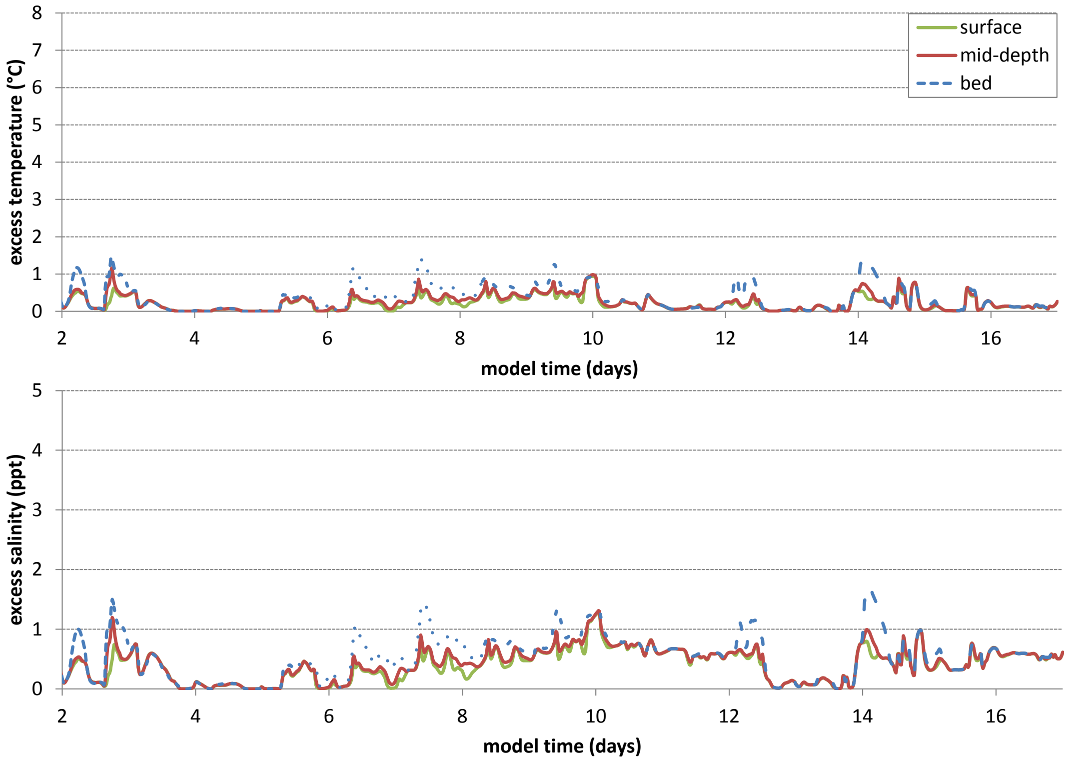

Figure C.2: Excess temperature and salinity at point A1, summer, observed wind, standard operation

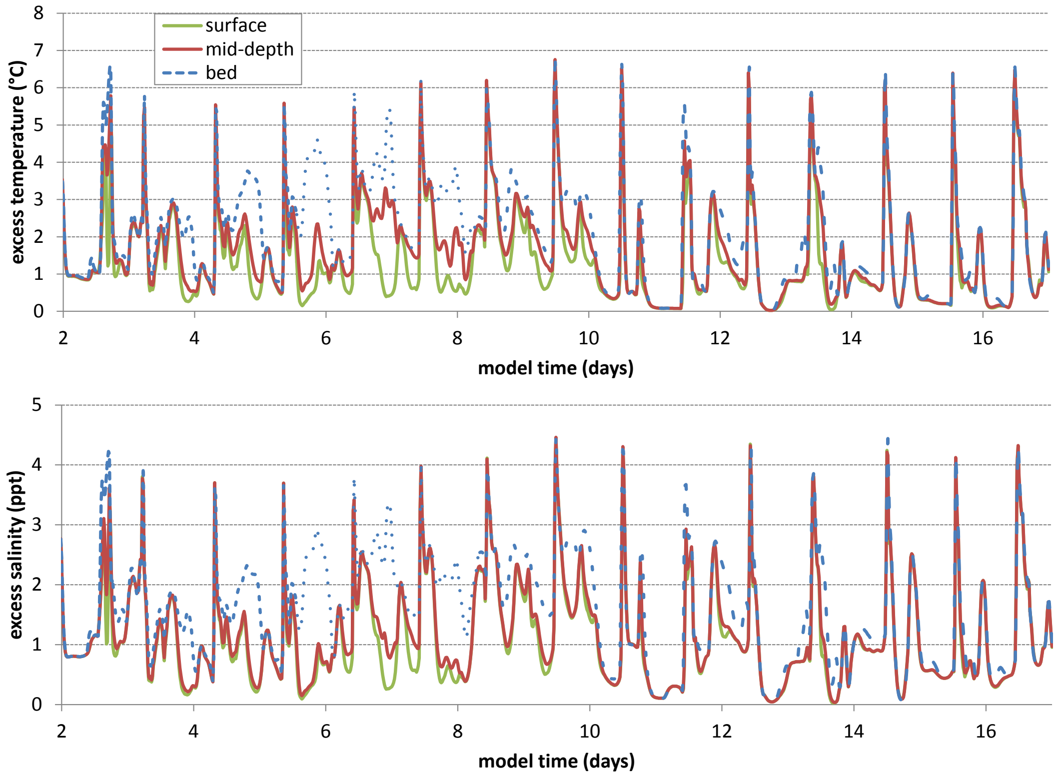

Figure C.3: Excess temperature and salinity at point A2, summer, observed wind, standard operation

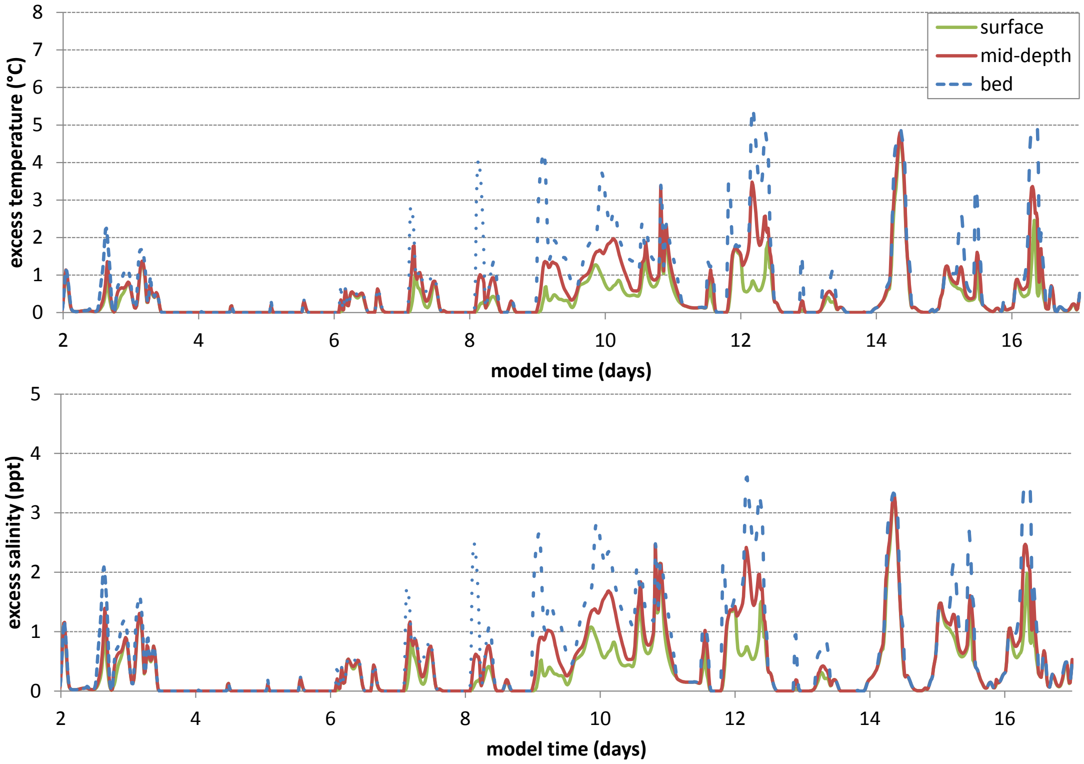

Figure C.4: Excess temperature and salinity at point A3, summer, observed wind, standard operation

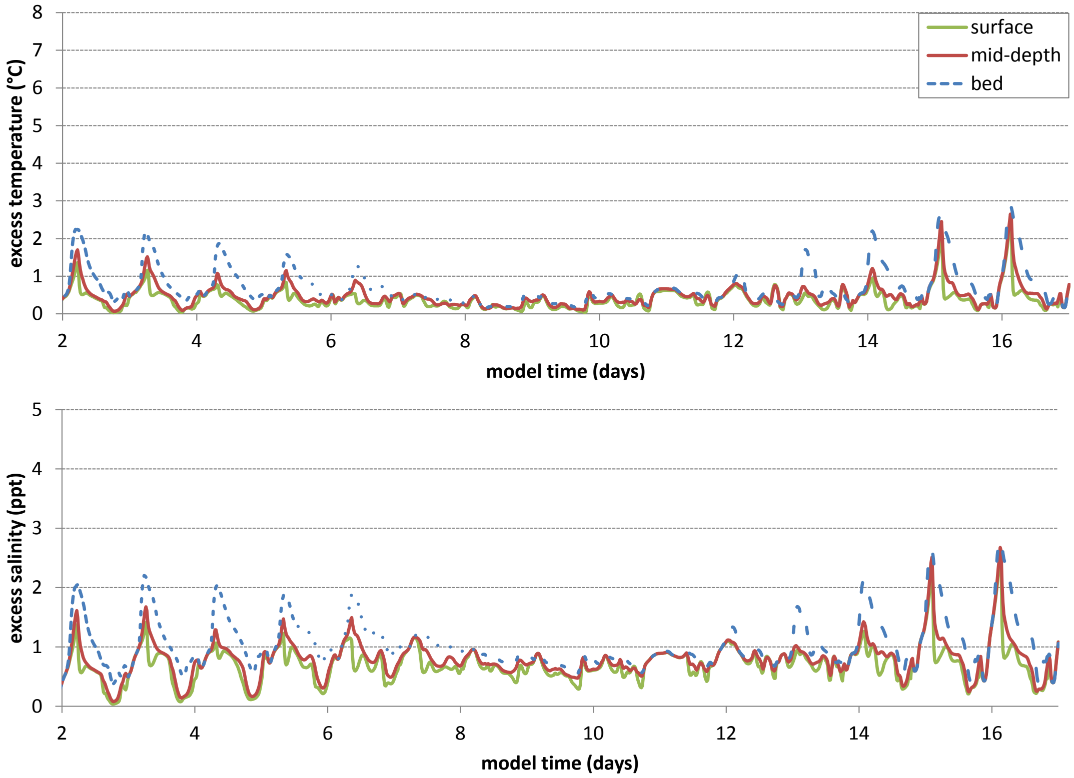

Figure C.5: Excess temperature and salinity at point A1, summer, calm, standard operation

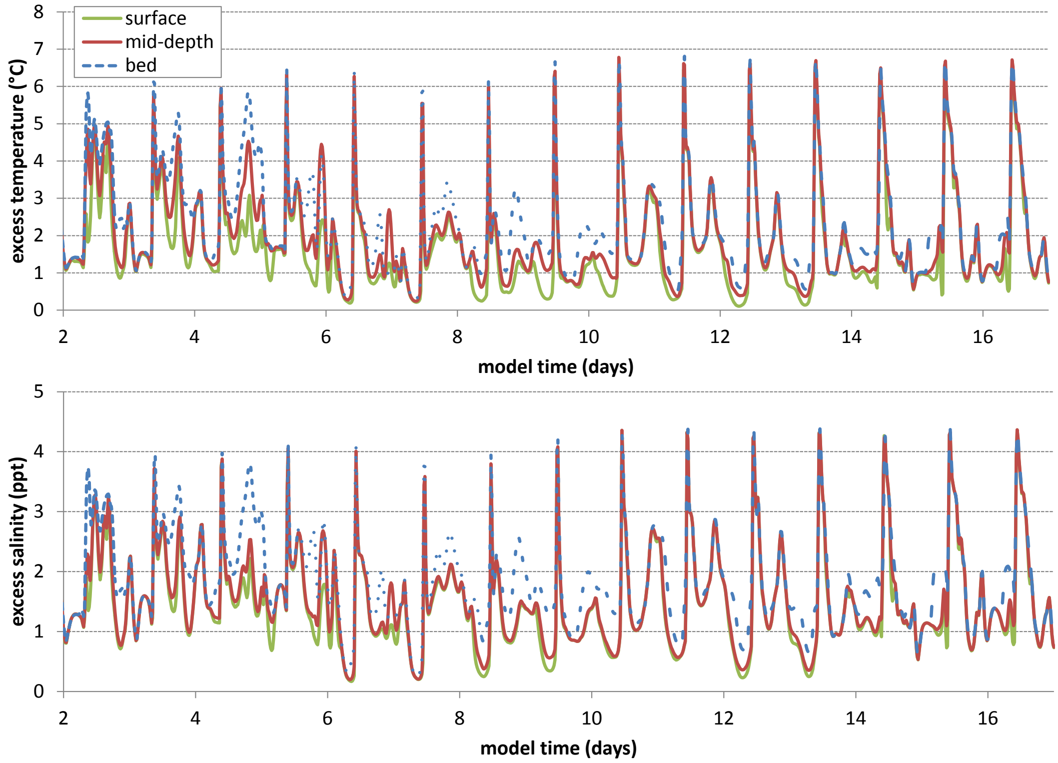

Figure C.6: Excess temperature and salinity at point A2, summer, calm, standard operation

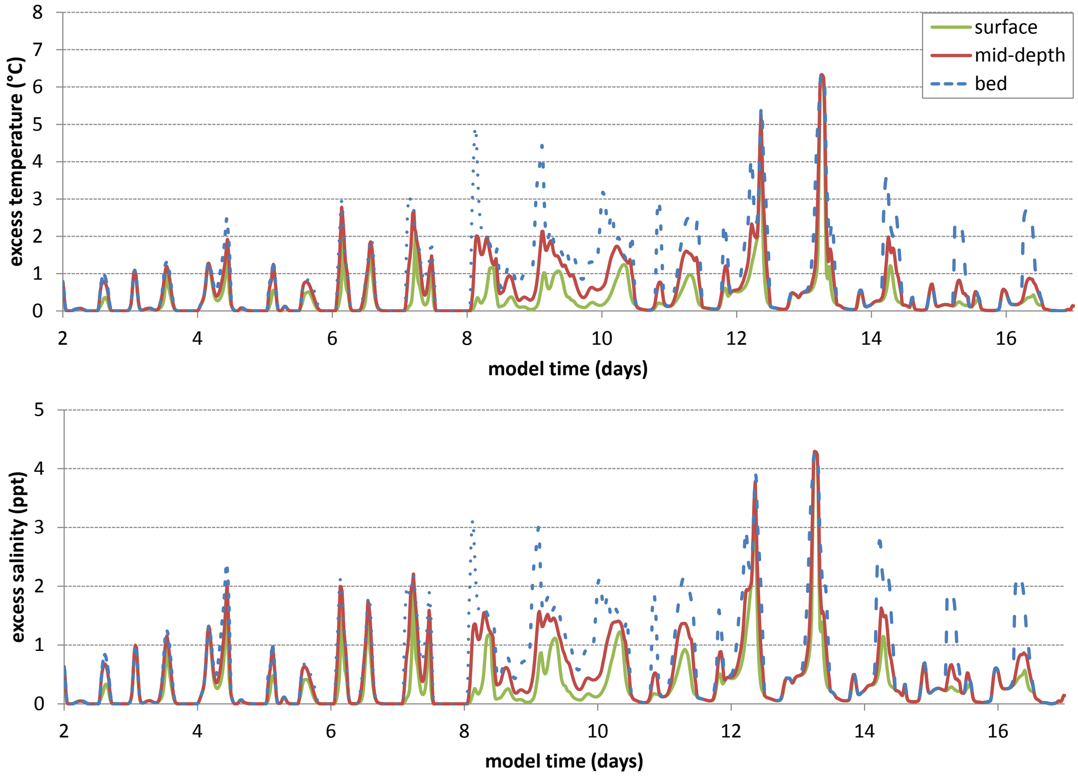

Figure C.7: Excess temperature and salinity at point A3, summer, calm, standard operation

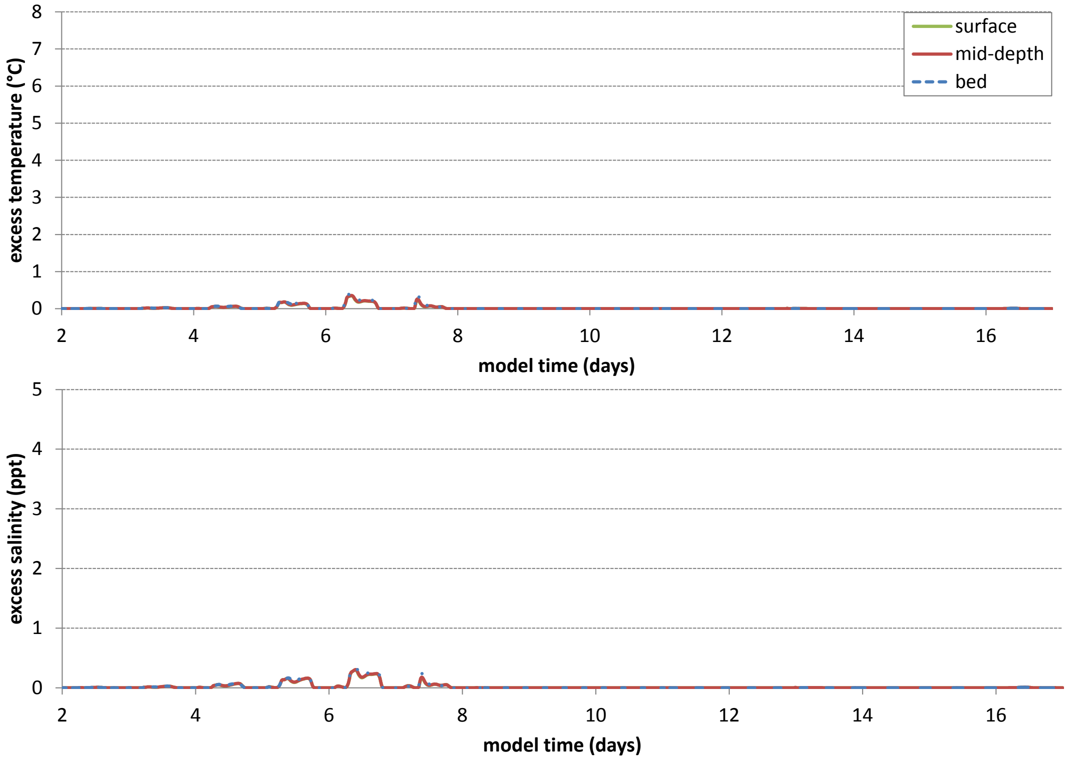

Figure C.8: Excess temperature and salinity at point A1, summer, north-west wind, standard operation

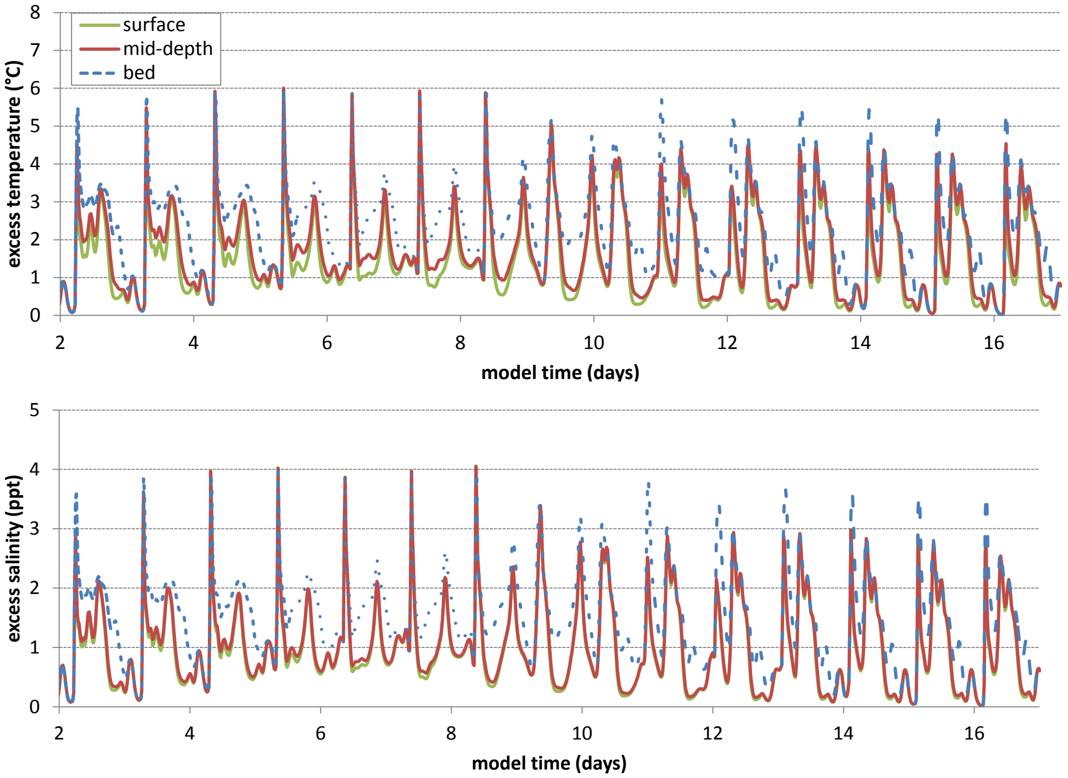

Figure C.9: Excess temperature and salinity at point A2, summer, north-west wind, standard operation

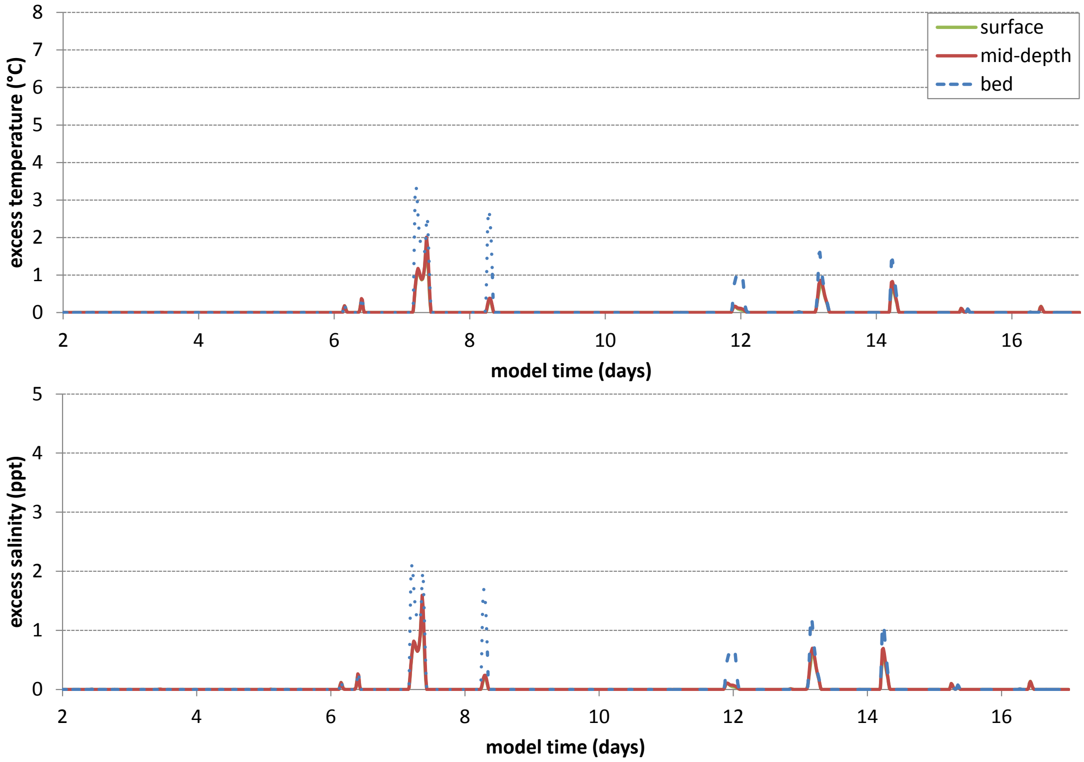

Figure C.10: Excess temperature and salinity at point A3, summer, north-west wind, standard operation

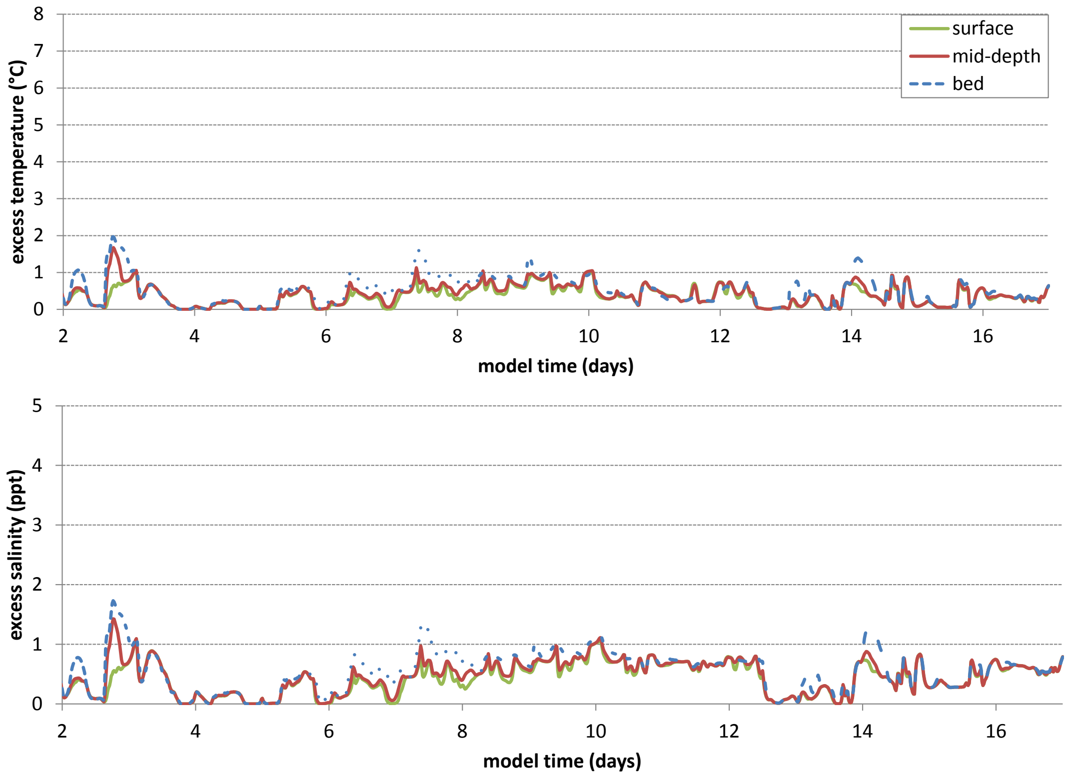

Figure C.11: Excess temperature and salinity at point A1, winter, observed wind, standard operation

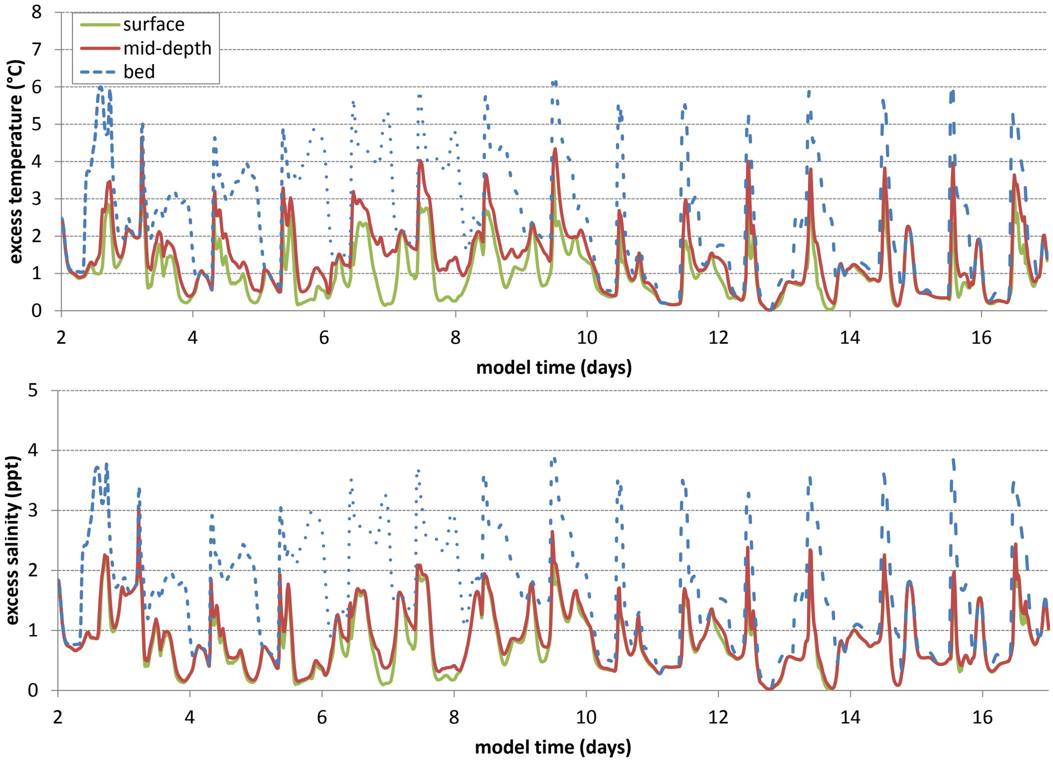

Figure C.12: Excess temperature and salinity at point A2, winter, observed wind, standard operation

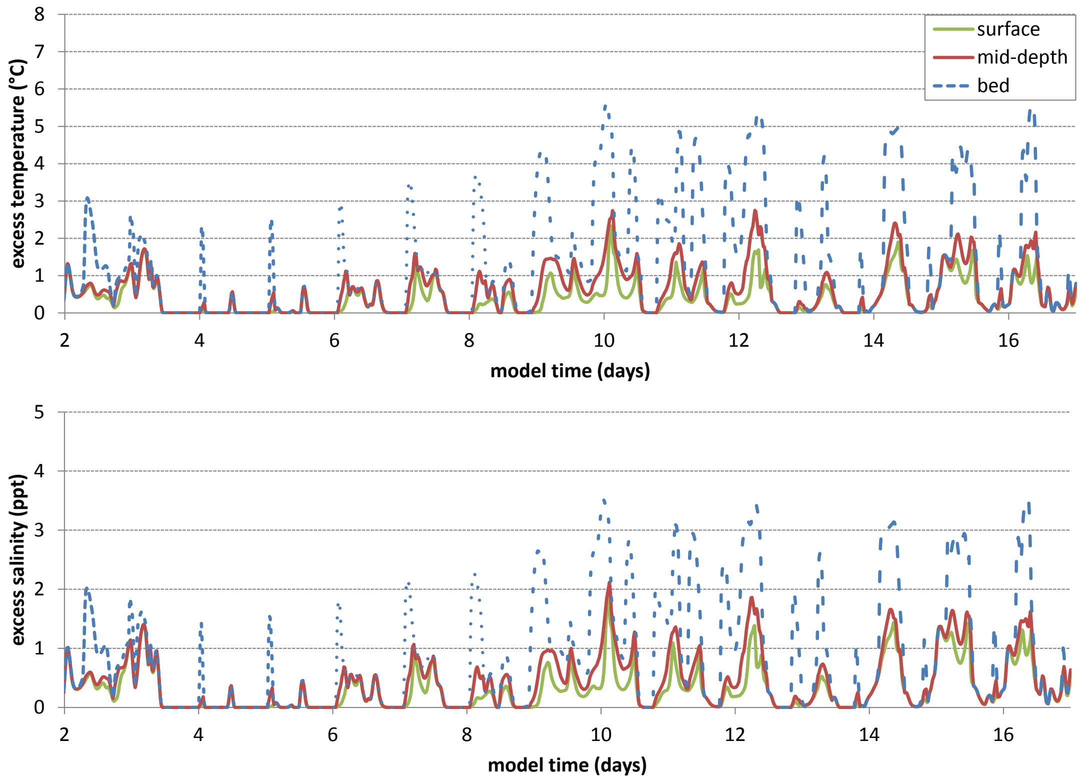

Figure C.13: Excess temperature and salinity at point A3, winter, observed wind, standard operation

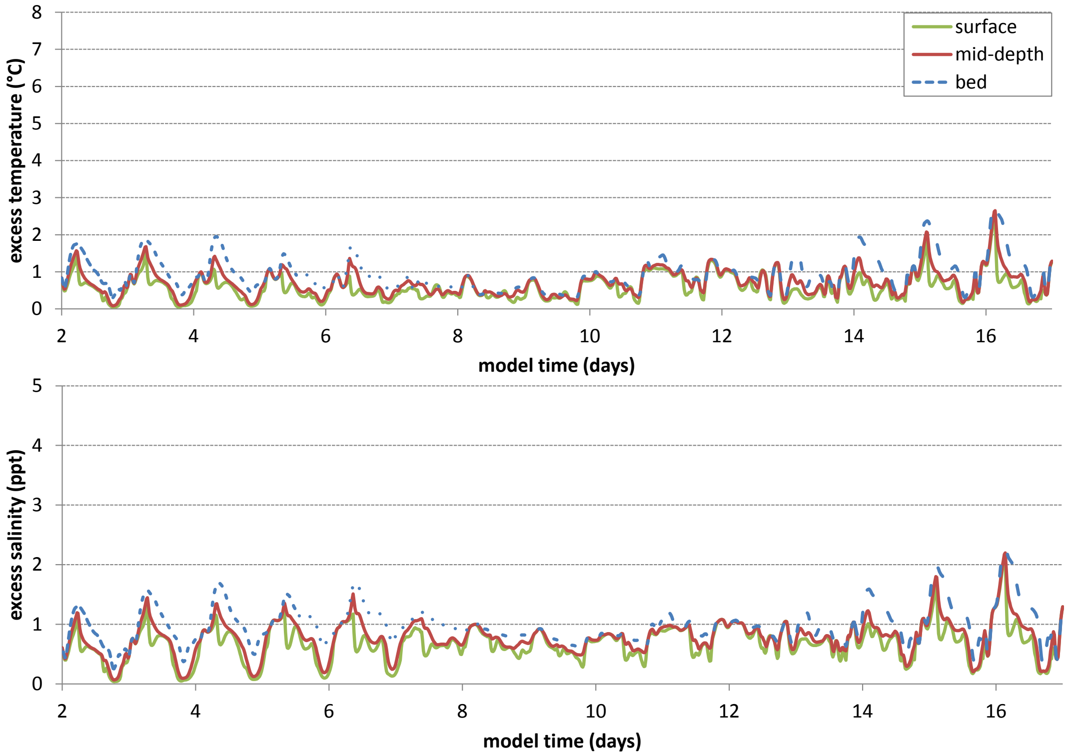

Figure C.14: Excess temperature and salinity at point A1, winter, calm, standard operation

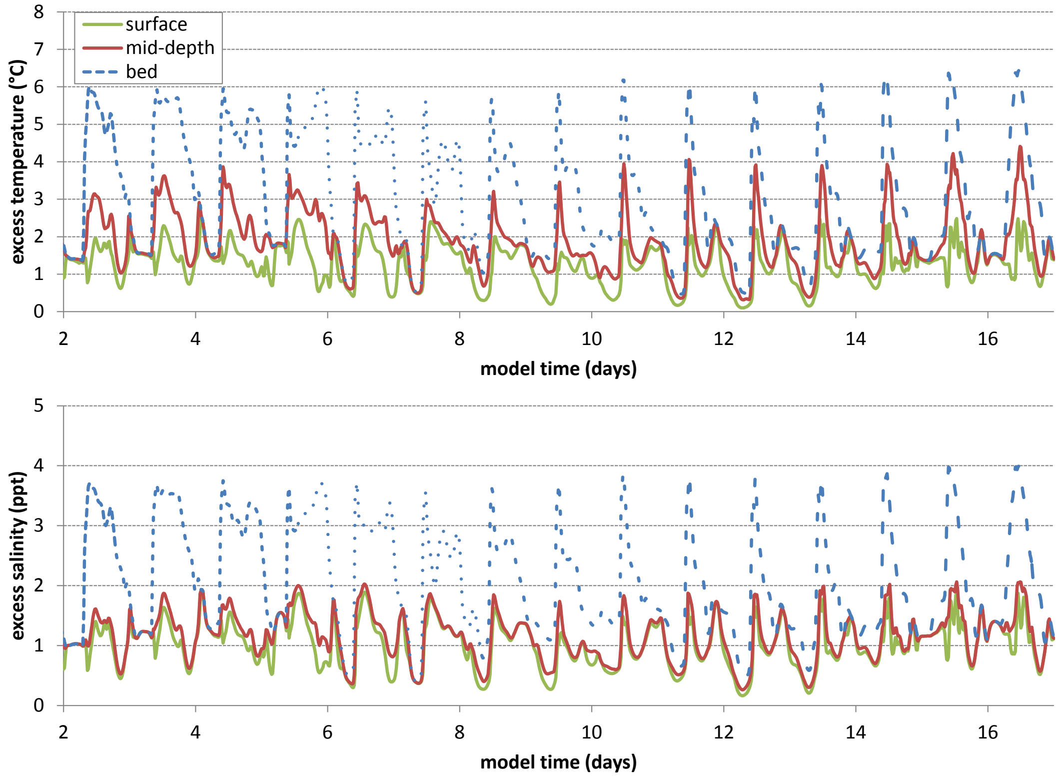

Figure C.15: Excess temperature and salinity at point A2, winter, calm, standard operation

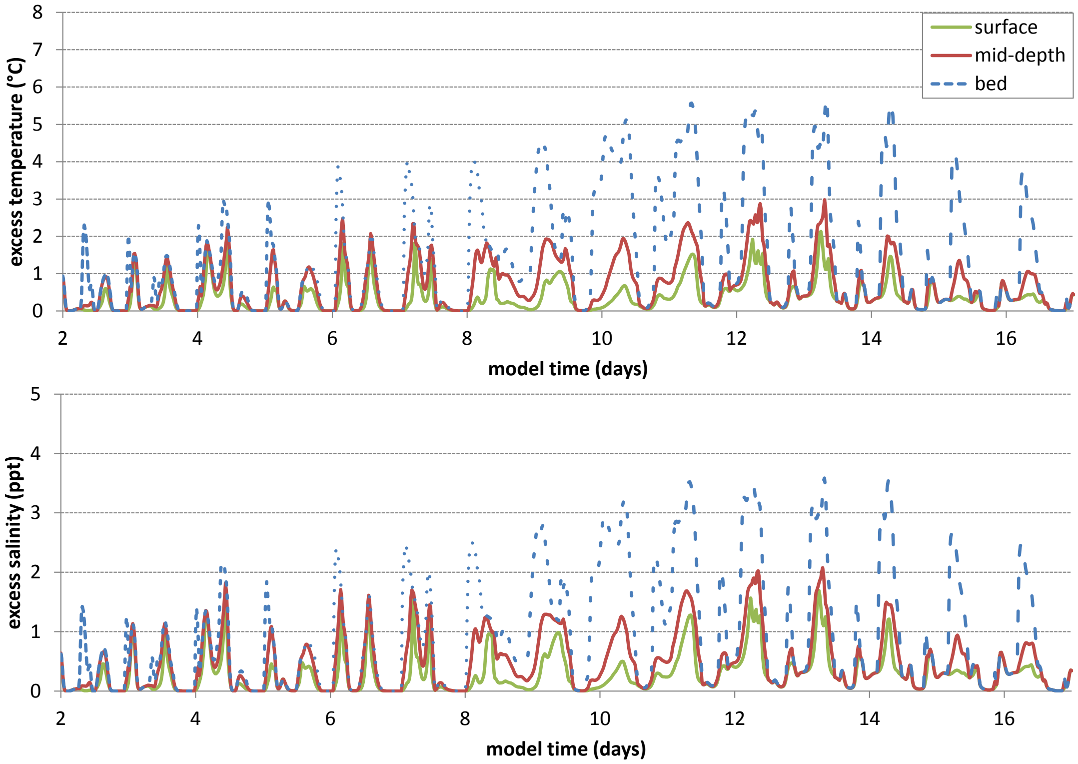

Figure C.16: Excess temperature and salinity at point A3, winter, calm, standard operation

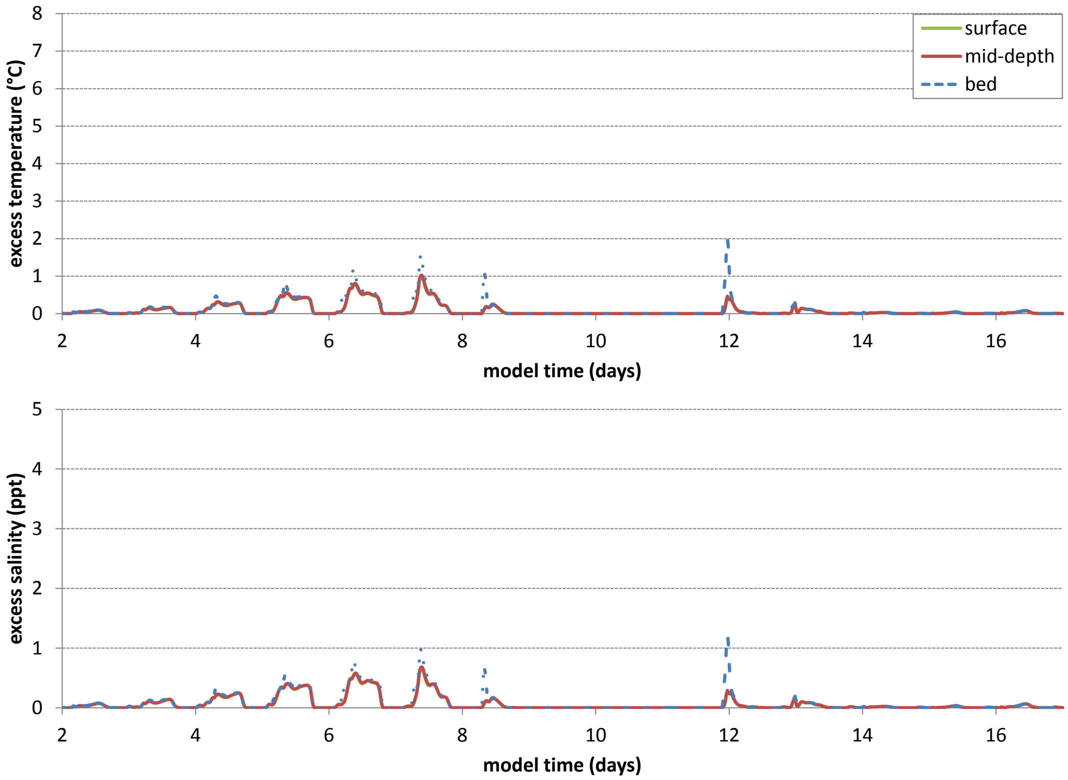

Figure C.17: Excess temperature and salinity at point A1, winter, north-west wind, standard operation

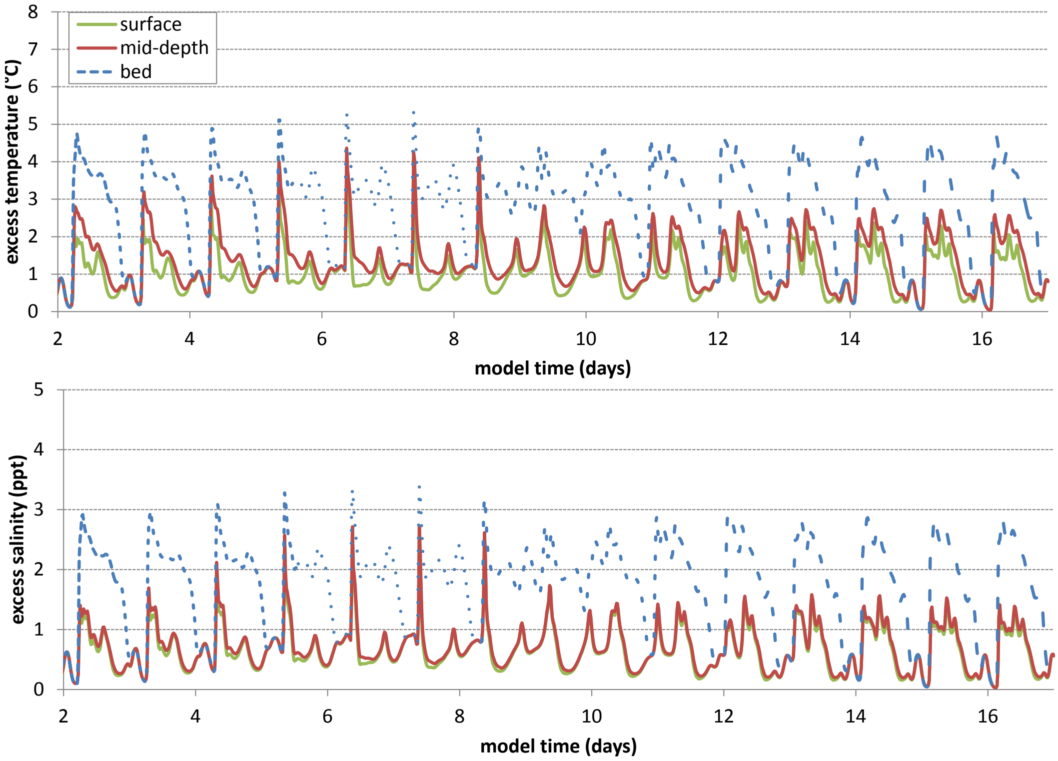

Figure C.18: Excess temperature and salinity at point A2, winter, north-west wind, standard operation

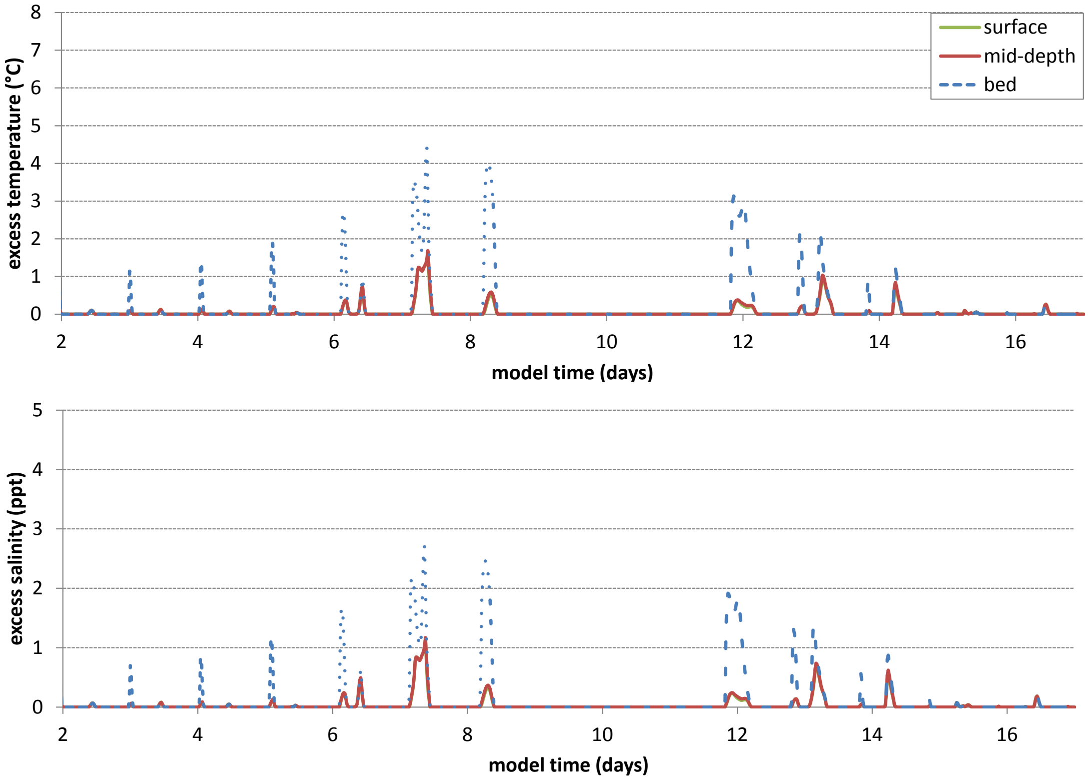

Figure C.19: Excess temperature and salinity at point A3, winter, north-west wind, standard operation

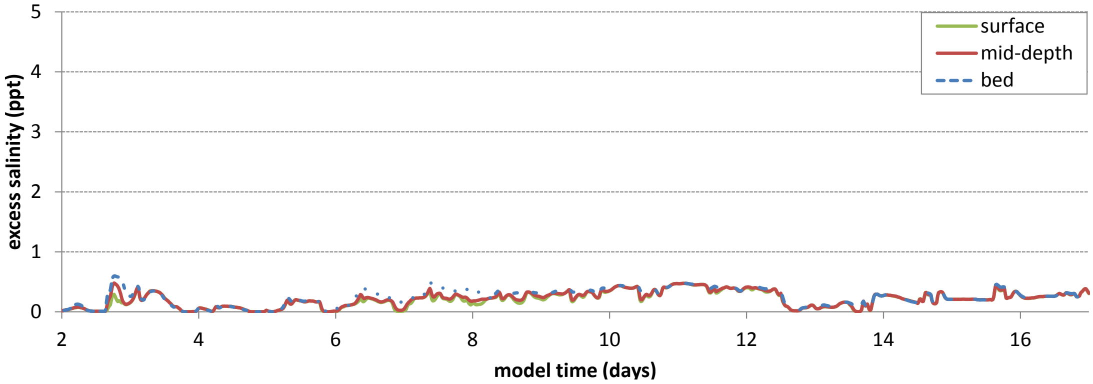

Figure C.20: Excess salinity at point A1, summer, observed wind, early operation

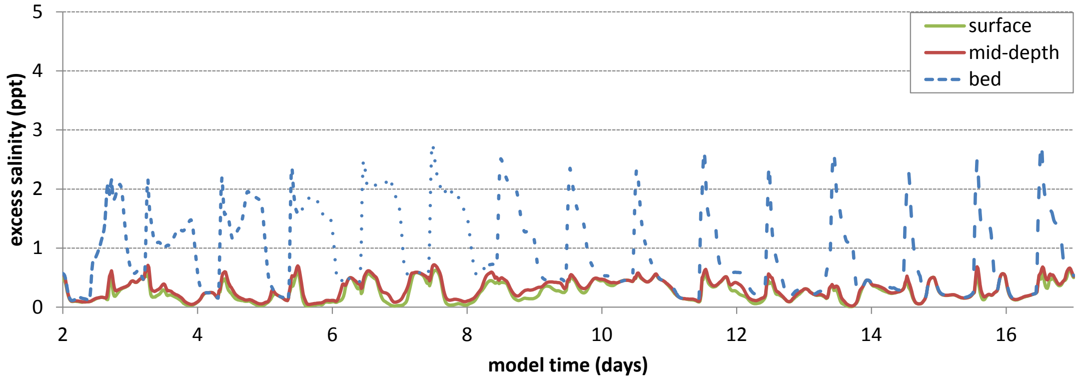

Figure C.21: Excess salinity at point A2, summer, observed wind, early operation

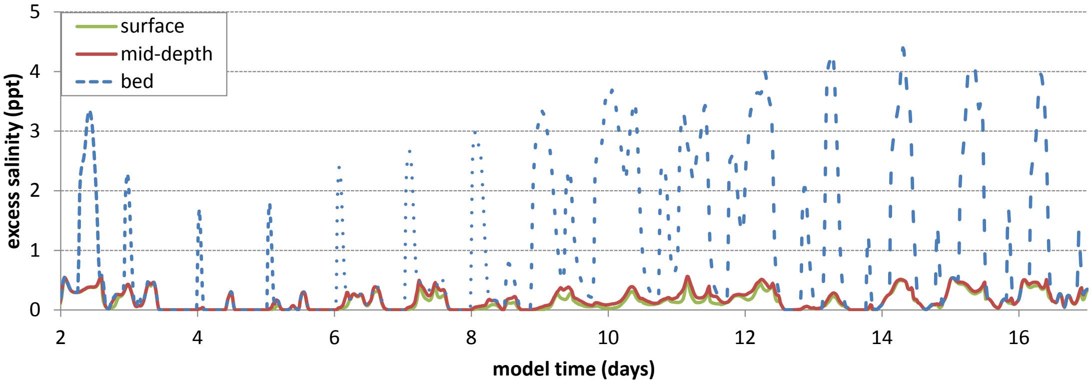

Figure C.22: Excess salinity at point A3, summer, observed wind, early operation

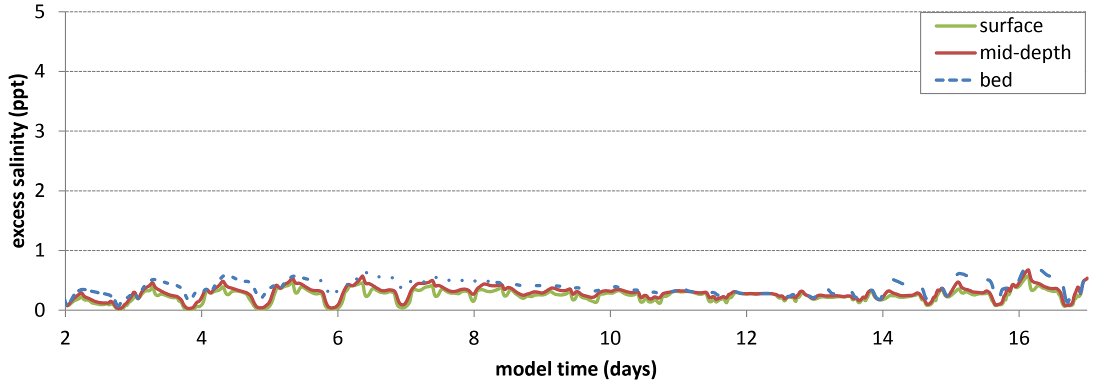

Figure C.23: Excess salinity at point A1, summer, calm, early operation

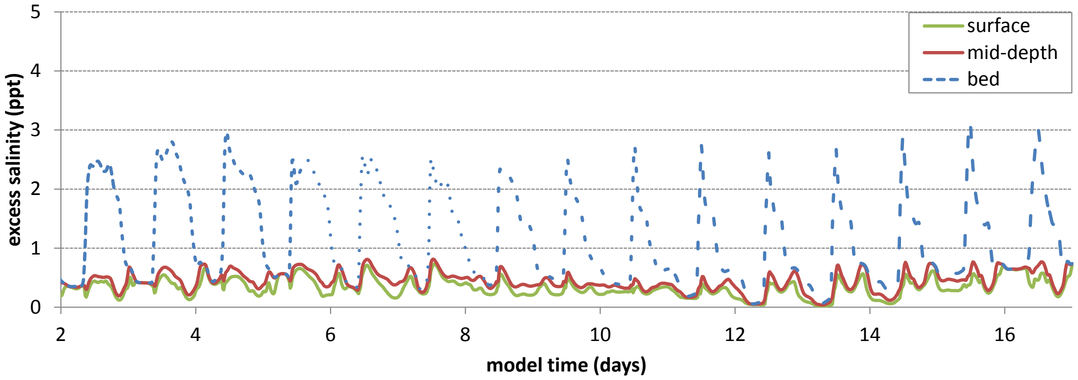

Figure C.24: Excess salinity at point A2, summer, calm, early operation

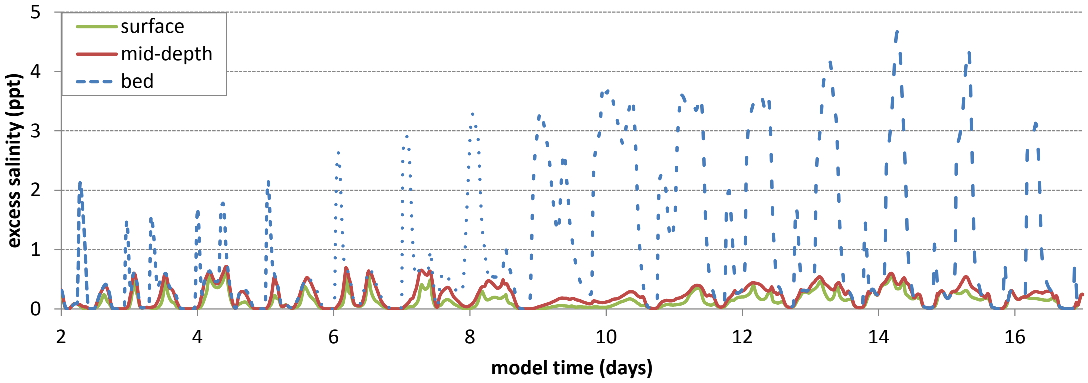

Figure C.25: Excess salinity at point A3, summer, calm, early operation

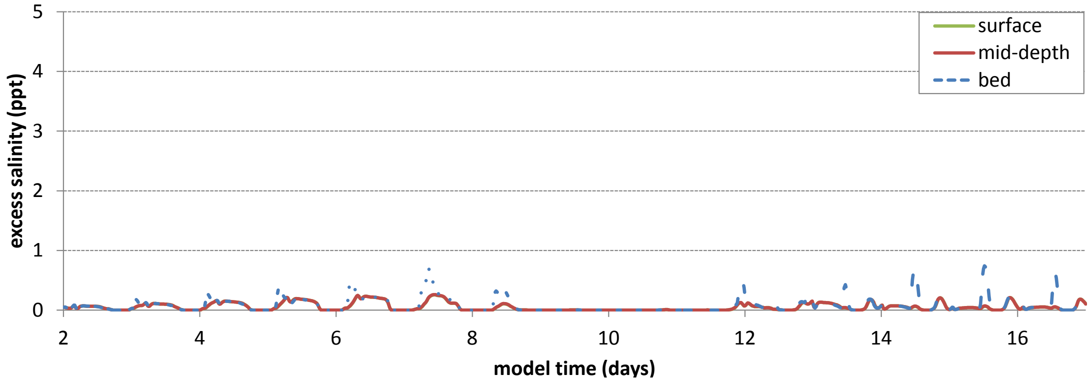

Figure C.26: Excess salinity at point A1, summer, north-west wind, early operation

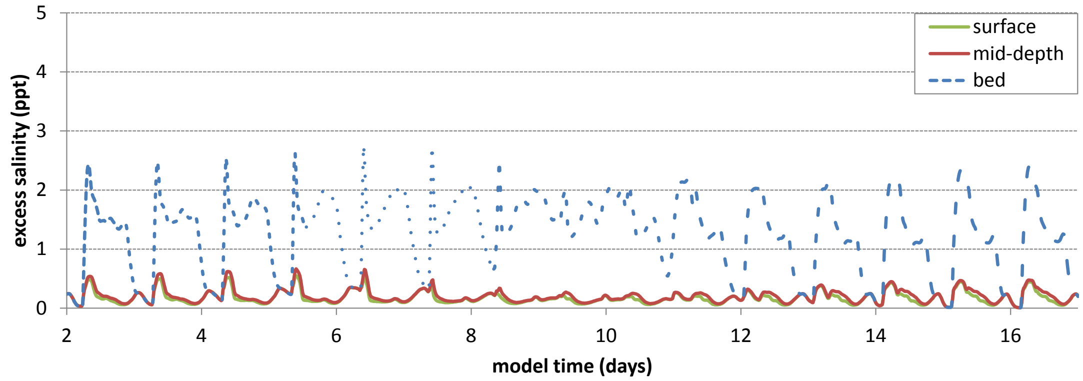

Figure C.27: Excess salinity at point A2, summer, north-west wind, early operation

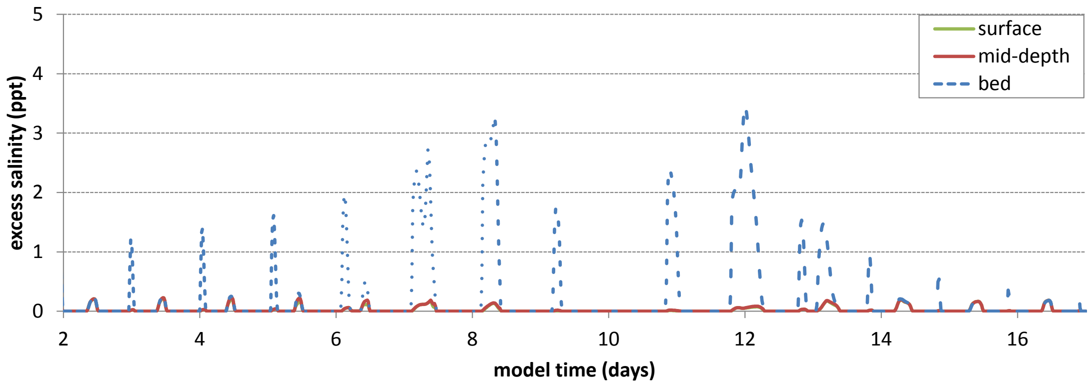

Figure C.28: Excess salinity at point A3, summer, north-west wind, early operation

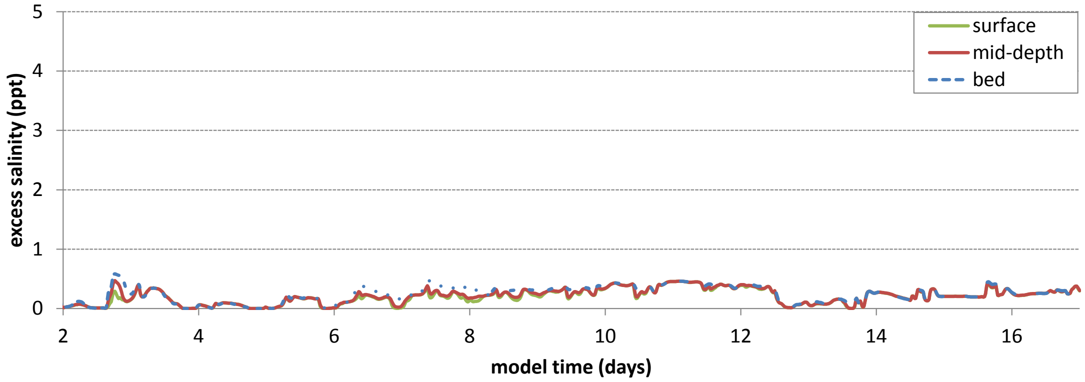

Figure C.29: Excess salinity at point A1, winter, observed wind, early operation

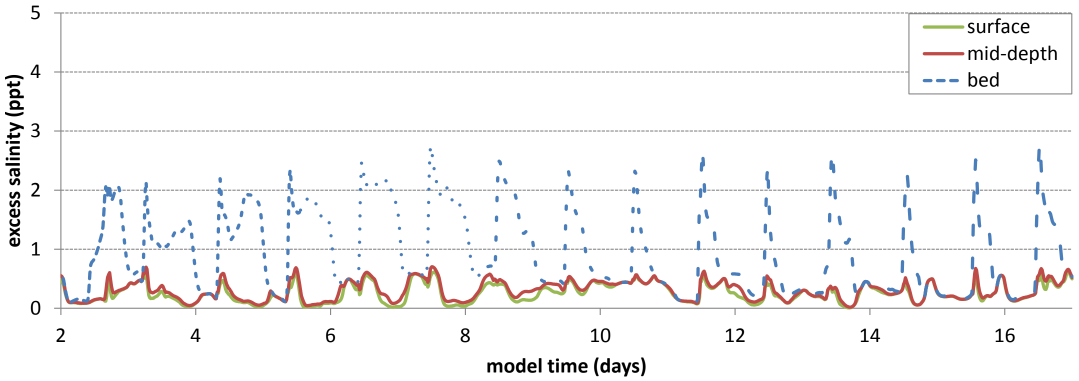

Figure C.30: Excess salinity at point A2, winter, observed wind, early operation

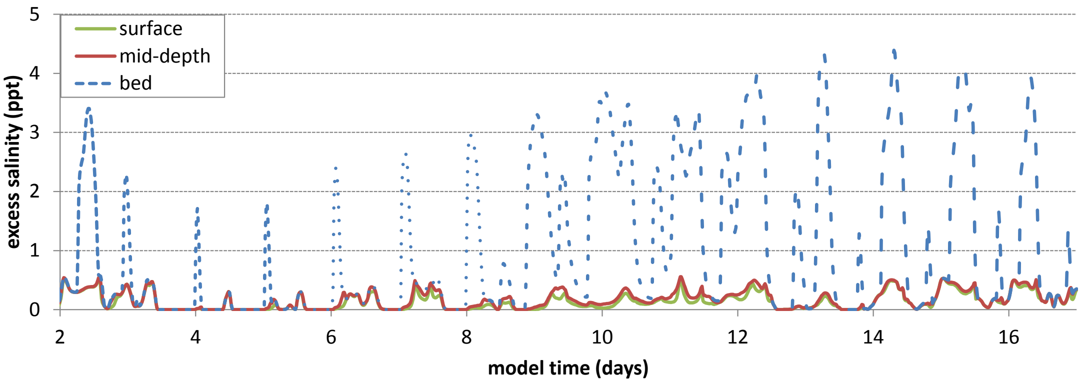

Figure C.31: Excess salinity at point A3, winter, observed wind, early operation

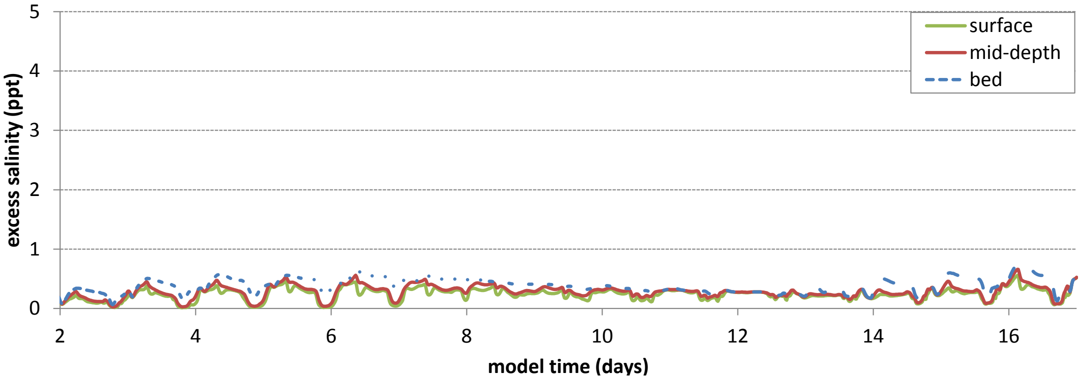

Figure C.32: Excess salinity at point A1, winter, calm, early operation

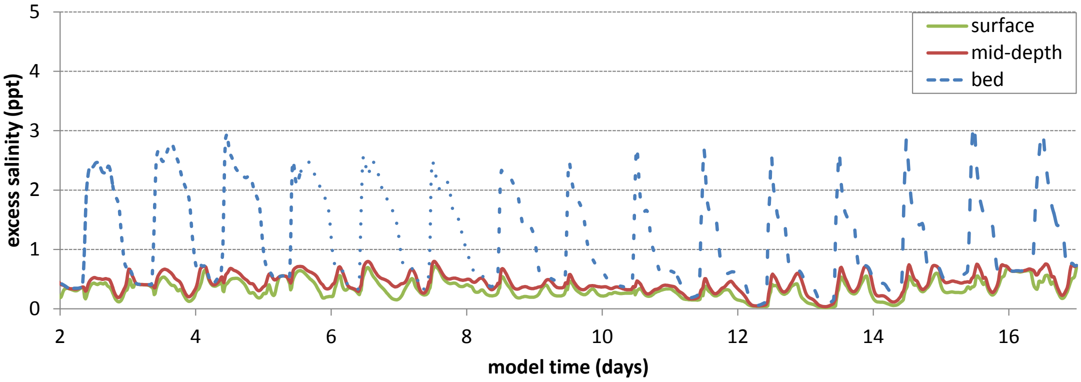

Figure C.33: Excess salinity at point A2, winter, calm, early operation

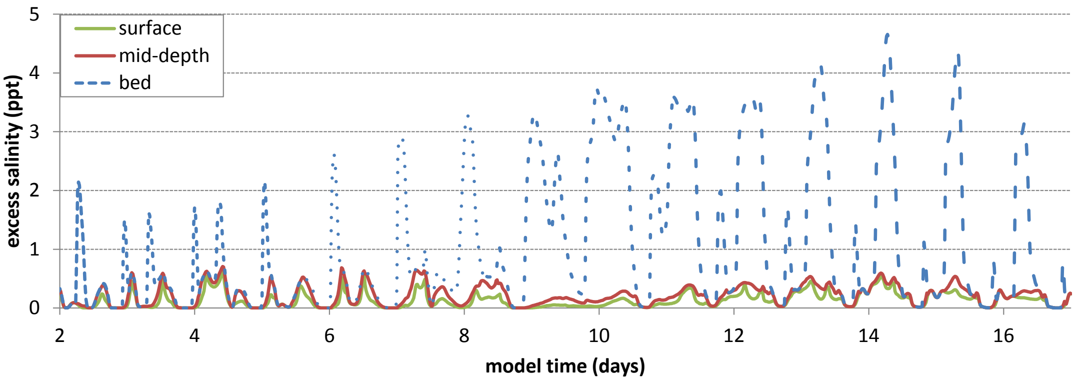

Figure C.34: Excess salinity at point A3, winter, calm, early operation

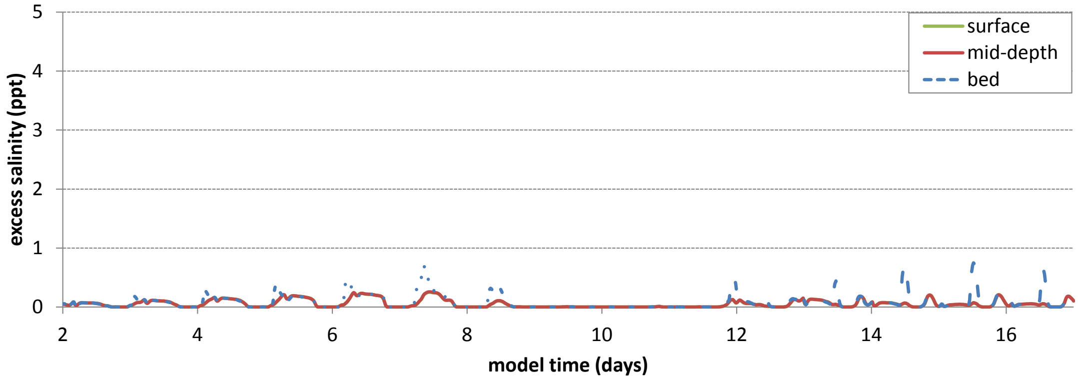

Figure C.35: Excess salinity at point A1, winter, north-west wind, early operation

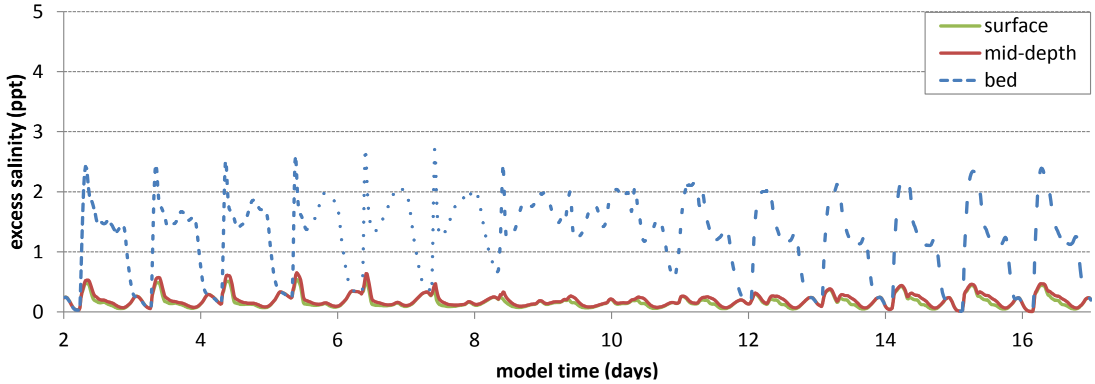

Figure C.36: Excess salinity at point A2, winter, north-west wind, early operation

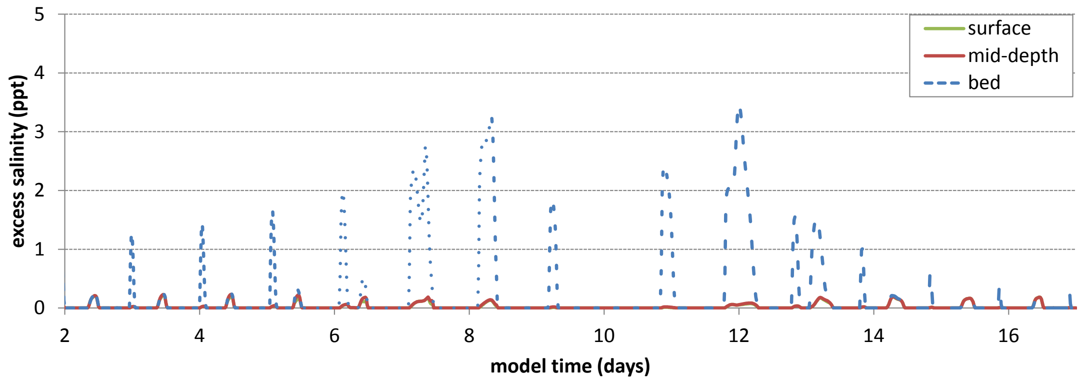

Figure C.37: Excess salinity at point A3, winter, north-west wind, early operation

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Umm Al Houl Power, Qatar

Recirculation & thermal dispersion studies: Revised layout

DKR5430-RT007-R02-00

November 2015

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1. Introduction

1.1. Background

A consortium led by Mitsubishi Corporation including Samsung C&T as EPC contractor has been awarded the construction and operation of a new Independent Water and Power Project (IWPP) known as Umm Al Houl Power (UHP), previously called Facility 'D', north of Mesaieed on the east coast of Qatar – Figure 1.1.

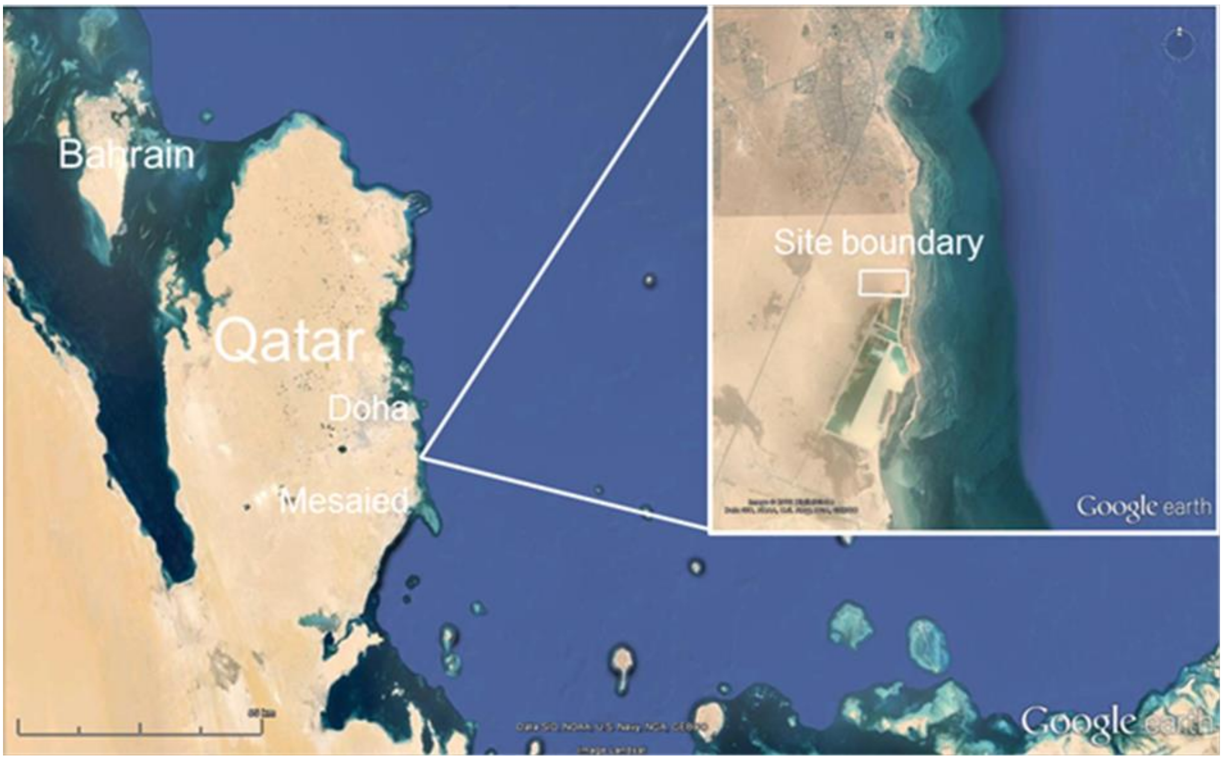

Figure 1.1: Site location

HR Wallingford is providing a range of studies to support the detailed design process and the Environmental & Social Impact Assessment (ESIA):

- Task 1 – Recirculation & thermal dispersion studies, including thermal dispersion ESIA chapter;
- Task 2 – Hydraulic design assessment for seawater intake & outfall structures;
  - Task 2a - Wave study;
  - Task 2b – Hydraulics of intake, outfall and pumping station, including transient analysis;
  - Task 2c – Scour protection for intake & outfall (conceptual design);
- Task 3 – Physical model study of pumping station;
- Task 4 – Sediment ingress & dispersion assessments;
- Task 5 – Metocean & bathymetric survey.

This report relates to Task 1 Recirculation & thermal dispersion studies and describes the investigation of the recirculation and dispersion of the thermal/saline plume from the UHP for a revised configuration of the intake and outfall structures. This report should be read in conjunction with HR Wallingford report DKR5430-RT001-R02 which includes:

- calibration of the hydrodynamic model;
- setup of the 3D dispersion model;
- recirculation and dispersion assessment of the previous intake and outfall configuration.

1.2. Report conventions

The horizontal coordinate system used throughout this report is Qatar National Grid (QNG). The vertical coordinate system is Qatar National Height Datum (QNHD) which is equivalent to mean sea level (MSL). Units are metres (m) in both dimensions.

2. Data received

Table 2.1 lists the data received that are relevant to Task 1.

Table 2.1: Relevant data received

Ref	From	Date received dd/mm/yyyy	Name	Filename	Contents
1	From surveyors MTEC	22/06/2015	Metocean Survey Al Whakrah Qatar Final Report Rev00; Data sets	307_Whakrah_Final_Report_Metocean_R01.pdf	ADCP velocity and wave data
2	From surveyors MTEC	14/05/2015	Bathymetric chart, Rev 00 12/05/2015	307_Al_Whakrah_bathymetric_chart_5k_r0.dwg	Bathymetric chart with 0.5m contours
3	From surveyors MTEC	21/05/2015	Bathymetric Survey; Al Wakrah, Qatar Final Report	307 Bathymetric survey_final_report_r0.doc	Bathymetric survey
4	Samsung C&T	22/06/2015	UHP Seawater flow rate	UHP_Seawater Flow Rate Design Data 150616.xlsx	Intake and outfall flow rates, temperature and salinity increases
5	Samsung C&T	22/06/2015	Intake head Structure	1005~1006 Intake Head Structure Sectional Details rev01.dwg	Drawings of intake head structure

Ref	From	Date received dd/mm/yyyy	Name	Filename	Contents
6	Samsung C&T	22/06/2015	Intake and discharge overall layout	1001_Intake Discharge Overall Layout_rev02.dwg	Overall layout of intake and outfalls
7	Samsung C&T	22/06/2015	Intake pipeline Plan	UHP-SCT-C00-UPZ-D-1002.dwg	Plan of intake pipeline
8	Samsung C&T	22/06/2015	Intake pipeline section	UHP-SCT-C00-UPZ-D-1021.dwg	Sections through intake pipelines
9	Samsung C&T	22/06/2015	Intake pipeline Profile	UHP-SCT-C00-UPZ-D-1022-1023.dwg	Longitudinal profile along intake pipelines , showing protection.
10	Samsung C&T	22/06/2015	Discharge pipeline sections	1010~1011 Discharge Pipeline Sectional Details(1).dwg	Sections through discharge pipelines
11	Samsung C&T	22/06/2015	Diffuser	1012 Discharge Pipeline Sectional Details(3).dwg	Details of outfall diffuser
12	Samsung C&T	22/06/2015	Discharge pipeline profile	1013-1014 Discharge Pipeline profile.dwg	Longitudinal profile along discharge pipelines , showing protection.
13	Samsung C&T	9/09/2015	Design change in armouring	Sept092015 Design change in armouring.pptx	Changes in armouring of intake and outfall pipelines
14	Samsung C&T	5/10/2015	Revised intake and discharge overall layout	UHP-SCT-C00-UPZ-D-1001_GENERAL ARRAGEMENT INTAKE&DISCHARGE KEY PLAN_Rev.B.pdf	Overall layout of intake and outfalls – revised layout
15	Samsung C&T	5/10/2015	Revised intake pipeline	UHP-SCT-C00-UPZ-D-Intake Pipeline Total.pdf	Plan of intake pipelines, sections and longitudinal profile – revised layout

Ref	From	Date received dd/mm/yyyy	Name	Filename	Contents
16	Samsung C&T	5/10/2015	Revised outfall pipeline	UHP-SCT-C00-UQZ-D-Discharge Pipeline Total.pdf	Plan of discharge pipelines, sections and longitudinal profile – revised layout

3. Layout

The difference between the revised and previous intake and outfall configurations relates to the rock armouring over the pipelines. The proposed locations of the intake and outfall are shown in Figure 3.1 and are unchanged from the previous layout. The intake will be located offshore at the end of a 2500 m long pipeline, where the bed level is approximately -5.5 m QNHD. A submerged outfall will be located at the end of a 2000 m long pipeline, with a diffuser located at a sea bed elevation of approximately -4.0 to -4.5 m QNHD.

Samsung provided concept drawings of the pipeline armouring (Reference 13, Table 2.1) and these were updated based on detailed longitudinal drawings of the pipelines (References 15 and 16, Table 2.1). The revised profiles of the intake and outfall pipeline armouring are shown in Figure 3.2 and Figure 3.3 respectively. The crest of the rock armouring over the intake pipeline will be at +1.36 m QNHD from the shoreline to around 1200 m offshore and at the level of the natural sea bed elevation for the remaining 1300 m. The crest of the rock armouring over the outfall pipeline will be at +1.36 m QNHD.

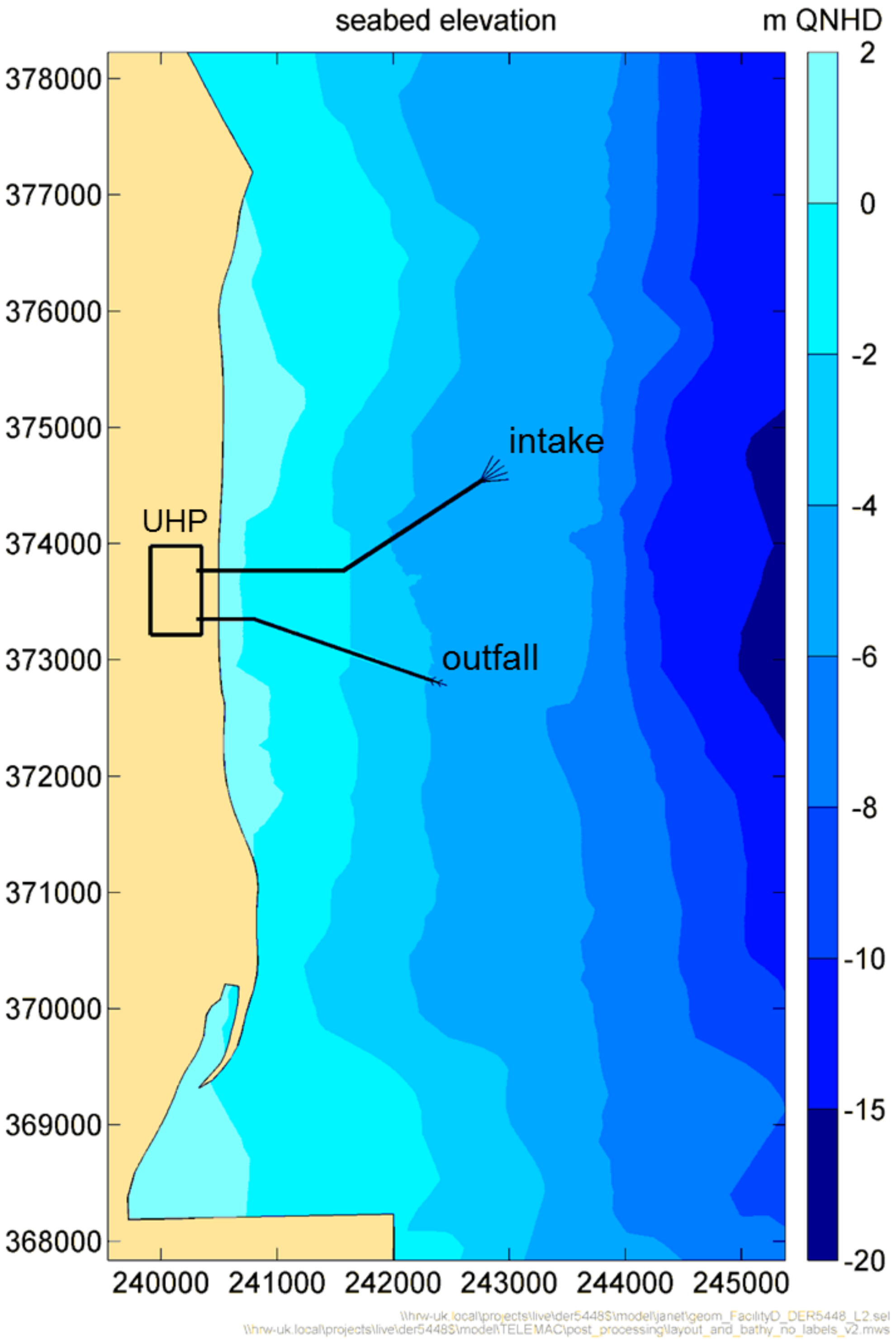

Figure 3.1: Intake and outfall locations

Source: Samsung C&T

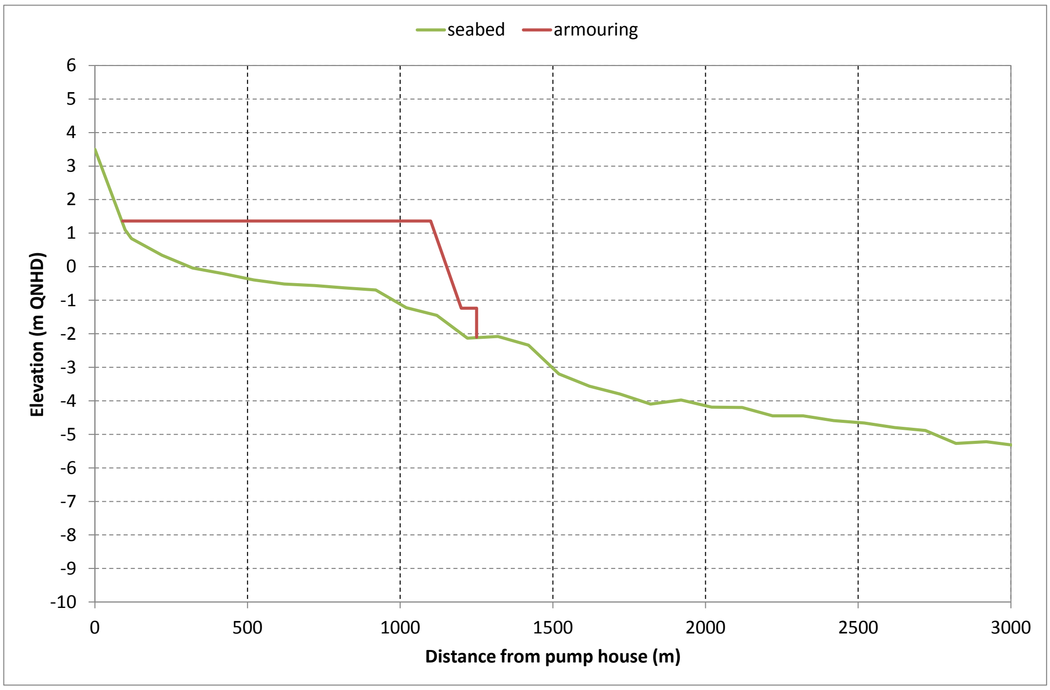

Figure 3.2: Profile of intake armouring

Source: Samsung C&T

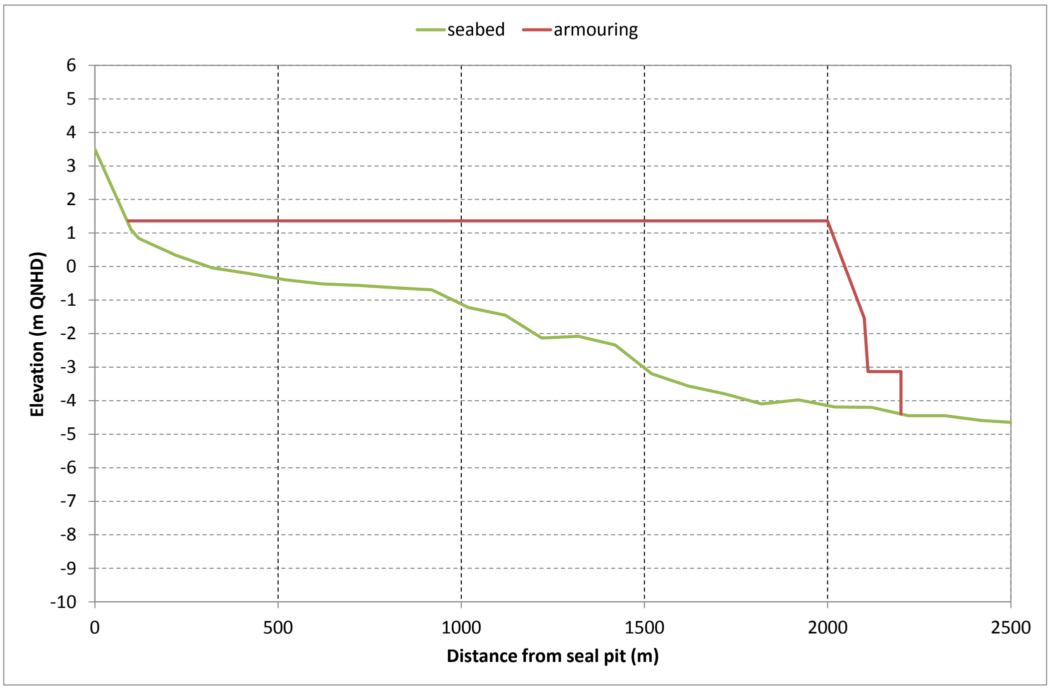

Figure 3.3: Profile of outfall armouring

Source: Samsung C&T

4. Model configuration

The calibrated TELEMAC-3D model used for the previous layout was updated to incorporate the revised intake and outfall pipeline armouring. The updated model bathymetry is shown in Figure 4.1. The vertical and horizontal mesh structure were unchanged.

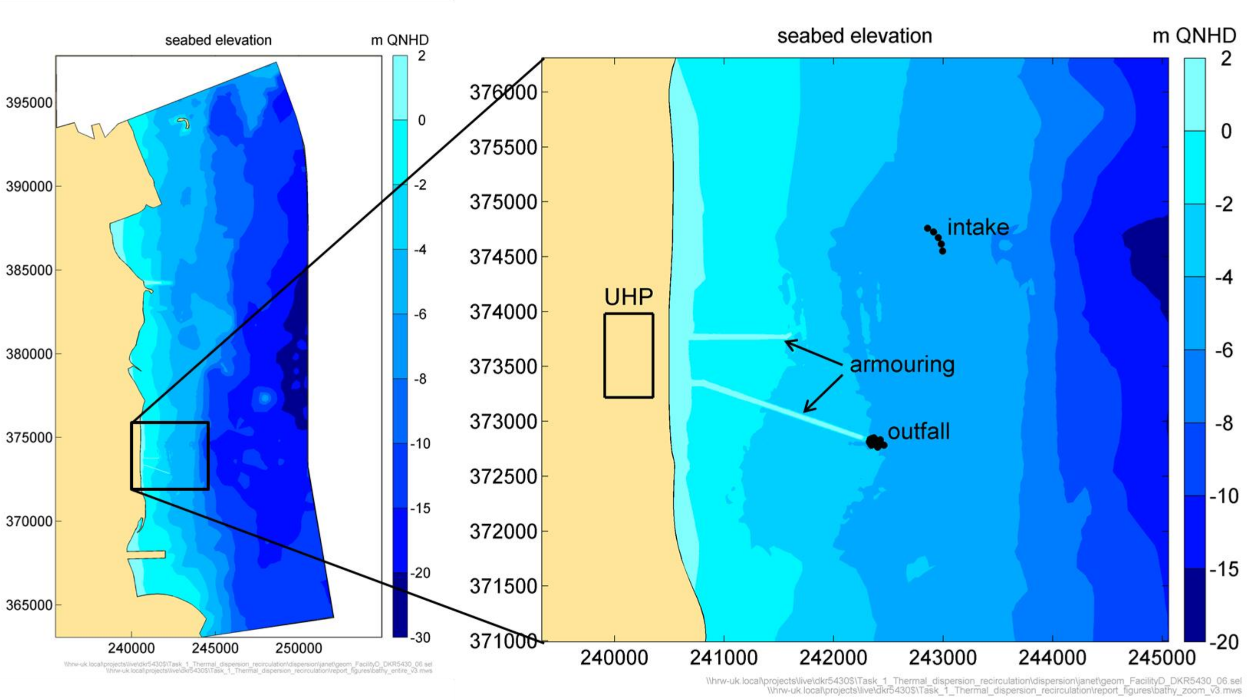

Figure 4.1: Model bathymetry – full extent and in the vicinity of the site

The boundary conditions developed for the calibration of the hydrodynamic model (see report DKR5430-RT001-R02) were used in all simulations. These conditions include a spring-neap cycle with the smallest neap tides between days 8 and 12 and the largest spring tides between day 14 and the end of the simulation (see Figure 4.2).

The intake and outfall were represented with the same method used for the previous layout. This included using no initial dilution based on the proposed outfall diffuser design. Two operating phases were again considered for the IWPP: a standard operational phase when cooling water will be required for the full power plant and all the desalination plants are in operation, and an early operational phase when only the Reverse Osmosis (RO) plant will be in operation with auxiliary cooling for a gas turbine generator.

Six environmental conditions were simulated for each operating phase. These were identified earlier in the study for the previous layout and were applied with the same parameters. The conditions are:

- Summer sea temperature with observed winds;
- Summer sea temperature under calm conditions;
- Summer sea temperature with a constant 6 m/s wind from north-west;
- Winter sea temperature with observed winds;
- Winter sea temperature under calm conditions;
- Winter sea temperature with a constant 6 m/s wind from north-west.

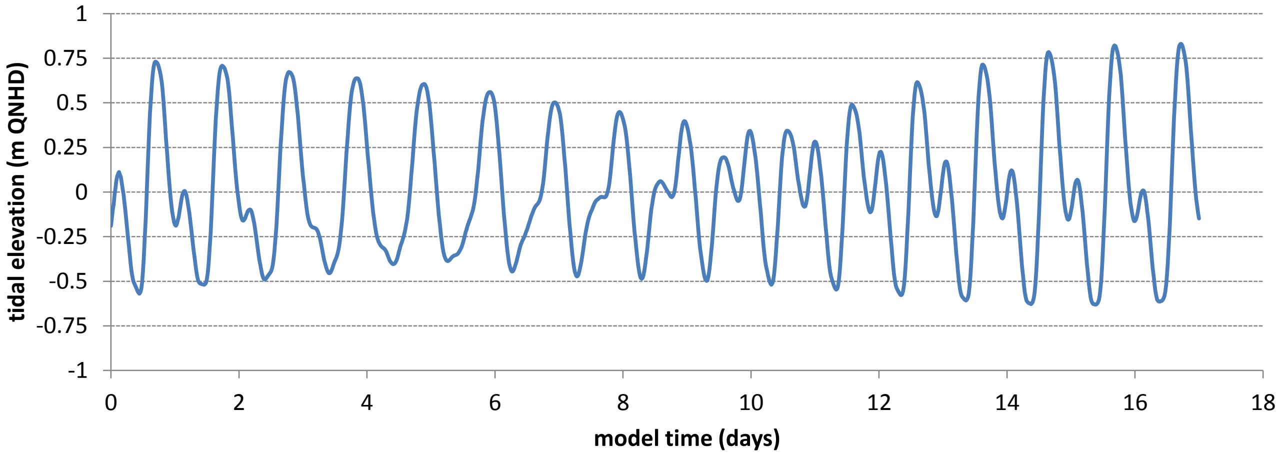

Figure 4.2: Model tidal elevation at the intake

5. Results

The dispersion of the IWPP saline and heated water was simulated under the six environmental conditions described in the previous chapter for the standard operational phase and the early phase of the plant (a total of twelve simulations). The simulations were run for 17 days to include a full spring-neap tidal cycle (15 days) plus an initial two days to allow the model to stabilize.

The change to the pipeline armouring will affect the currents in the vicinity of the site. Simulated peak ebb and peak flood depth-averaged currents are shown in Figure 5.1 for a representative tide (day 12 to 13). The pipeline armouring forms a blockage to the flow causing a larger region of weak currents (< 0.1 m/s) to form. At the offshore end of the outfall pipeline the flows are accelerated.

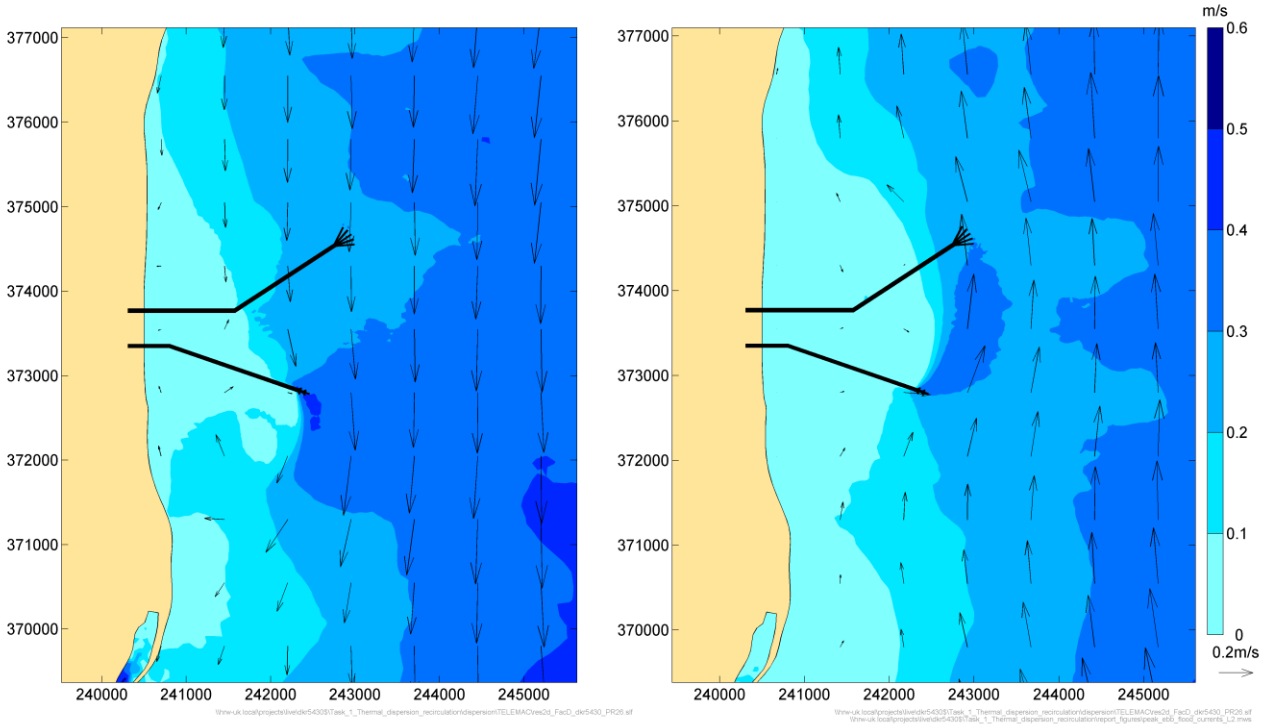

Figure 5.1: Simulated peak flood (left) and peak ebb (right) depth-averaged currents

5.1. Standard operation phase

The predicted maximum and average sea surface and sea bed excess temperatures were calculated over the last 15 days of the simulations. These are shown as contour plots in Figure 5.2 to Figure 5.7 for the standard operation phase. The 3°C temperature contour is at the boundary between the yellow and blue areas. The mean 3°C mixing zones are at most 2 km across, and the maximum 3°C mixing zones extend around 4-8 km alongshore and 3-4 km offshore. The increase in salinity is predicted to be less than 10% of the ambient salinity everywhere in the model throughout the simulations. As this means that the excess salinity is never predicted to exceed the environmental threshold, contour plots of the excess salinity for the standard operation phase are not shown in the main body of the report, but are included in Appendix A for completeness.

The excess temperatures and excess salinities show more similar patterns at the sea surface and the sea bed during summer conditions than during winter conditions. This is because in summer the discharge is almost neutrally buoyant. The increase in density between the ambient and the discharge is marginally larger in winter and therefore the plume sinks towards the seabed during these simulations. The wind from north-west generally reduces the plume extent northwards and offshore. The footprint of excess temperature is larger under calm conditions due to reduced atmospheric cooling.

The MoE regulations state that the size of the 3°C mixing zone should be determined from the ‘integrated vertical front’. This is understood to be the depth-averaged excess temperature. Mixing zone areas calculated for the six simulated environmental conditions are shown in Table 5.1 along with the mixing zone areas for the previous layout. The areas were calculated from time-averaging the depth-averaged excess temperature over 15 days and are generally smaller for the revised layout (0.04 km^2 to 0.06 km^2). This is because the outfall pipeline armouring generates faster currents at the outfall and thus increases the mixing of the effluent with ambient seawater.

Table 5.1: Areas over which the time-averaged and depth-averaged excess temperature exceeds 3°C under standard operation

	Previous layout		Revised layout	
	Area (m^2)	Area (km^2)	Area (m^2)	Area (km^2)
Summer, observed wind	81710	0.08	36989	0.04
Summer, calm	129960	0.13	55039	0.06
Summer, north-west wind	68723	0.07	39180	0.04
Winter, observed wind	54260	0.05	35626	0.04
Winter, calm	84415	0.08	49424	0.05
Winter, north-west wind	47188	0.05	51329	0.05

Mott MacDonald has identified sensitive habitats in the vicinity of the UHP site, particularly seagrasses and mixed oyster beds. In the dense seagrass region to the west of the outfall the excess temperatures for the revised layout are predicted to reach up to 4°C with an average of around 1°C. This is higher than was predicted for the previous layout by around 2°C in maximum values and 0.5°C on average. Excess salinities at the same location are predicted to reach up to 3 ppt with average values of around 1 ppt. These values are similar to those predicted for the previous layout.

The excess temperatures and salinities predicted at nearby mixed oyster bed habitats are similar to those for the previous layout.

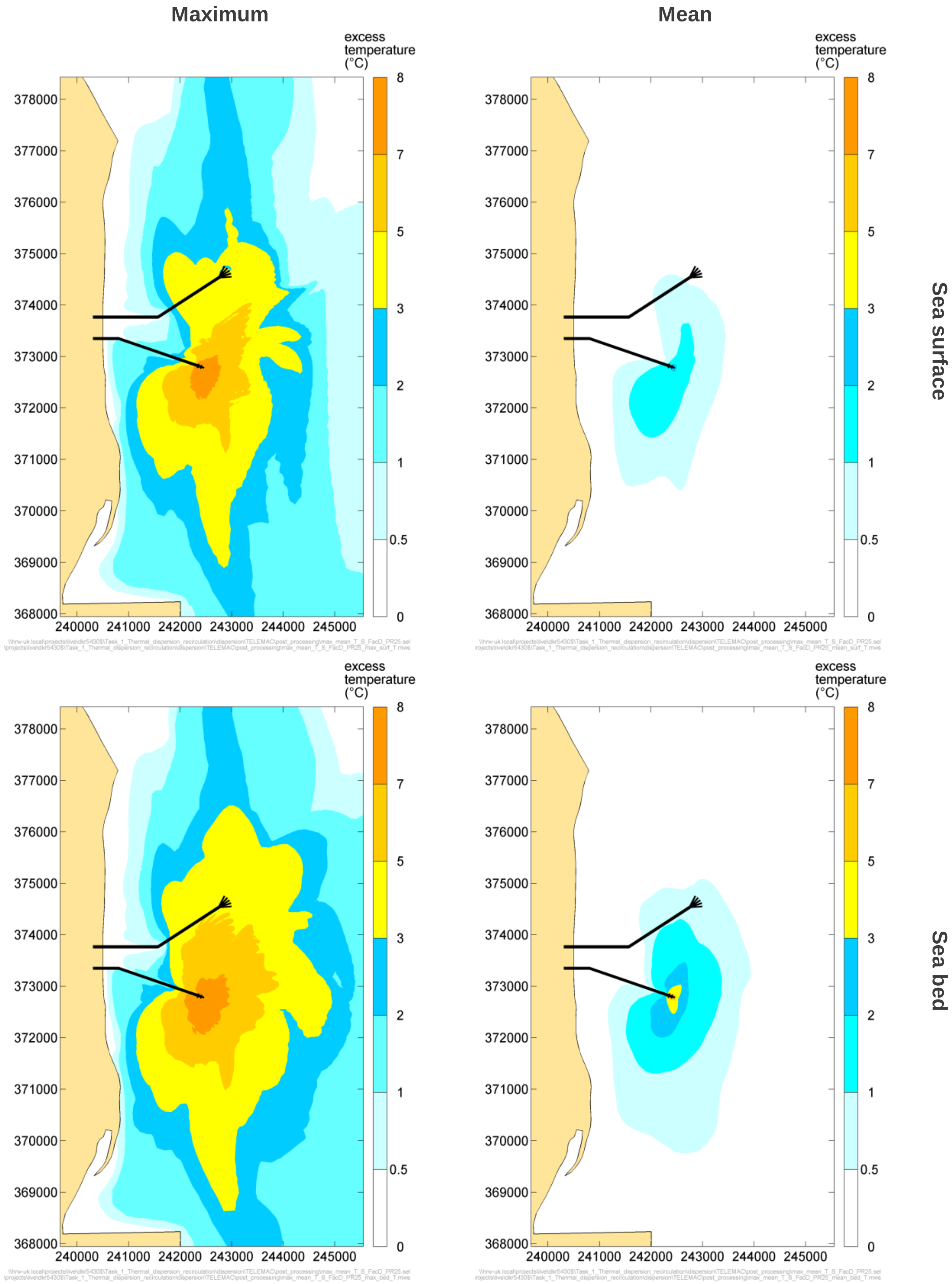

Figure 5.2: Maximum and mean sea surface and sea bed excess temperature, summer, observed wind, standard operation

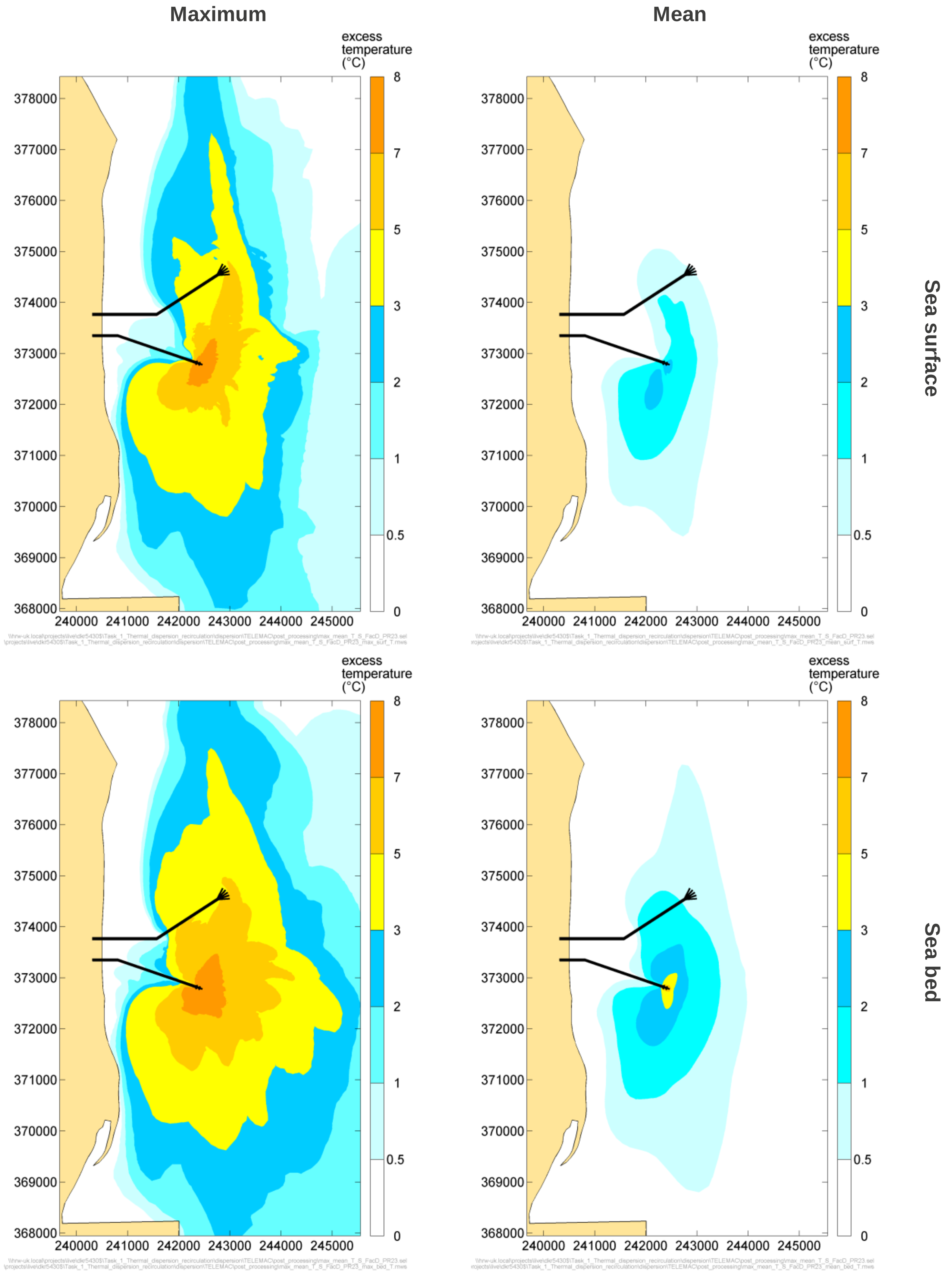

Figure 5.3: Maximum and mean sea surface and sea bed excess temperature, summer, calm, standard operation

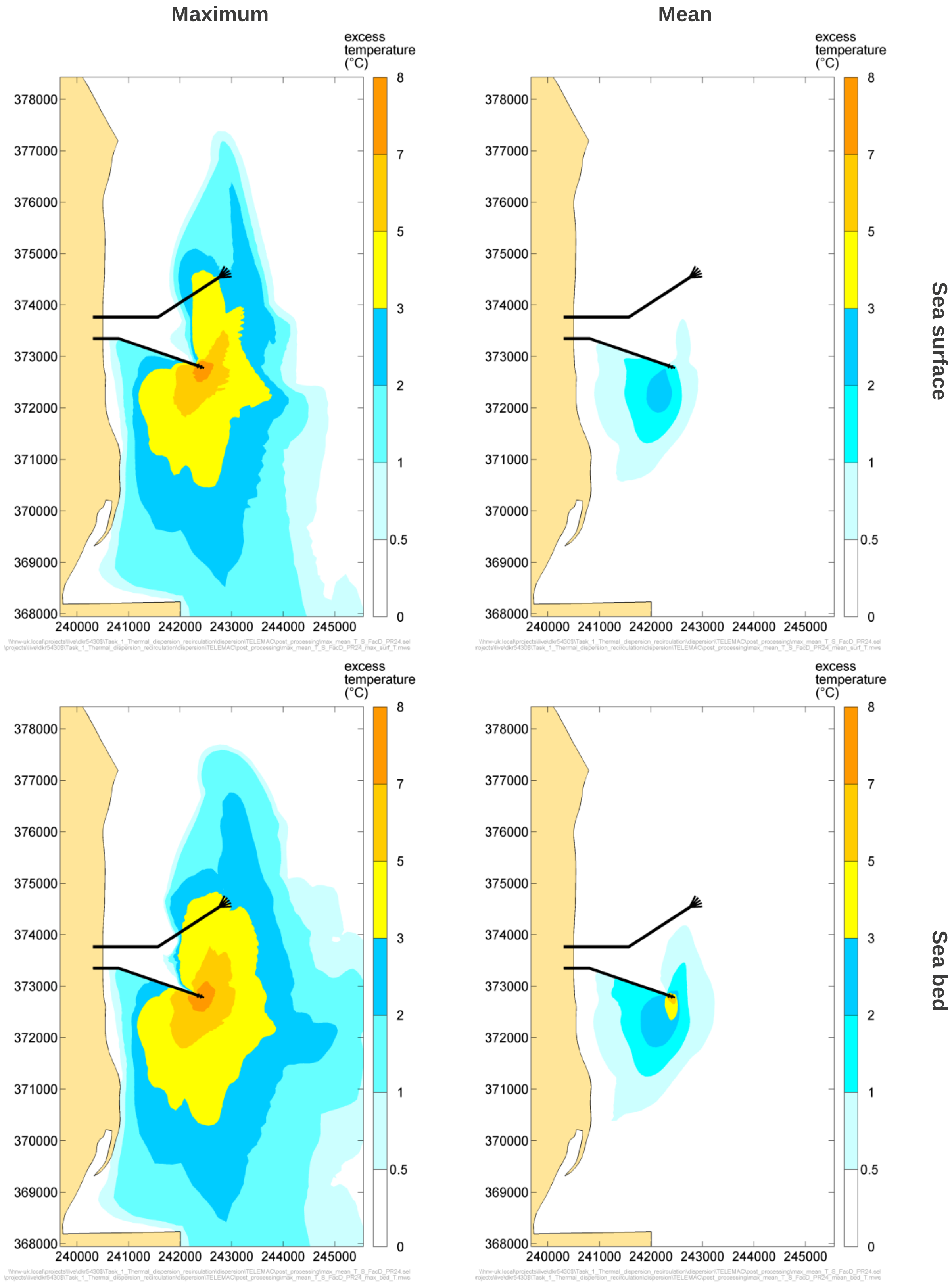

Figure 5.4: Maximum and mean sea surface and sea bed excess temperature, summer, north-west wind, standard operation

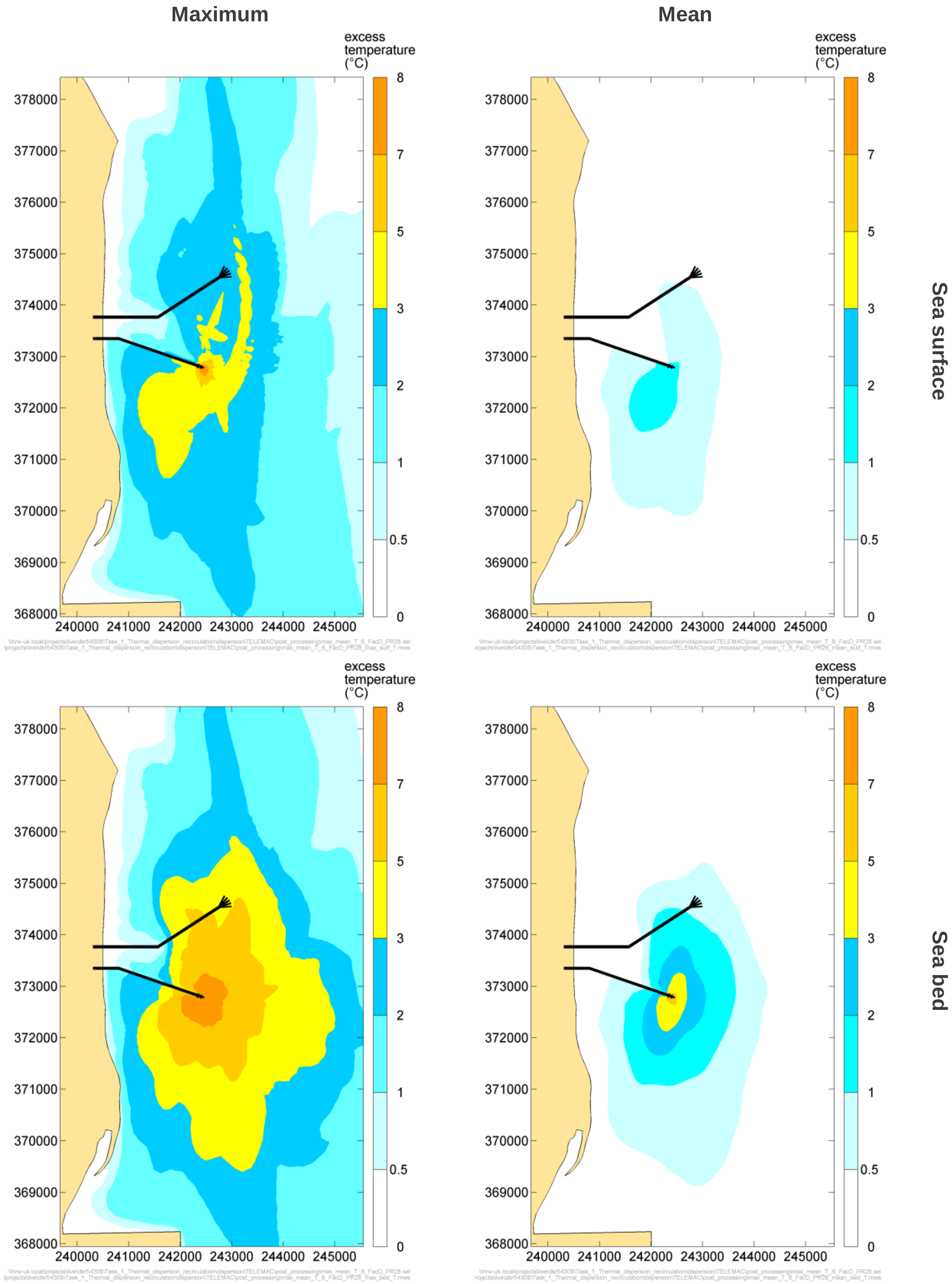

Figure 5.5: Maximum and mean sea surface and sea bed excess temperature, winter, observed wind, standard operation

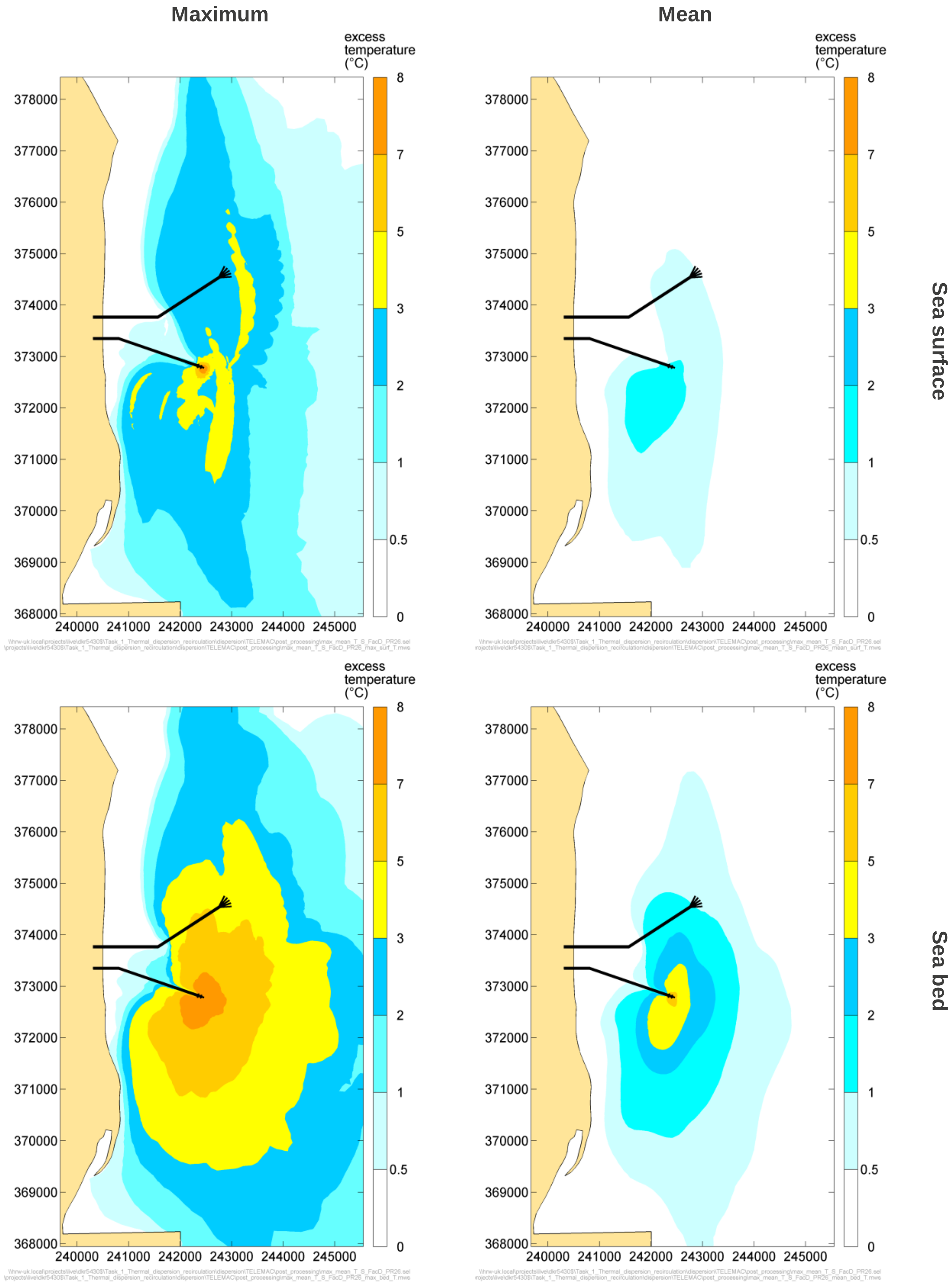

Figure 5.6: Maximum and mean sea surface and sea bed excess temperature, winter, calm, standard operation

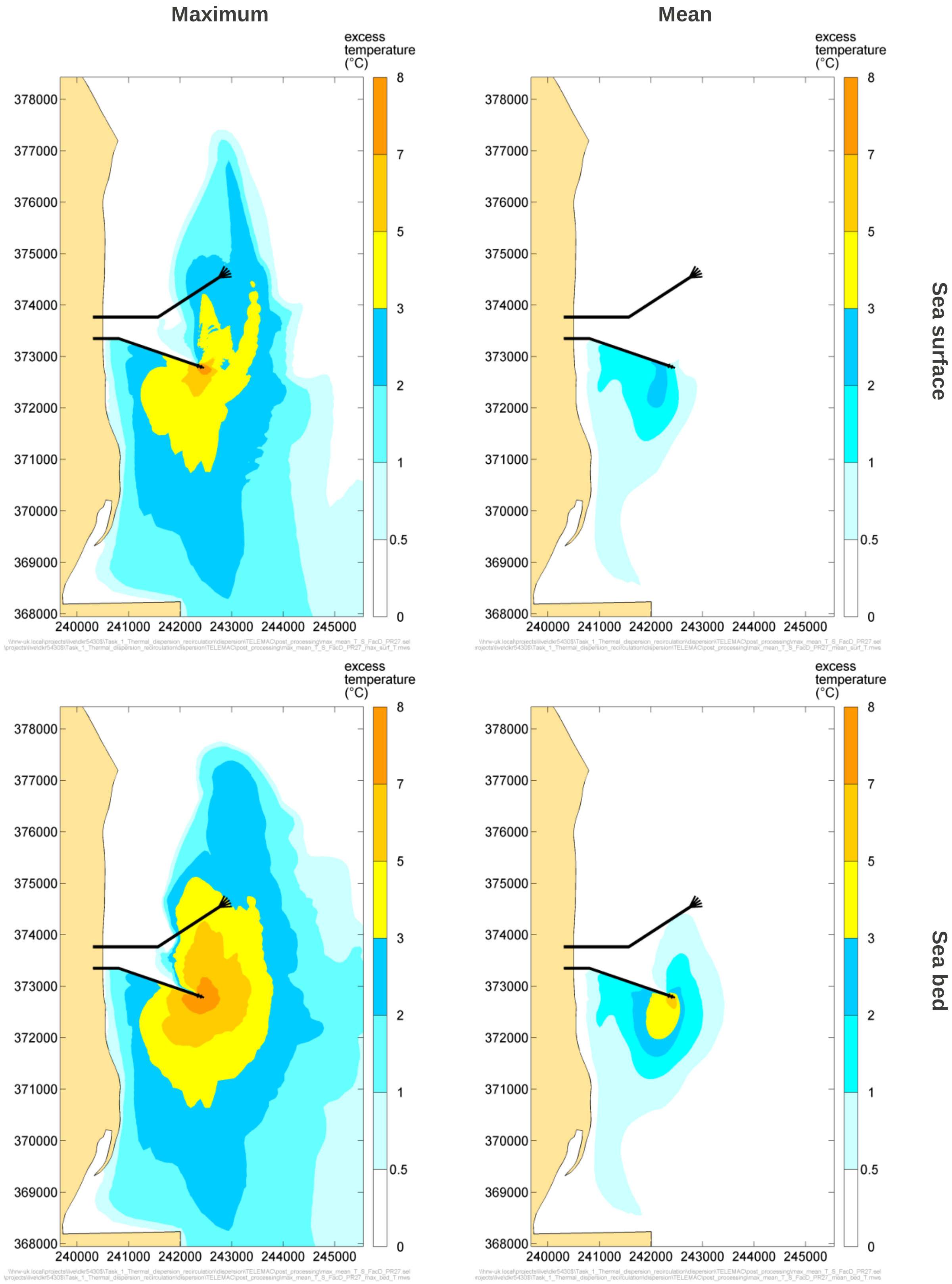

Figure 5.7: Maximum and mean sea surface and sea bed excess temperature, winter, north-west wind, standard operation

5.2. Early operation phase

Figure 5.27 to Figure 5.32 show contour plots of the maximum and mean sea surface and sea bed excess salinities for the early operation phase simulations. The extent of the 5 ppt mixing zone (approximately 10% of the background salinity) is marked by the boundary between the blue and the light green colours. The region where the maximum sea bed excess salinity is above 5 ppt extends around 2 km alongshore and 1 km offshore. Contour plots of the excess temperatures for the early operation phase are given in Appendix A, as the excess temperature is less than the environmental limit of 3°C at all times throughout the simulations.

The high density of the early operation phase discharge results in larger plume footprints at the sea bed than at the sea surface. Summer and winter ambient conditions give similar results in terms of plume extent. Results from the simulations with calm conditions and the observed wind condition are similar. This is because the observed winds are weak - around 3 m/s on average (see previous report). The stronger constant wind from north-west has more effect on the plume dispersion and reduces marginally the overall plume footprint.

The areas where average excess salinity at the sea bed is more than 10% (4.6 ppt) above the background salinity have been calculated. The results are shown in Table 5.2 for the previous and revised layouts. The area is found to be around 0.1 km^2 for both layouts and all conditions.

Table 5.2: Areas over which the time-averaged sea bed excess salinity exceeds 4.6 ppt during early operation phase

	Previous layout		Revised layout	
	Area (m^2)	Area (km^2)	Area (m^2)	Area (km^2)
Summer, observed wind	121942	0.12	122297	0.12
Summer, calm	127823	0.13	131658	0.13
Summer, north-west wind	60121	0.06	61209	0.06
Winter, observed wind	122699	0.12	122662	0.12
Winter, calm	128583	0.13	131461	0.13
Winter, north-west wind	59508	0.06	61837	0.06

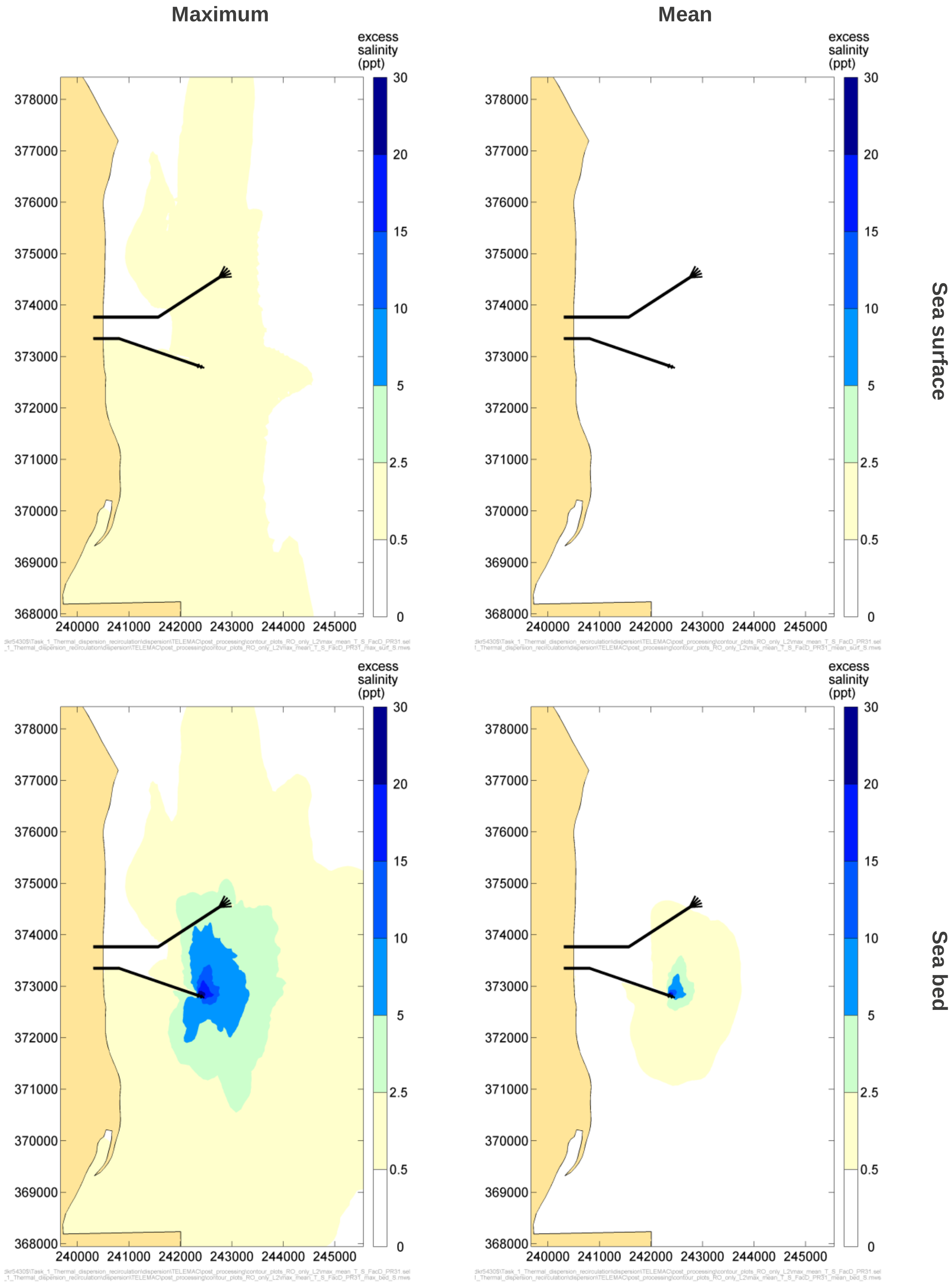

Figure 5.8: Maximum and mean sea surface and sea bed excess salinity, summer, observed wind, early operation

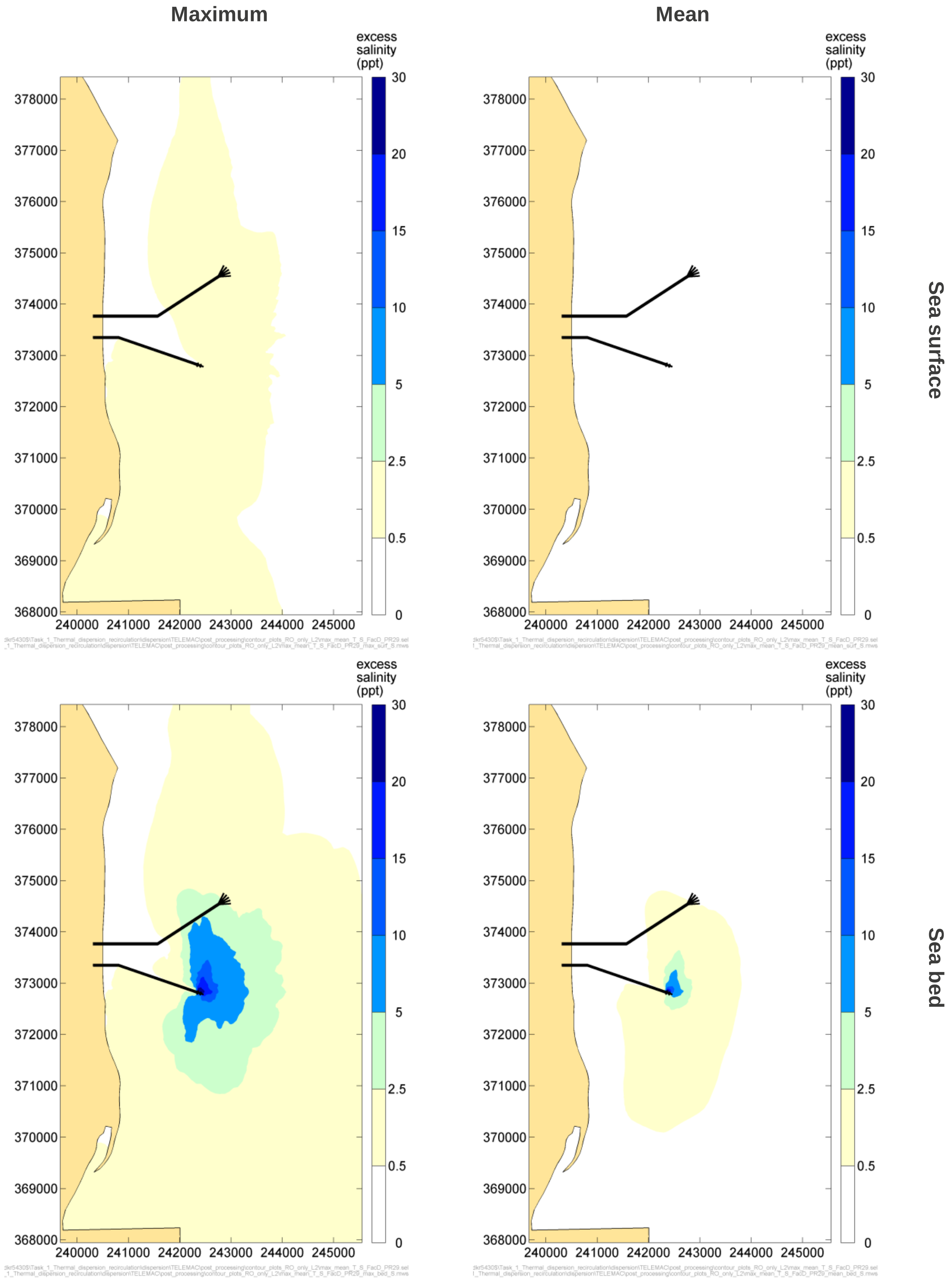

Figure 5.9: Maximum and mean sea surface and sea bed excess salinity, summer, calm, early operation

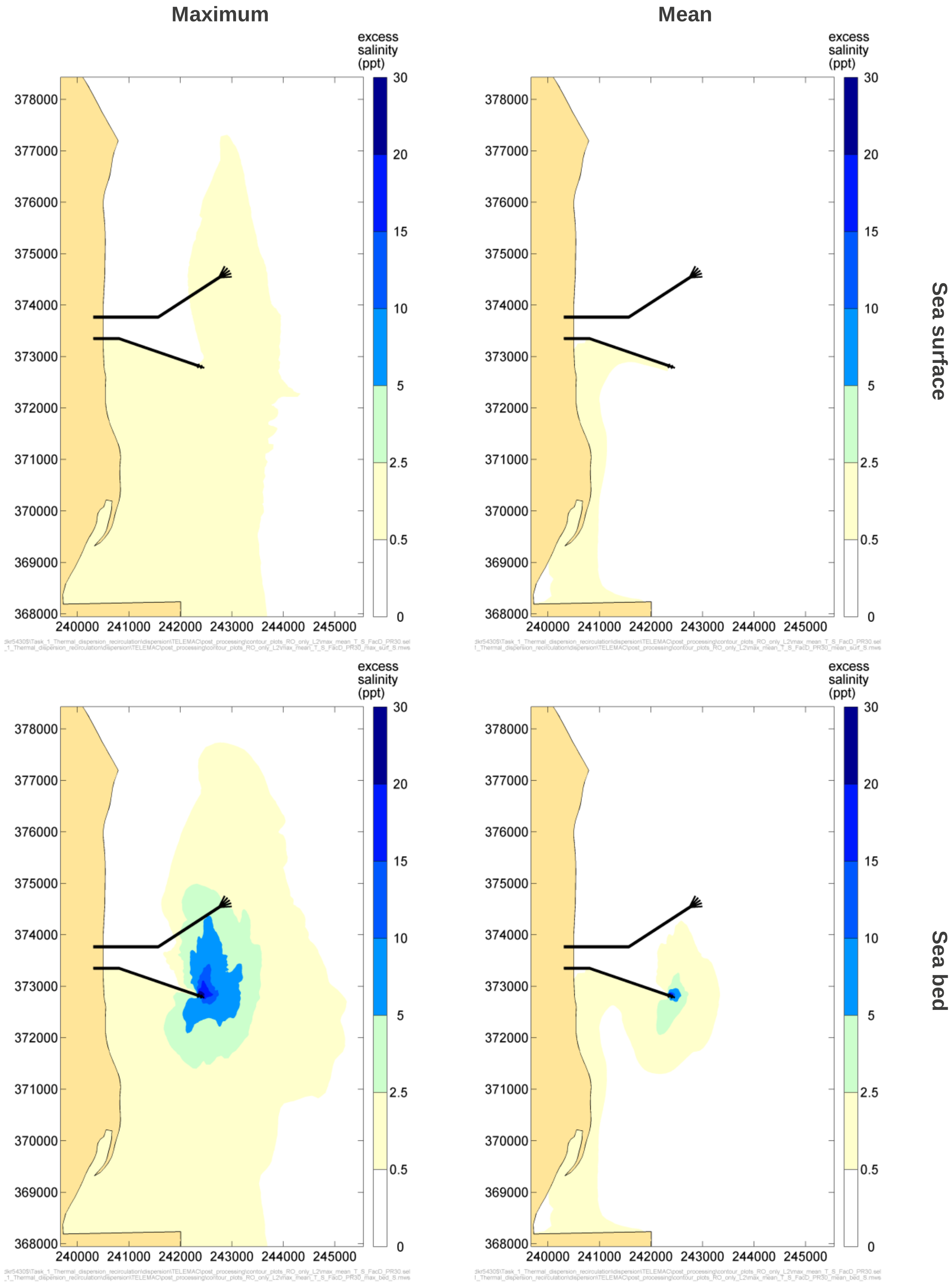

Figure 5.10: Maximum and mean sea surface and sea bed excess salinity, summer, north-west wind, early operation

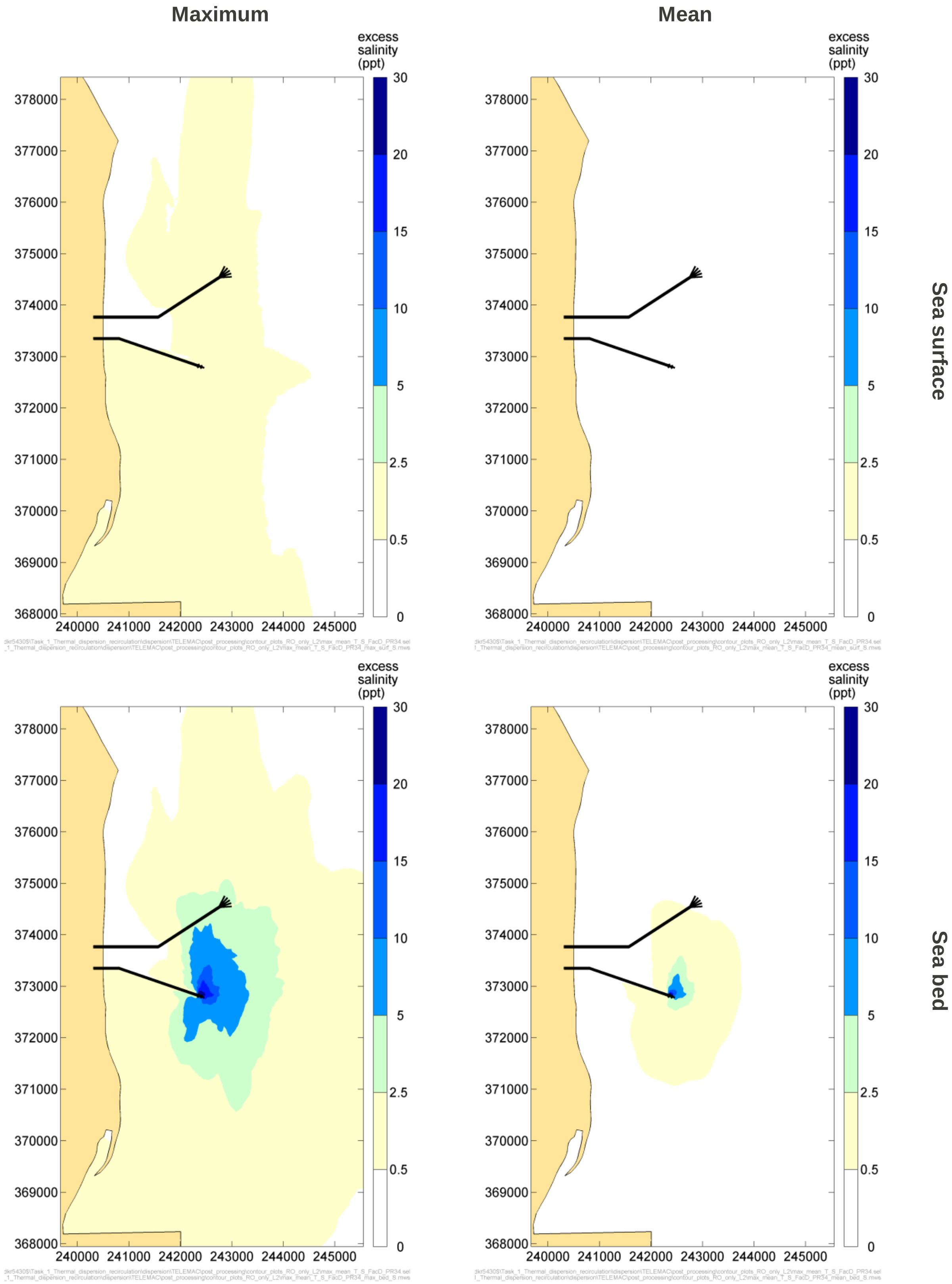

Figure 5.11: Maximum and mean sea surface and sea bed excess salinity, winter, observed wind, early operation

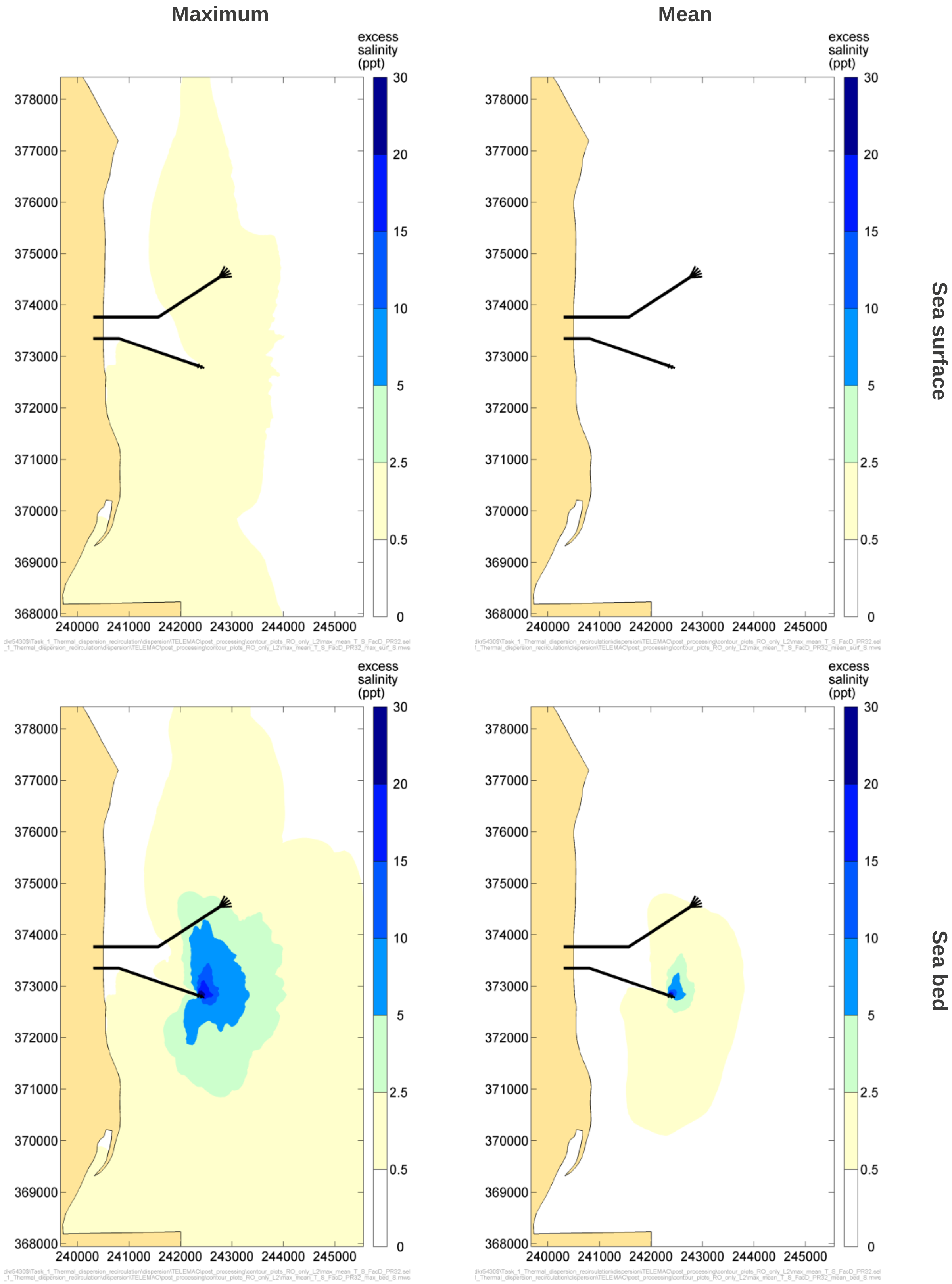

Figure 5.12: Maximum and mean sea surface and sea bed excess salinity, winter, calm, early operation

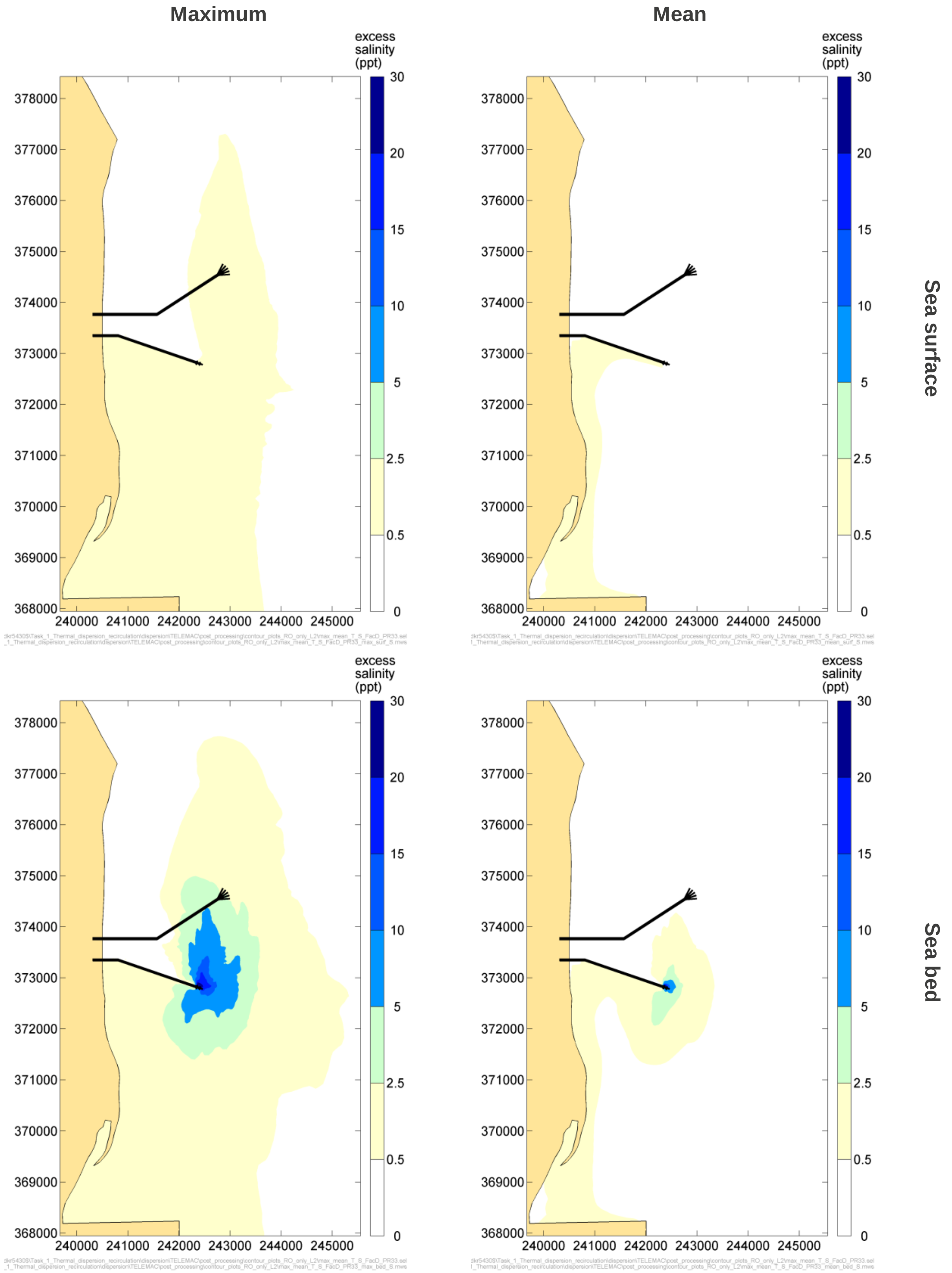

Figure 5.13: Maximum and mean sea surface and sea bed excess salinity, winter, north-west wind, early operation

5.3. Recirculation assessment

5.3.1. Recirculation during standard operation phase

During the standard operation phase five intake pipelines will be operational with the most southerly pipeline drawing seawater for desalination and the other four pipelines drawing cooling water for power generation (Figure 5.14). In the previous study recirculation values were similar at each intake and were reported for a single representative intake location. For the revised layout there is a variation in recirculation across the intakes. Therefore results are presented separately for the RO intake and the cooling water (CW) intakes. The results at the CW intakes are an average of the values at the four individual intakes.

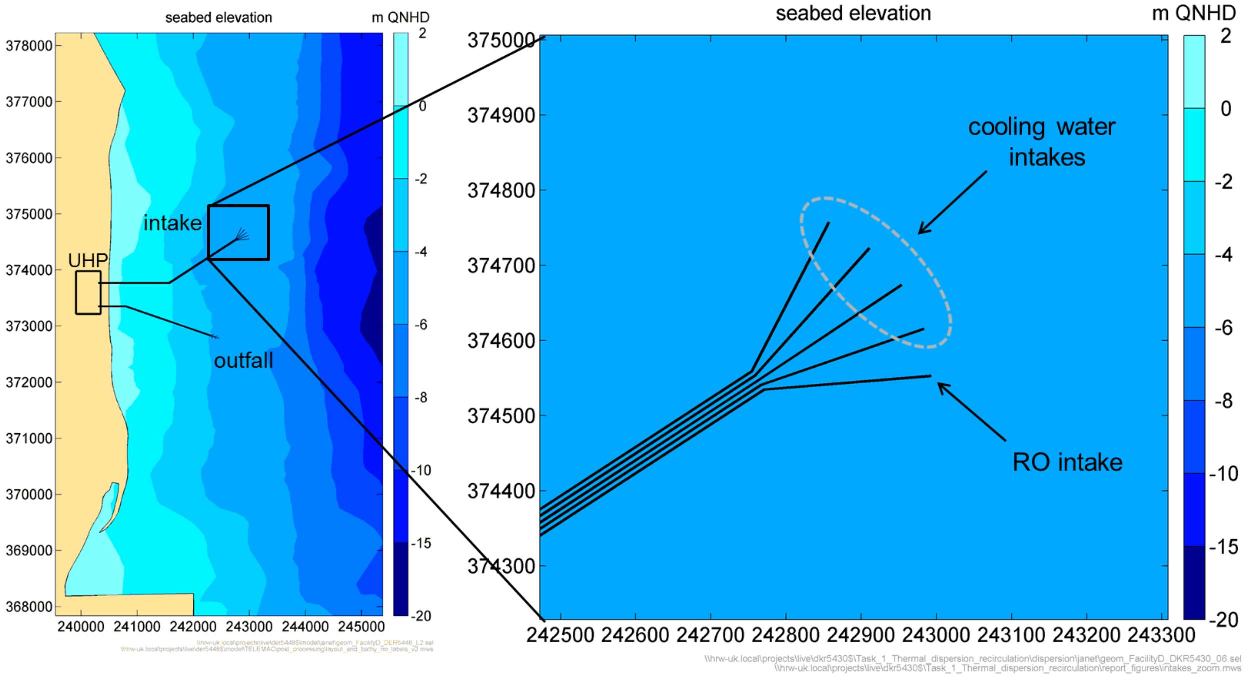

Figure 5.14: Intake streams

Table 5.3 to Table 5.6 show the maximum and average excess temperatures and salinities at the CW intakes. Recirculation values are highest under calm conditions with maximum temperatures of up to 4°C. This layout performs better in terms of peak recirculation temperatures at the CW intakes than the previous layout where peaks of up to around 6°C were predicted. The average excess temperature is less than 1°C in all simulations. This is similar to the average excess temperature at the intakes for the previous layout. Maximum excess salinities at the CW intakes are less than 3 ppt for all conditions. Average excess salinities are low and generally less than 0.5 ppt.

The maximum and average excess temperature and salinities at the RO intake are shown in Table 5.7 to Table 5.10. The average excess temperatures and salinities are similar to those predicted at the CW intakes. The maximum values are predicted to be higher, with maximum excess temperatures up to 5.5°C and maximum excess salinities up to 3.7 ppt.

Time series of excess temperatures and excess salinities at the CW intakes are presented in Figure 5.15 to Figure 5.20 for the standard operation phase simulations. The time series for the observed wind and calm conditions are broadly similar with a sequence of peaks of around 8-10 hours' duration generated during the north-going ebb phase of the tide. Recirculation is reduced by the north-west wind condition as the plume is transported further south, away from the intake.

Time series of excess temperatures and salinities at the RO intake are shown in Figure 5.21 to Figure 5.26. They indicate higher peak recirculation values than at the CW intakes.

At the RO intake, the peak excess temperatures and salinities under calm conditions and with observed wind occur around days 8 to 10 of the simulations during neap tides. There is a period during these tides when the flood tide stops and briefly changes direction. This allows the discharge plume to remain close to the outfall for a longer period than predicted during other tides, forming a 'slack-water pool'. The following ebb then carries this 'pool' directly northwards towards the intakes, giving rise to the high excess temperatures and salinities.

The presence of wind appears to mitigate this effect, particularly during periods of north-west winds. For the case with the observed wind, even though the wind speed during this period is low (around 2 m/s), the excess temperature at the intakes is reduced by up to 1.7°C at the RO intake compared to the calm case. Wind speeds less than 2 m/s ('calm' conditions) occur for about 10% of the time, and neap tides that could form similar slack water pools occur roughly two to four times a month (say 10% of the tides). It is therefore estimated that the peak excess temperatures predicted under calm conditions are likely to occur for less than 1% of the tides during a year. Analysis of the time series data shows that these peak events are likely to occur for much less than 1% of the period modelled under calm conditions, therefore it can be further estimated that peak excess temperatures greater than 5°C and excess salinities greater than 3 ppt are predicted to occur for less than 0.1% of the year at the RO intake.

Table 5.3: Maximum excess temperature at the CW intakes, standard operation

	Maximum excess temperature (°C)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	2.7	3.7	2.0	2.5	2.9	2.0
Near-surface	2.6	3.4	1.9	2.4	2.9	2.0
Mid-depth	2.7	3.7	2.0	2.5	2.9	2.0
Near-bed	3.0	4.0	2.0	2.7	3.1	2.3

Table 5.4: Average excess temperature at the CW intakes, standard operation

	Mean excess temperature (°C)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	0.4	0.6	0.2	0.4	0.6	0.2
Near-surface	0.3	0.5	0.2	0.3	0.5	0.2
Mid-depth	0.4	0.5	0.2	0.4	0.6	0.2
Near-bed	0.5	0.7	0.2	0.5	0.7	0.3

Table 5.5: Maximum excess salinity at the CW intakes, standard operation

	Maximum excess salinity (ppt)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	2.3	2.6	1.7	1.9	2.0	1.5
Near-surface	2.3	2.5	1.7	1.9	2.0	1.5
Mid-depth	2.3	2.6	1.7	1.9	2.0	1.5
Near-bed	2.4	2.8	1.8	1.9	2.0	1.6

Table 5.6: Average excess salinity at the CW intakes, standard operation

	Mean excess salinity (ppt)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	0.4	0.5	0.2	0.3	0.4	0.2
Near-surface	0.3	0.4	0.2	0.3	0.4	0.1
Mid-depth	0.3	0.5	0.2	0.3	0.4	0.2
Near-bed	0.4	0.6	0.2	0.4	0.5	0.2

Table 5.7: Maximum excess temperature at the RO intake, standard operation

	Maximum excess temperature (°C)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	3.7	5.4	2.1	2.8	3.0	2.4
Near-surface	3.7	5.3	2.1	2.7	2.8	2.3
Mid-depth	3.7	5.4	2.1	2.7	3.1	2.4
Near-bed	4.4	5.5	2.6	4.2	3.5	2.8

Table 5.8: Average excess temperature at the RO intake, standard operation

	Mean excess temperature (°C)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	0.5	0.6	0.2	0.5	0.6	0.2
Near-surface	0.4	0.5	0.2	0.4	0.5	0.2
Mid-depth	0.4	0.6	0.2	0.5	0.6	0.2
Near-bed	0.6	0.7	0.2	0.7	0.8	0.3

Table 5.9: Maximum excess salinity at the RO intake, standard operation

	Maximum excess salinity (ppt)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	2.8	3.6	1.8	2.0	2.1	1.7
Near-surface	2.8	3.6	1.8	2.0	2.0	1.7
Mid-depth	2.8	3.6	1.8	2.0	2.1	1.7
Near-bed	3.0	3.7	2.0	2.8	2.3	1.9

Table 5.10: Average excess salinity at the RO intake, standard operation

	Mean excess salinity (ppt)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	0.4	0.5	0.2	0.4	0.5	0.2
Near-surface	0.4	0.5	0.2	0.3	0.4	0.2
Mid-depth	0.4	0.5	0.2	0.4	0.5	0.2
Near-bed	0.5	0.6	0.2	0.5	0.6	0.2

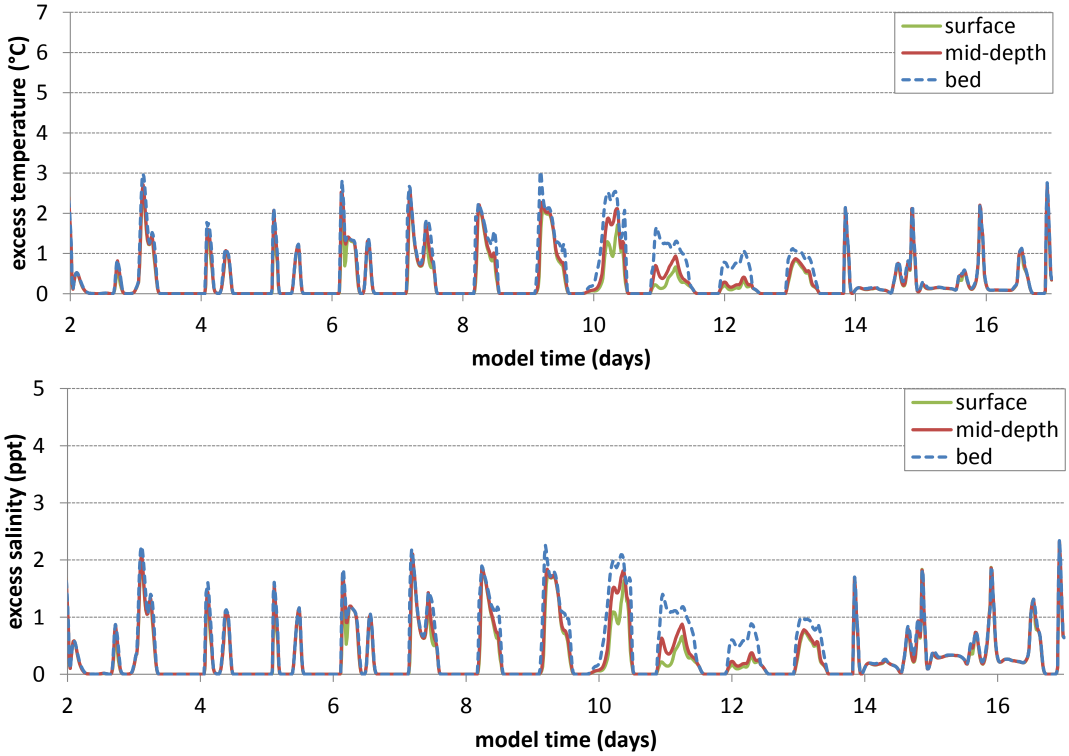

Figure 5.15: Excess temperature and salinity at the CW intakes, summer, observed wind, standard operation

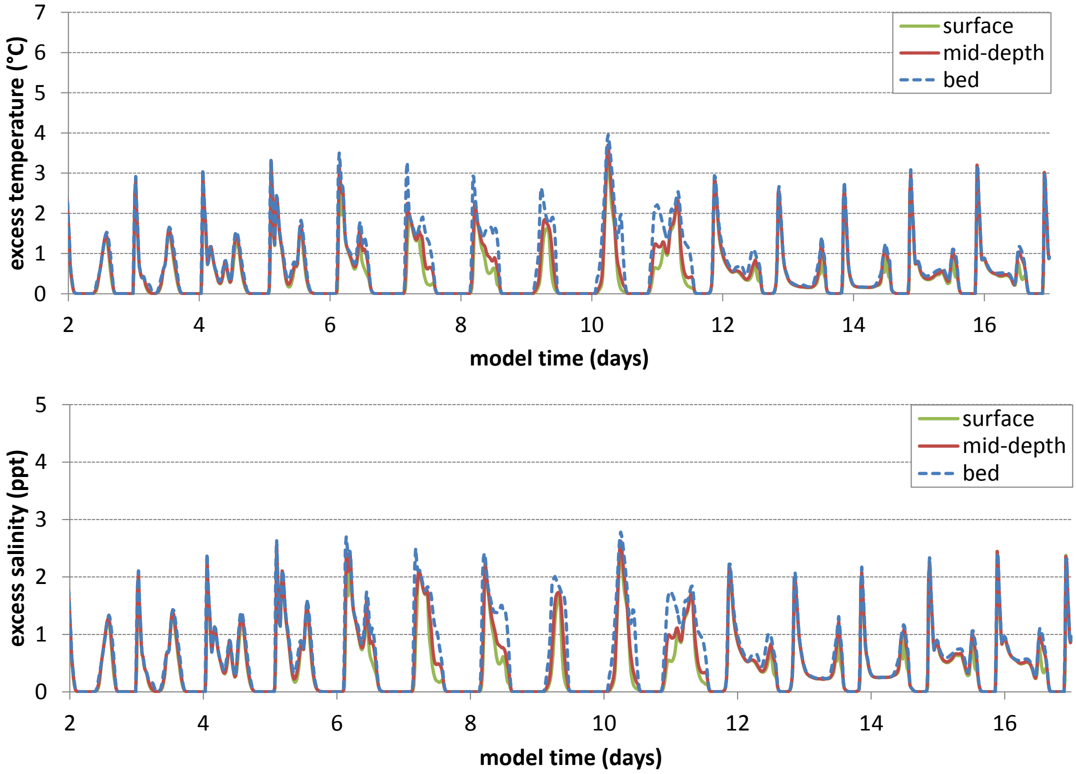

Figure 5.16: Excess temperature and salinity at the CW intakes, summer, calm, standard operation

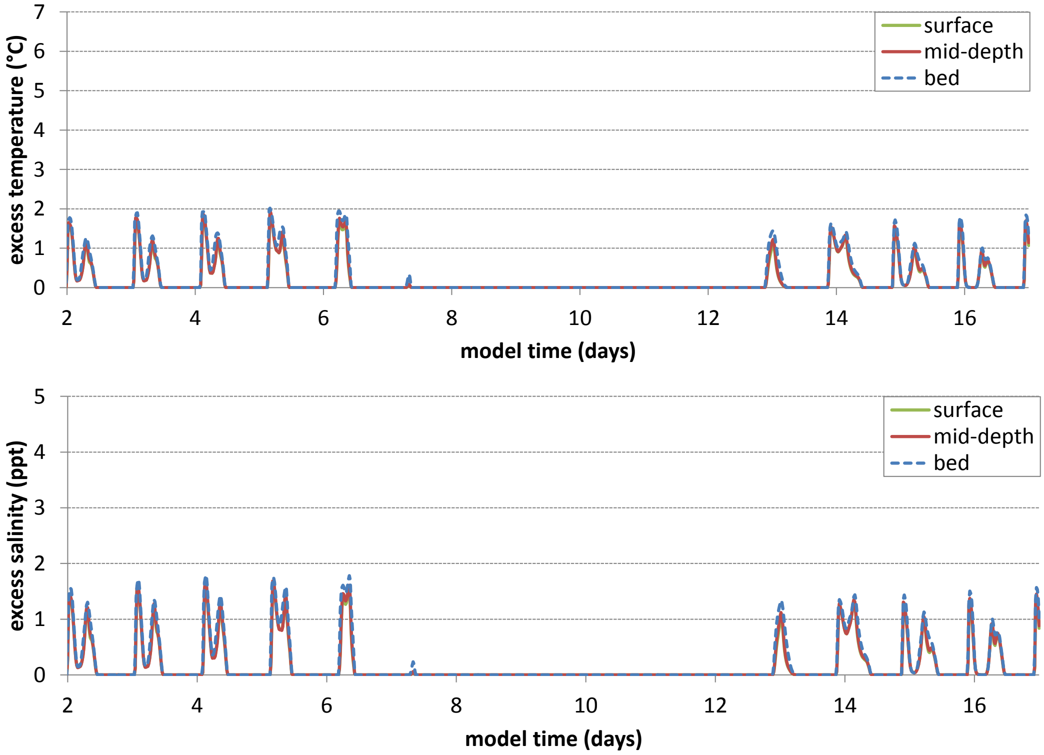

Figure 5.17: Excess temperature and salinity at the CW intakes, summer, north-west wind, standard operation

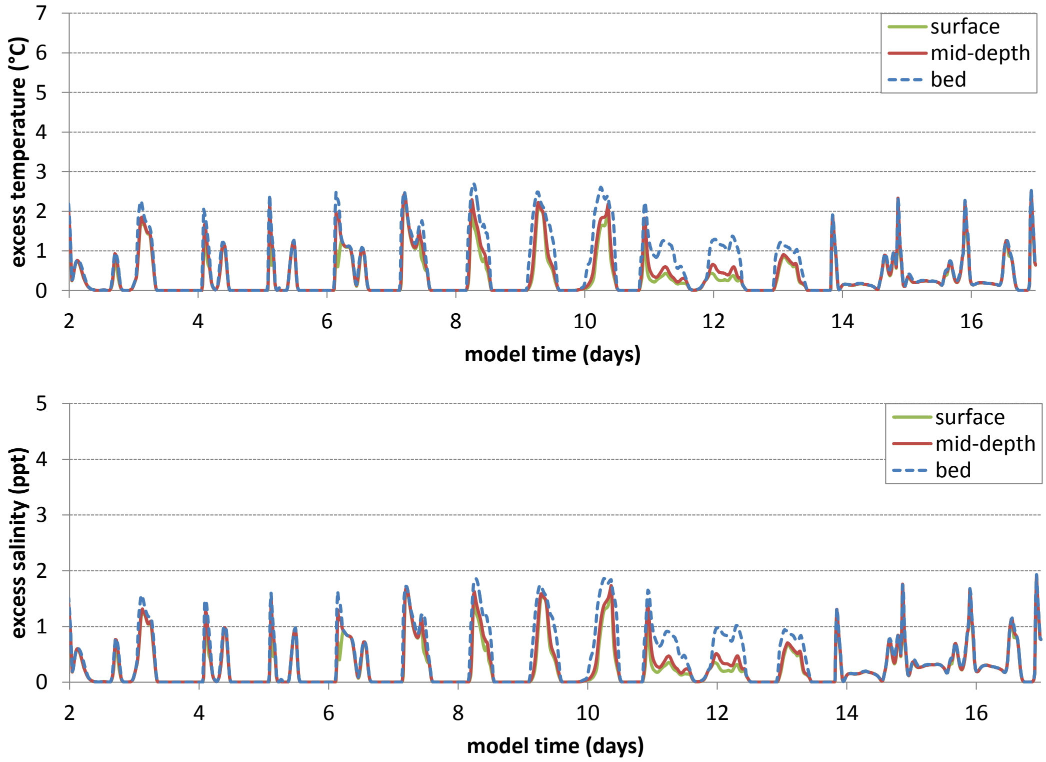

Figure 5.18: Excess temperature and salinity at the CW intakes, winter, observed wind, standard operation

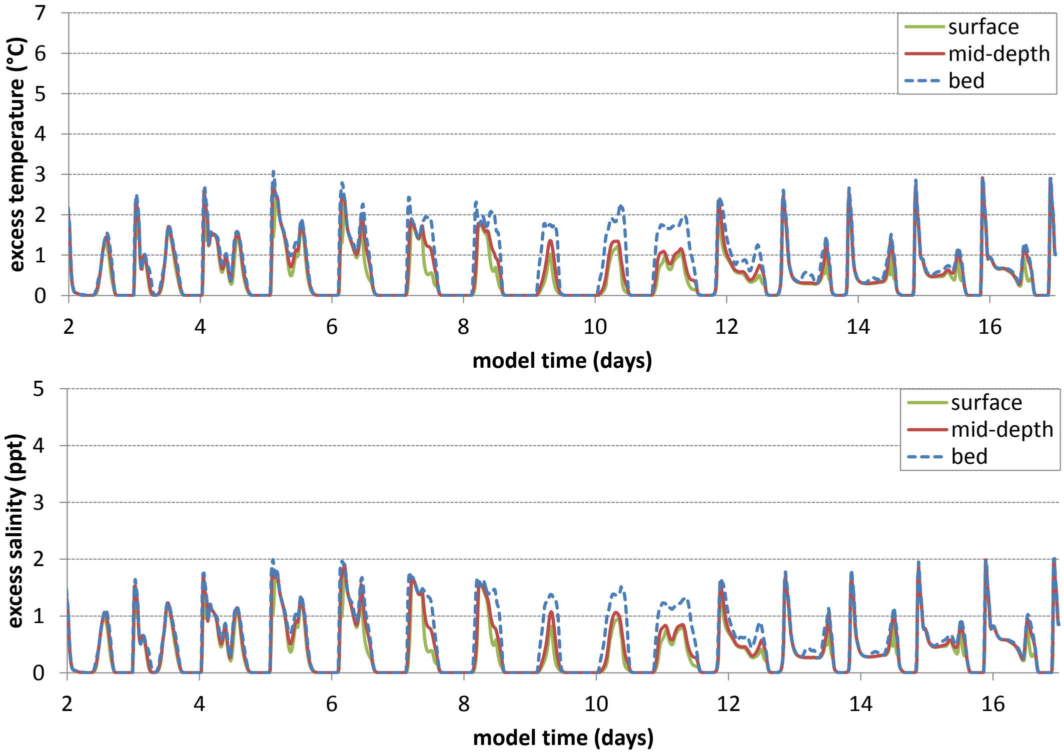

Figure 5.19: Excess temperature and salinity at the CW intakes, winter, calm, standard operation

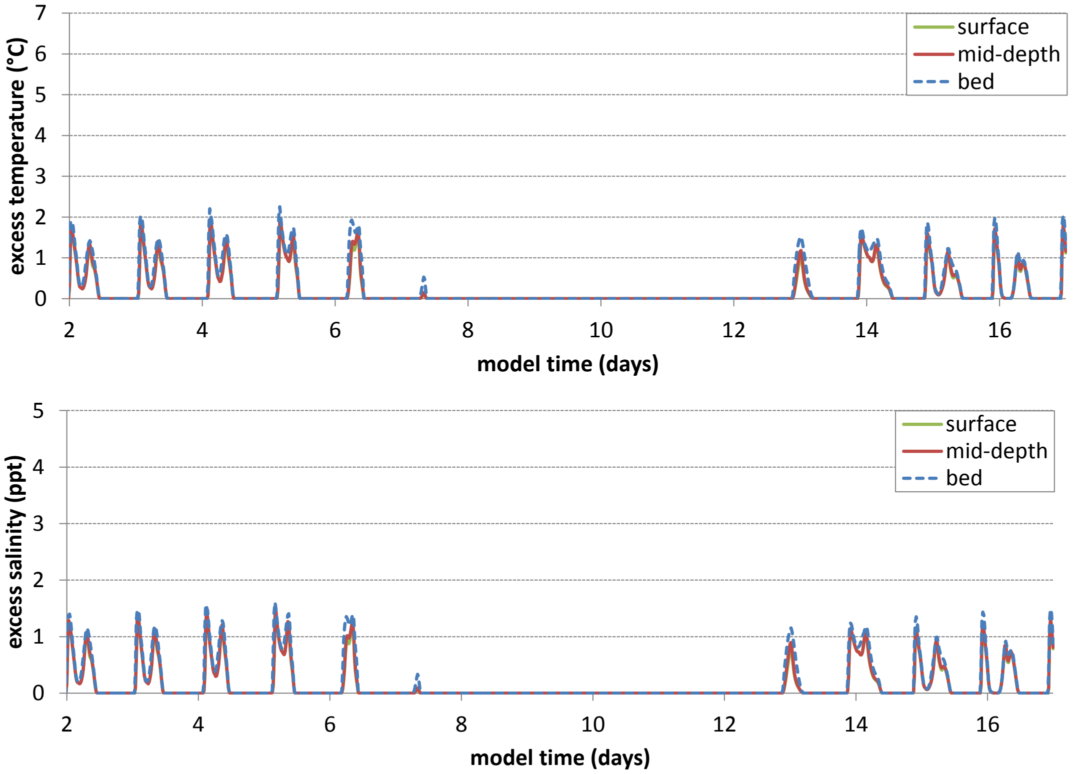

Figure 5.20: Excess temperature and salinity at the CW intakes, winter, north-west wind, standard operation

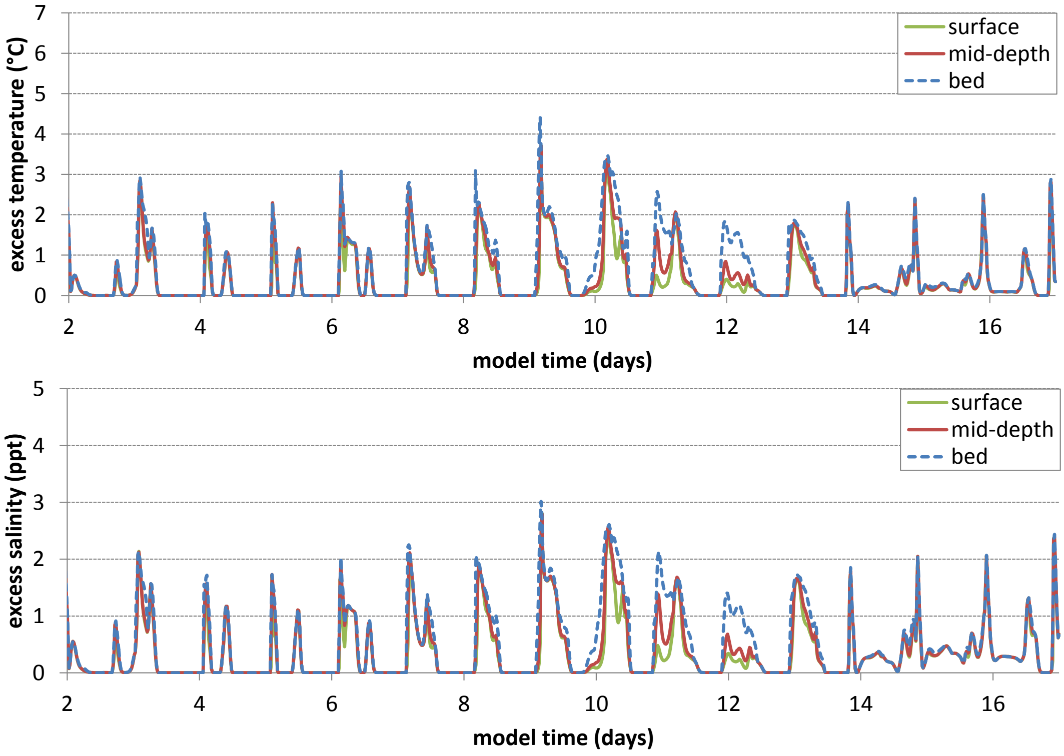

Figure 5.21: Excess temperature and salinity at the RO intake, summer, observed wind, standard operation

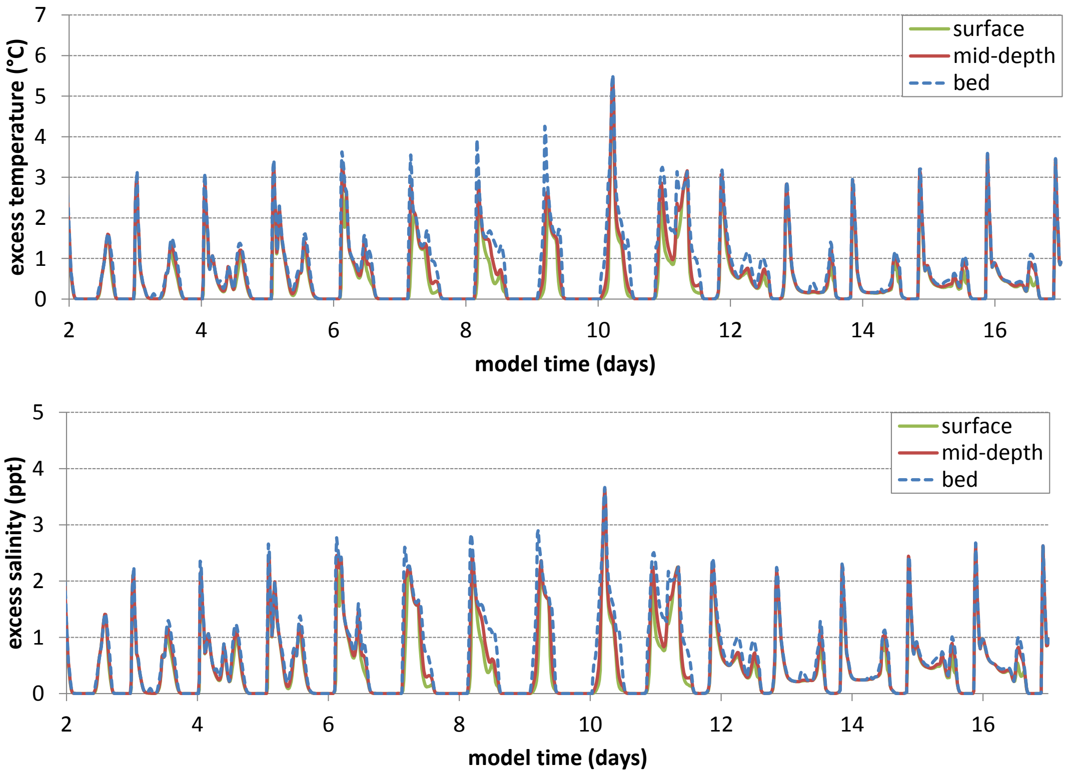

Figure 5.22: Excess temperature and salinity at the RO intake, summer, calm, standard operation

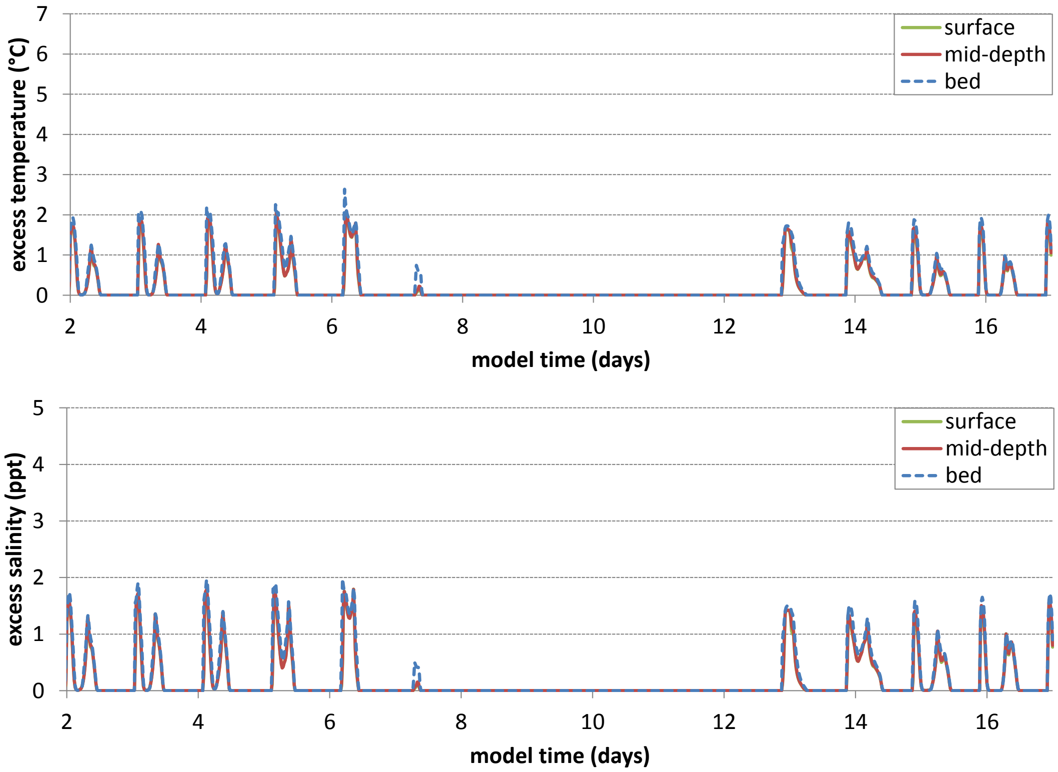

Figure 5.23: Excess temperature and salinity at the RO intake, summer, north-west wind, standard operation

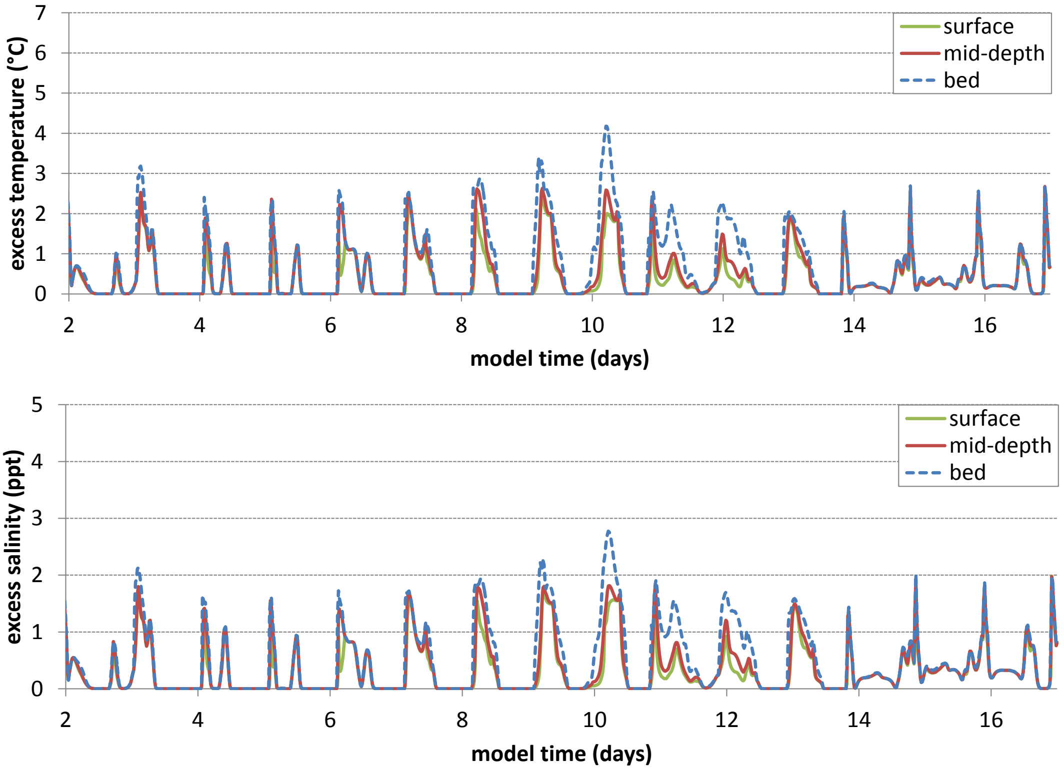

Figure 5.24: Excess temperature and salinity at the RO intake, winter, observed wind, standard operation

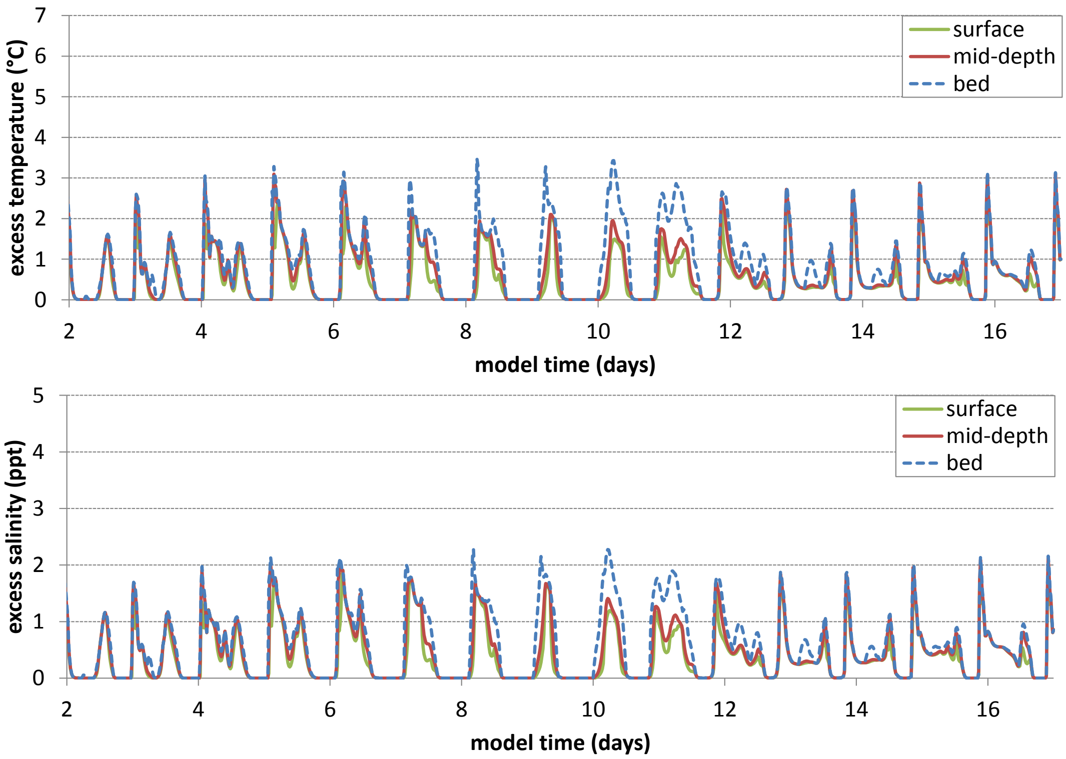

Figure 5.25: Excess temperature and salinity at the RO intake, winter, calm, standard operation

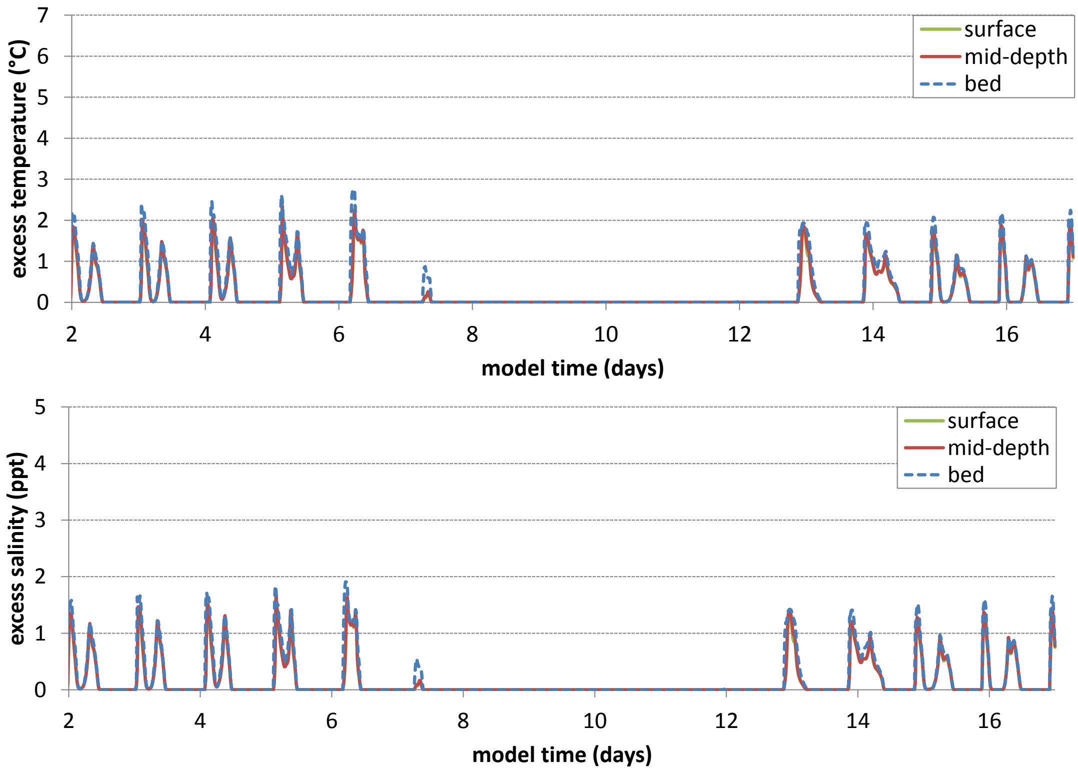

Figure 5.26: Excess temperature and salinity at the RO intake, winter, north-west wind, standard operation

5.3.2. Recirculation during early operation phase

During the early operation phase only the RO intake will be operational. Time series of the excess salinity at the RO intake are presented in Figure 5.27 to Figure 5.32 for the early operation phase simulations. They are broadly similar for the observed wind and calm conditions with peaks in excess salinity occurring during the north-going ebb phase of the tide. Recirculation levels are reduced with wind from north-west around days 7 to 13 when the tidal currents are weaker.

Table 5.11 and Table 5.12 present the maximum and average excess salinities at the RO intake for the early operation phase simulations. The values are generally similar to those predicted for the previous layout. Maximum excess salinities are predicted to be up to 2 ppt near the bed and up to 1 ppt at mid-depth and near-surface. The average excess salinity is less than 0.5 ppt for all simulations. Excess temperatures at the RO intake for the early operation phase are predicted to be less than 0.3°C for all simulations.

Table 5.11: Maximum excess salinity at the RO intake, early operation

	Maximum excess salinity (ppt)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	0.8	0.9	0.8	0.8	0.9	0.8
Near-surface	0.7	0.7	0.6	0.7	0.7	0.6
Mid-depth	0.9	1.0	0.8	0.9	0.9	0.7
Near-bed	1.8	1.4	1.4	1.8	1.3	1.4

Table 5.12: Average excess salinity at the RO intake, early operation

	Mean excess salinity (ppt)					
	Summer			Winter		
	Observed wind	Calm	North-west wind	Observed wind	Calm	North-west wind
Depth-averaged	0.2	0.2	0.1	0.2	0.2	0.1
Near-surface	0.2	0.2	0.1	0.1	0.2	0.1
Mid-depth	0.2	0.2	0.1	0.2	0.2	0.1
Near-bed	0.3	0.4	0.1	0.3	0.4	0.1

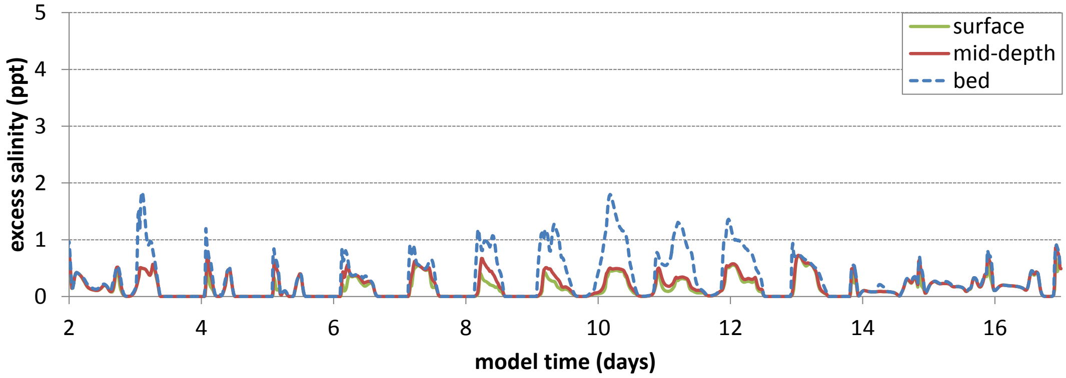

Figure 5.27: Excess salinity at the RO intake, summer, observed wind, early operation

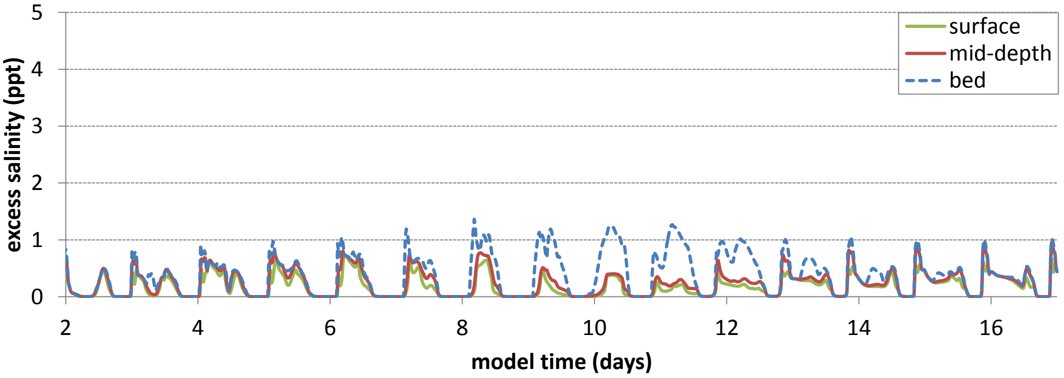

Figure 5.28: Excess salinity at the RO intake, summer, calm, early operation

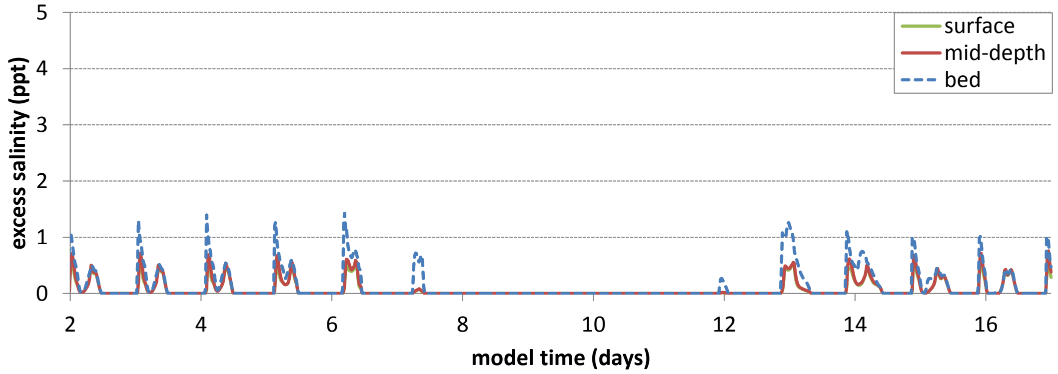

Figure 5.29: Excess salinity at the RO intake, summer, north-west wind, early operation

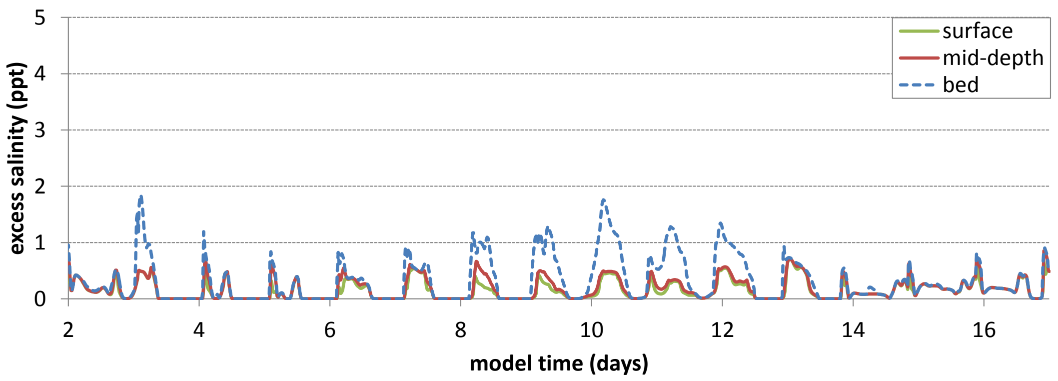

Figure 5.30: Excess salinity at the RO intake, winter, observed wind, early operation

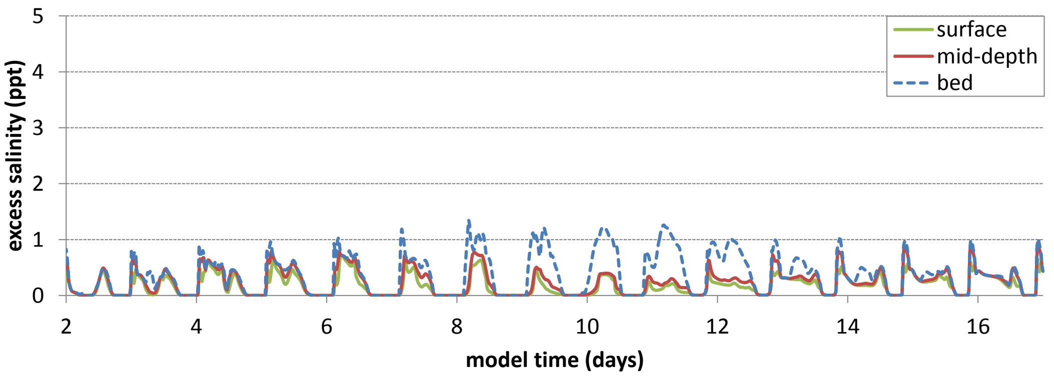

Figure 5.31: Excess salinity at the RO intake, winter, calm, early operation

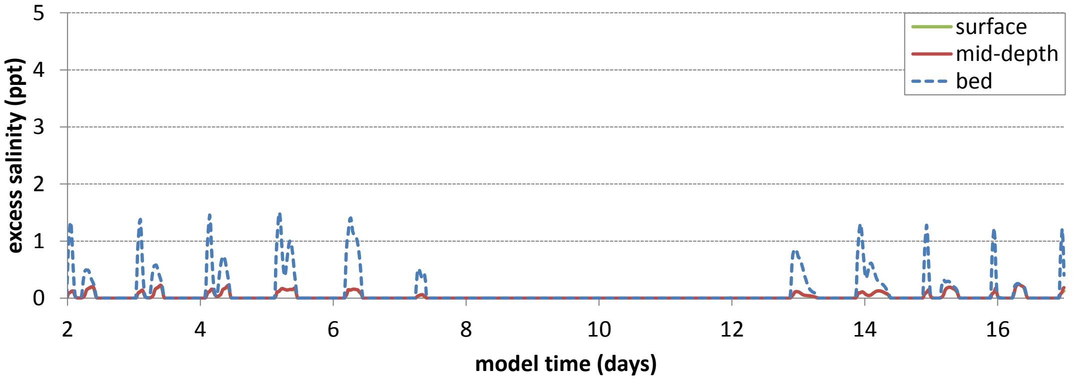

Figure 5.32: Excess salinity at the RO intake, winter, north-west wind, early operation

6. Conclusions

Thermal and saline dispersion have been assessed for the proposed UHP with a revised configuration of the intake and outfall. The assessment has been conducted with a previously calibrated 3D model. Two operational phases of UHP were simulated for a range of environmental conditions. The key findings are:

- During the standard operational phase the area where average temperatures are predicted to be more than 3°C above the ambient is smaller than predicted for the previous layout. The discharge salinity is sufficiently low that it does not require detailed assessment.
- During the early operation phase the model predicts that a region of the sea bed may be exposed to average salinities more than 10% above the background salinity and this region is of similar size for both the previous and revised layouts. The discharge temperature is sufficiently low that it does not require detailed assessment.
- The recirculation assessment indicates that maximum excess temperatures and salinities will vary across the five intakes. Peak recirculation levels are smaller at the cooling water intakes than at the RO intake, with maximum excess temperatures of up to 4°C predicted at the cooling water intakes and up to 5.5°C at the RO intake. In comparison to the previous layout, this indicates a reduction in the peak recirculation temperatures at the cooling water intakes by around 2°C.
- It is estimated that, based on the frequency of wind conditions and tidal ranges at the site, peak recirculation values at the RO intake are likely to occur for less 0.1% of the year.
- Under the tide and wind conditions considered, average excess temperatures at the UHP intakes will be less than 1°C and average excess salinities less than 1 ppt during the standard operation phase of the facility. These are similar to the predicted average values for the previous layout.
- During the early operation phase of the facility the predicted average recirculation temperatures and salinities are less than 0.1°C and 0.5 ppt respectively, which are similar to the values predicted for the previous layout.
- In the area of dense seagrasses to the west of the outfall, maximum excess temperatures are predicted to be up to 4°C under calm conditions. This is an increase of around 1°C to the maximum temperature predicted for the previous layout. Excess salinities in this area are predicted to be similar to those for the previous layout.
- At the nearby mixed oyster bed habitats predicted excess temperatures and excess salinities are similar to those for the previous layout.
- Near to the coast, the area of seawater between the proposed intake and outfall armoured pipelines will have reduced flushing potential and thus a higher risk of poor water quality.

Appendices

A. Additional dispersion modelling results

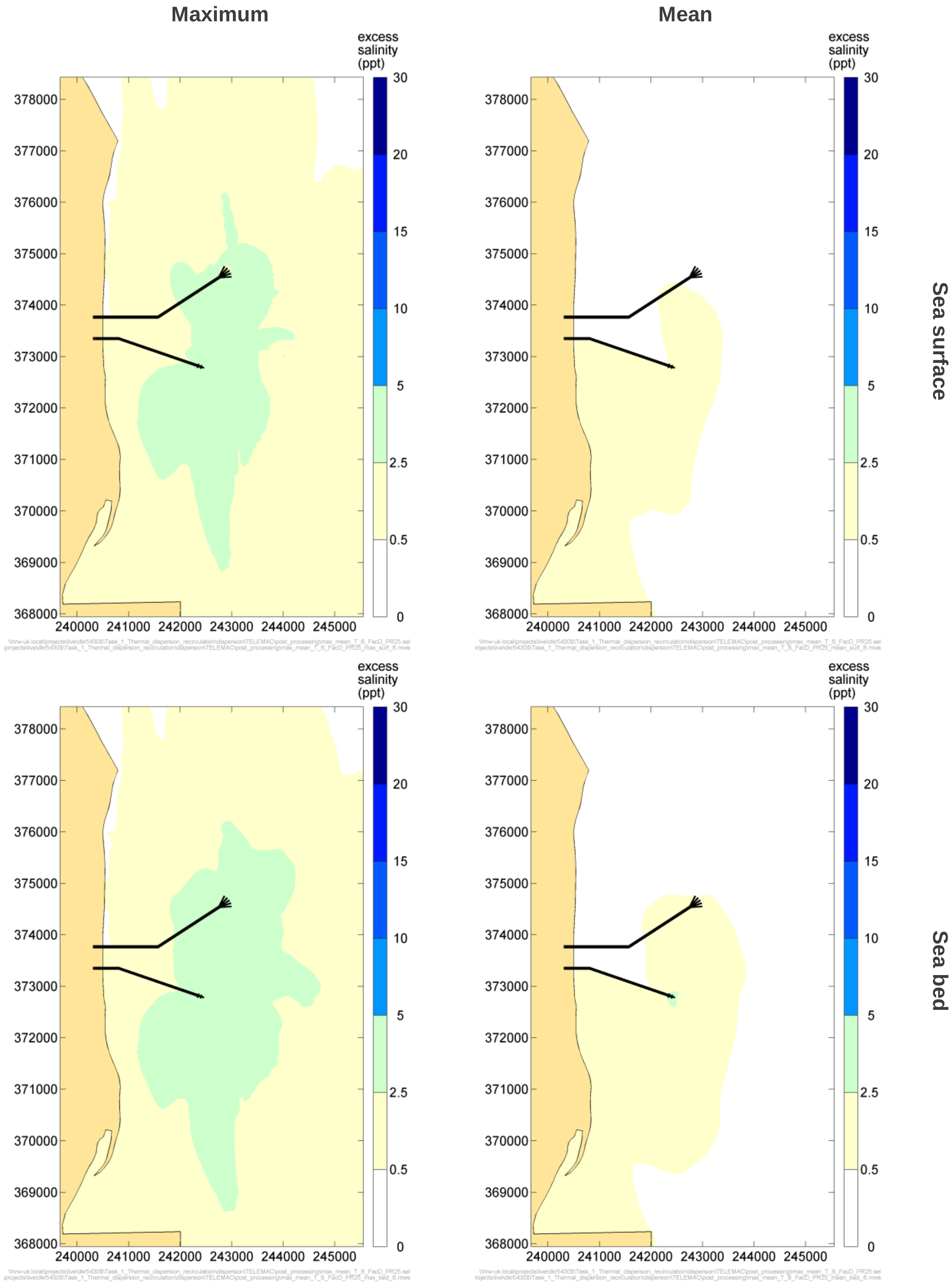

Figure A.1: Maximum and mean sea surface and sea bed excess salinity, summer, observed wind, standard operation

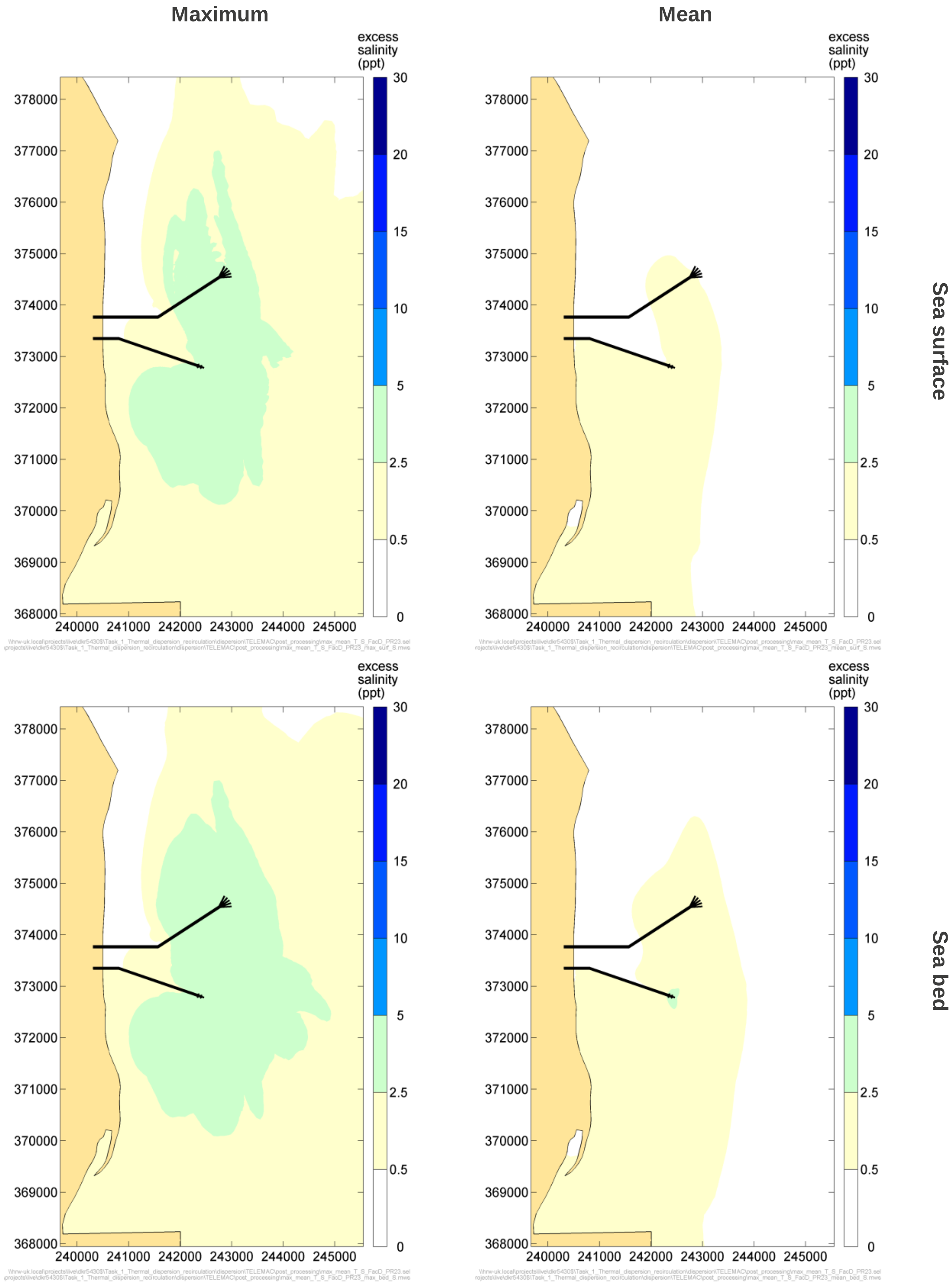

Figure A.2: Maximum and mean sea surface and sea bed excess salinity, summer, calm, standard operation

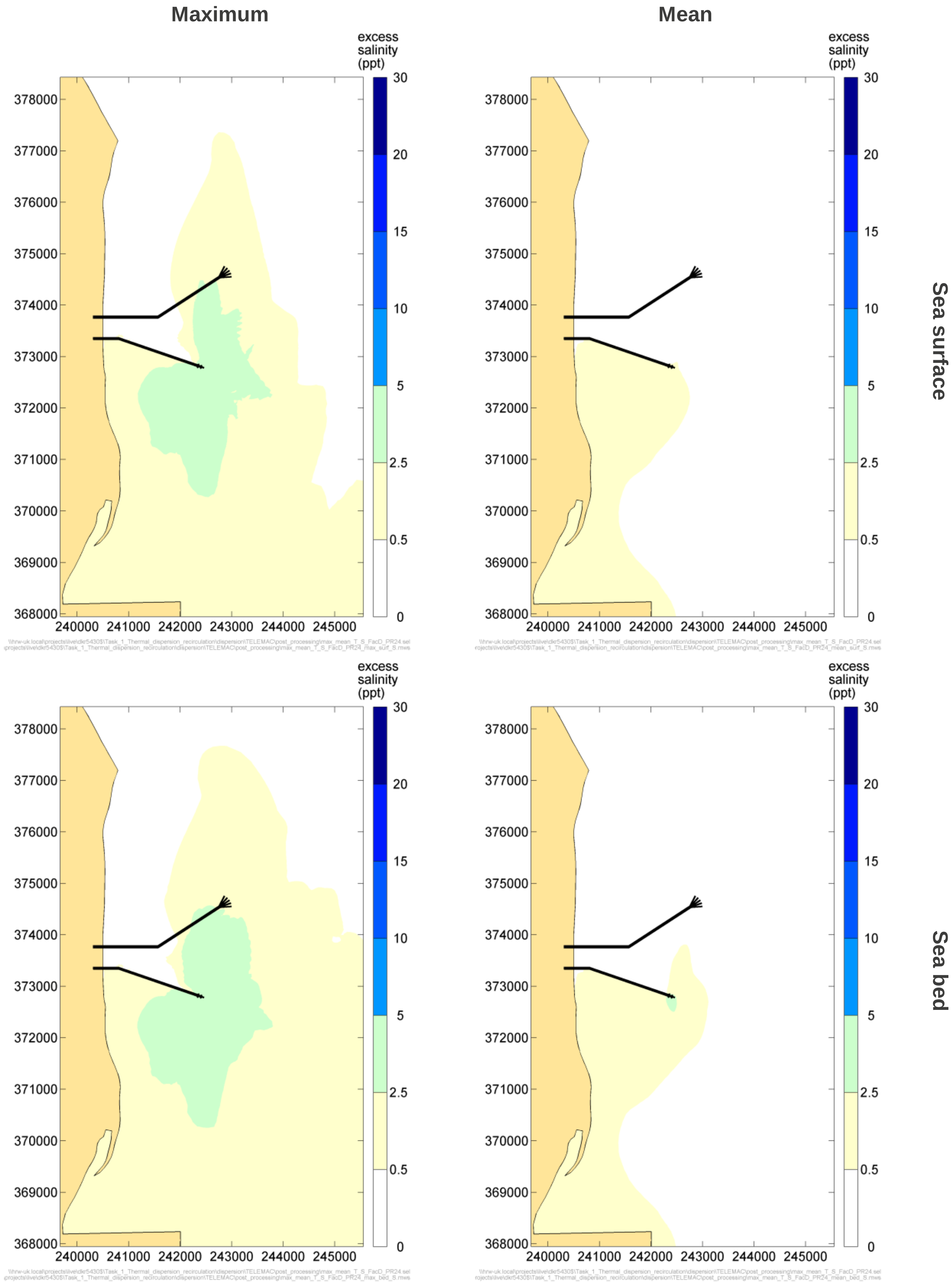

Figure A.3: Maximum and mean sea surface and sea bed excess salinity, summer, north-west wind, standard operation

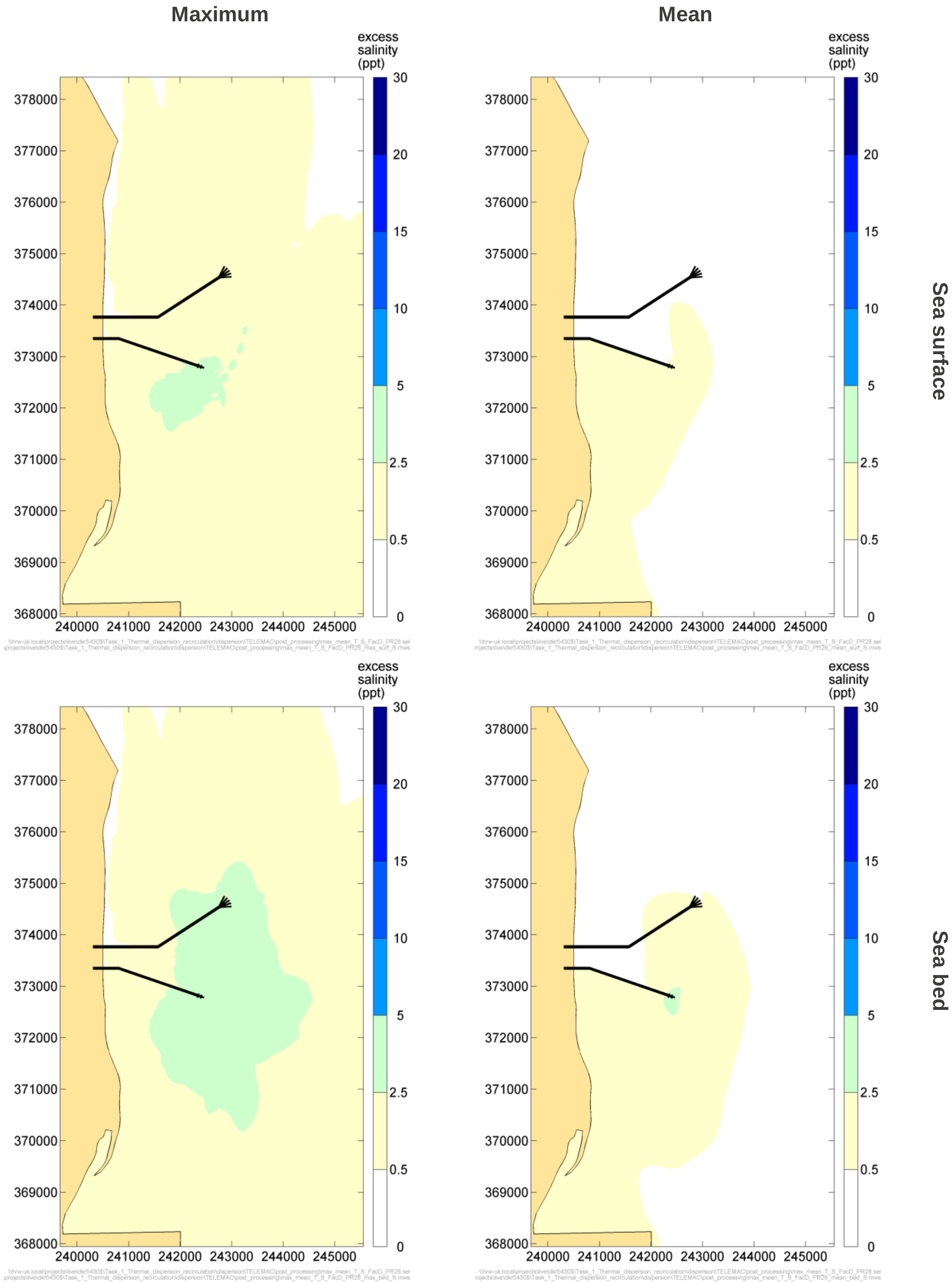

Figure A.4: Maximum and mean sea surface and sea bed excess salinity, winter, observed wind, standard operation

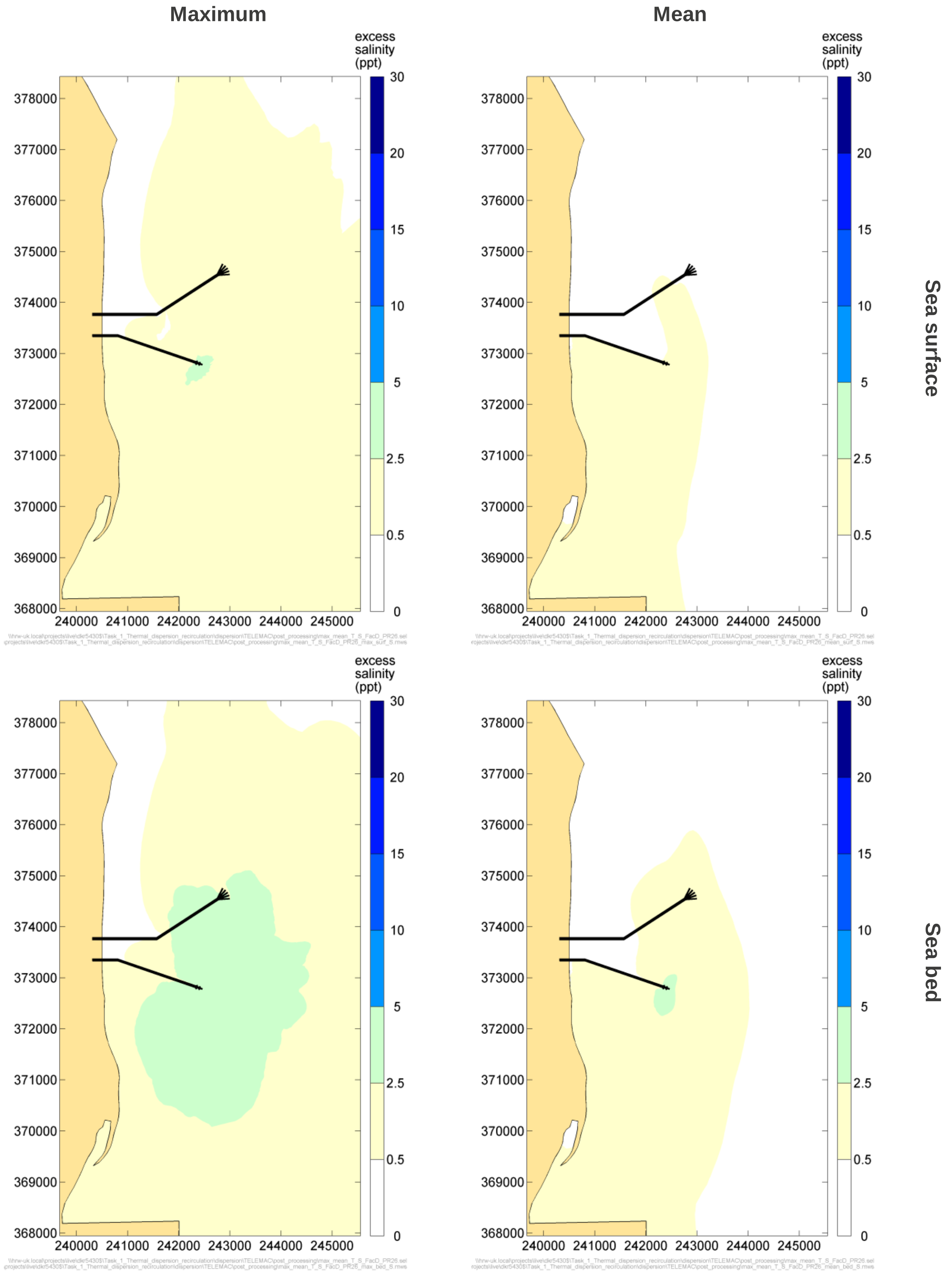

Figure A.5: Maximum and mean sea surface and sea bed excess salinity, winter, calm, standard operation

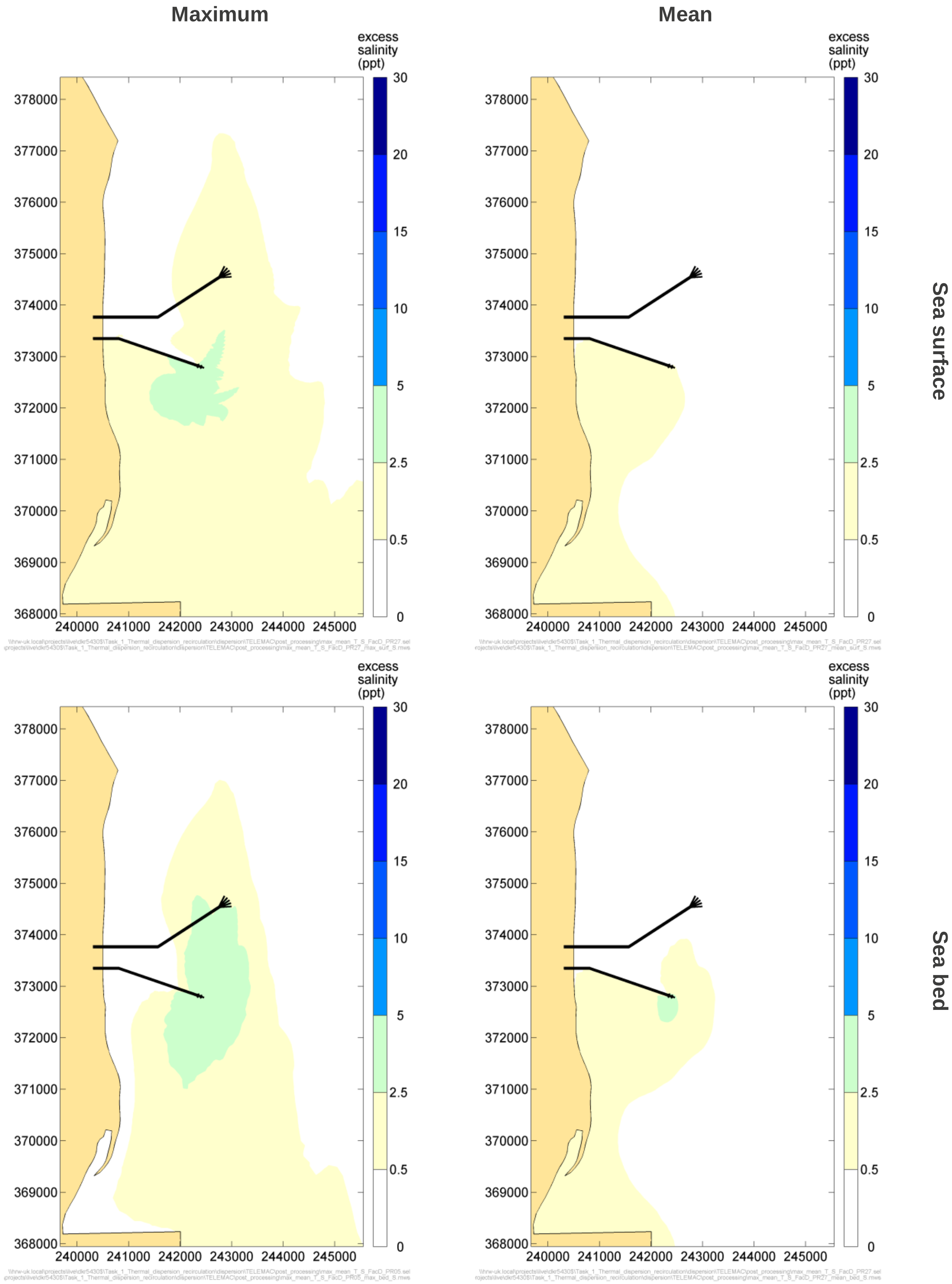

Figure A.6: Maximum and mean sea surface and sea bed excess salinity, winter, north-west wind, standard operation

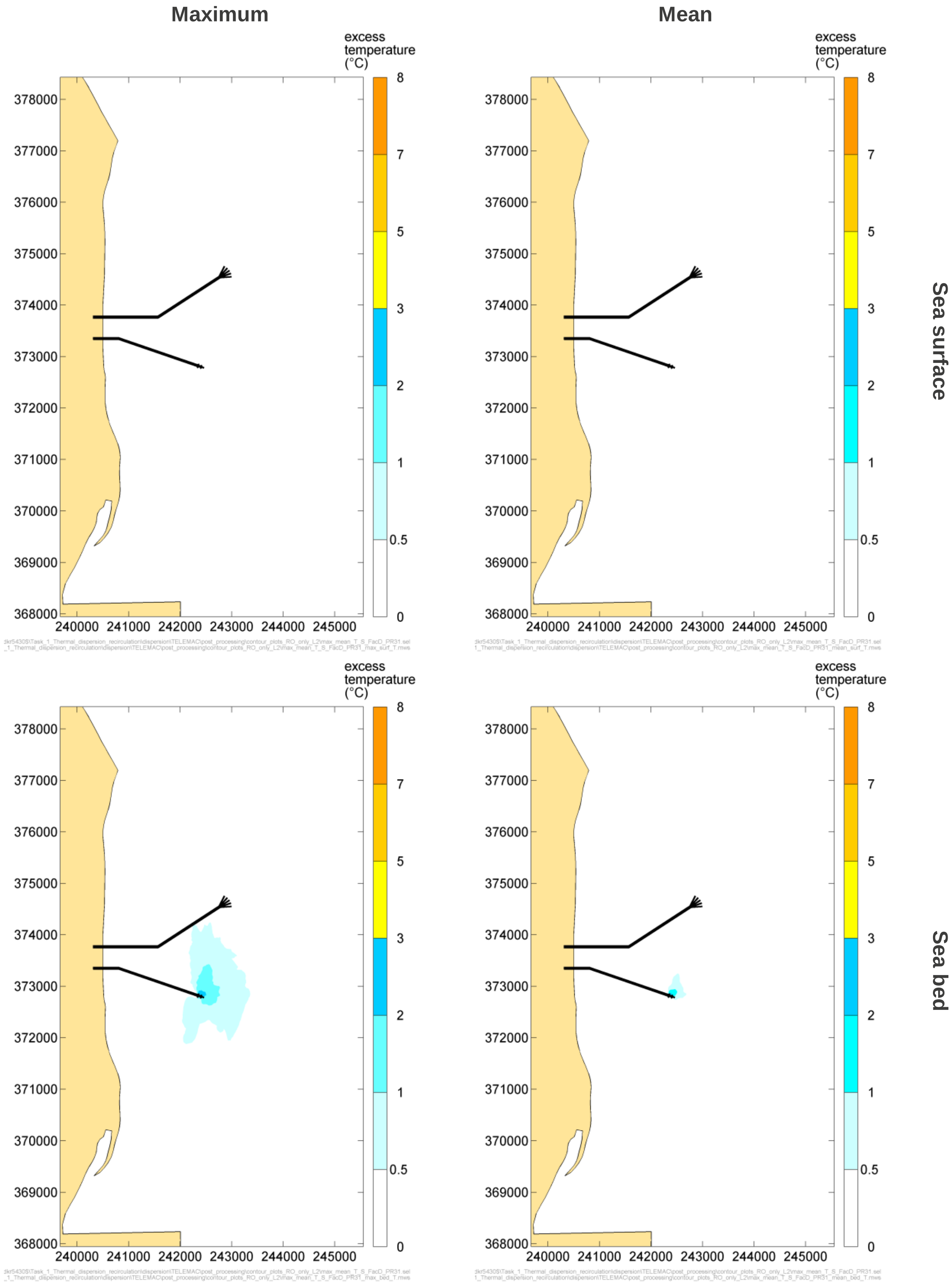

Figure A.7: Maximum and mean sea surface and sea bed excess temperature, summer, observed wind, early operation

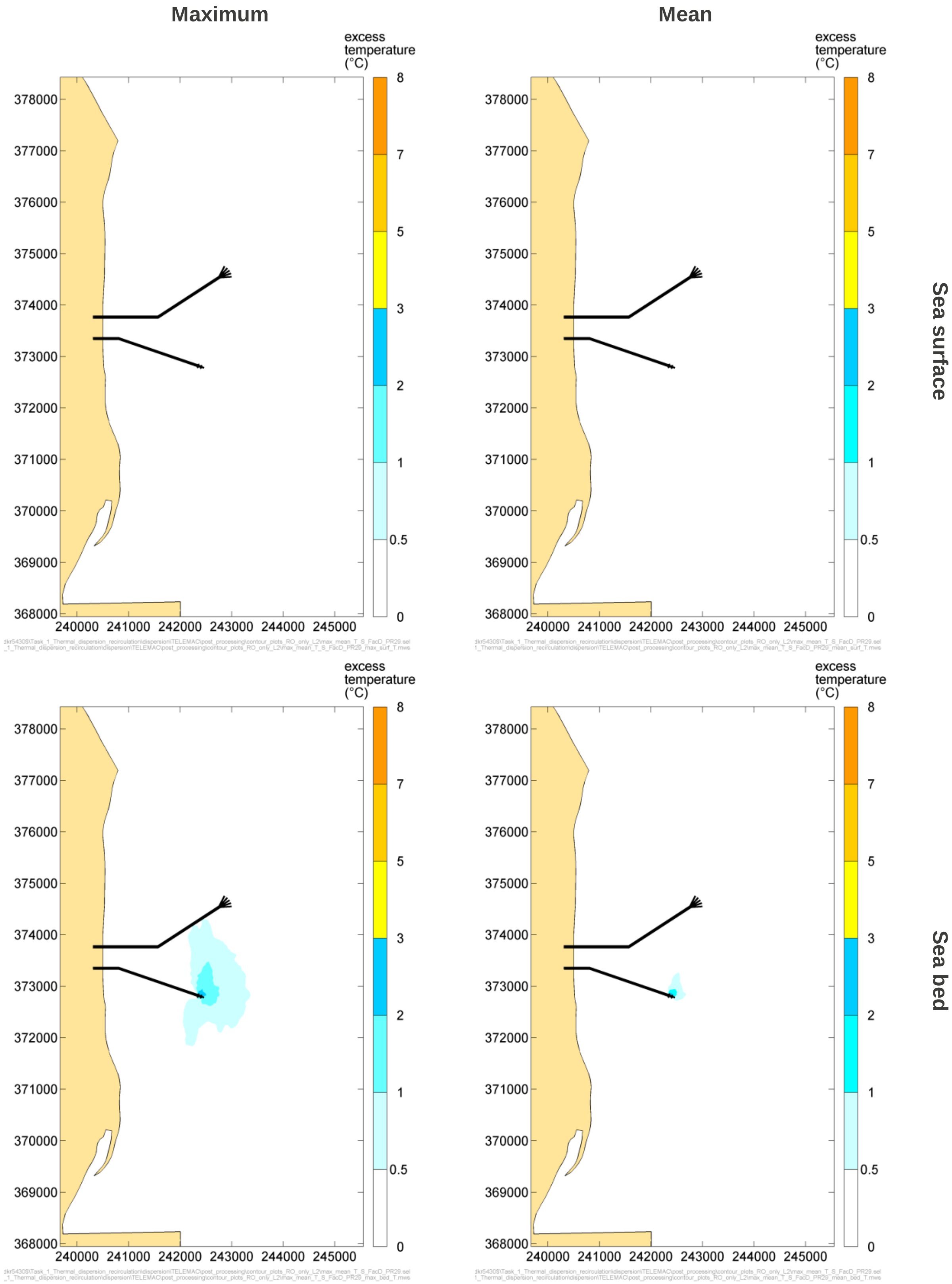

Figure A.8: Maximum and mean sea surface and sea bed excess temperature, summer, calm, early operation

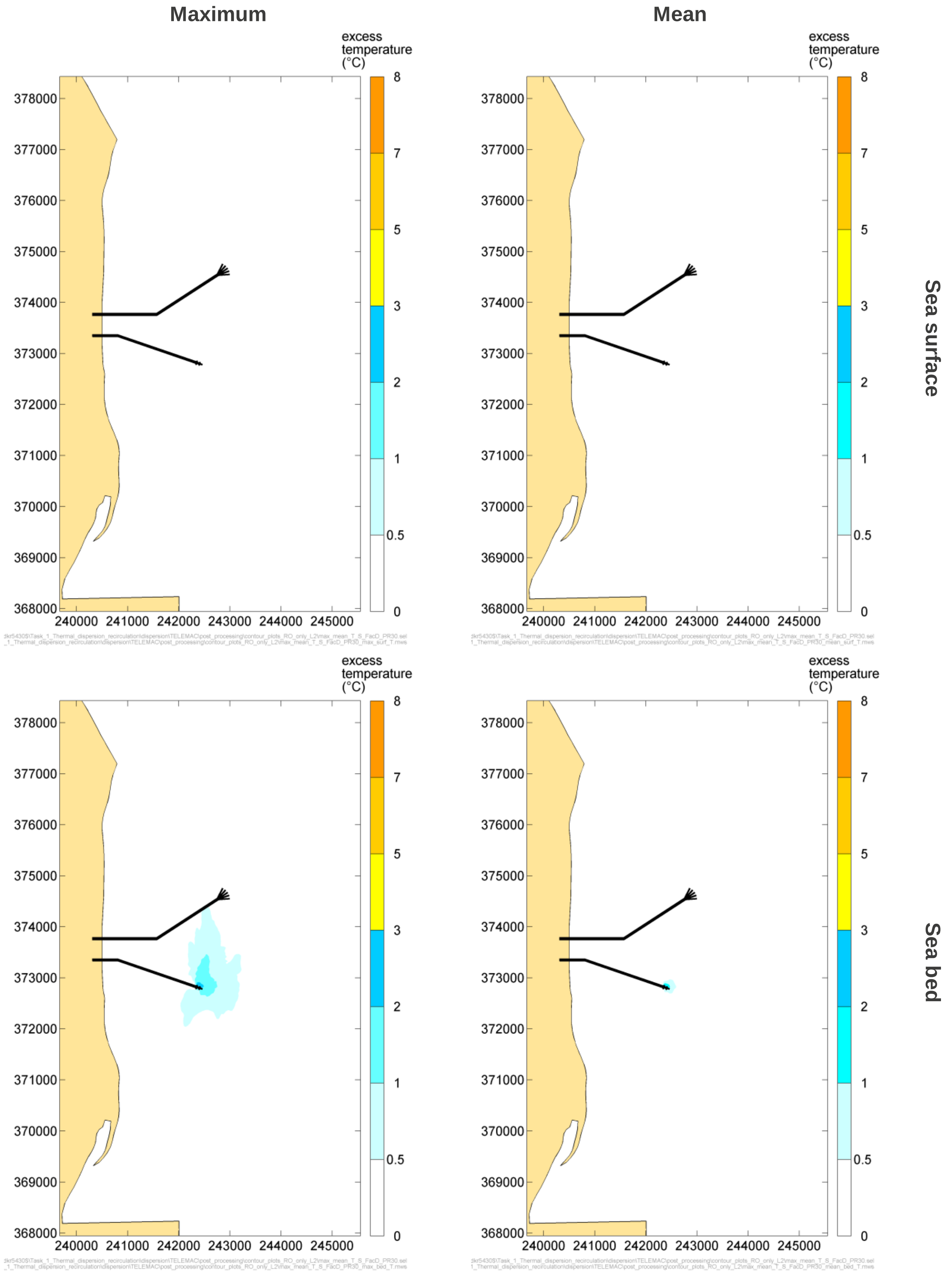

Figure A.9: Maximum and mean sea surface and sea bed excess temperature, summer, north-west wind, early operation

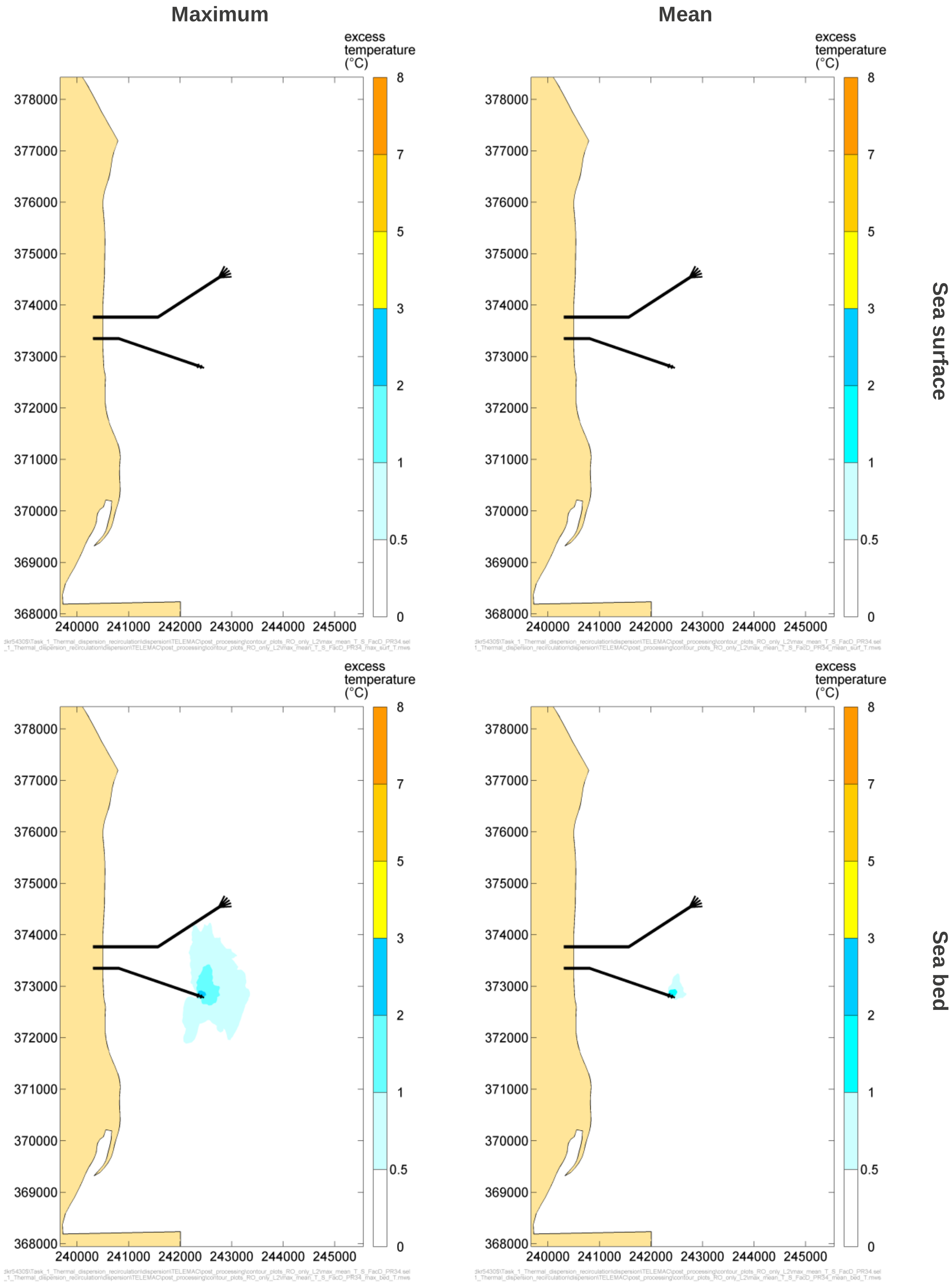

Figure A.10: Maximum and mean sea surface and sea bed excess temperature, winter, observed wind, early operation

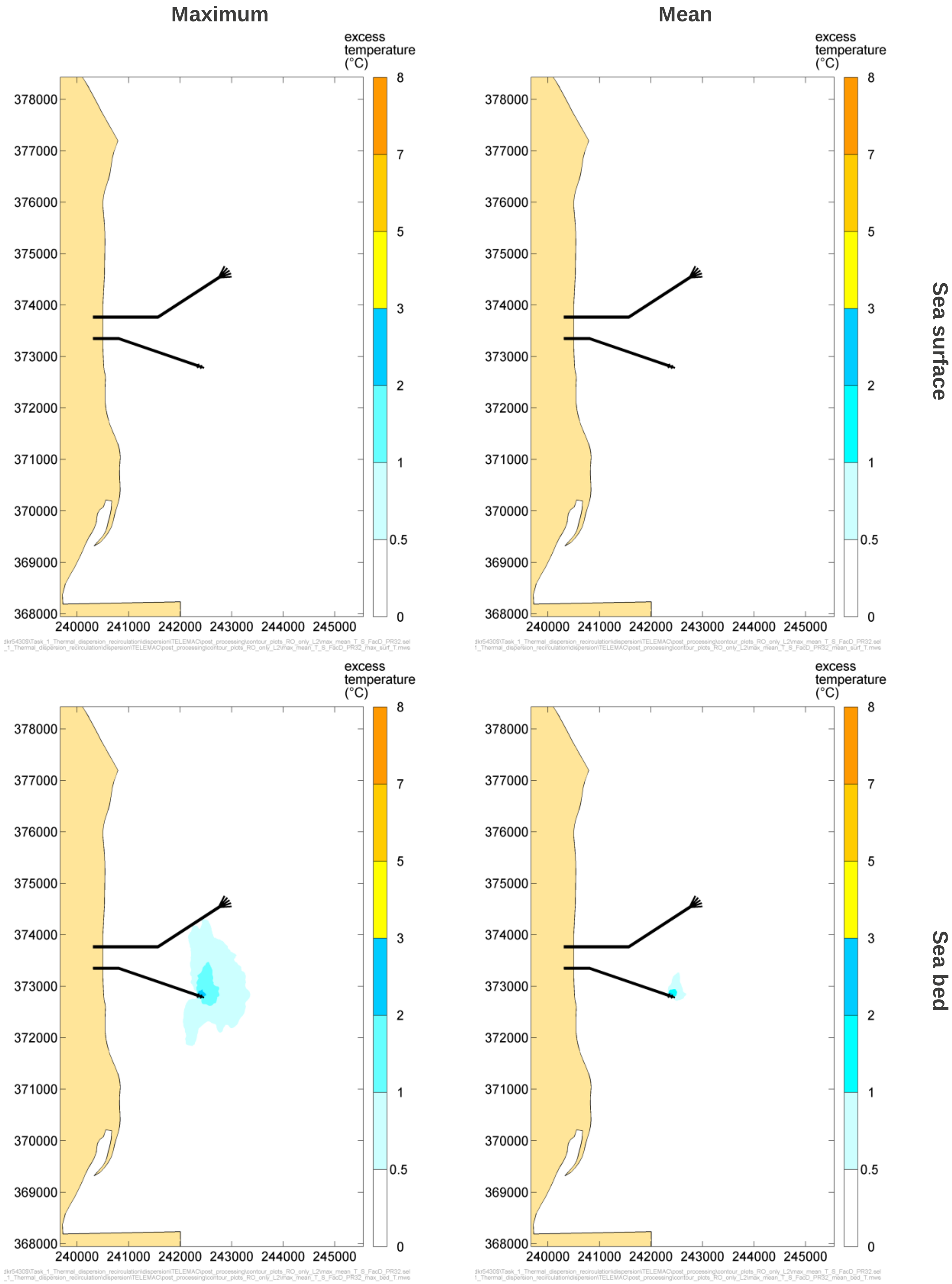

Figure A.11: Maximum and mean sea surface and sea bed excess temperature, winter, calm, early operation

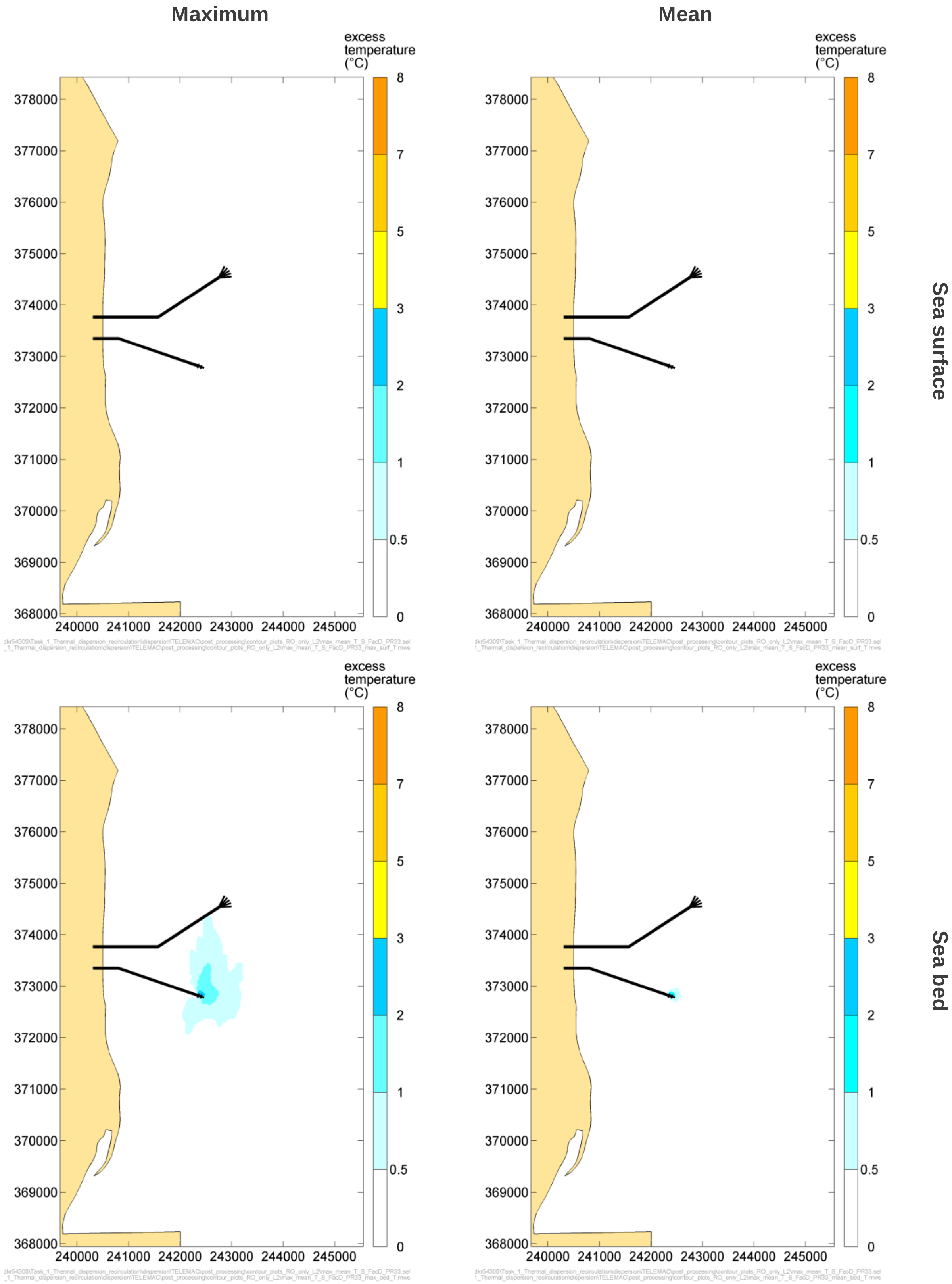

Figure A.12: Maximum and mean sea surface and sea bed excess temperature, winter, north-west wind, early operation

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Umm Al Houl Project, Qatar

Further recirculation study

DKR5955-RT001-R06-00 July 2018

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Executive Summary

Umm al Houl Independent Water and Power Project (IWPP) is currently under construction on the east coast of Qatar, south of Al Wakrah. The project is now to include an expansion of the Seawater Reverse Osmosis (RO) desalination plant to deliver an extra 60 MIGD of potable water. The new expansion will use the existing intake and outfall pipelines.

HR Wallingford has provided a range of studies to support Samsung C&T Corporation (Samsung C&T) in the detailed design process, including recirculation and thermal dispersion studies.

The thermal-saline dispersion model developed during the initial design of Umm Al Houl IWPP has been applied to assess the effects of an additional RO plant on temperature and salinity footprints. Three potential future operating conditions were tested, plus a Baseline case representing the previous operational case without the new RO plant.

The main conclusions of the modelling are:

Environmental compliance

- Temperature:
  - In all cases with the new RO plant in operation, the 3°C depth-averaged footprint will be reduced compared to the Baseline (from 0.05 km^2 to 0.01-0.04 km^2). The largest reduction is associated with a reduced excess temperature at discharge, while other reductions are associated with changes in plume behaviour due to increased salinity in the effluent leading to changes in buoyancy.
- Salinity:
  - The Baseline discharge salinity is only slightly more than 10% above the background. Therefore, only a small area around the outfall will have salinities greater than 10% above background.
  - For two of the future cases (Case 1 and Case 2b (winter)), the plume will form a denser layer at the bed. The average extent of the area with salinities more than 10% above background is predicted to be up to 0.09 km^2.
  - For the case with a smaller volume of reject brine from the RO plant (Case 2a (summer)), the average extent of the area with salinities more than 10% above background is predicted to be less than 0.02 km^2.

Recirculation

- Temperature:
  - Predicted maximum excess temperatures at the cooling water intakes are reduced compared to the Baseline by 1-2°C.
  - Predicted maximum excess temperatures at the RO intake are reduced compared to the Baseline by up to 3°C.
  - In all cases the mean excess temperature at both sets of intakes will be similar to the Baseline case (~ 0.5°C).
- Salinity:
  - Predicted maximum excess salinities at the cooling water intakes are reduced compared to the Baseline by 0.5-1 ppt.
  - Predicted maximum excess salinities at the RO intake are reduced compared to the Baseline by 1-1.5 ppt.
  - In all cases predicted mean excess salinities at both sets of intakes are similar to the Baseline case (~0.5 ppt).

Contents

Tables

1. Introduction

Umm al Houl Independent Water and Power Project (IWPP) is currently under construction on the east coast of Qatar, south of Al Wakrah (Figure 1.1). The project is now to include an expansion of the Seawater Reverse Osmosis (RO) desalination plant to deliver an extra 60MIGD of potable water. The new expansion will use the existing intake and outfall pipelines. Reject brine for the SWRO plants will also be used for cooling instead of being discharged directly to sea.

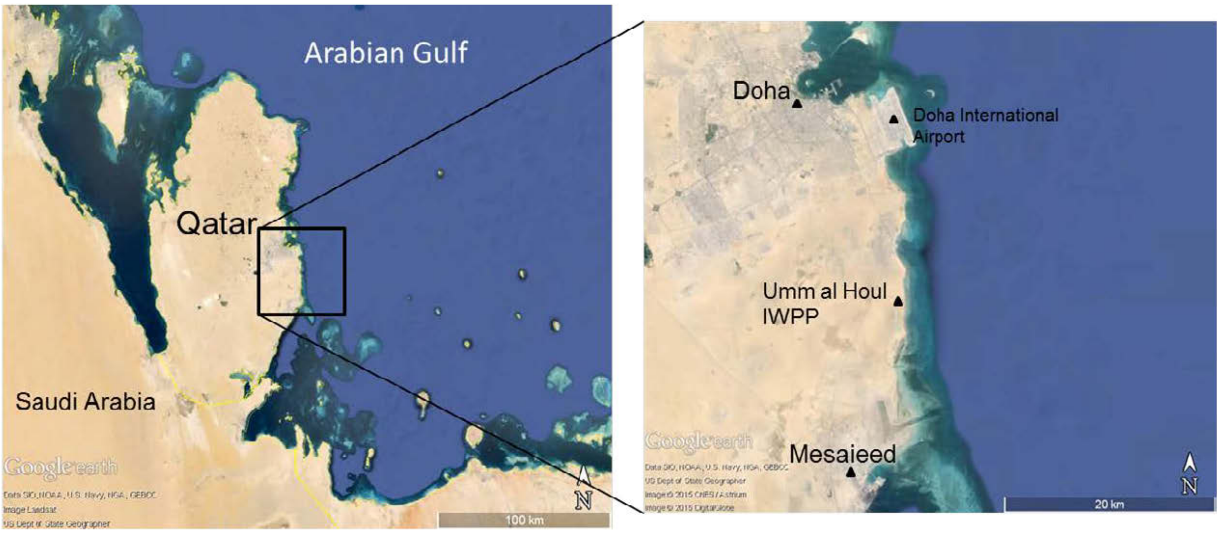

Figure 1.1: Site location

HR Wallingford has provided a range of studies to support Samsung C&T Corporation (Samsung C&T) in the detailed design process, including recirculation and thermal dispersion studies. Samsung C&T has requested that the model built by HR Wallingford for the previous stages of the project be reused to determine the effects of the additional discharge on the footprints of increased temperature and salinity. The original work was carried out by HR Wallingford in 2016.

This report should be read in conjunction with the following HR Wallingford study reports:

- **DKR5430-RT001-R02** (HR Wallingford, 2015a) which includes: calibration of the hydrodynamic model, setup of the 3D dispersion model, and recirculation/dispersion assessments for the previous intake and outfall configuration.
- **DKR5430-RT007-R02** (HR Wallingford, 2015b) which describes the investigation of the recirculation and dispersion of the thermal/saline plume from the IWPP for a revised configuration of the intake and outfall structures.

1.1. Report conventions

The horizontal coordinate system used throughout this report is Qatar National Grid (QNG). The vertical coordinate system is Qatar National Height Datum (QNHD) which is equivalent to mean sea level (MSL). Units are metres (m) in both dimensions. Temperatures are reported in °C. Salinity is reported in parts-per-thousand (ppt), which is approximately equivalent to kg/m^3 over the range of salinities tested.

2. Data received

The relevant data received are listed in Table 2.1. Items 17-23 are the latest information sources received for the present study. All other data sources were received or gathered during the previous assessments.

Table 2.1: Relevant data received

Ref	From	Date received dd/mm/yy	Name	Filename	Contents
1	From surveyors MTEC	22/06/15	Metocean Survey Al Whakrah Qatar Final Report Rev00; Data sets	307_Whakrah_Final_Report_Metocean_R01.pdf	ADCP velocity and wave data
2	From surveyors MTEC	14/05/15	Bathymetric chart, Rev 00 12/05/2015	307_Al_Whakrah_bathymetric_chart_5k_r0.dwg	Bathymetric chart with 0.5m contours
3	From surveyors MTEC	21/05/15	Bathymetric Survey; Al Wakrah, Qatar Final Report	307 Bathymetric survey_final_report_r0.doc	Bathymetric survey
4	Samsung C&T	22/06/15	UHP Seawater flow rate	UHP_Seawater Flow Rate Design Data 150616.xlsx	Intake and outfall flow rates, temperature and salinity increases
5	Samsung C&T	22/06/15	Intake head Structure	1005~1006 Intake Head Structure Sectional Details rev01.dwg	Drawings of intake head structure
6	Samsung C&T	22/06/15	Intake and discharge overall layout	1001_Intake Discharge Overall Layout_rev02.dwg	Overall layout of intake and outfalls
7	Samsung C&T	22/06/15	Intake pipeline Plan	UHP-SCT-C00-UPZ-D-1002.dwg	Plan of intake pipeline
8	Samsung C&T	22/06/15	Intake pipeline section	UHP-SCT-C00-UPZ-D-1021.dwg	Sections through intake pipelines
9	Samsung C&T	22/06/15	Intake pipeline Profile	UHP-SCT-C00-UPZ-D-1022-1023.dwg	Longitudinal profile along intake pipelines, showing protection.
10	Samsung C&T	22/06/15	Discharge pipeline sections	1010~1011 Discharge Pipeline Sectional Details(1).dwg	Sections through discharge pipelines
11	Samsung C&T	22/06/15	Diffuser	1012 Discharge Pipeline Sectional Details(3).dwg	Details of outfall diffuser

Ref	From	Date received dd/mm/yy	Name	Filename	Contents
12	Samsung C&T	22/06/15	Discharge pipeline profile	1013-1014 Discharge Pipeline profile.dwg	Longitudinal profile along discharge pipelines, showing protection.
13	Samsung C&T	9/09/15	Design change in armouring	Sept092015 Design change in armouring.pptx	Changes in armouring of intake and outfall pipelines
14	Samsung C&T	5/10/15	Revised intake and discharge overall layout	UHP-SCT-C00-UPZ-D-1001_GENERAL ARRAGEMENT INTAKE&DISCHARGE KEY PLAN_Rev.B.pdf	Overall layout of intake and outfalls – revised layout
15	Samsung C&T	5/10/15	Revised intake pipeline	UHP-SCT-C00-UPZ-D-Intake Pipeline Total.pdf	Plan of intake pipelines, sections and longitudinal profile – revised layout
16	Samsung C&T	5/10/15	Revised outfall pipeline	UHP-SCT-C00-UQZ-D-Discharge Pipeline Total.pdf	Plan of discharge pipelines, sections and longitudinal profile – revised layout
17	Samsung C&T	2/05/18	Email	Email (received 06:24)	Design flow rates and run cases
18	Samsung C&T	2/05/18	Email	Email (received 14:40)	Clarification of design flow rates
19	Samsung C&T	5/05/18	Seawater Discharge Pipelines	Discharge Pipeline [2017.05.10].pdf	Drawings for construction Plans, profiles, sections
20	Samsung C&T	5/05/18	Seawater Intake Pipeline	Seawater Intake Pipeline [2017.05.10]	Drawings for construction Plans, profiles, sections
21	Samsung C&T	20/06/18	Email	Email (received 06:20)	Clarification of discharge temperatures
22	DG-Europe (via Samsung C&T)	02/07/18	Flow diagrams for the various scenarios	(New RO Plant) Schematic Diagram for Recirculation Study	Spreadsheet containing flow diagrams
23	Samsung C&T	08/07/18	Email	Email (received 08:36)	Final clarification of discharge temperatures

3. Layout

The layout of the intake and outfall pipelines is the same as previously tested (HR Wallingford, 2015b). The proposed locations of the intake and outfall are shown in Figure 3.1 and are unchanged from the previous layout. The intake will be located offshore at the end of a 2500 m long pipeline, where the bed level is approximately -5.5 m QNHD. A submerged outfall will be located at the end of a 2000 m long pipeline, with a diffuser located at the seabed where the elevation is approximately -4.0 to -4.5 m QNHD.

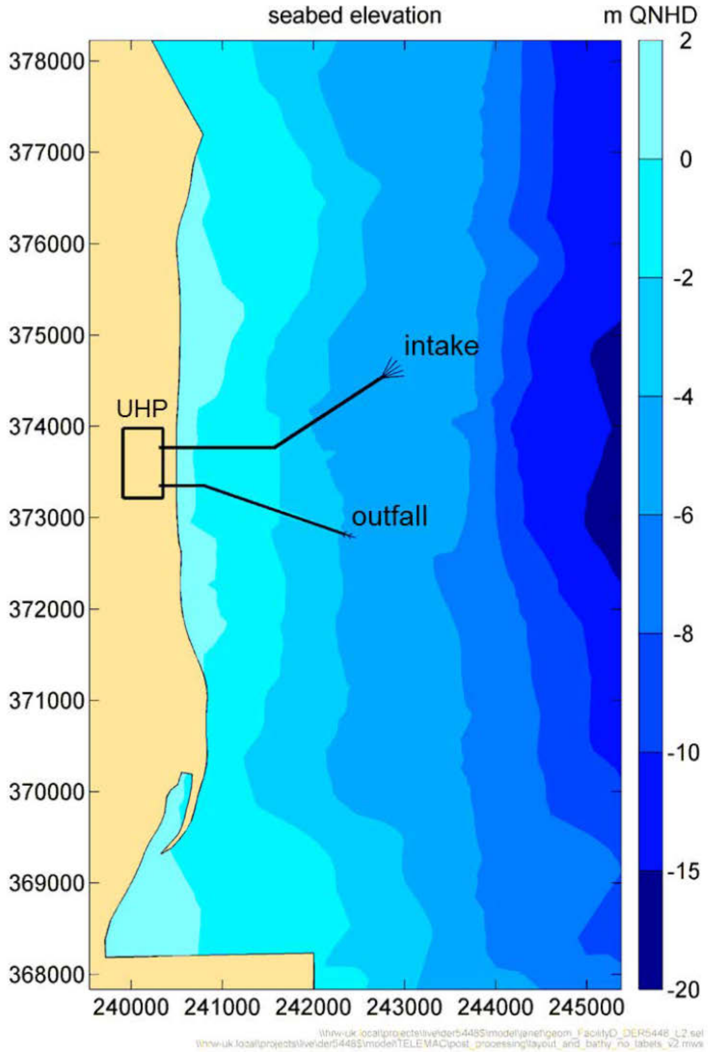

Figure 3.1: Intake and outfall locations

Source: Samsung C&T

The only difference from the previous simulations is the level of the crest of the rock armouring on both pipelines. On the intake pipeline, the crest height has been reduced from +1.36 m QNHD to +0.86 m QNHD for the section from 700 m to 1100m offshore from the pumping station (Figure 3.2), while the crest level on the armouring on much of the length of the outfall pipeline has been reduced from a maximum of +1.36 m QNHD to +0.86 m QNHD (References 19 and 20, Table 2.1) (see Figure 3.3).

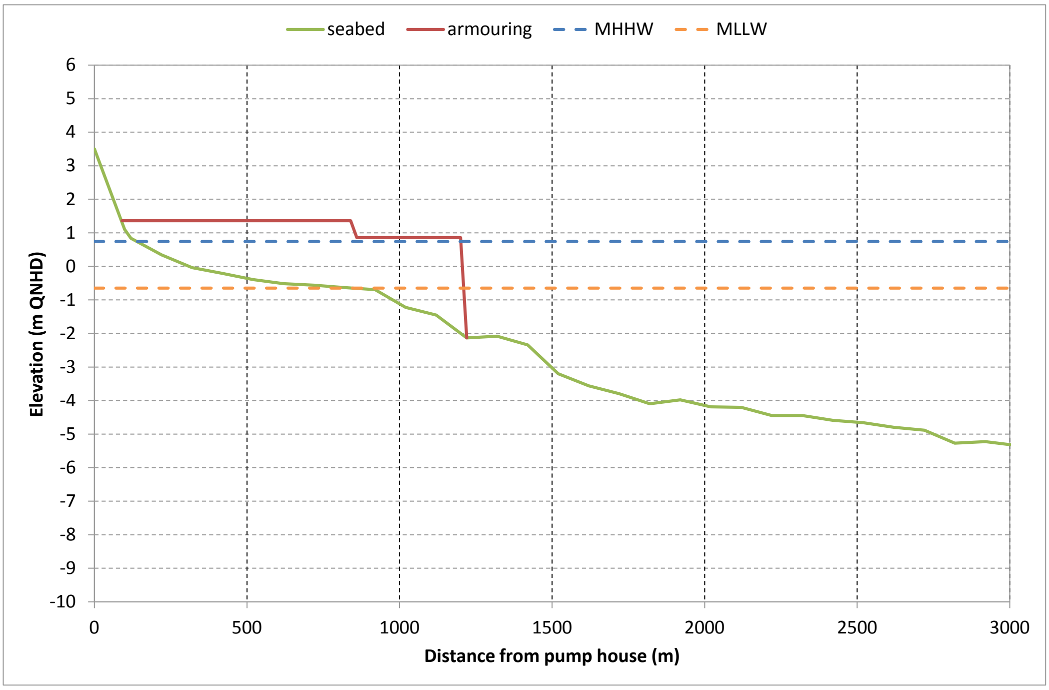

Figure 3.2: Profile of intake armouring

Source: Samsung C&T

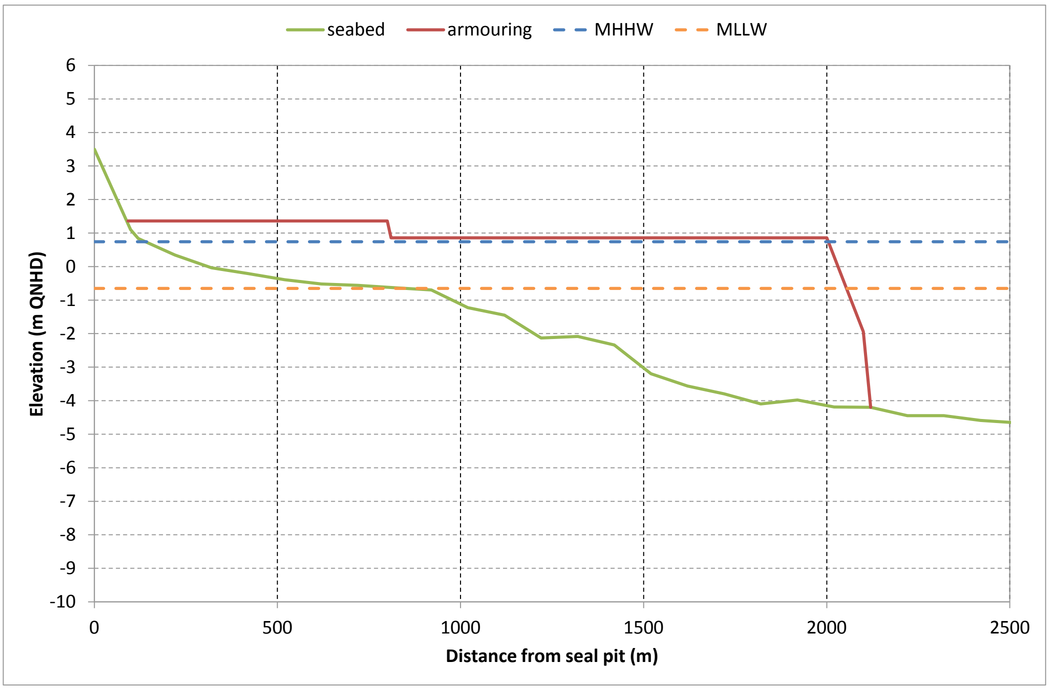

Figure 3.3: Profile of outfall armouring

Source: Samsung C&T

4. Model configuration

The calibrated TELEMAC-3D model used for the previous layout was updated to incorporate the revised intake and outfall pipeline armouring. The updated model bathymetry is shown in Figure 4.1. The vertical and horizontal mesh structure were unchanged.

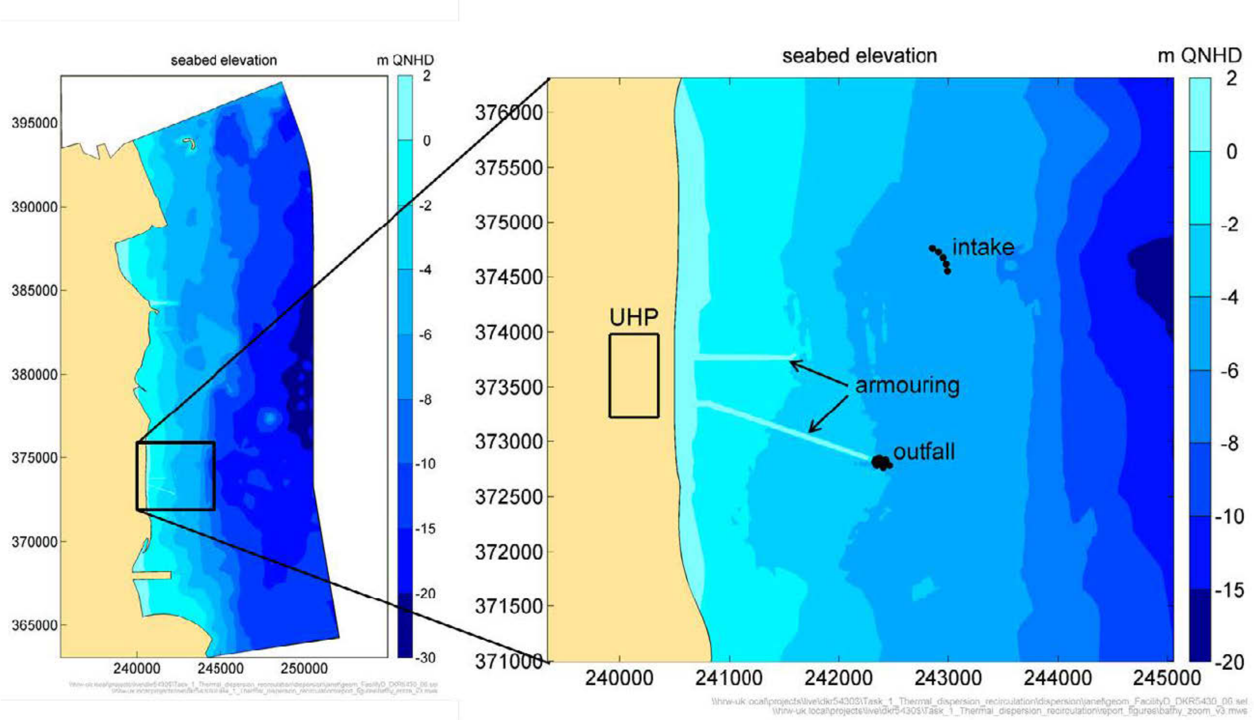

Figure 4.1: Model bathymetry – full extent and in the vicinity of the site

The boundary conditions developed for the calibration of the hydrodynamic model (HR Wallingford 2015a) were used in all simulations. These conditions include a spring-neap cycle with the smallest neap tides between days 8 and 12 and the largest spring tides between day 14 and the end of the simulation (see Figure 4.2).

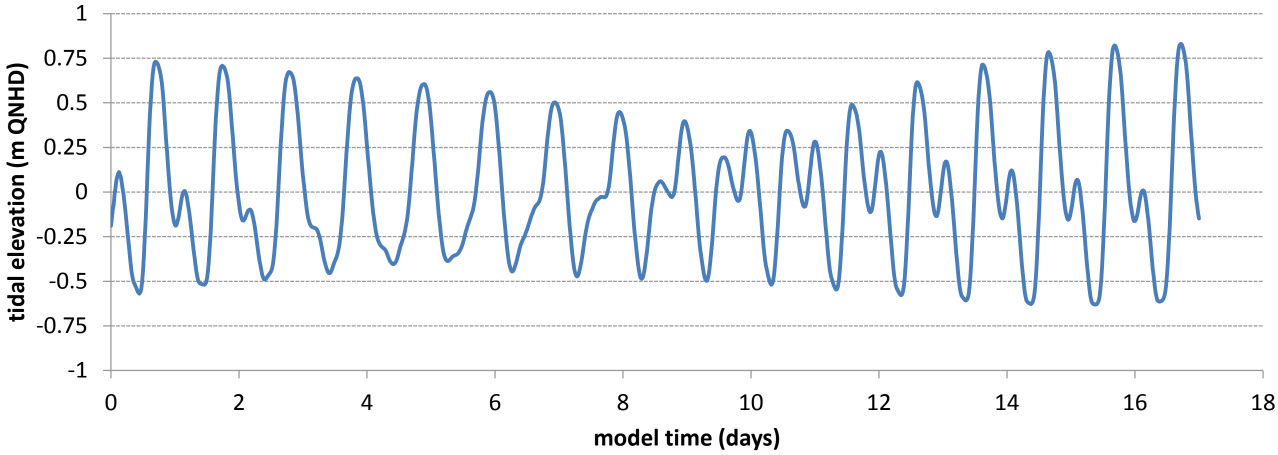

Figure 4.2: Model tidal elevation at the intake

The intake and outfall were represented with the same method used for the previous modelling.

The simulations include different combinations of four key facilities within the project:

- power plant;
- existing RO plant;
- multi-stage flash (MSF) desalination plant;
- additional new RO plant.

In future, reject brine from the existing and new RO plants will be reinjected into the Power Plant cooling water supply before being used by the Power Plant and pre mixed with the cooling water prior to discharge.

The proportion of the full capacity of each plant used in each of the four cases are shown in Table 4.1.

Table 4.1: Plant operation scenarios

	Proportion of plant full capacity in operation			
	Baseline	Case 1	Case 2a (summer)	Case 2b (winter)
Power plant	100%	100%	100%	50%
Existing RO plant	100%	100%	67%	100%
New RO plant	0	100%	67%	100%
MSF	100%	100%	100%	60%

The Baseline (or Original) condition corresponds to the operation previously modelled. However, as the layout of the armouring has been changed since the last modelling, the Baseline condition was re-run to ensure consistent comparisons with the future operations tests.

The same total intake flow rate was used for each case, 289,043 m^3/h (80.29 m^3/s). The discharge flow rates and input excess salinities are summarised in Table 4.2.

Table 4.2: Flow rates and salinity and temperature increases on discharge for each case

	Plant	Baseline	Case 1	Case2a	Case 2b
Discharge (m^3/hr)	Power[1]	159,200	159,387	159,325	79,787
	Stand-by STG/Condensers	0	0	0	79,600[2]
	Existing RO[3]	15,601	(15,601)	(10,400)	(15,601)
	Additional RO[3]	0	(15,629)	(10,419)	(15,629)
	MSF	81,962	81,962	81,962	49,177
	ACW[4]	6,200	6,200	6,200	6,200
	Total	262,963	247,552	247,488	214,767
Ambient salinity (ppt or kg/m^3)		45.9	45.9	45.9	45.9
Net ΔS (ppt or kg/m^3)		4.69	7.32	5.75	7.24
Net salt load (kg/s)		343	503	327	432
Ambient seawater temperature (°C)		35	35	38	18
Net ΔT (°C)		7.64	8.12	8.12	6.64[5]
Net thermal load (°C m^3/s)		558	558	558	396

Source: Samsung C&T

Notes: 1 This represents the flow to the operating power plant cooling systems including contributions from existing and additional RO plants in Cases 1, 2a and 2b

2 In Case 2b, 79,600 m^3/hr will be pumped through the stand-by STG/Condensers without any additional heat load or change in salinity

3 Figures in brackets for Additional RO Expansion are considered as negative contributions to the total power plant discharge

4 ACW is the auxiliary cooling water system

5 Net discharge excess temperature is as specified by Samsung C&T (References 21, Table 2.1). This should be 4.57°C (References 23, Table 2.1) but the modelling reported here is based on the higher value as agreed with Samsung C&T

Note that the discharge salinities for Cases 1 and 2b are significantly higher than the Baseline case or Case 2a. This means that the discharges in Cases 1 and 2b will be denser than the ambient conditions, while the other two cases will be near neutrally buoyant or slightly dense. The excess temperature used for Case 2b is higher than expected (see footnote to Table 4.2). However, the density of the plume is already dominated by the salinity, so that the salinity footprint is unlikely to be significantly different to that reported here.

Previously, the largest plume footprints were predicted during calm conditions with summer sea temperatures. For the present assessment, the simulations were all run for calm conditions but with different ambient seawater temperatures, as requested by Samsung C&T. The Baseline and Case 1 tests were run for a summer condition, Case 2a was run for high summer temperature, and Case 2b was for a winter temperature (as summarised in Table 4.2).

5. Results

The dispersion of the IWPP saline and heated water was simulated under the environmental conditions described in the previous chapter for each of the operational conditions. The simulations were run for 17 days to include a full spring-neap tidal cycle (15 days) with an initial two days to allow the model predictions to stabilize and reach a dynamic equilibrium. This is sometimes known as model “spin-up” time.

The pipeline armouring will affect the currents in the vicinity of the site. Simulated peak ebb and peak flood depth-averaged currents are shown in Figure 5.1 for a representative tide (day 12 to 13). The pipeline armouring forms a blockage to the flow causing a region of weak currents (< 0.1 m/s) to form. At the offshore end of the outfall pipeline the flows are accelerated.

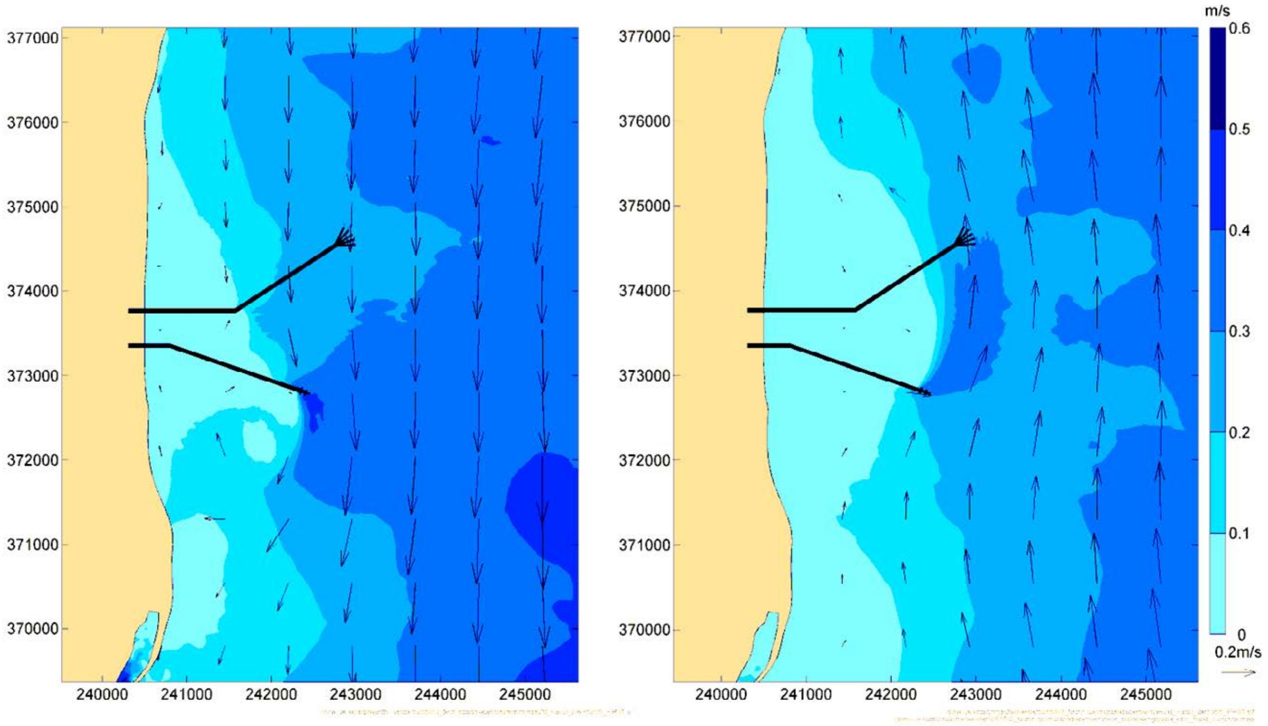

Figure 5.1: Simulated peak flood (left) and peak ebb (right) depth-averaged currents

5.1. Thermal/saline dispersion

5.1.1. Temperature and salinity limits

Qatar’s Ministry of Municipality and Environment (MME) specifies a threshold for temperature of 3°C above the ambient receiving water temperature. This temperature must not be exceeded at the edge of the mixing zone around the outfall. The MME regulations state that the size of the 3°C mixing zone should be determined from the ‘integrated vertical front’. This is understood to be the depth-averaged excess temperature. We have therefore calculated the average areas over which the depth-averaged excess temperature is above the mixing zone threshold in Section 5.1.4.

There are no specific local Qatari standards related to increases in salinity due to desalination plants. In the previous studies, the time-averaged excess salinity footprints were assessed at 10% of the background value at the seabed. This corresponds to an excess salinity of +4.59 ppt for the conditions assumed.

5.1.2. Predicted excess temperatures

Predicted maximum and average sea surface and sea bed excess temperatures were calculated over the last 15 days of the simulations. These are shown as contour plots in Figure 5.2 to Figure 5.5. The 3°C excess temperature contour is at the boundary between the yellow and blue areas.

As the combined discharges are denser than the receiving seawater, the largest footprints are predicted at the seabed. Smaller footprints are predicted at the water surface.

For the Baseline simulation, the mean +3°C contour extends a few hundred metres from the outfall at the seabed. The maximum predicted extents of the +3°C contour are around 5 km alongshore from the outfall and around 3 km offshore.

For the three future scenario tests, the maximum +3°C contour at the bed extends approximately 3-4 km alongshore from the outfall, and approximately 3 km offshore.

5.1.3. Predicted excess salinities

Contour plots of the maximum and mean excess salinities at the sea surface and seabed are shown in Figure 5.6 to Figure 5.9. The extent of the +5 ppt mixing zone (approximately 10% above the background salinity) is marked by the boundary between the blue and the light green colours.

As the excess salinity of the baseline discharge (+4.69 ppt) is only fractionally above the regulatory threshold (+4.59 ppt), the mixing zone for salinity will extend just a few metres from the outfall. The baseline mixing zone for salinity is therefore not visible in the plots, as it is too small to resolve accurately within a hydrodynamic model.

For the three future cases the maximum extent of the +5 ppt mixing zone is approximately 3 km alongshore from the outfall and 1.5 km offshore at the bed. There is a small zone near the outfall in all three future case, where the mean salinity exceeds +5 ppt at the bed.

5.1.4. Mixing zone areas

Thermal mixing zone areas calculated for all the cases are shown in Table 5.1. The areas were calculated from time-averaging the depth-averaged excess temperature over 15 days. For Cases 1 and 2b, the mixing zone is significantly smaller than the baseline case. In Case 2b, this is largely due to the reduced thermal heat load, while for Case 1 it is due to the fact the plume is now denser than the baseline and becomes more mixed through the depth.

Table 5.1: Areas over which the time-averaged and depth-averaged excess temperature exceeds 3°C

	Area (m^2)	Area (km^2)
Baseline	54795	0.05
Case 1 Summer, calm	20705	0.02
Case 2a Summer, calm	43359	0.04
Case 2b Winter, calm	5510	0.01

The footprint areas where average excess salinities exceed 10% above background are shown in Table 5.2. For the Baseline case, as the excess salinity of the discharge is only fractionally above the regulatory threshold, the mixing zone will extend just a few metres from the outfall. Case 1 and Case 2b have larger footprints than Case 2a, because they produce denser discharges that form thinner layers near the seabed.

For comparison, in the previous study an early operation condition was simulated with only the existing SWRO and the MSF plants operating. This produced a salinity footprint of 0.06 km^2.

Table 5.2: Areas over which the time-averaged near bed excess salinity exceeds 10% of background salinity

	Area (m^2)	Area (km^2)
Baseline	negligible	negligible
Case 1 Summer, calm	85589	0.09
Case 2a Summer, calm	15540	0.02
Case 2b Winter, calm	68638	0.07

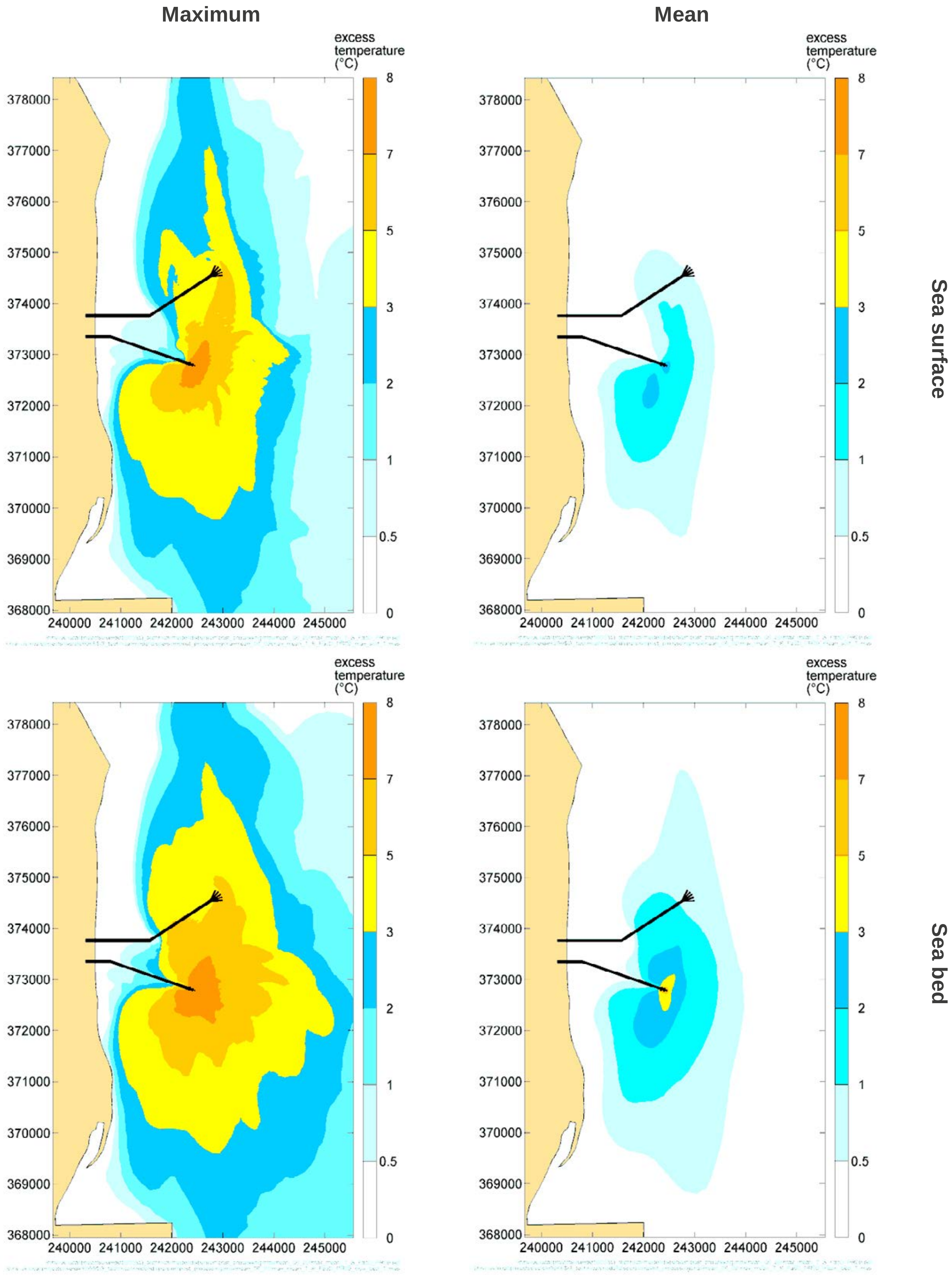

Figure 5.2: Maximum and mean sea surface and sea bed excess temperature, summer, calm, Baseline

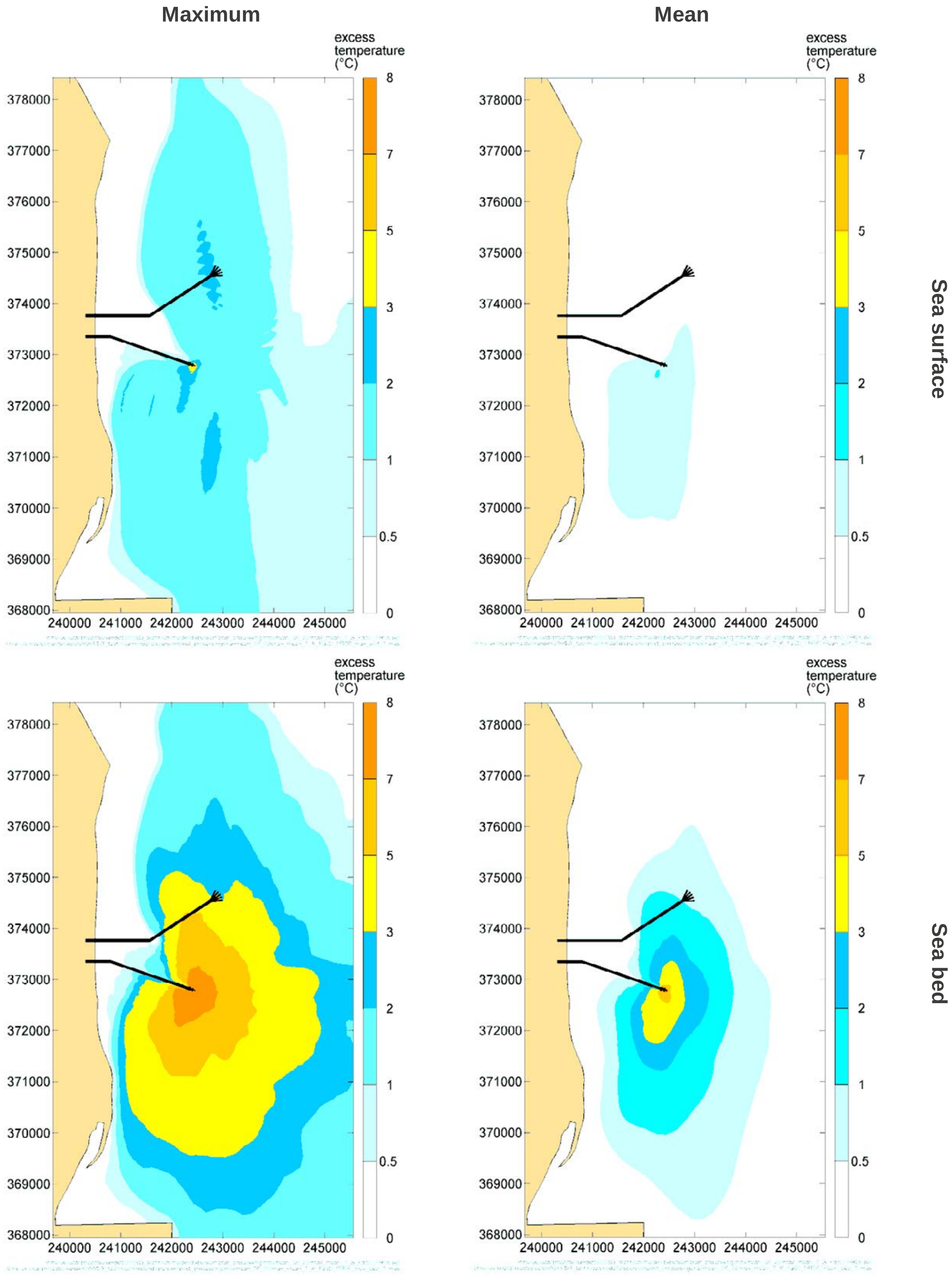

Figure 5.3: Maximum and mean sea surface and sea bed excess temperature, summer, calm, Case 1

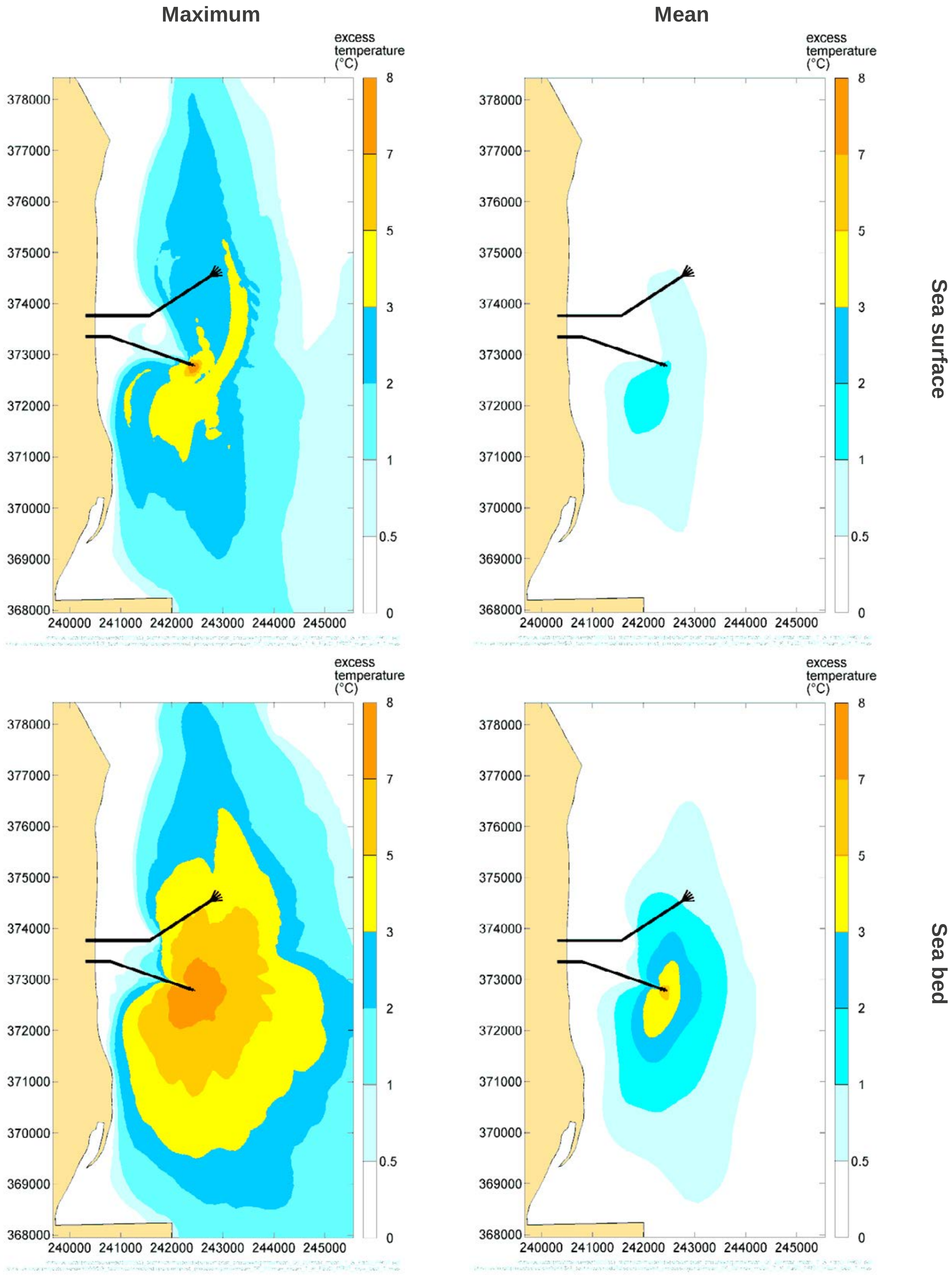

Figure 5.4: Maximum and mean sea surface and sea bed excess temperature, summer, Case 2a

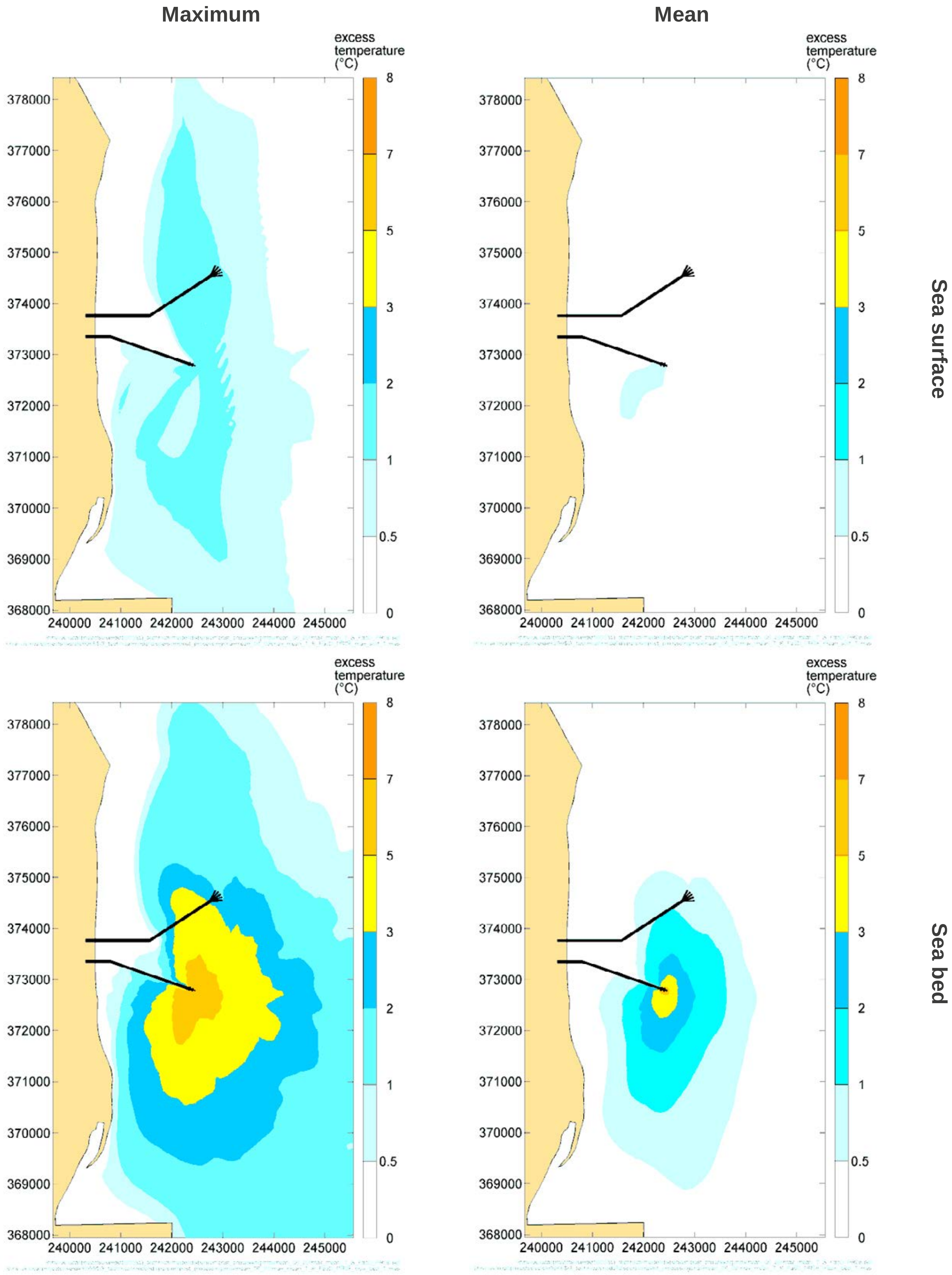

Figure 5.5: Maximum and mean sea surface and sea bed excess temperature, winter, calm, Case 2b

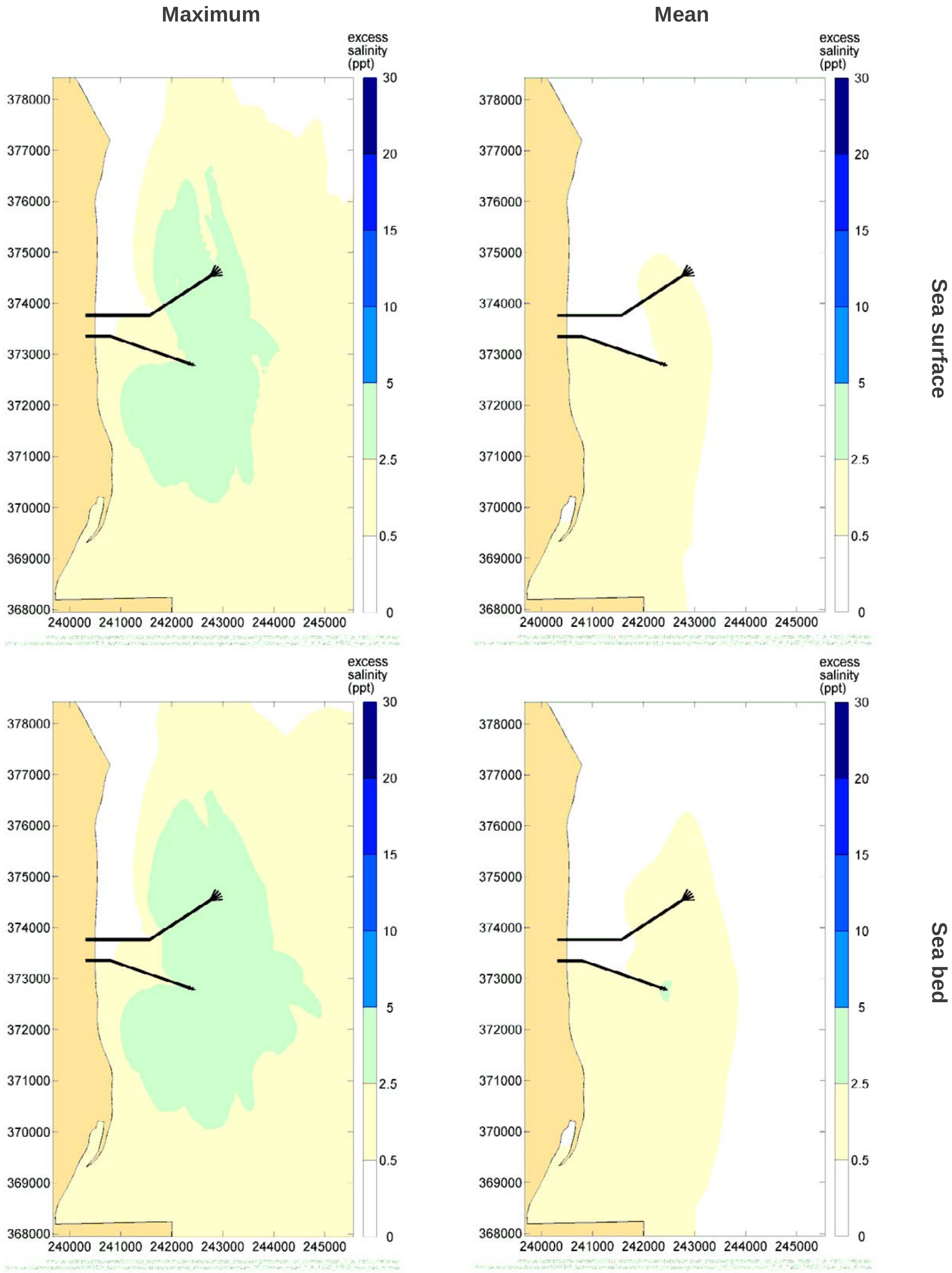

Figure 5.6: Maximum and mean sea surface and sea bed excess salinity, summer, calm, Baseline

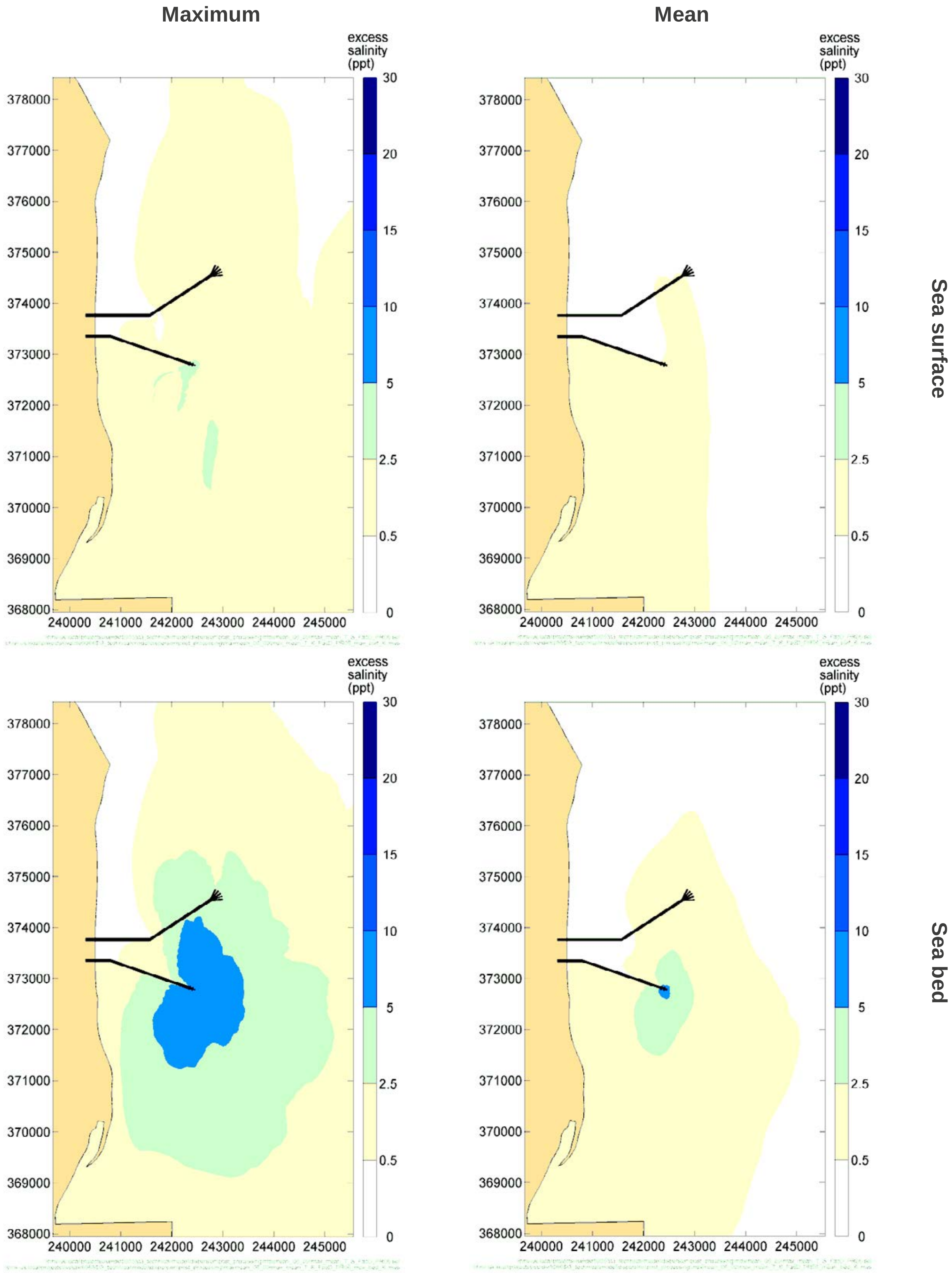

Figure 5.7: Maximum and mean sea surface and sea bed excess salinity, summer, calm, Case 1

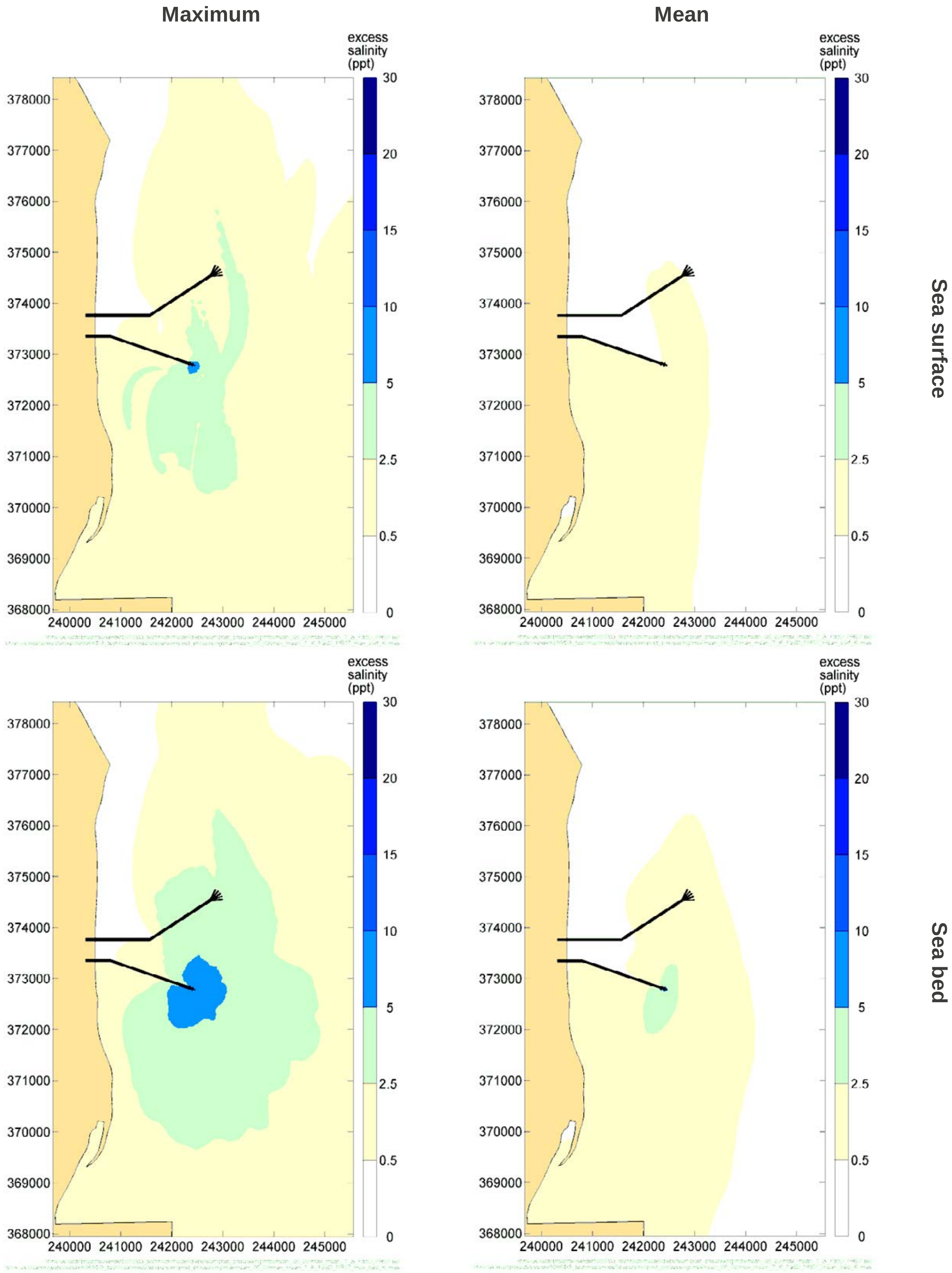

Figure 5.8: Maximum and mean sea surface and sea bed excess salinity, summer, Case 2a

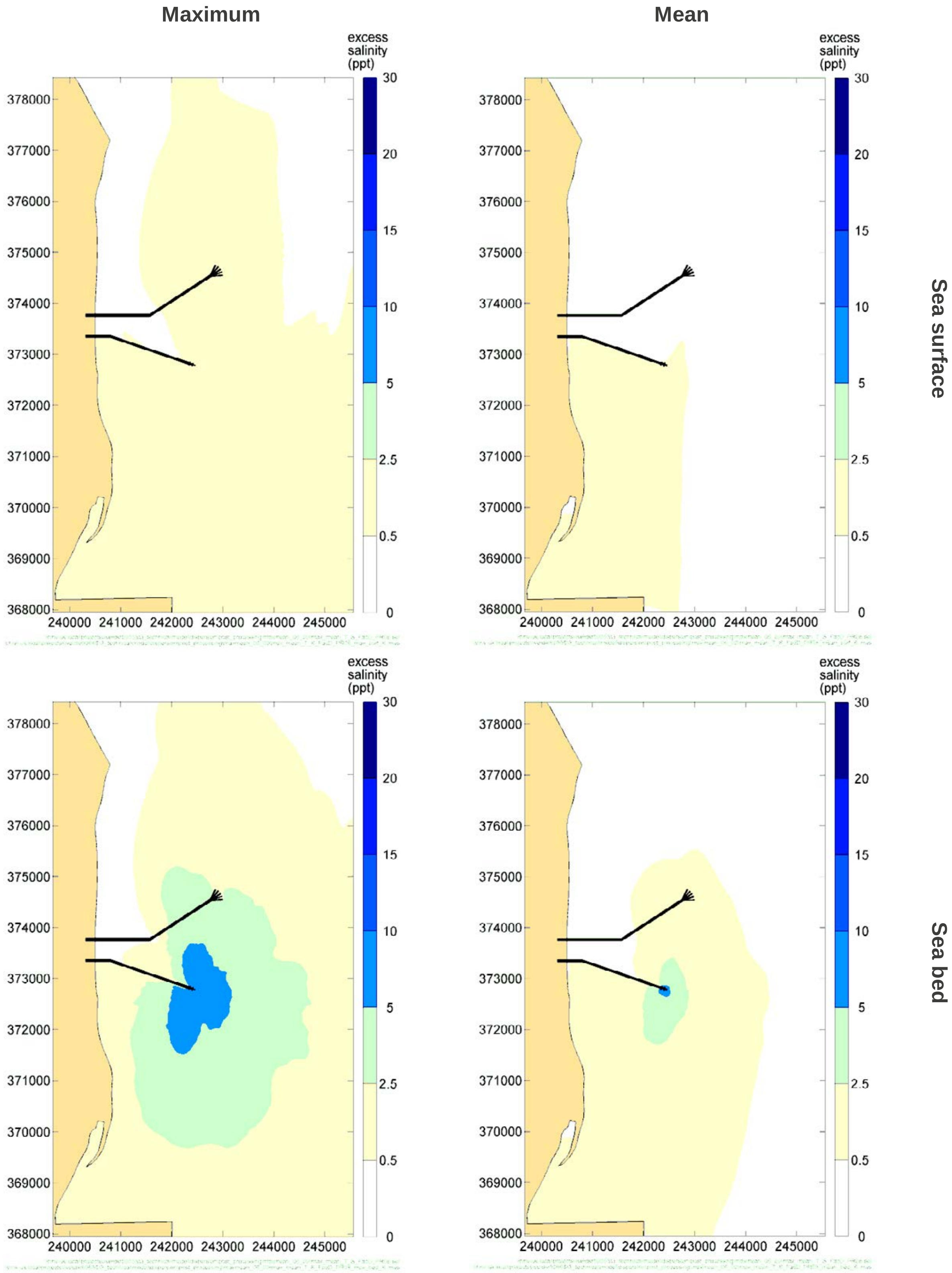

Figure 5.9: Maximum and mean sea surface and sea bed excess salinity, winter, calm, Case 2b

5.2. Recirculation assessment

During the normal operation phase five intake pipelines will be operational. The southernmost pipeline will draw seawater for desalination and the other four pipelines will draw cooling water for power generation (Figure 5.10). Results are presented separately for the RO intake and the cooling water (CW) intakes. The results at the CW intakes are an average of the values at the four individual intakes.

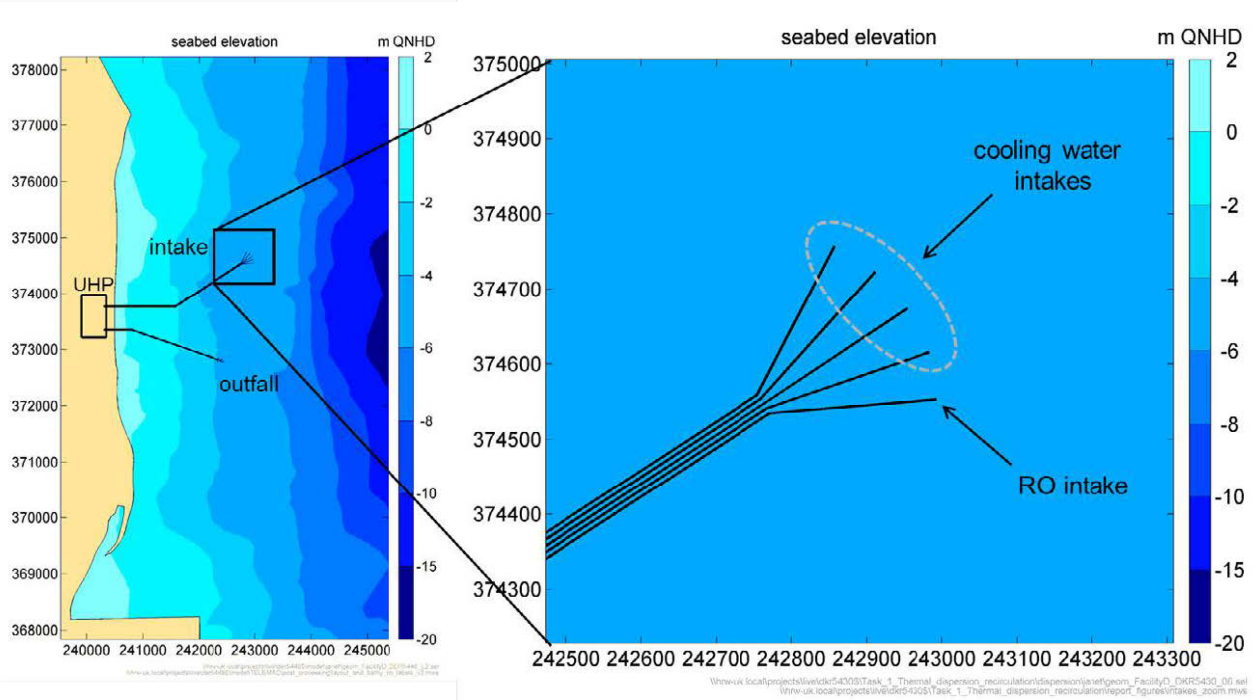

Figure 5.10: Intake streams

Maximum and average excess temperatures and salinities at the CW intakes are shown in Table 5.3 to Table 5.6. Recirculation levels are highest for the Baseline case with maximum temperatures of up to 3.8°C. Lower values are predicted for the future cases. The average excess temperature is less than 1°C in all cases. This is similar to the average excess temperature at the intakes predicted for the previous layout. Maximum excess salinities at the CW intakes are 2-3 ppt for the Baseline, with lower excess salinities (1.5 to 2.4 ppt) predicted for the future cases. Average excess salinities are relatively low and no more than 0.6 ppt.

The maximum and average excess temperatures and salinities at the RO intake are shown in Table 5.7 to Table 5.10 The average excess temperatures and salinities are similar to those predicted at the CW intakes. The maximum values are predicted to be higher, as the RO intake is slightly closer to the outfall. Baseline maximum excess temperatures are up to 5.5°C and maximum excess salinities up to 3.7 ppt. Again the results for the future cases are lower than the Baseline.

Time series of excess temperature and excess salinity at the CW intakes are presented in Figure 5.11 to Figure 5.14 for all four cases. The time series are broadly similar with a sequence of peaks of around 8-10 hours' duration generated during the north-going ebb phase of the tide.

Time series of excess temperatures and salinities at the RO intake are shown in Figure 5.15 to Figure 5.18. They indicate higher peak recirculation values than at the CW intakes.

Table 5.3: Maximum excess temperature (°C) at the CW intakes

	Baseline	Case 1	Case 2a	Case 2b
Depth-averaged	2.9	1.9	2.3	1.1
Near-surface	3.2	1.9	2.7	1.0
Mid-depth	3.4	2.2	2.7	1.4
Near-bed	3.8	2.4	3.0	1.7

Table 5.4: Average excess temperature (°C) at the CW intakes

	Baseline	Case 1	Case 2a	Case 2b
Depth-averaged	0.4	0.3	0.4	0.2
Near-surface	0.4	0.3	0.4	0.2
Mid-depth	0.5	0.4	0.4	0.3
Near-bed	0.6	0.5	0.6	0.4

Table 5.5: Maximum excess salinity (ppt) at the CW intakes

	Baseline	Case 1	Case 2a	Case 2b
Depth-averaged	2.2	2.0	2.0	1.4
Near-surface	2.5	2.1	2.3	1.4
Mid-depth	2.6	2.3	2.3	1.7
Near-bed	2.7	2.4	2.3	2.1

Table 5.6: Average excess salinity (ppt) at the CW intakes

	Baseline	Case 1	Case 2a	Case 2b
Depth-averaged	0.4	0.4	0.4	0.3
Near-surface	0.4	0.4	0.4	0.3
Mid-depth	0.5	0.5	0.4	0.3
Near-bed	0.5	0.6	0.6	0.5

Table 5.7: Maximum excess temperature (°C) at the RO intake

	Baseline	Case 1	Case 2a	Case 2b
Depth-averaged	5.4	2.2	2.8	1.4
Near-surface	5.3	1.8	2.6	1.1
Mid-depth	5.4	2.3	2.9	1.5
Near-bed	5.5	2.6	3.7	1.9

Table 5.8: Average excess temperature (°C) at the RO intake

	Baseline	Case 1	Case 2a	Case 2b
Depth-averaged	0.6	0.5	0.5	0.3
Near-surface	0.5	0.3	0.4	0.2
Mid-depth	0.6	0.4	0.5	0.3
Near-bed	0.7	0.7	0.7	0.5

Table 5.9: Maximum excess salinity (ppt) at the RO intake

	Baseline	Case 1	Case 2a	Case 2b
Depth-averaged	3.6	2.4	2.5	1.7
Near-surface	3.6	2.0	2.4	1.5
Mid-depth	3.6	2.5	2.5	1.8
Near-bed	3.7	2.6	2.8	2.3

Table 5.10: Average excess salinity (ppt) at the RO intake

	Baseline	Case 1	Case 2a	Case 2b
Depth-averaged	0.5	0.5	0.5	0.4
Near-surface	0.5	0.4	0.4	0.3
Mid-depth	0.5	0.5	0.5	0.4
Near-bed	0.6	0.8	0.7	0.6

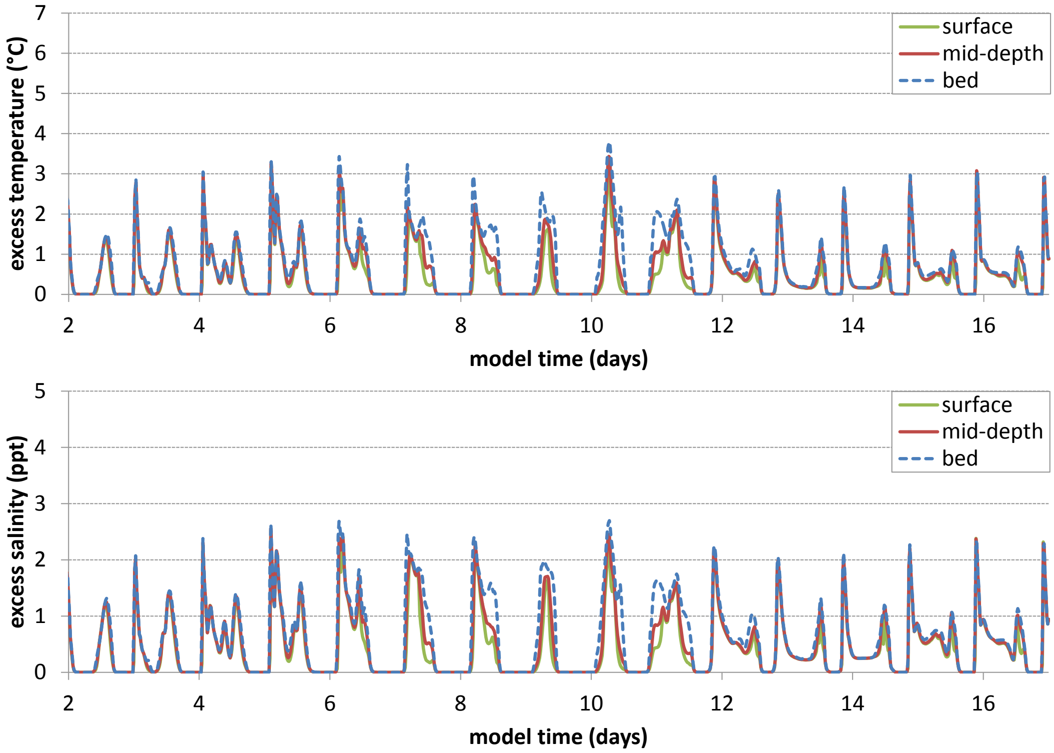

Figure 5.11: Excess temperature and salinity at the CW intakes, summer, calm, Baseline

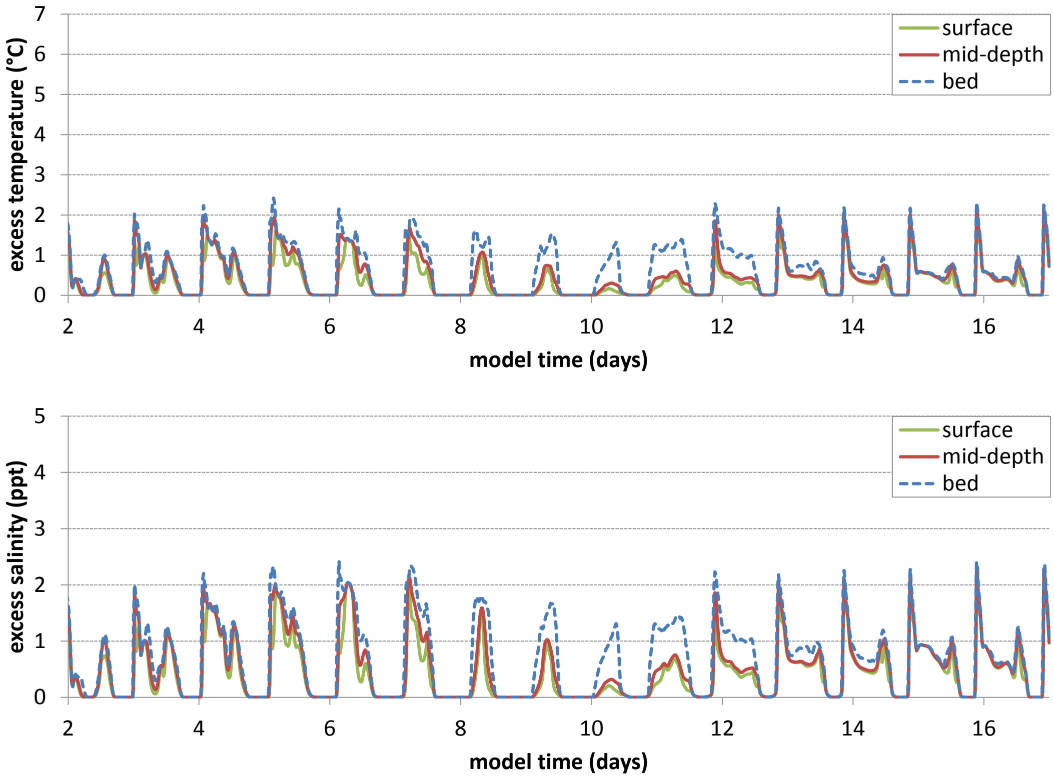

Figure 5.12: Excess temperature and salinity at the CW intakes, summer, calm, Case 1

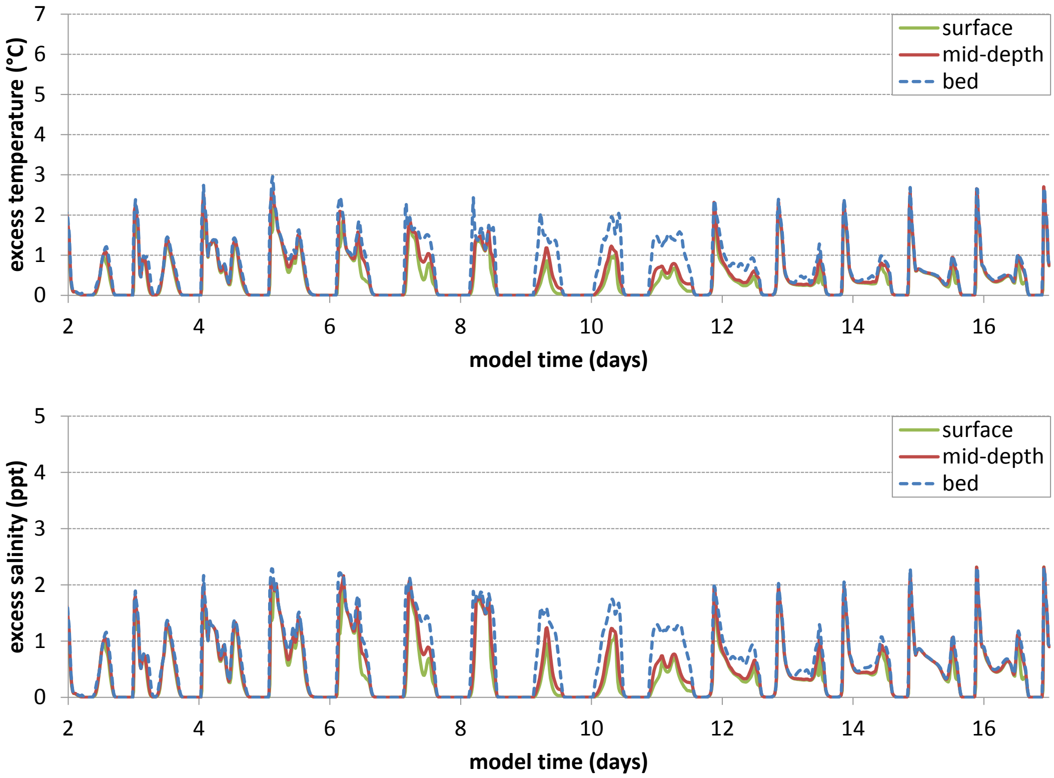

Figure 5.13: Excess temperature and salinity at the CW intakes, summer, calm, Case 2a

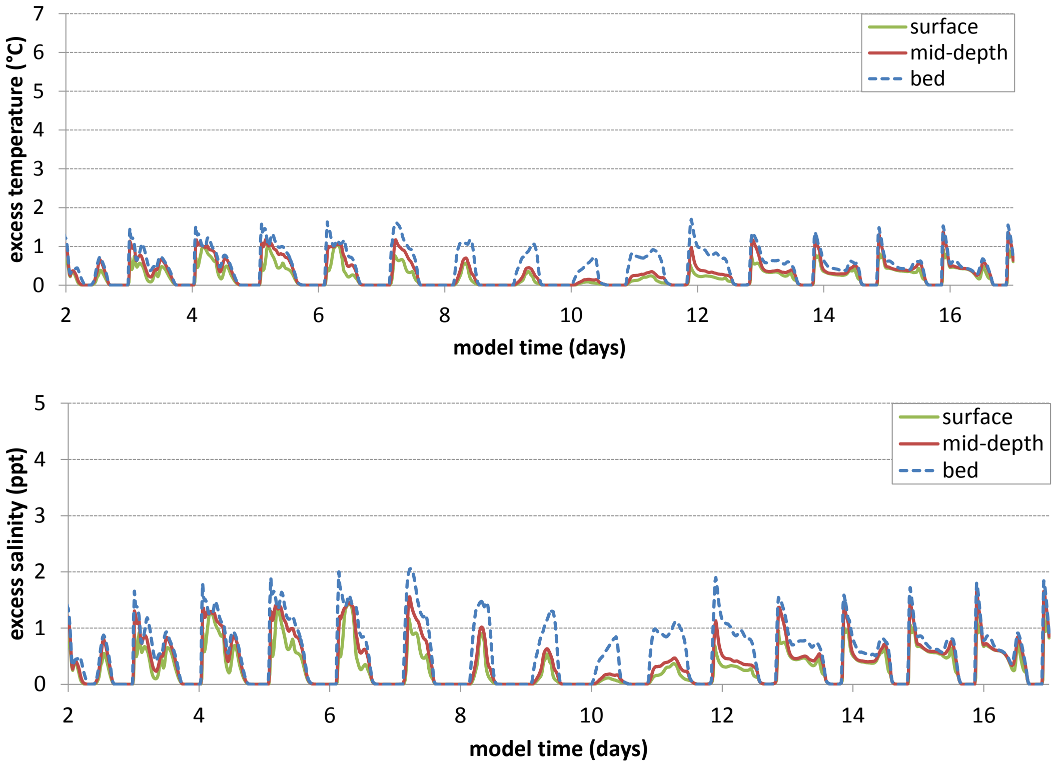

Figure 5.14: Excess temperature and salinity at the CW intakes, winter, calm, Case 2b

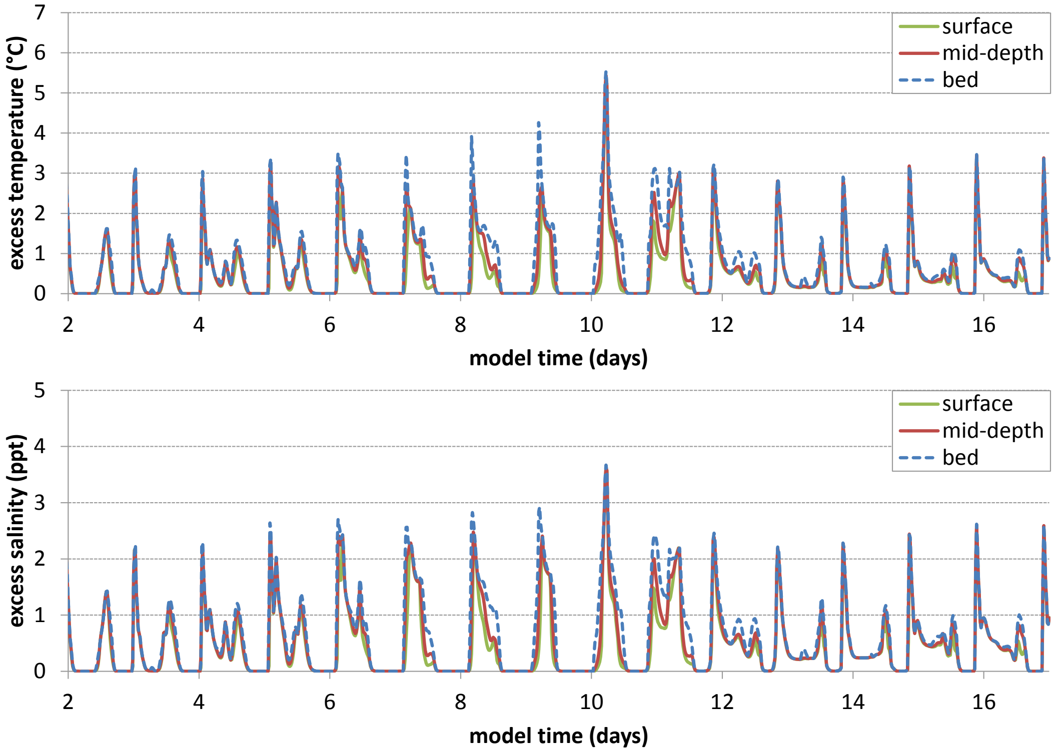

Figure 5.15: Excess temperature and salinity at the RO intake, summer, calm, Baseline

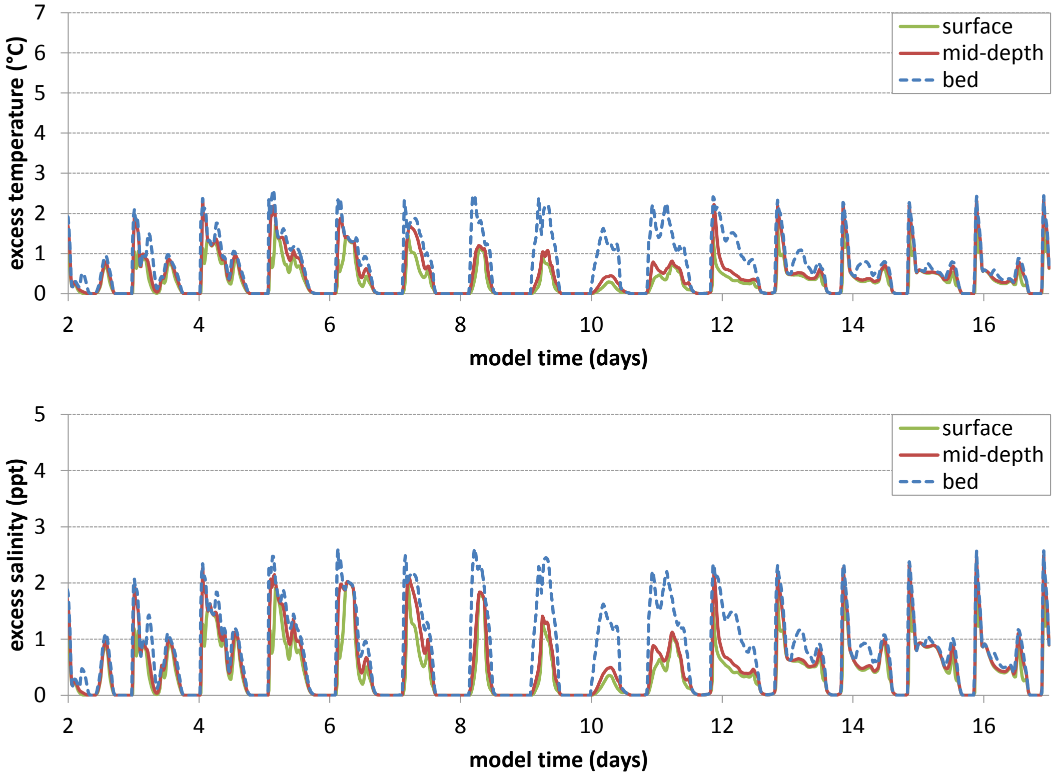

Figure 5.16: Excess temperature and salinity at the RO intake, summer, calm, Case 1

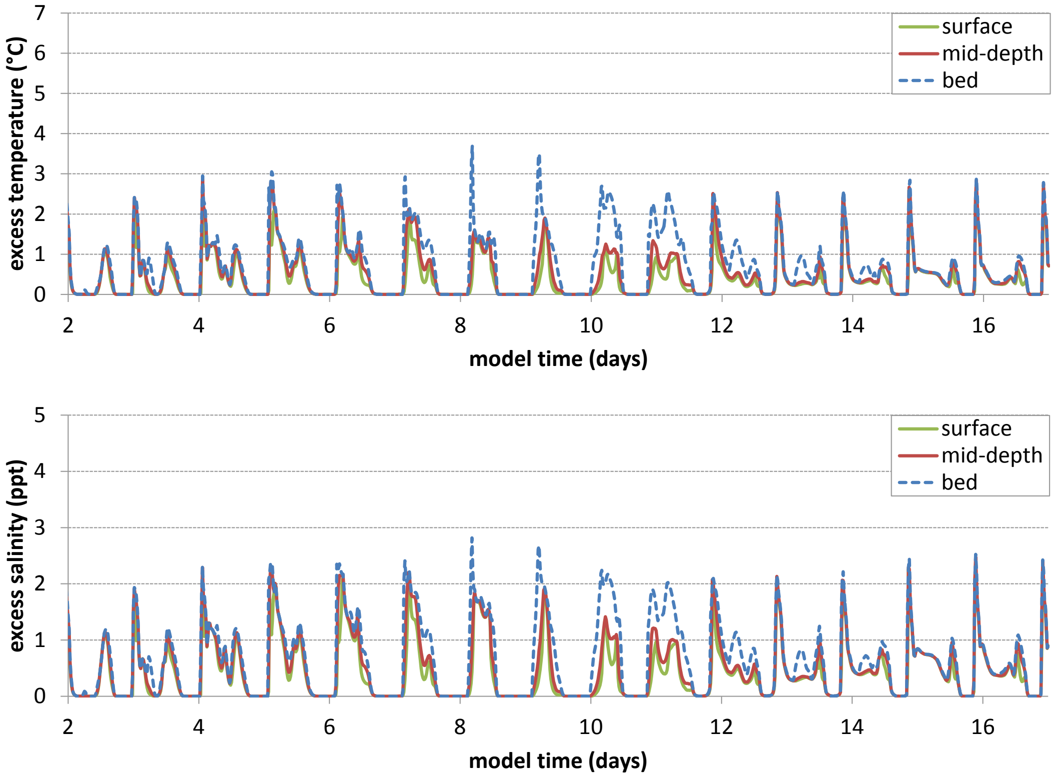

Figure 5.17: Excess temperature and salinity at the RO intake, summer, calm, Case 2a

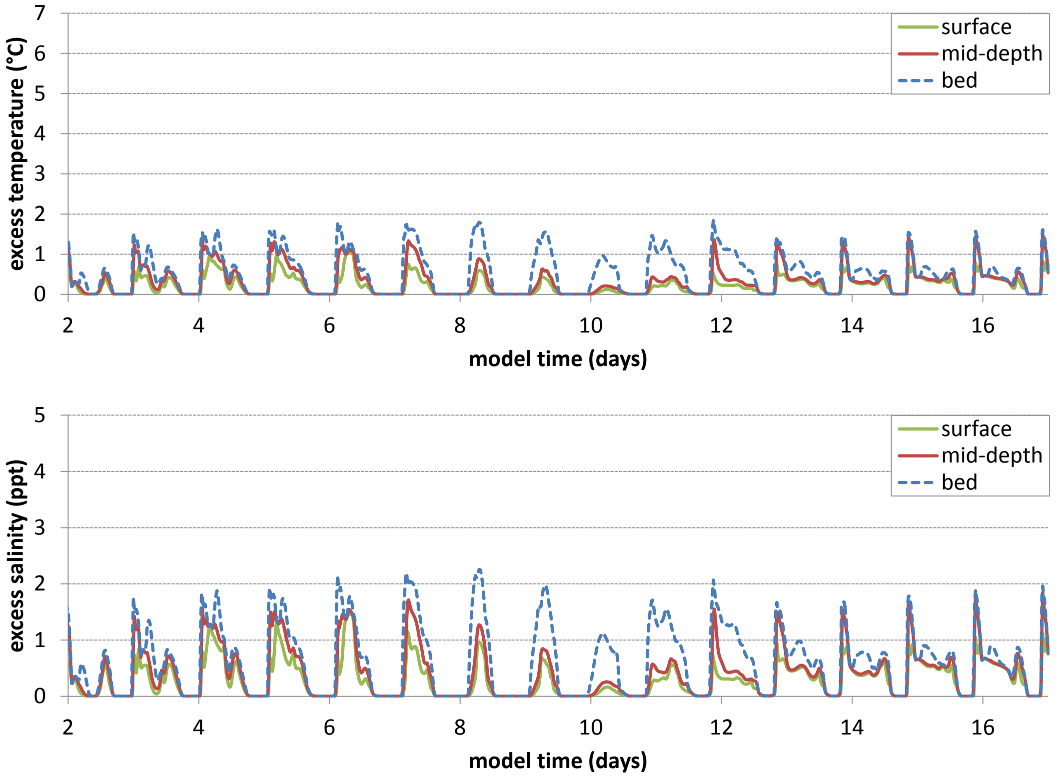

Figure 5.18: Excess temperature and salinity at the RO intake, summer, calm, Case 2b

6. Conclusions

The thermal-saline dispersion model developed during the initial design of Umm Al Houl IWPP has been applied to assess the effects of an additional SWRO plant on temperature and salinity footprints. Three potential future operating conditions were tested, plus a Baseline case representing the previous operational case without the new RO plant.

The main conclusions are:

Environmental compliance

- Temperature:
  - With all plants operating at full capacity (Case 1), the depth-averaged thermal footprint (0.02 km^2) would be smaller than for the Baseline case (without the additional RO plant (0.05 km^2)). The plume will tend to form a denser layer at the bed rather than being relatively well-mixed through the water column. The denser discharge will tend to form a dense plume near the bed rather than being relatively well-mixed through the water column. That behaviour combined with slightly reduced discharge rate leads to a smaller depth-averaged excess temperature footprint.
  - For the case with power plant operation at full capacity and both existing and future RO operating at 67% capacity (Case 2a), the plume will be slightly less dense than the ambient and will produce a larger depth-averaged thermal footprint (0.04 km^2) than the other two cases (Cases 1 and 2b).
  - In the case with reduced discharge from the power plant (Case 2b), the thermal footprint (0.01 km^2) will be reduced compared to the full operation cases.
- Salinity:
  - The Baseline discharge salinity is only slightly more than 10% above the background. Therefore, only a small area around the outfall will have salinities greater than 10% above background.
  - For Cases 1 and 2b, the plume will form a denser layer at the bed. The average extent of the area with salinities more than 10% above background is predicted to be up to 0.09 km^2 in these cases.
  - For Case 2a, with a smaller volume of reject brine from the RO plant, the plume is more mixed through the depth. The average extent of the area with salinities more than 10% above background is predicted to be less than 0.02 km^2.

Recirculation

- Temperature:
  - Predicted maximum excess temperatures at the cooling water intakes are reduced compared to the Baseline by 1-2°C.
  - Predicted maximum excess temperatures at the RO intake are reduced compared to the Baseline by up to 3°C.
  - In all cases the mean excess temperature at both sets of intakes will be similar to the Baseline case (~ 0.5°C).
- Salinity:
  - Predicted maximum excess salinities at the cooling water intakes are reduced compared to the Baseline by 0.5-1 ppt.
  - Predicted maximum excess salinities at the RO intake are reduced compared to the Baseline by 1-1.5 ppt.

- In all cases predicted mean excess salinities at both sets of intakes are similar to the Baseline case (~0.5 ppt).

7. References

HR Wallingford (2015a). Umm Al Houl Power, Qatar. Recirculation & thermal dispersion studies. DKR5430-RT001-R02-00.

HR Wallingford (2015b). Umm Al Houl Power, Qatar. Recirculation & thermal dispersion studies: Revised layout. DKR5430-RT007-R02-00.

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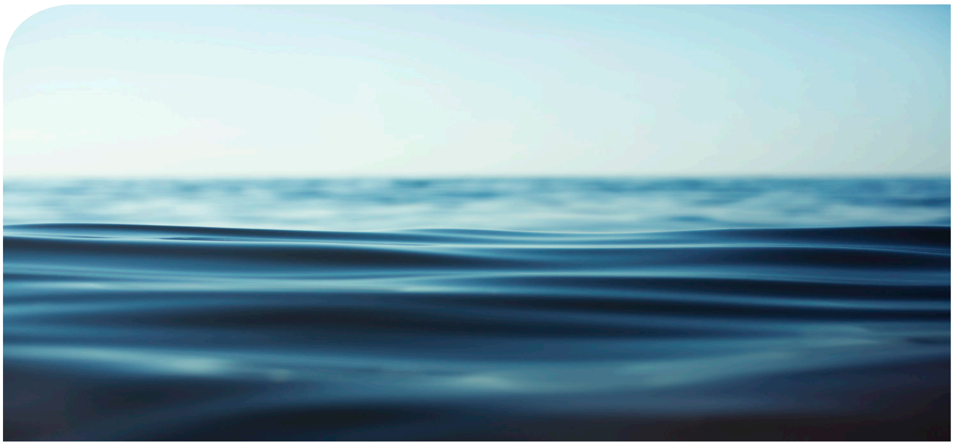

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