RPS

NORTH AYRSHIRE COUNCIL

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Ayrshire Shoreline Management Plan

Appendix C: Data Gap Analysis - Coastal Processes

IBE1107/D03

Final

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Ayrshire Shoreline Management Plan

Appendix C: Data Gap Analysis – Coastal Processes

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1 INTRODUCTION

1.1 BACKGROUND

The requirement for a Shoreline Management Plan covering the Ayrshire coastline including the Isle of Arran was identified by SEPA through the development of the Ayrshire Regional Flood Risk Management Strategy. The SMP is required to provide guidance to operating authorities and regulatory bodies as to future sustainable flood and coastal erosion risk management, essentially providing an agreed high level approach, intent and framework for management.

In order to develop a sustainable approach to management of the shoreline, an understanding of the present and future behaviour of the coast was required.

1.2 STUDY AREA

The boundaries of the Ayrshire SMP are the northern boundary of North Ayrshire which includes the town of Skelmorlie but excludes Wemyss Bay, while the southern limit of the SMP is the Galloway Burn on the north-eastern edge of Loch Ryan. The islands of Great Cumbrae and Arran are also included within the scope of the SMP.

While the spatial extent of the final SMP policy recommendations is limited to the mainland and associated island coastlines within the North and South Ayrshire Council areas it is likely that the coastal processes will not reflect these administrative boundaries. The implications of the SMP recommendations therefore must had to be considered for an area wider than the defined Ayrshire SMP boundaries, even though policy would not be set for these areas by the Ayrshire SMP. These implications and impacts had to be considered in developing the plan and policies for the Ayrshire and associated island shorelines if they were to be truly sustainable.

2 TIDAL MODELLING

2.1 TIDAL MODEL

The modelling of the hydrodynamic processes around the Firth of Clyde was undertaken using the MIKE 21 FM HD model which is the basic computational component of the MIKE modelling system and provides the hydrodynamic basis for all other modules.

The application areas for MIKE 21 FM HD are generally situations where flow and transport phenomena are important with particular emphasis on coastal and marine applications, where the flexibility inherited in the unstructured meshes can be utilized.

The modelling system is based on the numerical solution of the two-dimensional shallow water equations - the depth-integrated incompressible Reynolds averaged Navier-Stokes equations. Thus, the model consists of continuity, momentum, temperature, salinity and density equations. In the horizontal domain both Cartesian and spherical coordinates can be used.

2.1.1 Bathymetry

The analysis required the bathymetry around the north Irish Sea, the North Channel, the Firth of Clyde and the Sound of Jura to be included in the model. This was undertaken using a single flexible mesh grid system. The bathymetry data was derived from various sources including the INFOMAR, JIBS and MEDIN survey data as well as other surveys and digital chart data which RPS has collated for previous studies. Nearshore data was extracted from Lidar coverage of the shore line supplied by Ayrshire Council specifically for this project. The extent of the data used in the generation of the hydrodynamic model for this study is shown in Figure 2.1.

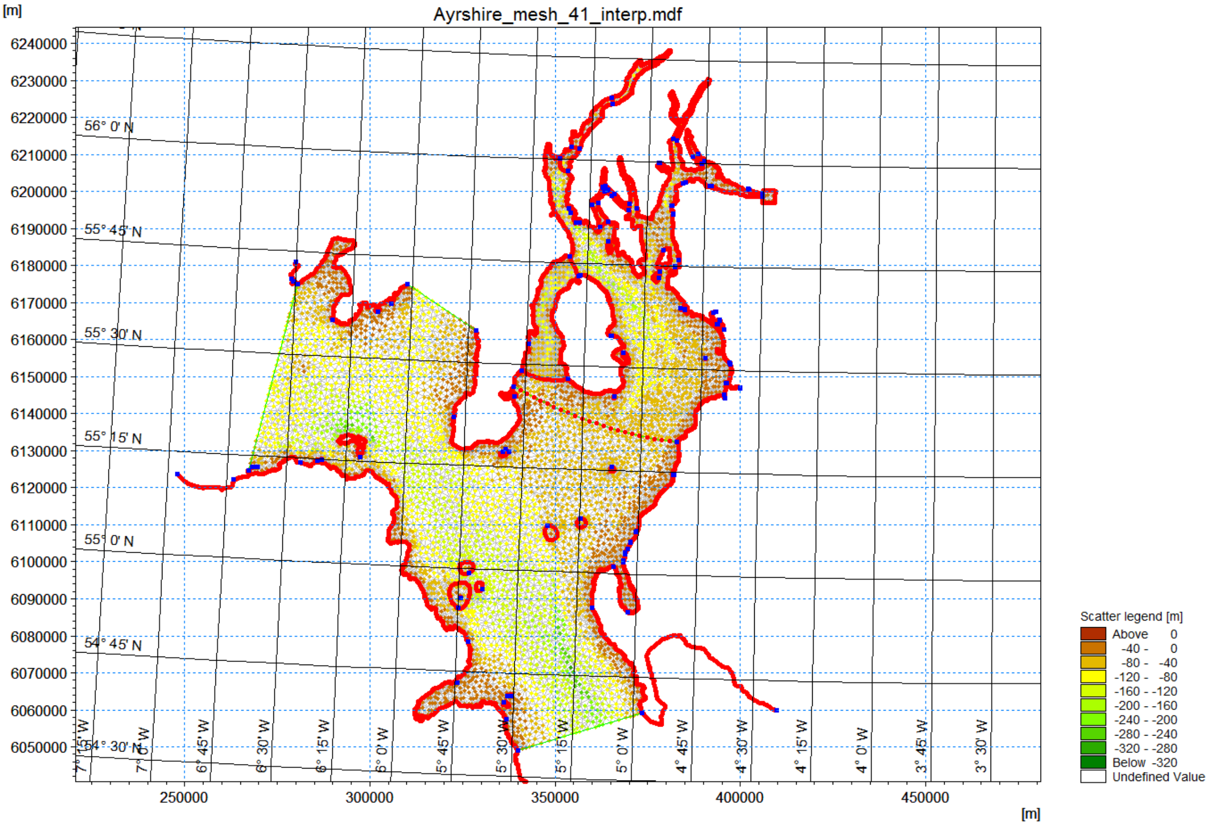


Figure 2.1 Extent of bathymetry data used for the wave transformation model

The bathymetry of the flexible mesh model is shown in Figure 2.2 and the model mesh in Figure 2.3. The model had open boundaries along its southern and north western sides, as well as across the entrance to the Sound of Jura. The southern boundary stretched from Ballywalter in Northern Ireland to the southern tip of the Mull of Galloway. The north west boundary ran from Port Wemyss, Islay to Portrush in Northern Ireland. The boundary across the Sound of Jura ran from Glenbarr on the Kintyre Peninsula to Ardmore, Islay.

The mesh resolution employed in this model varied from about 1.4km away from the area of interest down to about 20m at the approaches to the Ayrshire shoreline.

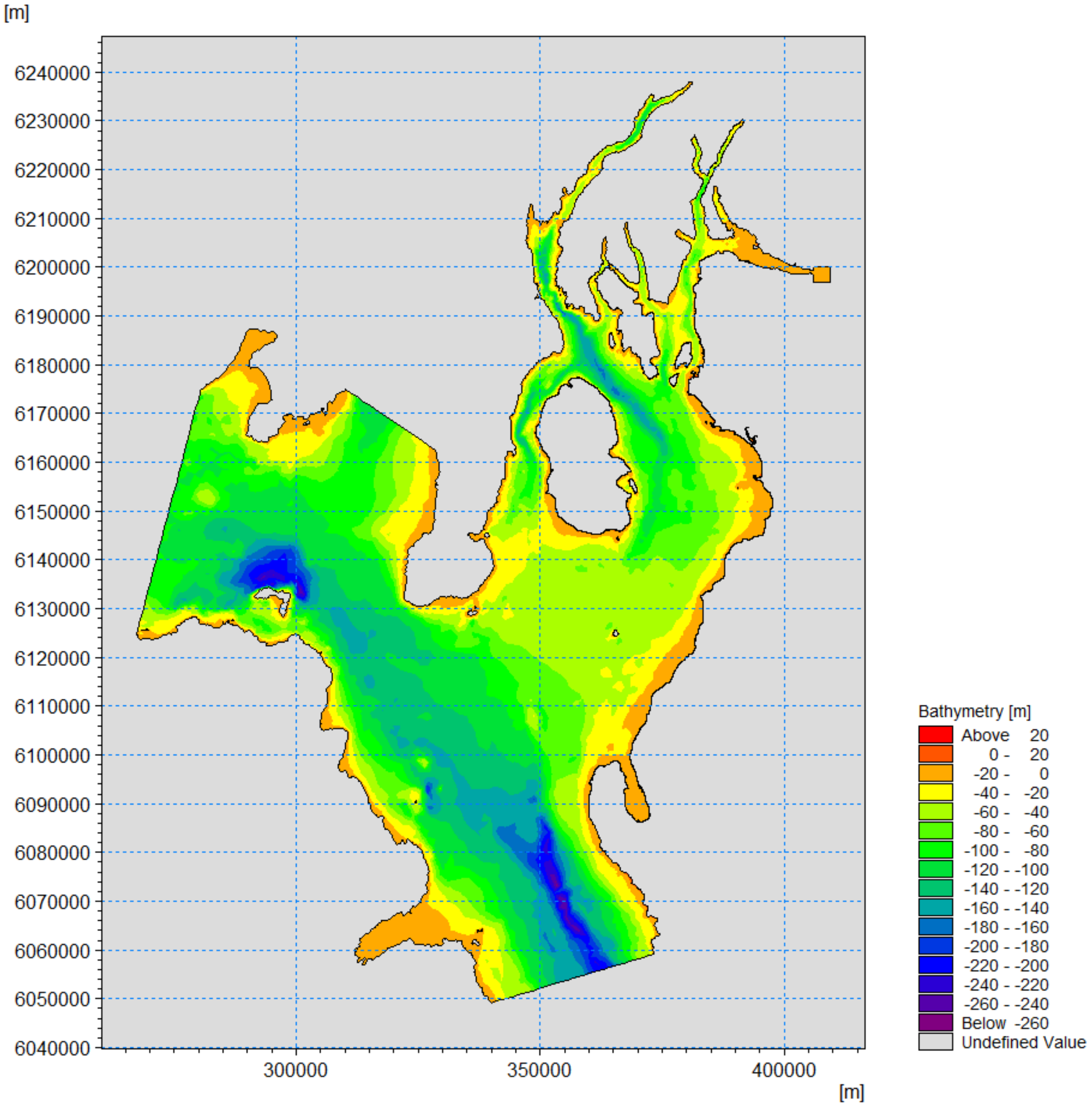


Figure 2.2 Model bathymetry – HD tidal model for Ayrshire SMP

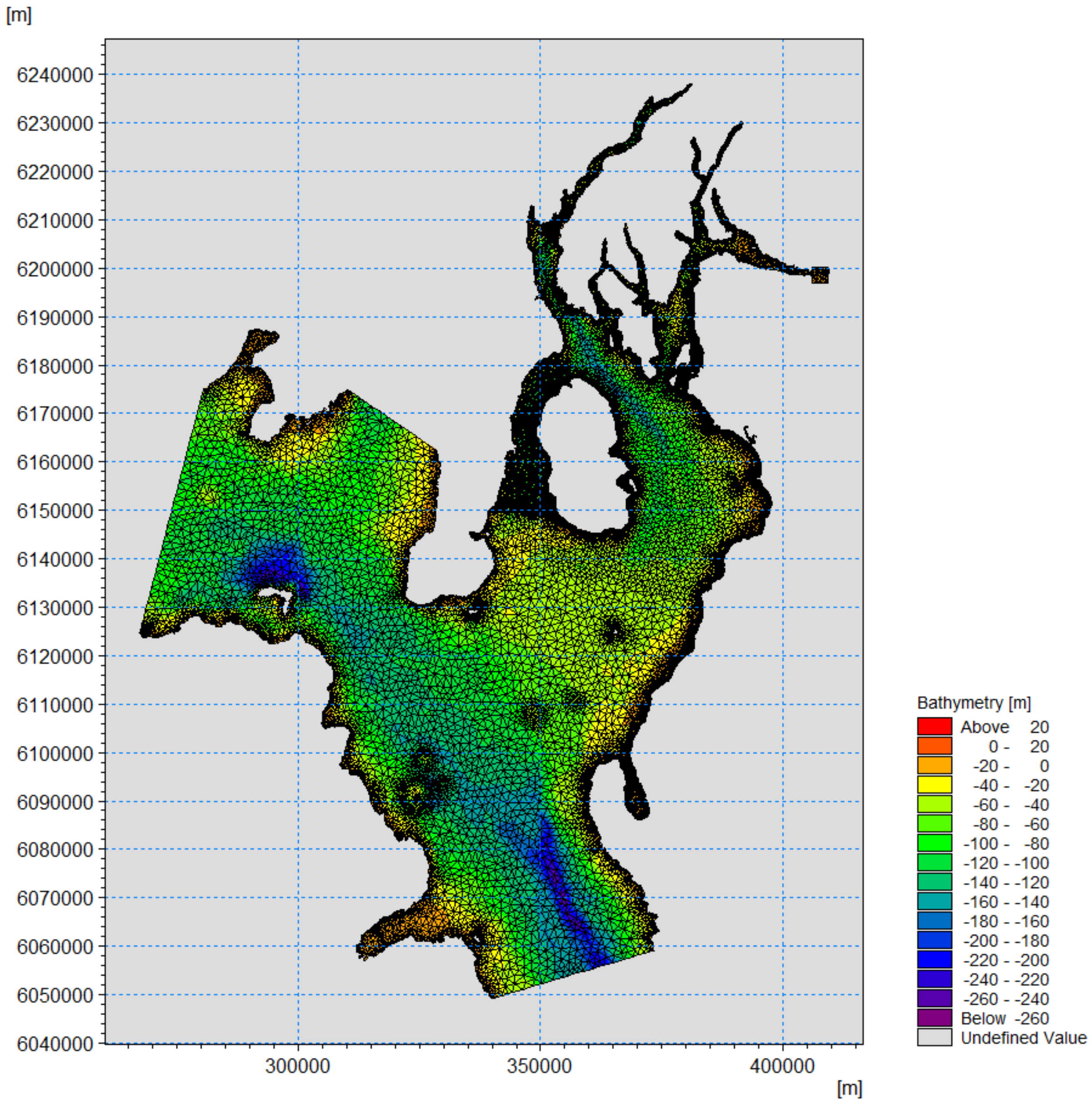


Figure 2.3 Model mesh – HD tidal model for Ayrshire SMP

2.1.2 Modelling Procedure

Boundary conditions were applied to the open boundaries at the southern and north western extents of the model domain, as well as the Sound of Jura boundary. These boundary conditions were extracted from the Irish Coast Waters Storm Surge forecast model operated by RPS. Model boundary conditions were extracted for a period of approximately 2 weeks allowing model simulations to be run for a typical spring/neap tidal cycle.

2.1.3 Model Calibration and Verification

Model calibration and verification was carried out to ensure that the model results were representative of actual conditions within the Firth of Clyde. This was achieved by comparing modelled water surface elevations with gauge records at Portpatrick, Bangor, Millport and Portrush. Modelled current speeds and directions were also compared with tidal stream data published by the United Kingdom Hydrographic Office (UKHO) on available Admiralty Charts.

Plots of tidal gauge records compared with modelled surface elevations at Portpatrick, Bangor, Millport and Portrush are shown in Figure 2.4 and Figure 2.5. Good model calibration has generally been achieved with good temporal correlation between the modelled and measured data. The tidal ranges at the Portpatrick and Bangor gauges are generally predicted to within 10%, however a maximum range difference of approximately 12% is observed at both locations towards the end of the simulation, with the modelled high water level being lower than the recorded level. The maximum range difference at Millport was found to be approximately 18%. This occurred during the neap cycle towards the start of the simulation and was due to the modelled range being larger than the recorded range. The maximum range difference at Portrush was found to be approximately 25%. Portrush is known to be a complex tidal gauge due to its proximity to the amphidromic point near Machrihanish.

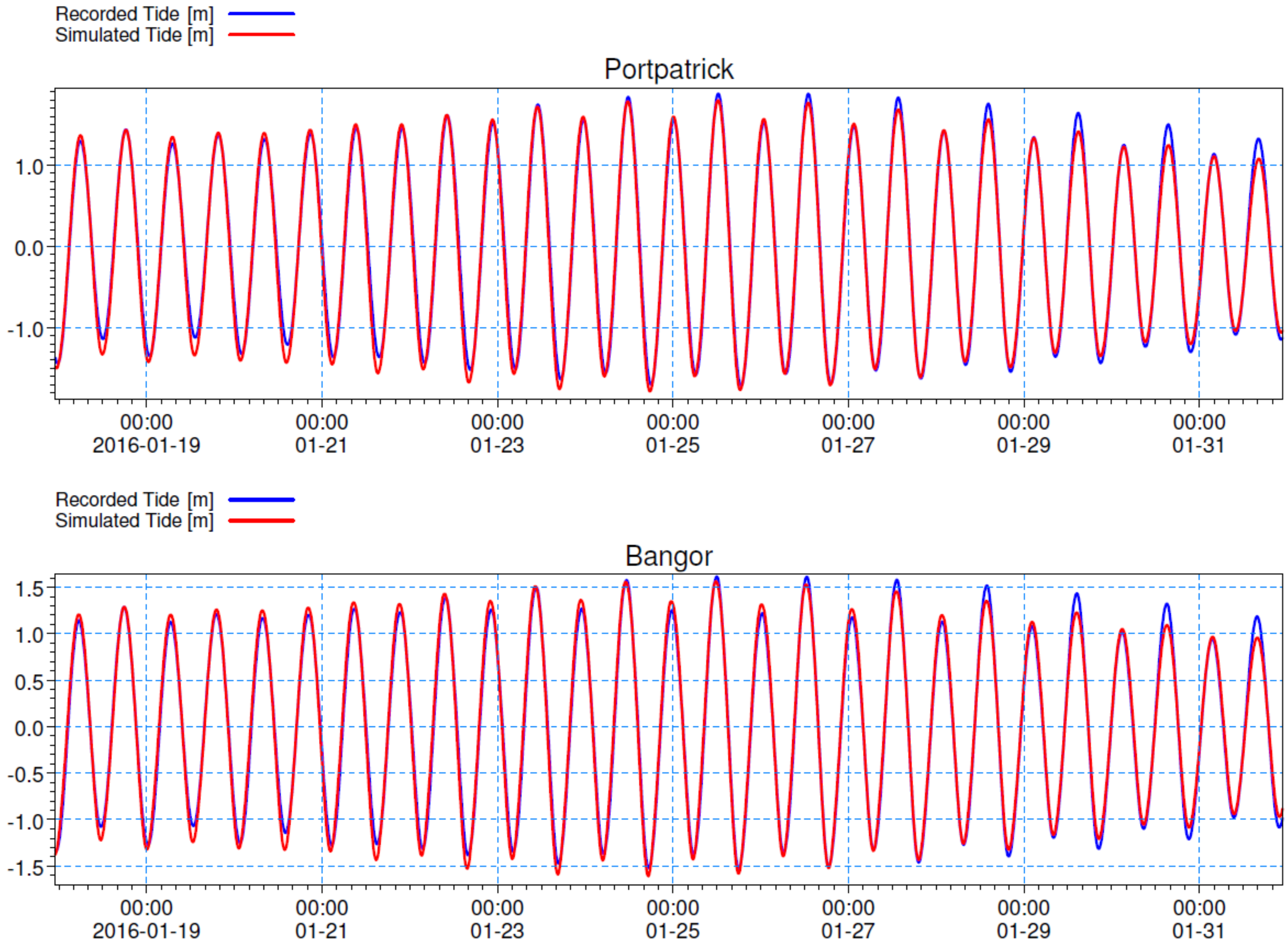


Figure 2.4 **Gauge record versus model simulated levels at Portpatrick and Bangor**

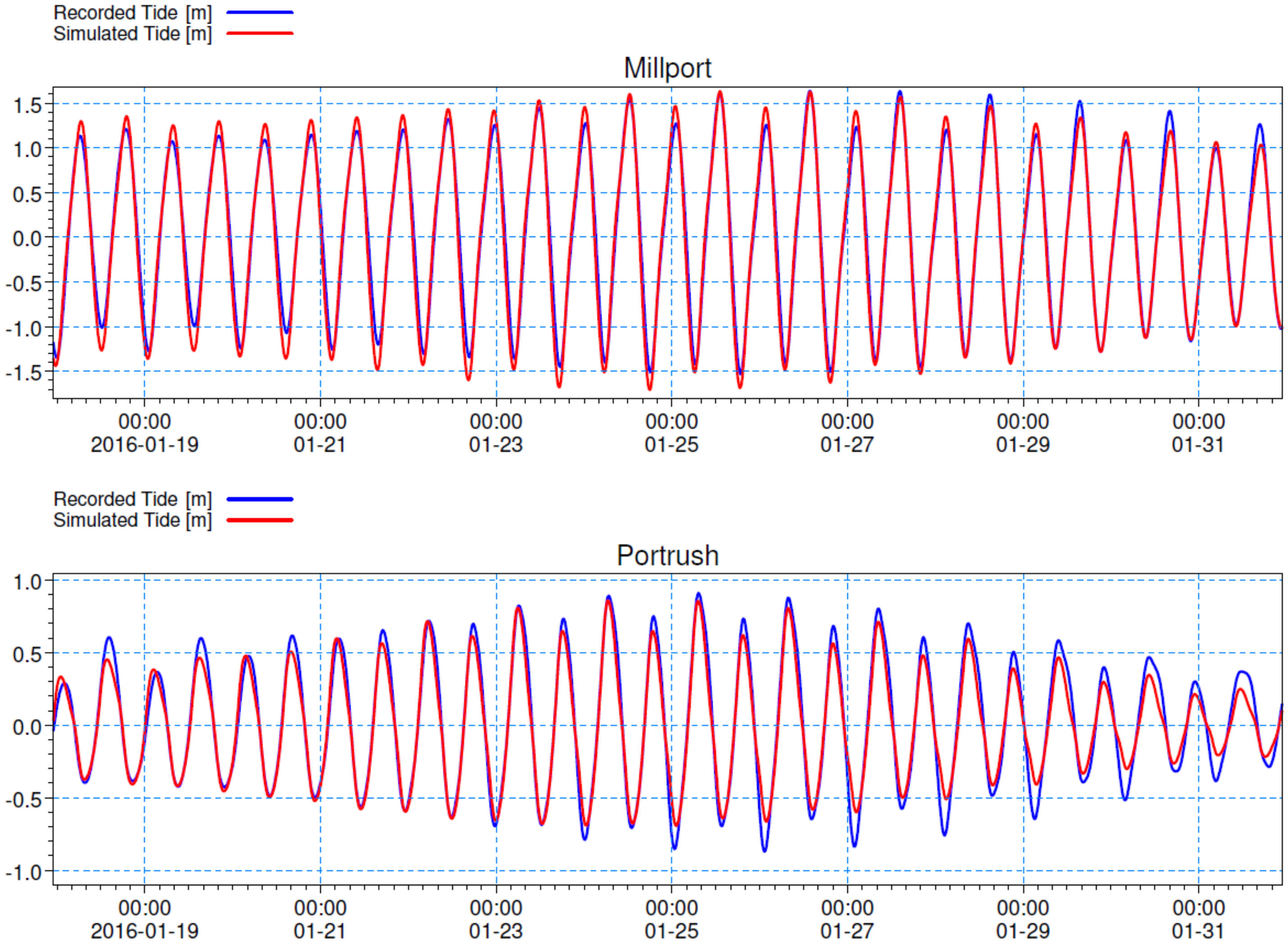


Figure 2.5 **Gauge record versus model simulated levels at Millport and Portrush**

A total of 18 tidal stream data points were also analysed in order to verify the model outputs. Tidal stream data provides a reasonable estimation of the current direction and speed at hourly intervals between six hours before and after high water (HW). Three of the points used are presented in this report as an example of the correlation achieved. The locations of these points are shown in Figure 2.6. It can be seen from Figure 2.7 to Figure 2.9 that good model verification has been achieved at these data points in terms of both current direction and speed.

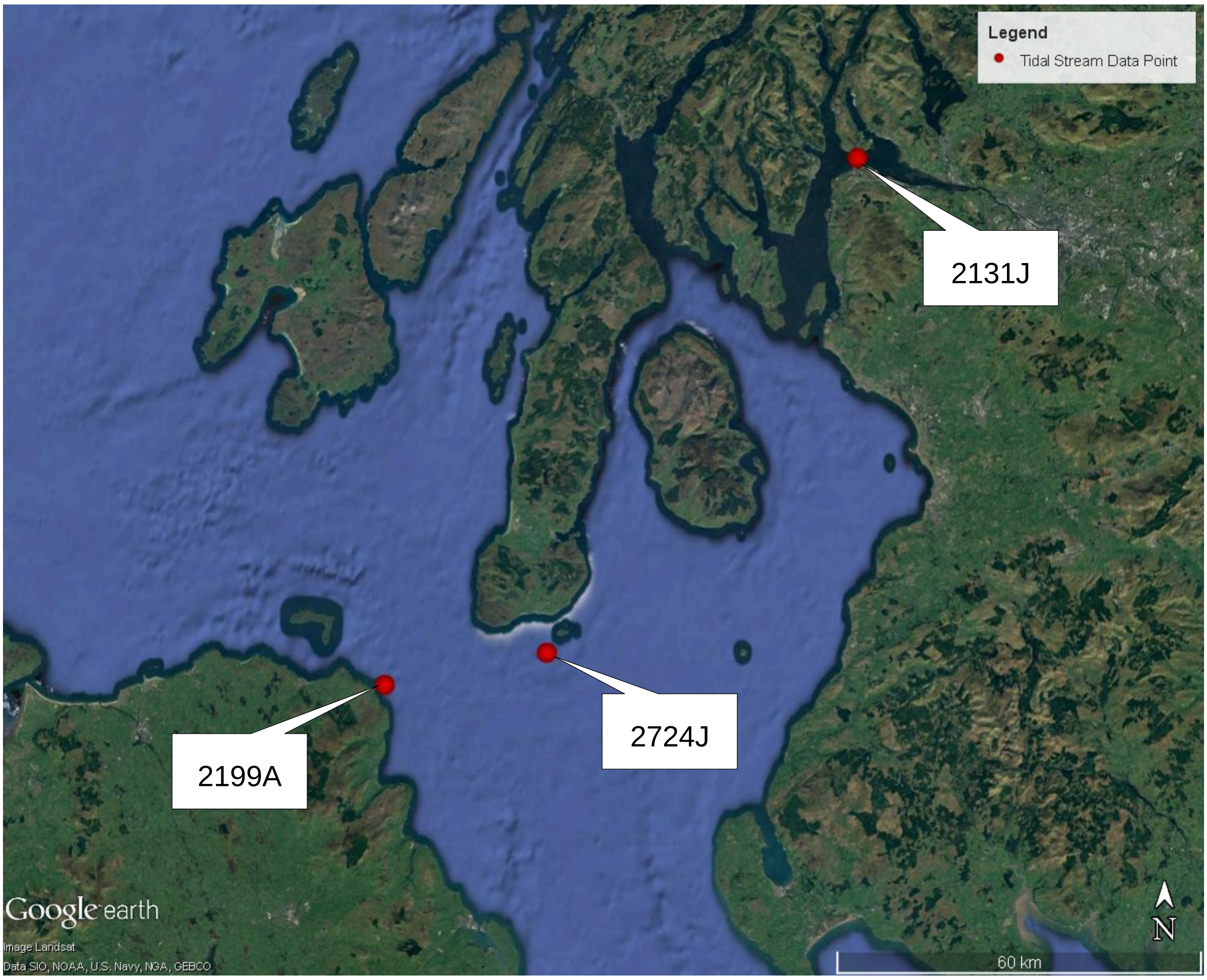


Figure 2.6 **Location of three of the tidal stream data points used for model verification**

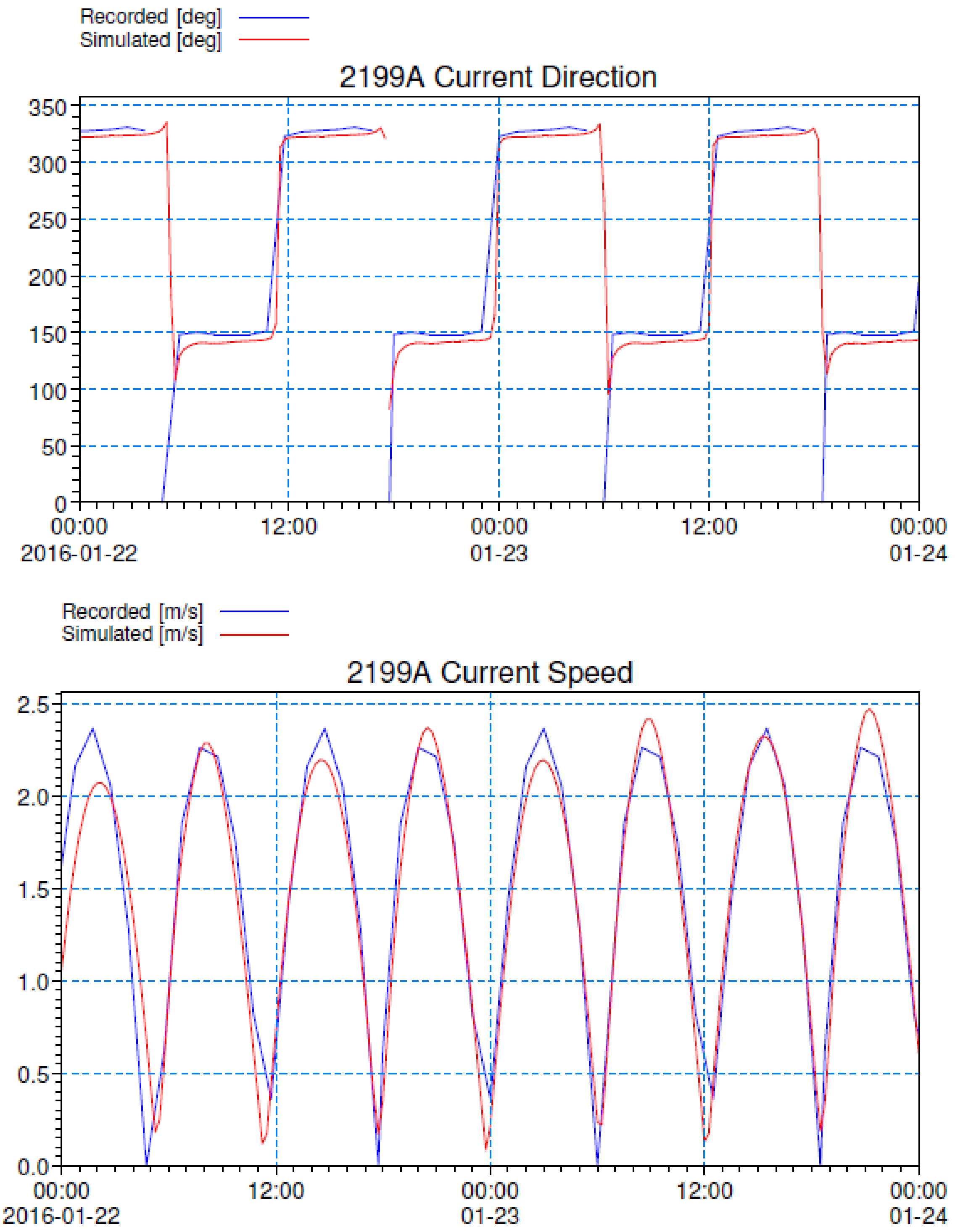
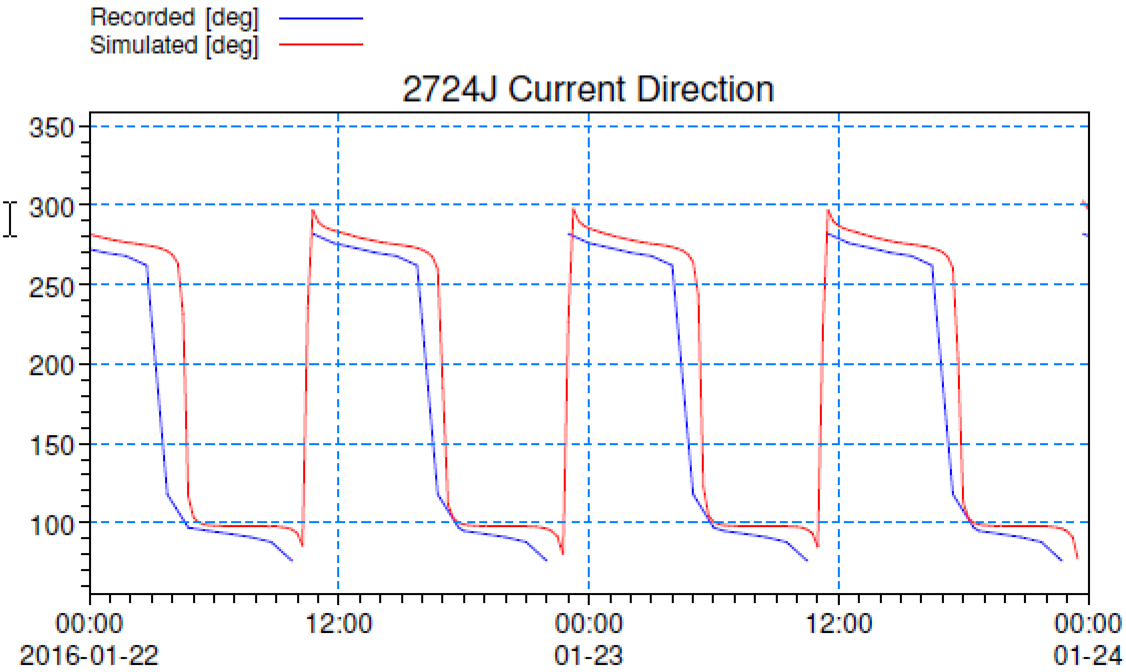


Figure 2.7 **Recorded and simulated current direction and speed at tidal stream data point 2199A**



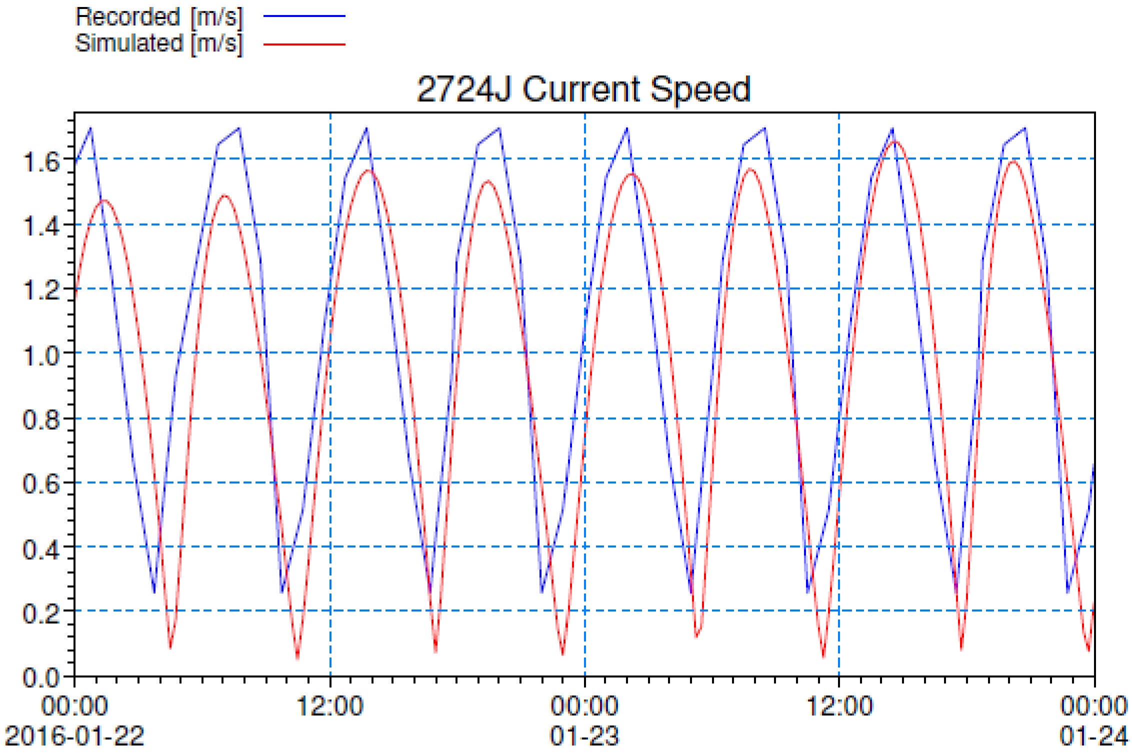


Figure 2.8 Recorded and simulated current direction and speed at tidal stream data point 2724J

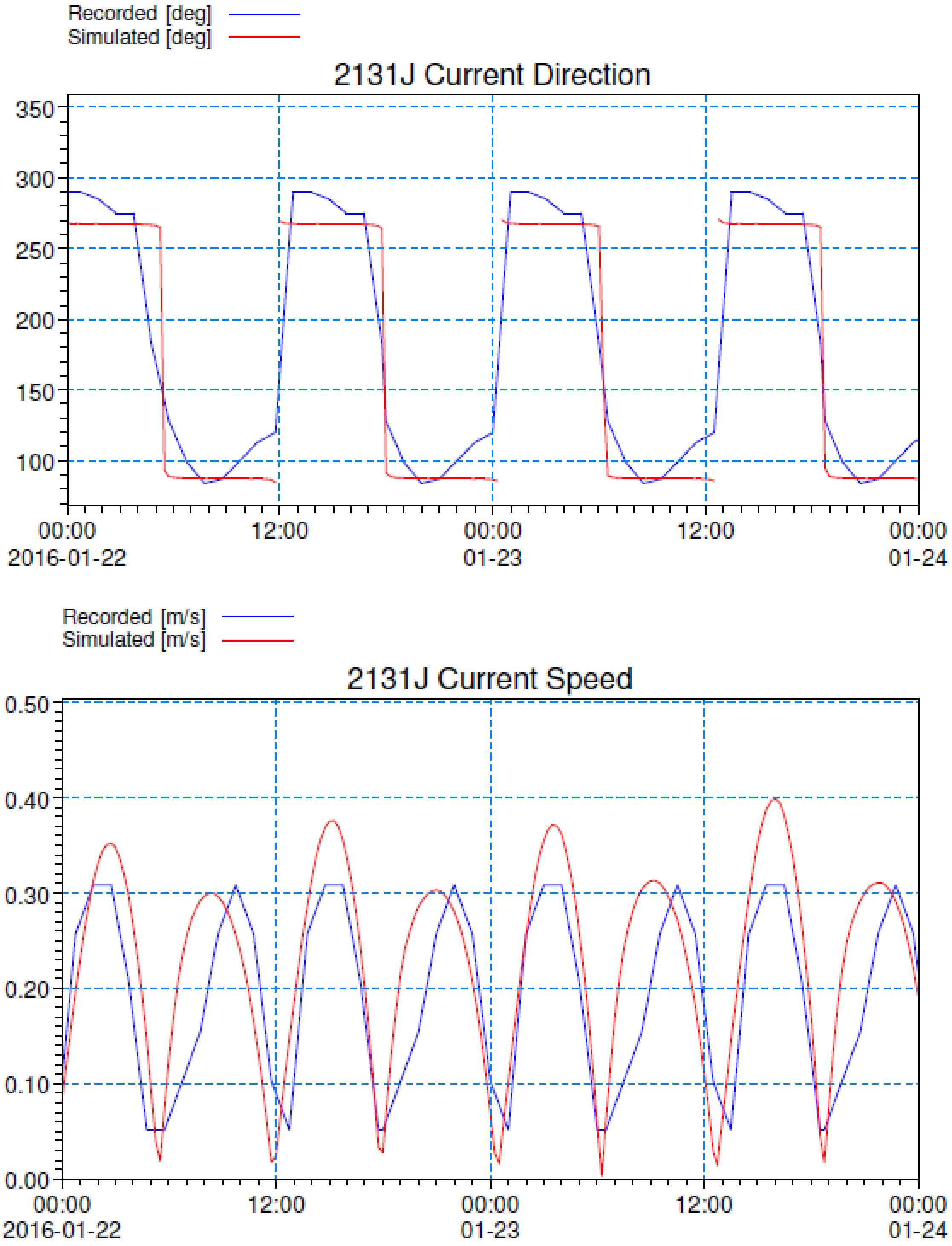


Figure 2.9 **Recorded and simulated current direction and speed at tidal stream data point 2131J**

The results presented here demonstrate acceptable model accuracy in terms of both water levels and tidal current speed and direction.

3 WIND AND WAVE DATA

3.1 DATA SOURCES

Wind and Wave data for the study was obtained from the European Centre for Medium range Weather Forecasts (ECMWF). The data from the ECMWF consisted of 3 hourly wind data derived for a point at 5.25°W, 55.25°N for the period 1983 to 2016. Wave data was also derived for a point at 6.5°W, 55.5°N for the period 1957 to 2002.

The ECMWF data point 5.25°W, 55.25°N is within the Firth of Clyde and representative of wind and wave conditions over this area, while the point at 6.5°W, 55.5°N is close to the western boundary of the wave transformation model and is exposed to long period swell waves from the Atlantic Ocean.

3.1.1 Wind Data

Figure 3.1 shows the wind rose for the dataset at 5.25°W, 55.25°N.

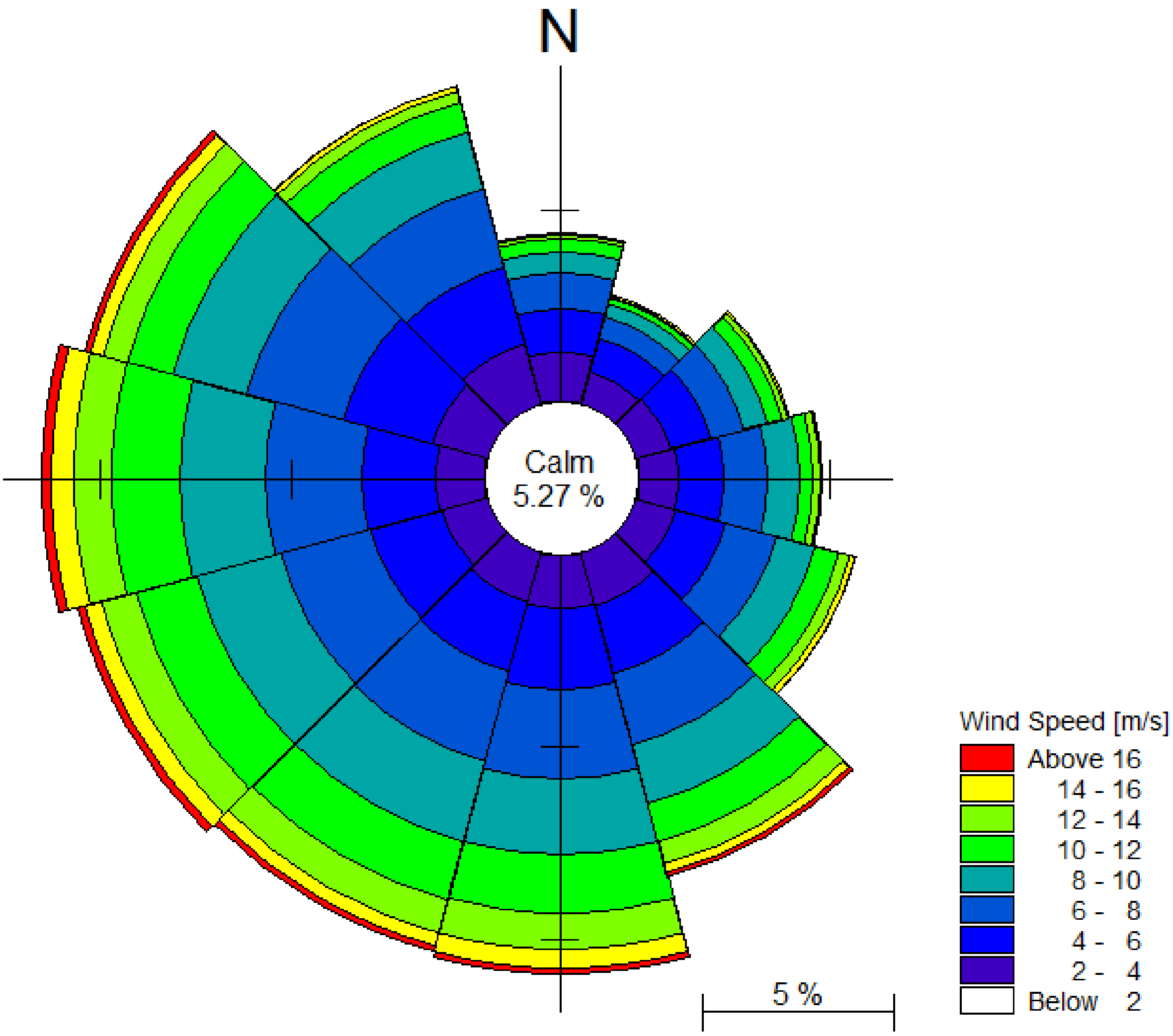


Figure 3.1 3 hourly wind rose for point 5.25°W, 55.25°N for period 1983-2016

It is known that the ECMWF UK waters wave model tends to under predict the extreme wind speeds in the Irish Sea by circa 15%, thus the wind speeds for wave generation in this study were increased by 15%. The wind rose for the data set at 5.25°W, 55.25°N after this 15% increase has been applied is shown in Figure 3.2.

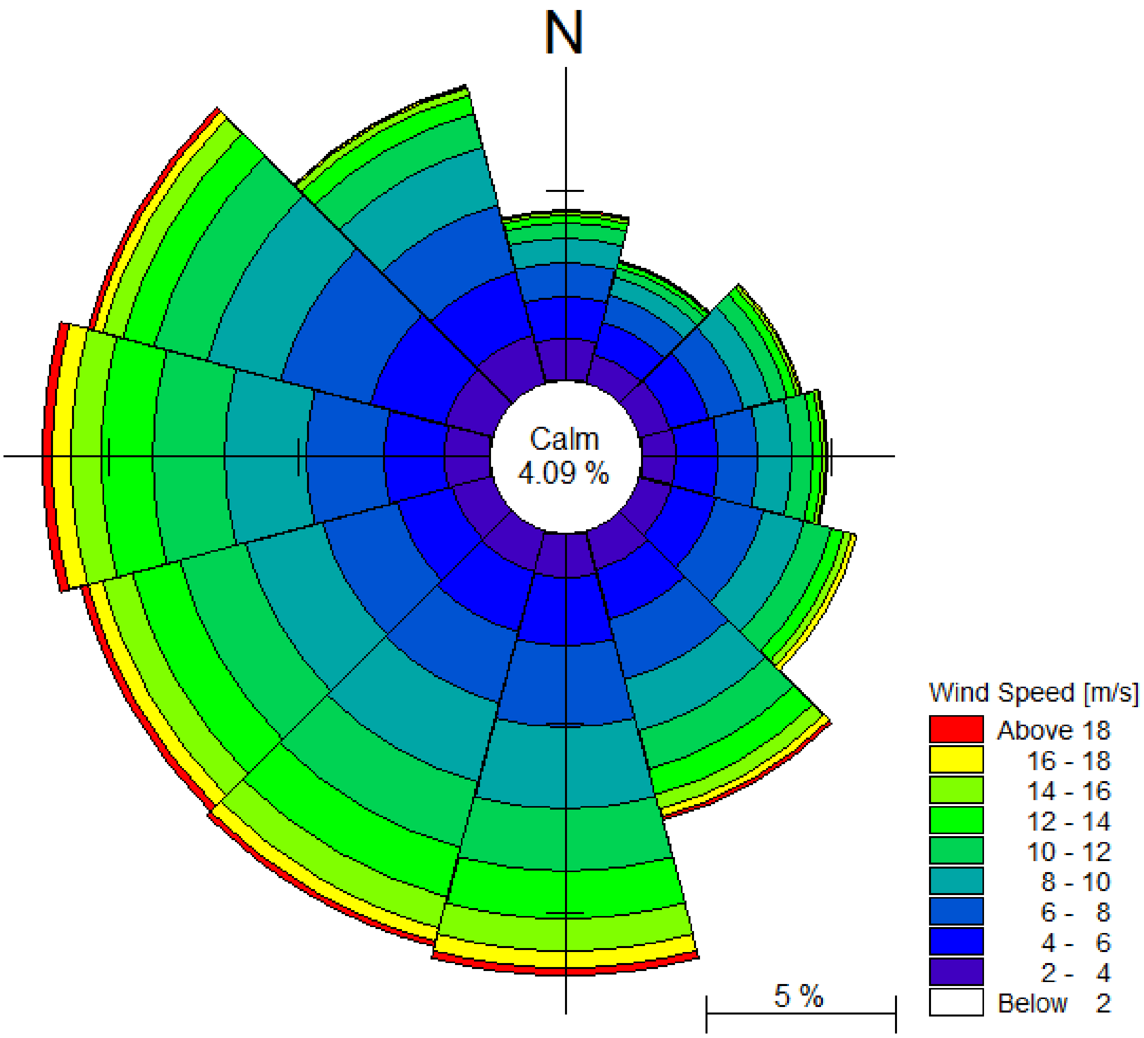


Figure 3.2 3 hourly wind rose for point 5.25°W, 55.25°N for period 1983-2016 with data increased by 15%

It can be seen from Figure 3.2 that the predominant wind directions are from 180-300°N. These directions were therefore selected for further analysis, resulting in 5 directional scenarios at 30° sectors.

Three wind speed scenarios were selected for analysis from each direction. The scenarios selected were 8, 12 and 19m/s, which correspond to a force 4, force 6 and force 8 winds respectively.

3.1.2 Wave Data

The waves which approach the Ayrshire shoreline are mostly generated across the fetches within the north Irish Sea and the Firth of Clyde. However, North Atlantic storm waves can propagate toward the southern extent of the Ayrshire shoreline through the North Channel. Thus, the wave data from the ECMWF model at a point 6.5°W, 55.5°N was used to define the western boundary condition. Figure 3.3 shows the wave rose for significant wave heights at 6.5°W, 55.5°N.

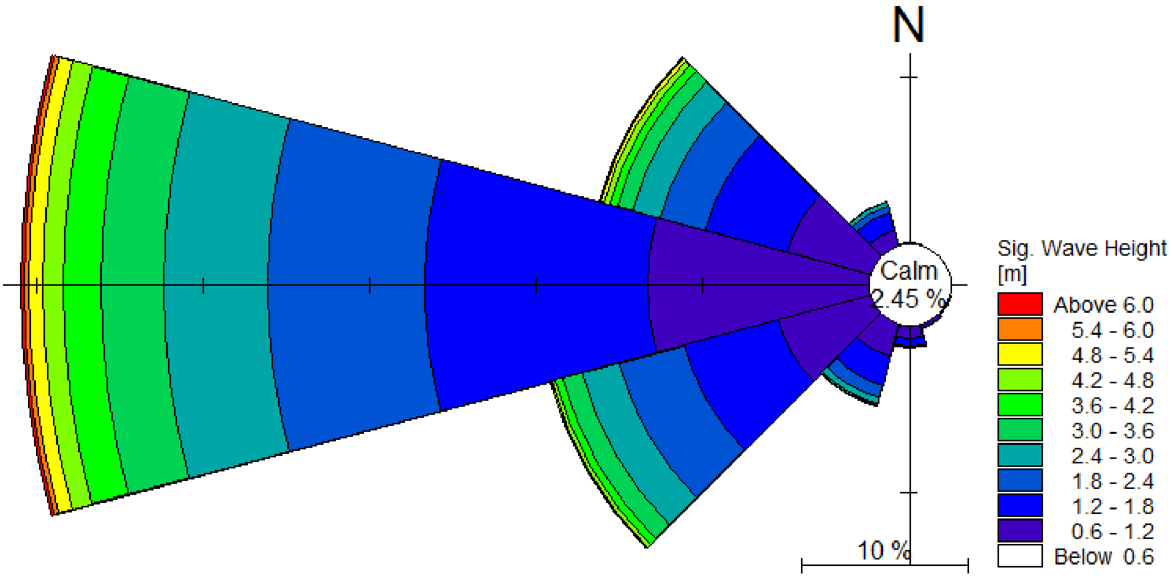


Figure 3.3 3 hourly wave rose for point 6.5°W, 55.5°N for period 1957-2002

It can be seen from Figure 3.3 that swell waves predominantly originate from the west at 6.5°W, 55.5°N. Swell waves originating from the North Atlantic at a direction of 270°N may refract around the Mull of Kintyre and enter the Firth of Clyde. A storm scenario considering long period swell waves from a direction of 270°N at the north western model boundary along with wind from 270°N was therefore considered in addition to the wind-only storm scenarios.

Table 3.1 Wave climate at western model boundary

Scenario	Direction	Hm0 [m]	Tp [s]
1	270	1.8	10.62
2	270	3.0	12.4
3	270	6.0	15.6

4 MODELLING THE WAVE CLIMATE

4.1 WAVE TRANSFORMATION MODELLING

4.1.1 Wave Transformation Model

The modelling of the wave transformation from the offshore boundary of the overall model to the Ayrshire shoreline was undertaken using the MIKE 21 SW model which is a new generation spectral wind-wave model based on unstructured meshes. The model simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas.

MIKE 21 SW includes the following physical phenomena:

- Wave growth by action of wind
- Non-linear wave-wave interaction
- Dissipation due to white-capping
- Dissipation due to bottom friction
- Dissipation due to depth-induced wave breaking
- Refraction and shoaling due to depth variations
- Diffraction
- Wave-current interaction
- Effect of time-varying water depth and flooding and drying

The discretization of the governing equation in geographical and spectral space is performed using a cell-centred finite volume method. In the geographical domain, an unstructured mesh technique is used. The time integration is performed using a fractional step approach where a multi-sequence explicit method is applied for the propagation of wave action.

MIKE 21 SW includes two different formulations:

- Directional decoupled parametric formulation
- Fully spectral formulation

Both formulations were used in the simulations. The fully spectral formulation is based on the wave action conservation equation, as described in e.g. Komen et al. (1994) and Young (1999), where the directional-frequency wave action spectrum is the dependent variable.

4.1.2 Modelling Procedure

The storm wave climate around the Ayrshire coastline was established by modelling the transformation of waves entering and generated within the Firth of Clyde from the south to the north west sectors. The wave transformation simulations were run for force 4, force 6 and force 8 winds for storm directions in intervals of 30° between 180°N to 300°N. The wave transformation simulations were run for each relevant 30° sector over two tidal cycles during spring tides.

Figure 4.1 to Figure 4.5 show the distribution of significant wave heights and mean wave directions in the north Irish Sea and Firth of Clyde during force 8 gales from 180°N through to 300°N. Figure 4.6 shows the distribution of significant wave heights and mean wave directions when long period waves from the North Atlantic are refracted into the Firth of Clyde during extreme storms, in combination with a force 8 gale from 270°N.

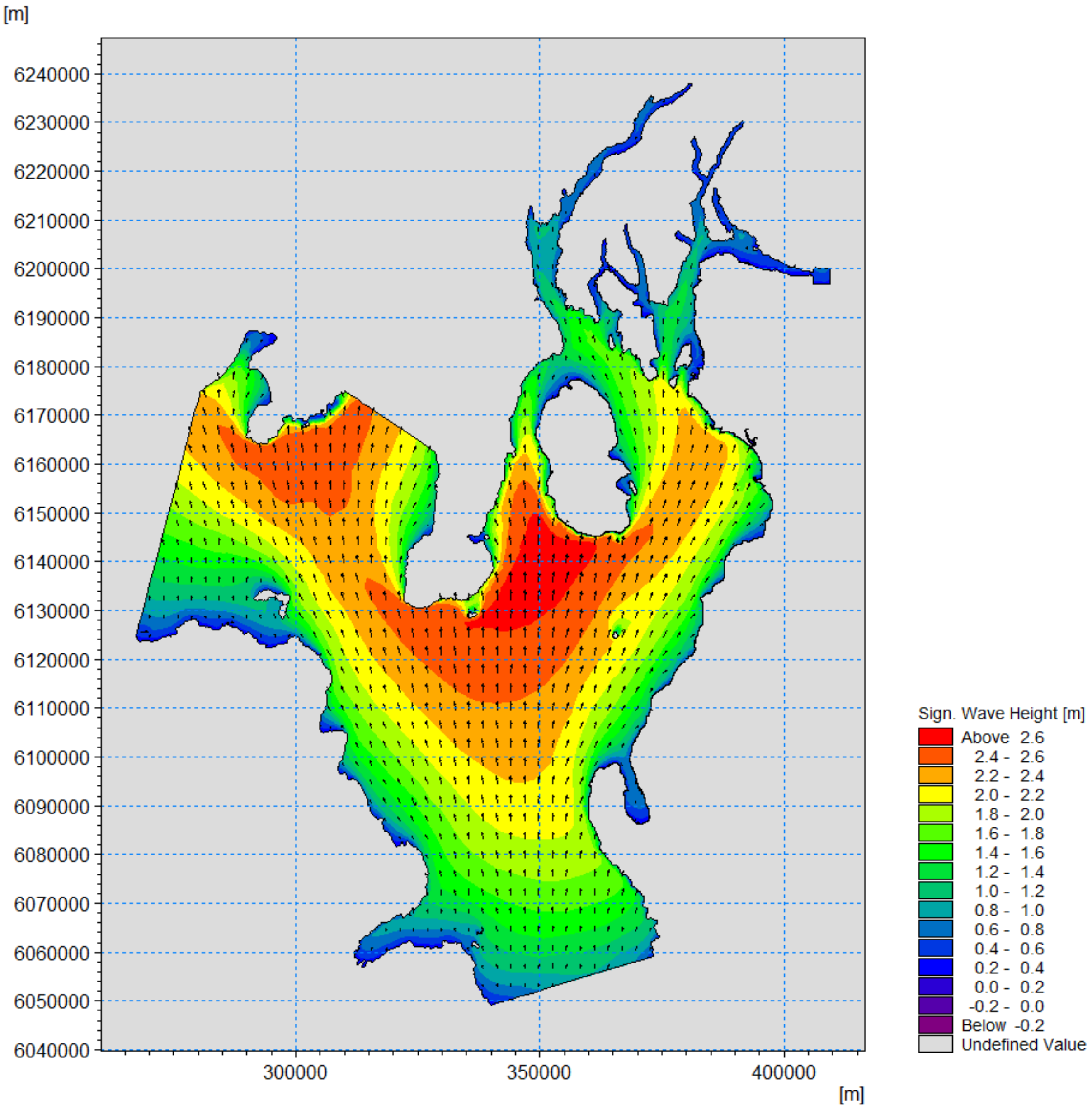


Figure 4.1 Significant wave height and mean wave direction during force 8 gale from 180°N

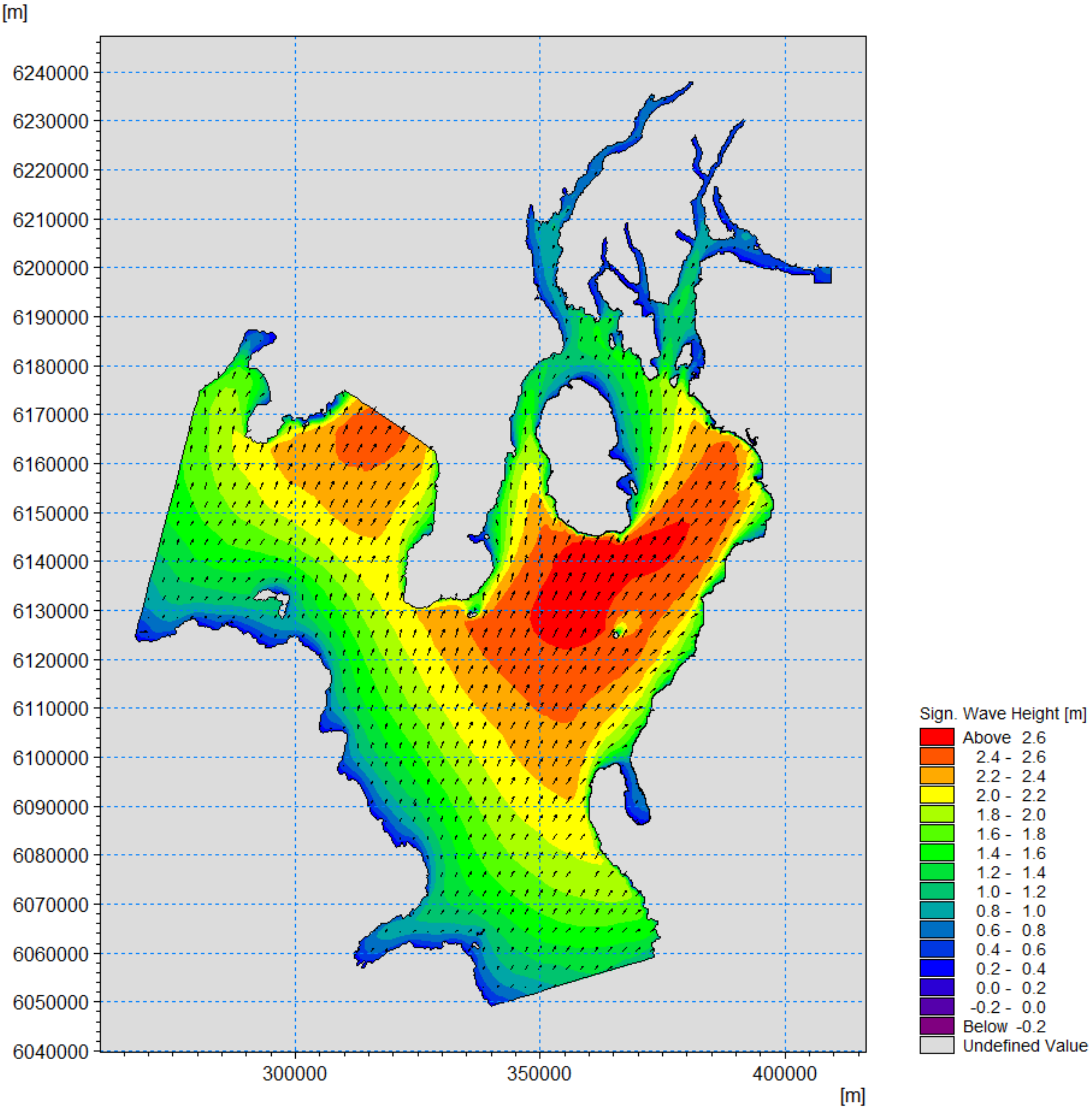


Figure 4.2 **Significant wave height and mean wave direction during force 8 gale from 210°N**

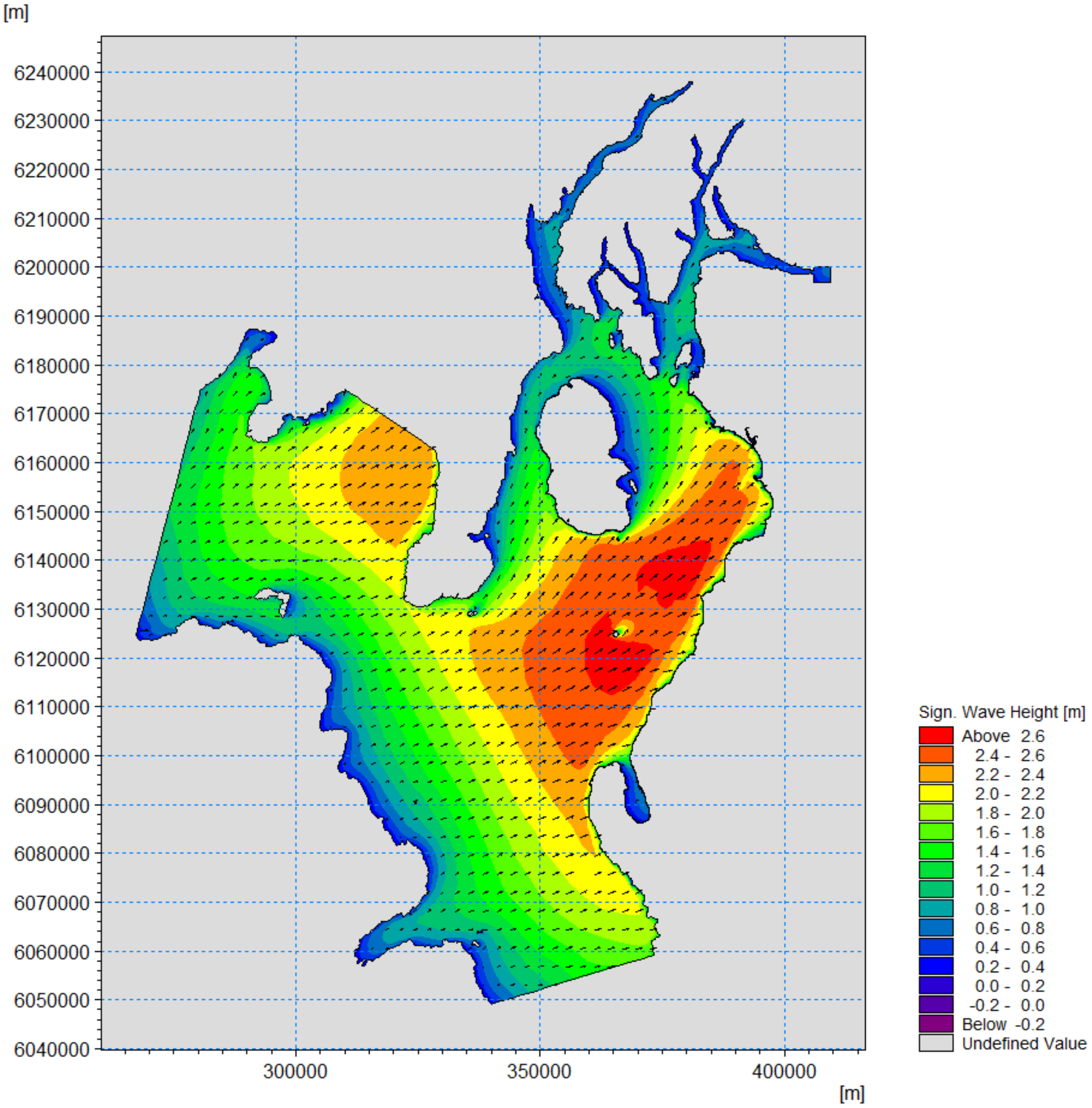


Figure 4.3 Significant wave height and mean wave direction during force 8 gale from 240°N

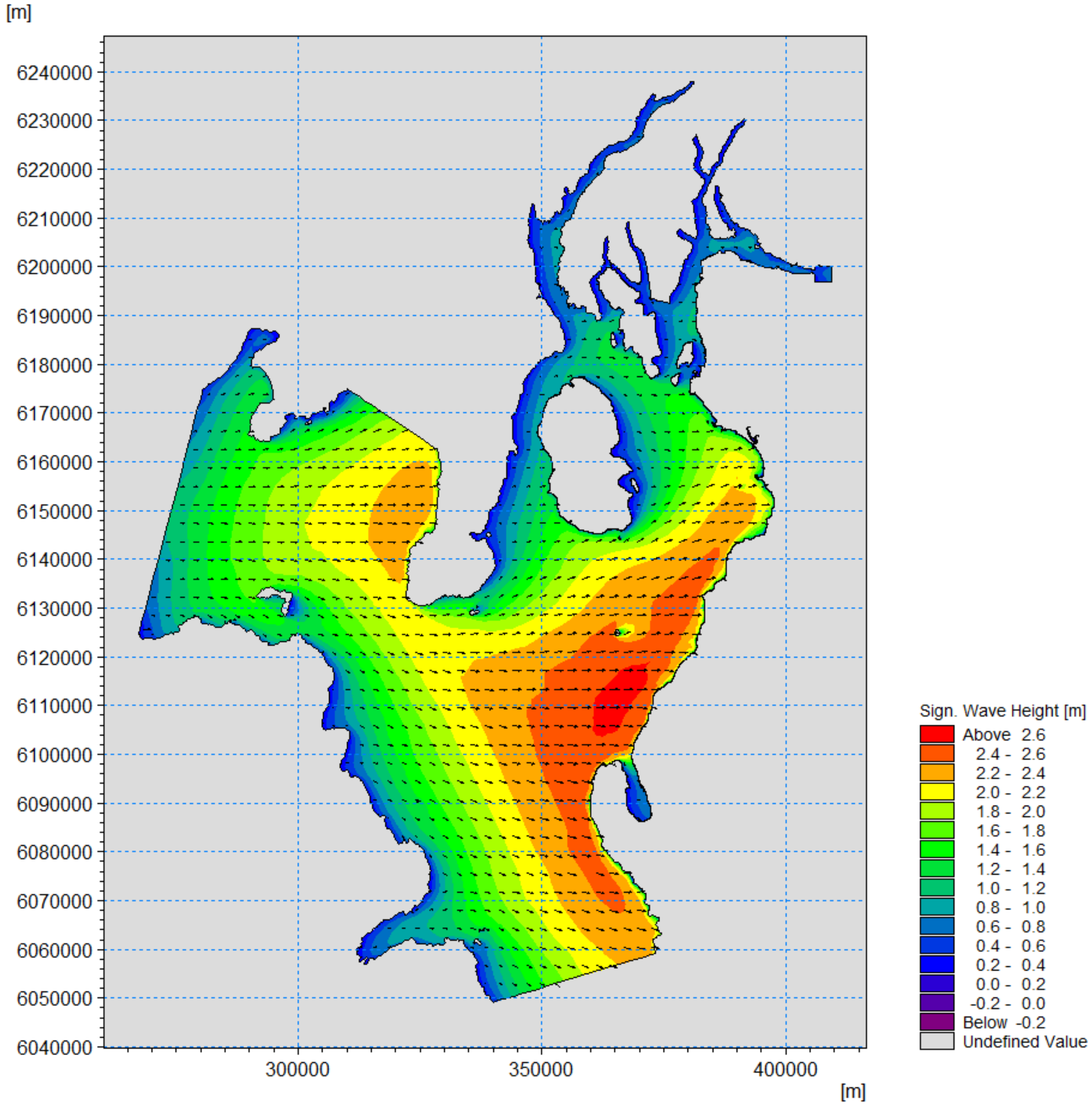


Figure 4.4 **Significant wave height and mean wave direction during force 8 gale from 270°N**

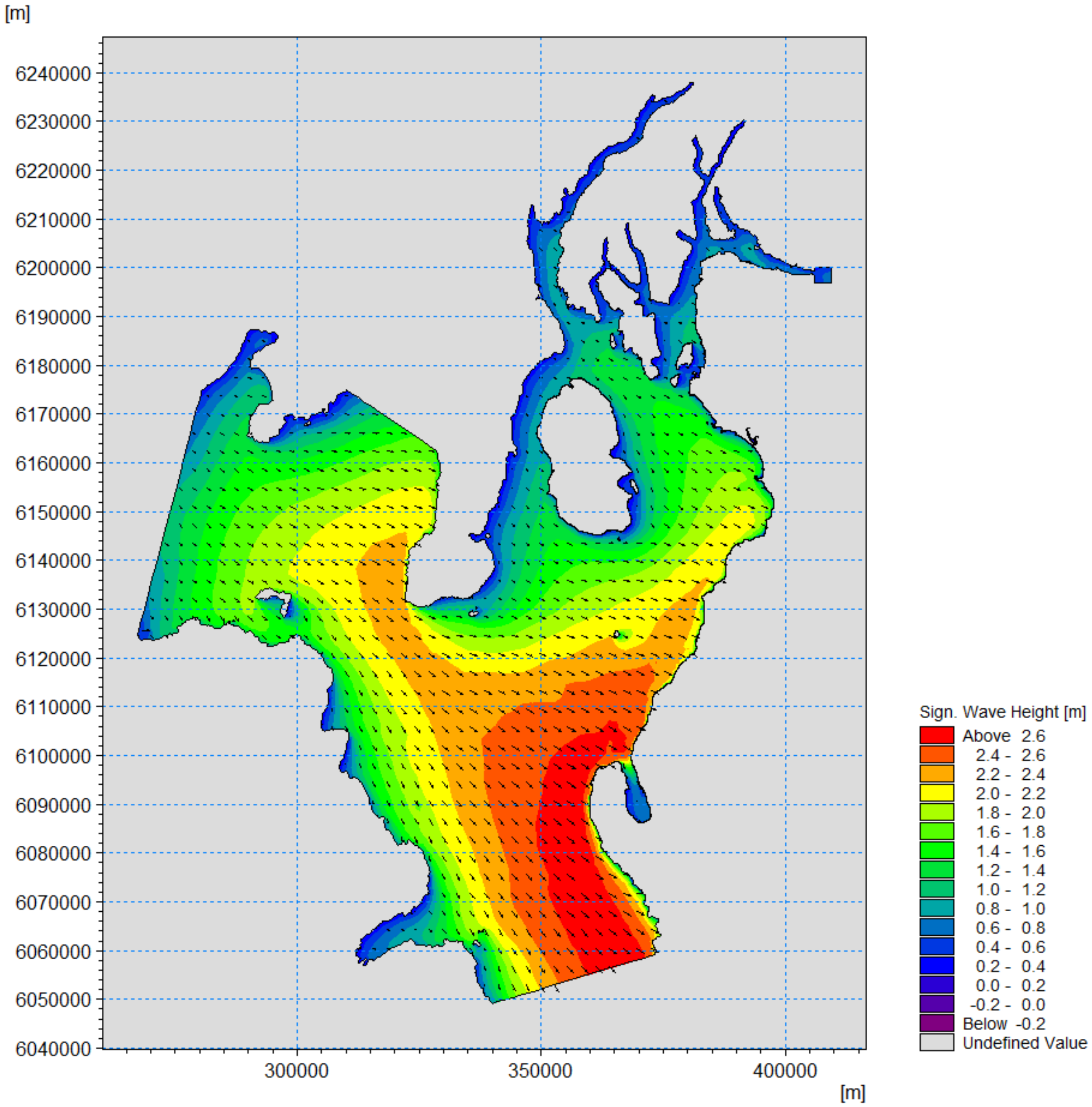


Figure 4.5 **Significant wave height and mean wave direction during force 8 gale from 300°N**

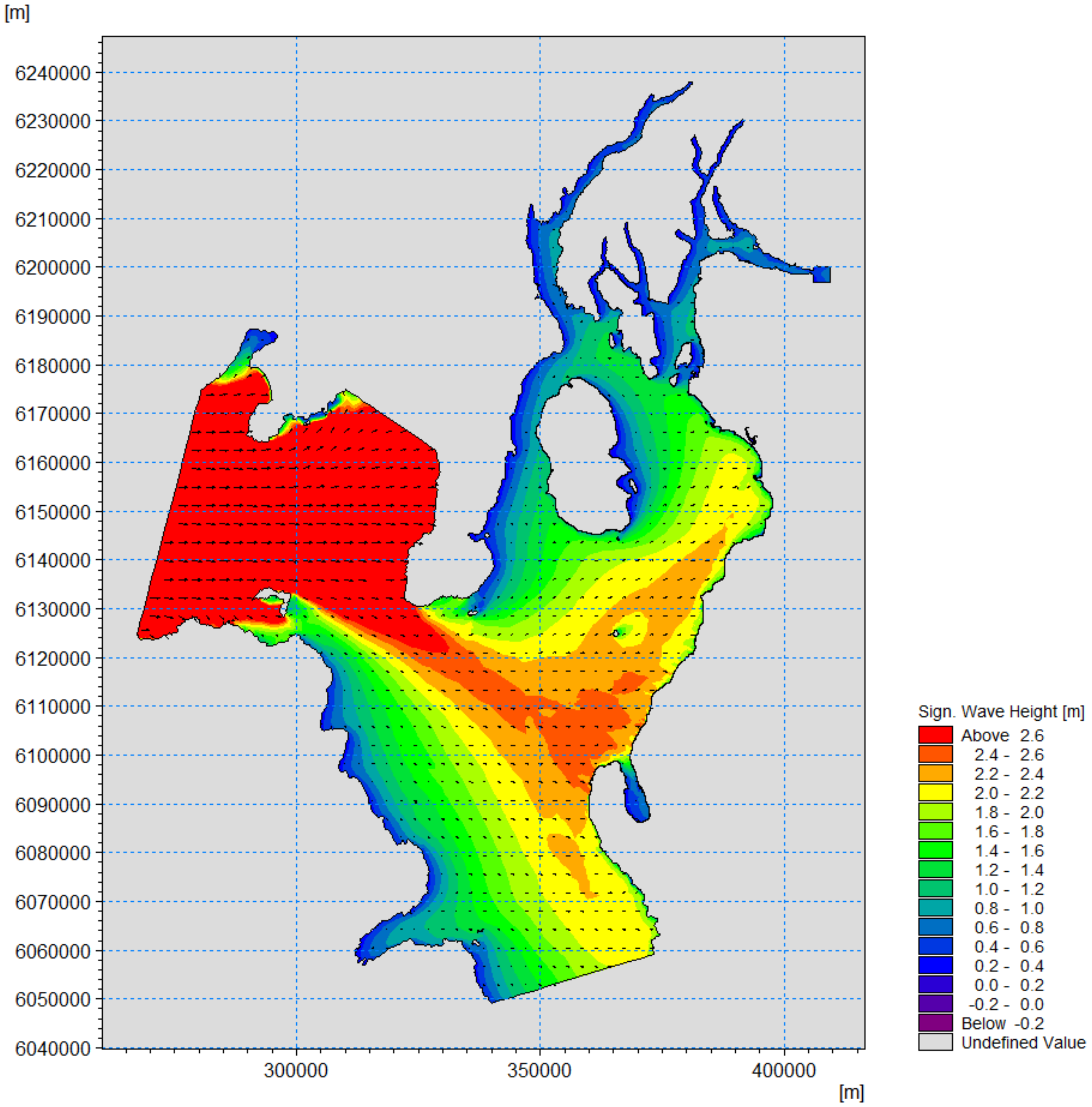


Figure 4.6 **Significant wave height and mean wave direction with long period waves entering from the North Atlantic during force 8 gale from 270°N**

4.1.3 Littoral Current Results

Littoral currents along the Ayrshire coastline were established directly from the results of the MIKE 21 SW simulations as these simulations consider the combined effect of tides and waves. An example of the littoral currents established from the model results is shown in Figure 4.7. This figure shows the magnitude and direction of the littoral currents in the vicinity of Troon for force 8 gales through directions from 180°N to 300°N.

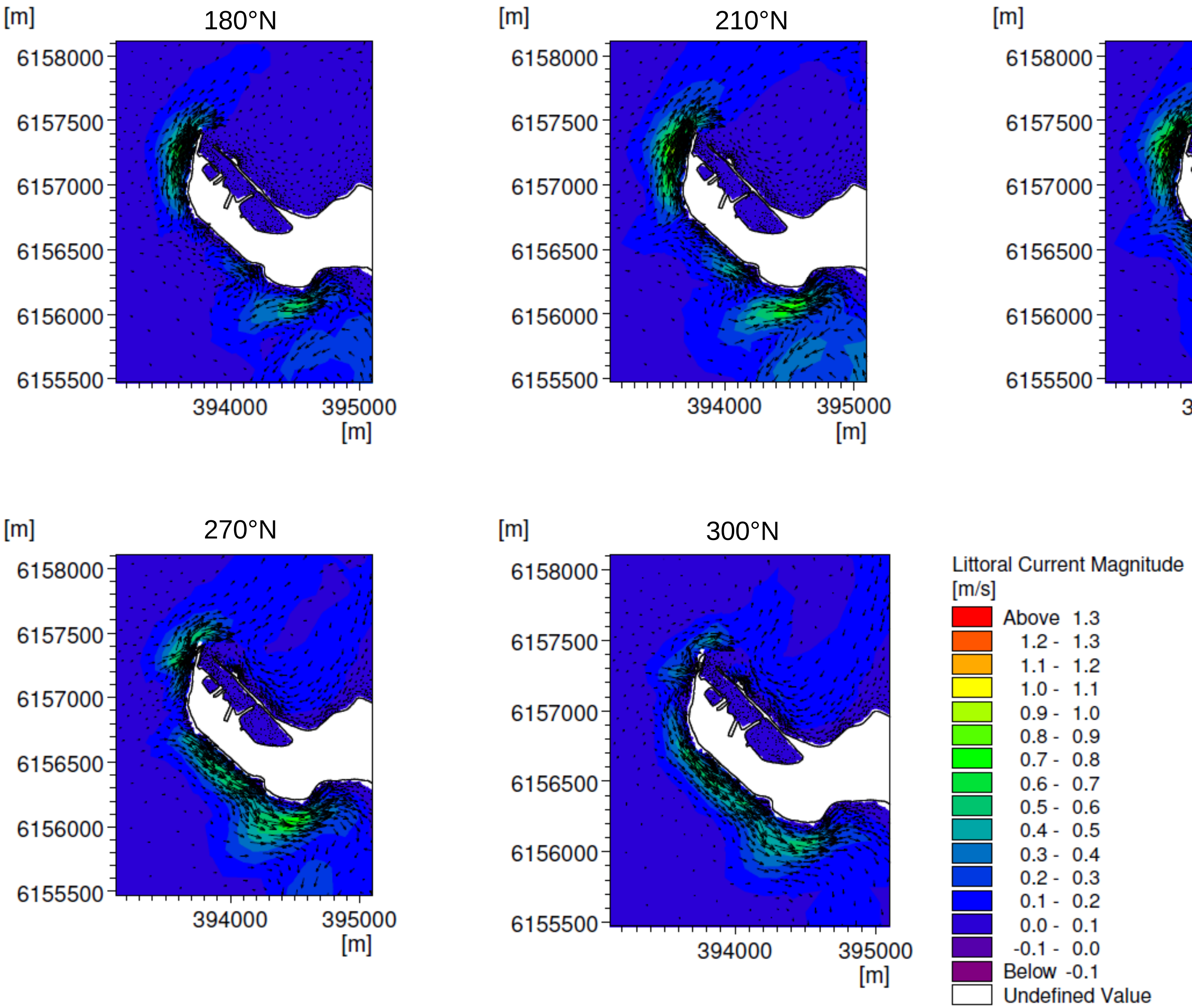


Figure 4.7 Littoral current magnitude and directions at Troon for force 8 gales between directions 180°N to 300°N

5 SEDIMENT TRANSPORT MODELLING

5.1 SEDIMENT TRANSPORT MODEL

The modelling of the sediment transport potential around the Ayrshire coastline was undertaken using the MIKE 21 ST model which is the module of the MIKE 21 modelling system that calculates the rates of non-cohesive sediment (sand) transport for both pure current and combined wave and current situations.

MIKE 21 ST can be applied to a wide range of sediment-transport related phenomena, including modelling of sediment transport fields in the littoral zone, in the vicinity of coastal structures, in tidal inlets, and under the sole or combined effects of tidal-, wind- and wave-driven currents in estuaries or coastal areas.

5.1.1 Sediment Transport Modelling Methodology

Results from the previously completed hydrodynamic (HD) and wave transformation (SW) model simulations were used as boundary data within the sediment transport (ST) model. The sediment transport model simulations were run for the same scenarios as the wave transformation model i.e. force 4, force 6 and force 8 winds for storm directions in intervals of 30° between 180°N to 300°N. The simulations were again run for each relevant 30° sector over two tidal cycles during spring tides.

5.1.2 Sediment Sampling

Random sediment samples were collected along the South Ayrshire coastline in order to determine a representative grain diameter to be used within the ST modelling. Samples and photographs were taken in June 2016 at 8 locations between Ballantrae and Dunure. The samples were mainly observed to be a medium sand, however the photographs recorded that coarser material including cobble is present along much of the coastline. However it was determined from the site visits that the movement of the medium sand was likely to be of most interest for the ST modelling, consequently a mean grain diameter of 0.4mm representing a medium sand was selected for use in determining the sediment transport potential.

5.1.3 Sediment Transport Modelling Results

The maximum potential sediment transport (suspended load and bed load) during each model simulation was analysed in order to establish the potential longshore drift along the Ayrshire coastline. This enabled sediment cells and sub-cells along the coastline to be identified. An example of the maximum potential sediment transport in the vicinity of Troon due to a force 8 gale from 240°N after a storm duration of 24 hours is shown in Figure 5.1. Potential sediment transport is observed from the southern tip to the northern tip of Troon Head; however as this headland is rocky and potential for sediment movement does not connect to the softer shorelines north and south of the headland this is considered an effective sub-cell boundary with little sediment transport across this point.

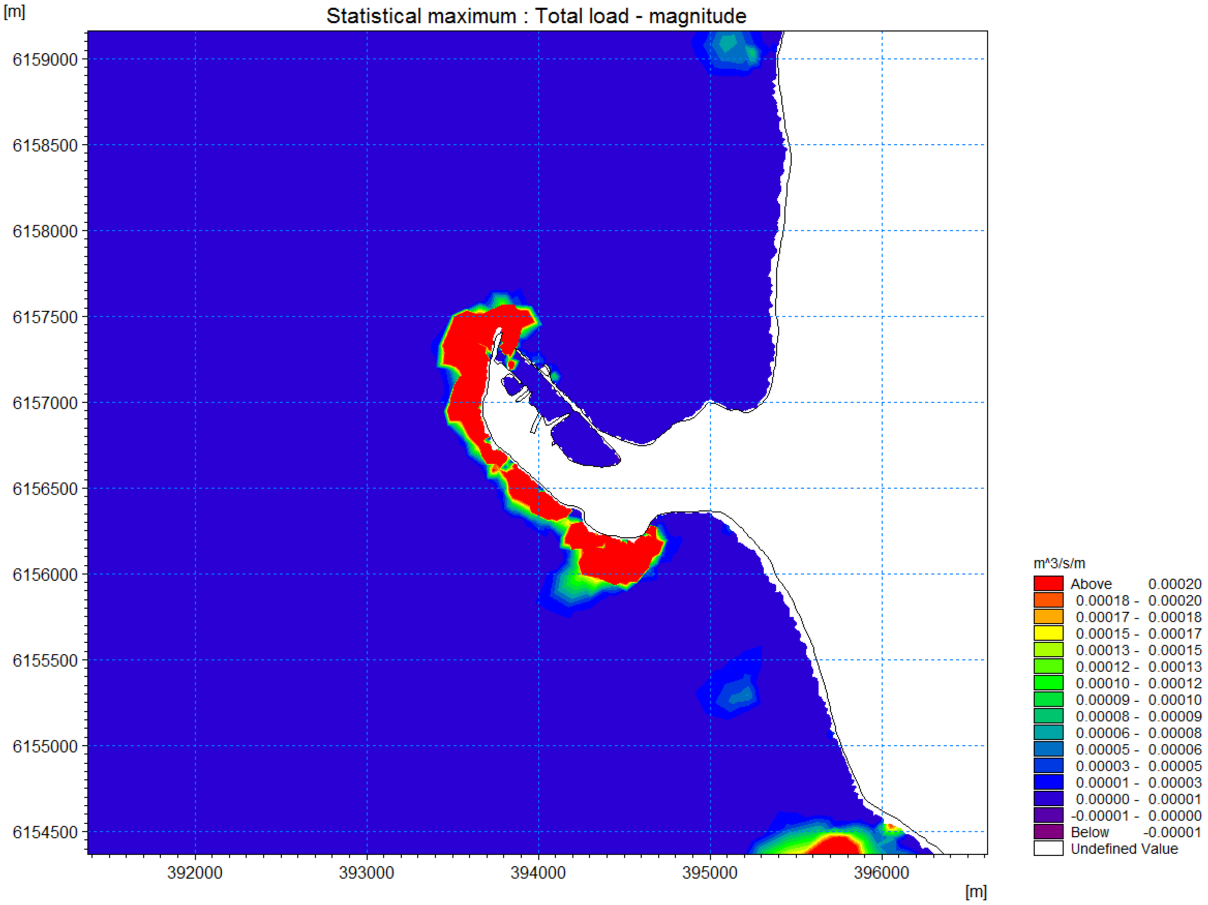


Figure 5.1 Maximum potential sediment transport due to force 8 gale from 240°N, gale duration 24 hours

5.1.4 Coastal Cell and Sub-Cell Boundaries

Eleven coastal cells for the Scottish coastline were categorised by H R Wallingford in 1997, between which the movement of sediment was considered to be relatively limited. These 11 coastal cells are shown in Figure 5.2. The Firth of Clyde is located within cell 6, between the Mull of Kintyre and the Mull of Galloway. The Firth of Clyde was further divided into 4 sub-cells (6a-6d) as shown in Figure 5.3.

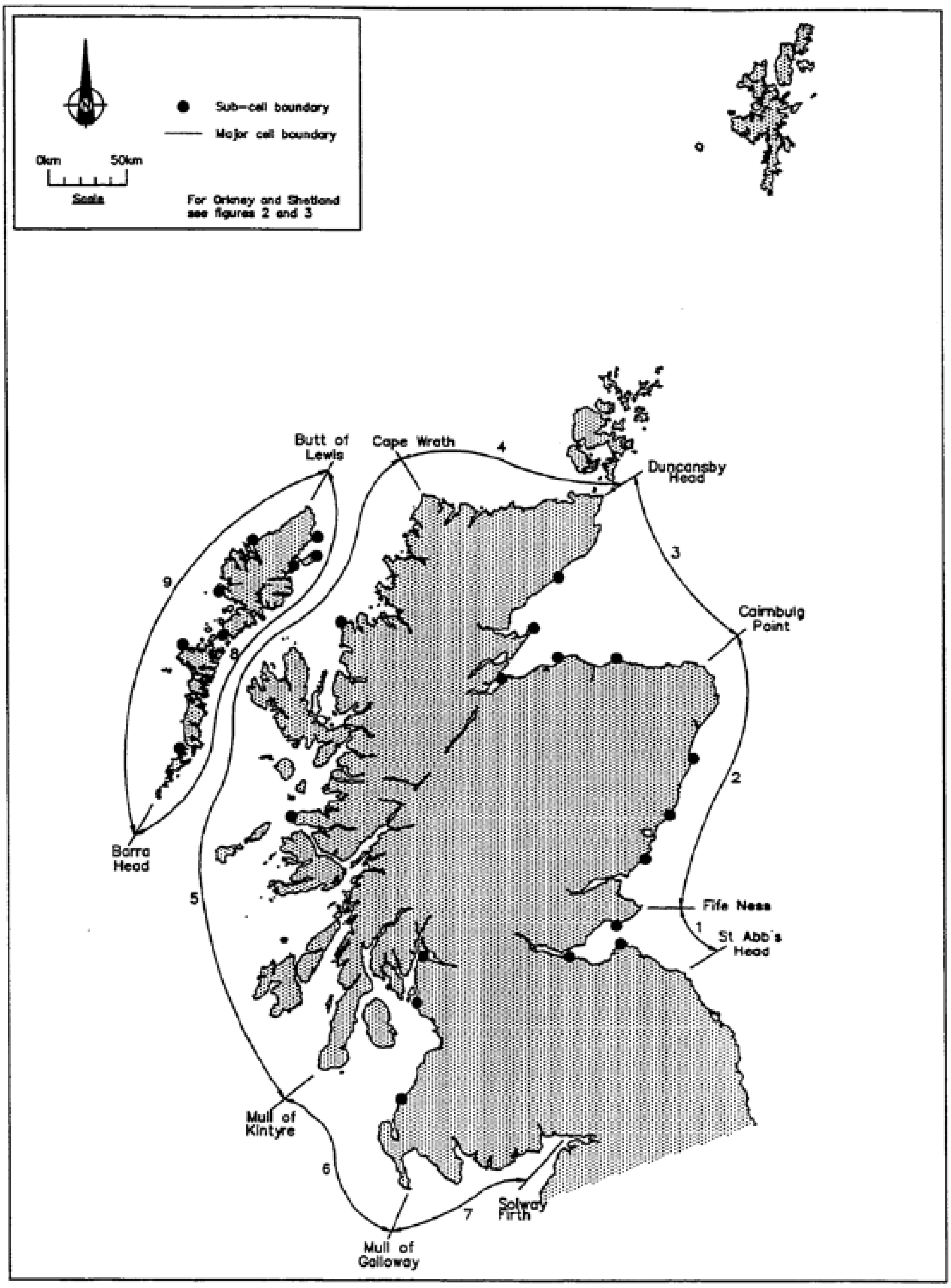


Figure 5.2 **Coastal cells in Scotland**

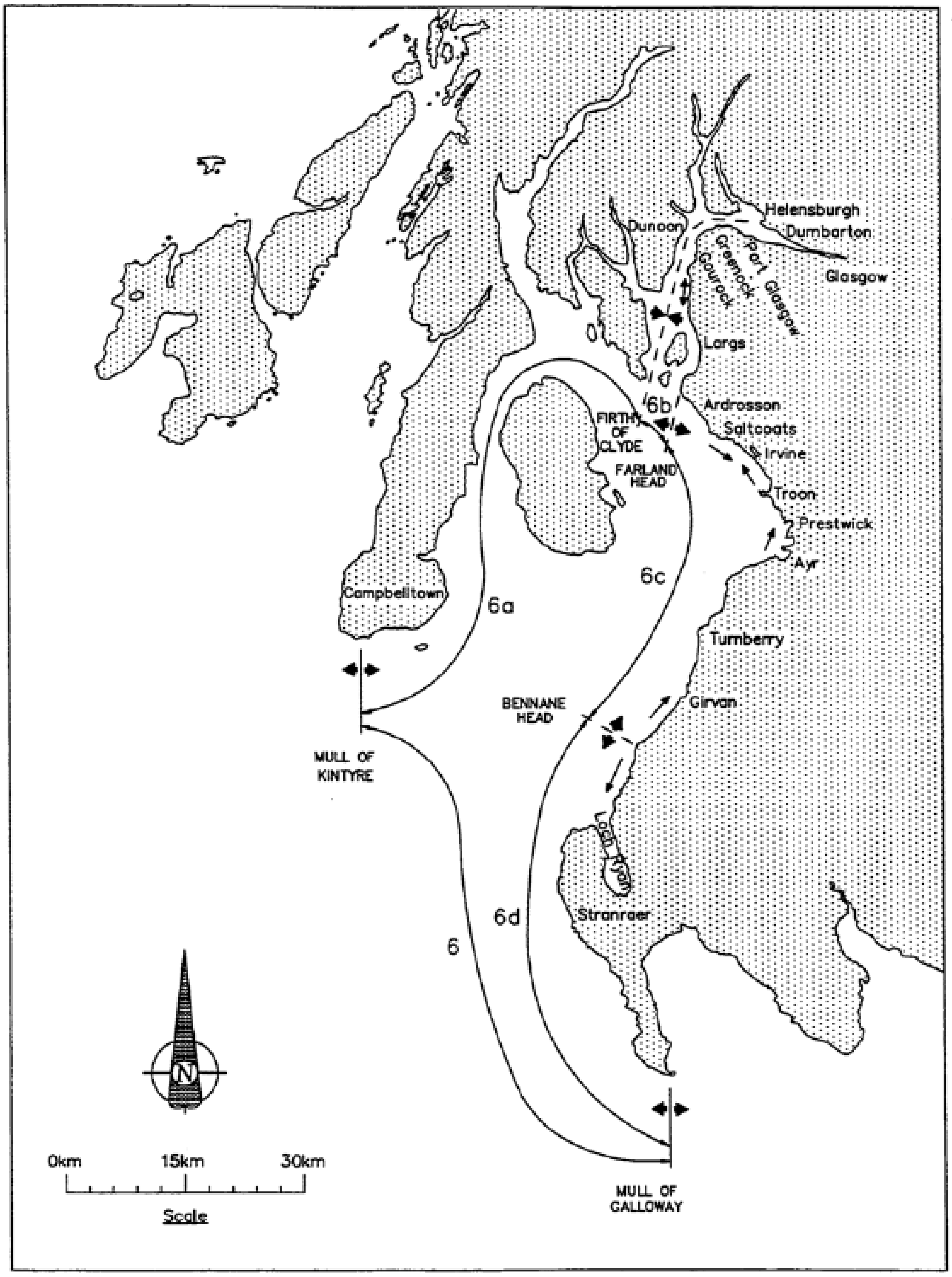
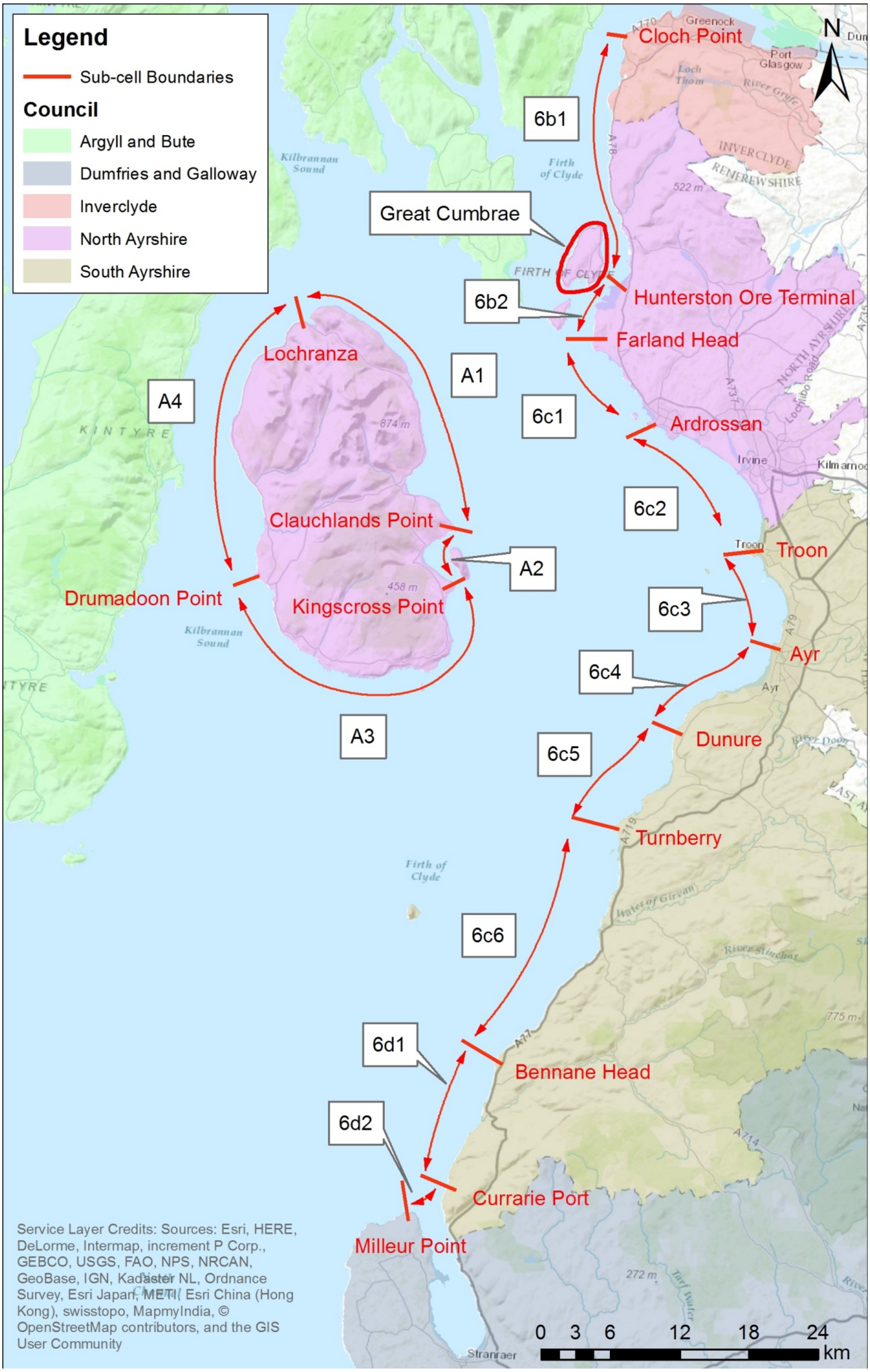


Figure 5.3 Coastal sub-cells from Mull of Kintyre to Mull of Galloway

The ST model results were used to further sub-divide the coastal sub-cells for the main Ayrshire and associated island coastlines. The sub-cell boundaries were defined by points across which there was limited sediment movement potential even during storm conditions. The boundary locations of the 15 sub-cells identified for the Ayrshire coast are shown in Figure 5.4 and defined in Table 5.1. The original naming convention adopted by Wallingford (1997) was maintained, with further divisions within an existing sub-cell defined by appending a number to the existing cell name e.g. 6b1, 6b2 etc.

The definition of these coastal sub-cells is critical in terms of the development of a sustainable Shoreline Management Plan for the Ayrshire coast as this defines the areas within which various measures can be applied without affecting adjoining sections of the coast, for example a policy of hold the line applied in a sub-cell will not affect coastal processes in an adjoining cell. Thus the sub-cells define the geographic boundaries for future studies associated with the detailed design of a wide range of coastal management measures with potential to impact on coastal sediment dynamics.



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 5.4 **Coastal sub-cell boundaries for the Ayrshire and Arran coastlines**

Table 5.1 Coastal sub-cell boundary locations

Sub-cell	Boundary locations
6b1	Cloch Point – Hunterston Ore Terminal
6b2	Hunterston Ore Terminal – Farland Head
6c1	Farland Head – Ardrossan
6c2	Ardrossan – Troon
6c3	Troon – Ayr
6c4	Ayr – Dunure
6c5	Dunure – Turnberry
6c6	Turnberry – Bennane Head
6d1	Bennane Head – Currarie Port
6d2	Currarie Port – Milleur Point
A1	Lochranza – Clauchlands Point
A2	Clauchlands Point – Kingscross Point
A3	Kingscross Point – Drumadoon Point
A4	Drumadoon Point – Lochranza
Great Cumbrae	Great Cumbrae

None of the sub-cells identified as part of the data gap analysis for the Ayrshire SMP interact with shoreline within Argyll and Bute Council.

Sub-cell 6b1, located between Cloch Point and Hunterston Ore Terminal, extends north of the North Ayrshire Council area to include part of the Inverclyde Council area. Objectives for shoreline management of this sub-cell will therefore need to be prepared in coordination with Inverclyde Council.

The shoreline of sub-cell 6d2, is composed of mainly of rock south of Currarie Port as far as Cairnryan, with no significant sediment movement. Softer sediments are present within Loch Ryan South of Cairnryan, however this is within the Dumfries and Galloway Council area and therefore outside the scope of the Ayrshire SMP.

5.1.5 LiDAR Gap Sensitivity Testing

Additional survey data of the Ayrshire Coastline between Ayr and Girvan not covered by the main LiDAR survey was made available to RPS in November 2016. Prior to this the present day modelling of the Ayrshire shoreline was completed using MEDIN and digital chart data to represent the shoreline in this area. Following receipt of the additional data the model mesh was re-generated with the new beach survey data included and the model was re-run using the updated mesh to test if including this high resolution data significantly altered the model results.

With the new survey data applied the bed levels in the model mesh adjacent to the shoreline at Turnberry point and along the cliffs at Dunure was found to increase. As a result the current speeds in the littoral zone were found to be lower. However these changes were not found to significantly affect sediment transport potential, and did not alter the location of sediment sub-cell boundaries.

6 CLIMATE CHANGE

The effect of climate change on coastal processes along the Ayrshire shoreline was simulated by reference to the UK Climate Projections UKCP09 guidance.

Predictions of future sea level rise, changes in storm surges and climate driven changes in waves are available from the report 'UK Climate Projections science report: Marine & coastal projections' by Lowe et al. (2009). However further research carried out since UKCP09 was published has resulted in recommendations to adopt higher values of projected sea level rise (IPCC, 2013). SEPA took cognisance of this research by IPCC when producing the coastal flood risk maps for Scotland and used the 2080 high emissions scenario 95th percentile relative sea level rise values from UKCP09 (SEPA, Flood Modelling Guidance for Responsible Authorities). The same sea level rise scenario has therefore been used in this study to assess the impact of climate change on the coastal processes around the Ayrshire shoreline. Predictions of relative sea level rise were extracted from the UKCP09 user interface and these predictions were used to update the model boundaries.

The projected rate of change in storm surge levels is relatively small at less than 0.5mm/year (Lowe et al., 2009). The effect of climate change on storm surges (50mm over 100 years) is therefore considered insignificant when assessing the coastal processes around the Ayrshire shoreline.

In terms of potential future changes to wave climate, a reduction in wave height to the north of the UK is projected (Lowe et al., 2009). Changes in wave period and direction are considered to be small, however it is noted that these are difficult to interpret. Since there is high uncertainty in the projected changes to wave climate, it was considered inappropriate to reduce the modelled wave height. The current scenario wave conditions were therefore retained for assessing the impact of climate change on coastal processes around the Ayrshire shoreline.

6.1 TIDAL MODELLING

The effect of sea level rise on tides within the Firth of Clyde was modelled. The tidal modelling as discussed in Section 2 was repeated using boundary conditions representative of a climate change scenario. Using predictions from UKCP09 as previously discussed, a sea level rise of 0.55m was applied to each model boundary.

This increased sea level was found to have little effect on tidal currents within the Firth of Clyde. Overall current speeds and directions were found to be very similar to those predicted from present day scenario modelling, as shown in Figure 6.1.

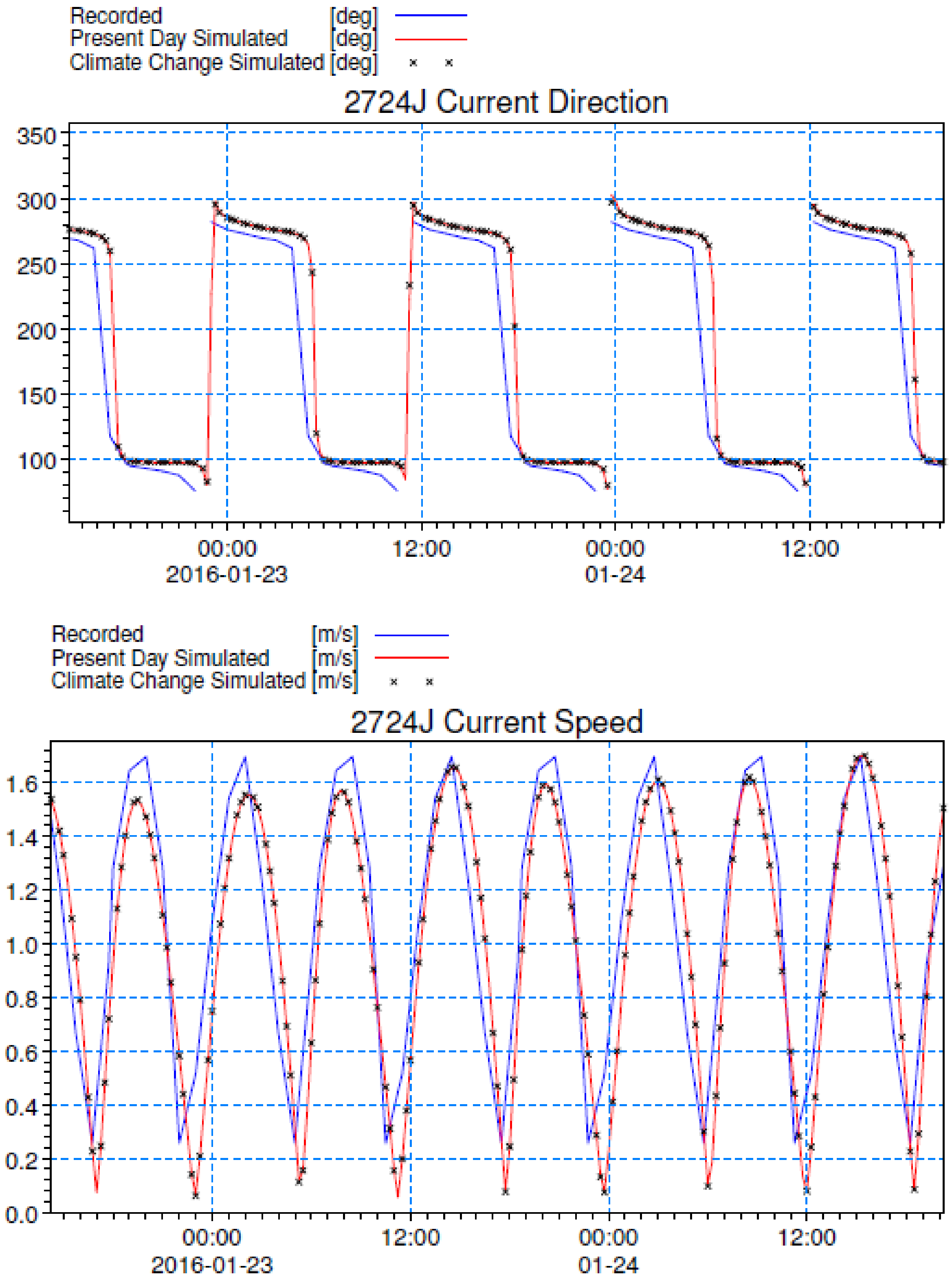


Figure 6.1 Recorded, simulated present day and simulated climate change current direction and speed at tidal stream data point 2724J

6.2 WAVE CLIMATE

The potential effect of sea level rise on the transformation of waves within the Firth of Clyde was simulated by re-running the previous model simulations with increased water levels. Revised wave transformation simulations were run for force 4, force 6 and force 8 winds for storm directions in intervals of 30° between 180°N to 300°N. The wave transformation simulations were run over two tidal cycles during spring tides. As previously discussed, potential changes in wave period and direction are considered to be small (Lowe et al., 2009) hence it was considered appropriate to use the present day wind conditions for these model simulations.

Increased sea level was found to have negligible effect on modelled wave heights, periods and directions for each model scenario. Figure 6.2 shows the distribution of significant wave heights and mean wave directions in the North Channel and Firth of Clyde during a force 8 gale from 240°N when a sea level rise of 0.55m is applied. There is negligible difference between these results and the equivalent present day scenario as shown in Figure 4.3.

6.2.1 Littoral Currents

The effect of 0.55m sea level rise on littoral currents along the Ayrshire coastline was established directly from the results of the MIKE 21 SW simulations. Figure 6.3 shows the magnitude and direction of the littoral currents in the vicinity of Troon for force 8 gales through directions from 180°N to 300°N with 0.55m of sea level rise applied.

Comparing the littoral currents shown in Figure 6.3 to the equivalent present day scenario shown in Figure 4.7, reveals subtle differences in both magnitude and direction. The littoral current adjacent to the shoreline is generally greater in the climate change scenario due to the increased water depth. Slight reductions in magnitude are generally observed at the offshore boundary of the littoral zone during the climate change runs.

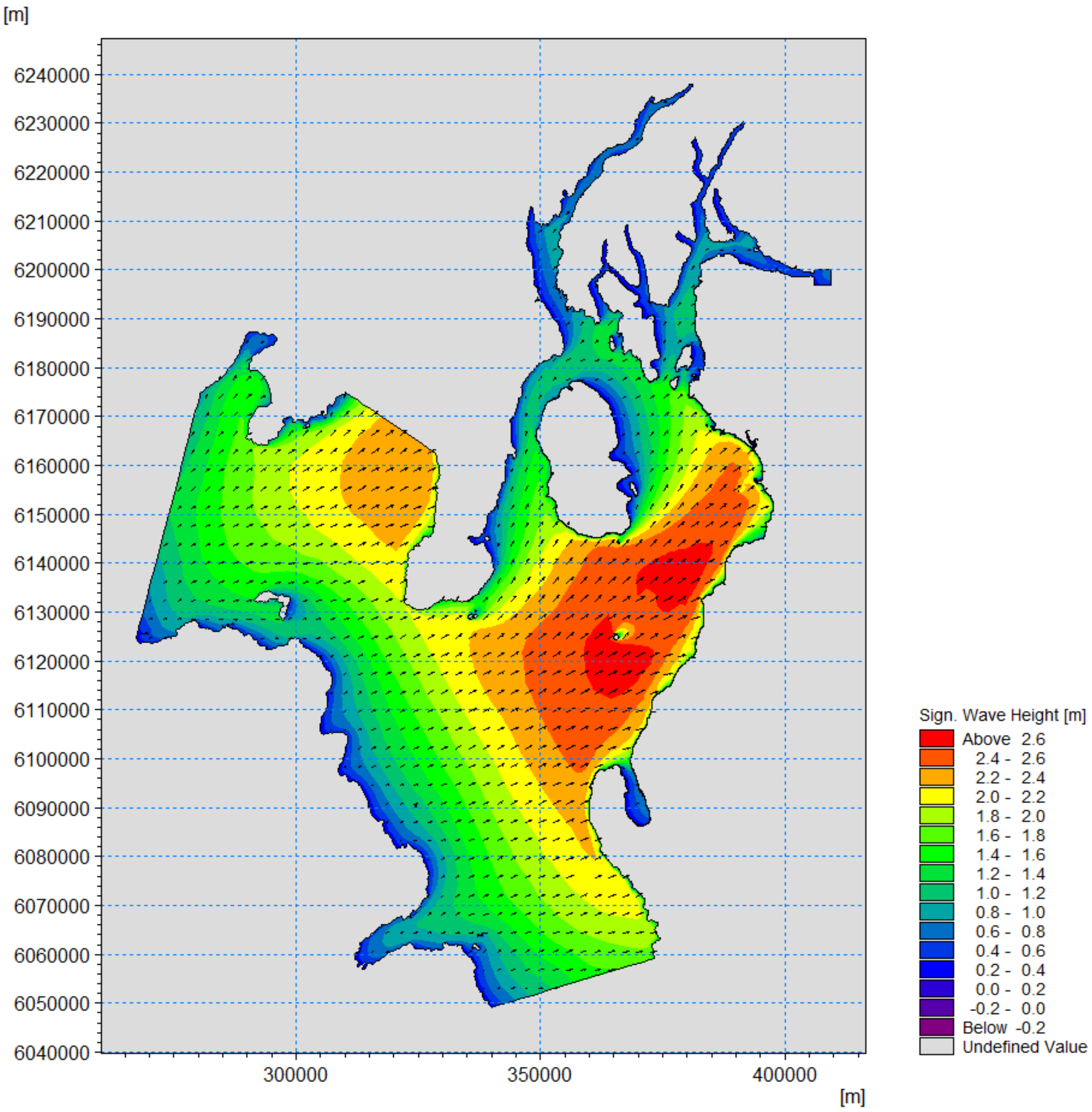


Figure 6.2 Significant wave height and mean wave direction during force 8 gale from 240°N with sea level rise

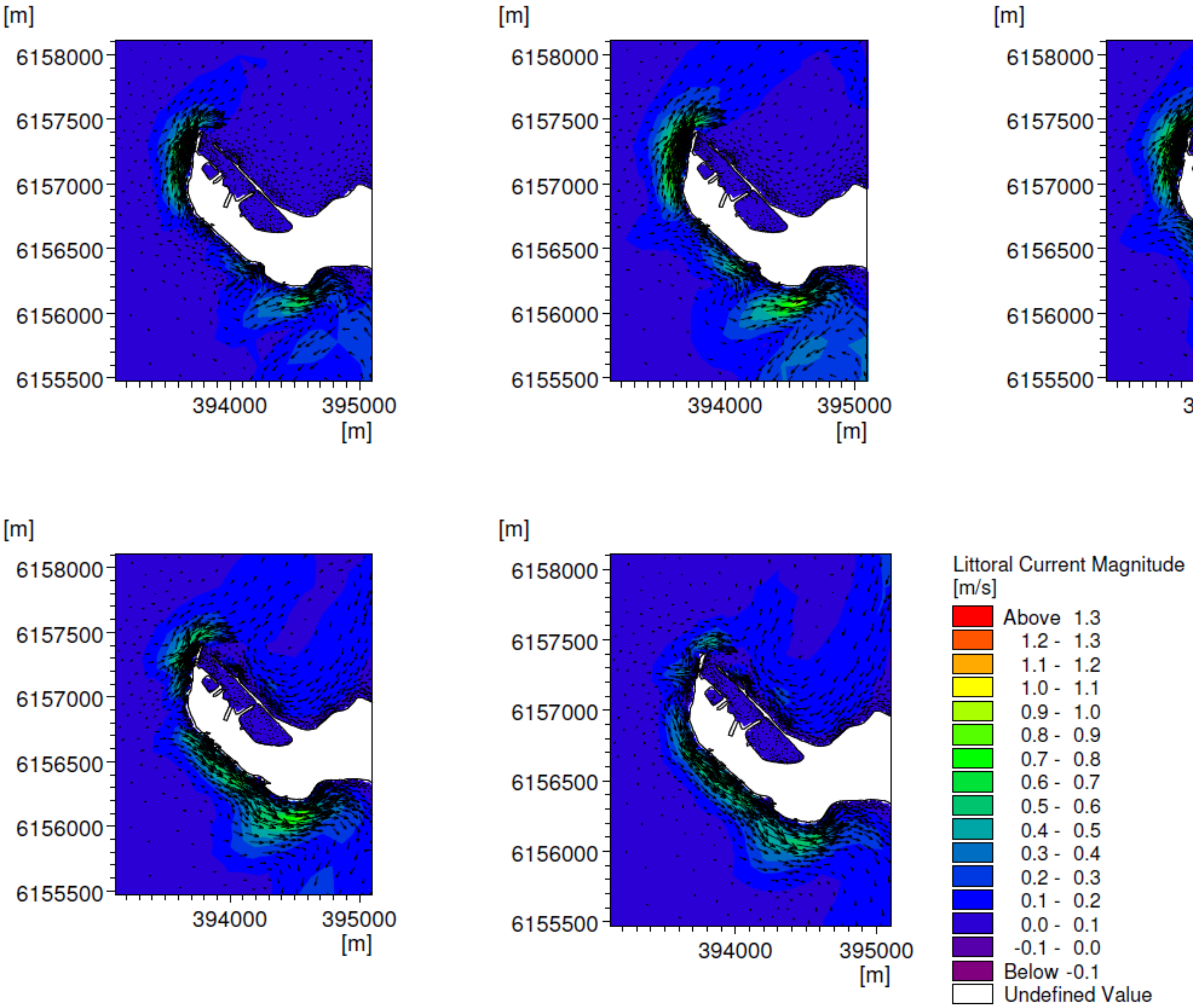


Figure 6.3 **Littoral current magnitude and directions at Troon for force 8 gales between directions 180°N to 300°N with sea level rise applied**

6.3 SEDIMENT TRANSPORT

The potential effect of sea level rise on sediment transport along the Ayrshire coastline was also modelled. Simulations were carried out as per the methodology described in Section 5, with a sea level rise of 0.55m applied to the model boundaries.

The maximum potential sediment transport (suspended load and bed load) during each model simulation was analysed and compared to the equivalent present day simulation in order to establish the potential impact of sea level rise on longshore drift along the Ayrshire coastline. An example of the maximum potential sediment transport in the vicinity of Troon due to a force 8 gale from 240°N with sea level rise is shown in Figure 6.4 and is similar to that determined during the present day modelling (Figure 5.1). The maximum potential sediment transport was found to be greater in the climate change scenarios however the increases observed are relatively minor and would not significantly affect the sediment budget along the Ayrshire coastline. The modelling results did not indicate that any sub-cell boundary locations would be changed by a sea level rise of 0.55m.

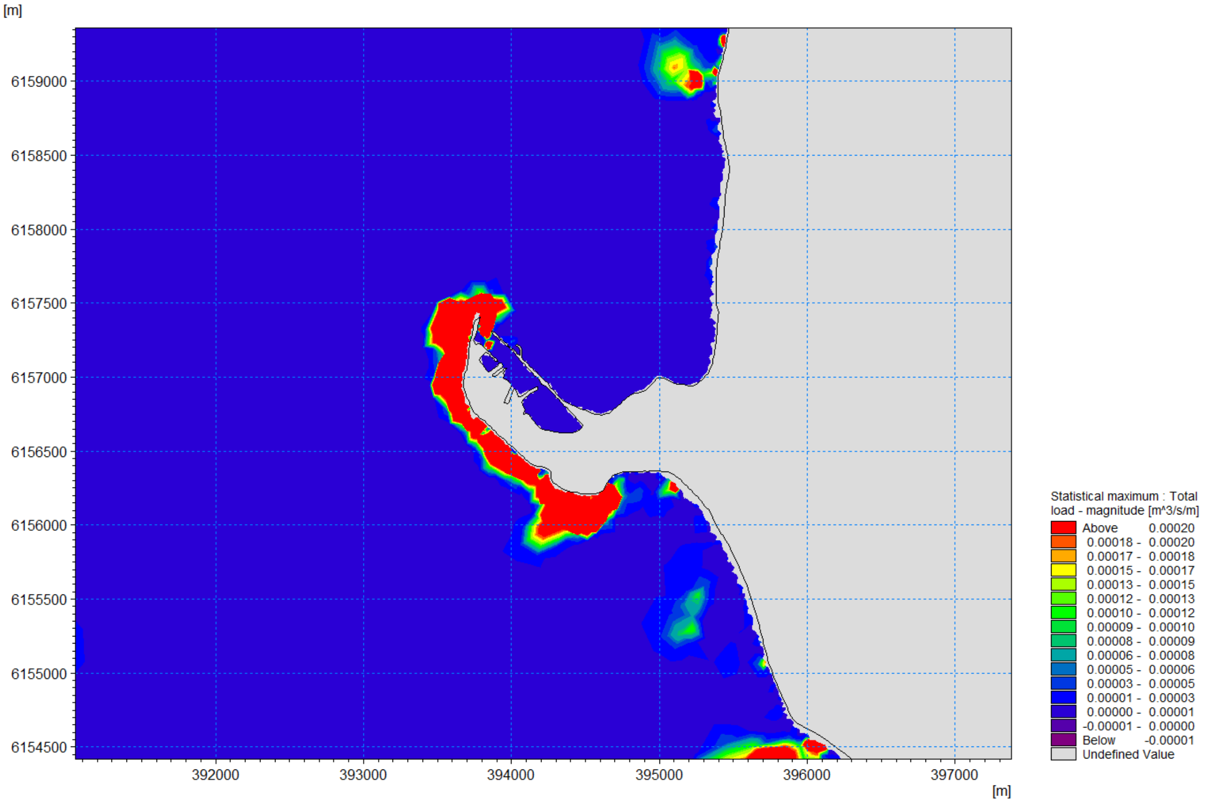


Figure 6.4 Maximum potential sediment transport due to force 8 gale from 240°N with sea level rise, storm duration 24 hours

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