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Sizewell Thermal Plume Modelling: GETM Stage 3 results with the preferred SZC cooling water configuration

Edition 3

Sizewell Thermal Plume Modelling: GETM Stage 3 results with the preferred SZC cooling water configuration.

Edition 3

Tiago Silva, Liam Fernand and
Berrit Bredemeier

Version and Quality Control

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List of Tables and Figures

Tables

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Executive summary

This report presents the results of the Stage 3 Sizewell thermal plume modelling of the preferred Sizewell C (SZC) cooling water configuration using the General Estuarine Transport Model (GETM).

Changes to the report since Edition 3 Prel A of TR302 (dated 28/9/2015)

This Edition 3 Prel B report provides a response to draft comments received on the Edition 3 Prel A version of the report from the Environment Agency (EA) of 16th December 2015 and in the Level 4 WDA conference call with the EA of 17th December 2015. In particular this report contains:

i. a revision of section 4.2;

ii. an extended analysis of potential thermal barriers to fish migration with additional evidence in section 4.2.3;

iii. clarification of the proposed methodology to be adopted to determine whether there are potential ecological effects in the areas of exceedance of existing thermal standards in section 4.4; and

iv. consequential changes to the Executive Summary.

Background

In the Sizewell Stage 1 modelling (BEEMS Technical Reports TR132, TR229) the setup of 2 different plume models was described and the simulated Sizewell B discharge was validated against observations. Stage 2 modelling (BEEMS Technical Report TR133, TR230) used the validated models to test initial Cooling Water (CW) configurations for the proposed SZC power station. The Stage 2a review (BEEMS Technical Report TR301) critically reviewed the performance of the models and selected the GETM model as the primary tool for assessing thermal plume effects as it was shown to produce the most accurate predictions and also to be the most conservative. An extended set of options for the selection of the SZC outfall location were then analysed and a preferred location identified on the basis of recirculation and environmental concerns – location O9 offshore of the Sizewell-Dunwich Bank (Figure 1).

This Stage 3 report presents simulations of the thermal plume for the preferred CW configuration (Configuration 12) with offshore intakes at I3 and I4 and two offshore outfalls at O9a and O9b (see Figure 1). The geotechnical data necessary to finalise the location of the outfall structure is not yet available. In TR301 the location O9 was selected as the furthest west that a SZC offshore discharge could be built. Modelling demonstrated that outfall locations further east would produce lower thermal effects and that O9 could be considered as bracketing the worst case option for environmental assessment purposes.

Sizewell B (SZB) will be operational until at least 2035 and therefore the modelling undertaken in this study is of the in combination effects of SZB and SZC. The Sizewell C cooling water system modelled in this report represents a realistic CW configuration with a total of 4 intake heads and 2 outfall heads instead of the one modelled in TR301. Outfall O9a is at the previous O9 location and O9b is 75m further east.

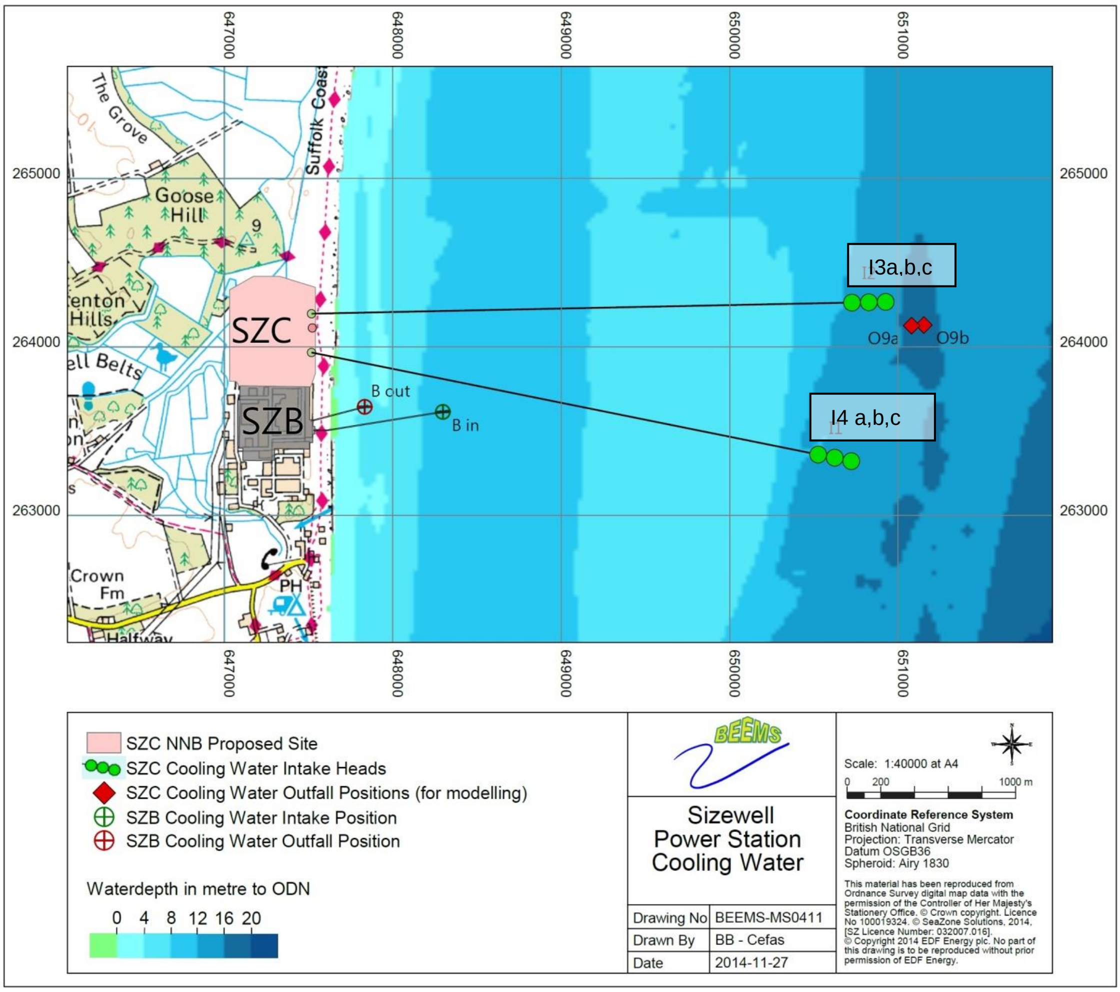


Figure 1 – Location of Sizewell B and preferred Sizewell C cooling water structures.

Modelled Sizewell plume results compared with thermal standards

The SZC and SZB plumes are separate at high plume temperatures but at lower temperatures, the SZC plume acts to increase the size and temperature of the SZB plume at the surface and the seabed (BEEMS Technical Report TR301). This means that examination of the thermal effects of SZC under the Water Framework Directive becomes an examination of the effects of the magnified Sizewell B plume (the Sizewell C plume is smaller and largely outside the WFD offshore limit).

Unlike chemical standards which normally have a clear evidence link to ecological effects, thermal standards are not always evidence based due to a lack of reliable data (BEEMS SAR008, Wither *et al*, 2012). In order to be protective of the most sensitive species, thermal standards have, therefore, been set on an indicative basis and, as such, they act as trigger values for further investigation of potential ecological effects.

The SZB and SZC discharge plumes intersect with two designated marine areas: the Outer Thames Special Protected Area (SPA) and the Suffolk Coastal Water Body under the Water Framework Directive (WFD). The magnified SZB plume marginally intersects with the Alde-Ore and Blyth(S) transitional waterbodies but modelling has demonstrated this does not cause exceedance of existing thermal standards in these areas.

a. *Habitat Regulation standards*

The thermal thresholds for marine SPAs are:

SPA	
Annual 98th %ile temperature	≤ 28ºC
Annual maximum uplift as a 100%ile	≤ 2ºC

The maximum uplift criteria applied to instantaneous plume temperatures at an hourly time step over a full yearly cycle with natural meteorological variability results in exceedance over a large area (9,368 ha at the surface for SZB and 22,452 ha for SZB+SZC, see Table 1), which according to WKTAG160 triggers the need for further evaluation of potential environmental impacts in those areas.

The area that exceeds the 28°C threshold is negligible (Table 1).

Table 1 Area values of the Outer Thames SPA (379771.66 ha) where the Habitats Regulation temperature thresholds are exceeded.

Model run	Position		Max excess temp. >2°C (100%ile)	98th %ile >28°C. Calculated from mean excess temp. >8.6°C	98th %ile >28°C Calculated using GETM absolute temperatures (**Not accurate, GETM absolute temperatures are over estimates**)
ReferenceV2 annual SZB	Surface	ha	9,368	0	0.75
		%	2.47	0	<0.01
	Seabed	ha	5,217	0	0
		%	1.37	0	0
Conf12 annual SZB+SZC	Surface	ha	22,452	0.13	4.31
		%	5.91	<0.01	<0.01
	Seabed	ha	16,444	0	1.44
		%	4.33	0	<0.01

Note: BEEMS Technical Report TR301 has demonstrated GETM absolute temperature predictions are overestimates (last column above)

b. *Water Framework Directive standards*

The thermal thresholds for marine waterbodies under WFD are:

WFD	High	Good	Moderate
Annual 98th percentile temperature	< 20ºC	20ºC < T ≤ 23ºC	23 ºC < T ≤ 28ºC
Annual maximum uplift as a 98%ile	≤ 2ºC	2ºC < Uplift ≤ 3ºC	Uplift > 3ºC

The WFD uplift criteria was assessed using the modelled excess temperature which is the difference in instantaneous temperature values between an effect run and the control run (no power station).

The area of the Suffolk Coastal waterbody exposed to temperatures >28 °C as a 98%ile is negligible and therefore the risk of lethality to marine species is not an issue of concern; indeed only 26ha of the seabed is exposed to temperatures >23 °C (the WFD Good threshold) (Table 2).

Application of the 3°C excess temperature standard shows that 1552 ha (10.6% of the waterbody area) at the seabed and 1862 ha (12.7% of the waterbody area) exceed the threshold and will, therefore, need to be subject to further investigation to determine whether there are consequential ecological effects (Table 3)

Table 2 Area values of the Suffolk Coastal waterbody (14653.59 ha) where the Water Framework Directive temperature standards are exceeded (absolute temperature)

Model run	Position		98th %ile >23°C. Calculated from mean excess temp.>3.6°C (Area above GOOD threshold)	98th %tile >28°C. Calculated from mean excess temp.>8.6°C	98th %ile absolute. temp >23°C (**Not accurate, GETM absolute temperatures are over estimates**)	98th %ile absolute temp. >28°C (**Not accurate, GETM absolute temperatures are over estimates**)
ReferenceV2 annual SZB	Surface	ha	26.5	0	292.81	0.75
		%	0.18	0	2.00	<0.01
	Seabed	ha	0.75	0	73.06	0
		%	<0.01	0	0.50	0
Conf12 annual SZB+SZC	Surface	ha	89.26	0.13	433.21	4.31
		%	0.61	<0.01	2.96	0.03
	Seabed	ha	25.75	0	144.80	1.44
		%	0.18	0	0.99	0.01

Note: BEEMS Technical Report TR301 has demonstrated GETM absolute temperature predictions are overestimates (last 2 columns above)

Table 3 Area values of the Suffolk Coastal waterbody (14653.59 ha) where the Water Framework Directive temperature standards are exceeded (temperature uplift)

Model run	Position		Excess temp. >2°C as a 98%ile	Excess temp. >3°C as a 98%ile (Area above GOOD threshold)
ReferenceV2 annual SZB	Surface	ha	2,433	1,264
		%	16.6	8.6
	Seabed	ha	2,128	669
		%	14.5	4.6
Conf12 annual SZB+SZC	Surface	ha	4,136	1,862
		%	28.2	12.7
	Seabed	ha	3,769	1,552
		%	25.7	10.6

c. Potential thermal barriers to fish migration

It is known from laboratory thermal preference experiments that fish species can choose to avoid areas of high temperature and there is, therefore, a possibility that thermal plumes could act as barriers to migration; principally in transitional waters.

Eight fish species that have formal conservation status may migrate along the Suffolk coast and, in principle, may be at risk of their migration being affected by the thermal plumes of Sizewell B and C: twaite shad (*Alosa fallax*), allis shad (*Alosa alosa*), river lamprey (*Lampetra fluviatilis*), sea lamprey (*Petromyzon marinus*), cucumber smelt (*Osmerus eperlanus*), salmon (*Salmo salar*), sea trout (*Salmo trutta*) and European eel (*Anguilla anguilla*). Each of these species other than the eel is anadromous (i.e. migrates from the sea into freshwater to spawn). The eel is catadromous, migrating into freshwater or transitional water to feed and grow, then migrating back to sea to spawn.

From BEEMS impingement data obtained at Sizewell B (BEEMS Technical report TR243) the following migratory species of conservation concern are known to be present (Allis shad and sea trout are rare and sea lamprey and salmon are absent from the multi-year impingement record):

- cucumber smelt;
- European eels;
- river lamprey; and
- twaite shad.

Existing thermal standards for transitional waters specify that an estuary’s cross section should not have an area larger than 25% with a temperature uplift above 2°C, for more than 5% of the time. At Sizewell the only transitional waterbodies that could be affected by the thermal plume are the Blyth(S) and the Alde-Ore. Application of the transitional waters standard to these estuaries shows that the standard is not exceeded and therefore that no thermal barriers to fish migration are predicted from the combined SZB+SZC thermal plume in those waterbodies.

There are no thermal standards to assess potential migration barriers for fish in coastal waters. However, if fish have to pass through a coastal plume on their migration route to or from an estuary there remains the possibility of the plume acting as a barrier to migration. If an attempt is made to apply the estuarine standard to a coastal location such as Sizewell, the problem is one of selecting the width of a transit corridor which brackets a reasonable estimate of how far offshore the fish species of interest could travel without experiencing loss of fitness effects.

For the purpose of this study a migration corridor of approximately 3km wide from the coast to the SZC outfalls was assumed based upon the fact that river lampreys and glass eels are known to be present at that distance offshore from BEEMS surveys. It is not known how far offshore smelt and silver eels migrate but given the total distances that they are known to migrate, a 3km wide corridor is considered unlikely to affect their fitness if they chose to avoid the hotter parts of the plumes. Applying the standard estuarine thermal barrier test to this transect leads to a prediction that the 25% occlusion threshold would be exceeded for 18.7% of the year, thereby triggering further ecological investigation.

An assessment was made of whether any of the 8 fish conservation species are considered likely to be undertaking migrations off Sizewell and also on whether avoidance of the thermal plumes was considered likely to affect the fitness of the fish. From the available evidence it was concluded that the following conservation species may undertake migrations off Sizewell and may be at risk from thermal barriers to migration:

- Cucumber smelt. (Adults to estuaries in February to April).
- European eel (Glass eels to estuaries in March to April and silver eels to the Sargasso in September to December)
- River lamprey. Adults to estuaries in August to December.

- Sea lamprey. Adults to estuaries in August to December. (uncertain but assumed the same as river lamprey because spawning period is similar)
- Sea trout. Post-smolts travelling south in July.

In common with most thermal standards the estuarine barrier to migration threshold has been set to act as an indicative trigger; its roots stem from older regulatory thresholds set to protect salmonids in rivers and estuaries. For this study the results from available laboratory thermal preference experiments were used and examination of modelling results shows that smelt, sea trout, glass eel and silver eel with avoidance thresholds of ≥3°C would not experience a barrier to migration in a transect from the coast to the Sizewell C outfalls.

The thermal avoidance threshold for river and sea lampreys is not known and a 2°C uplift criteria has been adopted as a precautionary approach. However, analysis of the plume modelling data shows that in the lamprey migration period of August to December the percentage of the cross section that would exceed 2°C uplift is a maximum of 75% (for 1h only) with a mean of 12%, 95%ile (184h during period) of 36% and 99%ile (37h during period) of 49%. There would, therefore, always be a route through the transect that did not present a thermal barrier to migration with more than half the transect available for 99% of the time. Given that the route that lampreys would take to return to a suitable river is determined by the location of their host when the lamprey decides to detach itself and considering the location of the nearest potential spawning locations in the Blyth and the Alde-Ore, statistically very few fish would seem likely to follow a path that takes them through the Sizewell thermal plumes. Given the high percentage of the transect that would be available for a Sizewell transit and the low likelihood that such a transit would actually take place, the Sizewell thermal plumes are not considered to present a barrier to migration for sea and river lampreys.

It is concluded that the presence of thermal plumes off Sizewell would not present a barrier to migrating fish of conservation concern.

Process for further investigation of potential ecological effects from the thermal plume

The potential effects of a thermal plume are predominantly on sessile and sedentary benthic organisms that cannot avoid the plume. However, by virtue of the plume buoyancy appropriately designed thermal outfalls do not result in large areas of elevated seabed temperature. Planktonic organisms that drift with the tidal currents are only potentially at risk when they enter the mixing zone where the plume dilutes in the receiving water.

The potential effects of a thermal plume are predominantly:

- chronic effects – long term effect on biological processes (e.g. growth, reproduction) where the concern is elevation of mean temperatures; and
- acute effects – lethal effects where temperatures approach critical thresholds for specific species.

In addition as fish are able to actively avoid areas of high temperatures, if they so choose, it is necessary to consider:

- any potential thermal barriers to fish migration and the linked concern about the potential displacement of fish prey out of marine bird foraging ranges.

This report does not present an ecological assessment of the potential effects of the Sizewell C thermal plume which will be presented in a future Marine Ecology synthesis report (BEEMS Technical Report TR313). Instead a process is described that will be used to determine the potential effects on marine ecology at Sizewell of:

i. absolute temperature;
ii. temperature uplift;
iii. barriers to fish migration; and
iv. displacement of the marine prey of SPA designated birds.

Results of Thermal Plume Meteorological Sensitivity Testing

Analysis of modelling results shows that the Sizewell B plume is sensitive to the wind forcing, with thermal effects on the area around Thorpeness being most dependent on the wind direction. However, the tides still define the North – South extent with the wind direction responsible for only slight east west variation in the centre of the plume. Modelling the annual cycle captures the natural wind variability and this is reflected in the mean and 95%ile maps. Thus in the future if the balance of wind direction changes, variations in the plume will be relatively small and contained within the 95%ile maps which have been derived from the annual run.

The 98th percentile of the excess temperatures in August is lower than the annual 98th percentile by 0.75°C around the Sizewell C outfall and by up to 2.5°C at the Sizewell B outfall. The mean excess temperatures for August showed little difference from the annual values with mean values slightly (~0.25°C) lower. This result is relevant to considerations of future climate. The evidence here is that the mean excess temperature in August when the background sea temperature is 19°C is very similar to the annual mean excess values when the background sea temperature is ~11°C. Thus when considering a future climate where the mean temperature may be significantly warmer (e.g. 2°C) the simulations from August indicate that the derived annual excess means for 2009 will be applicable to other time periods in the future. Or put more simply the excess temperature field is mostly independent of the background sea temperature.

It is the tides that determine the extent of the thermal plume; wind plays a secondary role, with background sea temperature having little effect.

Predicted thermal effects of the worst case SZC maintenance discharges

Under an unrealistic worst case condition when two out of four of the SZC pumps are under maintenance and the 2 reactors remain on full power, the flow of cooling water is halved but the waste heat from the reactors remains approximately the same, causing the excess temperature at the outfall to rise from 11.6 ºC to 23.2 ºC. Modelling has demonstrated that the warmer plume loses heat faster to the atmosphere resulting in less heat being mixed down into the water column. This reduces the size of the excess temperature plume compared to that during normal operation with all pumps running.

Predicted Plume Recirculation Effects

The offshore discharge for SZC with configuration 12 is an efficient method of losing heat to the atmosphere and it only causes a small additional increase in the mean excess temperatures at the SZB intakes from 0.95°C to 1.6°C (See Table 4). The introduction of the additional outfall 75 m to east of the O9 outfall does not significantly change the recirculation at either SZB or SZC compared with the results presented in BEEMS Technical Report TR301; the annual mean excess temperatures are slightly reduced at the SZB and SZC intakes whereas the 95th percentile excess temperatures are slightly increased at all intakes.

Table 4 Recirculation: excess temperature percentiles at the power station intake locations (referenced to the zero reference run with no power stations at Sizewell).

Run	**ReferenceV2 (SZB Only)**	**Conf12 (2 outfalls at location O9a and O9b) (SZB and SZC)**		
Intake	**SZB IB**	**SZB IB**	**SZC I3b**	**SZC I4b**
50th percentile	0.95ºC	1.60ºC	0.98ºC	0.98ºC
95th percentile	2.44ºC	3.10ºC	1.92ºC	1.92ºC
98th percentile	2.81ºC	3.60ºC	2.23ºC	2.27ºC

1 Background

This report presents the results of the Sizewell thermal plume Stage 3 modelling of the preferred Sizewell C (SZC) cooling water configuration using the General Estuarine Transport Model (GETM).

In the Sizewell Stage 1 modelling (BEEMS Technical Reports TR132, TR229) the setup of 2 different models was described and the simulated Sizewell B discharge was validated against observations. Modelling Stage 2 (BEEMS Technical Report TR133, TR230) used the validated models to test initial Cooling Water (CW) configurations for the proposed SZC power station. The Stage 2a review (BEEMS Technical Report TR301) critically reviewed the performance of the models and selected the GETM model as the primary tool for assessing thermal plume effects as it was shown to produce the most accurate predictions and also to be the most conservative. An extended set of options for the selection of the SZC outfall location were then analysed and a preferred location identified on the basis of recirculation and environmental concerns – location O9 offshore of the Sizewell-Dunwich Bank (Figure 2).

This Stage 3 report presents simulations of the thermal plume for the preferred CW configuration (configuration 12) with offshore intakes at I3 and I4 and an offshore outfall at O9 (see Figure 2). The geotechnical data necessary to finalise the location of the outfall structure is not yet available. In TR301 the location O9 was selected as the furthest west that a SZC offshore discharge could be built. Modelling demonstrated that outfall locations further east would produce lower thermal effects and that O9 could be considered as bracketing the worst case option for environmental assessment purposes.

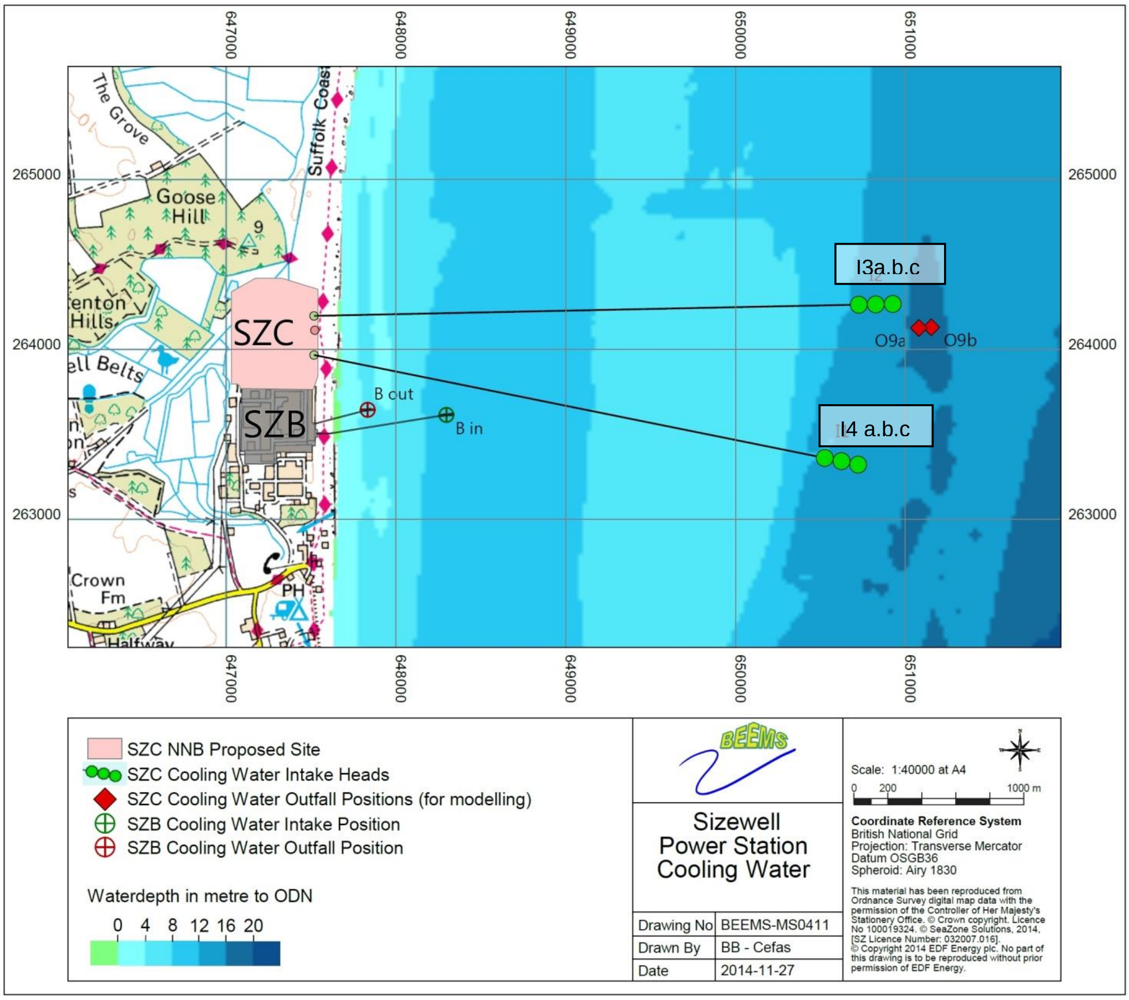


Figure 2 Location of Sizewell B and preferred Sizewell C cooling water structures.

Sizewell B (SZB) will be operational until at least 2035 and therefore the modelling undertaken in this study was of the in combination effect of SZB and SZC. The Sizewell C cooling water system modelled in this report represents a more realistic CW configuration with a total of 4 intake heads and 2 outfall heads instead of the one modelled in TR301. Outfall O9a is at the previous O9 location and O9b is 75m further east.

1.1 Model runs in this report

The three power station scenarios considered were:

a. ZeroReferenceV2: no power stations present;

b. ReferenceV2: present day situation with only Sizewell B; and

c. Conf12: Sizewell C with 4 intake heads and 2 outfalls, all offshore from the Sizewell-Dunwich bank, additionally to Sizewell B.

ZeroReferenceV2 and ReferenceV2 are updates to the model runs used in the GETM Stage 2 and the Stage 2a reports (BEEMS Technical Reports TR230 and TR301 respectively). The changes consisted of:

- Slight changes to the model domain to include shallower water closer to the coastline in order to improve plume mapping and area calculations); and
- Consequential changes to the model internal timestep to ensure numerical stability in the shallow water areas.

These changes did noticeably change thermal plume predictions (based upon inspection of plume contours and on detailed examination of the model predictions using outfall location O9 (see Section 7 of this report)

The GETM runs used in this report are listed in Table 5 and the location of the cooling water heads in Table 6 and Figure 2.

Table 5 - GETM runs used in the report.

Run ID	Description	Intake location	Discharge location	Discharge flow and Delta T (m^3s^{-1} @ °C)	Time period
ZeroReferenceV2 -annual	Pristine condition	n.a.	n.a.	n.a.	1/1/2009 00:00 -1/1/2010 00:00
ReferenceV2-annual	SZB	IB	OB	51.5 @ 11.0	1/1/2009 00:00 -1/1/2010 00:00
Conf12-annual	SZB and SZC	IB I3a,I3b I4a,I4b	OB O9a, O9b	51.5 @ 11.0 125 @ 11.6	1/1/2009 00:00 -1/1/2010 00:00
Conf12_maint-May	Maintenance at SZC	IB I3a,I3b	OB O9a	51.5 @ 11.0 62.5 @ 23.2	1/5/2009 00:00 -1/6/2009 00:00

The I3/I4 a and b locations are EDF Energy's preferred options for the SZC intake locations. The alternative I3/I4 c locations that were modelled in TR301 are reserve options; modelling in TR301 having confirmed that the intake temperatures for all 3 SZC head locations on each inlet tunnel would essentially be the same.

Table 6 - Location of power station cooling water intake and outfall heads.

	Latitude WGS84 (degrees N)	**Longitude WGS84 (degrees E)**	**Easting BNG (m)**	**Northing BNG (m)**	**Depth ODN (m)**
Sizewell B					
IB	52.21472	1.63332	648297	263612	9.0
OB	52.21525	1.62658	647834	263647	5.1
Sizewell C					
I3a	52.21948	1. 66931	650726	264262	12.9
I3b	52.21945	1. 67077	650826	264264	13.6
I3c	52.21942	1. 67222	650925	264266	13.1
I4a	52.21148	1. 66572	650526	263360	11.5
I4b	52.21126	1. 66714	650624	263341	13.5
I4c	52.21103	1. 66856	650722	263320	15.1
O9a Same location as O9 in TR301	52.21807	1.67435	651080	264125	16.9
O9b	52.21803	1.67544	651155	264125	16.8
WGS84: World Geodetic system 1984, BNG: British National Grid, ODN: Ordnance Datum Newlyn					

Figure 3 shows a schematic of the cooling water intakes and outfalls. The tidal amplitude is ±1.6 m and all the structures are continuously submerged. Table 7 shows the location of the intake and outfall structure in the water column.

In the GETM model the grid cells representing the intakes and outfalls are around 40 m wide and the water at the intakes is abstracted from the bottom half of the water column. At the outfall the water is injected evenly across the water column to represent the formation of a buoyant plume while avoiding vertical instabilities in a hydrostatic model.

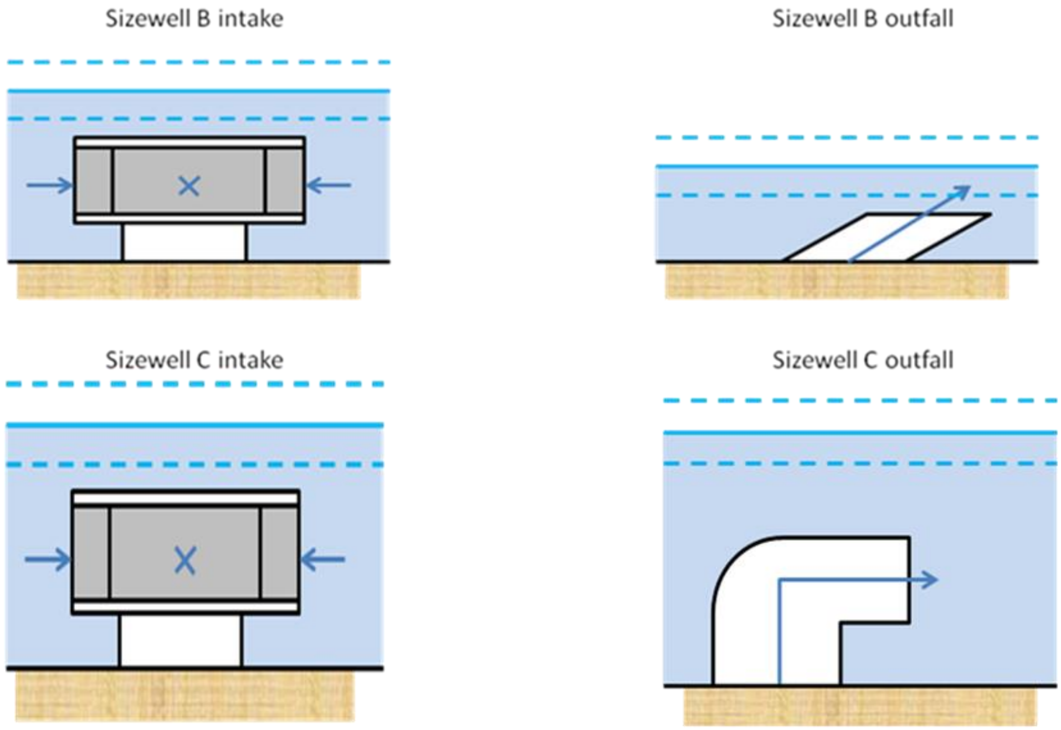


Figure 3 –Schematic of the intake and outfall structures at Sizewell B and C. Dashed lines represent the spring tide low and high water levels. Crosses represent a direction of flow perpendicular with and pointing into the page.

Table 7- Characterisation of the intake and outfalls.

	Elevation above existing seabed	**Local depth ODN**
Sizewell B intake	3.0 - 6.1 m	9.0 m
Sizewell B outfall	2.7 m	5.1 m
Sizewell C intake	1.0 - 3.8 m	13m (mean)
Sizewell C outfall	3.0 - 5.8 m	17m (mean)

1.2 Selection of the representative year for modelling

The EA modelling guidelines suggest that a representative year should be modelled. Selection of the year was made by examination of the inshore temperature network data managed by Cefas (Cefas 2013) for Sizewell. The data are supplied by EDF Energy (historically British Energy and CEGB) and are recorded at the inlet to the SZB condensers (See Table 8). The year 2009 was chosen to be modelled because:

a. the mean annual temperature in 2009 was very close to the mean annual temperature since 1967 - 11.9 °C compared to 11.8 °C; and
b. for the whole year each monthly temperature was within one standard deviation of the 44 year mean (no data are available for 1997).

Thus, in relation to temperature, 2009 is an average year.

The EA guidelines also suggest that the modelling year should be representative of the last 10 years. The mean annual temperature in the period 2003-2012 at Sizewell was 11.9 °C, the same as the 2009 average. However, January and February 2009 were cooler (i.e. > 1sd) than the 10 year average (Table 5).

The availability of boundary forcing elevation data and meteorological forcing are primary considerations for successful hydrodynamic modelling and both of these data were available for 2009 by mid-2010. As detailed in BEEMS Technical Report TR047, an oceanography field programme to collect calibration data for currents and tides was undertaken at Sizewell in September 2008 and a further thermal plume validation exercise in 2009. Thus separate calibration and validation studies have been carried out at Sizewell enabling estimates of the accuracy of the model to be determined.

Table 8. Monthly Mean Sea Temperatures (°C) at SZ B Power Station. Source: Cefas Inshore Temperature Network.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2009	4.9	4.4	6.3	9.4	12.7	16.2	18.6	19.8	17.4	13.8	11.6	7.9	11.9
1967 – 2012 mean	5.9	5.4	6.1	8.4	11.5	15.1	18.0	19.0	17.7	14.8	11.3	7.8	11.8
2002 – 2012 mean	6.8	6.3	6.1	8.5	11.5	15.1	18.0	19.0	17.7	14.8	11.3	7.8	11.9
Std dev.	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.6	1.5	1.6	1.7	1.5	

2 Limitations on the use of the GETM model absolute temperature predictions

The GETM model is an absolute temperature model that predicts actual temperatures. To calculate excess temperatures the results from a reference run with no power station (the zero reference run) are subtracted from the modelled power station run. BEEMS Technical Report TR301 presented an in depth analysis of the accuracy of the GETM model predictions using data from a SZB outage in October 2009 and concluded in section 4.1 of the report:

- *The measured excess temperature rise at the SZB inlets due to SZB was 1.04℃ in the period 21/10/09 to 1/11/09*
- *The modelled excess temperature (SZB - zero reference) was 1.4℃; i.e. the GETM error was +0.36C compared to the measured value*
- *Both the GETM zero reference and SZB models consistently over predicted absolute temperatures; during the outage period by approximately +0.5℃ and +0.8℃ respectively.*
- *Inspection of the annual SZB inlet temperature record showed that the predicted absolute temperatures when SZB was operational exceeded the measured values during all of 2009. The largest over predictions of absolute temperatures occurred in period June- mid July (+1.5 to +2.5℃).*

The comparison of observed SZB inlet temperatures with GETM predictions of absolute temperature over an annual cycle are shown in Figure 4 and the consistent over prediction of absolute temperature is clearly shown.

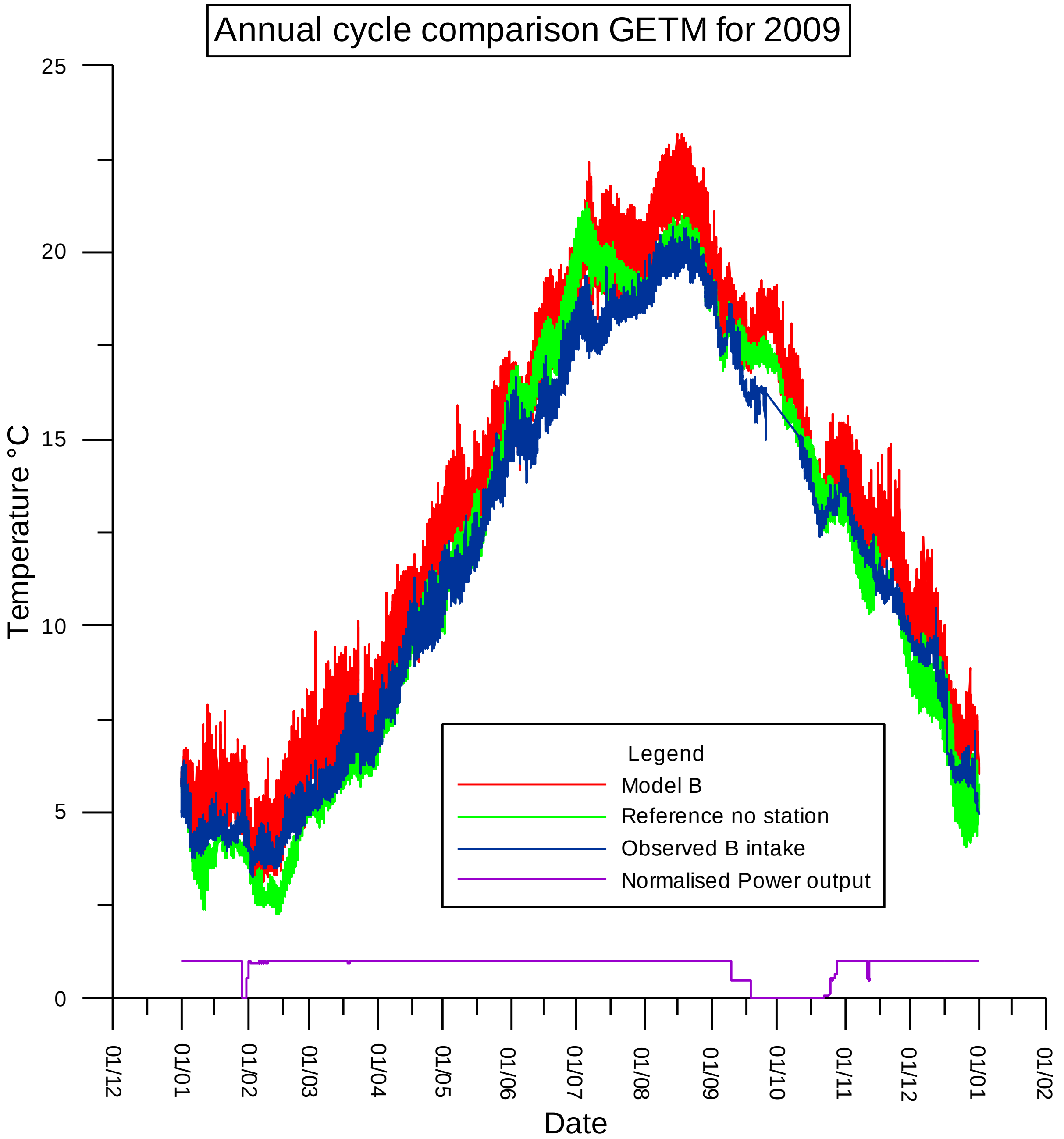


Figure 4 Annual comparison of GETM model of SZB only, zero reference (no power station) and observed data at the location of the Sizewell B inlets

The analysis in TR301 demonstrated that the GETM outputs of absolute temperature are over estimates, sometimes large over estimates, which are not directly suitable for assessment of compliance with regulatory standards; in particular calculation of absolute temperature plume areas can produce misleading results. However, the same report demonstrated that the estimates of excess temperatures obtained from subtracting the zero reference from the power station modelling runs are reliable; in effect the errors in absolute temperature prediction are largely cancelled out. (GETM excess temperature estimates remain over estimates but only at fractions of a degree centigrade)

3 Predicted Annual Thermal Plume Temperature Maps for SZB and SZB+SZC

3.1 Methodology for deriving annual temperature statistics

The three basic configurations were run for one year with meteorological forcing from the ERA atmospheric model with assimilation of observations, and boundary forcing from a larger scale model domain (BEEMS Technical Report TR229). The effect of the power stations is evaluated by calculating the difference in temperature between the intended run and the Zero Reference run, which has no power station discharge. The difference (excess temperature) is calculated for each hourly snapshot and the annual mean and the 98th percentile are calculated from the difference data.

For assessment against thermal standards unbiased estimates of absolute plume temperatures are also required. TR301 has demonstrated that the GETM absolute temperature estimates cannot reliably be used for this purpose as the model produces over estimates of absolute temperature. A more reliable prediction of 98th percentile absolute temperature can be derived at any location by adding the predicted mean temperature uplift due to the plume (i.e. the annual mean excess plume temperature) to the observed 98th percentile seawater background temperature. The actual seawater background temperature for Sizewell, outside the influence of the existing SZB plume, was calculated from observations from the Cefas Coastal Temperature Network (BEEMS Technical Report TR131 Ed 2) and the 98th percentile of the surface temperature for the period 2009-2013 was 19.4ºC. To calculate the plume area where temperatures are:

a) less than 28ºC as a 98th percentile then becomes calculating the area where the mean excess temperature is < 8.6ºC (i.e. 28ºC -19.4ºC).

b) less than 23ºC as a 98th percentile then becomes calculating the area where the mean excess temperature is < 3.6ºC (i.e. 23ºC -19.4ºC).

3.2 Modelled Plume Maps

Modelled GETM plume maps are presented in this report as follows:

Section	Figure	Modelled Plume temperatures
3.3	5	Annual 98%ile Surface excess temperatures SZB
3.3	6	Annual 98%ile Seabed excess temperatures SZB
3.3	7	Annual 98%ile Surface excess temperatures SZB+SZC
3.3	8	Annual 98%ile Seabed excess temperatures SZB+SZC
3.4	9	Annual mean Surface excess temperatures SZB
3.4	10	Annual mean Seabed excess temperatures SZB
3.4	11	Annual mean Surface excess temperatures SZB+SZC
3.4	12	Annual mean Seabed excess temperatures SZB+SZC

In Appendix A plume maps are presented for annual 100%ile surface and seabed excess temperatures for SZB and SZB+SZC

In Appendix B plume maps are presented for absolute plume temperatures using the method of section 3.1

In Appendix C plume maps are presented for absolute plume temperatures using GETM absolute temperatures (which are known to be over estimates)

3.3 Maps of annual 98%ile annual temperature statistics

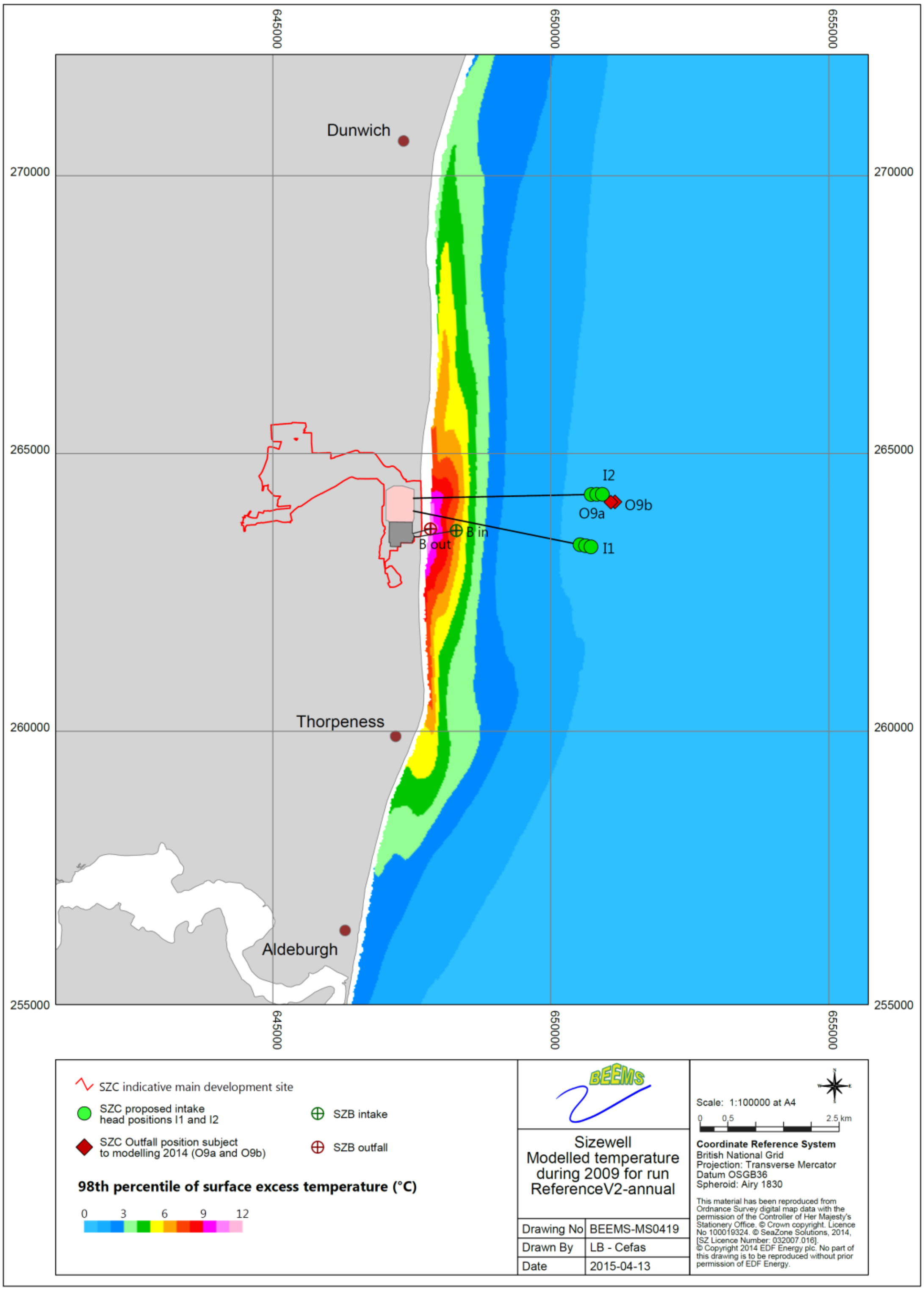


Figure 5 - 98th percentile of surface excess water temperature for run with only SZB operating (ReferenceV2).

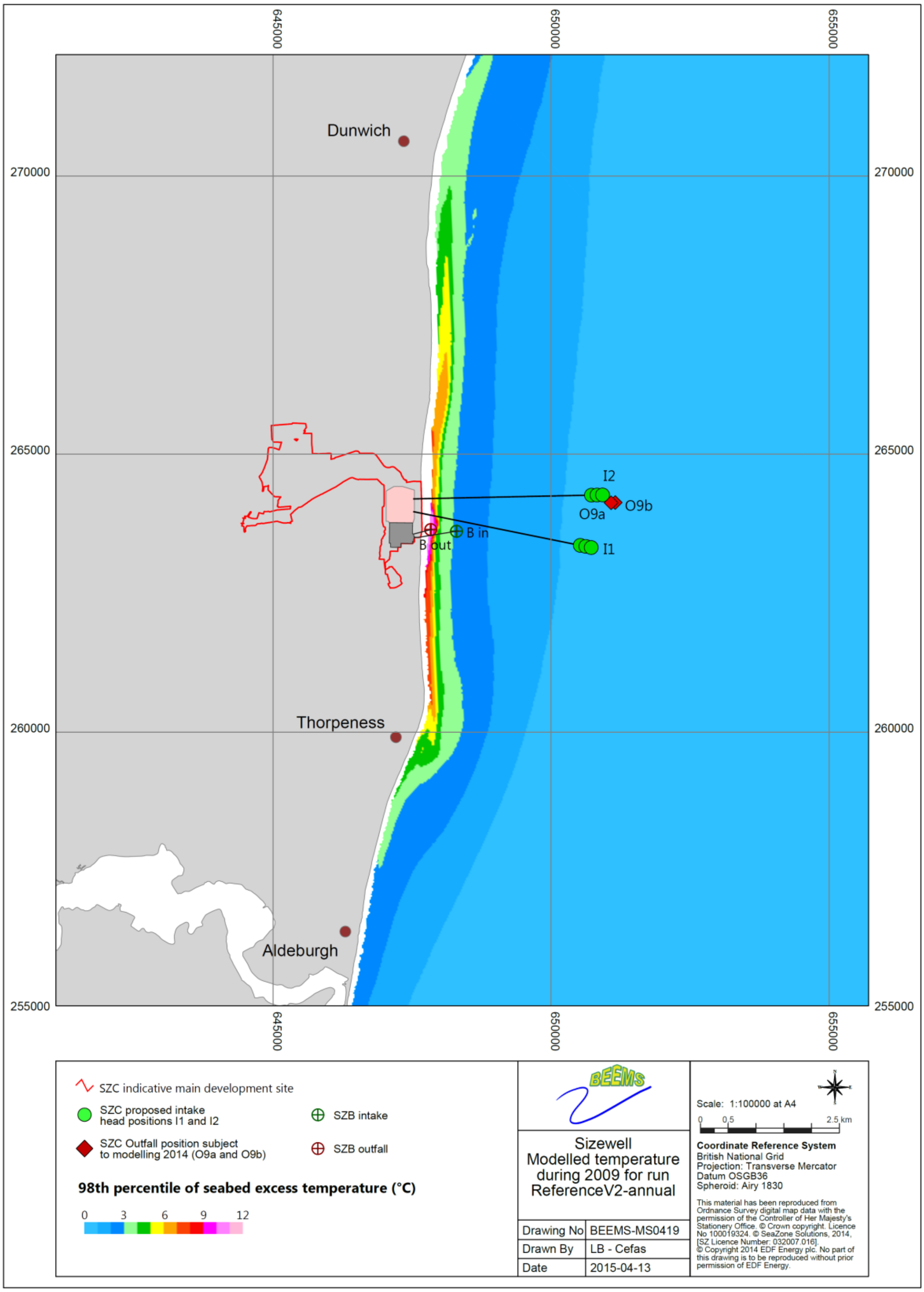


Figure 6 - 98th percentile of seabed excess water temperature for run with only SZB operating (ReferenceV2).

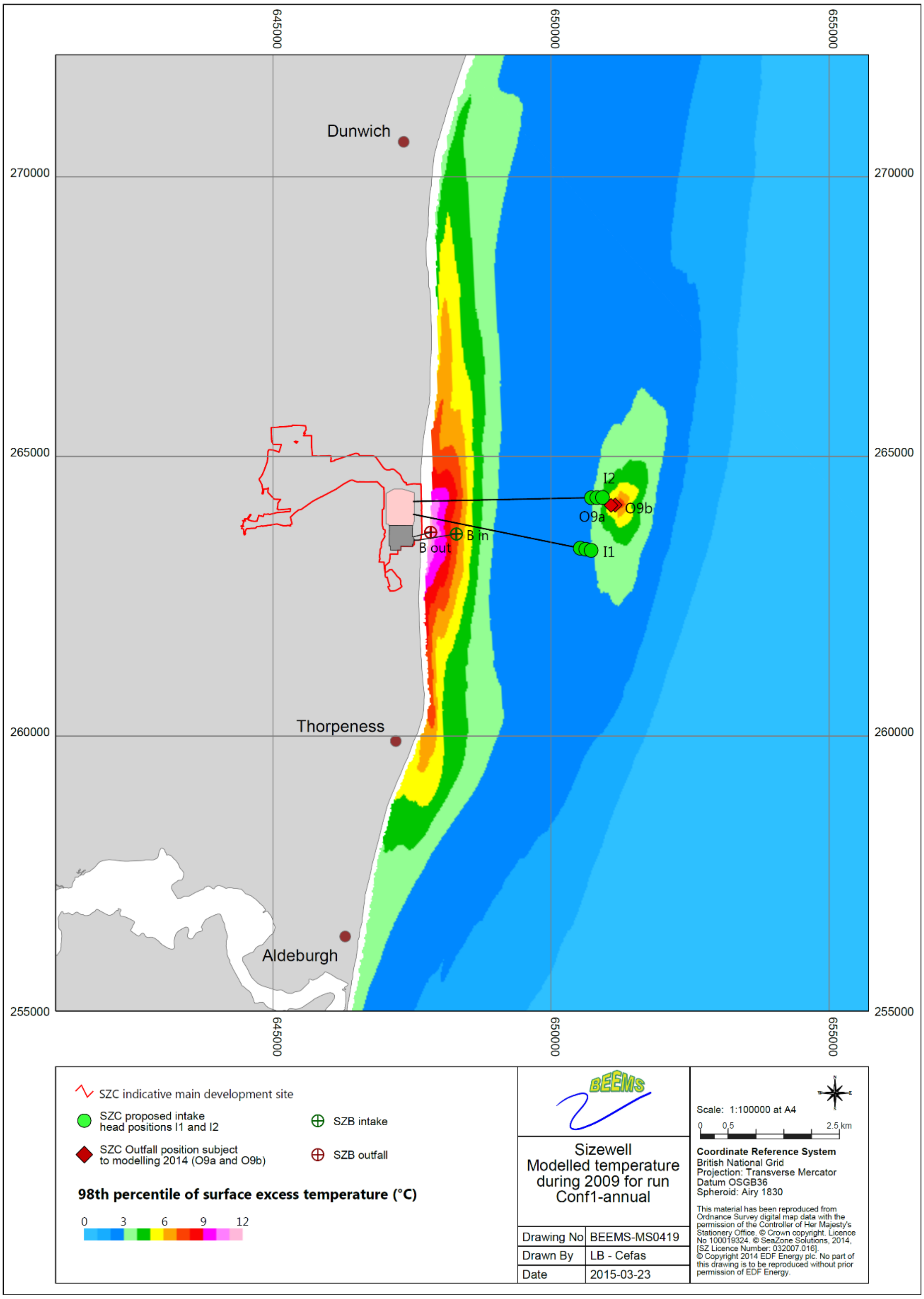


Figure 7. 98th percentile of excess surface water temperature for run with SZB and SZC operating (Conf12).

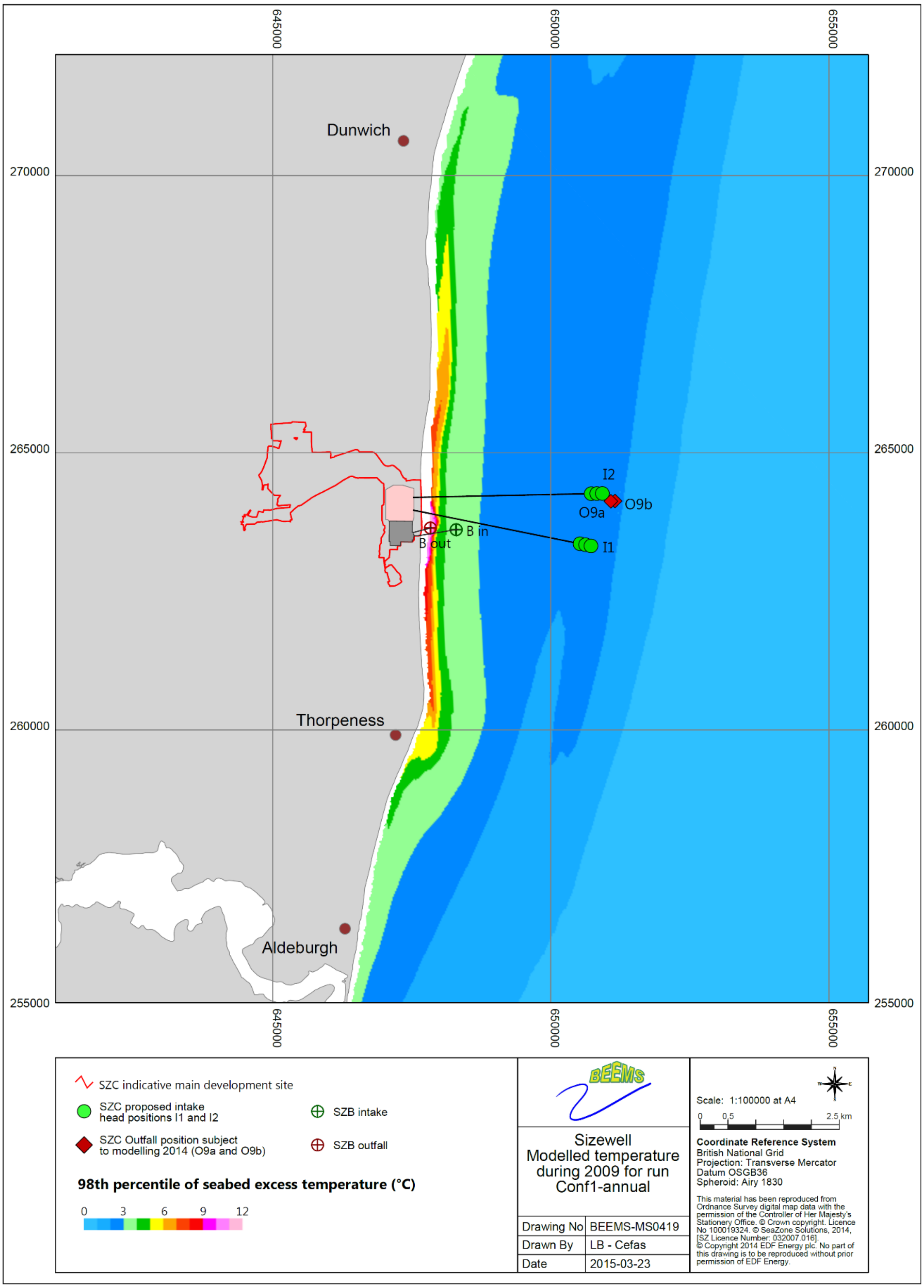


Figure 8 – Seabed 98th percentile of excess water temperature for run with SZB and SZC operating (Conf12).

3.4 Maps of annual mean excess temperature statistics for SZB and SZC operating

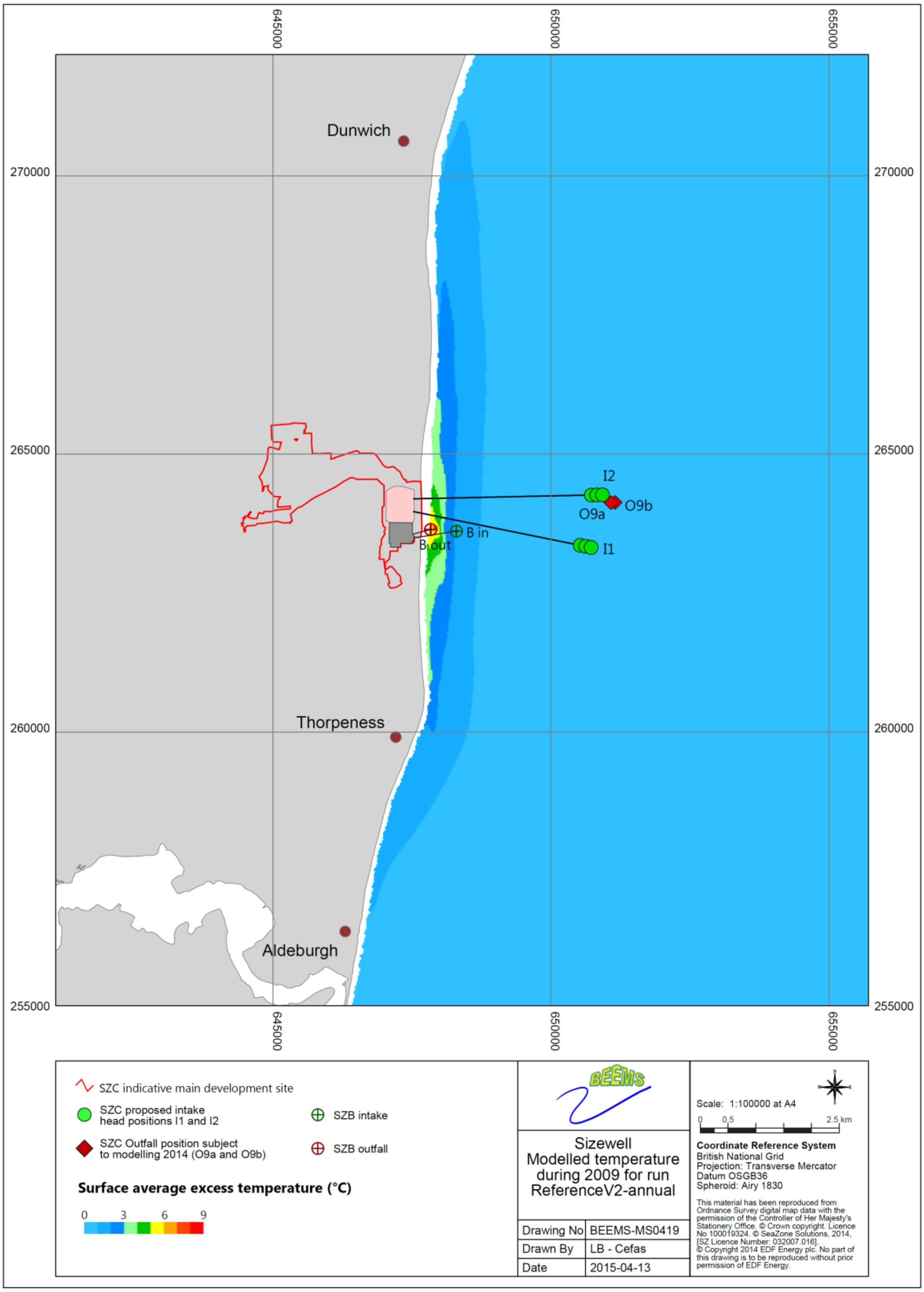


Figure 9 – Surface annual mean excess water temperature for run with only SZB operating (ReferenceV2).

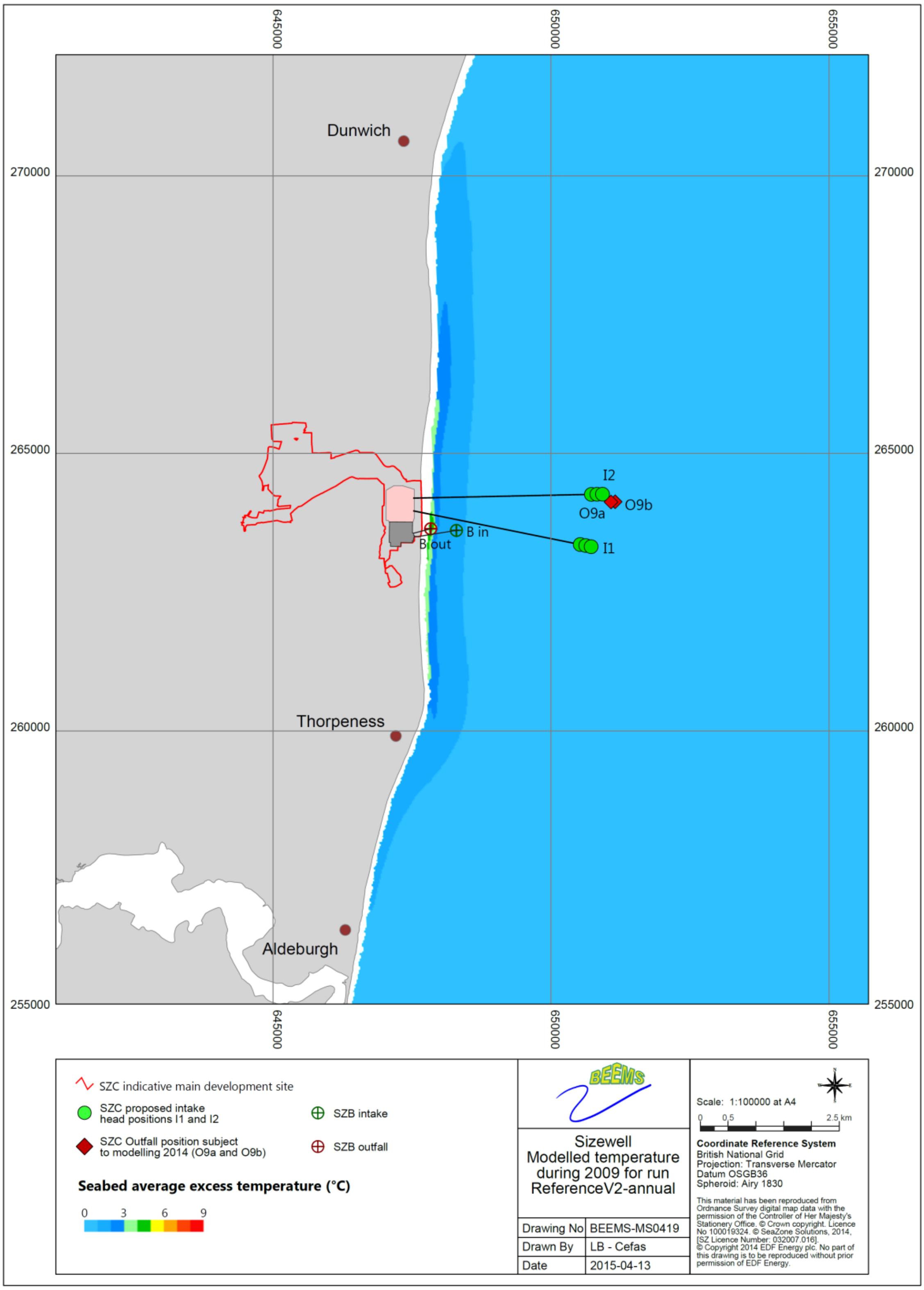


Figure 10 – Seabed annual mean excess water temperature for run with only SZB operating (ReferenceV2).

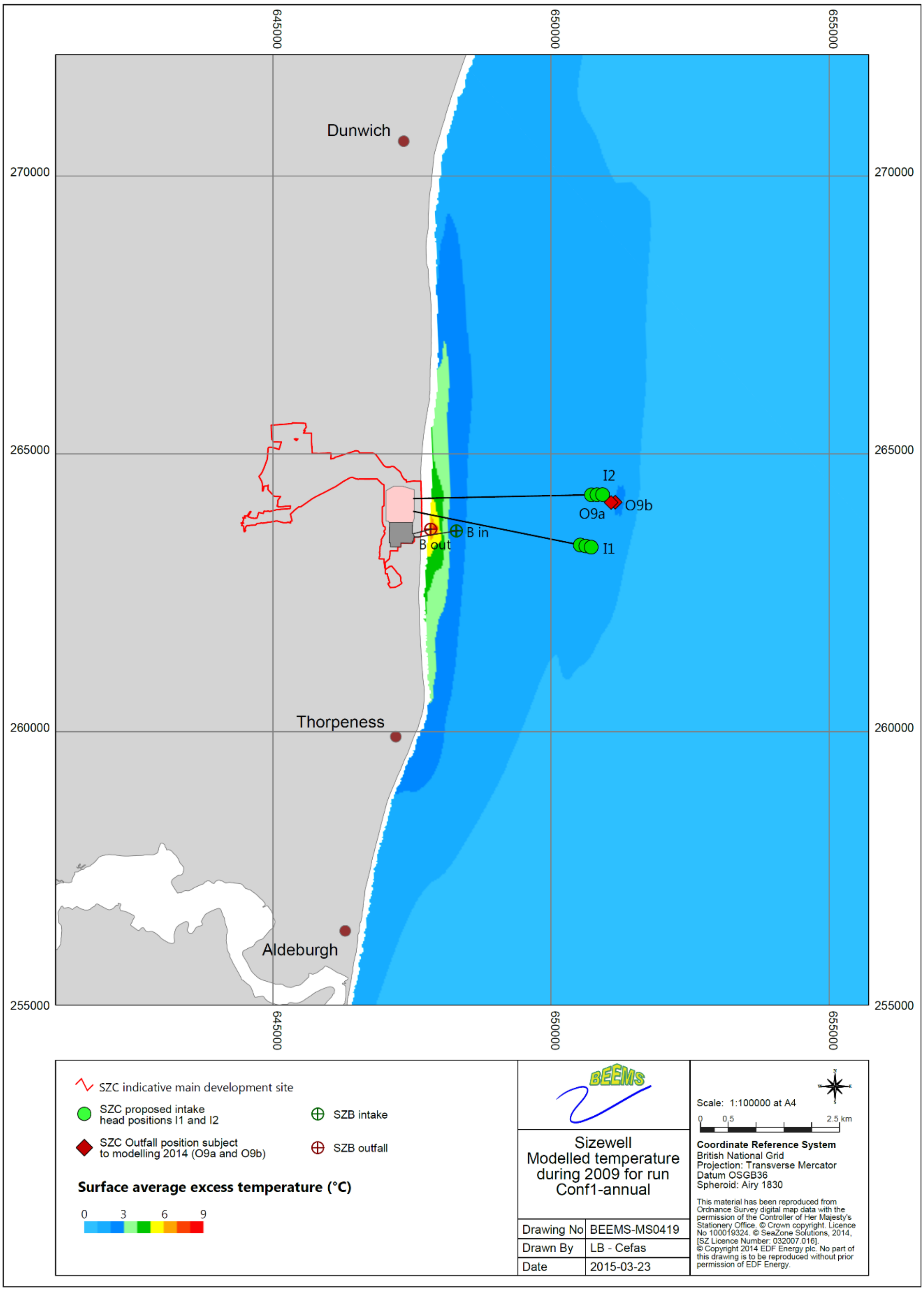


Figure 11 – Surface annual mean excess water temperature for run with SZB and SZC operating (Conf12).

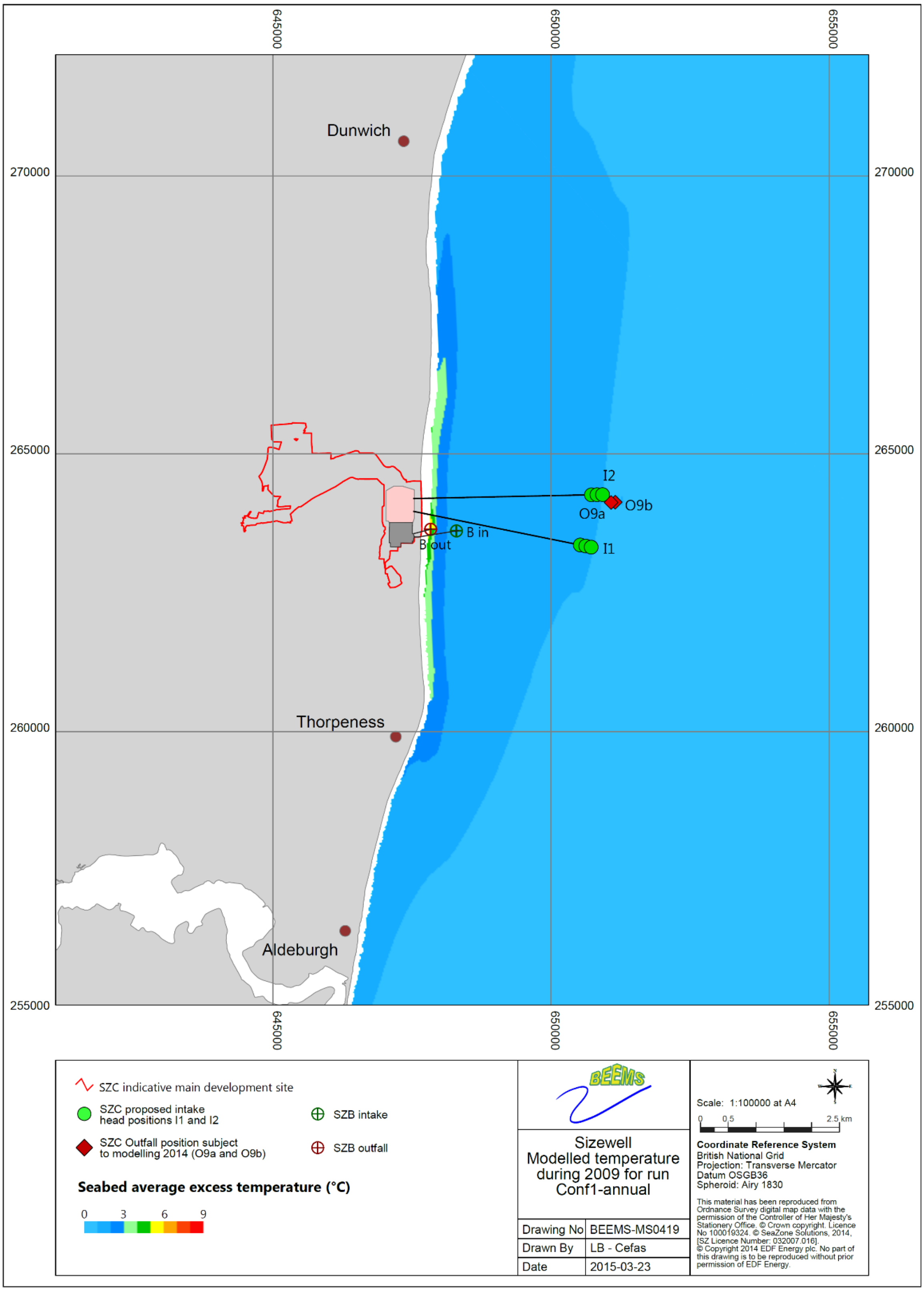


Figure 12 – Seabed annual mean excess water temperature for run with SZB and SZC operating (Conf12).

4 Thermal effects and thermal standards

4.1 Potential thermal effects on marine ecology

The potential effects of a thermal plume are predominantly on sessile and sedentary benthic organisms that cannot avoid the plume. However, by virtue of the plume buoyancy appropriately designed thermal outfalls do not result in large areas of elevated seabed temperature. Planktonic organisms that drift with the tidal currents are only potentially at risk when they enter the mixing zone where the plume dilutes in the receiving water.

The potential effects of a thermal plume are predominantly:

- Chronic effects – long term effect on biological processes (e.g. growth, reproduction) where the concern is elevation of mean temperatures
- Acute effects – lethal effects where temperatures approach critical thresholds for specific species

In addition as fish are able to actively avoid areas of high temperatures, if they so choose, it is necessary to consider:

- Any potential thermal barriers to fish migration and the linked concern about the potential displacement of fish prey out of marine bird foraging ranges

There is also a potential chronic effect at short ranges from some cross shore outfall designs due to daily temperature fluctuations caused by the passage of large magnitude thermal fronts over benthic organisms but this effect would not be expected in the vicinity of relatively deep water SZC discharge.

4.2 Compliance with existing thermal standards

Unlike chemical standards which normally have a clear evidence link to ecological effects, thermal standards are not always evidence based due to a lack of reliable data (BEEMS SAR008, Wither *et al*, 2012). Thermal standards have, therefore, been set on an indicative basis and, as such, they act as trigger values for further investigation of potential ecological effects.

4.2.1 Habitat standards

The Environment Agency recommends applying site based water quality standards, such as those under the Water Framework Directive, when applying Habitat Regulations to permissions to discharge (Operational instruction 141_07, 2008, updated 2012). Additionally it also refers to guidance on Marine Protected Areas (WQTAG 160,Guidance on assessing the impact of thermal discharges on European Marine Sites).

The thermal plume from the existing Sizewell B and proposed Sizewell C directly intersects with two designated marine areas: the Outer Thames Special Protected Area (SPA) and the Suffolk Coastal Water Body under the Water Framework Directive (Figure 13). Two threshold values are recommended as trigger assessments for SPAs:

1. Temperature uplift ≤ 2ºC as a Maximum Allowed Concentration (MAC) at the edge of the mixing zone

2. 98th percentile of the absolute temperature ≤ 28ºC

The uplift criteria is defined as a Maximum Allowed Concentration. In ecotoxicity studies MACs are normally defined as 95 or 98 %iles but the SPA uplift threshold is specified as a 100%ile i.e. a maximum temperature value. This metric is, therefore, very dependent on how the observations or model simulations are done and the time period considered. Using the GETM model the maximum taken from instantaneous temperature fields, saved every hour over a one year simulation, provides data on the area that exceeds 2°C excess temperature for at least 1 hour per year. I.e. for 1h in 8760h per annum. At this temperature threshold, this metric is not considered to have any link to specific ecological effects and it serves as a precautionary threshold to trigger further ecological investigation.

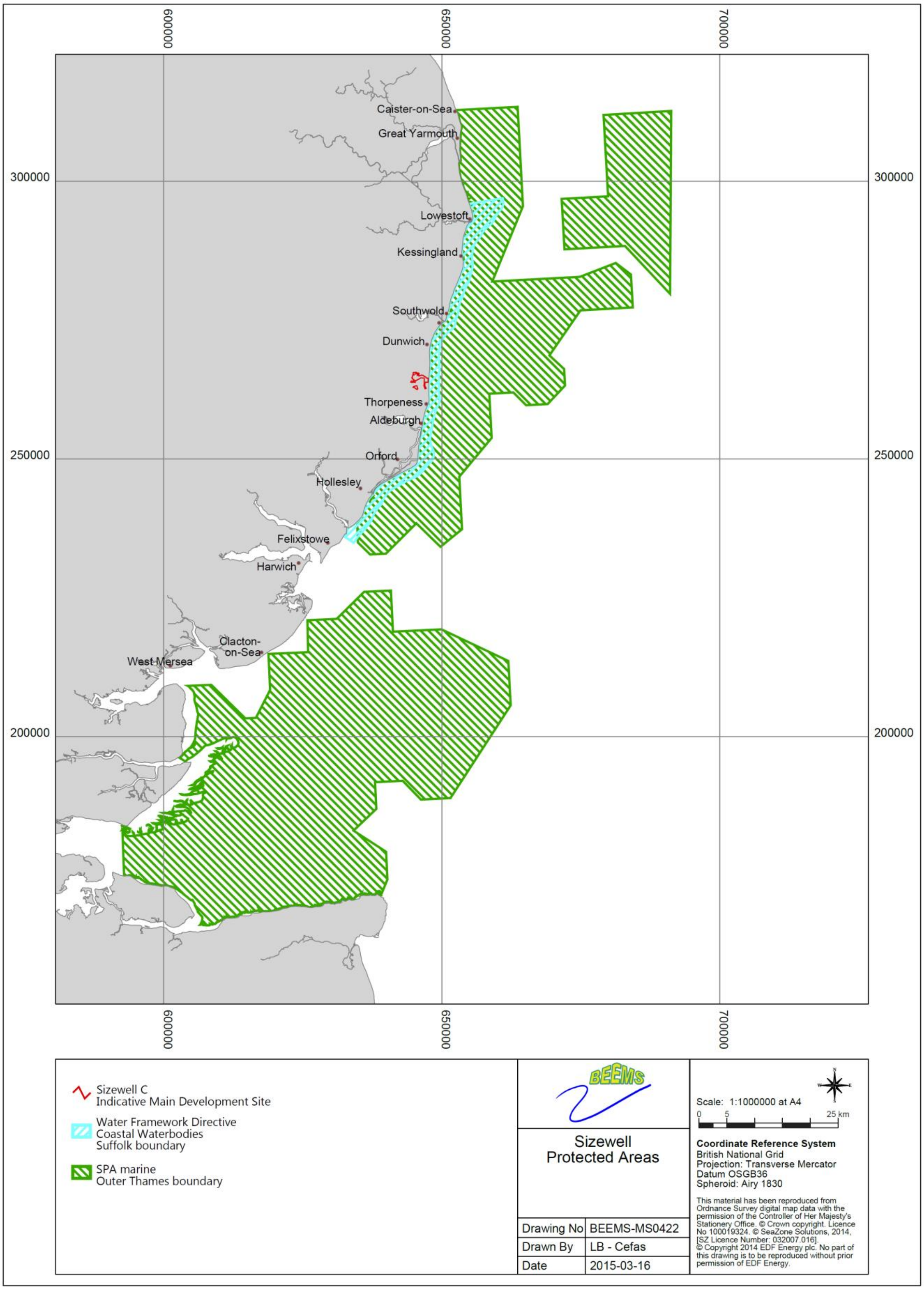


Figure 13 – Boundaries of the Outer Thames SPA and WFD Suffolk Coast water body.

The absolute temperature standard for SPAs of ≤ 28ºC as a 98%ile does have a better evidence link as it is known than the upper lethal temperature for many benthic organisms is in the range 30-33°C (BEEMS SAR008)

The plume maps at a 2ºC uplift as a 100%ile threshold are shown in Appendix A and the areas of exceedance are in Table 9. The 2ºC uplift threshold is exceeded between 5,217 ha at the seabed for SZB only to 22,452 ha at the surface for SZB + SZC. According to WKTAG160 the exceedance of the threshold requires further evaluation of the environmental impact within that area.

The second criteria for SPAs concerns the 98th percentile of the absolute temperature. The predicted areas within the SPA where the plume temperatures exceed 28ºC are shown in Table 9 and are always below 0.01% of the area of the SPA. This contrasts greatly with the criteria for maximum uplift that is exceeded across Sizewell Bay even for the SZB case. Table 9 calculates the areas of exceedance as described in section 3.1. At the request of the Environment Agency the area of exceedance has also been calculated using GETM absolute temperatures outputs which, as described in section 3.1, produce inaccurate temperature predictions that are overestimates. The plume maps of absolute temperatures are in Appendix C. Using either method, the area of the SPA exposed to risks of thermal lethality to marine species from temperatures > 28 °C is negligible.

Table 9 – Area of the Outer Thames SPA (379771.66 ha) where the Habitat temperature standards are exceeded.

Model run	Position		Max excess temp. >2°C (100%ile)	98th %ile >28°C. Calculated from mean excess temp. >8.6°C	98th %ile >28°C Calculated using GETM absolute temperatures (**Not accurate, GETM absolute temperatures are over estimates**)
ReferenceV2 annual SZB	Surface	ha	9,368	0	0.75
		%	2.47	0	<0.01
	Seabed	ha	5,217	0	0
		%	1.37	0	0
Conf12 annual SZB+SZC	Surface	ha	22,452	0.13	4.31
		%	5.91	<0.01	<0.01
	Seabed	ha	16,444	0	1.44
		%	4.33	0	<0.01

Note: BEEMS Technical Report TR301 has demonstrated GETM absolute temperature predictions are overestimates (last column above).

4.2.2 Water Framework Directive standards

The WFD standards for water quality apply for both absolute water temperatures and temperature uplift:

1. Annual 98th percentile of the absolute water temperature

T < 20ºC	=	High
20ºC < T ≤ 23ºC	=	Good
23 ºC < T ≤ 28ºC	=	Moderate
T > 28ºC	=	Poor

2. Annual 98th percentile uplift in water temperature

Uplift ≤ 2ºC	=	High
2ºC < Uplift ≤ 3ºC	=	Good

Uplift > 3ºC = Moderate

Tables 10 and 11 show the results of applying these standards to the predictions from the SZB+SZC thermal plume modelling.

Table 10 – Area of the Suffolk Coastal water body (14,653.59 ha) where the Water Framework Directive absolute temperature standards are exceeded.

Model run	Position		98th %ile >23°C. Calculated from mean excess temp.>3.6°C (Area above GOOD threshold)	98th %tile >28°C. Calculated from mean excess temp.>8.6°C	98th %ile absolute. temp >23°C (**Not accurate, GETM absolute temperatures are over estimates**)	98th %ile absolute temp. >28°C (**Not accurate, GETM absolute temperatures are over estimates**)
ReferenceV2 annual SZB	Surface	ha	26.5	0	292.81	0.75
		%	0.18	0	2.00	<0.01
	Seabed	ha	0.75	0	73.06	0
		%	<0.01	0	0.50	0
Conf12 annual SZB+SZC	Surface	ha	89.26	0.13	433.21	4.31
		%	0.61	<0.01	2.96	0.03
	Seabed	ha	25.75	0	144.80	1.44
		%	0.18	0	0.99	0.01

Note: BEEMS Technical Report TR301 has demonstrated that GETM absolute temperature predictions are overestimates (last 2 columns above).

Table 11 Area of the Suffolk Coastal water body (14,653.59 ha) where the Water Framework Directive uplift temperature standards are exceeded.

Model run	Position		Excess temp. >2°C as a 98%ile	Excess temp. >3°C as a 98%ile (Area above GOOD threshold)
ReferenceV2 annual SZB	Surface	ha	2,433	1,264
		%	16.6	8.6
	Seabed	ha	2,128	669
		%	14.5	4.6
Conf12 annual SZB+SZC	Surface	ha	4,136	1,862
		%	28.2	12.7
	Seabed	ha	3,769	1,552
		%	25.7	10.6

The area of the Suffolk Coastal waterbody exposed to temperatures >28 °C as a 98%ile is negligible and therefore the risk of lethality to marine species is not an issue of concern; indeed only 26ha of the seabed is exposed to temperatures >23 °C.

The 3°C excess temperature standard means that 1552 ha at the seabed and 1862 ha will need to be subject to further investigation to determine whether there are consequential ecological effects.

4.2.3 Potential thermal barriers to fish migration

It is known from laboratory thermal preference experiments that fish species can choose to avoid areas of high temperature and there is, therefore, a possibility that thermal plumes could act as barriers to migration; principally in transitional waters.

4.2.3.1 Description of the ecology of migratory fish that potentially transit past Sizewell

Eight fish species that have formal conservation status may migrate along the Suffolk coast and, in principle, may be at risk of their migration being affected by the thermal plumes of Sizewell B and C: twaite shad (*Alosa fallax*), allis shad (*Alosa alosa*), river lamprey (*Lampetra fluviatilis*), sea lamprey (*Petromyzon marinus*), cucumber smelt (*Osmerus eperlanus*), salmon (*Salmo salar*), sea trout (*Salmo trutta*) and European eel (*Anguilla anguilla*). Each of these species other than the eel is anadromous (i.e. migrates from the sea into freshwater to spawn). The eel is catadromous, migrating into freshwater or transitional water to feed and grow, then migrating back to sea to spawn.

From BEEMS impingement data obtained at Sizewell B (BEEMS Technical report TR243) the following migratory species of conservation concern are known to be present (Allis shad and sea trout are rare and sea lamprey and salmon are absent from the multi-year impingement record):

- cucumber smelt
- European eels
- river lamprey
- twaite shad

A summary of the ecology of the 8 migratory species that may be present at Sizewell is provided below.

Twaite shad (*Alosa fallax)*

Twaite shad (*Alosa fallax)* are distributed along most of the west coast of Europe from the eastern Mediterranean Sea to southern Norway and in the lower reaches of large rivers along these coasts that are accessible to the fish (i.e. rivers that lack barriers to migration). The species has declined substantially across Europe and in the UK; in the UK it is now known to breed only in the Severn River Basin District (in the Severn, the Wye, the Usk and the Tywi) and in the Solway Firth. Non-breeding populations are also found in the UK off the southern and eastern coasts, at Looe Bay, Hastings and Sizewell (Jolly *et al*., 2012). Genetic analyses have shown a lack of significant differences between *A.fallax* populations of the Solway and the River Tywi (approximately 300km apart) but the populations from Hastings - Sizewell exhibited strong genetic divergence from the west coast populations (Jolly *et al*., 2012). There are no known breeding locations on the UK North Sea coast and the sub adults found in impingement samples at Sizewell are not mature. A recent pooling of all available European data (ICES 2015) defined the following distinct genetic groups of A.fallax: **Atlantic**: 1 - Baltic sea (Curonian lagoon); 2 - North Sea (Nissum and Ringkobing Fjiords, Denmark, Scheldt estuary, Belgium, Solway, UK); 3 - Severn group, UK (Severn, Wye, Usk); 4 -Tywi, UK; 5 - west France (Charente); 6 - northwest Portugal (Minho, Lima, Mondego); 7- southwest Portugal (Tejo, Mira); 8 - south Portugal (Guadiana); 9 - Morocco (Sebou). The *A.fallax* found at Sizewell belong to the proposed North Sea breeding population which is possibly centred on the Scheldt.

At Sizewell in the period 2009 - 2013 twaite shad were impinged primarily in the spring and summer and none were impinged in winter. No individuals below a length of 105 mm were impinged and 50% were 310 mm or more. As would be expected there were no 0+ group fish in the record and all of the fish were immature sub adults. These fish are considered to be feeding in the southern North Sea and are not undertaking breeding migrations in the vicinity of Sizewell. Given the substantial distance from their European spawning grounds it is not considered that the fitness of the fish would be impaired if they chose to avoid the Sizewell thermal plumes.

Allis shad *(Alosa alosa)*

Alosa alosa is distributed along the eastern Atlantic seaboard from Norway to North Africa and also in the western Mediterranean. It has declined significantly throughout its range and is now extinct in several former areas. The most important spawning rivers for *A. alosa* are now French west coast and Portuguese rivers draining into the Atlantic (Maitland & Hatton-Ellis, 2003). Some recolonisation has occurred in rivers in north-western France. *Alosa alosa* was once abundant in the River Severn and supported a commercial fishery (Day, 1890, cited by Henderson, 2003). It was recorded as breeding in the River Wye in 1935 and is considered to have spawned in the River Severn and some other British rivers, but in recent years has been caught only rarely in UK waters, and no spawning has been recorded. There are, therefore, currently no known spawning sites for this species in the United Kingdom, and only two locations in the UK where individuals in breeding condition have been recorded: the river Tamar in SW England and the Solway Firth on the border between England and Scotland (Jolly *et al*., 2012). Immature adults are occasionally found in the Bristol Channel, the English Channel and the east coast. It is considered possible that British-caught specimens are part of the Loire–Gironde population (Henderson, 2003). In Ireland there are also no known spawning locations, but the species has a recorded presence in the rivers Slaney and Suir in breeding condition and there are some indications that spawning may be taking place. There is also evidence of hybridisation with *A. fallax* in those rivers (King & Roche, 2008).

Alosa alosa mature at between 3 and 8 years old, with most females maturing at 5 and 6 years (mean length 481 mm) and males at 4 and 5 years (mean length 421 mm) (Maitland & Lyle, 2005). Mature fish that have spent most of their lives in the marine environment cease feeding and move up the estuaries of large rivers at the end of February, migrating into freshwater during late spring (April–June), thus giving them the colloquial name 'May Fish'. Males migrate upstream first, followed by females 1 or 2 weeks later. In some of the larger European rivers, *A. alosa* have been known to ascend upstream for several hundred kilometres – for example, more than 500 km in the River Loire (Boisneau *et al*., 1985).They used to migrate upstream as far as Shrewsbury and Welshpool in the River Severn (Salmon Fisheries Commission, 1861). Spent *A. alosa* (fish that have spawned) migrate back to the sea, though most die after reproduction (i.e. they are semelparous). Most juveniles migrate rapidly through the estuarine environment to reach the marine environment by December of their first year and then remain at sea until they mature. Studies on population genetic structure for both *A. alosa* and *A. fallax* have demonstrated strong fidelity to breeding grounds, compatible with homing to natal spawning sites (Jolly *et al*., 2012)

The spawning migration into estuaries begins between February (southern populations, e.g. in France) and May (northern populations), lasts for three months, and is temperature-dependent. Spawning occurs in freshwater at night over substrata ranging from mud to sandy gravel at depths of 0.15–9.5 m. Eggs develop optimally at temperatures of 15–25°C. Incubation takes 72–120 h depending on temperature. Larvae measure 4.25–9.2 mm at hatching. Age-0 fish migrate seawards in the surface layers of the water column during autumn and winter (Aprahamian *et al*., 2003)

After hatching, the young remain in the slow-flowing reaches of the lower parts of rivers, and then move into the estuary and eventually into coastal waters and the open sea, occasionally having been recorded in water up to 300 m deep. The larvae grow rapidly to between 80 and 140 mm at age 1. Lochet (2008) determined by otolith microchemistry that *A. alosa* in the Gironde basin spend about 54–124 days in the freshwater environment after hatching, and then migrate through the estuarine environment in about 13 days. Thereafter they spend the rest of their lives in the marine environment until they return to the natal estuary once they become sexually mature.

At Sizewell only 1 fish was caught in the extensive BEEMS impingement sampling programme between 2009 and 2013. This fish was considered to be an adult straggler, feeding in the southern North Sea. Given the substantial distance from its probable French spawning ground it is not considered that the fitness of the fish would be impaired if it chose to avoid the Sizewell thermal plumes. The evidence indicates that *A.alosa* is not transiting off Sizewell.

River lamprey (*Lampetra fluviatilis*), sea lamprey (*Petromyzon marinus*)

Both river and sea lampreys migrate up rivers from the sea to spawn; both species are semelparous (they reproduce only once). Larvae bury themselves in the muddy substrates in freshwater for several years and once metamorphosis takes place the juvenile fish migrate to the sea to feed. The two species differ from other anadromous fishes in that their adult phase is parasitic. This feeding strategy should make homing problematic for lamprey cohorts that become widely dispersed through transport by the extensive range of hosts they parasitize for periods of several days to over two weeks per host, during which time they are transported by their hosts' movements. Owing to their non-specificity in host selection and the consequent implications for transport, sea lamprey have been found in the ocean from the surface to over 4000 m in depth. Genetic studies on sea lamprey have demonstrated that they do not home to their natal river and instead exhibit regional panmixia (i.e they can breed with any individuals in the population without genetic or behavioural constraints) using a 'suitable river' strategy to complete their life cycle. River suitability appears to be based upon the detection by adults of bile acid-based pheromones released by larvae. (Waldman et al 2008). Gaudron and Lucas, 2006 have reported that river lamprey also respond to bile acid pheromones and the species is therefore considered likely to adopt a similar life cycle strategy to the sea lamprey.

Given the parasitic use of host fish, mature adult lampreys are likely to be widely distributed at sea when they commence their migration to freshwater and therefore they cannot have a set migration route. The maximum range that sea lamprey can detect the pheromones given off by their larvae is not known but is unlikely to extend out of an estuary due to dilution effects; it is known that they can detect the pheromones for 650m in a river system (Johnson *et al*, 2009). It is possible that adult lampreys may detect the salinity signal from a freshwater discharge and use that to initially home in on a potentially suitable river, alternatively they may travel in a random direction until they encounter the coast. However, it is known that sea lamprey have to undergo substantial physiological changes in estuarine waters before they can ascend into freshwater rivers to search for larval pheromones. Whether they can energetically afford to reverse these changes if the river proves unsuitable is unknown. The point of this discussion is that there is no evidence for lampreys transiting off Sizewell and their migrations may consist of an offshore to the nearest suitable river transect with very few of such routes involving transiting the Sizewell discharge plumes given the distance of the nearest rivers; the Alde-Ore and Blyth respectively. However, it is possible that they may reject a river and then travel along the coast looking for the next potentially suitable candidate and in such circumstances small numbers of fish could transit off Sizewell.

River lamprey are widespread in catchments throughout the UK, except in northwest Scotland and in industrial areas where water quality is poor or where obstacles prevent the upstream migration of adults prior to spawning. River lampreys reach a size of 30-50cm. They are impinged at Sizewell throughout the year, with peaks in June (juveniles) and December. River lamprey migrate from their coastal feeding grounds into freshwater, to get ready to spawn, during the autumn and spring. Autumn migrants are sexually undeveloped while spring migrants enter from the sea in spawning condition (source: Scottish Natural Heritage). Adult river lampreys spawn in shallow nests in gravel and stony areas in freshwater from April to June, after which the adults die. The ammocoete larvae bury themselves in soft mud downstream of the nesting sites, where they filter-feed on micro-organisms and detritus for up to five years. They then metamorphose and migrate as young adults out to sea in spring at a length of 9−12 cm. They then spend one or two years feeding at sea before maturing at ~30 cm and returning to suitable freshwater habitat to spawn. At Sizewell the larger returning adults are impinged at low numbers throughout the year, but in much larger numbers in the period August to December. A limited, targeted offshore sampling survey detected similar numbers of juvenile river lamprey at the locations of the Sizewell B and proposed Sizewell C inlets (3km offshore) (BEEMS Technical report TR356). It is considered possible that some river lamprey are transiting off Sizewell.

The sea lamprey (*Petromyzon marinus*) is the largest of the 3 lamprey species found in the UK, reaching a size of approximately one metre in length. The species is uncommon in the UK and although found around the coast, the main population centres are concentrated on the Bristol Channel. After spending 18-24 months feeding at sea, adult sea lampreys migrate into rivers during the spring and early summer. They spawn between the months of May-July in areas of pebble and cobble substrate after which the adults die. Larvae bury themselves in soft mud downstream of the nesting sites for typically 4-7 years (up to 13 years). After metamorphosis juvenile sea lamprey migrate to the sea during late autumn. There are recorded breeding populations of sea lamprey in several East Anglian rivers (source: Environment Agency) and therefore it is possible that the some fish may be transiting off the Sizewell coast even though the species does not feature in the impingement record; possibly because the species is rare or because it occurs in densities too low to detect at sea due to its wide ranging offshore feeding behaviour.

Cucumber Smelt (*Osmerus eperlanus)*

The smelt or sparling *Osmerus eperlanus* is found from southern Norway around the western coast of Europe (including the Baltic Sea) to northwestern Spain. Although there are several non-migratory populations in large freshwater lakes in Scandinavia, it is usually found in coastal waters and migrates into large clean rivers to spawn (Wheeler, 1969). The smelt was once common in Great Britain and supported commercial fisheries in the estuaries of most large rivers from the Clyde and Tay south. Maitland (2003) reports that fisheries for smelt existed in the tidal reaches of all the Broads rivers in Norfolk until at least 2002; commercial fisheries 'yielding 3 to 6 t' per annum were still active in the River Waveney in 1991; smelt are occasionally taken in herring nets in the Orwell Estuary; and commercial fishermen were taking large catches – 190−250 kg per day in the Medway and the River Thames by 2002. (BEEMS Technical Report TR243)

Smelt were relatively abundant in inshore young-fish surveys using intertidal push nets and a 2 m beam trawl from 1981 to 1997 (Rogers *et al.,* 1998), particularly off the mouths of rivers such as the Yare, the Suffolk Stour and the Blackwater Estuary. After an absence from the River Thames in the first half of the 20th century, smelt were first captured at West Thurrock power station in 1966, and surveys of intake screens from 1967 on showed a fluctuating but steady increase in the Thames (Maitland, 2003). Wheeler (1969) reported large numbers of immature smelt in the whole of the lower tideway throughout the year.

Maitland (2003) reviewed information on smelt in England and concluded (for East Anglia) that thriving smelt populations exist along the Suffolk and Essex coasts, centred on the Broads rivers and estuaries entering Breydon Water; the estuaries of the Rivers Alde, Deben, Orwell and Stour, the Crouch and the Blackwater, and the estuaries and tidal reaches of the Thames, Lee, Medway and Swale. More recently Colclough 2013 confirmed that there are extensive populations in the Thames, Humber (including the tidal Trent and Ouse), Wash and Great Ouse, Norfolk Broads and Dee with more modest populations in the Alde/Ore, Ribble and Conwy.

The scientific literature suggests that the smelt is restricted to estuarine and riverine conditions and is hardly ever found in the open sea. However, the Sizewell B impingement record demonstrates that smelt are found in full salinity water all year round with peak abundance in the summer. The nearest estuary with a known smelt population is the Alde/Ore, approximately 25km to the south of Sizewell. The nearest estuary to the north is the Blyth, approximately 12km away, but no survey work has yet been conducted in the Blyth.

The smelt is a euryhaline species mainly found in estuaries, migrating upstream into the freshwater reaches in large shoals in the early spring. Smelt shed their adhesive eggs onto the river bed in the brackish reaches of tidal rivers during March and April, where they hatch in about 3−4 weeks. Spawning appears to be determined by temperature and tides. In the Thames, spawning takes place in the Wandsworth area of the estuary and 0+ fish first appear at 18mm at Greenwich in mid-May (Colclough 2002). At Sizewell 0+ fish first appear in July in the size range 40 - 80mm (BEEMS impingement data). According to Fishbase.org smelt become sexually mature in 3-4 years when they are 150-180 mm in length, Smelt of such a size are not commonly caught at Sizewell where impinged smelt are typically the range 70-130mm. A few large fish are caught in the period February - April (size range 170-210mm) (BEEMS impingement data)

In conclusion it is known that smelt reproduce in East Anglian rivers from the Thames to the Yare and there is, therefore, a possibility that migrating fish may be transiting off the Sizewell coast.

Atlantic Salmon (*Salmo salar*)
A fishery for Atlantic salmon and sea trout operates on the East Anglian coast, but the catch is predominantly of sea trout and fewer than 5 salmon are currently taken per year. There are no 'salmon rivers' (other than the Thames) between the Humber estuary and the Solent. The salmon 'stock' in the Thames is very small; it was originally restored by stocking, but fish release stopped in 1994 and the population subsequently declined steeply, reaching a low in 2005 with no returning salmon recorded. Adult salmon are still found in the Thames but genetic studies have confirmed that these are all strays from other south coast rivers or from northern France and there is no evidence of any reproduction taking place in the Thames (Griffiths *et al*.,

2011). The nearest stocks of any size to Sizewell are in the north-east from Whitby (River Esk) northwards and in the south from the Solent (Rivers Itchen and Test) westwards. (T. Potter 2015. pers. comm., 18 December). Salmon spawning takes place in late autumn in shallow excavations found in shallow gravelly areas in clean rivers and streams where the water flows swiftly. After 1-4 years in their native river (dependent upon latitude) salmon parr undergo physiological change into smolts. Salmon smolts leave freshwater between late March and May and are generally thought to move offshore quickly and head for their ocean feeding areas in the North Atlantic (in the Norwegian Sea or off Iceland) using surface currents. After 2-3 years at sea adult salmon return to their native rivers from their open ocean feeding areas at practically any time of the year although the largest runs usually occur in the summer and early autumn. Most salmon return and spawn only once. (MacKenzie *et al*. 2012, Dadswell *et al.* 2010).

It is considered unlikely that salmon are transiting off Sizewell; south coast fish migrate west then north, fish from Yorkshire and further north migrate north. The nearest salmon 'stock' to Sizewell in the Thames is derived from south coast UK rivers or France. Even if salmon were migrating past Sizewell, given the substantial distance that the species undertakes on its migrations to and from the North Atlantic it is not considered that they would suffer any impairment in fitness if they chose to avoid the Sizewell thermal plumes.

Sea Trout (*Salmo trutta*)

The sea trout is not a species in its own right, but a migratory form of the brown trout (*Salmo trutta* L.). The life history of sea trout is similar to that of Atlantic salmon in that they spend a variable time in freshwater as juveniles before undergoing the physiological changes that allow them to migrate to sea as smolts. After typically 1-3 years smolts migrate downstream to the sea between April - early June. Sea trout differ from Atlantic salmon in that they do not venture off to distant North Atlantic feeding grounds, but instead, remain largely in coastal areas. The length of time spent at sea varies considerably between individuals and some 'populations'. Adults return to spawn after 1 to 3 years at sea in May to November. Spawning takes place in their natal river and normally begins in mid-October and continues through to early January. Once on the spawning grounds, sea trout lay their eggs in gravel pockets or 'redds' that have been excavated by the female fish. The young trout will emerge from the gravel between mid-March and early May. Many of the spent adults, known as 'kelts', die, but a significant proportion of them survive and make their way back to the sea to recover and grow. Sea trout can spawn up to thirteen times in their lifetime. (de Laak 2012, Scottish Natural Heritage, I. Russel 2015. pers. comm., 16 December).

In the North Sea sea trout occur in 5 genetically distinct groupings – Moray Forth, North East UK, East UK (Humber to North Norfolk), East North Sea (Rhine – Denmark) and Western Norway. Fish caught by anglers in East Anglia are predominantly from the NE coast of the UK with small numbers from Denmark, the Rhine and a few from Norfolk and SW England (Living North Sea project: Fish migration from sea to source). Results from UK tagging studies have shown that the marine migration of most post-smolts is up to 100 - 150km from their natal river. However post-smolts from rivers between the Tweed and the Yorkshire Esk travel over the whole southern and central North Sea involving migrations of up to 750km. Tag returns from 1950s work shows that their route is down to East Anglia, across to the Frisian Islands / Waddensee and then, if they are returning after just one winter at sea, back to the Tweed. If spending two winters at sea, tag returns show that they can go as far as the tip of Denmark, at the mouth of the Baltic. On average, these 1950s smolts took 60 days from tagging in the Tweed estuary to get to the Great Yarmouth area of East Anglia (where most recaptures were made), a distance of about 445kms along the coastline. (Solomon 1994). It is often stated that sea trout remain close to the coast but for fish originating in North East coast rivers this reflects where they were historically caught in drift net fisheries. Records from fishing vessels show catches in the southern North Sea and it is evident that sea trout will travel 100km or more across open sea. (Solomon 1994). More recent acoustic tracking studies have shown that north east coast post-smolts generally migrate within 2-3m of the surface but have been observed to dive to depths of 80m.

Sea trout are rarely impinged at Sizewell; 2 fish were caught in the period 2009-2013. This is due either to their strong swimming ability or to the possibility that they migrate further offshore that the Sizewell B intakes. It is known that sea trout migrate down the east coast as far as Yarmouth; after which there is evidence that the fish cross the southern North Sea to the Netherlands; this would correspond to known residual circulation patterns in the North Sea. Tagging of smolts from the River Coquet on the North East coast produced recaptures off Norfolk in June/July, off the Netherlands in July/August and the Frisian Islands / Waddensee in September (Bendall). These data would imply that the fish took a direct route from just south of Yarmouth to journey to the Netherlands. However, there are insufficient data to be certain where sea trout crossing takes place and what percentage of the fish take which route to the east. There are also some tagging data that indicate that some sea trout may transit past Sizewell. Whether this is close to the coast or further offshore is unknown. Based upon known journey times a transit past Sizewell would take place approximately in July when the Sizewell plumes are at their smallest (see 4.2.3.3). Making a worst case assumption that the southerly migrating fish transit within 3km of the coast where their behaviour could be affected by the Sizewell thermal plumes the question is then if they chose to avoid the thermal plumes would it impact on their ability to migrate or their subsequent fitness?. Given the extensive migration journeys that the species takes (travelling approximately 7.5km per day) and its known behaviour which takes it some 100km offshore in the southern North Sea, it is not considered likely that if it chose to avoid the Sizewell plumes that this would reduce the fitness of the fish.

European Eel (*Anguilla anguilla*)

The European eel (*Anguilla anguilla*) has a complex life history. Leptocephalus larvae, derived from spawning in the eastern part of the Sargasso Sea, drift for as much as two or three years in the Gulf Stream and the North Atlantic Current to the continental shelf of Europe and North Africa. On reaching the continental shelf the larvae metamorphose to the unpigmented glass eel stage, settle out of the water column in estuaries in spring in the UK and metamorphose into pigmented elvers that may remain and feed in coastal marine or estuarine waters or begin active upstream migration in freshwater. There they disperse to feed and grow for up to 20 or more years as yellow eels (up to 50 years has been recorded) before maturing into the silver phase, at which stage they migrate back to their spawning grounds. Silver eels are believed to complete their return migration in deep water (~2000 m) using Gulf Stream counter-currents that help them move in a generally westward direction. Their passage is aided by anatomical changes such as modifications to their retina, which are similar to those of abyssal fish, and changes to the wall of the swimbladder that allow the eels to swim at such depths. Age at maturity ranges from 10 to 20+ years in northern temperate waters and is earlier for males than for females. (BEEMS Technical report TR243)

The scientific literature suggests that glass eels generally arrive in the North Sea in January to February. However, this is dependent on met-ocean conditions over Northern Europe and the relative strength of the Gulf Stream and associated currents around the British Isles. Observations suggest that eels enter the North Sea from both the English Channel and from the north, following currents that flow around Scotland and southwards into the southern North Sea. However, it is possible to catch glass eels in the southern North Sea from January to mid-May depending on the prevailing met-ocean conditions. Environment Agency eel recruitment data from fish weirs and traps on the Rivers Stour and Blackwater indicate that glass eels migrate upstream in rivers from April through the year and can be found as late in the year as September. However, numbers recorded in these local rivers in recent years appear to be peak in May/June. Sampling for glass eels on tributaries of the River Thames is carried out annually between April and September also suggesting that glass eels would be present in the East Anglia marine environment prior to entering freshwater, in or around April and May. Targeted glass eel surveys conducted in April and May 2015 as part of the BEEMS programme only succeeded in catching one glass eel in April on a flood tide at the location of the SZC intakes (3 km offshore) from a total of 105 tows. (BEEMS Technical Report TR356).

When sexual maturity is reached eels leave for their return journey to Sargasso in an anatomically distinct silver eel phase. Spawning migrations occur mainly during the second half of the year. A few specimens of nearly fully mature silver eels have been captured at Sizewell but only one mature eel in 2009 which was the first specimen in this condition observed by Pisces Conservation staff in over 30 years of impingement sampling.

In conclusion, glass eels transit past Sizewell on their passage to river estuaries and it is reasonable to assume that adult silver eels transit past Sizewell on their return migration to the Sargasso Sea.

4.2.3.2 Potential thermal barriers to migration in transitional waters

Existing thermal standards for transitional waters specify that an estuary's cross section should not have an area larger than 25% with a temperature uplift above 2°C, for more than 5% of the time. There are no such standards for coastal waters, nevertheless an assessment still needs to be made on whether a coastal plume could act as barrier to migration for those species that migrate between coastal and transitional waters.

At Sizewell the only transitional waterbodies that could be affected by the thermal plume are the Blyth(S) and the Alde-Ore. Figure 15 shows the SZB+SZC thermal plume at both estuaries as a 98th percentile at the surface.

Alde-Ore waterbody

As can be seen from Figure 15 the thermal plume only intersects the mouth of the Alde-Ore at excess temperatures in the 0°C to 1°C range as 98 percentiles. At these temperatures the standard for thermal barriers in estuarine waters cannot be exceeded.

Blyth(S) waterbody

The SZB+SZC thermal plume intersects the Blyth estuary at temperatures in the 2°C to 3°C range as 98 percentiles (Figure 15) and there is, therefore, a potential to exceed the estuarine thermal standard and to create an impact on the movement of migratory fish. The temperatures in the cross section across the estuary mouth were extracted from the GETM SZB+SZC model outputs and the time series of exceedance of the thermal standard is shown in Figure 14. Over the annual cycle the condition was violated in 307 hourly episodes or 3.50% of the time. This is below the 5% threshold in the standard and therefore no barriers to fish migration in the estuary are expected.

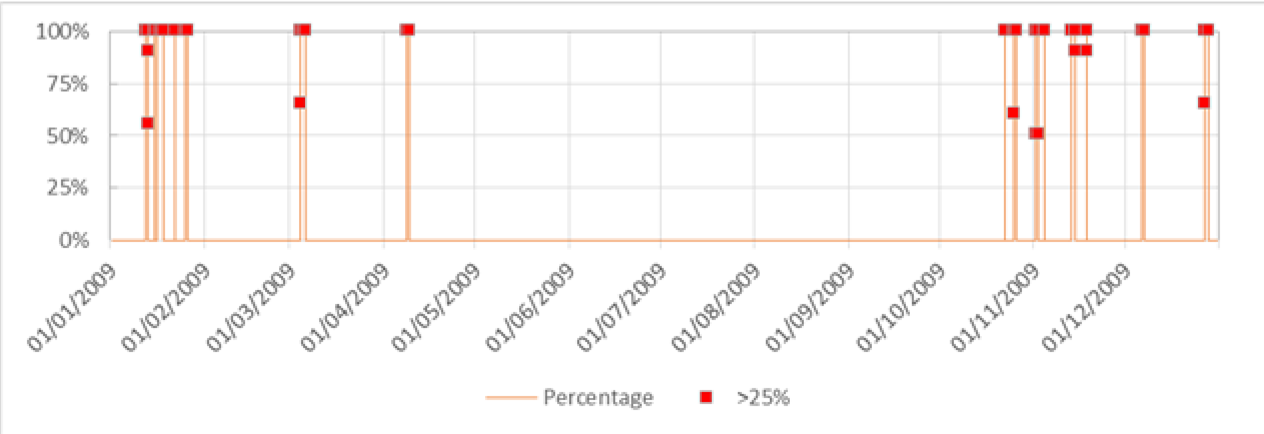


Figure 14 Relative area of the cross section of the river Blyth mouth that exceeds the 2°C thermal uplift threshold under the SZB+SZC scenario (hourly data).

Figure 14 does not show thee fine distribution of the hourly data clearly and it could be inferred that the winter period which corresponds to the river/sea lamprey migration period (see 4.2.3.3) could exhibit barriers to migration.

Table 12 Thermal barrier prediction for River Blyth with SZC+SZB operational – Number of hours that the estuary's cross section is predicted to have an area larger than 25% with a temperature uplift above 2°C, for more than 5% of the time

Month	**Total hours in with a potential thermal barrier in the period 1/9/09 to 31/12/15**	**Number of separate days subject to a potential barrier**
August	0	0
September	0	0
October	26	3
November	58	4
December	40	4
Total	**124**	**11**

Analysis shows that a potential thermal barrier was predicted to exist for a total of 124 hours in the period 1st August 2009 to 31st December 2009 i.e. 3.4% of the total period. There was no period when a potential barrier lasted for more than 1 day. Under such circumstances the analysis demonstrates that there would be no barrier to migration for river/sea lamprey (if they migrate in the river).

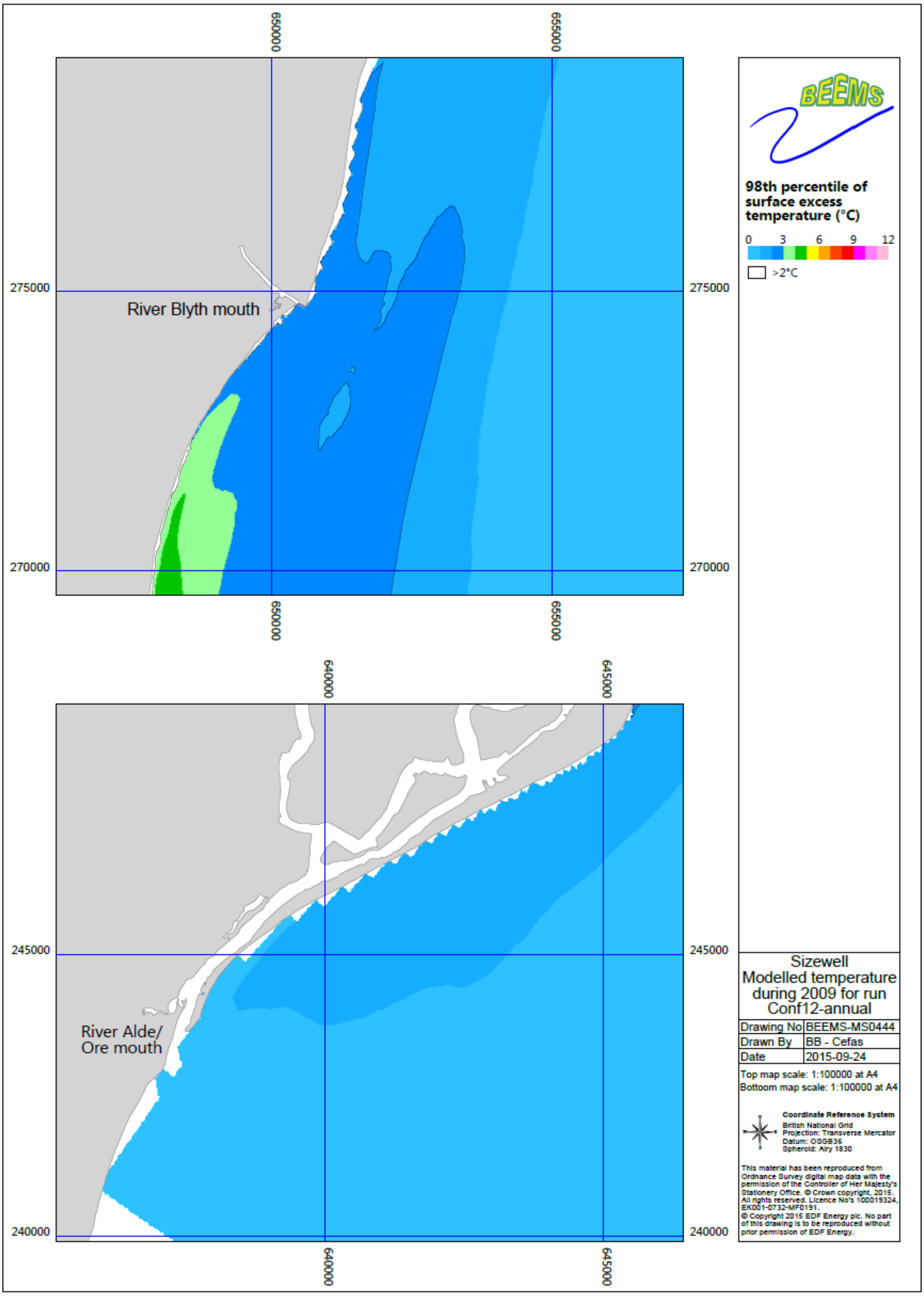


Figure 15 SZB+SZC thermal plume maps as 98%ile temperatures at the Blyth and Alde-Ore estuaries

4.2.3.3 Possibility of a thermal barrier to fish migration off Sizewell

There are no thermal standards to assess potential migration barriers for fish in coastal waters. However, if fish have to pass through a coastal plume on their migration route to or from an estuary there is a possibility of the plume acting as a barrier to migration. If an attempt is made to apply the estuarine standard to a coastal location such as Sizewell, the problem is one of selecting the width of a transit corridor which brackets a reasonable estimate of how far offshore the fish species of interest would normally travel or could travel without experiencing loss of fitness.

The conservation fish species that could be at risk from thermal barriers to migration were described In 4.2.3.1. An assessment was made of whether each of the species is considered likely to be undertaking migrations off Sizewell and also on whether avoidance of the thermal plumes was considered likely to affect the fitness of the fish. This analysis is summarised in Table 13 together with an assessment of whether further detailed assessment was considered necessary.

Table 13 Scoping to identify which conservation fish species required a more detailed assessment for potential barriers to migration off Sizewell

Species	Likelihood that species transits off Sizewell	Potential risk of disruption to migration/loss of fitness from avoidance of thermal plumes at Sizewell	Further assessment required
twaite shad	Unlikely	Highly unlikely[1]	No
allis shad	Unlikely	Highly unlikely[1]	No
river lamprey	Possible	Possible (adults returning from sea to any rivers populated by the same species)	Yes - on a precautionary basis
sea lamprey	Possible	Possible (adults returning from sea to any rivers populated by the same species)	Yes- on a precautionary basis
cucumber smelt	Likely	Likely	Yes
salmon	Unlikely	Highly unlikely	No
sea trout	Highly likely	Unlikely	Uncertain – Yes on a precautionary basis.
European eel – glass eel	Highly likely	Likely[2]	Yes
European eel – silver eel	Likely	Likely[2]	Yes

1. No east coast spawning rivers, adults most probably return to continental Europe
2. Based upon the assumption that the eels will migrate close to the coast (note this is not an established fact and at Hinkley Point glass eels have been observed migrating at 10km offshore in the middle of the Severn Estuary, BEEMS Technical report TR356)

In summary, from the available evidence it is assumed that the following conservation species may undertake migrations off Sizewell and be at risk from thermal barriers to migration:

- Cucumber smelt. (Adults to estuaries in February to April).
- European eel (Glass eels to estuaries in March to April and silver eels to the Sargasso in September to December)
- River lamprey. Adults to estuaries in August to December.
- Sea lamprey. Adults to estuaries in August to December. (uncertain but assumed the same as river lamprey because spawning period is similar)
- Sea trout. Post-smolts travelling south in July.

In common with most thermal standards the estuarine barrier to migration threshold has been set to act as an indicative trigger; its roots stem from older regulatory thresholds set to protect salmonids in rivers and estuaries. Wither *et al* 2012 present a summary of data from laboratory thermal preference experiments that show the avoidance thresholds for various species (Table 14).

Table 14 Published thermal avoidance thresholds for conservation fish species

Species	Avoidance threshold	Notes
Cucumber smelt	+4°C	
Eels: adults	+3°C	
Eels:elvers	>+12°C	No upper threshold found in experiments
Sea trout: juveniles	25°C	In July the baseline inshore temperature at Sizewell as a 95 percentile is calculated from mean temperature + 2 standard deviations or 18+2.8 =20.8°C (from Table 8) i.e. avoidance threshold = +4.2°C

Note: these are the temperatures that fish chose to avoid in laboratory controlled conditions. It is considered that such conditions are unlikely to be fully representative of the situation in the wild where mature migrating fish have an ecological imperative to undertake a migration in order to reproduce.

For the purpose of this study a migration corridor of approximately 3km wide from the coast to the SZC outfalls was assumed based upon the fact that river lampreys and glass eels are known to be present to at least that distance offshore from BEEMS surveys (BEEMS Technical Report TR356). It is not known how far offshore smelt and silver eels migrate but given the total distances that they are known to migrate, a 3km wide corridor is considered unlikely to affect their fitness if they chose to avoid the hotter parts of the plumes. Figure 16 shows the predicted thermal occlusion of a transect drawn from the coast to the SZC outfalls. Applying the standard estuarine thermal barrier test to this transect leads to a prediction that the 25% occlusion threshold would be exceeded for 18.7% of the year, thereby triggering further ecological investigation.

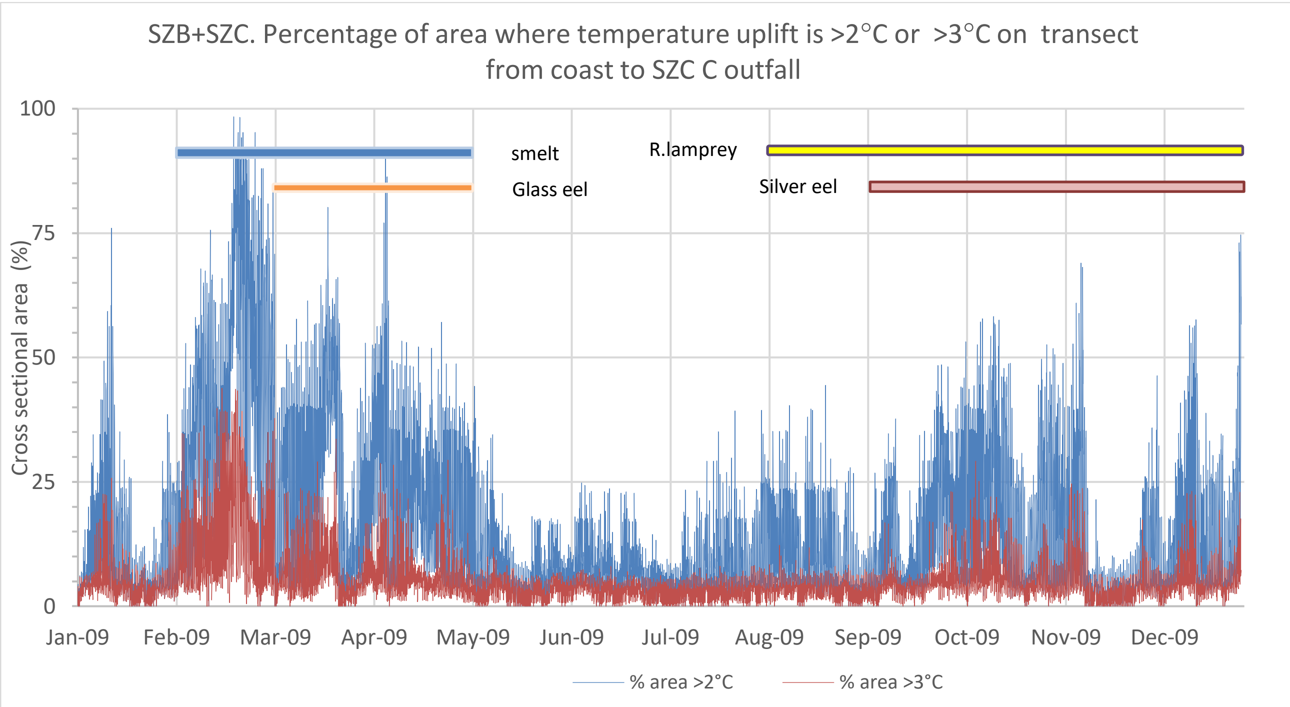


Figure 16. Percentage of Sizewell transect with >2°C and >3°C uplift shown against fish migration periods

The underlying data use to create Figure 16 was analysed to determine what percentage of the migration period for a particular species exceeded the standard thermal occlusion threshold and the results are shown in Table 15.

Table 15. Potential thermal occlusion during migration periods

Species	Assumed thermal threshold for this analysis	Percentage of migration period that the 25% occlusion threshold is exceeded	Migration period
smelt	3°C (4°C actual)	4.6%	February - April
sea trout	3°C (4°C actual)	0%	July
Glass eel	>+12°C	0%	March - April
Silver eel	3°C	0.07%	September - December
River and sea lamprey	2°C (worst case assumption)	13.2%	August - December

Smelt, sea trout, glass eel and silver eel with avoidance thresholds of ≥3°C would not experience a barrier to migration in a transect from the coast to the Sizewell C outfalls.

The thermal avoidance threshold for river and sea lampreys is not known and a 2°C uplift criteria has been adopted as a precautionary approach. However, analysis of the plume modelling data shows that in the lamprey migration period of August to December the percentage of the cross section that would exceed 2°C uplift is a maximum of 75% (for 1h only) with a mean of 12%, 95%ile (184h during period) of 36% and 99%ile (37h during period) of 49%. There would, therefore, always be a route through the transect that did not present a thermal barrier to migration with more than half the transect available for 99% of the time. However, as discussed in 4.2.3.1 the route that lampreys would take to return to a suitable river is determined by the location of their host when the lamprey decides to detach itself and considering the location of the nearest potential spawning locations in the Blyth and the Alde-Ore, statistically very few fish would seem likely to follow a path that takes them through the Sizewell thermal plumes. Given the high percentage of the transect that would be available for a Sizewell transit and the low likelihood that such a transit would actually take place, the Sizewell thermal plumes are not considered to present a barrier to migration for sea and river lampreys.

It is concluded that the presence of thermal plumes off Sizewell would not present a barrier to migrating fish of conservation concern.

4.3 Process for further investigation of potential ecological effects from the thermal plume

The purpose of this section is not to present the results of the ecological assessment but to outline what will be done and what standards/evidence will be used. The assessment itself will be presented in the Sizewell Marine Ecology synthesis (BEEMS Technical Report TR313).

4.3.1 Effects of absolute temperature

The environmental assessment task is to assess whether any species within the area of exceedance of the relevant standards that cannot avoid the plume could suffer toxicity due to the elevated temperatures. Much of the required evidence on thermal toxicity is summarised in BEEMS SAR008.

4.3.2 Effects of excess temperature

The interpretation of excess temperature statistics is more complex. Figures 17 and 18 show the instantaneous size of the SZB+SZC plumes at greater than 2°C and 3°C excess temperature (using hourly model outputs for 1 year). Note that Figures 17 and 18 show actual plume sizes, whereas the 98%ile plume maps presented in section 3 of this report show the area that exceeds 2°C uplift for more 7.3 days per annum, at any time during the year. In the 98%ile statistics the times of uplift exceedance are not necessarily consecutive and could be days or months apart.

The seasonality of the size of the excess temperature plume is highly pronounced and is due to differing meteorology at different times of the year. Similarly the relative size of the surface and seabed plumes changes with different mixing conditions during the year. For example the instantaneous 2°C excess temperature plume area at the seabed exceeds 4100ha at the end of February but is <100ha for periods in July. The winter periods of strong winds will drive the 98%ile statistics but will have limited potential to affect marine ecology outside of the growth season. Table 16 shows the mean size of the instantaneous 2°C and 3°C excess temperature plumes by month.

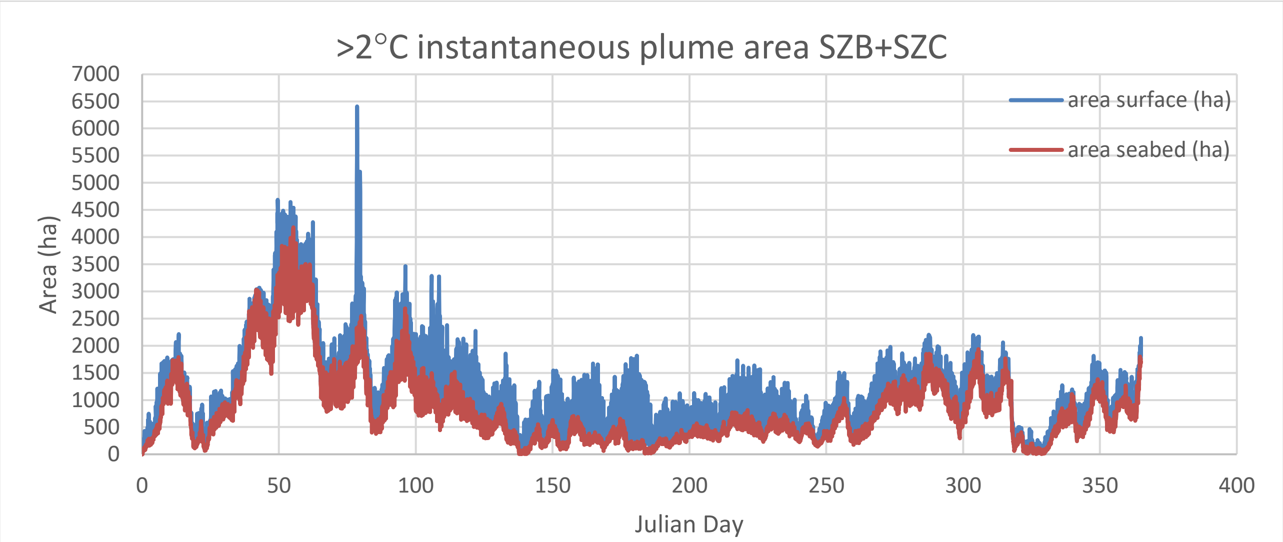


Figure 17 Instantaneous areas of SZB+SZC plume where the excess temperature is >2°C

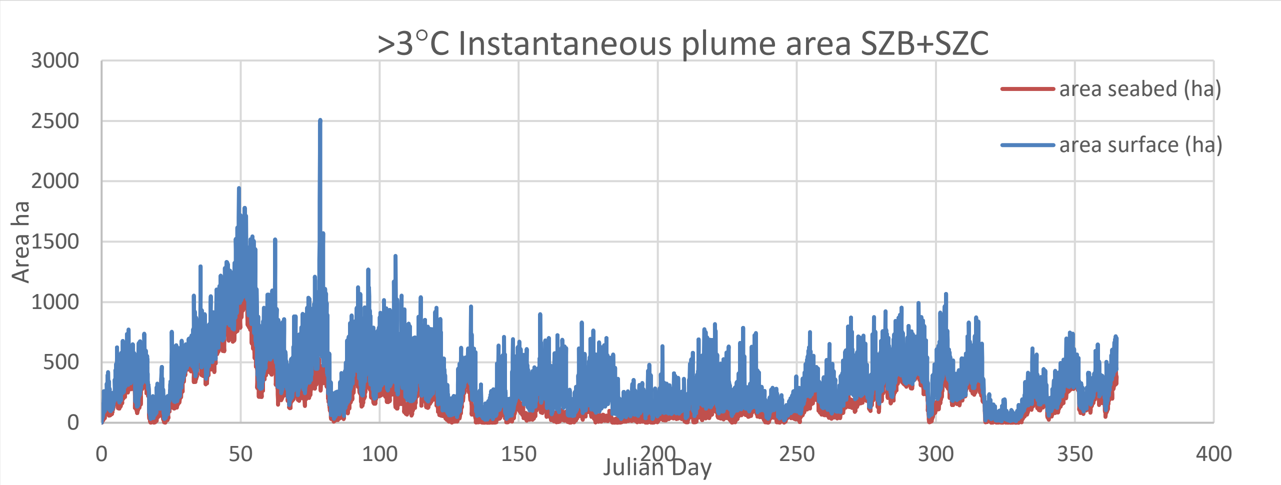


Figure 18 Instantaneous areas of SZB+SZC plume where the excess temperature is >3°C

Table 16 Size of instantaneous SZB+SZC plume at 2°C and 3°C excess temperature

	>2°C excess temperature (monthly mean size)		>3°C excess temperature (monthly mean size)	
Month	Surface ha	Seabed ha	Surface ha	Seabed ha
January	827	666	300	198
February	2,605	2,329	834	673
March	1,846	1,514	491	292
April	1,609	1,208	489	257
May	680	403	242	95
June	698	315	277	74
July	548	271	179	44
August	763	505	239	79
September	749	536	257	118
October	1,293	1,193	429	282
November	745	626	228	146
December	848	783	305	208
98%ile annual plume size	**3,495**	**3,092**	**1089**	**870**

Given the 98th percentile of the annual sea surface temperatures in Suffolk coastal waters of 19.4ºC (BEEMS Technical Report TR131 Ed 2), excess temperatures of 2 °C or 3 °C are well below those capable of causing lethality issues for organisms unable to avoid the plume. The ecological question then becomes one of determining whether any ecological impacts are caused by chronic exposure to elevated temperatures. The 98%ile temperature statistics are not useful for such a task, especially given the seasonal variability in the size of the seabed plume and, in common with normal ecological practice, annual mean excess temperatures will be used to assess the areas subject to chronic exposure.

The possibility of shorter term exposure causing effects during specific seasons will also be examined. E.g. if there was an important spawning area at Sizewell, the presence of the predicted large thermal plumes in February or March could be an important risk factor dependent upon species.

4.3.3 Barriers to fish migration

Section 4.2.3 has demonstrated that neither the Blyth(S) nor Alde-Ore estuaries are predicted to have thermal barriers to fish migration at the estuary mouth.

The remaining assessment is therefore whether the thermal plume offshore of Sizewell could act as a barrier to migration for those fish traversing the Sizewell frontage to or from the Blyth and/or Alde-Ore or more distant areas. Based upon impingement data collected at Sizewell B (BEEMS Technical Report TR243) the species potentially most at risk are cucumber smelt, river lamprey, glass and adult eels. In this coastal environment there is no obvious channel to be occluded and the choice of an eastern boundary has to consider potential bathymetric cues and what knowledge there is of the migratory behaviour of potentially affected species.

In the absence of a regulatory standard for coastal waters the existing transitional water standard has been applied as an initial screening tool across a transect from the coast to the location of the Sizewell C outfall. That test results in a prediction that the 25% occlusion threshold would be exceeded for 18.7% of the year, thereby triggering further ecological investigation.

Based upon experimental data on avoidance temperatures and an analysis of temperatures in the transect during the migration periods of cucumber smelt, river lamprey, glass and adult eels, section 4.2.3.3 predicted that there would be no thermal barriers to migration off Sizewell for these species.

4.3.4 Displacement of the marine prey of SPA designated birds

It is considered probable that migratory fish will be less susceptible to thermal barriers than fish that are not driven by an ecological imperative to migrate and there is a possibility that the prey of designated marine birds (predominantly pelagic species such as sprat) at Sizewell may will be displaced within or out of the birds' foraging ranges. The assessment task consists of:

- Determining the prey of specific marine species, for example red throated divers and little terns at the relevant times of the year
- Determining the fish behavioural sensitivity from the scientific literature or, in the absence of data, by adopting the indicative 2°C excess temp standard.
- Calculating the intersection between the bird foraging ranges and the thermal plume at appropriate excess temperatures and at relevant times of the year
- Assessing the significance of the prey displacement area (to be undertaken in the shadow HRA)

4.4 Summary of plume thermal thresholds to be used for ecological assessment

In summary the existing HRA and WFD thermal standards will be used to trigger the need for further investigation for any ecological effects. In those areas that exceed existing thermal standards the potential for ecological effects on the species expected form survey results to be present in the plume area will be subject to analysis using the procedure outlined in section 4.3 and using the thermal thresholds listed in Table 14 as indicative thresholds. If any species are found in the plume area that are known to be particularly sensitive to temperature the thresholds in Table 17 will be adjusted accordingly.

If no ecological effects are found then the thermal discharge will be considered compliant with HRA and WFD standards.

Table 17 Thermal thresholds to be used for detailed ecological assessment

Effect	Test	Evidence
Acute effects:	Determination of whether any marine species cannot avoid the plume @ 28°C absolute temperature as a 98th percentile	The majority of marine invertebrates have upper lethal temperatures > 30°C
Chronic effects:	Whether any species would be adversely effected by +2°C annual mean excess temperature	Observed temperature preferenda.
Thermal barriers to fish migration:	In line with practice for estuaries, the initial threshold will be : an appropriate offshore cross section (determined from consideration of bathymetry and where possible from species migratory behaviour) should not have an area larger than 25% with a temperature uplift above 2°C, for more than 5% of the time.	There is little evidence to suggest that existing thermal discharges have created barriers to cold-water migratory fish species such as salmon, sea trout, eel and smelt whose avoidance thresholds have been shown in laboratory experiments to be > +2°C For species where better evidence exists the 2°C threshold will be varied appropriately.

Table 18 shows the thermal plume areas that exceed the 2°C and 3°C annual mean excess temperature threshold. The corresponding plume maps are in Figures 9-12 in section 3 of this report.

Table 18 SZB+SZC thermal plume areas where the annual mean excess temperature exceeds 2°C and 3°C

Model run	Position		Mean excess temp. >2°C	Mean excess temp. >3°C
ReferenceV2 annual SZB	Surface	ha	194	52
		%	1.3	0.35
	Seabed	ha	59	2
		%	0.4	0.015
Conf12 annual SZB+SZC	Surface	ha	567	172
		%	3.87	1.18
	Seabed	ha	309	78
		%	2.11	0.53

5 Thermal Plume Sensitivity Testing

5.1 Plume Vertical structure

The SZB+SZC plume temperature profile over time is shown in
Figure 19 for a Neap tide and Figure 20 for a Spring tide. Both the Sizewell B and Sizewell C discharge plumes are heavily stratified. At the Sizewell C intake locations, (I3a is shown for example but all show similar features) during neap tides stratification is strong and the initially shallow buoyant plume is mixed down. Comparing the Conf12 and ZeroReferenceV2 run there is a general uplift of around 0.75 -1.0 °C but the main plume stays bouyant. During spring tide a similar effect occurs but as the tidal mixing is stronger the surface plume is mixed down further. However the direct surface plume does not reach the depth of the intake. Also evident in the Zero Reference plot is that there is a small temperature difference between the ebb and flood tides with the ebb tide being approximately 0.5 °C warmer. At the Sizewell B intake a similar situation occurs but, it is generally warmer and while there is stratification at high water slack (which occurs just after high water) and low water slack. In addition at peak flow on spring tides the plume is mixed down adding significantly to the over all near bed temperature.

Evident in both these results and the validation report (BEEMS Technical Report TR228), there is a strong stratification with the warm plume occupying a layer of up to 1 m thick at the surface. While the model has 20 vertical layers it is the thermal effects at the sea surface and bed that are most appropriate for environmental impact assessment. To make this point the maps of absolute mean and excess mean temperatures are included in Figures 21 and 22. For the rest of the report, for brevity, only the surface and bed layers are shown.

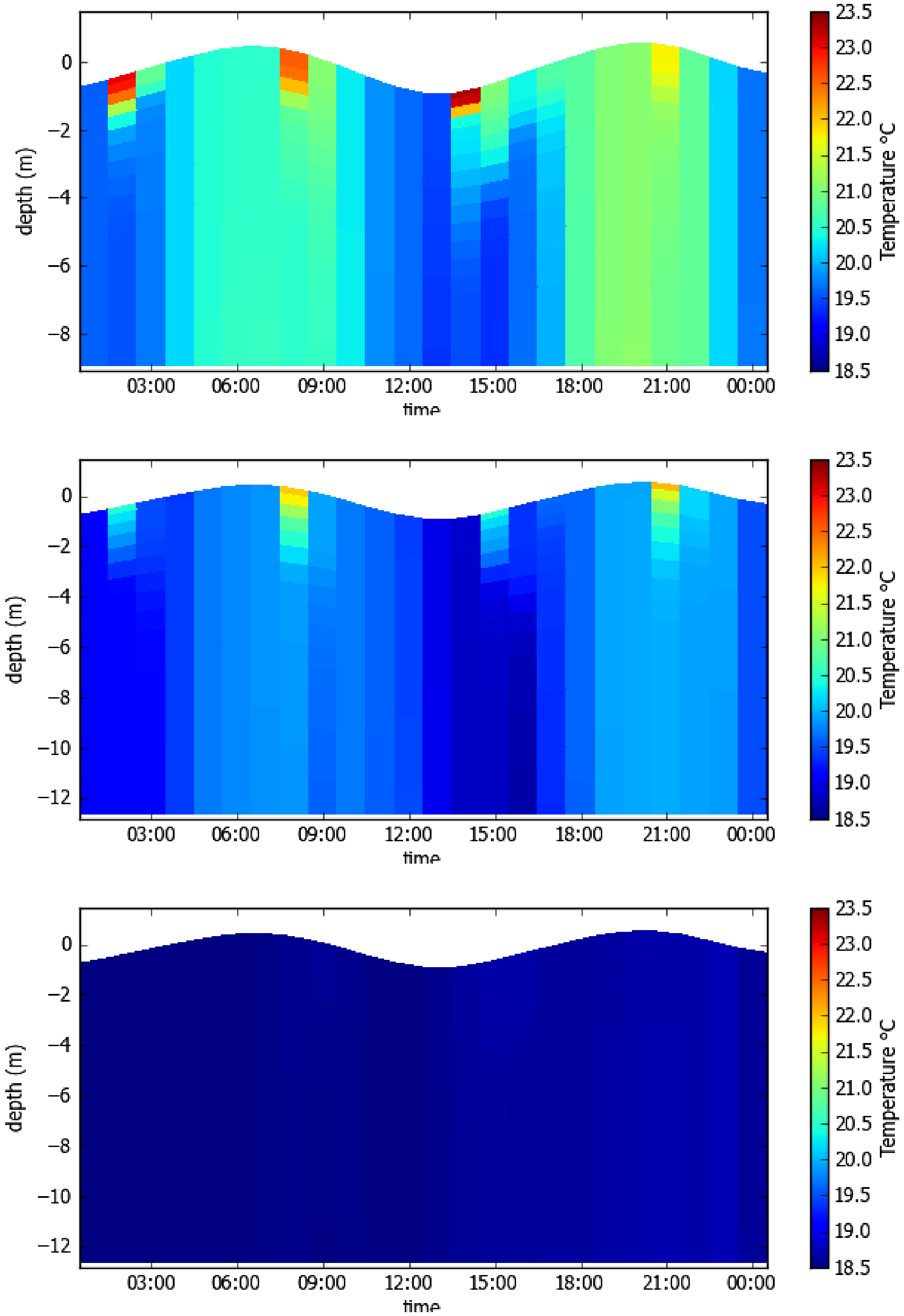


Figure 19 - Stratification during the 1st August 2009 Neap tides: Sizewell B intake for Conf12 (upper); Sizewell C intake (I3a) for Conf12 (middle) and Sizewell C intake for the zero reference run (lower).

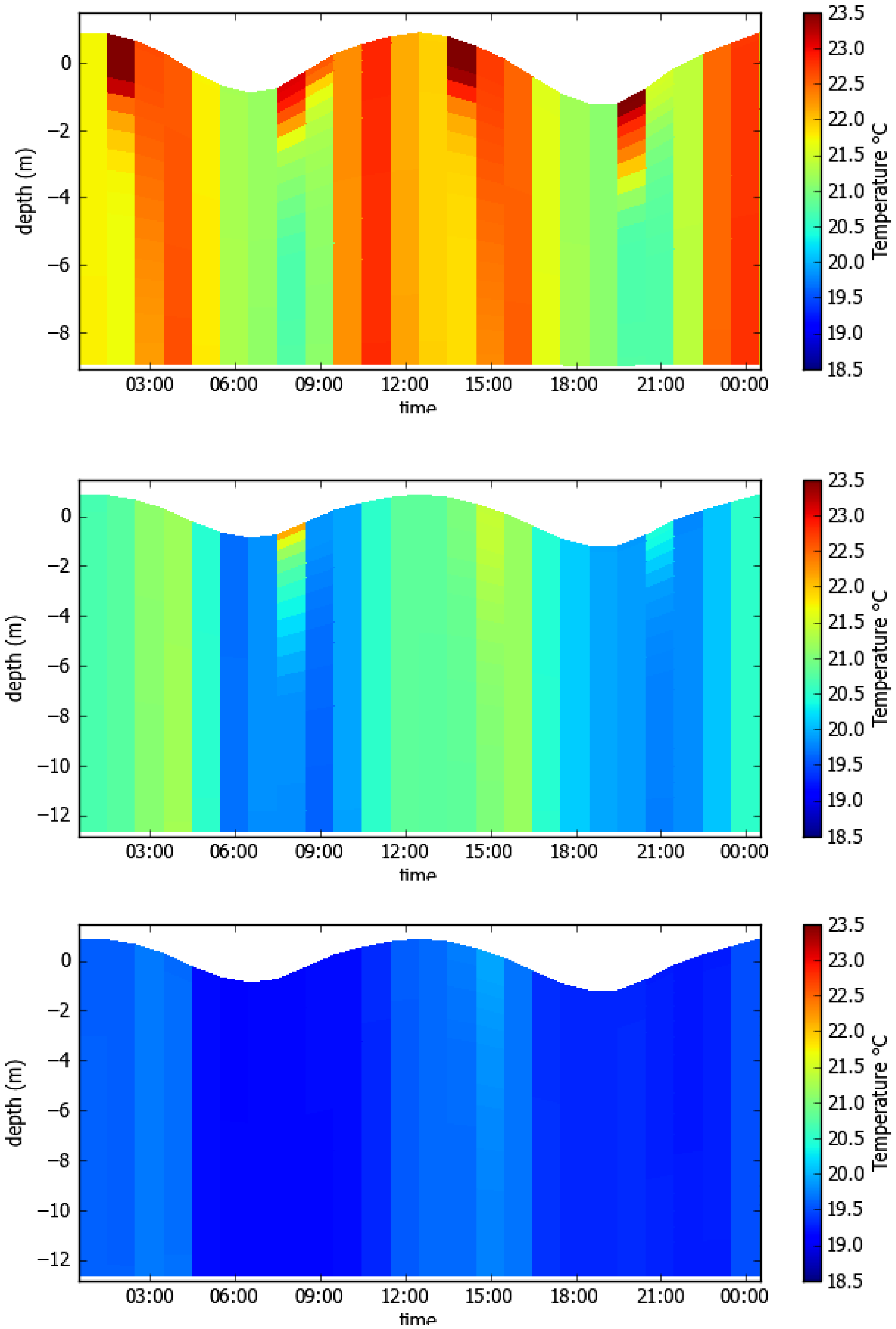


Figure 20 - Stratification during the 10th August 2009 Spring tides: Sizewell B intake for Conf12 (upper); Sizewell C intake (I3a) for Conf12 (middle) and Sizewell C intake for the zero reference run (lower).

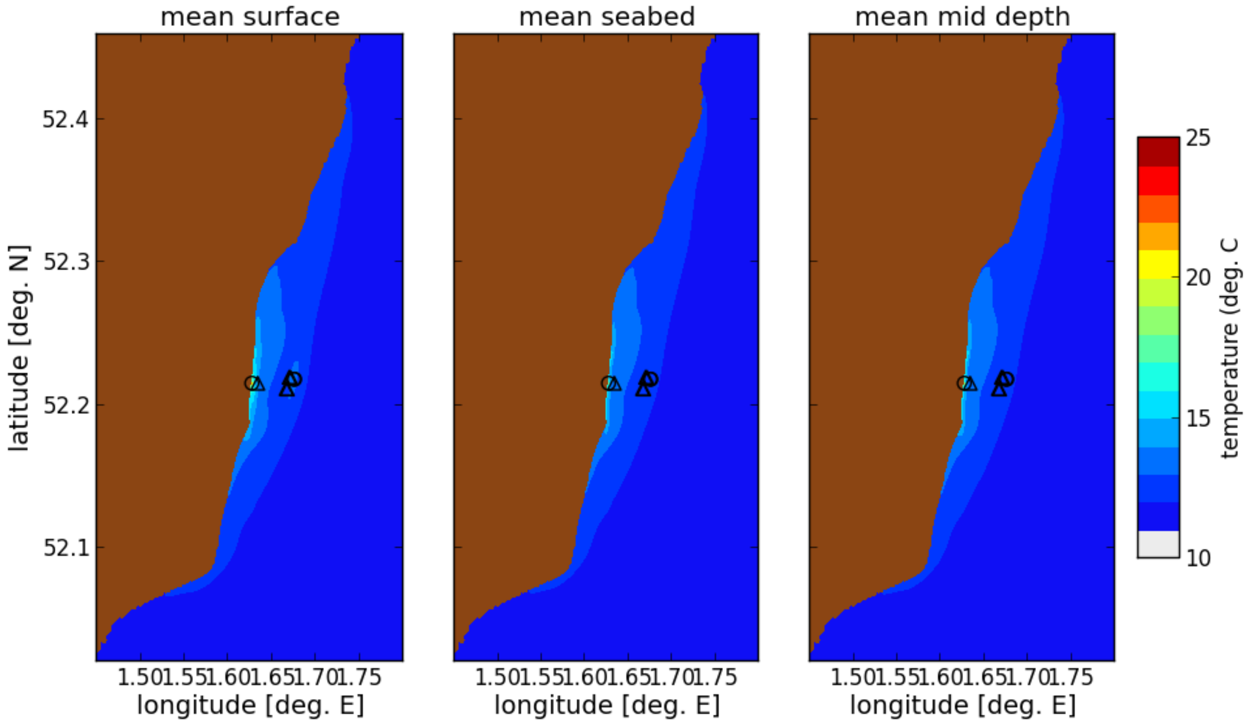


Figure 21 - Mean annual absolute water temperature at surface, mid depth and sea bed for run Conf12.

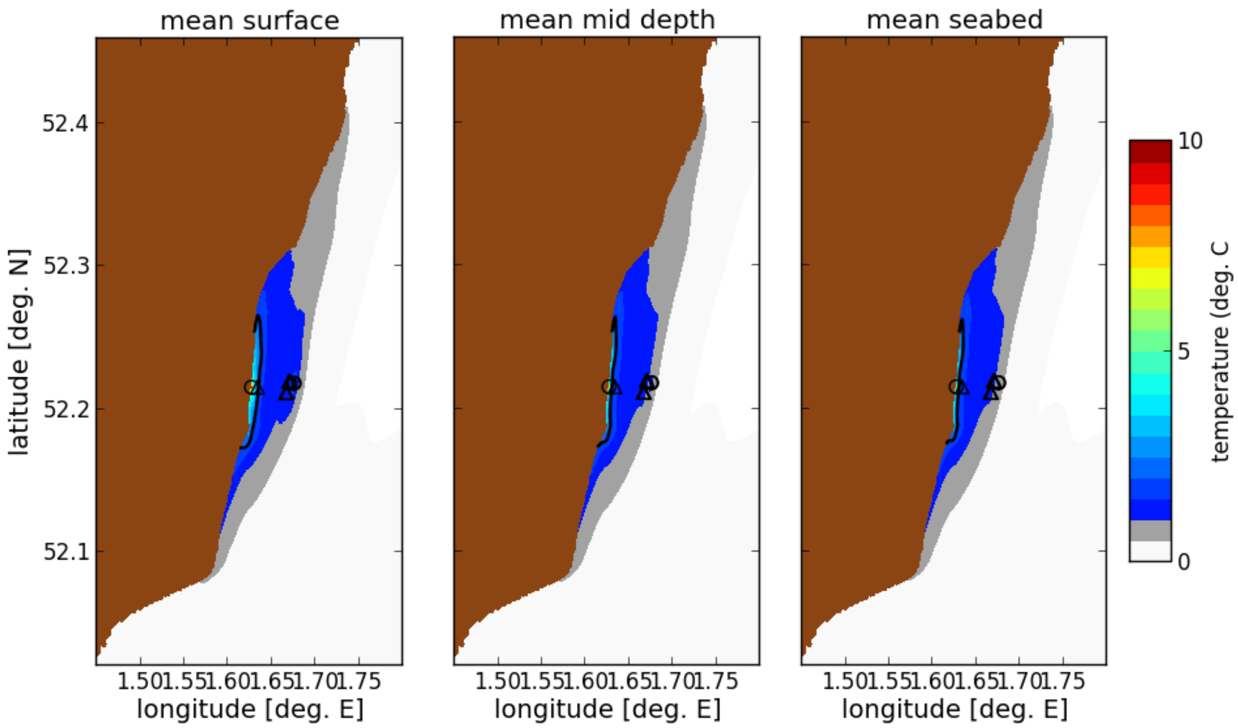


Figure 22 - Mean annual excess temperature at surface, mid depth and sea bed for run Conf12. The black line represents the 2 °C mean excess isothermal.

5.2 Effect of a worst case SZC maintenance scenario on plume temperatures

Sizewell C power station has two cooling water pump systems (i.e. a total of 4 pumps) that can work independently. In a worst case scenario when 2 out of 4 pumps were under maintenance the flow of cooling water would be halved but the heat content of 2 full power reactors would remain approximately the same raising the excess temperature at the outfall from 11.6ºC to 23.2 ºC. The concern with this scenario is whether the warmer water at the outfall would lead to larger, hotter plume which caused larger environmental impacts than the normal operation of SZC. This is of special concern during the spring bloom when biological activity is at a peak and so a maintenance scenario (Conf12_maint) was run for the month of May (see Table 5 for run details).

The results of the maintenance and normal SZC runs are shown for average excess temperature at the surface and bottom in Figures 23 to 26. The 2°C isotherm at the surface, defining the border between good and moderate water quality according to the WFD, has a maximum extent of 7.5 km during maintenance operations, compared with 9 km for regular operations (see Figures 23 and 24). The average excess bottom temperature has a much smaller area of exceedance and again the impact is smaller than for the maintenance case. This is because the hotter plume near to the discharge point transfers heat to the atmosphere much more efficiently than the normal cooler plume. This means that there is less heat to mix down into the water column, resulting in a smaller plume at the surface and at the bed. Whilst the excess temperature plume area is smaller for the maintenance run, the increased temperatures within SZC would cause more entrainment mortality to planktonic organisms. This will be analysed in more detail in the BEEMS Marine Ecology Synthesis report (BEEMS Technical Report TR313).

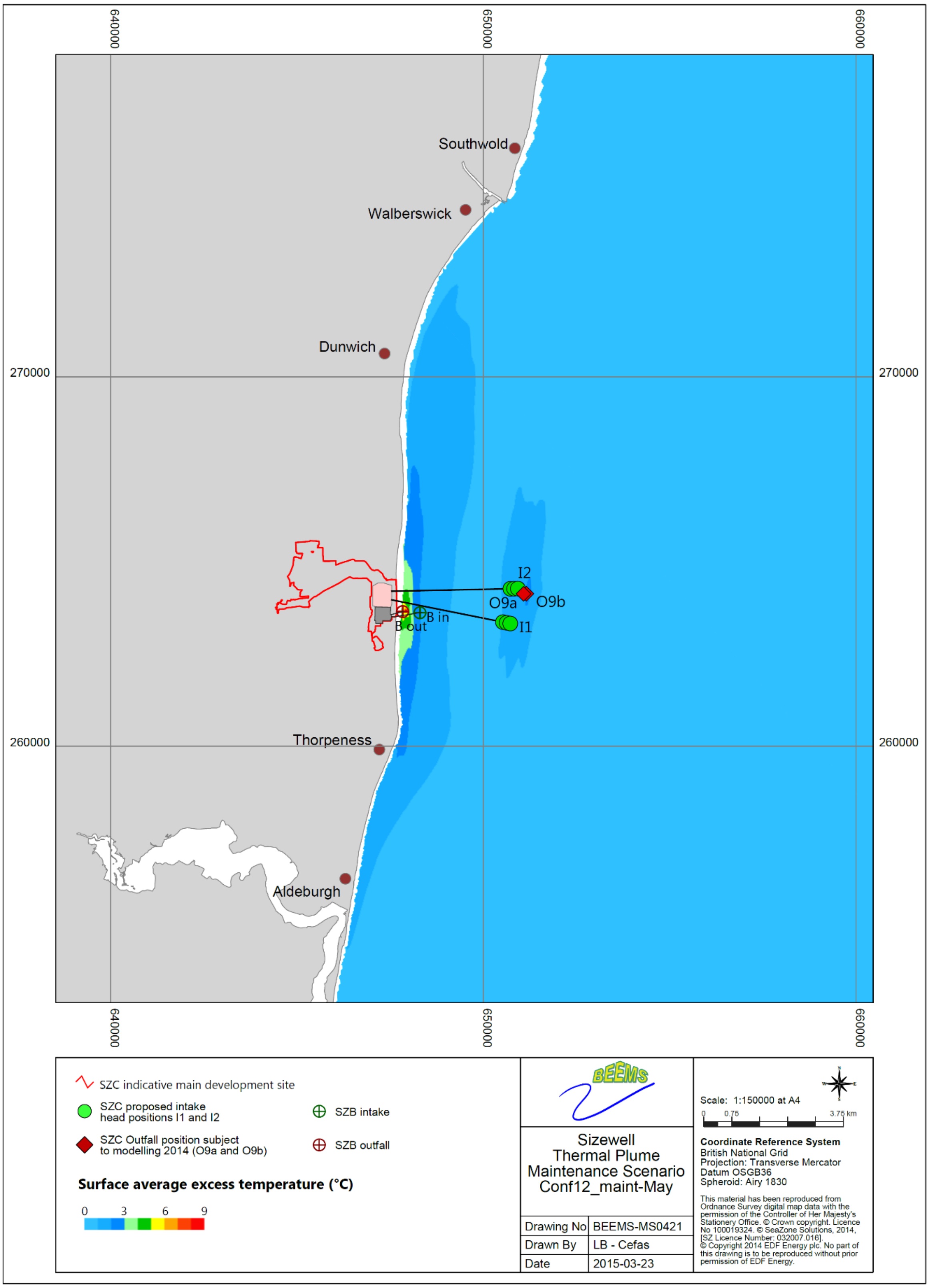


Figure 23 – May excess surface water temperature for maintenance run (Conf12_maint).

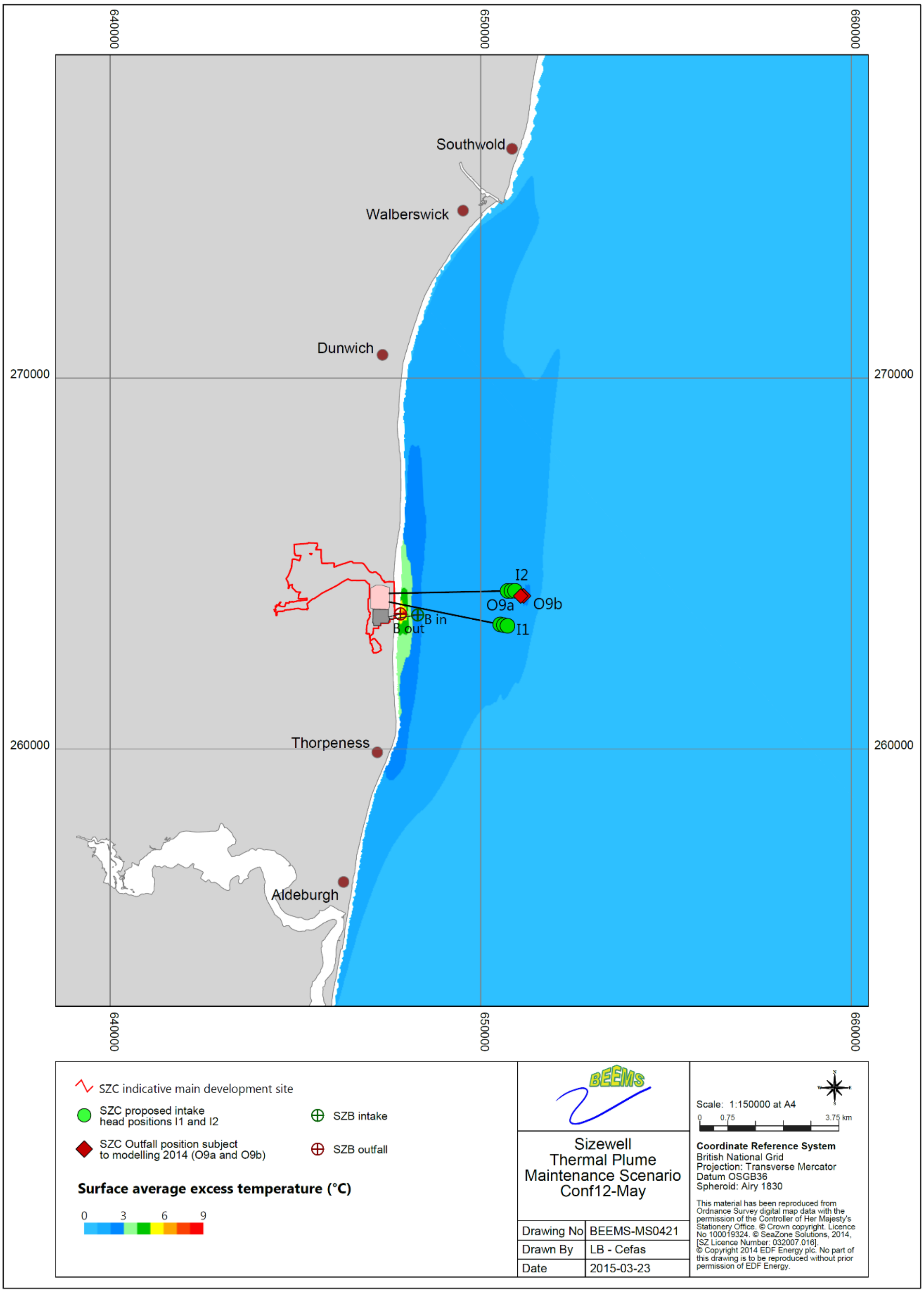


Figure 24 – May excess surface water temperature for run with regular SZB and SZC discharge (Conf12)

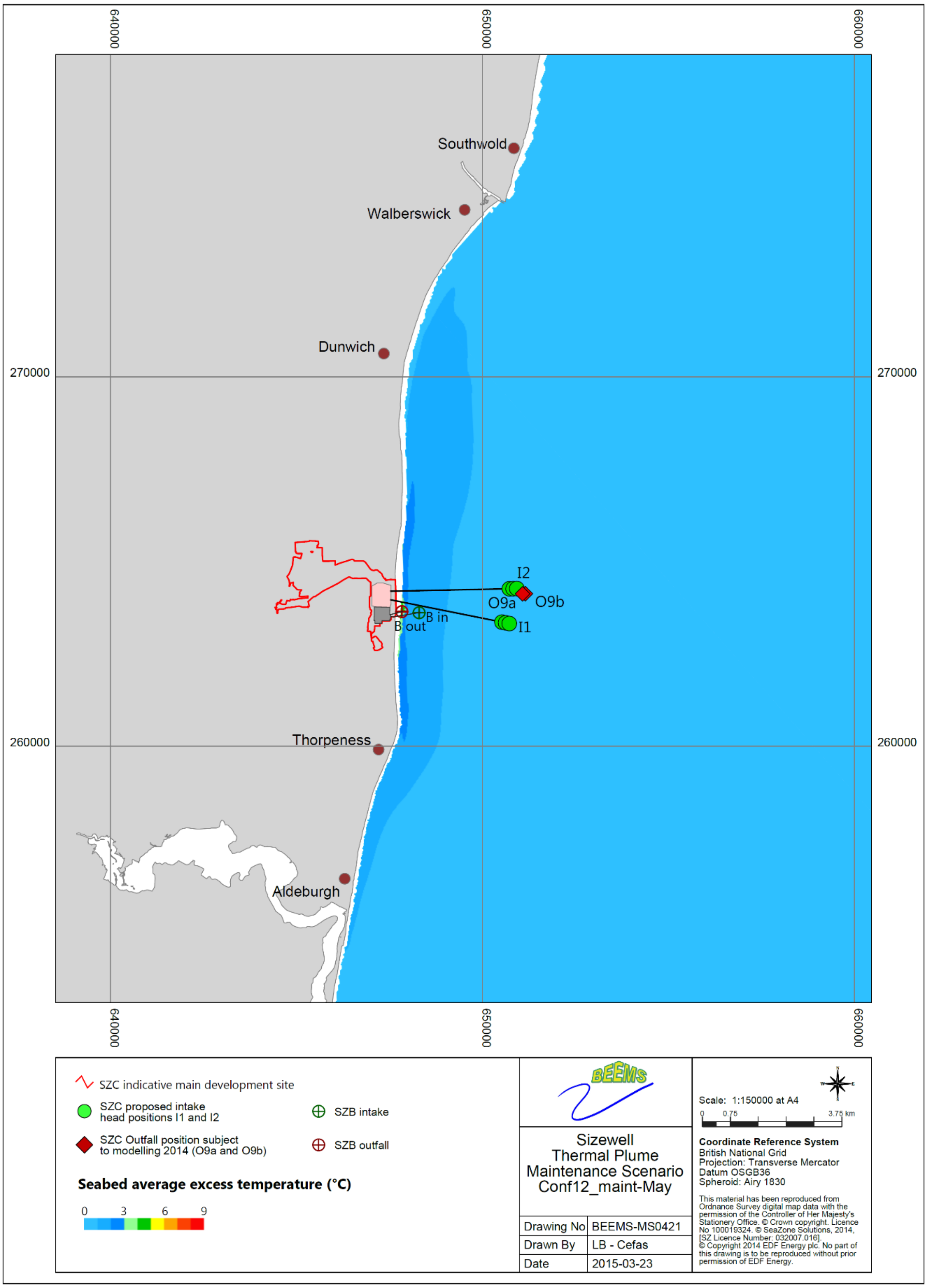


Figure 25 – May excess bottom water temperature for maintenance run (Conf12_maint).

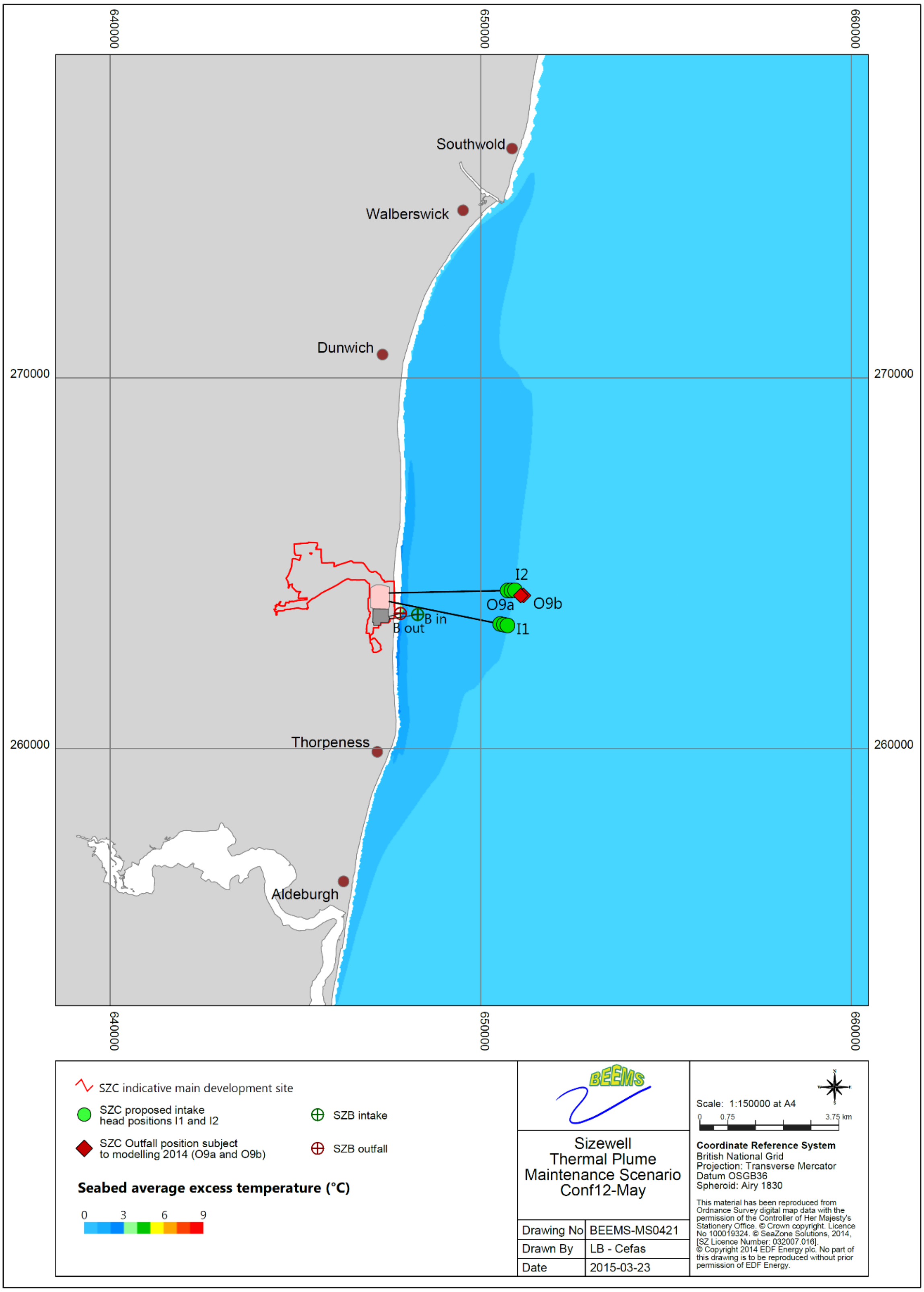
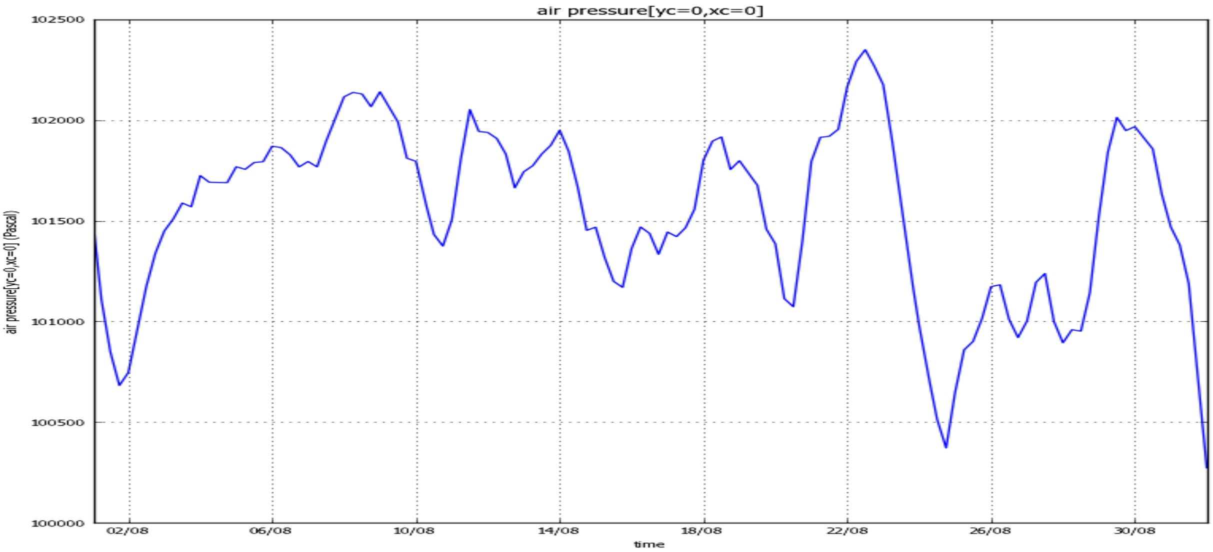


Figure 26 – May excess bottom water temperature for run with regular SZB and SZC discharge (Conf12)

5.3 Plume distribution under high sea temperatures

As discussed in Section 1.2 of this report, 2009 was a very average year with all the monthly averages within one standard deviation of the long term mean. The sea temperature for August 2009 was 0.8 °C above the mean. As the highest sea temperatures normally occur in August, analysis of this month is also useful for indicating what might happen in the future as sea temperatures rise. As can be seen in Figure 27 there were brief periods of high pressure in August.

The 98th percentile and mean temperatures for August are shown in Figure 28 and the difference between the annual and August temperatures are shown in Figure 29. The 98th percentile of the excess temperatures in August is lower than the annual 98th percentile by 0.75 °C around the Sizewell C outfall and by up to 2.5°C at the Sizewell B outfall. The mean excess temperatures for August showed little difference from the annual values with mean values slightly (~0.25 °C) lower. This result is relevant to considerations of future climate. . The operational life time of the station will be 60 years, potentially up to about 2085, when annual mean and maximum sea temperatures will undoubtedly be warmer. The evidence here is that the mean excess temperature in August when the background sea temperature is 19 °C is very similar to the annual mean excess values when the background sea temperature is ~11 °C. Thus when considering a future climate where the mean temperature may be significantly warmer (e.g. 2 °C) the simulations from August indicate that the derived annual excess means for 2009 will be applicable to other time periods in the future. Or put more simply the excess temperature field is mostly independent of the background sea temperature.


air pressure[yc=0,xc=0]
air pressure[yc=0,xc=0] (Pascal)
102500
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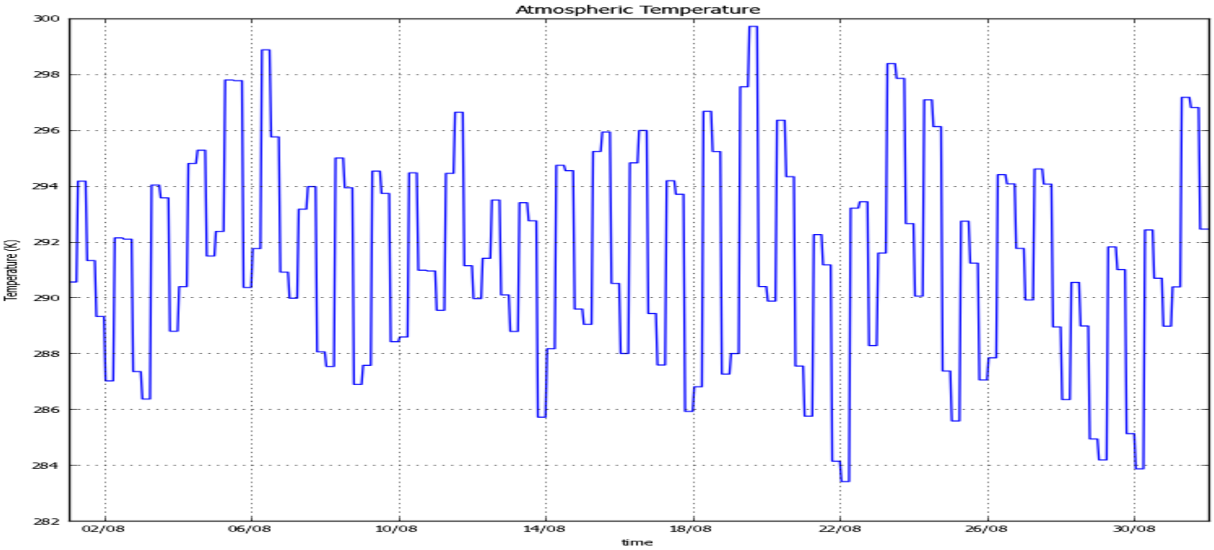
Atmospheric Temperature
Temperature (K)
300
298
296
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time

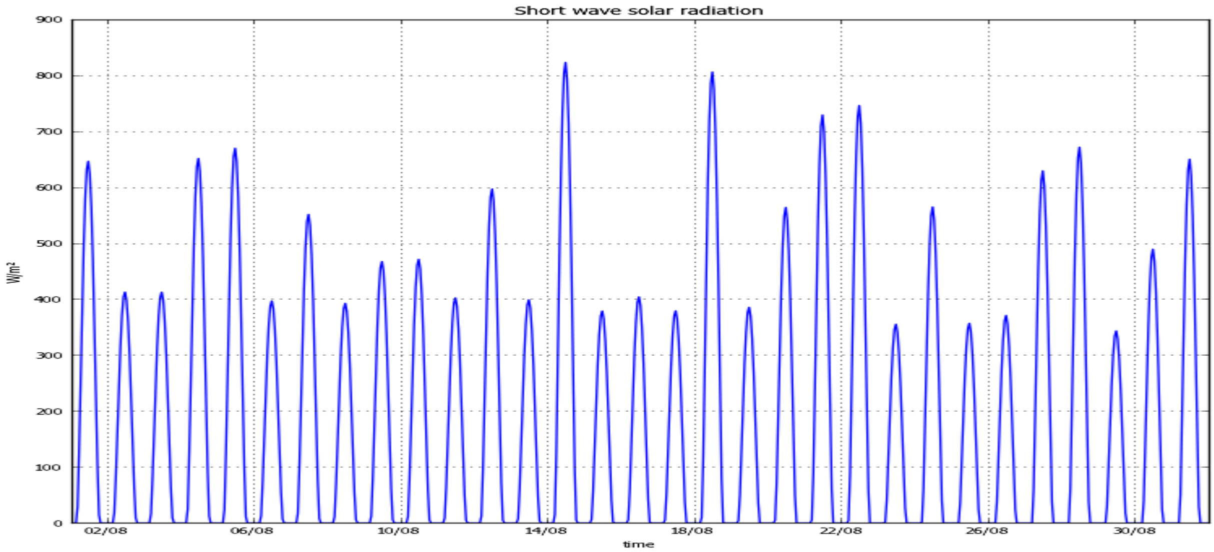

Figure 27 - Atmospheric Pressure, Temperature and shortwave radiation for August 2009. The same values are deployed across the domain.

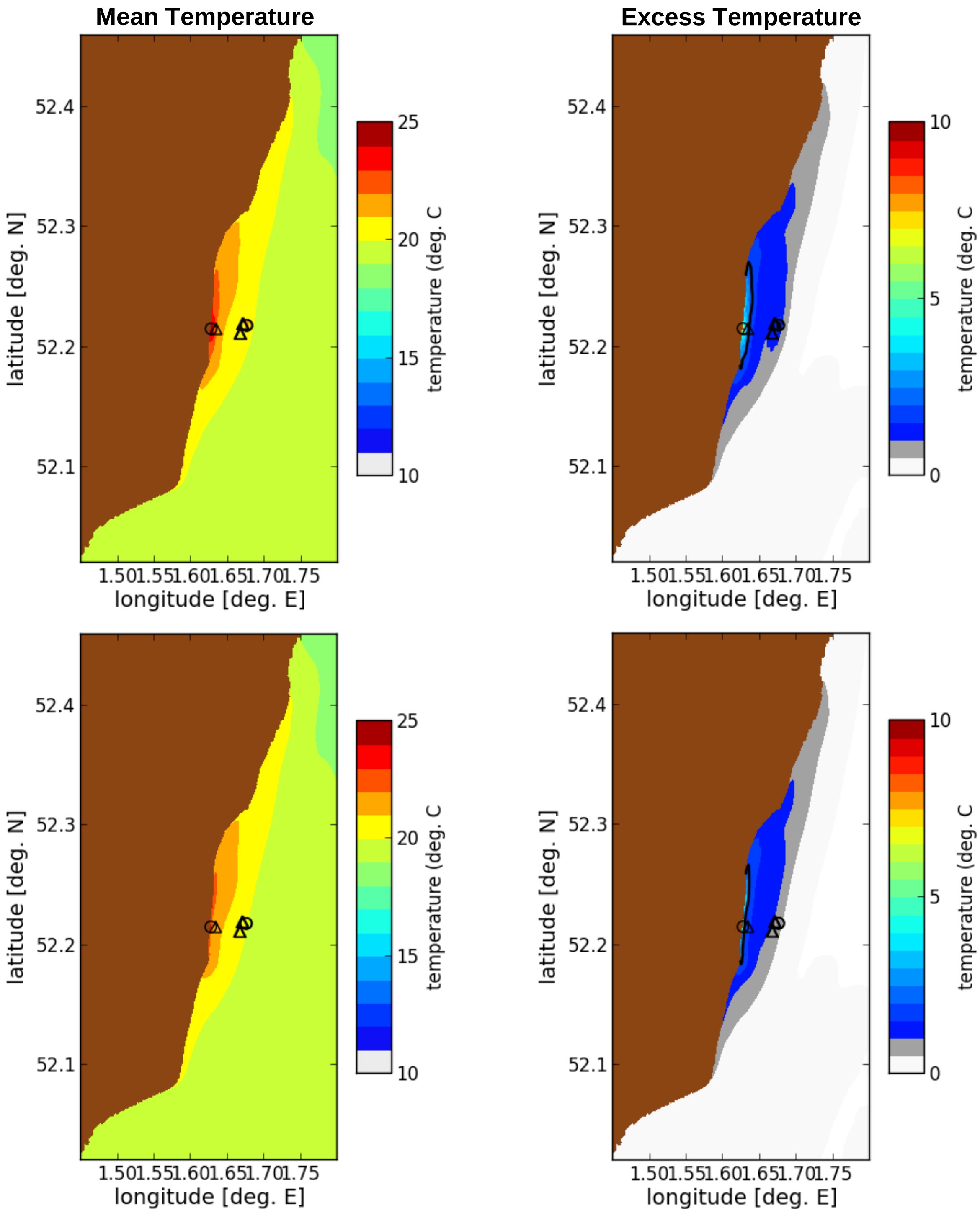

Figure 28 - Mean temperature during August for run SZB+SZC Conf12. The left panels show absolute temperature and the right pannels show excess temperature relative to no ZeroReferenceV2. The black line represents the 2 °C excess isothermal.

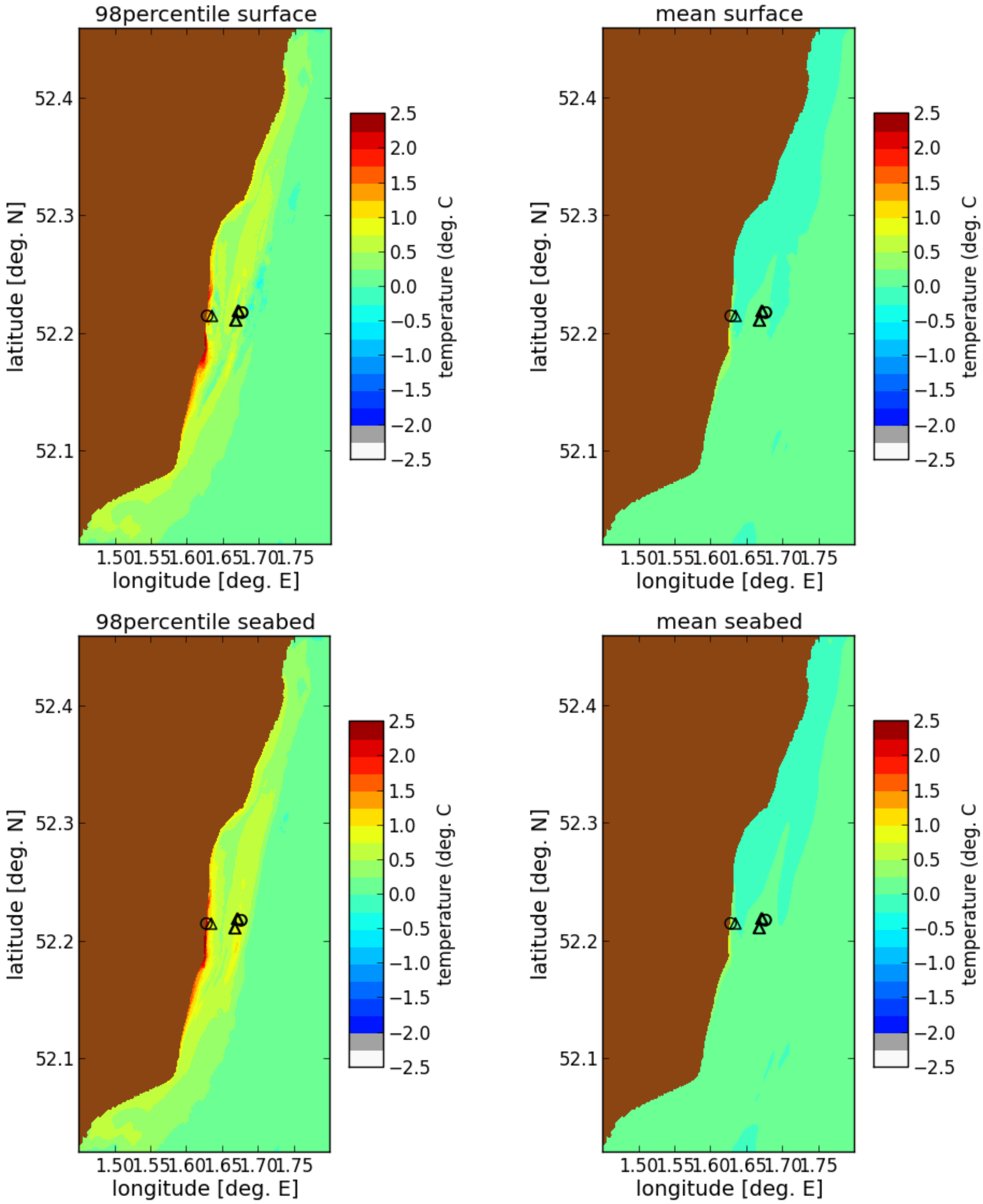

Figure 29 - Annual excess temperature minus the August excess temperature for SZB+SZC Conf12.

5.4 Thermal plume distribution under North East Winds and West Winds

During the month of May 2009 there were two wind events that were selected to study the effect of wind on the plume (see Figure 30): North Easterly of ~10 ms^{-1} on the 10th and 11th and Westerly ~8ms^{-1} on the 16th. During the NE episode (Figure 31) the SZB plume is pushed to the coast, but is still advected the full tidal excursion. A few days later the Westerly winds displace the plume slightly offshore (Figure 32). The area of Thorpeness is where this feature is most distinctive. These results show that whilst both the SZB plume and SZC surface plume are sensitive to the wind direction, it is the tides that still determine the North – South extent and that wind variability just gives an envelope of the plume location. The annual run where a range of wind forcing is considered therefore covers the likely plume extents under most realistic scenarios of present and future climate of wind conditions. For instance if winds from the East become dominant in the future the location of the mean plume will be slightly displaced from that shown here as a mean, but stay within the 95% plume distribution.

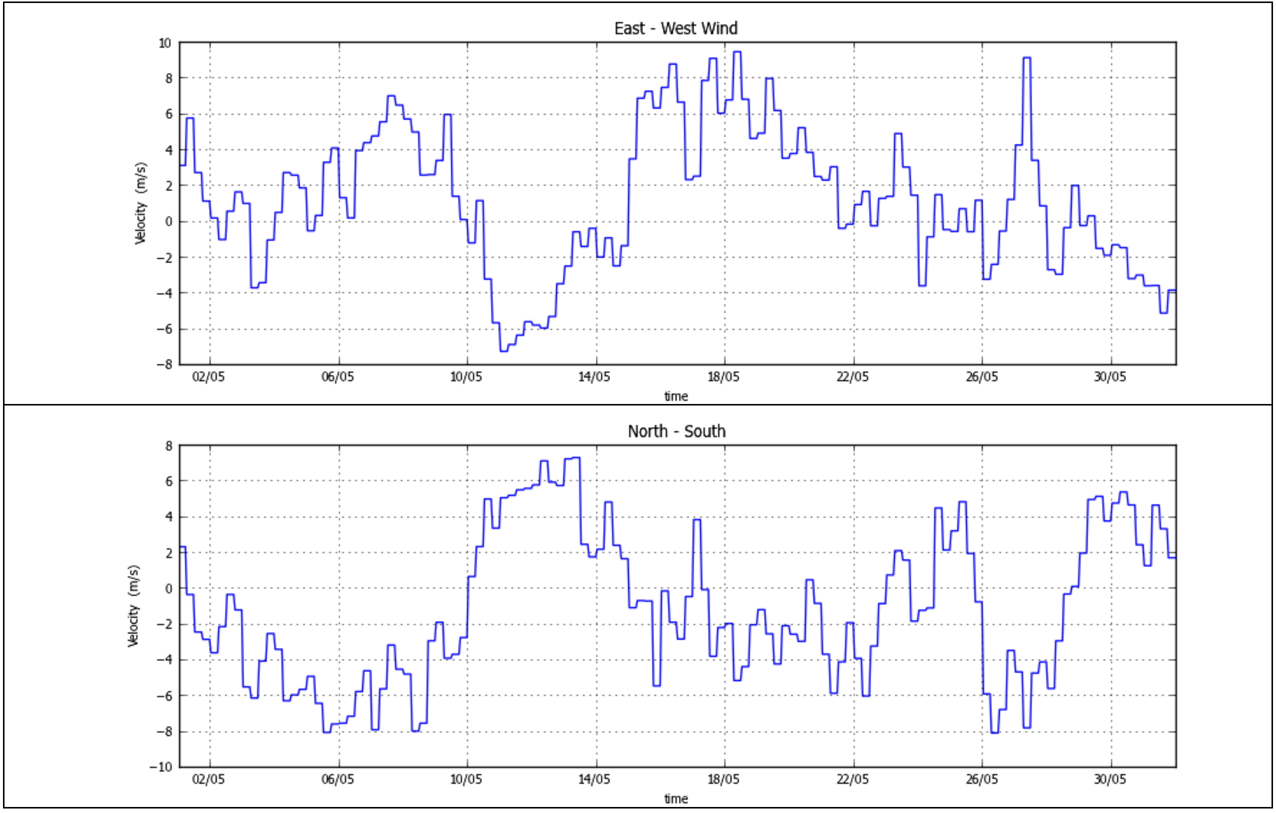

Figure 30 - U and V wind velocity for May

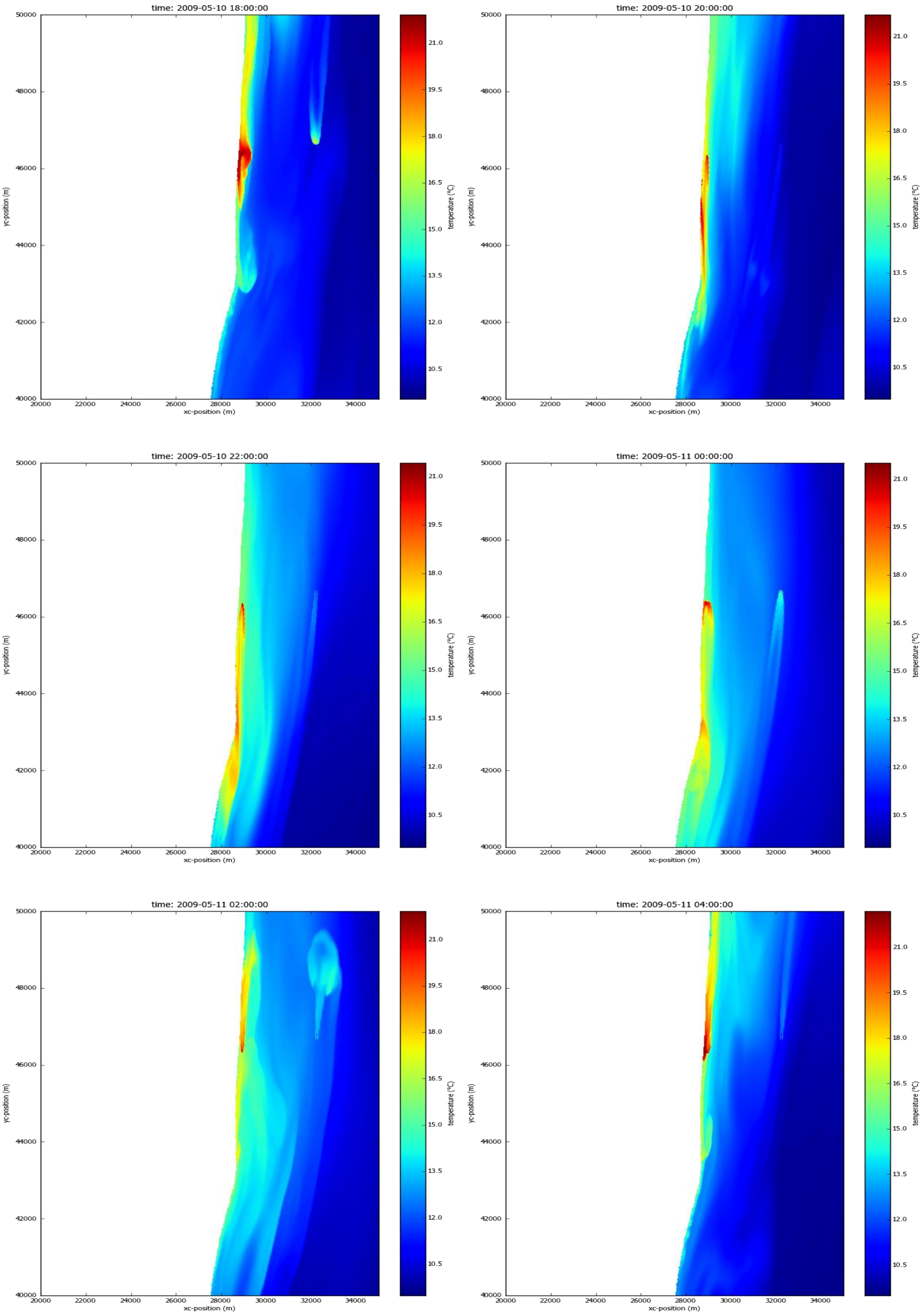

Figure 31 - Flow regime at 2 hourly intervals, under wind from the North East (18:00 – 04:00 10th – 11th May).

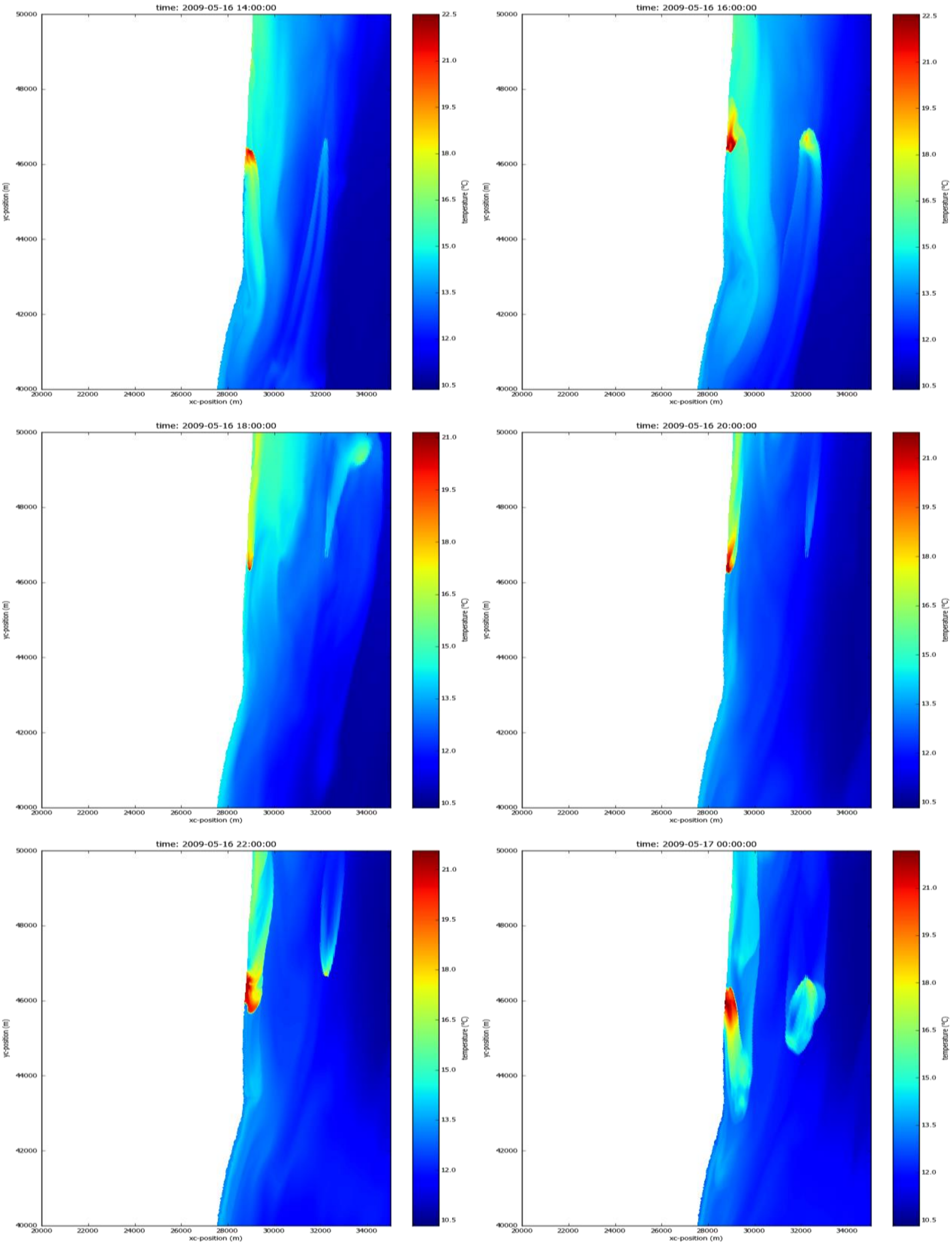

Figure 32 - Flow regime at 2 hourly intervals, under wind from the West (14:00 – 24:00 16th May)

5.5 Discussion of sensitivity test results

SZC Operational Thermal Plume

The tides at Sizewell are strong (>1 ms^{-1}) and it is their interaction with the bathymetry that dominants the shape of the plume and determines its effect at the sea bed. The general conceptual model of heat loss from a plume in a tidal environment is that initially the discharge plume will be buoyant and it will be advected by the current flows and lose heat to the atmosphere. There will come a point when the heat loss is sufficient that the difference in buoyancy between the surface and bed (stratification) does not overcome the vertical mixing due to the tides. The remaining heat energy is therefore mixed down and raises the general background; there is more tidal energy at Spring tides so stratification is broken down at a higher temperature and more heat added to the general water body. The specific relevance to Sizewell is that the two stations have different discharge depths, 5 m and 17 m for SZB and SZC respectively. As vertical tidal mixing is from the sea bed, the SZB discharge inshore in 5m water depth is mixed down more quickly than the offshore SZC discharge in 17m depth. Even though the SZB discharge is only 40% that of the SZC discharge, much of the total thermal uplift from SZB + SZC is dominated by the SZB discharge. The offshore SZC discharge only produces very small thermal effects at the seabed.

Analysis of the wind forcing shows both the SZB plume and SZC surface plume are sensitive to the wind direction, but that tides still determine the North – South extent and that wind variability just gives an envelope of the plume location. The annual run includes a range of wind forcing and therefore covers the likely plume extents under most realistic scenarios of the present and future climate of wind conditions. For instance if winds from the East become dominant in the future the location of the mean plume will be slightly displaced from that shown here as a mean, but stay within the 95% plume distribution.

The 98th percentile of the excess temperatures in August is lower than the annual 98th percentile by 0.75 °C around the Sizewell C outfall and by up to 2.5°C at the Sizewell B outfall. The mean excess temperatures for August showed little difference from the annual values with mean values slightly (~0.25 °C) lower. This result is relevant to considerations of future climate. The evidence here is that the mean excess temperature in August when the background sea temperature is 19 °C is very similar to the annual mean excess values when the background sea temperature is ~11 °C. Thus when considering a future climate where the mean temperature may be significantly warmer (e.g. +2 °C) the simulations from August indicate that the derived annual excess means for 2009 will be applicable to other time periods in the future. Or put more simply the excess temperature field is mostly independent of the background sea temperature.

Overall the offshore discharge for SZC with configuration 12 is an efficient method of losing heat to the atmosphere and it only causes a small additional increase in the mean excess temperatures at the SZB intakes from 0.95°C to 1.6°C (See Table 15). The introduction of the additional outfall 75 m to east of the O9 outfall does not significantly change the recirculation at either SZB or SZC compared with the data presented in BEEMS Technical Report TR301; the annual mean excess temperatures are slightly reduced at the SZB and SZC intakes whereas the 95th percentile excess temperatures are slightly increased at all intakes.

Effect of SZC maintenance discharges

When one of the SZC pump systems is under maintenance the flow of cooling water is halved but the waste heat from the reactors remains approximately the same, causing the excess temperature at the outfall to rise from 11.6 ºC to 23.2 ºC. Modelling has demonstrated that the warmer plume loses heat faster to the atmosphere resulting is less heat being mixed down into the water column. This reduces the size of the excess temperature plume compared to that during normal operation with all pumps running.

6 Analysis of recirculation temperatures at the SZB and SZC Intakes

The added heat in the cooling water can reach the power station intake, depending on the relative transport and mixing processes at the time. Raising the water temperature at the intake reduces the efficiency of the power station as the difference in temperature between the abstracted water and the condensers is reduced. At Sizewell recirculation of heat could occur between the intake and outfall of a single power station or between power stations (cross circulation).

Recirculation effects were analysed for a full year using the two runs already described: ReferenceV2 and Conf12 that represent Sizewell B alone and the combination of Sizewell B and C, respectively. The statistical distribution of the excess temperatures at the intake locations for the course of a full year was used to predict the amount of recirculation (Figure 33). The modelled excess temperature was extracted from mid-depth as this approximates the location in the water column of both Sizewell B and C intakes. For run ReferenceV2 that represents the Sizewell B discharge only, the excess temperatures at its intake were considered, while for Conf12 the excess temperatures were considered at the Sizewell B intake and one intake for each of the Sizewell C discharge tunnels (I3b and I4b) See Table 19.

Table 19 Configuration 12 Recirculation: excess temperature percentiles at the intakes. Excess temperatures were calculated by subtracting the ZeroReferenceV2 values at each time step.

Run	ReferenceV2 (SZB Only)	Conf12 (2 SZC outfalls at O9a and O9b) (SZB and SZC)		
Intake	**SZB IB**	**SZB IB**	**SZC I3b**	**SZC I4b**
50th percentile	0.95 ºC	1.60 ºC	0.98 ºC	0.98 ºC
95th percentile	2.44 ºC	3.10 ºC	1.92 ºC	1.92 ºC
98th percentile	2.81 ºC	3.60 ºC	2.23 ºC	2.27 ºC

The figures in Table 19 can be compared with those presented in BEEMS Technical Report TR301 in which a single discharge at O9 was modelled (reproduced in Table 20 below) as opposed to the 2 discharge points in this report.

Table 20 Configuration 9 Recirculation: excess temperature percentiles at the intakes. Excess temperatures were calculated by subtracting Zero Reference values at each time step.

Run	Conf9 (one SZC outfall at O9) (SZB and SZC)		
Intake	**SZB IB**	**SZC I3a**	**SZC I4a**
50th percentile	1.74 ºC	1.11 ºC	1.11 ºC
95th percentile	3.17 ºC	2.2 ºC	2.27 ºC

Note: TR301 demonstrated that mean and 95%ile temperatures at I3/I4a were within approximately ±0.1°C of those at I3/I4b.

The introduction of an additional outfall 75m east of the O9 outfall does not significantly change the recirculation at either SZB or SZC; the annual mean excess temperatures are slightly reduced at the SZB and SZC intakes whereas the 95%ile excess temperatures are slightly increased at all intakes.

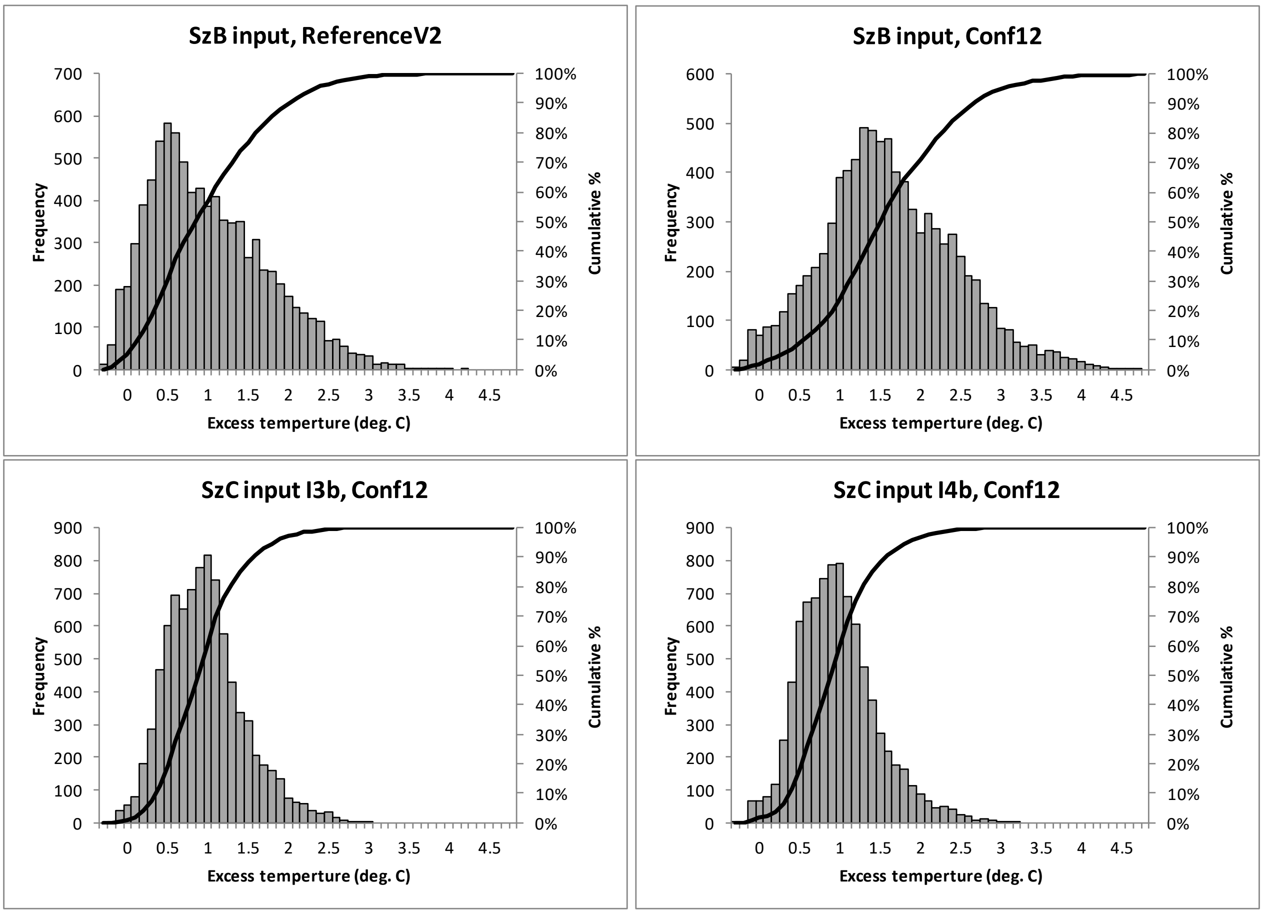

Figure 33 - Distribution of excess temperature values at the power station intake locations.

7 Conclusions

This report presents the results of the Stage 3 Sizewell thermal plume modelling of the preferred Sizewell C (SZC) cooling water configuration using the General Estuarine Transport Model (GETM).

The SZC and SZB plumes are separate at high plume temperatures but at lower temperatures, the SZC plume acts to increase the size and temperature of the SZB plume at the surface and the seabed (BEEMS Technical Report TR301). This means that examination of the thermal effects of SZC under the Water Framework Directive becomes an examination of the effects of the magnified Sizewell B plume (the Sizewell C plume is smaller and largely outside the WFD offshore limit).

Unlike chemical standards which normally have a clear evidence link to ecological effects, thermal standards are not always evidence based due to a lack of reliable data (BEEMS SAR008, Wither *et al*, 2012). In order to be protective of the most sensitive species, thermal standards have, therefore, been set on an indicative basis and, as such, they act as trigger values for further investigation of potential ecological effects.

The report assesses the predicted thermal plumes from SZB+SZC against existing HRA and WFD thermal standards. The SZB and SZC discharge plumes intersect with two designated marine areas: the Outer Thames Special Protected Area (SPA) and the Suffolk Coastal Water Body under the Water Framework Directive (WFD). The magnified SZB plume marginally intersects with the Alde-Ore and Blyth(S) transitional waterbodies but modelling has demonstrated this does not cause exceedance of existing thermal standards in these areas.

Key findings

a. The SZB+SZC combined plumes exceed the SPA >2°C uplift temperature standard for 22,452 ha (5.9% of the SPA area) and 16,444 ha (4.33% of the SPA area) at the surface and seabed respectively. The plume area that exceeds the 28 °C absolute temperature threshold is negligible (<1ha).

b. For the Suffolk coastal waterbody the 23 °C absolute temperature threshold is exceeded by 89ha at the surface and 26ha at the seabed. The areas exceeding the 3 °C uplift temperature threshold are 1862ha (12.7% of the waterbody area) at the surface and 1,552ha at the seabed (10.6% of the waterbody area).

c. No thermal barriers to fish migration are predicted at the Alde-Ore or Blyth(S) waterbodies or for fish migrating to or from these waterbodies via a route off the Sizewell coast.

Next steps

The areas where exceedance of existing thermal standards has been predicted will be subject to detailed analysis for potential ecological effects.

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Appendix A Annual maximum excess temperatures

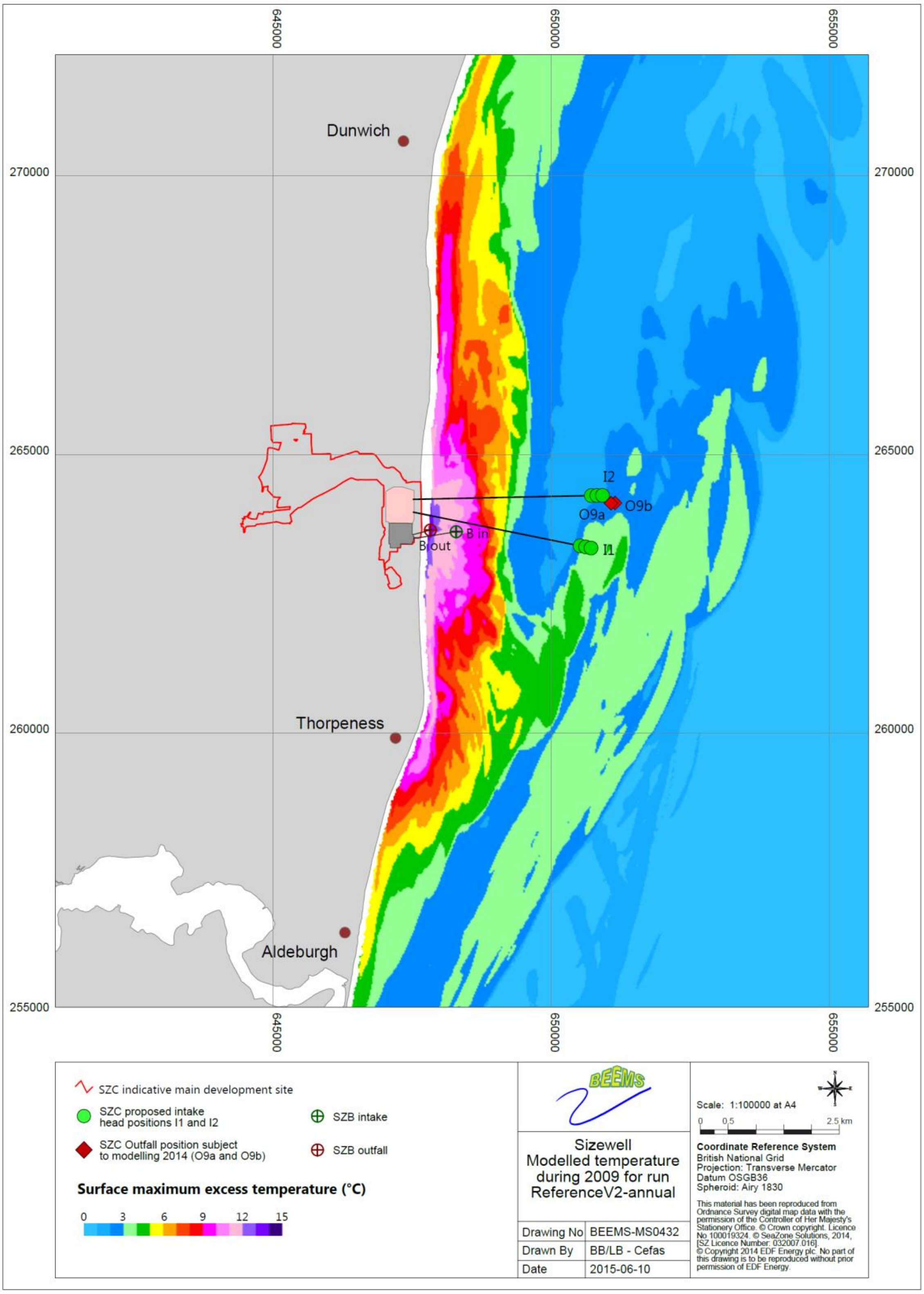

Figure 34 – Surface annual maximum excess temperature for SZB only (100%iles).

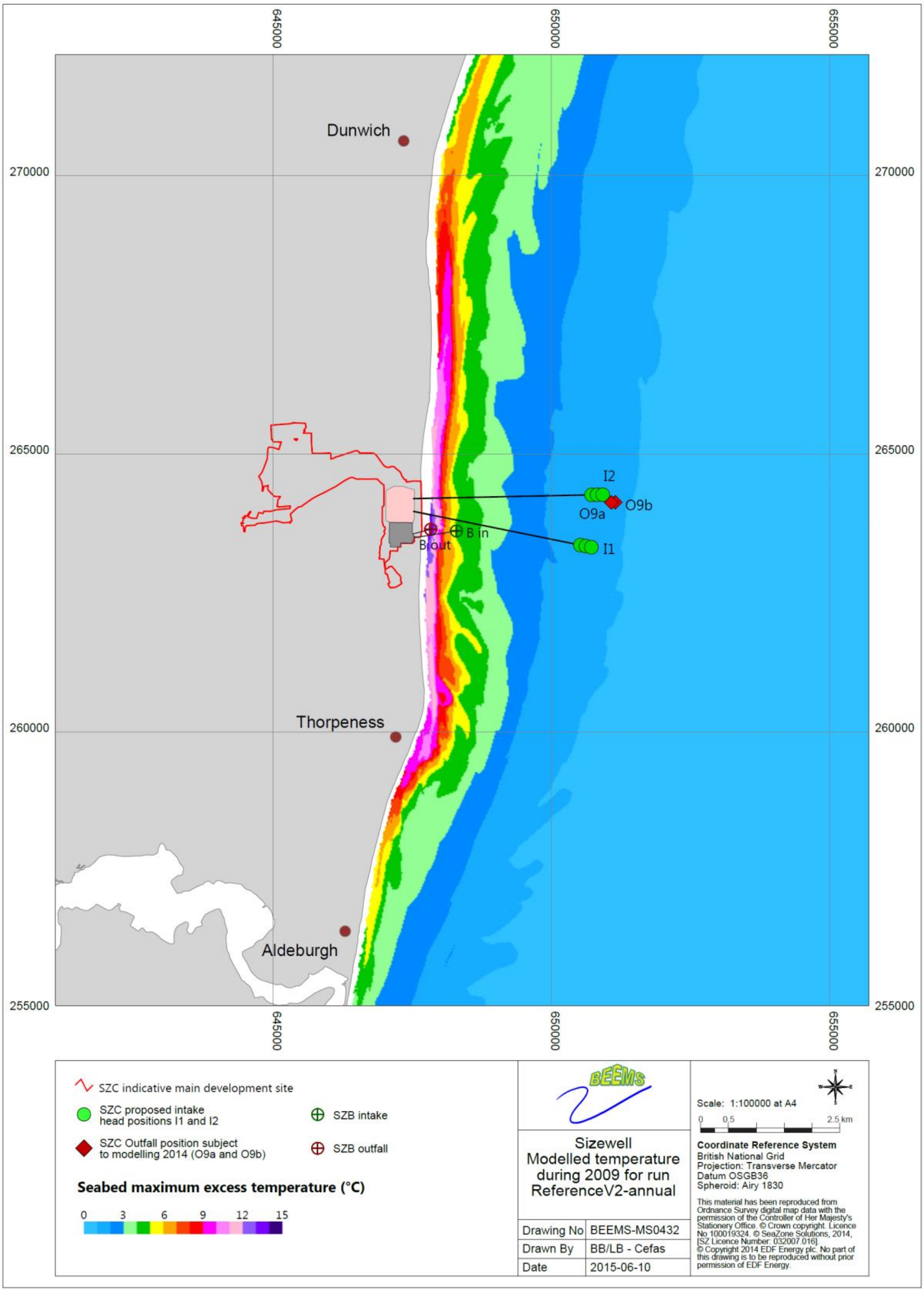

Figure 35 – Seabed annual maximum excess temperature for SZB only (100%iles).

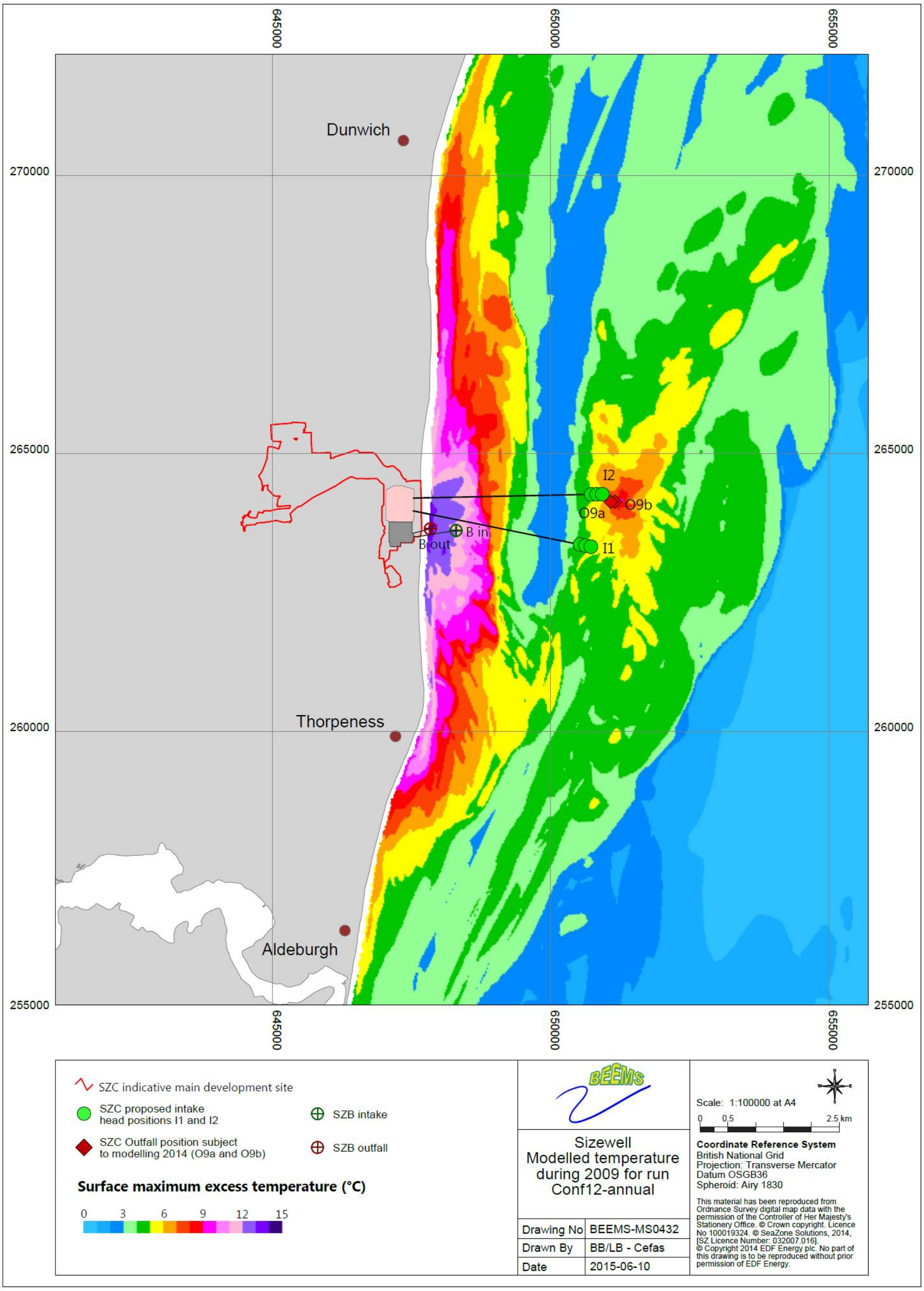

Figure 36 – Surface annual maximum excess temperature for SZB + SZC.

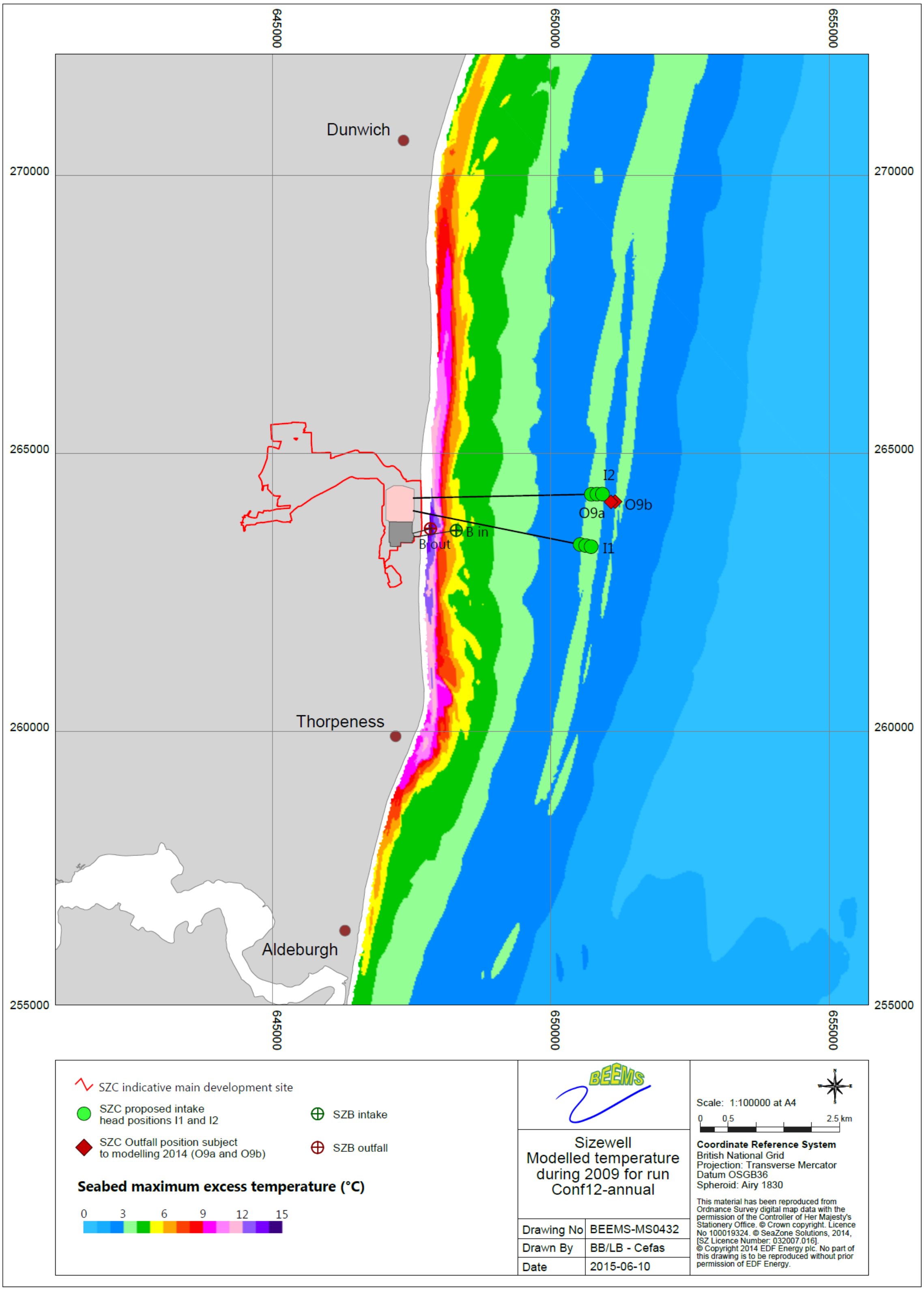

Figure 37 – Seabed annual maximum excess temperature for SZB + SZC.

Appendix B Annual Absolute temperatures >28C (Calculated as mean excess temperatures > 3.6°C)

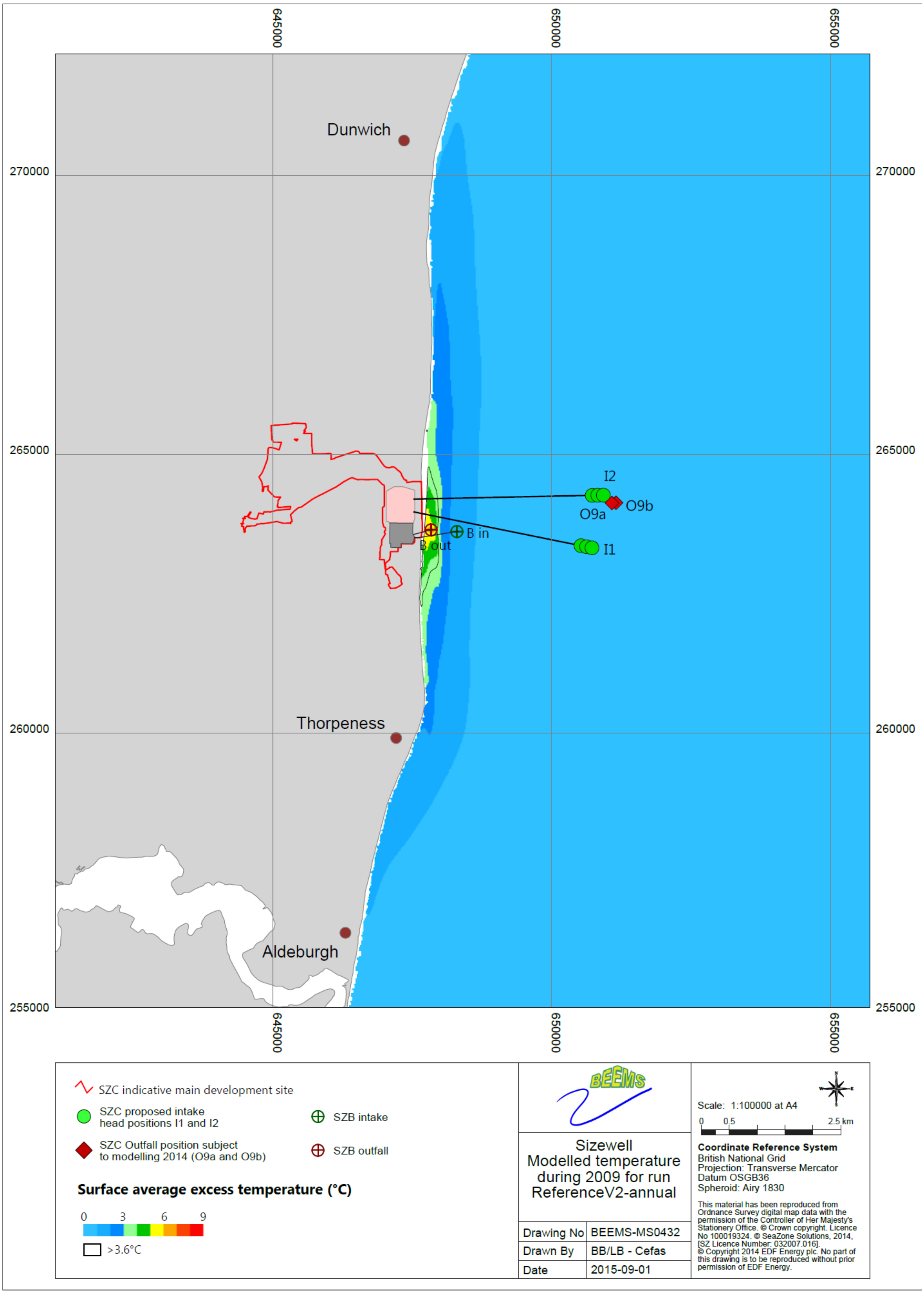
645000
650000
655000
270000
265000
260000
255000
Dunwich
Thorpeness
Aldeburgh
I2
O9a
O9b
I1
B in
B out
SZC indicative main development site
SZC proposed intake head positions I1 and I2
SZC Outfall position subject to modelling 2014 (O9a and O9b)
SZB intake
SZB outfall
Surface average excess temperature (°C)
0
3
6
9
>3.6°C
BEEMS
Sizewell
Modelled temperature during 2009 for run ReferenceV2-annual
Drawing No
BEEMS-MS0432
Drawn By
BB/LB - Cefas
Date
2015-09-01
Scale: 1:100000 at A4
0
0.5
2.5 km
Coordinate Reference System
British National Grid
Projection: Transverse Mercator
Datum OSGB36
Spheroid: Airy 1830
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Figure 38 Modelled 98th percentile of the surface water temperature for SZB only showing >23°C contour (shown as >3.6°C excess temperature)

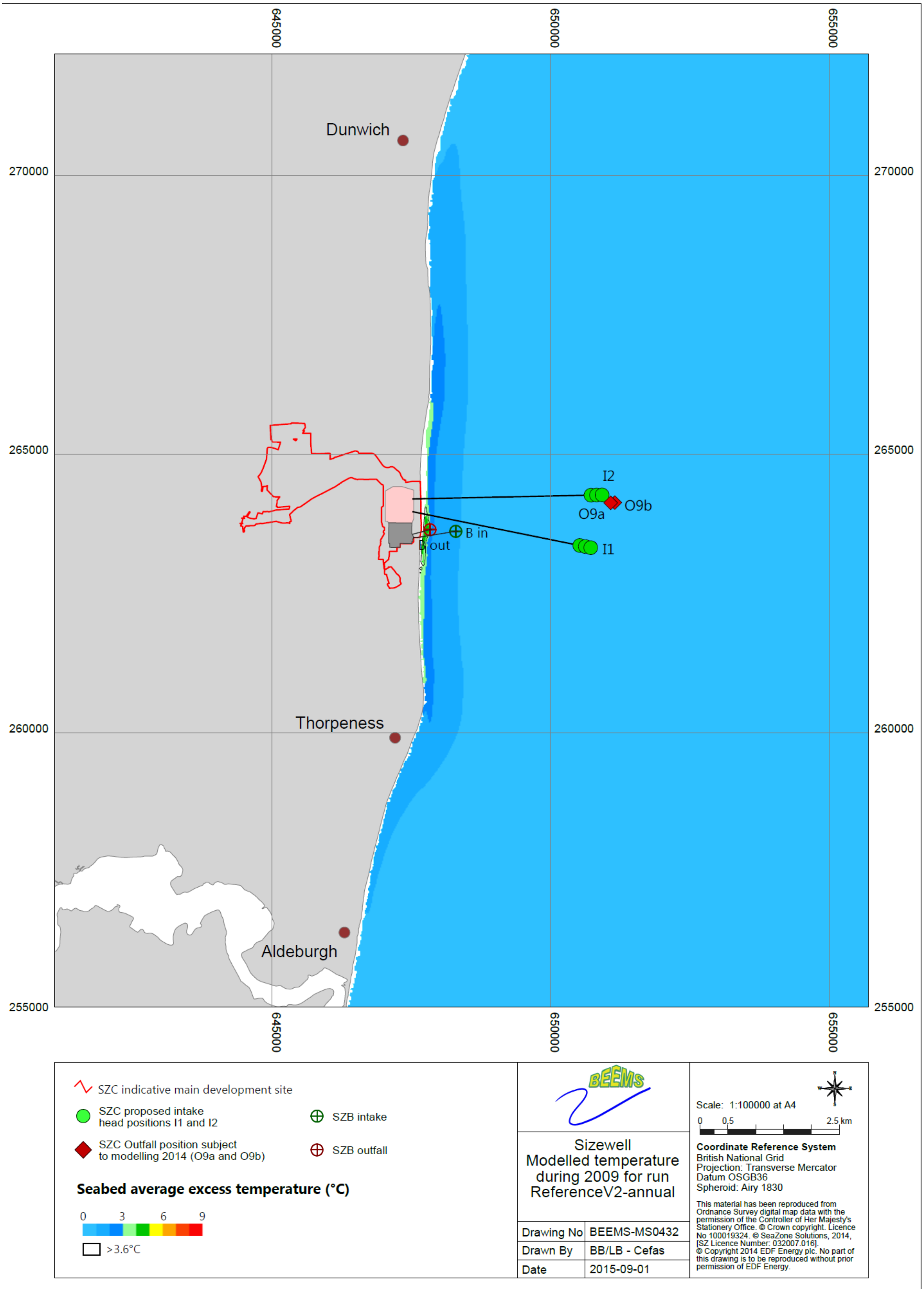
645000
650000
655000
270000
265000
260000
255000
Dunwich
Thorpeness
Aldeburgh
I2
O9a
O9b
B in
B out
I1
SZC indicative main development site
SZC proposed intake head positions I1 and I2
SZC Outfall position subject to modelling 2014 (O9a and O9b)
SZB intake
SZB outfall
Seabed average excess temperature (°C)
0
3
6
9
>3.6°C
BEEMS
Sizewell
Modelled temperature during 2009 for run ReferenceV2-annual
Drawing No BEEMS-MS0432
Drawn By BB/LB - Cefas
Date 2015-09-01
Scale: 1:100000 at A4
0
0.5
2.5 km
Coordinate Reference System
British National Grid
Projection: Transverse Mercator
Datum OSGB36
Spheroid: Airy 1830
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Figure 39 Modelled 98th percentile of the seabed water temperature for SZB only showing >23°C contour (shown as >3.6°C excess temperature)

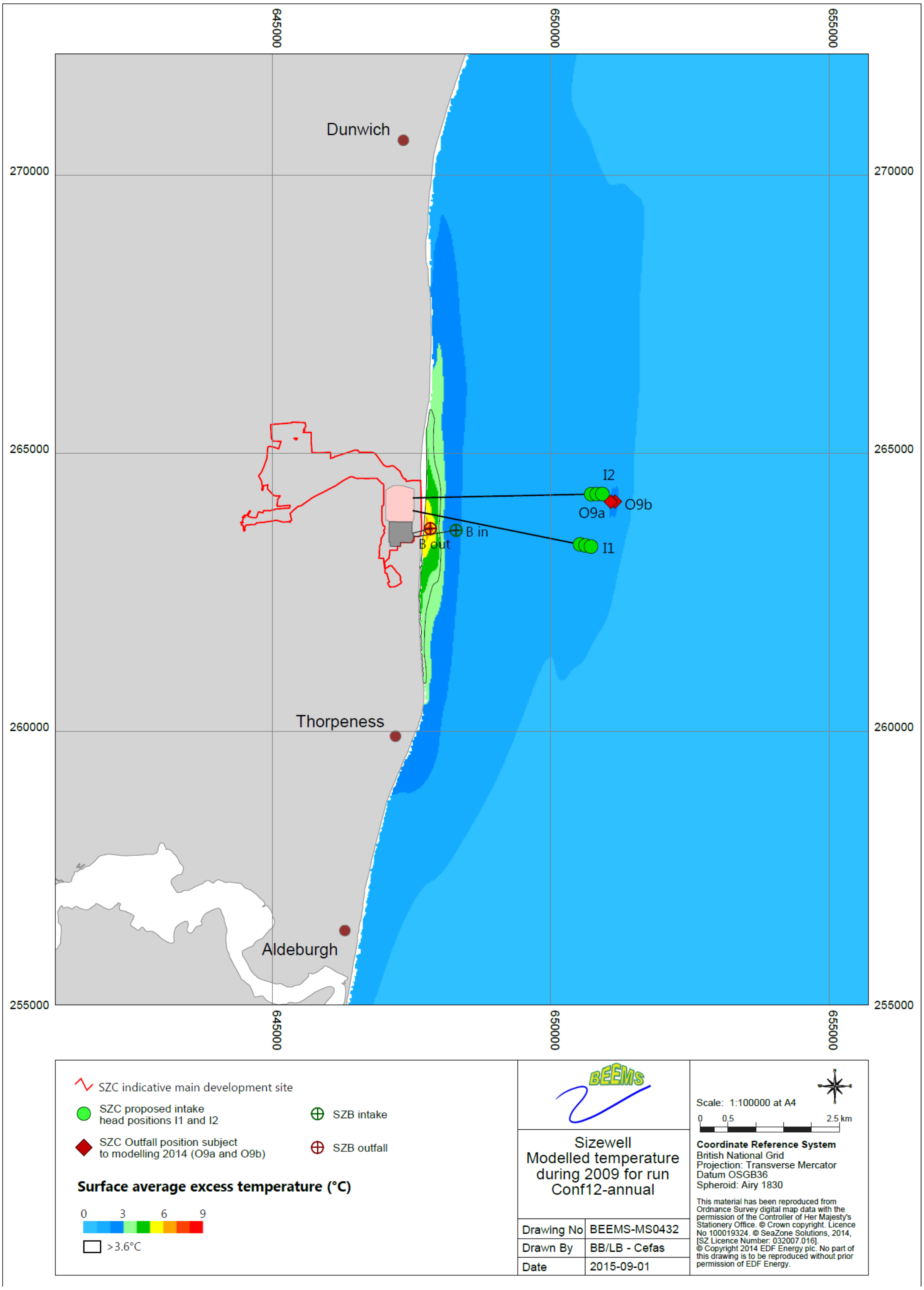

Figure 40 Modelled 98th percentile of the surface water temperature for SZB +SZC showing >23°C contour (shown as >3.6°C excess temperature)

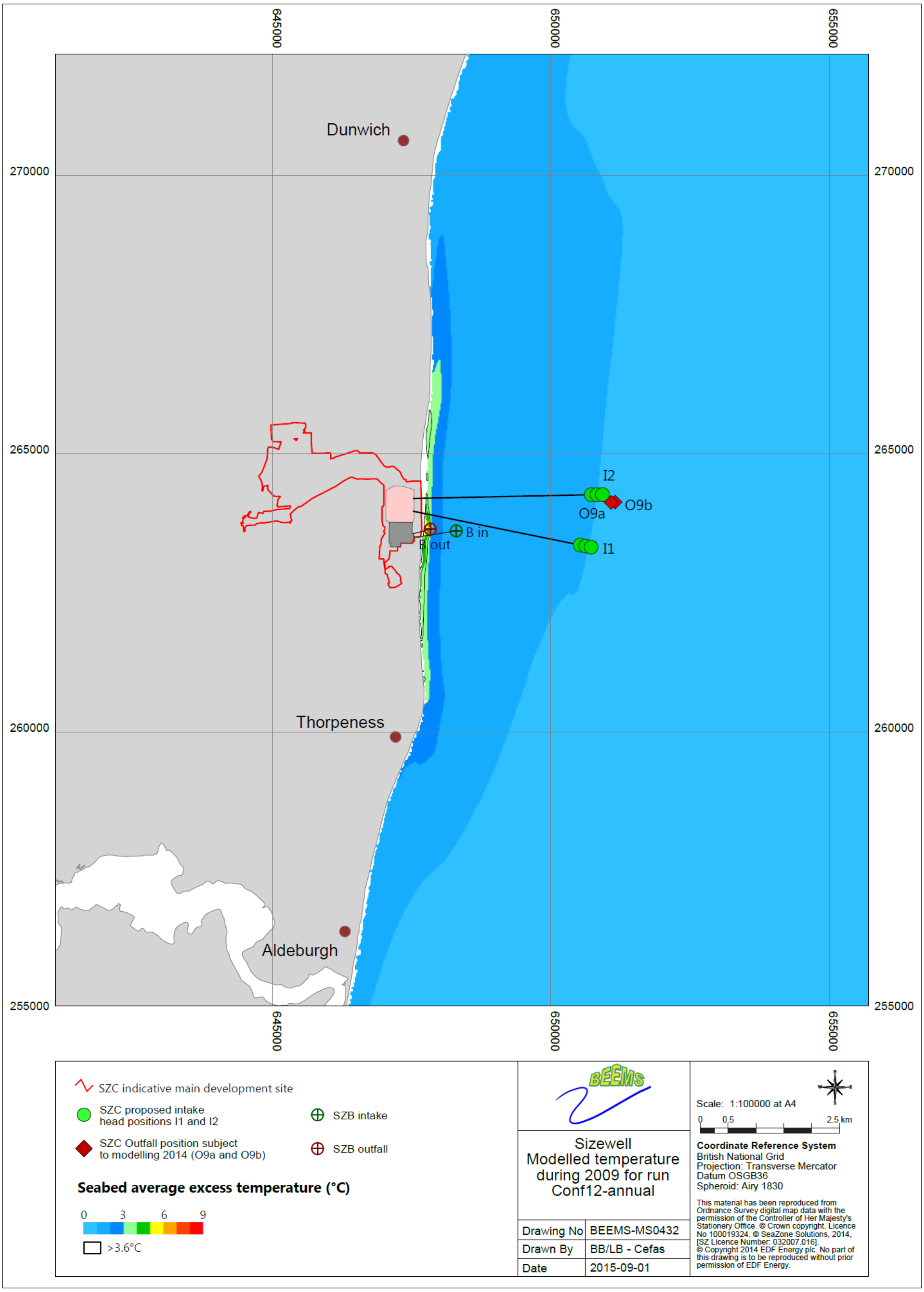

Figure 41 Modelled 98th percentile of the seabed water temperature for SZB +SZC showing >23°C contour (shown as >3.6°C excess temperature)

Appendix C Annual Absolute temperatures >28C (calculated using GETM absolute temperatures)

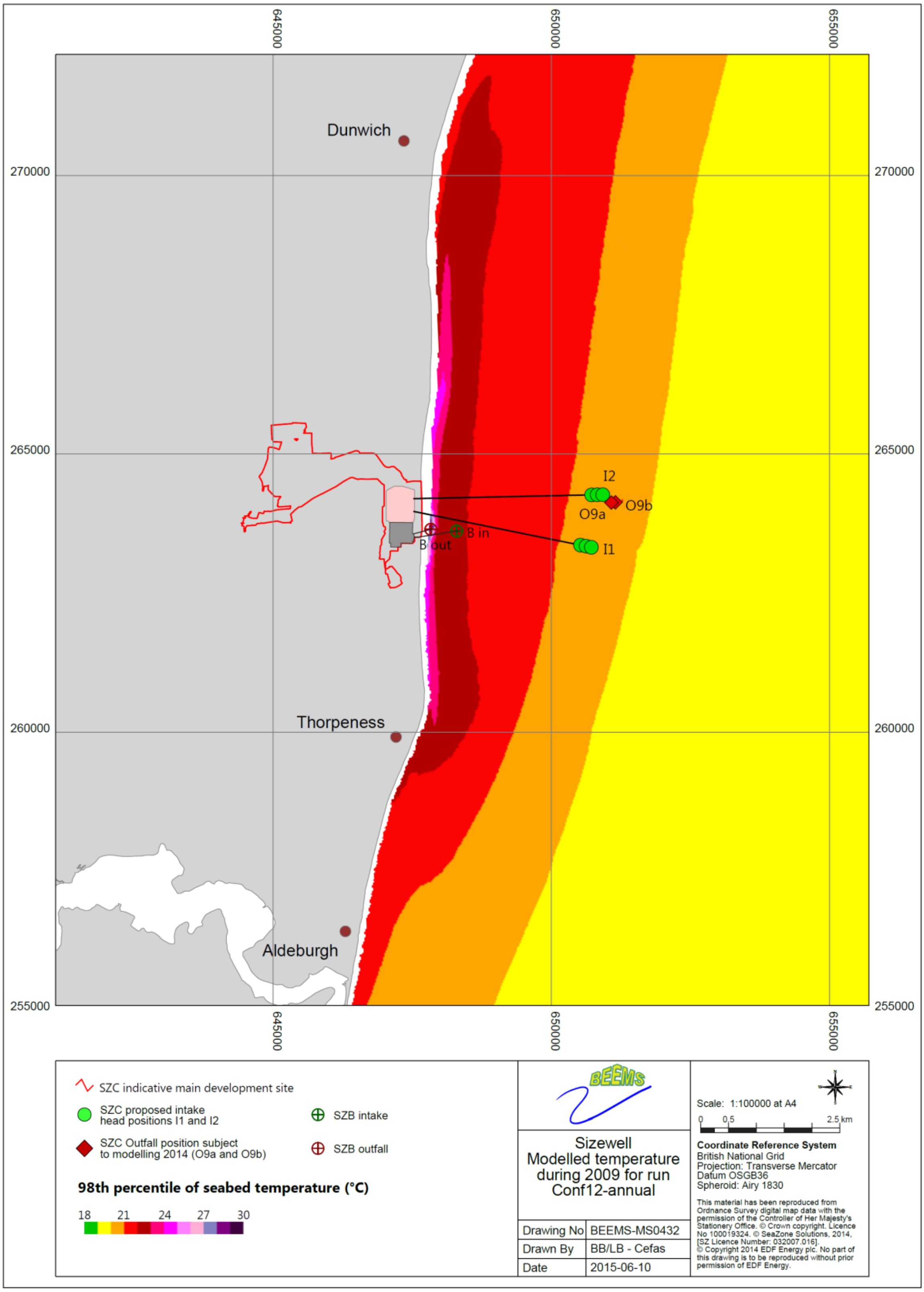

Figure 42 - Modelled 98th percentile of the surface water temperature for SZB only.

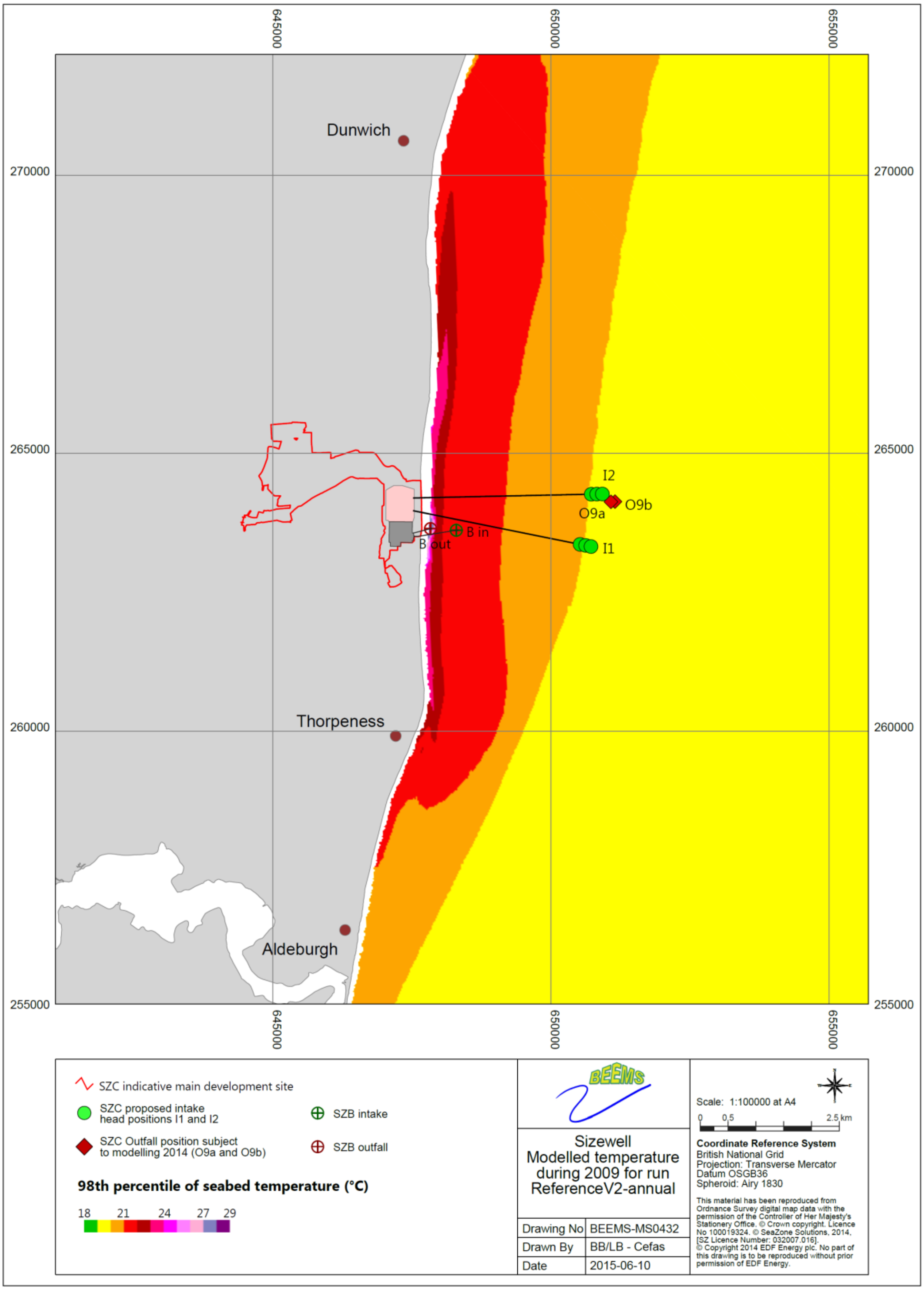

Figure 43 - Modelled 98th percentile of the seabed temperature for SZB only.

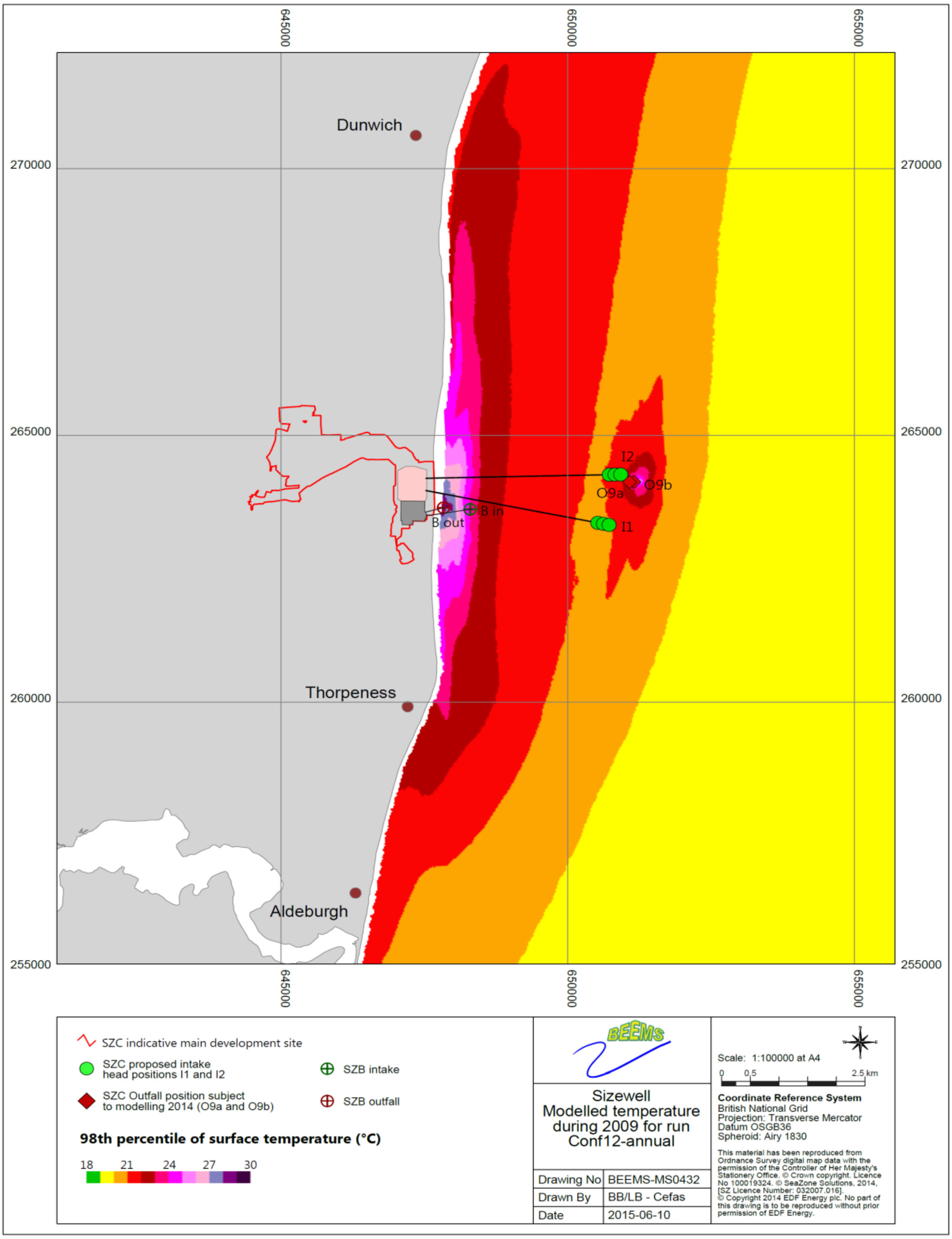

Figure 44 - Modelled 98th percentile of the surface water temperature for SZB+SZC.

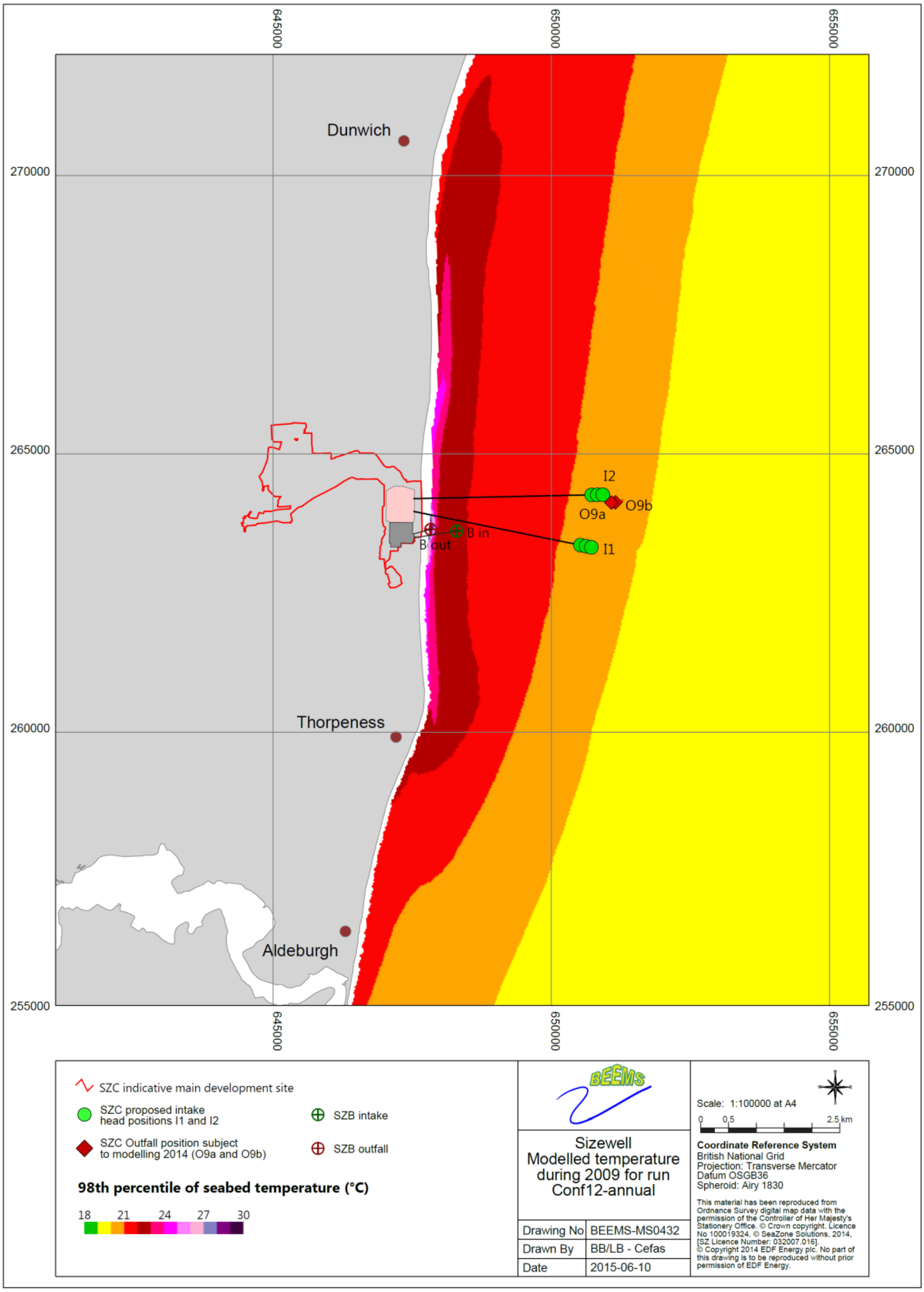

Figure 45 - Modelled 98th percentile of the seabed temperature for SZB+SZC.