STAR OF THE SOUTH OFFSHORE WIND PROJECT

Coastal Processes - Revised Layout Offshore Modelling Sensitivity Study

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1 EXECUTIVE SUMMARY

This report presents the results of a sensitivity study to assess the potential impacts on coastal processes of two revised wind farm design options for the Star of the South Offshore Wind Project located in Bass Strait near Gippsland, Victoria. The sensitivity study used wind wake modelling and wave modelling to compare the effects of the revised layouts with the original maximum design scenario (MDS) that was based on 200 wind turbine generators (WTGs) each with blade diameter of 220 m.

Star of the South had previously commissioned a study of coastal process impacts for a planned 2.2 GW offshore wind farm. Several realistic wind farm development alternatives were initially investigated before the 200 WTG development plan was identified as the MDS for detailed assessment purposes. The detailed assessment that followed indicated that the development would likely lead to a slight reduction in the height of waves and a small but systematic change in the direction of the waves approaching the coast.

Since the original coastal processes assessment was completed a part of the original project area has been excised. Compared to the original MDS the revised wind farm development will now be further offshore, smaller in area and lower in its total power output (1.8 GW). The change in area has triggered Star of the South to revise the range of some key project parameters.

The active development options now range between an option for a wind farm with 120 WTGs with 236 m blade diameter and a farm with 92 WTGs with 285 m diameter. This sensitivity study was designed to investigate whether the original MDS remained valid given the change in range of the key project parameters. The change in the shape of the development area could affect the small but systematic change in the direction of the waves approaching the coast that was found for the original MDS. Also, the largest WTGs considered under the revised options slightly exceed the size of the largest WTGs that were considered when the original MDS was established.

The results of sensitivity wind wake modelling showed that the revised layouts had similar but slightly lower wake losses than the original MDS, suggesting the MDS was a reasonable and conservative representation of the wake effects.

The wave modelling, which was applied to one of the revised layouts with 120 WTGs, showed that the changes in wave height and direction were similar in character but smaller in magnitude and spatial extent than the changes predicted for the original MDS.

The sensitivity study concluded that the original MDS layout remained valid as a conservative representation of the coastal process impacts that would be expected from either of the revised design options.

2 BACKGROUND

2.1 The Development Location

Star of the South is a proposed wind farm project that will be located offshore from Gippsland in the shelf waters of Bass Strait. The development aims to harness the strong ocean winds typical of the Bass Strait, create a clean energy hub in Victoria, and bring greater diversity, reliability, and security to the Australian electricity network.

The Star of the South project will occur within a recently revised development area, hereafter referred to as the Offshore Wind Farm Area (OWFA). The development area is 10-25 km from the Gippsland coast (Figure 2-1) and covers approximately 438 km^2. The wind farm is planned to have up to 120 wind turbine generators (WTGs).

To the north of the offshore wind farm area (OWFA) lies Ninety Mile Beach National Park and the inland lake system of Lakes Entrance and its surrounds. Further west and south of the OWFA is the peninsula containing Wilsons Promontory National Park, a land area which also encompasses the Corner Inlet Marine National Park and the Nooramunga Marine and Coastal Park. These areas are relatively sheltered from the highly-energetic Bass Strait conditions and contain an intricate network of shallow waterways, intertidal mudflats and sandy barrier islands of significant environmental value.

2.2 The Potential for Impacts from the Development on Coastal Processes

The primary marine and coastal environmental impacts from the project may occur via the potential for the built structures to modify existing wave and ocean current patterns. The magnitude of primary impact will govern the potential for related changes to patterns of sediment transport within the offshore project area and the neighbouring nearshore coastal zone. It is important to understand the physical environment and its potential dynamics over the expected lifetime of the proposed development.

Modifications to the local offshore hydrodynamic and wave climates may occur through the physical presence of the WTG monopile foundation structures and through the alteration of the wind climate acting on the ocean surface downwind from the OWFA. The monopiles will act as direct obstructions to the passage of waves and currents throughout the offshore wind farm area. The extraction of energy from the incoming wind will result in wind deficits in the lee of the offshore wind farm area, with the wake effects of individual WTGs being cumulative.

2.3 Previous Assessment of the Impacts from the Development on Coastal Processes

RPS previously worked with Star of the South to identify potential impacts to coastal processes from the project based on several wind farm design options that were under consideration in 2021 (RPS, 2021; Star of the South, 2021). The long timeframe for the development meant that it was important to allow for some degree of future design flexibility. Star of the South planned for flexibility by constraining their future development options within a range of realistic design alternatives, all of which were under active consideration. By assessing the key differences between the realistic development alternatives with respect to coastal process impacts, the development option that was anticipated to have maximum impact was identified. This option was then referred to as the maximum design scenario (MDS) for coastal processes impacts. The coastal process technical studies previously completed by RPS are summarised in Table 1.

Table 2.1 Timeline of previous Coastal Processes studies completed for the Star of the South project.

Date	Title	Key Outcomes
Sep 2021	Offshore Modelling Sensitivity Study	- Downwind of the OWFA, the wind wake effects were found to scale the total power output of the wind farm, i.e. a wind farm with a smaller number of large WTGs produced wake effects similar to a wind farm with a larger number of small WTGs when the power output was the same. - Downwind of the OWFA wind wake effects were insensitive to the internal arrangement of WTGs. - Identification of the MDS featuring 200 x 220 m WTGs.
Jan 2022	Offshore Modelling Calibration/Validation Study	- Wave and Hydrodynamic models established and validated for pre-development conditions against measured data
May 2022	Offshore Modelling Hindcast	- Establishment of wind farm development variants of the hydrodynamic and wave models based on the 200 x 220 m MDS with 12.5 m pile diameter. - 30 years hindcast modelling of waves pre and post development - 20 years modelling of waves pre and post development under a future climate scenario - 2 years hindcast modelling of currents pre and post development - 1 years modelling of currents pre and post development under a future climate scenario - Statistical summary maps showing relative changes to wave and currents - Model time-series output for the nearshore areas provided input to a coastal processes assessment (Stantec/Cardno)

The alterative development options that were initially assessed (RPS 2021a) all had similar nominal total power production capacity, approximately 2.2 GW, but featured either a smaller number of larger WTGs (123) or a larger number of smaller WTGs (200). Six different development options were considered. The layouts for all developments shared the common feature that their WTGs were arranged spatially so that the full extent of the OWFA was generally covered, but the internal arrangements of WTGs within the wind farm area differed for each layout. This meant that all the alternative wind farm designs that were considered had the same overall shape (i.e. outer perimeter), which is notable with respect to wind wake and wave blockage effects.

The magnitude of downwind wake effects from the alternative development options were all modelled and found to be broadly similar. This outcome was attributed to the fact that all the wind farm development alternatives covered the same area and were rated to similar total power output. The blockage and wake effects downwind of the development were found to be insensitive to the internal arrangement of the WTGs within the OWFA with the caveat that the overall shape and total power output of the wind farm alternatives remained the same.

Because wake effects were found to be similar for all development options that were considered, the MDS was selected based on the design configuration that led to the largest physical blockage of water by the WTG monopiles, with blockage determined by both the total number and diameter of the WTG monopiles.

The diameter of the monopiles that will be needed to support the WTGs is typically depends on the size of the WTGs and the water depth. Wider monopiles are generally needed to support larger turbines in deeper water. In 2021, Star of the South provided RPS with preliminary guidance indicating that monopile diameter was likely to be at least 8 m for smaller WTGs and up to 10 m for larger WTGs. Prior to detailed modelling Star of the South updated the engineering specifications for the monopiles so that maximum diameter specification for the larger WTGs was increased to 12.5 m. For the detailed modelling for environmental impact assessment RPS adopted the assumption that 12.5 m monopiles would be required for all potential WTGs sizes and water depths throughout the site. This assumption was practical because it maintained the flexibility of allowing for monopiles up to 12.5 m if required. The assumption of fixed monopile diameter meant that overall physical blockage of currents and waves would scale proportionately with a larger number of WTGs. Therefore a variant of the 200 WTG layout with 12.5 m monopiles (Figure 2-3), then known as the “Draft Wind Optimised Layout” was selected as the MDS layout for the purposes of detailed modelling of coastal processes.

Detailed hydrodynamic and wave modelling of the original MDS layout was completed by RPS (RPS, 2022a). The results of the wave modelling, which were derived from three decades of hindcast data, predicted some small but systematic changes to the height and direction of waves arriving to the coast. The implications of these changes for shoreline sediment transport were assessed in detail in a separate report (RPS, Stantec Australia, 2022). In contrast to the wave modelling results, the hydrodynamic modelling results indicated that the combined effects from the development would have very little influence on current speeds outside of the project perimeter. Because the nearest coastlines were several kilometres from the development area, the modelled differences in currents were concluded to be insignificant with respect to coastal processes (RPS, Stantec Australia, 2022).

2.4 Changes to the Development

The OWFA available to Star of the South was revised following the establishment of the Gippsland Declared Area after detailed modelling of the MDS layout had been completed (RPS 2022a). The revision to the OWFA was required to align with the Declared Area which is located 10km from the closest shoreline. A portion of the previously assessed OWFA layout nearest to the coast was excised from the development area by Star of the South to comply with the Declared Area. The excised portion amounts to 12% of the original permit area. There were no other boundary changes to OWFA to offset this loss, so the net effect is that the revised OWFA is smaller in area and focussed further offshore.

The mandatory change to the OWFA has led Star of the South to review the number, arrangement and the size of WTGs being considered for the development. The reduction in available area means that the nominal total power production capacity of the development planned by Star of the South has been revised downwards from 2.2 GW to 1.8 GW. Two revised indicative design layouts were provided to RPS by Star of the South for investigation of the sensitivity of impacts on coastal processes. These layouts span the smallest and largest WTGs being considered under the revised project design envelope (PDE):

- Smaller WTGs – the smallest WTG within the PDE. For the purpose of the EIA, it is assumed to be 120 of the smallest WTG, with a rotor diameter of up to 236 metres. Figure 2-1 presents the indicative layout for the smaller WTGs.
- Larger WTGs – the largest WTG within the PDE. For the purpose of the EIA, it is assumed to be 92 of the largest WTG, with a rotor diameter of up to 285 metres. Figure 2-2 presents the indicative layout for the larger WTGs.

RPS was requested by Star of the South to assess whether the coastal process impacts from these revised designs will fit within the envelope of impacts that were found for the original MDS, based on 200 WTGs. Because these two revised options are focussed further offshore and have a smaller total power production capacity than the original MDS it suggests intuitively that any downstream impacts from these developments on coastal processes are likely to be lesser. However, the wind wake effects for the revised WTGs were not explicitly assessed in the foundation sensitivity study that identified the MDS (RPS, 2021a). The wind wake and blockage effects may also be expected to change slightly in response to the change in the shape of the revised OWFA. This raises a possibility that the small but systematic changes in wave direction that were predicted under the MDS layout may be modified in a manner that is consequential to coastal processes.

2.5 Contemporary Review of the MDS

The summary details for the modelled representation of the revised layouts and the original MDS layout are presented in Table 2.1. In this study the wind wake effects for the two revised designs (labelled “120 WTGs” and “92 WTGs”) are calculated and then compared to the equivalent results for the original MDS (labelled “200 WTGs”). The second component of this study involves the development of a wave model to represent one of the two revised layouts. Pre and post development wave modelling will be presented for two different years, with each year selected to represent a different extreme of the annual wave climate. The wave results will be compared to the original modelled MDS results for the same two years.

Table 2.2 Summary of modelled wind farm designs

	Original MDS	Revised-1	Revised-2
Label	“200 WTGs”	“120 WTGs”	“92 WTGs”
Number of WTGs	200	120	92
WTG Power	12 MW	15 MW	19.5 MW
Hub Height	135 m	153 m	177 m
Rotor Diameter	220 m	236 m	285 m
Monopile Diameter	12.5 m	12.5 m	12.5 m
Nominal Wind Farm Power Output	2.4 GW	1.8 GW	1.8 GW
WTG Layout	Figure 2-3	Figure 2-1	Figure 2-2

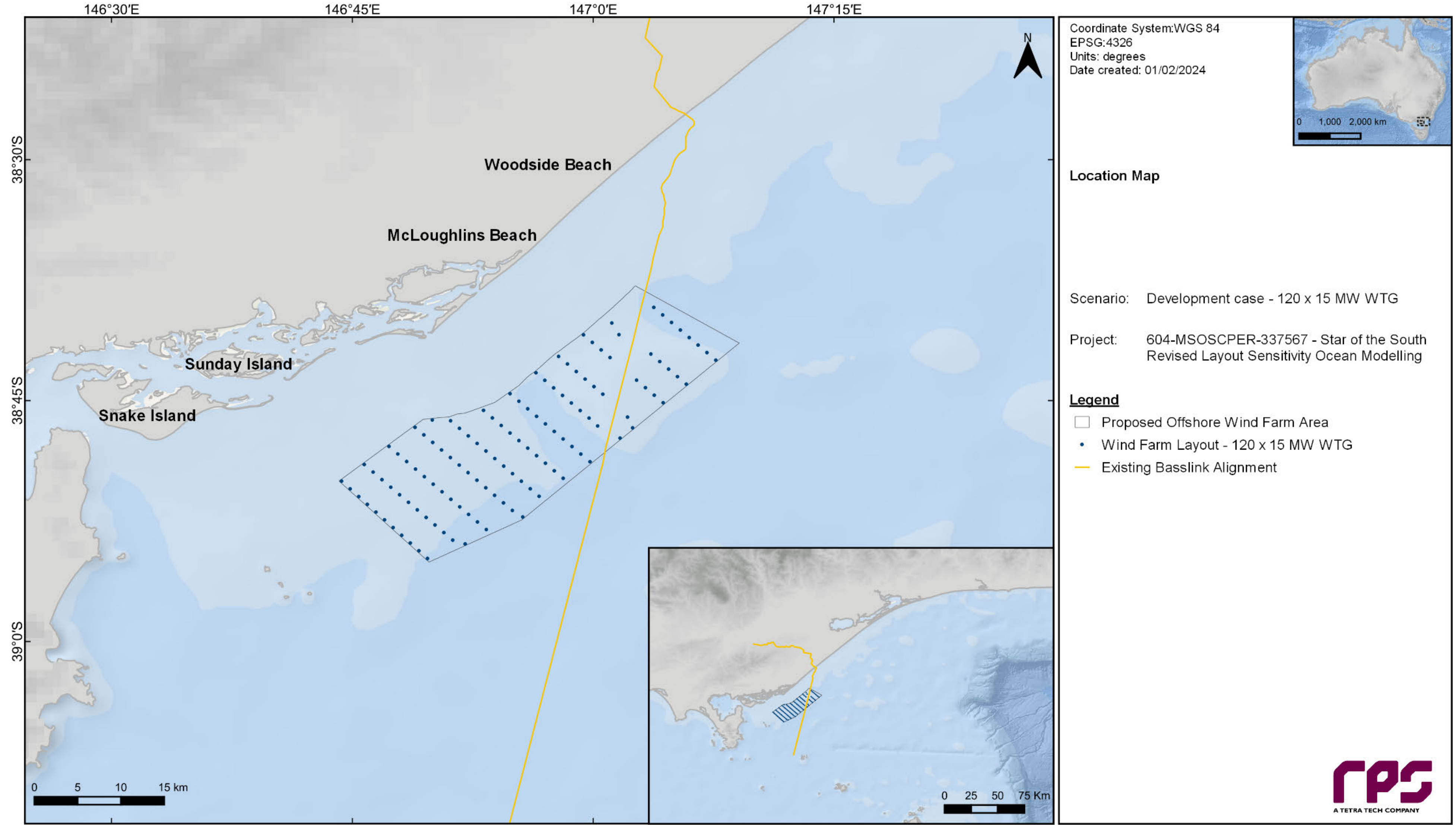


Figure 2-1 Overview of the Star of the South project location showing the updated proposed wind farm area and the indicative development layout of 120 of the smaller WTGs for assessment.

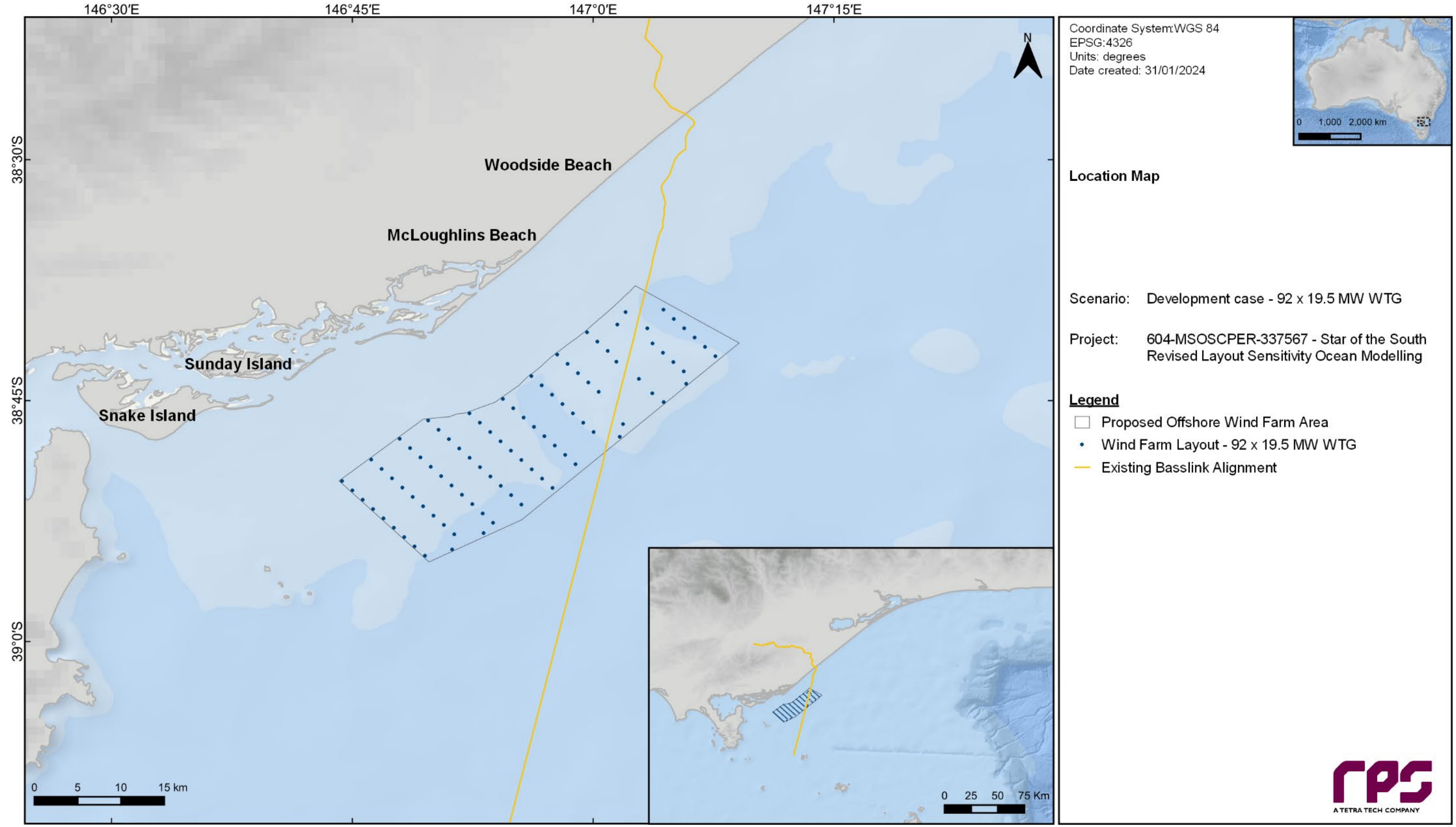


Figure 2-2 Overview of the Star of the South project location showing the updated proposed wind farm area and the indicative development layout of 92 of the larger WTGs for assessment.

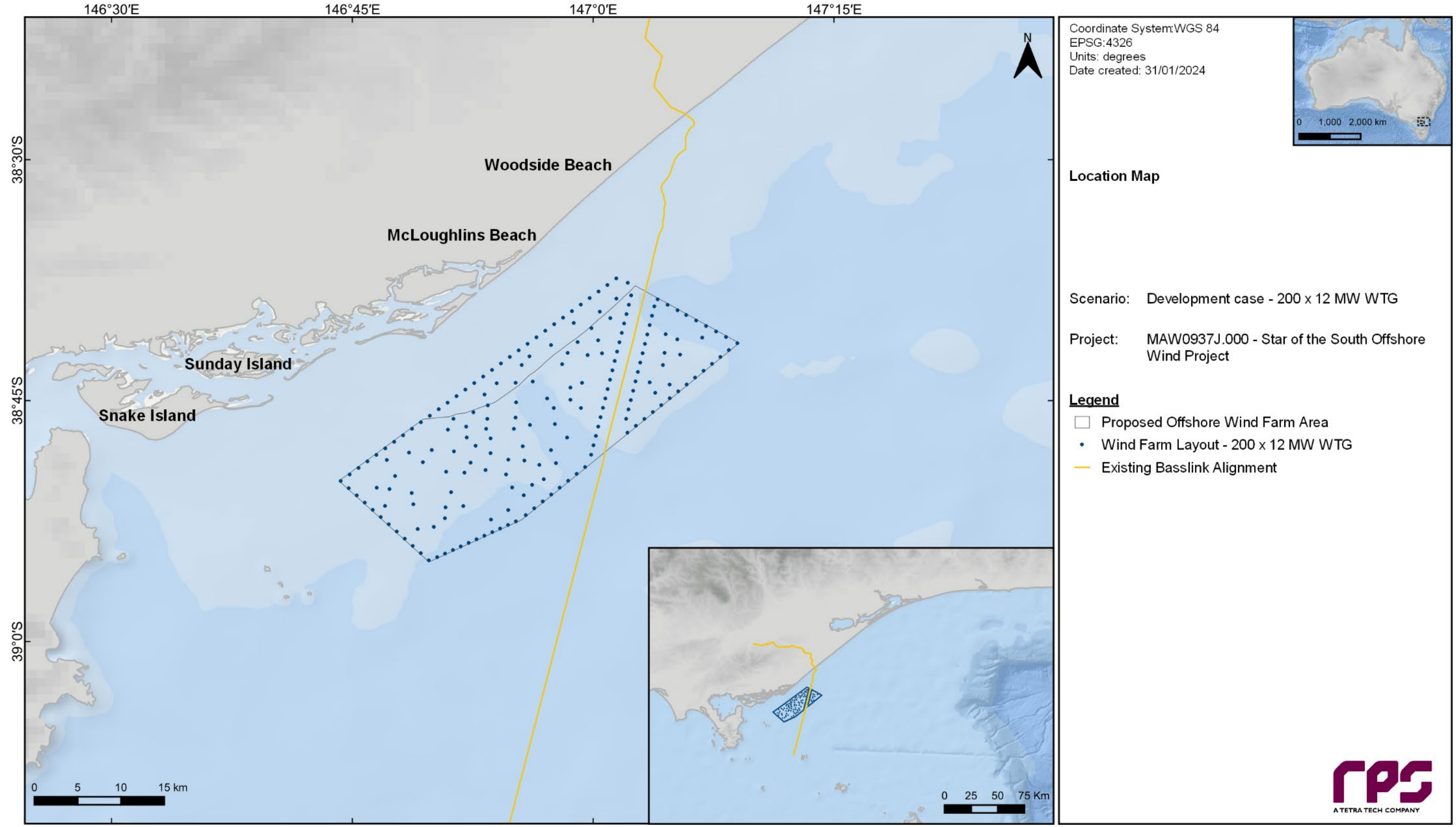


Figure 2-3 **Previous modelled MDS layout (200 WTGs). This case corresponds with Scenario SC1B from the Offshore Modelling Hindcast Study (RPS, 2021a). The revised OWFA is shown on the map to highlight the subset of the formerly planned WTGs locations that are now outside of the revised OWFA.**

3 METOCEAN CONTEXT

The two years selected, 1999 and 2004, were selected by Stantec Australia (2024) as representative of years with high occurrence of one of the two main regional climate systems that impact the metocean conditions and generate extreme events offshore of the Gippsland coast.

A summary of the regional climate and metocean conditions of the project site is presented here to put the years chosen to model for this sensitivity study into context, for more detail refer to the RPS (2024) and RPS, Stantec Australia (2022).

3.1 Regional Climate Conditions

Bass Strait lies on the boundary between the westerly-wind belt of the southern hemisphere and the subtropical trade-wind belt. As the trade wind belt moves southward with the thermal equator, the belt of variable winds is also moved further south. Hence, the path of the pressure systems across Australia is further south in summer than in winter. Throughout the whole year the wind seldom blows from any one direction for more than a few days at a time. This is largely due to the procession of highs and lows crossing the area from west to east. On average, the interval between successive high-pressure systems is about a week.

The deep depressions of the Southern Ocean move from west to east on tracks which, for the most part, lie well to the south of the continent. Troughs associated with these depressions, however, continuously affect the study area causing large variations of pressure. From time to time, deep and vigorous depressions invade these waters. Those affecting the study area can be considered in two main groups:

1. Southerly depressions (associated with south-west storms) - approach south-west Australia from the west or south-west and subsequently move towards directions varying between south-east and north-east. The majority of depressions move south eastwards to pass south of Tasmania, but many of them pass eastwards through Bass Strait, especially in winter. Fronts associated with the southerly depressions often result in initial strong north-west winds prior to the front that change rapidly to strong west to south-west winds as the front passes. South-west storms occur relatively frequently (typically several severe storms per year). Due to fetch and depth limitation, it is unlikely that extreme design-wave conditions will occur during a south-west storm at the project site.
2. East coast lows (associated with south-east storms) - depressions which develop or intensify off the east coast of Australia but are not primarily of tropical origin. These are usually slow moving initially, and later move more quickly southward or south eastward. These systems are termed “east-coast lows”. East-coast lows are generally associated with very strong east to south-east winds and high rainfall. South-east storms resulting from east-coast lows occur relatively infrequently (on average 1 to 2 per year). The waves they generate are however, unrestricted by fetch or water depth. As such they have the greatest potential for generating extreme wave conditions in eastern Bass Strait.

Nearly all southerly depressions, and many east-coast lows, have fronts associated with them. These depressions are the chief cause of unsettled weather in the study area. The two years selected for the sensitivity modelling were chosen to capture years with high proportions of these main groups of extreme events:

1. 2004 – is representative of a year with a high proportion and increased intensity of southerly depressions and associated south-west storms.
2. 1999 – is representative of a year with a high proportion and increased intensity of east coast lows and associated south-east storms.

3.2 Winds

The wind climate within the OWFA over the 30 year hindcast period (1999-2020) is presented in Figure 3.1 (a). The source data is from the Climate Forecast System Reanalysis (CFSR) hindcast data point nearest to the Wave Buoy station (see Figure 3.1 inset). The CFSR hindcast dataset was previously validated for use in the modelling (RPS, 2022b) and found to be well correlated to measured Bureau of Meteorology (BoM) wind data near the project site.

Strong winds are prevalent year-round, typically blowing from the west-southwest or northeast, aligned mostly longshore to the coastline. The prevailing winds in in the spring and summer months (October to March) are both from the west-southwest and northeast winds, with westerly winds more dominant in autumn and winter

(April to September). Monthly mean wind speeds can reach 14 knots (7.2 m/s), with maximum winds from the southwest recorded at over 50 knots (25.7 m/s).

Wind roses based on the subsets of data from the years selected for the sensitivity modelling are also presented in Figure 3.1 (b and c). Comparison of the wind roses shows that 1999 had a higher proportion of winds from the northeast to easterly sectors and reduced proportions from the west to southwest sectors when compared to the wind rose for the full 30-year hindcast period. This is typical of a year with strong east coast lows. In contrast the wind rose for 2004 shows reduced proportions of winds from the northeast to easterly sectors and increased proportions from the west to southwest sectors, typical of a year with strong southerly depressions.

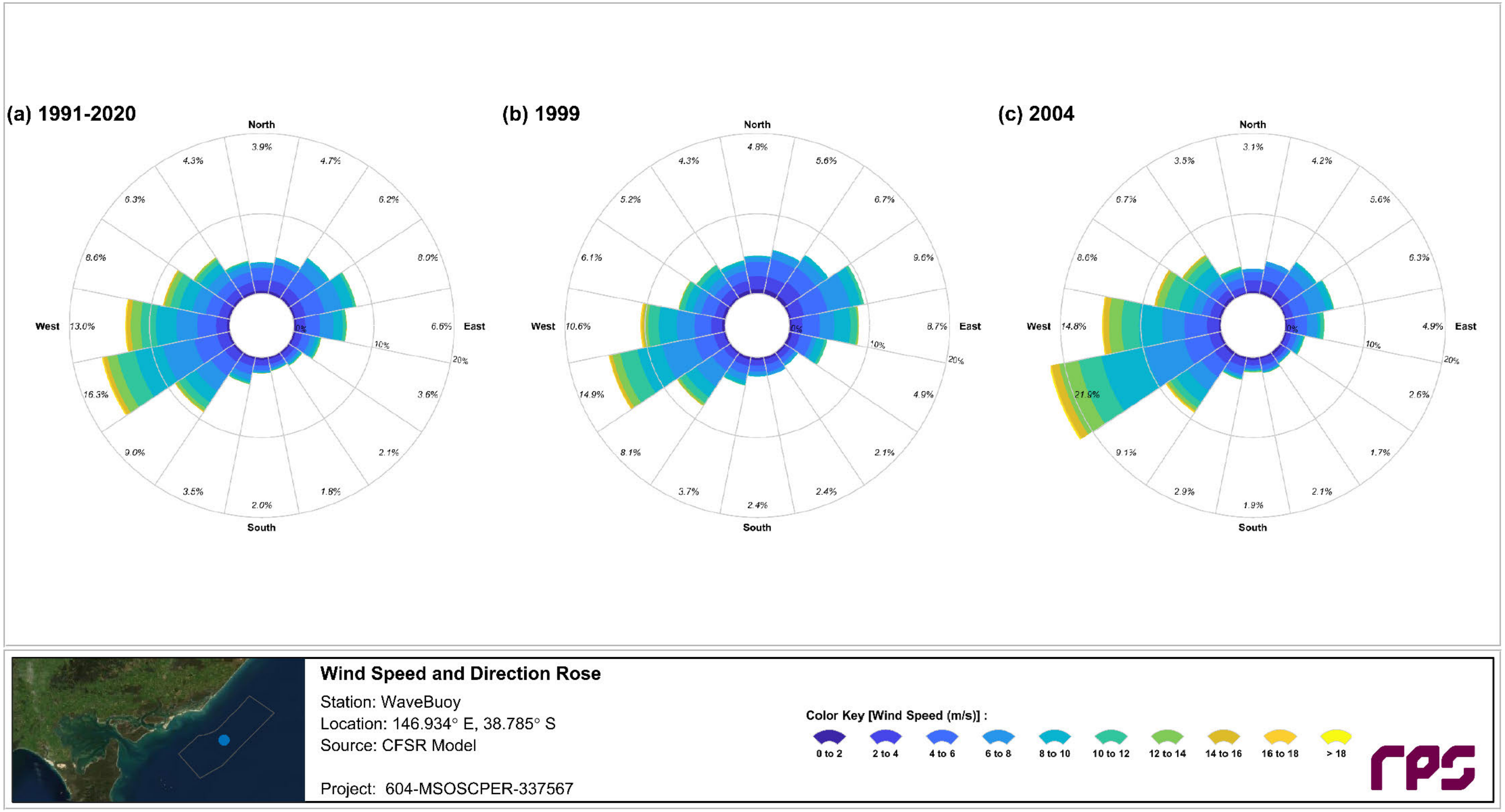


Figure 3.1 Comparison wind speed and direction roses at the Wave Buoy station within the OWFA for (a) 30 year hindcast period (1991 – 2020), (b) 1999 and (c) 2004, based on data from the CFSR model. Direction shown is the direction the wind is coming from.

3.3 Waves

Bass Strait is a high-energy environment exposed to frequent storms and high wave conditions, which are generally associated with strong west to south-west winds caused by the eastward passage of low-pressure systems across Bass Strait. Storms may occur several times a month typically resulting in wave heights of three to four metres, or in severe cases greater than 6 m (Jones, 1980). In eastern Bass Strait, especially east of Wilsons Promontory where the proposed OWFA is located, the influence of the swell from the Southern Ocean is much reduced and the wave climate is dominated by more locally generated waves from the storm-types discussed in Section 3.1. The sheltering effect of Wilsons Promontory can be seen in the spatial distribution of modelled base case 80th percentile significant wave heights (Figure 3.4), which shows that heights are lower at the coast and in the western end of the study area. The 50th and 95th Percentile maps show similar features and are available in the Appendix.

The annual wave climate at the Wave Buoy station over the 30 year hindcast period (1999-2020) is presented in Figure 3.2 (a) and Figure 3.3 (a) based on the SWAN wave hindcast data set prepared for the project (RPS, 2024). The wave hindcast model developed for the project was calibrated/validated against measured wave data at a number of locations within the project area, including the Wave Buoy station, and found to be a good representation of the wave conditions (RPS, 2022b).

Hindcast results indicate that significant wave heights at the Wave Buoy station are typically less than 2 m (~86 % of the time) but heights can range up to 4-6 m during extreme events. Mean wave periods are typically between 4 to 7 s (~88 % of the time), which is indicative of a sea wave dominated climate. Longer period waves with mean wave periods of up to 14 s are present, with higher proportions of longer period waves coming from the south to easterly sectors, due to the longer fetch in this direction. Waves at the study area exhibit a weak seasonal cycle with the highest significant wave heights and longest peak period waves occurring during winter and early spring.

Incoming waves at the Wave Buoy station are predominantly directed from the east to southwest sectors, with larger wave heights and higher proportions of waves most likely to originate from the southwest and the east-southeast sectors. The dominant wave directions align with the dominant local wind directions, with slight rotation of both directional extremes towards the south, due to refraction and shoaling of the waves as they move towards the coast.

The refraction and shoaling of the waves from both directions can be seen in Figure 3.5, which presents map views of mean wave direction over the project area for (a) 1999 and (b) 2004. The maps indicate the time average of mean wave direction for the Base scenario over the year. Figure 3.5 shows that for 1999 waves tend to approach the project area from both the south-east and south-west and are then refracted perpendicular to the coast, both wave directions becoming more southerly on approach to shore. For 2004 waves tend to approach the project area from the south-west and are then refracted perpendicular to the coast becoming more southerly on approach to shore.

Comparison of significant wave height and mean wave period roses at the Wave Buoy station are presented for the two years selected for the sensitivity modelling in Figure 3.2 and Figure 3.3 ((b) 1999 and (c) 2004). Comparison of the wave roses shows that 1999 has higher proportions of waves from the east to east-southeasterly sectors and reduced proportions from the southwest to south-southwest sectors when compared to the 30-year wave height rose, typical of a year with strong east coast lows. Whereas the wave roses for 2004 show reduced proportions of waves from the east to east-southeasterly sectors and increased proportions from the southwest to south-southwest sectors, typical of a year with strong southerly depressions.

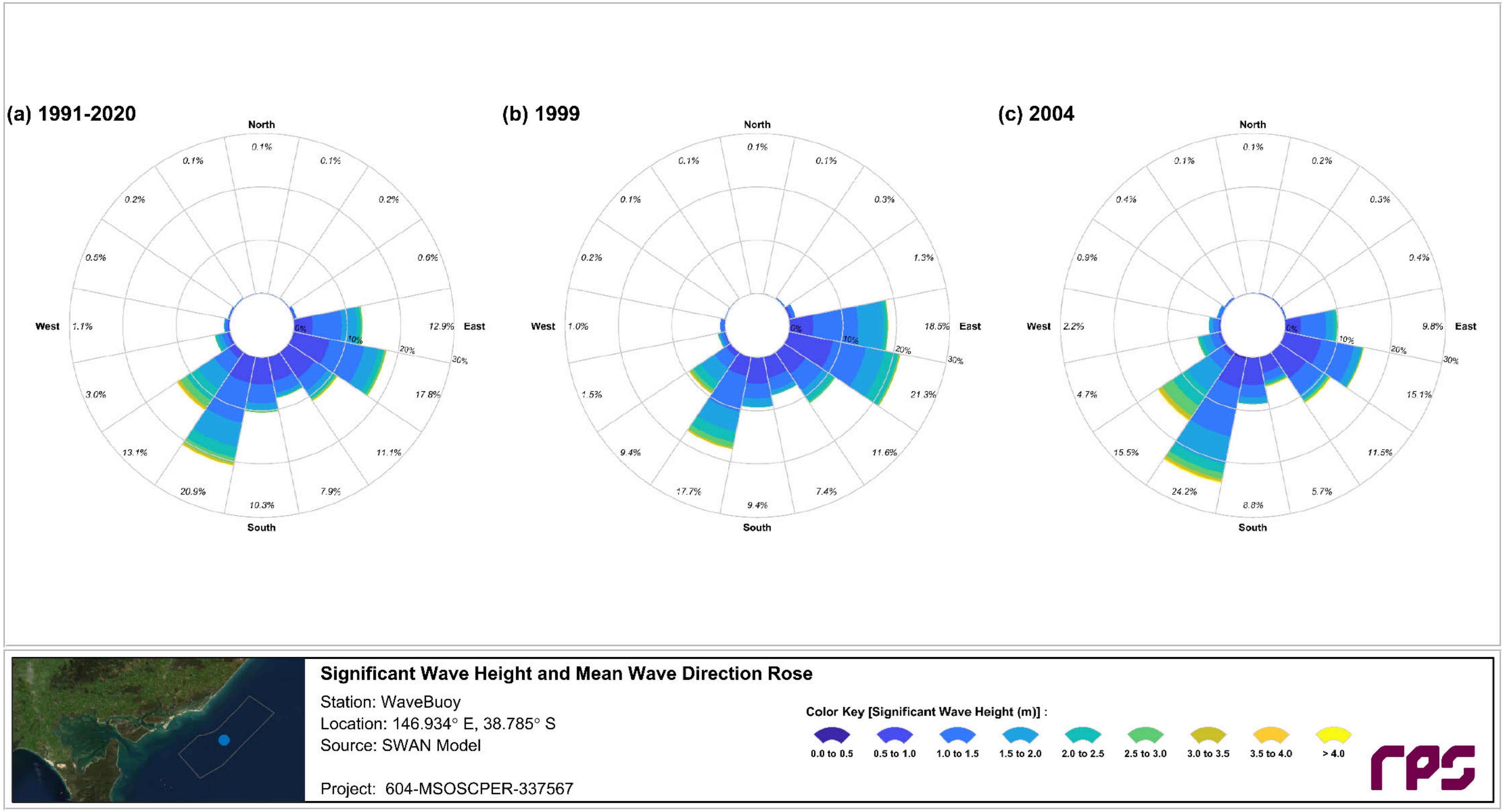


Figure 3.2 Comparison wave height and direction roses at the Wave Buoy station for (a) 30 year hindcast period (1991 – 2020), (b) 1999 and (c) 2004, based on data from the SWAN wave hindcast model. Direction shown is the direction the waves are coming from.

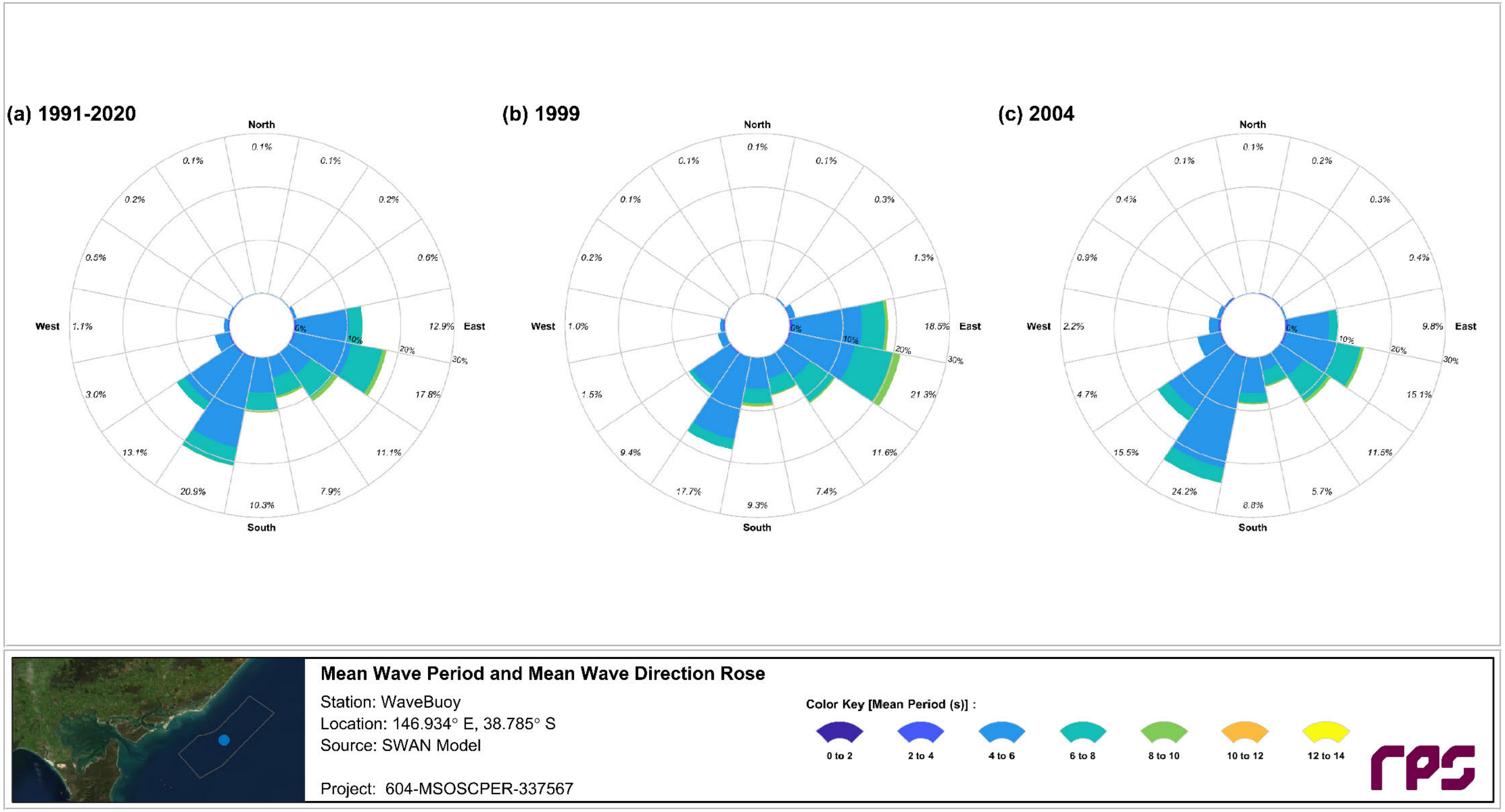


Figure 3.3 Comparison mean wave period and direction roses at the Wave Buoy station for (a) 30 year hindcast period (1991 – 2020), (b) 1999 and (c) 2004, based on data from the SWAN wave hindcast model. Direction shown is the direction the waves are coming from.

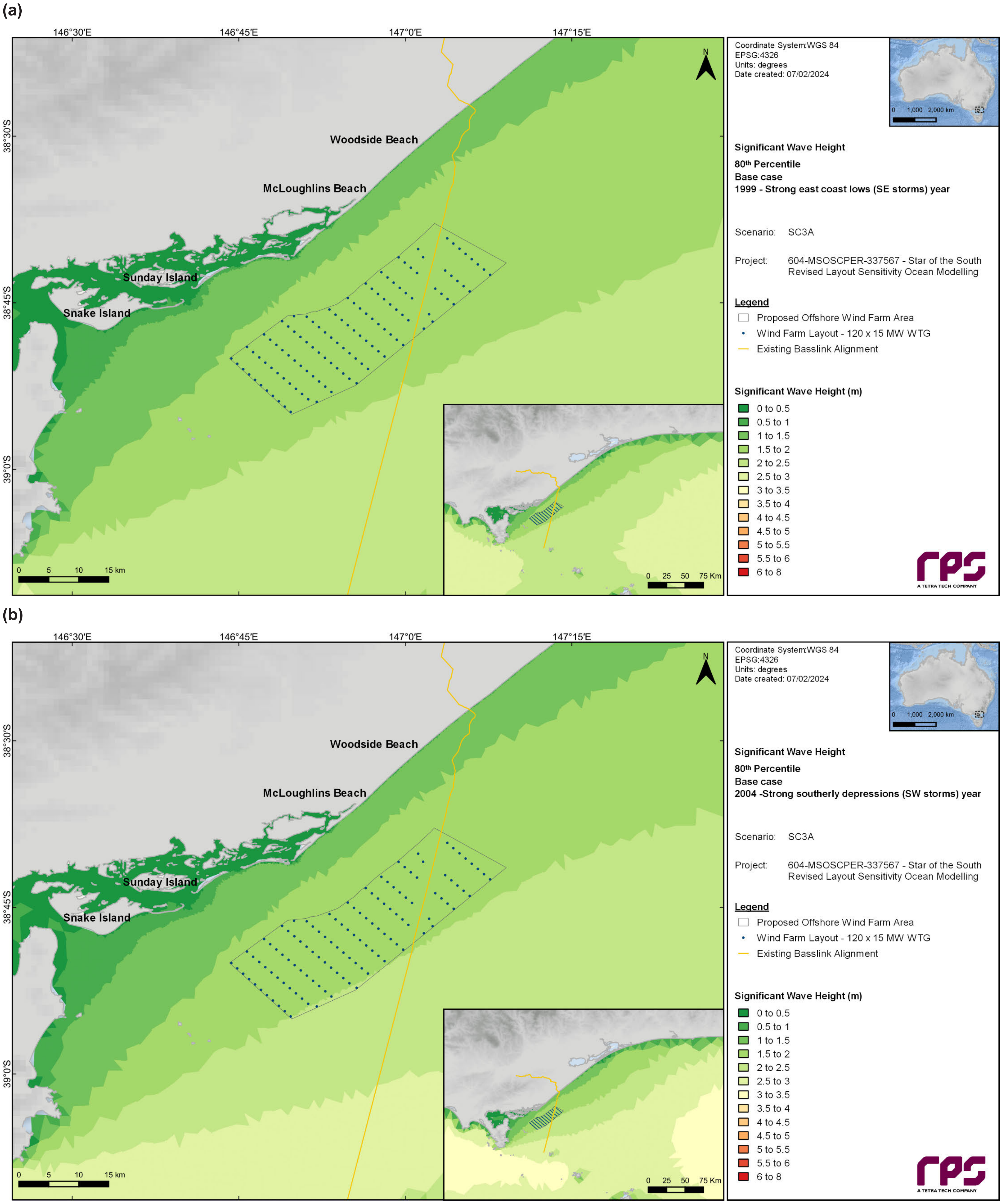


Figure 3.4 Map of modelled 80th percentile significant wave height in the Base scenario (SC3A) over the year (a) 1999 and (b) 2004 based on 2 hourly model output over the year. The OWFA and an indicative WTG layout is shown on the map for context.

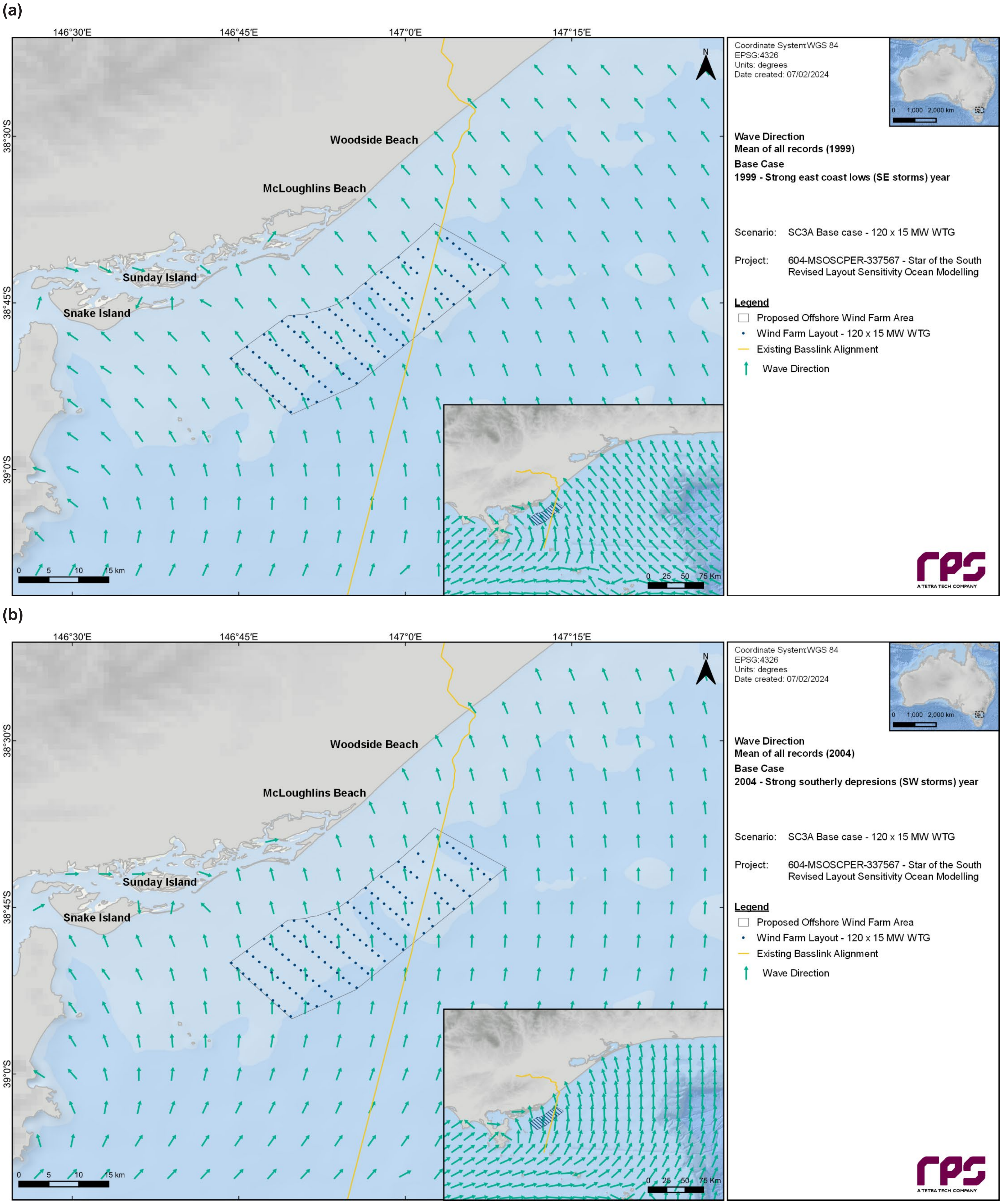


Figure 3.5 **Mapped mean wave direction (θ_m) in the Base scenario (SC3A) for the year (a) 1999 and (b) 2004. The arrows indicate unweighted time averages of wave directions from 2 hourly model output over the year. For visual clarity, the arrows are shown at a much lower resolution than that of the wave model grid. The OWFA and an indicative WTG layout is shown on the map for context.**

4 ASSESEMENT OF WIND WAKE EFFECTS

The wind wake effects for the two revised designs were characterised using the Wind Atlas Analysis and Application Program (WAsP), developed by DTU Wind Energy. WAsP is a tool used by wind energy proponents and analysts for wind data analysis, wind atlas generation, wind climate estimation, wind resource assessment, project siting and energy yield calculations for wind turbines and wind farms. Particularly relevant to this study, WAsP contains a model for wind farm wake effects, which is discussed further in RPS (2021).

Table 2.1 shows the two revised wind farm design alternatives. These designs were configured in WAsP the same way as the original MDS layout was previously assessed (RPS, 2021). The power and thrust curves for the revised 236 m dimeter WTG were configured following published benchmark data (Gaertner et al., 2020). The power and thrust curves for the revised 285 m dimeter WTG were not available from the published literature and were therefore extrapolated based on the available data for 5 MW (Jonkman et al., 2009) and 15 MW WTGs (Gaertner et al., 2020). This imitated the approach used to establish the power and thrust curves for the largest WTGs that featured in the original MDS assessment.

Wake effects were modelled using WAsP under representative wind forcing incident from twelve directional sectors (centred on 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300° and 330°). For each directional sector WAsP applied a statistical distribution of wind speed based on long-term wind data measured at Hogan Island.

Wind monitoring stations were set up in WAsP to profile the wake effects both within the OWFA and the wake-affected areas beyond the OWFA. Profiles from more than 700 stations were assessed to characterise the spatial changes in wake effects for each of the twelve directional sectors. The wake effects for each wind farm design were characterised at each station as a percentage reduction in wind speed, a factor that varies significantly with incident wind direction. The station results were spatially interpolated to fully map the wake zones over the wider project area for each of the twelve incident wind directions.

The wake results for the two revised development layouts and the original MDS layout were compared to each other across seven transects. The transects, which are all indicated in Figure 4-1, were selected to capture the most relevant wind directions affecting coastal processes. Each transect begins at the outer perimeter of the OWFA and extends either to the nearest coastline or far offshore to the northeast in the case of T1. The transects are arranged such that if the seven transect lines were projected inside the revised OWFA they would meet at a virtual origin, approximately coinciding with centre of the wind farm area.

The wake effects within the OWFA itself were calculated but are not presented because transect data through this region appears very noisy due to the intersection of the transects with the three different WTG layouts, which is essentially random. While the local details of the wake effects with the OWFA depend on the placement of the WTGs, in a general sense the wake losses will always build up through the wind farm and peak near the downwind edge of the for a given wind direction. Therefore, the transects indicated Figure 4-1 begin where wind wake effects are near maximum and then follow the wind speed recovery with distance away from the OWFA.

The wind wake results for transects T1 to T7 are indicated in Figure 4-2 to Figure 4-8. Each figure shows the wind speed reduction due to wind wake effects for the original MDS layout (“200x12”) and the two revised development options (“100x15” and “92x19”) compared on a common axis. It is clear from the results that the original MDS layout generally causes larger wake effects.

Near the beginning of the wake zone, within approximately 5 km from OWFA, the wake effects are relatively high for all layouts but also appear as irregular in their trend. The irregularity is due to the direct presence or absence of WTGs near the start of each transect. After this distance the wake effects for all layouts tend to show a smooth recovery of the wind speed with distance away from the OWFA. Beyond 5 km from the OWFA the wake effects for the original MDS are consistently and significantly larger than the wake losses for either of the revised development options. Within 5 km, the wake effects are also generally higher for the original MDS, and where they appear slightly lower it is likely only a local effect caused by the differing WTG placement between layouts.

For transects T1 to T6 the wake effects at a distance 10 km from the OWFA were approximately in the range of 8% to 12% for the original MDS layout and tended to be 2% to 4% lower than that for both revised layouts. For transect that is towards Wilsons Promontory, T7, the wake effects for all layouts were more similar than for the other transects but still tended to be slightly larger for the original MDS layout .

The wake effects for the two revised layout tended to be very similar to each other with no significant differences beyond 5 km. This is consistent with the results of the original sensitivity study (RPS 2021) which found that for a given OWFA perimeter the overall wake effects were related to the nominal total power output of the wind farm.

To provide an overall summary of results, the average wake loss with distance for all transects was calculated based for five distance categories from 5 km to 25 km downwind of the OWFA (Table 4.1). The average results confirm that the original MDS layout had larger wake losses for all distances, at least 2.4% larger for the distances up to 15 km. The average wake losses from the “92x19” layout tended to be slightly larger than the “120x15” layout, but the difference was only around 0.5%.

Table 4.1 Summary of average wind wake speed reductions with distance from OWFA for each layout, based on an average of all transect directions (T1 to T7)

	0 – 5 km	5 – 10 km	10 – 15 km	15 – 20 km	20 – 25 km
Original MDS	14.3%	11.5%	8.3%	6.5%	5.3%
Revised-1	11.9%	7.9%	5.9%	4.6%	3.8%
Revised-2	12.2%	8.5%	6.1%	5.1%	4.2%

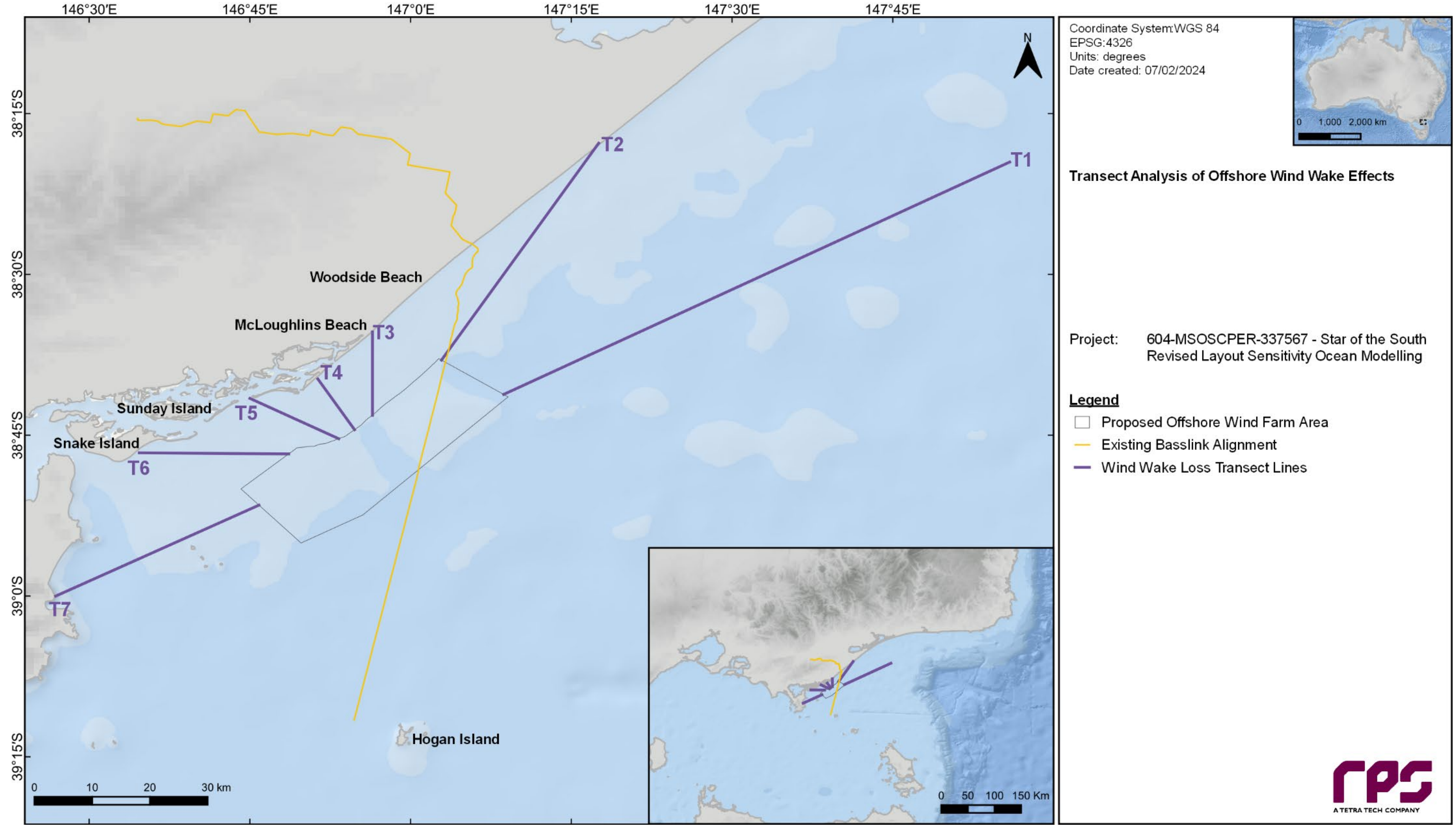


Figure 4-1 Map displaying the location of transect used to assess wind wake effects.

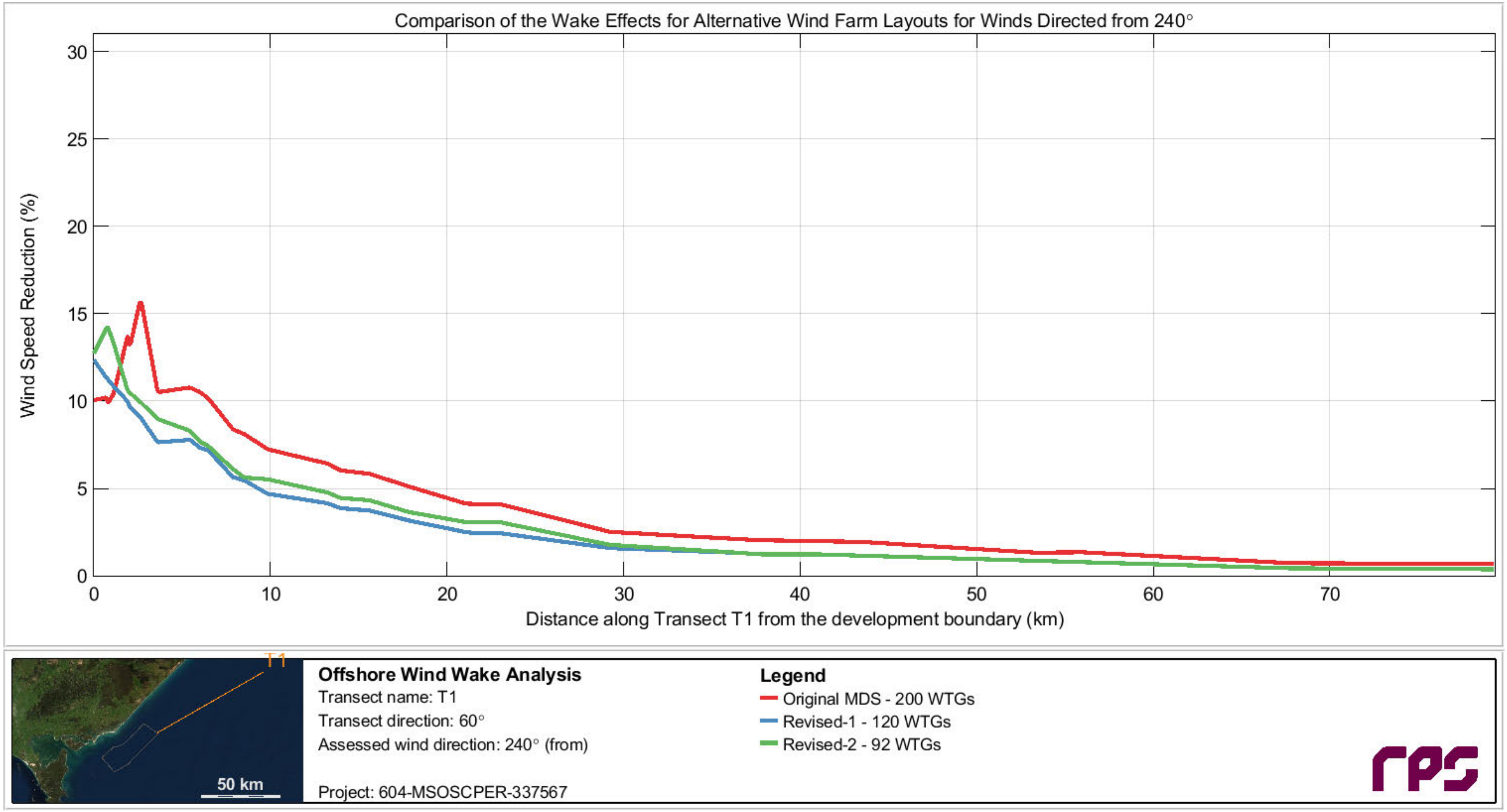


Figure 4-2 Comparison of predicted wind wake effects along transect T1 for winds directed from 240°

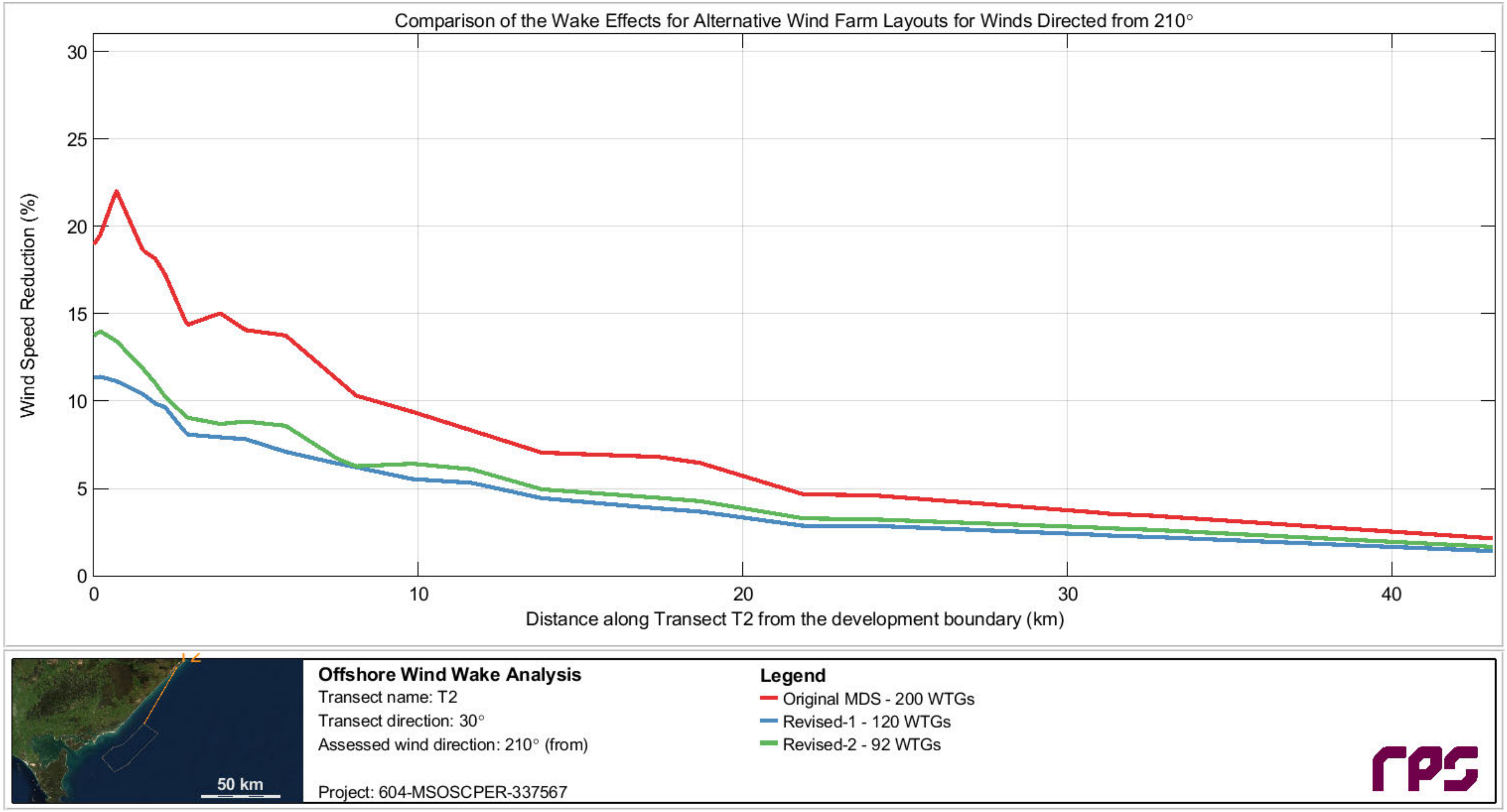


Figure 4-3 Comparison of predicted wind wake effects along transect T2 for winds directed from 210°

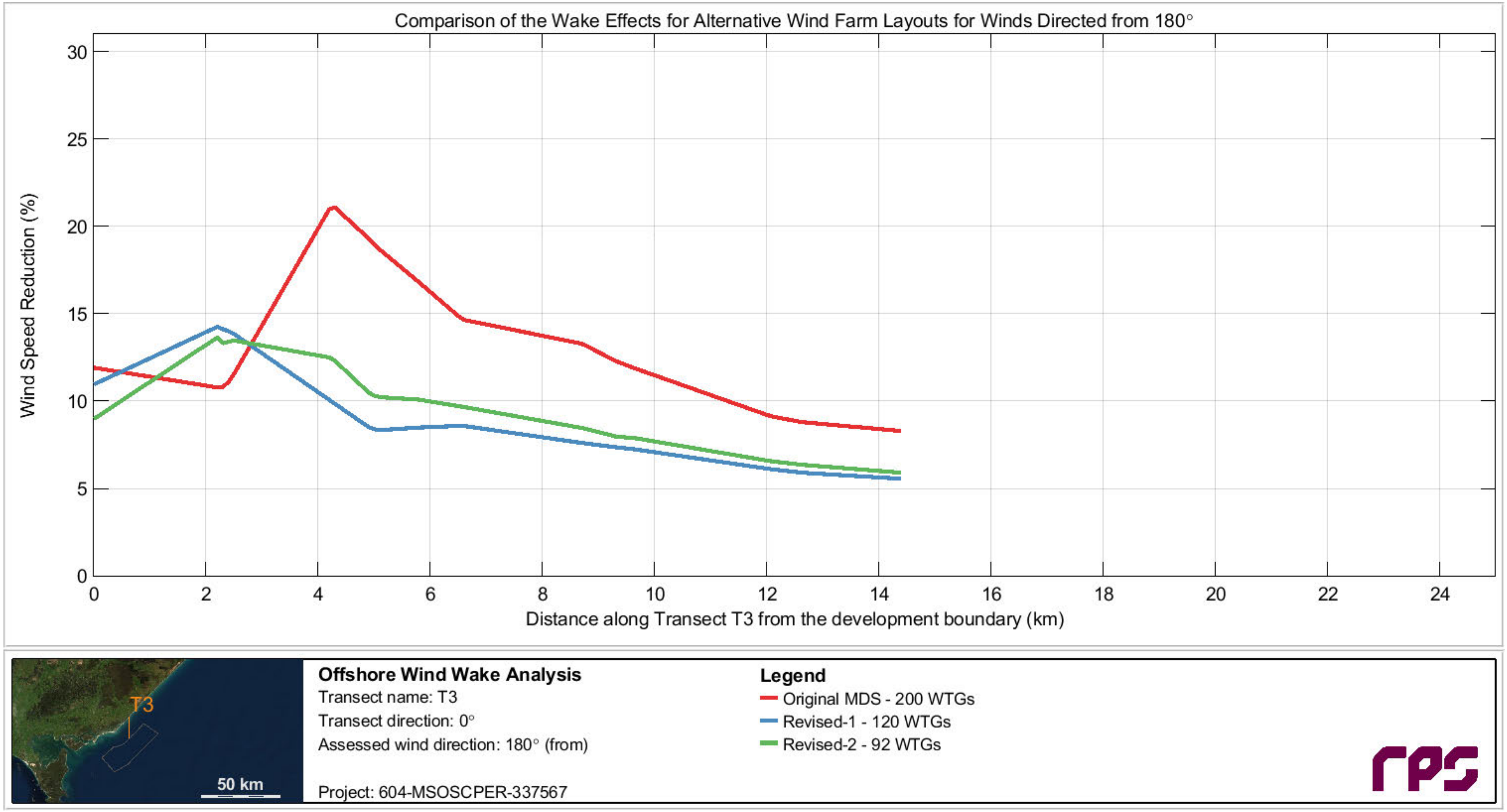


Figure 4-4 Comparison of predicted wind wake effects along transect T3 for winds directed from 180°

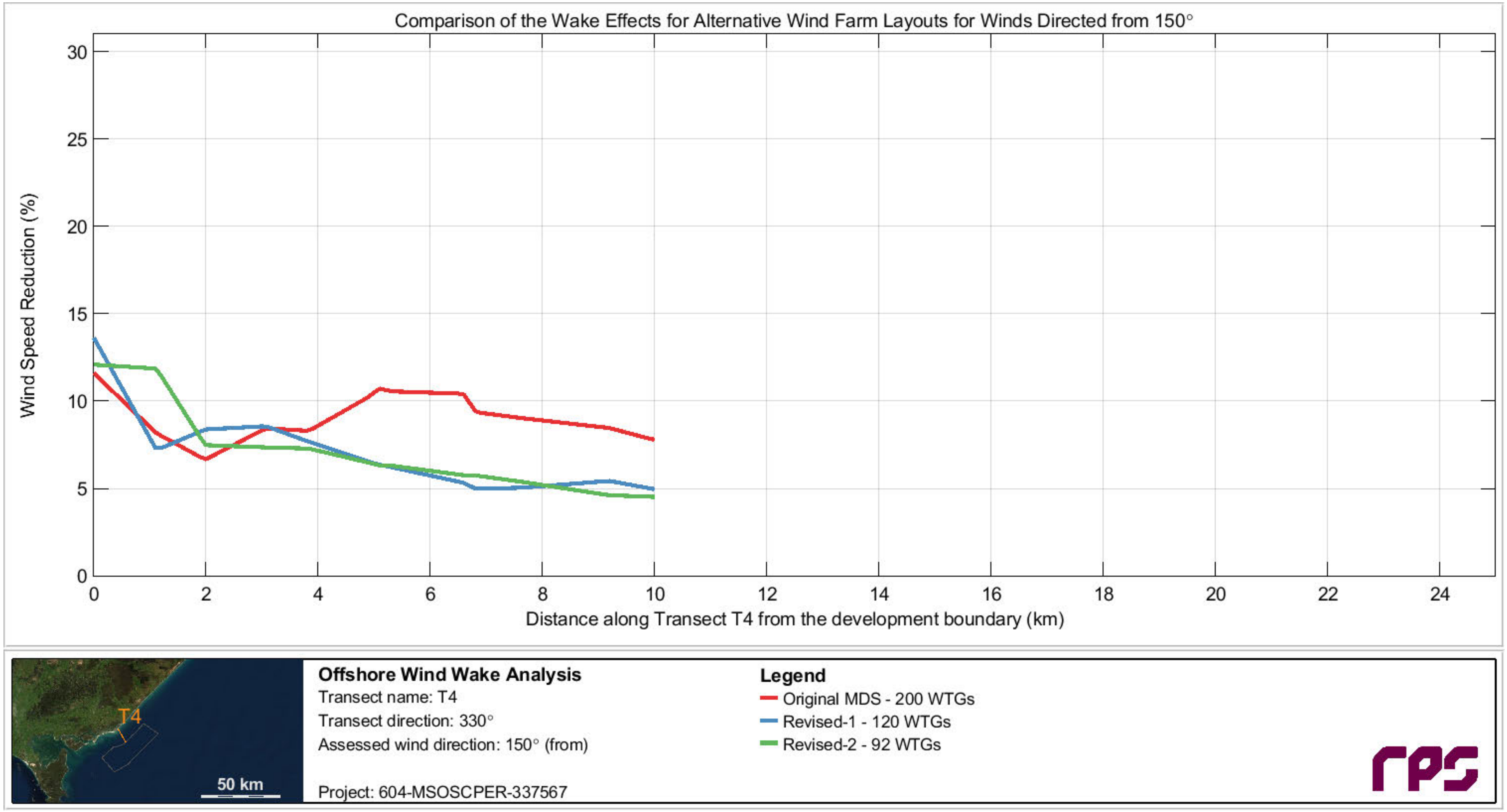
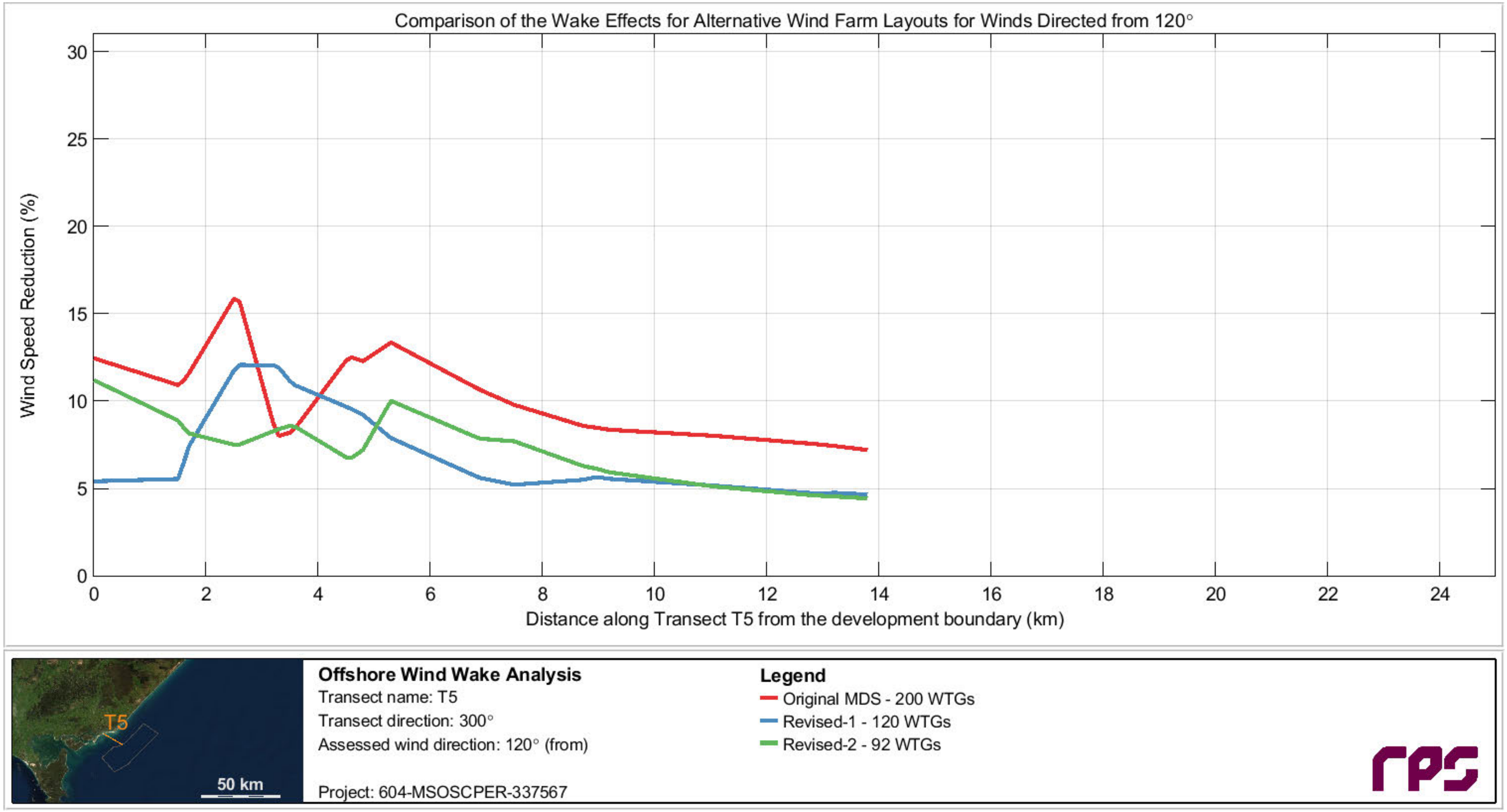


Figure 4-5 Comparison of predicted wind wake effects along transect T4 for winds directed from 330°



Offshore Wind Wake Analysis
Transect name: T5
Transect direction: 300°
Assessed wind direction: 120° (from)

Project: 604-MSOSCPER-337567

Legend
🟥 Original MDS - 200 WTGs
🟦 Revised-1 - 120 WTGs
🟩 Revised-2 - 92 WTGs

Figure 4-6 Comparison of predicted wind wake effects along transect T5 for winds directed from 120°

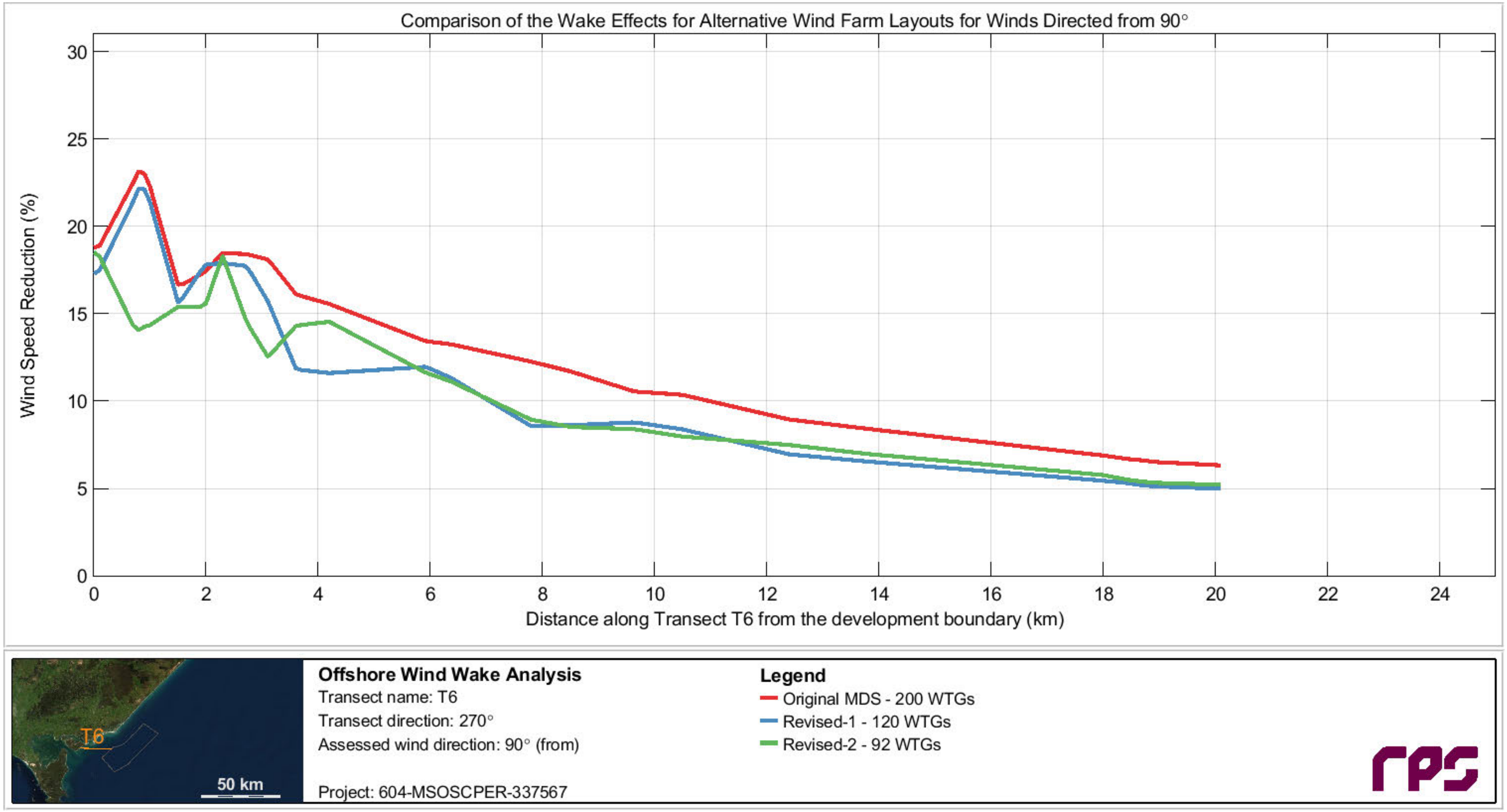


Figure 4-7 Comparison of predicted wind wake effects along transect T6 for winds directed from 90°

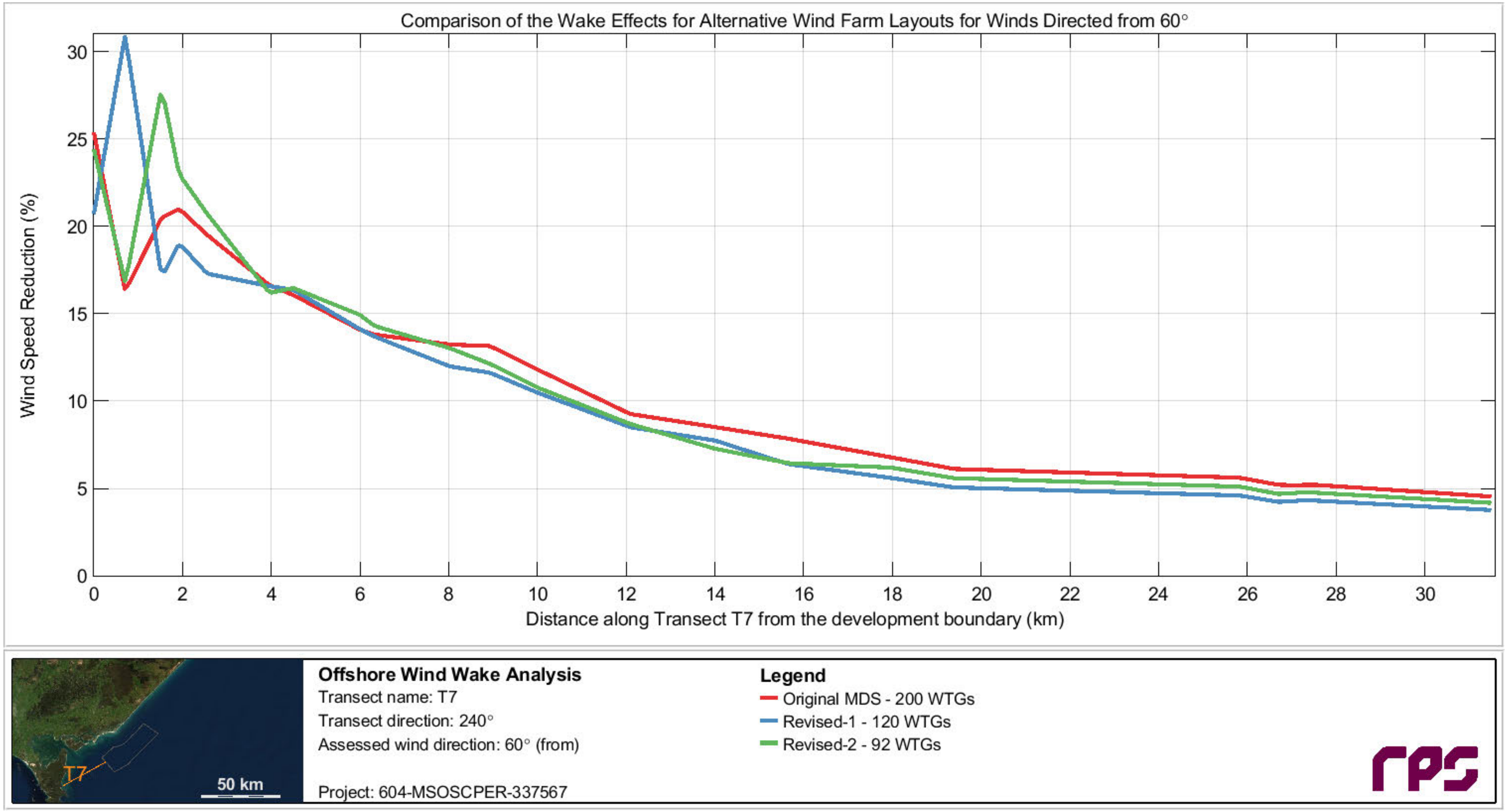


Figure 4-8 Comparison of predicted wind wake effects along transect T7 for winds directed from 60°

5 ASSESSMENT OF WAVE TRANSFORMATION

5.1 Overview

The wave climate effects for the revised design layouts were quantified using the Delft3D-SWAN model (SWAN). SWAN is a spectral phase-averaging wave model developed by the Delft University of Technology (Booij et al., 1999; Ris et al., 1999). SWAN is a numerical model for simulating realistic estimates of wave parameters in coastal areas for given wind, bottom and current conditions. The revised layout and associated wave model bathymetry are outlined in this report. The wave modelling methodology, data sources and all other inputs are the same as those applied to the detailed wave hindcast modelling, for more detail refer to RPS (2022a and 2022b).

As the predicted wind wake effects for the two revised layouts tended to be very similar to each other (Section 4), only one revised layout has been selected for the wave climate sensitivity modelling. The revised layout modelled was selected based on the design configuration that led to the largest physical blockage of waves by the WTG monopiles. Following the methodology of the previous detailed wave modelling (RPS, 2022b) it was assumed that 12.5 m diameter monopiles would be required for all potential WTG sizes and water depths throughout the site. Therefore, the revised layout of 120 WTGs, with 12.5 m diameter monopiles (Figure 2-1), was selected for sensitivity modelling and comparison to the predicted MDS layout results from the detailed hindcast modelling, to determine whether they are similar in character and the effects remain within the bounds predicted.

5.2 Updated SWAN Grids for Revised OWFA Layout

The computational grid for the SWAN model was defined using an unstructured mesh. This approach allowed a more efficient representation of complex features due to the ability to use finer mesh cells in the areas of interest (in and around the OWFA and along the coastal area of interest), and coarser mesh cells for the broader area. As the unstructured mesh has areas of increased resolution around each monopile it is specific to the windfarm layout being modelled, therefore it was necessary to update the model grid for the sensitivity modelling. The updated unstructured mesh over the whole model domain for the revised wind farm layout of 120 of the smaller WTGs is presented in Figure 5.1.

The computational mesh has a resolution of 10-12 km at the offshore boundaries which becomes progressively finer approaching the Gippsland coastline so that a resolution of approximately 50 m is achieved around each of the monopiles and a resolution of 100-300 m is achieved within the nearshore zone. Figure 5.2 and Figure 5.3 show progressively zoomed in views of the computational mesh and bathymetry in the vicinity of the OWFA and nearshore zone.

The use of an identical grid mesh in both the pre-development and post-development scenarios ensures that no small differences between the scenario outputs can be attributed to interpolation idiosyncrasies from differing grids. No wave obstacles on wind wake effects were be implemented in the pre-development scenarios (i.e. the two Base Cases).

5.3 Wave Modelling Scenarios

Pre and post development wave modelling with the updated SWAN model grid were completed for the two selected years (1999 and 2004), which were each selected to represent a different extreme of the annual wave climate. Simulations using the “120 WTG” grid mesh were completed for both pre-development and post development cases.

The naming convention for wave modelling results needs to distinguish between the different development options, the different grid meshes that were used by the wave model and the two different years modelled. Modelling results that that were produced using a “200 WTG” grid mesh are labelled with a ‘SC1’ prefix for consistency with RPS (2022b). A prefix of ‘SC3’ is used in the to designate all wave modelling scenarios that were produced using the “120 WTG” grid mesh (the ‘SC2’ prefix was skipped to avoid potential confusion with the original MDS climate change scenarios). The letters ‘A’ and ‘B’ in the scenario labels distinguishes pre-development and post-development model configurations, respectively.

A total of four new wave model runs were completed for this study using the 120 WTG grid mesh:

1. SC3A 1999 - Base Case for 1999

2. SC3A 2004 - Base Case for 2004
3. SC3B 1999 – Development Case 1999
4. SC3B 2004 – Development Case 2004

In addition, a further four sets of wave model results from the original MDS study with the 200 WTG grid mesh were reanalysed for this study:

5. SC1A 1999 - Base Case for 1999
6. SC1A 2004 - Base Case for 2004
7. SC1B 1999 – Development Case 1999
8. SC1B 2004 – Development Case 2004

For each of the wave modelling scenarios a set of time-series of predicted wave parameters at half-hourly time steps was delivered to the wider Star of the South project team (Stantec) to allow coastal landform sensitivity assessment to proceed in parallel to this study. It is not possible to present this data in its entirety in report format, so this report will summarise only the key spatial and temporal trends in the data using statistical methods.

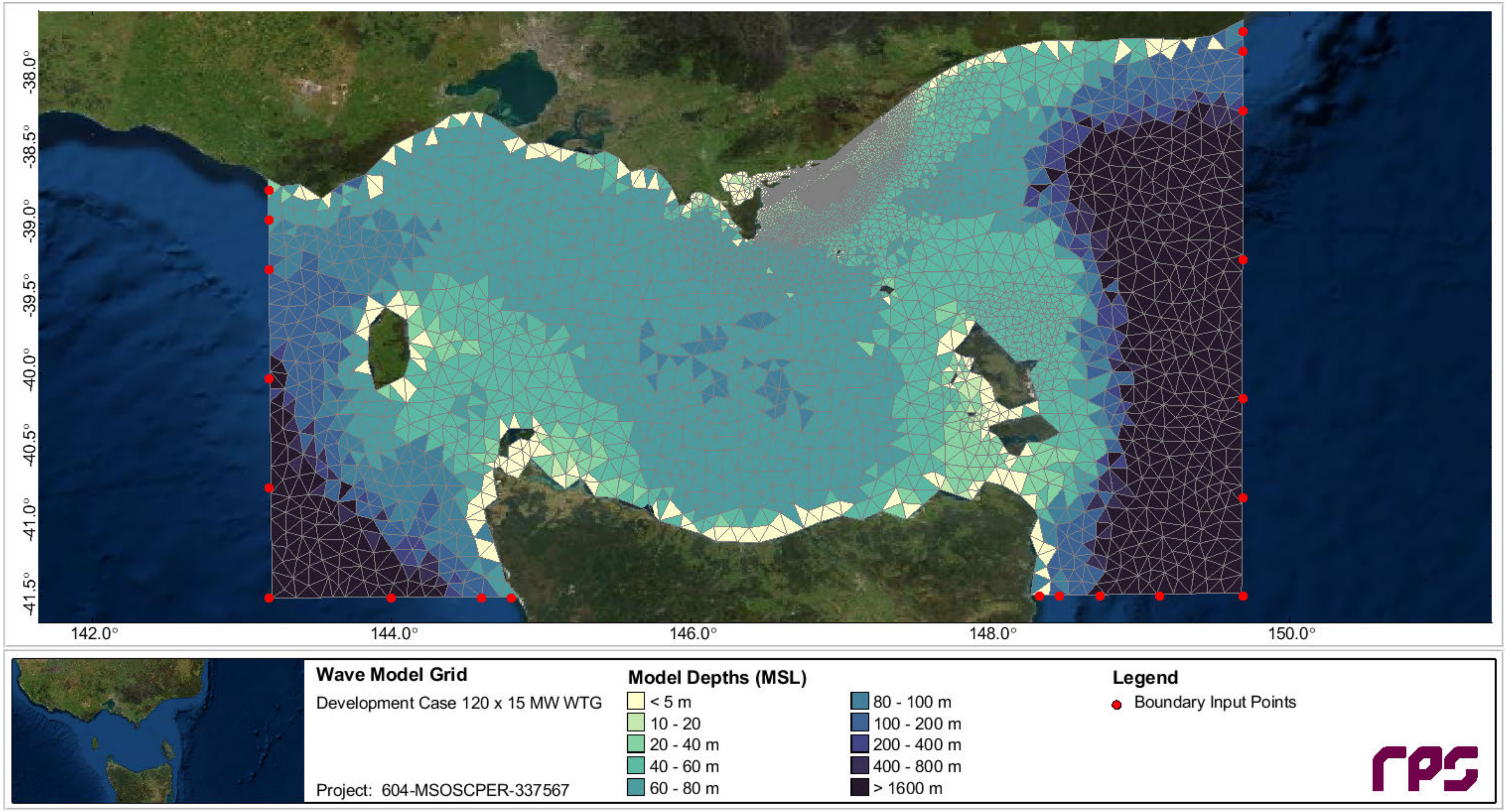


Figure 5.1 SWAN wave model domain, showing the updated unstructured computational mesh and bathymetry over the entire domain, for the revised wind farm layout of 120 of the smaller WTGs.

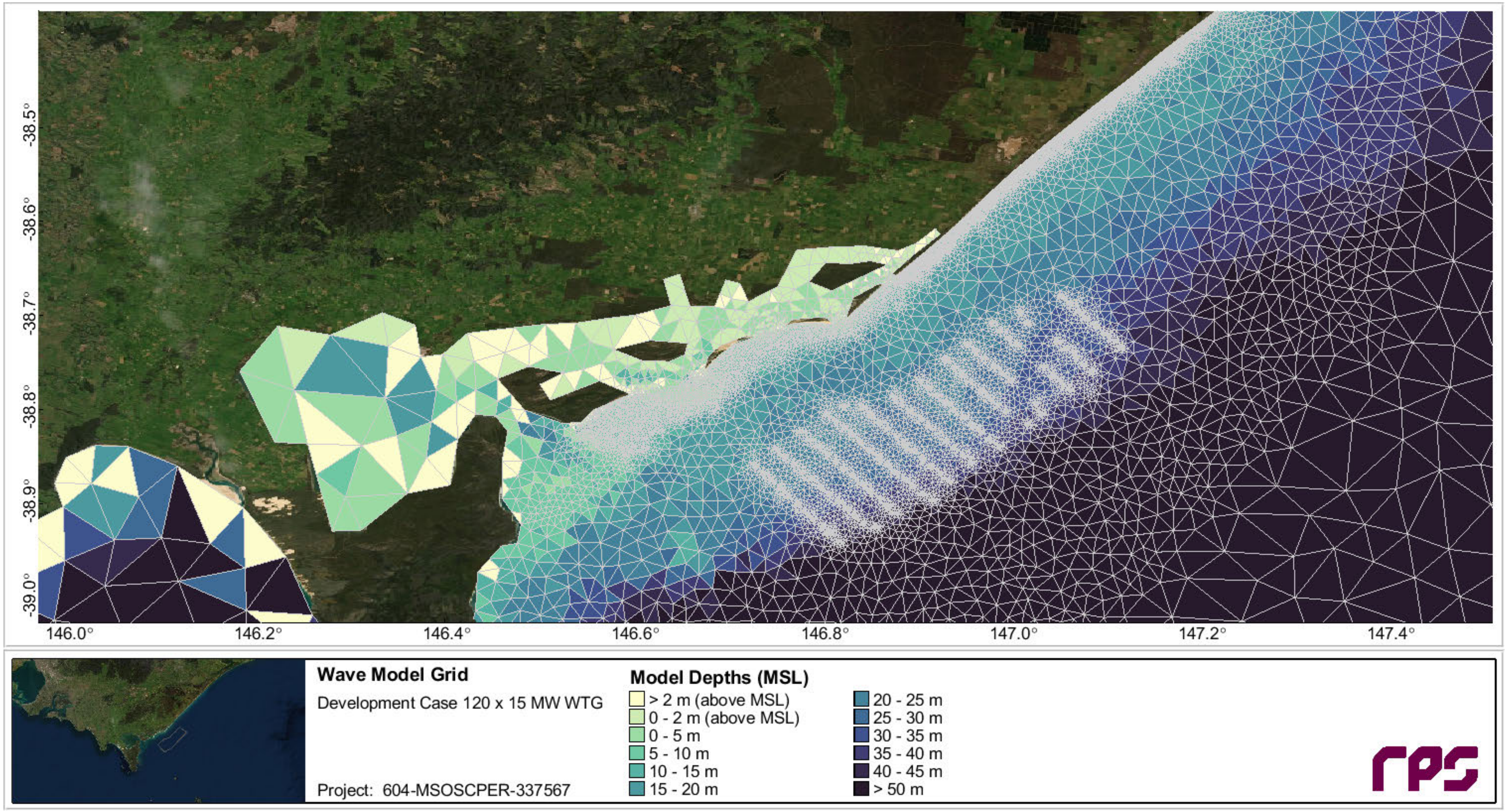


Figure 5.2 SWAN wave model grid, showing the updated high-resolution unstructured computational mesh and bathymetry around the OWFA monopiles and along the coastal area of interest, for the revised wind farm layout of 120 of the smaller WTGs.

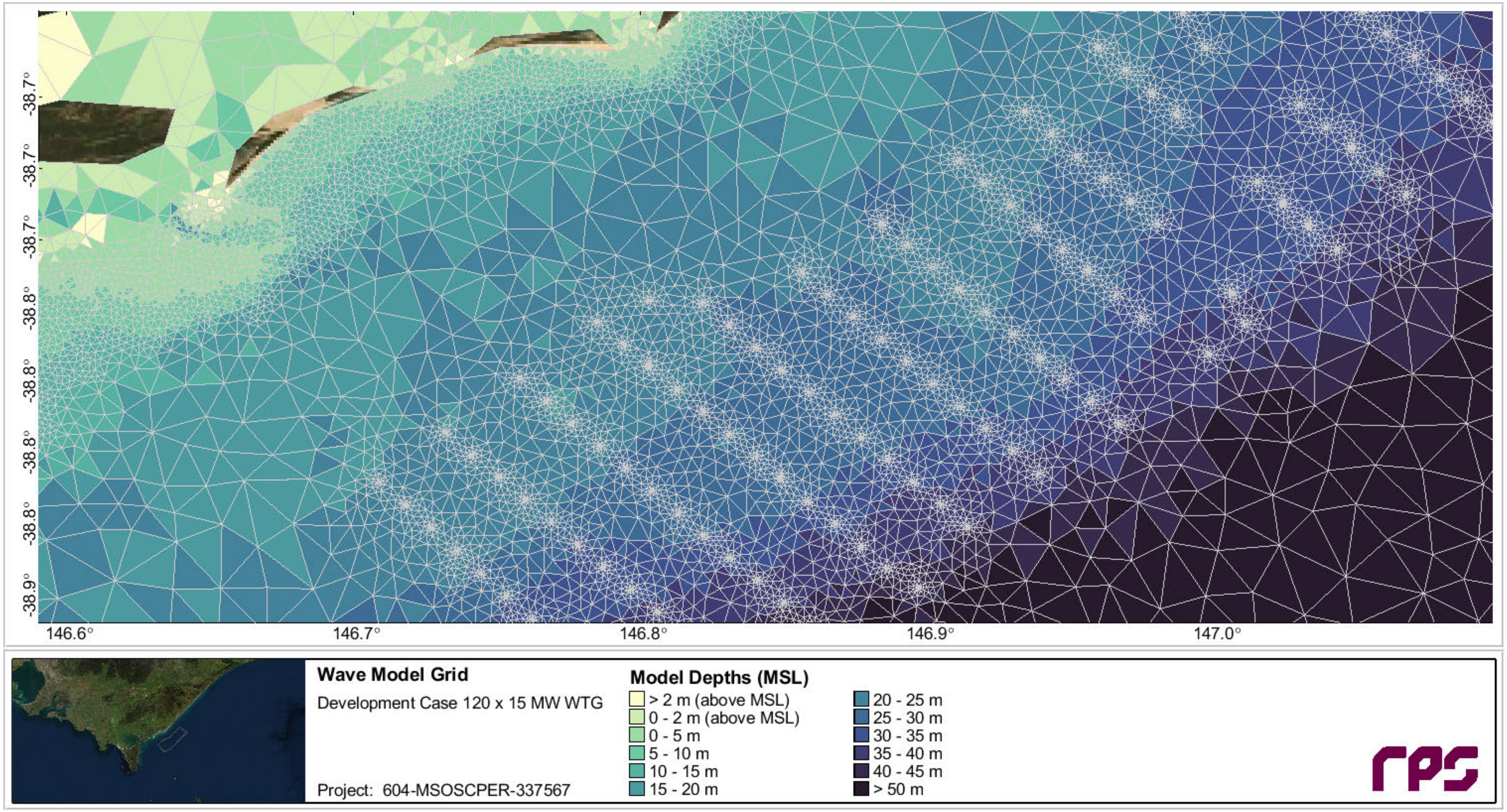


Figure 5.3 SWAN wave model grid, showing a detailed view of the updated high-resolution unstructured computational mesh and bathymetry around the OWFA monopiles and along the coastal area of interest, for the revised wind farm layout of 120 of the smaller WTGs.

5.4 Comparison to Previous MDS Results

The predicted wave changes for the revised layout (SC3B) were evaluated by comparison to the pre-development wave model results from the same grid (SC3A). The overall reduction in wave energy for the revised development was characterised by mapping the differences between the 50th, 80th and 95th percentiles of significant wave height for the development scenario with corresponding percentiles for the pre-development result. This was done independently for both years, 1999 and 2004. Plotting the relative difference maps between scenarios for each percentile serves to highlight small but systematic changes. The same analysis was done for the pre and post development results produced with the original MDS layout “200 WTG” grid mesh (SC1).

The 80th percentile significant wave height difference maps for (a) SC1 and (b) SC3 for 1999 and 2004 are presented in Figure 5-4 and Figure 5-5, respectively. The difference maps indicate that the 80th percentile wave heights are expected to be reduced in the range of 0.05-0.15 m in some areas that are within or near the OWFA, compared to pre-development conditions. The reduction of wave heights in this range is concentrated on the northeastern part of the project area and this is because that area is leeward from the median wave and wind direction. In general, the spatial difference maps indicate that the largest differences occur within and near to the outer edges of the OWFA, with changes diminishing in magnitude towards the coast.

The difference maps for the two selected years show different main directions of the ‘wake’ zone (areas where waves are reduced), with 1999 showing the largest reductions to the northwest between the OWFA and the coast and 2004 showing the largest reductions to the northeast, leeward from the dominant wave direction for that year.

The revised layout development scenario (SC3) 80th percentile difference maps clearly show a smaller affected area for wave ‘wake’ zone when compared to the original MDS development layout scenario (SC1). The magnitudes of the differences were also lower. The 80th percentile wave height differences for the revised scenario are less than 0.1 m outside the OWFA for both modelled years. Differences within the range of 0.05 m to 0.1 m extend up to 7 km from the boundary of the OWFA compared to 30 km for the original development scenario.

The median and 95th percentile significant wave height difference maps for (a) SC1 and (b) SC3 for 1999 and 2004 are presented in Appendix (Figure 8.3 to Figure 8.6). The median and 95th percentile significant wave height difference maps show similar relative trends to the 80th percentile, with smaller ‘wake’ zones and difference magnitudes at the median and larger at the 95th percentile. Both the median and 95th percentile significant wave height difference maps show that the revised layout development scenario is predicted to have a smaller wave ‘wake’ zone and lower magnitude differences when compared to the original MDS development layout scenario.

Figure 5-6 and Figure 5-7 show maps of the small changes in mean wave direction that are expected under, (a) SC1 and (b) SC3 development scenarios for 1999 and 2004. The changes in mean wave direction under both Development scenarios, for both modelled years, are small in absolute terms but the patterns of relative difference between both scenarios can be distinguished clearly. The mean wave difference maps show that waves arriving near to the west corner of the OWFA have their mean directions deflected clockwise in the range of 1° to 4°. Waves arriving near the east corner of the OWFA have their mean directions deflected anticlockwise in the range of 1° to 5°. The patterns of deflection are relatively symmetrical and are caused by a slight filtering of the mean wave directions in the presence of the development monopiles.

The mean direction difference maps for the two selected years show slightly different shapes and magnitudes to the areas with clockwise and anticlockwise rotation, with 1999 showing symmetrical areas of clockwise and anticlockwise rotation and 2004 showing a larger area with higher magnitudes to the northeast of anticlockwise rotation, reflecting the higher proportion of waves arriving at the site from the southwest during this year.

As was described for the significant wave height difference maps, the revised layout development scenario (SC3) mean direction difference maps show smaller affected areas and lower magnitudes of difference, when compared to the maps for the original MDS development layout scenario (SC1). The predicted mean direction differences outside the OWFA for the revised scenario are less than ±3° and differences of greater than ±1° extend to 25-48 km from the boundary of the OWFA compared to 37-62 km for the original development scenario.

The changes in wave height and wave direction distributions within the OWFA under each of the Development scenarios has also been compared by referencing joint frequency table data for the Wave Buoy station for 1999 and 2004. In Table 5.1 and Table 5.2 the joint frequency data for the Base scenario is supplemented with two additional end columns and end rows to summarise the difference in totals relative to each Development scenario. The tables indicate a small but consistent change in the distribution of significant wave heights for both development scenarios, however the revised layout scenario (SC3B) shows less change with a total of 3.1-3.4% compared with 3.4-3.9% increase in the percentage of total waves under 1.5 m height and approximately corresponding decreases in larger waves (allowing for rounding tolerance). The tabulated differences also confirm that changes in the directional distributions are predicted to be small, however are also smaller for the revised layout scenario (SC3B).

To examine the changes in significant wave height, mean wave period and mean wave direction near the coastline inshore of the OWFA, for each of the Development scenarios – which were often below the minimum threshold values shown on the spatial difference maps – tabulated probability distributions of predicted changes at seven of the time-series output locations have been prepared for 1999 and 2004 (Table 5.3 to Table 5.8). Figure 5.8 shows the output locations used for the analysis, note six of these points have been chosen as representative of the range of changes along the 10 m depth contour, with the Wave Buoy location used as a reference for the magnitude of changes within the OWFA. The tables collectively summarise the probability of any changes under the revised Development layout scenario (SC3) and the original MDS Development layout scenario (SC1) for each variable, and the likelihood that any changes would fall between the ranges indicated within each table.

The distribution of reduction in wave heights under each development scenario was calculated from the 1999 results (Table 5.3) and from the 2004 results (Table 5.4). At the Wave Buoy location the total probability of any decrease exceeding 0.02 m across both years was in the range of 81% to 88% for scenario SC1 and 74% to 77% for SC3. Just over half (54%) of the decreases in significant wave height for SC1 were in the range of 0.02 m to 0.06 m and there was a similar proportion (51%) in the same range for SC3 (Table 5.3).

Table 5.3 and Table 5.4 also show that the probability of wave height reduction was significantly lower at the 10 m contour stations (‘c10’ stations) than the Wave Buoys station. The three stations located directly inshore of the OWFA (Figure 5.8) had the highest probabilities of a reduction in wave height: 35-48% (c10pt12), 61-72% (c10pt17) and 53-55% (c10pt22) for scenario SC1, reducing to 24-35% (c10pt12), 23-30% (c10pt17) and 15-19% (c10pt22) for scenario SC3.

The probabilities of changes in mean wave directions (above a threshold of 1°) under each of the Development scenarios are summarised for 1999 and 2004 in Table 5.5 and Table 5.6, respectively. Because the direction in which waves are deflected is significant, the changes presented in Table 5.5 are grouped according to clockwise and anticlockwise deflections. The results for the ‘c10’ stations show that across these stations the proportion of incoming waves that are deflected in either direction ranges from 22% (c10pt17) to 37% (c10pt07) for scenario SC1, reducing to 4% (c10pt17) to 27% (c10pt07) for Scenario SC3. For both development layouts a large majority of the deflections are within the range of 1° to 3°.

Although the deflections are small, the spatial trends are consistent with the previously presented maps of wave direction difference (Figure 5-6 and Figure 5-7) in the sense that those stations west of the central Wave Buoy station (c10pt01, c10pt07 and c10pt12) tend to have clockwise deflections, and anticlockwise deflections for stations to the east (c10pt22 and c10pt28).

The probabilities of changes in mean wave period above a threshold of 0.1 seconds for each of the Development scenarios are summarised for 1999 and 2004 in Table 5.7 and Table 5.8, respectively. At the Wave Buoy station 42-50% of the recorded waves have a slightly longer period under the original MDS Development (SC1), which reduced to 38-42% for the revised development scenario (SC3). All recorded increases in period ranged between 0.1 and 0.6 seconds. This result is consistent with expectations given that the development in broad terms is expected to act as a slight filter to incoming waves, with relatively more disruption to shorter-period waves. At the ‘c10’ stations the probability of changes in mean wave period are much smaller than at the Wave Buoy, with the revised development layout scenario (SC3) having lower probability of changes in mean wave period over all stations.

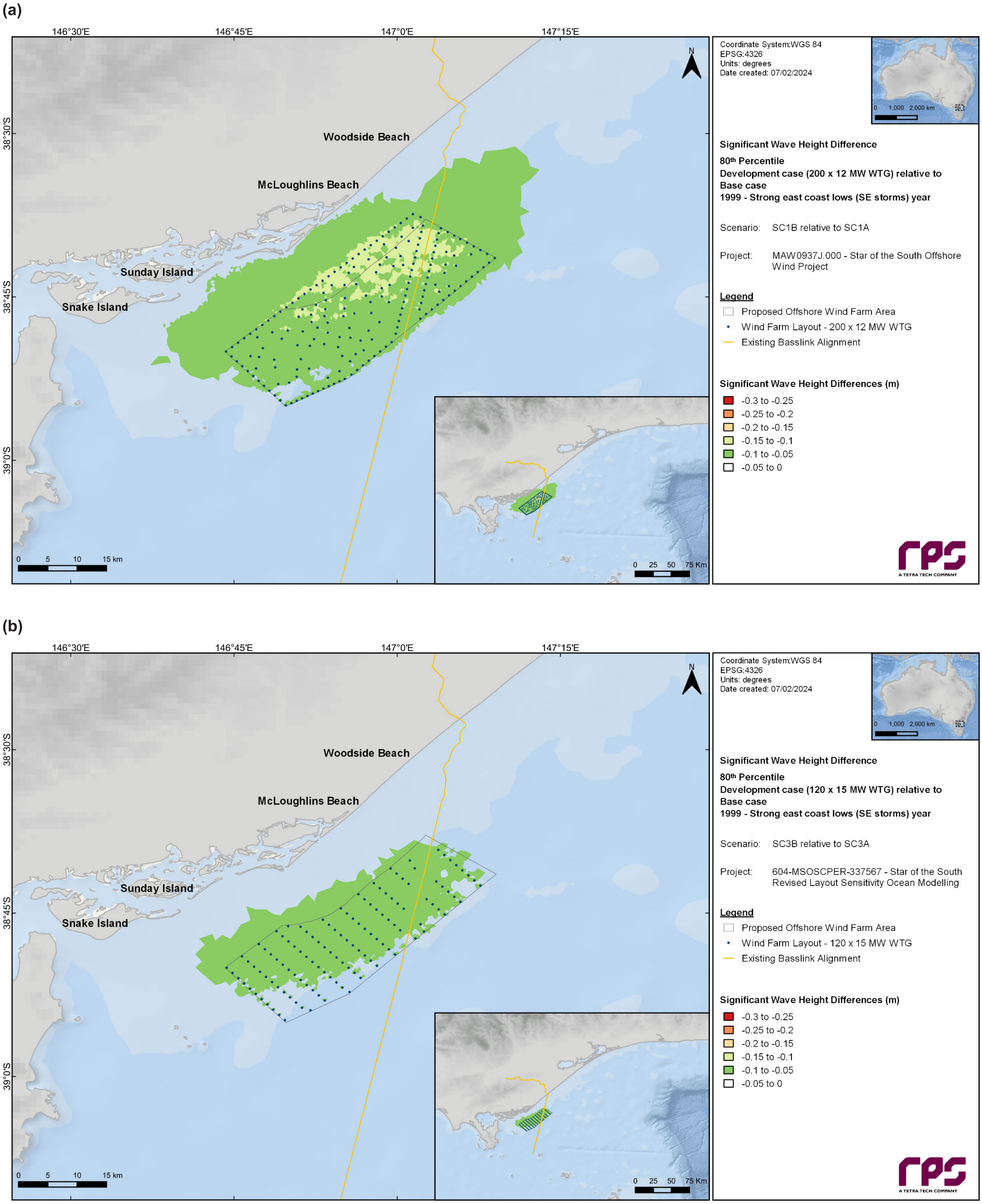


Figure 5-4 Map of predicted change in the annual 80th percentile significant wave height for the year 1999 based on (a) the original MDS development option (200 WTGs) and (b) the selected revised development option (120 WTGs)

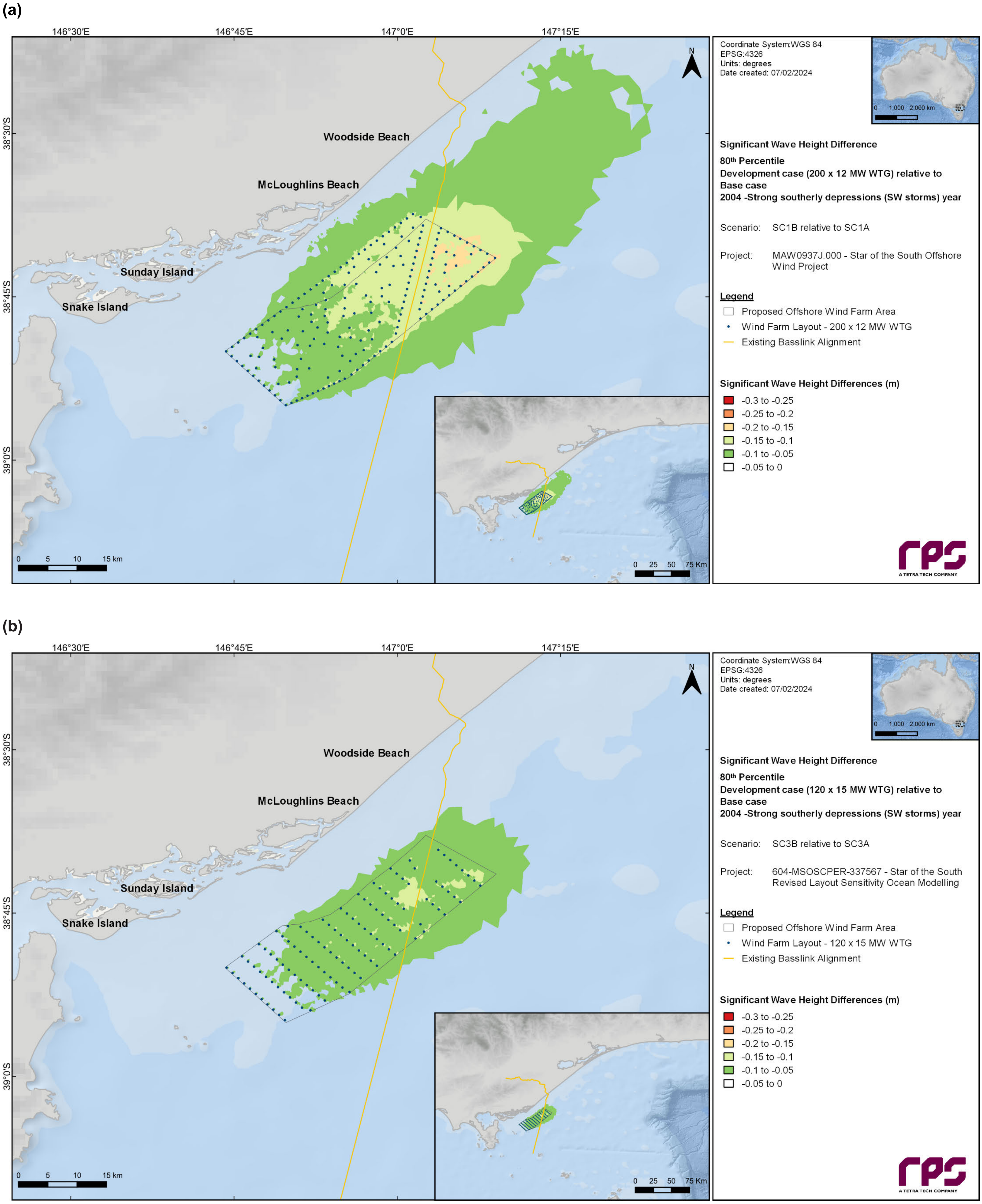


Figure 5-5 Map of predicted change in the annual 80th percentile significant wave height for the year 2004 based on (a) the original MDS development option (200 WTGs) and (b) the selected revised development option (120 WTGs)

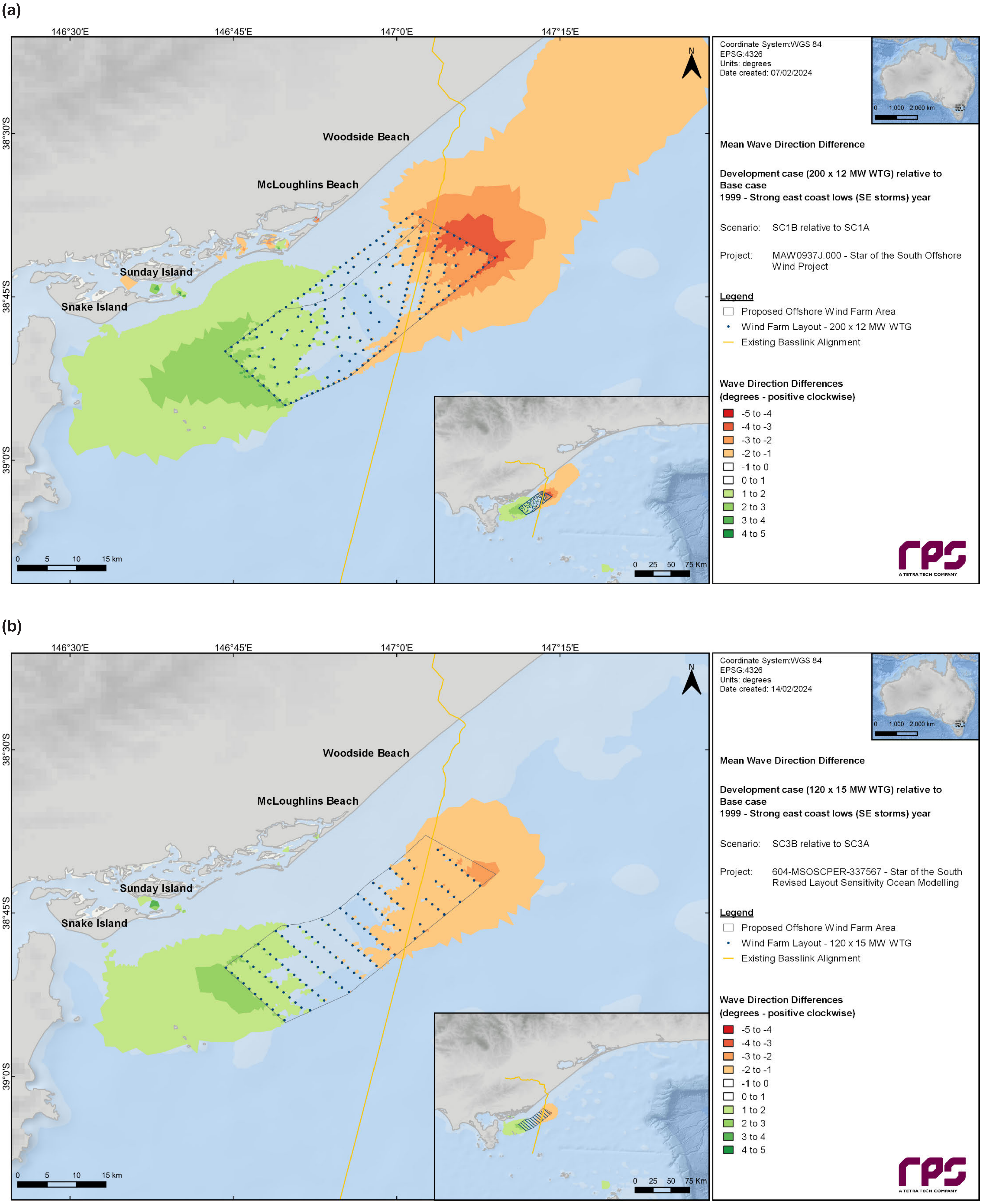


Figure 5-6 **Map of predicted change in the annual mean wave direction for the year 1999 based on (a) the original MDS development option (200 WTGs) and (b) the selected revised development option (120 WTGs)**

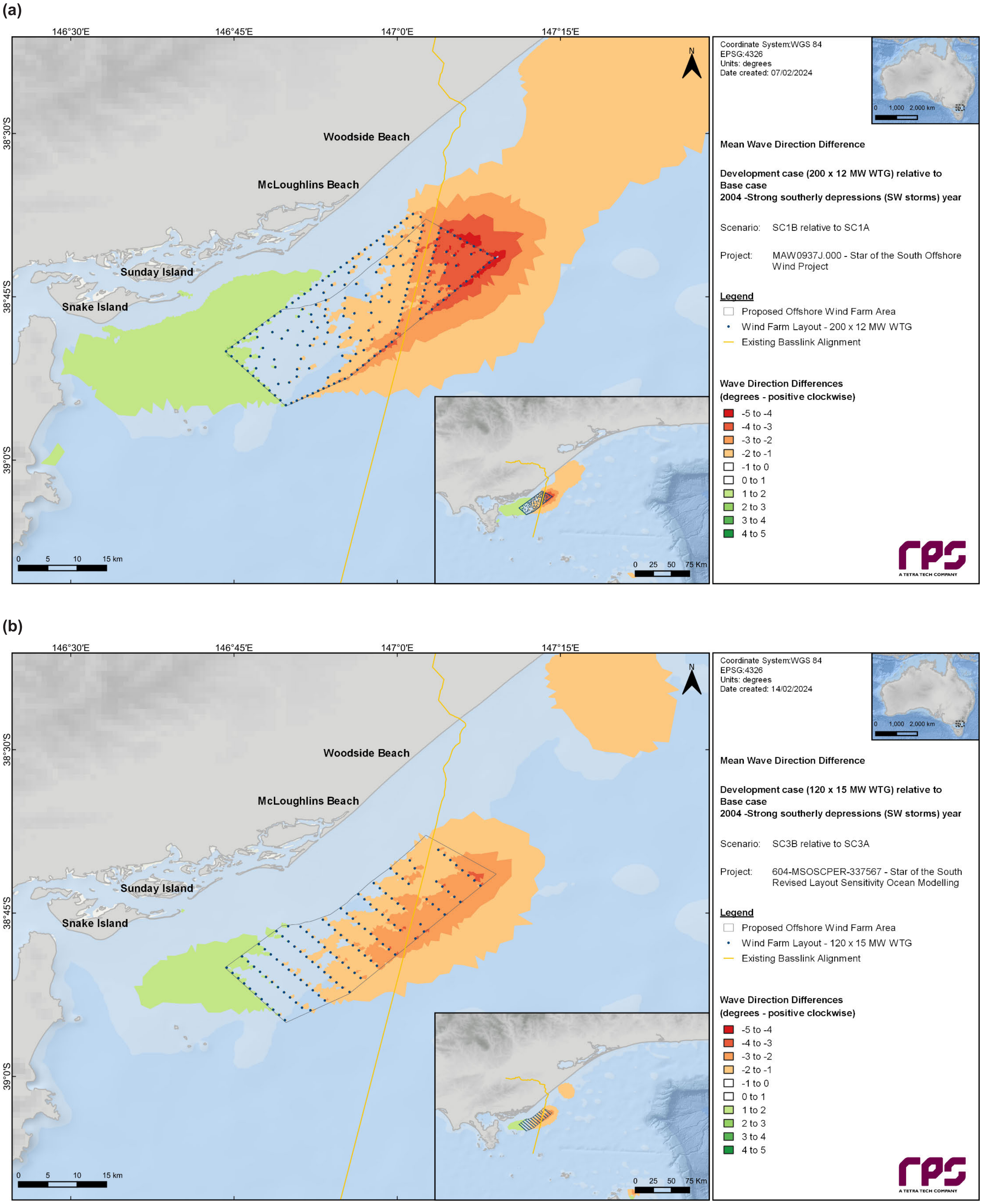


Figure 5-7 Map of predicted change in the annual mean wave direction for the year 2004 based on (a) the original MDS development option (200 WTGs) and (b) the selected revised development option (120 WTGs)

Table 5.1 Joint frequency table for significant wave height (H_s) and mean wave direction (θ_m). Percentage distributions for the Base scenario (SC1A) at the Wave Buoy station for 1999 are shown, based on hourly model output. The 'Difference' row and column indicate how the total percentage distributions changed for this location (i.e. absolute change in percentage distribution) when modelled under the Development scenario (SC1B and SC3B). In these cells, positive values (purple font) represent increases in percentage in the Development scenario while negative values (green font) represent decreases. Wave directions are abbreviated as North (N), East (E), West (W) and South (S), and indicate the direction from which waves are incoming.

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total (%)	Difference SC1B	Difference SC3B
0.00-0.25 m	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.25-0.50 m	-	-	-	-	*	0.1	*	0.1	0.1	*	0.1	-	-	-	-	-	0.4	0.4	0.2
0.50-0.75 m	*	*	*	0.1	1.9	2.8	2.0	1.5	1.8	1.2	0.3	0.1	*	*	0.1	*	11.7	1.9	1.4
0.75-1.00 m	*	*	0.1	0.4	2.6	5.6	2.8	2.5	3.1	2.5	0.6	0.2	0.3	0.1	*	0.1	21.0	1.0	0.7
1.00-1.25 m	*	*	0.2	0.5	3.9	3.6	2.4	1.1	1.5	3.2	0.9	0.2	0.4	0.1	*	*	18.1	0.4	0.5
1.25-1.50 m	*	*	*	0.3	4.3	2.8	1.4	1.2	1.2	3.5	1.7	0.5	0.3	*	*	-	17.4	0.3	0.5
1.50-1.75 m	-	-	-	*	3.0	2.1	1.0	0.7	1.1	2.3	1.8	0.3	-	*	-	-	12.3	-1.2	-1.1
1.75-2.00 m	-	-	-	-	1.8	1.5	0.5	0.1	0.4	1.5	1.4	*	*	-	-	-	7.2	-0.9	-0.8
2.00-2.25 m	-	-	-	-	0.5	1.5	0.4	0.1	0.1	1.2	0.9	0.1	-	-	-	-	4.7	-0.4	-0.2
2.25-2.50 m	-	-	-	-	0.2	1.2	0.6	0.1	*	0.9	0.7	*	-	-	-	-	3.7	-0.6	-0.5
2.50-2.75 m	-	-	-	-	0.2	0.2	0.2	0.1	*	0.6	0.4	*	-	-	-	-	1.7	-0.2	-0.2
2.75-3.00 m	-	-	-	-	*	0.1	0.1	*	-	0.4	0.2	*	-	-	-	-	0.8	-0.3	-0.3
3.00-3.25 m	-	-	-	-	*	0.1	-	-	-	0.1	0.2	*	-	-	-	-	0.5	-0.1	*
3.25-3.50 m	-	-	-	-	*	*	-	-	-	0.2	0.1	*	-	-	-	-	0.3	-0.1	-0.1
3.50-3.75 m	-	-	-	-	*	*	-	-	-	0.1	*	-	-	-	-	-	0.1	-0.1	-0.1
3.75-4.00 m	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	*	*	*
>4.00 m	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	*	-	*
Total (%)	0.1	0.1	0.3	1.3	18.4	21.5	11.5	7.3	9.4	17.7	9.4	1.5	1.0	0.2	0.1	0.1	100		
Difference SC1B	*	-0.1	-0.1	-0.5	-2.4	2.4	0.8	0.6	0.4	0.2	-0.9	-0.1	-0.2	*	*	*			
Difference SC3B	-	*	-0.1	-0.3	-1.8	1.5	1.0	0.4	0.6	-0.1	-1.1	-0.1	-0.1	-	*	*			

* Denotes values below 0.1 % but >0 and – denotes a value of 0.

Table 5.2 Joint frequency table for significant wave height (H_s) and mean wave direction (θ_m). Percentage distributions for the Base scenario (SC1A) at the Wave Buoy station for 2004 are shown, based on hourly model output. The 'Difference' row and column indicate how the total percentage distributions changed for this location (i.e. absolute change in percentage distribution) when modelled under the Development scenario (SC1B and SC3B). In these cells, positive values (purple font) represent increases in percentage in the Development scenario while negative values (green font) represent decreases. Wave directions are abbreviated as North (N), East (E), West (W) and South (S), and indicate the direction from which waves are incoming.

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total (%)	Difference SC1B	Difference SC3B
0.00-0.25 m	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.25-0.50 m	-	-	-	-	-	*	*	*	0.2	0.4	-	-	-	-	-	-	0.7	0.3	0.2
0.50-0.75 m	*	0.1	0.1	*	0.9	2.3	1.6	1.4	2.5	1.9	0.3	0.1	*	*	0.1	*	11.4	1.4	1.1
0.75-1.00 m	*	0.1	0.1	0.1	2.1	4.8	4.3	1.6	2.4	3.6	0.6	0.5	0.4	0.1	0.1	*	20.8	1.8	1.1
1.00-1.25 m	0.1	*	*	0.1	2.5	4.3	2.5	0.9	1.3	4.7	1.5	0.6	0.7	0.4	0.3	0.1	20.2	*	0.8
1.25-1.50 m	*	*	-	0.1	2.1	1.9	1.1	0.6	1.0	4.6	1.5	0.9	0.4	0.2	-	*	14.3	-0.1	*
1.50-1.75 m	*	*	*	-	1.1	0.9	0.6	0.3	1.0	3.2	2.6	0.8	0.3	0.2	*	*	11.0	-0.6	-0.4
1.75-2.00 m	-	-	-	-	0.2	0.5	0.4	0.1	0.1	2.2	2.4	0.7	0.4	0.1	-	-	7.0	-0.9	-0.9
2.00-2.25 m	-	-	-	-	0.3	0.1	0.1	0.2	*	1.3	1.6	0.5	0.1	*	-	-	4.3	-0.6	-0.4
2.25-2.50 m	-	-	-	-	0.3	0.1	0.1	0.1	*	0.6	1.7	0.2	*	-	-	-	3.1	*	-0.1
2.50-2.75 m	-	-	-	-	0.2	0.1	0.2	0.1	*	0.6	1.2	0.1	-	-	-	-	2.6	-0.3	-0.2
2.75-3.00 m	-	-	-	-	*	*	0.2	0.1	0.1	0.5	1.1	0.1	-	-	-	-	2.1	-0.2	-0.3
3.00-3.25 m	-	-	-	-	-	0.1	0.1	*	*	0.4	0.5	*	-	-	-	-	1.2	-0.5	-0.6
3.25-3.50 m	-	-	-	-	-	-	*	0.1	-	0.1	0.3	*	-	-	-	-	0.5	-0.2	-0.2
3.50-3.75 m	-	-	-	-	-	-	*	*	-	*	0.1	-	-	-	-	-	0.2	*	-0.1
3.75-4.00 m	-	-	-	-	-	-	*	*	-	*	0.1	-	-	-	-	-	0.2	*	*
>4.00 m	-	-	-	-	-	-	0.1	0.1	-	0.2	0.1	-	-	-	-	-	0.5	-0.1	-0.1
Total (%)	0.1	0.2	0.3	0.4	9.8	15.1	11.5	5.7	8.7	24.3	15.5	4.6	2.2	0.9	0.4	0.1	100.0		
Difference SC1B	-0.1	-0.1	-0.1	*	-1.7	0.9	1.2	0.4	0.7	0.6	-1.2	-0.2	-0.2	-0.1	-0.1	*			
Difference SC3B	-	-0.1	-0.1	*	-1.3	0.9	0.8	0.3	0.9	0.8	-1.9	-0.3	-0.1	-	*	*			

* Denotes values below 0.1 % but >0 and – denotes a value of 0.

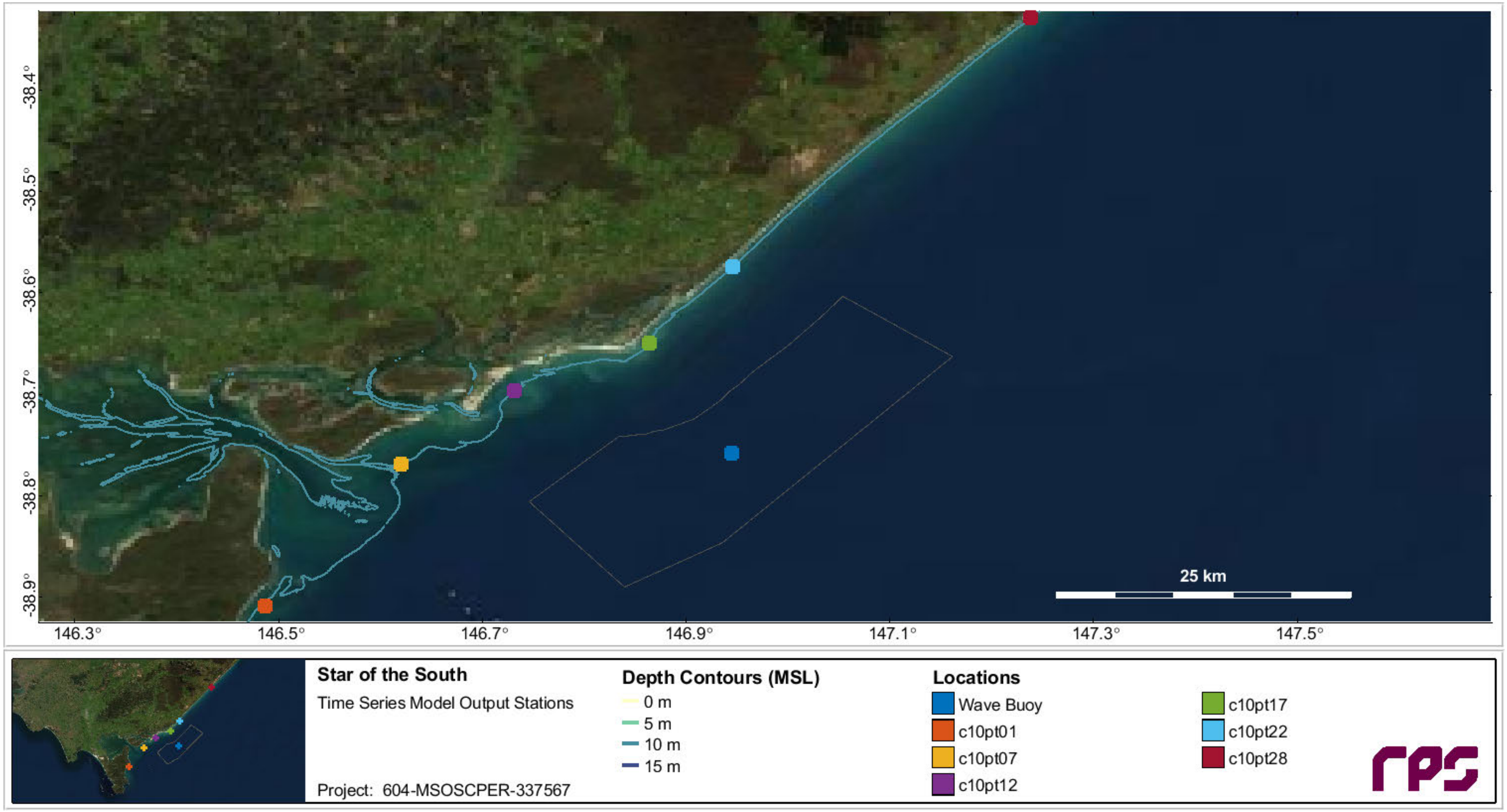


Figure 5.8 Locations of time series model output points referenced in the discussion of model results in the sensitivity study. Note there were 69 output point locations in total, but these 7 have been used as representative of the range of outcomes for discussion.

Table 5.3 Probability distributions of predicted decreases in significant wave height (H_S) in the Development scenarios (SC1B and SC3B) relative to the Base scenarios (SC1A and SC3A) for 1999 at selected stations. The percentages indicate the probability that the decrease in wave height will fall within the ranges indicated. Only decreases above a minimum threshold of 0.02 m are reported.

Station	0.02-0.04 m		0.04-0.06 m		0.06-0.08 m		0.08-0.10 m		0.10-0.12 m		0.12-0.14 m		0.14-0.16 m		>0.16 m		Total (%) decrease >0.02 m	
	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B
Wave Buoy	31	33	23	18	15	11	9	5	6	3	2	2	1	1	0	1	**88**	**74**
c10pt01	14	11	3	2	1	-	-	-	-	-	-	-	-	-	-	-	**18**	**14**
c10pt07	19	19	10	9	5	3	3	2	2	1	1	1	1	-	-	-	**40**	**35**
c10pt12	19	20	12	9	7	3	4	2	2	1	2	-	1	-	1	-	**48**	**35**
c10pt17	36	22	16	5	10	2	4	-	2	-	2	-	1	-	1	-	**72**	**30**
c10pt22	35	12	12	2	4	1	1	-	1	-	-	-	-	-	-	-	**53**	**15**
c10pt28	14	12	8	4	4	1	1	-	-	-	-	-	-	-	-	-	**26**	**17**

Table 5.4 Probability distributions of predicted decreases in significant wave height (H_S) in the Development scenarios (SC1B and SC3B) relative to the Base scenarios (SC1A and SC3A) for 2004 at selected stations. The percentages indicate the probability that the decrease in wave height will fall within the ranges indicated. Only decreases above a minimum threshold of 0.02 m are reported.

Station	0.02-0.04 m		0.04-0.06 m		0.06-0.08 m		0.08-0.10 m		0.10-0.12 m		0.12-0.14 m		0.14-0.16 m		>0.16 m		Total (%) decrease >0.02 m	
	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B
Wave Buoy	25	29	19	16	13	11	8	7	6	5	4	3	3	2	3	3	**81**	**77**
c10pt01	9	7	2	2	1	-	-	-	-	-	-	-	-	-	-	-	**12**	**9**
c10pt07	15	14	6	5	4	2	2	1	-	-	-	-	-	-	-	-	**28**	**22**
c10pt12	16	16	9	6	5	1	2	1	2	-1	1	-	-	-	-	-	**35**	**24**
c10pt17	34	19	15	2	5	1	3	-	2	-	1	-	-	-	-	-	**61**	**23**
c10pt22	37	16	12	2	3	1	1	-	-	-	-	-	-	-	-	-	**55**	**19**
c10pt28	17	18	10	7	5	2	3	-	1	-	-	-	-	-	-	-	**36**	**27**

Table 5.5 Probability distributions of predicted changes in mean wave direction (θ_m) in the Development scenarios (SC1B and SC3B) relative to the Base scenarios (SC1A and SC3A) for 1999 at selected stations. The percentages indicate the probability that the change in wave direction will fall within the ranges indicated. Only changes above a minimum threshold of 1° are reported.

	Anticlockwise Deflection of Mean Wave Direction										Clockwise Deflection of Mean Wave Direction									
	1-3°		3-5°		5-7°		7-9°		Total (%) anticlockwise >1°		1-3°		3-5°		5-7°		7-9°		Total (%) clockwise >1°	
	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B
WaveBuoy	29	30	5	5	1	2	1	1	36	37	25	24	7	5	2	1	1	-	35	31
c10pt01	3	2	-	-	-	-	-	-	3	3	28	21	1	-	-	-	-	-	30	22
c10pt07	2	3	1	-	-	-	-	-	3	3	31	21	3	2	1	-	-	-	34	23
c10pt12	2	2	-	-	-	-	-	-	2	2	31	8	3	-	-	-	-	-	34	9
c10pt17	4	1	-	-	-	-	-	-	4	2	17	2	1	-	-	-	-	-	18	2
c10pt22	17	4	1	-	-	-	-	-	18	4	5	1	-	-	-	-	-	-	5	1
c10pt28	29	16	3	1	-	-	-	-	32	18	1	1	-	-	-	-	-	-	1	1

Table 5.6 Probability distributions of predicted changes in mean wave direction (θ_m) in the Development scenarios (SC1B and SC3B) relative to the Base scenarios (SC1A and SC3A) for 2004 at selected stations. The percentages indicate the probability that the change in wave direction will fall within the ranges indicated. Only changes above a minimum threshold of 1° are reported.

	Anticlockwise Deflection of Mean Wave Direction										Clockwise Deflection of Mean Wave Direction									
	1-3°		3-5°		5-7°		7-9°		Total (%) anticlockwise >1°		1-3°		3-5°		5-7°		7-9°		Total (%) clockwise >1°	
	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B
WaveBuoy	28	38	7	6	2	1	1	1	38	45	15	16	4	3	2	1	1	-	23	21
c10pt01	4	2	-	-	-	-	-	-	4	2	23	16	2	1	-	-	-	-	25	17
c10pt07	4	2	-	-	-	-	-	-	4	2	25	16	4	2	1	-	-	-	30	18
c10pt12	3	1	-	-	-	-	-	-	4	2	26	9	4	-	1	-	-	-	31	9
c10pt17	8	2	1	-	-	-	-	-	8	2	20	2	2	-	-	-	-	-	22	2
c10pt22	17	4	1	-	-	-	-	-	18	4	12	2	-	-	-	-	-	-	12	2
c10pt28	29	22	5	2	1	-	-	-	35	25	1	1		-	-	-	-	-	1	1

Table 5.7 Probability distributions of predicted changes in mean wave period (T_m) in the Development scenarios (SC1B and SC3B) relative to the Base scenarios (SC1A and SC3A) for 1999 at selected stations. The percentages indicate the probability that the change in wave period will fall within the ranges indicated. Only changes above a minimum threshold of 0.1 s are reported.

	Decrease in Mean Wave Period						Increase in Mean Wave Period											
	0.1-0.2 s		0.2-0.3 s		Total (%) decrease >0.01 s		0.1-0.2 s		0.2-0.3 s		0.3-0.4 s		0.4-0.5 s		0.5-0.6 s		Total (%) increase >0.01 s	
	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B
WaveBuoy	-	-	-	-	-	-	33	32	11	8	4	2	2	1	1	-	50	43
c10pt01	-	-	-	-	-	-	3	2	-	-	-	-	-	-	-	-	4	2
c10pt07	3	2	-	-	3	2	8	5	2	1	1	-	-	-	-	-	11	6
c10pt12	4	1	-	-	4	1	12	8	6	2	2	-	-	-	-	-	20	10
c10pt17	2	-	-	-	2	-	16	4	5	1	2	-	1	-	-	-	24	6
c10pt22	2	1	-	-	2	1	11	2	2	1	1	-	-	-	-	-	14	3
c10pt28	1	1	-	-	1	1	15	11	5	3	2	2	1	1	-	-	23	17

Table 5.8 Probability distributions of predicted changes in mean wave period (T_m) in the Development scenarios (SC1B and SC3B) relative to the Base scenarios (SC1A and SC3A) for 2004 at selected stations. The percentages indicate the probability that the change in wave period will fall within the ranges indicated. Only changes above a minimum threshold of 0.1 s are reported.

	Decrease in Mean Wave Period						Increase in Mean Wave Period											
	0.1-0.2 s		0.2-0.3 s		Total (%) decrease >0.01 s		0.1-0.2 s		0.2-0.3 s		0.3-0.4 s		0.4-0.5 s		0.5-0.6 s		Total (%) increase >0.01 s	
	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B	SC1B	SC3B
WaveBuoy	2	-	-	-	2	-	26	28	11	7	3	2	1	1	-	-	42	38
c10pt01	1	-	-	-	2	-	3	1	5	-	-	-	-	-	-	-	9	2
c10pt07	4	1	-	-	4	1	6	3	1	1	-	-	-	-	-	-	8	4
c10pt12	5	1	1	-	6	1	9	5	3	1	1	-	1	-	-	-	13	6
c10pt17	4	-	-	-	4	-	11	4	4	1	2	-	1	-	-	-	17	6
c10pt22	8	1	-	-	8	1	9	3	3	1	1	-	-	-	-	-	14	4
c10pt28	3	1	-	-	3	1	16	15	4	4	2	2	1	1	-	-	23	22

6 CONCLUSIONS

The focus of this sensitivity study was to quantify the bounds of predicted coastal impacts for two revised wind farm designs and assess whether either of these options will affect the definition of the MDS that was established and modelled previously (RPS 2022a).The sensitivity study used wind wake modelling and wave modelling to compare the effects of the revised development options for the Star of the South project with the original maximum design scenario (MDS) that was based on 200 wind turbine generators with 220 m blade diameter.

Two revised development options were evaluated against the original MDS with respect to wind wake effects. All the development alternatives showed similar profiles of initial wake loss and then wind speed recovery with distance away from the OWFA. The predicted wind wake losses within 10 km of the OWFA were in the range of 7-15% for all development alternatives. The wake losses for the 200 WTG development option were on average higher (~2.5 %) than the wake losses for either of the revised development options. The 120 WTG and 92 WTG development options both had similar wake losses and wake recovery profiles. The wake losses for the 200 WTG development appear to be a reasonable, although slightly conservative, representation of the wake losses that would be expected from either of the revised development options.

The revised development option that had the larger number of monopiles, the 120 WTG option, was further investigated using a wave model. The 120 WTG option was selected because both of the revised options have similar wind wake effects, but the 120 WTG has more the direct blockage of waves due to its larger number of monopiles. The wave model was applied to investigate whether the change in the shape of the development, the reduction in the maximum number of WTGs and the reduction in wind wake effects relative to the MDS could alter the character of the coastal process impacts. The potential for changes in the waves was characterised with a focus on two selected years from the previous hindcast assessment period (1990-2020). The years 1999 and 2004 were selected as representative of a year with a high proportion of south-west storms and a year with a high proportion of south-east storms, respectively. These years were selected to bookend the two most important types of storm conditions affecting coastal processes. The wave modelling results for the revised 120 WTG development option were compared directly with to the 1999 and 2004 hindcast wave modelling results for the original 200 WTG development.

The statistics from the mapped wave model results showed changes to wave height and direction were concentrated in similar areas for both the 200 WTG and 120 WTG layouts, but the magnitude and spatial extent of the effect areas were consistently smaller for the latter. This indicates that the changes predicted for the revised layout were similar but smaller than the for the original MDS layout.

Differences in the patterns of statistical change to wave direction and wave height were evident between the 1999 and 2004 years that were selected for analysis. The mapped areas of change were well correlated with the prevailing swell directions for each of these different years, and this was found for both layouts. This suggests that regardless of whether incident wave forcing is predominantly from the south-west or the south-east, the blockage and wind wake effects from either of the revised development options will be like those already established under the MDS scenario. The sensitivity study showed that the predicted changes to wave conditions for the 200 WTG development conservatively represent the changes that would be expected from a smaller development option (fewer WTGs) centred further offshore.

7 REFERENCES

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RPS 2021b, '*Star of the South offshore wind project: Coastal processes – Offshore modelling sensitivity study*', Report MAW0937J.000 (rev. 2, 10 December 2021) prepared by

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8 APPENDIX

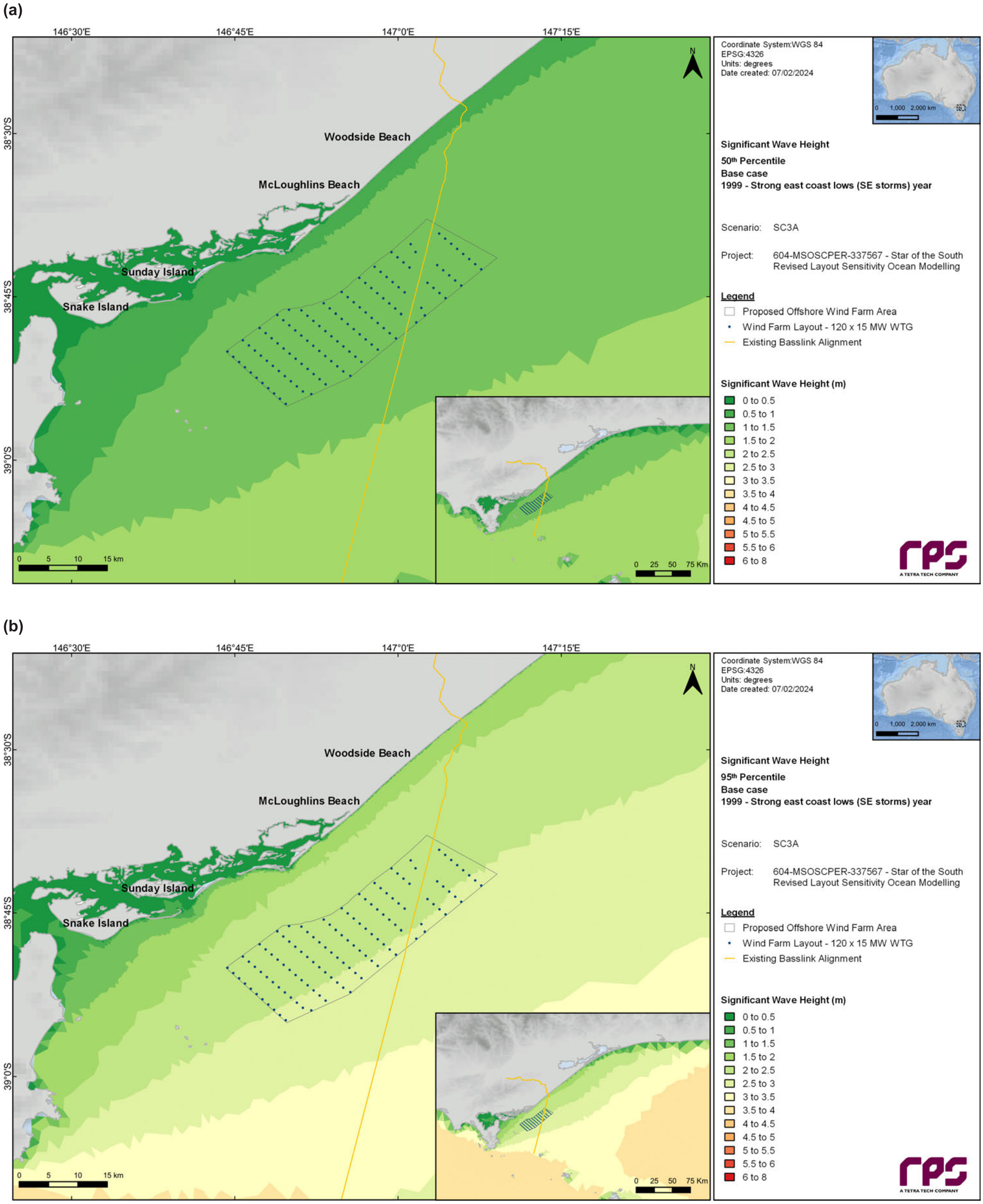

Figure 8.1 Map of modelled annual wave height for the year 1999 based on the pre-development conditions for (a) the 50th percentile significant wave height and (b) the 95th percentile significant wave height.

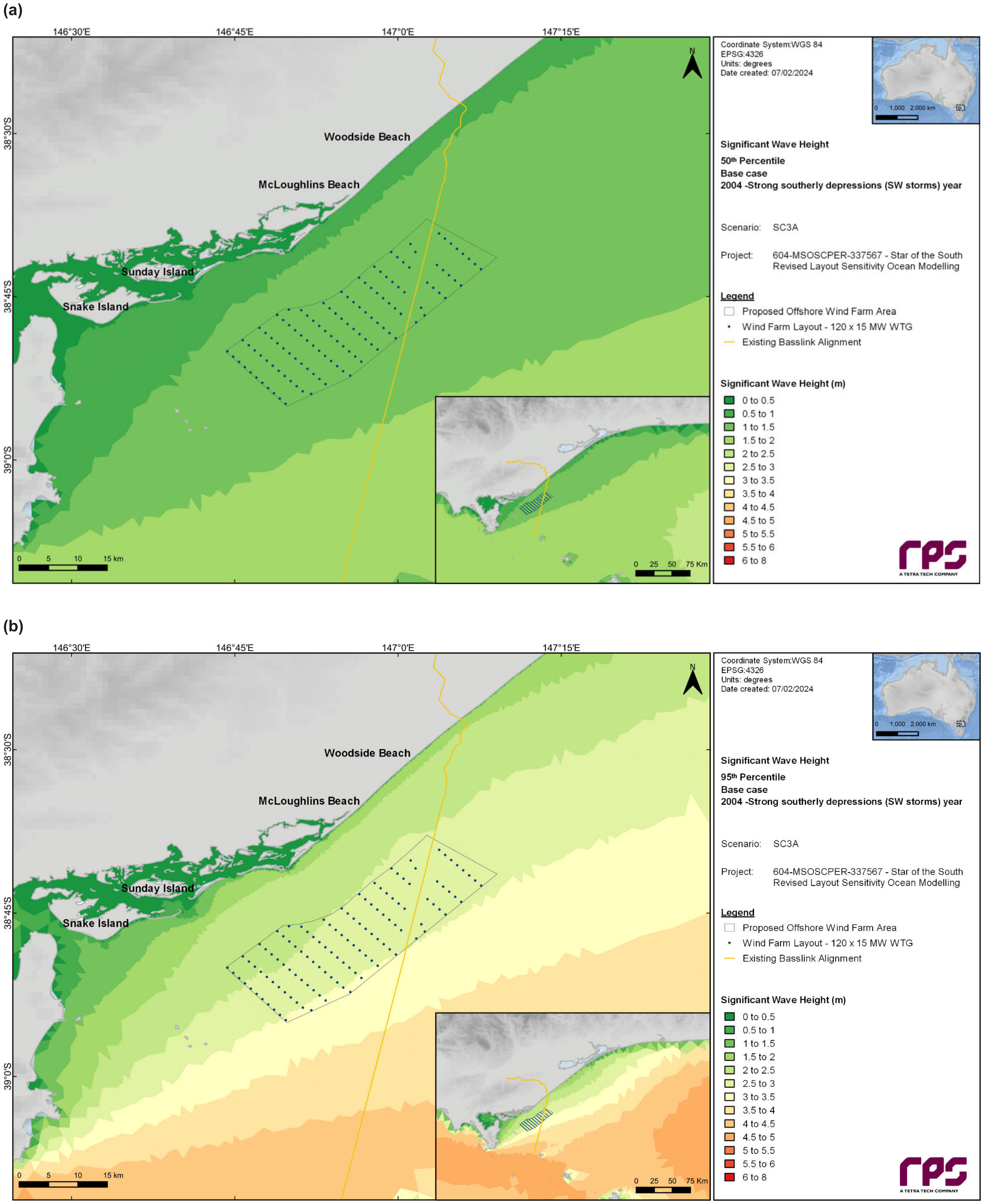

Figure 8.2 Map of modelled annual wave height for the year 2004 based on the pre-development conditions for (a) the 50th percentile significant wave height and (b) the 95th percentile significant wave height. The boundary of the OWFA and an indicative layout of WTGs is shown for context but the model results are for the pre development state.

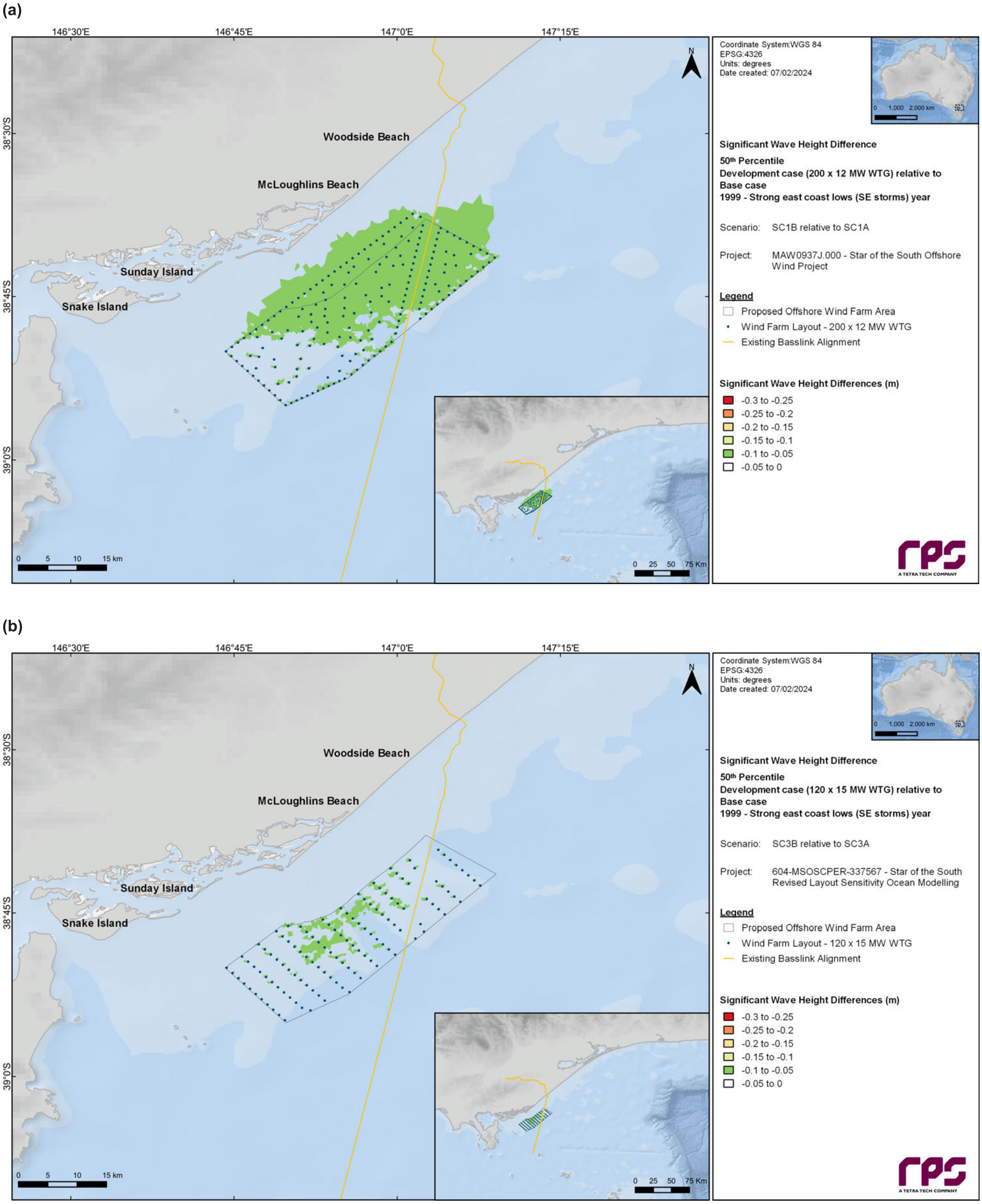

Figure 8.3 Map of predicted change in the annual 50th percentile significant wave height for the year 1999 based on (a) the original MDS development option (200 WTGs) and (b) the selected revised development option (120 WTGs)

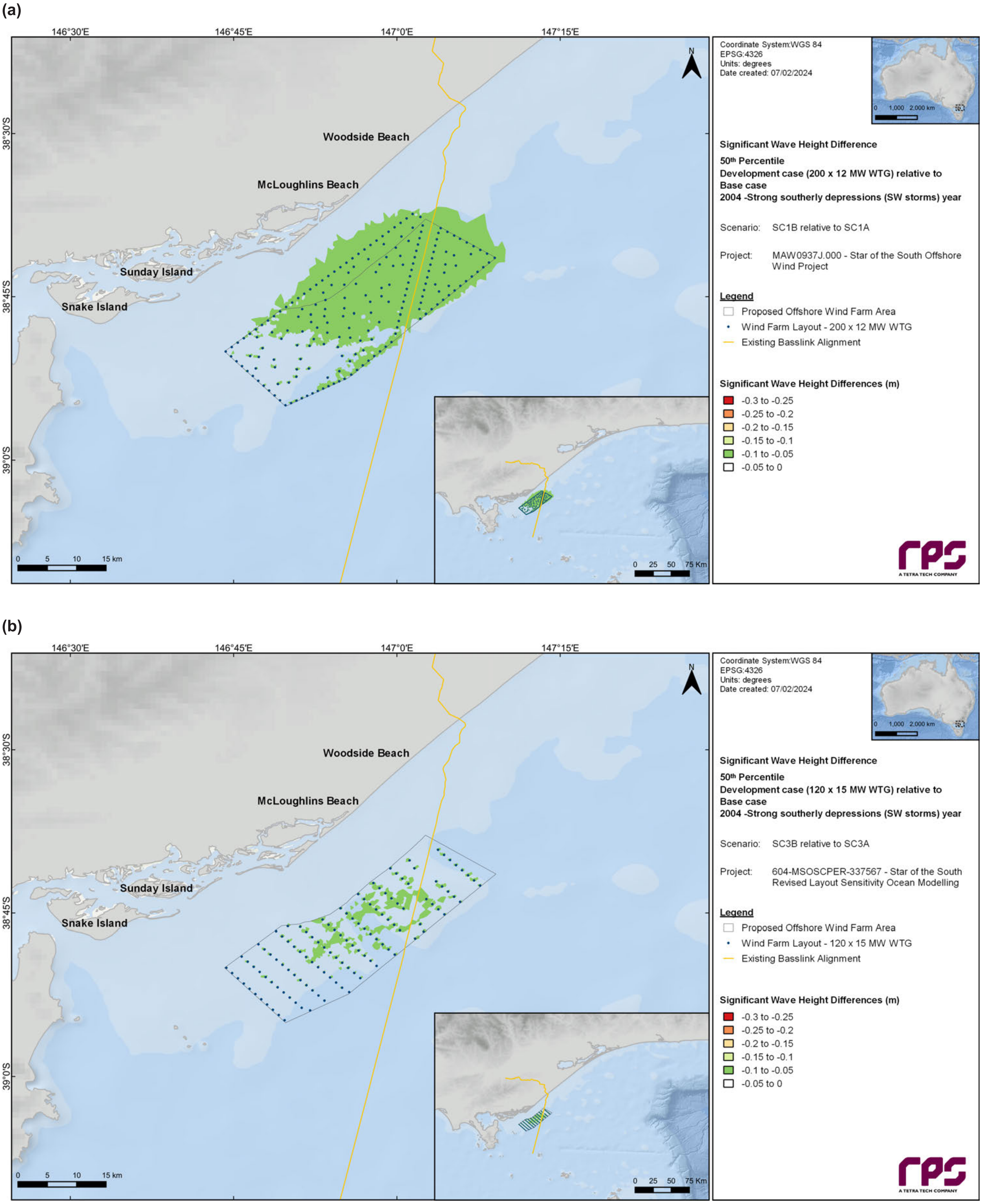

Figure 8.4 Map of predicted change in the annual 50th percentile significant wave height for the year 2004 based on (a) the original MDS development option (200 WTGs) and (b) the selected revised development option (120 WTGs)

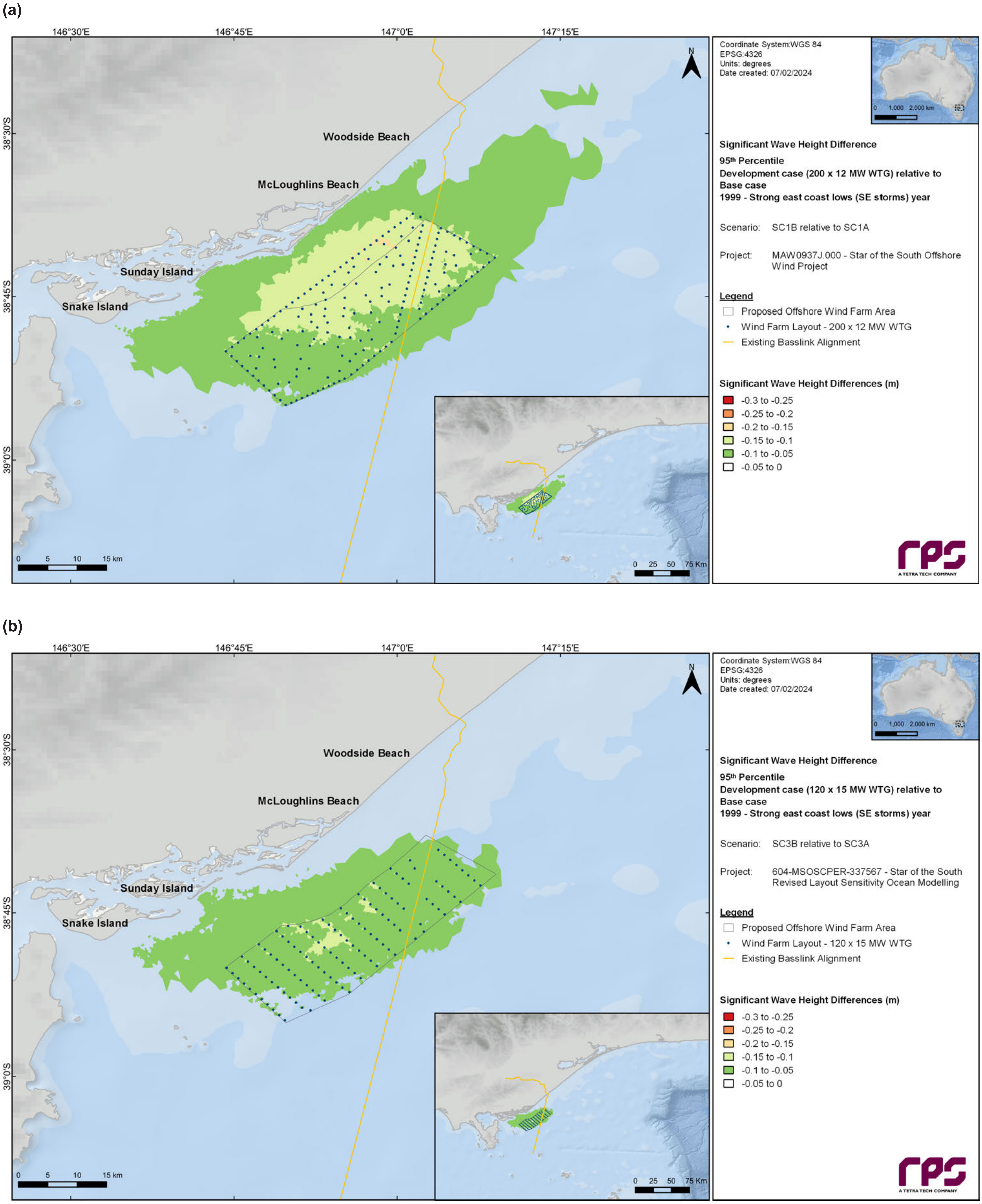

Figure 8.5 Map of predicted change in the annual 95th percentile significant wave height for the year 1999 based on (a) the original MDS development option (200 WTGs) and (b) the selected revised development option (120 WTGs)

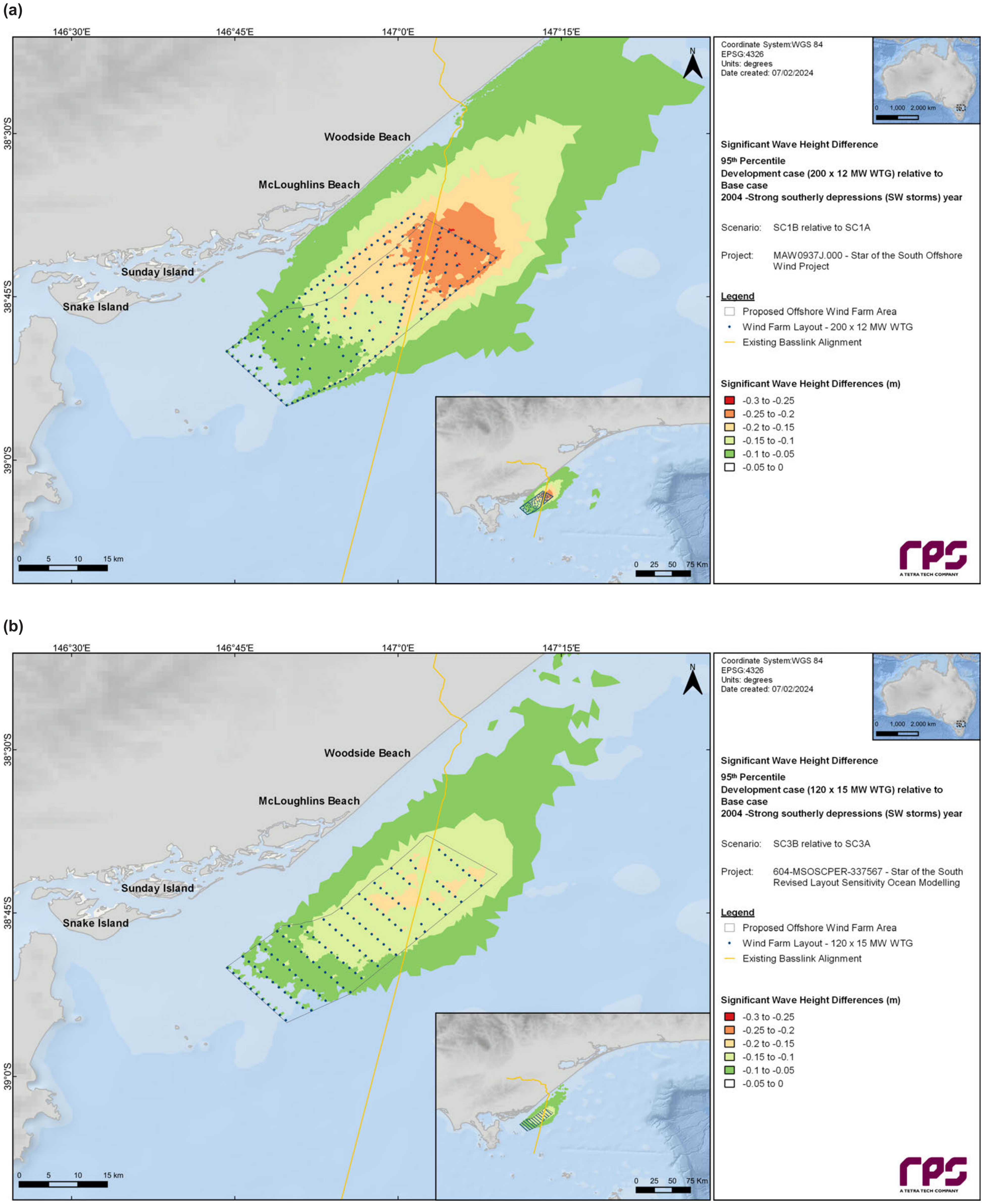

Figure 8.6 Map of predicted change in the annual 95th percentile significant wave height for the year 2004 based on (a) the original MDS development option (200 WTGs) and (b) the selected revised development option (120 WTGs)