Consulting Port and Coastal Engineers

KOEBERG NUCLEAR POWER STATION: COASTAL PROCESSES TECHNICAL INFORMATION IN SUPPORT OF THE COASTAL WATERS DISCHARGE PERMIT APPLICATION

Addendum Report: Dispersion Modelling of Additional Thermal Discharges

REV.00

13 February 2019

Eskom
Cape Town, South Africa

PRDW
Consulting Port and Coastal Engineers

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Specialist Study

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1. INTRODUCTION

1.1 Background

An application for a Coastal Waters Discharge Permit (CWDP) for the Koeberg Nuclear Power Station (KNPS) was submitted in 2017. The submission was supported by the following specialist reports, which together served to characterise and assess the discharges from the power station:

- Dispersion Modelling of Thermal, Chemical, Sediment and Radionuclide Discharges (PRDW, 2017)
- Marine Ecology Specialist Study (Lwandle, 2017)

Subsequent to the submission, further scenarios for thermal discharges were identified by Eskom. These scenarios have since been assessed for inclusion in the application, as described in the following reports:

- Addendum Report: Dispersion Modelling of Additional Thermal Discharges (this document), which describes the characterisation and presents the dispersion modelling of the additional discharge scenarios; and
- Addendum Report: Marine Ecology Assessment of Additional Thermal Discharges (Lwandle, 2019), in which the ecological impacts of the additional scenarios are assessed.

It is imperative that these reports be read together, since references are made between the reports rather than duplication of information. Furthermore, methodologies (such as the model setup and calibration or impact rating methodology) are not repeated in these reports, but rather rely on the reader having access to the original specialist reports referenced above where such topics are discussed in detail.

1.2 Report structure

The discharge characterisation of the abnormal thermal discharge scenarios is presented in Section 2. In Section 3 a summary of the modelling approach is given, while reference is made to descriptions of the model setup and calibration in the main report. The model results are presented and discussed in Section 4. The ecological impacts of the abnormal thermal discharge scenarios are assessed by Lwandle (2019), where the conclusions of the study are also drawn. A list of references is given in Section 5.

2. DISCHARGE CHARACTERISATION

In the discharge characterisation for the Circulating Water System (CRF) presented in Section 3.2.2 of the dispersion modelling report (PRDW, 2017), one scenario for abnormal operating conditions relating to a pump trip in one CRF train was presented and assessed. This scenario was described as follows:

> *"In the event of the trip of one CRF pump, the change in temperature (ΔT) in the second train of the same reactor unit may increase from the normal 11.7°C to 22.7°C. The duration of this discharge scenario is 12 hours, which is the estimated time required to bring the stand-by pump into operation. For the current study, this event is conservatively (worst case) considered to occur during a refuelling outage (i.e. only one reactor unit is operational), thereby not including any dilution of the train with elevated ΔT into the flow from other CRF trains with a normal ΔT."*

Subsequent to the above assessment, a second scenario for abnormal operating conditions was identified by Eskom. A CRF train of an operational reactor unit may be taken out of service for reasons other than a pump trip, for example in the case of blockages in the turbine condenser tubes. As with the pump trip scenario, with one train out of service the change in temperature (ΔT) in the remaining train of the same reactor unit may increase from the normal 11.7°C to 22.7°. The time required for the repairs necessary to bring the train back into service is estimated to not exceed two weeks. This may occur while either one or two reactor units are operational.

Table 2-1 presents an overview of the abnormal conditions, with cases at full reactor power being Case 1 (one reactor unit operational) and Case 6 (two reactor units operational). For reference, the previously assessed pump trip scenario is shown as Case 0.

Table 2-1: Overview of abnormal thermal discharge scenarios.

Scenario	Number of reactor units operational	Total number of CRF trains in service	Power level of affected reactor unit [%]	Combined delta T of all CRF trains [°C]	Duration of elevated temperature [days]	Comment
Case 0	1	1	100	22.7	0.5	Pump trip scenario, previously assessed.
Case 1			100	22.7	14	One train out of service due to reasons other than pump trip, e.g. condenser tube blockage.
Case 2			70	16.0		
Case 3			60	15.0		
Case 4			50	14.0		
Case 5			40	13.0		
Case 6	2	3	100	15.0		
Case 7			70	13.4		
Case 8			60	13.0		
Case 9			50	12.7		
Case 10			40	12.3		

When a CRF train is taken out of service the operational procedures of the KNPS allow for a reduction in the power level of the affected reactor unit, which reduces the ΔT in its remaining CRF train. A range of possible power reductions is shown in Table 2-1, which for each case also shows the corresponding combined ΔT from all CRF trains remaining in service. Cases 1 to 5 are for one reactor unit operational and Cases 6 to 10 for two reactor units operational. It should be noted that due to system efficiency the ΔT does not reduce linearly with reductions in the reactor power level.

The highest ΔT's (and therefore the highest absolute temperatures immediately beyond the outfall) arise when a train is taken out of service with only one reactor unit operational. The whole range of power reductions was assessed for this scenario, i.e. Cases 1 to 5. For the two unit cases, the elevated temperature in the remaining train of the affected reactor unit is diluted into the two trains of the reactor unit operating normally, resulting in significantly lower ΔT's at discharge. However, since the discharge rate is much larger for the two unit cases, these may result in larger areas of chronic impacts. Therefore, two cases were also assessed with two units operational.

The cases assessed in this report are highlighted in green in Table 2-1. The discharge characterisation of these is presented in Table 2-2 and Table 2-3.

Table 2-2: Discharge characterisation for cases with one reactor unit operational.

ΔT Releases - 1 CRF Unit Operational, one train temporarily out of service									
Stream	Discharge [m³/h]	ΔT [°C]					Duration [days]	Release interval [days]	Total duration per year [hrs]
		CRF @ 100%	CRF @ 70%	CRF @ 60%	CRF @ 50%	CRF @ 40%			
CRF	163 944 (2 trains)	11.7					Continuous before and after train removed		
	81 972 (1 train)	22.7	16	15	14	13	14	Unplanned	-
SEC	12 700	12					Continuous		

Table 2-3: Discharge characterisation for cases with two reactor units operational.

ΔT Releases - 2 CRF Units Operational, one train temporarily out of service						
Stream	Discharge [m³/h]	ΔT [°C]		Duration [days]	Release interval [days]	Total duration per year [hrs]
		CRF @ 100%	CRF @ 70%			
CRF	327 888 (4 trains)	11.7		Continuous before and after train removed		
	245 916 (3 trains)	15.0	13.4	14	Unplanned	-
SEC	12 700	12		Continuous		

3. MODEL SETUP AND CALIBRATION

For a discussion of the setup and calibration of the 3D dispersion model and the adopted modelling approach, the reader is referred to Sections 5.1 to 5.4 of the dispersion modelling report (PRDW, 2017).

The new abnormal thermal discharge scenarios were treated as batch releases each lasting for a period of two weeks. For the remainder of the time the plant is operating normally, either with one or two reactor units operational depending on the case considered. For each case, the batch releases were repeated 17 times in the modelled year to increase the range of environmental conditions sampled. Since this release is unplanned and occurs only under abnormal conditions, the real frequency of releases is unknown.

4. MODEL RESULTS AND DISCUSSION

The cases highlighted in green in Table 2-1 were modelled and post-processed to produce statistical outputs informing the ecological assessment (Lwandle, 2019). For each case, the following outputs were produced:

- Contour plots of maximum absolute temperature highlighting the site-specific temperature thresholds for acute (30°C) and chronic (25°C) impacts: surface and seabed;
- Contour plots of maximum (i.e. from the worst of the modelled batch repetitions) duration that the threshold for chronic effects (25°C) is exceeded: surface and seabed.
- For the worst batch, time series of the absolute temperature at the surface and seabed at three locations near the outfall.

The locations of the time series outputs are shown in Figure 4-1. The three locations where time series are presented are those labelled as "100 m from discharge", "Breakwater" and "1 000 m radius".

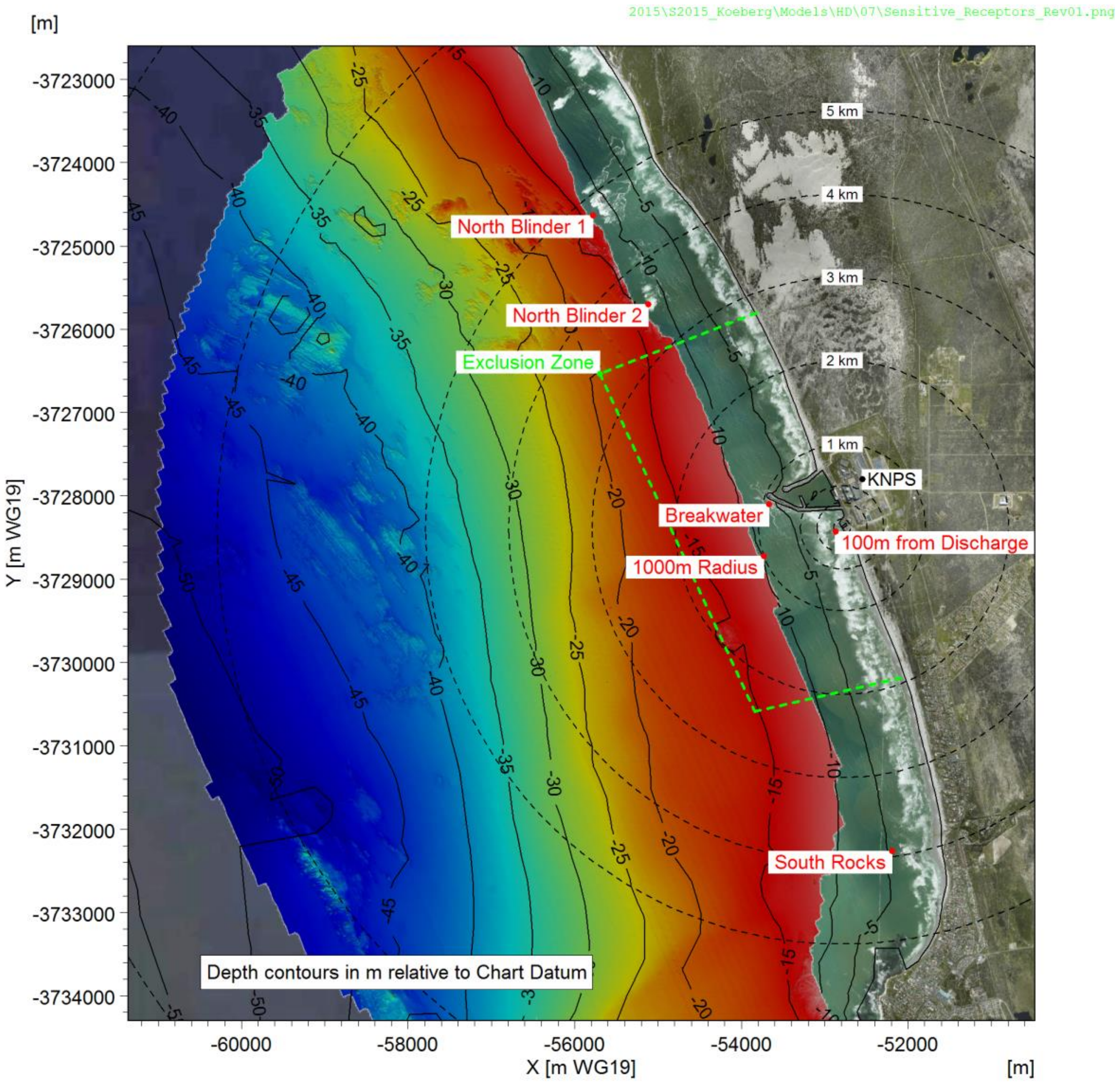

Figure 4-1: Sensitive receptor locations.

The contour plots of the near-surface maximum absolute temperature for Case 1 (one unit, no power reduction) and Case 6 (two units, no power reduction) are presented in Figure 4-2 and Figure 4-3.

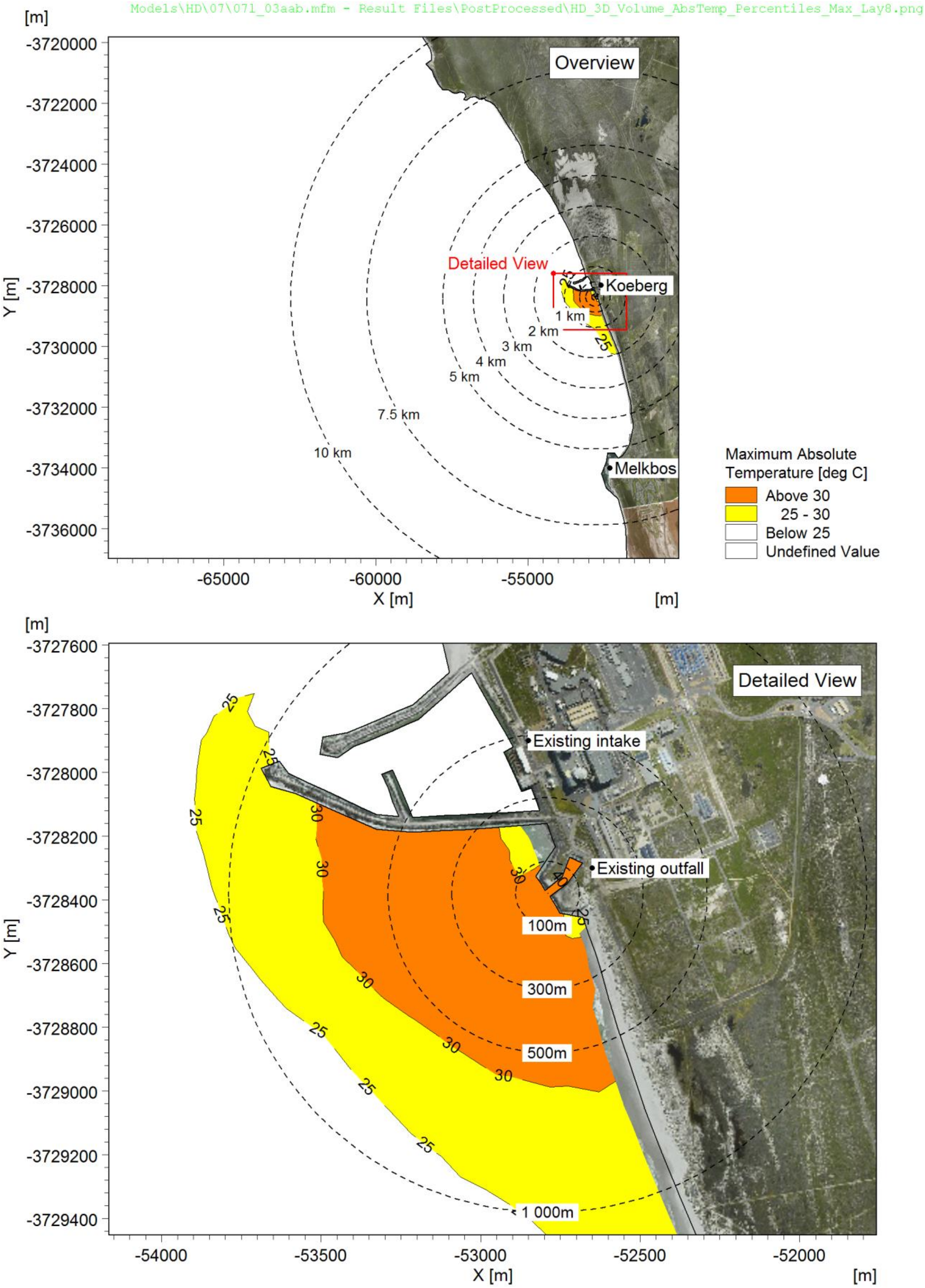

Figure 4-2: Maximum absolute temperature near the surface: Case 1 (one unit operational, 100% power).

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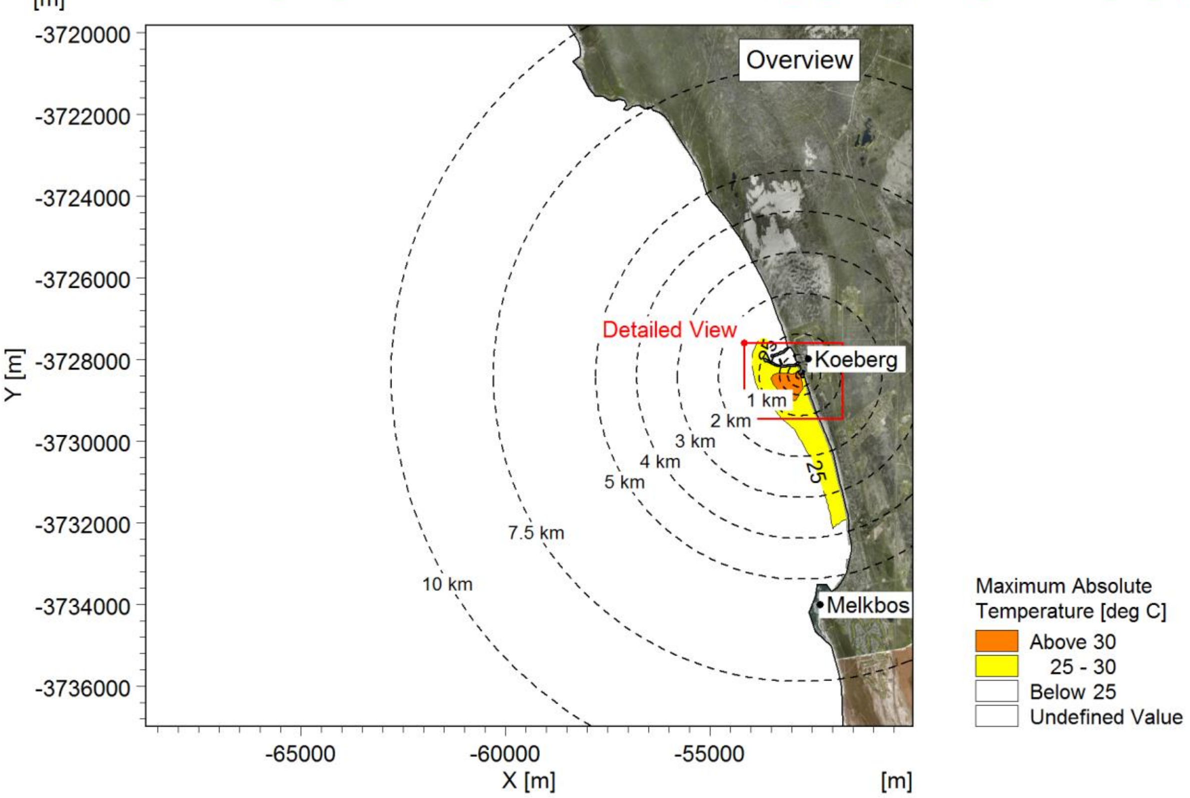

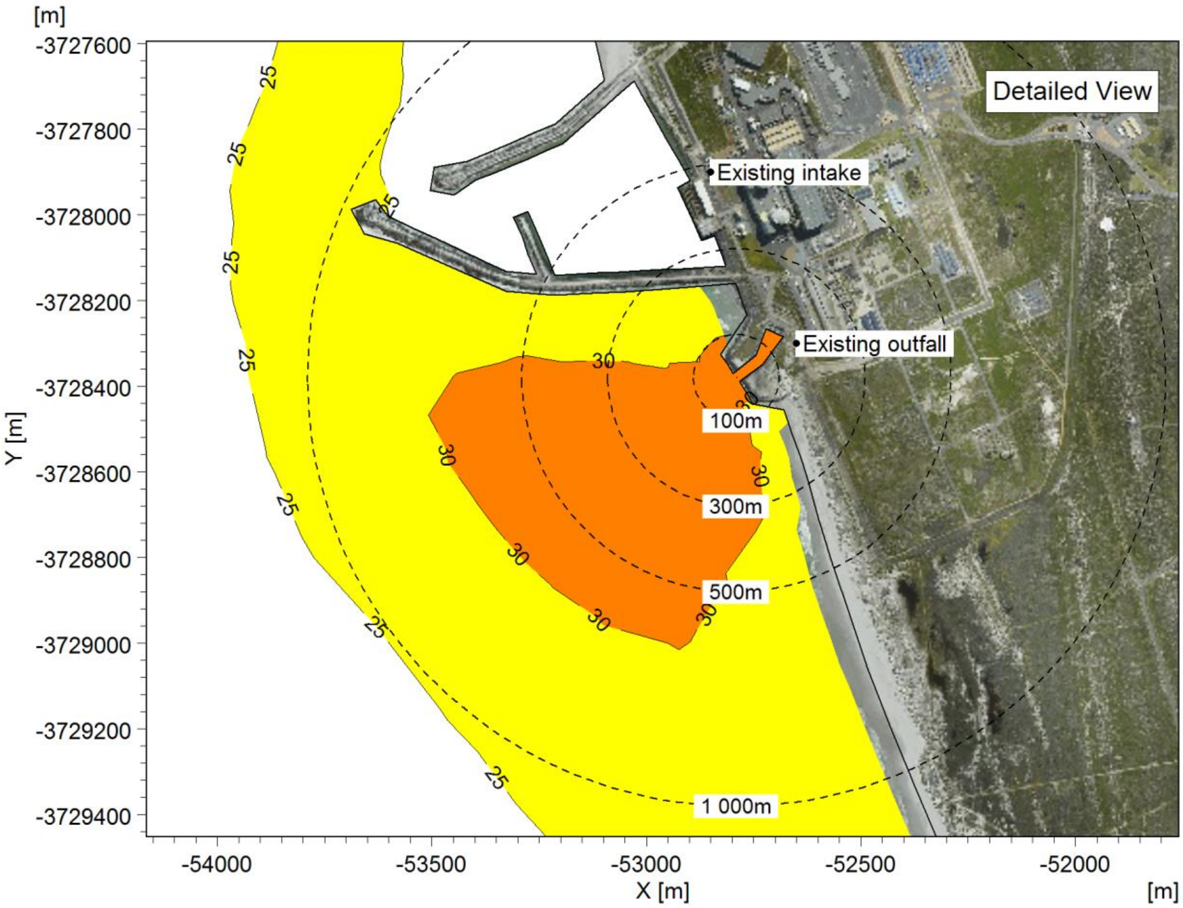

Figure 4-3: Maximum absolute temperature near the surface: Case 6 (two units operational, 100% power).

Case 1 has a higher temperature at discharge and therefore generally has a larger extent over which the acute threshold of 30°C is exceeded. However, while Case 6 has a lower temperature at discharge, its larger discharge rate results in a larger extent over which the chronic threshold of 25°C is exceeded. This is also true when investigating the duration that the temperature exceeds the chronic threshold, as is seen from Figure 4-4 and Figure 4-5.

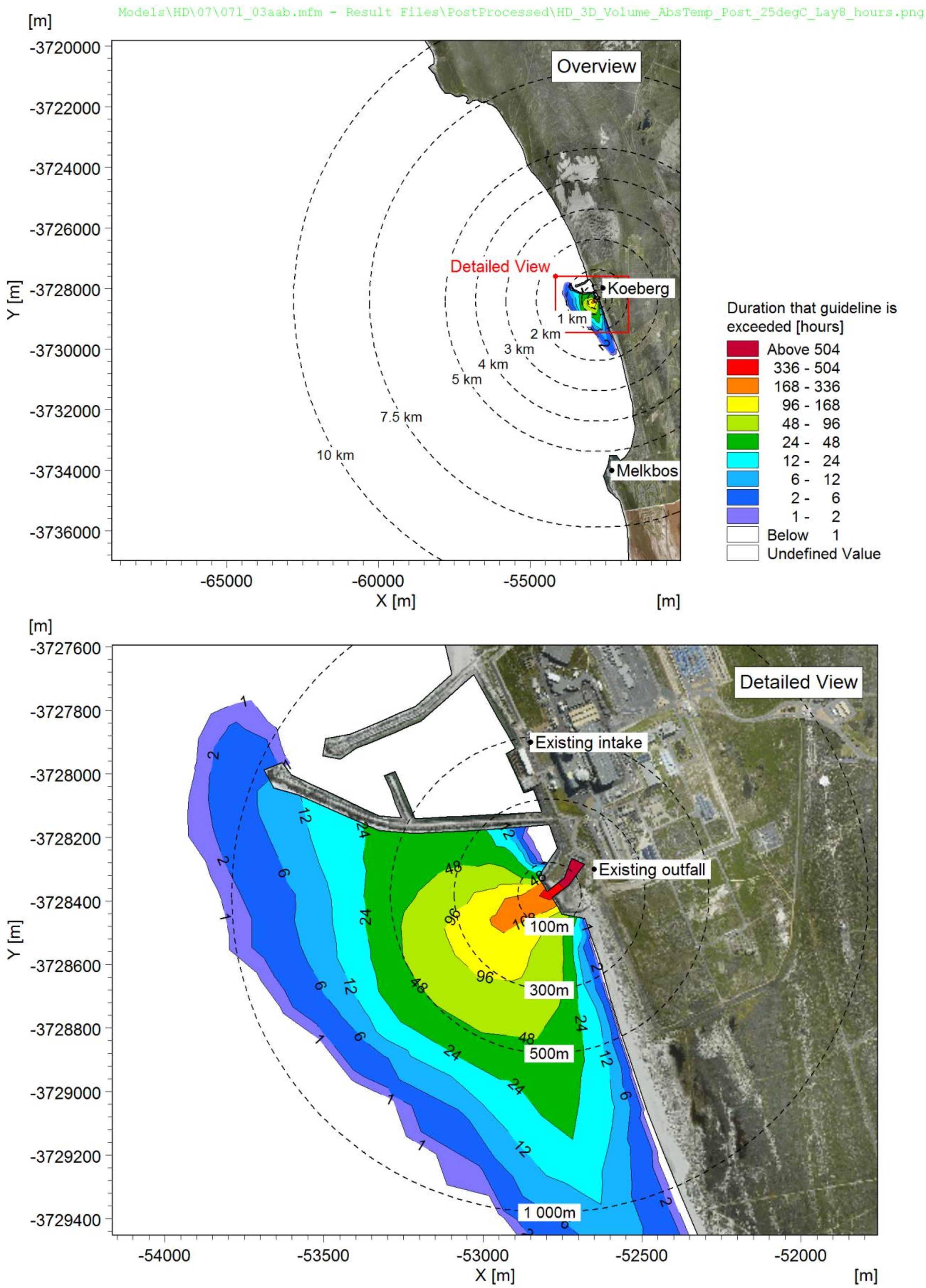

Figure 4-4: Duration that the chronic threshold of 25°C is exceeded near the surface: Case 1 (one unit operational, 100% power).

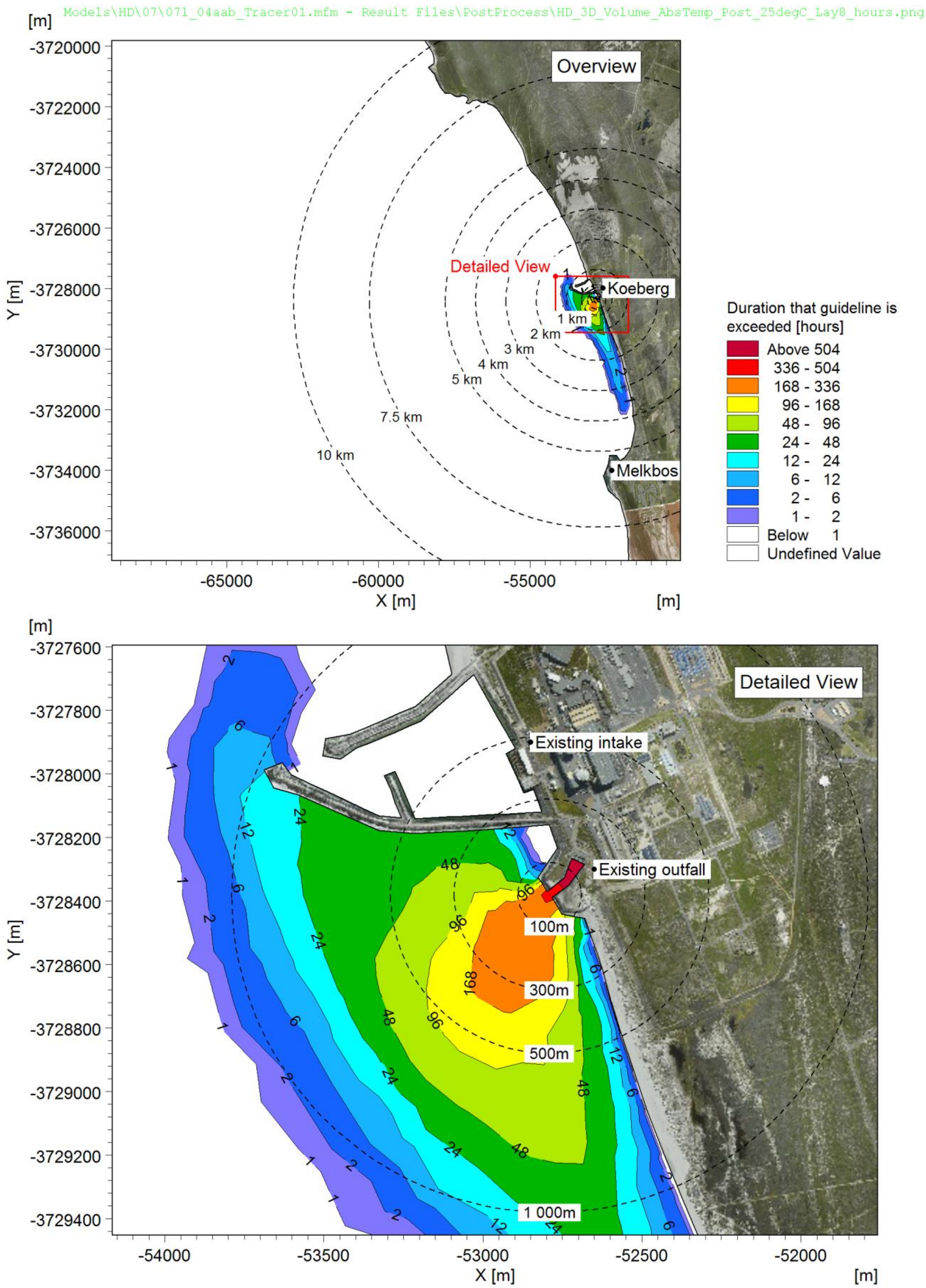

Figure 4-5: Duration that the chronic threshold of 25°C is exceeded near the surface: Case 6 (two units operational, 100% power).

The time series output at 100 m from the discharge and at the breakwater output point are shown in Figure 4-6 and Figure 4-7 for the worst of the modelled batches. The figures show the absolute temperature for Cases 1 to 5 (one reactor unit operational). The baseline temperature (without any thermal discharge) and the temperature with one reactor unit operating normally are also shown for reference. The 14 day duration over which the elevated temperature discharge occurs is indicated on the figures.

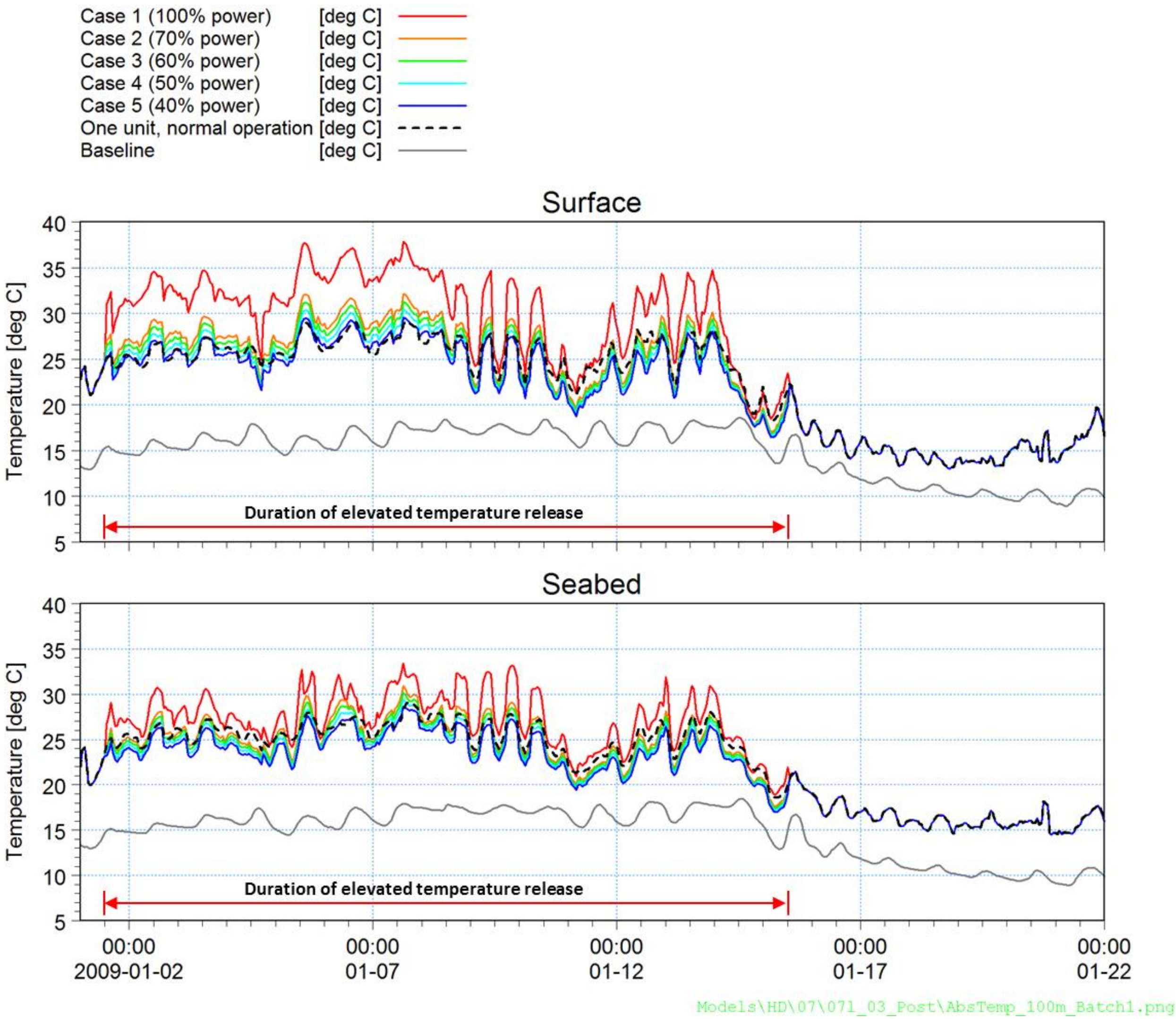

Figure 4-6: Time series of absolute temperature at 100 m from the discharge. Cases 1 to 5, seabed and surface.

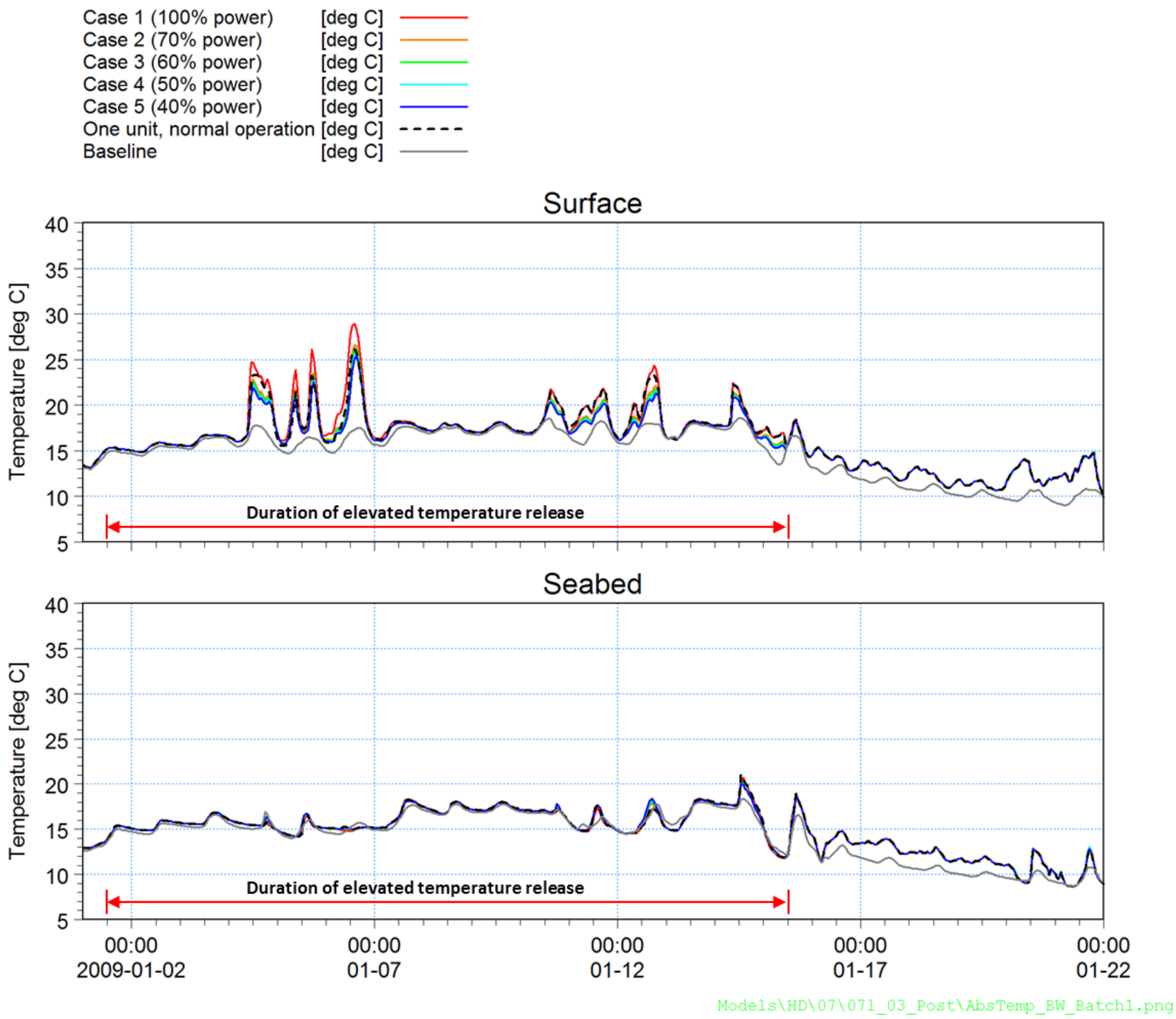

Figure 4-7: Time series of absolute temperature at the breakwater output location. Cases 1 to 5, seabed and surface.

At 100 m from the discharge, a significant difference in temperature between the normal operation and the abnormal cases (1 to 5) can be seen. Further away from the discharge, e.g. at the breakwater output location, the difference becomes much smaller. Elevated temperature above the baseline also becomes intermittent, since this only occurs when the plume is advected northward by the ambient wave and wind-driven currents.

In the worst of the modelled batches for Case 1, the acute threshold (30°C) is exceeded at the surface for approximately 9 days at 100 m from the discharge. At the breakwater output location, the threshold is never reached. With a power reduction to 70%, at 100 m from the discharge the acute threshold is exceeded for approximately 1.5 days over the 14 day period of elevated temperature.

The full set of results is presented in Annexure A. A summary of key outputs as used in the marine ecology assessment is presented in Table 4-1 to Table 4-4. Selected statistics for Case 0 are also shown for reference.

Table 4-1: Results summary: plume extent.

Scenario	Number of reactor units operational	Power level of affected unit [%]	Maximum extent of plume where maximum absolute temperature exceeds threshold for acute effects (>30°C) [m]		Maximum extent of plume where threshold for chronic effects (>25°C) is exceeded for at least 96h [m]	
			Seabed	Surface	Seabed	Surface
Case 0[(a)]	1	100	100	200	N/A[(b)]	N/A[(b)]
Case 1		100	150	750	175	350
Case 2		70	100	350	125	200
Case 3		60	50	250	100	175
Case 4		50	25	50	100	150
Case 5		40	-	-	75	125
Case 6	2	100	225	700	300	575
Case 7		70	150	300	250	450

Notes:

(a) Pump trip scenario, previously assessed.

(b) Elevated temperature release occurs for 12 hours only

Table 4-2: Results summary: plume area.

Scenario	Number of reactor units operational	Power level of affected unit [%]	Area of plume where maximum absolute temperature exceeds threshold for acute effects (>30°C) [ha]		Area of plume where threshold for chronic effects (>25°C) is exceeded for at least 96h [ha]	
			Seabed	Surface	Seabed	Surface
Case 0[(a)]	1	100	1.2	2.2	N/A[(b)]	N/A[(b)]
Case 1		100	3.5	50.4	1.3	8.3
Case 2		70	1.1	9.4	1.1	1.7
Case 3		60	0.8	2.6	1.0	1.2
Case 4		50	0.5	0.7	0.9	1.0
Case 5		40	0.4	0.4	0.7	1.0
Case 6	2	100	4.4	39.5	5.7	19.2
Case 7		70	1.6	4.1	4.8	10.3

Notes:

(a) Pump trip scenario, previously assessed.

(b) Elevated temperature release occurs for 12 hours only

Table 4-3: Results summary: maximum duration that temperature exceeds the threshold for acute effects (>30°C).

Scenario	Number of reactor units operational	Power level of affected unit [%]	Maximum duration that temperature exceeds threshold (>30°C) [hours]					
			100 m from discharge		Breakwater		1 000 m from discharge	
			Seabed	Surface	Seabed	Surface	Seabed	Surface
Case 1	1	100	72	215	0	0	0	0
Case 2		70	2	37	0	0	0	0
Case 3		60	1	16	0	0	0	0
Case 4		50	0	7	0	0	0	0
Case 5		40	0	0	0	0	0	0
Case 6	2	100	79	99	0	0	0	0
Case 7		70	8	27	0	0	0	0

Table 4-4: Results summary: maximum duration that temperature exceeds the threshold for chronic effects (>25°C).

Scenario	Number of reactor units operational	Power level of affected unit [%]	Maximum duration that temperature exceeds threshold (>25°C) [hours]					
			100 m from discharge		Breakwater		1 000 m from discharge	
			Seabed	Surface	Seabed	Surface	Seabed	Surface
Case 1	1	100	267	274	0	9	0	0
Case 2		70	177	234	0	4	0	0
Case 3		60	151	225	0	4	0	0
Case 4		50	128	209	0	3	0	0
Case 5		40	107	179	0	2	0	0
Case 6	2	100	303	315	0	23	0	1
Case 7		70	290	301	0	15	0	0

To assess the impact on pelagic organisms it is also of use to understand what proportion of the thermal plume is effluent (i.e. that which has passed through the cooling water system) and what proportion is entrained ambient water which may contain pelagic organisms thus exposed to the increased temperature. The scatter plots shown in Figure 4-8 compare the absolute temperature and percentage entrained water for Case 1 and Case 6. The plots are compiled from time series extracted at the six sensitive receptor locations (surface and seabed) shown in Figure 4-1.

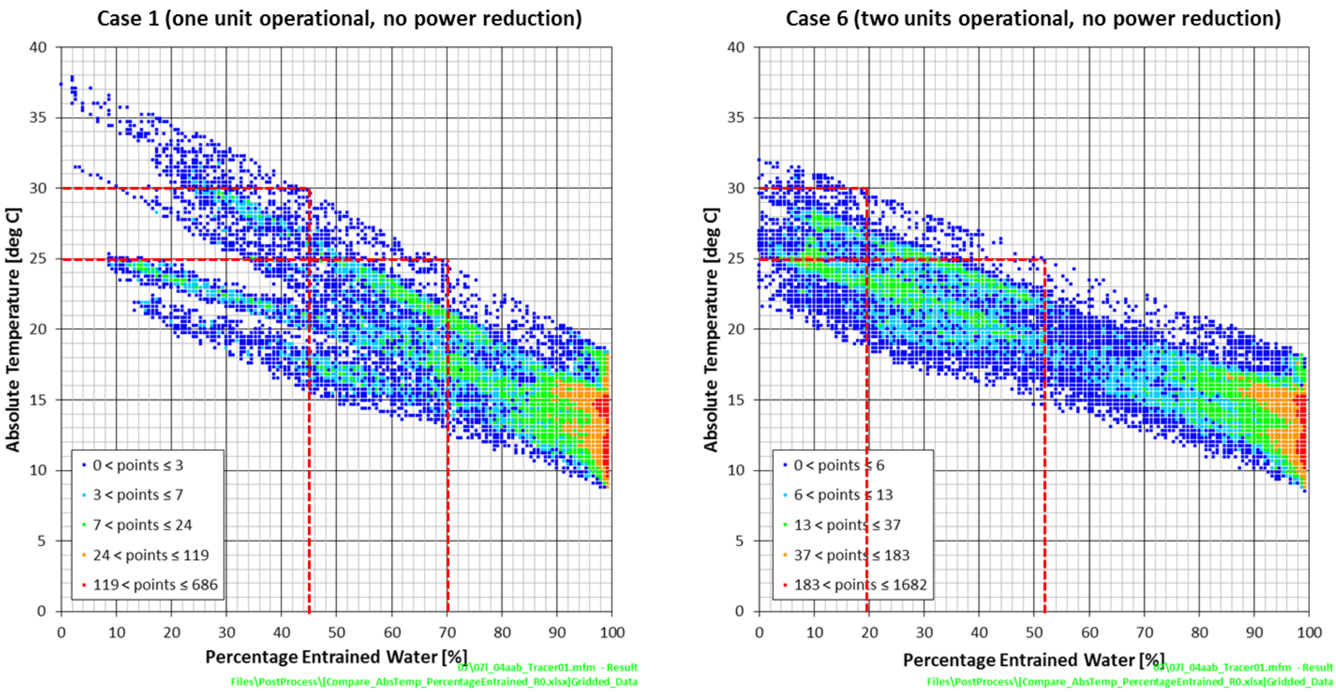

Figure 4-8: Relationship between absolute temperature and entrainment of ambient seawater for Case 1 (left) and Case 6 (right). 100% entrainment means pure ambient seawater, while 0% entrainment means pure effluent.

For Case 1, the threshold of 30°C may be exceeded with up to approximately 45% entrained ambient water, while the threshold of 25°C may be exceeded with up to approximately 70% entrained water. For Case 6, since the absolute temperature at discharge is lower than for Case 1, the amount of entrainment needed before the plume temperature drops to below the thresholds reduces to approximately 20% and 52%.

Based on the results presented here, the ecological impacts of the abnormal thermal discharge scenarios are assessed by Lwandle (2019), where the conclusions of the study are also drawn.

5. REFERENCES

Lwandle, 2017. *KNPS Marine Discharge Assessment in support of the CWDP Application: Marine Ecology Specialist Study. Doc Ref: LT-267 Rev-06,* Cape Town: Lwandle Technologies (Pty) Ltd..

Lwandle, 2019. *Koeberg Nuclear Power Station CWDP. Addendum Report: Assessment of Additional Thermal Discharge Scenarios. LT-267 WS V1.0,* Cape Town: Lwandle.

PRDW, 2017. *Koeberg Nuclear Power Station: Coastal processes technical information in support of the Coastal Waters Discharge Permit Application. Dispersion Modelling of Thermal, Chemical, Sediment and Radionuclide discharges. Doc no. S2015-RP-CE-001-R5.,* Cape Town: PRDW Pty (Ltd.).

ANNEXURE A | FULL SET OF MODEL RESULTS

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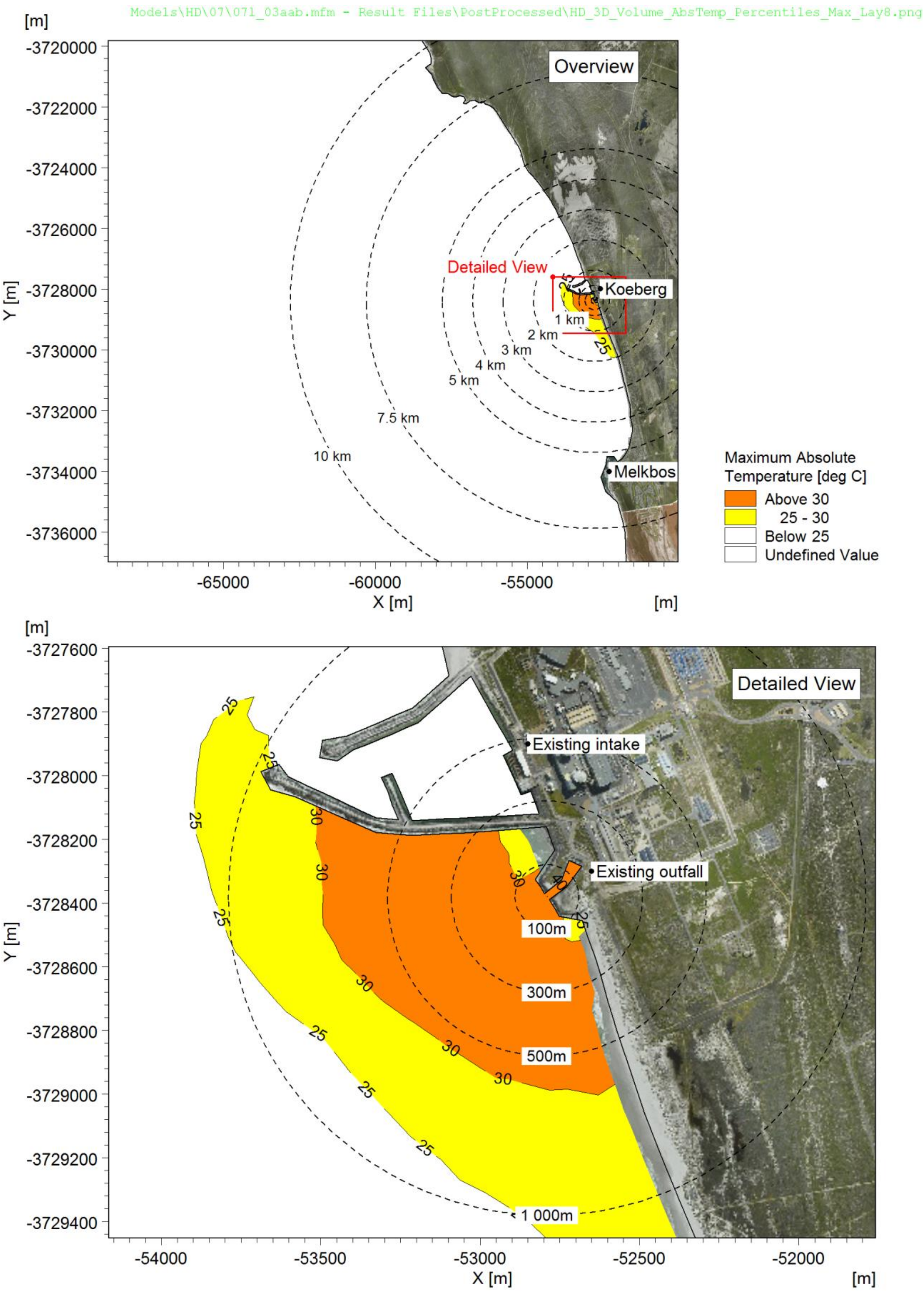

Figure A-1: Maximum absolute temperature near the surface: Case 1 (one unit operational, 100% power).

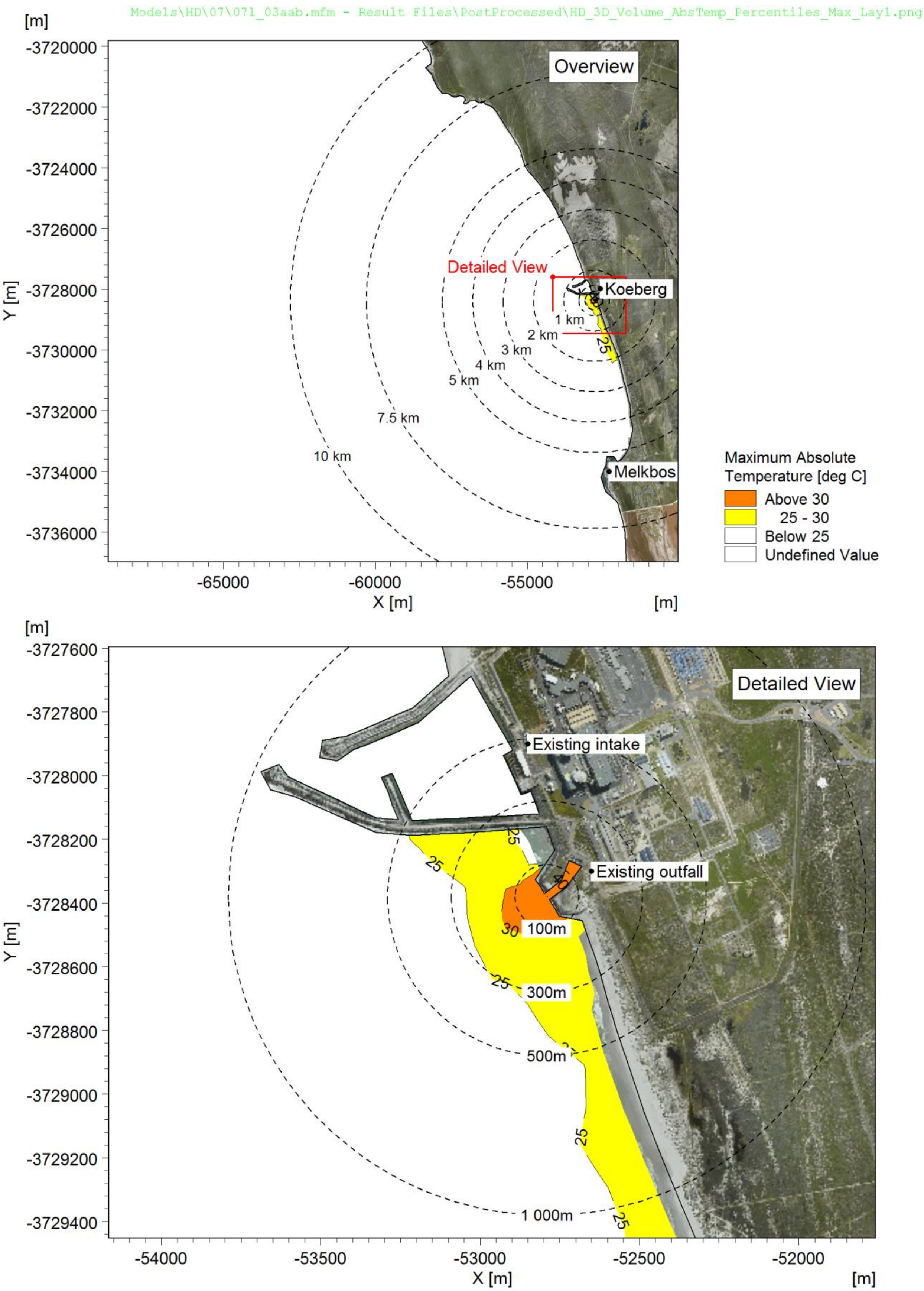

Figure A-2: Maximum absolute temperature near the seabed: Case 1 (one unit operational, 100% power).

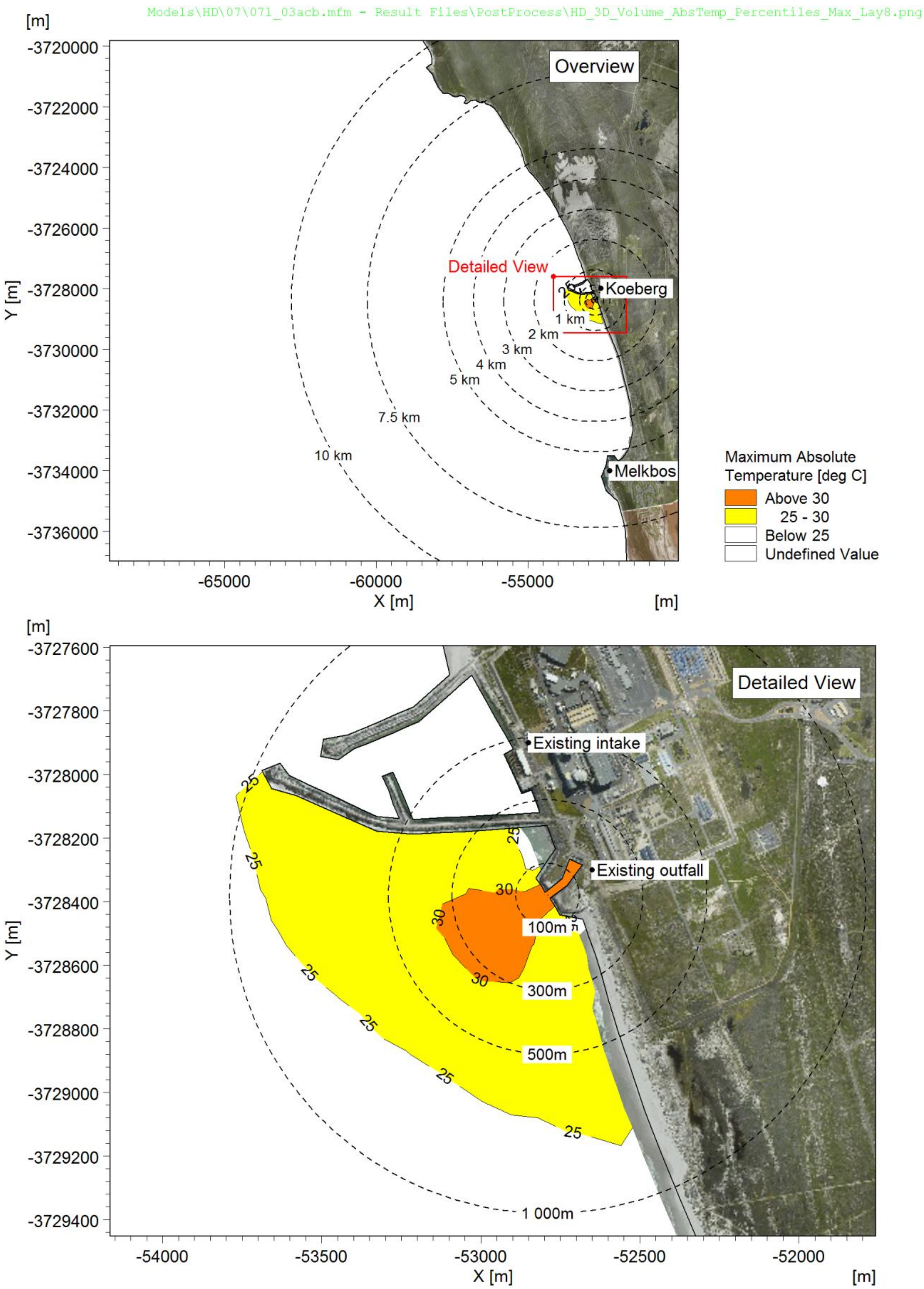

Figure A-3: Maximum absolute temperature near the surface: Case 2 (one unit operational, 70% power).

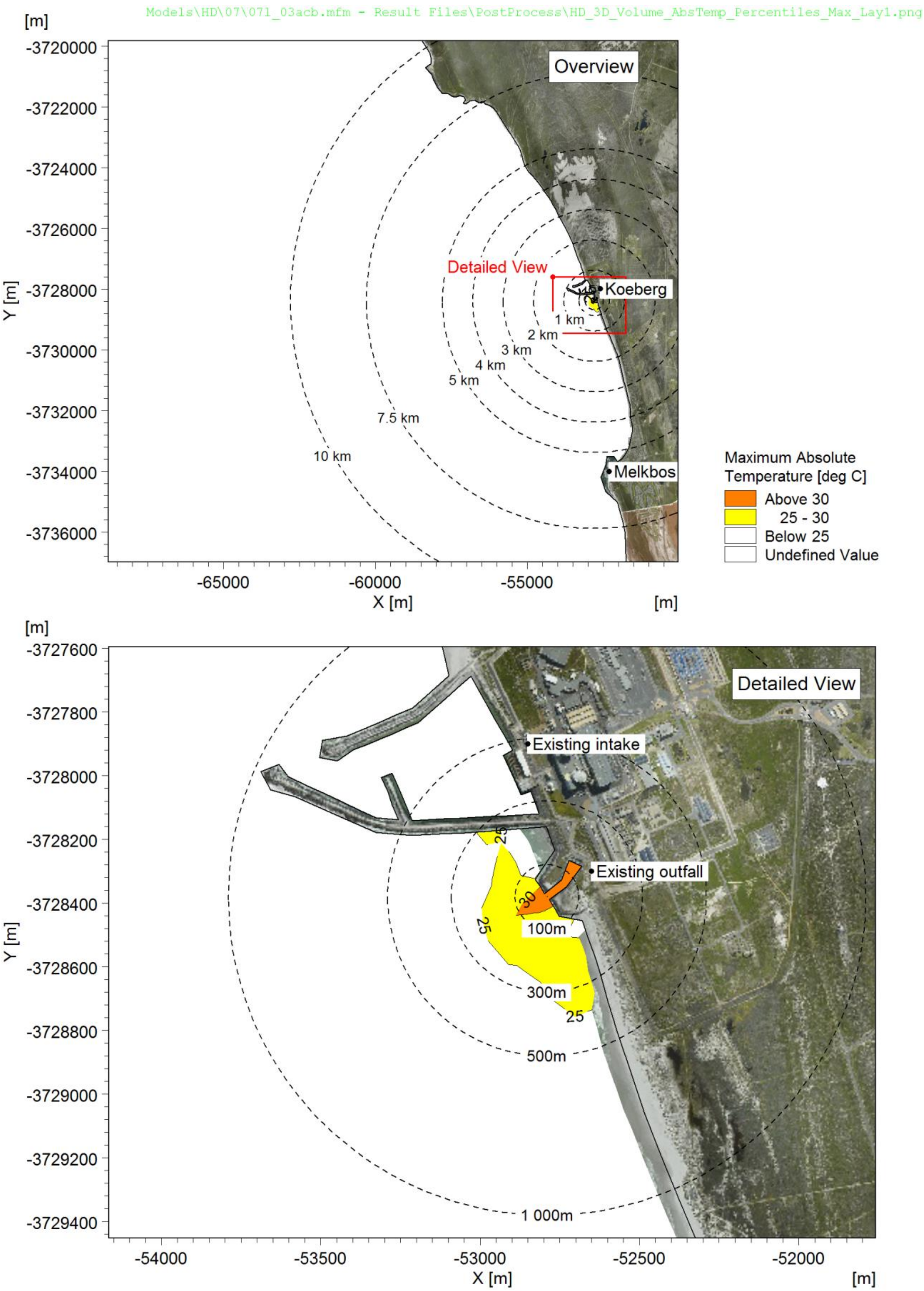

Figure A-4: Maximum absolute temperature near the seabed: Case 2 (one unit operational, 70% power).

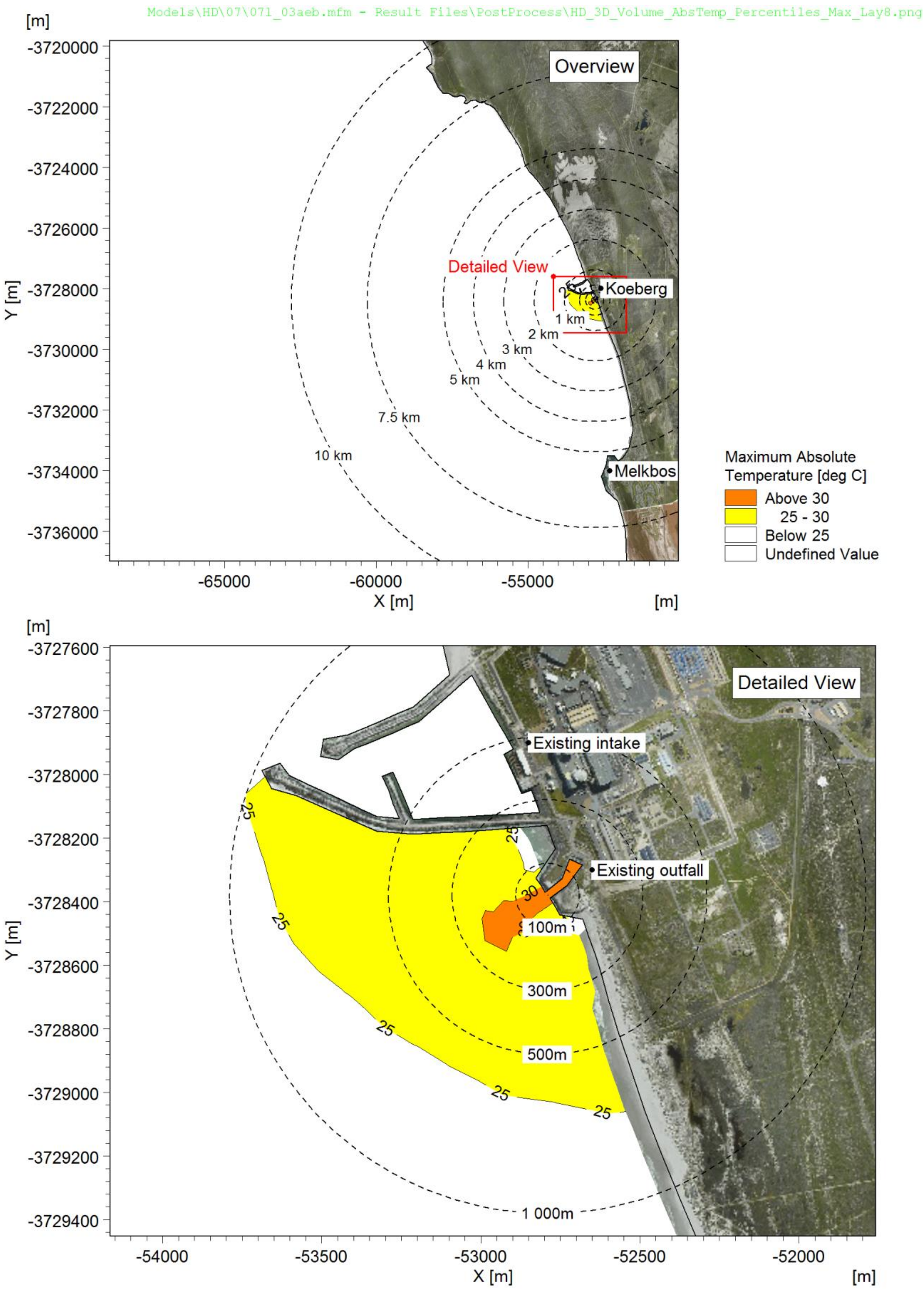

Figure A-5: Maximum absolute temperature near the surface: Case 3 (one unit operational, 60% power).

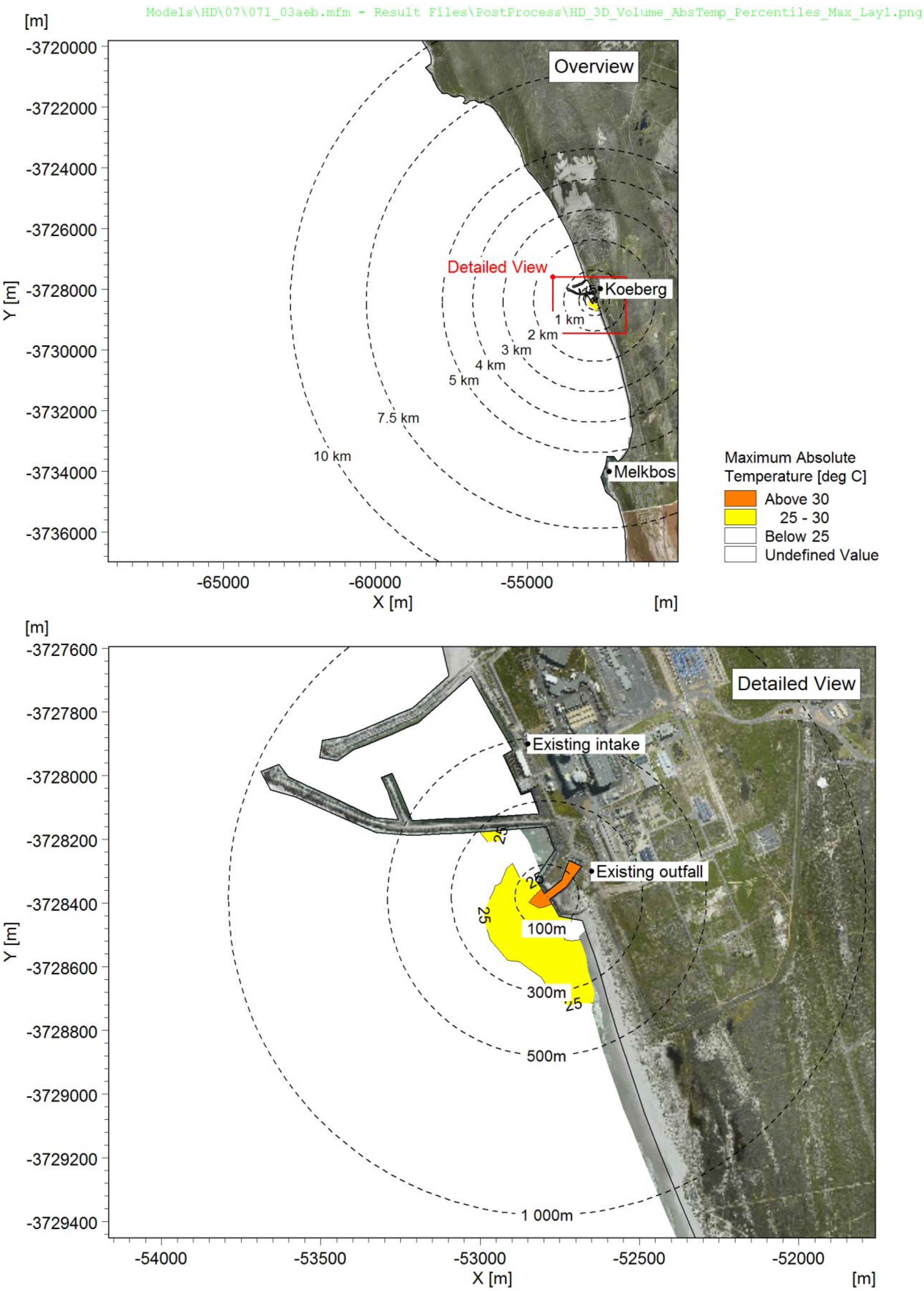

Figure A-6: Maximum absolute temperature near the seabed: Case 3 (one unit operational, 60% power).

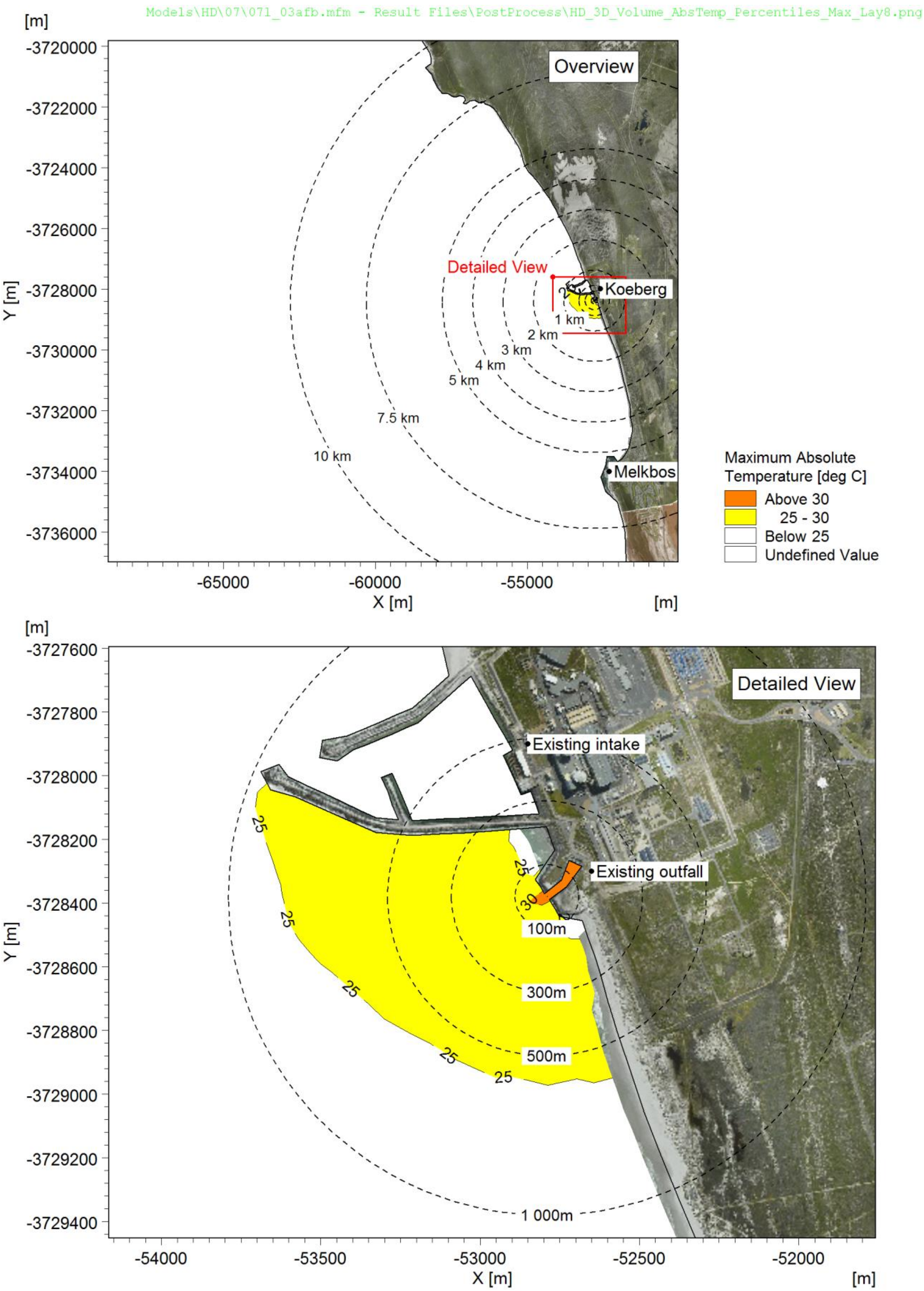

Figure A-7: Maximum absolute temperature near the surface: Case 4 (one unit operational, 50% power).

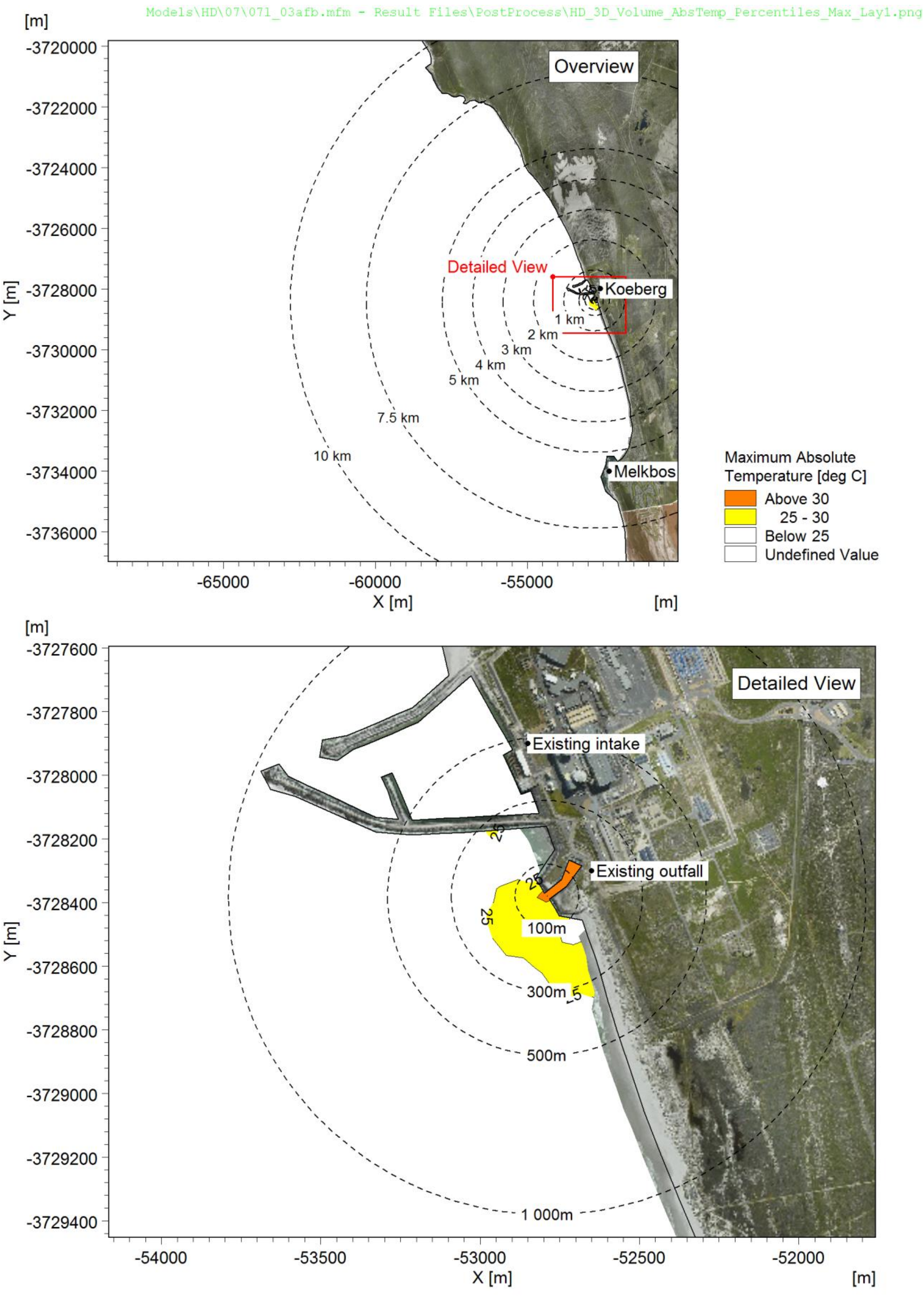

Figure A-8: Maximum absolute temperature near the seabed: Case 4 (one unit operational, 50% power).

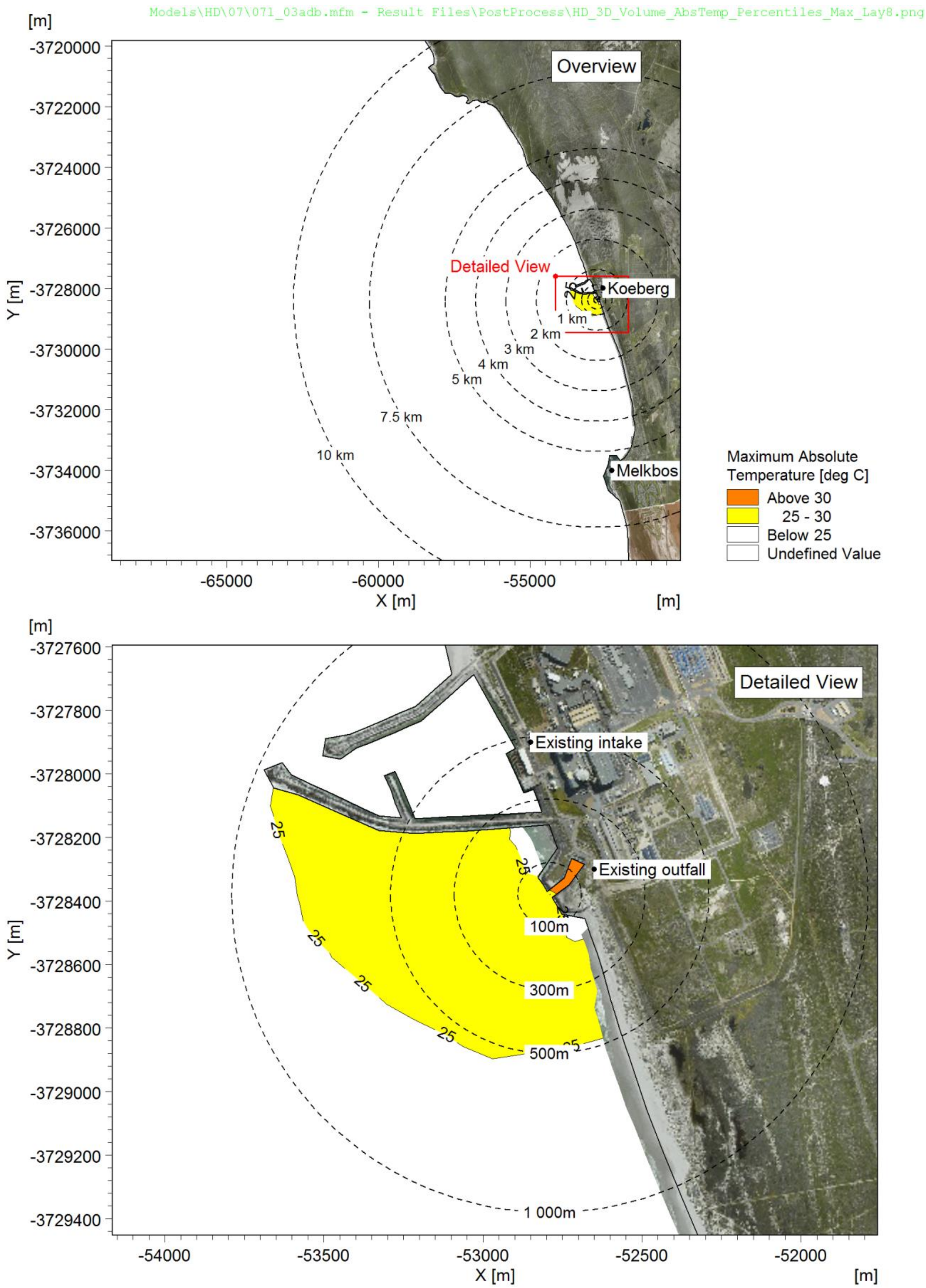

Figure A-9: Maximum absolute temperature near the surface: Case 5 (one unit operational, 40% power).

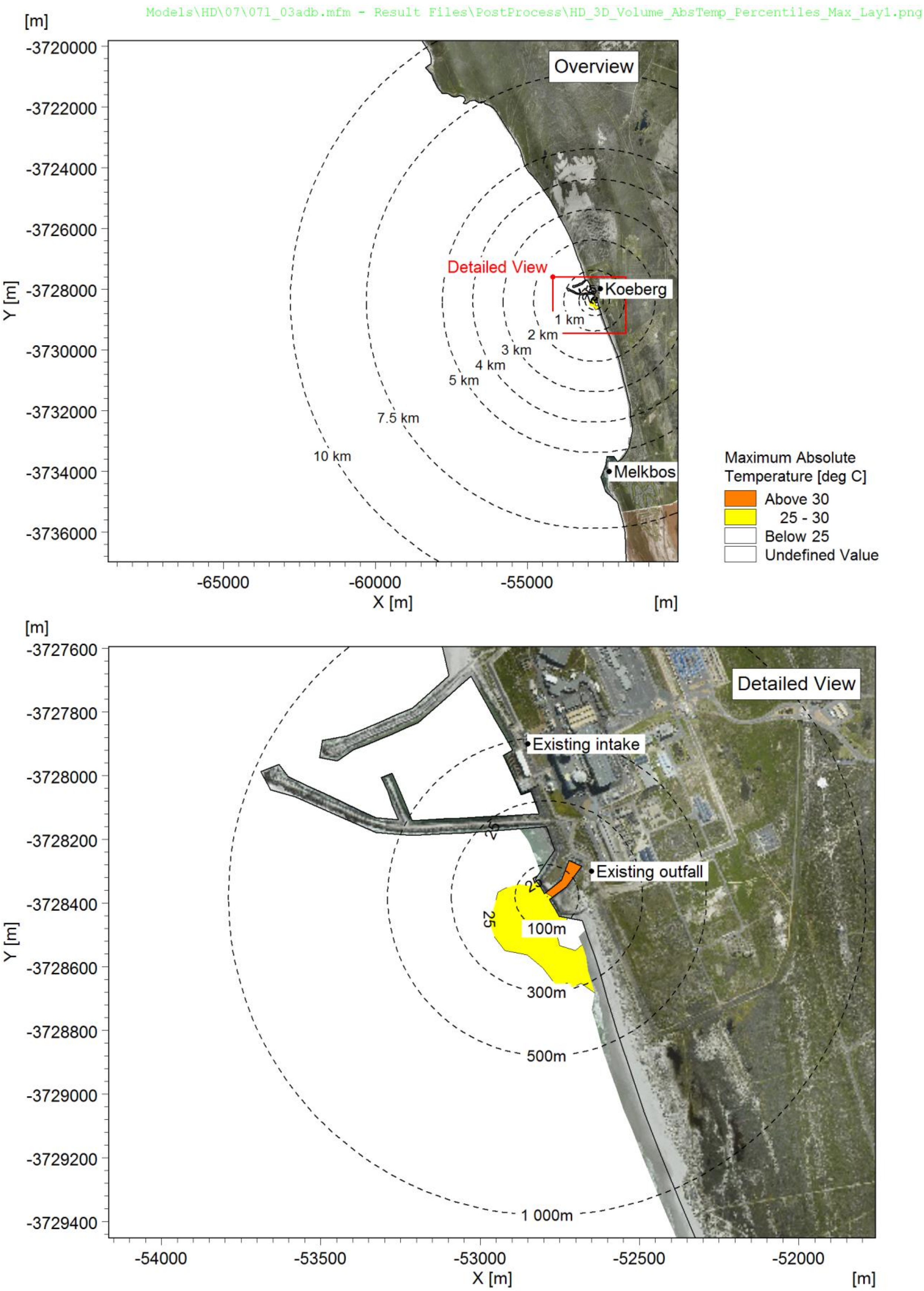

Figure A-10: Maximum absolute temperature near the seabed: Case 5 (one unit operational, 40% power).

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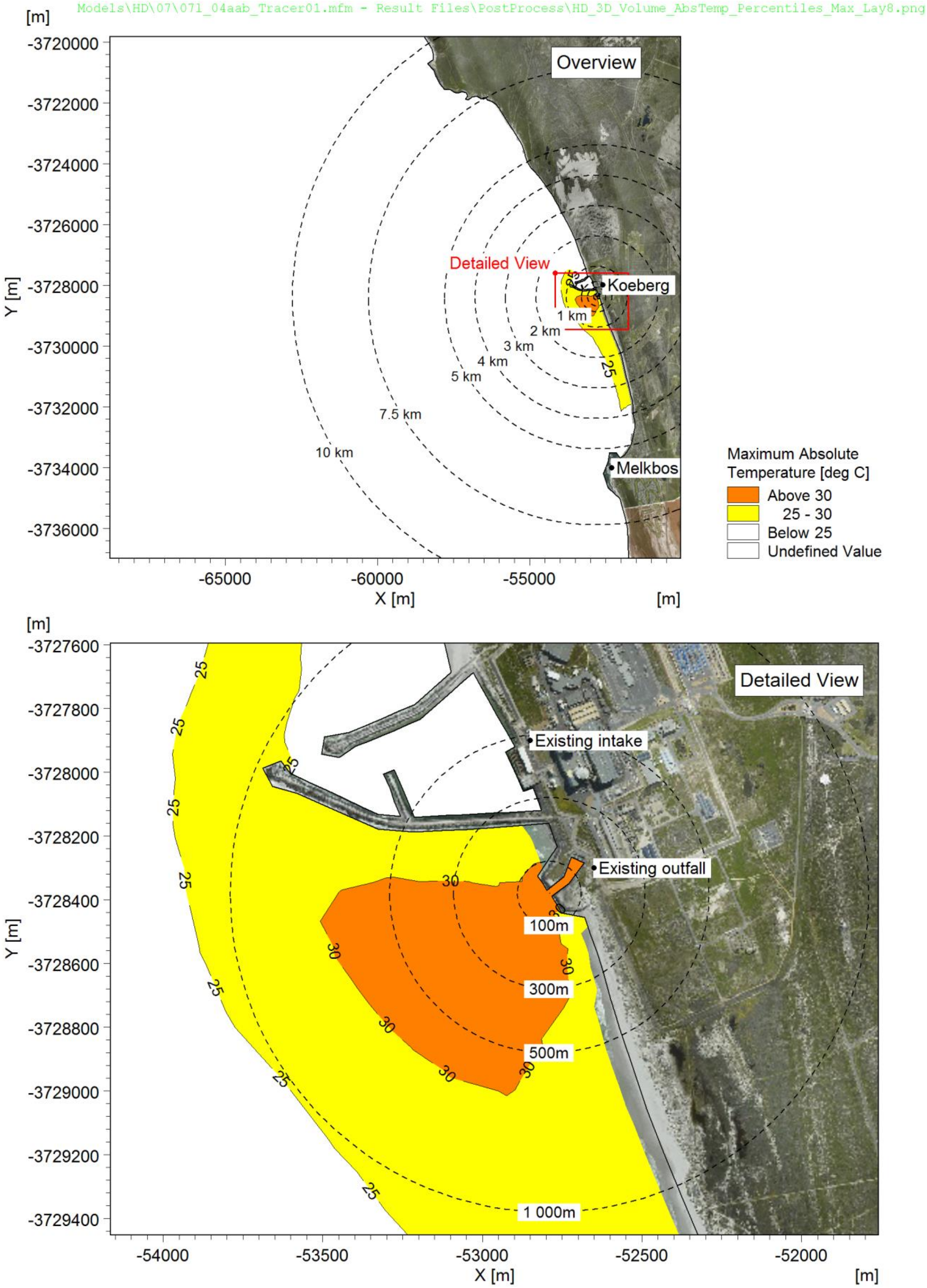

Figure A-11: Maximum absolute temperature near the surface: Case 6 (two units operational, 100% power).

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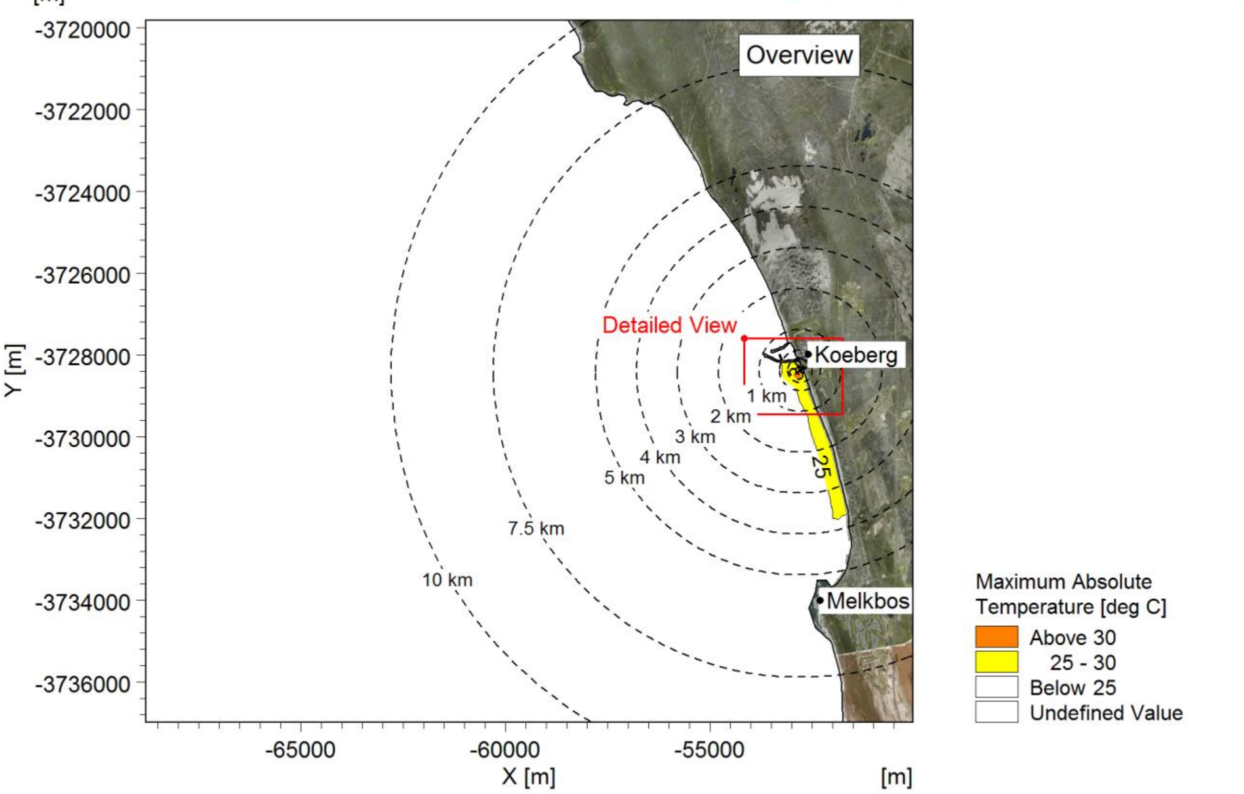


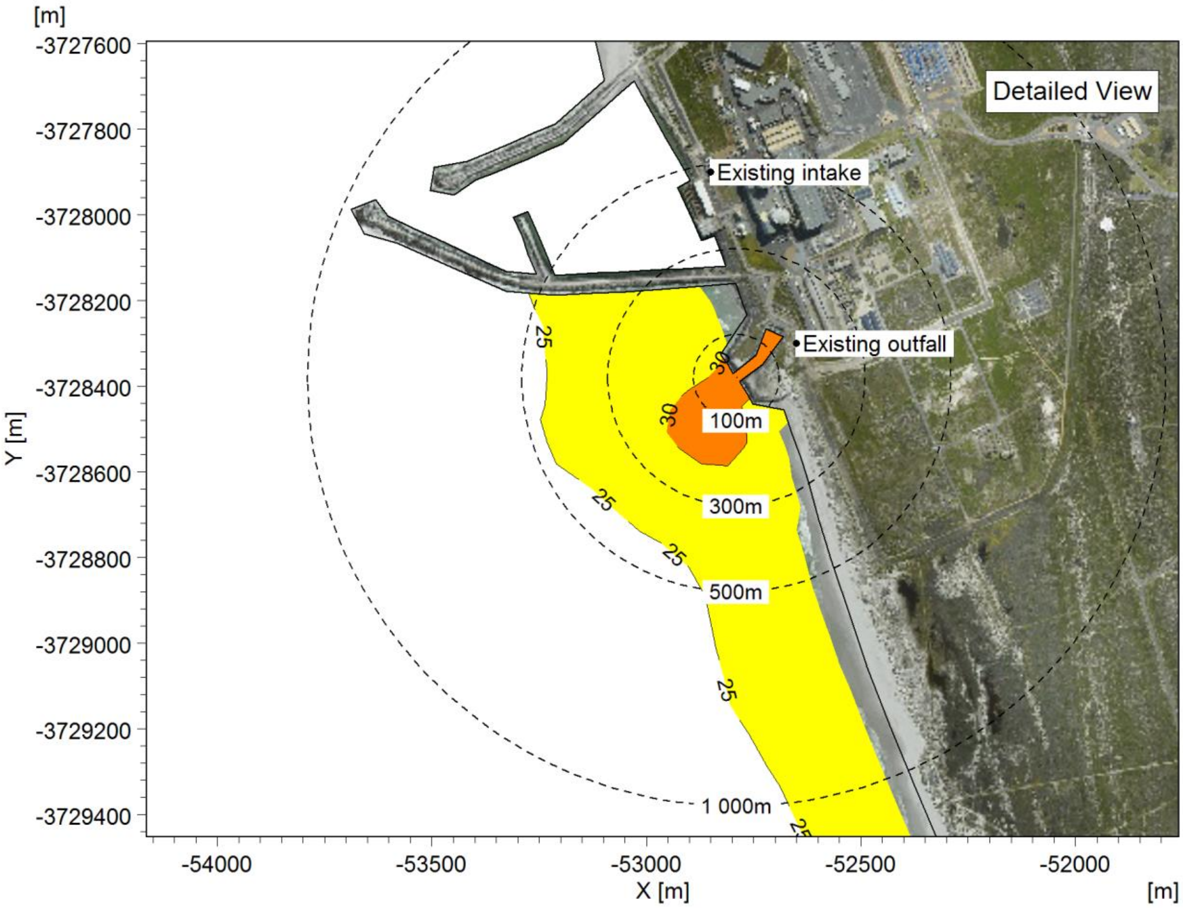


Figure A-12: Maximum absolute temperature near the seabed: Case 6 (two units operational, 100% power).

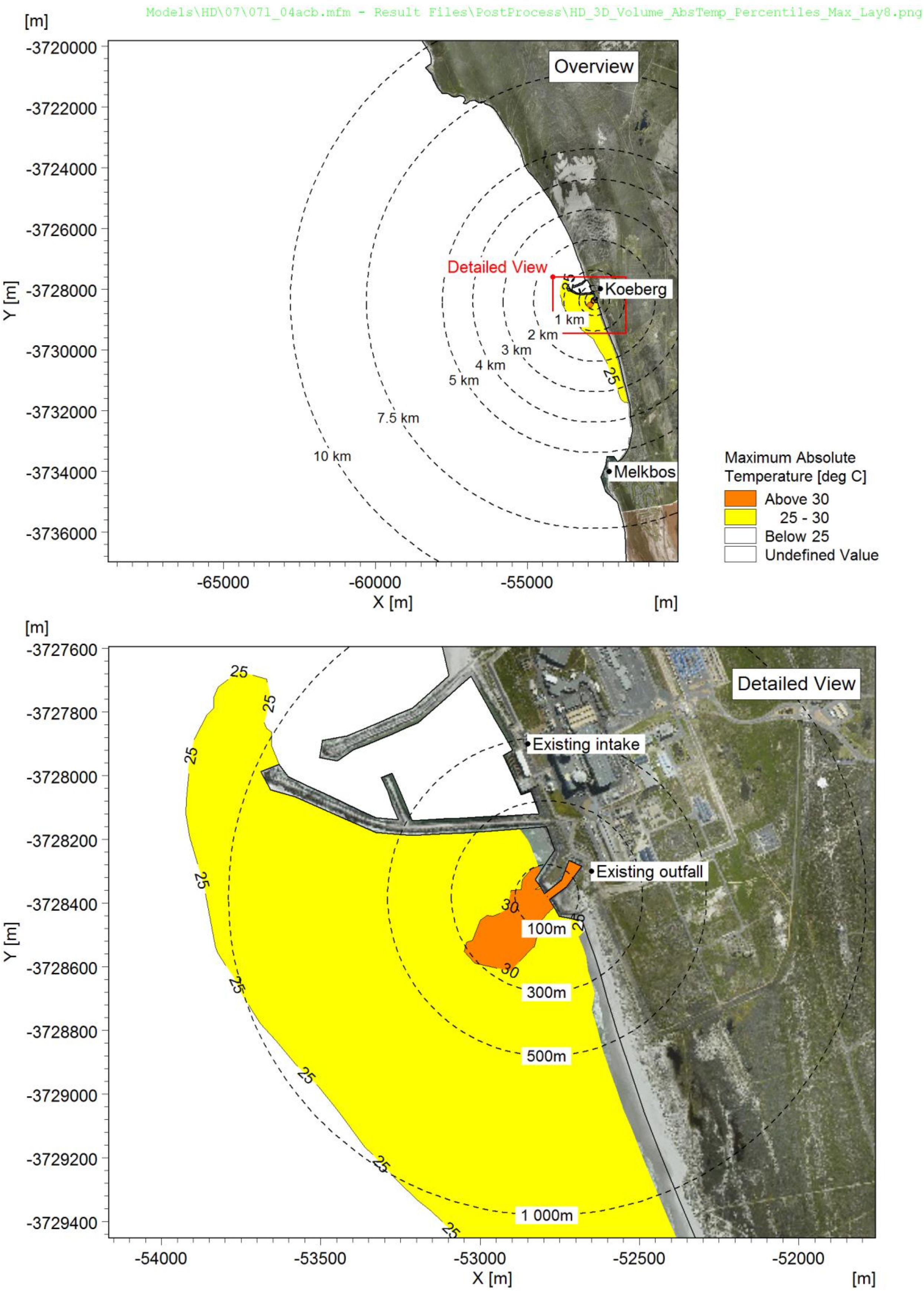


Figure A-13: Maximum absolute temperature near the surface: Case 7 (two units operational, 70% power).

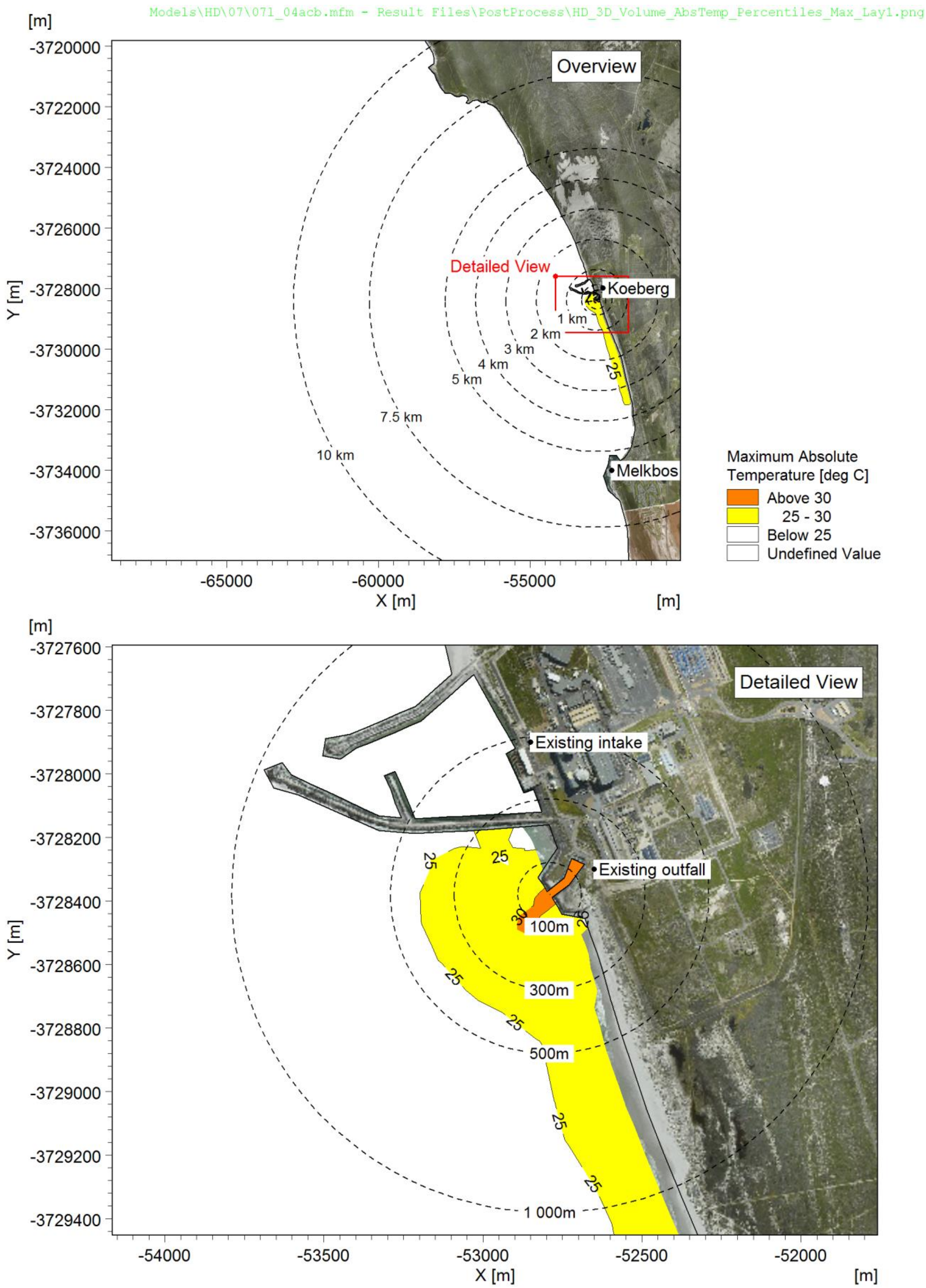


Figure A-14: Maximum absolute temperature near the seabed: Case 7 (two units operational, 70% power).

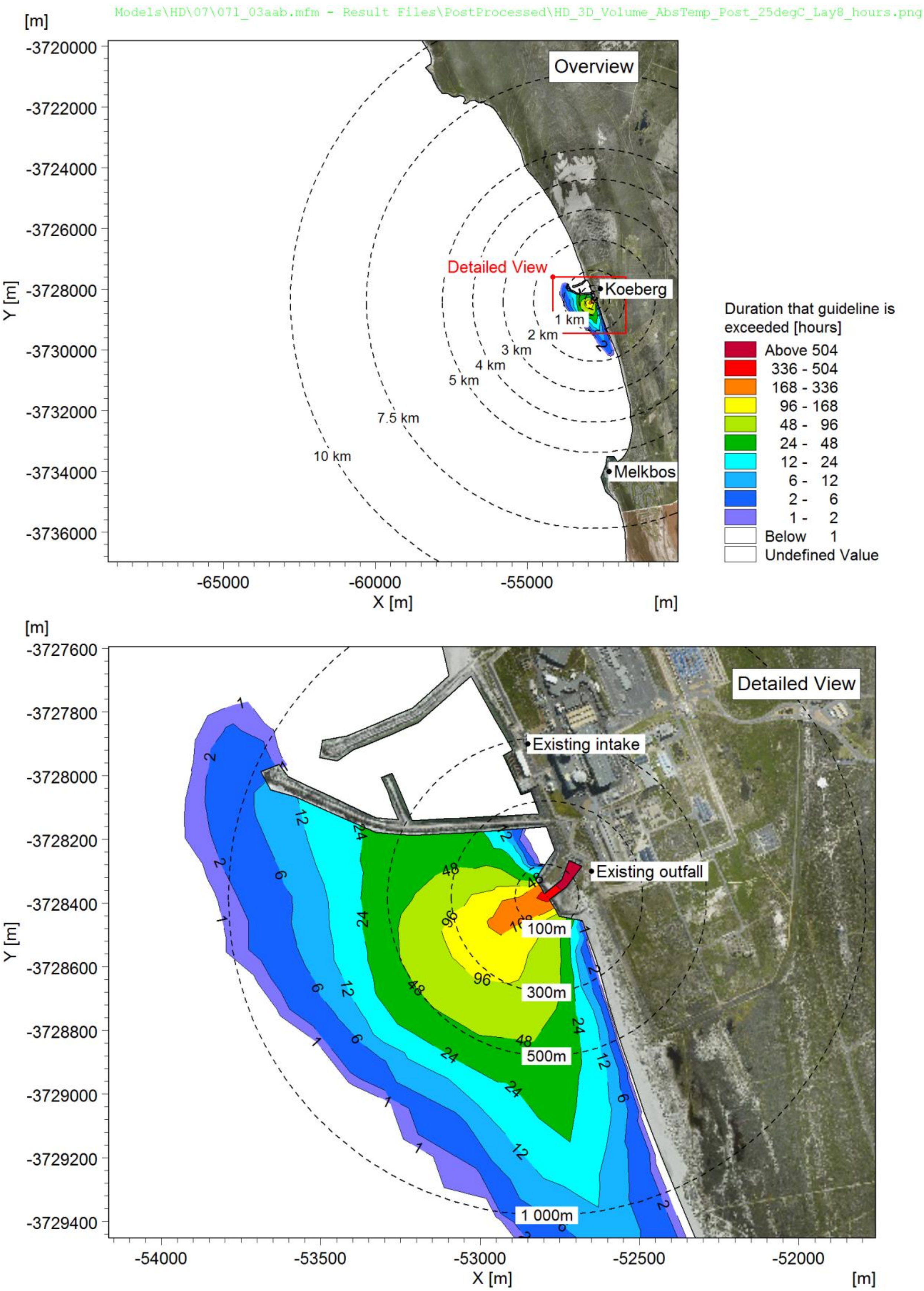


Figure A-15: Duration that the chronic threshold of 25°C is exceeded near the surface: Case 1 (one unit operational, 100% power).

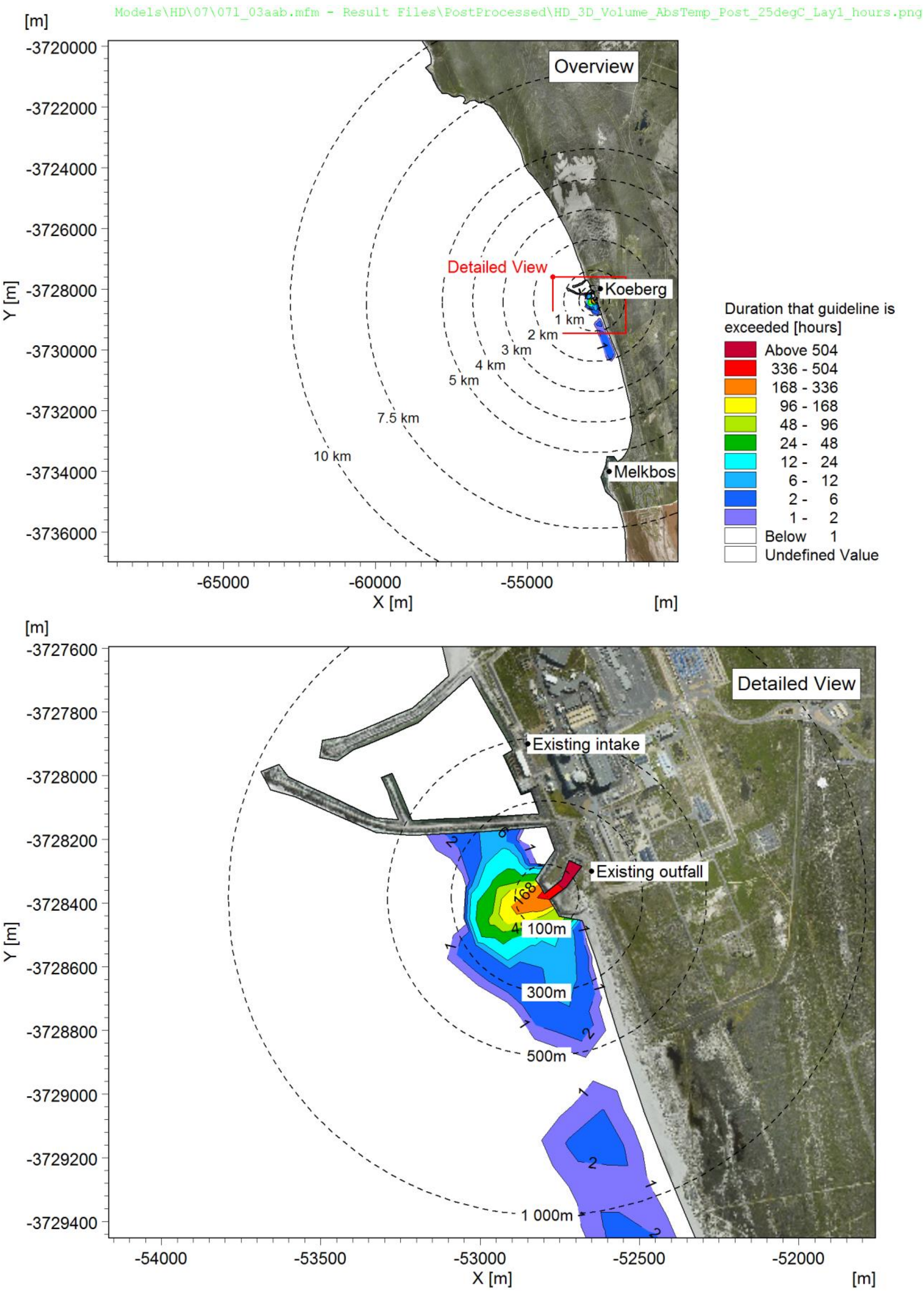


Figure A-16: Duration that the chronic threshold of 25°C is exceeded near the seabed: Case 1 (one unit operational, 100% power).

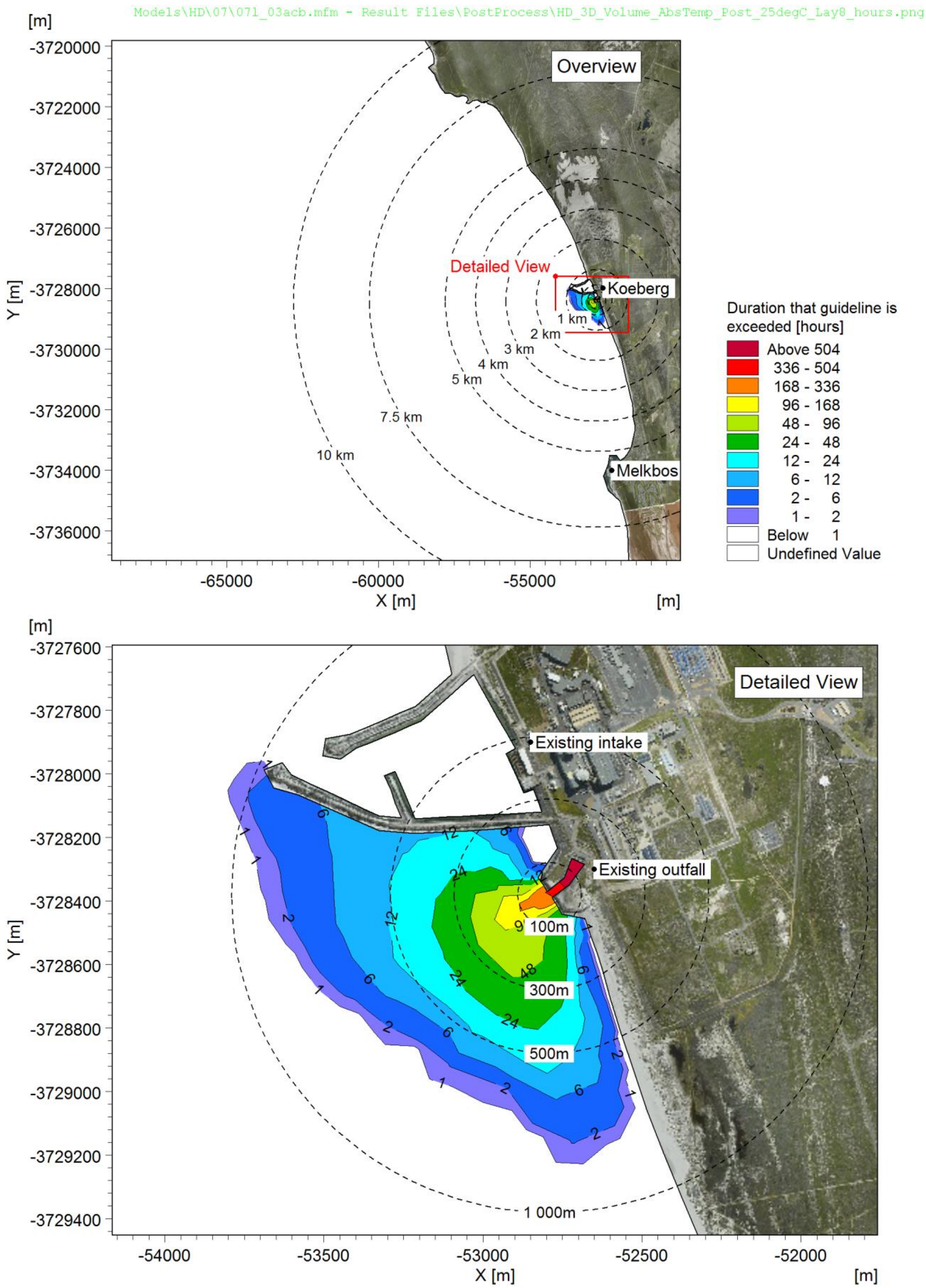


Figure A-17: Duration that the chronic threshold of 25°C is exceeded near the surface: Case 2 (one unit operational, 70% power).

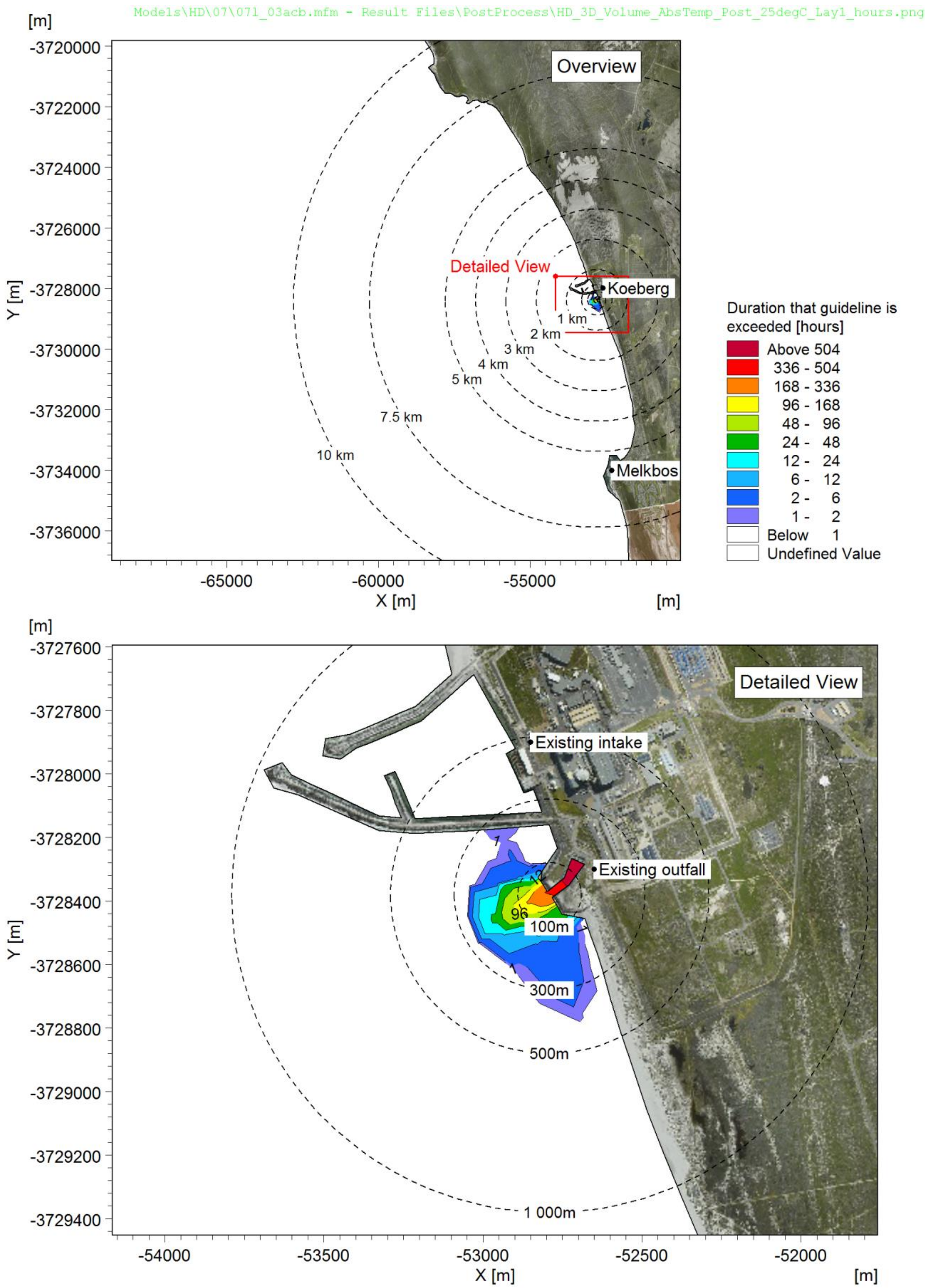


Figure A-18: Duration that the chronic threshold of 25°C is exceeded near the seabed: Case 2 (one unit operational, 70% power).

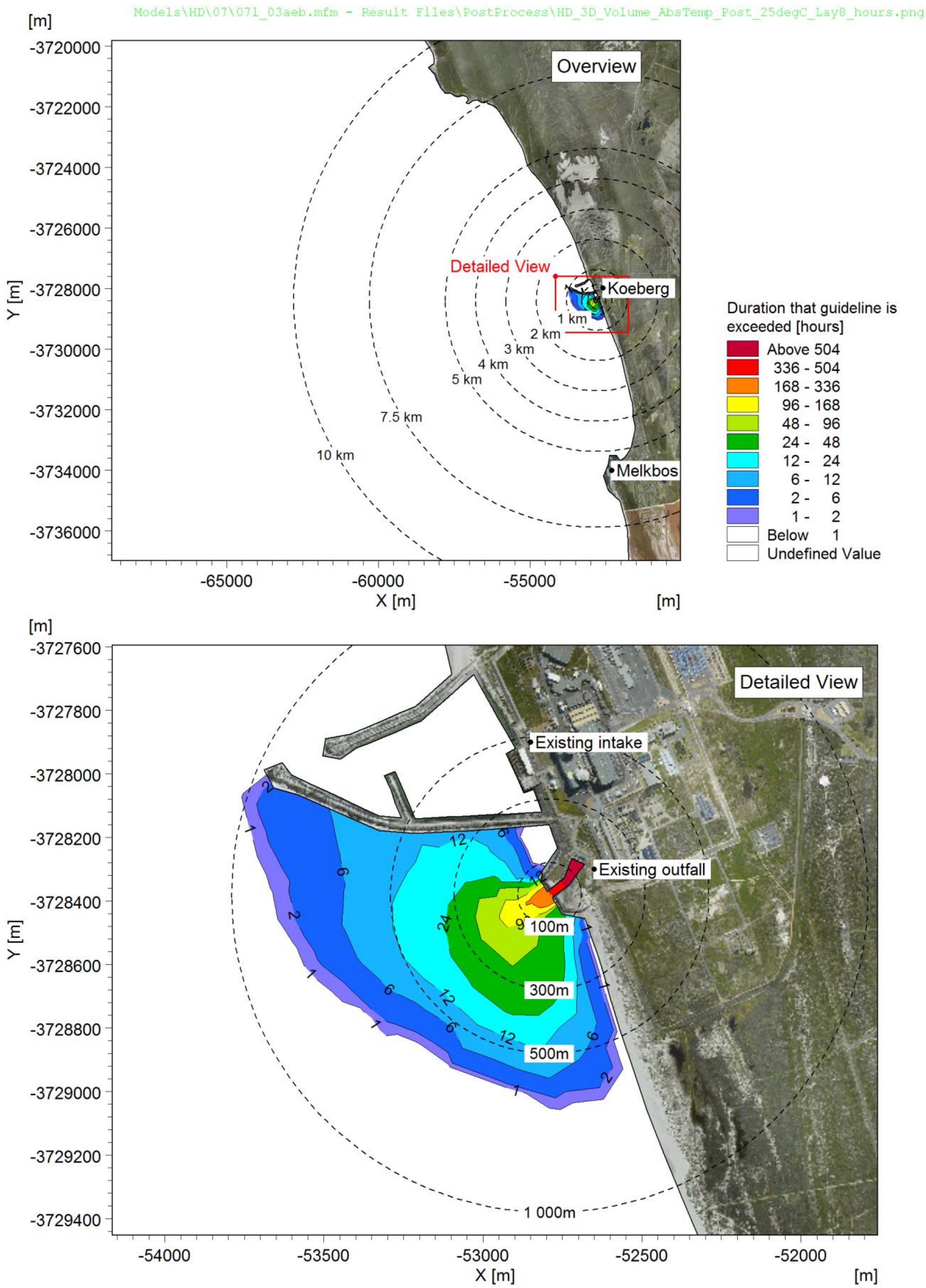


Figure A-19: Duration that the chronic threshold of 25°C is exceeded near the surface: Case 3 (one unit operational, 60% power).

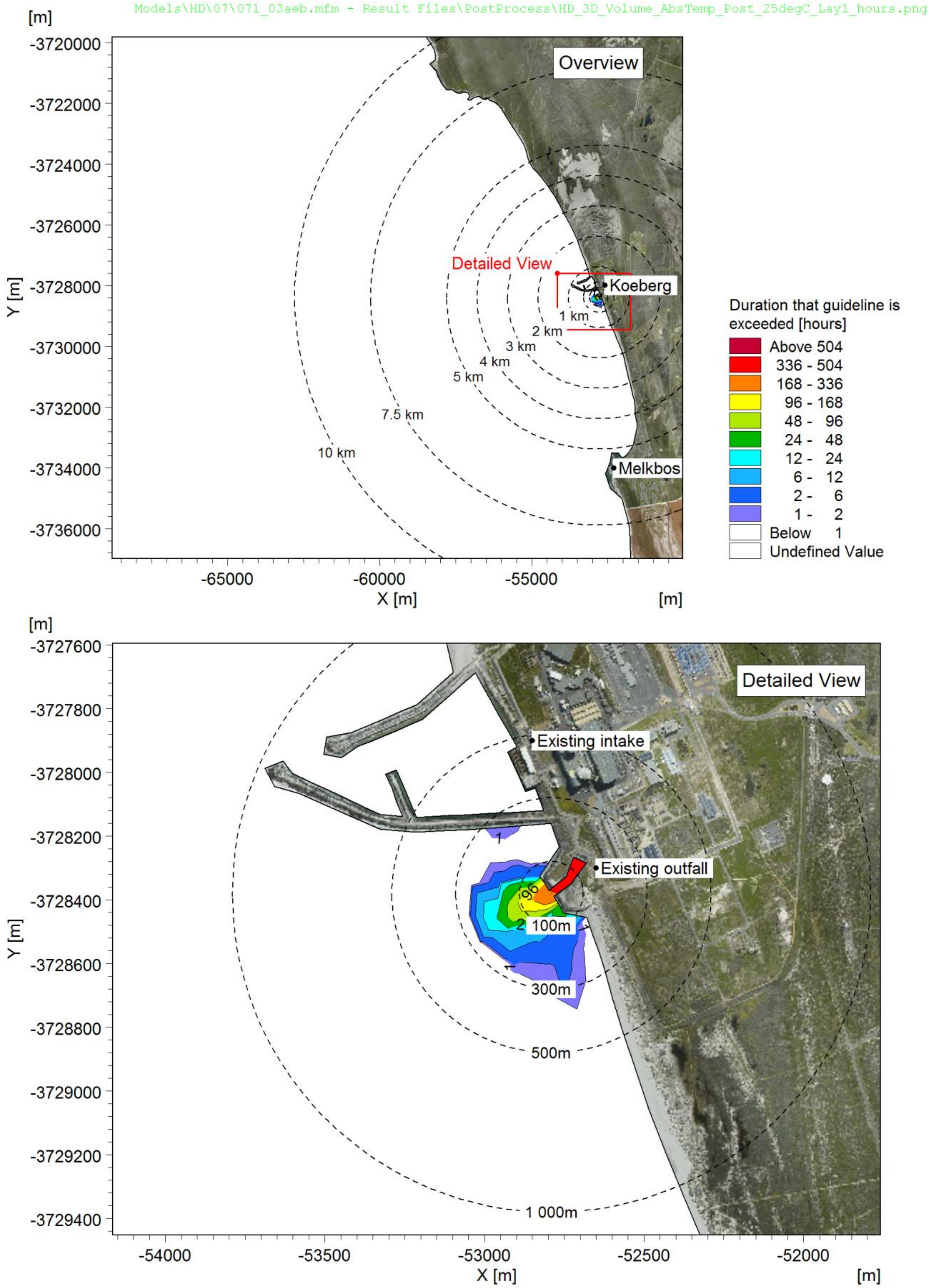
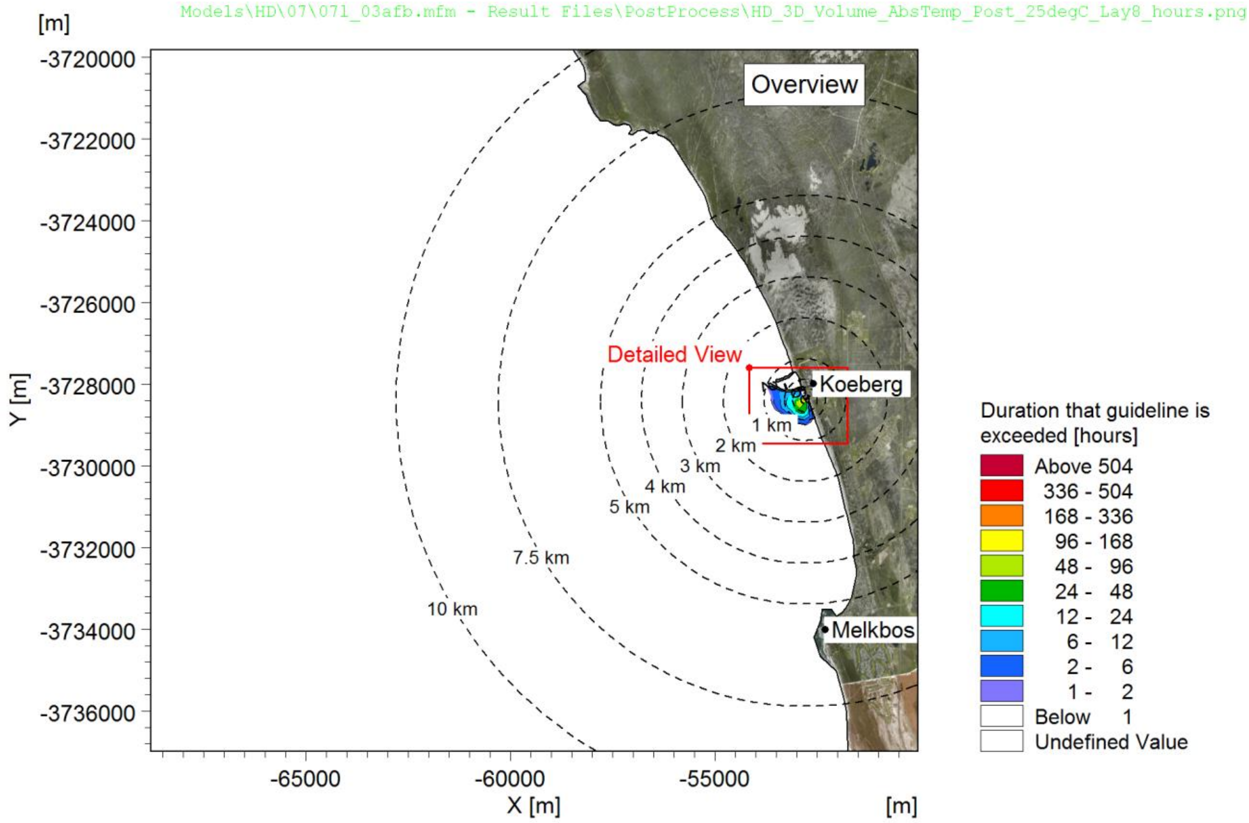


Figure A-20: Duration that the chronic threshold of 25°C is exceeded near the seabed: Case 3 (one unit operational, 60% power).



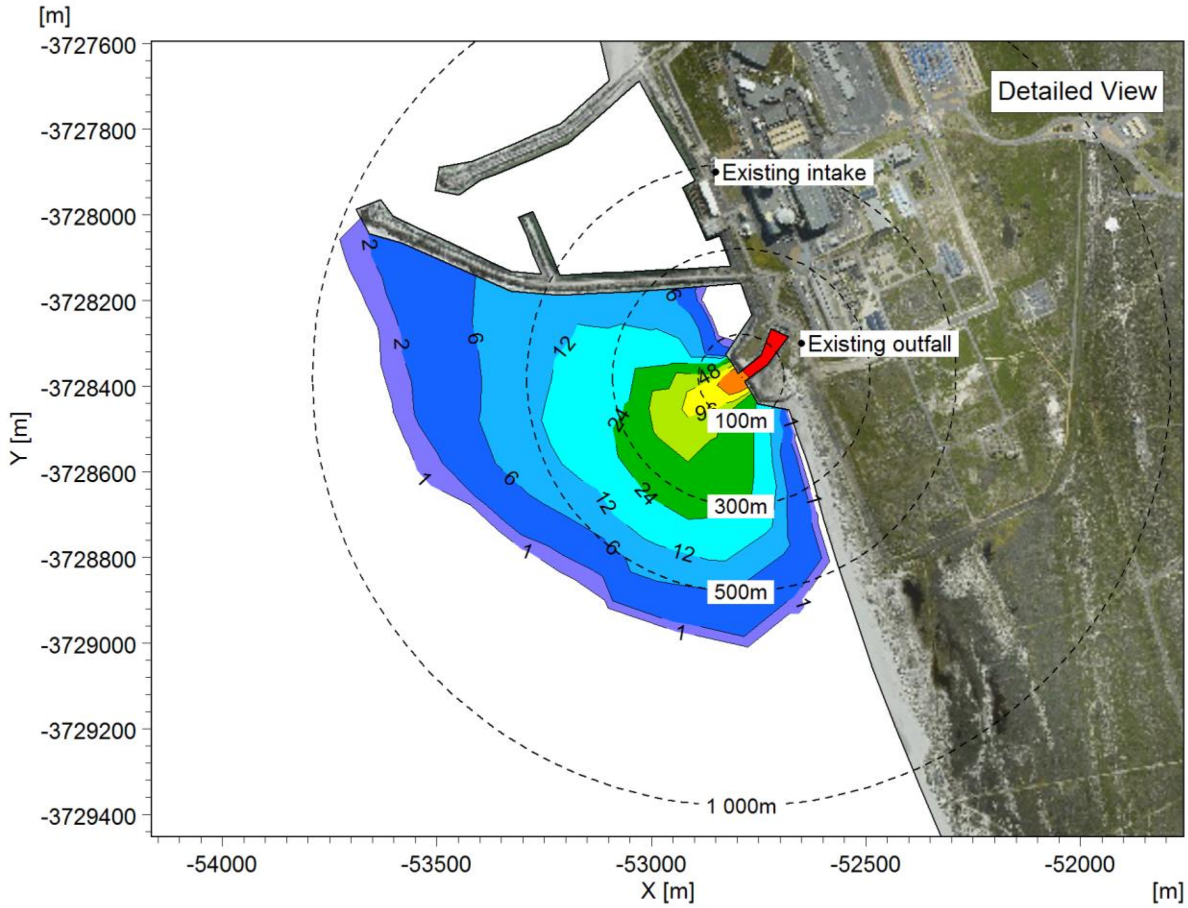


Figure A-21: Duration that the chronic threshold of 25°C is exceeded near the surface: Case 4 (one unit operational, 50% power).

Models\HD\07\071_03afb.mfm - Result Files\PostProcess\HD_3D_Volume_AbsTemp_Post_25degC_Lay1_hours.png

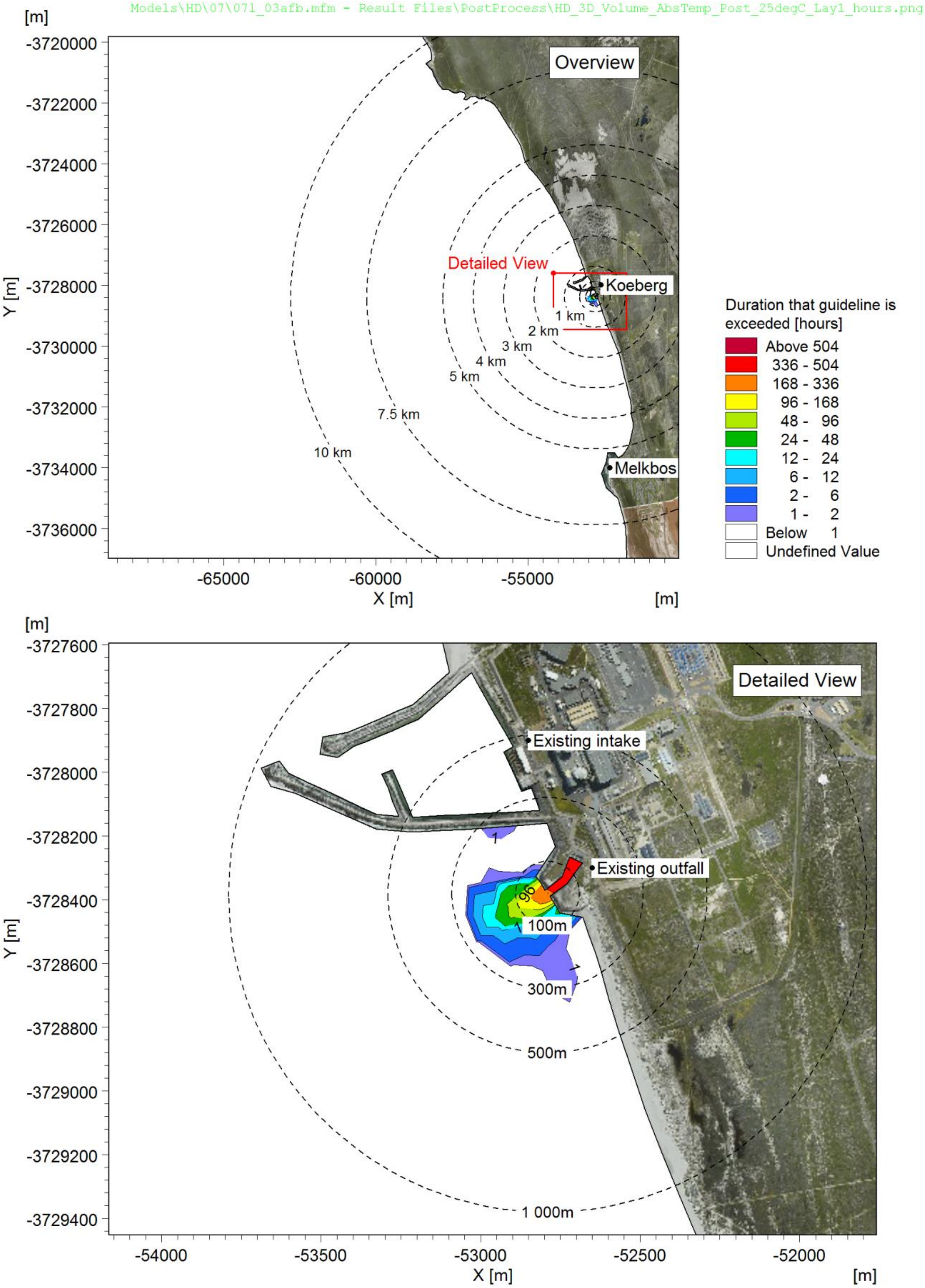
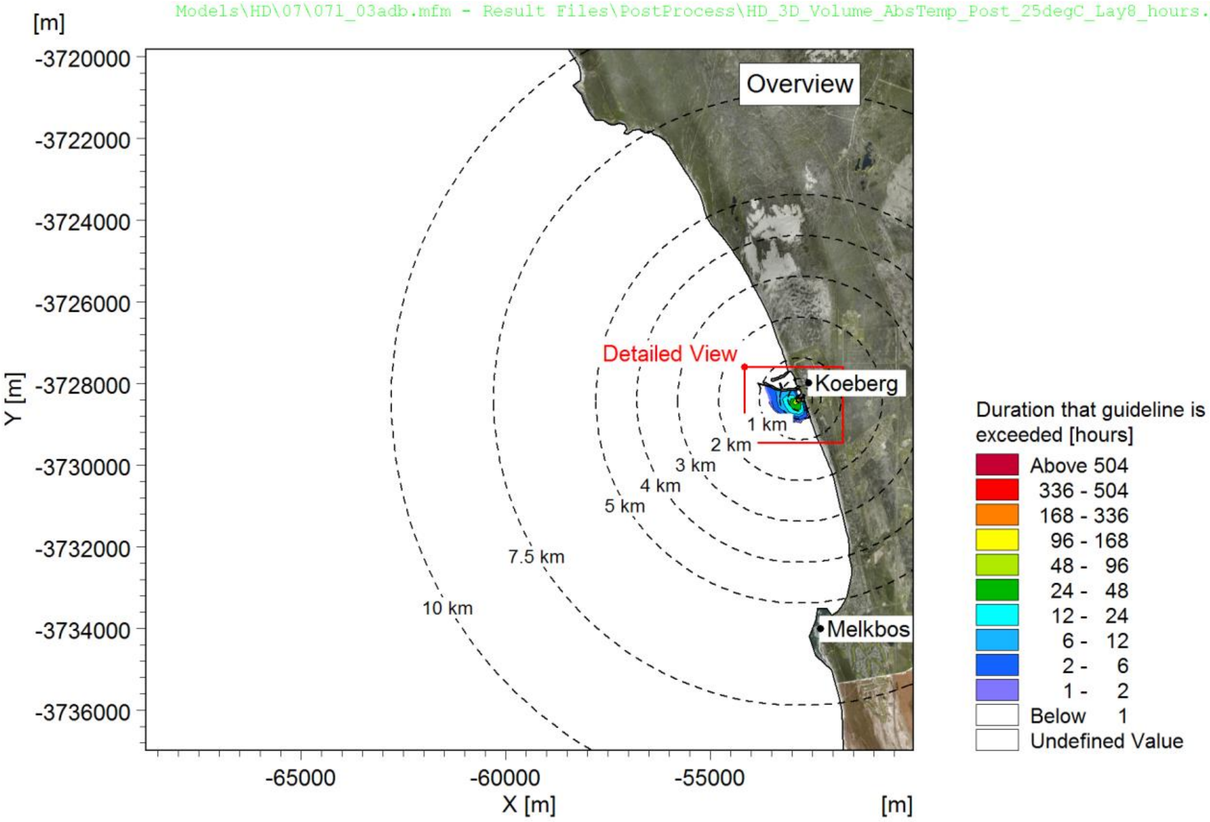


Figure A-22: Duration that the chronic threshold of 25°C is exceeded near the seabed: Case 4 (one unit operational, 50% power).



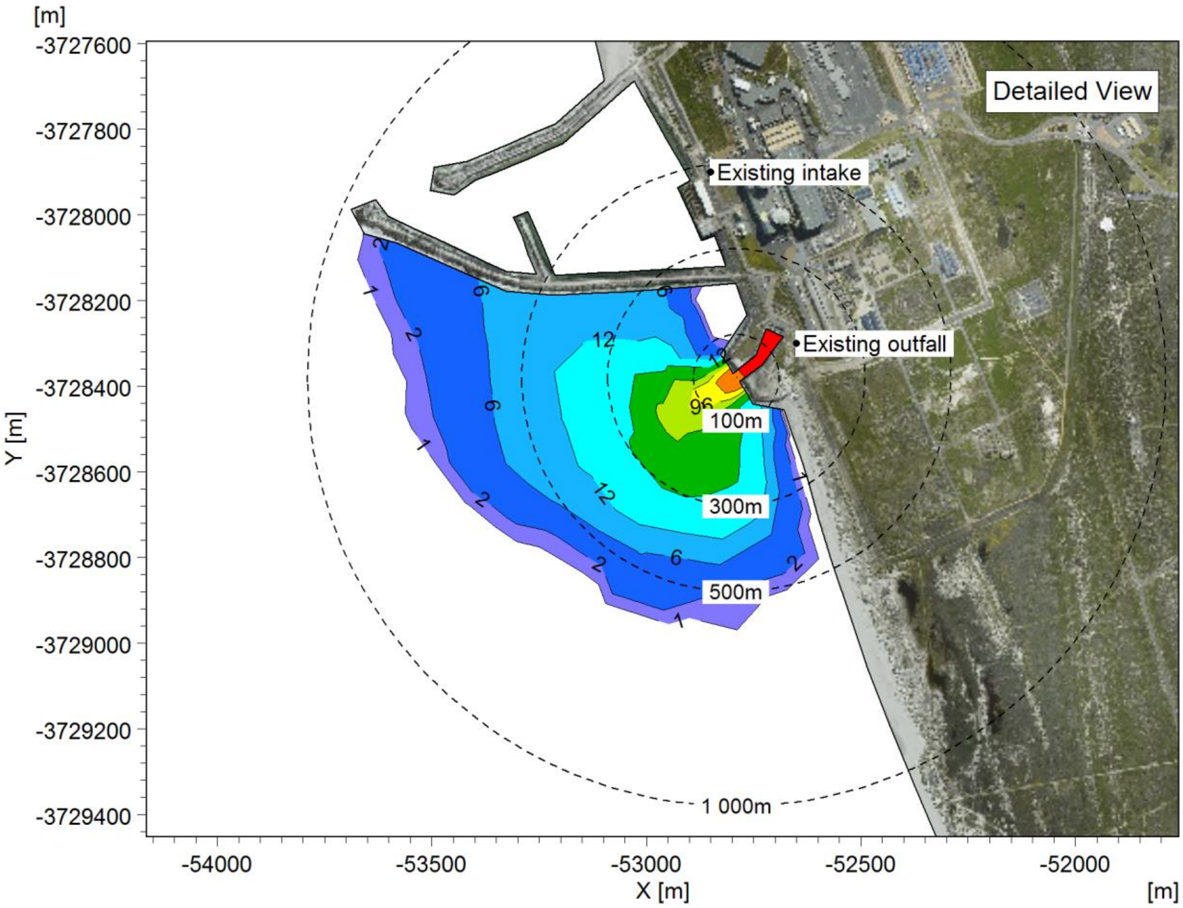


Figure A-23: Duration that the chronic threshold of 25°C is exceeded near the surface: Case 5 (one unit operational, 40% power).

Models\HD\07\071_03adb.mfm - Result Files\PostProcess\HD_3D_Volume_AbsTemp_Post_25degC_Lay1_hours.png

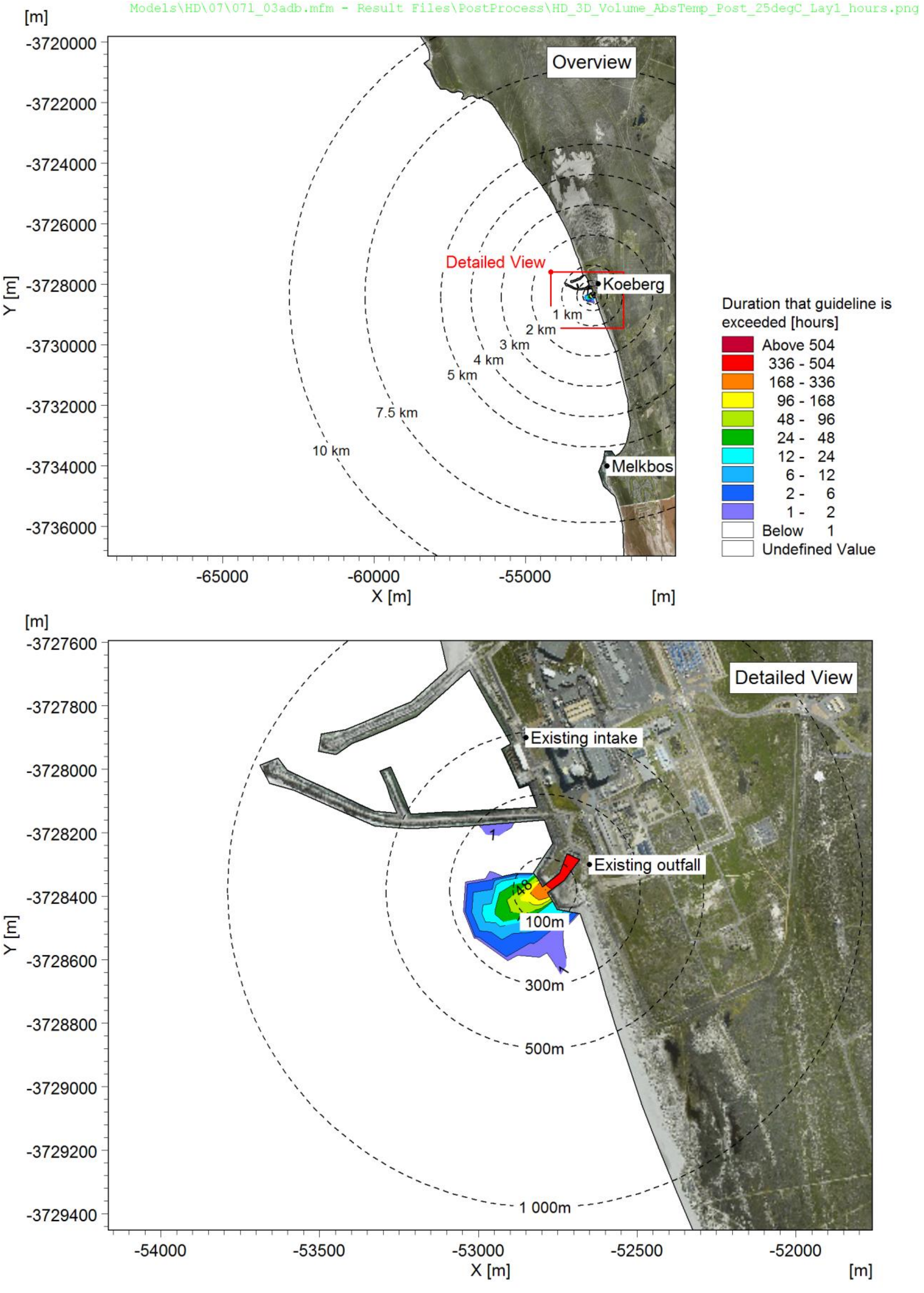


Figure A-24: Duration that the chronic threshold of 25°C is exceeded near the seabed: Case 5 (one unit operational, 40% power).

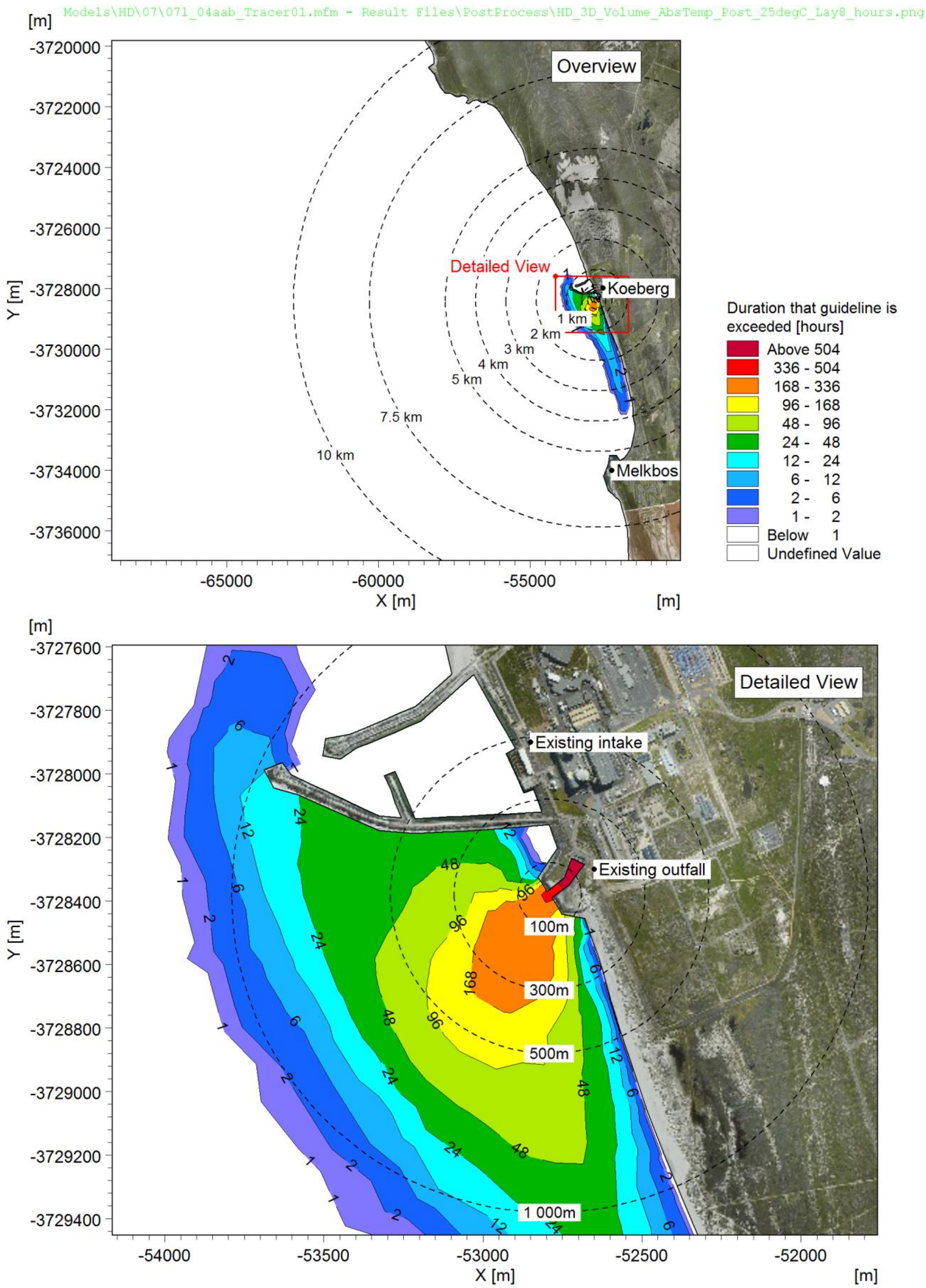


Figure A-25: Duration that the chronic threshold of 25°C is exceeded near the surface: Case 6 (two units operational, 100% power).

Models\HD\07\071_04aab_Tracer01.mfm - Result Files\PostProcess\HD_3D_Volume_AbsTemp_Post_25degC_Lay1_hours.png

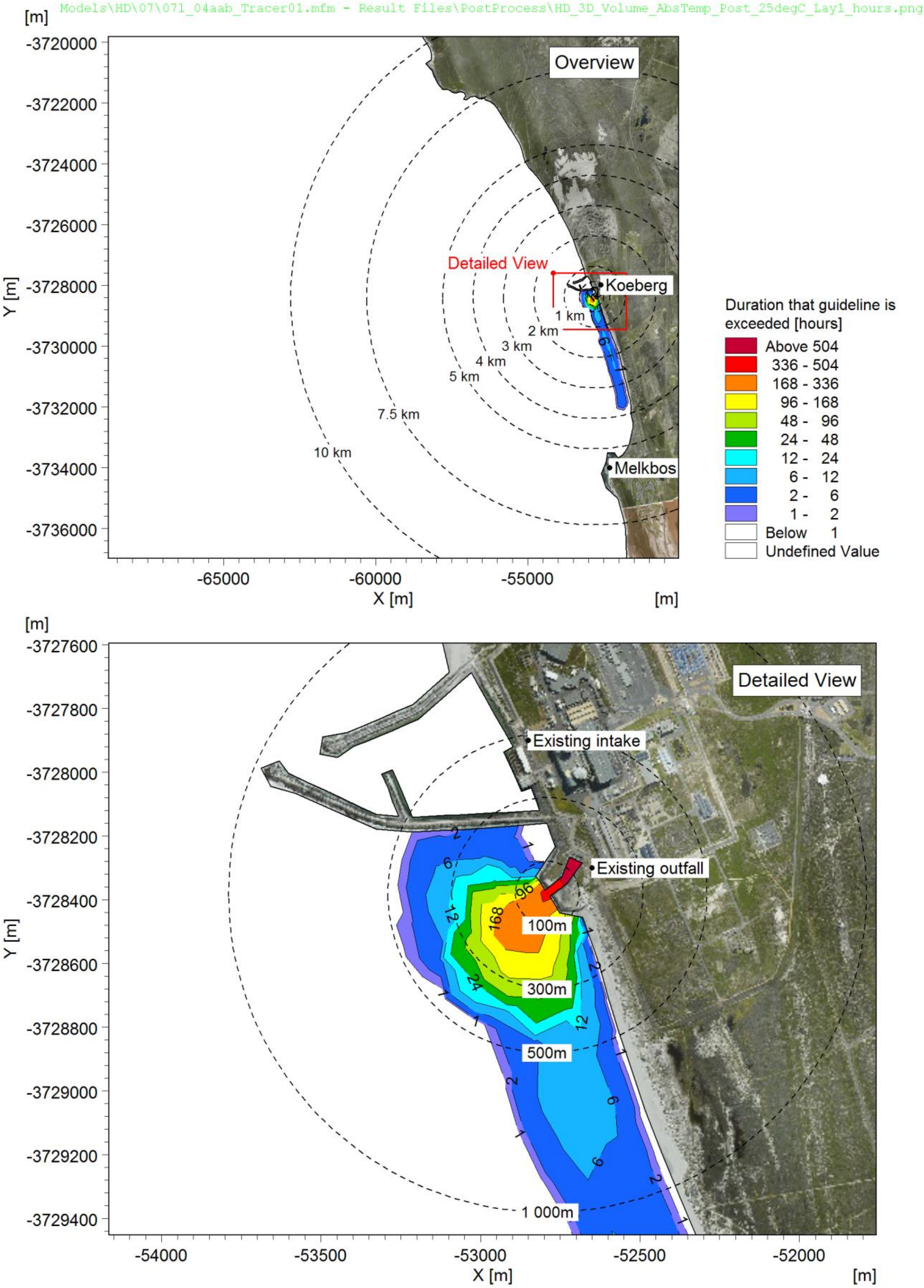


Figure A-26: Duration that the chronic threshold of 25°C is exceeded near the seabed: Case 6 (two units operational, 100% power).

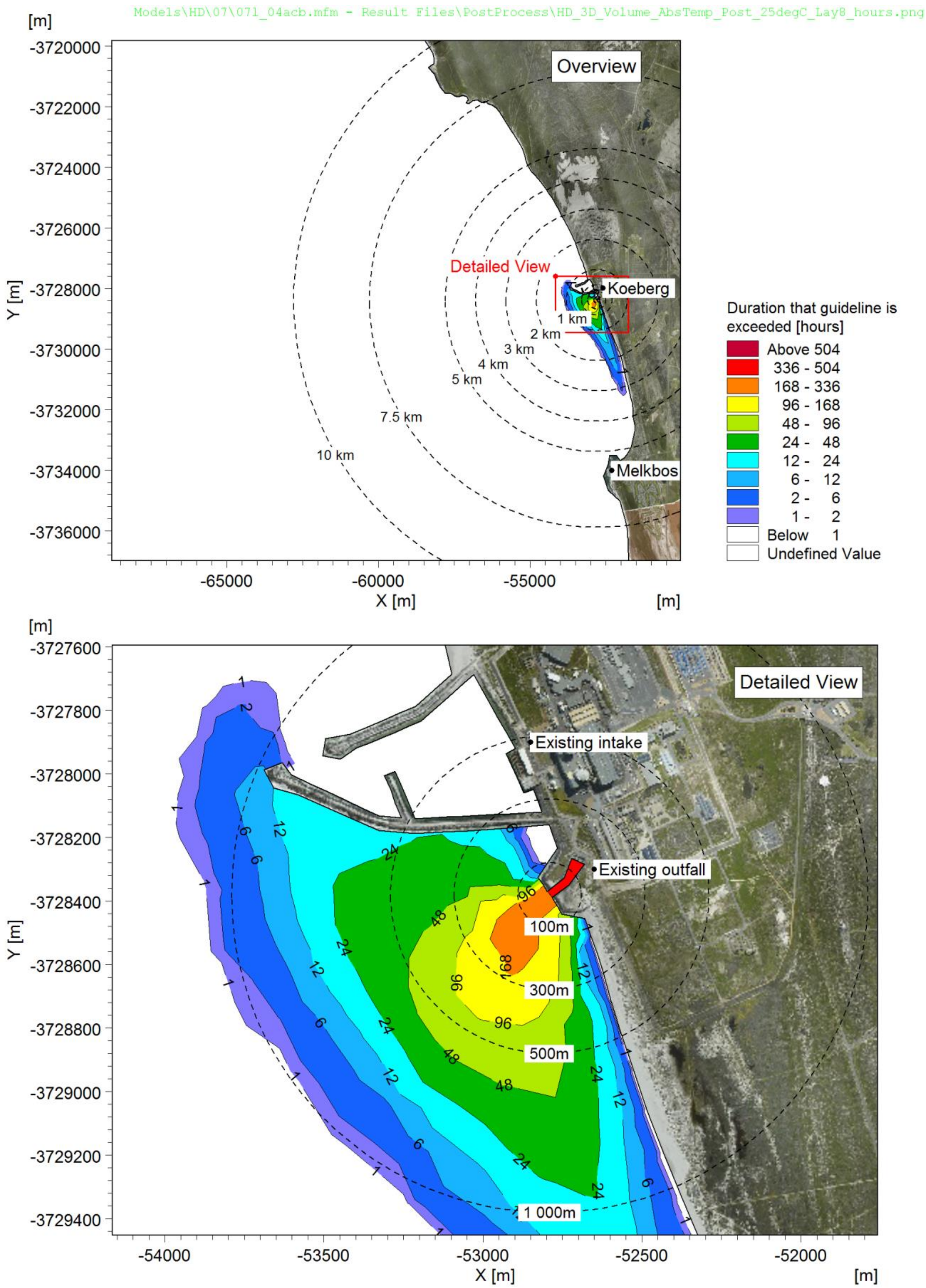


Figure A-27: Duration that the chronic threshold of 25°C is exceeded near the surface: Case 7 (two units operational, 70% power).

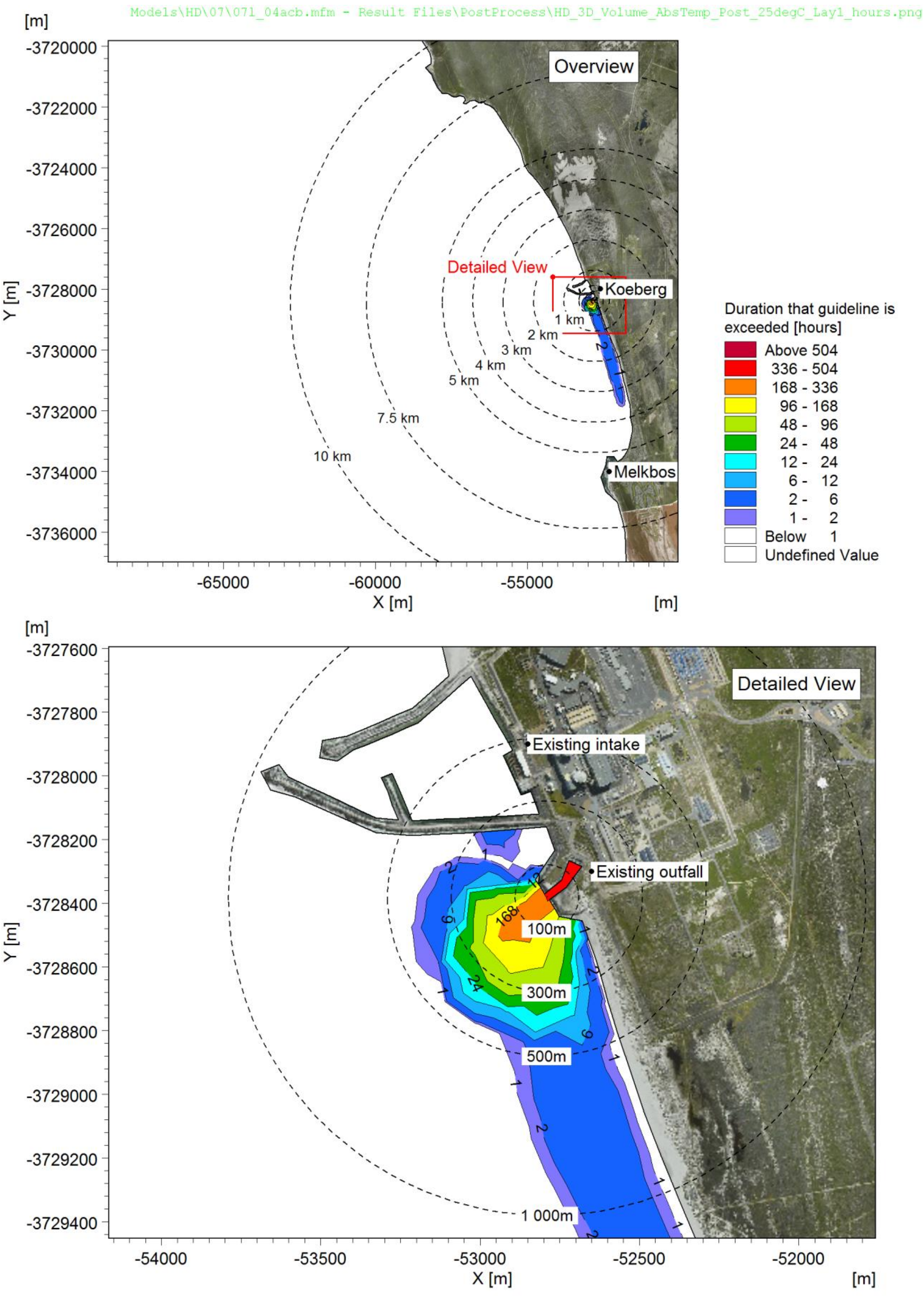


Figure A-28: Duration that the chronic threshold of 25°C is exceeded near the seabed: Case 7 (two units operational, 70% power).

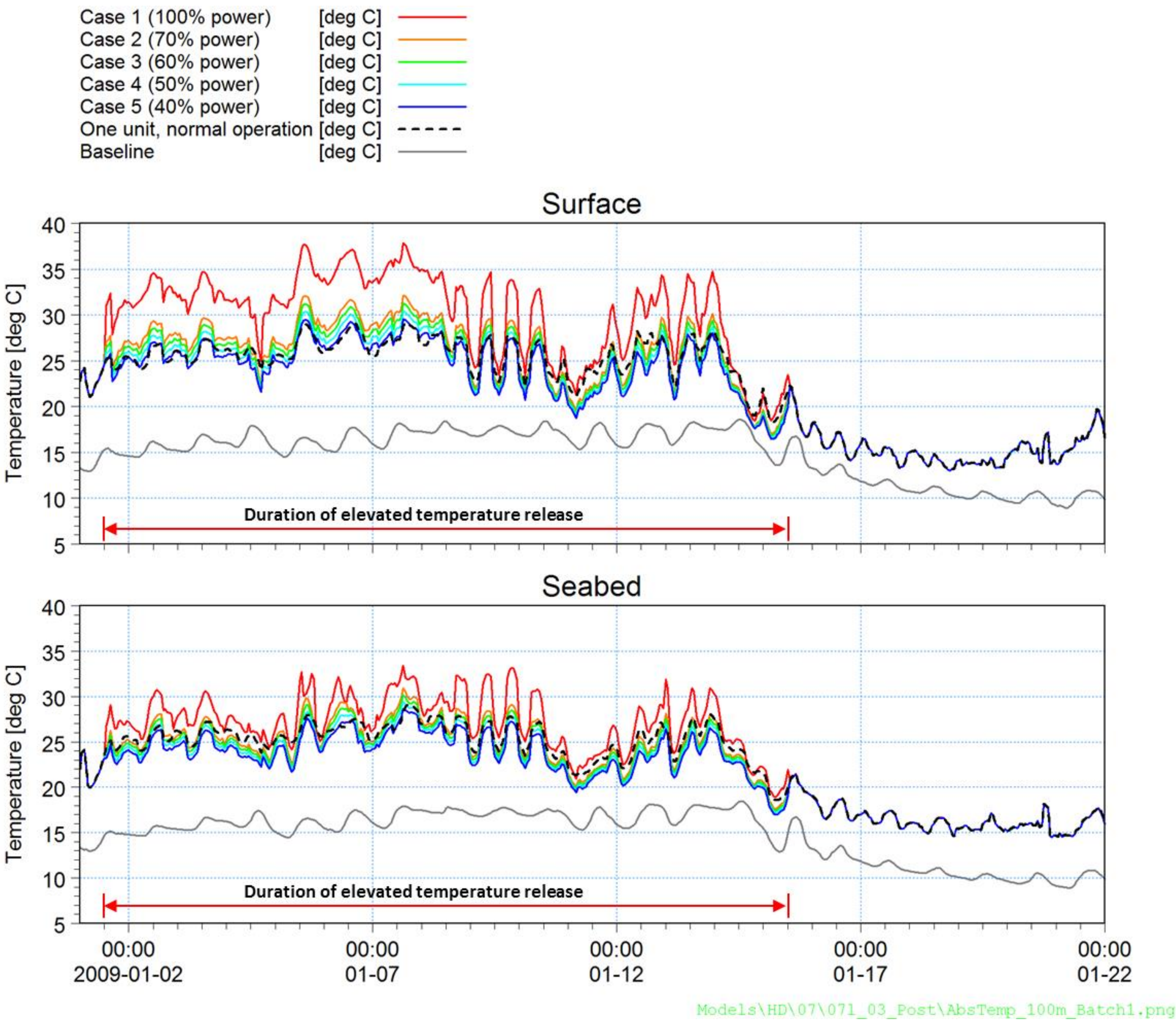


Figure A-29: Time series of absolute temperature at 100 m from the discharge. Cases 1 to 5, surface and seabed. Time series location shown in Figure 4-1.

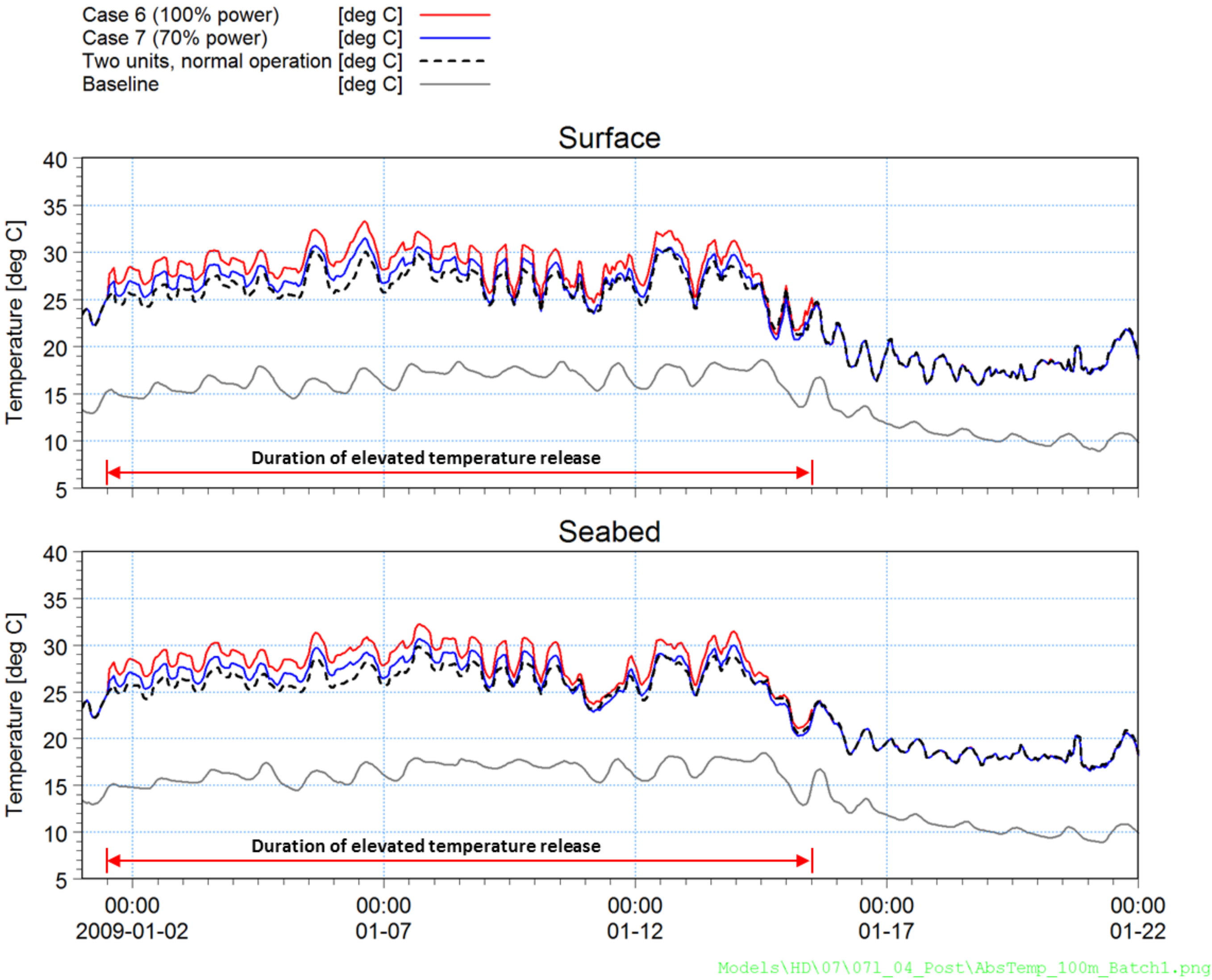


Figure A-30: Time series of absolute temperature at 100 m from the discharge. Cases 6 to 7, surface and seabed. Time series location shown in Figure 4-1.

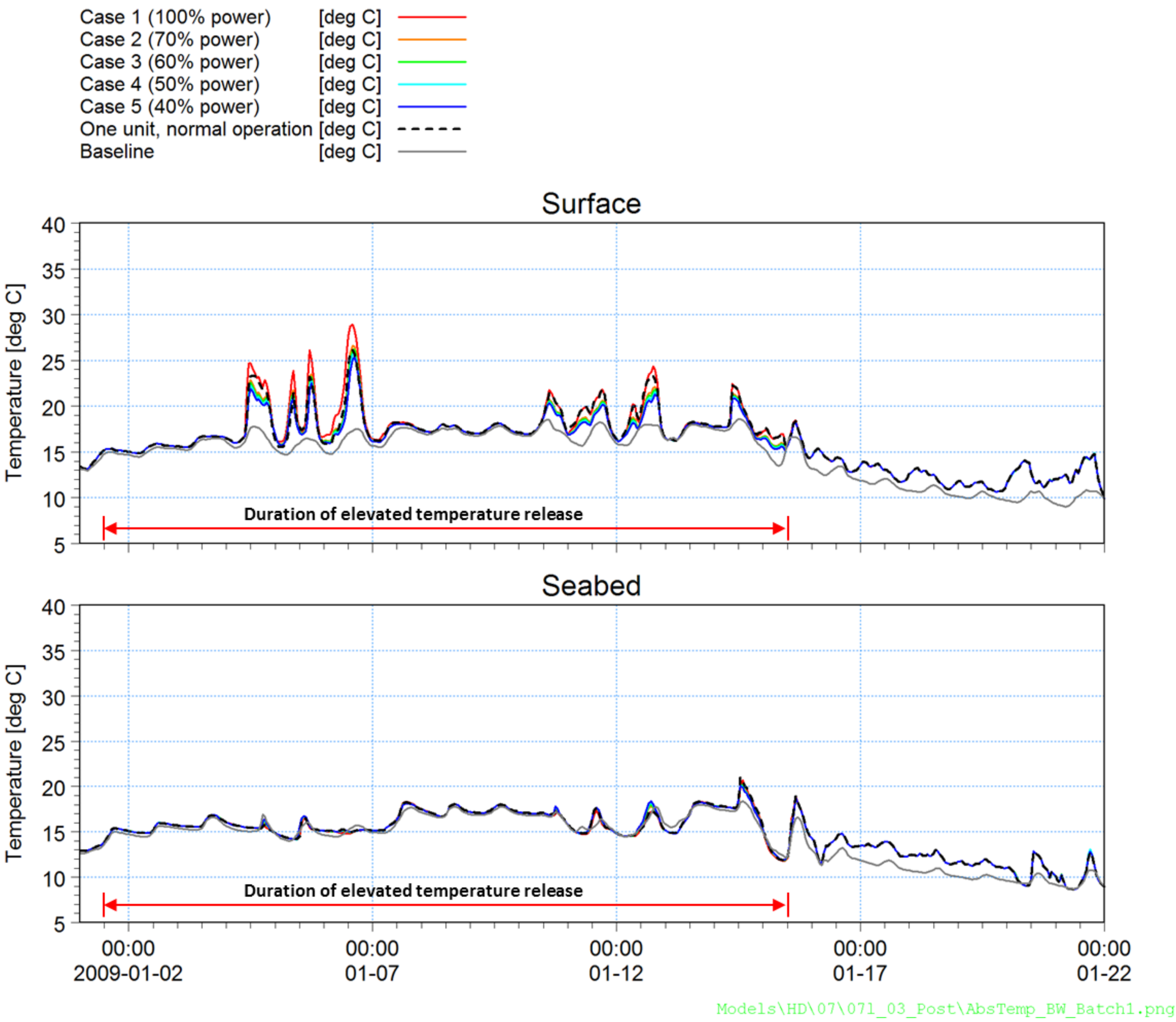


Figure A-31: Time series of absolute temperature at the breakwater output location. Cases 1 to 5, surface and seabed. Time series location shown in Figure 4-1.

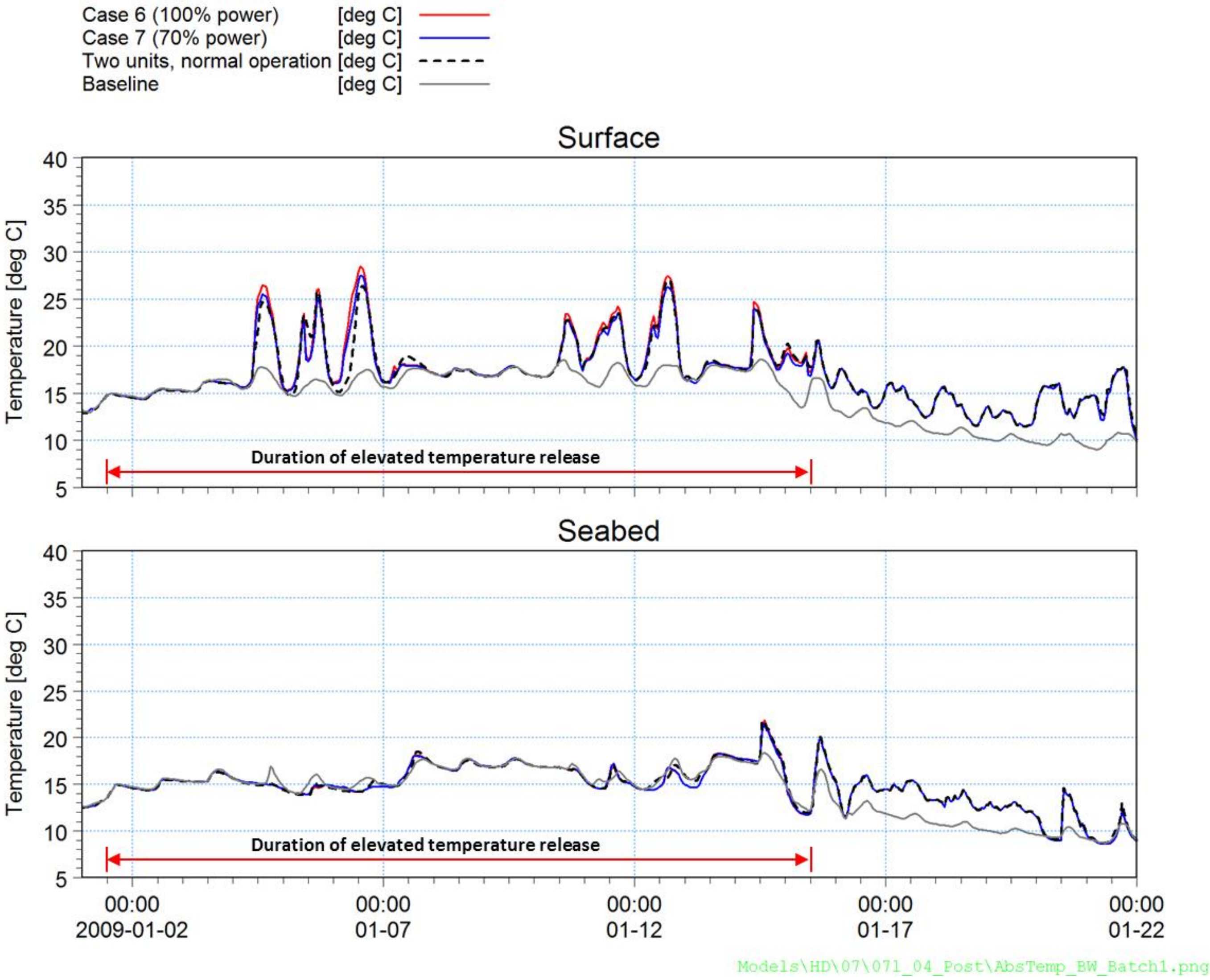


Figure A-32: Time series of absolute temperature at the breakwater output location. Cases 6 to 7, surface and seabed. Time series location shown in Figure 4-1.

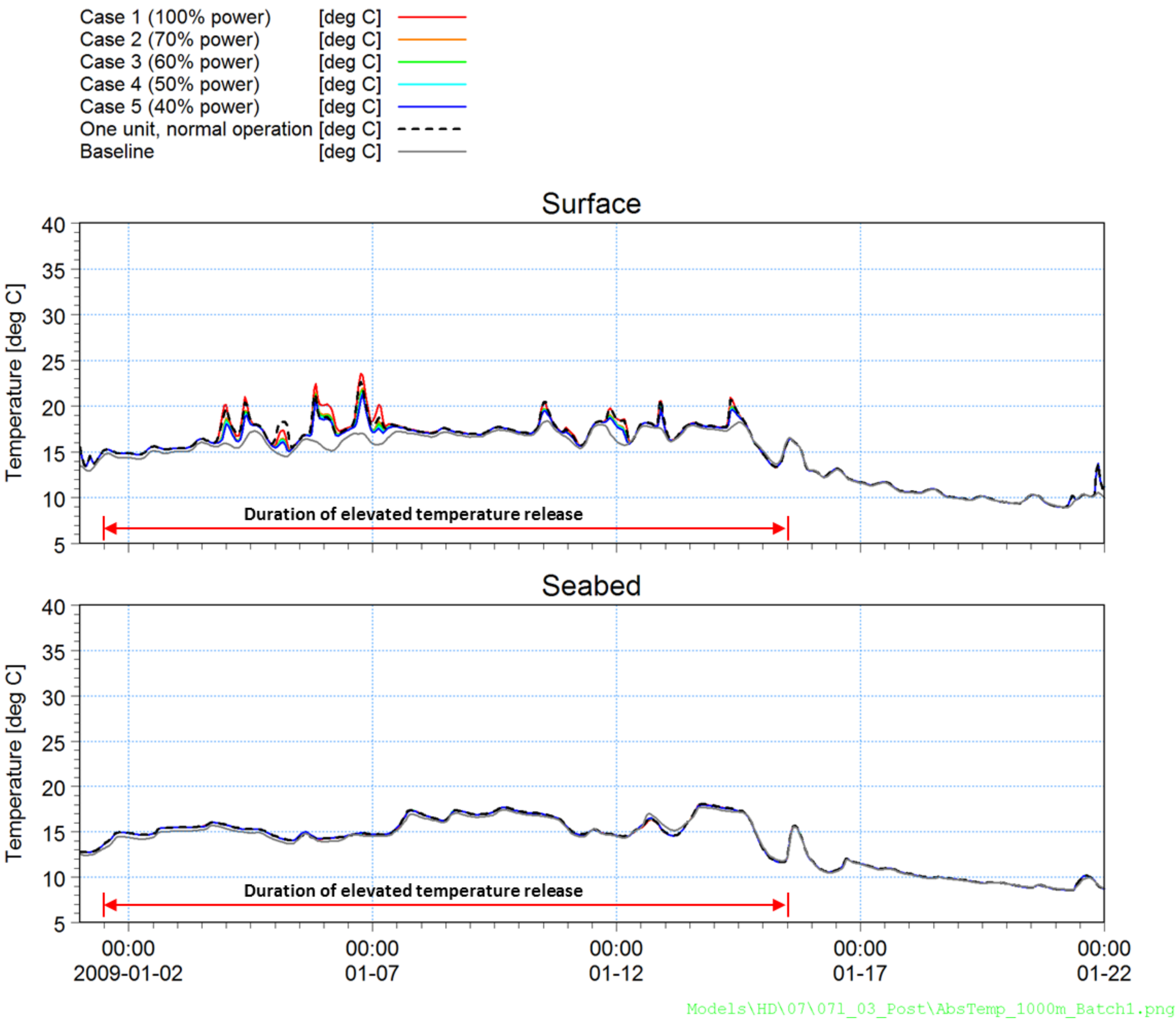


Figure A-33: Time series of absolute temperature at 1000 m from the discharge. Cases 1 to 5, surface and seabed. Time series location shown in Figure 4-1.

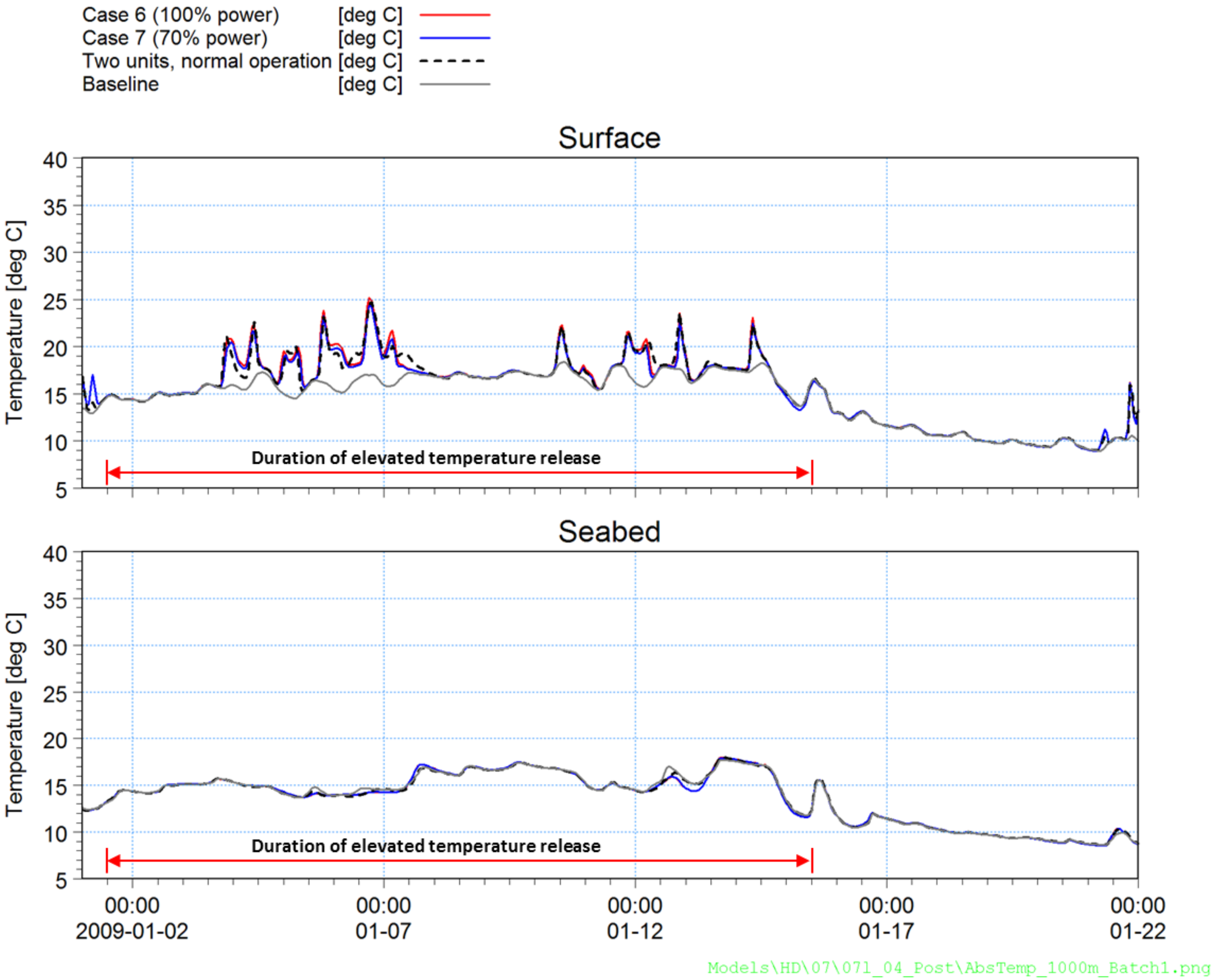


Figure A-34: Time series of absolute temperature at 1000 m from the discharge. Cases 6 to 7, surface and seabed. Time series location shown in Figure 4-1.