

Appendix D Technical Memorandum – Numerical Modelling Assessment



Port of Cairns Long-term Maintenance Dredging Management Plan 2021-2031 Numerical Modelling

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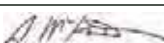
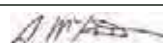
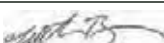
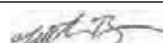
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Executive Summary

Maintenance dredging is required on an ongoing annual basis to maintain designated navigation depths, and comprises a major portion of Ports North's operational, maintenance, and environmental management responsibilities for the Port of Cairns. Numerical models have been developed, calibrated/validated, and used to support the environmental assessment of maintenance dredging activities at the Port of Cairns. The suite of numerical modelling tools comprises of:

- Digital Elevation Model covering the Port of Cairns, Trinity Inlet, Trinity Bay and the surrounding Great Barrier Reef Lagoon.
- TUFLOW FV 3D hydrodynamic model covering the Port of Cairns, Trinity Inlet, Trinity Bay and the surrounding Great Barrier Reef Lagoon.
- SWAN nested wave modelling system for coupling with the hydrodynamic and sediment transport model.
- TUFLOW FV 3D sediment transport model (coupled with the hydrodynamic and wave models).

The modelled hydrodynamics, waves, and sediment transport are influenced by various boundary condition inputs derived from targeted data recordings, regional models and global models which represent the following forcing:

- Wind;
- Tides;
- Ocean currents, salinity and temperature;
- Air temperature, radiation, precipitation and humidity; and
- Fluvial discharge.

Model Calibration and Validation

Model calibration and validation was undertaken utilising data recorded during instrument deployments in 2013 (for the Cairns Shipping Development Project) and maintenance dredge plume monitoring in 2011 (as a deliverable under the LTMP 2010-2020). The 2013 campaign involved the deployment of various fixed-location instruments for continuous recording of water levels, currents, waves, salinity, temperature, and turbidity. The 2011 campaign involved boat-based dredge plume measurements at both the dredging and Dredge Material Placement Area (DMPA). This data was used to inform key modelling assumptions regarding the maintenance dredging plume source rates.

Calibration of the hydrodynamic, wave, and sediment transport models was conducted for the simulation period from 1st March 2013 to 29th June 2013.

Hydrodynamic model calibration principally considered the ability of the model to predict both water levels and currents over multiple tidal cycles and a range of wind conditions. The following conclusions were made about the hydrodynamic model calibration performance:

- Water level predictive skill was generally very good across the calibration period, including both spring and neap tides.

- Current speeds and directions were generally well predicted by the numerical model, including both neap and spring tide periods and a range of wind speeds and directions.
- The influence of ocean circulation on the currents within the GBR lagoon were occasionally noticeable within the hydrodynamic model but was often less significant than tide and/or local wind forcing.

Wave model calibration principally considered the model ability to predict wave heights, periods, and directions. The following conclusions were made about the wave model calibration performance:

- Significant wave height and direction was generally well predicted over the calibration period.
- The wave model predicts periods of dominant sea and swell states at each location and this is reflected in comparisons with the peak wave period recordings. At times, the peak wave period is over-predicted and represents times when slightly too much offshore swell energy is propagated into Great Barrier Reef lagoon. This typically occurs during periods of low wind-driven wave energy with corresponding significant wave heights less than 0.5m. This is not expected to have any significant consequence on subsequent assessments.
- Comparison of recorded and predicted wave directional energy spectrum suggests the predicted directional spread of wave energy is somewhat narrower than recorded. Again, this is not expected to have any significant consequence on subsequent assessments.

The Sediment Transport model calibration principally considered the model ability to predict the ambient Total Suspended Solids (TSS) response to a range of tidal, wind and wave conditions. The following conclusions were made about the Sediment Transport model calibration performance:

- The response in the TSS signal due to wind-driven wave and current events is well represented in the model with respect to both magnitude and timing at the offshore location.
- The recorded TSS concentration at inner channel locations exhibits a clear tidal signal comprised of semi-diurnal and spring-neap variations. These are reasonably well captured by the model. At times, the model under predicts the TSS signal at the inshore locations, some of which can be attributed to the influence of biological sources of turbidity (e.g. algae and detritus) which are present in the data but not simulated by the model.
- Generally, given the significant complexities of modelling ambient sediment transport processes, TSS concentration prediction throughout the calibration period is considered adequate for assessing the impacts to water quality associated with the proposed dredging.

The ability of the modelling system to represent sediment plumes due to dredging activities was calibrated against data obtained from a targeted plume monitoring campaign undertaken during routine maintenance dredging activities in 2011. This exercise demonstrated the ability of the model to adequately represent dredge plume advection and dispersion following the application of appropriate dredge plume source terms to the model.

An independent model validation assessment was undertaken for the period from July to October 2013. The outcomes of the validation assessment generally confirmed the calibration phase conclusions about hydrodynamic, wave and sediment transport model performance.

Impact Assessments

The calibrated and validated numerical models were then applied to assess the potential impact of maintenance dredging activities by considering several scenarios related to the anticipated plume generation, dispersion, settling and re-suspension of dredge-related sediments. The modelling scenarios were developed in consultation with the Great Barrier Reef Marine Park Authority and accounted for:

- The likely typical and upper limit (maximum) dredging volume in any single year, including ‘continuous’ and ‘split’ dredging campaigns; and
- Inter-annual and seasonal variation in the environmental conditions.

The magnitude, extent, and duration of impacts were directly assessed by simultaneously simulating both the ambient and dredging related contributions to suspended sediment in the water column.

Potential increases to turbidity and sedimentation (deposition) rate due to future maintenance dredging activity was analysed statistically. The 50th and 95th percentile impacts considered nine (9) unique maintenance dredging simulations to derive an ‘ensemble’ impact result, which represents the highest increase to the 50th and 95th percentiles of the turbidity and deposition rate at each location in the model. This is considered representative of the so-called “worst case” impacts due to maintenance dredging activity.

Using the percentiles of turbidity results and environmental thresholds derived from local datasets, turbidity ‘zones of impact’ were developed for:

- The period of dredging and placement at the DMPA; and
- A 12-month period following dredging.

The zones of impact results indicate the following:

- Turbidity in the nearshore environment where channel dredging occurs is expected to remain within natural variability.
- There is a ‘zone of influence’ extending out from the channel dredging area along the coast to the north-west. The ‘zone of influence’ also extends east out to Cape Grafton. While this zone indicates the predicted extent of detectable plumes, the turbidity in this zone is predicted to remain within natural variability and therefore ecological impacts are not predicted to occur.
- For dredge material placement at the proposed DMPA, a ‘zone of influence’ is predicted to extend up to approximately 7 km north-west and south-east of the proposed DMPA. There is also a ‘zone of low to moderate impact’ predicted within the vicinity (up to approximately 1 km) of the proposed DMPA.
- In the 12-month period following dredging, resuspension of dredge material from the proposed DMPA is not predicted to result in any turbidity zones of impact. Approximately 94% of the placed material is predicted to remain within the DMPA.
- Areas of elevated sediment deposition rates are predicted to be confined to the channel and the DMPA, with some slightly elevated deposition rates predicted to the east of these areas. These areas do not coincide with coral reefs within the study area.
- While some areas of elevated sediment deposition rates are predicted to extend over some historical seagrass areas; however, are not expected to be impacted by the predicted deposition rates. This accords

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with long term seagrass monitoring which has not shown any measurable effects from deposition or smothering associated with maintenance dredging or placement.

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1 Introduction

1.1 Background

Ports North is preparing a Long-term Maintenance Dredging Management Plan (LMDMP) 2021-2031 which sets the framework for the ongoing responsible environmental management of maintenance dredging at the Port of Cairns. The purpose of the LMDMP is to document how Ports North will manage natural sediment accumulation within the navigable waters at the Port of Cairns, whilst ensuring the safe and efficient operation of the Port and the ongoing protection of local environmental values and the Outstanding Universal Value (OUV) of the Great Barrier Reef World Heritage Area (GBRWHa).

The LMDMP supports an application for the continued placement of dredge material within the Great Barrier Reef Marine Park and for sea dumping pursuant to the *Environment Protection (Sea Dumping) Act 1981*. It is designed to achieve the following objectives:

- Provide a transparent long-term framework for maintenance dredging and material placement at the Port of Cairns for years 2021-2031, whilst recognising the existing proactive and environmentally responsible management approach
- Maintain the safe navigation of the port
- Ensure that maintenance of navigable depths does not adversely impact upon local environmental values, including the Outstanding Universal Value of the GBRWHa
- Detail a robust long-term planning approach to managing port sediment within port infrastructure
- Outline operational, planning, consultation and monitoring arrangements
- Apply continual improvement practices in the management of sediment and dredging actions
- Provide a framework for maintenance dredging of the Port consistent with the Queensland Maintenance Dredging Strategy (Department of Transport and Main Roads).

The scope of the LMDMP relates specifically to the Port of Cairns and the maintenance of the swing basins, berths, marinas, entrance channel, and placement of dredged material at a proposed (new) dredge material placement area (DMPA) shown in Figure 1-1 and Figure 1-2.

Maintenance dredging is required on an ongoing annual basis to maintain designated navigation depths, and comprises a major portion of Ports North's operational, maintenance, and environmental management responsibilities. All maintenance dredging campaigns have been subject to detailed environmental planning and management, with further targeted monitoring undertaken in 2011 (to inform key modelling assumptions), 2015 (to capture DMPA plume extents), and 2019 (to quantify fine sediment released during dredging).

This report presents the development of numerical models, model calibration/validation and model inputs to support the environmental assessment of the proposed maintenance dredging activities for the purposes of obtaining ongoing approvals.

1.1.1 Cairns Shipping Development Project (CSDP)

The CSDP was completed in 2019 and included the following work relevant to future maintenance dredging requirements:

- Upgraded channel design included widening the existing channel to 130m and increasing the declared depth to -9.4mLAT. It also includes an extension of the existing channel for approximately 1km offshore. The channel was dredged to depths greater than the declared depth in some areas (up to a maximum of 1.7m) to allow for siltation between maintenance dredging campaigns.
- Expansion of the existing Crystal swing basin adjacent to Wharves 1-3 for specific use by cruise ships. Furthermore, a relocation of the existing main swing basin to a location further south close to Tropical Reef Shipyard was completed to provide future capacity for expansion of HMAS Cairns and to provide a wider and deeper inner channel for the full length of the Inner Port. The relocated main swing basin is referred to as the Smith's Creek swing basin.

This capital dredging program has slightly increased the amount of maintenance dredging required (in the order of approximately 6%) in comparison to previous approvals, and this has been considered as part of this modelling exercise.

An earlier version of the project involved placement of approximately 4 million tonnes of capital dredge material at the existing Dredge Material Placement Area. Data gathering and modelling undertaken for impact assessment purposes have also informed this report.

1.2 Objectives and Purpose

Key objectives of the numerical modelling include:

- (1) Development of a suite of numerical modelling tools capable of simulating the hydrodynamic, wave and sedimentation processes relevant to the study area.
- (2) Assessment of turbid plume dispersion associated with dredging and dredge material placement for consideration of potential environmental impacts to water quality, sensitive ecological receptors and the values of the Great Barrier Reef Marine Park.
- (3) Documentation of the modelling and findings.

1.3 Maintenance Dredging Activities for Assessment

A map showing the existing channel outline, existing and proposed DMPA is provided in Figure 1-1.

1.3.1 Dredging Equipment

Previous maintenance dredging within the Port of Cairns has been undertaken by two types of equipment:

- TSHD *Brisbane*: within the outer channel and swing basins
- Grab Dredge *Willunga*: inner port areas including wharves, marina, and navy basins.

In any single year, the bulk of the maintenance dredge volume (about 90%) is removed by TSHD *Brisbane* over an approximate four (4) week period. Smaller volumes (about 10%) are removed from

the inner port areas by Grab Dredge *Willunga*, with the plant operating for up to eight (8) weeks continuously in any single year.

Future annual dredge volume forecasts have been prepared by Ports North based on the historical requirements observed over the last 10-years and forecast maintenance requirements associated with the current (post-CSDP) channel, inner harbour, and berth configuration. Siltation modelling of the outer channel post-CSDP showed a possible volumetric increase of 6% per annum (BMT WBM, 2017). This has been considered when developing the total maintenance dredging volumes summarised in Table 6-1 and adopted for the modelling assessments.

Table 1-1 Total Maintenance Dredging Volumes adopted for Modelling Assessments

Maintenance Volume in any Single Year Adopted for Modelling	Wet Volume (cu.m)	Dry Volume (Tonnes)
TSHD <i>Brisbane</i> Annual Average Volume	885,000	307,000
TSHD <i>Brisbane</i> Maximum Volume	1,185,000	412,000
Grab Dredge <i>Willunga</i> , up to 8 weeks continuous dredging	25,000	20,000
Total Dredge Volume in a Typical Year	910,000	327,000
Total Dredge Volume in a Maximum Year	1,210,000	432,000

1.3.2 Offshore Placement

During the process of preparing the LMDMP, a new marine DMPA in the mid-shore region of Trinity Bay has been identified through a site selection process, immediately adjacent to the existing DMPA. Figure 1-1 shows the location of the disused DMPA, the existing approved DMPA (1990-2021), and the proposed new DMPA site (2022-2031).

A detail of the site is shown in Figure 1-2 with further information about the characteristics of the site listed in Table 1-2.

Table 1-2 Proposed New DMPA

Characteristic	Description
Coordinates/ Location	The coordinates at the centroid of the new DMPA are 374737.87 / 8144856.72. It is situated to the northeast of the existing DMPA, sharing a common boundary with the existing site to the south and with the boundary of port limits to the north.
Area	The diameter of the new DMPA is approximately 840m. The surface area of the new DMPA is 2.288 sq.km. This is 16% less than the current DMPA which has a 1 km diameter. Owing to the deeper water present at the new site, a 1 km diameter is not seen as being required and adopting this smaller area will marginally reduce temporary habitat disturbance as well as aid efforts required in even spreading of dredge material.
Depth	The depth of the new DMPA ranges from -15 m to -18 m LAT with an average depth of -16.5 m below LAT (slightly deeper than the existing DMPA).
Distance to Receptors	In terms of the distance of the new DMPA to notable features and sensitive receptors the following apply: <ul style="list-style-type: none"> • Buffer distance to Reef Islands and Inner Reef – 14.5 km

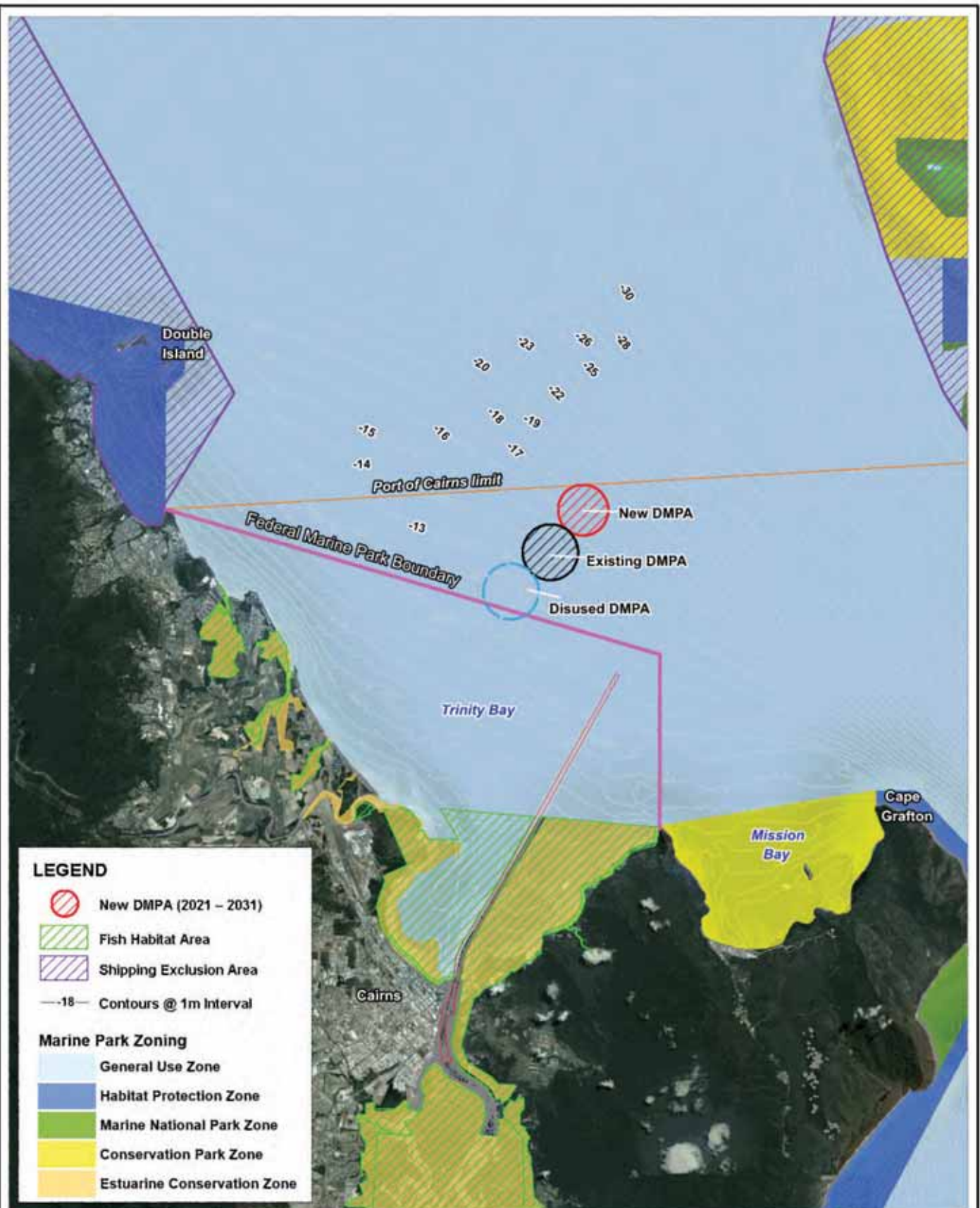
Characteristic	Description
	<ul style="list-style-type: none"> • Buffer distance to end of the maintained shipping channel – 4.7 km • Distance from the DMPA to the port terminal – 16.4 km • Distance from the DMPA to Crystal swing basin – 16.3 km • Distance from the DMPA to Smiths Creek swing basin – 17.9 km • Distance from the DMPA to Cape Grafton seagrass – 11.8 km • Distance from the DMPA to Double Island Reef – 14.1 km • Distance from the DMPA to Rocky Island Reef – 13.1 km

1.3.2.1 Observations at the Existing DMPA

Over the period since 2010, the extent to which material placed at the DMPA has been retained has been considered through review of repeated hydrographic surveys. The 2010 pre-dredge and 2020 post-dredge surveys are shown in Figure 1-3 and Figure 1-4). Across the DMPA and adjacent areas survey analysis suggests the following:

- Placement of material has been managed to achieve an overall ‘even’ placement process, including re-orientating of defined placement sectors (the sector rotation is illustrated in Figure 1-3 and Figure 1-4);
- The central and southern portion have seen the greatest elevation change, with the central portion of the site has shallowed by around 2.1 m; and
- Connectivity of the former DMPA to the southwest and the present site is evident and there has been a filling of the area between the two mounds.

An overall filling or dome shape has generally developed across the site as anticipated, with a change in elevation of 0.4m to 2.1m, indicating an average filling in the order of 1.2m. There is no evidence of any areas where substantial reductions in depth has occurred between surveys, indicating the general retention of material within the DMPA. Furthermore, no significant bed elevation changes to the areas outside the of the DMPA have been detected.



Title:
Study Area

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Approx. Scale



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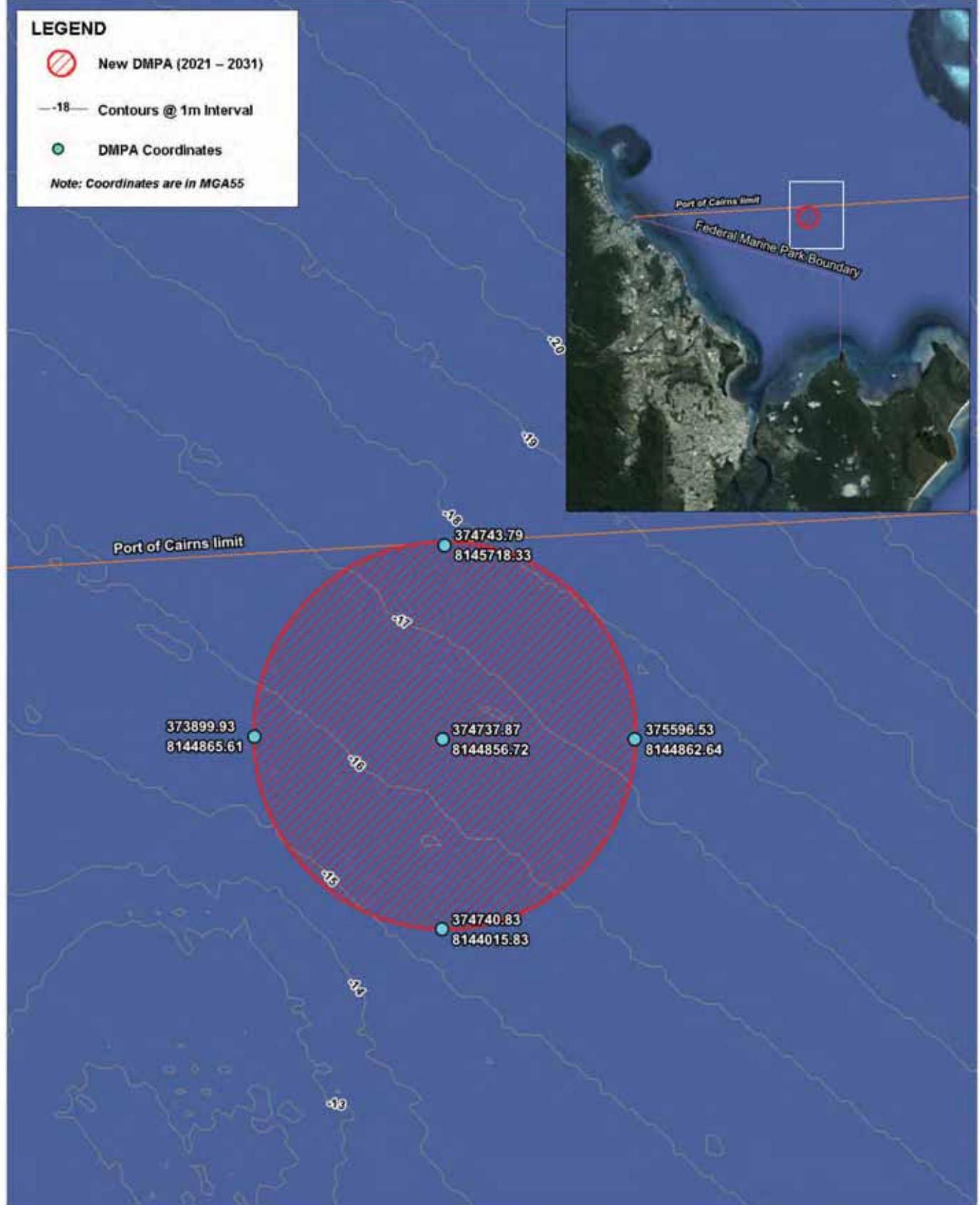
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 New DMPA (2021 – 2031)

—18— Contours @ 1m Interval

 DMPA Coordinates

Note: Coordinates are in MGA55



Title:

Details of the Proposed DMPA

Figure:

1-2

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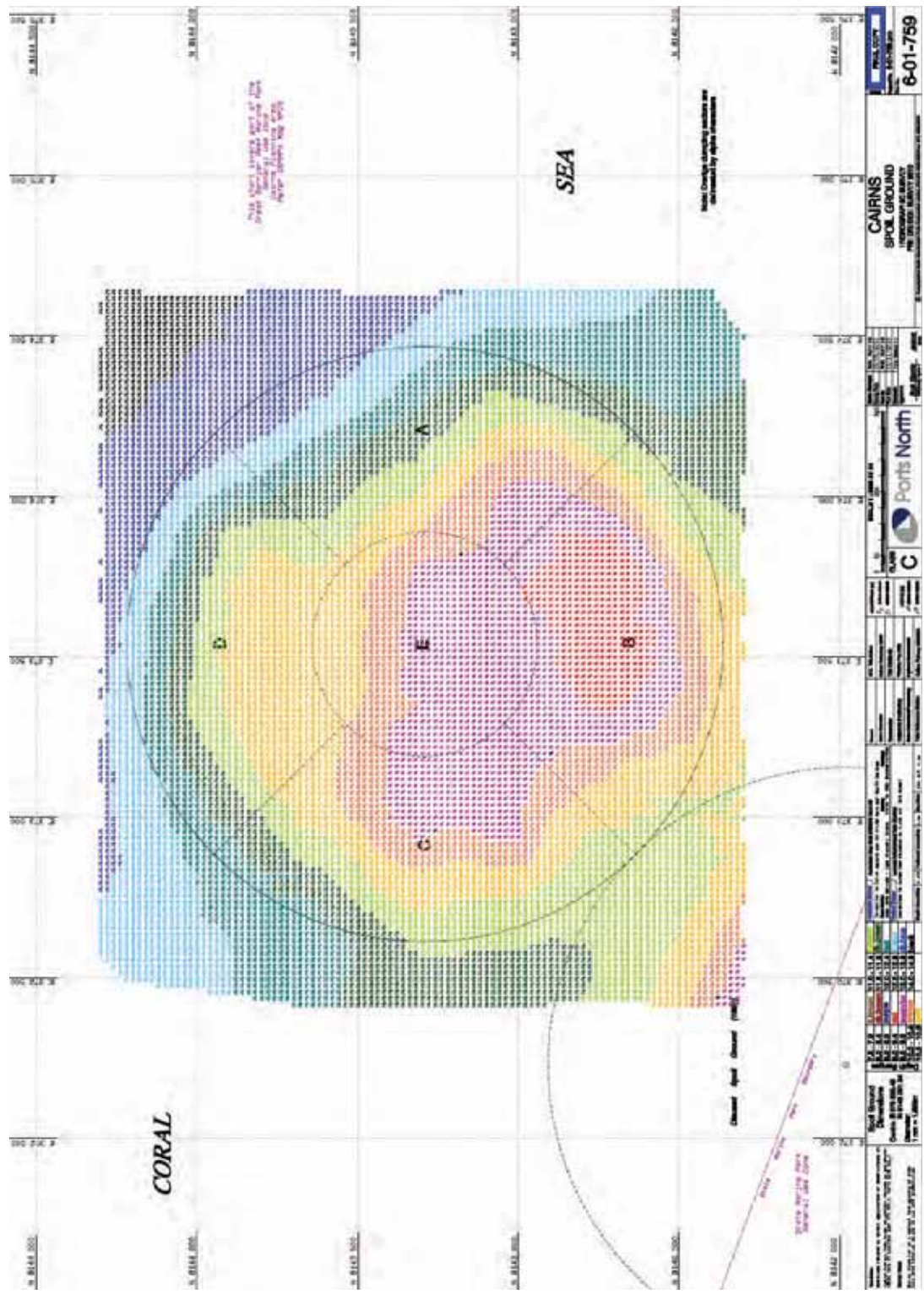
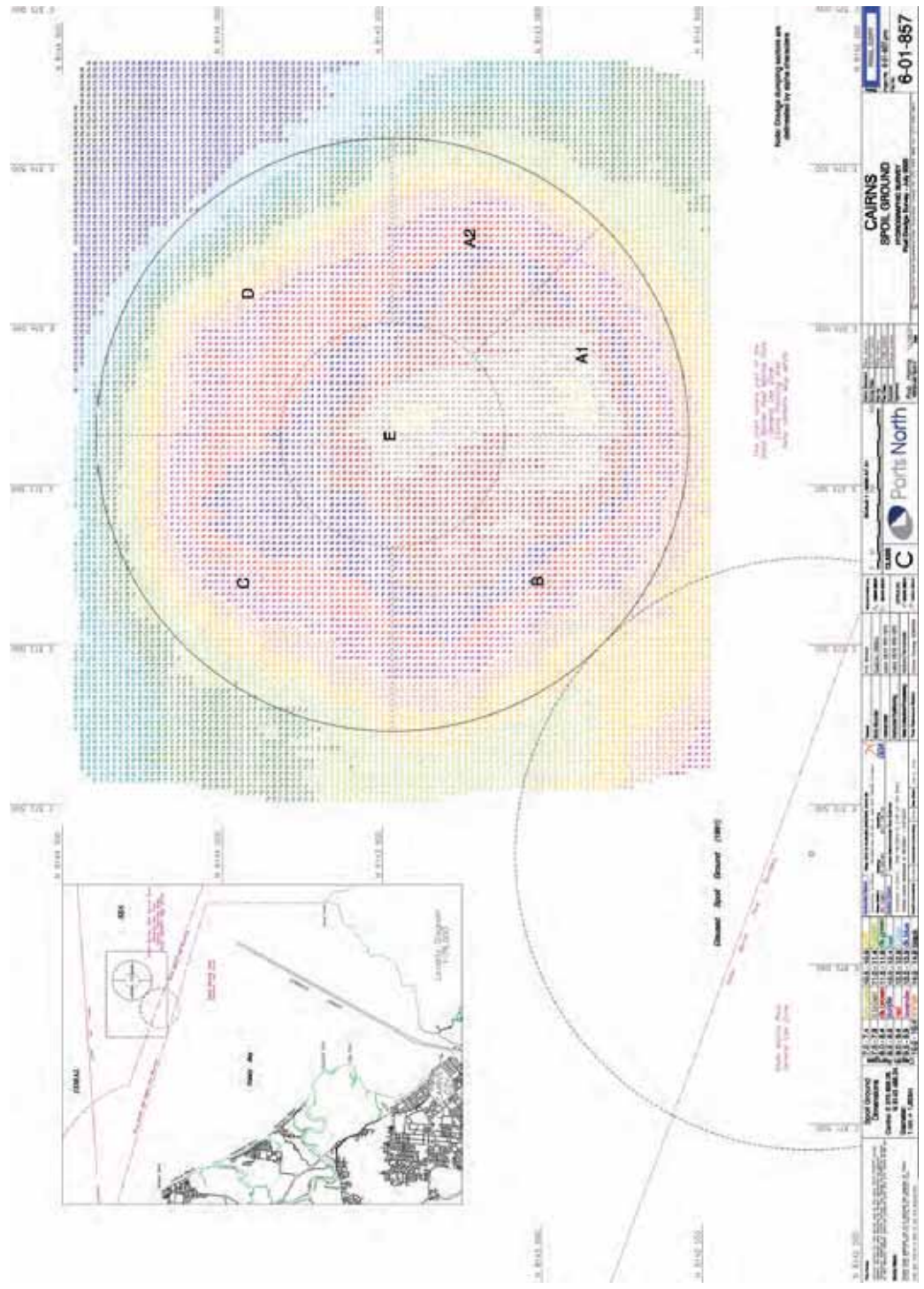


Figure 1-3 2010 Pre-Dredge Survey at the Existing DMPA





2 Numerical Model Descriptions

Multiple numerical model tools have been used to undertake the coastal hydrodynamic and sedimentation process assessments relevant to the LMDMP. These tools are introduced and described in this Section.

2.1 Hydrodynamic (TUFLOW FV)

The hydrodynamic modelling component of these assessments has been undertaken using the TUFLOW FV software, which is developed and distributed globally by BMT (<https://www.tuflow.com/products/tuflow-fv/>). TUFLOW FV is a numerical hydrodynamic model for the two-dimensional (2D) and three-dimensional (3D) Non-Linear Shallow Water Equations (NLSWE). The model is suitable for solving a wide range of hydrodynamic systems ranging in scale from open channels and floodplains, through estuaries to coasts and oceans.

The Finite-Volume (FV) numerical scheme employed by TUFLOW FV solves the NLSWE on either structured rectilinear grids or unstructured meshes comprised of triangular and/or quadrilateral elements. The flexible mesh allows for seamless boundary fitting along complex coastlines or open channels as well as accurately and efficiently representing complex bathymetries with a minimum number of computational elements. The flexible mesh capability is particularly efficient at resolving a range of scales in a single model without requiring multiple domain nesting. Further details regarding the numerical scheme employed by TUFLOW FV are provided in the TUFLOW FV Science Manual (BMT WBM, 2013).

2.1.1 Advection Dispersion Modelling

A system for modelling the natural re-suspension of sediment and the advection and dispersion of a sediment plume produced during maintenance dredging has been developed using the Sediment Transport (ST) module of TUFLOW FV coupled with the 3D hydrodynamic and spectral wave models.

To accurately capture advection and dispersion, the model requires input of dispersion coefficients and sediment characteristics. These inputs determine the resultant spread of fluid and suspended matter throughout the model domain. The choice of dispersion coefficients is discussed in Section 3.6.1.

The turbulence model (GOTM, refer Section 2.1.3.4) was coupled with the hydrodynamic model for the purposes of deriving vertical turbulent mixing parameters.

The ST module is described in Section 2.3.

2.1.2 Model Domain, Mesh and Bathymetry

The hydrodynamic model domain is shown in Figure 2-1 and extends from Innisfail in the south to beyond Cooktown and includes the Great Barrier Reef lagoon, offshore reefs, Trinity Inlet and the lower Barron River.

The model consists of 33,336 surface mesh cells with resolution varying from 5 km (2D cell side length) at the offshore boundary, increasing to 20 m in the vicinity of shipping channels and port infrastructure. Figure 2-2 shows detail of the model mesh in the vicinity of the Port of Cairns.

Numerical Model Descriptions

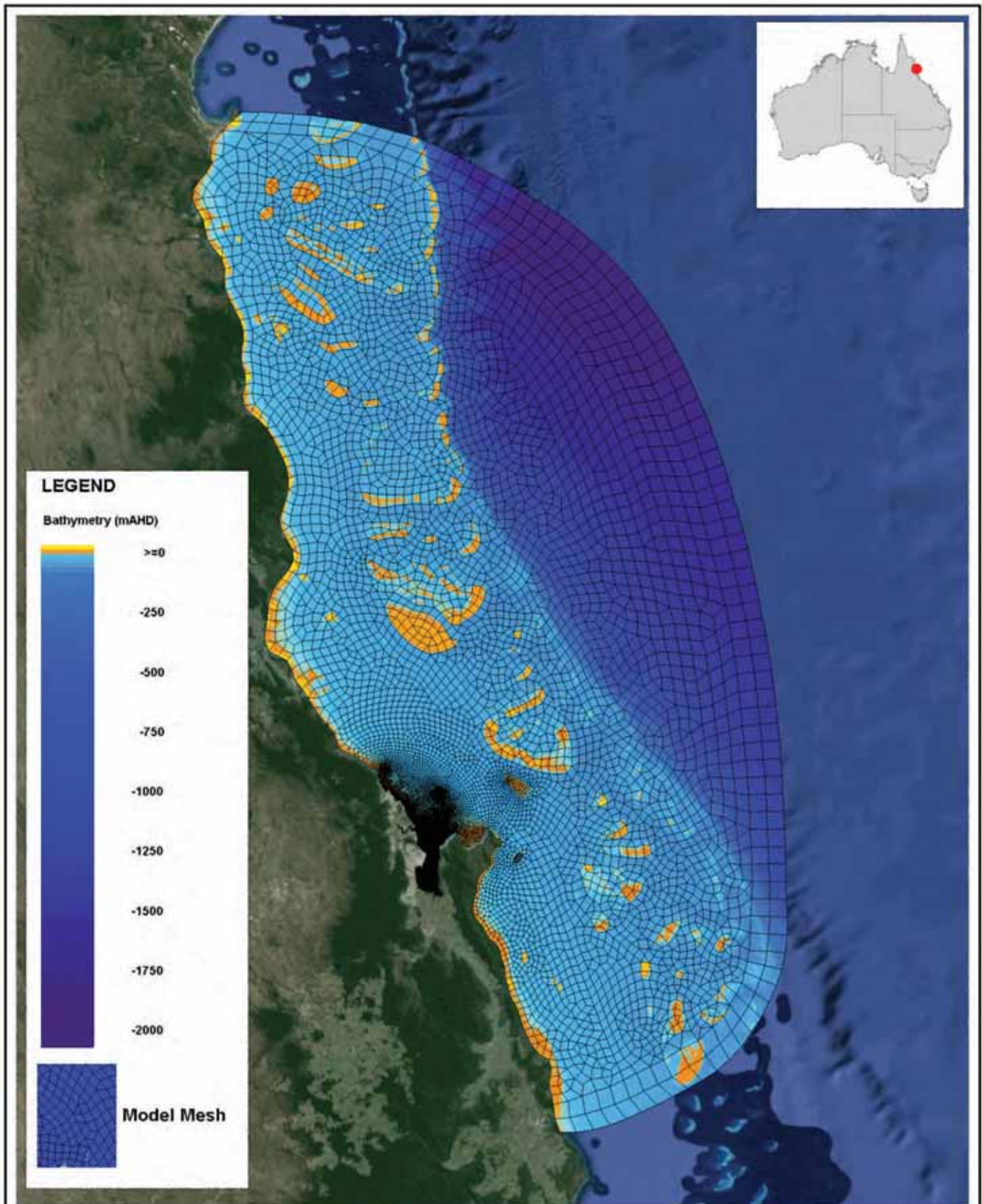
Figure 2-1 and Figure 2-2 also show the model bathymetry (note with different bathymetry elevation colour schemes) which has been derived from the following sources, listed in decreasing order of priority:

- Numerous hydrographic survey datasets of the Port of Cairns, shipping channel and DMPA provided by Ports North;
- Australian Hydrographic Service Navigation Chart AUS264 (Cairns Southern Sheet);
- Australian Hydrographic Service Navigation Chart AUS263 (Cairns Northern Sheet);
- Australian Hydrographic Service Navigation Chart AUS262 (Approaches to Cairns); and
- James Cook University Project 3DGBR (Beaman, 2010).

The hydrodynamic model adopts a hybrid sigma/z-coordinate vertical grid configuration, including:

- Three (3) surface “sigma” layers to represent the free surface to -2.5 mAHD;
- An additional six (6) fixed “z” layers between -2.5 mAHD and -10 mAHD; and
- Up to an additional 18 layers in areas where bed elevation is below -10 mAHD.

Near the channel and proposed DMPA, the vertical layers in the model varies between ~7 layers across the shallow flats adjacent to the channel and ~15 layers in deeper water surrounding the DMPA. The deepest sections of the coastal model domain (>2,000 m deep) are represented with 37 layers.



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TUFLOW FV Model Mesh & Bathymetry

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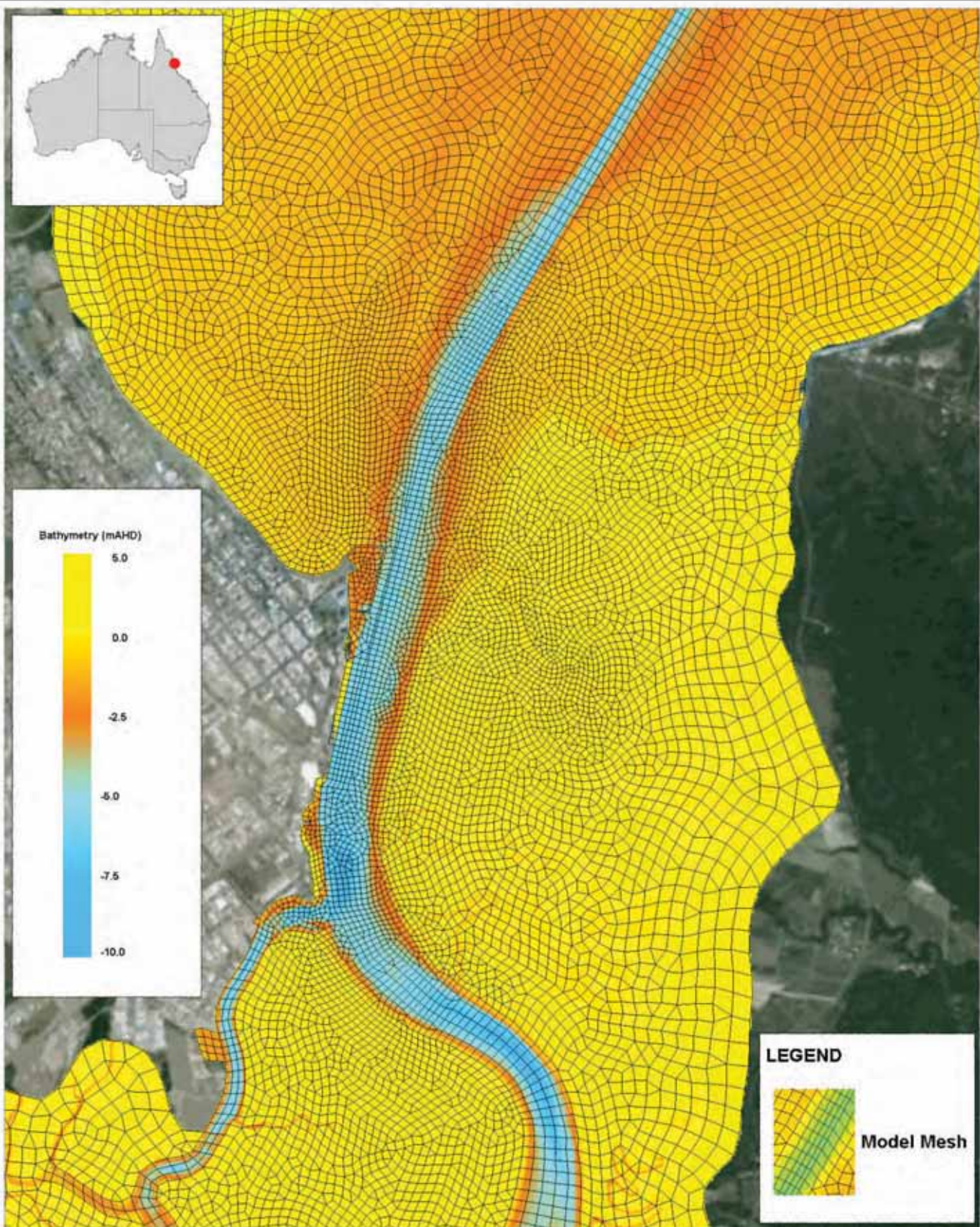
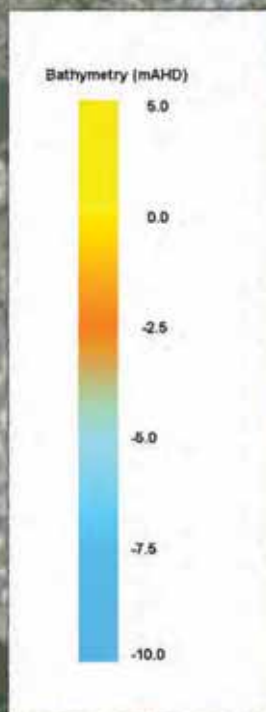
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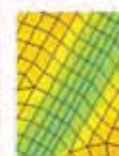
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Model Mesh

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TUFLOW FV Hydrodynamic Model Mesh Detail

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Numerical Model Descriptions

2.1.3 Boundary Conditions

The local hydrodynamics simulated by TUFLOW FV are influenced by boundary condition inputs. Information regarding appropriate boundary condition forcing for the study area was obtained from the following sources:

- Local data recordings;
- Output from a regional Coral Sea tide model developed by BMT; and
- Output from global models developed by third parties.

Details of the specific information sources used to develop boundary conditions applied to the hydrodynamic model is provided below.

2.1.3.1 Wetting and Drying

TUFLOW FV simulates the wetting and drying of intertidal areas. The minimum wetting and drying depths were set to 0.005 m and 0.1 m respectively. Numerically, the drying value corresponds to a minimum depth below which the mesh cell is dropped from computations (subject to the status of surrounding cells). The wet value corresponds to a minimum depth below which cell momentum is set to zero, in order to avoid unphysical velocities at very low depths.

2.1.3.2 Wind

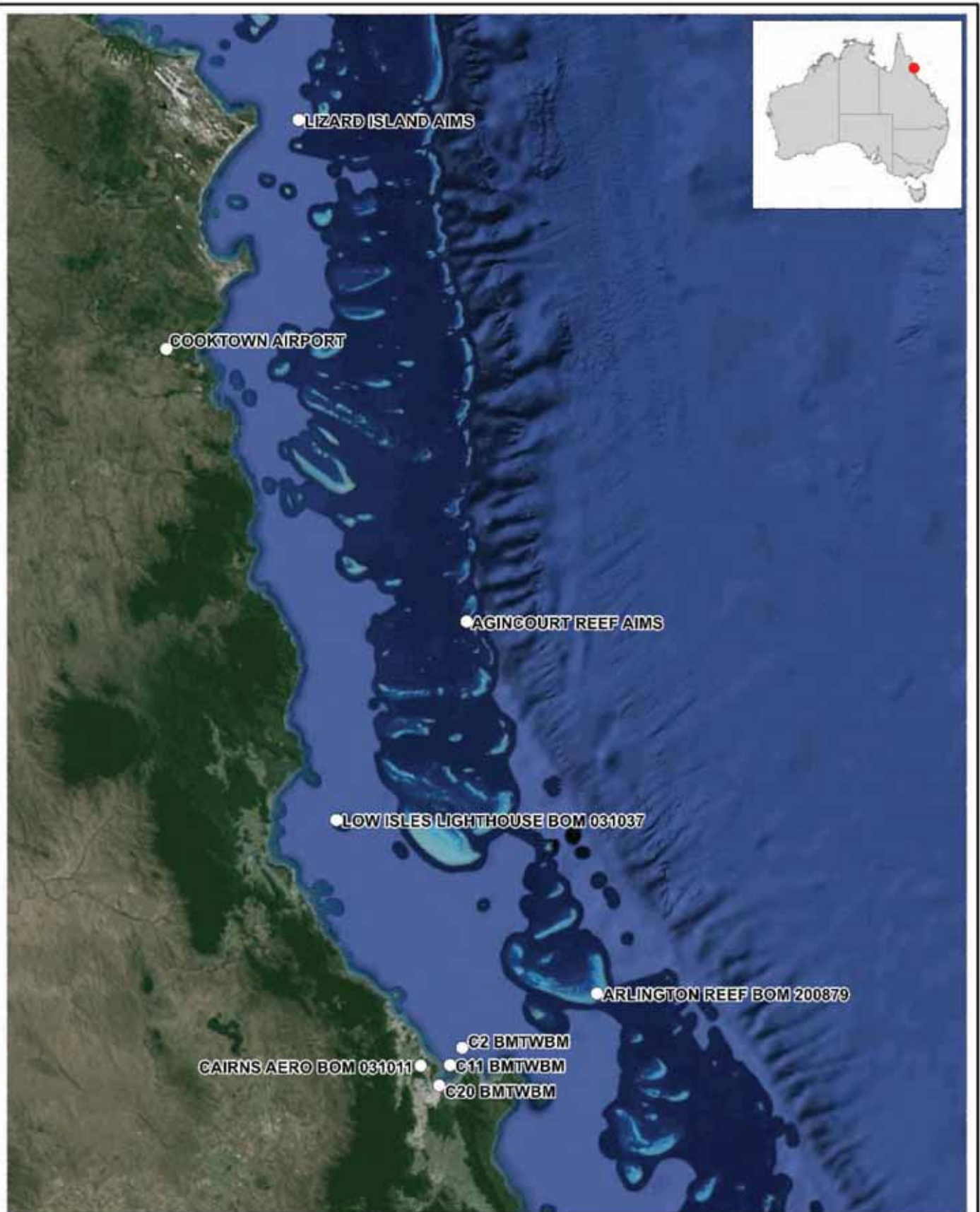
For the primary model calibration and validation periods, the wind boundary condition applied to both the hydrodynamic and wave model (refer Section 2.2) was derived from targeted measurements along the existing shipping channel commissioned by Ports North and historical wind records supplied by:

- Commonwealth Bureau of Meteorology (BOM); and
- Australian Institute of Marine Science (AIMS) (<http://www.aims.gov.au/docs/data/data.html>).

The locations of the various weather stations and their names are indicated in Figure 2-3. The wind data was converted to 10 m above mean sea level following the log-law conversion described in the Coastal Engineering Manual (U.S. Army Corps of Engineers, 2002). The processed weather station data was interpolated temporally and spatially on to a grid covering the model domain using scattered interpolation techniques. The constructed wind field methodology is illustrated in Figure 2-4. While this approach provides a very good representation of the wind field throughout the study area that is suitable for hydrodynamic and wave modelling purposes, it is noted that the precise details of the transition of winds over-land to over-sea are not captured.

For other modelling periods, a spatially and temporally varying wind field derived from the NOAA CFSR (<https://climatedataguide.ucar.edu/climate-data/climate-forecast-system-reanalysis-cfsr>) and CFSv2 global model datasets was adopted (Saha et al. 2010; 2014).

These global model datasets include assimilation with BOM observations from 1972 to present.



Title:
Weather Station Locations

Figure:
2-3

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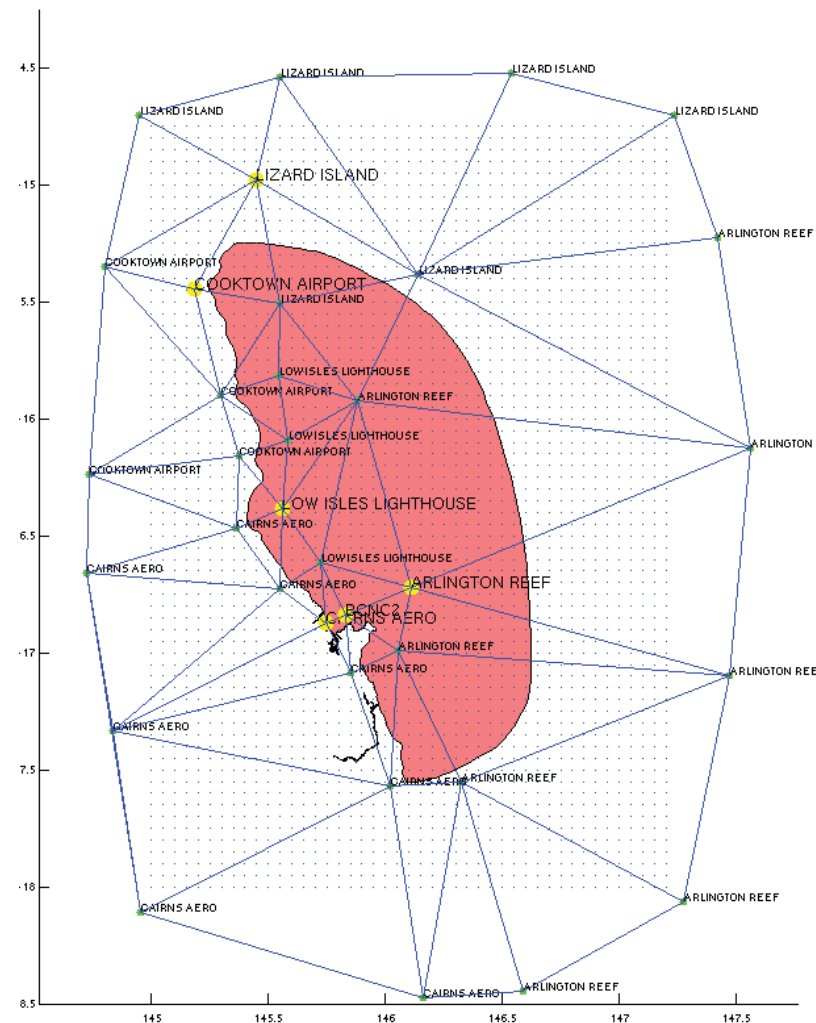


Figure 2-4 Illustration of Constructed Wind Field Methodology

2.1.3.3 Tide

The developed model extent included an open boundary that required temporal definition of water surface elevations. Due to the large extent of the model domain, tidal elevations vary spatially and temporally along the length of the offshore boundary. Tidal data along the offshore boundary was extracted from a calibrated tide model of the Coral Sea developed by BMT. The spatial extent of the Coral Sea model and the encompassed Cairns model are shown in Figure 2-5. The Coral Sea tide model boundary conditions were generated using tidal constituents supplied by the Bureau of Meteorology, National Tide Centre (NTC). The locations for NTC tidal constituent data are indicated by the yellow diamonds in Figure 2-5.

2.1.3.4 Regional Currents, Salinity and Temperature

The model calibration process suggested regional current forcing from the East Australian Current (EAC) influenced the study area at certain times. Furthermore, 3D temperature and salinity stratification effects are also expected to influence vertical velocity structures and hence overall

Numerical Model Descriptions

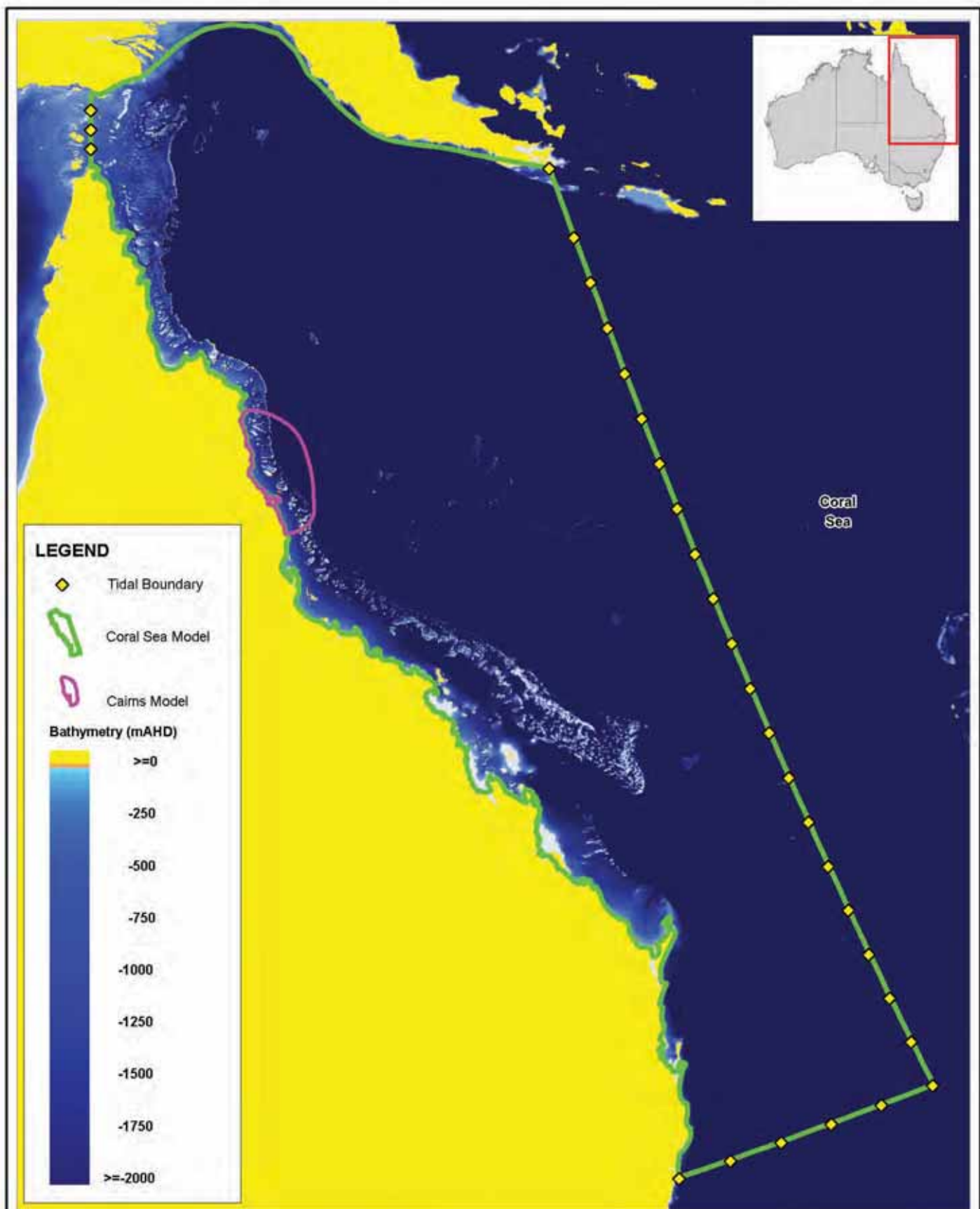
circulation throughout the study area. The model was therefore provided with regional current forcing (residual water level, current magnitude and direction), temperature and salinity profiles at the open boundary. These were derived from the ocean general circulation model, HYCOM (<http://hycom.org/>) and varied both in space (longitude, latitude and elevation) and time.

The General Ocean Turbulence Model (GOTM) was coupled with the 3D TUFLOW FV hydrodynamic model in order to simulate the vertical mixing processes in the presence of density stratification (<http://www.gotm.net/>).

The model was warmed up for a minimum period of 6 weeks prior to all calibration and impact assessments, in order to develop the internal salinity and temperature distributions contributing to density stratification.

2.1.3.5 Air Temperature, Radiation, Precipitation and Humidity

Atmospheric heat fluxes and water column heat dynamics were simulated internally within TUFLOW FV. Boundary condition data including air temperature, long and short-wave radiation, precipitation and relative humidity were derived from the CFSR (<https://climatedataguide.ucar.edu/climate-data/climate-forecast-system-reanalysis-cfsr>) global model. These model input fields were spatially uniform but varied in time in order to represent both seasonal and higher-frequency variations (e.g. diurnal).



Title:
TUFLOW FV Coral Sea Model Extent

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0 250 500km
Approx. Scale



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Numerical Model Descriptions

2.2 Waves (SWAN)

The wave modelling component of these assessments has been undertaken using the spectral wave model SWAN.

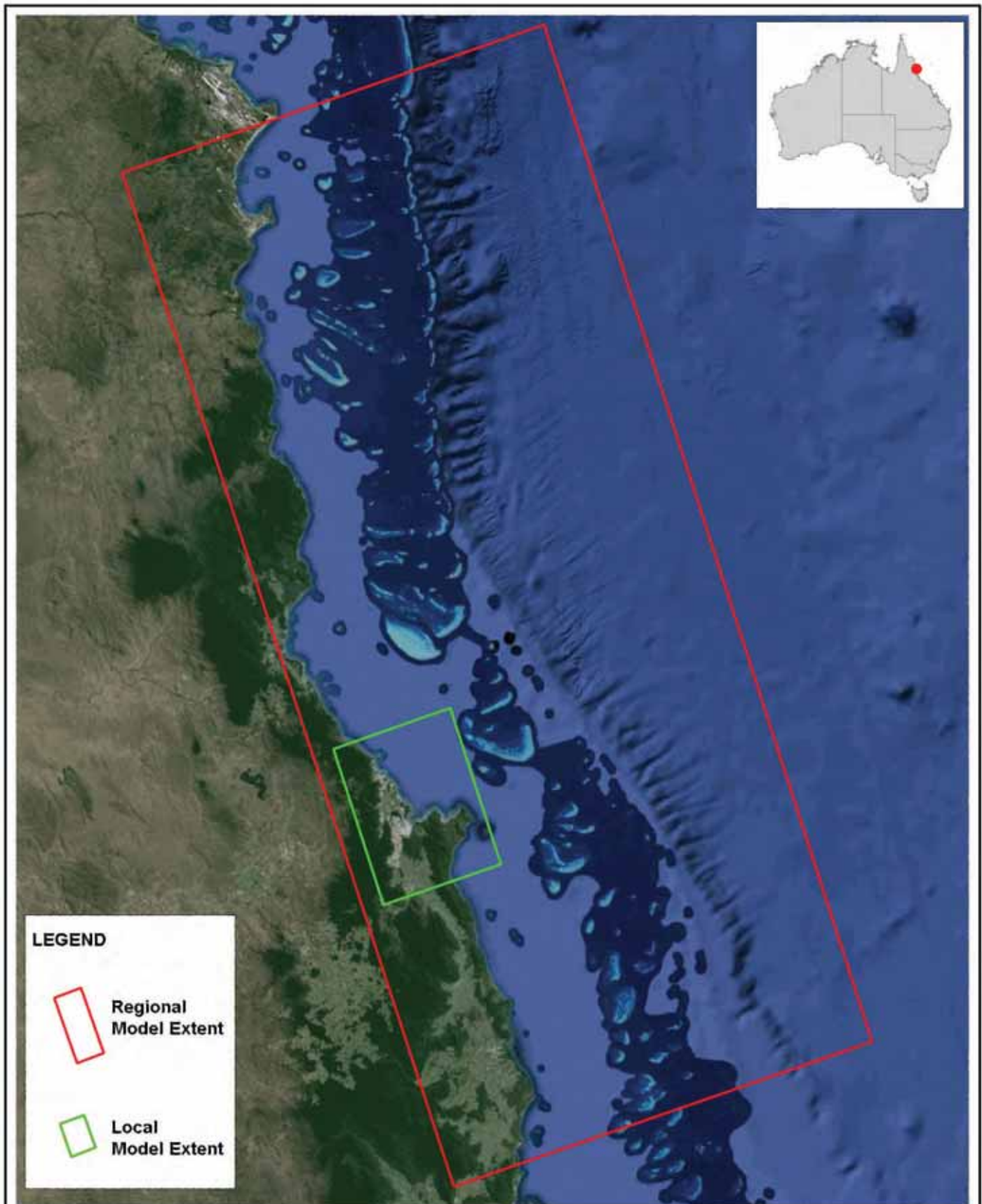
SWAN (Delft University of Technology, 2006) is a third-generation spectral wave model, which simulates the generation of waves by wind, dissipation by whitecapping, depth-induced wave breaking, bottom friction, and wave-wave interactions in both deep and shallow water. SWAN simulates wave/swell propagation in two-dimensions, including shoaling and refraction due to spatial variations in bathymetry and currents. This is a global industry standard modelling package that has been applied with reliable results to many investigations worldwide.

For sediment re-suspension and dispersion modelling the SWAN wave model was coupled with the 3D TUFLOW FV hydrodynamic and advection-dispersion models. This required the wave simulations to be completed separately, with the model output stored at hourly intervals on regular grids. During the subsequent sediment re-suspension and dispersion simulations, the wave conditions were linearly interpolated spatially from the grids to the TUFLOW FV mesh.

2.2.1 Model Domain and Bathymetry

A nested grid wave modelling approach has been adopted and is shown in Figure 2-6. The nested system comprises a regional (500 m grid resolution) model covering the Great Barrier Reef lagoon and extending beyond the continental shelf. Wave propagation and forces imposed on the seabed in the vicinity of the Port of Cairns have been assessed using a local sub-model (100 m grid resolution).

The wave model bathymetry has been derived from the same sources adopted for hydrodynamic modelling. The Digital Elevation Model (DEM) constructed from these combined sources is presented together with the hydrodynamic model mesh in Section 2.1.2.



Title:
SWAN Nested Wave Model Extents

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2-6

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Numerical Model Descriptions

2.2.2 Boundary Conditions

Wave parameters in coastal areas estimated by SWAN are determined from the model inputs specified by the user. Appropriately representing the swell and wind conditions relevant to the study area are key inputs. The boundary conditions developed for the wave assessments are described below.

2.2.2.1 Swell

Offshore swell conditions were derived from global Wavewatch III model output (<http://polar.ncep.noaa.gov/waves/>) and applied to the offshore boundary of the regional wave model. The swell conditions were specified as spatially uniform but variable in time wave parameters (significant wave height, peak period, peak direction).

2.2.2.2 Wind

The wind field applied to the TUFLOW FV hydrodynamic model and described in Section 2.1.3.2 was also applied to the wave models.

2.3 Sediment Transport (ST)

The resuspension, dispersion and settling of the natural bed sediments throughout the study area was estimated using the TUFLOW FV ST module coupled with the calibrated wave and hydrodynamic models. Various assessments also simulated the additional resuspension, dispersion and settling of sediment released into the water column and placed on the bed by proposed maintenance dredging activities.

The ST module allows for the simulation of multiple sediment fractions in suspension and within the bed. Ambient sediments have been represented by four (4) fractions ranging from cohesive clays and silts to non-cohesive sand fractions. Dredging related sediments have been represented by an additional four (4) fractions where applicable.

Bed shear stress is calculated in the ST model from the non-linear interaction of currents and waves using the procedure of Soulsby (1997). A Root-Mean-Square combined wave-current bed shear stress is used as the representative value in the sediment erosion and deposition calculations.

The modelled rate of sediment deposition, Q_d (g/m²/s), is a function of the near-bed sediment concentration (TSS), the still-water fall velocity, and the bed shear stress (τ_b), according to Equation 2-1. As such, sediment settling may be reduced below its still water value by the action of bed shear stress and associated mixing in the water column. Non-cohesive sediment fractions were modelled without a critical shear stress for deposition, meaning that they can always potentially settle regardless of the bed shear stress.

$$Q_d = w_s \cdot TSS \cdot \max \left(0, 1 - \frac{\tau_b}{\tau_{cd}} \right)$$

Equation 2-1

The rate of erosion, Q_e (g/m²/s), is calculated according to Equation 2-2. Erosion will occur in response to the combined wave-current driven bed shear stress (τ_b) when this exceeds a critical threshold (τ_{ce}).

Numerical Model Descriptions

$$Q_e = E \cdot \max \left(0, \frac{\tau_b}{\tau_{ce}} - 1 \right)$$

Equation 2-2

It is commonly considered that the behaviour of sand-mud mixtures with sand content >90% will be dominated by the sand processes, with the mud being released from or trapped within the sand interstices (e.g. Whitehouse et al., 2000). Sediments with >5-15% mud content will tend to become cohesive with behaviour dominated by the finer fraction (e.g. Mitchener & Torfs, 1996). Most surficial bed sediments within the study area comprise sand-mud mixtures (>50% mud content) where the erosion properties are dominated by the cohesive sediment fractions. For this reason, a common critical erosion threshold and rate-coefficient was applied across all cohesive and non-cohesive sediment fractions.

The ST model was extensively calibrated and validated using ambient suspended sediment measurements, as described in Sections 3.6 (calibration) and Section 5.5 (validation). Through the calibration process, ST model parameters were adjusted in order to provide the best agreement possible between model predictions and measurements. A critical component of the calibration process was the initialisation of bed material composition (i.e. the relative proportions of each sediment fraction at each computational node within the model domain). This was best achieved through running “bed warmup” simulations, which were undertaken prior to running the predictive assessments.

The General Ocean Turbulence Model (previously described in Section 3.4.1) was used to control the vertical mixing of sediment. A Smagorinsky model was used for the estimation of the horizontal sediment diffusivity.

2.4 GBRMPA Guidelines Cross-check

The following table provides a cross-check of the modelling approach with the GBRMPA hydrodynamic modelling guidelines (GBRMPA, 2012).

Numerical Model Descriptions

Table 2-1 GBRMPA Guidelines Cross-Check Summary

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
2, 5	3D Hydrodynamic Model	All modelling assessments undertaken using 3D TUFLOW FV HD Model.	2.1
5	3D Sediment Plume Modelling	All plume modelling assessments undertaken using 3D TUFLOW FV ST Model.	2.3
6	Tidal forcing	Model uses spatially varying tidal forcing.	2.1.3.3
6	Wind forcing	Spatially/temporally varying wind field.	2.1.3.2
6	Wave forcing	SWAN wave model coupled with HD and ST models.	2.2
6	Ocean Current Forcing	Model simulates ocean currents. Uses HYCOM forcing at open boundaries.	2.1.3.4
6	Stratification represented	GOTM turbulence model with salinity/temperature density coupling.	2.1.3.4
7	Hydrodynamic Calibration	HD model calibration undertaken. Independent validation undertaken.	3.4 5.3
7	Sediment Plume Calibration	ST model calibrated against long-term ambient turbidity datasets. Model validation performed against 2011 maintenance dredging monitoring data.	3.6 4 5.5
8	Wave-Current induced bed shear stress	Represented using Soulsby (1997).	2.3
8	Wave-induced mud fluidization	Wave induced resuspension mechanism included. Model calibrated/validated to suspended sediment measurements over multiple wave events.	3.6 4 5.5
10, 11, 12	Baseline Data	6-12 month baseline hydrodynamic datasets. 12 month baseline water quality dataset.	3.2 5.1
13a-c	Sediment Transport Modelling of multiple particle sizes	4 ambient sediment size fractions represented.	3.6.1 4
13d	Sediment size of material to be dredged	Additional 4 dredge sediment size fractions represented.	4
13e	Accurately represent ambient conditions	Model calibration/validation shows acceptable performance over a range of ambient conditions.	3 5

Numerical Model Descriptions

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
13e	Representative impact assessment periods.	Consideration of representativeness of impact assessment period in context of long-term climate.	3.3 5.2
13f	Represent dredging sediment sources	Likely sources based on monitoring and detailed model calibration.	4
13g	Duration of simulations	Dredging simulation includes the entire maintenance dredging campaign.	6.1
14c	Model horizontal resolution	Flexible mesh model (TUFLOW FV) with sufficiently high resolution in key areas of interest. Sufficiently large domain to consider long term and far-field fate of sediment.	2.1.2
14a-b	Model vertical scheme/resolution	Hybrid z-coordinate scheme with sigma surface layers. Up to 27 layers depending on depth.	2.1.2
15	Range of impact levels assessed	Range of physical impacts assessed in modelling report.	7
2, 3, 4, 16	Spatially based impact assessments	Model output used to derive spatial percentile contours of change to turbidity and sedimentation as a result of dredging activities. Spatial Zone of Influence also derived from model output.	7
16	Extent, severity & Duration of impacts assessed	A moving 30 day window analysis of the model output was used to derive the extent, severity and duration of turbidity impacts in the context of ambient turbidity statistics derived from baseline data.	7.1
9	Impact zoning scheme	Model outputs used to inform an impact zoning scheme, developed from the methodologies set out in the dredging environmental assessment guidelines produced by the Western Australia Environmental Protection Agency (WA EPA 2016).	7.4
16	"Best Case" and "Worst Case" Scenarios	Best Case (typical dredging in a single year) and Worst Case (maximum dredging in a single year) Scenarios assessed on both variable metocean conditions and dredging campaigns/	7
17	Impact thresholds	Impact thresholds derived from site specific baseline water quality data	7.1 (also refer LMDMP

Numerical Model Descriptions

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
		and biological criteria derived from literature.	main document
18	Sensitive receptors	Impact zones have been overlaid on sensitive habitat maps.	7.4
19	Map output	Impact zone maps can be made available to GBRMPA in a suitable GIS format.	On request
20	Mid-depth and near sea floor turbidity impacts assessed	Turbidity impact maps have been prepared for depth-average and near bed.	Appendix I
20	Sedimentation assessed	Sedimentation rate increases due to dredging and total sedimentation attributable to dredging have been derived.	7
20	Time series outputs	Time series outputs of turbidity at key locations.	Appendix J
21	Units consistency	Water Quality modelling assessments output in turbidity units (consistent with baseline datasets). Sedimentation assessments output in rate units of mg/cm ² /day.	NA
22	DMPA site justified	DMPA Options assessment undertaken and reported separately.	Refer LMDMP main documents
23	Independent peer review	Completed by The Australian Institute of Marine Science (AIMS). Following recommended amendments to the report, the modelling framework was confirmed to have sufficient skill required to support decision-making. Email confirmation from GBRMPA was sent to Ports North Monday, 26 July 2021 8:49AM.	NA

3 Model Calibration

3.1 Model Performance Metrics

Three metrics were adopted to guide model calibration, including:

- Index of Agreement (IOA),
- Mean Absolute Error (MAE), and
- Root Mean Square Error (RMSE).

The IOA was originally developed by Willmott (1981) and subsequently modified in Willmott *et al.* (1985):

$$IOA = 1 - \frac{\sum_{i=1}^N |O - P|^2}{\sum_{i=1}^N (|P - \bar{O}| + |O - \bar{O}|)^2}$$

where O is the observed data and P is the model predictions over a given time period divided into N increments. The overbar denotes the time averaged mean of the given variable. Following Willmott (1981) and Willmott *et al.* (1985), the IOA can vary from 0 to 1 with higher values indicating better model predictive skill. While there are no generic guidelines for the interpretation of the IOA, a value above 0.5 is generally considered to indicate satisfactory model performance.

The MAE and RMSE were adopted to quantify the model error in dimensional units and, as suggested by their names, provides a measure of model performance on an average sense, with RMSE showing bias to larger discrepancies. The MAE and RMSE are computed as follows:

$$MAE = N^{-1} \sum_{i=1}^N |O - P|$$

$$RMSE = \left(N^{-1} \sum_{i=1}^N (O - P)^2 \right)^{1/2}$$

In addition to the visual data-model comparisons for selected time windows presented throughout this section, model performance with respect to water level, current magnitude, current direction, significant wave height and peak energy wave period is presented in the context of these metrics.

3.2 Baseline Calibration Data

Extensive data collection to support the CSDP commenced in February 2013 and involved the deployment of various fixed-location instruments for continuous recording of water levels, currents, waves, salinity, temperature, and turbidity. In addition, atmospheric conditions (wind, temperature, relative humidity, light, rainfall, and barometric pressure) have been recorded at three locations along the shipping channel. This provided the primary datasets for model calibration and validation purposes.

Continuous data recording locations referred to throughout this report are indicated in Figure 3-2. The type of instruments deployed at each location varies and is summarised in Table 3-1 with a full description of the data collection campaign described in BMT WBM (2014). The following data types have been used for numerical model calibration and validation.

Water Level Data

The water level variation due to tidal and atmospheric forcing is derived from pressure sensors mounted on Seabird, Greenspan, or Acoustic Doppler Current Profiler (ADCP) instruments. The data has been reduced to datum using additional data from the Cairns Standard Port gauge.

Current Data

Current data has been obtained using fixed, bottom-mounted Nortek AWAC or Teledyne RD Instrument Sentinel Workhorse ADCP equipment. These instruments were configured to continuously record the vertical current profile (current magnitude and direction) in 0.5m bins throughout the water column. The recorded data has been depth-averaged over the entire water column and also over the top, middle, and bottom 33.3% of the water column for model calibration purposes. The current directions are in the nautical convention for currents: 0° is north and clockwise is positive with the bearing indicating the direction currents are heading.

Wave Data

The ADCP instruments deployed for the CSDP also record local wave conditions. The wave recordings have been processed to provide time series of Significant Wave Height (H_{sig}), Peak Wave Period (T_p) and Wave Direction. Additional wave data from the Cairns Wave Buoy operated by the Department of Environment and Science (DES) has also been used for wave model calibration. Wave directions are in the nautical convention for waves: 0° is north and clockwise is positive with the bearing indicating the direction waves are propagating from.

Total Suspended Solids (TSS) Data

Continuous measurements of near bed turbidity have been obtained using fixed, bottom-mounted YSI 6600 EDS Nephelometer instruments. The recorded turbidity levels in Nephelometric Turbidity Units (NTU) were converted into Total Suspended Sediment (TSS) concentrations using an NTU-TSS relationship based on 84 co-located *in-situ* turbidity measurements and water samples. The measurements and samples were collected as part of the CSDP baseline data collection (BMT WBM, 2014) and during a previous Cairns maintenance dredging monitoring campaign (BMT WBM, 2011). The ultimate dataset includes nearshore and offshore locations and both dredging and non-dredging periods. The derived NTU-TSS relationship specific to the study area is shown in Figure 3-1.

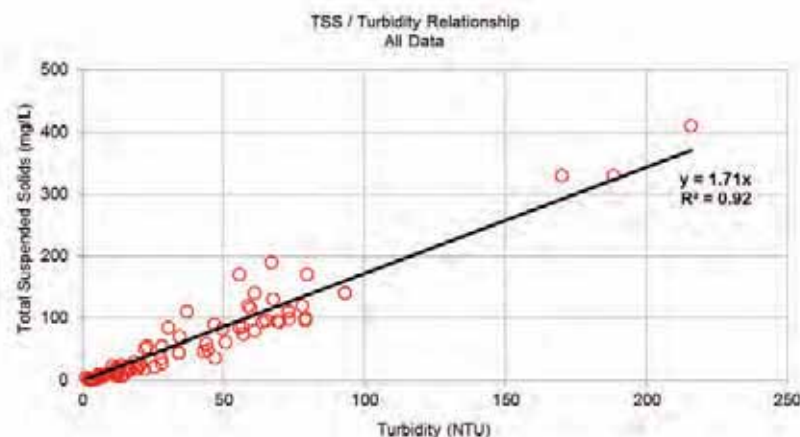
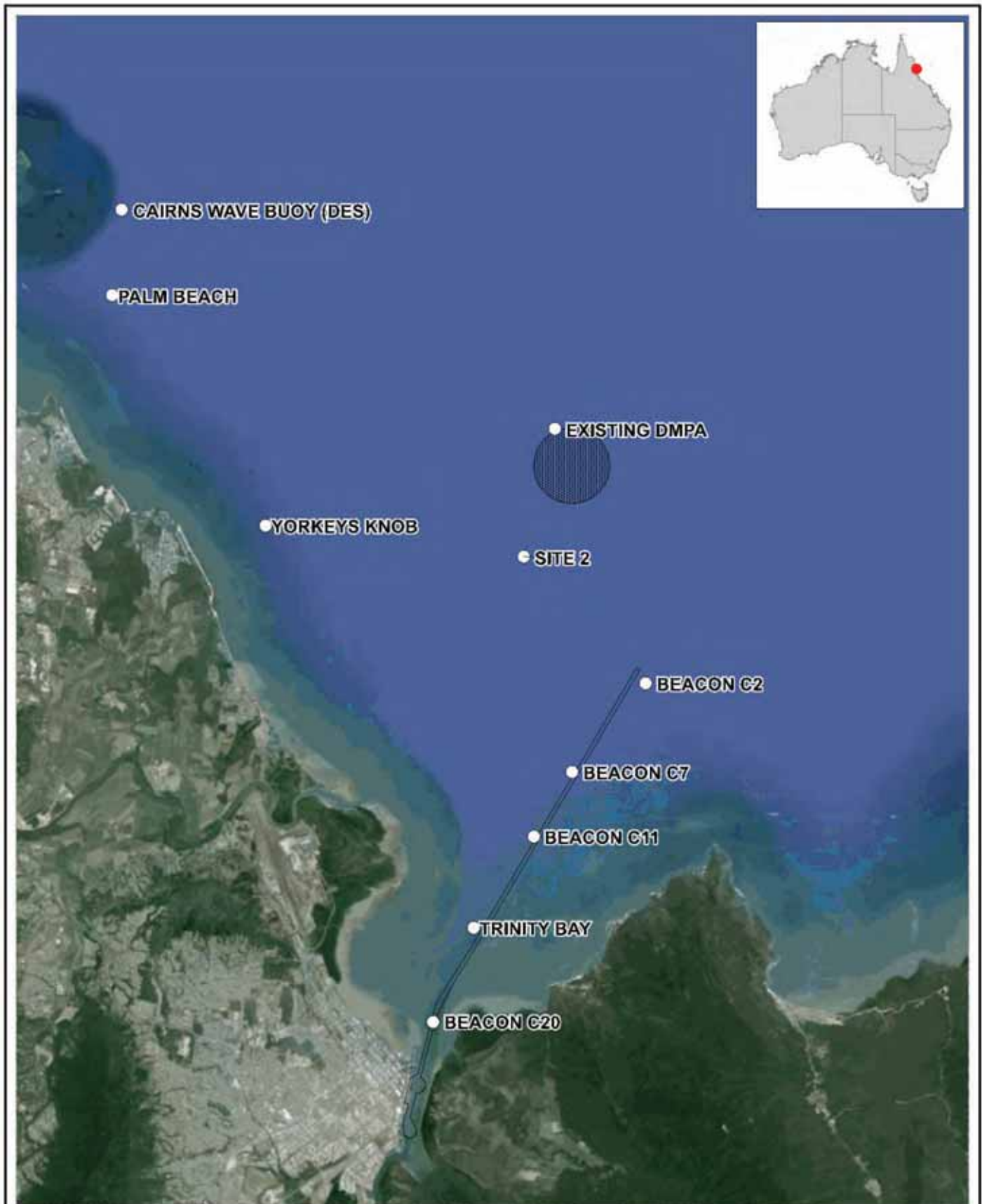


Figure 3-1 NTU-TSS Relationship Established for the Study Area



Title:
Data Recording Locations

Figure:
3-2

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Model Calibration

Table 3-1 Model Calibration Continuous Data Recording Locations and Instruments Summary

Location and Coordinates (decimal degrees)	Deployment Period	Mooring Type	Tide Recorder	ADCP	Nephelometer	CTD	Data Redundancy or Additional Data
Existing DMPA 145.8104, -16.7804	15/02/2013 – 15/04/2014	MSI Trawl resistant bed mounted frame	20m range Seabird Model SBE26 plus	600 kHz Nortek AWAC	YSI Model 6600 EDS water quality instrument fitted with turbidity sensor	Not required, though was collected using YSI Model 6600	Tide (depth), non- directional waves, water temperature, electrical conductivity, PAR (Photosynthetically Available Radiation)
Site 2 145.8040, -16.8089	15/02/2013 – 22/08/2013	MSI Trawl resistant bed mounted frame	NA	600 kHz Nortek AWAC	YSI Model 6600 EDS water quality instrument fitted with turbidity sensor	Not required, though was collected via YSI Model 6600	Tide (depth), water temperature, electrical conductivity.
Outer Channel Beacon C7 145.8162,-168561	20/02/2013 – 15/04/2014	Ocean Sciences Sea Spider bed mounted frame. CTD deployed from floating Sealite Model 600 marker buoy.	NA	600 kHz Nortek AWAC	YSI Model 6600 EDS water quality instrument fitted with turbidity sensor	Teldyne RD Instruments Citadel CTD deployed from floating buoy	Tide (depth), water temperature, conductivity
Outer Channel Beacon C11 145.8078, -16.8706	20/02/2013 – 24/08/2013	Ocean Sciences Sea Spider bed mounted frame. CTD deployed from floating Sealite Model 600 marker buoy.	NA	1200 kHz Teledyne RD Instruments Workhorse Sentinel	YSI Model 6600 EDS water quality instrument fitted with turbidity sensor	Teldyne RD Instruments Citadel CTD deployed from floating buoy	Tide (depth), water temperature, conductivity
Beacons C2, C11 and C20. 145.8316,-16.8335 145.8088,-16.8692 145.7869,-16.9106	15/02/2013 – 15/04/2014 ¹	Fixed to Beacons C2, C11 and C20	NA	NA	NA	NA	Envirodata Model Maestro Weather Station (wind, rain, relative humidity, atmospheric pressure, solar radiation)

¹ Approximate deployment period for weather stations

3.3 Calibration Period Characteristics

The study area experiences a tropical climate. The mean annual rainfall for the Cairns region is around 2000 mm/year, with most of the rainfall occurring during the north-west monsoon influenced “wet season” months from November to April. The “dry season” period typically occurs from May to October where the synoptic meteorological pattern is strongly influenced by the Coral Sea trade winds.

The model calibration simulation period was from February to June 2013 and therefore includes late wet season and early dry season months. The representativeness of this period relative to wind, rainfall, and wave climate long-term averages is discussed below.

3.3.1 Wind

Wind roses for the model calibration period and the long-term average of the calibration period months (i.e. February to June inclusive) are compared in Figure 3-3 (offshore location) and Figure 3-4 (Cairns Aero). Note that at the offshore location the simulation period wind rose is based on recorded data from Arlington Reef (consistent with the constructed wind field described in Section 2.1.3.2) while the long term average is based on recordings from nearby Green Island (approximately 15 km to the south west) where a longer data record was available. The simulation period wind characteristics are as follows:

- The offshore wind roses show the predominance of south to south-easterly trade winds. The offshore directional spread of winds for the simulation period appears consistent with the long-term average however the 10-minute wind speed exceeds 14m/s (approximately 27 knots) on slightly fewer occasions than average.
- There are significant orographic influences within the nearshore regions of the study area, and this is reflected in the Cairns Aero wind roses which are distinctly different to the more exposed locations within the GBR lagoon. The Cairns Aero wind directional spread is predominantly south-south-west to south-easterly. The roses also reveal a subtle land breeze/sea breeze cycle which occurs along the coastal margin of the study area. The Cairns Aero simulation period wind rose is considered consistent with the long-term average.

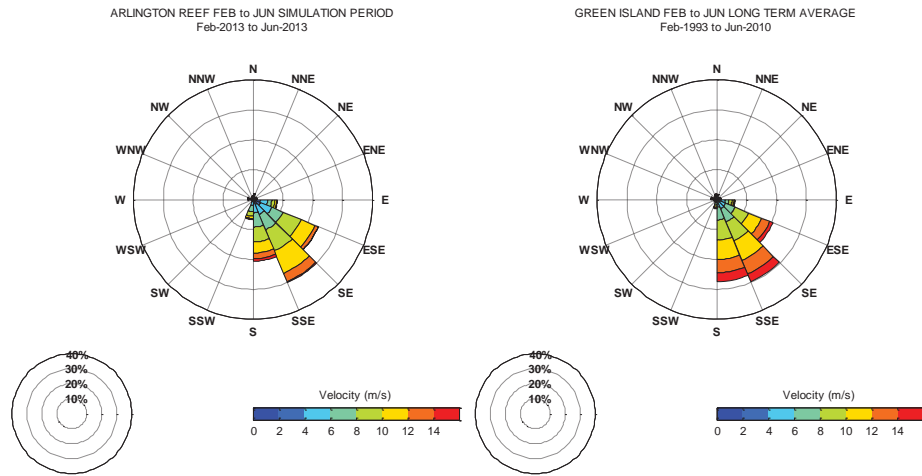


Figure 3-3 Offshore Wind Roses – February to June 2013 Simulation Period (left) and February to June Long Term Average (right)

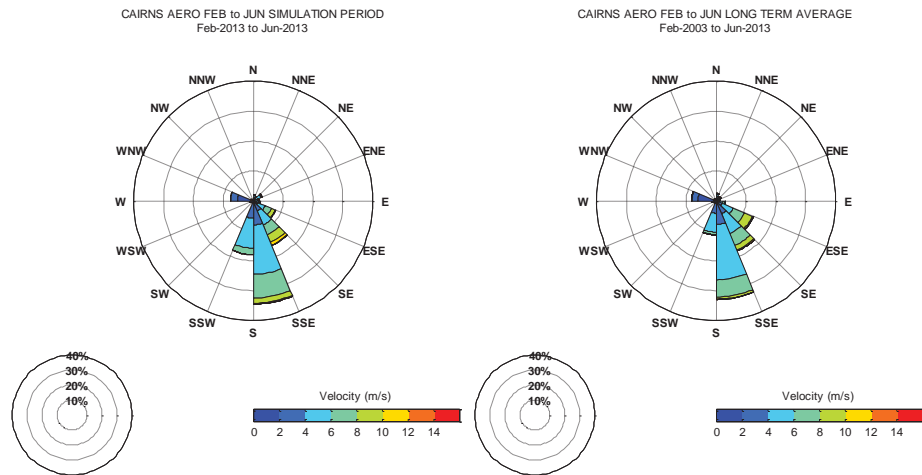


Figure 3-4 Cairns Aero Wind Rose – February to June 2013 Simulation Period (left) and February to June Long Term Average (right)

3.3.2 Waves

On a regional scale, the GBR partially shelters the North Queensland coastline from the deep ocean waves propagating westward from the Coral Sea. Gaps in the offshore reef network (such as Trinity Opening to the north-east of Cairns) allow some swell to penetrate to the GBR lagoon, albeit with significantly attenuated energy.

On a more local scale, Cape Grafton shelters Trinity Bay and Cairns beaches from the south-easterly sea waves generated within the GBR lagoon. Fetches within the GBR lagoon are generally limited to 30-50 km by the large mid shelf reef complexes. Non-cyclonic winds rarely exceed 13 m/s (approximately 25 knots) and locally generated sea wave heights recorded at the Cairns Waverider buoy are typically less than 1.4 m and have a 3-5 second period (BPA, 1984).

A simulation period wave rose at the Cairns Waverider buoy location is presented in Figure 3-5. The wave rose is based on model output since the Cairns buoy recordings are non-directional and therefore provide no information regarding wave direction. Considering the limited swell energy entering the study area and the good representativeness of the simulation period wind conditions (refer Section 3.3.1) it is likely based on the wind-climate assessment that the simulation period wave climate (dominated by locally generated wind waves) is likewise representative of prevailing conditions. The largest significant wave height at the Cairns buoy for the simulation period was approximately 1.4 m with a mean significant wave height close to 0.6 m. Additional recorded wave data from various locations throughout the study area is presented in Section 3.5.2.

A summary of maximum wave heights (H_{max}) recorded at the Cairns buoy is provided in Table 3-2. Historical peak wave conditions occur during the wet season months and are typically associated with tropical cyclone events.

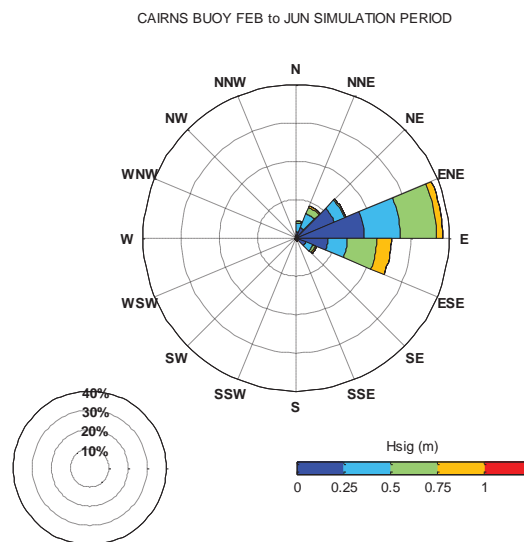


Figure 3-5 Cairns Buoy Wave Rose – February to June 2013 Simulation Period

Table 3-2 Top 10 Significant Wave Heights Recorded at the Cairns Buoy to 2019/20 (data provided by DES)

Rank	Date/Time	Maximum Wave Height, H_{max} (m)
1	12/04/2014 02:00	5.6
2	28/02/2000 01:00	5.0
3	23/01/2013 23:00	4.7
4	11/02/1999 22:00	4.6
5	23/12/1990 20:54	4.5
6	03/02/2011 04:30	4.1
7	12/01/2009 07:00	3.4
8	10/12/2018 02:30	3.4
9	03/01/1979 03:00	3.3
10	31/01/1977 09:00	3.3

3.4 Hydrodynamic Model Calibration

3.4.1 Hydrodynamic Model Parameterisation

The TUFLOW FV model calibration was undertaken in 3D baroclinic mode using a hybrid sigma/z-coordinate layer scheme. Between the model surface and -2.5 mAHD three sigma layers were applied and able to vary in vertical thickness depending on the tidally dominated changes in water surface elevation. Below -2.5 mAHD, a z-coordinate scheme was applied with vertical layer thicknesses of 1-2 m in shallow water (between depths of -2.5 mAHD and -25 mAHD) increasing in deeper offshore areas beyond the edge of the continental shelf. A maximum of 24 z-layers were resolved in the deeper sections of the model domain. This high degree of vertical resolution in the top ~25 m of the water column was necessary in order to simulate vertical stratification. This also allows for detailed representation of the vertical distribution of dredge plume suspended sediment.

Salinity and temperature were simulated within the model as density-coupled scalar constituents in order to incorporate baroclinic density gradient forcing and more importantly the effect of vertical density stratification on the water column turbulent mixing. The turbulence model (GOTM – www.gotm.net) was coupled with the hydrodynamic model for the purposes of deriving vertical turbulent mixing parameters.

The TUFLOW FV model configurations and parameterisations are summarised in Table 3-3, including the bottom roughness length scales for the four generic bed surfaces represented throughout the model domain. It is noted that variation of the bottom roughness length scale across the shallow, offshore reefs was the key focus of the model calibration process. The adopted model parameters are typically “default” values and/or within the range of accepted literature values. An example TUFLOW FV simulation control file is provided in Appendix A.

Table 3-3 Summary of TUFLOW FV Model Configuration and Parameterisations

Model Configuration Description	Model/Value
Momentum mixing model	Smagorinsky
Scalar mixing model	Smagorinsky
Bottom drag model	Derived from application of the “log-law”
Bottom roughness length scales:	
Deep water	0.05 m
Shallow reefs (less than 20m depth)	1.00 m
Reef passes	0.10 m
Mangroves and fringing reefs	0.50 m
GOTM turbulence model	2-equation k-omega with default parameters

3.4.2 Hydrodynamic Model Calibration Results

The hydrodynamic model calibration period was from 1 March 2013 to 29 June 2013. This period incorporated representative spring and neap tide conditions, a range of meteorological conditions and offshore EAC forcing. This enabled assessment of the model’s ability to adequately represent a range of conditions and its suitability for use in impact assessments.

In the following sections calibration plots at each continuous data recording location are presented, including:

- Water level and depth-average current time series (six-day period);
- Top, middle and bottom third of water column current velocity and direction (six-day period);
- Depth-average current polar plots (entire calibration period); and
- Near-bed water temperature time series (entire calibration period).

The presentation of time series data over a six-day period is provided to allow clear visualisation of the model/data comparison. The selected six-day period includes a significant south easterly wind event between 11/04/2013 and 14/04/2013 and the times series plots show the associated hydrodynamic response.

In addition to the above, Appendix B, Appendix C and Appendix D provide further model calibration results for the entire calibration period:

- Appendix B: top and bottom half of water column current velocity and direction time series (entire calibration period);
- Appendix C: top and bottom half of water column current polar plots (entire calibration period); and
- Appendix D: Current velocity Quantile-Quantile (Q-Q) plots (entire calibration period).

3.4.2.1 Site 1 Existing DMPA

Model calibration results at the Existing DMPA continuous data recording location show the following:

- Figure 3-6 (top plot) suggests variations in water level amplitude at the DMPA are accurately predicted by the model during both spring and neap tides. Tidal phasing is also appropriately represented however the model appears to slightly lag the recordings (in the order of minutes). This minor discrepancy is likely to be due to the limited set of tidal constituents used to force the regional-scale Coral Sea model (which provides tidal boundary conditions to the 3D model) and/or the complicated flow patterns and flow resistance between the networks of offshore reefs not being precisely represented by the model.
- The current speed at the DMPA is also predicted well by the model. The depth-average current velocity (Figure 3-6, middle plot) and current velocity layer (Figure 3-7) time series plots show an increase in current magnitude between 11/04/2013 and 13/04/2013. This period corresponds to a south-easterly wind event and the hydrodynamic response to this meteorological forcing is clearly reproduced by the model throughout the water column.
- The recorded data presented in Figure 3-7 show a slightly stratified water column with regard to current magnitude. This generally behaviour is well predicted by the model.
- Figure 3-6 (bottom plot) and Figure 3-8 suggest current direction is predicted well by the model. Figure 3-8 also shows a relatively uniform current direction throughout the water column for the period shown.
- Predicted and recorded distributions of depth-average current magnitude and direction at the DMPA are presented as polar plots in Figure 3-9. The polar plots are based on the entire calibration period and show good overall consistency. These plots also identify a current residual at the DMPA to the northwest for the calibration period.

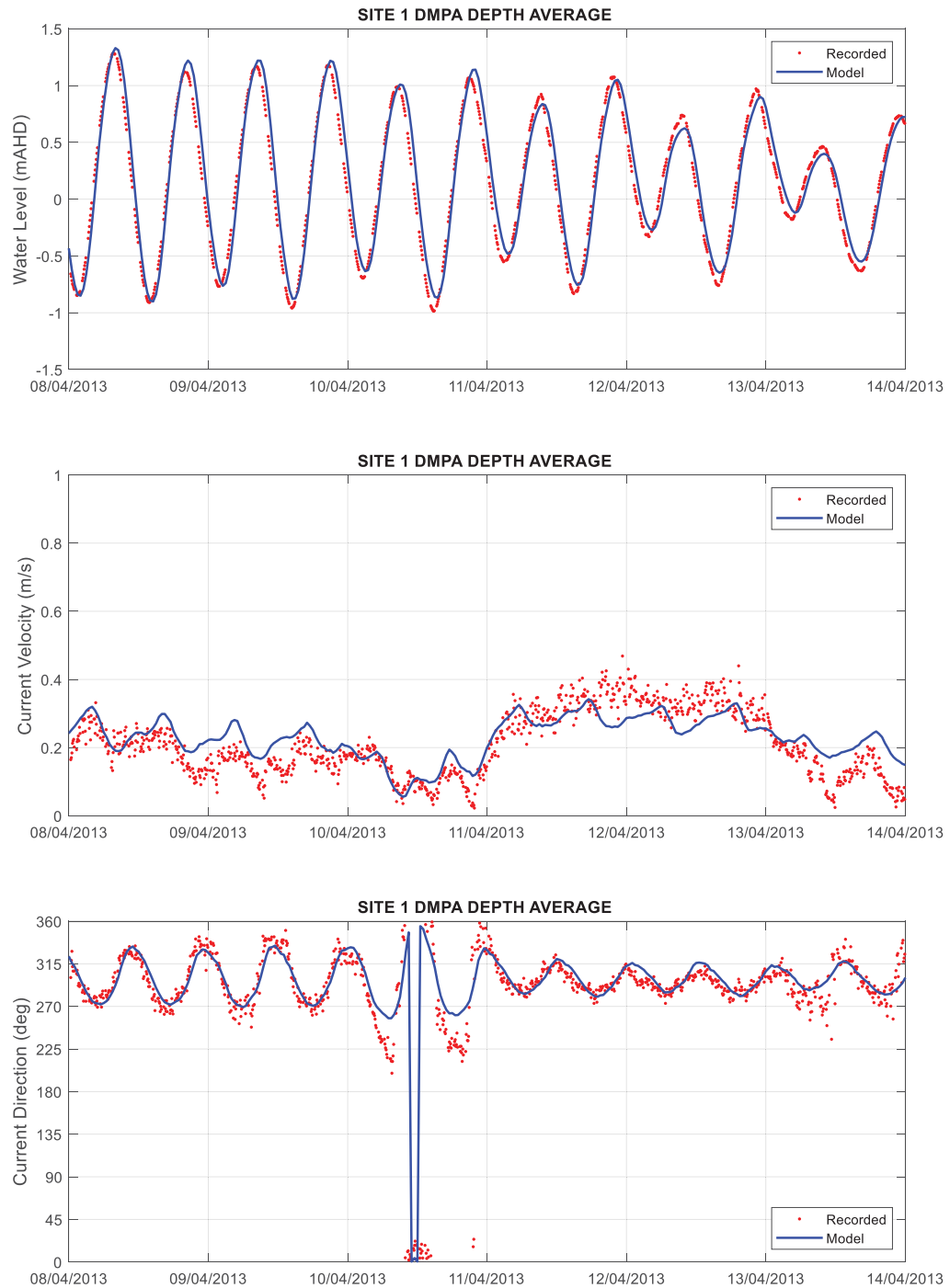


Figure 3-6 Hydrodynamic Model Calibration 3D Depth Average – Site 1 DMPA

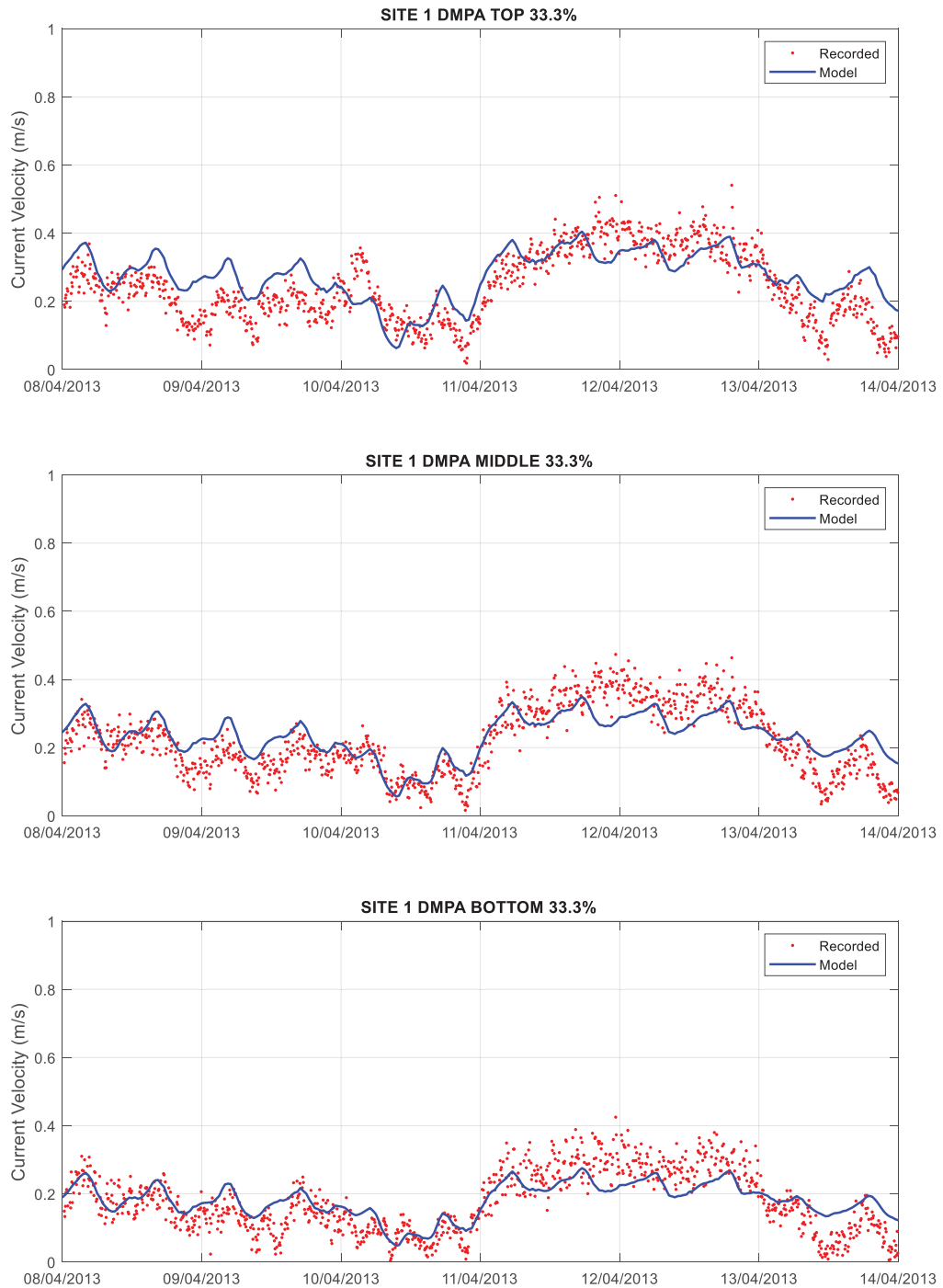


Figure 3-7 Hydrodynamic Model Calibration Current Velocity Layers – Site 1 DMPA

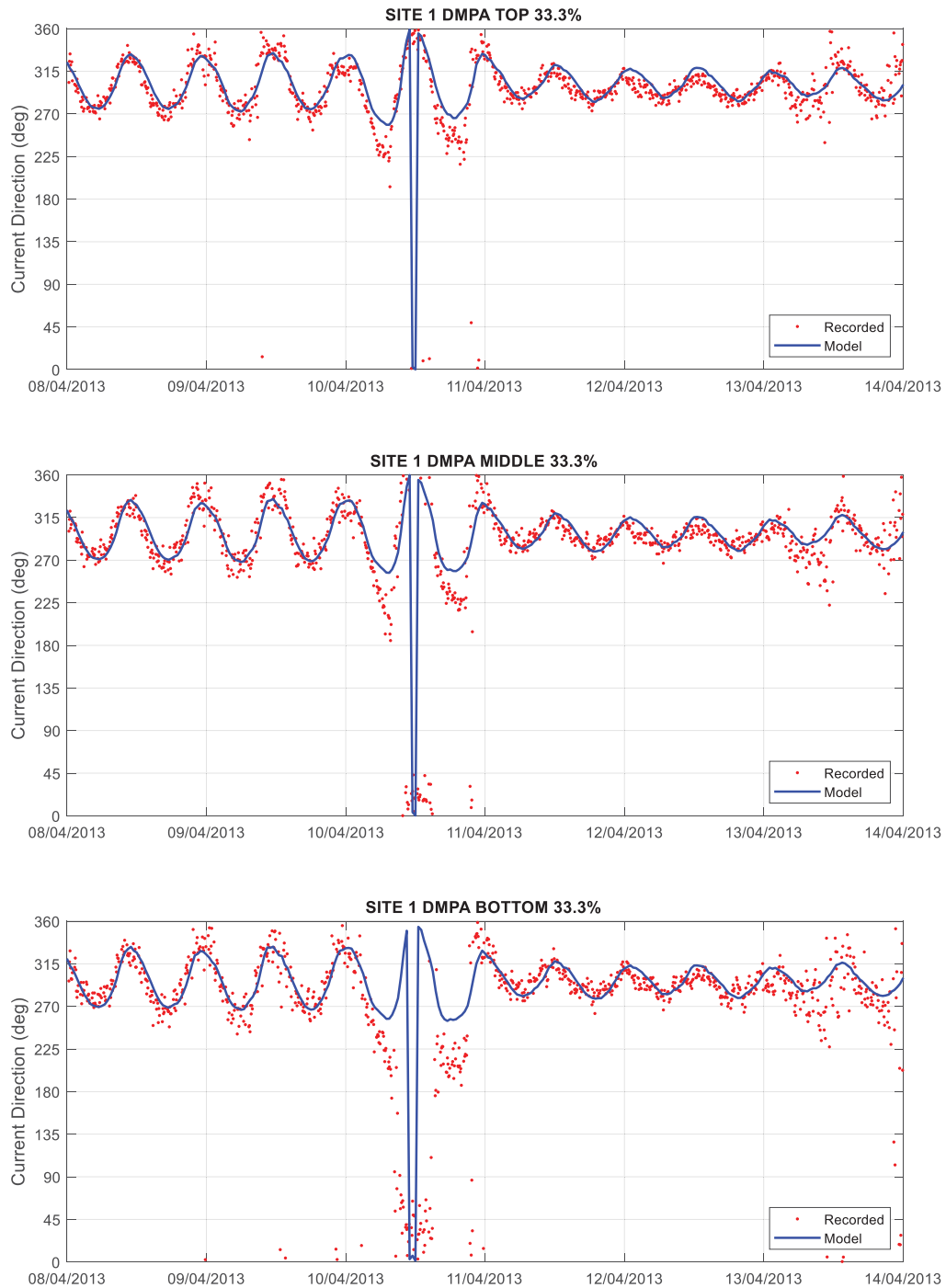


Figure 3-8 Hydrodynamic Model Calibration Current Direction Layers – Site 1 DMPA

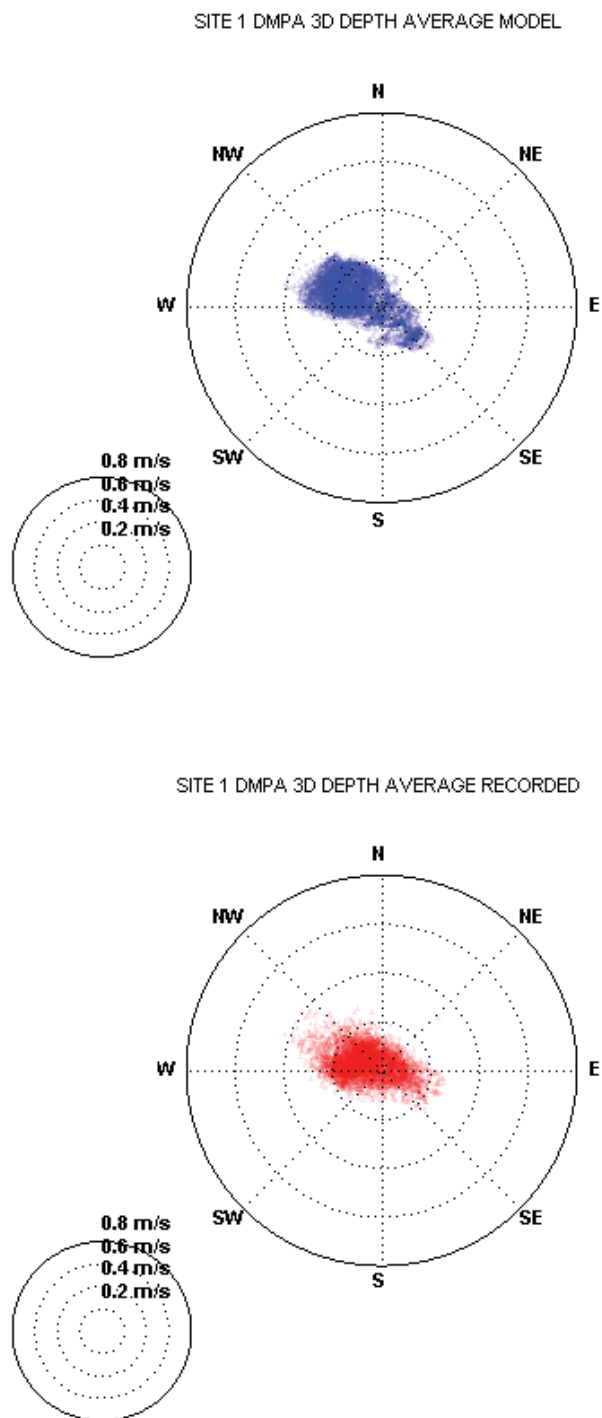


Figure 3-9 Current Polar Plot Validation – Site 1 DMPA

3.4.2.2 Site 2

Model calibration results at the Site 2 continuous data recording location show the following:

- Figure 3-10 (top plot) suggests variations in water level amplitude at Site 2 are accurately predicted by the model during both spring and neap tides. Similar to the DMPA site, the model appears to slightly lag the recordings (in the order of minutes) with regarding to phasing.
- An increase in current magnitude between 11/04/2013 and 13/04/2013 associated with south easterly winds was also recorded at Site 2 and is generally reproduced by the model. The depth-average current velocity (Figure 3-10, middle plot) and current velocities throughout the water column (Figure 3-11) during the wind event are slightly smaller in magnitude compared to the recordings. Furthermore, Figure 3-11 suggests slightly greater current magnitude stratification is predicted.
- Figure 3-10 (bottom plot) and Figure 3-12 suggest current direction is generally predicted well by the model. During the final day of the period shown, Figure 3-12 suggests some inconsistency between the recorded and predicted current direction. This corresponds to a neap tide period and therefore a time when tidal forcing is low and meteorological forcing dominates the hydrodynamic conditions. The inaccurate current direction prediction is most likely due to inaccuracies with the constructed wind field in the vicinity of Site 2.
- Predicted and recorded distributions of depth-average current magnitude and direction at Site 2 are presented as polar plots in Figure 3-13. Despite the short periods of current direction discrepancy described above, the model and recordings show good overall consistency in current distribution over the entire calibration period. Like the DMPA location, Site 2 shows a current residual towards the northwest.

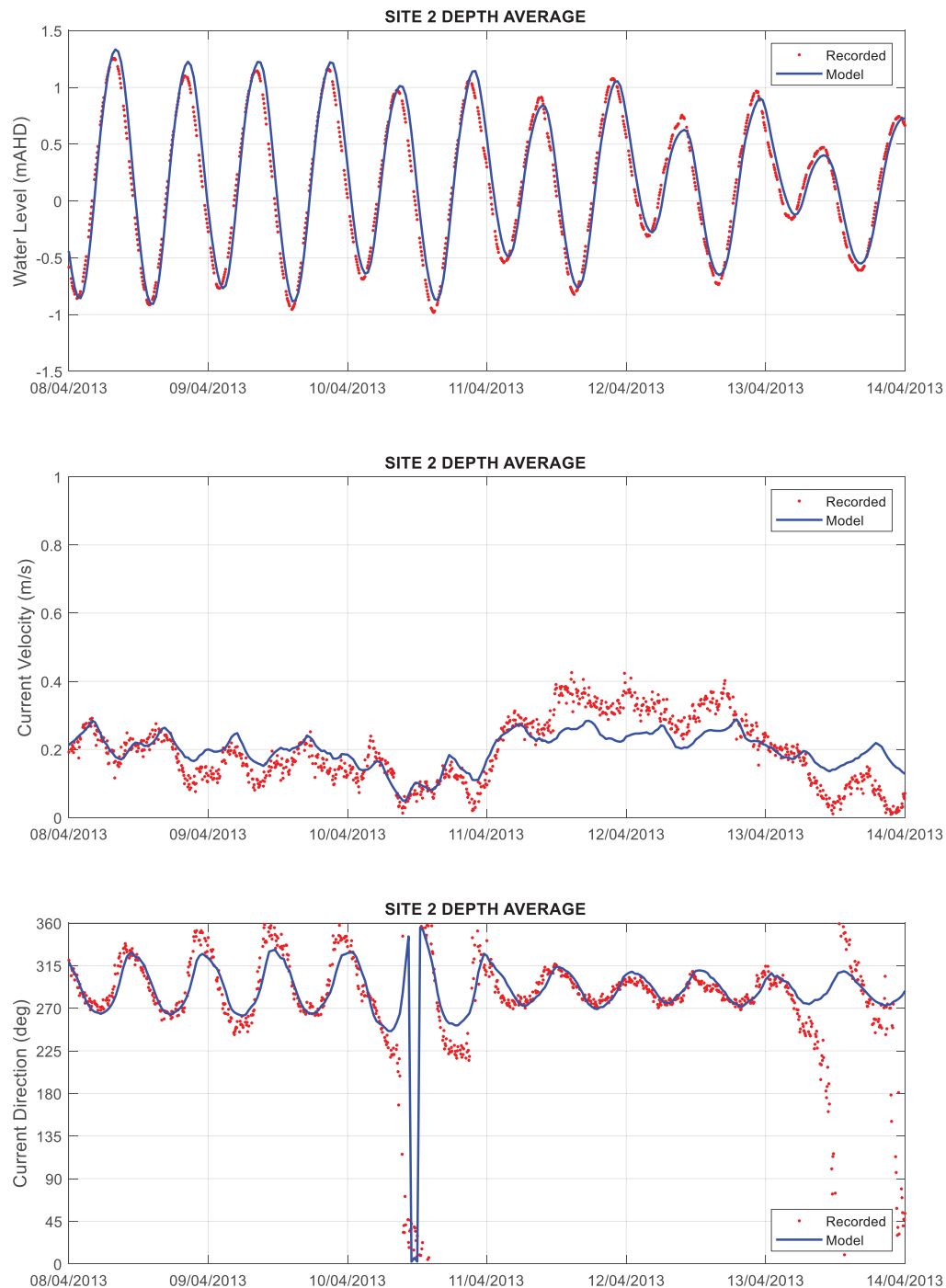


Figure 3-10 Hydrodynamic Model Calibration 3D Depth Average – Site 2

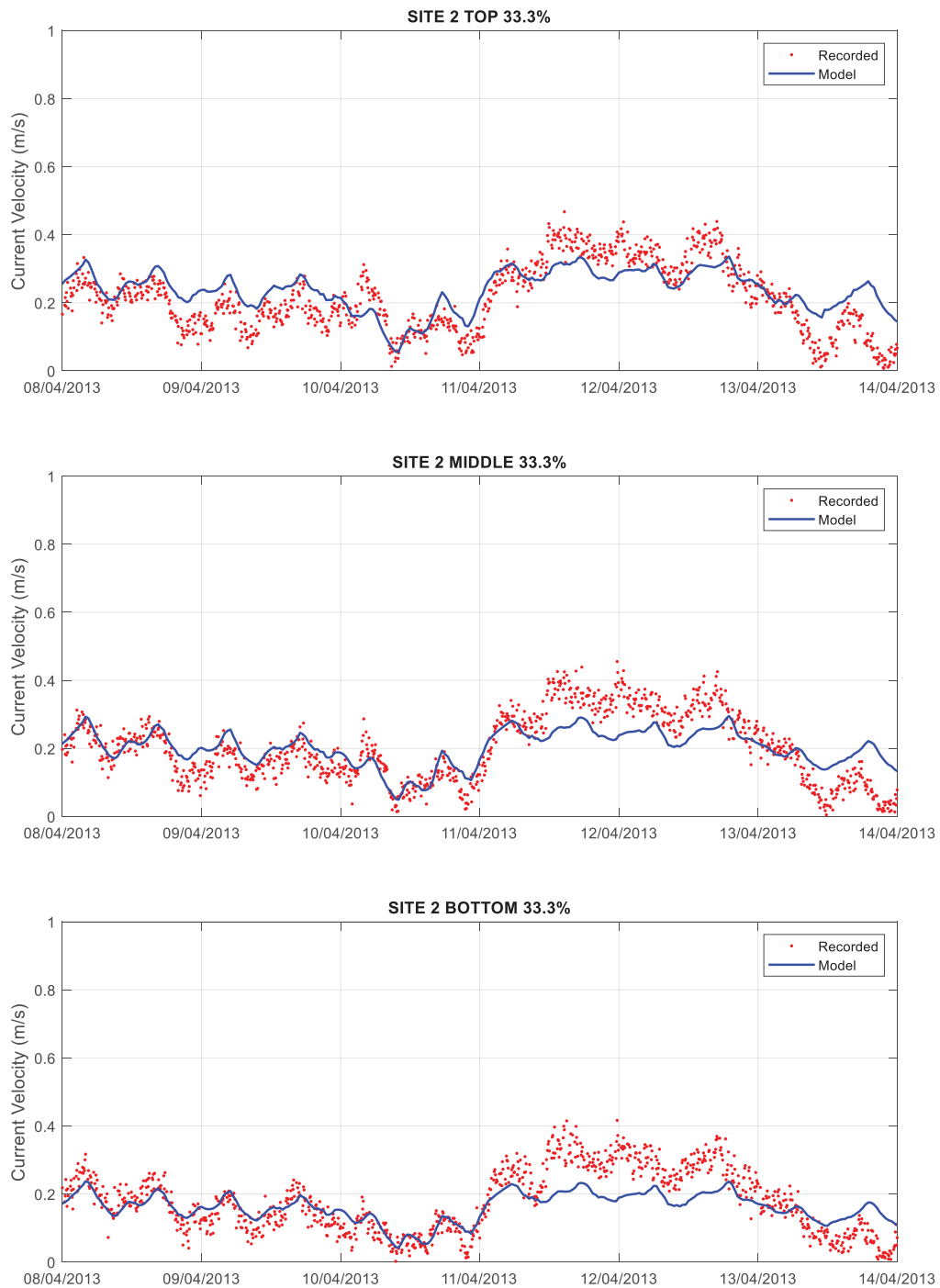


Figure 3-11 Hydrodynamic Model Calibration Current Velocity Layers – Site 2

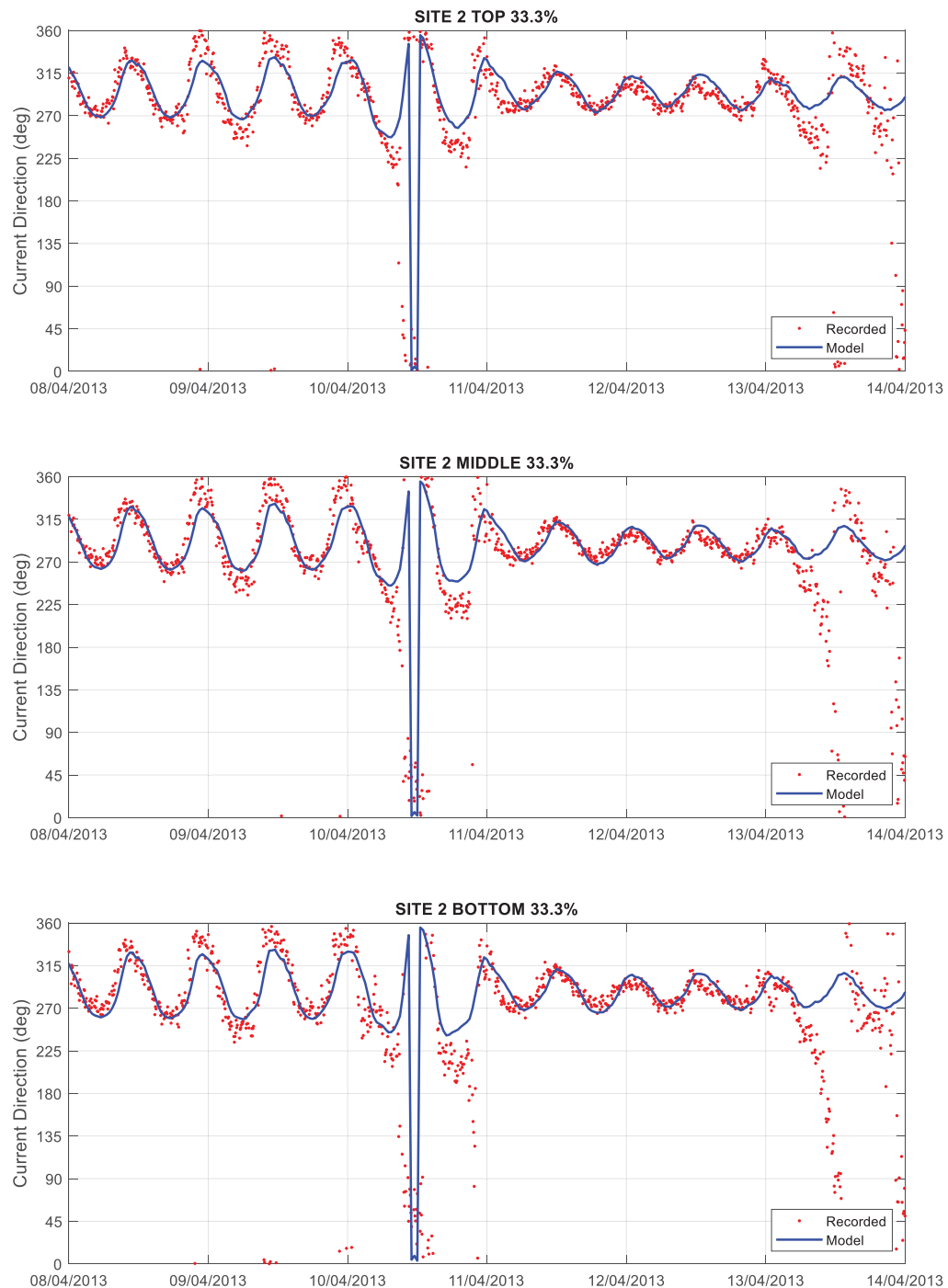


Figure 3-12 Hydrodynamic Model Calibration Current Direction Layers – Site 2

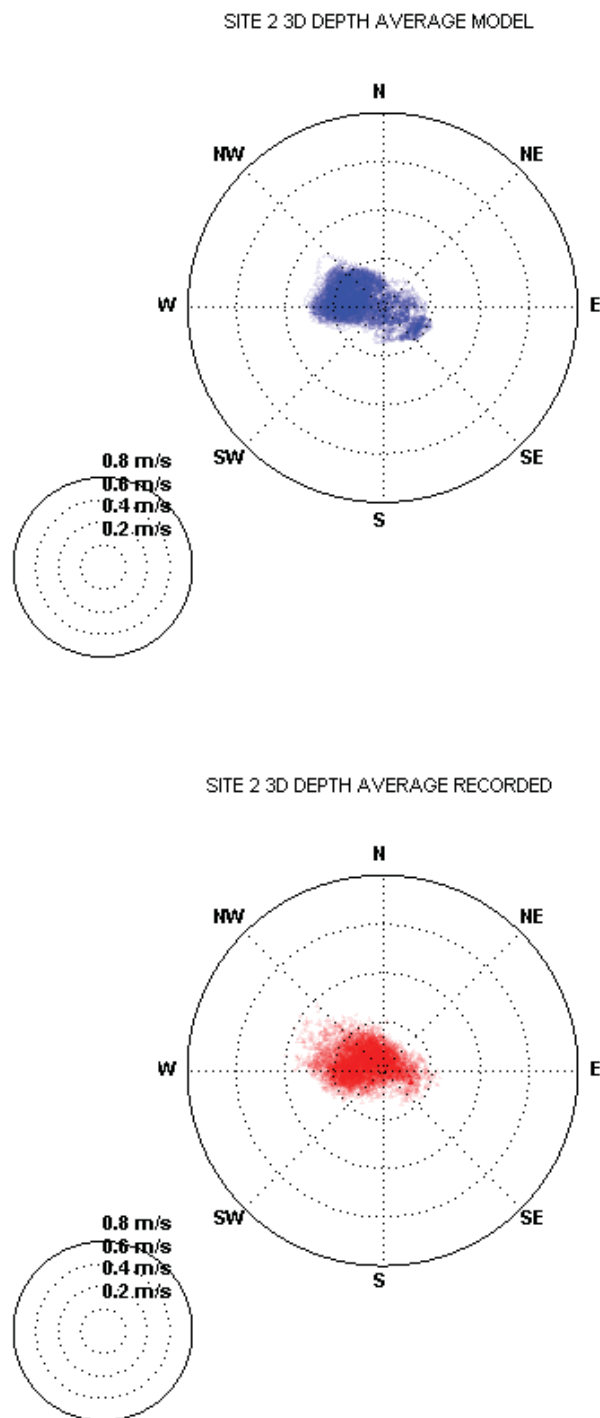


Figure 3-13 Current Polar Plot Validation – Site 2

3.4.2.3 Site 3 Beacon C7

Model calibration results at the Beacon C7 continuous data recording location show the following:

- Figure 3-14 (top plot) suggests variations in water level amplitude at Beacon C7 are accurately predicted by the model during both spring and neap tides. The slight phase discrepancy evident at offshore data recording locations is also apparent at Beacon C7.
- Current data from Beacon C7 shows a strong tidal signal which is only slightly less dominant during the south easterly wind event between 11/04/2013 and 13/04/2013. The depth-average current velocity (Figure 3-14, middle plot) and current velocity layer (Figure 3-15) time series calibration plots suggest good model predictive skill.
- Some discrepancy between recorded and predicted current direction is evident in Figure 3-14 (bottom plot) and Figure 3-16 during and after the south easterly wind event between 11/04/2013 and 13/04/2013. It is assumed this is due to the inaccuracies in the constructed wind field which is not expected to capture all the orographic effects around the hills to the east of the shipping channel.
- Predicted and recorded distributions of depth-average current magnitude and direction at Beacon C7 are presented as polar plots in Figure 3-17. Despite some current direction discrepancy described above, the model and recordings show good overall consistency in current distribution over the entire calibration period.

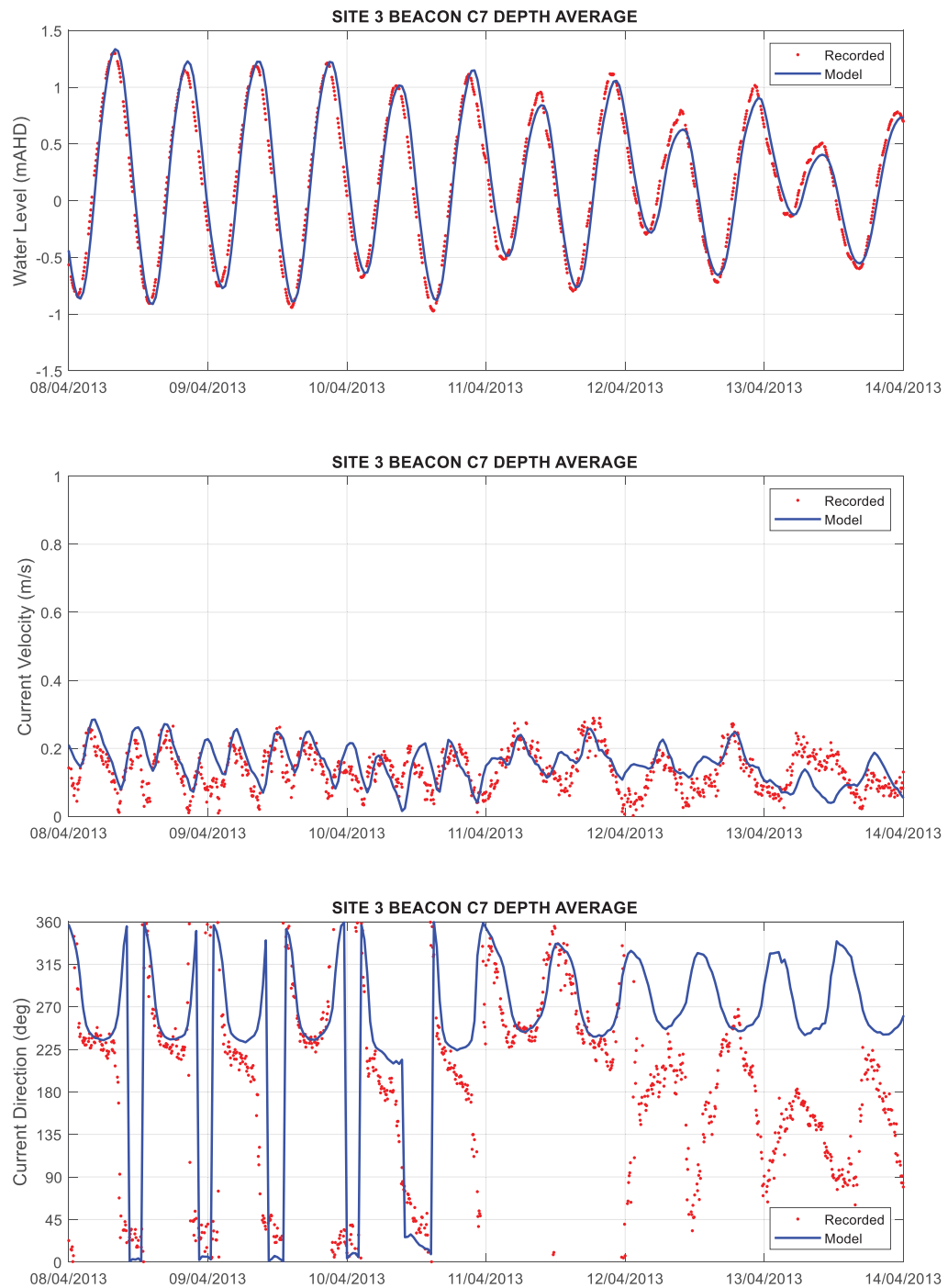


Figure 3-14 Hydrodynamic Model Calibration 3D Depth Average – Site 3 Beacon C7

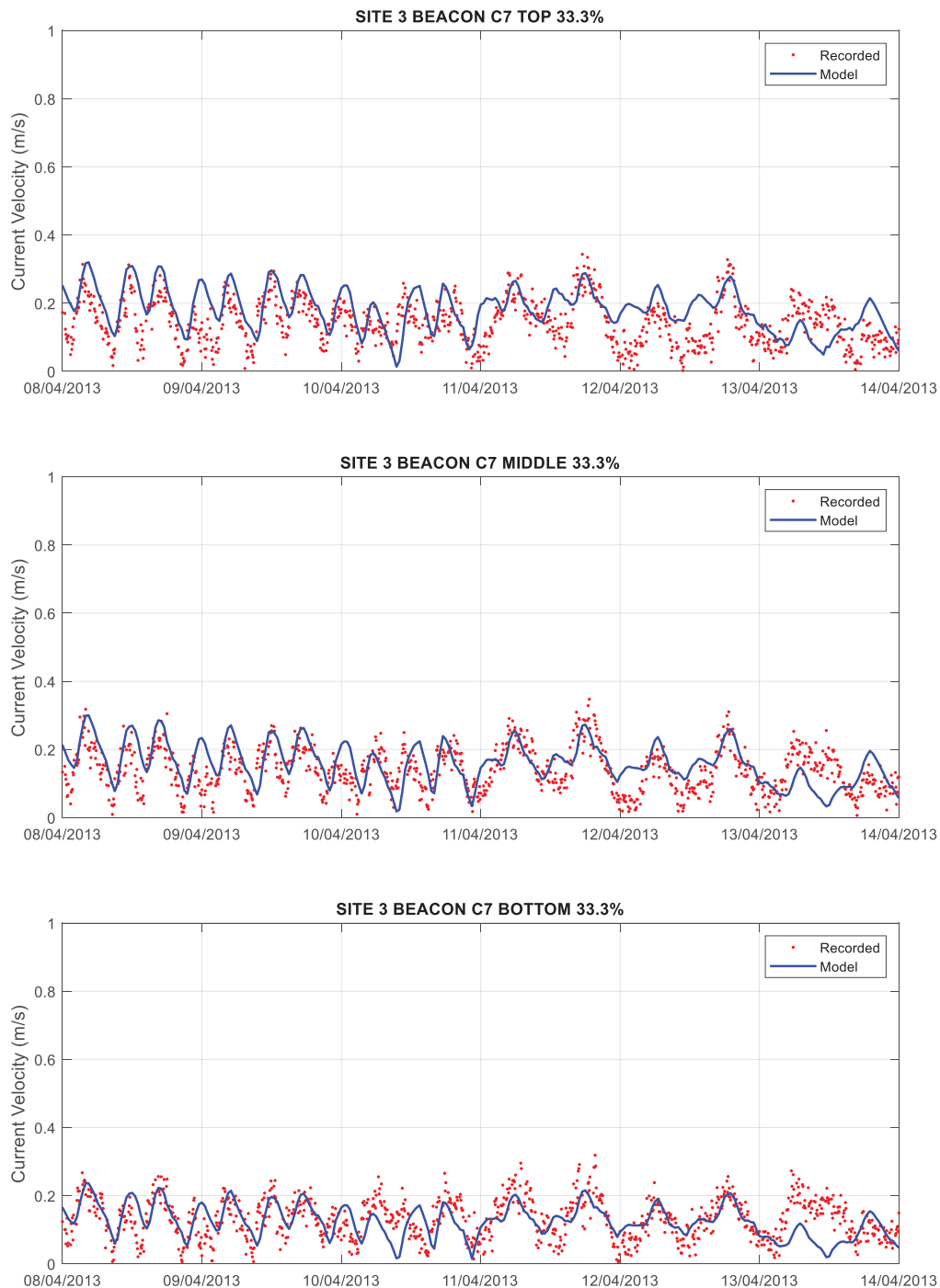


Figure 3-15 Hydrodynamic Model Calibration Current Velocity Layers – Site 3 Beacon C7

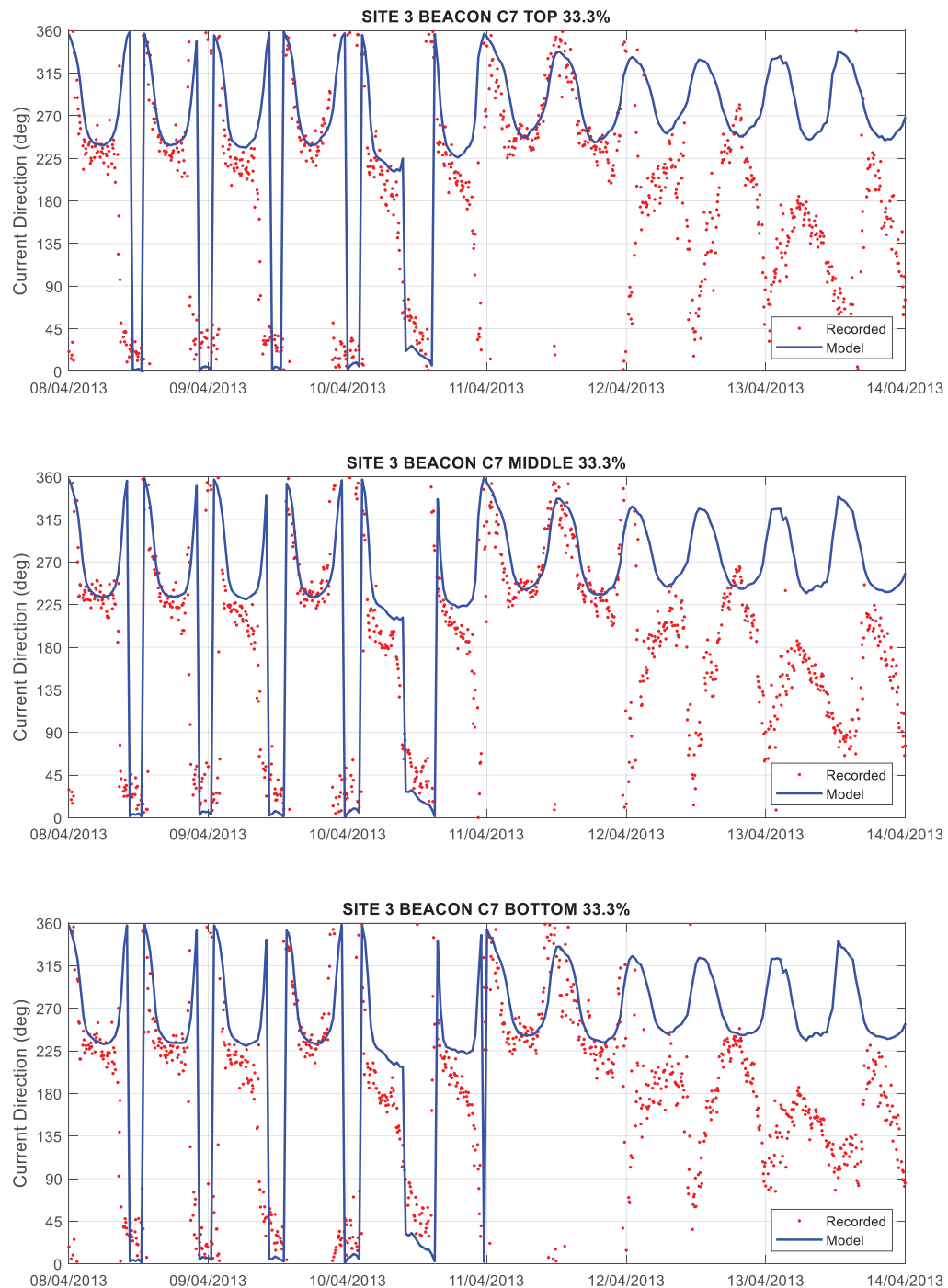


Figure 3-16 Hydrodynamic Model Calibration Current Direction Layers – Site 3 Beacon C7

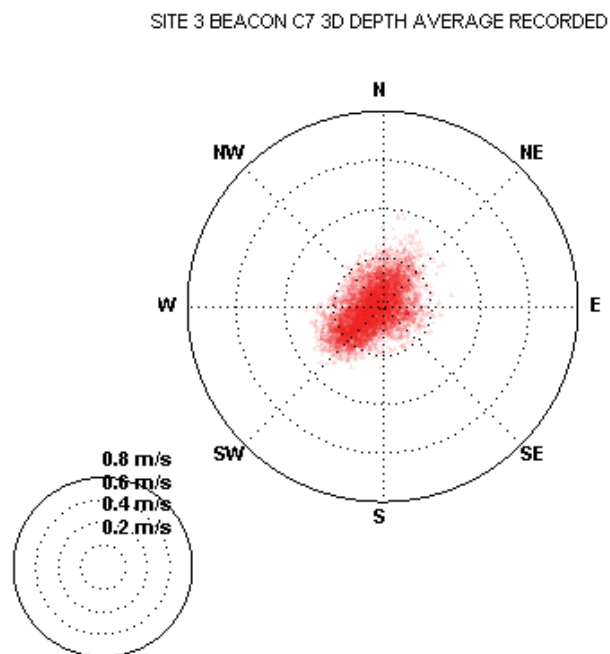
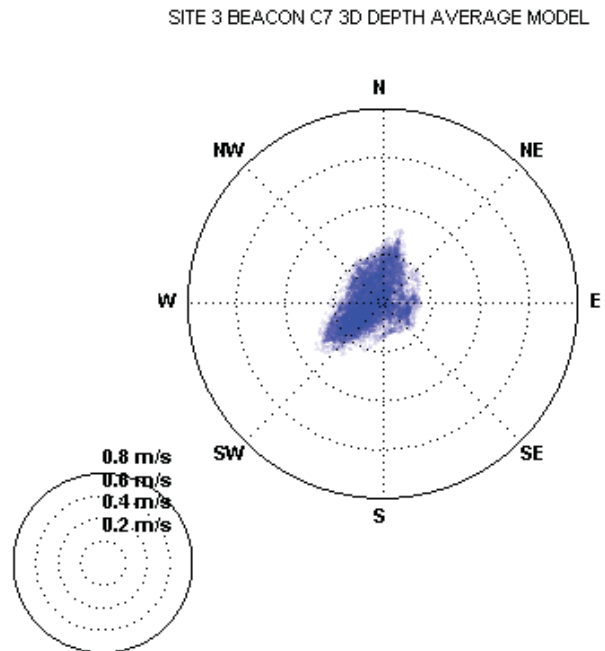


Figure 3-17 Current Polar Plot Validation – Site 3 Beacon C7

3.4.2.4 Site 4 Beacon C11

Model calibration results at the Beacon C11 continuous data recording location show the following:

- Figure 3-14 (top plot) suggests variations in water level amplitude at Beacon C11 are accurately predicted by the model during both spring and neap tides.
- Current data from Beacon C11 shows a strong tidal signal with a higher peak velocity (occasionally exceeding 0.6m/s) during the ebb tide phase. A minor over-prediction bias in peak velocity is evident during the flood tide phase. Better model predictive skill is observed during the more dominant ebbing tides.
- The flood and ebb current direction interchanges between approximately 205 degrees during flood tides and 15 degrees during ebb tides. This behaviour is generally well predicted by the model. Some minor discrepancy between recorded and predicted current direction is evident in Figure 3-18 (bottom plot) and Figure 3-20 during the south easterly wind event between 11/04/2013 and 13/04/2013. Compared to Beacon C7, the current direction discrepancy is less evident at Beacon C11 and the currents appear to remain dominated by tidal forcing.
- Predicted and recorded distributions of depth-average current magnitude and direction at Beacon C11 are presented as polar plots in Figure 3-21. The predicted current distribution shows less directional spreading compared to the recordings. Nevertheless, good overall consistency over the entire calibration period has been achieved.

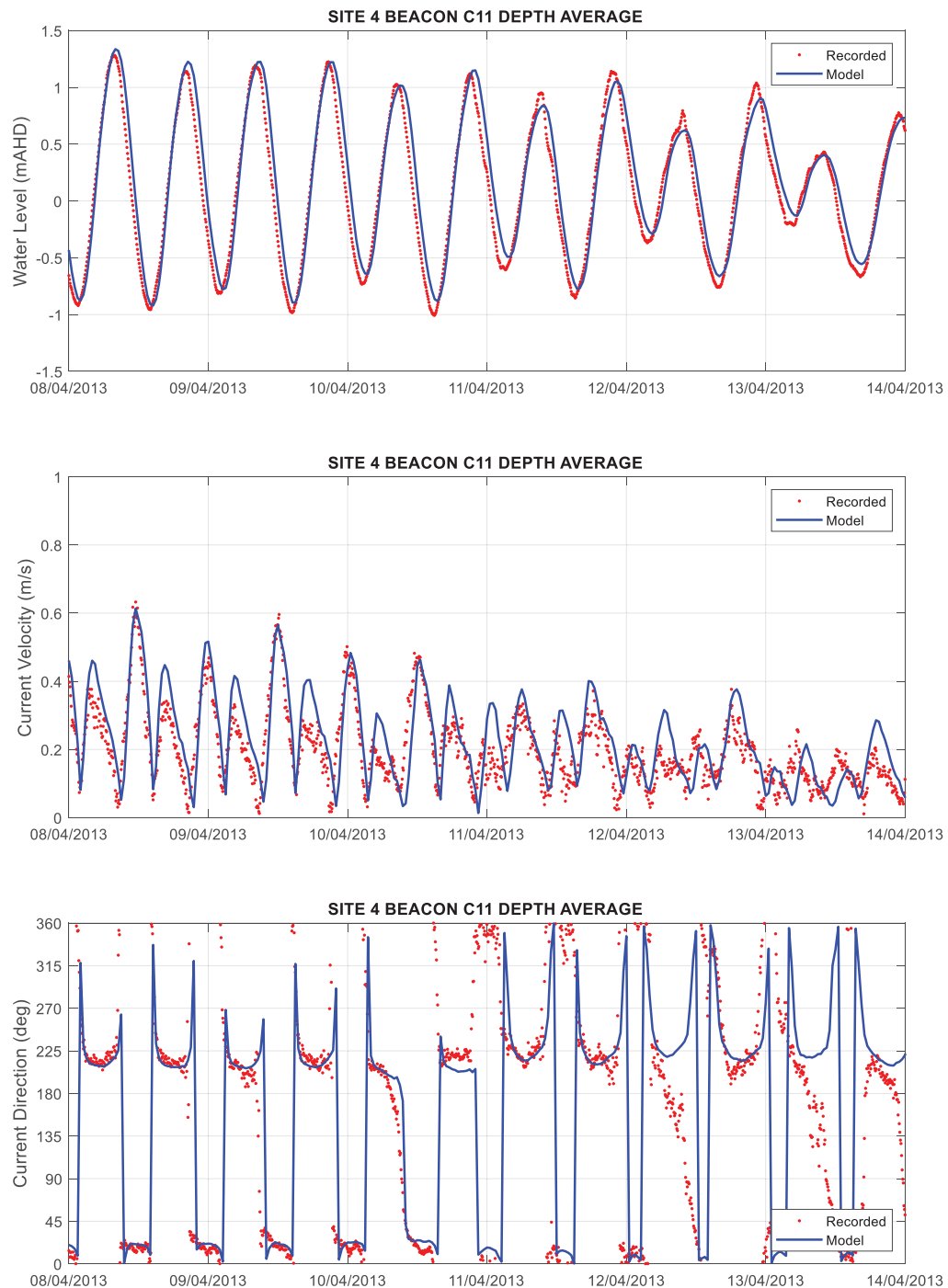


Figure 3-18 Hydrodynamic Model Calibration 3D Depth Average – Site 4 Beacon C11

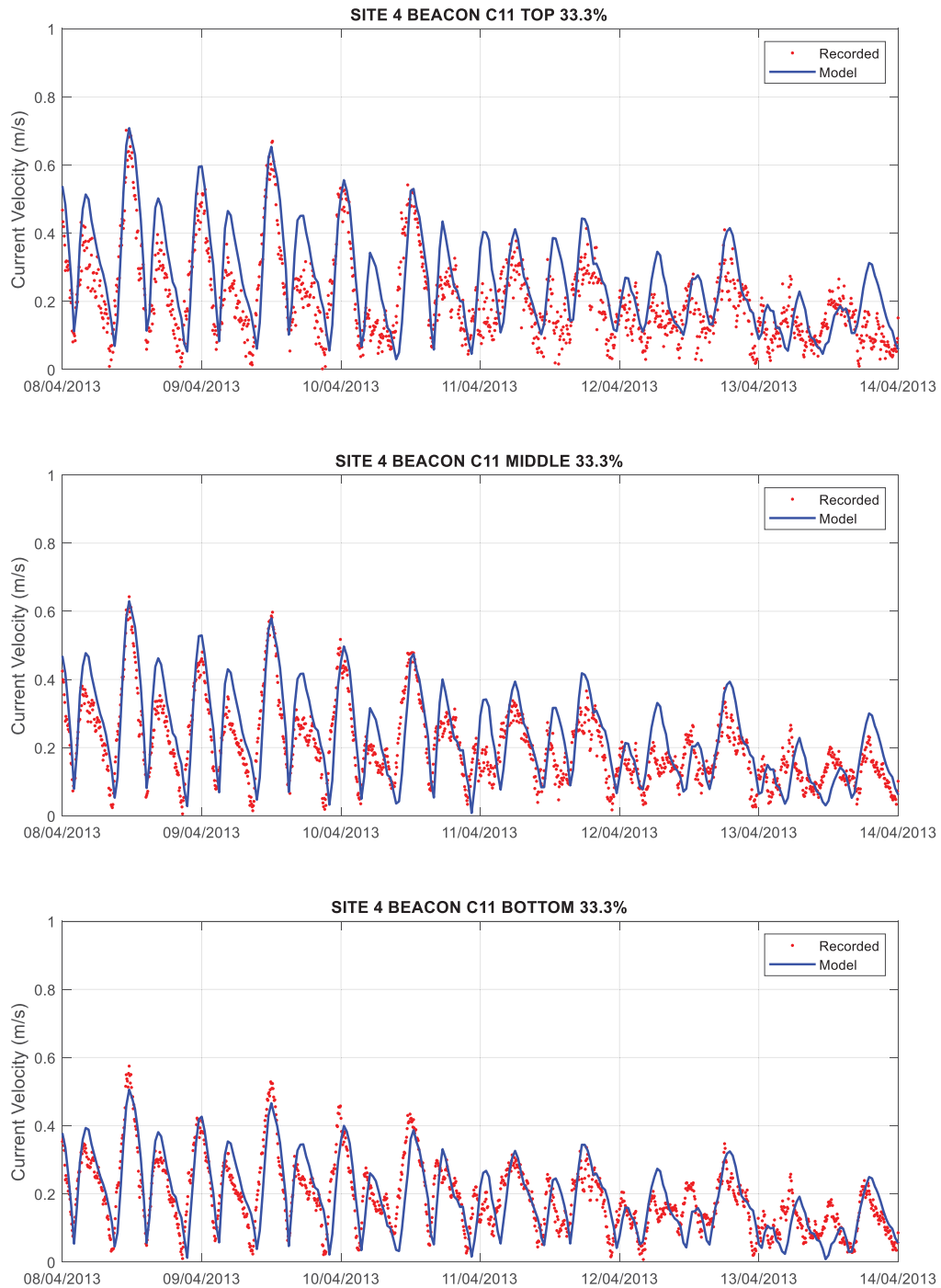


Figure 3-19 Hydrodynamic Model Calibration Current Velocity Layers – Site 4 Beacon C11

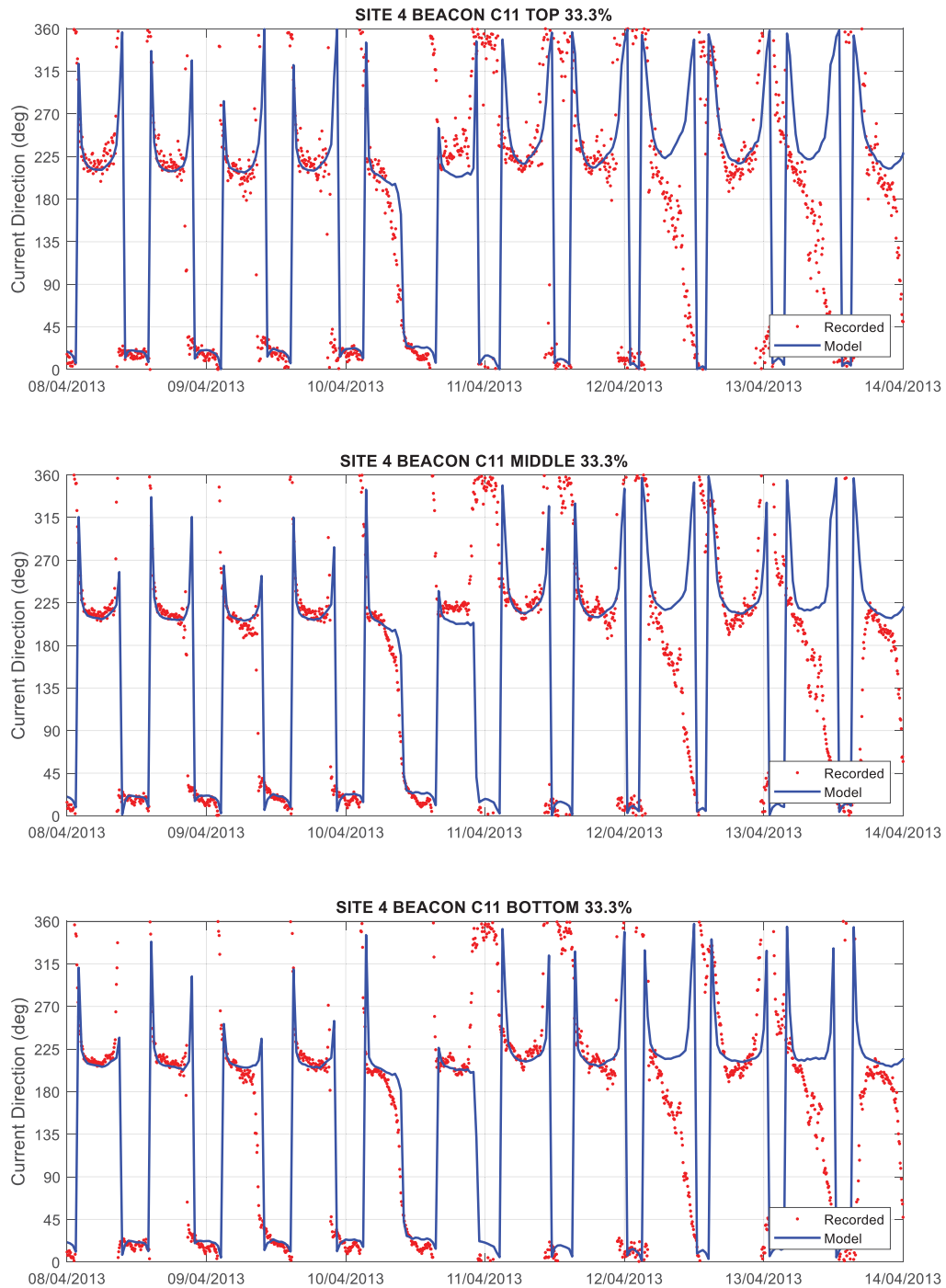


Figure 3-20 Hydrodynamic Model Calibration Current Direction Layers – Site 4 Beacon C11

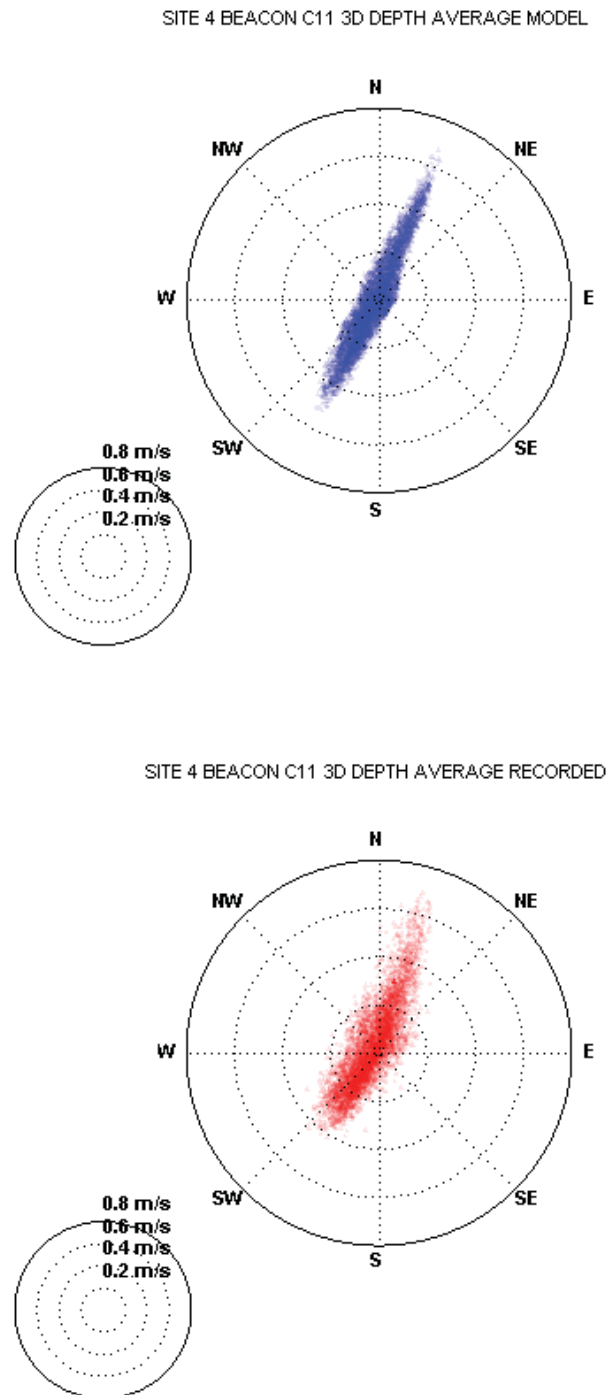


Figure 3-21 Current Polar Plot Validation – Site 4 Beacon C11

3.4.3 Water Temperature Calibration

Comparisons of the modelled near-bed water temperature with continuous measurements obtained using YSI Model 6600 EDS nepholometers (co-located with the ADCP instruments) are shown in Figure 3-22 to Figure 3-25. The model accurately simulates the gradual cooling trend observed during the calibration period.

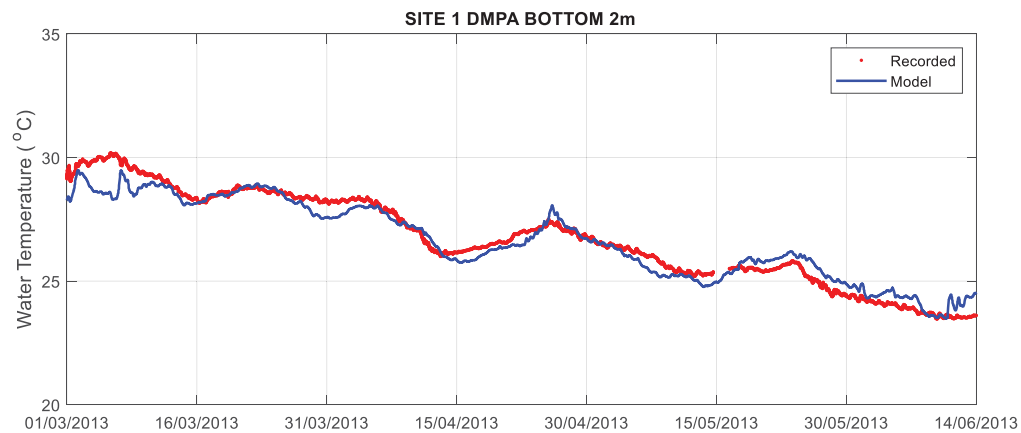


Figure 3-22 Hydrodynamic Model Calibration Near Bed Temperature – Site 1 DMPA

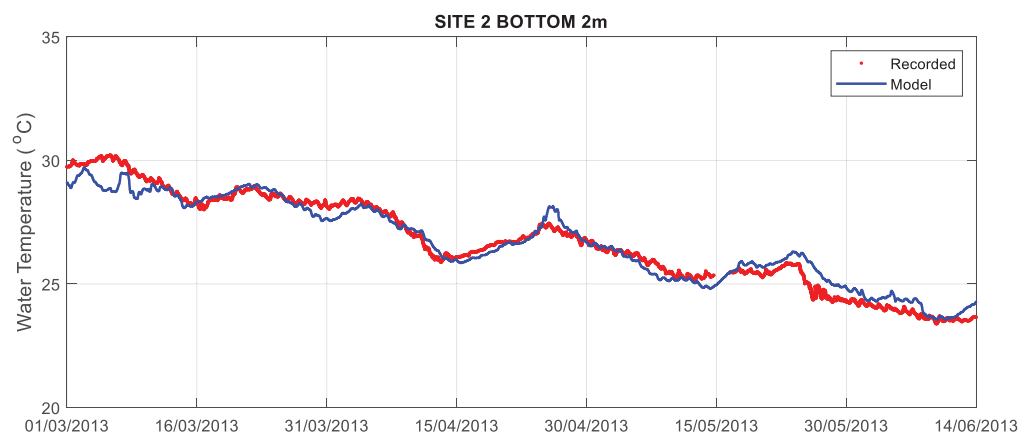


Figure 3-23 Hydrodynamic Model Calibration Near Bed Temperature – Site 2

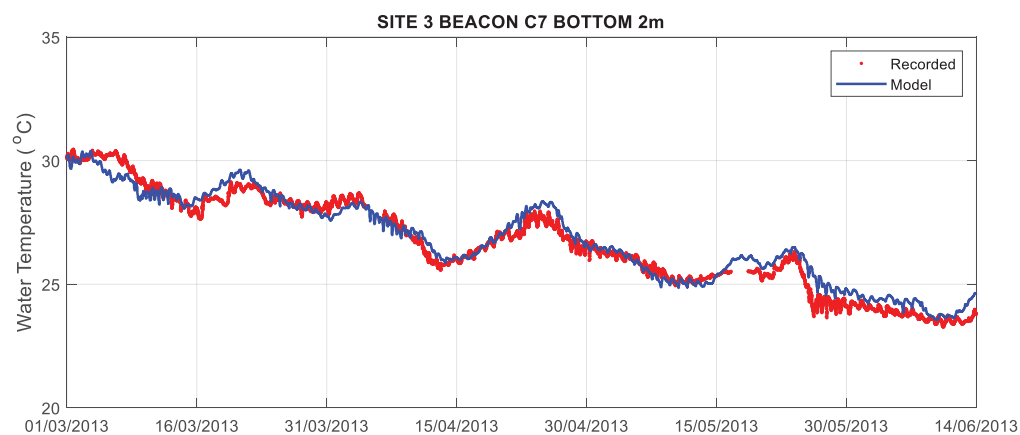


Figure 3-24 Hydrodynamic Model Calibration Near Bed Temperature – Site 3 Beacon C7

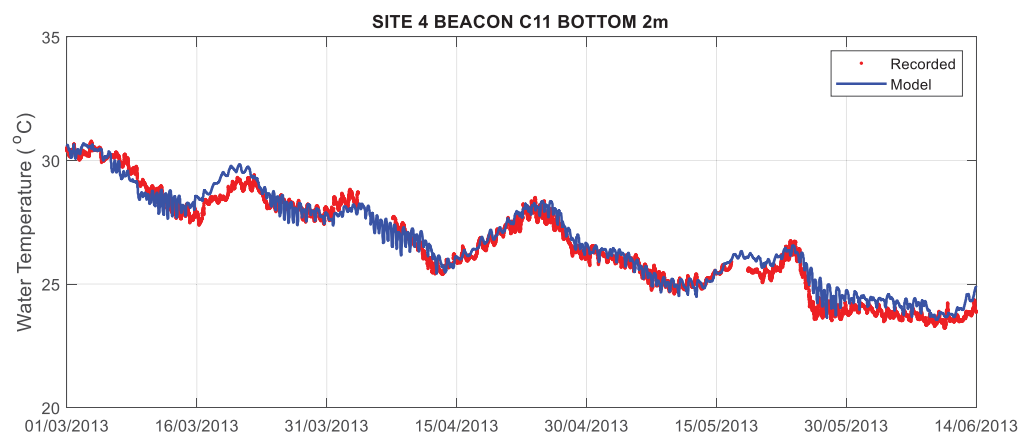


Figure 3-25 Hydrodynamic Model Calibration Near Bed Temperature – Site 4 Beacon C11

3.4.4 Summary of Calibration Period Hydrodynamic Model Performance

Hydrodynamic model predictive skill in terms of IOA, MAE and RMSE over the calibration period is summarised in Table 3-4, Table 3-5 and Table 3-6.

Table 3-4 Model Performance Metrics – Water Level Calibration

Metric	Site 1 DMPA	Site 2	Site 3 Beacon C7	Site 4 Beacon C11
IOA	0.98	0.98	0.97	0.96
MAE (m)	0.13	0.12	0.13	0.15
RMSE (m)	0.17	0.17	0.20	0.23

Table 3-5 Model Performance Metrics – Current Magnitude E-W

Metric	Water Level Averaging	Site 1 DMPA	Site 2	Site 3 Beacon C7	Site 4 Beacon C11
IOA	Entire column	0.78	0.78	0.80	0.91
	Top one-third	0.75	0.73	0.79	0.89
	Middle one-third	0.77	0.77	0.79	0.91
	Bottom one-third	0.81	0.82	0.78	0.90
MAE (m/s)	Entire column	0.09	0.08	0.06	0.04
	Top one-third	0.11	0.10	0.07	0.06
	Middle one-third	0.10	0.08	0.06	0.05
	Bottom one-third	0.07	0.06	0.05	0.04
RMSE (m/s)	Entire column	0.11	0.10	0.08	0.06
	Top one-third	0.15	0.13	0.09	0.07
	Middle one-third	0.12	0.11	0.08	0.06
	Bottom one-third	0.08	0.08	0.07	0.05

Table 3-6 Model Performance Metrics – Current Magnitude N-S

Metric	Water Level Averaging	Site 1 DMPA	Site 2	Site 3 Beacon C7	Site 4 Beacon C11
IOA	Entire column	0.78	0.81	0.92	0.94
	Top one-third	0.77	0.78	0.91	0.92
	Middle one-third	0.76	0.78	0.91	0.95
	Bottom one-third	0.75	0.76	0.87	0.94
MAE (m/s)	Entire column	0.06	0.04	0.04	0.07
	Top one-third	0.07	0.05	0.05	0.09
	Middle one-third	0.06	0.05	0.04	0.06
	Bottom one-third	0.05	0.04	0.04	0.06
RMSE (m/s)	Entire column	0.07	0.06	0.05	0.09
	Top one-third	0.08	0.07	0.06	0.11
	Middle one-third	0.08	0.06	0.06	0.09
	Bottom one-third	0.06	0.06	0.06	0.08

3.5 Wave Model Calibration

3.5.1 Wave Model Parameterisation

The SWAN wave model computations were undertaken in third-generation mode which considers various physical processes that add/withdraw wave energy to/from the wave field. Physical processes activated and considered important to the study area include:

- Linear wind growth (Cavaleri and Malanotte-Rizzoli, 1981)
- Exponential wind growth (Komen et al., 1984)
- Bottom friction (Collins, 1972)
- Depth-induced wave breaking (Battjes and Janssen, 1978)
- Whitecapping (Komen et al., 1984)
- Wave-wave interactions (Hasselmann et al., 1985).

Except for friction, the default values for the model coefficients as described in Delft University of Technology (2006) were adopted. Friction coefficients were adjusted as part of the calibration process. Table 3-7 summarises the SWAN model configuration and parameterisations.

Table 3-7 Summary of SWAN Model Configuration and Parameterisations

Model Configuration Description	Model/Value
Offshore boundary (500m grid only)	Wavewatch III with 30deg directional spreading
Generation mode	GEN3 with default parameters
Bottom friction model	Collins (1972)
<u>Bottom friction coefficients:</u>	
Default (offshore areas)	0.025
Reef passes	0.1
Computational mode	Non-stationary two-dimensional

3.5.2 Wave Model Calibration Results

Continuous time series of recorded significant wave height, peak wave period and wave direction were available at the following locations indicated in Figure 3-2:

- Cairns Wave Buoy operated by DES;
- DMPA;
- Site 2;
- Beacon C7; and
- Beacon C11.

Except for the Cairns Wave Buoy, wave recording instruments were deployed to support the CSDP and is presented for the period 01/03/2013 to 30/06/2013.

The recorded peak period data at all locations shows the wave conditions varying between dominant “swell” and dominant locally generated “sea” states. The amount of Coral Sea swell energy reaching the recording locations is limited by the GBR. Swell state conditions dominate the peak energy parameters only when the local wind conditions are particularly mild. The swell wave train component is characterised by longer peak wave periods (>6 s) and generally small significant wave heights.

Sea state wave conditions are characterised by shorter wave periods (typically 3-5 s) and are generated by local winds acting on the sea surface within the Great Barrier Reef lagoon. Due to the complex arrangement of reef passes, fetch lengths and local bathymetry, the wave climate in the study area can at times be multi-modal, meaning that it is made up of multiple component wave trains with distinct wave periods and directions.

Figure 3-26 uses 2D wave energy spectrum model output to illustrate typical wave conditions for the Cairns region. The left spectral plot shows a time when the wave climate is dominated low frequency (longer period) swell wave energy entering the Great Barrier Reef lagoon from the north-easterly directional sector. In contrast, the spectral plot on the right shows a time when a sea state generated by south-easterly winds is dominant. The locally generated wind waves are of high frequency (shorter period) compared to the swell wave energy wave field which has an independent direction and period.

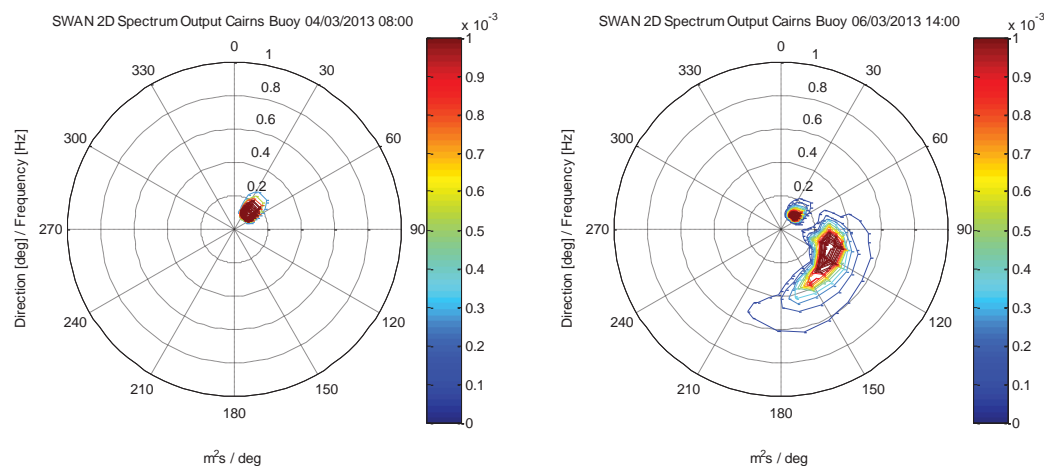


Figure 3-26 Example Wave Energy Spectrum showing Dominant Swell (left) and Wind Generated Sea (right) States

3.5.2.1 Cairns Wave Buoy

Non-directional wave recordings were provided by DES for the period 01/01/2011 to 28/02/2013. The results of the local model (100 m grid resolution) calibration to a selected period of this data set is provided in Figure 3-27. The significant wave height prediction is generally good, particularly during the event associated with ex-Tropical Cyclone Oswald (23-24 January 2013) with a peak significant wave height close to 2.4 m. At other times the recorded data and model predictions show mild wave conditions with significant wave heights typically less than 1 m.

The peak wave period at the Cairns Buoy is also represented well by the model with times of dominant swell and sea states reproduced. At times, the peak wave period is over predicted and

represents times when slightly too much swell energy reaches the buoy location. This typically occurs during periods of low wind-driven wave energy. The consequence of too much long period (swell) wave energy in terms of the maintenance dredging assessments is a slight over prediction of sediment suspension.

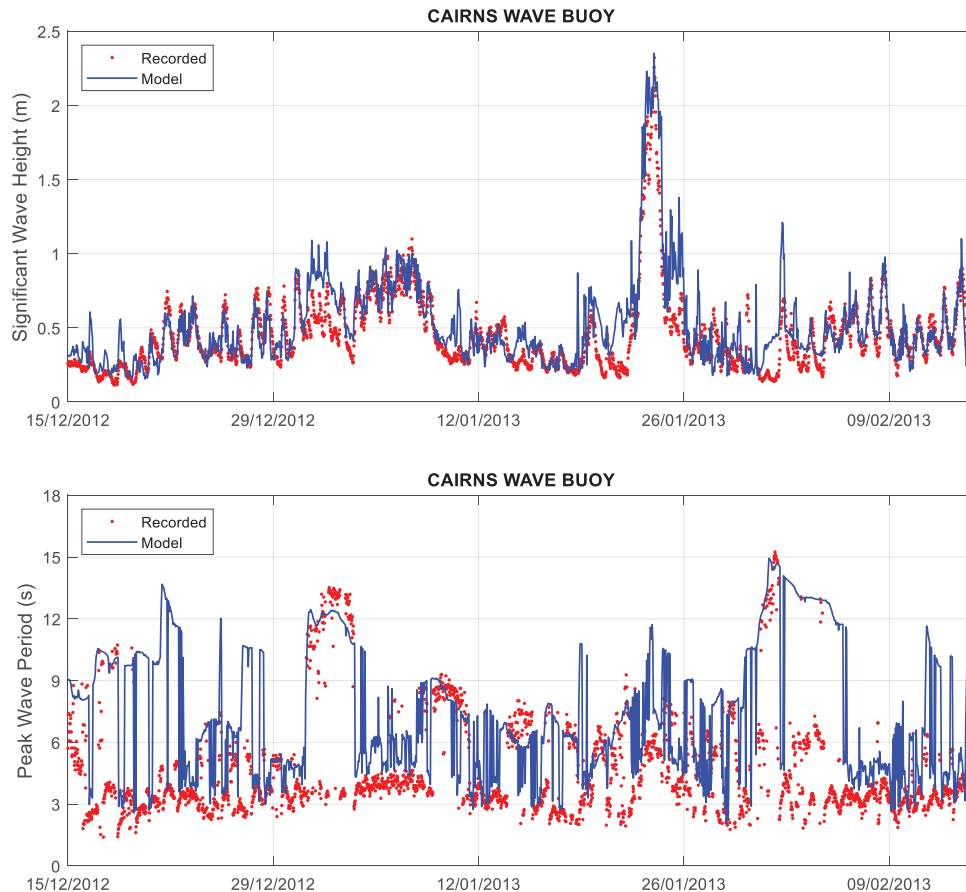


Figure 3-27 SWAN Wave Model Calibration – Cairns Wave Buoy

3.5.2.2 Targeted Wave Recordings

Predicted wave parameters (significant wave height, peak wave period and wave direction) are compared to continuous time series data in Figure 3-28 to Figure 3-31. Recorded and predicted 2D wave energy spectral plots are compared in Figure 3-32 and Figure 3-33. The wave model predictive skill is satisfactory and considered appropriate for assessing the potential impacts associated with maintenance dredging. Key features of the wave calibration results include:

- Significant wave height at Site 1 and Site 2 is predicted well. The dominant wave direction (from the east to south east) at these locations is generally represented by the model.
- A slight significant wave height over-prediction is evident at the Beacon C7 and Beacon C11 where the south-easterly fetch length is particularly limited. The over prediction in wave height is probably attributable to the effects of wind drag over land, and the transition from over land to over sea winds, not being precisely resolved by the derived wind field. The consequence of

this minor inaccuracy in terms of the maintenance dredging assessments is a slight over prediction of wave-driven sediment suspension.

- The wave model predicts periods of dominant sea and swell states at each location and this is reflected in comparisons with the peak wave period recordings. As observed at the Cairns Wave Buoy location, occasionally the peak wave period is over-predicted and represents times when slightly too much offshore swell energy is propagated into GBR lagoon.
- Due to wave refraction processes, the dominant wave direction of the longer period swell waves at Beacon C7 and Beacon C11 is progressively east to north-easterly. This general pattern is represented by the model.
- The energy spectrum comparisons correspond to a 20 minute time-averaged period when swell state (Figure 3-32) and sea state (Figure 3-33) wave conditions dominant. Despite relative robust predictions of wave parameters, the spectral comparison suggests the predicted directional spread of wave energy is somewhat narrower than recorded.

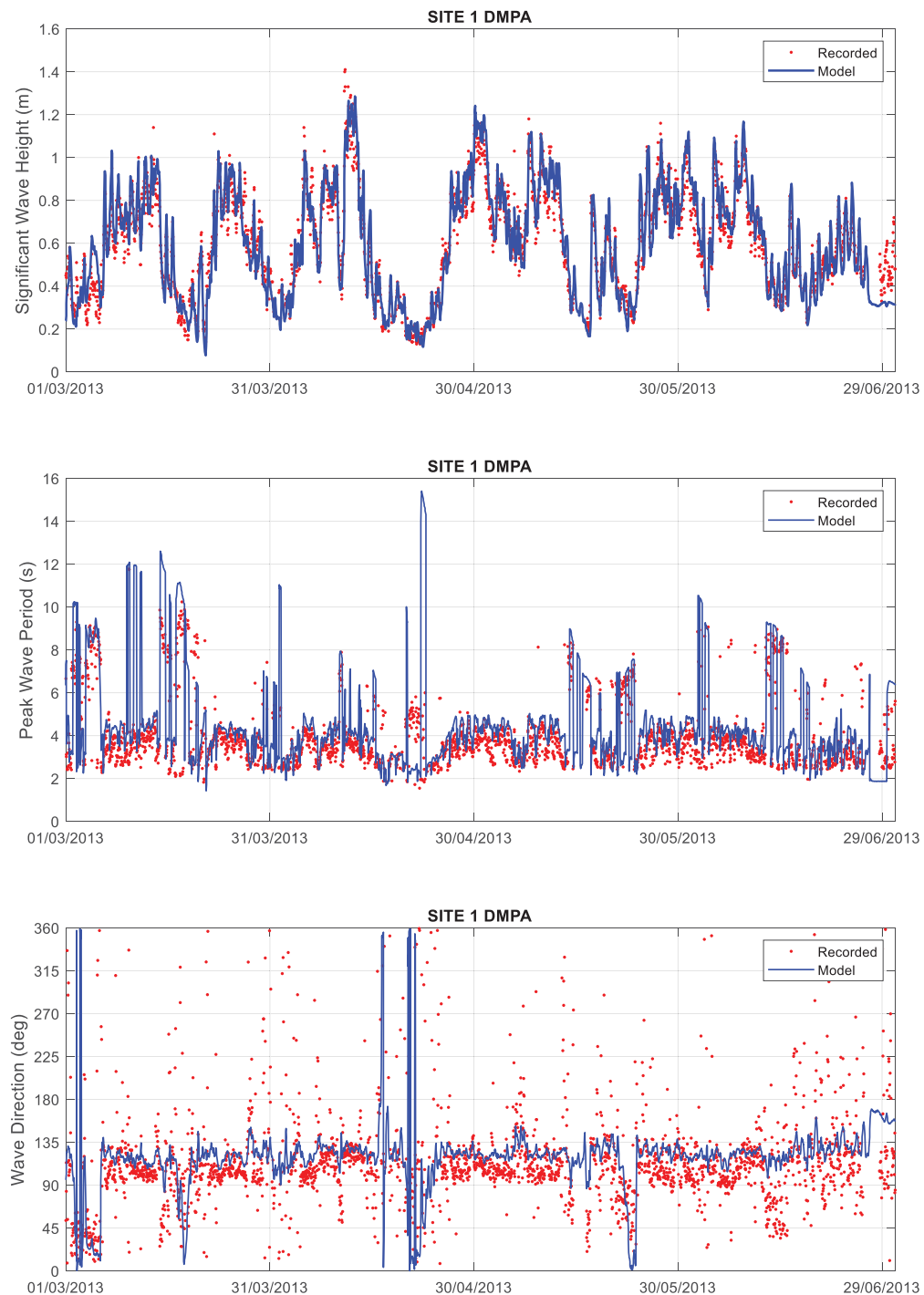


Figure 3-28 SWAN Wave Model Calibration – Site 1 DMPA

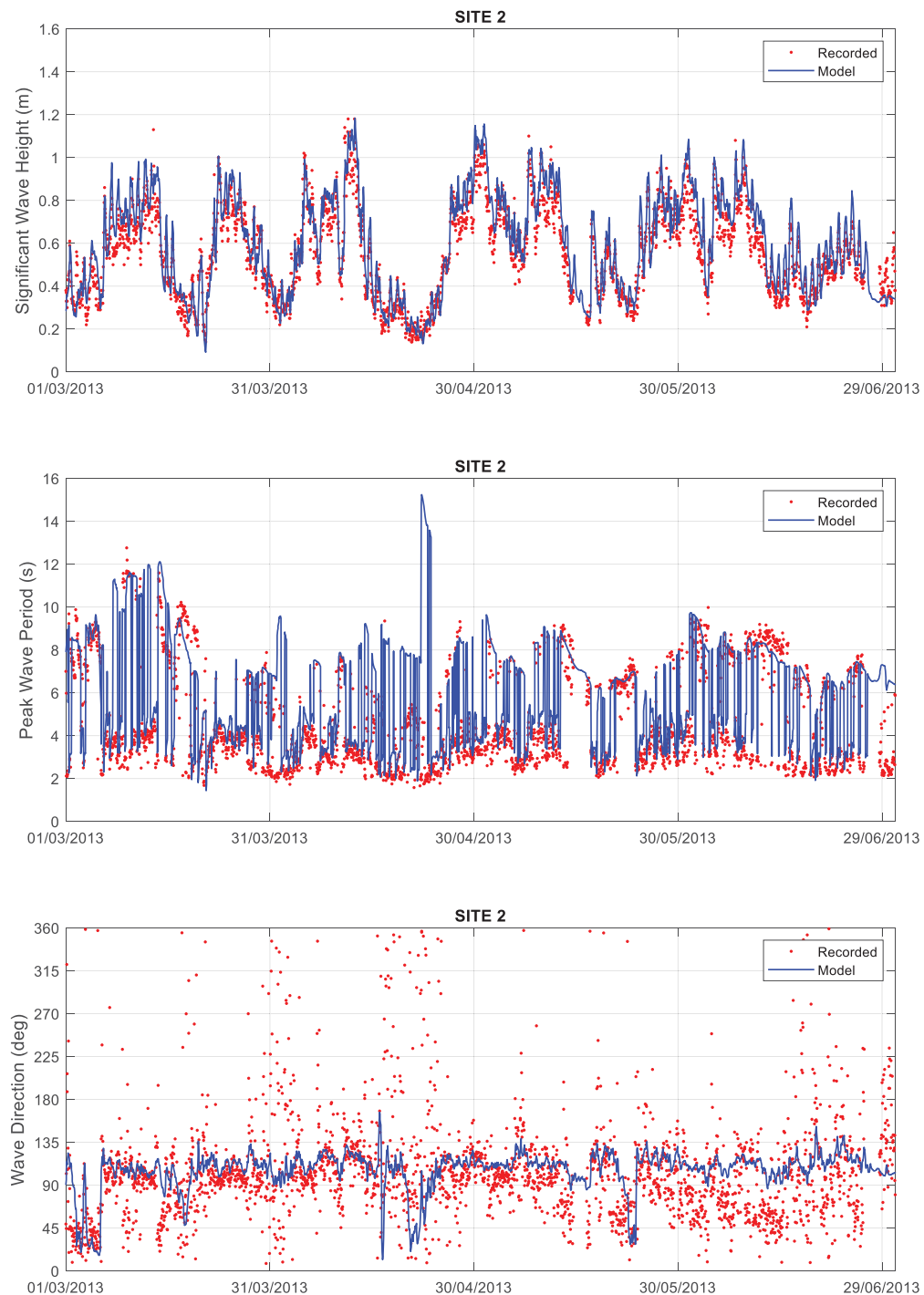


Figure 3-29 SWAN Wave Model Calibration – Site 2

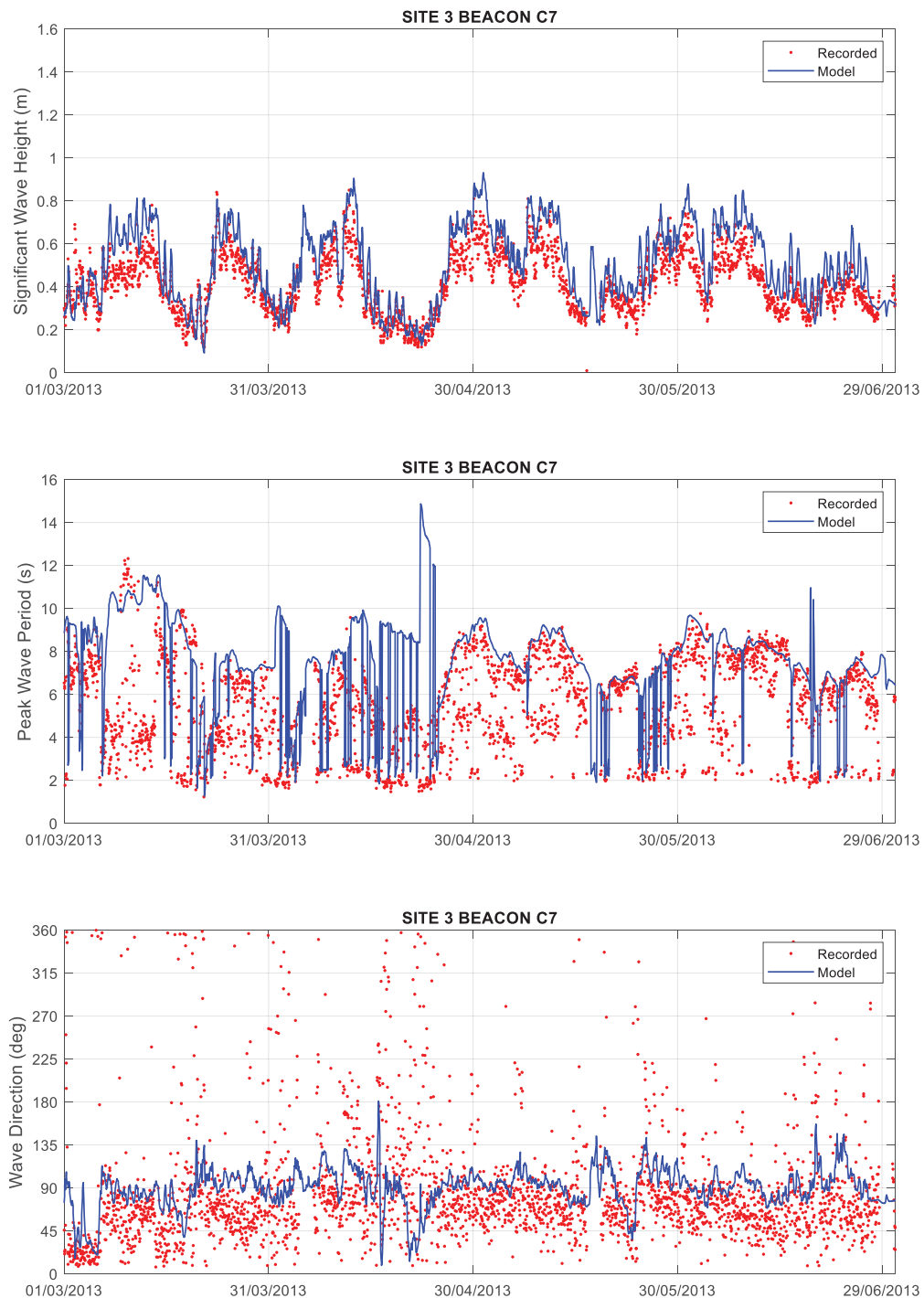


Figure 3-30 SWAN Wave Model Calibration – Site 3 Beacon C7

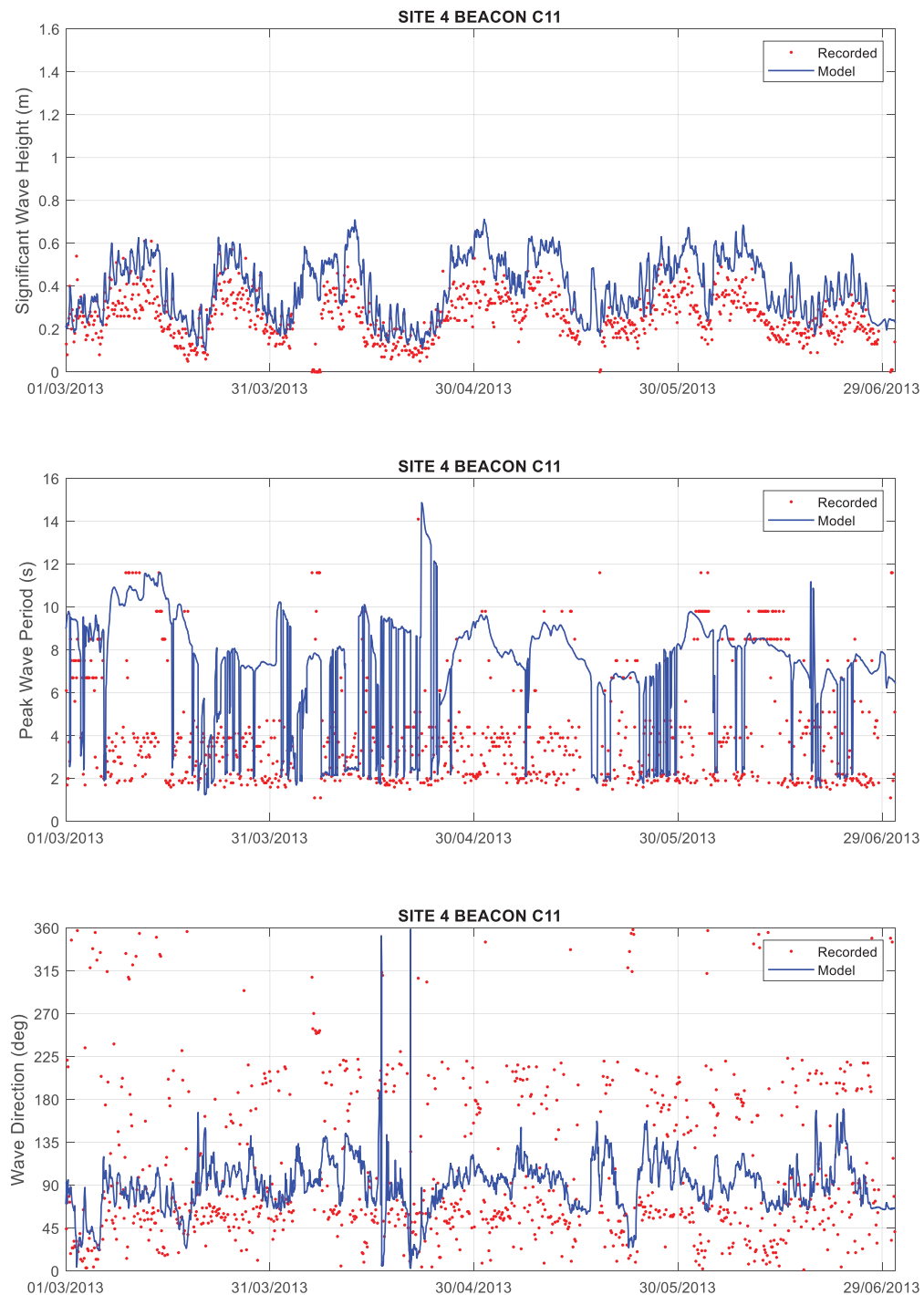


Figure 3-31 SWAN Wave Model Calibration – Site 4 Beacon C11

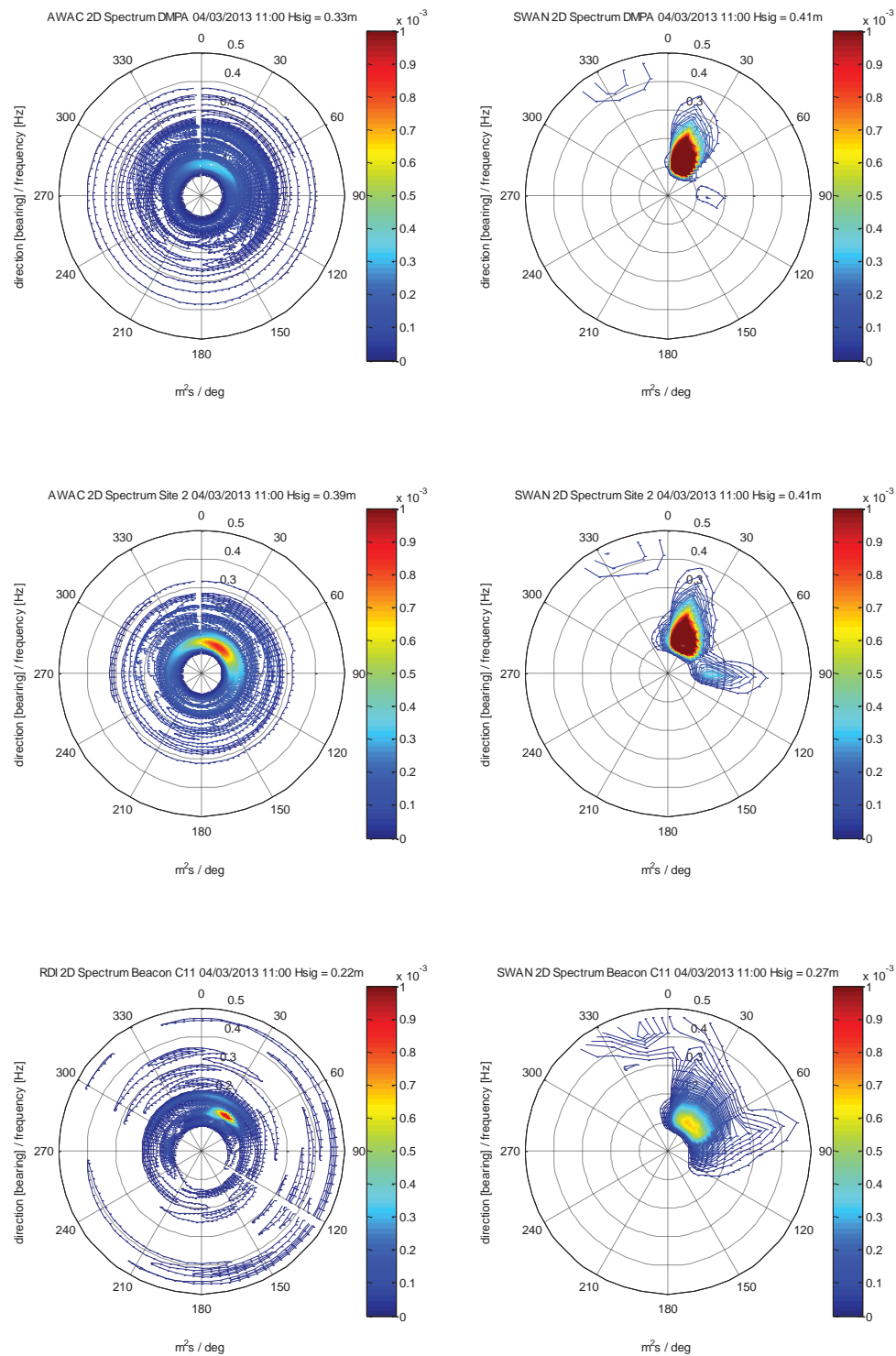


Figure 3-32 Recorded (left) and Predicted (right) 2D Wave Energy Spectrum: Dominant Swell State

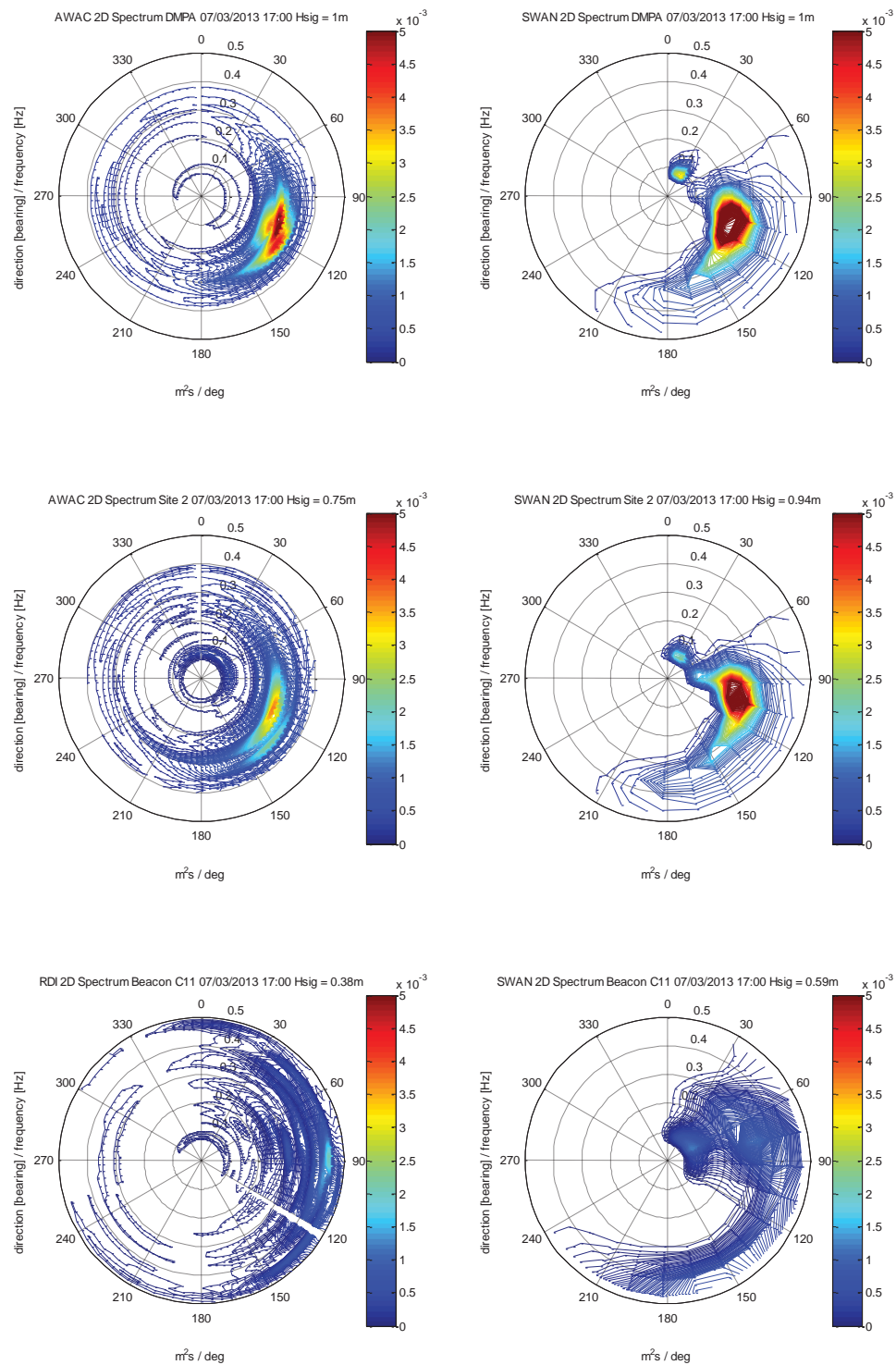


Figure 3-33 Recorded (left) and Predicted (right) 2D Wave Energy Spectrum: Dominant Sea State

3.5.3 Summary of Wave Model Performance

Wave model predictive skill in terms of IOA, MAE and RMSE over the calibration period is summarised in Table 3-8 and Table 3-9.

Table 3-8 Model Performance Metrics – Significant Wave Height Calibration

Metric	Cairns Wave Buoy	Site 1 DMPA	Site 2	Site 3 Beacon C7	Site 4 Beacon C11
IOA	0.92	0.97	0.96	0.86	0.67
MAE (m)	0.10	0.07	0.07	0.10	0.14
RMSE (m)	0.14	0.09	0.09	0.12	0.17

Table 3-9 Model Performance Metrics – Peak Energy Wave Period Calibration

Metric	Cairns Wave Buoy	Site 1 DMPA	Site 2	Site 3 Beacon C7	Site 4 Beacon C11
IOA	0.56	0.67	0.63	0.53*	0.44*
MAE (s)	2.35	1.12	1.88	2.55	3.76
RMSE (s)	3.33	2.01	2.87	3.43	4.58

**significant scatter in wave period measurements*

3.6 Sediment Re-suspension Model Calibration

3.6.1 Sediment Re-suspension Model Parameterisation

The re-suspension, dispersion and settling of the natural bed sediments throughout the study area was estimated using the TUFLOW FV ST module coupled with the calibrated wave and hydrodynamic models. Simulated ambient TSS concentration was calibrated to continuous recordings of near-bed turbidity converted to TSS using the site-specific NTU-TSS relationship shown in Figure 3-1. Estimates of the average annual channel sedimentation derived from hydrographic survey measurements provided by Ports North were also used to further validate the model's predictive skill.

The sediments existing in the natural bed were represented using four sediment classes. The TUFLOW FV cohesive sediment module simulates the exchange of sediments between the bed and the water column. The effective clear water sediment settling velocity of each sediment fraction is directly specified and is assumed to have no dependence on suspended sediment concentration. A distinction between the siliceous and carbonaceous sands has been made because the typical shape of the particles results in markedly different settling velocities. The erosion and settling characteristics of each sediment class is summarised in Table 3-10.

Table 3-10 Characteristics of Simulated Sediment Classes

	Siliceous Sand	Silt	Clay	Carbonaceous Sand
Still Water Fall Velocity, W_s (m/s)	3×10^{-2}	1×10^{-3}	1×10^{-4}	1×10^{-2}
Critical Shear Stress Erosion, T_{ce} (Pa)	0.2	0.2	0.2	0.2
Critical Shear Stress Deposition, T_{cd} (Pa)	0.2	0.18	0.18	0.2
Erosion Rate Constant, E (g/m ² /s)	0.1	0.1	0.1	0.1
Sediment Particle Density, ρ_s (kg/m ³)	2650	2650	2650	2650

The composition of the natural bed relates to the proximity of sediment sources and the bed shear stress climate (due to currents and waves) that causes redistribution of the sediment. The inner shelf (from the coastline to approximately 20 m depth) is dominated by terrigenous sediments, reflective of fluvial sources and the limited cross shelf mixing. The relative carbonate content within the seabed generally increases with distance from the coastline where it usually forms the dominant sediment class beyond the 20m depth contour (the beginning of the middle shelf between 20-40m depth). The carbonaceous grains are predominantly sand and gravel sized particles.

Within Trinity Bay, there is a strong correlation between the local bed shear stress climate and the proportion of siliceous sand within the seabed as described in BPA (1984), Carter et al. (2002), Mathews et al. (2007) and observed in sediment samples collected by Ports North within Trinity Bay. The wave component of the bed shear stress increases towards the coastline and so too does the sand content within the natural bed. Sands will also form the dominant sediment fraction in areas where the current component of the bed shear stress is conducive to the erosion of finer sediments.

The composition of the natural bed and the bed shear stress climate were considered using a two-staged approach to develop a representative “initial condition” distribution of bed sediments. To account for the sediment sources, the relative proportions of the four sediment classes in the “pre-warmup” bed were assigned based on existing information (e.g. BPA, 1984; Carter et al., 2002 and Mathews et al., 2007) and depending on the proximity to the coastline:

- Between the coastline and the 15 m depth contour the initial bed comprised of:
 - 4.5 % siliceous sand;
 - 75 % silt;
 - 20 % clay; and
 - 0.5 % carbonaceous sand.
- Beyond the 15 m depth contour the initial bed comprised of:
 - 3.75 % siliceous sand;
 - 25 % silt;
 - 1.25 % clay; and

- 70 % carbonaceous sand.

Consideration was given to the bed shear stress climate by undertaking an initial “warmup” simulation which included a large wave event and representative tide and regional current forcing. This process allowed the composition of the “pre-warmup” bed to redistribute toward a quasi-equilibrium assumed to be representative of the natural bed. The warmup simulation also provided a means to smoothen the transition from terrigenous sediments that dominant the nearshore to the predominantly carbonaceous sediments found offshore. The “pre-warmup” and “post-warmup” bed sediment distributions are presented in Figure 3-34.

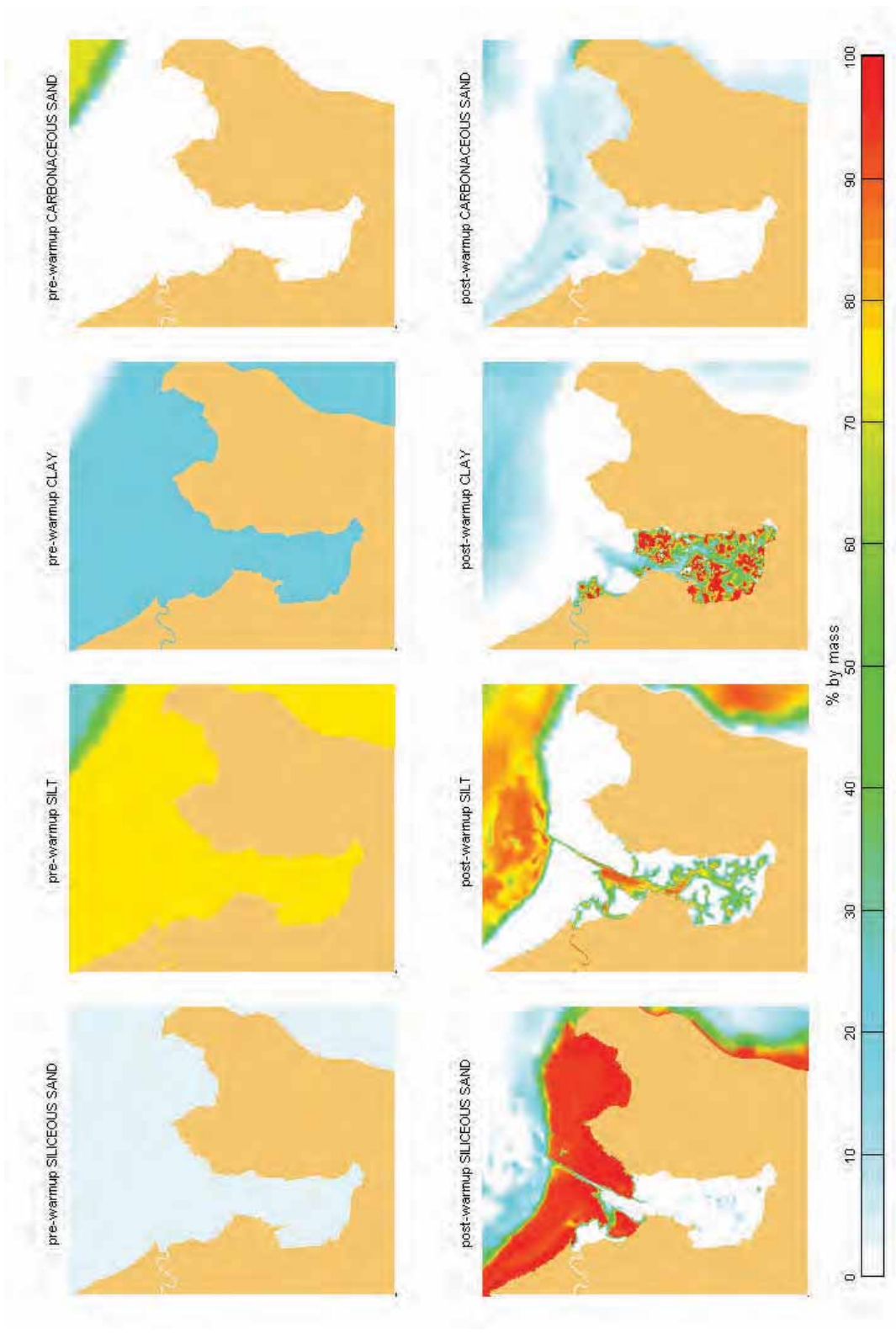


Figure 3-34 “Pre-Warmup” and “Post-Warmup” Bed Sediment Distributions

3.6.2 Sediment Re-suspension Model Calibration Results

The calibration period described in Section 3.3 was used for sediment module calibration. This period incorporated several wave events and multiple spring-neap tidal cycles and therefore represents a typical range of conditions.

In Section 3.6.2.1 the ambient TSS calibration plots at each continuous data recording location (DMPA, Site 2, Beacon C7 and Beacon C11) are presented. In addition, the mass of sediment that settled in the dredged channel during the calibration period has been used to derive an annual siltation depth. This is compared long-term annual siltation records in Section 3.6.2.2.

3.6.2.1 Targeted Turbidity Recordings

Active offshore material placement activities associated with dredging at Wharf 12 and the Marlin Marina were being undertaken during the calibration period (Ports North 2013, pers. comm. 14 October)². There are several short periods of elevated TSS recorded at the DMPA due to these activities, most notably during early April when a peak TSS concentration close to 500mg/L was observed for a short period. No attempt was made to simulate the material placement activities as the focus of the initial sediment module calibration was the re-suspension of natural bed sediments. Detailed calibration of the model to dredging and offshore placement activities is described in Section 4.

Sediment module calibration results at the continuous data recording locations are presented in Figure 3-35 to Figure 3-38 and demonstrate the following:

- The near bed, background ambient TSS concentration (approximately 25mg/L) is under predicted by the model. This behaviour has been observed by BMT in previous North Queensland Port assessments (e.g. Port of Townsville) and the recorded background ambient TSS during calm conditions is understood to be due in part to non-sediment based biological sources such as planktonic algae. A better representation of lower TSS levels could be achieved by adopting a more complex NTU-TSS relationship that does not intercept zero when converting the measured nephelometer data.
- The response in the natural TSS signal due to wind-driven wave and current events between 11-14 April and in early May is particularly well represented in the model with respect to both magnitude and timing at the offshore locations (DMPA and Site 2).
- The recorded TSS concentration at Beacon C7 and Beacon C11 exhibits a tidal signal. Close inspection suggests that a phase lag between peak tidal currents and peak TSS concentration is present, suggesting that plumes of suspended sediment are sourced from beyond the immediate surrounds of the nephelometer and advected with the tides over the instrument.
- Ambient TSS concentration prediction throughout the calibration period is considered adequate, particularly at offshore locations. It is noted that short peaks in TSS concentration along the inner channel are at times under predicted. In terms of the maintenance dredging assessments, an under prediction in ambient TSS will lead to conservative dredge impact predictions.

² Backhoe dredging and material placement at the DMPA via a barge

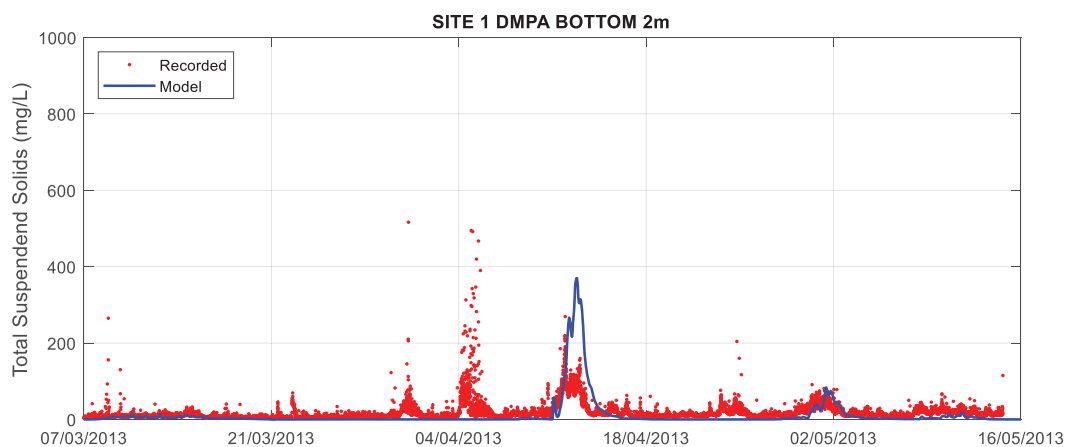


Figure 3-35 Sediment Re-suspension Calibration – DMPA

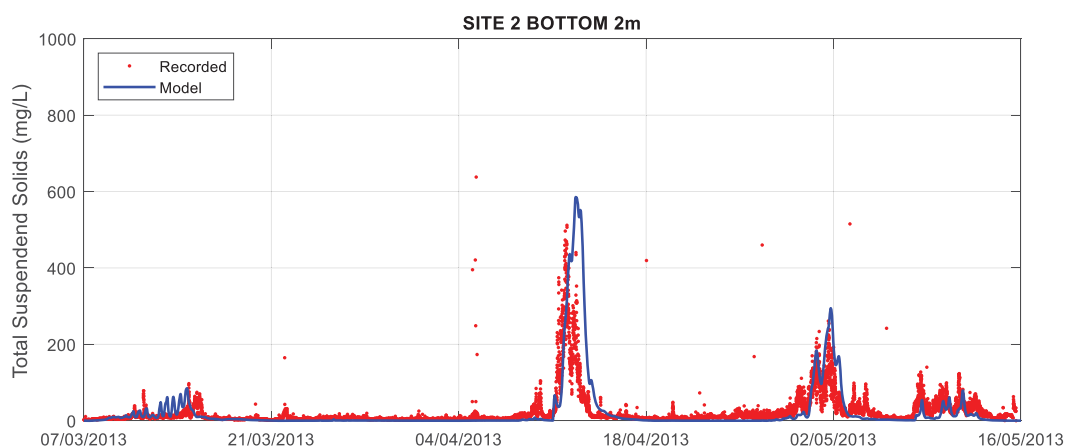


Figure 3-36 Sediment Re-suspension Calibration – Site 2

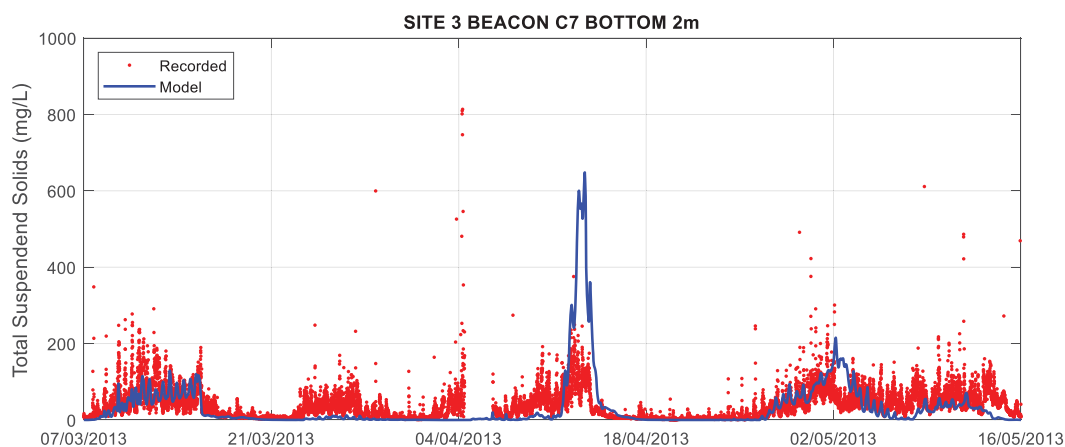


Figure 3-37 Sediment Re-suspension Calibration – Beacon C7

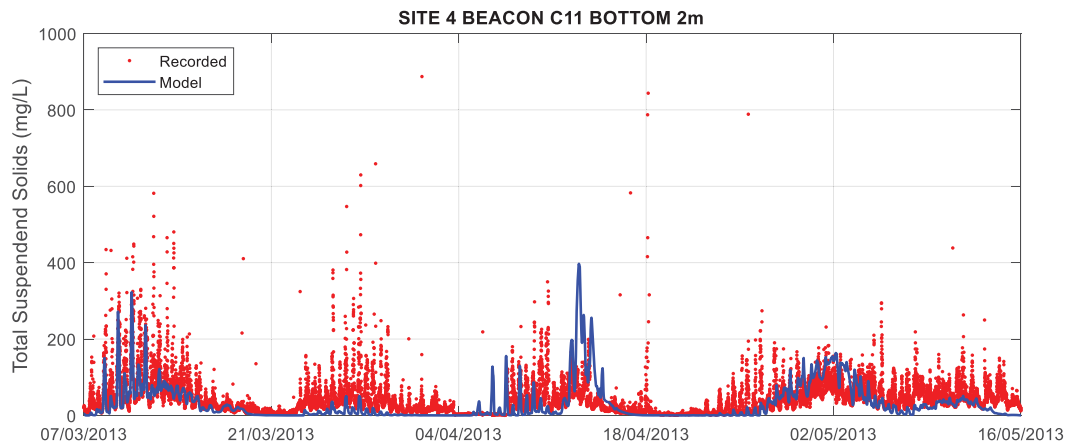


Figure 3-38 Sediment Re-suspension Calibration – Beacon C11

3.6.2.2 Channel Sedimentation Calibration

The mass of sediment which settled in the dredged channel during the calibration period was used to derive an annual siltation depth. As a validation of the sediment transport model performance this estimate was compared with the measured sedimentation provided by Ports North and presented in Figure 3-39. The conditions which resulted in the re-suspension and deposition of sediments in the study area during the calibration period were reasonably representative of longer-term conditions (as detailed in Section 3.3).

The measured localised peaks in siltation close to Beacon C11 and C18 are represented by the model. The derived annual siltation volume of approximately 480,000 m³ (from Berth 1 to Beacon C1) is larger than the long-term average (for years 1990-2010) provided by Ports North however less than the maximum (approximately 760,000 m³) for the reported period. The predicted siltation rates and total volume are therefore considered to be towards the upper end of the historical limit.

Siltation modelling of the outer channel post-CSDP showed a possible volumetric increase of 6% per annum (BMT WBM, 2017). This and other developments relevant to future maintenance dredging are discussed further in Section 6.

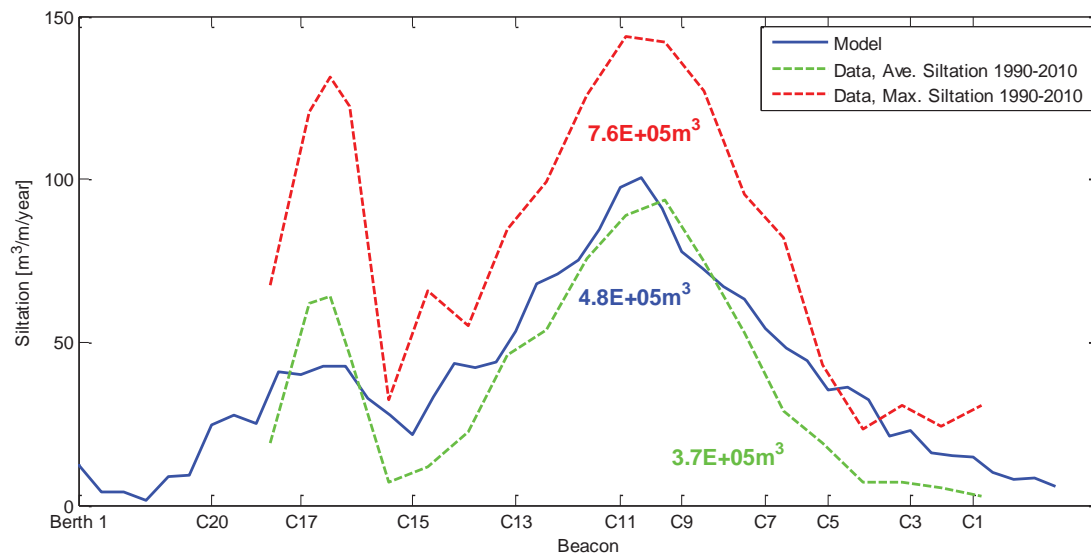


Figure 3-39 Estimated and Measured Annual Siltation of Shipping Channel

4 Maintenance Dredge Plume Advection-Dispersion Calibration

4.1 Targeted Plume Monitoring Program

In 2010, a Long Term Management Plan (LTMP) for Dredging and Disposal 2010-2020 (Worley Parsons, 2010) was developed for the Port of Cairns and approved by the Great Barrier Reef Marine Park Authority (GBRMPA) and the Port of Cairns Technical Advisory Consultative Committee (TACC). An environmental monitoring program within the LTMP requires verification of the “typical” extents of plumes of suspended sediment generated during maintenance dredging operations. Information gathered from the monitoring program is intended to assist in the management of future dredging operations.

Maintenance dredging of the Port and entrance channel was undertaken in August 2011 by the trailing arm suction hopper dredger (TSHD) *Brisbane*, operated by the Port of Brisbane Pty Ltd. BMT was commissioned by Ports North to monitor the extent of turbid plume development during maintenance dredging operations by *TSHD Brisbane* in accordance with the LTMP and their environmental management system. Maintenance dredge plume monitoring was also undertaken in 2015 however this subsequent campaign was not for the specific purpose of collecting data for model calibration purposes.

Dredge plume monitoring was conducted by BMT in the nearshore and offshore areas of the Port of Cairns from 28th – 30th August 2011. These measurements have been used to assist the calibration of the advection-dispersion model and to guide the adoption of specific sediment loading rates for the proposed dredging activities.

Monitoring of the extents of dredging and placement plumes within the Port of Cairns occurred over 3 days between the Sunday 28th and the Tuesday 30th August 2011 using the research support vessel *Viking* as a platform for all measurements.

DMPA plume measurements were completed during light winds and generally calm seas on Sunday 28th August 2011. Three dumping events were monitored on this day, consisting of one ebb tide event beginning in the late morning and two flood tide events in the afternoon.

Dredge plume monitoring about the shipping channel coincided with periods of moderate south-easterly trade winds on the 29th and 30th August 2011, with wind strengths typically ranging between 15 and 20 knots with occasional rain squalls. The windy conditions together with strong spring tide currents generated significant natural re-suspension of muddy seabed sediments in the shallow Port waters during the monitoring.

4.1.1 Data Processing

Measurements of turbidity in Nephelometric Turbidity Units (NTU) and Total Suspended Solids (TSS) results from the laboratory were compared in order to establish the TSS – NTU relationship shown in Figure 3-1. The turbidity measurements (converted into TSS) and the water sample TSS results were then used as the basis for converting the ADCP backscatter measurements to TSS concentrations.

Maintenance Dredge Plume Advection-Dispersion Calibration

It is noted that the TSS-NTU relationship for Cairns has been further developed using additional measurements and water samples collected as part of the CSDP. The relationship adopted for the maintenance dredging assessments has been previously presented in Figure 3-1.

4.1.2 Geotechnical Assumptions

Maintenance dredge material has been represented as per previous studies (BMT WBM, 2017; BMT WBM, 2014) using three sediment fractions. The parameters of each fraction are shown in Table 4-1 with the silt and clay fractions making up the bulk of the maintenance material (collectively referred to as 'fines').

Table 4-1 Nominal Maintenance Dredge Material Sediment Fraction Parameters

Sediment Fraction	Distribution (%)	Settling Velocity (m/s)
Sand	5	1×10^{-2}
Silt	65	5×10^{-4}
Clay	30	1×10^{-4}

4.2 Model Parameters

Dredging works create plumes of suspended sediment through several potential sources/mechanisms. The major sources considered for modelling the *TSHD Brisbane* were:

- Sediment entrainment at the drag head during dredging;
- Overflow of sediment from the hopper; and
- Placement of material at the DMPA by hopper release.

The measured 3D TSS concentrations from the January 2011 ADCP transects were compared to simulations of plume dispersion using the TUFLOW FV sediment transport module coupled with the calibrated hydrodynamic models in order to calibrate the dredge plume source parameters.

The *TSHD Brisbane* dredge logs were obtained and used to locate the dredge and also to determine the mode of operation (i.e. dredging, dredging with overflow or dumping).

Prediction of dredge plume impacts involves several components, namely:

- Source rate definition (i.e. mass load and characteristics of sediment entrained by the dredging activities);
- Prediction of plume advection/dispersion; and
- Prediction of plume settling.

The first of these is the most variable and depends intimately on the type of dredging activities and equipment as well as the material being excavated. As such, this component of the dredge plume modelling is also the most subject to variation. Initially, the source parameters were chosen based on advice from the dredging consultant (see Appendix E), experience on similar projects and literature values. These parameters were then modified during the calibration process based on comparisons with the measured data and following leading practice guidelines including Kemps and

Maintenance Dredge Plume Advection-Dispersion Calibration

Masini (2017) and Becker et al. (2015). The source terms adopted after model calibration are summarised in Table 4-2.

Table 4-2 Plume Generation Assumptions

Source Term Description (and Input in the Vertical Dimension)	Release Rate (%)	Fines Mass Flux (kg/s)	Total Mass of Fines (Tonnes)
Dredging without Overflow (input to water column)	0.15	1	279
Overflow Dredging (input to water column)	39.1	250	97,167
Dumping Passive Plume (input to water column)	13.3	200	41,520
Dumping Dynamic Plume (input near bed)	6.66	100	20,760
Dumping Bed (input added to DMPA and immediately available for resuspension)	80.0	1,200	249,120

For modelling purposes, the plume source rates have the units kg/s (flux) and are entered as a timeseries boundary condition, developed from actual dredge logs described above. The hydrodynamic and meteorological conditions during dredging varies in time and space and this is captured by the model.

Examples of the plume validation exercise are illustrated in Figure 4-1 to Figure 4-5 for channel dredging and Figure 4-6 to Figure 4-9 for DMPA placement. The upper panels in each figure show transects through the dredge plume, with contour plots of TSS measured by the ADCP (on the left) and modelled (on the right). The lower panels show a plan view of depth-averaged TSS, with the model results in the background and the ADCP-measured TSS shown as a black-bordered line along the transect. A red cross marks the start point (0 m chainage in the upper panel) of the transect. The channel dredging figures represent five individual transects during a 36-minute period and are presented in chronological order. The DMPA placement figures represent four individual transects during a 55-minute period following a single hopper release. The first figure in each series is annotated to aid interpretation.

The plume advection-dispersion validation results generally indicate that the model is accurately reproducing the pattern of suspended sediment distribution associated with dredge plumes. The accuracy of the ADCP data in the near field is sometimes uncertain due to bubbles and turbulence generated by the dredge propeller wash (as noted on Figure 4-6 and Figure 4-9). Given the complexity of data collection campaign and the modelling task, the highly three-dimensional nature of plumes and the temporal variation in the actual dredge discharge, a high degree of model predictive skill is demonstrated.

Maintenance Dredge Plume Advection-Dispersion Calibration

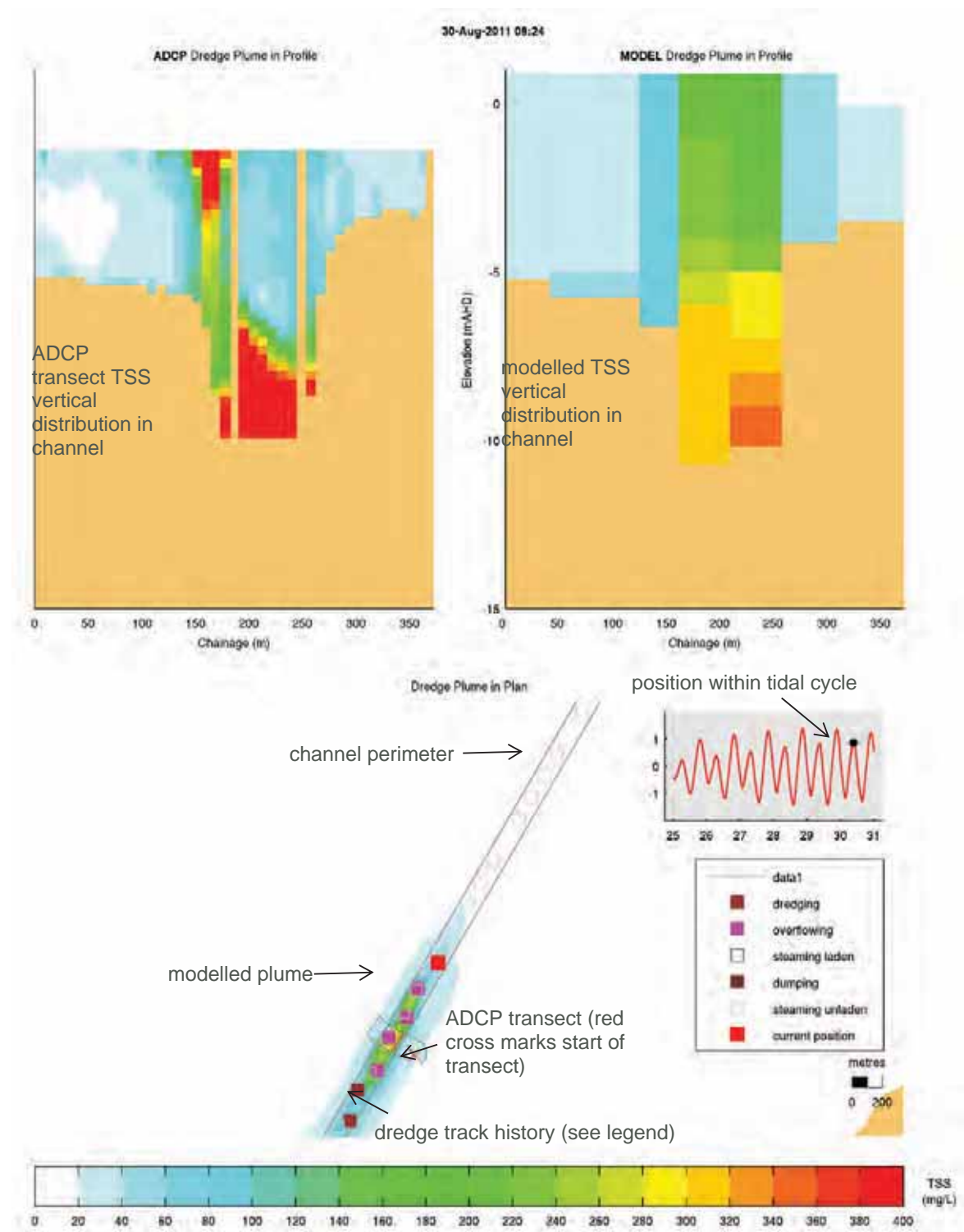


Figure 4-1 Maintenance Dredging Plume Validation, 30/08/2011 09:24: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

Maintenance Dredge Plume Advection-Dispersion Calibration

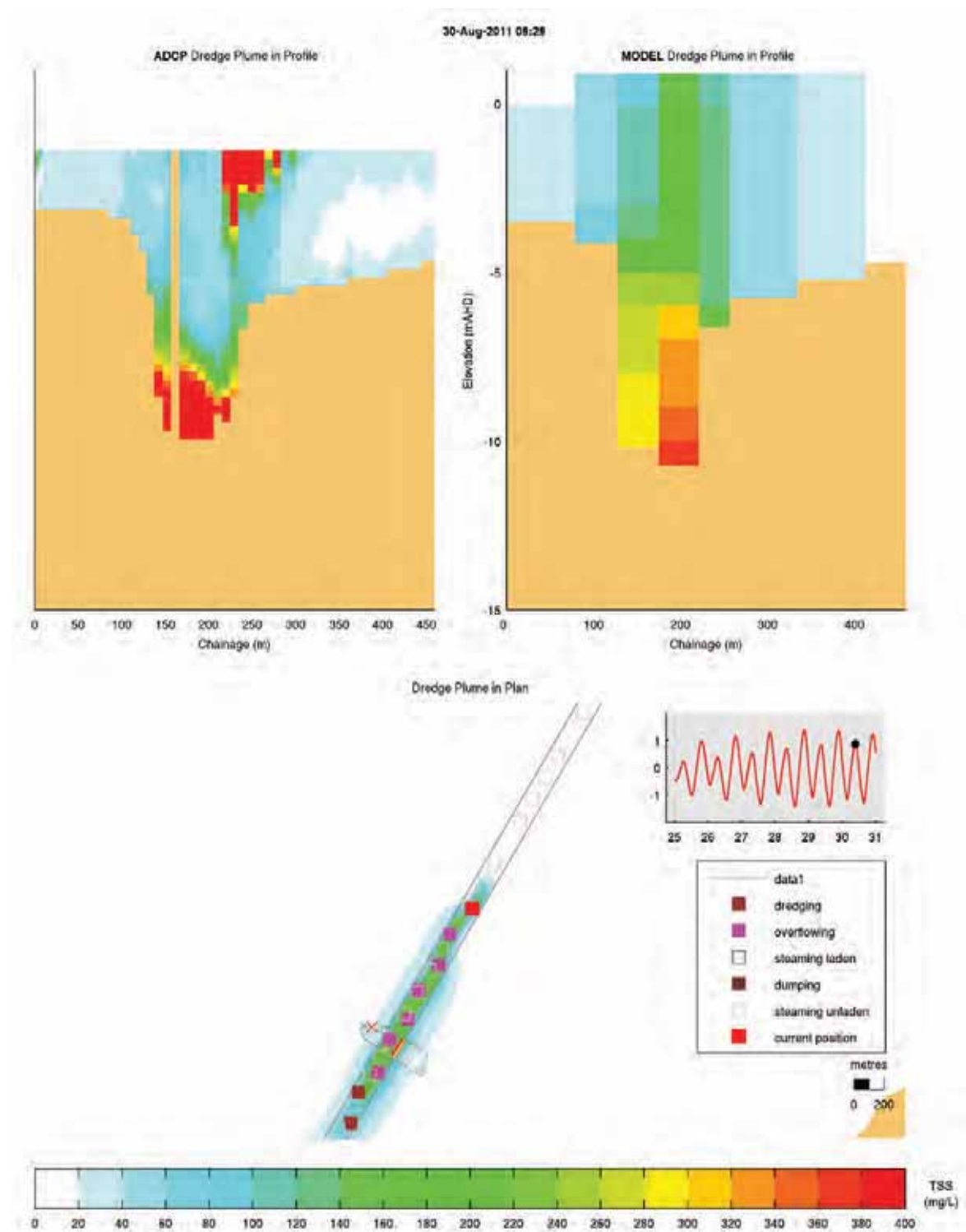


Figure 4-2 Maintenance Dredging Plume Validation, 30/08/2011 09:29: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

Maintenance Dredge Plume Advection-Dispersion Calibration

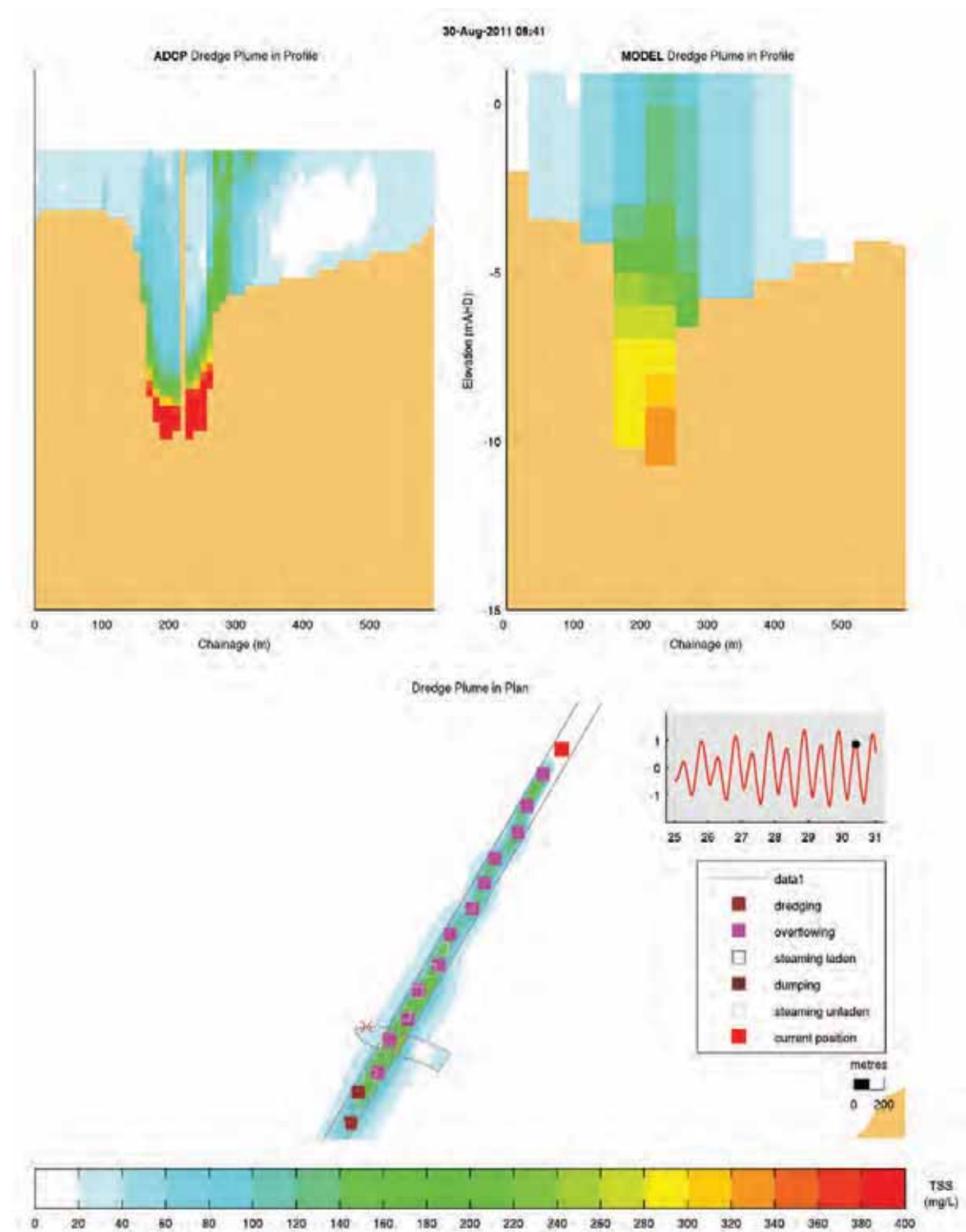


Figure 4-3 Maintenance Dredging Plume Validation, 30/08/2011 09:41: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

Maintenance Dredge Plume Advection-Dispersion Calibration

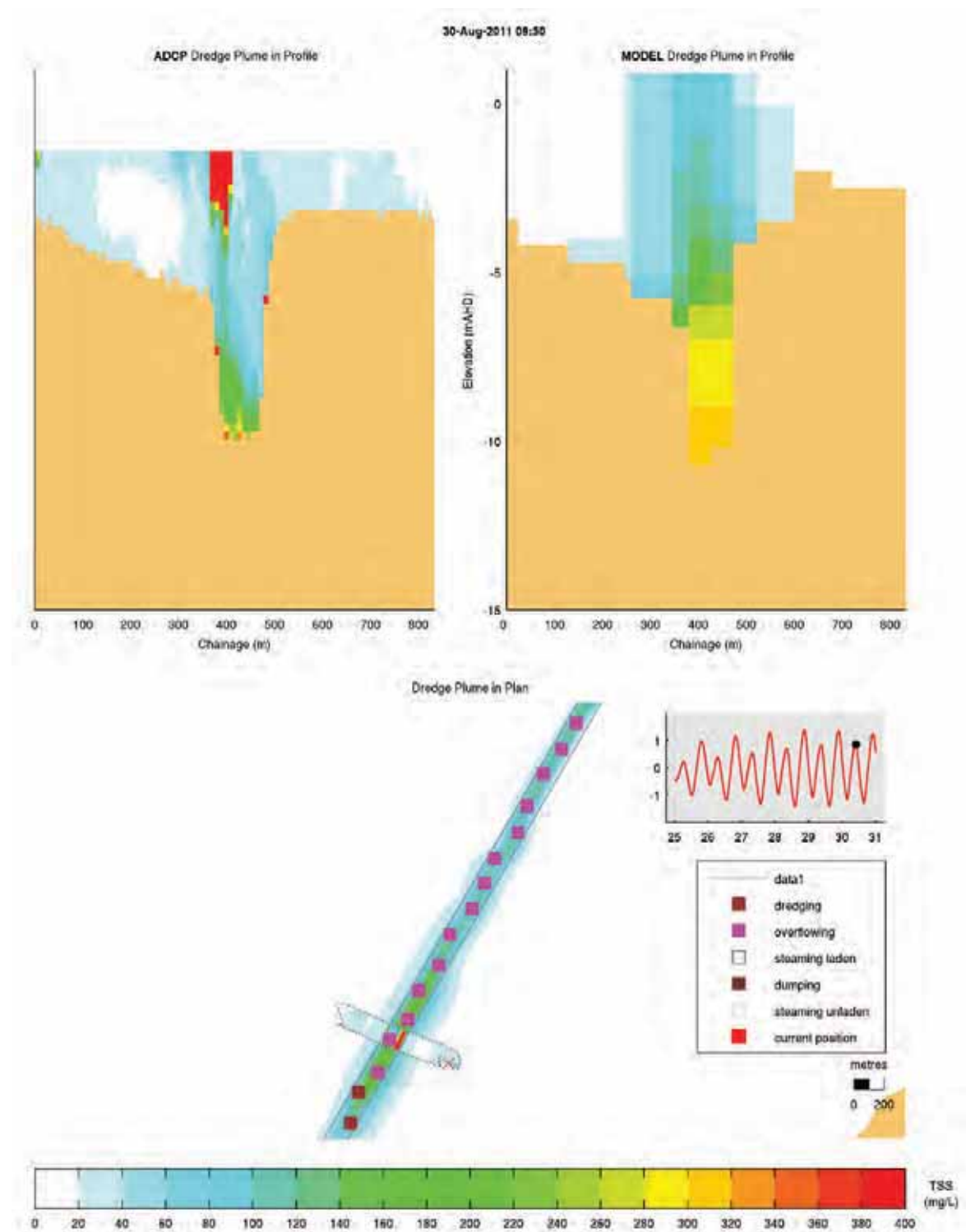


Figure 4-4 Maintenance Dredging Plume Validation, 30/08/2011 09:50: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

Maintenance Dredge Plume Advection-Dispersion Calibration

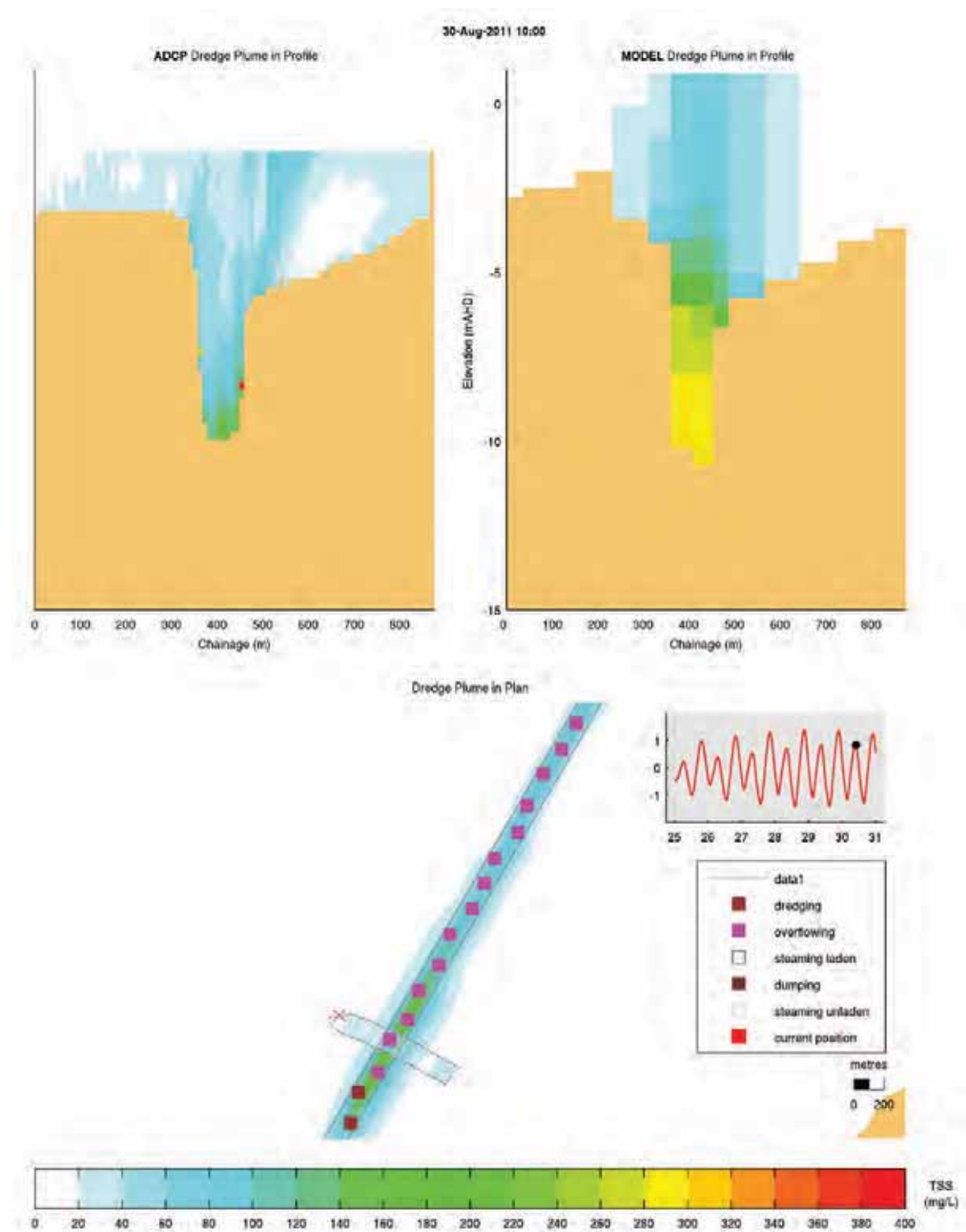


Figure 4-5 Maintenance Dredging Plume Validation, 30/08/2011 10:10: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

Maintenance Dredge Plume Advection-Dispersion Calibration

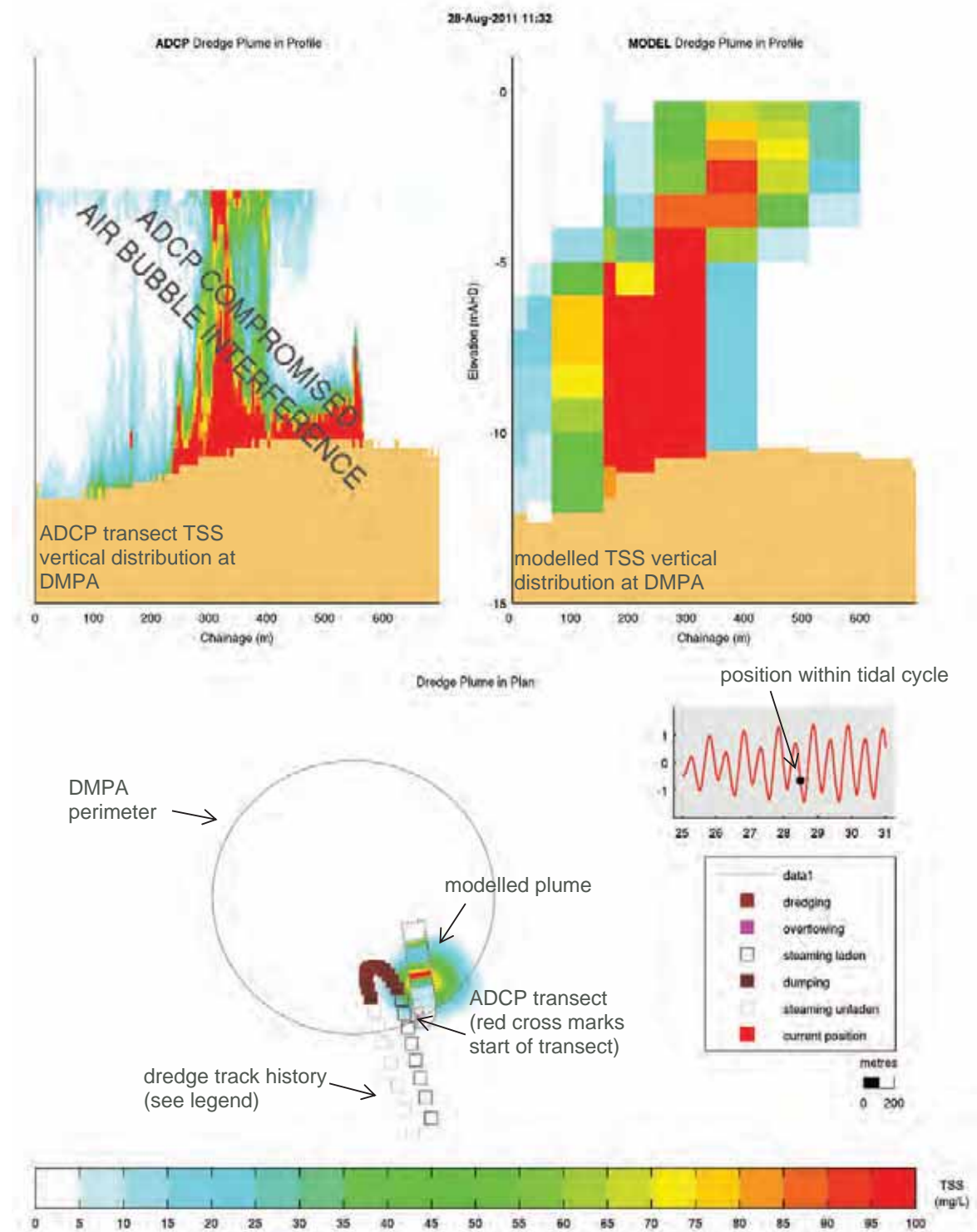


Figure 4-6 DMPA Plume Validation, 28/08/2011 11:32: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

Maintenance Dredge Plume Advection-Dispersion Calibration

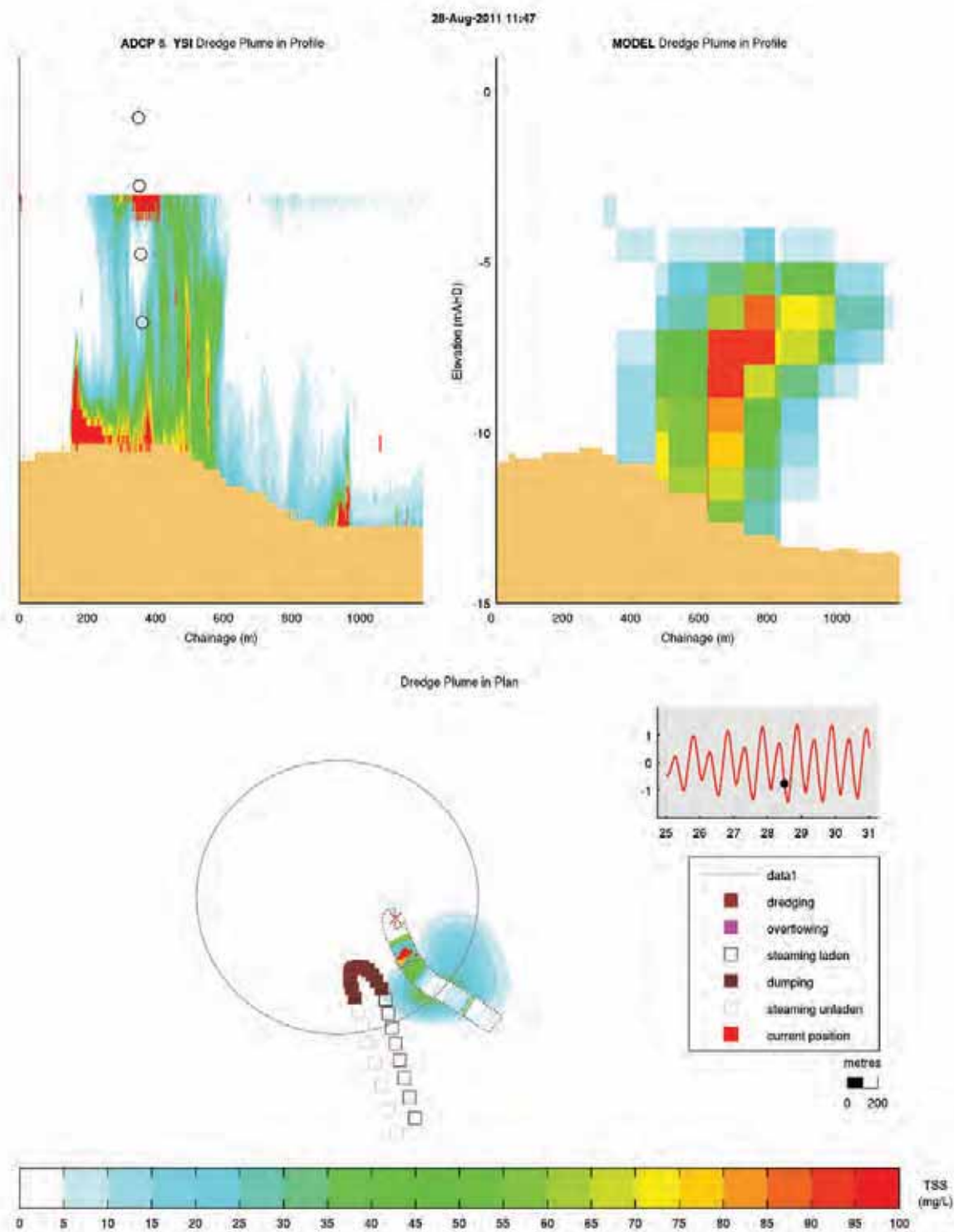


Figure 4-7 DMPA Plume Validation, 28/08/2011 11:47: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

Maintenance Dredge Plume Advection-Dispersion Calibration

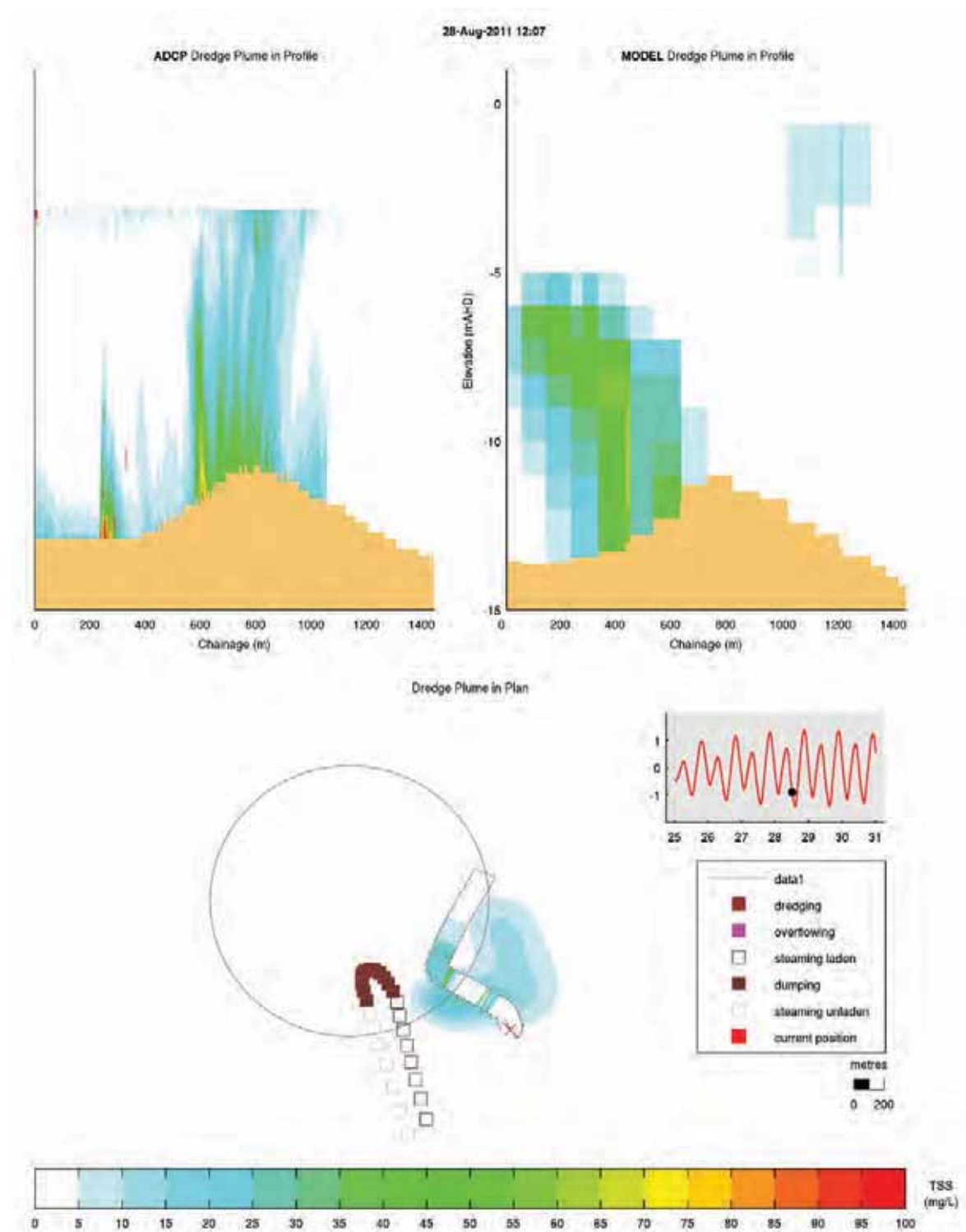


Figure 4-8 DMPA Plume Validation, 28/08/2011 12:07: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

Maintenance Dredge Plume Advection-Dispersion Calibration

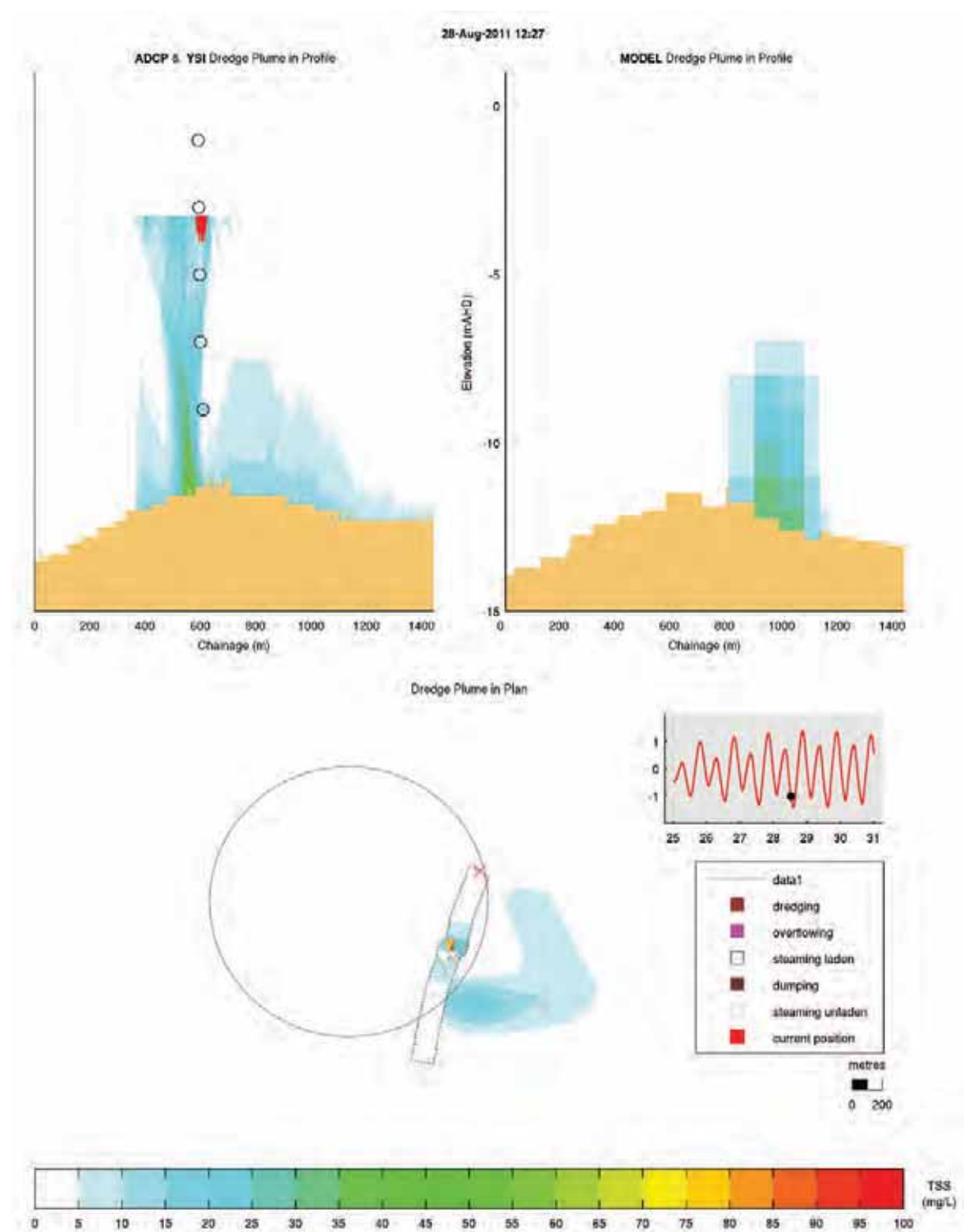


Figure 4-9 DMPA Plume Validation, 28/08/2011 12:27: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

5 Model Validation

5.1 Baseline Validation Data

The baseline validation data was obtained as part of the CSDP data collection campaign. Relevant information regarding this campaign has been previously provided in Section 3.2.

5.2 Validation Period Characteristics

As described in Section 3.3, the study area experiences a tropical climate. The “dry season” period typically occurs from May to October where the synoptic meteorological pattern is strongly influenced by the Coral Sea trade winds.

The model calibration simulation period was from July to October 2013 and therefore dominated by dry season months. The representativeness of this period relative to the wind and wave climate long term averages is discussed below.

5.2.1 Wind

Wind roses for the validation period and the long term average of the simulation period months (i.e. June to October inclusive) are compared in Figure 5-1 (offshore location) and Figure 5-2 (Cairns Aero). Note that at the offshore location the simulation period wind rose is based on recorded data from Arlington Reef (consistent with the constructed wind field described in Section 2.1.3.2) while the long term average is based on recordings from nearby Green Island (approximately 15km to the south west) where a longer data record was available. The validation period wind characteristics are as follows:

- The offshore wind roses show the predominance of south to south-easterly trade winds. The offshore directional spread of winds for the simulation period appears consistent with the long-term average however the 10-minute wind speed exceeds 14 m/s (approximately 27 knots) on fewer occasions than average. This is consistent with the calibration period/long term average assessment and the slight difference in wind magnitude may be influenced by the comparison being across two different weather station locations.
- As described in Section 3.3.1, there are significant orographic influences within the nearshore regions of the study area and this is reflected in the Cairns Aero wind roses which are distinctly different to the more exposed locations within the GBR lagoon. The Cairns Aero wind directional spread is predominantly south-south-west to south-easterly. The roses also reveal a subtle land breeze/sea breeze cycle which occurs along the coastal margin of the study area. The Cairns Aero validation period wind rose is considered consistent with the long-term average.

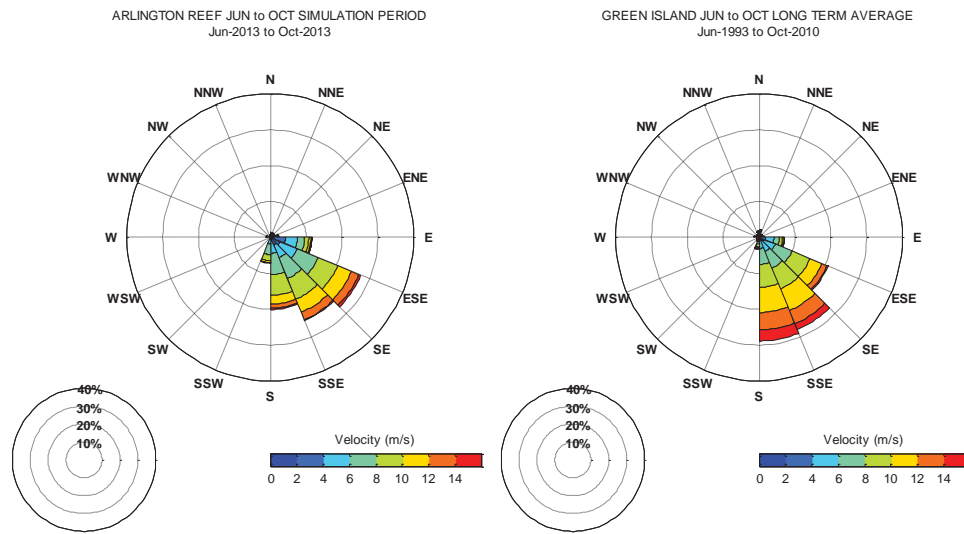


Figure 5-1 Offshore Wind Roses – June to November 2013 Simulation Period (top) and June to November Long Term Average (bottom)

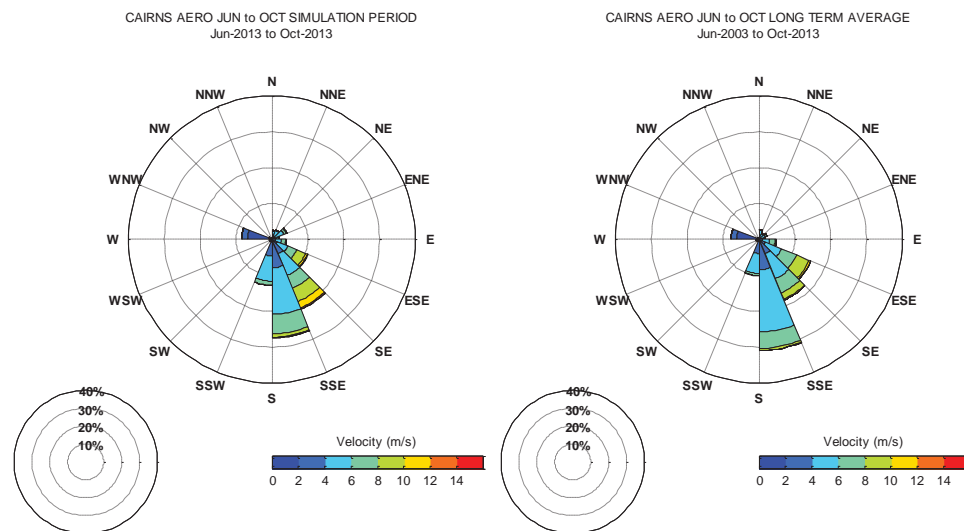


Figure 5-2 Cairns Aero Wind Roses – June to November 2013 Simulation Period (top) and June to November Long Term Average (bottom)

5.2.2 Waves

A validation period wave rose at the Cairns Waverider buoy location is presented in Figure 5-3. As discussed previously in Section 3.3.2, study area is dominated by locally generated wind waves. The largest significant wave height at the Cairns buoy for the validation period was approximately 1.7m with a mean significant wave height close to 0.7m. The validation period includes a number of wave events with significant wave heights above 1m, driven by the strong Coral Sea trade winds.

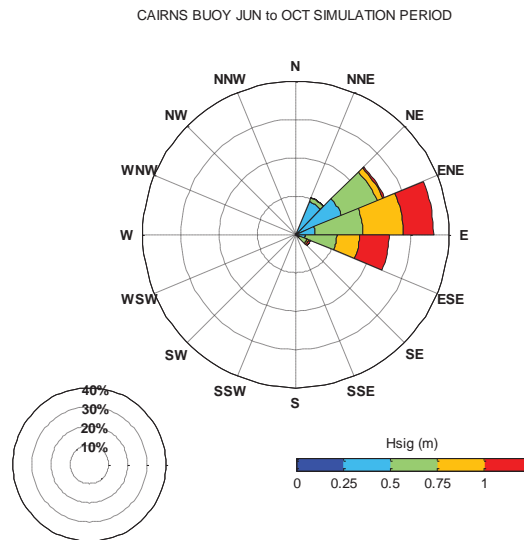


Figure 5-3 Cairns Buoy Wave Rose –June to October 2013 Simulation Period

5.3 Hydrodynamic Model Validation

The hydrodynamic model validation period was from July 2013 to October 2013. The validation simulation was completed using the model parameters adopted for the final calibration simulation (refer Section 3.4 and Appendix A). The simulation period incorporated representative spring and neap tide conditions, a range of meteorological conditions and offshore EAC forcing. In contrast to the calibration period (March to June), the validation period includes “dry season” months typically characterised by strong Coral Sea trade winds. Considering both the calibration and validation periods enabled assessment of the model’s predictive skill for a range of conditions.

In the following sections model validation plots at the DMPA and Beacon C7 are presented. The presentation generally follows the format in Section 3 and includes:

- Water level and depth-average current time series (six-day period);
- Top, middle and bottom third of water column current velocity and direction (six-day period);
- Depth-average current polar plots (entire calibration period);
- Near-bed water temperature time series (entire calibration period); and
- Cairns Port and Trinity Inlet (Swallows Landing) water level time series (two-week period).

The six-day period selected for clear visualisation of the time series comparison includes large spring tides and relatively light wind conditions.

In addition to the above, Appendix F, Appendix G and Appendix H provide further model validation results for the entire validation period:

- Appendix F: top and bottom half of water column current velocity and direction time series (entire validation period);
- Appendix G: top and bottom half of water column current polar plots (entire validation period); and
- Appendix H: Current velocity Quantile-Quantile (Q-Q) plots (entire validation period).

5.3.1 Hydrodynamic Model Validation Results

Generally, the model validation results indicated a predictive skill consistent with the calibration results. The validation results confirm that the adopted model parameters are appropriate for the range of seasonal hydrodynamic conditions typically encountered at Cairns. The validation results are briefly described below.

5.3.1.1 Site 1 DMPA

Model validation results at the DMPA continuous data recording location show the following:

- Figure 5-4 (top plot) suggests variations in water level amplitude at the DMPA are accurately predicted by the model during both spring and neap tides. Tidal phasing is also appropriately represented.
- The current speed at the DMPA is also predicted well by the model. The depth-average current velocity (Figure 5-4, middle plot) and current velocity layer (Figure 5-5) time series plots indicate a very small offshore current magnitude with little variation over depth for the six day period shown.
- Figure 5-4 (bottom plot) and Figure 5-6 suggest current direction is predicted well by the model, with the general flood and ebb tide patterns clearly represented. The top plot in Figure 5-6 shows some minor scatter in the data associated with light winds influencing the currents in the surface layer.
- Predicted and recorded distributions of depth-average current magnitude and direction at the DMPA are presented as polar plots in Figure 5-7. The polar plots are based on the entire validation period and show good overall consistency.

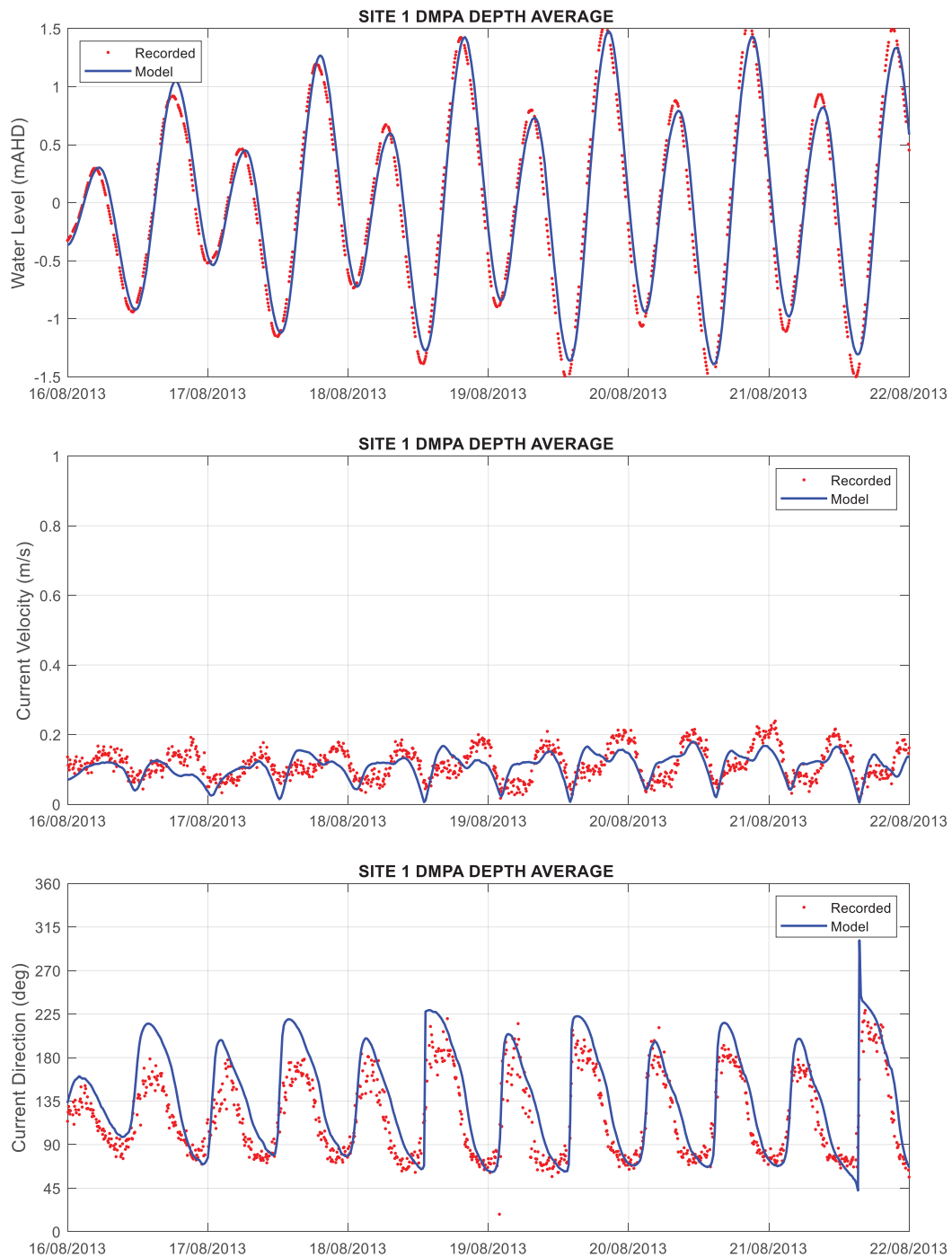


Figure 5-4 Hydrodynamic Model Validation 3D Depth Average – Site 1 DMPA

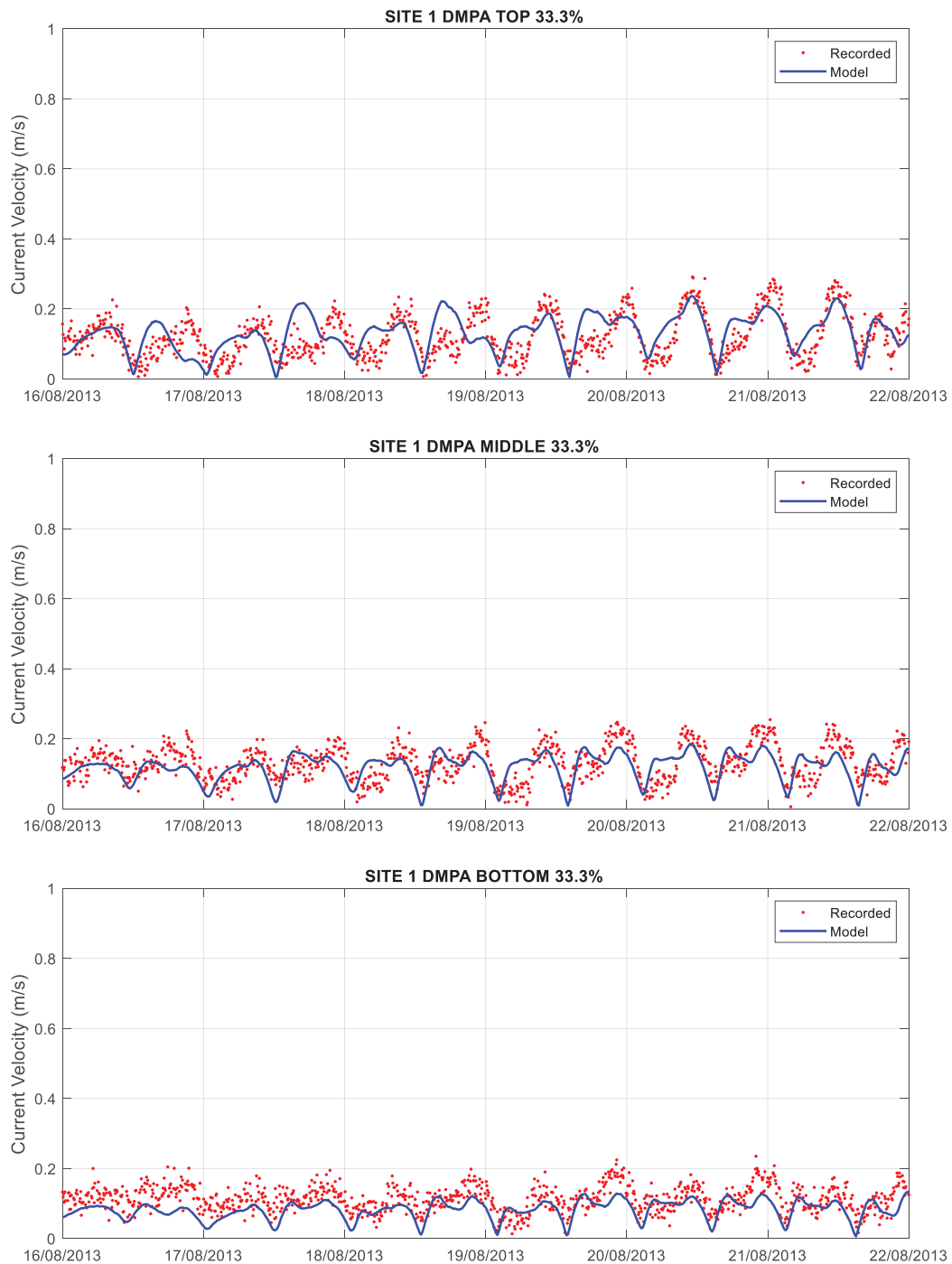


Figure 5-5 Hydrodynamic Model Validation Current Velocity Layers – Site 1 DMPA

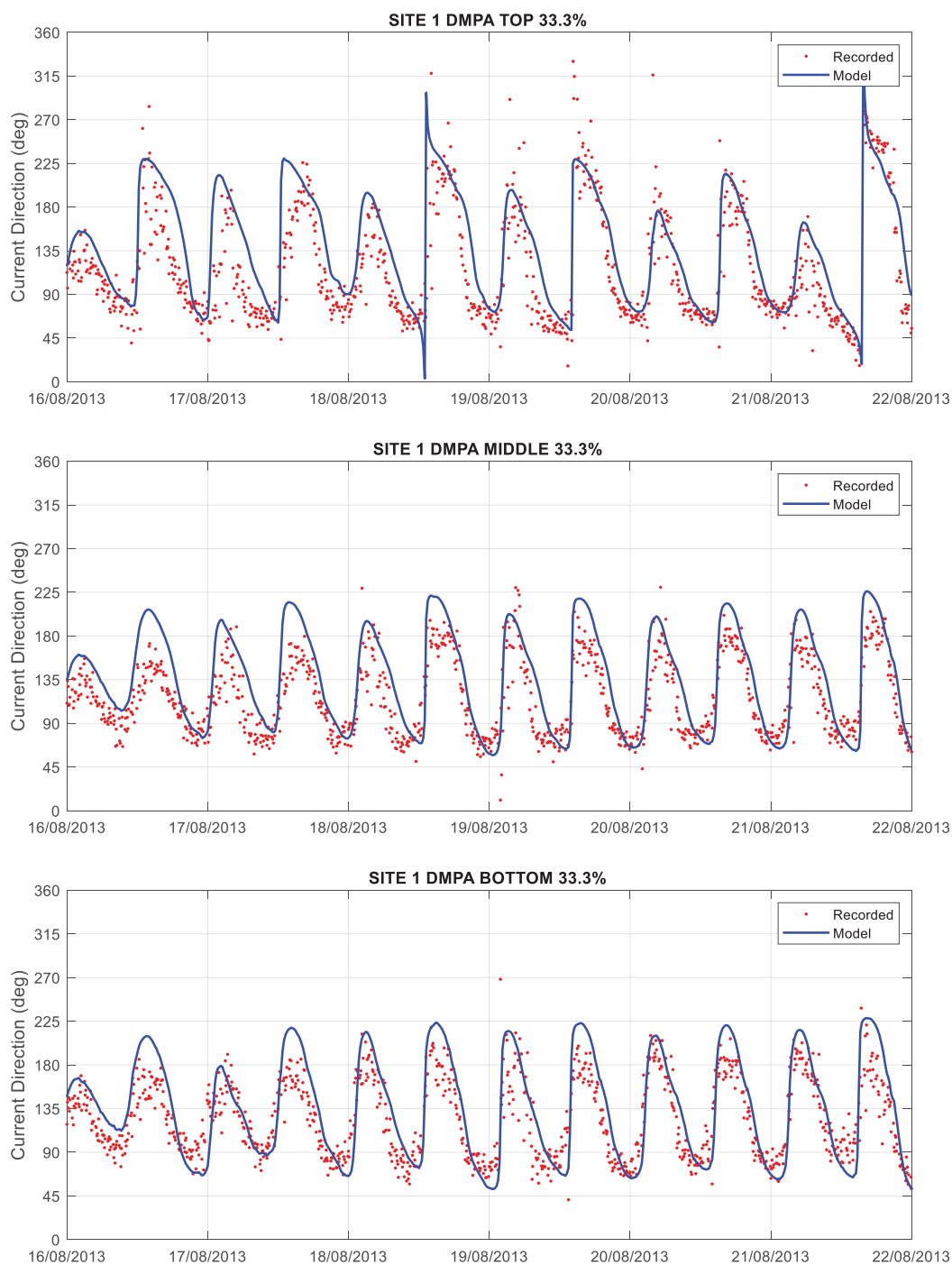


Figure 5-6 Hydrodynamic Model Validation Current Direction Layers – Site 1 DMPA

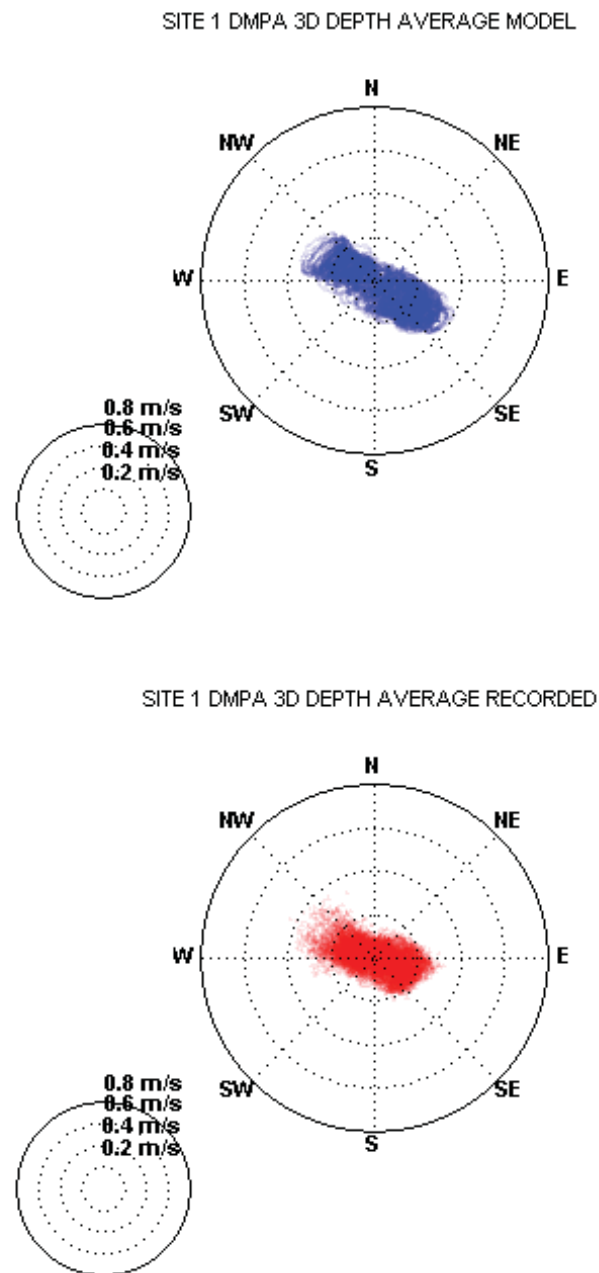


Figure 5-7 Current Polar Plot Validation – Site 1 DMPA

5.3.1.2 Site 3 Beacon C7

Model validation results at the Beacon C7 continuous data recording location show the following:

- Figure 5-8 (top plot) suggests variations in water level amplitude at Beacon C7 are accurately predicted by the model during both spring and neap tides.
- In contrast to the DMPA location further offshore, the Beacon C7 current velocity plots show a clear increase in tidal magnitude during the spring tides. The depth-average current velocity (Figure 5-8, middle plot) and current velocity layer (Figure 5-9) time series calibration plots suggest good model predictive skill, occasionally slightly under predicting the peak ebb currents.
- Figure 5-8 and Figure 5-10 suggest current direction is generally well predicted at Beacon C7 over the six-day period shown.
- Predicted and recorded distributions of depth-average current magnitude and direction at Beacon C7 are presented as polar plots in Figure 5-11. The polar plots are based on the entire validation period and show good overall consistency.

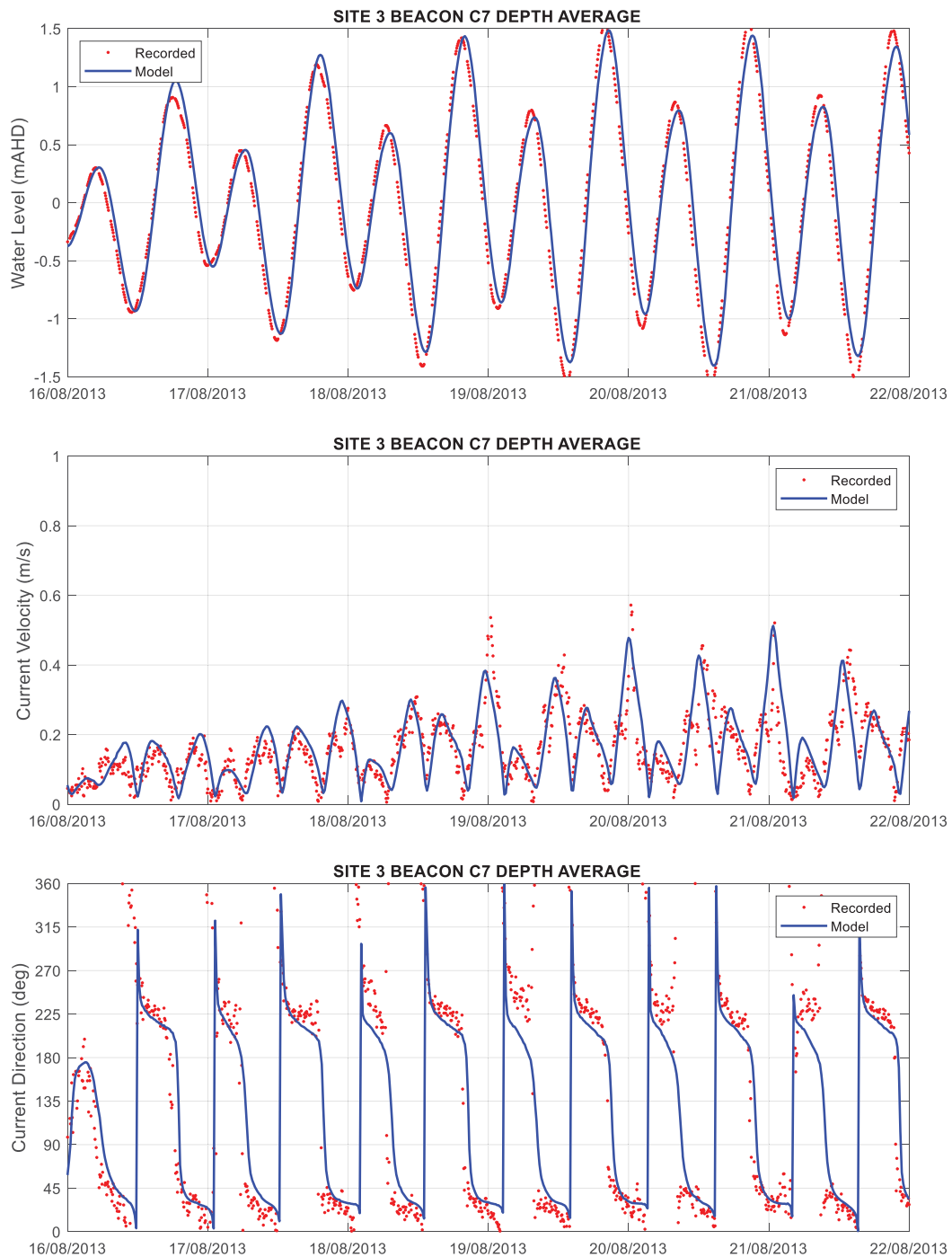


Figure 5-8 Hydrodynamic Model Validation 3D Depth Average – Beacon C7

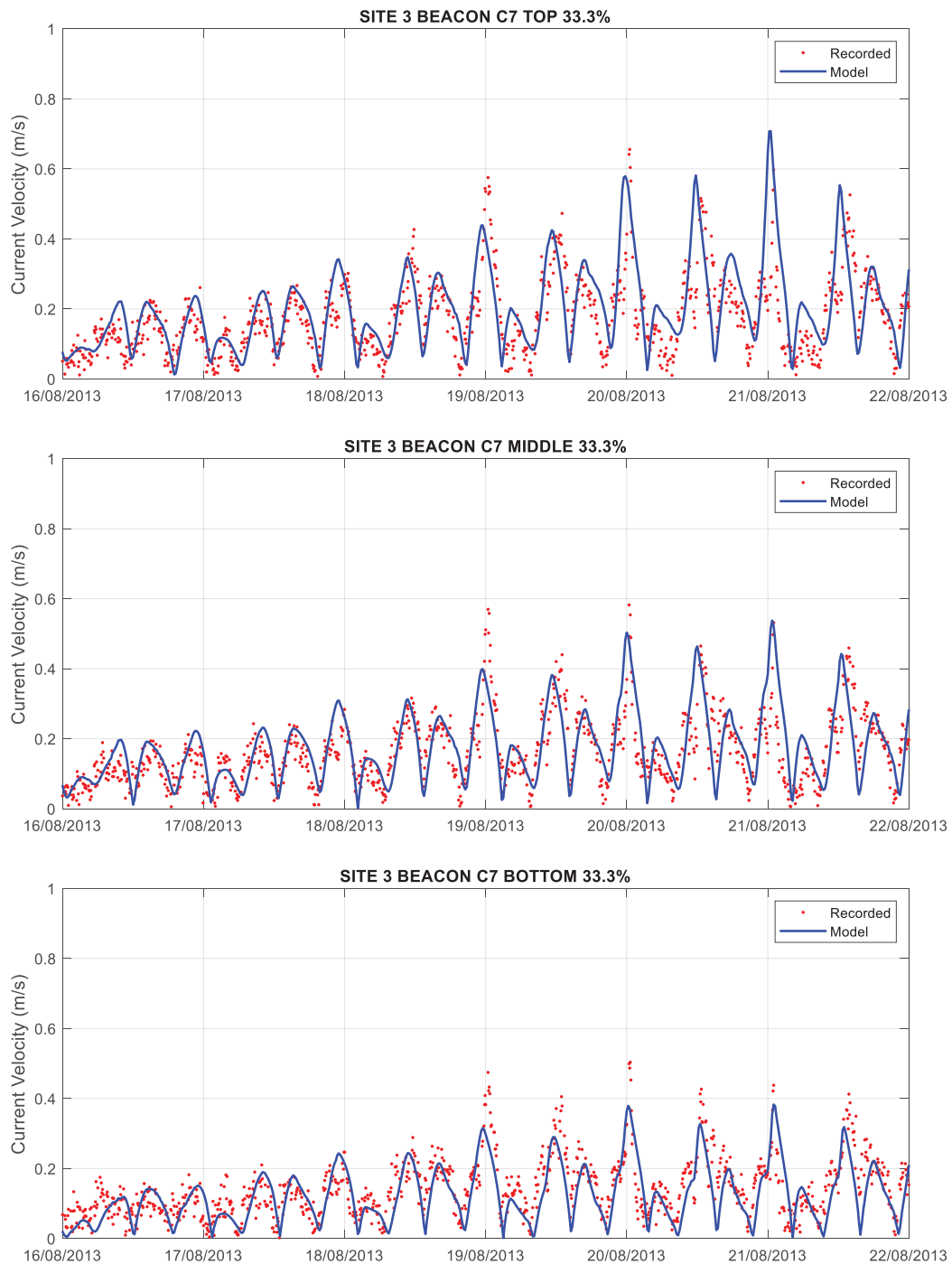


Figure 5-9 Hydrodynamic Model Validation Current Velocity Layers – Beacon C7

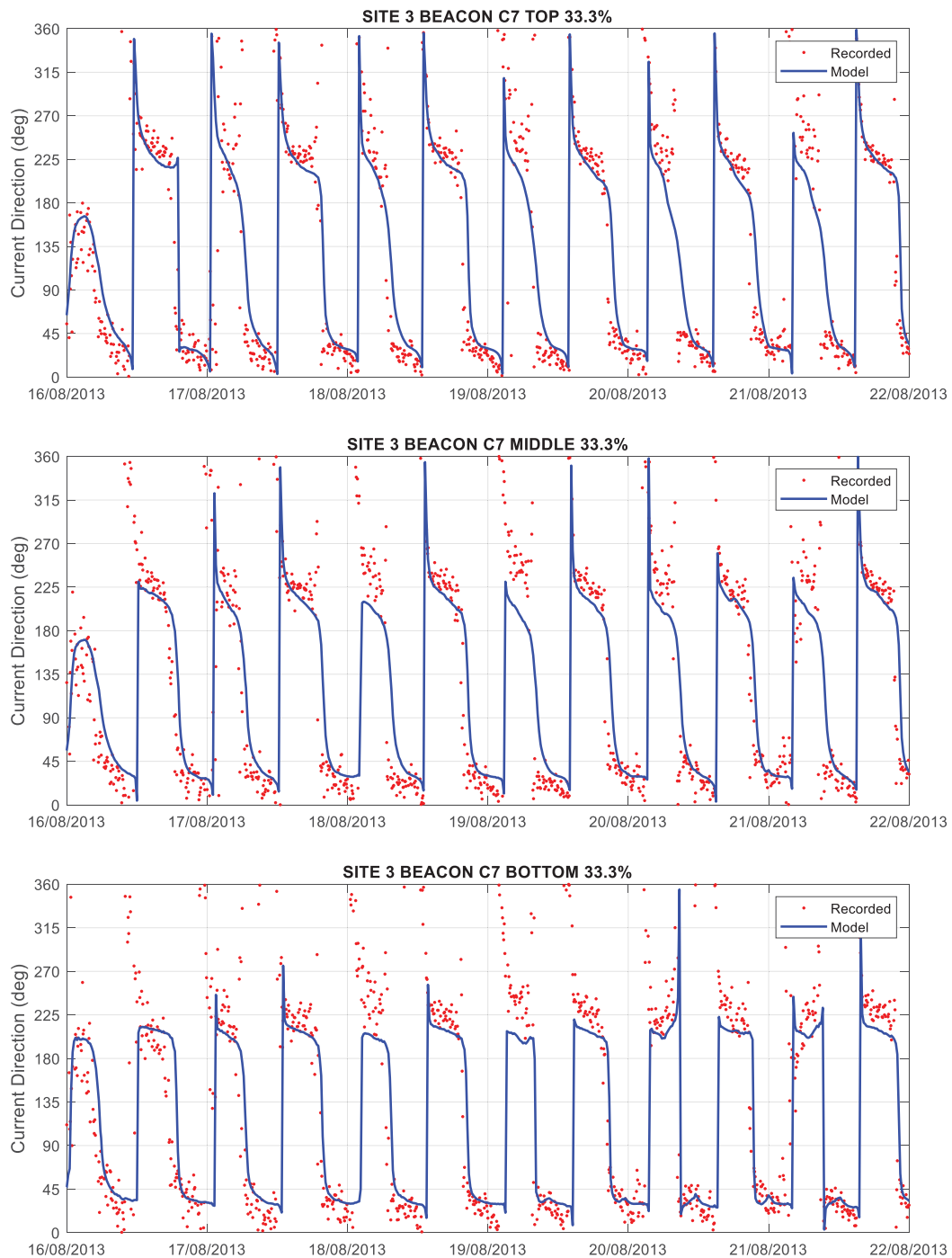


Figure 5-10 Hydrodynamic Model Validation Current Direction Layers – Beacon C7

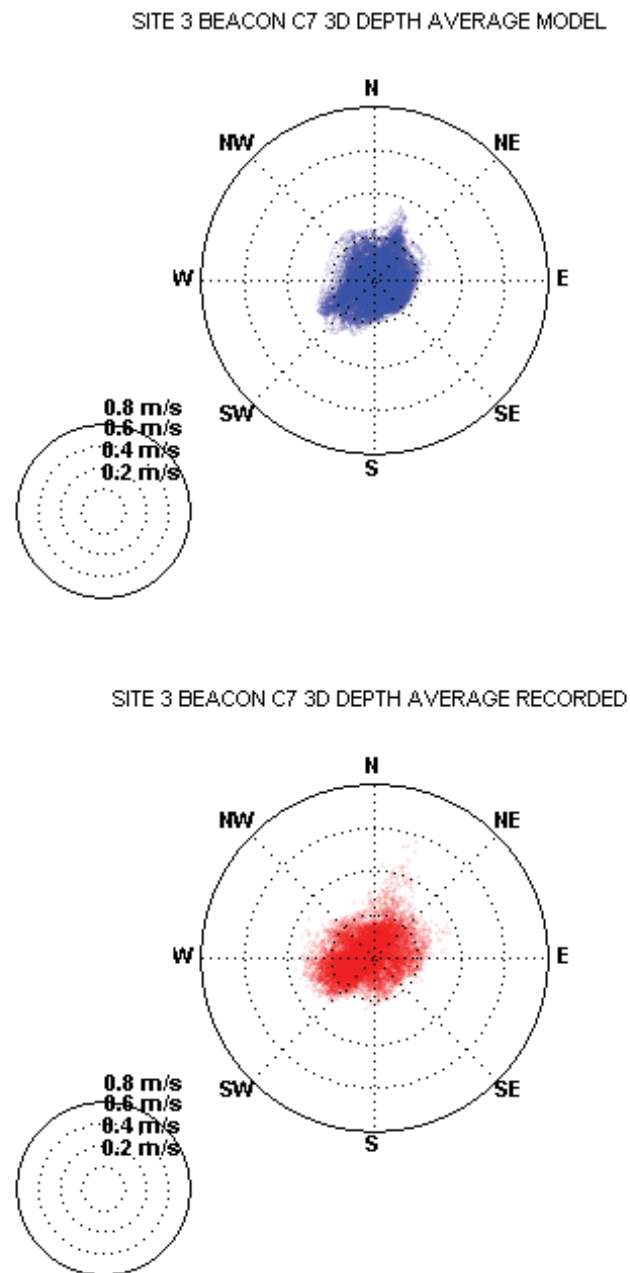


Figure 5-11 Current Polar Plot Validation – Site 3 Beacon C7

5.3.1.3 Cairns Port Gauge and Swallows Landing

Additional continuous water level data was obtained from the Cairns Standard Port Gauge (provided by MSQ) and a pressure transducer deployed near Swallows Landing (southern Trinity Inlet, refer Figure 3-2). These datasets were obtained to further validate the hydrodynamic model performance within the inner port and Trinity Inlet. Figure 5-12 and Figure 5-13 demonstrate satisfactory water level prediction at the Port Gauge and near Swallows Landing.

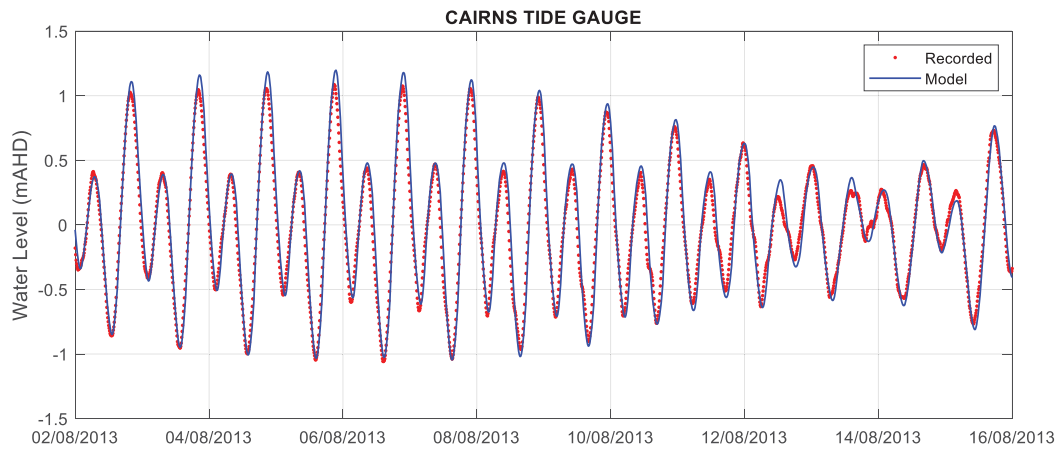


Figure 5-12 Hydrodynamic Model Validation Water Level – Cairns Port Gauge

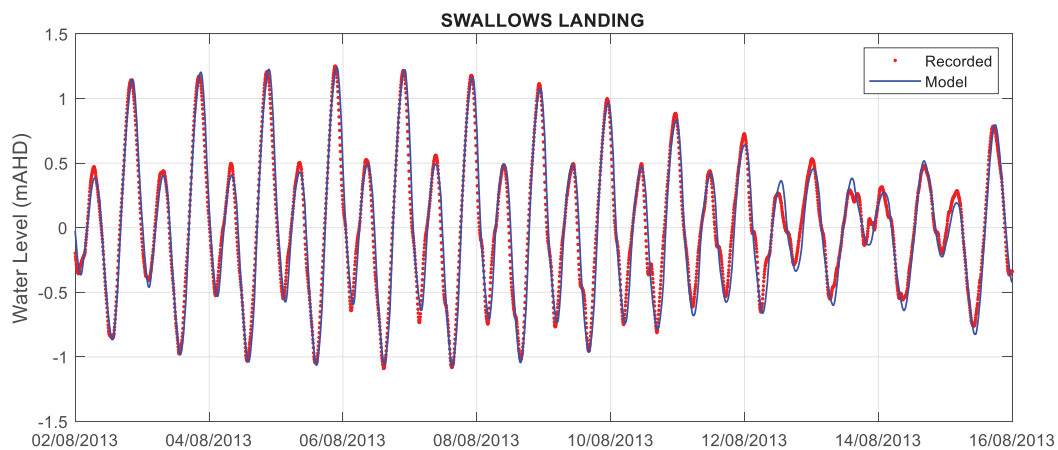


Figure 5-13 Hydrodynamic Model Validation Water Level – Swallows Landing

5.3.2 Temperature and Salinity Validation

Comparisons of the modelled near-bed water temperature with continuous measurements obtained using YSI Model 6600 EDS nepholometers (co-located with the ADCP instruments at the DMPA and Beacon C7) are shown in Figure 5-14 and Figure 5-15. The model represents the gradual warming trend during the validation period; however, the rate of warming is slightly over predicted from late-July to mid-August.

Surface salinity data recorded using a Teldyne RD Instruments Citadel CTD deployed from floating buoy at Beacon C7 is compared to the predicted salinity in Figure 5-16. Salinity is shown to be relatively constant and slightly over predicted by the model. It is noted that the recovery of reliable salinity data collected as part of CSDP was limited due to rapid bio-fouling of the instrument sensors after each deployment.

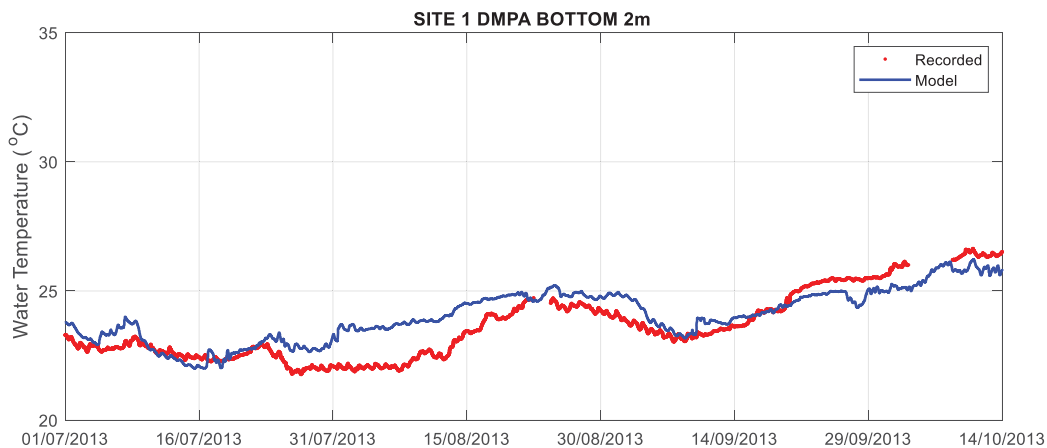


Figure 5-14 Hydrodynamic Model Validation Near Bed Temperature – Site 1 DMPA

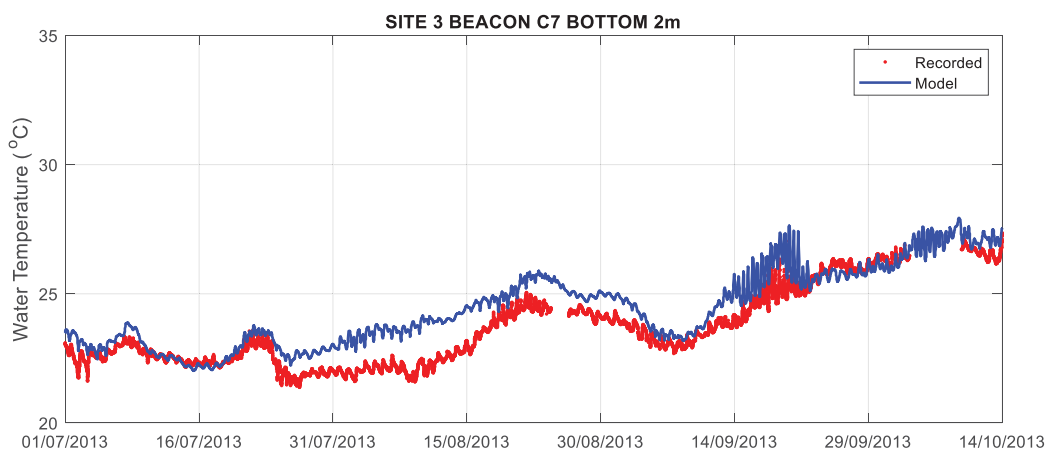


Figure 5-15 Hydrodynamic Model Validation Near Bed Temperature – Site 3 Beacon C7

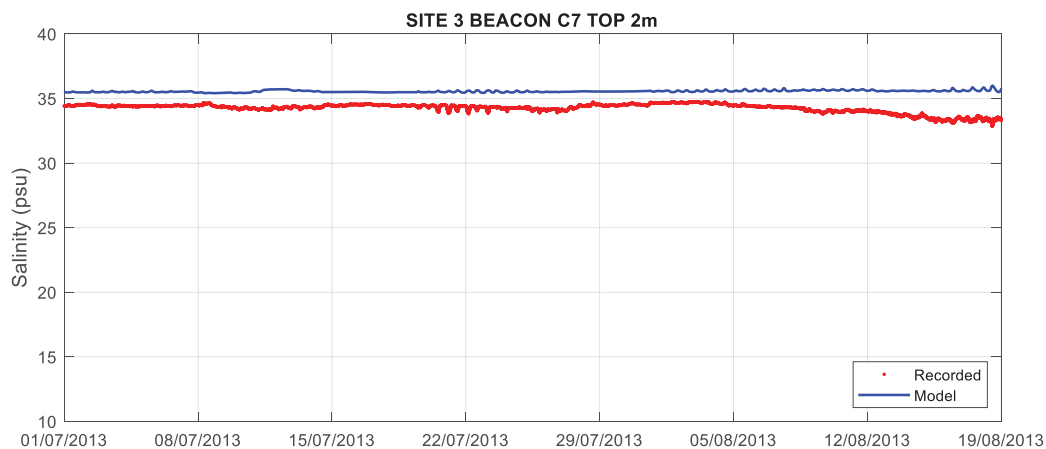


Figure 5-16 Hydrodynamic Model Validation Surface Salinity – Site 3 Beacon C7

5.3.3 Summary of Validation Period Hydrodynamic Model Performance

Hydrodynamic model predictive skill in terms of IOA, MAE and RMSE over the validation period is summarised in Table 5-1, Table 5-2 and Table 5-3.

Table 5-1 Model Performance Metrics – Water Level Validation

Metric	Site 1 DMPA	Site 3 Beacon C7	Cairns Gauge	Swallows Landing
IOA	0.96	0.95	0.99	0.98
MAE (m)	0.13	0.14	0.11	0.13
RMSE (m)	0.21	0.23	0.13	0.16

Table 5-2 Model Performance Metrics – Current Magnitude E-W

Metric	Water Level Averaging	Site 1 DMPA	Site 3 Beacon C7
IOA	Entire column	0.85	0.89
	Top one-third	0.85	0.91
	Middle one-third	0.86	0.88
	Bottom one-third	0.83	0.78
MAE (m/s)	Entire column	0.08	0.05
	Top one-third	0.10	0.05
	Middle one-third	0.08	0.05
	Bottom one-third	0.07	0.06
RMSE (m/s)	Entire column	0.10	0.06
	Top one-third	0.12	0.07
	Middle one-third	0.10	0.07
	Bottom one-third	0.09	0.07

Table 5-3 Model Performance Metrics – Current Magnitude N-S

Metric	Water Level Averaging	Site 1 DMPA	Site 3 Beacon C7
IOA	Entire column	0.84	0.91
	Top one-third	0.80	0.89
	Middle one-third	0.84	0.89
	Bottom one-third	0.83	0.88
MAE (m/s)	Entire column	0.05	0.04
	Top one-third	0.06	0.05
	Middle one-third	0.05	0.05
	Bottom one-third	0.04	0.04
RMSE (m/s)	Entire column	0.06	0.06
	Top one-third	0.08	0.07
	Middle one-third	0.06	0.06
	Bottom one-third	0.05	0.05

5.4 Wave Model Validation

Wave model validation was based on recorded significant wave height, peak wave period and wave direction data from ADCP instruments deployed at the DMPA and Beacon C7. Predicted and recorded wave parameters are presented for the period 01/06/2013 to 30/10/2013 in Figure 5-17 and Figure 5-18.

5.4.1.1 Cairns Wave Buoy – 2016 Directional Data

The non-directional Cairns Waverider buoy was replaced in early 2016 with a directional instrument. Directional wave recordings were provided by DES and the results of the local model (100 m grid resolution) validation to a selected period in 2016 is provided in Figure 5-19.

5.4.2 Wave Model Validation Results

Predicted wave parameters are compared to continuous time series data at the DMPA and Beacon C7 in Figure 5-17 and Figure 5-18. The wave model validation satisfactory and considered appropriate for assessing the potential impacts associated with maintenance dredging. Key features of the wave calibration results include:

- Significant wave height validation is acceptable with a slight over prediction at Beacon C7 (consistent with the calibration results). As discussed in Section 3.5.2, over-prediction in wave height is probably attributable to the effects of wind drag over land, and the transition from over land to over sea winds, not being precisely resolved by the constructed wind field. In the context of the maintenance dredging assessments, this is likely to cause an over prediction of sediment re-suspension and is therefore considered a conservative result.
- Significant wave height prediction at the Cairns Buoy location is predicted well, wind drag over land effects are less likely to influence the conditions at this location, where it is exposed to the prevailing
- The wave model predicts periods of dominant sea and swell states at each location and this is reflected in comparisons with the peak wave period recordings. At times, the peak wave period is over-predicted at the DMPA and represents periods when slightly too much offshore swell energy is propagated into GBR lagoon. Again, this will cause a slight over prediction in sediment re-suspension and is therefore a conservative result.
- Wave period prediction at the Cairns Buoy location is more consistent with the data, possible due to the more reliable permanent instrument.
- The dominant wave direction of the at the DMPA, Beacon C7 and Cairns Buoy is generally from the east to south easterly sector throughout the validation periods. This general pattern is represented by the model.

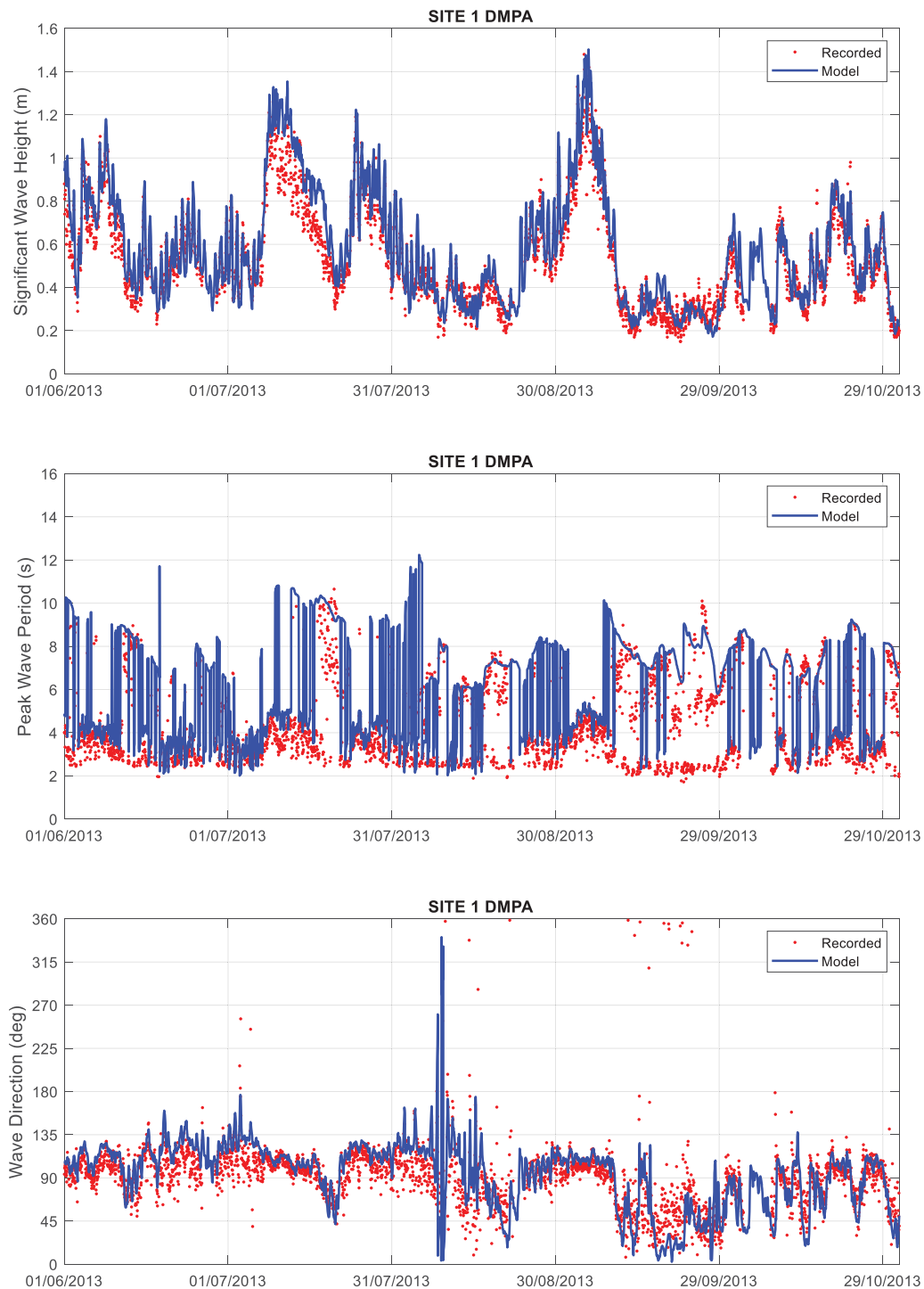


Figure 5-17 SWAN Wave Model Validation – Site 1 DMPA

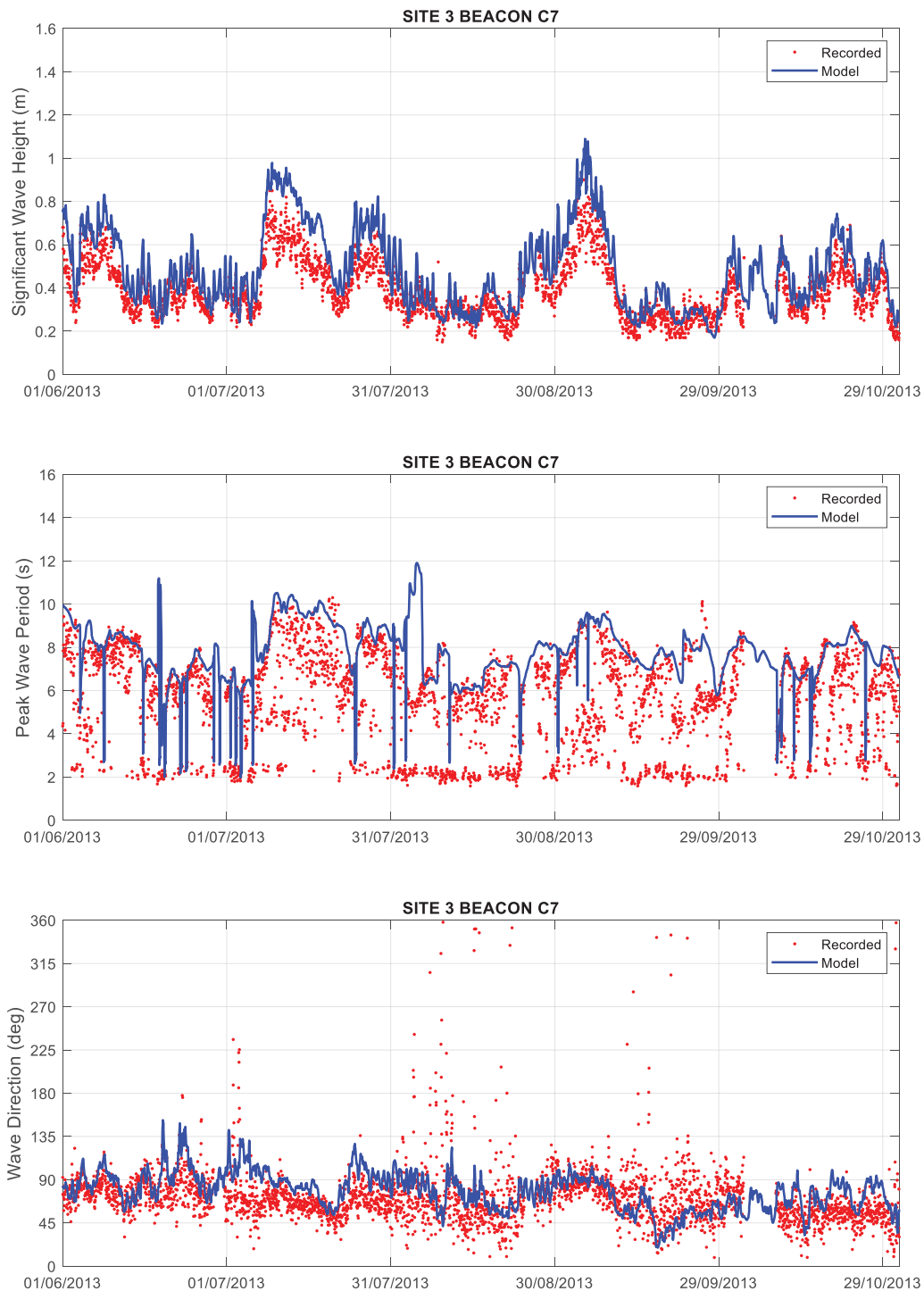


Figure 5-18 SWAN Wave Model Validation – Site 3 Beacon C7

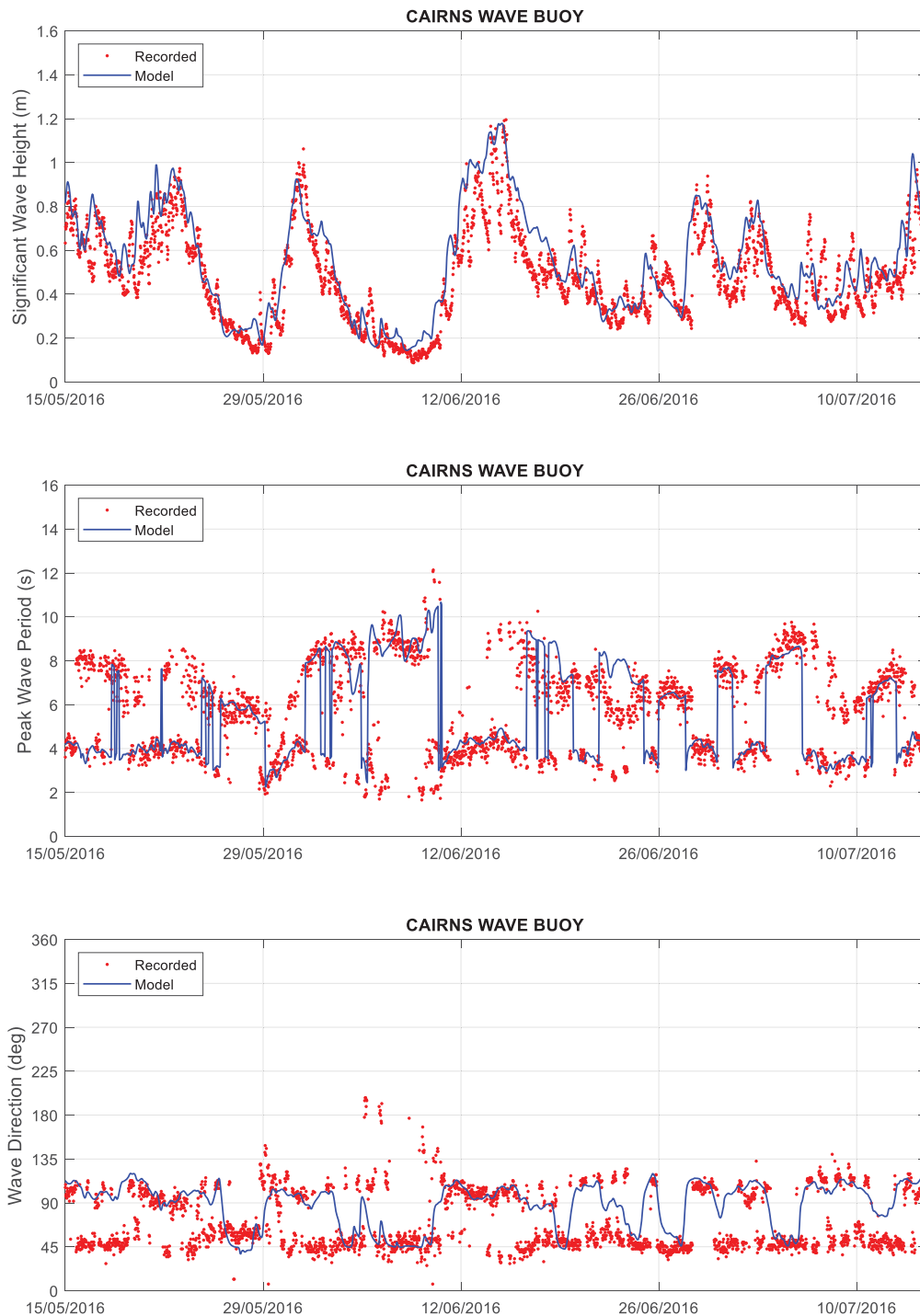


Figure 5-19 SWAN Wave Model Validation – Cairns Wave Buoy 2016 Directional Data

5.4.3 Summary of Validation Period Wave Model Performance

Wave model predictive skill in terms of IOA, MAE and RMSE over the validation periods is summarised in Table 5-4 and Table 5-5.

Table 5-4 Model Performance Metrics – Significant Wave Height Validation

Metric	Site 1 DMPA	Site 3 Beacon C7	Cairns Buoy
IOA	0.95	0.85	0.84
MAE (m)	0.08	0.10	0.12
RMSE (m)	0.11	0.13	0.15

Table 5-5 Model Performance Metrics – Peak Energy Wave Period Validation

Metric	Site 1 DMPA	Site 3 Beacon C7	Cairns Buoy
IOA	0.53*	0.49*	0.67
MAE (s)	2.17	2.68	1.48
RMSE (s)	3.05	3.80	2.21

**significant scatter in wave period measurements*

5.5 Sediment Re-suspension Model Validation

5.5.1 Sediment Re-suspension Model Validation Results

Baseline turbidity data collected for the CSDP was used to further validate the sediment transport module. The natural sediment re-suspension validation simulation adopted the calibrated model parameters described in Section 3.6.1.

5.5.2 Targeted Turbidity Recordings

Ambient TSS validation plots at four baseline data recording locations (Trinity Bay, Yorkeys Knob and Palm Beach, indicated in Figure 3-2) are presented in Figure 5-20 to Figure 5-22 and demonstrate the following:

- Given the complexities of modelling the re-suspension of natural bed sediments, the ambient TSS concentration prediction throughout the validation period is considered adequate. Together with the TSS calibration results presented in Section 3.6.2.1, the model demonstrates a relatively high degree of predictive skill both temporally and spatially.
- Natural re-suspension in Trinity Bay is reasonably well predicted with the short periods of elevated TSS associated with spring tide periods being represented by the model.
- There is a lag in predicted elevated TSS at Yorkeys Knob and Palm Beach during early September. Nevertheless, the magnitude and duration of natural turbidity event is represented by the model.

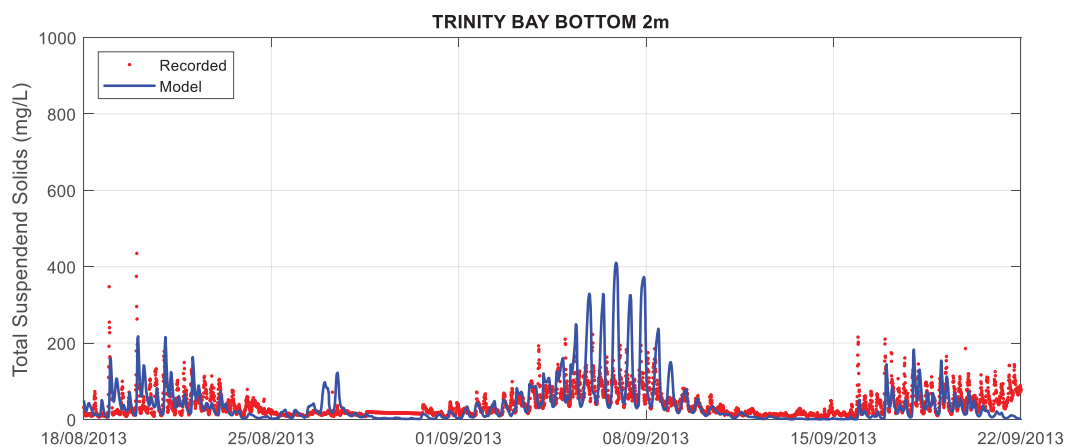


Figure 5-20 Sediment Re-suspension Validation – Trinity Bay

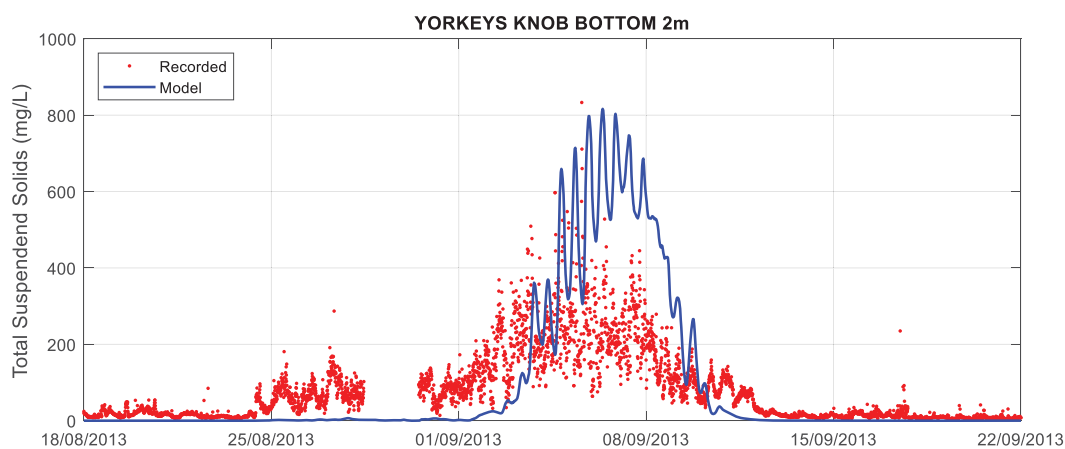


Figure 5-21 Sediment Re-suspension Validation – Yorkeys Knob

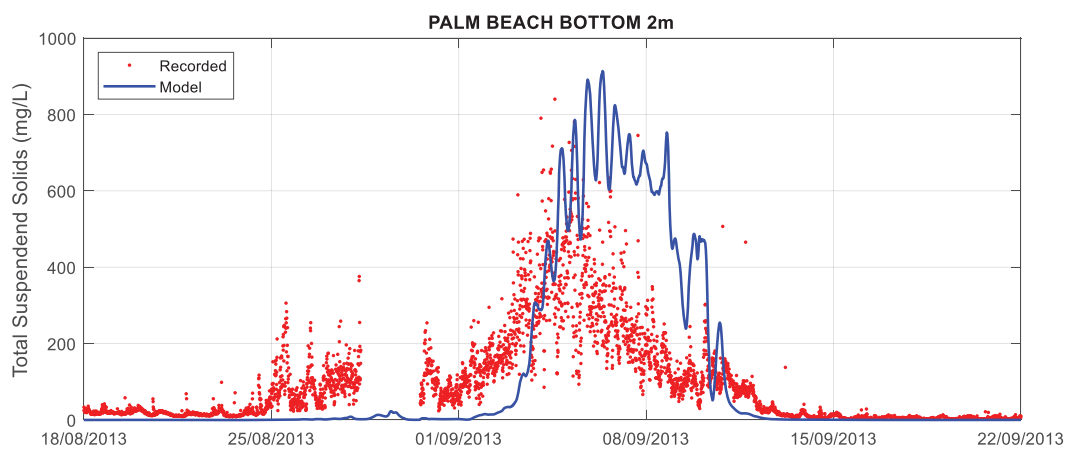


Figure 5-22 Sediment Re-suspension Validation – Palm Beach

6 Maintenance Dredging Assessment Scenarios

6.1 Introduction

The revised Port of Cairns LMDMP proposes the continuation of marine placement of annual dredge material at a new offshore DMPA. The new DMPA is in slightly deeper waters to the existing site and will alleviate capacity constraints in the long term (next 30+ years).

The current assessment reviews the sustainability of future maintenance dredging activity in accordance with the revised LMDMP. The assessment evaluates the environmental impacts of potential future maintenance dredging activities to water quality and marine ecology.

This section reviews the assumptions undertaken in developing modelling scenarios that are representative of likely future maintenance dredging activities. The adopted scenarios were developed in consultation with GBRMPA and are designed to span the range of possible metocean conditions and maintenance dredge volumes.

6.1 Basis of Maintenance Dredge Campaign Modelling

Previous maintenance dredging within the Port of Cairns has been undertaken by two plants:

- TSHD *Brisbane*: within the outer channel and swing basins
- Grab Dredge *Willunga*: inner port areas including wharves, marina and navy basins.

In any single year, the bulk of the maintenance dredge volume (about 90%) is removed by TSHD *Brisbane* over an approximate four (4) week period. Smaller volumes (about 10%) are removed from the inner port areas by Grab Dredge *Willunga*, with the plant operating for up to eight (8) weeks continuously in any single year.

Future annual dredge volume forecasts have been prepared by Ports North based on the historical requirements observed over the last 10-years and forecast maintenance requirements associated with the current (post-CSDP) channel, inner harbour and berth configuration. Siltation modelling of the outer channel post-CSDP showed a possible volumetric increase of 6% per annum (BMT WBM, 2017). This has been considered when developing the total maintenance dredging volumes summarised in Table 6-1 and adopted for the modelling assessments.

Table 6-1 Total Maintenance Dredging Volumes adopted for Modelling Assessments

Maintenance Volume in any Single Year Adopted for Modelling	Wet Volume (cu.m)	Dry Volume (Tonnes)
TSHD <i>Brisbane</i> Annual Average Volume	885,000	307,000
TSHD <i>Brisbane</i> Maximum Volume	1,185,000	412,000
Grab Dredge <i>Willunga</i> , up to 8 weeks continuous dredging	25,000	20,000
Total Dredge Volume in a Typical Year	910,000	327,000
Total Dredge Volume in a Maximum Year	1,210,000	432,000

The modelling scenarios described in the following sections have been designed to account for:

- The likely typical and upper limit (maximum) dredging volume in any single year; and

Maintenance Dredging Assessment Scenarios

- Interannual and seasonal variation in the environmental conditions.

6.1.1 TSHD *Brisbane* Assumptions

The 2013 maintenance dredging campaign was determined to be representative of a 'typical' campaign in terms of volume prior to the CSDP (Ports North 2020, pers. comm. 13 March). This campaign involved 311 loads of material from the outer channel which were placed at the existing DMPA.

Siltation modelling of the outer channel post-CSDP showed a possible volumetric increase of 6% per annum (BMT WBM, 2017). To account for this increase, every 16th cycle was repeated in the historic 2013 campaign to create a post-CSDP 'synthetic' campaign with a total of 330 loads of outer channel maintenance material relocated to the DMPA.

Representative programs for the Smith Creek Swing Basin, the Crystal Swing Basin and the Inner Harbour areas were also developed and added to the synthetic campaign. A summary of the additional volumes from these locations is shown in Table 6-2. For the swing basins, each cycle consisted of 8 passes with each pass taking 6 minutes followed by 12 minutes of repositioning. For the Inner Harbour a single South-North pass was assumed to occur over a 40-minute period. For all cycles, overflow was assumed to occur after 20 minutes of dredging activity. The load distribution for the actual and synthetic campaigns are compared in Figure 6-1 and illustrated in Figure 6-2.

To account for additional steaming time to the proposed DMPA, all voyages to the existing DMPA were replaced with synthetic voyages to the proposed DMPA using median steaming times from the historic campaign. Placement locations were then randomly generated to occur within one of the 109 horizontal cells (model elements) that represent the DMPA.

Details of TSHD *Brisbane* sediment plume generation for numerical modelling purposes is presented in Section 4 and is based on monitoring data and a detailed model calibration exercise. The adopted plume sources rates are also presented below in Section 6.1.3.

Table 6-2 Summary of TSHD *Brisbane* Maintenance Campaign Dry Mass Removal by Area

Location	Number of Loads\Cycles	Total Wet Volume* (cu.m)	Total Dry Mass* (Tonnes)	Average Dry Mass Per load (Tonnes)
Outer Channel	330	861,792	289,494	877
Crystal Swing Basin	3	5,040	4,032	1,344
Smith Creek Swing Basin	6	8,400	6,720	1,120
Inner Harbour	7	8,400	6,720	960
Total	346	892,269	309,966	895
* Volume and mass removal quantities by area are based on the forecast by Ports North and differ marginally to the synthetic campaign total volume/mass.				

Maintenance Dredging Assessment Scenarios

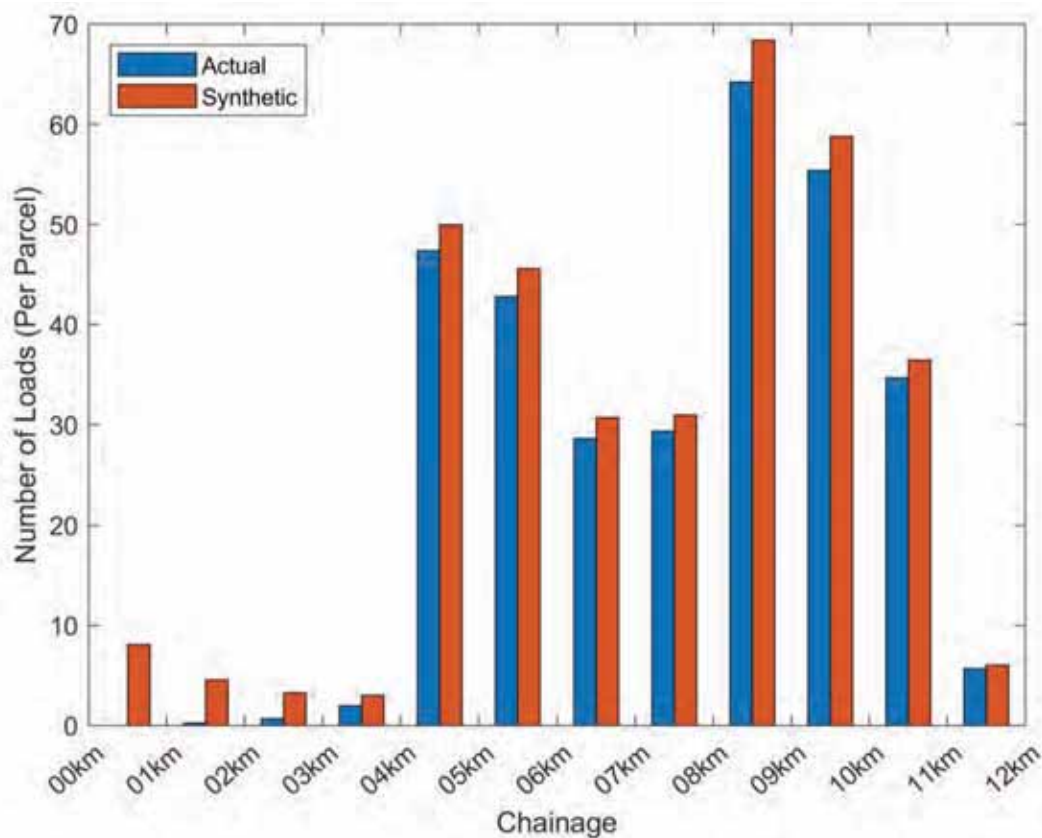


Figure 6-1 Comparison of Historic 2013 and Typical Semi-Synthetic Campaign Load Distribution along the chainages of the Entrance Channel (landward (0kms) to seaward (12kms))

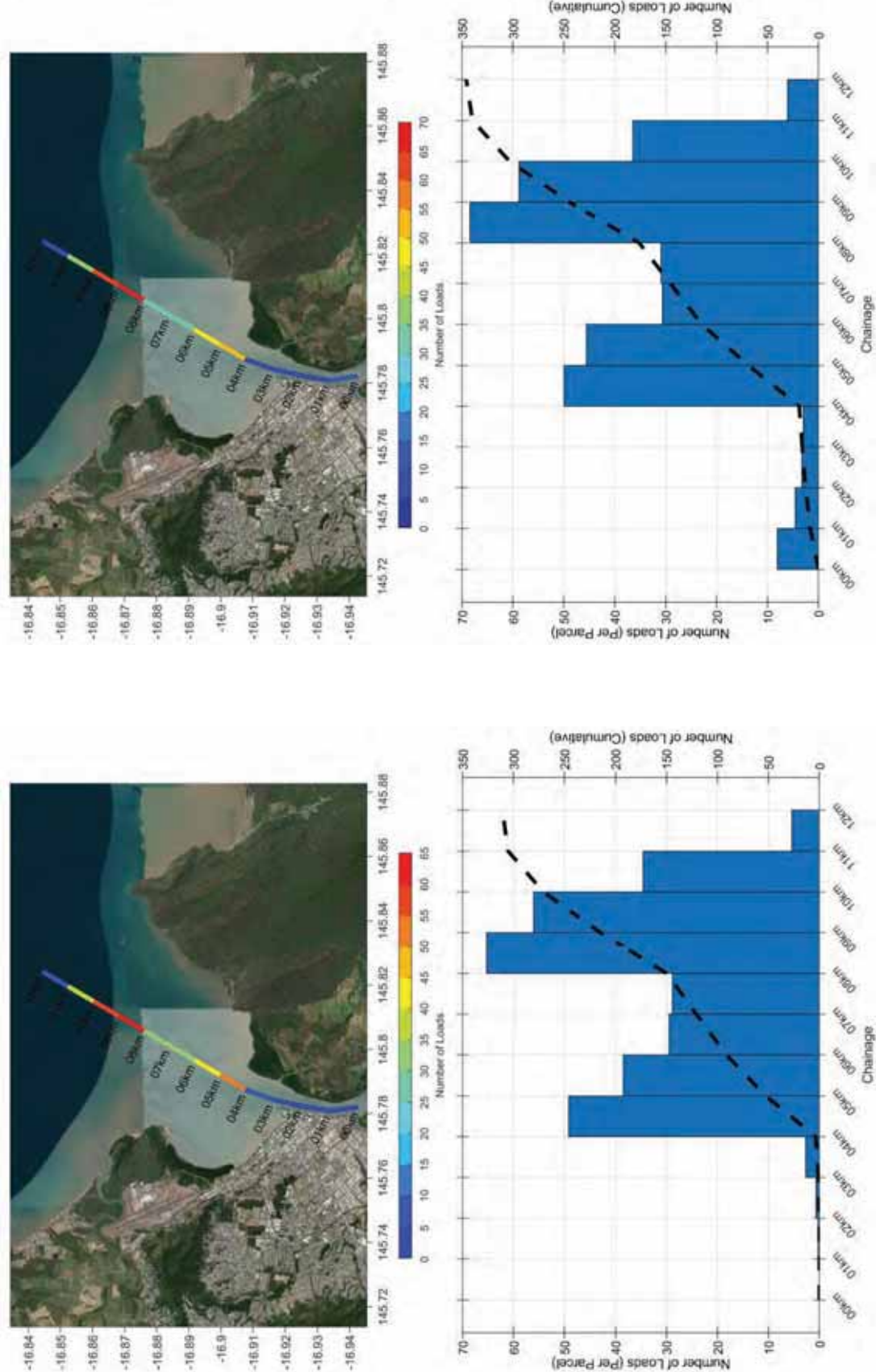


Figure 6-2 Load distribution of the Historic 2013 Maintenance Dredge Campaign (Left) and the Semi-Synthetic Expected Future Campaign (Right)



Maintenance Dredging Assessment Scenarios

6.1.2 Grab Dredge *Willunga* Assumptions

Maintenance dredging outside of the main navigation channel, inner harbour, and swing basins is typically undertaken by the small Grab Dredge *Willunga* that is owned and operated by Ports North. The *Willunga* is a grab-bucket dredge fitted with a 2.5m³ clamshell bucket grab. The dredge is supported by two barges (*GHT22* and *AD501*) which are towed to the DMPA by port tugs, usually on a 3-hour return cycle.

The *Willunga* typically operates during normal port daylight working hours with two barge cycles occurring per day. In any single year the dredge operates continuously (5 days per week) and works on a subset of the inner port areas. The largest annual campaign undertaken by the *Willunga* is typically at the inner and outer berths of the HMAS Cairns Navy Base. Based on historical records, Ports North have estimated a yearly average forecast of approximately 20,741 dry tonnes (~26,297 wet cu.m) to be dredged annually between the inner and outer Navy Base berths for the next 10-years as part of the revised LMDMP.

The modelling scenarios include the *Willunga* operating for 8 weeks at the HMAS Cairns Navy Base, representing the largest typical maintenance dredging campaign that occurs in any single year in the inner port area. Simultaneously to this campaign, the *TSHD Brisbane* will arrive and undertake continuous dredging of the main navigation channel for 4-weeks (Refer to Section 6.1.1). Two barge cycles per day relocate material to the proposed DMPA with the placement location randomly generated to ensure an even spread across the DMPA.

The *Willunga* has been assumed to take 2.5 hours to fill a barge and then have a 0.5 hour pause while the second barge is towed into position, before resuming dredging for another 2.5 hours. The main sediment release source is the dredge material dripping from the grab whilst raising and descending through the water column.

Table 6-3 Summary of Grab Dredge *Willunga* Maintenance Campaign Dry Mass Removal by Area

Location	Number of Loads/Cycle	Total Wet Volume (cu.m)	Total Dry Mass (Tonnes)	Average Dry Mass Per Load (Tonnes)
Navy Base Inner	49	15,767	12,794	261
Navy Base Outer	31	10,530	7,946	256

Table 6-4 Workday schedule of *Willunga* during modelling scenarios

Action	Time
Dredging	2.5 hours
Barge change-over	0.5 hours
Dredging	2.5 hours

Maintenance Dredging Assessment Scenarios

6.1.3 Maintenance Dredge Campaign Scenarios

Two maintenance dredge campaign scenarios have been adopted for modelling. These campaigns represent conservative ‘continuous’ and ‘split’ scenarios with TSHD *Brisbane* and Grab Dredge *Willunga* simultaneously active. Development of these scenarios has been based on a review of past campaigns and the known dredge windows (i.e. the typical timing of dredging has been in the dry season due to the favourable metocean conditions).

The first dredge scenario represents a conservative continuous case where the Grab Dredge *Willunga* undertakes an eight week continuous dredging campaign at the HMAS Cairns Navy Base with the TSHD *Brisbane* arriving two weeks into this campaign to concurrently undertake a four week continuous campaign along the main navigation channel, inner harbour and swing basins as described above in Section 6.1.1.

The second dredge scenario represents a conservative split campaign where TSHD *Brisbane* undertakes the four weeks of main navigation channel, inner harbour and swing basin dredging starting at the same time as the Grab Dredge *Willunga*’s eight-week campaign. The TSHD *Brisbane* then returns to undertake an additional one week of outer channel dredging at the end of the *Willunga*’s 8-week campaign, representing a one month split between the initial TSHD *Brisbane* dredging campaign.

A summary of the adopted dredging scenarios is provided in Table 2-1. The dredging-related plume generation assumptions are summarised in Table 4-2. This is based on a combination of monitoring and detailed model calibration to represent TSHD *Brisbane* activities within the Port of Cairns (refer Section 4) and previous advice from Pro Dredging & Marine regarding plume generation by TSHD and backhoe equipment (Pro Dredging & Marine 2013, see Appendix E). The plume source rates for a grab dredge (in this case the *Willunga*) are assumed to be the same as a backhoe dredge (Becker et al., 2014).

Table 6-5 Summary of adopted dredge scenarios

Scenario Name	Description
Dredge Scenario 1 Continuous campaign	<p>TSHD Brisbane Small/medium TSHD Continuous operation for 4-weeks along the main navigation channel, inner harbour and swing basins</p> <p>Willunga Small Grab Dredge Continuous operation for 8 weeks around the HMAS Cairns Navy Base</p>
Dredge Scenario 2 Split-campaign	<p>TSHD Brisbane Small/medium TSHD Continuous operation for 4-weeks along the main navigation channel, inner harbour and swing basins followed by one week of outer channel dredging one month later.</p> <p>Willunga Small Grab Dredge</p>

Maintenance Dredging Assessment Scenarios

Scenario Name	Description
	Continuous operation for 8 weeks around the HMAS Cairns Navy Base

Table 6-6 Plume Source Rate Assumptions Adopted for Modelling

Dredge Plant	Source Term	Release Rate (%)	Fines Mass Flux (kg/s)	Total Mass of Fines (Tonnes)
TSHD <i>Brisbane</i>	No Overflow Dredging	0.15	1	279
	Overflow Dredging	39.1	250	97,167
	Dumping Passive Plume (water column)	13.3	200	41,520
	Dumping Dynamic Plume (near bed)	6.7	100	20,760
	Dumping Bed (added to DMPA)	80.0	1,200	249,120
Grab Dredge <i>Willunga</i>	Dredging Passive Plume (water column)	0.45	0.12	89
	Dredging Dynamic Plume (near bed)	2.55	0.70	502
	Dumping Passive Plume (water column)	17.0	147	3350
	Dumping Bed (added to DMPA)	83.0	717	16,354

6.1.4 Maintenance Dredging Metocean Condition Scenarios – Wave Climate

The modelling assessments cover a range of background meteorological and metocean conditions to capture seasonal and interannual variation and their potential influence on dredging-related impacts to turbidity and deposition.

Three individually selected years have been adopted to represent the range of conditions that could occur during maintenance dredging activities over the next 10 years. Historical wave data from the Cairns Wave Rider Buoy (operated by the Queensland Government) has been used to calculate average monthly wave power over the past 10-years. The seasonal wave power results and correspond quarterly averaged wave heights and wind speeds are shown in Figure 6-3 and Figure 6-4. Individual years have been selected to represent 'energetic', 'typical', and 'mild' conditions:

- **Energetic Year - 2014**

This year has the highest average monthly wave power that has occurred during Autumn, while

Maintenance Dredging Assessment Scenarios

having the fourth and eighth highest for Winter and Spring respectively. Dredge scenario 1 will be simulated during Autumn and hence simulate the most energetic quarterly wave conditions that were observed during the last 10 years.

- **Typical year - 2013**

This year is average in terms of wave power throughout the whole year and follows typical seasonal trends with more energy occurring throughout the middle of the year. This year has been used as a representative typical year in past dredge plume modelling projects and has also adopted for the current assessment.

- **Mild year - 2016**

This year is characterised by generally low average monthly wave power throughout the year with no standout months, and hence provides a good estimation of a 'mild' year.

Maintenance Dredging Assessment Scenarios

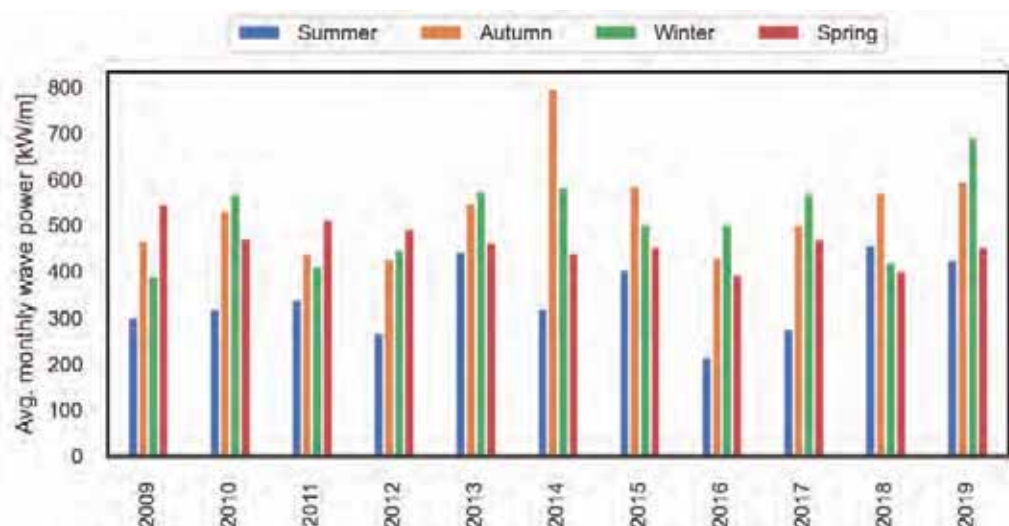


Figure 6-3 Average monthly wave power recorded at the Cairns Wave Rider Buoy

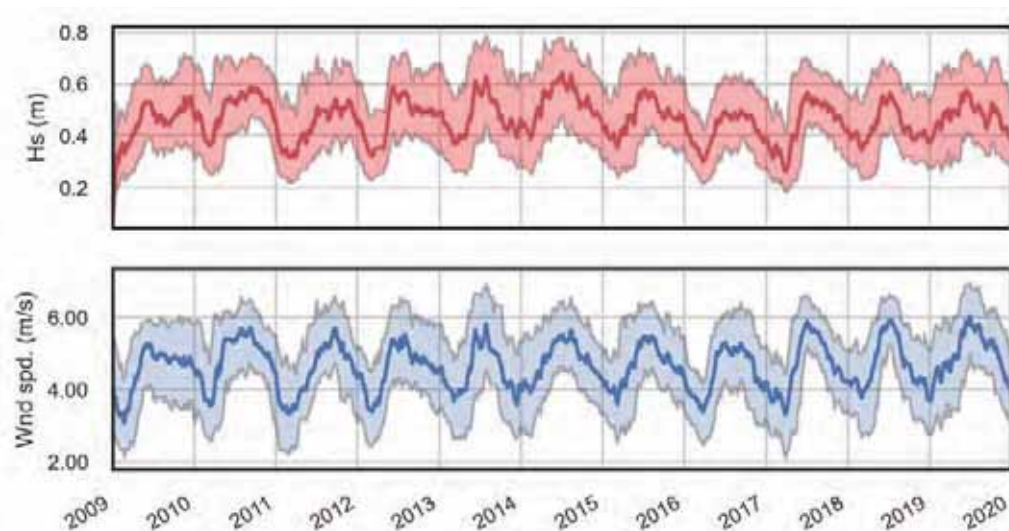


Figure 6-4 Rolling quarterly averaged wave height (Cairns Wave Rider Buoy) and Wind speed (ECMWF ERA5). The solid line shows the mean and shading denotes the upper and lower quartiles

Maintenance Dredging Assessment Scenarios

6.1.5 Maintenance Dredging Metocean Condition Scenarios – Simulated Net Currents

The modelled residual or 'net' current for the periods adopted for maintenance dredging assessment are provided below:

- 2013 (typical year based on wave climate):
 - Figure 6-5 top - winter months (typical dredging period)
 - Figure 6-5 bottom - spring months (late dredging period)
- 2014 (energetic year based on wave climate):
 - Figure 6-6 top - winter months (typical dredging period)
 - Figure 6-6 bottom - spring months (late dredging period)
- 2016 (mild year based on wave climate):
 - Figure 6-7 top - winter months (typical dredging period)
 - Figure 6-7 bottom - spring months (late dredging period).

Current seasonality is clearly shown across all years, with the winter months characterised by net north-westerly directed currents and the spring months characterised by net south-easterly directed currents in the vicinity of the DMPA.

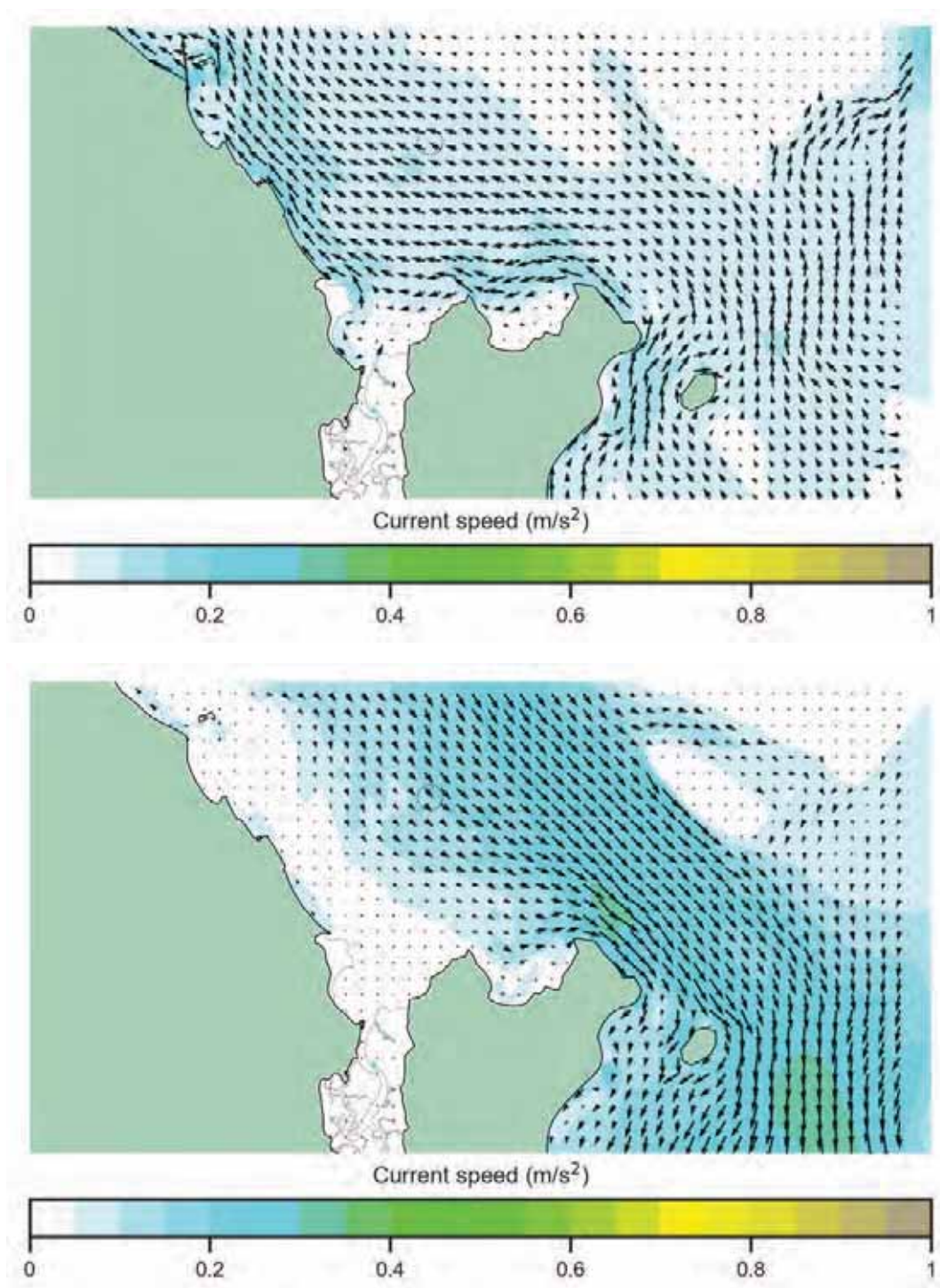


Figure 6-5 Simulated Net Currents in a 2013 (Typical Year): Winter (top) and Spring (bottom)

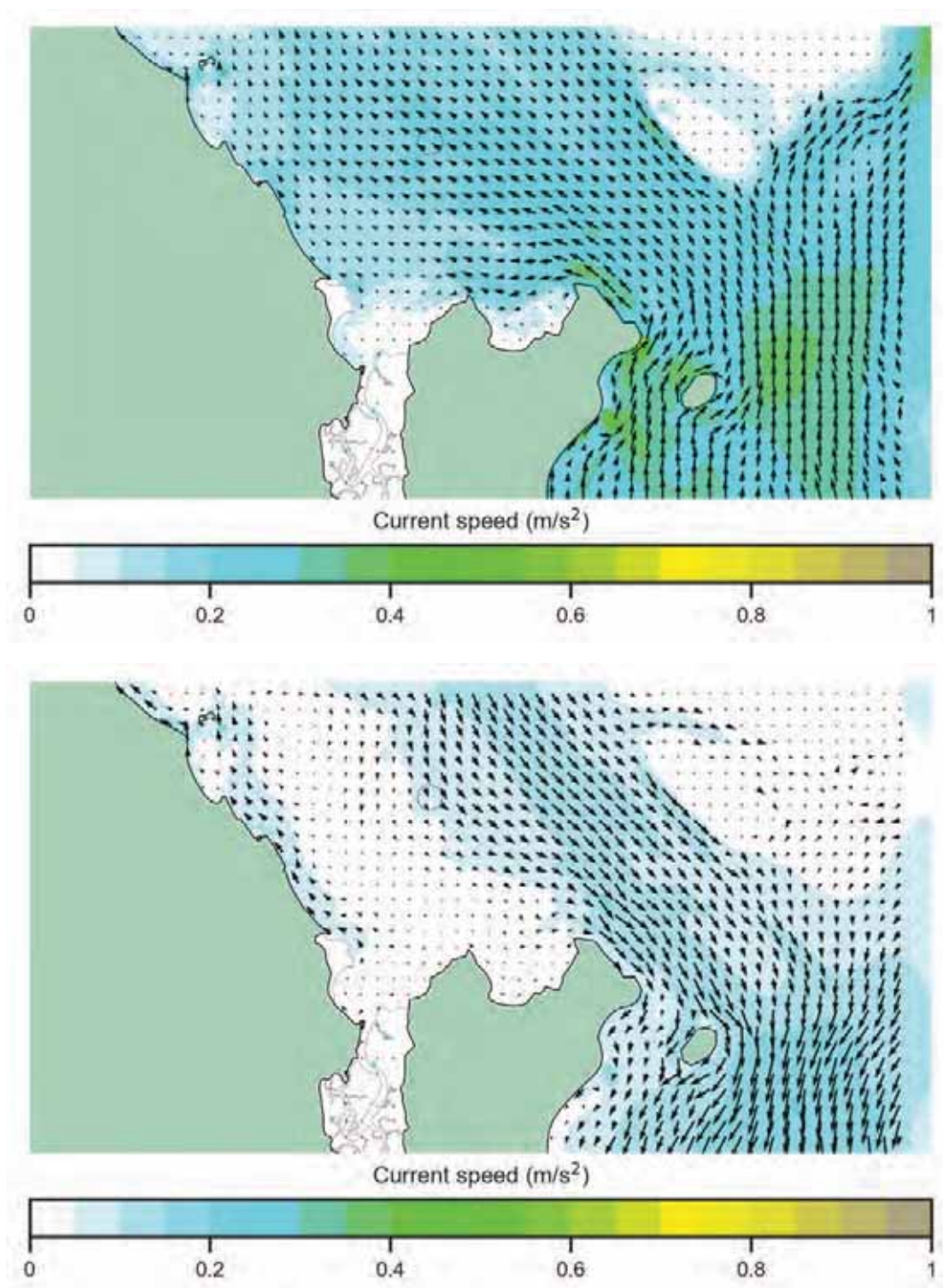


Figure 6-6 Simulated Net Currents in 2014 (Energetic Year): Winter (top) and Spring (bottom)

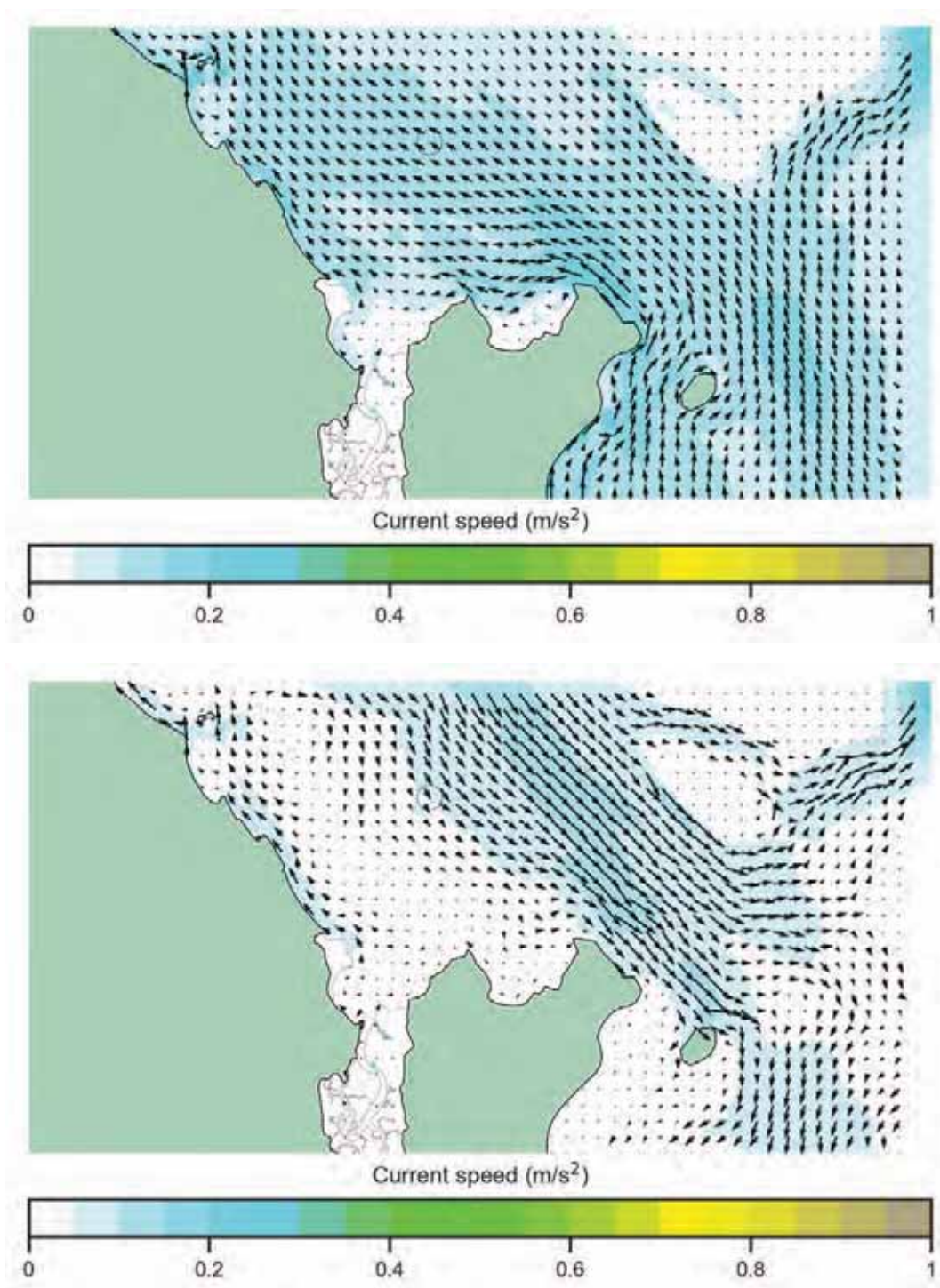


Figure 6-7 Simulated Net Currents in 2016 (Mild Year): Winter (top) and Spring (bottom)

Maintenance Dredging Assessment Scenarios

6.2 Dredging Impact Modelling Scenarios

6.2.1 Maintenance Dredge Campaign Scenarios

The historical timing of maintenance dredging campaigns at the Port of Cairns has generally been dependent on the availability of the TSHD *Brisbane*, as it is the only sizeable TSHD dredger based in Queensland.

Historical records over the past 10 years show that TSHD *Brisbane* has typically visited Cairns in late Autumn or Winter. Additionally, the *Brisbane* may occasionally visit in split campaigns typically undertaking 3-4 weeks of dredging followed by another week of dredging later in the year.

To account for variation in time of year when the *Brisbane* is available to visit Cairns in the future, **Dredge scenario 1** has been simulated twice for each representative year starting in autumn, as well as a second simulation beginning in winter. Each 10-week simulation includes one week at the beginning (warmup) and end (cool down) without dredging.

Dredge scenario 2, representative of a split campaign, begins in September, with TSHD *Brisbane* and Grab Dredge *Willunga* commencing simultaneously. TSHD *Brisbane* returns for another week of dredging at the conclusion of the *Willunga*'s 8-week campaign, thus totalling 5-weeks of TSHD *Brisbane* dredging. Each 11-week simulation includes one week at the beginning (warmup) and end (cool down) without dredging.

A summary of the matrix of the modelling scenarios (nine unique simulations) adopted in this assessment is presented in Table 6-7.

Table 6-7 Adopted Maintenance Dredge Modelling Scenarios

	Autumn/Winter	Winter/Spring	Split Campaign
Energetic Year (2014)	Dredge Scenario 1	Dredge Scenario 1	Dredge Scenario 2
Typical Year (2013)	Dredge Scenario 1	Dredge Scenario 1	Dredge Scenario 2
Mild Year (2016)	Dredge Scenario 1	Dredge Scenario 1	Dredge Scenario 2

6.2.2 DMPA Resuspension Scenarios

Dredged material placed at the proposed new DMPA site may undergo natural resuspension during moderate to energetic metocean conditions and may occasionally move outside of the placement area.

In addition to the maintenance dredge modelling campaign scenarios described above, two modelling simulations have also been undertaken to assess long-term resuspension impacts at the new DMPA.

Two simulation scenarios/periods aligning with previous modelling work have been selected for modelling:

- 12-Month resuspension simulation for typical weather conditions from November 2011 to November 2012
- Extreme event (Cyclone Yasi) resuspension simulation from the 10th of January to the 20th of February 2011.

The 12-month resuspension assessment has used the historical period from the 01/11/2011 to 01/11/2012. Analysis of the wind (Figure 6-8) and oceanographic (Figure 6-9) conditions for 2012 indicate this period is reasonably representative of the average annual conditions and is therefore considered to be an appropriate basis for an 'expected case' impact assessment.

The 'worst case' resuspension simulation used the period between 10/01/2011 to 20/02/2011 covering Tropical Cyclone (TC) Yasi. Modelled CFSR wind fields are shown in Figure 6-10 and Figure 6-11. The maximum mean wind speed of 26 m/s (93 km/h) was measured offshore from Cairns by the Arlington Reef weather station operated by the BOM, suggesting Category 2 winds were experienced within the vicinity of the proposed DMPA. TC Yasi had intensified to a Category 5 system when it crossed the coast near Mission Beach, approximately 140 km south of Cairns.

Maintenance Dredging Assessment Scenarios

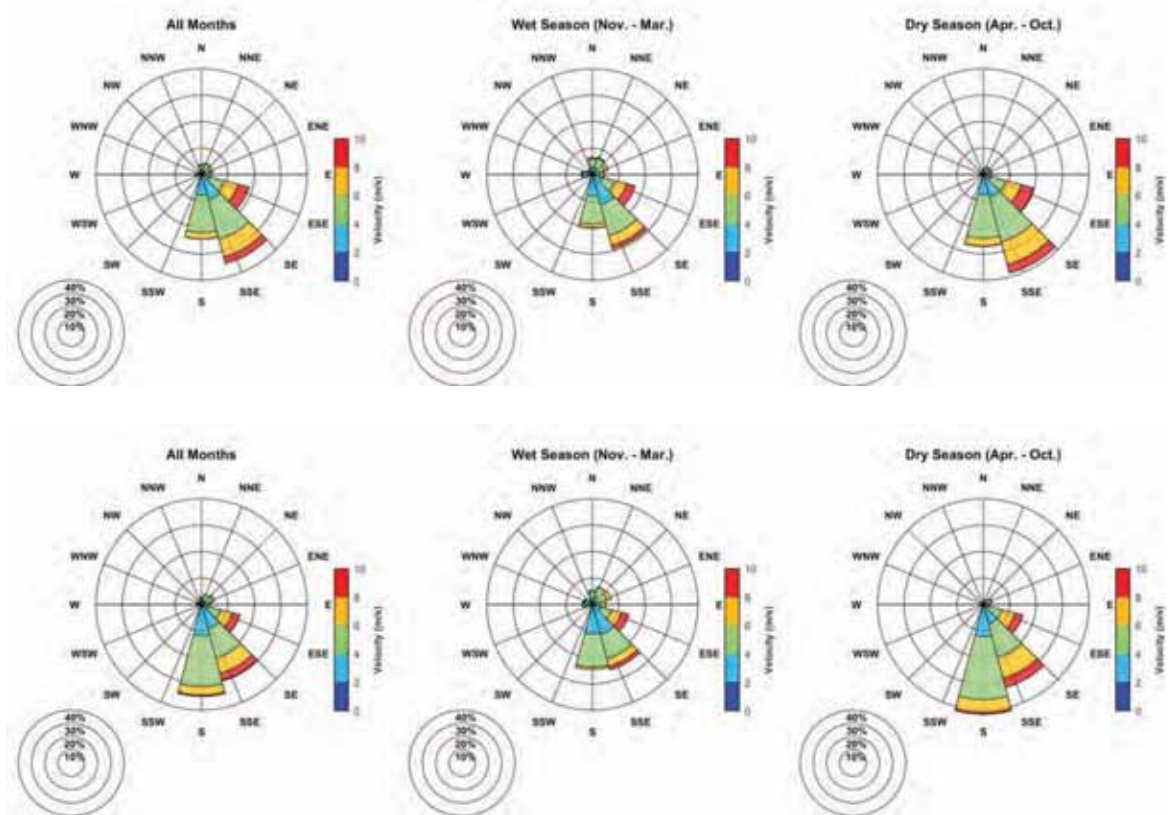


Figure 6-8 Rose Plot for 1995-2015 (top) and 2012 (bottom) Observed Wind at Cairns Aero (Note: DMPA Resuspension Simulation 01/11/2011 – 01/11/2012)

Maintenance Dredging Assessment Scenarios

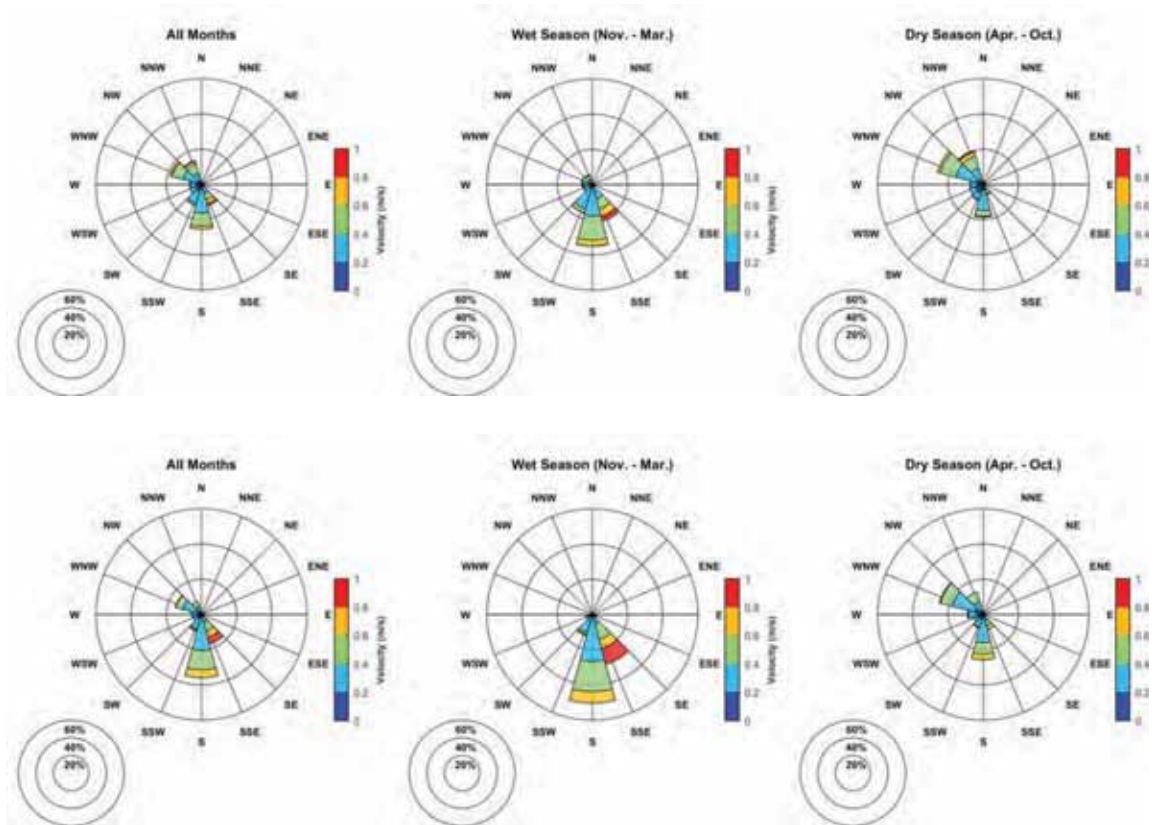


Figure 6-9 Rose Plot for 2011-2016 (top) and 2012 (bottom) HYCOM Surface Currents at Offshore Location

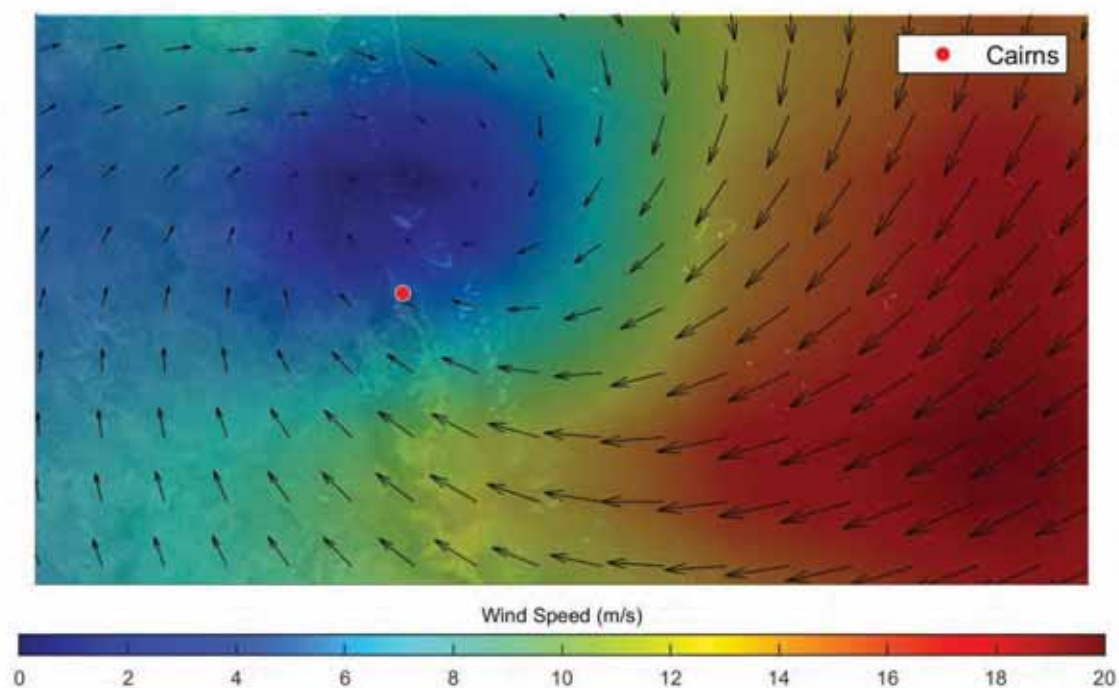


Figure 6-10 CFSR Wind Field of Tropical Cyclone Yasi on 02/02/2011 at 22:00

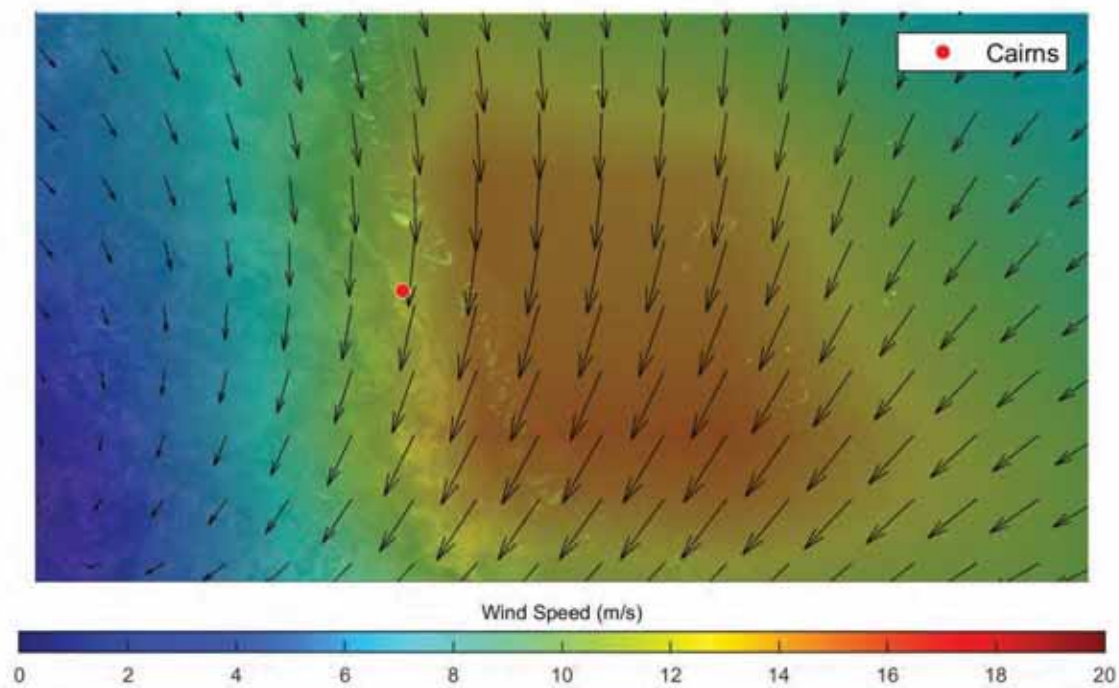


Figure 6-11 CFSR Wind Field of Tropical Cyclone Yasi on 03/02/2011 at 10:00

7 Maintenance Dredging Impact Assessment

7.1 Percentile Assessment Methodology

Spatial representations of the direct maintenance dredging impacts are based on percentile exceedance analysis of the model results and were derived by applying a moving 30-day analysis window over the entire simulation. The 30-day window period has been chosen for several reasons including that in a physical hydrodynamic context it represents the approximate duration of two consecutive spring-neap tidal cycles, while in an ecological context it is a meaningful timescale for assessing impacts to several key sensitive receptors in the area (e.g. the dominant seagrass *Halophila ovalis*). The moving window analysis was undertaken by moving the 30-day analysis window in 10-day increments across the entire model simulation duration (excluding model warmup).

The percentile impact plots correspond to the predicted increase in turbidity or sedimentation (deposition) over ambient conditions that are attributable to the dredging. Impacts at each percentile level were calculated for every 30-day window during the simulation, and the maximum increase at each location in the model domain is presented. Different locations within the model will have experienced their worst period at different times during the simulation and the different percentile statistics may also have occurred during different 30-day windows. It is important to note that the presented turbidity percentile plots do not represent the plume extent at any one instant in time.

Percentile values considered in this report are 95th, 80th, 50th, and 20th which correspond to exceedance durations of 36hrs (5%), 6 days (20%), 15 days (50%) and 24 days (80%) respectively for the 30-day window. The highest percentiles correspond to relatively acute and short-lived increases in turbidity/sedimentation while the lower percentiles correspond to more chronic longer-term increases.

The spatial percentile exceedance dredging impact plots are presented in tandem with the equivalent modelled ambient percentile statistics, calculated as the average over all 30-day windows during the simulation period. This allows the increases in turbidity or sedimentation due to dredging to be seen relative to the modelled ambient conditions.

Key features of the moving window percentile analysis include:

- Consideration of a range of impact durations from acute to chronic;
- Can be applied to a long-term programme and capture periods of high intensity versus low intensity impacts; and
- A similar analysis applied to the baseline data can quantify the ambient conditions including natural variability across different periods. This can be used to derive meaningful thresholds for the impacts.

Twelve months of baseline turbidity monitoring was undertaken for the CSDP (described in the LMDMP document), which has allowed for the derivation of contour limits for the presentation of the percentile impact plots that are meaningful at specific sites. It should be noted that different thresholds (and therefore different contour limits) are appropriate for the different percentiles.

Maintenance Dredging Impact Assessment

In order to illustrate this, the results of applying a moving 30 window analysis to the 12 month Trinity Bay baseline monitoring dataset, is shown in Figure 7-1. The x-axis represents the different percentile values extracted from the moving 30-day window analysis moving from frequently exceeded on the left to rarely exceeded on the right. The different curves are statistics representing the variability of the percentile analysis results across the different 30-day periods (making up the entire baseline monitoring period). The lower curve represents the least turbid conditions experienced across the monitoring period while the upper limit represents the most turbid conditions. The solid green line is the mean of all the different 30-day window conditions.

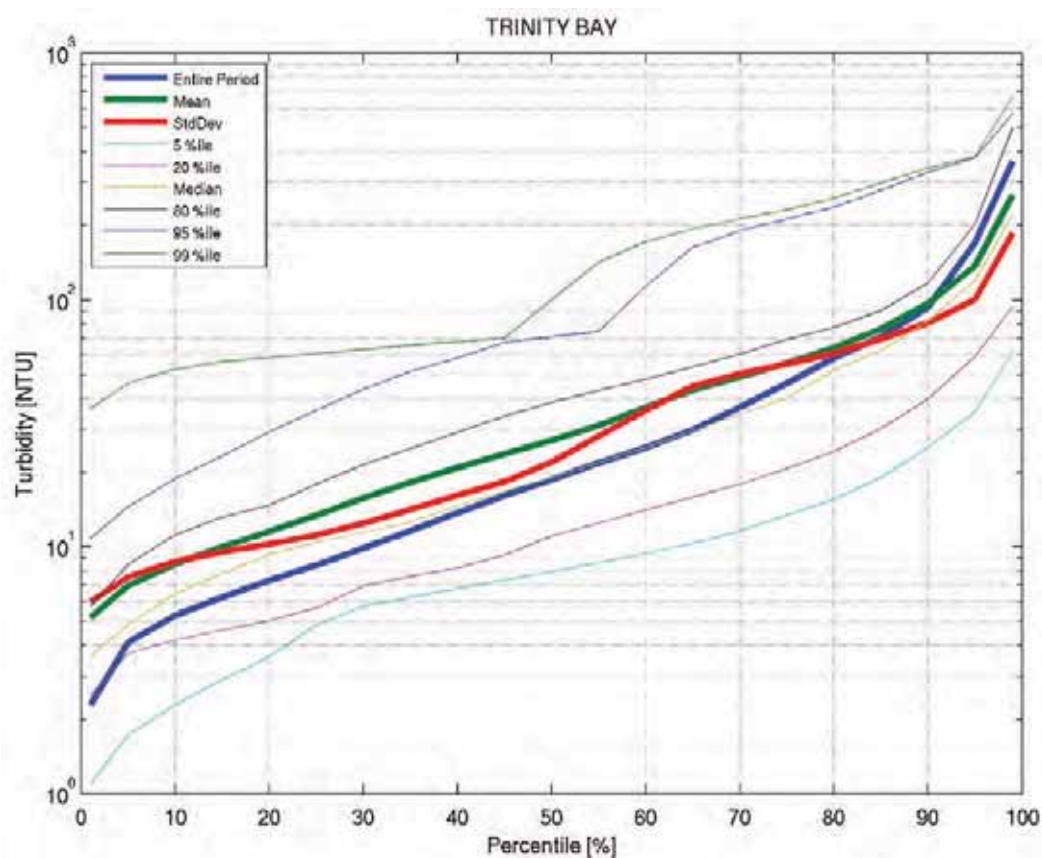


Figure 7-1 Trinity Bay Baseline Turbidity Statistics

A study of the baseline water quality statistics at various monitoring sites around Trinity Bay was undertaken as part of the CSDP (and described in the LMDMP document) which resulted in the following contouring limits in Table 7-1 being adopted for presenting the water quality impact data. Notwithstanding substantial spatial variation, at most sites the lower contour limit is well below the lowest level experienced during the baseline data collection campaign (for that percentile) and the upper contour limit is generally also well below the highest experienced level. Therefore, these contour limits are expected to fairly (if not conservatively) represent the significance of the increases in turbidity due to dredging.

Maintenance Dredging Impact Assessment

Table 7-1 Turbidity percentile contour limits

Percentile	Lower Limit (NTU)	Upper Limit (NTU)
95 th	10	200
50 th	2	40

For the case of assessing sedimentation increases due to maintenance dredging activities, sufficient site-specific baseline sedimentation data was not available and therefore threshold values from literature (SKM & APASA, 2013) have been used to inform the contour selection, which is summarised in Table 7-2. For the same reason only the 95th percentile and 50th percentile sedimentation impacts were considered for the sedimentation impact assessment.

Table 7-2 Sedimentation percentile contour limits

Percentile	Lower Limit (mg/cm ² /day)	Upper Limit (mg/cm ² /day)
95 th	5	100
50 th	0.5	10

7.2 “Worst Case” Maintenance Dredge Campaign Results

Potential increases to turbidity and deposition rate due to future maintenance dredging activity has been analysed statistically. The percentile impacts process described above has been undertaken on each of the nine (9) unique maintenance dredging simulations to derive percentile impact results. These results have subsequently been combined to form a “Worst Case” ensemble model result, which represents the highest increase to the 50th and 95th percentiles of the turbidity and deposition rate at each location in the model. The “Worst Case” impacts due to dredging activity represents the possible levels of impact if weather conditions are adverse.

Note: Hydrodynamic and sediment transport modelling was completed in 3D (refer Section 2.1). The presented percentile turbidity impacts below represent the ensemble depth-averaged and maximum over water column results. The depth-averaged and near bed (bottom 1 m) results for each unique simulation are presented in Appendix I. Timeseries turbidity plots for each unique simulation are presented in Appendix J.

The following results are presented below:

- **Figure 7-2:** 95th percentile modelled ambient depth averaged turbidity (top) and impact of dredging on the 95th percentile of depth averaged turbidity (bottom)
- **Figure 7-3:** 95th percentile modelled ambient maximum turbidity (top) and impact of dredging on the 95th percentile of maximum turbidity (bottom)
- **Figure 7-4:** 50th percentile modelled ambient depth averaged turbidity (top) and impact of dredging on the 50th percentile depth averaged turbidity (bottom)
- **Figure 7-5:** 50th percentile modelled ambient maximum turbidity (top) and impact of dredging on the 50th percentile of maximum turbidity (bottom)

Maintenance Dredging Impact Assessment

- **Figure 7-6:** Impact of dredging on the 95th percentile average deposition rate
- **Figure 7-7:** Impact of dredging on the 50th percentile average deposition rate
- **Figure 7-8:** Impact of dredging on the 95th percentile maximum deposition rate
- **Figure 7-9:** Impact of dredging on the 50th percentile maximum deposition rate.

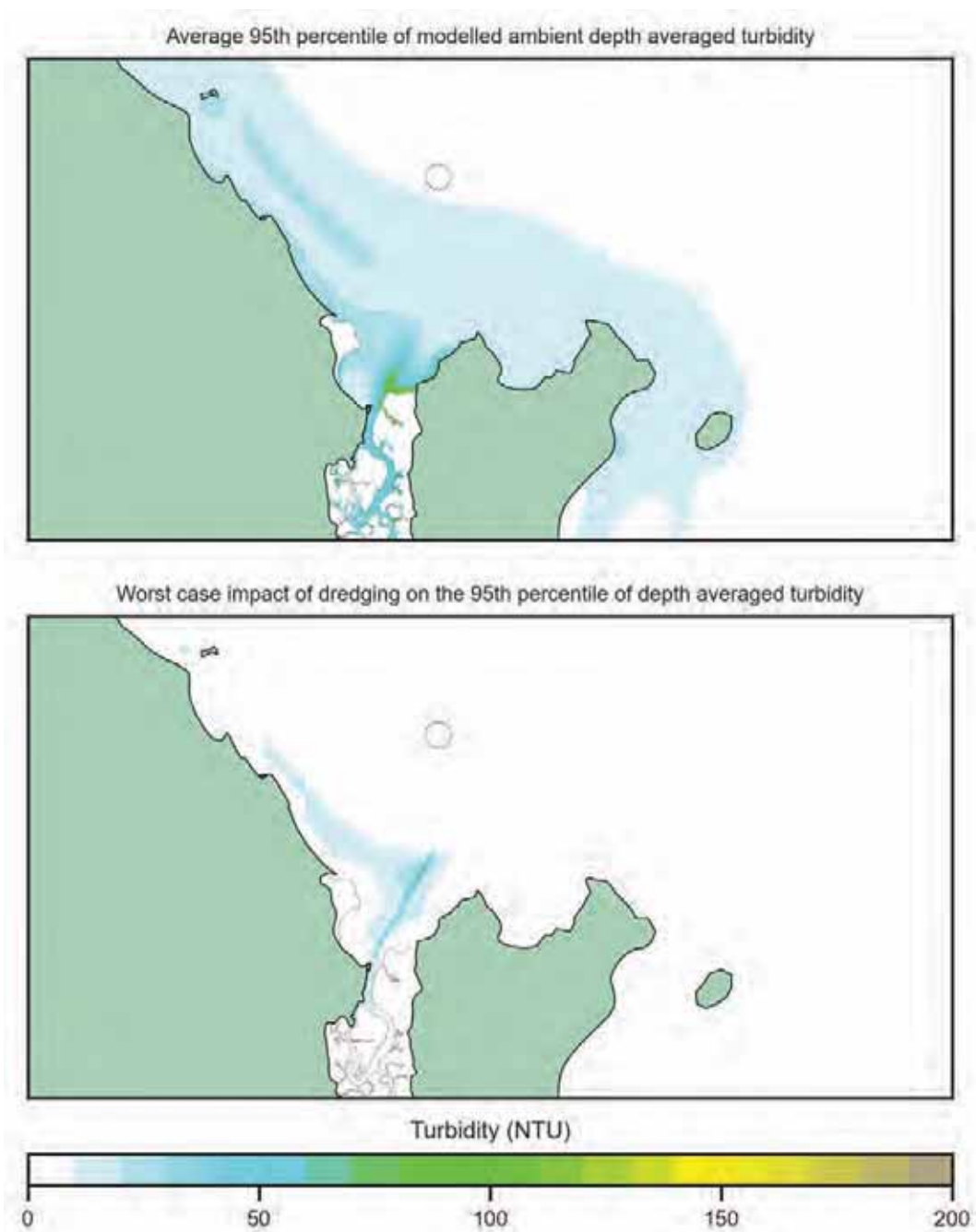


Figure 7-2 95th percentile modelled ambient depth averaged turbidity (top) and impact of dredging on the 95th percentile of depth averaged turbidity (bottom)

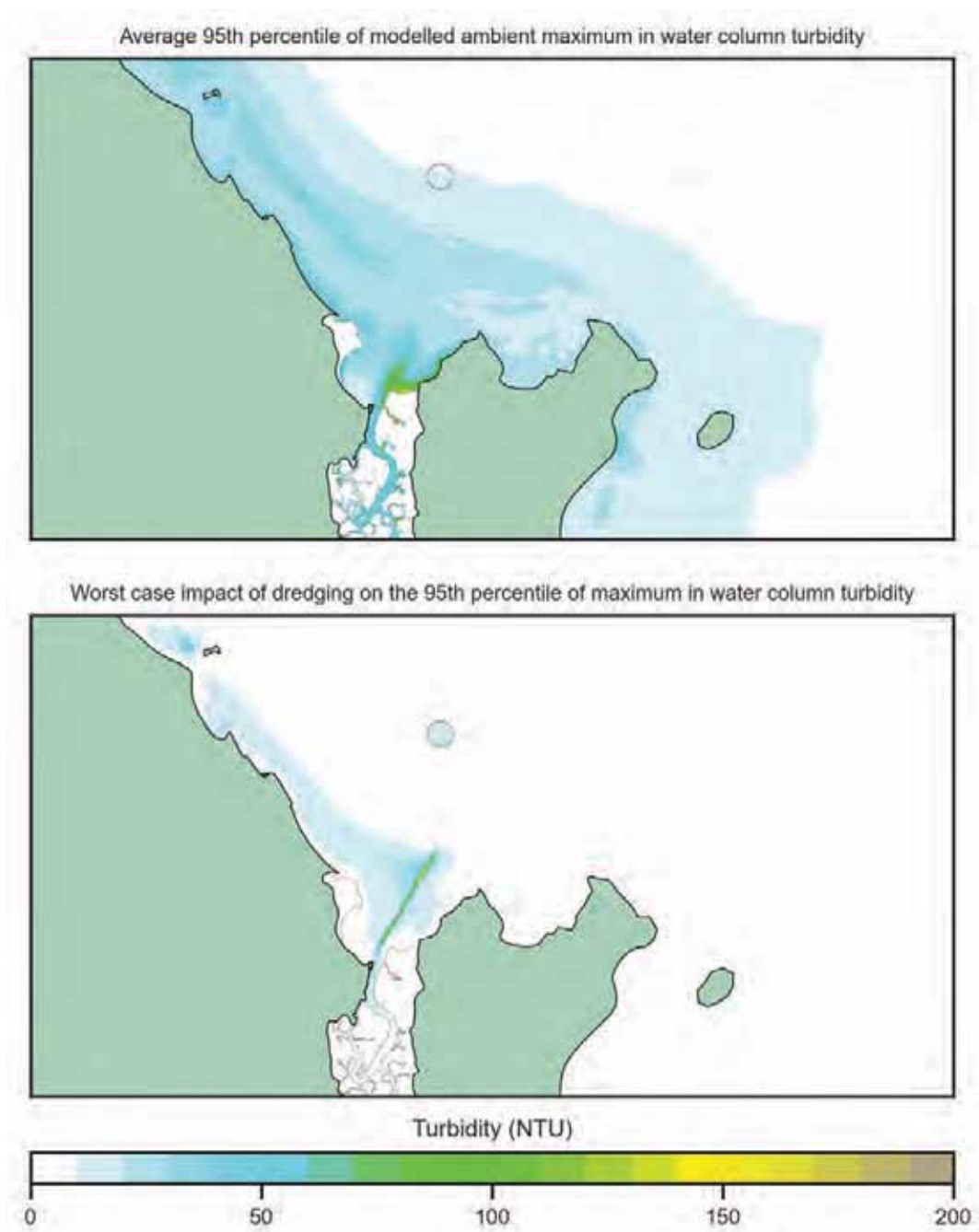


Figure 7-3 95th percentile modelled ambient maximum turbidity (top) and impact of dredging on the 95th percentile of maximum turbidity (bottom)

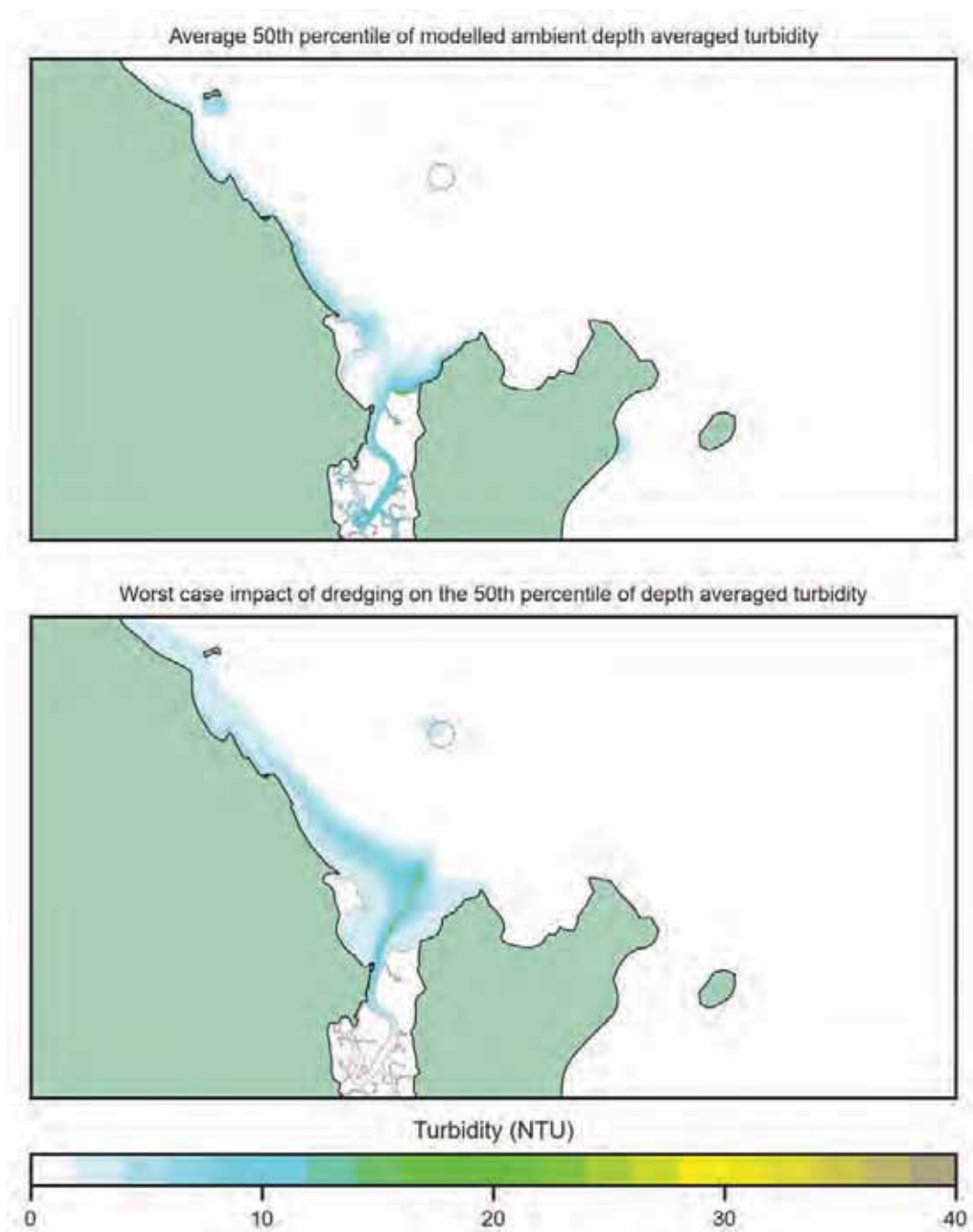


Figure 7-4 50th percentile modelled ambient depth averaged turbidity (top) and impact of dredging on the 50th percentile depth averaged turbidity (bottom)

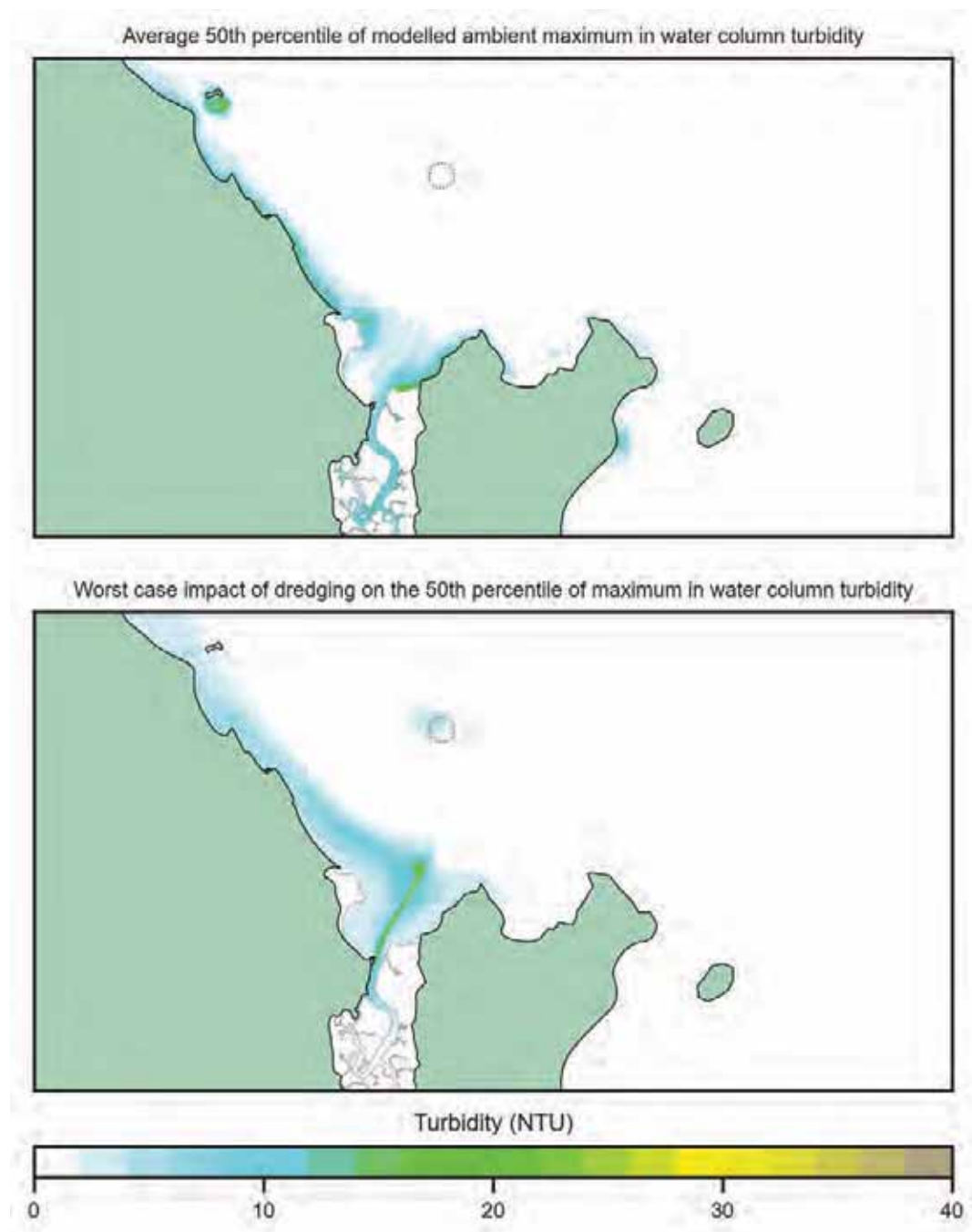


Figure 7-5 50th percentile modelled ambient maximum turbidity (top) and impact of dredging on the 50th percentile of maximum turbidity (bottom)

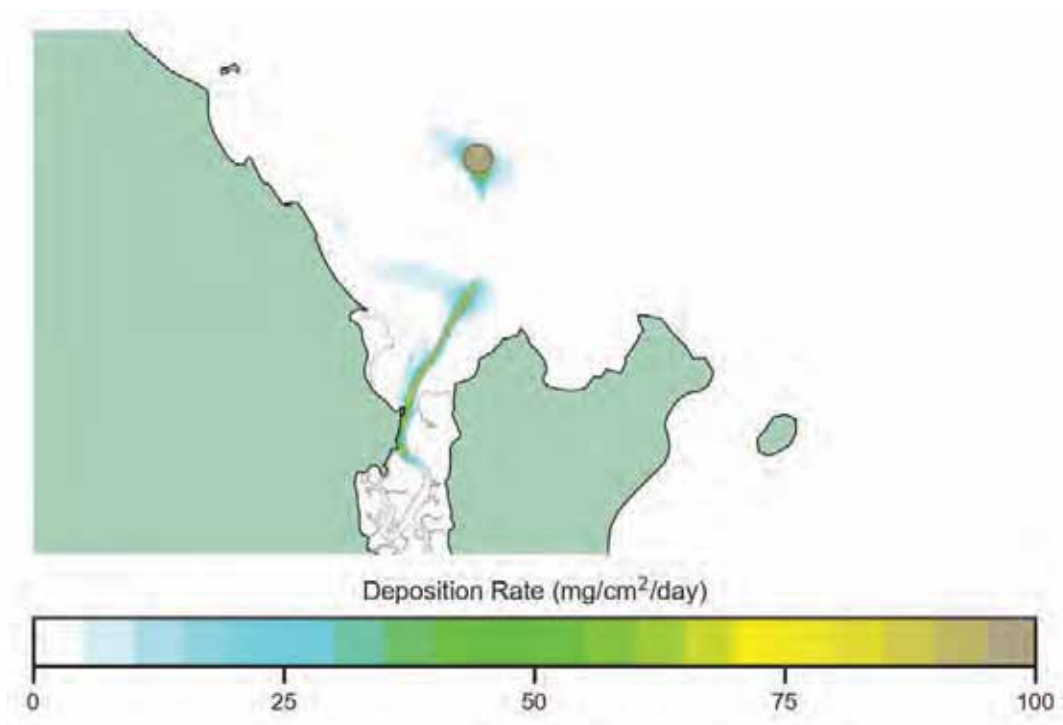


Figure 7-6 Impact of dredging on the 95th percentile average deposition rate

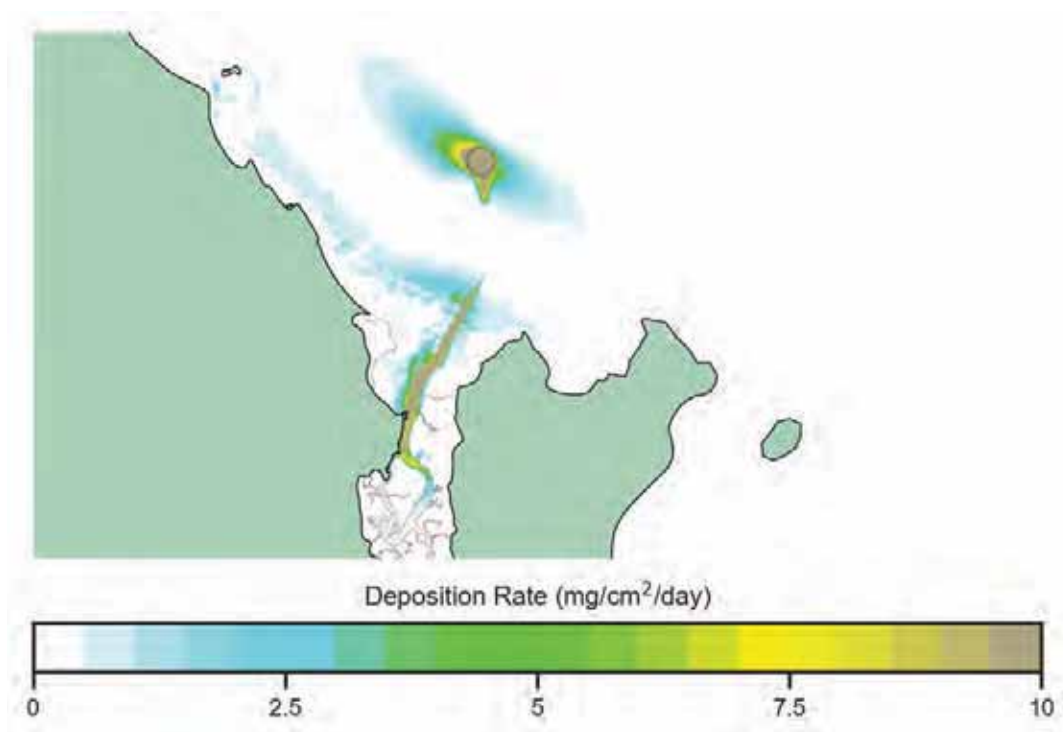


Figure 7-7 Impact of dredging on the 50th percentile average deposition rate

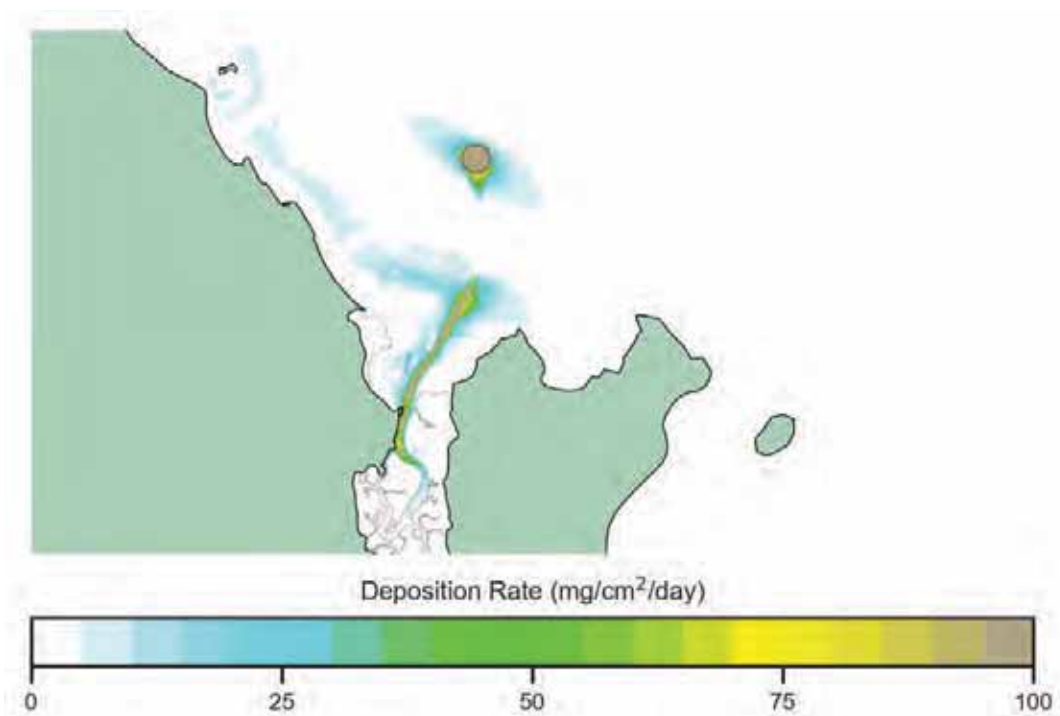


Figure 7-8 Impact of dredging on the 95th percentile maximum deposition rate

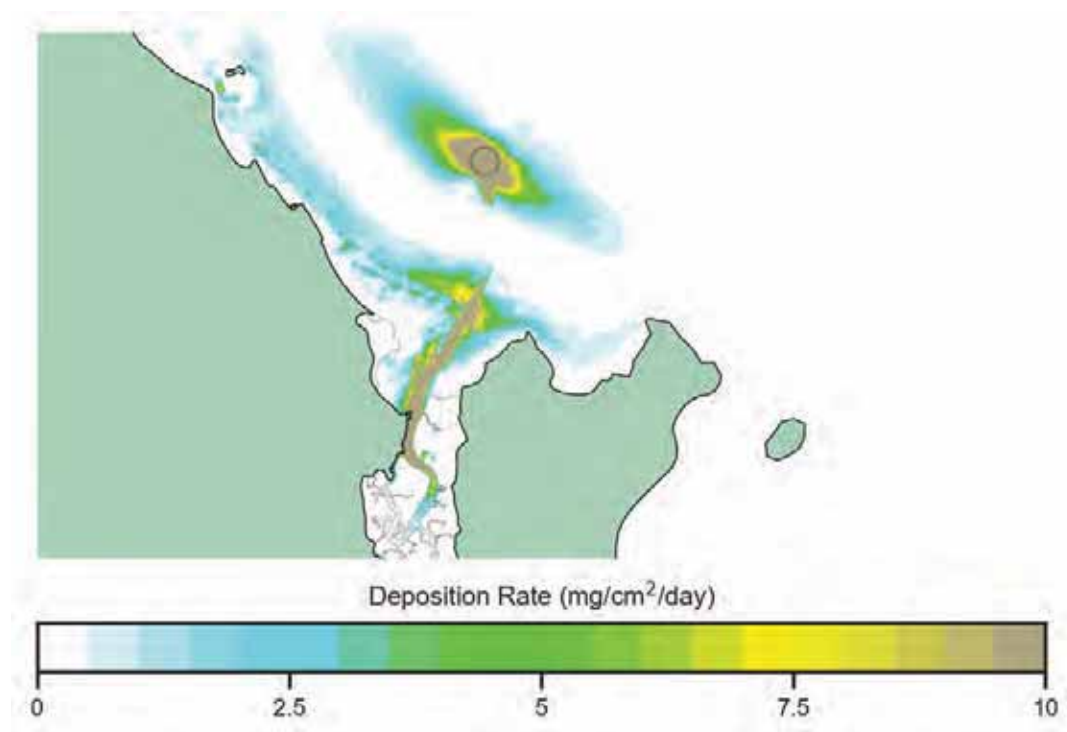


Figure 7-9 Impact of dredging on the 50th percentile maximum deposition rate

7.3 DMPA Resuspension Results

Sediments placed within the DMPA during a maintenance dredging campaign are available resuspension by the prevailing coastal processes. The numerical modelling tools have been used to assess the retentiveness of the proposed DMPA for the scenarios introduced in Section 6.2.2, namely:

- 12-Month resuspension simulation for typical weather conditions from November 2011 to November 2012
- Extreme event (Cyclone Yasi) resuspension simulation from the 10th of January to the 20th of February 2011.

For each modelling scenario, the mass of dredge-related sediment within the DMPA was tracked to determine the amount of material that is resuspended and subsequently settles outside of the DMPA. Mass time series are presented in Figure 7-10 and Figure 7-11 and a summary of the results is provided in Table 7-3.

The results indicate that once the material has been placed, the amount of mass transported out of the DMPA over a typical 12-month period is lower than an extreme weather event. Both resuspension simulations indicate the amount of mass 'lost' is small relative to the amount placed on an annual basis (<10%).

Table 7-3 Summary of DMPA Retention

Simulation	Initial Mass (Tonnes)	Final Mass (Tonnes)	Net Loss (Tonnes)	Percent Loss (%)
Typical 12-month Resuspension	247,000	231,000	16,000	6.47
Extreme Event (TC Yasi) Resuspension	247,000	226,000	21,000	8.50

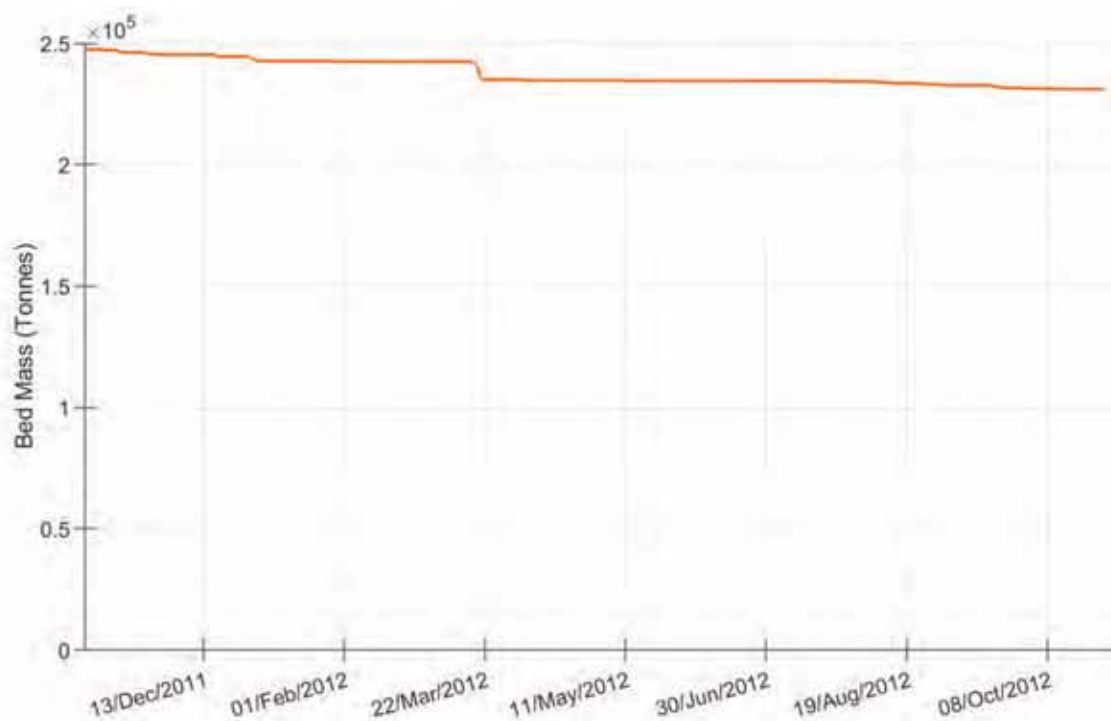


Figure 7-10 Proposed DMPA Bed Mass Time Series for 12-Month Post Dredge Simulation

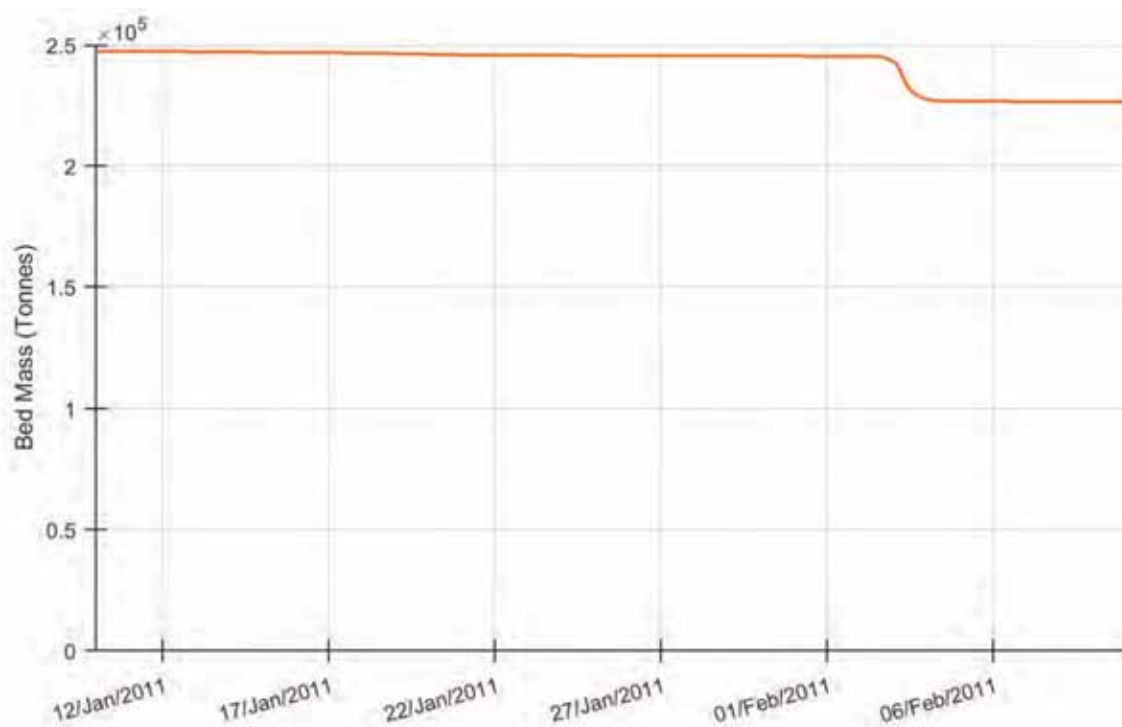


Figure 7-11 Proposed DMPA Bed Mass Time Series for Cyclone Yasi Post Dredge Simulation

7.4 Zones of Impact

7.4.1 Zones of Impact Assessment Methodology

A water quality risk assessment methodology was developed and accepted by state and commonwealth agencies as part of the CSDP EIS using the outputs from the dredge plume numerical modelling. This same methodology is described in the LMDMP and has been used as part of the maintenance dredging assessment to consider the effects of excess sedimentation due to dredge-related activities as well as increased water column turbidity.

Impact predictions are presented as 'zones of impact' and are derived using the percentile exceedance plots described above. The zones of impact approach is now recognised as 'best practice' in dredging environmental assessments and are commonly used in environmental assessments of dredging projects in Australia, building on the methodologies set out in the dredging environmental assessment guidelines produced by the Western Australia Environmental Protection Agency (WA EPA 2016).

The zones adopted for the current assessment include the following:

- Zone of High Impact = water quality impacts resulting in predicted mortality of ecological receptors with recovery time greater than 24 months.
- Zone of Low to Moderate Impact = water quality impacts resulting in predicted sub-lethal impacts to ecological receptors and/or mortality with recovery between 6 months (lower end of range) to 24 months (upper end of range).
- Zone of Influence = extent of detectable³ plume, but no predicted ecological impacts.

It is important to note that the recovery times outlined for the various zones should be considered as indicative only, noting that such timeframes are dependent on a range of factors that are extremely complex and difficult to accurately predict. The zones and their 'recovery timeframes' represent a means for comparing the likelihood that significant, detectable impact to sensitive receptors could occur, and assume that recovery timeframes are dependent on the magnitude of impact.

A concept design of the zones of impact is shown in Figure 7-12 (WA EPA 2016).

³ 'Detectable' plume in terms of detectable above background conditions by instrumentation deployed in the water column

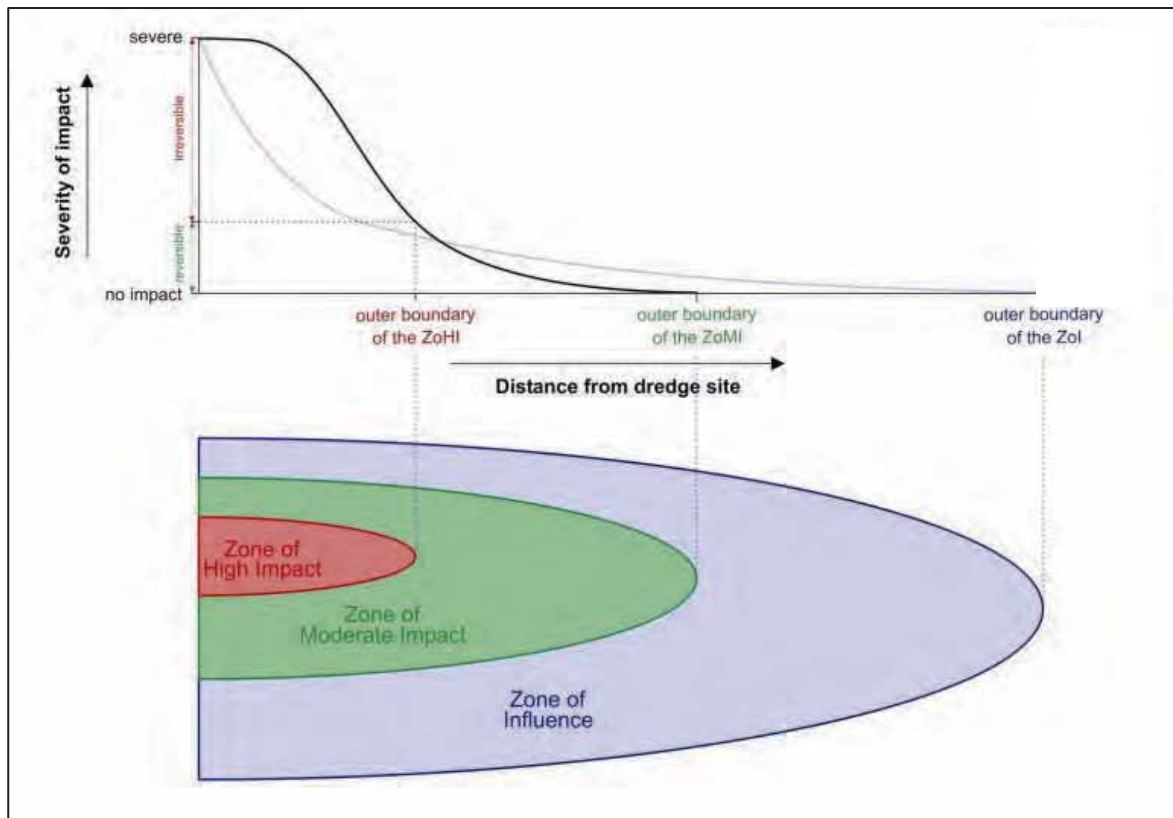


Figure 7-12 Concept design of impact zones (WA EPA 2016)

The impact zones were delineated using thresholds related to the excess turbidity and sediment deposition. These threshold values, and the methodology used to develop them, are described in the main LMDMP document.

Zones of impact were developed for the following model simulations:

- Maintenance dredge campaign scenarios, including placement at the proposed DMPA, based on the “Worst Case” ensemble model result.
- Long term (12 month) resuspension following final placement at the proposed DMPA.

7.4.2 Zones of Impact Results

The results are presented as turbidity zones of impact for the period during maintenance dredging and placement at the proposed DMPA (depth averaged result in Figure 7-13 and maximum over water column result in Figure 7-14) and the 12-month resuspension period following completion of dredging (Figure 7-15).

As mentioned previously, these zones of impact represent a ‘worst case’ ensemble of all nine scenarios modelled. As the nine different scenarios would not occur simultaneously in any one year, the zones of impact are more representative of a long-term risk map of potential impacts over different weather conditions and dredging methodologies.

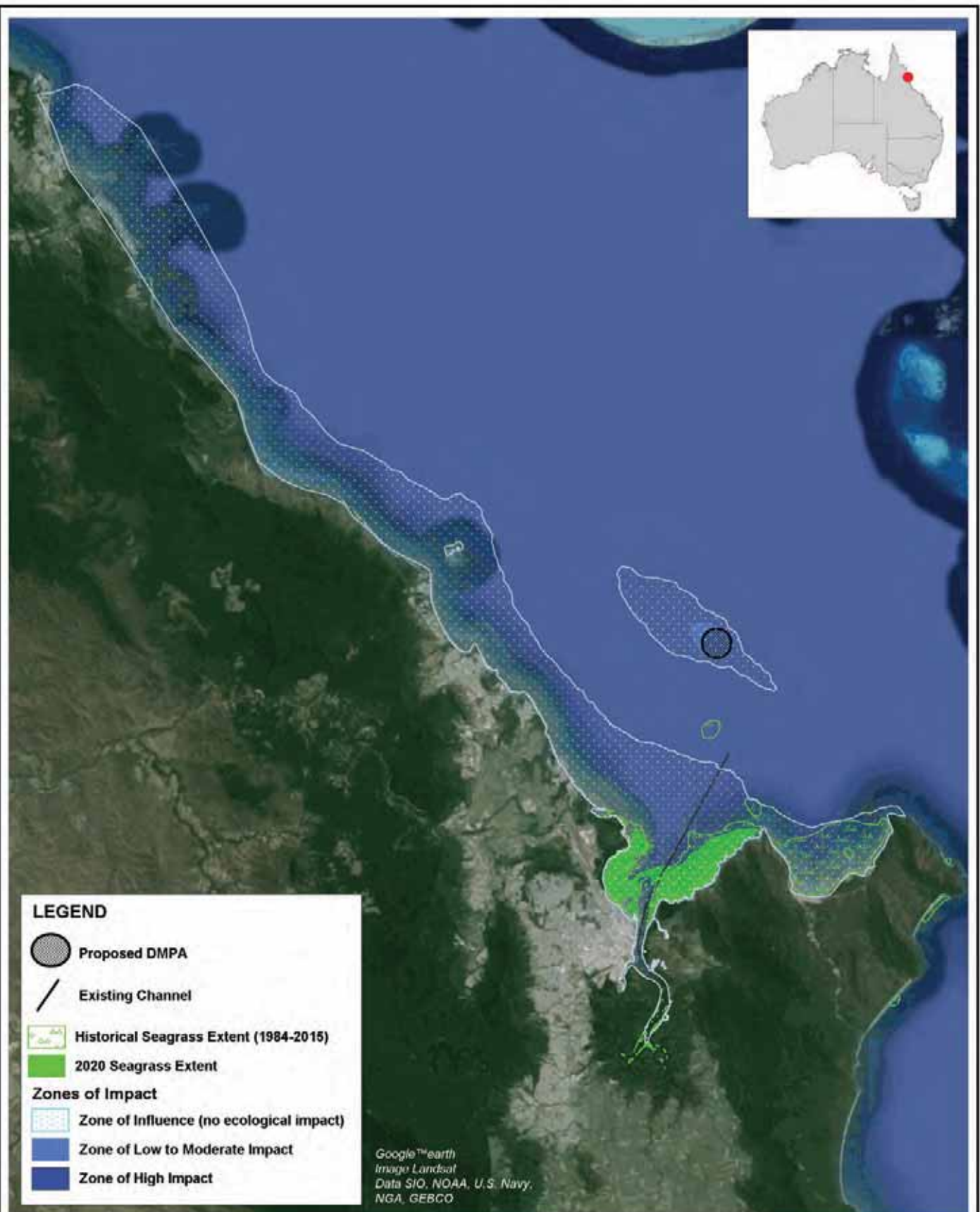
Also shown on the turbidity zone of impact figures are seagrass extents (from annual monitoring undertaken by JCU). These seagrass extents are shown as the historical maximum seagrass extent (from monitoring data collected between 1984 and 2015) and the most recently available seagrass extent from 2018.

The turbidity zones of impact figures indicate the following:

- Increases in turbidity due to maintenance dredging of the channel are not predicted to cause any 'zones of high impact' in the nearshore environment, including areas of sensitive ecological receptors. In other words, turbidity in the nearshore environment where channel dredging would occur is expected to remain within natural variability (i.e. maintaining 20th, 50th and 80th percentiles of natural turbidity).
- There is a 'zone of influence' extending out from the channel dredging area along the coast to the north-west along the coast. The 'zone of influence' also extends east out to Cape Grafton. While this zone indicates the predicted extent of detectable plumes, the turbidity in this zone is predicted to remain within natural variability and therefore ecological impacts are not predicted to occur.
- For dredge material placement at the proposed DMPA, a 'zone of influence' is predicted to extend up to approximately 7 km north-west and south-east of the proposed DMPA. There is also a 'zone of low to moderate impact' predicted within the vicinity (up to approximately 1 km) of the proposed DMPA.
- In the 12 month period following dredging, resuspension of dredge material from the proposed DMPA is not predicted to result in any turbidity zones of impact as indicated in Figure 7-15. This is due to placed material predicted to mostly remain at the DMPA.

Sediment deposition zones of impact (separate to broader turbidity impacts as shown above) have not been produced for this assessment of maintenance dredging; but the sediment deposition percentile plots presented as part of the modelling in Figure 7-6 and Figure 7-7 indicate the following:

- Areas of elevated sediment deposition rates (predicted to be confined to the channel and the DMPA, with some slightly elevated deposition rates predicted to the east of these areas under the 'chronic' scenario) do not coincide with any areas containing coral reefs within the study area (including Double Island and Rocky Island). As such, no deposition or smothering impacts on corals are expected to occur.
- While some areas of elevated sediment deposition rates are predicted to extend over some historical seagrass areas, seagrasses are typically less sensitive to sediment deposition and are not expected to be impacted at the deposition rates predicted by the modelling. This accords with long term seagrass monitoring as outlined in Chapter 3 of the LMDMP which has not shown any effects from deposition or smothering associated with maintenance dredging or placement.



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**Zones of Impact - Depth-Averaged Turbidity
Maintenance Dredging**

Figure:
7-13

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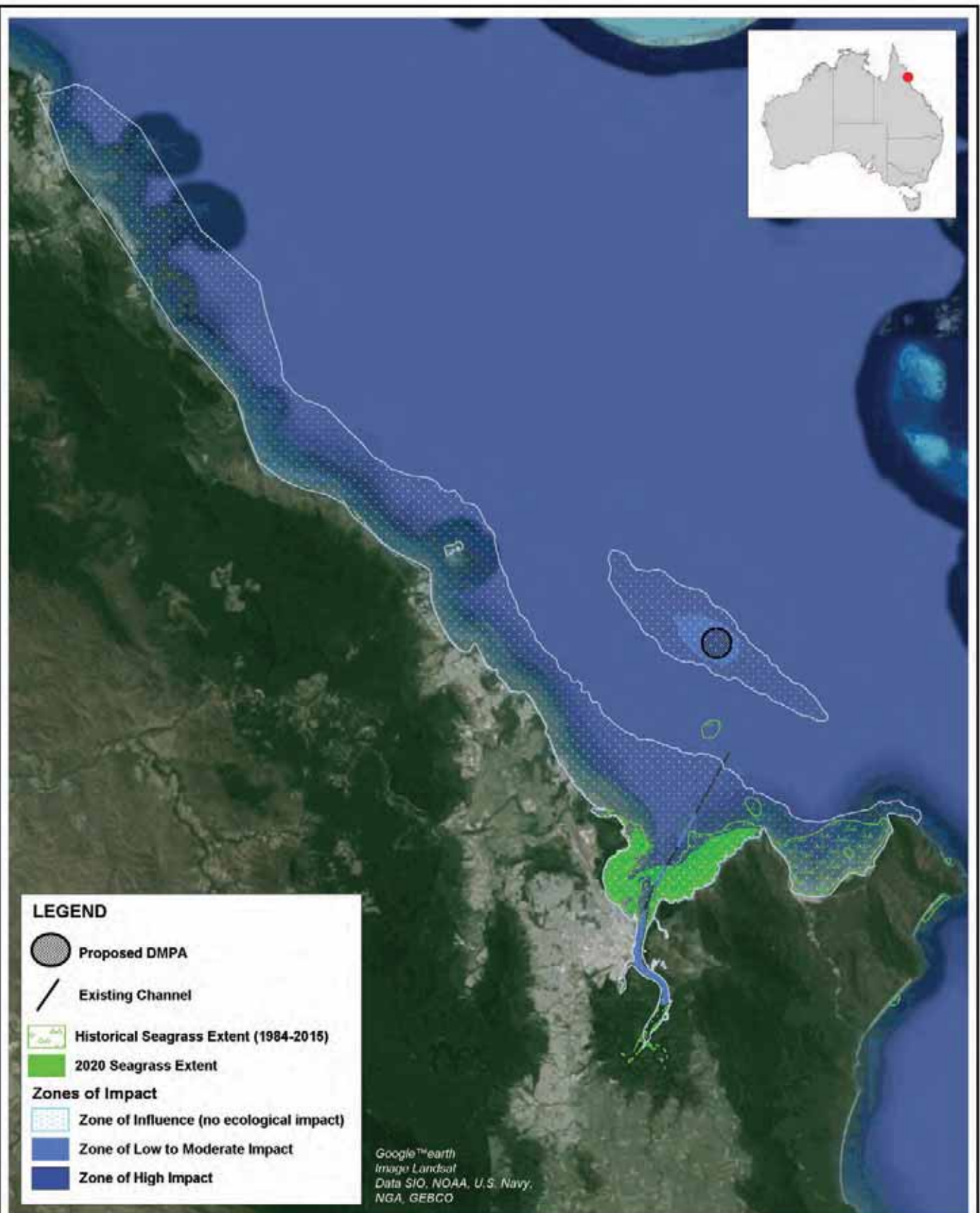
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Approx. scale



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**Zones of Impact - Maximum Turbidity
Maintenance Dredging**

Figure:
7-14

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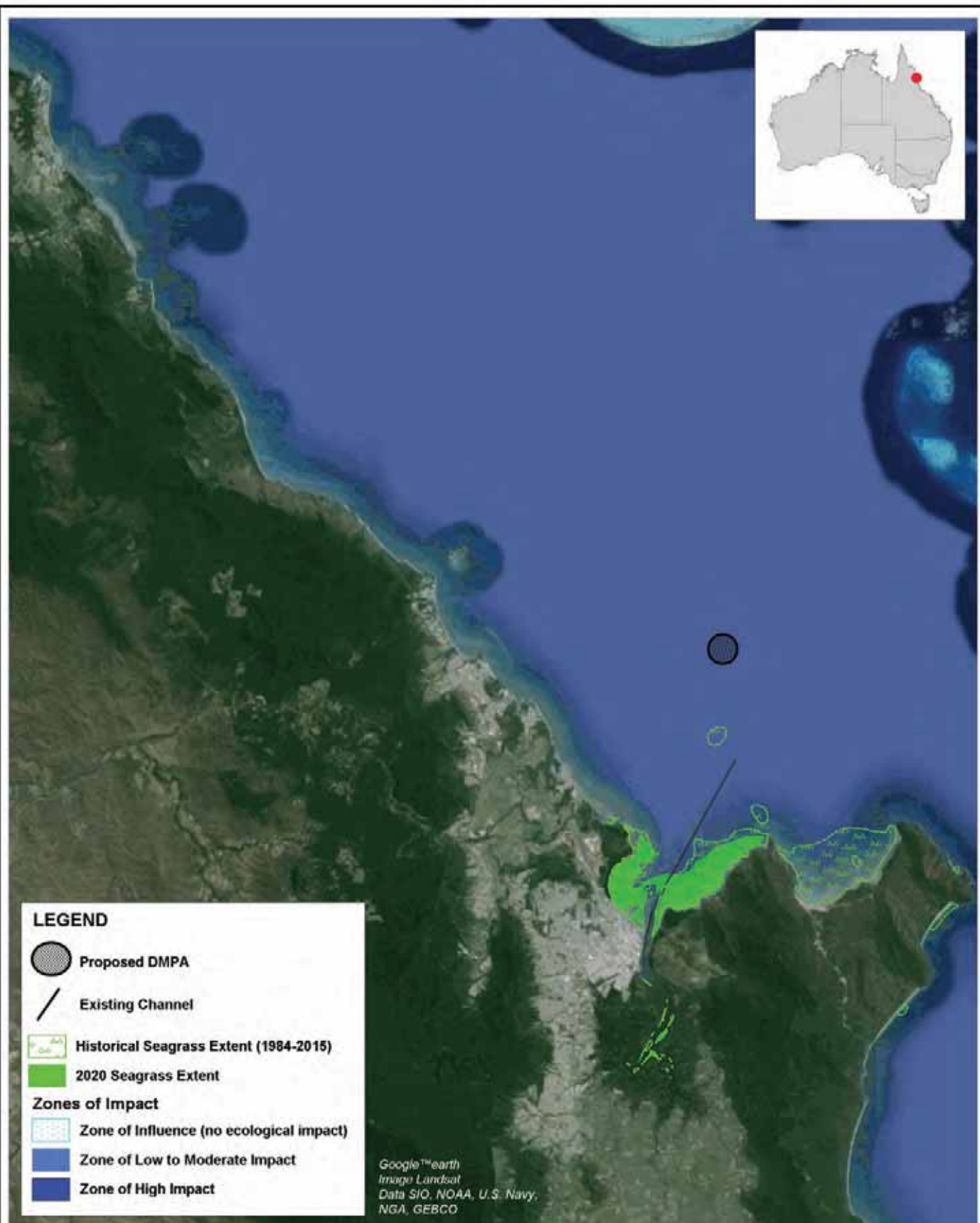
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Zones of Impact - Turbidity - 12 Month Resuspension

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7-15

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Appendix A Example TUFLOW FV Simulation Control File

An example TUFLOW FV hydrodynamic simulation control file show model settings and parameters is presented in Figure A-1 and Figure A-2. The adopted model parameters are typically “default” values and/or within the range of accepted literature values.

Example TUFLOW FV Simulation Control File

```

0 10 20 30 40 50 60 70 80 90 100
1 ! Cairns local model
2
3 ! SIMULATION CONFIGURATION
4 !
5 spherical == 1
6 include salinity == 1,1
7 include temperature == 1,1
8 include heat == 1
9 momentum mixing model == Smagorinsky
10 scalar mixing model == Smagorinsky
11 vertical mixing model == External
12 bottom drag model == ks
13 spatial order == 2,2
14 equation of state == UNESCO
15 !
16
17 !TIME COMMANDS
18 !
19 cfl external == 0.9
20 cfl internal == 0.9
21 time format == ISODATE
22 start time == 17/02/2013 00:00:00
23 end time == 27/06/2013 08:00:00
24 display dt == 300.
25 timestep limits == 0.1, 15.0
26 turbulence update dt == 300.
27
28 !MODEL PARAMETERS
29 !
30 stability limits == 10.,20.
31 cell wet/dry depths == 5.0e-3, 1.0e-1
32 cell 3d depth == 5.0e-1
33 reference density == 1025.0
34 reference salinity == 35.0
35 reference temperature == 26.0
36 kinematic viscosity == 1.0e-6
37 global horizontal eddy viscosity == 0.5
38 global horizontal eddy viscosity limits == 1.0, 9999.0
39 global horizontal scalar diffusivity == 0.2
40 global horizontal scalar diffusivity limits == 1.0, 9999.0
41 global vertical eddy viscosity limits == 1.0e-4, 1.0
42 global vertical scalar diffusivity limits == 0., 1.0
43
44 !GEOMETRY
45 !
46 geometry 2d == ..\geo\CAI_EIS_013_EIS_option1a.2dm
47 cell elevation file == ..\geo\cell_centres\CAI_EIS_013_EIS_option1a_centres_inspected.csv
48
49 vertical mesh type == s
50 layer faces == ..\geo\sfaces\CAI_slayer_003.csv
51 sigma layers == 4
52 min bottom layer thickness == 0.5
53
54 echo geometry == 1
55
56 material == 1,6,7,8,9 !default
57 bottom roughness == 0.05
58 end material
59
60 material == 2 !reefs (<20 depth) in GER chain
61 bottom roughness == 1.0
62 vertical eddy viscosity limits == 1.0, 1.0
63 end material
64
65 material == 3 !reef pass

```

Figure A-1 Example TUFLOW FV Hydrodynamic Model Simulation Control File (continued over page)

Example TUFLOW FV Simulation Control File

```

0 10 20 30 40 50 60 70 80 90 100
86 bottom roughness == 0.1
87 end material
88
89 material == 4 !open boundary
90 bottom roughness == 1.0
91 vertical eddy viscosity limits == 1.0e-4, 1.0
92 horizontal eddy viscosity limits == 10.0, 9999.0
93 end material
94
95 material == 5 !mangroves and inner reefs
96 bottom roughness == 0.5
97 end material
98
99 material == 10 !deep water
100 bottom roughness == 0.05
101 end material
102
103 !BOUNDARY CONDITIONS
104 !
105
106 ! ncep
107 include == ..\bc\ncep\BC_ncep_2013.fvc
108
109 ! hycom
110 include == ..\bc\hycom\BC_hycom_2013.fvc
111
112 ! tides
113 include == ..\bc\tides\BC_Tide_2013_002_sub-type5.fvc
114
115 ! wind
116 include == ..\bc\wind\BC_Wind_2011-2013_001.fvc
117
118 !INITIAL CONDITIONS
119 !
120
121 initial condition ogcm
122 initial condition quiescent
123
124 !OUTPUT COMMANDS
125 !
126
127 output dir == /scratch2/B20180/TUFLOWFV/output
128
129 output == netcdf
130 output parameters == h,v,w,sal,temp
131 output interval == 1800.
132 output compression == 1
133 end output
134
135 write restart dt == 6.0

```

Figure A-2 Example TUFLOW FV Hydrodynamic Model Simulation Control File (continued from previous page)

Appendix B Calibration Period Current Time Series Plot

Top and bottom half of water column current velocity and direction time series calibration plots are presented for the entire simulation period:

- DMPA, Figure B-1 to Figure B-7
- Site 2, Figure B-8 to Figure B-14
- Beacon C7, Figure B-15 to Figure B-21
- Beacon C11, to Figure B-28.

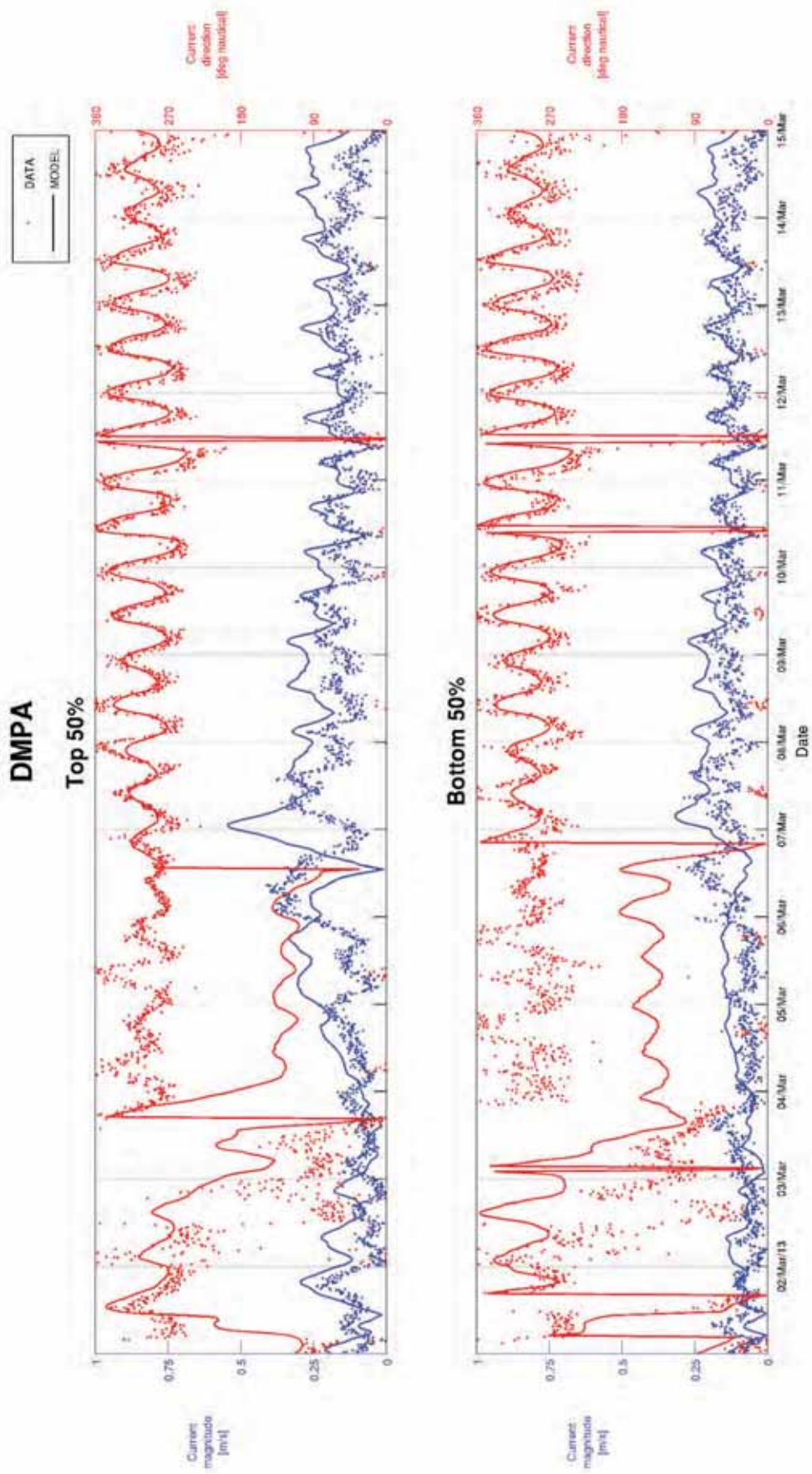


Figure B-1 Top 50% and Bottom 50% Current Calibration – DMPA 01/03/2013 to 15/03/2013

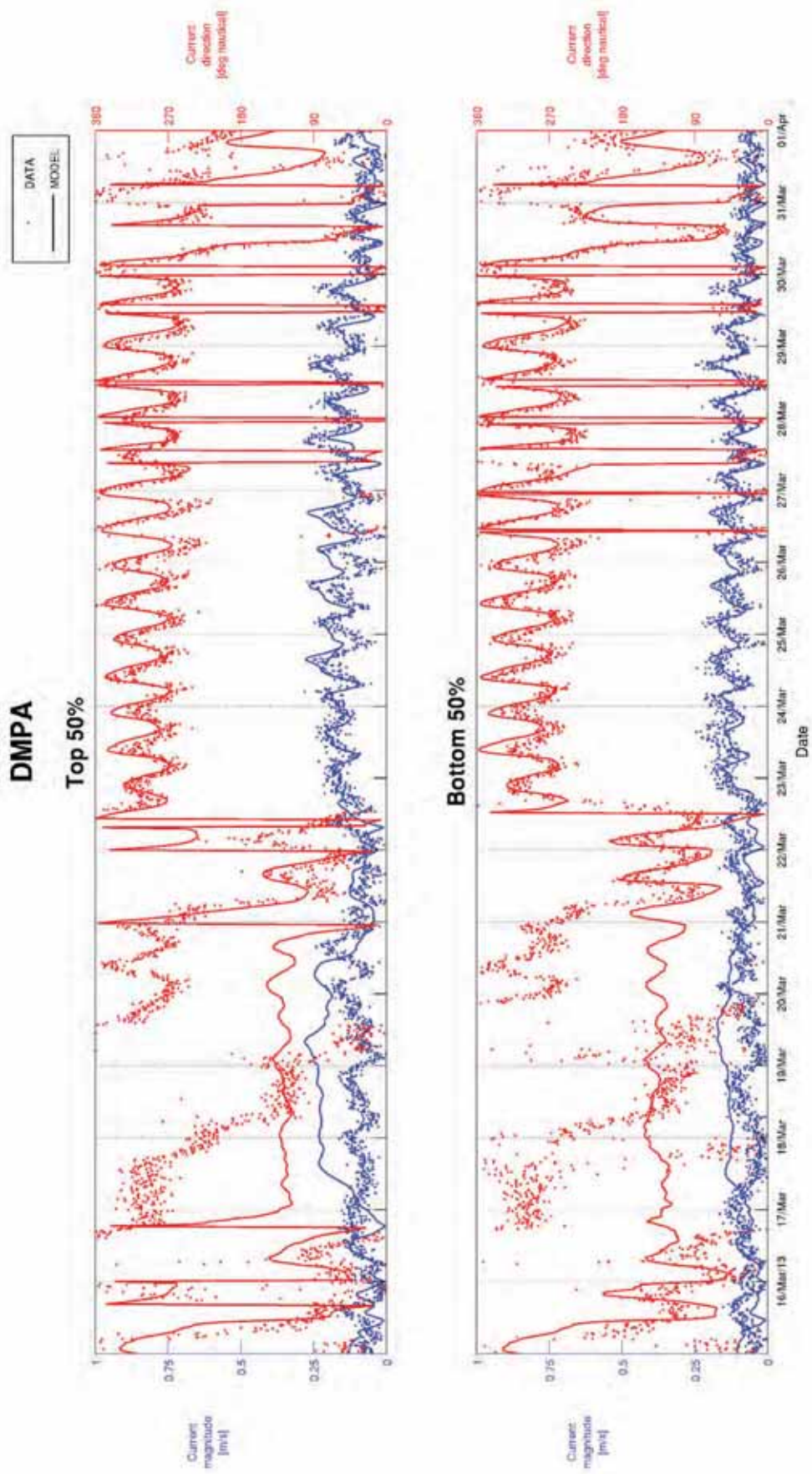


Figure B-2 Top 50% and Bottom 50% Current Calibration – DMPA 15/03/2013 to 01/04/2013

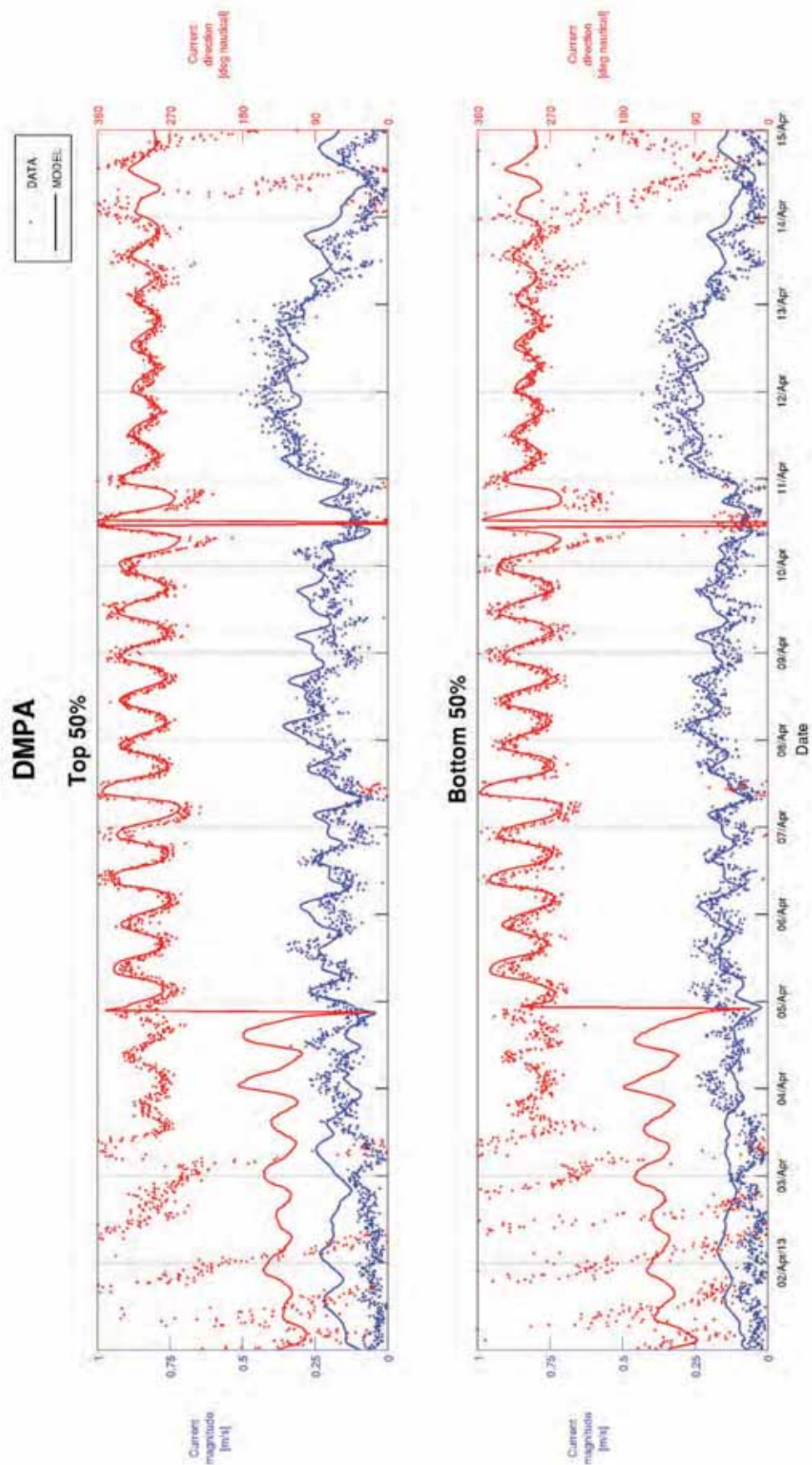


Figure B-3 Top 50% and Bottom 50% Current Calibration –DMPA 01/04/2013 to 15/04/2013

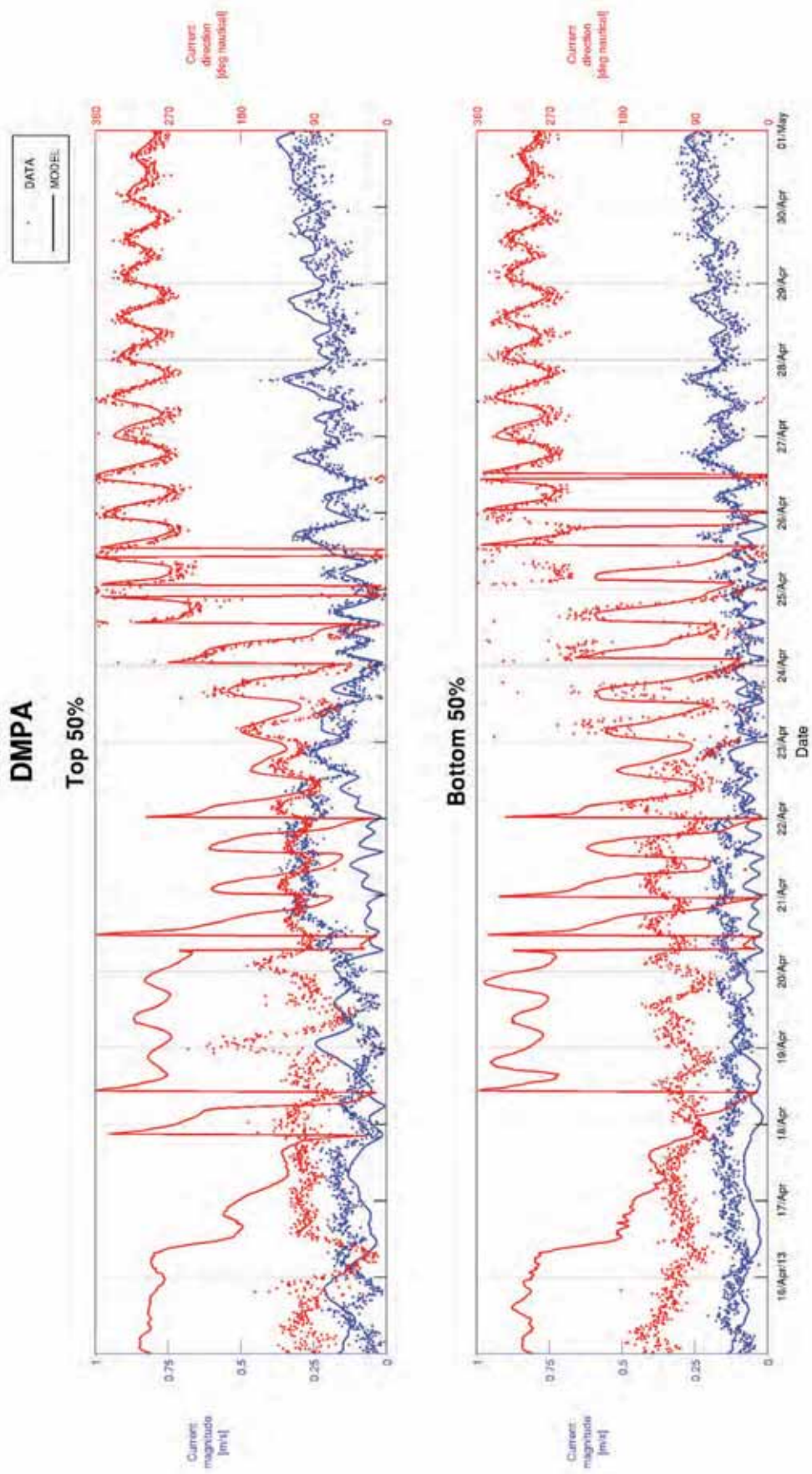


Figure B-4 Top 50% and Bottom 50% Current Calibration – DMPA 15/04/2013 to 01/05/2013

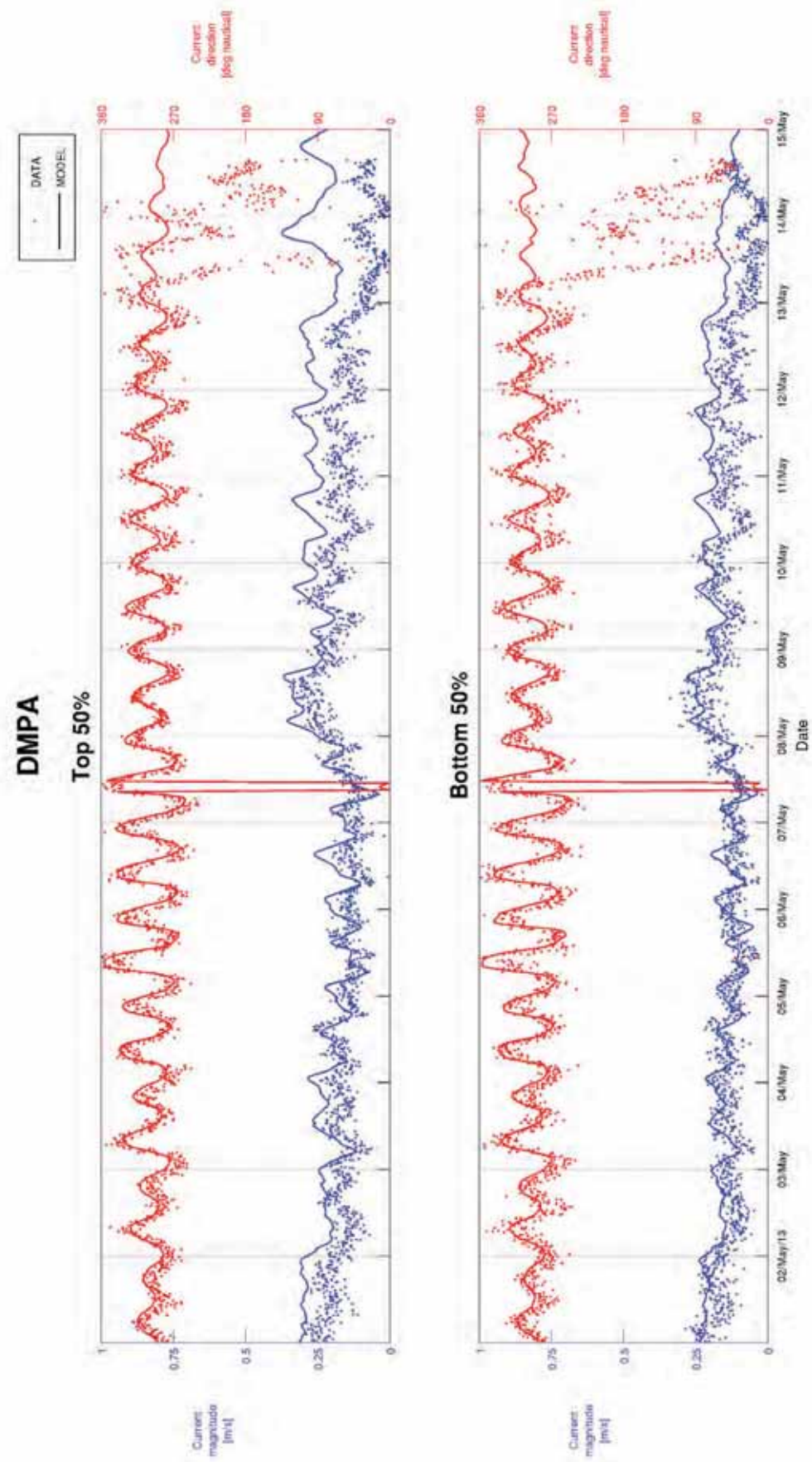


Figure B-5 Top 50% and Bottom 50% Current Calibration – DMPA 01/05/2013 to 15/05/2013

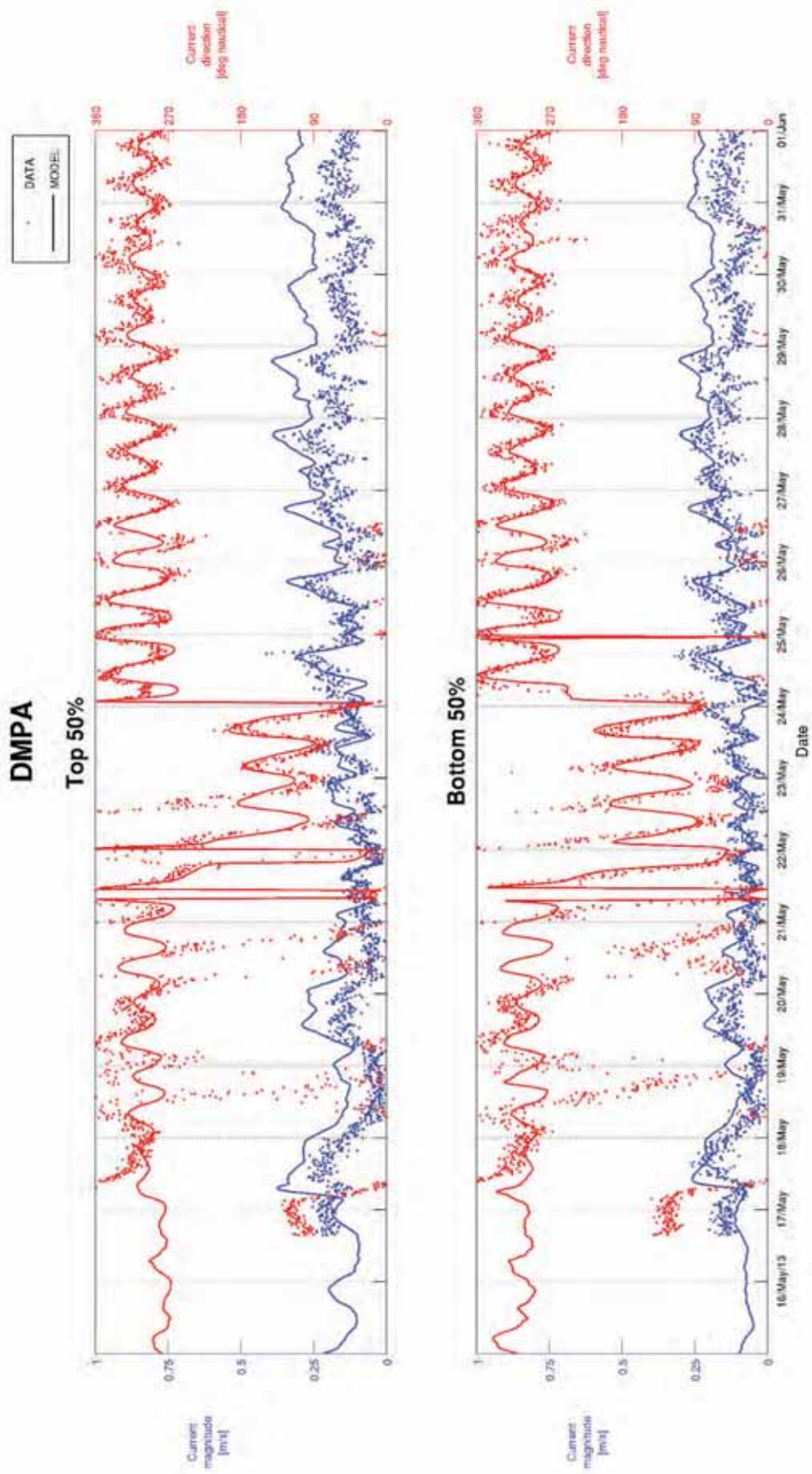


Figure B-6 Top 50% and Bottom 50% Current Calibration – DMPA 15/05/2013 to 01/06/2013

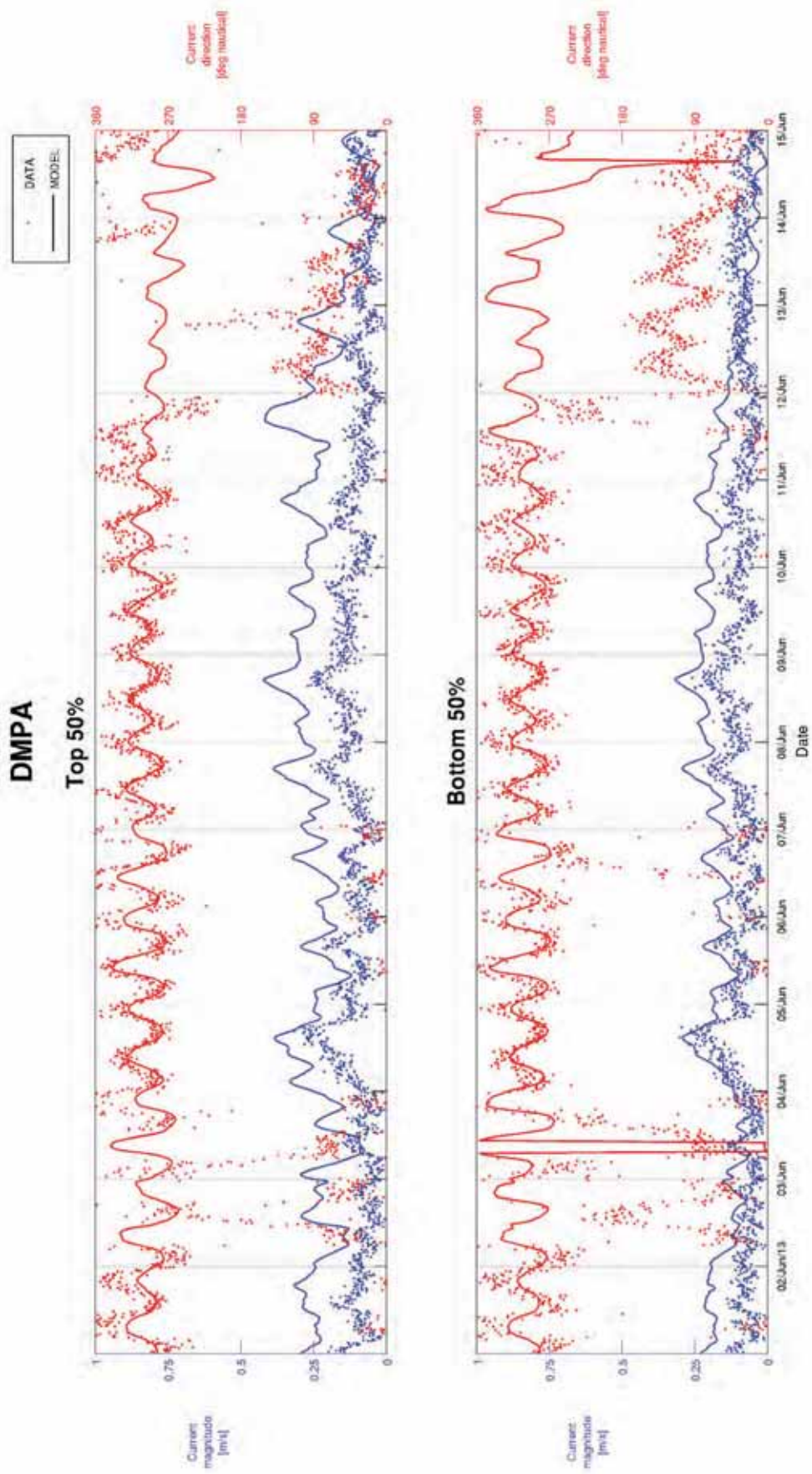


Figure B-7 Top 50% and Bottom 50% Current Calibration – DMPA 01/06/2013 to 15/06/2013

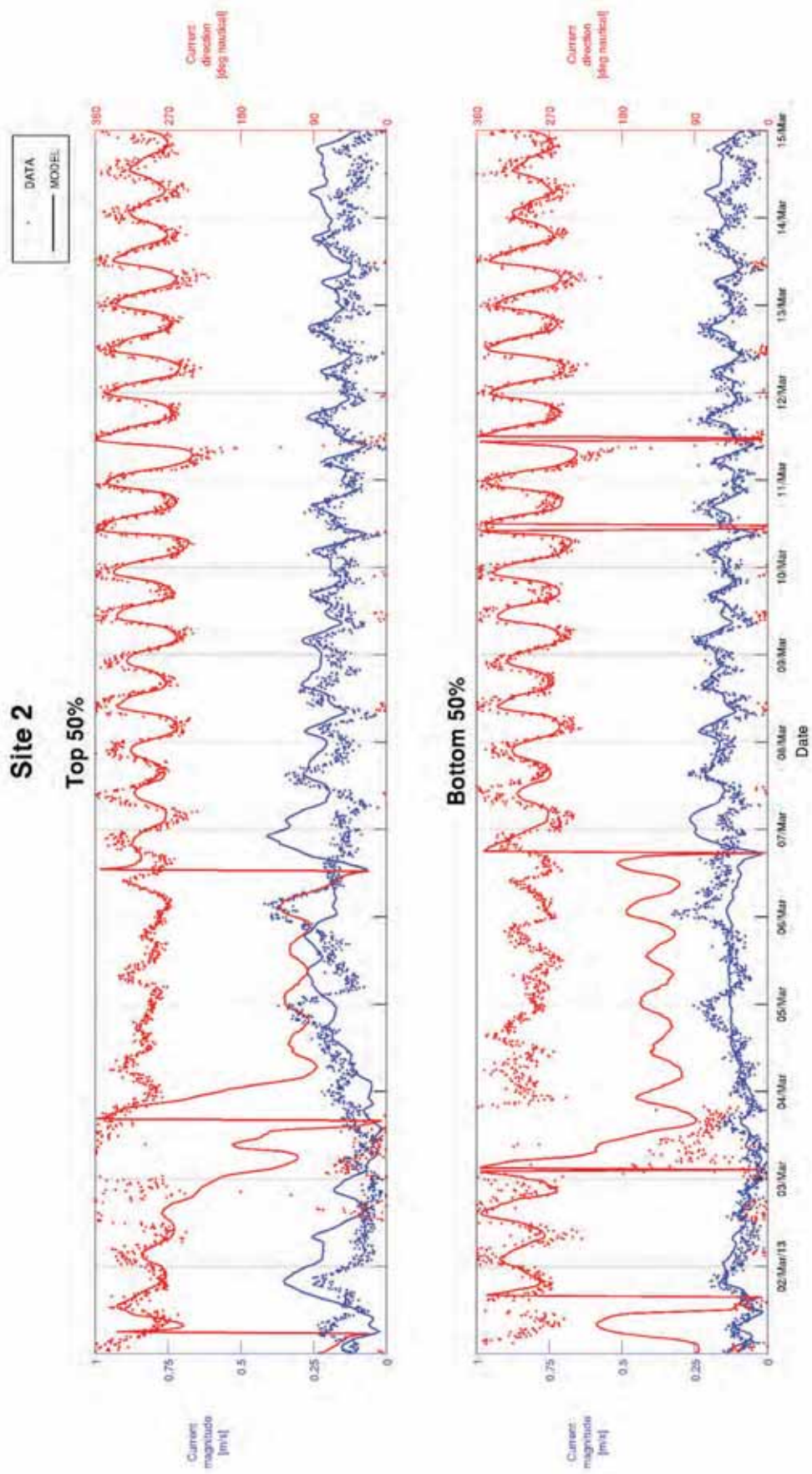


Figure B-8 Top 50% and Bottom 50% Current Validation – Site 2 01/03/2013 to 15/03/2013

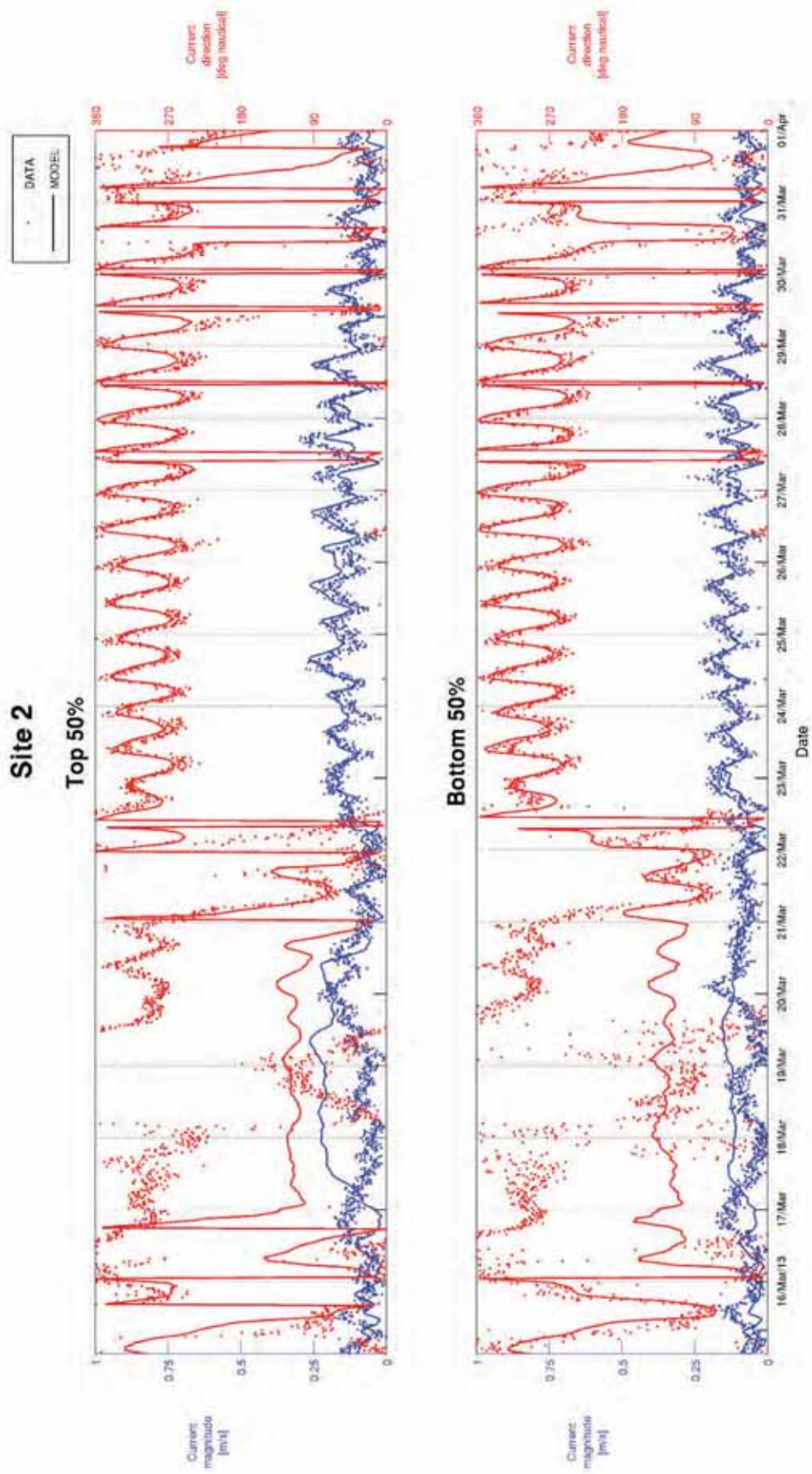


Figure B-9 Top 50% and Bottom 50% Current Calibration – Site 2 15/03/2013 to 01/04/2013



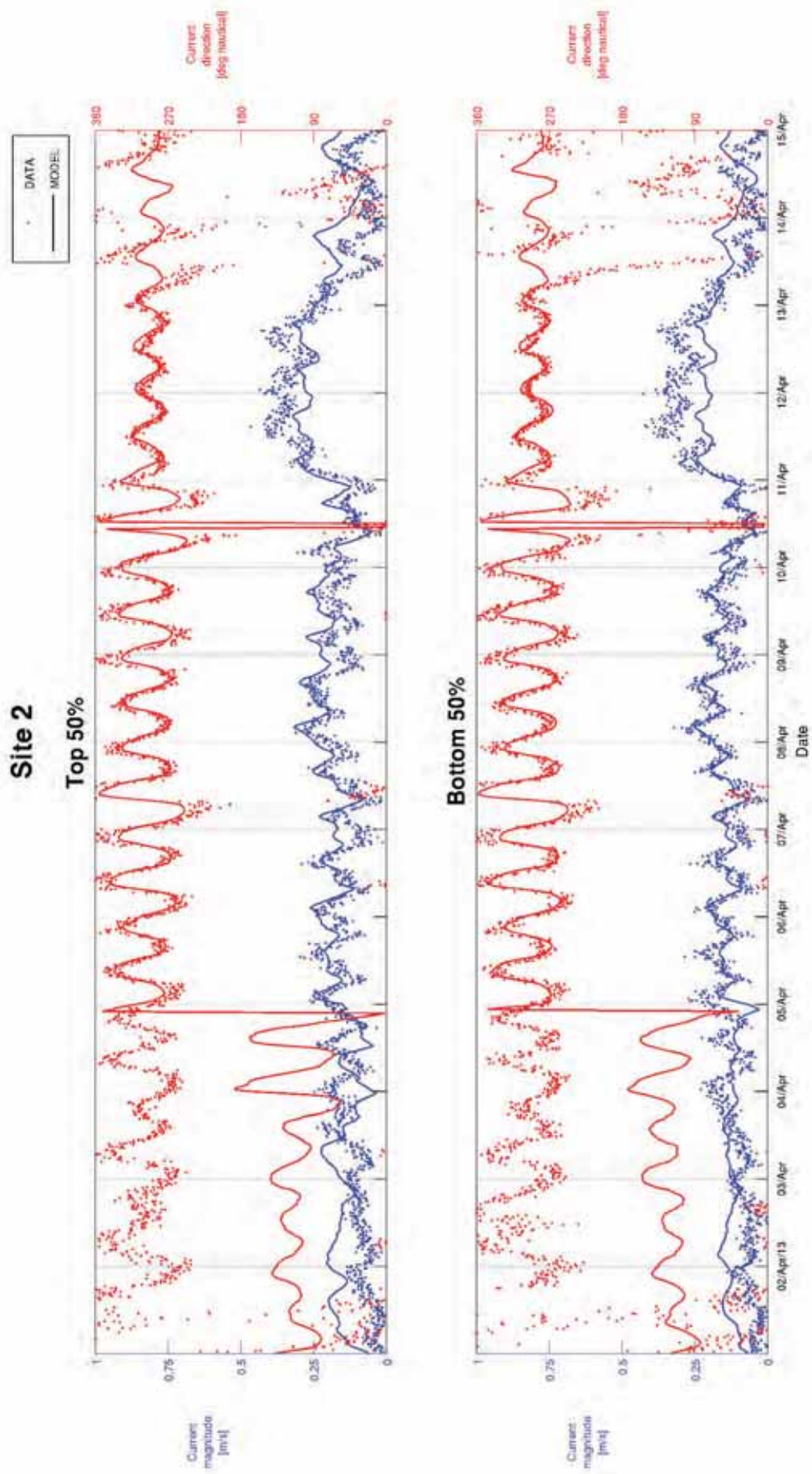


Figure B-10 Top 50% and Bottom 50% Current Calibration – Site 2 15/04/2013 to 01/05/2013

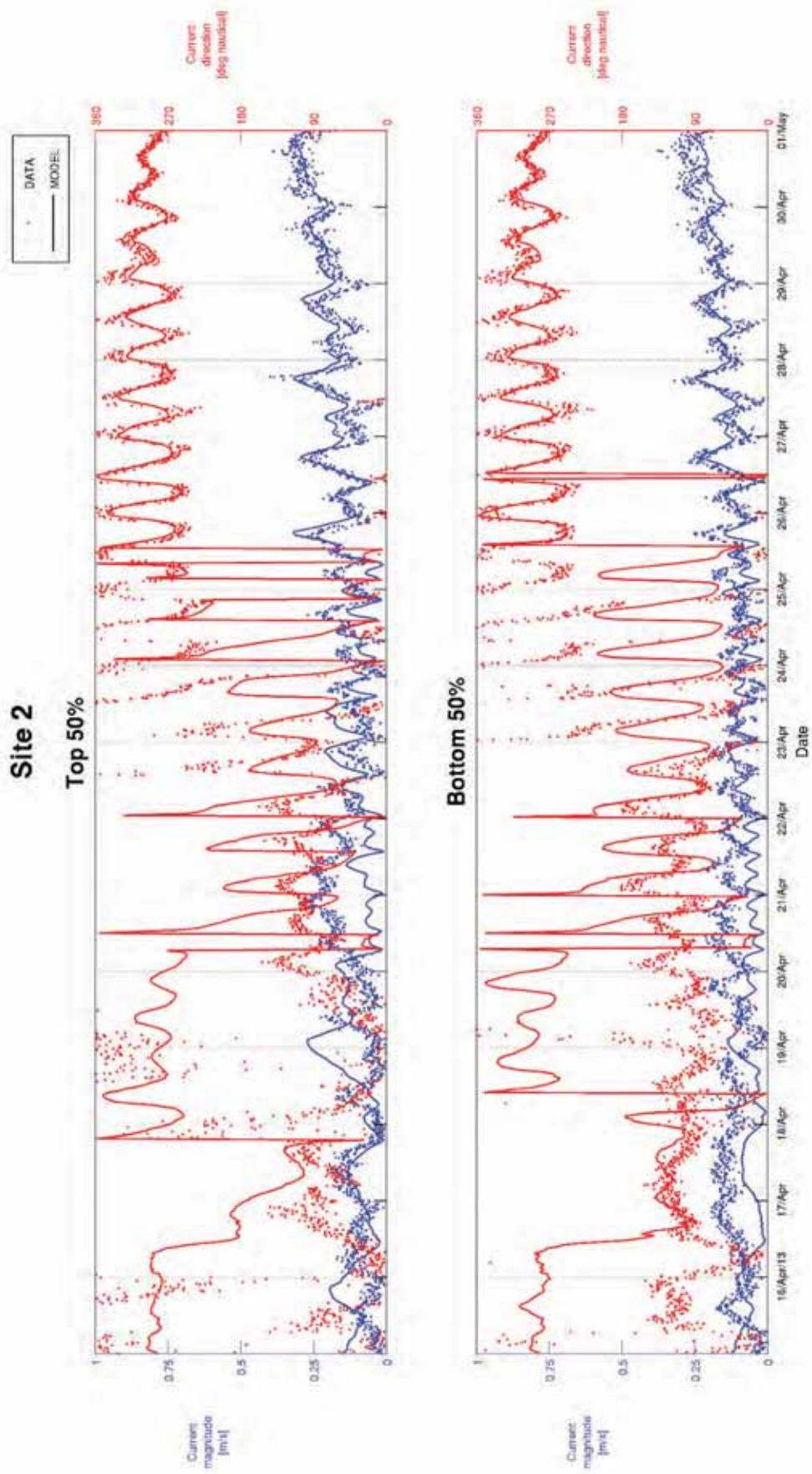


Figure B-11 Top 50% and Bottom 50% Current Calibration – Site 2 15/04/2013 to 01/05/2013

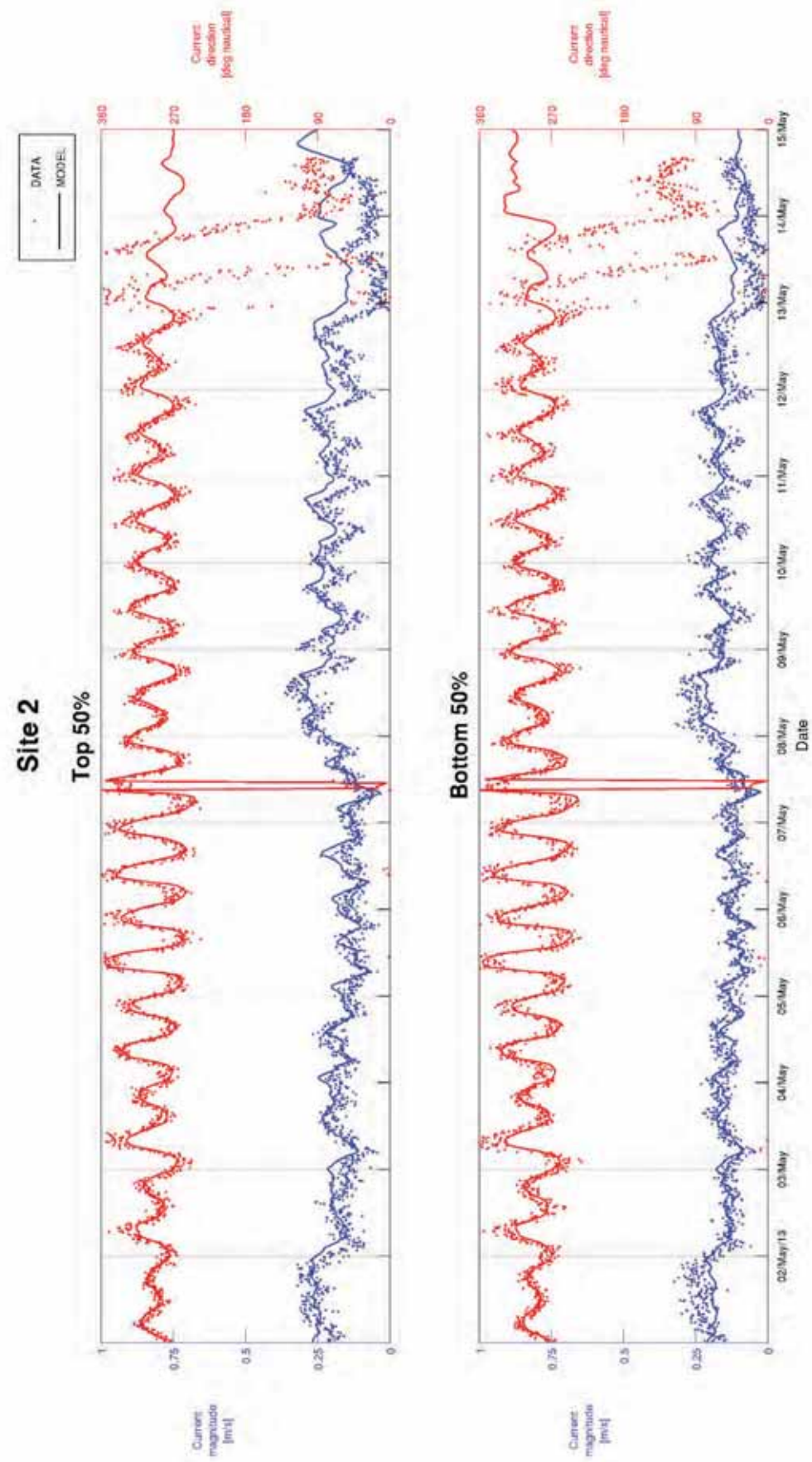


Figure B-12 Top 50% and Bottom 50% Current Calibration – Site 2 01/05/2013 to 15/05/2013



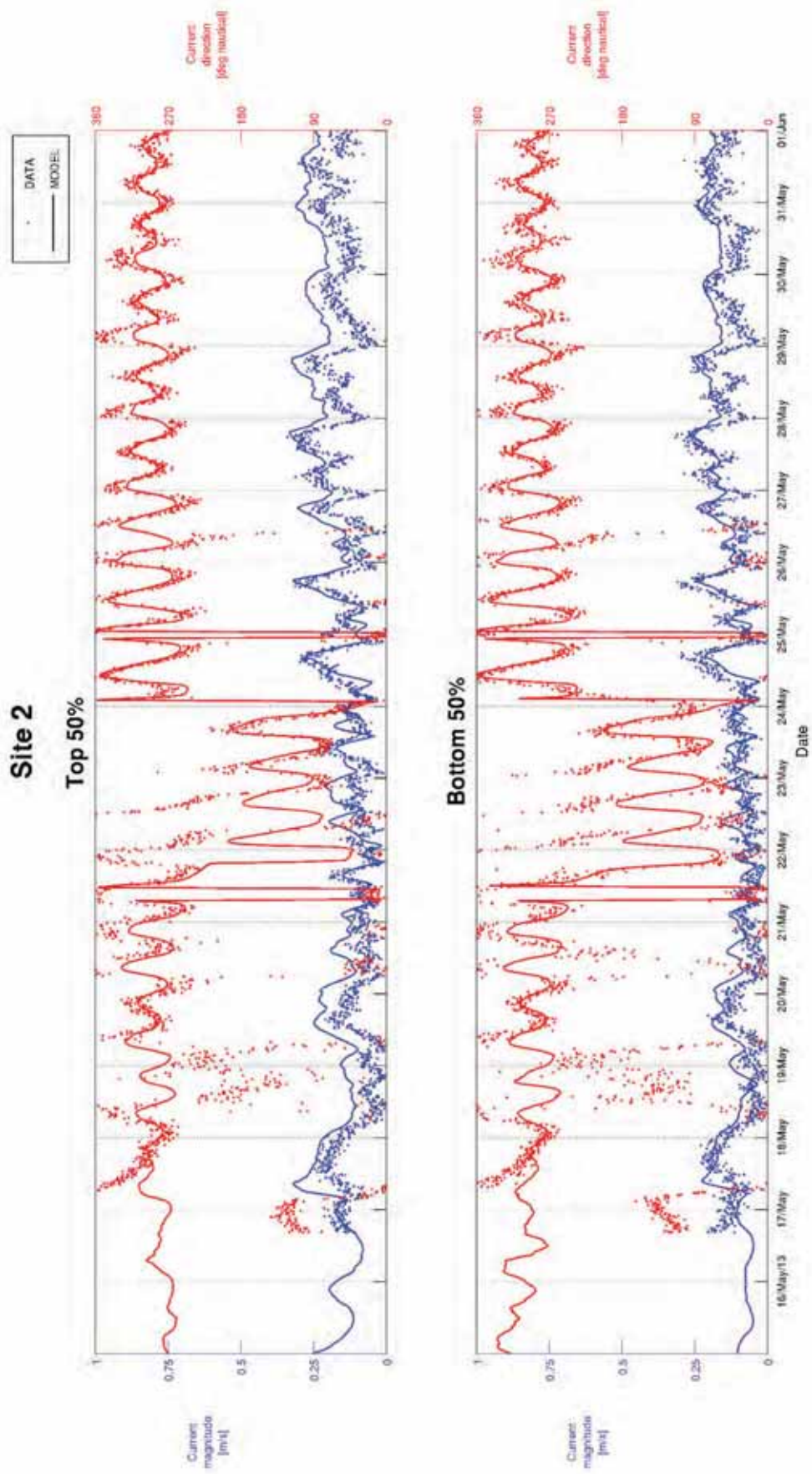


Figure B-13 Top 50% and Bottom 50% Current Calibration – Site 2 15/05/2013 to 01/06/2013



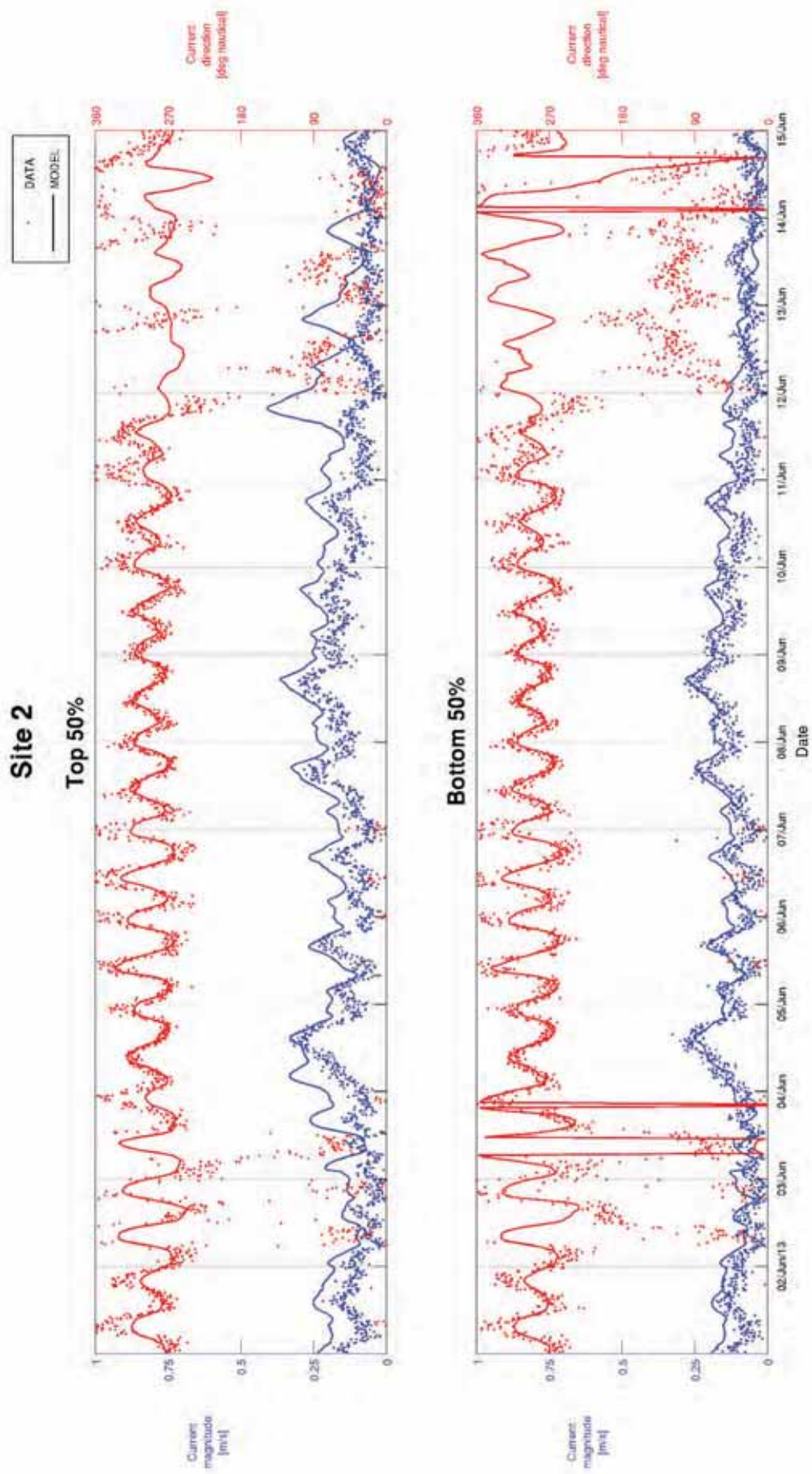


Figure B-14 Top 50% and Bottom 50% Current Calibration – Site 2 01/06/2013 to 15/06/2013

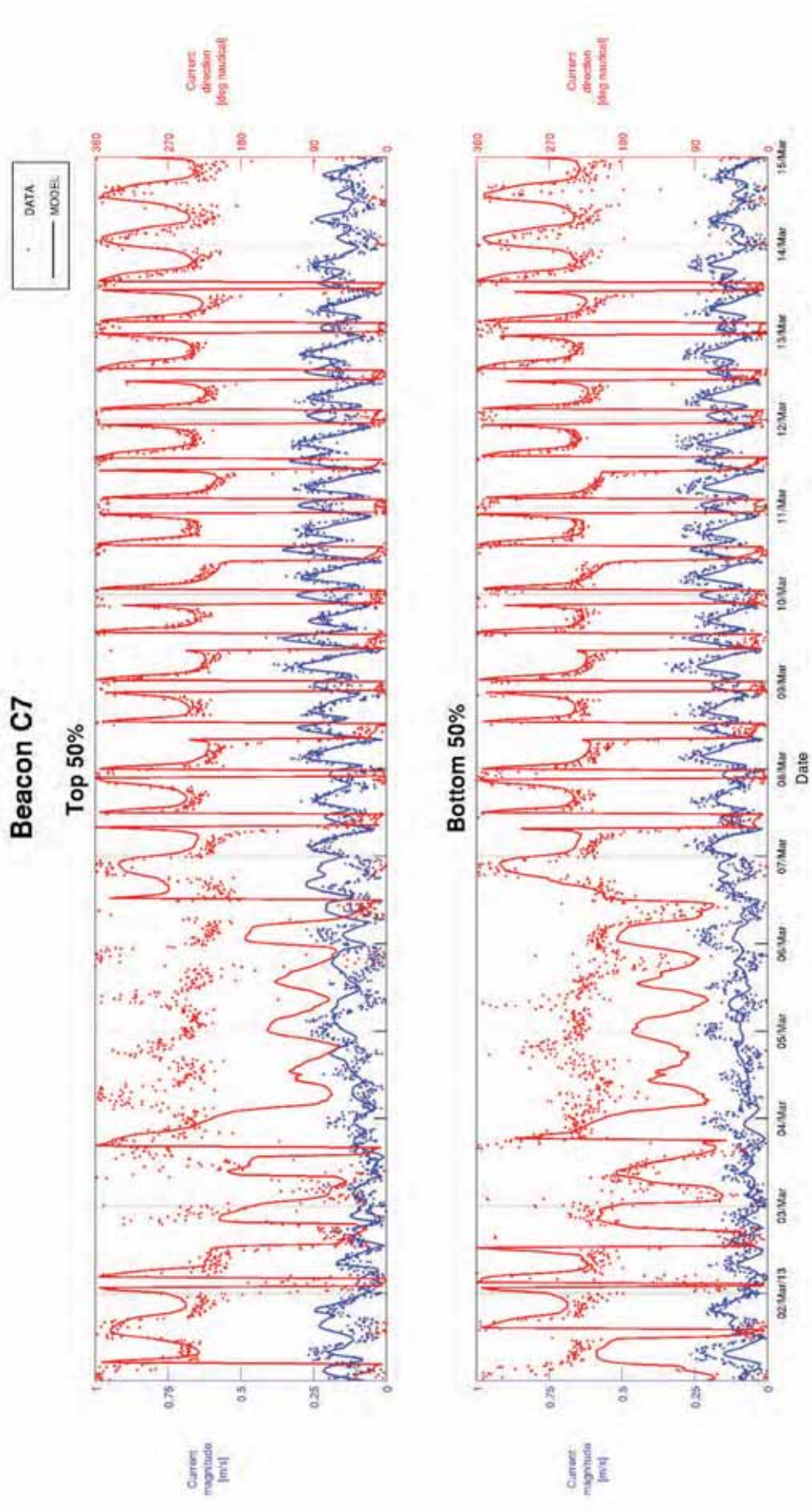


Figure B-15 Top 50% and Bottom 50% Current Calibration – Beacon C7 01/03/2013 to 15/03/2013

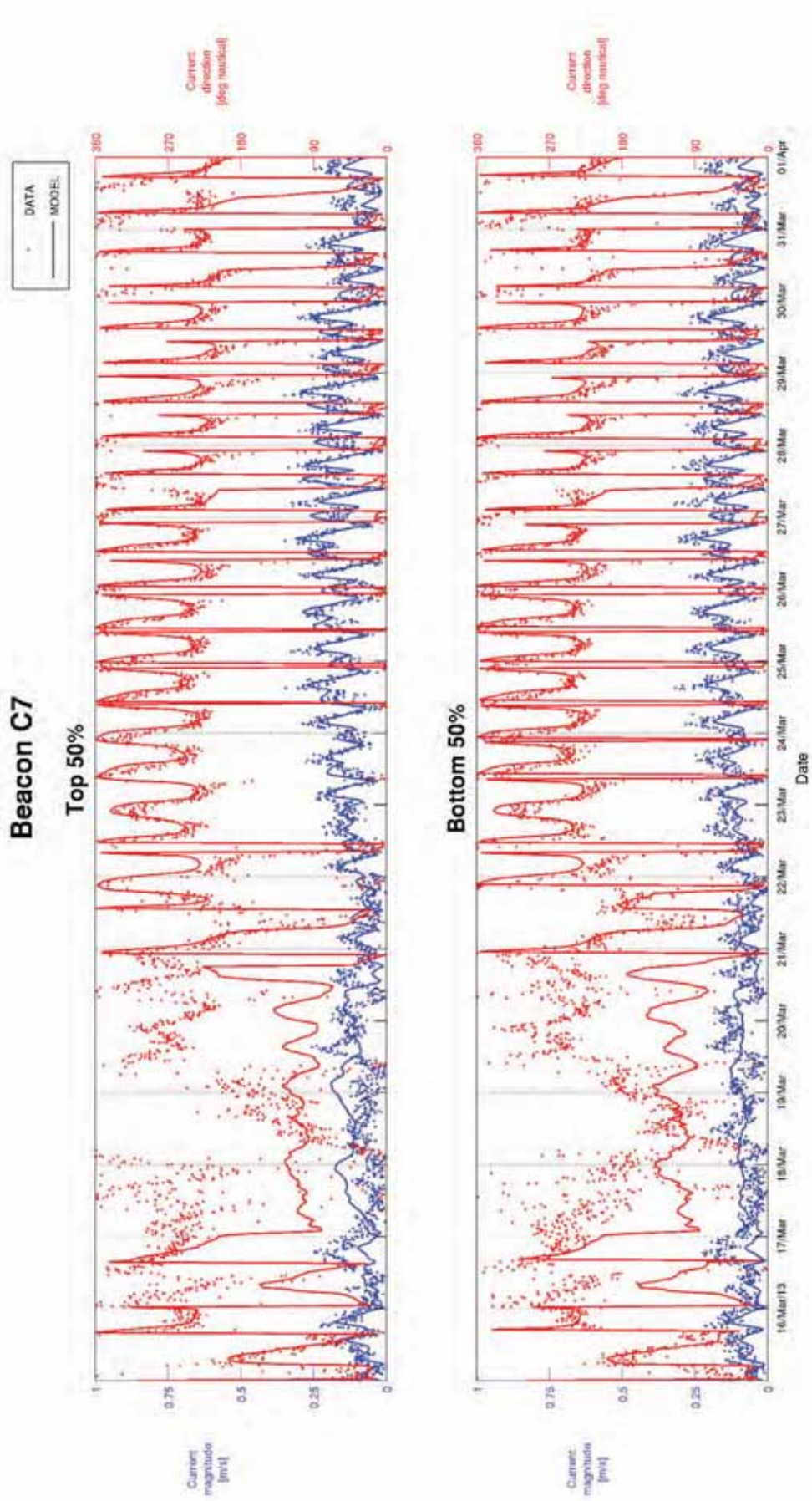


Figure B-16 Top 50% and Bottom 50% Current Calibration – Beacon C7 15/03/2013 to 01/04/2013

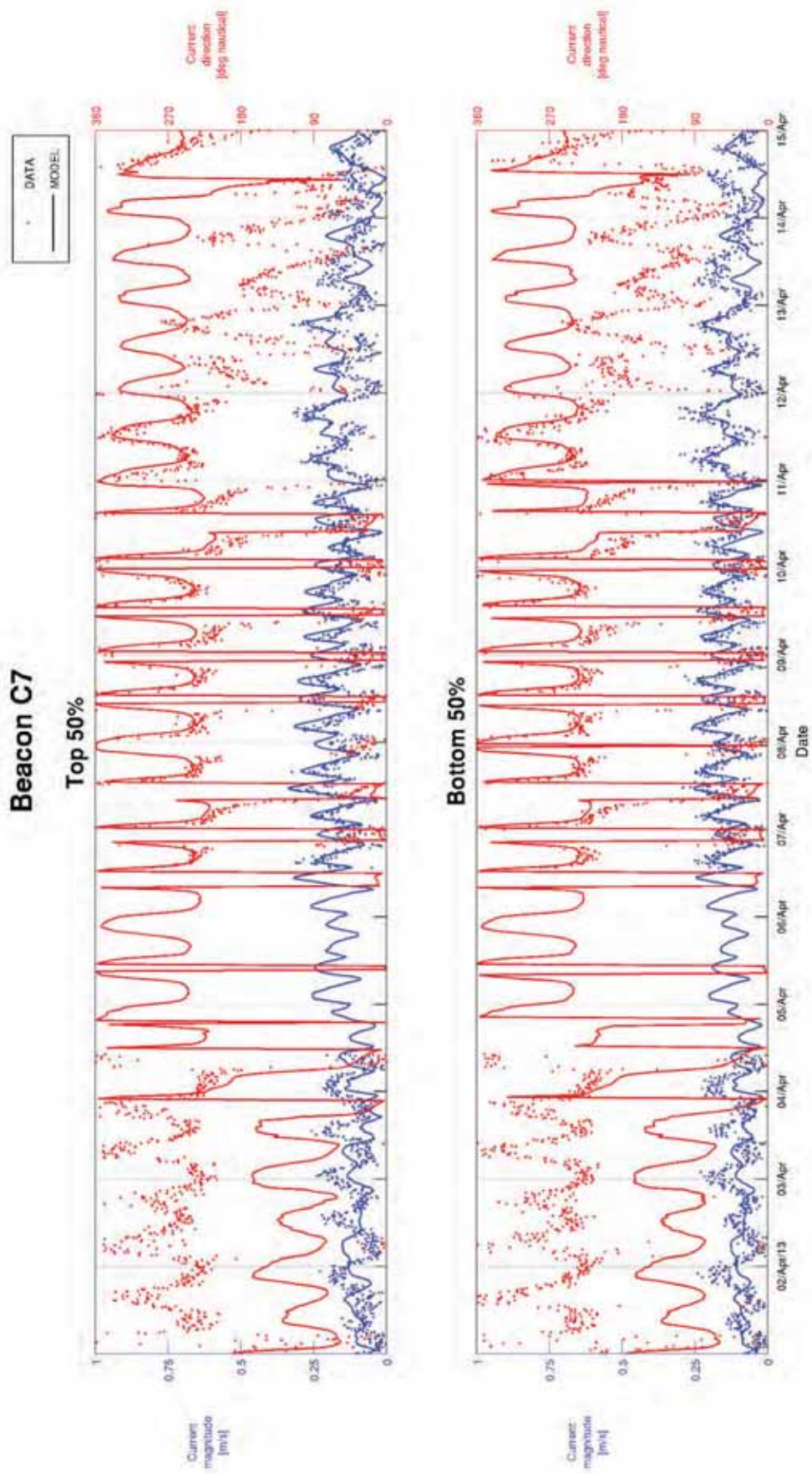


Figure B-17 Top 50% and Bottom 50% Current Calibration – Beacon C7 01/04/2013 to 15/04/2013

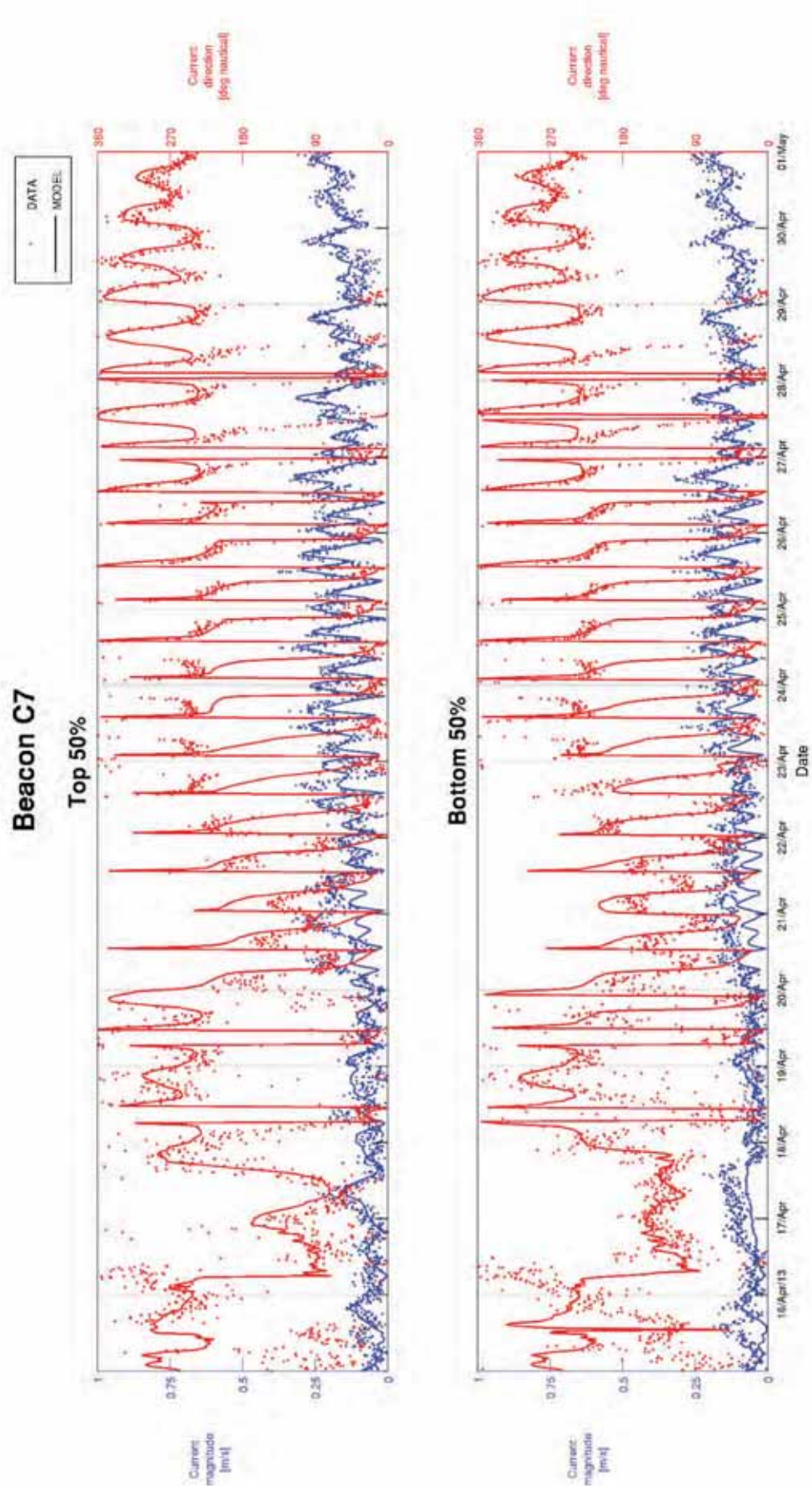


Figure B-18 Top 50% and Bottom 50% Current Calibration – Beacon C7 15/04/2013 to 01/05/2013

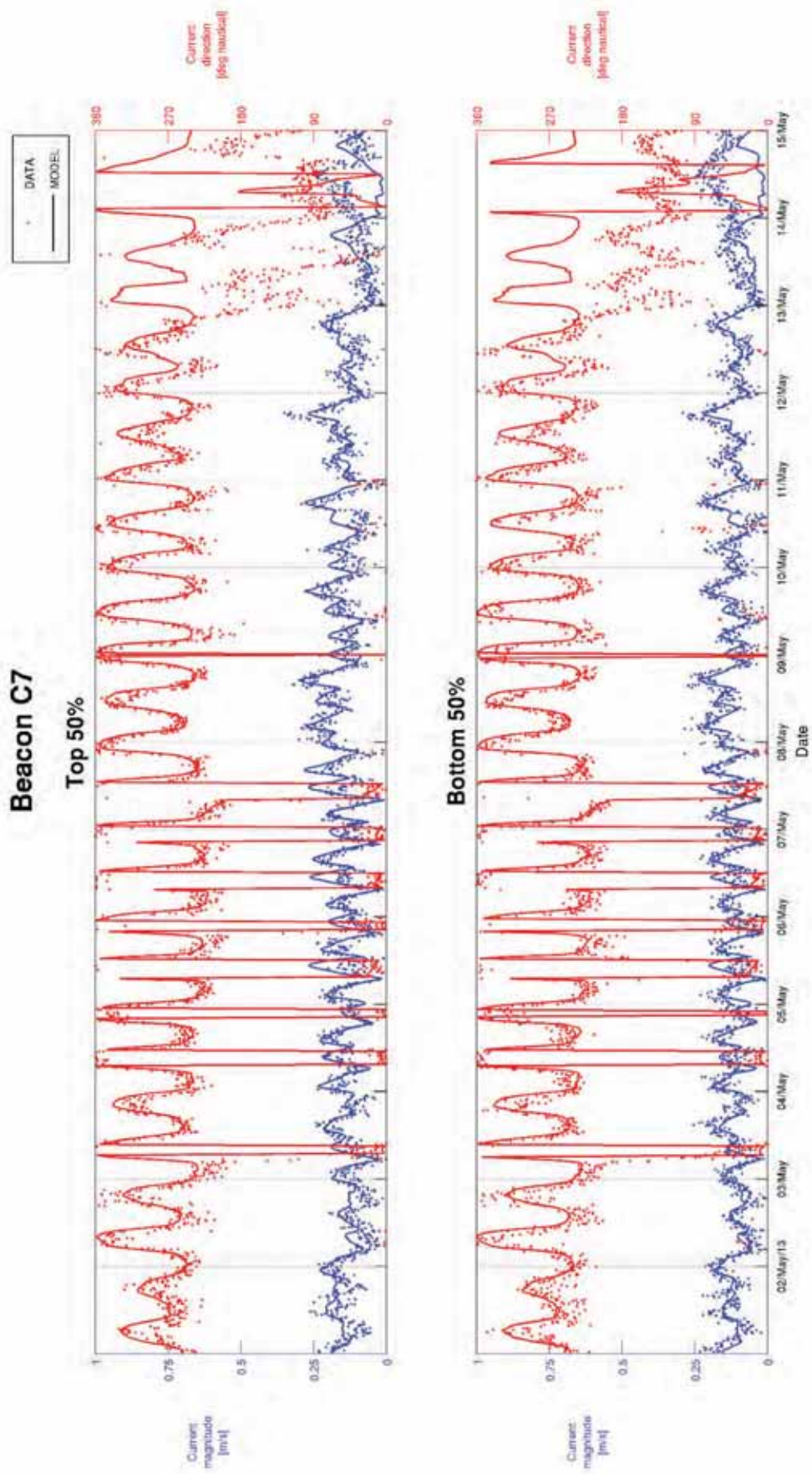


Figure B-19 Top 50% and Bottom 50% Current Calibration – Beacon C7 01/05/2013 to 15/05/2013

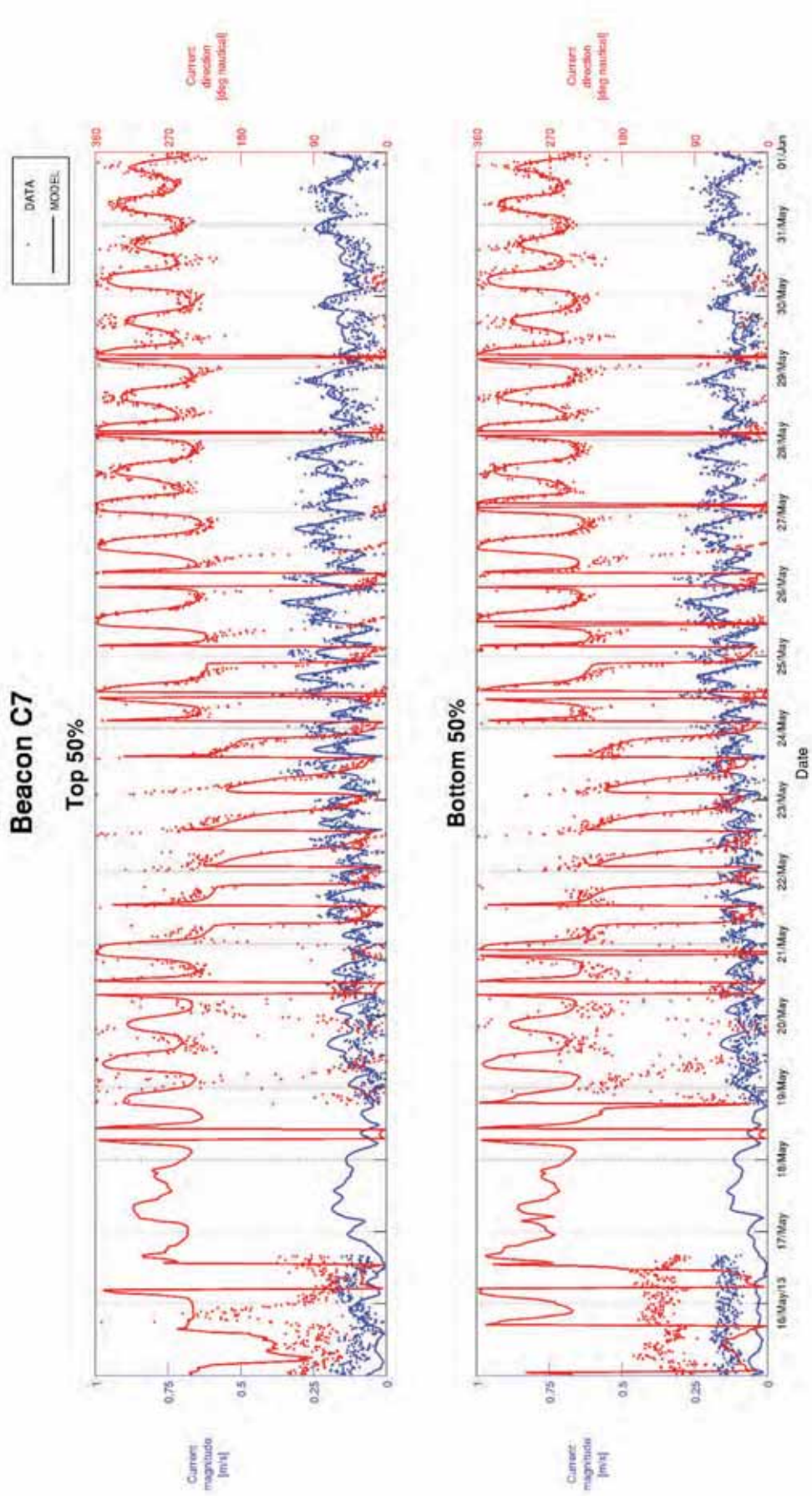


Figure B-20 Top 50% and Bottom 50% Current Calibration – Beacon C7 15/05/2013 to 01/06/2013

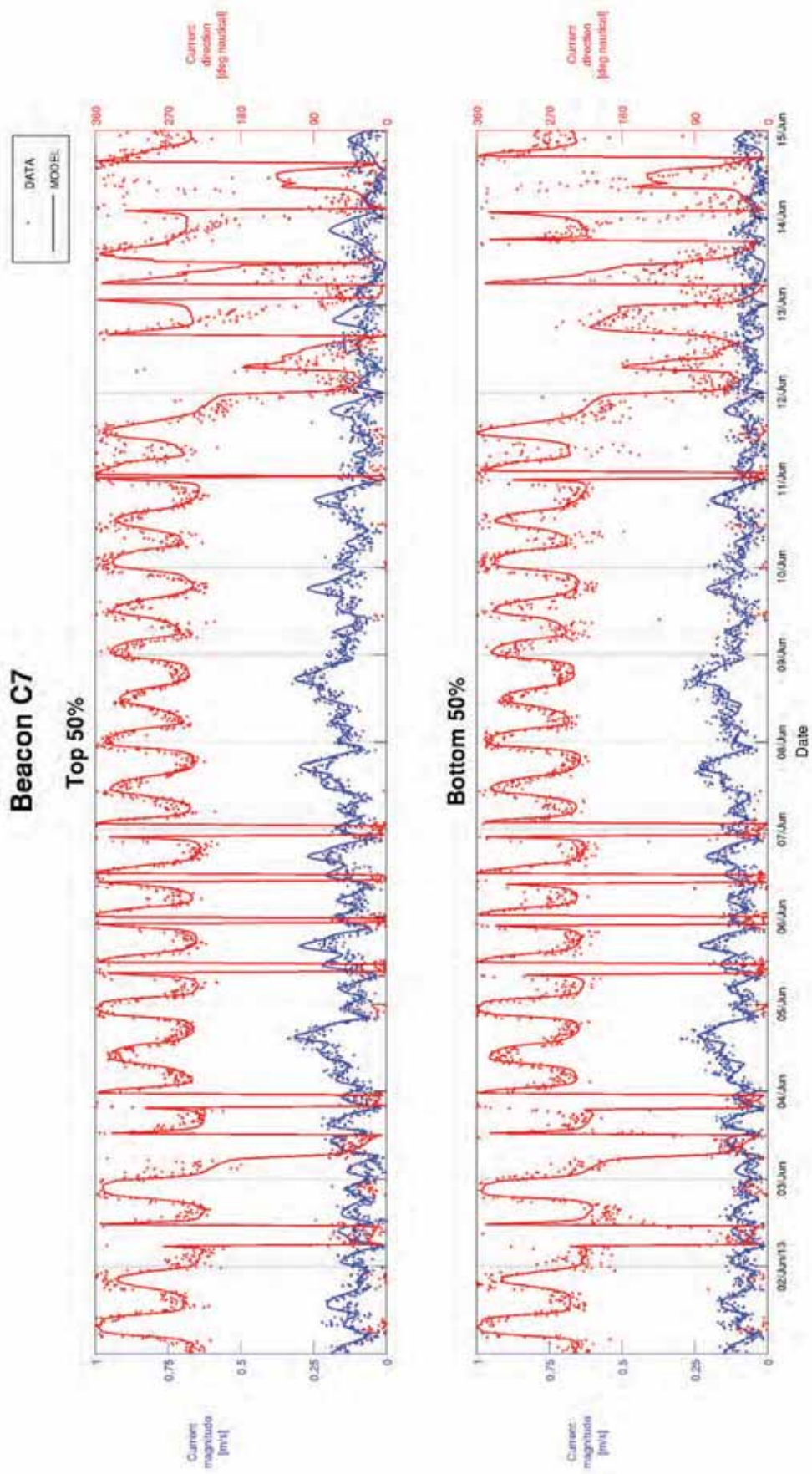


Figure B-21 Top 50% and Bottom 50% Current Calibration – Beacon C7 01/06/2013 to 15/06/2013

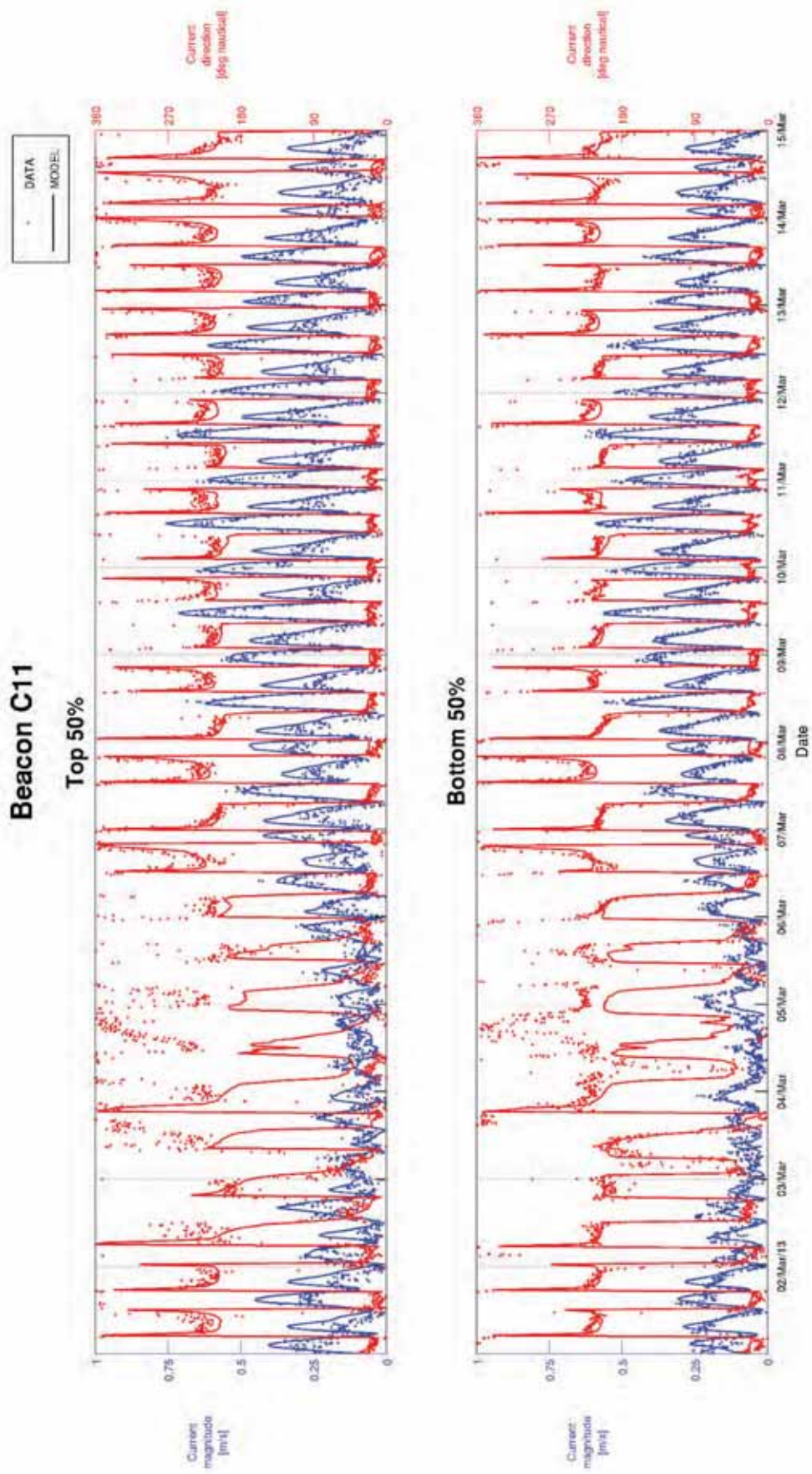


Figure B-22 Top 50% and Bottom 50% Current Calibration – Beacon C11 01/03/2013 to 15/03/2013

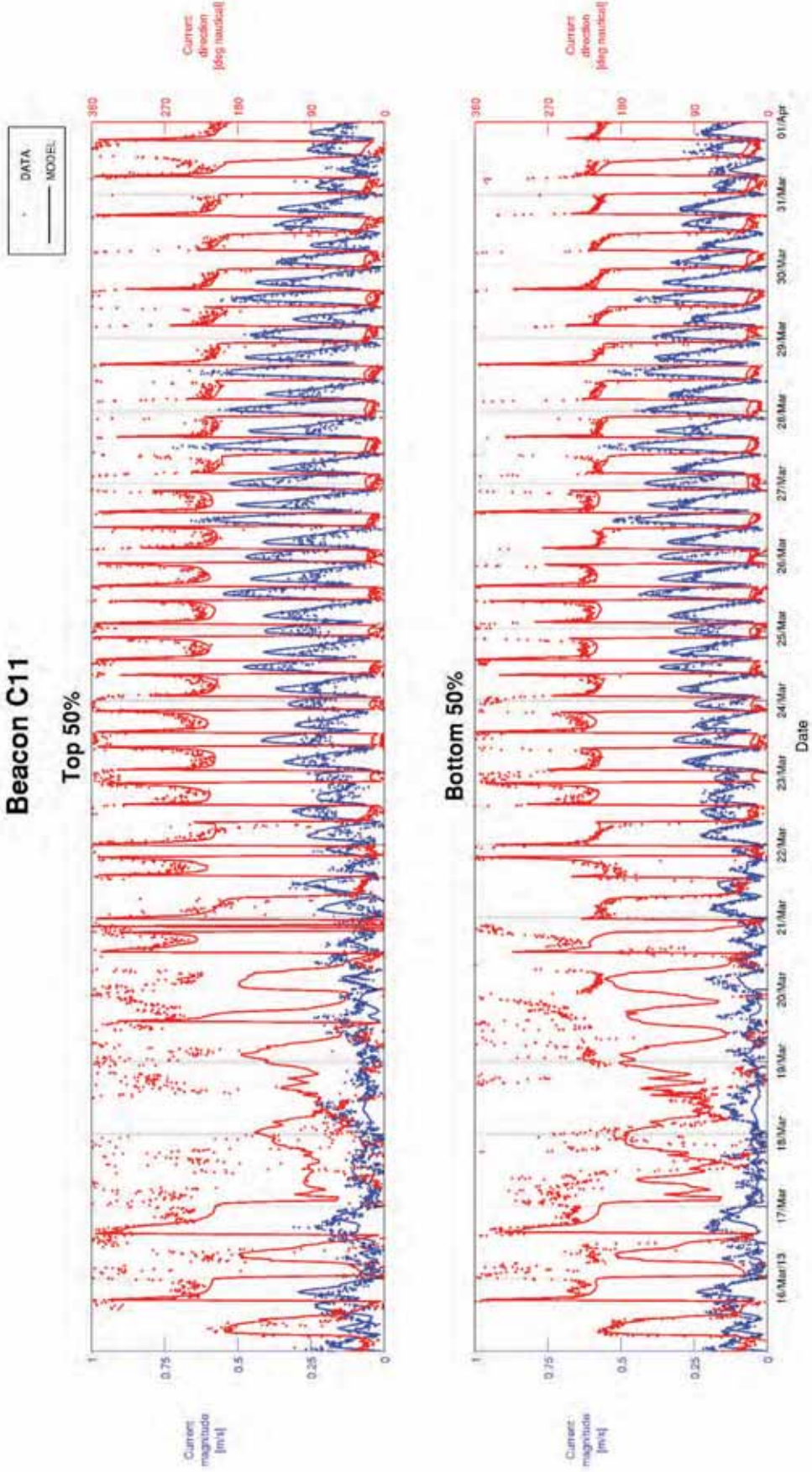


Figure B-23 Top 50% and Bottom 50% Current Calibration – Beacon C11 15/03/2013 to 01/04/2013



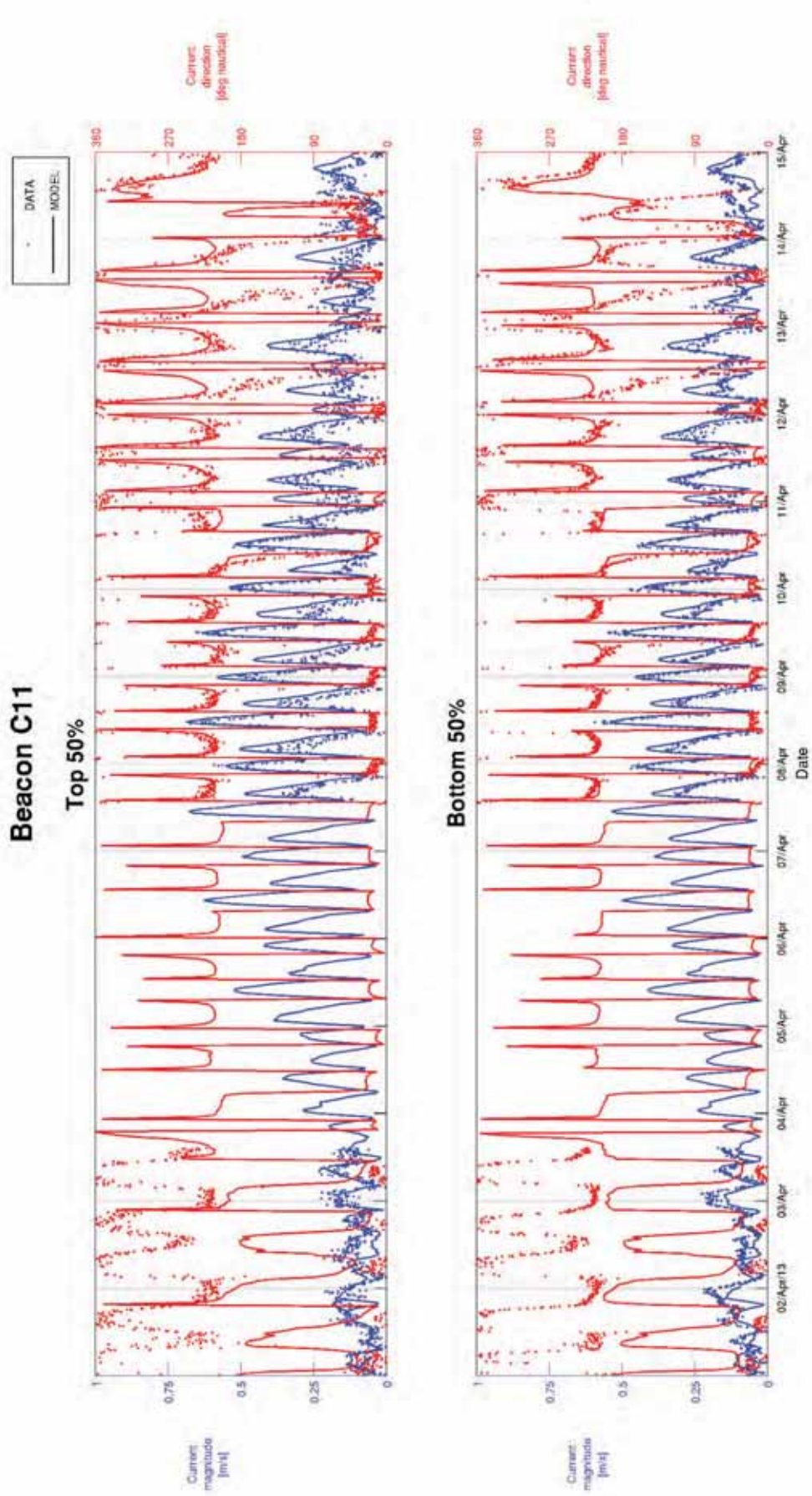


Figure B-24 Top 50% and Bottom 50% Current Calibration – Beacon C11 01/04/2013 to 15/04/2013



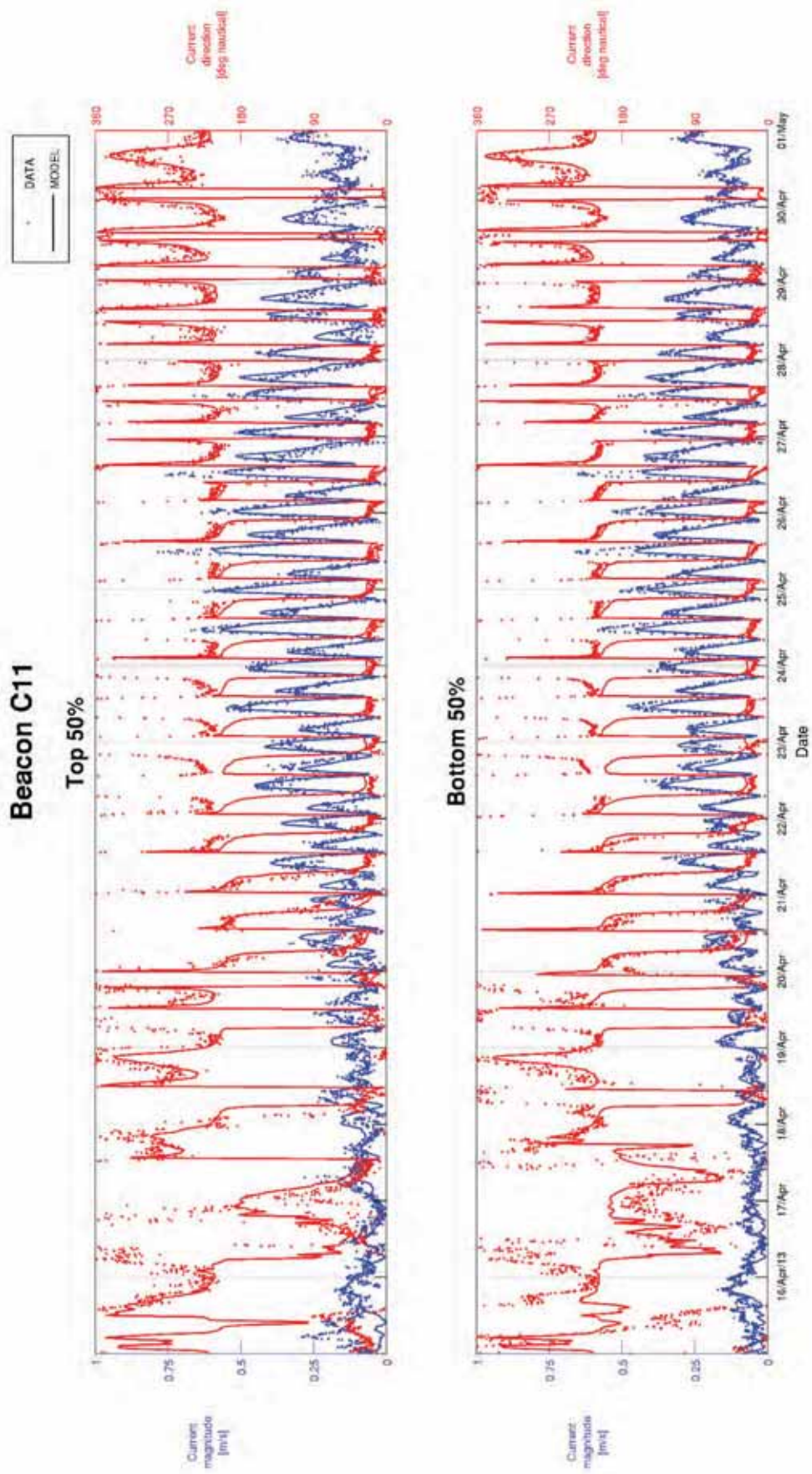


Figure B-25 Top 50% and Bottom 50% Current Calibration – Beacon C11 15/04/2013 to 01/05/2013

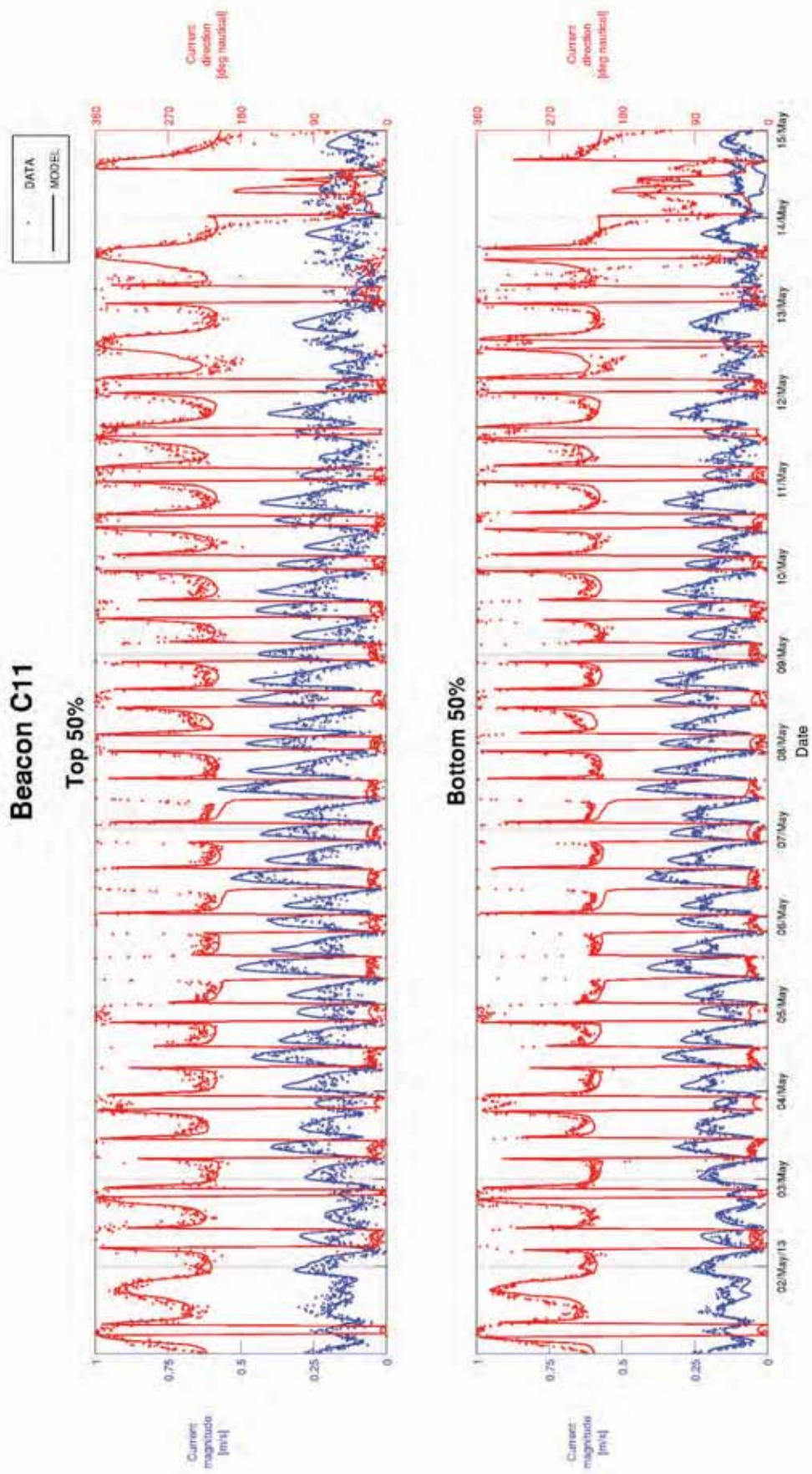
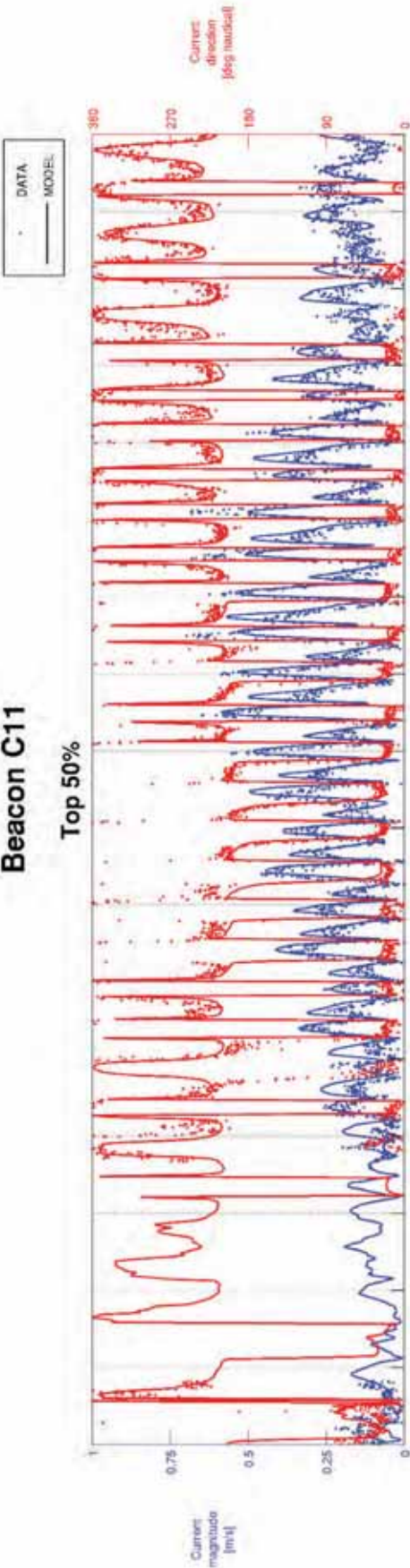


Figure B-26 Top 50% and Bottom 50% Current Calibration – Beacon C11 01/05/2013 to 15/05/2013

Calibration Period Current Time Series Plot

Beacon C11

Top 50%



Bottom 50%

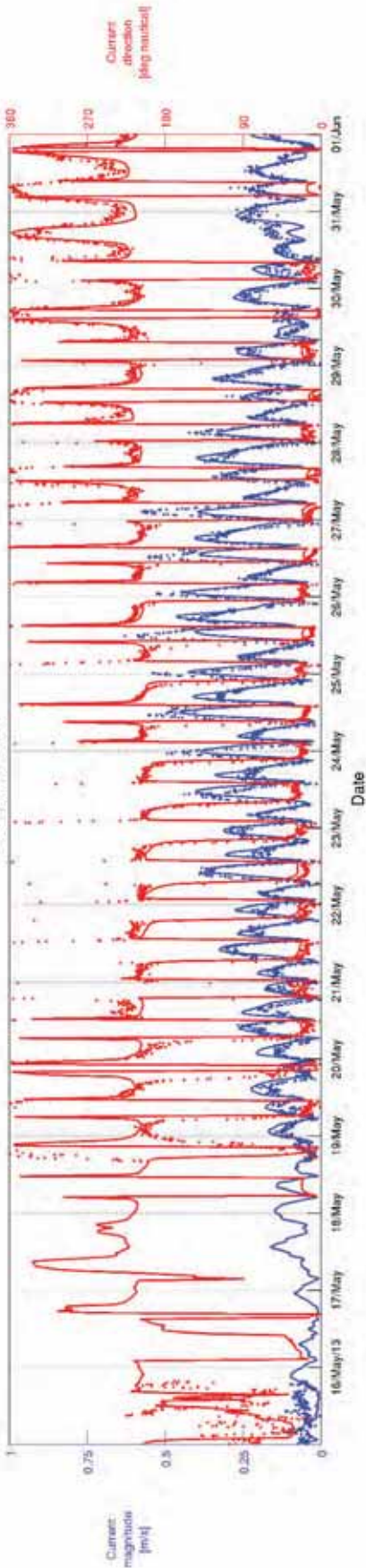


Figure B-27 Top 50% and Bottom 50% Current Calibration – Beacon C11 15/05/2013 to 01/06/2013

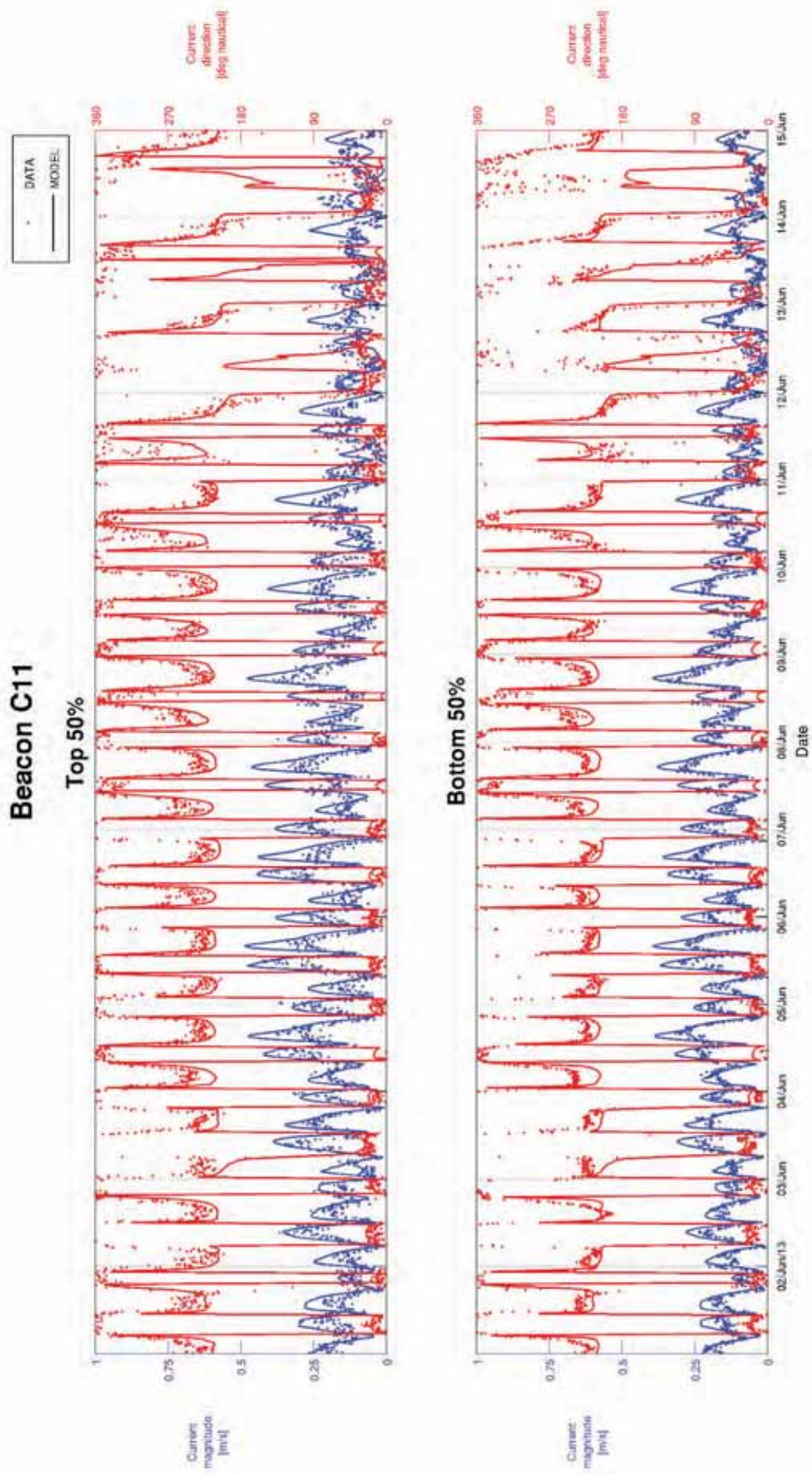


Figure B-28 Top 50% and Bottom 50% Current Calibration – Beacon C11 01/06/2013 to 15/06/2013



Appendix C Calibration Period Current Polar Plots

Top and bottom half of water column current polar plots for the entire simulation period are presented:

- DMPA, Figure C-1 and Figure C-2
- Site 2, Figure C-3 and Figure C-4
- Beacon C7, Figure C-5 and Figure C-6
- Beacon C11, Figure C-7 and Figure C-8.

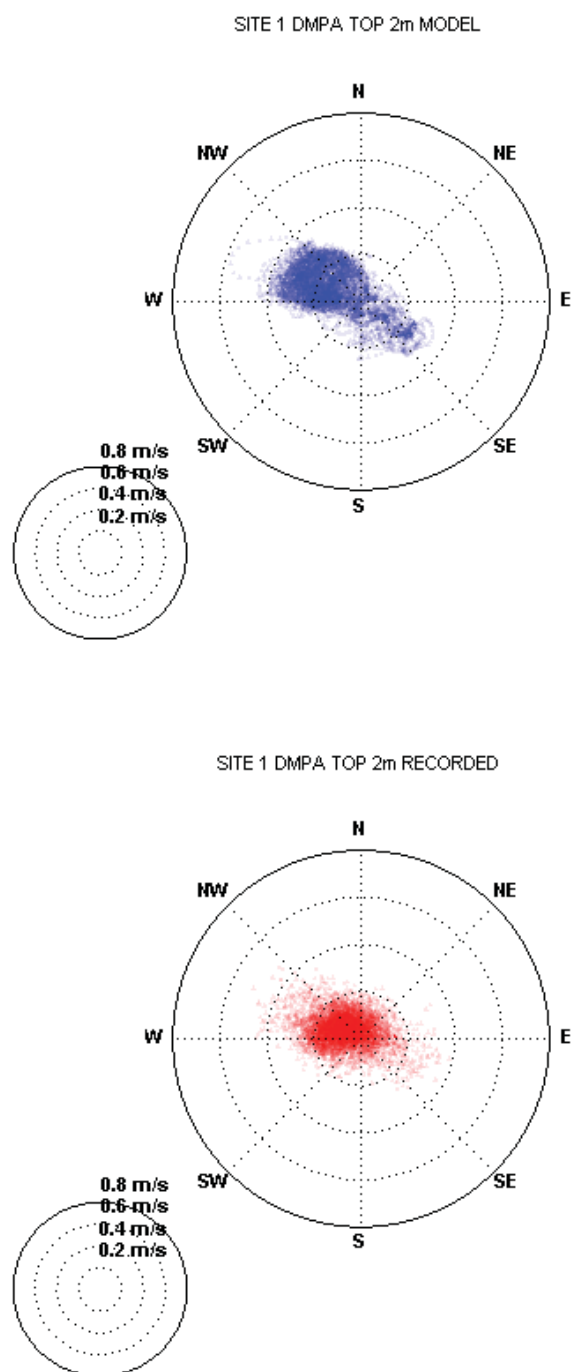


Figure C-1 Current Polar Plot Calibration – DMPA Top 2m of Water Column

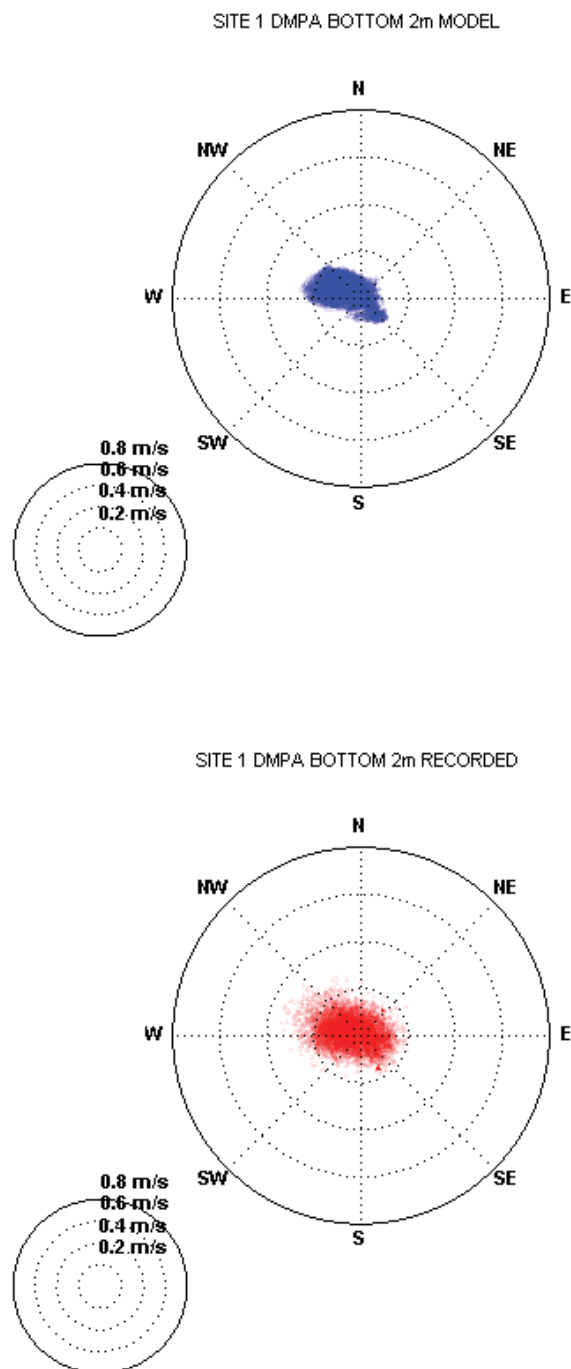


Figure C-2 Current Polar Plot Calibration – DMPA Bottom 2m of Water Column

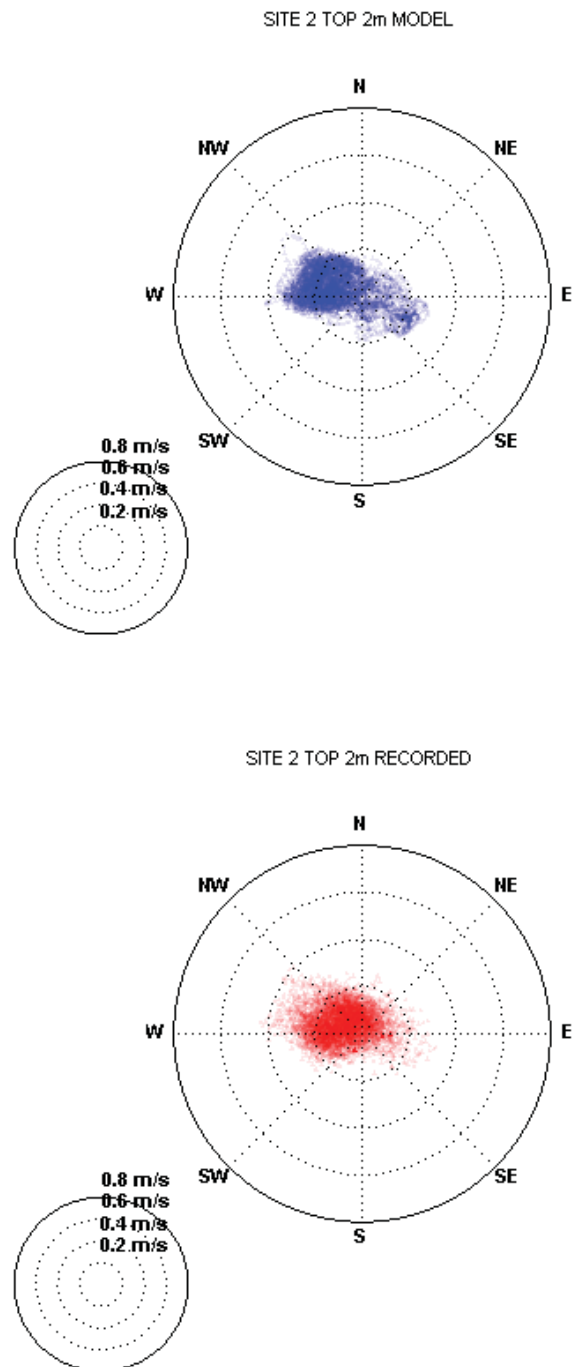


Figure C-3 Current Polar Plot Calibration – Site 2 Top 2m of Water Column

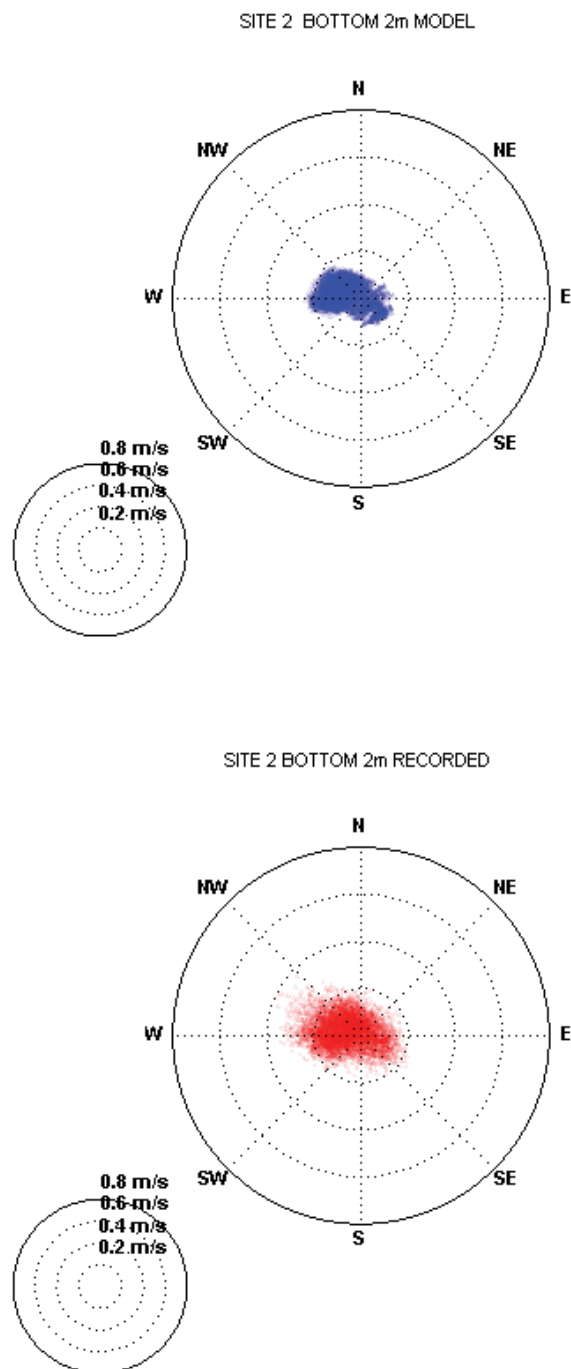


Figure C-4 Current Polar Plot Calibration – Site 2 Bottom 2m of Water Column

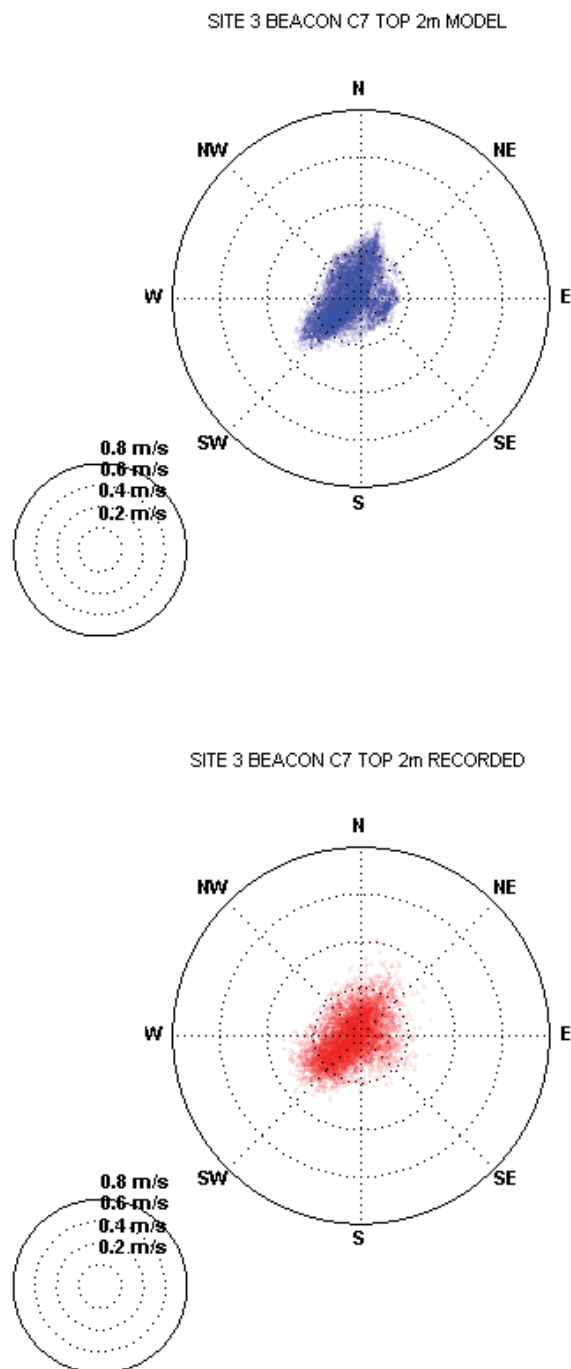


Figure C-5 Current Polar Plot Calibration – Beacon C7 Top 2m of Water Column

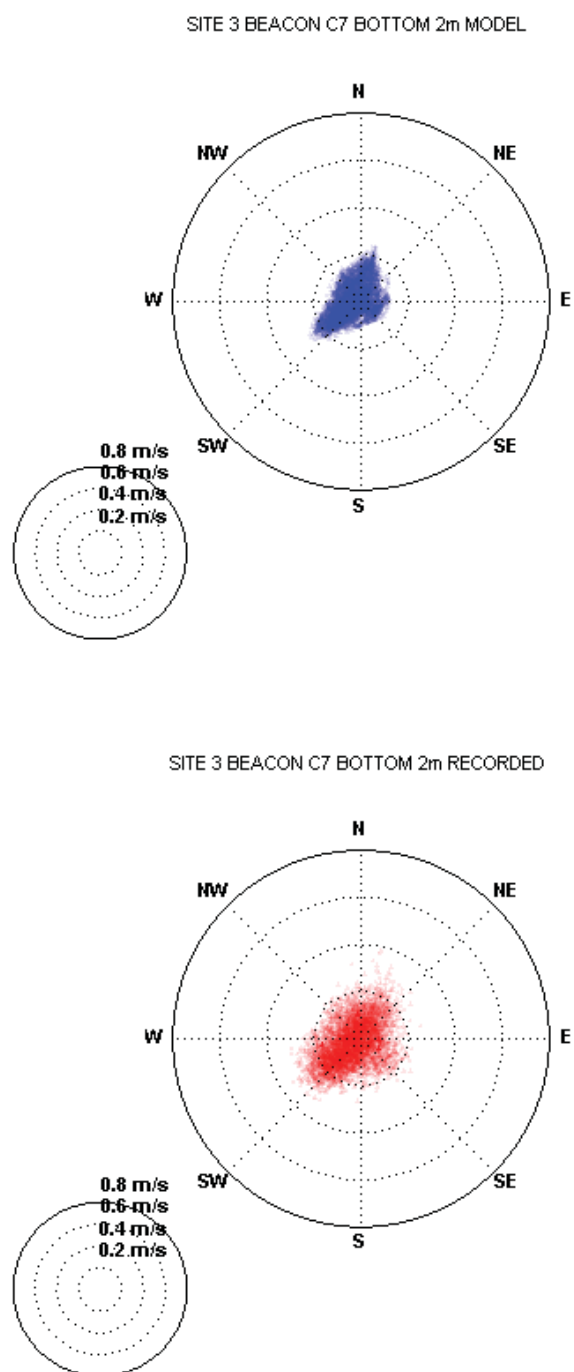


Figure C-6 Current Polar Plot Calibration – Beacon C7 Bottom 2m of Water Column

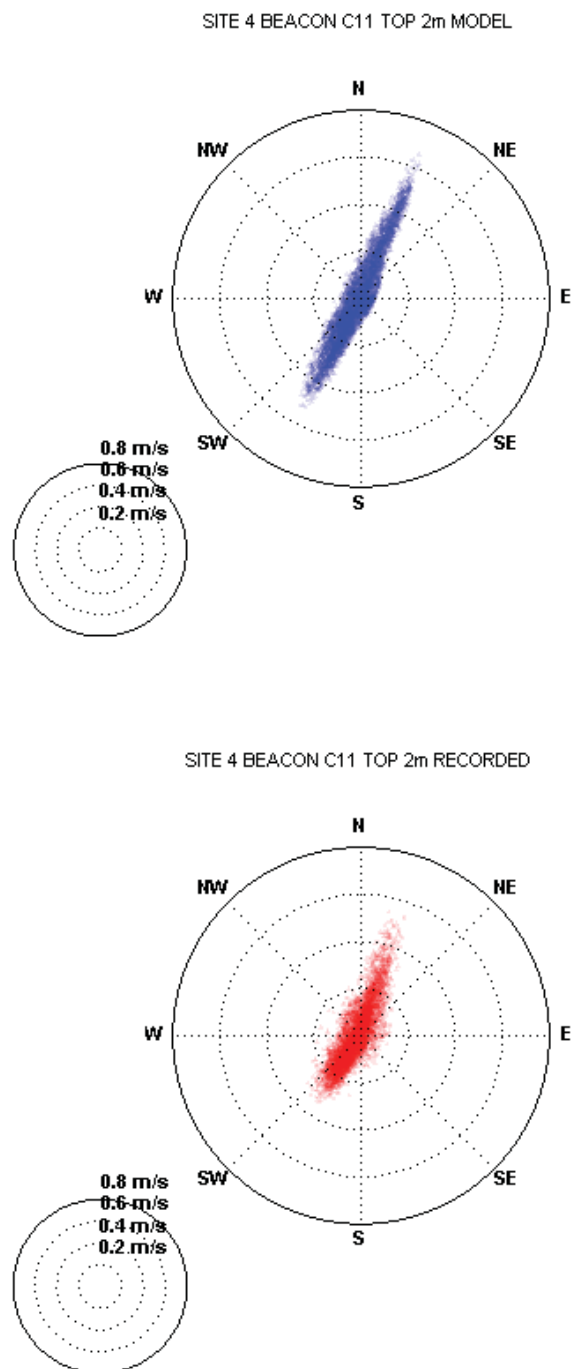


Figure C-7 Current Polar Plot Calibration – Beacon C11 Top 2m of Water Column

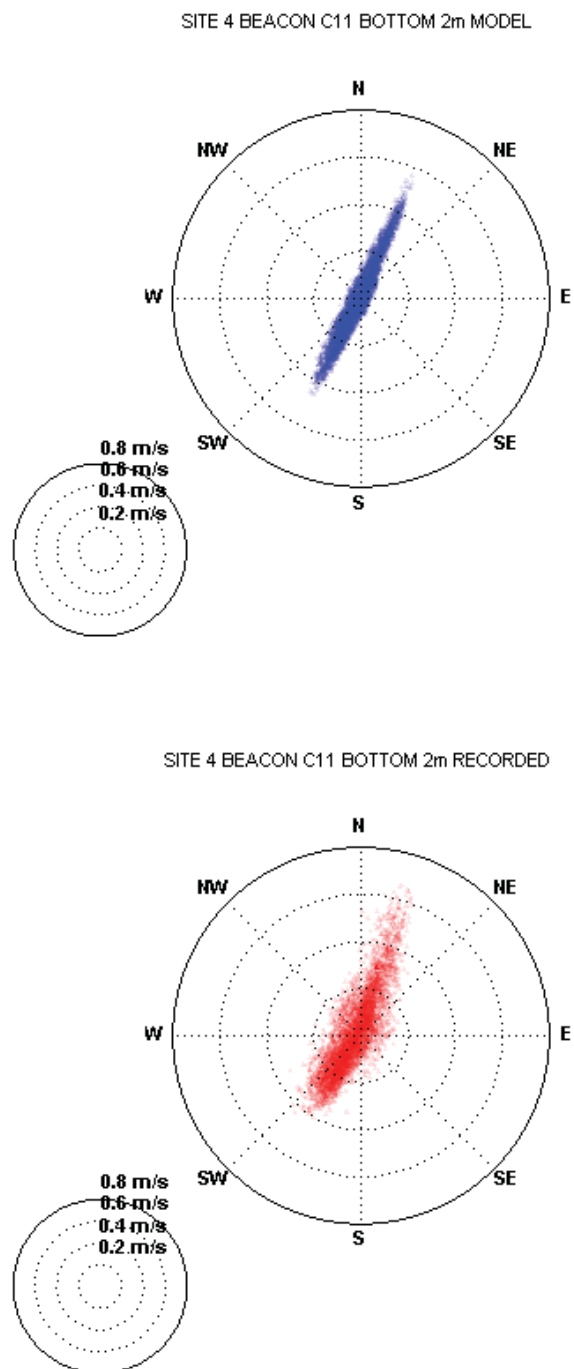


Figure C-8 Current Polar Plot Calibration – Beacon C11 Bottom 2m of Water Column

Appendix D Calibration Period Current Q-Q Plots

Recorded data and model output distributions of current components (x and y) and current speed are compared:

- DMPA, Figure D-1
- Site 2, Figure D-2
- Beacon C7, Figure D-3
- Beacon C11, Figure D-4.

DMPA

Top 50%

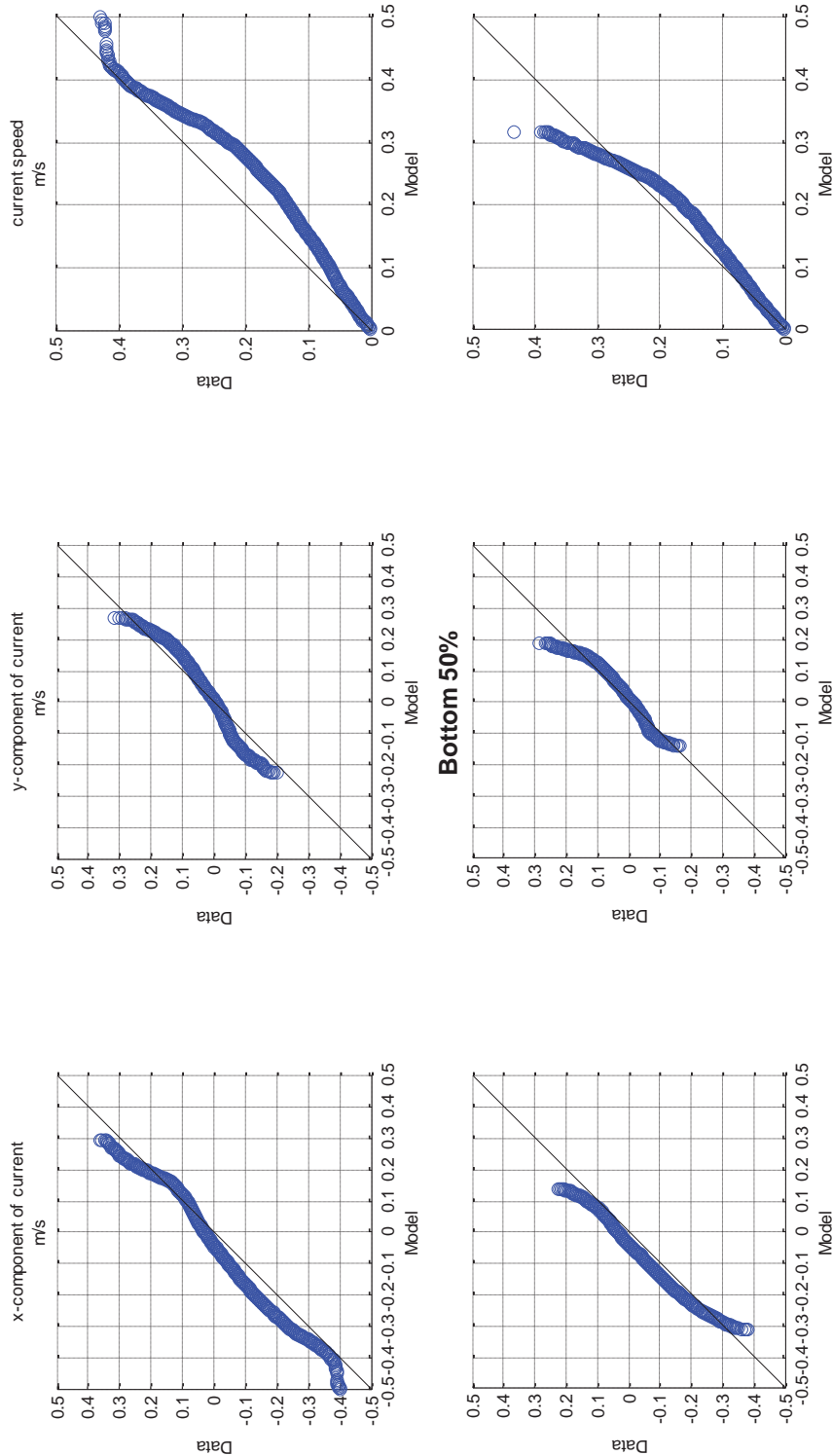


Figure D-1 Current Q-Q Plot – DMPA

Site 2

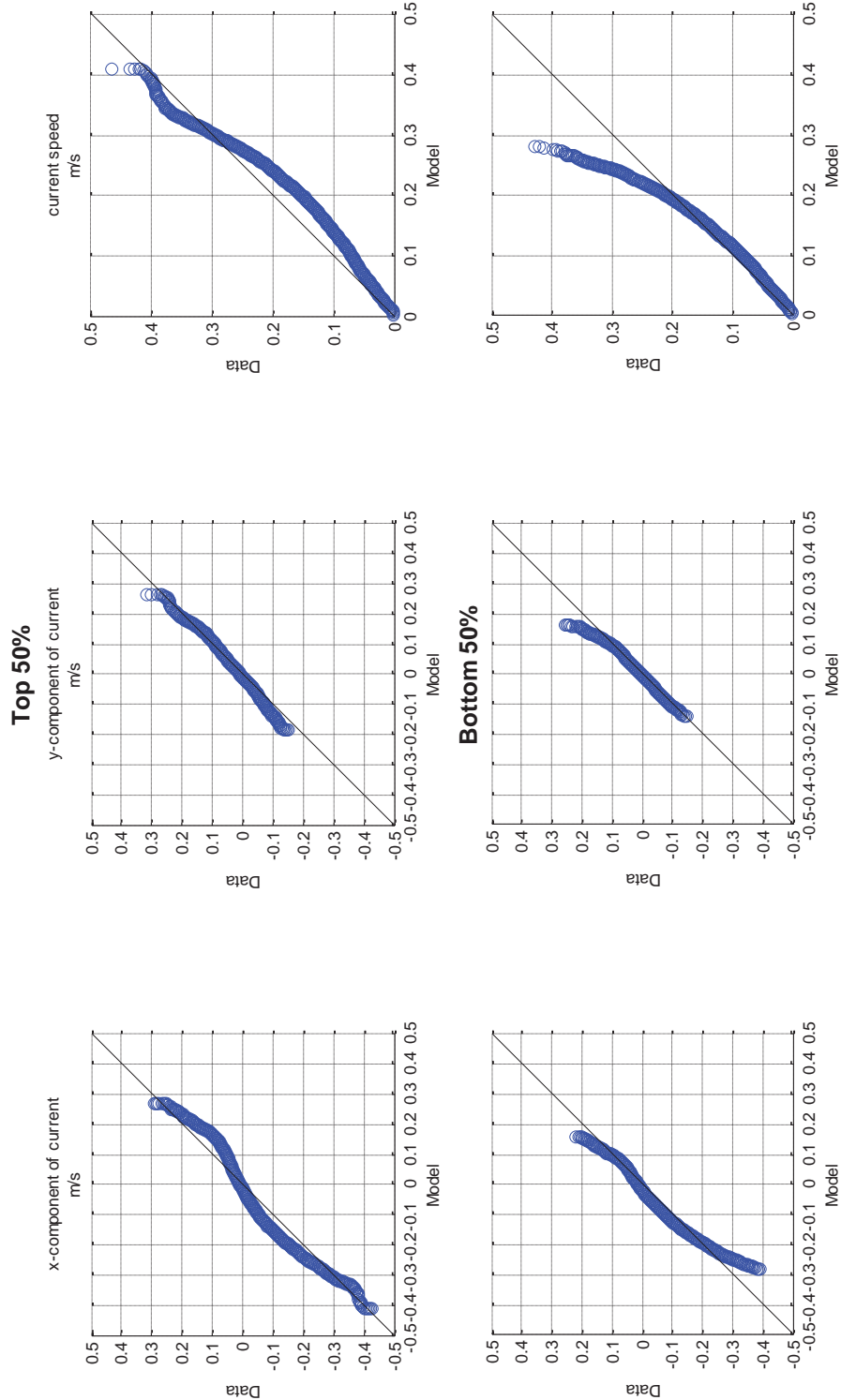


Figure D-2 Current Q-Q Plot – Site 2



Beacon C7

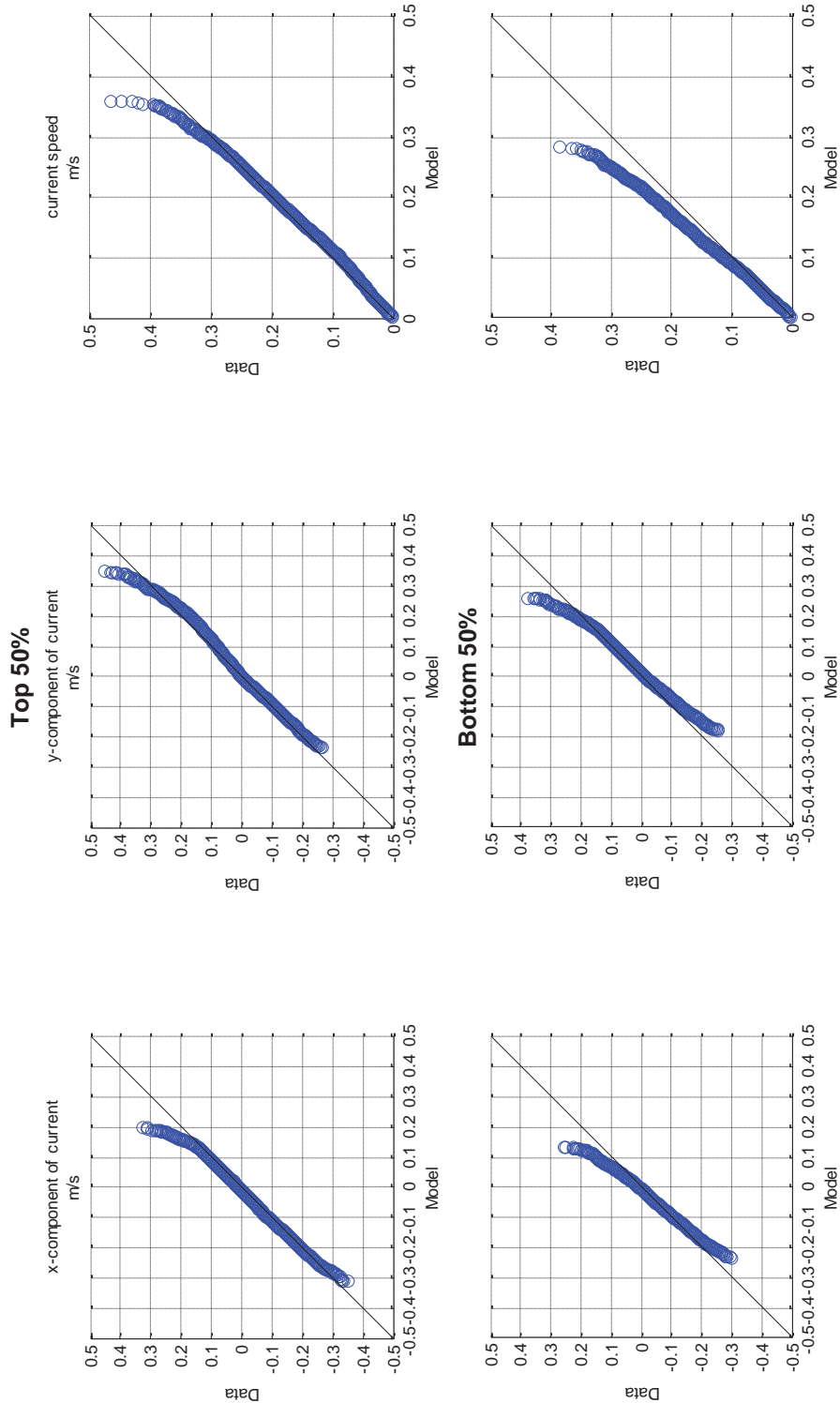


Figure D-3 Current Q-Q Plot – Beacon C7

Beacon C11

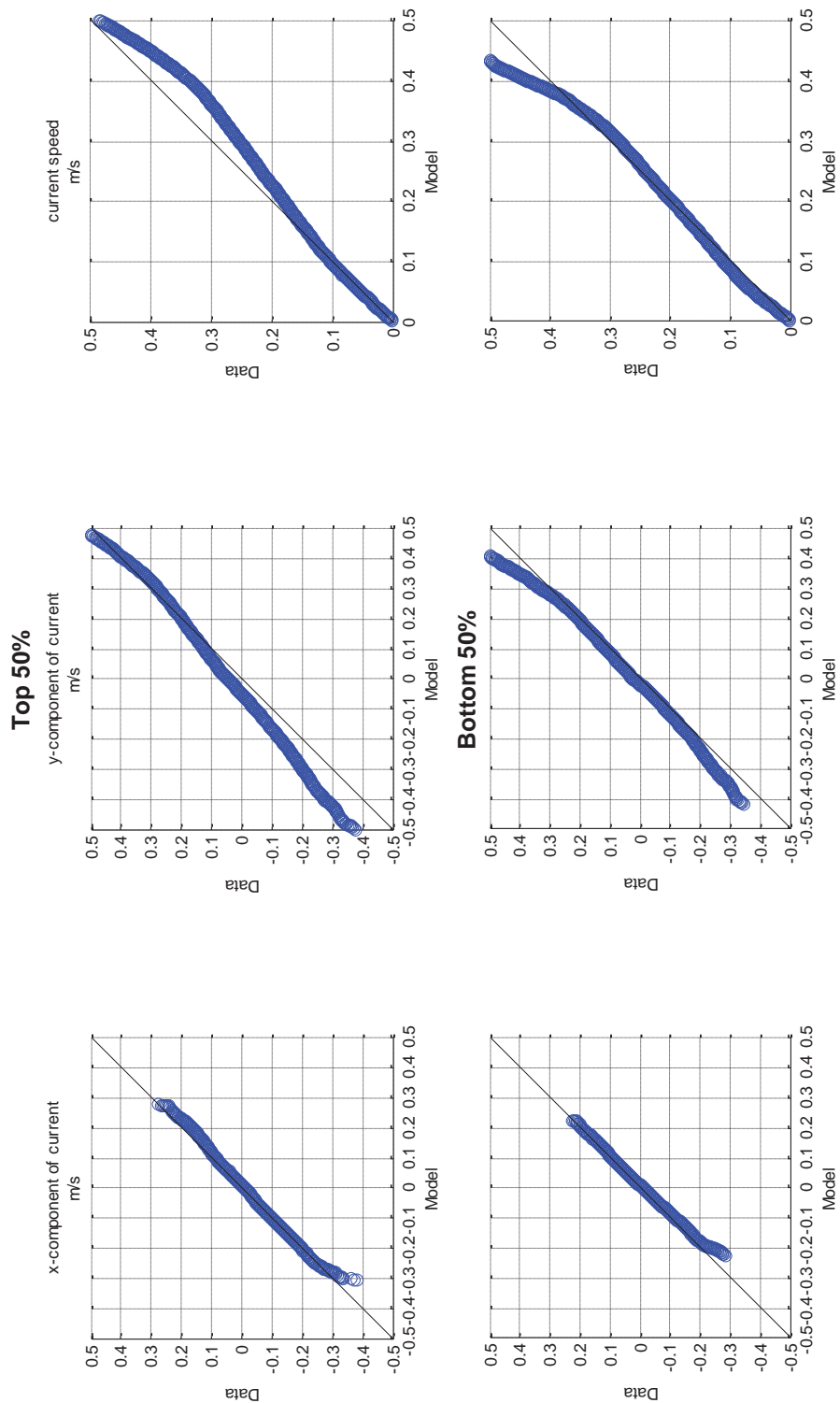


Figure D-4 Current Q-Q Plot – Beacon C11



Appendix E Dredging Consultant Advice

