Port Kembla Re-Gasification Project

Updated Hydrodynamic Plume Modelling

59919002

Prepared for

AIE

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Cardno

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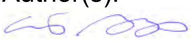

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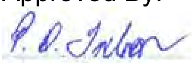

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1 Introduction

AIE are proposing to install a floating storage and regasification unit (FSRU), which is to be moored permanently within the Port Kembla Inner Harbour (IH) at Berth 101 and would receive liquid gas periodically from a visiting LNG carrier.

As part of the process, the facility would draw-in seawater from within the inner harbour and then discharge colder water back into the harbour as part of the liquid gas warming process

AIE have engaged Cardno to provide numerical modelling and coastal processes investigations in support of their design process. Cardno's tasks for this project involve, in total, four studies:

1. Thermal modelling to predict the near field dispersion and far field transport of the cold water discharged by the FSRU under all four seasons; and
2. Conservative tracer modelling to estimate the mixing and dilution of sodium hypochlorite discharged as part of the outfall strea,.

This report presents the investigations and outcomes of these studies.

1.1 Project Description

The proposed FSRU will be will be constructed at Berth 101 in the Port Kembla Inner Harbour. The proposed layout of the new berth is presented in **Figure 1.1**.

2 Data

2.1 General

A range of data items were required to set up and operate the numerical models applied to this study, and then to assess the impacts. Some of these inputs were prepared and adopted for the previous ICP modelling studies undertaken by Lawson and Treloar. The following section describes the inputs used in the modelling process and the sensitivity of the model to each of these inputs.

These inputs are described in Table 2.1, below.

Figure 2-1 Data requirements for the various modelling studies

Input	Required for	Source
Bathymetry	Hydrodynamic modelling	Surveys and nautical charts, described below
Tidal Forcing	Hydrodynamic Modelling	Global tide models
Measured ADCP data	Long wave analysis	Port Authority of NSW
Heat Loads	Thermal Plume Modelling	Cardno's previous studies, WorleyParsons for FSRU data
Meteorological forcing	Thermal Plume Modelling	Cardno's previous studies, BoM
Seawater Temperature	Thermal Plume Modelling	Cardno's previous studies at Port Kembla
Salinity	Thermal Plume Modelling	Cardno's previous studies at Port Kembla

This data has been collated and is described in the relevant sections of the report.

3 Hydrodynamic Model

3.1 General

The scope of work to be undertaken by Cardno included modelling the cooling water outflows associated with the FSRU during operations, as well as predicting the extent and magnitude of sodium hypochlorite which is generated in the heating water process.

In order to undertake these studies, a 3-Dimensional hydrodynamic model is required. For this study, Cardno's existing, calibrated 3D model of Port Kembla has been extended and applied.

3.2 DELFT 3D

Whilst the hydrodynamics required for this application could be modelled successfully by many models, it is our experienced opinion that no other package offers the same extensive cooling water modelling capabilities and backup experience as the Deltares modelling system Delft3D.

The Delft3D modelling system includes wind, pressure, tide and wave forcing, three dimensional current, stratification, sediment transport, cooling water and water quality descriptions and is capable of using rectilinear or curvilinear coordinates.

Delft3D has been used recently by Cardno Lawson Treloar for cooling water re-circulation studies in Lake Macquarie, in Lake Illawarra for power station investigations and in the Hunter River to assess the impact of a heated nitric acid spill near Kooragang Island. During these projects, the model produced either good agreement between modelled output and observed temperature data or was readily accepted by regulators.

Delft3D is comprised of several modules that provide the facility to undertake a range of studies. All studies generally begin with the Delft3D-FLOW module. From Delft3D-FLOW, details such as velocities, water levels, density, salinity, vertical eddy viscosity and vertical eddy diffusivity can be provided as inputs to the other modules. The wave and sediment transport modules work interactively with the FLOW module through a common communications file.

3.2.1 Hydrodynamic Numerical Scheme

The Delft3D FLOW module is based on the robust numerical finite-difference scheme developed by G. S. Stellling (1984) of the Delft Technical University in The Netherlands. Since its inception, the Stelling Scheme has had considerable development and review by Stelling and others.

The Delft3D Stelling Scheme arranges modelled variables on a staggered Arakawa C-grid. The water level points (pressure points) are designated in the centre of a continuity cell and the velocity components are perpendicular to the grid cell faces. Finite difference staggered grids have several advantages including:

- Boundary conditions can be implemented in the scheme in a rather simple way;
- It is possible to use a smaller number of discrete state variables in comparison with discretisations on non-staggered grids to obtain the same accuracy; and
- Staggered grids minimise spatial oscillations in the water levels.

Delft3D can be operated in 2D (vertically averaged) or 3D mode. In 3D mode, the model uses the σ-coordinate system first introduced by N Phillips in 1957 for atmospheric models. The σ-coordinate system is a variable layer-thickness modelling system, meaning that over the entire computational area, irrespective of the local water depth, the number of layers is constant. As a result a smooth representation of the bathymetry is obtained. Also, as opposed to fixed vertical grid size 3D models, the full definition of the 3D layering system is maintained into the shallow waters and until the computational point is dried.

From a user point of view, the construction of a 3D model from a 2D model using the σ-coordinate system in Delft3D is effected by entering how many layers are required and the percentage of the depth for each layer. It is most common to define more resolution at the surface and at the bed where the largest vertical gradients occur. Boundary conditions can also be adjusted from depth averaged to specific discharges and concentrations per layer also.

Horizontal solution is undertaken using the Alternating Direction Implicit (ADI) method of Leendertse for shallow water equations. In the vertical direction (in 3D mode) a fully implicit time integration method is also applied.

Vertical turbulence closure in Delft3D is based on the eddy viscosity concept.

3.2.2 Wetting and Drying of Intertidal Flats

Many estuaries and embayments contain shallow intertidal areas; consequently Delft3D incorporates a robust and efficient wetting and drying algorithm for handling this sort of phenomenon.

Careful refinement in the intertidal areas and appropriate setting of drying depths to minimise discontinuous movement of the boundaries ensures oscillations in water levels and velocities are minimised and the characteristics of the intertidal effects are modelled accurately.

3.2.3 Conservation of Mass

Problems with conservation of mass, such as a 'leaking mesh', do not occur within the Delft3D system.

However, whilst the Delft3D scheme is unconditionally stable, inexperienced use of Delft3D, as with most modelling packages, can result in potential mass imbalances.

Potential causes of mass imbalance and other inaccuracies include: -

- Inappropriately large setting of the wet/dry algorithm and unrefined inter-tidal grid definition;
- Inappropriate bathymetric and boundary definition causing steep gradients; and
- Inappropriate timestep selection (i.e. lack of observation of the scheme's allowable Courant Number condition) for simulation

3.2.4 Other Issues

Note that there were a number of processes not included in the modelling, such as currents caused by shipping and freshwater floods. Shipping would cause greater mixing and flooding would transport surface plumes further downstream. Both processes would be intermittent and transitory.

3.3 Model Setup

3.3.1 Grid Resolution and Extent

Figure 3.1 presents the model grid applied to this study. A rectilinear grid of 30m resolution was applied, with 251 by 253 grid cells in the north-south and east-west directions, respectively.

The model has been run with 10 vertical sigma layers, of varying thickness as described in **Table 3-1** below. The model includes higher vertical resolution at the surface and near the seabed.

Table 3-1 Vertical Grid Resolution

Sigma Layer	Thickness (% of water depth)
1 (surface layer)	2
2	5
3	9
4	14
5 (mid-depth)	20
6	20
7	14
8	9
9	5
10 (bottom layer)	2

3.3.2 Bathymetry

Bathymetric data is required to describe the seabed of the harbour basins, Allans Creek and the shoreline perimeter of the waterways of Port Kembla. This detailed information was available from a range of sources including

1. Recent bathymetric survey data provided by WorleyParsons inside the Inner and Outer Harbours
2. Nautical charts offshore of Port Kembla (AUS Chart 195)
3. Survey data in Cardno's internal database from previous projects in Port Kembla.

The model bathymetry is depicted in **Figure 3.1**. The model bathymetry has been defined based upon the datasets depicted in **Section 2.2** of this report. Before interpolating the bathymetric data onto the model grid, each dataset was transformed to common horizontal and vertical datums (MGA zone 56 and AHD). The data interpolation process was also prioritised such that where overlapping survey data is available, the more recent surveyed data is used.

3.3.3 Boundary Conditions

Offshore tidal boundary conditions were extracted from a combination of the DTU10 (Technical University of Denmark Tidal Model), which is based on a finite element solution of the global tides with data assimilated from seventeen years of satellite altimeter readings. The methodology of the global tide models is described in Cheng and Anderson (2010). DTU10 provides up to twelve tidal constants on a 1/8 degree resolution full global grid. The tides are provided as complex amplitudes of earth-relative sea-surface elevation for ten primary (M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1, S_1 and M_4) harmonic constituents. Four additional constituents (M_f, M_m, MS_4 and MN_4) were sourced from the TPx07.2 tide model, which uses along track averaged altimeter data from the TOPEX/Poseidon and Jason (on TOPEX/Poseidon tracks since 2002) satellites.

3.3.4 Time-Step

A time-step of 6 seconds was adopted to fulfil accuracy requirements based on the Courant Number.

4 Thermal Plume Modelling

4.1 Introduction

During the operational phase of the project, the FSRU will use seawater for its internal processes. The seawater would be drawn into the FSRU through the hull of the floating unit and used for heating. The seawater is then discharged back into the port through an outlet in the hull. During this process the seawater is cooled by a maximum of 7 degrees compared to the water drawn in through the intake.

Two FSRU's are currently being considered for the project, both of which have differing intake and discharge arrangements.

There are also a number of cooling water intakes and outfalls currently in operation within Port Kembla, operated by BlueScope Steel. The discharge and heat load for these existing intakes/outfalls have been taken from Cardno's previous cooling water investigations in Port Kembla (Cardno Lawson Treloar, 2007).

The discharge data applied in the model are presented below in **Tables 4.1** to **4.4**. Note that the warming water modelling has been undertaken for ambient conditions (i.e. without the existing cooling water discharges) and typical existing summer, winter, spring and autumn conditions. In these simulations the average flows from the existing intakes and outfalls have been applied to the model, as described in the following tables..

Table 4-1 Cooling water flows – summer conditions

Modelled Drain Flows - Summer Conditions					
Model Source No	Drain	Ambient Condition		Existing Condition	
		Flow (m^3/s)	ΔT(°C)	Flow (m^3/s)	ΔT(°C)
1	Main Drain	-	-	1.174	7.1
2	No.2 Blower Station	-	-	7.953	6.44
3	Iron Making East	-	-	0.208	4.05
4	3500mm Plate Mill Drain	-	-	0.395	2.84
5	Slab Mill Drain	0.013	31.41*	0.013	31.41*
6	No. 1 Flat Products East Drain	-	-	0.112	4.64
7	Allans Creek Flow	0.17	22.5*	0.17	22.5*
8	North Gate Drain	0.077	28.06*	0.077	28.06*

* presented as absolute temperature rather than excess

Table 4-2 Cooling water flows – winter conditions

Modelled Drain Flows - Winter Conditions					
Model Source No	Drain	Ambient Condition		Existing Condition	
		Flow (m^3/s)	ΔT(°C)	Flow (m^3/s)	ΔT(°C)
1	Main Drain	-	-	1.517	6.28
2	No.2 Blower Station	-	-	8.211	7.11
3	Iron Making East	-	-	0.100	3.06
4	3500mm Plate Mill Drain	-	-	0.408	2.41
5	Slab Mill Drain	0.016	21.37*	0.016	21.37*
6	No. 1 Flat Products East Drain	-	-	0.196	4.35
7	Allans Creek Flow	0.170	16.80*	0.170	16.80*
8	North Gate Drain	0.102	17.98*	0.102	17.98*

* presented as absolute temperature rather than excess

Table 4-3 Cooling water flows – Autumn conditions

Modelled Drain Flows - Autumn Conditions					
Model Source No	**Drain**	**Ambient Condition**		**Existing Condition**	
		Flow (m³/s)	**ΔT(°C)**	**Flow (m³/s)**	**ΔT(°C)**
1	Main Drain	-	-	1.174	7.1
2	No.2 Blower Station	-	-	7.953	6.44
3	Iron Making East	-	-	0.208	4.05
4	3500mm Plate Mill Drain	-	-	0.395	2.84
5	Slab Mill Drain	0.013	27*	0.013	27*
6	No. 1 Flat Products East Drain	-	-	0.112	4.64
7	Allans Creek Flow	0.17	20.6*	0.17	20.6*
8	North Gate Drain	0.077	25*	0.077	25.0*

* presented as absolute temperature rather than excess

Table 4-4 Cooling water flows – Spring conditions

Modelled Drain Flows - Spring Conditions					
Model Source No	**Drain**	**Ambient Condition**		**Existing Condition**	
		Flow (m³/s)	**ΔT(°C)**	**Flow (m³/s)**	**ΔT(°C)**
1	Main Drain	-	-	1.517	6.28
2	No.2 Blower Station	-	-	8.211	7.11
3	Iron Making East	-	-	0.100	3.06
4	3500mm Plate Mill Drain	-	-	0.408	2.41
5	Slab Mill Drain	0.016	23.0*	0.016	23.0*
6	No. 1 Flat Products East Drain	-	-	0.196	4.35
7	Allans Creek Flow	0.170	16.8*	0.170	16.8*
8	North Gate Drain	0.102	19.0*	0.102	19.0*

* presented as absolute temperature rather than excess

4.2 FSRU Outflows

In Cardno’s previous investigation, two separate FSRU’s were simulated. As the results were similar for both vessels, the updated modelling presented in this report has focussed on only one FSRU.

FSRU, Q = 2.917 m^3/s (10,500 m^3/hour);

The ΔT of the FSRU that has been applied to the model is -7ºC (i.e., cools the seawater passing through the plant by seven degrees). Heating water is drawn-in through the hull of vessel, and discharged horizontally out of the side of the vessel.

4.3 Nearfield Modelling

In order to properly model and understand the plume behaviour, both near and far field modelling has been undertaken. The main purpose of the near field assessment was to estimate the plume width, height and dilution at the end of the near field region. This data is then fed into the Delft3D modelling system to simulate the far field dispersion.

4.3.1 CORMIX

CORMIX is a nearfield analytical model developed by Mixzon Inc. and is used by the U.S. E.P.A. for regulatory investigations. It describes the development of a positively or negatively buoyant jet(s) as it discharges into the receiving water environment. It includes single port, multi-port and surface channel discharges. The model is useful in describing the interaction in mixing zones – where a discharge is introduced to a receiving water. The model includes the effects of density difference, receiving water velocity, depth of the jet(s) below the surface, merging of jets, wind mixing, discharge port configuration and discharge rate.

Cardno has used this system for a number of outfall diffuser systems with success. CORMIX has been shown to suitably predict mixing effects. As part of investigations undertaken for Hunter Water for augmentation of the Belmont ocean outfall, Cardno Lawson Treloar undertook a field verification of the CORMIX model. That work entailed the measurement of salinity in the water column near the existing outfall in known discharge and receiving water conditions. Analyses of the results showed that CORMIX provided realistic results though it slightly under-estimated dilution. The ‘map’ of dilution above a discharge point is spatially and temporally very variable and this characteristic needs to be considered in analyses of this type by recognising this variability in any sampling that may be undertaken

For this assessment, CORMIX was selected from a suite of available near-field models and was used to assess the mixing zone effects. The results of the CORMIX modelling are provided below.

4.3.2 CORMIX Results

For this assessment the CORMIX modelling has been undertaken using the CORMIX 1 model, which is for submerged single port discharges.

Note that CORMIX does not natively support a cool water discharge. To overcome this, the model has been setup based on the ambient and discharged density based on a seven degree temperature difference, and a conservative tracer with an initial concentration of 7 was applied to the effluent.

Given the modelling is predicting only very small current speeds in the area (typically of the order of 2cm/s), the near field modelling has been undertaken under calm conditions and under low cross currents (0, 0.05 and 0.1 m/s).

As the ship moves up and down with the tide, near field mixing has been assessed under three tidal conditions, these being LAT, MSL and MHWS. At LAT the vessel is closest to the seabed, and as such this is expected to be the scenarios with the least near field mixing.

A total of 36 near field simulations were undertaken to estimate the plume characteristics at the end of the near field mixing zone. These characteristics are presented below in Table 4-5.

Table 4-5 Simulated Plume Dilution at the End of the Near Field

Season	Water Level	Current Speed (m/s)	Centreline Distance to end of nearfield (m)	Plume 1/e vertical thickness (m)	Plume horizontal half width (m)	Mixing Zone Radius (m)	centreline dilution	average dilution	Dilution at plume edge
Summer	LAT	0	32.84	4.16	4.16	37.0	4	6.8	10.9
Summer	LAT	0.05	31.94	4.22	4.22	36.16	4.1	7.0	11.1
Summer	LAT	0.1	30.33	4.43	4.43	34.76	4.6	7.8	12.5
Summer	MSL	0	34.57	4.42	4.42	38.99	4.4	7.5	12.0
Summer	MSL	0.05	33.75	4.49	4.49	38.24	4.6	7.8	12.5
Summer	MSL	0.1	31.95	4.74	4.74	36.69	5.1	8.7	13.9
Summer	MHWS	0	35.85	4.58	4.58	40.43	4.7	8.0	12.8
Summer	MHWS	0.05	34.81	4.67	4.67	39.48	4.9	8.3	13.3
Summer	MHWS	0.1	32.98	4.95	4.95	37.93	5.6	9.5	15.2
Winter	LAT	0	31.23	3.98	3.98	35.21	3.9	6.6	10.6
Winter	LAT	0.05	30.38	4.03	4.03	34.41	4	6.8	10.9
Winter	LAT	0.1	29.09	4.21	4.21	33.3	4.5	7.7	12.2
Winter	MSL	0	33.01	4.22	4.22	37.23	4.4	7.5	12.0
Winter	MSL	0.05	32.05	4.29	4.29	36.34	4.5	7.7	12.2
Winter	MSL	0.1	30.62	4.5	4.5	35.12	5	8.5	13.6
Winter	MHWS	0	34.02	4.37	4.37	38.39	4.7	8.0	12.8
Winter	MHWS	0.05	33.13	4.45	4.45	37.58	4.8	8.2	13.0
Winter	MHWS	0.1	31.52	4.69	4.69	36.21	5.4	9.2	14.7
Spring	LAT	0	34.38	4.36	4.36	38.74	4.1	7.0	11.1
Spring	LAT	0.05	33.48	4.43	4.43	37.91	4.2	7.1	11.4
Spring	LAT	0.1	31.67	4.66	4.66	36.33	4.7	8.0	12.8
Spring	MSL	0	36.36	4.63	4.63	40.99	4.5	7.7	12.2
Spring	MSL	0.05	35.43	4.72	4.72	40.15	4.7	8.0	12.8
Spring	MSL	0.1	33.46	5	5	38.46	5.3	9.0	14.4
Spring	MHWS	0	37.7	4.8	4.8	42.5	4.8	8.2	13.0
Spring	MHWS	0.05	36.59	4.91	4.91	41.5	5	8.5	13.6
Spring	MHWS	0.1	34.73	5.2	5.2	39.93	5.7	0.0	0.0
Autumn	LAT	0	33.42	4.23	4.23	37.65	4.1	7.0	11.1
Autumn	LAT	0.05	32.51	4.3	4.3	36.81	4.2	7.1	11.4
Autumn	LAT	0.1	30.82	4.51	4.51	35.33	4.6	7.8	12.5
Autumn	MSL	0	35.3	4.49	4.49	39.79	4.4	7.5	12.0
Autumn	MSL	0.05	34.27	4.57	4.57	38.84	4.6	7.8	12.5

Season	Water Level	Current Speed (m/s)	Centreline Distance to end of nearfield (m)	Plume 1/e vertical thickness (m)	Plume horizontal half width (m)	Mixing Zone Radius (m)	centreline dilution	average dilution	Dilution at plume edge
Autumn	MSL	0.1	32.55	4.83	4.83	37.38	5.2	8.8	14.1
Autumn	MHWS	0	36.51	4.66	4.66	41.17	4.7	8.0	12.8
Autumn	MHWS	0.05	35.46	4.76	4.76	40.22	4.9	8.3	13.3
Autumn	MHWS	0.1	33.6	5.05	5.05	38.65	5.6	9.5	15.2

4.4 Discussion

The EPA guidelines for cold water discharges are that the future median seawater temperature at the edge of the near field mixing zone should be greater than the ambient 20th percentile temperature. Based on long term seawater temperature measurements outside of the port, the ambient 20th and 50th percentile seawater temperatures are provided in Table 4-6.

Table 4-6 Ambient seawater temperature offshore of Port Kembla

Season	Seawater Temperature (ºC)		
	20th Percentile	**Median**	**80th Percentile**
Summer	20.0	21.2	22.4
Autumn	19.2	20.5	21.8
Winter	15.6	16.6	17.4
Spring	16.4	17.5	18.7

The above table indicates that to comply with the EPA requirements, the seawater temperature decrease at the edge of the nearfield mixing zone should be less than 1ºC to 1.3ºC, depending on the season.

Applying a temperature decrease of 7ºC at the point of discharge to the dilution values predicted by CORMIX, the centreline, average and plume edge temperatures at the edge of the nearfield mixing zone are presented overleaf in Table 4-7.

This table indicates that the temperature at the edge of the plume, at the end of the nearfield region is predicted to be up to 0.7 degrees lower than the ambient conditions. It is noted that the largest decrease in temperature predicted at the edge of the near field meets the EPA requirements.

The CORMIX modelling indicates that the nearfield mixing zone is semi-circular in shape with a maximum radius of 42.5m extending horizontally from the point of discharge.

Table 4-7 Simulated temperature decrease at the end of the near field

Season	Water Level	Current Speed (m/s)	Centreline Distance to end of nearfield (m)	Plume 1/e vertical thickness (m)	Plume horizontal half width (m)	Mixing Zone Radius (m)	Centreline temp Decrease [deg C]	Average Temp Decrease [deg C]	Temp decrease at edge of nearfield mixing zone [deg C]
Summer	LAT	0	32.84	4.16	4.16	37.0	1.75	1.0	0.6
Summer	LAT	0.05	31.94	4.22	4.22	36.16	1.7	1.0	0.6
Summer	LAT	0.1	30.33	4.43	4.43	34.76	1.53	0.9	0.6
Summer	MSL	0	34.57	4.42	4.42	38.99	1.59	0.9	0.6
Summer	MSL	0.05	33.75	4.49	4.49	38.24	1.53	0.9	0.6
Summer	MSL	0.1	31.95	4.74	4.74	36.69	1.36	0.8	0.5
Summer	MHWS	0	35.85	4.58	4.58	40.43	1.48	0.9	0.5
Summer	MHWS	0.05	34.81	4.67	4.67	39.48	1.43	0.8	0.5
Summer	MHWS	0.1	32.98	4.95	4.95	37.93	1.26	0.7	0.5
Winter	LAT	0	31.23	3.98	3.98	35.21	1.78	1.1	0.7
Winter	LAT	0.05	30.38	4.03	4.03	34.41	1.73	1.0	0.6
Winter	LAT	0.1	29.09	4.21	4.21	33.3	1.57	0.9	0.6
Winter	MSL	0	33.01	4.22	4.22	37.23	1.6	0.9	0.6
Winter	MSL	0.05	32.05	4.29	4.29	36.34	1.55	0.9	0.6
Winter	MSL	0.1	30.62	4.5	4.5	35.12	1.4	0.8	0.5
Winter	MHWS	0	34.02	4.37	4.37	38.39	1.5	0.9	0.6
Winter	MHWS	0.05	33.13	4.45	4.45	37.58	1.45	0.9	0.5
Winter	MHWS	0.1	31.52	4.69	4.69	36.21	1.3	0.8	0.5
Spring	LAT	0	34.38	4.36	4.36	38.74	1.72	1.0	0.6
Spring	LAT	0.05	33.48	4.43	4.43	37.91	1.66	1.0	0.6
Spring	LAT	0.1	31.67	4.66	4.66	36.33	1.48	0.9	0.5
Spring	MSL	0	36.36	4.63	4.63	40.99	1.56	0.9	0.6
Spring	MSL	0.05	35.43	4.72	4.72	40.15	1.5	0.9	0.6
Spring	MSL	0.1	33.46	5	5	38.46	1.31	0.8	0.5
Spring	MHWS	0	37.7	4.8	4.8	42.5	1.46	0.9	0.5
Spring	MHWS	0.05	36.59	4.91	4.91	41.5	1.4	0.8	0.5
Spring	MHWS	0.1	34.73	5.2	5.2	39.93	1.22	0.7	0.5
Autumn	LAT	0	33.42	4.23	4.23	37.65	1.74	1.0	0.6
Autumn	LAT	0.05	32.51	4.3	4.3	36.81	1.68	1.0	0.6

Season	Water Level	Current Speed (m/s)	Centreline Distance to end of nearfield (m)	Plume 1/e vertical thickness (m)	Plume horizontal half width (m)	Mixing Zone Radius (m)	Centreline temp Decrease [deg C]	Average Temp Decrease [deg C]	Temp decrease at edge of nearfield mixing zone [deg C]
Autumn	LAT	0.1	30.82	4.51	4.51	35.33	1.51	0.9	0.6
Autumn	MSL	0	35.3	4.49	4.49	39.79	1.57	0.9	0.6
Autumn	MSL	0.05	34.27	4.57	4.57	38.84	1.52	0.9	0.6
Autumn	MSL	0.1	32.55	4.83	4.83	37.38	1.34	0.8	0.5
Autumn	MHWS	0	36.51	4.66	4.66	41.17	1.48	0.9	0.5
Autumn	MHWS	0.05	35.46	4.76	4.76	40.22	1.42	0.8	0.5
Autumn	MHWS	0.1	33.6	5.05	5.05	38.65	1.24	0.7	0.5

5 Far Field Modelling of Temperature

The near field modelling presented in the previous section describes the plume behaviour in the near field zone. As near field models are steady state they do not include affects such as accumulation of pollutants or recirculation between the intake and the outfall. To assess the potential for these effects, far field modelling using a 3-dimensional hydrodynamic model has been applied.

5.1 Scenarios

Far field modelling was undertaken in Deflt3D for sixteen scenarios. These scenarios included ambient (i.e. without any industrial discharges), and combinations of BlueScope and the future proposed FSRU warming water discharge. For each discharge simulation, typical conditions have been simulated under summer, autumn, winter and spring. These simulations are outlined in Table 5-1 below.

Table 5-1 Far field dispersion simulations

Simulation	Season	Bluescope Cooling Water Discharges	FSRU Warming Water Discharges	Description
1	Summer	-	-	Ambient in summer
2	Summer	Yes	-	Existing Conditions in Summer
3	Summer	Yes	Yes	Future bluescope and FSRU in summer
4	Summer	-	Yes	Future FSRU only in summer
5	Autumn	-	-	Ambient in summer
6	Autumn	Yes	-	Existing Conditions in Autumn
7	Autumn	Yes	Yes	Future bluescope and FSRU in Autumn
8	Autumn	-	Yes	Future FSRU only in Autumn
9	Winter	-	-	Ambient in Winter
10	Winter	Yes	-	Existing Conditions in Winter
11	Winter	Yes	Yes	Future bluescope and FSRU in Winter
12	Winter	-	Yes	Future FSRU only in Winter
13	Spring	-	-	Ambient in Spring
14	Spring	Yes	-	Existing Conditions in Spring
15	Spring	Yes	Yes	Future bluescope and FSRU in Spring
16	Spring	-	Yes	Future FSRU only in Spring

For the FSRU simulations, the Delft3D model was coupled with CORMIX in the sense that the outlet flow was distributed over the horizontal and vertical grid cells covered by the plume at the end of the near field zone.

Ambient seawater temperature was assumed to be 22ºC in summer, 20.6 ºC in Autumn, 16.8ºC in winter and 17.6 ºC in Spring. An ambient salinity of 33.5 PSU was applied in all of the simulations. These are consistent with the previous cooling water simulations undertaken by Cardno at Port Kembla.

Each simulation was undertaken over a period of 45 days, with the first 5 days being discarded – to allow for development of dynamic heat content equilibrium. Simulations included solar heating and cooling.

5.1.2 Results

Far field modelling results are presented in **Appendices A** through **D.** These results include contour plots of the 20th, 50th and 80th seawater temperature percentiles during each of the simulations.

Comparison plots for the assessing the results against the EPA requirements (i.e. the future median temperature minus the ambient 20th percentile temperature) are presented in **Figures 5.1** to **5.12.** In these plots, the areas in blue exceed the EPA requirements for cold water discharge, and the red colours comply.

The modelling results are summarised in Table 5-2. The modelling undertaken for the project predicts that the FSRU will comply with the EPA requirements when considered in combination with the BlueScope discharges. The model also indicates that the discharge will comply with the EPA guideline values considering the case where the BlueScope cooling water system is not operating. Note that the model does predict that the temperature decrease will exceed the EPA guideline values in an area covering approximately 50m x 100m during summer and autumn. This area is similar to the nearfield zone predicted by CORMIX (radius of 42.5m from the point of discharge), and given the model resolution (~30m), is considered to be compliant.

Table 5-2 Summary of Far Field Modelling Results

Comparison Figure	Season	Future Discharges	Ambient Discharges	Outcome
5.1	Summer	FSRU	none	Approx 50m x 100m area near the seabed exceeds EPA requirements for Temperature. Mid depth and surface comply
5.2	Summer	FSRU and BlueScope	none	Complies
5.3	Summer	FSRU and BlueScope	BlueScope	Complies
5.4	Autumn	FSRU	none	Approx 50m x 100m area exceeds EPA requirements for Temperature Mid depth and surface comply
5.5	Autumn	FSRU and BlueScope	none	Complies
5.6	Autumn	FSRU and BlueScope	BlueScope	Complies
5.7	Winter	FSRU	none	Complies
5.8	Winter	FSRU and BlueScope	none	Complies
5.9	Winter	FSRU and BlueScope	BlueScope	Complies
5.10	Spring	FSRU	none	Complies

5.11	Spring	FSRU and BlueScope	none	Complies
5.12	Spring	FSRU and BlueScope	BlueScope	Complies

6 Sodium Hypochlorite Modelling

6.1 General

It is understood that sodium hypochlorite will be present in the warming water discharge. Concentrations at the point of discharge are predicted to be up to 20 ug/l.

The near field mixing and dispersion of the sodium hypochlorite has been undertaken to assess the potential concentrations in the near field mixing zone, as well as in the far field model.

For this study, sodium hypochlorite has been modelled as a conservative pollutant. That is, the model assumes the pollutant does not degrade, and concentrations have been assessed based on mixing and dilution.

6.2 Near Field Mixing

Applying a discharge concentration of 20 ug/l at the point of discharge to the dilution values predicted by CORMIX, the centreline, average and plume edge concentrations at the end of the nearfield mixing zone are presented overleaf in Table 6-1.

This table indicates that the sodium hypochlorite concentration at the edge of the plume, at the end of the nearfield region is predicted to be up to 1.9 ug/l. The average concentration within the plume is predicted to be 3.0 ug/l, or less.

Considering the ANZECC guidelines for fresh water, a guideline value of 3ug/l is recommended. The near field modelling indicates that the sodium hypochlorite concentration at the edge of the near field zone is less than 2 ug/l, and therefore is predicted to comply with this value.

Table 6-1 Simulated temperature decrease at the end of the near field

Season	Water Level	Current Speed (m/s)	Centreline Distance to end of nearfield (m)	Plume 1/e vertical thickness (m)	Plume horizontal half width (m)	Mixing Zone Radius (m)	Centre Chlorine Conc [ug/l]	Average Chlorine Conc [ug/l]	Chlorine conc at edge of nearfield mixing zone [ug/l]
Summer	LAT	0	32.84	4.16	4.16	37.0	5.0	2.9	1.8
Summer	LAT	0.05	31.94	4.22	4.22	36.16	4.9	2.9	1.8
Summer	LAT	0.1	30.33	4.43	4.43	34.76	4.3	2.6	1.6
Summer	MSL	0	34.57	4.42	4.42	38.99	4.5	2.7	1.7
Summer	MSL	0.05	33.75	4.49	4.49	38.24	4.3	2.6	1.6
Summer	MSL	0.1	31.95	4.74	4.74	36.69	3.9	2.3	1.4
Summer	MHWS	0	35.85	4.58	4.58	40.43	4.3	2.5	1.6
Summer	MHWS	0.05	34.81	4.67	4.67	39.48	4.1	2.4	1.5
Summer	MHWS	0.1	32.98	4.95	4.95	37.93	3.6	2.1	1.3
Winter	LAT	0	31.23	3.98	3.98	35.21	5.1	3.0	1.9
Winter	LAT	0.05	30.38	4.03	4.03	34.41	5.0	2.9	1.8
Winter	LAT	0.1	29.09	4.21	4.21	33.3	4.4	2.6	1.6
Winter	MSL	0	33.01	4.22	4.22	37.23	4.5	2.7	1.7
Winter	MSL	0.05	32.05	4.29	4.29	36.34	4.4	2.6	1.6
Winter	MSL	0.1	30.62	4.5	4.5	35.12	4.0	2.4	1.5
Winter	MHWS	0	34.02	4.37	4.37	38.39	4.3	2.5	1.6
Winter	MHWS	0.05	33.13	4.45	4.45	37.58	4.2	2.5	1.5
Winter	MHWS	0.1	31.52	4.69	4.69	36.21	3.7	2.2	1.4
Spring	LAT	0	34.38	4.36	4.36	38.74	4.9	2.9	1.8
Spring	LAT	0.05	33.48	4.43	4.43	37.91	4.8	2.8	1.8
Spring	LAT	0.1	31.67	4.66	4.66	36.33	4.3	2.5	1.6
Spring	MSL	0	36.36	4.63	4.63	40.99	4.4	2.6	1.6
Spring	MSL	0.05	35.43	4.72	4.72	40.15	4.3	2.5	1.6
Spring	MSL	0.1	33.46	5	5	38.46	3.8	2.2	1.4
Spring	MHWS	0	37.7	4.8	4.8	42.5	4.2	2.5	1.5
Spring	MHWS	0.05	36.59	4.91	4.91	41.5	4.0	2.4	1.5
Spring	MHWS	0.1	34.73	5.2	5.2	39.93	3.5	2.1	1.3
Autumn	LAT	0	33.42	4.23	4.23	37.65	4.9	2.9	1.8
Autumn	LAT	0.05	32.51	4.3	4.3	36.81	4.8	2.8	1.8
Autumn	LAT	0.1	30.82	4.51	4.51	35.33	4.3	2.6	1.6

Season	Water Level	Current Speed (m/s)	Centreline Distance to end of nearfield (m)	Plume 1/e vertical thickness (m)	Plume horizontal half width (m)	Mixing Zone Radius (m)	Centre Chlorine Conc [ug/l]	Average Chlorine Conc [ug/l]	Chlorine conc at edge of nearfield mixing zone [ug/l]
Autumn	MSL	0	35.3	4.49	4.49	39.79	4.5	2.7	1.7
Autumn	MSL	0.05	34.27	4.57	4.57	38.84	4.3	2.6	1.6
Autumn	MSL	0.1	32.55	4.83	4.83	37.38	3.8	2.3	1.4
Autumn	MHWS	0	36.51	4.66	4.66	41.17	4.3	2.5	1.6
Autumn	MHWS	0.05	35.46	4.76	4.76	40.22	4.1	2.4	1.5
Autumn	MHWS	0.1	33.6	5.05	5.05	38.65	3.6	2.1	1.3

6.3 Far Field Modelling

As noted in the previous sections, near field modelling describes the plume behaviour in the near field zone of the discharge. These models are steady state they do not include affects such as accumulation of pollutants or recirculation between the intake and the outfall. To assess the potential for these effects, far field modelling using a 3-dimensional hydrodynamic model has been applied.

Far field modelling of sodium hypochlorite was undertaken in Deflt3D, using the same model applied to the temperature dispersion modelling, however extended to include the advection/dispersion of a conservative tracer.

As per the warming water simulations, the sodium hypochlorite simulation was undertaken over a period of 45 days, with the first 5 days being discarded – to allow for development of dynamic equilibrium. The simulations also included the heating and cooling water discharges, as well as solar heating and cooling.

The maximum concentration of sodium hypochlorite simulated by the model is presented in **Figure 6.1**. This figure shows that the sodium hypochlorite concentration within the port is predicted to be approximately 1.5 ug/l through the upper water column. The maximum concentration is predicted to be slightly larger near the seabed, where concentrations outside of the near field mixing zone are predicted to reach up to 3 ug/l. There is a small area, less than 50m in radius, where the concentration is predicted to exceed 3 ug/l, however this at the point of discharge, and would be considered the near field mixing zone.

7 Discussion

This report presents the outcomes of the updated dispersion modelling studies undertaken for the proposed FSRU berth in Port Kembla. The main outcomes from the modelling are:

1. The near field mixing zone is predicted to be semi-circular in shape, with a 42.5m radius originating from the point of discharge;
2. Near field modelling indicates that the relevant water quality objectives for temperature and chlorine will be met in the near field zone;
3. Thermal plume modelling has been undertaken for the operational phase of the project, under all four seasons. The modelling predicts that the combination of the FSRU and BlueScope and the FSRU discharge will meet the water quality objectives for cold water discharges;
4. Water quality objectives are also met considering the case of the FSRU discharging without the BlueScope cooling water system in operation..
5. Far field simulations of sodium hypochlorite were undertaken to estimate the peak concentration in the far field. This modelling indicates that the peak concentration will be less than 3 ug/l outside of the initial mixing zone.

8 References

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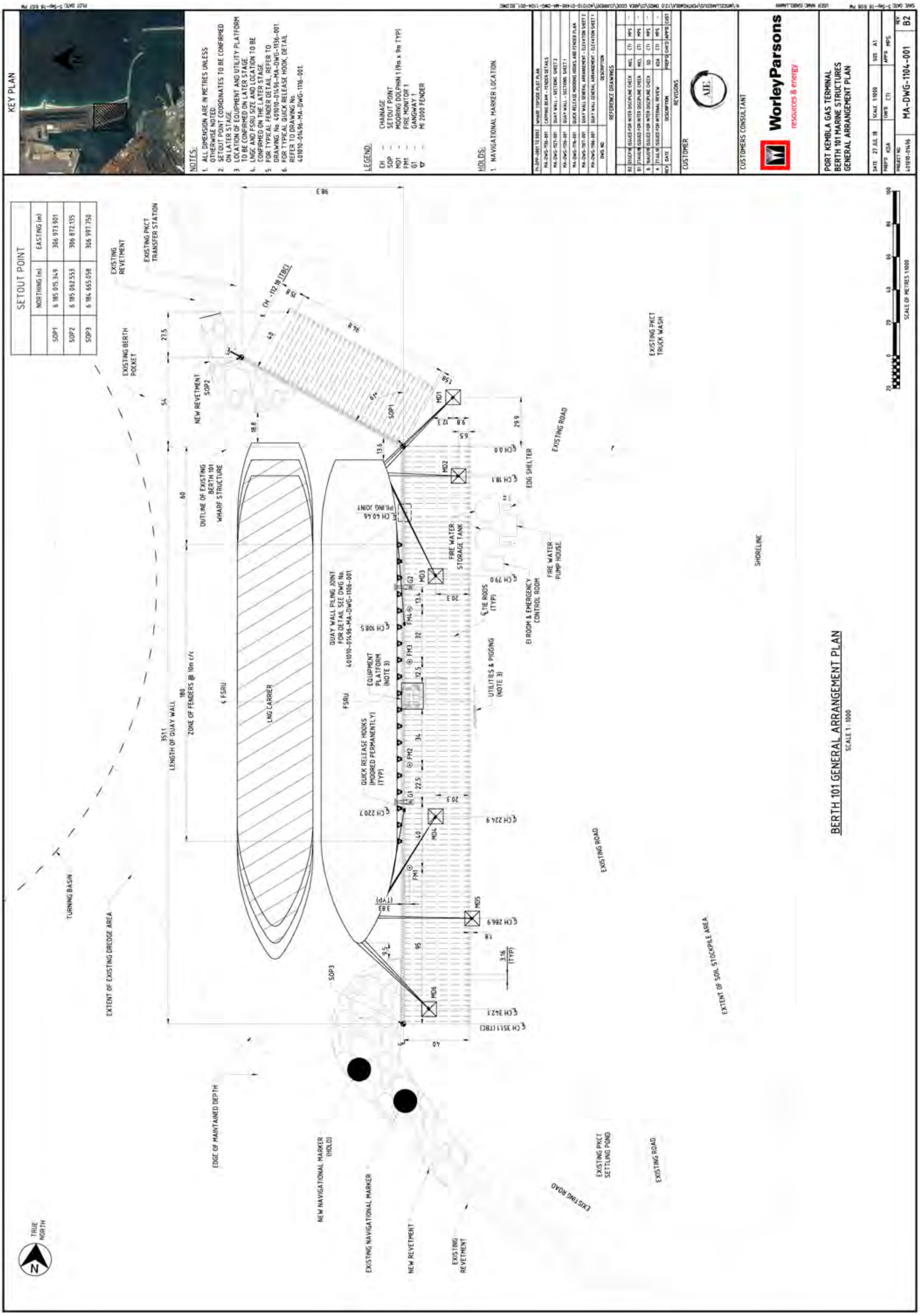
FIGURES



Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

General arrangement of the proposed FSRU berth

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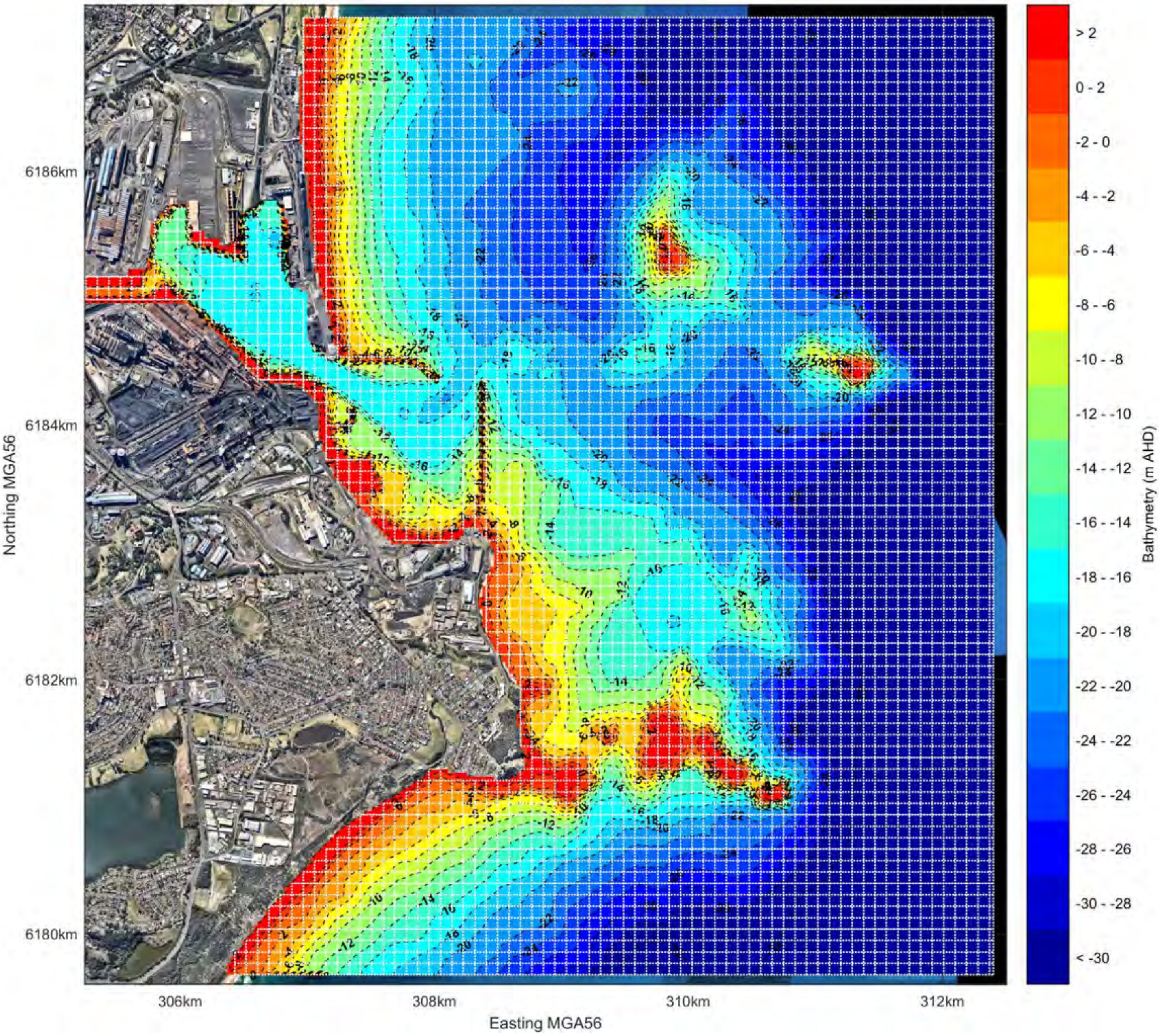
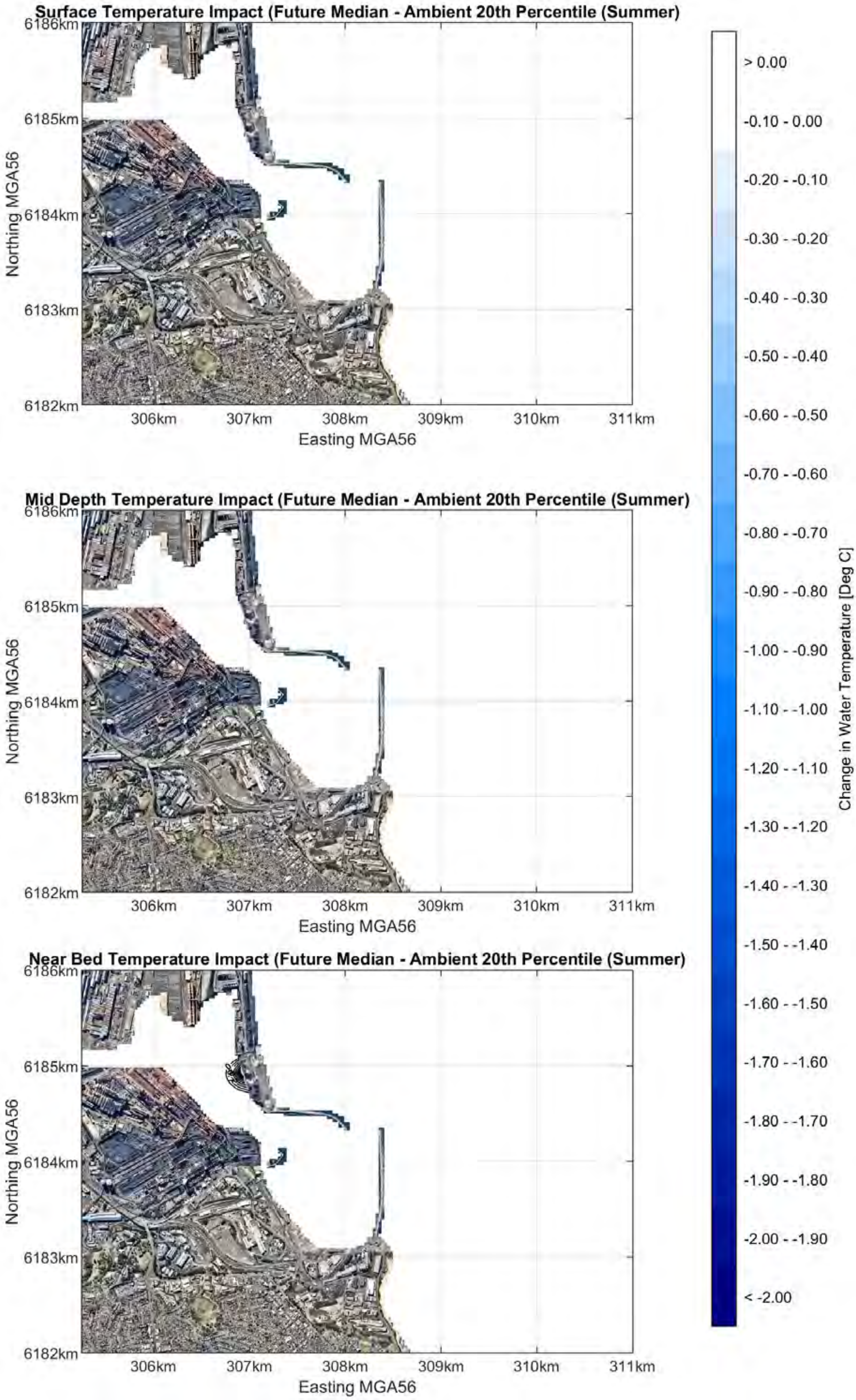
Figure 1.1



6186km
6184km
6182km
6180km
Northing MGA56
306km
308km
310km
312km
Easting MGA56
> 2
0 - 2
-2 - 0
-4 - -2
-6 - -4
-8 - -6
-10 - -8
-12 - -10
-14 - -12
-16 - -14
-18 - -16
-20 - -18
-22 - -20
-24 - -22
-26 - -24
-28 - -26
-30 - -28
< -30
Bathymetry (m AHD)



Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Summer)
Future FSRU compared to ambient

Figure 5.1

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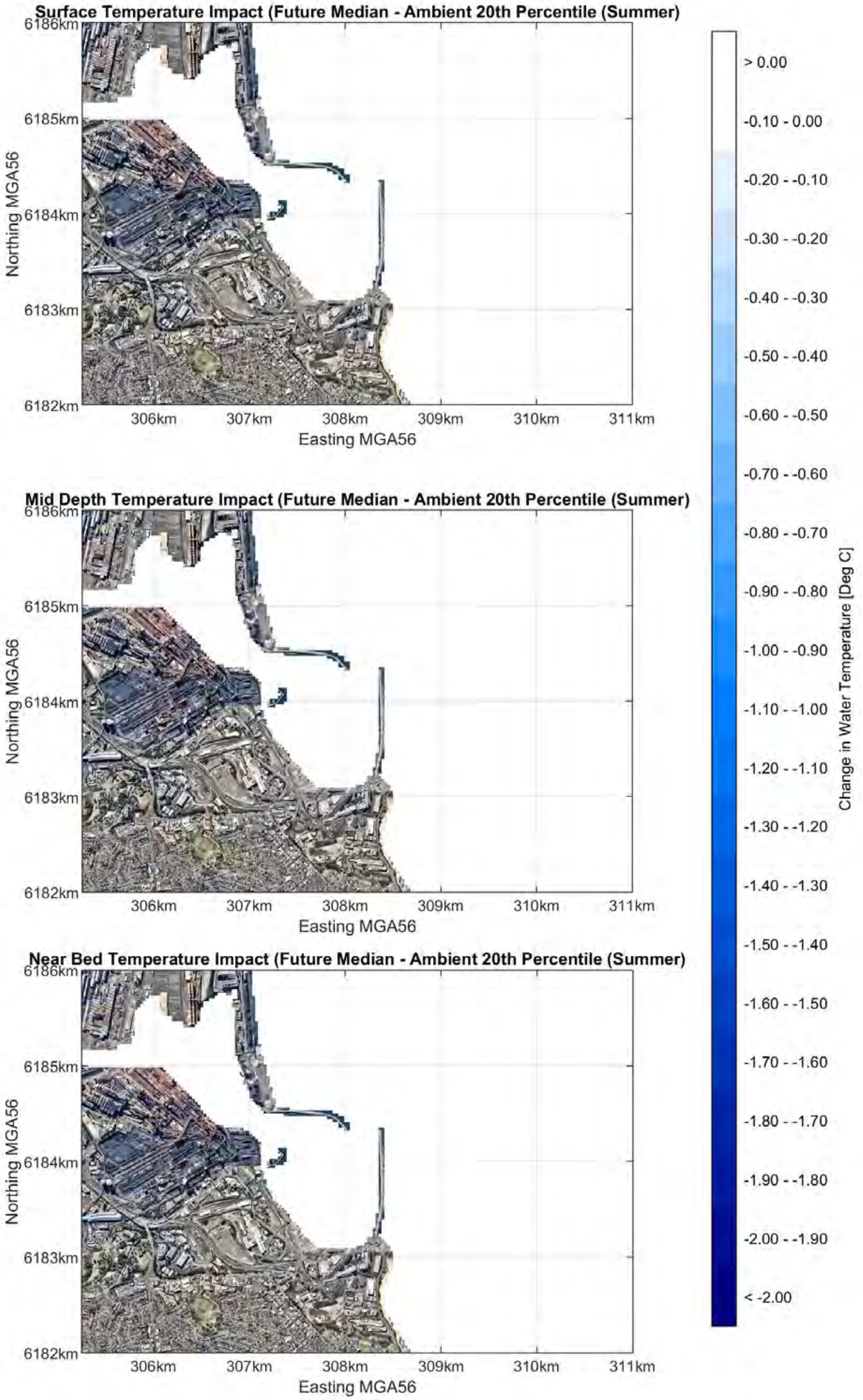

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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Summer)
Future FSRU+BS compared to ambient

Figure 5.2

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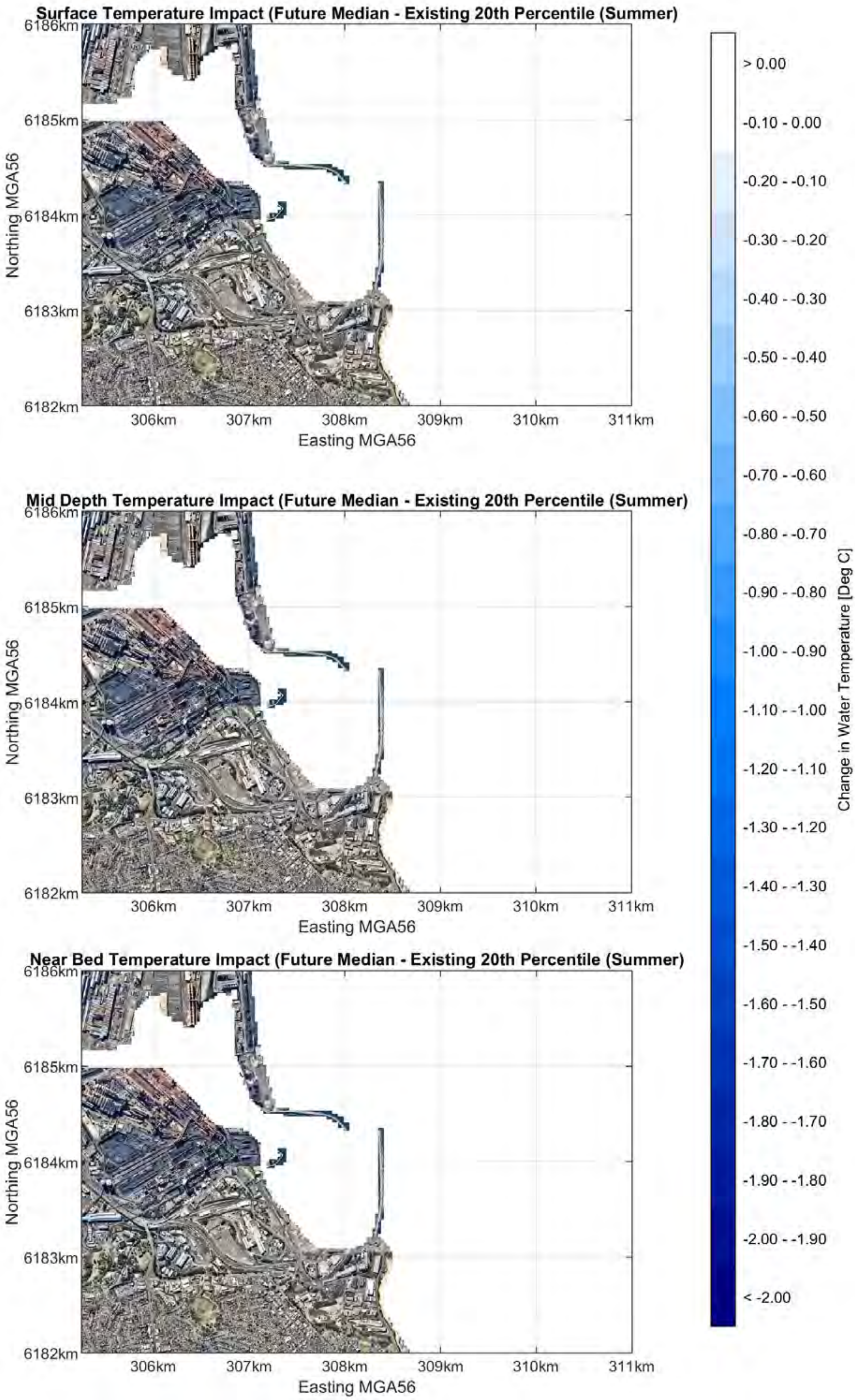

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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Summer)
Future FSRU+BS compared to existing

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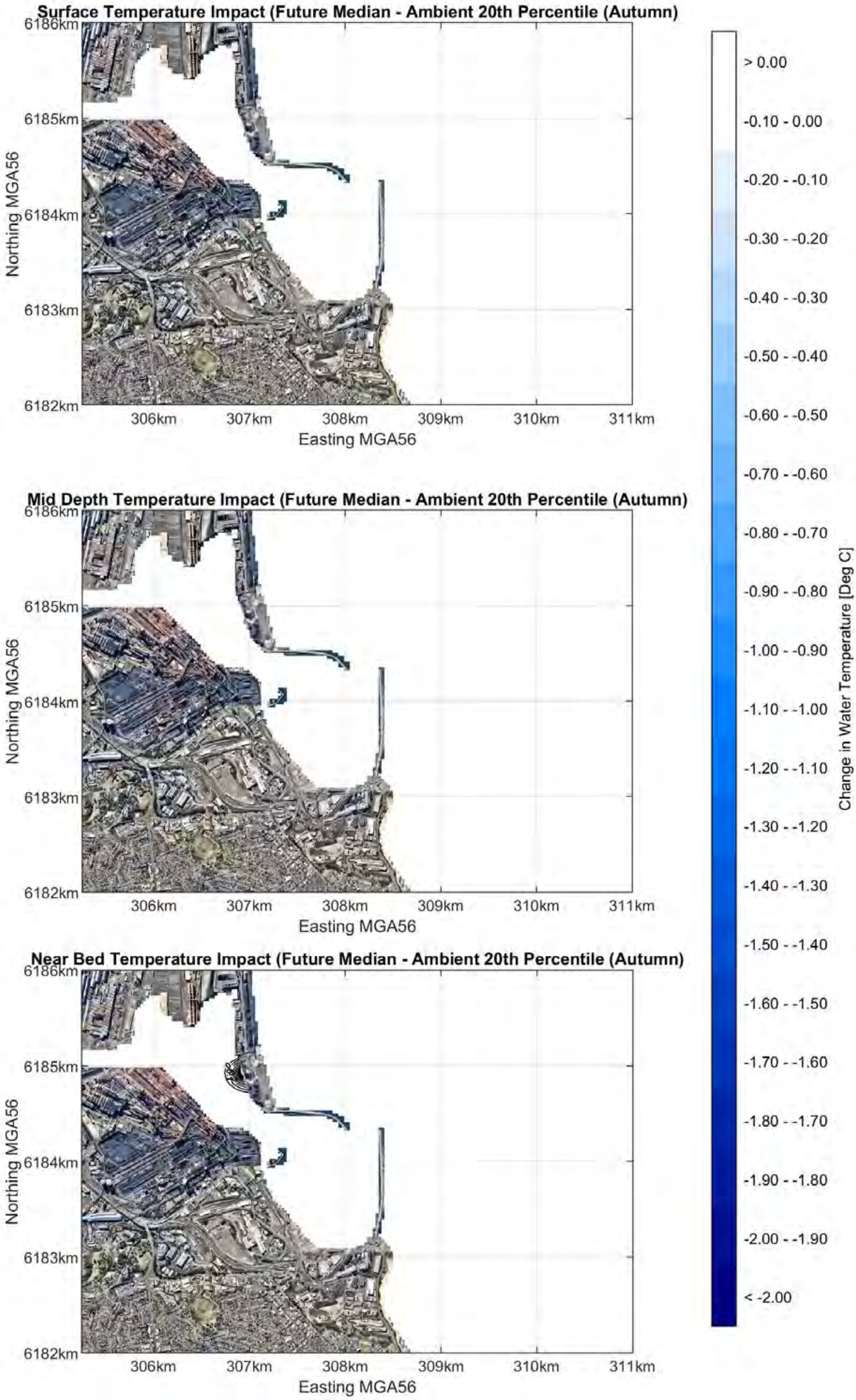
Figure 5.3



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Autumn)
Future FSRU compared to ambient

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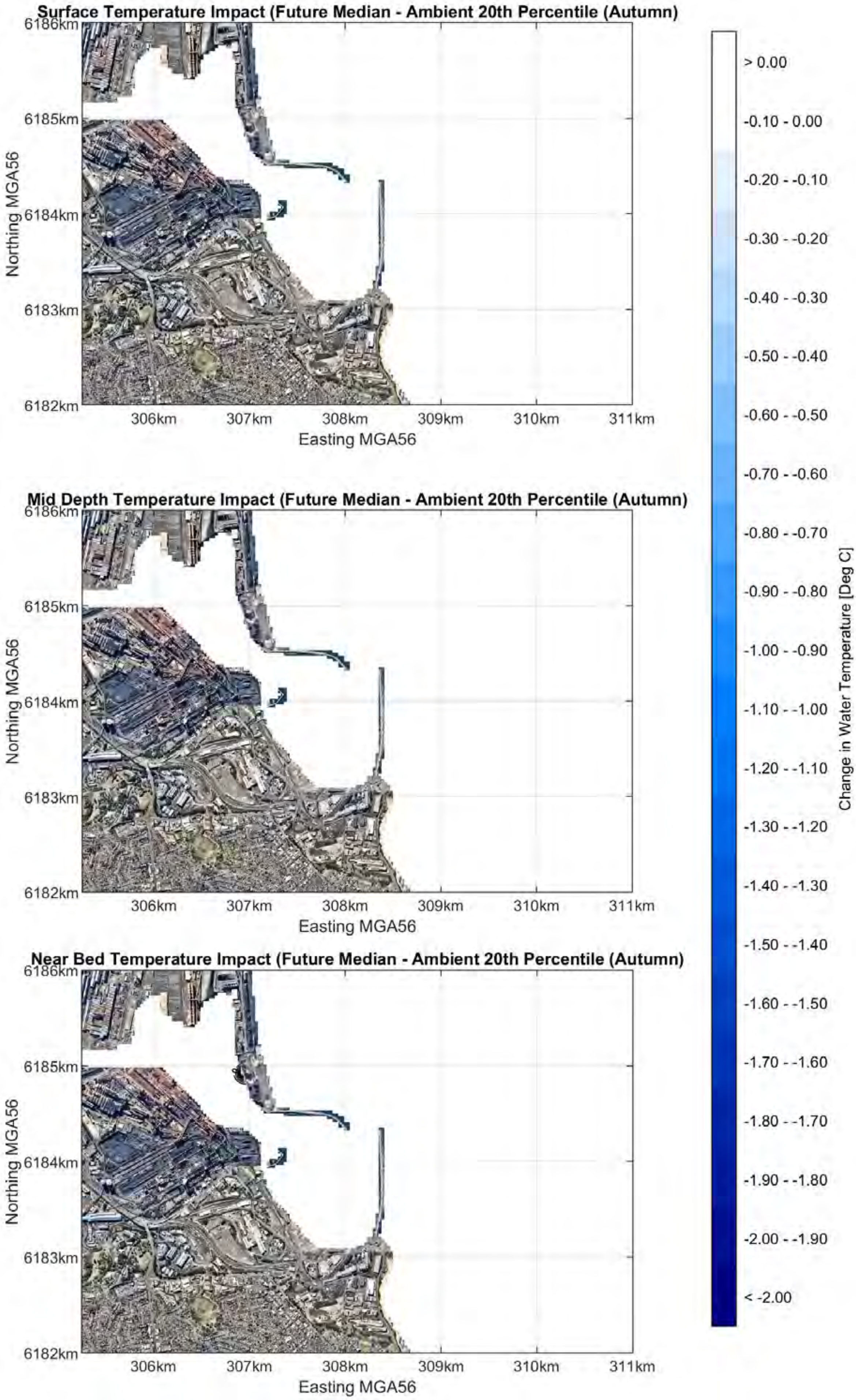
Figure 5.4



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Autumn)
Future FSRU+BS compared to ambient

Figure 5.5

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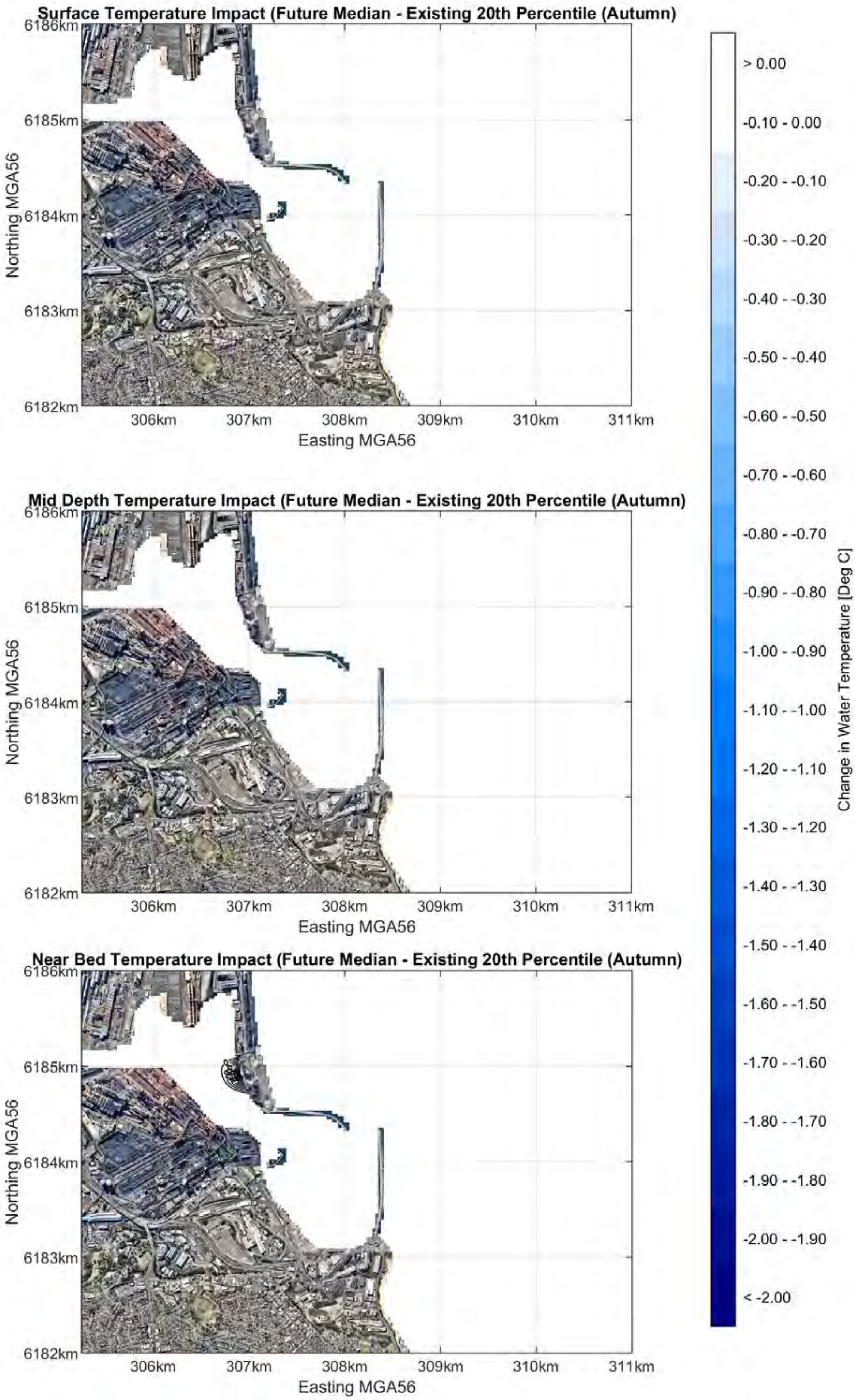

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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Autumn)
Future FSRU+BS compared to existing

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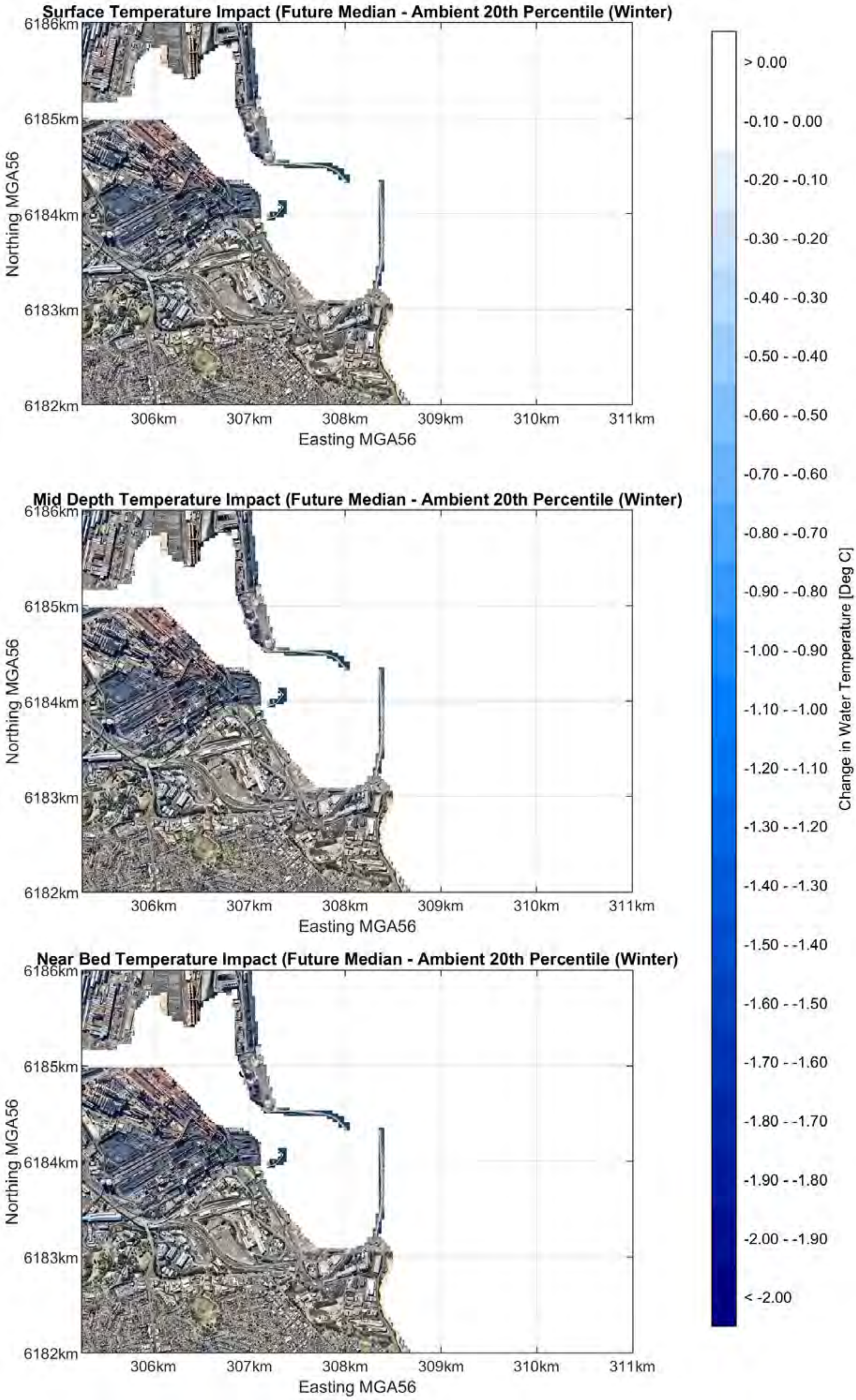
Figure 5.6



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Winter)
Future FSRU compared to ambient

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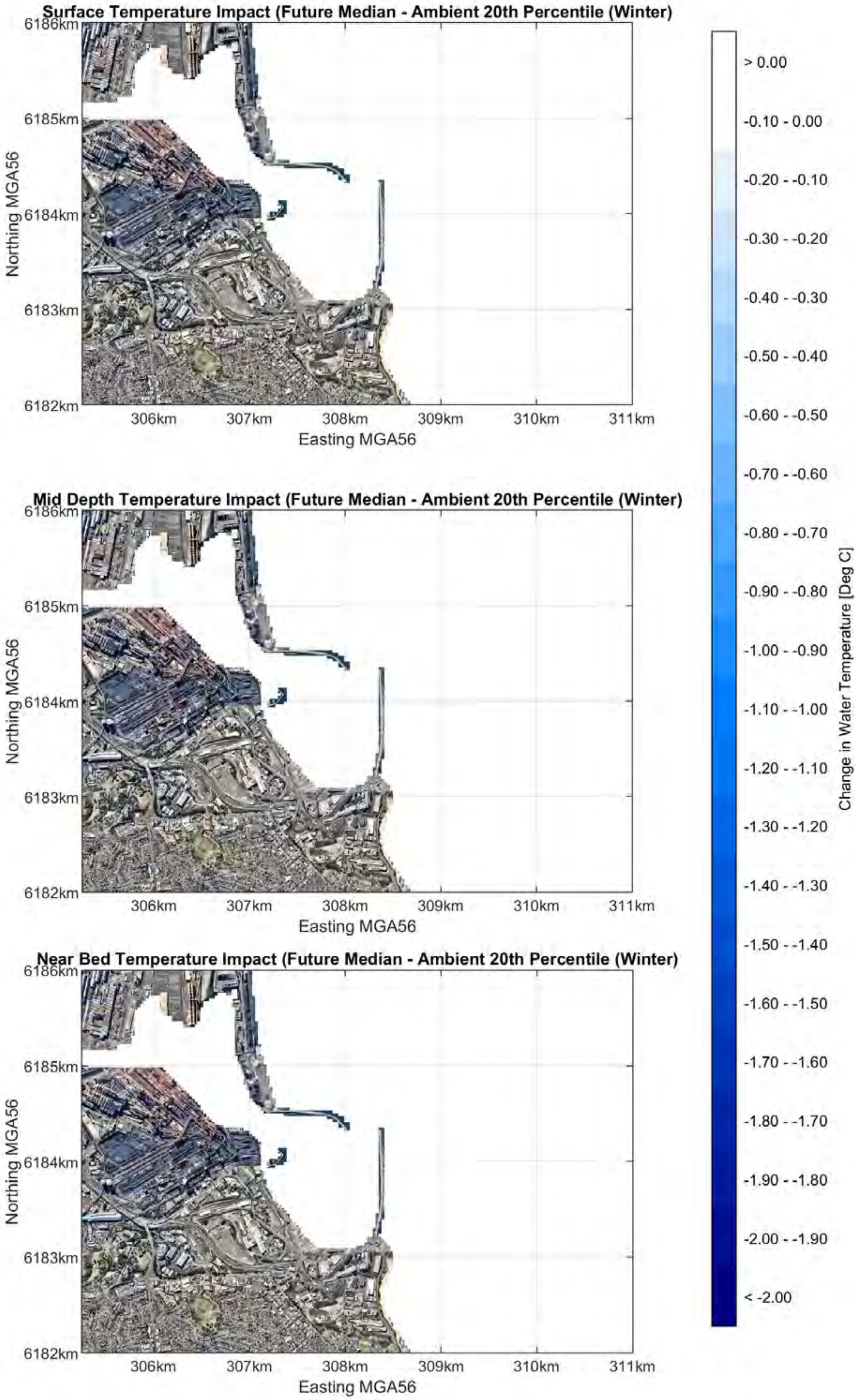
Figure 5.7



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Winter)
Future FSRU+BS compared to ambient

Figure 5.8

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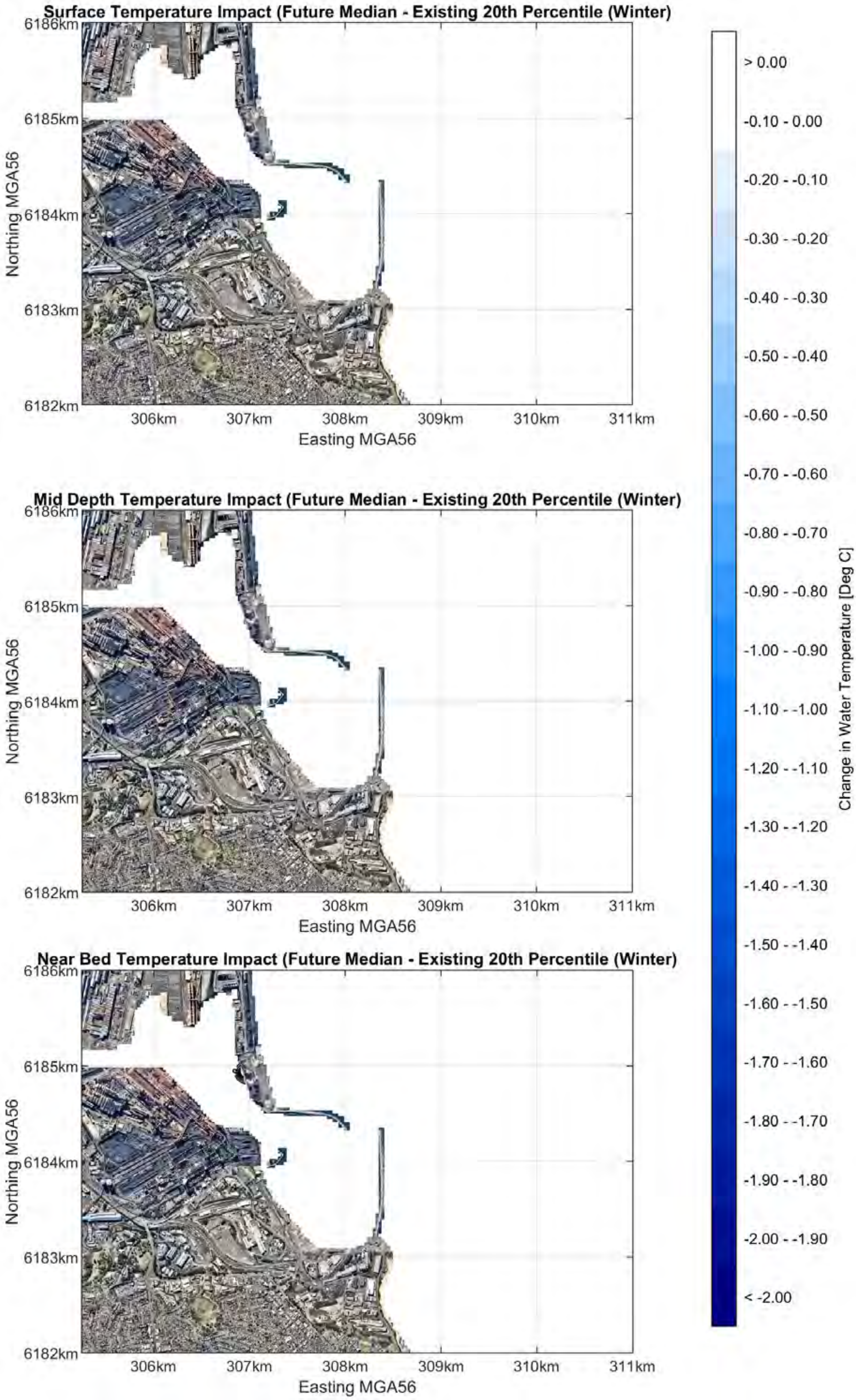

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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Winter)
Future FSRU+BS compared to existing

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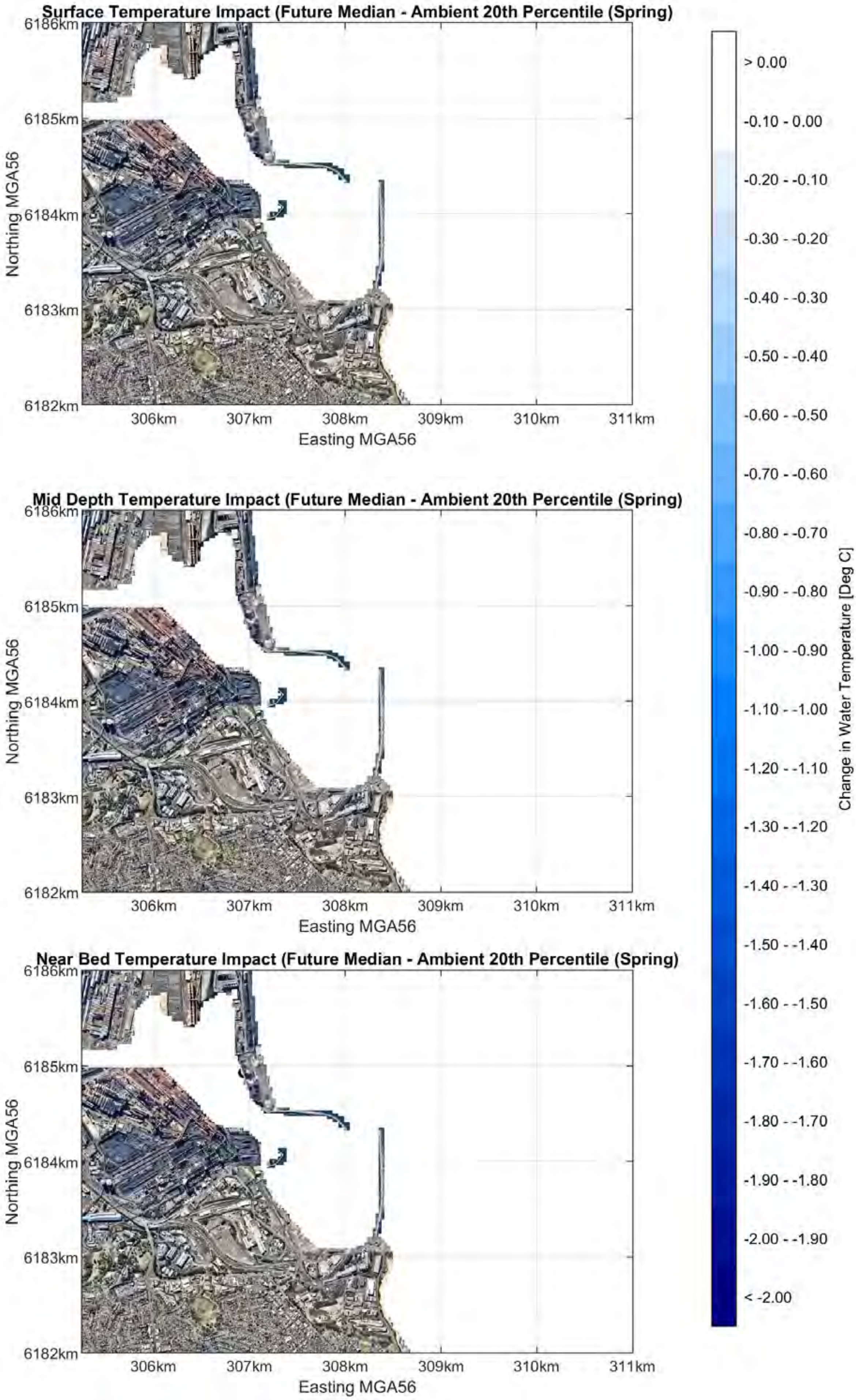
Figure 5.9



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Spring)
Future FSRU compared to ambient

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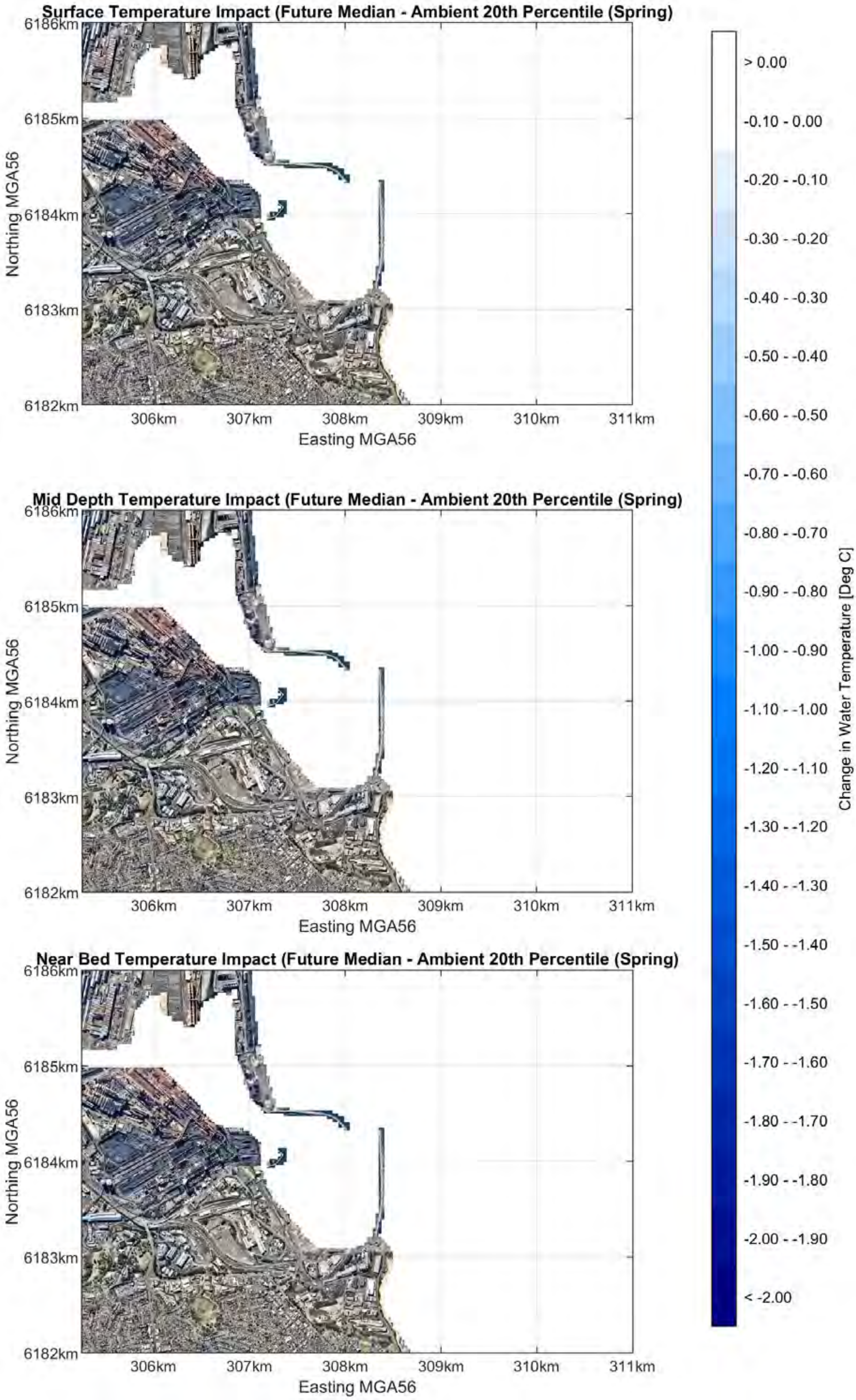
Figure 5.10



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Spring)
Future FSRU+BS compared to ambient

Figure 5.11

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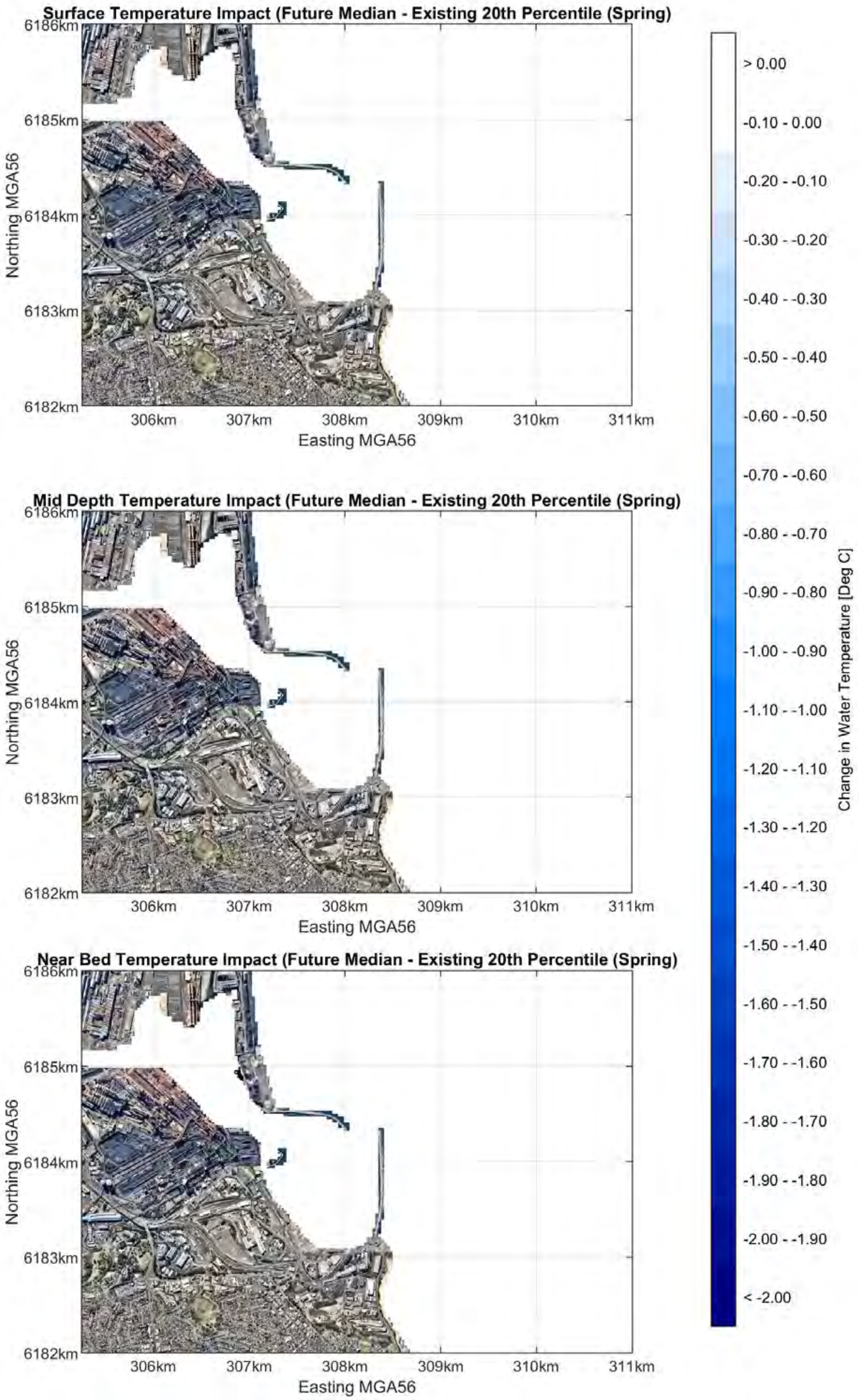

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Comparison to EPA guidelines (Spring)
Future FSRU+BS compared to existing

Figure 5.12

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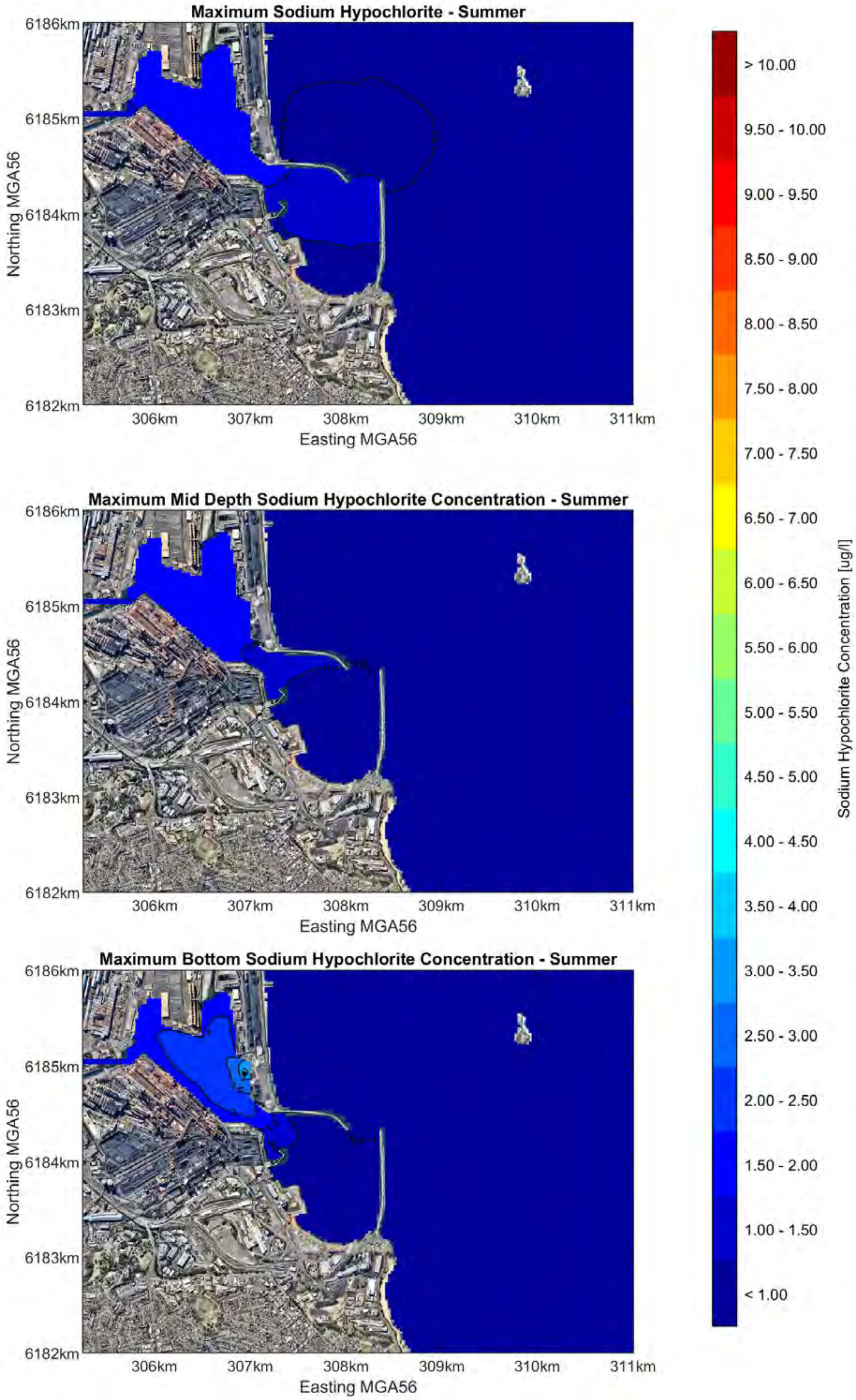

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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Maximum sodium hyperchloride concentration during the simulation periods

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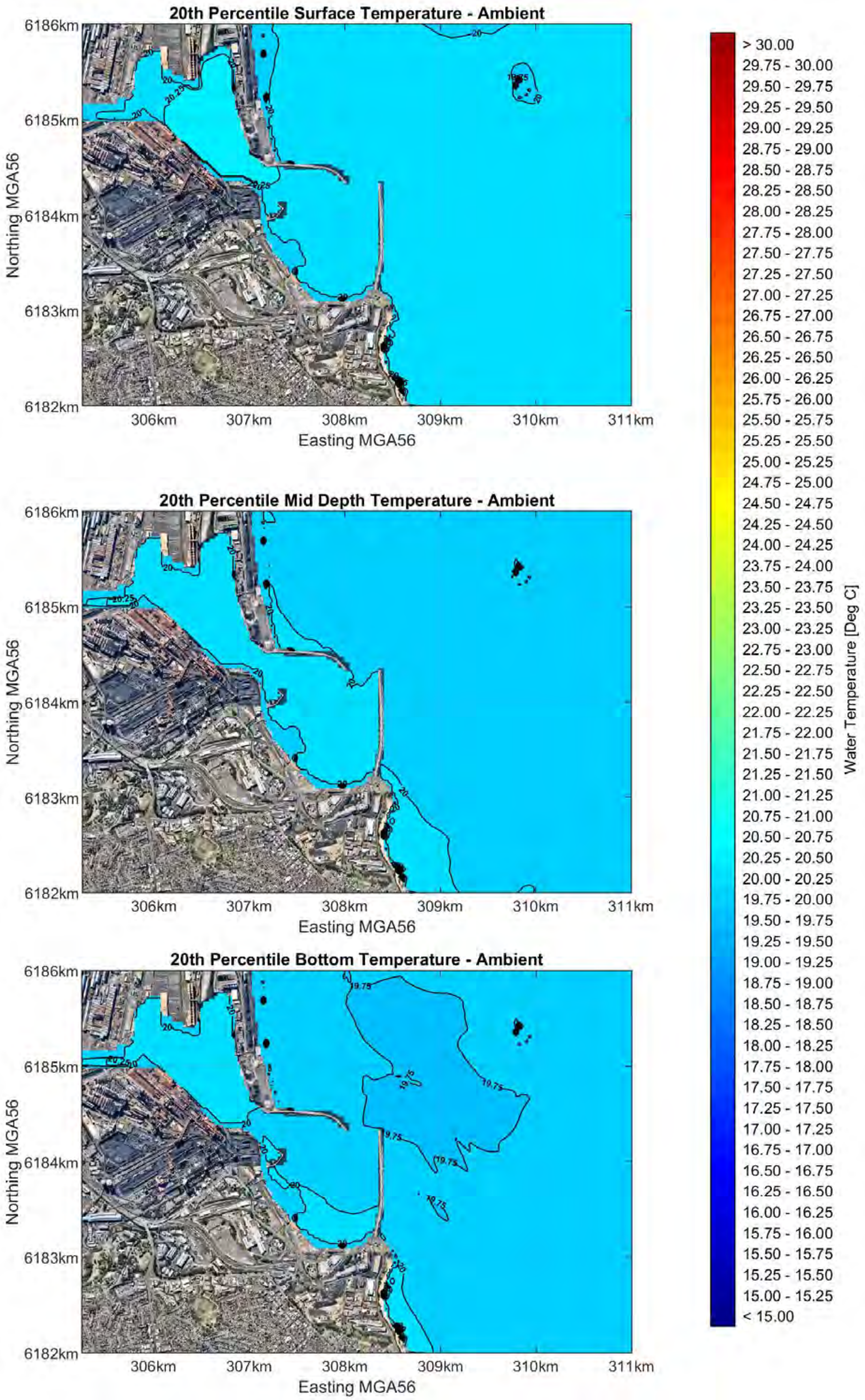
Figure 6.1

APPENDIX

A

SUMMER THERMAL PLUME



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
Ambient, 20th percentile

Appendix A1

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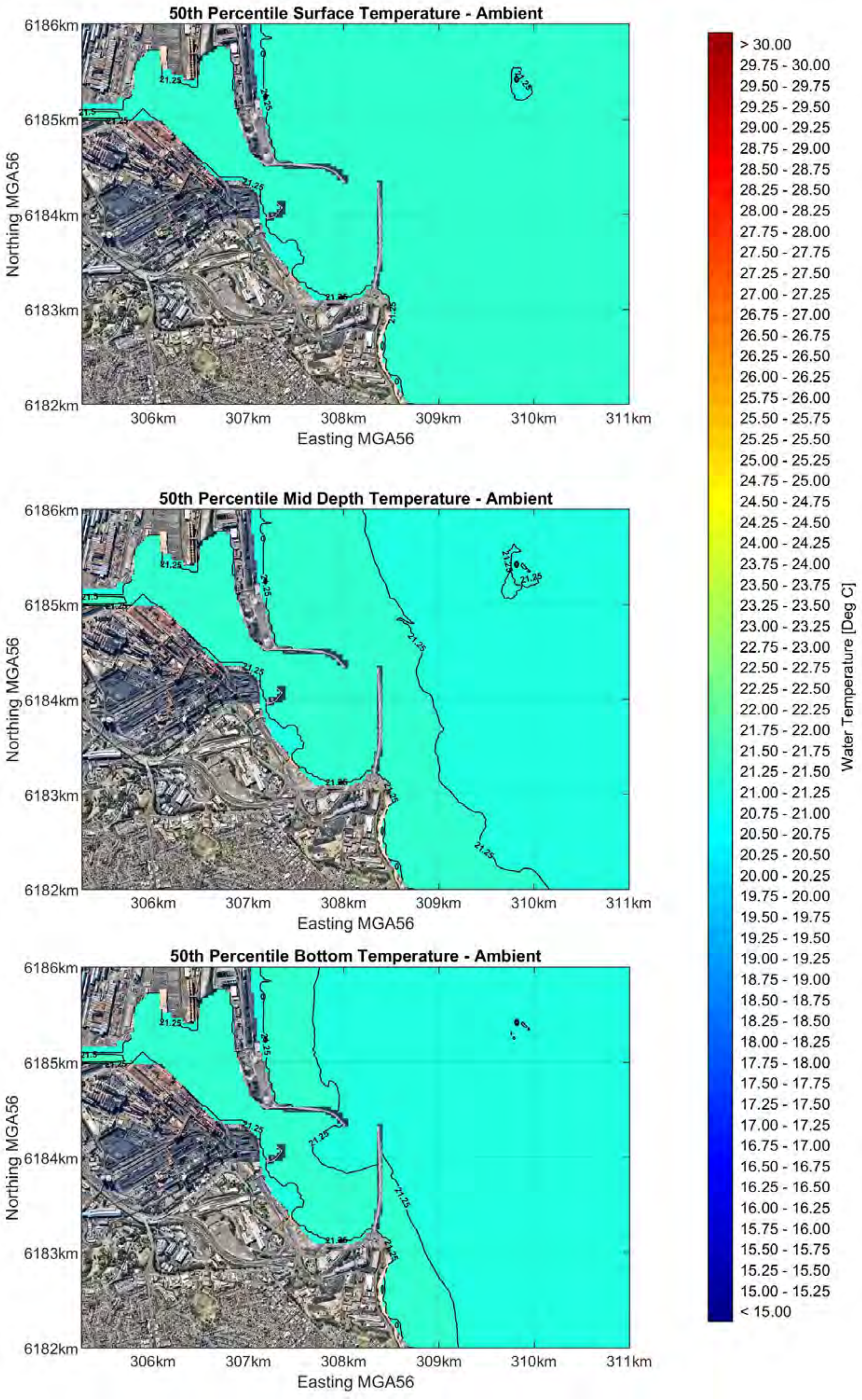

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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
Ambient, 50th percentile

Appendix A2

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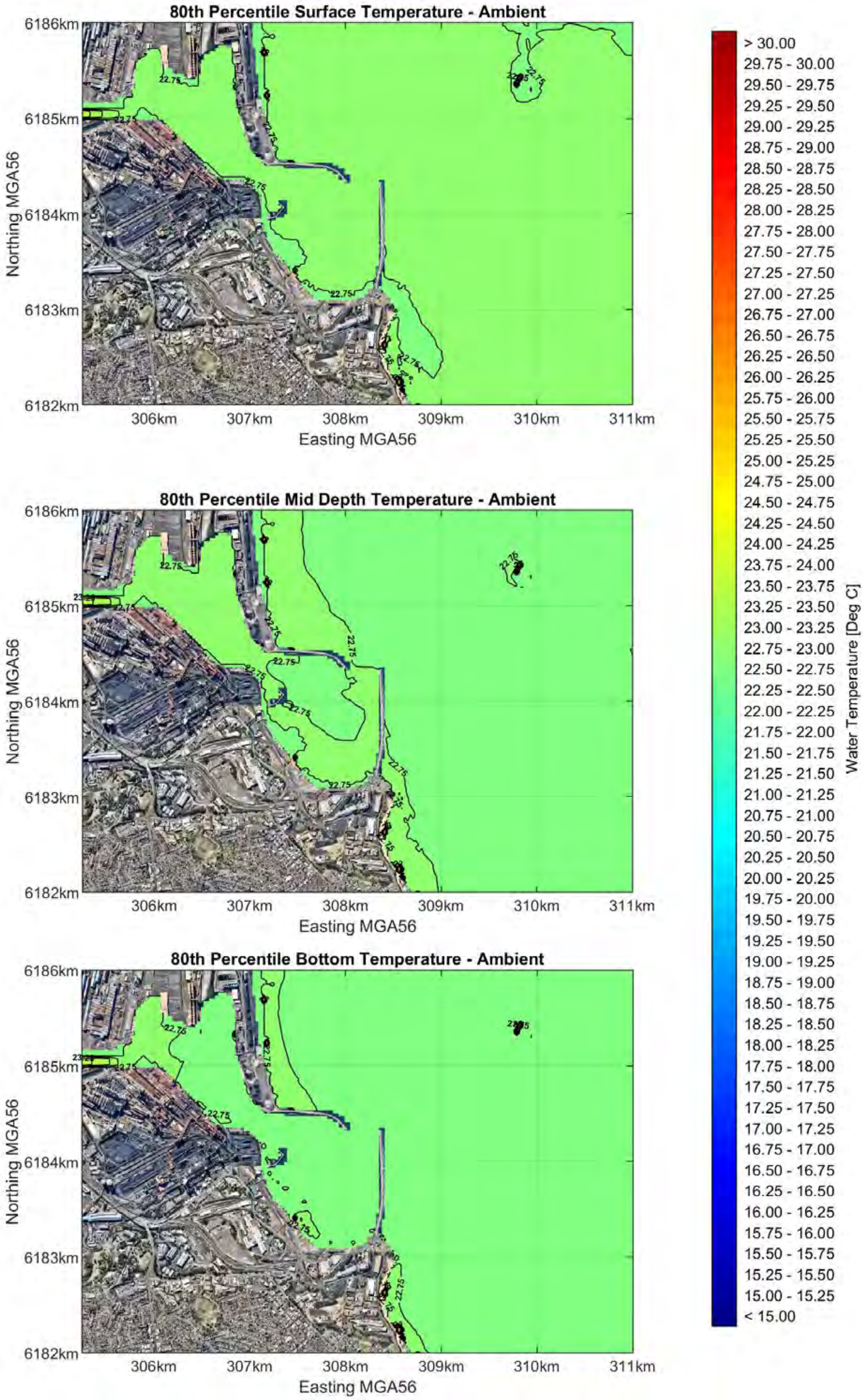

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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
Abmient, 80th percentile

Appendix A3

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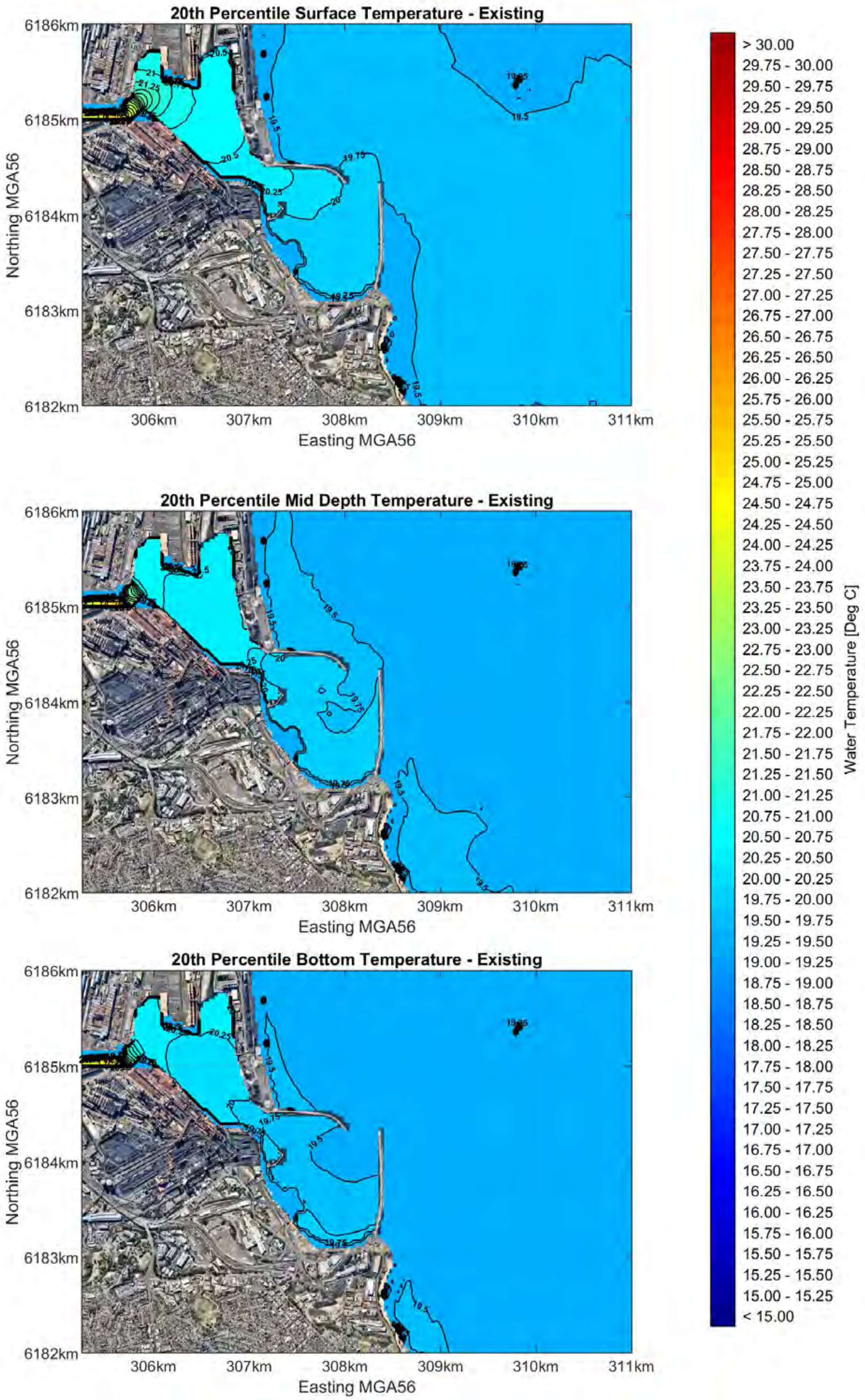

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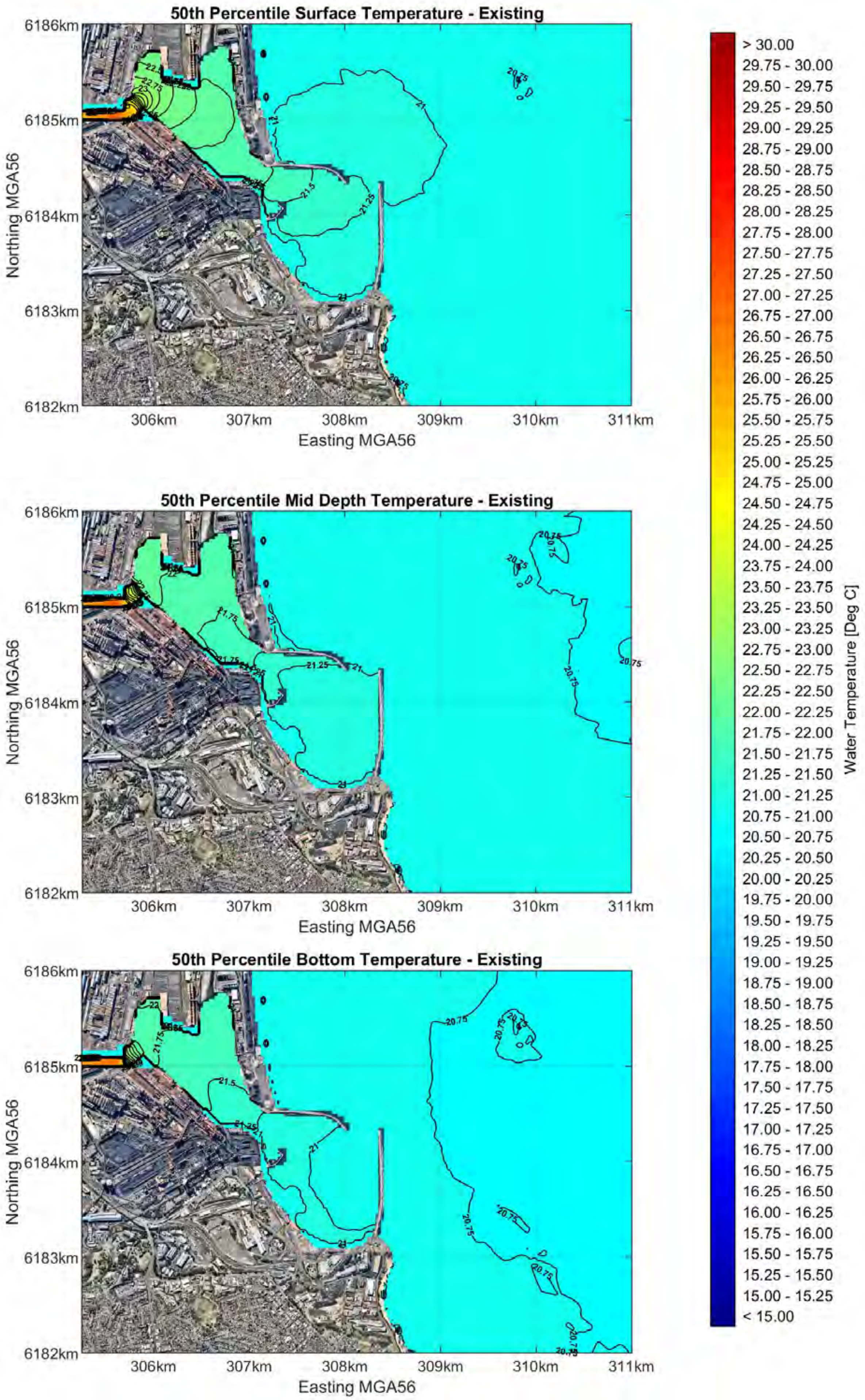
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
Existing, 20th percentile

Appendix A4

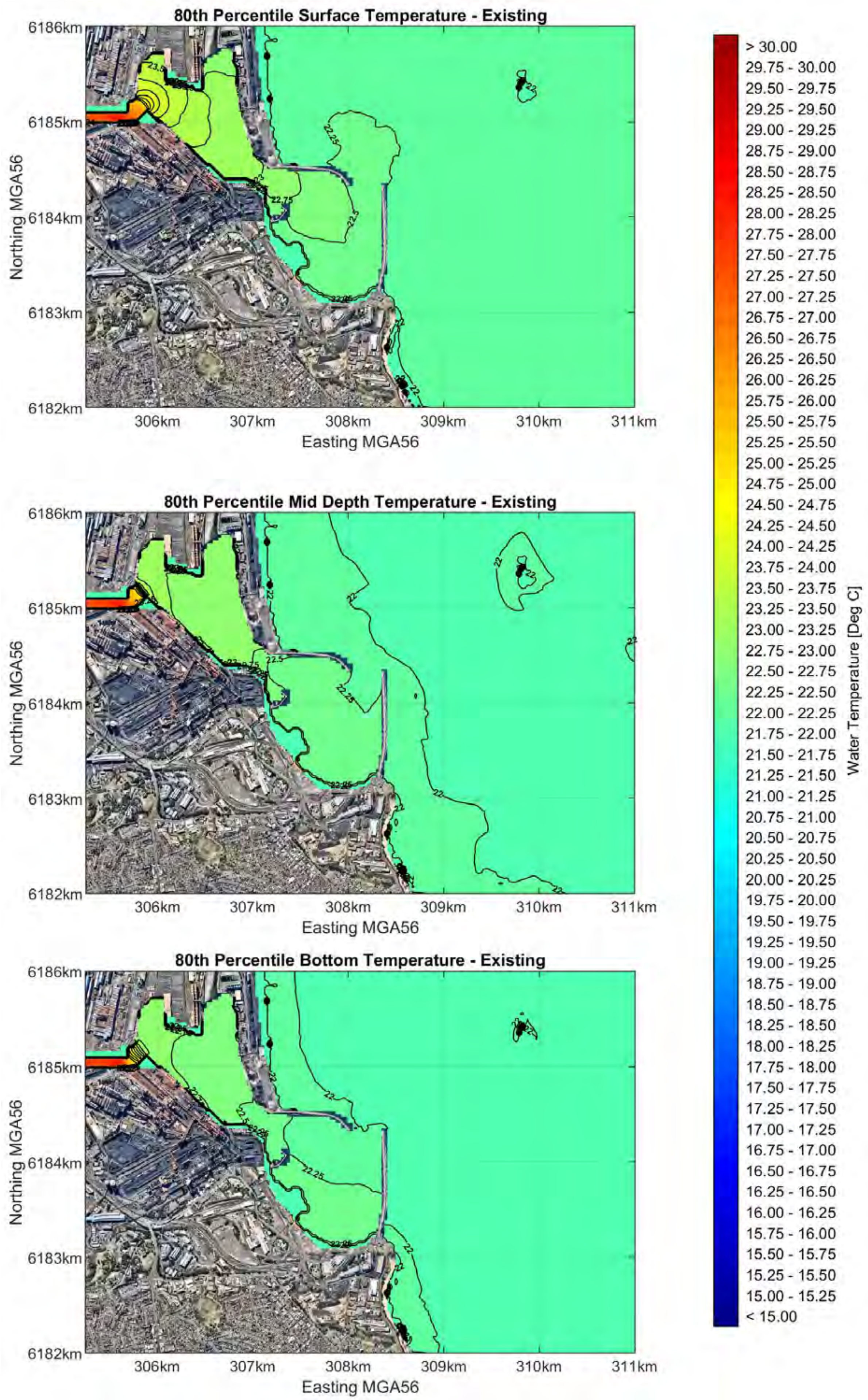


Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
Existing, 50th percentile

Appendix A5

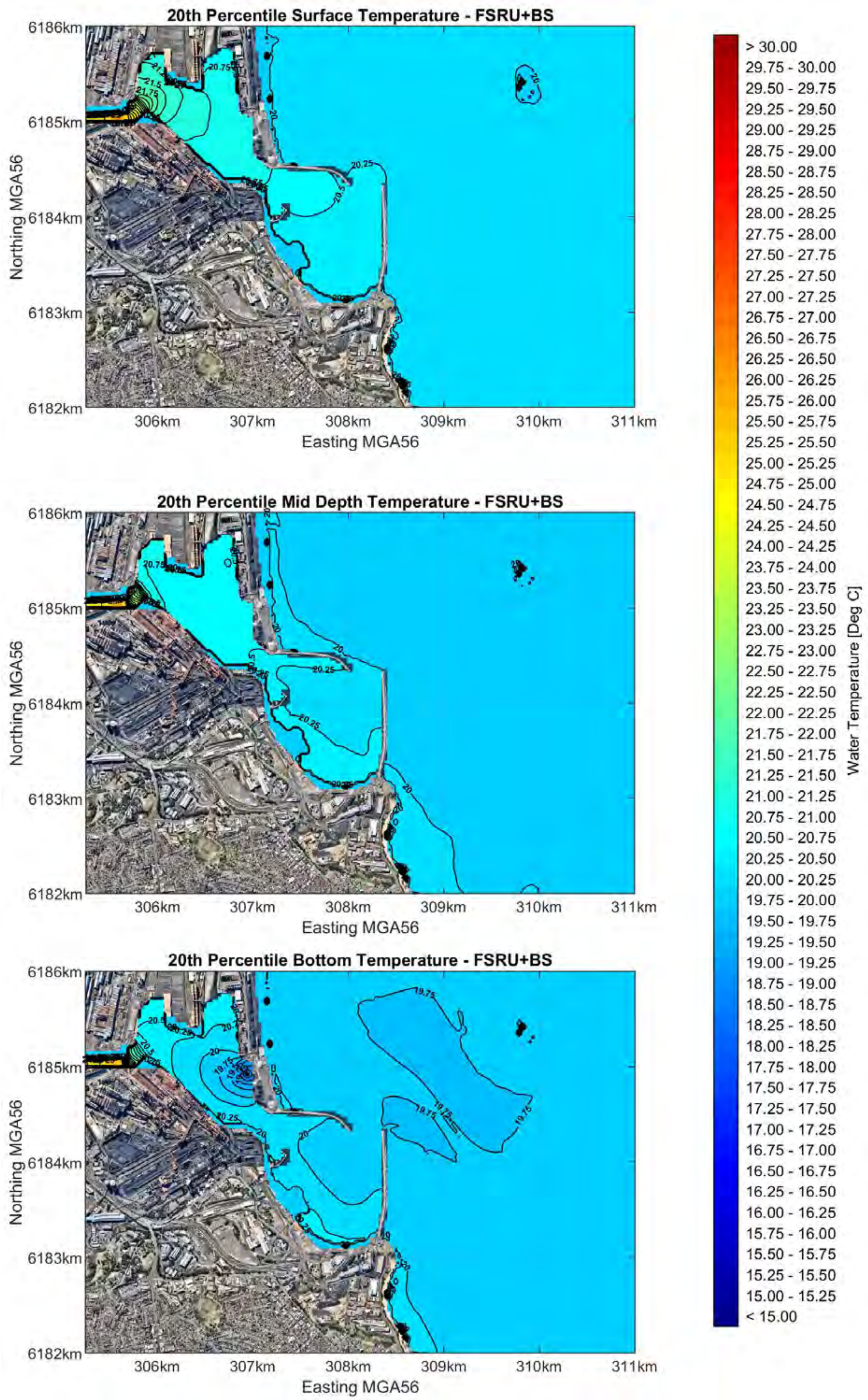


Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
Existing, 80th percentile

Appendix A6



Cardno

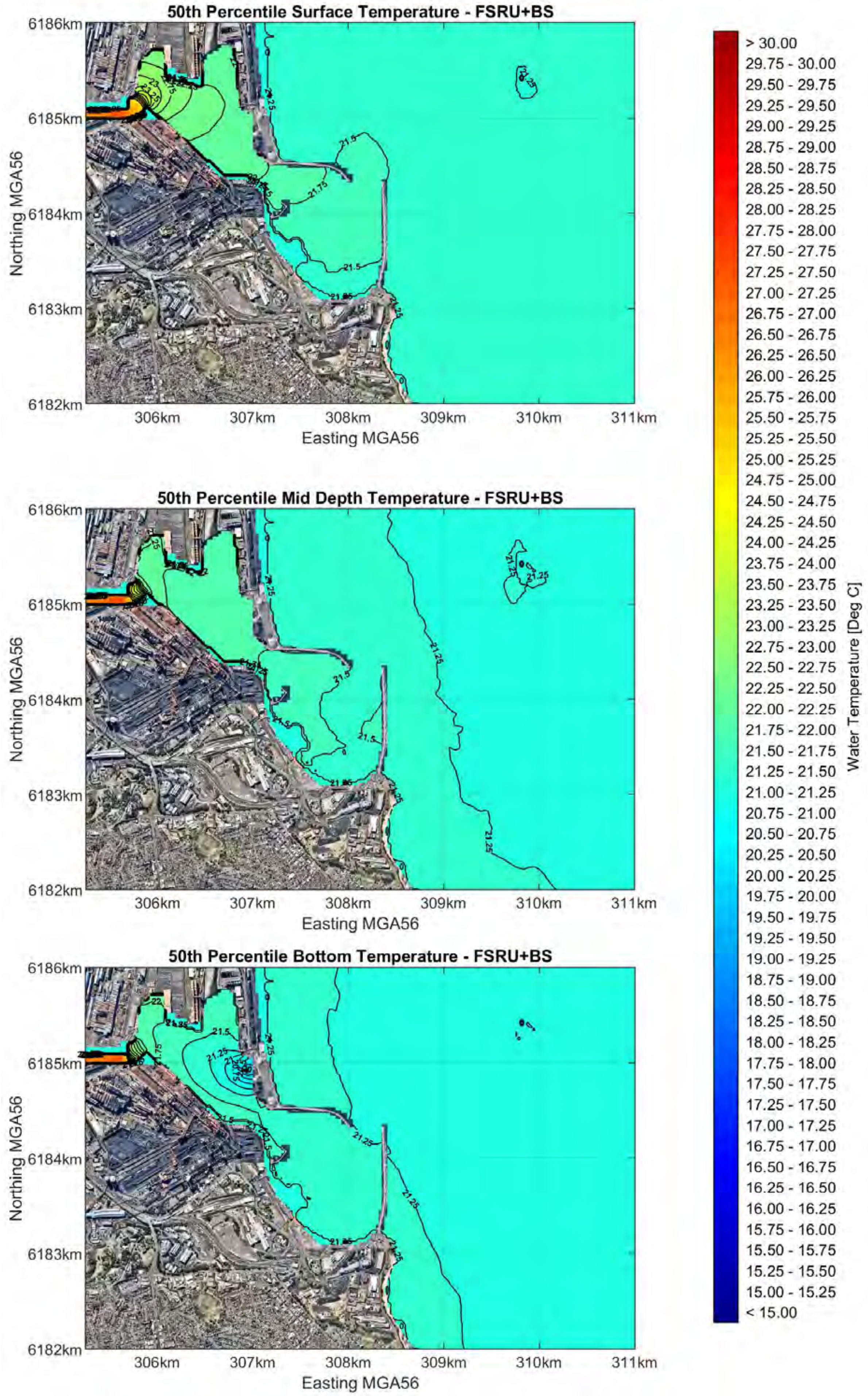
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
FSRU and Bluescope, 20th percentile

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\

Appendix A7



Cardno

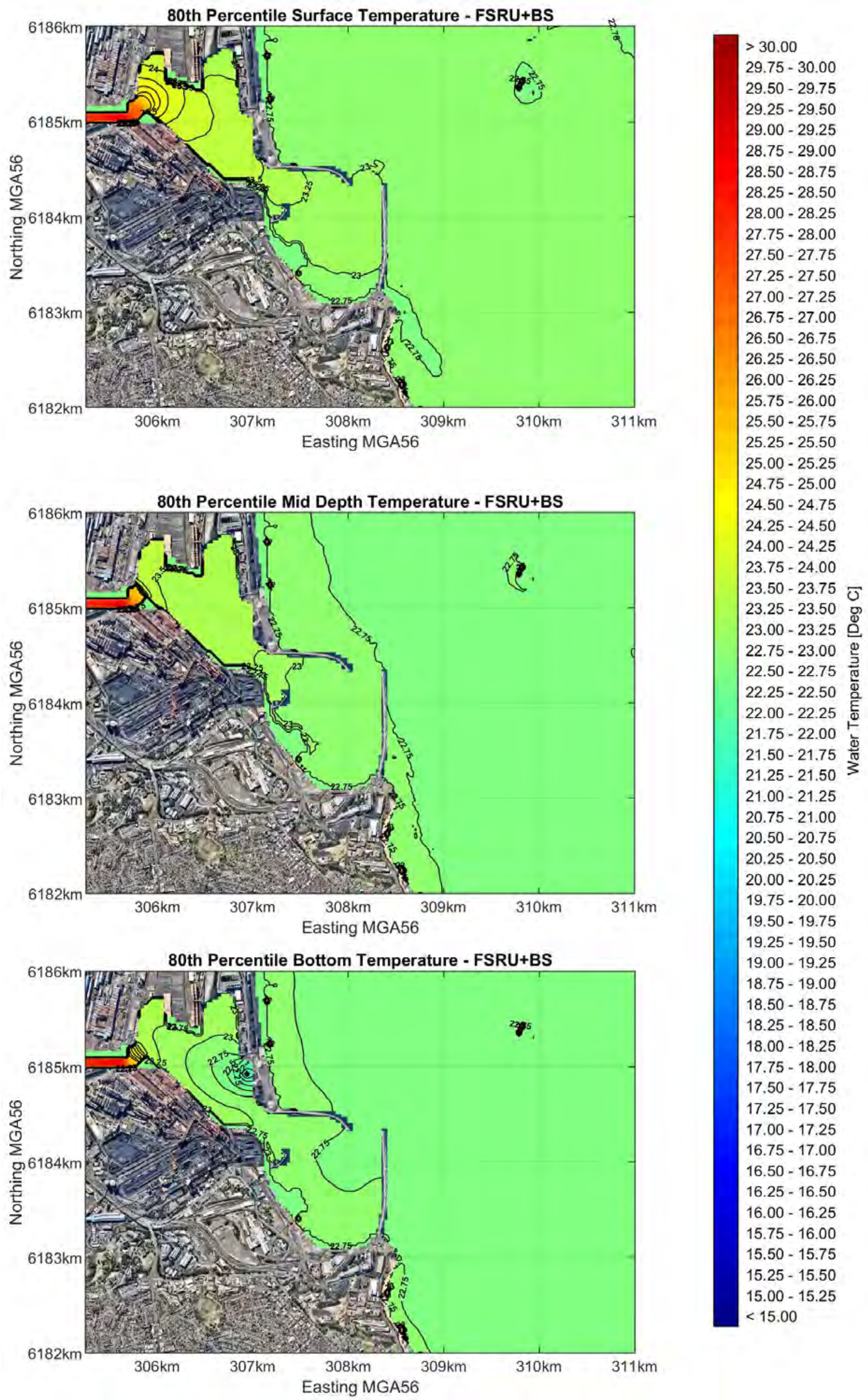
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
FSRU and Bluescope, 50th percentile

Appendix A8

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\



Cardno

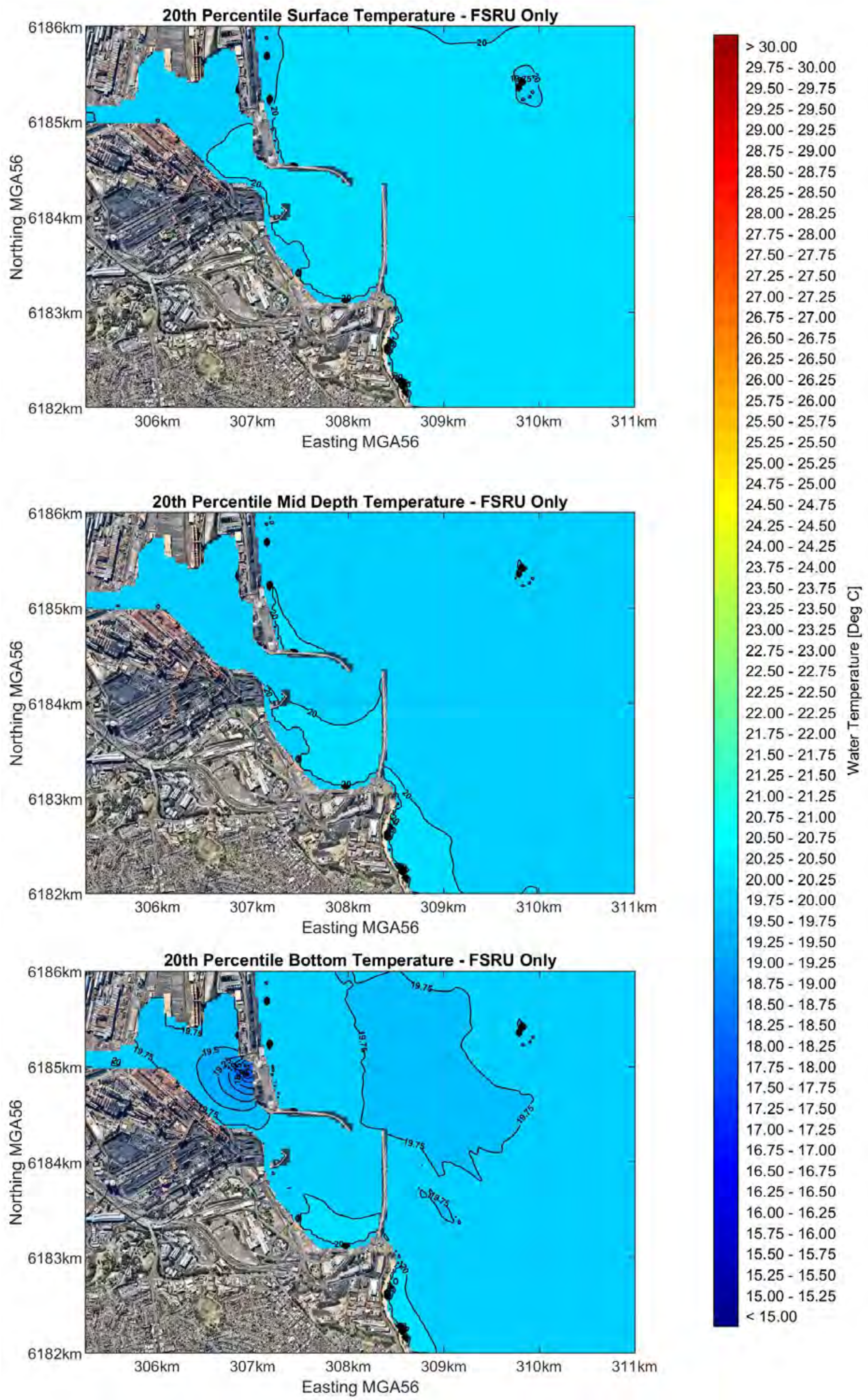
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
FSRU and Bluescope, 80th percentile

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\

Appendix A9



20th Percentile Surface Temperature - FSRU Only
20th Percentile Mid Depth Temperature - FSRU Only
20th Percentile Bottom Temperature - FSRU Only
6186km
6185km
6184km
6183km
6182km
Northing MGA56
306km
307km
308km
309km
310km
311km
Easting MGA56
> 30.00
29.75 - 30.00
29.50 - 29.75
29.25 - 29.50
29.00 - 29.25
28.75 - 29.00
28.50 - 28.75
28.25 - 28.50
28.00 - 28.25
27.75 - 28.00
27.50 - 27.75
27.25 - 27.50
27.00 - 27.25
26.75 - 27.00
26.50 - 26.75
26.25 - 26.50
26.00 - 26.25
25.75 - 26.00
25.50 - 25.75
25.25 - 25.50
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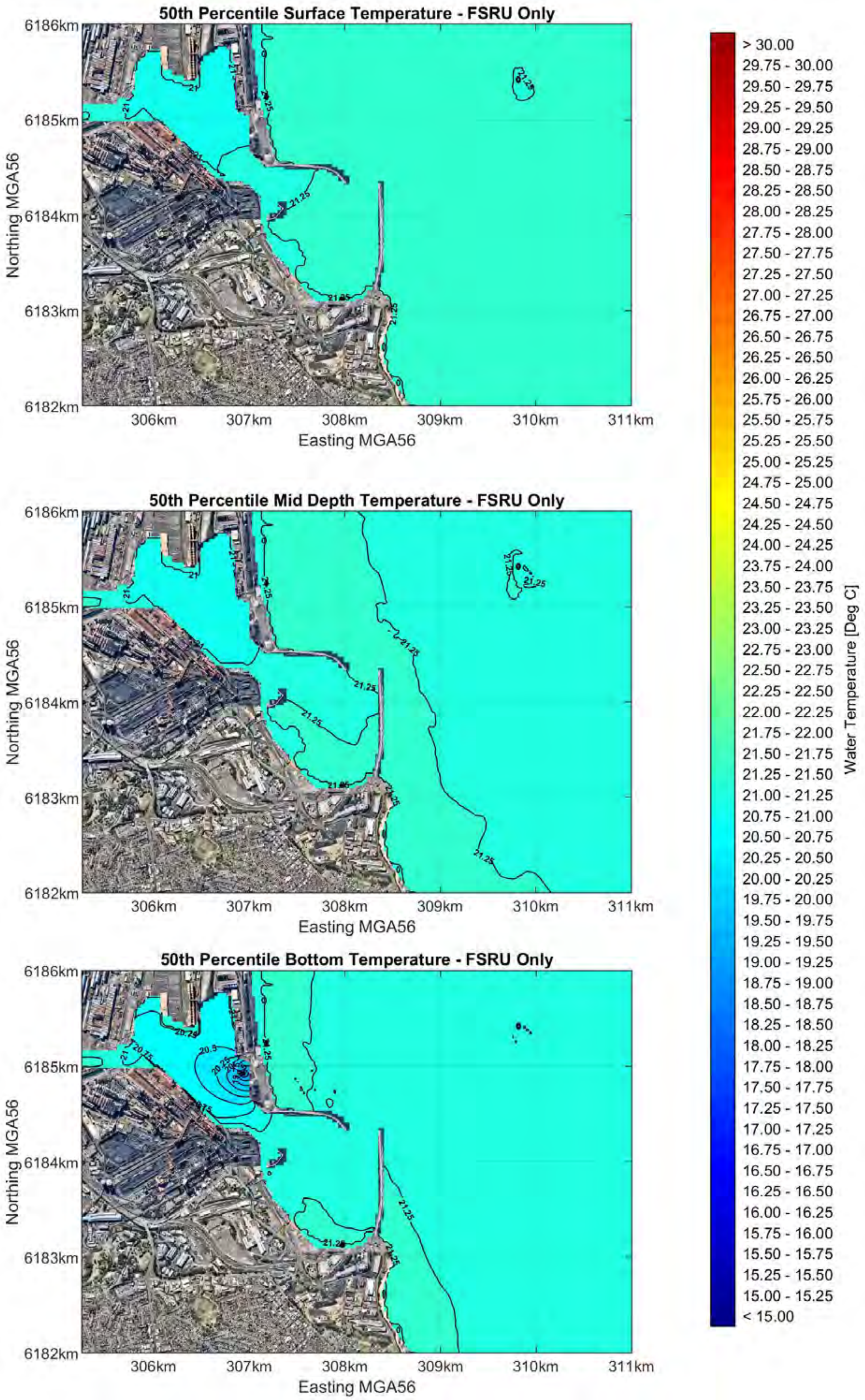
24.75 - 25.00
24.50 - 24.75
24.25 - 24.50
24.00 - 24.25
23.75 - 24.00
23.50 - 23.75
23.25 - 23.50
23.00 - 23.25
22.75 - 23.00
22.50 - 22.75
22.25 - 22.50
22.00 - 22.25
21.75 - 22.00
21.50 - 21.75
21.25 - 21.50
21.00 - 21.25
20.75 - 21.00
20.50 - 20.75
20.25 - 20.50
20.00 - 20.25
19.75 - 20.00
19.50 - 19.75
19.25 - 19.50
19.00 - 19.25
18.75 - 19.00
18.50 - 18.75
18.25 - 18.50
18.00 - 18.25
17.75 - 18.00
17.50 - 17.75
17.25 - 17.50
17.00 - 17.25
16.75 - 17.00
16.50 - 16.75
16.25 - 16.50
16.00 - 16.25
15.75 - 16.00
15.50 - 15.75
15.25 - 15.50
15.00 - 15.25
< 15.00
Water Temperature [Deg C]



Cardno

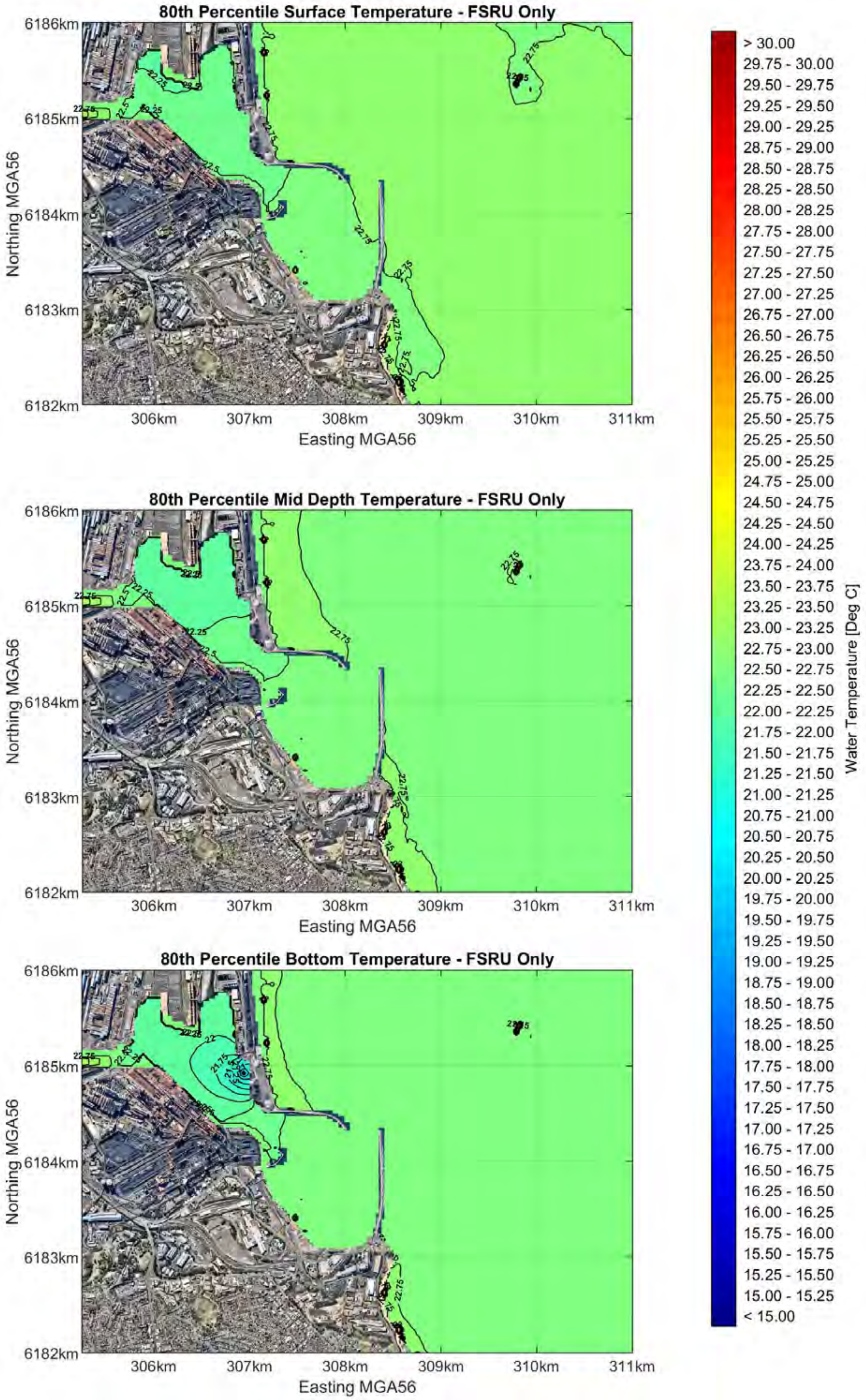
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
FSRU only, 50th percentile

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\

Appendix A11



Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Summer seawater temperature simulation results
FSRU only, 80th percentile

Appendix A12

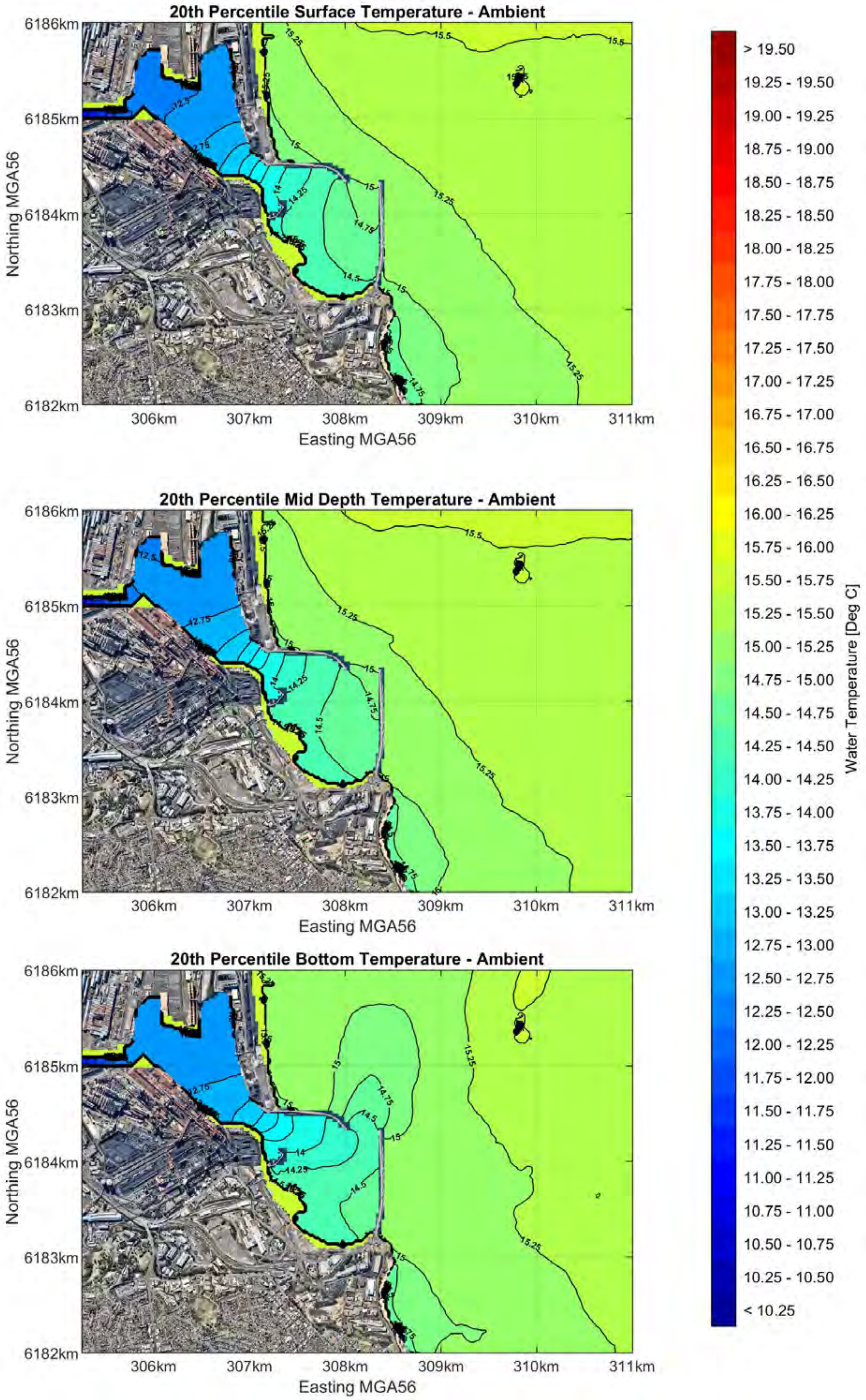
59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\

APPENDIX

B

WINTER THERMAL PLUME

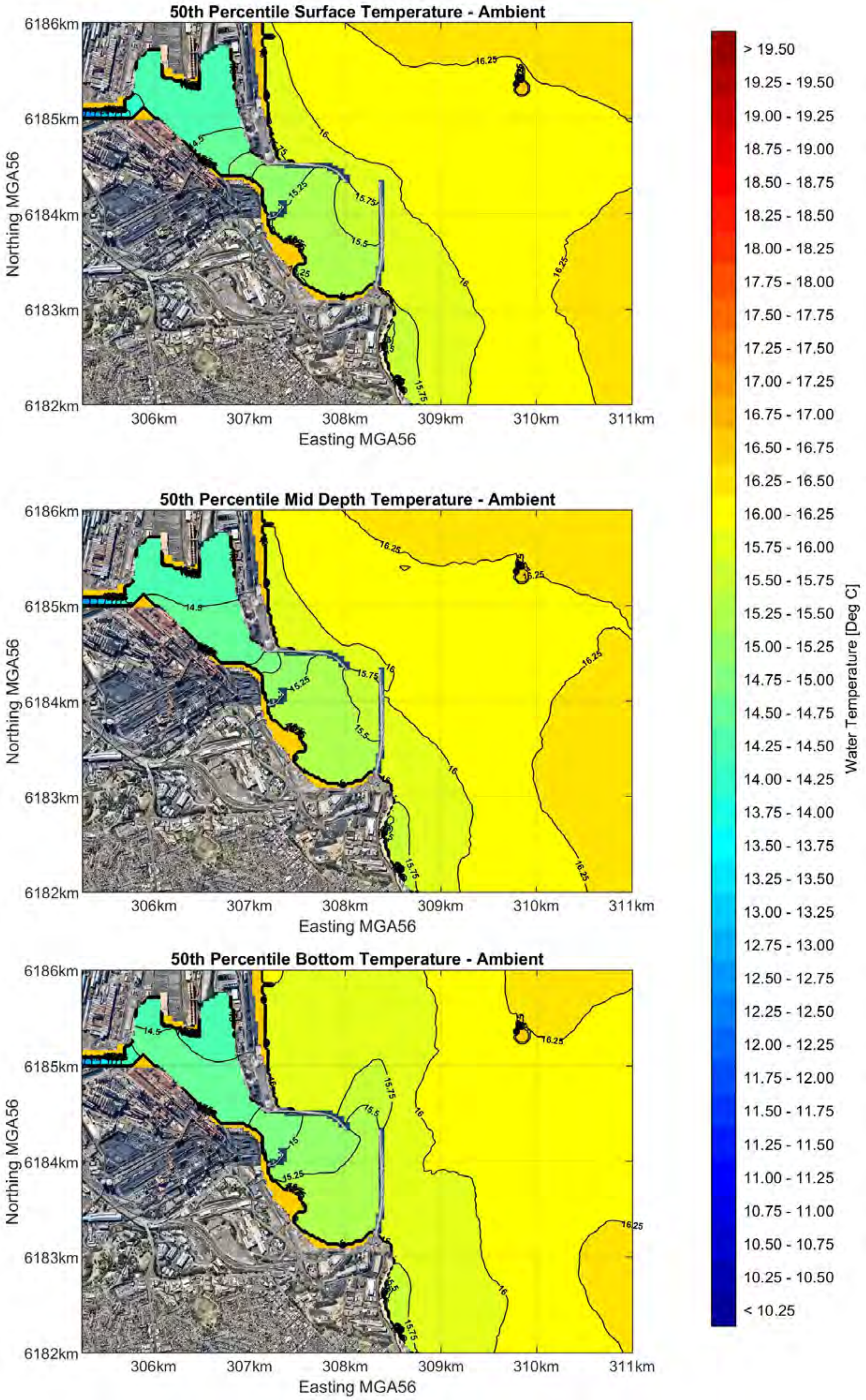


Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Winter seawater temperature simulation results
Ambient, 20th percentile

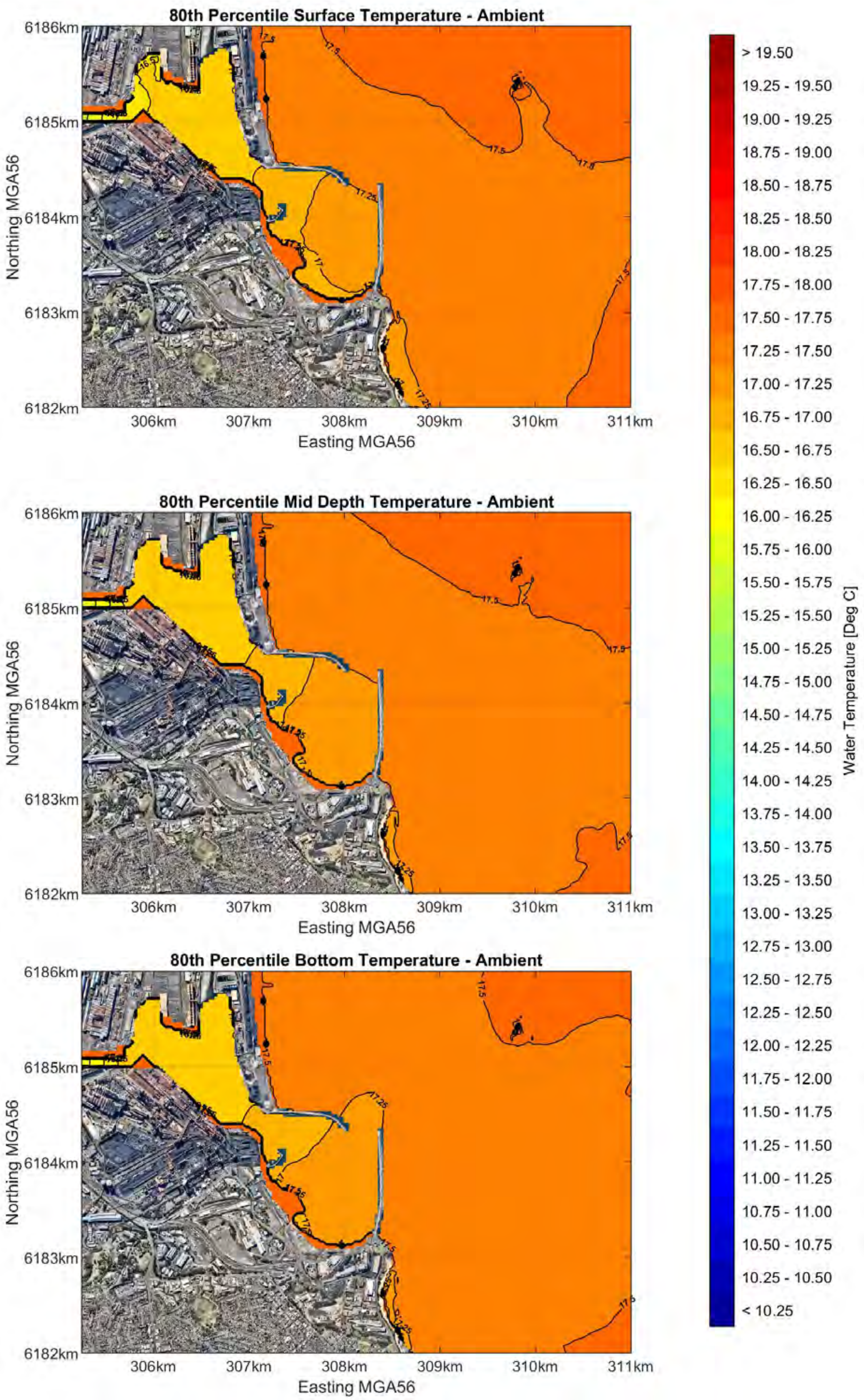
Appendix B1



Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Winter seawater temperature simulation results
Ambient, 50th percentile

Appendix B2

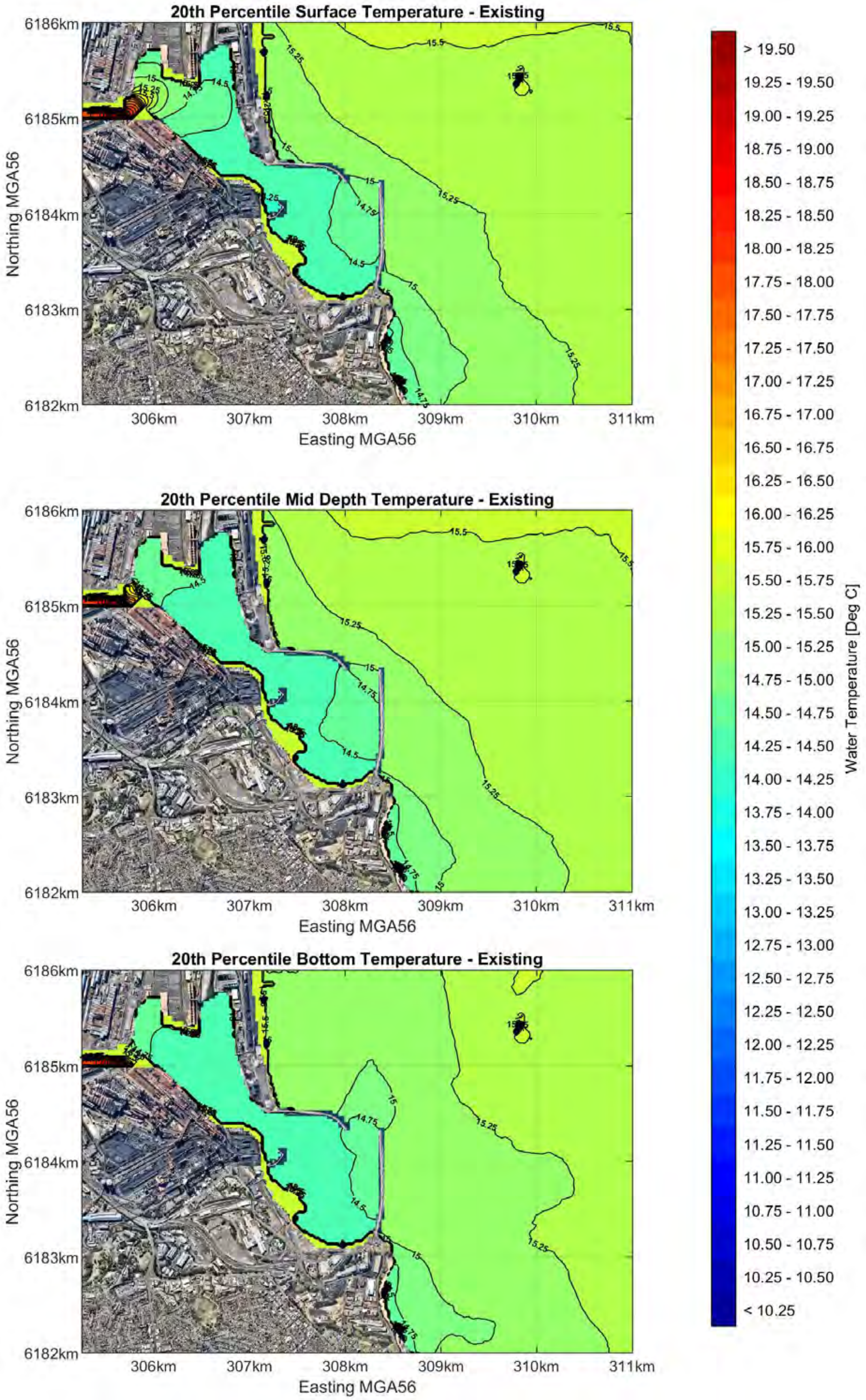


Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Winter seawater temperature simulation results
Abmient, 80th percentile

Appendix B3



Cardno

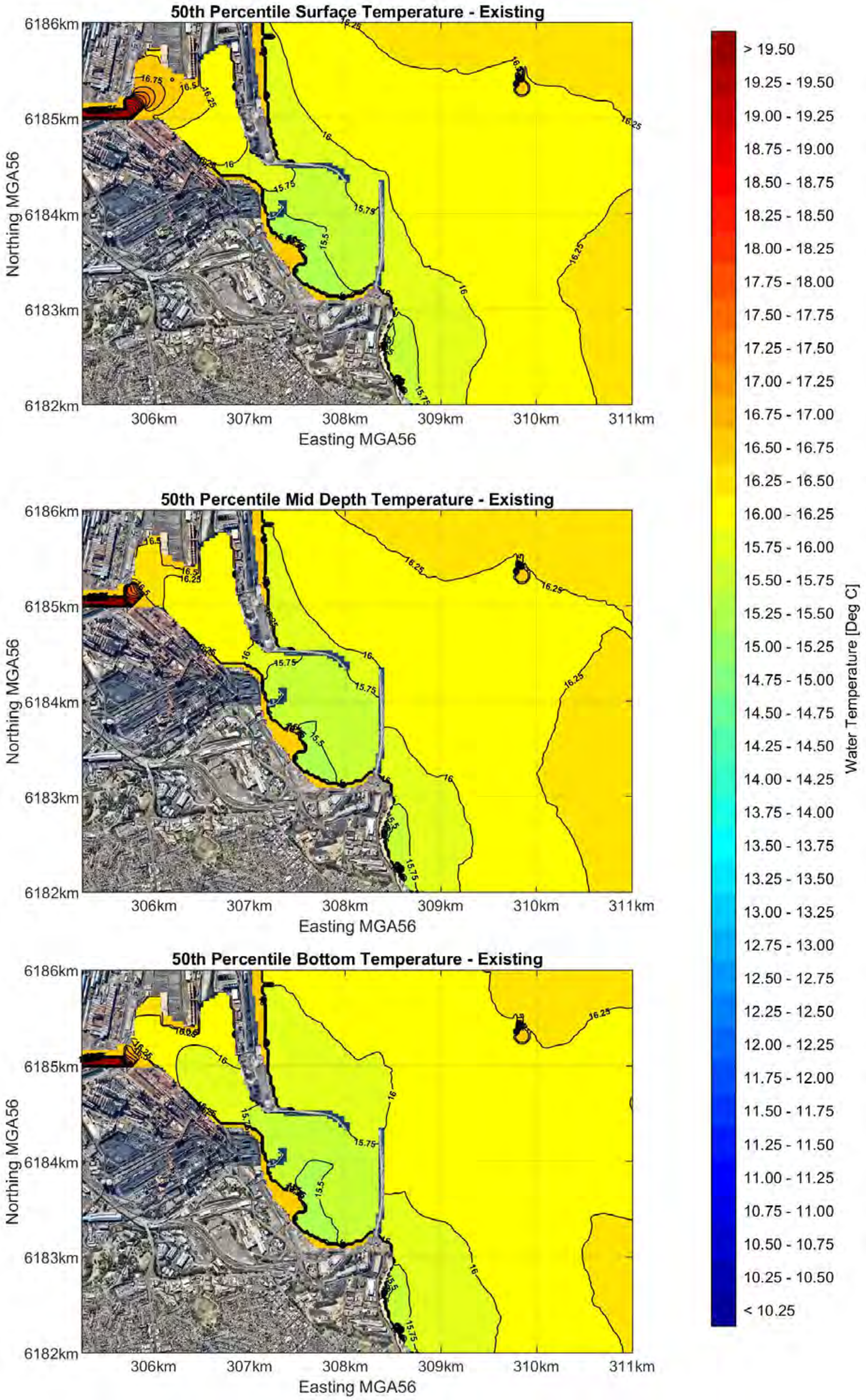
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Winter seawater temperature simulation results
Existing, 20th percentile

Appendix B4

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\



Cardno

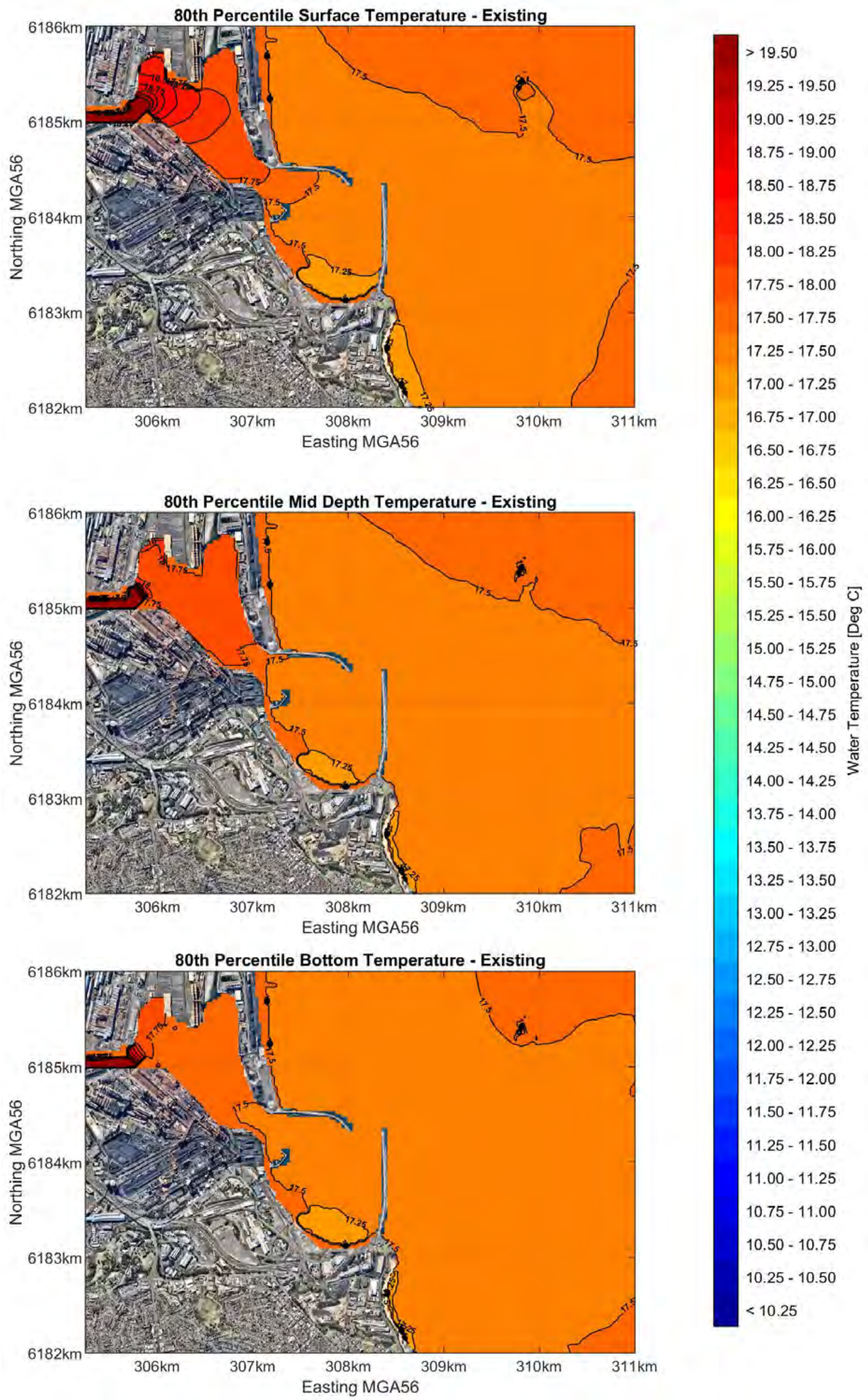
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Winter seawater temperature simulation results
Existing, 50th percentile

Appendix B5

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\


80th Percentile Surface Temperature - Existing
80th Percentile Mid Depth Temperature - Existing
80th Percentile Bottom Temperature - Existing
Northing MGA56
Easting MGA56
6186km
6185km
6184km
6183km
6182km
306km
307km
308km
309km
310km
311km
17.5
17.75
17.25
Water Temperature [Deg C]
> 19.50
19.25 - 19.50
19.00 - 19.25
18.75 - 19.00
18.50 - 18.75
18.25 - 18.50
18.00 - 18.25
17.75 - 18.00
17.50 - 17.75
17.25 - 17.50
17.00 - 17.25
16.75 - 17.00
16.50 - 16.75
16.25 - 16.50
16.00 - 16.25
15.75 - 16.00
15.50 - 15.75
15.25 - 15.50
15.00 - 15.25
14.75 - 15.00
14.50 - 14.75
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13.50 - 13.75
13.25 - 13.50
13.00 - 13.25
12.75 - 13.00
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11.75 - 12.00
11.50 - 11.75
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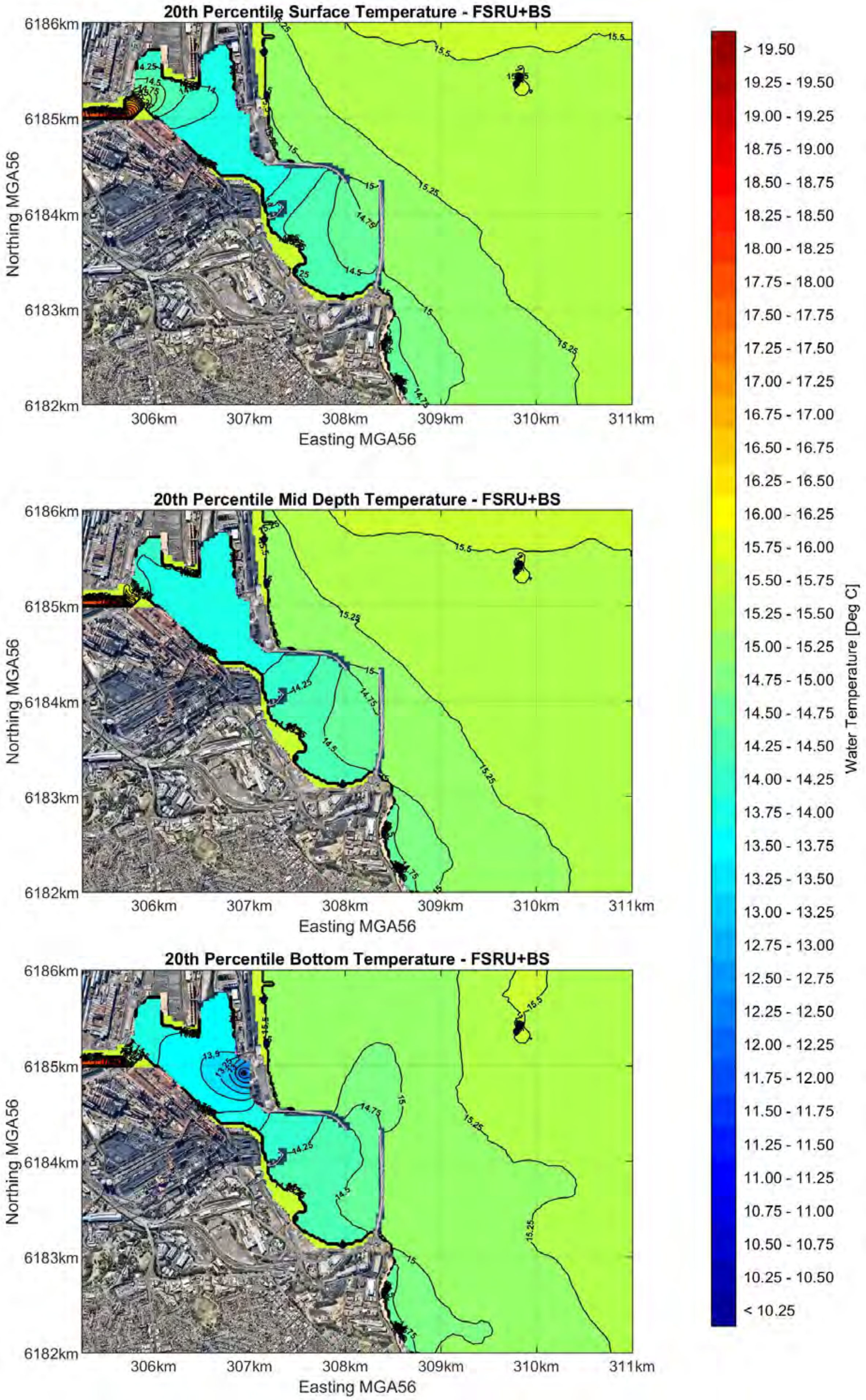
10.25 - 10.50
< 10.25


20th Percentile Surface Temperature - FSRU+BS
20th Percentile Mid Depth Temperature - FSRU+BS
20th Percentile Bottom Temperature - FSRU+BS
Northing MGA56
Easting MGA56
6186km
6185km
6184km
6183km
6182km
306km
307km
308km
309km
310km
311km
Water Temperature [Deg C]
> 19.50
19.25 - 19.50
19.00 - 19.25
18.75 - 19.00
18.50 - 18.75
18.25 - 18.50
18.00 - 18.25
17.75 - 18.00
17.50 - 17.75
17.25 - 17.50
17.00 - 17.25
16.75 - 17.00
16.50 - 16.75
16.25 - 16.50
16.00 - 16.25
15.75 - 16.00
15.50 - 15.75
15.25 - 15.50
15.00 - 15.25
14.75 - 15.00
14.50 - 14.75
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14.00 - 14.25
13.75 - 14.00
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12.00 - 12.25
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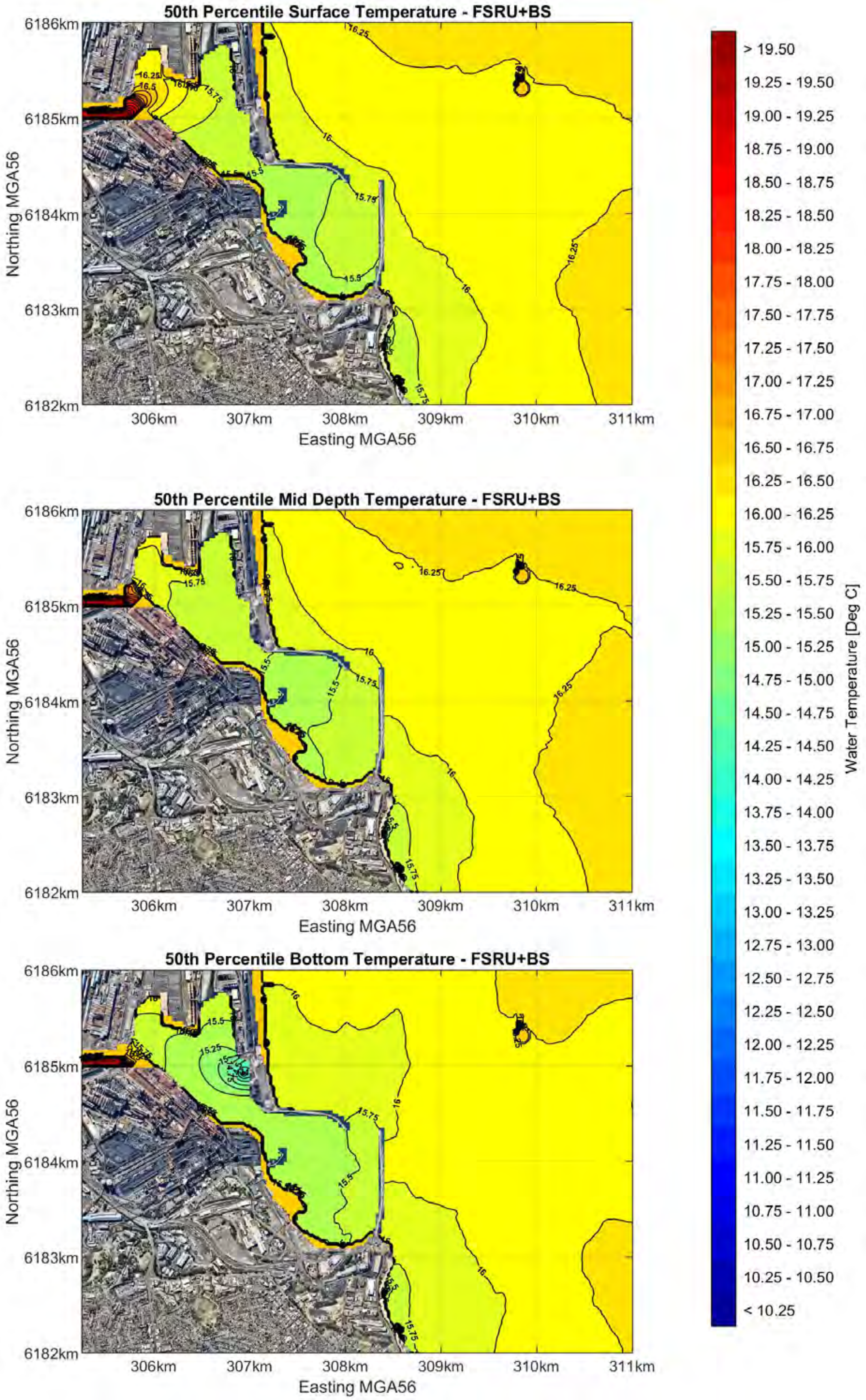
10.25 - 10.50
< 10.25



Cardno

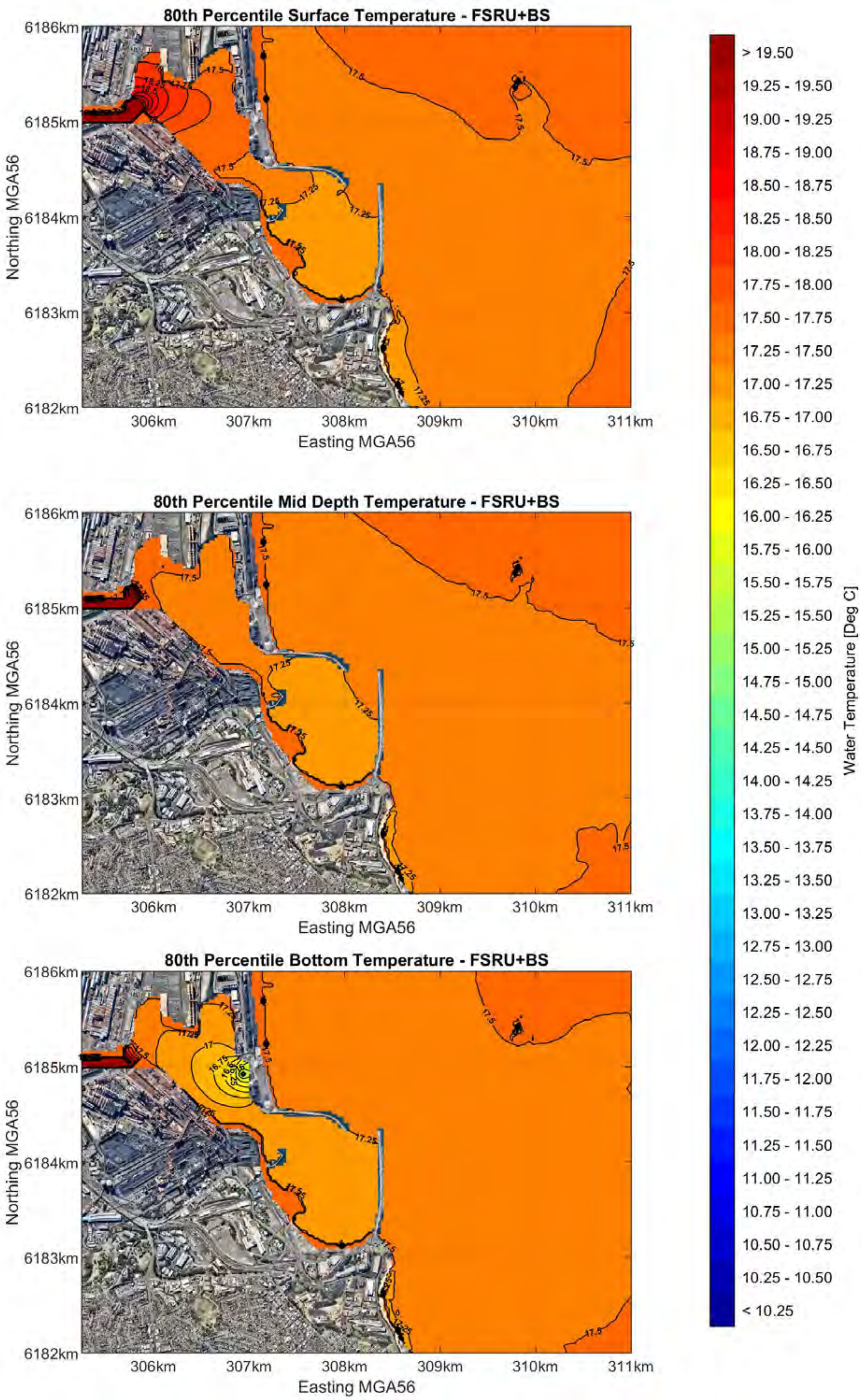
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Winter seawater temperature simulation results
FSRU and Bluescope, 50th percentile

Appendix B8

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\



Cardno

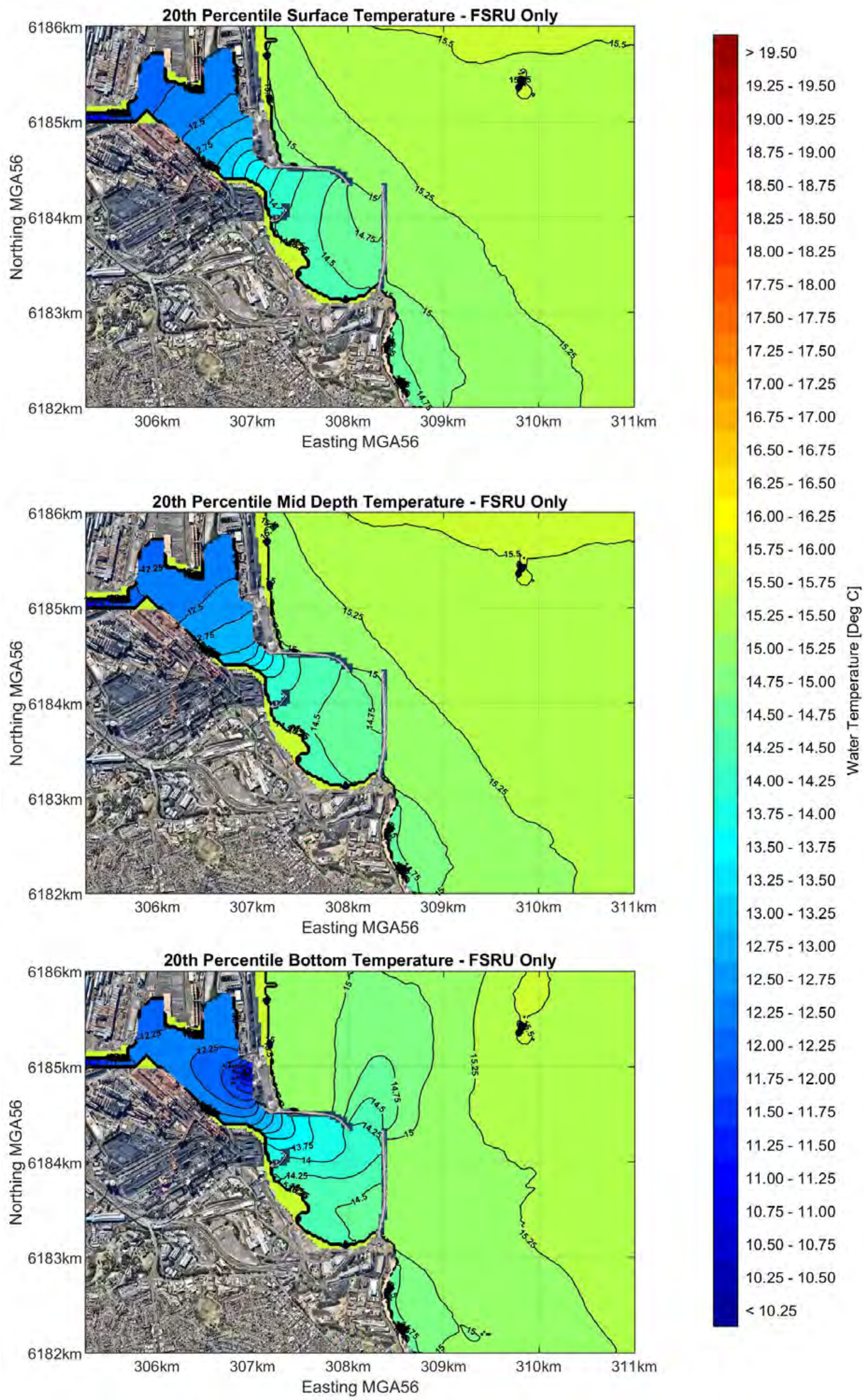
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Winter seawater temperature simulation results
FSRU and Bluescope, 80th percentile

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\

Appendix B9



Cardno

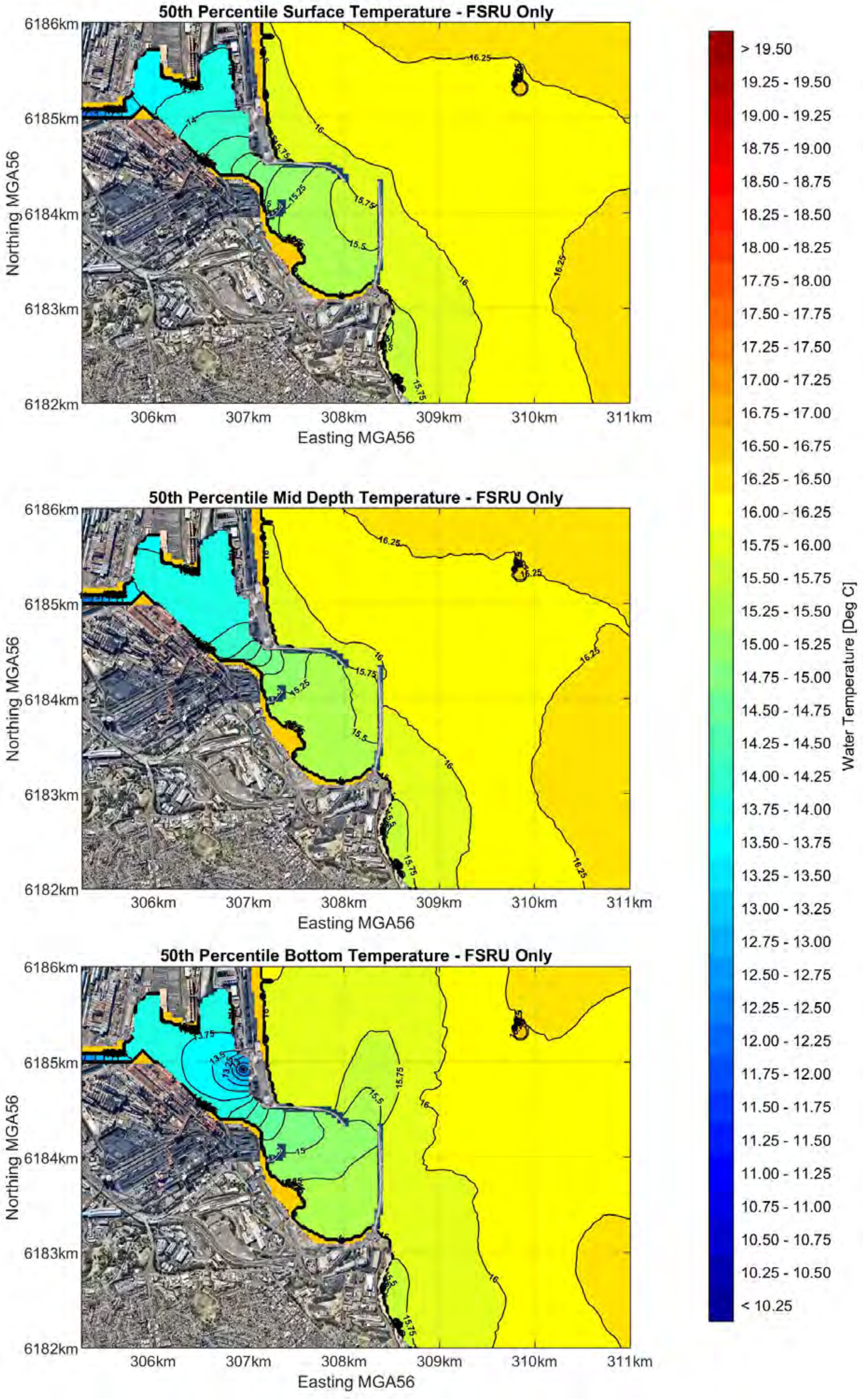
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Winter seawater temperature simulation results
FSRU only, 20th percentile

Appendix B10

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\


50th Percentile Surface Temperature - FSRU Only
50th Percentile Mid Depth Temperature - FSRU Only
50th Percentile Bottom Temperature - FSRU Only
Northing MGA56
6186km
6185km
6184km
6183km
6182km
Easting MGA56
306km
307km
308km
309km
310km
311km
Water Temperature [Deg C]
> 19.50
19.25 - 19.50
19.00 - 19.25
18.75 - 19.00
18.50 - 18.75
18.25 - 18.50
18.00 - 18.25
17.75 - 18.00
17.50 - 17.75
17.25 - 17.50
17.00 - 17.25
16.75 - 17.00
16.50 - 16.75
16.25 - 16.50
16.00 - 16.25
15.75 - 16.00
15.50 - 15.75
15.25 - 15.50
15.00 - 15.25
14.75 - 15.00
14.50 - 14.75
14.25 - 14.50
14.00 - 14.25
13.75 - 14.00
13.50 - 13.75
13.25 - 13.50
13.00 - 13.25
12.75 - 13.00
12.50 - 12.75
12.25 - 12.50
12.00 - 12.25
11.75 - 12.00
11.50 - 11.75
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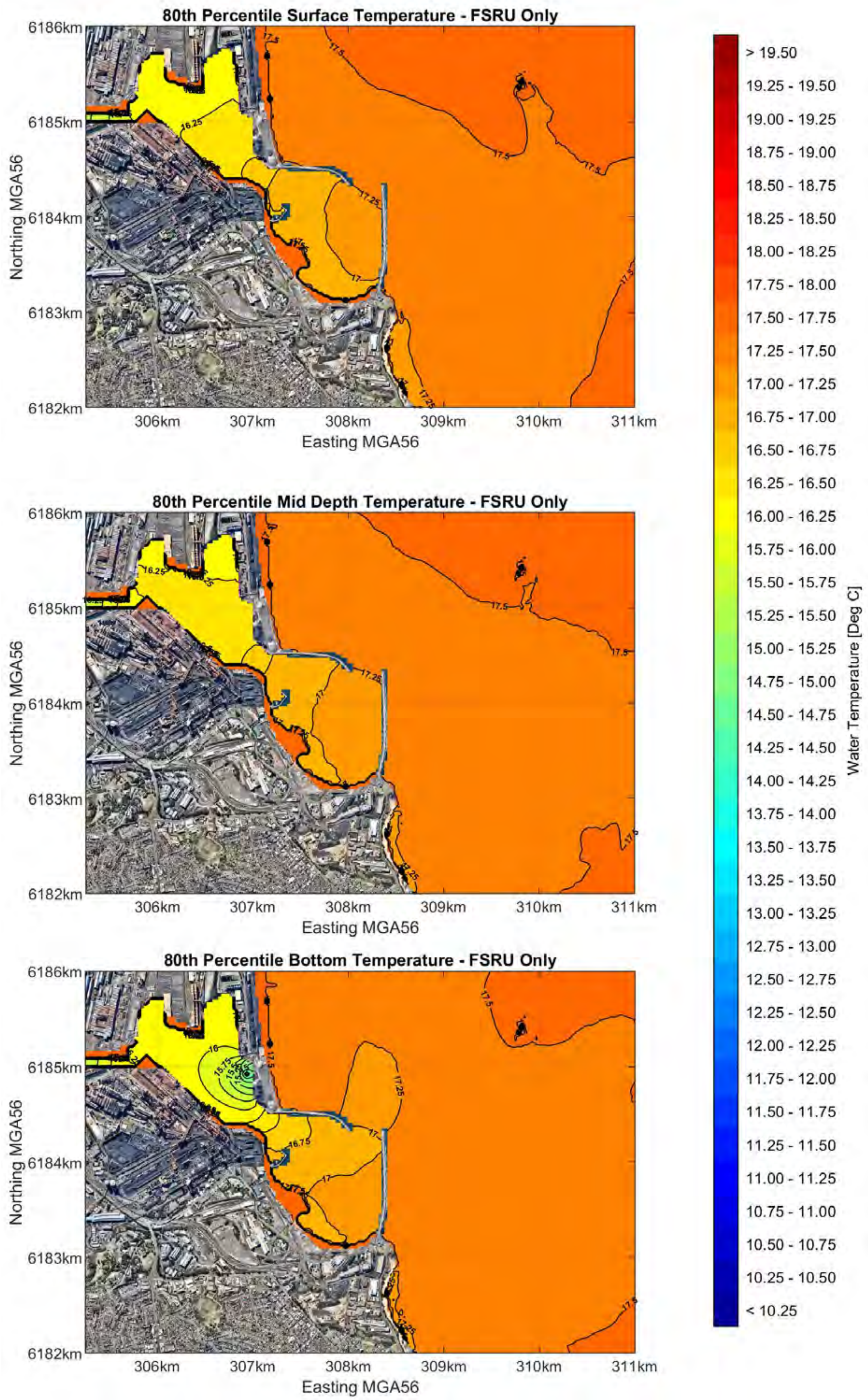
10.25 - 10.50
< 10.25



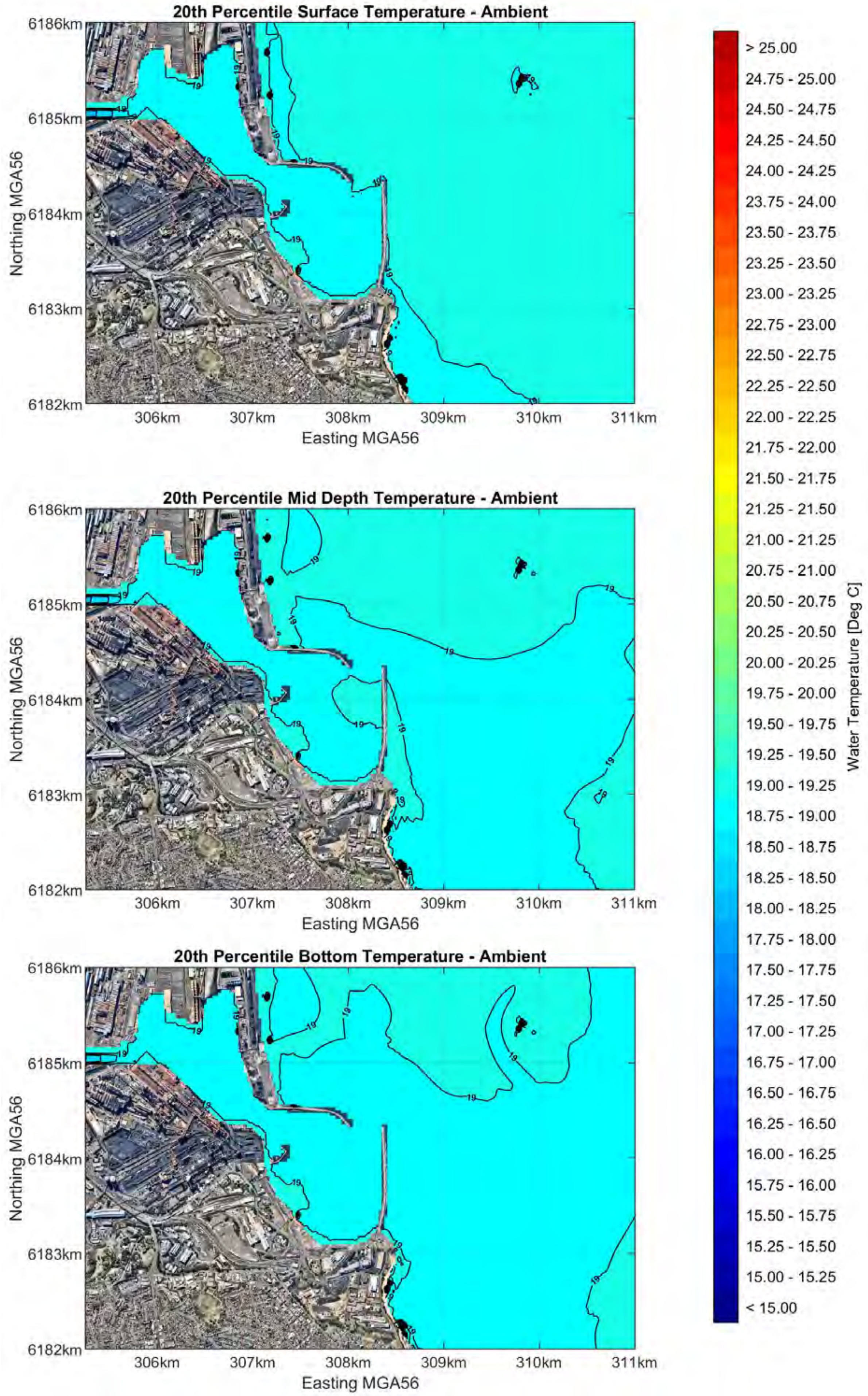
Winter seawater temperature simulation results
FSRU only, 80th percentile

Appendix B12

APPENDIX

C

AUTUMN THERMAL PLUME



Cardno

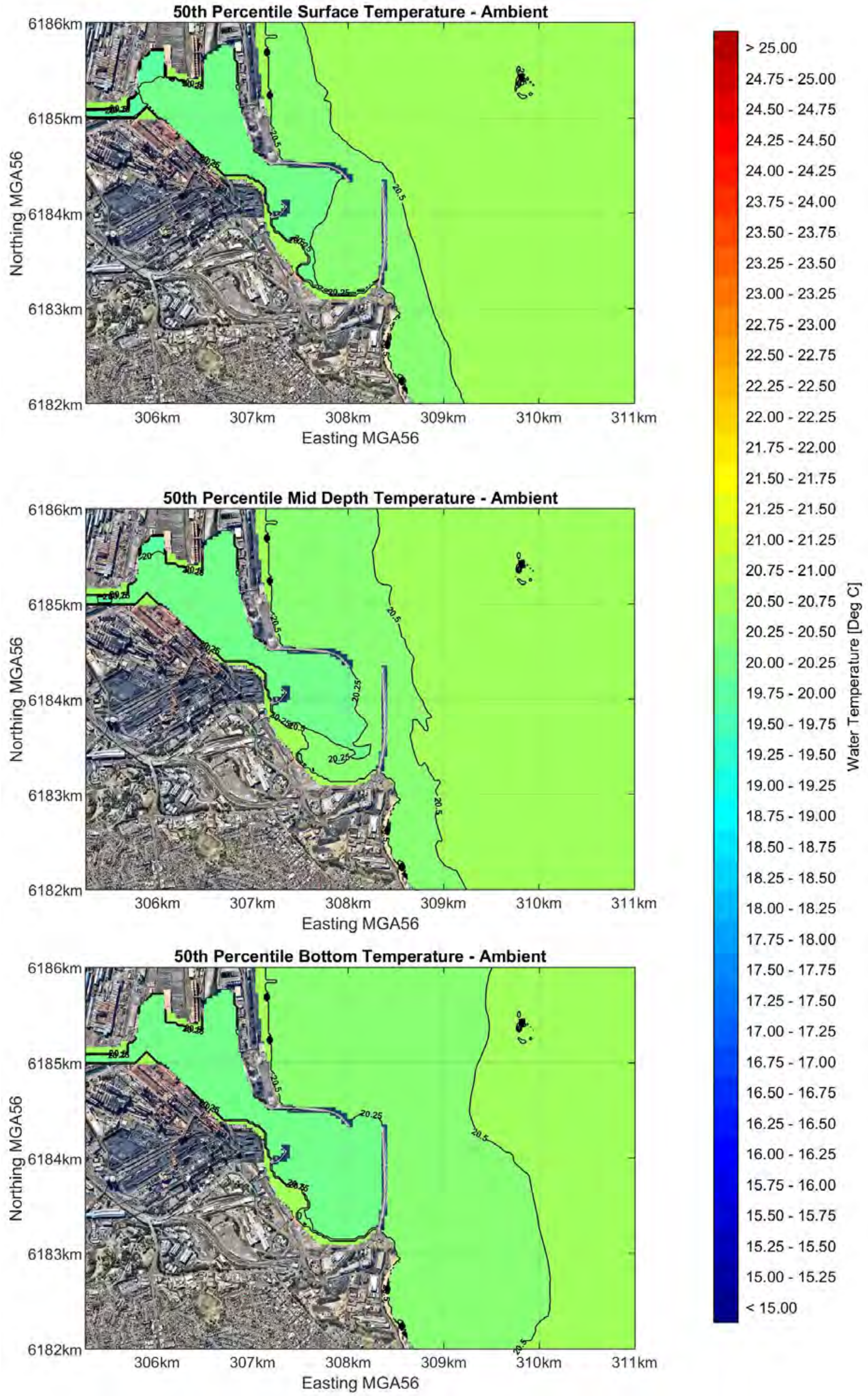
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
Ambient, 20th percentile

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\

Appendix C1



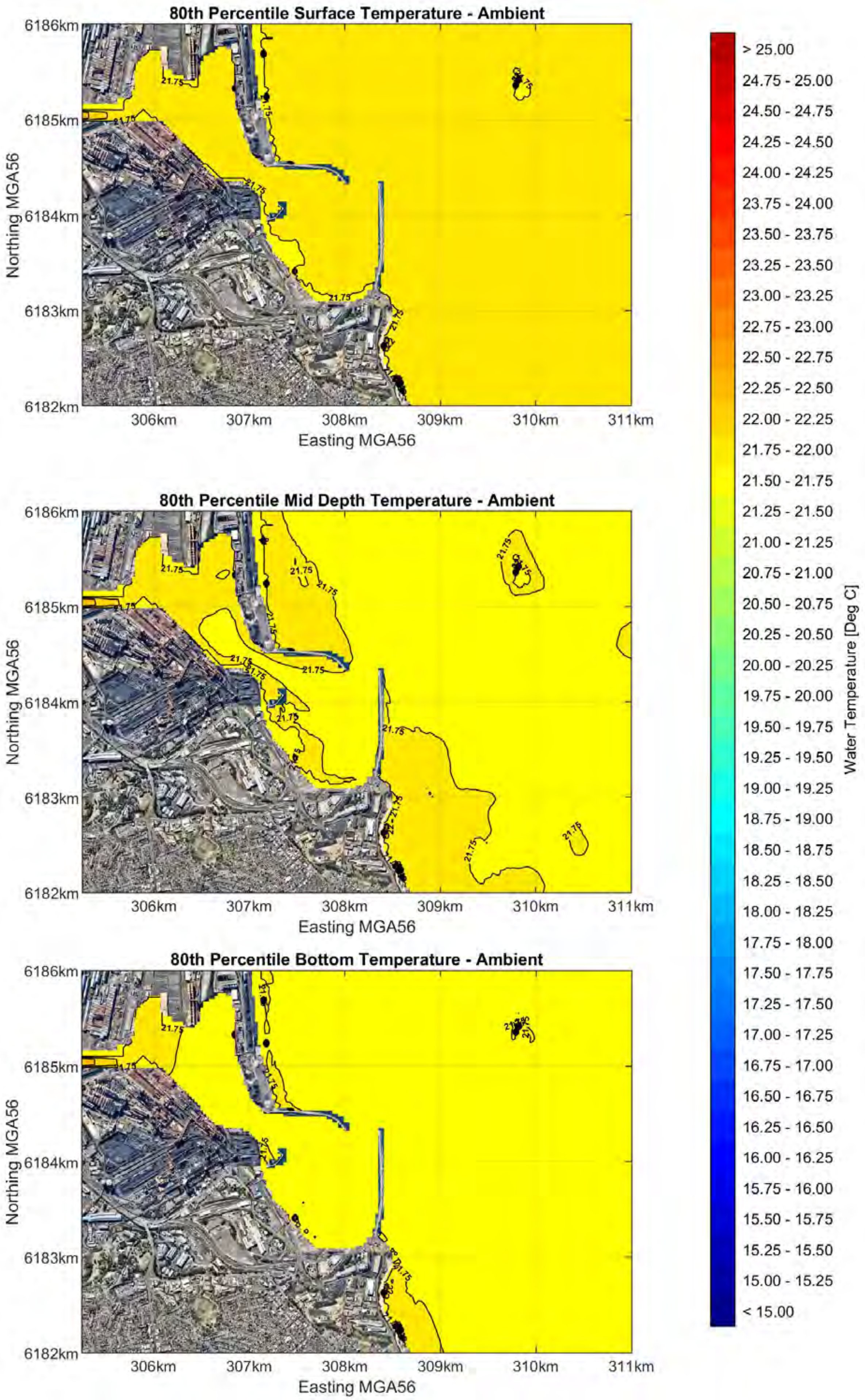
Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
Ambient, 50th percentile

Appendix C2

59919002 Jan 2019
N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\



Cardno

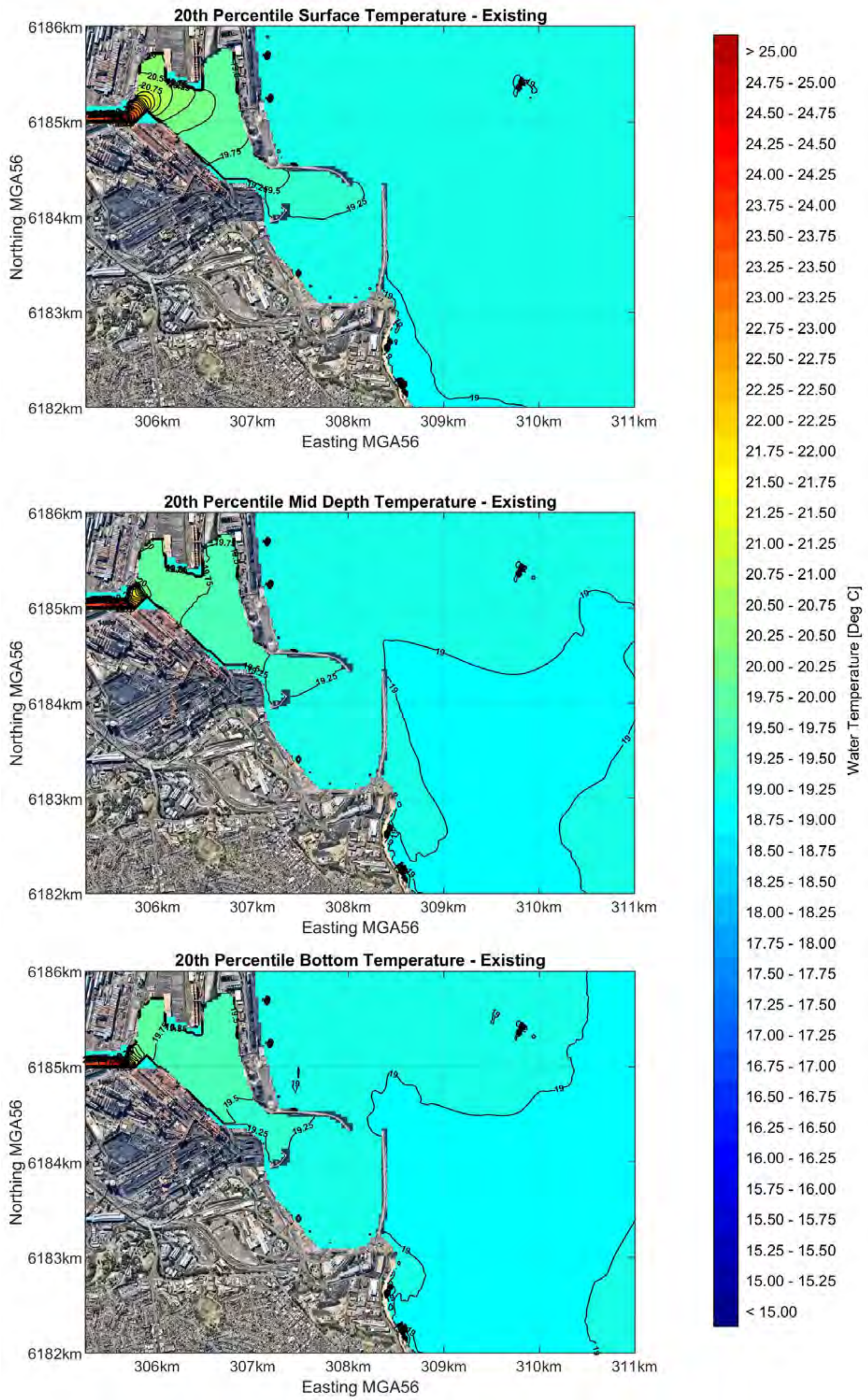
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
Abmient, 80th percentile

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\

Appendix C3



Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
Existing, 20th percentile

Appendix C4

59919002 Jan 2019

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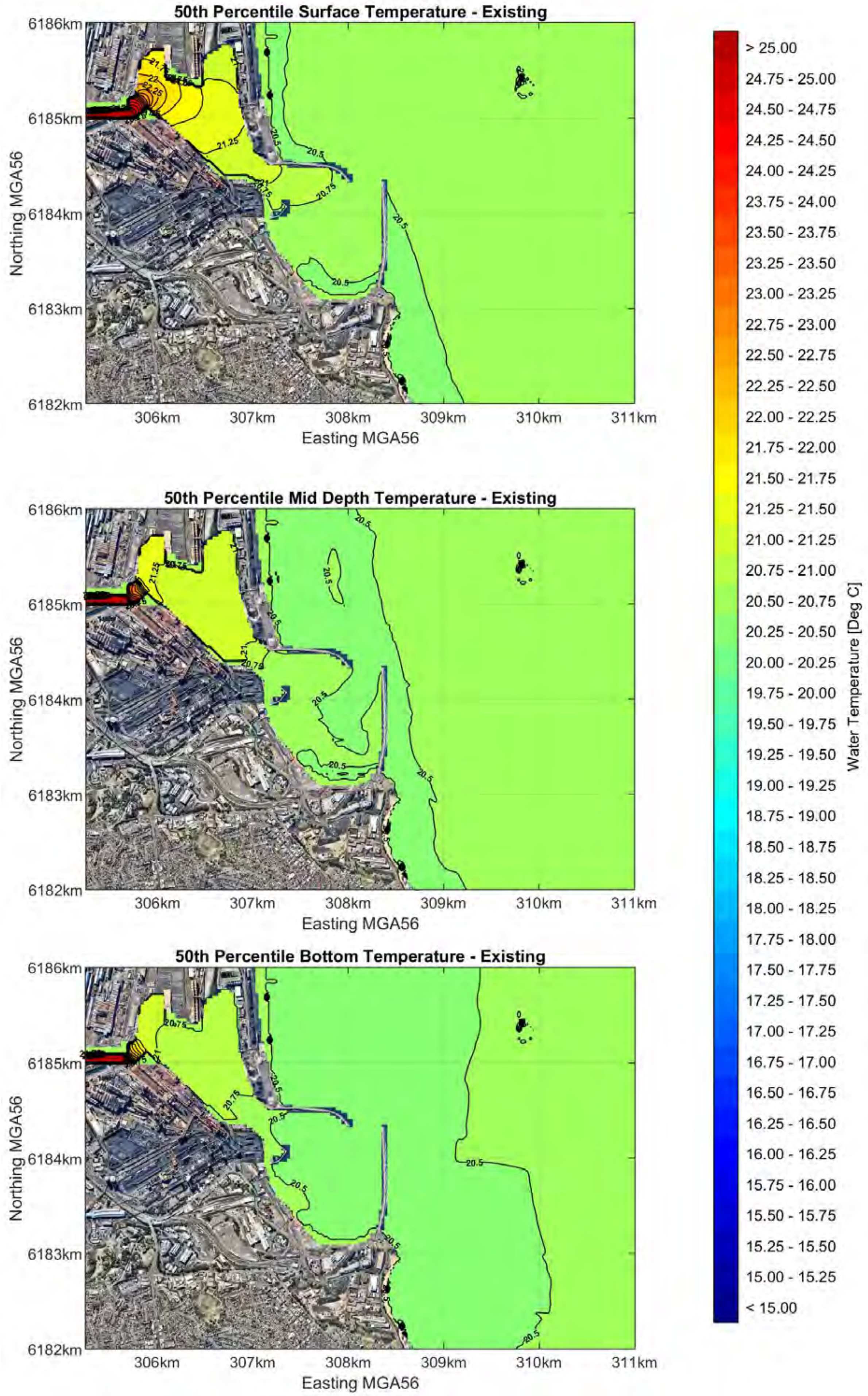

Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
Existing, 50th percentile

Appendix C5

59919002 Jan 2019

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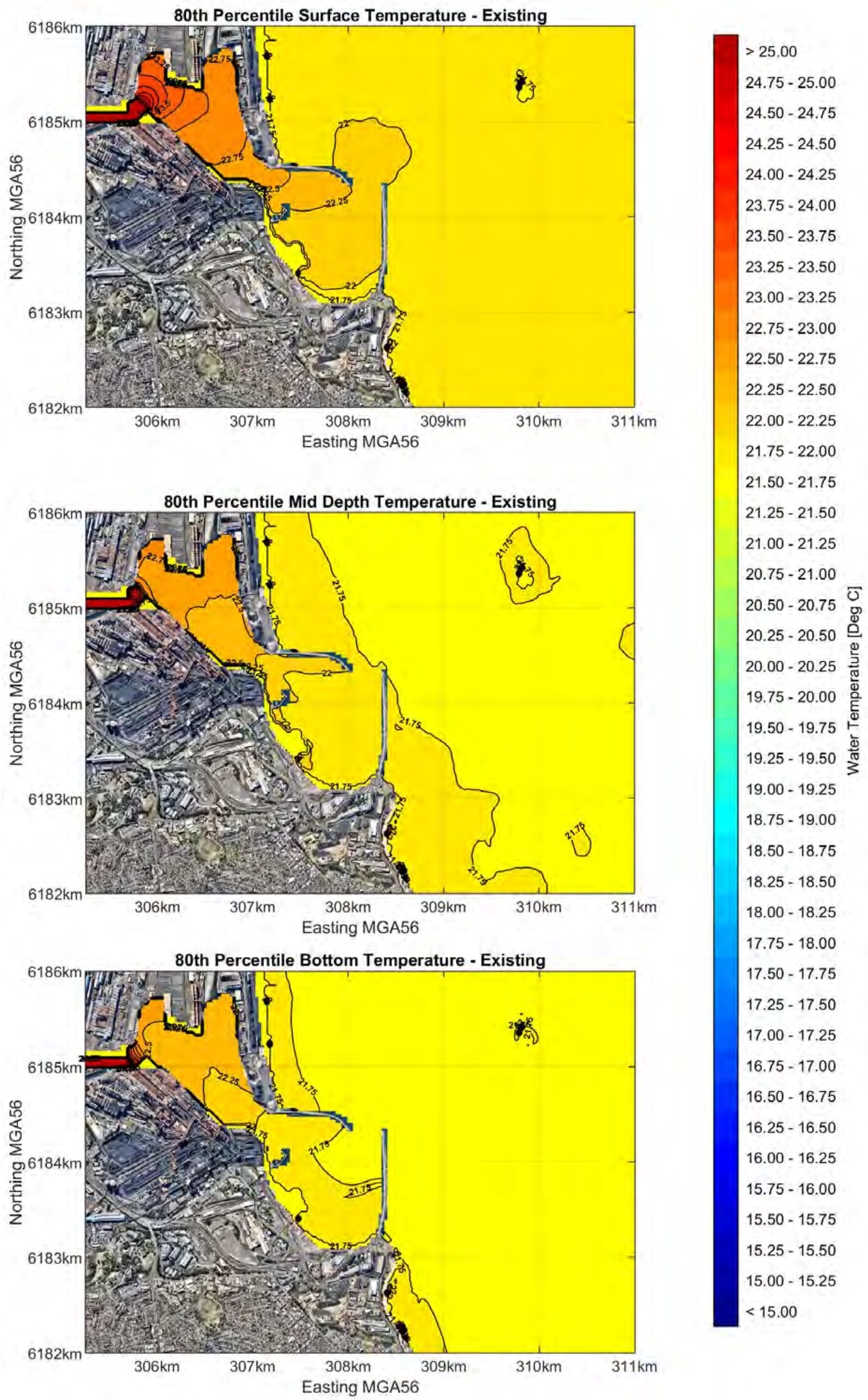
80th Percentile Surface Temperature - Existing
80th Percentile Mid Depth Temperature - Existing
80th Percentile Bottom Temperature - Existing
Northing MGA56
Easting MGA56
6186km
6185km
6184km
6183km
6182km
306km
307km
308km
309km
310km
311km
> 25.00
24.75 - 25.00
24.50 - 24.75
24.25 - 24.50
24.00 - 24.25
23.75 - 24.00
23.50 - 23.75
23.25 - 23.50
23.00 - 23.25
22.75 - 23.00
22.50 - 22.75
22.25 - 22.50
22.00 - 22.25
21.75 - 22.00
21.50 - 21.75
21.25 - 21.50
21.00 - 21.25
20.75 - 21.00
20.50 - 20.75
20.25 - 20.50
20.00 - 20.25
19.75 - 20.00
19.50 - 19.75
19.25 - 19.50
19.00 - 19.25
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18.25 - 18.50
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17.75 - 18.00
17.50 - 17.75
17.25 - 17.50
17.00 - 17.25
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16.50 - 16.75
16.25 - 16.50
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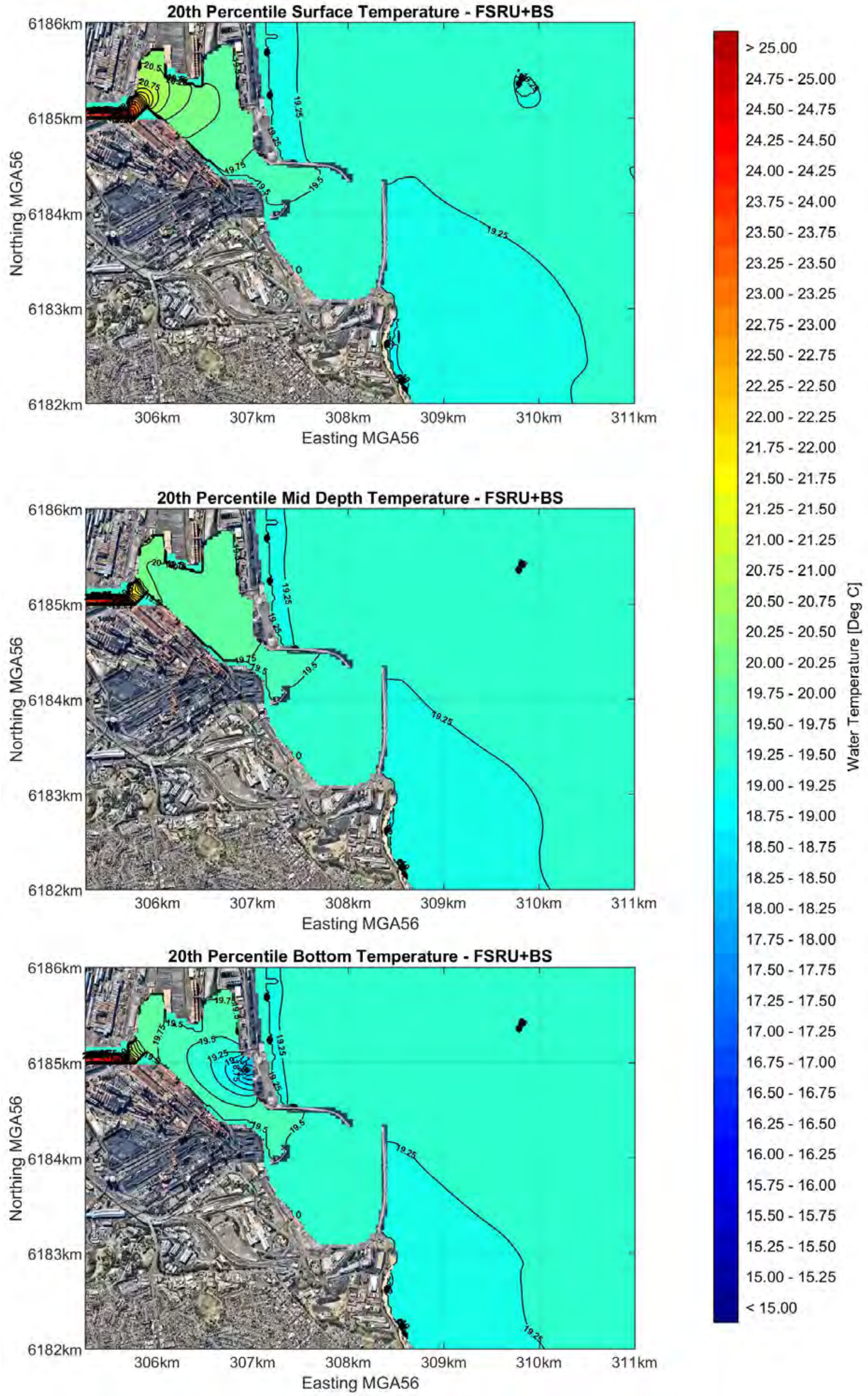
15.00 - 15.25
< 15.00
Water Temperature [Deg C]



Cardno

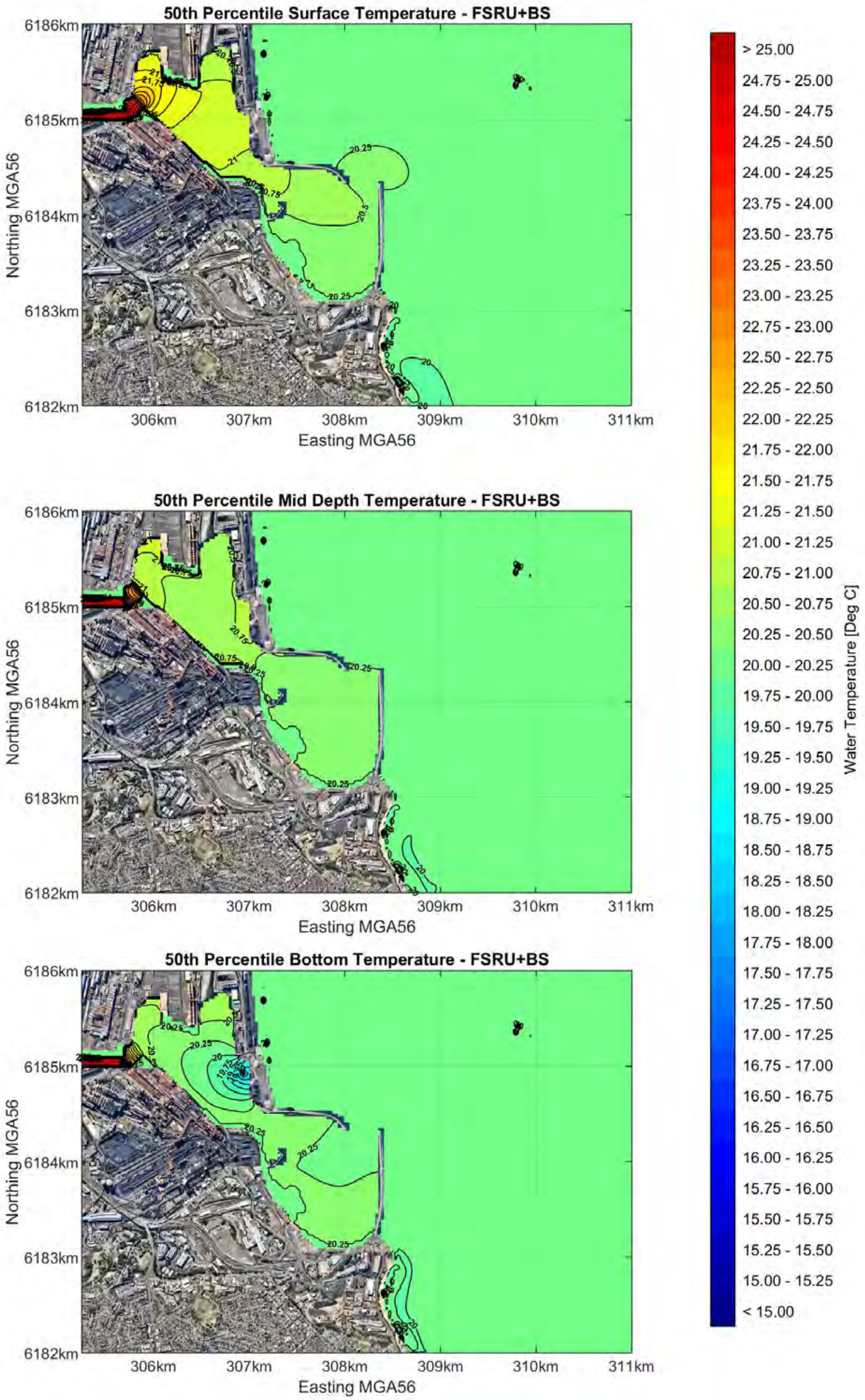
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
FSRU and Bluescope, 20th percentile

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\

Appendix C7



Cardno

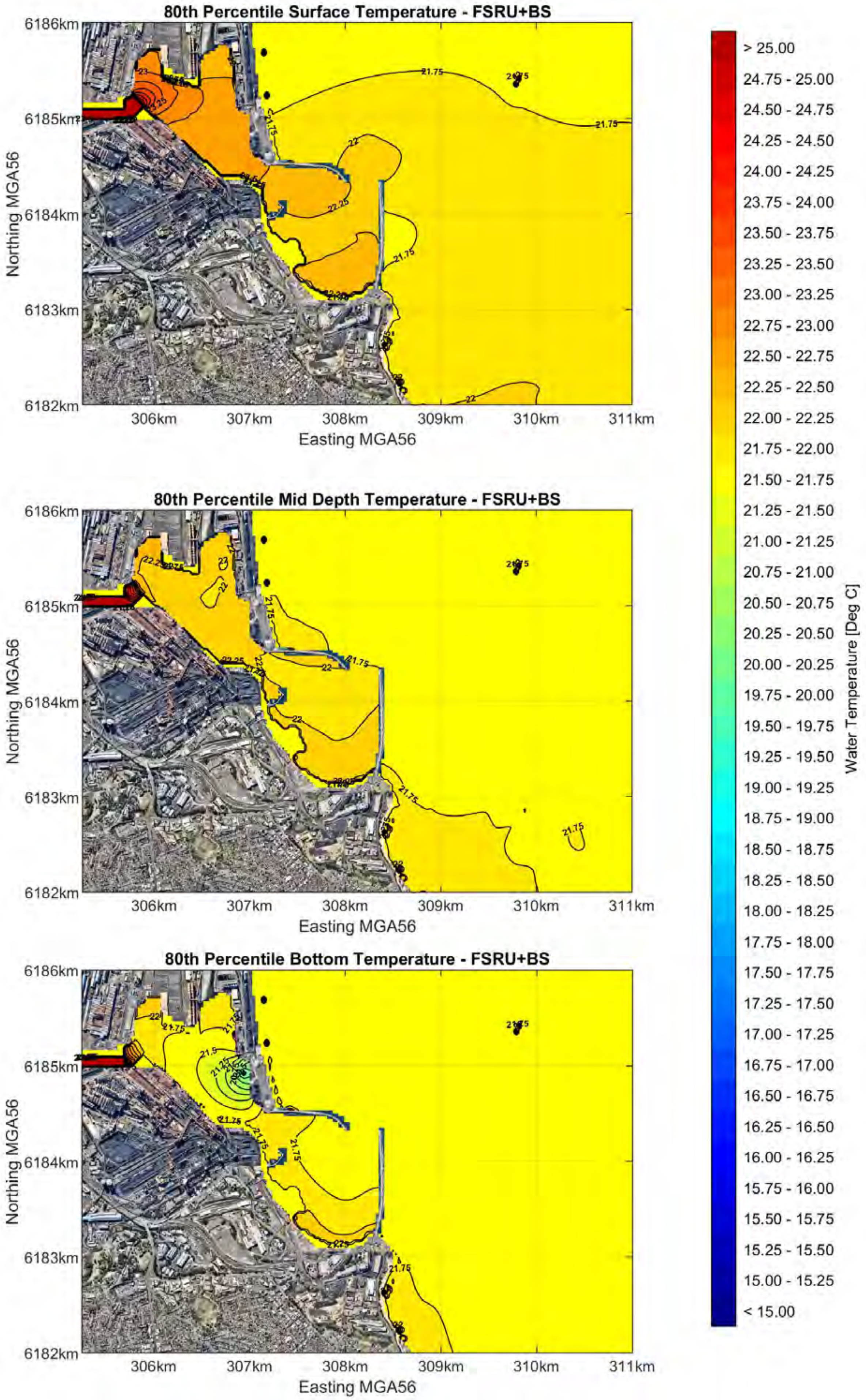
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
FSRU and Bluescope, 50th percentile

Appendix C8

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\



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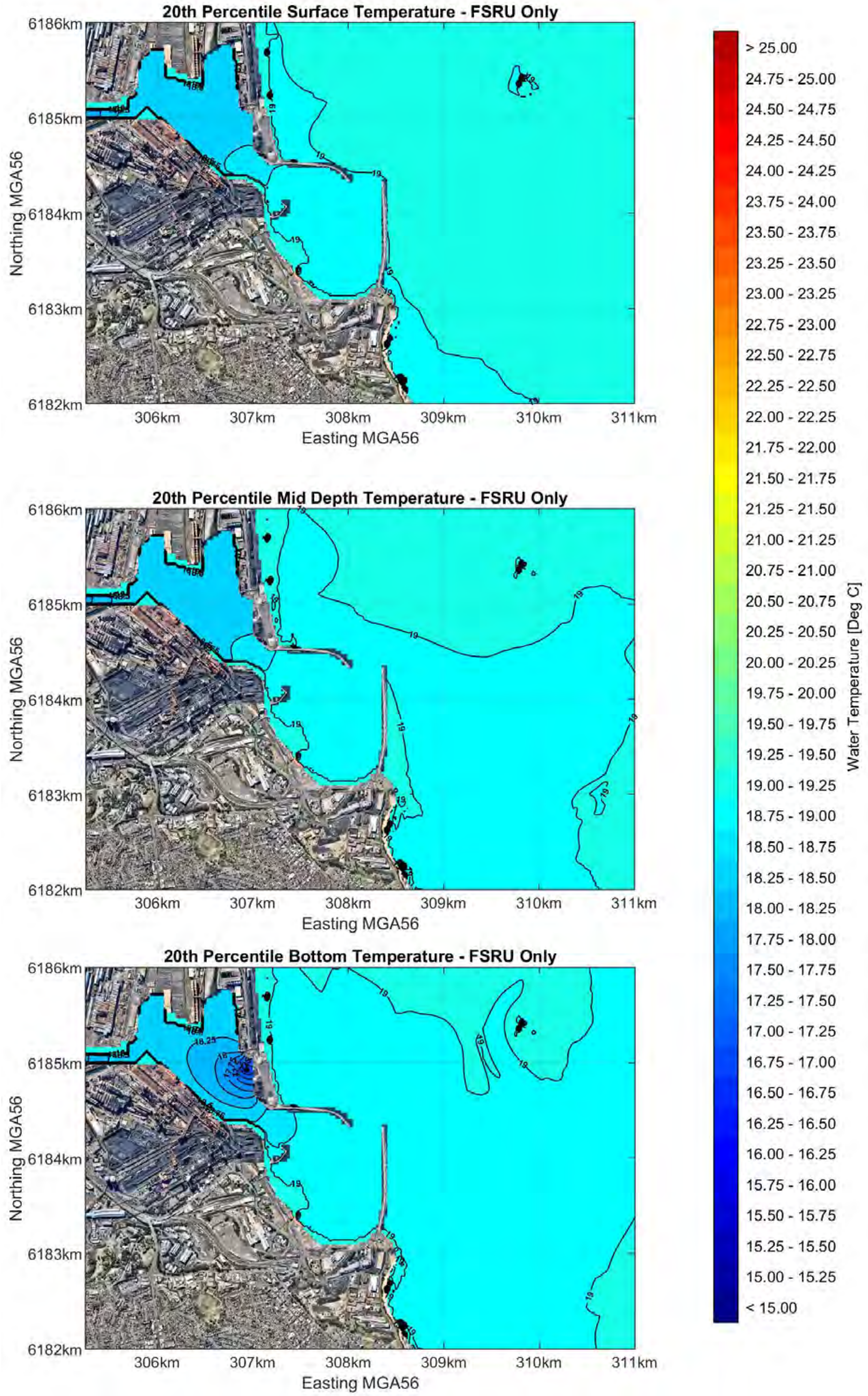
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
FSRU and Bluescope, 80th percentile

Appendix C9

59919002 Jan 2019

N:\Projects\599\FY19\002_N:\Projects\599\FY19\002_Port Kembla Long Waves\

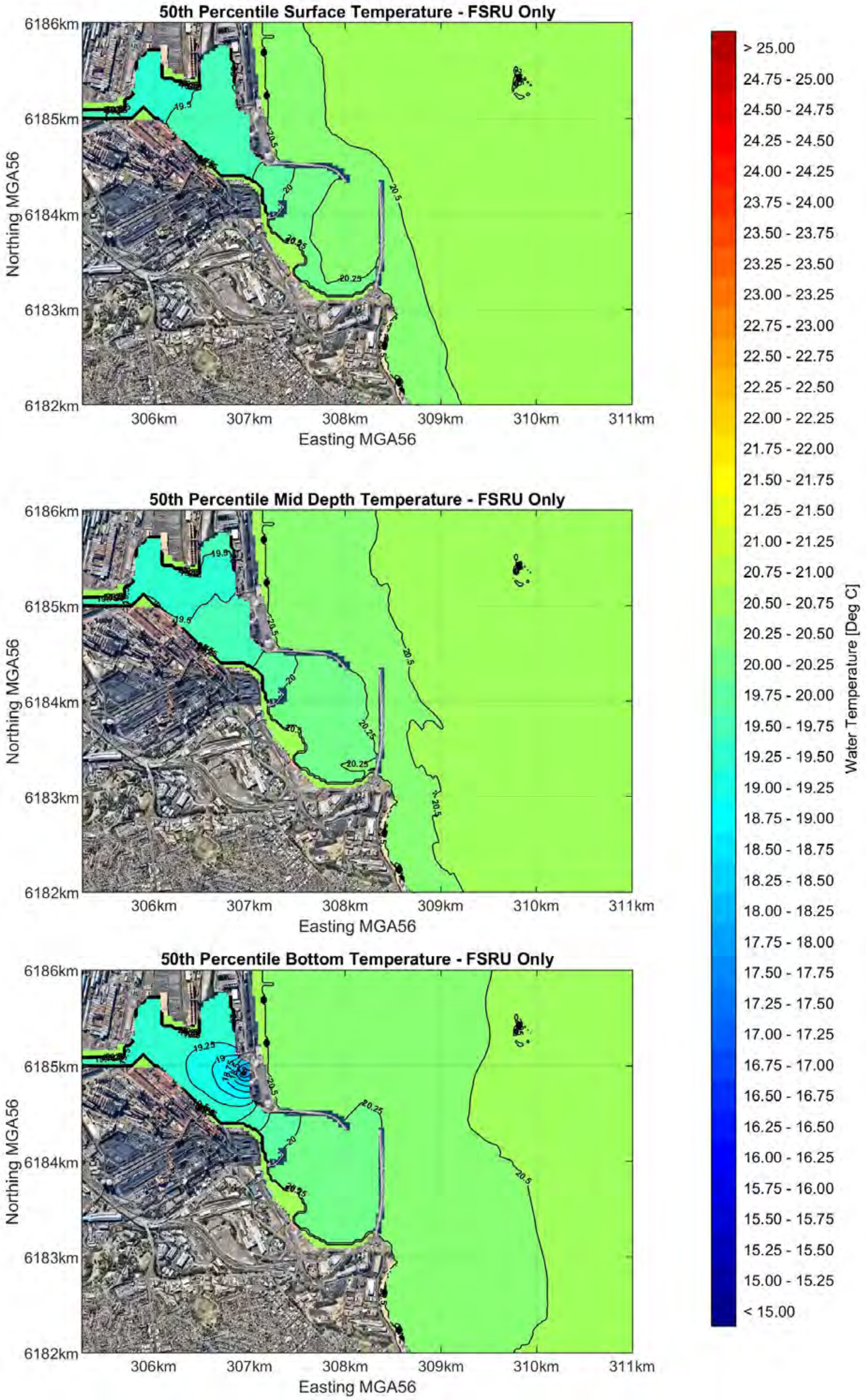


Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
FSRU only, 20th percentile

Appendix C10


50th Percentile Surface Temperature - FSRU Only
50th Percentile Mid Depth Temperature - FSRU Only
50th Percentile Bottom Temperature - FSRU Only
Northing MGA56
Easting MGA56
6186km
6185km
6184km
6183km
6182km
306km
307km
308km
309km
310km
311km
> 25.00
24.75 - 25.00
24.50 - 24.75
24.25 - 24.50
24.00 - 24.25
23.75 - 24.00
23.50 - 23.75
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21.75 - 22.00
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18.75 - 19.00
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18.00 - 18.25
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17.00 - 17.25
16.75 - 17.00
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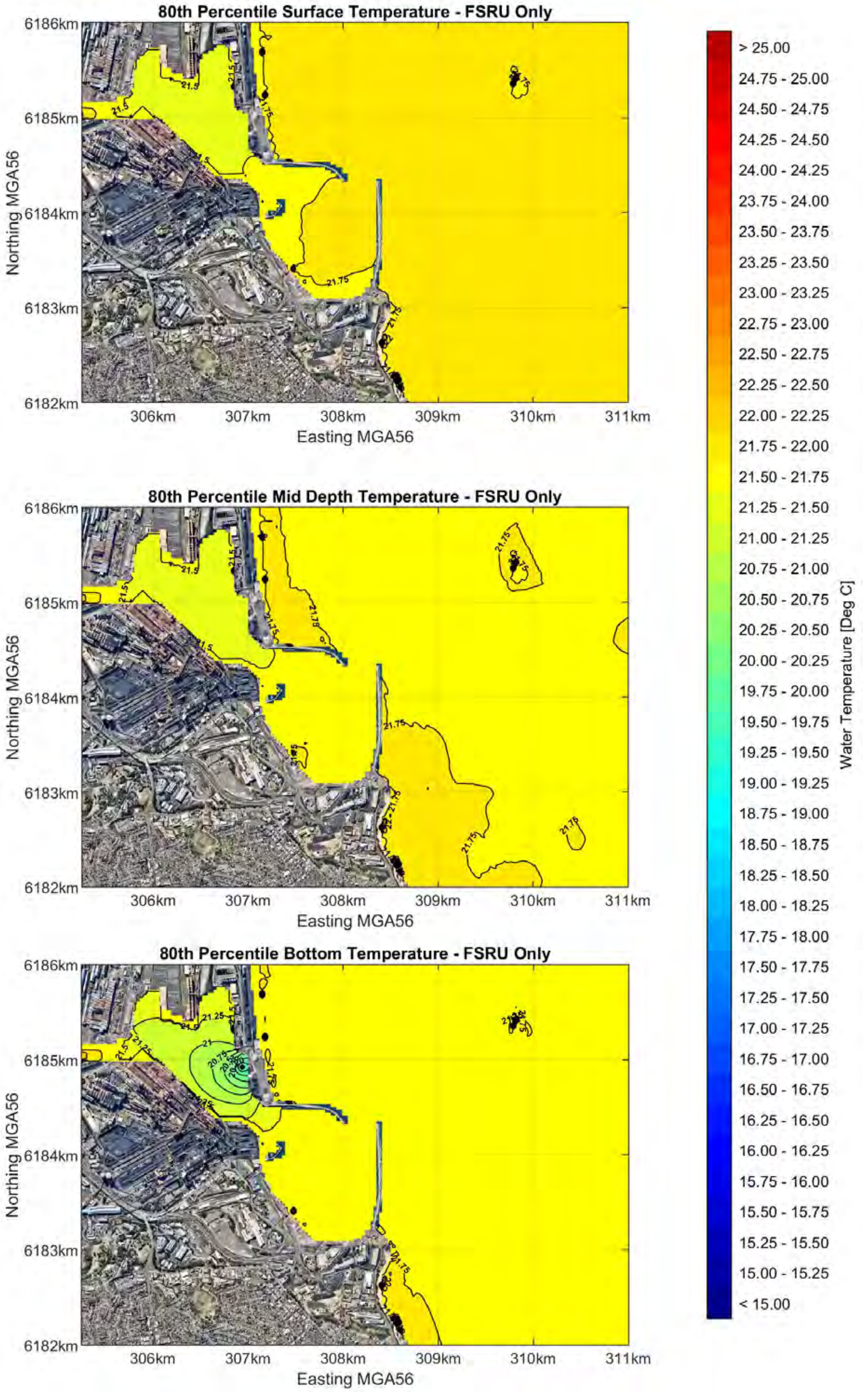
16.25 - 16.50
16.00 - 16.25
15.75 - 16.00
15.50 - 15.75
15.25 - 15.50
15.00 - 15.25
< 15.00
Water Temperature [Deg C]



Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Autumn seawater temperature simulation results
FSRU only, 80th percentile

59919002 Jan 2019

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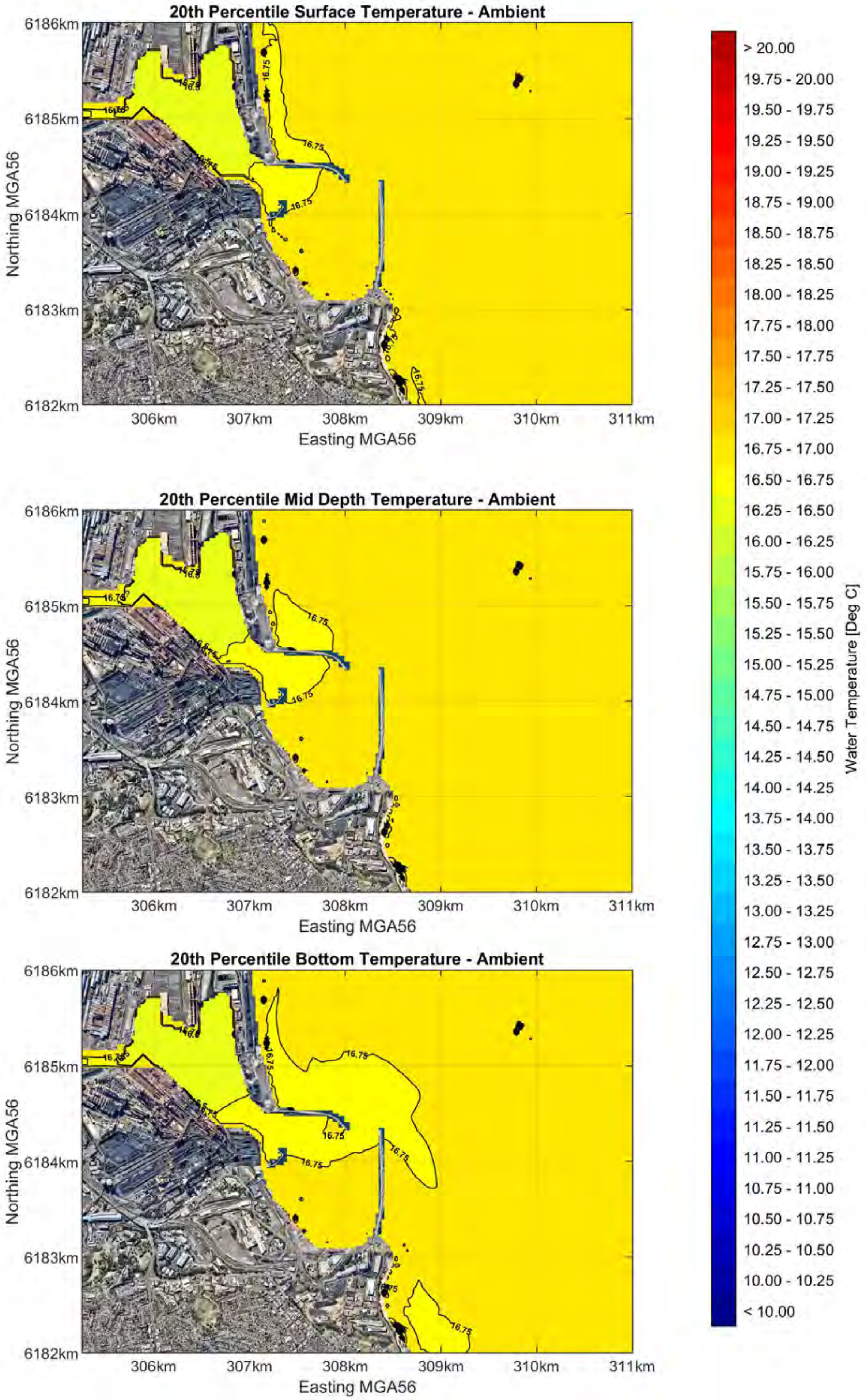
Appendix C12

APPENDIX

D

SPRING THERMAL PLUME



Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
Ambient, 20th percentile

Appendix D1

59919002 Jan 2019
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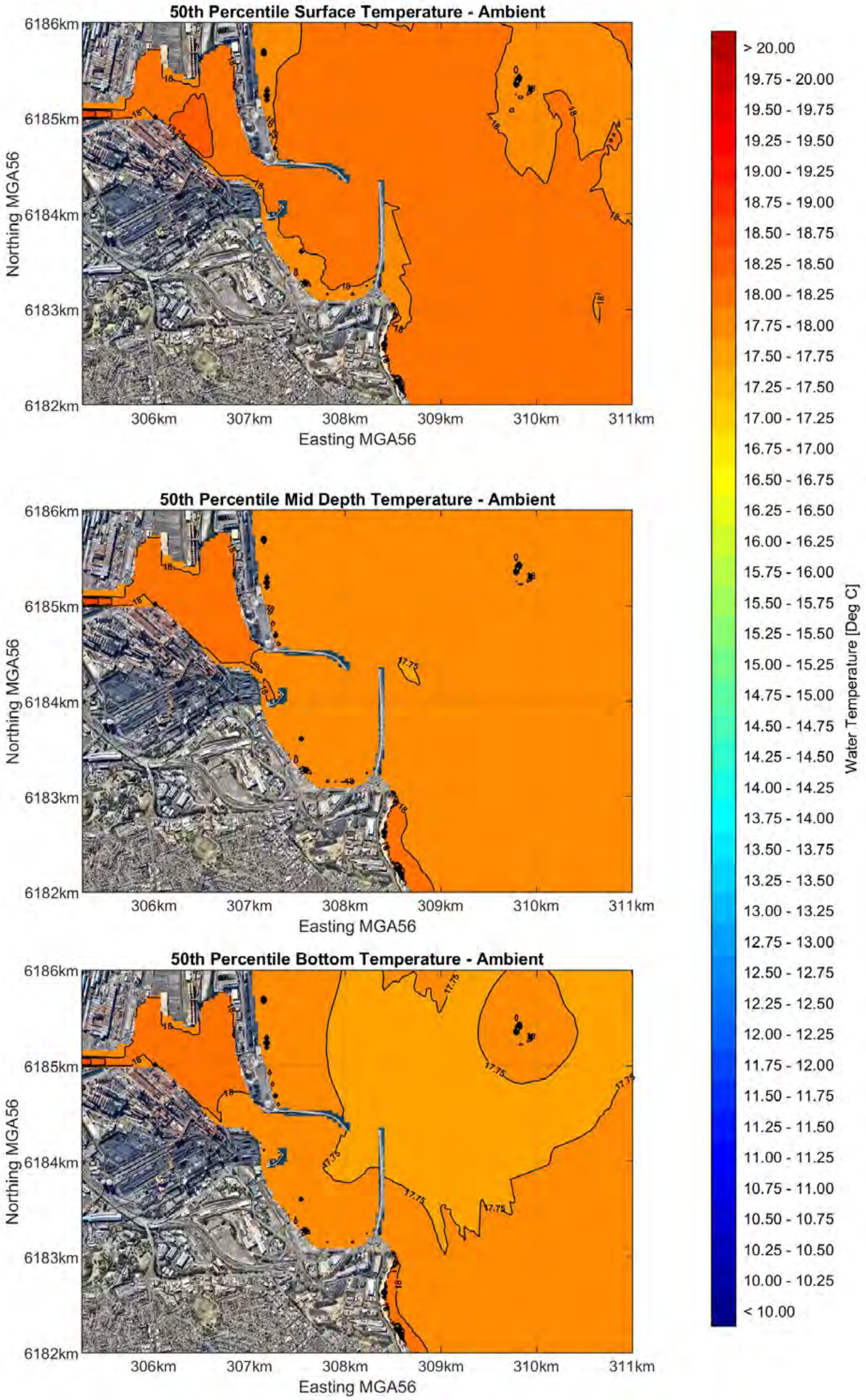
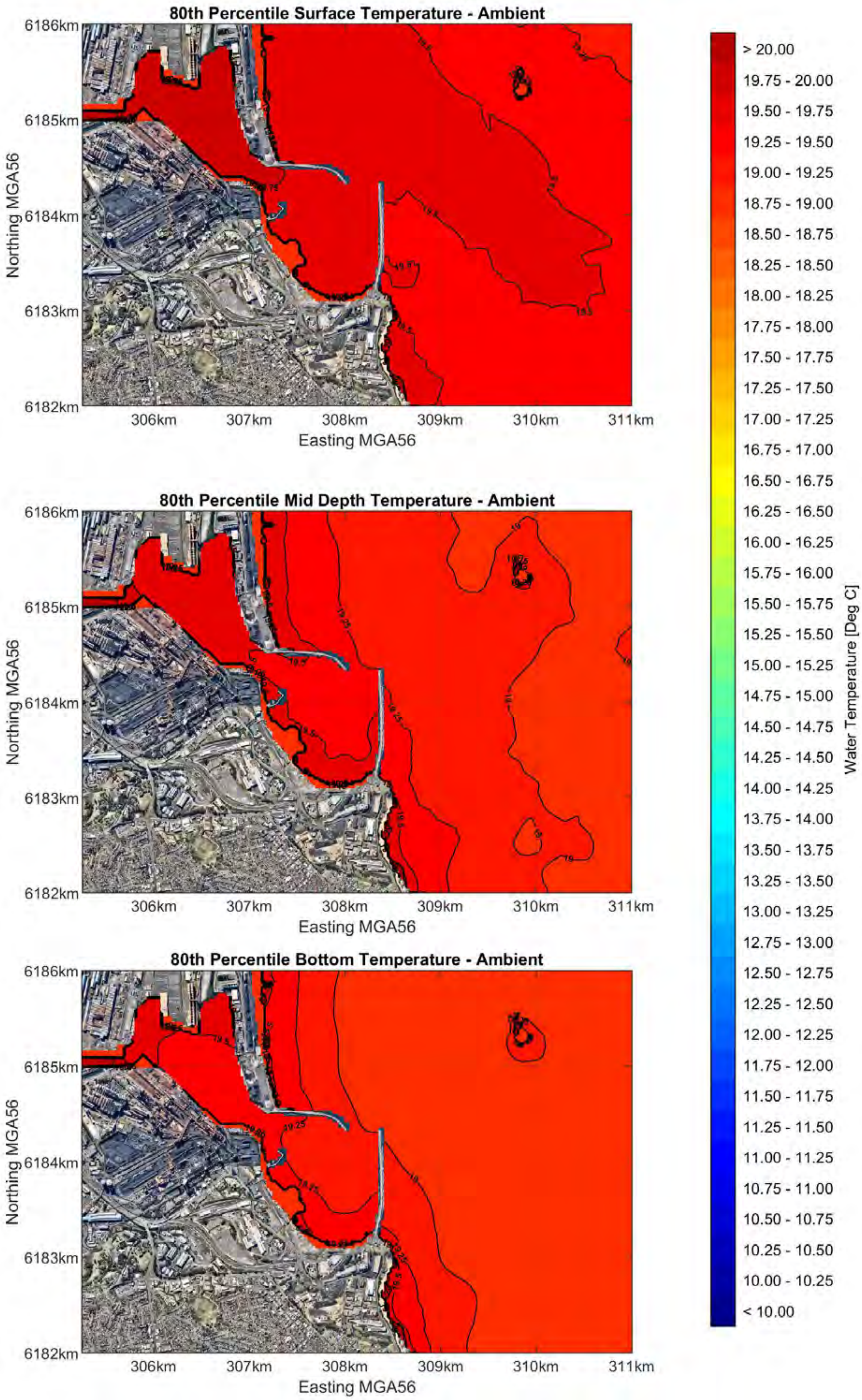


Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
Ambient, 50th percentile

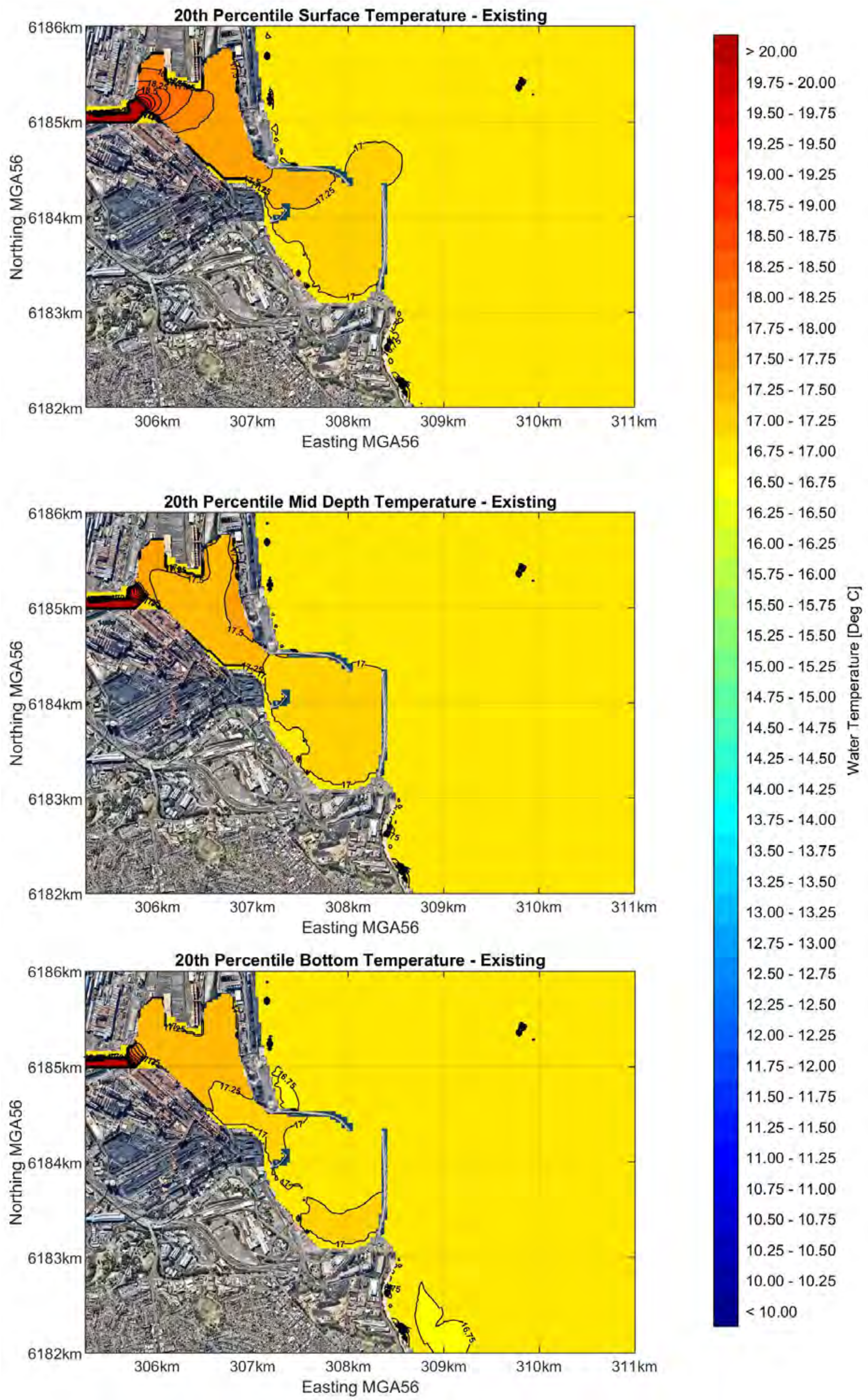
Appendix D2



Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
Abmient, 80th percentile

Appendix D3

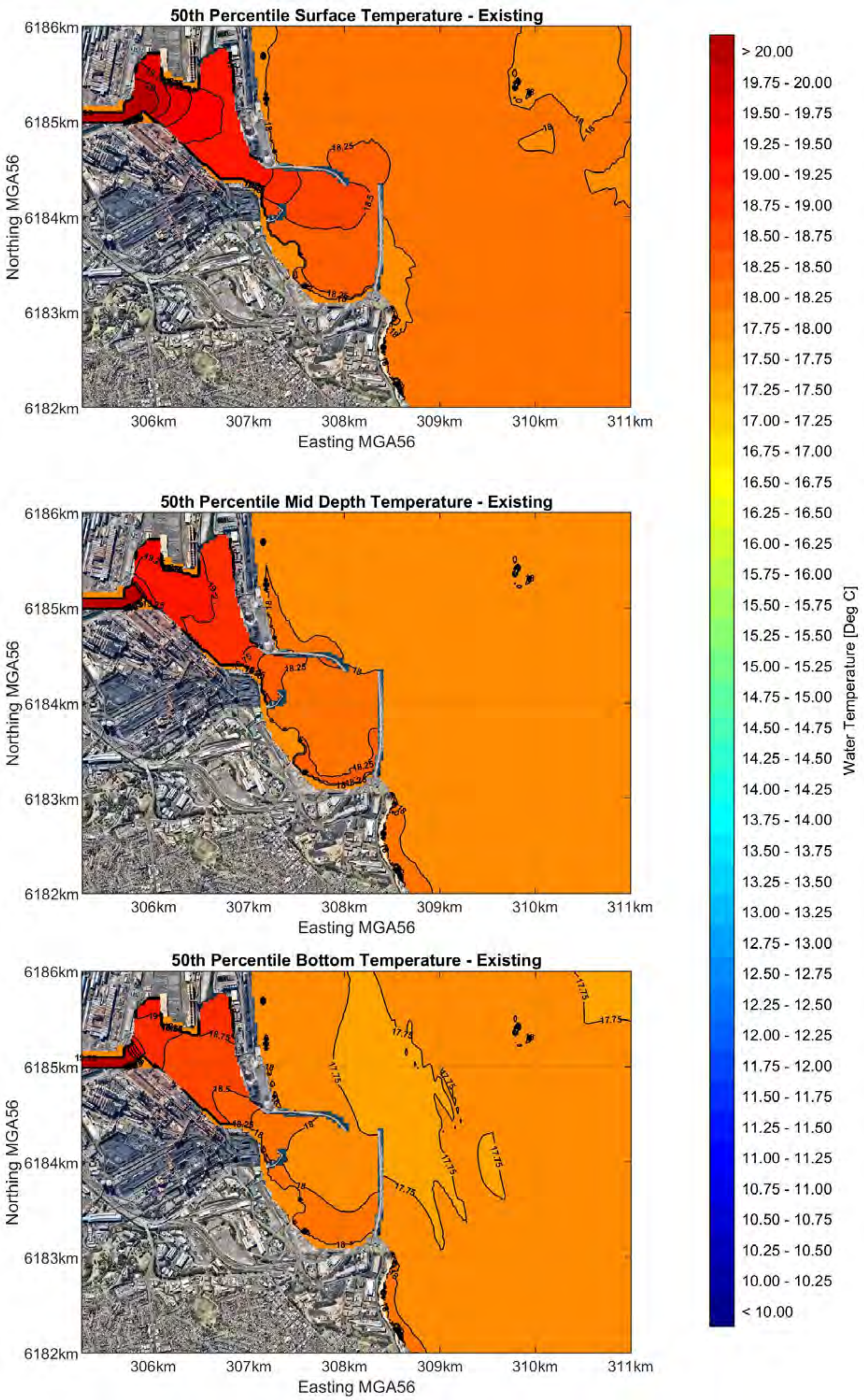


Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
Existing, 20th percentile

Appendix D4



Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
Existing, 50th percentile

Appendix D5

59919002 Jan 2019

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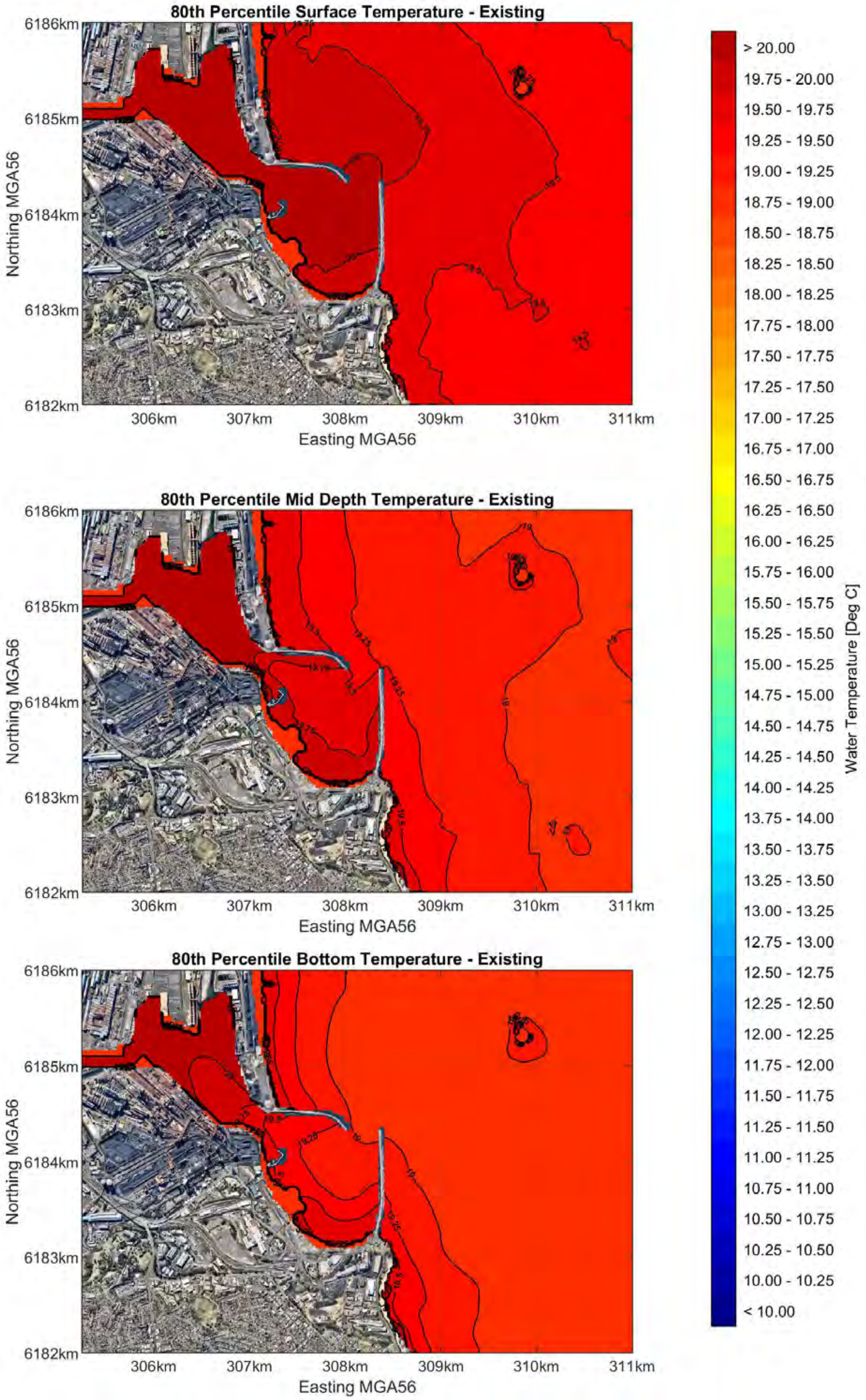
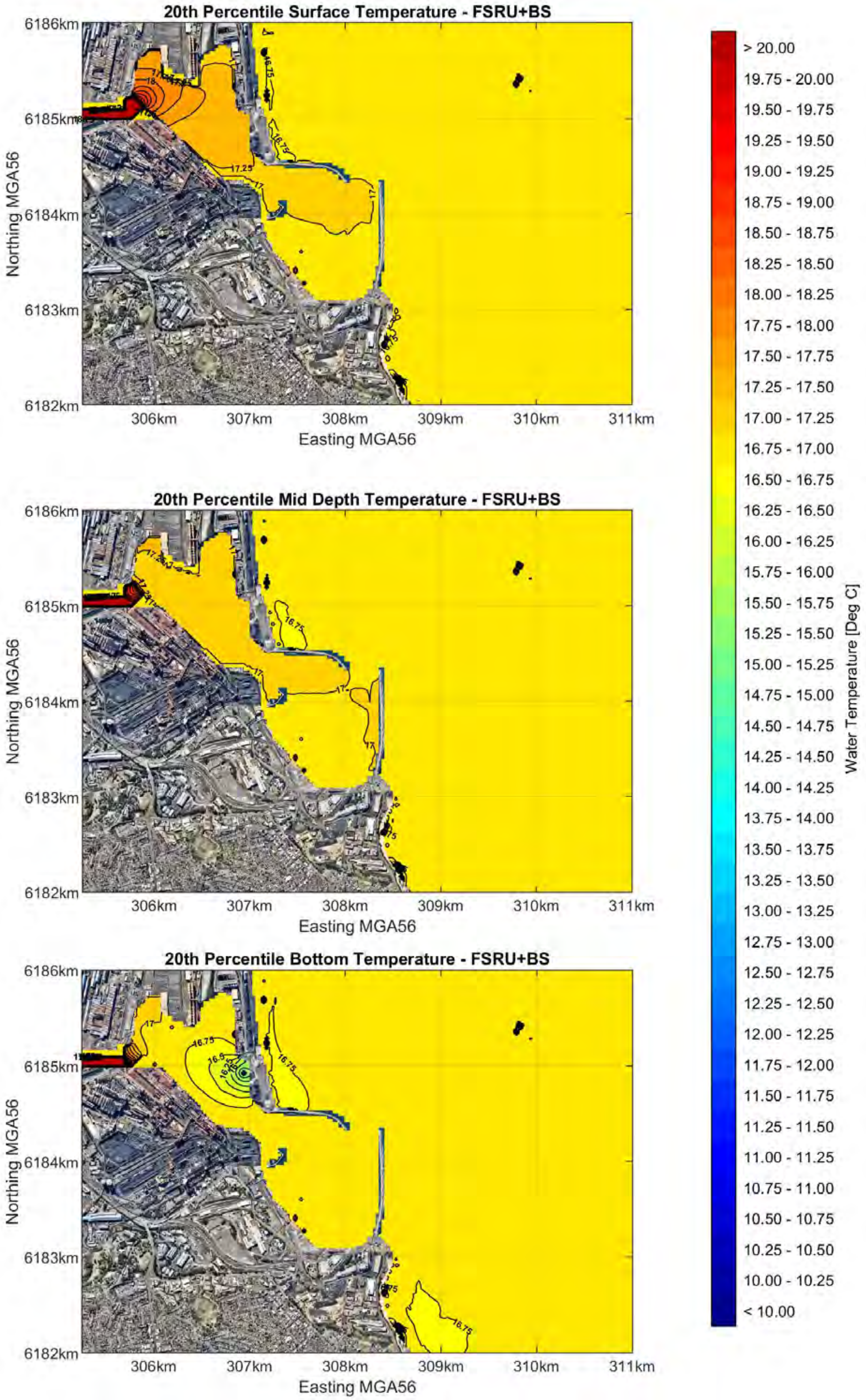


Cardno

Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
Existing, 80th percentile

Appendix D6



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
FSRU and Bluescope, 20th percentile

59919002 Jan 2019

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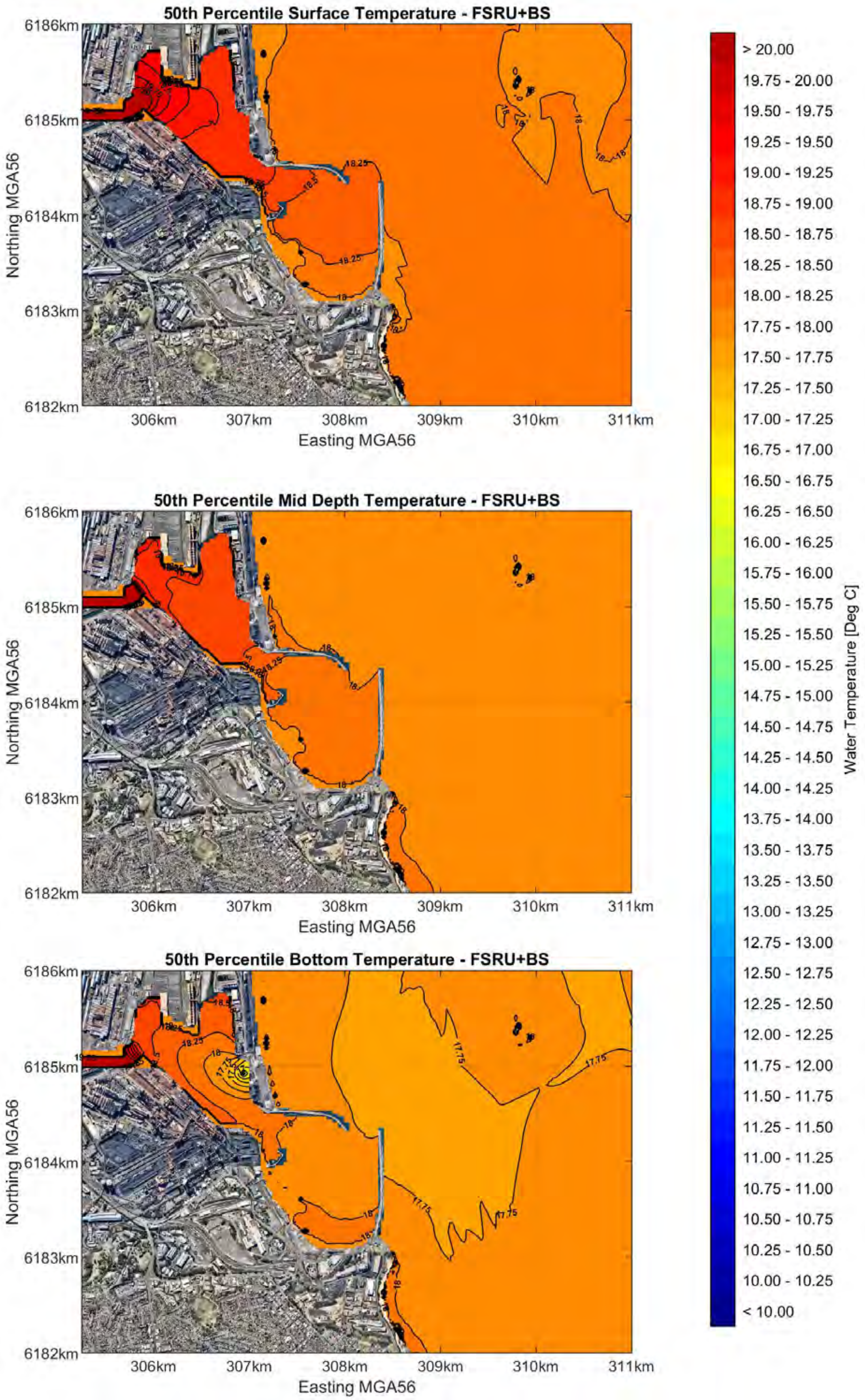
Appendix D7



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
FSRU and Bluescope, 50th percentile

59919002 Jan 2019
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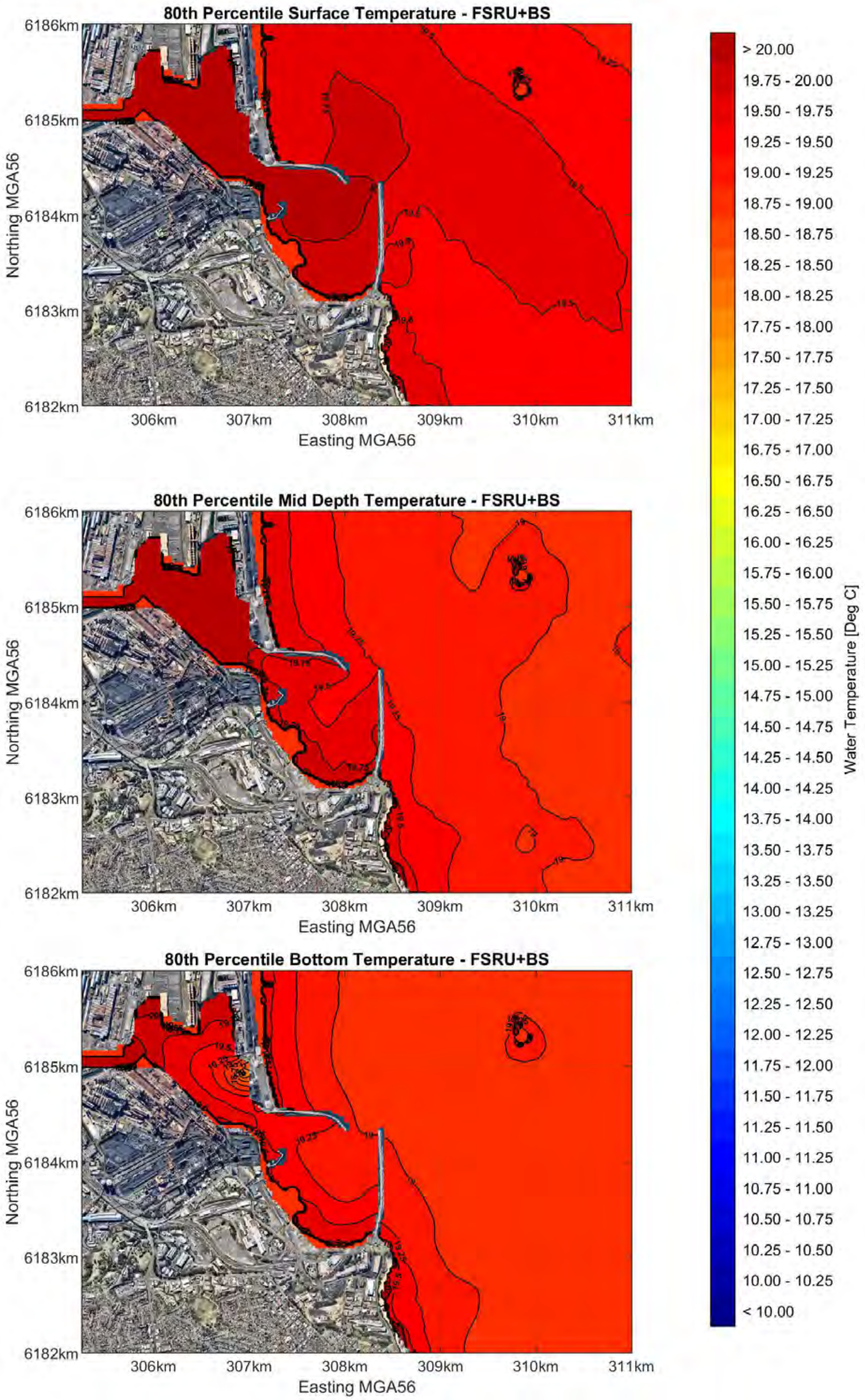
Appendix D8



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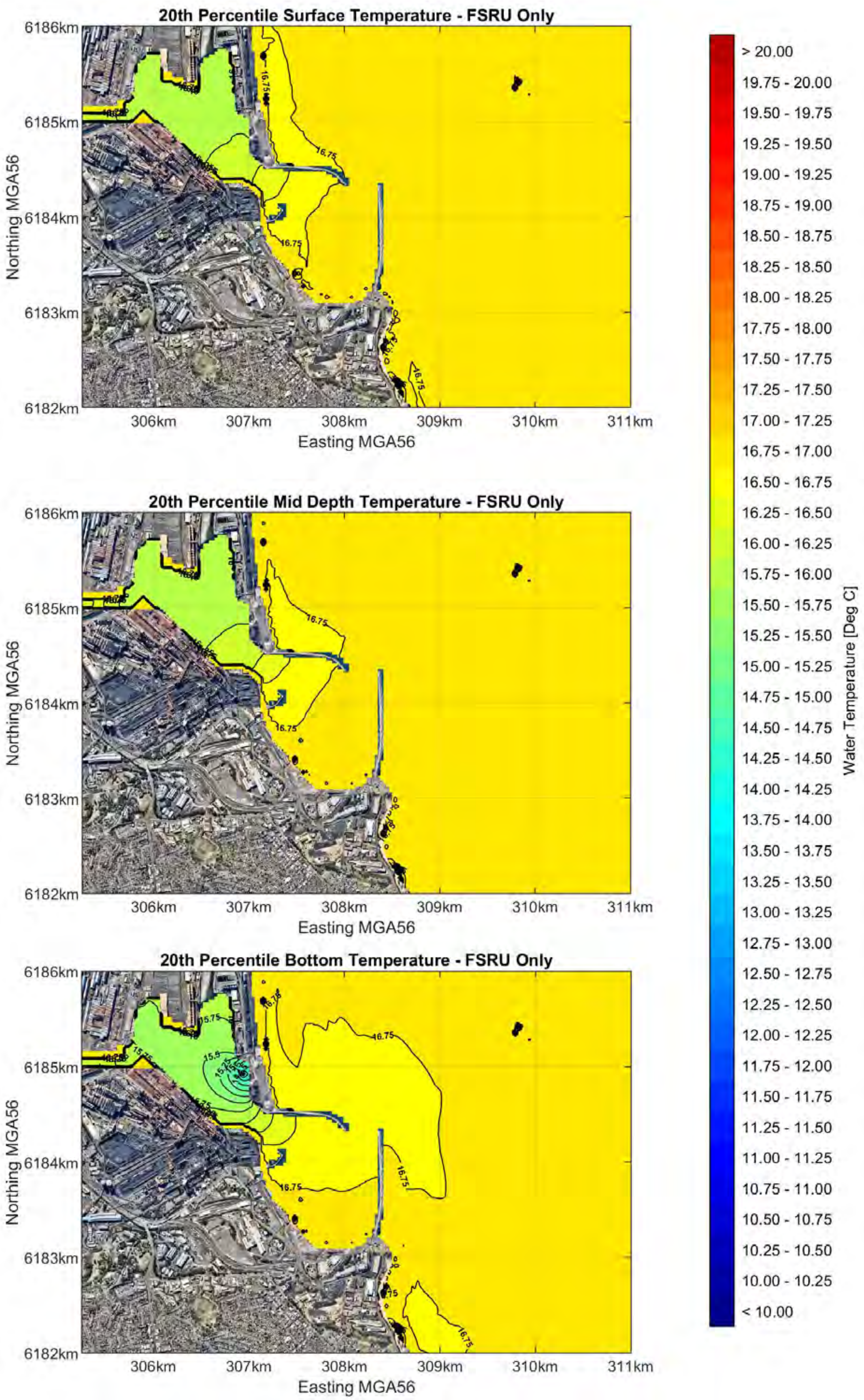
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
FSRU and Bluescope, 80th percentile

Appendix D9



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
FSRU only, 20th percentile

Appendix D10

59919002 Jan 2019

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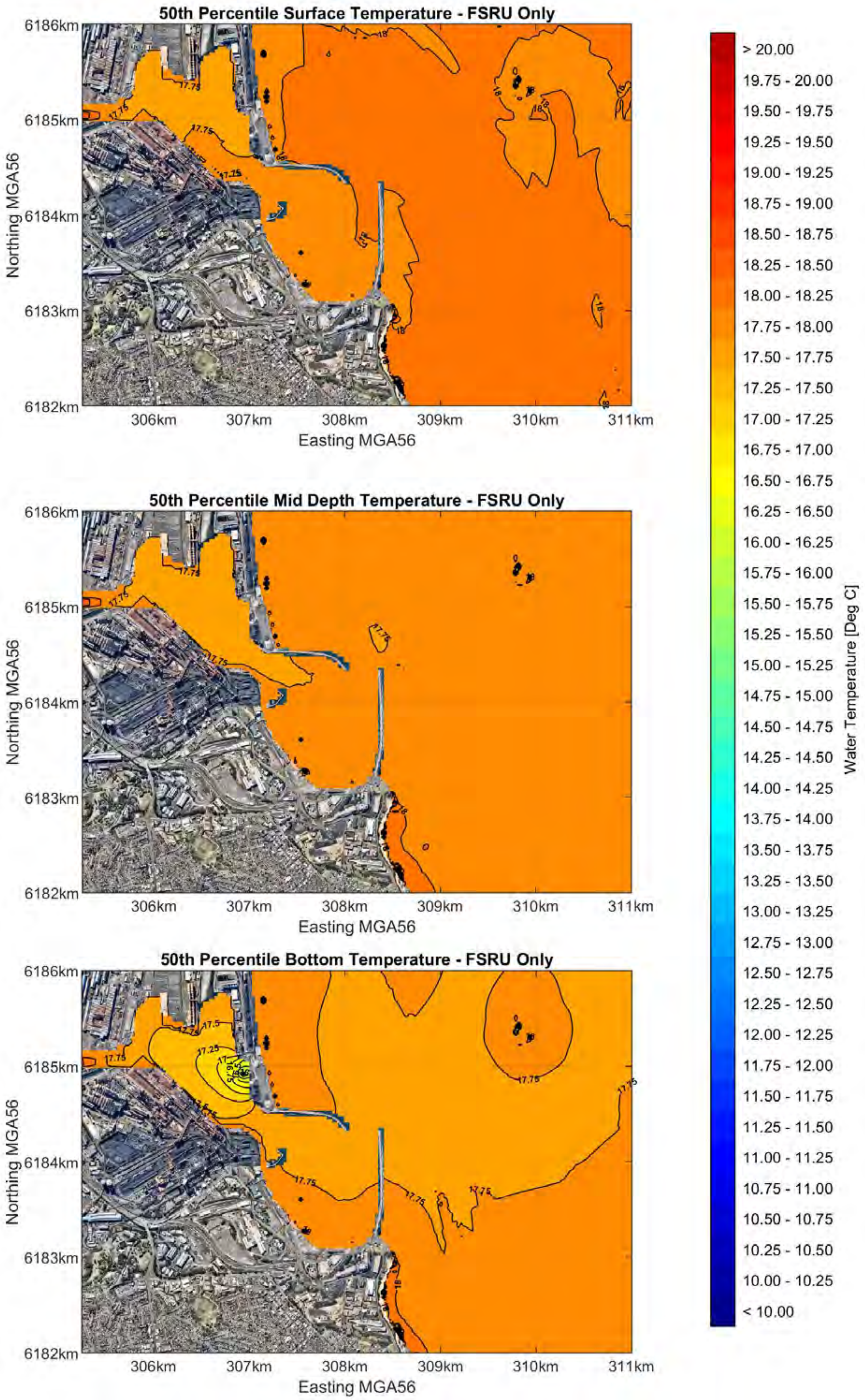

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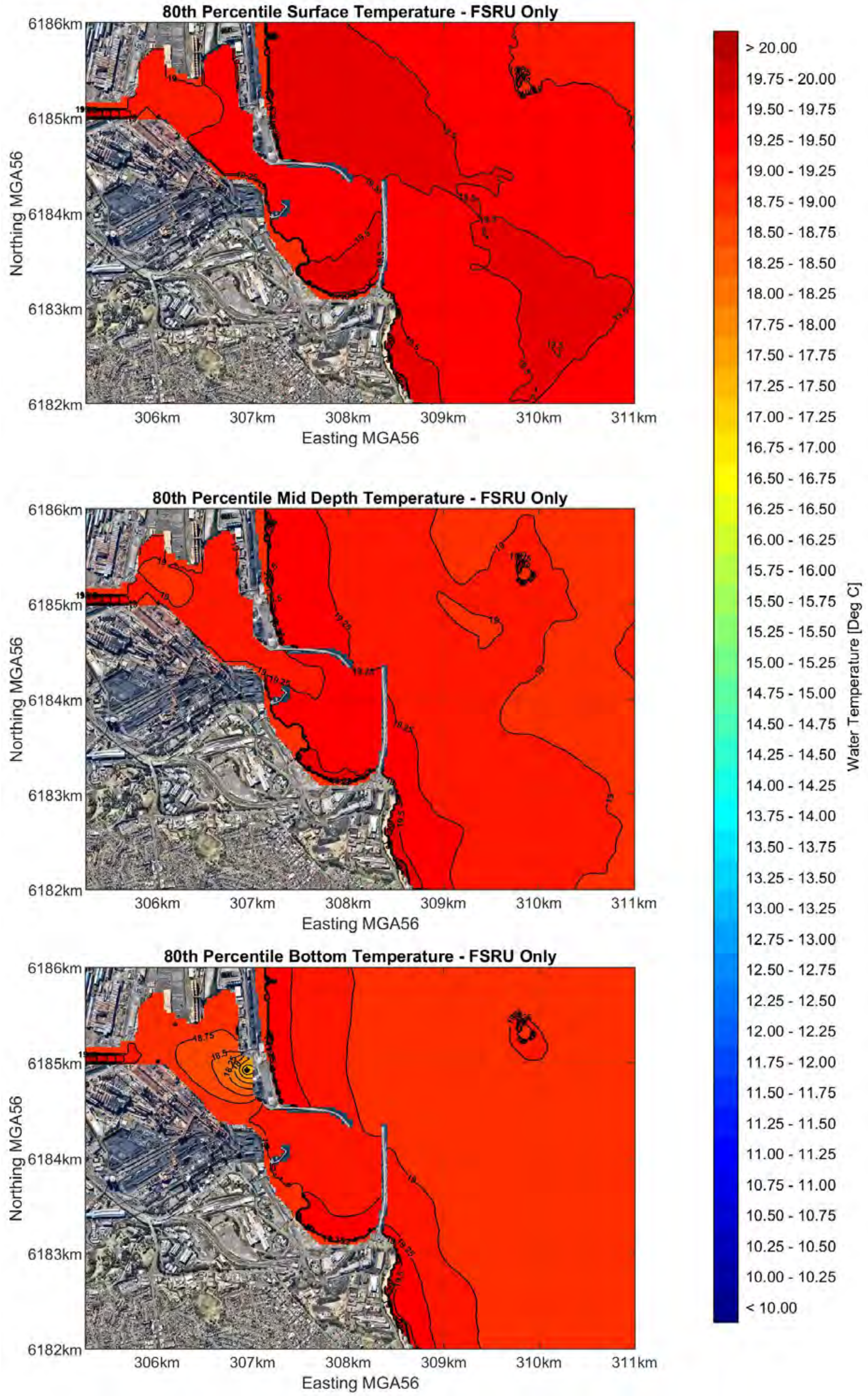
Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
FSRU only, 50th percentile

Appendix D11



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Port Kembla Regasification Project − Updated Hydrodynamic Plume Modelling

Spring seawater temperature simulation results
FSRU only, 80th percentile

59919002 Jan 2019

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Appendix D12

About Cardno

Cardno is a professional infrastructure and environmental services company, with expertise in the development and improvement of physical and social infrastructure for communities around the world. Cardno's team includes leading professionals who plan, design, manage and deliver sustainable projects and community programs. Cardno is an international company listed on the Australian Securities Exchange [ASX:CDD].

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