Port Expansion Project EIS

Appendix H1

Hydrodynamic and Advection-Dispersion Modelling Technical Report

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Appendix H1:
Townsville Port Expansion EIS Hydrodynamic and Advection-Dispersion Modelling Technical Report

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Title :	Townsville Port Expansion EIS: Hydrodynamic Impact Assessment
Author :	Paul Guard, Jesper Nielsen, Ian Teakle
Synopsis :	This technical appendix outlines and summarises hydrodynamic modelling undertaken to assess hydrodynamic and water quality impacts of the proposed Port of Townsville expansion project.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 BACKGROUND

Evaluation of the impact of the proposed port expansion at the Port of Townsville (POT) requires a thorough understanding of the hydrodynamic and coastal processes operating within Cleveland Bay, as well as appropriate tools to support assessment of these processes. This information is necessary to optimise the port and channel design configuration from an operational and ongoing maintenance perspective as well as for consideration of construction techniques and potential adverse impacts. Wind, waves, water levels, currents and sediment transport are all interrelated and can influence the design, and positioning of the project in a number of ways.

There has been extensive data collection carried out in Cleveland Bay over many years as well as numerous studies and numerical modelling of the hydrodynamic and coastal processes.

BMT WBM (WBM) was responsible for and is in possession of the extensive oceanographic data collected in 1992 – 1993 for the modelling and monitoring of the Platypus Channel deepening and extension works at that time. WBM also undertook data collection and modelling of Cleveland and Halifax Bays associated with a proposed Nickel Ore import facility in the 1990s. This included modelling and assessment of dredging and siltation of Platypus Channel.

Other important reports reviewed as part of the current study include:

- JCU/AIMS report, "Water Circulation and Fate of Dredge Spoil, Cleveland Bay, Townsville" (1991). This study by JCU and AIMS involved oceanographic data collection and modelling of water circulation in Cleveland Bay to investigate the fate of dumped dredge material.
- GHD report, "Outer Harbour Hydrodynamic Modelling Report and Appendices" (2004). This report provides an investigation of hydrodynamic processes in the Outer Harbour and outputs of the Delft 3D model used by GHD. It also provides an overview and summary of historical data and investigations of hydrodynamic behaviour in Cleveland Bay and in the Outer Harbour area and provides a basis for assumptions about sediment transport patterns and their relationship to wind and wave processes.

As part of the Preliminary Engineering and Environmental Study (PEES) for the port expansion which was undertaken in 2008/2009 (BMT WBM, 2009), WBM was engaged to develop and employ a suite of numerical modelling tools to assess the range of potential hydrodynamic, water quality and coastal process impacts from future port expansion. WBM has continued to develop this suite of modelling tools as part of this EIS, and has assessed the potential impact of the proposed port expansion, principally using the hydrodynamic model TUFLOW-FV. This technical appendix describes the model development and validation process and the results of the impact assessments.

1.2 OBJECTIVES AND PURPOSE

Key objectives of the hydrodynamic modelling assessment of the port expansion are:

- Development of a suite of numerical modelling tools capable of simulating the hydrodynamic, wave and sedimentation processes of Cleveland Bay, in particular around Townsville Harbour;

- Assessment of the implications of the specific design configuration with respect to currents, coastal processes and sedimentation for assessment of impacts;
- Assessment of turbid plume dispersion associated with dredging for consideration of potential environmental impacts;
- Identification of any further data collection and model validation requirements necessary for detailed design and impact assessment purposes; and
- Documentation of the modelling and findings.

The modelling work presented in this technical appendix was independently peer reviewed. A letter confirming the outcomes of the peer review process is included as Appendix H1 of the EIS.

1.3 PROPOSED PORT CONFIGURATIONS FOR ASSESSMENT

For the purposes of hydrodynamic impact assessment, the geometric configurations of the Port during the various stages of the Project have been consolidated into seven scenarios as described in Table 1-1. The scenarios are described in more detail in Section 4.2. The proposed staging of the expansion and associated geometry is shown in Figure 1-1 to Figure 1-4.

Table 1-1 Hydrodynamic Impact Assessment Geometric Configurations

Label	Geometry
EXISTING CASE	EXISTING INNER HARBOUR AND CHANNELS
BASE CASE	EXISTING CASE PLUS • NEW BERTH 10 WHARF AND BERTH POCKET. • NEW BERTH 8 POCKET, DEPARTURE AREA AND TUG MANOEUVERING AREA. • NEW MARINE PRECINCT, BASIN AND DREDGED CHANNEL. • WIDEN WESTERN SIDE OF PLATYPUS CHANNEL CH 600 TO CH 1900. •TRUNCATION AT JUNCTION OF SEA AND PLATYPUS CHANNEL. (Figure 1-1)
DEVELOPED CASE 1	BASE PLUS • NE BREAKWATER, NE REVETMENT, EASTERN REVETMENT
DEVELOPED CASE 2	DEVELOPED CASE 1 PLUS • RECLAMATION BUNDS
DEVELOPED CASE 2 WITH WESTERN BREAKWATER	DEVELOPED CASE 2 PLUS • WESTERN BREAKWATER
ULTIMATE CASE	DEVELOPED CASE 2 PLUS • ALL DREDGING COMPLETE TO STAGE C (Figure 1-4)
ULTIMATE CASE WITH WESTERN BREAKWATER	ULTIMATE PLUS • WESTERN BREAKWATER

Figure 1-1 Port Expansion Staging and Geometry – Base Case

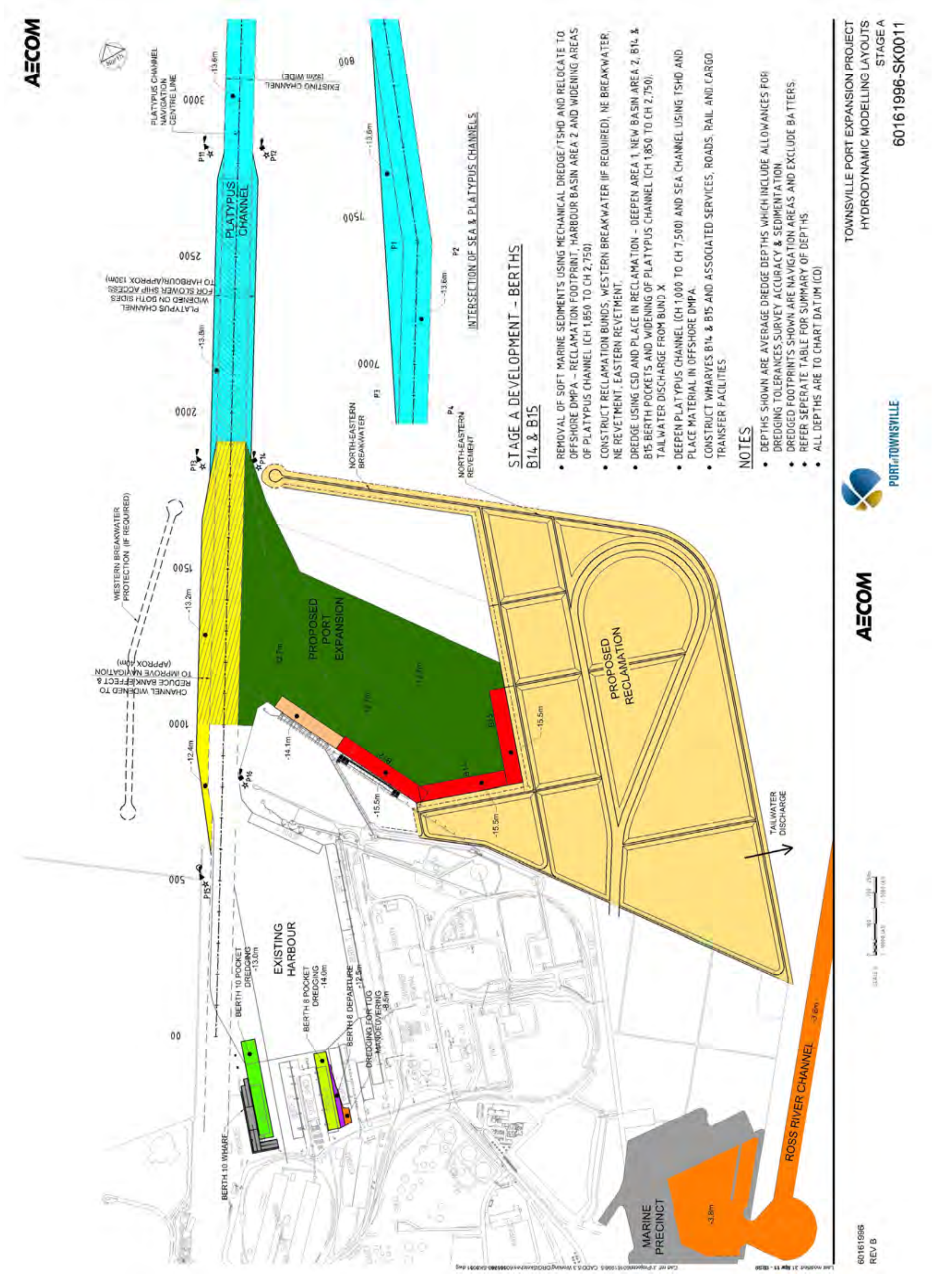


Figure 1-2 Port Expansion Staging and Geometry – Stage A

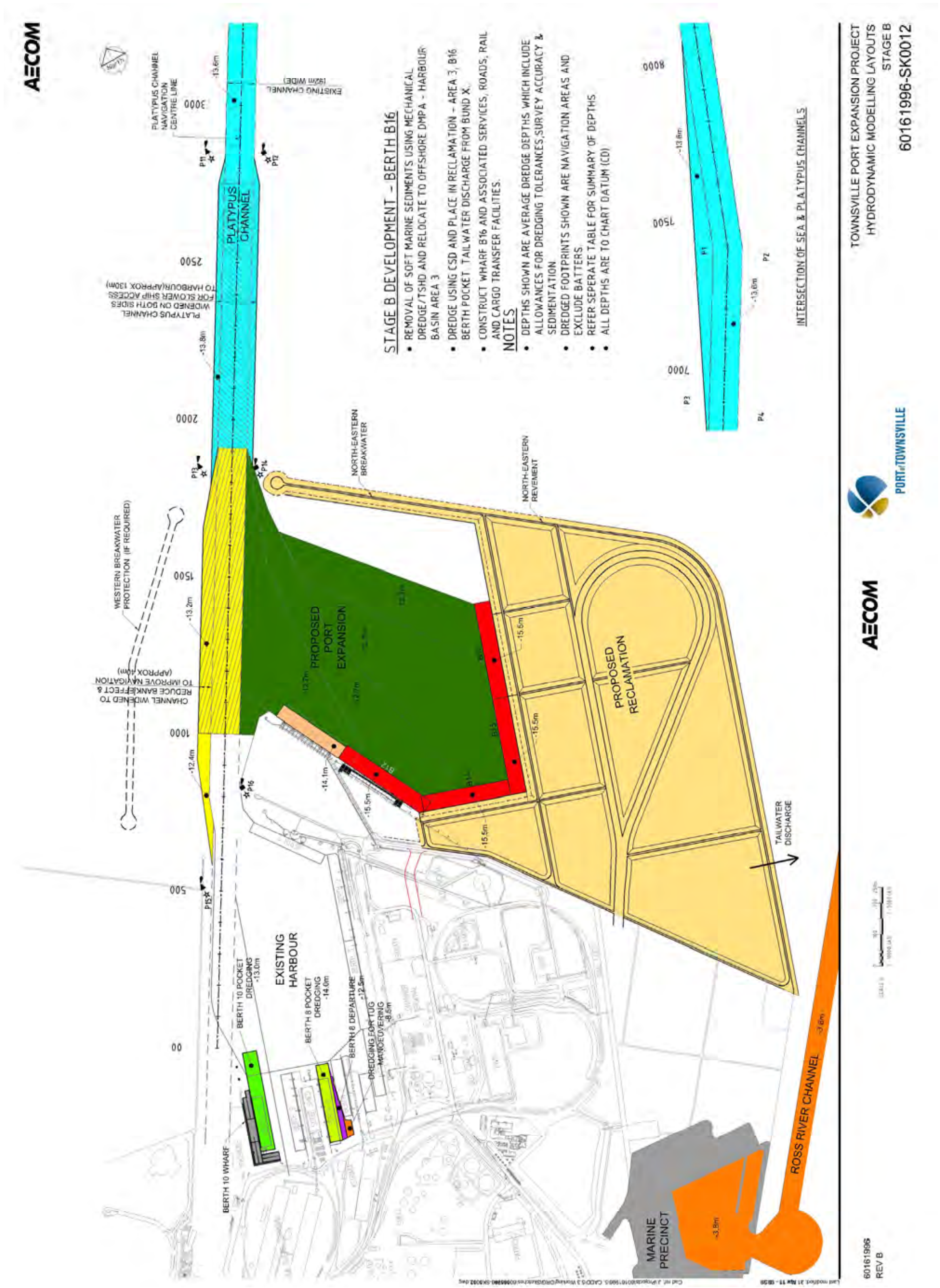


Figure 1-3 Port Expansion Staging and Geometry – Stage B

Figure 1-4 Port Expansion Staging and Geometry – Stage C

2 METHODOLOGY AND MODEL DEVELOPMENT

2.1 APPROACH

The methodology for evaluation of hydrodynamic (HD) and advection-dispersion (AD) processes was based on three-dimensional modelling. The package that was used to this end was TUFLOW-FV, which is a 3D flexible mesh hydrodynamic model that handles both HD and AD components. A baroclinic model configuration with density coupling from both temperature and salinity has been applied in order to represent stratification processes that occur within the Great Barrier Reef lagoon. Details of the TUFLOW-FV numerical model are provided in Attachment A of this appendix.

A spectral wave model (SWAN) was also developed for assessing changes to the wave climate. These models have been used by BMT WBM on several other major studies including:

- Gladstone Western Basin Dredging and Disposal Project (coastal studies);
- Murray River Mouth, Coorong & Lower Lakes Environmental & Morphological Modeling; and
- MetOcean and Sedimentation Study for LNG Import Terminal, Pipavav Port, India.

The modelling framework offers the ability to simulate hydrodynamics, sediment resuspension, transport and deposition and dissolved pollutant transport, and is well suited to the needs of this study.

One advantage of employing a flexible mesh model is its ability to adjust the spatial resolution of the computational network, and in particular, to increase resolution in areas of specific interest to the study. In the current study, these areas include the proposed works sites, and the existing infrastructure in the immediate vicinity, such as breakwaters and docks. The flexible mesh has been constructed to resolve these structures, with resolution also being commensurately reduced in areas where it was not needed, such as outside Cleveland Bay. As such, simulation times and efficiencies were not constrained by the highest resolution required.

Formal calibration of the numerical modelling was also undertaken as part of the study. Data used for calibration included Acoustic Doppler Current Profiler (ADCP) velocity and water level measurements from the Preliminary Engineering and Environmental Study (PEES) undertaken for the port expansion in 2008/2009 and two ADCP deployments in Cleveland Bay undertaken as part of this study.

2.2 HYDRODYNAMIC MODEL EXTENT AND MESH DEFINITION

The base hydrodynamic model network extends over an area of some 28,400 km^2, incorporating the Port of Townsville, Cleveland Bay, Halifax Bay and Bowling Green Bay. The modelled area represents a reach length of approximately 350km, extending from Abbott Point at the south-eastern extent to Lucinda in the north-west. The model extent includes the whole of the Great Barrier Reef lagoon between these points, and extends through reef passes into the Coral Sea.

There are a number of tidal waterways adjacent to the Port including the Ross River at Townsville, which are incorporated into the model. The modelling of the Ross River and Ross Creek focuses on representation of the tidal storage and exchange within the system as well as the delivery of fluvial (freshwater) flows into the model domain. Other waterways such as Crocodile Creek and Black River flow into the ocean along the modelled reach, but have not been included in the model as they are far from the area of interest. The model domain also extends south of the Burdekin River, which is a major source of fluvial discharge and suspended sediment to the Great Barrier Reef lagoon. The model is therefore capable of simulating freshwater plumes due to runoff from the Burdekin River catchment and the associated sediment delivery and lagoon stratification.

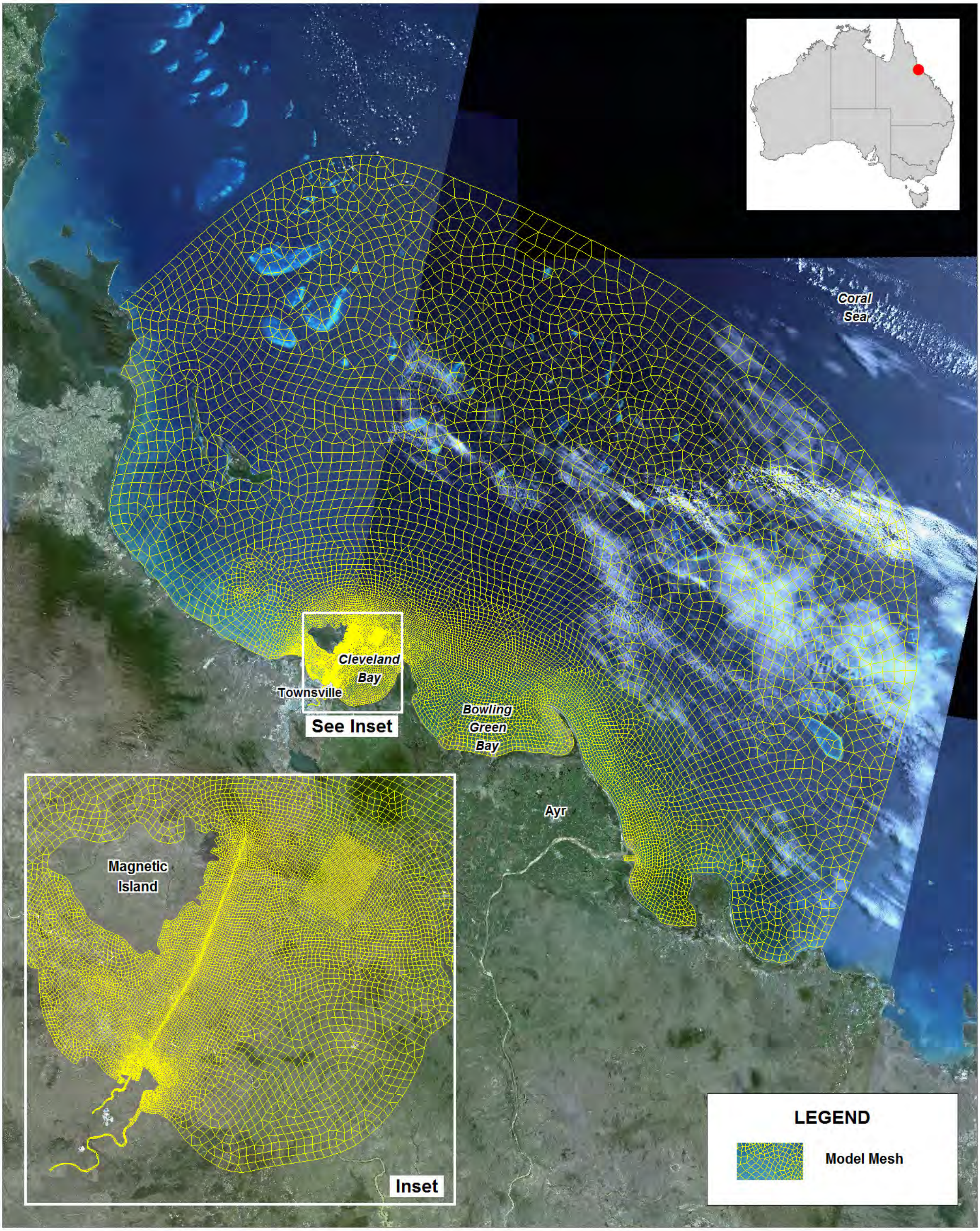
The developed model mesh for the study area is shown in Figure 2-1. In developing the model mesh, particular focus was given to a number of key areas to ensure a suitable model representation of ambient conditions. Where appropriate, the resolution of the model mesh was increased to provide a more accurate representation of local conditions. Some key areas are discussed below:

- There are numerous islands within the study area (eg. Magnetic Is., Herald Is., Great Palm Is.), which can have an influence on flow distribution. Local adjustment of the mesh resolution has been undertaken to define the land boundaries, and the adjacent flow channels around the islands, which are typically characterised by rapid changes in bed elevation.
- Ross Creek flows into the Port of Townsville harbour. The model has been extended for approximately 3.5 km upstream of the Port in order to adequately define the tidal storage and simulate the tidal flux through the harbour.
- The Ross River is a major waterway which discharges into Cleveland Bay immediately to the south-east of the Port of Townsville facilities. The model has been extended for approximately 10 km upstream of the river mouth. This provides the opportunity to adequately define the tidal storage within the river system and simulate the tidal flux.
- The resolution of the mesh has been adapted to represent in detail the Platypus Channel out from Townsville to the sea, as well as the Port in the immediate vicinity of the Ross River confluence in order to enhance the representation of local (potentially complex) hydraulic conditions.
- The domain coverage extends well beyond Cleveland Bay into the Great Barrier Reef lagoon and includes the Burdekin River, which is the major fluvial source into the study area. The Burdekin is an important driver of hydrodynamics through the introduction fresh water and of regional morphology through its supply of sediments into the nearshore region.
- The existing Townsville Port Dredge Material Placement Area (DMPA) has been refined to a typical mesh dimension of approximately 100 metres, since this is an important area for investigation of dredge plume and dredge material resuspension dynamics.

2.3 ADVECTION DISPERSION MODELLING

A system for modelling the advection and dispersion of a sediment plume produced during dredging has been developed as part of this study using the cohesive sediment module of TUFLOW-FV coupled with the 3D hydrodynamic model.

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 dredge plume source terms, dispersion coefficients, particle size distributions and settling velocities is discussed in Section 3.



Title:

Port of Townsville TUFLOW-FV Model Mesh

Figure: 2-1

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0 5 10km
Scale - Inset

0 20 40km
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2.4 SWAN WAVE MODELS

A spectral wave model for Cleveland Bay was established to assess the wave climate in the context of the proposed development and for coupling with the hydrodynamic model.

The SWAN (Delft University of Technology, 2006) numerical model was used for this purpose. SWAN is a third-generation spectral wave model, which is capable of simulating 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 such investigations worldwide.

A regional model covering a large section of the Great Barrier Reef lagoon and Coral Sea was established and wind boundary conditions were extracted from global NCEP model reanalyses. Wave propagation to the immediate vicinity of the Port has been assessed by establishing a nested sub-model over the section of the TUFLOW-FV model within the Great Barrier Reef lagoon. The wind boundary conditions for the nested model were the same as those developed for the TUFLOW-FV hydrodynamic model, as described in Section 2.7.

The SWAN model domains are shown in Figure 2-2.

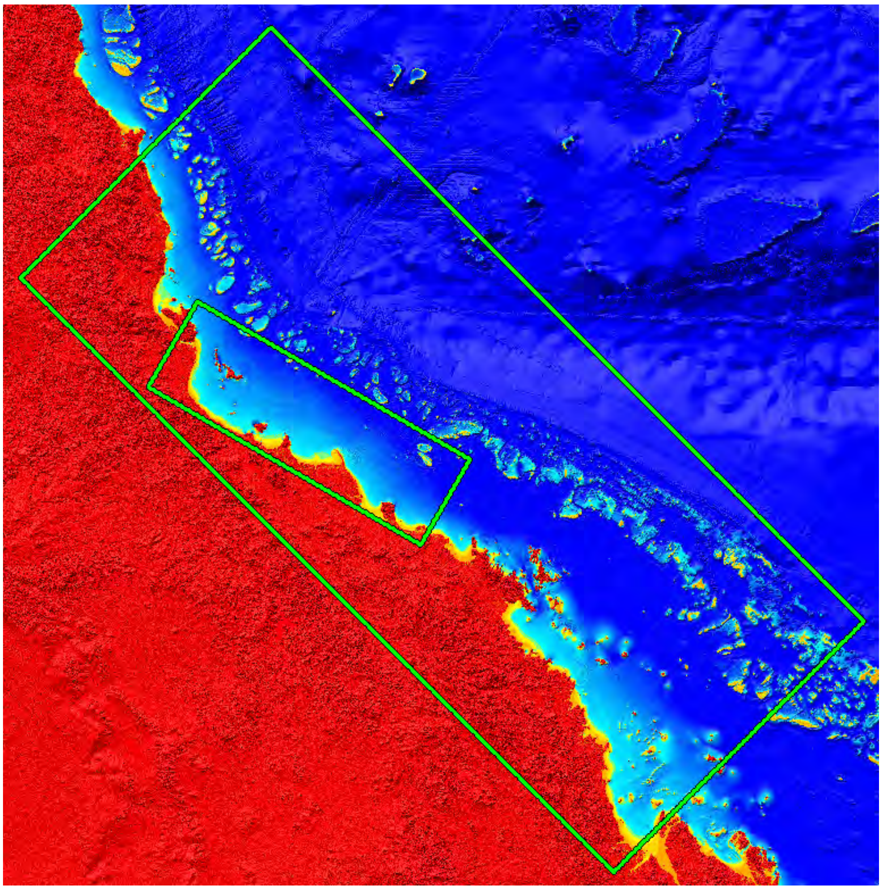


Figure 2-2 Regional and Nested SWAN Domains

2.5 BATHYMETRY

Hydrographic (bathymetric) data for both the hydrodynamic and wave models was sourced from the following:

- Local hydrographic survey data supplied by Port of Townsville;
- Bathymetric data of Cleveland Bay and the Great Barrier Reef Lagoon from external sources;
- Navigation charts (AUS 256) covering Cleveland Bay, Ross River and Ross Creek;
- Geoscience Australia Australian Waters DEM (250m grid); and
- Project 3DGBR: a high-resolution depth model for the Great Barrier Reef and Coral Sea (Reef and Rainforest Research Centre, 2010).

All these were converted to metres above Australian Height Datum (mAHD).

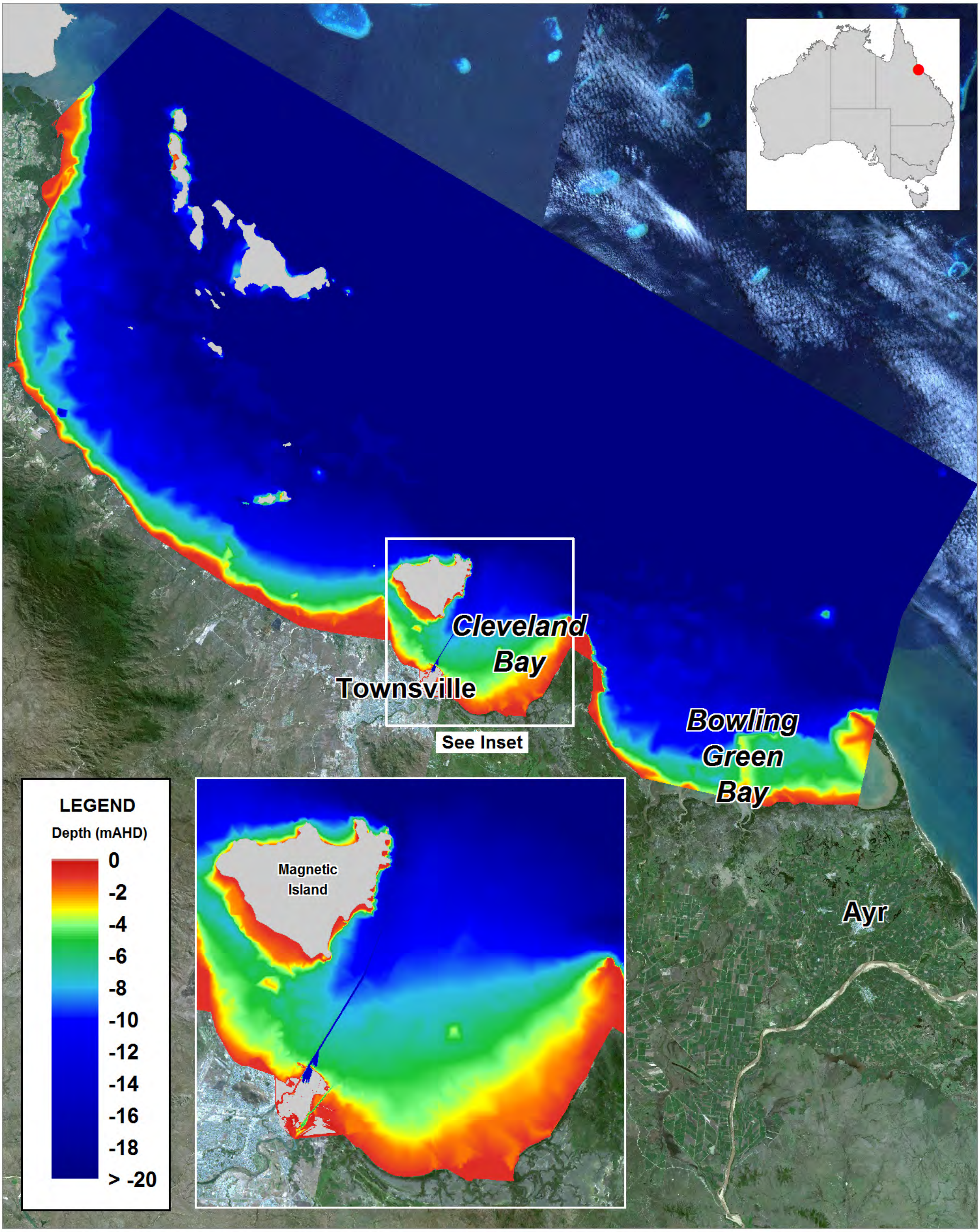
A Digital Elevation Model (DEM) of the study area was derived from the various survey components. The DEM of the model region is shown in Figure 2-3.

In developing the hydrodynamic model, consideration was given to the underlying bathymetry in defining the mesh configuration. For example, model resolution was enhanced at locations of rapidly varying bathymetry or expected high velocity/flow regions based on main channel definition.

A point inspection of the DEM was used to define the bed level at the model mesh nodes located at the vertices of the individual elements of the mesh.

2.6 TIDAL BOUNDARY CONDITIONS

The developed model extent included an open boundary that required temporal definition of water surface elevations. This boundary is shown in Figure 2-1. Due to the large extent of the model domain, tidal elevations vary spatially and temporally along the length of the boundary. Tidal data along these boundaries was extracted from a BMT WBM calibrated tide model of the Great Barrier Reef lagoon and Coral Sea, the spatial extent of which is shown in Figure 2-4. The regional tide model boundary conditions were forced by tidal constituents supplied by the Bureau of Meteorology, National Tide Centre.



Title:

Bathymetry of Model Area

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0 15 30km
Scale - Main Map

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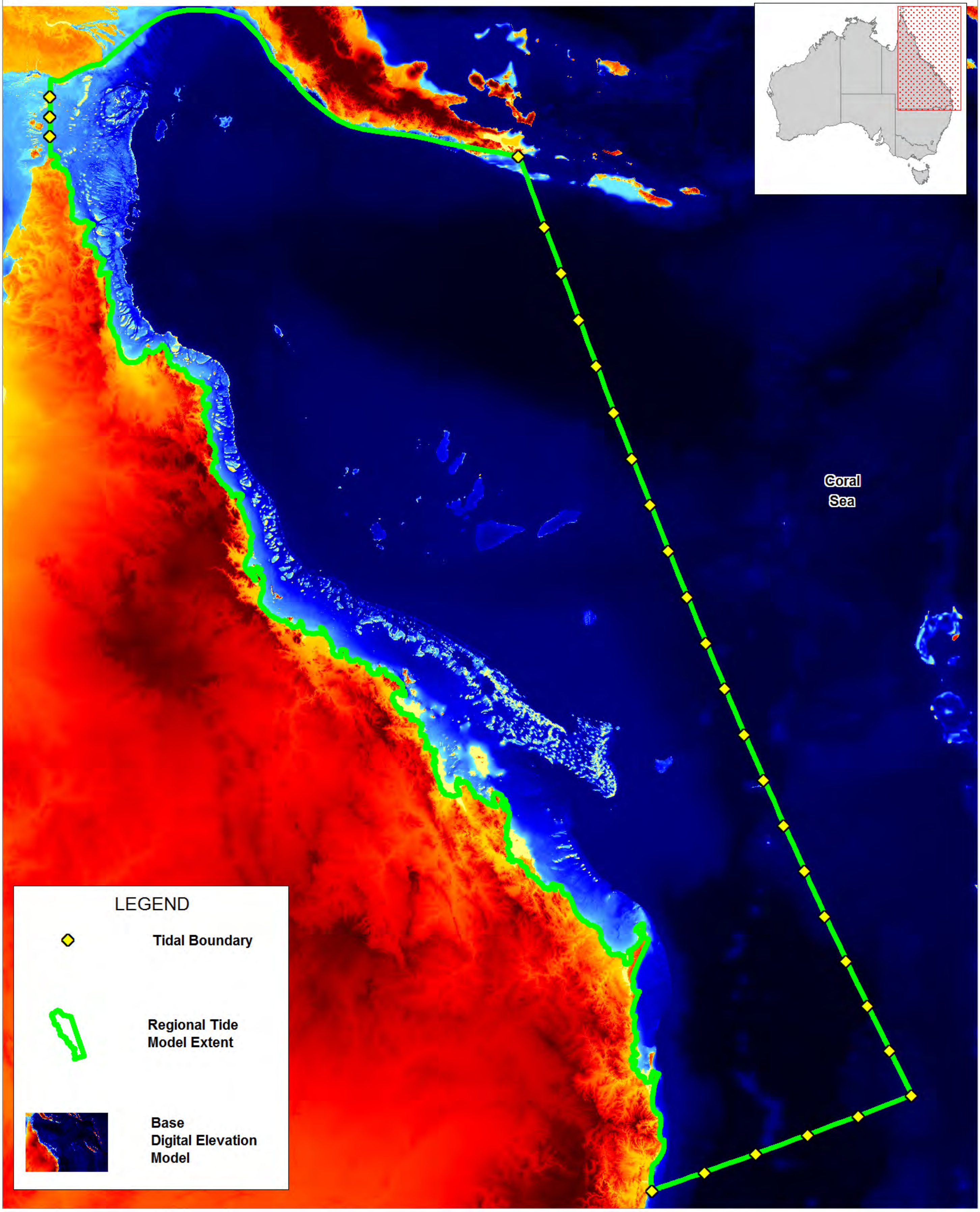

Title:

Regional Tide Model Extent

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0 200 400km

Approx. Scale

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2.7 SALINITY AND TEMPERATURE BOUNDARY CONDITIONS

The model calibration process confirmed that 3D temperature and salinity stratification effects were significant to vertical velocity structures and hence overall circulation with Cleveland Bay. The model was therefore provided with temperature and salinity profiles at all external boundaries. 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/).

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 obtained from global NCEP model reanalyses (NOAA, 2012). These model input fields were spatially uniform but varied in time in order to represent both seasonal and higher-frequency variations (e.g. diurnal).

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.

2.8 WIND BOUNDARY CONDITIONS

The Port of Townsville provided wind data (speed and direction) at ten minute intervals at the entrance to the Port (P14) for the period 2006 to 2011. A spatially interpolated wind field was constructed using additional data from the Townsville Airport, Lucinda Point and Alva Beach stations of the Bureau of Meteorology (BOM) and data from Australian Institute of Marine Science (AIMS) stations as shown in Figure 2-5. A three hour moving average of each dataset was obtained and spatially interpolated to develop a consistent and continuous dataset over the periods used for calibration and impact assessment purposes.

Figure 2-5 Wind Stations Used for the Spatially Interpolated Wind Field

2.9 FLUVIAL DISCHARGE BOUNDARY CONDITIONS

Daily-average freshwater flows and suspended sediment loads in Ross River and Ross Creek were derived from existing catchment models developed by BMT WBM (2010).

Freshwater flows in the Burdekin River were obtained from DERM via the online "Watershed" data delivery service (http://watermonitoring.derm.qld.gov.au/host.htm). The paper by Bainbridge et al (2012) which describes field measurements of the 2010-11 wet season Burdekin River plume was used to develop an approximate relationship for sediment load from the Burdekin River as a function of instantaneous flow rate as shown in Figure 2-6.

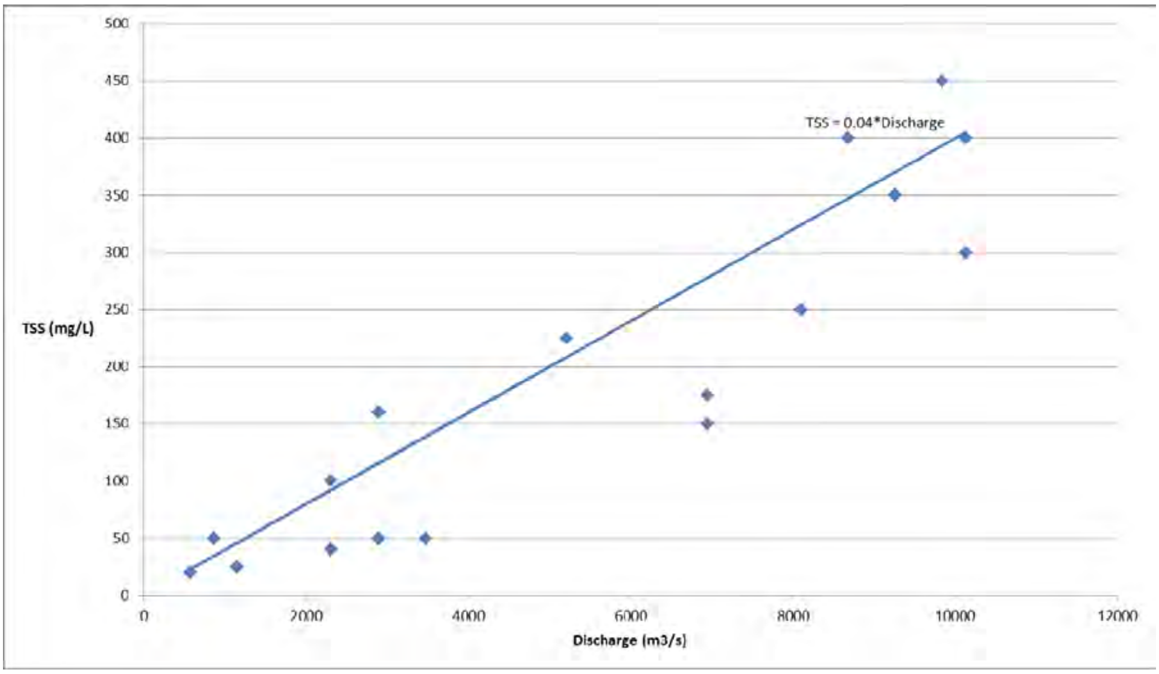


Figure 2-6 Burdekin River Sediment Rating Derived from Bainbridge et al. (2012).

Catchment inflow boundary conditions were applied as time-varying inputs extracted for the selected simulation periods and represent best-estimates of actual catchment flows at particular times rather than generalised or averaged inflows.

2.10 MATERIAL PROPERTIES

Within the TUFLOW-FV model, various hydraulic properties, for example hydraulic roughness, can be assigned to groupings of model elements. This involves the specification of a spatial distribution of various material types with common properties. For example all model elements representing mangrove areas can be given a material type classification, from which it is possible to prescribe a common Nikuradse "k_s" roughness coefficient. A representation of this material classification adopted for the model is shown in Figure 2-7. This distribution was based on the bathymetry of the model, with three main areas defined as follows:

- Deep water - k_s = 0.02m;
- Reef - k_s = 100m (to represent very low conveyance across under-resolved reef structures); and
- Rocky coast - k_s = 0.5m.

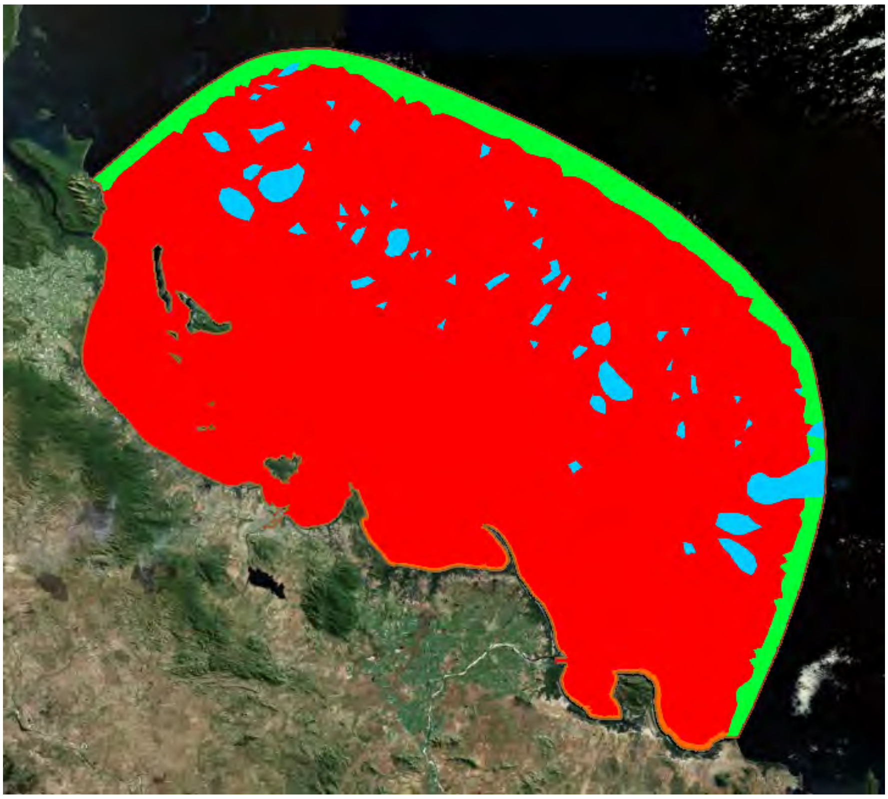


Figure 2-7 Material Distribution
Deep Water (Red), Reef (Blue), and Rocky Coast (Orange)
(Green Areas Represent Boundary Regions)

3 MODEL CALIBRATION AND VALIDATION

3.1 HYDRODYNAMIC MODEL CALIBRATION AND VALIDATION

3.1.1 CALIBRATION AND VALIDATION DATA

During PEES a bottom-mounted ADCP was deployed in Cleveland Bay in the vicinity of Platypus Channel, from the 4th September to the 11th February, 2009. The deployment location was chosen to provide representative current and wave conditions in central Cleveland Bay at a water depth of approximately 5m. This deployment provided a range of tide, wind and wave conditions during typical (but different) spring and summer periods. A full description of the data is provided in the Oceanographic Data Collection Report (BMT WBM 2009) prepared as part of PEES.

In addition, the model has been validated against ADCP data collected at two other locations between October 2010 and February 2011. One ADCP was deployed near the eastern shore of Magnetic Island, and the other was deployed at the existing DMPA location. These ADCP deployment sites are shown in Figure 3-2. The data retrieved has been processed and analysed to provide the appropriate parameters necessary for model calibration and validation purposes.

Simultaneous regional data has also been collated from other sources including:

- Offshore wave data from the DERM Waverider buoy; and
- Tide level data from regional tide gauges.

This data has also been used as part of the model calibration and validation process where needed.

With respect to waves, the Townsville Waverider buoy (DERM) is located about 25 km east of the port, 5 km north of Cape Cleveland where the water depth is approximately 15m. Therefore it does not provide a direct indication of the wave climate within Cleveland Bay or at the study site. Therefore, in addition to collecting current data, the ADCPs deployed in this study also measured local wave conditions.

3.1.2 MODEL PARAMETERISATION

The TUFLOW-FV model was run in 3D hydrodynamic mode using a z-coordinate scheme with layer thicknesses of less than 1 m down to an elevation of -13 m AHD and 2 m or less down to an elevation of -25 m AHD. A maximum of 30 layers were resolved in the deeper sections of the model domain, with the bottom layer thickness varying according to the local depth below -25 m AHD. This high degree of vertical resolution in the top 25 m of the water column was necessary in order to simulate vertical stratification within the water column. This also allowed 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 turbulence.

The General Ocean Turbulence Model was coupled with the hydrodynamic model for the purposes of deriving vertical turbulent mixing parameters. A 2-equation k-omega model was adopted with default parameters.

3.1.3 HYDRODYNAMIC MODEL CALIBRATION RESULTS

The model was run in 3D baroclinic mode over two calibration periods from 1st October 2008 to 1st November 2008 and from 1st December 2010 to 1st February 2011. These periods incorporated representative spring and neap tide conditions and a range of meteorological conditions. This enabled assessment of the ability of the model to adequately represent a range of conditions and its suitability for use in impact assessments.

The calibration and validation results in terms of comparison of simulated water levels and velocities against observed data are presented in the following sections.

3.1.3.1 WATER LEVELS

Validation plots of observed versus simulated water levels are shown in Figure 3-1 for the Townsville storm tide gauge, for representative spring and neap tide conditions. Both figures show that the modelled water levels are consistent with measurements in terms of phasing and amplitude.

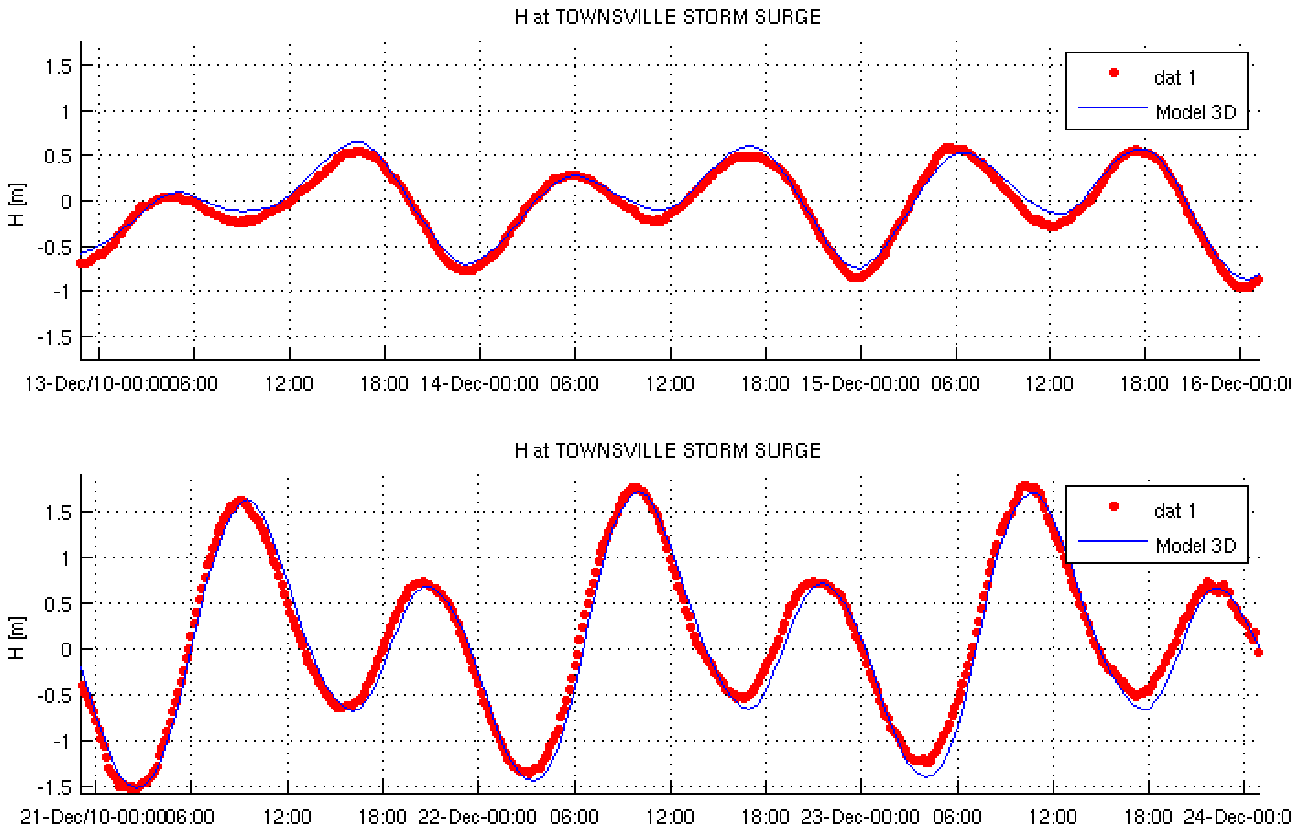


Figure 3-1 Water Level Validation – Townsville Storm Surge Gauge (2010)

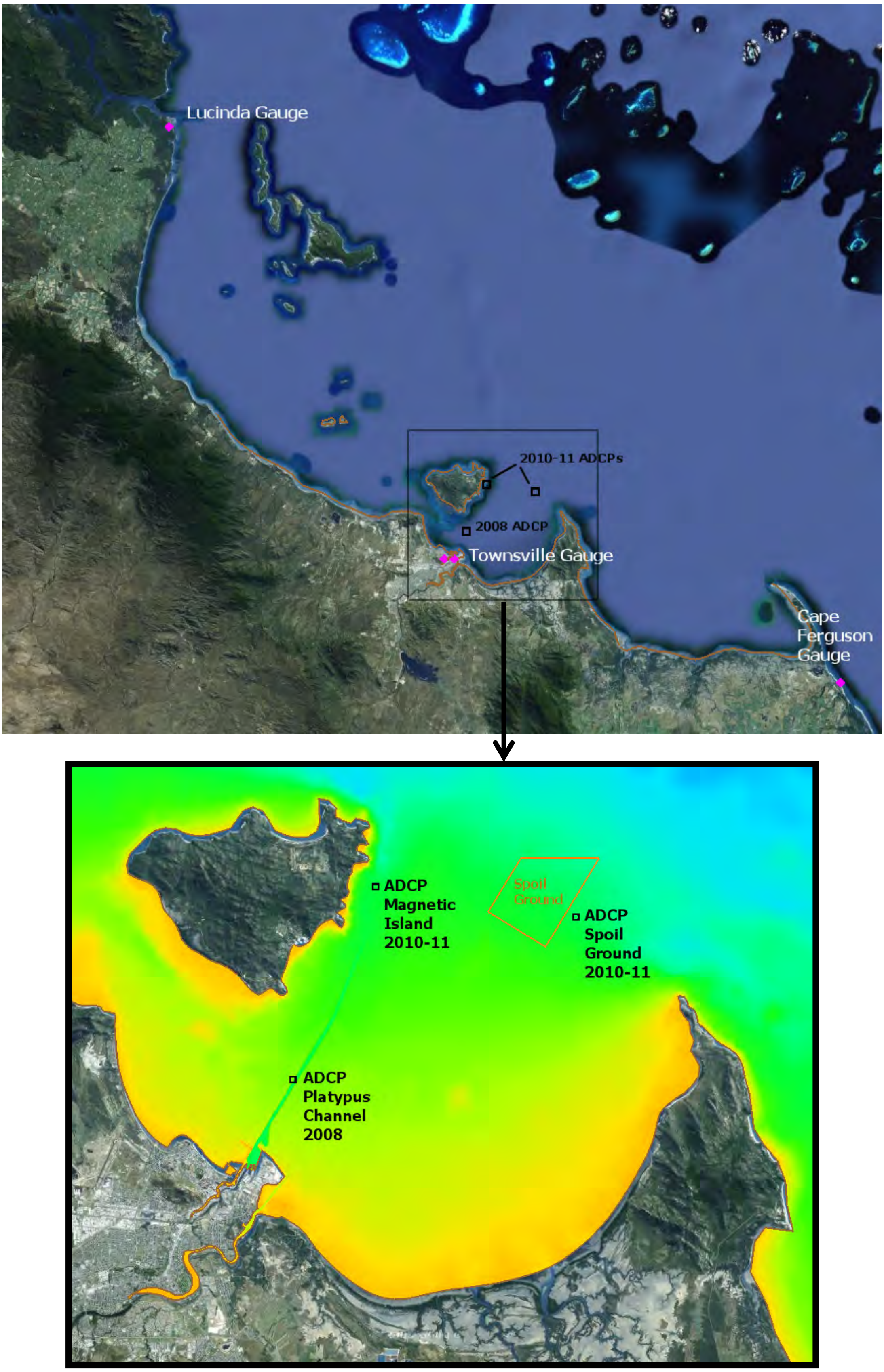


Figure 3-2 Location of Model Calibration Points

3.1.3.2 WATER TEMPERATURE

A comparison of modelled temperature from the summer 2010/11 validation period with measurements from the AIMS Cape Cleveland station is shown below. Following an initial over-prediction in temperature the model can be seen to be in reasonable agreement with the measurements.

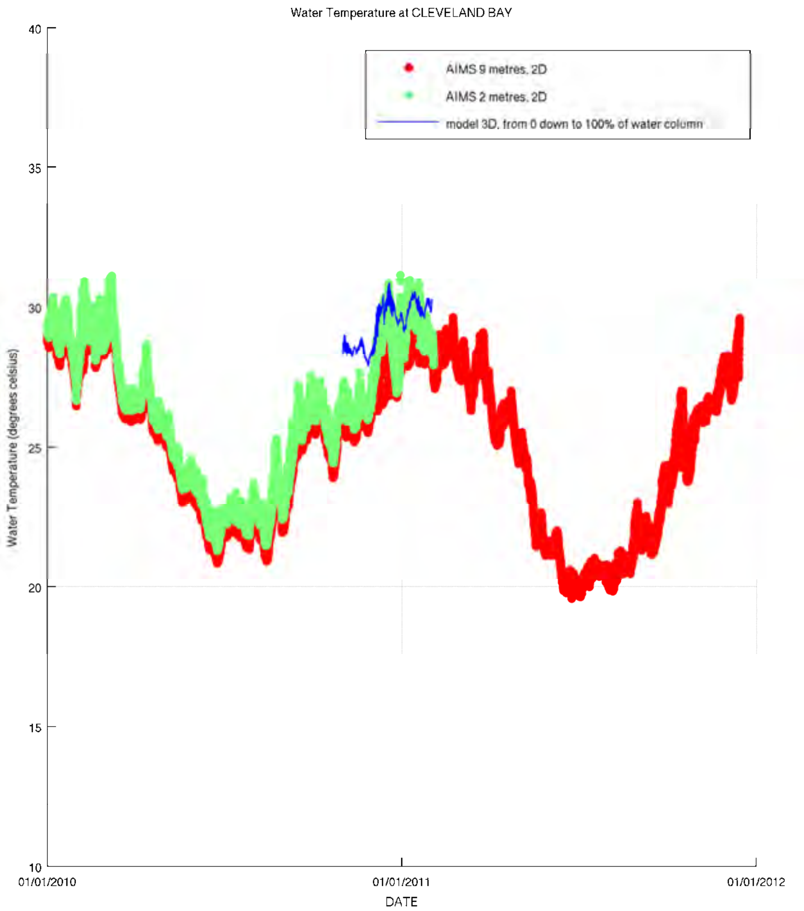


Figure 3-3 Temperature Validation – AIMS Cape Cleveland Station.

3.1.3.3 *SALINITY*

The summer of 2010/11 was one of the wettest on record for the study area and resulted in significant flood flows from the major Burdekin River catchment which discharges into the Great Barrier Reef lagoon approximately 100km south-east from Townsville. Bainbridge et al. (2012) have described a campaign of measurements focussed on the Burdekin River plume during this period, and include comparisons with a series of MODIS satellite images of the plume.

Figure 3-4 shows a surface salinity plot from the TUFLOW-FV model for the 4th of January 2011 together with the MODIS satellite image from the same date (http://oceancolor.gsfc.nasa.gov/). These model results show reasonably good qualitative agreement with the plume spatial distributions which are discernible from the MODIS satellite images. The remaining surface salinity snapshots for comparison with the Bainbridge et al. Figure 3 are provided in Attachment B of this appendix.

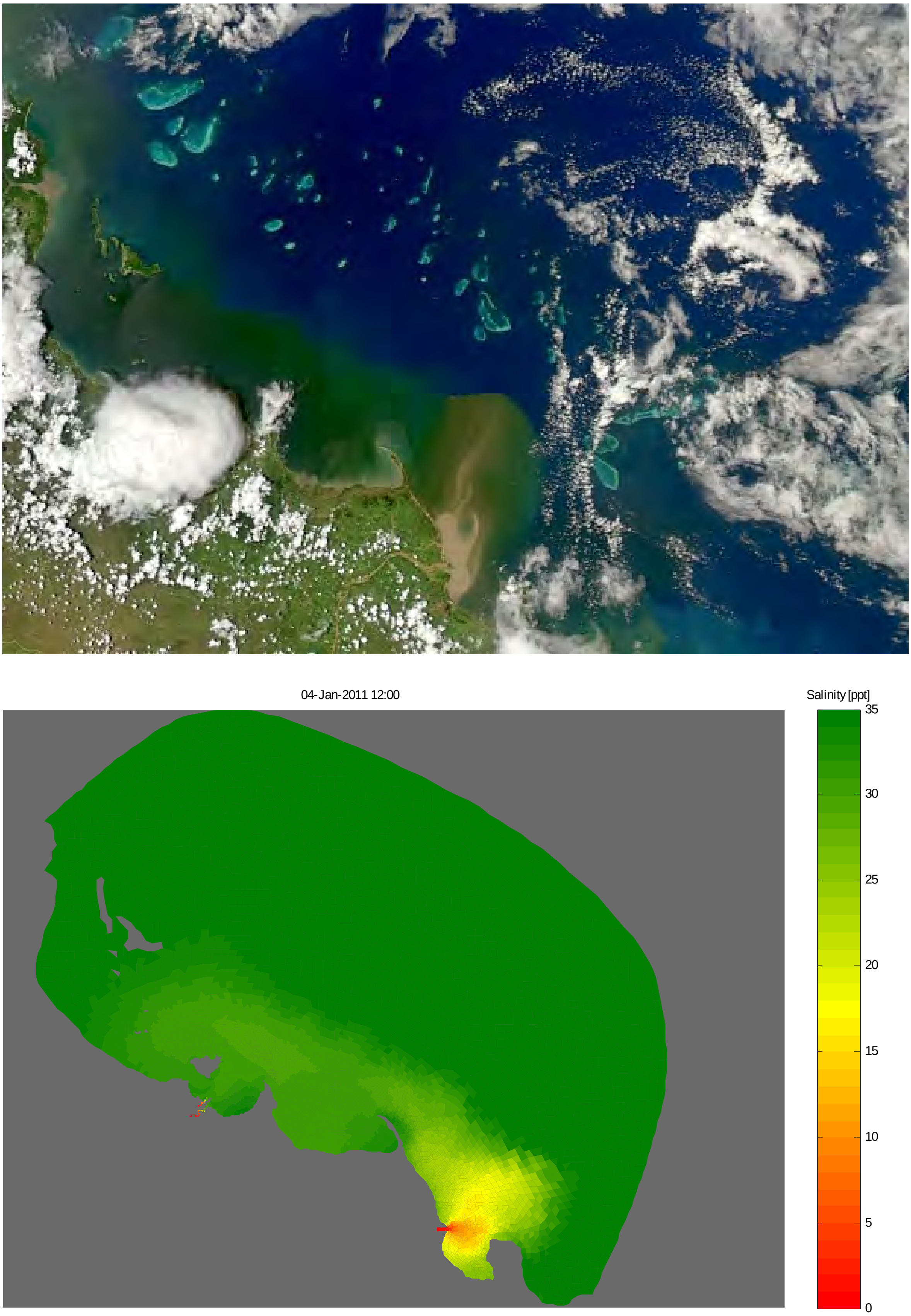


Figure 3-4 Modelled Surface Salinity on the 4th January 2011 (bottom) and the MODIS Satellite Image for the Same Date (top).

3.1.3.4 *CURRENT VELOCITIES*

Model outputs were compared against the ADCP current velocity magnitude and direction measurements (see Figure 3-2 for ADCP locations). The ADCP data was post processed to provide time series averages of the velocities in the top 50% and bottom 50% of the profile, to allow comparison with the three dimensional output of the model.

Vertical variations in current speed and direction that were indicative of stratification within the water column were sometimes observed in the measured ADCP data, particularly from the 2010-11 summer/wet season deployments. An example velocity profile measured at the DMPA ADCP is shown in Figure 3-5, and can be seen to illustrate the degree of vertical current profile variation that occurred during the significant catchment runoff events in January 2011. Also shown in this figure are the model predictions which demonstrate that the turbulence scheme is able to successfully capture these processes.

The time series model versus data comparisons are shown in Figure 3-6 to Figure 3-11. It can be seen that the velocity magnitude predicted by the TUFLOW-FV model is generally within the bounds of the accuracy of the recorded data. In particular, spring tide conditions are reproduced accurately in terms of both timing and amplitude at all three ADCP locations.

Velocity directions are generally well reproduced by the model, except for the 2010 Magnetic Island data where the model sometimes misses the full rotation of the velocity vectors. Overall the model predicts the general hydrodynamic characteristics within the region of interest with sufficient detail for the purposes of this study.

During the 2010 monitoring campaign it is understood that the salinity influence from the Burdekin River flood plume may have begun to influence the DMPA and Magnetic Island monitoring sites from around the 9th December. At this time, the surface currents at the DMPA site are seen in both the data and the model predictions to “decouple” from the near-bed currents. While the agreement at the DMPA site is good the model skill at predicting the Magnetic Island ADCP current behaviour is not as good as for the preceding period.

Current roses for the top and bottom 50% of the profile at the ADCP deployment locations are presented in Figure 3-12 to Figure 3-17. The top panel is the model output, and the bottom panel is the measured ADCP data.

Agreement between the model and data for both directions and magnitudes is excellent for the 2008 data collected near the Platypus Channel.

Compared to the data at the Magnetic Island location in 2010, the model does a good job of estimating current magnitudes, but tends to overestimate the directional spread in the bottom 50% of the water column and underestimate the spread in the top 50% of the water column.

At the DMPA location, the model underestimates the directional spread in the bottom 50% of the water column and slightly underestimates velocity magnitudes in some directions. In the top 50% of the water column at the DMPA, velocity magnitudes for currents travelling towards the West are somewhat underestimated, and the predominant direction is biased slightly to the south with respect to the data.

Overall, the model performance is considered to be acceptable for the purposes of the present study.

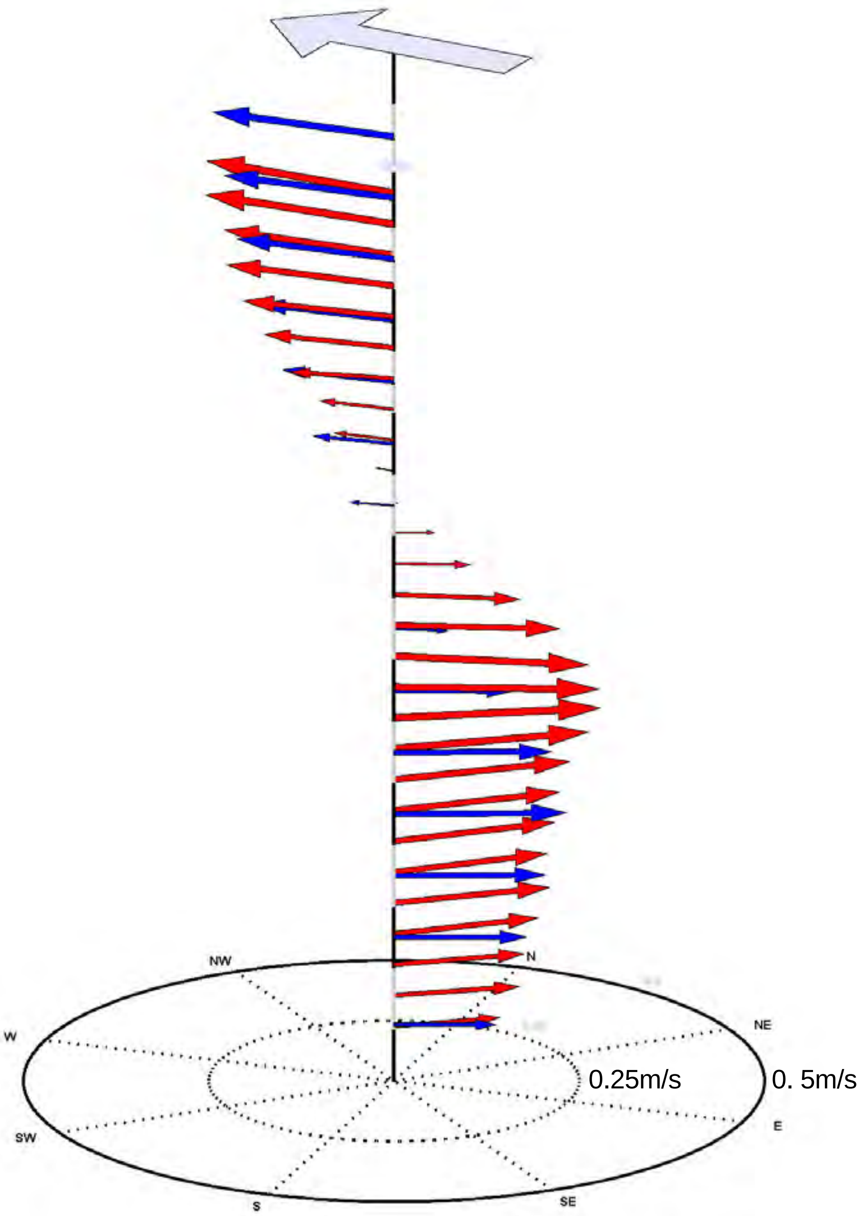


Figure 3-5 Velocity Profile at the DMPA ADCP
Blue Arrows – Model; Red Arrows – Data
The Grey Arrow at the Top of the Profile Indicates the Wind Direction

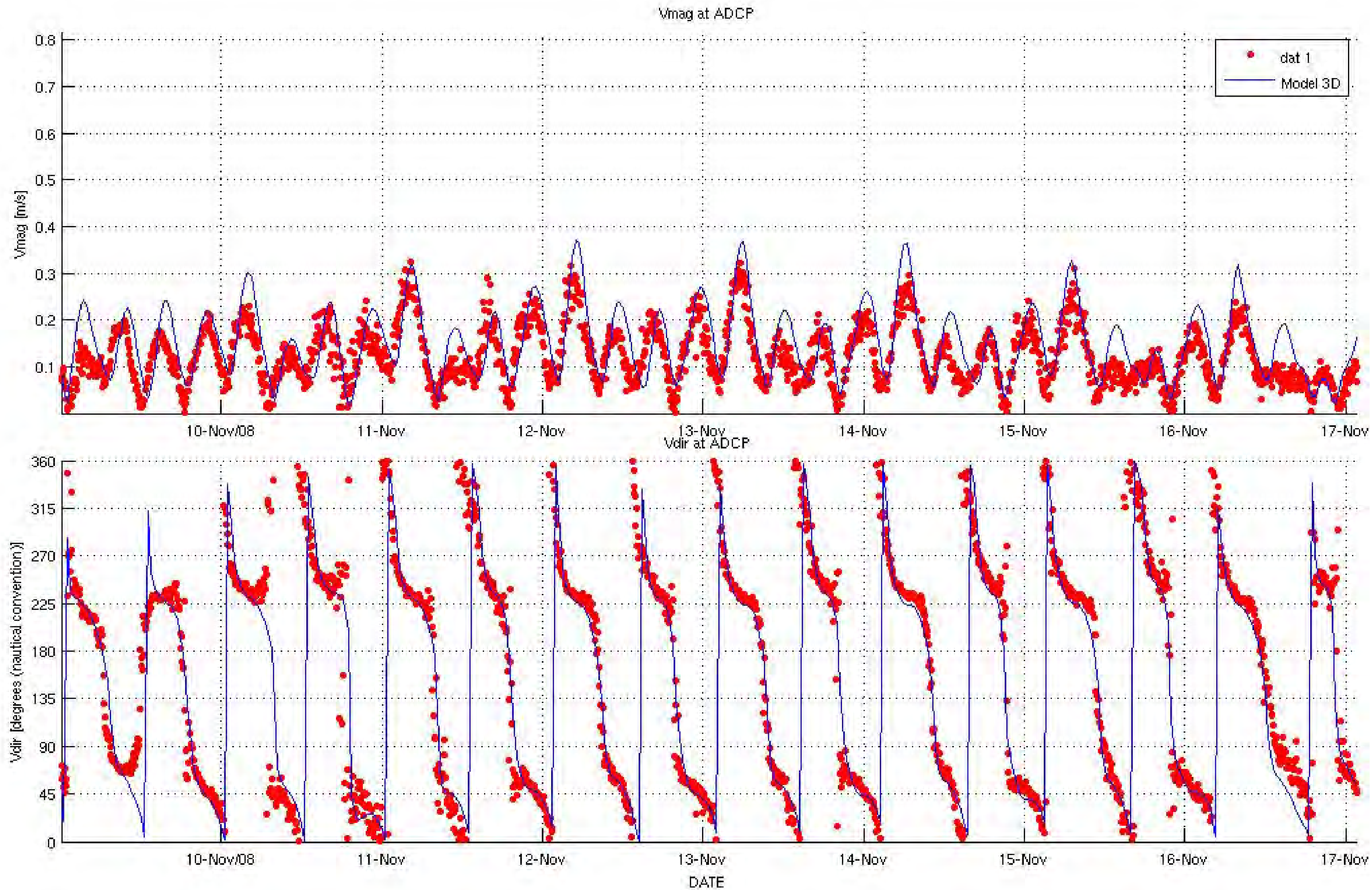


Figure 3-6 Velocity Magnitude Validation Time Series – 2008 PEES ADCP Data – Top 50%

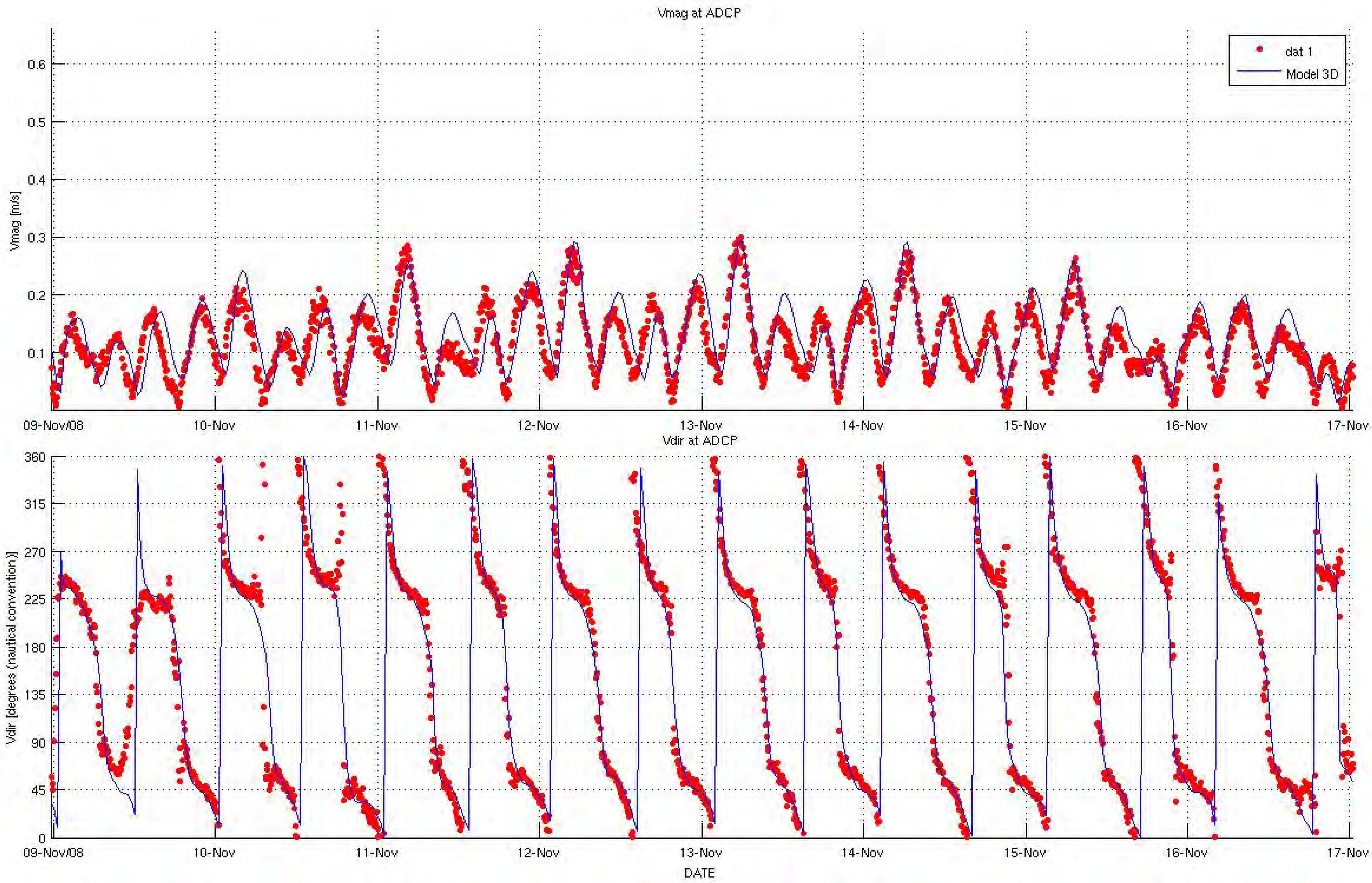


Figure 3-7 Velocity Direction Validation Time Series – 2008 PEES ADCP Data – Bottom 50%

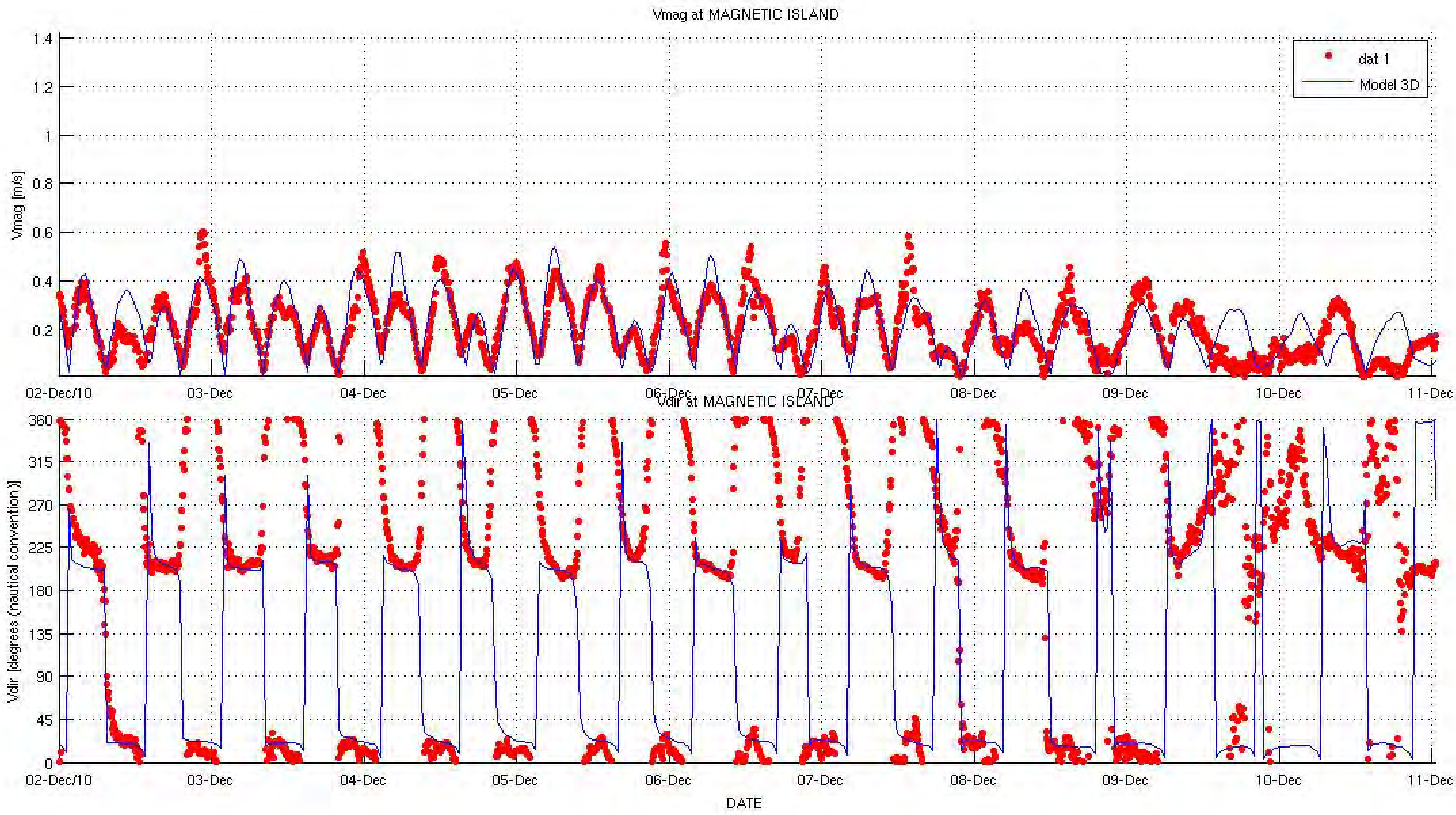


Figure 3-8 Velocity Validation Time Series – 2010 Magnetic Island ADCP Data – Top 50%

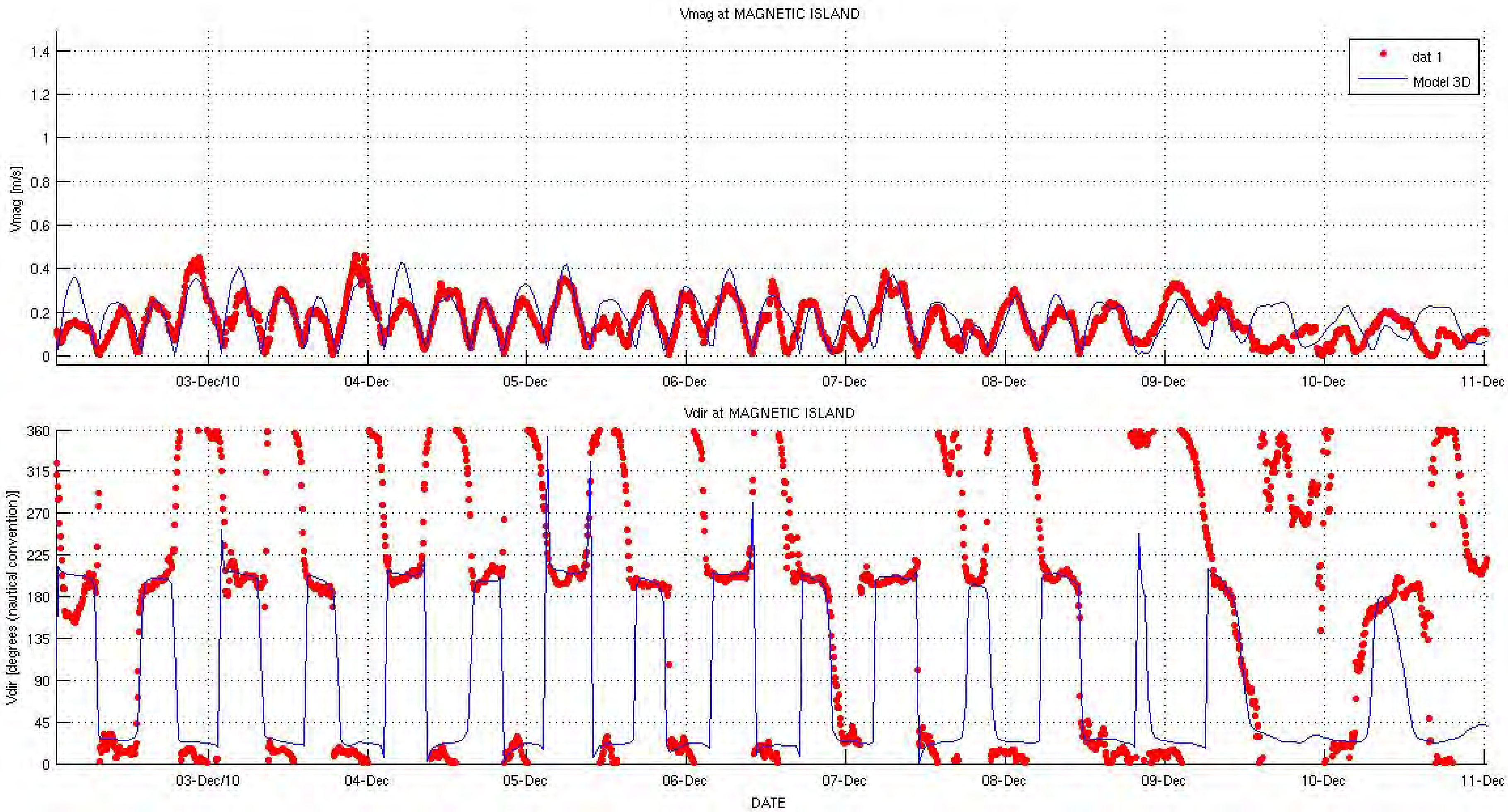


Figure 3-9 Velocity Validation Time Series – 2010 Magnetic Island ADCP Data – Bottom 50%

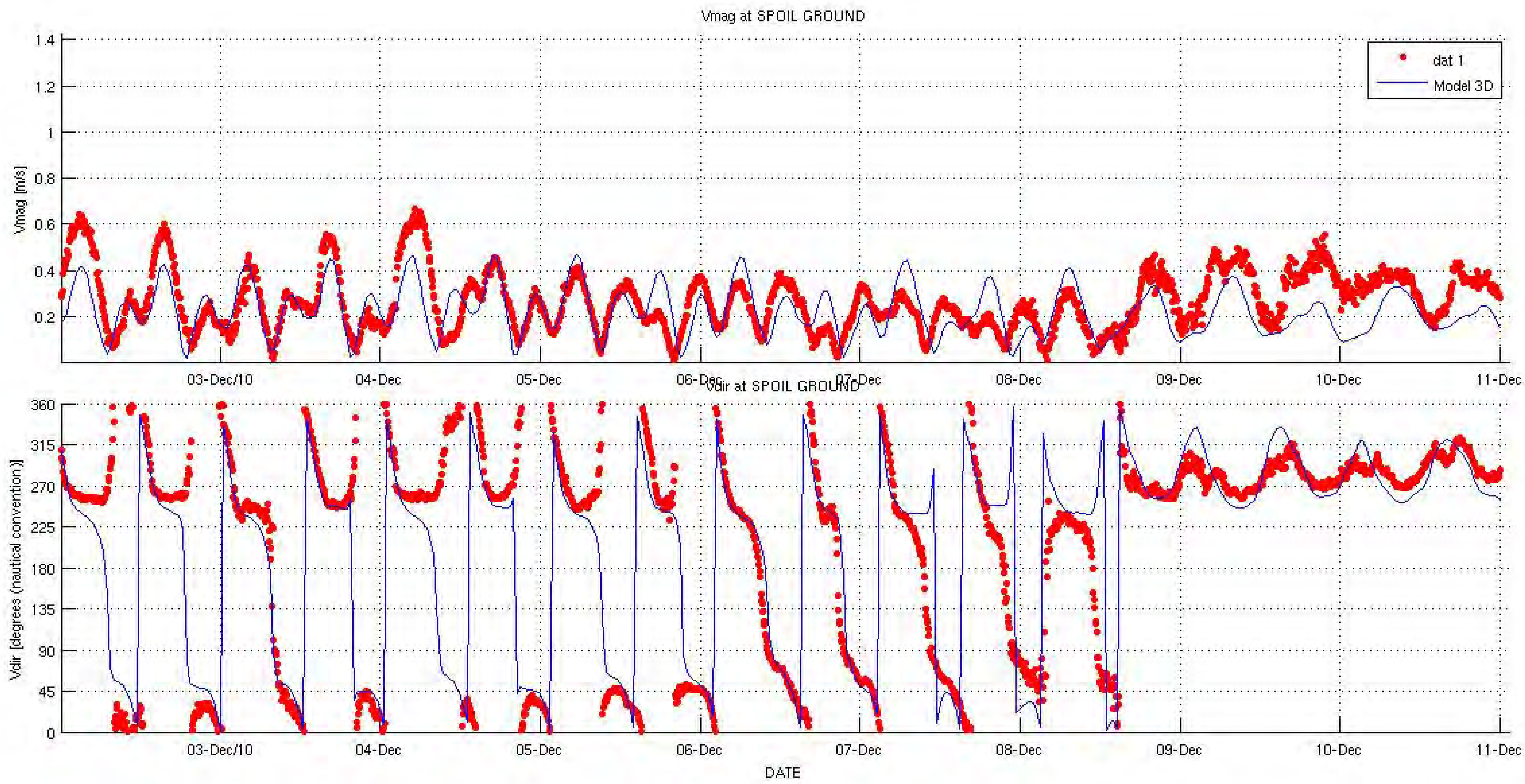


Figure 3-10 Velocity Validation Time Series – 2010 DMPA ADCP Data – Top 50%

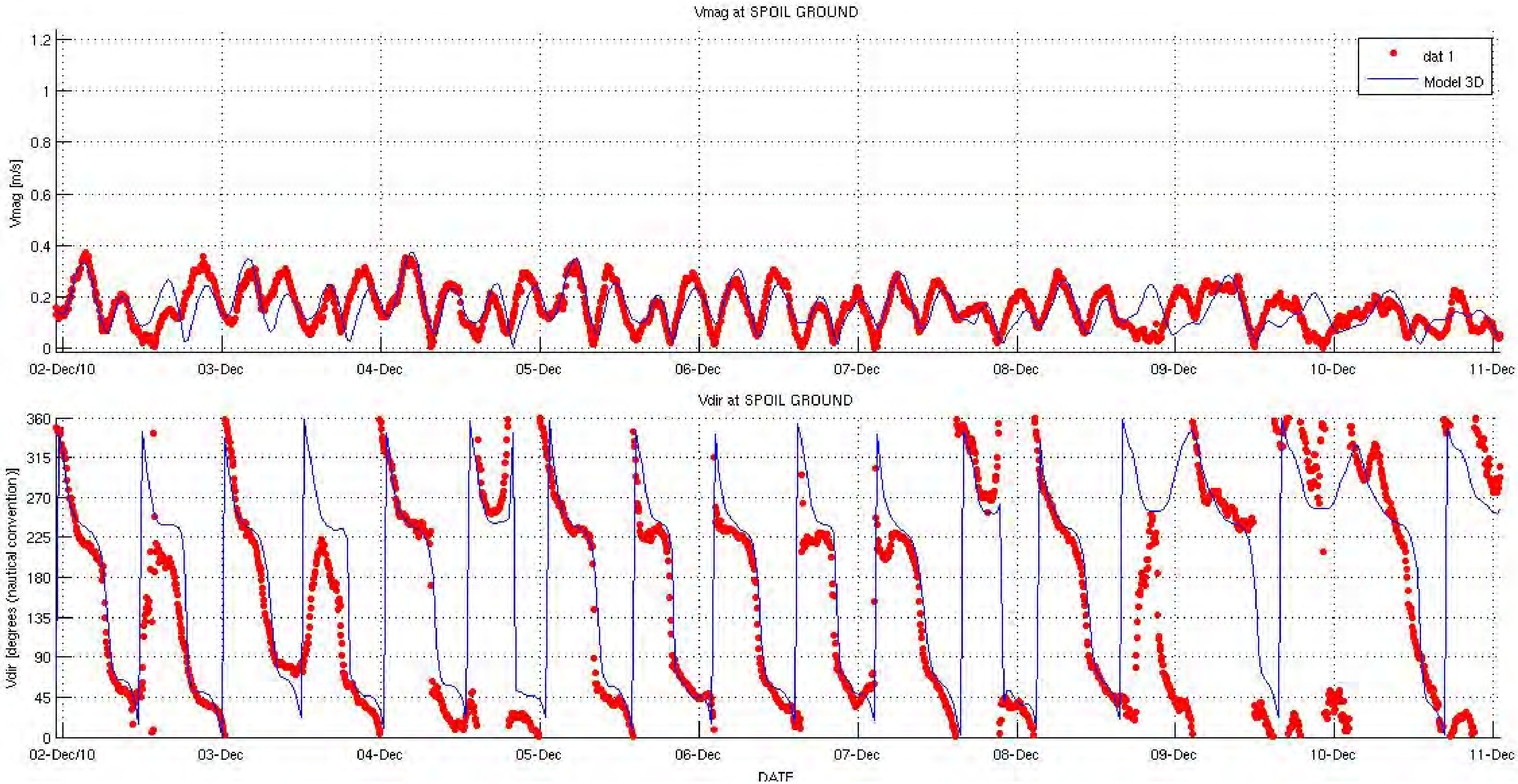
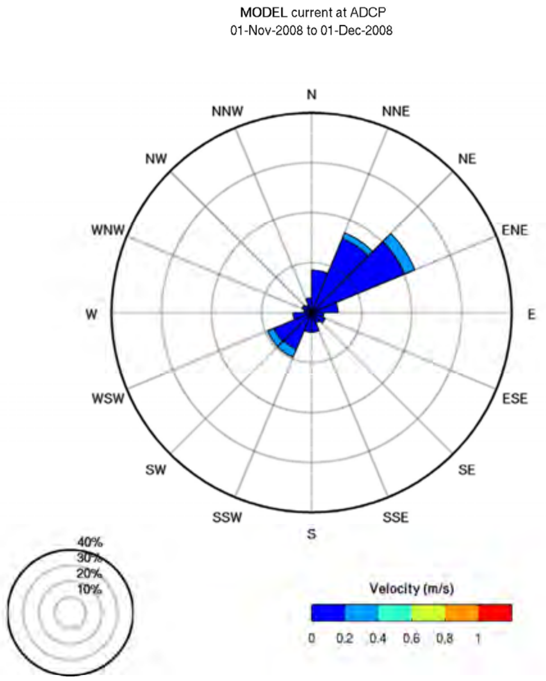


Figure 3-11 Velocity Validation Time Series – 2010 DMPA ADCP Data – Bottom 50%



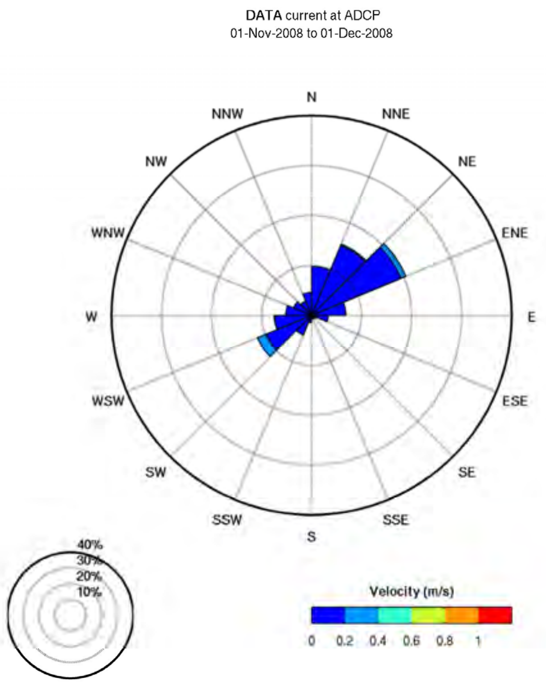
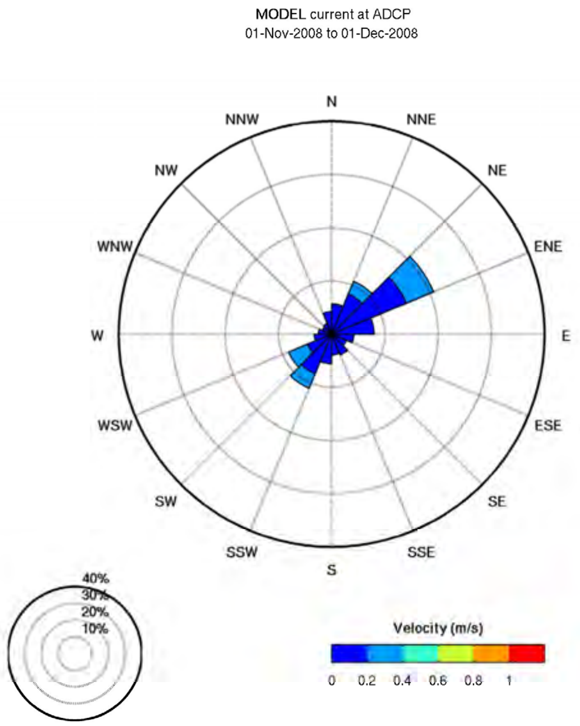


Figure 3-12 Velocity Validation Rose Plot – 2008 Platypus Channel ADCP Data – Bottom 50% Top – Model, Bottom – Data



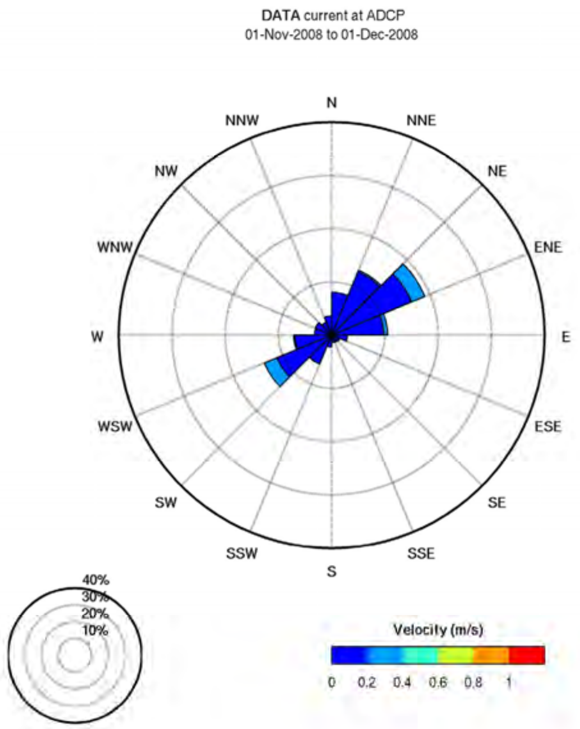
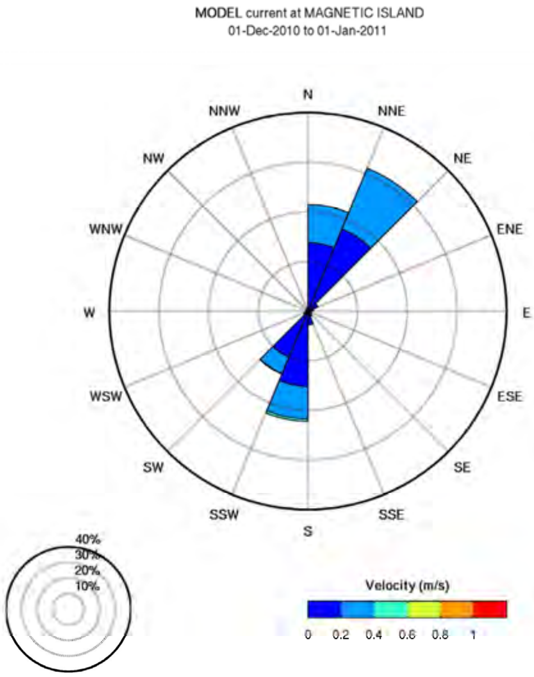


Figure 3-13 Velocity Validation Rose Plot – 2008 Platypus Channel ADCP Data – Top 50%
Top – Model, Bottom – Data



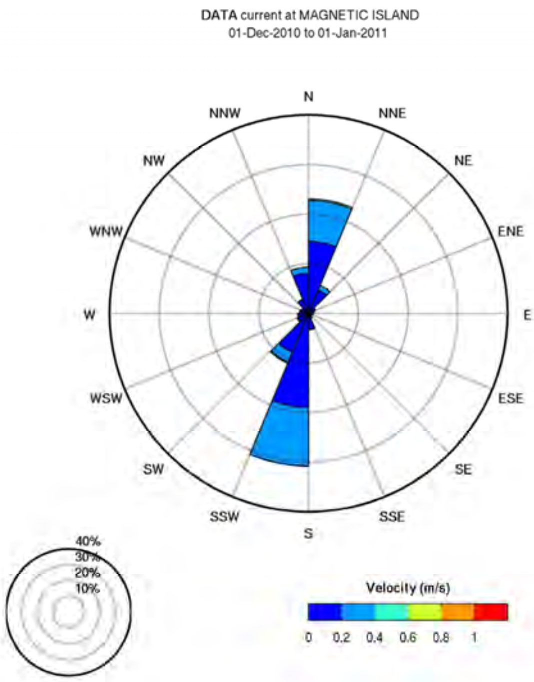
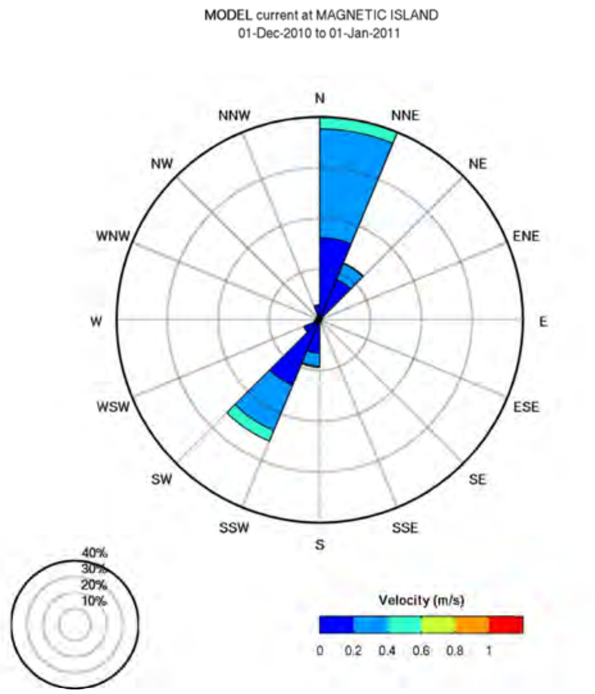


Figure 3-14 Velocity Validation Rose Plot – 2010 Magnetic Island ADCP Data – Bottom 50%
Top – Model, Bottom – Data



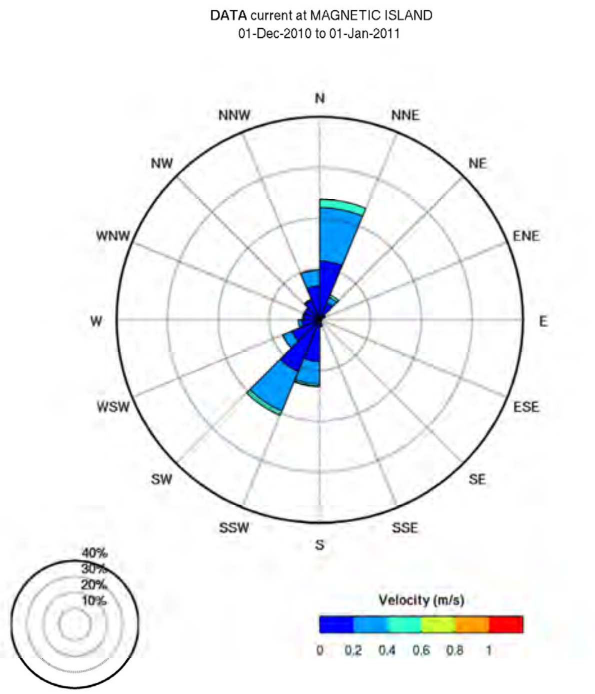
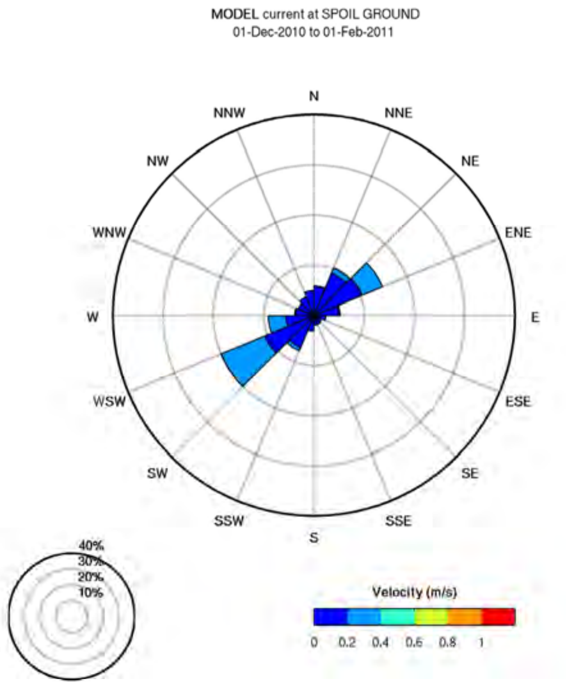


Figure 3-15 Velocity Validation Rose Plot – 2010 Magnetic Island ADCP Data – Top 50%
Top – Model, Bottom – Data



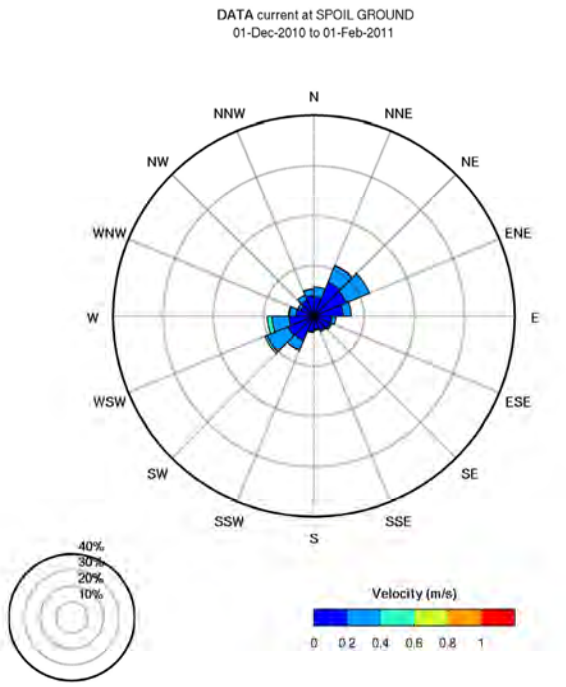
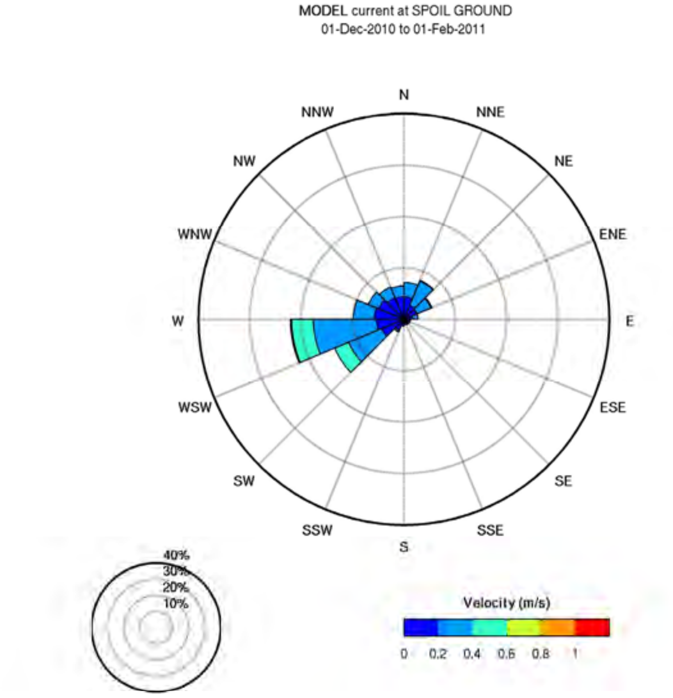


Figure 3-16 Velocity Validation Rose Plot – 2010 DMPA ADCP Data – Bottom 50%
Top – Model, Bottom – Data



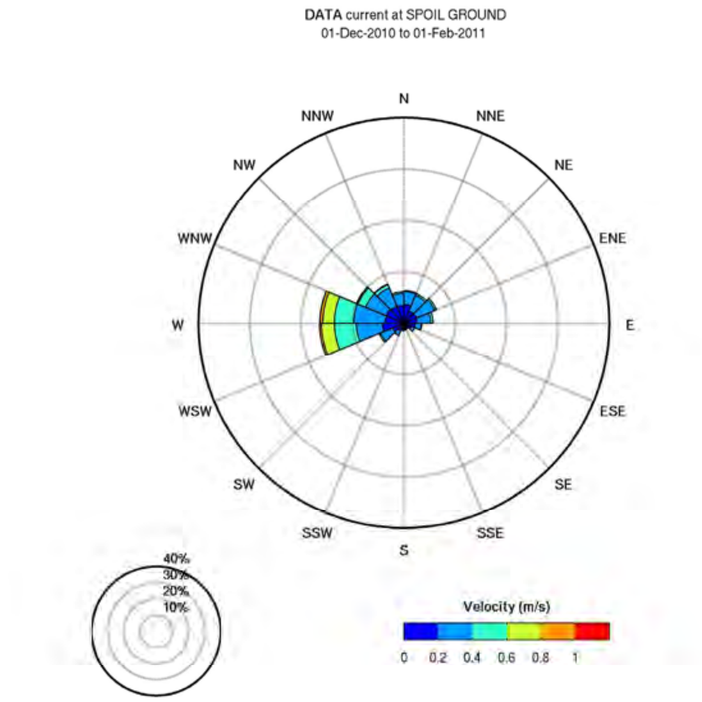


Figure 3-17 Velocity Validation Rose Plot – 2010 DMPA ADCP Data – Top 50%
Top – Model, Bottom – Data

3.2 SWAN WAVE MODEL CALIBRATION RESULTS

Measured wave data from the two ADCPs deployed in 2010 and from the DERM Waverider Buoy were used to calibrate and validate the SWAN wave models (for deployment locations see Figure 3-2).

The results of the nested wave model calibration are shown in Figure 3-18, Figure 3-19 and Figure 3-20. Agreement between the measured and modelled wave heights, directions and peak periods is generally good, particularly with the DERM wave buoy and the Magnetic Island ADCP. Some under-prediction bias is evident relative to the DMPA ADCP significant wave height measurements; however it is unclear why this would be significantly different from the DERM wave buoy which was located within a relatively short distance of the DMPA. Some under-prediction bias is probably attributable to the non-stationary assumptions made in the wave model predictions.

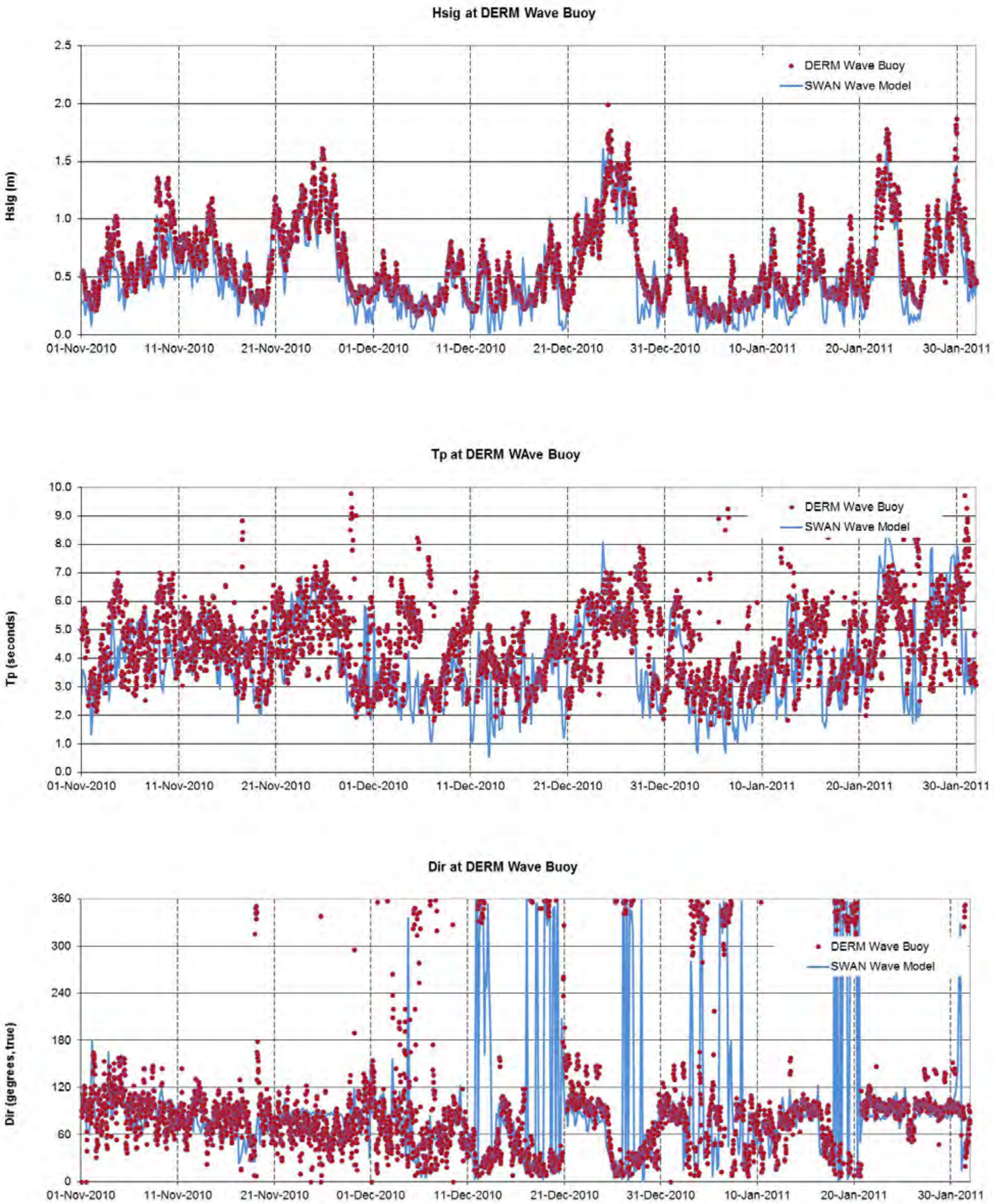


Figure 3-18 Wave Model Calibration – DERM Waverider Buoy

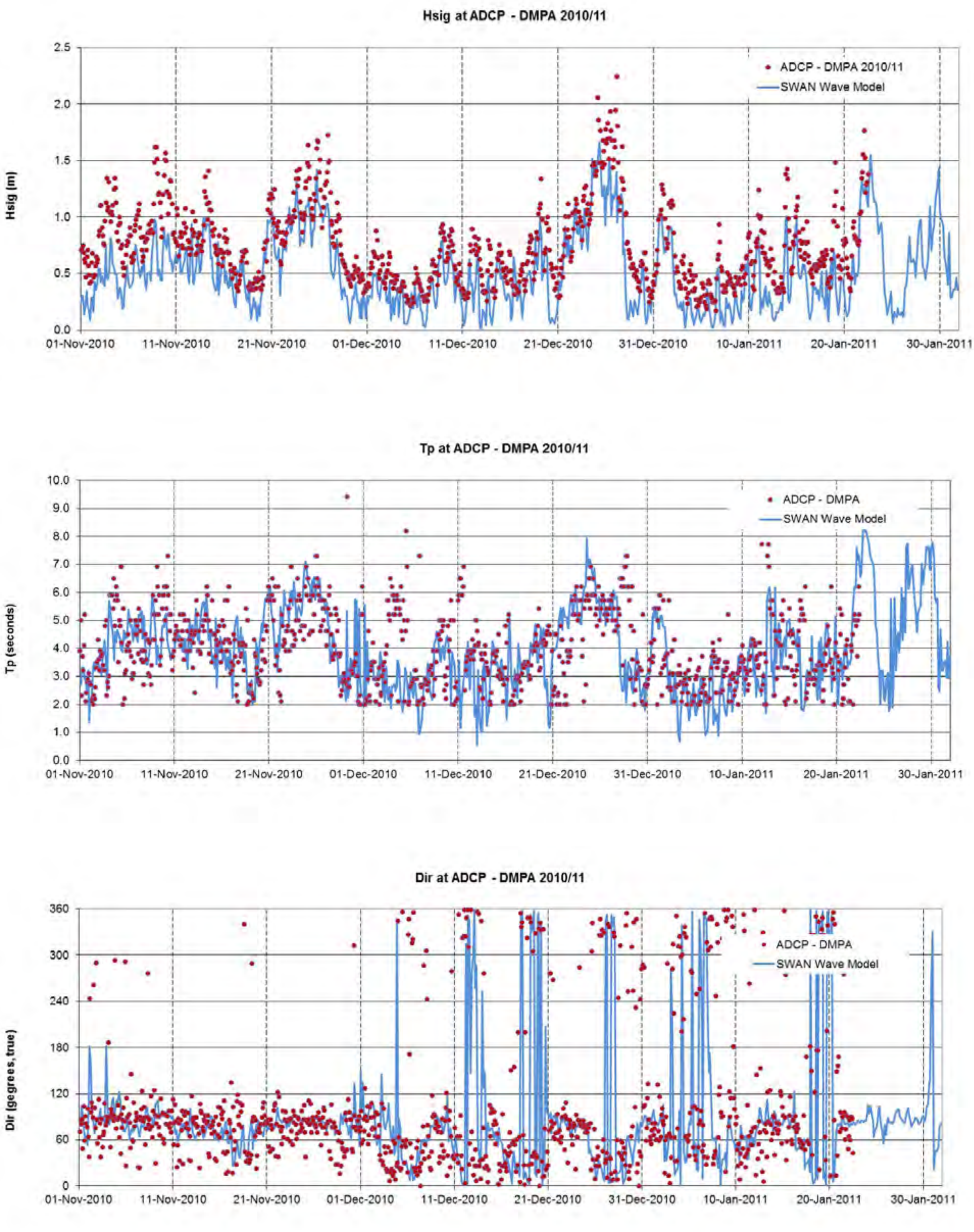


Figure 3-19 Wave Model Calibration – DMPA ADCP

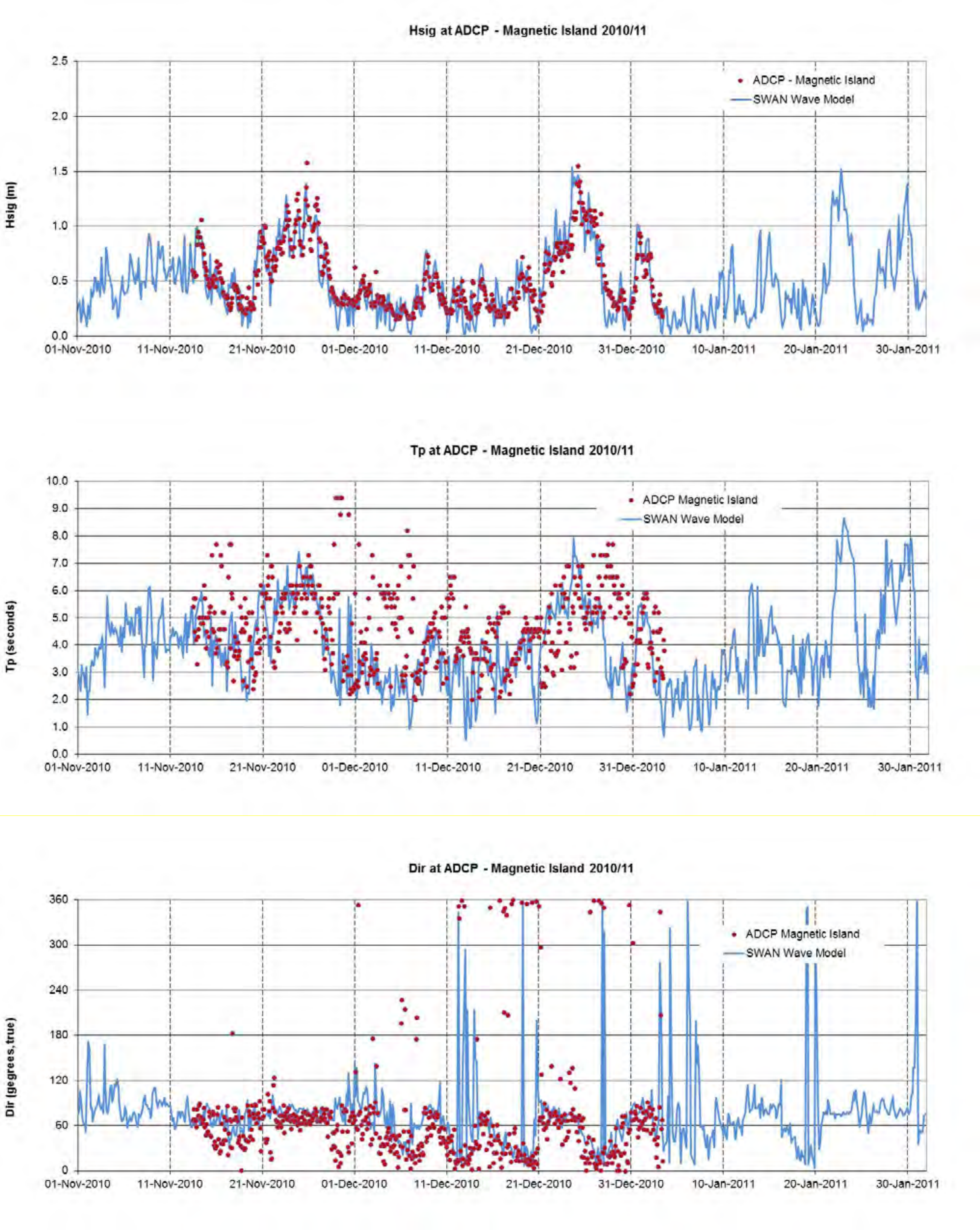


Figure 3-20 Wave Model Calibration – Magnetic Island ADCP

3.3 ADVECTION-DISPERSION PLUME MODELLING VALIDATION

3.3.1 DATA COLLECTION

Dredge plume monitoring was conducted by BMT WBM in the nearshore and offshore areas of the Port of Townsville from 2nd - 5th January 2010. These measurements were used to assist in the validation of the advection-dispersion model and to guide the adoption of specific sediment loading rates for the proposed dredging activities.

The BMT WBM vessel “Resolution II” was used to undertake the field work. Weather conditions were relatively mild throughout the monitoring campaign. The vessel was equipped with an Acoustic Doppler Current Profiler (ADCP) which was configured in backscatter echo intensity mode to show in real time a surrogate of the suspended particle concentrations within the water column below the vessel. The ADCP was configured with real time navigation data from a differential GPS system as well as the ADCP’s own inertial navigation system so that recorded backscatter intensities were time tagged and spatially located in real earth coordinates. Simultaneous measurements (water column profiles, water sample collection and backscatter echo intensities) were conducted on a series of transects through the dredge plume at each monitoring location.

3.3.2 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 3-21. 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. Plume water samples were also analysed for suspended sediment Particle Size Distribution (PSD), with the results shown in Figure 3-22.

3.3.3 MODEL PARAMETERS

Dredging works cause the generation of plumes of suspended sediment through a number of potential sources/mechanisms. The major sources considered for the modelling of the Trailing Suction Hopper Dredge (TSHD) Brisbane were:

- Sediment entrainment at the draghead during dredging;
- Overflow of sediment from the hopper; and
- Placement of material at the Dredge Material Placement Area (DMPA) by hopper release.

The measured 3D TSS concentrations from the January 2011 ADCP transects were compared to simulations of plume dispersion using the 3D TUFLOW-FV coupled advection-dispersion and hydrodynamic model in order to calibrate the model parameters.

The dredging 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 a number of 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 (e.g., type and size of dredge) 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 engineering judgement, experience on similar projects and literature values. These parameters were then modified during the calibration process on the basis of comparisons with the measured data. The source terms adopted after model calibration are summarised below:

TSHD "BRISBANE"

- Total source while overflow dredging in the channel: 250kg/s.
- Total source while overflow dredging in the outer harbour: 50kg/s.
- Dumping source: 200kg/s.

A higher rate of sediment release was adopted during channel dredging than during outer harbour dredging in order to more closely match the measured plume concentrations. The dredge travelled at a higher speed during channel dredging and did not have the manoeuvring constraints found in the outer harbour, and therefore tended to release more sediment.

The material released during dredging was assumed to be composed of 30% clay, 65% silt and 5% fine sand (based on the particle size distribution of sampled sediment - Figure 3-22), with assumed settling velocities of 1×10^{-4} m/s, 5×10^{-4} m/s and 1×10^{-2} m/s respectively.

The dredge plume boundary condition was applied as a depth-averaged source into the model as there was no consistent indication in the near-field ADCP data that the source was particularly concentrated in any one part of the water column during either dredging or dumping.

The General Ocean Turbulence Model (http://www.gotm.net/) was used to control vertical mixing of both momentum and sediment. A Smagorinsky model was used for the estimation of the horizontal eddy viscosity and diffusivity coefficients.

Examples of the results of the plume model validation exercise are illustrated in Figure 3-23 and Figure 3-24. The full collection of plume model validation plots are presented in Attachment C of this appendix. 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 of the transect (0m chainage in the upper panel).

The plume model validation results generally indicate that the model is accurately reproducing the pattern of suspended sediment distribution associated with dredge plumes. The magnitude of the suspended sediment concentration is overestimated in some cases, especially during dredging in the outer harbour. The accuracy of the ADCP data in the near field is sometimes uncertain due to bubbles and turbulence generated by the dredge propwash. Given the complexity of the modelling task, and the highly three-dimensional nature of plumes and temporal variation in dredge discharge, the model performance is considered to be good.

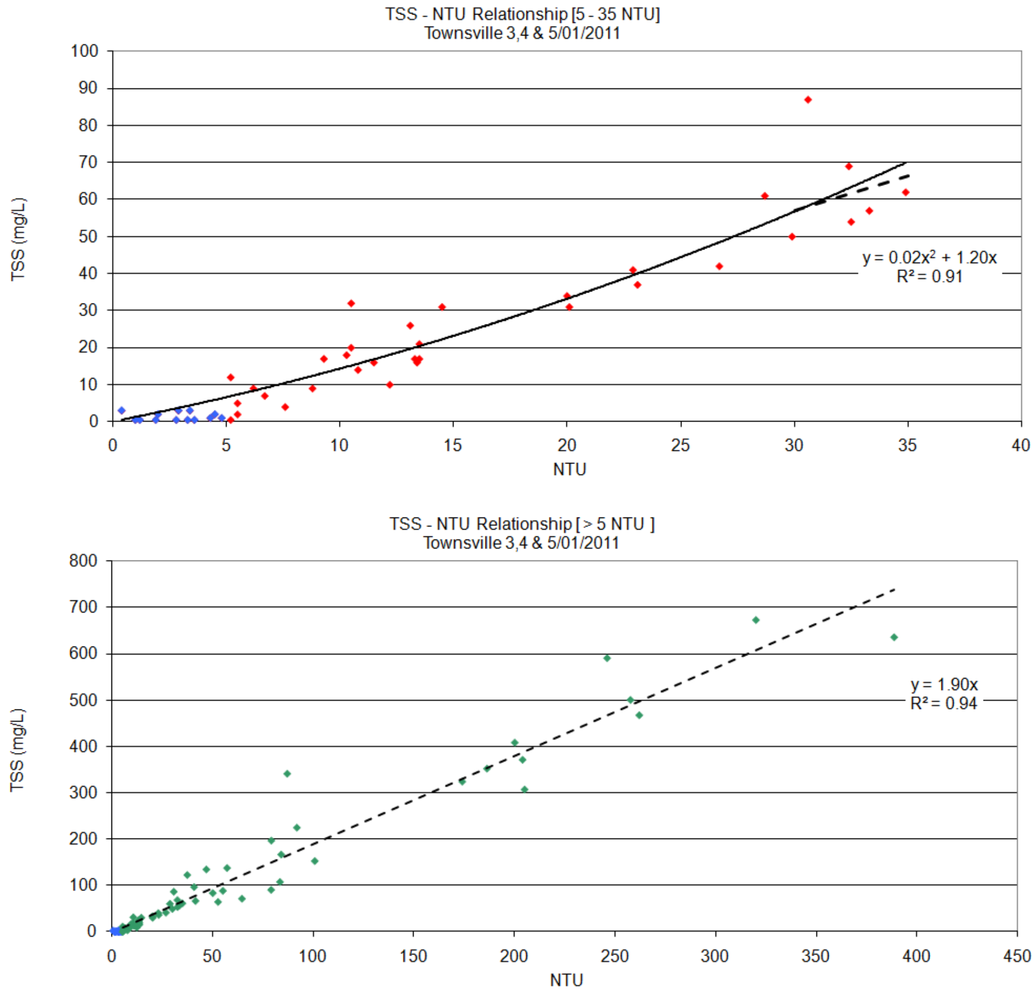


Figure 3-21 TSS – NTU Relationship for Maintenance Dredging Plume Material

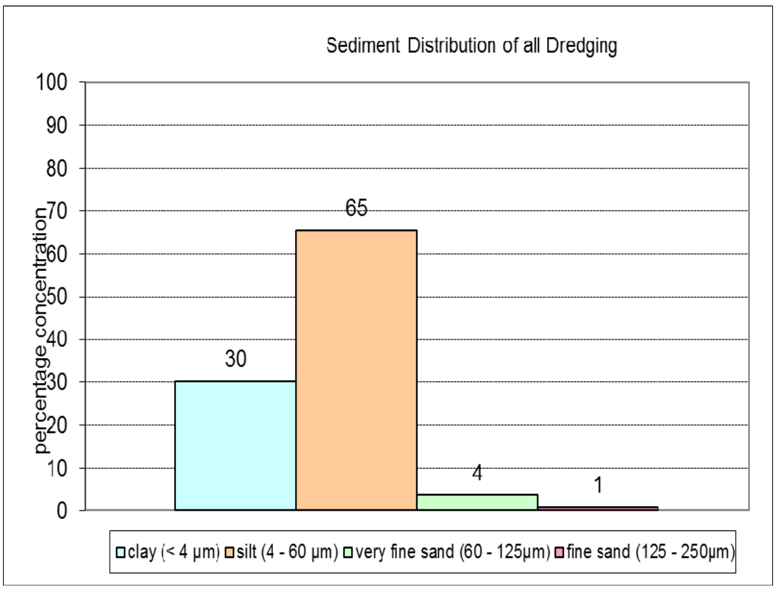


Figure 3-22 Dredge Plume Particle Size Distribution

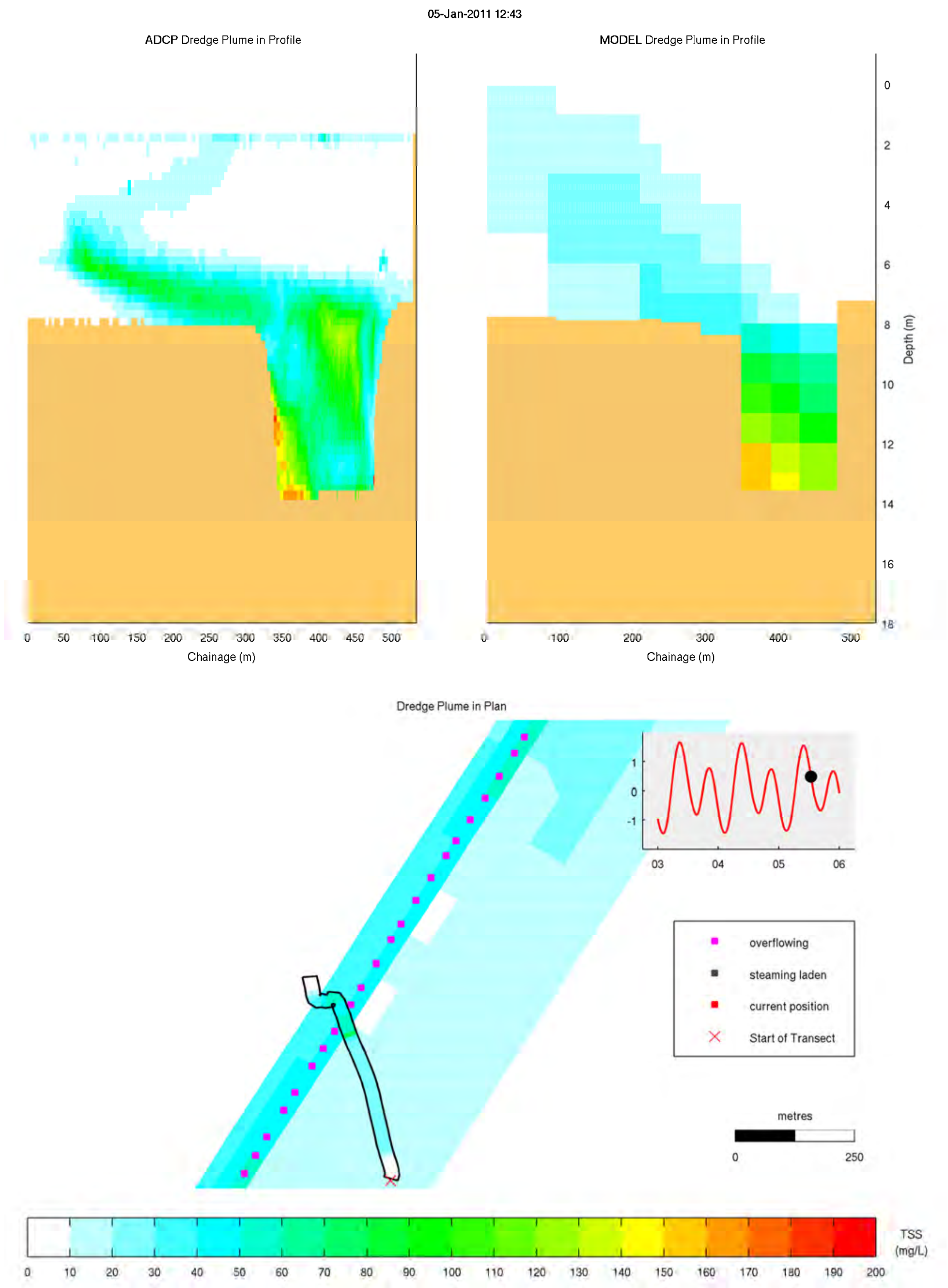


Figure 3-23 Dredge Plume Model Validation – Platypus Channel – 5/1/2011 ADCP Data

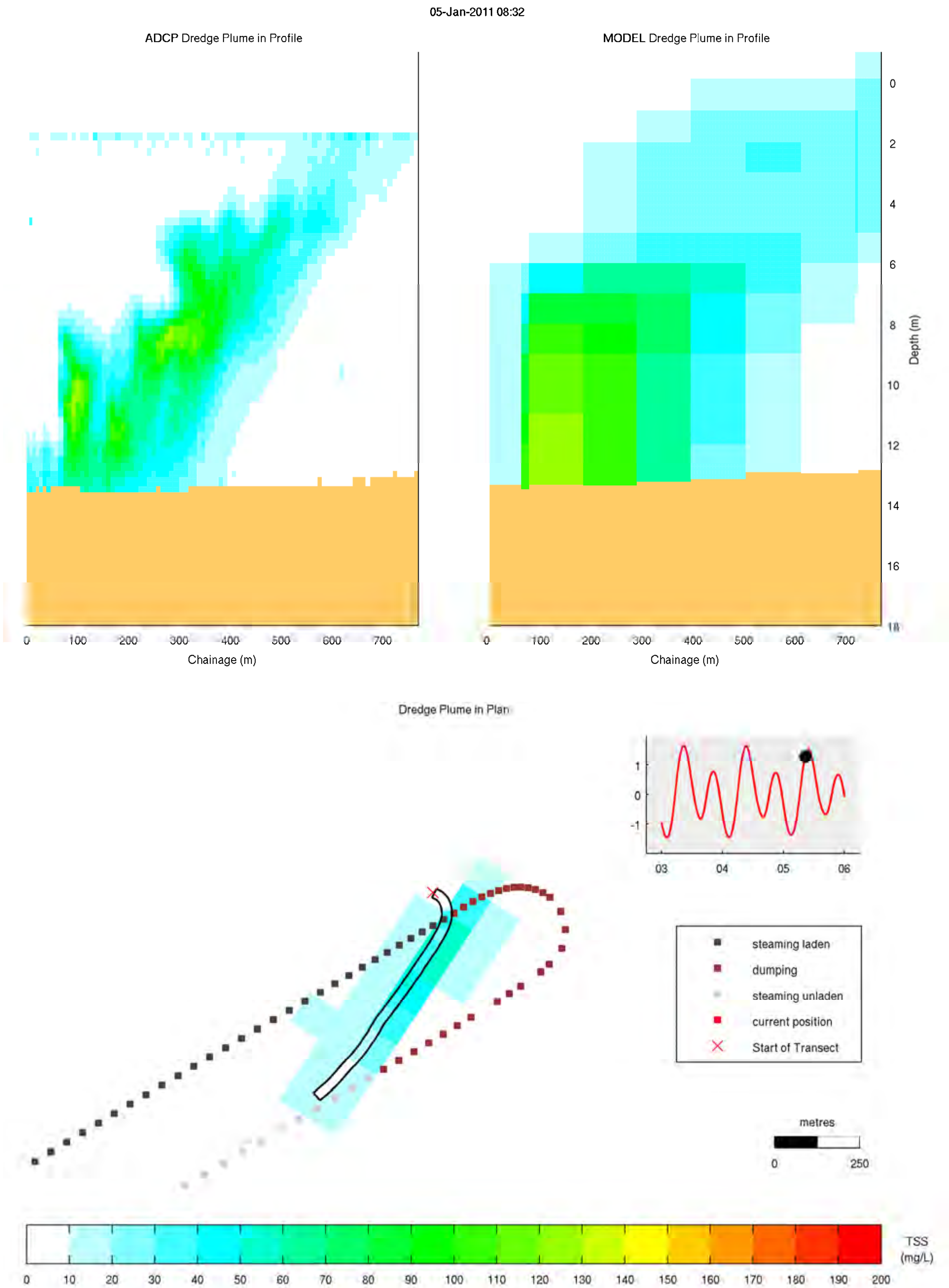


Figure 3-24 Dredge Plume Model Validation – DMPA – 5/1/2011 ADCP Data

3.4 RESUSPENSION MODEL VALIDATION

In order to use the TUFLOW-FV model to estimate the natural sediment resuspension dynamics in the study area, the model was calibrated using available measurements of ambient turbidity.

The cohesive sediment module of TUFLOW-FV simulates the exchange of sediments between the bed and the water column. The effective clear water sediment settling velocity of each sediment fraction, w_s, is directly specified and is assumed to have no dependence on either suspended sediment concentration (e.g. flocculation or hindered settling). The modelled rate of sediment deposition (in g/m^2/s) is a function of the near-bed sediment concentration (TSS), the still-water fall velocity (w_s) and the bed shear stress (τ_b), according to the relationship:

$$Q_d = w_s.TSS.\max\left(0,\ 1-\frac{\tau_b}{\tau_{cd}}\right) \quad \text{units [g/m}^2\text{/s]}$$

where τ_{cd} is a model parameter defining the critical shear stress for deposition. As such, sediment settling is reduced below its still water value by the action of bed shear stress and associated vertical mixing in the water column. The rate of erosion is calculated according to:

$$Q_e = E.\max\left(0,\ \frac{\tau_b}{\tau_{ce}}-1\right) \quad \text{units [g/m}^2\text{/s]}$$

where Q_e is the erosion rate, E is the erosion rate constant and τ_{ce} is the critical bed shear stress for erosion.

The General Ocean Turbulence Model was used to control vertical mixing of both momentum and sediment. A Smagorinsky model was used for the estimation of the horizontal eddy viscosity and diffusivity coefficients.

The calibration process led to the adoption of the following model parameters:

- Critical shear stress for erosion τ_{ce} = 0.2 Pa;
- Critical shear stress for deposition τ_{cd} = 0.1 Pa; and
- Erosion rate constant E = 0.005 g/m^2/s.

The initial model bed was composed of 25% clay, 50% silt and 25% fine sand, with assumed settling velocities of 1 x 10^{-4} m/s, 5 x 10^{-4} m/s and 1 x 10^{-2} m/s respectively. The model was run for an initial "warm up" period to allow the sediment types to redistribute within the model. This process allowed the bed composition in each area to evolve towards an initial condition which was likely to reflect the actual local natural bed composition.

Measurements of turbidity caused by suspended sediments in the water column were made as part of the PEES study (BMT WBM, 2009). The turbidity measurements were converted into Total Suspended Sediment (TSS) concentrations using an established relationship (see Figure 3-21). The model was run for the period 01/10/2008 to 01/11/2008 to coincide with available turbidity measurements. Calibration of sediment erosion and deposition parameters resulted in reasonable overall agreement between modelled and measured TSS at six sites (see Figure 3-25) as shown in Figure 3-26 and Figure 3-27.

The model successfully reproduced the elevated TSS levels recorded at Cape Pallarenda (Site 8) and Magnetic Island (Site 7) and the Strand (Site 6) during major natural resuspension events (associated with increased incident wave energy). The modelled TSS levels at Geoffrey Bay were generally lower than the measurements, while the modelled levels at the Platypus Channel and Outer Harbour (Site 2 and Site 3) were also frequently lower than the recorded levels. The reason for the latter result is likely due to the fact that maintenance dredging was being undertaken during this period.

The validation results indicate that the model is able to adequately reproduce natural variations in ambient turbidity in the study area.

2 Outer Harbour	146.8507°E	19.2195°S
3 Platypus Channel	146.8704°E	19.1827°S
4 Geoffrey Bay	146.8704°E	19.1547°S
6 Strand	146.8184°E	19.2432°S
7 Cockle Bay	146.8042°E	19.1754°S
8 Cape Pallarenda	146.7775°E	19.1807°S

Figure 3-25 Locations Used for Model Calibration

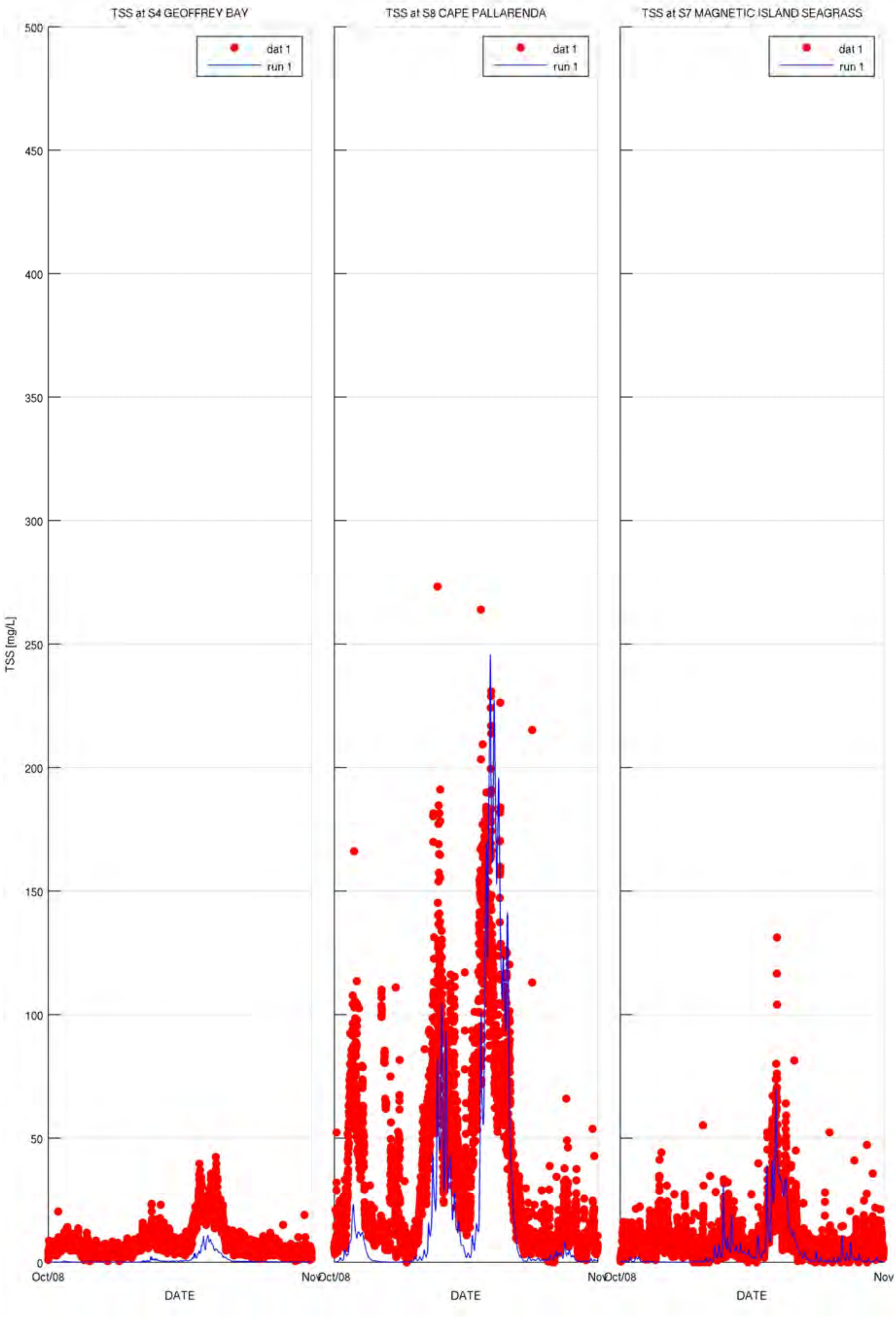


Figure 3-26 Measured and Modelled Suspended Sediment Concentrations at Sites 4, 8 and 7

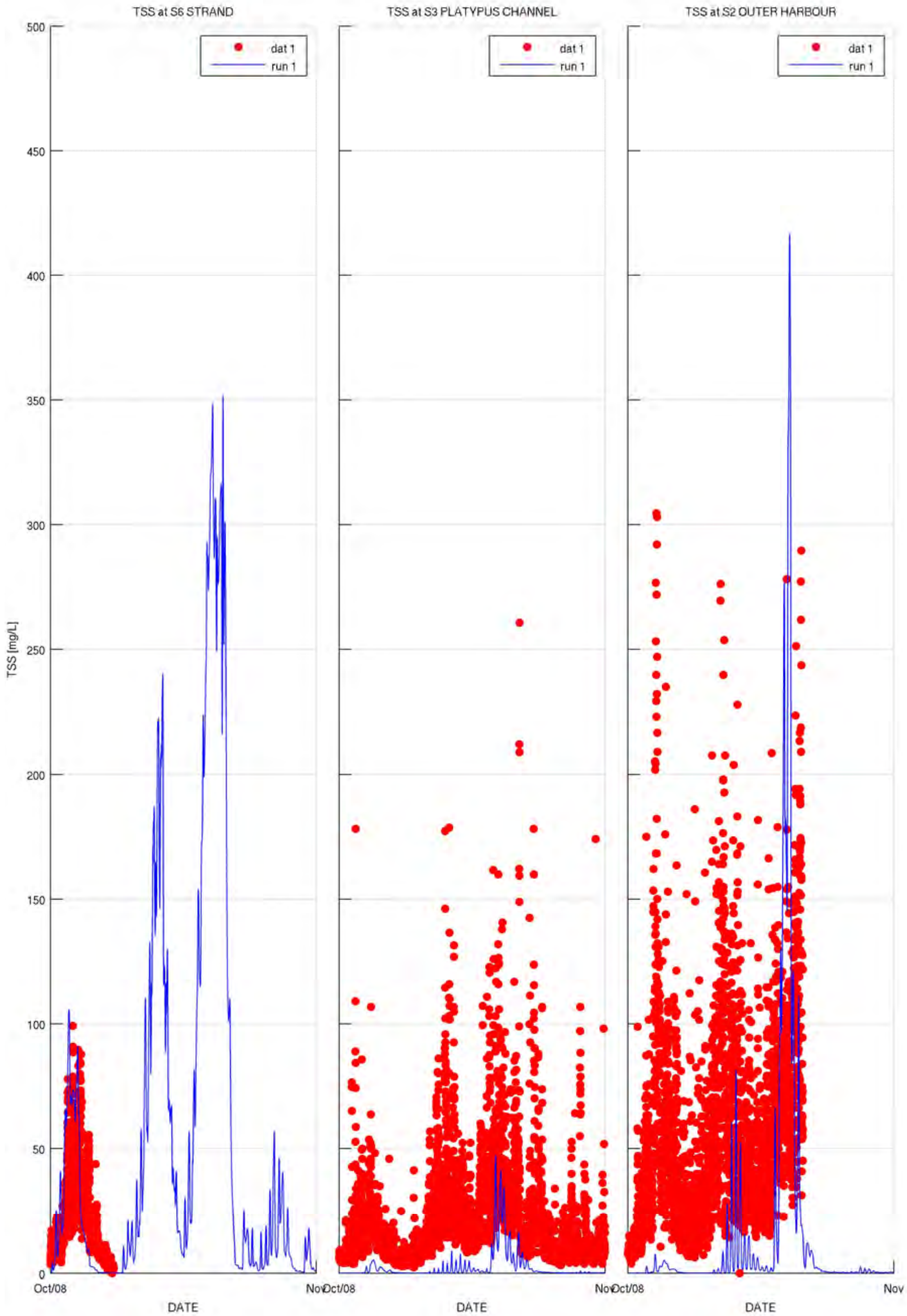


Figure 3-27 Measured and Modelled Suspended Sediment Concentrations at Sites 6, 3 and 2

4 HYDRODYNAMIC IMPACT ASSESSMENTS

Following setup, calibration and validation of both the hydrodynamic and advection dispersion models, a series of hydrodynamic scenarios were executed and interrogated. The general intent of these scenarios was to provide direct information on design conditions and potential hydrodynamic impacts. These scenarios are described below.

4.1 EXISTING HYDRODYNAMICS

The validated hydrodynamic model was firstly used to illustrate the existing patterns of hydrodynamics within the study area.

For this purpose the model was run from 1/11/2010 to 1/12/2010, a period which included a period of the prevailing strong SE winds. The wind magnitude and direction for the period in the vicinity of the Port is shown in Figure 4-1. The wind rose measured at the Cleveland Bay gauge (for location refer Figure 2-5) and the wave rose measured at the DERM waverider buoy for this period are shown in Figure 4-2. The wave and wind roses for the same locations during the period 2008-2011 are shown in Figure 4-3. Comparison of these figures indicates that the modelled period is broadly representative of the average conditions, though with a slightly higher percentage of SE winds.

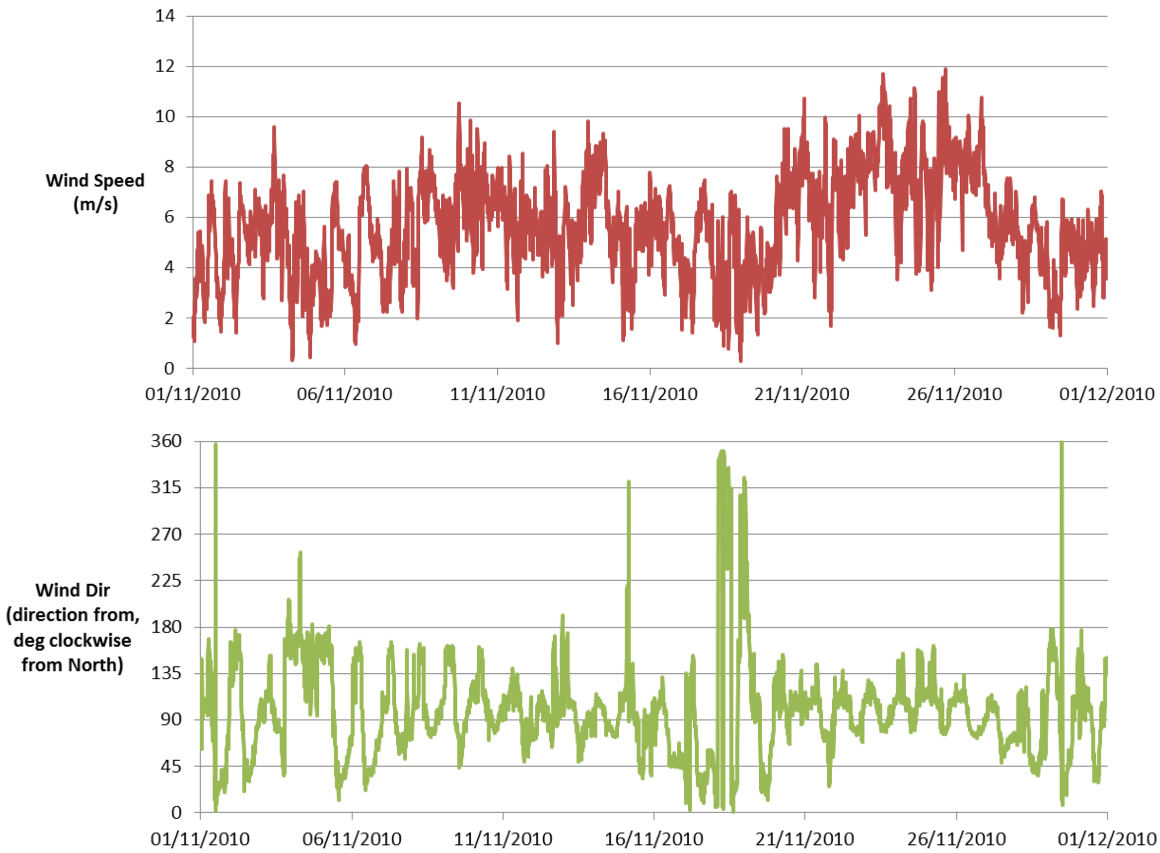
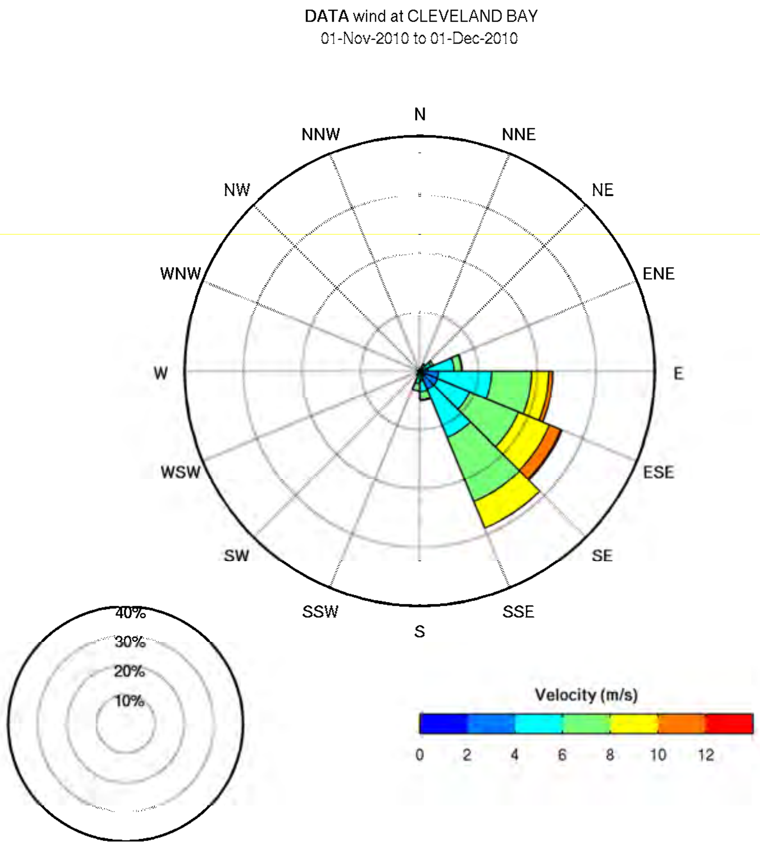


Figure 4-1 Wind Speed and Direction at the Port of Townsville During the Modelling Period (10 minute averages measured at 10 metres elevation)



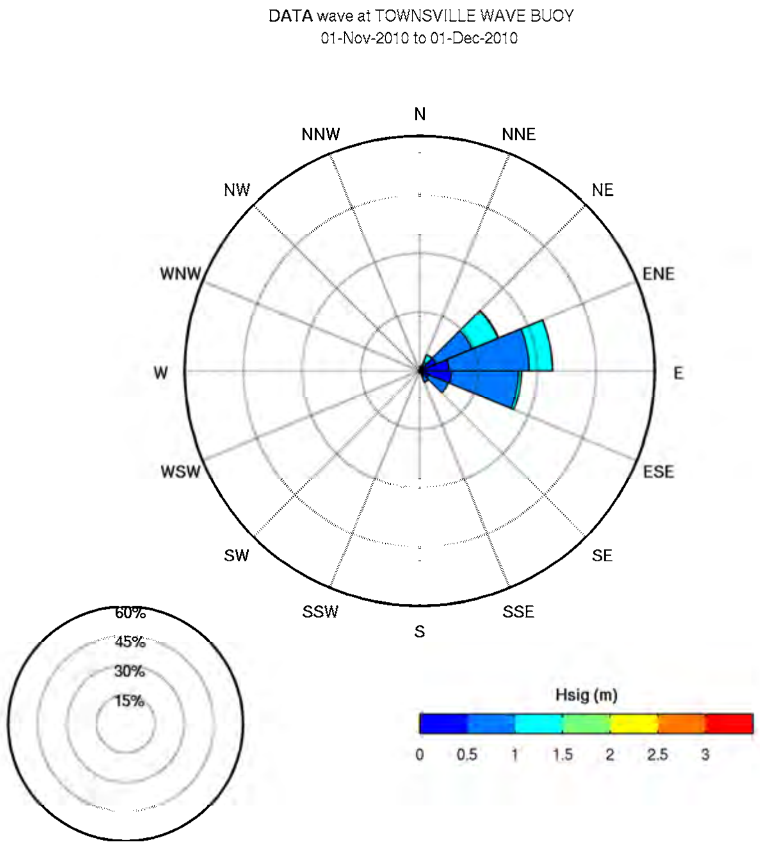
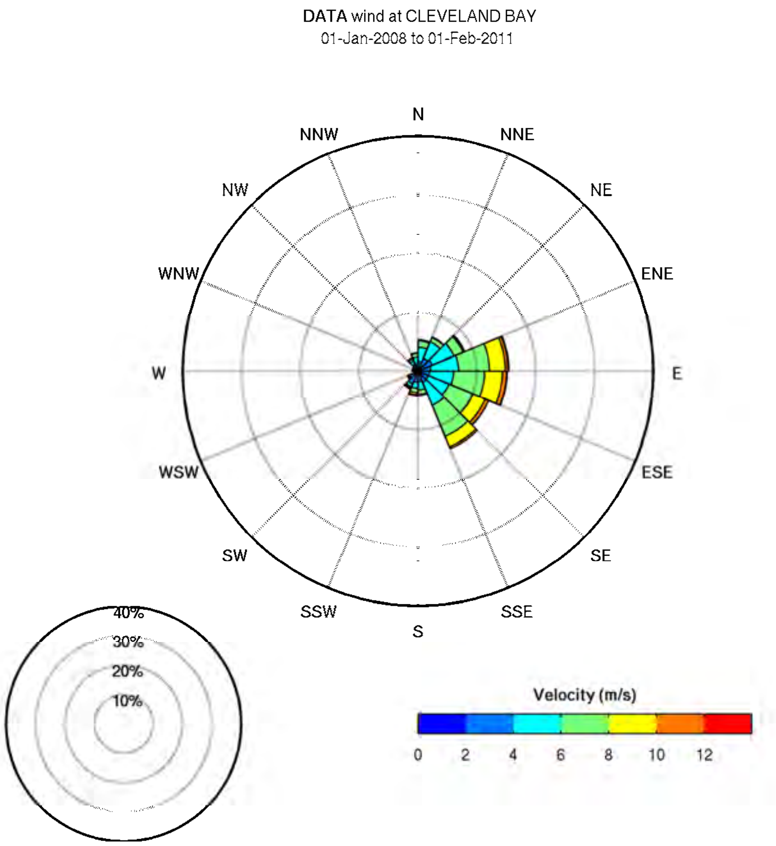


Figure 4-2 Wind (top) and Wave (bottom) Roses for the Modelling Period



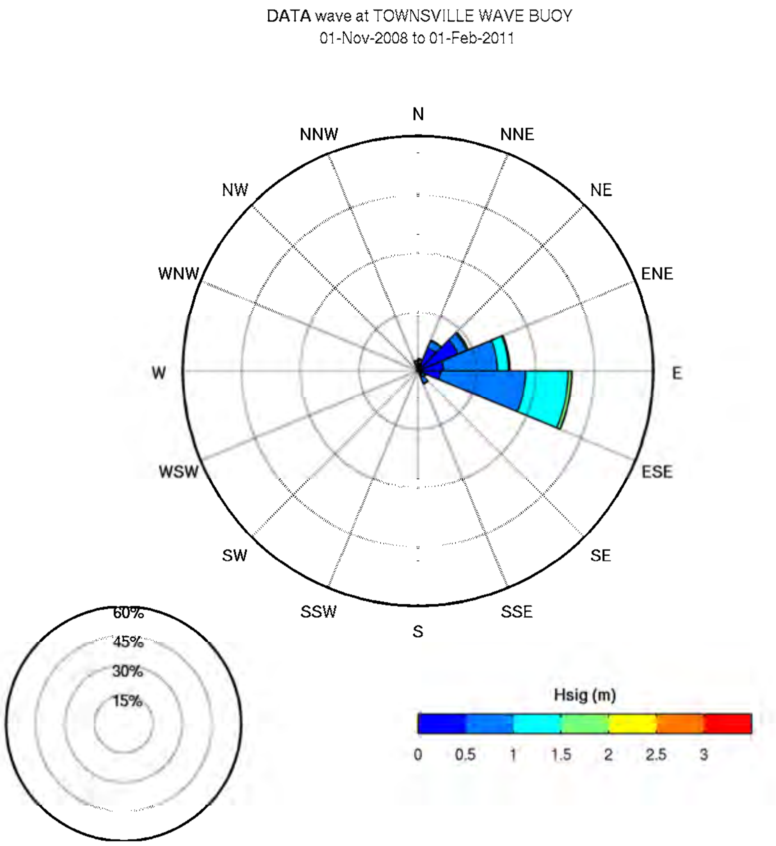


Figure 4-3 Wind (top) and Wave (bottom) Roses for the Period 2008-2011

Figure 4-4 shows the typical tidal current pattern in Cleveland Bay during low-wind spring tidal conditions. The flow can be seen to be predominantly in a south-west (flooding) to north-east (ebbing) direction.

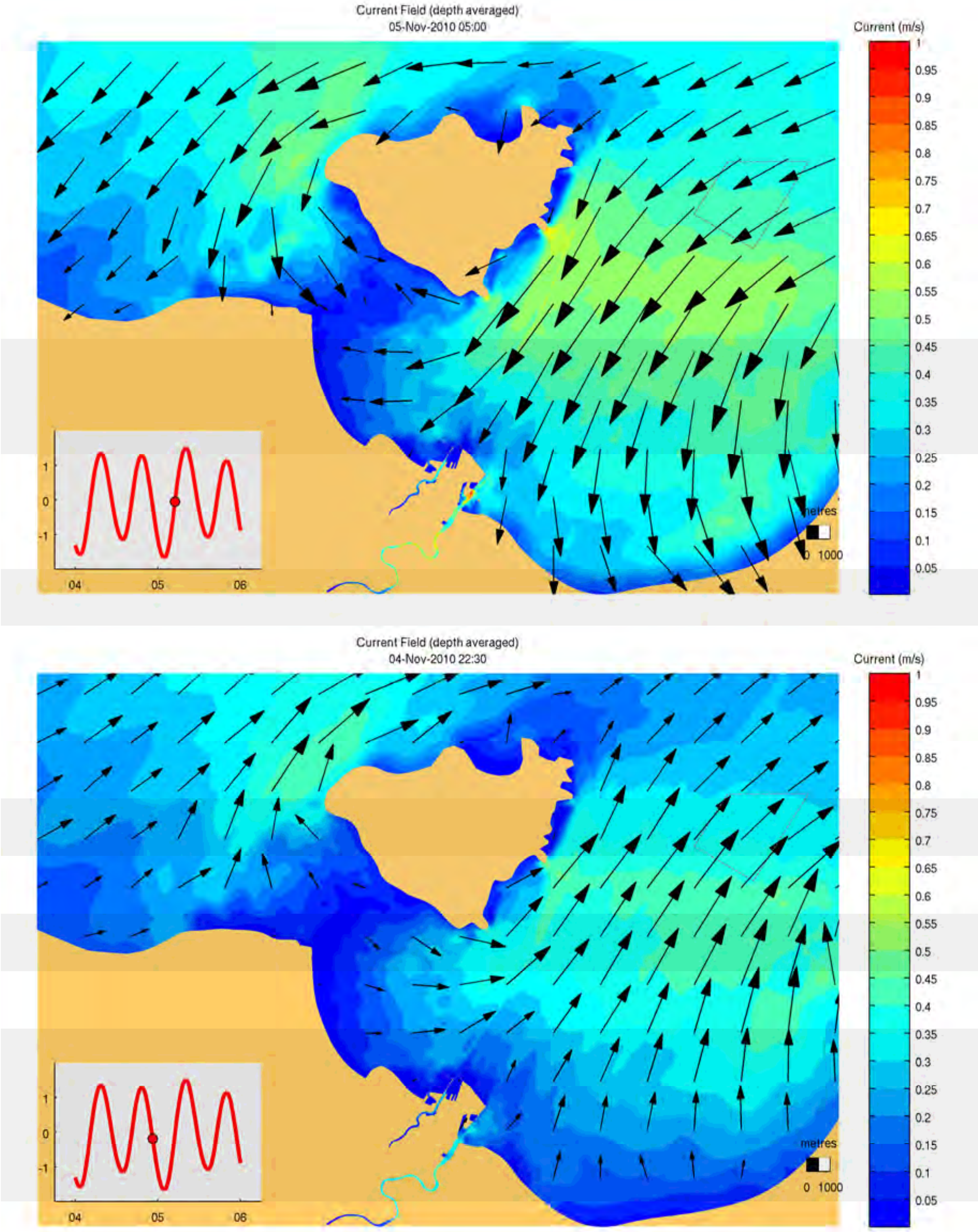


Figure 4-4 Typical Tidal Current Flow Pattern in Cleveland Bay: Flood Tide (top) and Ebb Tide (bottom)

Figure 4-5 shows the effects of relatively strong south-east wind conditions on the flood and ebb tide current patterns. The major difference from the no-wind pattern is the relatively strong ebb tide flow driven to the north-west between Cape Pallarenda and Magnetic Island.

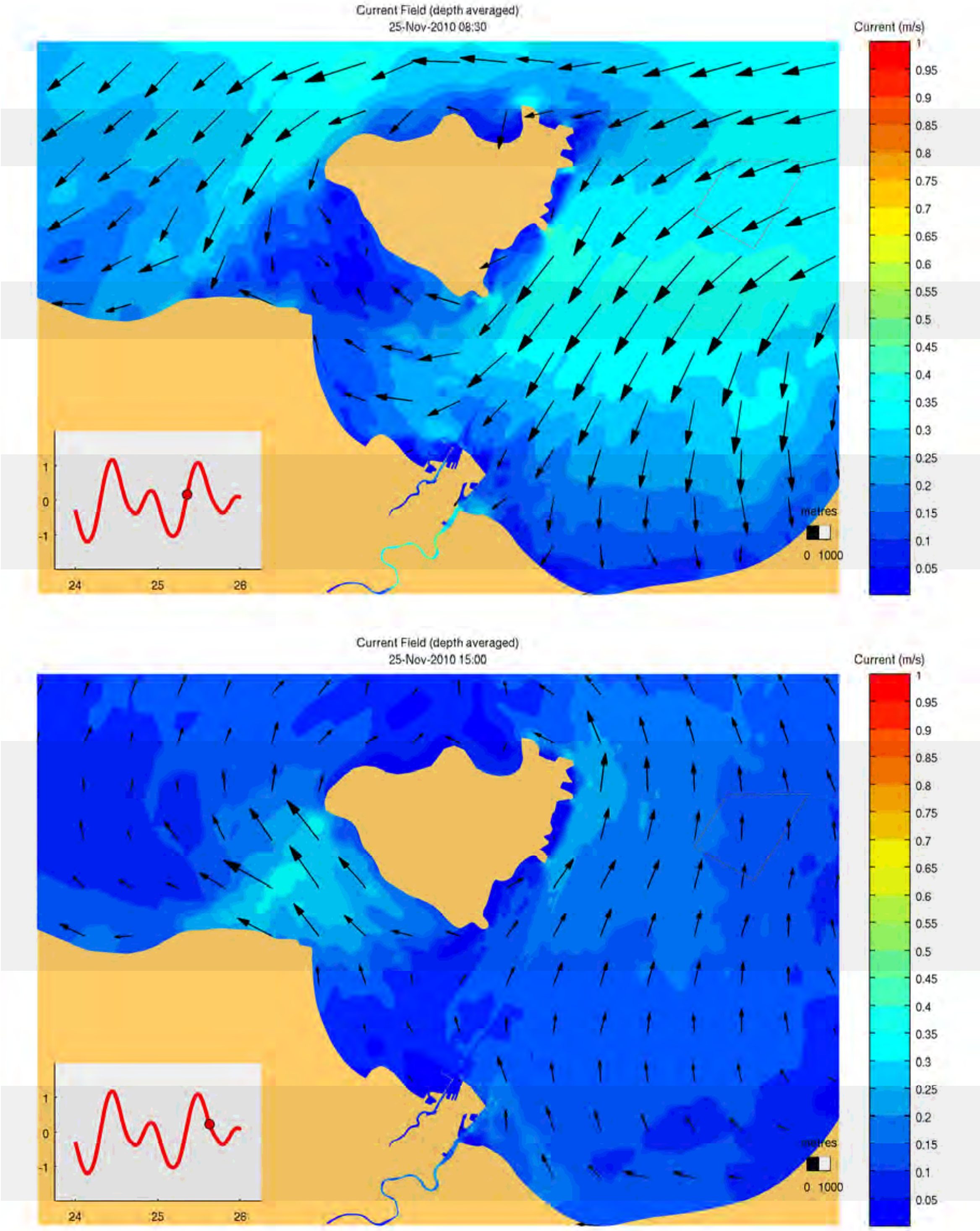


Figure 4-5 Influence of Prevailing Wind Forcing on Current Patterns: Flood Tide (left) and Ebb Tide (right)

The residual depth-averaged currents for the simulated period are shown below in Figure 4-6 which again shows the net effect of the ebb-tide flow to the north-west at Cape Pallarenda. The wind-driven net north-west drift in the Great Barrier Reef lagoon offshore of Cleveland Bay can also be seen.

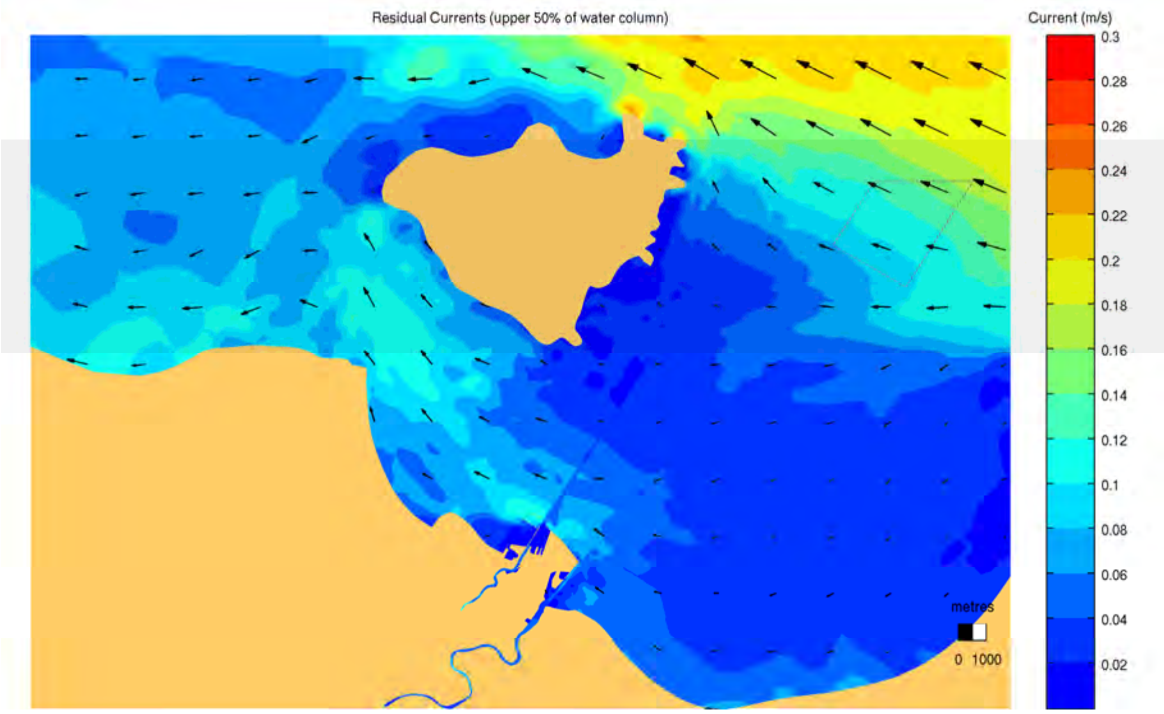


Figure 4-6 Typical Residual Depth-Averaged Current through Cleveland Bay due to Prevailing Winds from the Southeast

4.2 HYDRODYNAMIC IMPACT SCENARIOS

Various combinations of bathymetric configurations and reclamation phases were considered in the hydrodynamic modelling scenarios based on the likely staging of the development. The six scenarios assessed included a Base Case (representative of conditions at the time of development of the port expansion), three Developed Cases (derived from the concept plan shown in Figure 1-4), and two Ultimate Cases, as described here:

1 Base Case. This included all dredging associated with Berth 12 and the Marine Precinct;

2 Developed Case 1. This included dredging of Berth 12 with the North-East breakwater, the North-East revetment, and the Eastern revetment;

3 Developed Case 2. This included dredging of Berth 12 with the North-East breakwater, the North-East revetment, the Eastern revetment and the reclamation bunds;

4 Developed Case 2 with Western Breakwater. This was the same as 3) above, but with the western breakwater added;

5 Ultimate Case. This included full dredging of the constructed harbour and deepening of the approach channel to -14.5mAHD; and

6 Ultimate Case with Western Breakwater. This was the same as 5) above, but with the western breakwater added.

Model layouts for these scenarios are shown in Figure 4-7 to Figure 4-12.

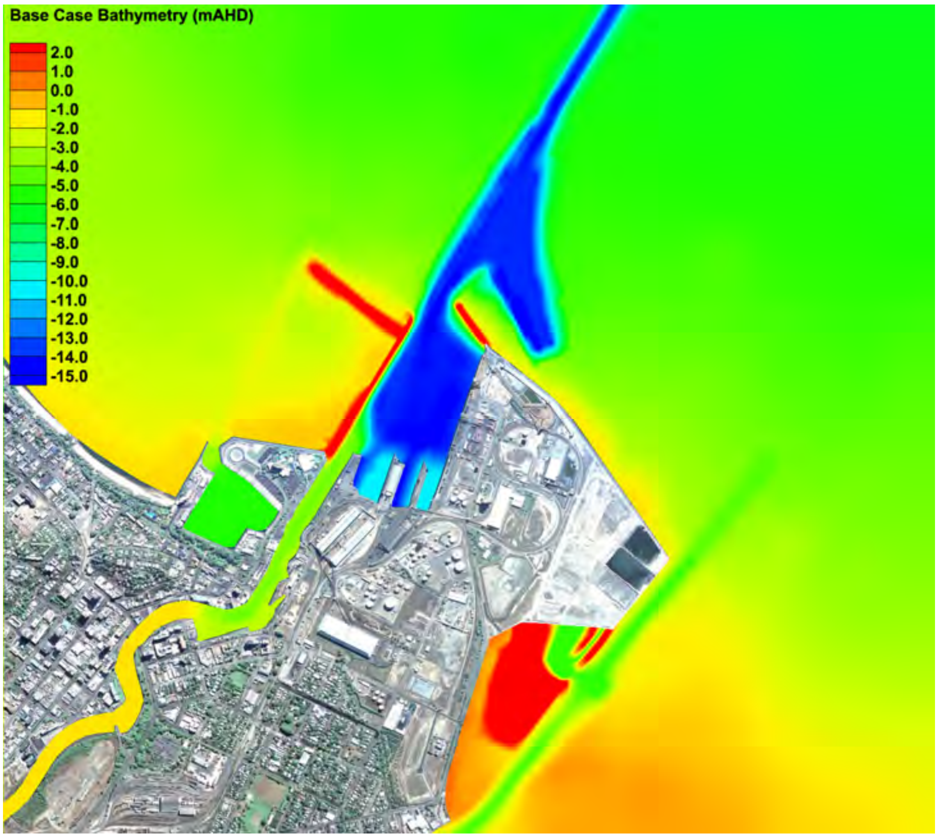


Figure 4-7 Base Case Model Bathymetry

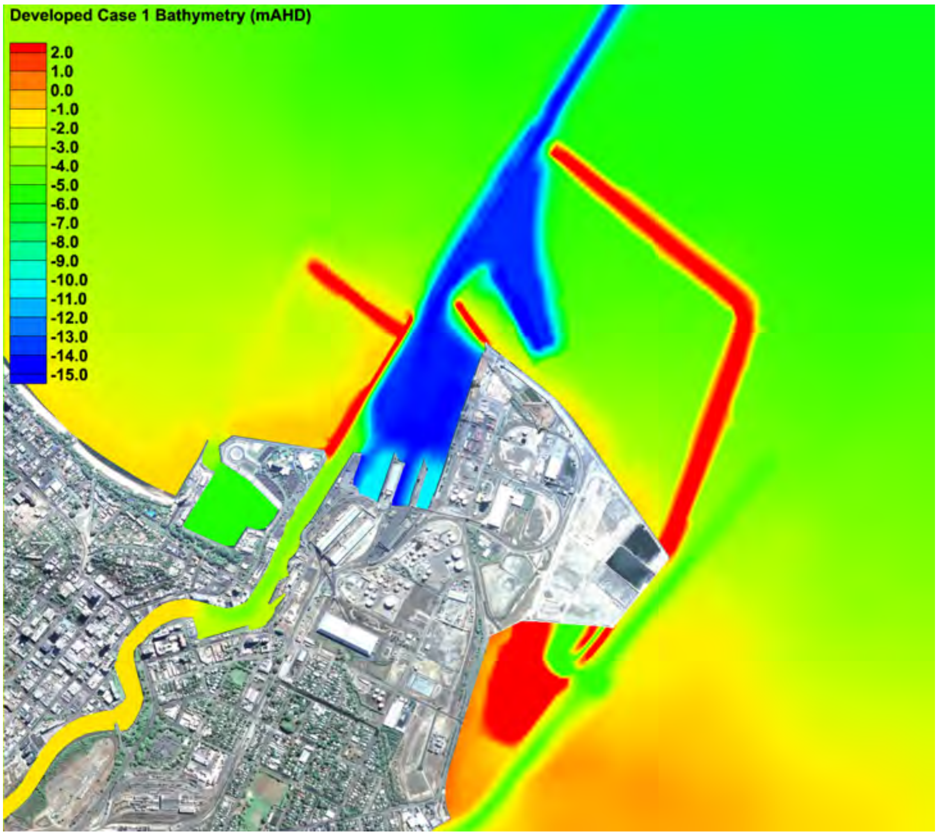


Figure 4-8 Developed Case 1 Model Bathymetry

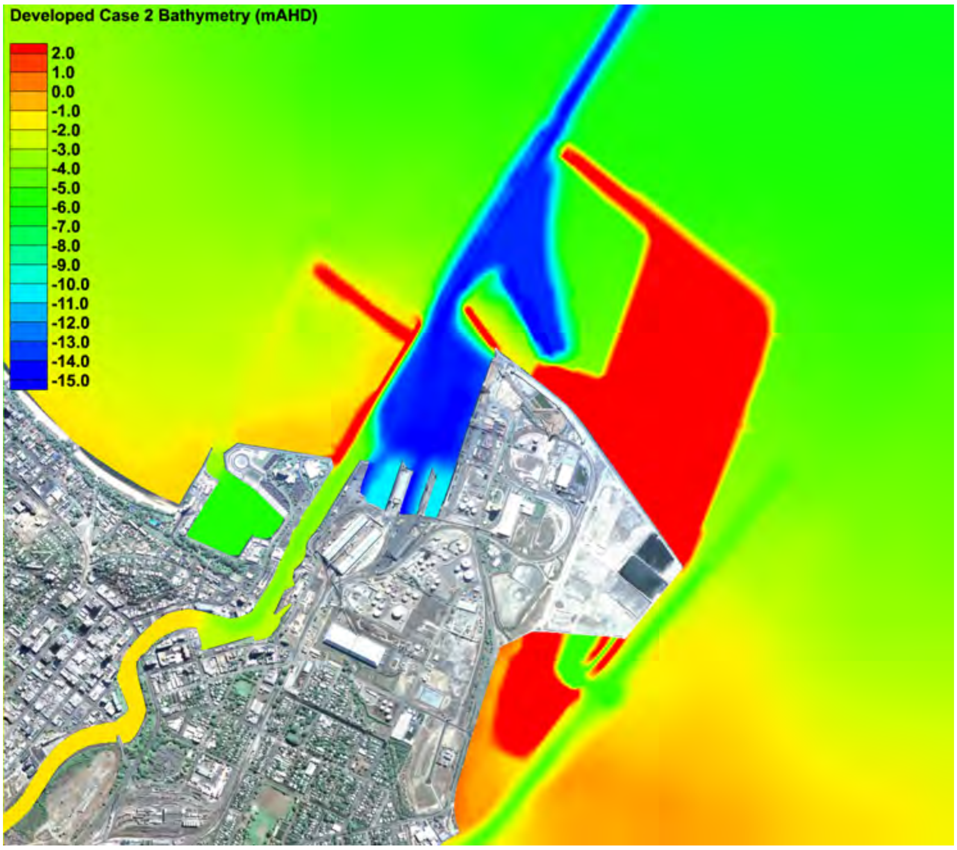


Figure 4-9 Developed Case 2 Model Bathymetry

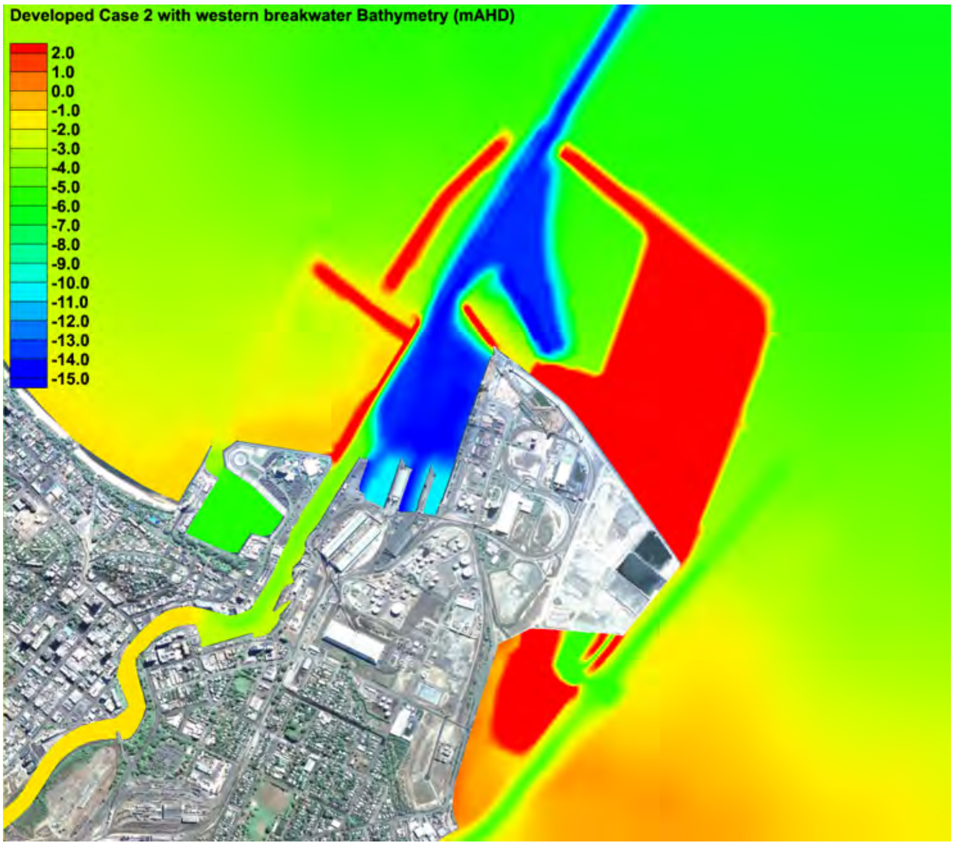


Figure 4-10 Developed Case 2 with Western Breakwater Model Bathymetry

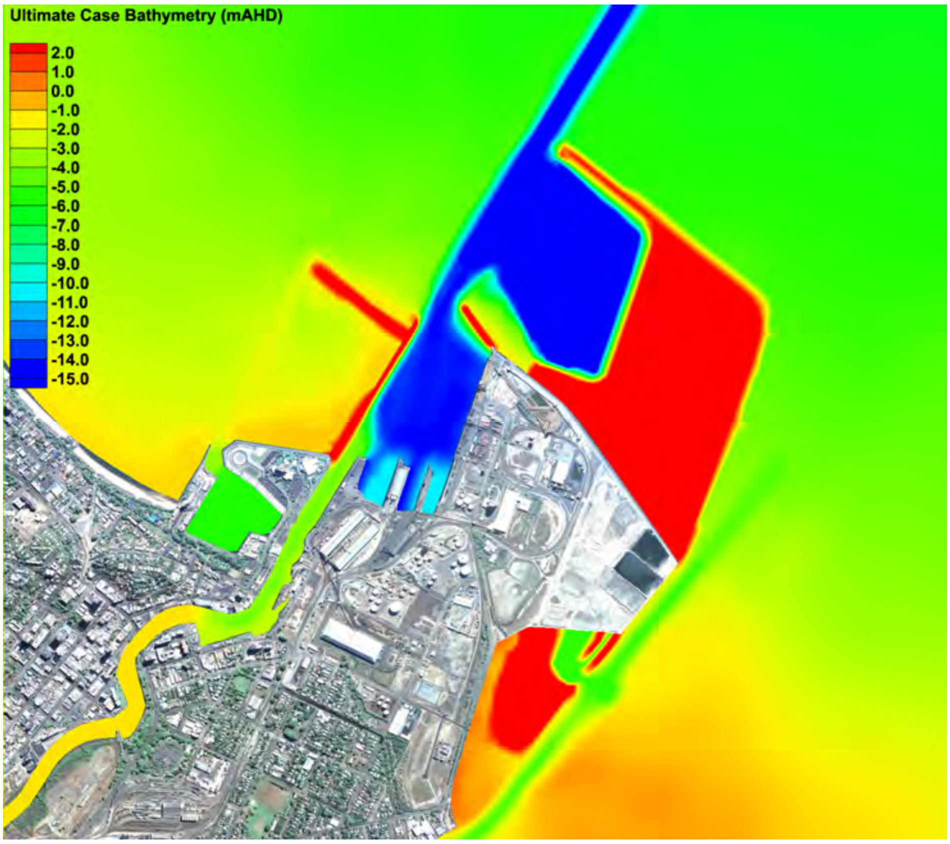


Figure 4-11 Ultimate Case Model Bathymetry

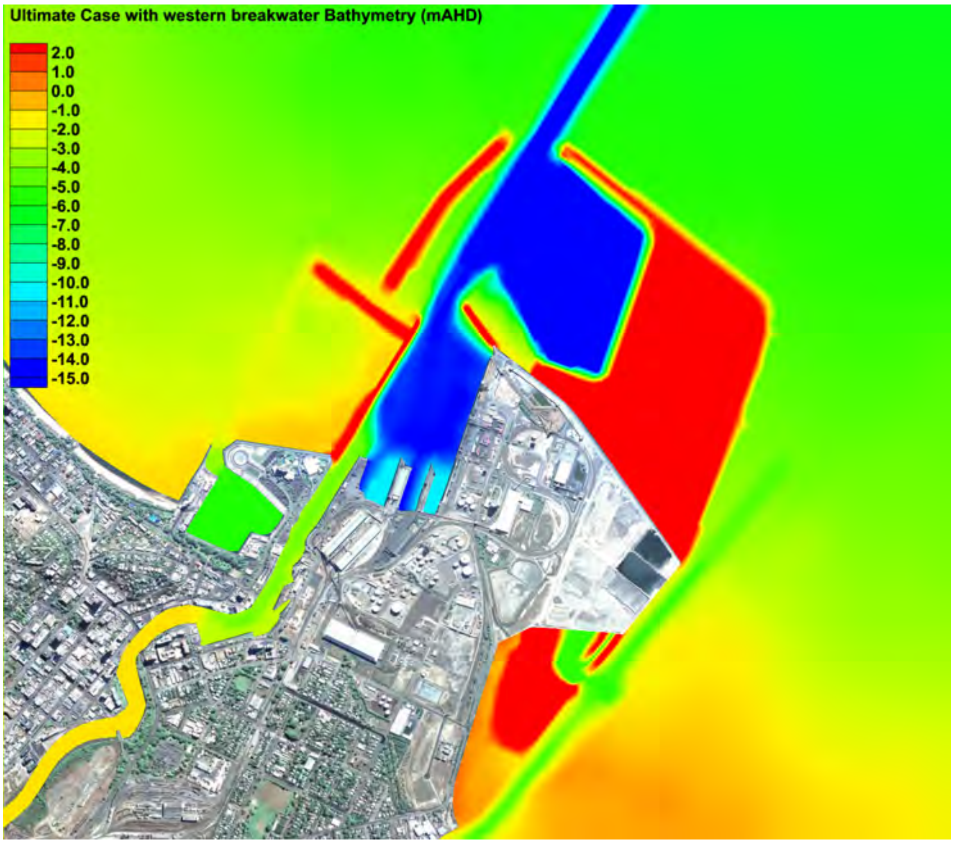


Figure 4-12 Ultimate Case with Western Breakwater Model Bathymetry

For impact assessment purposes the model was run from 1/11/2010 to 1/12/2010, a period which included relatively strong trade winds as discussed in Section 4.1. Hydrodynamic impacts were assessed by comparing the two Ultimate Cases with the Base Case. The intermediate development cases were used for certain dredge plume impact assessment scenarios outlined in Section 6.

4.3 HYDRODYNAMIC MODELLING RESULTS AND DISCUSSION

Results are presented below in term of resultant impact at specific times between the Base Case and Ultimate configuration. Figure 4-13 illustrates the tide level near the port for the simulation and the times at which the typical current patterns and impacts have been extracted.

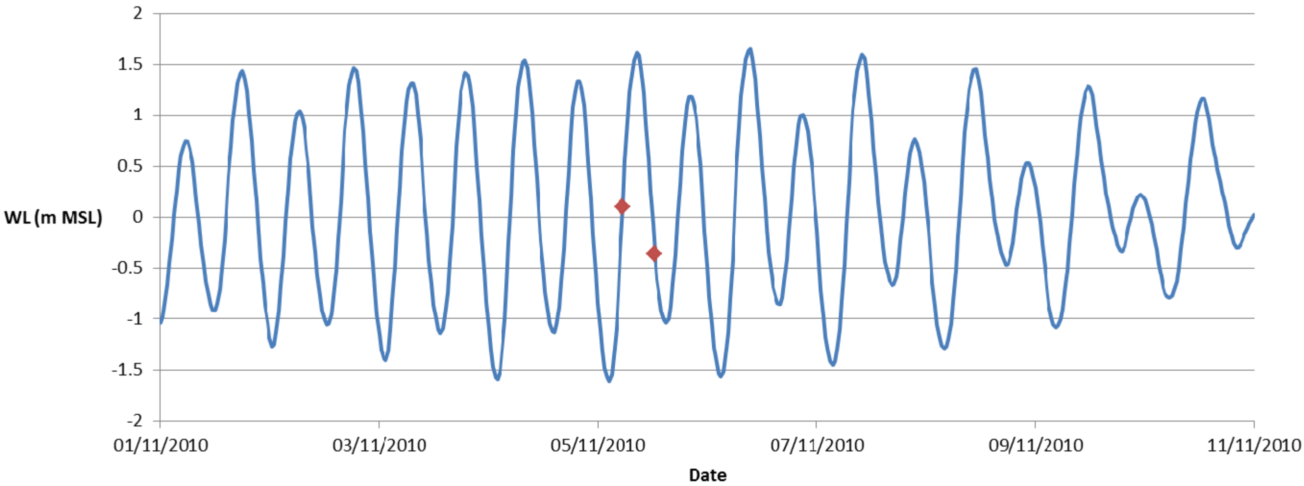


Figure 4-13 Hydrodynamic Impact Assessment Tide Levels

Changes to current patterns in the vicinity of the Port were assessed for a flood tide and an ebb tide during a period of spring tides. Spatial plots of the changes in velocity magnitudes between the Base Case and Ultimate Case are shown in Figure 4-14 and Figure 4-15.

Spatial water level impact plots are not shown due to the negligible magnitude of the changes.

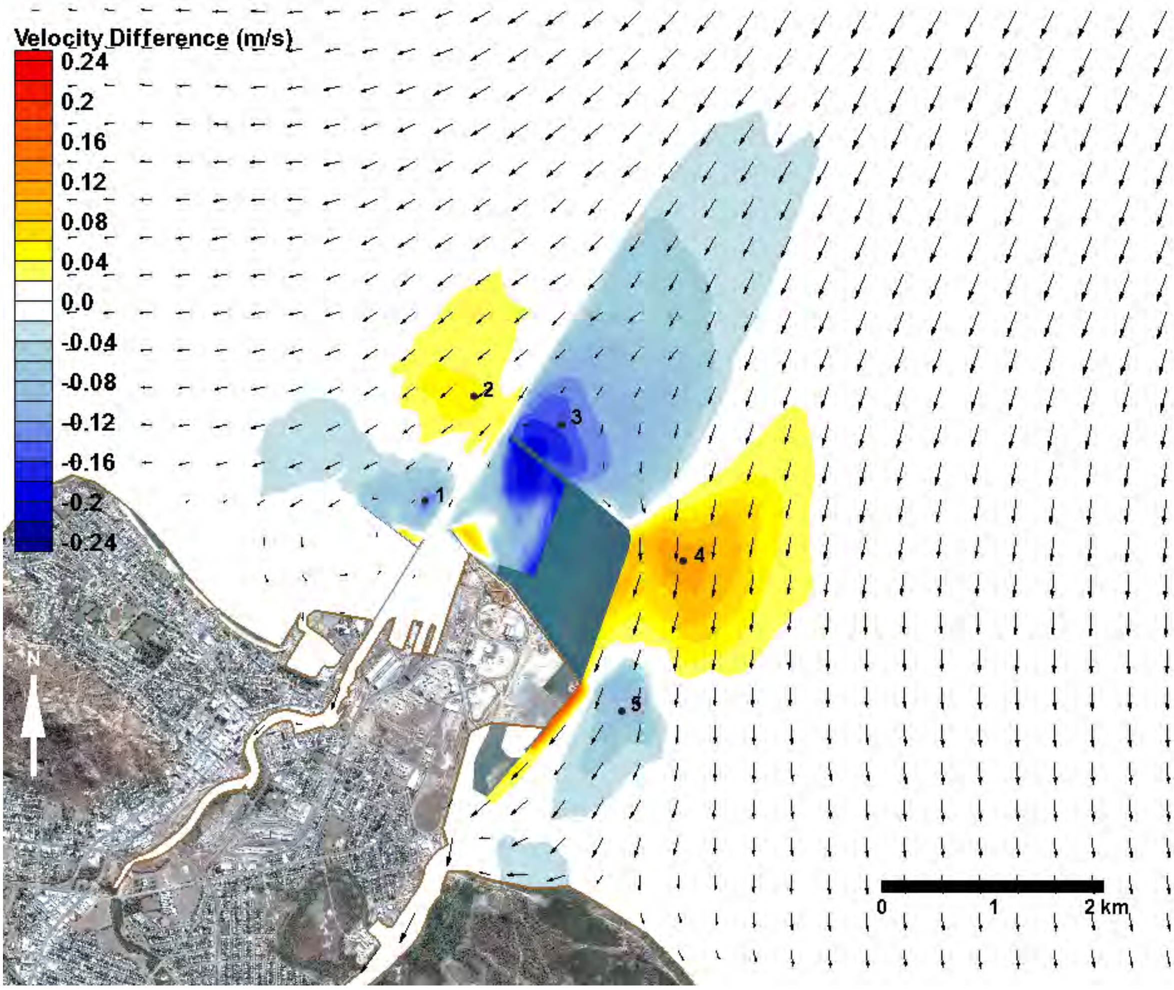


Figure 4-14 Difference Between Ultimate Case and Base Case during Flooding Tide

Figure 4-14 illustrates the difference in velocity in the Ultimate Case compared to the Base Case during a flood tide. Reductions in velocity magnitude are in blue, and increases in yellow / red. It is seen that there are reductions of up to 0.12m/s in depth averaged velocity adjacent to the existing breakwater near Site 1. The velocities to the north of the new north-eastern revetment (near Site 3) are reduced by up to 0.2m/s. Velocities within the new port expansion harbour area are up to 0.2m/s lower than the Base Case due to the increases in depth and sheltering by breakwaters. There are increases in velocity of up to 0.1m/s relative to the Base Case to the east of the new reclamation area (near Site 4). Velocity increases of less than 0.2m/s are predicted to occur in the Ross River entrance channel to the east of the existing port reclamation on flooding tides.

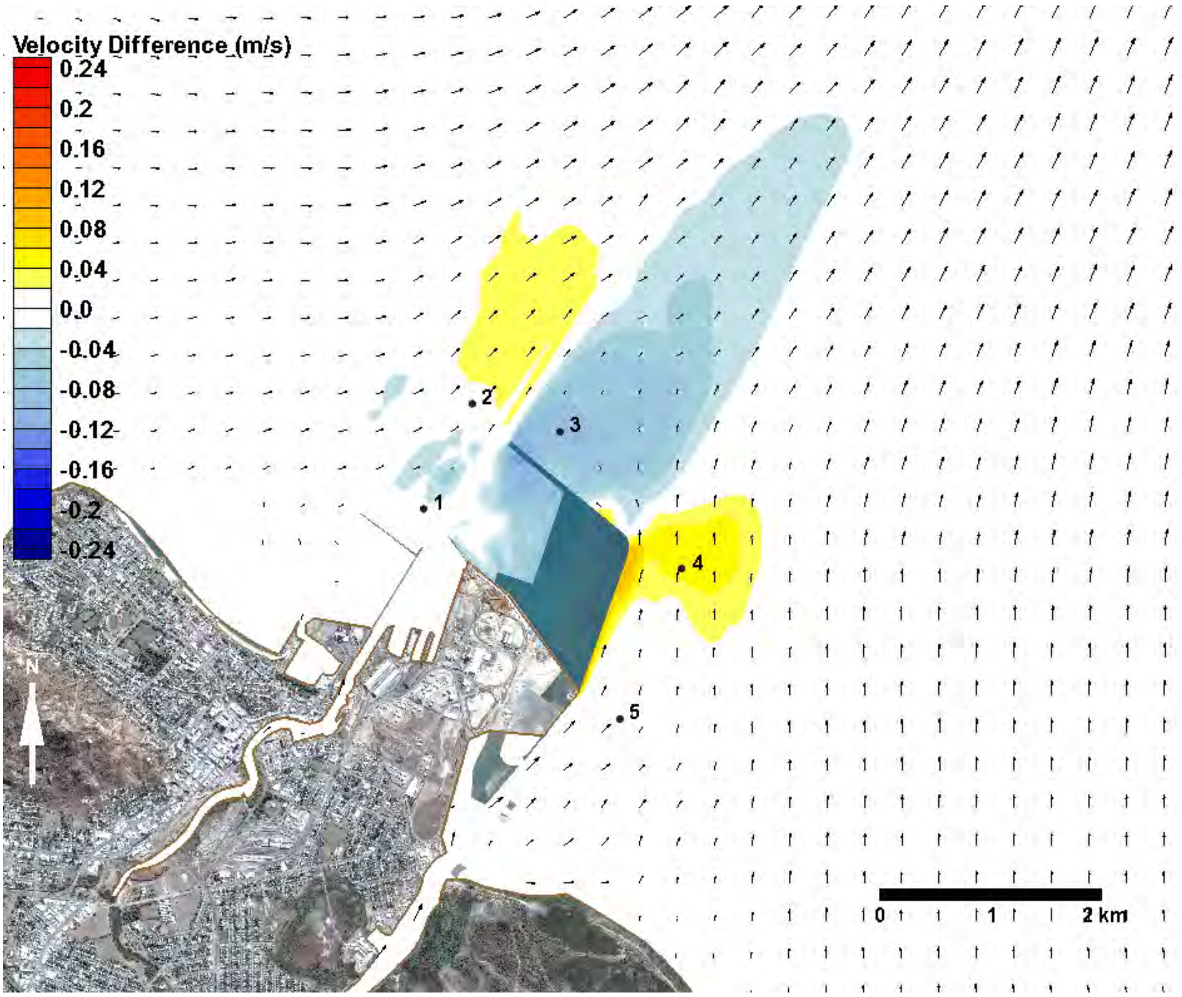


Figure 4-15 Difference Between Ultimate Case and Base Case during Ebb Tide

Figure 4-15 illustrates the difference in velocity in the Ultimate Case compared to the Base Case during an ebb tide. Reductions in velocity magnitude are in blue, and increases in yellow / red. The velocities to the north of the new north-east breakwater (near Site 3) are up to 0.1m/s lower in the Ultimate Case than in the Base Case. Velocities within the new port expansion harbour area are up to 0.12m/s lower than the Base Case due to the increases in depth and sheltering by breakwaters. There are increases in velocity of up to 0.08m/s relative to the Base Case to the east of the proposed port expansion (near Site 4) due to the diversion of tidal flows around the reclamation area.

Time series of water level and depth-average velocity were extracted at the five locations shown in Figure 4-14 and Figure 4-15. Water level percentiles for the Base Case and Ultimate Case are shown in Figure 4-16. The velocity magnitude time series for the Ultimate Cases are compared to the Base Case in Figure 4-17 and Figure 4-18.

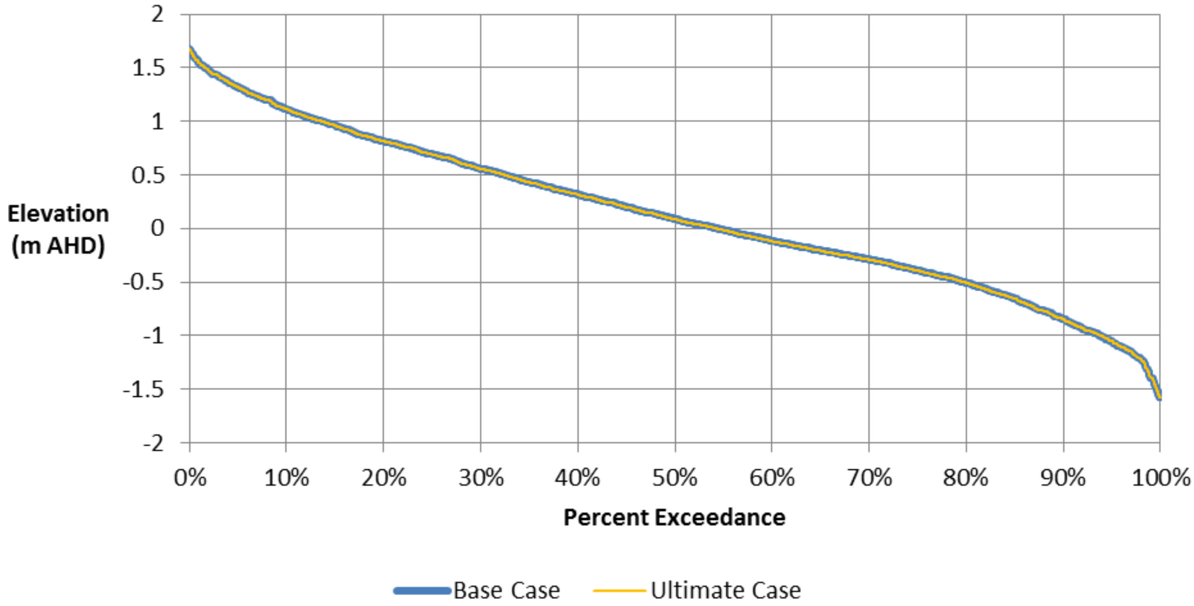


Figure 4-16 Water Level Exceedance Plot for the Base Case and Ultimate Case

It is seen in Figure 4-16 that no change in water levels is predicted for the ultimate port expansion development case relative to the Base Case. The model results indicate that no water level impacts will occur at any location due to the port expansion development.

Figure 4-17 illustrates the change in velocity magnitude at Sites 1 and 2 for the ultimate development cases (Ultimate Case and Ultimate Case with Western Breakwater). There is a general reduction in velocities at Site 1 for the developed cases, and a slight increase at Site 2. The reductions at Site 1 are associated with the proximity of the new north-east breakwater and revetment, while the increase at Site 2 is due to the redistribution of tidal flows associated with the port expansion. None of the changes in velocity are significant in terms of direct environmental impact. Morphological impacts driven by these velocity changes are considered in Section 5. In general the current velocity changes are unlikely to create any additional problems for ship navigation except perhaps at the entrance to the Marine Precinct harbour, which can expect up to a 0.2 m/s increase in entrance cross-currents during flood tides.

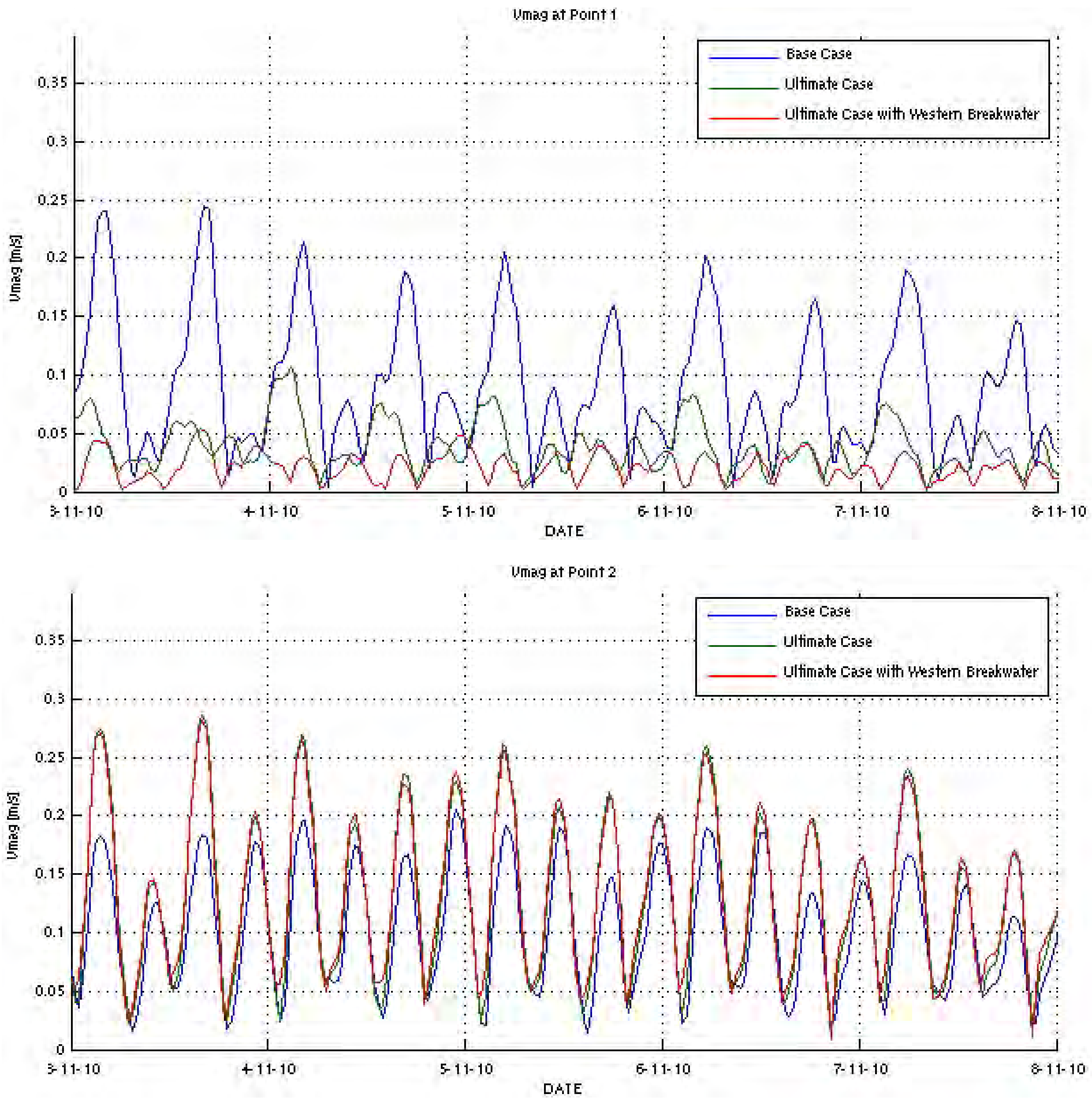


Figure 4-17 Velocity Magnitude Time Series at Sites 1 and 2 for Base Case and Ultimate Cases

Figure 4-18 illustrates the change in velocity magnitude at Sites 3, 4 and 5 for the ultimate development cases (Ultimate Case and Ultimate Case with Western Breakwater). There is a general decrease in velocities at Site 3 for the developed cases, and an increase at Site 4. The decrease at Site 3 is caused by additional sheltering afforded by the port expansion footprint while the increase at Site 4 is associated with the tidal currents being diverted around the new reclamation area. None of the changes in velocity are significant in terms of direct environmental or shipping impact. Morphological impacts driven by these velocity changes are considered in Section 5.

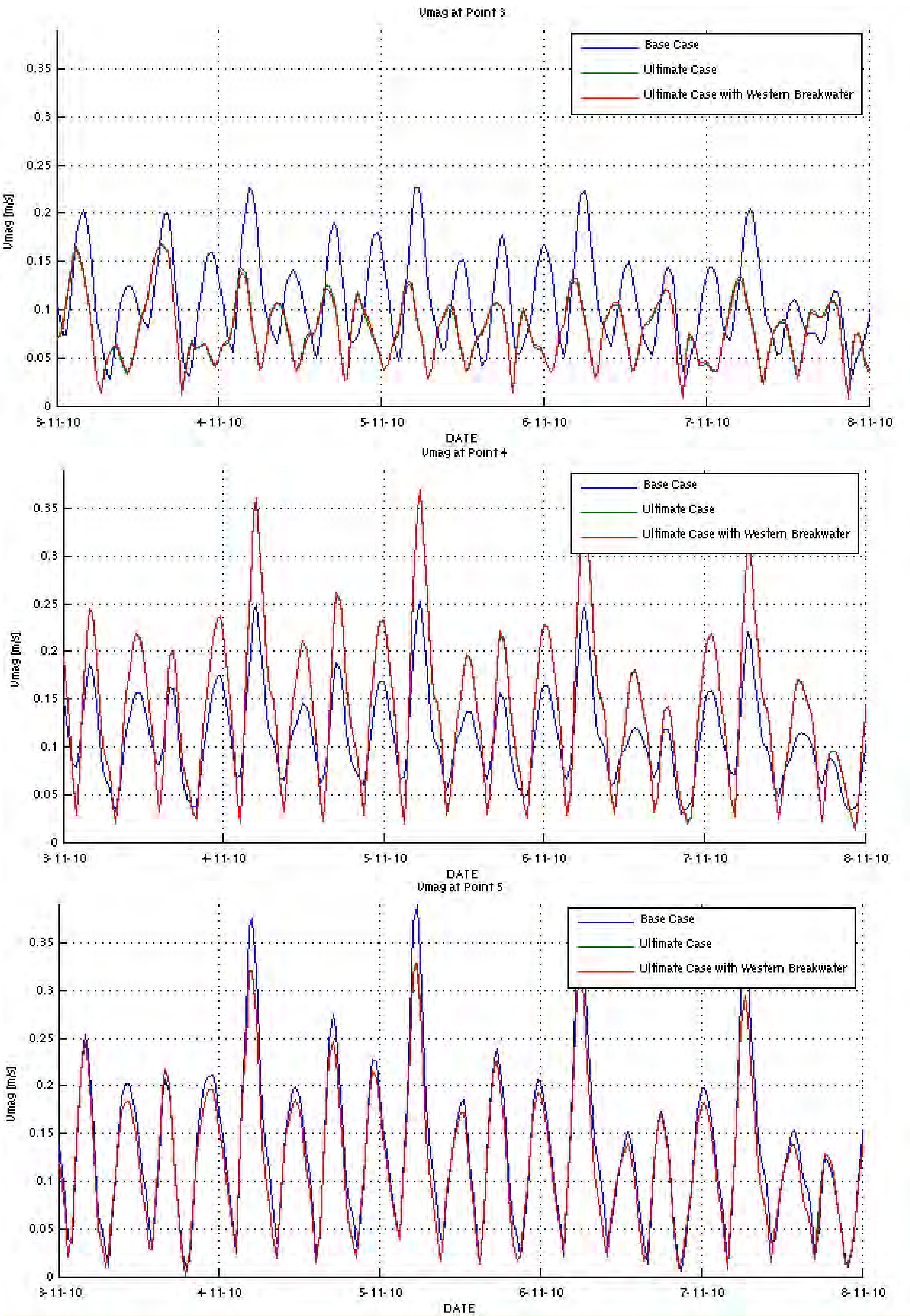


Figure 4-18 Velocity Magnitude Time Series at Sites 3, 4 and 5 for Base Case and Ultimate Cases

4.4 SUMMARY OF HYDRODYNAMICS RESULTS

The hydrodynamic impacts of the proposed port expansion are not large in magnitude or extent, being confined to changes in velocity magnitude in the immediate vicinity of the proposed breakwaters and reclamation area. Water levels at all locations in the vicinity of the proposed works will not change as a result of the Project.

Velocity magnitudes decrease by up to 0.2 m/s adjacent to the new breakwater structures and within the port expansion harbour area on both the flood and ebb tides in the Ultimate Case. There are increases in velocities of up to 0.2 m/s in the Ultimate Case in some areas as shown in Figure 4-14 and Figure 4-15. No significant change in tidal current velocities is predicted in the existing Inner Harbour in the Ultimate Case port expan sion scenarios considered in these assessments.

5 CLEVELAND BAY MORPHOLOGY AND SEDIMENTATION

5.1 GENERAL EFFECTS

The proposed PEP will alter the bathymetry and hydrodynamics of in some parts of Cleveland Bay in the vicinity of the Port such that the local sedimentation processes will be altered to a significant extent. Impacts on sedimentation processes and the marine seabed morphology relate predominantly to:

- Effects that the reclamation and breakwater structures will have on both waves and currents and associated sediment re-suspension, transport and deposition;
- Effects that deepening and widening the channels will have on sediment deposition in those dredged areas of the marine seabed; and
- Effects that alterations of the harbour basin configuration and depths have on hydrodynamics and deposition there.

This section considers impacts of the PEP on siltation processes associated with the harbour and channels, at adjoining nearshore seabed areas (e.g. adjacent to The Strand) and at the offshore Dredge Material Placement Area (DMPA).

5.2 SEDIMENT TRANSPORT

In the context of determining impacts on sedimentation processes, including siltation rates in the harbour and shipping channels, the TUFLOW-FV model was used to simulate the re-suspension of fine material due to the action of waves and currents for the Base Case and Ultimate Case to determine the potential impact of the project on bed morphology and siltation rates. The model was run for the period 01/11/2010 to 01/12/2010 with the prevailing winds and tides as described in Section 4.1.

Residual sediment transport rates were calculated by averaging results over a period of approximately 1 month, ensuring that the start and end points both coincided with similar high tide levels. It is acknowledged that the long-term residual may differ from the values derived over this limited time period, however the selected period was adopted based on being reasonably representative of prevailing climatic conditions and should not therefore be grossly different from the longer term residual. The morphological and sediment transport impacts are also based on predicted changes over the November 2010 simulation period, and a similar caveat applies.

The Base Case residual suspended sediment transport patterns are shown in Figure 5-1, which indicates a net transport in the north-west direction with highest transport rates in the shallower inshore parts of Cleveland Bay. A concentrated region of higher transport is shown immediately offshore of the existing port and the partial interception of the suspended sediment flux by the dredged approach channel can be inferred by the pronounced reduction in transport from updrift to downdrift of this feature.

The Ultimate Case residual sediment transport and corresponding impact (difference from Base Case) are shown in Figure 5-2 and Figure 5-3 respectively. It can be seen that Outer Harbour extension will redirect the residual suspended sediment drift around the reclamation. A small net reduction in fine sediment drift from east to west of the port may occur due to the combined interception effect of the outer harbour extension and the wider and deeper Platypus channel.

The predicted patterns of changes in deposition rates are shown in Figure 5-4 and indicate a zone of slightly increased sedimentation potential to the east of the port and its approach channel. A slight reduction in sedimentation potential is predicted to the west of the channel, including offshore from The Strand.

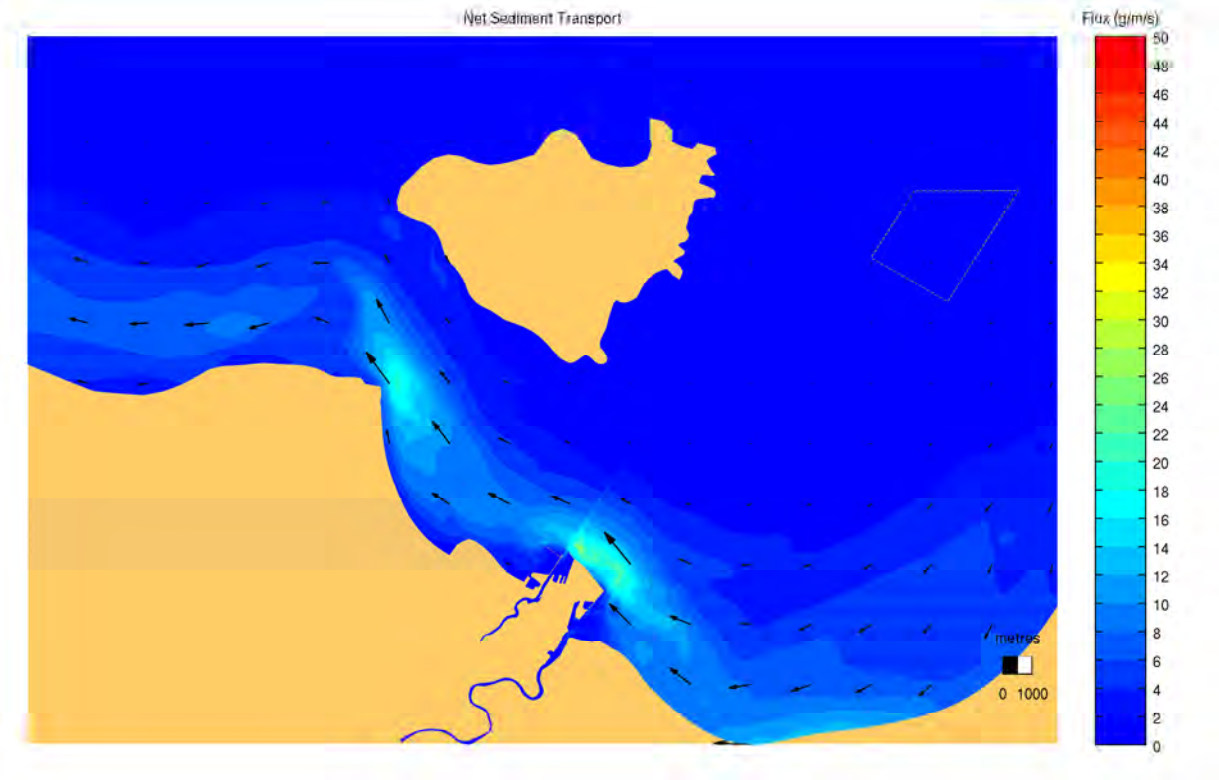


Figure 5-1 Modelled Base Case Residual Suspended Sediment Transport

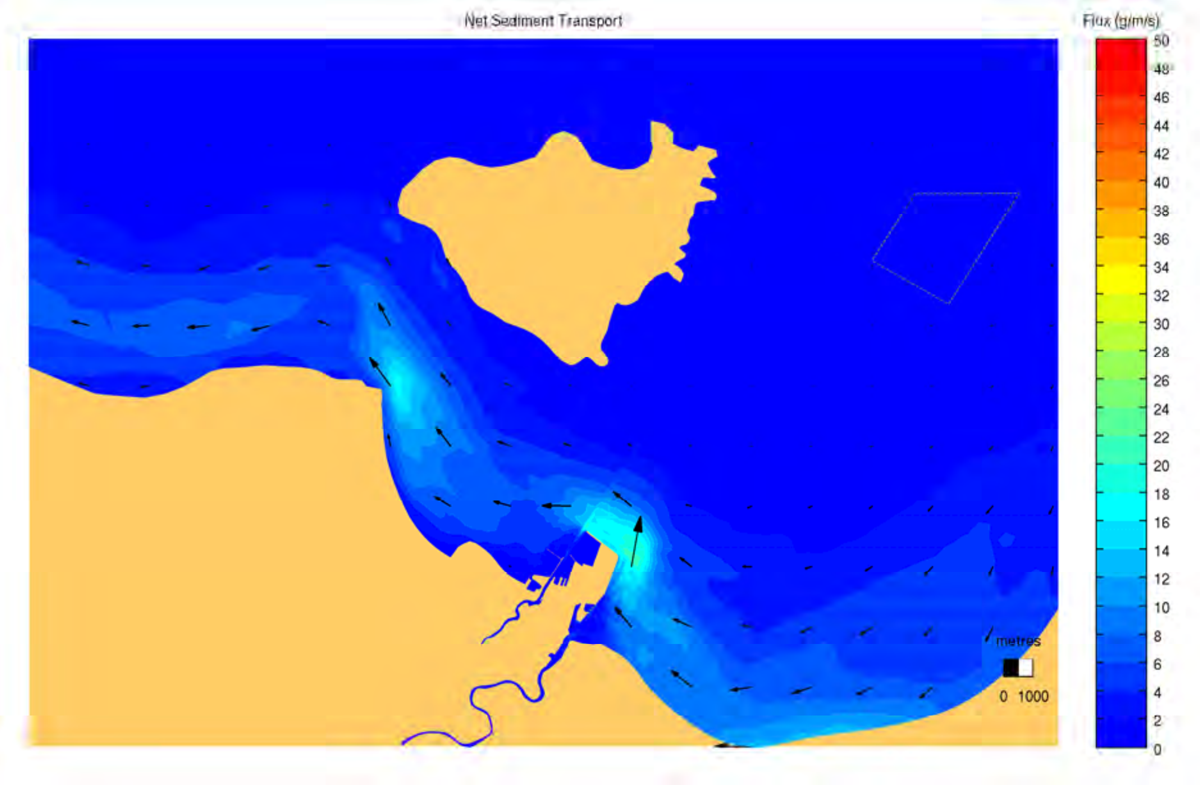


Figure 5-2 Modelled Ultimate Case Residual Suspended Sediment Transport

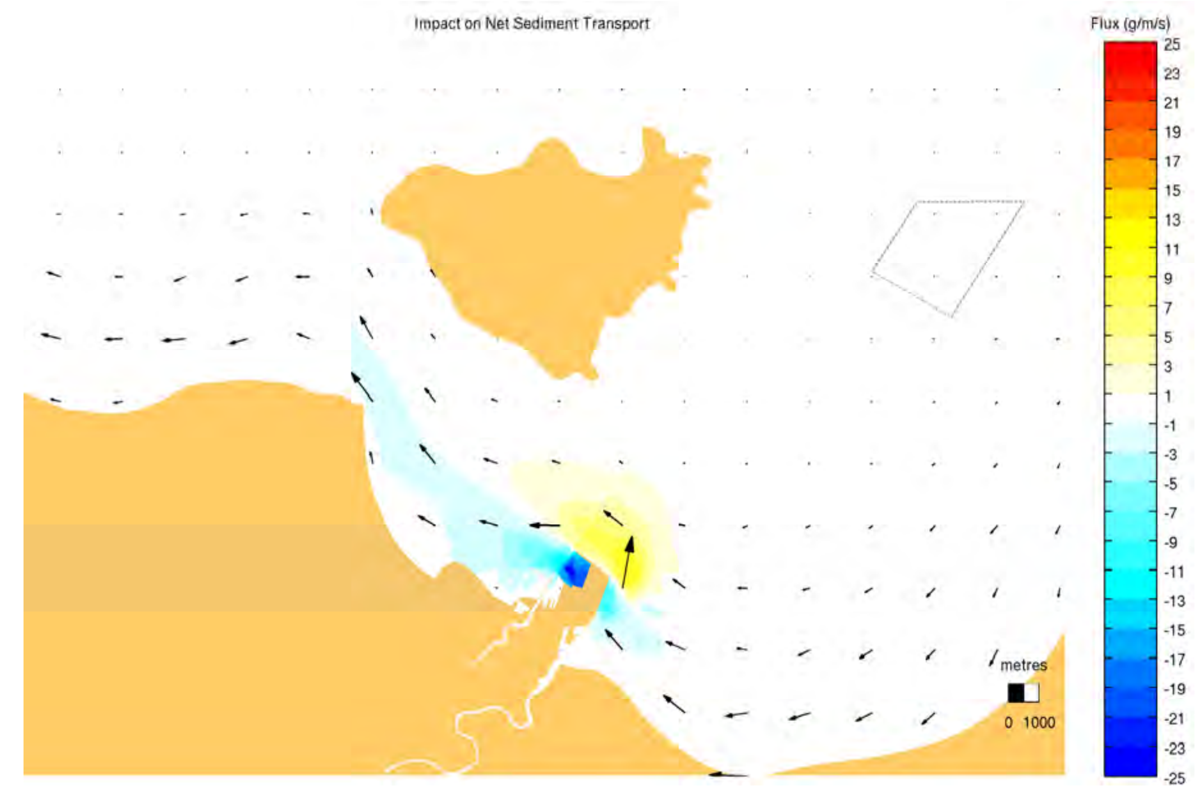


Figure 5-3 Ultimate Case Residual Suspended Sediment Transport Impacts

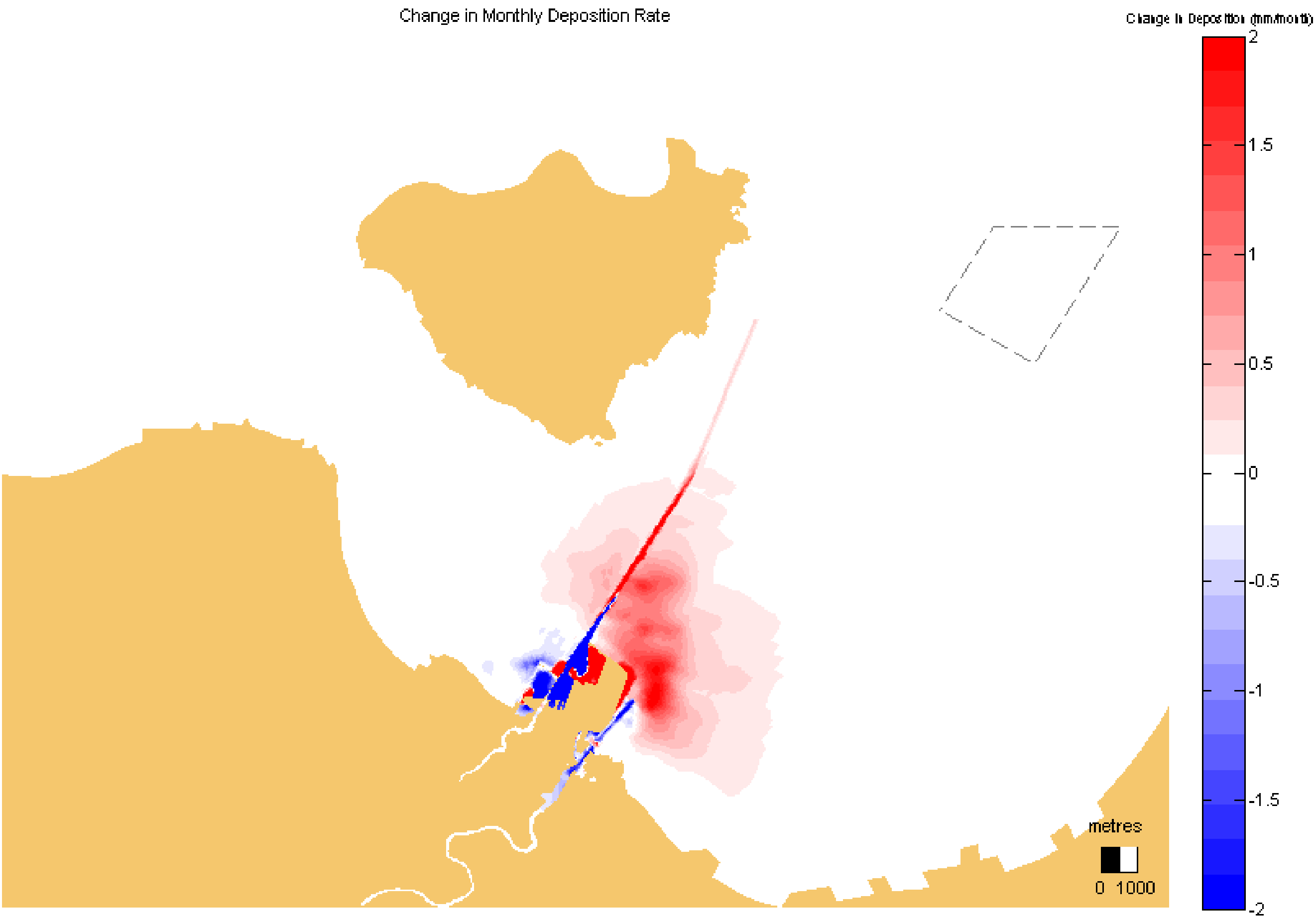


Figure 5-4 Change in Sediment Deposition Rate between the Base Case and Ultimate Case

5.3 CHANNEL SILTATION

The modelled Base Case siltation distribution in terms of bed level change (in mm per month) is shown in Figure 5-5 and the modelled annual siltation volumes are summarised in Table 5-1 for the regions shown in Figure 5-8. The modelled base case sedimentation rates were found to be in reasonable agreement with annual average historic dredging volumes for the existing dredged areas (GHD, 2008).

The distribution of modelled Ultimate Case siltation depths is also shown in Figure 5-6 and the modelled annual siltation volumes for the ultimate case are summarised in Table 5-1. The change in siltation rates due to the port expansion are shown in Figure 5-7 (note that these results are identical to Figure 5-4 but the plot scale has been changed to show the higher siltation rates in the dredged channel areas). It is apparent that there is a reduction in siltation rates within the new enclosed outer harbour area and in the inner part of the Platypus Channel. There is a predicted increase in siltation in the outer part of the Platypus Channel, consistent with the broader pattern of siltation rate changes discussed in Section 5.2.

Sedimentation volumes within the existing inner harbour are predicted to be reduced by around 45% and sedimentation volumes within the outer harbour are predicted to decrease by around 50% relative to the base case (which includes a dredged area for Berth 12). The Ultimate Case reclamation and breakwaters act to significantly reduce the efficiency of suspended sediment transport into the outer and inner harbour dredged areas. It should be noted that the Ultimate Case assessments have been undertaken without the western breakwater in place. A modest decrease in predicted sedimentation would most likely occur with the addition of the western breakwater.

Associated with these reductions within the expanded harbour areas, the annual volume of sedimentation occurring within the Platypus Channel is predicted to increase by around 5%. This is partly due to the increased channel width as part of the ultimate development, as well as diversion of the sediment transport path to the shorter remaining section of that channel where infill depths of about 1m/yr may be expected in the nearshore parts.

Table 5-1 Modelled Annual Sedimentation Volumes (m^3)

Dredge Area	Base Case	Ultimate Case	Percentage Change
Inner Harbour	65,000	35,000	-46%
Outer Harbour	184,000	93,000	-49%
Platypus Channel	189,000	199,000	+5%
Total (modelled)	438,000	327,000	-25%

Overall, this modelling indicates that the total quantity of siltation within the inner harbour, outer harbour and Platypus Channel combined may be reduced by around 110,000m^3 per year (about 25% for that area) relative to the present situation. This is primarily due to the reduced suspended sediment net transport flux around the expanded port. Siltation further seaward along Sea Channel will not be affected by the harbour expansion works. The material depositing in the new enclosed outer harbour area will be entirely very fine silts without the minor component of coarser silt/sand that deposits in the existing dredged basin and berth areas exposed at the present time.

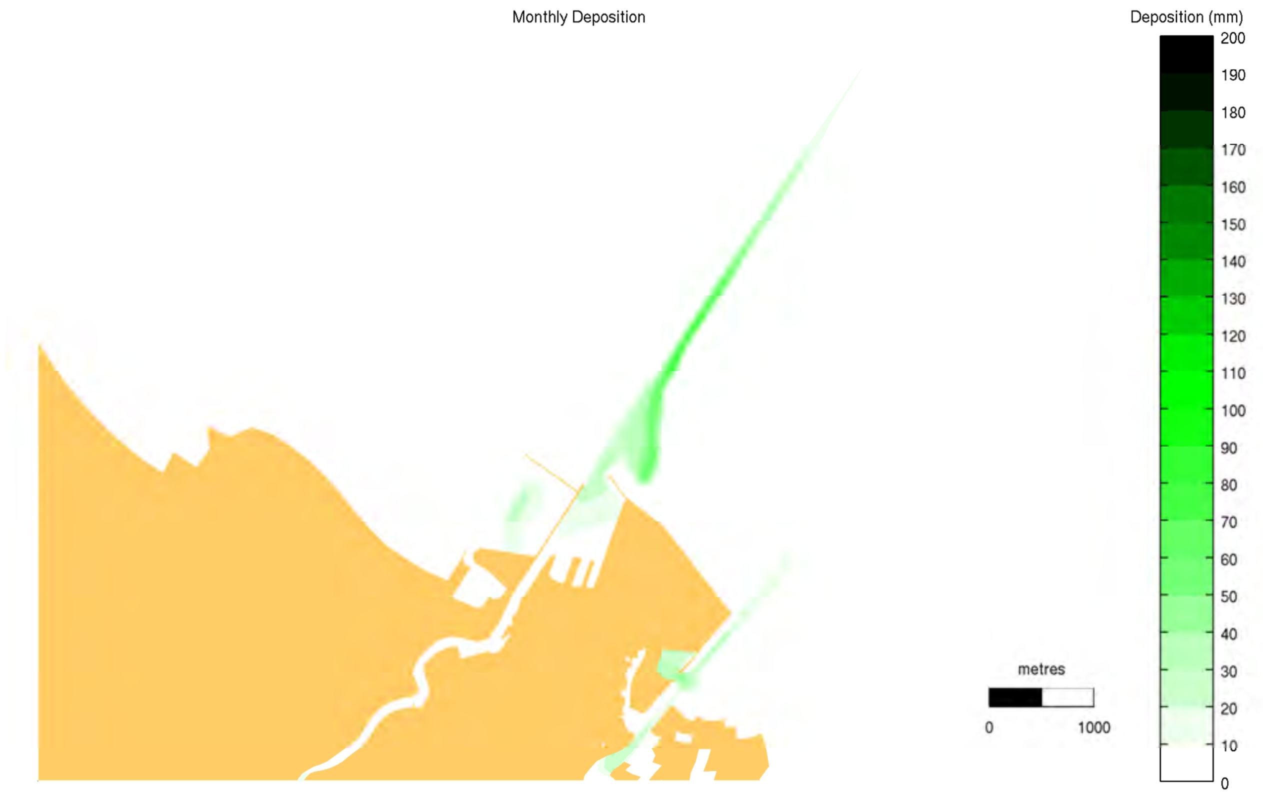


Figure 5-5 Modelled Base Case Siltation Rate (mm/month)

Figure 5-6 Modelled Ultimate Case Siltation Rate (mm/month)

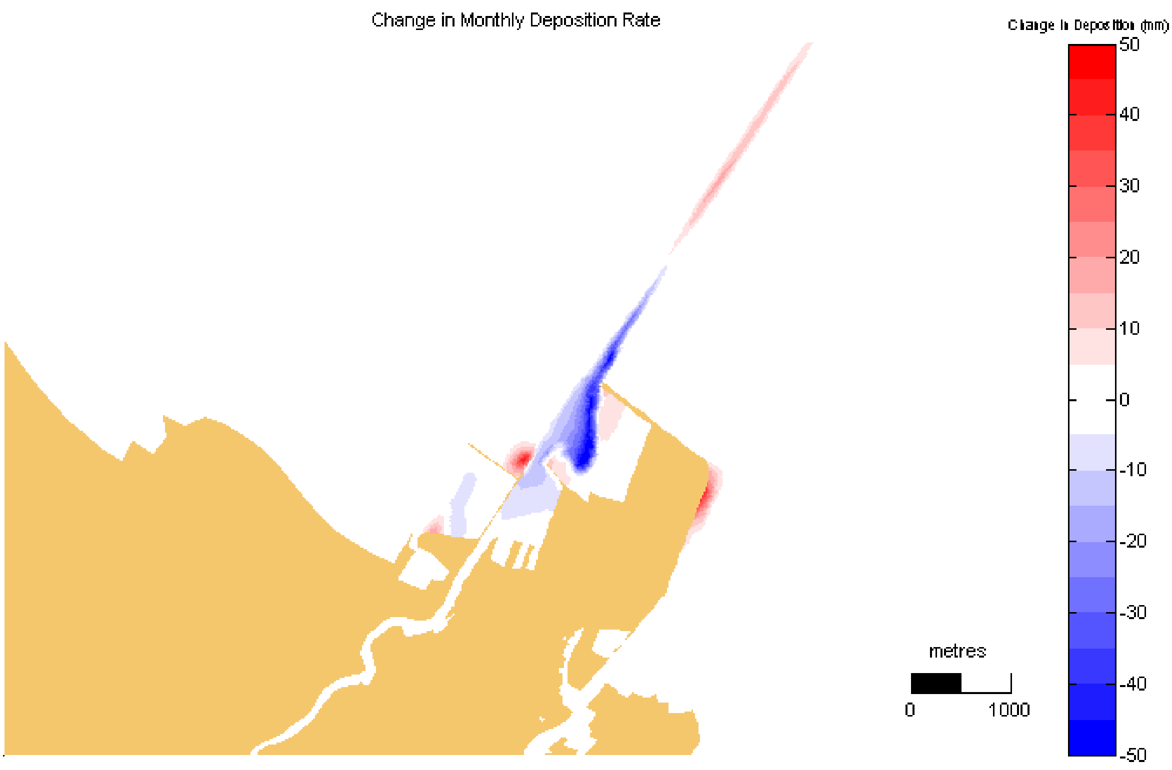


Figure 5-7 Difference in Siltation Rate between the Ultimate Case and Base Case

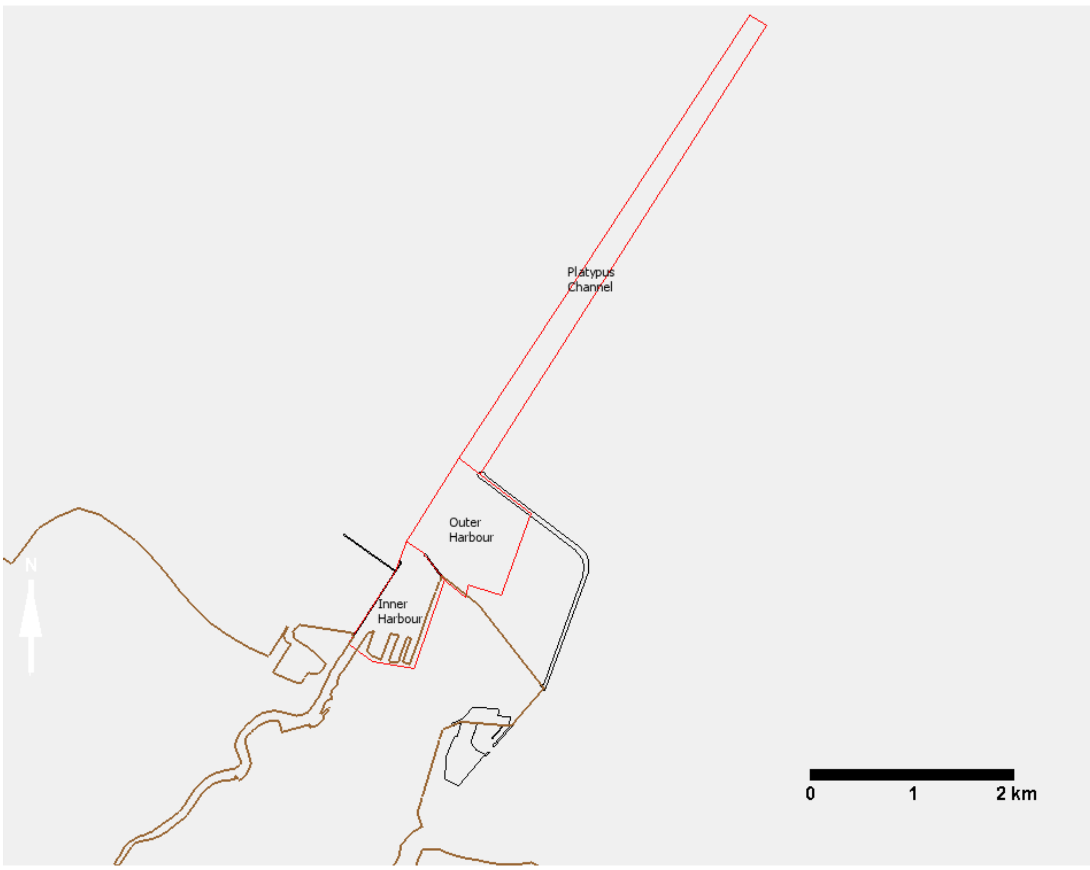


Figure 5-8 TUFLOW-FV Sedimentation Model Regions

5.4 DREDGE MATERIAL PLACEMENT AREA ASSESSMENT

The Townsville Port Expansion project and other capital dredging projects planned for the port are expected to generate approximately 6.5 million cubic metres of surplus material that either has unsuitable engineering properties for reclamation purposes or is otherwise associated with channel deepening. This is in addition to the ongoing maintenance dredging requirements which have historically been about 0.2-0.5 million cubic metres per annum (GHD 2008). It is proposed to place this material in the existing designated Dredge Material Placement Area (DMPA). The existing DMPA is preferred over alternative DMPA sites as discussed in Part A of the EIS.

Ambient waves and currents have the potential to resuspend the dredge material and distribute the sediment more widely. The fate of resuspended sediment from the DMPA was previously studied using numerical models (Bode et al., 1994) and tracer experiments (Sinclair Knight Merz, 1995). ETS Worldwide recently undertook another tracer experiment which included placement at the existing DMPA (ETS Worldwide, 2012).

The 3D modelling study undertaken by Bode *et al* (1994) showed that particles released from the DMPA tend to drift towards Magnetic Island under prevailing south-easterly and southerly winds. They also showed that particles released from the more landward (south-western) end of the DMPA have a greater tendency to drift towards the bays and beaches of Magnetic Island than particles released at the seaward (north-eastern) end of the DMPA. Three-dimensional effects were evident in the results due to the differing vertical structure of tide-driven and wind-driven currents.

The fluorescent tracer experiments conducted by Sinclair Knight Merz (1995) indicated that sediments at the DMPA are highly mobile; however the results were inconclusive due to the limited size of the field sampling area. The results did indicate that possibly 80-90% of silt-sized material was dispersed beyond the 1.5km square sampling grid within the DMPA.

The recent fluorescent tracer experiments undertaken by ETS Worldwide confirmed that the existing DMPA is dispersive and found that tracer particles were transported and deposited in almost all directions. The results did indicate a dominant trend for dispersion to the NE and SW (the dominant tidal current directions), and also indicated that material is transported from the spoil ground to the NE coastline of Magnetic Island.

The TUFLOW-FV numerical model was used to investigate the likely re-suspension and dispersion of material from the DMPA during the period 01/10/2008 to 01/11/2008. This period included predominantly east-south-east winds and a number of significant wave events with significant wave heights H_s above 1m as shown in Figure 5-9.

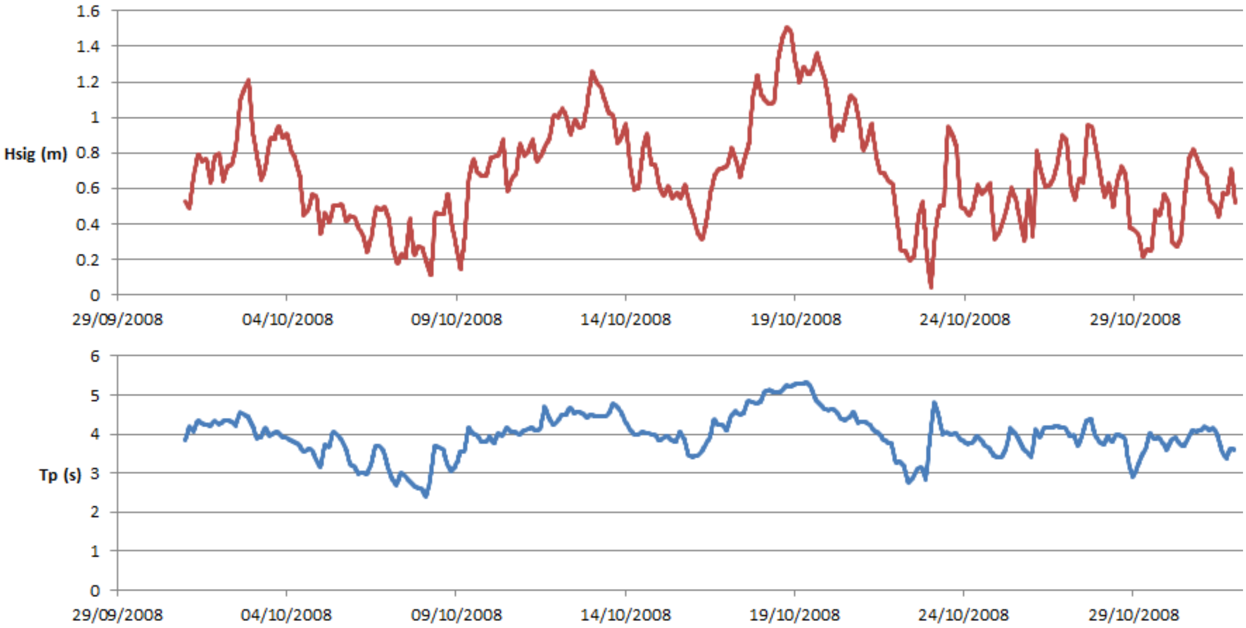


Figure 5-9 Wave Conditions at the DMPA during the Simulation Period

The DMPA Preliminary Capacity Assessment (refer Part A of the EIS) has indicated that the height of the mound of sediment one month after placement may be an average of 0.7 metres above the existing bed elevation. Therefore, for the purposes of this assessment, the elevation of the DMPA was increased by 0.7m relative to the baseline surveyed level.

The relative erodability of the sediment to be placed at the DMPA compared to naturally occurring sediment is unknown. It would be expected that the softer material removed during the first stage of dredging in the Outer Harbour may be more easily resuspended than the stiffer clay material to be removed during the channel deepening works. In order to make a conservative estimate of the amount of resuspension, a critical bed shear stress for erosion of 0.12 N/m^2 was adopted for the silt and clay components of the dredged material.

The bed shear stress calculated at the DMPA based on the modelled current and wave magnitudes is shown in Figure 5-10. Note the correlation between the bed shear stress magnitude and the wave height shown in Figure 5-9. The critical shear stress for erosion (τ_{ce} = 0.12N/m^2) was exceeded throughout the largest wave event during this period, indicating that the sediment is likely to resuspend and disperse during moderate wave events (H_s > 1.2m) of sufficiently long period (T_p > 4s).

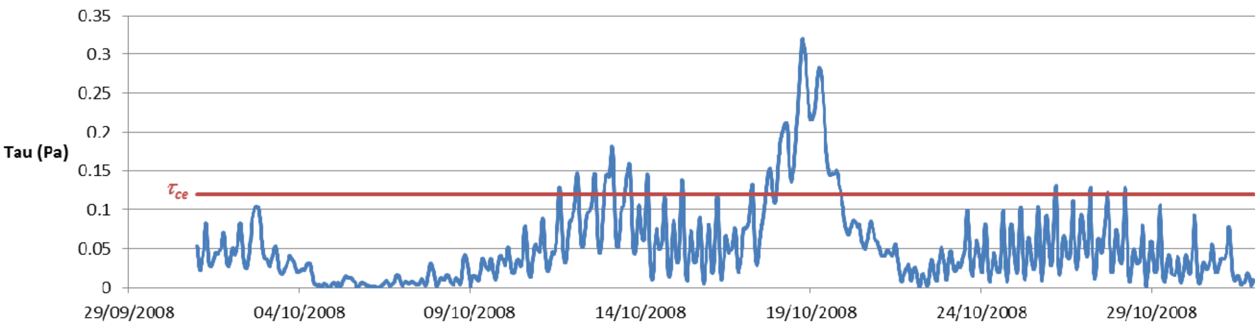


Figure 5-10 Bed Shear Stress at the DMPA during the Simulation Period

The fate of sediment resuspended from the DMPA was also investigated. The sediment composition at the DMPA was assumed to be equivalent to the bulk average of the dredged sediment from the channel. The Total Suspended Sediment (TSS) exceeded for 1% of the simulation period due to sediment resuspended from the DMPA is shown in Figure 5-11. The corresponding deposition of resuspended sediment is shown in Figure 5-12. It is noted that the plume of resuspended sediment during typical conditions does tend to migrate around the north-east shoreline of Magnetic Island, in agreement with the results of Bode et al. (1994) and ETS Worldwide (2012).

However the depth-average concentration due to the resuspended DMPA sediment is at most times negligible, and even during resuspension events is very low (always below 10mg/L in this simulation). There is a tendency for some of the sediment to deposit near the north-east coast of Magnetic Island (where the water depth increases) and in Horseshoe Bay. However, this result must be put into context with existing conditions, since the load of sediment from the DMPA will be a small proportion of the total sediment in suspension in the bay. To illustrate this point, Figure 5-13 shows the modelled Total Suspended Sediment concentration (TSS) in Horseshoe Bay, Magnetic Island, together with the modelled TSS that is due to sediments resuspended at the DMPA. Modelling indicates that, on average, the proportion of sediment in suspension at that location which originated at the DMPA is between 0 to 30% of the total during such transport events.

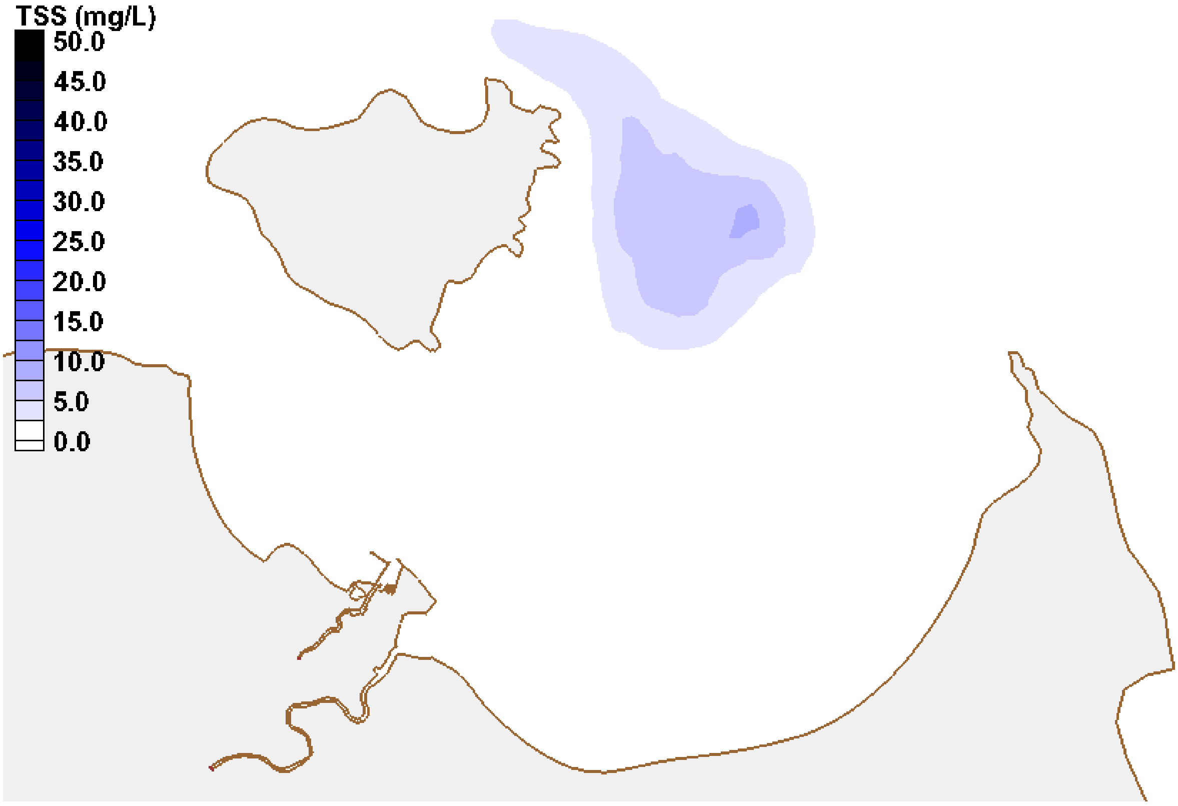


Figure 5-11 Suspended Sediment Concentration Exceeded for 1% of the Simulation Period due to Re-Suspension from the DMPA

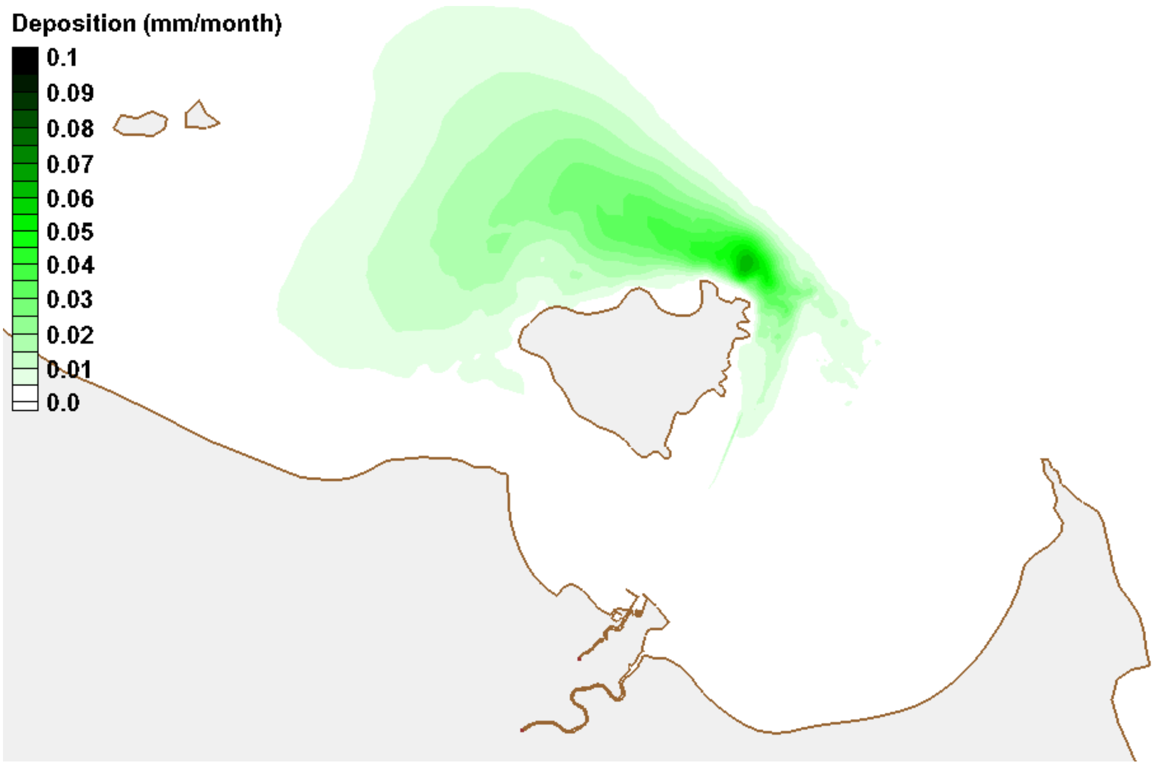


Figure 5-12 Sediment Deposition due to Re-Suspension from the DMPA during the One Month Simulation Period

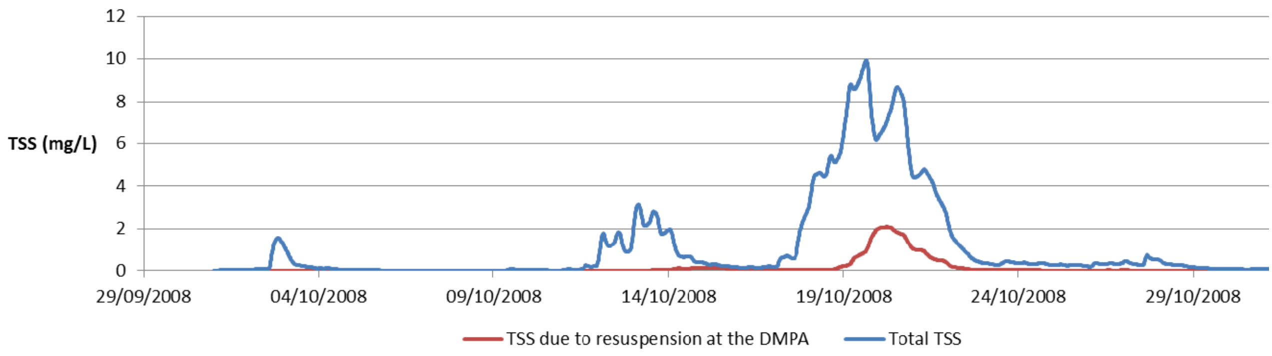


Figure 5-13 Time Series of Total Suspended Sediment Concentration in Horseshoe Bay, Magnetic Island, (Blue – Total; Red – Amount due to Sediment Re-Suspension from DMPA)

5.5 FINE FLUVIAL SEDIMENTS FROM ROSS RIVER

To assess the potential for changes to siltation patterns supplied by fluvial sediment from Ross River, the TUFLOW-FV model was used to investigate the fate of sediment discharged from the river in the Ultimate Case compared to the Base Case. Catchment modelling was undertaken as part of another BMT WBM study (BMT WBM, 2010) for a period of 30 years (1/4/1978 to 31/3/2008). A major inflow event representing the second greatest peak flow during the 30 year period was used for the impact assessment. The 1% exceedance level suspended sediment concentrations due to the fluvial discharge for the Ultimate Case configuration are shown in Figure 5-15. These may be compared with those for the Base Case configuration in Figure 5-14. The difference between the Ultimate and Base cases is shown in Figure 5-16.

The model results indicate that nearshore areas near The Strand are more sheltered from these suspended sediment discharges in this case and the PEP may help to reduce the amount of fine Ross River sediment that reaches and deposits in that area. There is a corresponding increase in the Ross River flood plume concentrations to the immediate east of the Port development.

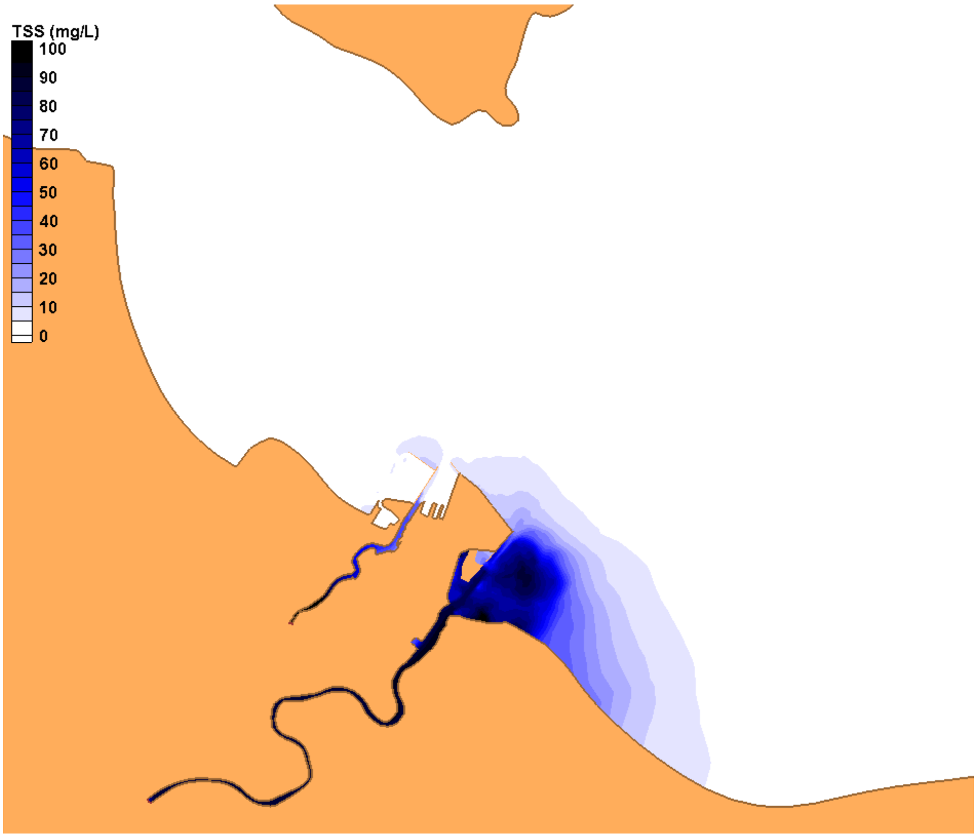


Figure 5-14 Depth-Averaged TSS Exceeded for 1% of the Simulation Period due to Ross River and Ross Creek Sediment Discharge in the Base Case

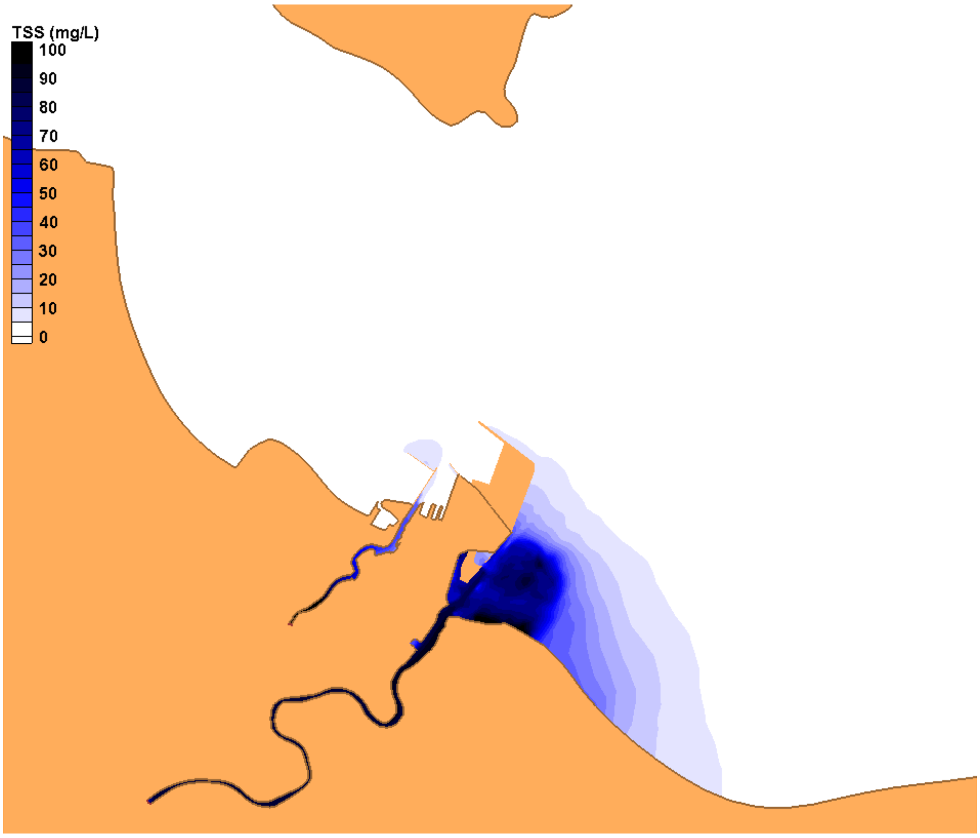


Figure 5-15 Depth-Averaged TSS Exceeded for 1% of the Simulation Period due to Ross River and Ross Creek Sediment Discharge in the Ultimate Case

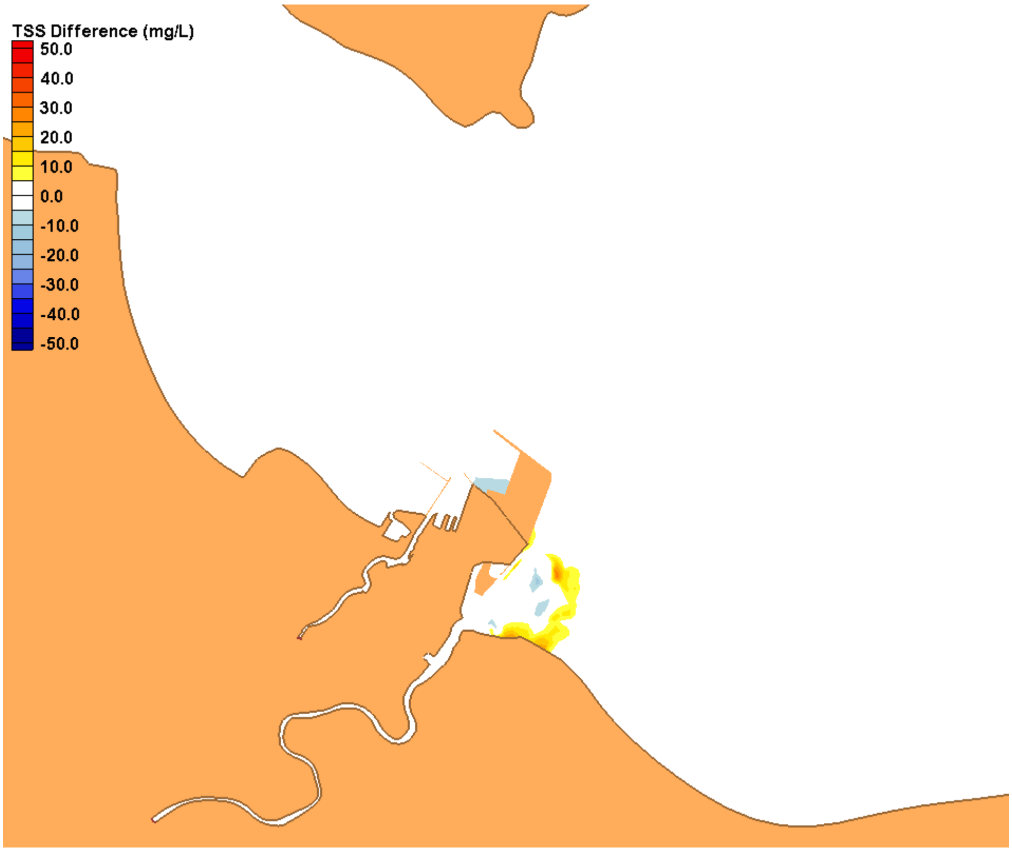


Figure 5-16 Difference in Depth-Averaged TSS Exceeded for 1% of the Simulation Period due to Ross River and Ross Creek Sediment Discharge (Ultimate Case Minus Base Case)

6 DREDGE PLUME ASSESSMENT

6.1 MODELLING SCENARIOS AND INPUT PARAMETERS

The validated 3D advection-dispersion model was used to simulate the likely impact of dredge plumes produced during the construction of the project. For this purpose a number of plume dispersion scenarios were developed based on the various stages of the port expansion works and the number and type of dredges to be used during each stage of the works.

A summary of the dredge plume scenarios is given in Table 6-1. Cycle times for each dredging operation are provided, based on a 24-hour working day. The first stage of the dredging works involves removal of soft surface sediments along the footprint of the north and north-east revetments and the north-west breakwater using a mechanical dredge and barges (Scenario 1a). Scenario 1b involves removal of soft surface sediments along the footprint of the western breakwater, also using a mechanical dredge and barges. The next stage of construction involves placement of rock along the north and north-east revetments and the north-west breakwater (Scenario 2a). The placement of rock at the western breakwater is modelled in Scenario 2b. Scenario 3a involves removal of soft surface sediments from the expanded Outer Harbour area using a small Trailing Suction Hopper Dredge (TSHD). The channel deepening dredging operation, to be carried out using a medium-sized TSHD (~10,000m^3 capacity), is modelled in Scenarios 4a and 4b. Scenario 4c involves a Cutter Suction Dredge (CSD) deepening the Outer Harbour (with an associated tailwater discharge on the eastern side of the reclamation area) and a mechanical dredge widening the Platypus Channel. Scenario 4d involves the same dredging activities as Scenario 4c but with the western breakwater in place.

Prediction of dredge plume impacts involves a number of 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 (e.g., type and size of dredge) as well as the material being excavated. The sediment release rates and particle size distributions for each scenario were supplied to BMT WBM (derived by AECOM and its dredging consultants) according to the type of dredge, mode of operation and sediment type. Three sediment fractions were modelled which represent the portion of plume material that remains in suspension for more than a few minutes and is advected and dispersed by ambient currents. The three sediment fractions – clay, silt and fine sand – were assigned settling velocities of 1×10^{-4} m/s, 5×10^{-4} m/s and 1×10^{-2} m/s respectively. The sediment types assumed for each scenario and corresponding sediment fraction percentages are summarised in Table 6-2. The modelled vertical distribution of each plume source is also provided in Table 6-2. The General Ocean Turbulence Model (http://www.gotm.net/) was used to control vertical mixing of both momentum and sediment. A Smagorinsky model was used for the estimation of the horizontal eddy viscosity and diffusivity coefficients.

A dry density of 800kg/m^3 was adopted for the calculation of sediment deposition rates.

The critical bed shear stresses for erosion and deposition were the same as those derived as part of the natural resuspension validation exercise discussed in Section 3.4

- Critical shear stress for erosion τ_{ce} = 0.2 Pa;
- Critical shear stress for deposition τ_{cd} = 0.1 Pa; and
- Erosion rate constant E = 0.0005 g/m^2/s.

No sediment other than the dredge plume sediment was modelled in each of the plume simulations. After the dredge plume sediment was input into the model, it was allowed to advect, disperse and settle to the bed and then remain available for resuspension for the remainder of the simulation. In reality, the dredge plume sediment would mix with naturally occurring sediment in suspension and only a small proportion of any resuspension that occurs would involve sediment that had been dredged. To account for this "dilution" effect, the erosion rate constant for the dredging simulations was reduced by a factor of 10 relative to the rate derived for natural sediment in Section 3.4. This reduction in the erosion rate is considered to be a conservative estimate since the dredged material is expected to be less than 10% of the surface layer available for resuspension.

6.2 PORT EXPANSION DREDGING SCENARIOS

For all scenarios except the channel dredging operation, the model was run for the same period as the hydrodynamic impact assessment (01/11/2010 to 01/12/2010), a period which included relatively strong SE winds. The wind magnitude and direction for this period in the vicinity of the Port is shown in Figure 4-2. The release rate and sediment composition for these scenarios was determined according to the highest likely release rate of clay material.

The effects of increased turbidity from dredging plumes have been estimated by determining the 'excess' Total Suspended Sediment (TSS) above background levels and comparing to known tolerance limits of key sensitive receptors. The methodology is explained in the Marine Ecology chapter of the EIS. Results from the 3D hydrodynamic model have been depth-averaged for presentation.

Results are presented here in terms of spatial plots of depth-averaged TSS levels above background that are exceeded for a certain percentage of the time. The first week of the dredging simulation in each scenario is excluded from the calculation so that the results are representative of a steady-state dredging campaign. The total amount of dredge plume sediment that is deposited during the modelling period is also calculated and converted into a monthly deposition rate. Note that the results are shown across the same spatial extent for all scenarios for direct comparison purposes, and some show no apparent effects where their area of impact is relatively small.

Time series of depth-averaged TSS and sediment deposition at the locations shown in Figure 6-1 are presented in Attachment D of this appendix.

Table 6-1 Plume Modelling Scenarios

Label	Description	Geometry	Plume Source	Rate (kg/s)	Time per Cycle (h)	Cycle Time (h)
1a	Mechanical Dredge @ NE breakwater and NE&E revetment	BASE	Mechanical dredge	0.3	continuous	N/A
			Barge overflow	0.03	0.38	3.87
			Barge dump	16.7	0.17	
1b	Mechanical dredge @ Western breakwater	BASE	Mechanical dredge	0.3	continuous	N/A
			Barge overflow	0.03	0.38	3.87
			Barge dump	16.7	0.17	
2a	Rock drop at the NE breakwater and NE&E revetment	BASE	Rock drop	0.48	continuous	N/A
2b	Rock drop at the Western breakwater	BASE	Rock drop	0.48	continuous	N/A
3a	Small TSHD (removing surface sediments)	DEV 1	Small TSHD draghead	0.31	0.42	3.75
			Small TSHD propwash	54	0.31	
			Small TSHD dump	90.3	0.17	
4a	Medium TSHD in Platypus and Sea channels during Summer (11.5 week campaign)	DEV 2	Medium TSHD draghead	65	0.43 (A) 2 (B) 2.33 (C) 2.33 (D)	3 (A) 5.5 (B) 6.8 (C) 6.8 (D)
			Medium TSHD propwash/overflow	235	0.22 (A) 1.62 (B) 1.95 (C) 1.95 (D)	
			Medium TSHD dump	400	0.17	
4b	As for 4a during Winter (11.5 week campaign)	DEV 2	As for 4a			
4c	CSD in outer harbour Mechanical dredge widening channel	DEV 2	CSD cutting head	0.28	continuous	N/A
			Tailwater discharge	0.208	continuous	
			Mech dredge	0.23	continuous	
			Barge overflow	0.02	0.52	5.2
			Barge dump	33.4	0.17	
4d	As for 4c with Western Breakwater	DEV 2 WB	As for 4c			

Table 6-2 Assumed Sediment Composition and Vertical Distribution of Plume Sources

Plume Source	Vertical Distribution	Modelled Sediment Type	Fine Sand	Silt	Clay
Mech dredge (breakwaters/revetments)	uniform	soft surface sediments	3%	67%	31%
Barge overflow	top 2m	soft surface sediments	0%	70%	30%
Barge placement	uniform	soft surface sediments	0%	70%	30%
Rock drop (breakwaters/revetments)	uniform	soft surface sediments	3%	67%	31%
Small TSHD draghead	bottom 2m	soft surface sediments	5%	58%	37%
Small TSHD propwash	uniform	soft surface sediments	5%	53%	42%
Small TSHD placement	uniform	soft surface sediments	5%	53%	42%
Medium TSHD draghead (channel dredging)	bottom 1.5m	seaward end of sea channel	11%	37%	53%
Medium TSHD propwash/overflow	uniform	elsewhere	13%	15%	71%
Medium TSHD placement	uniform				
CSD cutting head (outer harbour)	bottom 3m	vStiff-Hard sandy clay	9%	0%	91%
Tailwater discharge	uniform	clay overflow	0%	0%	100%
Mech dredge (widening channel)	uniform	firm-stiff sandy clay	5%	32%	63%
Barge overflow	surface	firm-stiff sandy clay	4%	26%	70%
Barge placement	uniform	firm-stiff sandy clay	11%	22%	67%

Figure 6-1 Sites for Time Series Outputs

6.2.1 SCENARIO 1A AND 1B

This scenario involves a mechanical dredge operating at the north-east breakwater and north & north-east revetments (1a) and a mechanical dredge operating at the western breakwater (1b). In both cases barges deliver sediment to the offshore DMPA. Since the geographic extent and magnitude of plume concentrations is very small, only the 1% exceedance plots are presented. Figure 6-2 and Figure 6-3 present the above background TSS exceeded for 1% of the simulation period in scenarios 1a and 1b respectively. Figure 6-4 and Figure 6-5 present the total deposition thickness over the one month simulation period.

Figure 6-2 shows the above-background TSS exceeded for 1% of the one month simulation period with a mechanical dredge operating at the north-east breakwater (note that the area impacted in this scenario is very small). The area which experiences TSS levels more than 5mg/L above background for 1% of the time is limited to approximately 100 metres in diameter in the immediate vicinity of the dredge and the highest 1% exceedance TSS is approximately 7mg/L at the dredge location.

Figure 6-3 shows the above-background TSS exceeded for 1% of the one month simulation period with a mechanical dredge operating at the western breakwater. The area that experiences above-background TSS levels greater than 5mg/L for 1% of the time is located primarily to the north and west of the existing breakwater.

Figure 6-4 shows the total modelled thickness of sediment deposited during the one month simulation period due to a mechanical dredge operating at the north-east breakwater. The model results indicate that the sediment deposition associated with this dredging activity is restricted to an area within approximately 50 metres of the dredge, and the maximum rate of deposition is approximately 1mm/month.

Figure 6-5 shows the total thickness of sediment deposited during the one month simulation period with a mechanical dredge operating at the western breakwater. The sediment deposition during this dredging activity is limited to two small areas on either side of the existing breakwater and the maximum deposition thickness is approximately 2mm/month at the dredge location.

Figure 6-2 Scenario 1a - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Simulation Period

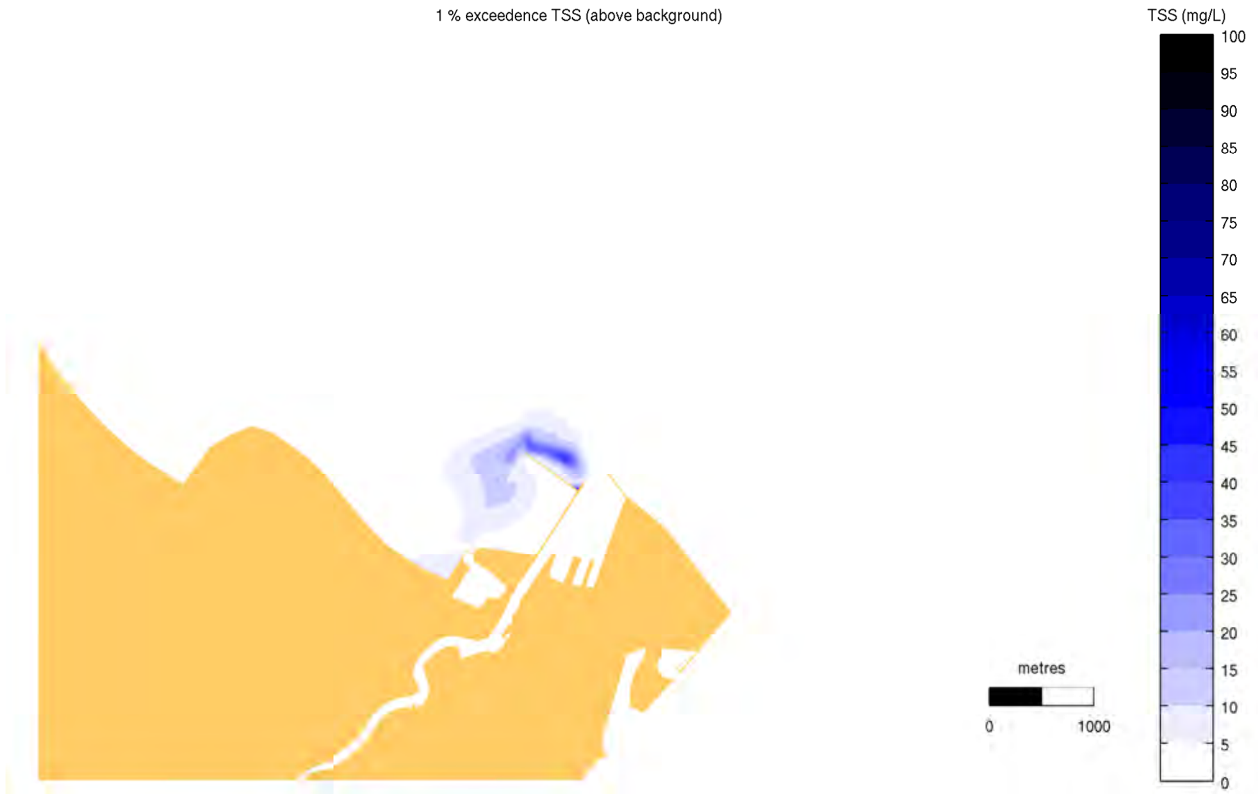


Figure 6-3 Scenario 1b - Above Background Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Simulation Period

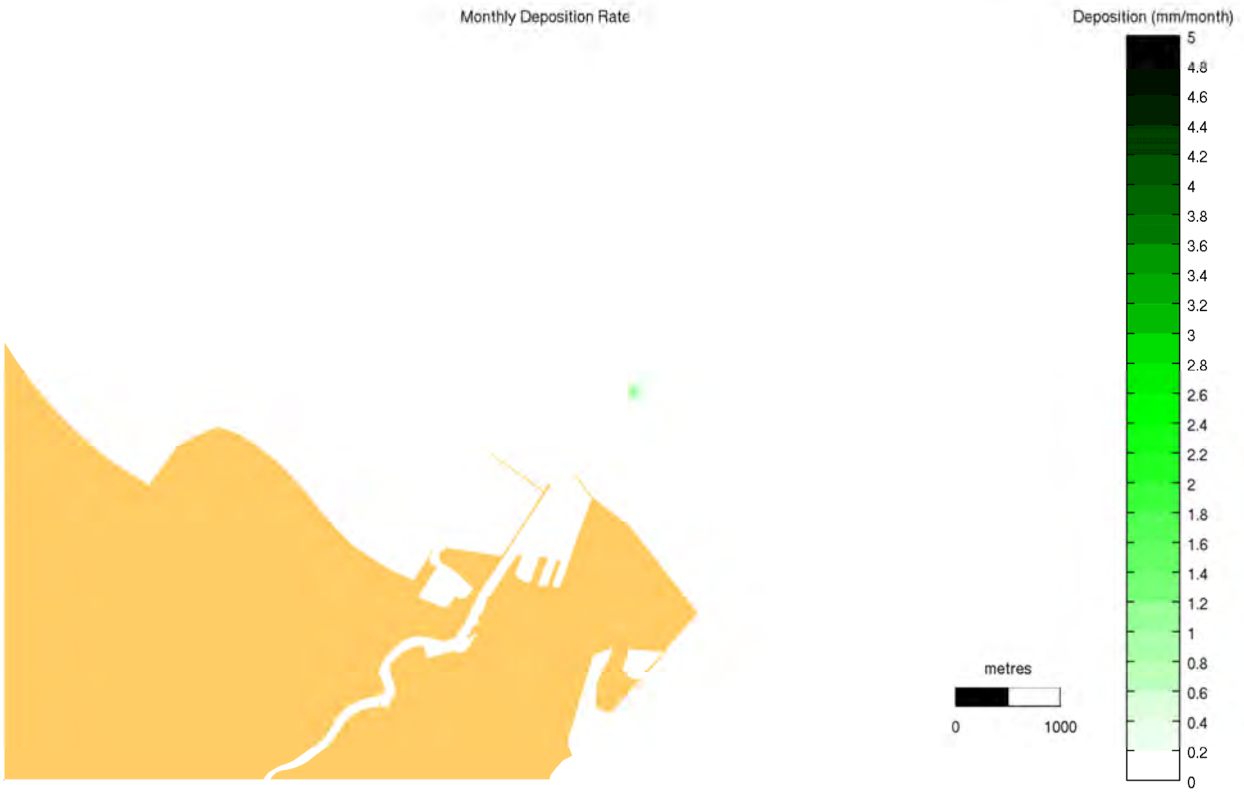


Figure 6-4 Scenario 1a – Modelled Sediment Deposition Rate (mm/month)

Figure 6-5 Scenario 1b –Modelled Sediment Deposition Rate (mm/month)

6.2.2 SCENARIO 2A AND 2B

This scenario involves rock placement at the north east breakwater and north & north east revetments (1a) and rock placement at the western breakwater (1b). Since the geographic extent and magnitude of plume concentrations is very small, only the 1% exceedance plots are presented. Figure 6-6 and Figure 6-7 present the above background TSS exceeded for 1% of the simulation period in scenarios 2a and 2b respectively. Figure 6-8 and Figure 6-9 present the total deposition thickness over the one month simulation period.

Figure 6-6 shows the modelled above-background TSS exceeded for 1% of the time during rock placement at the north-east breakwater (Scenario 2a). The area that experiences above-background TSS levels greater than 5mg/L for 1% of the time is mostly within about 400m of the existing revetment.

Figure 6-7 shows the above-background TSS exceeded for 1% of the time during rock placement at the western breakwater. The area that experiences above-background TSS levels greater than 5mg/L for 1% of the time is primarily to the west and south-west of the western breakwater.

Figure 6-8 shows the modelled deposition of sediment deposited during the one month simulation period during rock placement at the north-east breakwater. Deposition occurs primarily in the vicinity of the dredge and the dredged areas near the marine precinct and the existing outer harbour. The maximum deposition rate is approximately 2.8mm/month at the dredge location.

Figure 6-9 shows the modelled deposition of sediment deposited during the one month simulation period during rock placement at the western breakwater. The sediment deposition during this dredging activity is limited to two small areas on either side of the existing breakwater and the maximum deposition thickness is approximately 2mm/month to the west of the existing breakwater.

Figure 6-6 Scenario 2a - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Simulation Period

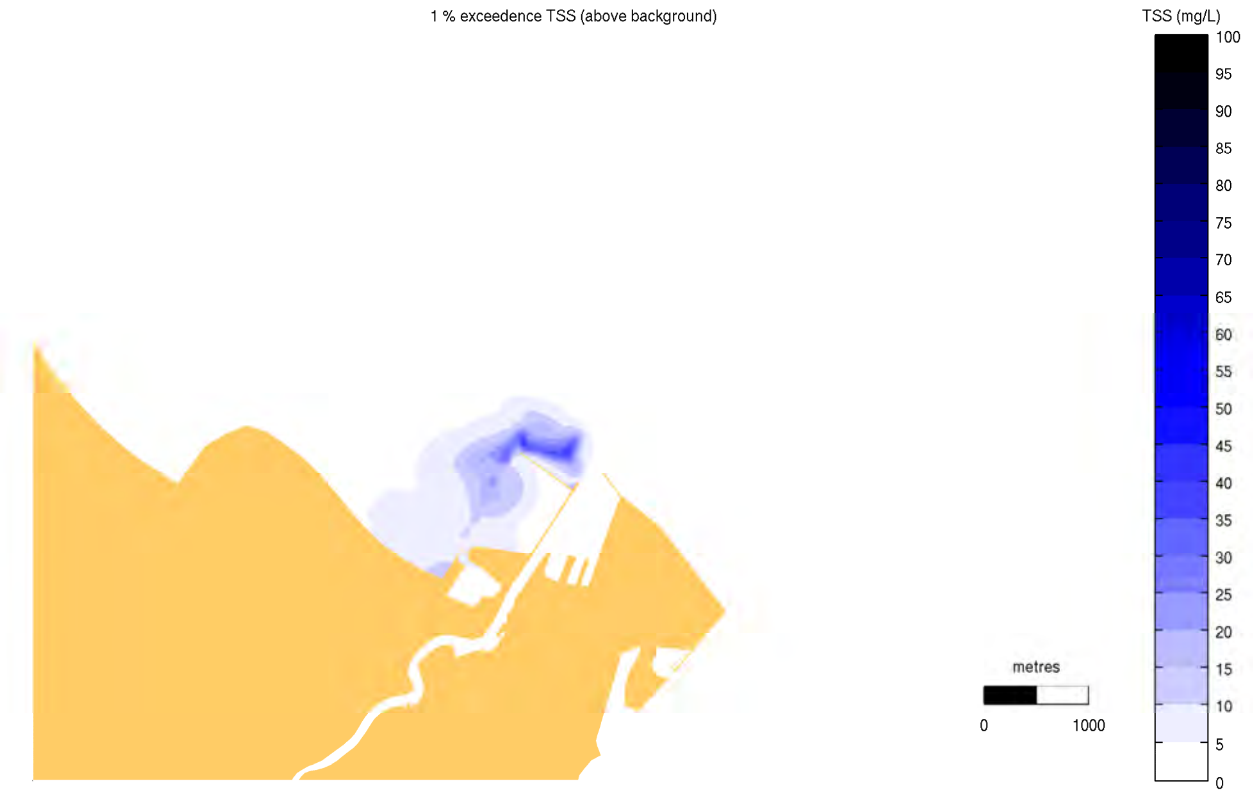


Figure 6-7 Scenario 2b - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Simulation Period

Figure 6-8 Scenario 2a – Modelled Sediment Deposition Rate (mm/month)

Figure 6-9 Scenario 2b – Modelled Sediment Deposition Rate (mm/month)

6.2.3 SCENARIO 3A

This scenario involves a small Trailing Suction Hopper Dredge removing soft surface sediments in the outer harbour.

The 1%, 5% and 50% exceedance plots are presented in Figure 6-10, Figure 6-11 and Figure 6-12 respectively. The model results show that the impacts of a TSHD removing soft surface sediments in the outer harbour are localised and the sediment plumes do not extend far beyond the confines of the port. The above background TSS exceeded for 1% of the time is less than 10mg/L outside the Project Area. The area affected by 1% exceedance TSS levels above 5mg/L is limited to within 900m of the northern end of the new breakwater.

Figure 6-13 presents the total deposition thickness over the one month simulation period. The model results indicate that the impacts of a TSHD removing soft surface sediments in the outer harbour are localised and the modelled deposition rate outside of the project area is less than 2mm/month.

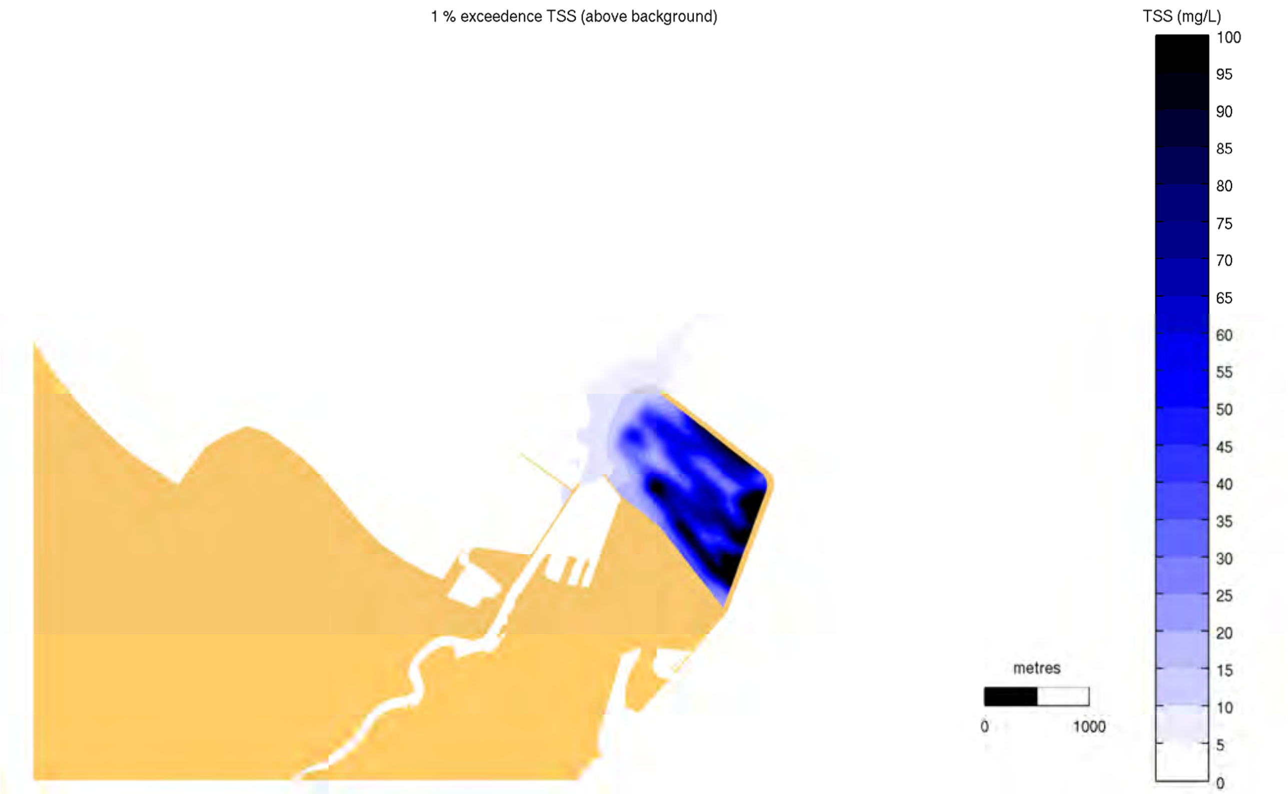


Figure 6-10 Scenario 3a - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Simulation Period

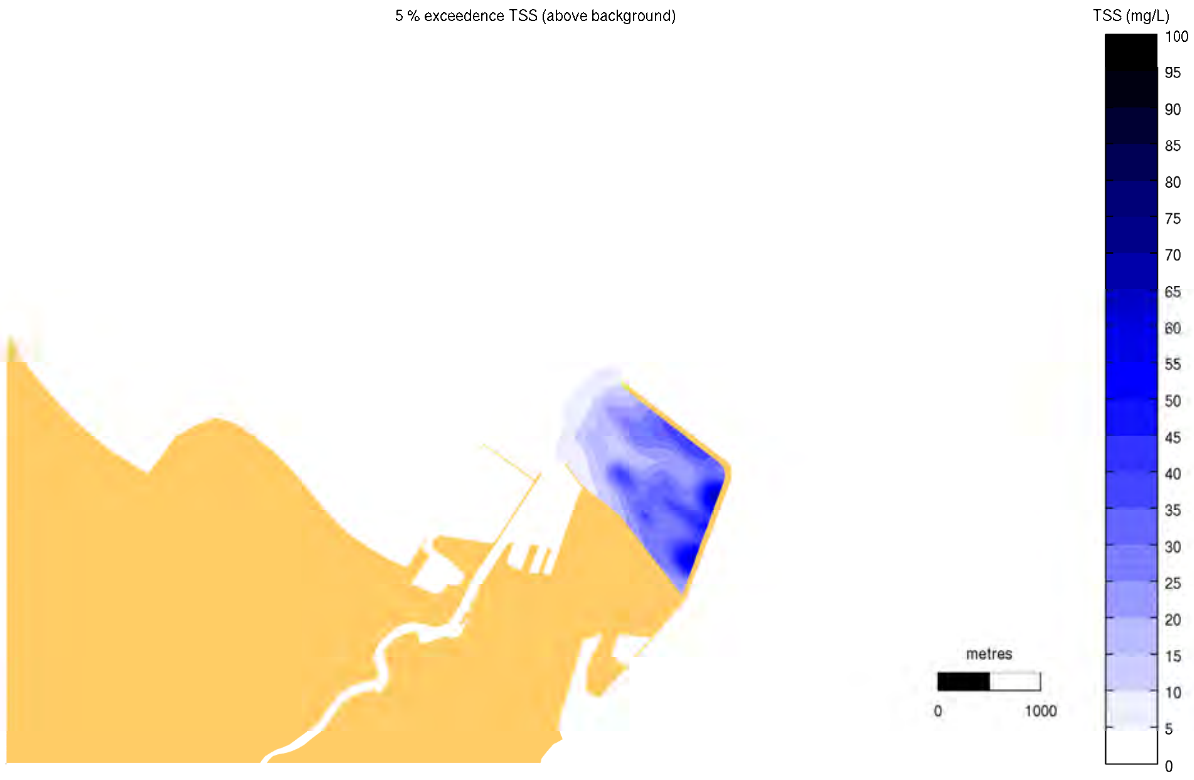


Figure 6-11 Scenario 3a - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 5% of the Simulation Period

Figure 6-12 Scenario 3a - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 50% of the Simulation Period

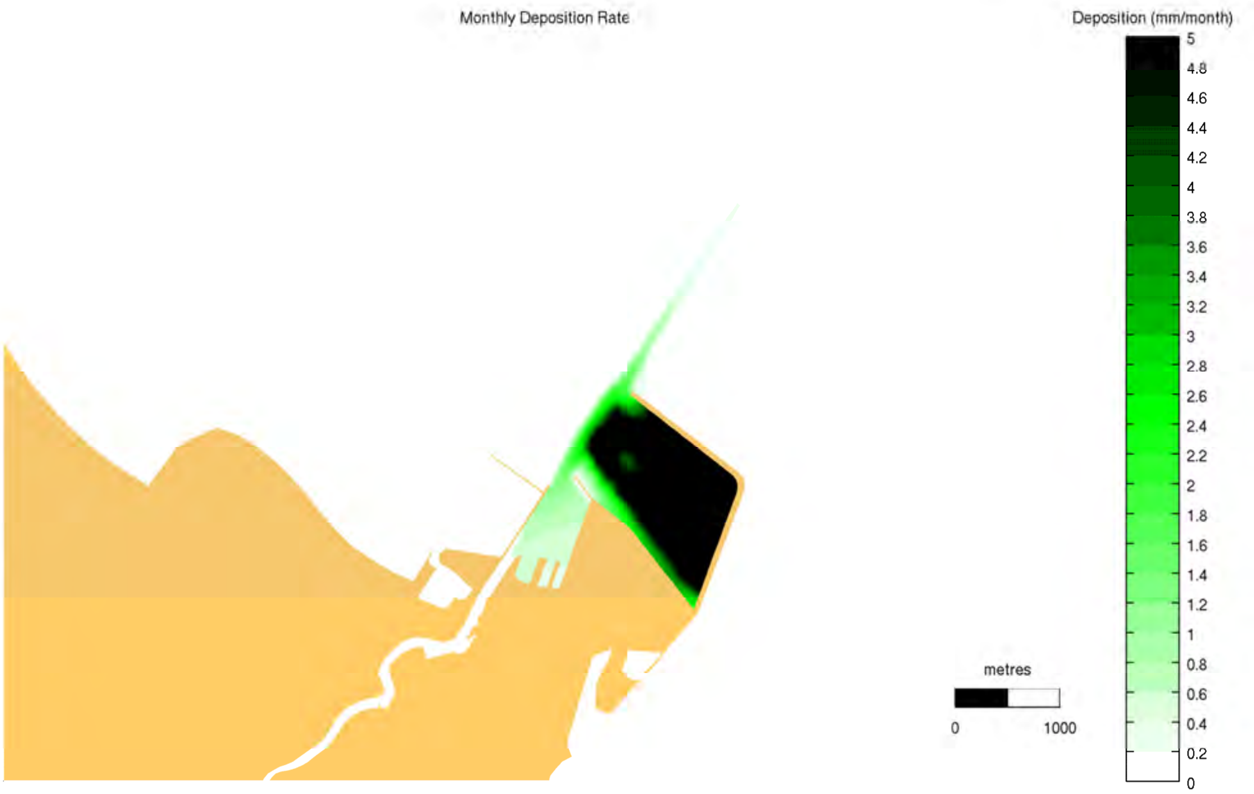


Figure 6-13 Scenario 3a – Modelled Sediment Deposition Rate (mm/month)

6.2.4 SCENARIO 4C

This scenario involves a medium CSD operating in the outer harbour, and a mechanical dredge widening the channel on the approaches to the outer harbour.

Figure 6-14 shows the levels of above background TSS exceeded for 1% of the one month simulation period. Impacts are restricted to very small areas in the vicinity of the CSD and the tailwater discharge location.

Figure 6-15 shows the modelled monthly deposition rate associated with this dredging activity. The impacts are restricted to the confines of the channel.

Figure 6-14 Scenario 4c - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Simulation Period

Figure 6-15 Scenario 4c – Modelled Sediment Deposition Rate (mm/month)

6.2.5 SCENARIO 4D

This scenario involves a medium CSD operating in the outer harbour, and a mechanical dredge widening the channel on the approaches to the outer harbour, with the western breakwater in place. The 1% exceedance plot is presented in Figure 6-16. Figure 6-17 presents the total deposition thickness over the one month simulation period. There is no significant difference in the results for Scenario 4b compared to Scenario 4a (the influence of the western breakwater is negligible).

Figure 6-16 Scenario 4d - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Simulation Period

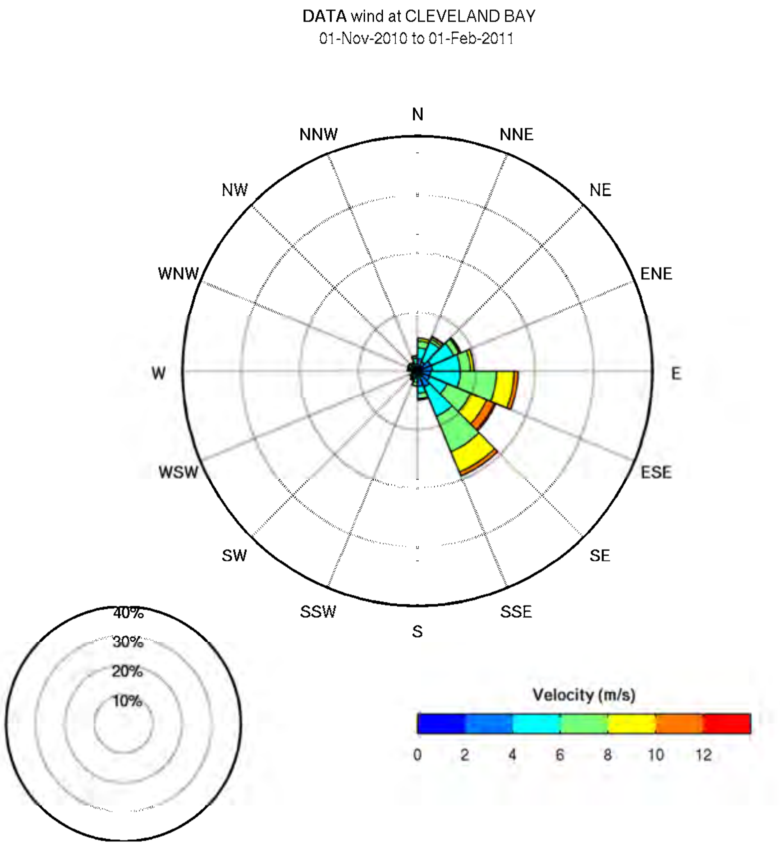
Figure 6-17 Scenario 4d – Modelled Sediment Deposition Rate (mm/month)

6.3 CHANNEL DREDGING SCENARIOS

The TSHD operating in the channel involves the largest rate of release of fine sediment to Cleveland Bay and has the greatest potential to cause impacts to sensitive receiving environments. For this reason, the entire channel dredging program was simulated, during representative summer and winter periods.

The summer period used for modelling purposes (Scenario 4a) was 1/11/2010 to 1/02/2011. The wind and wave roses for this period are shown in Figure 6-18. The conditions during this period were similar to the average conditions during 2008 to 2011 (shown in Figure 4-3) and are consistent with long term (1998-2011) summer wind records from the Townsville Aero weather station.

The winter period used for modelling purposes (Scenario 4b) was 1/05/2010 to 1/08/2010. The wind and wave roses for this period are shown in Figure 6-19. The wave conditions during this period included a greater proportion of E-ESE waves than the average conditions during the period 2008 to 2011 (shown in Figure 4-3). The selected winter period wind conditions are consistent with the long term (1998-2011) winter wind records from the Townsville Aero weather station. The wind speed and wave energy are greater overall for the winter period than for the summer period, and this is shown in subsequent model results to have implications for dredge plume material resuspension.



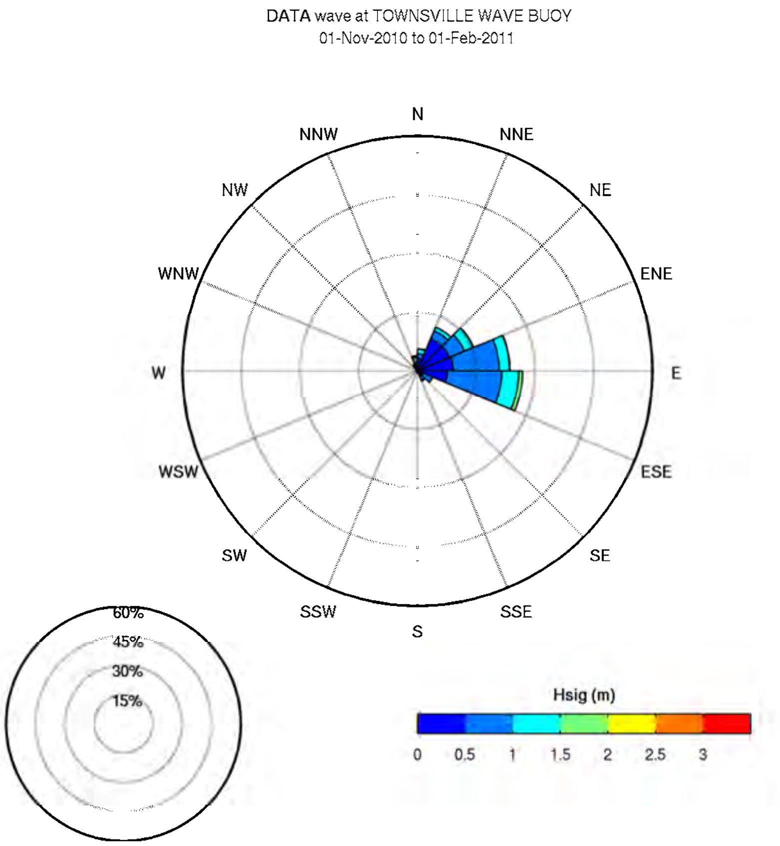
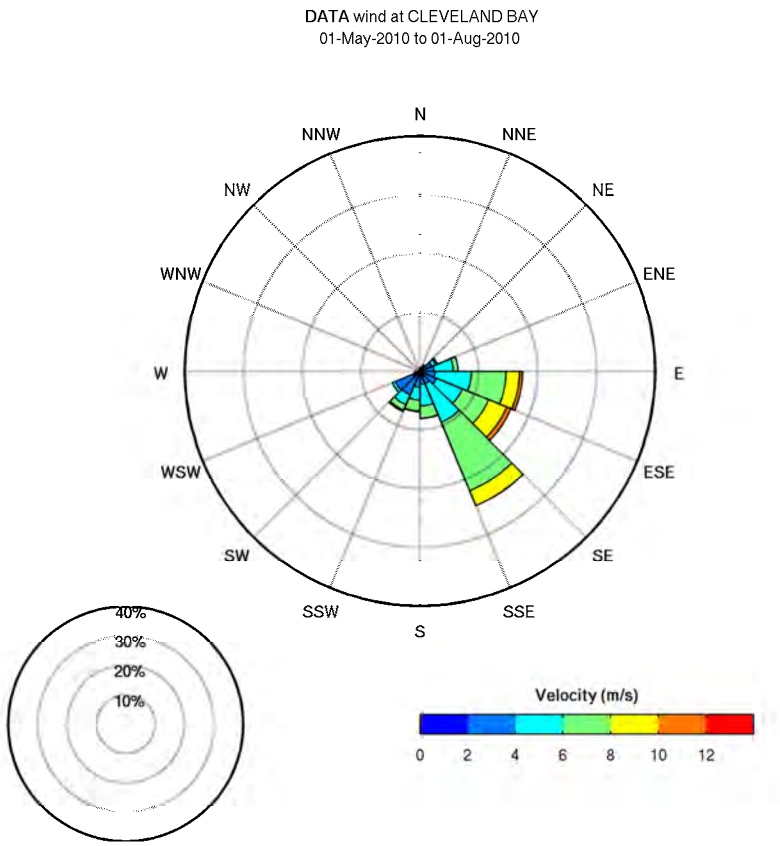


Figure 6-18 Wind (top) and Wave (bottom) Roses for the Summer Period 1/11/2010 to 1/02/2011



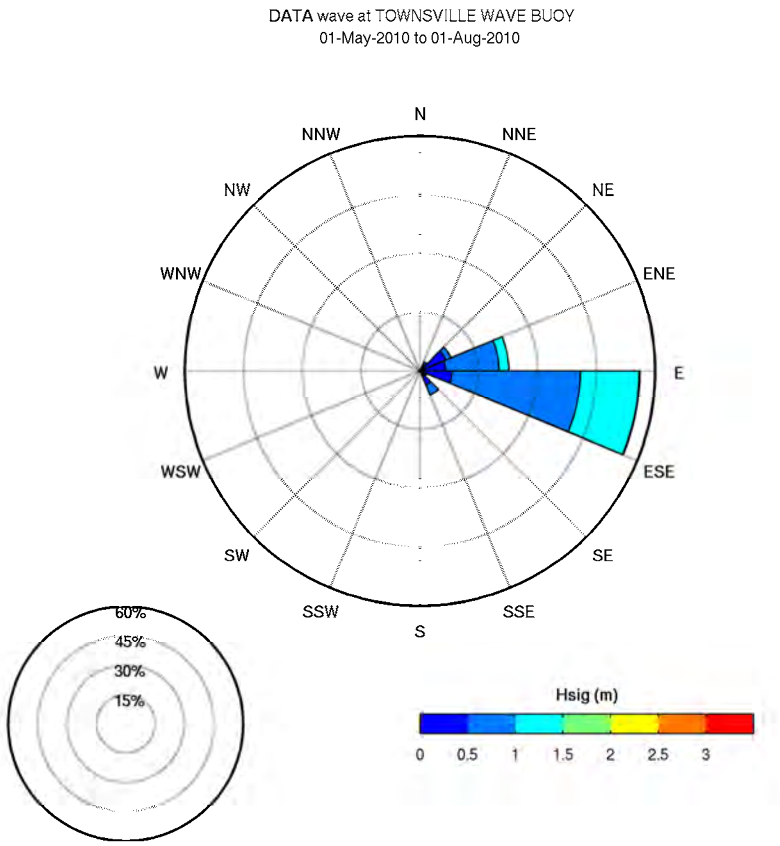


Figure 6-19 Wind (top) and Wave (bottom) Roses for the Winter Period 1/05/2010 to 1/08/2010

The sediment composition for modelling purposes was determined according to the bulk average sediment properties in the relevant section of the channel, derived from bore logs. The proposed deepening of the channel in Stage C of the Port Expansion Project was selected for the impact assessment modelling, since it involves a northward extension of the channel. However, the impact assessment is valid for the Stage A channel works as well due to the similar length and production volumes involved.

The channel dredging operation was divided into four sections, shown conceptually in Figure 6-20. For the purposes of the impact assessment presented here, it was assumed that the dredge undertakes dredging tracks in these sections in a repeating sequence A, B, C, D, A, B, C, D, A, B etc.. The cycle time for each track was estimated based on the likely dredging speed and the types of sediments likely to be encountered in each section. Since the borehole data indicated mostly soft surface sediments in section ‘A’, the dredge track was shorter (reflecting the shorter time taken to fill the dredge) and therefore there were three alternate dredge tracks in this section.

The sediment discharge rates for each potential source of turbidity (drag head, overflow / propeller wash and placement at the DMPA) were estimated based on the expected plume dimensions and concentrations provided to BMT WBM by AECOM and its dredging consultants. The source rates and vertical distributions used in the channel dredging simulations are provided in Table 6-2.

The combined drag head, overflow and propeller wash discharge rate of 300kg/s was somewhat higher than the source rate derived for the TSHD ‘Brisbane’ in the dredge plume validation assessment presented in Section 3.3 (250kg/s).

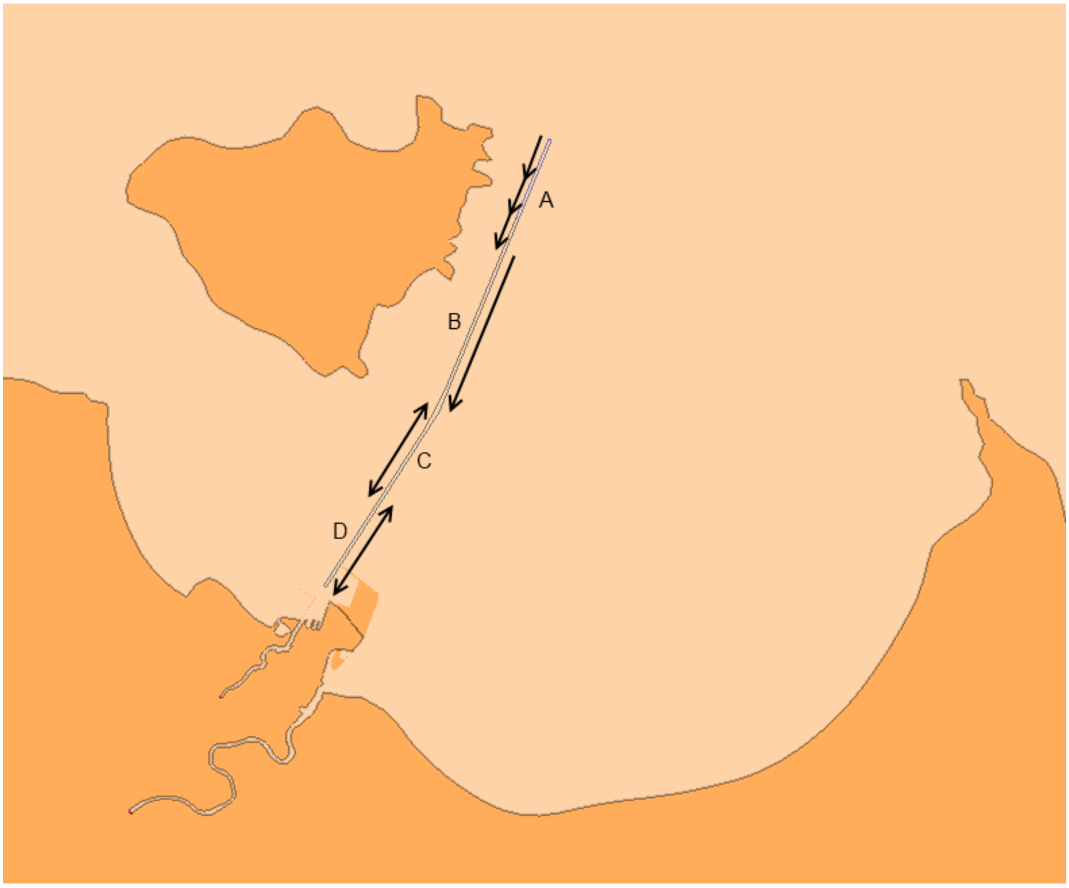


Figure 6-20 Dredge Tracks Used for Channel Dredging Scenarios

6.3.1 SCENARIO 4A

This scenario involved a medium TSHD operating in the Sea Channel and Platypus Channel for an 11.5 week campaign during a summer period (1/11/2010 to 20/1/2011).

Typical model snapshots of above-background Total Suspended Solids (TSS) levels during the channel dredging campaign are shown in Figure 6-21 and Figure 6-22.

In the top panel of Figure 6-21, the dredge has just completed overflow dredging in Section A (the northern end of the Sea Channel to the east of Magnetic Island) and residual plumes are present near the Port and to the west of Platypus Channel.

In the bottom panel of Figure 6-21, the dredge has just completed overflow dredging in Section B (the southern end of the Sea Channel) and residual plumes remain near the Port and to the west of Platypus Channel.

In the top panel of Figure 6-22, the dredge has just completed overflow dredging in Section C (the northern end of the Platypus Channel) and residual plumes are present between Magnetic Island and the mainland, adjacent to the Port and to the east of Magnetic Island.

In the bottom panel of Figure 6-22, the dredge has just completed overflow dredging in Section D (the southern end of the Platypus Channel) and residual plumes are present to the south east of Magnetic Island, and along the coast towards Cape Pallarenda.

Figure 6-23 shows the modelled levels of above background TSS exceeded for 1% of the time during the dredging campaign. The overflow and propeller wash from the TSHD is the dominant source of the plume material. The large spatial extent of the area of influence is partly due to resuspension of previously settled dredged material during periods of increased wave energy. Above-background TSS levels of greater than 5mg/L are experienced for 1% of the time over a wide area including the channel between Magnetic Island and the mainland. The 1% exceedance TSS drops to less than 60mg/L within 500 metres of the edge of the Platypus Channel.

Figure 6-24 and Figure 6-25 show the levels of above background TSS exceeded for 5% and 50% of the time during the dredging campaign. The smaller area influenced by plumes at these percentage levels reflects the large temporal variation in TSS levels, which is also seen in the time series in Attachment D.

Figure 6-26 shows the modelled rate of sediment deposition during the dredging campaign. The rate of sediment deposition drops to below 5mm per month within a few hundred metres of the channel.

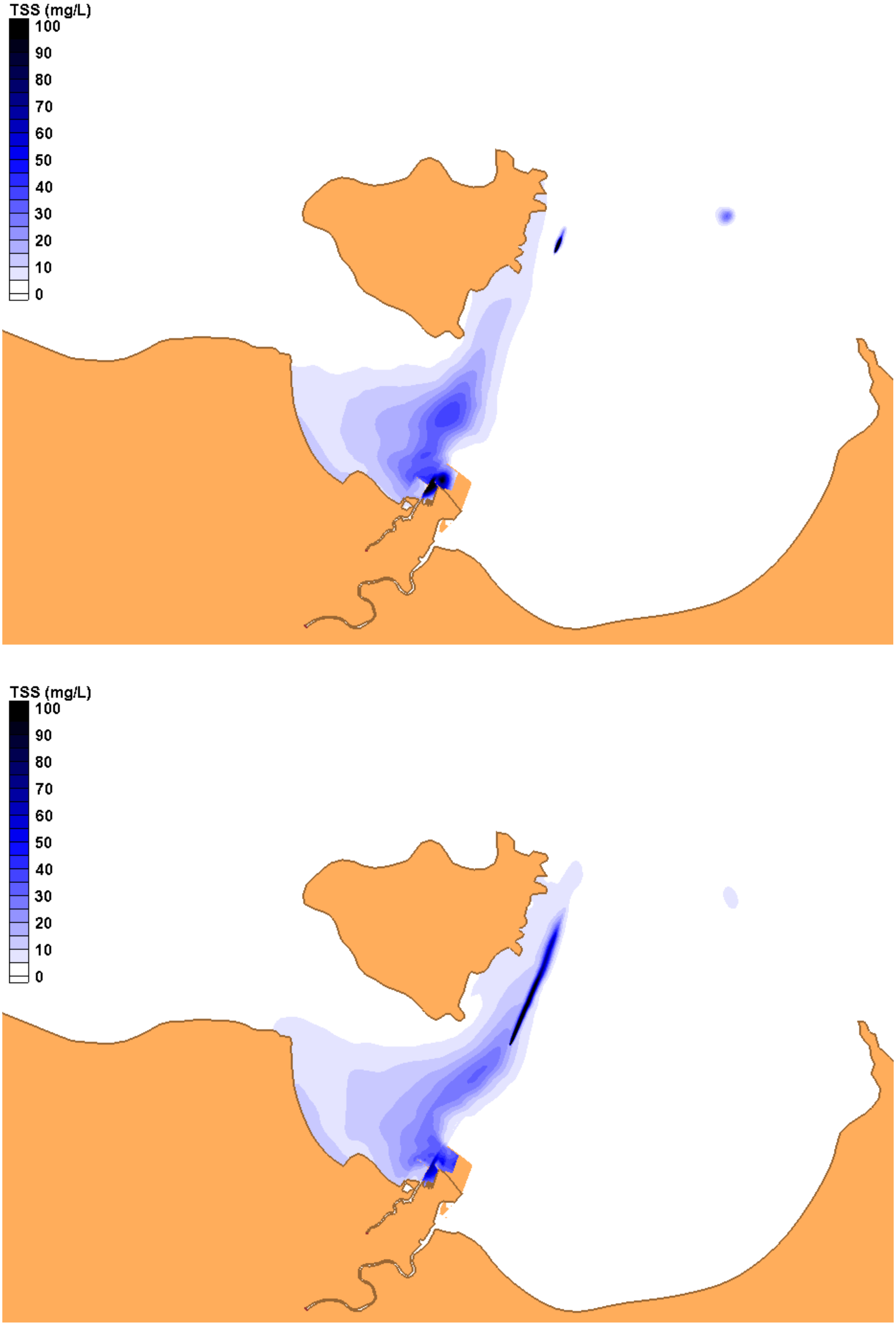


Figure 6-21 Snapshots of Above-Background TSS during TSHD Channel Dredging (Top - 11:00 8/11/2010; Bottom – 16:00 8/11/2010)

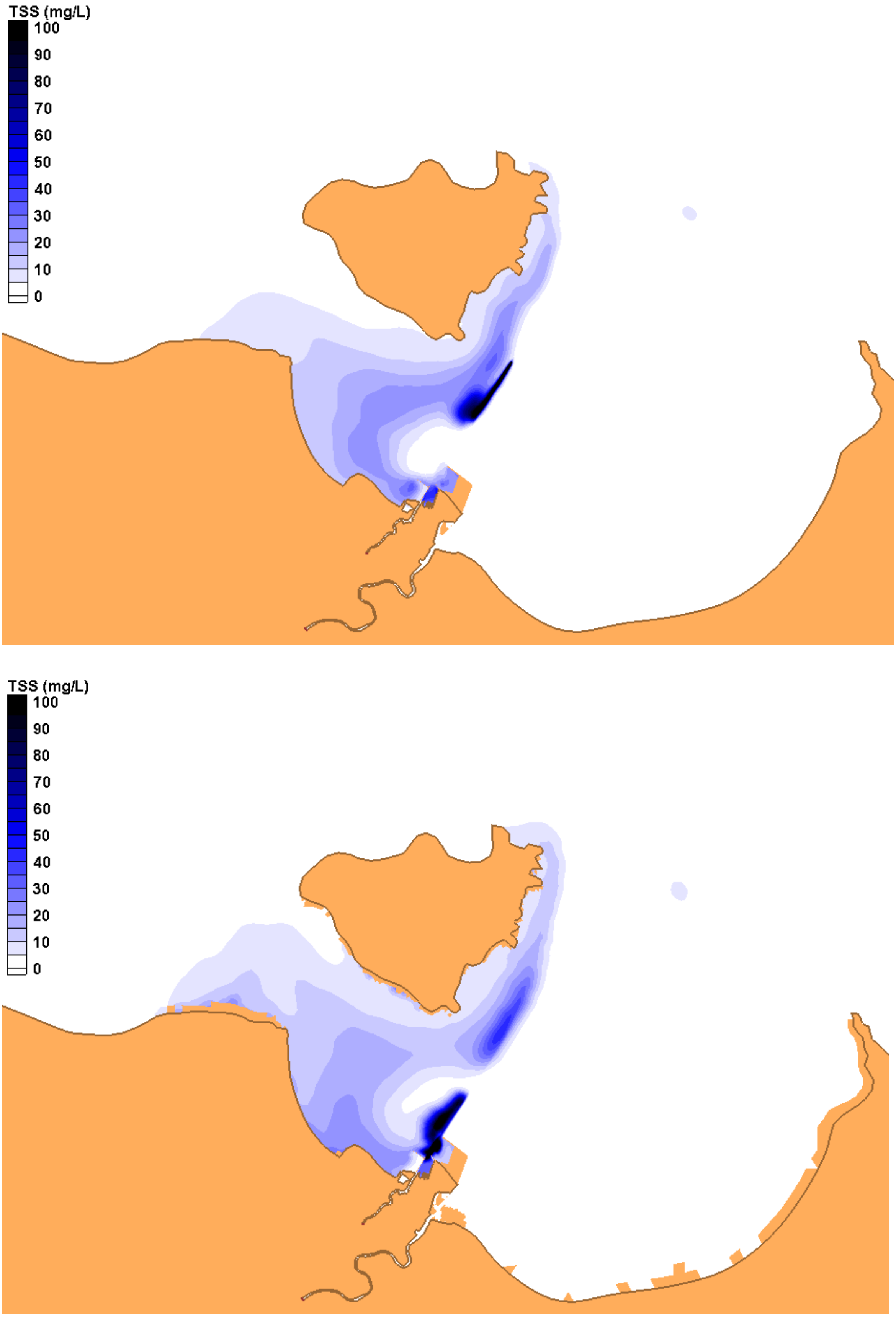


Figure 6-22 Snapshots of Above-Background TSS during TSHD Channel Dredging (Top - 23:00 8/11/2010; Bottom – 06:00 9/11/2010)

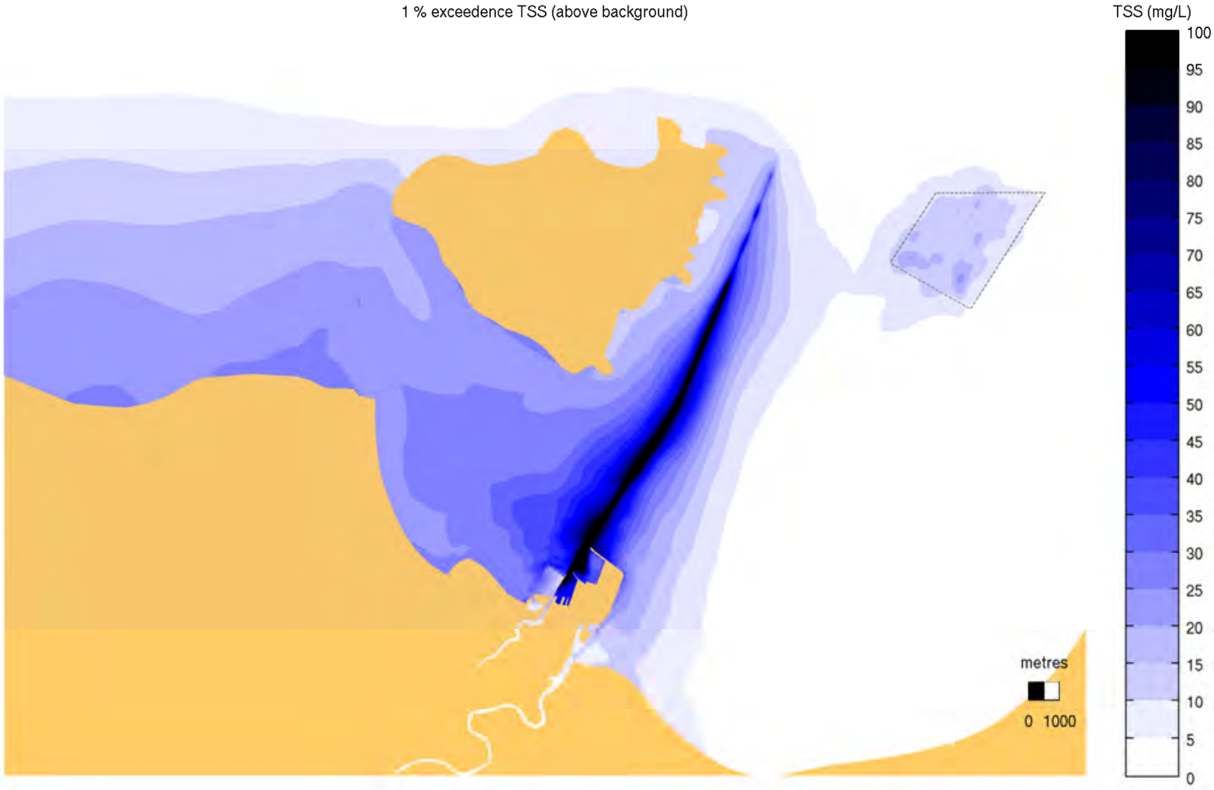


Figure 6-23 Scenario 4a - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Summer Simulation Period

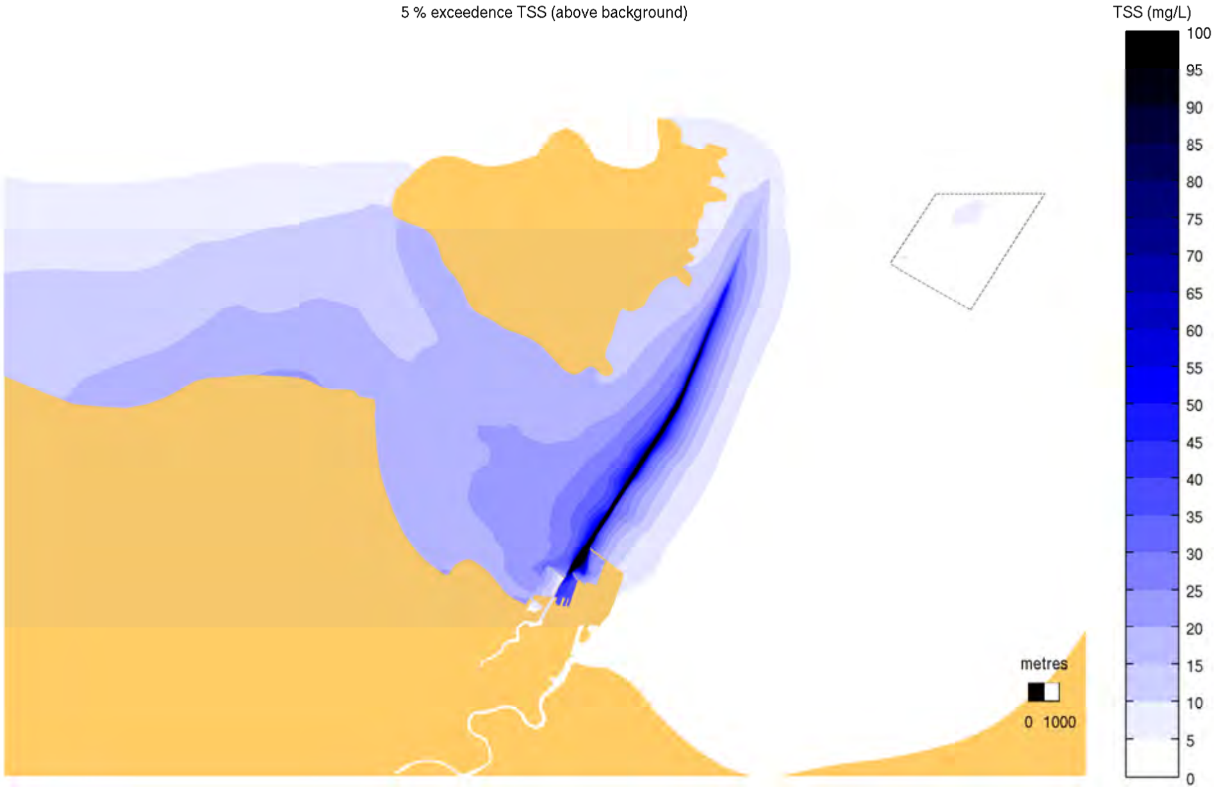


Figure 6-24 Scenario 4a - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 5% of the Summer Simulation Period

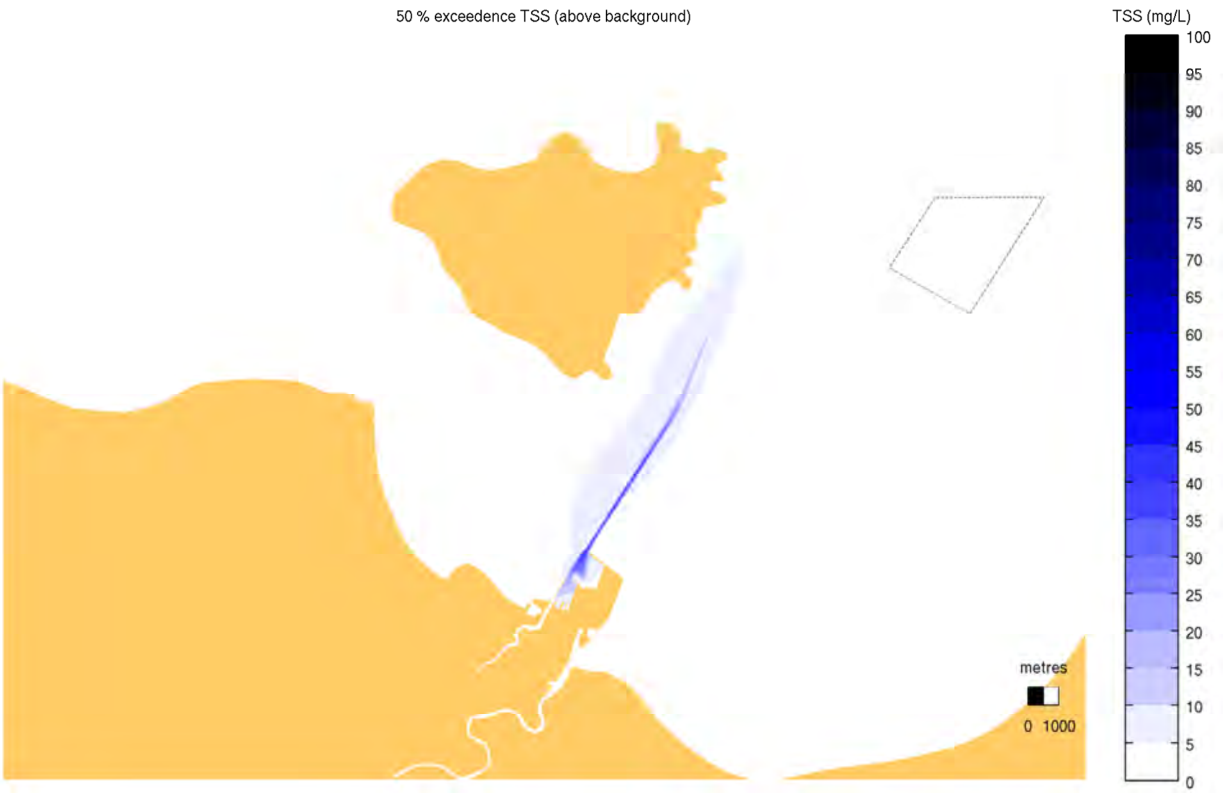


Figure 6-25 Scenario 4a - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 50% of the Summer Simulation Period

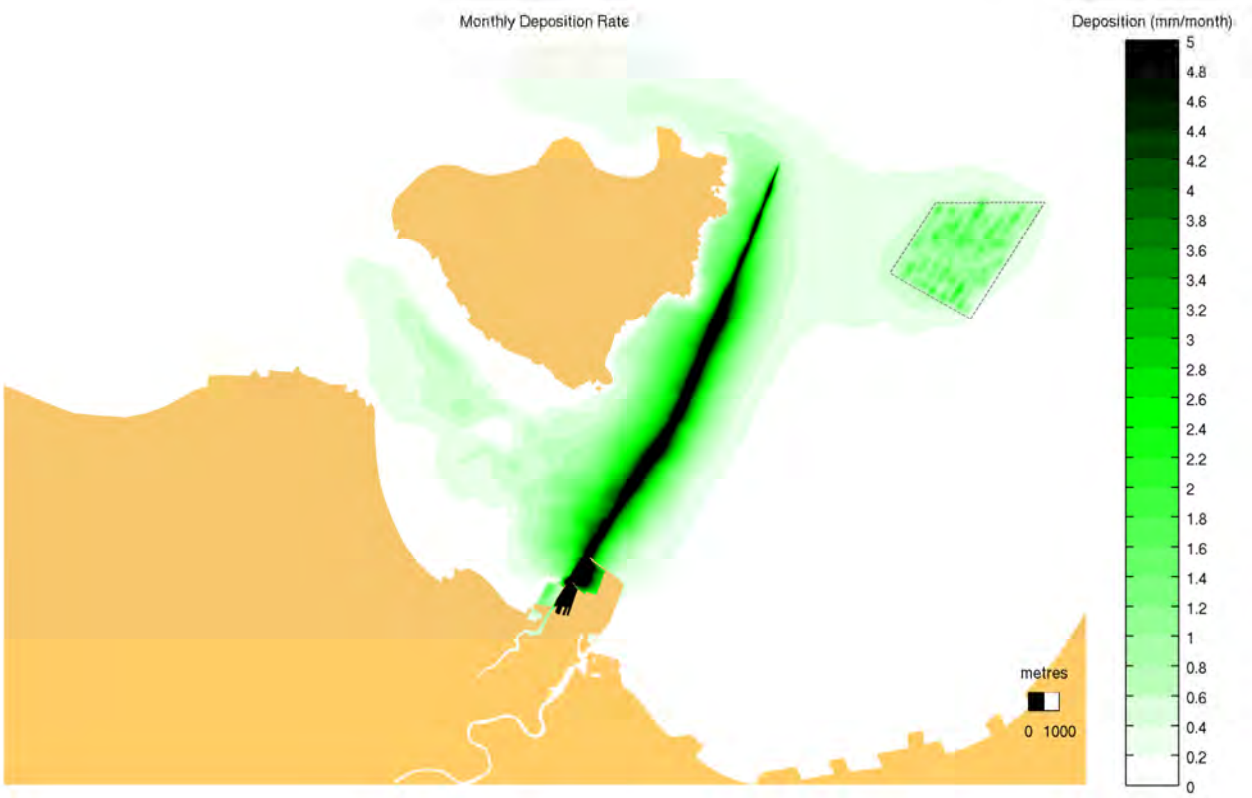


Figure 6-26 Scenario 4a – Modelled Sediment Deposition Rate during the Summer Simulation Period (mm/month)

6.3.2 SCENARIO 4B

This scenario involved a medium TSHD operating in the Sea Channel and Platypus Channel for an 11.5 week campaign during a winter period (1/5/2010 to 20/7/2010).

Figure 6-29 shows the levels of above-background TSS exceeded for 1% of the time during the dredging campaign. It should be noted that the 1% exceedance level is only experienced for a very short time and is almost equal to the maximum level experienced during the simulation period. The overflow and propeller wash from the TSHD is the dominant source of the plume material. Above-background TSS levels of greater than 5mg/L are experienced for 1% of the time over a wide area including the channel between Magnetic Island and the mainland. The 1% exceedance TSS drops to less than 60mg/L within 1000 metres of the edge of the Platypus Channel.

The above-background TSS level model results for the winter simulation period were generally higher than the results for the summer period. This was largely due to the timing and magnitude of wave-related resuspension events. Figure 6-27 illustrates the time series of significant wave height for the summer and winter simulation periods at a point near Cape Pallarenda. The winter period includes a relatively calm period up to the end of June, by which time a significant amount of dredge material has been input to the model and has settled out. When the wave height increases towards the end of June, this material is mostly resuspended, and contributes to higher levels of above-background TSS. Figure 6-28 shows the corresponding time series of above-background TSS at the same point during the summer and winter periods. The higher levels in the winter simulation period are largely associated with the timing of the wave-related resuspension events. It is noted, therefore, that the results are sensitive to the choice of modelling period. However the impact assessment is robust due to the large range of meteorological conditions included within the chosen modelling period.

Figure 6-30 and Figure 6-31 show the levels of above background TSS exceeded for 5% and 50% of the time during the dredging campaign. The smaller area impacted at these percentage levels reflects the large temporal variation in TSS levels, which is also seen in the time series in Attachment D.

Figure 6-32 shows the modelled rate of sediment deposition during the dredging campaign. The rate of sediment deposition drops to below 5mm per month within a few hundred metres of the channel.

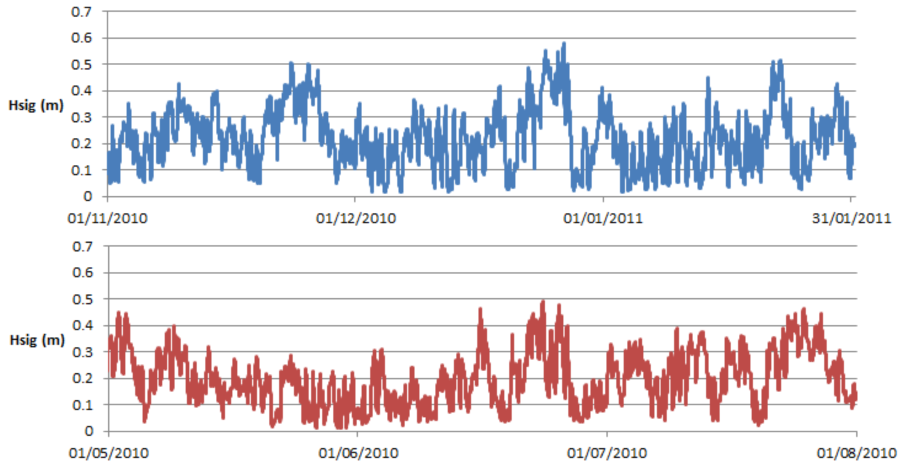


Figure 6-27 Modelled Significant Wave Height Time Series for the Summer (Top) and Winter (Bottom) Periods near Cape Pallarenda (Site 8)

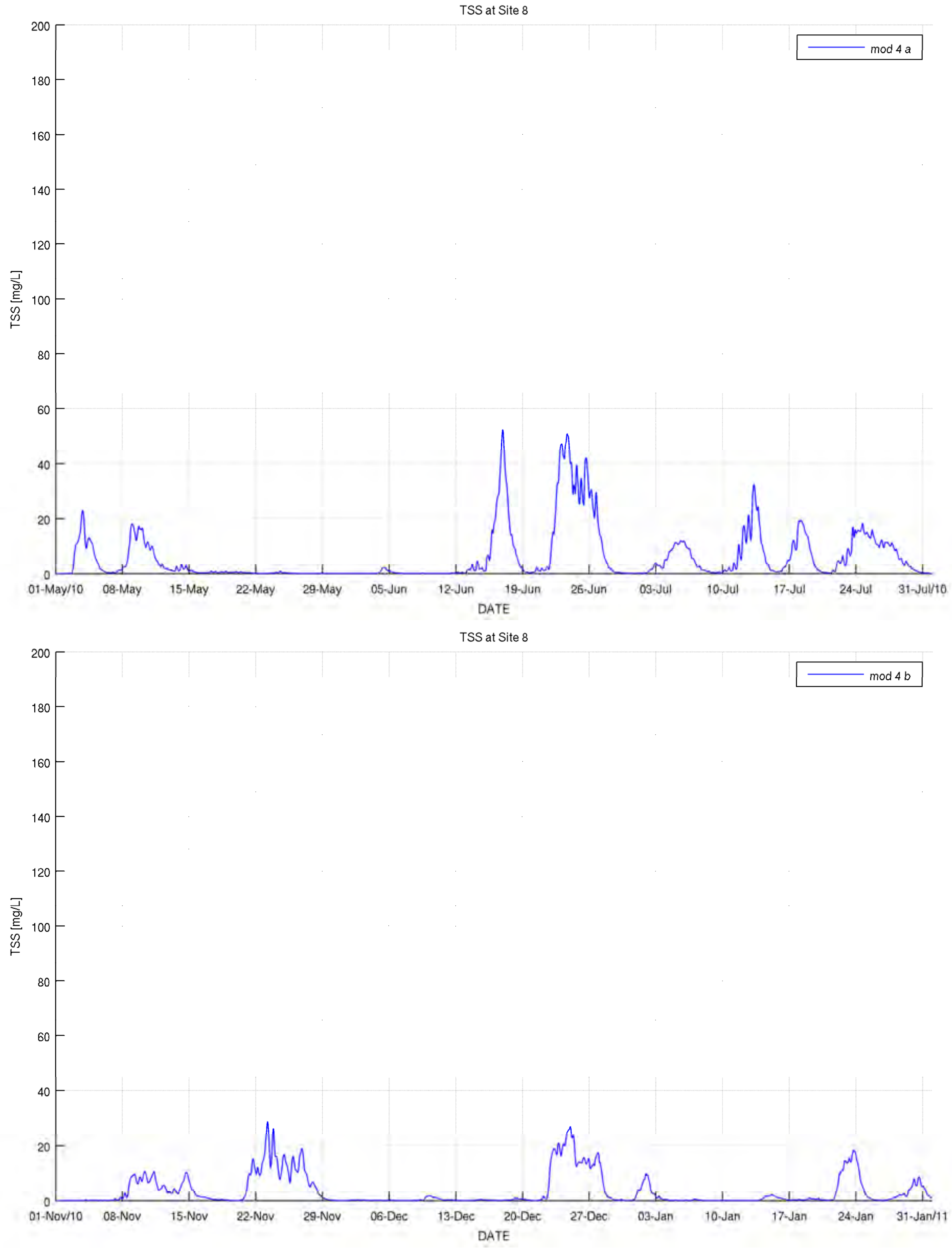


Figure 6-28 Time Series of Above-Background Total Suspended Solids near Cape Pallarenda (Site 8) Showing the Effects of Wave Resuspension of Previously Deposited Dredge Material Top Panel – Winter Bottom Panel - Summer

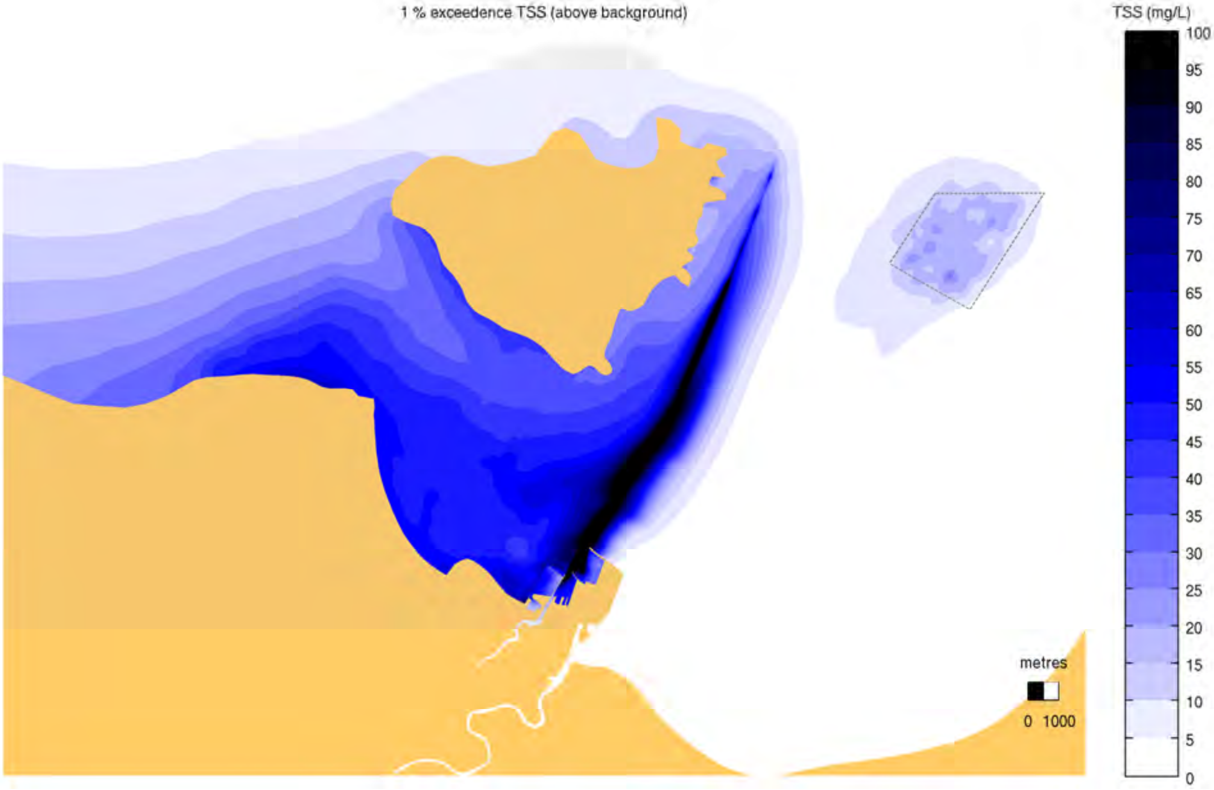


Figure 6-29 Scenario 4b - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Winter Simulation Period

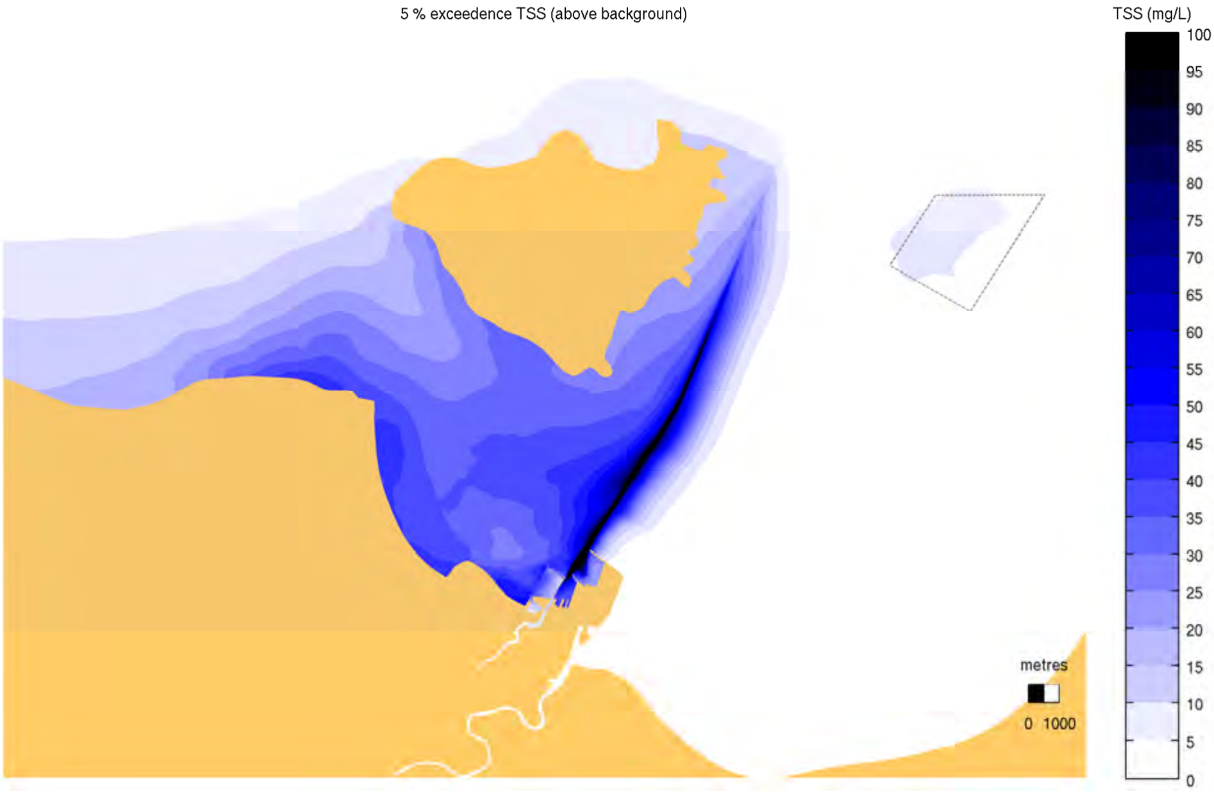


Figure 6-30 Scenario 4b - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 5% of the Winter Simulation Period

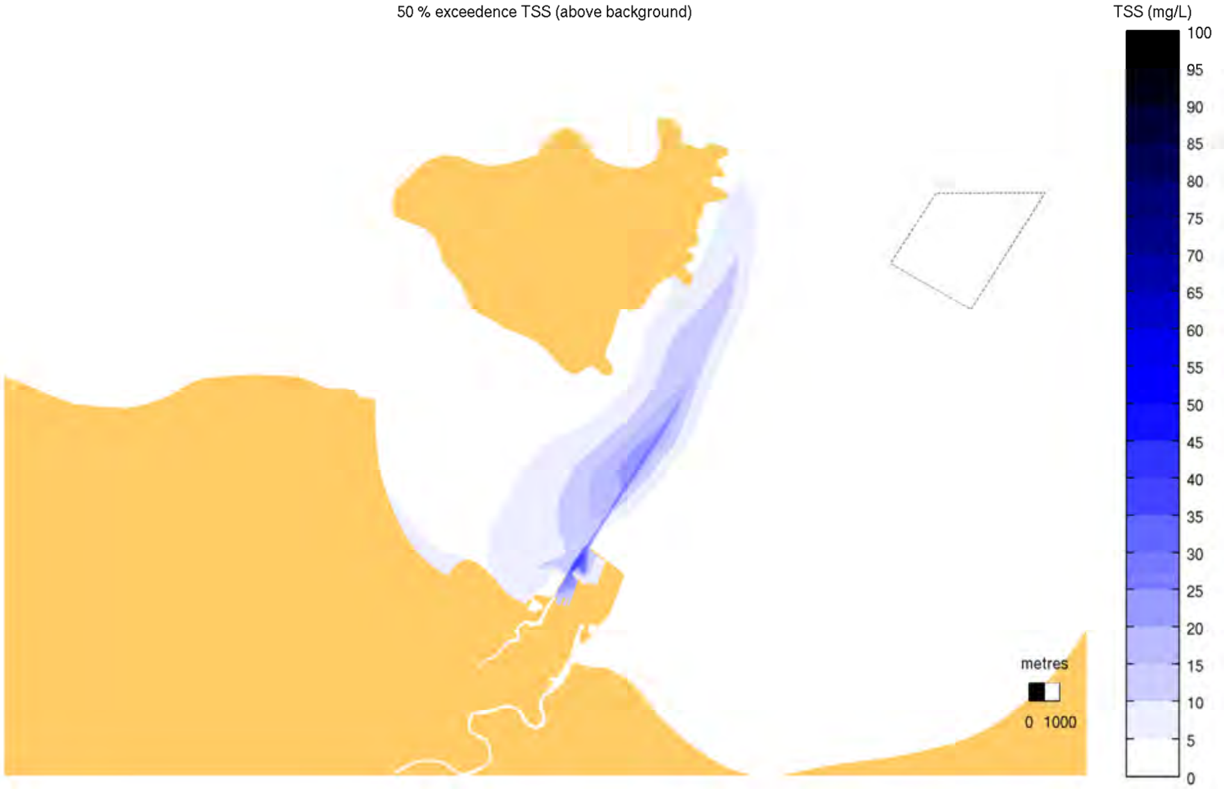


Figure 6-31 Scenario 4b - Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 50% of the Winter Simulation Period

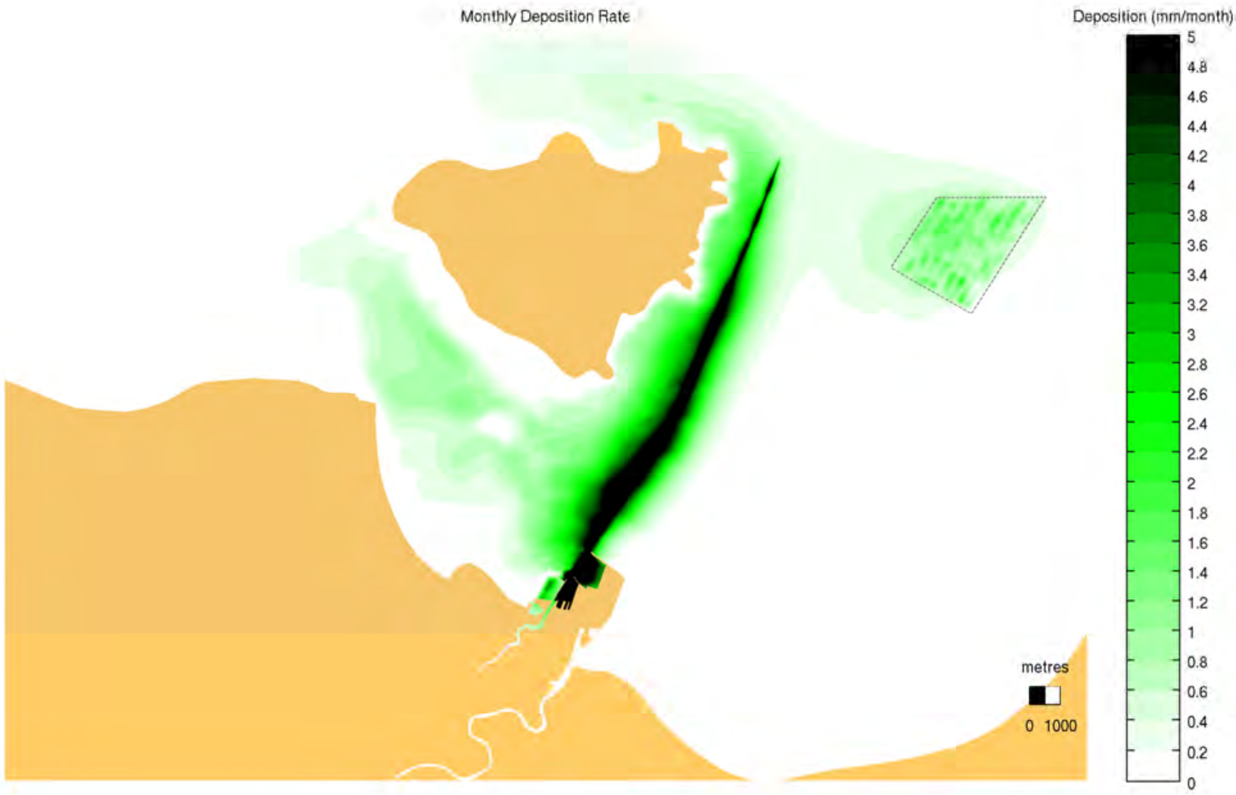


Figure 6-32 Scenario 4b – Modelled Sediment Deposition Rate during the Winter Simulation Period (mm/month)

6.3.3 SENSITIVITY ANALYSIS – NORTHERLY WIND SCENARIO

To assess the potential impact of dredging during a period of sustained strong northerly winds, the TSHD channel dredging was simulated for the period 30/01/2010 to 13/02/2010. The wind and wave roses for this period are shown in Figure 6-33. The 1%, 5% and 50% exceedance plots are presented in Figure 6-34, Figure 6-35 and Figure 6-36 and the sediment deposition rate is presented in Figure 6-37.

Despite the prevalent northerly wind condition, the plume impacts do not extend very far to the south and south east of the channel. The reason for the limited areal extent of the plume impacts (comparing Figure 6-34 with Figure 6-23, for example) is primarily due to the shorter simulation period and therefore reduced total volume of dredged sediment available for resuspension. The conclusion can be drawn that sensitive receptors along the southern and eastern coastlines of Cleveland Bay are unlikely to be affected by sediment plumes generated by dredging during the channel deepening campaign.

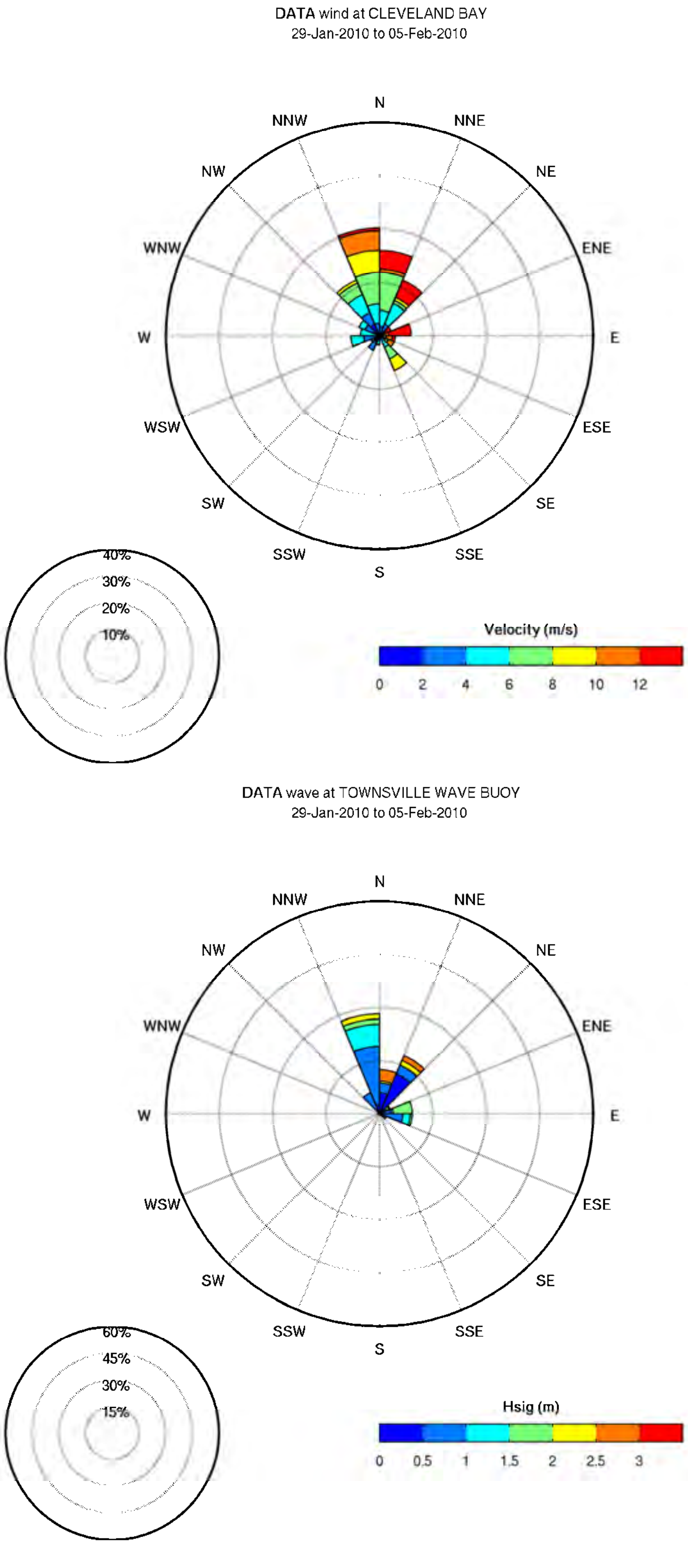


Figure 6-33 Wind (top) and Wave (bottom) Roses during the Period 30/01/2010 to 05/02/2010

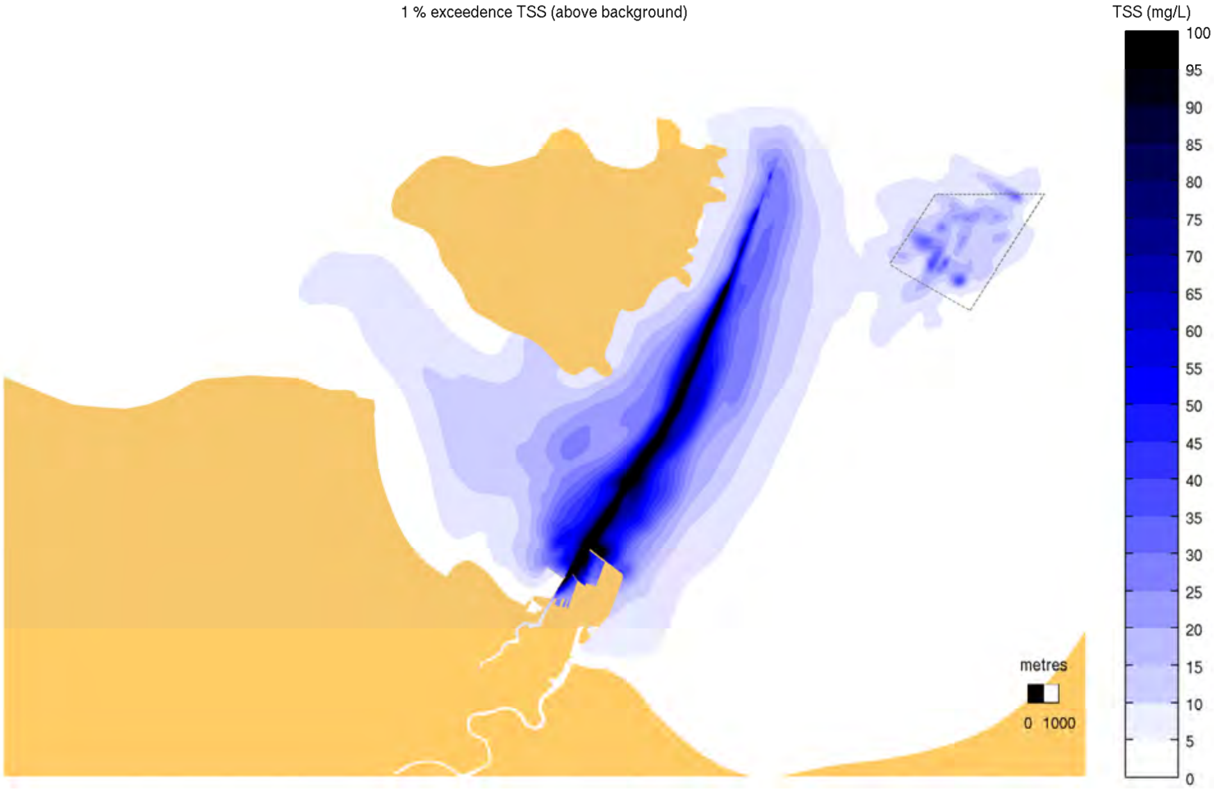


Figure 6-34 Northerly Wind Channel Dredging Scenario (Modified 4a) – Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Simulation Period

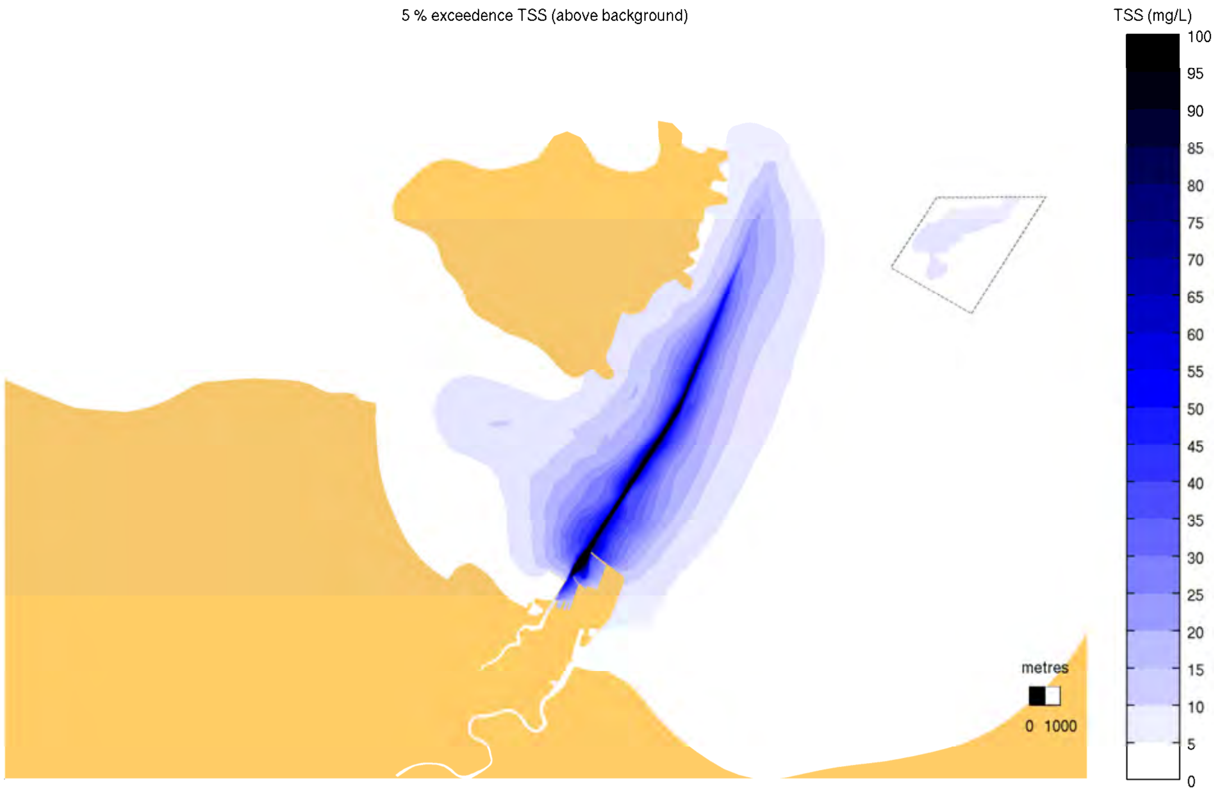


Figure 6-35 Northerly Wind Channel Dredging Scenario (Modified 4a) – Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 5% of the Simulation Period

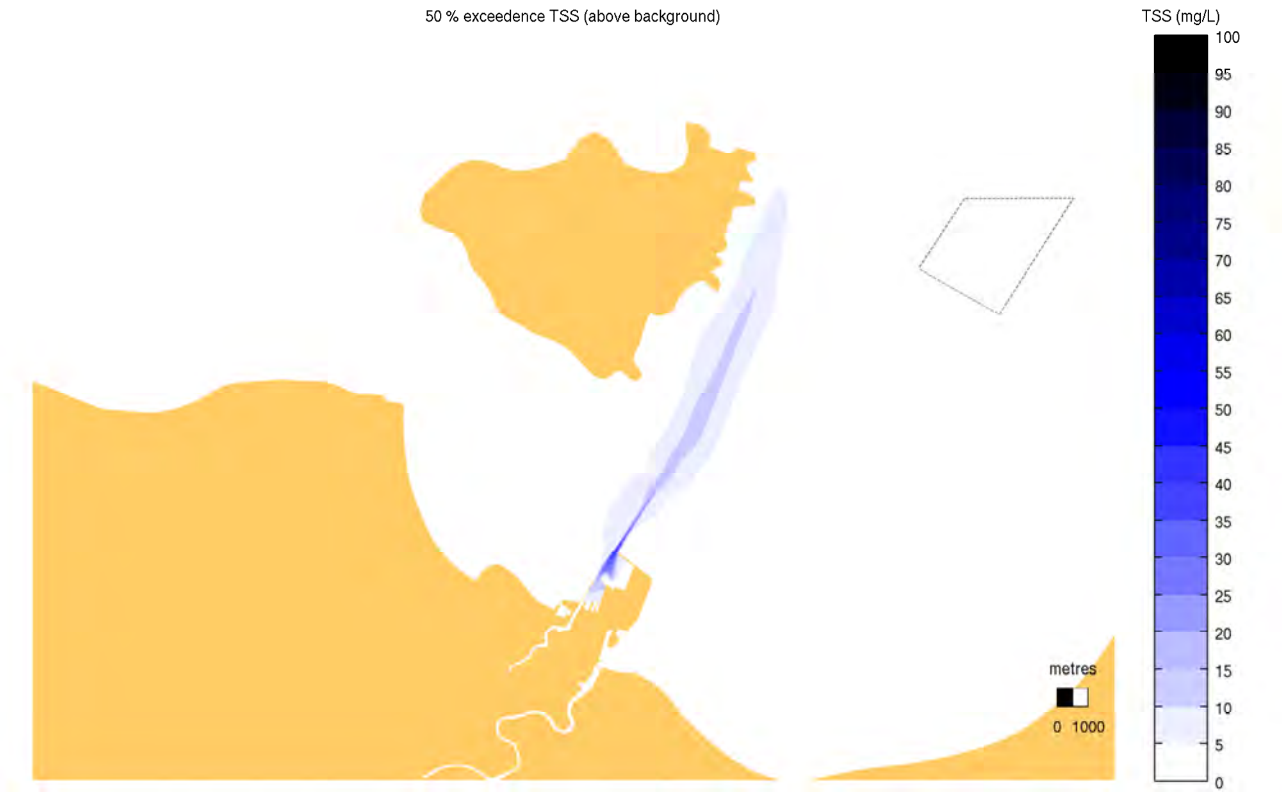


Figure 6-36 Northerly Wind Channel Dredging Scenario (Modified 4a) – Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 50% of the Simulation Period

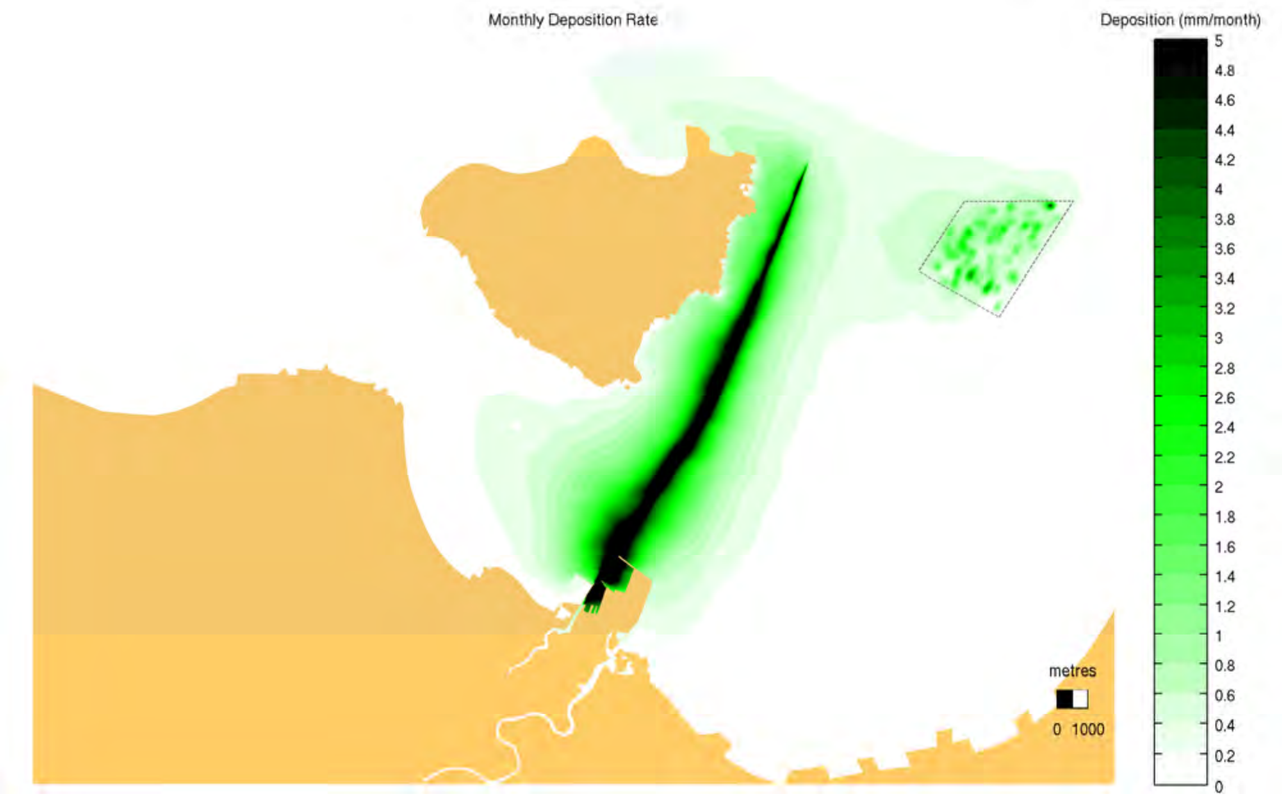


Figure 6-37 Northerly Wind Channel Dredging Scenario (Modified 4a) – Modelled Sediment Deposition Rate (mm/month)

6.3.4 MITIGATION SCENARIO

An example of a mitigation strategy based on timing the channel dredging operations according to the tidal state was modelled in order to estimate the potential reduction in turbidity impacts. The mitigation scenario was undertaken for the winter period for comparison with Scenario 4b.

For this scenario, instead of observing a strict order of sequential dredging tracks (A, B, C, D) the dredge operator would decide whether to undertake dredging in the two central sections ('B' and 'C') based on a tidal condition criterion. Dredging within these two central sections was identified to pose a greater risk to sensitive receptor sites to the west of the channel. The selection criterion was primarily targeted at avoiding overflow dredging on the flood tide within sections 'B' and C'.

If the model indicated that there would be an ebb tide condition one hour after the conclusion of the period of overflow, the dredge would undertake a 'B' or 'C' track, followed by a 'D' or 'A' track. If the model indicated that there would be a flood tide condition one hour after the conclusion of the period of overflow, the dredge would undertake a 'D' or 'A' track, followed by a 'B' or 'C' track. In addition, each 'A' cycle was broken up into two consecutive dredging tracks, with no overflow allowed (two dredging periods of 13 minutes each with no overflow, instead of a single 26 minute period which included 13 minutes of overflow).

The 1%, 5% and 50% exceedance plots are presented in Figure 6-38, Figure 6-39 and Figure 6-40, and the sediment deposition rate is presented in Figure 6-41.

Figure 6-42 and Figure 6-43 present the difference in the 5% and 50% exceedance level TSS respectively between the mitigation case and the Scenario 4b expected case. It is seen that the mitigation case provides widespread reductions in above-background TSS levels to the west of the channel and between Cape Pallarenda and Magnetic Island. The above-background 5% exceedance TSS levels near Cape Pallarenda are reduced by up to 10mg/L, and at Geoffrey Bay by up to 3mg/L. The above-background 50% exceedance TSS levels along the eastern embayments of Magnetic Island are reduced by between 0.5 and 1mg/L.

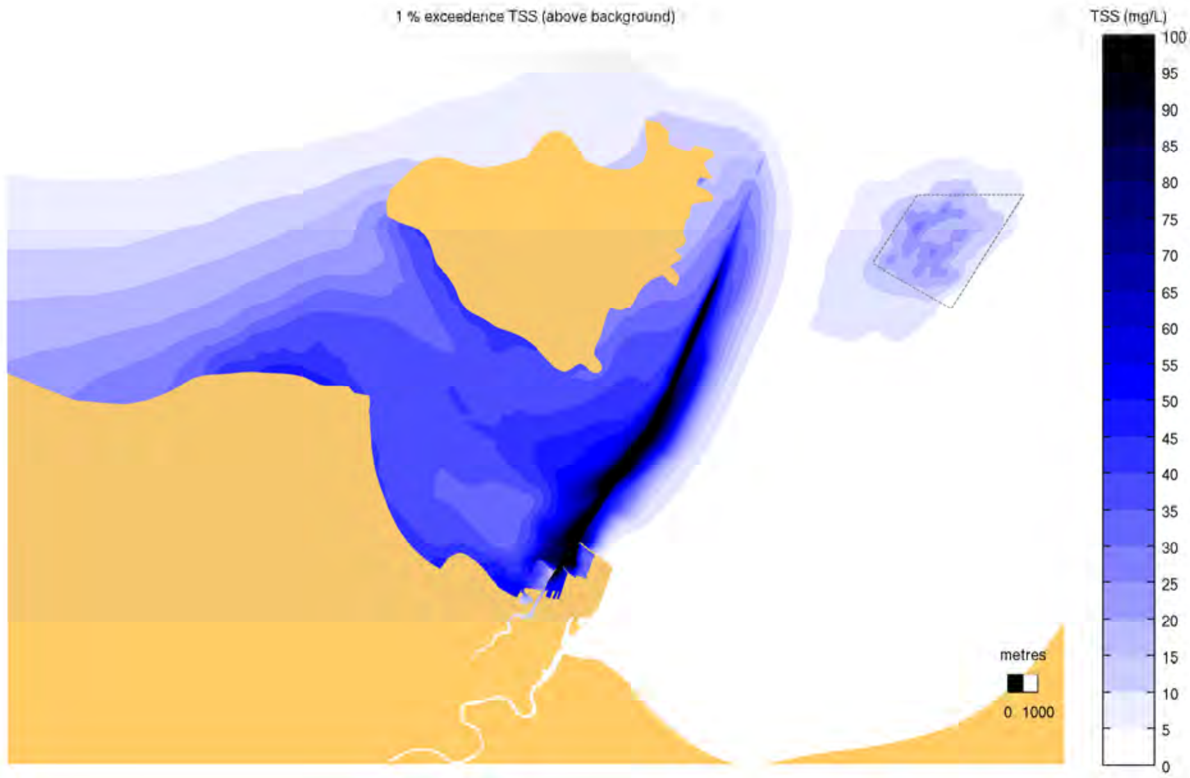


Figure 6-38 Mitigation Scenario – Winter – Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 1% of the Simulation Period

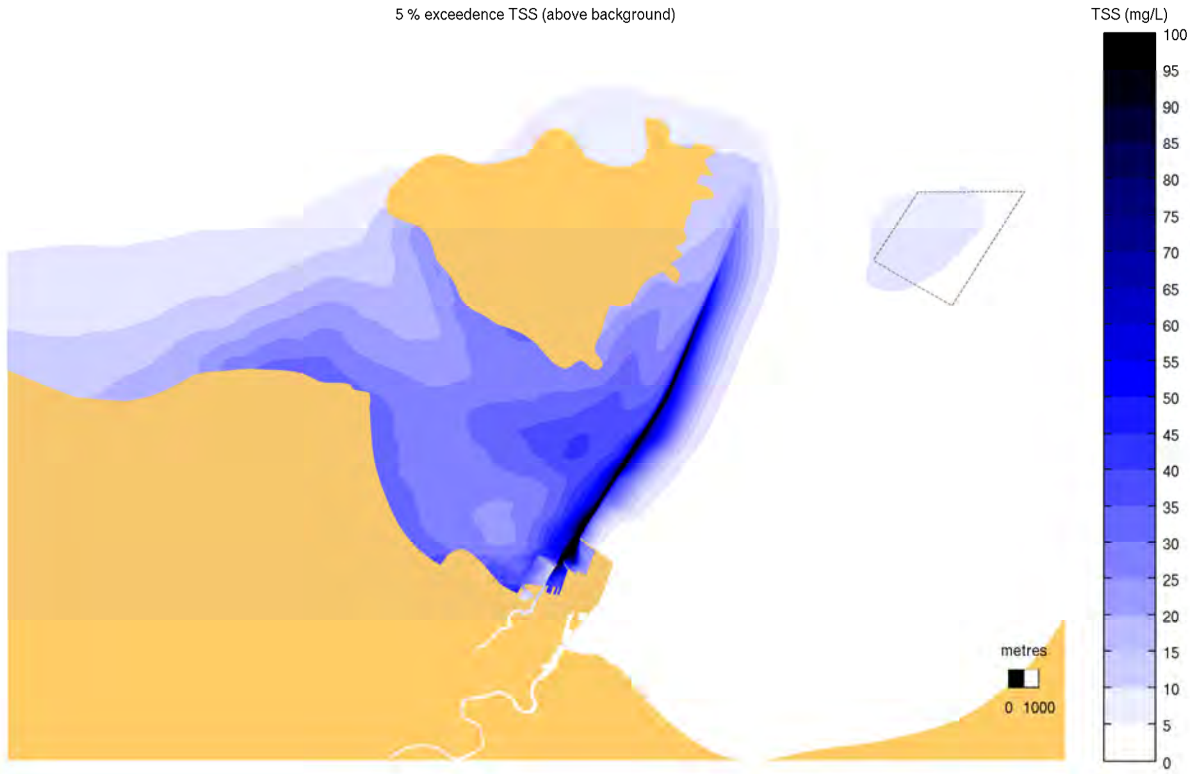


Figure 6-39 Mitigation Scenario – Winter – Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 5% of the Simulation Period

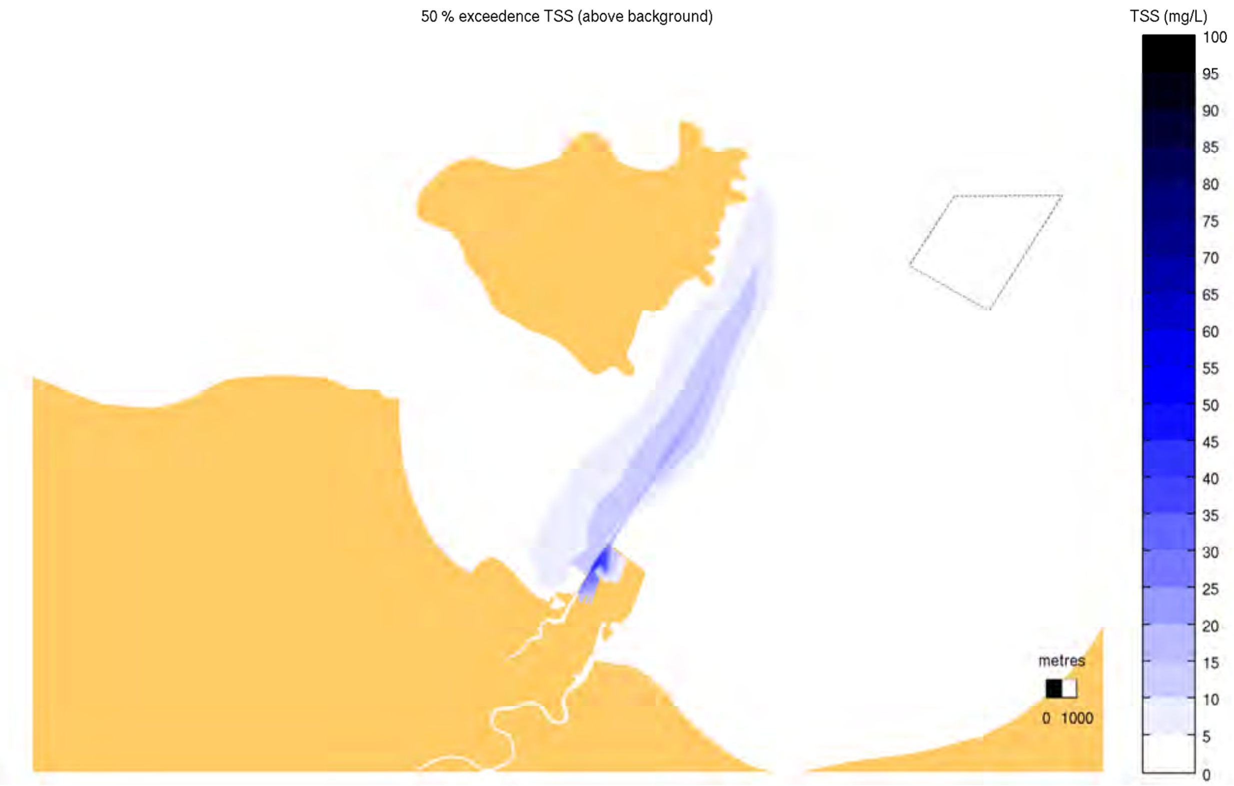


Figure 6-40 Mitigation Scenario – Winter – Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 50% of the Simulation Period

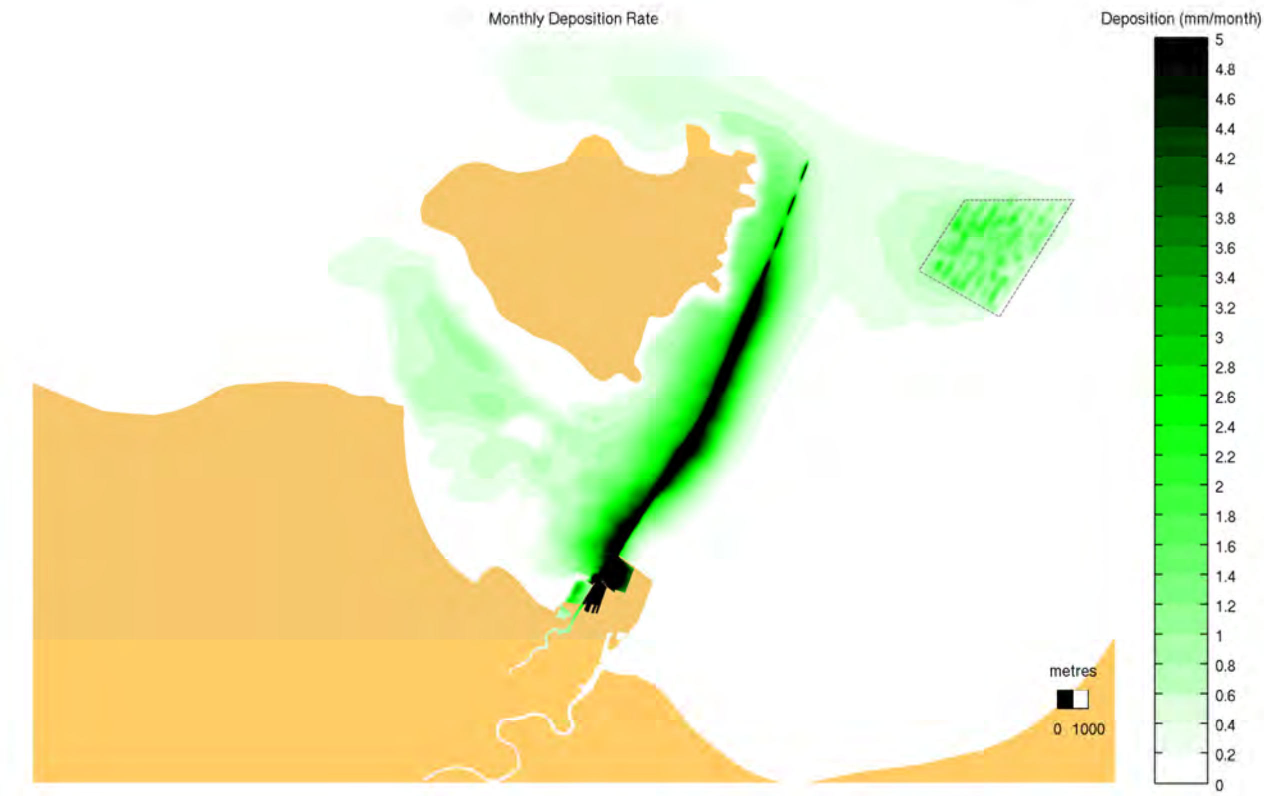


Figure 6-41 Mitigation Scenario – Winter – Modelled Sediment Deposition Rate (mm/month)

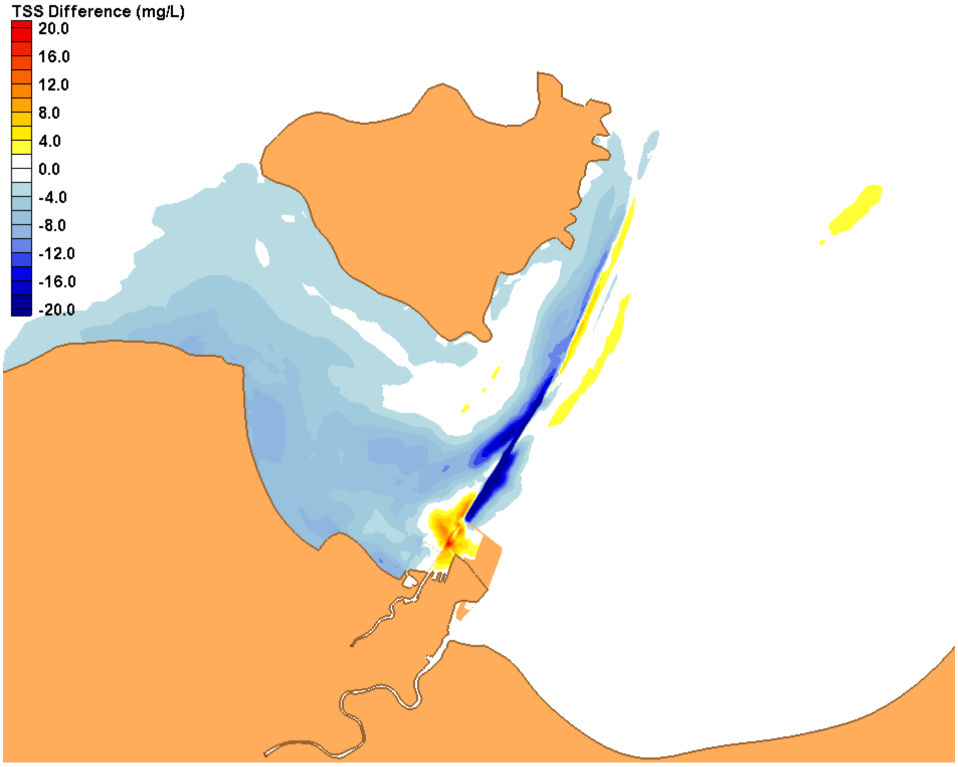


Figure 6-42 Mitigation Scenario – Winter – Difference in Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 5% of the Simulation Period (Mitigation Case Minus Expected Case)

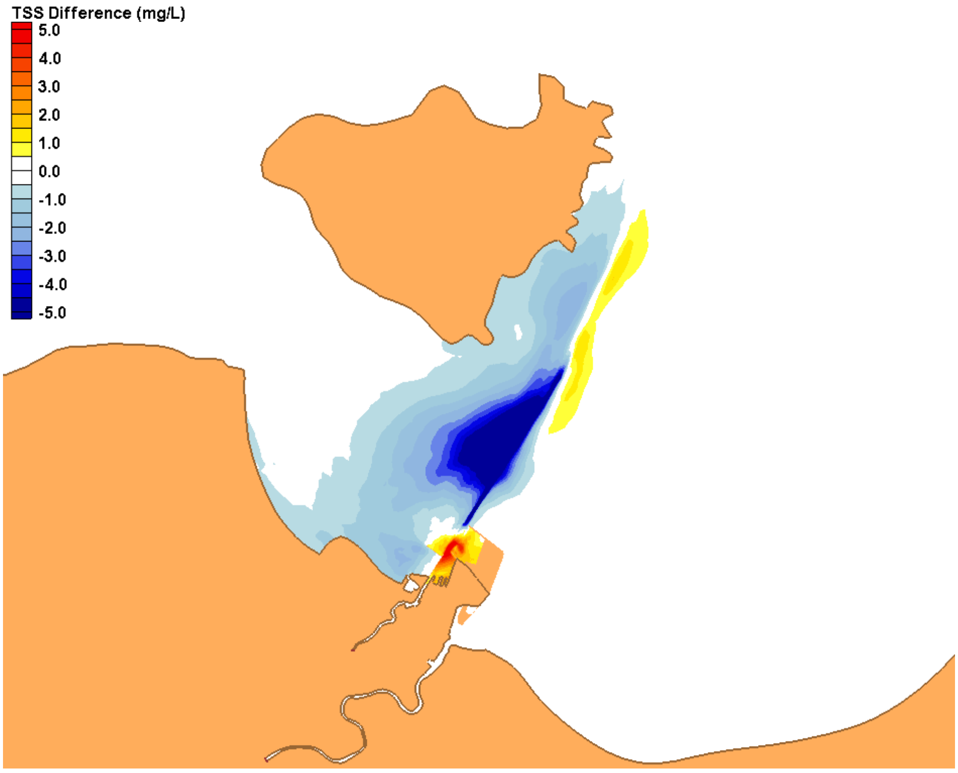


Figure 6-43 Mitigation Scenario – Winter – Difference in Above Background Total Suspended Sediment Concentration (mg/L) Exceeded for 50% of the Simulation Period (Mitigation Case Minus Expected Case)

6.4 SUMMARY OF PLUME DISPERSION RESULTS

The plume modelling results were used to inform the assessment of ecological impacts as discussed in the Marine Ecology chapter of the EIS. A full discussion of the impact of dredging plumes on marine flora and fauna can be found in that chapter.

In general terms the largest impact from dredging operations would occur during the deepening of the Platypus and Sea Channels. The entrainment of sediment by overflow of the TSHD hopper and propeller wash produces a plume of significant magnitude and extent which is predicted to cause elevated suspended sediment concentrations at sensitive receptor sites along the periphery of Magnetic Island.

The plumes caused by dredging in the outer harbour and by placement at the DMPA cause an impact at the local level but do not disperse over a wide area. The increase in suspended sediment concentrations at the locations shown in Figure 6-1 from dredge plumes produced at these sites is minimal.

It should be noted that the dredge plume impacts presented here are predicted increases in Total Suspended Solids above ambient background levels. Any measurements or observations of suspended sediment concentrations or turbidity during the dredge campaign will be the total and include the natural ambient conditions as well as the contribution of dredging.

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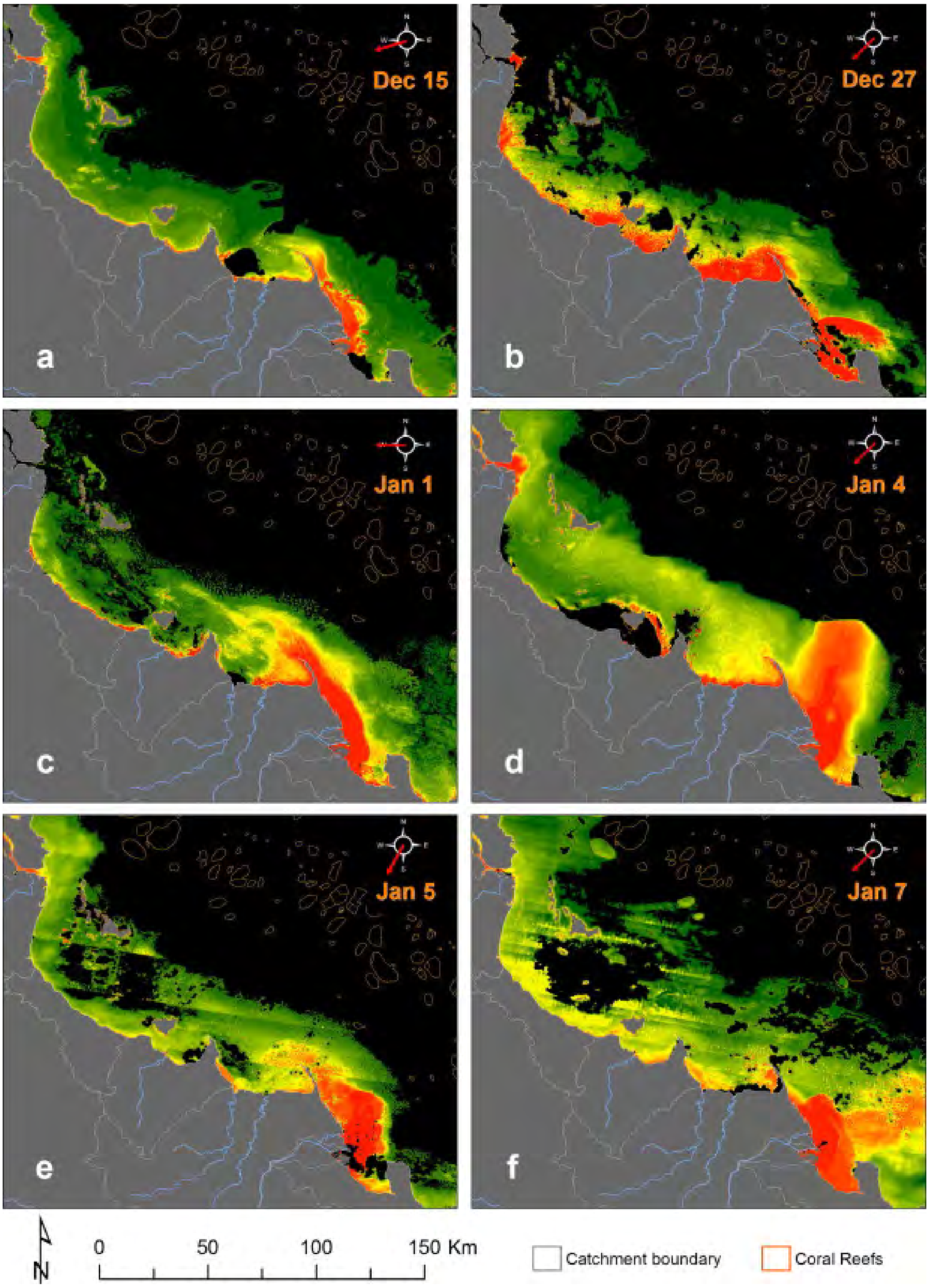
BMT WBM

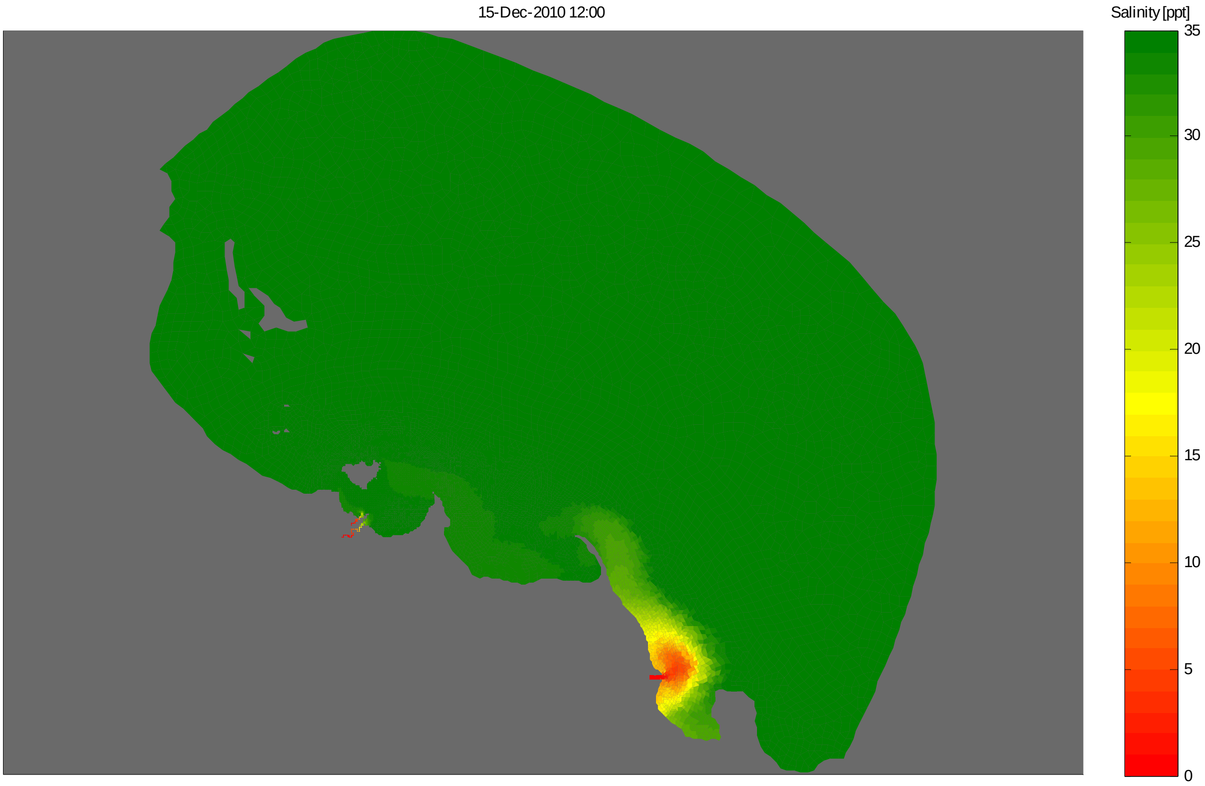
ATTACHMENT A: TUFLOW-FV DESCRIPTION

ATTACHMENT B: SUMMER 2010/11 RIVER PLUMES

MODIS satellite images reproduced from Figure 3 of Bainbridge et al. (2012) show the evolution of the Burdekin River flood plume from the 15/12/10 to 07/01/11.



Model snapshots of surface salinity at equivalent times (showing the extent of the river plume) are provided on the following pages for comparison purposes.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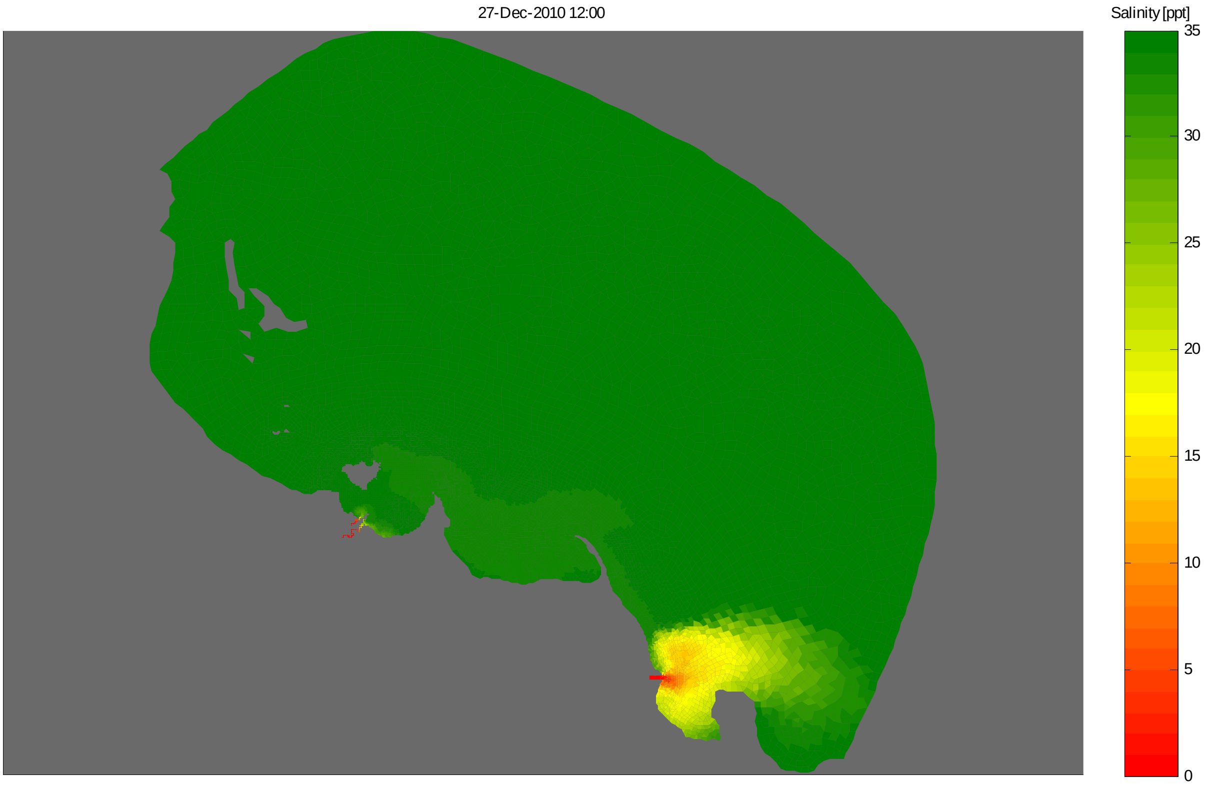
Salinity [ppt]
35
30
25
20
15
10
5
0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Salinity [ppt]
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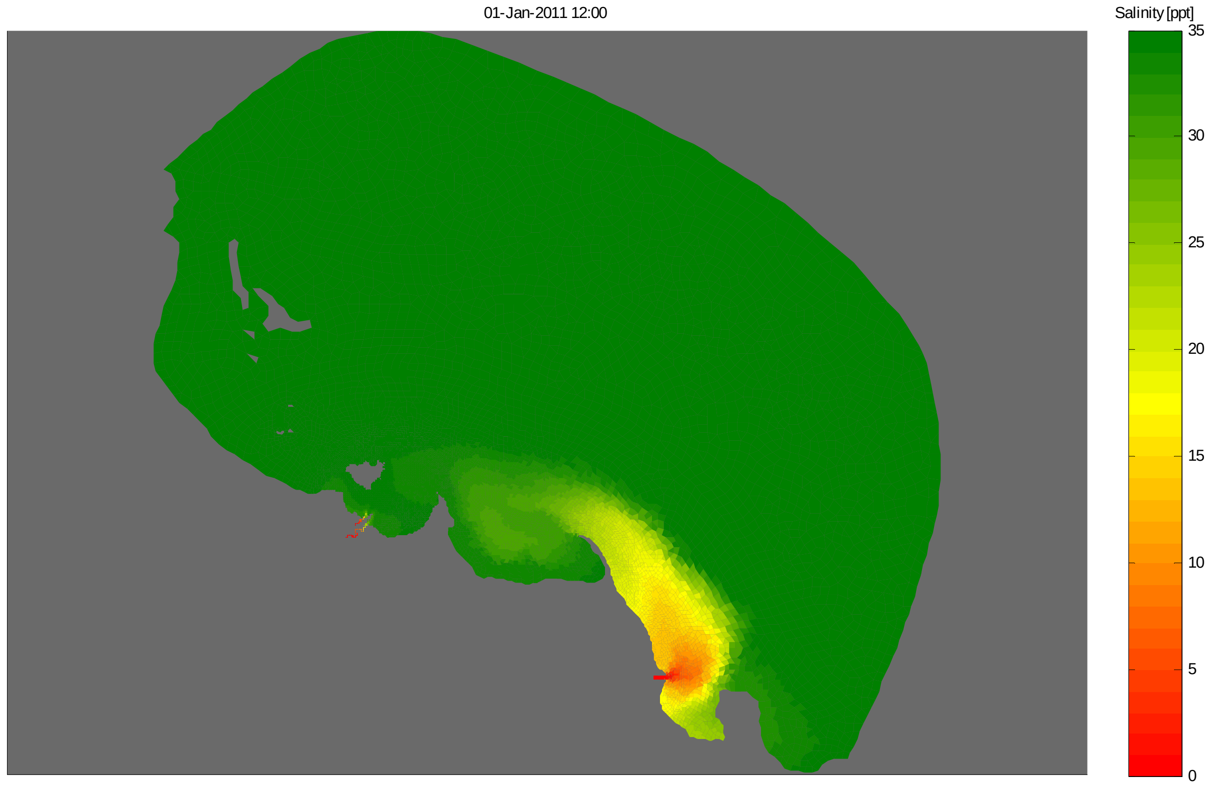
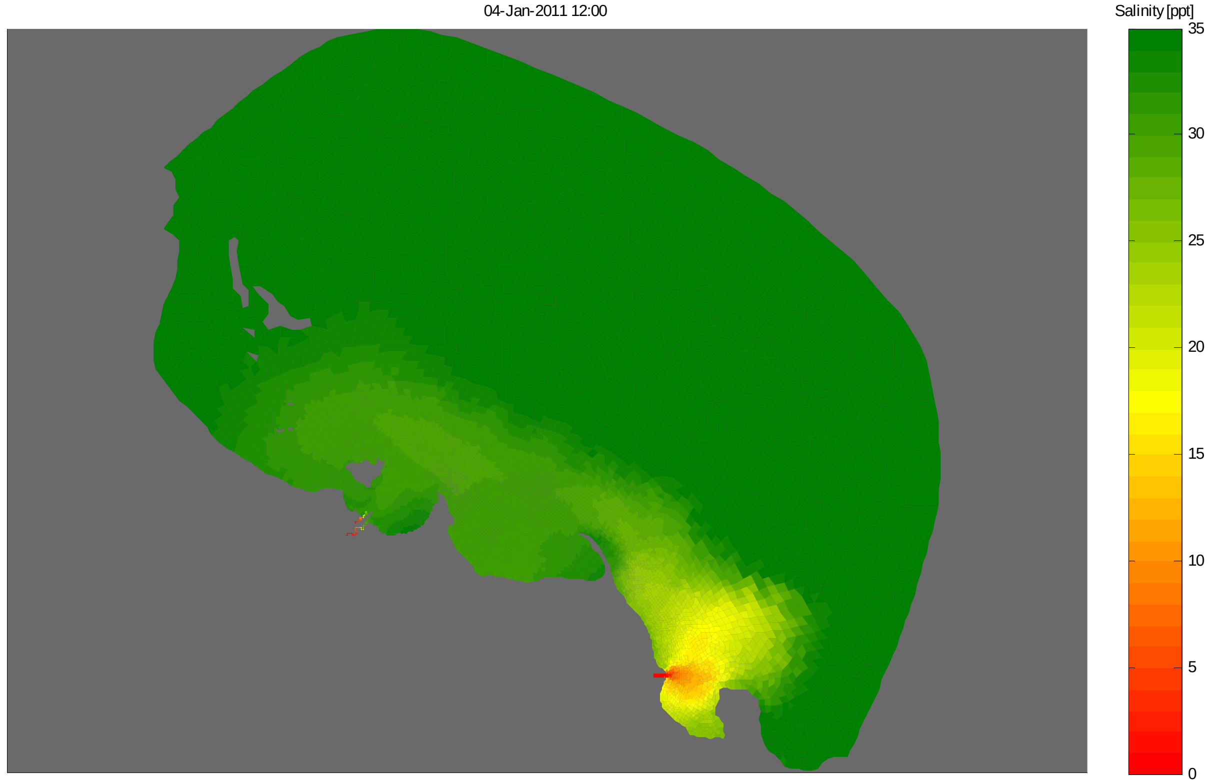
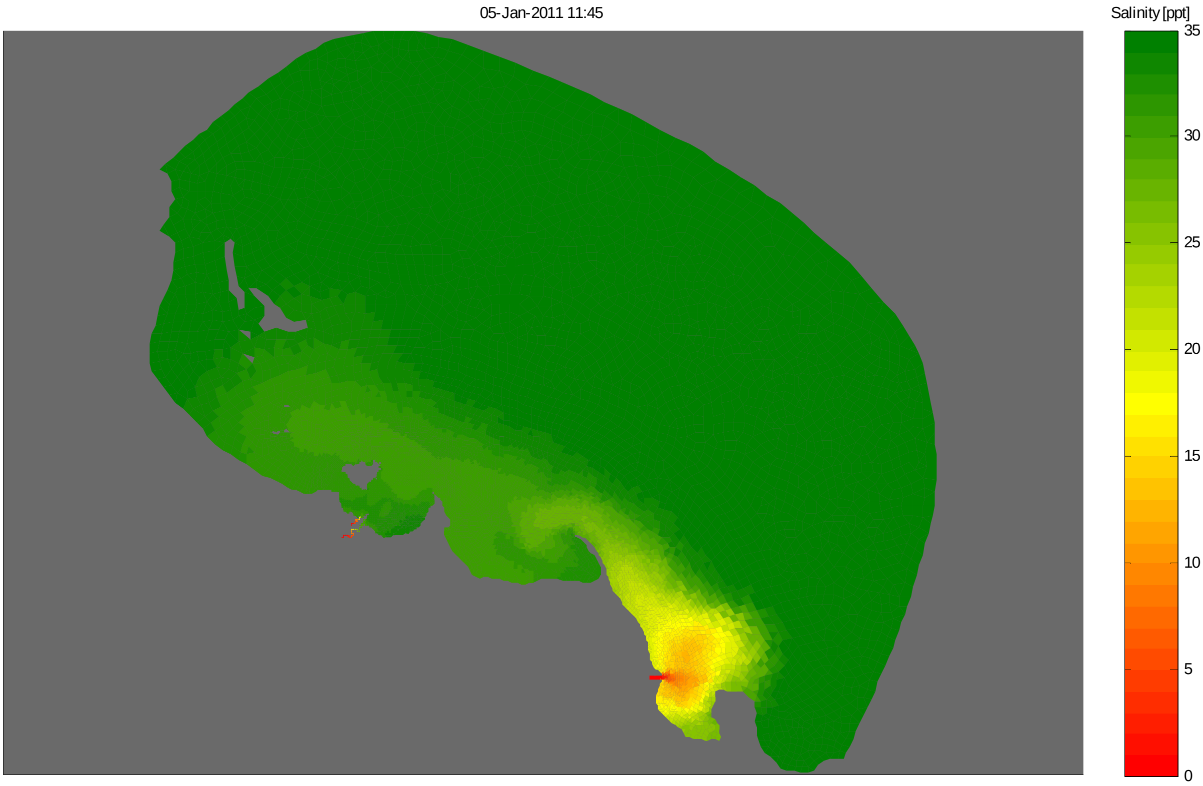
30
25
20
15
10
5
0


01-Jan-2011 12:00
Salinity [ppt]
35
30
25
20
15
10
5
0


04-Jan-2011 12:00
Salinity [ppt]
35
30
25
20
15
10
5
0



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Salinity [ppt]
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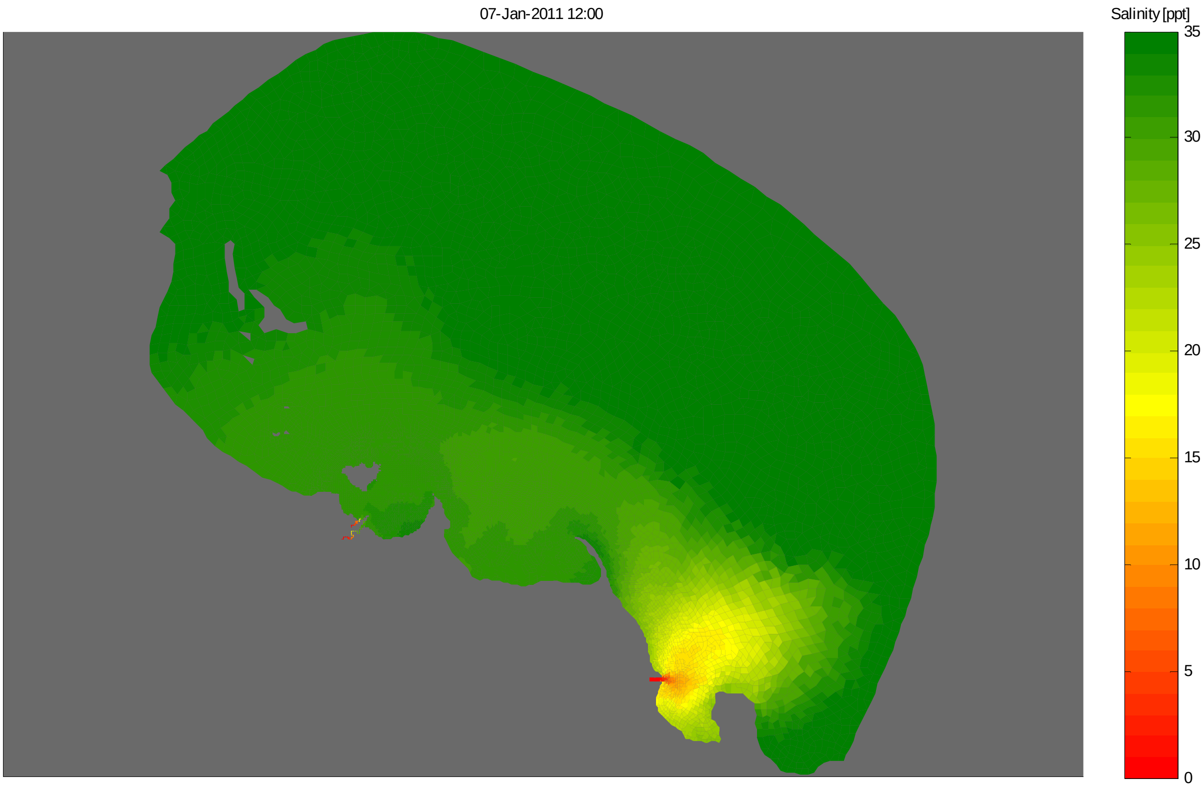
30
25
20
15
10
5
0



07-Jan-2011 12:00
Salinity [ppt]
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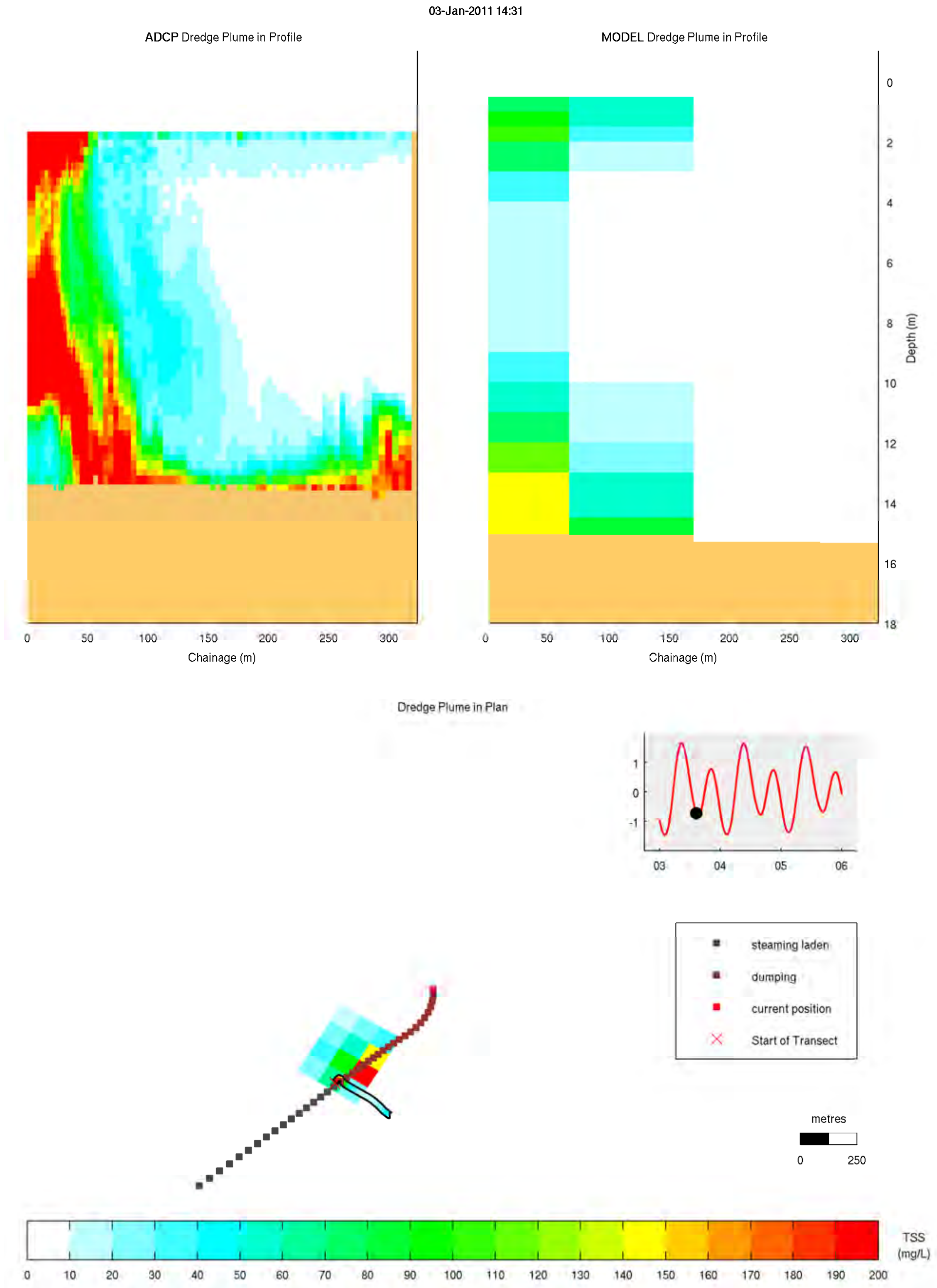
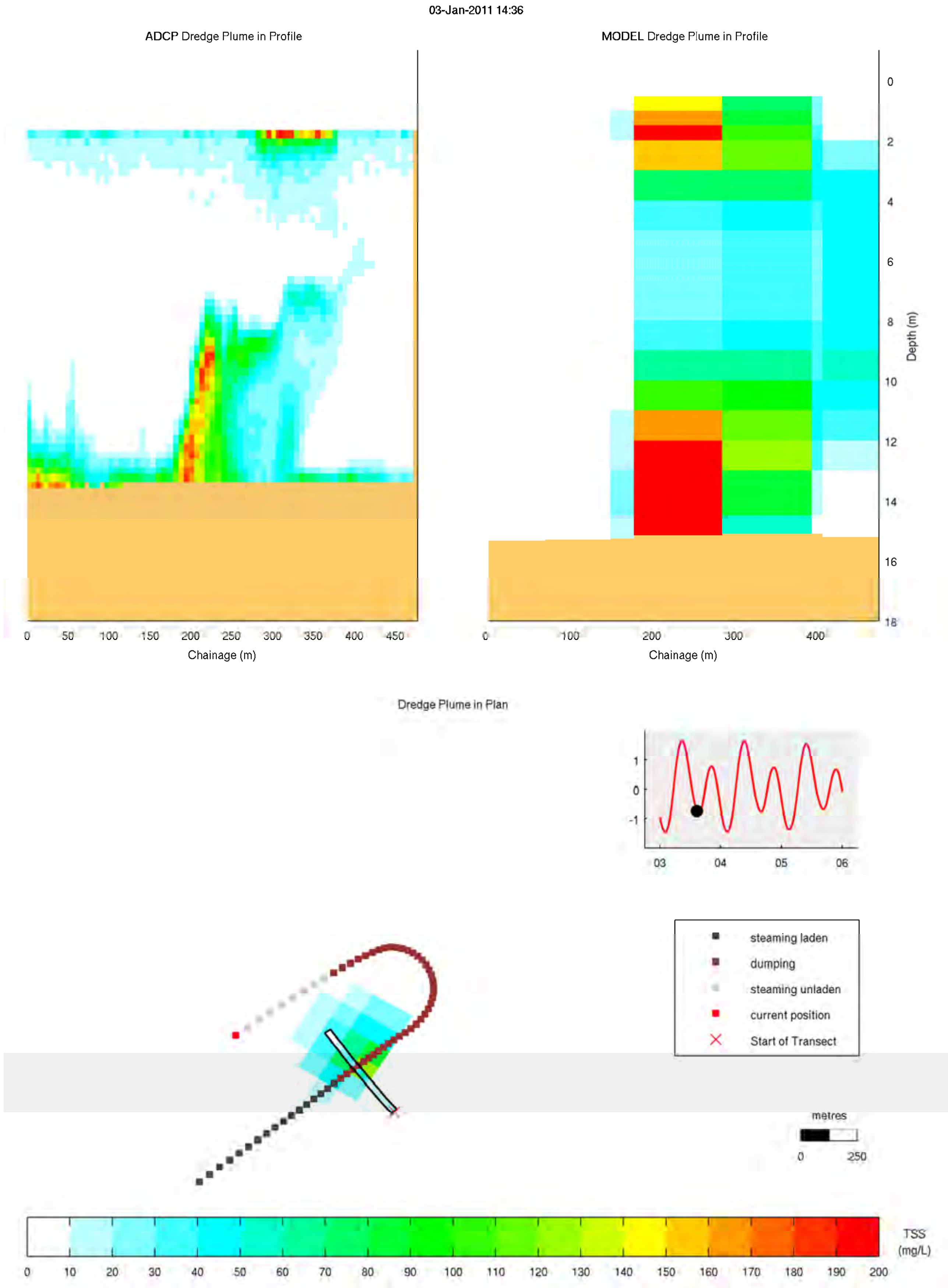
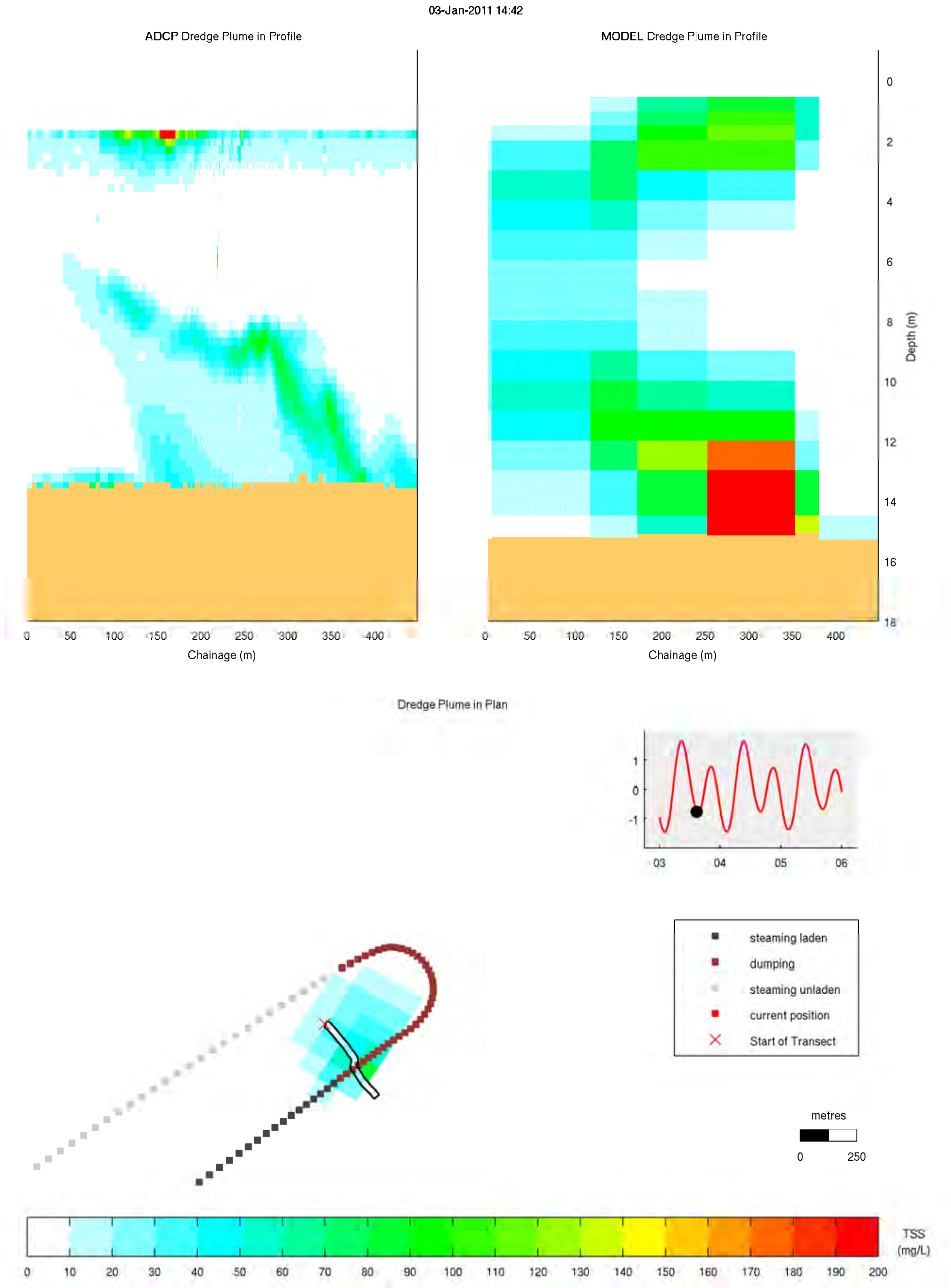
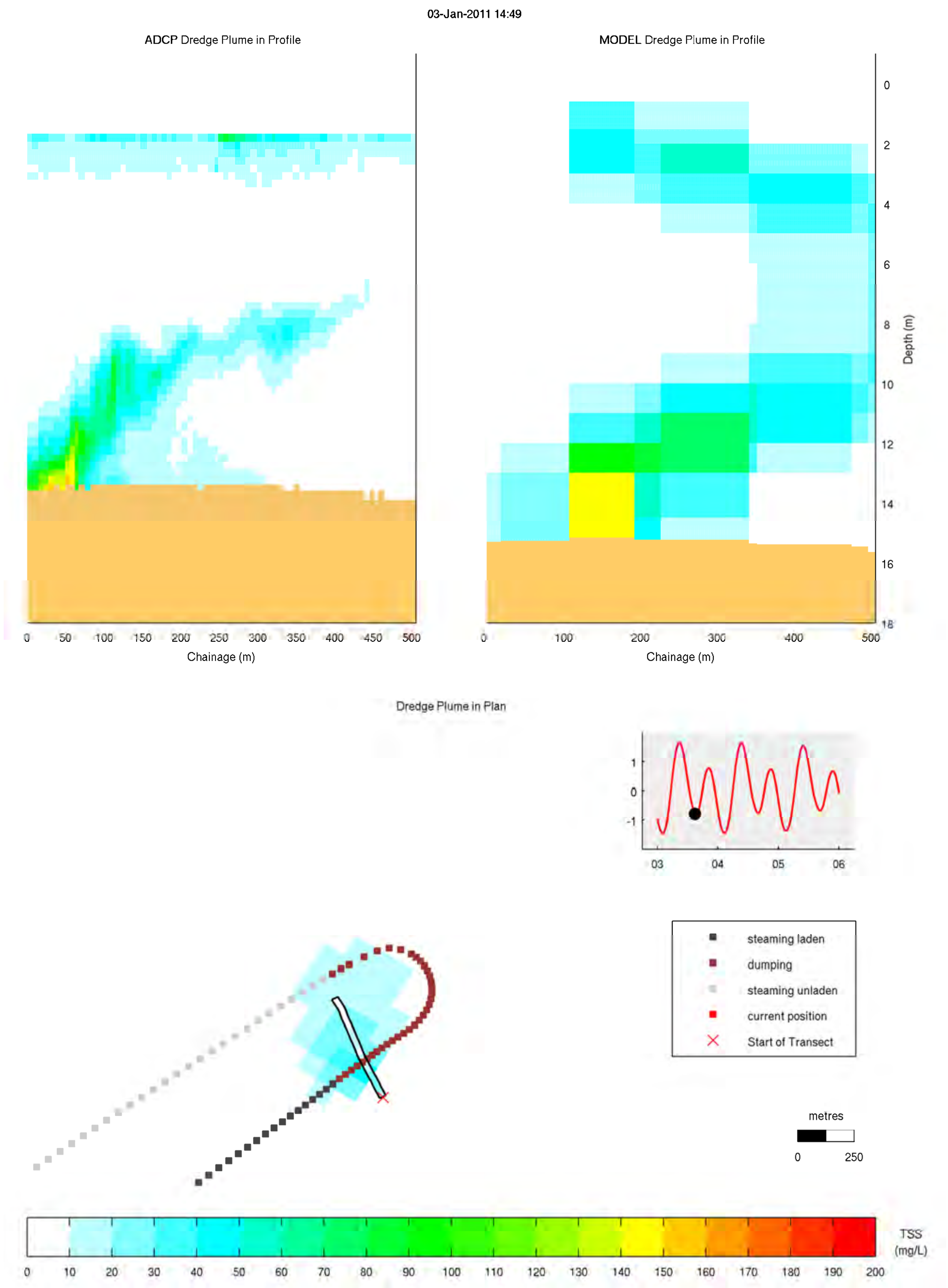
30
25
20
15
10
5
0

ATTACHMENT C: DREDGE PLUME MODEL CALIBRATION PLOTS

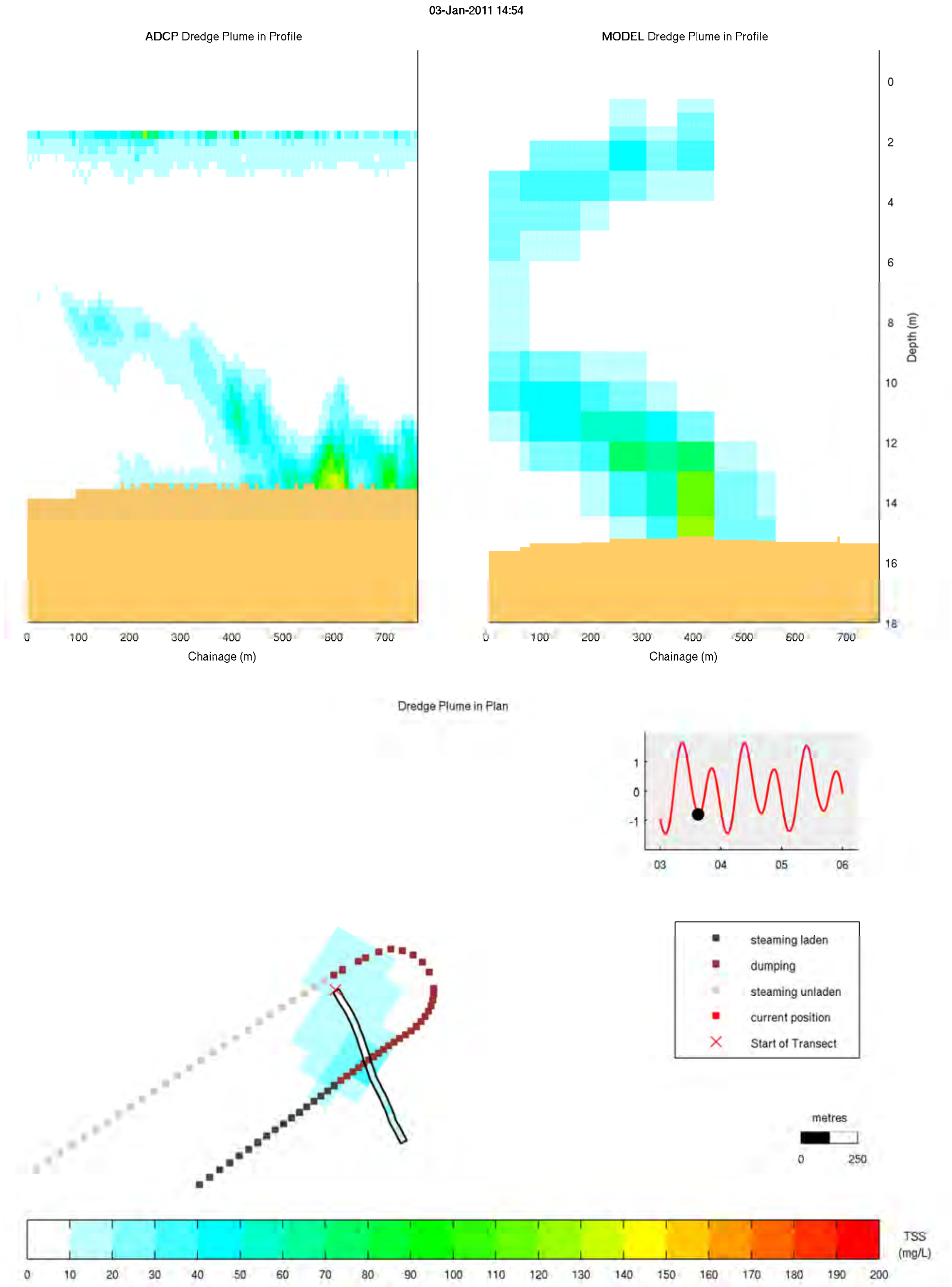



03-Jan-2011 14:36
ADCP Dredge Plume in Profile
Chainage (m)
MODEL Dredge Plume in Profile
Chainage (m)
Depth (m)
Dredge Plume in Plan
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)


03-Jan-2011 14:42
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 50 100 150 200 250 300 350 400
Chainage (m)
0 2 4 6 8 10 12 14 16 18
Depth (m)
Dredge Plume in Plan
1 0 -1
03 04 05 06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS (mg/L)


03-Jan-2011 14:49
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0 50 100 150 200 250 300 350 400 450 500
Chainage (m)
0 100 200 300 400 500
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)

BMT WBM



03-Jan-2011 14:54
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
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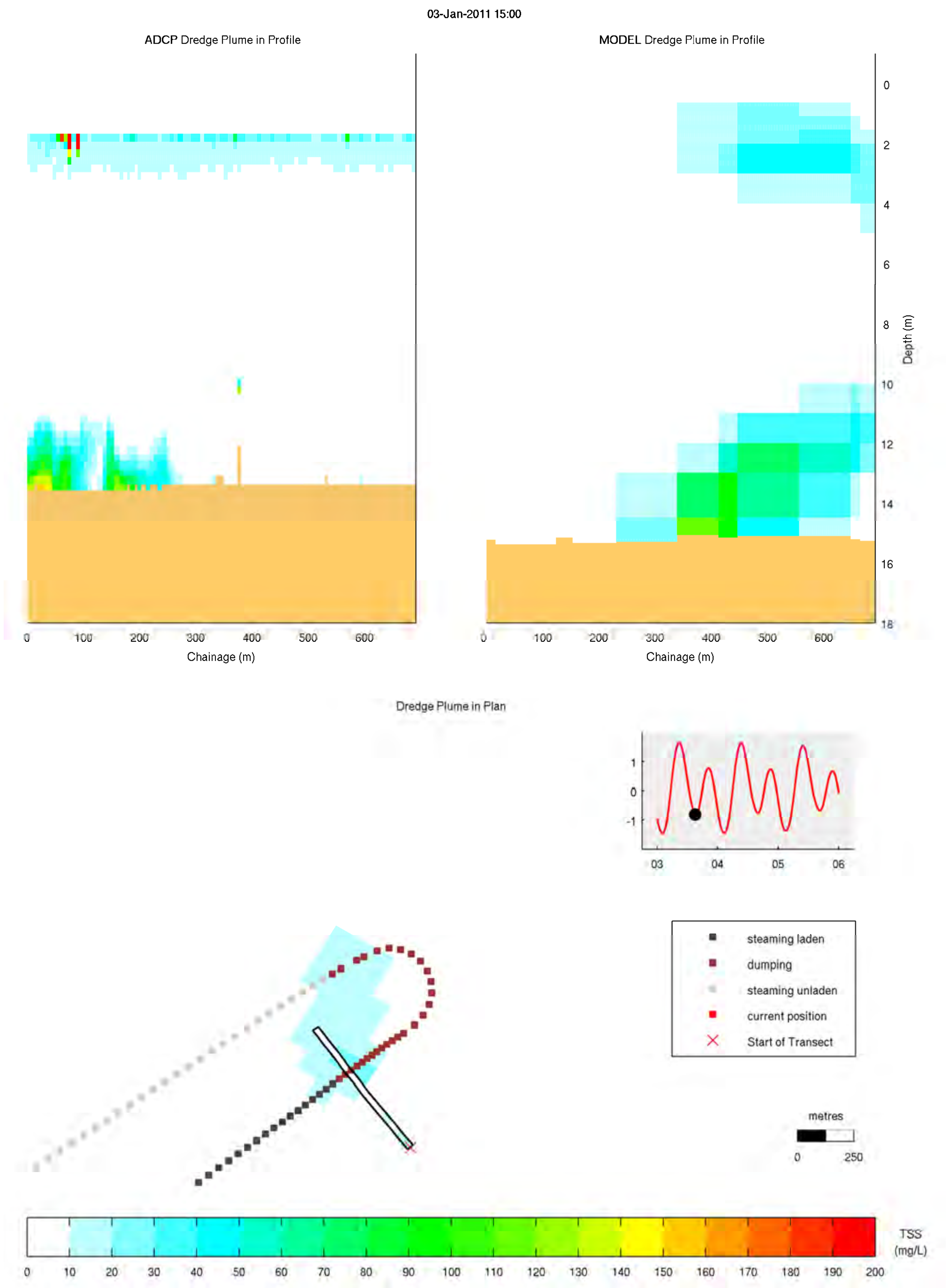
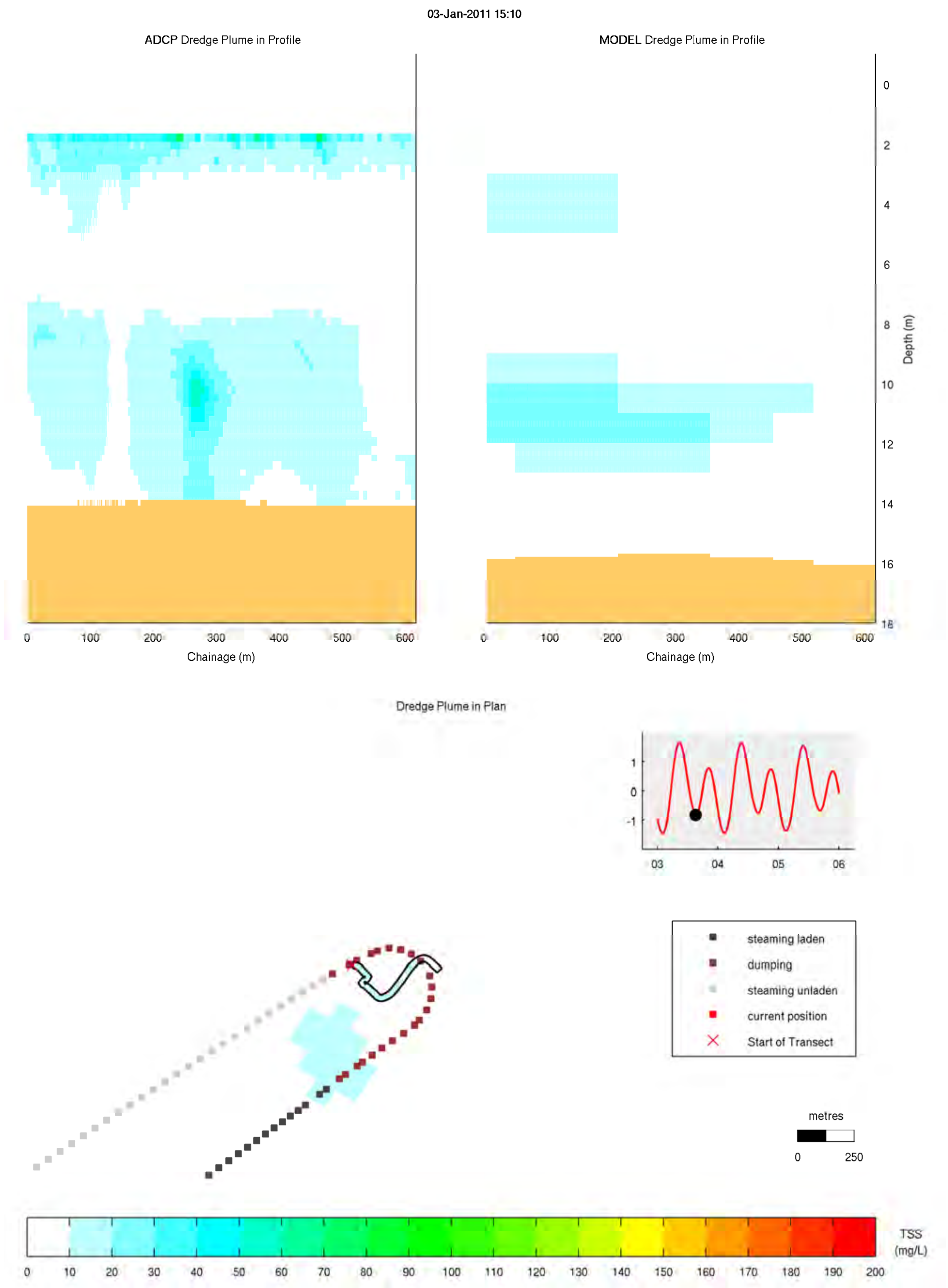
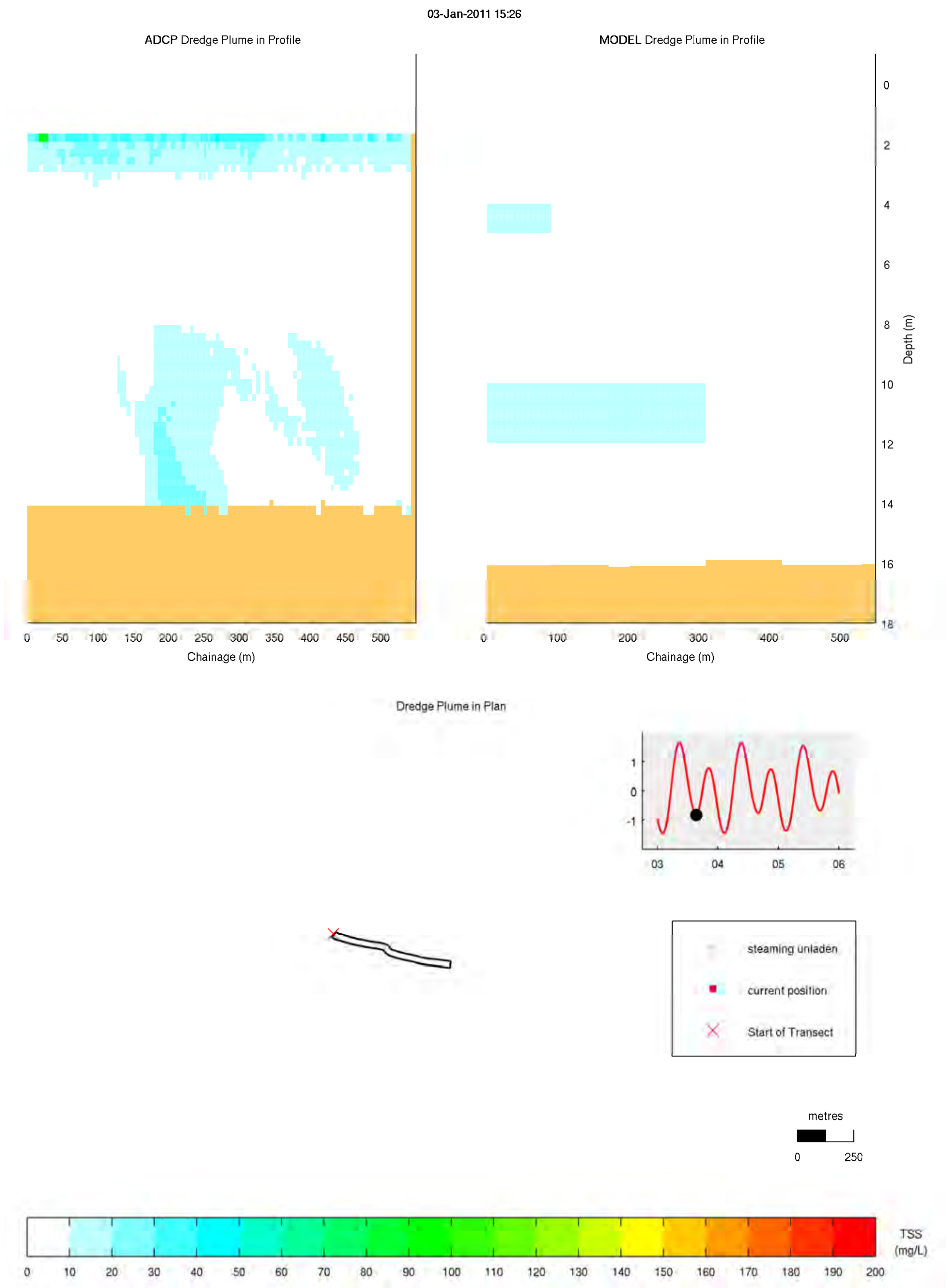
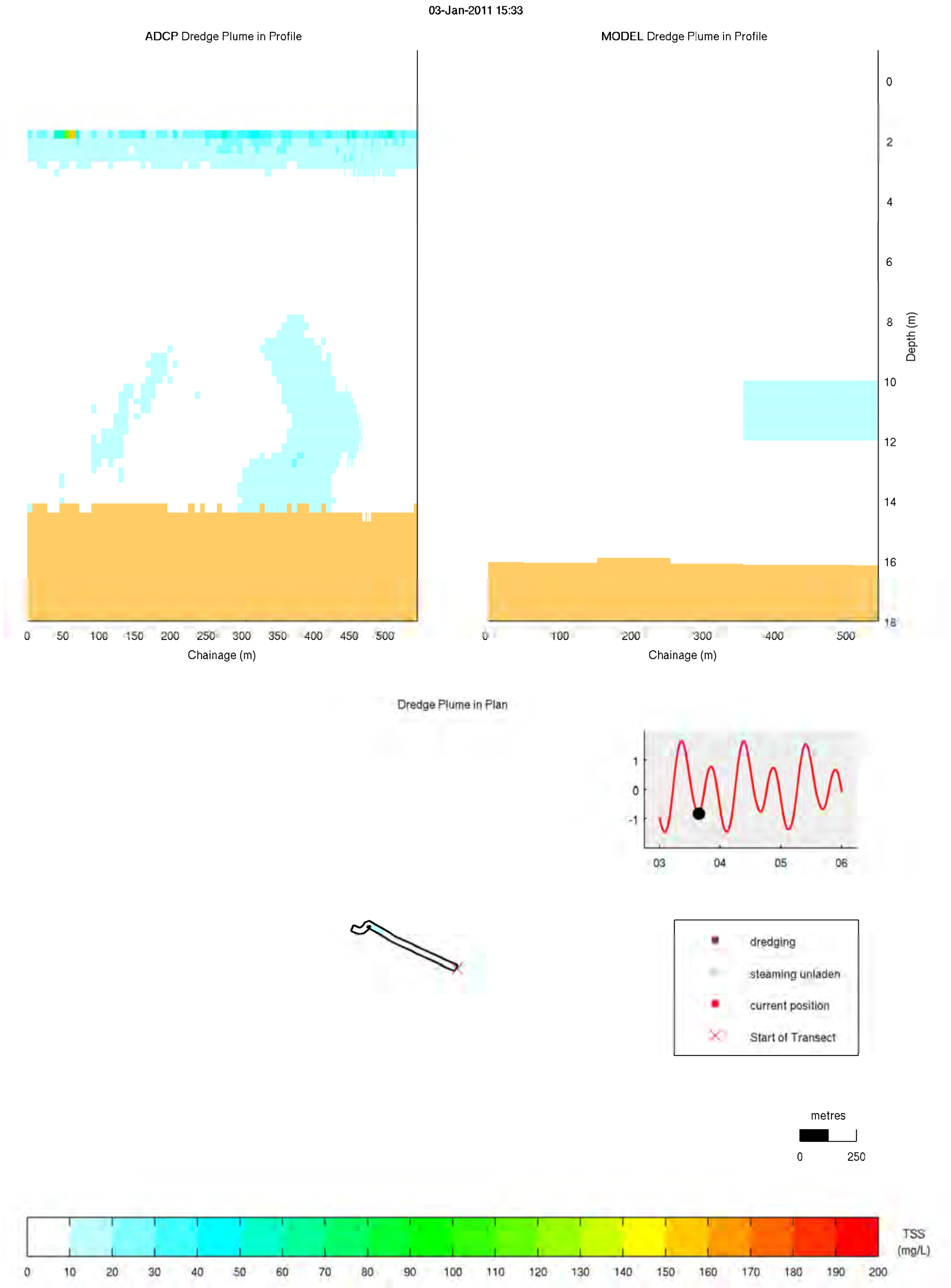
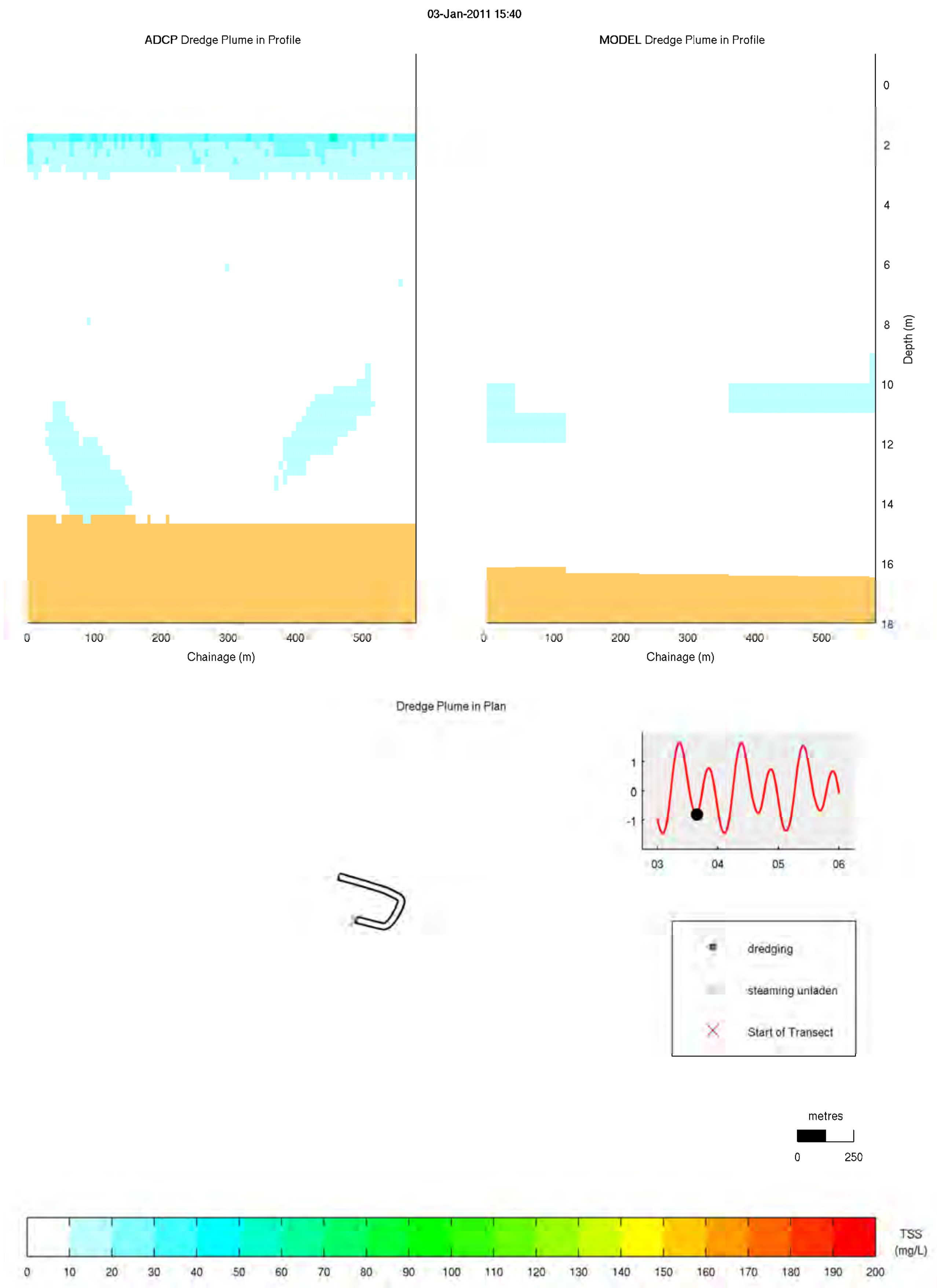
Chainage (m)
0 2 4 6 8 10 12 14 16 18
Depth (m)
Dredge Plume in Plan
1 0 -1
03 04 05 06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS (mg/L)

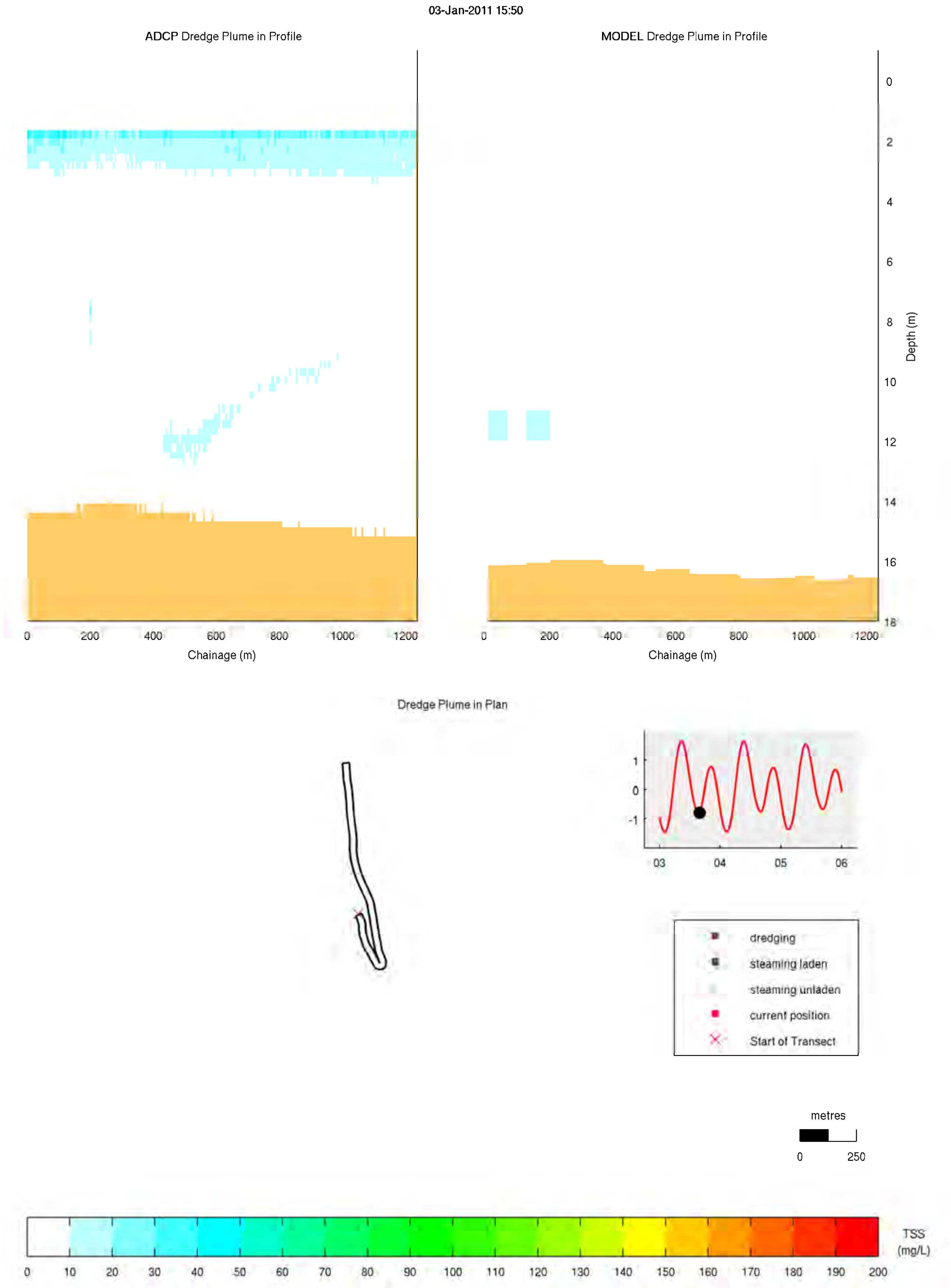

03-Jan-2011 15:00
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
0
2
4
6
8
10
12
14
16
18
0 100 200 300 400 500 600
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)


03-Jan-2011 15:10
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)

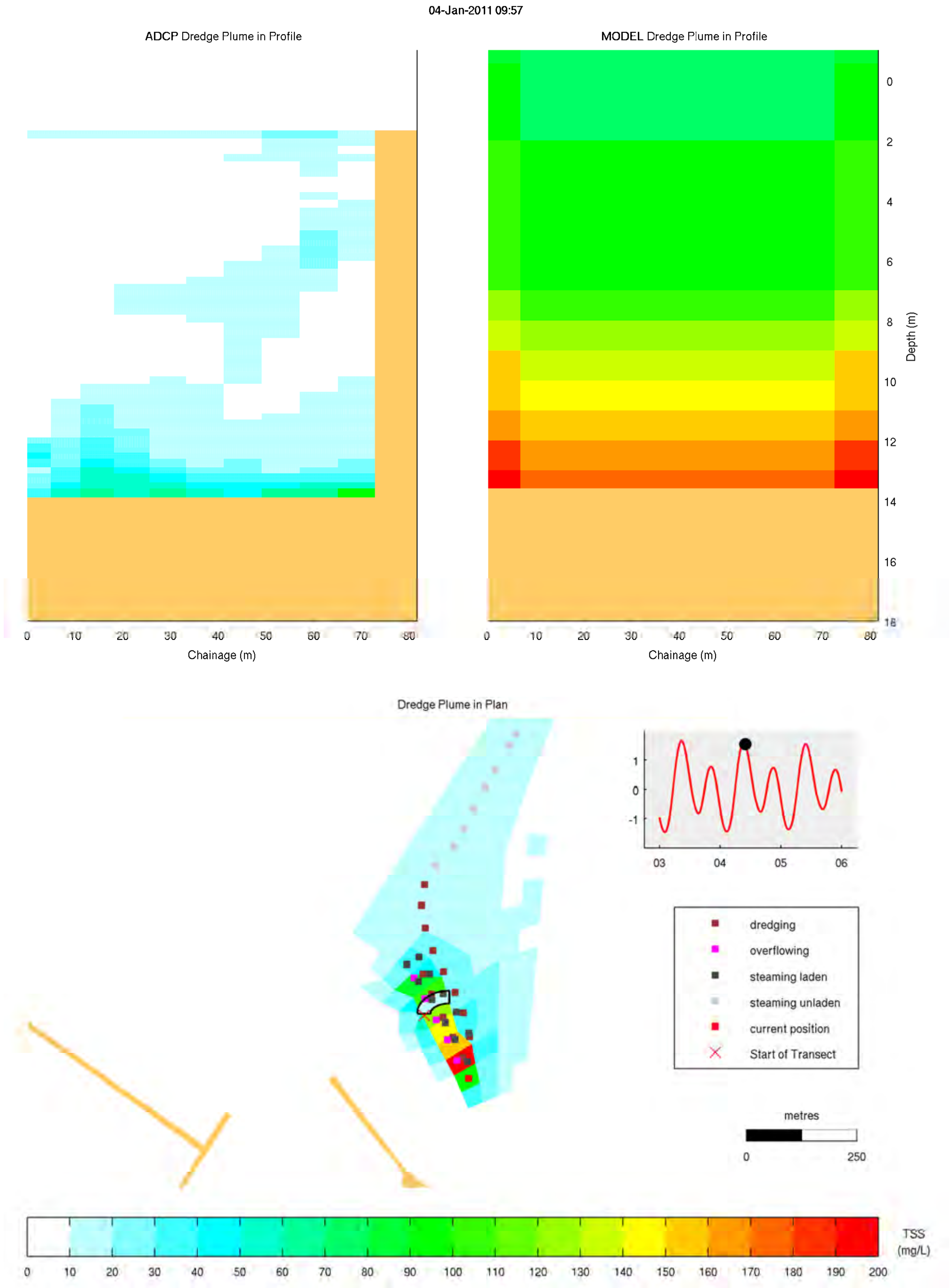

03-Jan-2011 15:26
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
0
2
4
6
8
10
12
14
16
18
0 50 100 150 200 250 300 350 400 450 500
Chainage (m)
0 100 200 300 400 500
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)

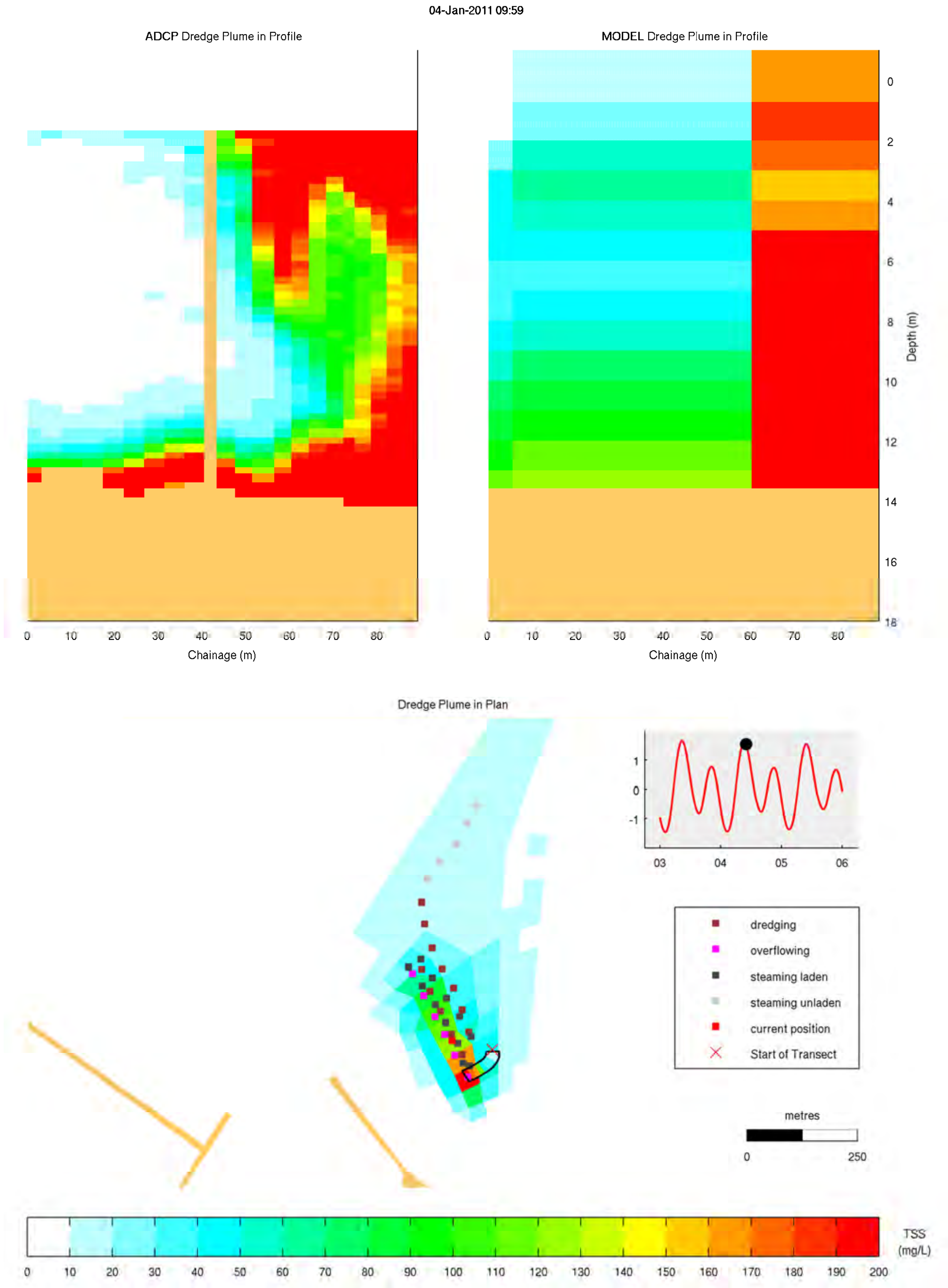

03-Jan-2011 15:33
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0 50 100 150 200 250 300 350 400 450 500
Chainage (m)
0 100 200 300 400 500
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
dredging
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)

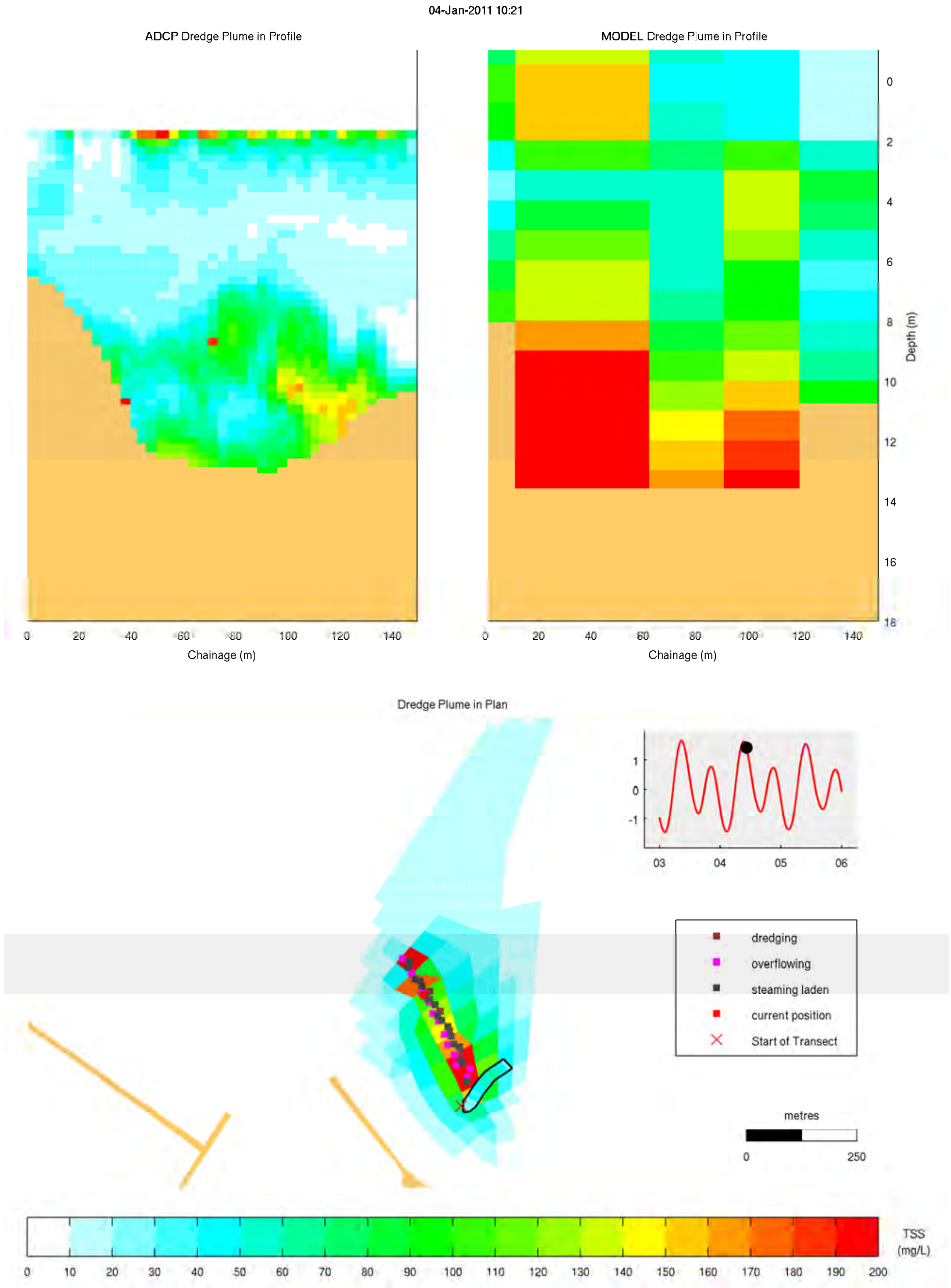

03-Jan-2011 15:40
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
dredging
steaming unladen
Start of Transect
metres
0
250
TSS (mg/L)

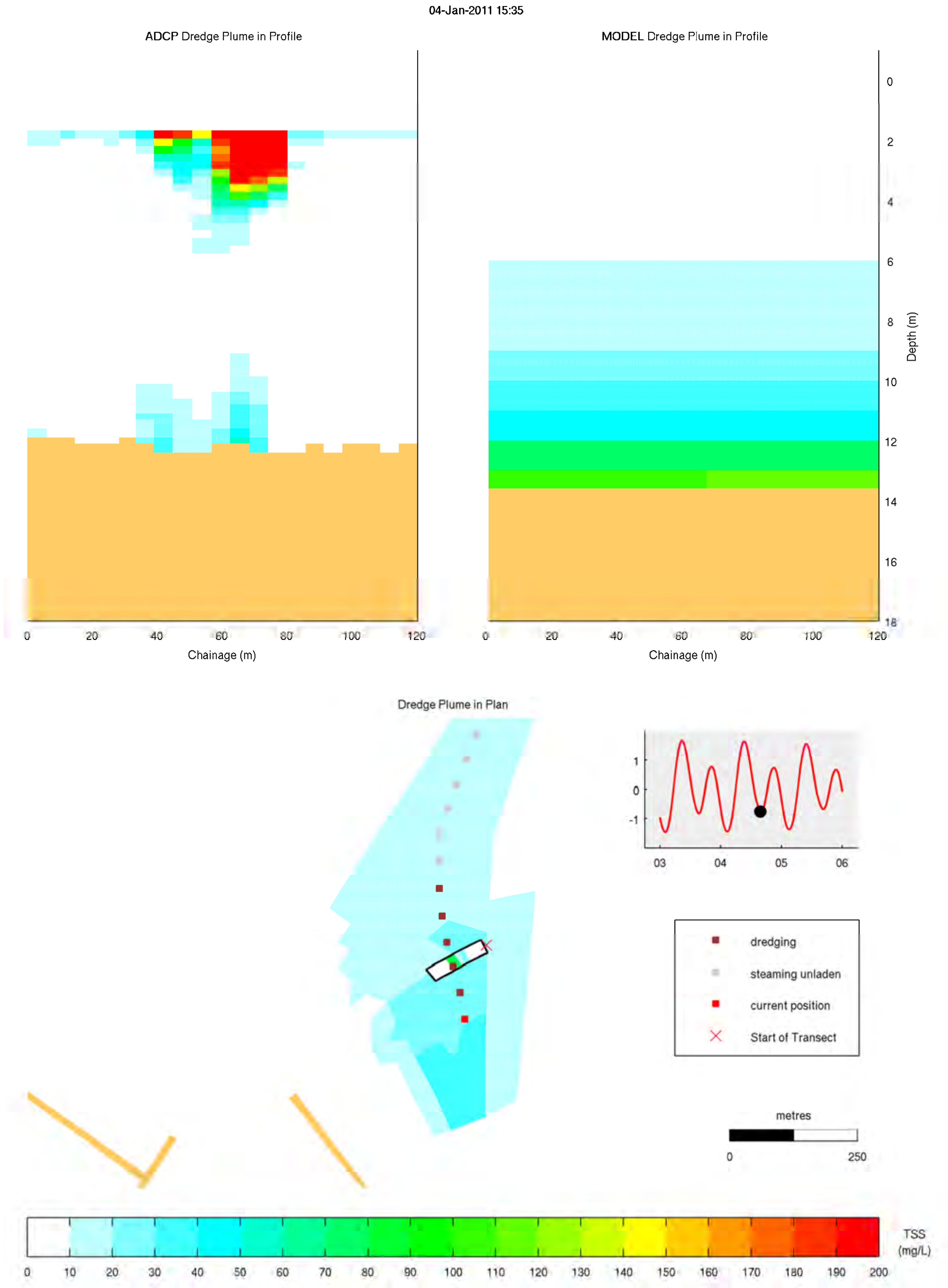

03-Jan-2011 15:50
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 2 4 6 8 10 12 14 16 18
Depth (m)
0 200 400 600 800 1000 1200
Chainage (m)
Dredge Plume in Plan
1 0 -1
03 04 05 06
dredging
steaming laden
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)

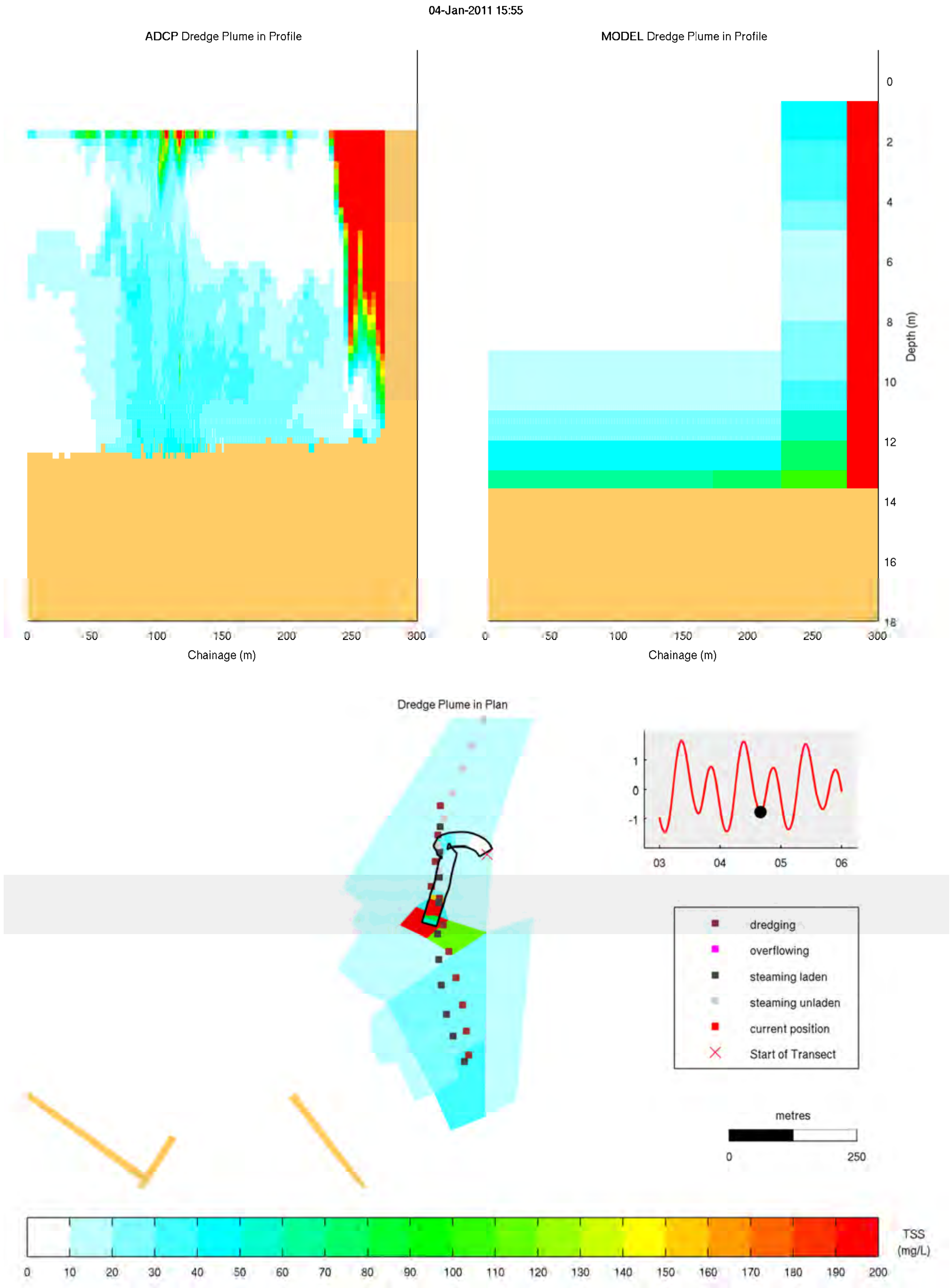
BMT WBM

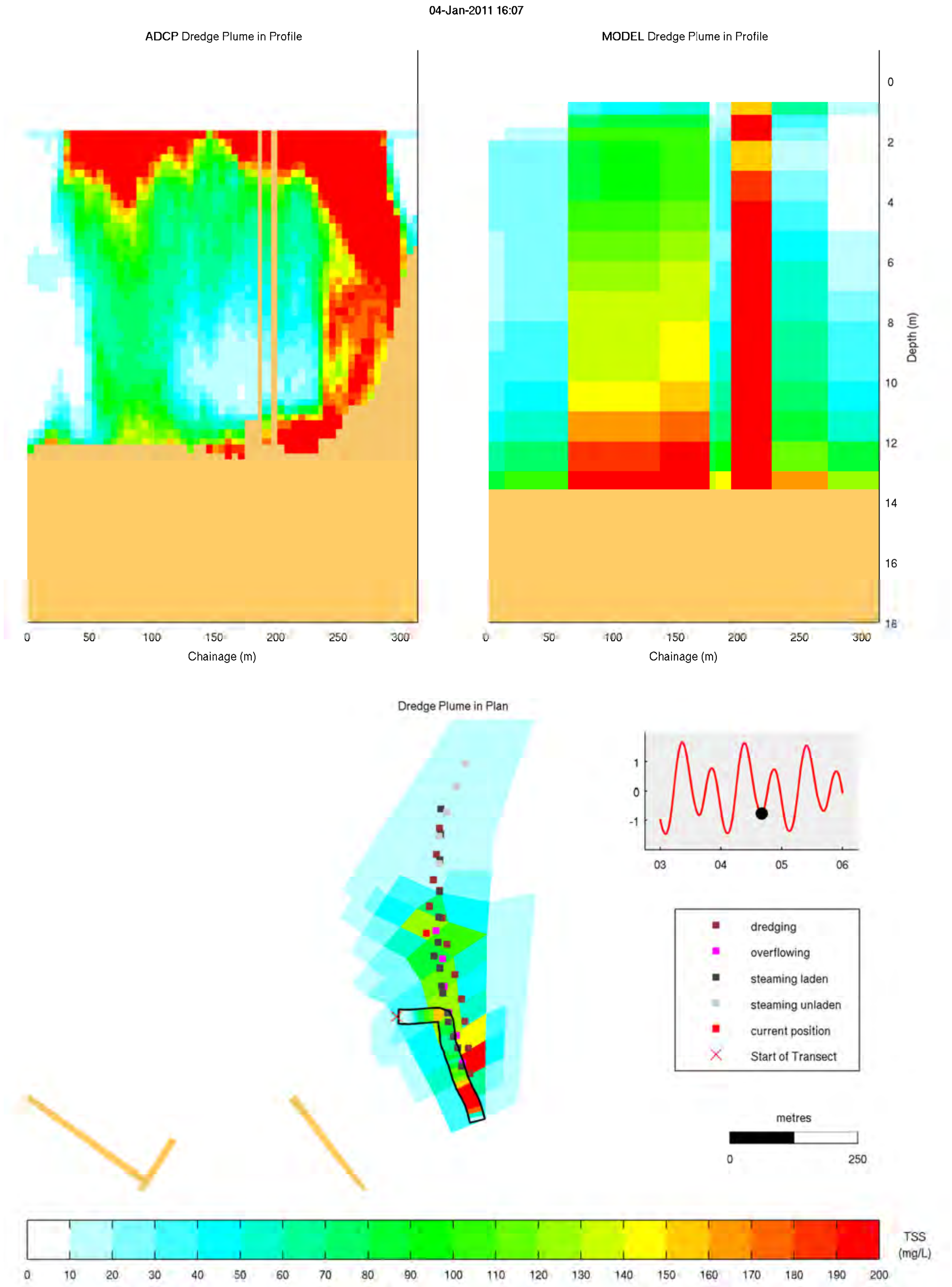

04-Jan-2011 09:57
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
0 10 20 30 40 50 60 70 80
0 2 4 6 8 10 12 14 16 18
Dredge Plume in Plan
1 0 -1
03 04 05 06
dredging
overflowing
steaming laden
steaming unladen
current position
Start of Transect
metres
0 250
TSS (mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

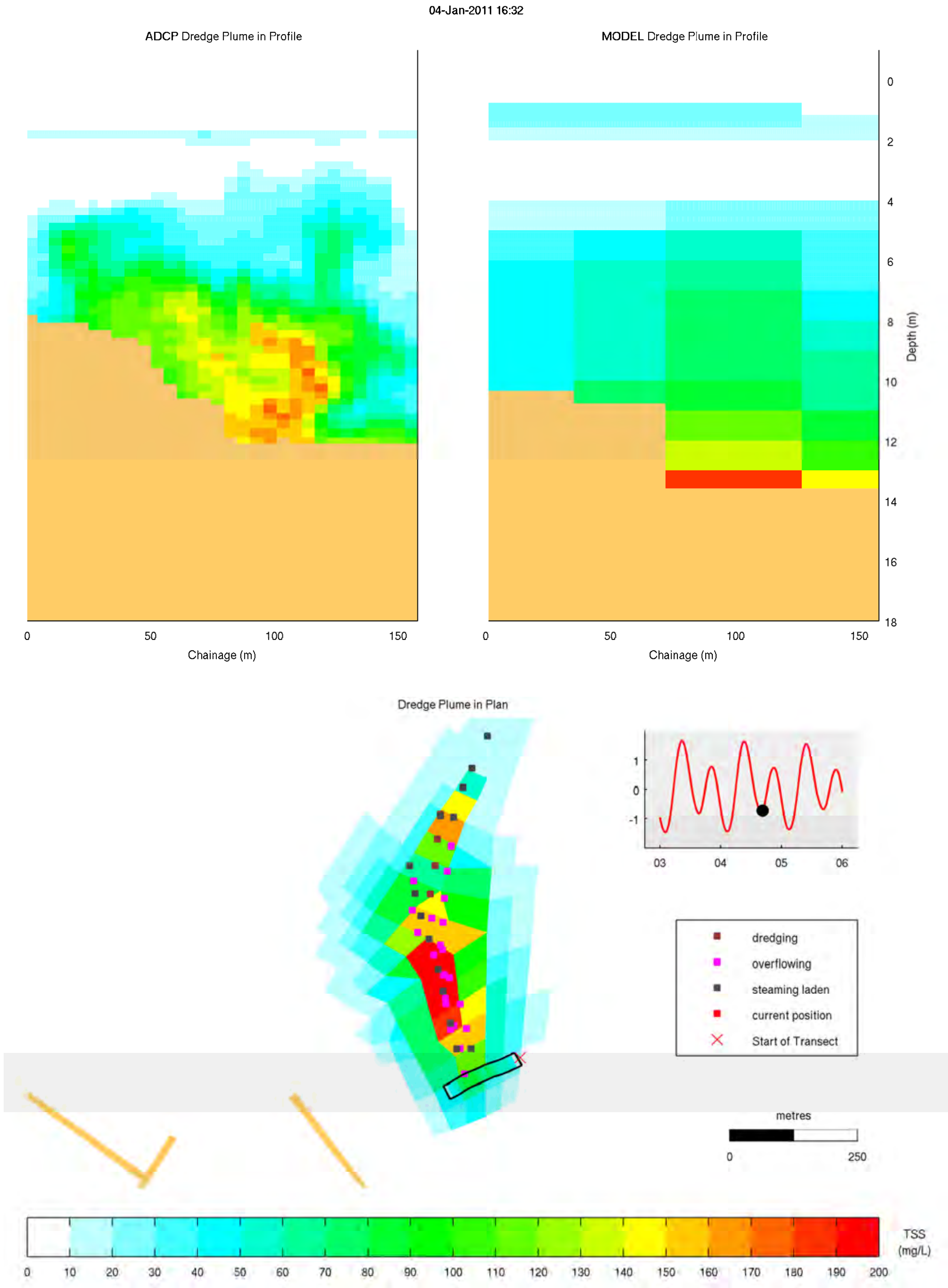

04-Jan-2011 09:59
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
dredging
overflowing
steaming laden
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)

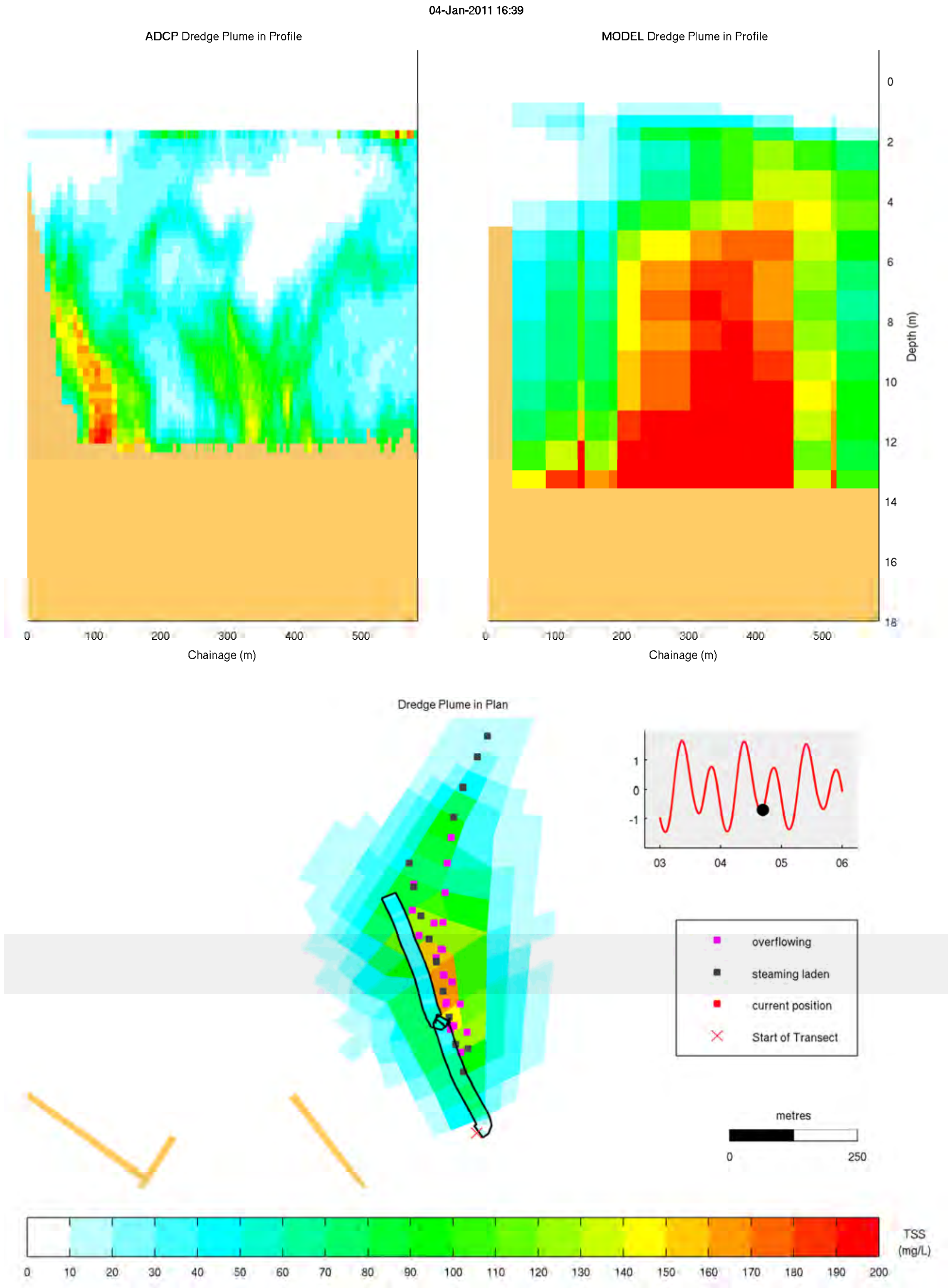

04-Jan-2011 10:21
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
20
40
60
80
100
120
140
Chainage (m)
0
2
4
6
8
10
12
14
16
18
Depth (m)
Dredge Plume in Plan
1
0
-1
03
04
05
06
dredging
overflowing
steaming laden
current position
Start of Transect
metres
0
250
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TSS (mg/L)

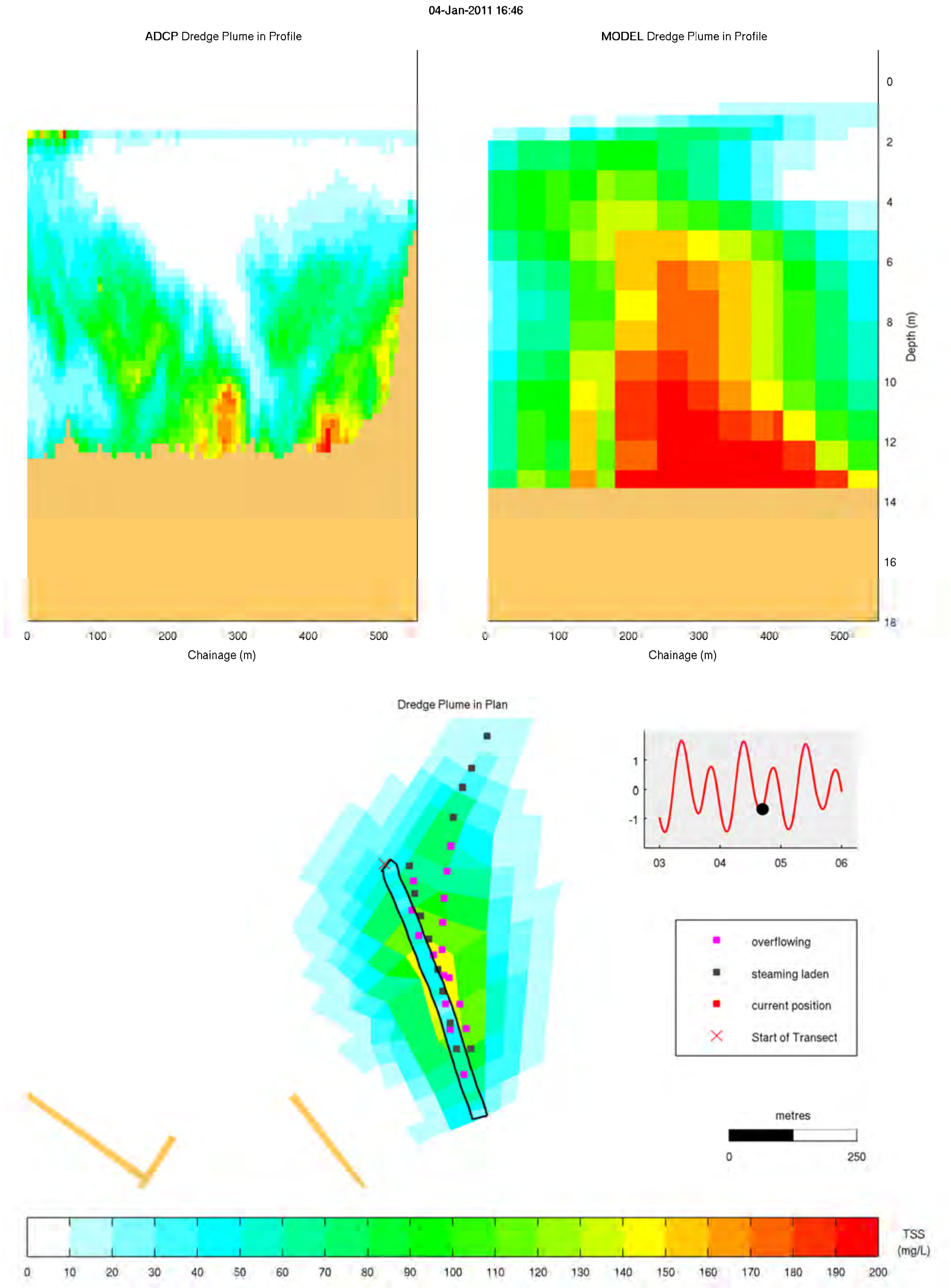

04-Jan-2011 15:35
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0
20
40
60
80
100
120
Chainage (m)
Chainage (m)
Dredge Plume in Plan
1
0
-1
03
04
05
06
dredging
steaming unladen
current position
Start of Transect
metres
0
250
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TSS
(mg/L)

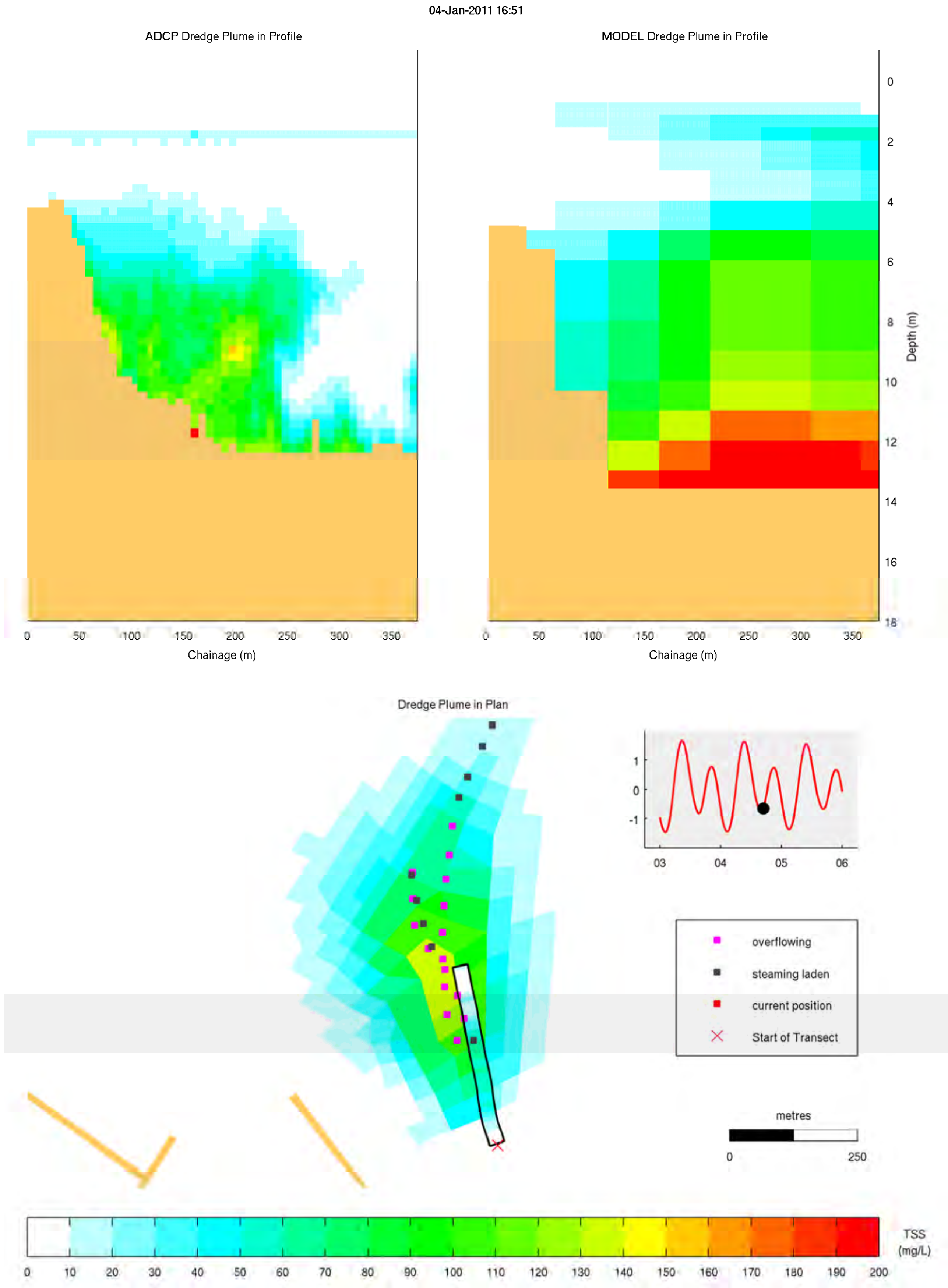

04-Jan-2011 15:55
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 50 100 150 200 250 300
Chainage (m)
Depth (m)
0 2 4 6 8 10 12 14 16 18
Dredge Plume in Plan
1 0 -1
03 04 05 06
dredging
overflowing
steaming laden
steaming unladen
current position
Start of Transect
metres
0 250
TSS (mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

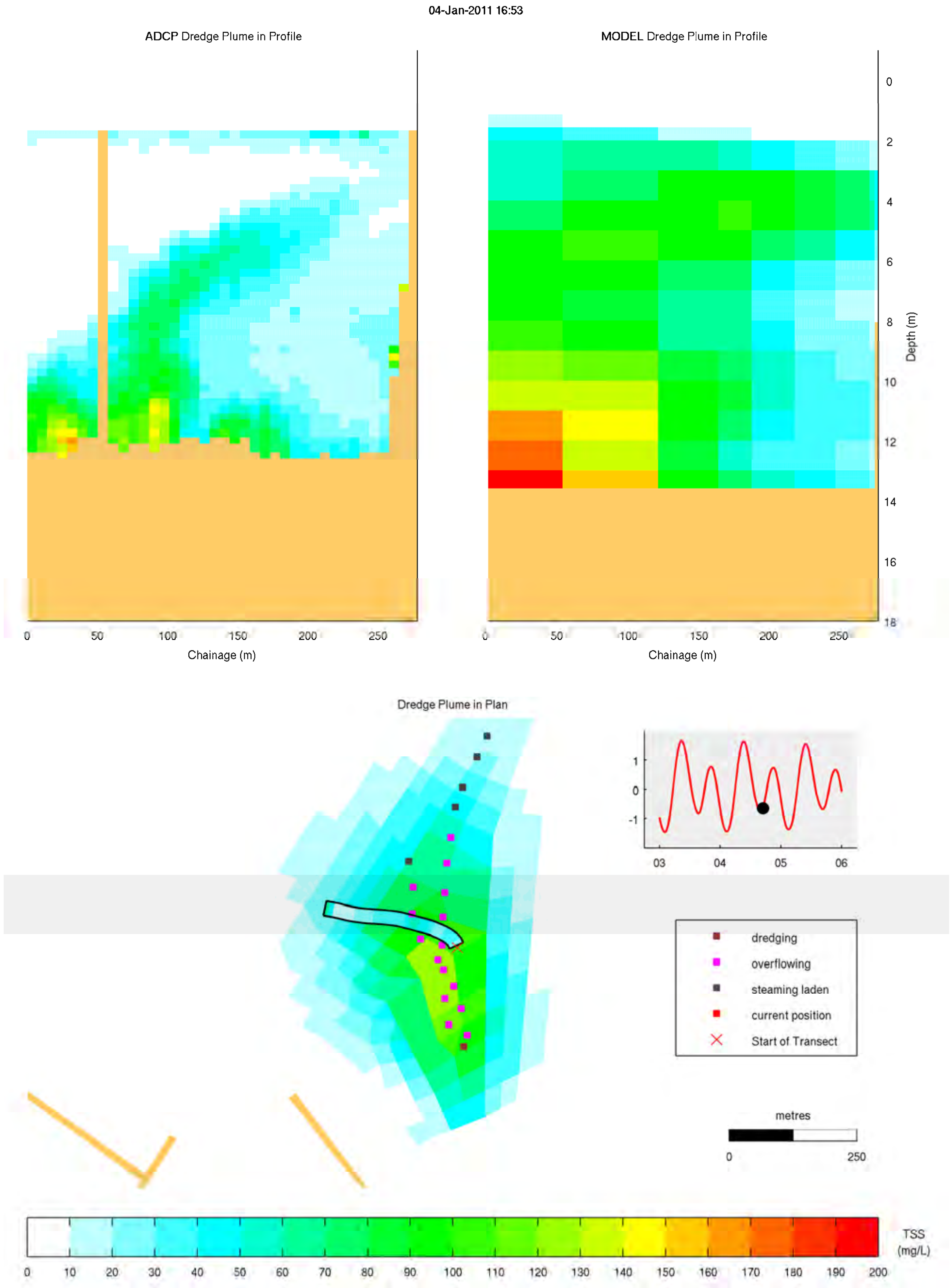

04-Jan-2011 16:07
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
dredging
overflowing
steaming laden
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200


04-Jan-2011 16:32
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
dredging
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS
(mg/L)

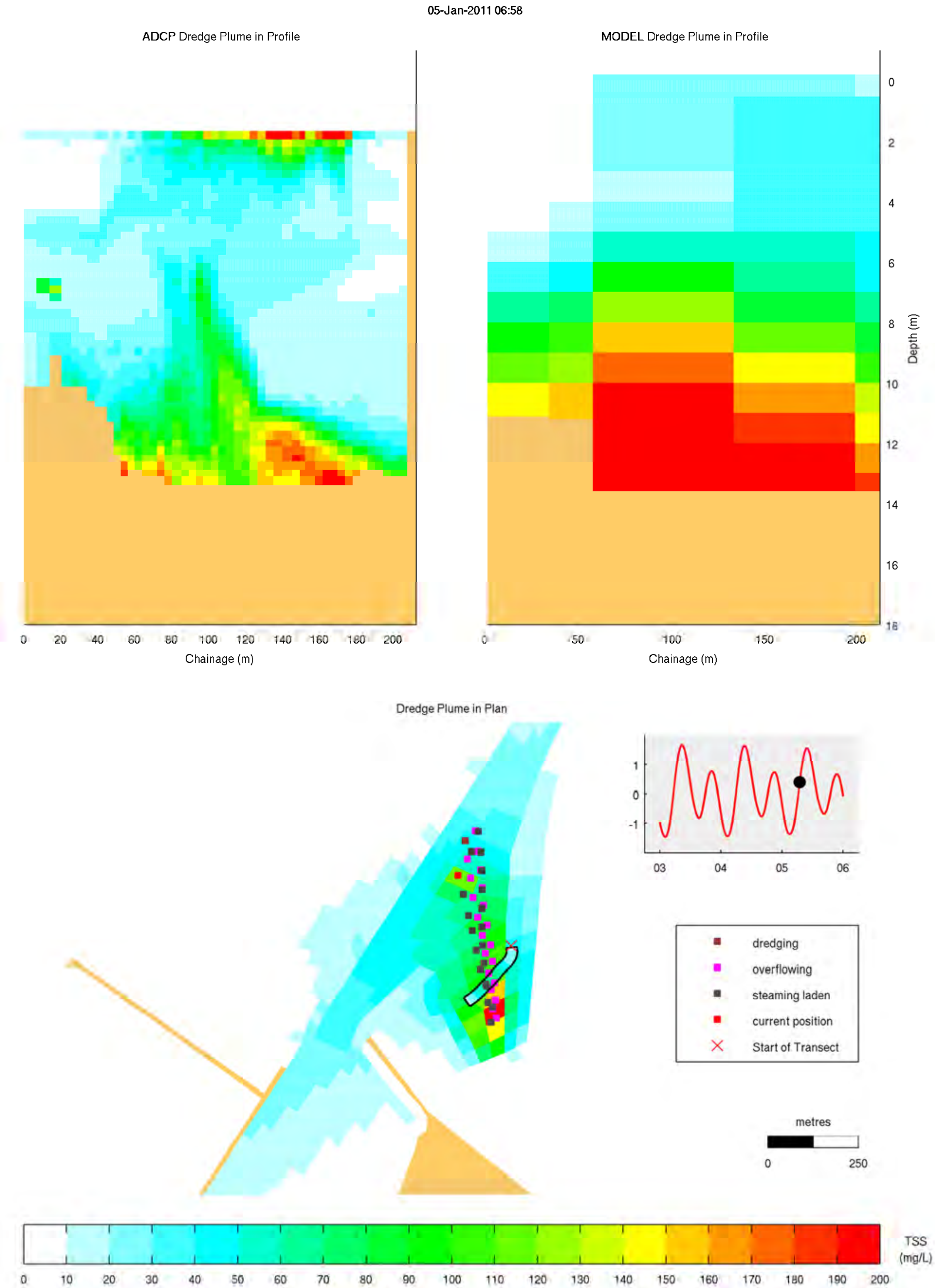

04-Jan-2011 16:39
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS
(mg/L)

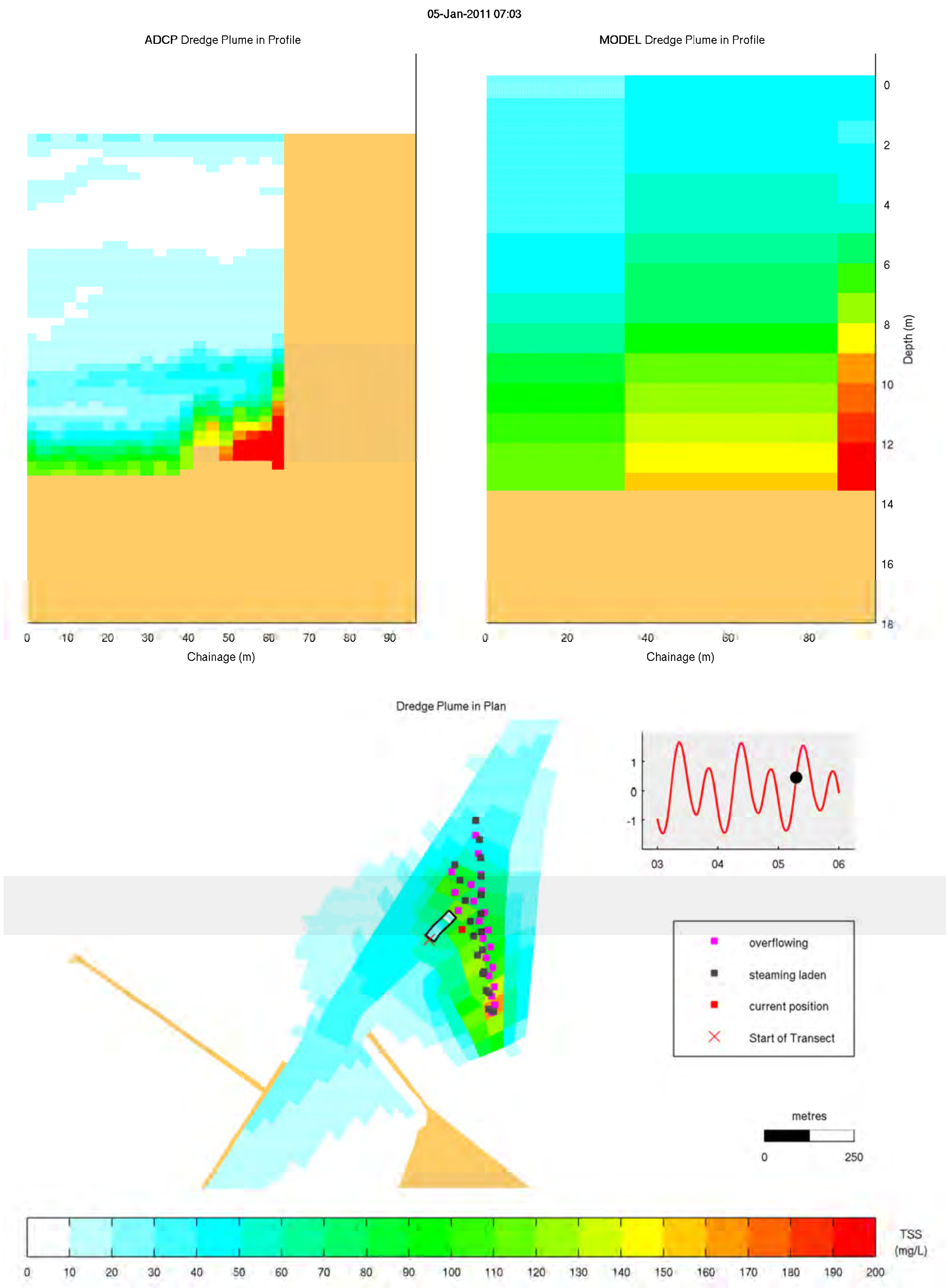

04-Jan-2011 16:46
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
0
100
200
300
400
500
0
2
4
6
8
10
12
14
16
18
Dredge Plume in Plan
1
0
-1
03
04
05
06
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS
(mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

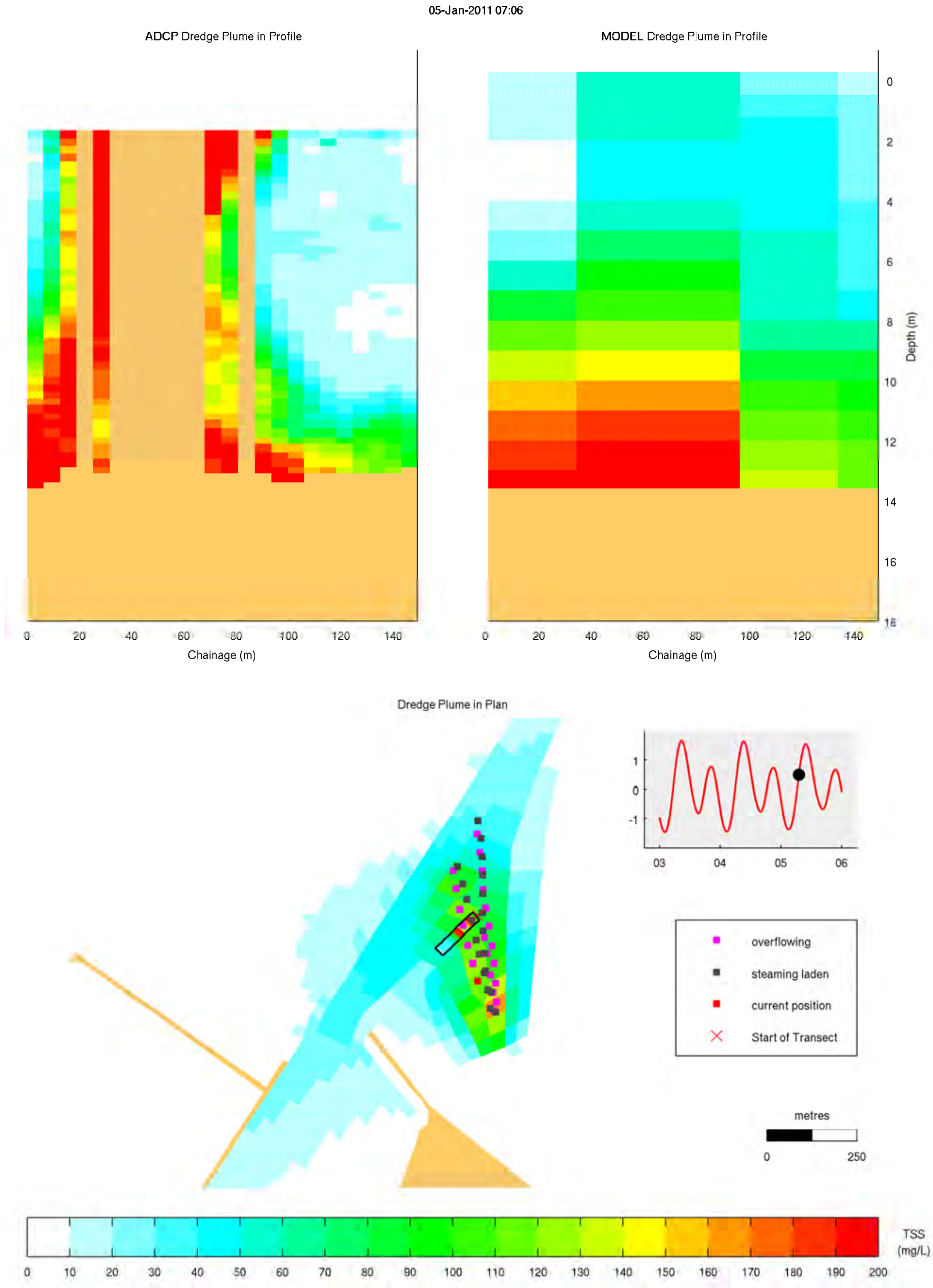

04-Jan-2011 16:51
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
03
04
05
06
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS
(mg/L)

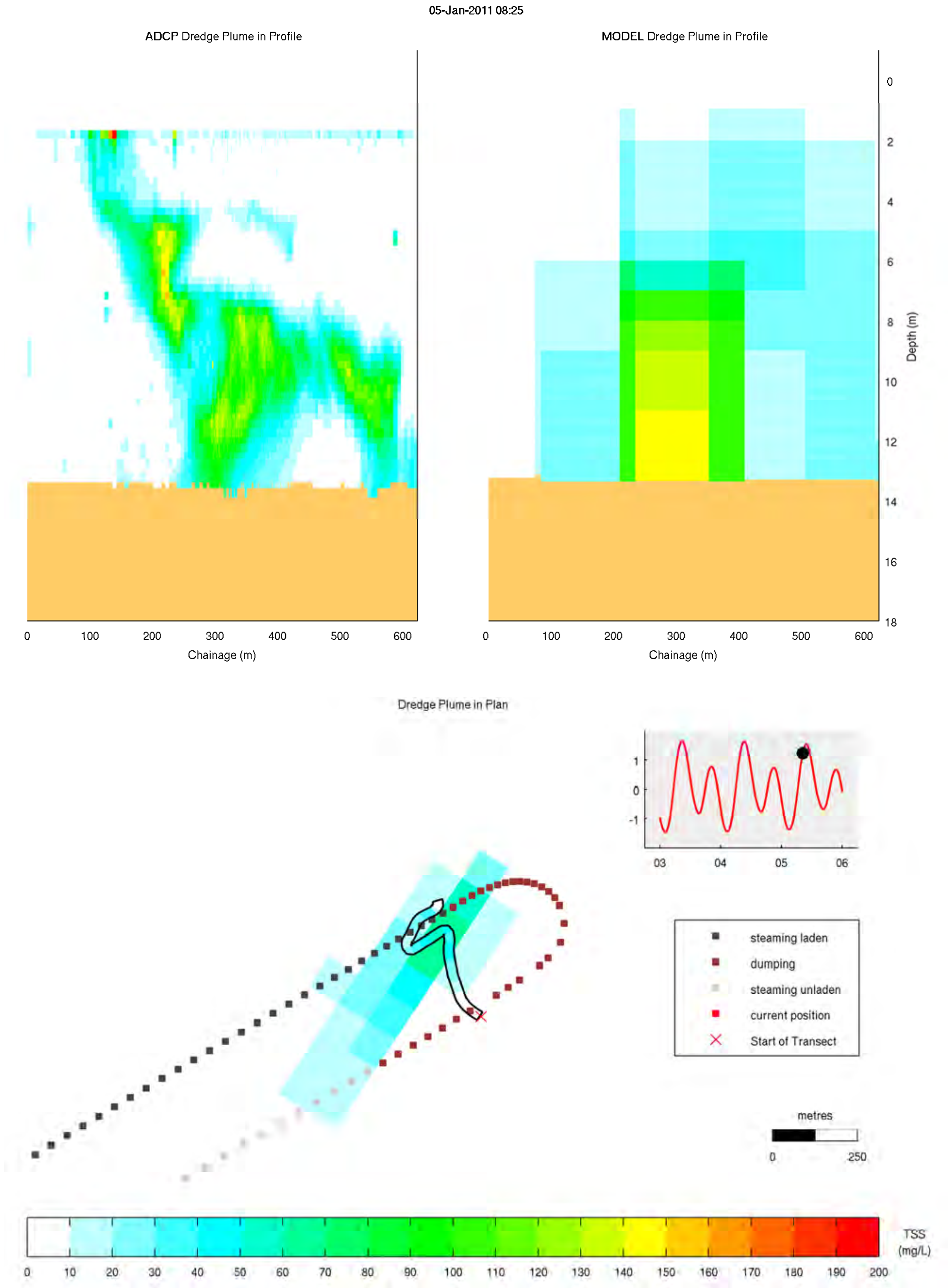


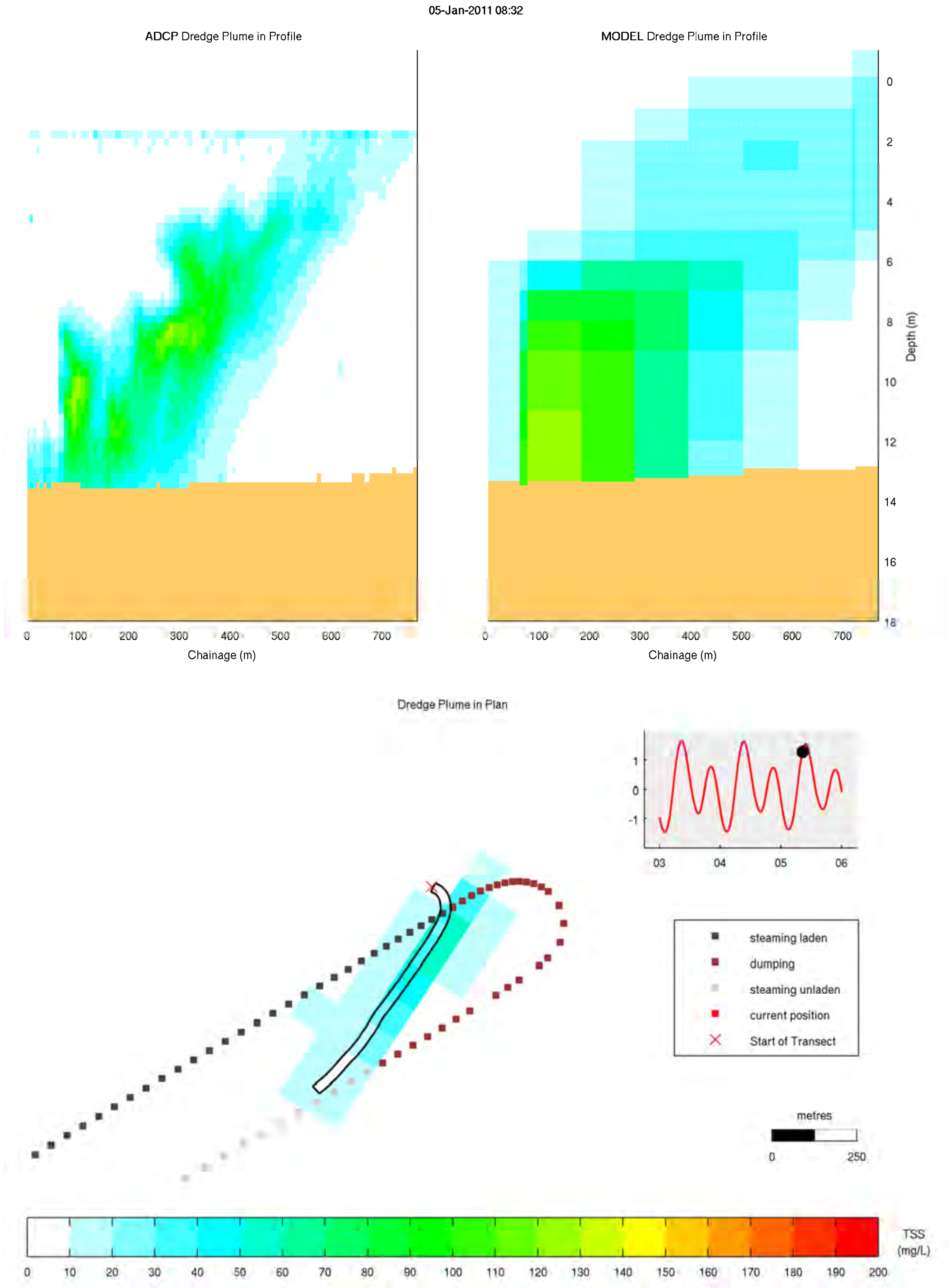
04-Jan-2011 16:53
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 2 4 6 8 10 12 14 16 18
Depth (m)
0 50 100 150 200 250
Chainage (m)
Dredge Plume in Plan
1 0 -1
03 04 05 06
dredging
overflowing
steaming laden
current position
Start of Transect
metres
0 250
TSS (mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

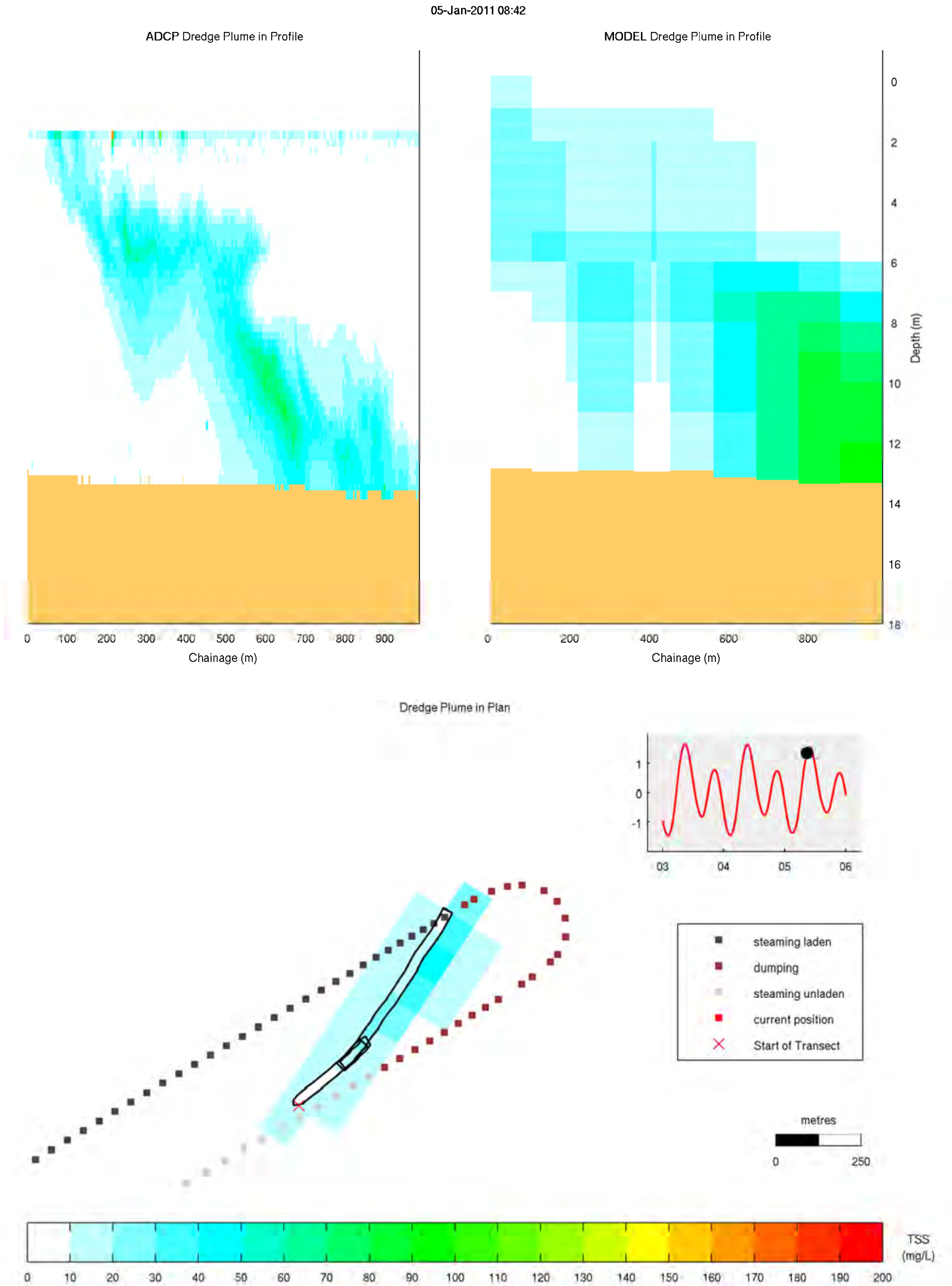

05-Jan-2011 06:58
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
0
2
4
6
8
10
12
14
16
18
0 20 40 60 80 100 120 140 160 180 200
0 50 100 150 200
Dredge Plume in Plan
1
0
-1
03 04 05 06
dredging
overflowing
steaming laden
current position
Start of Transect
metres
0 250
TSS
(mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200


05-Jan-2011 07:03
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
03
04
05
06
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS
(mg/L)

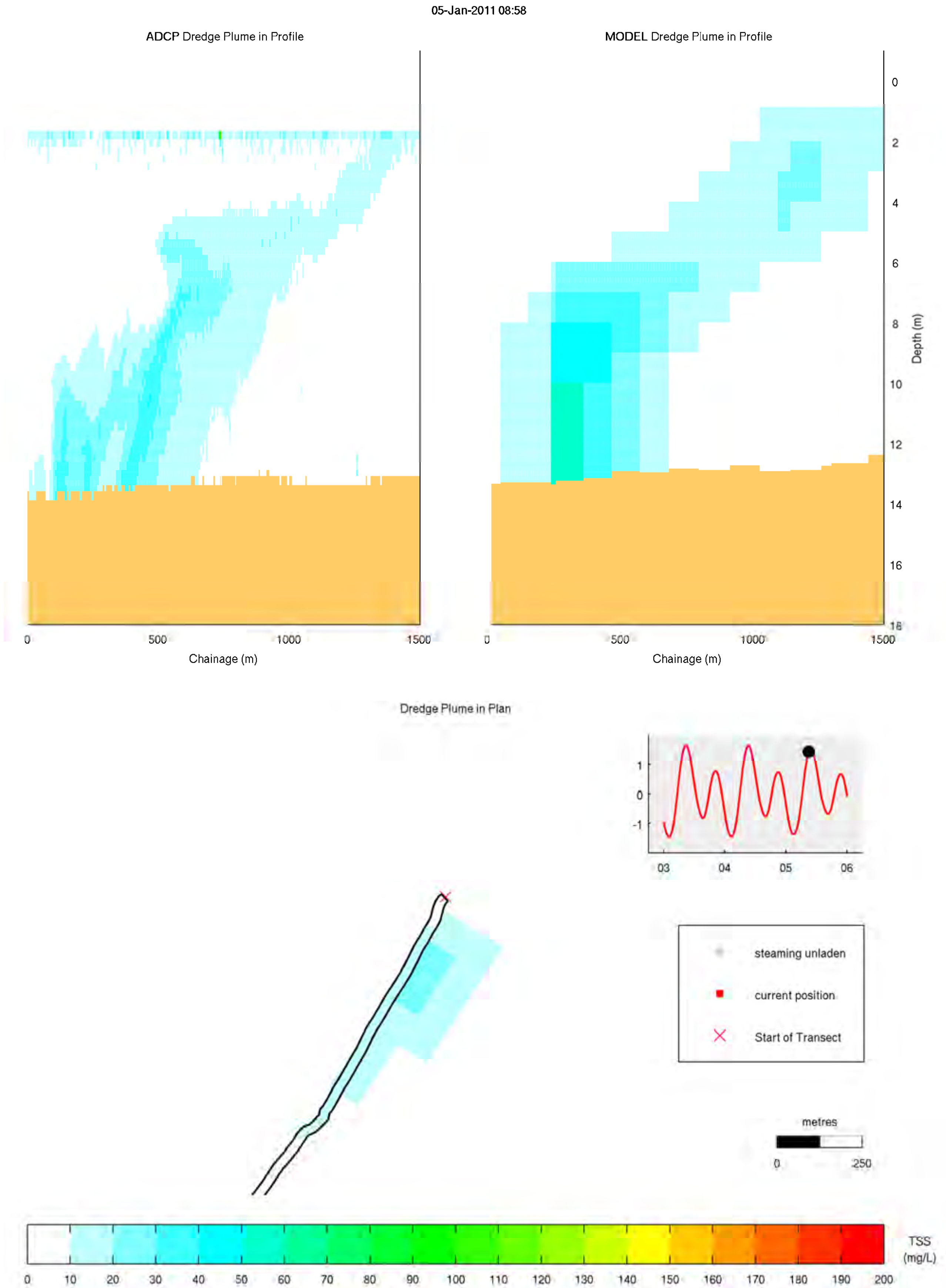

05-Jan-2011 07:06
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS
(mg/L)

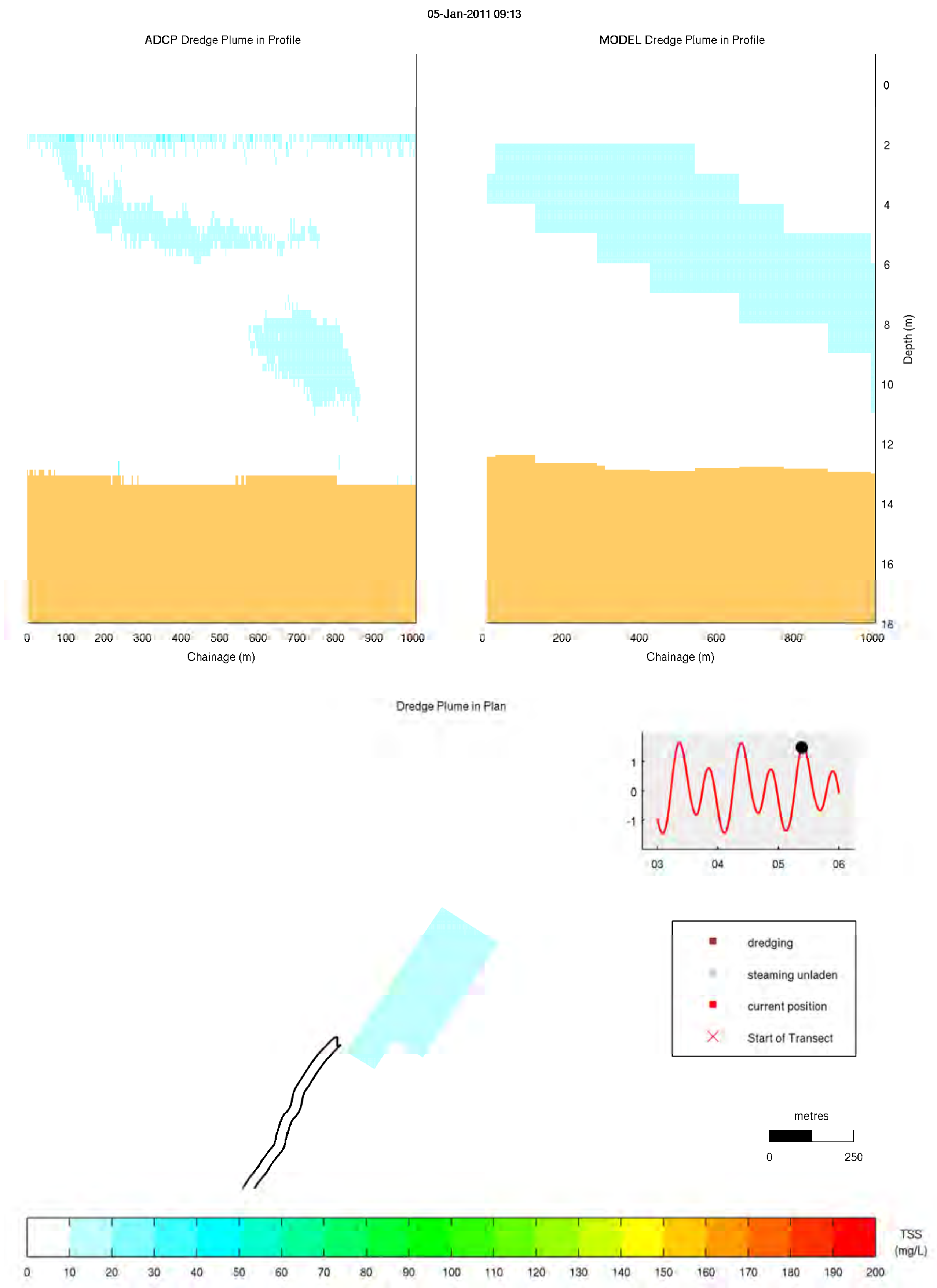

05-Jan-2011 08:25
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0
100
200
300
400
500
600
Chainage (m)
Dredge Plume in Plan
1
0
-1
03
04
05
06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TSS
(mg/L)


05-Jan-2011 08:32
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 100 200 300 400 500 600 700
Chainage (m)
Depth (m)
0 2 4 6 8 10 12 14 16 18
Dredge Plume in Plan
1 0 -1
03 04 05 06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)

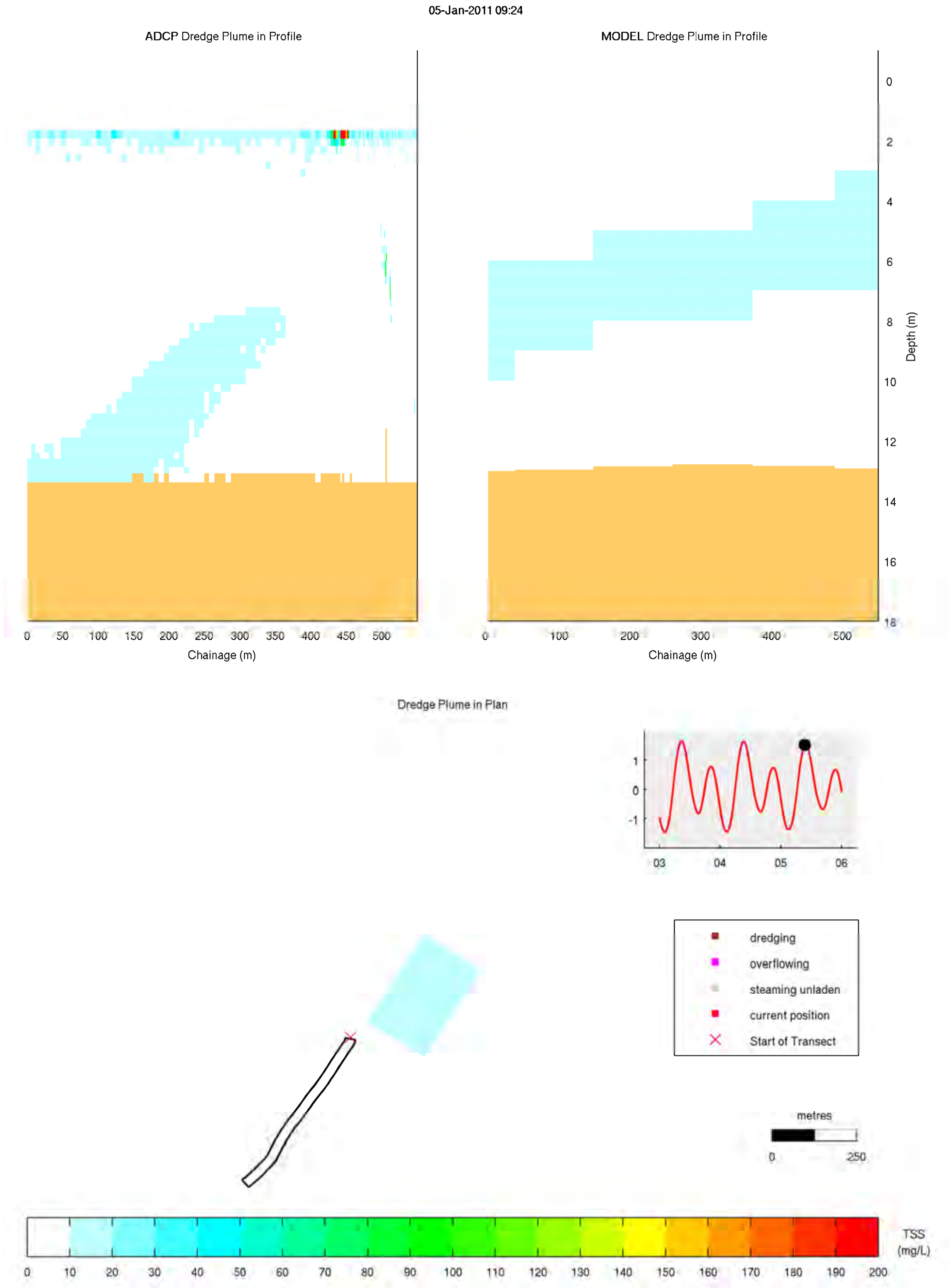


05-Jan-2011 08:42
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 100 200 300 400 500 600 700 800 900
Chainage (m)
0 200 400 600 800
Chainage (m)
0 2 4 6 8 10 12 14 16 18
Depth (m)
Dredge Plume in Plan
1 0 -1
03 04 05 06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS (mg/L)

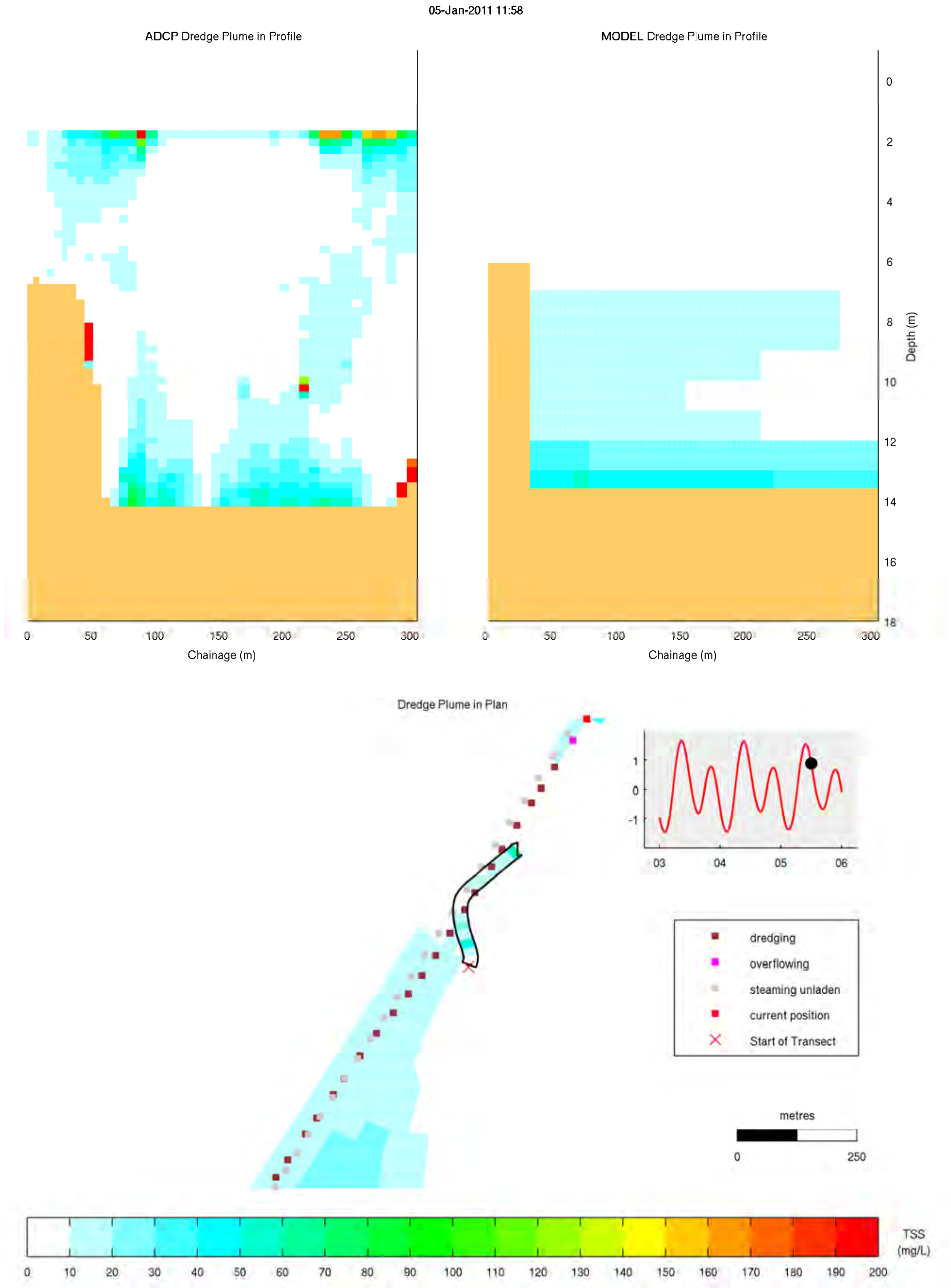

05-Jan-2011 08:58
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0
500
1000
1500
Chainage (m)
0
500
1000
1500
Chainage (m)
Dredge Plume in Plan
1
0
-1
03
04
05
06
steaming unladen
current position
Start of Transect
metres
0
250
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TSS
(mg/L)

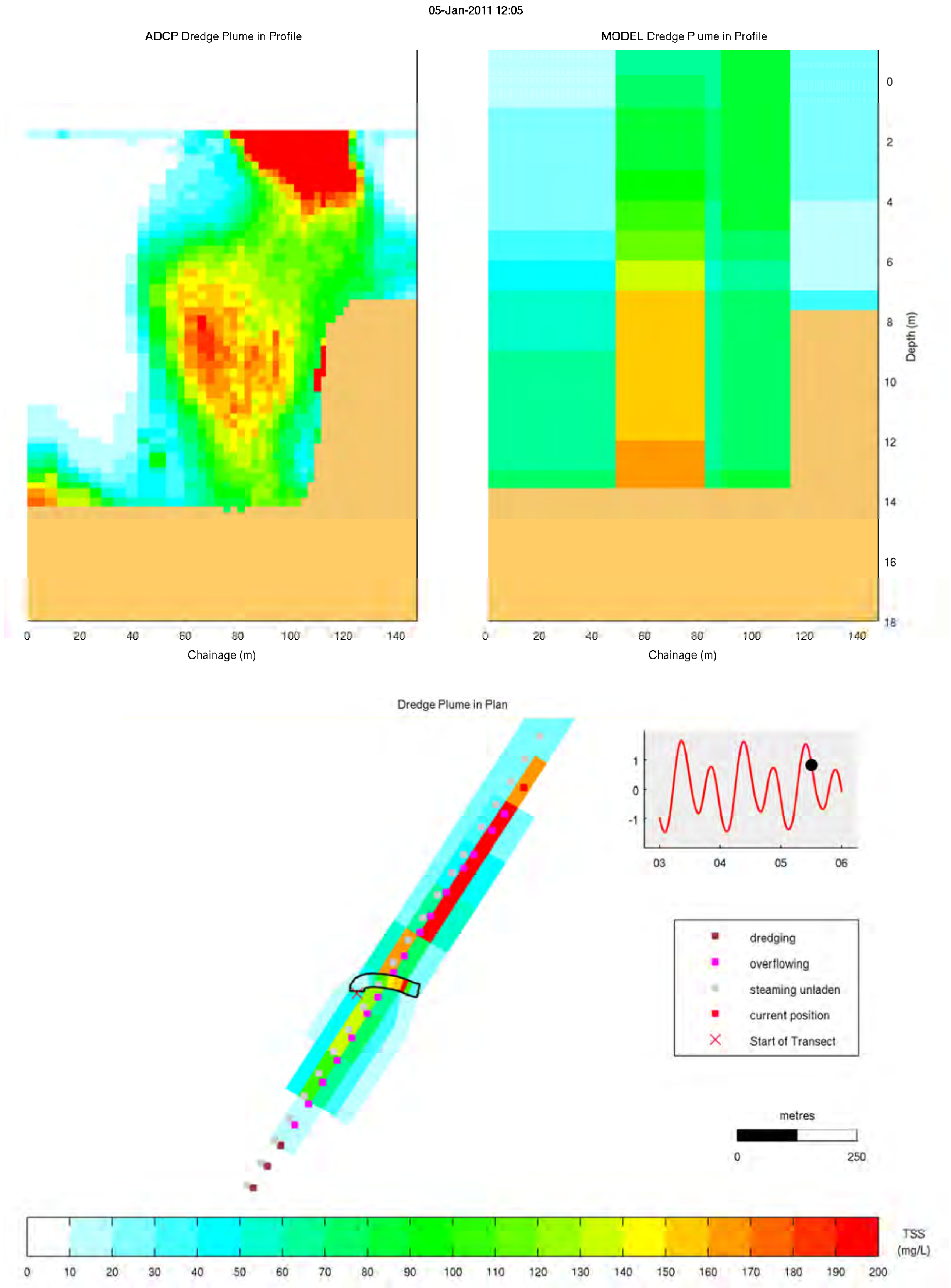


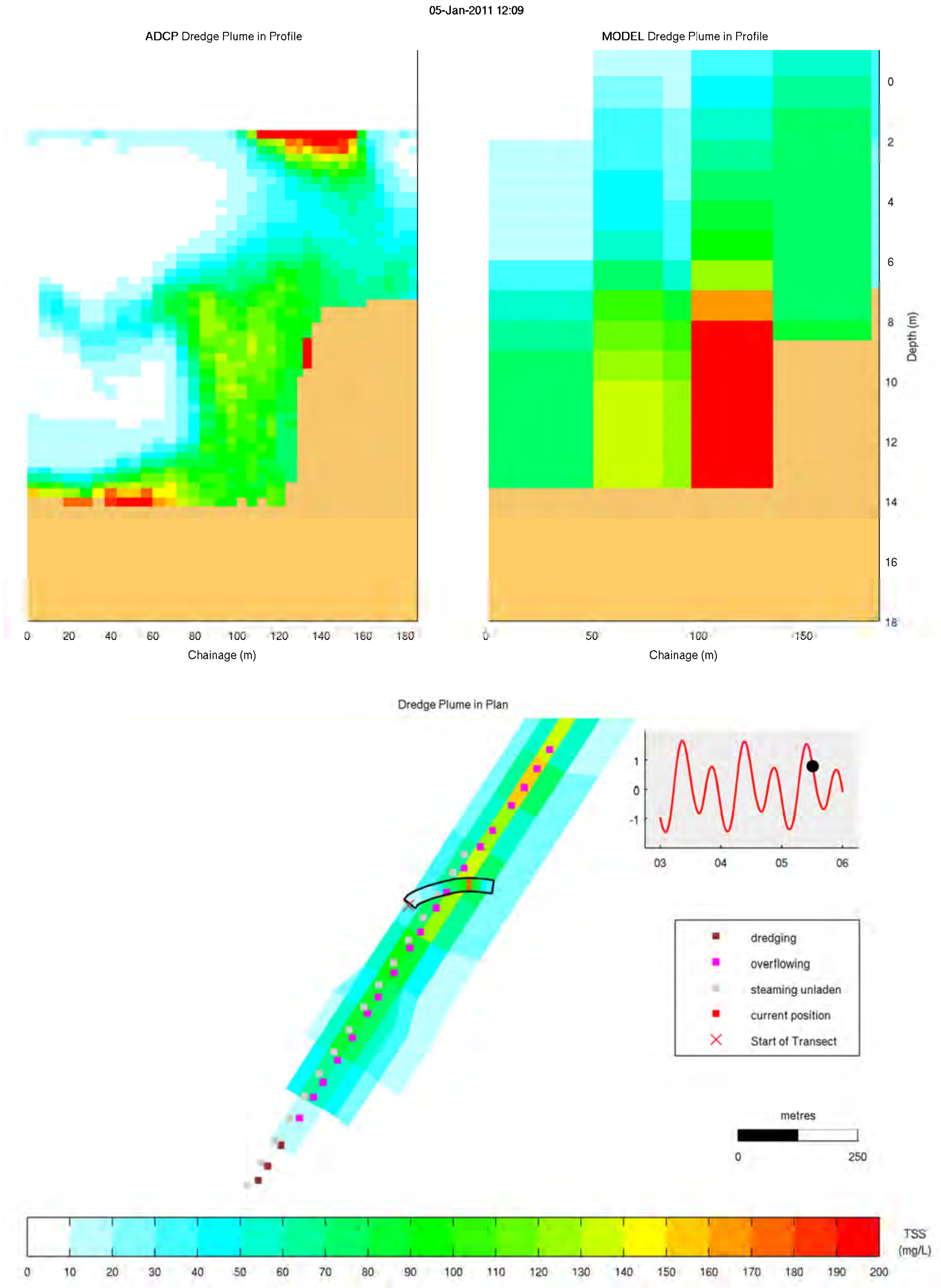
05-Jan-2011 09:13
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0 100 200 300 400 500 600 700 800 900 1000
Chainage (m)
0 200 400 600 800 1000
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
dredging
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)

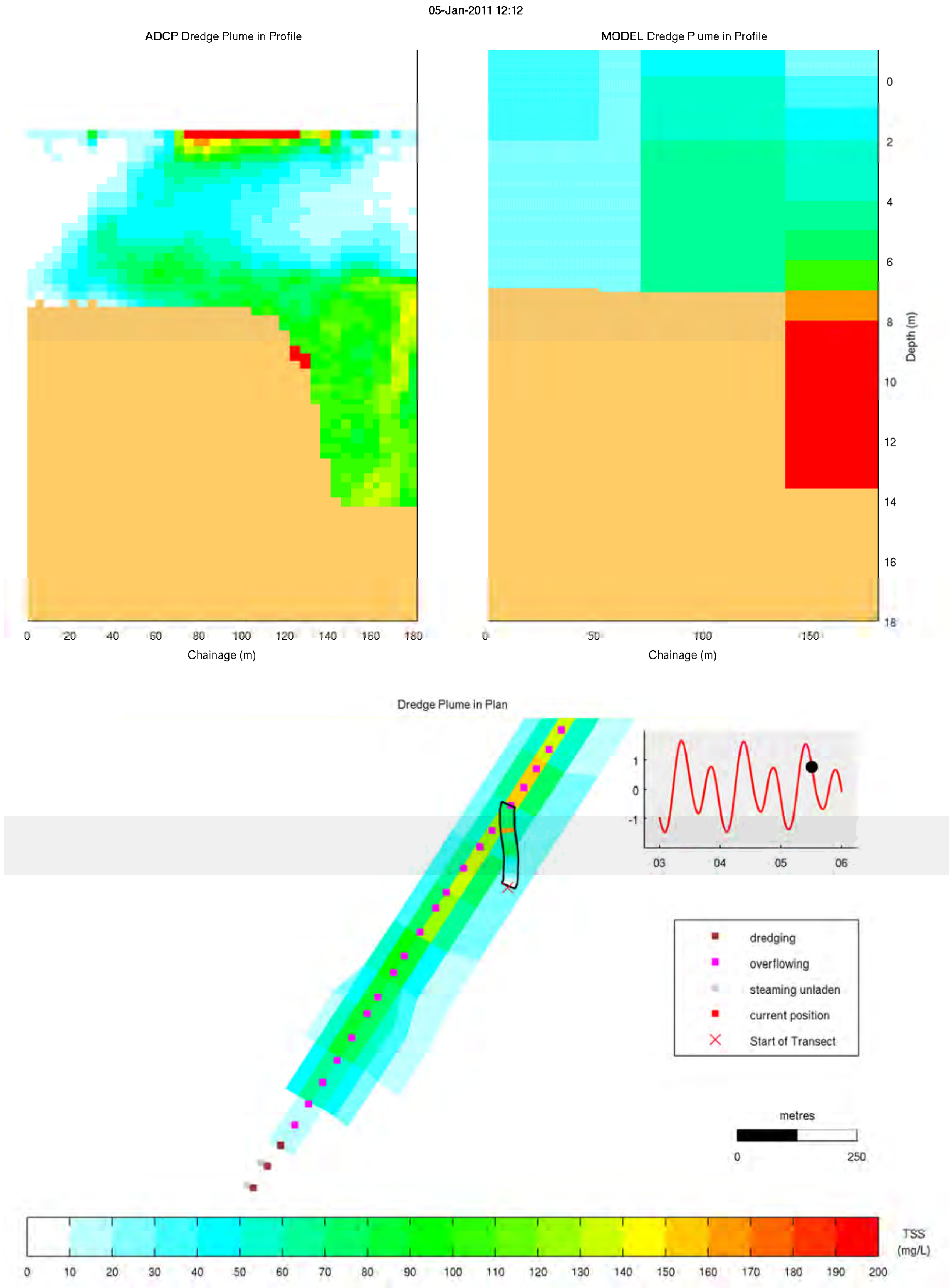


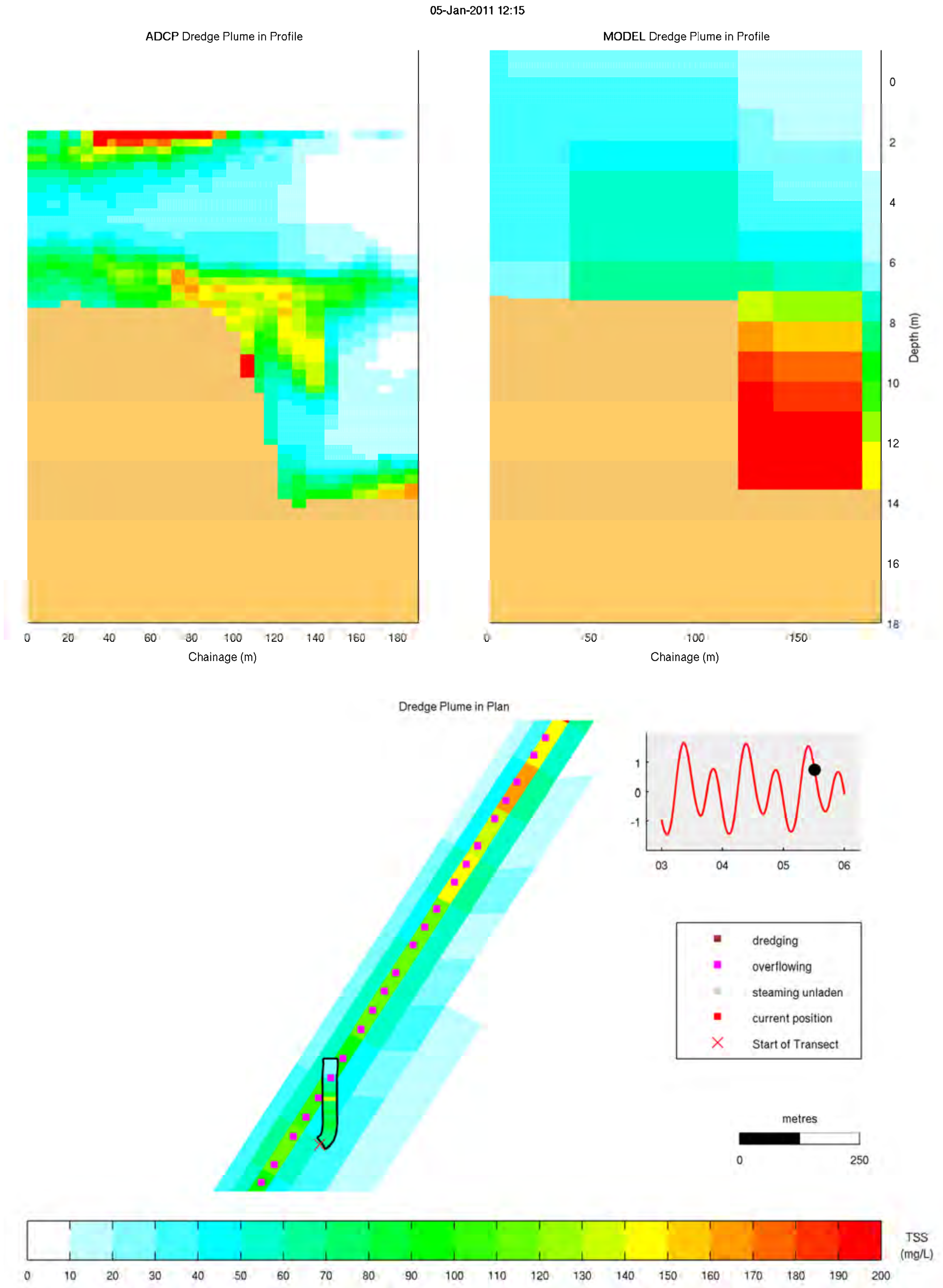
05-Jan-2011 09:24
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
250
300
350
400
450
500
0
100
200
300
400
500
Dredge Plume in Plan
1
0
-1
03
04
05
06
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

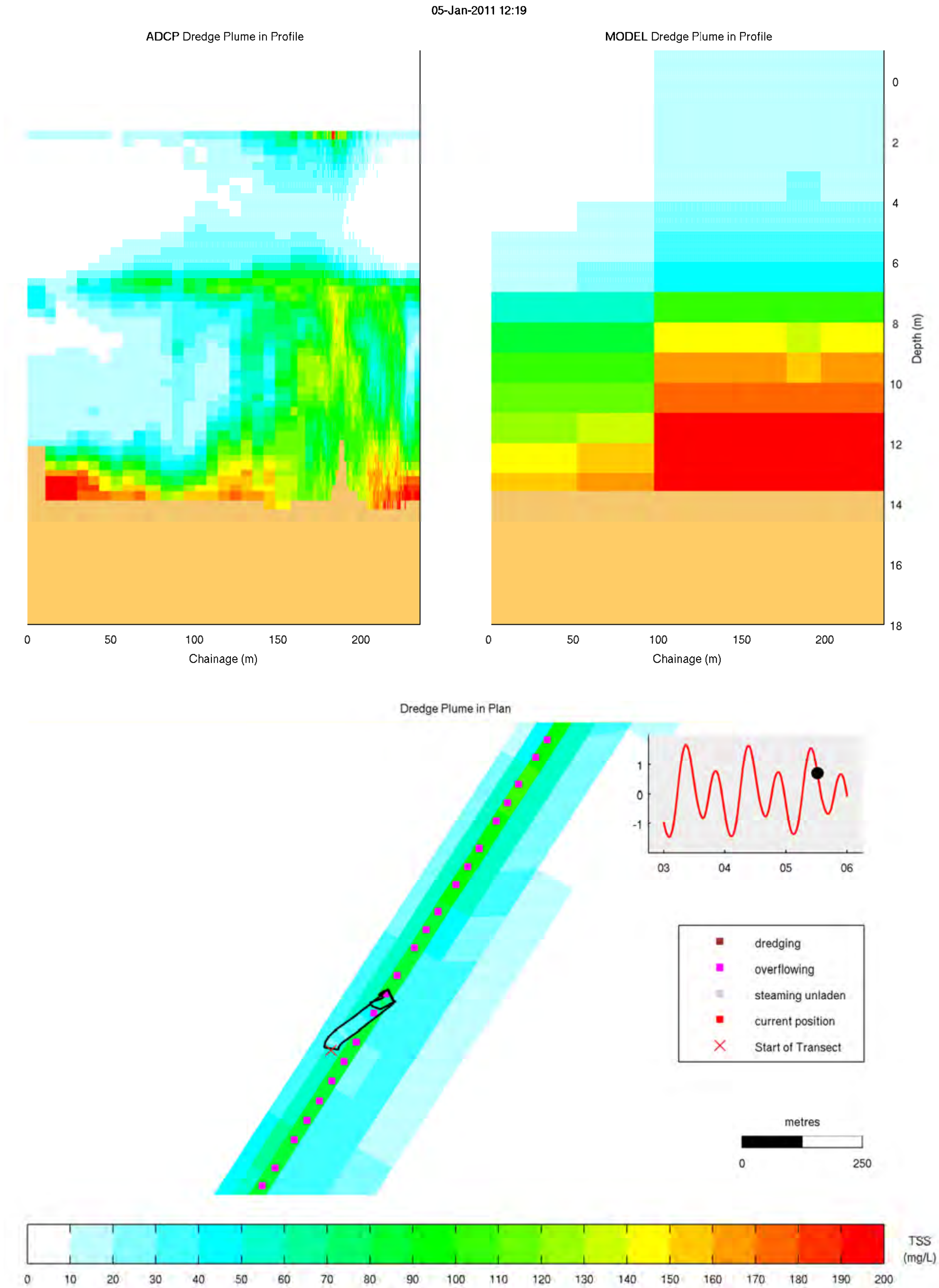

05-Jan-2011 11:58
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)

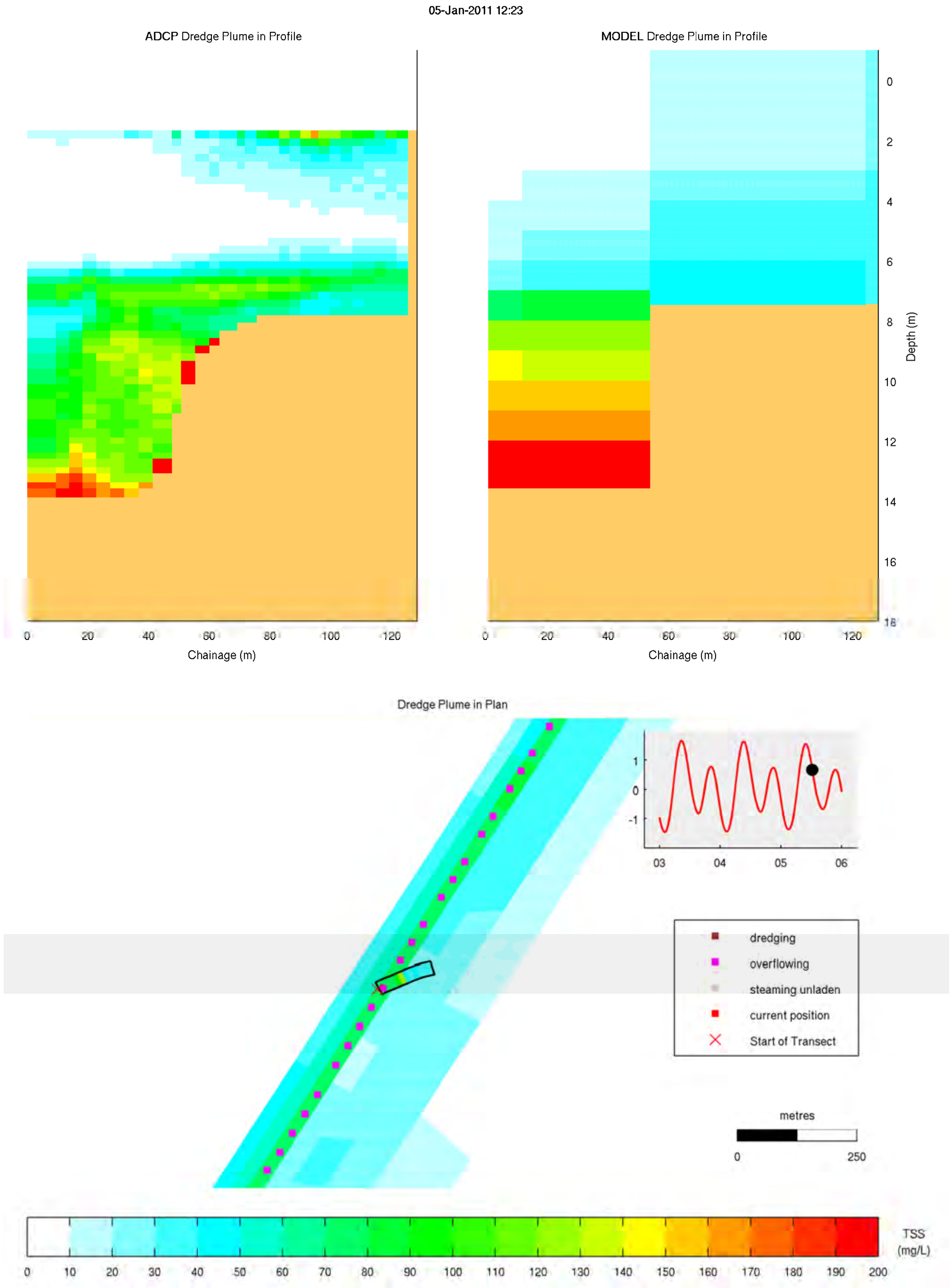

05-Jan-2011 12:05
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)

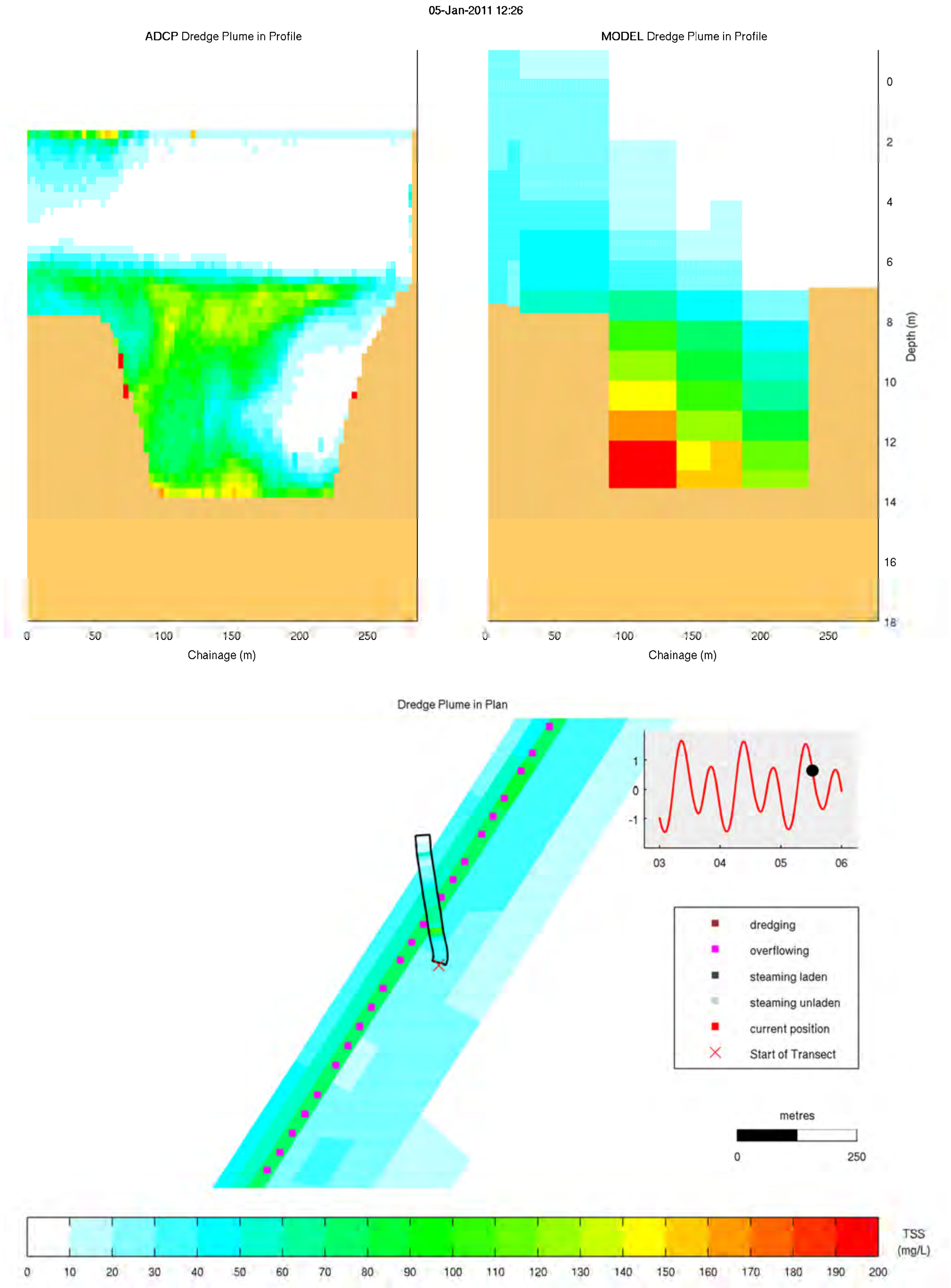

05-Jan-2011 12:09
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 20 40 60 80 100 120 140 160 180
Chainage (m)
0 50 100 150
Chainage (m)
0 2 4 6 8 10 12 14 16 18
Depth (m)
Dredge Plume in Plan
1 0 -1
03 04 05 06
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)

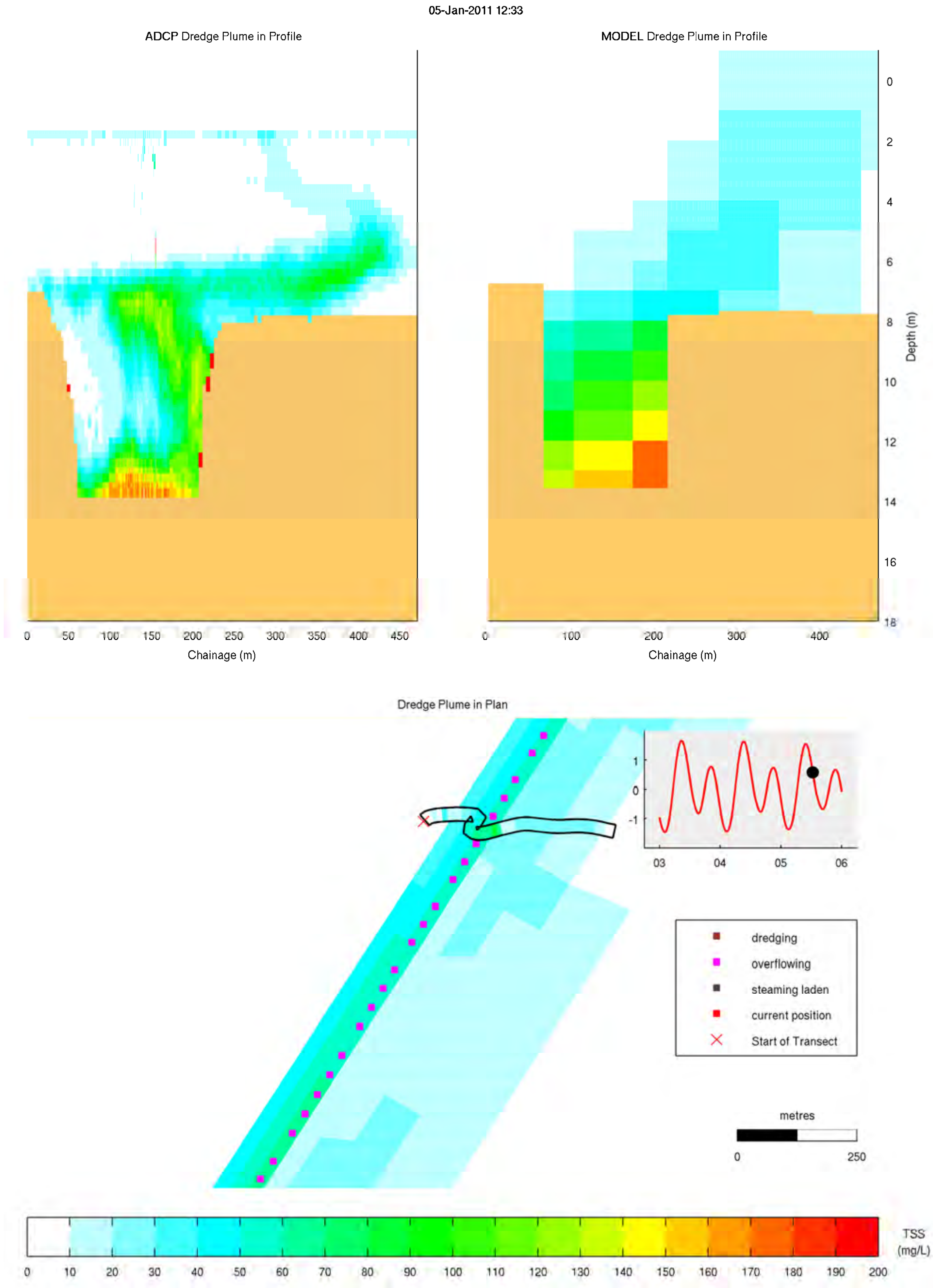

05-Jan-2011 12:12
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
03
04
05
06
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)

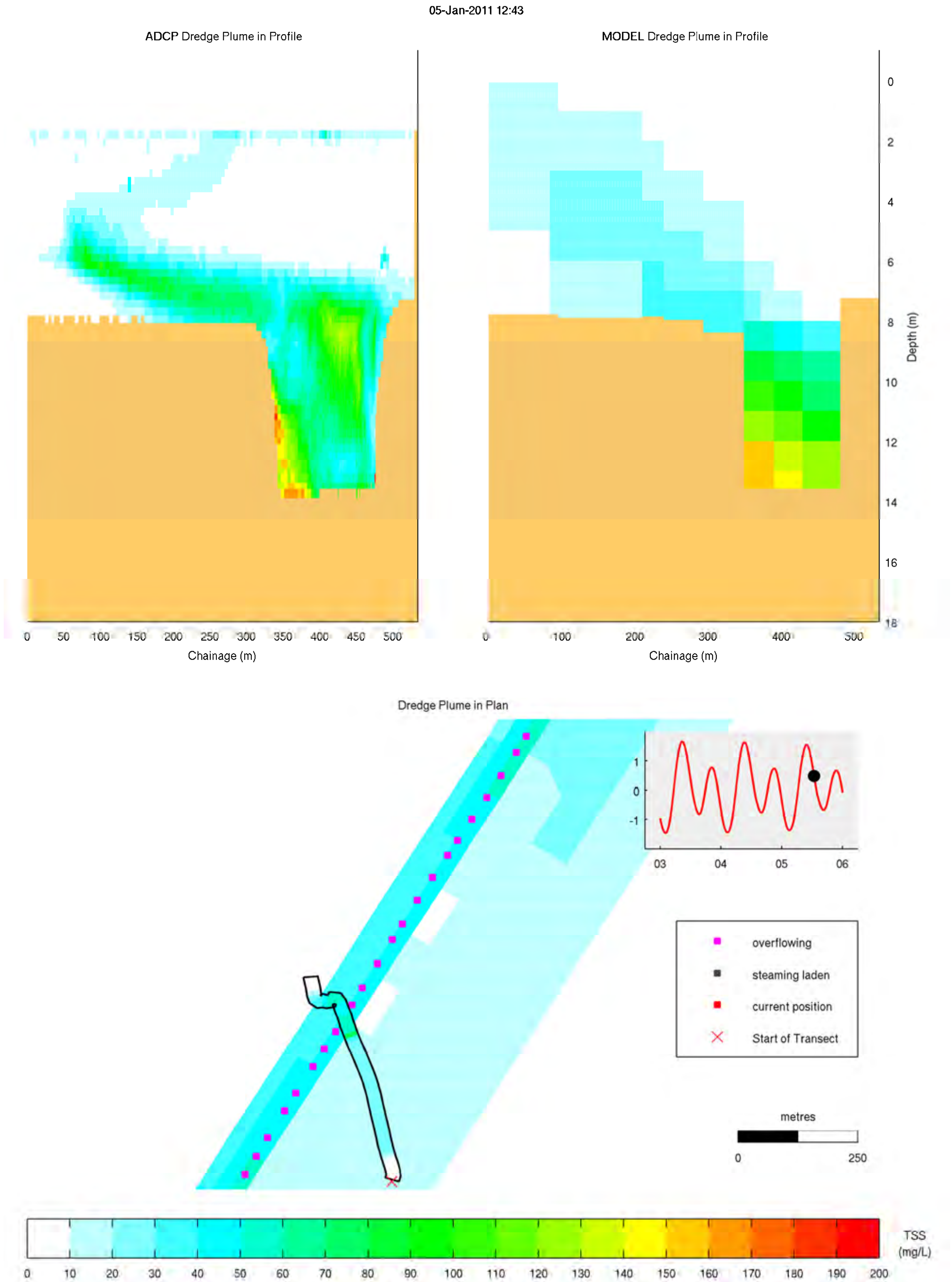

05-Jan-2011 12:15
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)

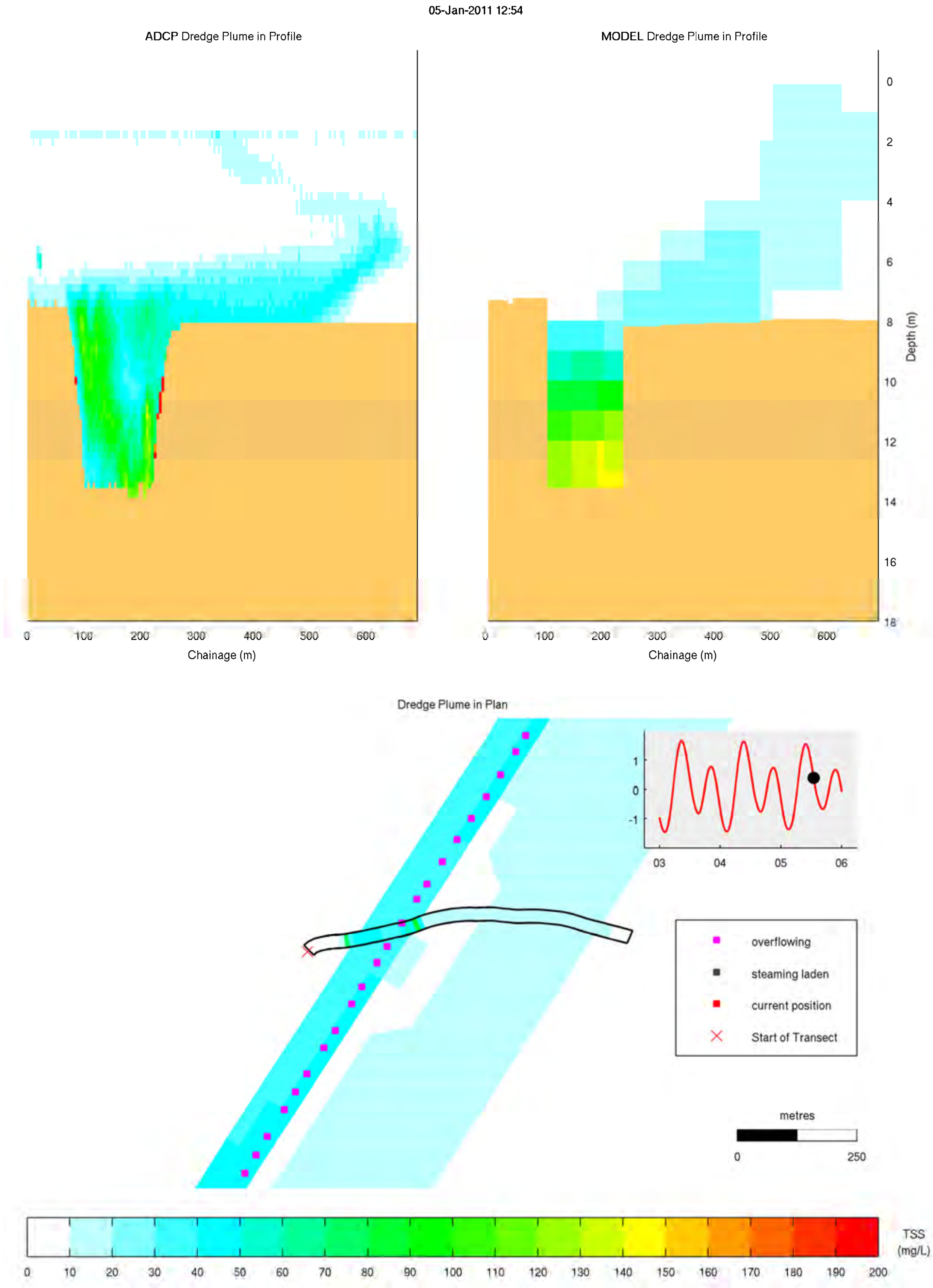

05-Jan-2011 12:19
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)

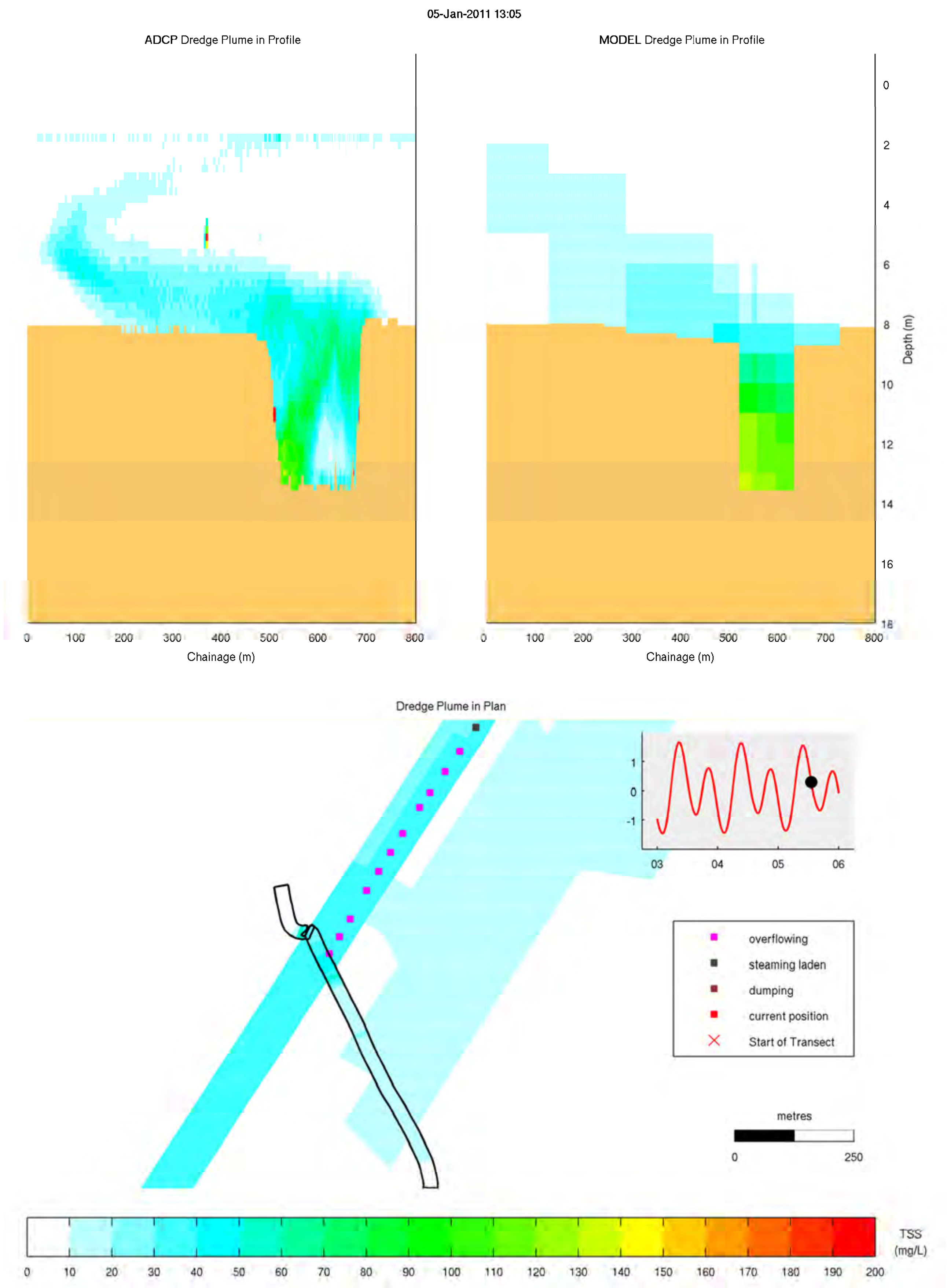

05-Jan-2011 12:23
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

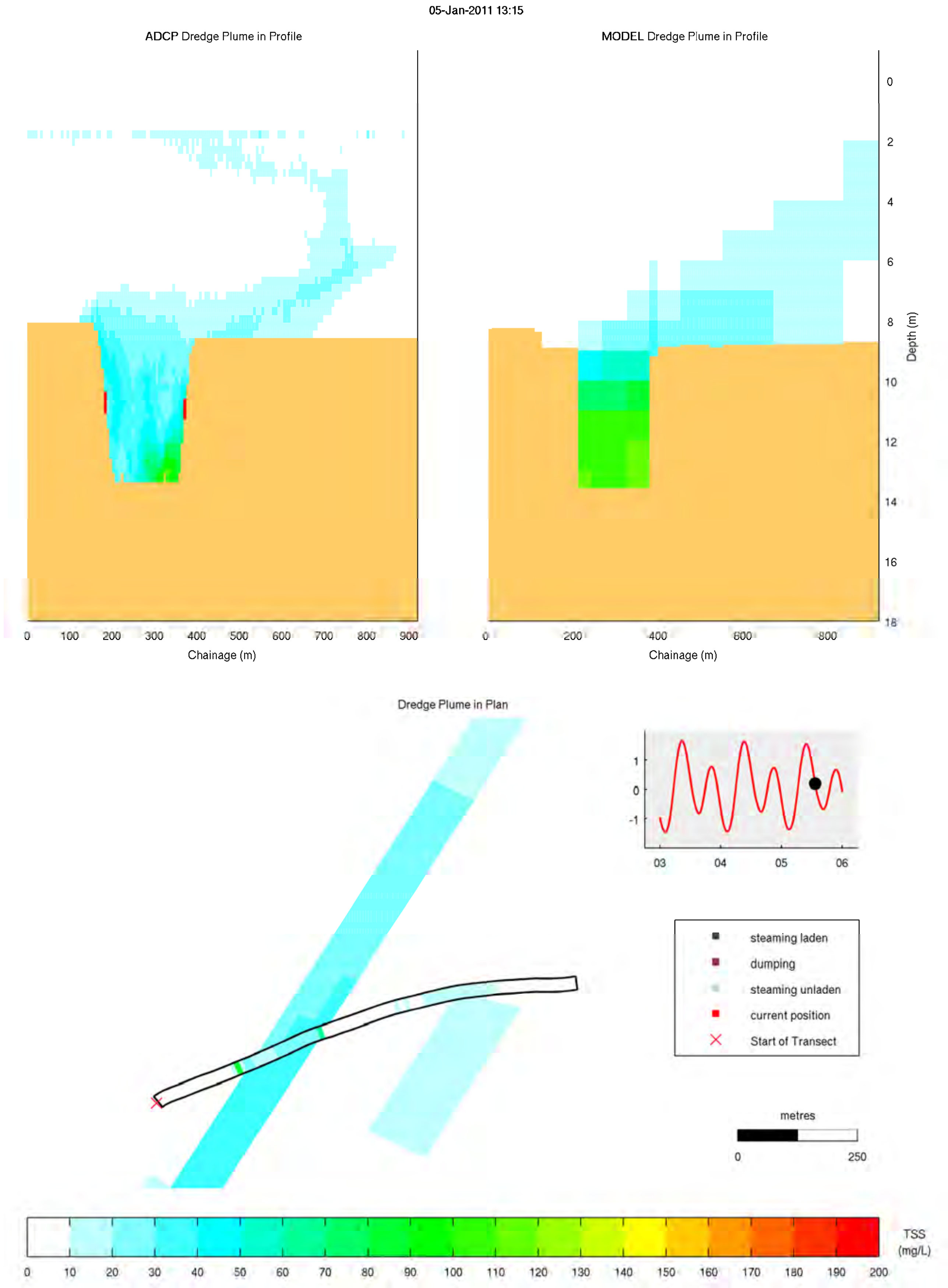

05-Jan-2011 12:26
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
dredging
overflowing
steaming laden
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)

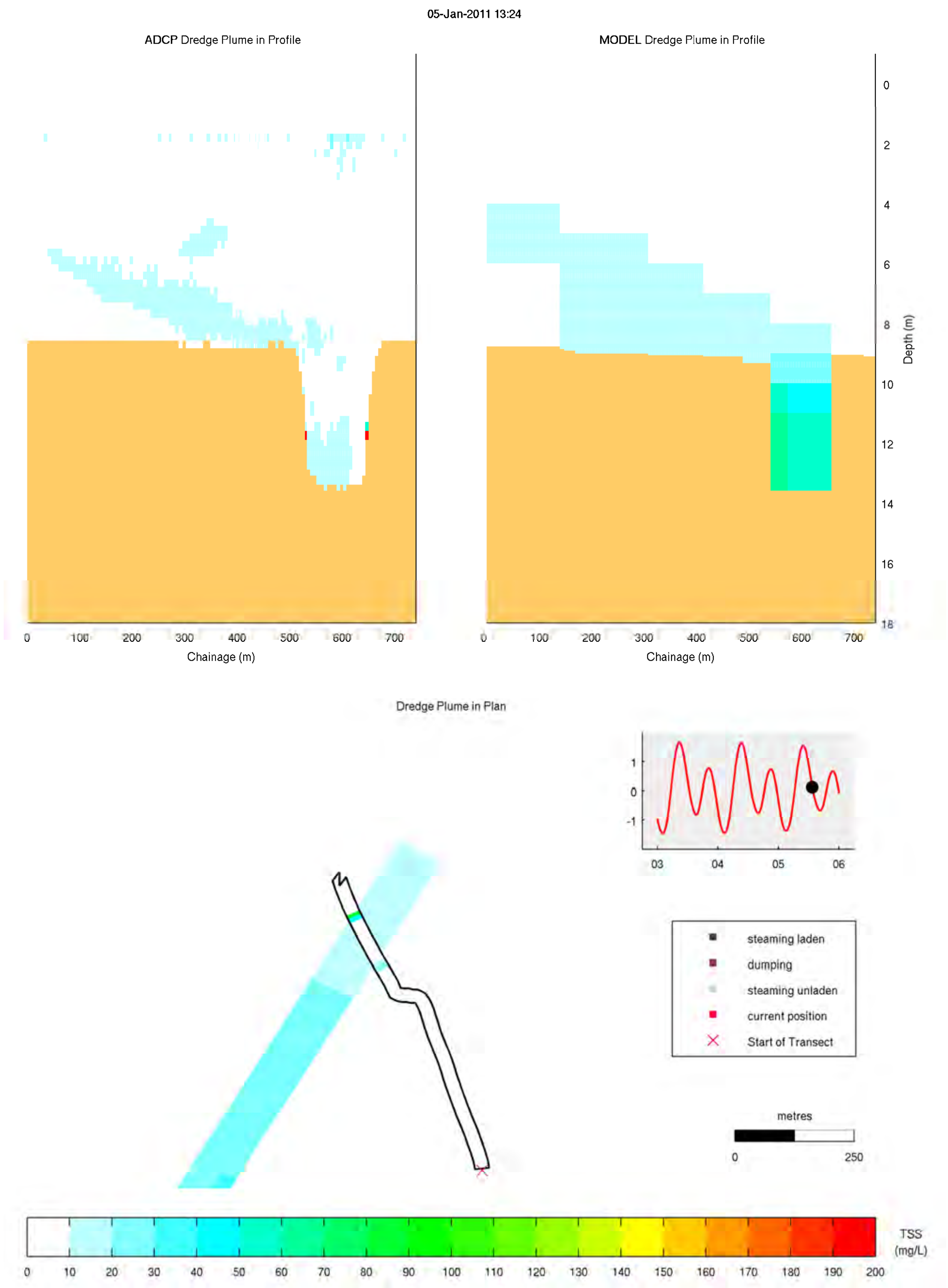

05-Jan-2011 12:33
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 50 100 150 200 250 300 350 400 450
Chainage (m)
0 100 200 300 400
Chainage (m)
0 2 4 6 8 10 12 14 16 18
Depth (m)
Dredge Plume in Plan
1 0 -1
03 04 05 06
dredging
overflowing
steaming laden
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS (mg/L)


05-Jan-2011 12:43
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
0
2
4
6
8
10
12
14
16
18
0 50 100 150 200 250 300 350 400 450 500
Chainage (m)
0 100 200 300 400 500
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
overflowing
steaming laden
current position
Start of Transect
metres
0 250
TSS (mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200


05-Jan-2011 12:54
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 100 200 300 400 500 600
Chainage (m)
0 2 4 6 8 10 12 14 16 18
Depth (m)
Dredge Plume in Plan
1 0 -1
03 04 05 06
overflowing
steaming laden
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS (mg/L)

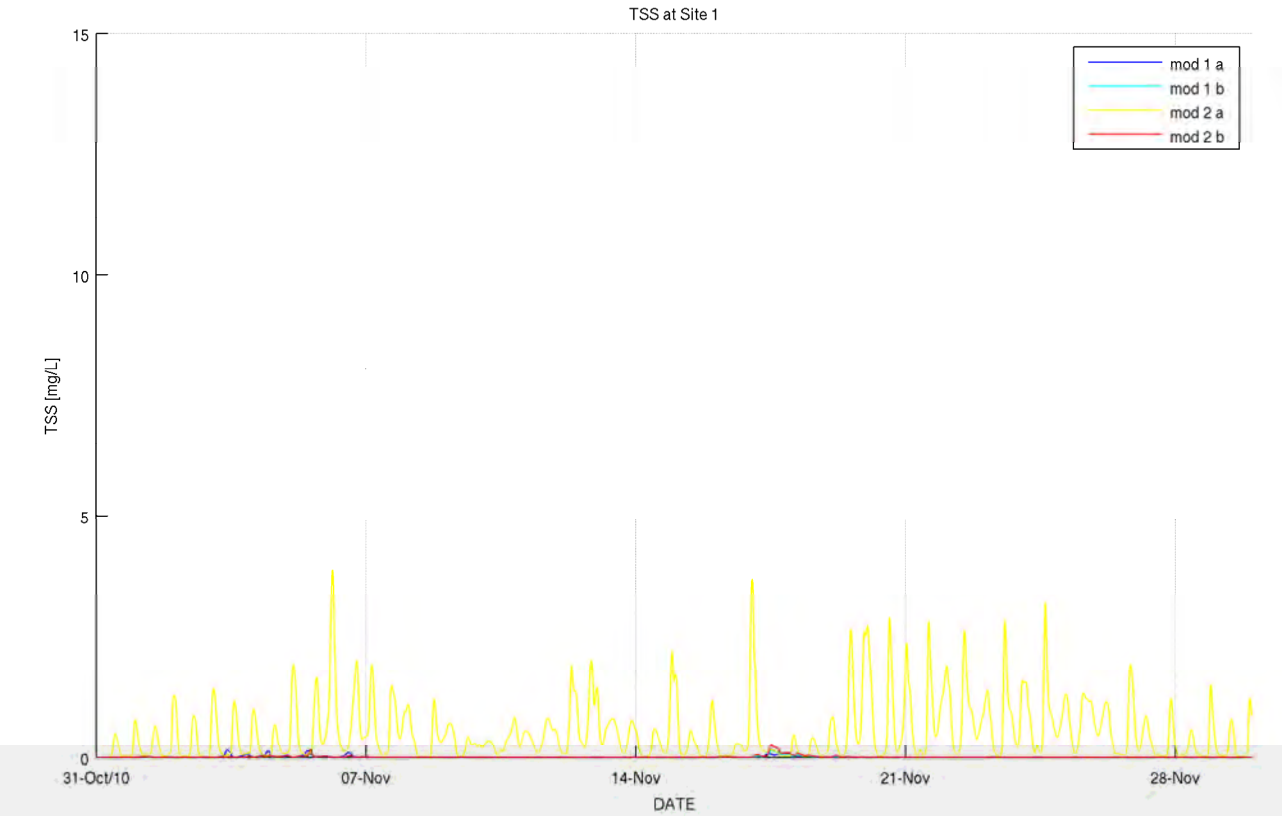

05-Jan-2011 13:05
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
overflowing
steaming laden
dumping
current position
Start of Transect
metres
0
250
TSS
(mg/L)

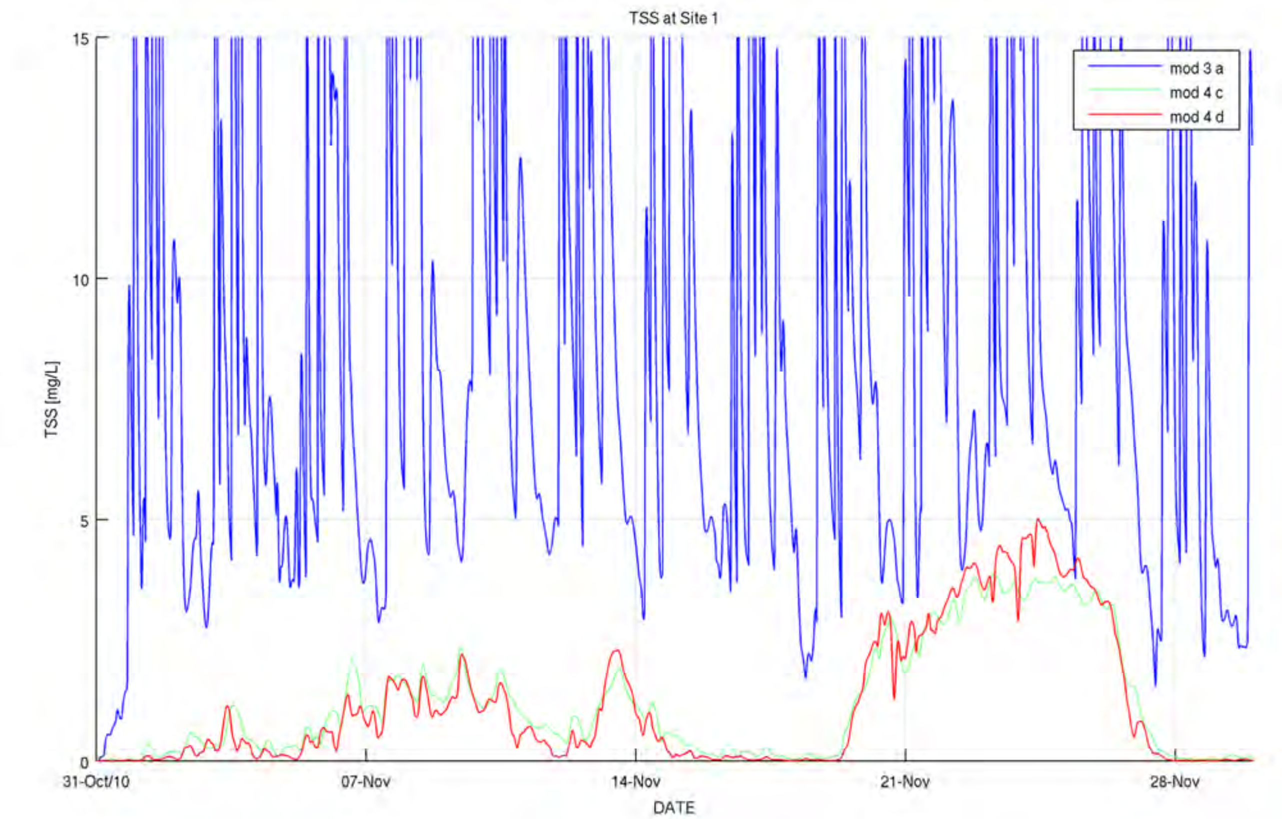

05-Jan-2011 13:15
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0 100 200 300 400 500 600 700 800 900
Chainage (m)
0 200 400 600 800
Chainage (m)
0 2 4 6 8 10 12 14 16 18
Depth (m)
Dredge Plume in Plan
1 0 -1
03 04 05 06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS (mg/L)

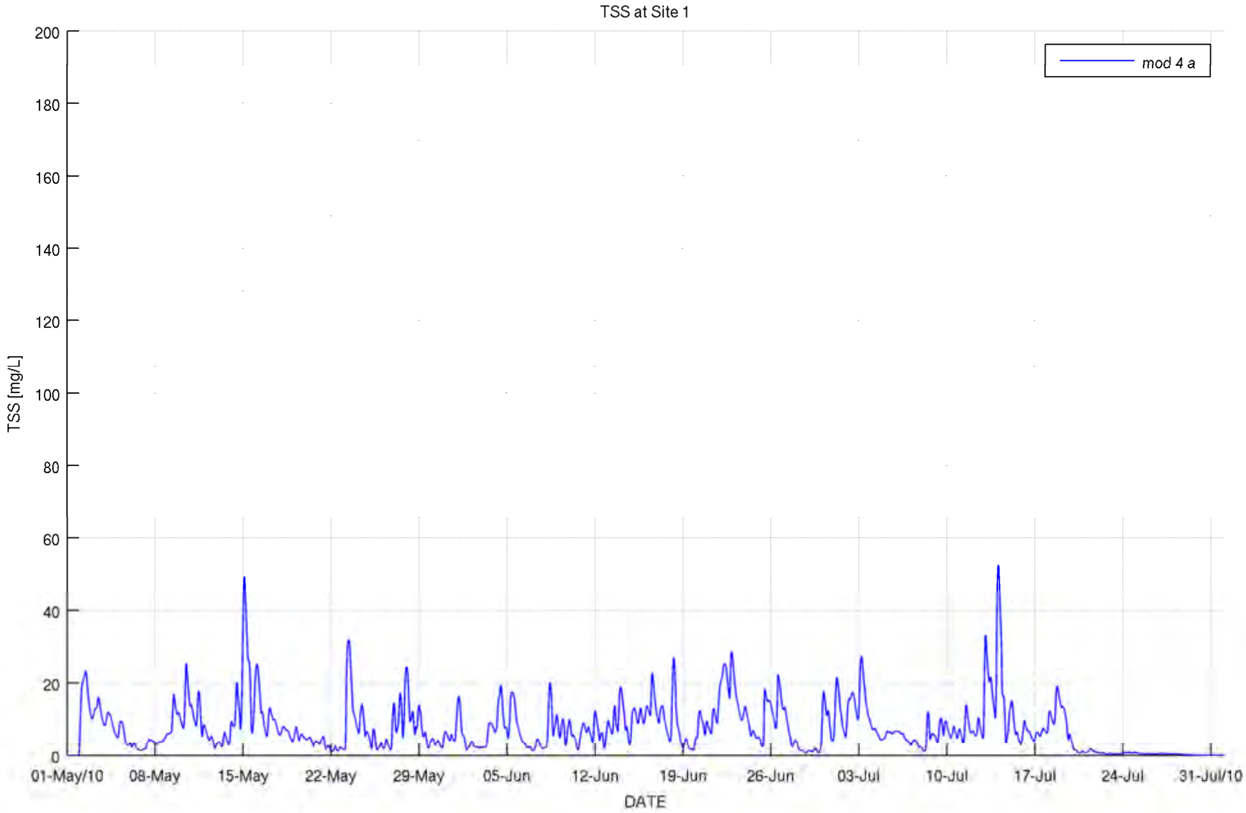

05-Jan-2011 13:24
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
0
2
4
6
8
10
12
14
16
18
0 100 200 300 400 500 600 700
Chainage (m)
0 100 200 300 400 500 600 700
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

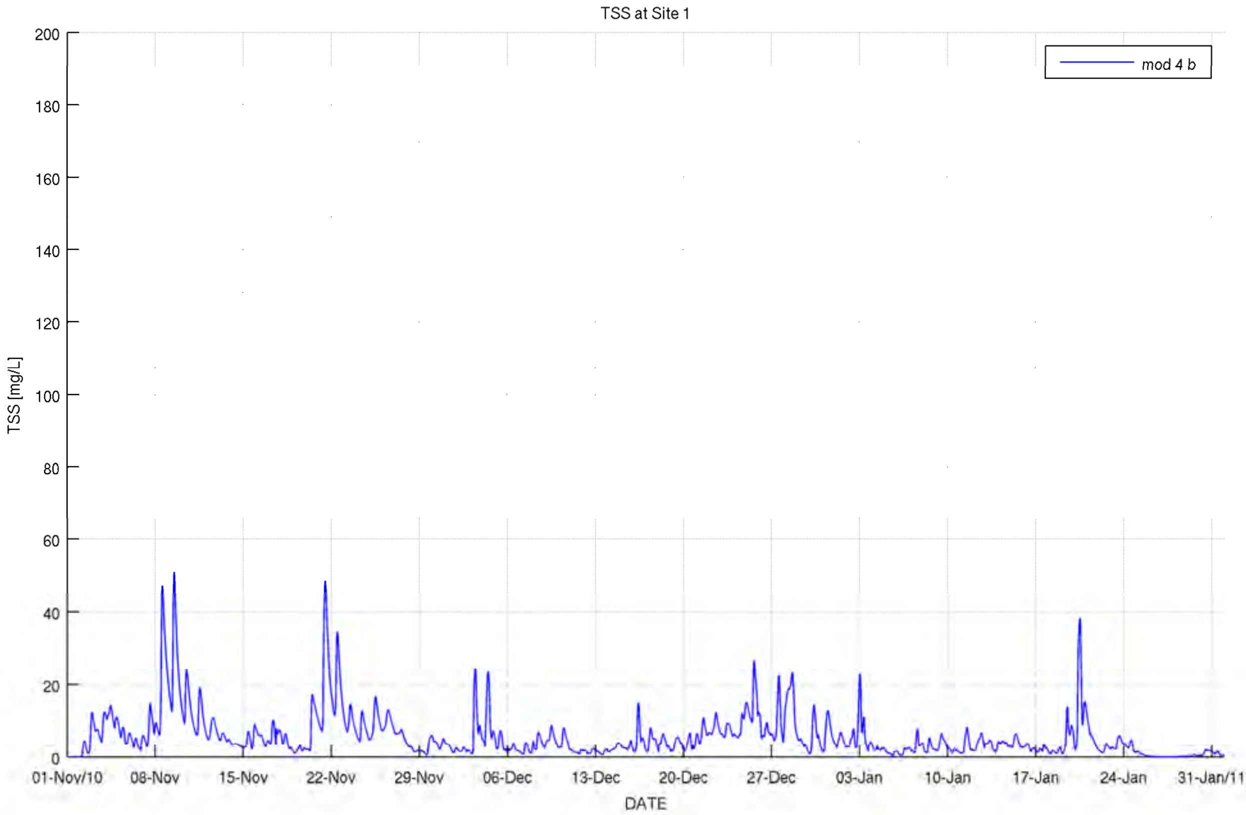
ATTACHMENT D: PLUME MODELLING TIME SERIES OUTPUT

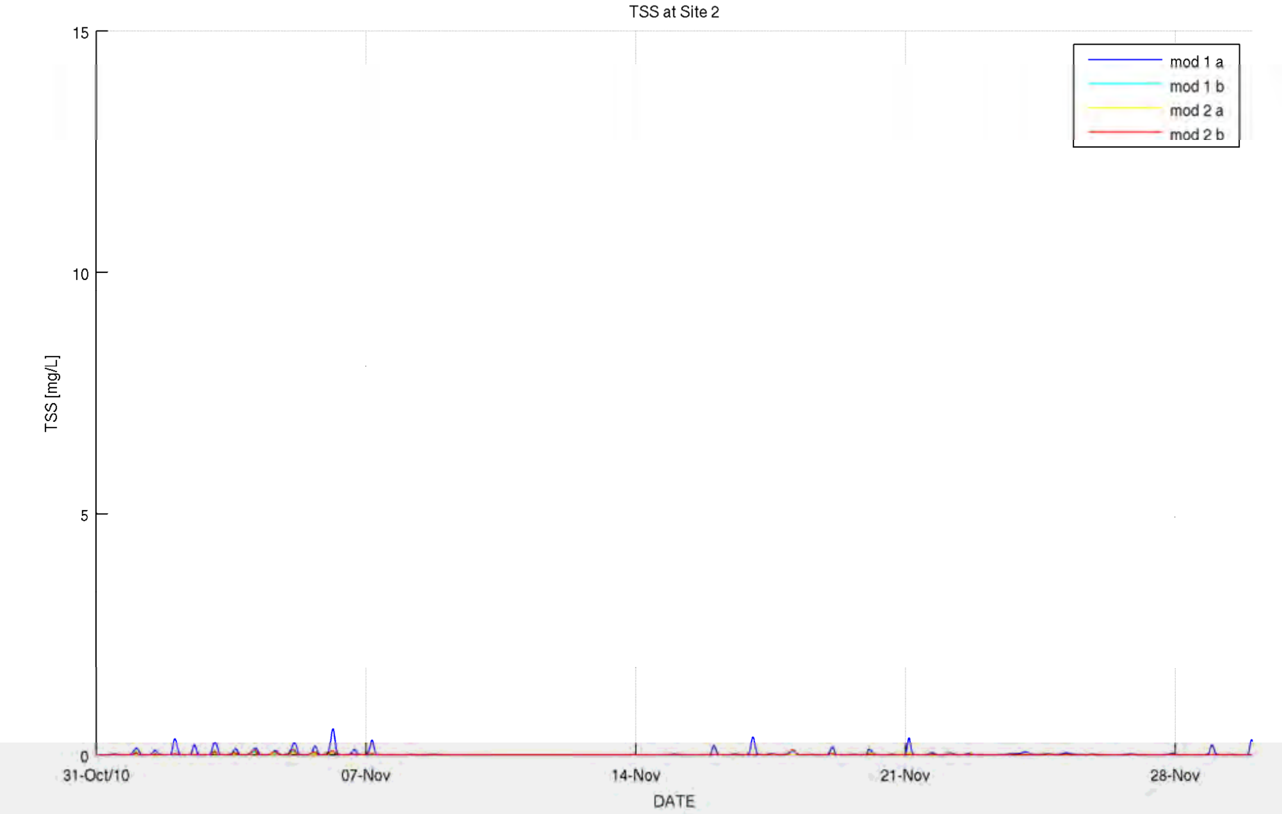
Above-Background TSS Time Series Plots

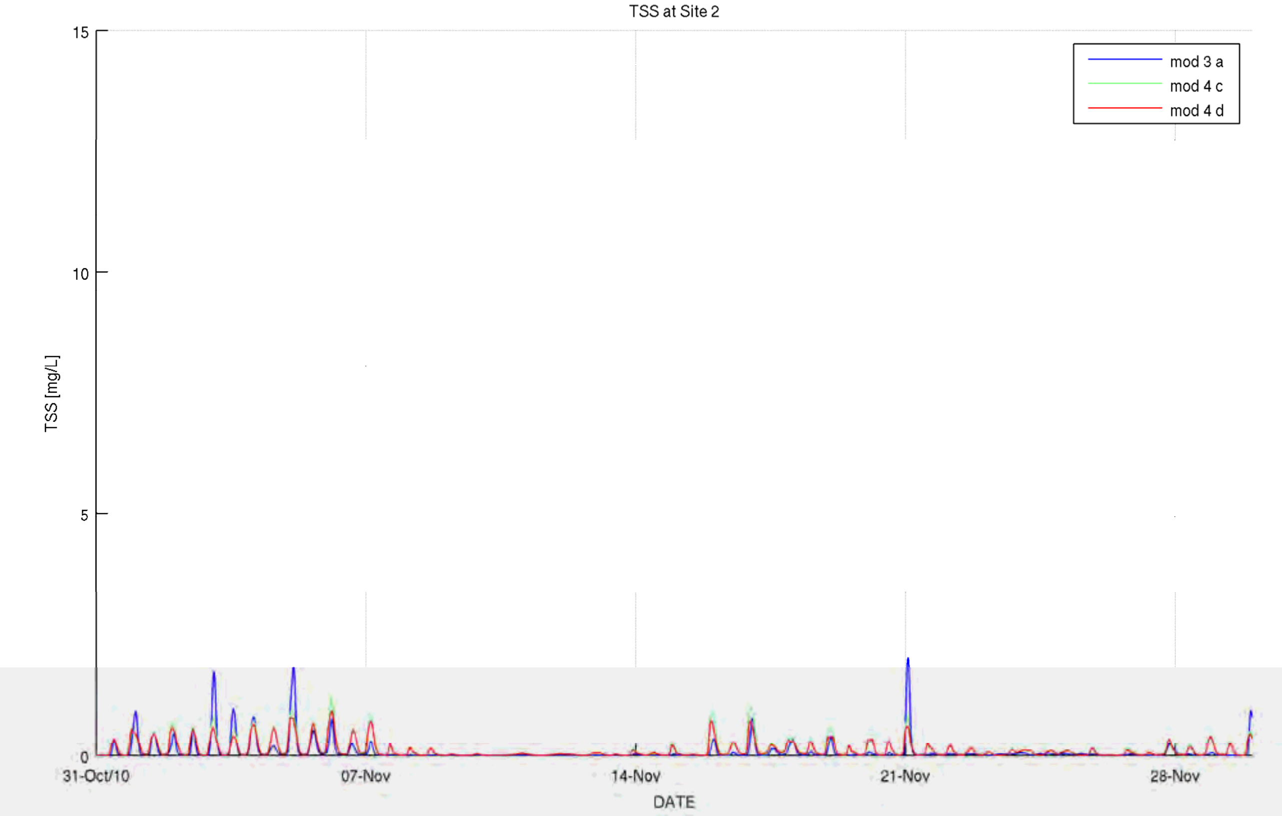


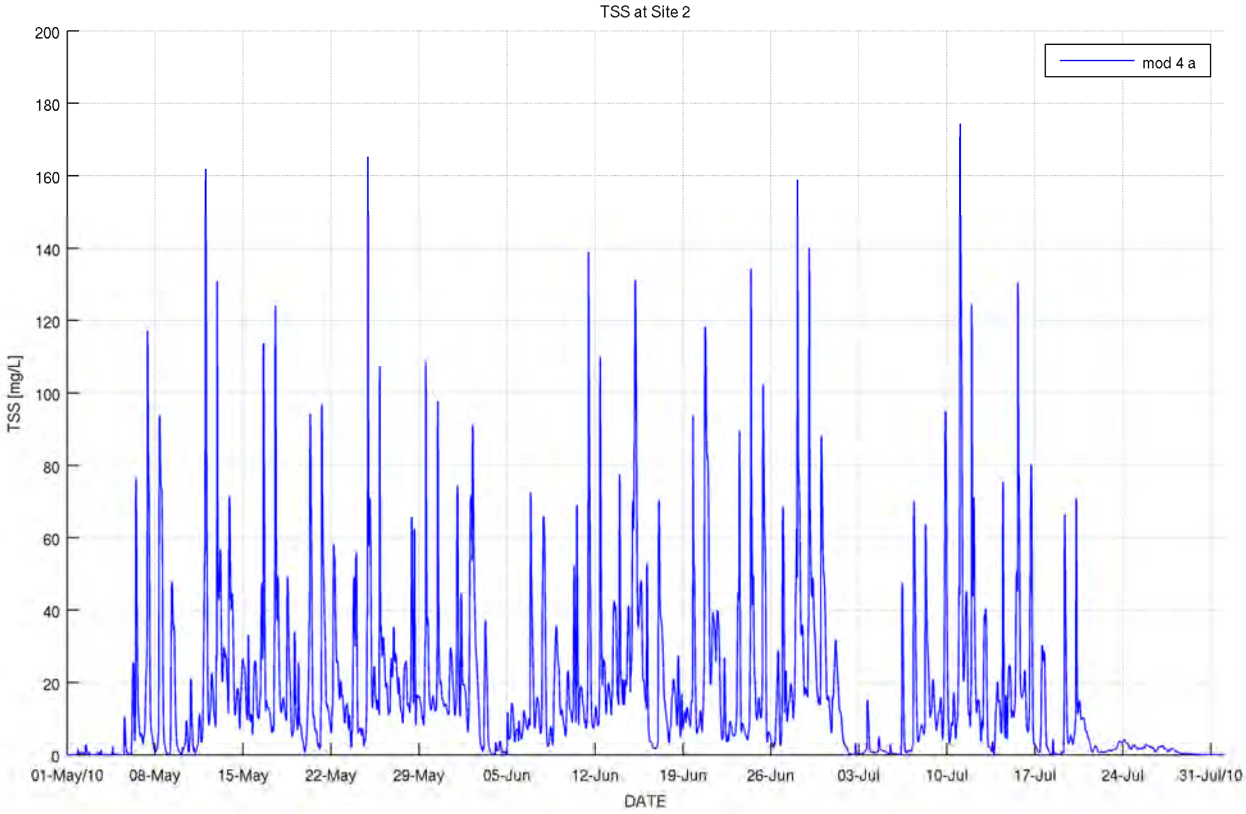


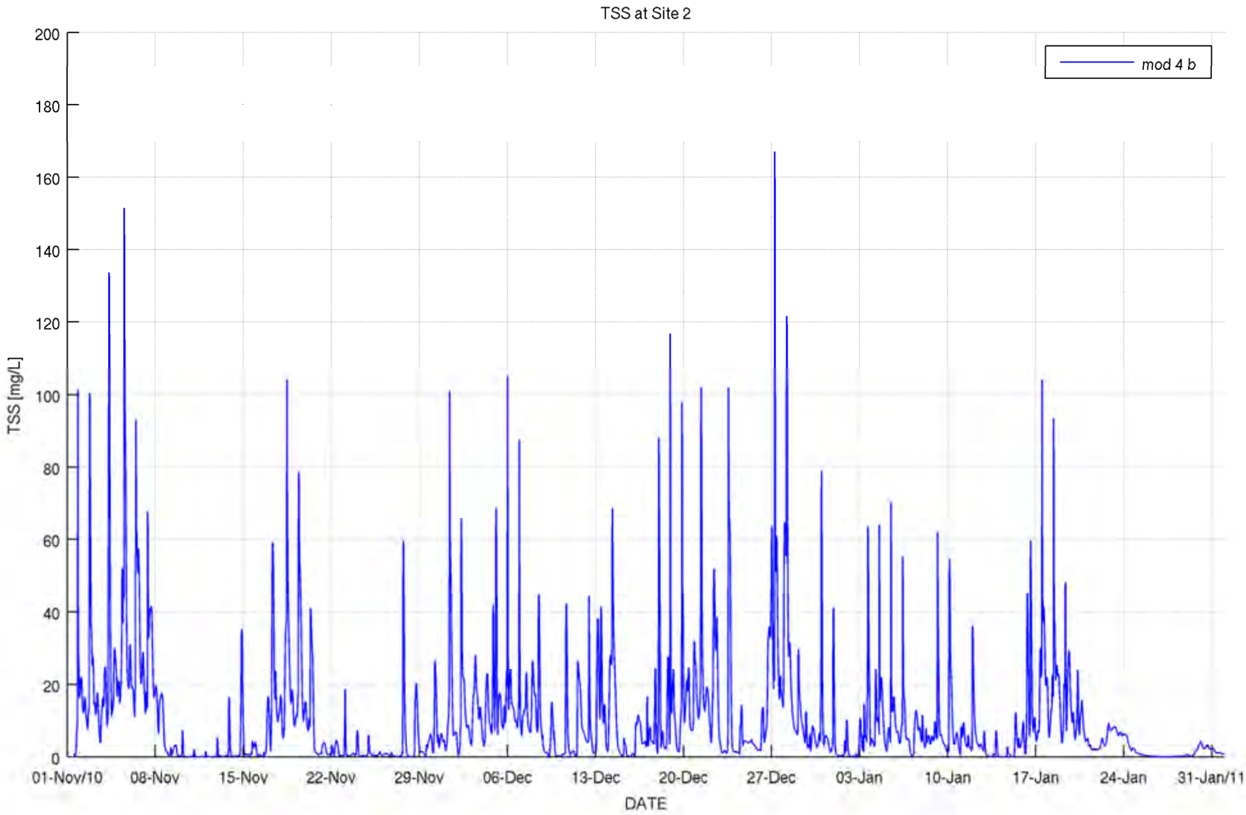

TSS at Site 1
mod 4 a
TSS [mg/L]
0
20
40
60
80
100
120
140
160
180
200
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

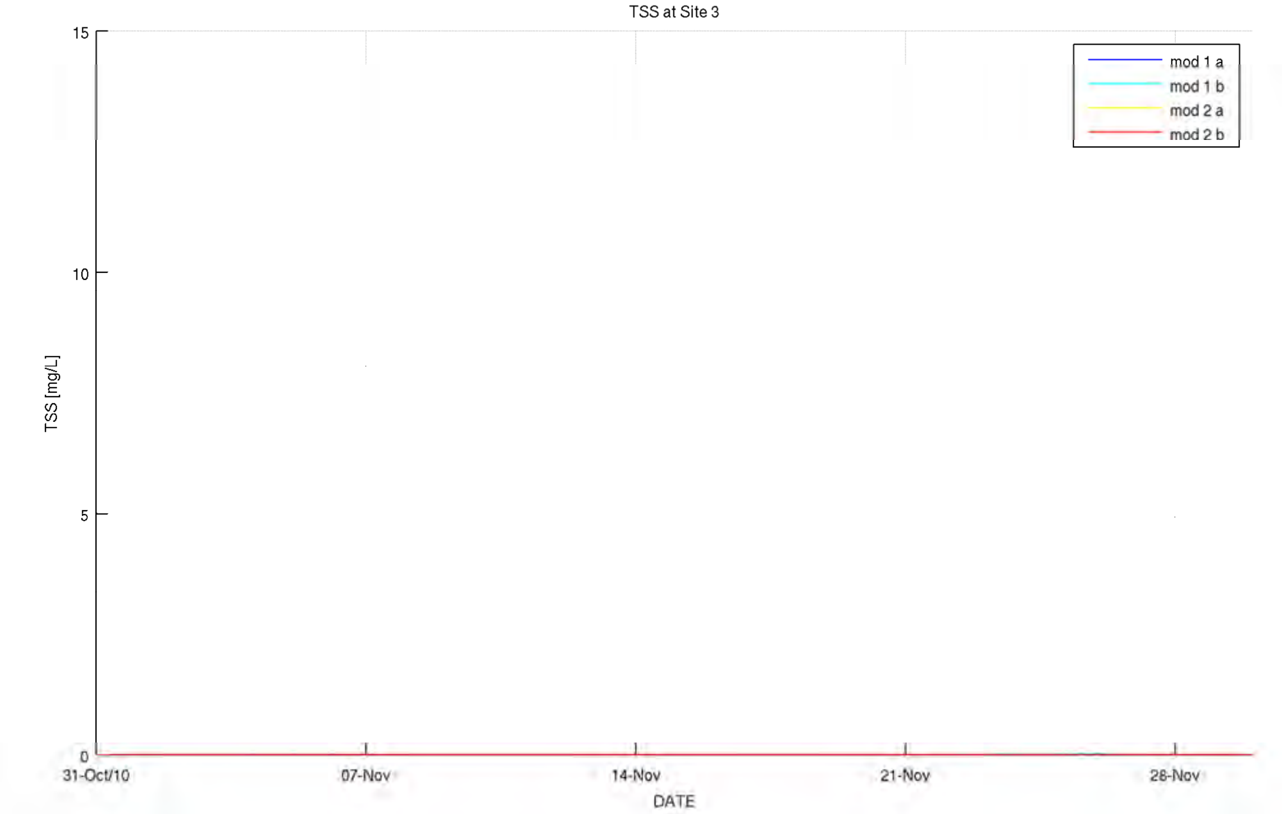

TSS at Site 1
mod 4 b
TSS [mg/L]
0
20
40
60
80
100
120
140
160
180
200
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

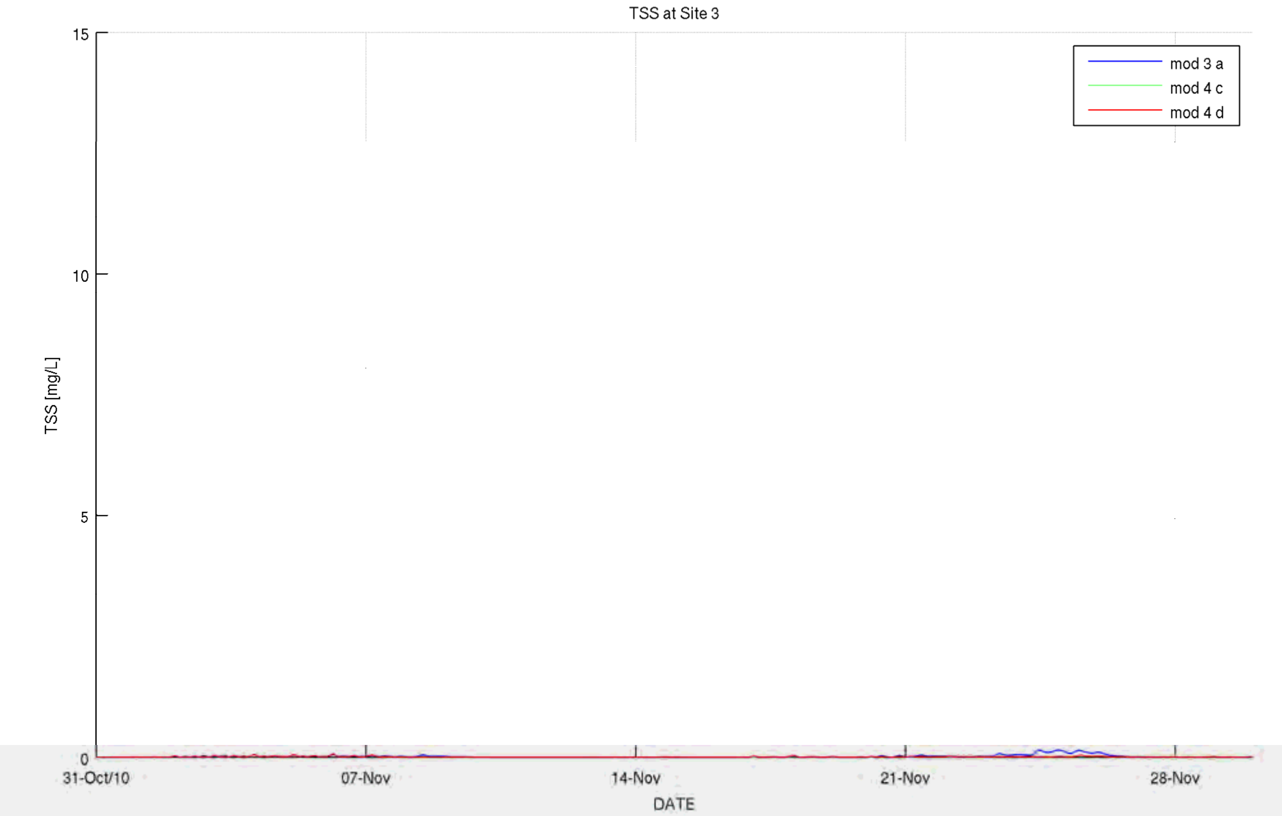

TSS at Site 2
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b

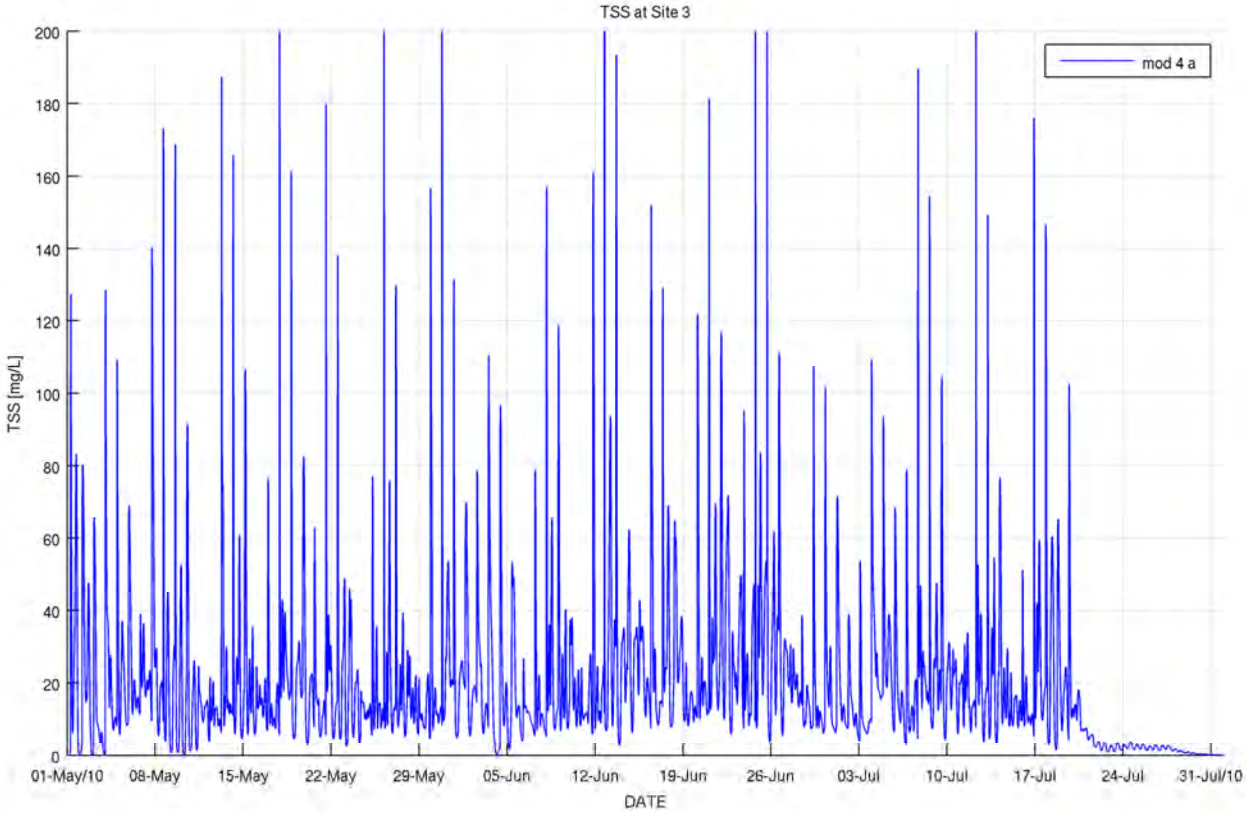

TSS at Site 2
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d

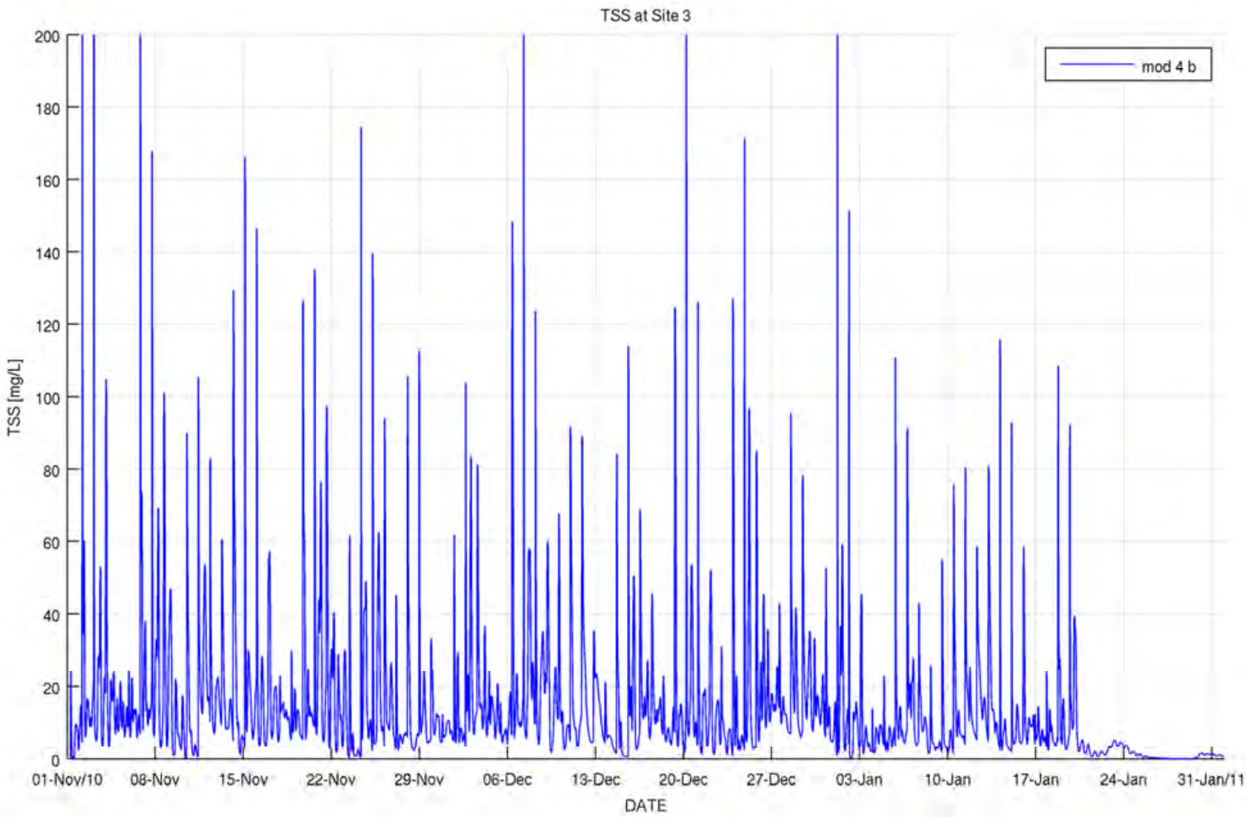

TSS at Site 2
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

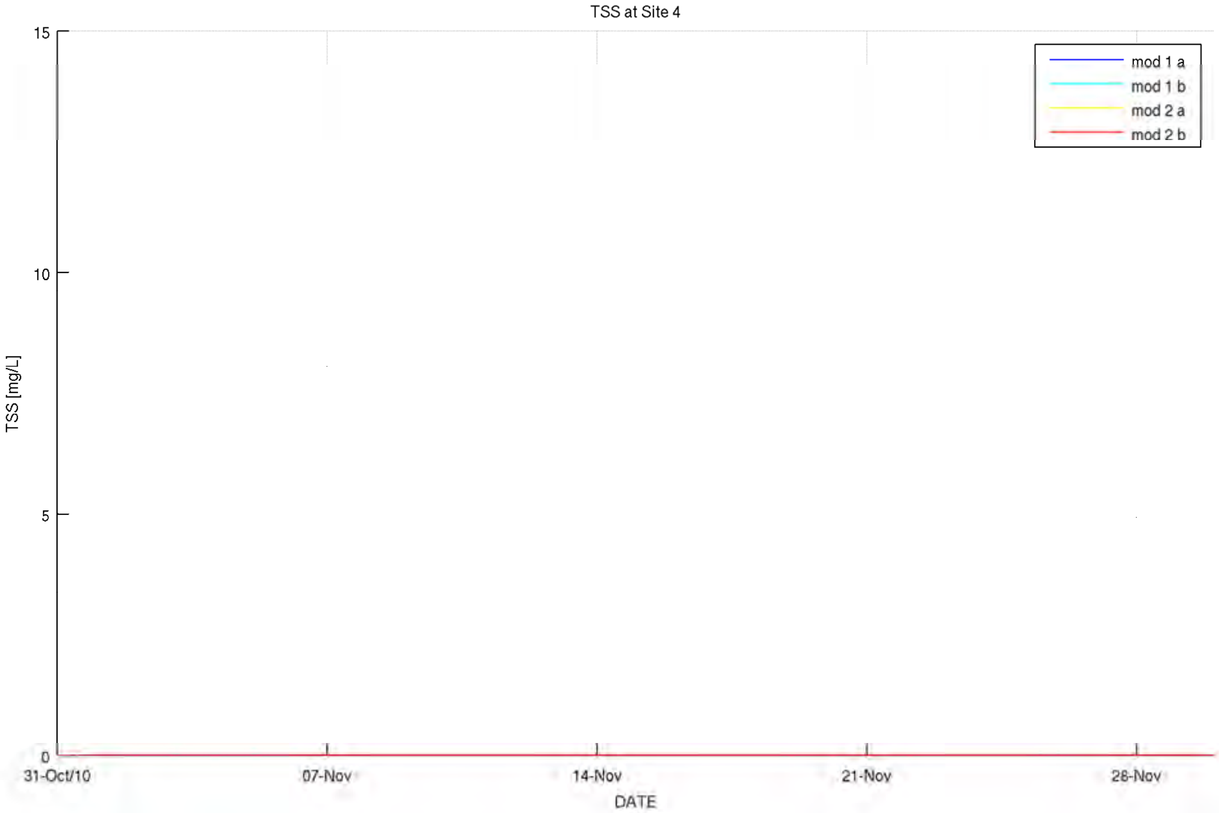

TSS at Site 2
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

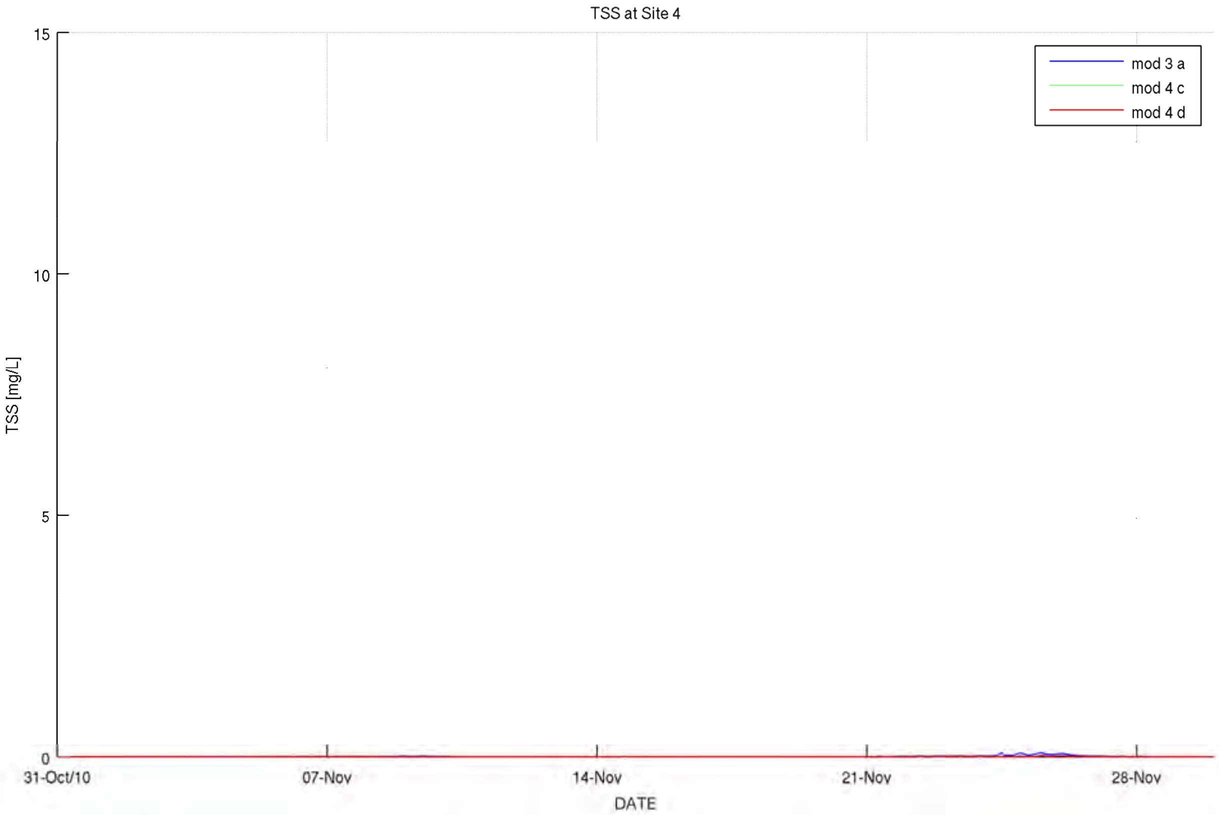

TSS at Site 3
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b

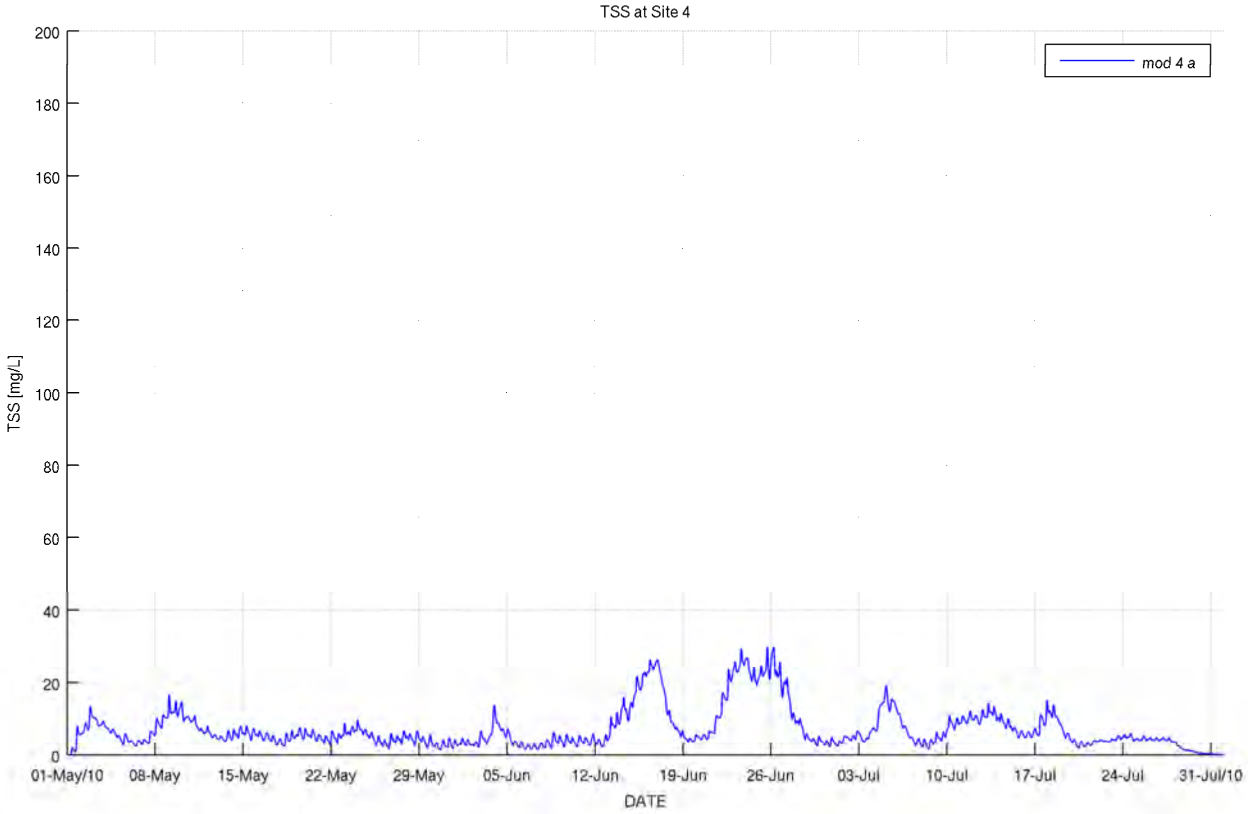

TSS at Site 3
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 3
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

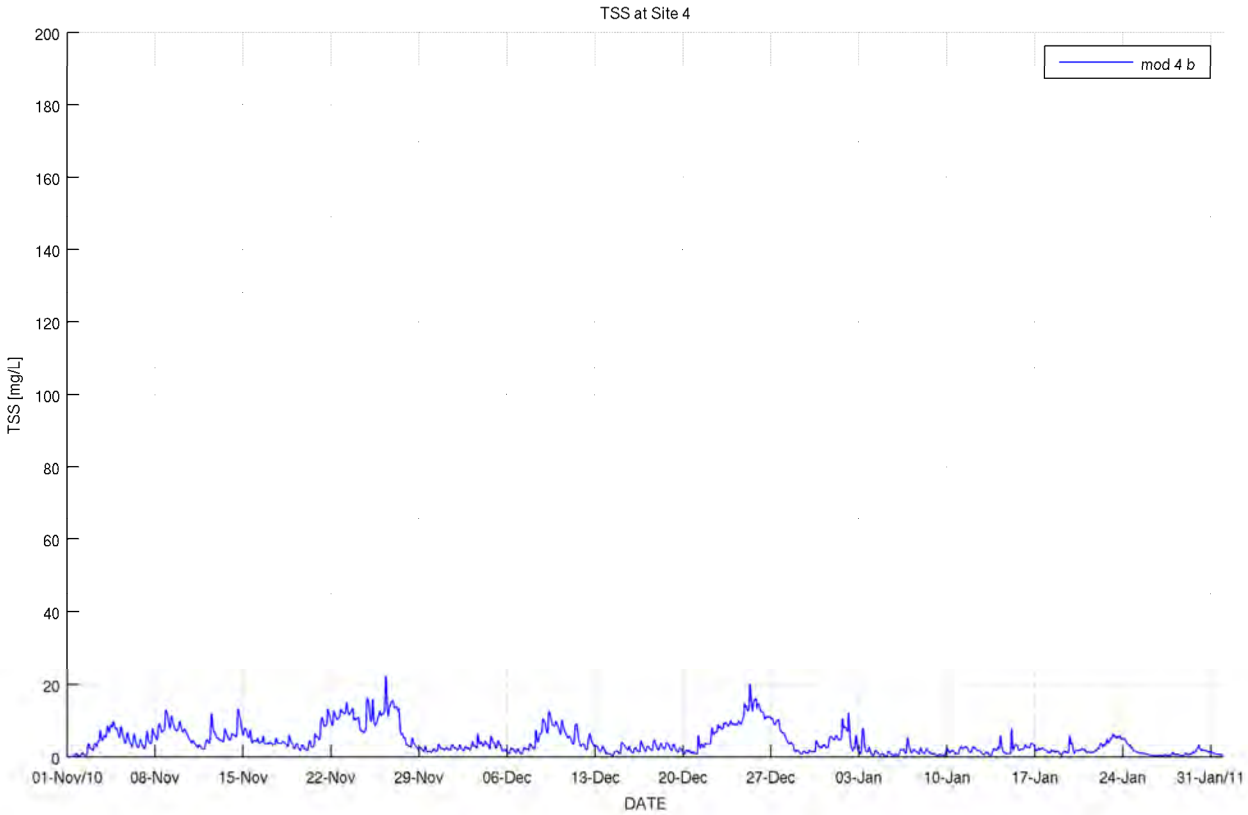

TSS at Site 3
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


TSS at Site 4
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b

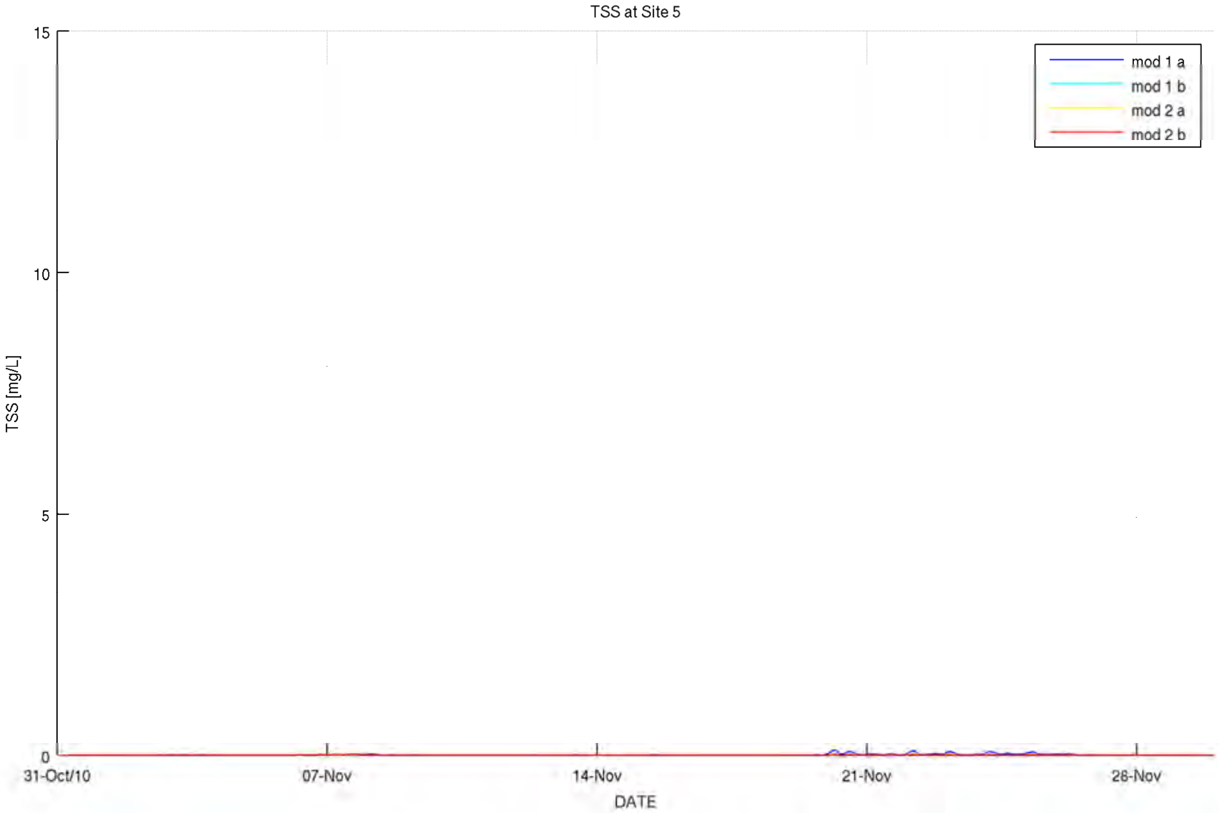

TSS at Site 4
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d

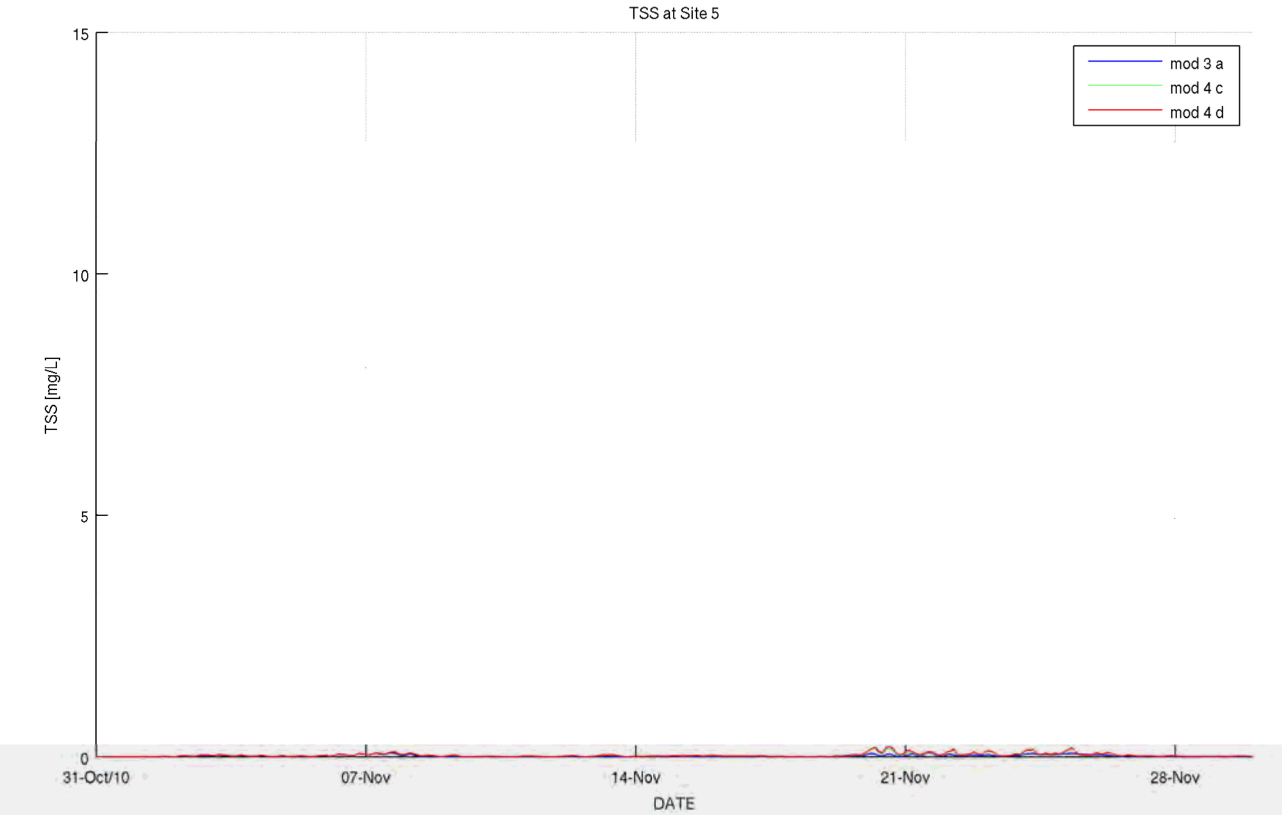


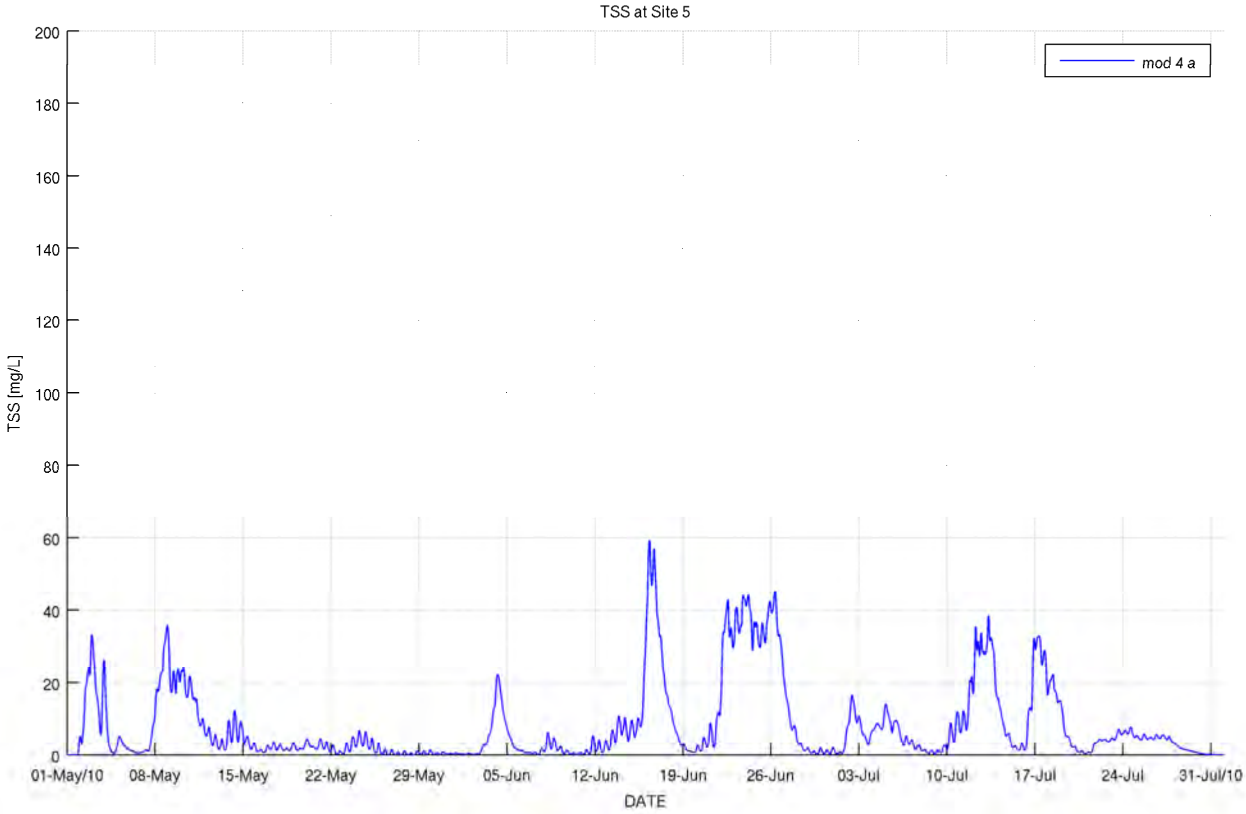
TSS at Site 4
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

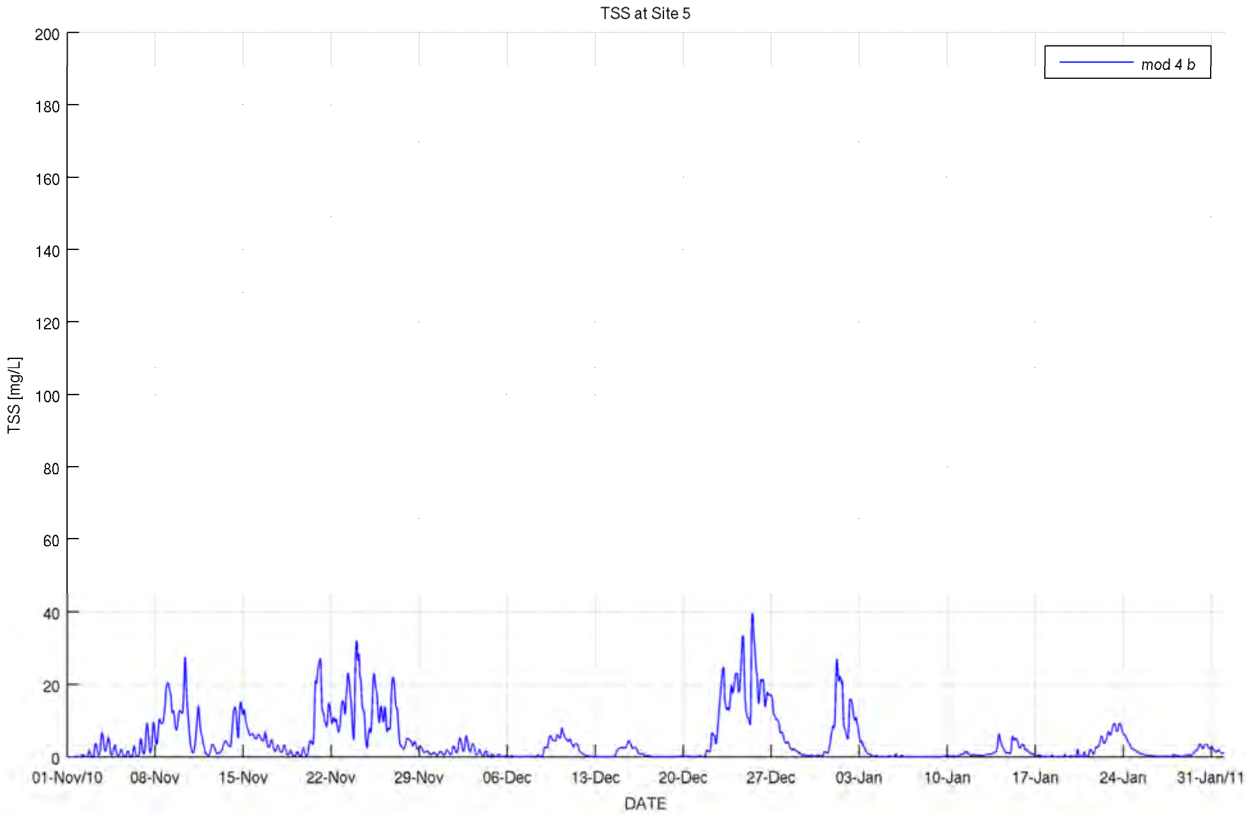


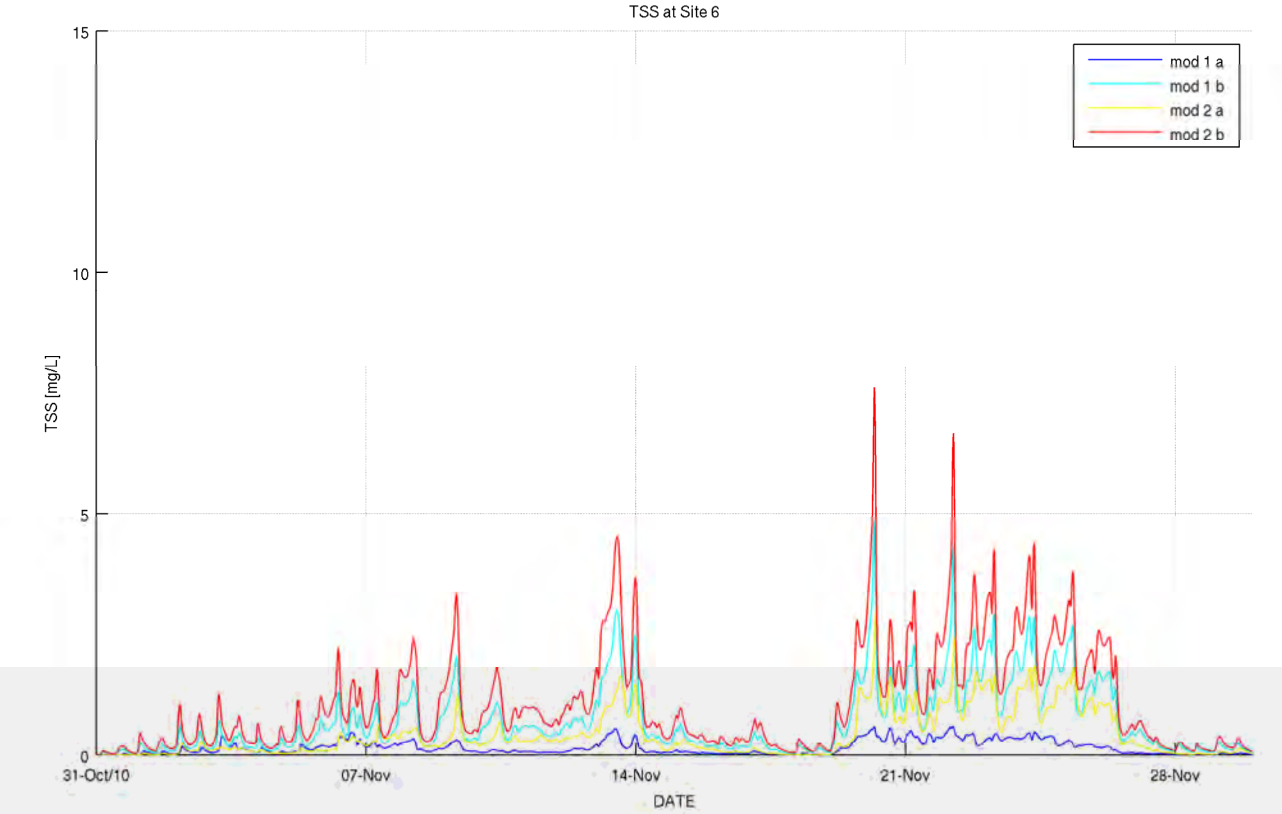
TSS at Site 4
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

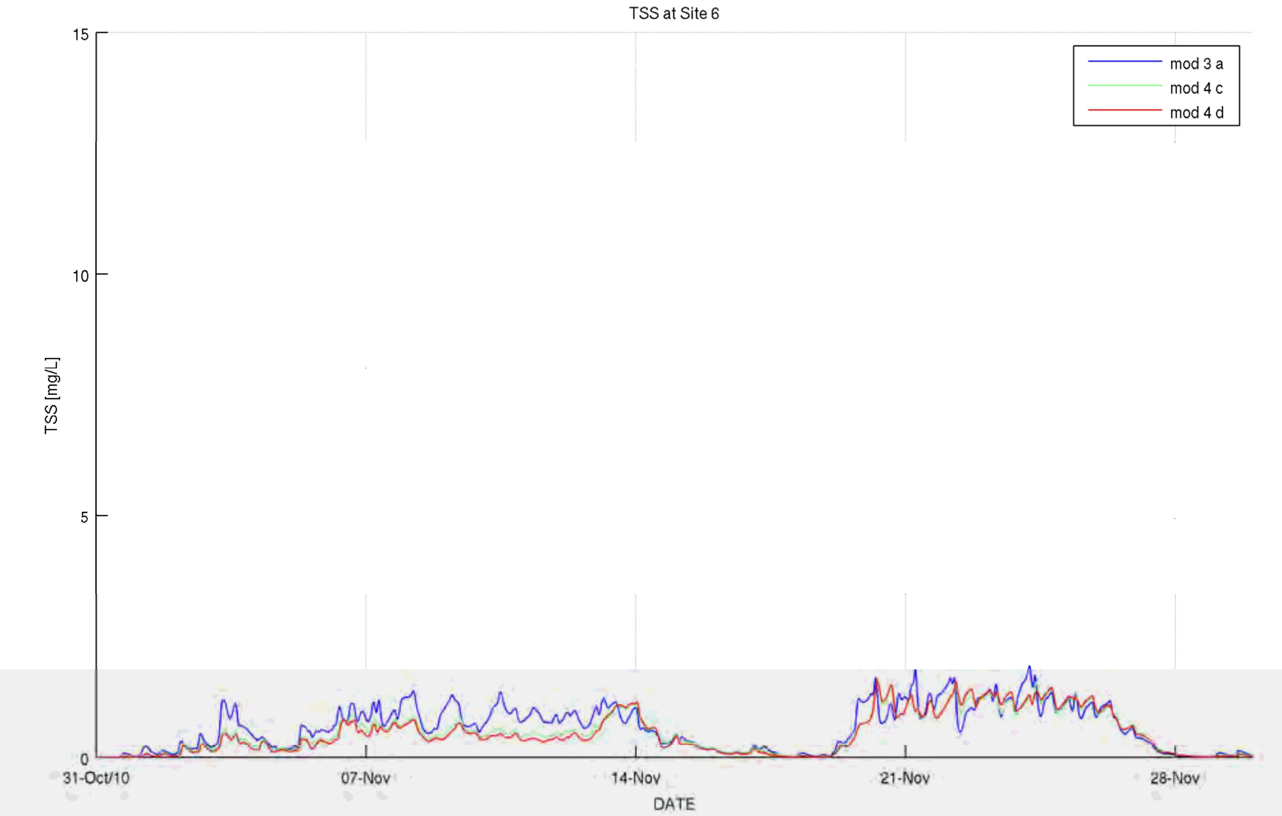

TSS at Site 5
TSS [mg/L]
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b
0
5
10
15
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov

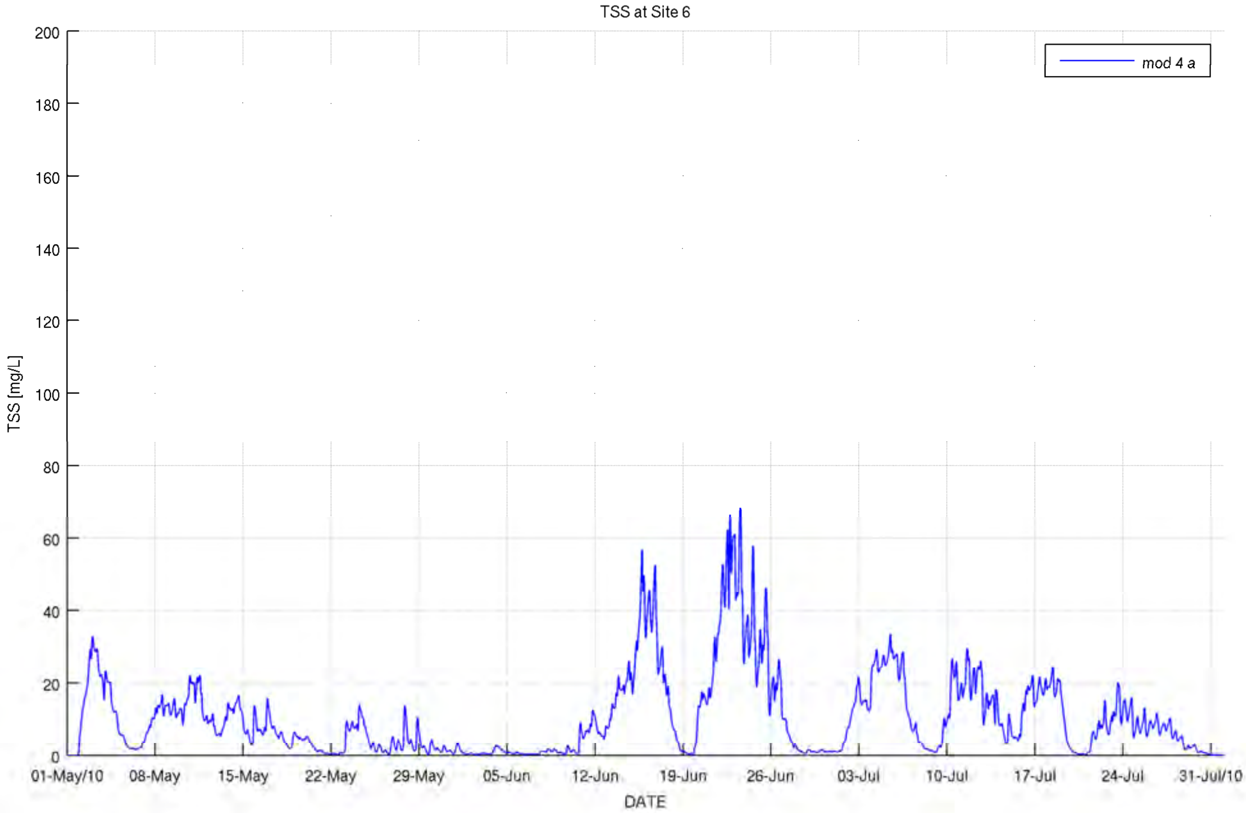

TSS at Site 5
TSS [mg/L]
DATE
mod 3 a
mod 4 c
mod 4 d
0
5
10
15
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov

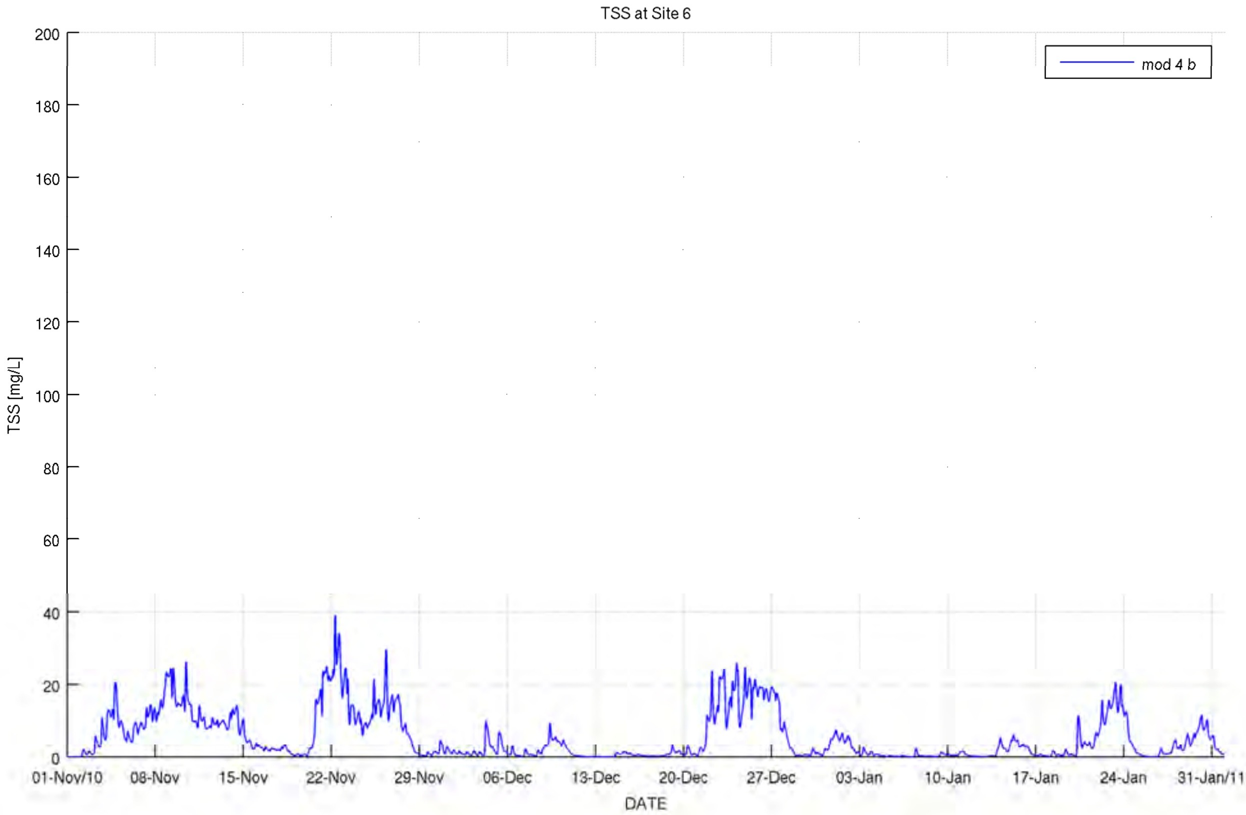

TSS at Site 5
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 5
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


TSS at Site 6
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 6
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 6
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 6
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
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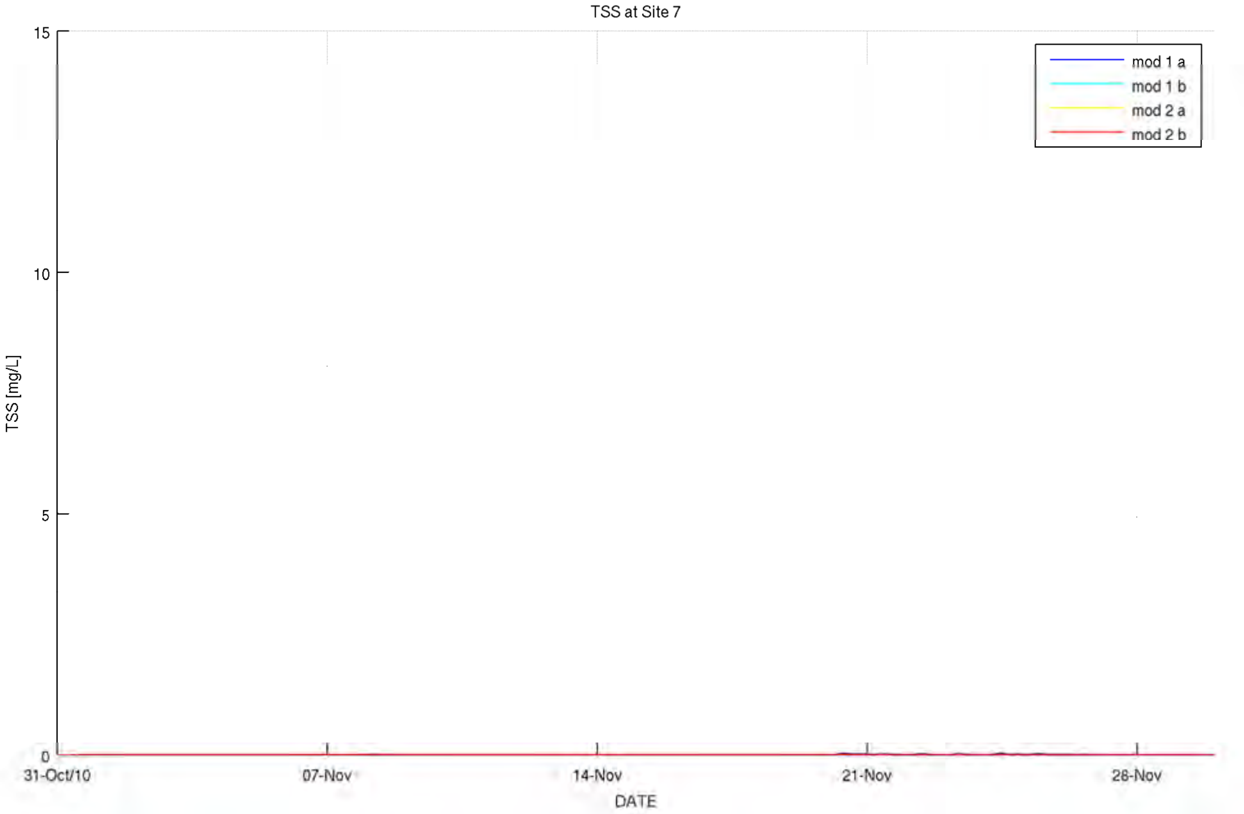
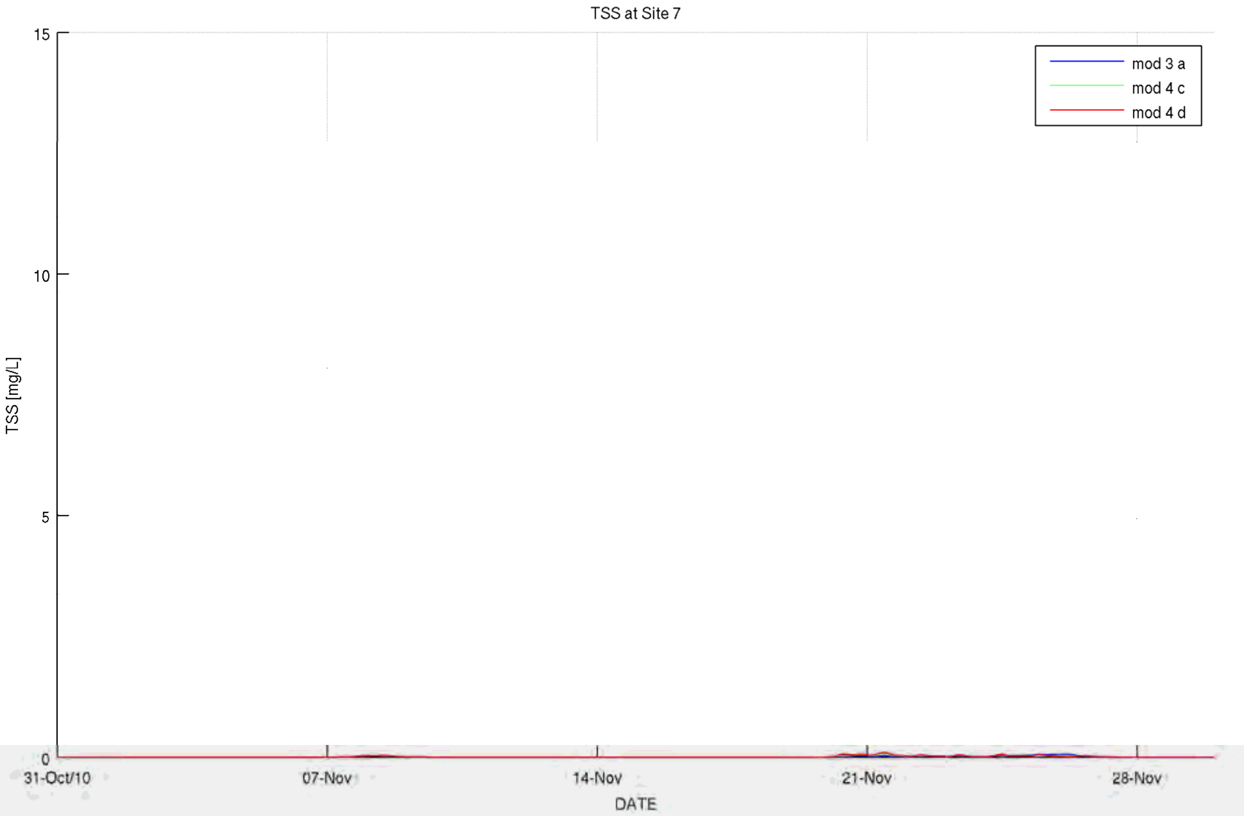
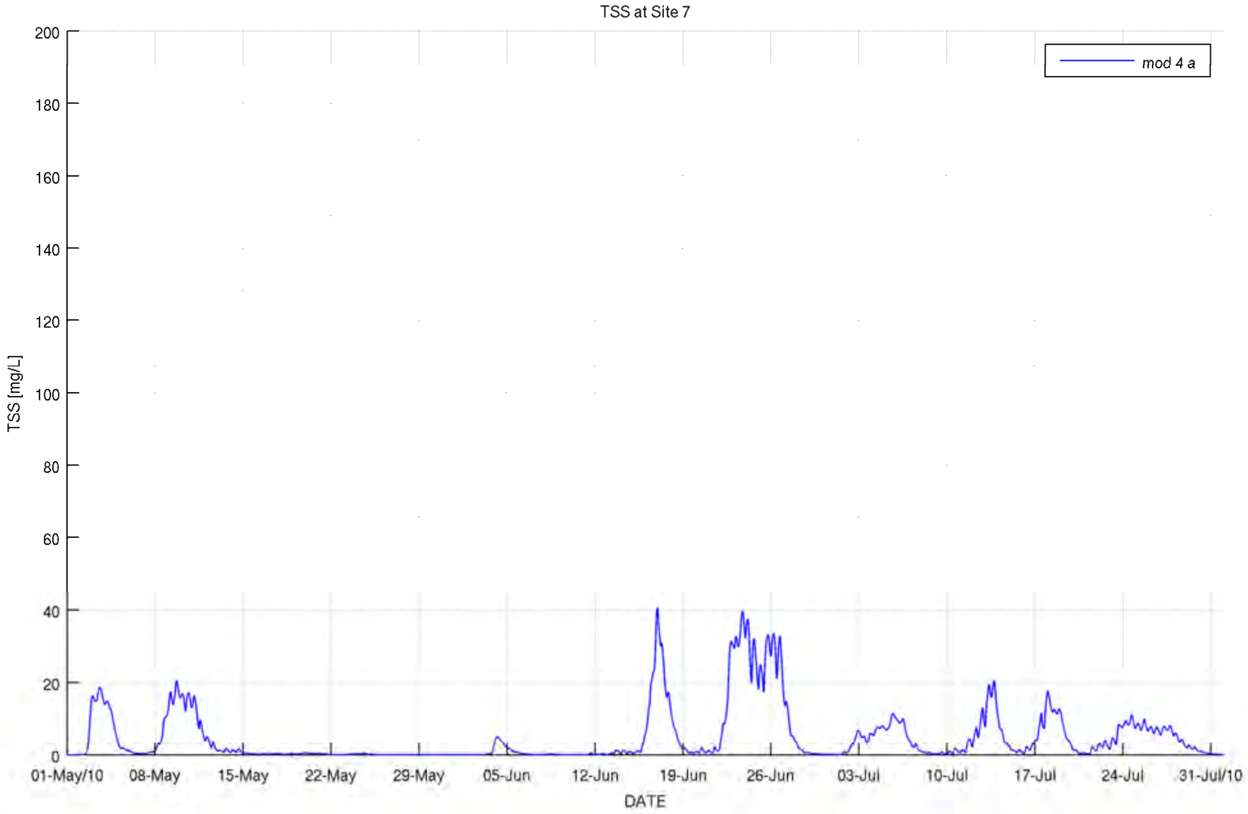
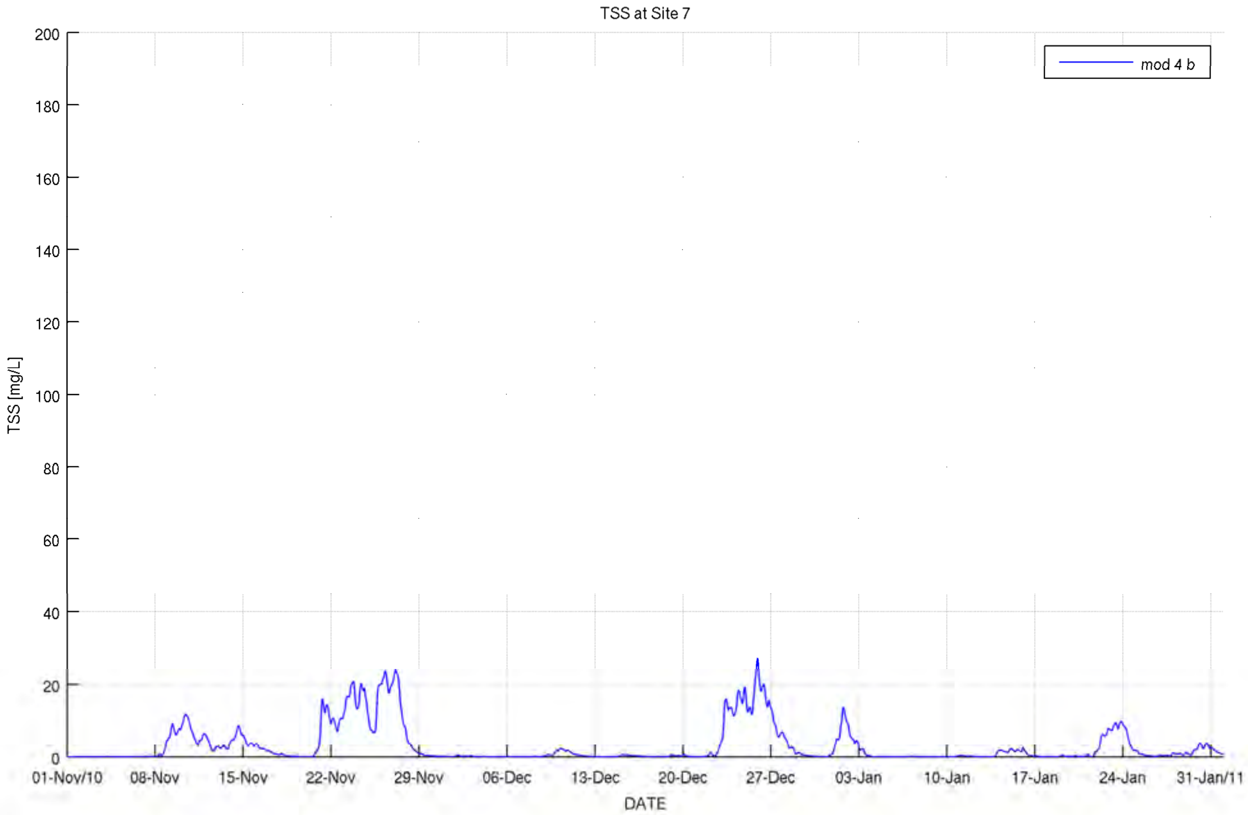
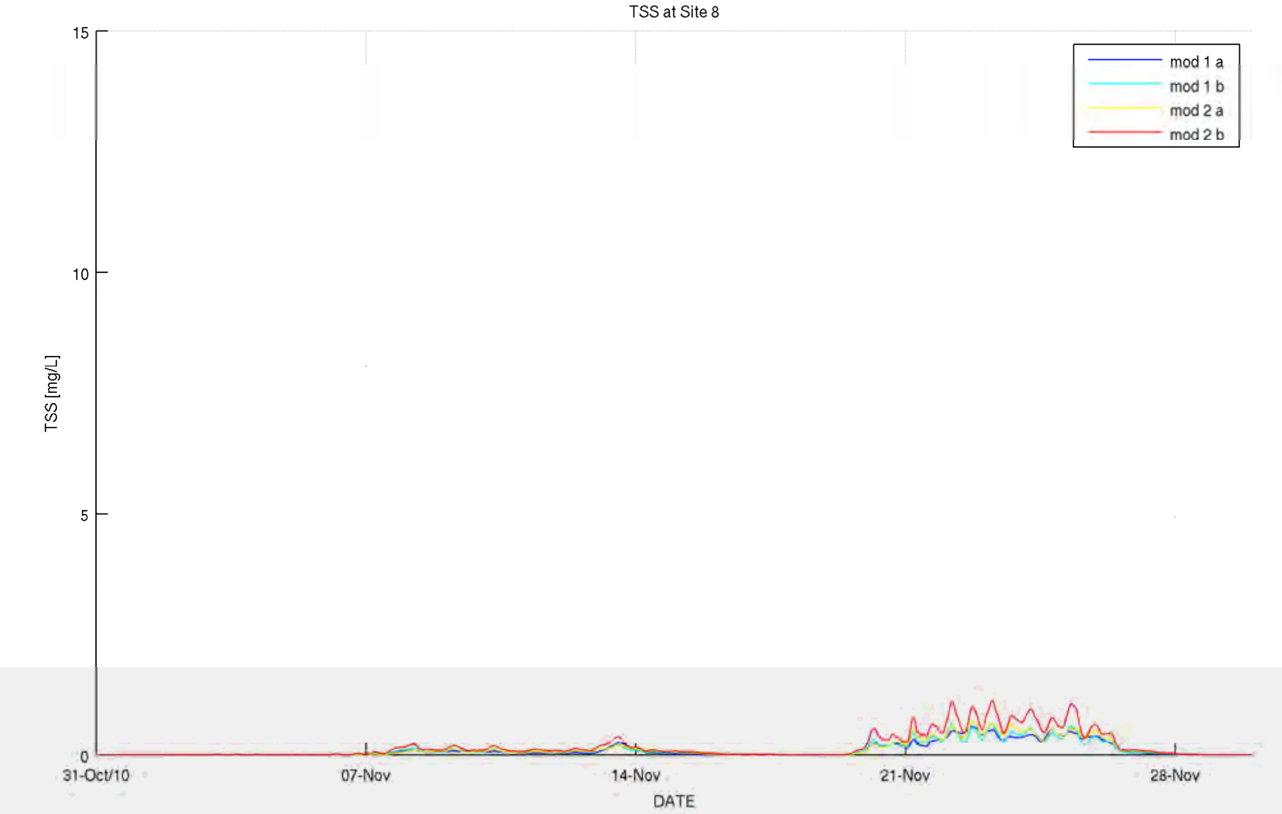
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

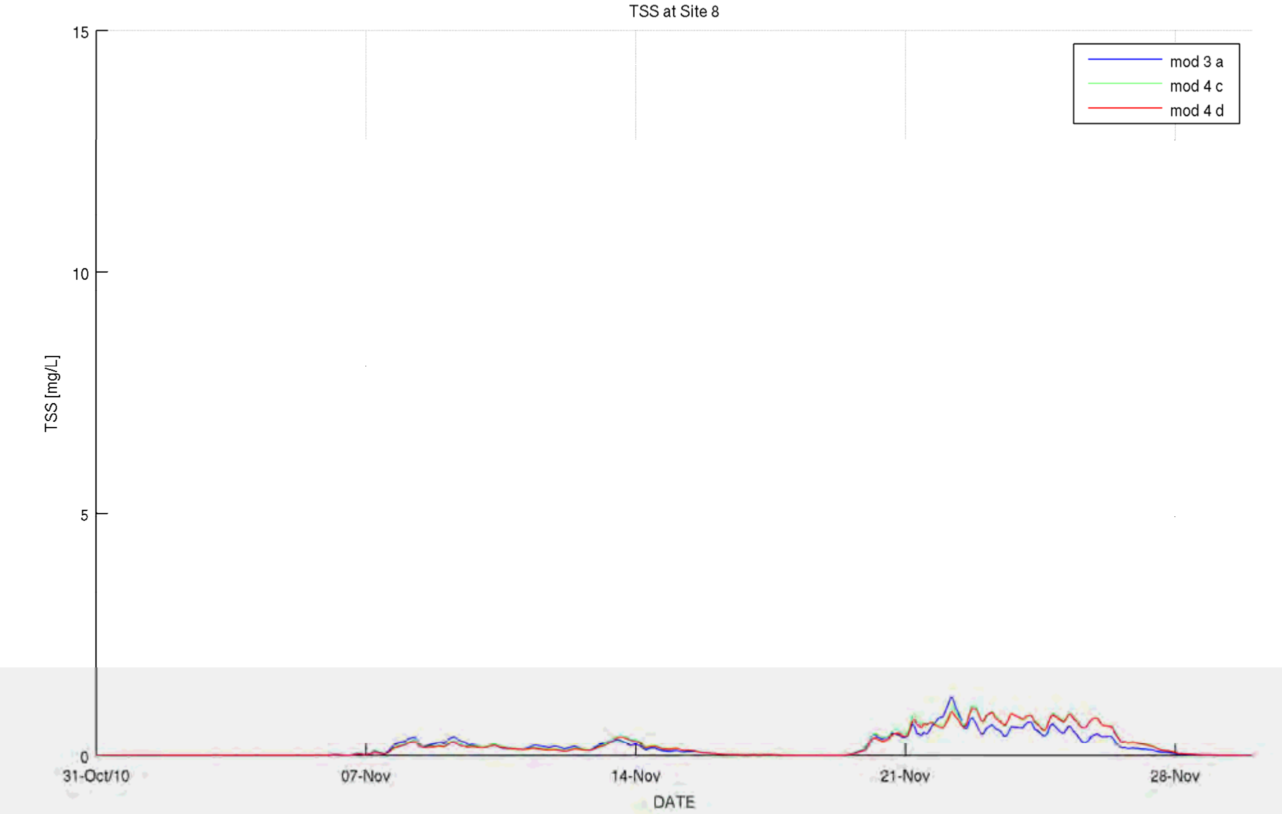

TSS at Site 7
mod 1 a
mod 1 b
mod 2 a
mod 2 b
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE

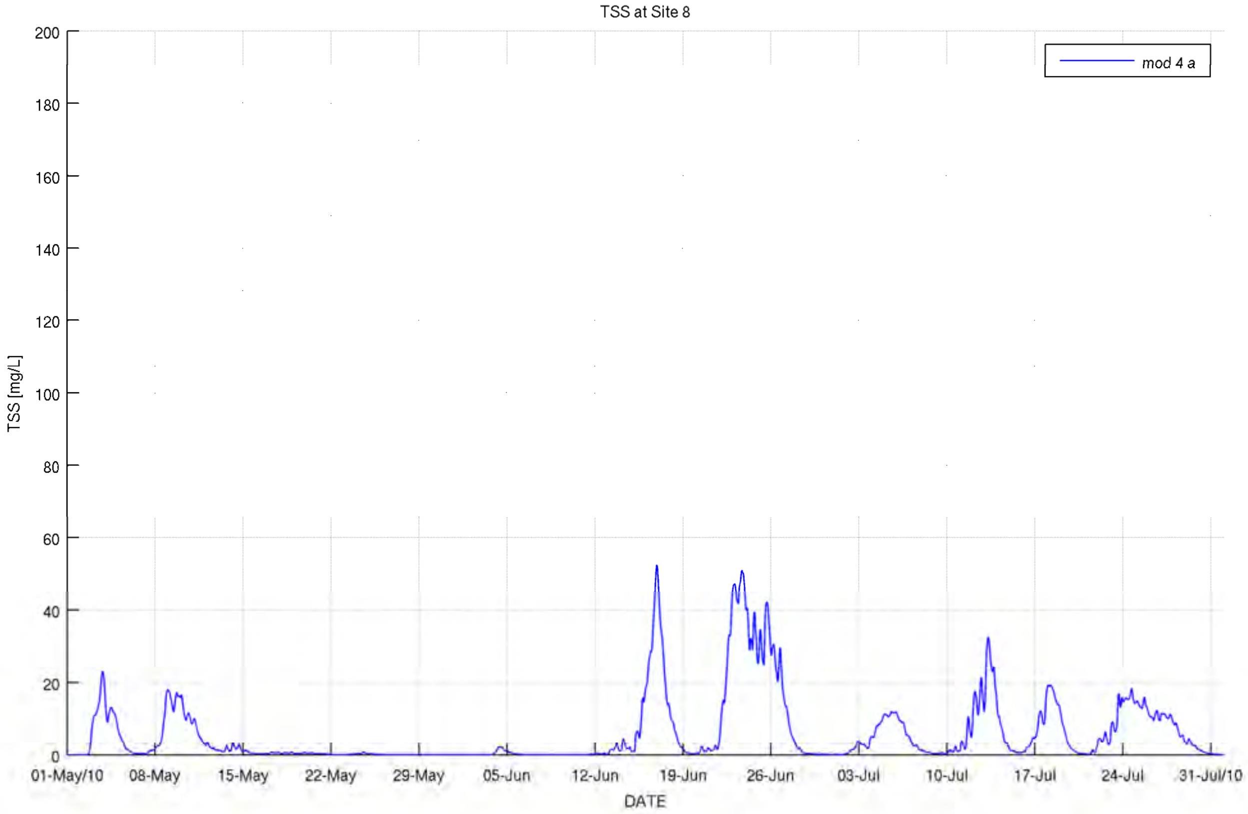

TSS at Site 7
mod 3 a
mod 4 c
mod 4 d
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE

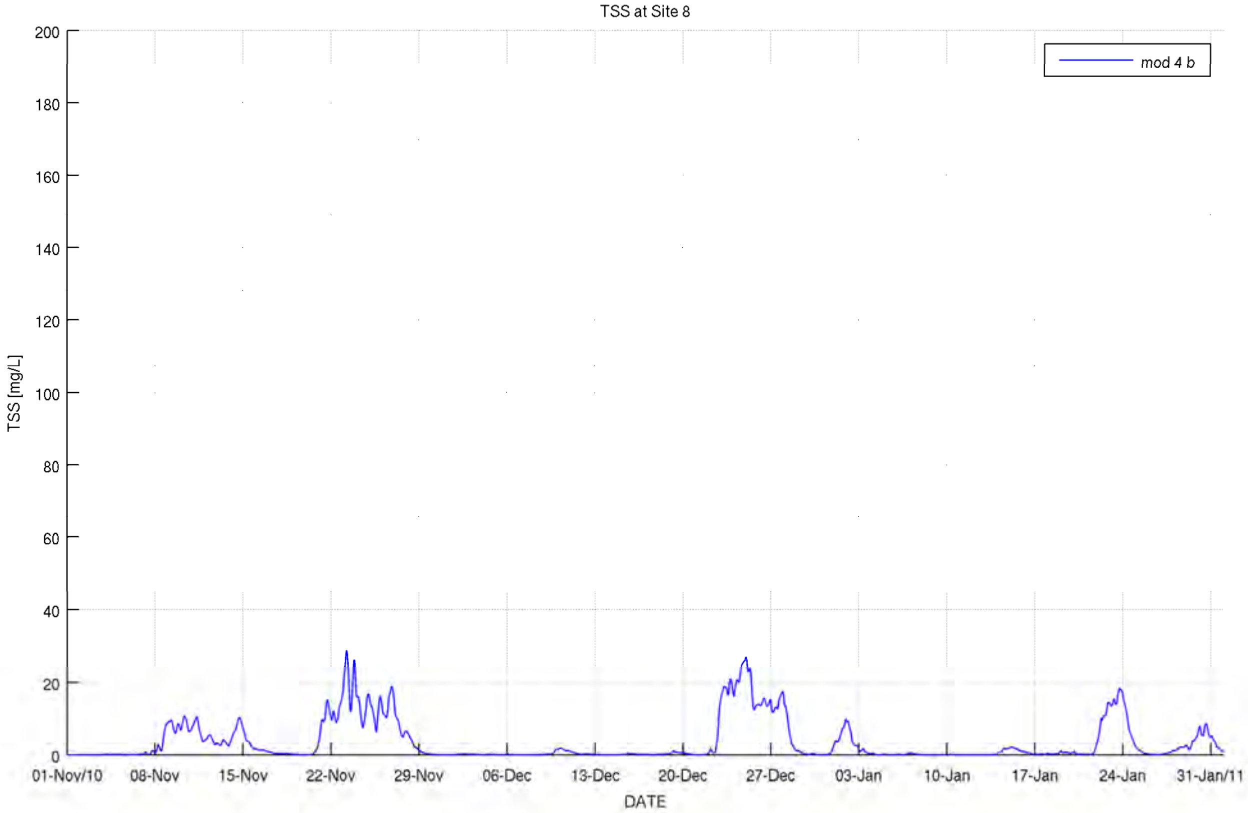

TSS at Site 7
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 7
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


TSS at Site 8
TSS [mg/L]
15
10
5
0
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 8
TSS [mg/L]
15
10
5
0
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 8
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 8
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
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13-Dec
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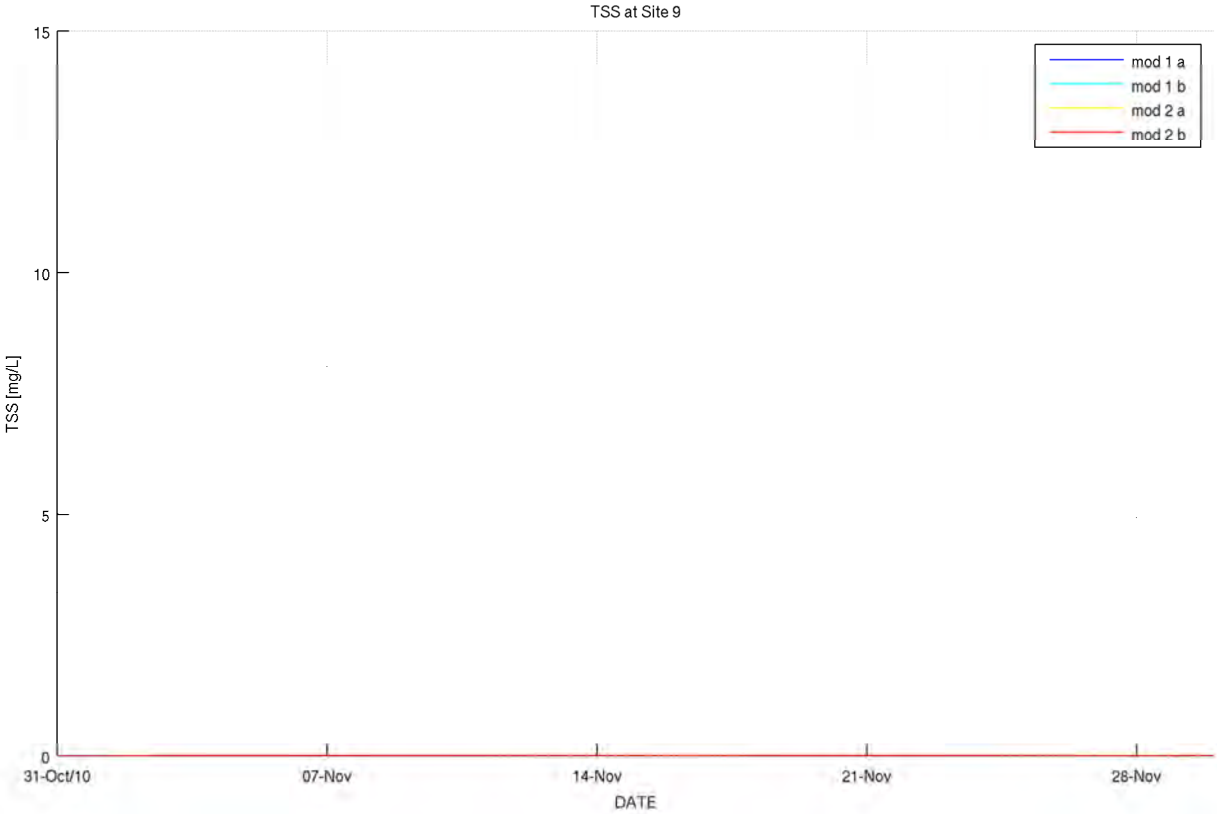
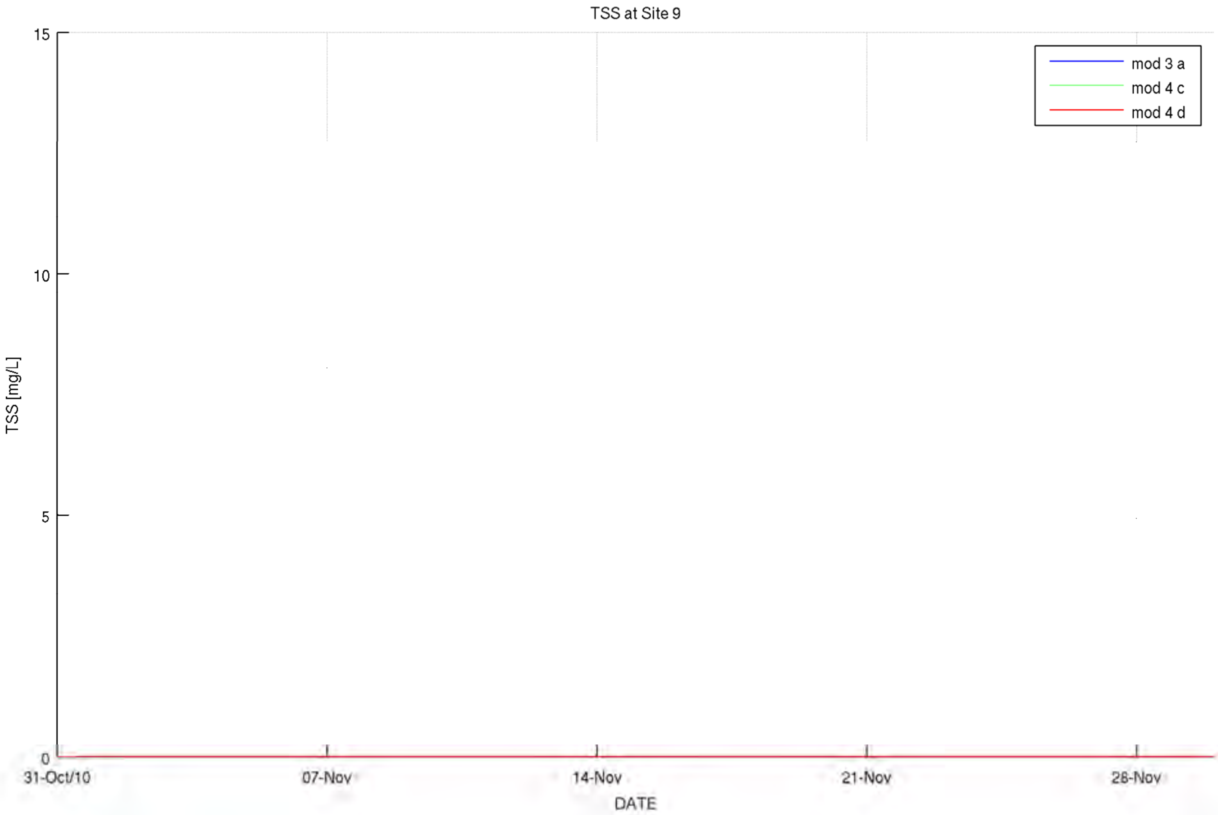
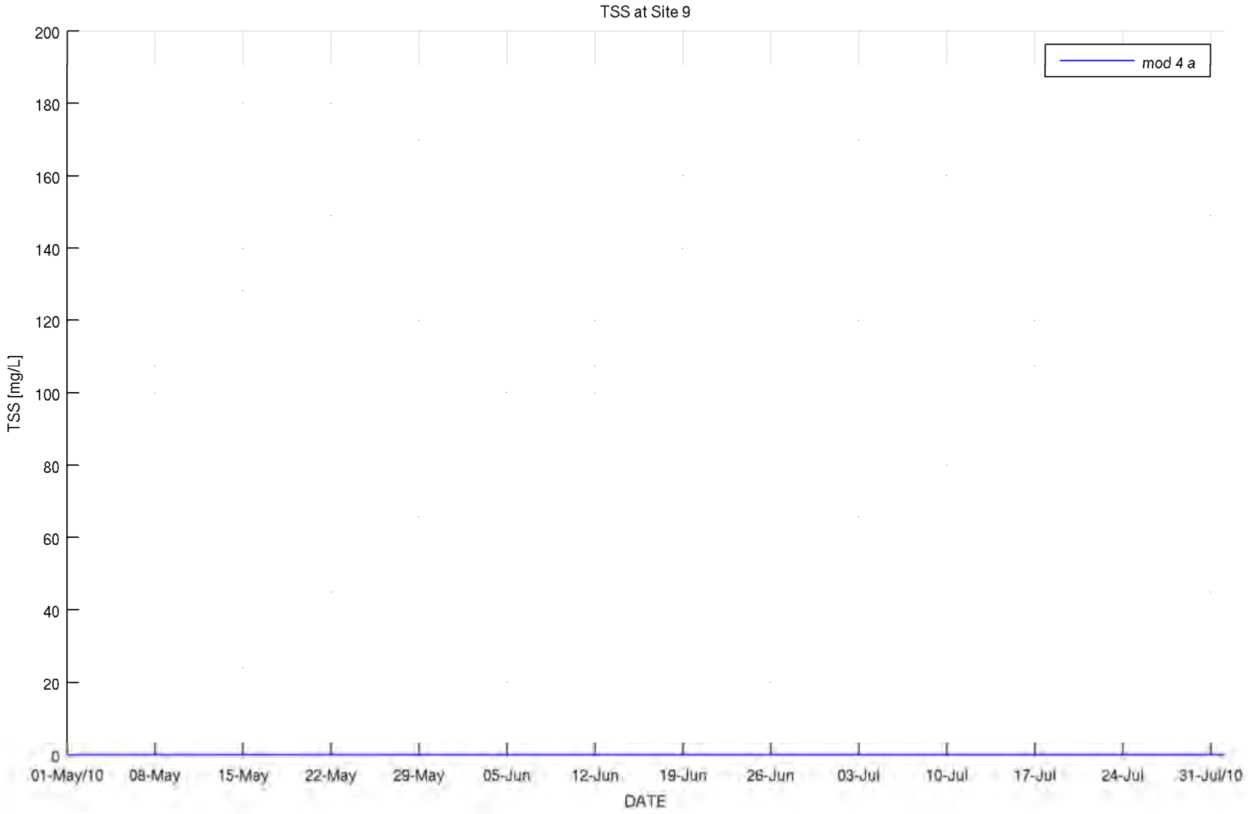
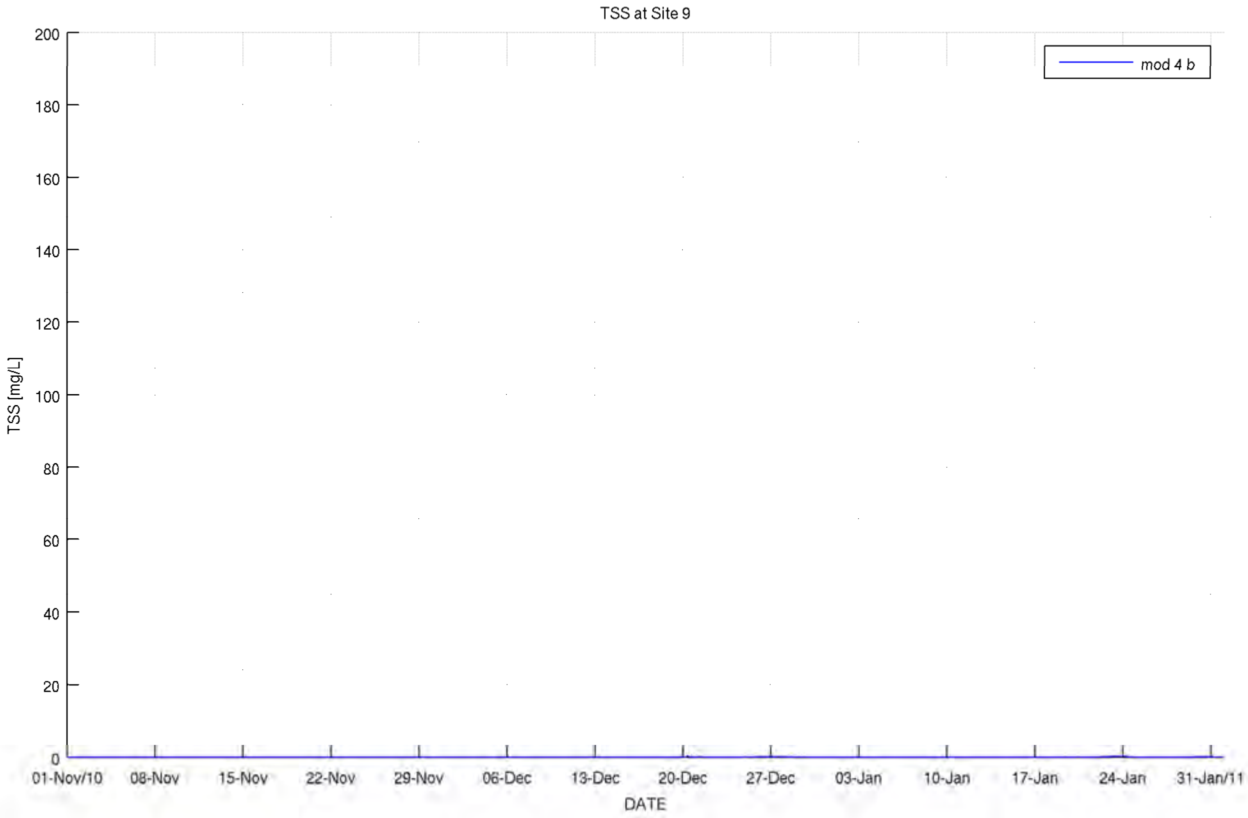
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


TSS at Site 9
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 9
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 9
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 9
mod 4 b
TSS [mg/L]
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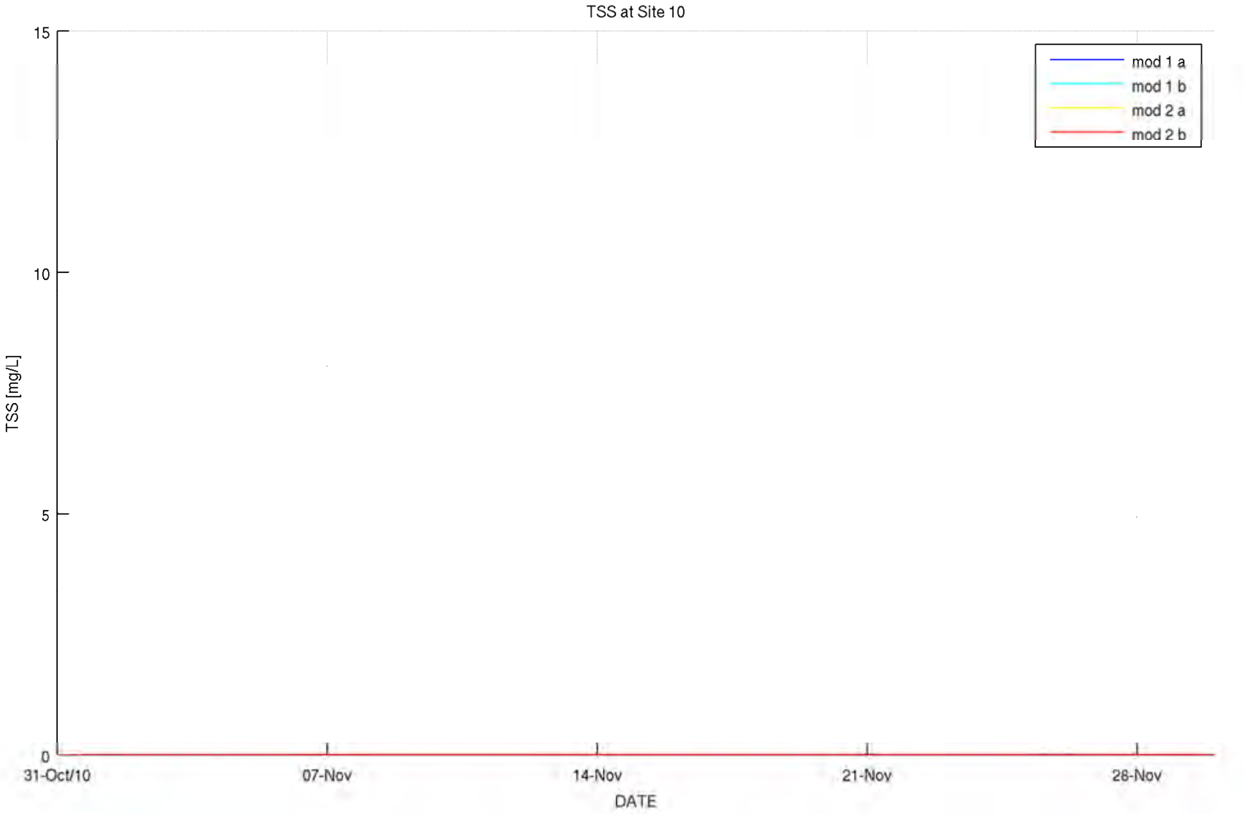
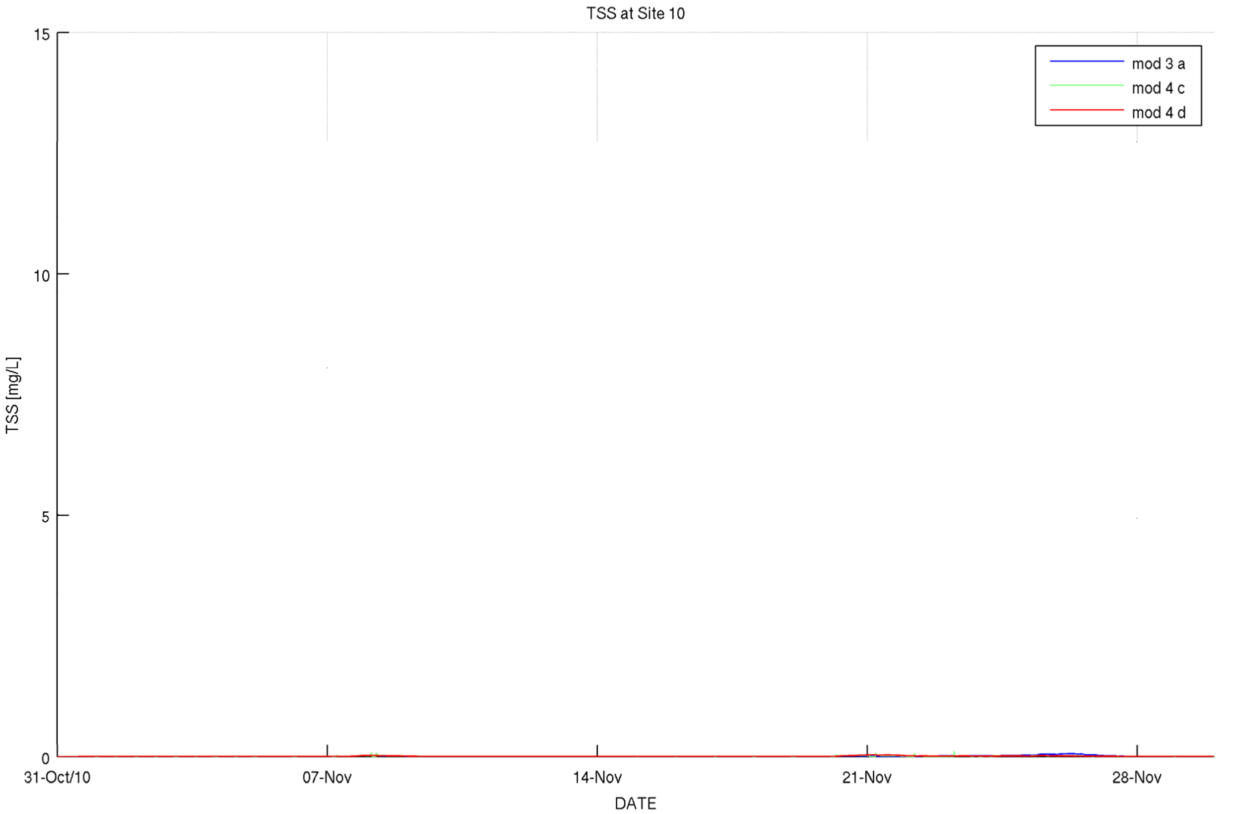
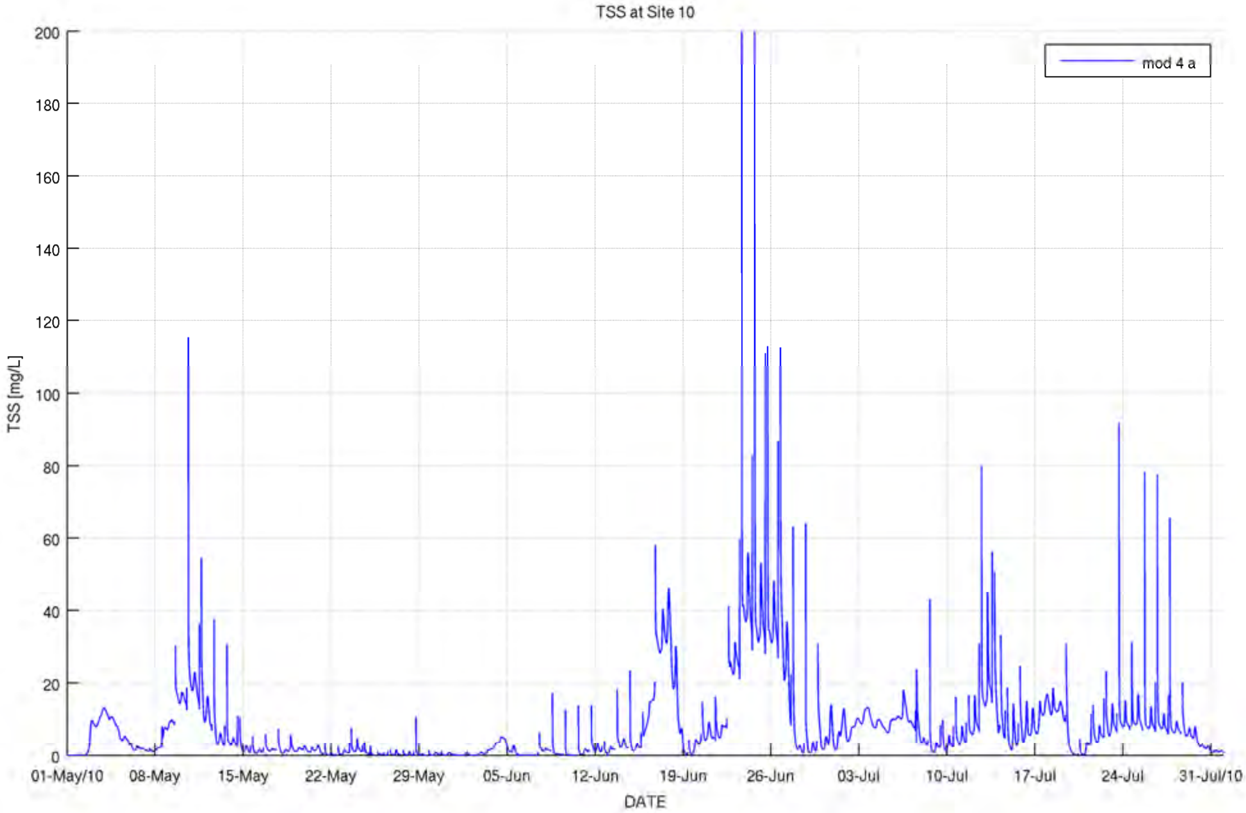
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


TSS at Site 10
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 10
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 10
mod 4 a
TSS [mg/L]
0
20
40
60
80
100
120
140
160
180
200
01-May/10
08-May
15-May
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12-Jun
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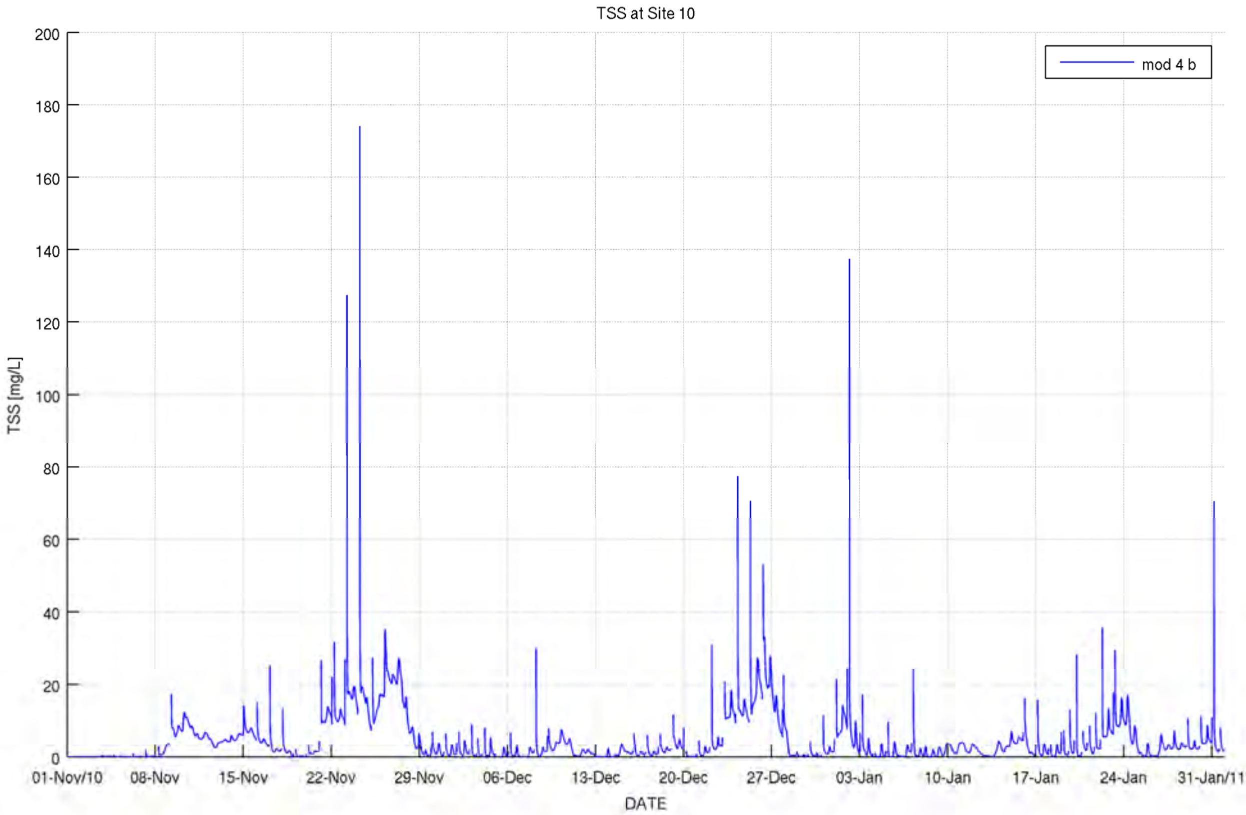
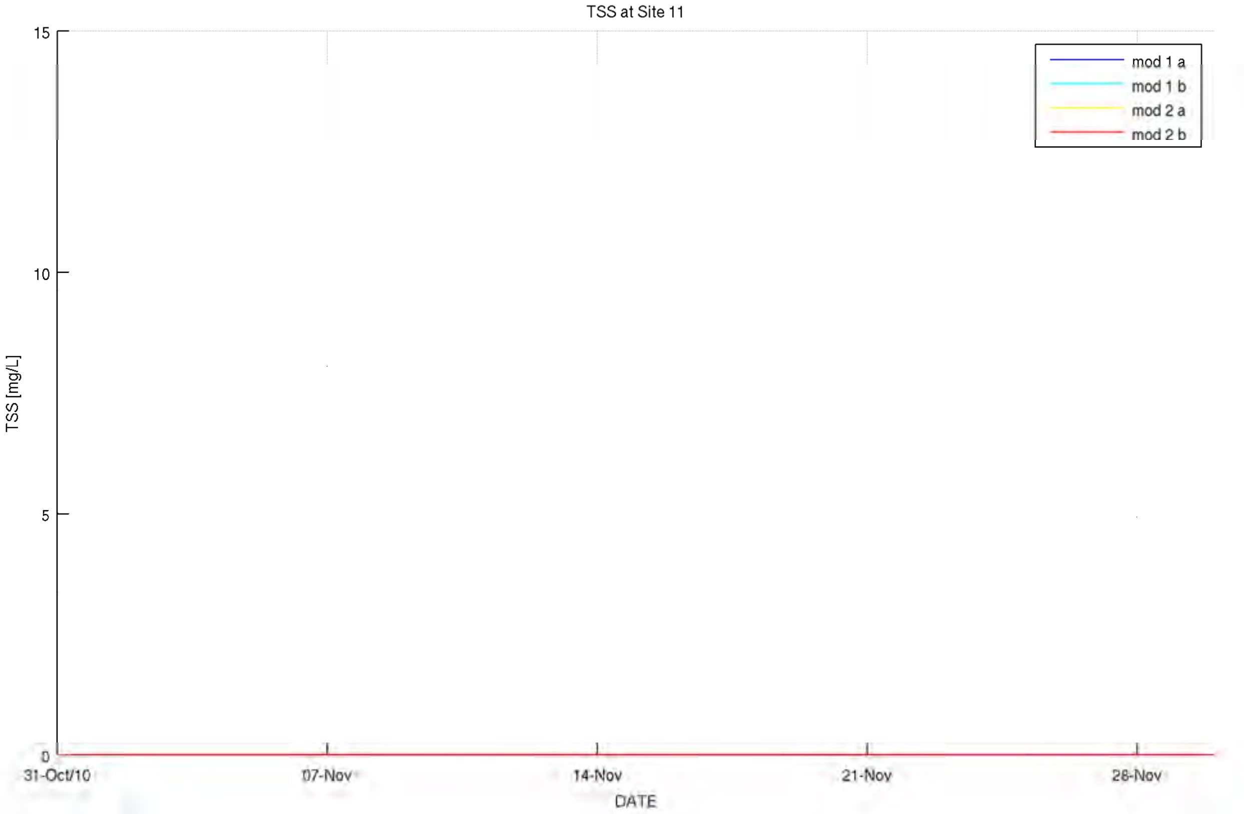
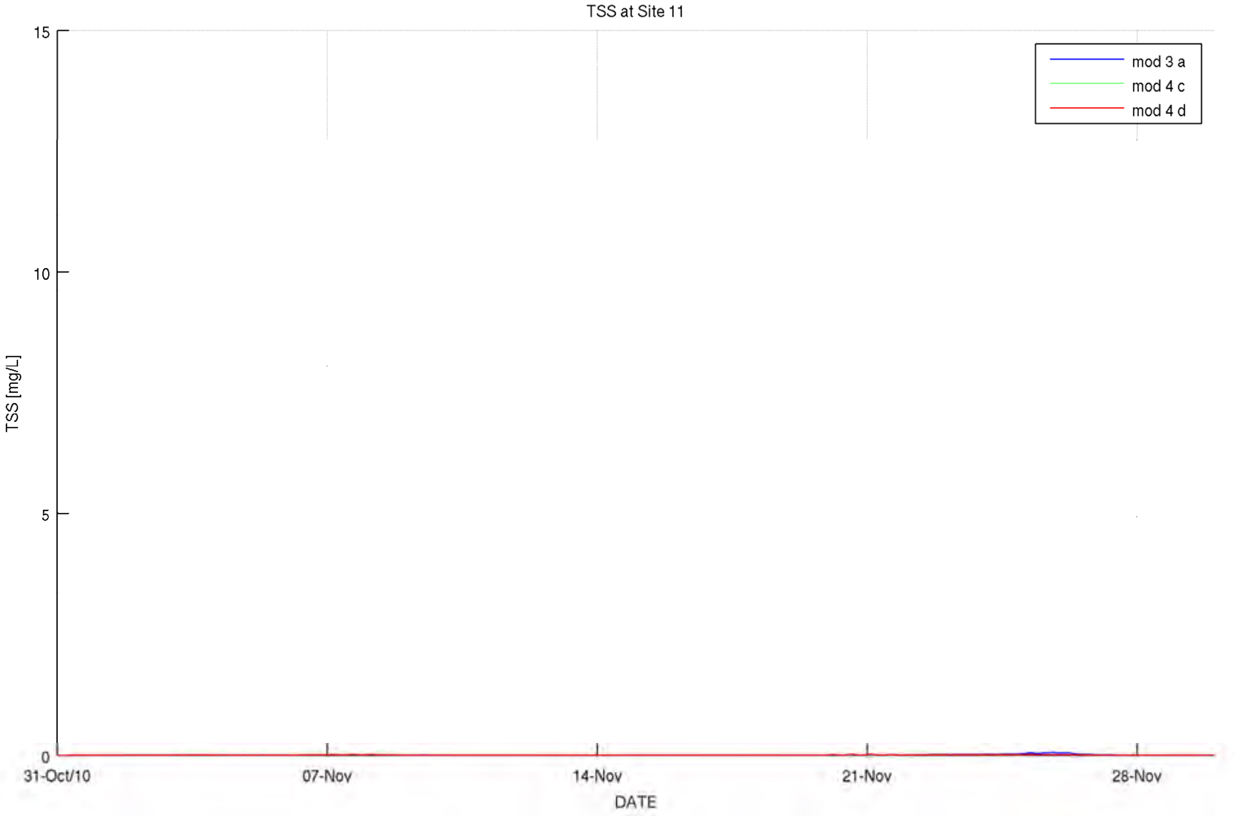
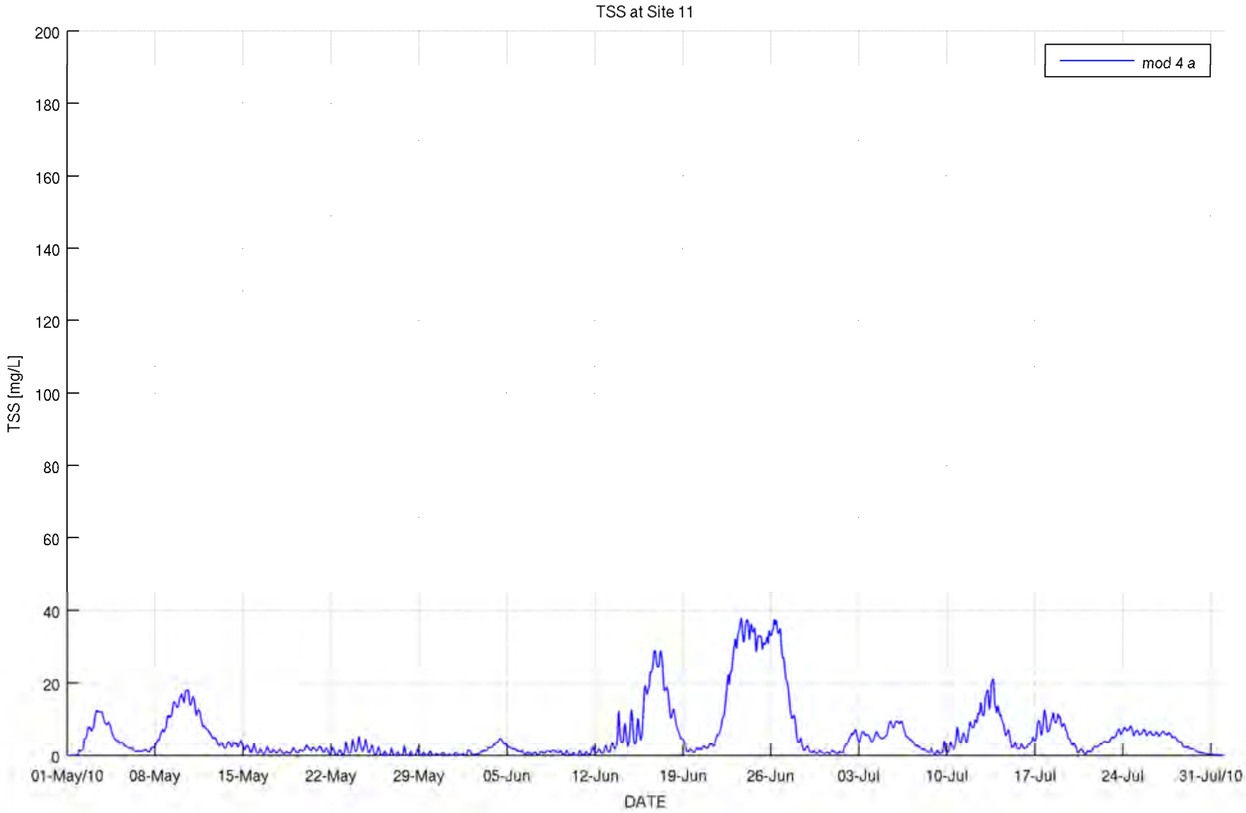
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 10
mod 4 b
TSS [mg/L]
0
20
40
60
80
100
120
140
160
180
200
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


TSS at Site 11
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 11
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 11
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
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03-Jul
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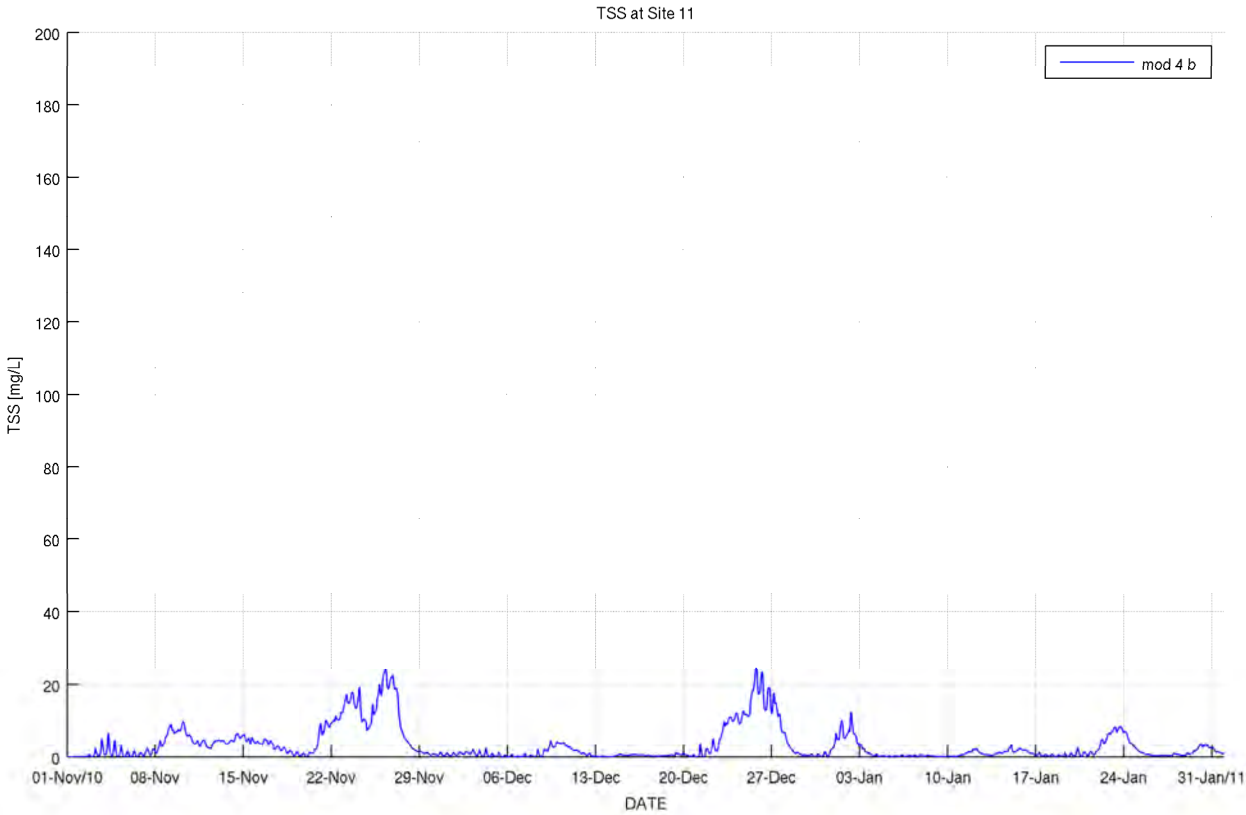
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 11
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
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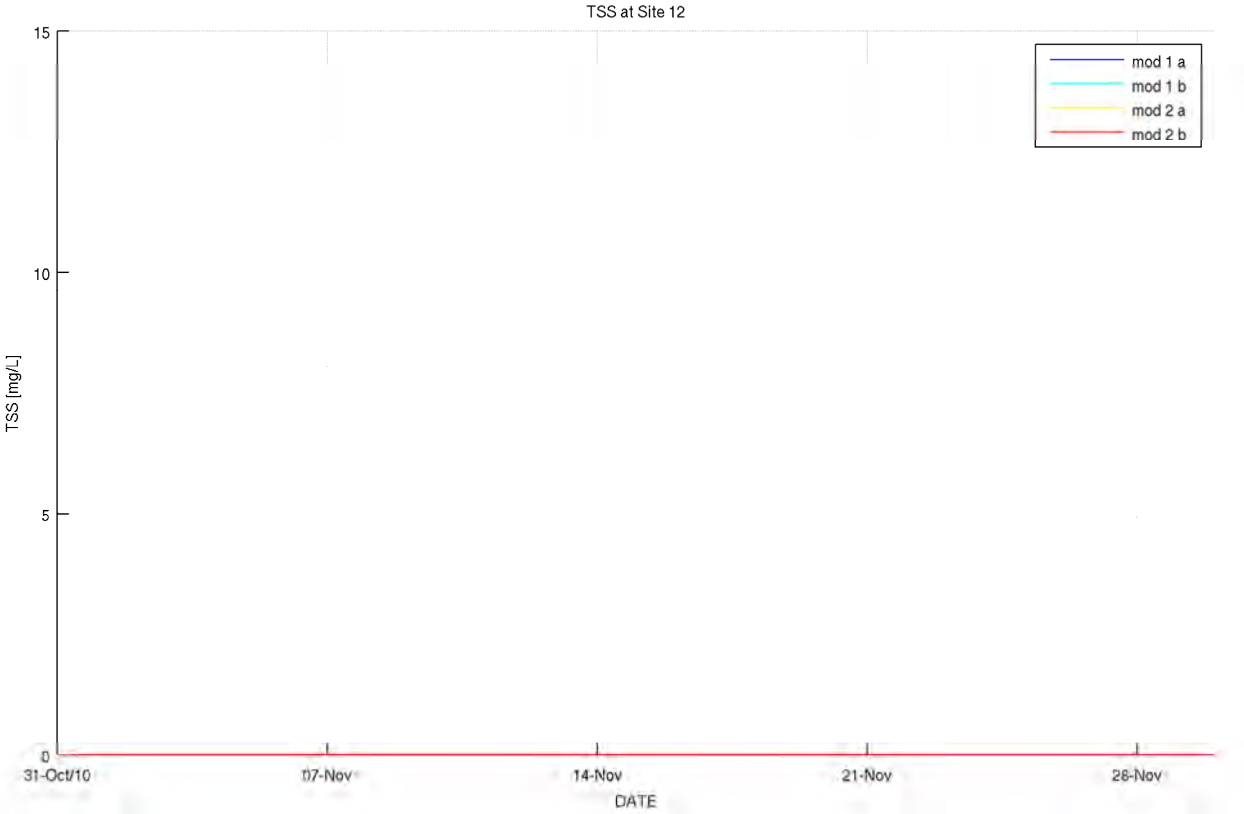
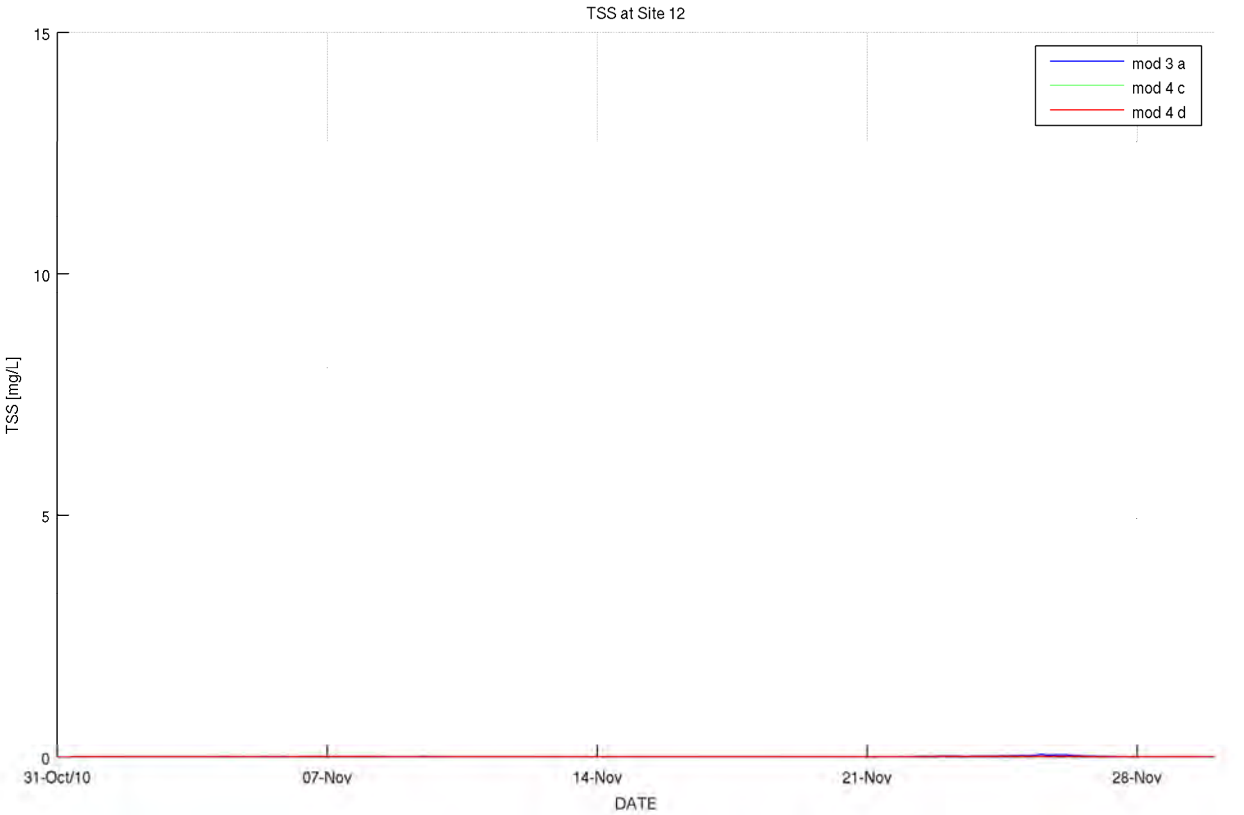
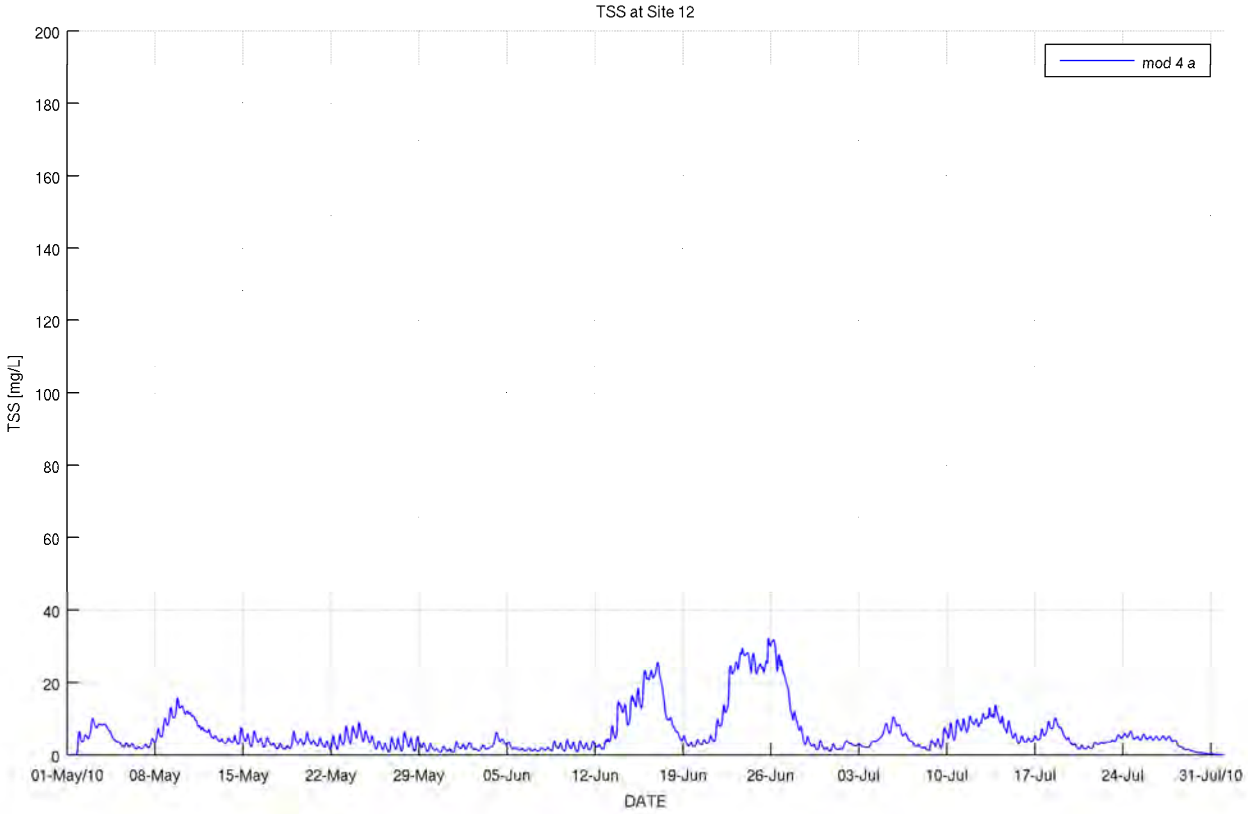
24-Jan
31-Jan/11
DATE


TSS at Site 12
mod 1 a
mod 1 b
mod 2 a
mod 2 b
TSS [mg/L]
15
10
5
0
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE


TSS at Site 12
mod 3 a
mod 4 c
mod 4 d
TSS [mg/L]
15
10
5
0
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE


TSS at Site 12
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
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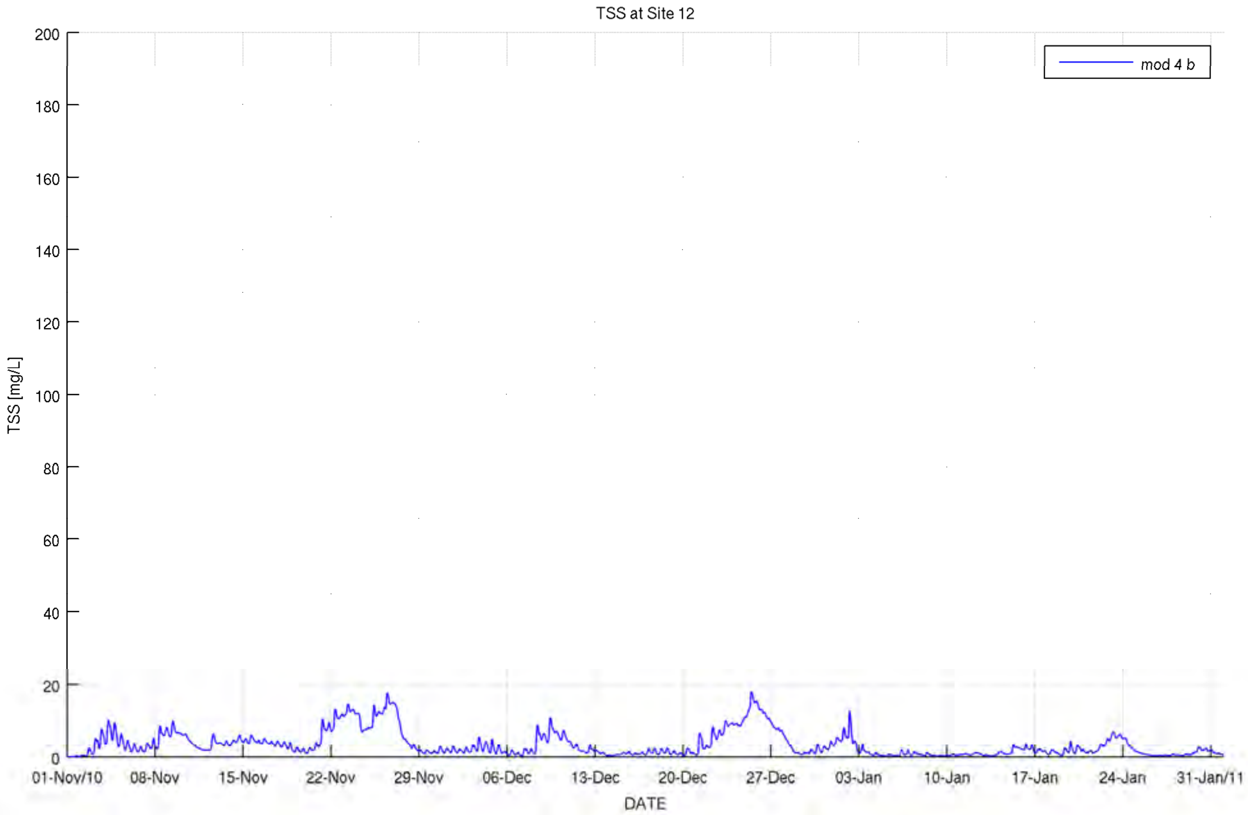
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 12
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
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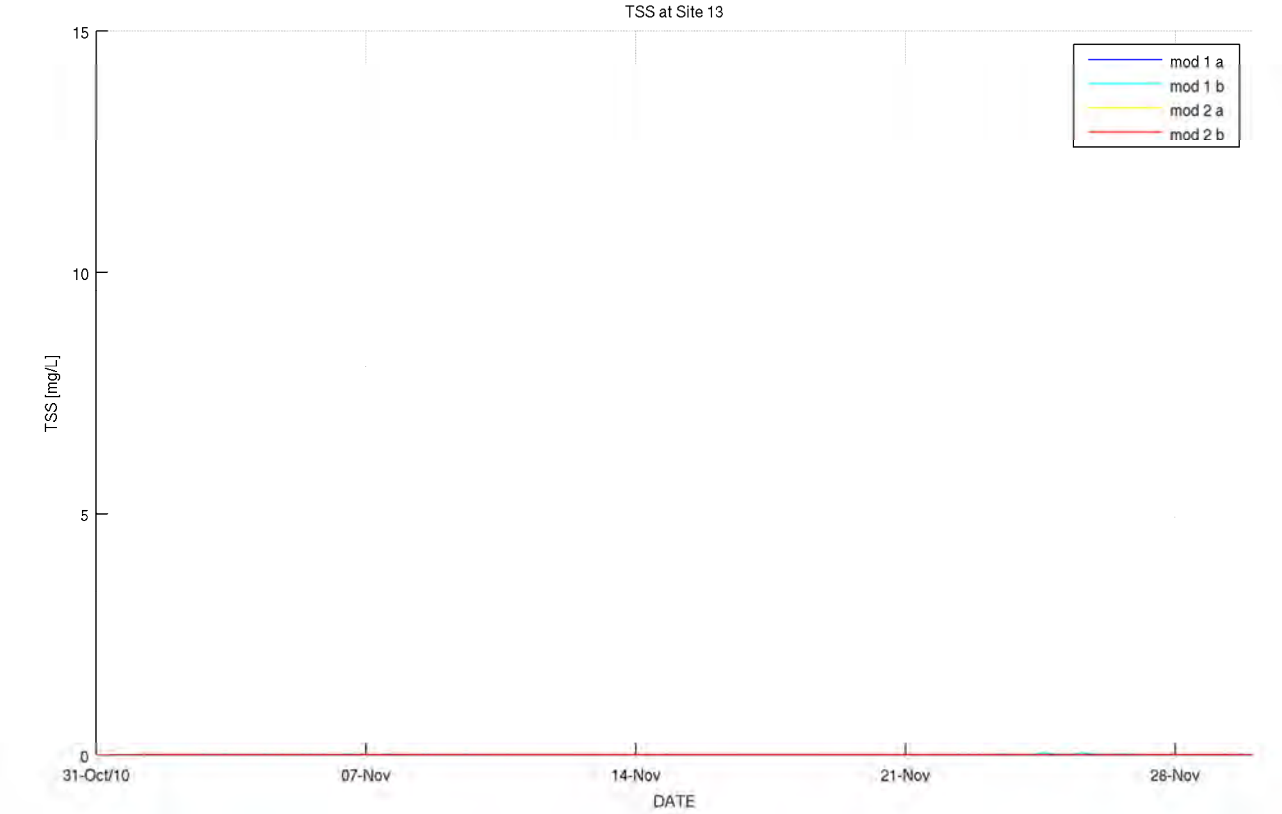
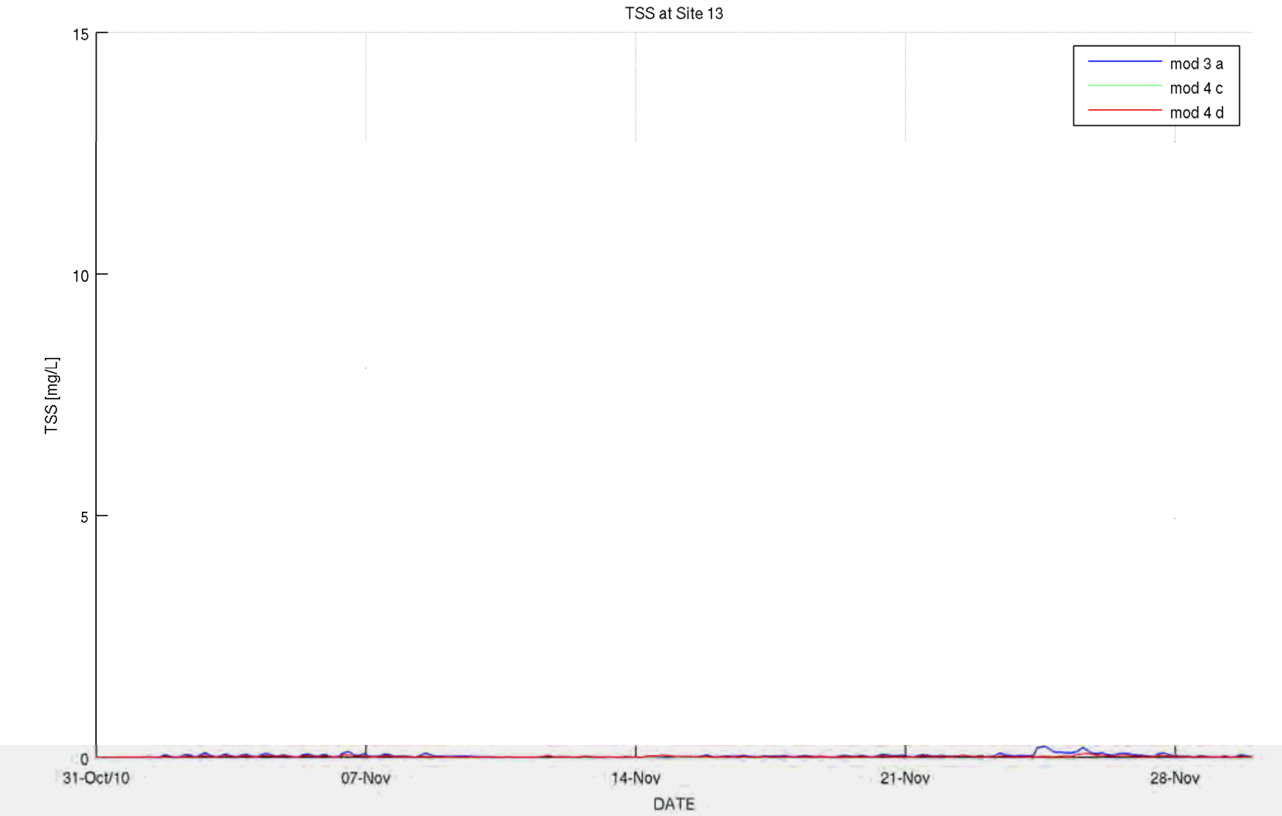
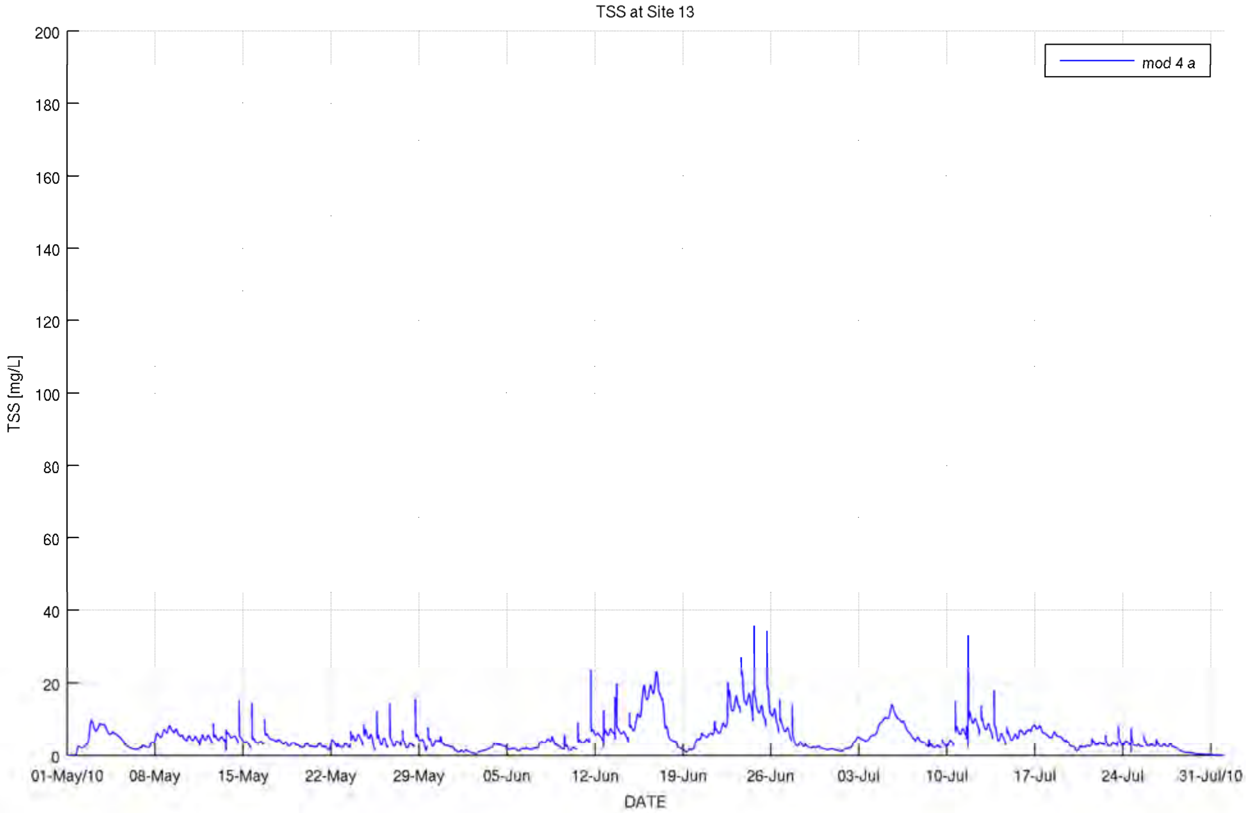
24-Jan
31-Jan/11
DATE


TSS at Site 13
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 13
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 13
mod 4 a
TSS [mg/L]
0
20
40
60
80
100
120
140
160
180
200
01-May/10
08-May
15-May
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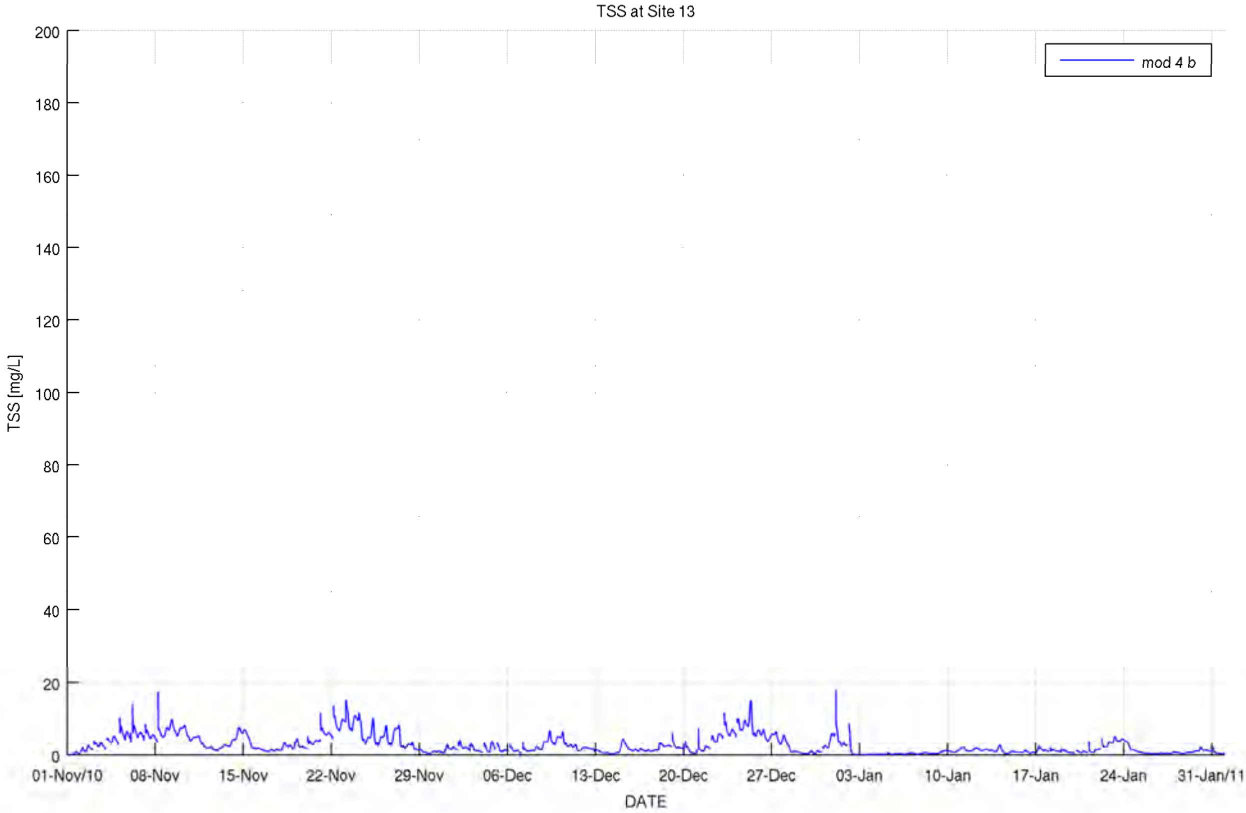
24-Jul
31-Jul/10
DATE


TSS at Site 13
mod 4 b
TSS [mg/L]
0
20
40
60
80
100
120
140
160
180
200
01-Nov/10
08-Nov
15-Nov
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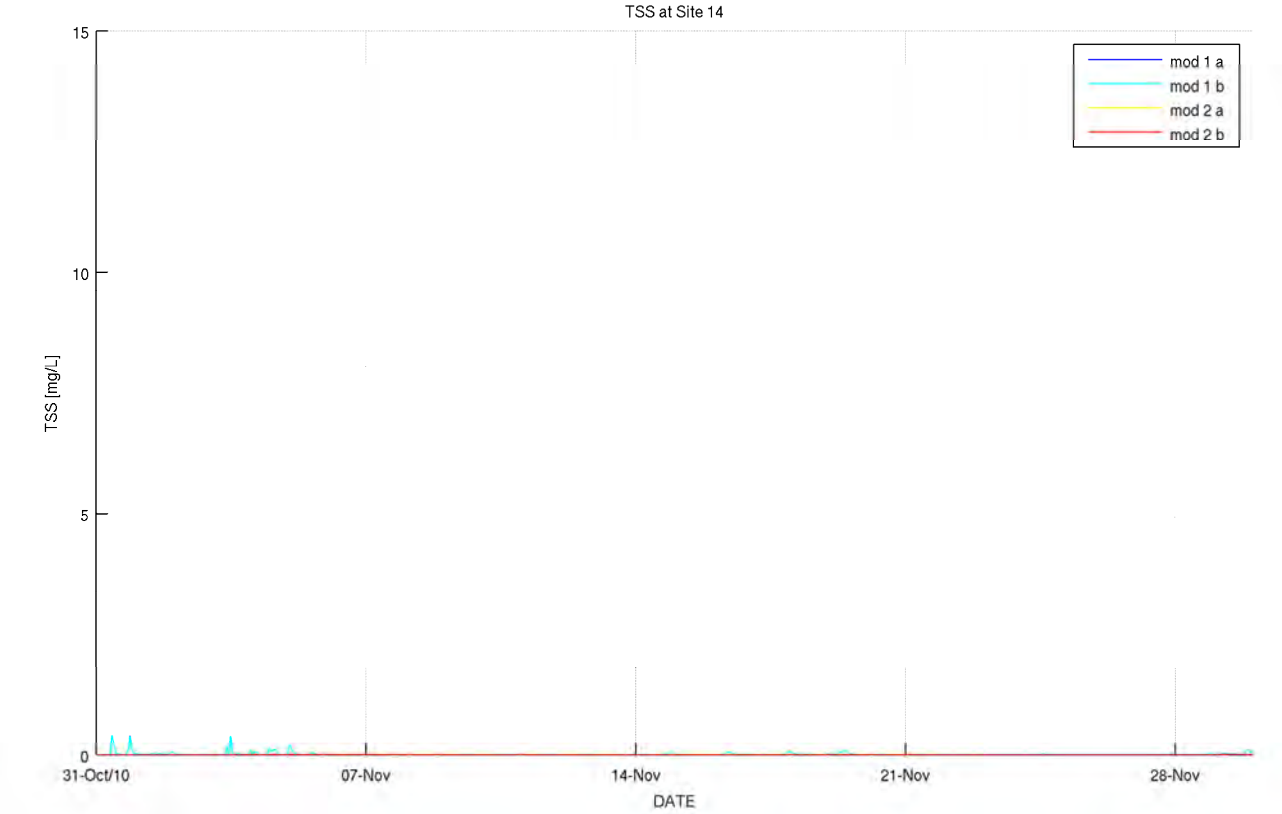
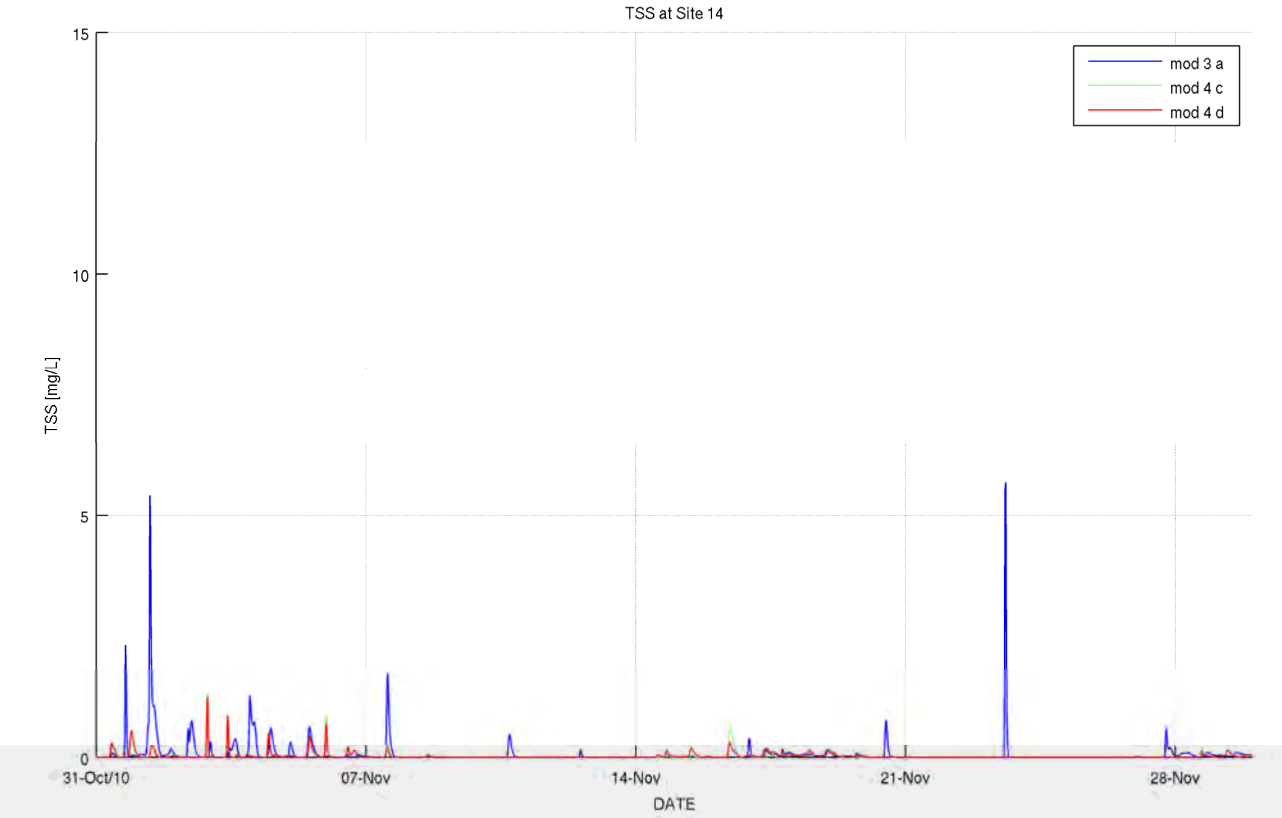
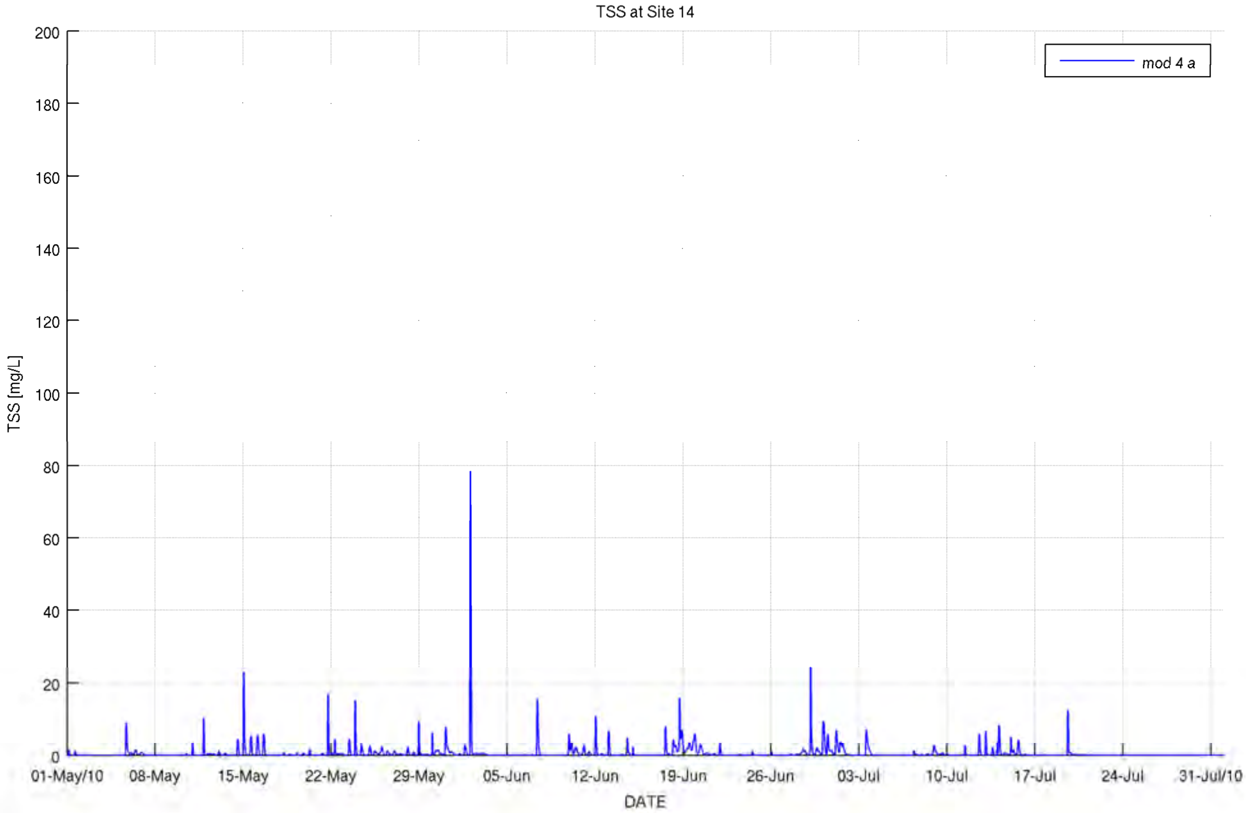
24-Jan
31-Jan/11
DATE


TSS at Site 14
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 14
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 14
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
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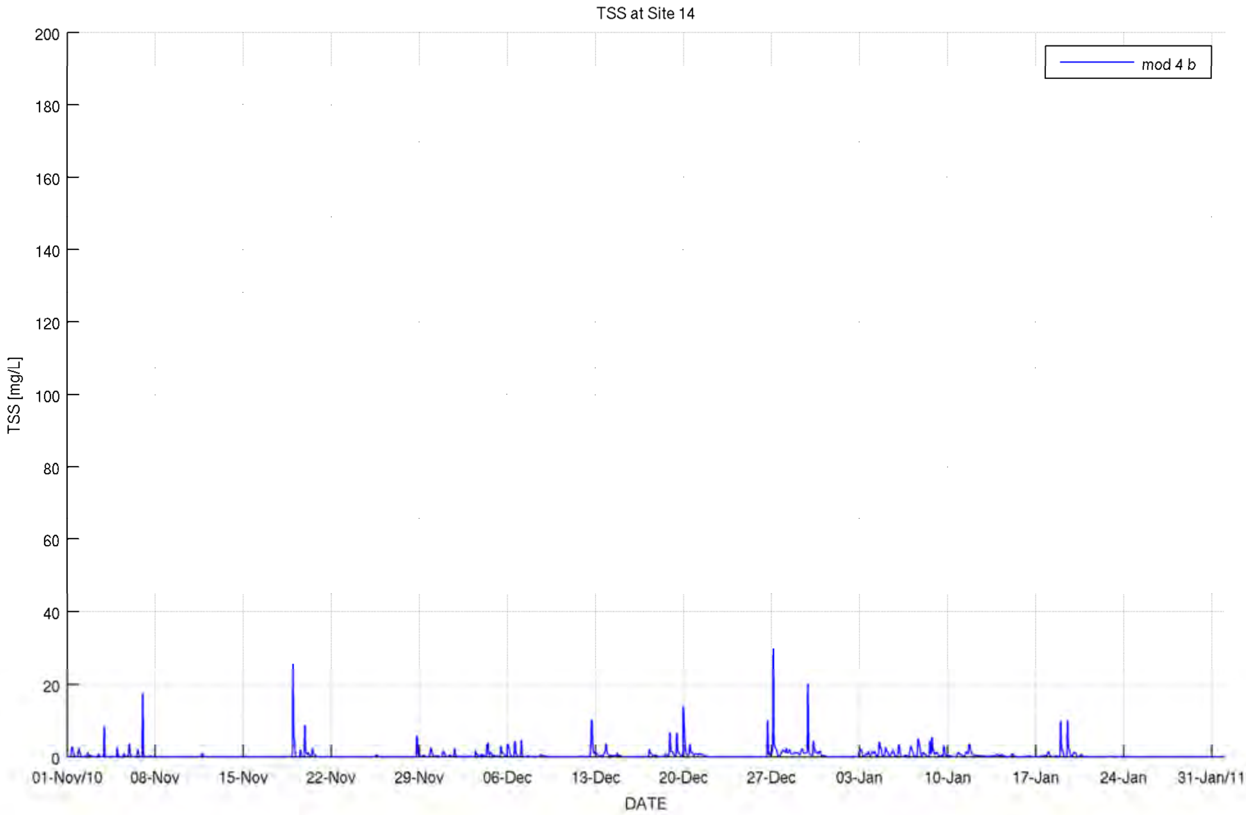
24-Jul
31-Jul/10
DATE


TSS at Site 14
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
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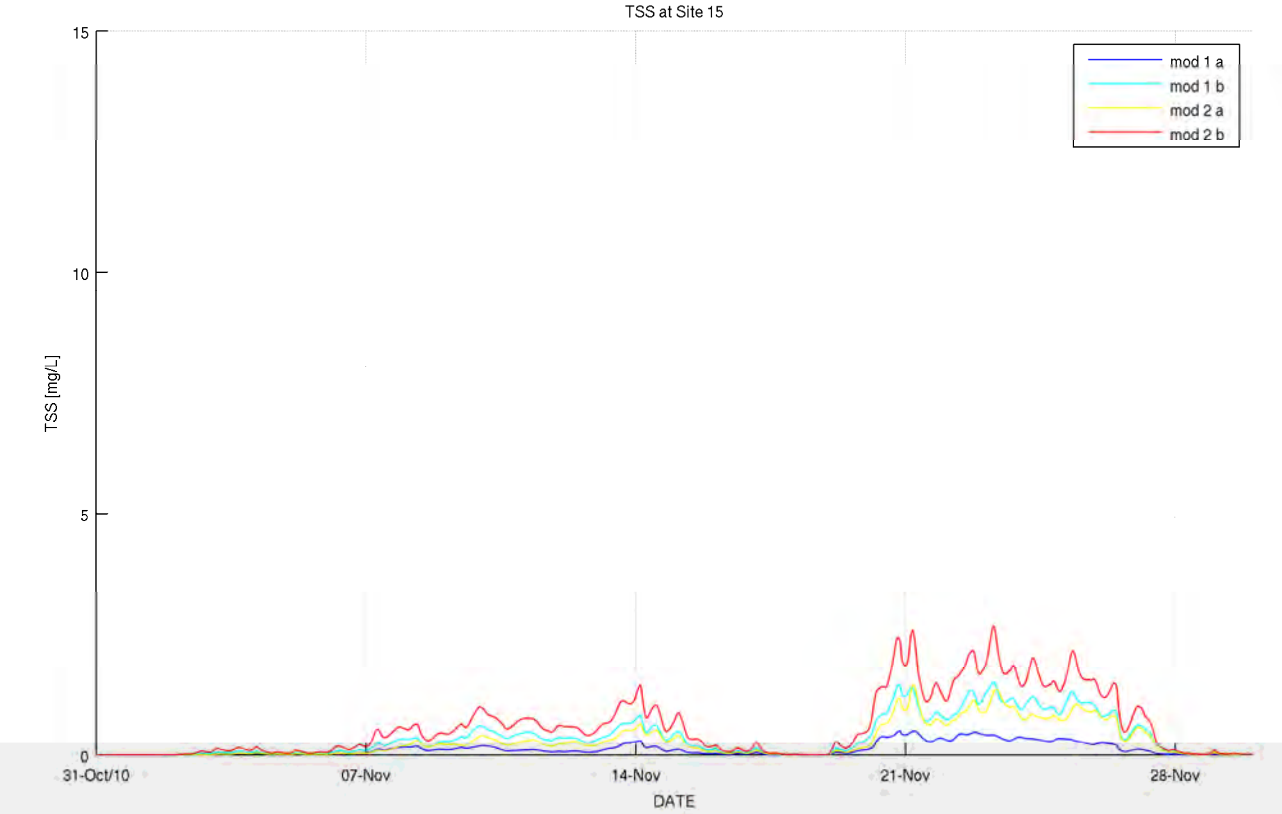
24-Jan
31-Jan/11
DATE


TSS at Site 15
15
10
5
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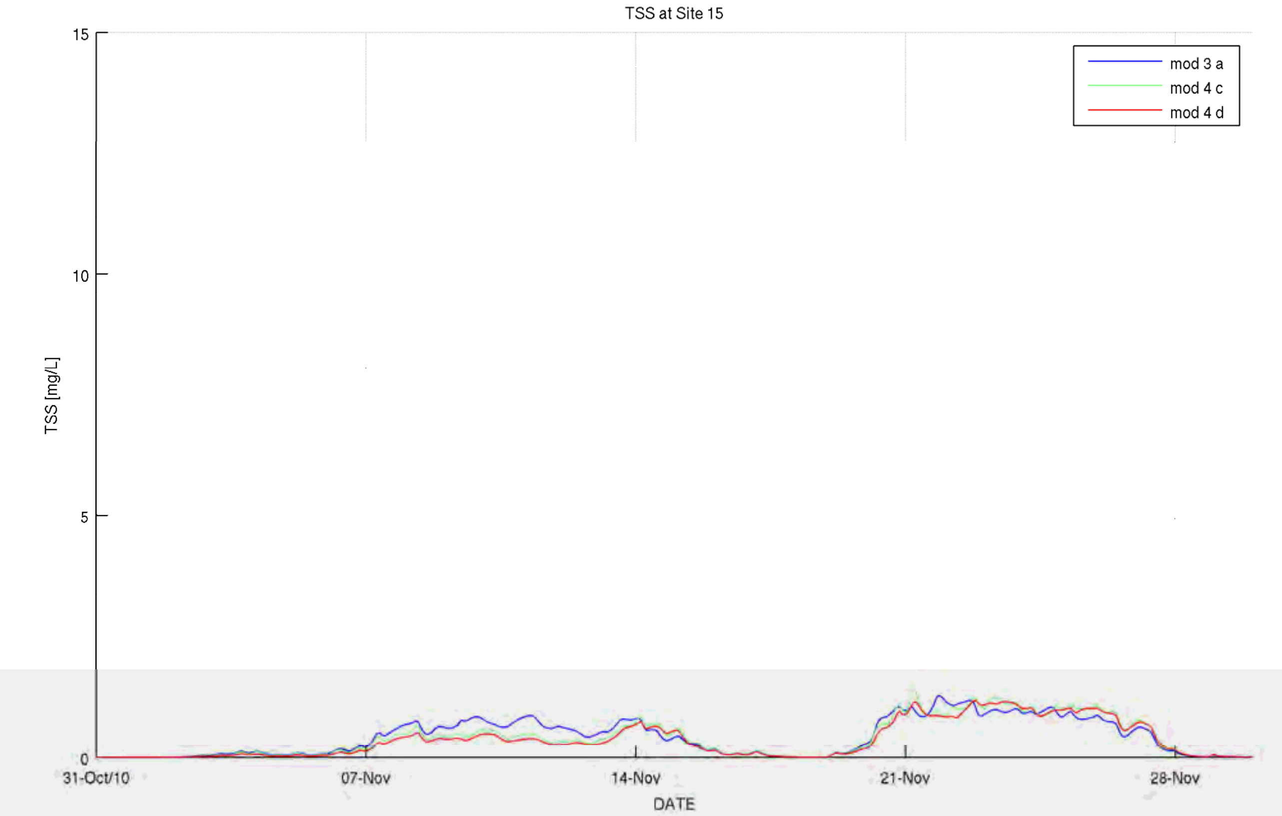
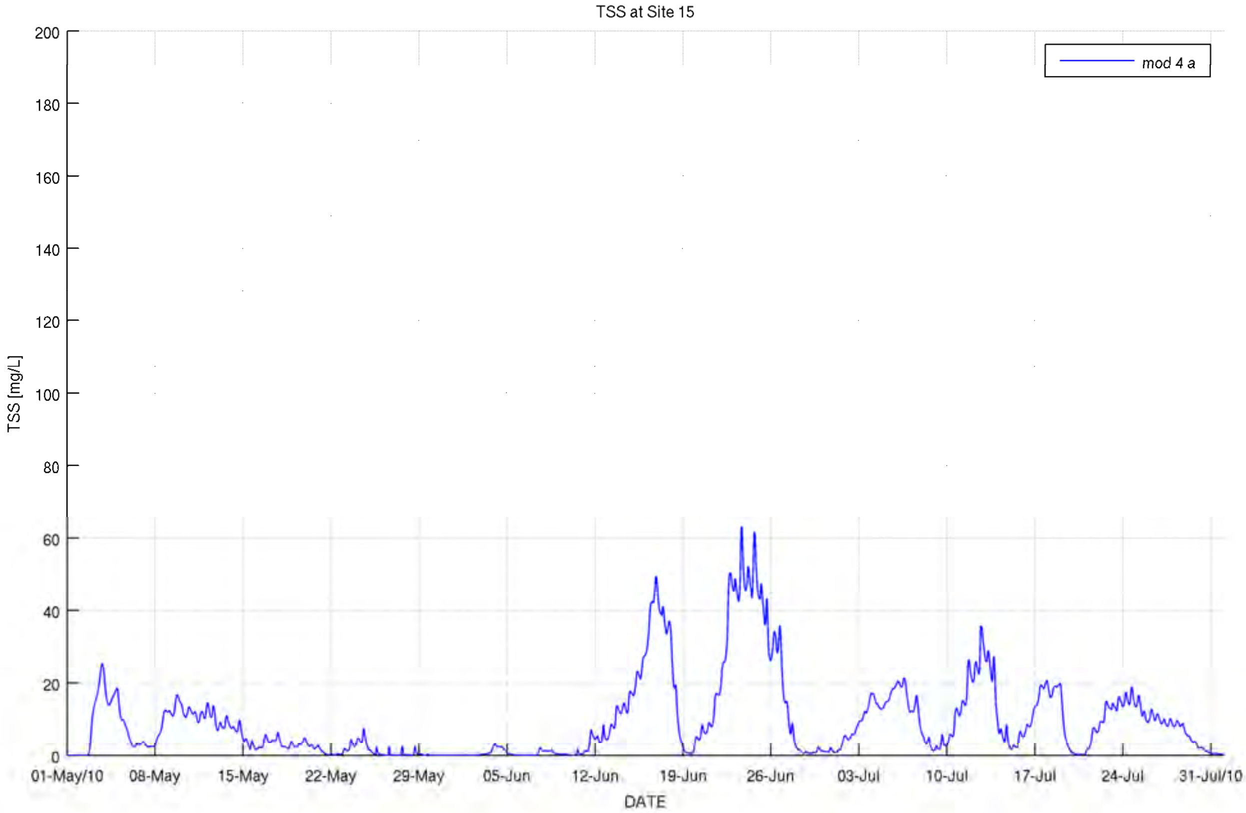
TSS [mg/L]
mod 1 a
mod 1 b
mod 2 a
mod 2 b
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE


TSS at Site 15
15
10
5
0
TSS [mg/L]
mod 3 a
mod 4 c
mod 4 d
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE


TSS at Site 15
mod 4 a
TSS [mg/L]
200
180
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140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
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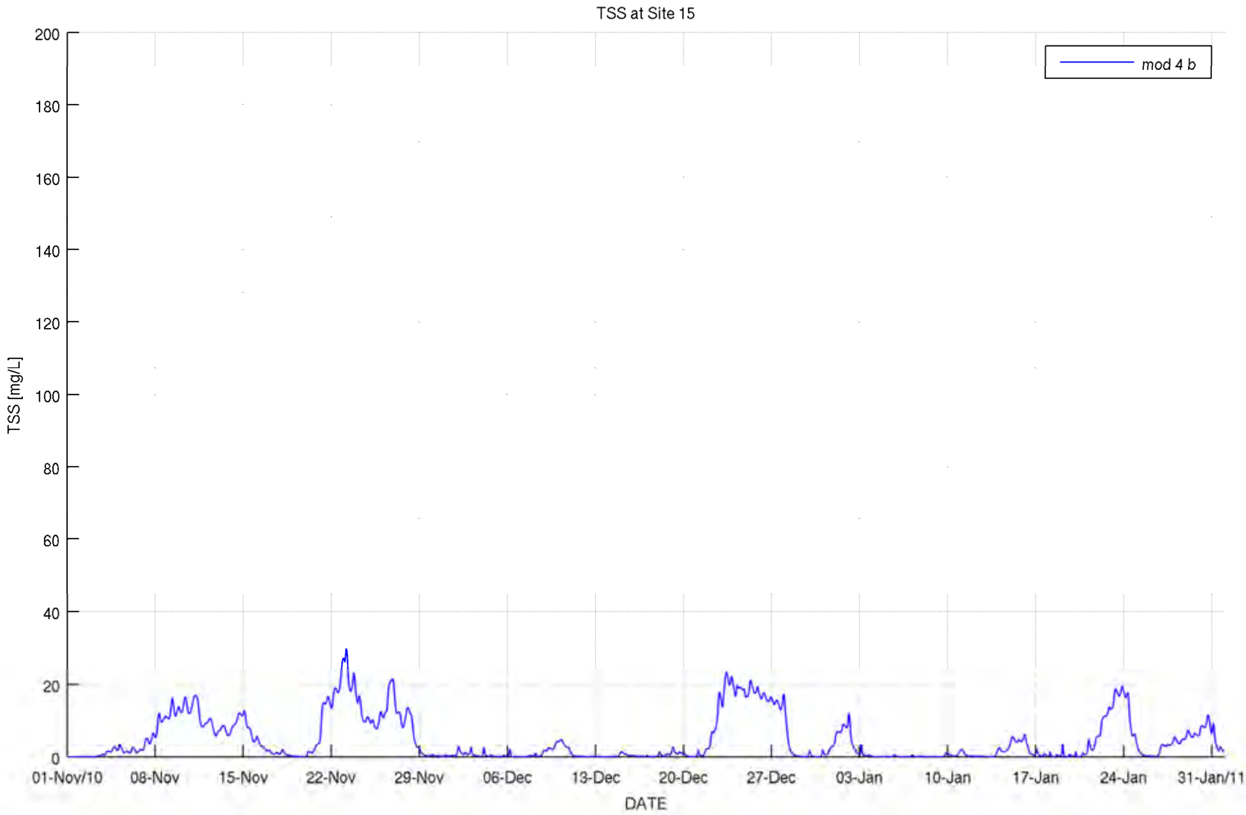
24-Jul
31-Jul/10
DATE


TSS at Site 15
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
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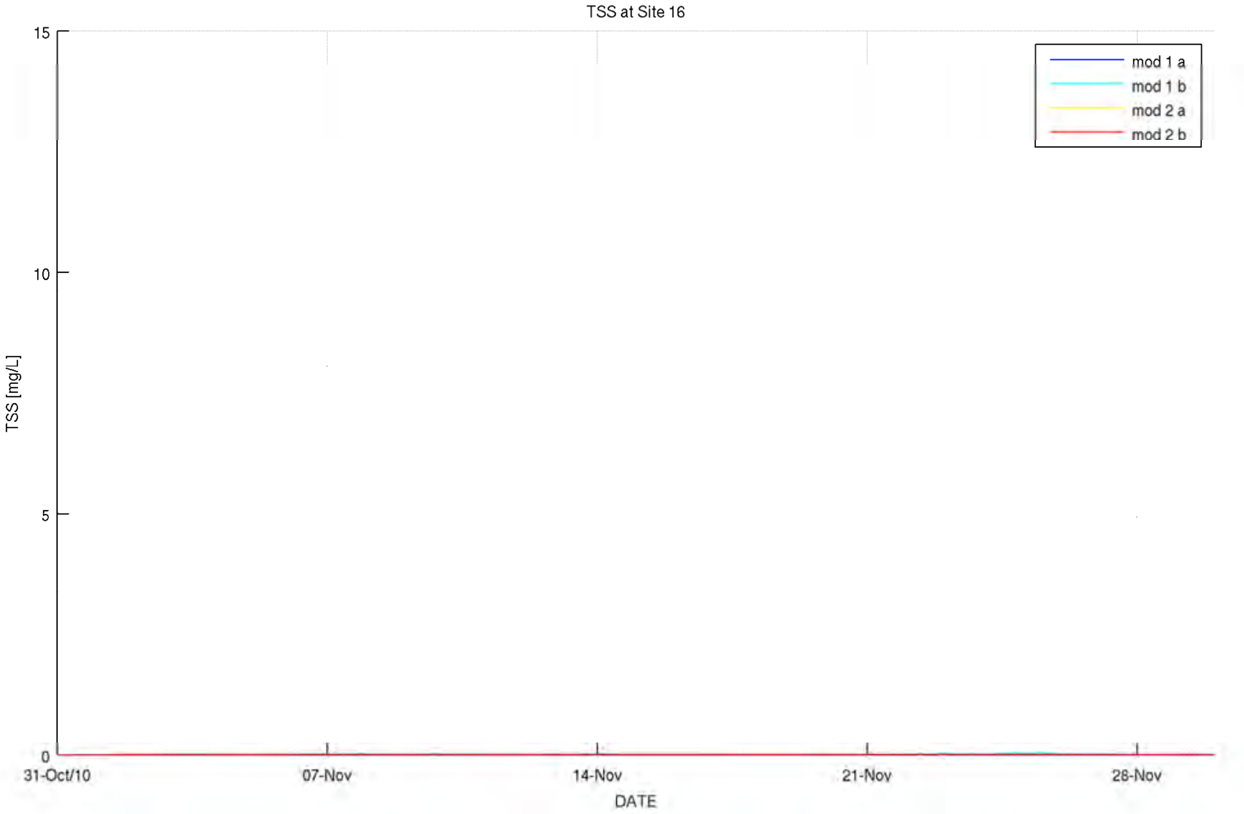
24-Jan
31-Jan/11
DATE


TSS at Site 16
mod 1 a
mod 1 b
mod 2 a
mod 2 b
TSS [mg/L]
15
10
5
0
31-Oct/10
07-Nov
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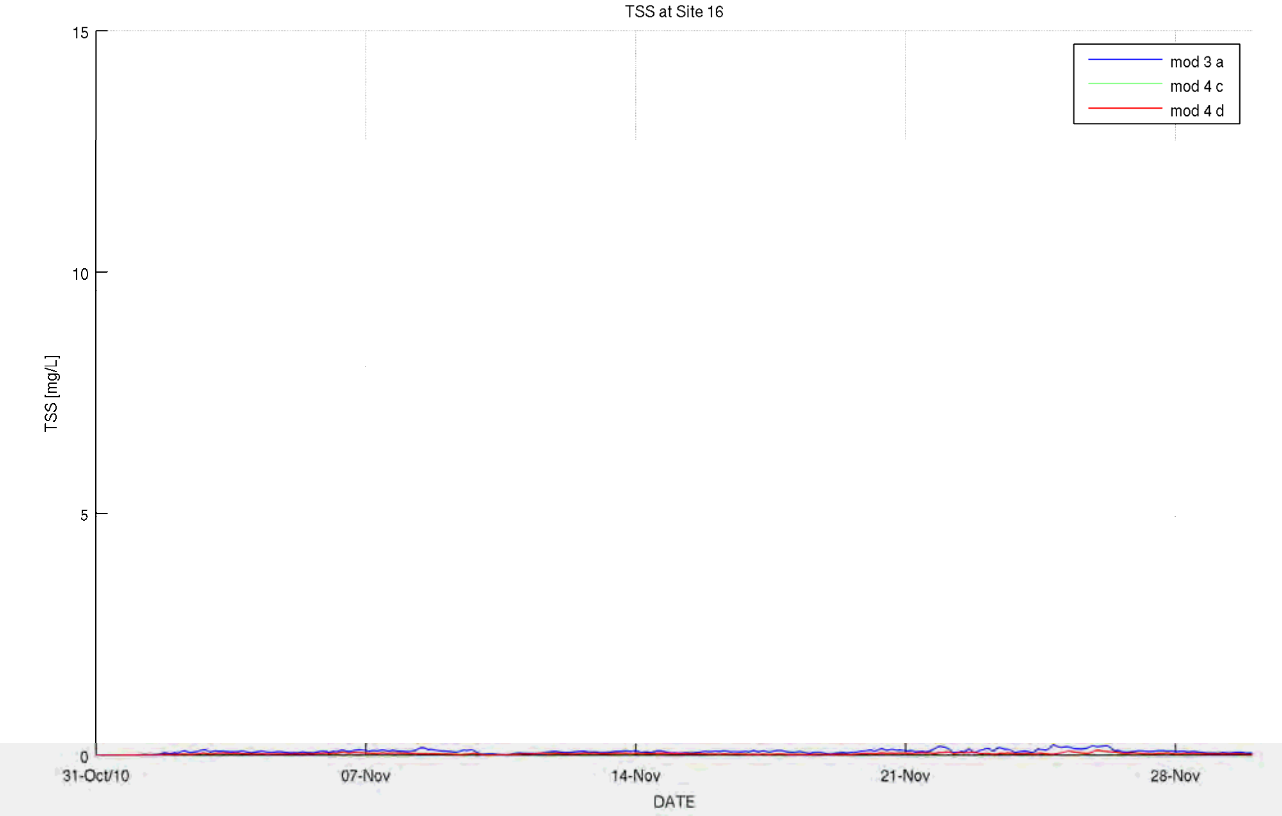
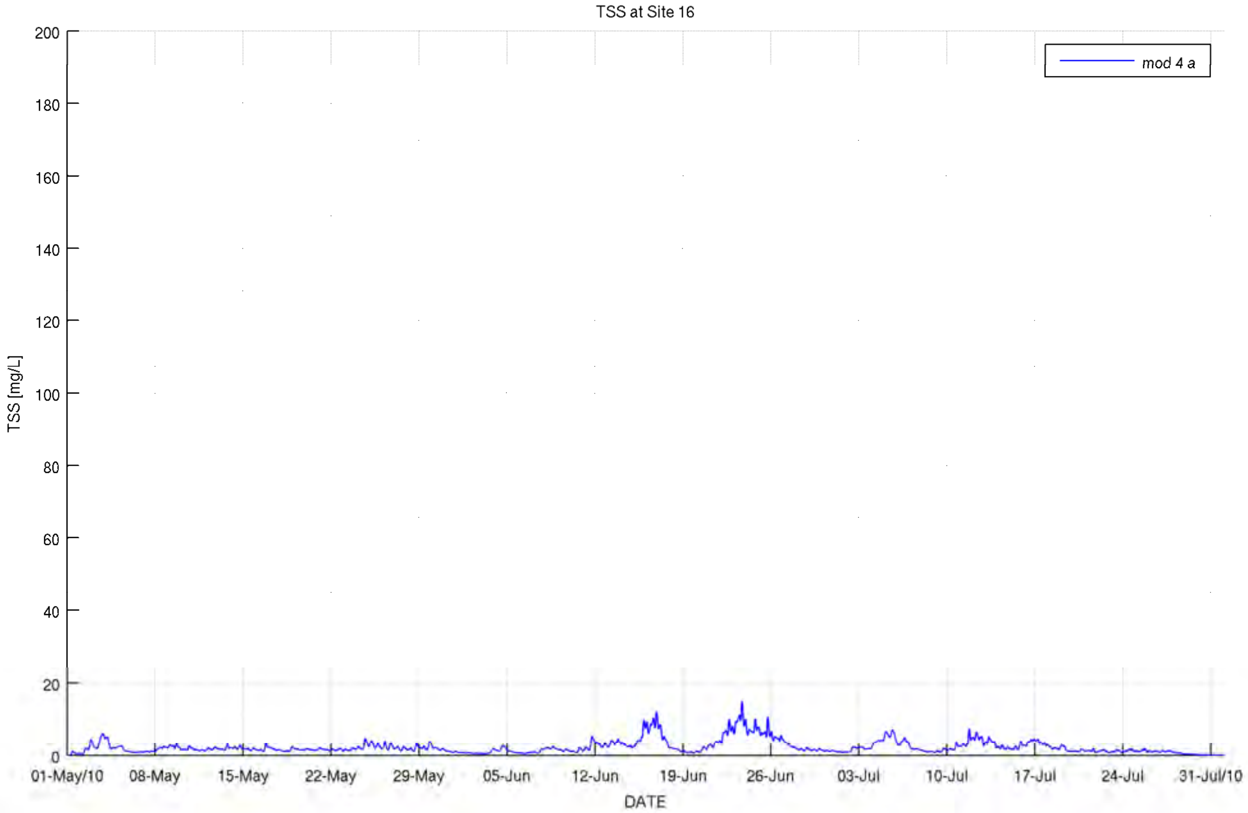
21-Nov
28-Nov
DATE


TSS at Site 16
mod 3 a
mod 4 c
mod 4 d
TSS [mg/L]
15
10
5
0
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE


TSS at Site 16
mod 4 a
TSS [mg/L]
200
180
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140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
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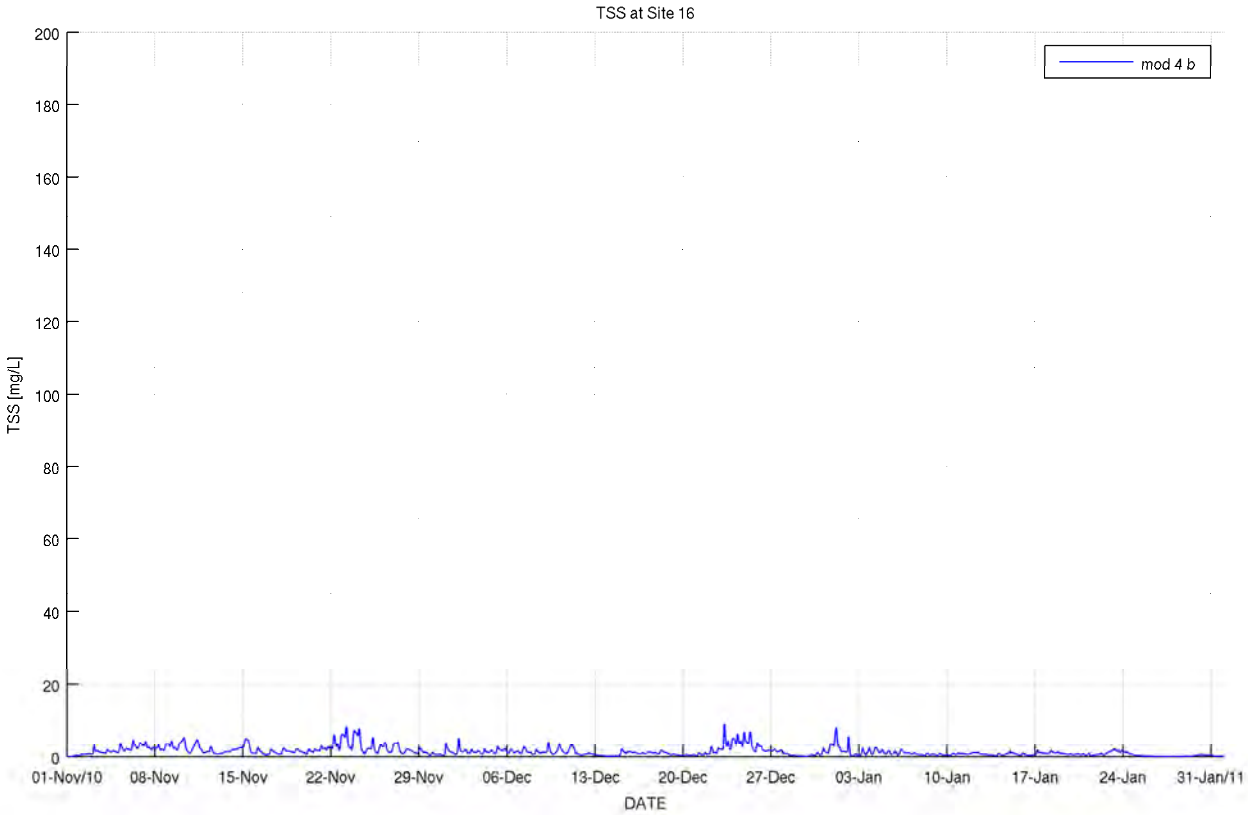
24-Jul
31-Jul/10
DATE


TSS at Site 16
mod 4 b
TSS [mg/L]
200
180
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120
100
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60
40
20
0
01-Nov/10
08-Nov
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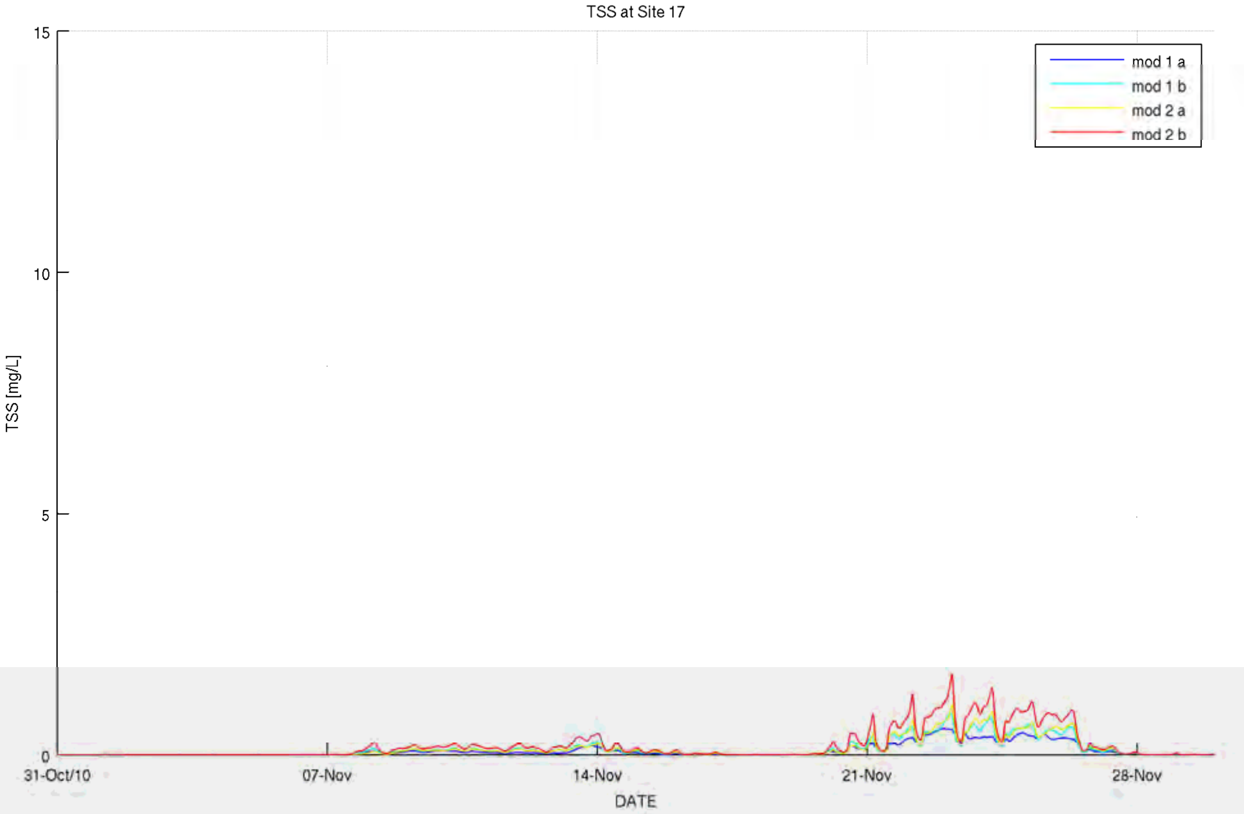
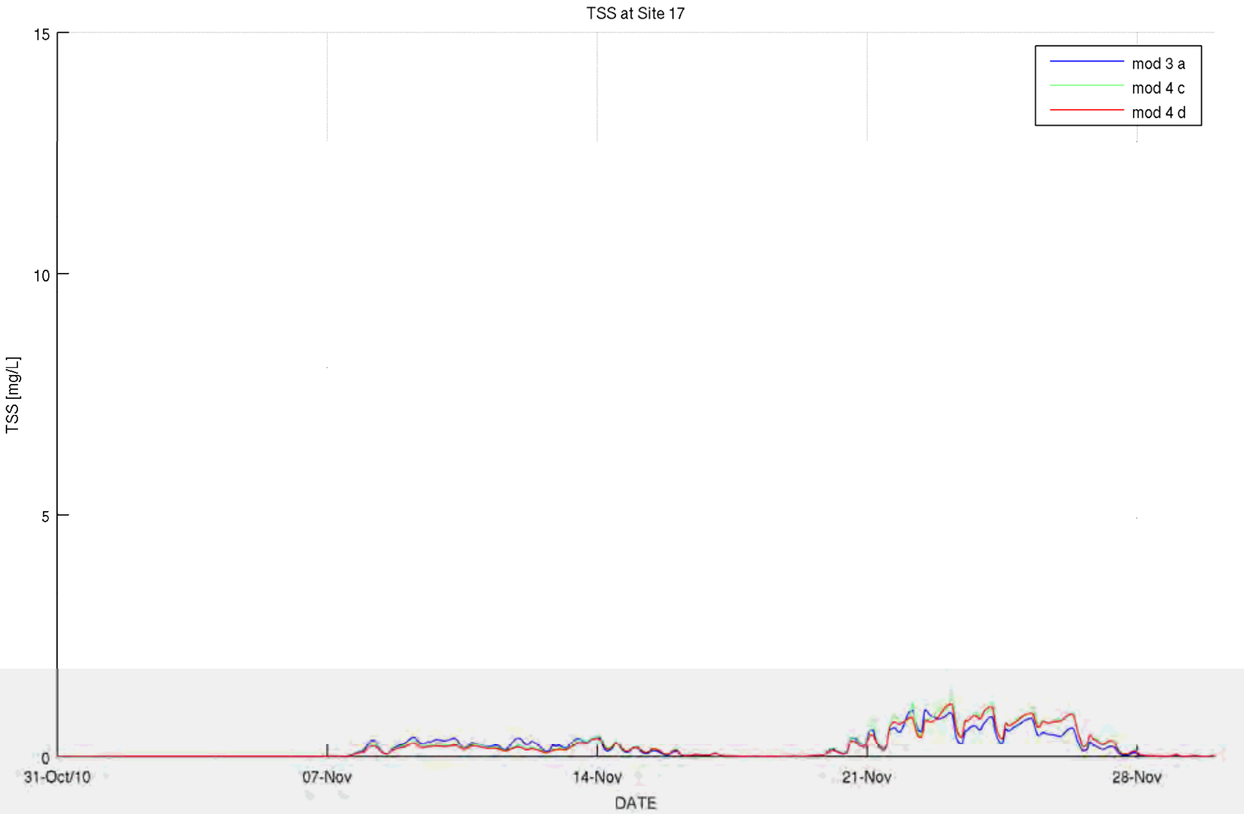
24-Jan
31-Jan/11
DATE


TSS at Site 17
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 17
15
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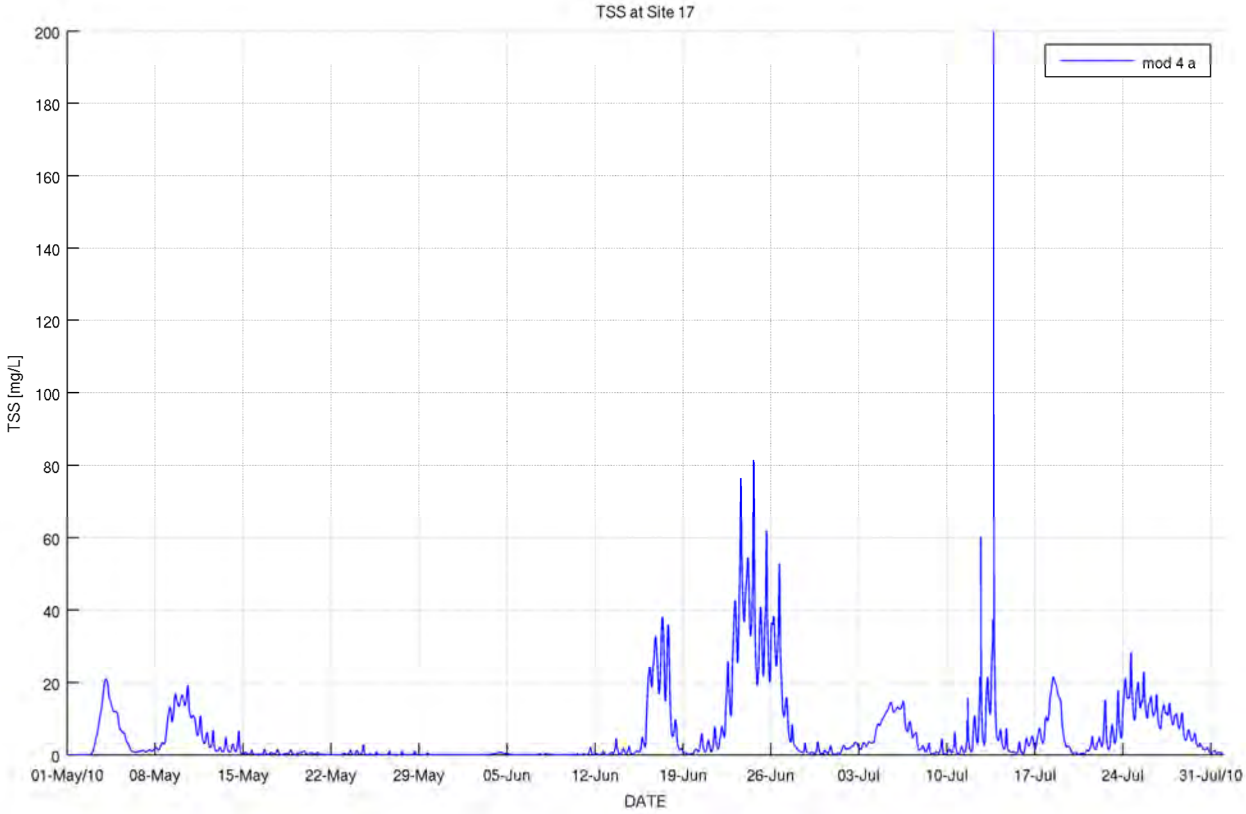
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 17
mod 4 a
TSS [mg/L]
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01-May/10
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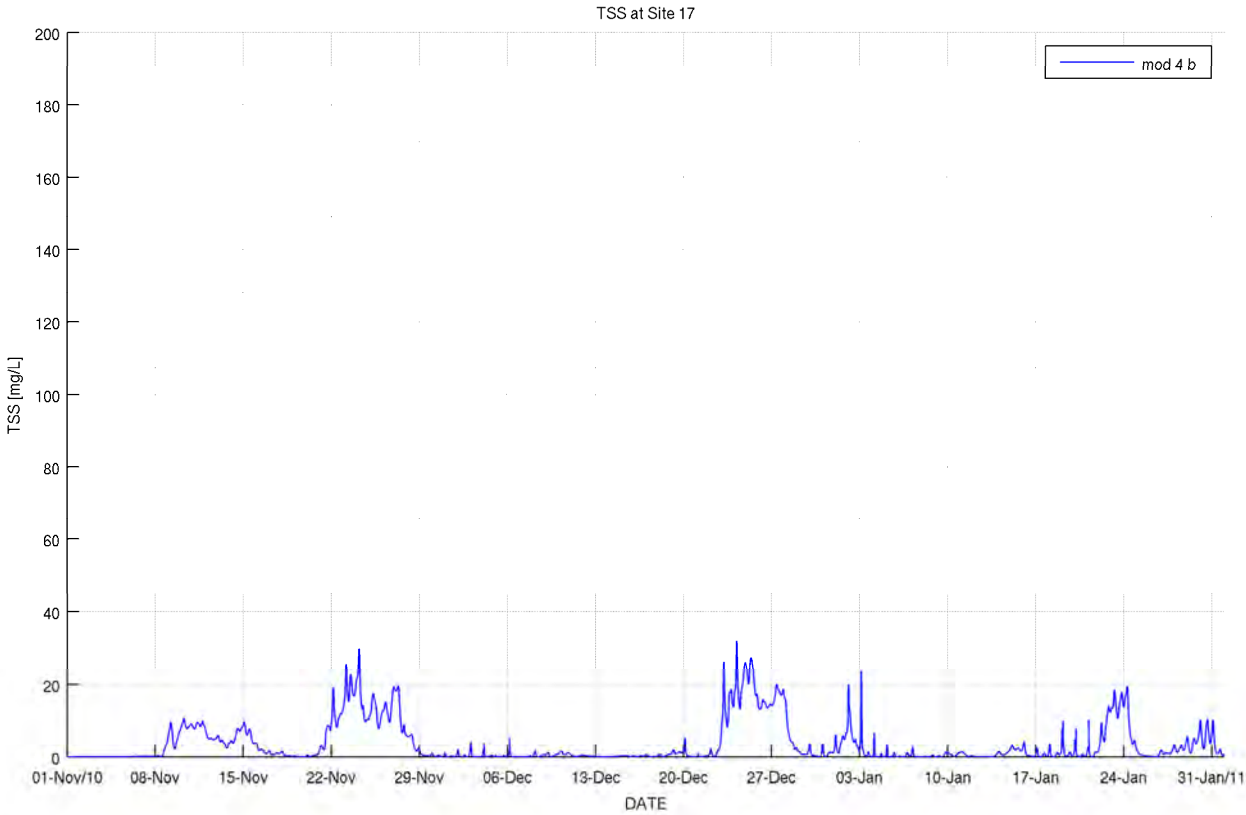
31-Jul/10
DATE


TSS at Site 17
mod 4 b
TSS [mg/L]
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180
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100
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60
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0
01-Nov/10
08-Nov
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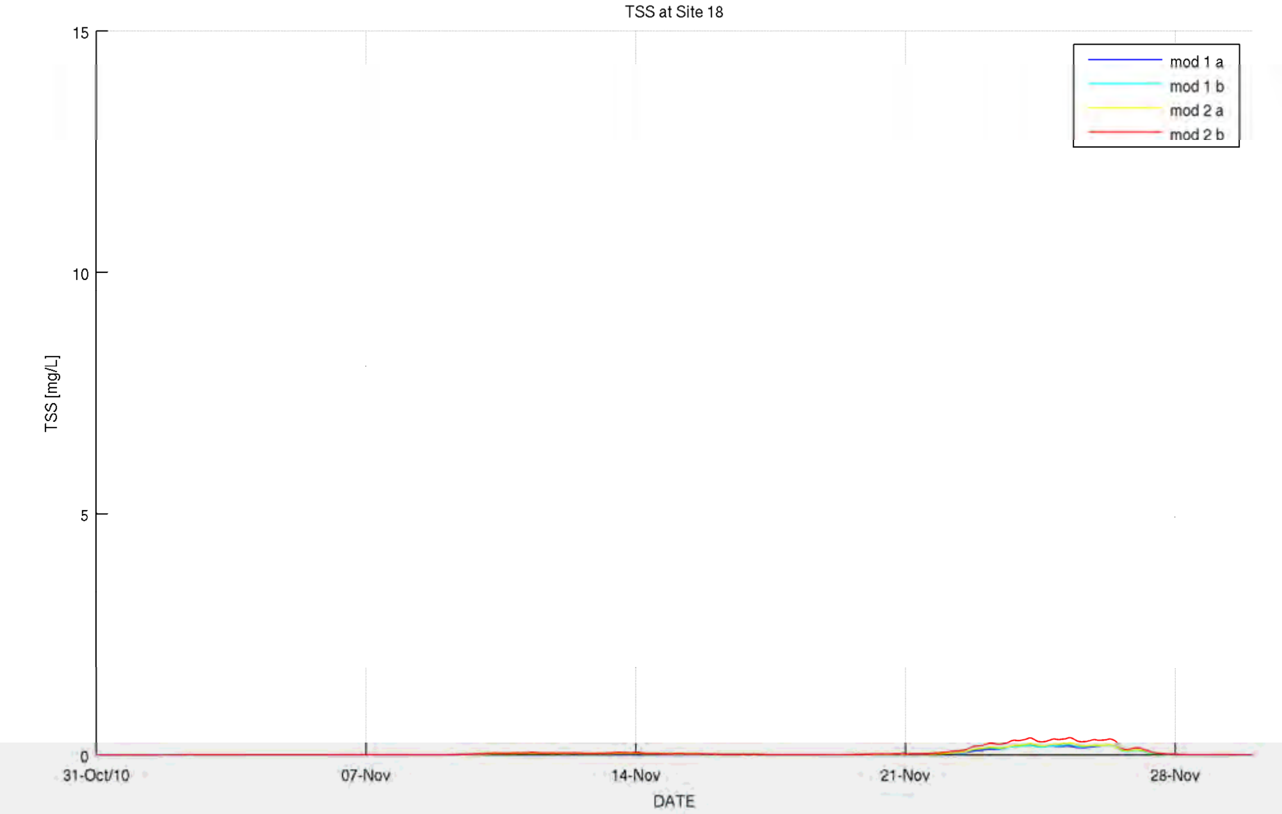
24-Jan
31-Jan/11
DATE


TSS at Site 18
15
10
5
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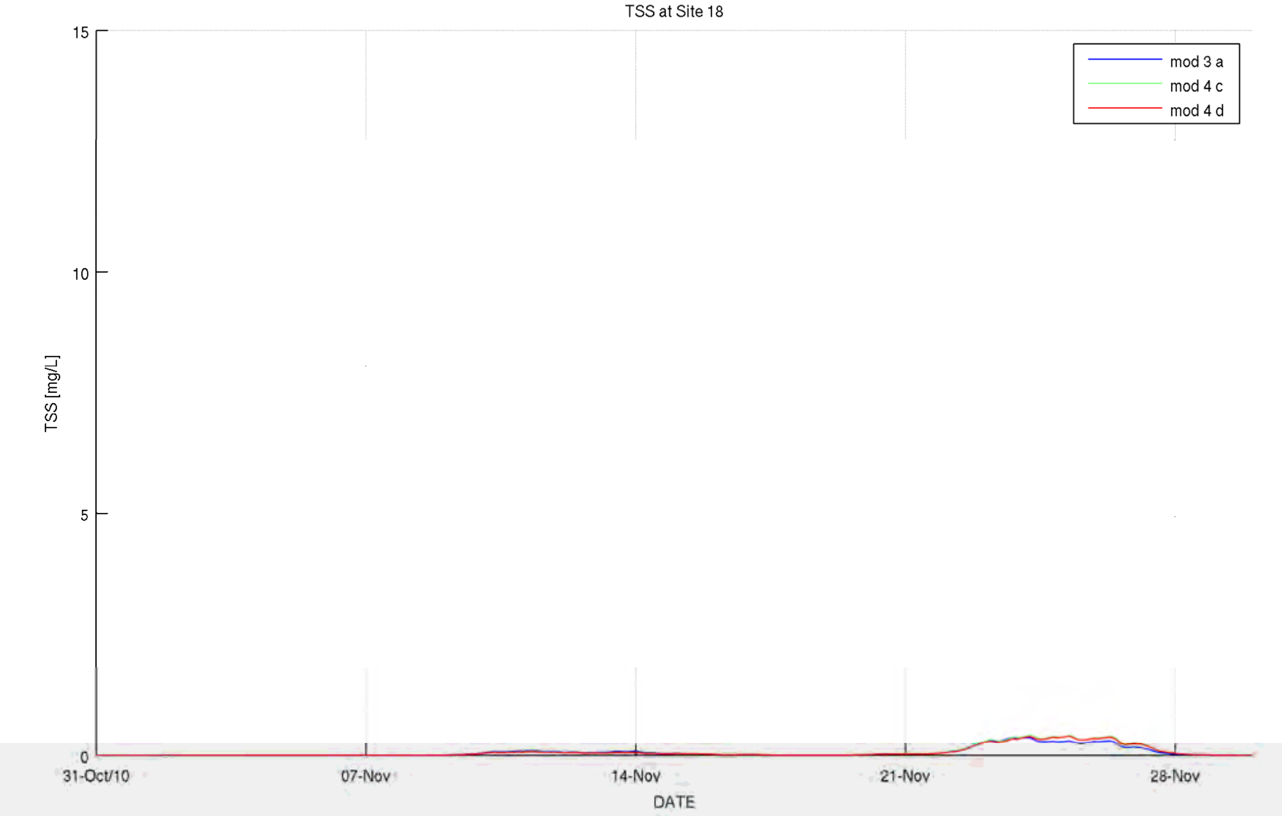
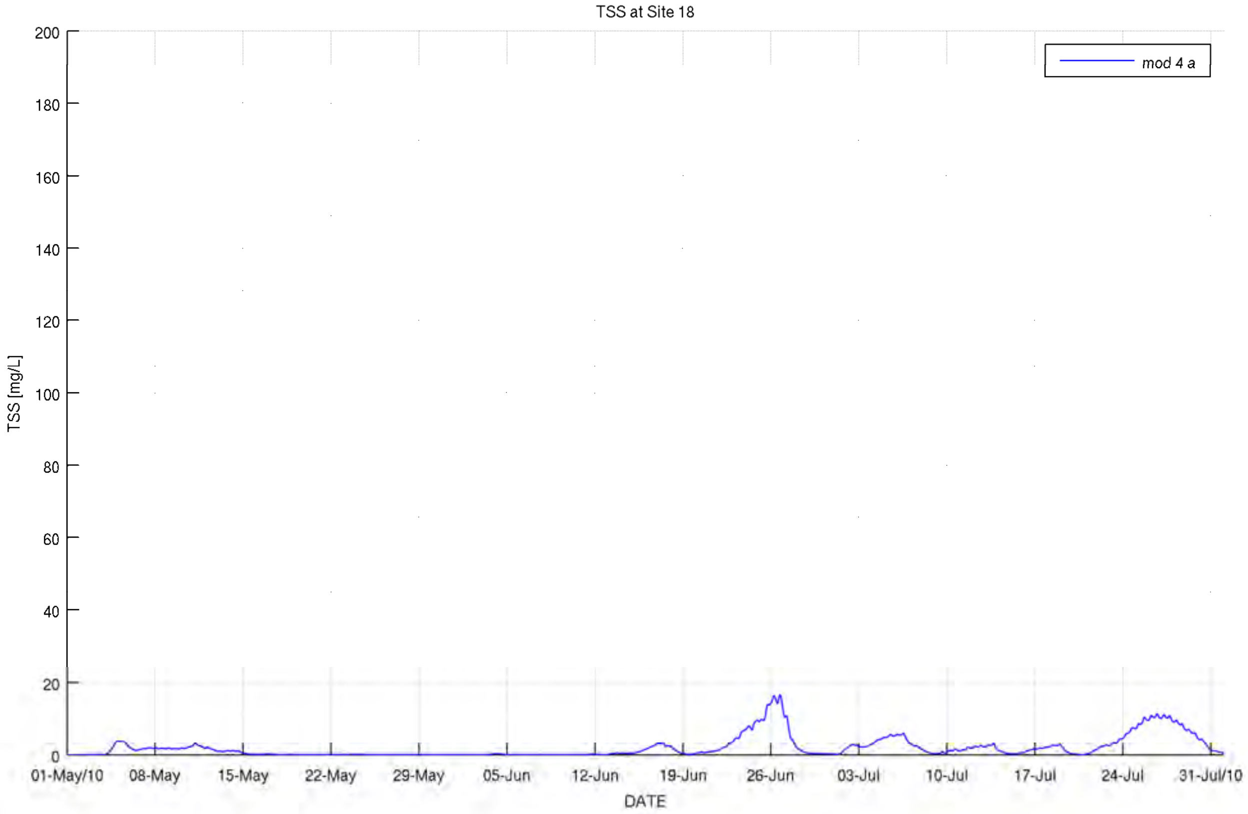
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 18
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 18
mod 4 a
200
180
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100
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60
40
20
0
TSS [mg/L]
01-May/10
08-May
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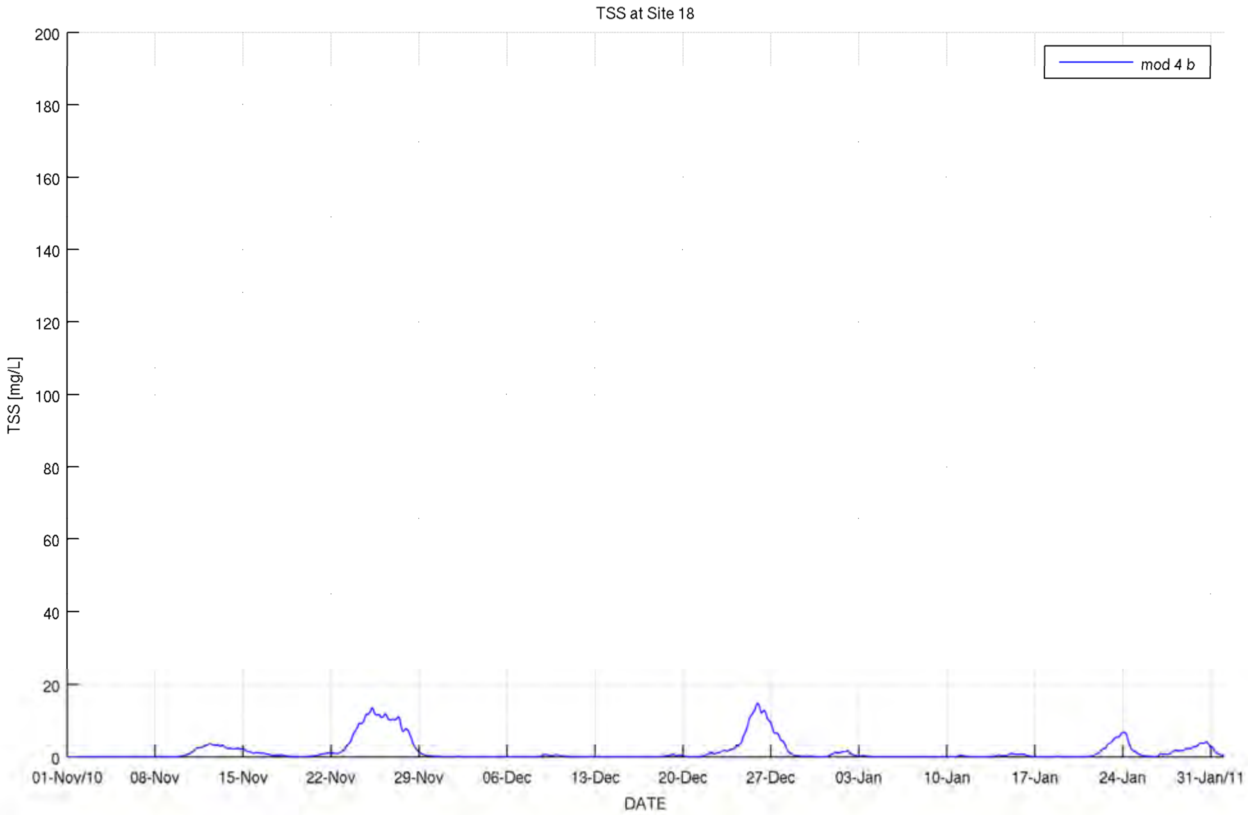
DATE


TSS at Site 18
mod 4 b
200
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60
40
20
0
TSS [mg/L]
01-Nov/10
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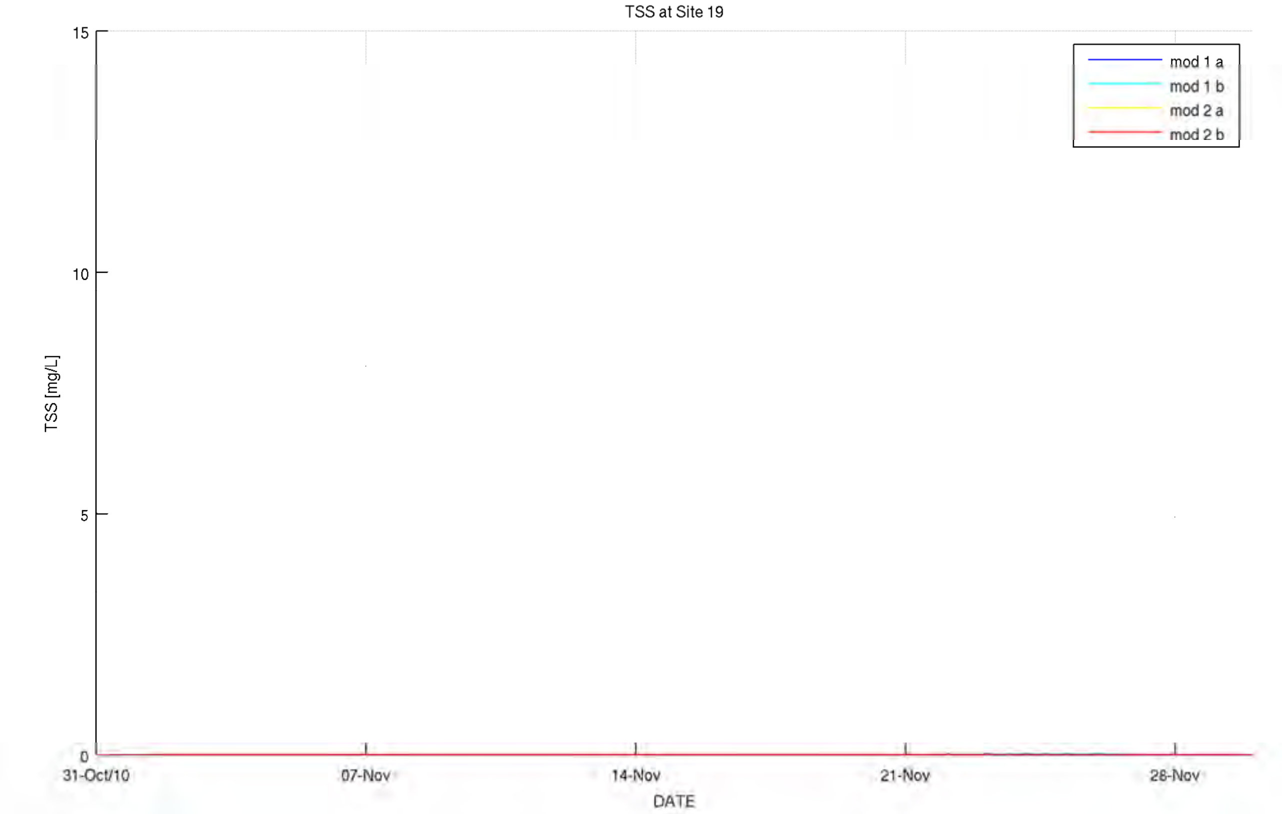
31-Jan/11
DATE


TSS at Site 19
15
10
5
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TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
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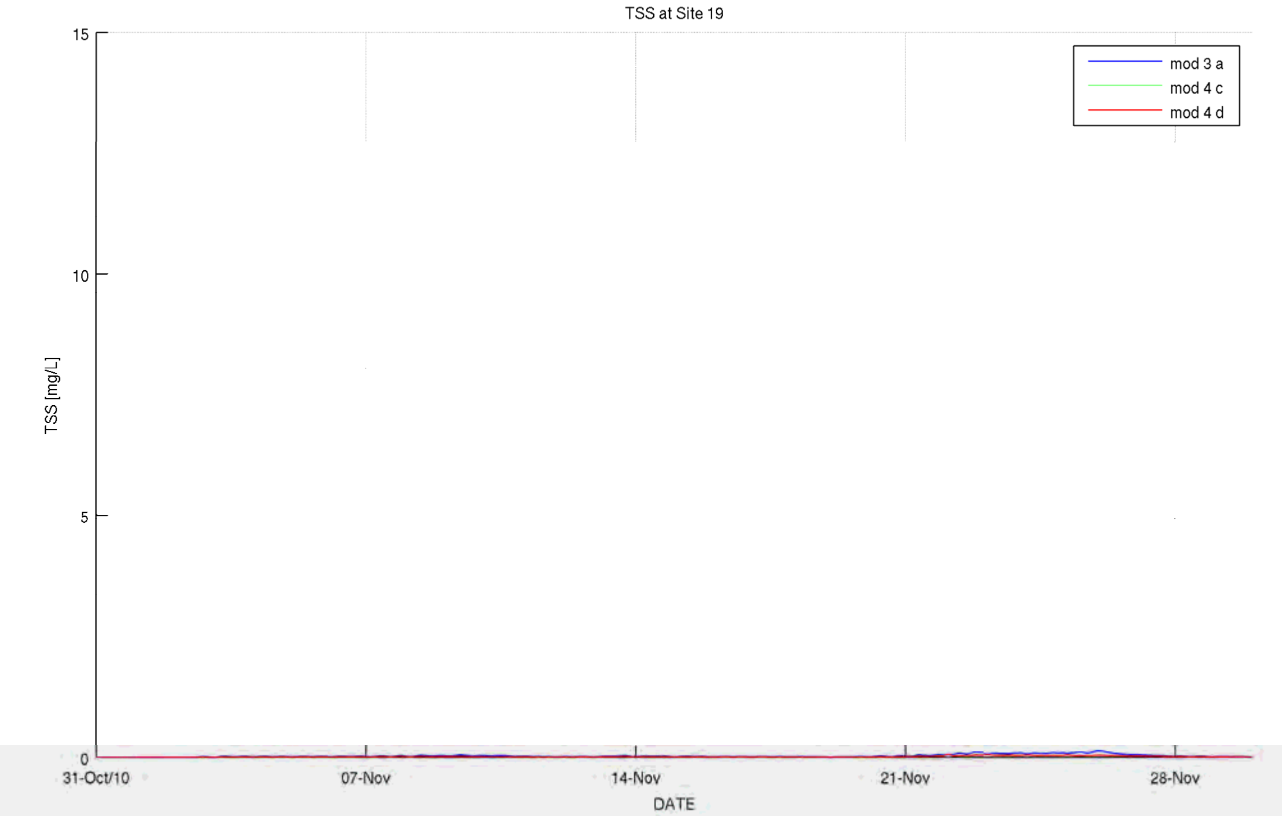
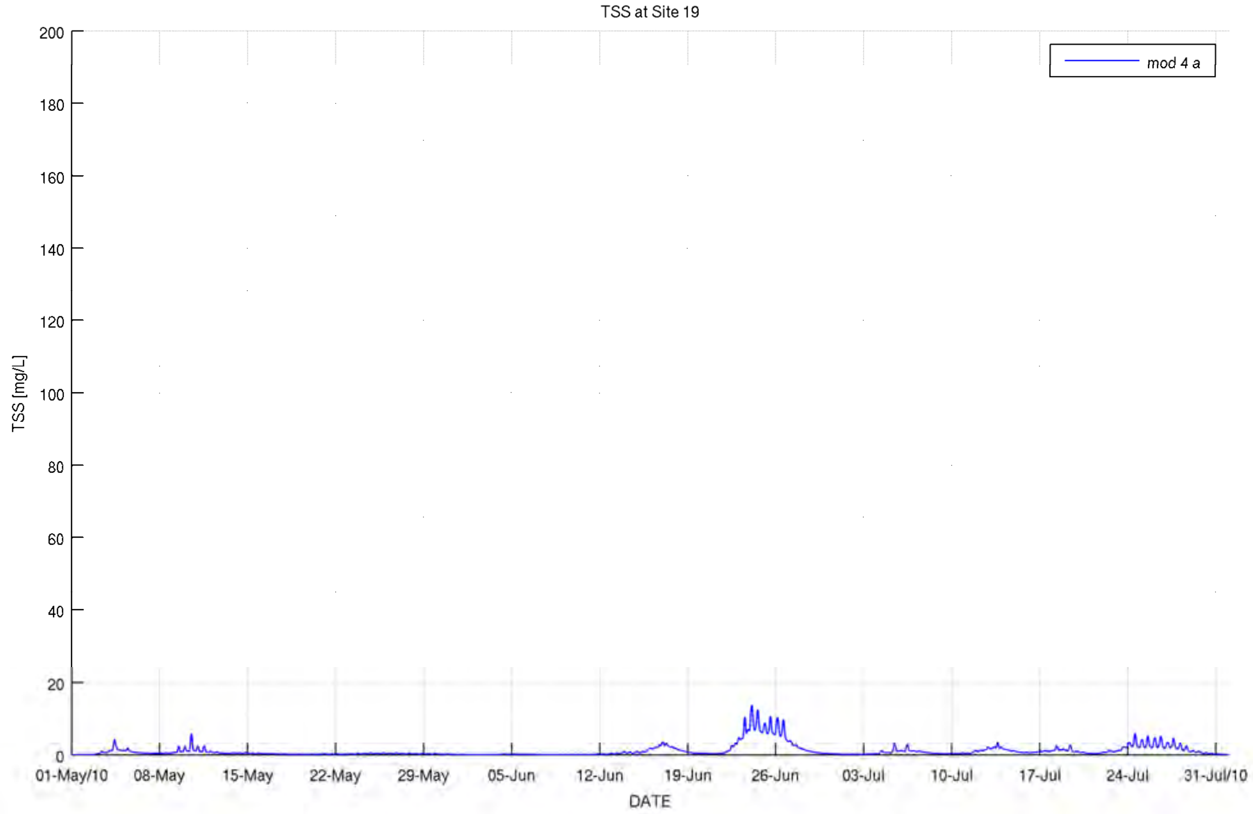
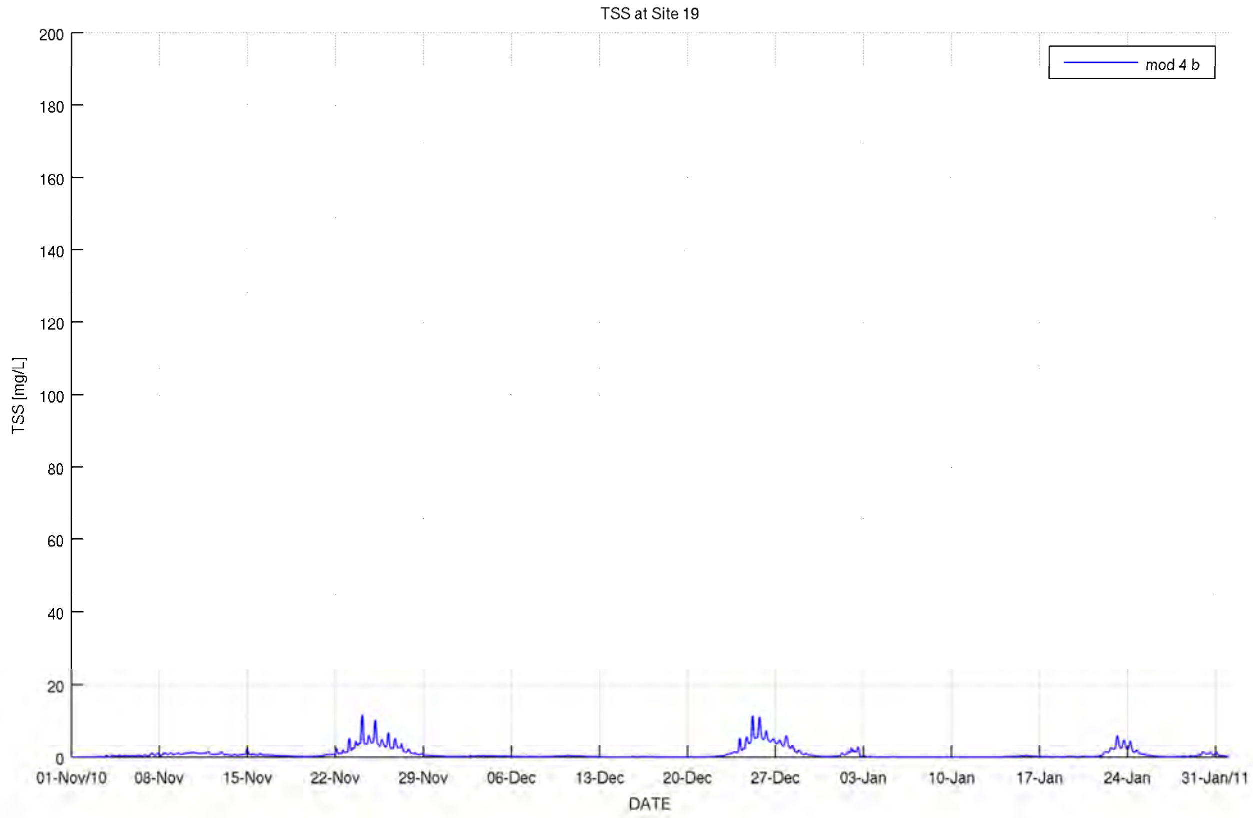
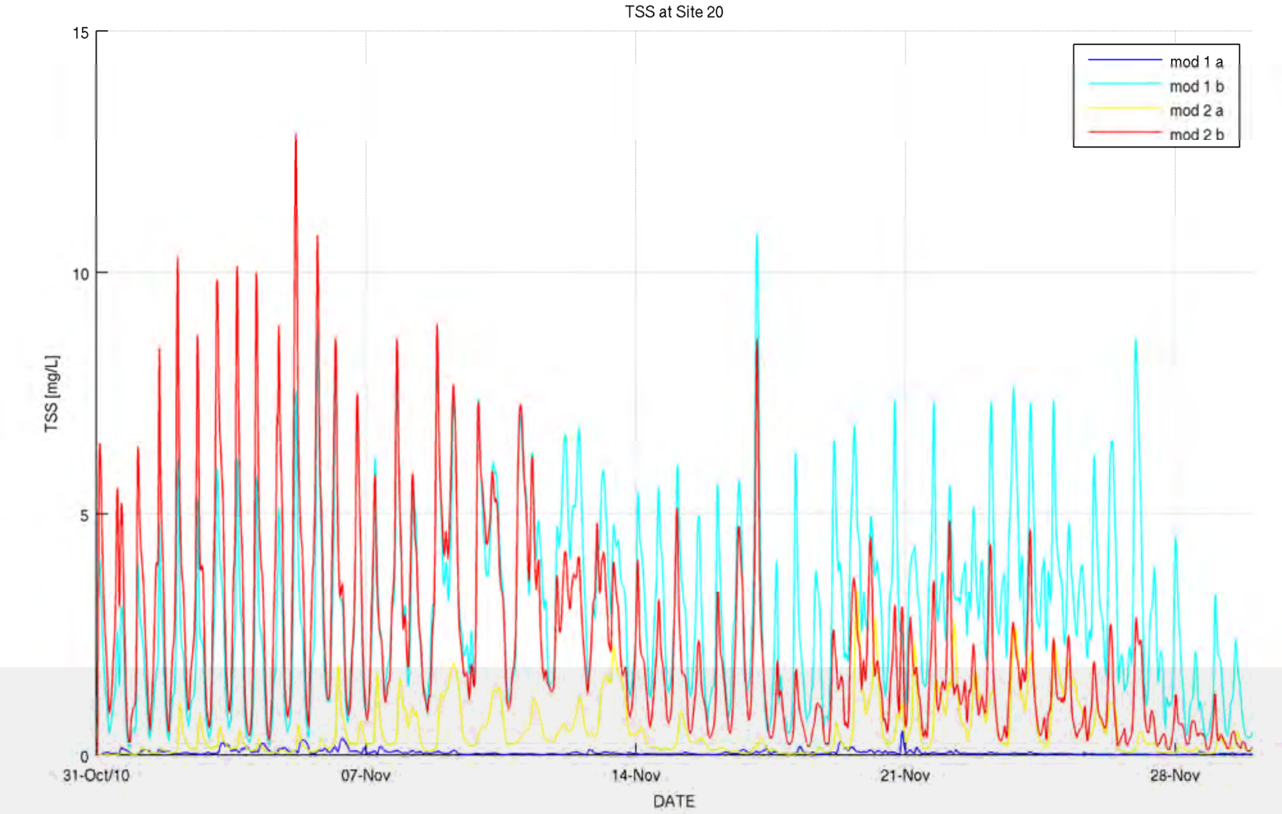
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b

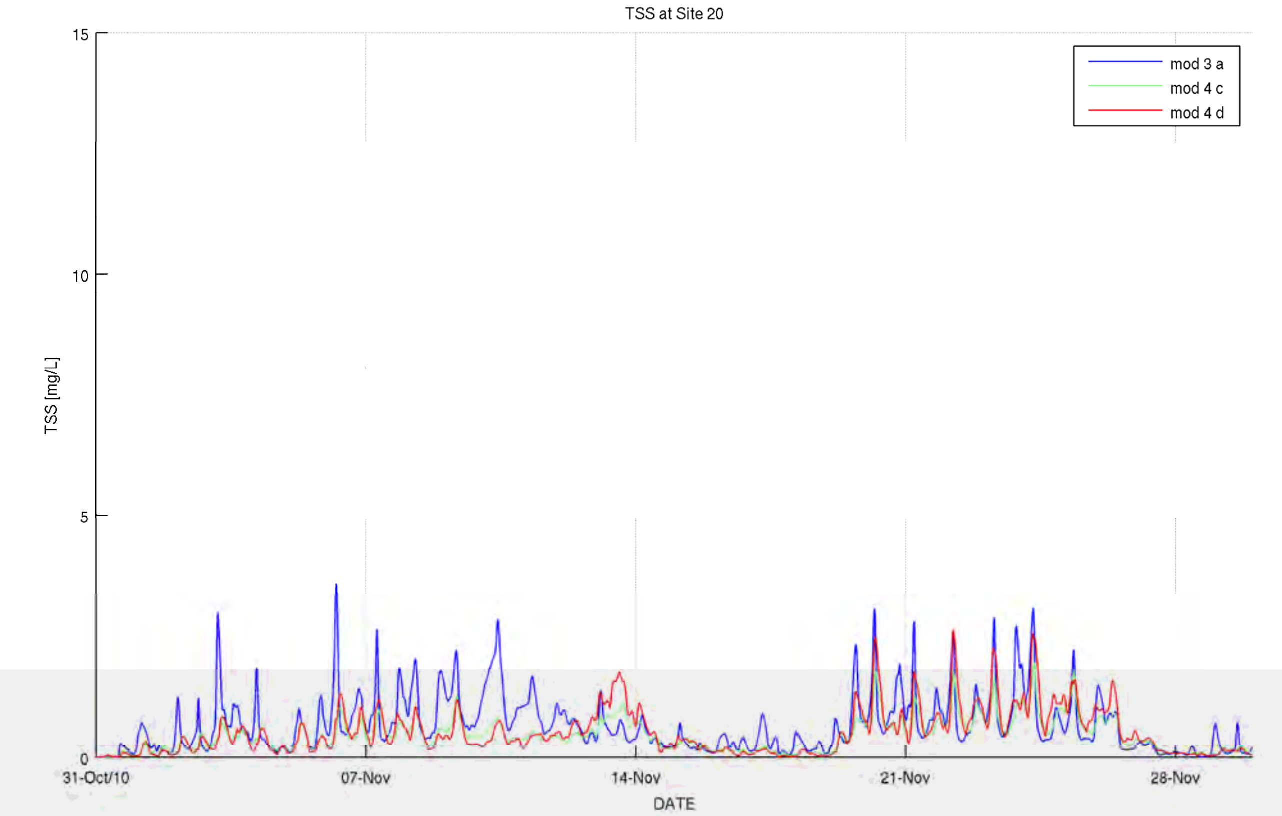

TSS at Site 19
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d

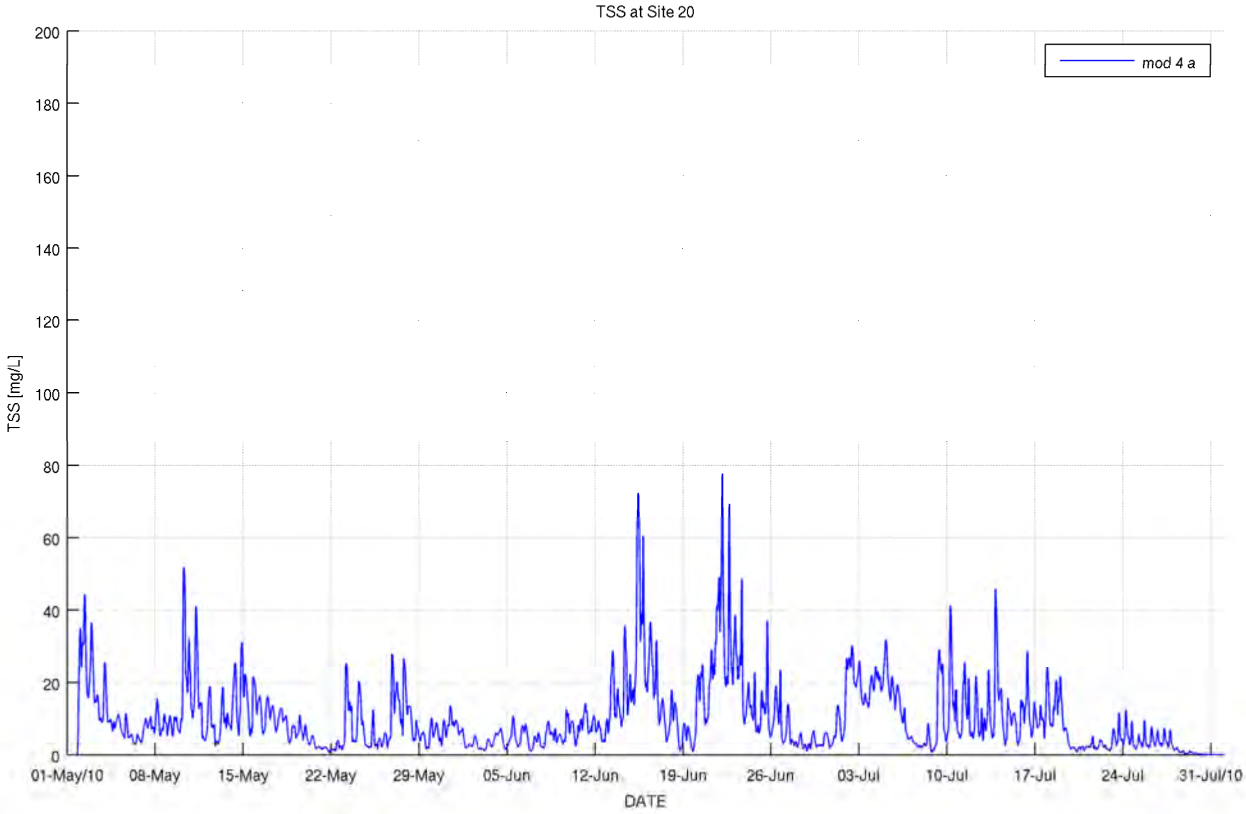
BMT WBM


TSS at Site 19
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 19
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


TSS at Site 20
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


TSS at Site 20
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d


TSS at Site 20
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
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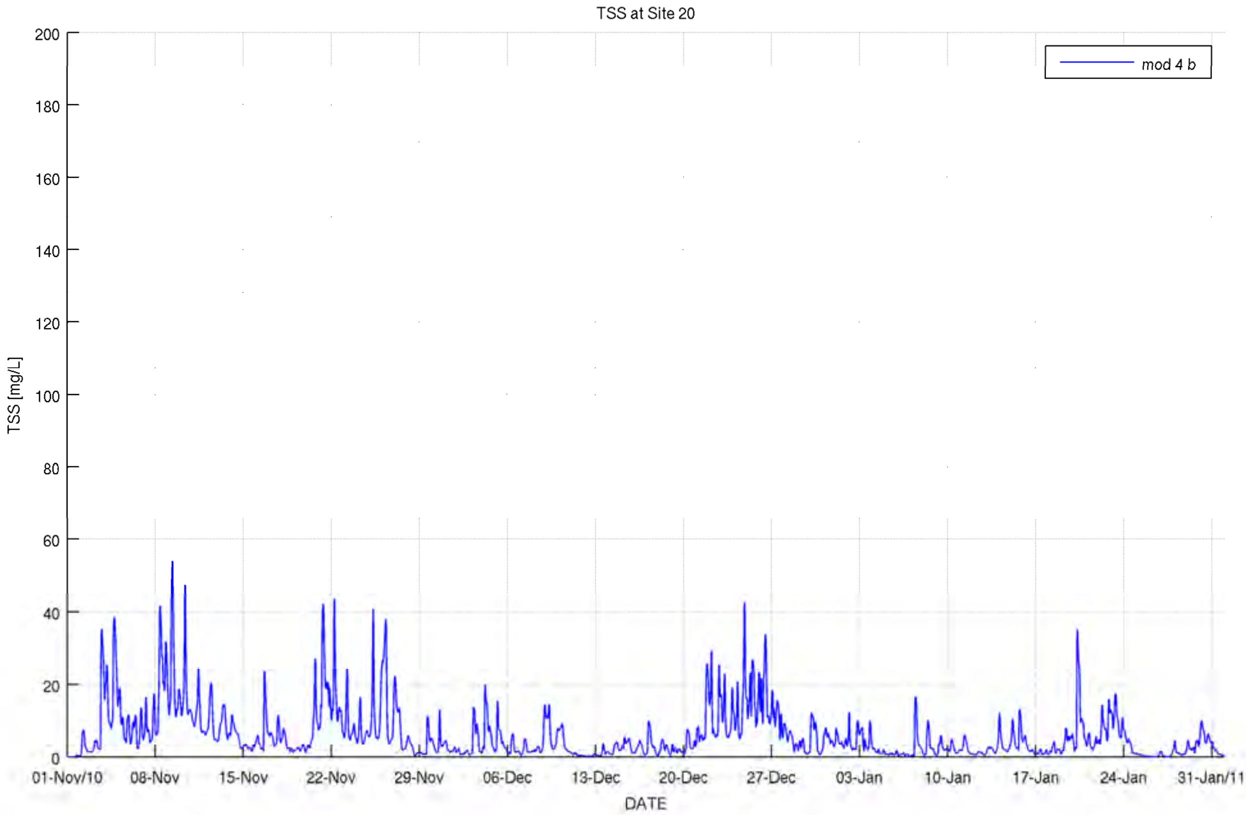
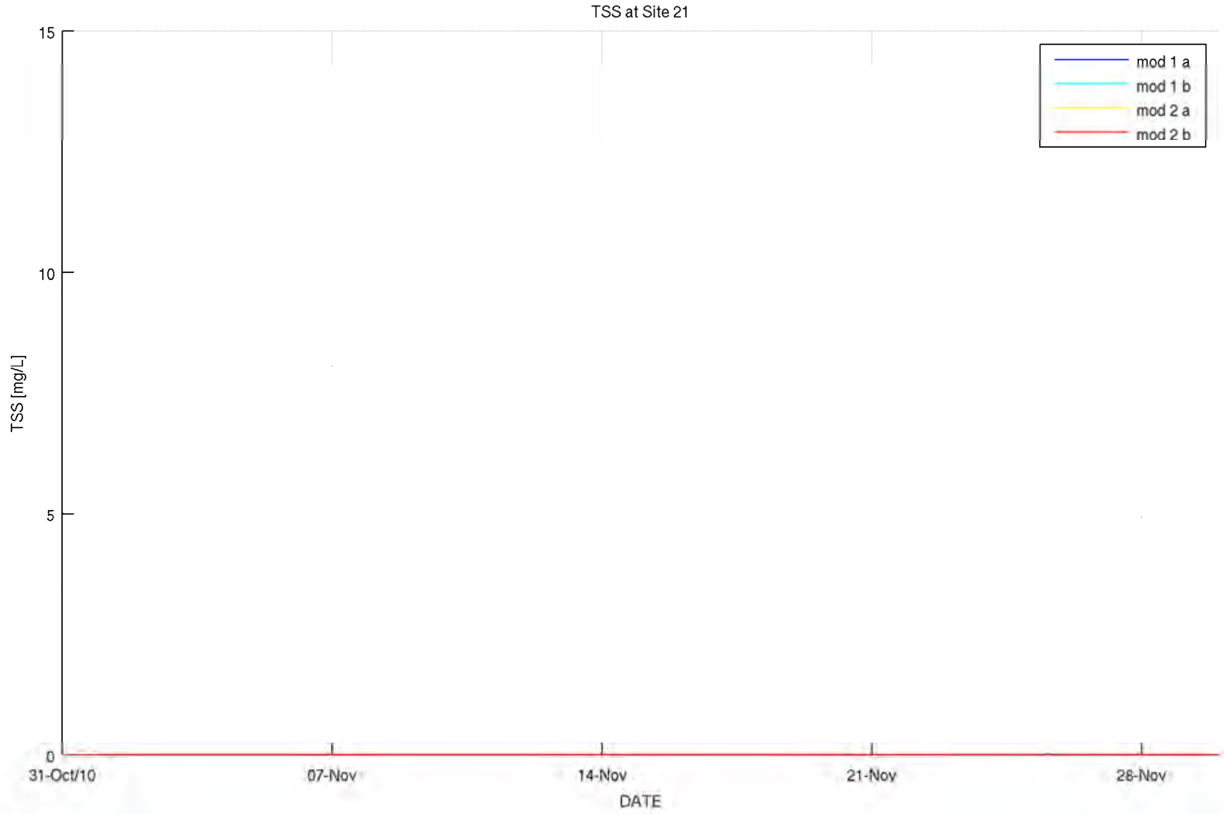
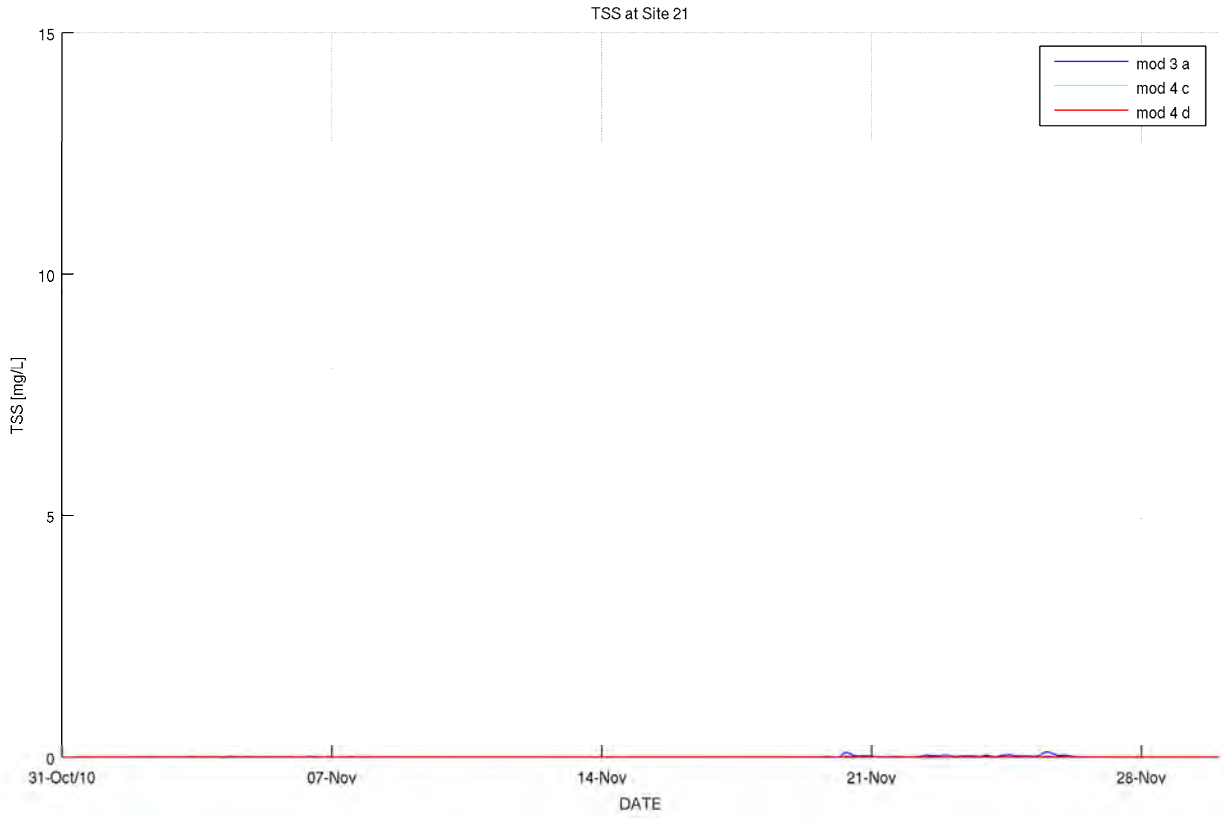
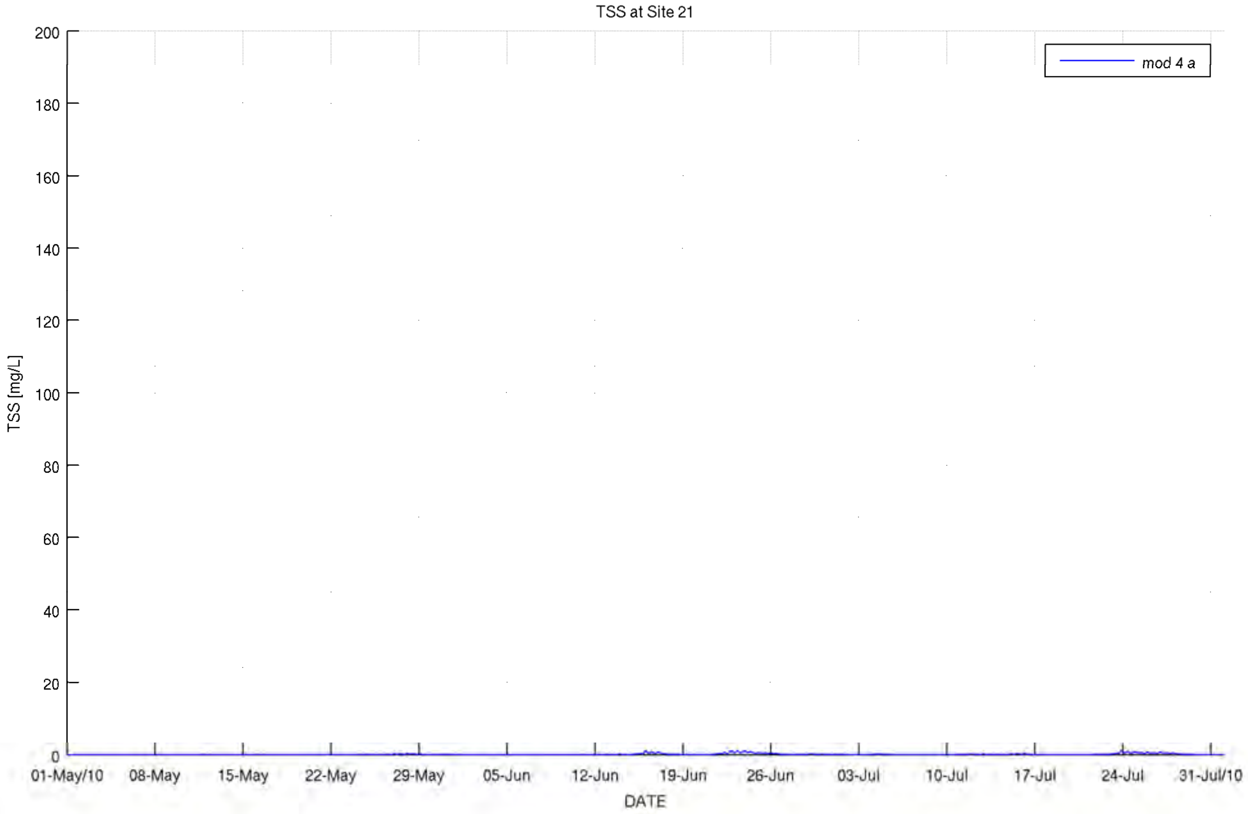
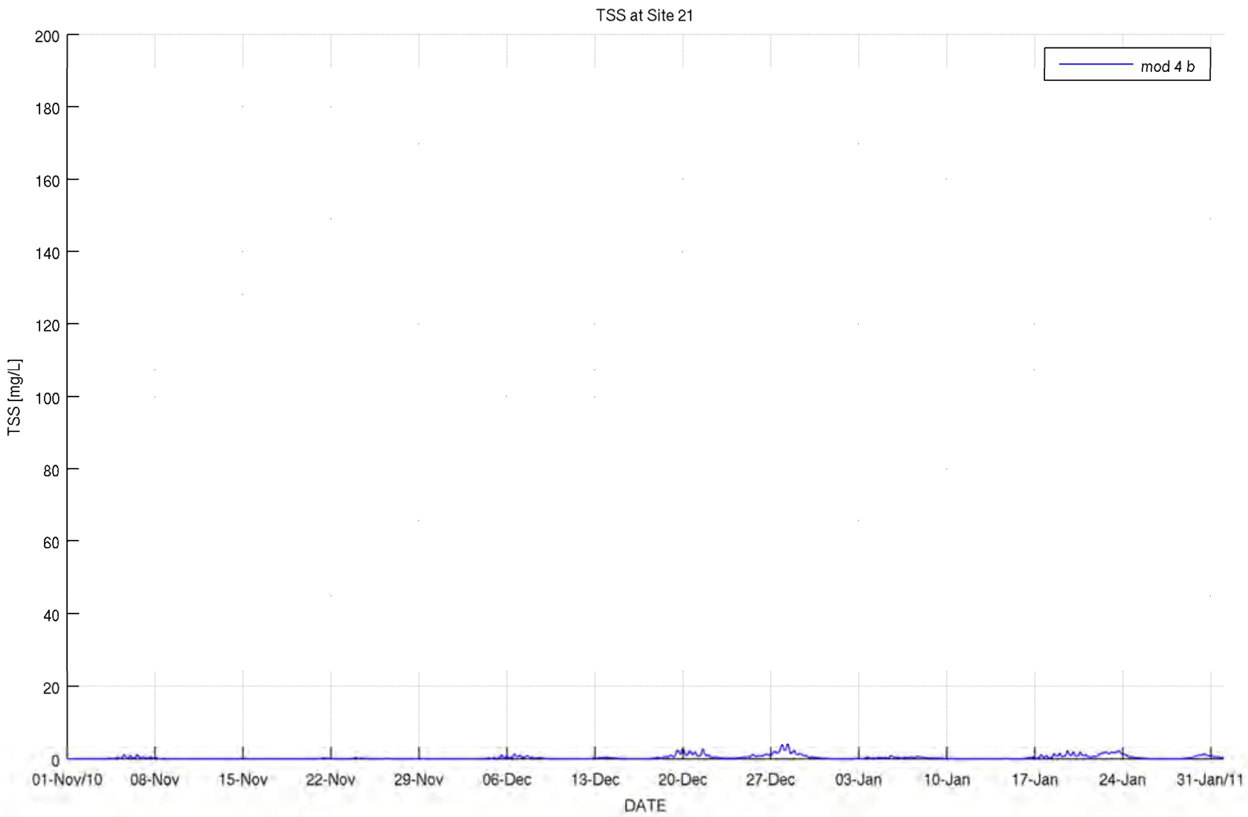
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

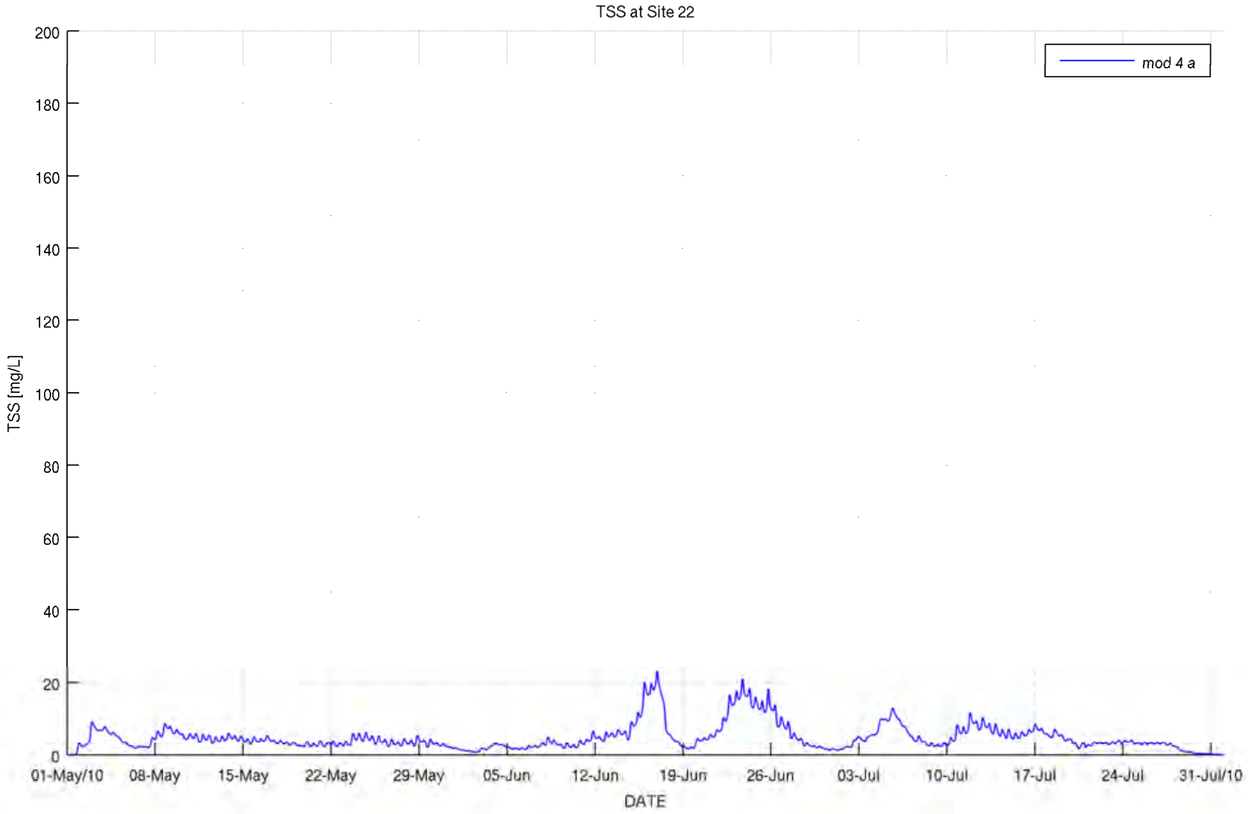

TSS at Site 20
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

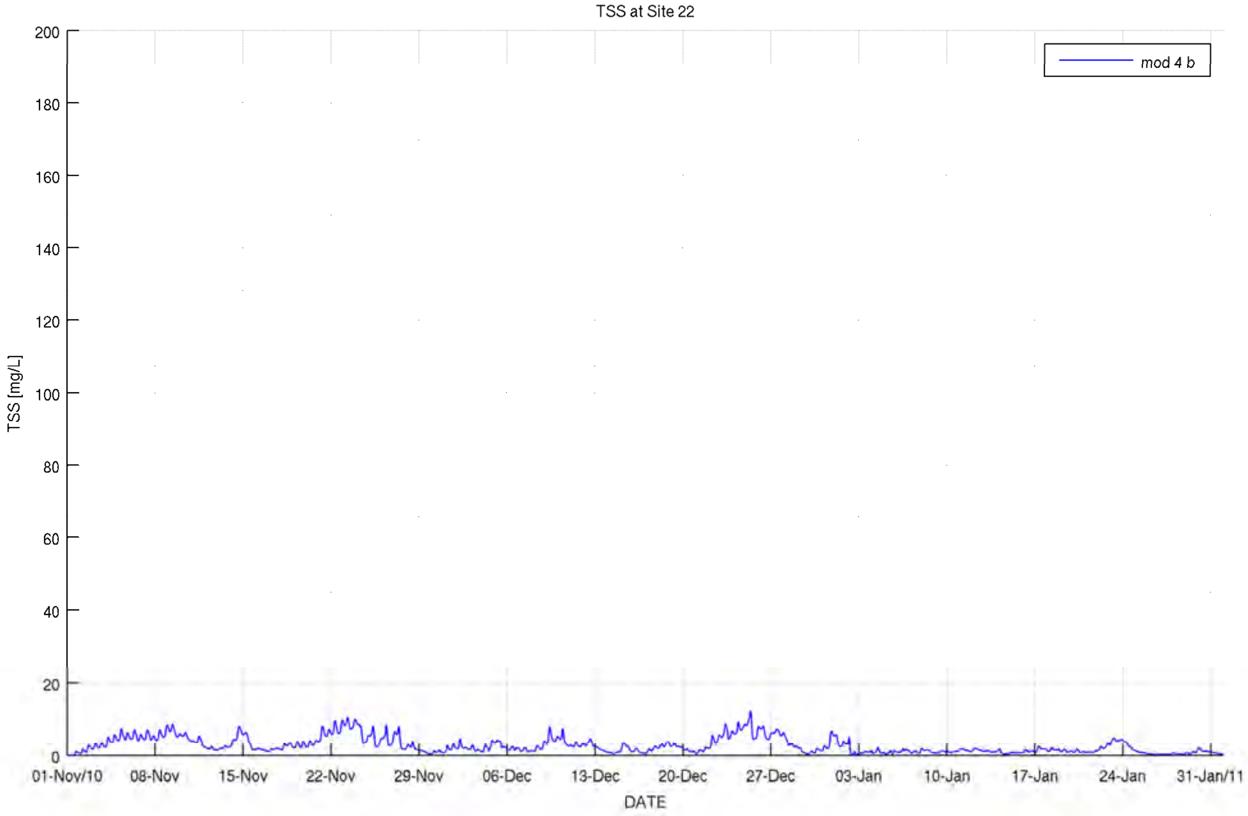

TSS at Site 21
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b

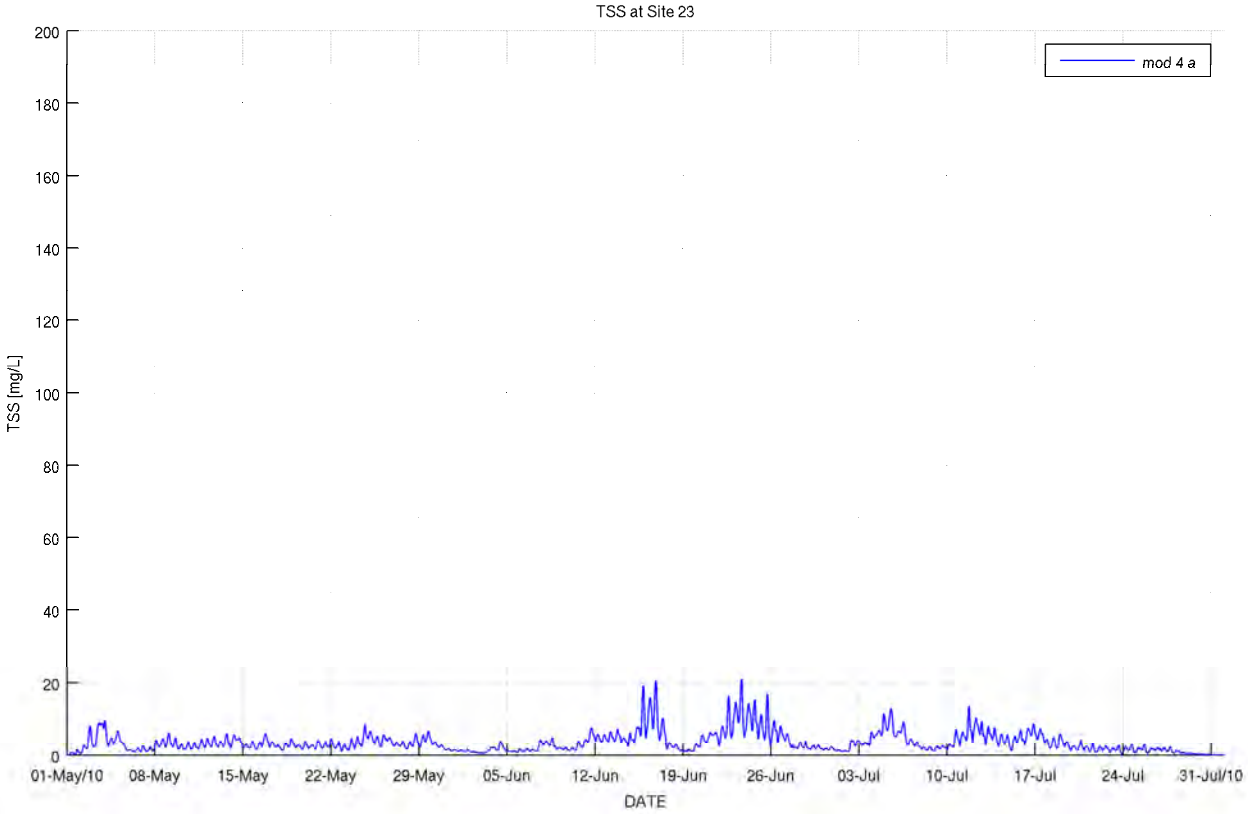

TSS at Site 21
15
10
5
0
TSS [mg/L]
31-Oct/10
07-Nov
14-Nov
21-Nov
28-Nov
DATE
mod 3 a
mod 4 c
mod 4 d

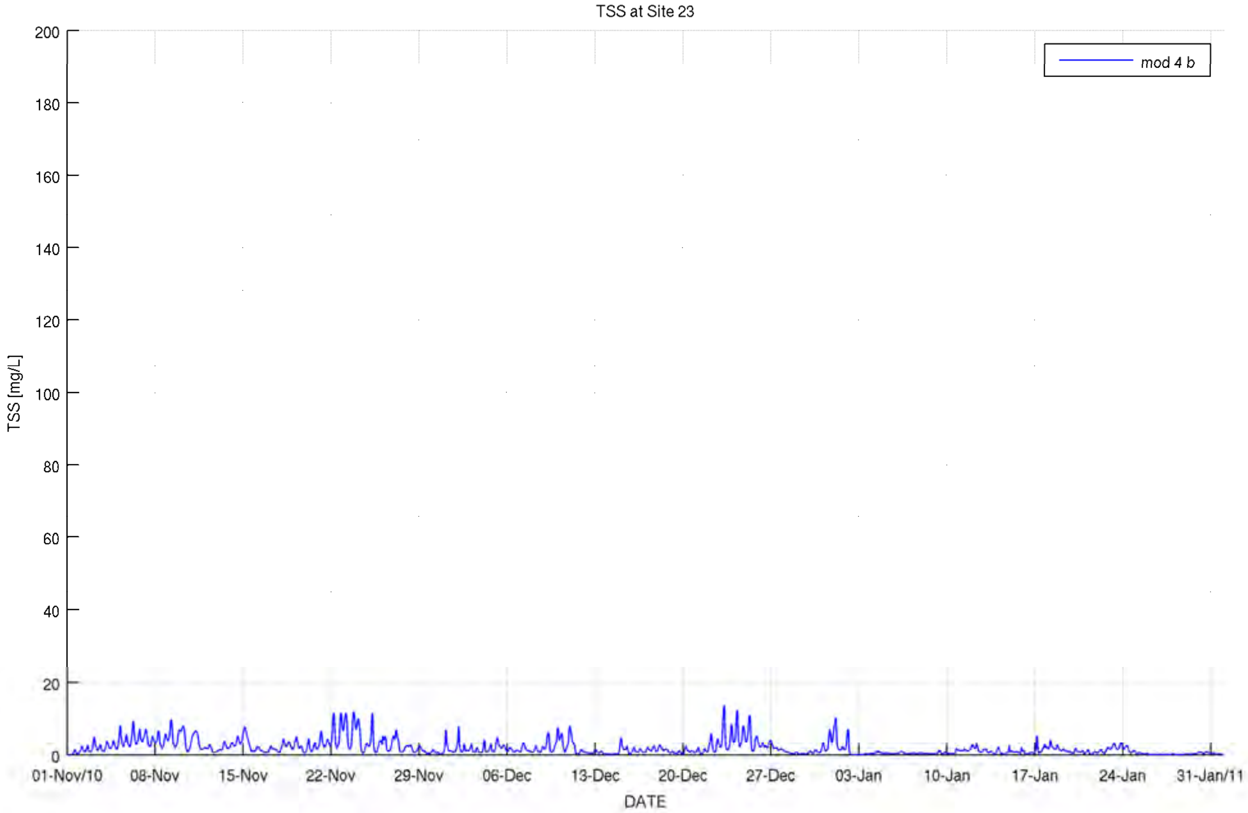

TSS at Site 21
mod 4 a
TSS [mg/L]
0
20
40
60
80
100
120
140
160
180
200
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


TSS at Site 21
mod 4 b
TSS [mg/L]
0
20
40
60
80
100
120
140
160
180
200
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

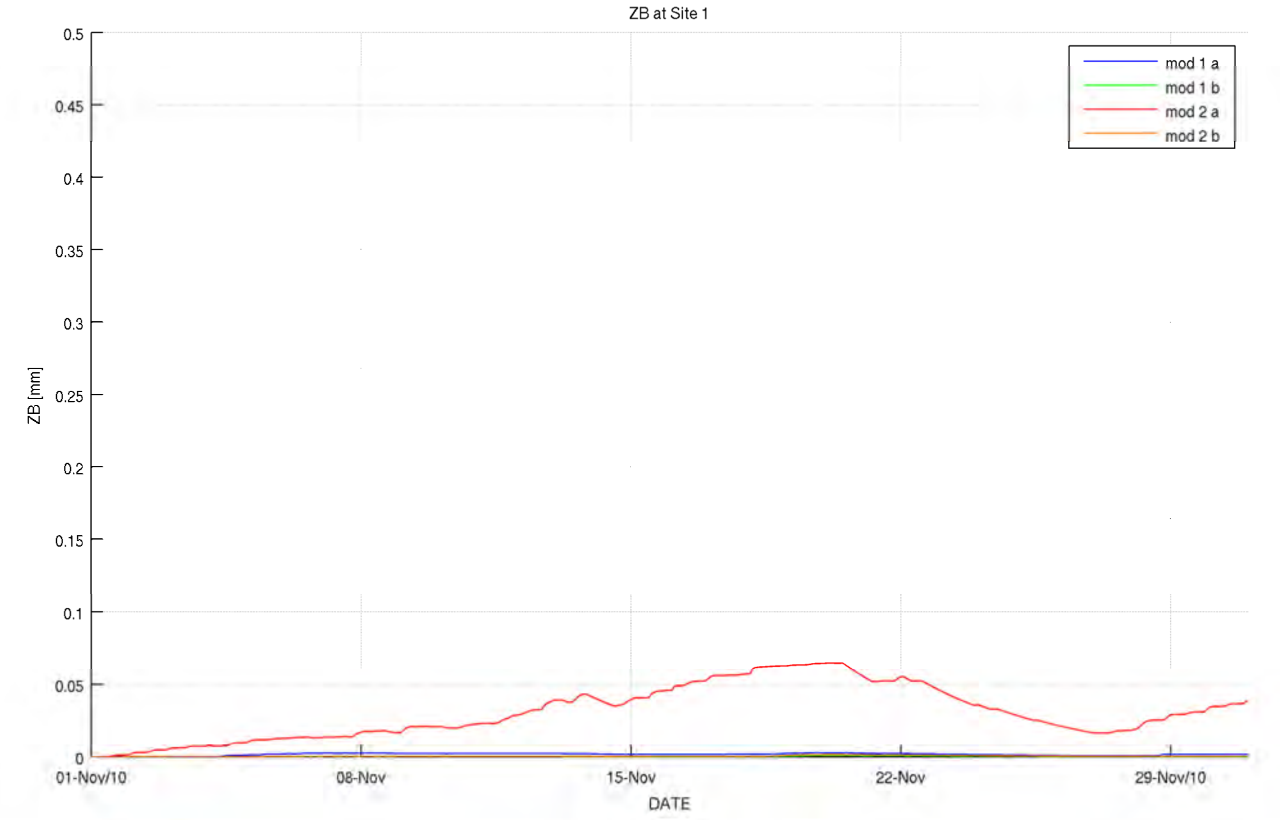

TSS at Site 22
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

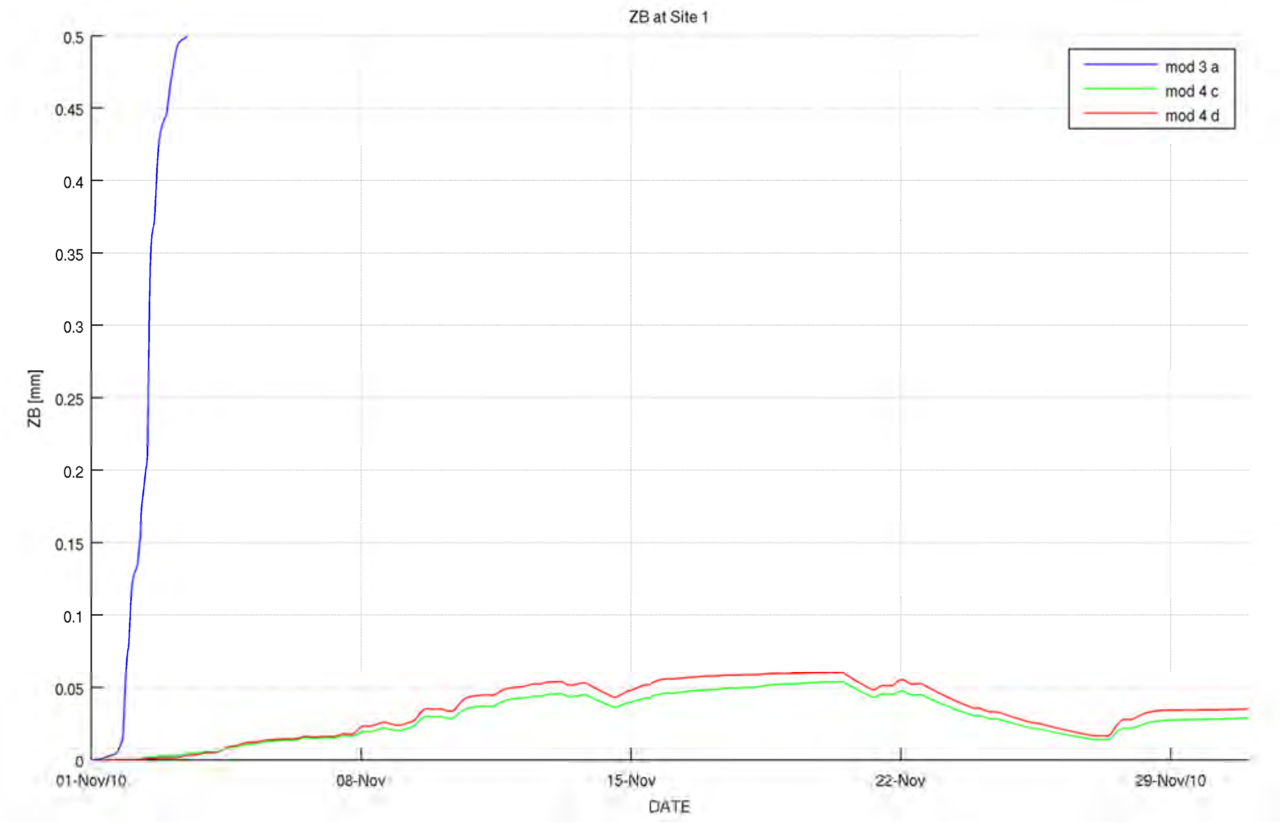

TSS at Site 22
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

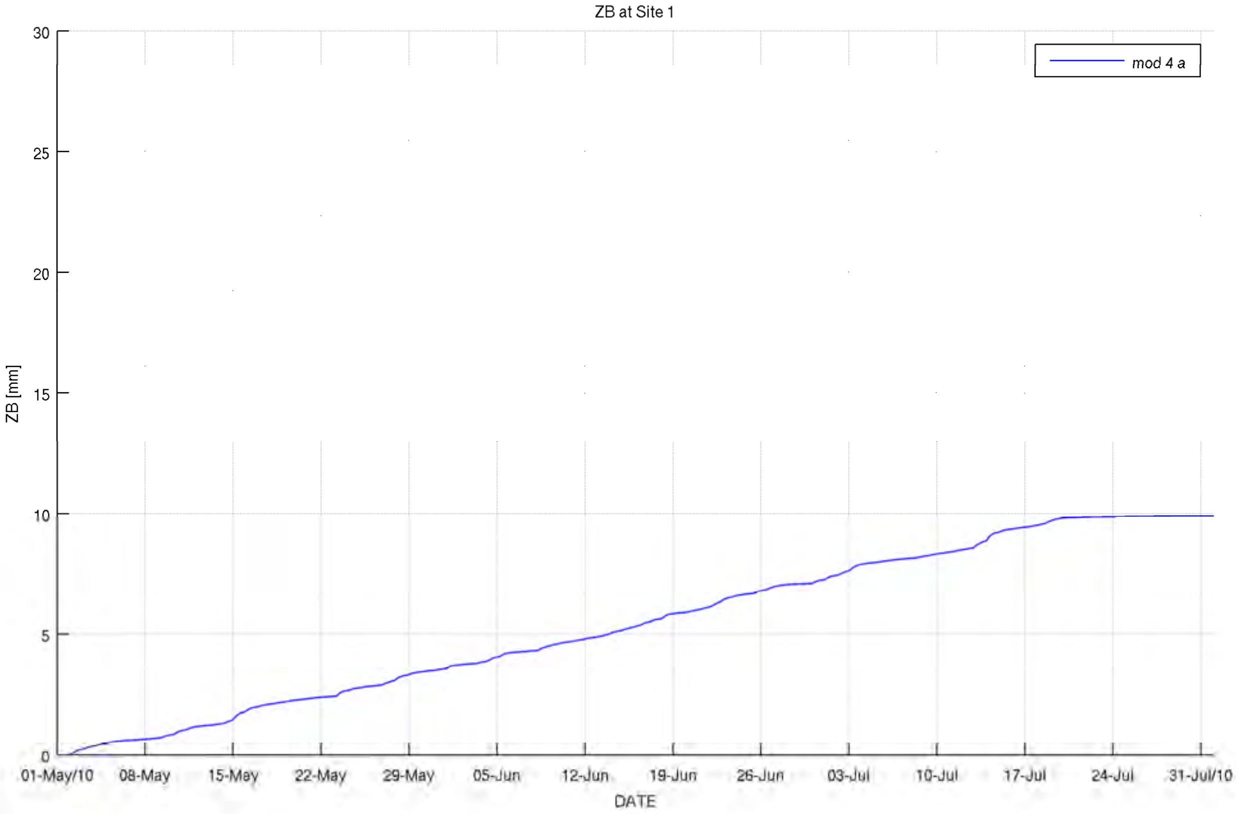

TSS at Site 23
mod 4 a
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

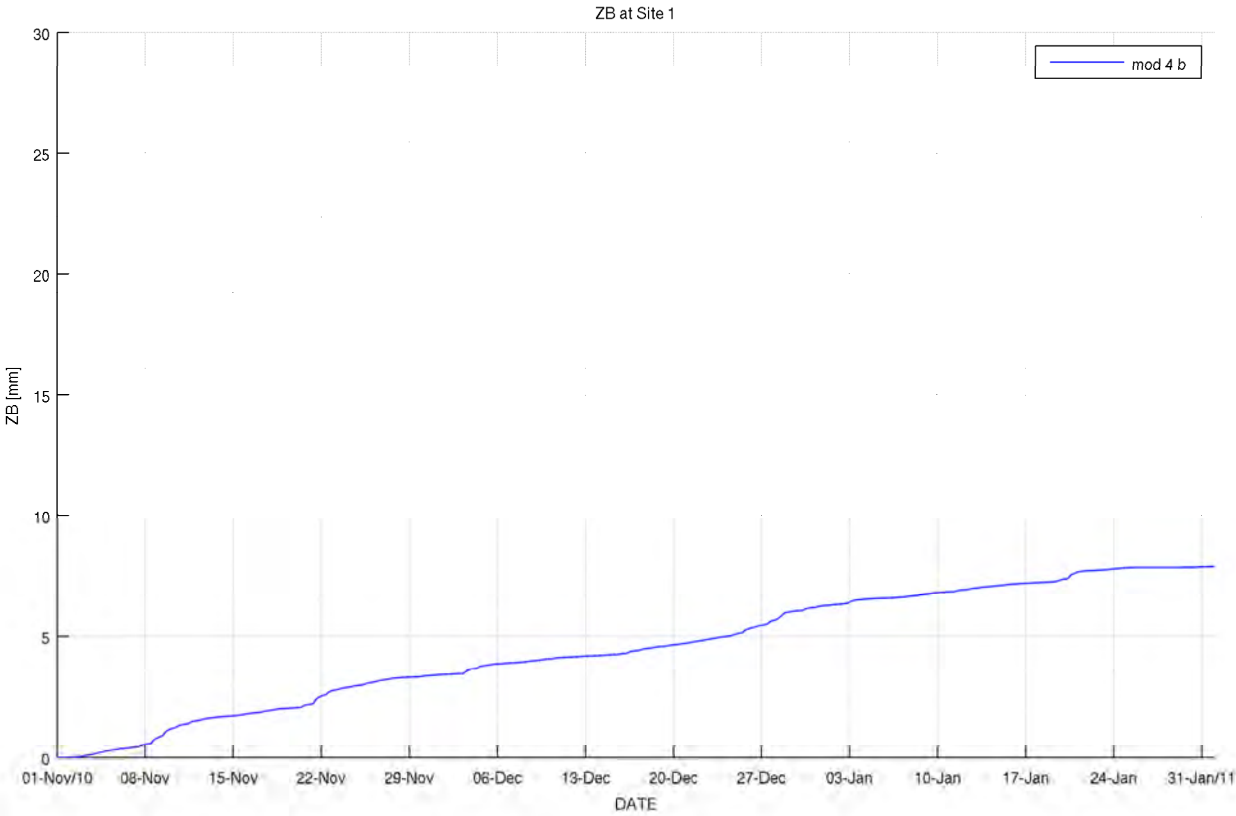

TSS at Site 23
mod 4 b
TSS [mg/L]
200
180
160
140
120
100
80
60
40
20
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

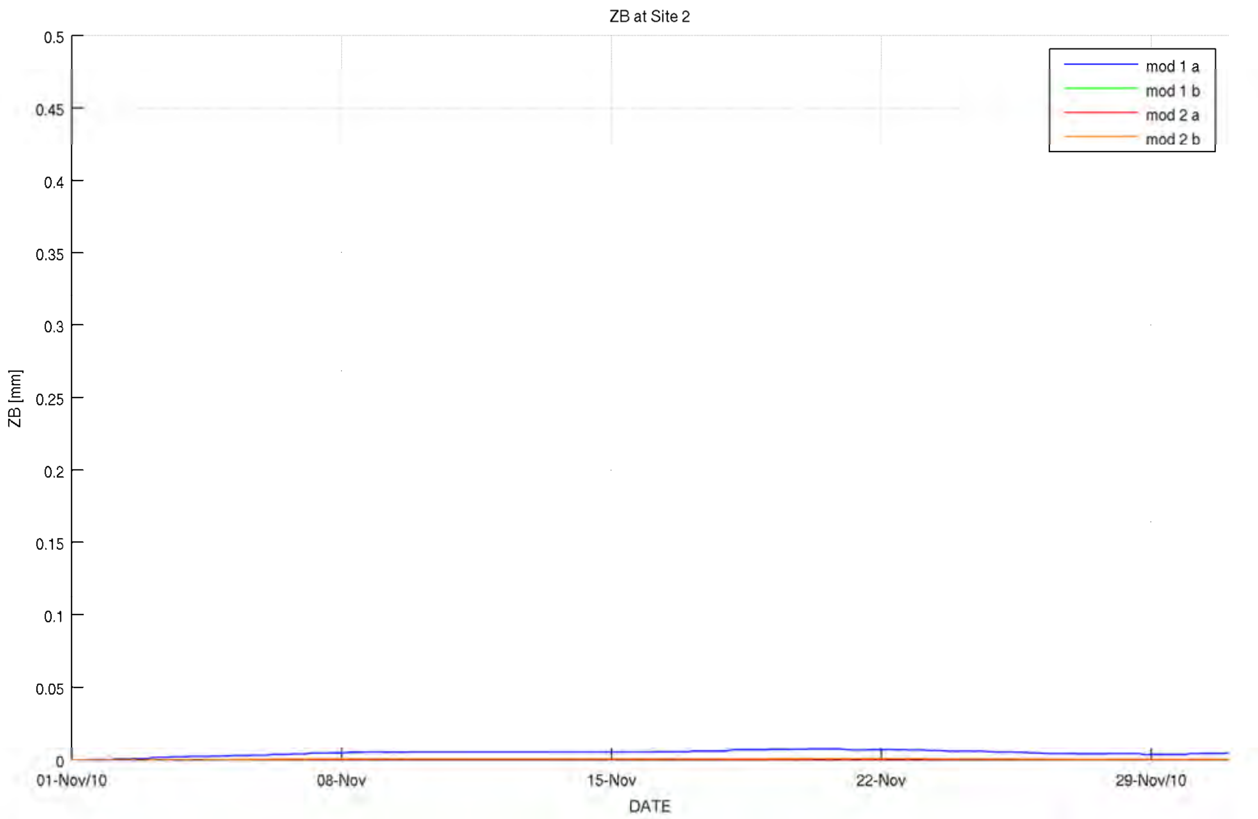
Sediment Deposition Time Series Plots

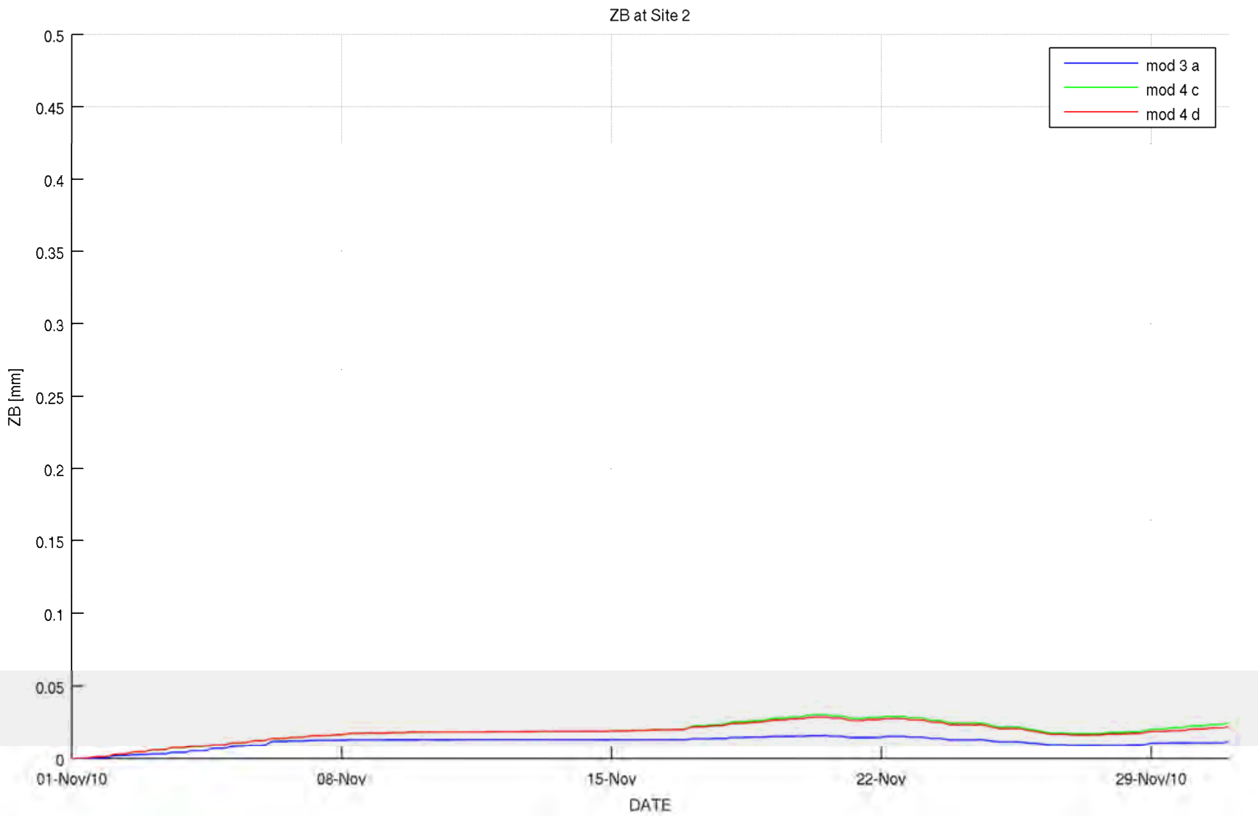


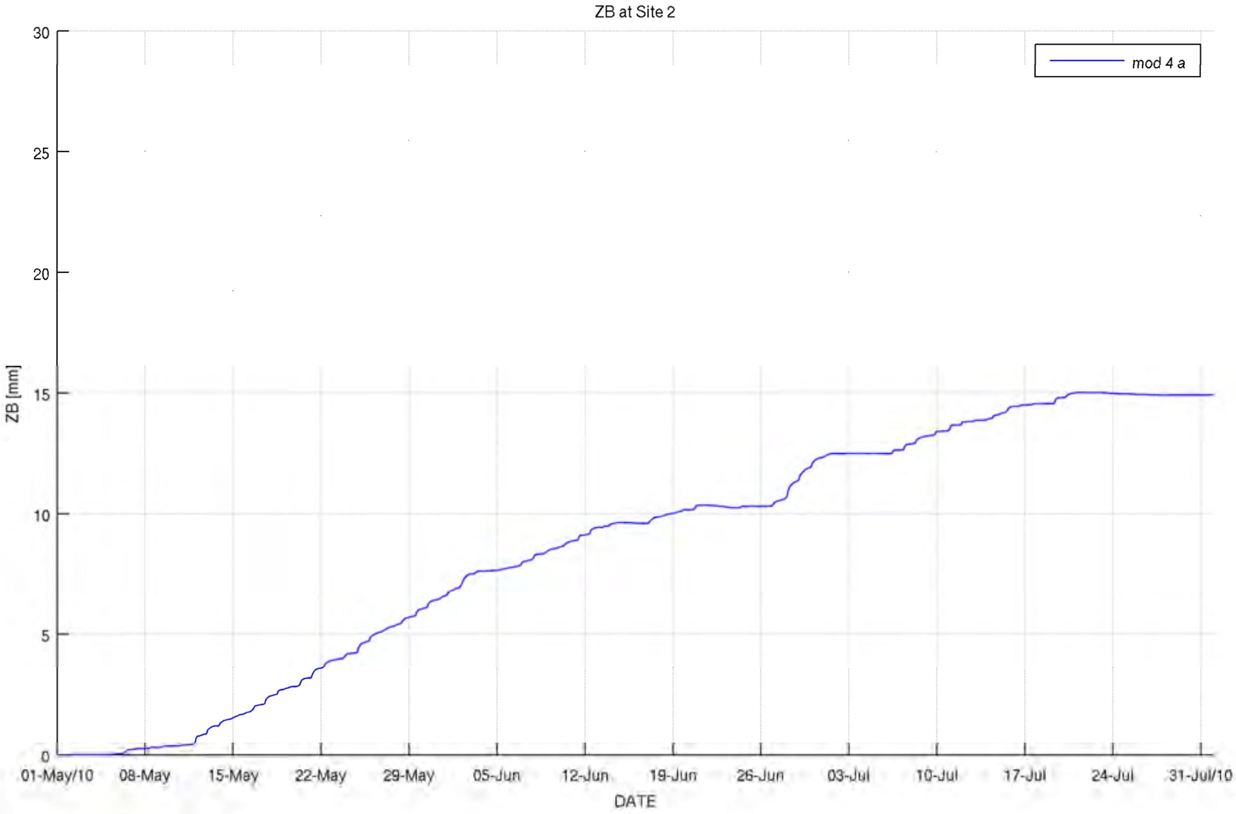



ZB at Site 1
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 1
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 2
ZB [mm]
DATE
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 2
ZB [mm]
DATE
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
mod 3 a
mod 4 c
mod 4 d


ZB at Site 2
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
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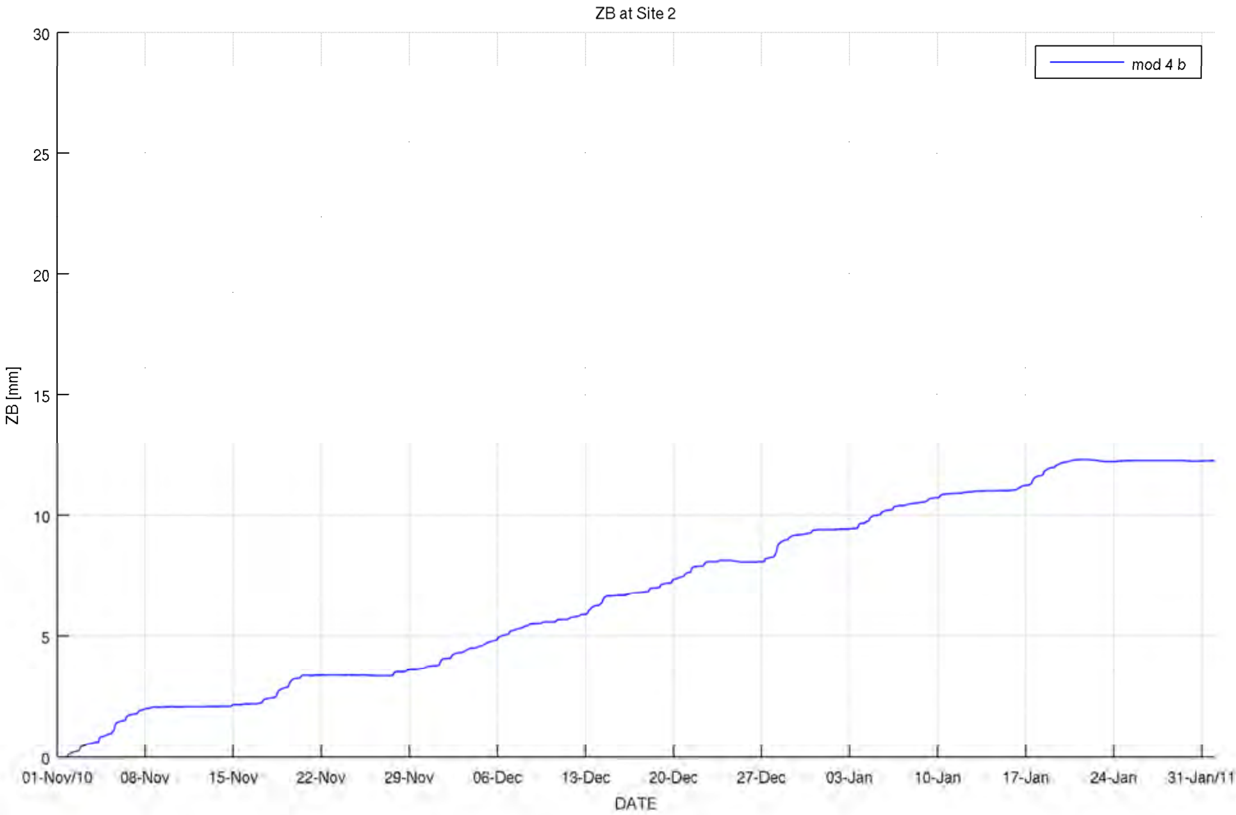
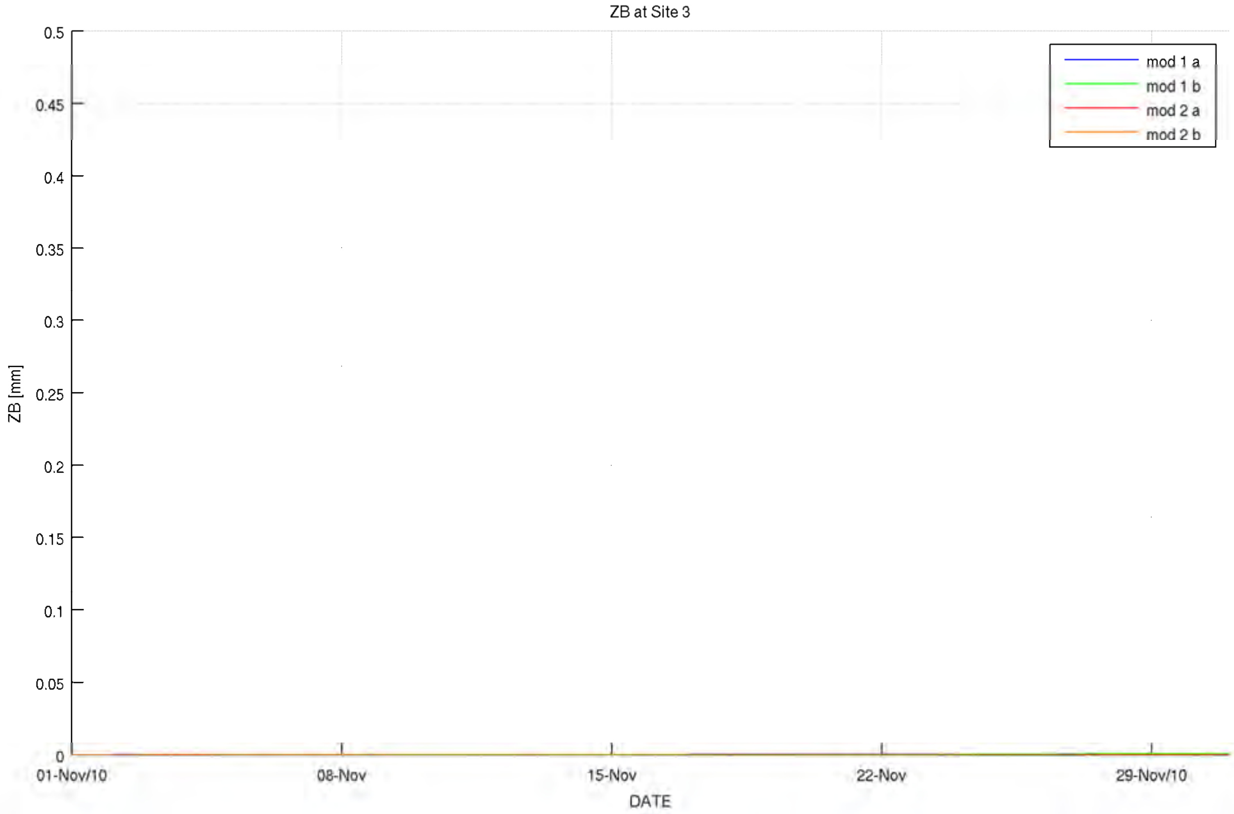
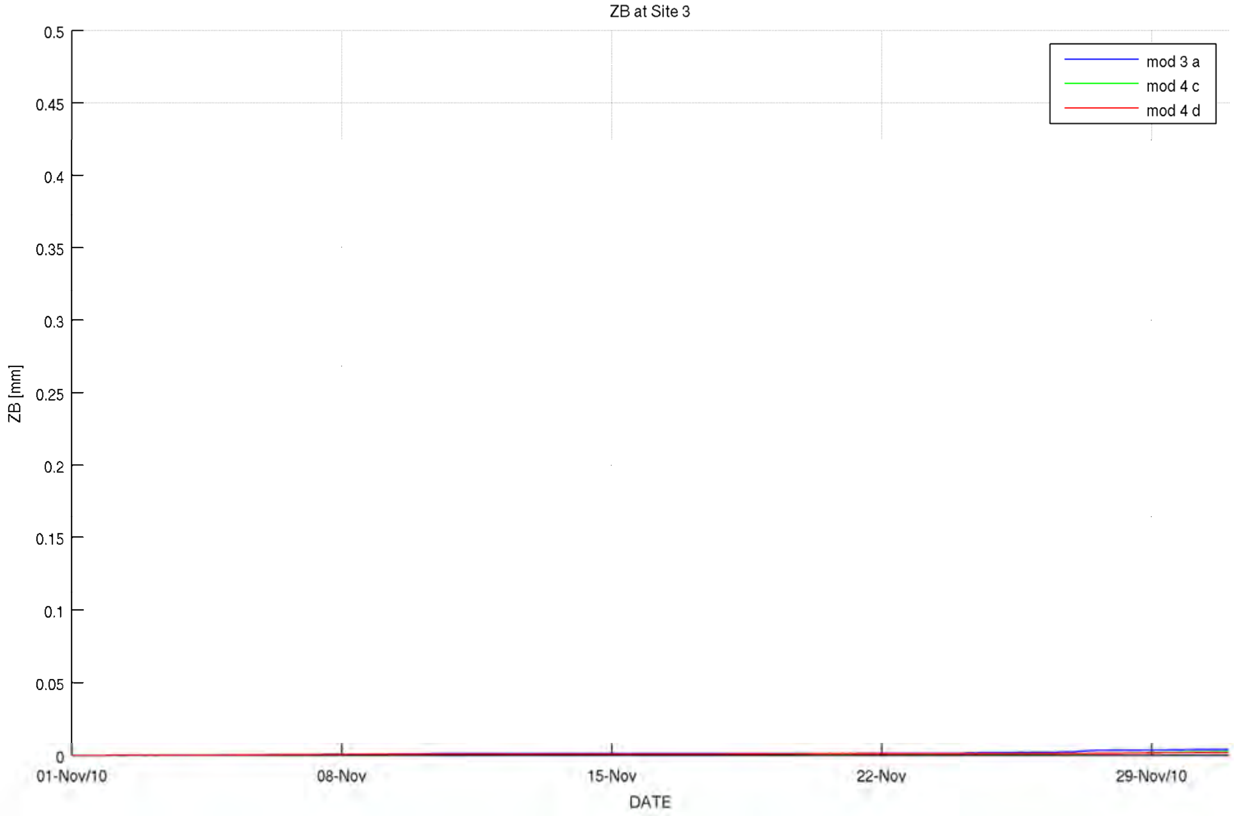
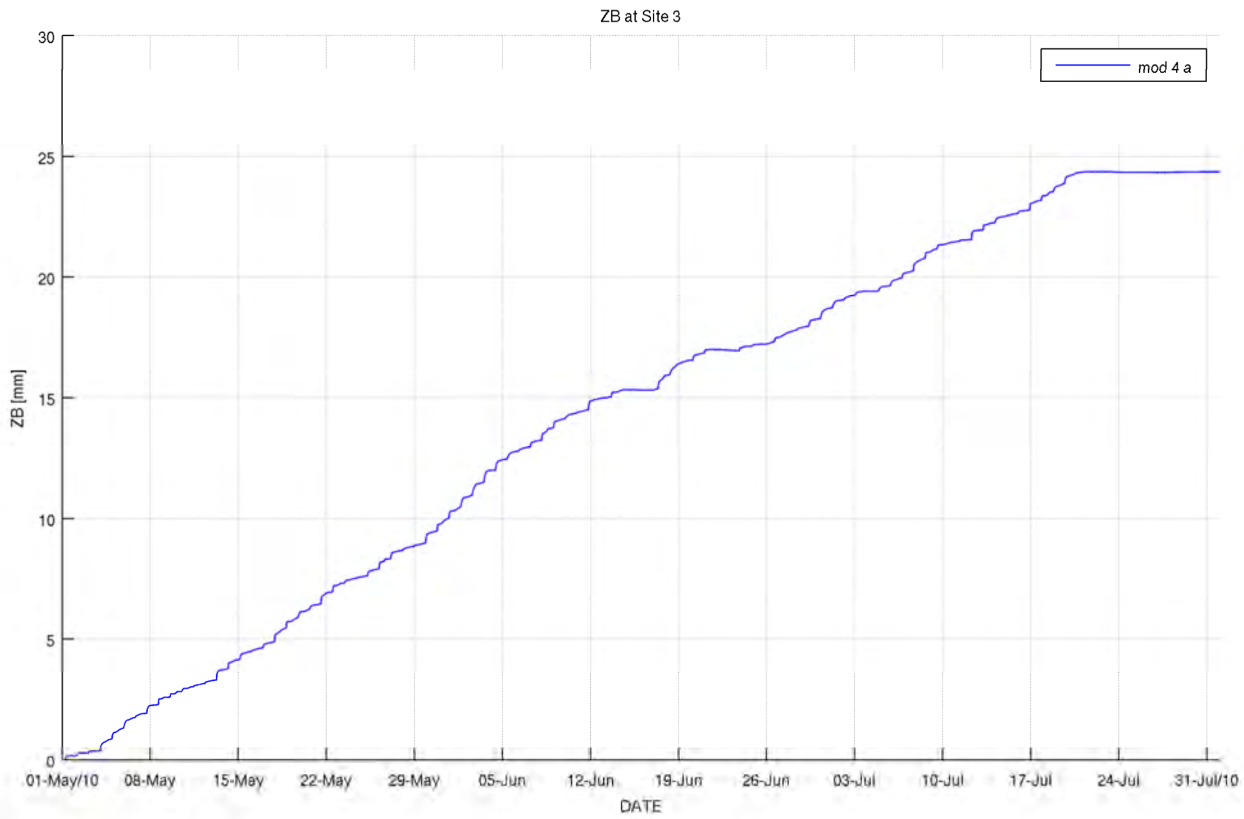
24-Jul
31-Jul/10
DATE


ZB at Site 2
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 3
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 3
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d


ZB at Site 3
mod 4 a
ZB [mm]
0
5
10
15
20
25
30
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
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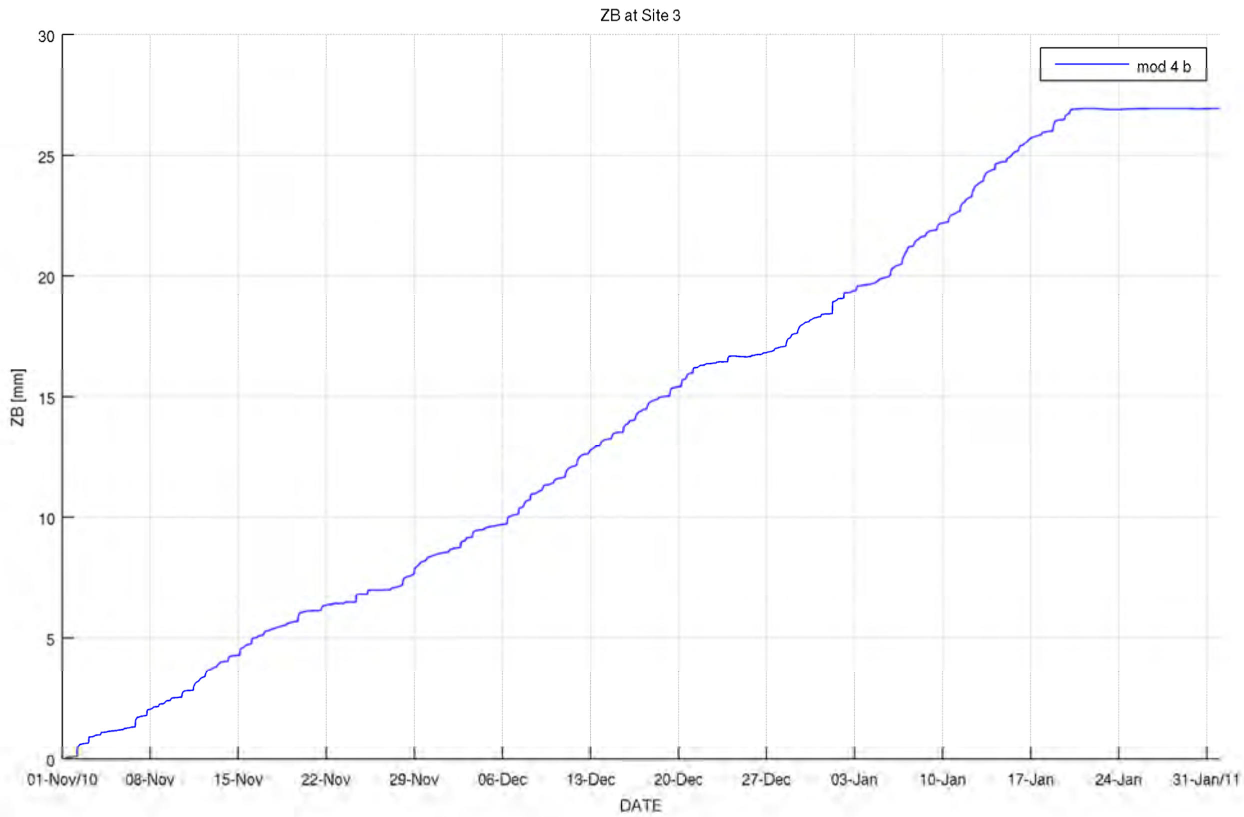
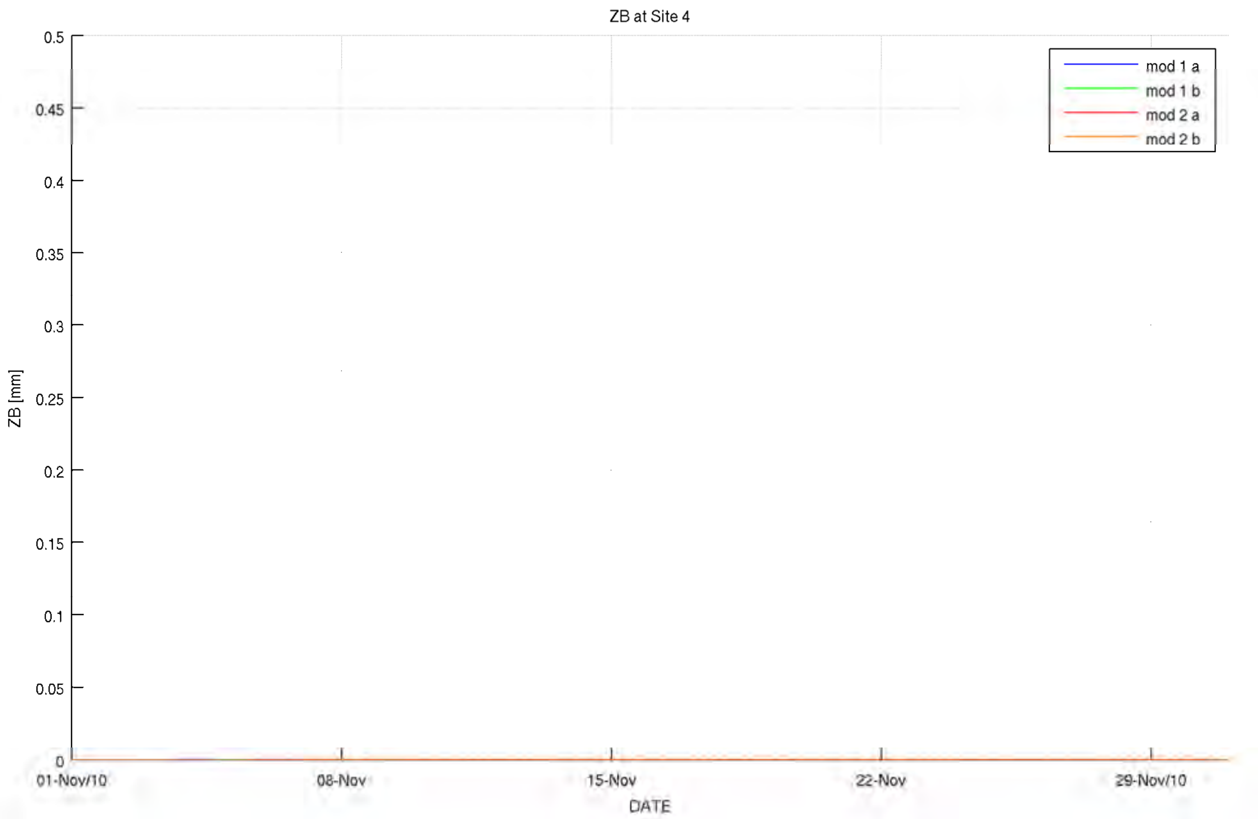
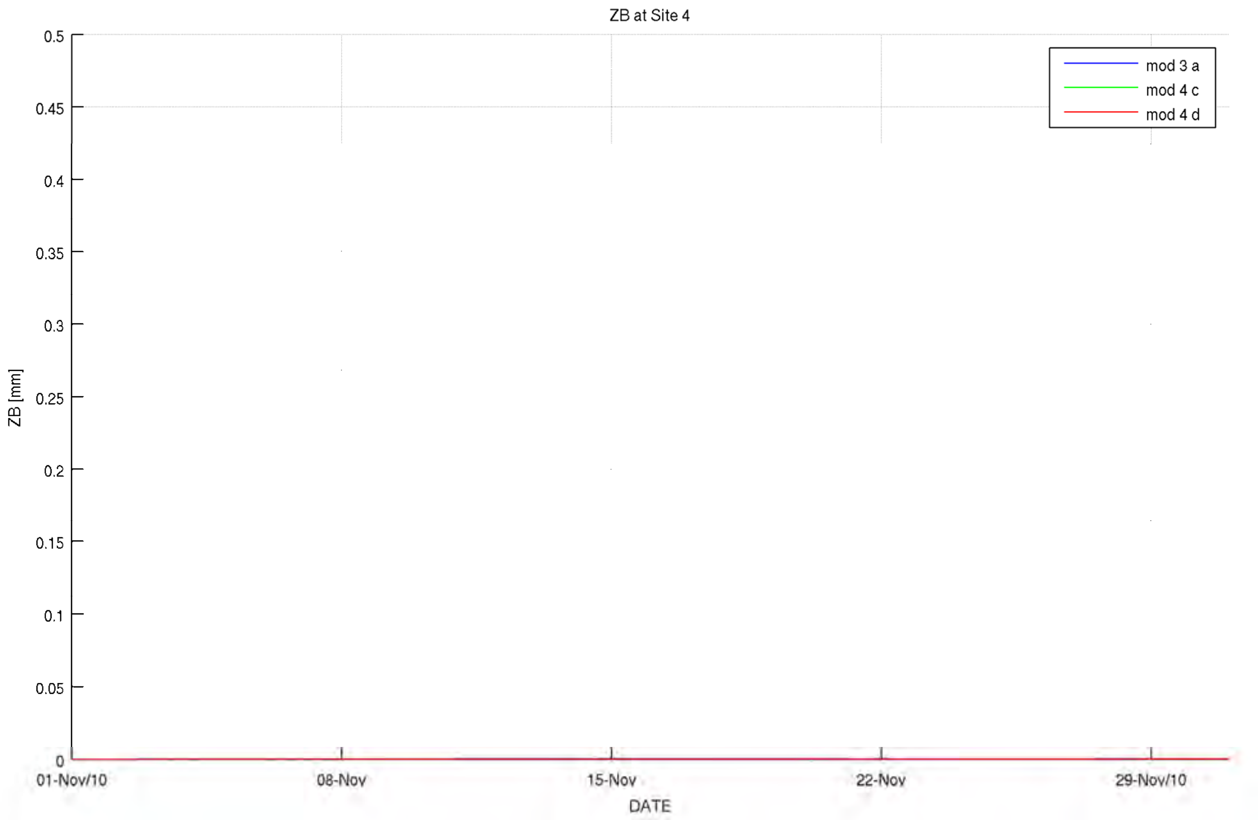
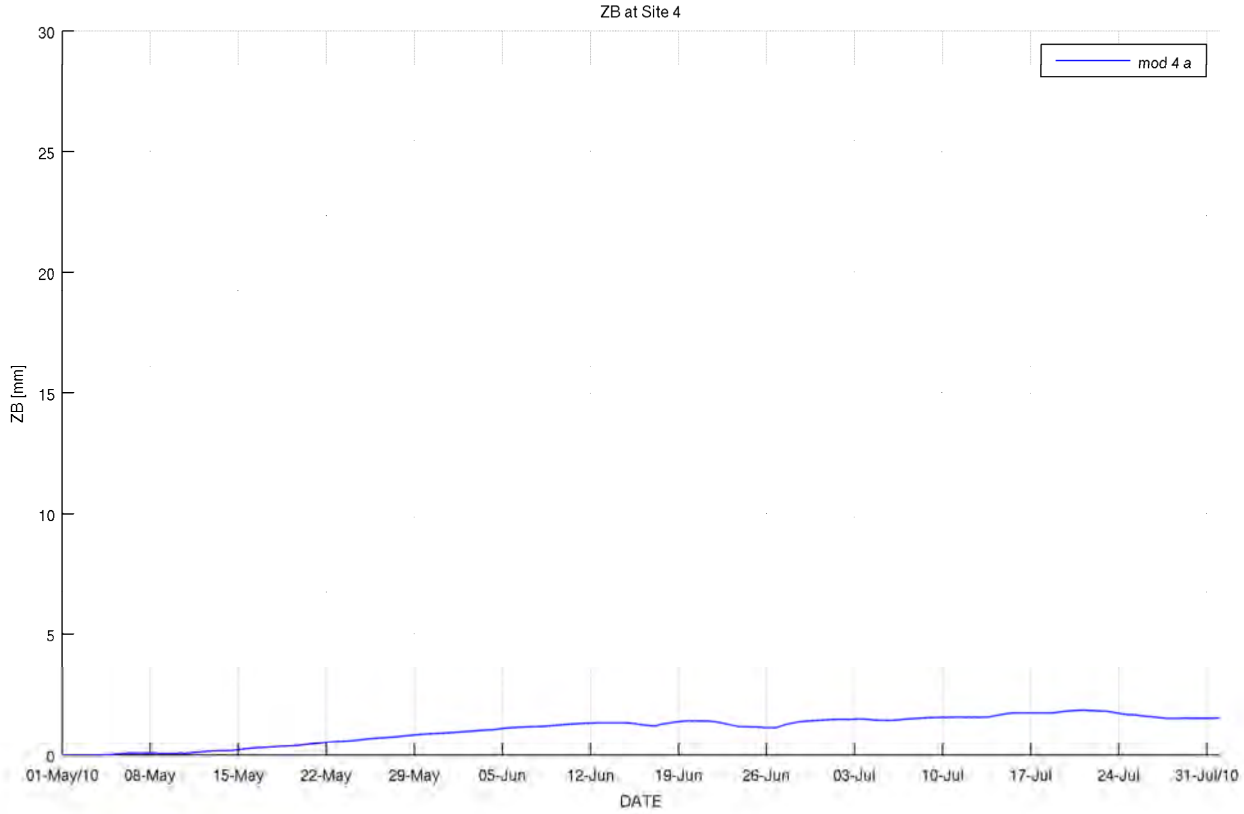
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 3
mod 4 b
ZB [mm]
0
5
10
15
20
25
30
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 4
mod 1 a
mod 1 b
mod 2 a
mod 2 b
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE


ZB at Site 4
mod 3 a
mod 4 c
mod 4 d
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE


ZB at Site 4
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
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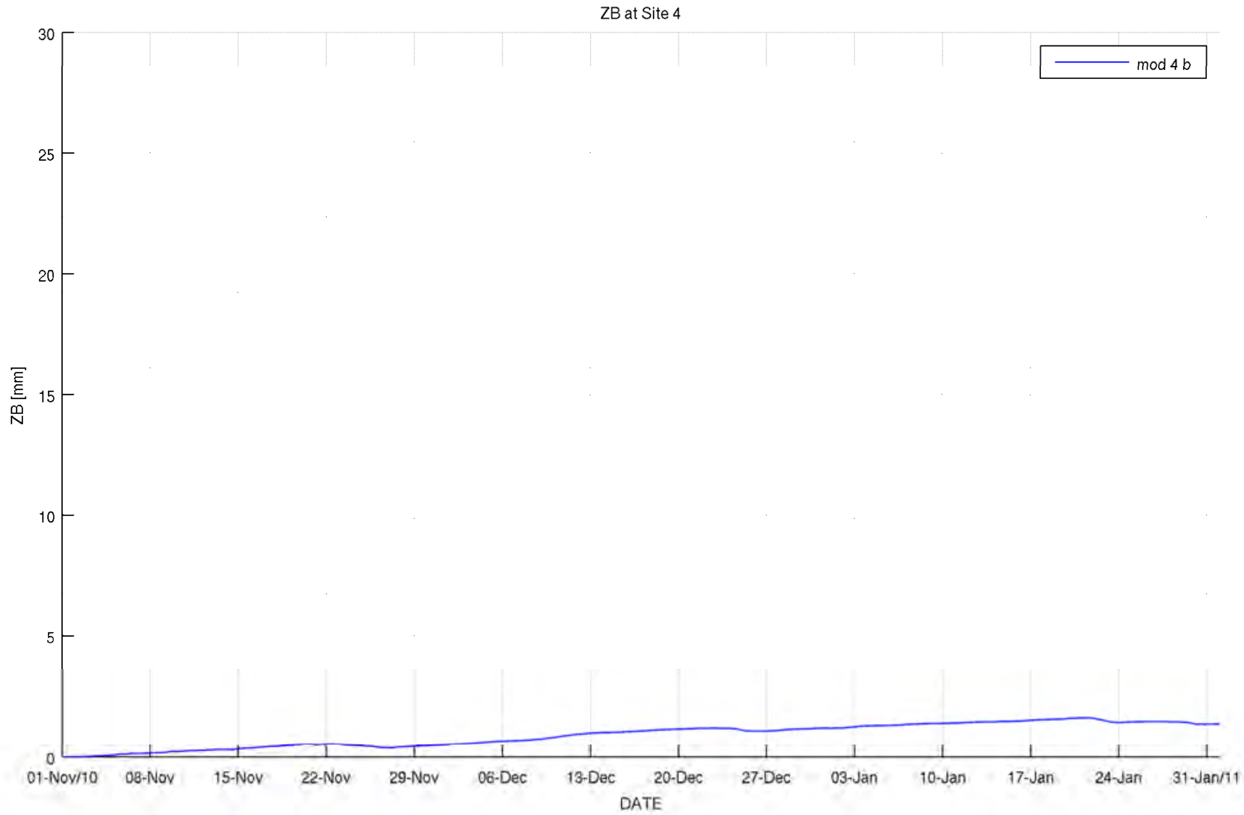
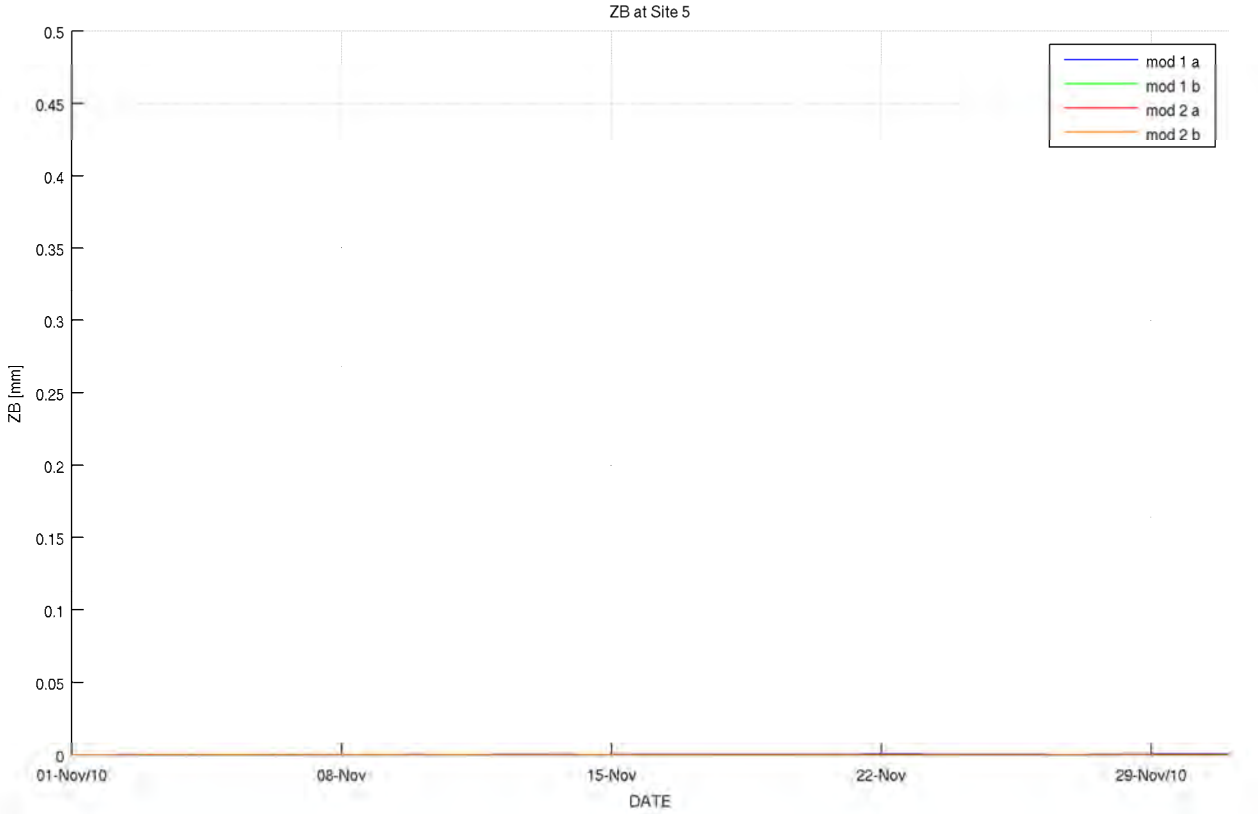
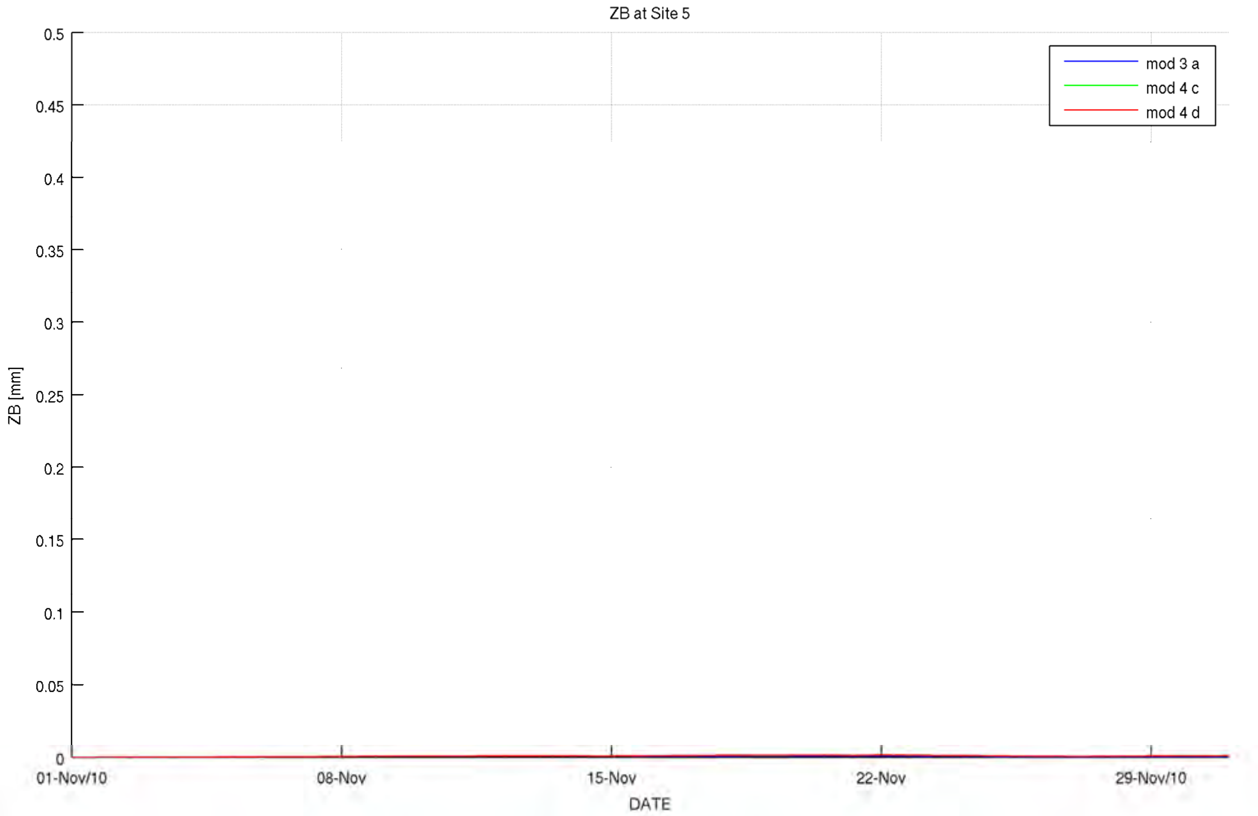
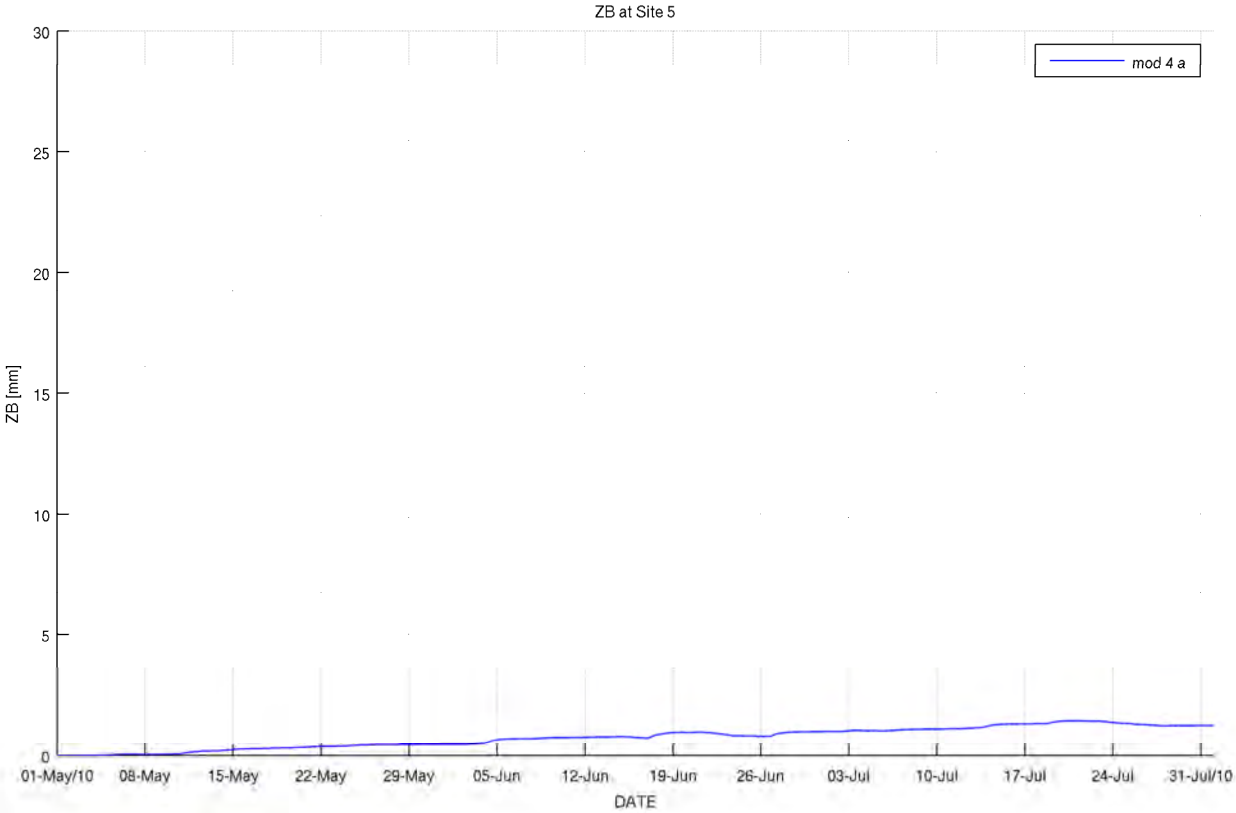
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 4
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 5
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 5
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d


ZB at Site 5
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
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26-Jun
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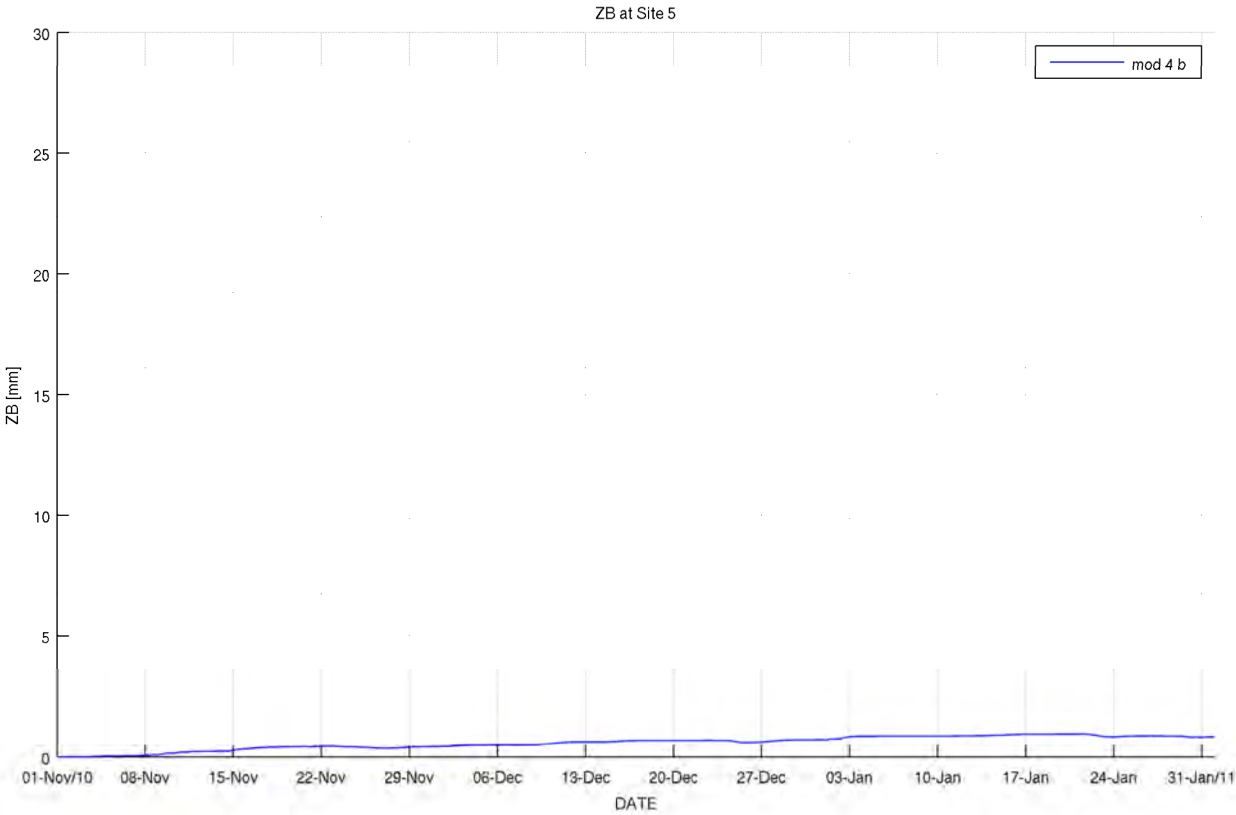
24-Jul
31-Jul/10
DATE


ZB at Site 5
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
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29-Nov
06-Dec
13-Dec
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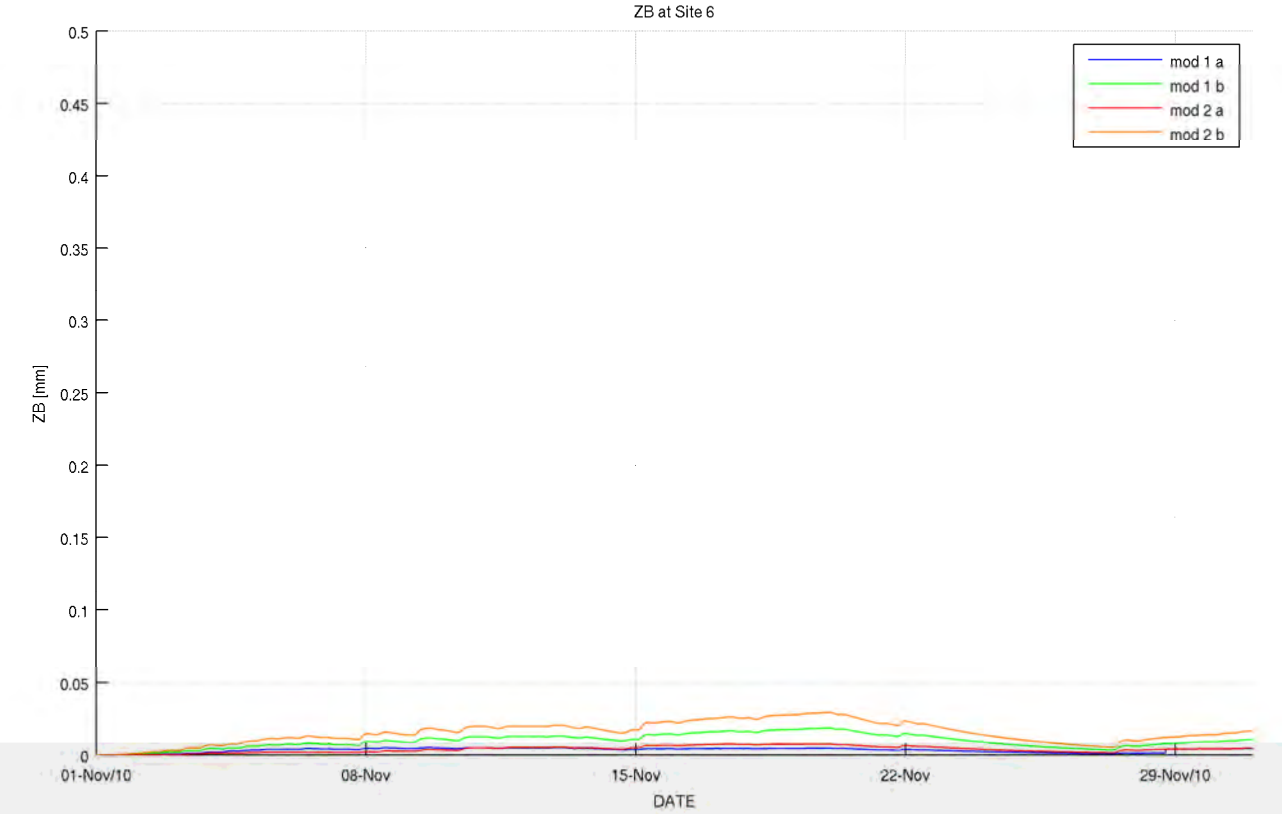
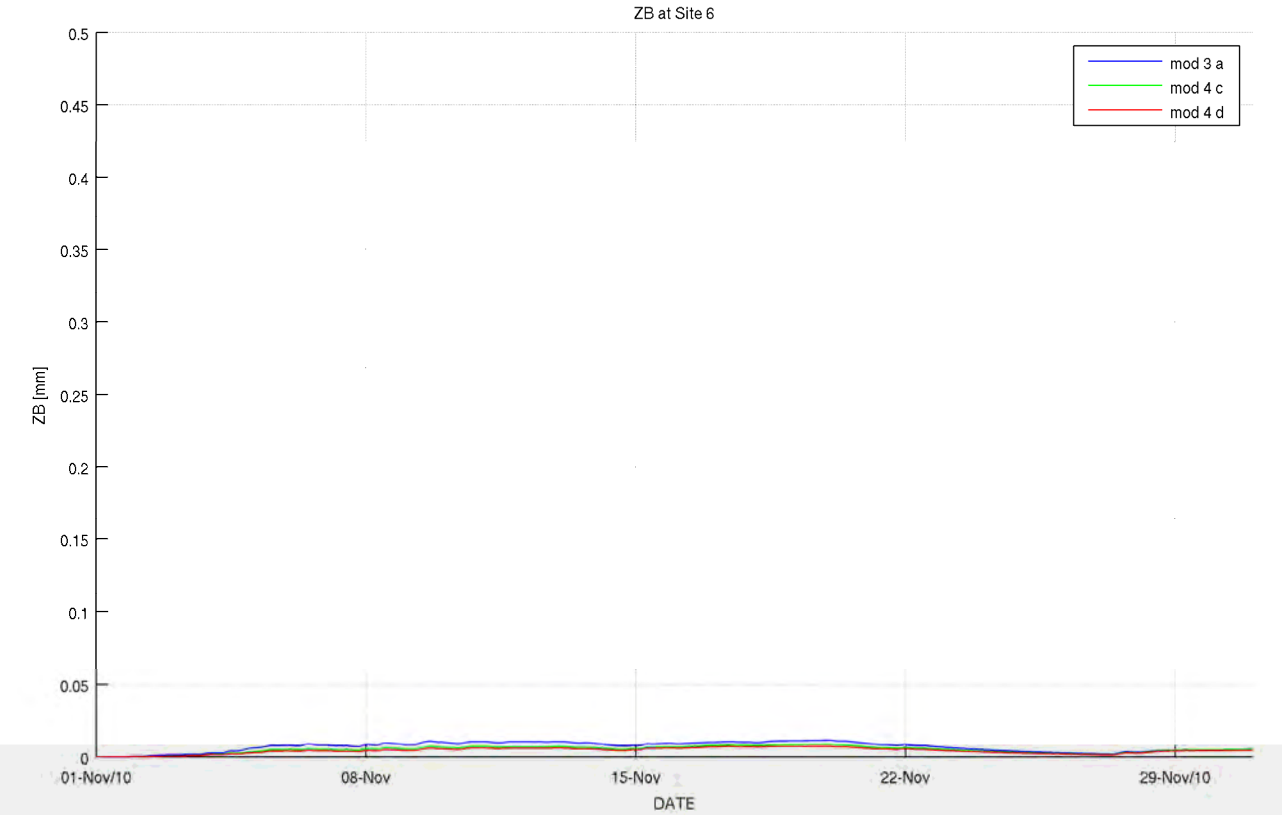
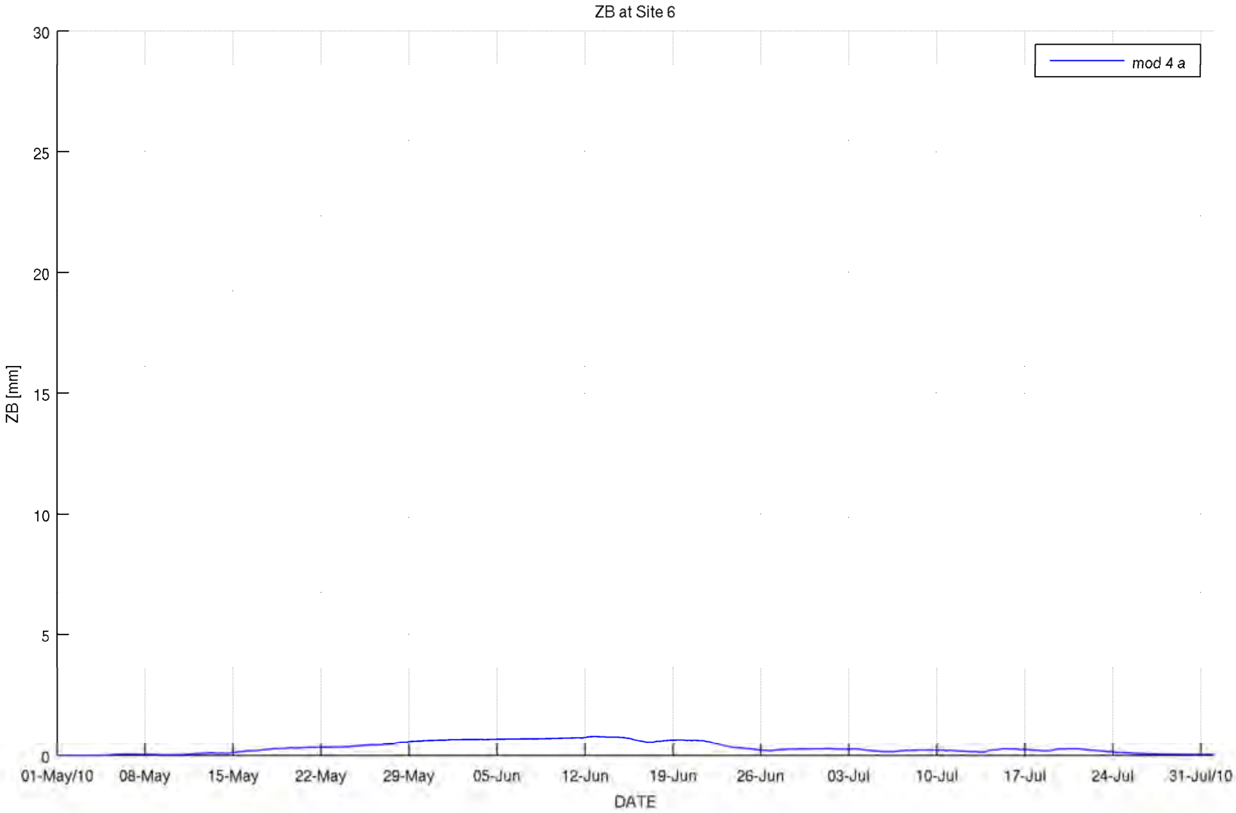
24-Jan
31-Jan/11
DATE


ZB at Site 6
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 6
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d


ZB at Site 6
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
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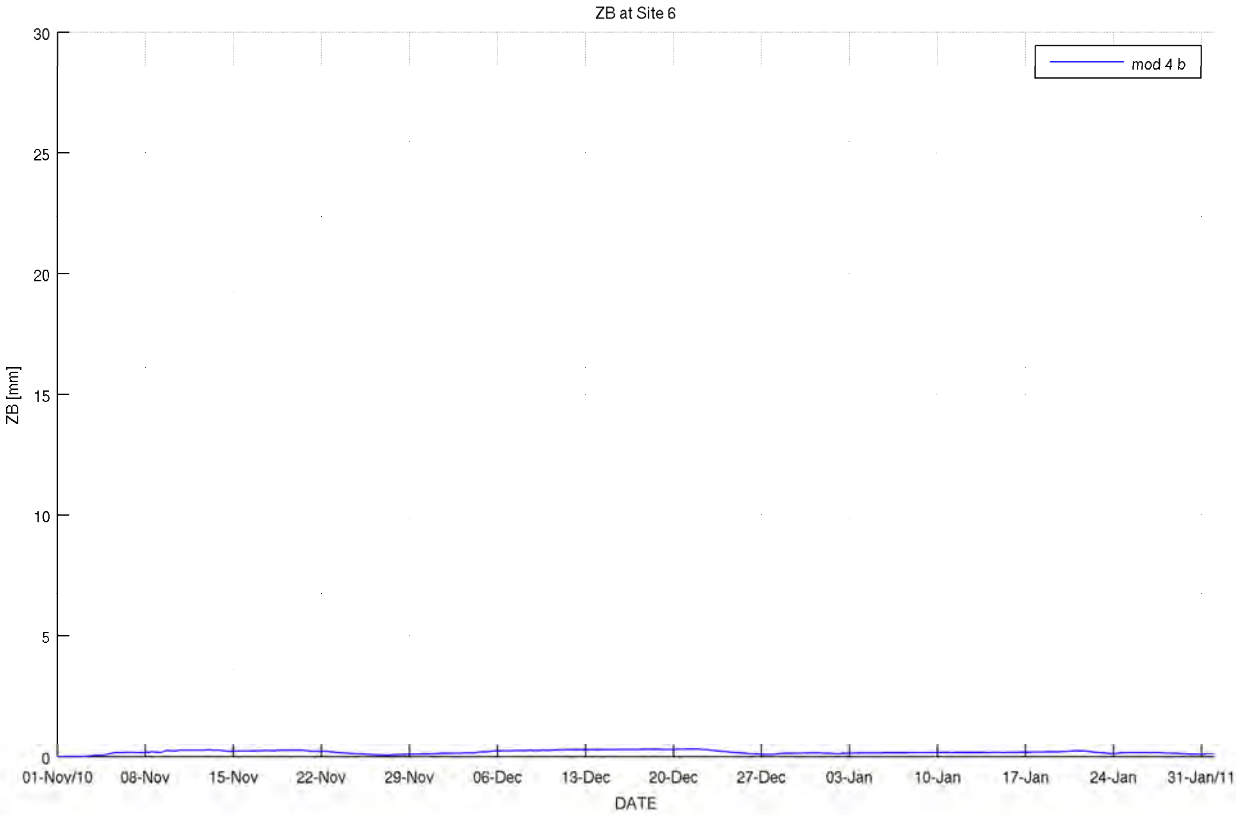
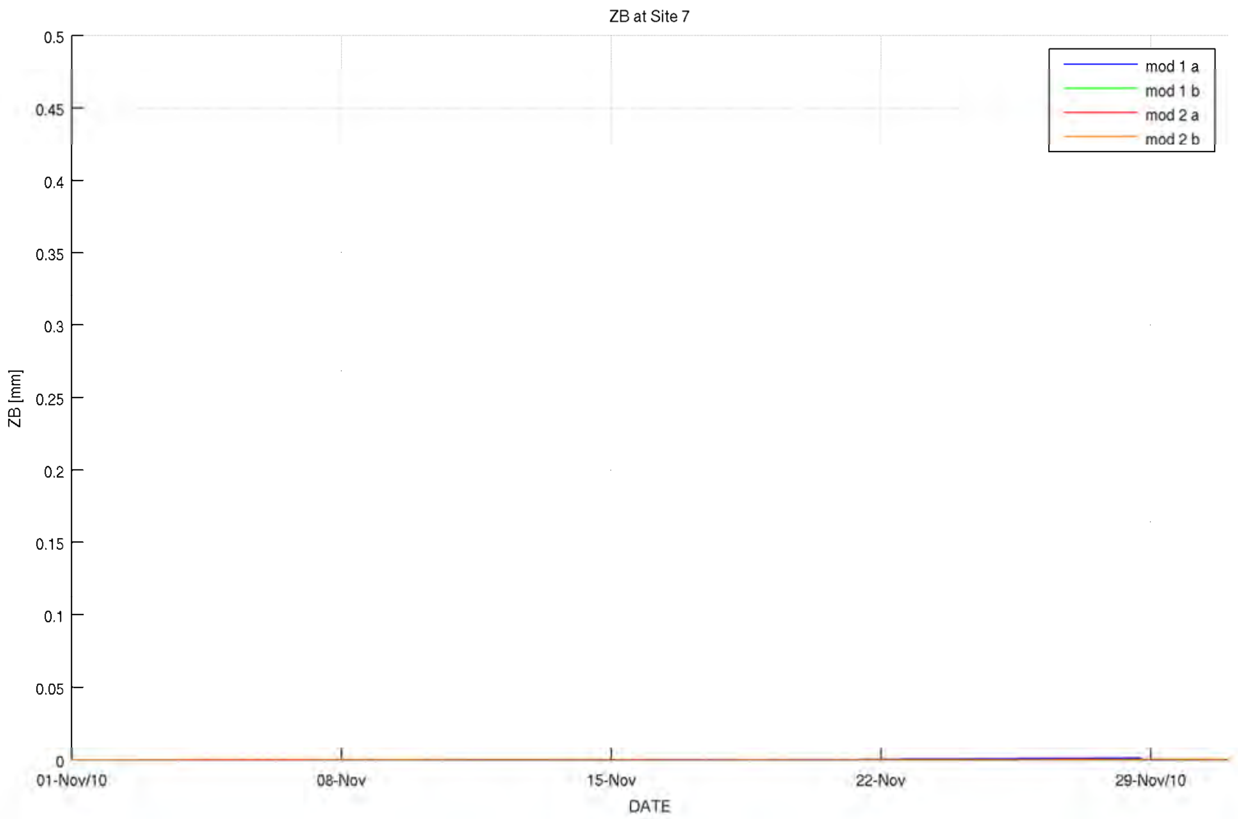
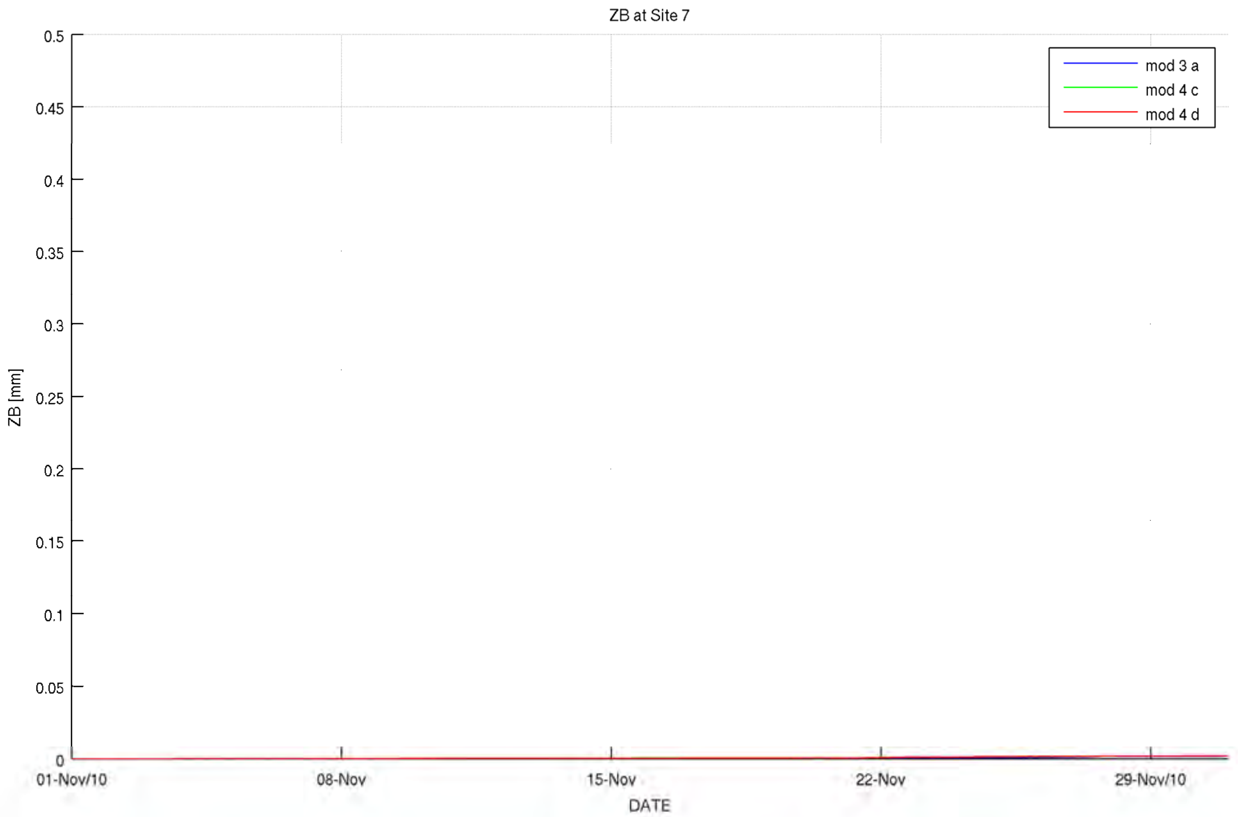
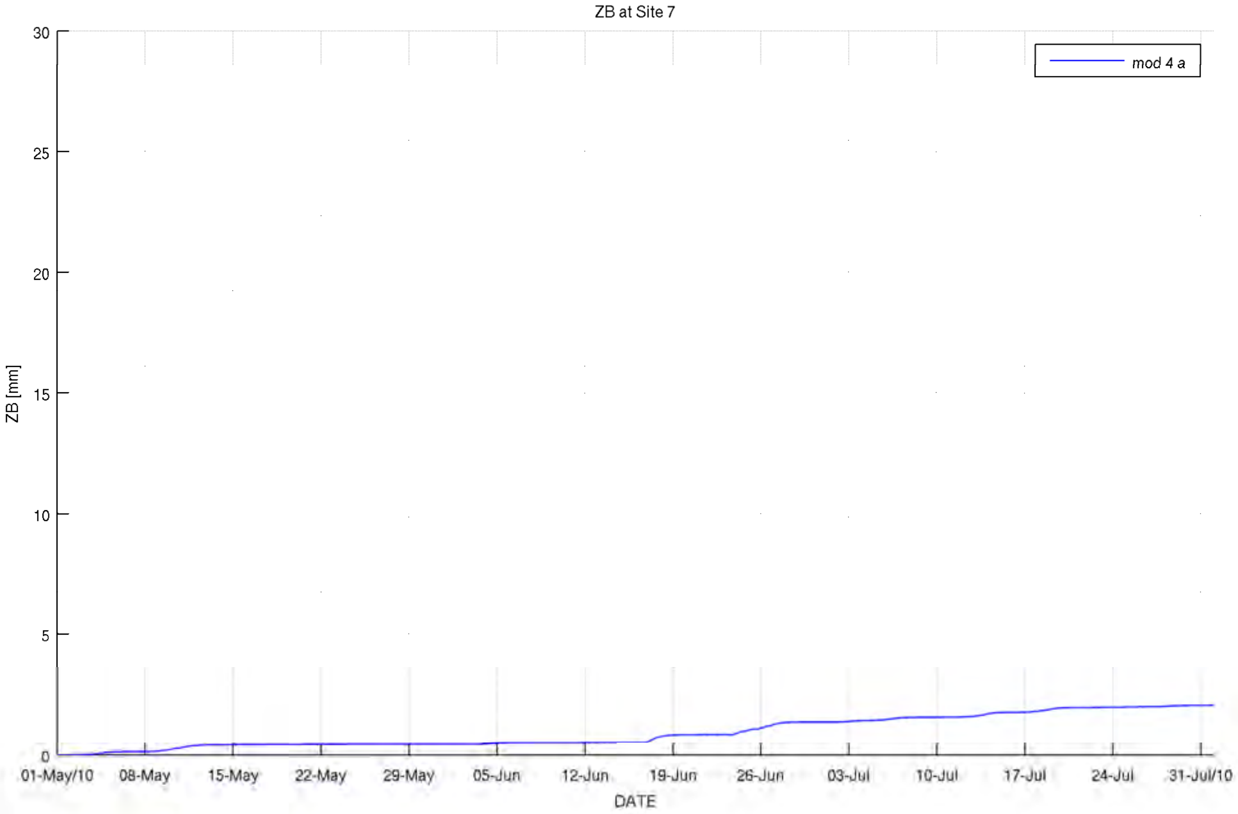
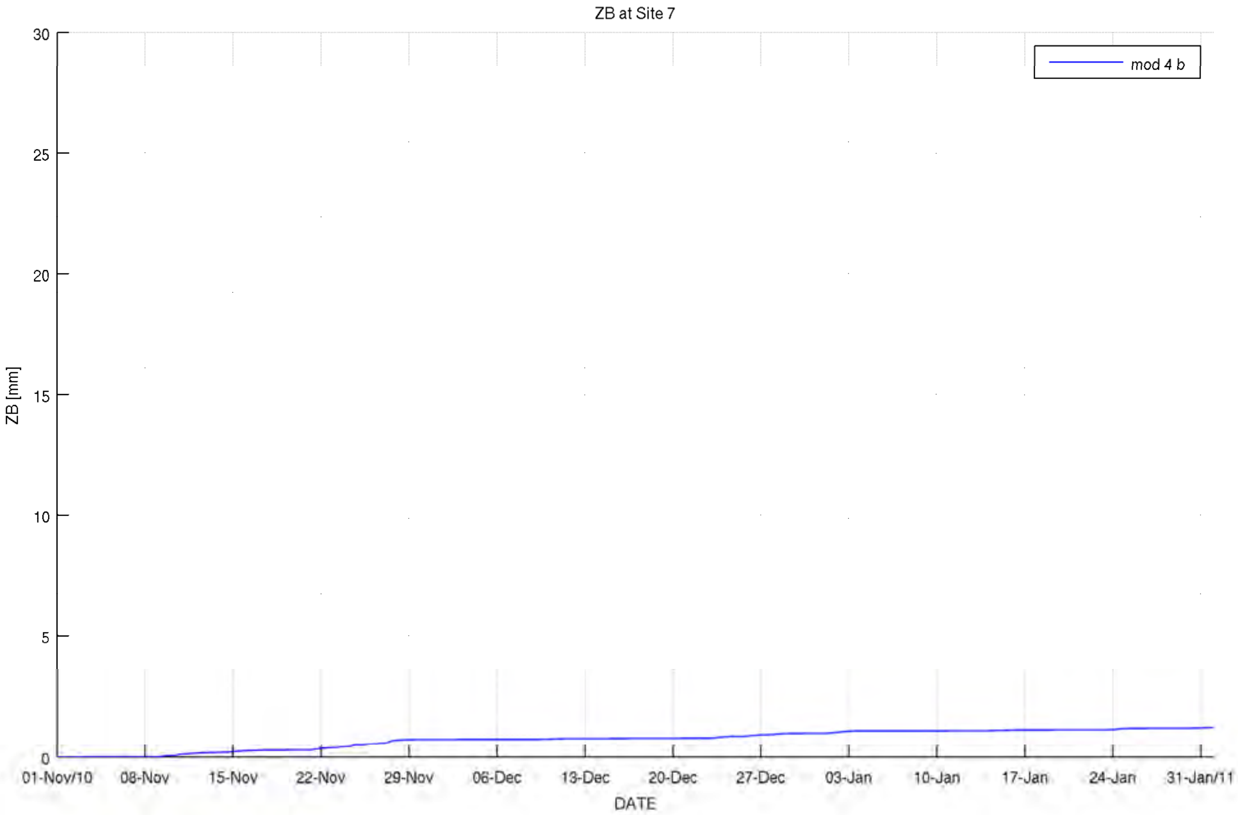
17-Jul
24-Jul
31-Jul/10
DATE

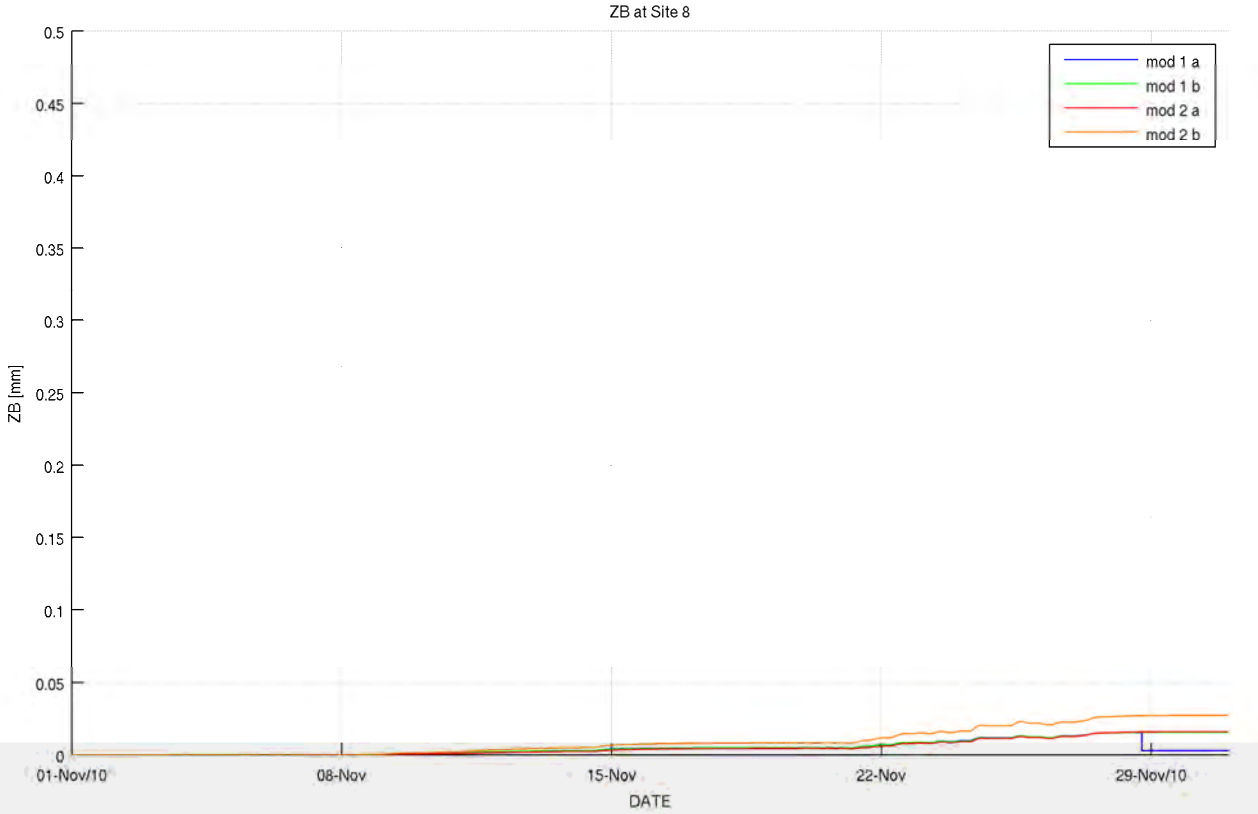

ZB at Site 6
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

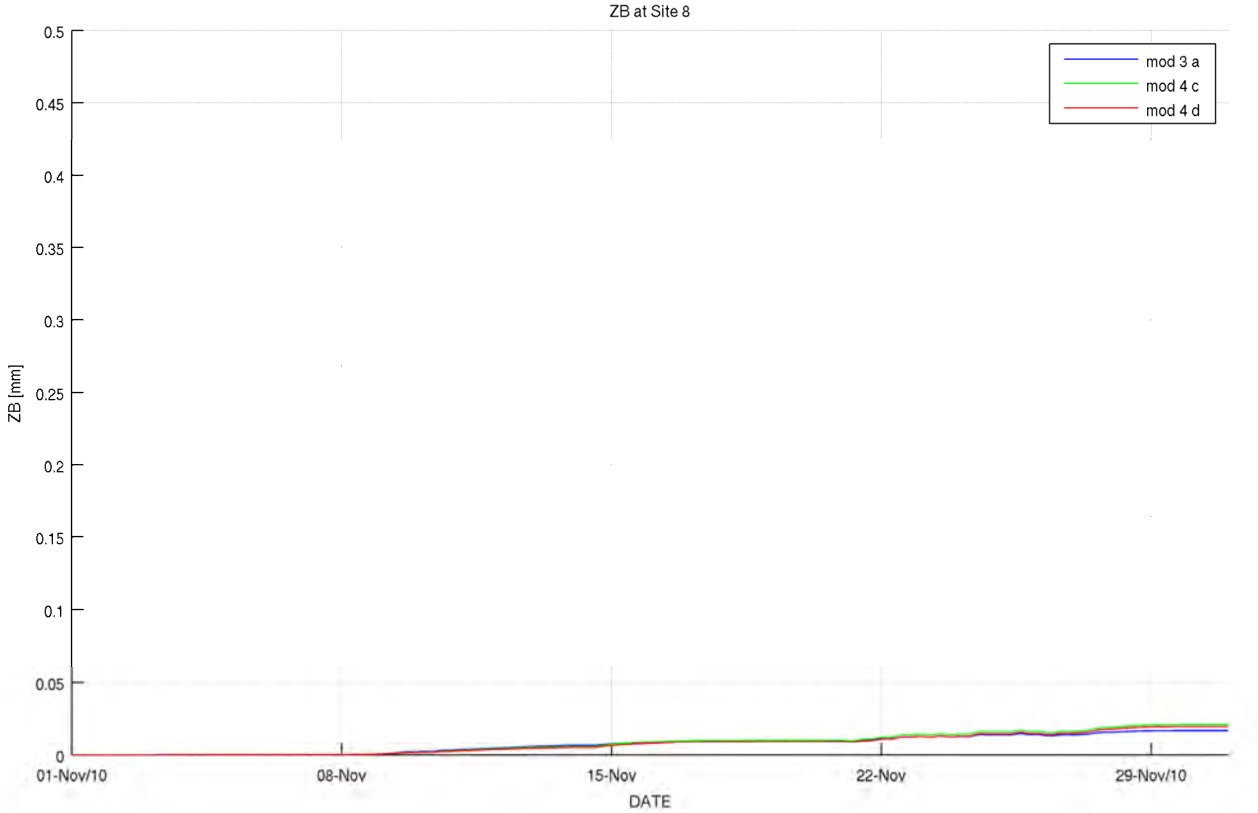

ZB at Site 7
mod 1 a
mod 1 b
mod 2 a
mod 2 b
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

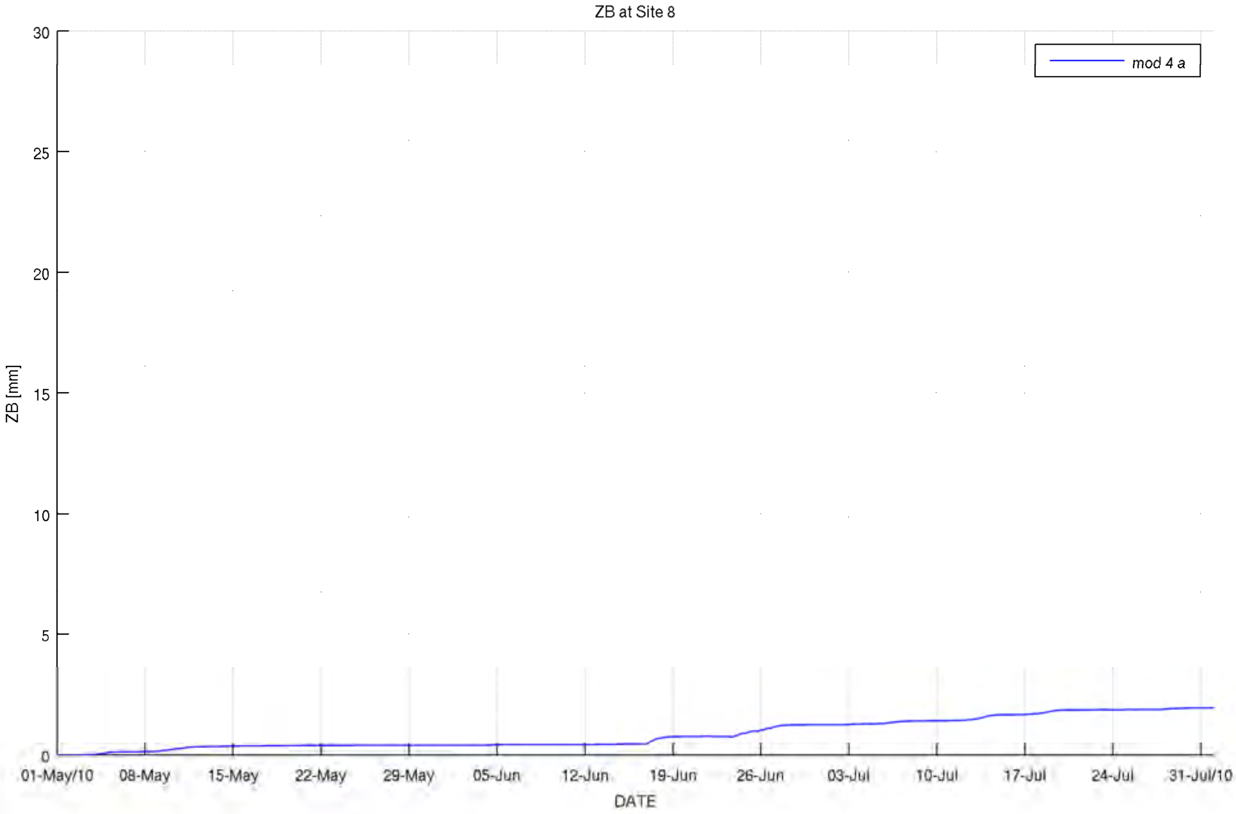

ZB at Site 7
mod 3 a
mod 4 c
mod 4 d
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

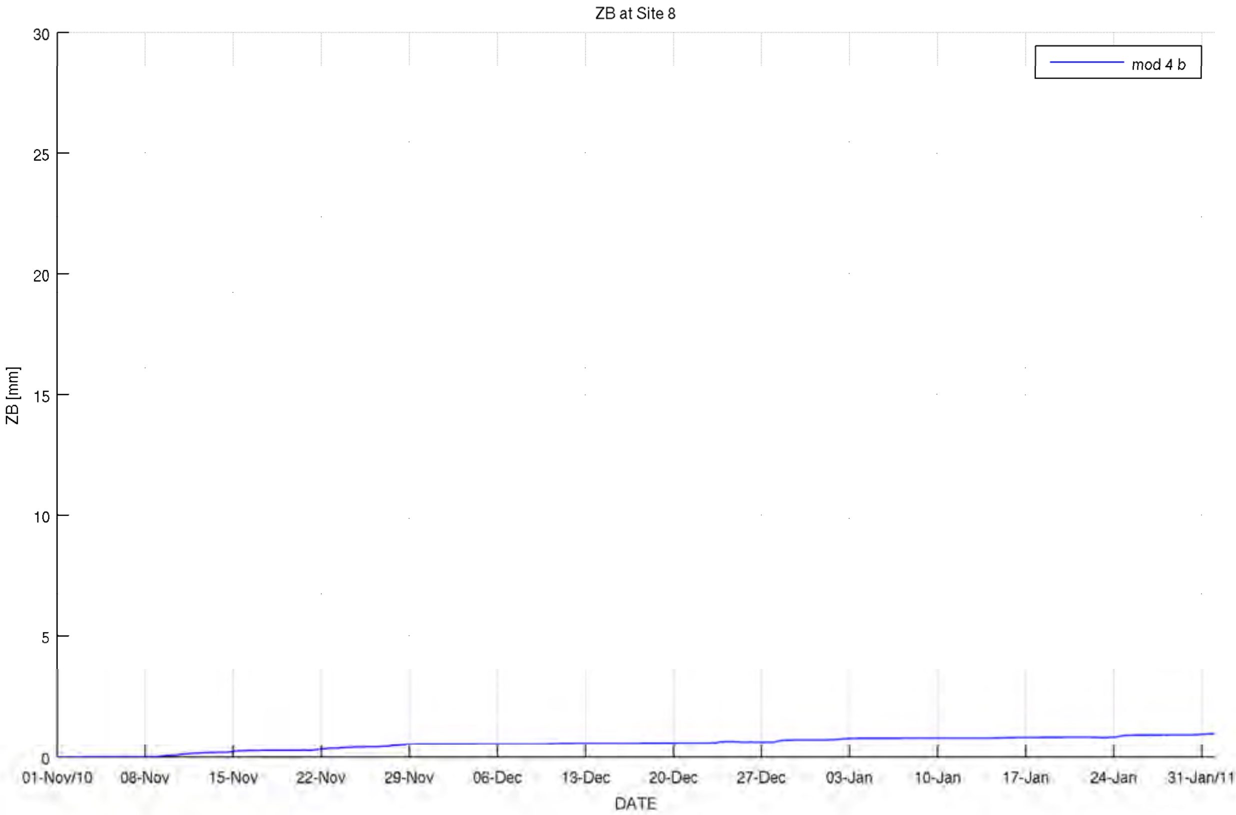

ZB at Site 7
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

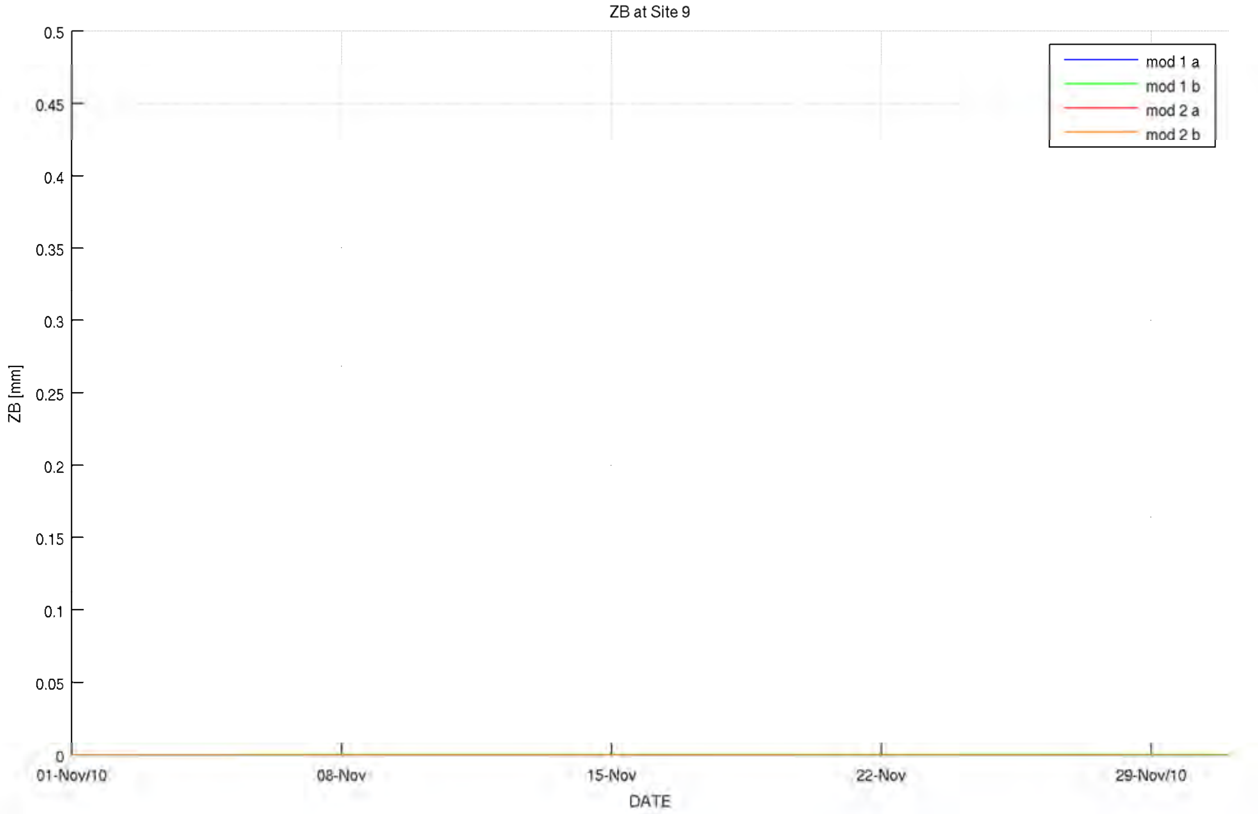

ZB at Site 7
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

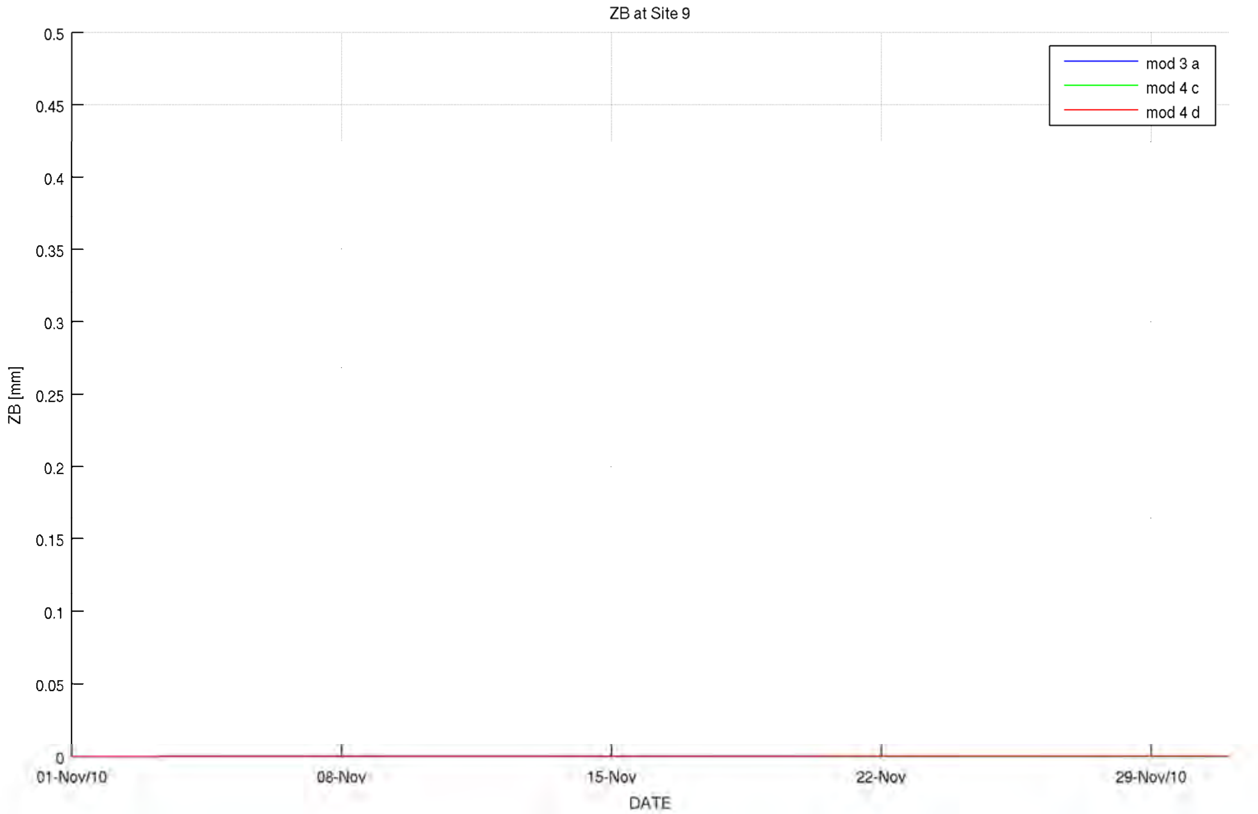

ZB at Site 8
mod 1 a
mod 1 b
mod 2 a
mod 2 b
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

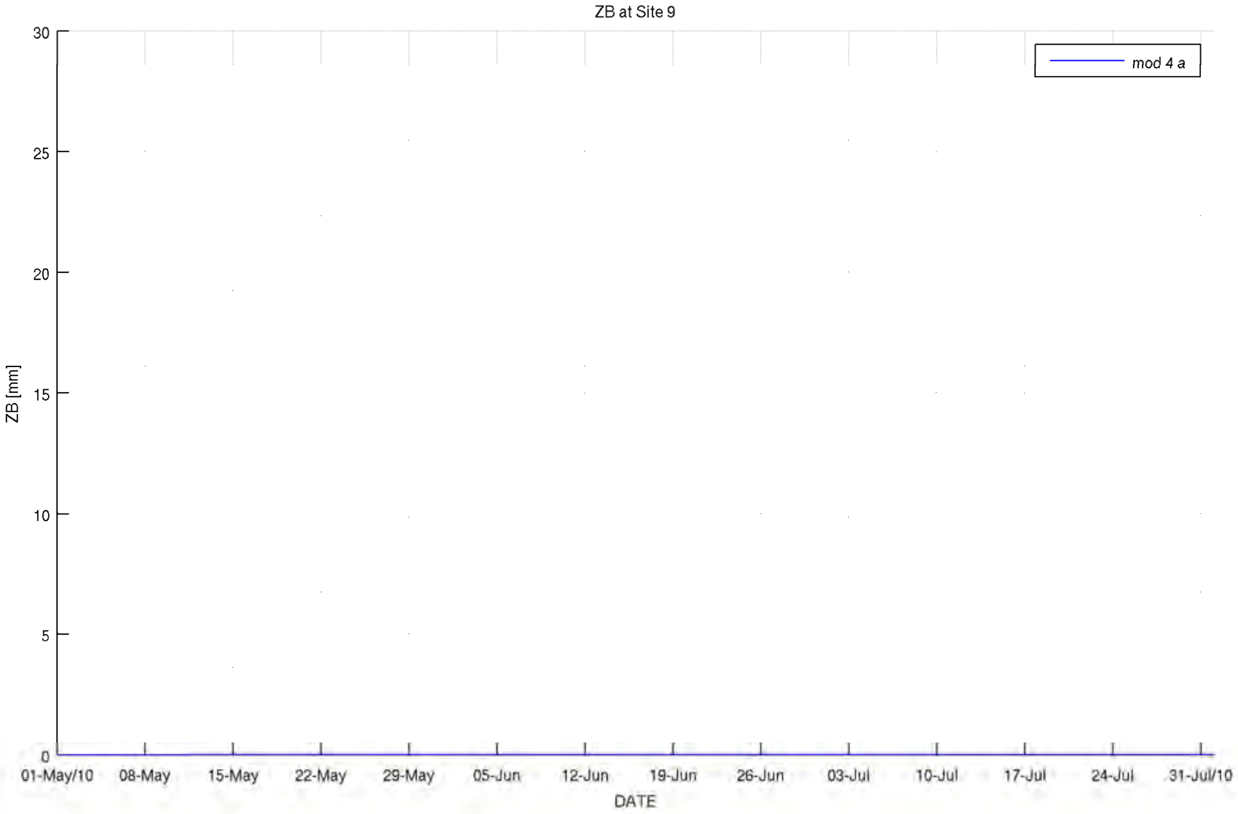

ZB at Site 8
mod 3 a
mod 4 c
mod 4 d
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

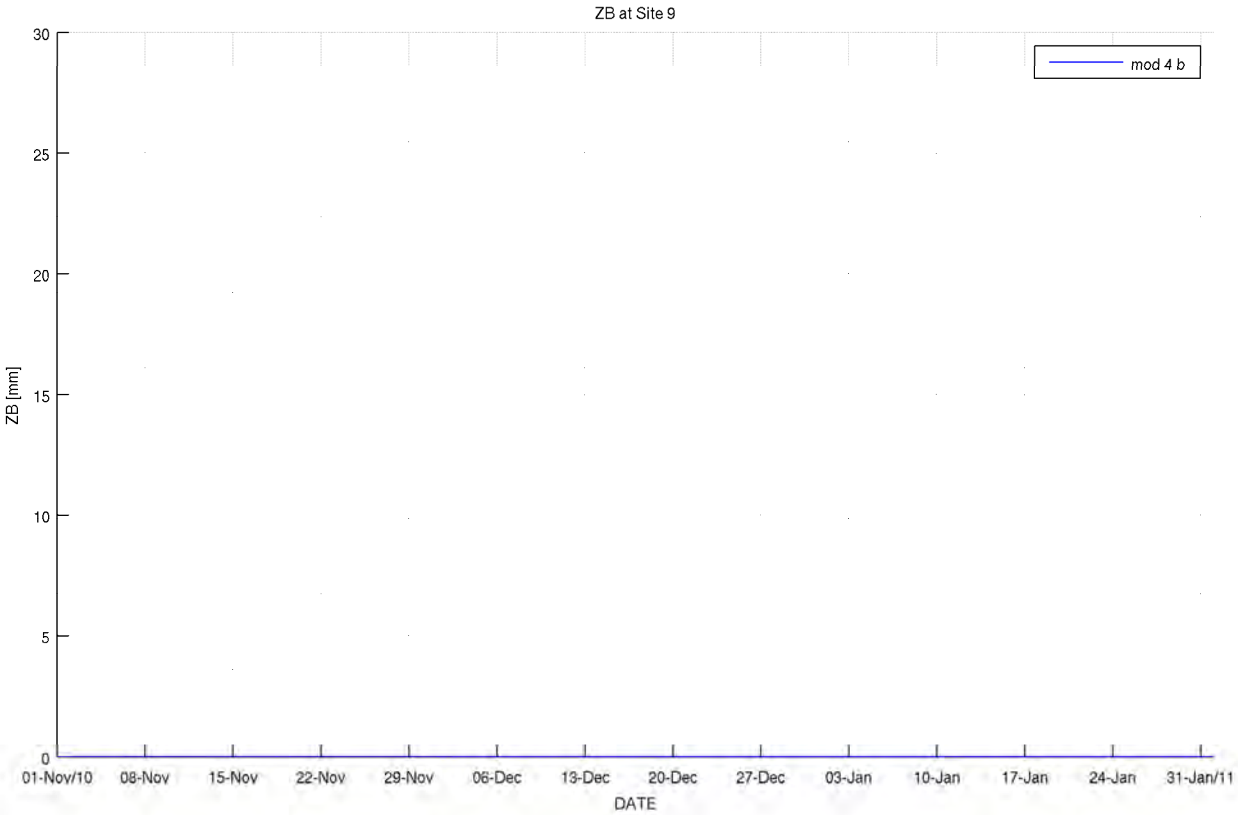

ZB at Site 8
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

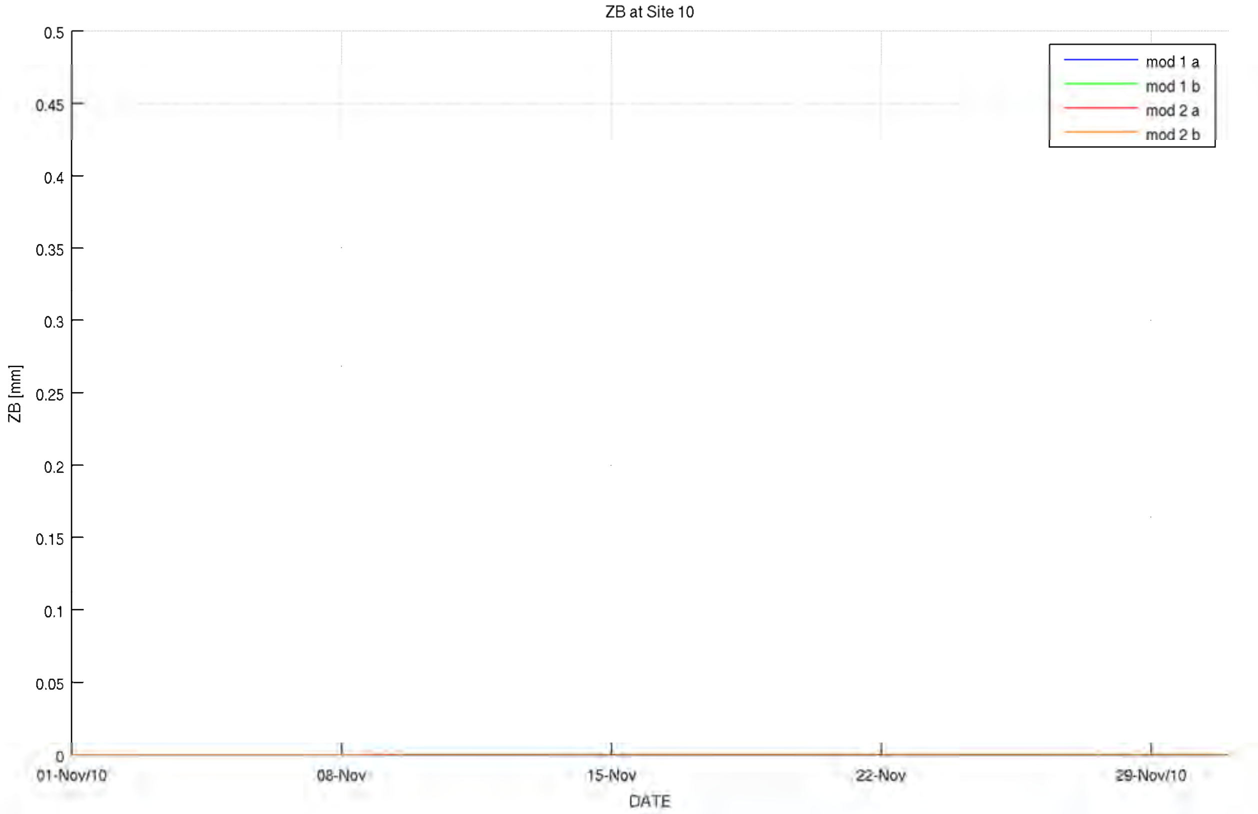

ZB at Site 8
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

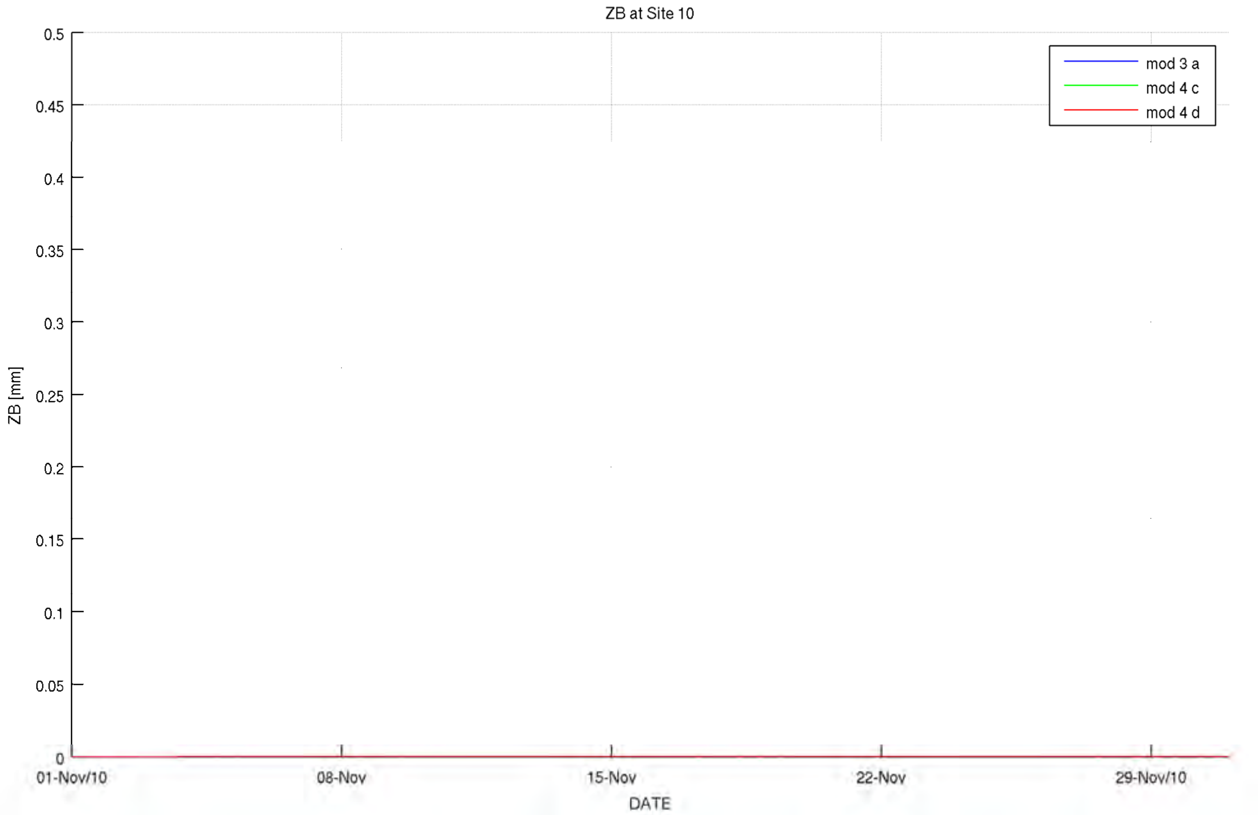

ZB at Site 9
mod 1 a
mod 1 b
mod 2 a
mod 2 b
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

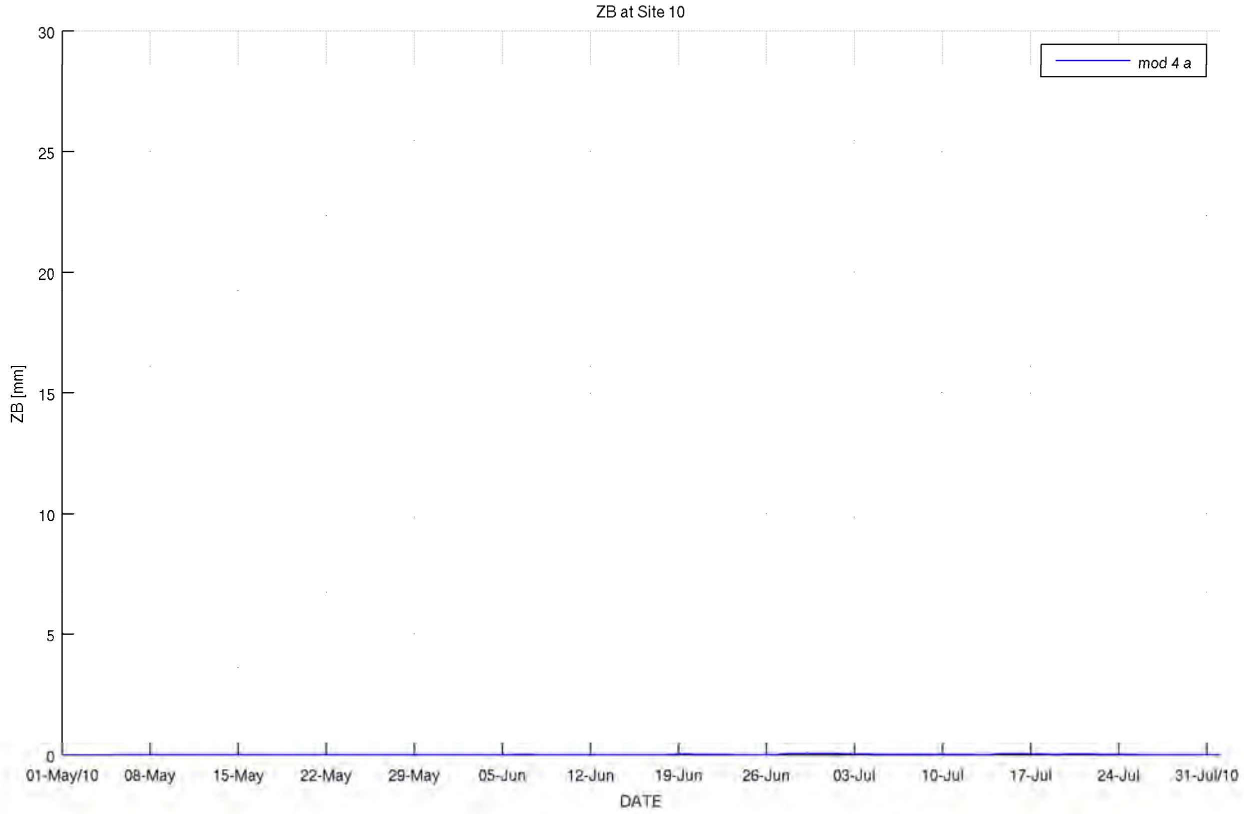

ZB at Site 9
mod 3 a
mod 4 c
mod 4 d
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

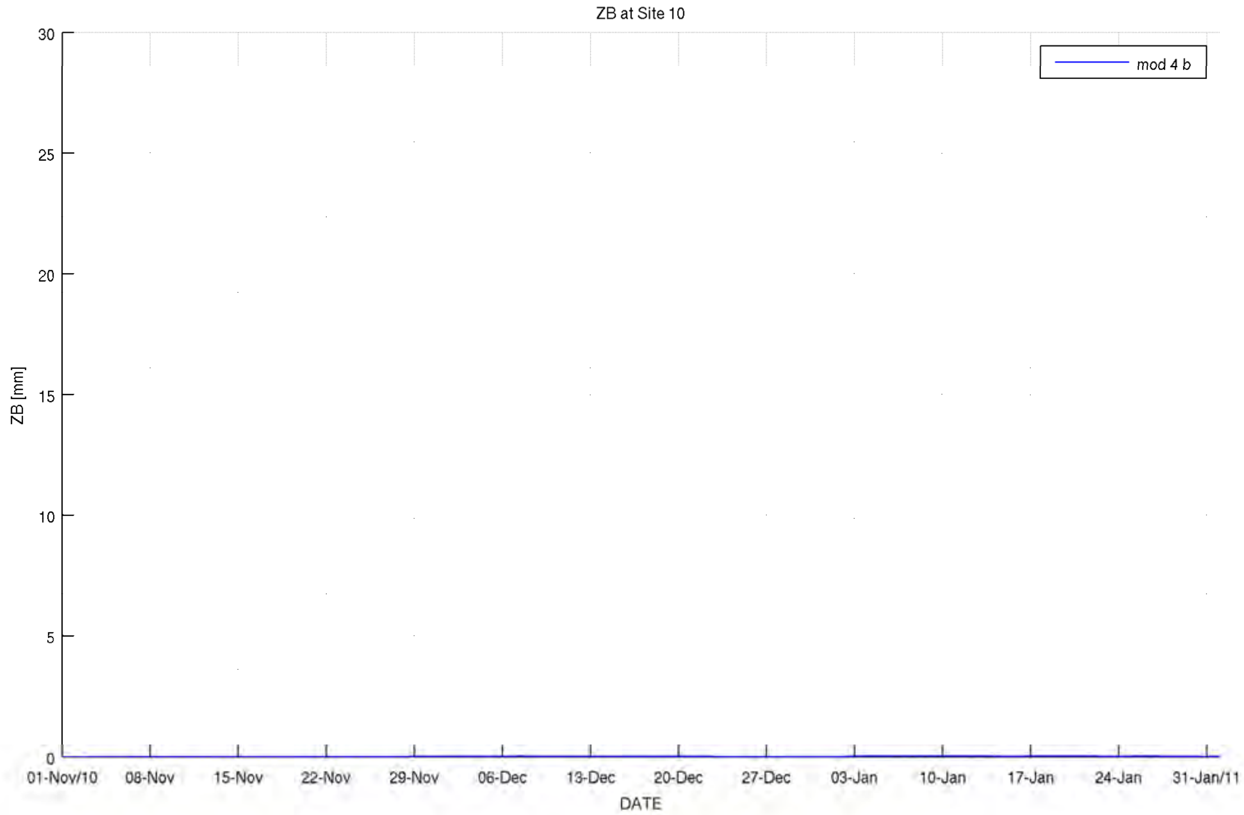

ZB at Site 9
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

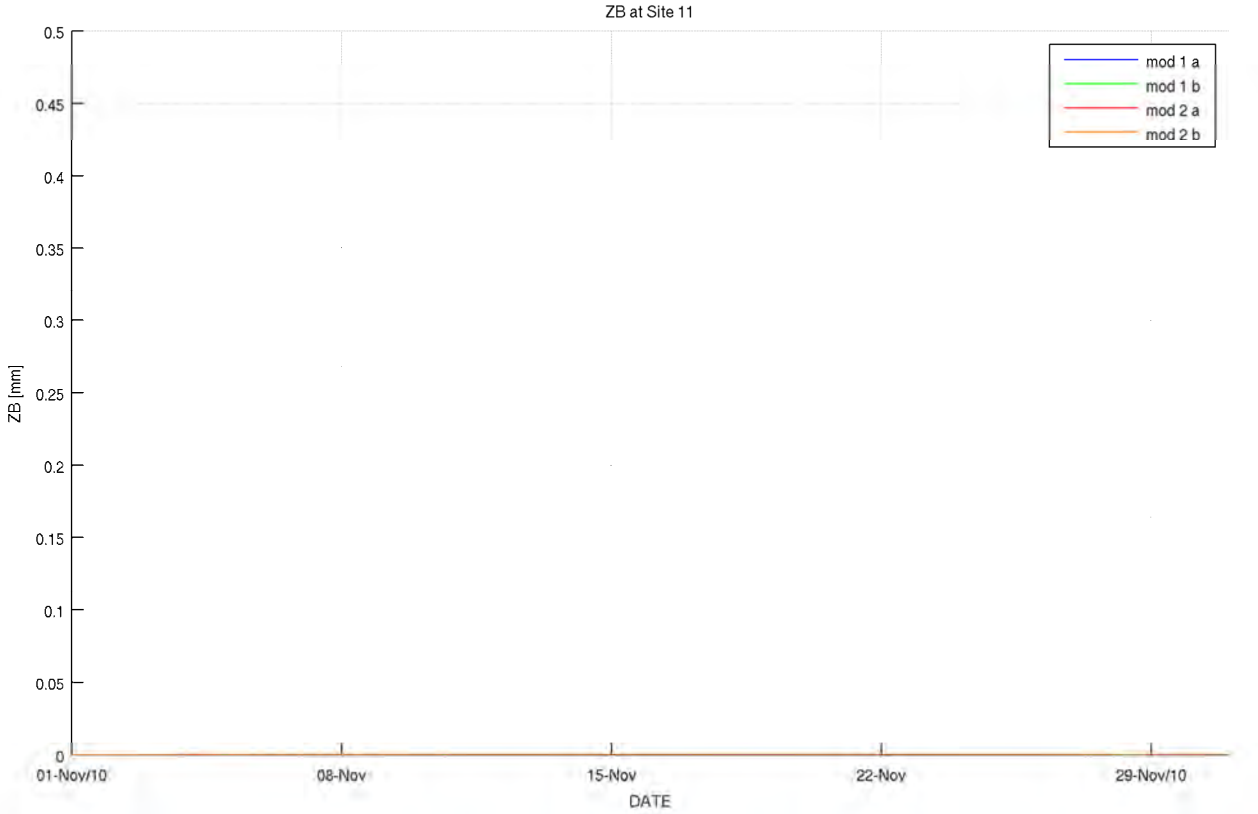

ZB at Site 9
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

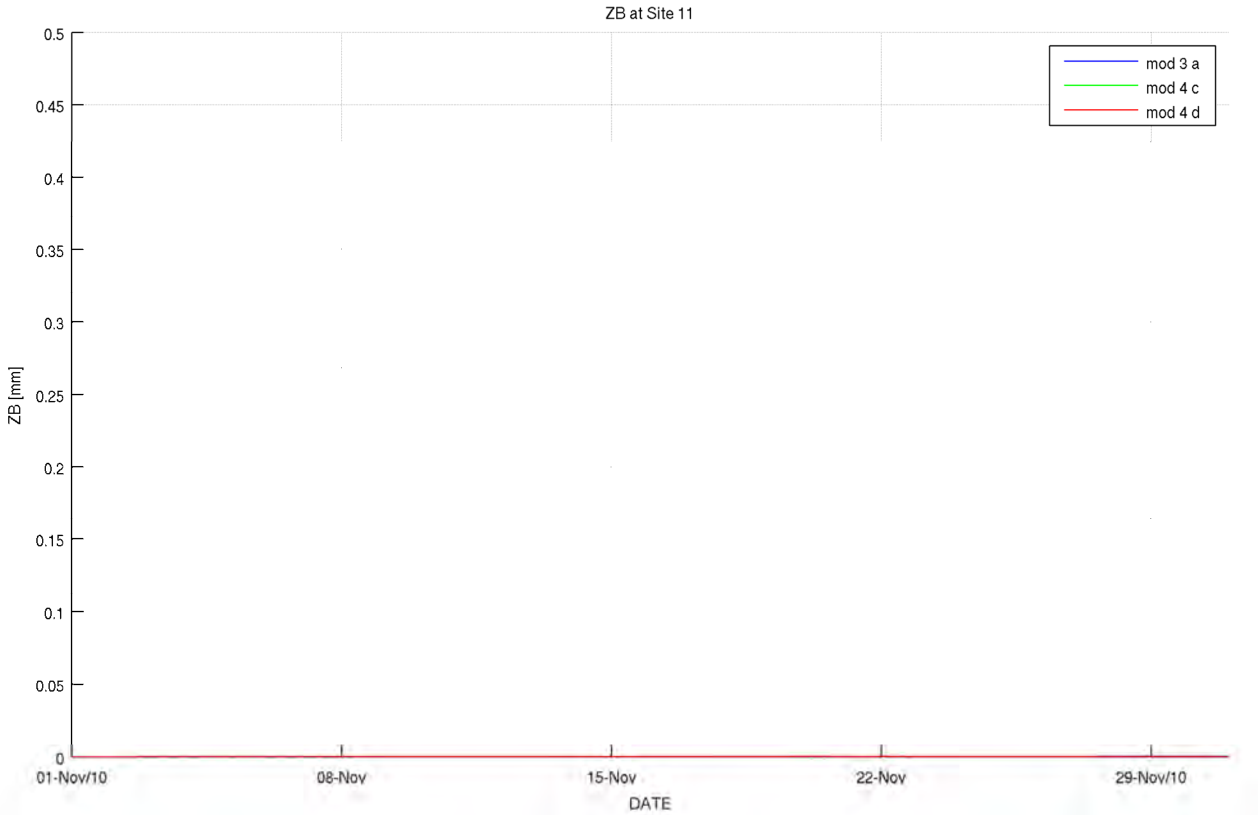

ZB at Site 10
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b

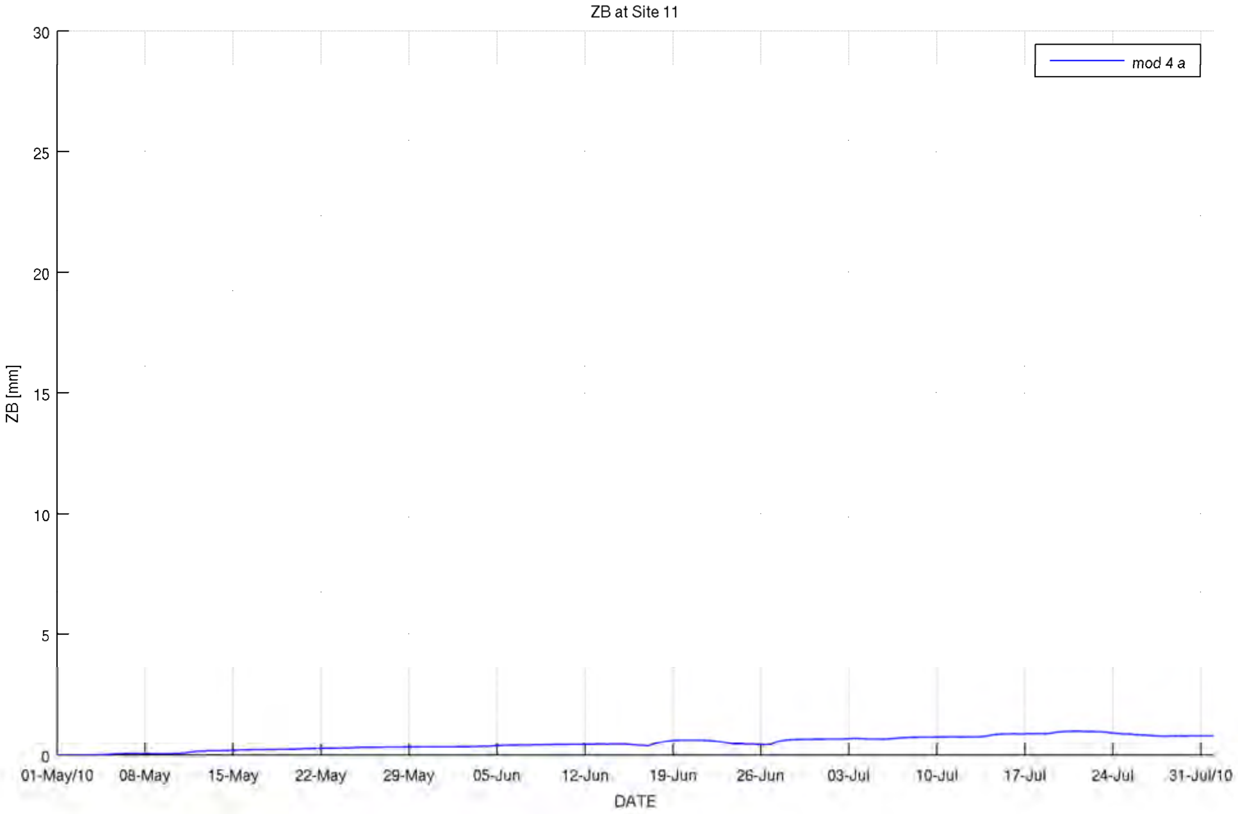

ZB at Site 10
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d

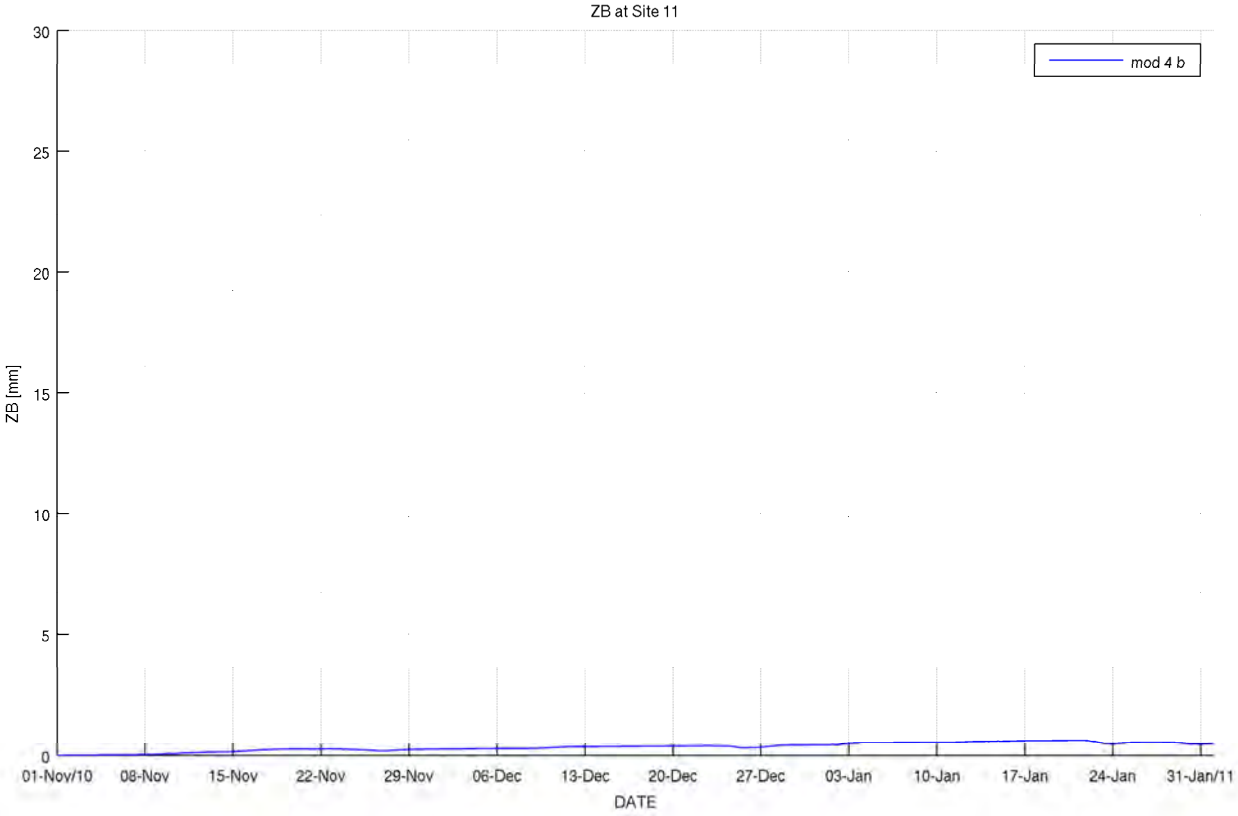

ZB at Site 10
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 10
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 11
mod 1 a
mod 1 b
mod 2 a
mod 2 b
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE


ZB at Site 11
mod 3 a
mod 4 c
mod 4 d
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE


ZB at Site 11
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 11
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
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27-Dec
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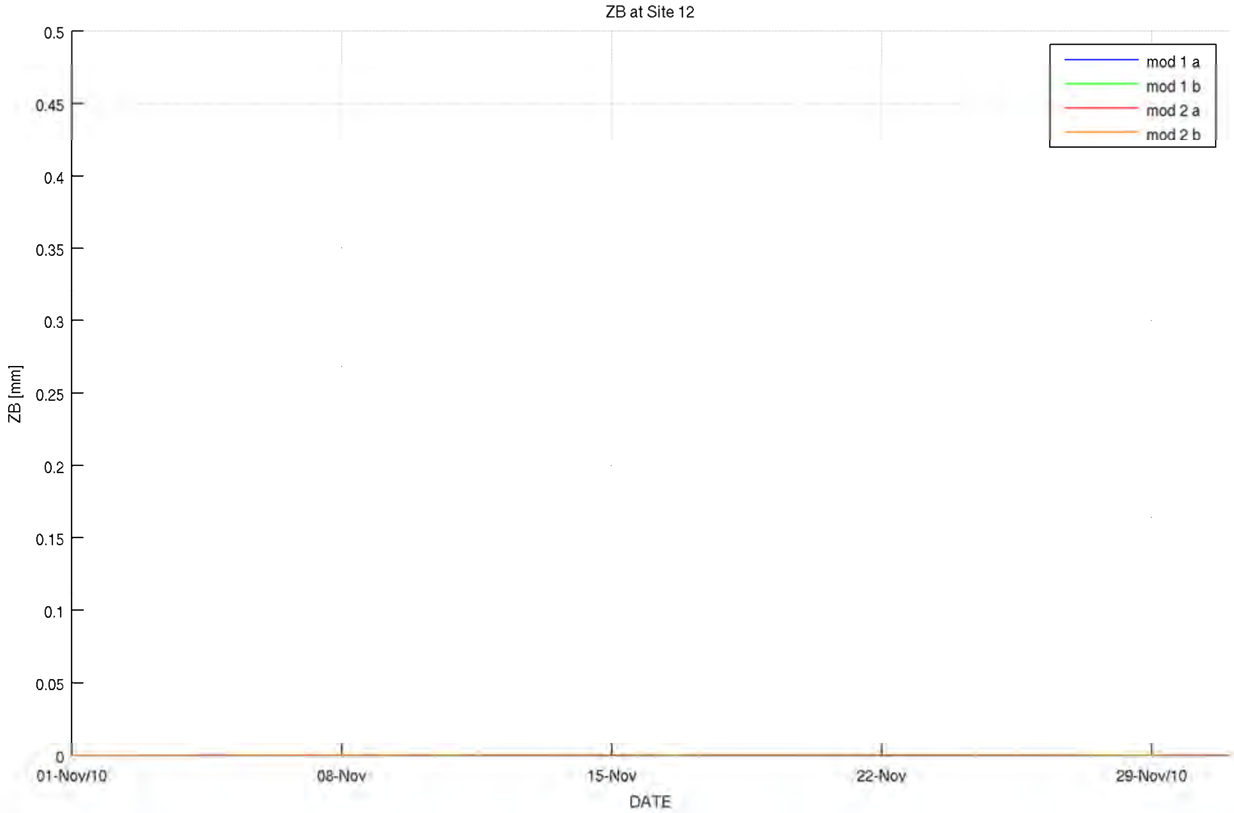
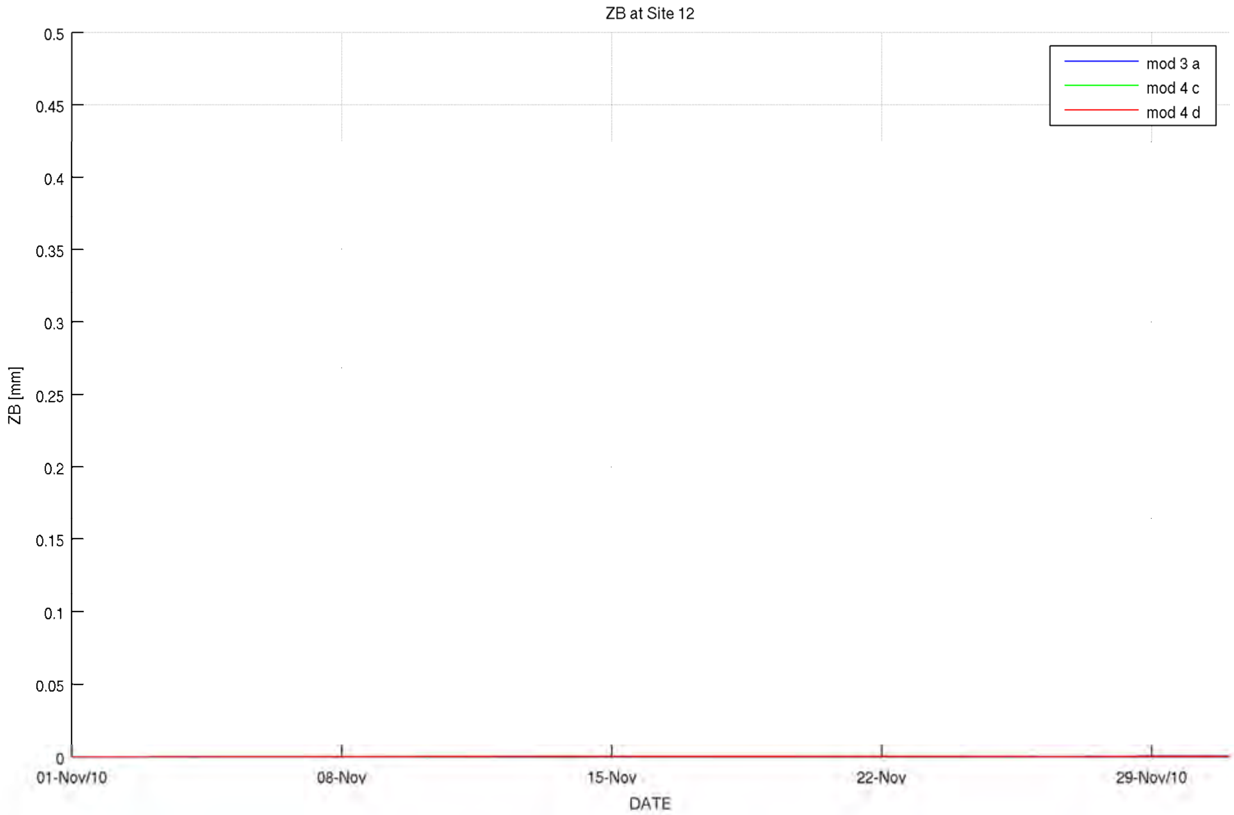
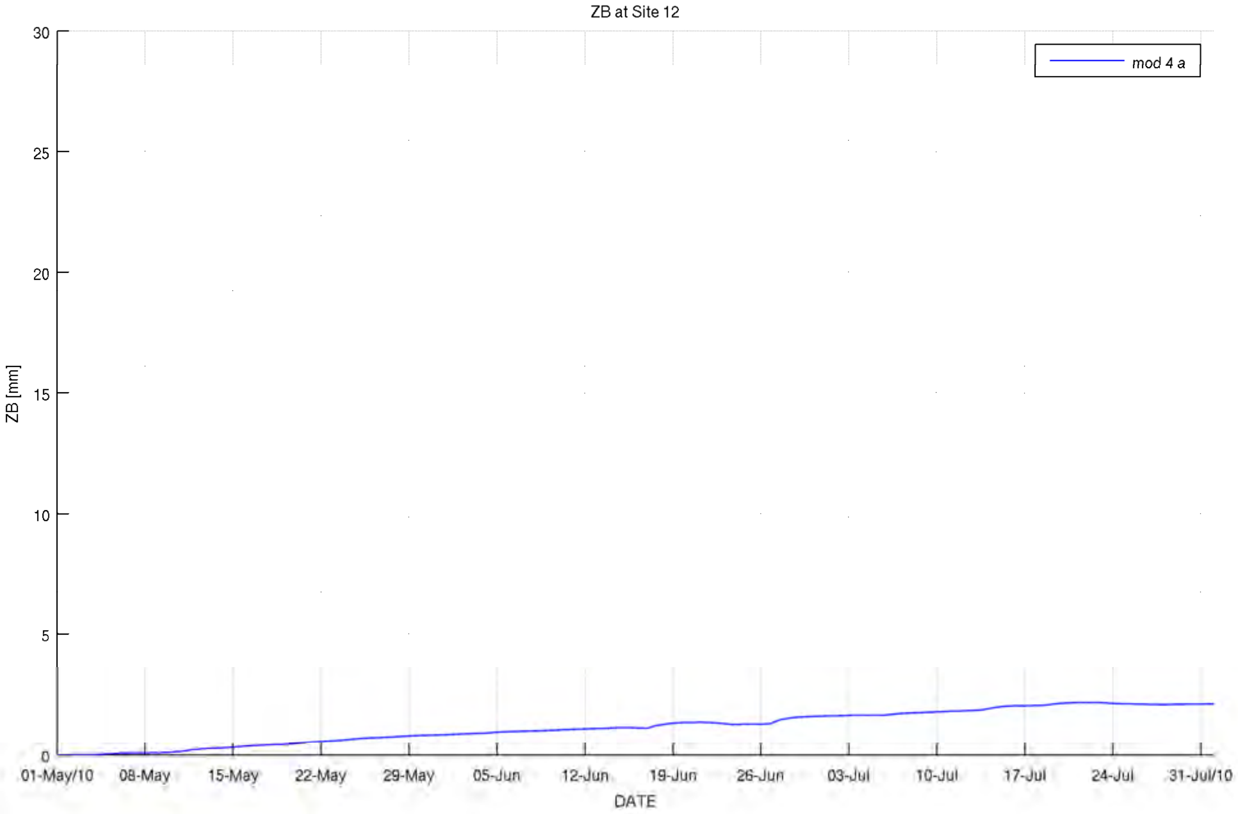
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 12
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 12
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d


ZB at Site 12
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
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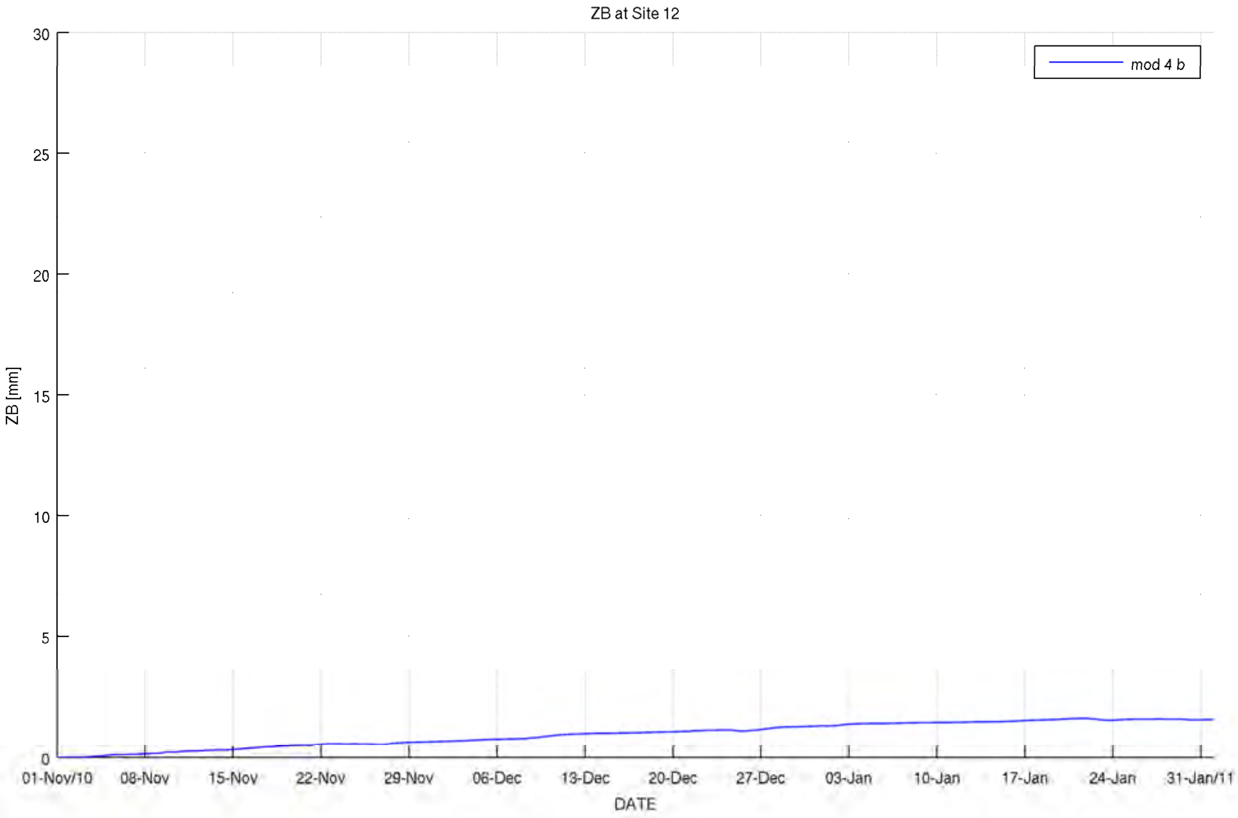
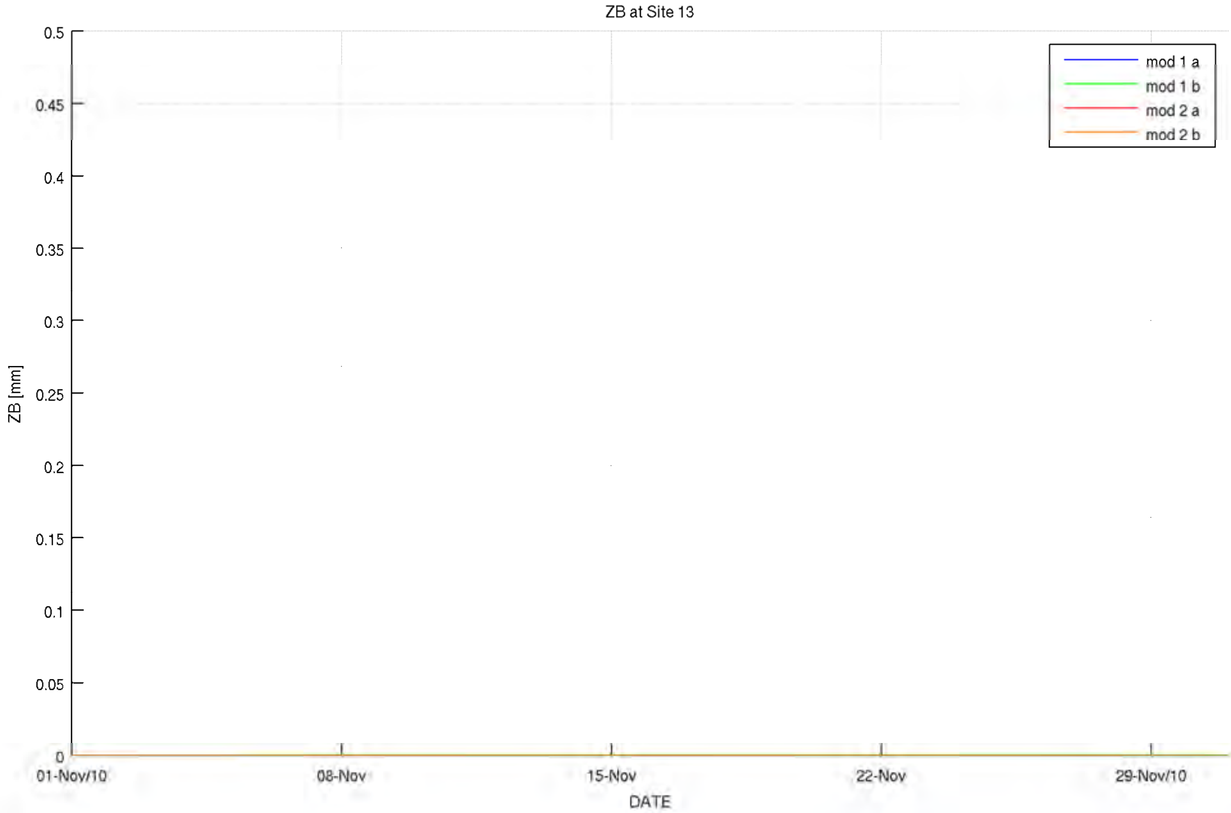
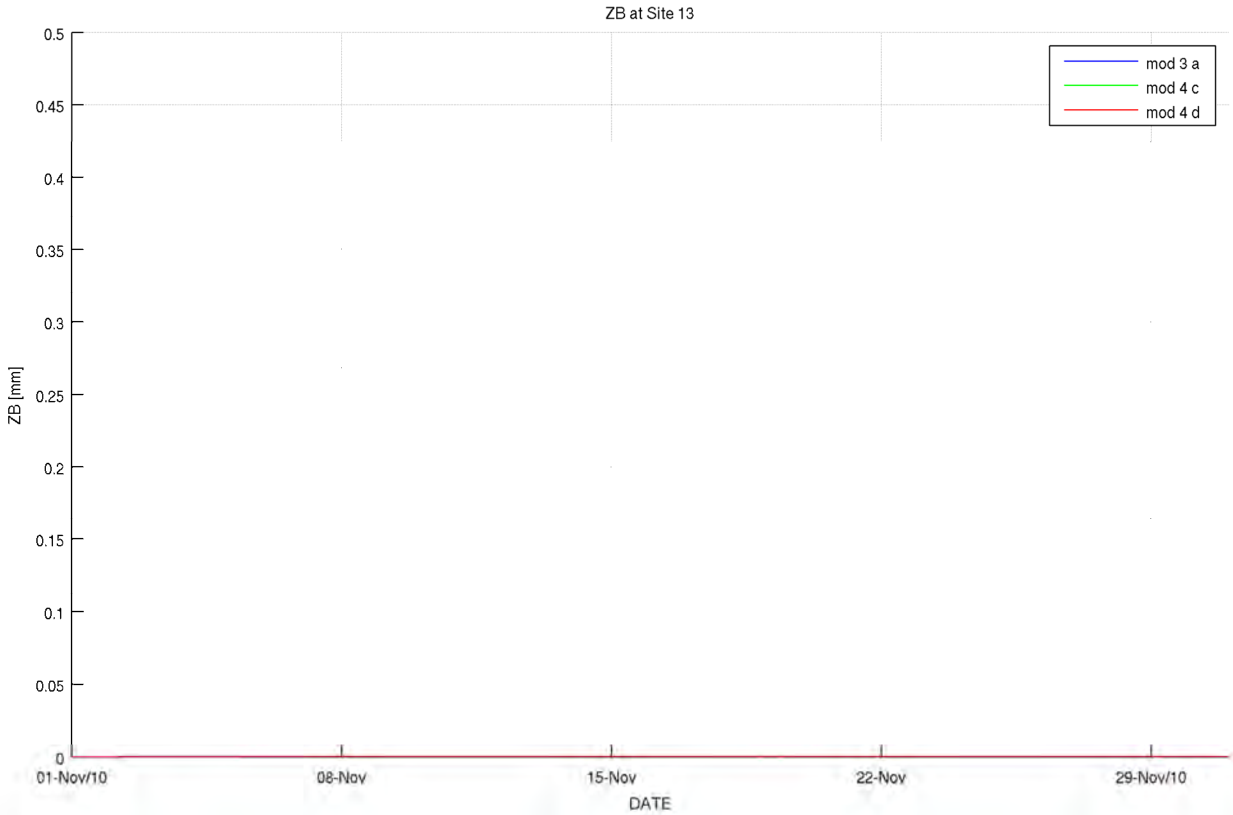
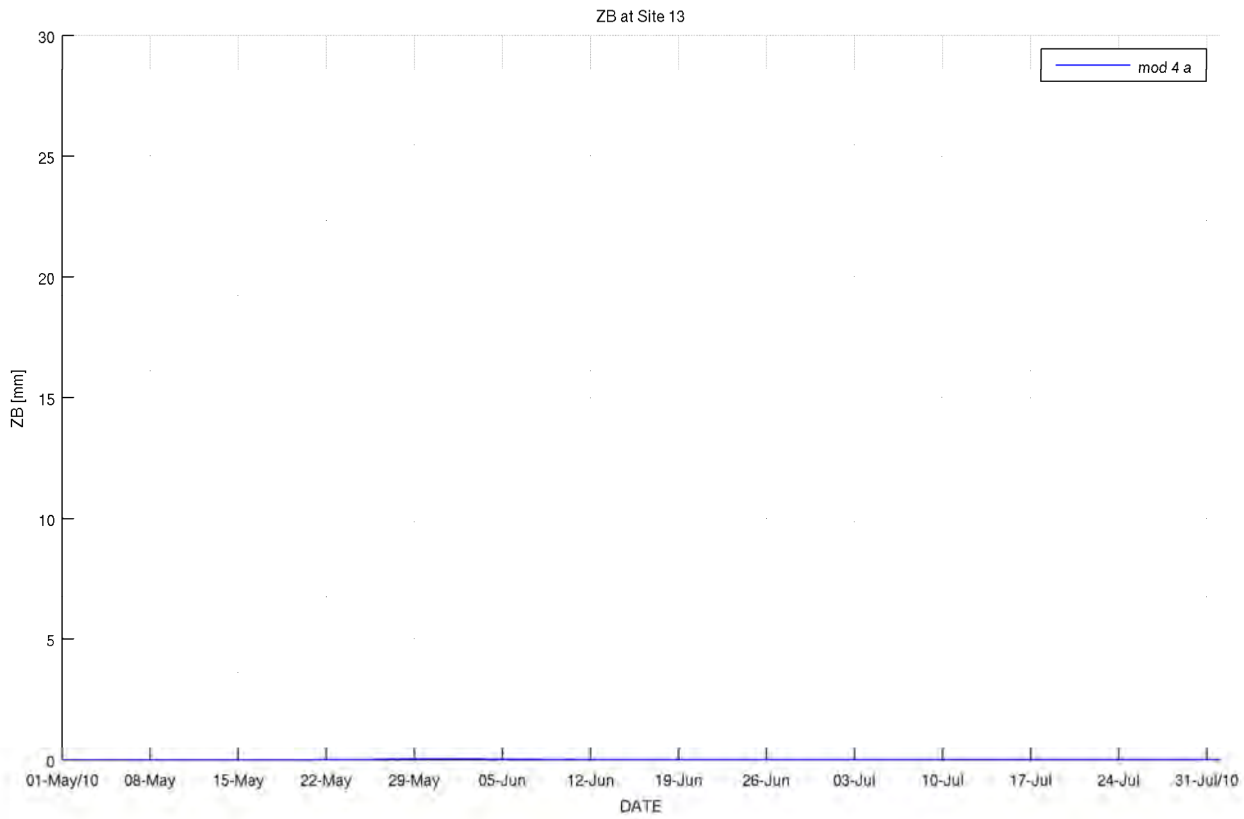
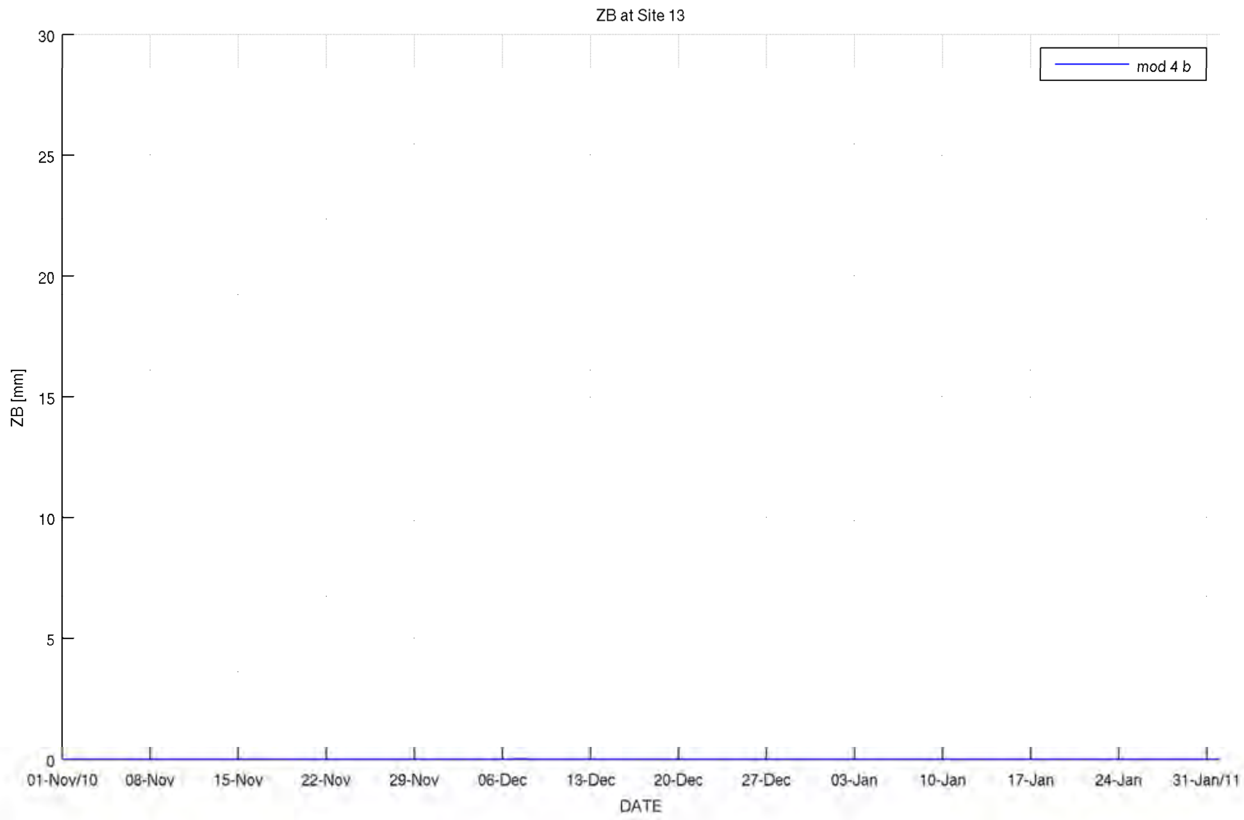
24-Jul
31-Jul/10
DATE

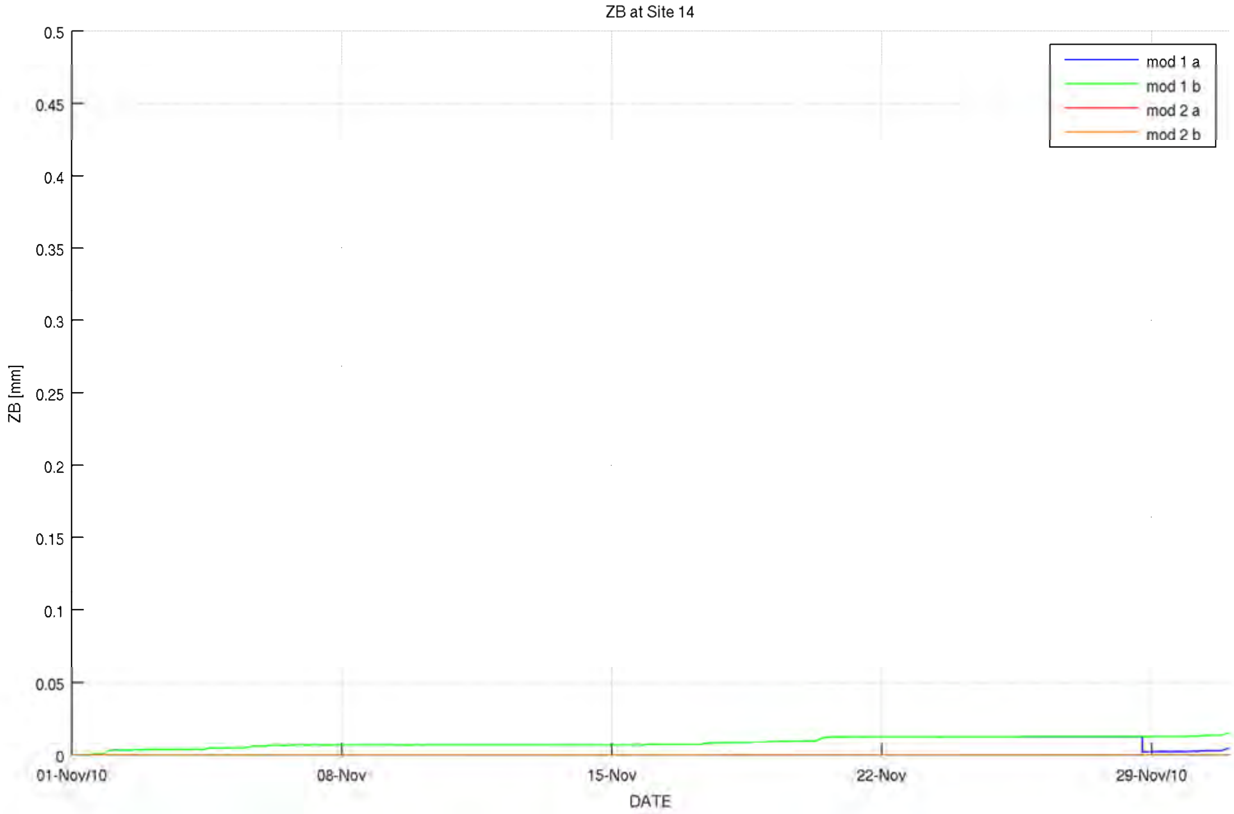

ZB at Site 12
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

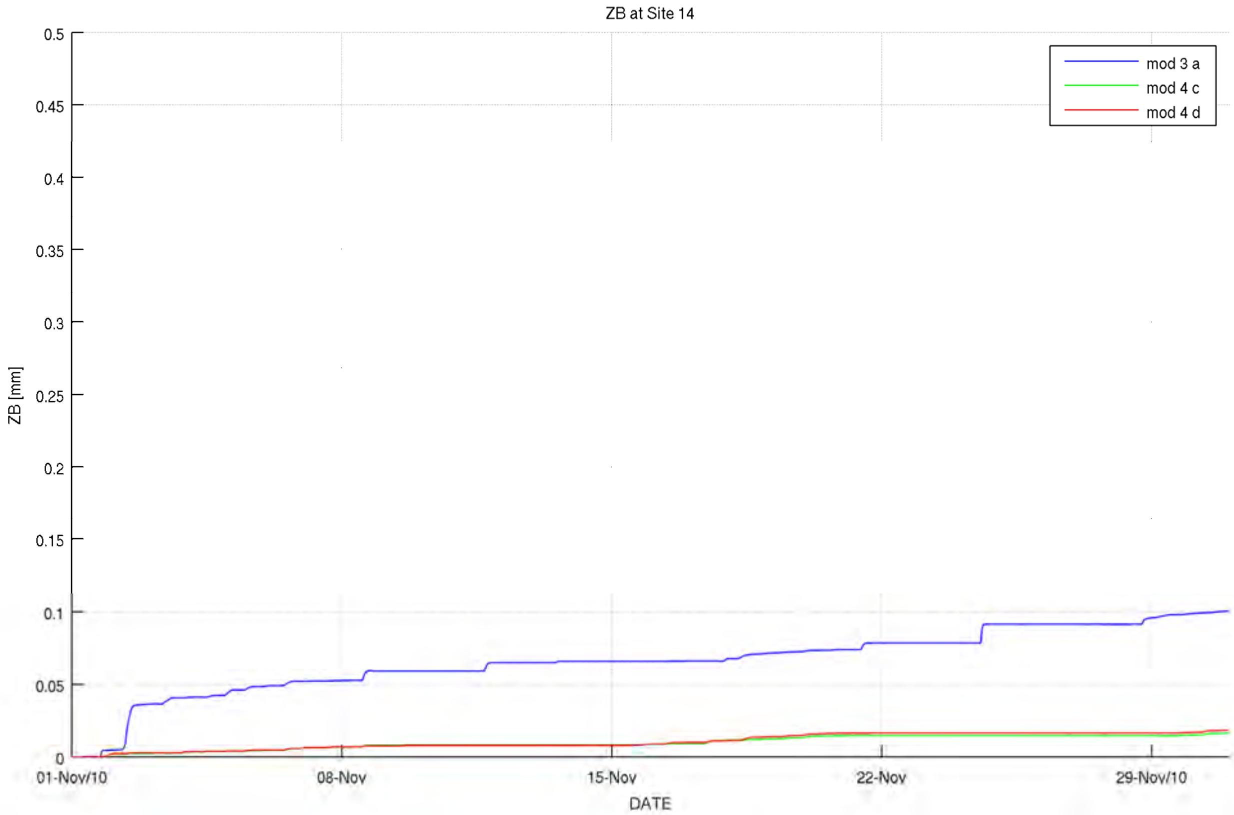

ZB at Site 13
mod 1 a
mod 1 b
mod 2 a
mod 2 b
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

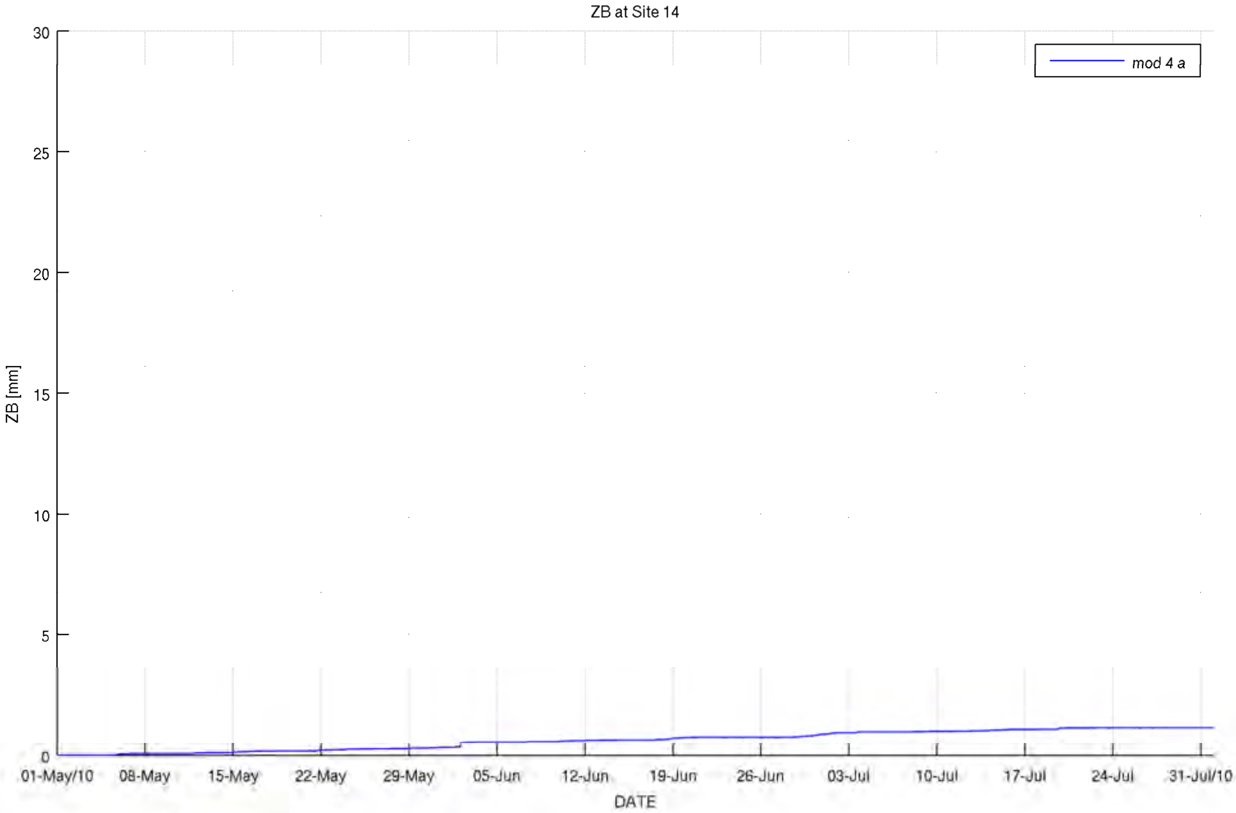

ZB at Site 13
mod 3 a
mod 4 c
mod 4 d
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

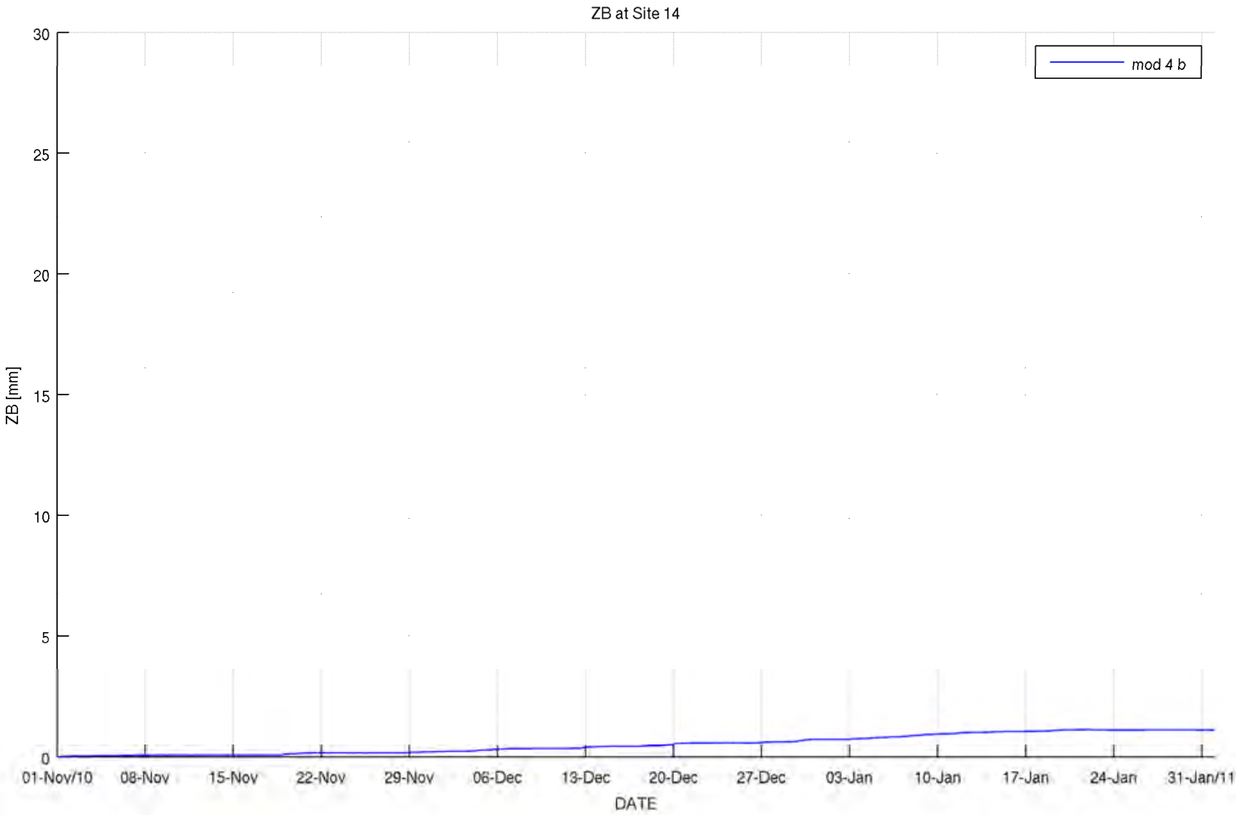

ZB at Site 13
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

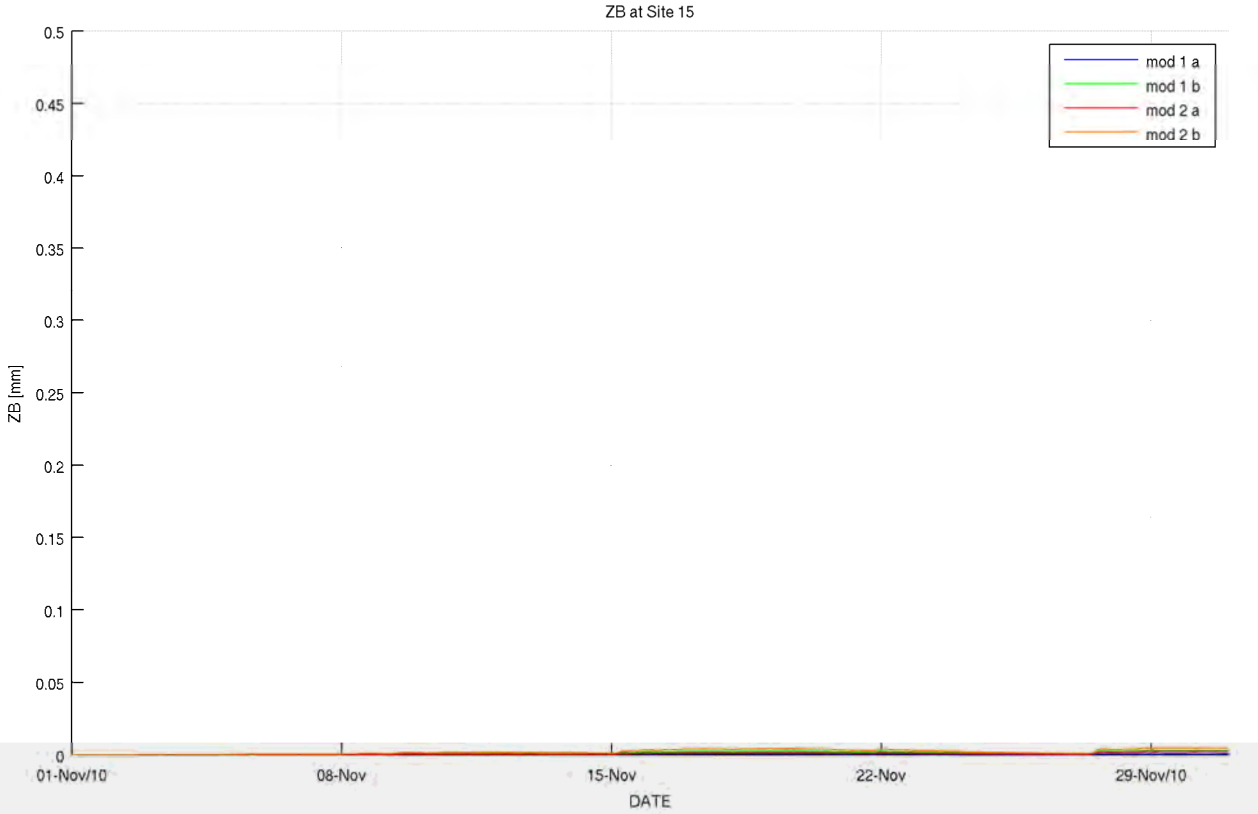

ZB at Site 13
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

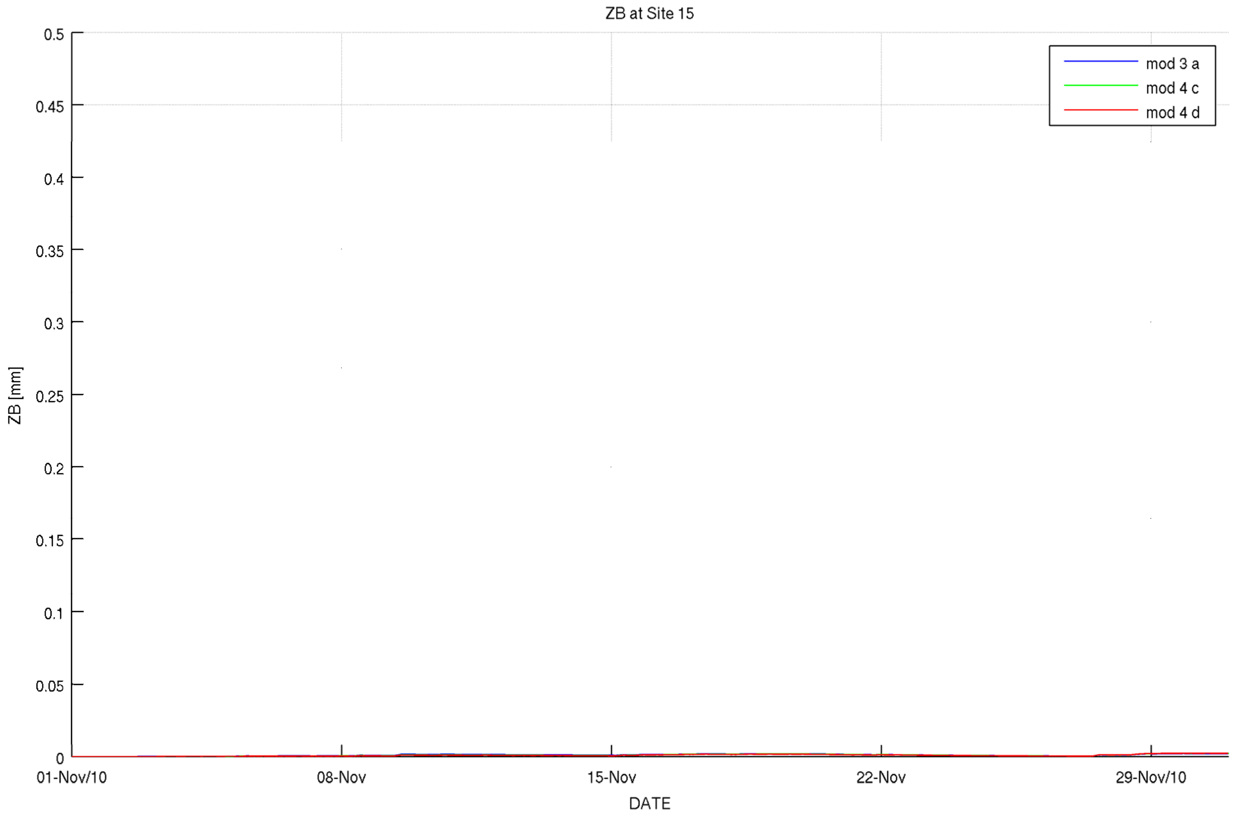

ZB at Site 14
mod 1 a
mod 1 b
mod 2 a
mod 2 b
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

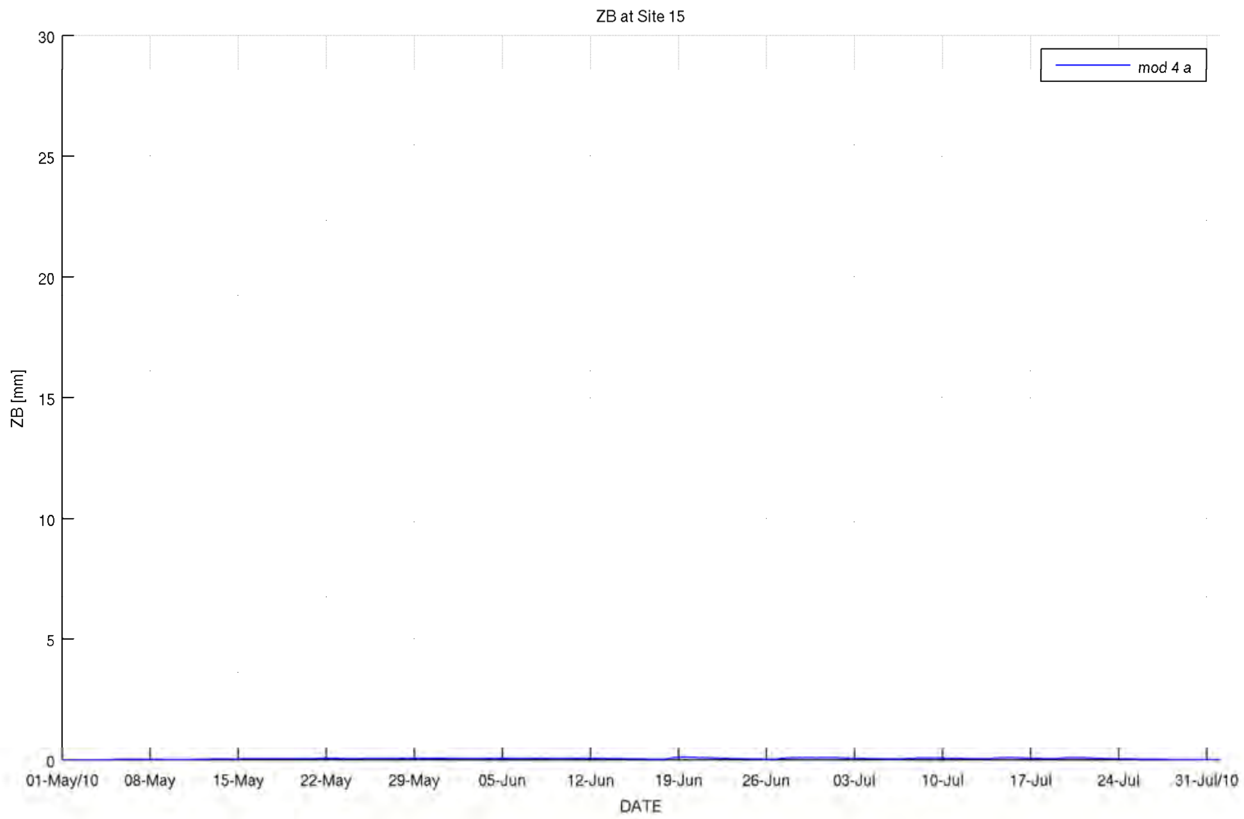

ZB at Site 14
mod 3 a
mod 4 c
mod 4 d
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

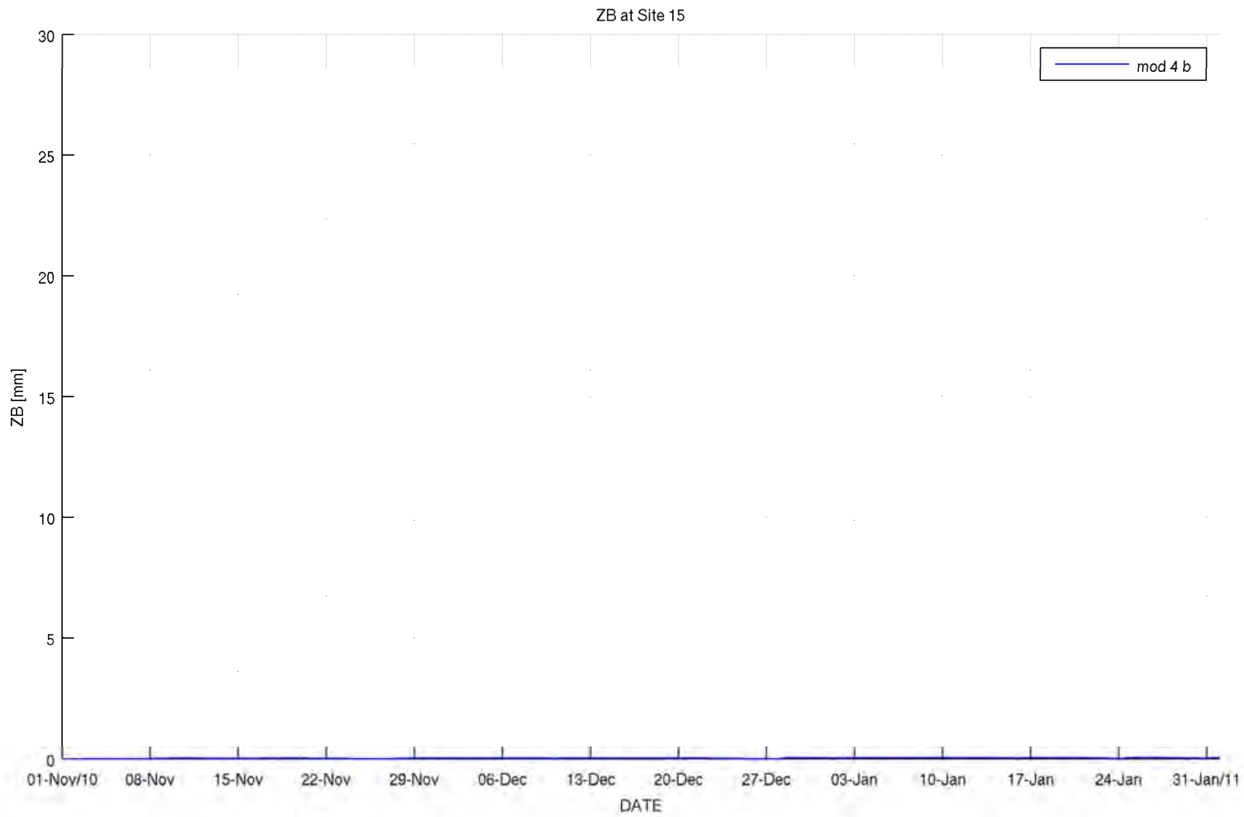

ZB at Site 14
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

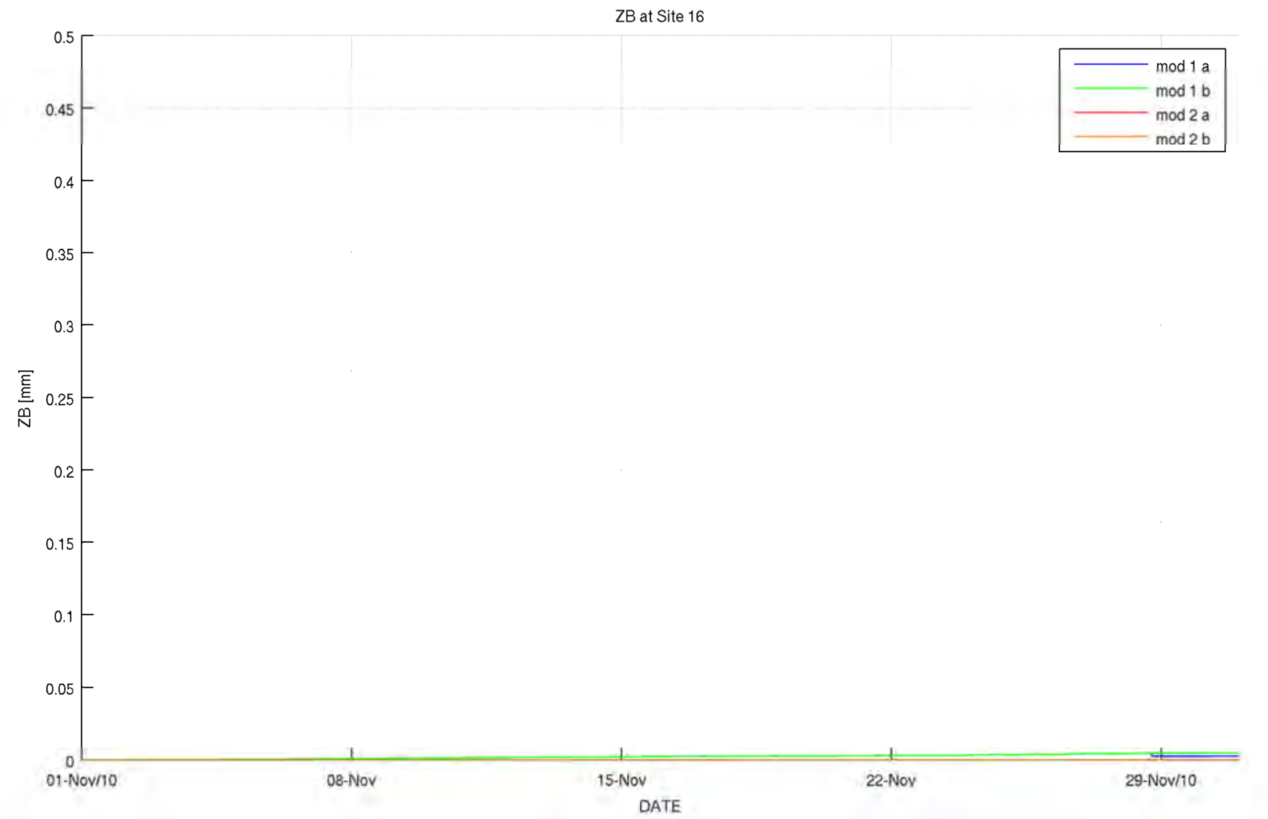

ZB at Site 14
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

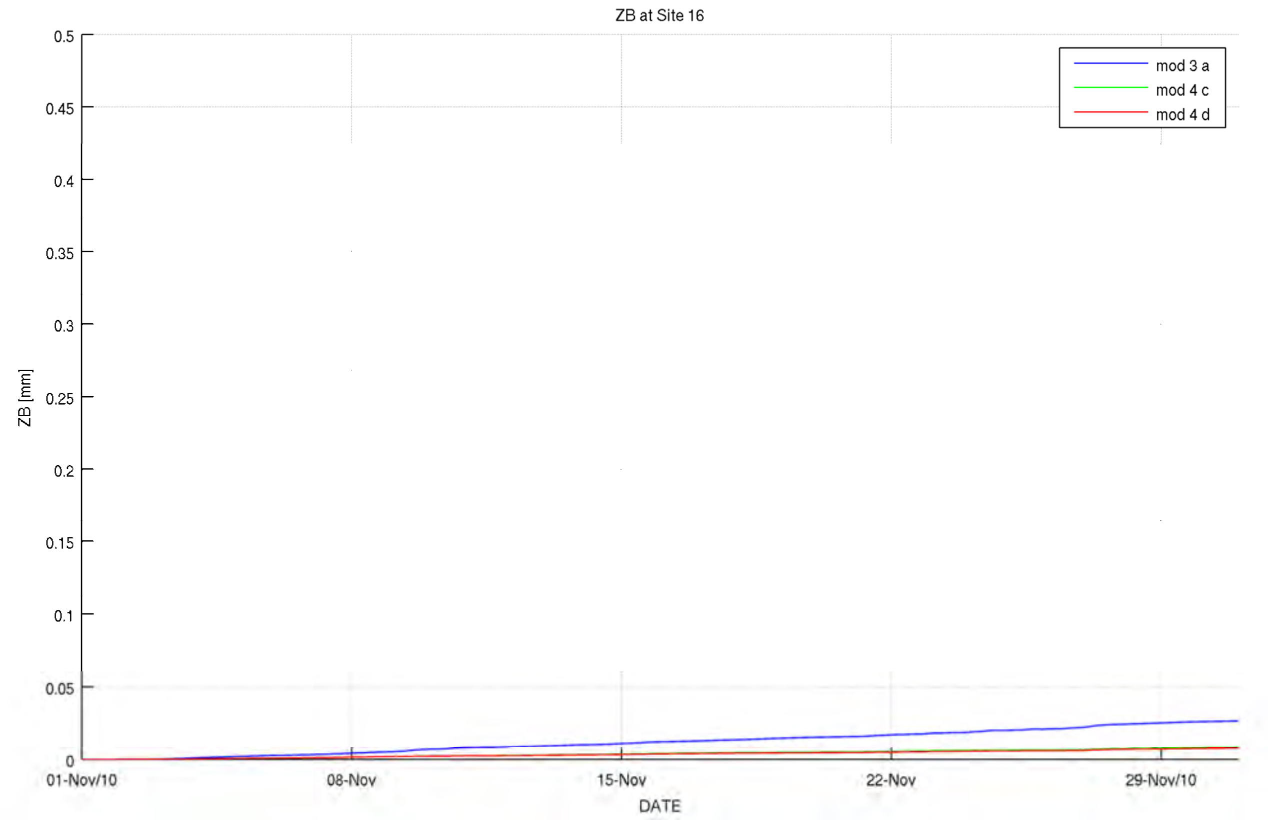

ZB at Site 15
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b

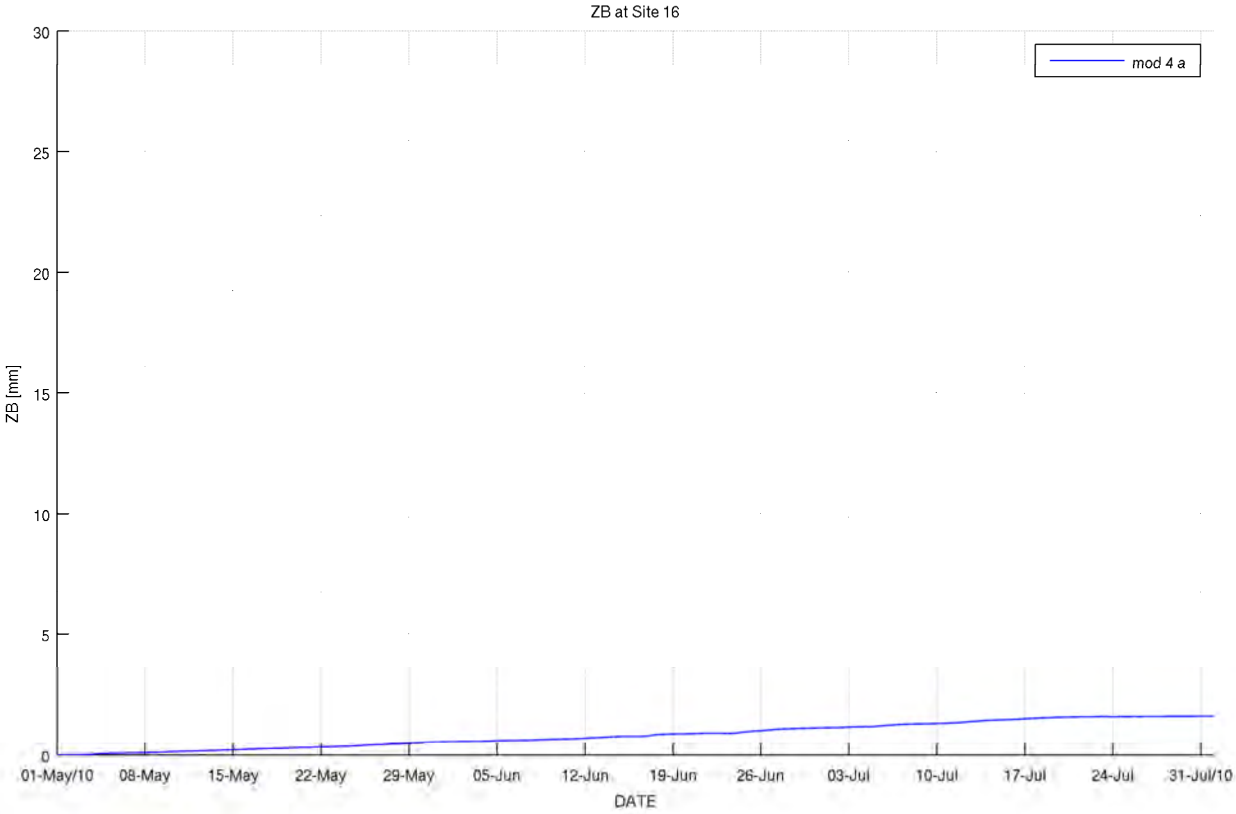

ZB at Site 15
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d

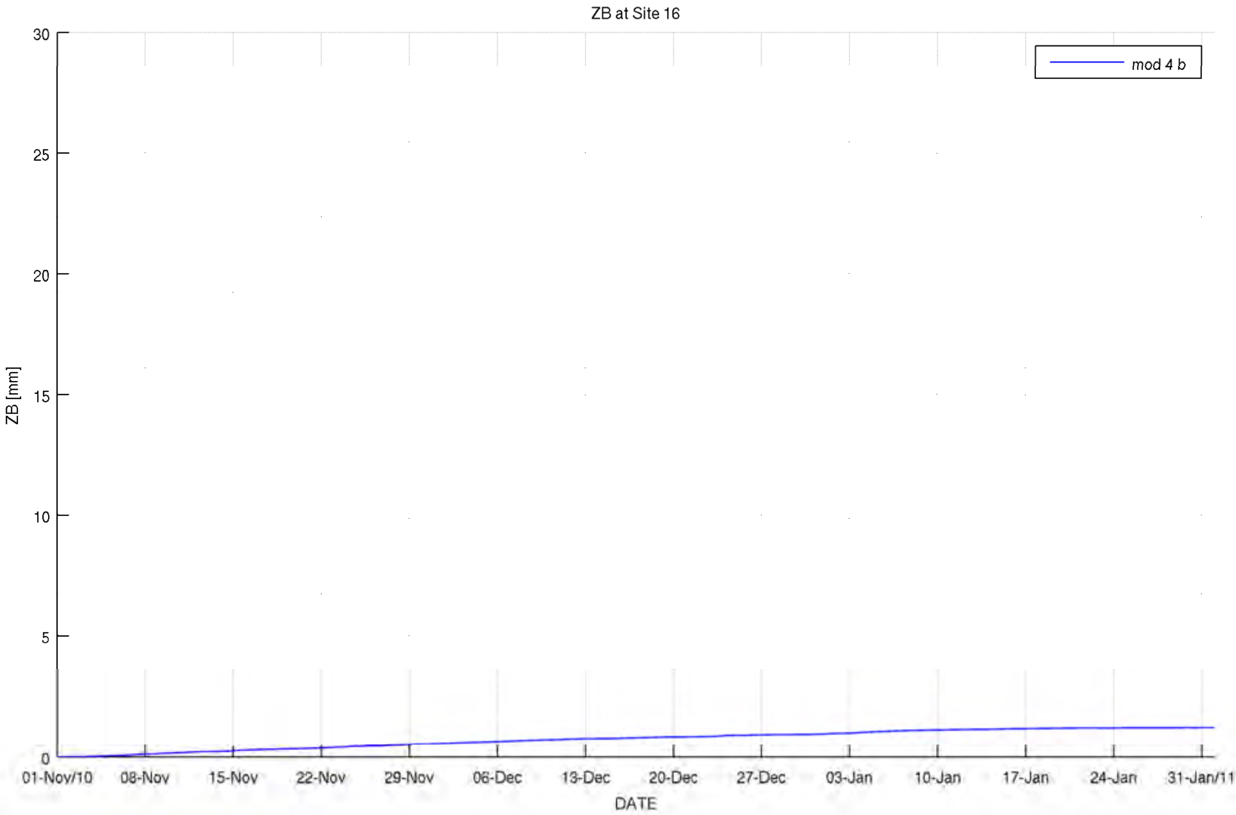

ZB at Site 15
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

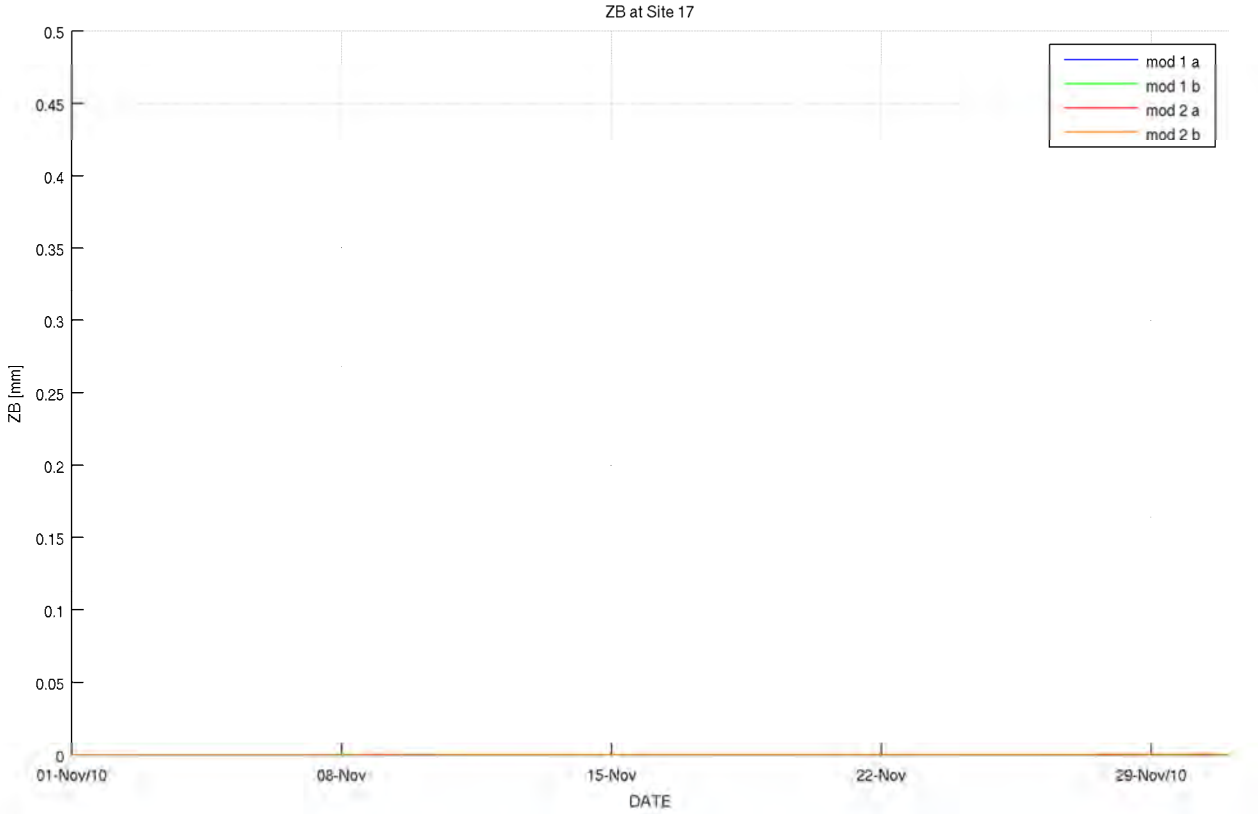

ZB at Site 15
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

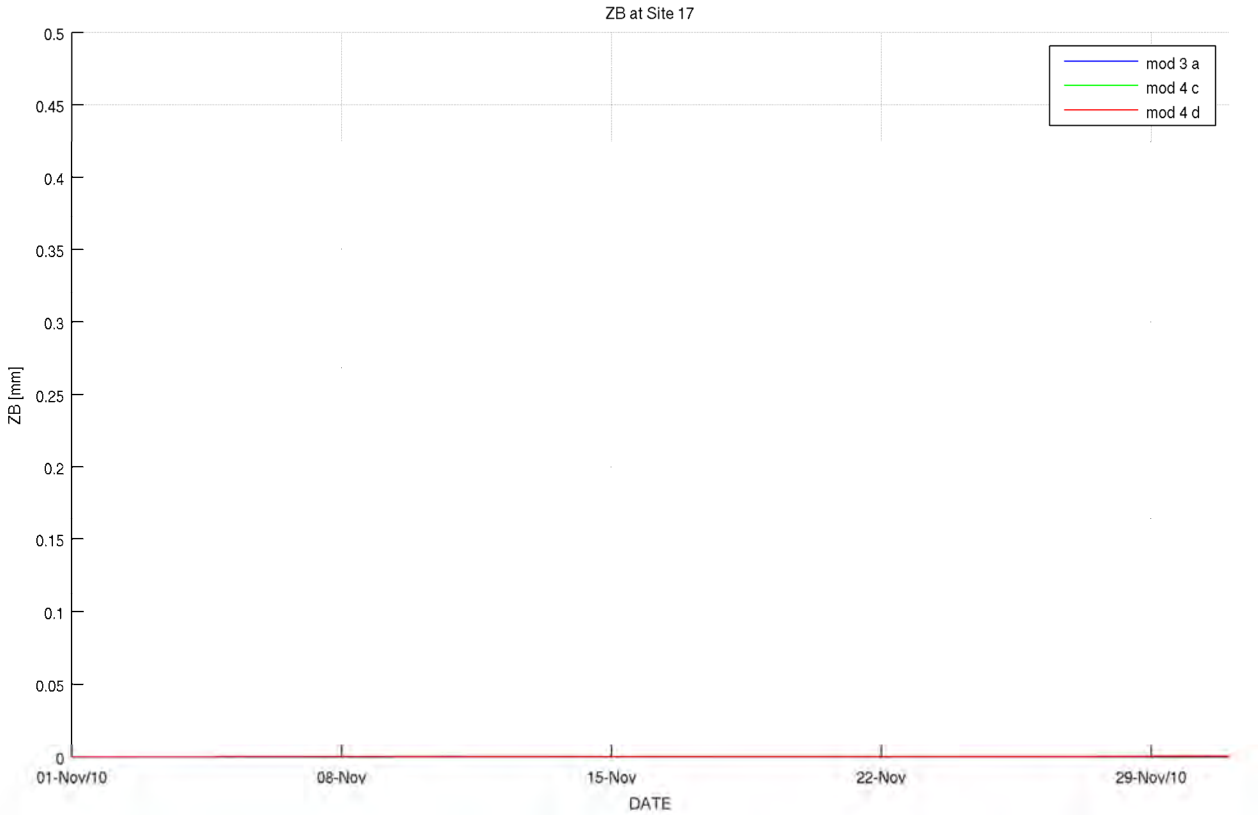

ZB at Site 16
ZB [mm]
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10

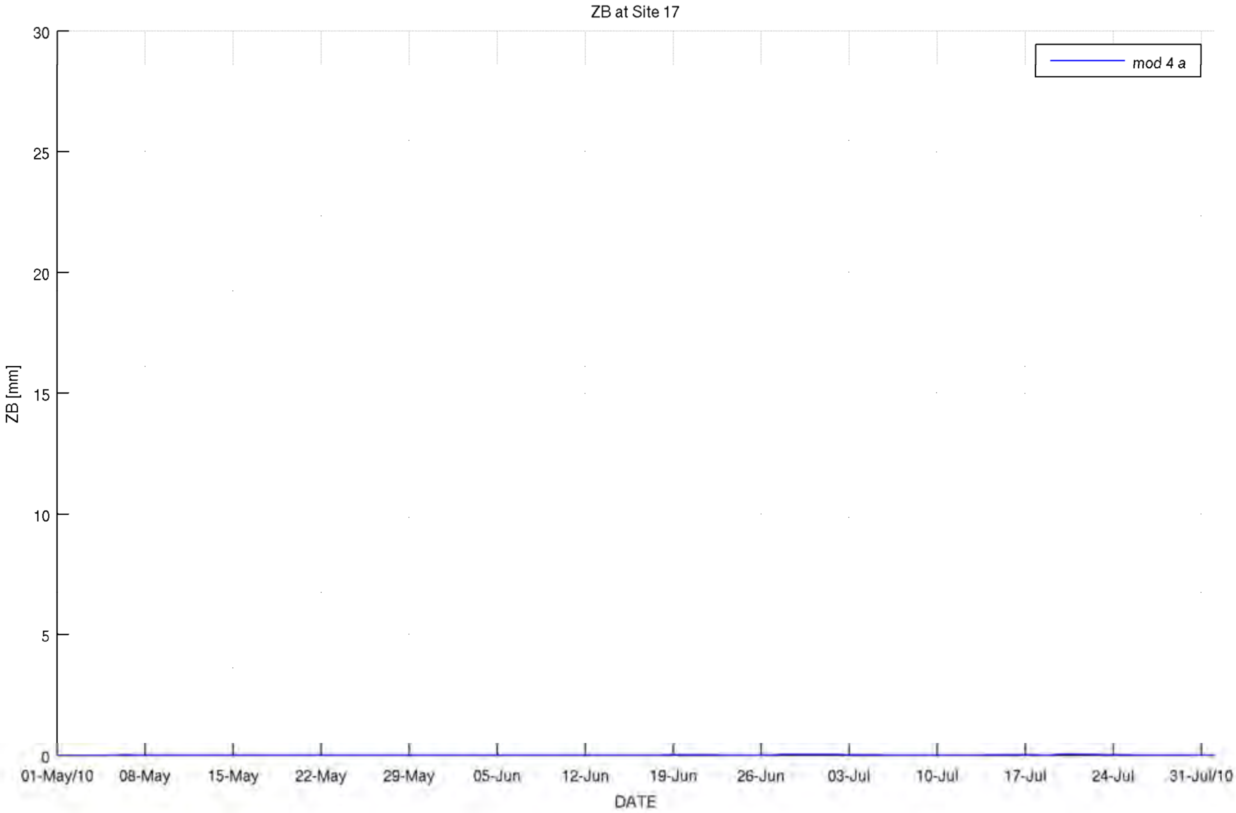

ZB at Site 16
ZB [mm]
DATE
mod 3 a
mod 4 c
mod 4 d
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10

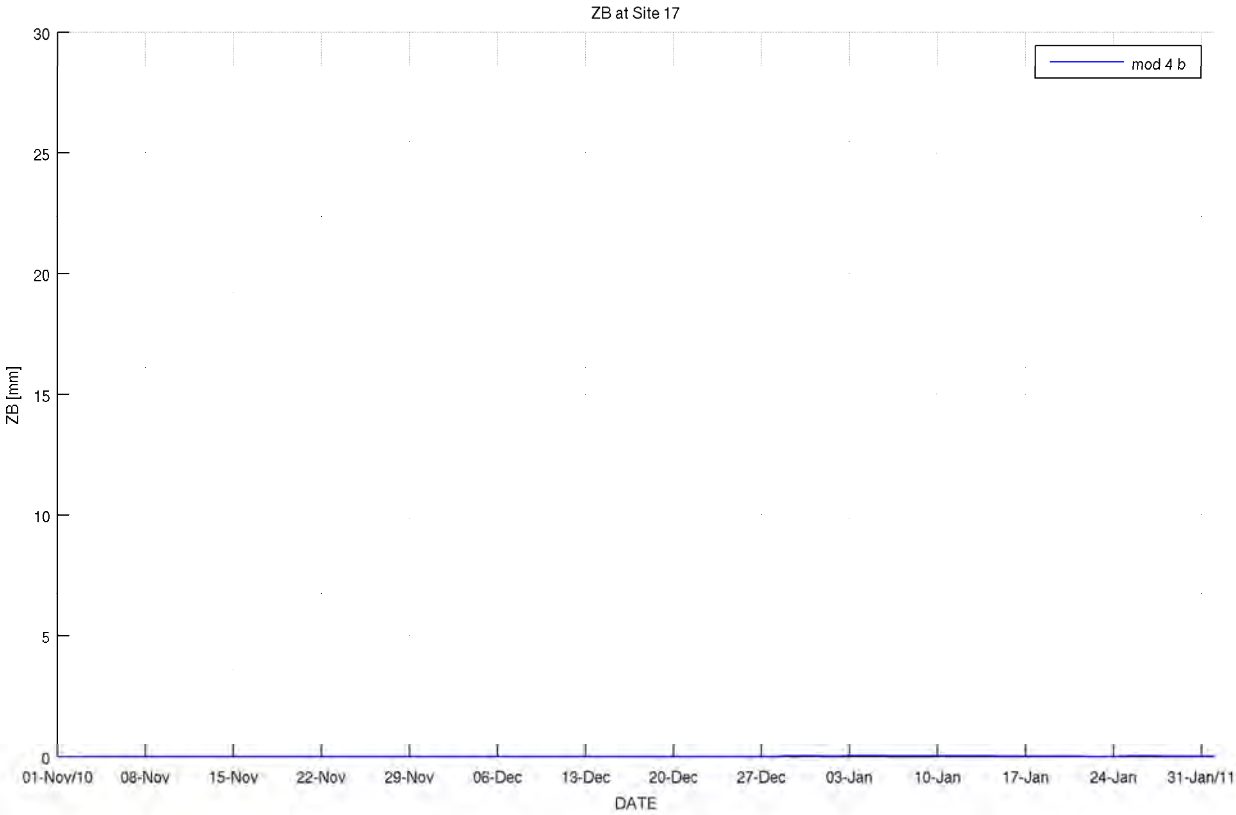

ZB at Site 16
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE

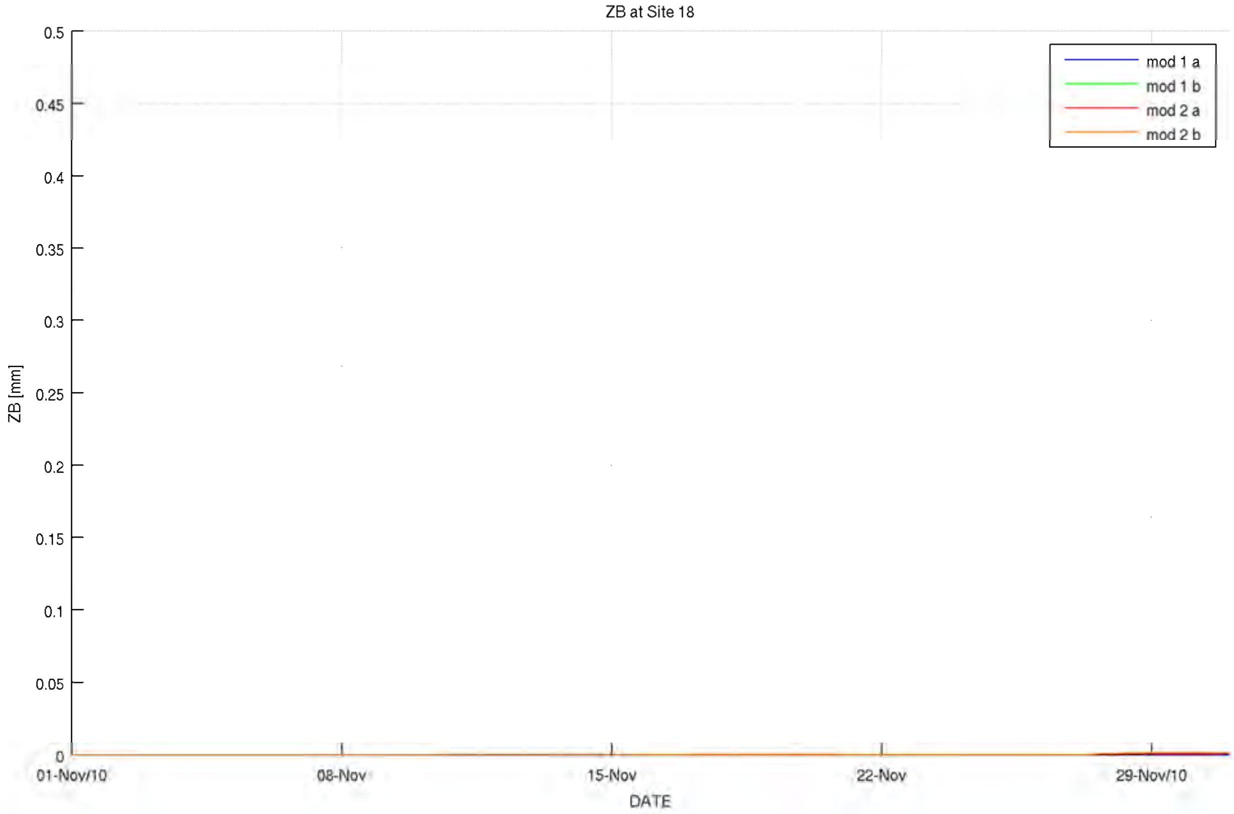

ZB at Site 16
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

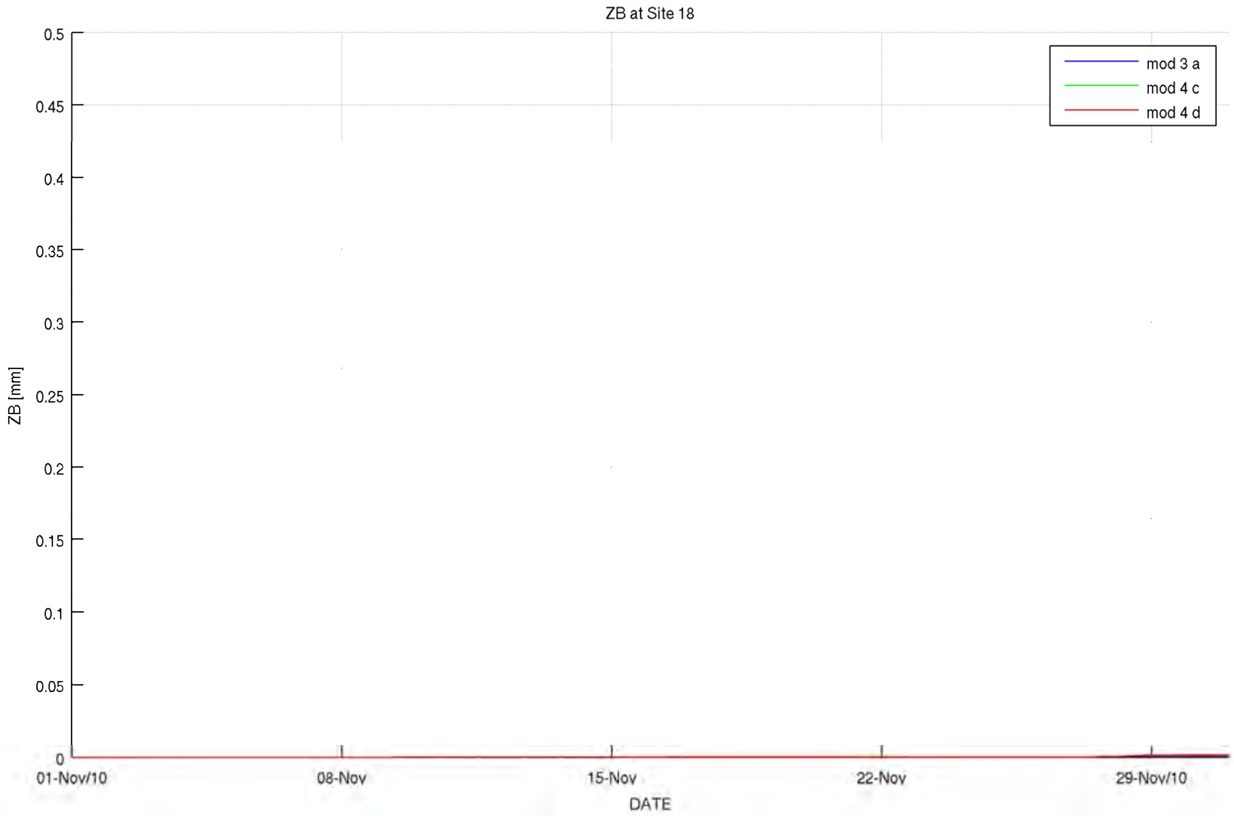

ZB at Site 17
mod 1 a
mod 1 b
mod 2 a
mod 2 b
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

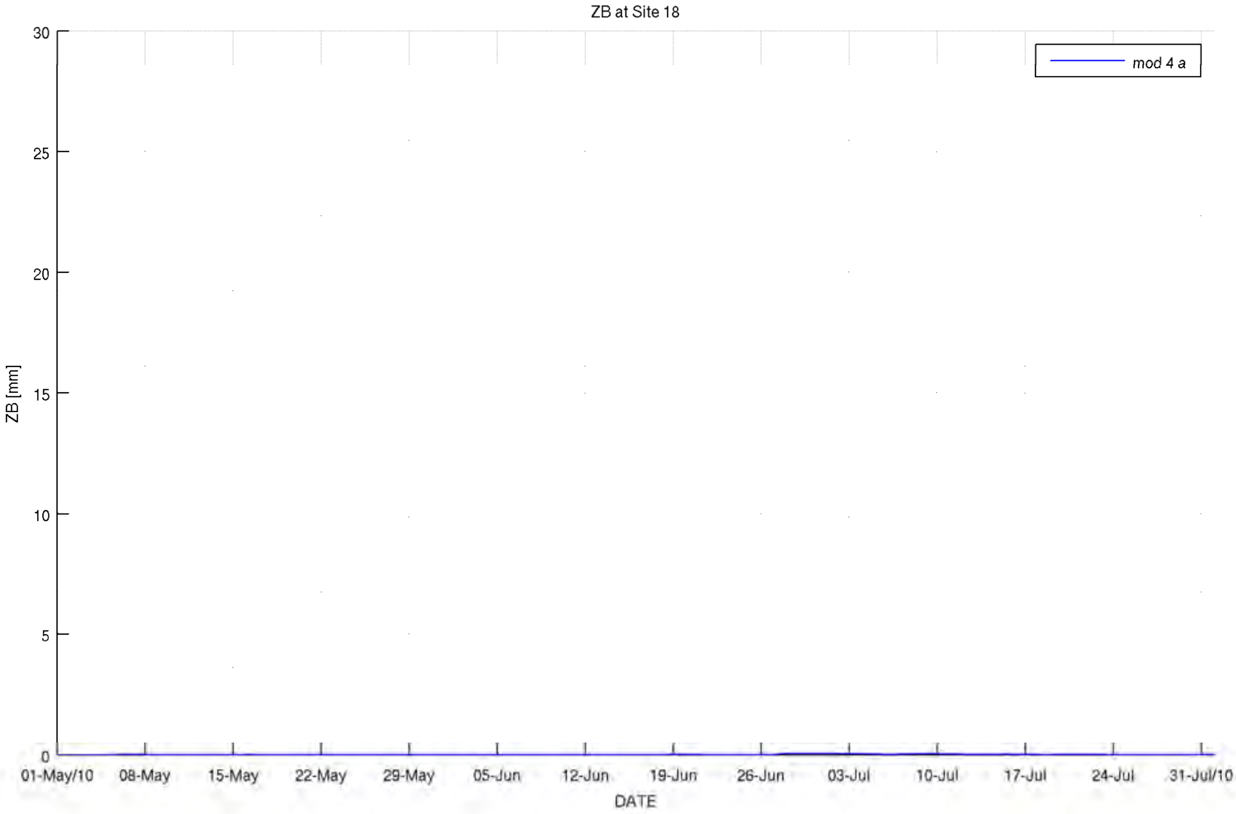

ZB at Site 17
mod 3 a
mod 4 c
mod 4 d
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE

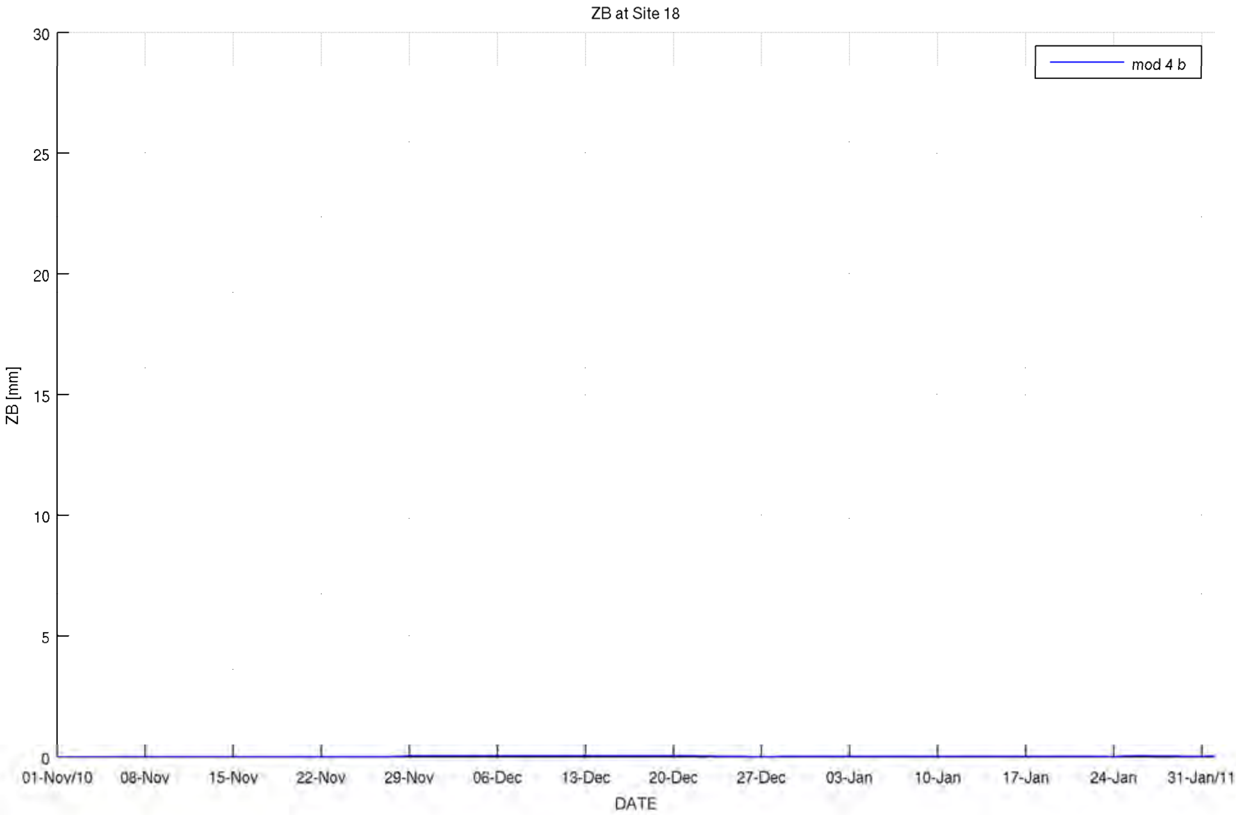

ZB at Site 17
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 17
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 18
mod 1 a
mod 1 b
mod 2 a
mod 2 b
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE


ZB at Site 18
mod 3 a
mod 4 c
mod 4 d
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE


ZB at Site 18
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 18
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
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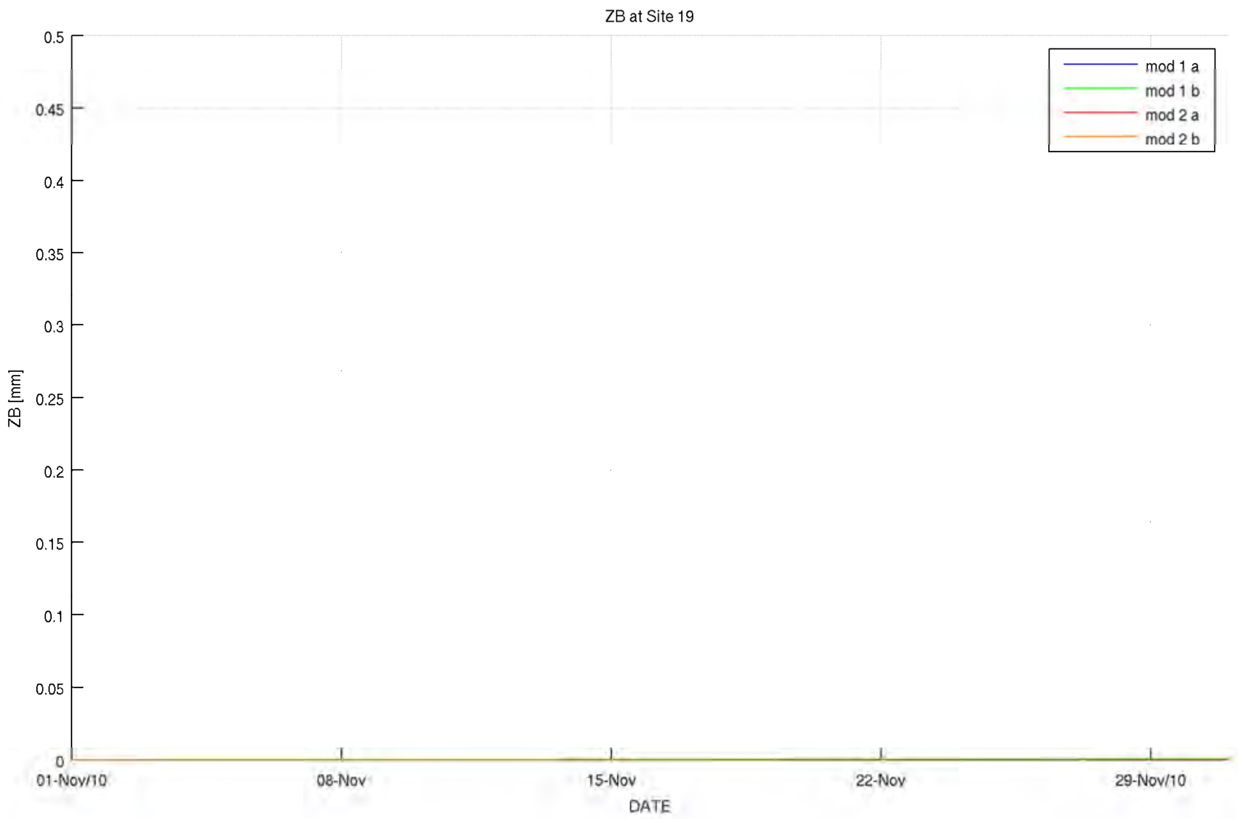
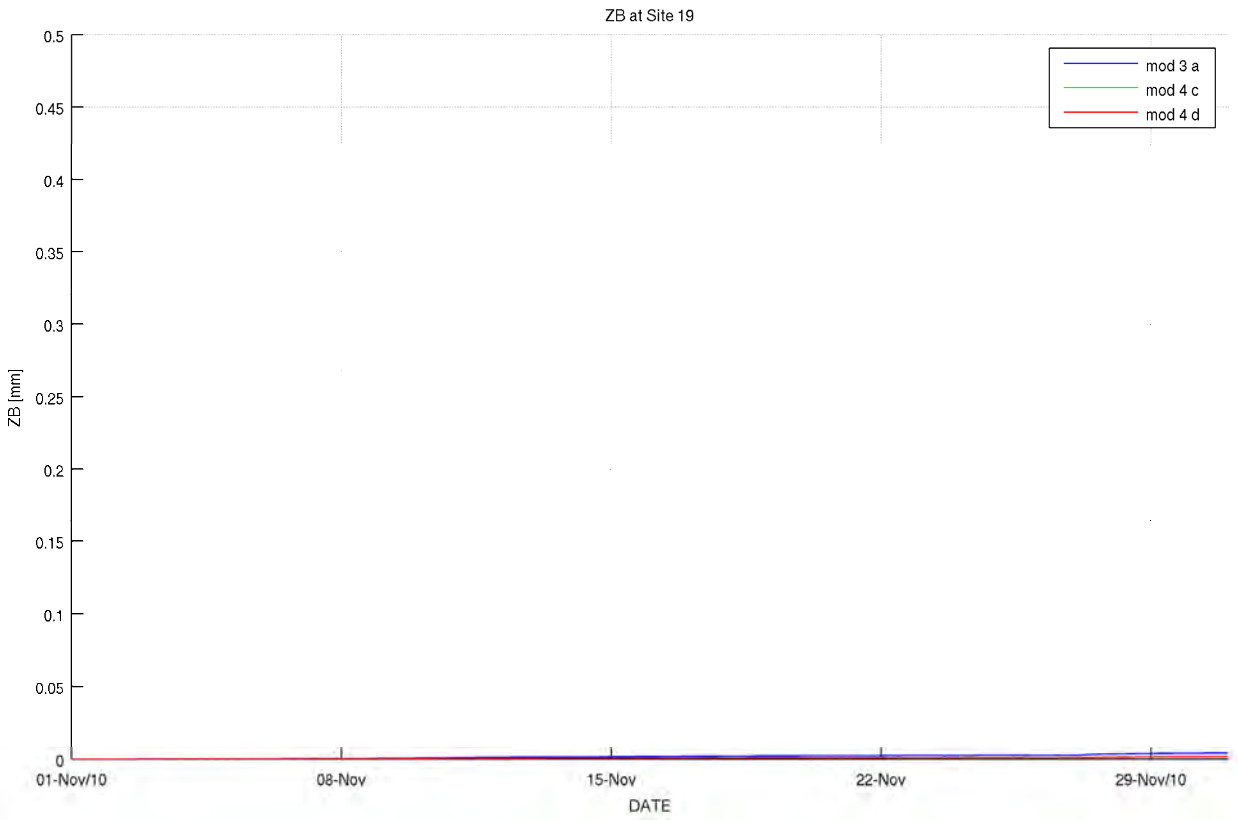
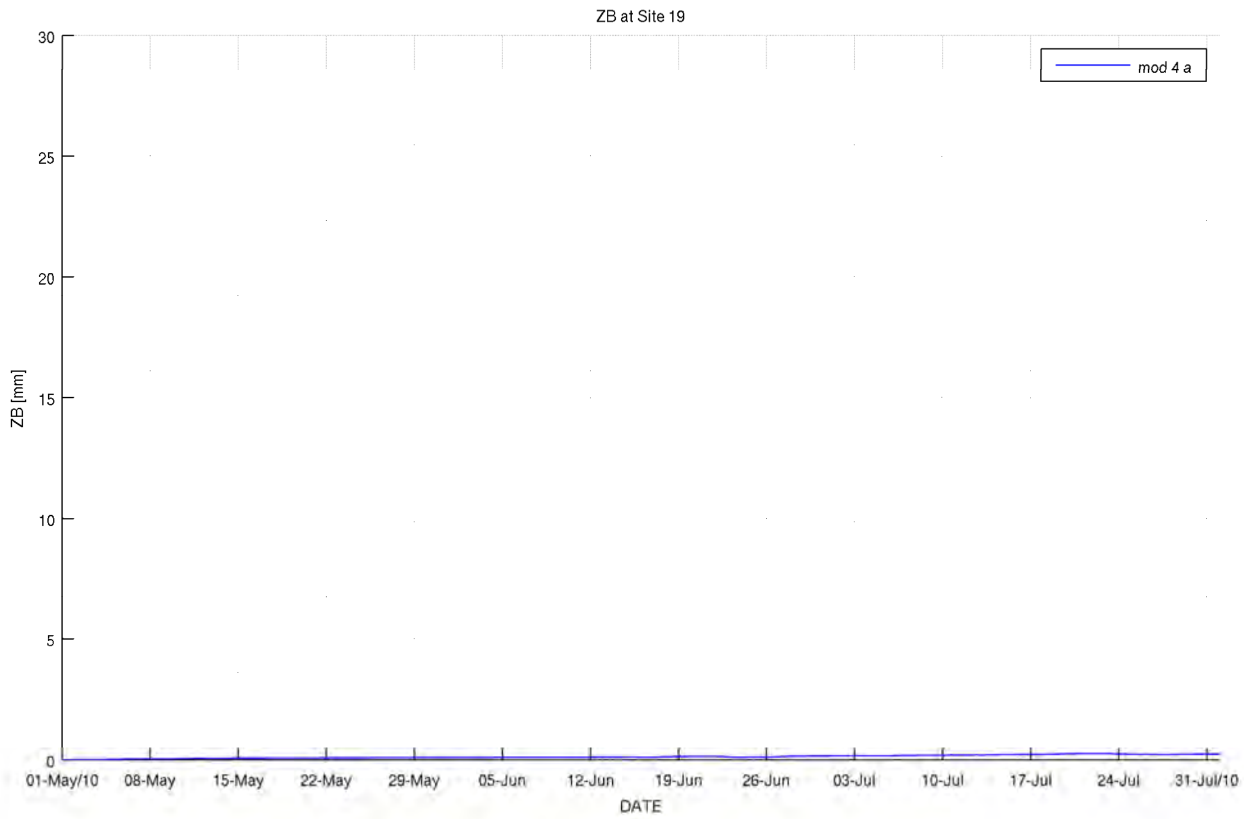
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 19
ZB [mm]
DATE
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 19
ZB [mm]
DATE
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
mod 3 a
mod 4 c
mod 4 d


ZB at Site 19
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
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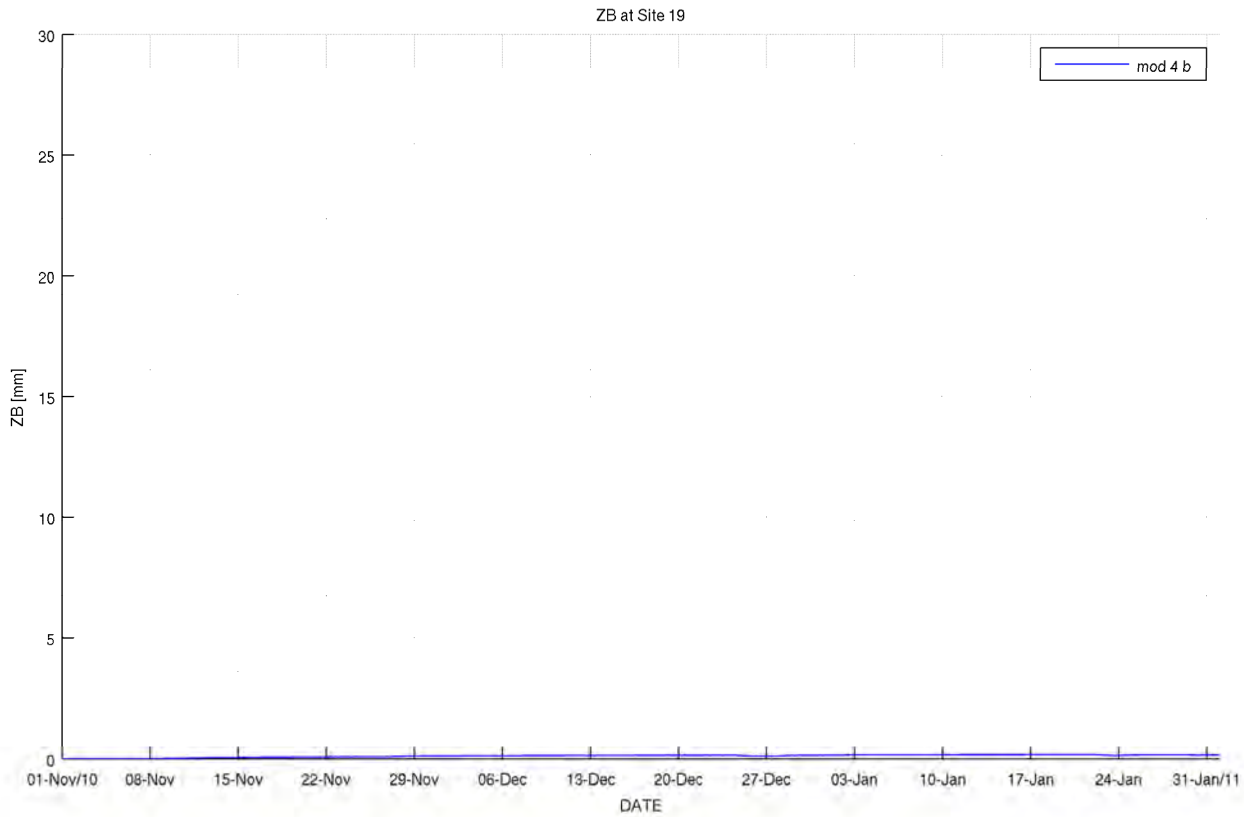
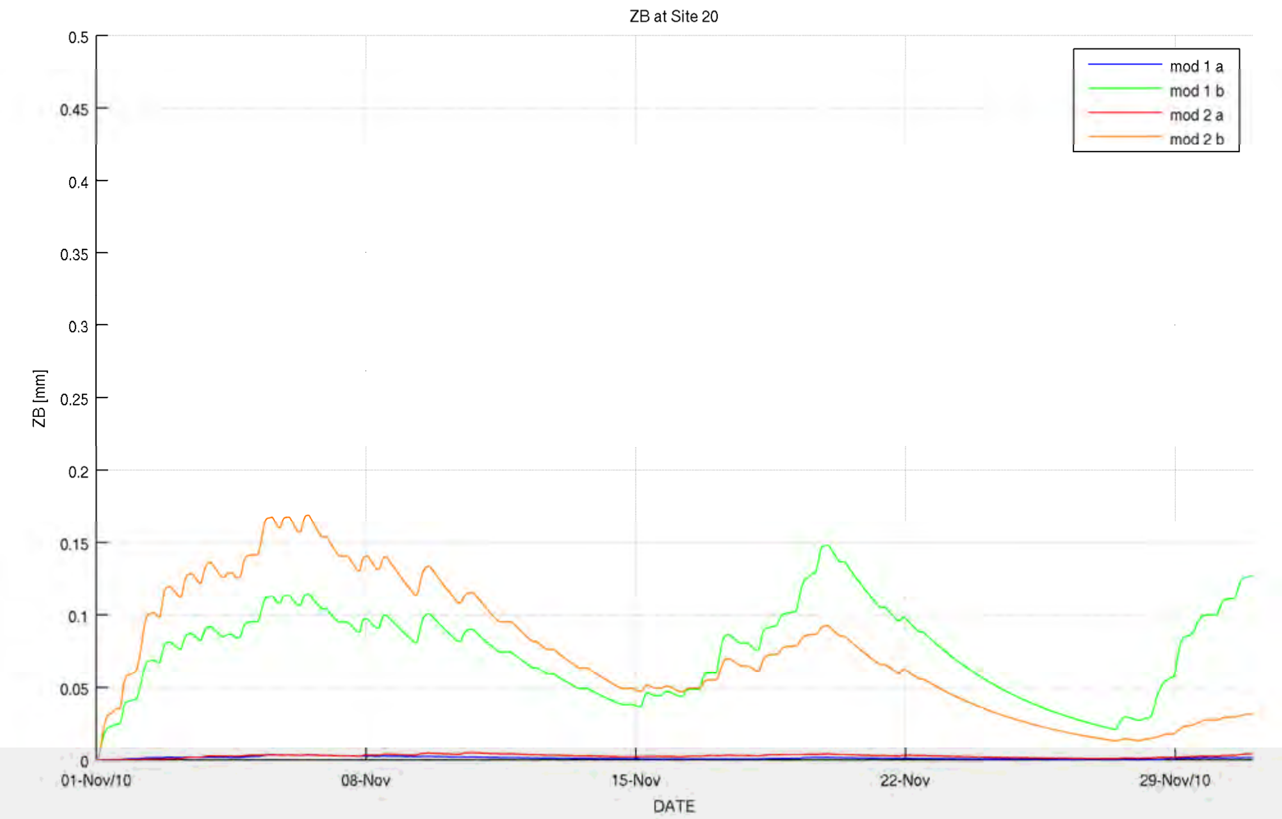
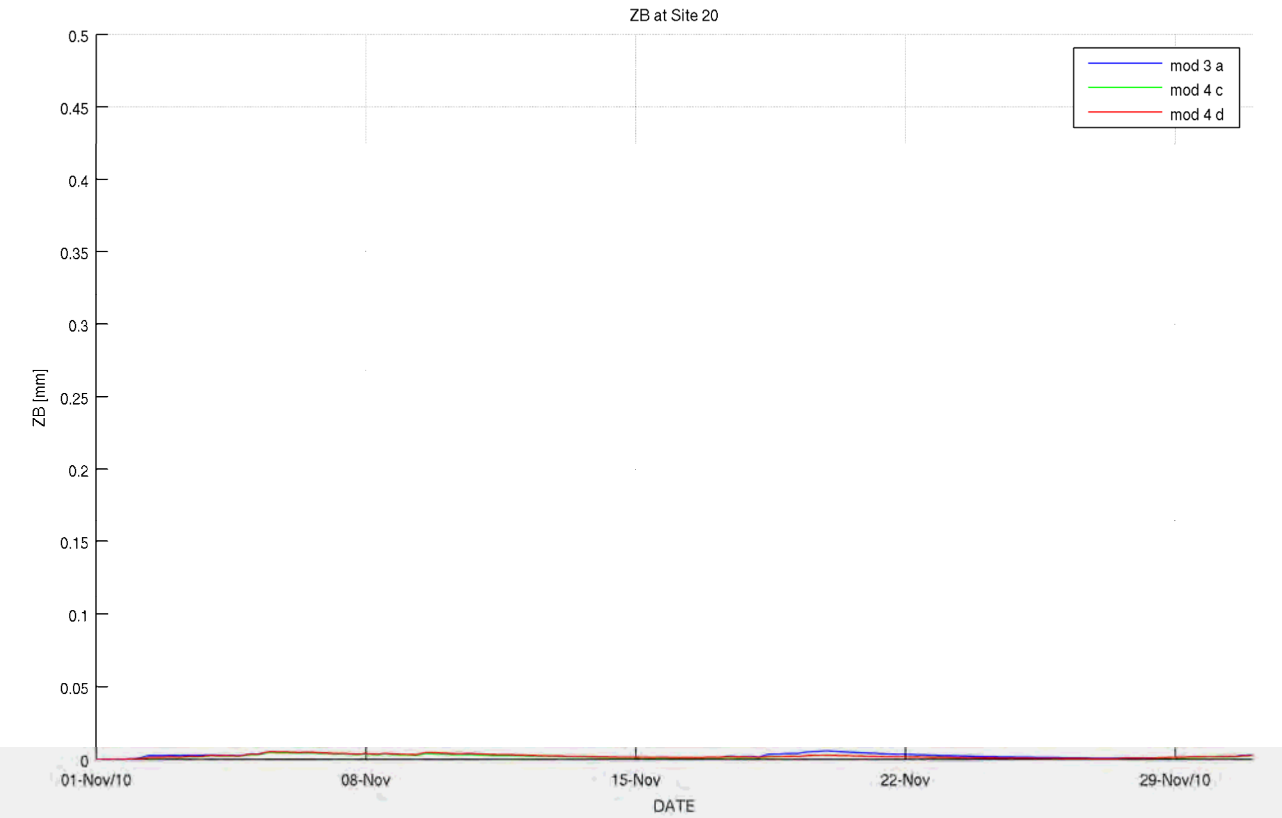
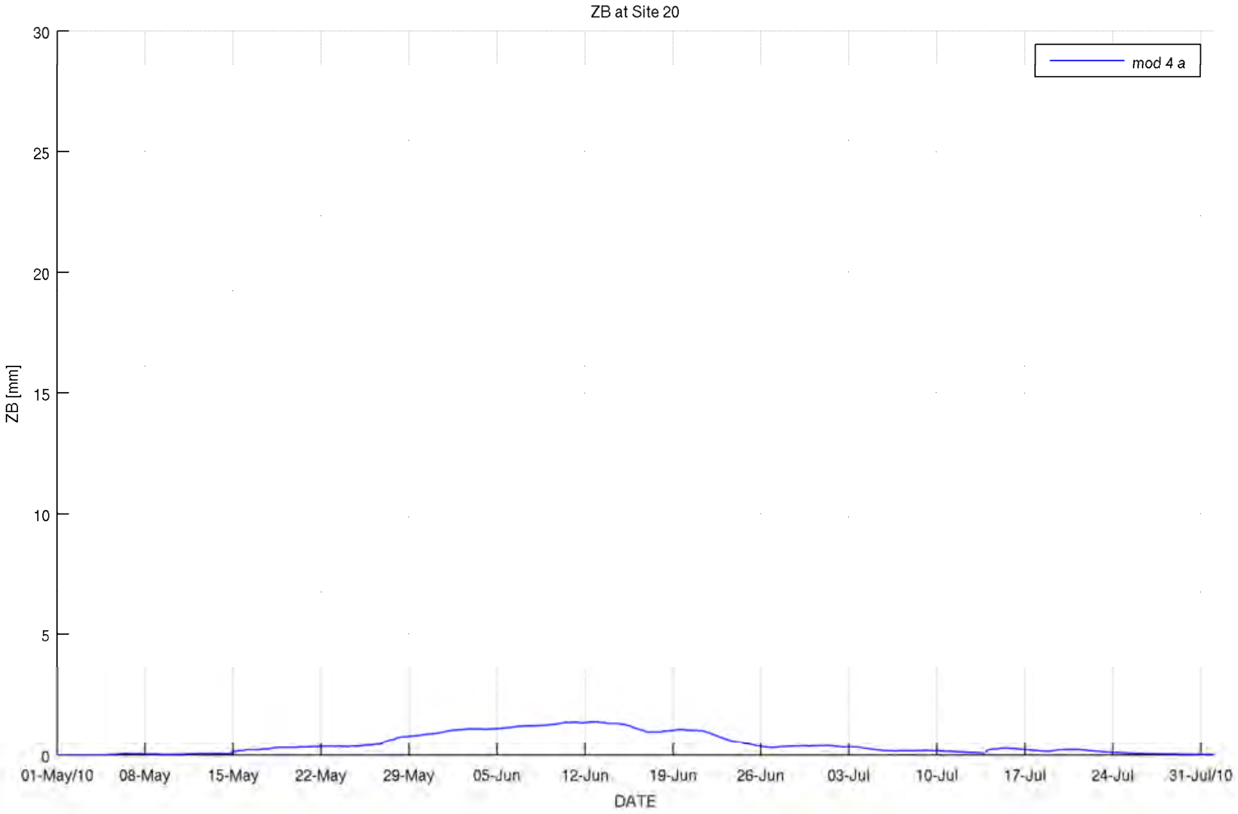
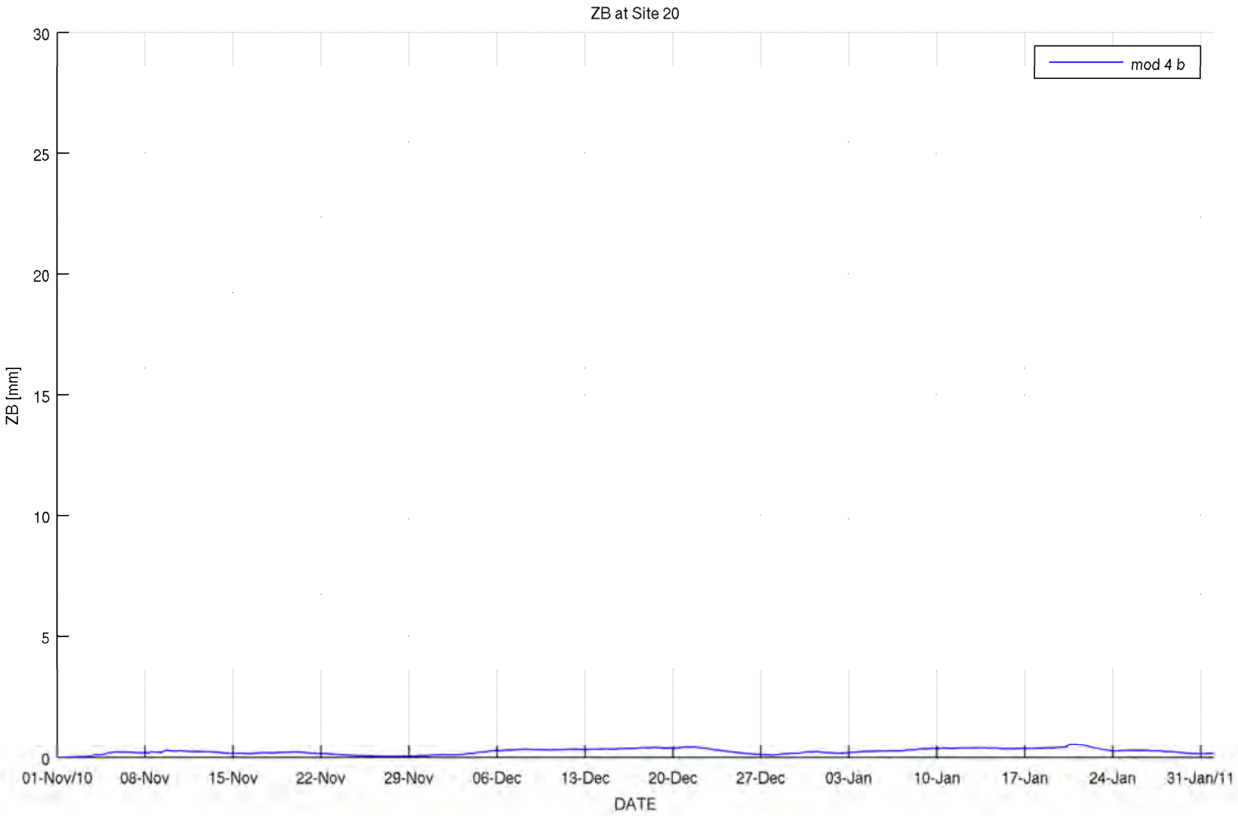
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 19
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 20
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 20
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d


ZB at Site 20
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
26-Jun
03-Jul
10-Jul
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 20
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
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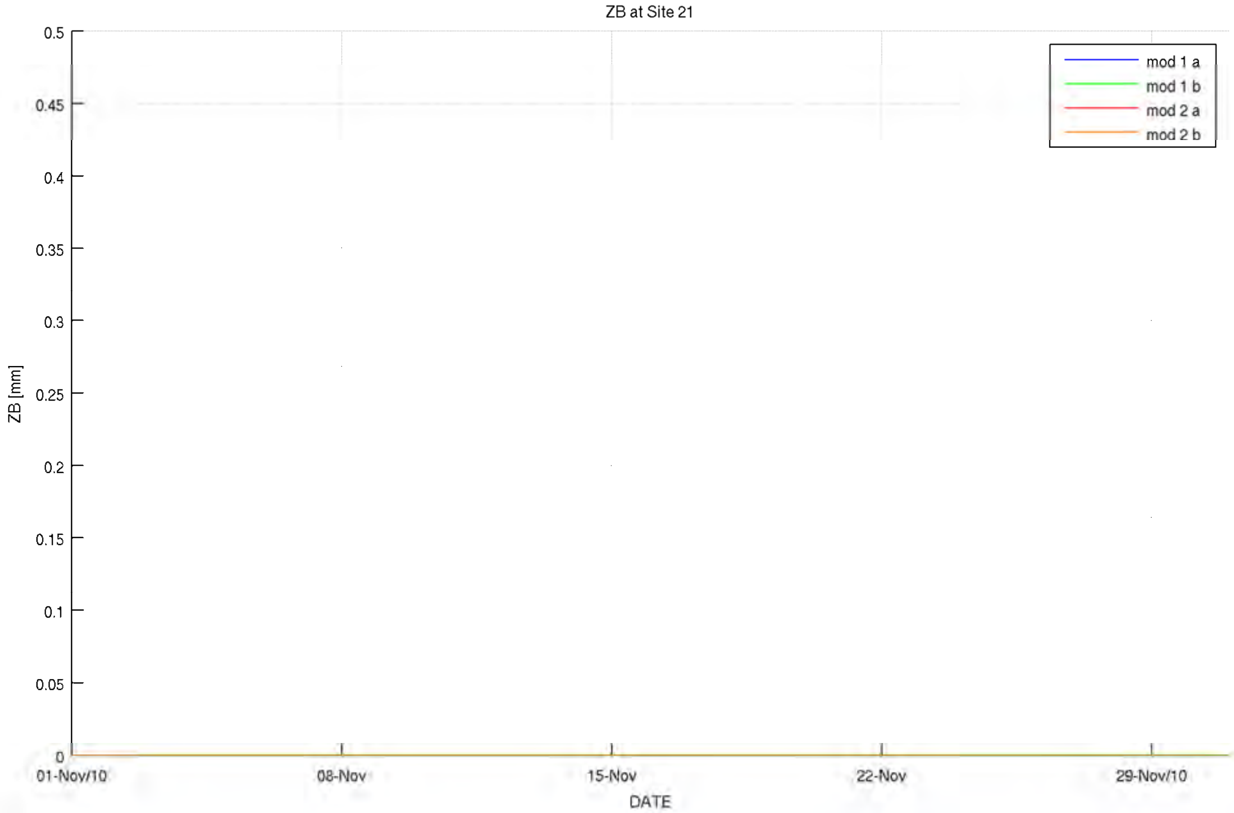
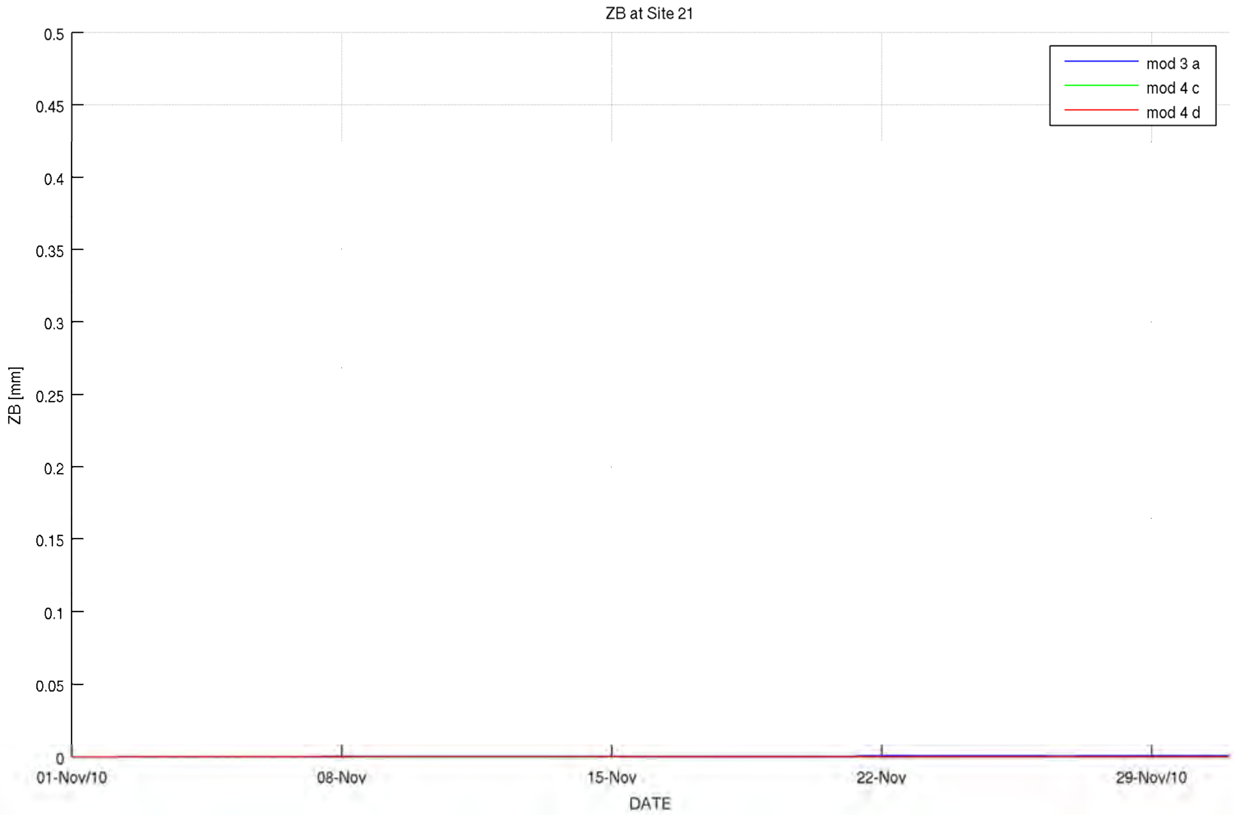
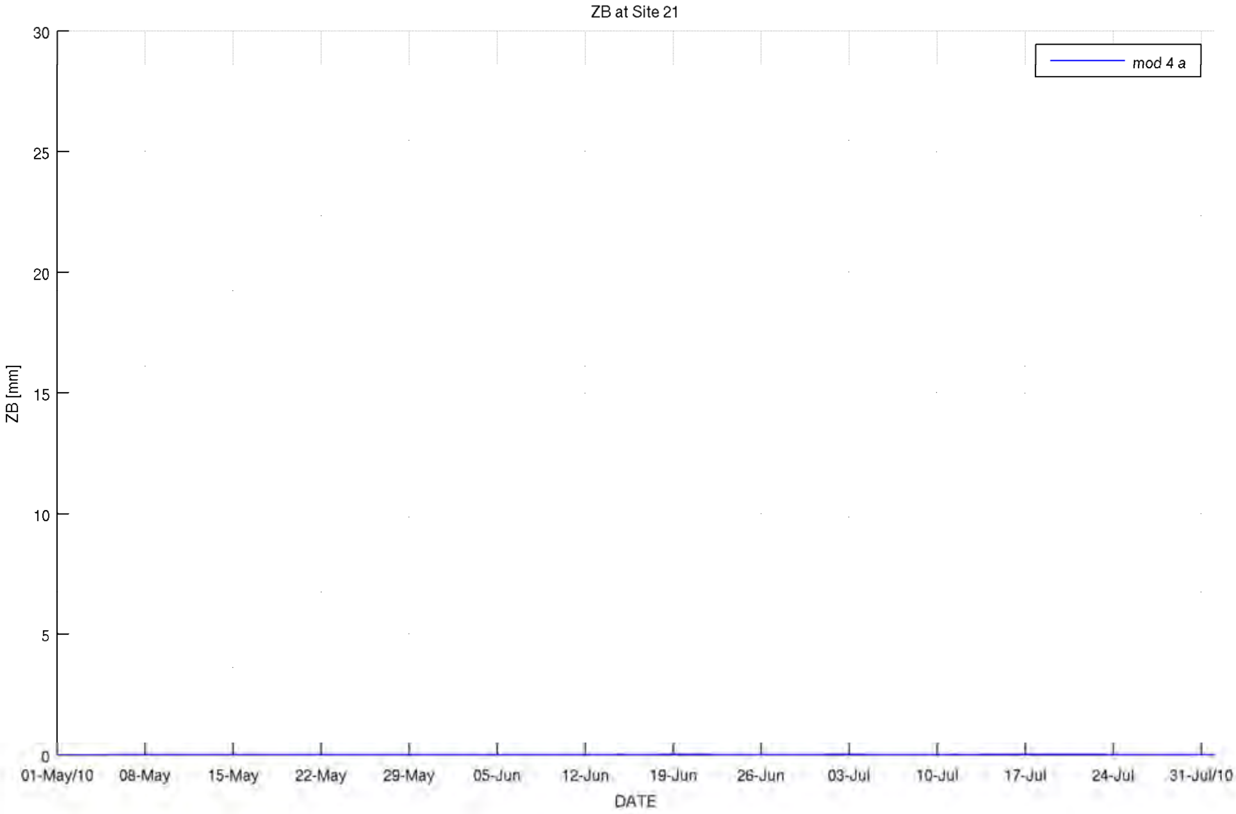
24-Jan
31-Jan/11
DATE


ZB at Site 21
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 21
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d


ZB at Site 21
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
19-Jun
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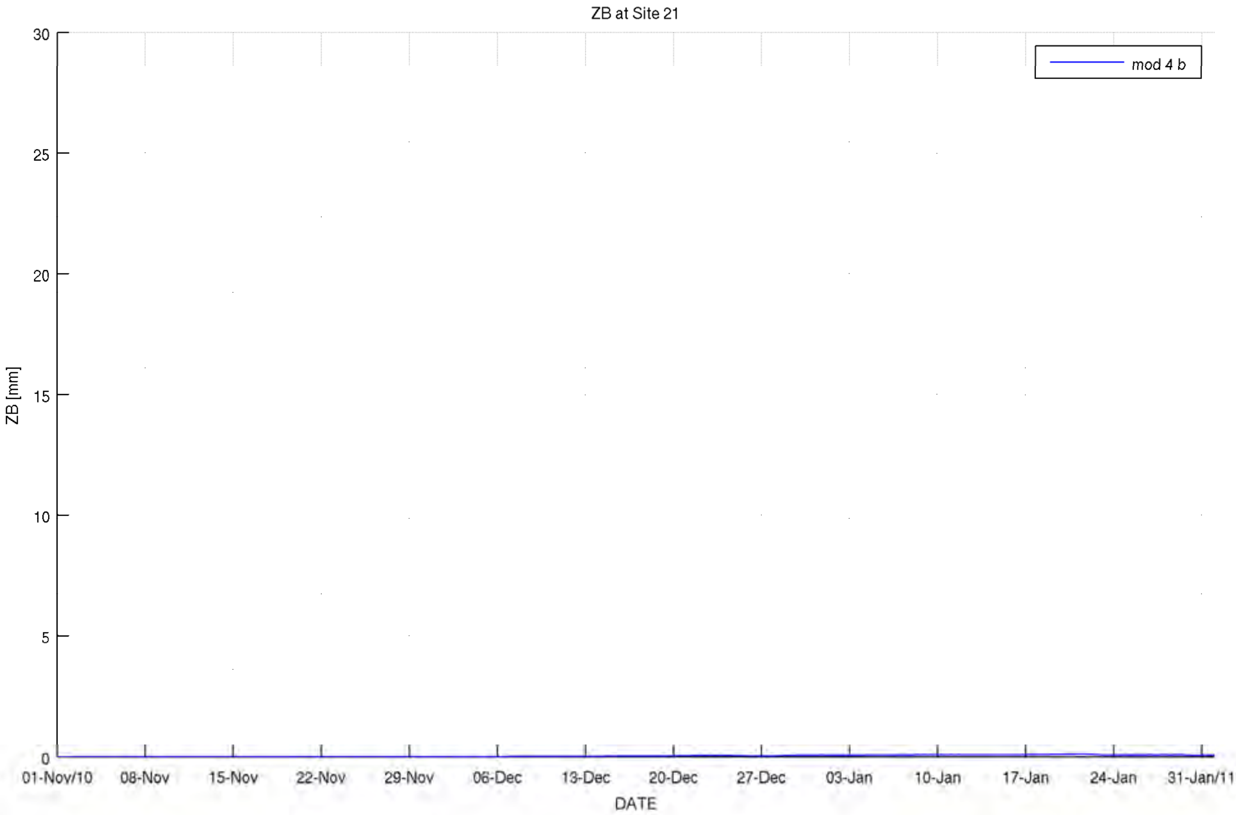
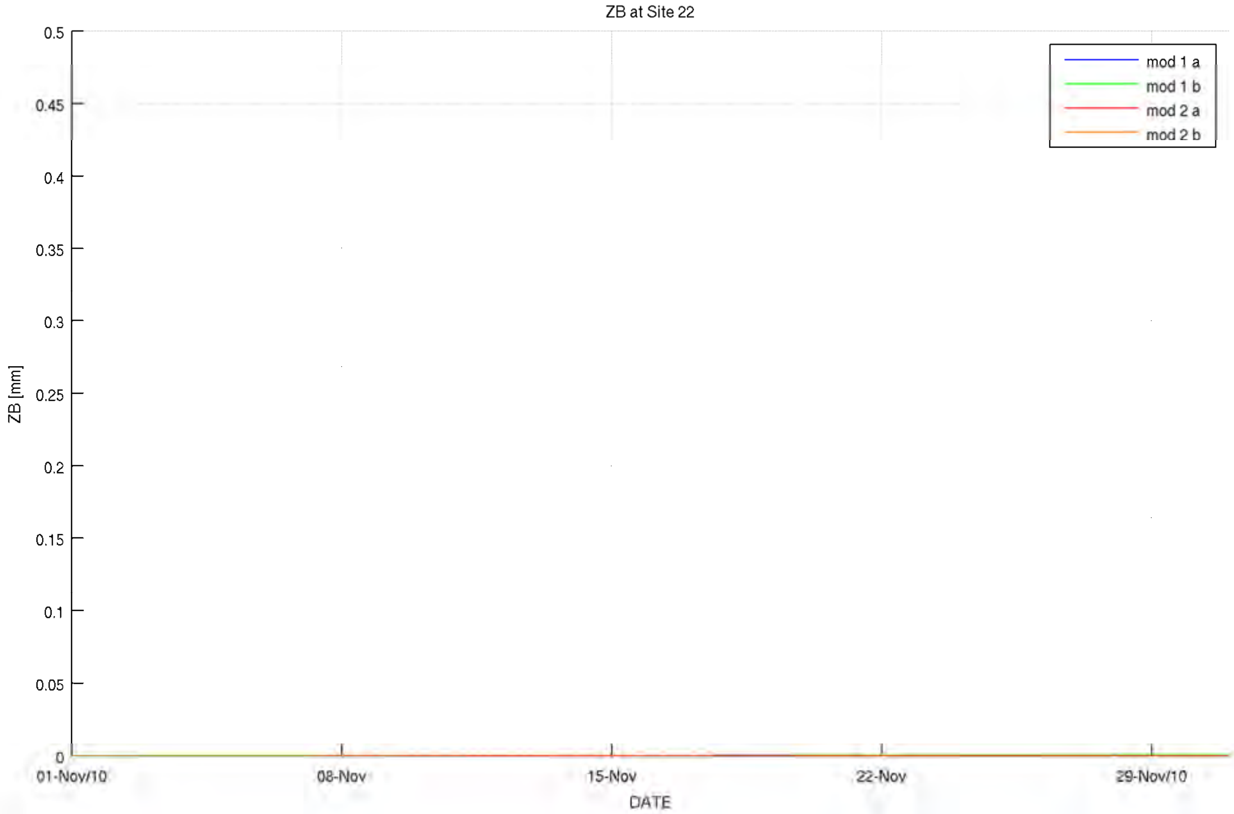
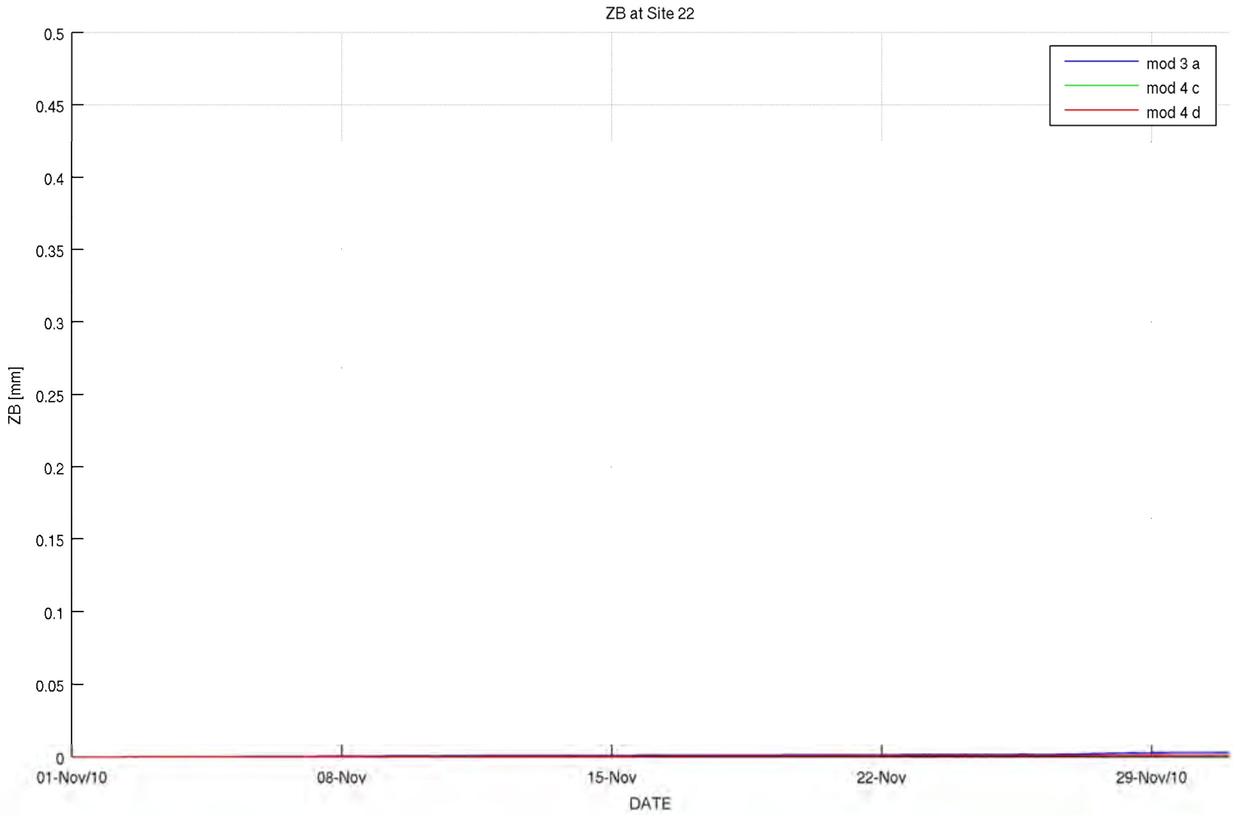
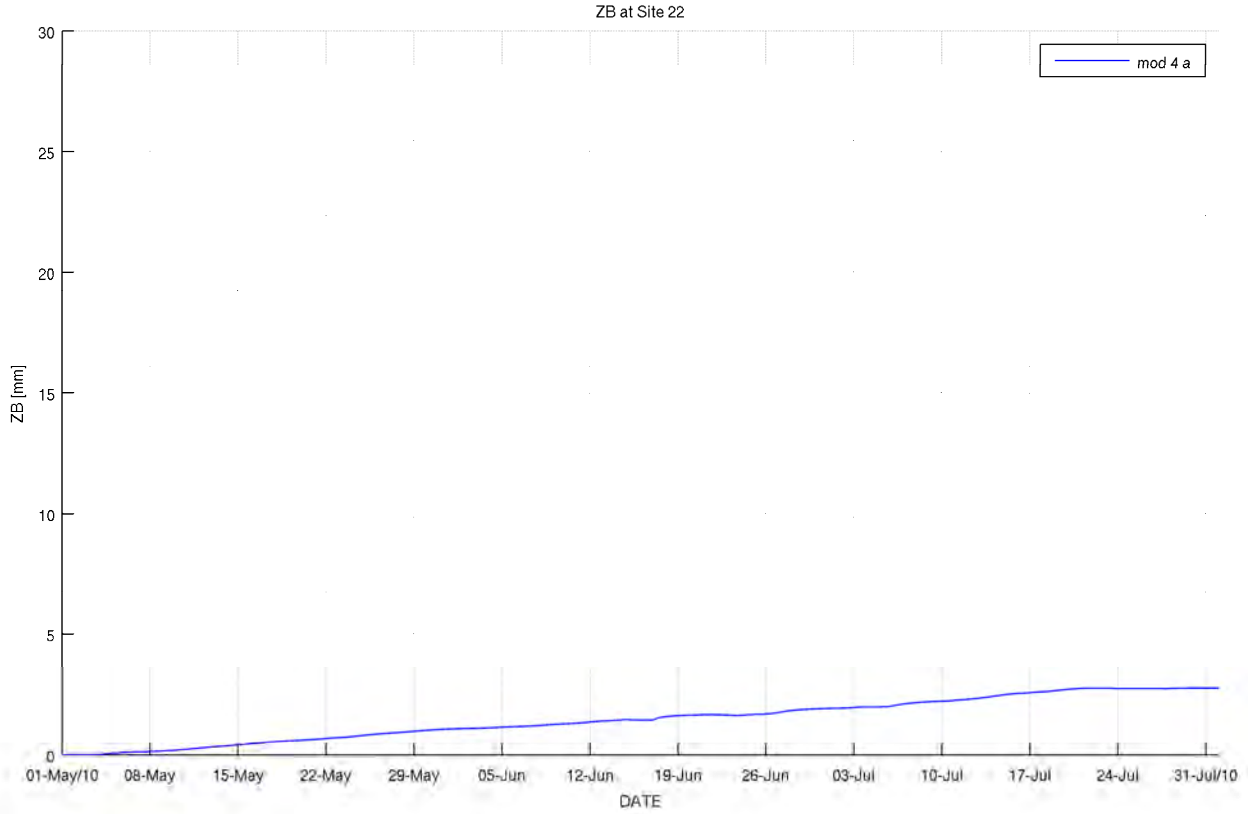
24-Jul
31-Jul/10
DATE


ZB at Site 21
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 22
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 22
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d


ZB at Site 22
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
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26-Jun
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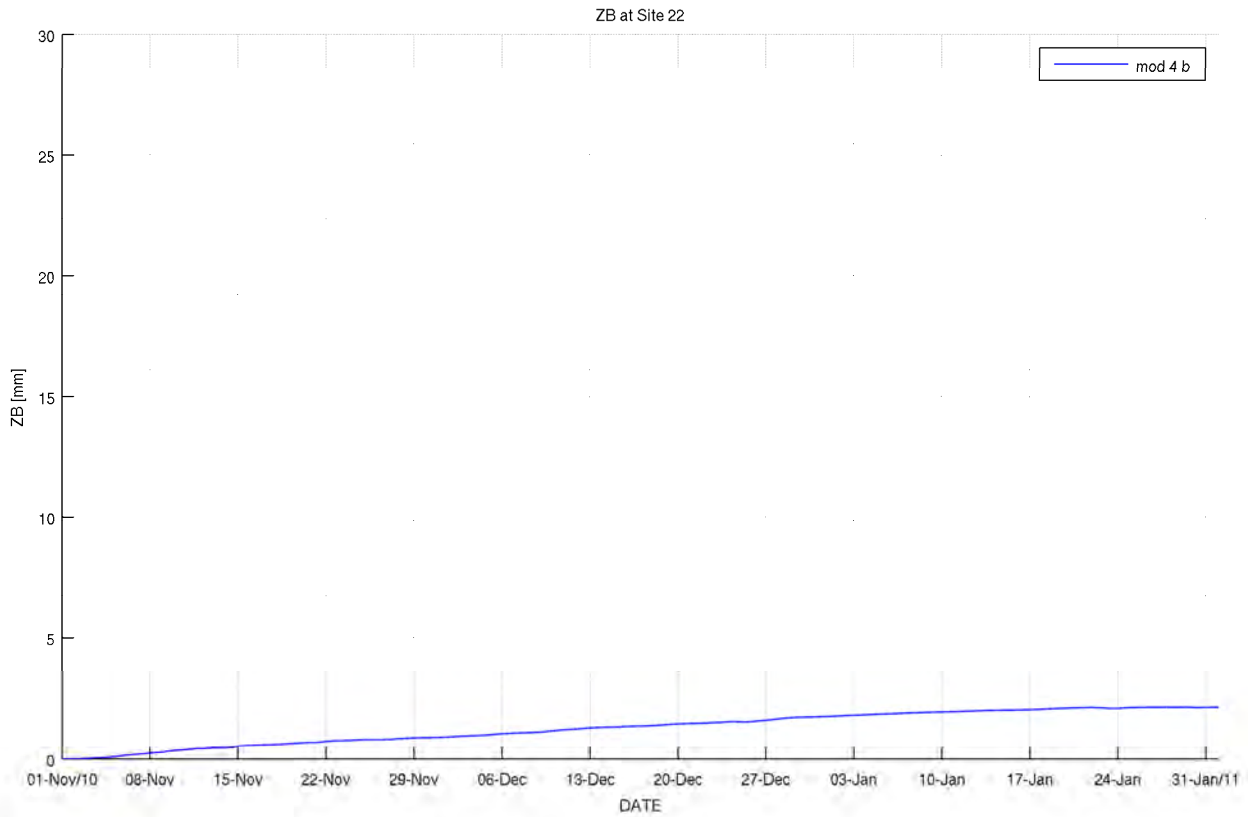
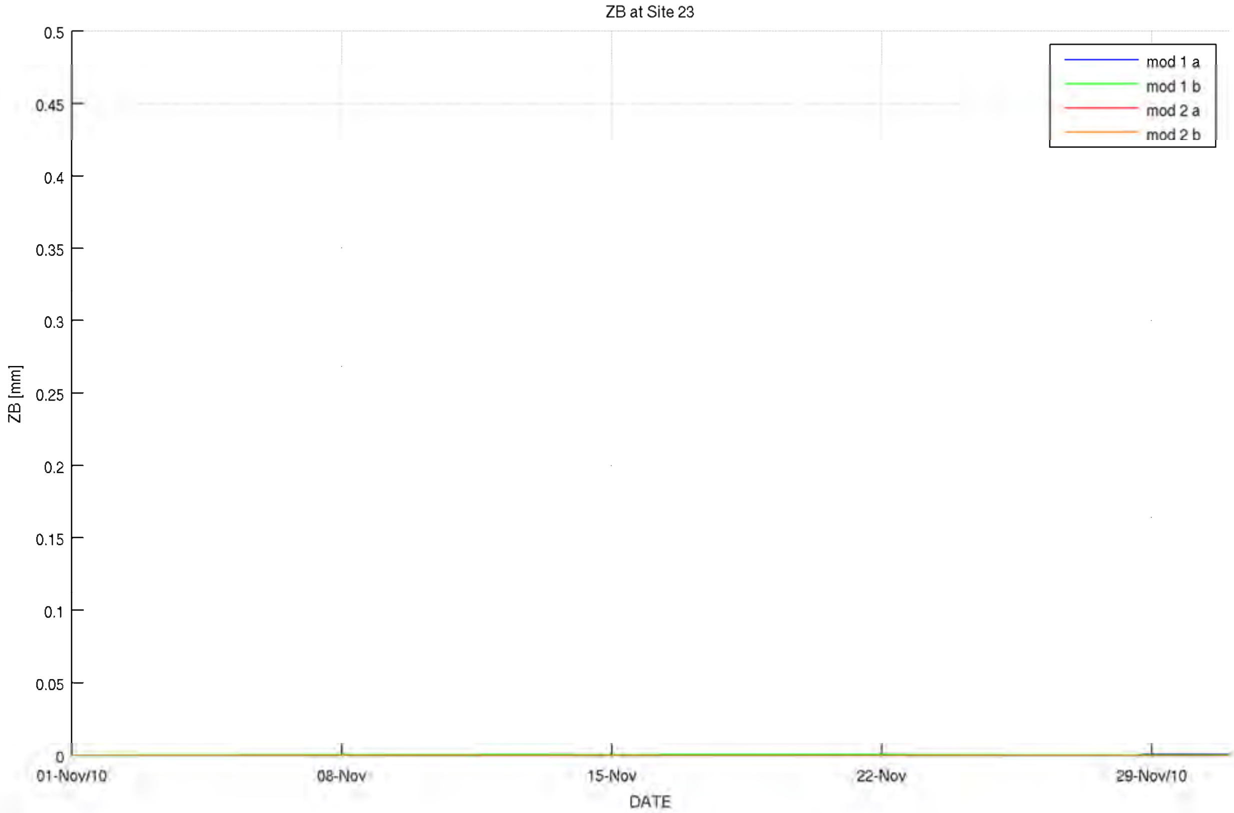
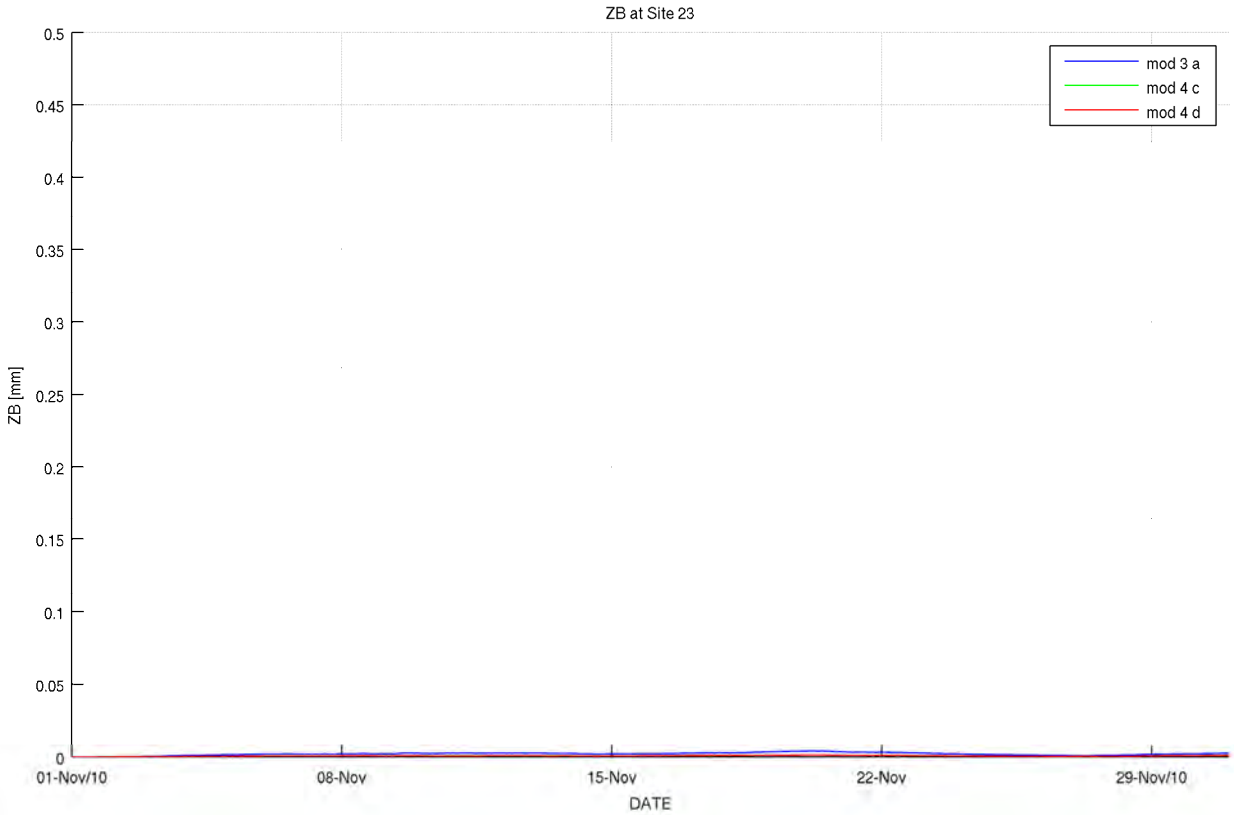
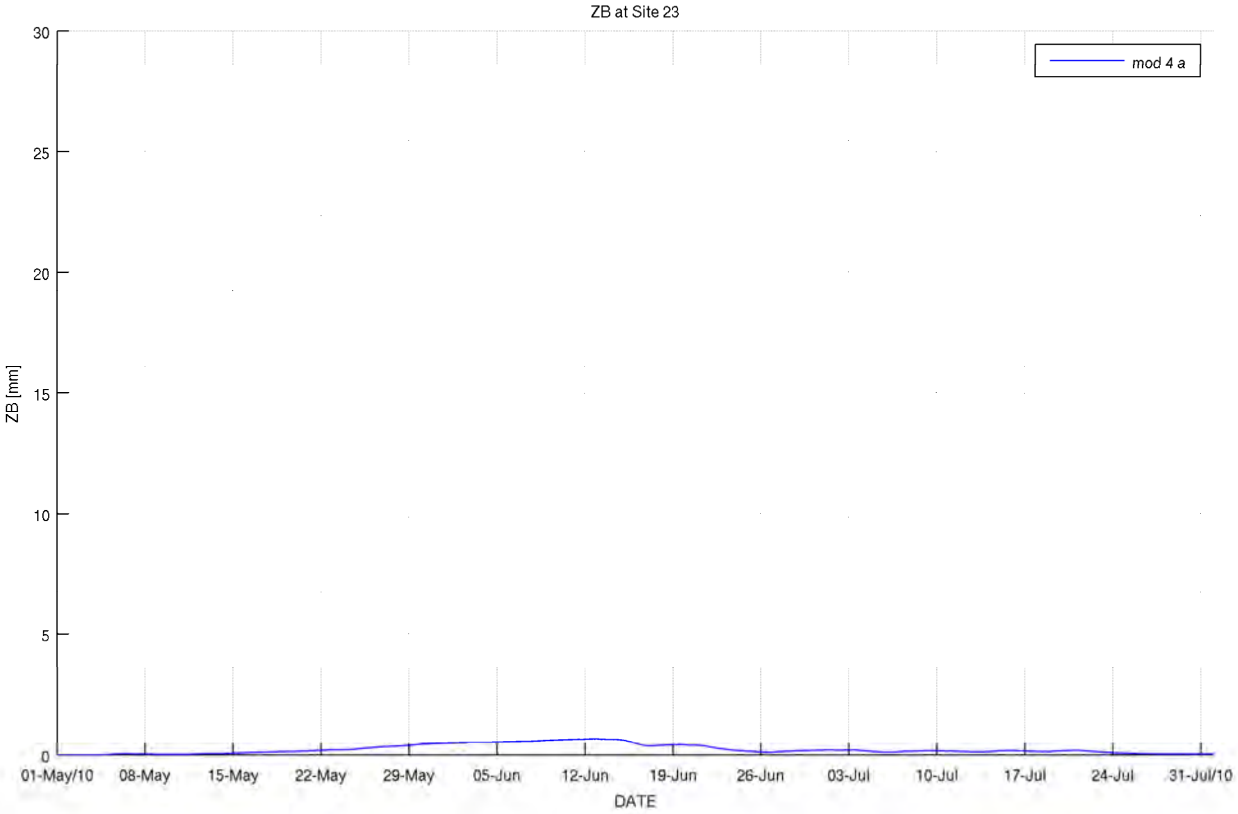
17-Jul
24-Jul
31-Jul/10
DATE


ZB at Site 22
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE


ZB at Site 23
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 1 a
mod 1 b
mod 2 a
mod 2 b


ZB at Site 23
ZB [mm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov/10
DATE
mod 3 a
mod 4 c
mod 4 d


ZB at Site 23
mod 4 a
ZB [mm]
30
25
20
15
10
5
0
01-May/10
08-May
15-May
22-May
29-May
05-Jun
12-Jun
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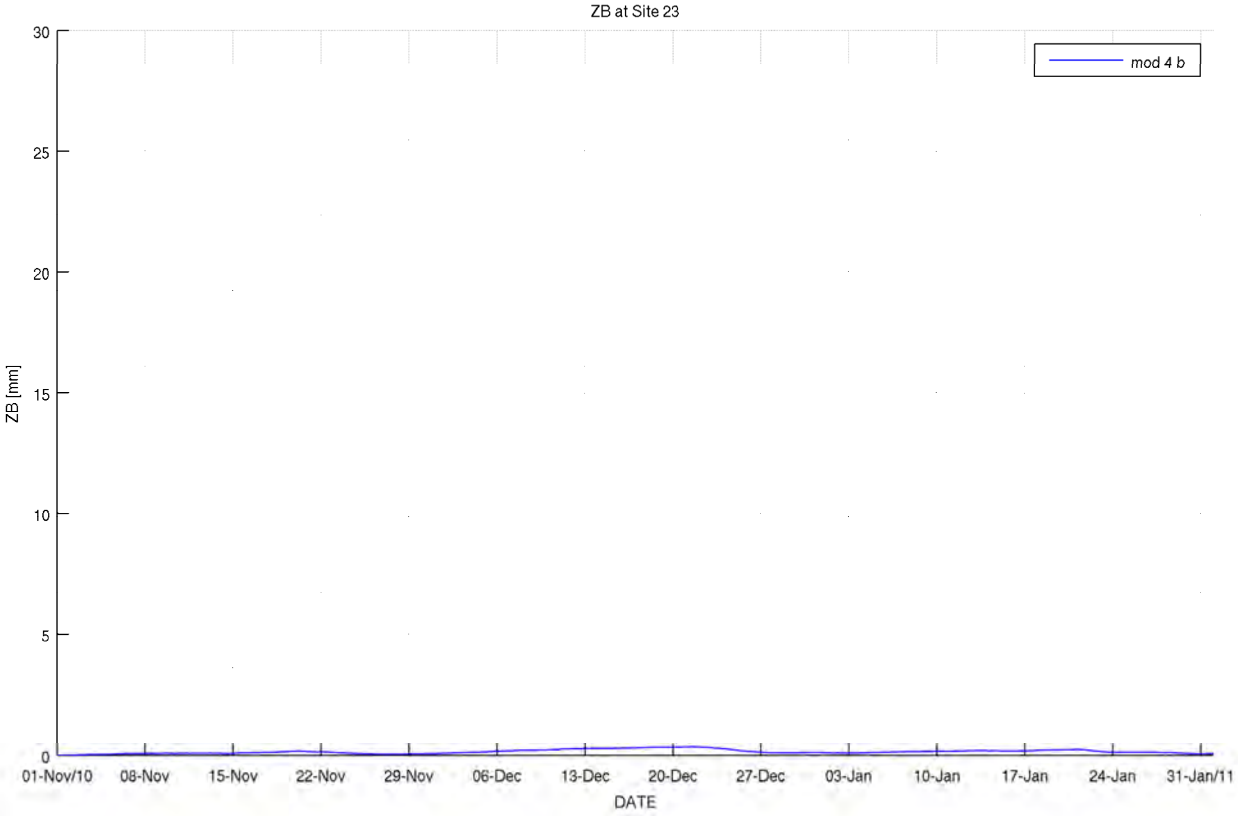
24-Jul
31-Jul/10
DATE


ZB at Site 23
mod 4 b
ZB [mm]
30
25
20
15
10
5
0
01-Nov/10
08-Nov
15-Nov
22-Nov
29-Nov
06-Dec
13-Dec
20-Dec
27-Dec
03-Jan
10-Jan
17-Jan
24-Jan
31-Jan/11
DATE

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BMT WBM Mackay	Suite 1, 138 Wood Street Mackay 4740 PO Box 4447 Mackay QLD 4740 Tel +61 7 4953 5144 Fax +61 7 4953 5132 Email mackay@bmtwbm.com.au Web www.bmtwbm.com.au
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BMT WBM Perth	Suite 3, 1161 Hay Street West Perth 6005 Tel +61 8 9328 2029 Fax +61 8 9484 7588 Email perth@bmtwbm.com.au Web www.bmtwbm.com.au
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BMT WBM Vancouver	401 611 Alexander Street Vancouver British Columbia V6A 1E1 Canada Tel +1 604 683 5777 Fax +1 604 608 3232 Email vancouver@bmtwbm.com Web www.bmtwbm.com.au