Appendix 7.1: Physical Processes Technical Report

Array EIA Report

2024

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1. INTRODUCTION

1. This Physical Processes Technical Report provides information relating to the physical processes for the offshore components of the Ossian Array (hereafter referred to as simply 'the Array'). It describes the current baseline conditions and discusses the potential changes to physical processes due to the operation and maintenance of the Array. This report discusses the baseline conditions of the Array, describing the current hydrography and sedimentology.

2. For the purposes of this Physical Processes Technical Report, physical processes are defined as encompassing the following elements:

   - bathymetry;
   - wind and waves;
   - tidal currents and elevation;
   - seabed substrate and geology;
   - suspended sediments; and
   - sediment transport (which is influenced by the elements listed above).

3. Throughout the remainder of this Technical Report, the elements listed above are collectively referred to as 'physical processes'.

2. STUDY AREA

4. The physical processes study area is comprised of the area that encompasses the site boundary plus the area of one spring tidal excursion (i.e. the area in which seabed that may be influenced by changes to physical processes due to the Array) (Figure 2.1). One spring tidal excursion is defined as the distance suspended sediment is transported prior to being carried back on the returning tide.

5. From published Admiralty data (UKHO, 2023), a dominant current direction of north/south is evident and a mean spring tidal excursion of 8 km has been determined for this direction in the physical processes study area, reducing to 4 km for the east/west tidal regime. Further details are provided in section 4.3.

6. Figure 2.1 shows the physical processes study area relative to the nearest designated area, Firth of Forth Banks Complex Marine Protected Area (MPA), 25 km to the west of the site boundary.

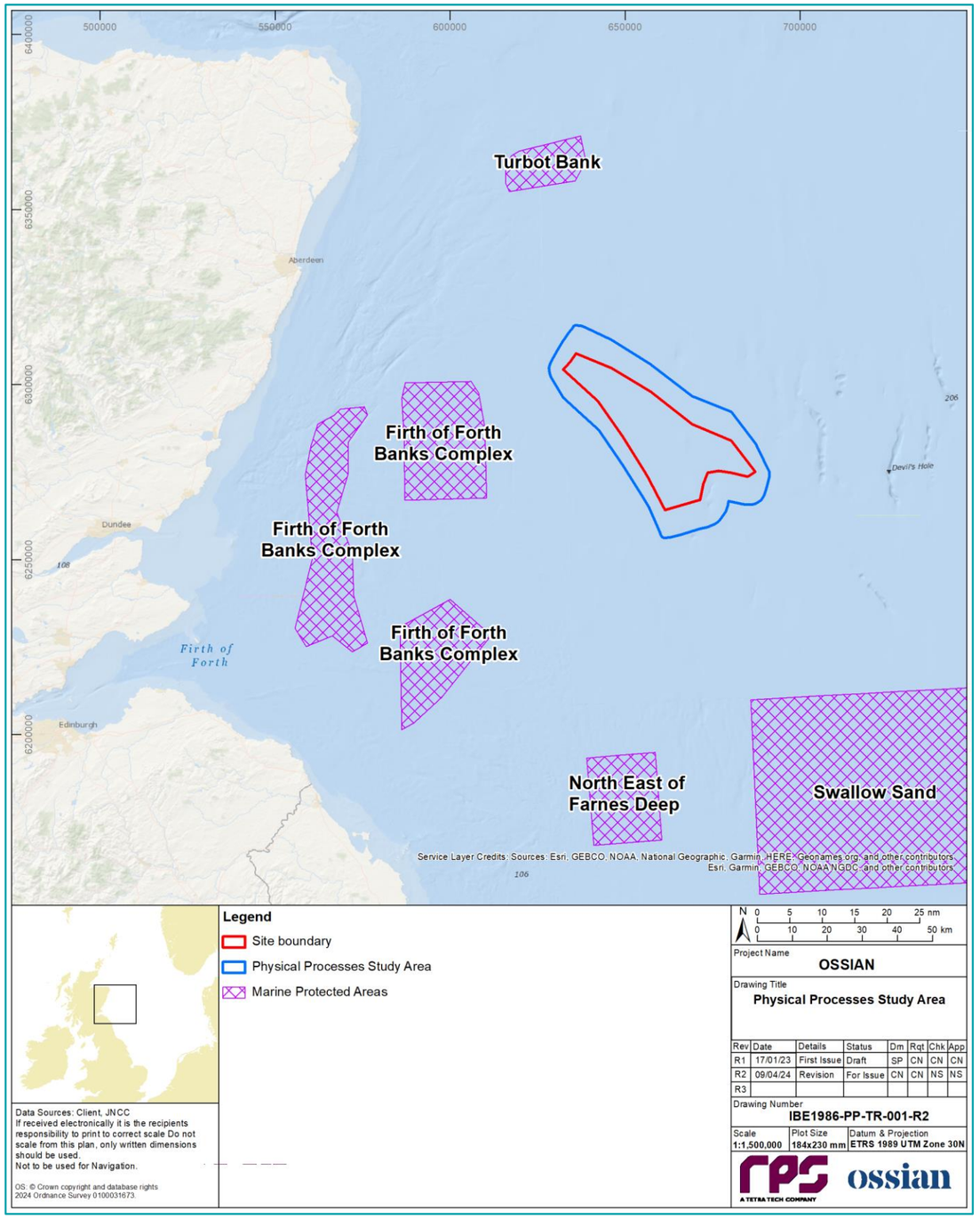

Figure 2.1: Physical Processes Study Area

3. METHODOLOGY

3.1. DESKTOP STUDY

7. Following stakeholder engagement, it was agreed that four impact pathways should be scoped in which are anticipated to be small or insignificant, negating the need for physical processes numerical modelling.

8. A qualitative approach has therefore been adopted, involving a detailed desktop review of existing studies and datasets to gather baseline information on physical processes within the physical processes study area. Table 3.1 summarises the studies and datasets used.

Table 3.1: Summary of Key Desktop Reports

Title	Source	Year	Reference
Climate Forecast System Reanalysis (CFSR) – Global, Meteorological Parameters (including 10m wind) at 0.2 °	NCEP NOAA (DHI Metocean on Demand)	2023	NCEP NOAA, 2023
Joint Nature Conservation Committee (JNCC) Marine Protected Area (MPA) Mapper	JNCC Marine Protected Area (MPA)MPA	2023	JNCC, 2023
Marine Environmental Data Information Network (MEDIN) bathymetry data	MEDIN – bathymetry data	2023	MEDIN, 2023
Seawater Density Calculator	WKC Group	2023	WKC Group, 2023
United Kingdom Hydrographic Office (UKHO) – Published Charts and Tide tables	UKHO Charts 273 1:200000 and 1409 1:200000 incorporating tidal diamonds with current stream data	2023	UKHO, 2023
Berwick Bank Wind Farm Environmental Impact Assessment (EIA) Report, Volume 2, Chapter 7: Physical Processes – Tidal ranges, current speeds, sediment transport	SSE Renewables	2022	SSE Renewables (SSER), 2022
Scottish Shelf Model 3.02 – 27 Year Reanalysis. Scottish Shelf Waters Reanalysis Service (SSW-RS)	Marine Scotland	2022	Barton *et al*., 2022
European Centre for Medium-Range Weather Forecasts (ECMWF) European Wave Model	ECMWF	2021	ECMWF, 2021
Analysis of tidal currents in the North Sea from shipboard acoustic Doppler current profiler data	Continental Shelf Research, 162, 1-12	2018	Vindenes *et al.,* 2018
The Scottish Shelf Model 1990 – 2014 climatology version 2.01	Marine Scotland	2018	De Dominicis *et al*., 2018
British Geological Survey (BGS) Seabed Geology Layers	Marine Scotland – British Geological Survey (BGS)	2017	Marine Scotland, 2017
Monthly averages of non-algal SPM	Cefas Climatology Data	2016	Cefas, 2016
Neart na Gaoithe Offshore Environmental Statement, Chapter 9: Physical Processes– MetOcean data	Mainstream Renewable Power Ltd.	2012	Mainstream Renewable Power Ltd, 2012
Seagreen Alpha and Bravo Offshore Wind Farms Environmental Statement, Volume 3 Technical Appendices: Appendix E2: Metocean and Geophysical Surveys	Royal HaskoningDHV	2012	Royal HaskoningDHV, 2012a
Seagreen Alpha and Bravo Offshore Wind Farms Environmental Statement, Volume 3 Technical Appendices: Appendix E3 – Geomorphological Assessment – Tide, Wave, Geomorphology	Royal HaskoningDHV	2012	Royal HaskoningDHV, 2012b
Climatology of Surface and Near-bed Temperature and Salinity on the North-West European Continental Shelf for 1971–2000, Marine Science Scotland Scottish Shelf Model	Berx and Hughes, Marine Scotland	2009	Berx and Hughes, 2009
Firth of Forth and Tay Developers Group, Collaborative Oceanographic Survey, Specification and Design. Work Package 1 – sediment transport data	HR Wallingford	2009	HR Wallingford, 2009
The Geology of the Central North Sea	United Kingdom Offshore Regional Report. London, Her Majesty's Stationery Office (HMSO). 79-100	1994	Gatliff *et al*., 1994
The Influence of Stratigraphy on the Variation in Geotechnical Properties of the Offshore Quaternary Succession, Scotland	Geological Society, London, Engineering Geology Special Publications (Vol 7, 119-126)	1991	Bone *et al*., 1991

3.2. SITE-SPECIFIC SURVEYS

9. Table 3.2 provides a summary of the surveys undertaken to inform the physical processes baseline and assessment.

Table 3.2: Summary of Surveys undertaken to Inform Physical Processes

Title	Extent of Survey	Overview of Surveyor	Surveyor Contractor	Date	Reference to Further Information
Geophysical survey	Site boundary	Geophysical survey to establish bathymetry, seabed geology, morphology and sediments	Ocean Infinity	March – July 2022	Volume 3, appendix 8.1, annex A
Metocean survey	Site boundary	Metocean survey to establish wave and current data at three locations within the site boundary (Figure 3.1)	Partrac	August 2022 – August 2023	Volume 3, appendix 7.1, annex A

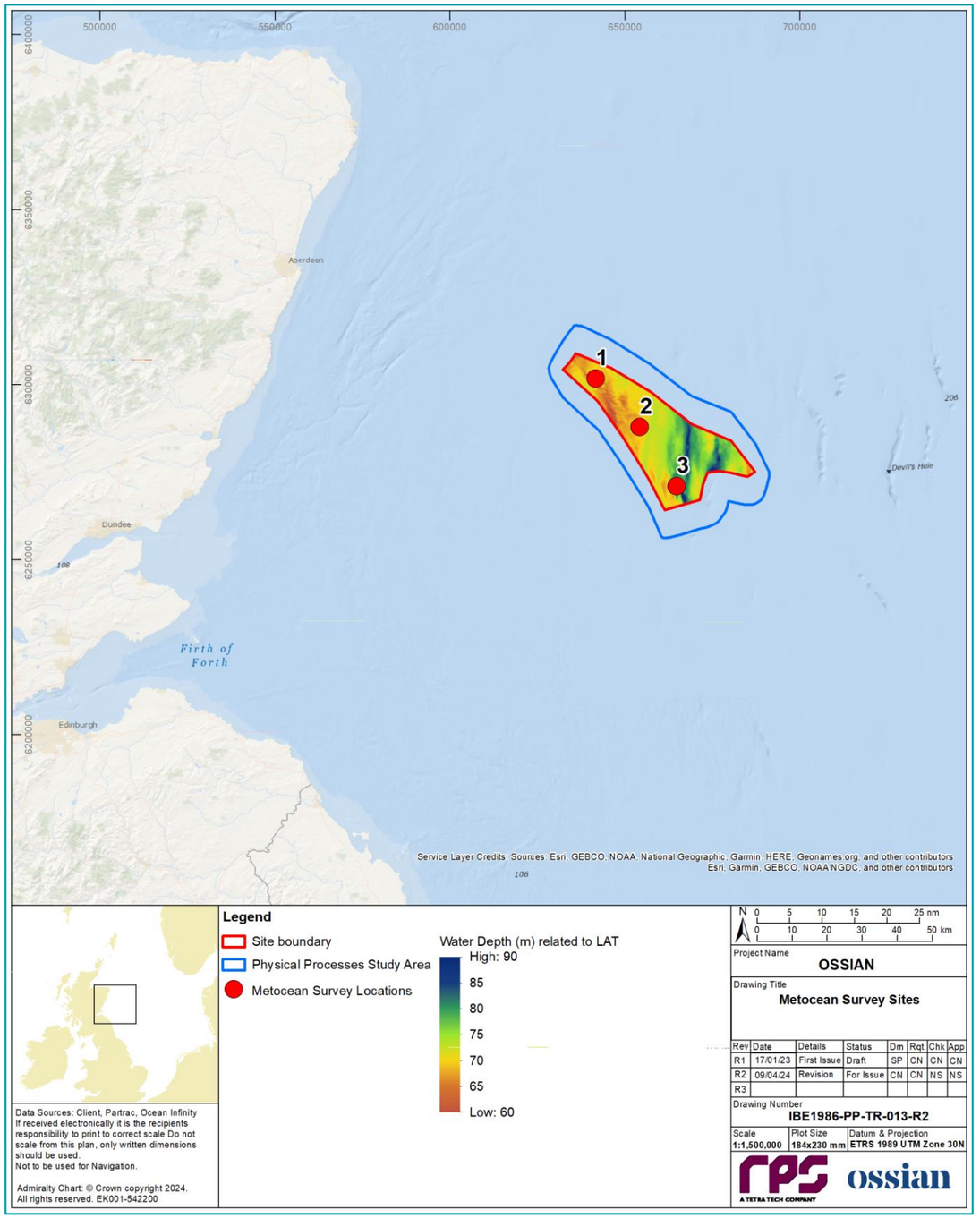

Figure 3.1: Location of Metocean Survey Sites

4. BASELINE ENVIRONMENT

10. The physical processes baseline has been compiled through a comprehensive review of desktop sources and site-specific survey data. A summary of the baseline environment is presented in the following sections.

4.1. BATHYMETRY

11. Site-specific geophysical data collected by Ocean Infinity in 2022 suggests the water depth within the site boundary varies between 63.82 m and 88.66 m relative to Lowest Astronomical Tide (LAT), and average depths of generally 74.47 m below LAT (volume 3, appendix 8.1, annex A). Minimum water depths are found in the north-west of the physical processes study area and maximum depths towards the south (Figure 4.1).

12. Digital Terrain Model (DTM) data available from MEDIN shows a localised depression area to the south of the physical processes study area, within the physical processes study area, with water depths up to 154 m below LAT (MEDIN, 2023). The shallowest location within the physical processes study area is to the north-west of the physical processes study area at 59 m below LAT.

13. The bathymetry within the physical processes study area consists of gentle slopes and generally deepens towards the east. These gentle seafloor gradients range from 0° to 5°, with numerous localised steeper areas observed within ripple areas and flanks of rippled scour depressions. Larger sediment features generally run in a direction from north to south, while smaller sediment features run in a more east to west direction.

14. Figure 4.1 shows the bathymetry collected during the site-specific survey within the site boundary (volume 3, appendix 8.1, annex A) with additional coverage across the physical processes study area, provided by the MEDIN dataset (MEDIN, 2023). Table 4.1 shows the difference in values for the two datasets. As expected, there is a slight difference as a result of different raster resolution and increased accuracy of the Ocean Infinity data. The data is deemed sufficient for assessment.

Table 4.1: Difference in Bathymetry of the MEDIN and Ocean Infinity Data (Locations as per Figure 4.1)

Location	Water depth (m to LAT) MEDIN dataset	Water depth (m to LAT) Ocean Infinity dataset	Difference in MEDIN and Ocean Infinity Data (m)
Metocean survey Location 1	68.20	68.93	0.73
Metocean survey Location 2	71.00	72.39	1.39
Metocean survey Location 3	78.90	81.55	2.65

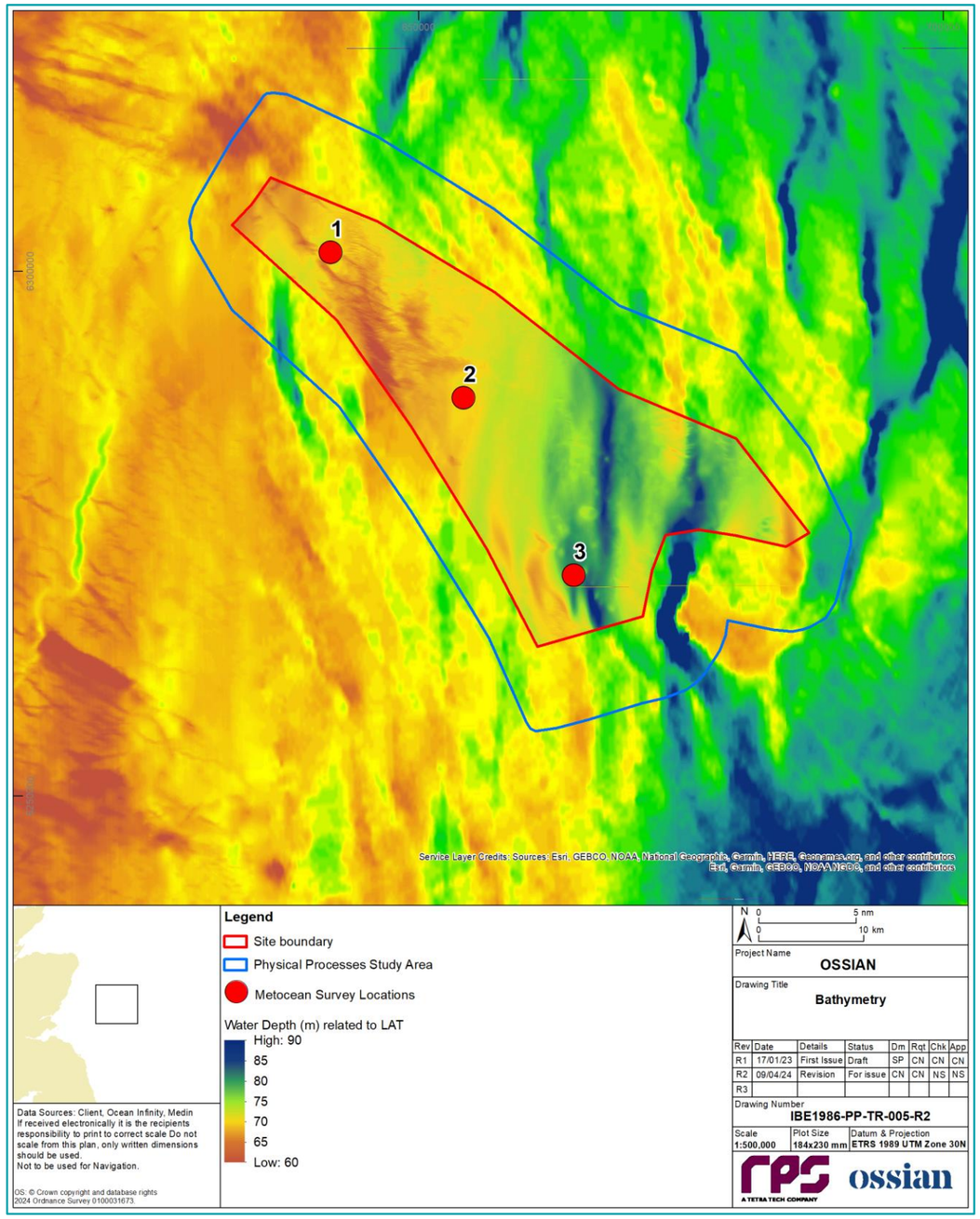

Figure 4.1: Bathymetry Across the Physical Processes Study Area

4.2. WIND AND WAVES

15. In the North Sea, the propagation of tidal waves (as well as the dominant residual circulation) generally follows cyclonic patterns (Vindenes *et al.*, 2018). Throughout the North Sea, strong winds can occur with a large variation in wave height due to fetch limitations and water depth effects (Figure 4.11). Waves in the northern North Sea, where the Array will be located, can be generated either by local winds or from remote wind systems (swell waves) (Royal HaskoningDHV, 2012b).

16. The baseline wind conditions were examined at the physical processes study area by extracting a point within the site boundary from the CFSR dataset by the National Centers for Environmental Prediction (NCEP), part of the National Oceanic and Atmospheric Administration (NOAA). This is a global high accuracy modelled dataset with mean hourly values at a spatial resolution of 0.2 to 0.3 , representative of wind speeds at 10 m above the sea surface. The point was extracted at 56°41.6911'N, 0°25.3224'W (4 km south-east of metocean survey Location 2 as a central point in the physical processes study area) and is representative of conditions across the physical processes study area, covering over 44 years of data from 1979 to 2023. This long term dataset was validated using site specific measurements undertaken by a Floating Light Detection and Ranging (FLiDAR) campaign in 2022/2023, alongside the metocean measurements by Partrac (volume 3, appendix 7.1, annex A). The twelve month FLiDAR dataset provided a range of horizontal wind speeds at two locations within the site boundary, for a series of heights above Mean Sea Level (MSL) (volume 3, appendix 7.1, annex A). The locations of the FLiDAR deployments can be seen in Figure 4.1 (sites 1 and 3).

17. A wind rose was created using the plot composer within the MIKE suite of software. Using the CFSR data at this point, Figure 4.2 demonstrates that the dominant wind directional sectors are from the south-west through to the south, with wind speeds up to 31.5 m/s. This is corroborated by the measured data, which also includes the south and south westerly sectors as the most dominant. The chosen colour palette of the wind rose presents data above a selected threshold of 4 m/s, with 12.78% of the data falling below that threshold and labelled as 'Calm'. A scalebar representing 10% of the dataset has also been included.

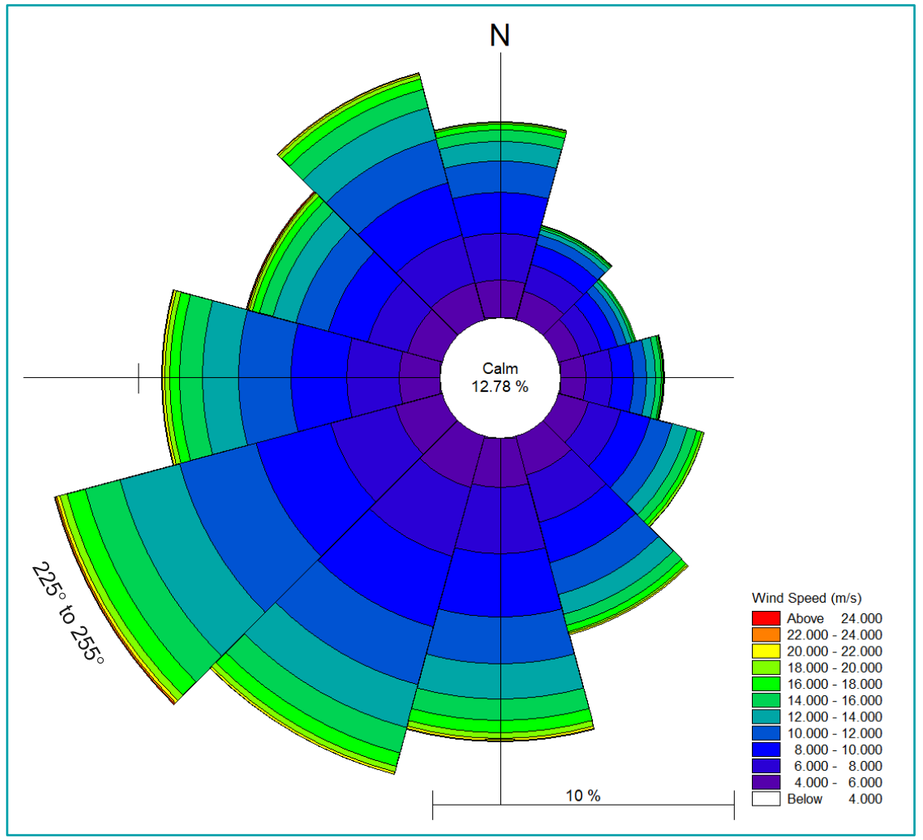

Figure 4.2: Wind Rose at Point 56° 41.6911' N, 0° 25.3224' W Within Site Boundary (NCEP NOAA, 2023)

18. An Extreme Value Analysis (EVA) was undertaken on the long term, mean hourly CFSR wind dataset for the dominant wind directional sector 225° to 255° and also on the complete dataset (omni-directional). This established the return periods for the predominant wind direction. The EVA plot and table for the 225° to 255° directional sector can be found in Figure 4.3 and Table 4.2, respectively, whilst the plot and table for the omni-directional assessment can be found in Figure 4.4 and Table 4.3 respectively. A 1 in 10 year wind speed from 225° to 255° is shown to be 28.97 m/s, or 29.40 m/s when all directional sectors are considered. This increases to 34.39 m/s and 33.37 m/s for a 1 in 200 year wind speed for 225° to 255° and omni-directional, respectively.

19. The site-specific measured data by Partrac at 12 m above MSL were used to validate the CFSR 1 in 1 year return period wind speed of 25.29 m/s. The maximum wind speeds at both Partrac survey locations, measured at ten minute intervals over a twelve month period, were within 5% to 7% of the CFSR 1 in 1 year return period value, produced using mean hourly data at 10 m above MSL. It is noted that maximum wind speeds will vary annually, thus this validation ensures the estimates produced by the statistical analysis broadly align with measured data. Furthermore, the Partrac data provides an indication of the variation in horizontal wind speed with height above MSL. There is a circa 18% reduction in horizontal wind speed from a height of 150 m above MSL to 12 m above MSL at both survey locations. The horizontal wind speeds at the water surface will be subject to a further reduction.

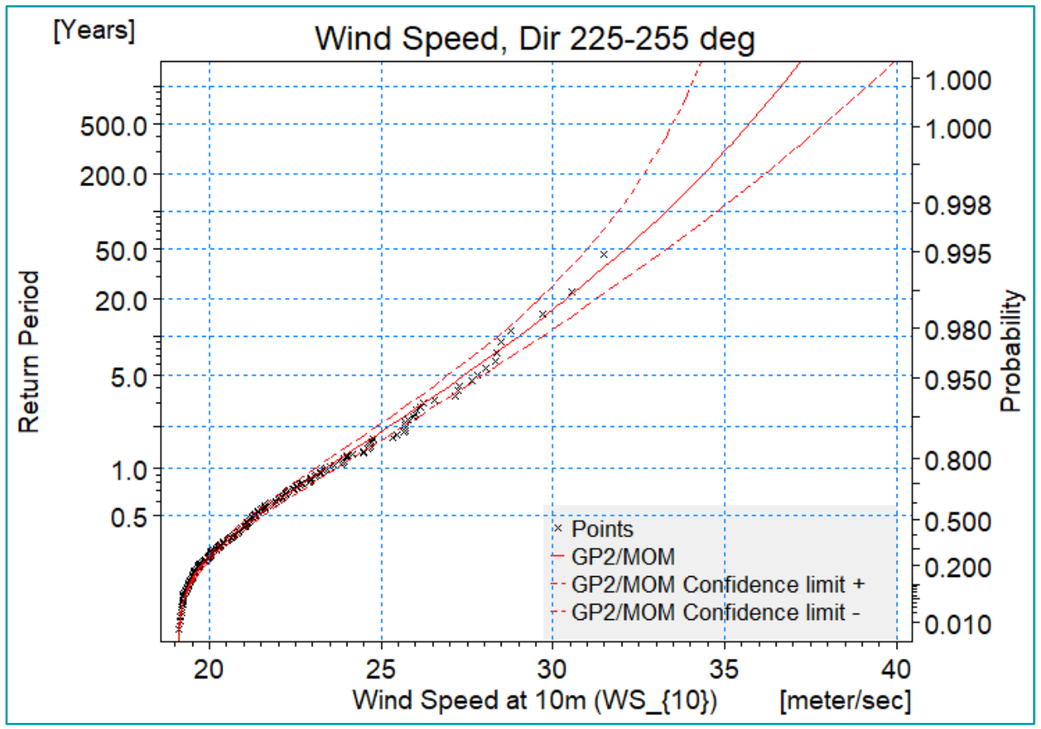

Figure 4.3: EVA Plot of Wind Speed (Directional Sector 225° to 255°)

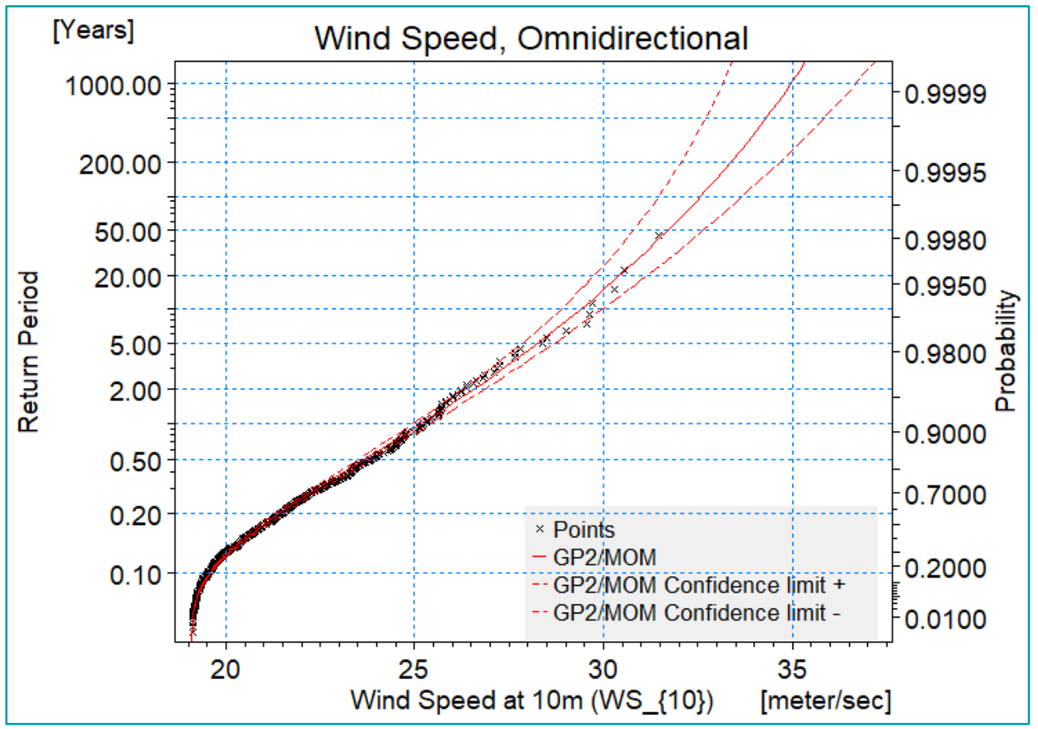

Figure 4.4: EVA Plot of Wind Speed (Omni-Directional)

Table 4.2: EVA Table of Wind Speed (Directional Sector 225°–255°)

Wind Speed		
Dir 225-255 deg		
		D/E Combination
	Return Period [years]	GP2/MOM
Estimated quantile	2.00	25.230
	5.00	27.443
	10.00	28.974
	20.00	30.391
	50.00	32.106
	100.00	33.291
	200.00	34.390
	1000.00	36.636
Average quantile	2.00	25.241
	5.00	27.471
	10.00	29.014
	20.00	30.438
	50.00	32.153
	100.00	33.330
	200.00	34.411
	1000.00	36.583
Standard deviation	2.00	0.386
	5.00	0.504
	10.00	0.642
	20.00	0.833
	50.00	1.157
	100.00	1.445
	200.00	1.761
	1000.00	2.569
Goodness-of-fit statistics	SLSC	0.015
	PPCC1	0.998
	PPCC2	0.998

Table 4.3: EVA Table of Wind Speed (Omni-Directional)

Wind Speed		
Omnidirectional		
		D/E Combination
	Return Period [years]	GP2/MOM
Estimated quantile	2.00	26.585
	5.00	28.258
	10.00	29.403
	20.00	30.454
	50.00	31.712
	100.00	32.574
	200.00	33.365
	1000.00	34.961
Average quantile	2.00	26.596
	5.00	28.273
	10.00	29.420
	20.00	30.470
	50.00	31.722
	100.00	32.576
	200.00	33.356
	1000.00	34.913
Standard deviation	2.00	0.288
	5.00	0.419
	10.00	0.549
	20.00	0.702
	50.00	0.928
	100.00	1.113
	200.00	1.305
	1000.00	1.766
Goodness-of-fit statistics	SLSC	0.010
	PPCC1	0.999
	PPCC2	0.999

20. To inform the baseline wave regime within the physical processes study area, data from the metocean buoys within the site boundary were analysed. These buoys were deployed at three locations within the site boundary from August 2022 for a period of 12 months (Figure 3.1). The locations ensured data was collected over an acceptable spatial domain within the site boundary. Easterly (winds approaching from the east) and east-south-easterly events provided the most extreme records within the dataset at all three locations, as shown in Figure 4.5, Figure 4.6 and Figure 4.7 for Sites 1, 2 and 3, respectively (volume 3, appendix 7.1, annex A). These are joint occurrence plots depicting the percentage of time significant wave heights for a range of values occur in combination with each directional sector. The most extreme event occurred from the east during November 2022, with maximum significant wave heights (Hs) of 8.66 m at Site 1 in the north of the site boundary, 8.70 m at Site 2 in the centre of the Array, and 8.96 m at Site 3 in the south of the Array. Peak wave periods (Tp) up to 20 s were recorded (volume 3, appendix 7.1, annex A).

21. Figure 4.5, Figure 4.6 and Figure 4.7 also show that the dominant wave directional sectors at all three sites are from the north and north-north-easterly directions, (volume 3, appendix 7.1, annex A). Waves recorded from these directions represented between 27.6% and 28.1% of the total dataset and approached up to 6 m in significant wave height at Site 1 and up to 5.5 m at Sites 2 and 3 (volume 3, appendix 7.1, annex A). High energy waves approaching 20 s were also recorded at all three sites, as shown in Figure 4.8, Figure 4.9 and Figure 4.10, with peak wave periods ranging from 4 s to 12 s for 90% of occurrences.

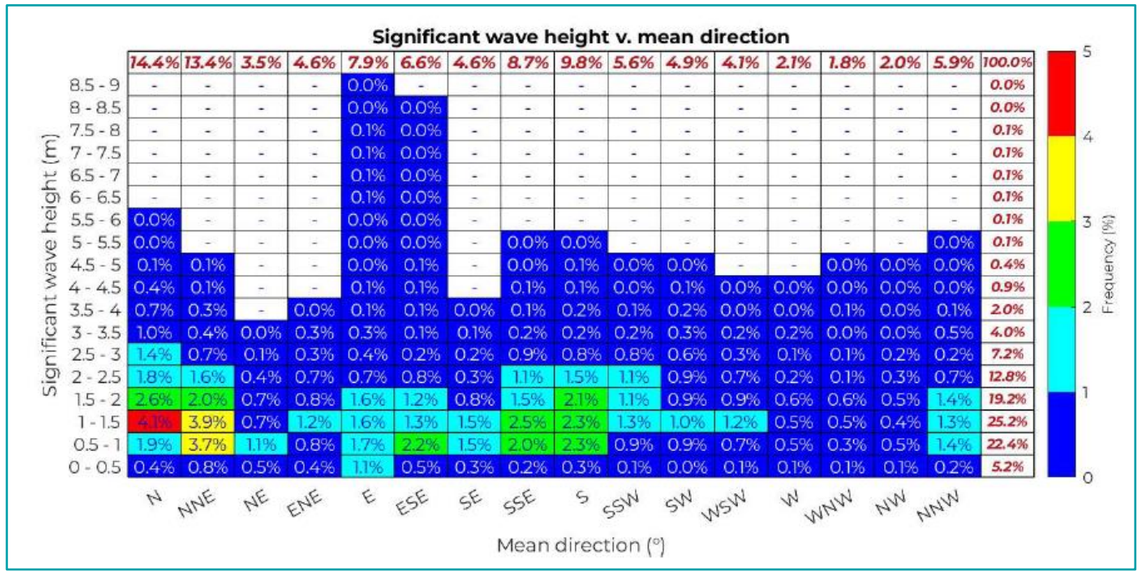

Figure 4.5: Significant Wave Height and Mean Wave Direction Joint Occurrences at Site 1 (volume 3, appendix 7.1, annex A)

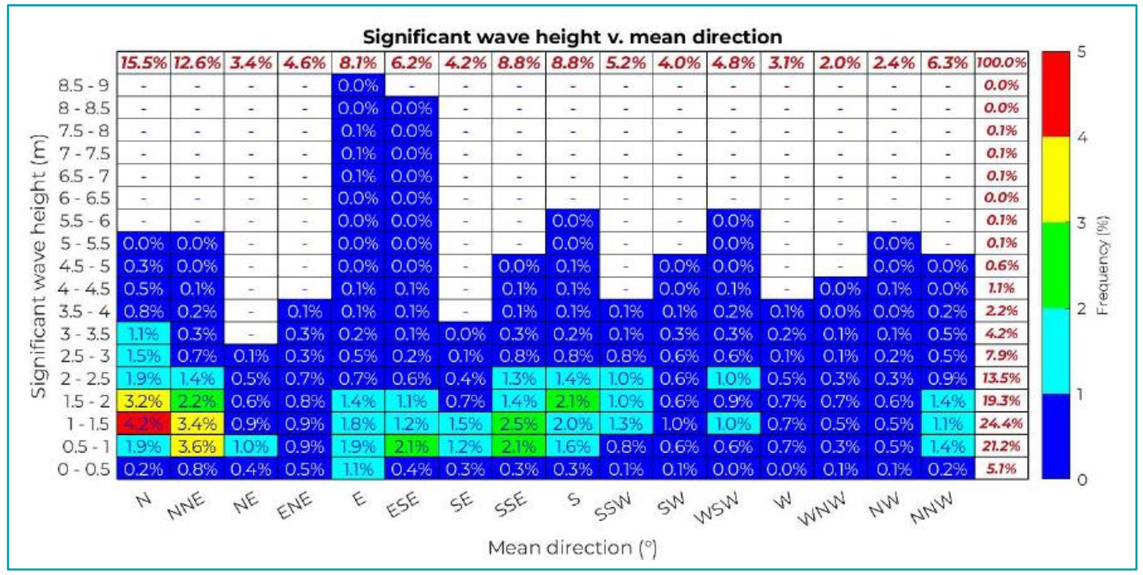

Figure 4.7: Significant Wave Height and Mean Wave Direction Joint Occurrences at Site 3 (volume 3, appendix 7.1, annex A)

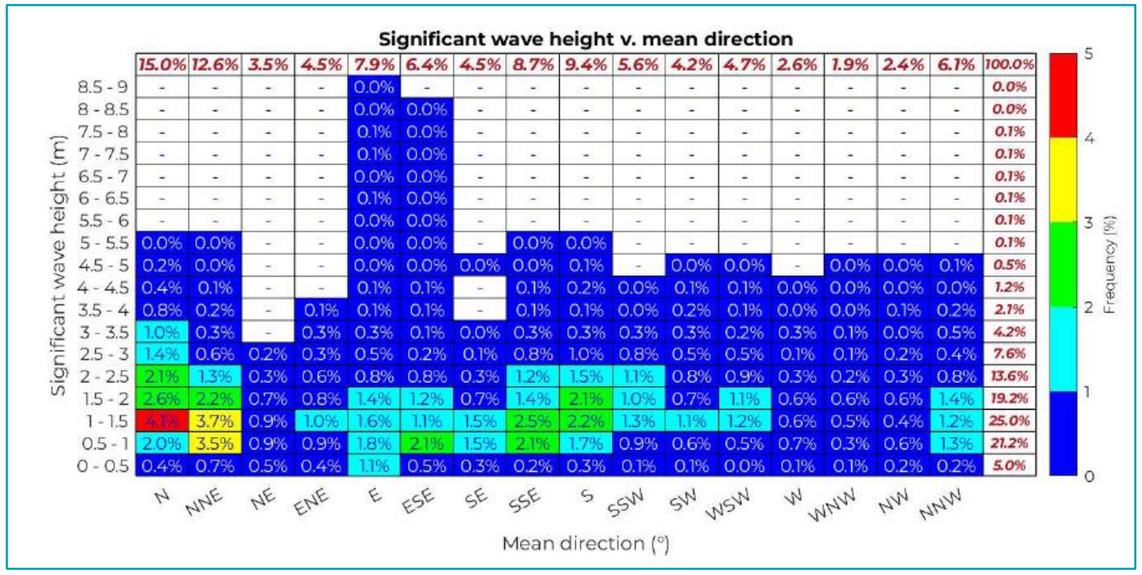

Figure 4.6: Significant Wave Height and Mean Wave Direction Joint Occurrences at Site 2 (volume 3, appendix 7.1, annex A)

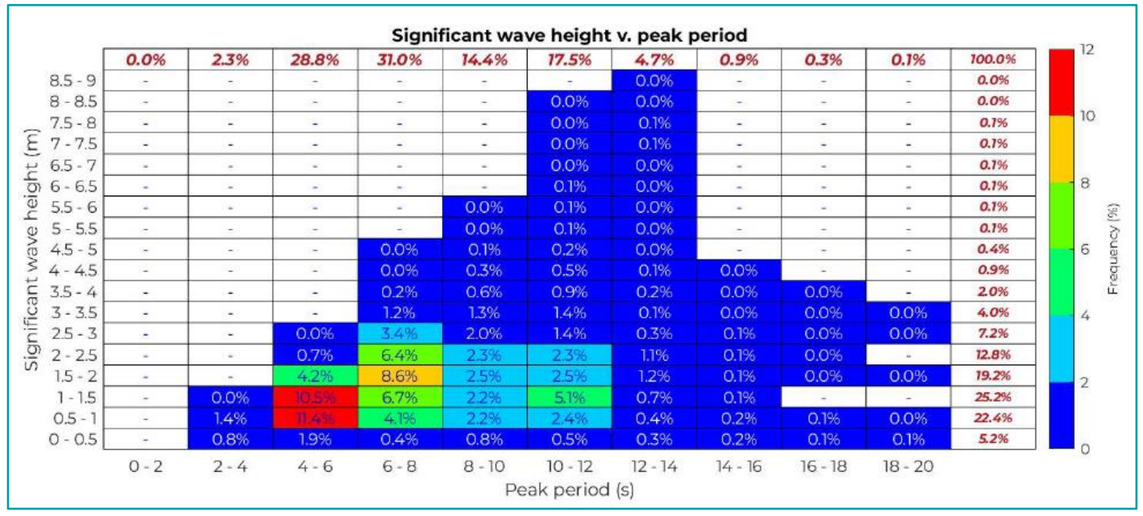

Figure 4.8: Significant Wave Height and Peak Wave Period Joint Occurrences at Site 1 (volume 3, appendix 7.1, annex A)

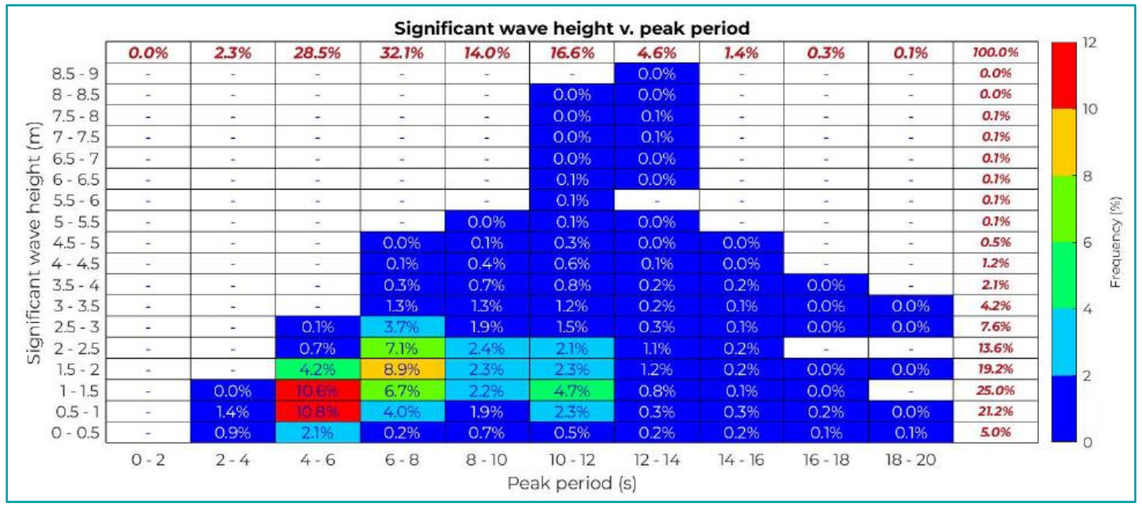

Figure 4.9: Significant Wave Height and Peak Wave Period Joint Occurrences at Site 2 (volume 3, appendix 7.1, annex A)

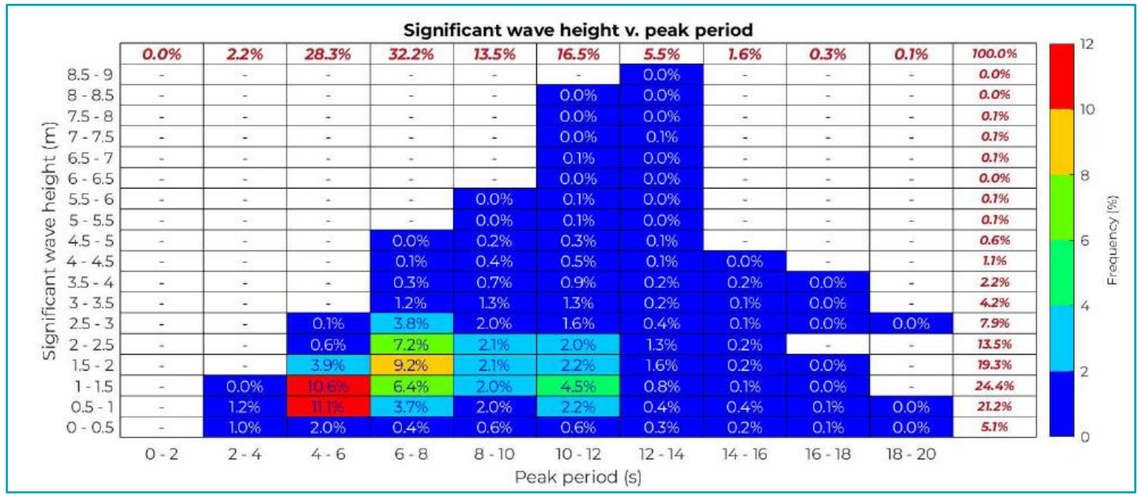

Figure 4.10: Significant Wave Height and Peak Wave Period Joint Occurrences at Site 1 (volume 3, appendix 7.1, annex A)

22. In addition to the field data collected during site-specific survey carried out by Partrac (volume 3, appendix 7.1, annex A), the longer term baseline wave conditions were assessed at the physical processes study area by extracting a point within the site boundary from the ECMWF operational European wave model (ECMWF, 2021). The point is located at 56 41.6911'N, 0°25.3224'W (4 km south-east of metocean survey Location 2 as central point in the physical processes study area) and is representative of over 21 years of data from 2000 to 2021. Figure 4.11 represents a rose plot of the spectral significant wave height (Hm0) at this point, with the dominant wave direction from the north (345° to 015°) and wave heights up to 8.2 m. This is broadly in line with the measured data by Partrac (volume 3, appendix 7.1, annex A). Figure 4.12 shows a rose plot of the peak wave periods (Tp), with high energy waves up to 24 s present within the site boundary.

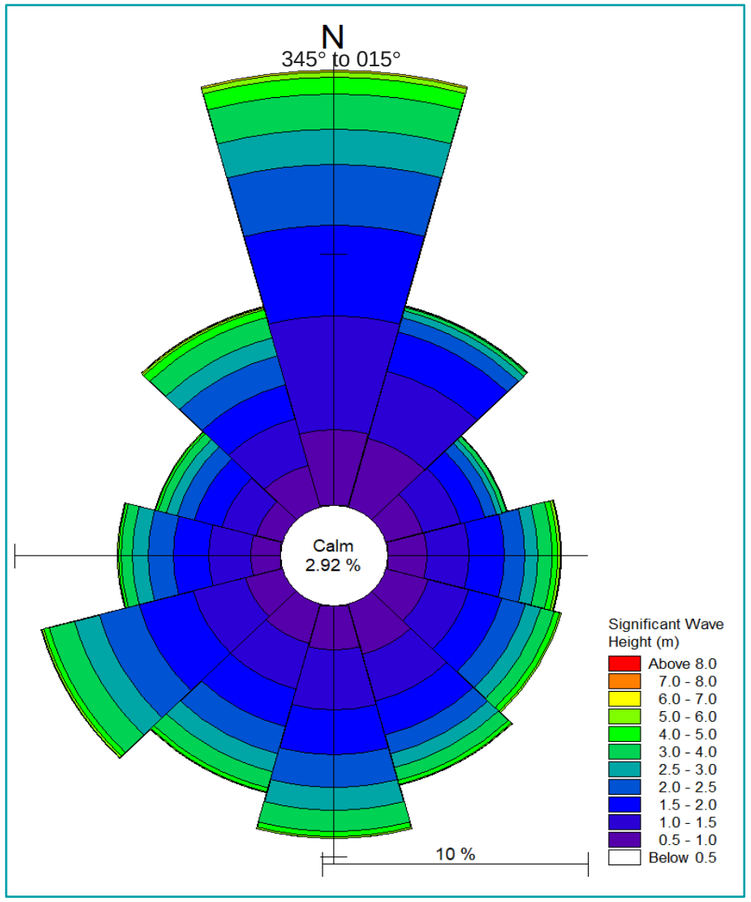

Figure 4.11: Significant Wave Height Rose Plot at Point 56° 41.6911' N, 0° 25.3224' W Within Site Boundary (ECMWF, 2021)

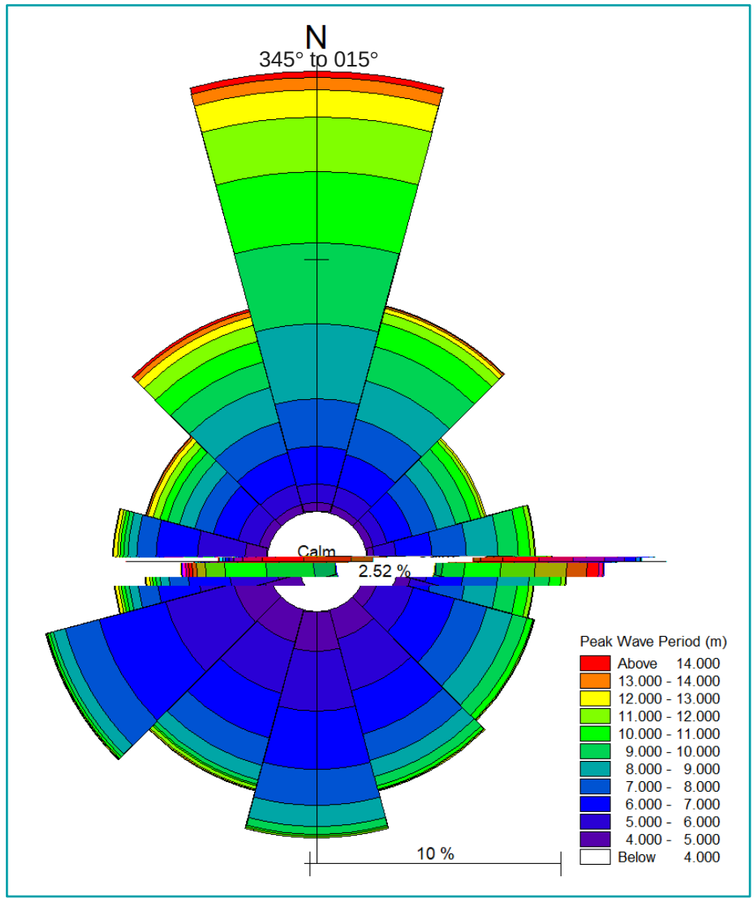

Figure 4.12: Peak Wave Period Rose Plot at Point 56° 41.6911' N, 0° 25.3224' W Within Site Boundary (ECMWF, 2021)

23. Furthermore, metocean data collected from the Round 3 Firth of Forth Zone, have also been used to support the physical processes baseline for the wave regime. Eight metocean buoys were deployed within the Round 3 Firth of Forth Zone, with the nearest buoys approximately 57 km west from the site boundary, with others further inshore towards the Firth of Forth. In the Round 3 Firth of Forth Zone during the stormiest event over the 13 month wave buoy deployment, in January 2012 a significant wave height of 6.7 m was recorded which correlates with a one in one year sea wave climate return period event. Peak spectral wave periods of up to 20 s were recorded during this deployment, associated with strong winds and storms that are characteristic of the North Sea (Royal HaskoningDHV, 2012a). Metocean data were also collected at the Neart na Gaoithe Offshore Wind Farm during 2010. The highest significant wave height recorded was 6 m and wave periods ranged between two and nine seconds (Mainstream Renewable Power Ltd, 2012).

24. The data from the Round 3 Firth of Forth Zone and the Neart na Gaoithe Offshore Wind Farm provide a more holistic representation of the wave climate across this North Sea region, providing recorded data of extreme storm events during different periods of time. This is useful as an approximate validation of the ECMWF dataset within the site boundary. As expected, due to the longer time period of the ECMWF dataset and the location of the physical processes study area, which is further offshore than the Round 3 Firth of Forth Zone and Neart na Gaoithe Offshore Wind Farm, the significant wave heights and peak wave periods are marginally higher than these other sites, with values up to 8.2 m and up to 24 s. As the location of the physical processes study area is further offshore than the Round 3 Firth of Forth Zone and Neart na Gaoithe Offshore Wind Farm, it is exposed to greater fetch lengths and influenced less by land.

25. The Atlas of UK Marine Renewable Energy Resources presented annual mean wave power ranges from 16.17 kW/m to 19.65 kW/m and annual mean significant wave height ranges from 1.87 m to 2.05 m within the physical processes study area (ABPmer, 2008). Figure 4.13 shows the variation in annual mean significant wave height across the physical processes study area using these data.

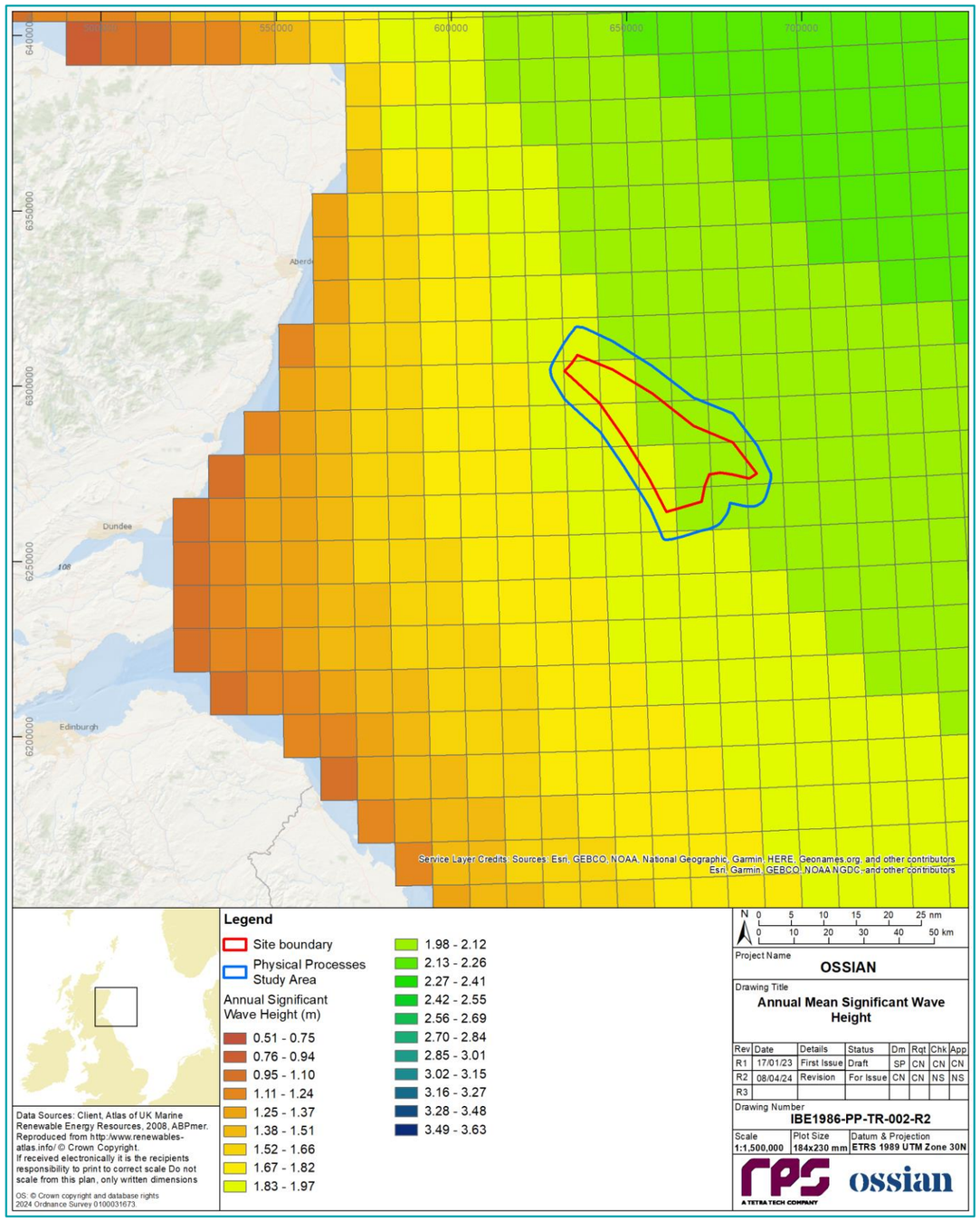

Figure 4.13: Annual Mean Significant Wave Height (m) (ABPmer, 2008)

4.3. TIDAL CURRENTS AND ELEVATION

26. The UKHO states that the mean tidal range at the Standard Port of Leith is approximately 3.6 m whilst the Standard Port at Montrose is 3 m. Leith lies within the Firth of Forth to the south-west of the physical processes study area, whilst Montrose is situated to the west, approximately 100 km from the Array. The two sites have the tidal characteristics as shown in Table 4.4 in metres referenced to Chart Datum (CD).

Table 4.4: Tidal Levels at Standard Ports (UKHO, 2023)

Tidal Level (m CD)	Leith	Montrose
Lowest Astronomical Tide (LAT)	-0.1	0.2
Mean Low Water Springs (MLWS)	0.8	0.8
Mean Low Water Neaps (MLWN)	2.0	1.9
Mean Sea Level (MSL)	3.2	2.9
Mean High Water Neaps (MHWN)	4.4	3.8
Mean High Water Springs (MHWS)	5.6	4.9
Highest Astronomical Tide (HAT)	6.3	5.6

27. Tidal processes are often characterised by the natural tidal elevation of an area. To inform the baseline tidal regime within the physical processes study area, data from the site-specific metocean buoys were analysed. These buoys were deployed within the site boundary from August 2022 for a period of 12 months, as shown in Figure 3.1. Maximum current speeds were recorded in July at each location, with maximum depth-averaged current speeds during the autumn or winter months when the water column was well mixed (volume 3, appendix 7.1, annex A). Currents were dominated by semi-diurnal tidal flow and surface currents strongly rectilinear, orientated north and south, with nearbed currents orientated in a north-north-east and south-south-west direction (volume 3, appendix 7.1, annex A). Further data available from the metocean data collated within the Seagreen 2011 survey campaign in the Round 3 Firth of Forth Zone also shows a semi-diurnal tidal regime (Royal HaskoningDHV, 2012b). Tidal elevations across the outer Firth of Forth are governed by a southerly directed flood tide which moves along the eastern coastline of Scotland into the Firth of Forth and around Fife Ness. Across the mouth of the Firth, the flood tidal stream has a general east-south-east pattern, whilst the ebb tidal stream runs in a west-north-west direction (Royal HaskoningDHV, 2012b).

28. The site-specific Partrac survey showed the mean spring tidal range to vary from 2.41 m in the north of the site boundary, to 2.34 m in the south, whilst the mean neap tidal range varied from 1.20 m to 1.17 m (volume 3, appendix 7.1, annex A). At all sites, currents flow in a south-south-westerly direction near the bed and a southerly direction near the surface. Mean current speeds of 0.21 m/s and 0.27 m/s were captured near the bed and surface respectively at Site 1 in the north, with smaller mean differences at Site 2 and Site 3 between the surface and bed values (volume 3, appendix 7.1, annex A). The maximum recorded current speed occurred at Site 1 in July 2023, where a value of 0.91 m/s was reached near the surface, whilst the maximum depth-averaged speed of 0.68 m/s occurred in October 2022 at Site 1 (volume

3, appendix 7.1, annex A). Maximum depth averaged current speeds of 0.66 m/s and 0.62 m/s occurred in January 2023 at Sites 2 and 3, respectively (volume 3, appendix 7.1, annex A).

29. In addition to the field data collected during the Partrac site-specific survey (volume 3, appendix 7.1, annex A), the baseline tidal currents were examined within the physical processes study area by reviewing the Atlas of UK Marine Renewable Energy Resources, which showed peak current speeds of up to 0.55 m/s and 0.28 m/s in the north of the physical processes study area, during mean spring and mean neap tides, respectively (ABPmer, 2008). At the south of the physical processes study area, peak current speeds of 0.4 m/s and 0.2 m/s were shown for mean spring and mean neap tides, respectively (ABPmer, 2008). The Partrac metocean study recorded marginally higher depth-averaged current speeds of 0.68 m/s in the north and 0.62 m/s in the south of the physical processes study area (volume 3, appendix 7.1, annex A), accounting for meteorological conditions in the measured data, with a broadly similar pattern. Figure 4.14 shows the variation in peak current speeds during a mean spring tide across the physical processes study area. The Atlas of UK Marine Renewable Energy Resources also shows a spring tidal range of between 1.91 m to 2.51 m across the physical processes study area, with the greatest range in the west to the smallest range in the east (ABPmer, 2008). This is in line with the values captured by the site-specific metocean study of 2.34 m to 2.41 m (volume 3, appendix 7.1, annex A).

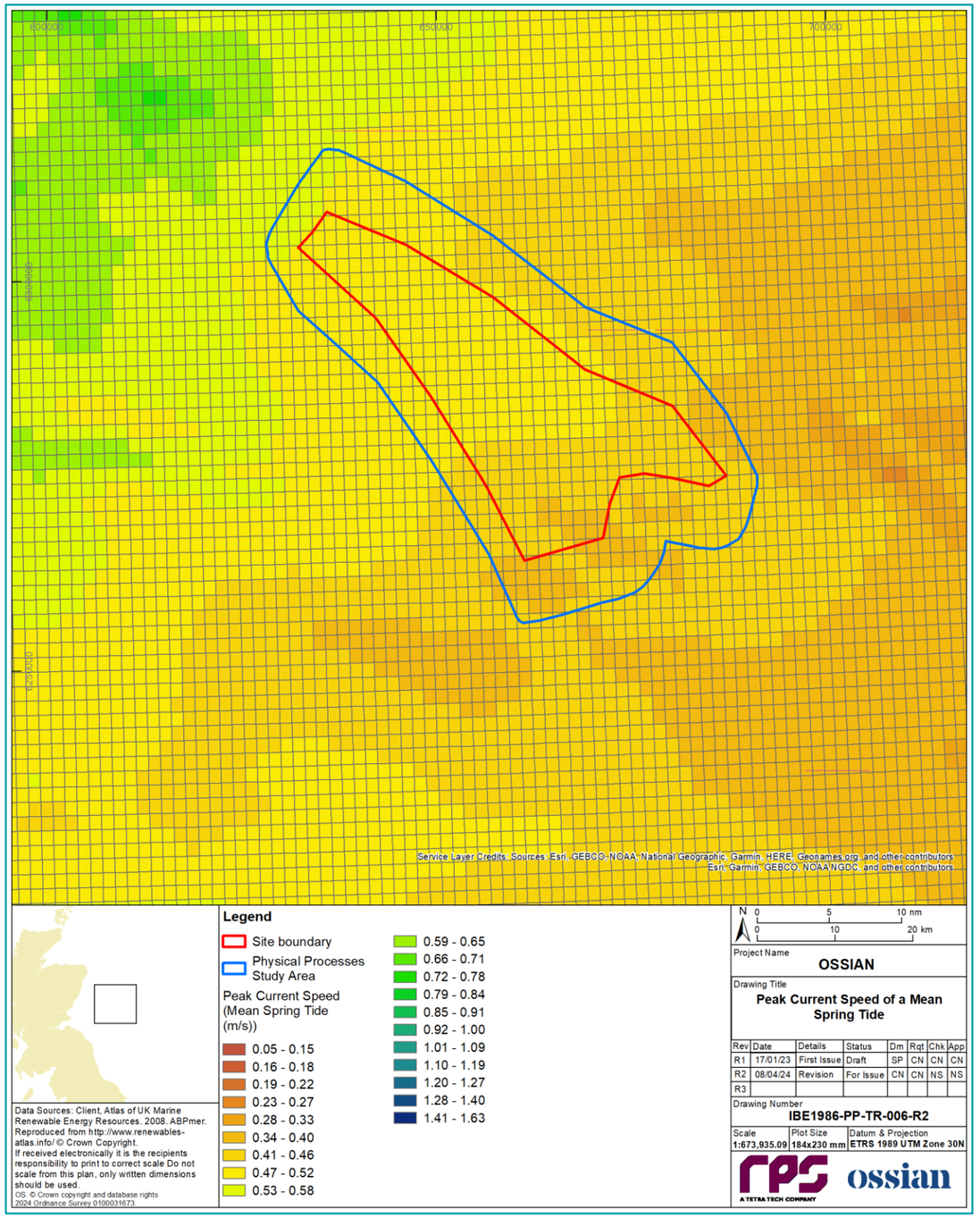

Figure 4.14: Peak Current Speed of a Mean Spring Tide (ABPmer, 2008)

30. Furthermore, Admiralty tidal diamonds to the north and south-west of the physical processes study area show a predominant north-south current direction, with maximum spring tide current speeds up to 0.36 m/s to the south-west of the physical processes study area, with current speeds up to 0.51 m/s to the north of the physical processes study area. Locations of tidal diamonds 273A and 1409J can be seen in Figure 4.15, with current speeds and directions outlined in Table 4.5. The data are taken from Admiralty Charts 273 and 1409, tidal diamonds A and J, respectively. These values broadly align with the Atlas of UK Marine Renewable Energy Resources.

31. Tidal diamonds 273A and 1409J were used to define the physical processes study area as outlined in section 2. The summation of the linearly orientated north/south current speeds over the flood and ebb tide, provided an indication of the potential distance a particle could travel from the site boundary under spring tide conditions. The greatest distance calculated was less than 8 km, based on tidal diamond 1409J, when currents flow in a north/south direction. The extent of the physical processes study area in this north/south orientation was thus defined as a conservative 8 km. Flow in the east/west orientation is much less significant at both tidal diamonds 273A and 1409J, occurring at low speeds towards slack water, however a conservative extent of 4 km was assumed to provide an appropriate buffer to the site boundary and inform the physical processes study area, as shown in Figure 4.15.

Table 4.5: Admiralty Tidal Diamond Current Speeds (UKHO, 2023)

273A		Spring tide		1409J		Spring tide	
Hours		Current speed (m/s)	Current Direction (°)	Hours		Current speed (m/s)	Current Direction (°)
Before High Water (HW) Dover	6	0.15	52	Before HW Aberdeen	6	0.51	14
	5	0.31	15		5	0.36	18
	4	0.36	16		4	0.10	27
	3	0.36	7		3	0.10	180
	2	0.31	357		2	0.31	192
	1	0.10	339		1	0.46	193
HW Dover	0	0.10	240	HW Aberdeen	0	0.51	190
After HW Dover	1	0.21	204	After HW Aberdeen	1	0.46	192
	2	0.36	188		2	0.21	200
	3	0.36	188		3	0.05	340
	4	0.31	177		4	0.26	9
	5	0.10	160		5	0.41	12
	6	0.10	55		6	0.51	14

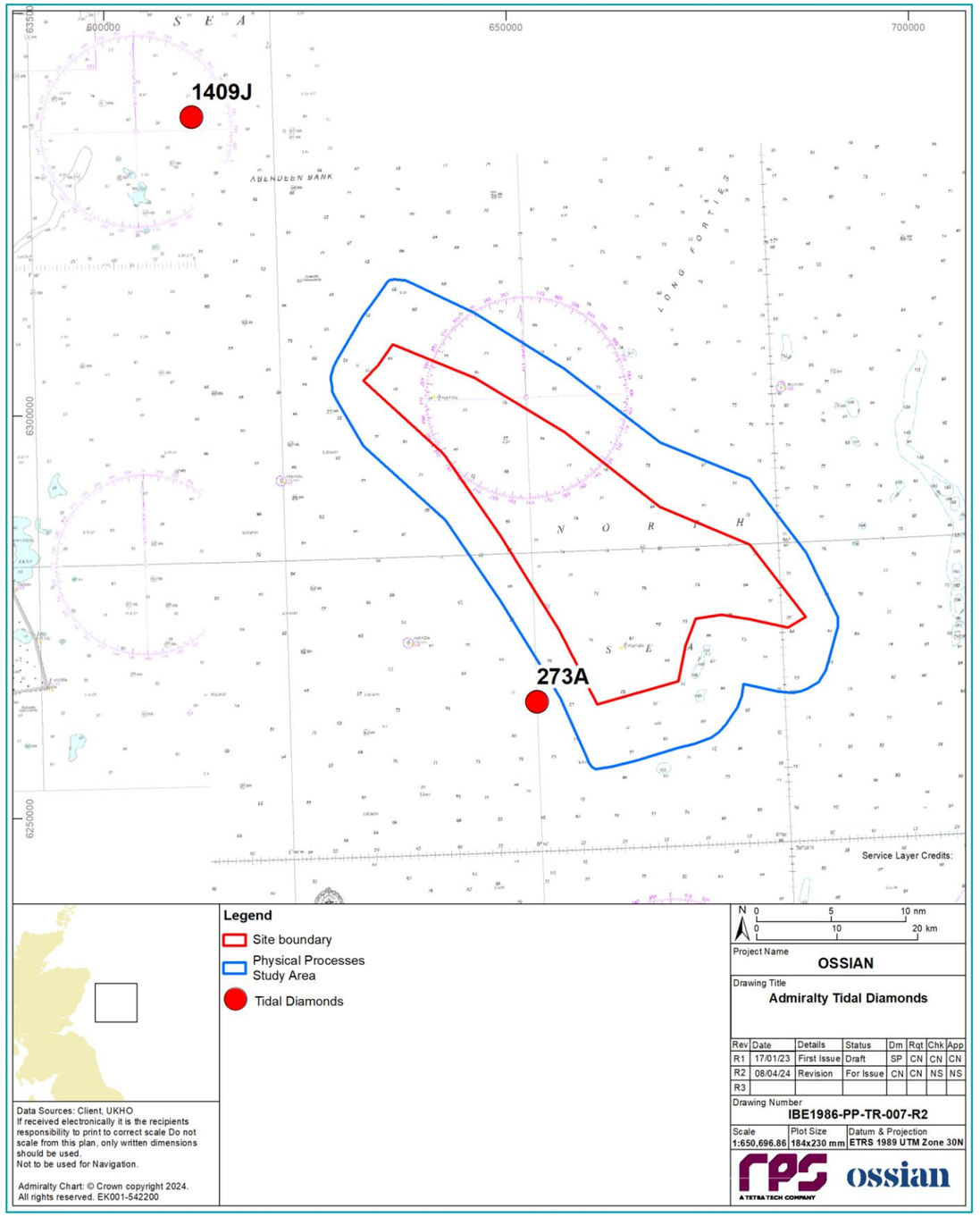

Figure 4.15: Location of Admiralty Tidal Diamonds

32. In addition, Metocean surveys conducted across the nearby Round 3 Firth of Forth zone provided an overview of tidal current flows in the area 50.75 km to the south-west of the Array, offshore of the Firth of Forth. A maximum current speed of 0.91 m/s was recorded in April 2011 within the northern part of Seagreen 1 Offshore Wind Farm and Seagreen 1A Project (formerly known as Seagreen Alpha and Bravo) at a point circa 75 km from the site boundary to the south-west. Within the central to southern area of the Round 3 Firth of Forth Zone, the maximum current speed ranged from 0.72 m/s to 0.77 m/s, with maximum speeds ranging from 0.68 m/s to 0.76 m/s towards the coast (Royal HaskoningDHV, 2012b).

33. According to the Berwick Bank Offshore Wind Farm EIA Report, a mean tidal range of 3.25 m and current speeds between 0.5 m/s and 0.6 m/s during peak flood and ebb tides were established for the Berwick Bank Offshore Wind Farm, located 56.77 km to the south-west of the Array (SSER, 2022).

4.4. WATER COLUMN PROCESSES

34. A 30 year temperature and salinity climatology for the 1971 to 2000 period for the North-West European Shelf is available from the International Council for the Exploration of the Sea (ICES) and World Ocean Data Centre (WODC) (Berx and Hughes, 2009). Nearbed and surface salinity and temperature monthly mean values are available across the physical processes study area at a resolution of approximately 10 km. To establish the baseline water column processes within the physical processes study area and to identify levels of stratification, the differences between nearbed and surface salinity monthly mean values were calculated from this dataset. Extent and timing of stratification are relevant in terms of the impact on primary productivity, higher trophic levels and ecosystem services.

35. A representative sample of the results at a point towards the centre of the physical processes study area (56° 39.0000’ N, 0° 25.0020’ W) is shown in Table 4.6. This point was selected to illustrate the seasonal patterns of stratification within the physical processes study area, due to its close alignment with mean surface and nearbed salinity and temperature values across all available data points within the physical processes study area. The results show that the largest surface and bed salinity differences occur in August, with May and June also showing some of the largest differences. The full dataset confirms that this is applicable across the physical processes study area. Salinity values at the bed are reported to be less than 0.1 Practical Salinity Units (PSU) different from the salinity values at the surface for all months and across the physical processes study area. As expected, the month of August also shows the biggest differential in temperature, with the surface up to 7.27°C warmer than the bed. The greatest difference in temperature occurs towards the south of the physical processes study area. Figure 4.16 and Figure 4.17 show the August monthly mean values for surface and nearbed salinity respectively across the physical processes study area. Similarly, Figure 4.18 and Figure 4.19 show the August monthly mean values for surface and nearbed temperature.

36. The water depth at point 56.6500°N, 0.4167°W is 73.69 m according to the results of the site-specific geophysical survey (volume 3, appendix 8.1, annex A). Therefore, the hydrostatic pressure at this point equates to 8.490 bar. Using the online ‘Seawater Density Calculator’ by WKC Group, the nearbed density for the August monthly mean can be calculated as 1026.78 kg/m^3 (WKC Group, 2023). In comparison, the surface density equates to 1,025.86 kg/m^3, a difference of less than 1 kg/m^3.

37. Considering the mean differences in salinity through the water column across the physical processes study area are reported to be less than 0.1 PSU for all months, as discussed in paragraph 34, the physical processes study area can be considered as being subject to weak seasonal stratification, with evidence of relatively thorough mixing, even in the summer months.

38. The site-specific metocean survey campaign by Partrac between 2022 and 2023 captured salinity and temperature data close to the bed at three locations within the site boundary, as shown in Figure 3.1. Through the summer months, temperatures slowly increase, however most of the heat is retained in the upper stratified layer (volume 3, appendix 7.1, annex A). Current shear was observed with strongest currents in the upper mixed layer during the summer months (volume 3, appendix 7.1, annex A). Maximum nearbed temperatures were recorded in October, when the surface waters that were subject to increased temperatures in the summer months have become fully mixed with the deeper layers (volume 3, appendix 7.1, annex A). This mixing occurs relatively quickly, with the bed temperatures then cooling slowly until March, when temperatures reach a minimum (volume 3, appendix 7.1, annex A). This is in line with patterns expected with seasonal stratification.

39. The highest nearbed temperature and salinity values were recorded at Site 1 in the north, 12.91°C and 35.1 PSU, respectively, with a mean salinity value of 35.02 PSU. This compares to maximum temperatures of 12.49°C and 12.13°C at Sites 2 and the deeper Site 3, respectively, and mean salinity values of 34.85 PSU and 34.92 PSU during November and December (volume 3, appendix 7.1, annex A). Minimum temperatures ranging from 6.77°C to 6.90°C were also captured (volume 3, appendix 7.1, annex A).

Table 4.6: Monthly Mean Salinity and Temperature Variation at 56° 39.0000’ N, 0° 25.0020’ W (Berx and Hughes, 2009)

Month	Nearbed Salinity (PSU)	Surface Salinity (PSU)	Surface minus Bed Salinity (PSU)	Nearbed Temperature (°C)	Surface Temperature (°C)	Surface minus Bed Temperature (°C)
January	34.9189	34.8987	-0.0202	7.1624	7.2050	0.0426
February	34.8504	34.8339	-0.0165	6.4398	6.5043	0.0645
March	34.8603	34.8125	-0.0478	6.3148	6.2000	-0.1148
April	34.7772	34.7928	0.0156	6.4304	6.6245	0.1941
May	34.7887	34.7363	-0.0524	6.4009	7.4732	1.0723
June	34.8025	34.7435	-0.0590	7.3158	10.6907	3.3749
July	34.8107	34.7776	-0.0331	7.7465	12.7474	5.0009
August	34.8133	34.7279	-0.0854	8.6354	14.5727	5.9373
September	34.8514	34.8262	-0.0252	10.3334	12.3809	2.0475
October	34.9649	34.9166	-0.0483	10.3747	11.4691	1.0944
November	34.8541	34.8297	-0.0244	9.9175	9.9806	0.0631
December	34.9164	34.9446	0.0282	9.2149	9.2223	0.0074

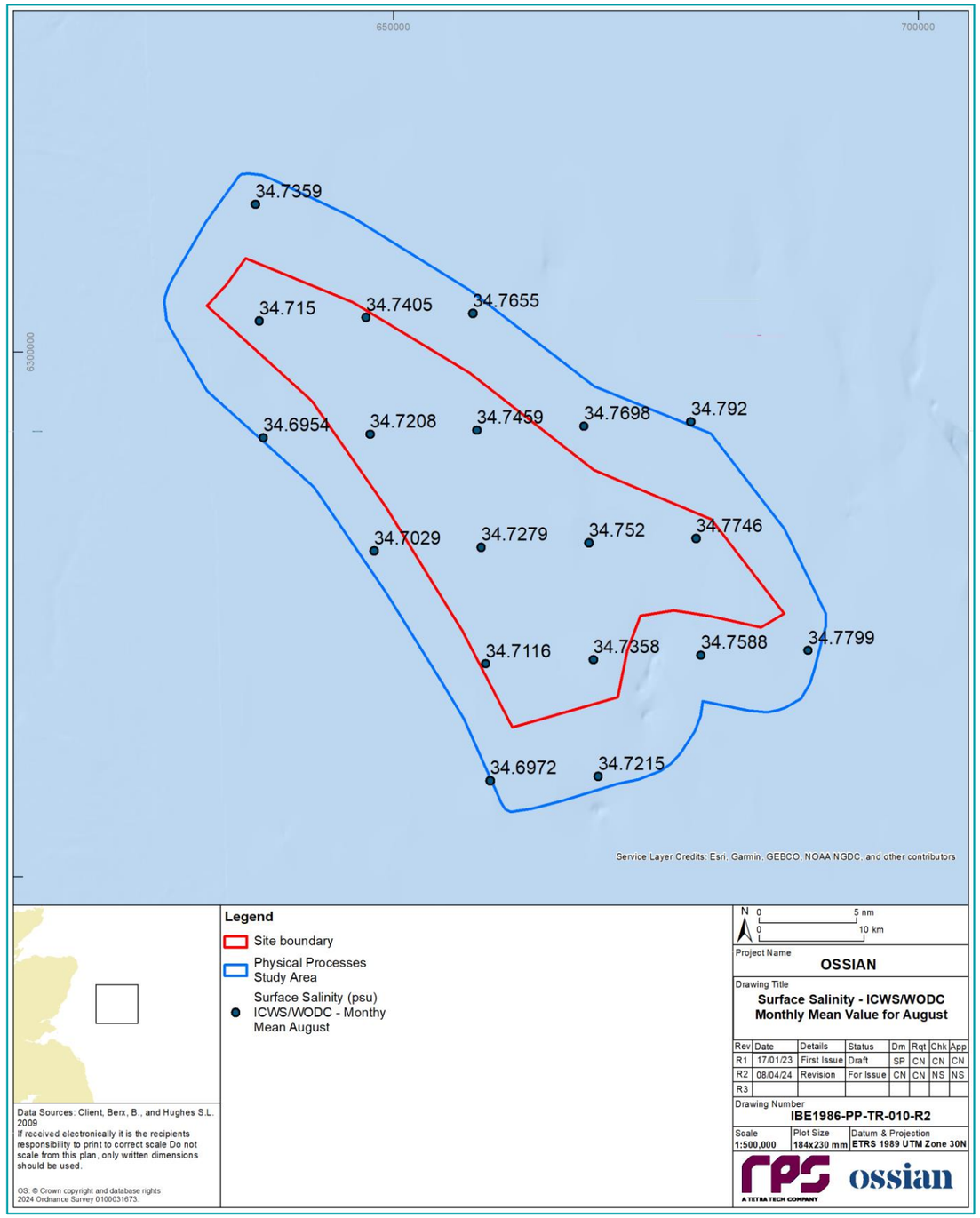

Figure 4.16: Surface Salinity – Monthly Mean Value for August (PSU) (Berx and Hughes, 2009)

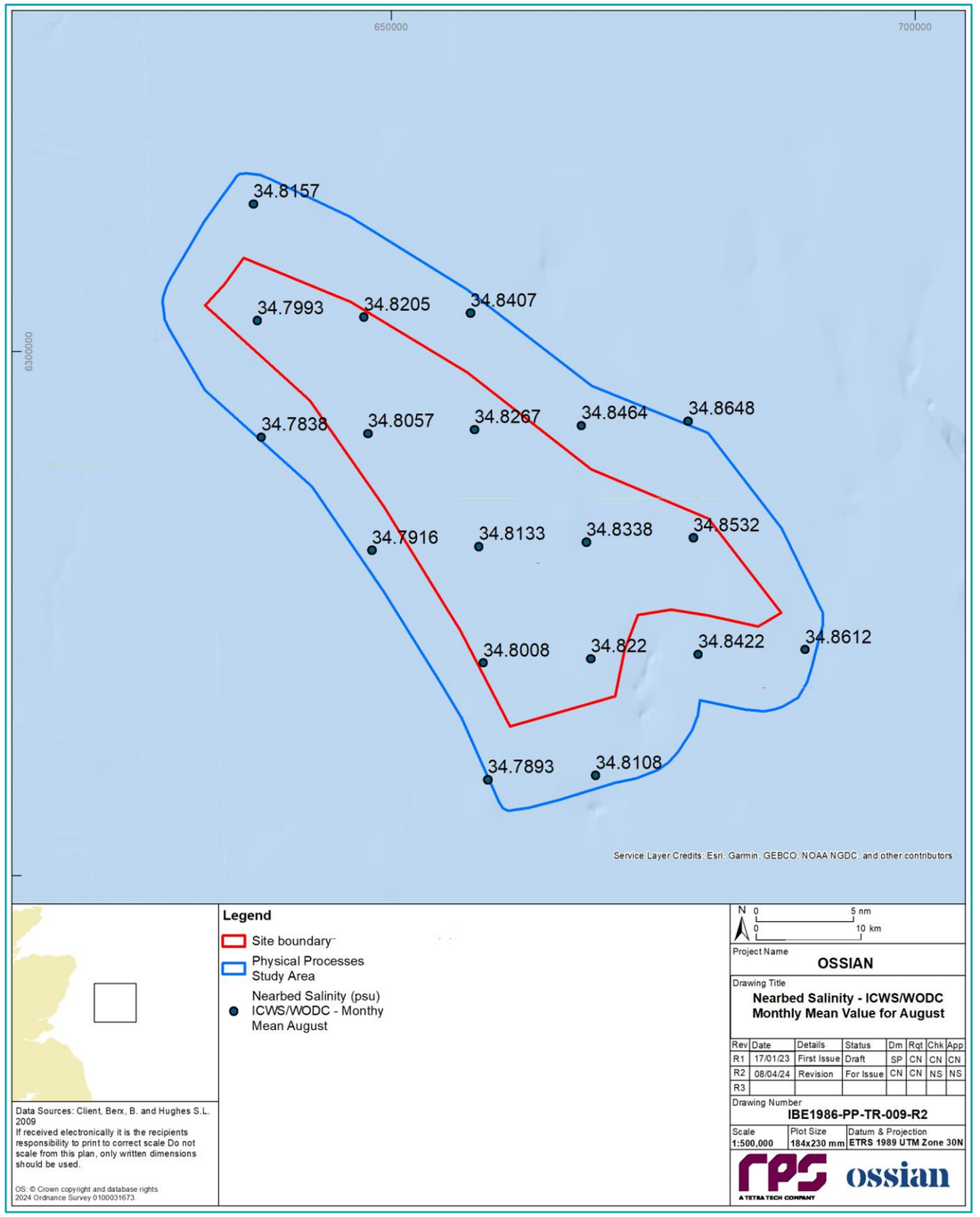

Figure 4.17: Nearbed Salinity – Monthly Mean Value for August (PSU) (Berx and Hughes, 2009)

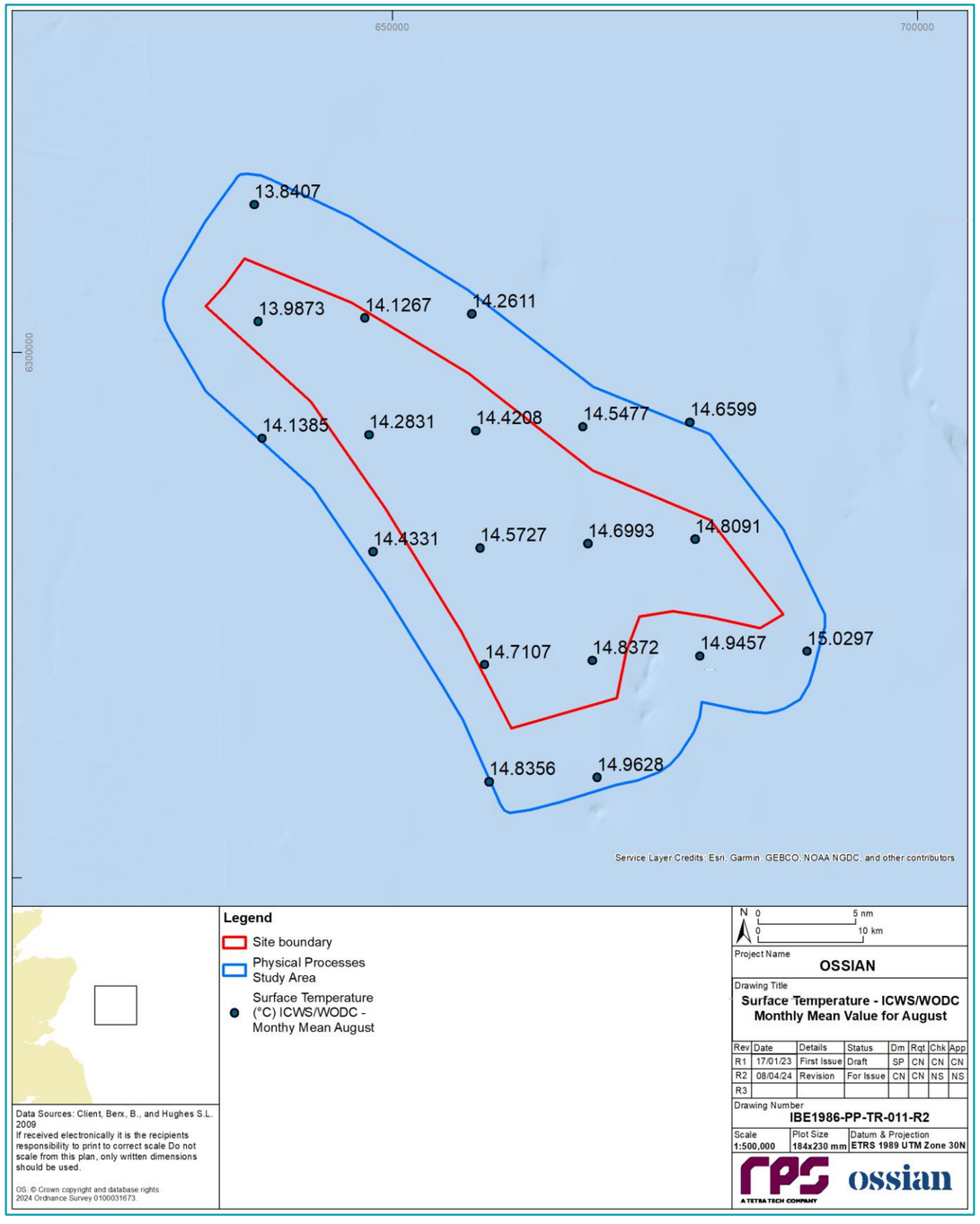

Figure 4.18: Surface Temperature – Monthly Mean Value for August (°C) (Berx and Hughes, 2009)

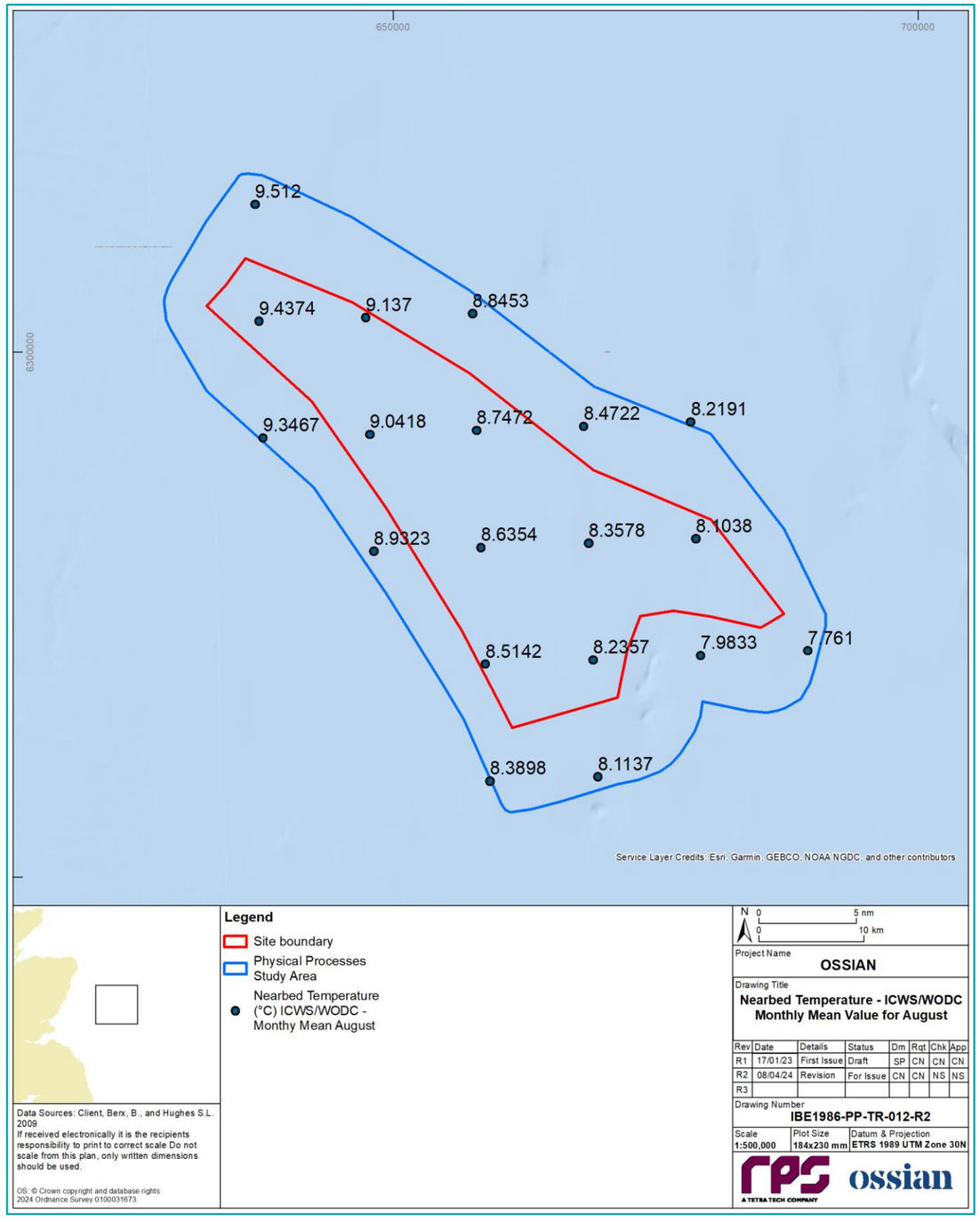

Figure 4.19: Nearbed Temperature – Monthly Mean Value for August (°C) (Berx and Hughes, 2009)

40. The Scottish Shelf Waters Reanalysis Service (SSW-RS) (Barton *et al.*, 2022) provides a 27 year reanalysis dataset (1993 to 2019) of the Scottish Shelf Model (De Dominicis *et al.*, 2018), which covers the Scottish continental shelf waters. The hindcast model provides three-dimensional currents, temperature and salinity data. To further establish the baseline water column processes within the physical processes study area, and how this is affected in both calm and stormy conditions, data have been extracted from the model during the month of August, which has been established as the most critical for seasonal stratification (paragraph 34). In order to assess a range of wind conditions, the year 2016 has been selected, as this was a particularly stormy period, with wind speeds close to 20 m/s on 08 August 2016, in comparison to a low of 0.72 m/s on 15 August 2016. For analysis, 08 August 2016 has been deemed as the storm event period and 15 August 2016 as the calm period.

41. Figure 4.20 and Figure 4.21 show the salinity through the water column on 08 August 2016 under storm conditions, with Figure 4.22 and Figure 4.23 showing the salinity on 15 August 2016 under calm conditions. Similarly, Figure 4.24 to Figure 4.27 show the same water column plots for temperature under both storm and calm conditions. Each set of plots show the salinity or temperature at the sea surface and various depths through the water column, along with the values at the seabed.

42. Within the physical processes study area, the salinity plots under storm conditions show similar salinity conditions from the surface until circa 19 m depth, with further changes until circa 27 m depth, when conditions become very similar to those experienced at the bed. This implies that under the most critical month of August and under storm conditions, the stratified layer is no more than 25 m to 30 m of the water column, or circa 35% of the depth. The salinity plots under calm conditions show a very similar pattern, with depths of stratification reaching circa 27 m. This implies that the effects of wind on the weak stratification in this area are very low. Furthermore, under storm conditions, the effect of wind speeds on salinity would be expected to be evident between the surface and circa 5 m depth, where the wind has the most potential influence on the mixing. However, this is not the case, with the surface and 3.9 m depth plots appearing virtually identical in Figure 4.20, thus underpinning the limited effect of the wind on the water column mixing processes in the physical processes study area.

43. With regard to temperature, both storm and calm plots show a similar pattern to salinity, as expected, with temperatures from a depth of circa 35 m almost identical to temperatures at the bed. This provides further evidence that during the most critical month of August, the variation in density and hence the stratified layer is limited to the top 35% to 50% of the water column. No mixing is evident in the lower half of the water column. The differences between surface and bed salinity within the physical processes study area are less than 0.1 PSU, therefore any stratification even under the most extreme conditions is classified as weak.

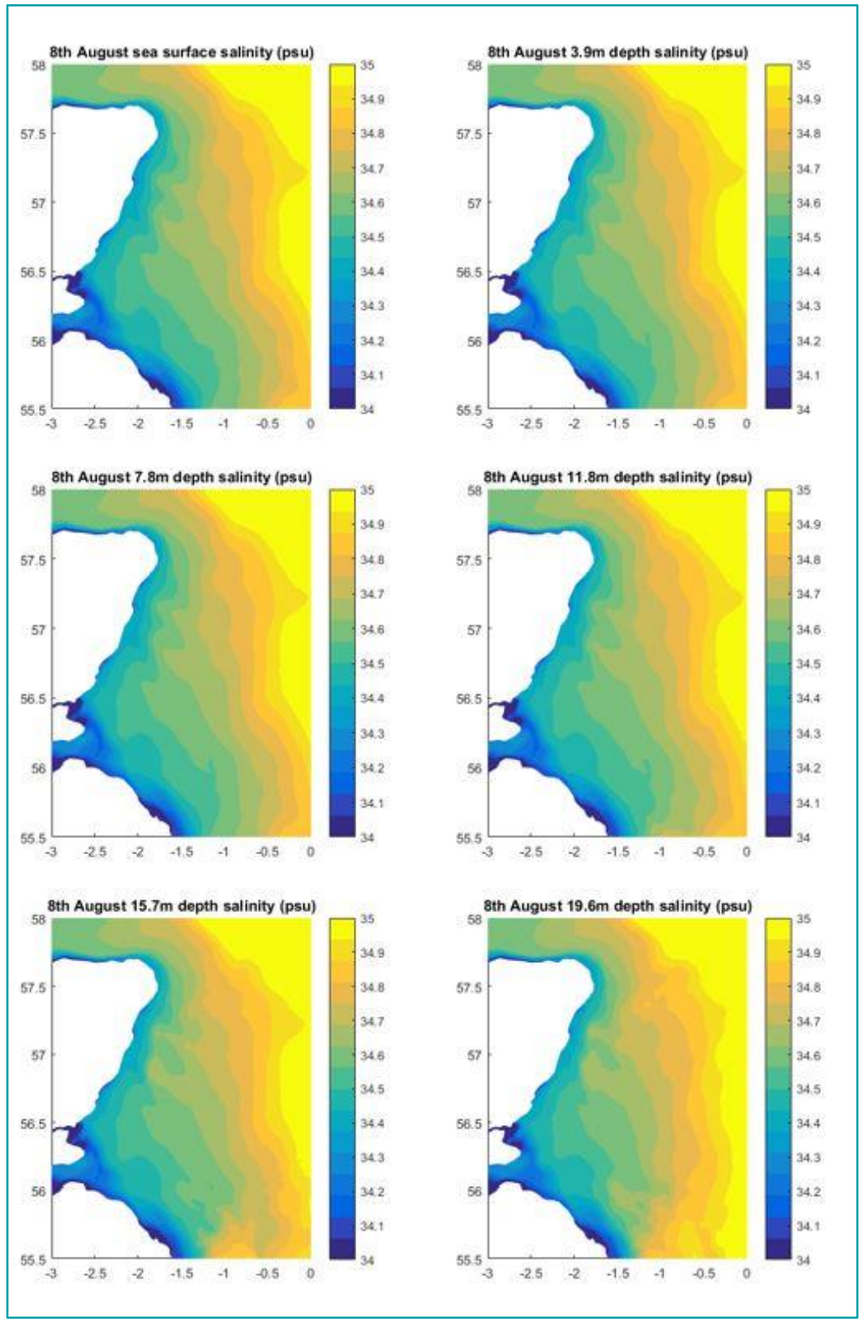

Figure 4.20: SSW-RS Water Column Salinity – 08 August 2016 (Storm Conditions). Axes Show Longitude and Latitude (Barton *et al.*, 2022)

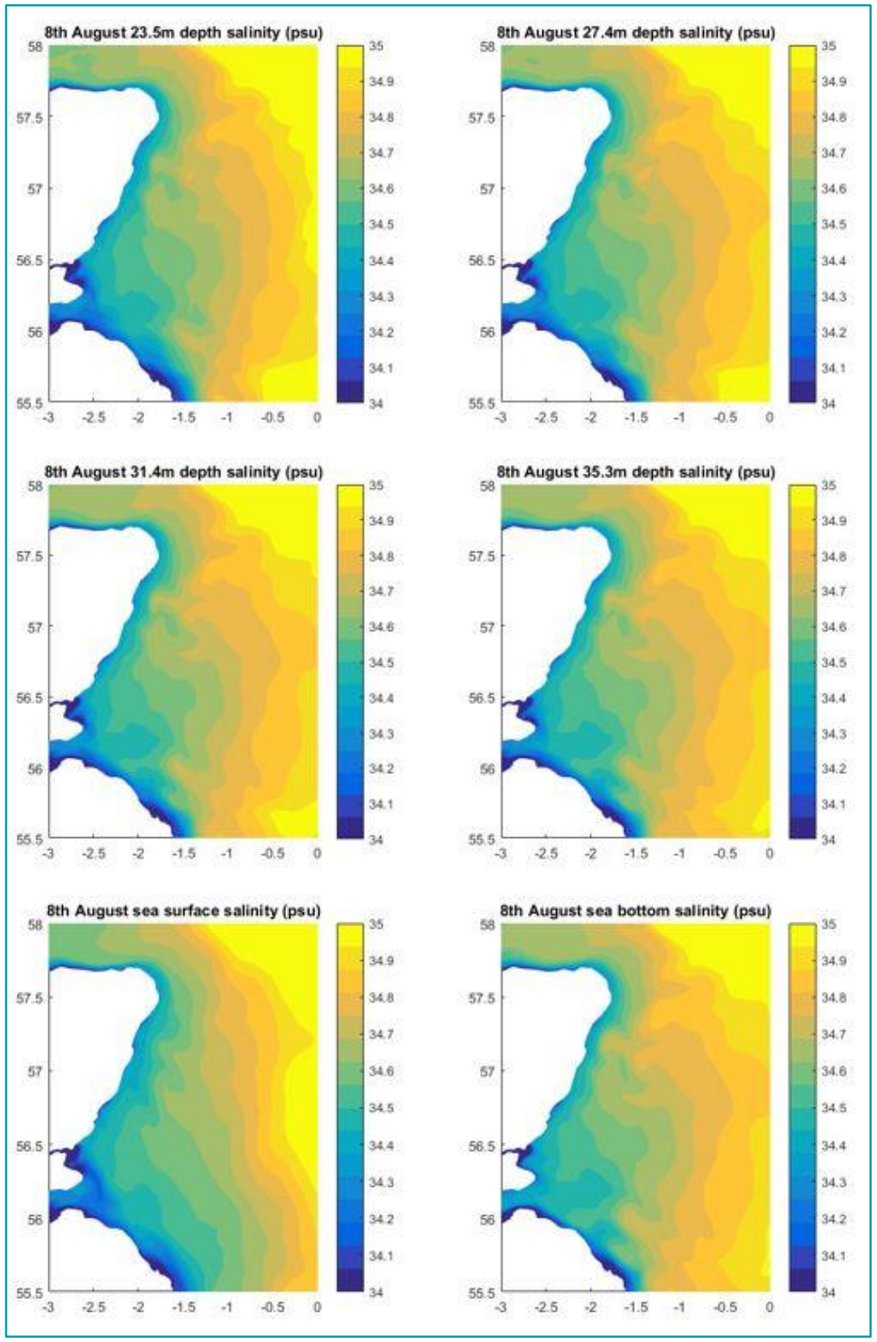

Figure 4.21: SSW-RS Water Column Salinity – 08 August 2016 (Storm Conditions). Axes Show Longitude and Latitude (Barton *et al*., 2022)

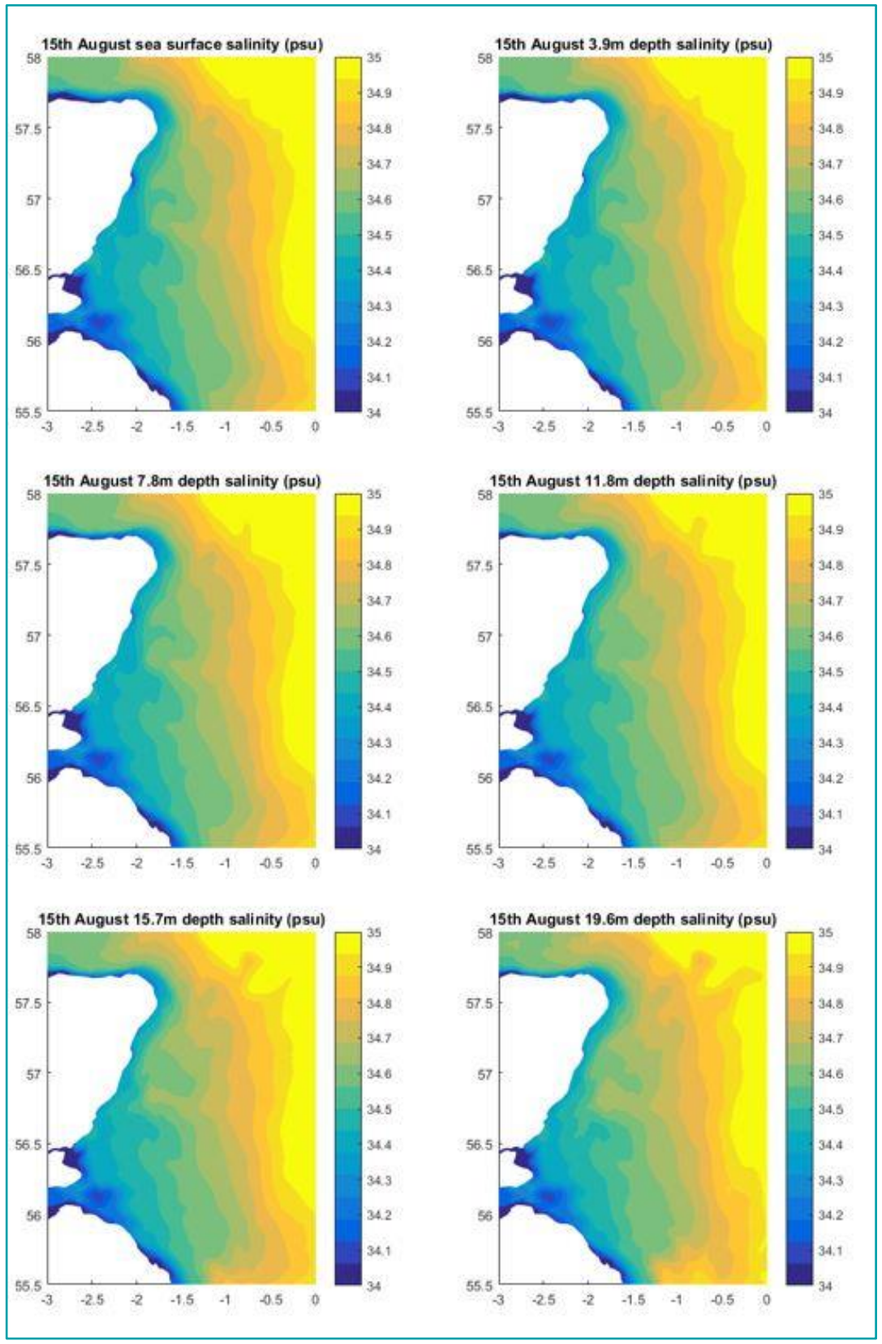

Figure 4.22: SSW-RS Water Column Salinity – 15 August 2016 (Calm Conditions). Axes Show Longitude and Latitude (Barton *et al*., 2022)

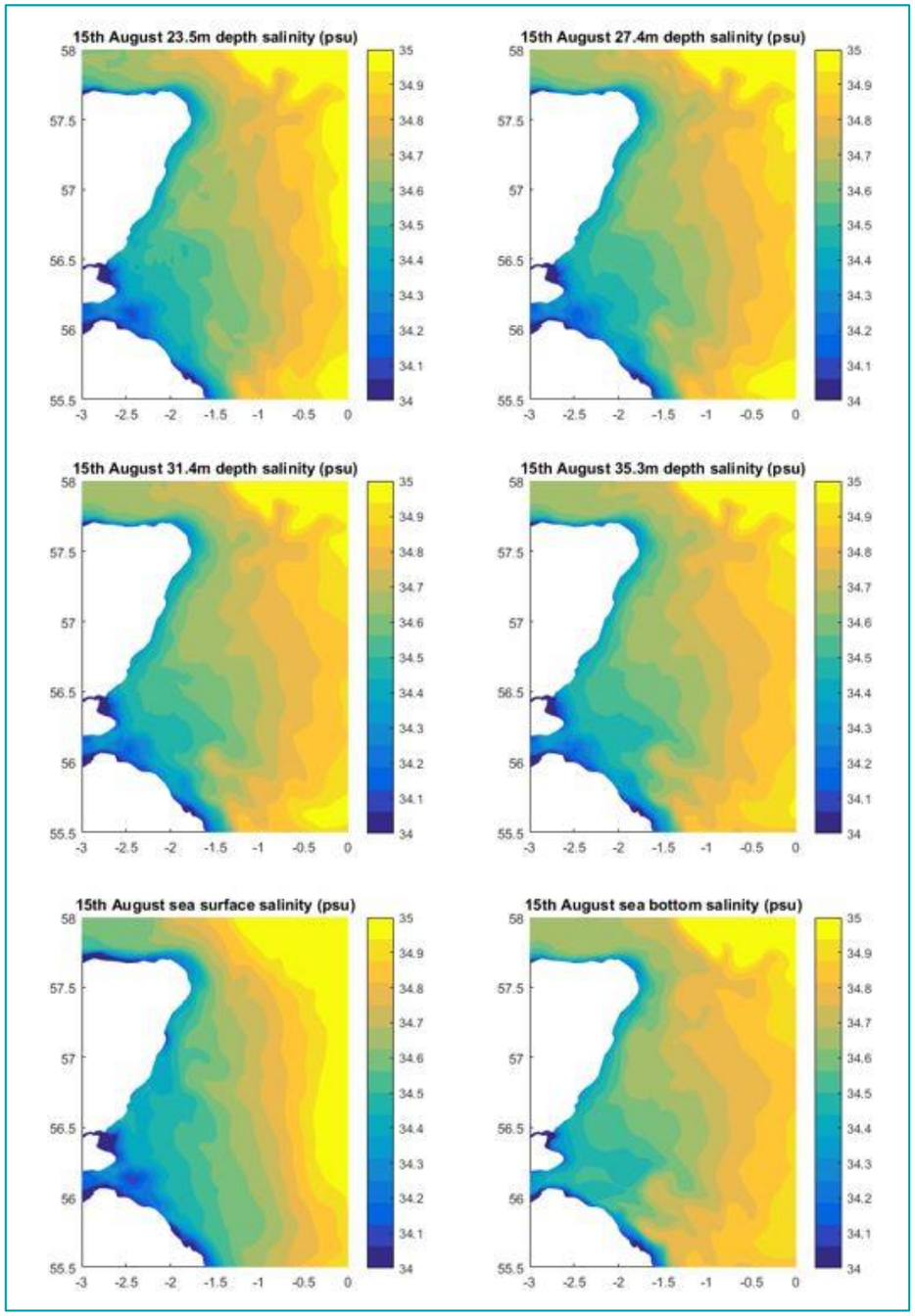

Figure 4.23: SSW-RS Water Column Salinity – 15 August 2016 (Calm Conditions). Axes Show Longitude and Latitude (Barton *et al*., 2022)

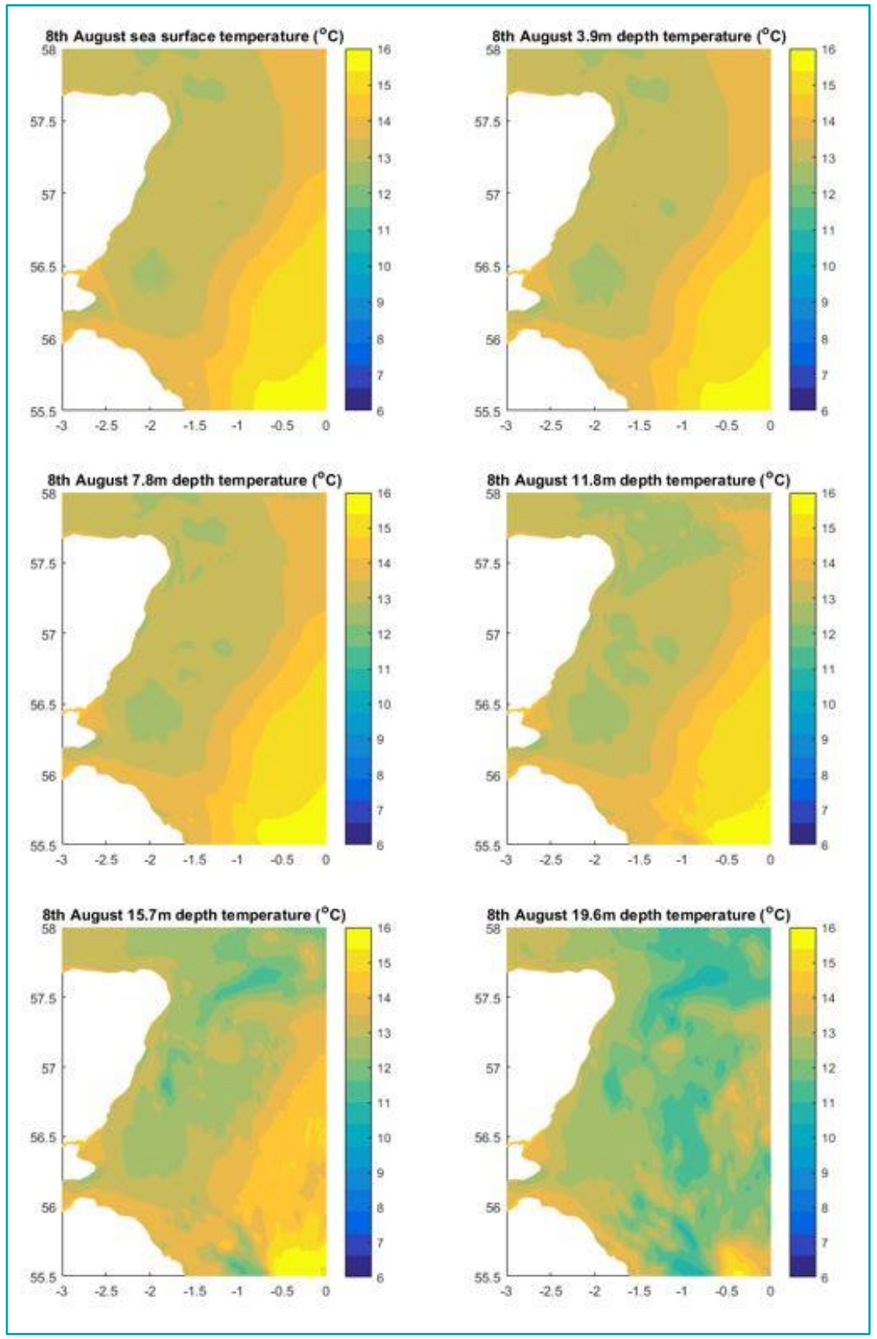

Figure 4.24: SSW-RS Water Column Temperature – 08 August 2016 (Storm Conditions). Axes Show Longitude and Latitude (Barton *et al*., 2022)

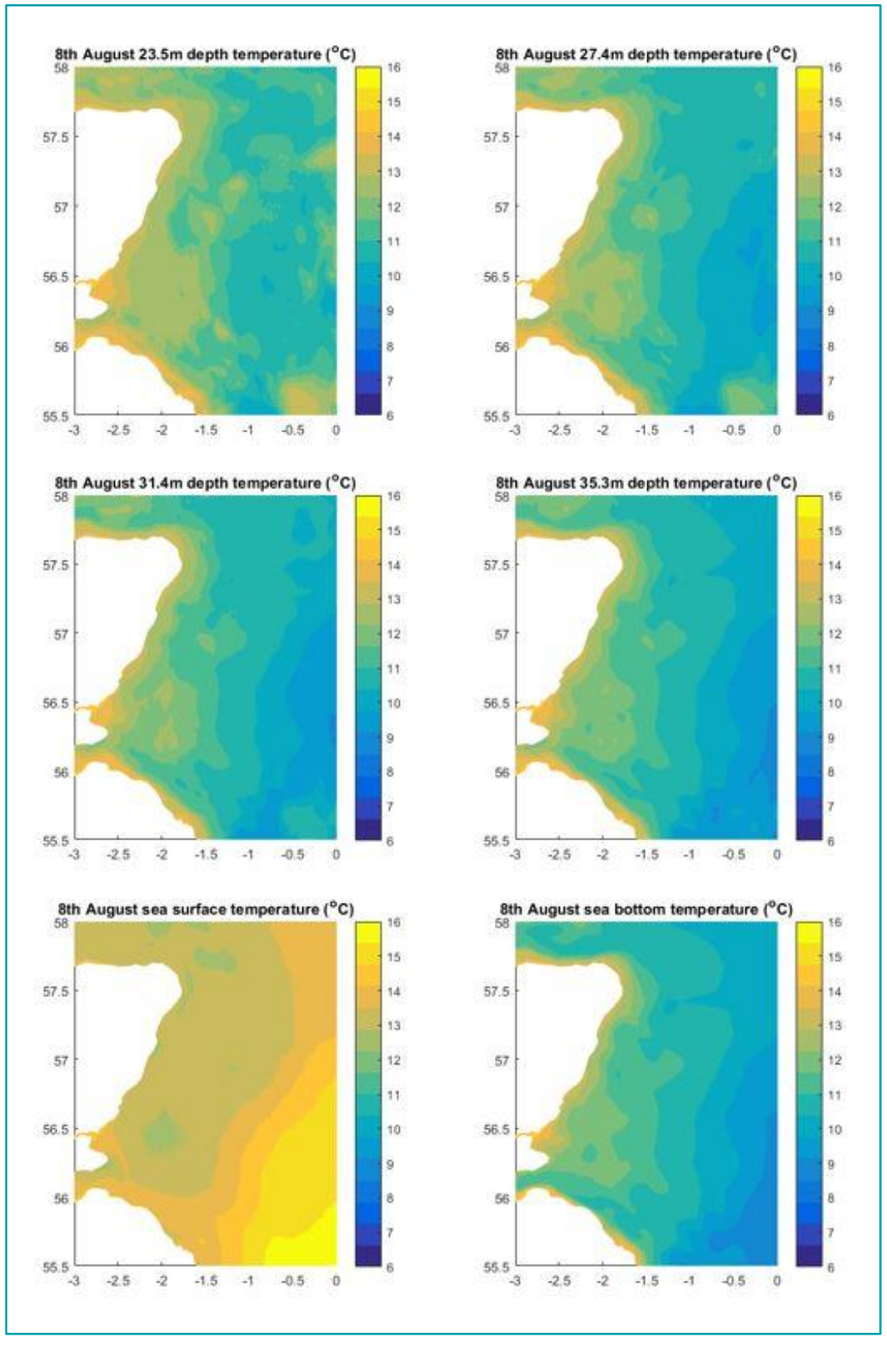

Figure 4.25: SSW-RS Water Column Temperature – 08 August 2016 (Storm Conditions). Axes Show Longitude and Latitude (Barton *et al*., 2022)

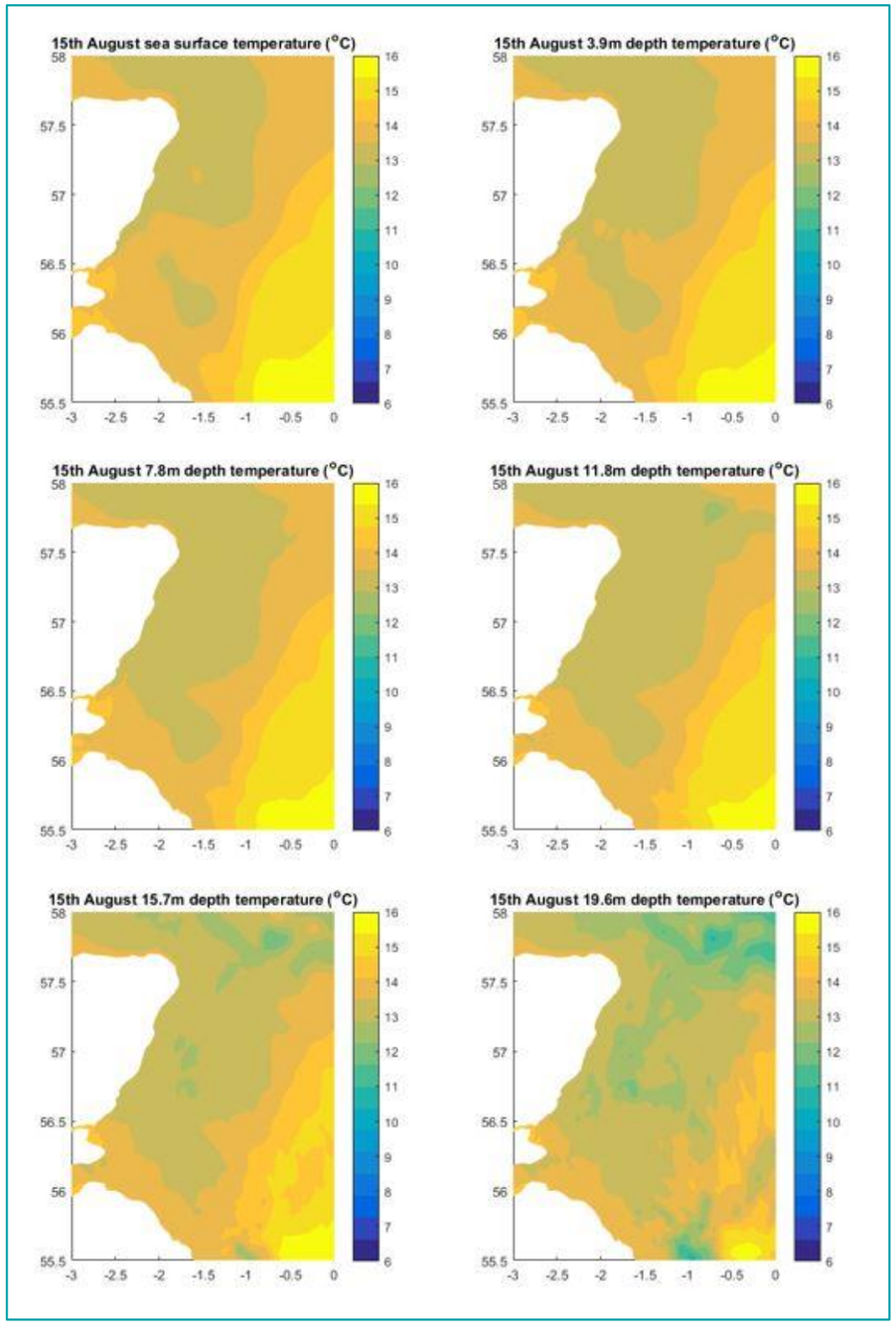

Figure 4.26: SSW-RS Water Column Temperature – 15 August 2016 (Calm Conditions). Axes Show Longitude and Latitude (Barton *et al*., 2022)

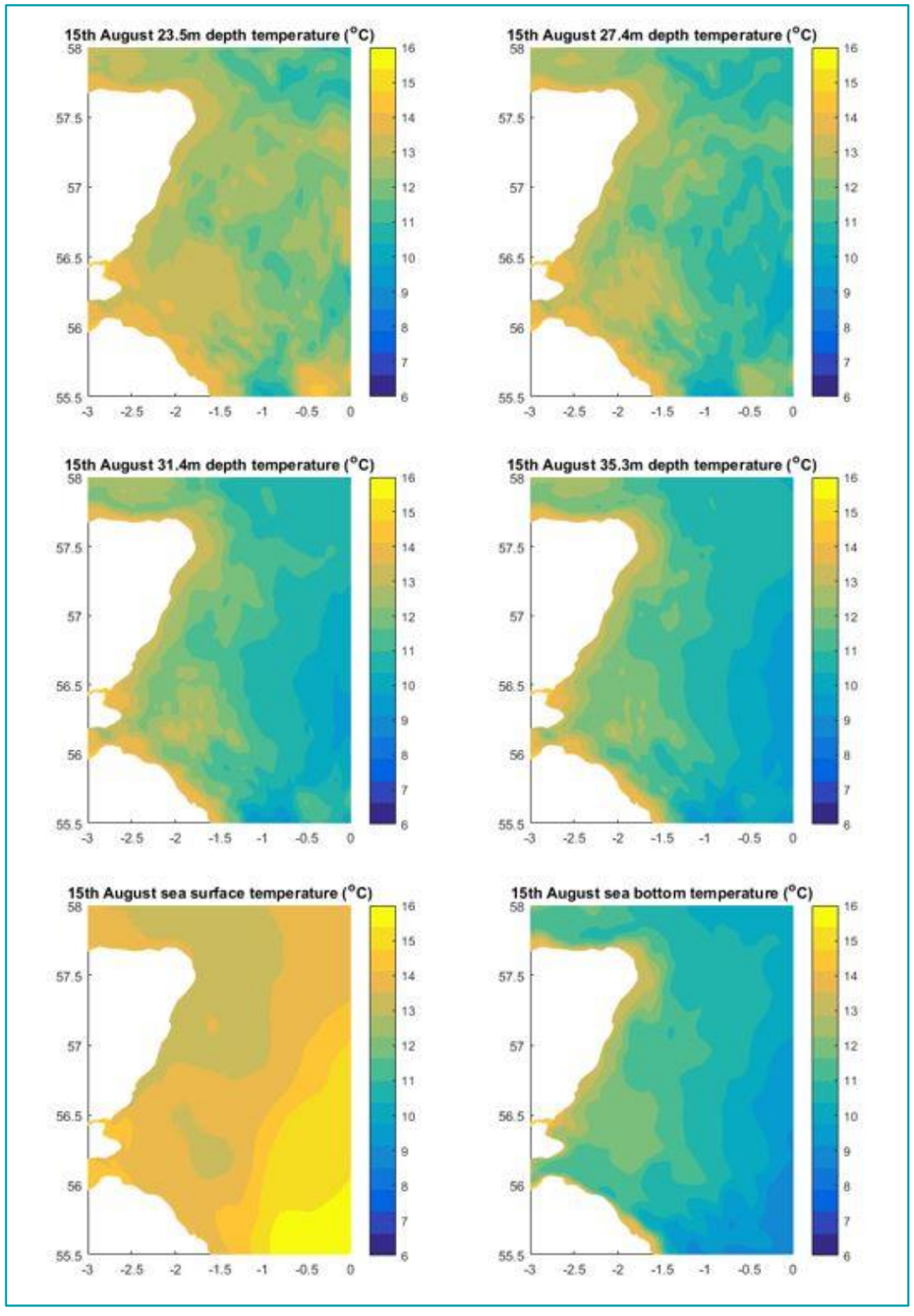

Figure 4.27: SSW-RS Water Column Temperature – 15 August 2016 (Calm Conditions). Axes Show Longitude and Latitude (Barton *et al*., 2022)

4.5. GEOLOGY

44. Baseline information on the geology within the site boundary provides an understanding of the origin and stability of the seabed and the geology which will be encountered when installing the offshore structures, such as platform foundations.

45. The physical processes study area is part of a complex glacial system, in which the subsequent sedimentary depositions in the Quaternary sediments are affected by the alternating glacial and interglacial stages that affected the northern hemisphere. The ground model was defined from Two Dimensional (2D) Ultra High Resolution Seismic (UHRS) and Sub-Bottom Profiler (SBP) data integrated with bathymetric, backscatter and Sidescan Sonar (SSS) data that was collected in 2022 during site-specific surveys by Ocean Infinity (volume 3, appendix 8.1, annex A). A total of five geological units were identified, with a total of five interpreted horizons, aided in interpretation through the delineation of localised geological features (volume 3, appendix 8.1, annex A).

46. The Quaternary sequence within the site boundary represents the repeated phases of erosion and deposition that are associate with the Pleistocene glaciations (Gatliff *et al*., 1994). The glacial and glaciomarine sediments from this period are highly eroded and then re-deposited, as seen in the large channel systems which are open, infilled and buried. These channels can reach depths of 200 m and widths of up to 3 km with very steep slopes up to 27° (Bone *et al*., 1991). The sedimentary infills of these channels can differ in density from the surrounding sediments, with organic rich layers with very high and variably coefficients of compressibility present in some channels. Boulders, and other coarse material, can occur at the bases of channels. Within the central North Sea, pockmarks in areas of soft clay indicate gas escape (Bone *et al*., 1991). Furthermore, trapped gas is widespread throughout the central North Sea, and is frequently trapped where lithological changes occur within the Quaternary or Tertiary, such as levels of glacial erosion (Bone *et al*., 1991).

47. Offshore marine bedrock data (scale 1:250,000) provided by the BGS illustrates that the physical processes study area is dominated by chalk and palaeocene rocks (mudstone, sandstone and lignite) (Marine Scotland, 2017).

48. The geological morphology within the site boundary is varied and includes the following features:

- megaripples;
- sand waves;
- boulders (primarily in the north-west of the site boundary);
- recent marine soft sediment deposits; and
- deep channel structures (down to 60 m) with sedimentary infill (south-eastern corner).

4.6. SEABED SUBSTRATE

49. Particle Size Analysis (PSA) conducted for the site-specific benthic studies showed that sediment composition had limited variation across the site boundary (volume 3, appendix 8.1, annex A). Sand comprised the dominant sediment fraction with mean content of 86.4%, while mud content was low overall with a mean content of 9.1% (comprising 8.0% silt and 1.1% clay). The gravel content was the lowest with a mean, but variable, content of 4.5%.

50. The recent geophysical surveys identified that the seabed within the site boundary consists primarily of sand, with some areas of gravel and occasional diamicton (poorly sorted mixed sediments). Gravel areas are more frequent in the north-west, with occasional diamicton also observed in this area, as illustrated in Figure 4.28. This is in line with the BGS seabed sediment mapping (scale 1:250,000), which shows sand as the dominant material across much of the physical processes study area, with some areas of slightly gravelly sand and gravelly sand towards the north (Marine Scotland, 2017). The seabed within the site boundary is relatively flat, with a general slope towards the east. The presence of megaripples and sand waves across the site boundary indicates mobile sediments. The presence of furrows indicates sedimental erosion. Furthermore, the furrows are the most recent mobile sediment feature as they were observed to cut into the megaripples and sand waves.

51. Occasional boulder fields (5 to 20 boulders within a maximum area of 2,500 m^2) and numerous boulder fields (≥ 20 boulders within a maximum area of 2,500 m^2) are distributed across the site boundary, most frequently in the west, within areas of gravel and diamicton. The boulder fields within the areas of diamicton are denser than in other seabed substrates. Manmade seafloor features are present across the site boundary, with linear debris (such as wire and rope) observed most frequently, and occasional linear scars or trawl marks are present (due to anthropogenic activity, such as trawling) as illustrated in Figure 4.29.

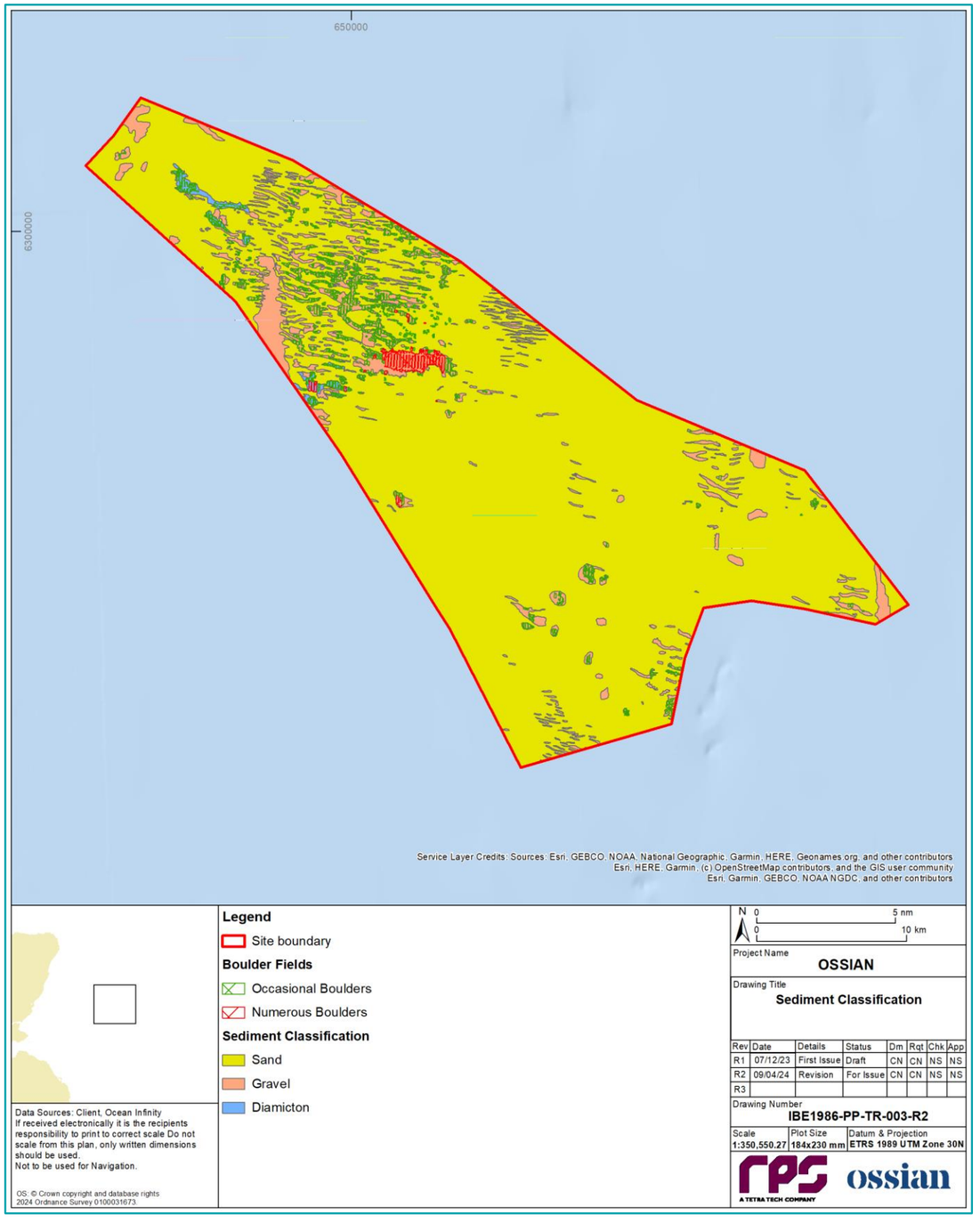

Figure 4.28: Sediment Classification Across the Site Boundary

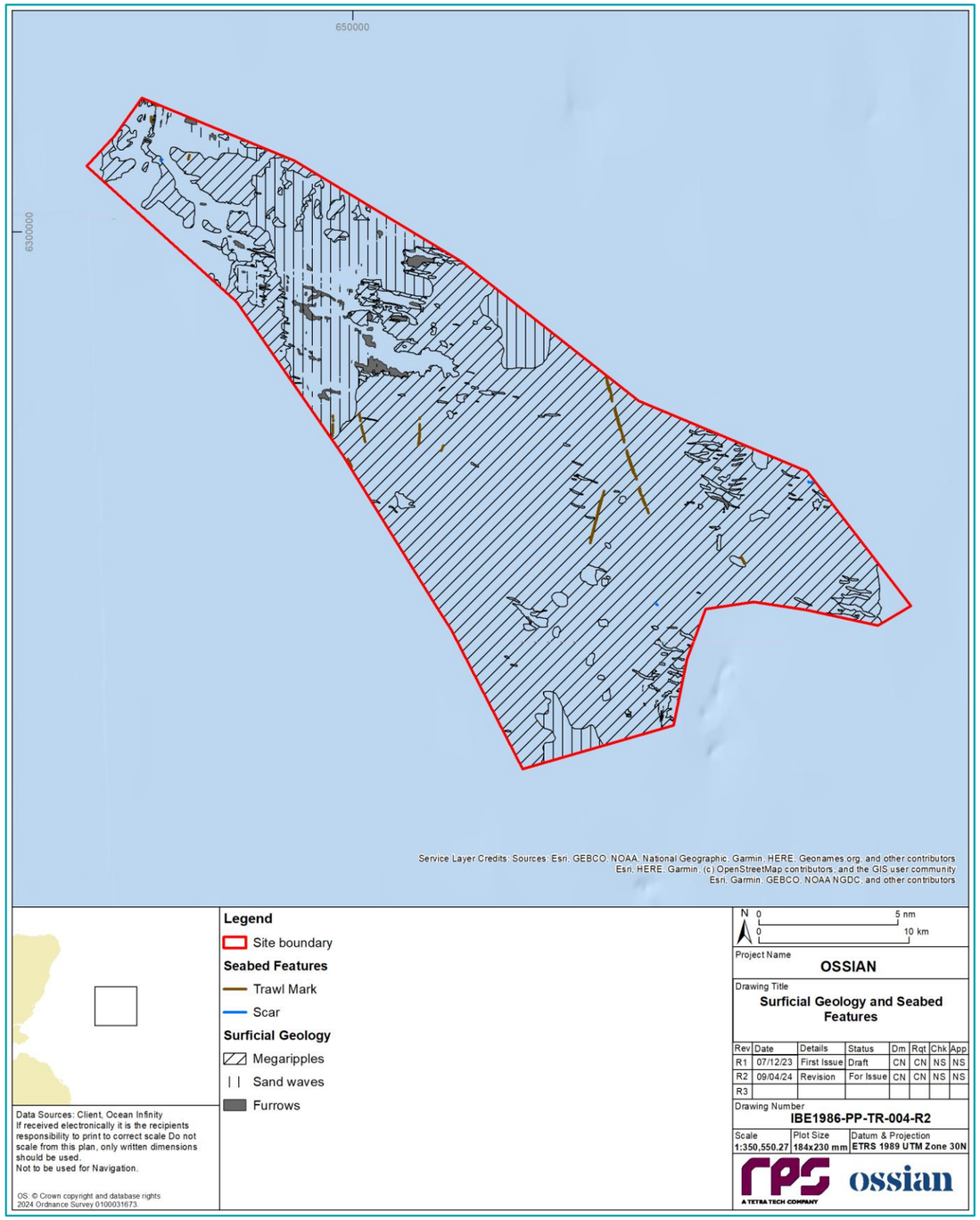

Figure 4.29: Seabed Features Within the Site Boundary

4.7. SUSPENDED SEDIMENT AND SEDIMENT TRANSPORT

52. Finer sediment fractions (e.g. fine sand, mud and silt) are more likely to be suspended as they readily mobilise within the water column. HR Wallingford (2009) has reported that sand transport rates are relatively low over much of the central North Sea, due to increased water depth and lower tidal current speeds than other regions.

53. The spatial distribution of average non-algal Suspended Particulate Matter (SPM) for the majority of the United Kingdom Continental Shelf (UKCS) is presented in the Cefas Climatology Report (Cefas, 2016). Based on the data provided within Cefas (2016), the average SPM associated with the physical processes study area has been estimated at between 0 mg/l and 1 mg/l between 1998 and 2015, as shown in Figure 4.30. SPM levels are generally higher in the winter months (up to 3 mg/l in January and December) than the remainder of the year (Cefas, 2016), however, due to the tidal influence, even during summer months the levels remain elevated. These baseline SPM conditions within the physical processes study area can be described as very low in the context of the UKCS, where plumes associated with large rivers which discharge into, for example, the Thames Estuary or the Bristol Channel show mean values of SPM above 30 mg/l (Cefas, 2016).

54. There was no site-specific suspended sediment sampling undertaken for the Array, however site-specific surveys were conducted for the Seagreen 1 Offshore Wind Farm in March and June 2011 (Royal HaskoningDHV, 2012b), albeit at least 50.72 km away from the site boundary and situated within shallower water (39.77 m to 64.82 m). Nonetheless, Total Suspended Solids (TSS) were low at four sampling stations in March and June 2011, with TSS levels of <5 mg/l in most samples (Royal HaskoningDHV, 2012b). TSS were generally higher in March, with values of 10 mg/l to 11 mg/l recorded several times, and a maximum value of 18 mg/l (Royal HaskoningDHV, 2012b).

55. At the Seagreen 1 Offshore Wind Farm, suspended Sediment Concentrations (SSCs) are primarily influenced by tidal currents, with fluctuations occurring across the spring-neap cycle and the different tidal stages (high water, peak ebb, low water, peak flood) observed throughout the March and June datasets (Royal HaskoningDHV, 2012b). Wave-driven currents during storms can temporarily elevate SSCs and can cause levels to rise significantly, which then gradually decrease to baseline conditions following storm events. Due to the seasonal nature and frequency of storms, SSC levels demonstrate a broadly seasonal pattern. These effects on SSCs during storm events are less significant in deeper waters, which have a lower degree of wave penetration than in shallower waters. Therefore, it can be inferred that the TSSs will be lower within the physical processes study area than at the Seagreen 1 Offshore Wind Farm and therefore likely below a maximum value of 10 mg/l during a winter storm, as discussed within paragraph 54.

56. Low sediment transport rates due to low residual current speeds were reported within the Berwick Bank Offshore Wind Farm array area (SSER, 2022). Based on the results from the physical processes modelling conducted as part of the Berwick Bank Offshore Wind Farm application, it can be seen that the tide within the site boundary moves in an approximate north to south direction, with the flood tide going to 190° and the ebb tide to 15°, and peak spring currents of around 0.5 m/s. Residual currents were minimal in the order of 0.008 m/s in a south-south-west direction of approximately 190°. Therefore, the net sediment transport in the region was limited to below 0.003 m^3/d/m. The seabed material at the Array is primarily gravelly sand (paragraph 227), therefore using the Wentworth scale, movement would only occur for a small proportion of the tidal cycle (typically less than half). Based on the physical processes modelling results closest to the Array (Berwick Bank Offshore Wind Farm), sediment transport would increase during storm conditions, with the largest and most frequent waves approaching from the northerly sector, therefore, net sediment transport under storm conditions would be in a southerly direction (SSER, 2022). It is anticipated that low rates of sediment transport would exist across the physical processes study area, to the similar tidal regime and wave climate.

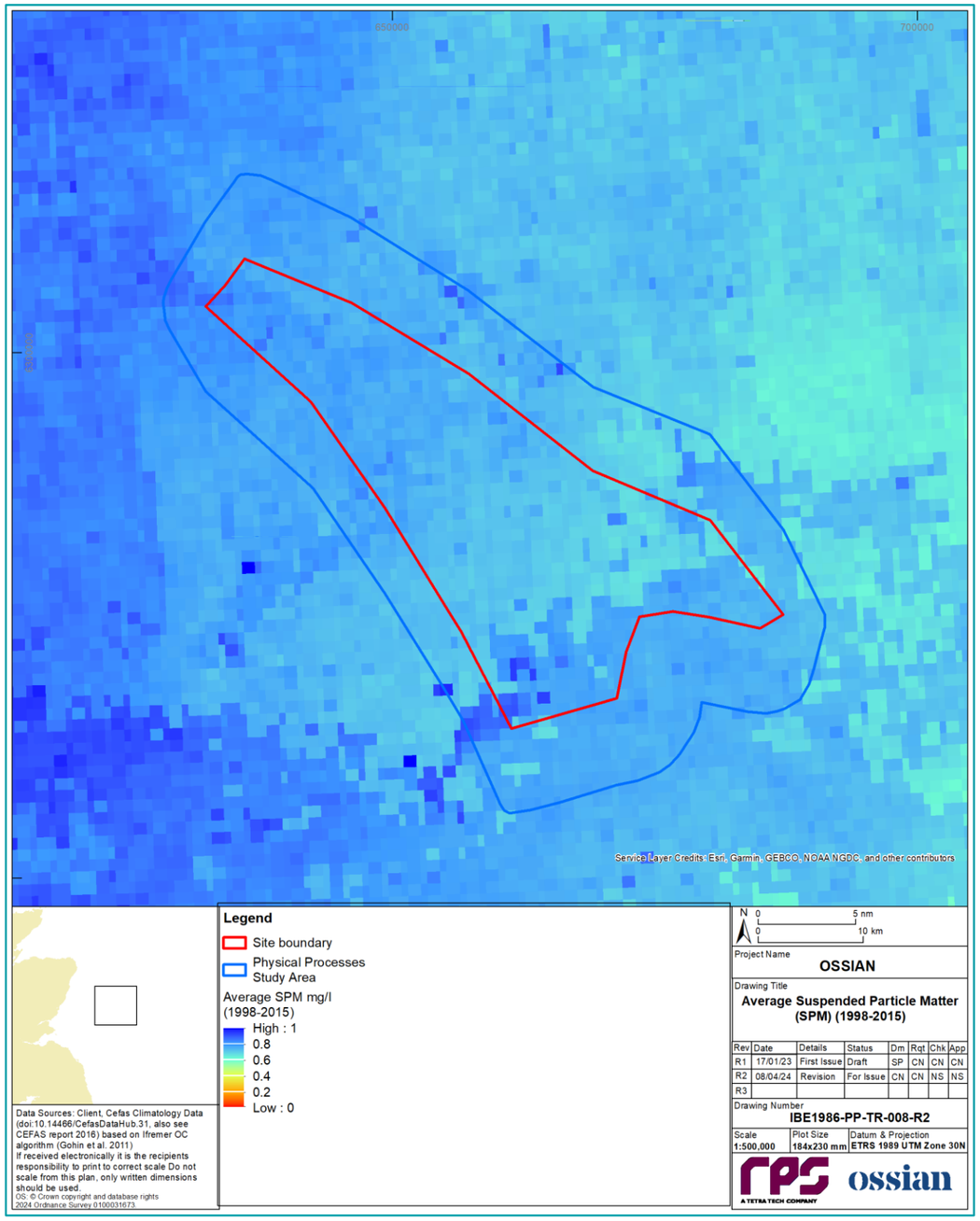

Figure 4.30: Average Suspended Particulate Matter (SPM) (1998 to 2015)

5. SUMMARY

57. The Array is located within an area which is situated at a significant distance from a range of designations, the closest of which is the Firth of Forth Banks Complex MPA at circa 25 km. A physical processes study area has been defined as the area encompassing the site boundary plus the area of one spring tidal excursion, which extends to a maximum of 8 km from the Array. The impact on physical processes will be assessed, following a thorough characterisation of the baseline, as outlined in this Technical Report. The baseline assessment includes tidal current, wave climate, water column processes and suspended sediments and sediment transport under both calm and storm conditions.

58. The dominant wind direction across the physical processes study area is from the south-west, with wind speeds likely up to 31.5 m/s. The dominant wave direction is from the north and north-north-east, with peak wave periods up to 20 s and maximum significant wave heights up to 8.96 m.

59. Baseline tidal conditions are defined by current flow in a south-south-westerly direction near the bed and a southerly direction near the surface, with a mean spring tidal range of 2.34 m to 2.41 m. Mean current speeds up to 0.27 m/s were recorded during the site-specific metocean survey, with a maximum speed of 0.91 m/s.

60. Salinity through the water column across the physical processes study area has been reported to be less than 0.1 PSU throughout the year, with the greatest surface and bed salinity differences evident in August.

61. Geology within the site boundary is varied and includes megaripples, sand waves, boulders, recent marine soft sediment deposits and deep channel structures with sedimentary infill. Sand is the main component of the seabed substrate across the site boundary, with lower quantities of mud and gravel.

62. Average SPM levels have been estimated at between 0 mg/l and 1 mg/l across the physical processes study area, with low sediment transport rates anticipated.

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ANNEX A: METOCEAN AND LIDAR SURVEY REPORT

63. Please find Annex A attached to this document separately.

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