

## Evaluation climate projections sea water temperature at Dutch coast



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# Contents

	<b>Contents</b>	<b>4</b>
	<b>List of Figures</b>	<b>5</b>
	<b>List of Tables</b>	<b>7</b>
<b>1</b>	<b>Introduction</b>	<b>8</b>
<b>2</b>	<b>Analysis of observed and projected seawater temperature</b>	<b>9</b>
2.1	Approach	9
2.2	Observed seawater temperature	9
2.3	Projected seawater temperatures	11
2.4	Data comparisons and corrections	12
2.5	Results showing the climate projections	14
<b>3</b>	<b>Assessment of uncertainty</b>	<b>19</b>
3.1	Overview	19
3.2	Model uncertainty	19
3.3	Uncertainty due to natural variability	22
<b>4</b>	<b>Conclusions and recommendations</b>	<b>23</b>
<b>5</b>	<b>Acknowledgements</b>	<b>24</b>
	<b>List of references</b>	<b>25</b>

# List of Figures

Figure 2.1	Rijkswaterstaat measurement locations (source figures: waterinfo.rws.nl).	10
Figure 2.2	Rijkswaterstaat seawater temperature measurements at the considered four stations from 2017 to 2025 with 10-minutes resolutions.	11
Figure 2.3	NorthSea-KNMI seawater temperature data locations.	12
Figure 2.4	Time series of both measured and modelled (all 16 ensembles for scenario SSP245) seawater temperature at Terneuzen. The thick black and blue lines indicate the mean of the respectively measured and projected summer months.	13
Figure 2.5	Time series of both measured and modelled (all 16 ensembles for scenario SSP245) seawater temperatures at Terneuzen, the latter corrected by adding 1°C. The thick black and blue lines indicate the mean of the respectively measured and projected seawater temperature in the summer months. The box-plots (boxes, line and blue and red pluses) of the modelled data are also given.	13
Figure 2.6	Time series of both measured and projected mean summer seawater temperature at Terneuzen for climate scenario SSP245, the latter corrected by adding 1°C. The ensemble projections are indicated as so-called boxplots, with each box representing the 25th to the 75th percentile. The dashed vertical lines extend to the smallest and largest values within 1.5 times the quartiles. The red markers above and below are individual outliers. The bold lines indicate the mean of the summer month ensembles.	14
Figure 2.7	Time series of both measured and projected mean summer seawater temperature at Terneuzen for climate scenario SSP585, the latter corrected by adding 1°C based on the comparison with measurements. The ensemble projections are indicated as so-called boxplots, with each box representing the 25th to the 75th percentile. The dashed vertical lines extend to the smallest and largest values within 1.5 times the quartiles. The red markers above and below are individual outliers. The bold lines indicate the mean of the summer month ensembles.	15
Figure 2.8	Time series of both measured and projected mean summer seawater temperature at Vlissingen for climate scenario SSP585, the latter corrected by adding 1°C based on the comparison with measurements. The ensemble projections are indicated as so-called boxplots, with each box representing the 25th to the 75th percentile. The dashed vertical lines extend to the smallest and largest values within 1.5 times the quartiles. The red markers above and below are individual outliers. The bold lines indicate the mean of the summer month ensembles.	15
Figure 2.9	Monthly box-plots of projected sea surface temperature (SST) at Terneuzen for climate scenario SSP585 (top panel) and SSP245 (lower panel). The ensemble projections are corrected by adding 1°C based on the comparison with measurements. Each box represents the 25th to the 75th percentile. The whiskers indicate the range between the minimum and maximum values.	16
Figure 2.10	Monthly box-plots of projected sea surface temperature (SST) at Vlissingen for climate scenario SSP585 (top panel) and SSP245 (lower panel). The ensemble projections are corrected by adding 1°C based on the comparison with measurements. Each box	

represents the 25th to the 75th percentile. The whiskers indicate the range between the minimum and maximum values. 16

Figure 2.11 Monthly box-plots of projected sea surface temperature (SST) at Hoek van Holland for climate scenario SSP585 (top panel) and SSP245 (lower panel). Each box represents the 25th to the 75th percentile. The whiskers indicate the range between the minimum and maximum values. 17

Figure 2.12 Monthly box-plots of projected sea surface temperature (SST) at Terneuzen for climate scenario SSP585 (top panel) and SSP245 (lower panel). The ensemble projections are corrected by adding 1°C based on the comparison with measurements. Each box represents the 25th to the 75th percentile. The whiskers indicate the range between the minimum and maximum values. 17

Figure 2.13 Monthly seawater temperature increase relative to 2020 for climate scenarios SSP245 and SSP585 and for all four locations based on the corrected (except Vlissingen) Northsea-KNMI projections. 18

Figure 3.1 Projected monthly-average seawater temperature from various climate models for Terneuzen, indicating a model uncertainty in the order of +/- 1.5°C. The models with continuous lines indicate models with spatial resolution of less than 50 km and the dashed lines indicate models with about 100 km. 21

Figure 3.2 Time-series of Northsea-KNMI ensemble projections and measurements at Terneuzen between 2020 and 2023, indicating a natural variability (i.e. range of the ensembles) in the order of +/- 4°C. 22

# List of Tables

Table 2.1	Considered Rijkswaterstaat seawater temperature measurements.	10
Table 3.1	Overview of applied global and regional climate models	21

# 1 Introduction

The Dutch government is considering developing an additional nuclear power plant in the Netherlands and has selected nine potential sites across four locations: Sloegebied (Borssele), Terneuzen, Maasvlakte II and Eemshaven. Over the past years, Deltares has conducted several studies for the Ministry of Economic Affairs and Climate (EZK). The primary objective of these studies was to assess the availability and capacity of cooling water at the selected plant locations under current environmental conditions. Each location presents unique geographical and environmental characteristics that could influence the operational performance of the plant, particularly with respect to cooling water availability. In line with regulatory guidelines, the modelling focused on comparing temperature increases from discharged cooling water against a uniform ambient water temperature. This will provide initial technical information to possible vendors which need to carry out their own technical studies towards an initial design of such a plant. In the long term, the studies will serve as input for the permit application for the abstraction and discharge of cooling water to the competent authority, in this case Rijkswaterstaat.

For the locations in Borssele cooling water availability and a first summary of known regulations has been published (Deltares, 2024). In these studies, it is stated that there is no regulatory framework that takes climate change into account. However, it is possible and recommended to assess whether the intended discharges will still comply with current regulations in a relevant future reference year. Despite the uncertainties, a first assessment of climate projections is presented in (Deltares, 2024). Based on these studies, EZK requested Deltares to provide insights into expected seawater temperature increases at the selected plant locations based on the latest climate projections, and to quantify the associated uncertainties. This study aims to analyse this topic.

The key findings of this assessment are that:

- under SSP245, exceedance of the 25°C cooling water limit during the summer months July and August is rare and is only expected to occur occasionally at the end of this century.
- under SSP585, persistent exceedance of 25°C during the summer months July and August is projected for all locations by 2100, with Terneuzen surpassing this threshold from 2080 onwards.

Given that the model uncertainties fall within the uncertainty due to natural variability, the projections given in this report should be considered with an uncertainty of  $\pm 4^{\circ}\text{C}$ , which corresponds to a standard deviation of approximately  $2^{\circ}\text{C}$ .

This report briefly presents the approach, results and findings regarding the observed and projected seawater temperatures (Chapter 2) and its uncertainties (Chapter 3) at the considered plant locations, wrapping up with concluding remarks and recommendation (Chapter 4).

The findings of this study can be used as input of the cooling water studies, in order to assess the operational performance of the nuclear power plant over its expected lifetime. The results can be used as context for the feasibility of discharge permits, as part of the technical feasibility phase. As there is no regulatory framework available that takes climate change into account, using the results of this report does not guarantee permits or acceptance of the developments.

## 2 Analysis of observed and projected seawater temperature

### 2.1 Approach

To assess the current climate and projected seawater temperature at the four considered plant locations, the following steps were taken:

1. Collect available seawater temperature records for 2015 – 2024 from Rijkswaterstaat to enable comparisons with climate model projections over the same years (Section 2.2).
2. Retrieve projected daily seawater temperature time-series for 2015 – 2100 from a climate model simulation that were used by the Royal Dutch Meteorological Institute (KNMI) to support their climate scenarios (KNMI, 2024). The considered model results are referred to as the *NorthSea-KNMI* data and consist of daily mean seawater temperatures from runs with 16 ensemble members for current climate and the available future climate scenarios (*Shared Socioeconomic Pathways, SSP*) SSP245 and SSP585 (Section 2.3).
3. Determination of daily mean, 95% percentile (q95) and maxima of observed and projected seawater temperatures during the summer months (July & August, noting that these months are most critical for the nuclear power plant's operational efficiency), and validation of the model data statistics against the observations (Section 2.4).
4. Bias correction of the model projections based on the comparisons with the current climate observations (Section 2.4).
5. Determination of the ensemble mean summer sea surface temperature projections and monthly trends for the time horizons of 2050 and 2100 (Section 2.5).
6. Determine the projected summer temperature changes and internal climate variability on the basis of the bias-corrected NorthSea-KNMI data. In order to assess the model uncertainty, seawater temperature projections from climate models, other than the one used by KNMI, have also been considered (Section 3.3).

Climate scenarios SSP245 and SSP558 refer to the scenarios developed by the IPCC (Intergovernmental Panel on Climate Change) to assess climate impacts, adaptation, and mitigation strategies under different socio-economic pathways (IPCC, 2021):

- SSP245 assumes moderate global development and climate action, leading to intermediate emissions and about 2.7–3°C warming by 2100. It reflects a world with partial sustainability efforts and continued fossil fuel use.
- SSP585 represents a high-emissions pathway with minimal climate mitigation, driven by fossil-fuelled growth. It projects >4°C warming by 2100, making it a worst-case scenario for climate impacts.

Note that the presented analyses in this report rely on daily and monthly average temperatures. There are daily variations of the seawater temperature, especially at the surface. These are, however, not considered to significantly affect the results of this study.

### 2.2 Observed seawater temperature

Digital time-series of seawater temperature measurements from Rijkswaterstaat for the past 10 years (Figure 2.2) were collected from [waterinfo.rws.nl](https://waterinfo.rws.nl) for the stations indicated in Figure 2.1 and listed in Table 2.1. The measurements are assumed to be representative for the seawater temperature at the considered plant locations. This is considered a valid assumption given the relative short distance between the measurement and the anticipated plant locations (< 10 km).

Table 2.1 Considered Rijkswaterstaat seawater temperature measurements.

Station name	Lat. – Lon. coordinates	Nearest considered plant location	Collected years	Time increments	Missing data
EEMSHVMPL	53° 28' 27" N 6° 49' 18" E	Eemshaven	2017 – 2024	10 minutes	8.2%
HOEKVHLD	51° 58' 34" N 4° 07' 22" E	Rotterdam – Maasvlakte II	2015 – 2024	1 hour (2015) 10 min. (2016 >)	4.2%
VLISSGN	51° 26' 15" N 3° 36' 7" E	Borssele – Sloehaven	2015 – 2024	1 hour (2015) 10 min. (2016 >)	0.8%
TERNZWSZDE	51° 20' 13" N 3° 48' 37" E	Terneuzen – Paulinapolder	2015 – 2024	10 minutes	4.8%

The collected seawater temperature measurements were used to compare and where necessary correct the NorthSea-KNMI temperature projections for the considered plant locations, as presented in the next section.



Figure 2.1 Rijkswaterstaat measurement locations (source figures: waterinfo.rws.nl).

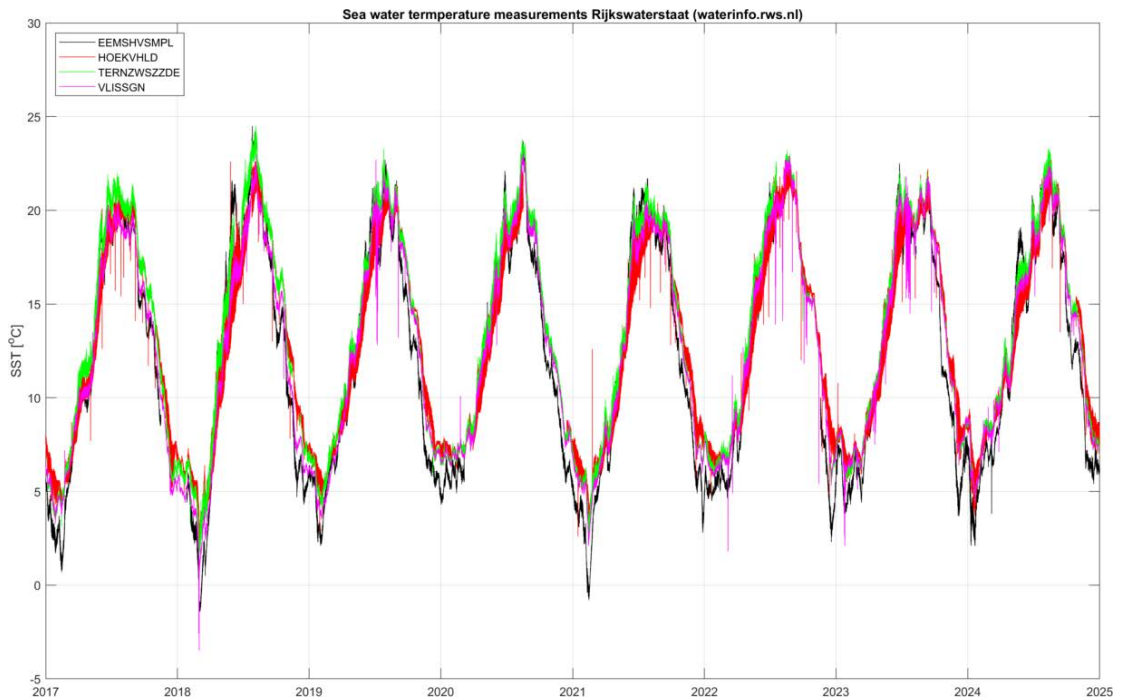


Figure 2.2 Rijkswaterstaat seawater temperature measurements at the considered four stations from 2017 to 2025 with 10-minutes resolutions.

## 2.3 Projected seawater temperatures

Daily-mean seawater temperature projections (16 ensemble members) for 2015 – 2100 were provided by the Royal Netherlands Meteorological Institute (KNMI) at the locations indicated in Figure 2.3. The seawater temperature projections originate from the EC-Earth3<sup>1</sup> global climate model and were used by KNMI as basis in their assessment of the *National Climate Scenarios 2023*<sup>2</sup>. According to KNMI (2024), the EC-Earth3 model has been retuned with the aim of reducing an observed negative temperature bias over large parts of the Northern Hemisphere, including Europe. The EC-Earth model has a spatial resolution of about 100 km. As such, the data does not fully represent the estuaries in which three of the four considered plant locations are located. The daily-mean seawater temperature projections from KNMI will be further referred to as the *NorthSea-KNMI* dataset in this report. Seawater temperature projections were also collected from other climate models to assess model uncertainty. These are presented and discussed in Section 3.2.

<sup>1</sup> [EC-Earth — SMHI](#): EC-Earth is a global climate model system, developed by the European EC-Earth consortium with SMHI as core partner. The model in its different configurations and resolutions is used for climate change projections, predictions and process studies. EC-Earth3, the current version, is prepared for the 6<sup>th</sup> phase of the Climate Model Intercomparison Project CMIP6.

<sup>2</sup> The KNMI'23 National Climate Scenarios ([KNMI'23-klimaatscenario's](#)) provide a scientifically grounded framework for anticipating the impacts of climate change in the Netherlands. Developed by the Royal Netherlands Meteorological Institute (KNMI), these scenarios translate global climate projections from the IPCC into specific insights for The Netherlands, helping policymakers, planners, and researchers prepare for future conditions.

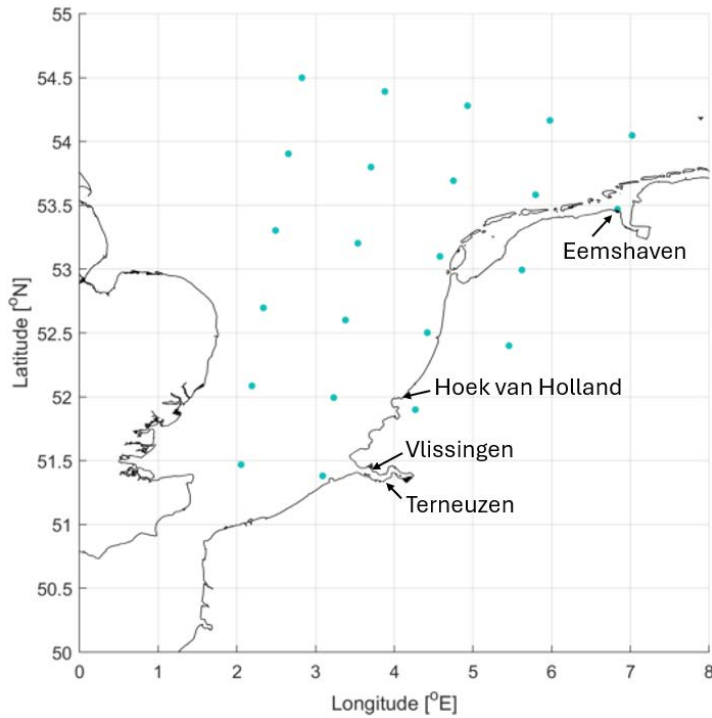


Figure 2.3 NorthSea-KNMI seawater temperature data locations.

## 2.4 Data comparisons and corrections

In this section, the results are presented of the comparisons between measured and current climate model seawater temperatures. As according to the governing CIW guidelines (Rijkswaterstaat, 2004) the average temperature of the water body may not exceed 25 °C, focus of the analyses is first on the summer months. At the end of the section the (bias-corrected) projected seawater temperature at the four locations for all months are given.

Figure 2.4 presents time-series of measured seawater temperature at Terneuzen (refer to Section 2.2) as well as the current climate and projected 16 ensemble members from NorthSea-KNMI for an available data location closest to Terneuzen (N51.4°, E3.1°). The thick black and blue lines represent the mean of the respective measured and modelled temperatures for the summer months. The plot shows that the model temperatures are on average 1°C lower than the measurements. This bias may be attributed to the NorthSea-KNMI model, that due to its coarseness is unable to depict local effects at the Terneuzen site.

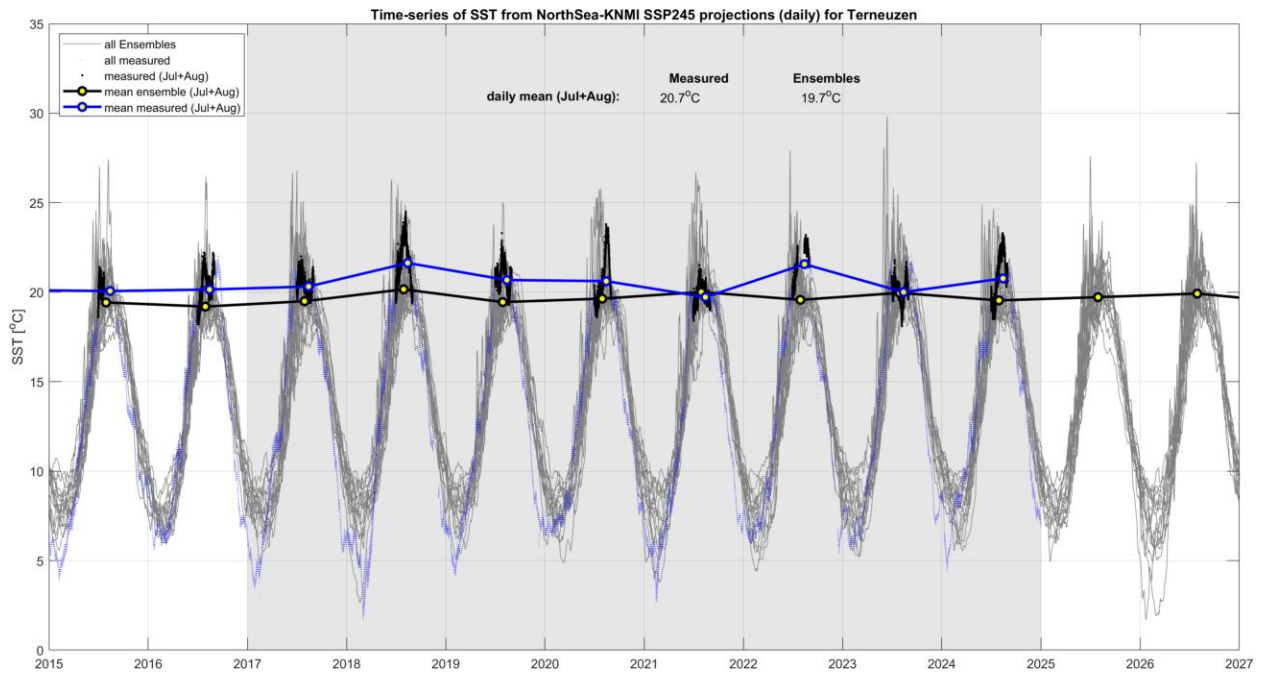


Figure 2.4 Time series of both measured and modelled (all 16 ensembles for scenario SSP245) seawater temperature at Terneuzen. The thick black and blue lines indicate the mean of the respectively measured and projected summer months.

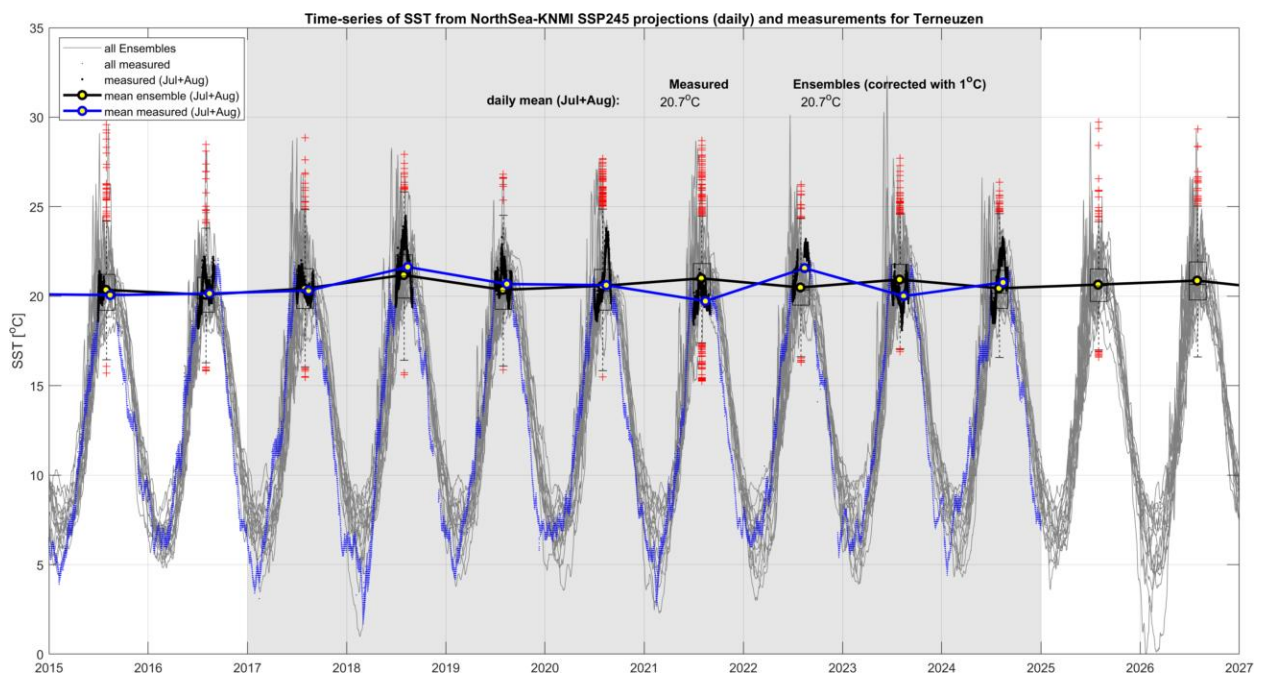


Figure 2.5 Time series of both measured and modelled (all 16 ensembles for scenario SSP245) seawater temperatures at Terneuzen, the latter corrected by adding 1°C. The thick black and blue lines indicate the mean of the respectively measured and projected seawater temperature in the summer months. The box-plots (boxes, line and blue and red pluses) of the modelled data are also given.

Figure 2.5 presents the same, but then with the projected ensembles being bias corrected with +1°C, resulting in improved agreement with the measurements. Also included in this figure are so called box-plots that represent the distribution of the 16 members of model ensemble. The length of each box represents the middle 50% of the data, from the 25<sup>th</sup> to the 75<sup>th</sup> percentile.

The dashed vertical lines extend to the smallest and largest values within 1.5 times the quartiles. The red markers above and below are individual outliers.

The projected seawater temperature ensembles for Eemshaven were also bias corrected with +1°C and for Hoek van Holland with -0.5°C. The ensembles for Vlissingen were not corrected.

## 2.5 Results showing the climate projections

Figure 2.6 and Figure 2.7 present bias-corrected ensemble timeseries of mean summer seawater temperature at Terneuzen for SSP245 and SSP585, respectively, using boxplots to illustrate distribution and uncertainty across ensemble members. Under SSP585, ensemble mean summer temperatures are projected to exceed 25 °C consistently after approximately 2080, whereas this threshold is not expected to be reached under SSP245.

For Vlissingen, the SSP585 projections, shown in Figure 2.8, indicate a similar pattern, although the persistent exceedance of 25 °C is projected to occur around 2100. Comparable trends are observed for Hoek van Holland and Eemshaven under SSP585 (not shown).

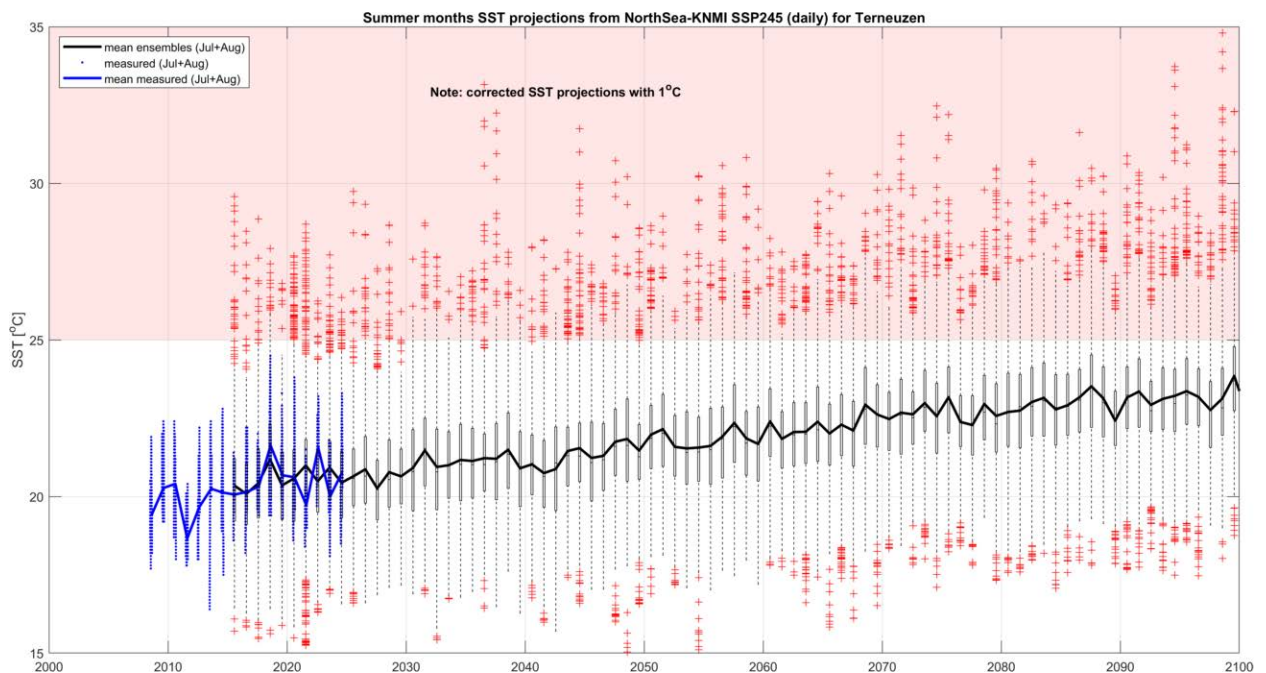


Figure 2.6 Time series of both measured and projected mean summer seawater temperature at Terneuzen for climate scenario SSP245, the latter corrected by adding 1°C. The ensemble projections are indicated as so-called boxplots, with each box representing the 25th to the 75th percentile. The dashed vertical lines extend to the smallest and largest values within 1.5 times the quartiles. The red markers above and below are individual outliers. The bold lines indicate the mean of the summer month ensembles.

Seasonal variability is examined in greater detail in Figure 2.9, which presents monthly boxplots of projected seawater temperatures at Terneuzen for SSP245 and SSP585, based on the bias-corrected ensemble data. This monthly analysis is presented for Vlissingen, Hoek van Holland and Eemshaven in respectively Figure 2.10 to Figure 2.12. These figures indicate that at all four locations the limit of 25 °C is exceeded in 2100 for the SSP585 scenario, while for the SSP245 scenario the seawater temperature stay below the limit. Terneuzen is an exception, there the limit is exceeded for data exceeding the 75th percentile.

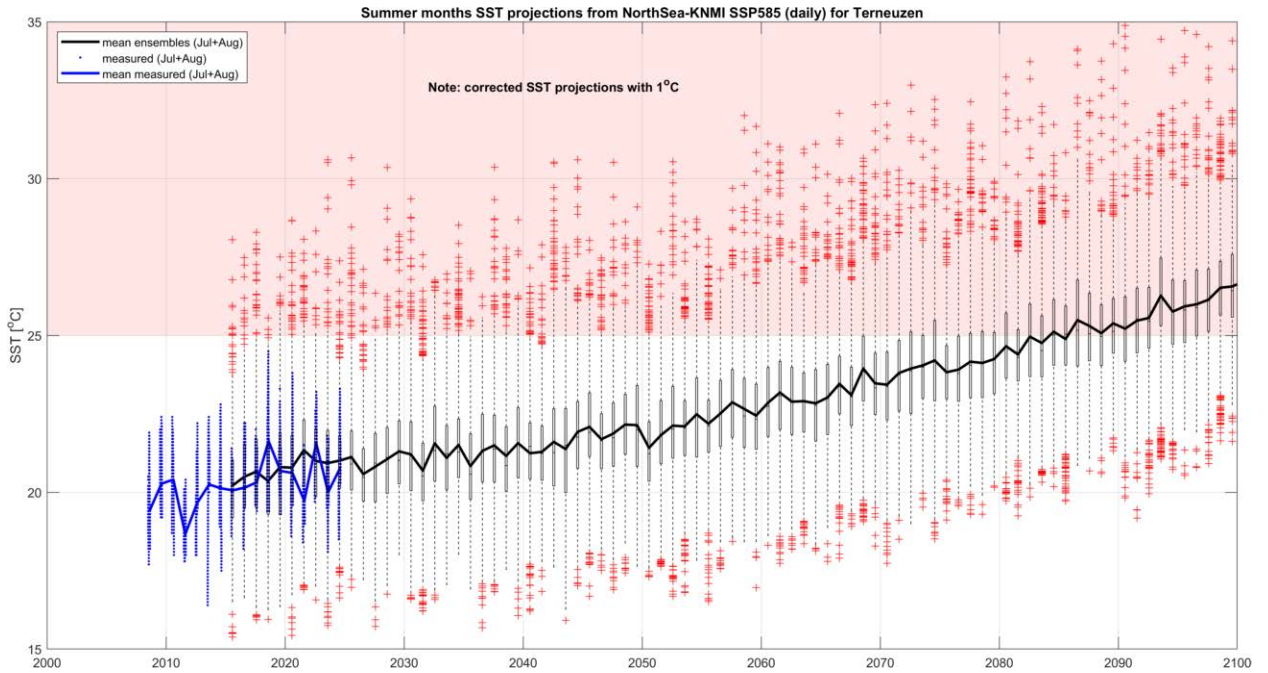


Figure 2.7 Time series of both measured and projected mean summer seawater temperature at Terneuzen for climate scenario SSP585, the latter corrected by adding 1°C based on the comparison with measurements. The ensemble projections are indicated as so-called boxplots, with each box representing the 25th to the 75th percentile. The dashed vertical lines extend to the smallest and largest values within 1.5 times the quartiles. The red markers above and below are individual outliers. The bold lines indicate the mean of the summer month ensembles.

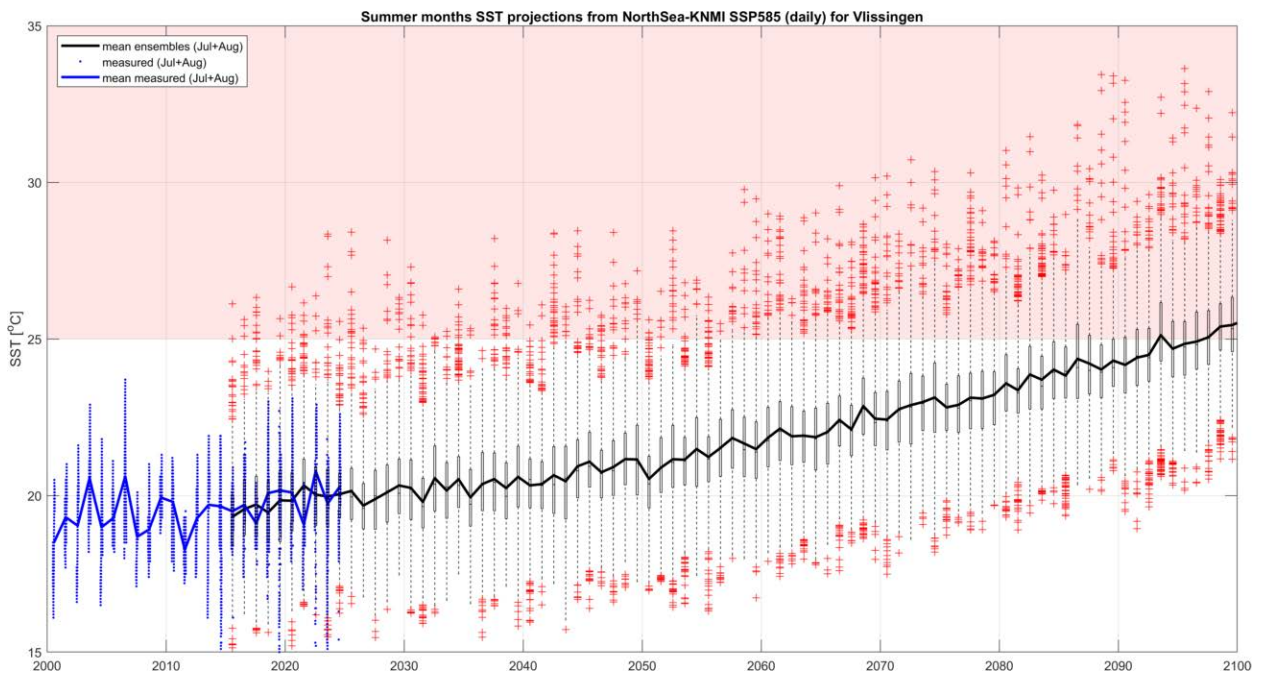


Figure 2.8 Time series of both measured and projected mean summer seawater temperature at Vlissingen for climate scenario SSP585, the latter corrected by adding 1°C based on the comparison with measurements. The ensemble projections are indicated as so-called boxplots, with each box representing the 25th to the 75th percentile. The dashed vertical lines extend to the smallest and largest values within 1.5 times the quartiles. The red markers above and below are individual outliers. The bold lines indicate the mean of the summer month ensembles.

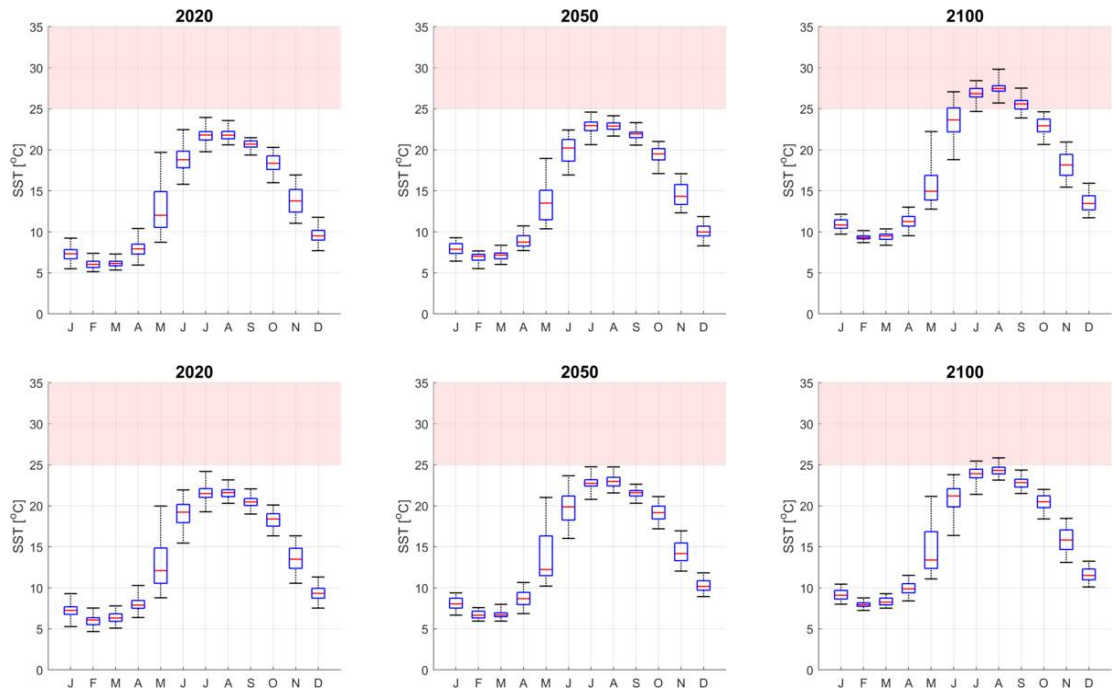


Figure 2.9 Monthly box-plots of projected sea surface temperature (SST) at Terneuzen for climate scenario SSP585 (top panel) and SSP245 (lower panel). The ensemble projections are corrected by adding 1°C based on the comparison with measurements. Each box represents the 25th to the 75th percentile. The whiskers indicate the range between the minimum and maximum values.

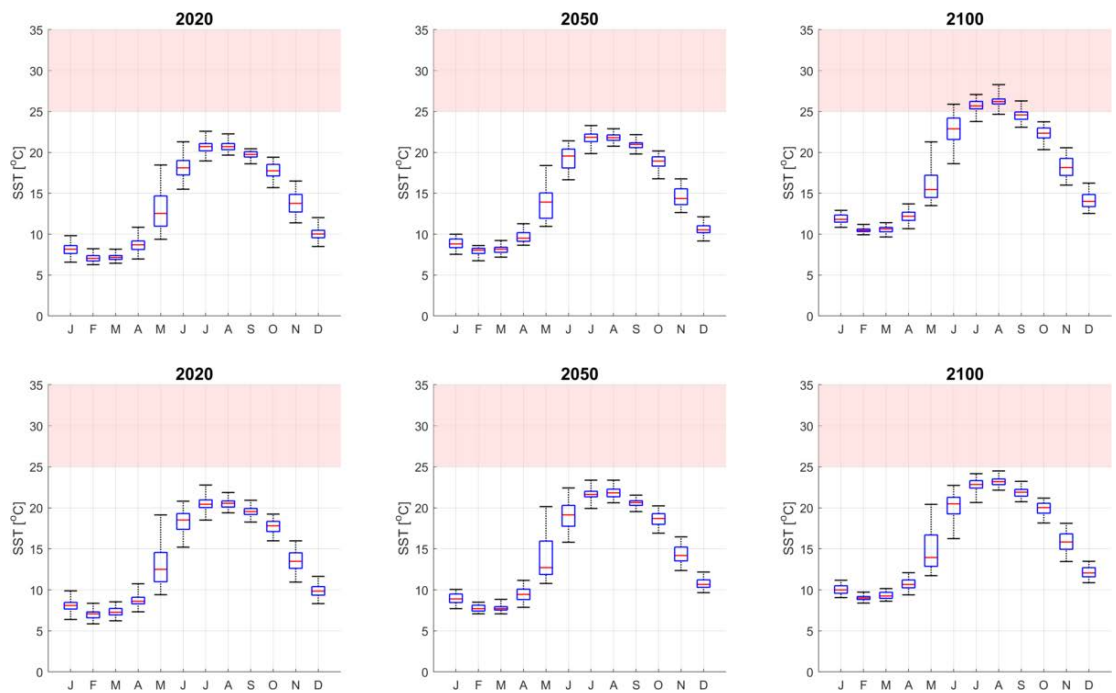


Figure 2.10 Monthly box-plots of projected sea surface temperature (SST) at Vlissingen for climate scenario SSP585 (top panel) and SSP245 (lower panel). The ensemble projections are corrected by adding 1°C based on the comparison with measurements. Each box represents the 25th to the 75th percentile. The whiskers indicate the range between the minimum and maximum values.

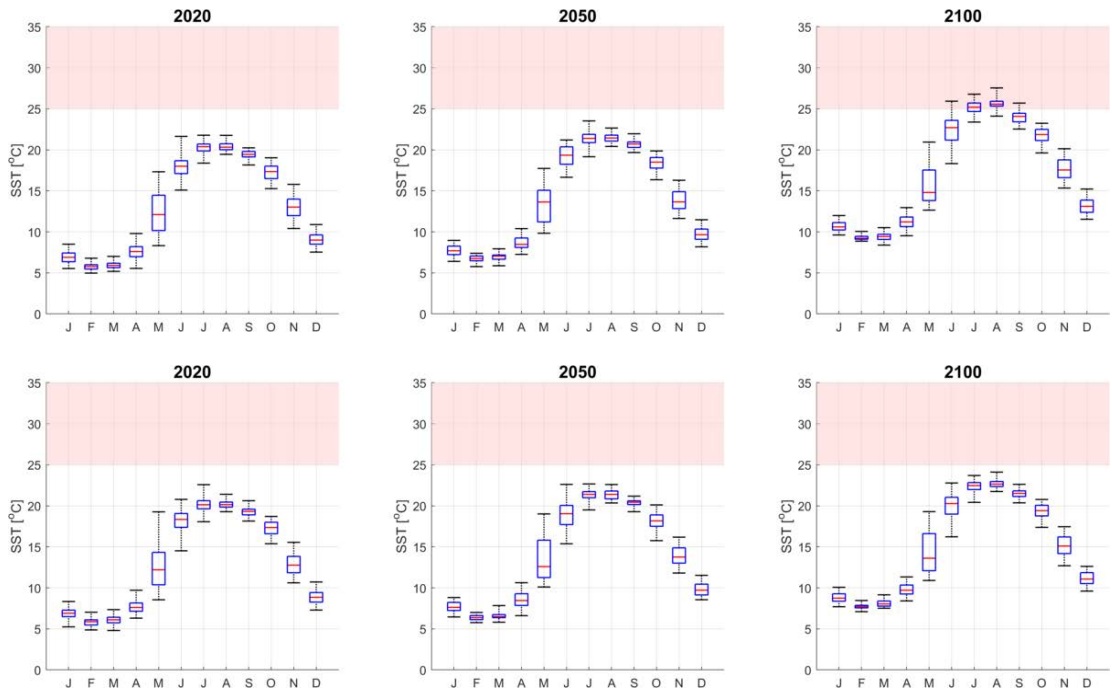


Figure 2.11 Monthly box-plots of projected sea surface temperature (SST) at Hoek van Holland for climate scenario SSP585 (top panel) and SSP245 (lower panel). Each box represents the 25th to the 75th percentile. The whiskers indicate the range between the minimum and maximum values.

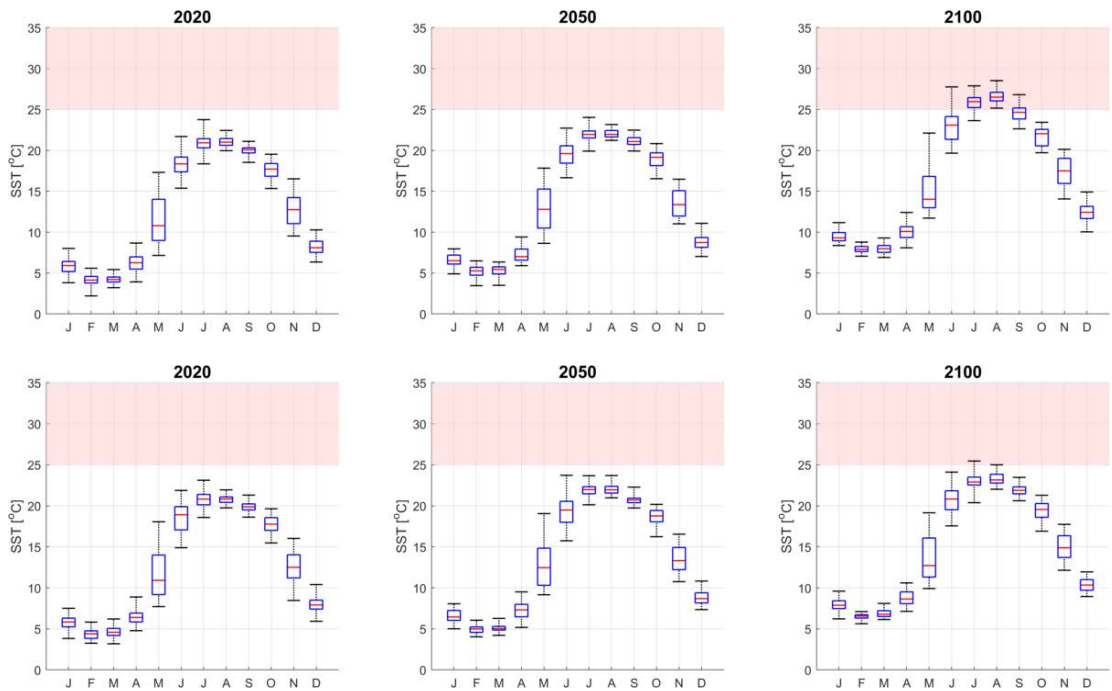


Figure 2.12 Monthly box-plots of projected sea surface temperature (SST) at Terneuzen for climate scenario SSP585 (top panel) and SSP245 (lower panel). The ensemble projections are corrected by adding 1°C based on the comparison with measurements. Each box represents the 25th to the 75th percentile. The whiskers indicate the range between the minimum and maximum values.

Finally, the tables in Figure 2.13 synthesize the projected temperature increase relative to the baseline year 2020 for both SSP245 and SSP585 across all four locations (based on the corrected NorthSea-KNMI ensemble means), providing an overview of expected warming trends and indicating their rather limited regional differences.

Hoek van Holland						
	SSP2-4.5			SSP5-8.5		
	2020	2050	2100	2020	2050	2100
Jan	0.0	0.7	1.8	0.0	0.8	3.7
Feb	0.0	0.5	1.8	0.0	1.0	3.4
Mar	0.0	0.4	1.9	0.0	1.1	3.5
Apr	0.0	0.8	2.1	0.0	0.9	3.6
May	0.0	0.4	1.4	0.0	1.5	2.7
Jun	0.0	0.7	1.9	0.0	1.3	4.7
Jul	0.0	1.3	2.3	0.0	1.0	4.8
Aug	0.0	1.2	2.5	0.0	1.1	5.2
Sep	0.0	1.1	2.2	0.0	1.3	4.6
Oct	0.0	0.8	2.1	0.0	1.1	4.5
Nov	0.0	1.0	2.3	0.0	0.6	4.5
Dec	0.0	0.9	2.2	0.0	0.7	4.1
Year		0.8	2.1		1.0	4.1

Eemshaven						
	SSP2-4.5			SSP5-8.5		
	2020	2050	2100	2020	2050	2100
Jan	0.0	0.6	2.1	0.0	0.6	3.4
Feb	0.0	0.6	2.1	0.0	1.1	3.7
Mar	0.0	0.4	2.2	0.0	1.2	3.8
Apr	0.0	0.9	2.2	0.0	0.7	3.8
May	0.0	1.5	1.8	0.0	2.0	3.2
Jun	0.0	0.6	1.9	0.0	1.3	4.7
Jul	0.0	1.2	2.1	0.0	1.0	5.0
Aug	0.0	1.1	2.3	0.0	0.9	5.5
Sep	0.0	0.8	2.0	0.0	1.0	4.6
Oct	0.0	1.0	1.8	0.0	1.5	4.3
Nov	0.0	0.8	2.4	0.0	0.6	4.7
Dec	0.0	0.8	2.4	0.0	0.6	4.3
Year		0.9	2.1		1.1	4.3

Vlissingen						
	SSP2-4.5			SSP5-8.5		
	2020	2050	2100	2020	2050	2100
Jan	0.0	0.8	1.9	0.0	0.6	3.6
Feb	0.0	0.6	1.9	0.0	1.0	3.4
Mar	0.0	0.4	2.0	0.0	1.0	3.5
Apr	0.0	0.8	2.0	0.0	0.8	3.5
May	0.0	0.2	1.4	0.0	1.4	2.9
Jun	0.0	0.6	2.0	0.0	1.4	4.8
Jul	0.0	1.2	2.4	0.0	1.1	5.0
Aug	0.0	1.3	2.6	0.0	1.1	5.5
Sep	0.0	1.1	2.4	0.0	1.2	4.8
Oct	0.0	0.9	2.2	0.0	1.2	4.6
Nov	0.0	0.7	2.4	0.0	0.6	4.4
Dec	0.0	0.8	2.2	0.0	0.5	4.0
Year		0.8	2.1		1.0	4.2

Terneuzen						
	SSP2-4.5			SSP5-8.5		
	2020	2050	2100	2020	2050	2100
Jan	0.0	0.8	1.8	0.0	0.6	3.5
Feb	0.0	0.6	1.9	0.0	1.0	3.3
Mar	0.0	0.4	1.9	0.0	1.0	3.3
Apr	0.0	0.8	2.0	0.0	0.8	3.3
May	0.0	0.1	1.3	0.0	1.5	2.9
Jun	0.0	0.6	2.0	0.0	1.4	4.9
Jul	0.0	1.3	2.4	0.0	1.1	5.0
Aug	0.0	1.4	2.7	0.0	1.1	5.7
Sep	0.0	1.1	2.4	0.0	1.2	4.9
Oct	0.0	0.8	2.1	0.0	1.1	4.6
Nov	0.0	0.7	2.3	0.0	0.5	4.4
Dec	0.0	0.9	2.2	0.0	0.5	3.9
Year		0.8	2.1		1.0	4.1

Figure 2.13 Monthly seawater temperature increase relative to 2020 for climate scenarios SSP245 and SSP585 and for all four locations based on the corrected (except Vlissingen) Northsea-KNMI projections.

## 3 Assessment of uncertainty

### 3.1 Overview

The considered climate model projections of seawater temperatures are subject to a range of uncertainties. Namely:

1. **Model uncertainty:** One major source of uncertainty arises from the limitations of climate models themselves. Global Climate Models (GCMs, such as the EC-Earth3 model as used by KNMI) often lack the spatial resolution necessary to accurately simulate the fine-scale processes that dominate coastal and estuarine dynamics, as could be seen in the validation presented in Section 2.4. The systematic errors in the considered model results – estimated to be in the order of  $\pm 1^\circ\text{C}$  – have been bias-corrected using the available observations. Even when calibrating climate model results with observations, the projections from different climate models differ. The reasons are twofold. First, models apply different horizontal resolutions (with or without downscaling), which determines whether or not a model can capture small-scale processes such as coastal currents, bathymetry or mixing. Second, models incorporate distinct representations of physical processes, parameterizations, and numerical schemes, which contribute to structural uncertainty. In Section 3.2 we quantify the model uncertainty by considering projections of the North Sea seawater temperature by a comparison of 5 different GCMs and 1 regional climate model (RCM).
2. **Natural variability:** Climate model ensembles provide a means to quantify natural variability by simulating multiple realizations of the same scenario with slightly different initial conditions. Because each ensemble member represents a plausible evolution of the climate system under identical external forcing, the spread among members reflects internal variability. In Section 3.3, we quantify the uncertainty due to evaluating the natural variability in the considered ensembles.
3. **Future climate scenario:** Another layer of uncertainty stems from the choice of greenhouse gas emission scenarios. Different Shared Socioeconomic Pathways (SSPs) lead to divergent temperature outcomes due to varying levels of radiative forcing, as can be seen in the differences between the SSP245 and SSP585 projections in Section 2.5. While the IPCC does not assign probabilities to scenarios, SSP245 is often treated as a realistic baseline because it aligns closely with present emission trajectories and policy commitments. SSP5-8.5 is widely regarded as a pessimistic or worst-case scenario that is unlikely under current policy trends. The range between the trends, given in for instance Section 2.5 or Figure 2.13, can be interpreted in terms of uncertainties in the scenarios.

### 3.2 Model uncertainty

Monthly projected seawater temperatures for 2015 – 2100 were collected from 5 global and 5 regional climate models developed by European institutes and one by NOAA (see

Table 3.1). All datasets were downloaded using the ESGF portal<sup>3</sup>, except for the NorthSea-KNMI data, which were provided directly by KNMI. These data were converted from daily to monthly means to enable assessment of model uncertainties.

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<sup>3</sup> <https://aims2.llnl.gov/search/cmip6/>

Table 3.1 Overview of applied global and regional climate models

Name global climate model	Model resolution	Name regional climate model	Model resolution
AWI-CM-1-1-MR	8 – 25 km	MPI-ESM1-2-HR	55 km
CNRM-CM6-1-HR	25 km	EC-Earth3	100 km
HadGEM3-GC31-MM	25 km	CNRM-ESM2-1	100 km
NOAA-GFDL-CM4	25 km	NorESM2-MM	100 km
CMCC-CM2-SR5	100 km	NorthSea-KNMI	100 km

To enable direct intercomparison across models, the projected monthly mean seawater temperature time series (2015 – 2100) for each model – taken at the grid point closest to each plant location – were normalized by subtracting the mean temperature for the 2015–2025 period.

Figure 3.1 presents the projected monthly mean seawater temperatures from the collected multi-model ensemble for Terneuzen. The models show a more or less uniform trend and range, indicating a model uncertainty in the order of +/- 1.5°C. Note also that for both climate scenarios the NorthSea-KNMI projections fall well within the range of the model ensembles, although somewhat in the lower range before 2060 and in the upper range after 2060.

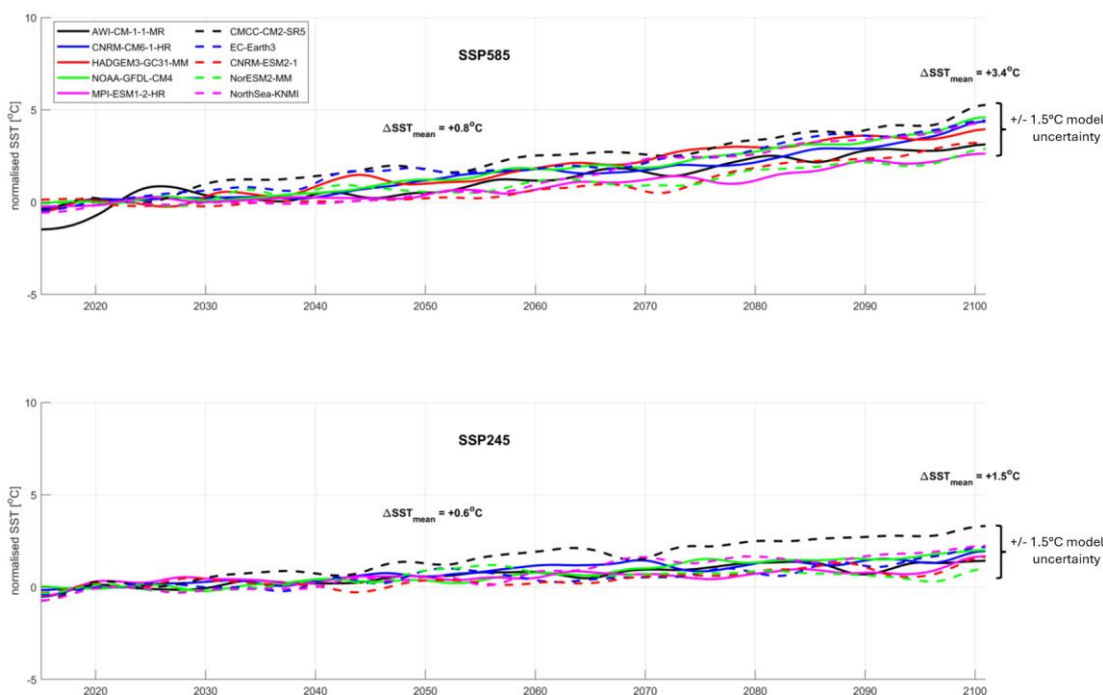


Figure 3.1 Projected monthly-average seawater temperature from various climate models for Terneuzen, indicating a model uncertainty in the order of +/- 1.5°C. The models with continuous lines indicate models with spatial resolution of less than 50 km and the dashed lines indicate models with about 100 km.

### 3.3 Uncertainty due to natural variability

Figure 3.2 shows the range of the NorthSea-KNMI ensembles for Terneuzen, indicating a natural variability in the order of  $\pm 4^{\circ}\text{C}$ . Similar ranges of natural variability are found at the other locations. Given that the found trends in the seawater temperature by 2100, at least for SSP585, exceed these uncertainties, the trends can be considered significant.

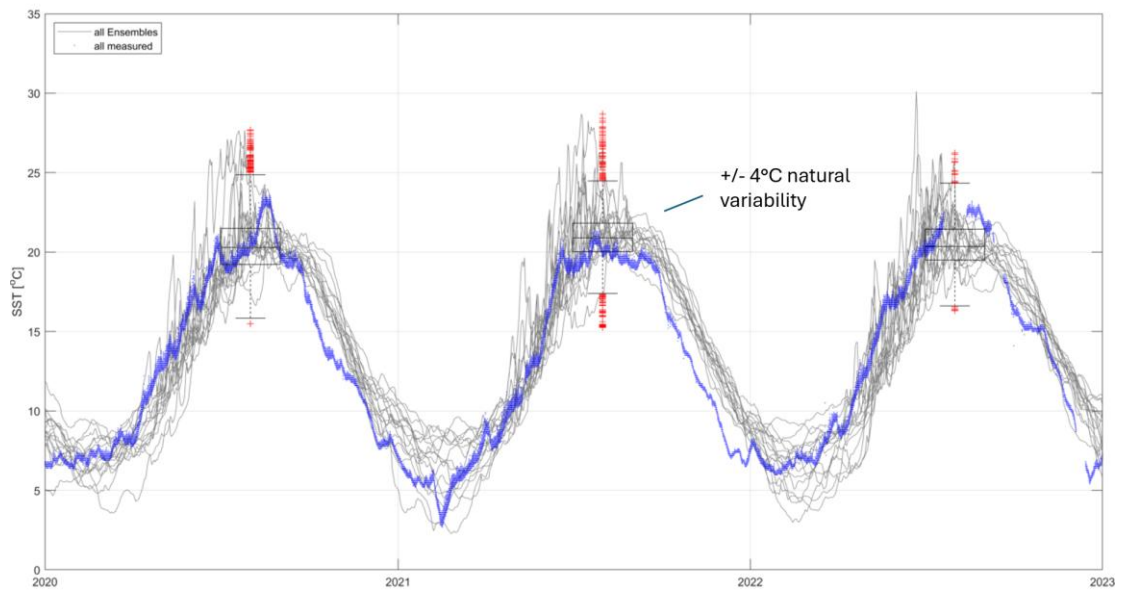


Figure 3.2 Time-series of Northsea-KNMI ensemble projections and measurements at Terneuzen between 2020 and 2023, indicating a natural variability (i.e. range of the ensembles) in the order of  $\pm 4^{\circ}\text{C}$ .

## 4 Conclusions and recommendations

This report evaluates current and future seawater temperatures along the Dutch coast at four potential nuclear power plant locations: Sloegebied (Borssele), Terneuzen, Maasvlakte II, and Eemshaven. The analysis aims at supporting long-term planning for cooling water availability as input for the assessment of the operational performance and the environmental impact of potential nuclear facilities.

Observed seawater temperature data from Rijkswaterstaat (2015–2025) were collected and compared with climate projections from KNMI's North Sea dataset, based on the EC-Earth3 model. Two future climate scenarios of greenhouse gas emissions were considered:

- SSP245 – Moderate emissions, ~2.7–3°C global warming by 2100.
- SSP585 – High emissions, >4°C global warming by 2100.

Modelled seawater temperatures were compared against observations, and corrected for a systematic bias of approximately +1°C. The analysis focused on summer months (July–August) and monthly trends for 2050 and 2100. Currently the average summer temperature is about 22°C, which is projected to increase by about 2 to 4°C by 2100, depending on scenario and location.

The key findings of this assessment are that:

- Under SSP245, exceedance of the 25°C cooling water limit during the summer months July and August is rare and is only expected to occur occasionally at the end of this century.
- Under SSP585, persistent exceedance of 25°C during the summer months July and August is projected for all locations by 2100, with Terneuzen surpassing this threshold from 2080 onwards.

Ranges of uncertainties were assessed for natural variability, model differences, and scenario assumptions. The uncertainties are estimated to be:

- ±4°C in terms of natural variability, and
- ±1.5°C in terms of model uncertainties.

Given that the model uncertainties fall within the uncertainty due to natural variability, the projections given in this report should be considered with an uncertainty of ±4°C, which corresponds to a standard deviation of approximately 2°C. Note that the presented analysis relies on daily average temperatures. There are daily variations of the seawater temperature, especially at the surface. These are, however, not considered to significantly affect the results of this study. This means that the consideration of an extra allowance for daily variation is not considered necessary.

The magnitude of the uncertainties indicates that the projected trends in the daily-averaged seawater temperature – an increase of up to 5.7°C by 2100 under SSP585 in Terneuzen – are significant, i.e. they are larger than the uncertainties. However, there are considerable uncertainties in the projected temperatures linked to the representation of local processes in global climate models and future scenario of greenhouse gas emissions.

For the coming decades, we recommend the monitoring and updating of the climate projections to reflect evolving climate conditions.

## 5 Acknowledgements

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## List of references

- IPCC, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Chapter 4: Future Global Climate: Scenario-based Projections and Near-term Information. [Chapter 4 | Climate Change 2021: The Physical Science Basis](#)
- Rijkswaterstaat, 2004. CIW beoordelingssystematiek warmtelozingen. Ministerie van Verkeer en Waterstaat. Version: 25 November 2004. [ciw42004-11beoordelingssystematiek\\_warmtelozingen.pdf](#)
- KNMI, 2024. KNMI National Climate Scenarios 2023 for the Netherlands. Scientific report WR-23-02, version 2. [KNMI23\\_climate\\_scenarios\\_scientific\\_report\\_WR23-02.pdf](#)
- Deltares, 2024. Samenvatting regelgevend kader Borssele. Brief 11209639-002-GEO-0008. [Samenvatting+regelgeving+koelwater+Borssele.pdf](#)
- Deltares, 2024. Evaluatie voor locatie Borssele II, Beschikbaarheid van koelwater. Rapport 11209639-002-GEO-0005. [Evaluatie-voor-locatie-borssele-II-koelwater.pdf](#)

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