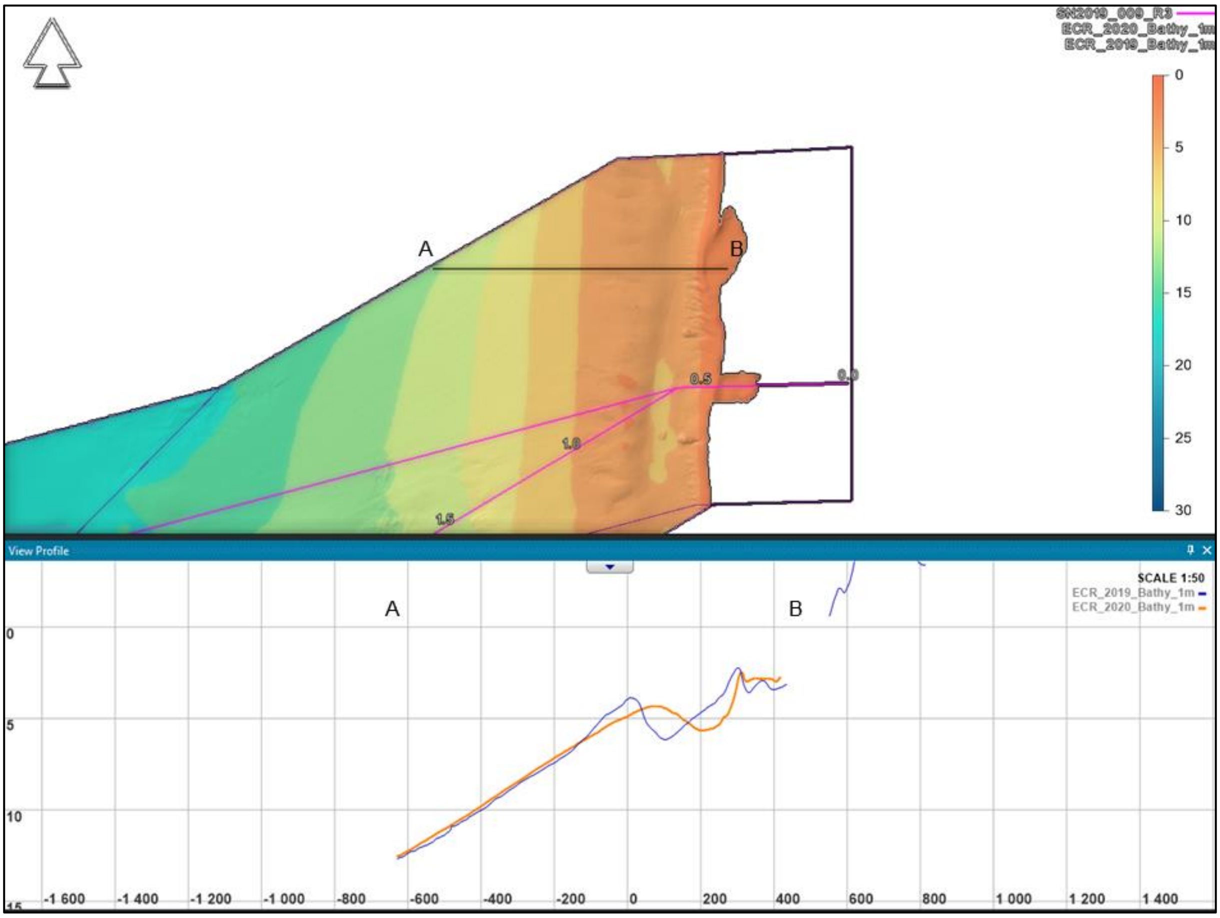

Figure 20 Profile through the northern part of the dynamic nearshore zone with 2020 bathy surface shown.
In the profile panel the 2020 bathymetry is orange and 2019 shown in blue. NaviModel depth convention is positive down.

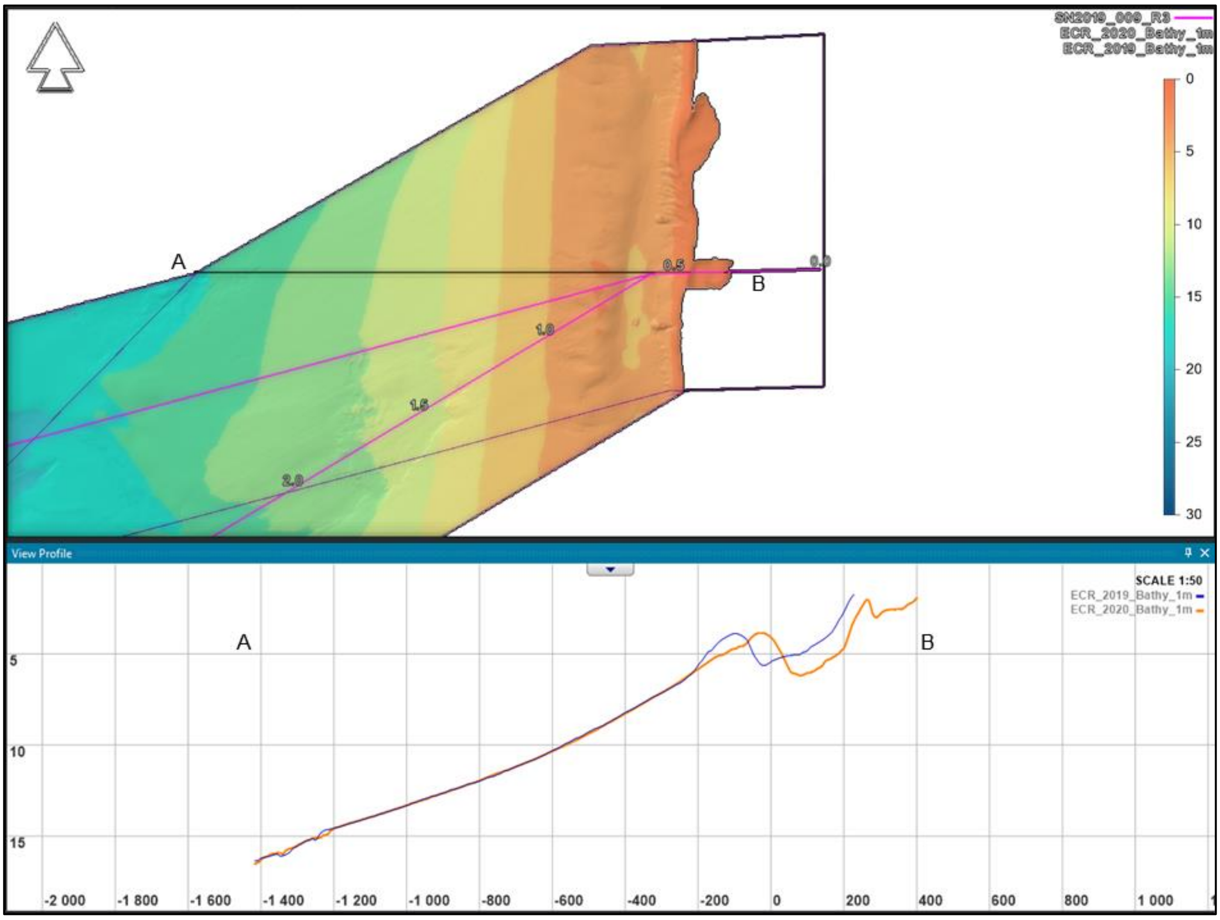

Figure 21 Profile through the central part of the dynamic nearshore zone with 2020 bathy surface shown.
In the profile panel the 2020 bathymetry is orange and 2019 shown in blue. NaviModel depth convention is positive down.

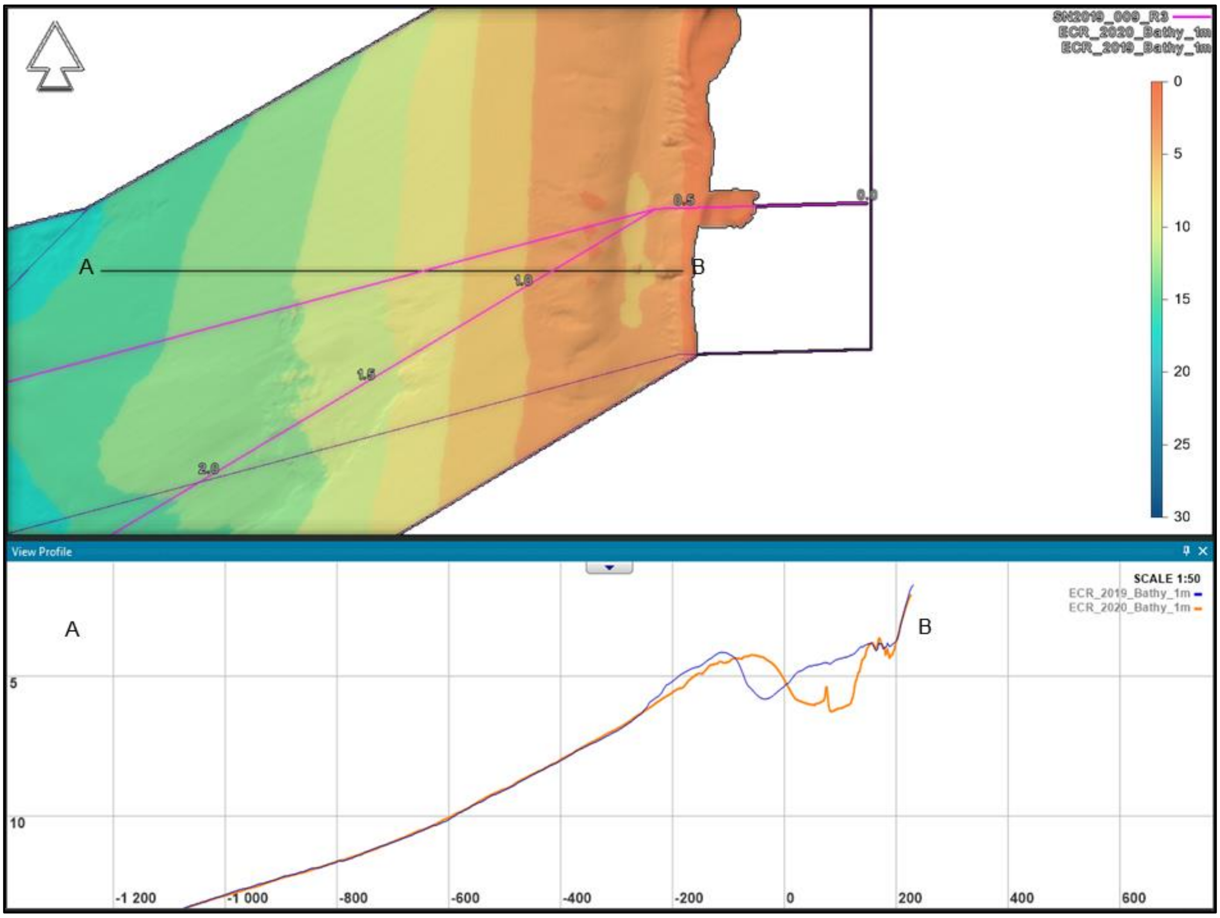

Figure 22 Profile through the southern part of the dynamic nearshore zone with 2020 bathy surface shown.
In the profile panel the 2020 bathymetry is orange and 2019 shown in blue. NaviModel depth convention is positive down.

Another feature of interest in the overlapping zone between R2 and R3 is the sinuous area which has increased in depth since the 2019 survey (Figure 23). The feature existed in the 2019 DTM but has become more pronounced in 2020 with depth changes ranging between -0.2 m and -1.0 m. This feature runs for approximately 1.8 km between 444691 m E, 6256525 m N (nearshore) to 443,207.44E 6,256,708.63N m (offshore).

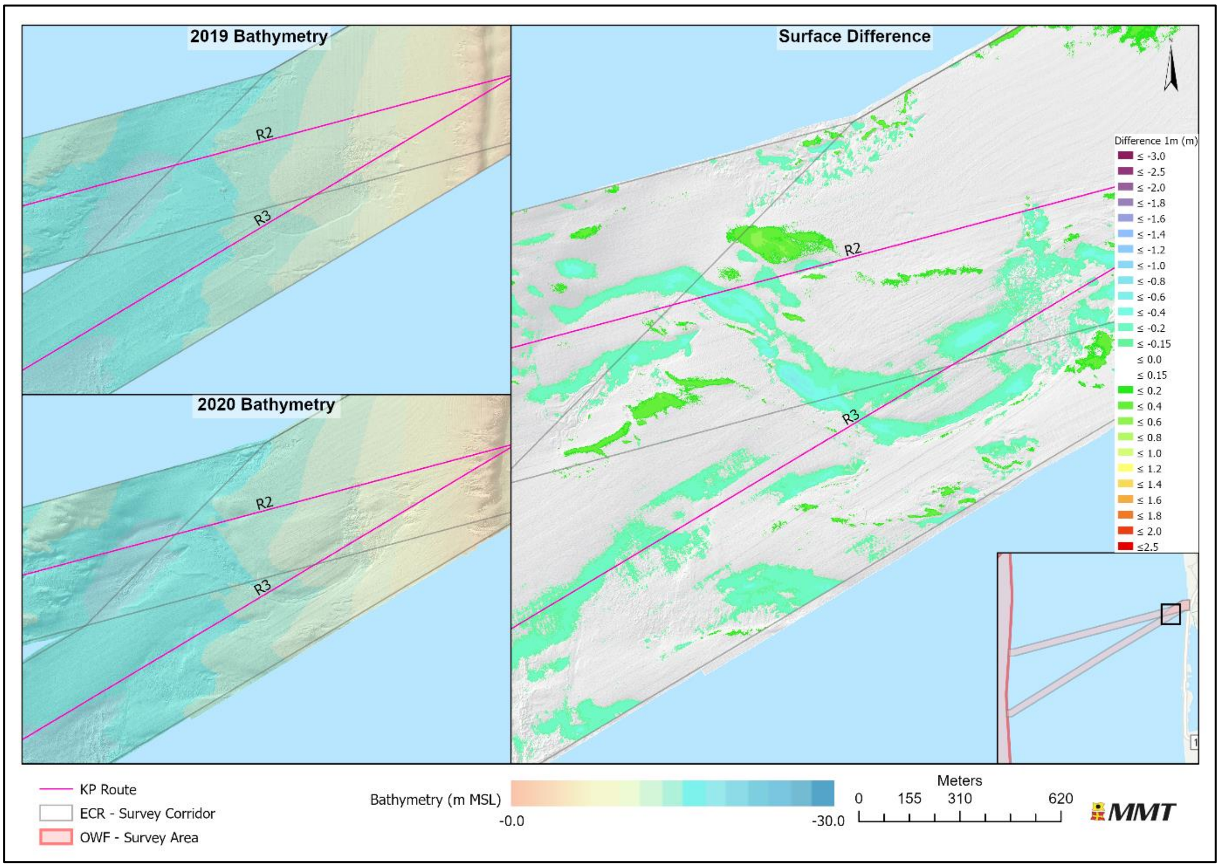

Figure 23 Sinuous erosional feature in overlapping zone of R2 and R3.

7.2| ROUTE 2: KP 0.000 TO KP 21.444

Profiles were generated from the bathymetry surfaces and the difference results along the cable routes. The profile comparison chart for R2 is shown in Figure 24. The depth information was extracted at 1m intervals along the route and all the information is stored in a spreadsheet that is supplied in Appendix C| This can be used to inspect areas of interest closely by altering the minimum and maximum X-axis values.

Overall the chart shows that, along the axis of R2 the depths have mostly remained stable. The difference line in the upper portion of the chart shows that depth variability is mostly within +/-0.5 m with far greater variability occurring in the first 1 km of the route in the dynamic nearshore zone.

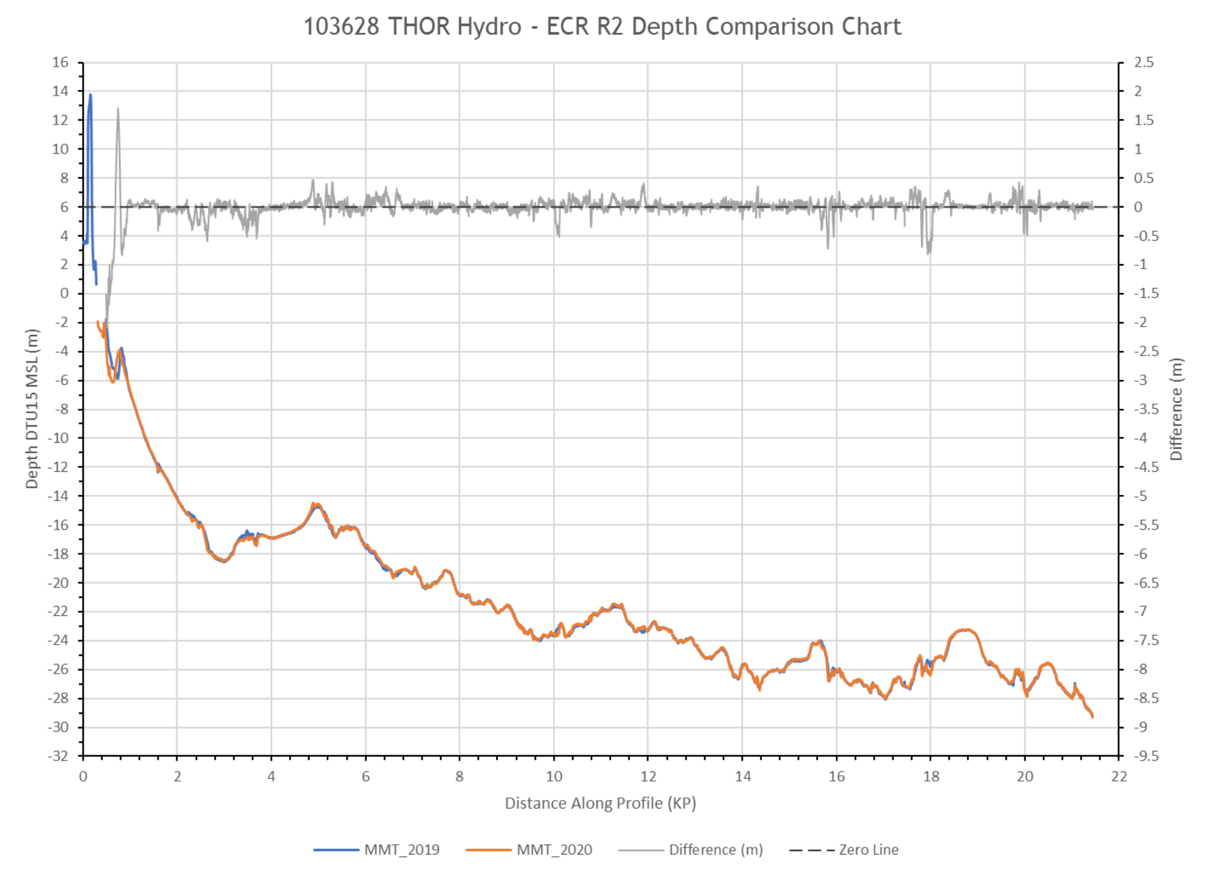

Figure 24 R2 Depth Profile Comparison Chart

Along the non-overlapping parts of R2 (KP 2.75 to the end of the route at KP 21.444) the surface difference results show that there are mobile areas separated by extensive zones where depth changes are within the vertical uncertainty of the bathymetry data. Prominent areas of mobility which are associated with the changing positions of sandwave crests are located between:

- KP 3.0 to KP 5.5
- KP 15.0 to 16.0
- KP 17.5 to KP 18.5
- KP19.5 to 20.5

In the section between KP 5.5 and 15.0 mobility is present but is associated with smoother seabed which does not exhibit sandwaves. Mobile areas relate to redistribution of sediment over larger, less defined areas with depth changes typically ranging between +/-0.5 m.

Examples of seabed mobility along R2 are presented in Figure 25 to Figure 28.

Figure 25 shows the surface difference results between KP 4.0 and KP 6.5. A profile line drawn through a region where the colourmap indicates sediment mobility shows the bathymetry data from 2019 (blue) and 2020 (orange). The profiles show that the crests of the sandwaves have moved from left to right in the profile and this corresponds to a direction of ca. 020°. Measurements from the 2019 to 2020 sandwave crest positions shows that the sandwaves have shifted by ca. 40 m. The surface difference results in close proximity to the profile line show depth changes range between -0.95 m to +0.75 m.

The depth profiles in the image are vertically exaggerated 50 times and show that the steepest side of many bedforms is on their southern side. The steeper face of asymmetric bedforms (the lee side) is normally indicative of the direction of movement, however the degree of exaggeration may be distorting the appearance of what might be considered symmetrical bedforms when viewed at lower degrees of exaggeration. The direction of movement is therefore derived from the displacement of features that can be correlated between profiles, such as crests and troughs that have similar forms, rather than interpreted from the morphology of the bedform itself.

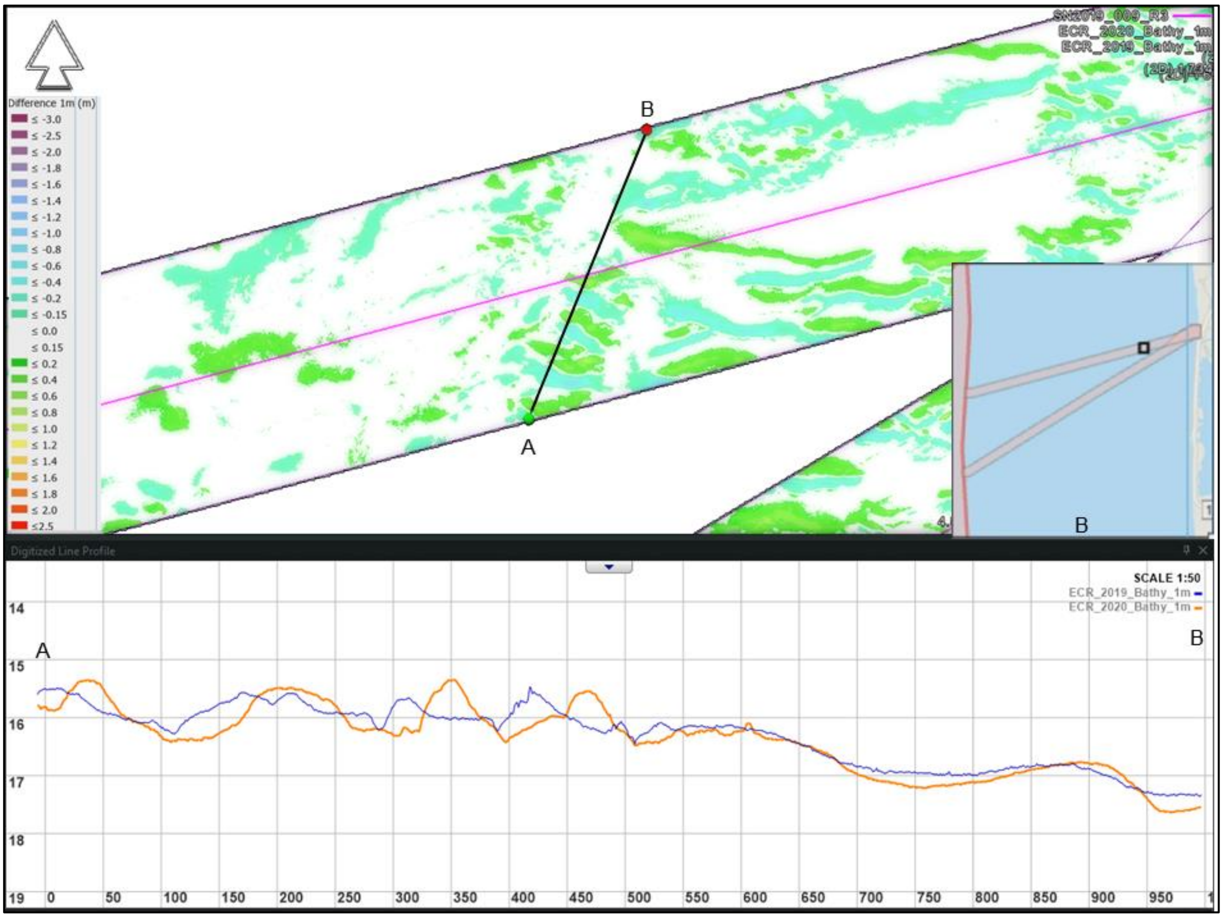

Figure 25 Profile across ECR R2 between KP 5.0 and 5.5.
Upper panel shows surface difference results and lower panel shows depth profiles from 2019 DTM (blue) 2020 DTM (orange). NaviModel depth convention is positive down.

Figure 26 shows an expansive area of mobile seabed that is located between KP 15.0 and 16.0 on R2. The depth changes here range between -0.93 m to +1.02 m. The profile across the area indicates the bedforms have moved northwards (ca. 007°) between 15 m and 30 m which, appears dependent on the scale of the feature being measured. The lower amplitude, steeper features appear to have moved less than the larger, smoother features along the measured profile.

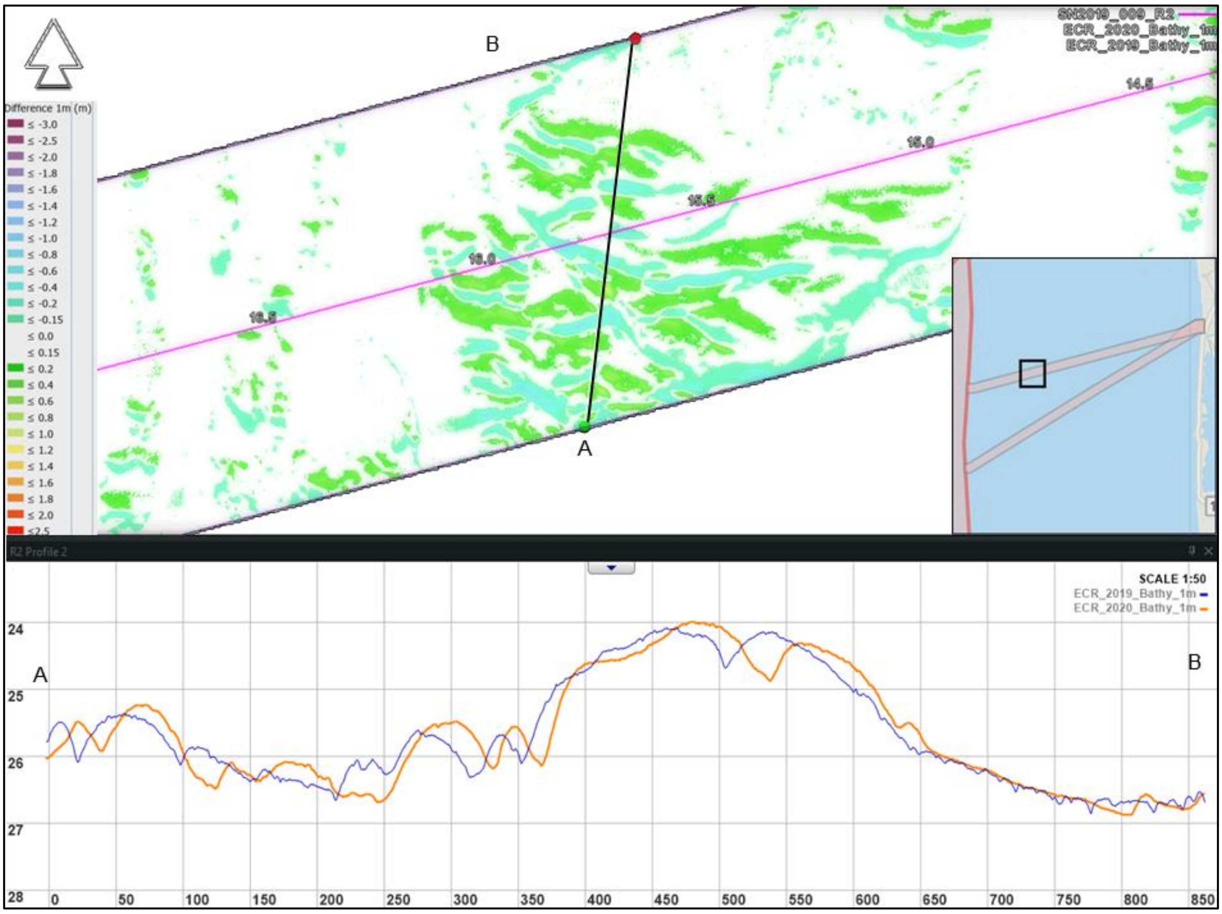

Figure 26 Profile across ECR R2 between KP 15.0 and 16.0.
Upper panel shows surface difference results and lower panel shows depth profiles from 2019 DTM (blue) 2020 DTM (orange). NaviModel depth convention is positive down.

Figure 27 shows the surface difference results and depth profiles in the region around KP 18.5 on R2. The sandwaves here show on average 18 m of displacement towards 013°.

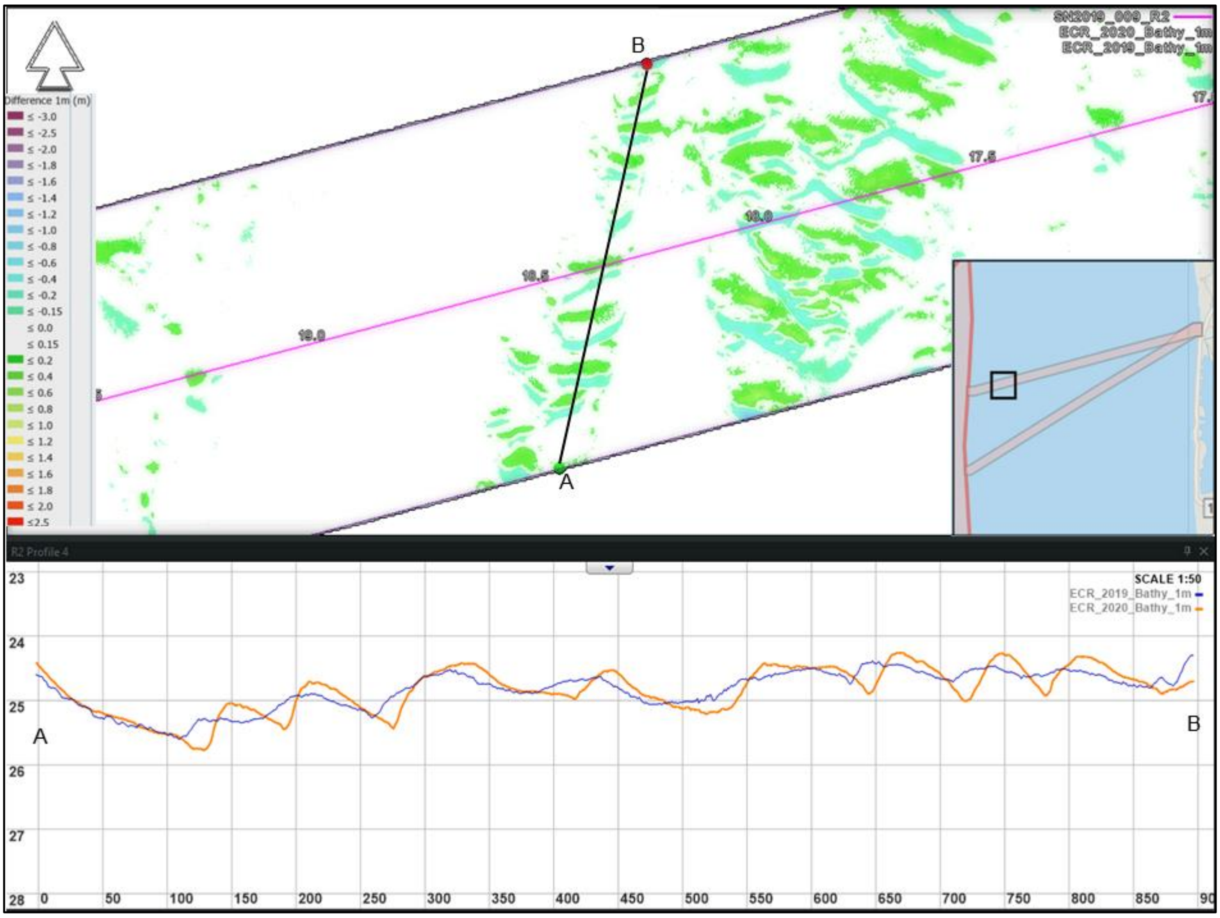

Figure 27 Profile across ECR R2 at KP 18.5
Upper panel shows surface difference results and lower panel shows depth profiles from 2019 DTM (blue) 2020 DTM (orange). NaviModel depth convention is positive down.

Figure 28 shows an area of mobility that spans the R2 route around KP 20. The profile crosses an area with a more complex morphology than previous examples. At the southern end of the profile the bedforms are smoother, measurements indicate a displacement of 20 m towards 020°. There is a zone where it is not possible to correlate the crestlines of bedforms between the two surveys and there it appears that there are mobile patches of sediment over more consolidated material that is not being displaced. Towards the north of the profile the is a 200 m stretch of stable seabed before displacement of mobile sediments is observed. Within the mobile area around the profile depth changes of -0.90 m to +0.90 m were observed.

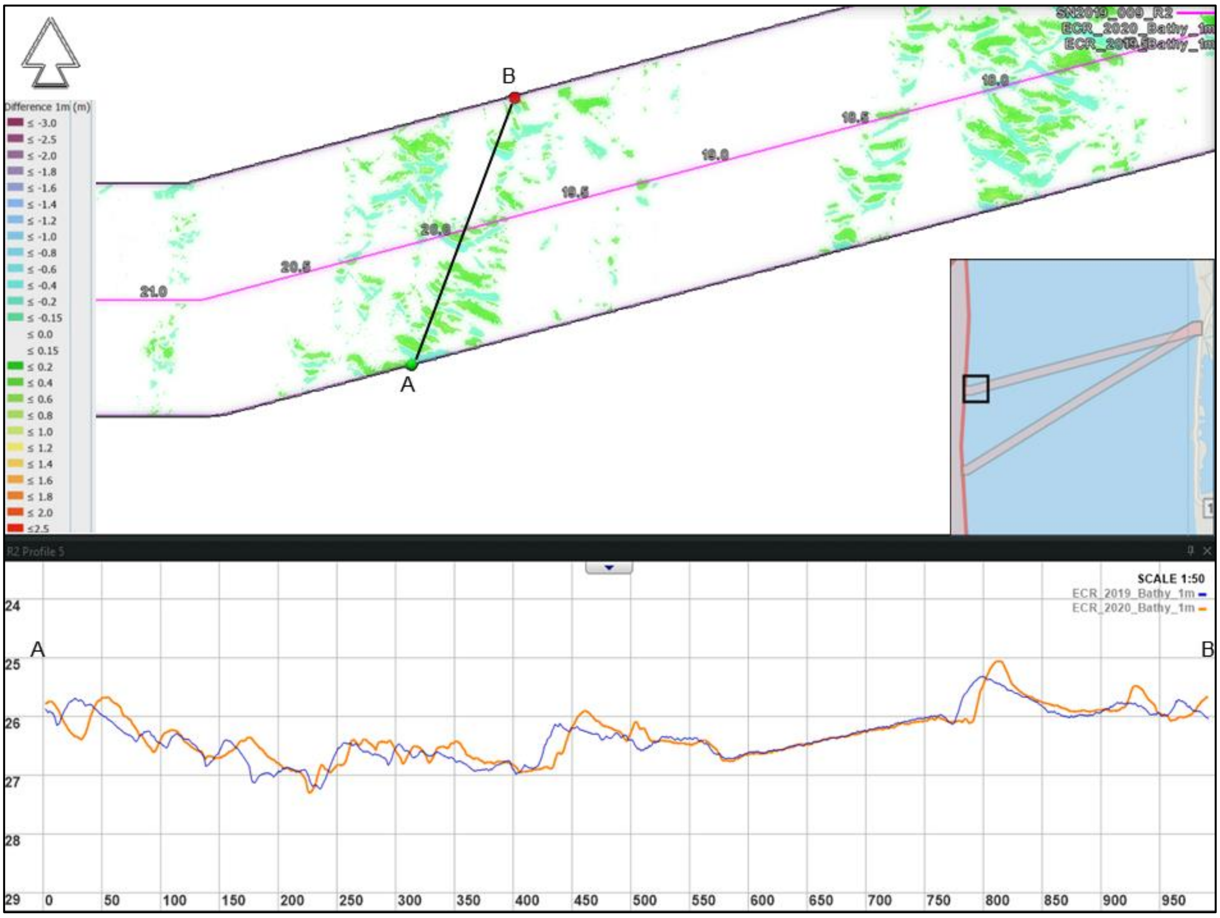

Figure 28 Profile across ECR R2 at KP 20
Upper panel shows surface difference results and lower panel shows depth profiles from 2019 DTM (blue) 2020 DTM (orange). NaviModel depth convention is positive down.

7.3| ROUTE 3: KP 0.000 TO KP 24.401

Profiles were generated from the bathymetry surfaces and the difference results along the cable routes. The profile comparison chart for R3 is shown in Figure 29. The depth information was extracted at 1 m intervals along the route and all the information is stored in a spreadsheet that is supplied in Appendix C|. This can be used to inspect areas of interest closely by altering the minimum and maximum X-axis values.

Overall the chart shows that, along the axis of R3 the depths have mostly remained stable. The difference line in the upper portion of the chart shows that depth variability is mostly within +/-0.5 m with far greater variability occurring in the first 1 km of the route in the dynamic nearshore zone.

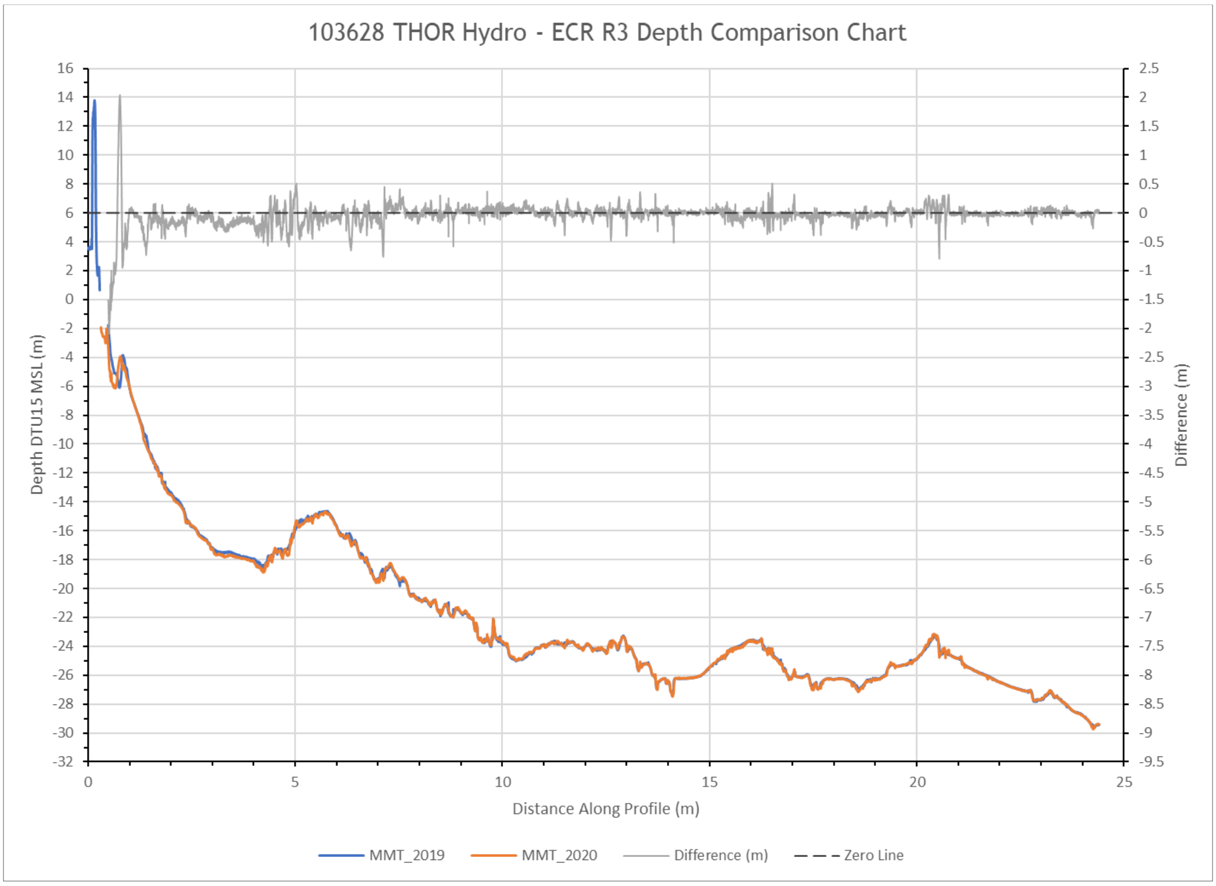

Figure 29 R3 Depth Comparison Profile Chart

The R3 route becomes distinct from the nearshore zone from KP 2.0 and from here until KP 4.0 the seabed appears largely stable with mobility constrained to the central part of the corridor where there has been an increase in depth (typically -0.20 to -0.30 m and up to -0.50 m) in the form of a sinuous channel.

From KP 4.0 to KP 8.0 the route crosses an expansive area of mobile seabed associated with the re-working of smooth and irregular bedforms separated by zones of consolidated seabed.

More sparsely distributed areas of mobility are present between KP 11.0 and the end of the route at KP 24.4. Prominent areas of mobility are located:

- At KP 11.5
- Between KP 12.5 and KP 14.5

- Between KP 15.0 and KP 16.5
- Between KP 18.5 and KP 21.25

Examples of mobile seabed are shown in Figure 30 to Figure 32.

Figure 30 shows a profile through the area of mobile seabed between KP 4.0 and KP 8.0. The profile suggests that the bedform crests have moved towards 010° by approximately 50 m. Depth changes within this area range between -1.05 m to +0.80 m and the degree of horizontal displacement is highly variable. The bedforms here, as along much of the route, have indistinct morphologies, being generally smooth, gently sloping dome-like features, which are highly variable over large areas.

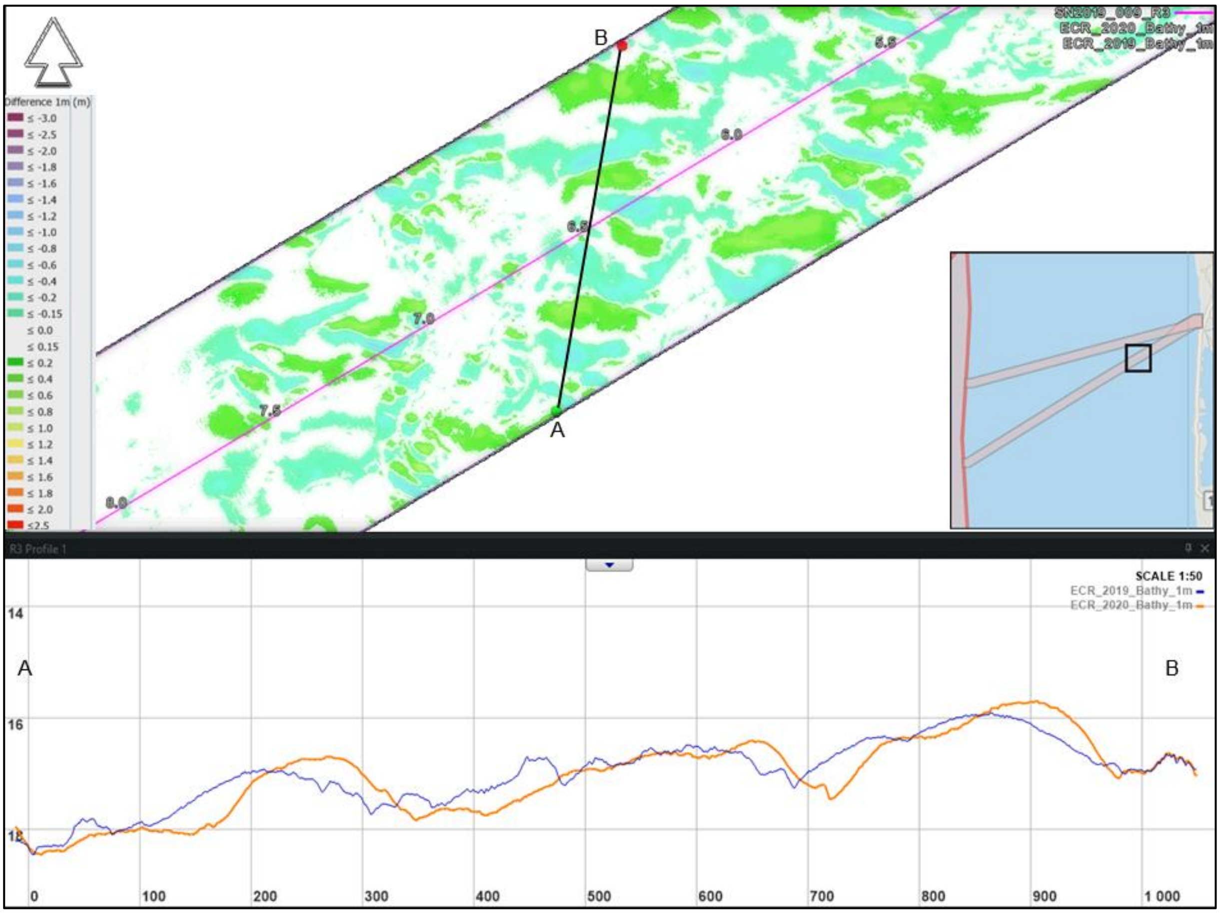

Figure 30 Profile across ECR R3 at KP 6.5
Upper panel shows surface difference results and lower panel shows depth profiles from 2019 DTM (blue) 2020 DTM (orange). NaviModel depth convention is positive down.

Figure 31 shows a mobile area around KP 12.5 on R3. The depth changes in this area range between -0.75 m to +0.65 m with horizontal displacements along the profile line ranging between 15 m and 30 m with the greater displacement being associated with the larger features present.

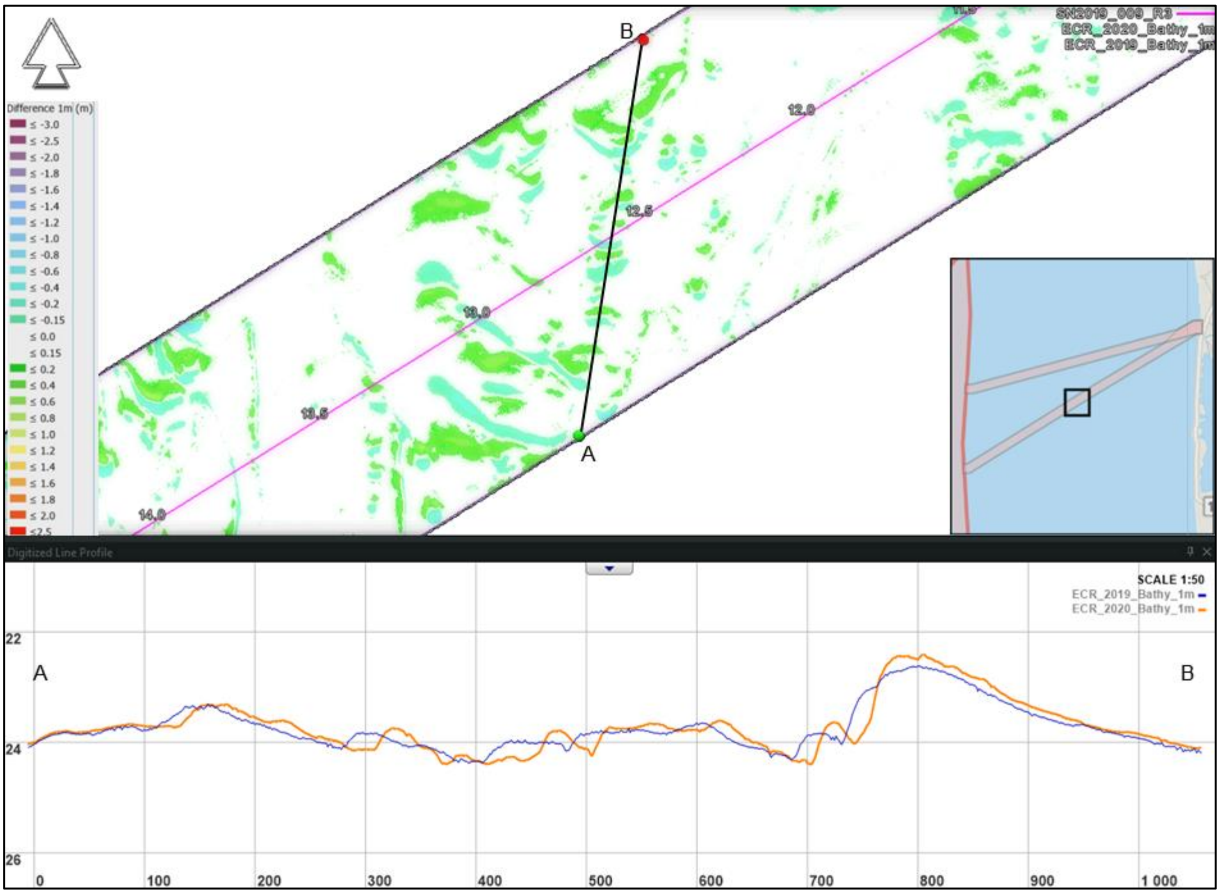

Figure 31 Profile across ECR R3 at KP 12.5
Upper panel shows surface difference results and lower panel shows depth profiles from 2019 DTM (blue) 2020 DTM (orange). NaviModel depth convention is positive down.

Figure 32 shows depth profiles and surface difference results in the mobile area around KP 20.5. Depth changes within this area range between -1.0 m and +0.55 m. The profiles indicate an average bedform displacement of 30 m. The orientation of bedform displacement here is towards 025°.

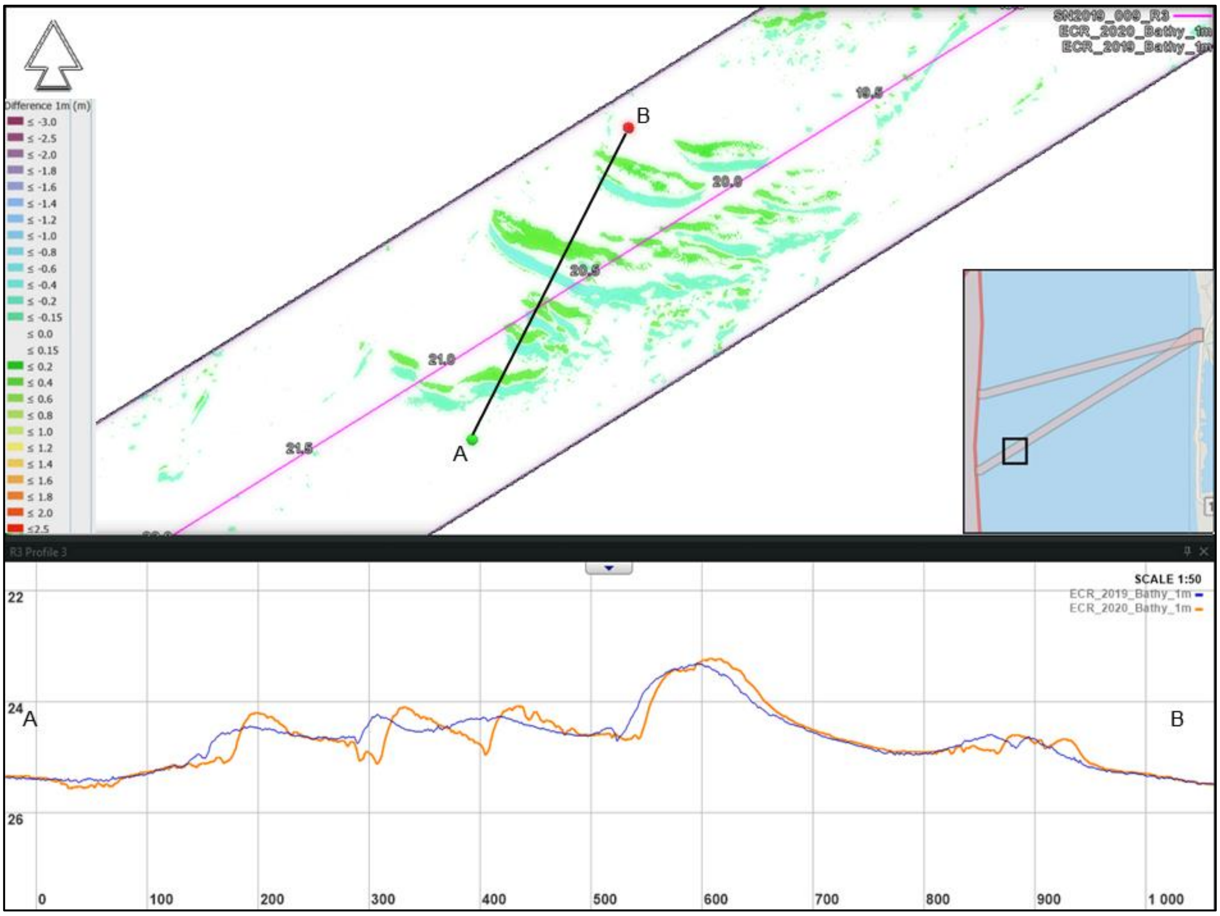

Figure 32 Profile across ECR R3 at KP 20.5
Upper panel shows surface difference results and lower panel shows depth profiles from 2019 DTM (blue) 2020 DTM (orange). NaviModel depth convention is positive down.

8| CONCLUSIONS

A hydrographic survey was successfully carried out along the two selected options for the Thor OWF export cable route, R2 and R3. MBES data was collected from hull mounted survey vessels in the nearshore and offshore areas of the survey corridors.

The survey was conducted in a safe manner and good quality data was acquired throughout.

In the nearshore zone the R2 and R3 survey corridors overlap and in this area the seabed was found to be highly dynamic, relative to the offshore parts of the survey corridors. The maximum positive (depositional) and negative (erosional) depth changes were found here; +2.22 m and -2.71 m respectively. These depth changes related to an increase in depth of a channel that runs parallel to the shoreline between KP 0.485 and KP 0.680 (relative to the R2 route) and a shoreward shift in position of a bar feature between KP 0.680 and KP 0.790 (relative to the R2 route). The scoured channel in the nearshore area exposed a wreck that had only been partially observed in the 2019 bathymetry data.

The surface difference results showed that areas of mobile seabed were present along the offshore parts of both R2 and R3 with changes in depth typically within +/-0.5 m range, according to depth profiles extracted from the cable route positions. The association of positive and negative depth changes that were indicative of bedform migration suggested that transport was generally in a north-northeasterly direction with measurements ranging between 007° and 025°. Measurements of horizontal displacement range between 15 m and 50 m since the 2019 survey was conducted and the range of depth changes observed was typically within +/-1.0 m.

A qualitative comparison of both routes suggested that R2 exhibited a greater degree of mobility since there are extensive sections of R3 where changes in depth were within the vertical uncertainty range of the MBES data (+/-0.15 m). This is offset however by an extensive area of mobile seabed between KP 4.0 and KP 8.0 of R3. This mobile zone extends into R2 but only intersects the route in two sections between KP 3.25 and KP 3.80 and KP 4.80 and KP 5.50.

9| RESERVATIONS AND RECOMMENDATIONS

The hydrographic survey results represent two snapshots in time and the changes observed may appear to be the result of longer-term sediment movements during the period of time between the two surveys. This may largely be true for the deeper parts of the survey corridors however the nearshore zone, where the greatest changes in depth have been observed, is likely to be much more dynamic. The changes recorded here could well relate to a single storm event that occurred at any time since the first survey was completed.

If the changes in depth observed in the nearshore zone have implications for the installation of the export cable it may be useful to conduct further surveys to get a better understand the rate of change in this area.

For example, it may be beneficial to perform a sequence of surveys over the course of a year to observe seasonal changes in depth or perhaps try to survey immediately after a storm event to see what effect it has on the water depths adjacent to the beach.

Rather than perform a more time consuming 100% coverage MBES survey, the outline of the bar and channel could be defined by a sequence of east-west survey orientated survey lines widely spaced across the corridor. The acquired depth profiles would then be used to define the positions of the key bathymetric features within a short period of time.

10 | DATA INDEX

The deliverables listed in Table 14 accompany this report.

Table 14 Deliverables.

NO	DATA TYPE	DATA PRODUCT
1	101_MBES	01_Ungridded_Soundings
2	101_MBES	02_Grid_0_50_ascii
3	101_MBES	03_Grid_0_50_geotiff
4	101_MBES	04_Grid_1_00_ascii
5	101_MBES	05_Grid_1_00_geotiff
6	101_MBES	06_Grid_5_00_ascii
7	101_MBES	07_Grid_5_00_geotiff
8	101_MBES	08_Contour_curves
9	101_MBES	09a_TVU_1_00_ascii
10	101_MBES	09b_TVU_1_00_geotiff
11	101_MBES	09c_THU_1_00_ascii
12	101_MBES	09d_THU_1_00_geotiff
13	101_MBES	09f_SVP
14	101_MBES	09g_SurfDiff_1_00_ascii
15	101_MBES	09h_SurfDiff_1_00_geotiff
16	109 Operations Report	103628-ENN-MMT-SUR-REP-OPEREP
17	110 Geophysical Report	103628-ENN-MMT-SUR-REP-SURVECR-02.docx
18	Charts (PDF Booklet)	103628-ENN-MMT-SUR-MXD-NUR2__Surface_Difference.pdf
19	Charts (PDF Booklet)	103628-ENN-MMT-SUR-MXD-NUR2_Bathymetry.pdf
20	Charts (PDF Booklet)	103628-ENN-MMT-SUR-MXD-NUR3__Surface_Difference.pdf
21	Charts (PDF Booklet)	103628-ENN-MMT-SUR-MXD-NUR3_Bathymetry.pdf
22	GIS Database (Features)	SN2020_009_F_ECR_20201013.gdb
23	GIS Database (Rasters)	SN2020_009_R_ECR_20201013.gdb

APPENDIX A | ROUTE POSITION LIST (RPL)

APPENDIX B | CHART LIST

APPENDIX C | PROFILE GRAPHS