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Climate-driven changes in infrastructure design assumptions

Report generated using ClimateVision pro V0.1.0

September 2024

CALLENDAR
Climate intelligence

Table of content

Table of content....2
1. Introduction and goals....3
2. Executive summary....4
3. Average surface temperature....6
4. Maximum temperature....12
5. Minimum temperature....16
6. Average precipitations....20
7. Maximum daily precipitations....25
8. Wind speed....29
9. Sea level....33
10. Wind waves....36
Appendix A: Models used....40
Appendix B: Definitions and abbreviations....41
Appendix C: legal notices....43

For more information see legal and IP notices in AppendixC.

1. Introduction and goals

Companies engaged in the design and construction of both on- and off-shore infrastructures rely on meteorological and oceanographic assumptions. Variables such as temperature, wind, precipitation, wave height, and sea level play pivotal roles in project feasibility, design, and operation. However, these assumptions, typically grounded in a study of past weather records, may become inadequate over a project's lifetime, especially under the influence of climate change.

This report is designed to help address this challenge. It provides a summary of future local climate projections crucial for designing resilient infrastructures.

It was generated automatically based state-of-the-art climate projections using ClimateVision pro, Callendar’s tool designed to automatically generate precise and actionable local climate insights.

This report is delivered with:

- A user guide detailing the data and methodology used,
- Spreadsheets containing the raw and intermediate data for the project site.

2. Executive summary

The objective of this report is to provide an overview of the available scientific knowledge on current and future climate for the following geographic point:

Confidential

This report is based on meteorological reanalyses from the European Centre for Medium-Range Weather Forecasts (ECMWF) and climate projections produced for the Intergovernmental Panel on Climate Change (IPCC) 6th assessment report. The sources and methods used are introduced in each chapter and detailed in the attached methodological note.

These data show the following local trends, all changes are relative to the 1985-2014 reference period:

- The **temperature** is currently increasing by about 0.4°C per decade and will most likely continue to increase at a similar pace over the next few decades. The influence of emissions on temperatures becomes significant afterward. In a low emissions scenario, the warming could stabilize around +1.2°C compared to 2000. It should continue to rise in the other scenarios and could exceed +3.5°C at the end of the 21st century in a high emissions scenario.

- In an intermediate or high emissions scenario, **extreme heat waves** are likely to become more severe during the second half of the 21st century. The daily temperature of the 100-year heat wave could increase by 3.9°C in a high emission scenario. **Cold spells** are likely to become less pronounced over the 21st century.

- **Average precipitations** show no significant trend over the reference period and are not expected to vary significantly during the 21st century.

- The evolution of extreme precipitations events over the 21st century is uncertain.

- Extreme wind speeds could decrease during the 21st century.

- By mid-century, sea level is likely to rise by about 20 centimetres compared to the average 1985-2014 level. By 2080, it could rise by about 0.3 to 0.5 metre depending on the level of emissions and the assumptions made with a low probability to exceed 137 cm in a pessimistic scenario.

- The evolution of extreme wave heights over the 21st century is uncertain.

3. Average surface temperature

1. Overview of the data and methods used

The past climate is based on the closest data point of the ERA5 reanalysis. The spatial resolution of these data is 0.25°. Future climate projections are based on 7 models from the CMIP6 project[1]. Projections are downscaled and corrected using the past climate as a reference.

Please note that values for the reference period are based on reanalysis data, a widely used method for reconstructing past atmospheric conditions by combining observations and high-resolution weather models. Depending on specific local features, results may differ from in-situ observations or reanalysis corrected with in-situ observations.

2. Average surface temperature

Over the reference period (1985-2014), the median annual temperature was 27.6°C with a 90% confidence interval extending from 26.8 to 28.1°C.
A strong warming trend is visible in the historical data. Over the period 1991-2020, the temperature has increased on average by about 0.35°C per decade.

[1] The models used are listed in Appendix A.

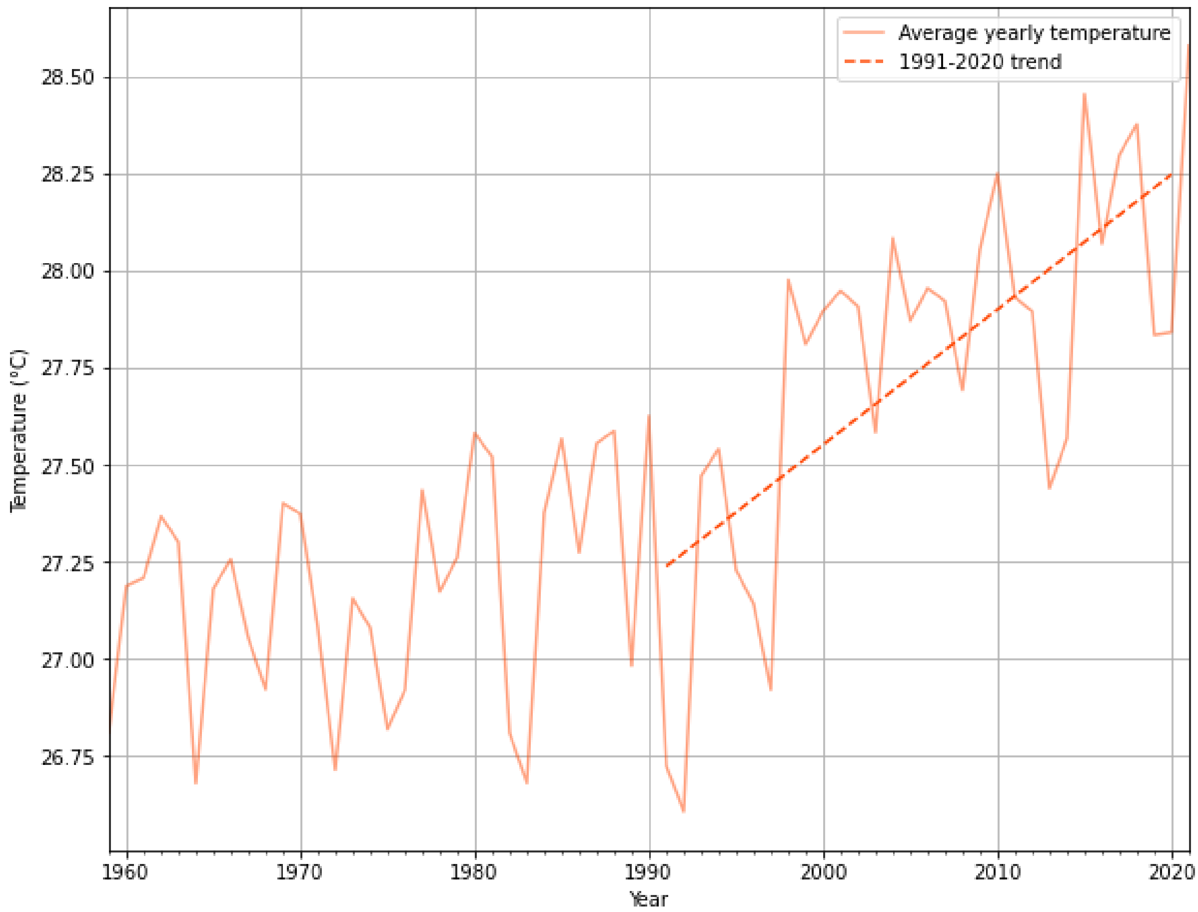


Figure 1: Average annual temperature and trend

3. Future projections

Temperature is very likely to increase significantly during the 21st century.

Over the next three decades, the best estimate of annual average temperature is approximately 28.6°C with little influence from the emissions scenario.

This is consistent with the warming trend observed over the last 3 decades. The median projection for average annual temperature is higher than the natural variability (90 CI). This strongly suggests that historical temperatures do not provide good guidance even for short-term project design.

The influence of emissions on temperatures becomes significant around the middle of the century. By 2050, the average yearly temperature is projected to be 0.6°C higher in the worst-case emissions scenario (SSP5-8.5) compared to the best-case scenario (SSP1-2.6). At the end of the century, this difference approaches 2.5 degrees.

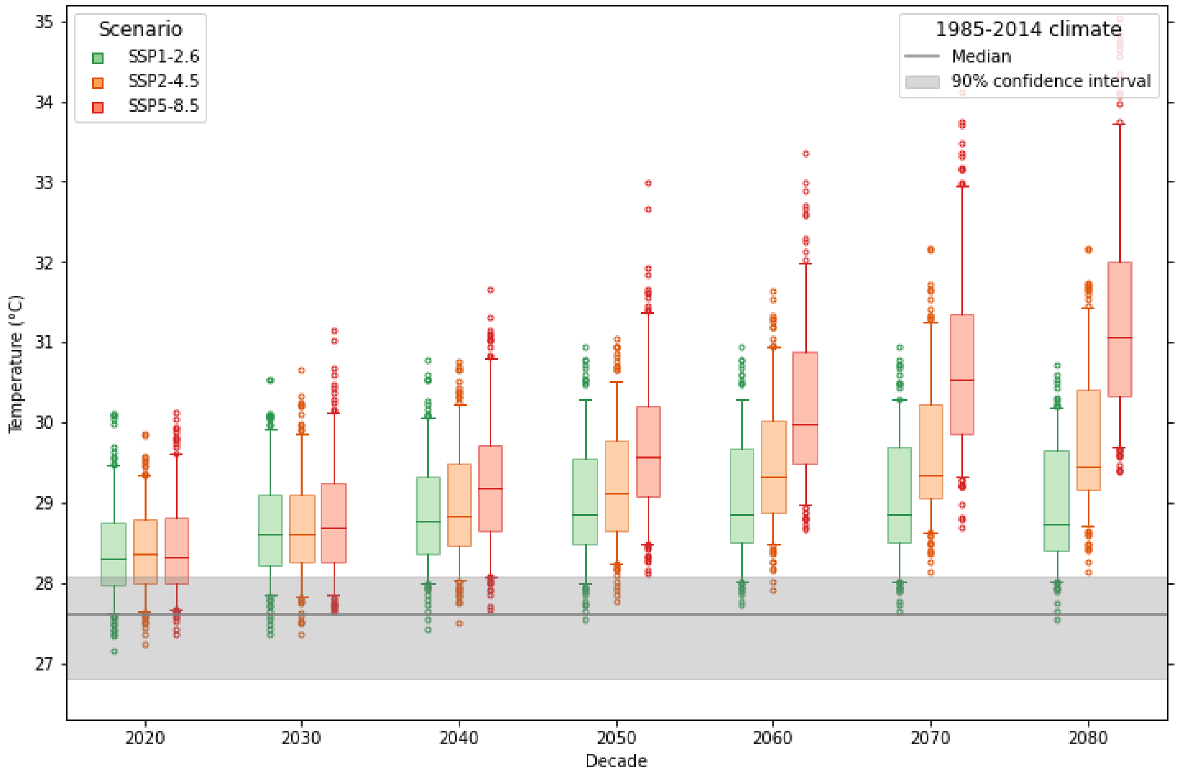
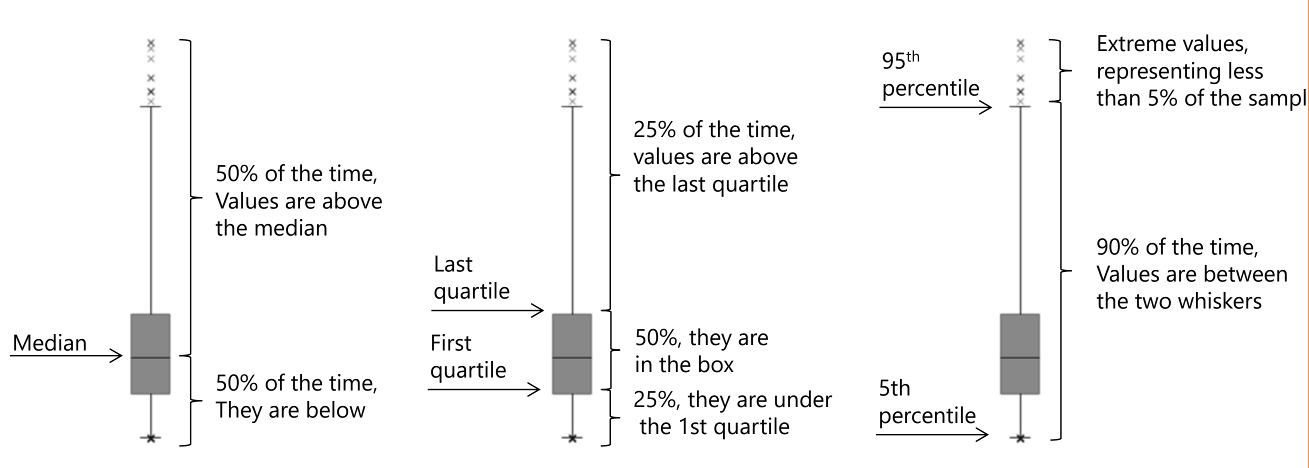


Figure 2 : Annual temperature, multimodel boxplot

Box 1: how to read a boxplot

A boxplot is a graphical method to simply convey the distribution of data. It allows to visually estimate the most important data percentiles (minimum, maximum, median, first and last quartiles) and various key characteristics of a sample (spread, skewness, outliers, etc.).

Several variations of this visual data display exist. In this document, boxplots can be read as follows:



The difference is more pronounced for the upper bound of the confidence interval: the gap between the 95th percentile of temperature of the worst-case and best-case scenario is 0.9°C by mid-century and 3.5°C for the 2080 decade. The high emission scenario thus leads to a disproportionate increase in the severity of the warmest years.

	Scenario			Uncertainties
	SSP1-2.6 (Low GHG emissions scenario)	SSP2-4.5 (Intermediate GHG emissions scenario)	SSP5-8.5 (Very high GHG emissions scenario)	
Reference (1985-2014)	27.6°C			
Short term (2020-2049)	28.6 [27.8, 29.9]	28.6 [27.8, 29.9]	28.7 [27.8, 30.1]	Low
Mid-century (2035-2064)	28.8 [28.0, 30.2]	29.0 [28.2, 30.4]	29.4 [28.3, 31.1]	Medium
End of century (2070-2099)	28.7 [28.0, 30.2]	29.5 [28.7, 31.4]	31.1 [29.7, 33.7]	High scenario and model uncertainties

Figure 3: Average temperature projections (median and 90% confidence interval)

In the low emissions scenario, the warming stabilizes in the second half of the century at around 1.2°C. Temperature continues to rise in the other scenarios. At the end of the century, the temperature increase is about 1.9°C compared to 2000 in the SSP2-4.5 and 3.5°C for the SSP5-8.5.

4. Individual model projections

All models indicate that the annual temperature will rise beyond the natural climate variability (90% confidence interval) in all emission scenarios. But there is a significant dispersion among models for long-term warming, especially in the high emission scenario. As a result, uncertainties remain high for the end of the century.

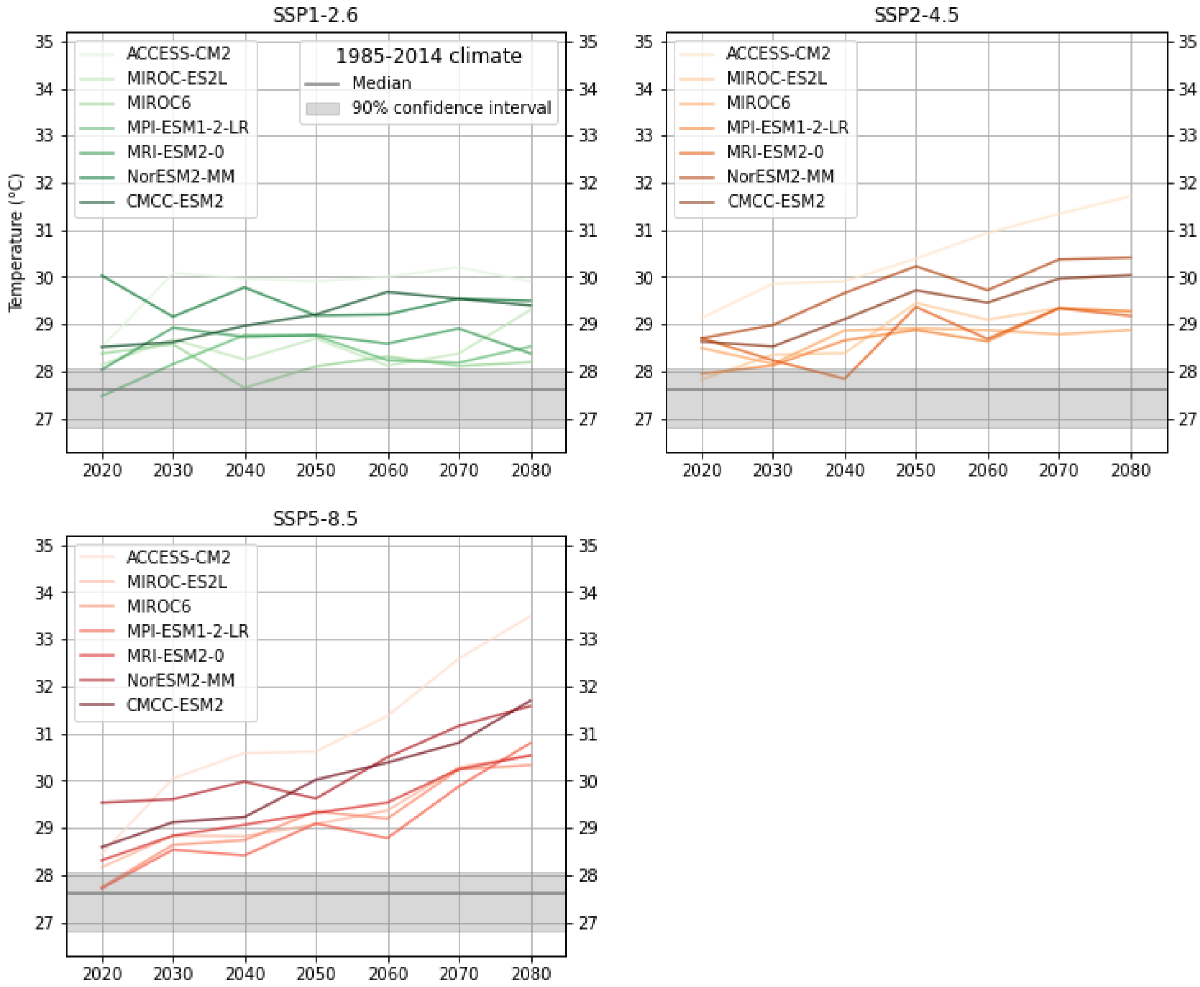


Figure 4: Average temperature by decade (30 year rolling average)

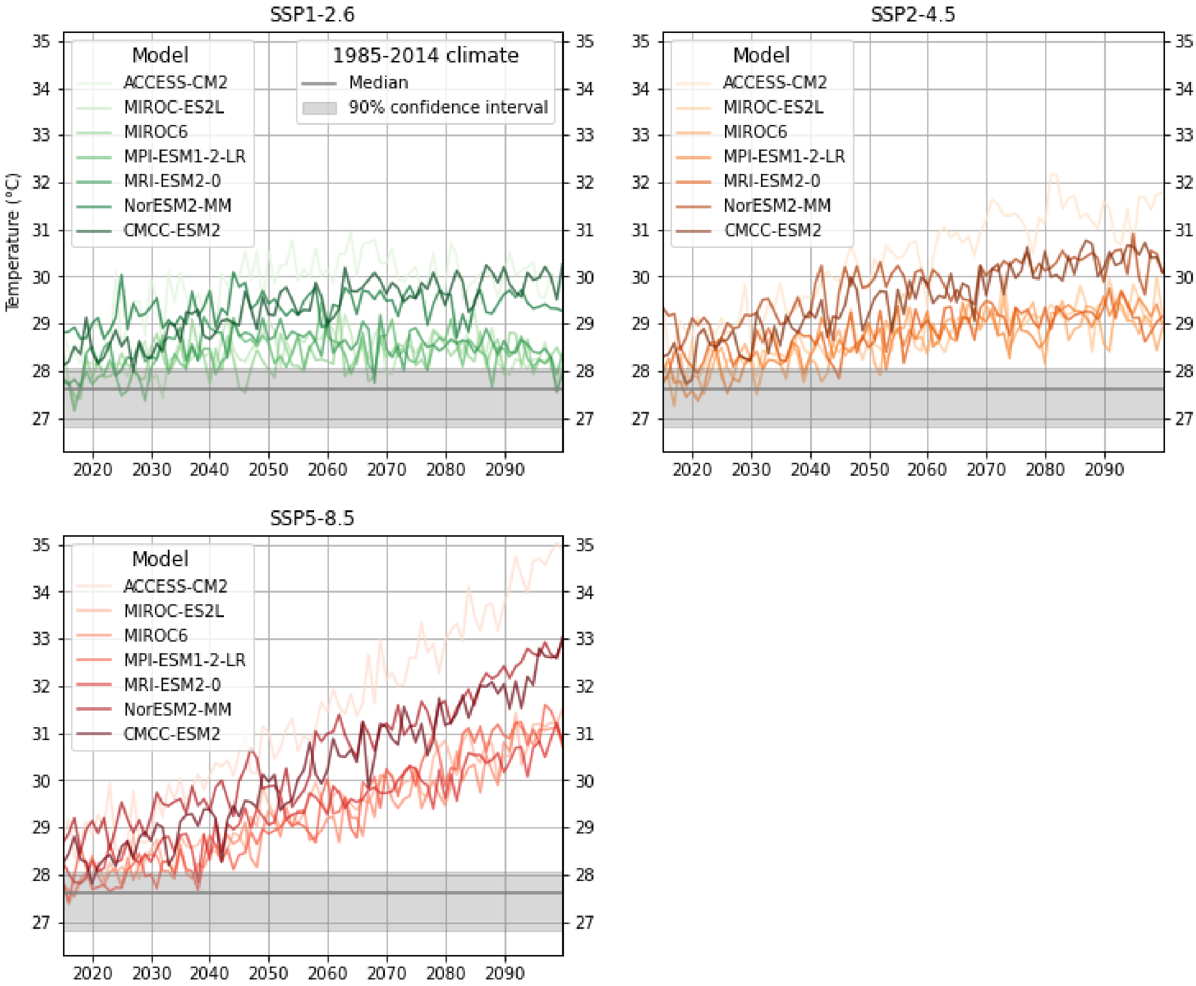


Figure 5: annual temperature simulation

4. Maximum temperature

1. Overview of the data and methods used

The past climate is based on the closest data point of the ERA5 reanalysis. The spatial resolution of these data is 0.25°. Future climate projections are based on 7 models from the CMIP6 project. Projections are downscaled and corrected using the past climate as a reference.

Temperature extremes for a given return time are evaluated from the known maxima and a Generalized extreme value distribution.

Please note that values for the reference period are based on reanalysis data, a widely used method for reconstructing past atmospheric conditions by combining observations and high-resolution weather models. Depending on specific local features, results may differ from in-situ observations or reanalysis corrected with in-situ observations.

2. Reference climate

Over the reference period (1985-2014), the maximum hourly temperature observed was 42.8°C in July 2021 and the maximum daily temperature was 38.8°C in July 1999.

Over these 30 years, the maximum hourly temperature was 40.7°C on annual average and the maximum daily temperature 36.9°C.

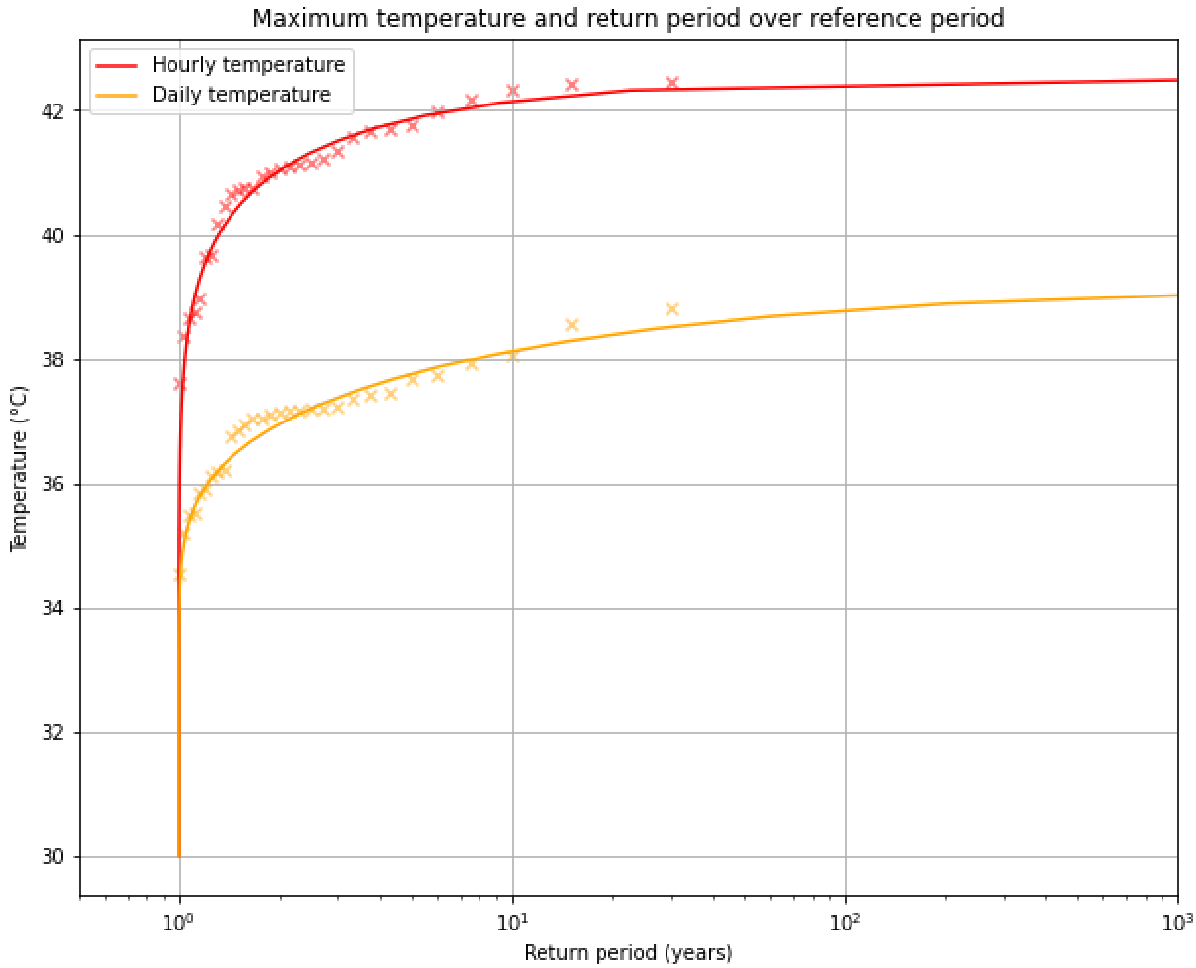


Figure 6: Return periods for maximum temperature on the reference period

RETURN PERIOD (years)	MAXIMUM TEMPERATURE (°C)	
	Hourly average	Daily average
5	41.5	37.3
10	42.0	37.7
20	42.3	38.1
50	42.6	38.5
100	42.7	38.8

Figure 7: Hourly and daily maximum temperatures for selected return periods

3. Future projections

Extreme heat waves are likely to become more severe in the second half of the 21st century.

There is a broad consensus among the models on the evolution of heat extremes. For the high emission scenario (SSP5-8.5), all models indicate an increase in maximum daily temperature after the middle of the century. For the medium emission scenario (SSP2-4.5), the increase should become significant by the end of the century.

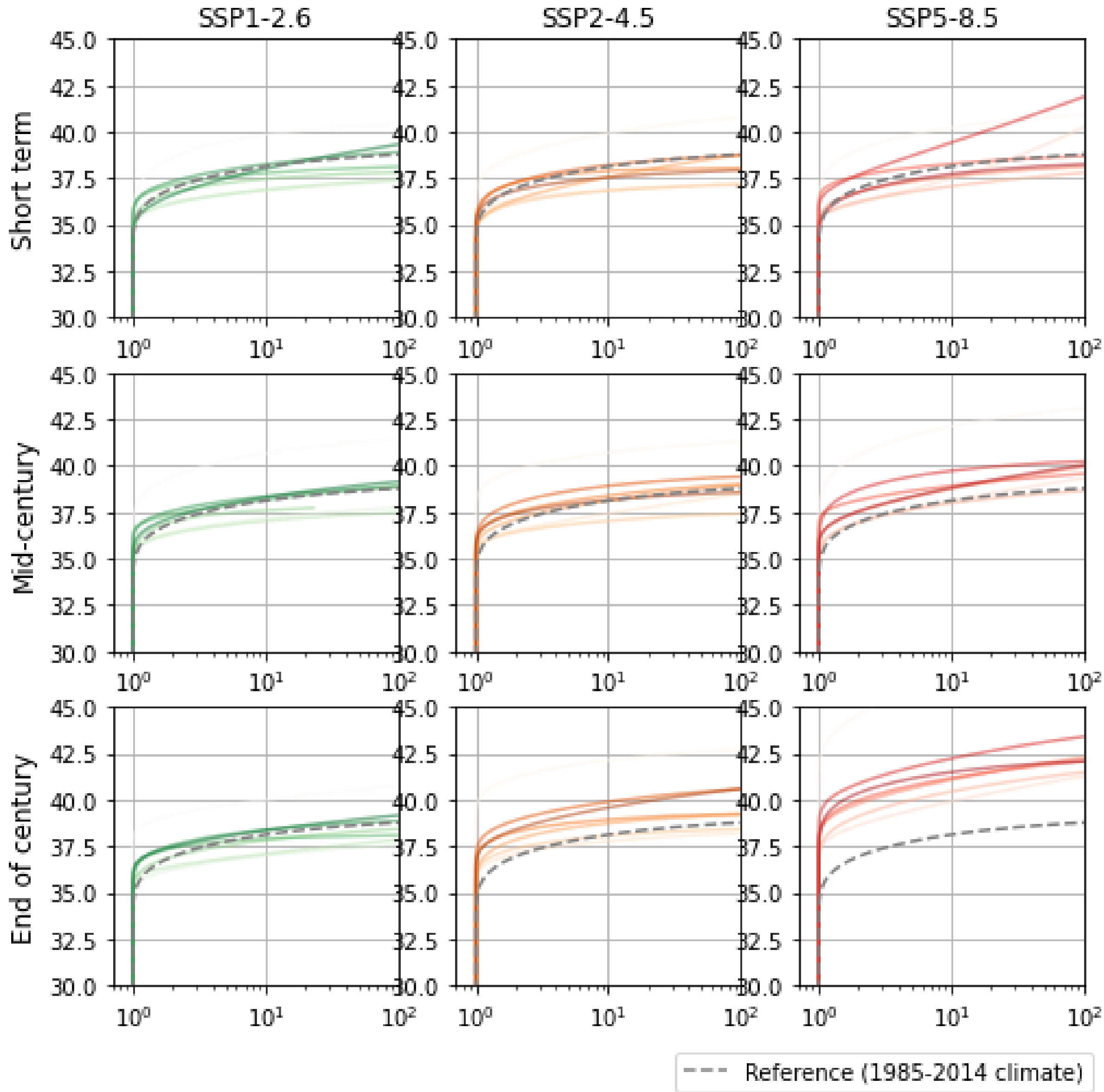


Figure 8: Daily maximum temperature, multimodel return level plots for selected time horizons

The evolution is less certain for hourly temperatures. Some models suggest that maximum temperature could stay unchanged or decrease even in the high emissions scenario.

Based on the multimodel median, over the century, the maximum hourly temperature for a 100-year heat wave could increase by 1.2°C in a low emission scenario, 2.0°C in a medium emissions scenario and 4.0°C in a high emission scenario compared to 2000. The increase should be of the same order of magnitude for shorter return periods.

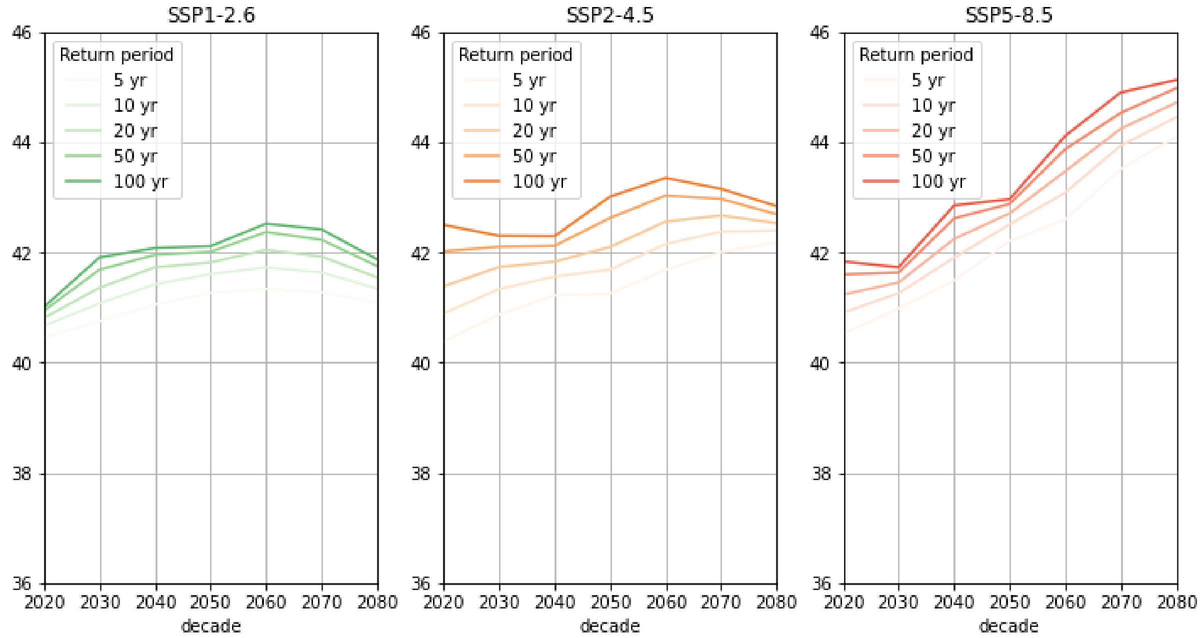


Figure 9: Evolution of hourly temperature for extreme heatwave based on multimodel median

For daily averaged temperatures, the 100-year heat wave could increase by 0.6°C in a low emission scenario, 1.5°C in a medium emissions scenario and 3.9°C in a high emission scenario. The increase should be of the same order of magnitude for shorter return periods:

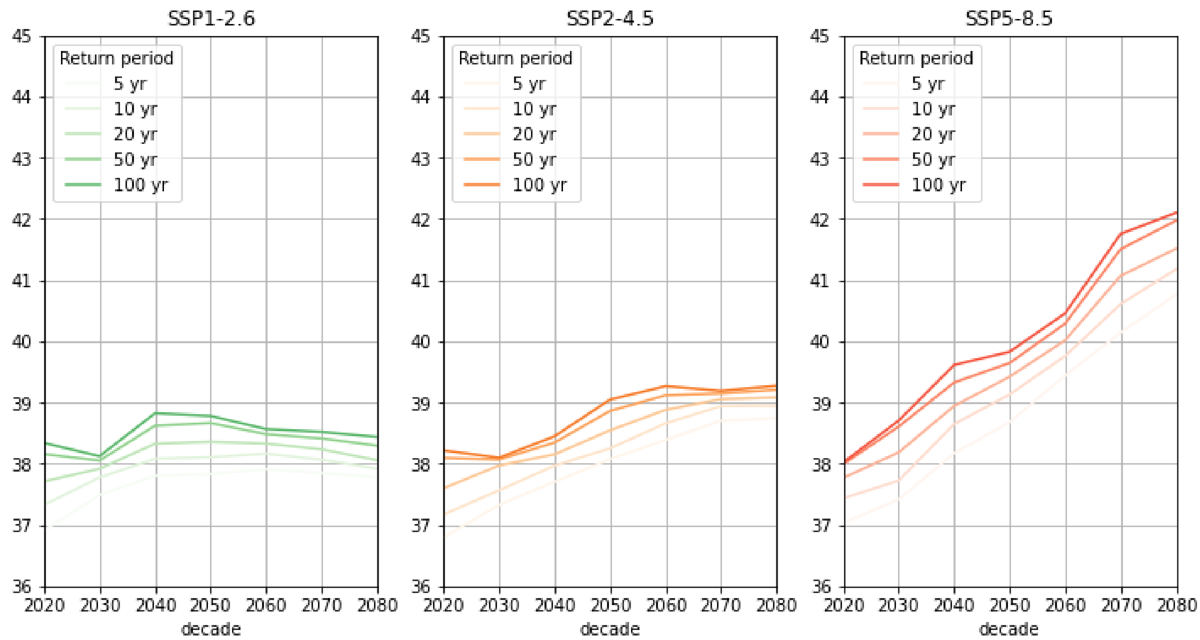


Figure 10: Evolution of daily temperature for extreme heatwave based on multimodel median

5. Minimum temperature

1. Overview of the data and methods used

The past climate is based on the closest data point of the ERA5 reanalysis. The spatial resolution of these data is 0.25°. Future climate projections are based on 7 models from the CMIP6 project. Projections are downscaled and corrected using the past climate as a reference.
Temperature extremes for a given return time are evaluated from the known maxima and a Generalized extreme value distribution.

Please note that values for the reference period are based on reanalysis data, a widely used method for reconstructing past atmospheric conditions by combining observations and high-resolution weather models. Depending on specific local features, results may differ from in-situ observations or reanalysis corrected with in-situ observations.

2. Reference climate

Over the reference period (1985-2014), the minimum hourly temperature observed was 11.7°C in January 1992 and the minimum daily temperature was 14.7°C in February 2008. Over these 30 years, the minimum hourly temperature was 14.0°C on annual average and the minimum daily temperature 17.3°C.

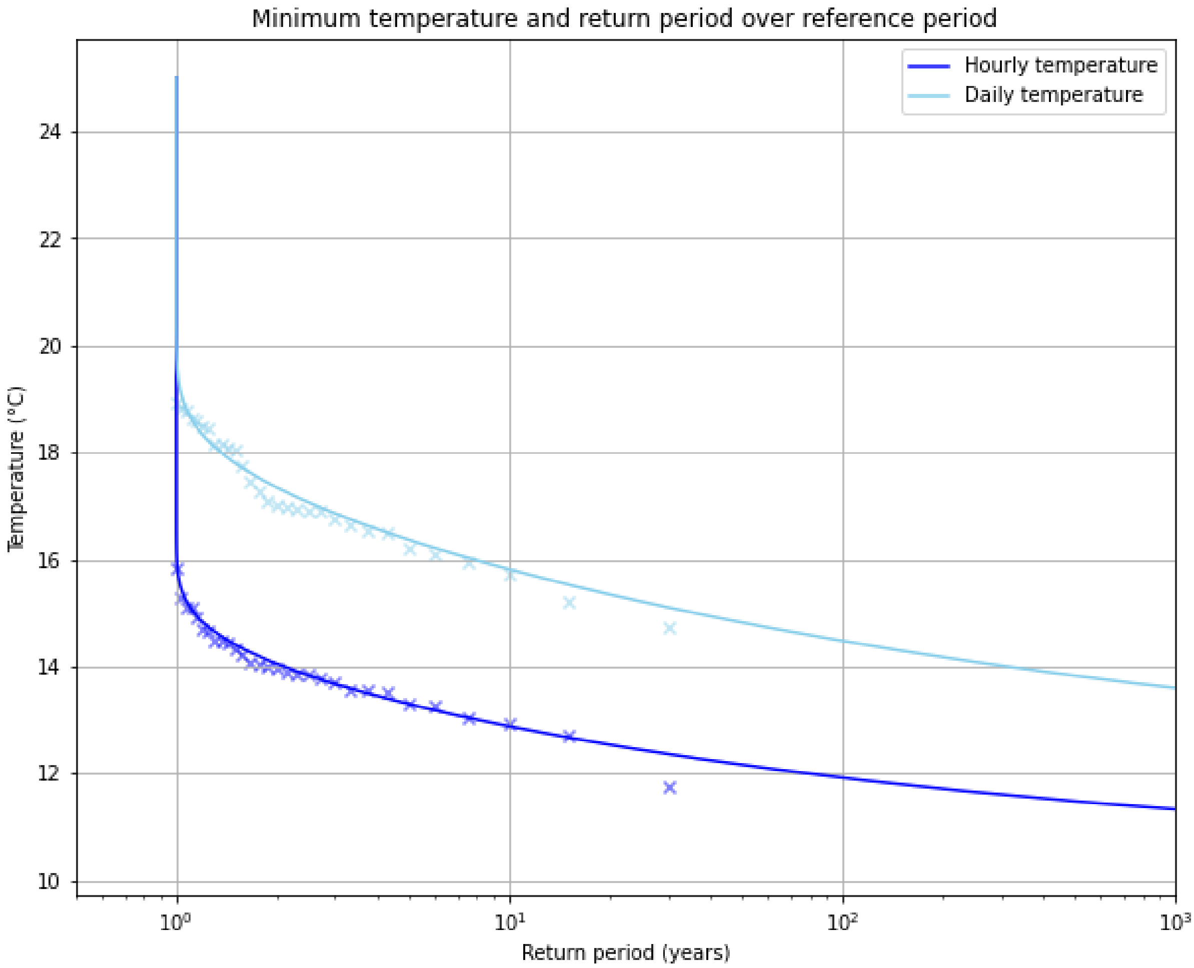


Figure 11: Return periods for minimum temperature on the reference period

RETURN PERIOD (years)	MINIMUM TEMPERATURE (°C)	
	Hourly average	Daily average
5	12.7	16.0
10	12.1	15.3
20	11.5	14.7
50	10.9	13.9
100	10.4	13.3

Figure 12: Hourly and daily minimum temperatures for selected return periods

3. Future projections

Cold spells are likely to become less pronounced over the 21st century.

There is a broad consensus among the models on the evolution of minimum daily temperature. Most models indicate an increase in minimum daily temperature for all scenarios, time horizons and return periods. This evolution is more marked for high emission scenarios and for long time horizons.

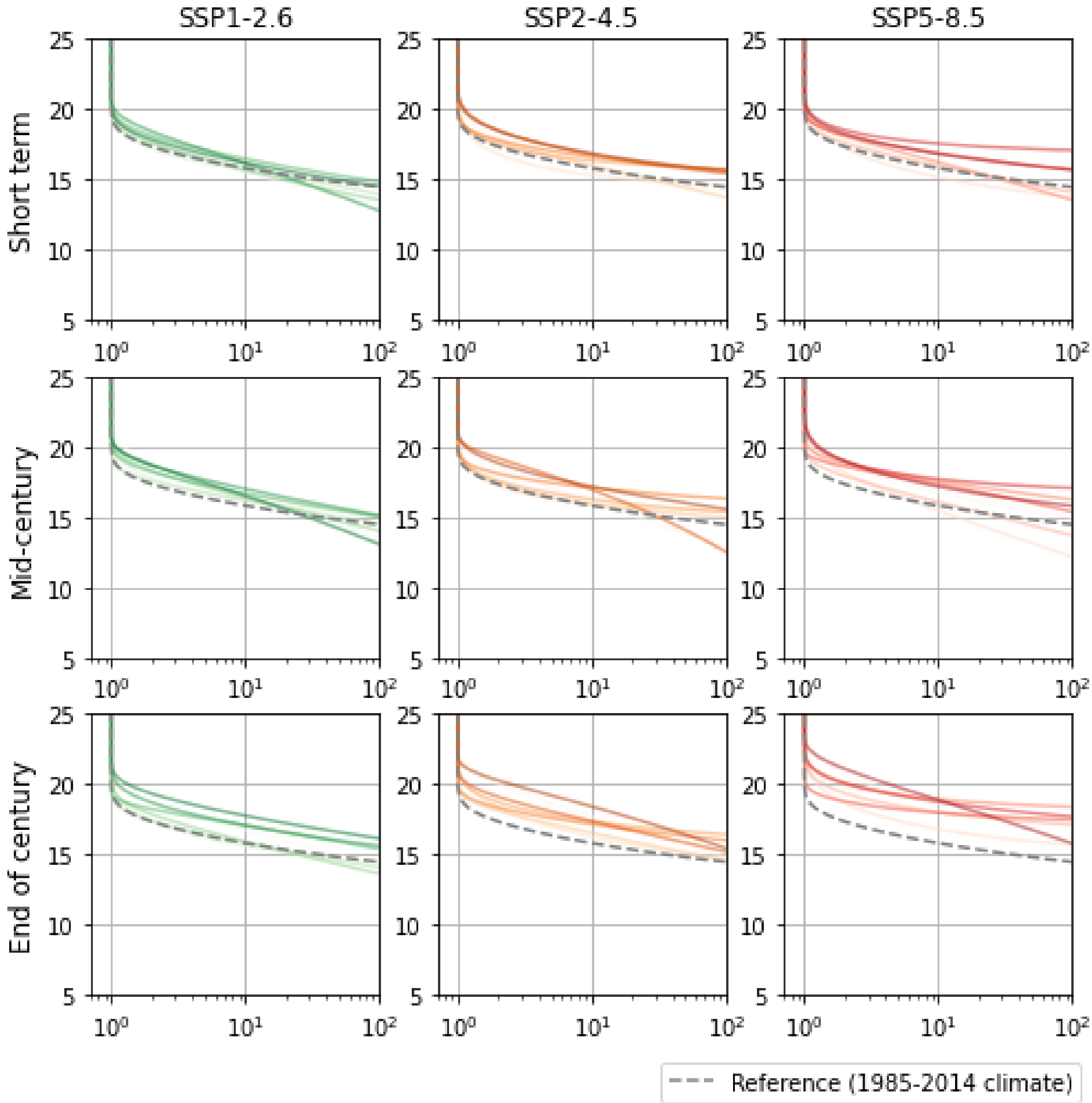


Figure 13: Daily minimum temperature, multimodel return level plots for selected time horizons

Based on the best estimate, over the century, the minimum hourly temperature for a 100-year heat wave could increase by 0.4°C in a low emission scenario, 0.9°C in a medium emissions scenario and 2.4°C in a high emission scenario.

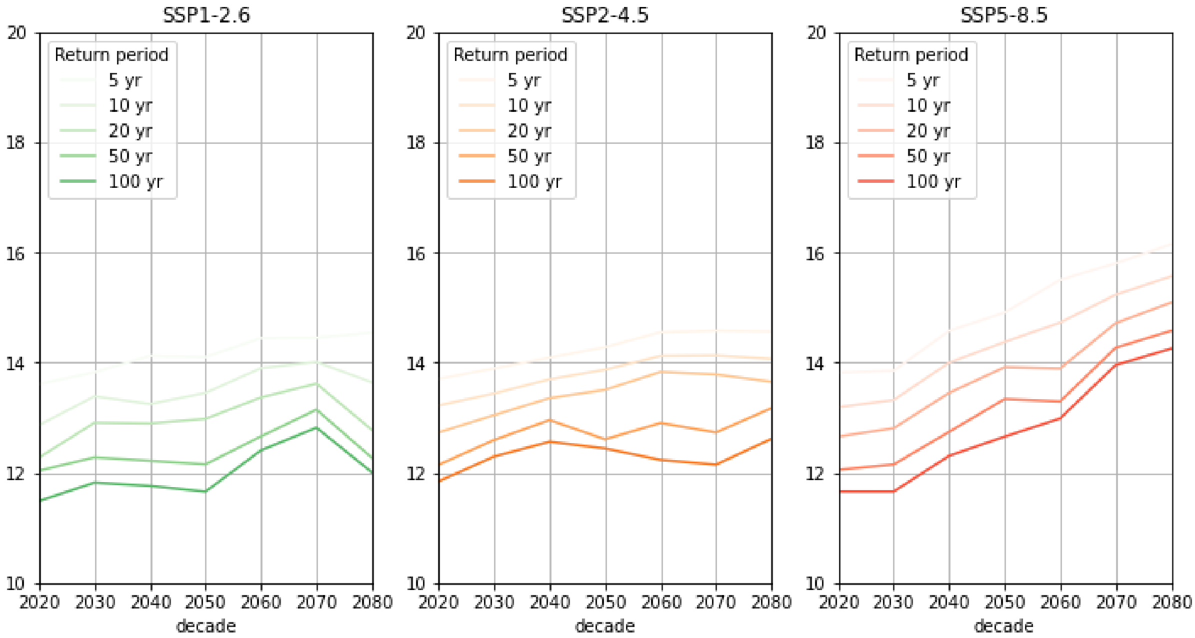


Figure 14: Evolution of hourly temperature for cold spells based on multimodel median

For daily averaged temperatures, the 100-year heat wave could increase by 0.7°C in a low emission scenario, 1.3°C in a medium emissions scenario and 2.5°C in a high emission scenario. The increase should be of the same order of magnitude for shorter return periods:

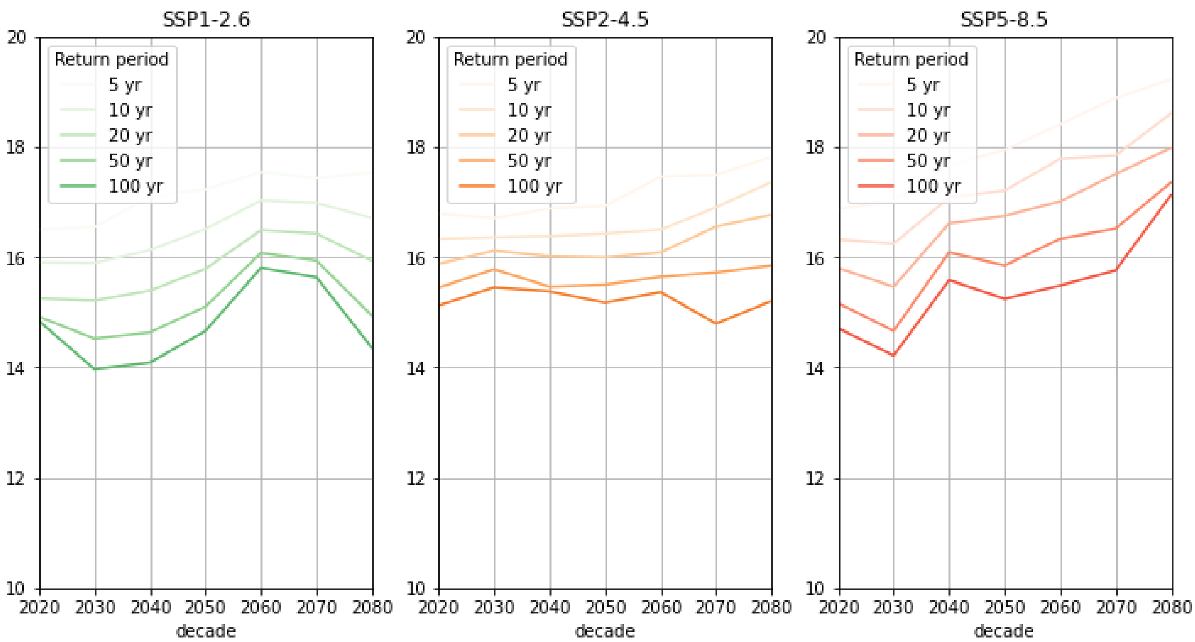


Figure 15: Evolution of daily temperature for cold spells based on multimodel median

6. Average precipitations

1. Overview of the data and methods used

The past climate is based on the closest data point of the ERA5 reanalysis. The spatial resolution of these data is 0.25°. Future climate projections are based on 7 models from the CMIP6 project. Projections are downscaled and corrected using the past climate as a reference.

Please note that values for the reference period are based on reanalysis data, a widely used method for reconstructing past atmospheric conditions by combining observations and high-resolution weather models. Depending on specific local features, results may differ from in-situ observations or reanalysis corrected with in-situ observations.

2. Reference climate and observed trend

Over the reference period (1985-2014), the median annual precipitations were 64 mm/m^2 with a 90% confidence interval extending from 23 to 204 mm/m^2.year. On average 96% of the days were without precipitations (daily total ≤ 1 mm/m^2.day).

The trend in precipitation is downward over the reference period.

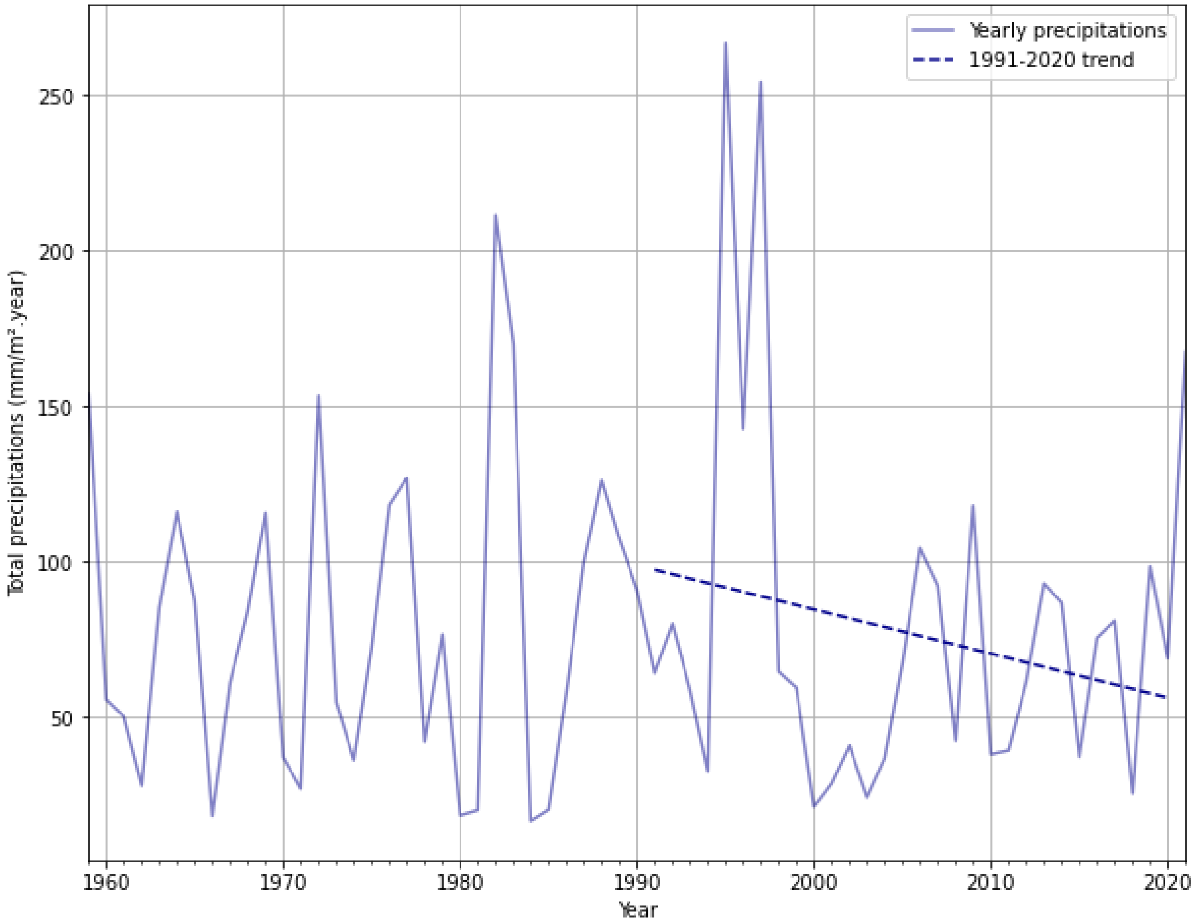


Figure 16: Total annual precipitations and trend

3. Future projections

Average annual precipitations are not expected to vary significantly during the 21st century.

	Scenario			Uncertainties
	SSP1-2.6 (Low GHG emissions scenario)	SSP2-4.5 (Intermediate GHG emissions scenario)	SSP5-8.5 (Very high GHG emissions scenario)	
Reference (1985-2014)	64 mm/m².year			
Short term (2020-2049)	75 mm/m².year [23, 238]	76 mm/m².year [18, 284]	77 mm/m².year [21, 242]	Low
Mid-century (2035-2064)	76 mm/m².year [19, 281]	69 mm/m².year [15, 261]	74 mm/m².year [21, 271]	Low
End of century (2070-2099)	63 mm/m².year [17, 214]	73 mm/m².year [19, 379]	85 mm/m².year [23, 431]	Low

Figure 17: Total annual precipitations projections (median and 90% confidence interval)

Over the next three decades, the best estimate of annual total precipitations is approximately 75 mm/m^2.year with little influence from the emissions scenario. This is consistent with the trend observed over the last 3 decades.

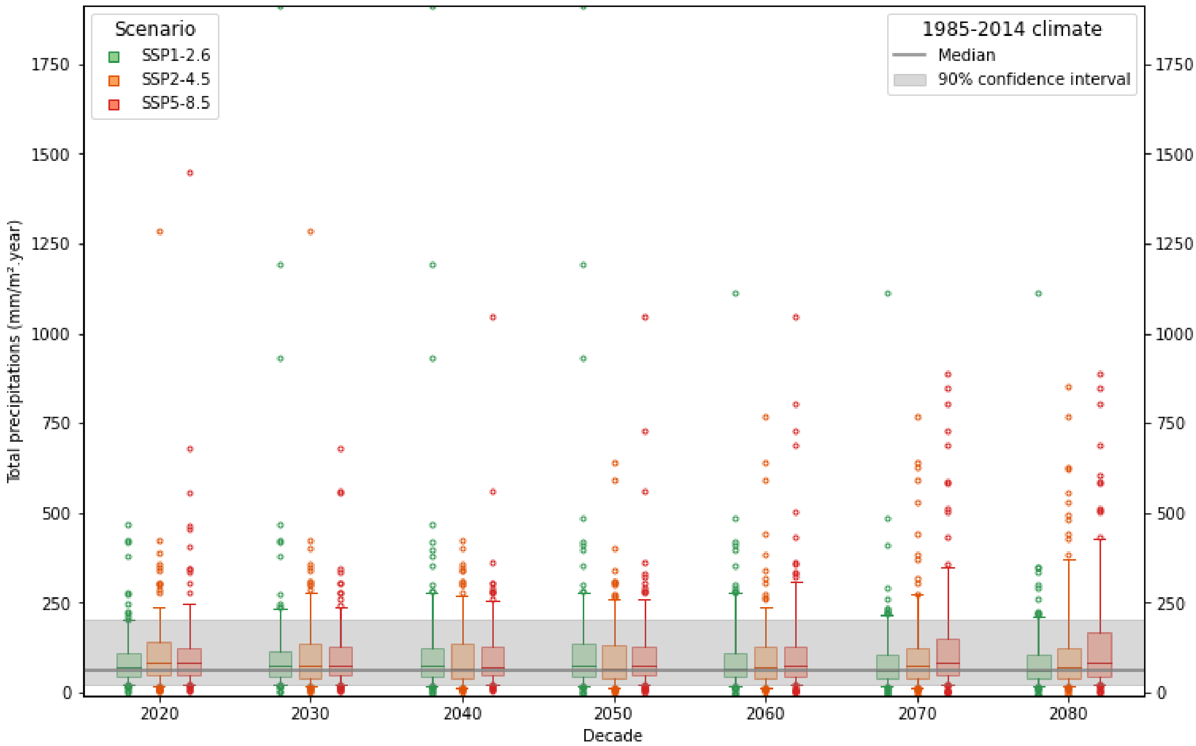


Figure 18 : Total annual precipitations, multimodel boxplot

In all emissions scenarios, the total annual rainfall pattern is expected to remain comparable to the current climate.

4. Individual model projections

All models indicate that the total annual rainfall will remain close to the current climate median and in most cases within its the 90% confidence interval. As a result, uncertainties regarding rainfall pattern are low.

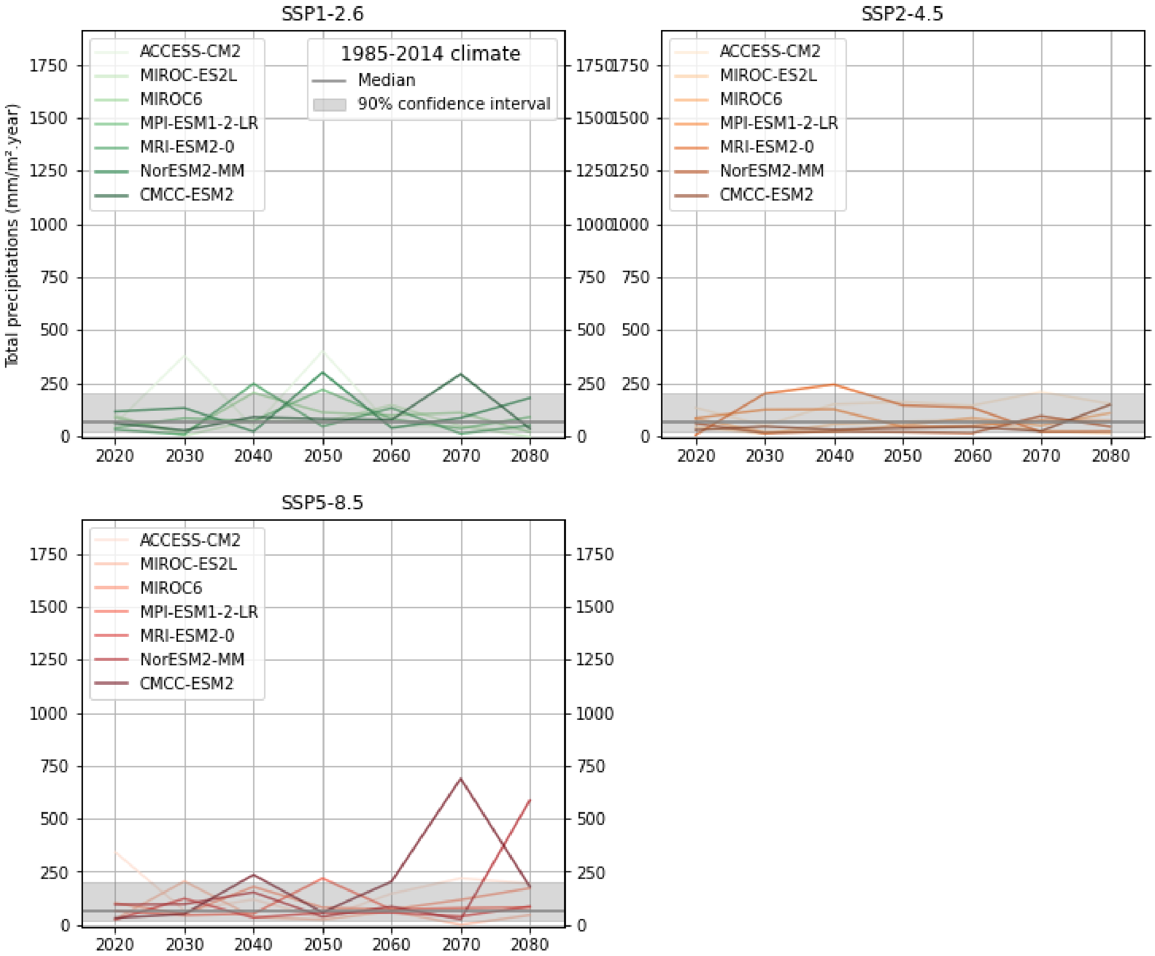


Figure 19: Total annual precipitations by decade (30 year rolling average)

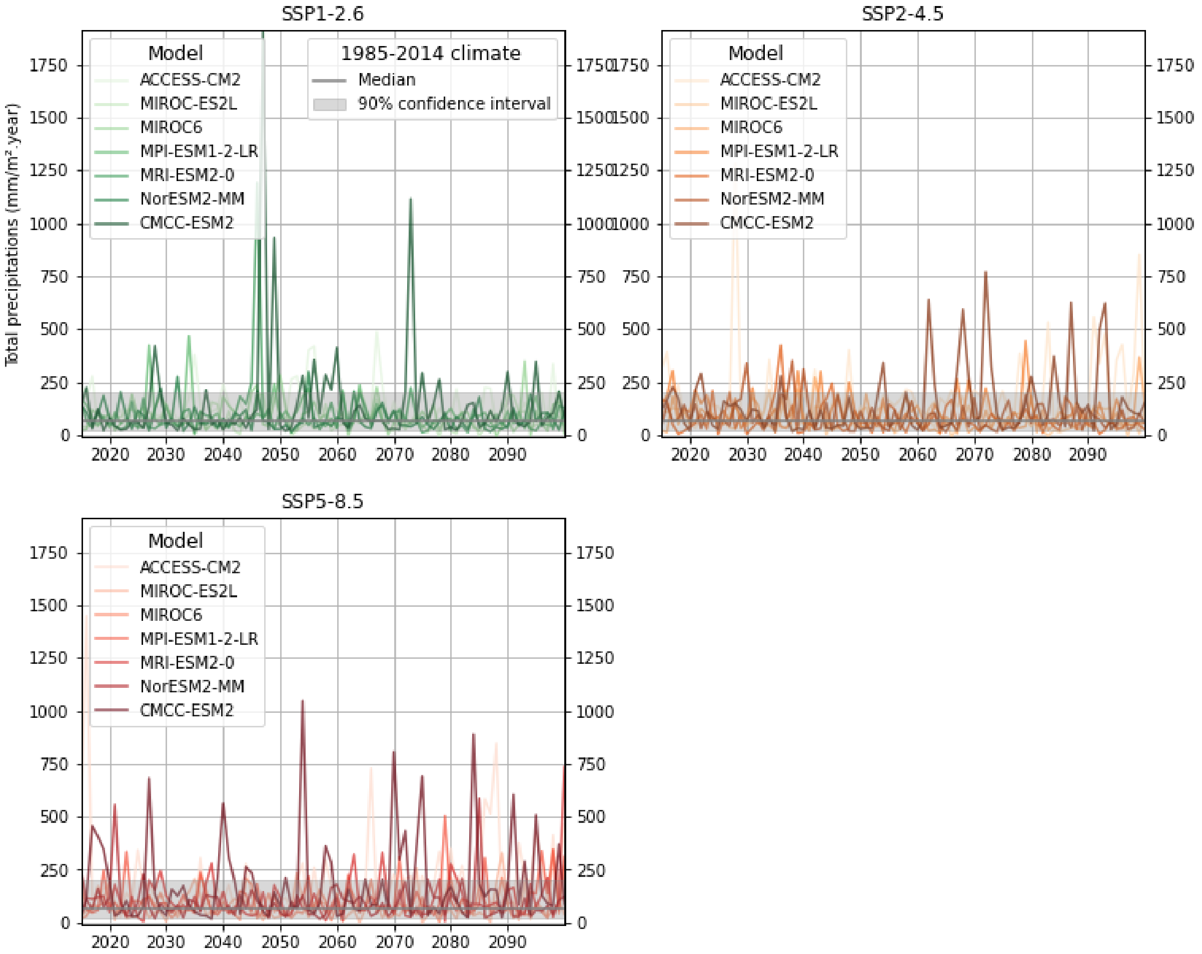


Figure 20: Total annual precipitations simulations

7. Maximum daily precipitations

1. Overview of the data and methods used

The past climate is based on the closest data point of the ERA5 reanalysis. The spatial resolution of these data is 0.25°. Future climate projections are based on 7 models from the CMIP6 project. Projections are downscaled and corrected using the past climate as a reference.
Precipitations extremes for a given return time are evaluated from the known maxima and a Generalized extreme value distribution.

Please note that values for the reference period are based on reanalysis data, a widely used method for reconstructing past atmospheric conditions by combining observations and high-resolution weather models. Depending on specific local features, results may differ from in-situ observations or reanalysis corrected with in-situ observations.

2. Reference climate

Over the reference period (1985-2014), the maximum amount of rainfall during a single day was 60 mm/m^2.day in July 1995. Over these 30 years, the wettest day received 20 mm/m^2.day on average.

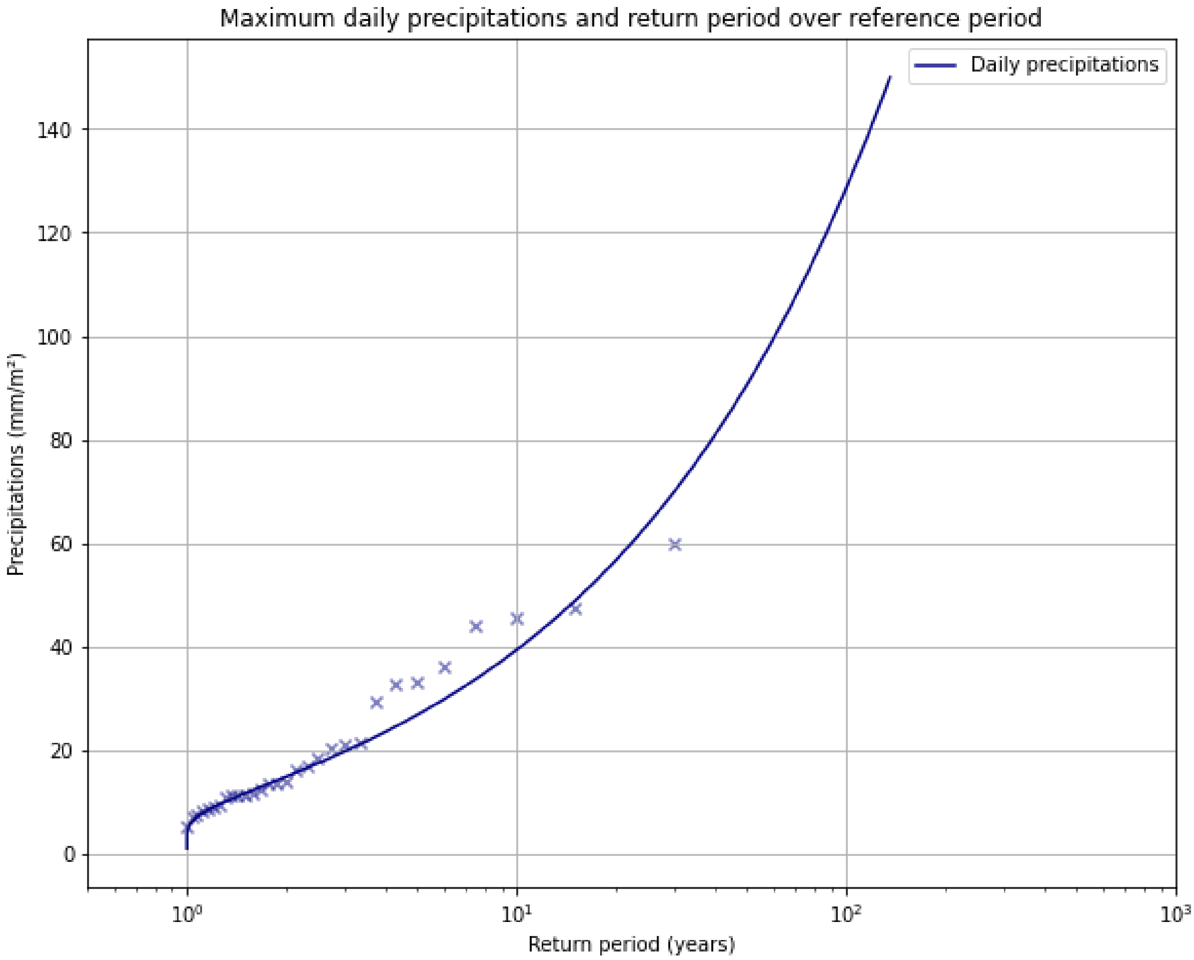


Figure 21: Return periods for maximum daily precipitations over the reference period

Return period	Maximum daily precipitations
5	28 mm/m^2.day
10	39 mm/m^2.day
20	52 mm/m^2.day
50	72 mm/m^2.day
100	92 mm/m^2.day

Figure 22: Maximum daily precipitations for selected return periods

3. Future projections

The severity of extreme precipitations events over the 21st century is uncertain.

There is a no consensus among the models on the evolution of precipitations extremes. However, some models project a significant increase in extreme precipitation even for low emission scenario and short return periods.

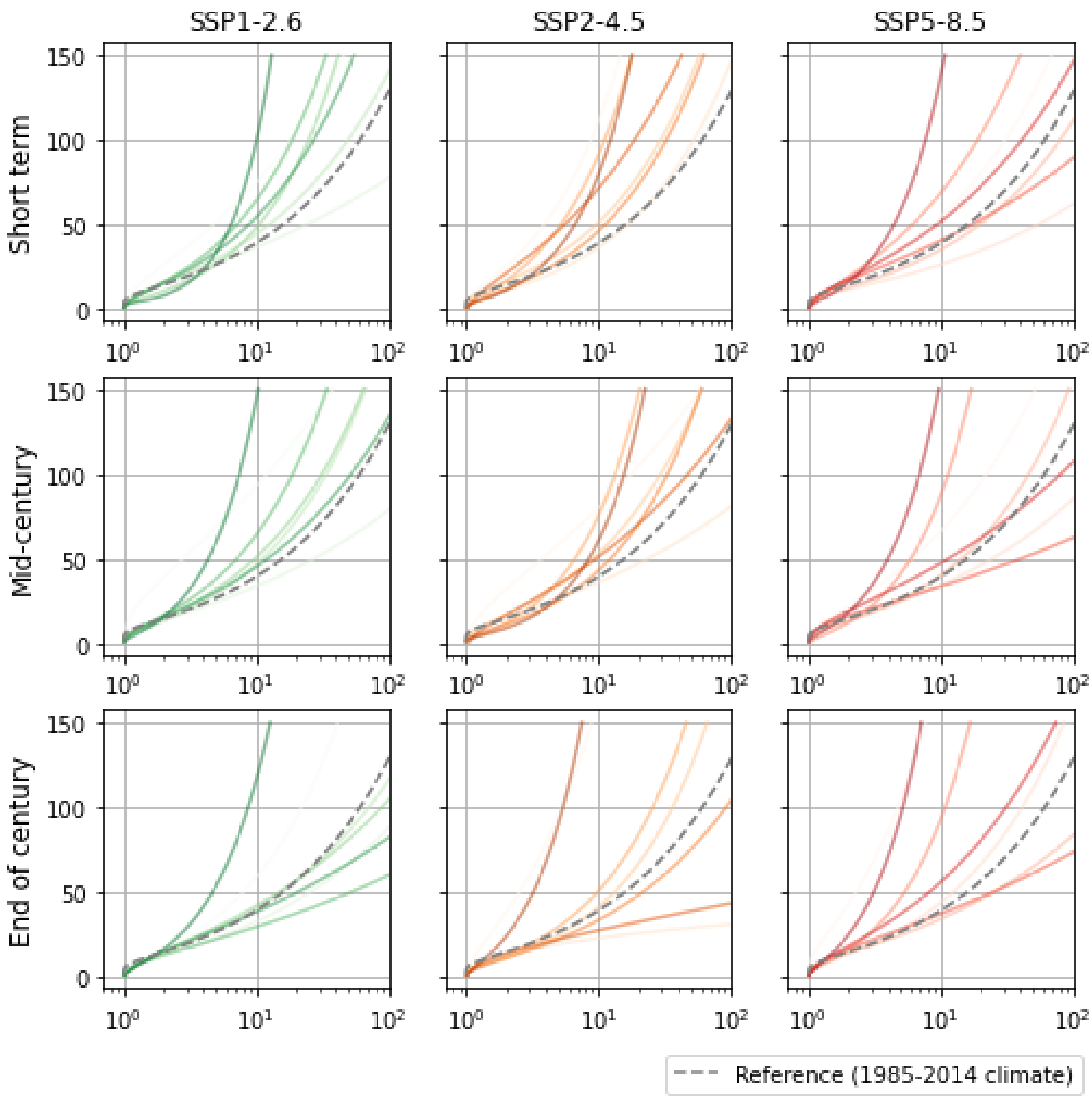


Figure 23: Daily precipitations, multimodel return level plots for selected time horizons

Multimodel medians tend to remain stable but values are to be considered with care as there is little consensus among projections.

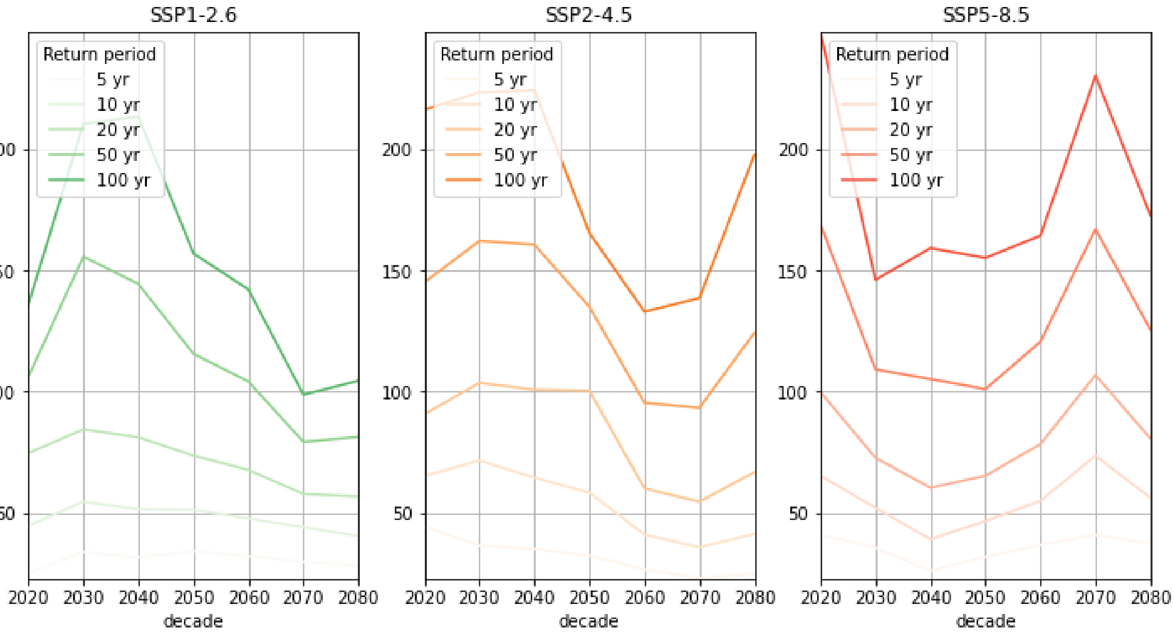


Figure 24: Evolution of daily precipitations for extreme rainfall events based on multimodel median

8. Wind speed

1. Brief overview of the data and methods used

The past climate is based on the closest data point of the ERA5 reanalysis. The spatial resolution of these data is 0.25°. The spatial resolution of these data is 0.25°. Future climate projections are based on 7 models from the CMIP6 project[2]. Projections are downscaled and corrected using the past climate as a reference. Reference and projections use a 3-hour time step.

Wind speeds over 10 minutes, 1 minute and 3 seconds are extrapolated using an empirical model from the ISO 19901-1:2015.
The wind speed extremes for a given return time are evaluated from the known maxima and a generalized extreme value distribution. The 95th centile is used as an estimate of the wind speed corresponding to a 1-yr return period.

Please note that values for the reference period are based on reanalysis data, a widely used method for reconstructing past atmospheric conditions by combining observations and high-resolution weather models. Depending on specific local features, results may differ from in-situ observations or reanalysis corrected with in-situ observations.

2. Reference climate

Over the reference period (1985-2014), the maximum wind speed observed over a 3-hour period at 10 metres was 13.8 m.s^{-1} in February 2003.
This is equivalent to a maximum wind speed of 15.3 m.s^{-1} over a 10-minute period, 16.6 m.s^{-1} over 1 minute and 18.2 m.s^{-1} over 3 seconds.

[2] The models used in this section are different from those used in the previous chapters. See Appendix A.

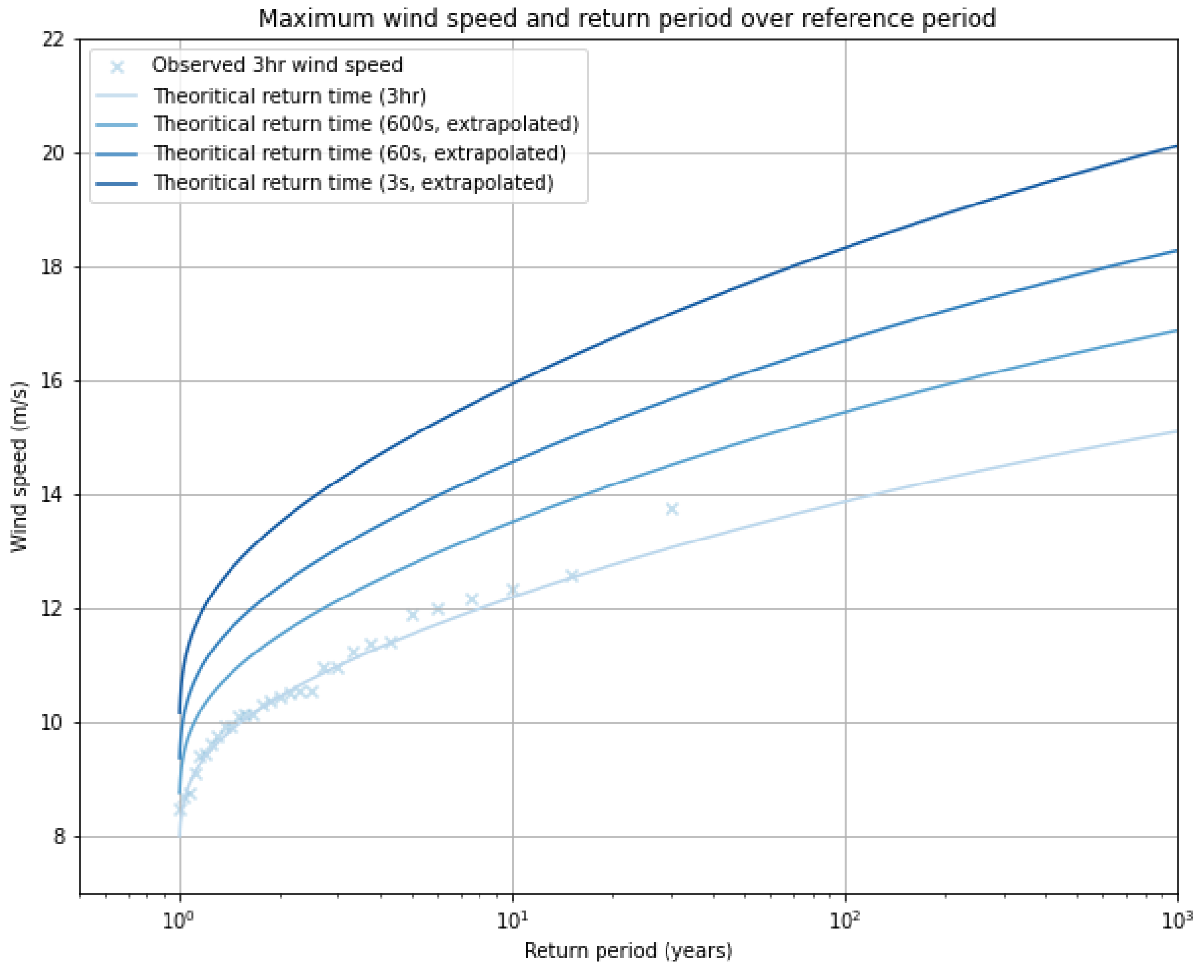


Figure 25: Return periods for maximum wind speeds on the reference period

Based on observations during the reference period, the maximum wind speed for a 100-year return period can be estimated at approximately 15.4 $m.s^{-1}$ over a 10-minute period, 16.7 $m.s^{-1}$ over 1 minute and 18.3 $m.s^{-1}$ over 3 seconds.

RETURN PERIOD	THEORETICAL MAXIMUM WIND SPEED ($m.s^{-1}$)			
	3 hours	10 minutes	1 minute	3 seconds
1 (95th centile)	5.8	6.3	6.7	7.2
5	11.6	12.9	13.9	15.1
10	12.3	13.6	14.7	16.0
20	12.8	14.2	15.4	16.8
50	13.4	15.0	16.2	17.7
100	13.9	15.4	16.7	18.3

Figure 26: Maximum wind speeds for selected return periods

3. Future projections

Most models point to a decrease in maximum wind speed. However, some models indicate a possible increase in a high emissions scenario.

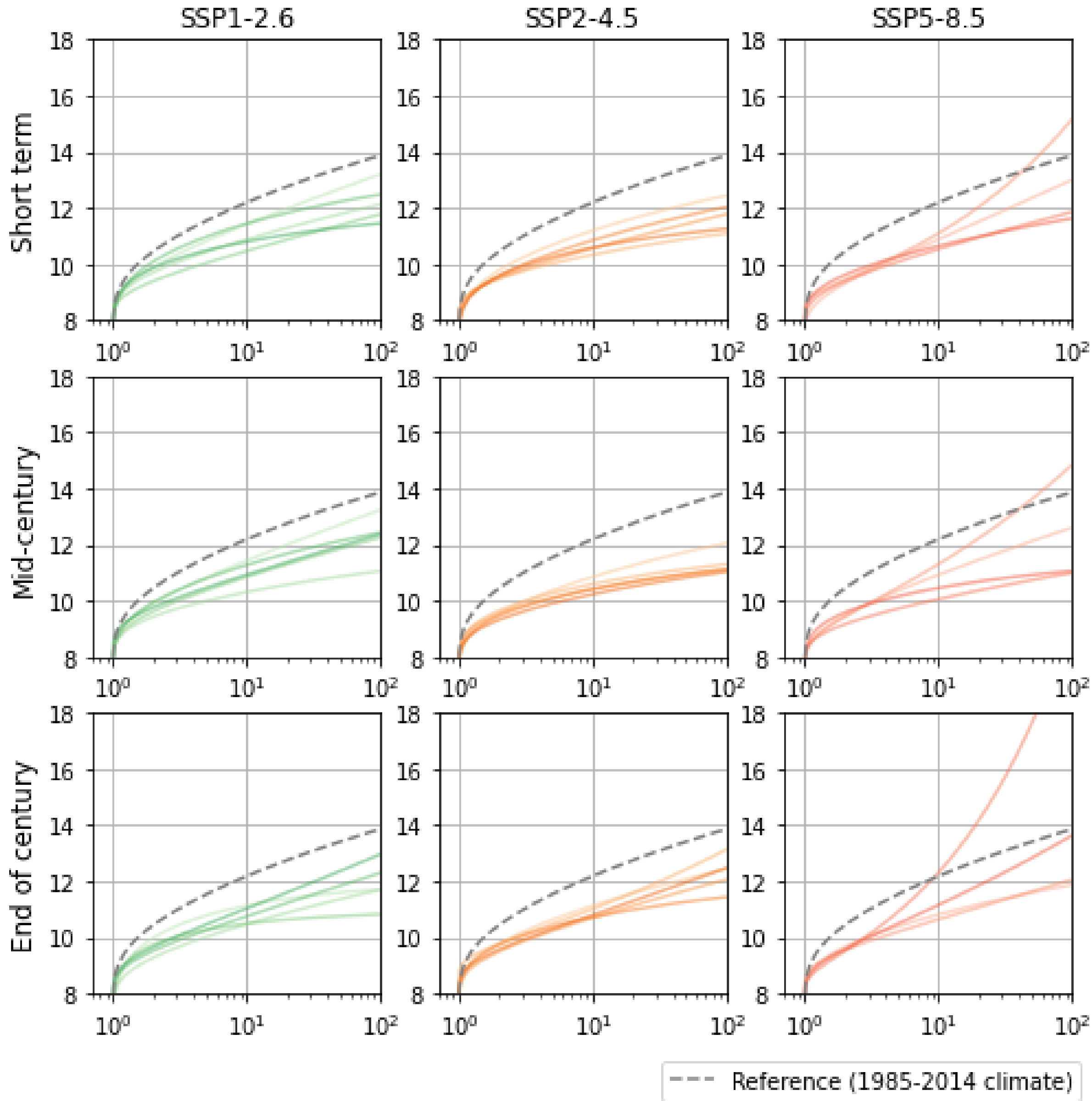


Figure 27: 3-hour maximum wind speed, multimodel return level plots for selected time horizons

Based on the multimodel median, over the century, the 3-hour maximum wind speed for a 100-year event could decrease by approximately 1 $m.s^{-1}$ in a high emission scenario and 2 $m.s^{-1}$ in a low emissions scenario.

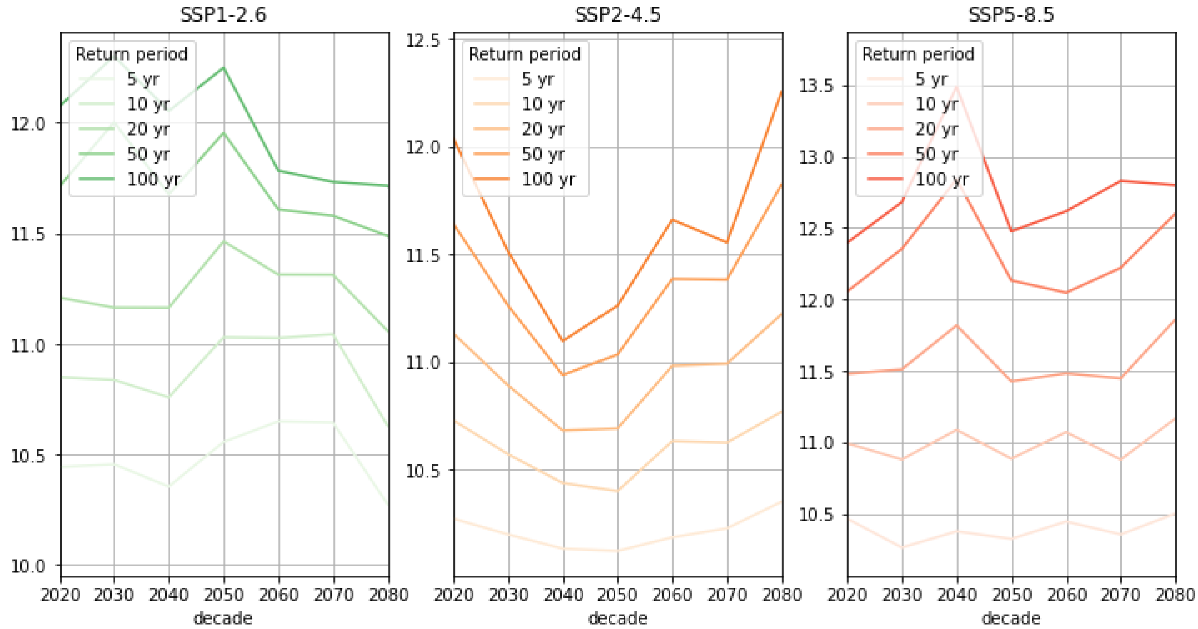


Figure 28: Evolution of extreme 3-hr wind speed based on multimodel median

EMISSIONS SCENARIO	MID-CENTURY 100-YR MAXIMUM WIND SPEED ($m.s^{-1}$)			
	3 hours	10 minutes	1 minute	3 seconds
SSP1-2.6	12.2	13.6	14.6	16.0
SSP2-4.5	11.3	12.4	13.4	14.6
SSP5-8.5	12.5	13.8	14.9	16.3

Figure 29: 100-year return period extreme wind at the mid-21st century based on multi-model median

EMISSIONS SCENARIO	END OF CENTURY 100-YR MAXIMUM WIND SPEED ($m.s^{-1}$)			
	3 hours	10 minutes	1 minute	3 seconds
SSP1-2.6	11.7	13.0	14.0	15.3
SSP2-4.5	12.3	13.6	14.6	16.0
SSP5-8.5	12.8	14.2	15.3	16.8

Figure 30: 100-year return period extreme wind at the end of the 21st century based on multi-model median

9. Sea level

1. Overview of the data and methods used

Future sea level is based on the closest data point of the IPCC's 6th assessment report's projections. The spatial resolution of these data is 1°.

Box 2: Assumptions for sea level projections

While there is a high level of confidence that sea levels will continue to rise in the coming decades and centuries due to the warming of the Earth's atmosphere and oceans caused by human activities, the exact level at some point in the future is still uncertain.

To reflect those uncertainties, the IPCC's Sixth Assessment Report provide two sets of projections:
- "Medium confidence" projections include only processes that can be projected skillfully with at least medium confidence,
- "Low confidence" projections consider processes whose quantification is highly uncertain regarding the timing of their possible onset and/or their effect on sea level rise.

Low confidence projections are on average higher and the gap between the two projections increases with time and greenhouse gases concentrations.

The projection to be used depends on the lifespan of the project, on its ability to adapt to a faster-than-expected sea level rise, and on the level of risk that is deemed acceptable.
According to the IPCC, stakeholders that are risk tolerant (e.g., those planning for investments that can be easily adapted to unforeseen conditions) may prefer to use projections in the medium confidence range while those with a low risk tolerance (e.g., those planning for long-term investment in critical infrastructure) may wish to consider sea level rise that falls within the high-end scenario.

2. Best estimate

Based on median projections, by mid-century, sea level is likely to have risen by about 20 centimetres compared to the average level over the period 1985-2014. This result is not very sensitive to the emission scenario or assumptions used.

By 2080, the sea level could have risen by about 29 to 52 centimetres depending on the level of emissions and the assumptions made with a low probability to exceed 137 cm in a pessimistic scenario.

3. Medium confidence projections

Considering only processes that can be modelled with medium or high confidence, the median projection for sea level by 2050 compared to the average from 1985-2014 is expected to be approximately 20 centimetres with the upper bound of the 90% confidence interval below 40 centimetres.

Figure 31: Sea level compared to 1985-2014 average, medium confidence projections

The influence of emission levels remains limited in the second half of the century. In 2080, the median projection varies from 29 to 47 centimetres, depending on the scenario, with the upper bound of the confidence interval between 59 and 84 centimetres.

	Scenario		
	SSP1-2.6 (Low GHG emissions scenario)	SSP2-4.5 (Intermediate GHG emissions scenario)	SSP5-8.5 (Very high GHG emissions scenario)
Mid-century (2050)	17 cm [5, 32]	19 cm [7, 34]	22 cm [9, 39]
End of century (2080)	29 cm [8, 59]	36 cm [13, 68]	47 cm [23, 84]

Figure 32: Sea level medium confidence projection compared to 1985-2014 average (median and 90% confidence interval)

4. Low confidence projections

Considering all the processes, even when their modelling is still uncertain, does not change the median projection for 2050 but the 90% confidence interval is wider, with its upper bound between 40 and 54 centimetres depending on the emissions scenario.

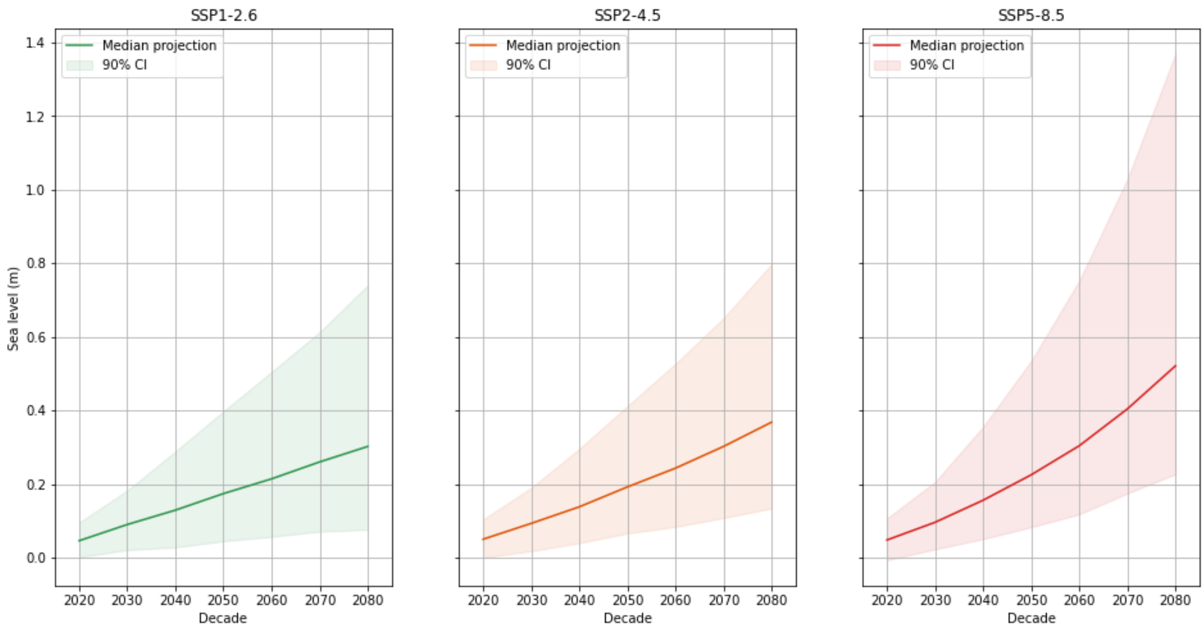


Figure 33: Sea level compared to 1985-2014 average, low confidence projections

With these assumptions, median projections for the second half of the century do not change significantly. But the uncertainties are larger, with the upper bound of the confidence interval between 74 and 137 centimetres depending on the scenario.

	Scenario		
	SSP1-2.6 (Low GHG emissions scenario)	SSP2-4.5 (Intermediate GHG emissions scenario)	SSP5-8.5 (Very high GHG emissions scenario)
Mid-century (2050)	17 cm [5, 40]	19 cm [7, 41]	22 cm [8, 54]
End of century (2080)	30 cm [8, 74]	37 cm [13, 80]	52 cm [23, 137]

Figure 34: Sea level low confidence projection compared to 1985-2014 average (median and 90% confidence interval)

10. Wind waves

1. Brief overview of the data and methods used

The past climate is based on the closest data point of the ERA5 reanalysis. The spatial resolution of these data is 0.5°. Future wind waves projections are based on 3 models, 2 from the Australian CSIRO and 1 from the Chinese First Institute of Oceanography. Projections are downscaled and corrected using the past climate as a reference. All projections use a 3-hour time step.
Waves projections for the scenario SSP2-4.5 are available only from the FIO's model.

Extremes significant waves height for a given return time are evaluated from the known maxima and a generalized extreme value distribution. Corresponding Maximum wave height and peak wave period are evaluated using empirical models.

Please note that values for the reference period are based on reanalysis data, a widely used method for reconstructing past atmospheric conditions by combining observations and high-resolution weather models. Depending on specific local features, results may differ from in-situ observations or reanalysis corrected with in-situ observations.

2. Reference climate

Over the reference period (1985-2014), the Maximum significant wave height observed over a 3-hour period was 3.1 metres in February 2003. This corresponds to a maximum wave height of around 5.7 metres.
The peak wave period during this observation was 7.4 seconds.

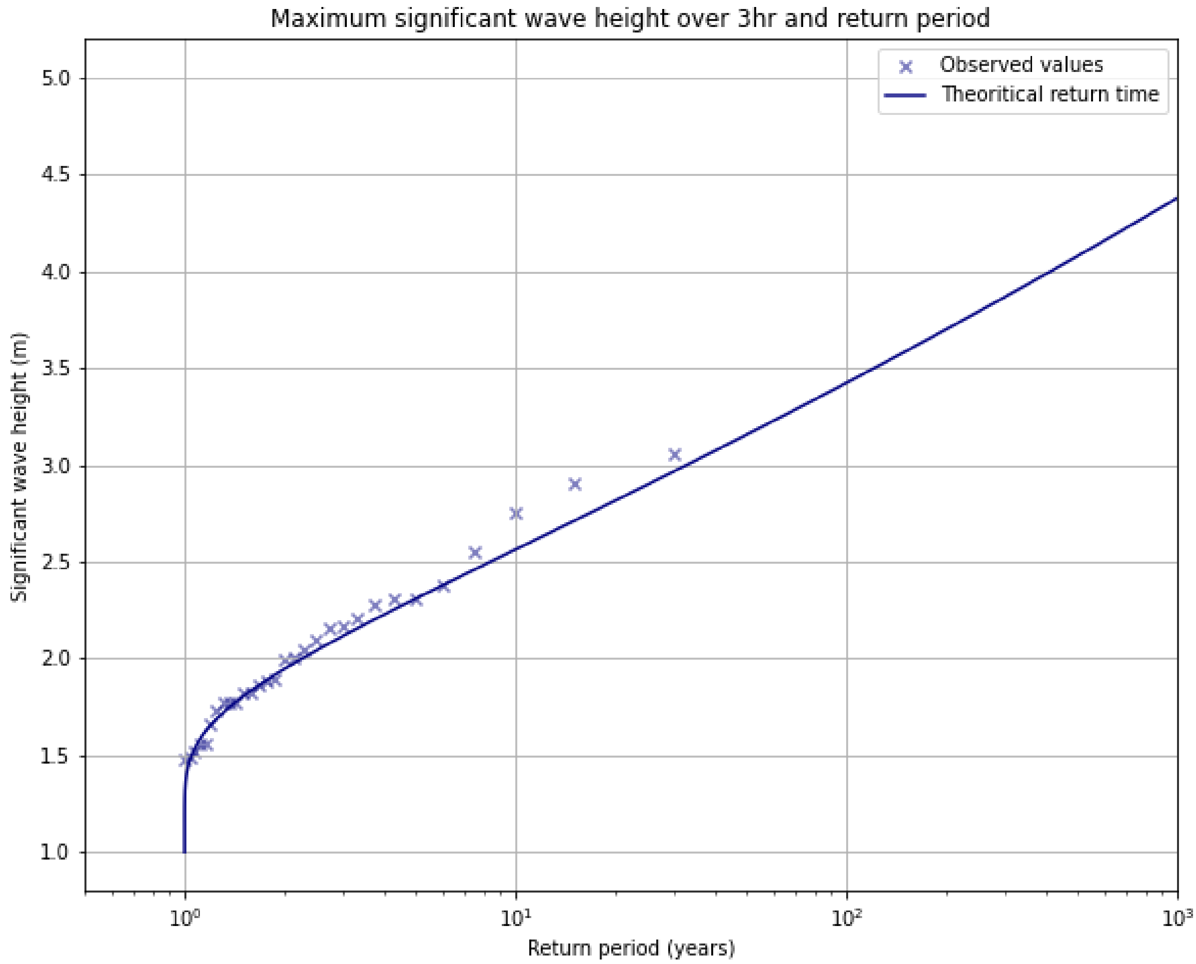


Figure 35: Return periods for maximum wave height during the reference period

Based on observations during the reference period, the maximum significant wave height for a 100-year return period can be estimated at approximately 3.4 metres.

RETURN PERIOD	MAXIMUM WAVE (m)		PEAK WAVE PERIOD (s)
	Significant height	Maximum height	
5	2.3	4.3	6.6
10	2.6	4.8	6.9
20	2.8	5.2	7.1
50	3.2	5.9	7.4
100	3.4	6.3	7.5

Figure 36: Maximum wave heights and peak period for selected return periods

3. Future projections

The evolution of extreme wave heights over the 21st century is uncertain. There is no consensus between models on the direction and magnitude of this evolution.

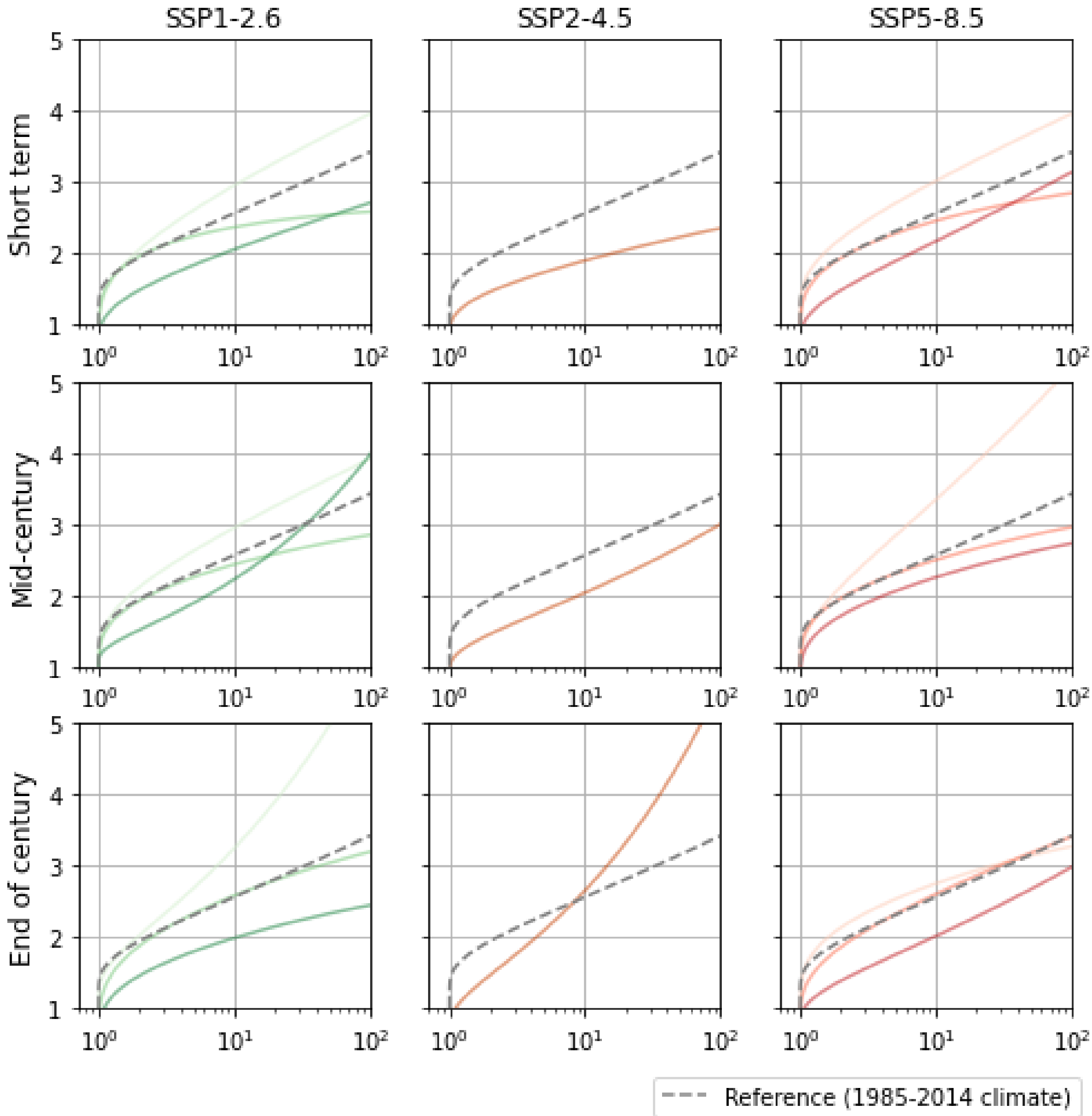


Figure 37: Significant wave height, multimodel return level plots for selected time horizons

It is not possible to make a reliable estimate of future extreme wave heights over the century on the basis of these projections. However, some models suggest that a significant increase is possible, particularly for long-return periods.

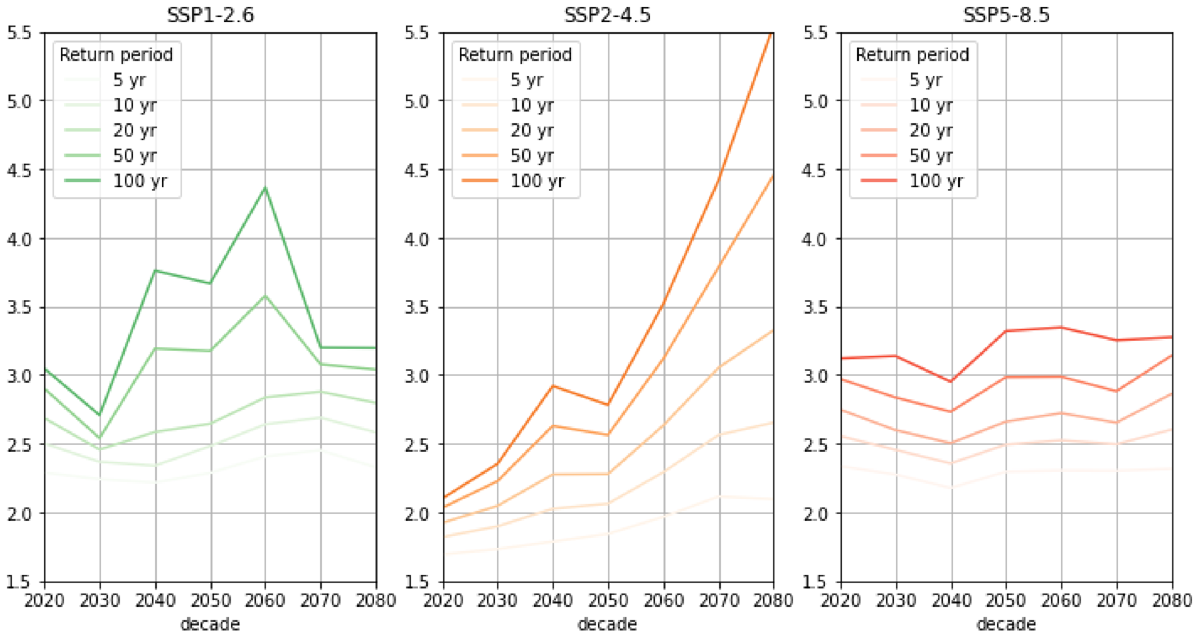


Figure 38: Evolution of extreme significant wave heights based on multimodel median

EMISSIONS SCENARIO	MID-CENTURY 100-YR EXTREME (m)		PEAK WAVE PERIOD (s)
	Significant height	Maximum height	
SSP1-2.6	3.7	6.8	7.7
SSP2-4.5	2.8	5.2	7.1
SSP5-8.5	3.3	6.2	7.5

Figure 39: 100-year return period extreme wave height at the mid-21st century based on multi-model median

EMISSIONS SCENARIO	END OF CENTURY 100-YR EXTREME (m)		PEAK WAVE PERIOD (s)
	Significant height	Maximum height	
SSP1-2.6	3.2	5.9	7.4
SSP2-4.5	5.6	10.3	9.0
SSP5-8.5	3.3	6.1	7.5

Figure 40: 100-year return period extreme wave height at the end of the 21st century based on multi-model median

Appendix A: Models used

The projections used in this report come from the following global circulation models for all chapters except wind and waves:

Model	Producer	Country
ACCESS-CM2	CSIRO	Australia
CMCC-ESM2	CMCC	Italy
MIROC-ES2L	MIROC	Japan
MIROC6	MIROC	Japan
MPI-ESM1-2-LR	MPI-M	Germany
MRI-ESM2-0	MRI	Japan
NorESM2-MM	NCC	Norway

Due to the limited availability of projections with a 3-hour time step, a different set of models had to be used for the wind chapter. It consists of the following models:

Model	Producer	Country
CMCC-ESM2	CMCC	Italy
MIROC6	MIROC	Japan
MPI-ESM1-2-LR	MPI-M	Germany
CMCC-CM2-SR5	CMCC	Italy
CNRM-CM6-1	CNRM	France
CNRM-ESM2-1	CNRM	France
IPSL-CM6A-LR	IPSL	France

Due to the limited availability of wave projections, only 3 models were used:

Model	Producer	Country
ACCESS-CM2	CSIRO	Australia
EC-EARTH3	European consortium	Europe
FIO-ESM v2.0	FIO	China

Waves projections for the scenario SSP2-4.5 were available only from the FIO's model.

Appendix B: Definitions and abbreviations

Best estimate: In this document "best estimate" always refers to the multimodel median projection, i.e.: the middle value in the range of possible outcome yield by the set of models being used.

Bias: The difference between the observed data and modeled results that occurs due model imperfections.

Coupled Model Intercomparison Project (CMIP): A project of the World Climate Research Program to coordinate global climate modeling efforts. The projections produced within the framework of the CMIP project serve as a reference for the IPCC reports: the 5th wave of the CMIP project (CMIP5) corresponds to the 5th IPCC assessment report published in 2014, the 6th wave (CMIP6) is being finalized and corresponds to the 6th IPCC assessment report, published in 2021.

Correction: Bias correction or adjustment of modeled values to reflect the observed distribution and statistics.

Downscaling: Derivation of local to regional-scale (10-100 kilometers) information from larger scale modeled or observed data. There are two main approaches: dynamical downscaling and statistical downscaling.

European Centre for Medium-Range Weather Forecasts (ECMWF): European Centre for Medium-Range Weather Forecasts

Emissions Scenario: Estimates of future greenhouse gas emissions released into the atmosphere. Such estimates are based on possible projections of economic and population growth and technological development, as well as physical processes within the climate system.

ERA5: ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate. It provides hourly estimates of a large number of atmospheric, land and oceanic climate variables 1940 to present on a regular 0.25°x0.25° grid.

General Circulation Model (GCM): A global computer model of the climate system that can be used to simulate past, present and future climate. GCMs represent the effects of such factors as reflective and absorptive properties of atmospheric water vapor, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures, and ice boundaries.

Shared Socioeconomic Pathways (SSP): SSPs are a set of scenarios developed by the scientific community to explore different possible futures of socioeconomic development and their implications for greenhouse gas emissions and climate change. In this document, 3 SSPs are uses: SPP1-2.6 (low emissions scenario), SPP2-4.5 (intermediate emissions scenario) and SPP5-8.5 (very high emissions scenario).

Spatial downscaling: Refers to the methods used to derive climate information at finer spatial resolution from coarser spatial resolution GCM output.

Reanalysis: Reconstruction of historical weather and climate conditions using a combination of observational data, including surface weather stations, satellites, buoys, and other instruments, and numerical models.

Reference period: In accordance with the recommendations of the World Meteorological Organization, this document uses a reference period of 30 years. The reference period for all variables is 1985-2014. This period was chosen to be consistent with the standards of the CMIP6 project.

Return period: Refers to the average time interval between occurrences of an extreme event of a certain magnitude. As extrems events with long return periods are very rare, return period is typically calculated statistical methods such as the generalized extreme value (GEV) distribution.

Appendix C: legal notices

1. ERA5

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2. CMIP6

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Model	Producer	License
ACCESS-CM2	CSIRO	CC BY-SA 4.0
CMCC-ESM2	CMCC	CC BY-SA 4.0
MIROC-ES2L	MIROC	CC BY-SA 4.0
MIROC6	MIROC	CC BY-SA 4.0
MPI-ESM1-2-LR	MPI-M	CC BY-SA 4.0
MRI-ESM2-0	MRI	CC BY-SA 4.0
NorESM2-MM	NCC	CC BY-SA 4.0
CMCC-CM2-SR5	CMCC	CC BY-SA 4.0
CNRM-CM6-1	CNRM-CERFACS	CC BY-NC-SA 4.0
CNRM-ESM2-1	CNRM-CERFACS	CC BY-NC-SA 4.0
IPSL-CM6A-LR	IPSL	CC BY-NC-SA 4.0

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3. CSIRO

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Consult https://data.csiro.au/collection/csiro:53176

4. FIO

CSIRO waves data is licensed under a Creative Commons International License CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Consult https://figshare.com/collections/Simulated_long-term_3-hourly_ocean_surface_waves_parameters_from_FIO-ESM_v2_0_CMIP6_experiments_for_past_present_and_future_climate_research/4839729/1

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