Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the Environment

KNMI'14

climate scenarios *for the Netherlands*

A guide for professionals in climate adaptation

Contents

KNMI is the national data and knowledge institute for climate science. As an agency of the Ministry of Infrastructure and the Environment KNMI advises the Dutch government on climate change. Being a scientific institute, KNMI contributes to international climate research and represents the Netherlands in the Intergovernmental Panel on Climate Change (IPCC). KNMI is constantly optimizing the measuring network and refining climate models, which run on the KNMI super-computer. Calculations carried out using these models form the basis of the KNMI climate scenarios for the Netherlands, which provide an applied product to policy advisors and other professionals to help them taking appropriate decisions for a safe and sustainable Netherlands in a changing climate.

Season [A)]	Variable	Indicator	Climate [B)] 1951-1980	Climate [B)] 1981-2010 = reference period
	Global temperature rise:			
	Change in air circulation pattern:			
Year	Sea level at North Sea coast	absolute level [E)]	4 cm below NAP	3 cm above NAP
		rate of change	1.2 mm/year	2.0 mm/year
	Temperature	mean	9.2 °C	10.1 °C
	Precipitation	mean amount	774 mm	851 mm
	Solar radiation	solar radiation	346 kJ/cm^2 [F)]	354 kJ/cm^2
	Evaporation	potential evaporation (Makkink)	534 mm [F)]	559 mm
	Fog	number of hours with visibility < 1 km	412 hours	300 hours [G)]
Winter	Temperature	mean	2.4 °C	3.4 °C
		year-to-year variation [H)]	-	± 2.6 °C
		daily maximum	5.1 °C	6.1 °C
		daily minimum	-0.3 °C	0.5 °C
		coldest winter day per year	-7.5 °C	-5.9 °C
		mildest winter day per year	10.3 °C	11.1 °C
		number of frost days (min temp < 0°C)	42 days	38 days
		number of ice days (max temp < 0°C)	11 days	7.2 days
	Precipitation	mean amount	188 mm	211 mm
		year-to-year variation [H)]	-	± 96 mm
		10-day amount exceeded once in 10 years [I)]	80 mm	89 mm
		number of wet days (≥ 0.1 mm)	56 days	55 days
		number of days ≥ 10 mm	4.1 days	5.3 days
	Wind	mean wind speed	-	6.9 m/s
		highest daily mean wind speed per year	-	15 m/s
		number of days between south and west	44 days	49 days
Spring	Temperature	mean	8.3 °C	9.5 °C
	Precipitation	mean amount	148 mm	173 mm
Summer	Temperature	mean	16.1 °C	17.0 °C
		year-to-year variation [H)]	-	± 1.4 °C
		daily maximum	20.7 °C	21.9 °C
		daily minimum	11.2 °C	11.9 °C
		coolest summer day per year	10.3 °C	11.1 °C
		warmest summer day per year	23.2 °C	24.7 °C
		number of summer days (max temp ≥ 25°C)	13 days	21 days
		number of tropical nights (min temp ≥ 20°C)	< 0.1 days	0.1 days
	Precipitation	mean amount	224 mm	224 mm
		year-to-year variation [H)]	-	± 113 mm
		daily amount exceeded once in 10 years [I)]	44 mm	44 mm
		maximum hourly intensity per year	14.9 mm/hour	15.1 mm/hour
		number of wet days (≥ 0.1mm)	45 days	43 days
		number of days ≥ 20 mm	1.6 days	1.7 days
	Solar radiation	solar radiation	149 kJ/cm^2 [F)]	153 kJ/cm^2
	Humidity	relative humidity	78%	77%
	Evaporation	potential evaporation (Makkink)	253 mm [F)]	266 mm
	Drought	mean highest precipitation deficit during growing season [J)]	140 mm	144 mm
		highest precipitation deficit exceeded once in 10 years [I)]	-	230 mm
Autumn	Temperature	mean	10.0 °C	10.6 °C
	Precipitation	mean amount	214 mm	245 mm

Scenario change values for the climate around **2050** C) (2036-2065)				Scenario change values for the climate around **2085** C) (2071-2100)				Natural variations averaged over 30 years D)
G_L	G_H	W_L	W_H	G_L	G_H	W_L	W_H	
+1 °C	+1 °C	+2 °C	+2 °C	+1.5 °C	+1.5 °C	+3.5 °C	+3.5 °C	
Low value	High value	Low value	High value	Low value	High value	Low value	High value	
+15 to +30 cm	+15 to +30 cm	+20 to +40 cm	+20 to +40 cm	+25 to +60 cm	+25 to +60 cm	+45 to +80 cm	+45 to +80 cm	± 1.4 cm
+1 to +5.5 mm/year	+1 to +5.5 mm/year	+3.5 to +7.5 mm/year	+3.5 to +7.5 mm/year	+1 to +7.5 mm/year	+1 to +7.5 mm/year	+4 to +10.5 mm/year	+4 to +10.5 mm/year	± 1.4 mm/year
+1.0 °C	+1.4 °C	+2.0 °C	+2.3 °C	+1.3 °C	+1.7 °C	+2.8 °C	+3.7 °C	± 0.16 °C
+4%	+2.5%	+5.5%	+5%	+5%	+5%	+6%	+7 %	± 4.2%
+0.6%	+1.6%	-0.8%	+1.2%	-0.5%	+1.1%	-0.8%	+1.4 %	± 1.6%
+3%	+5%	+4%	+7%	+2.5%	+5.5%	+6%	+10 %	± 1.9%
-110 hours	-110 hours	-110 hours	-110 hours	-120 hours	-120 hours	-120 hours	-120 hours	± 39 hours
+1.1 °C	+1.6 °C	+2.1 °C	+2.7 °C	+1.3 °C	+2.0 °C	+2.8 °C	+4.1 °C	± 0.48 °C
-8%	-16%	-13%	-20%	-10%	-17%	-13%	-24%	-
+1.0 °C	+1.6 °C	+2.0 °C	+2.5 °C	+1.2 °C	+2.0 °C	+2.7 °C	+3.8 °C	± 0.46 °C
+1.1 °C	+1.7 °C	+2.2 °C	+2.8 °C	+1.4 °C	+2.1 °C	+3.0 °C	+4.4 °C	± 0.51 °C
+2.0 °C	+3.6 °C	+3.9 °C	+5.1 °C	+2.7 °C	+4.1 °C	+4.8 °C	+7.3 °C	± 0.91 °C
+0.6 °C	+0.9 °C	+1.7 °C	+1.7 °C	+1.0 °C	+1.2 °C	+2.4 °C	+3.1 °C	± 0.42 °C
-30%	-45%	-50%	-60%	-35%	-50%	-60%	-80%	± 9.5%
-50%	-70%	-70%	-90%	-60%	-80%	-80%	< -90%	± 31%
+3%	+8%	+8%	+17%	+4.5%	+12%	+11%	+30%	± 8.3%
+4.5%	+9%	+10%	+17%	+6.5%	+12%	+14%	+30%	-
+6%	+10%	+12%	+17%	+8%	+12%	+16%	+25%	± 11%
-0.3%	+1.4%	-0.4%	+2.4%	+0.3%	+1.0%	-0.9%	+3%	± 4.7%
+9.5%	+19%	+20%	+35%	+14%	+24%	+30%	+60%	± 14%
-1.1%	+0.5%	-2.5%	+0.9%	-2.0%	+0.5%	-2.5%	+2.2%	± 3.6%
-3%	-1.4%	-3%	0.0%	-2.0%	-0.9%	-1.8%	+2.0%	± 3.9%
-1.4%	+3%	-1.7%	+4.5%	-1.6%	+6.5%	-6.5%	+4%	± 6.4%
+0.9 °C	+1.1 °C	+1.8 °C	+2.1 °C	+1.2 °C	+1.5 °C	+2.4 °C	+3.1 °C	± 0.24 °C
+4.5%	+2.3%	+11%	+9%	+8%	+7.5%	+13%	+12%	± 8.0%
+1.0 °C	+1.4 °C	+1.7 °C	+2.3 °C	+1.2 °C	+1.7 °C	+2.7 °C	+3.7 °C	± 0.25 °C
+3.5%	+7.5%	+4%	+9.5%	+5%	+9%	+6.5%	+14%	-
+0.9 °C	+1.4 °C	+1.5 °C	+2.3 °C	+1.0 °C	+1.7 °C	+2.6 °C	+3.8 °C	± 0.35 °C
+1.1 °C	+1.3 °C	+1.9 °C	+2.2 °C	+1.4 °C	+1.7 °C	+2.9 °C	+3.7 °C	± 0.18 °C
+0.9 °C	+1.1 °C	+1.6 °C	+2.0°C	+1.0 °C	+1.4 °C	+2.3 °C	+3.1°C	± 0.43 °C
+1.4 °C	+1.9 °C	+2.3 °C	+3.3 °C	+2.0 °C	+2.6 °C	+3.6 °C	+4.9 °C	± 0.52 °C
+22%	+35%	+40%	+70%	+30%	+50%	+90%	+130%	± 13%
+0.5%	+0.6%	+1.4%	+2.2%	+0.9%	+1.2%	+4.5%	+7.5%	-
+1.2%	-8%	+1.4%	-13%	+1.0%	-8%	-4.5%	-23 %	± 9.2%
+2.1 to +5%	-2.5 to +1.0%	+1.4 to +7%	-4 to +2.2%	+1.2 to +5.5%	-2.5 to +1.9%	-0.6 to +9%	-8.5 to +2.3%	-
+1.7 to +10%	+2.0 to +13%	+3 to +21%	+2.5 to +22%	+2.5 to +15%	+2.5 to +17%	+5 to +35%	+5 to +40%	± 15%
+5.5 to +11%	+7 to +14%	+12 to +23%	+13 to +25%	+8 to +16%	+9 to +19%	+19 to +40%	+22 to +45%	± 14%
+0.5%	-5.5%	+0.7%	-10%	+2.1%	-5.5%	+4%	-16%	± 6.4%
+4.5 to +18%	-4.5 to +10%	+6 to +30%	-8.5 to +14%	+5 to +23%	-3.5 to +14%	+2.5 to +35%	-15 to +14%	± 24%
+2.1%	+5%	+1.0%	+6.5%	+0.9%	+5.5%	+3%	+9.5%	± 2.4%
-0.6%	-2.0%	+0.1%	-2.5%	0.0%	-2.0%	-0.6%	-3%	± 0.86%
+4%	+7%	+4%	+11%	+3.5%	+8.5%	+8%	+15%	± 2.8%
+4.5%	+20%	+0.7%	+30%	+1.0%	+19%	+13%	+50%	±13%
+5%	+17%	+4.5%	+25%	+3.5%	+17%	+14%	+40%	-
+1.1 °C	+1.3 °C	+2.2 °C	+2.3 °C	+1.6 °C	+1.6 °C	+3.3 °C	+3.8 °C	± 0.27 °C
+7%	+8%	+3%	+7.5%	+7.5%	+9%	+5.5%	+12%	± 9.0%

Key figures

Explanatory notes

The table shows the effects of human-induced global climate change on the climate of the Netherlands.
The estimated ranges of natural variations in the climate are also provided. These are indicated by the grey circles in the figure on page 7.
If climate change according to the scenarios is large compared to the change due to natural variations then future climate differs demonstrably from the climate of the past century. On the other hand, if climate change according to the scenarios is relatively small then natural variations will continue to be the dominant factor in adaptation planning.
The table can be used to compare the trends in future climate with trends observed in the past. For this purpose, the future changes should be compared to the difference between the averages for 1951-1980 and the reference period of 1981-2010.

Sample calculation

The final column provides an overview of natural climate variations averaged over 30 years. The figures in this column provide reference values for the changes according to the four scenarios. For the future climate, the positive and negative natural variations in the 30-year average values will be superimposed on the scenario changes. They are depicted as grey bands in the scenario figures later in this report. These 30-year natural variations do not change in the scenarios. Besides this, there are also daily, monthly and annual variations, which for some indicators do change in the scenarios. For temperature, for example, the year-to-year variation decreases in winter and increases in summer. The following example provides an illustration.

To obtain information on the range for winter precipitation in a particular year around 2050 based on the W_L- scenario, the following needs to be taken into account:

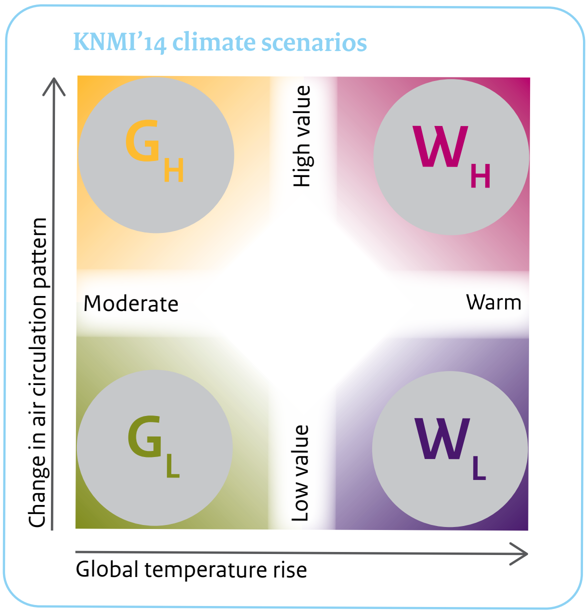
1) the mean amount of 211 mm in the reference period 1981-2010
2) the scenario increase of 8%, which gives a scenario mean of 1.08 × 211 = 228 mm
3) the natural variations in the 30-year averages of ± 8.3% (of 228 mm), which equals ± 19 mm
4) the year-to-year variations of ± 96 mm and their increase of 10%, which gives a scenario year-to-year variation of ± (1.10 × 96) or ± 106 mm.

Adding 3) and 4) quadratically gives future variations of ± 108 mm. Combining this with 2) yields 228 ± 108 mm, or a range of between 120 and 336 mm for precipitation in a given winter somewhere around 2050 under the W_L - scenario. By comparison, the range for the 1981-2010 reference period is 211 ± 96 mm, or between 115 and 307 mm. Although the year-to-year variations are much lager than the scenario changes, this result indicates that extreme wet winters, for example with more than 300 mm precipitation, will occur more often in the future.
The two columns for the observations show that the increase in winter precipitation over 30 years has been about as large as the natural variations in the 30-year averages. Note that this example does not take into account the dependency between precipitation in subsequent winters [1].

[A] winter = December, January, February; spring = March, April, May; summer = June, July, August; autumn = September, October, November; information on all indicators for all seasons is available at www.climatescenarios.nl
[B] averages for the Netherlands; for temperature only observations taken at De Bilt have been used, and for wind only Den Helder / De Kooy; for precipitation the number of stations for which 60 years of data is available is less than in the climate atlas; the difference between the averages for 1951-1980 and for the reference period 1981-2010 roughly corresponds to a 30 year trend
[C] scenario values have been rounded taking into account the magnitude of the change and the differences between the four scenarios
[D] 30-year averages fall in the given range with 90% probability
[E] the absolute increase, without land subsidence, falls in the given range with 90% probability
[F] the time series for solar radiation observations, which is also used for potential evaporation and precipitation deficit, starts in 1958
[G] the reference climate is 1971-2000 because the time series for visual fog observations ended in 2002
[H] annual means fall in the given range with 90% probability
[I] for these indicators, 30-year periods are actually too short to determine the values accurately
[J] growing season runs from 1 April until 30 September

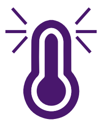
KNMI'14 climate scenarios summarized

KNMI presents the KNMI'14 climate scenarios: four new scenarios for future climate change in the Netherlands. Each scenario provides a consistent picture of the changes in 12 climate variables, including temperature, precipitation, sea level, and wind. Not only the changes in the mean climate are depicted, but also changes in the extremes such as the coldest winter day and the maximum hourly precipitation per year. The changes are for two different time horizons: around 2050 and around 2085, relative to the reference period of 1981-2010, published in the KNMI climate atlas [2)].
The KNMI'14 scenarios are the four combinations of two possible values for the global temperature increase, 'Moderate' and 'Warm', and two possible changes in the air circulation pattern, 'Low value' and 'High value'. Together they span the likely changes in the climate of the Netherlands according to the newest insights.
By providing these KNMI'14 scenarios KNMI offers a guide for evaluating the consequences of climate change and for developing options and strategies for climate adaptation. They will enable users to include climate change when making decisions to ensure that the Netherlands will have a safe and sustainable future.

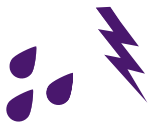


Overall changes

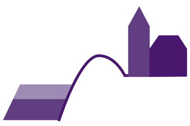
- temperature will continue to rise
- mild winters and hot summers will become more common



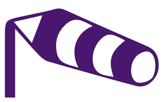
- precipitation in general and extreme precipitation in winter will increase
- intensity of extreme rain showers in summer will increase
- hail and thunderstorms will become more severe



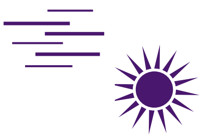
- sea level will continue to rise
- the rate of sea level change will increase



- changes in wind speed are small



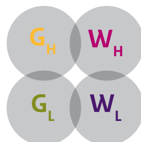
- number of days with fog will diminish and visibility will further improve
- solar radiation at the earth's surface will increase slightly



Scenario differences and natural variations

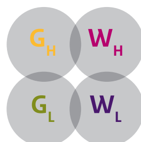
- changes in temperature differ between the four scenarios
- changes in 2050 and 2085 are greater than the natural variations at the 30 year-time scale

- more dry summers in two (G_H and W_H) of the four scenarios
- natural variations in precipitation are relatively large and thus the scenarios are less distinct

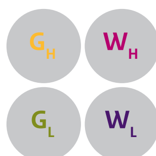


- rate of sea level rise greatly depends on global temperature rise
- there is no distinction between scenarios with different air circulation

- more frequent westerly wind in winter in two (G_H and W_H) of the four scenarios
- the wind and storm climate exhibits large natural variations



- natural variations differ for different climate variables



Introduction

IPCC: "Human influence on the climate system is clear." This is the short key message of the Fifth Assessment Report of the UN climate panel IPCC published in September 2013. Human influence has been detected in warming of the atmosphere and the oceans, in changes in the global water cycle, in reductions in snow and ice, in sea level rise, and in changes in some extremes. Continued emissions of greenhouse gases will cause further changes [3].

KNMI'14 climate scenarios

The KNMI'14 climate scenarios translate the global findings in the IPCC 2013 report [3] to the situation in the Netherlands. The IPCC report does not provide results for individual countries.

The climate scenarios for the Netherlands are based on observational evidence and the latest climate model calculations performed for the IPCC, augmented with calculations performed using the KNMI climate model for Europe.

Taking into account the judgement of experts, the KNMI'14 scenarios depict four vertices. Future human-induced climate change in the Netherlands is likely to occur within these vertices.

Why new scenarios now?

The KNMI'14 scenarios serve as an update to the previous generation of future climate scenarios issued in 2006. These KNMI'06 scenarios acquired an official status in the National Water Plan [4] and were integrated with socio-economic scenarios in the 'Delta Scenarios' used for the Dutch Delta Programme [5].

Several reasons exist for publishing a new set of climate scenarios now. The IPCC recently issued a new assessment report and additional questions have arisen from various sectors in society. The National government also requested KNMI to provide up-to-date scenarios to support the next phase of the national climate adaptation policy.

Scenarios plus natural variations

In addition to the scenario information for human-induced changes, a measure of natural variations in the climate is presented. Natural variations are for example the day-to-day variations in weather, or the occurrence of cold spells in winter. As a result of such natural variations, not every consecutive year will be successively warmer in a warming climate.

The longer the period of averaging, the smaller the influence of natural variations on this average is (Figure 1). But even averages over 30 years – the benchmark of what is seen as normal weather – are affected. For precipitation and wind, in particular, natural variations in the 30-year average climate may be substantial when compared to the magnitude of the scenario changes that also refer to 30-year averages.

Natural climate variations are caused by interactions between the atmosphere, land, ice and oceans. These variations can mask human-induced climate change by inducing trends that temporarily oppose the overall scenario picture (see page 29 for an example).

Tools for adaptation planning

The KNMI'14 scenarios are intended as a tool to support impact studies or to develop adaptation options and strategies. They will enable users to consider climate change in decision-making processes about the future, even though the future climate is uncertain.

Increasingly, public and private sector organisations use climate scenarios in long-term planning to reduce exposure to climate risks and exploit potential new opportunities. KNMI facilitates this process without being prescriptive about which scenario is the most favourable or what action to take.

The scenarios have been developed as a generic set of variables for a wide range of users. They provide a common framework for adaptation planning in different sectors of society.

User liaison was a key element in the scenario development process. A large group of users was involved in choosing the relevant climate variables and indicators.

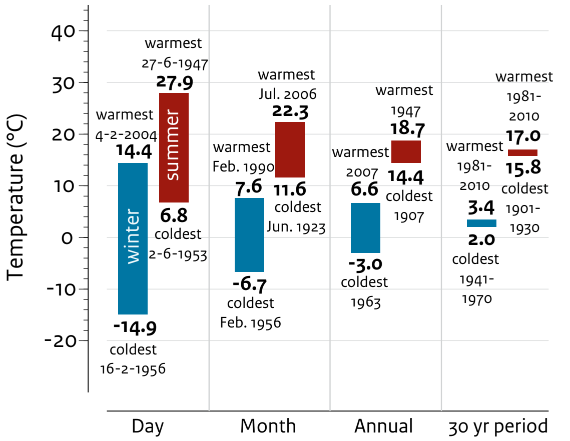


Figure 1 Temperature variations observed at De Bilt (Netherlands) since 1901 on different time scales. The observed variations are the result of natural variations superimposed on the global warming signal.

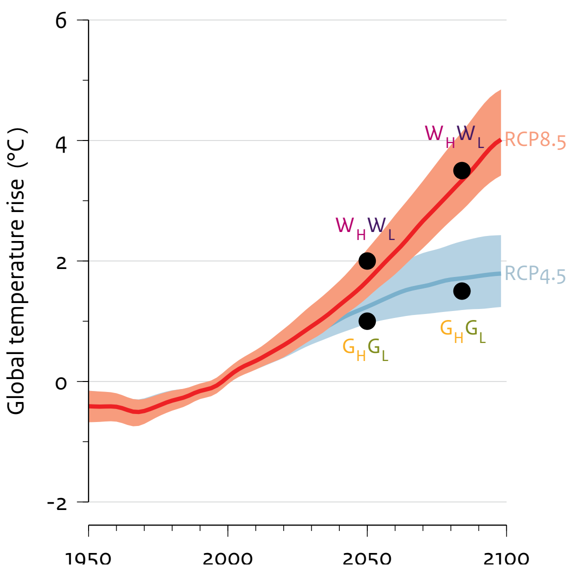


Figure 2 Global temperature rise relative to 1981-2010 based on climate model calculations performed for the IPCC 2013 report [3]. Two different IPCC emission scenarios (see page 3): RCP4.5 (stabilization) and RCP8.5 (high emissions). Coloured bands: model spread; lines: model means; dots: global temperature rise determined for the KNMI'14 climate scenarios for the Netherlands.

Scenario classification: G versus W

The different IPCC scenarios for future emissions of greenhouse gases and pollutants, in conjunction with land use changes, form the basis for the KNMI'14 scenarios. Figure 2 shows the resulting global mean temperature increase until 2100 based on climate model calculations.
The global mean temperature increase is the first classification criterion distinguishing the scenarios. In the G scenarios, the global mean temperature increase is 1 °C in 2050 and 1.5 °C in 2085 relative to 1981-2010; in the W scenarios the increase is 2 °C in 2050 and 3.5 °C in 2085 relative to 1981-2010. G stands for *Gematigd*, i.e. Dutch for moderate; W stands for *Warm*, i.e. Dutch for warm. These ranges of future warming include about 80% of the latest climate model calculations.
Because these calculations run until 2100, the maximum possible time horizon for the KNMI'14 scenarios is limited to the 30-year period around 2085. The year 2050 was chosen as the first time horizon because it was also the first time horizon used in the KNMI'06 climate scenarios.

Scenario classification: L versus H

Besides the global mean temperature rise, the change in air circulation pattern has a substantial influence on climate change in the Netherlands. Therefore, the change in air circulation was taken as the second classification criterion to distinguish the scenarios. In the Low or L scenarios (G_L and W_L) the influence of circulation change is small; in the High or H scenarios (G_H and W_H) the influence of circulation change is large.
In the H scenarios more frequent westerly winds occur in winter. This leads to mild and more humid weather compared to the L scenarios. In summer, high-pressure systems have a greater influence on the weather in the H scenarios. Compared to the L scenarios these high pressure systems cause more easterly winds, which implies warmer and drier weather for the Netherlands.
The latest calculations with the global climate models used for the IPCC indeed indicate these changes in air circulation. They have been translated to the Netherlands using the KNMI climate model for Europe.
In a final step, using the 12 climate variables including temperature, precipitation and solar radiation, 22 indicators relevant for user applications, such as the warmest summer day per year (relevant e.g. for healthcare) or the maximum hourly precipitation intensity per year (for sewage capacity), have been evaluated.

Temperature

Observations

IPCC: The globally averaged surface air temperature data show a warming of about 0.9 °C over the period 1880–2012. A reduced temperature trend is observed over the past 15 years, primarily due to natural variations of the ocean circulation. However, sea level, energy storage in the oceans, glaciers and snow cover have continued to indicate warming in this period [3].

The Netherlands has also become warmer. Average temperatures in De Bilt increased by 1.8 °C between 1901 and 2013. Most of this increase, 1.4 °C, occurred between 1951 and 2013 (Figure 3). The increase since 1951 is about twice the global increase averaged over all land and oceans. The warming was similar for our neighbouring countries. Land masses generally warm faster than the oceans. In winter (December, January, February) more frequent westerly winds have led to milder temperatures. In summer (June, July, August), an increase in solar radiation (see page 18) has contributed to the additional warming. This increase in solar radiation is due mainly to a reduction in air pollution.

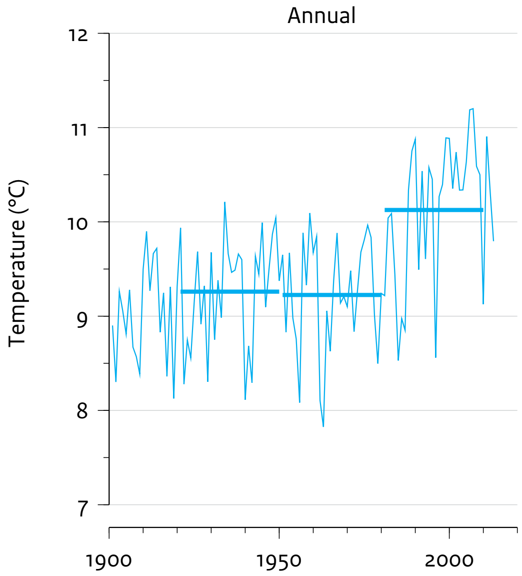


FIGURE 3 Observed annual mean temperature at De Bilt (Netherlands). Horizontal bars: 30-year averages.

Future

IPCC: Global warming at the end of the 21st Century will exceed 2.0 °C relative to pre-industrial (about 1.3 °C relative to 1981-2010) for three of the four IPCC emission scenarios (see page 30). The warming will not be uniform over the globe with stronger warming over the continents and in the polar regions [3].

In all four scenarios for the Netherlands, the temperature will increase further(Figure 4). The mean temperature increase in 2050 is largest for winter (December, January, February) and smallest for spring (March, April, May). The G_H and W_H scenarios show a stronger warming in the Netherlands compared to the global average warming. But in none of the scenarios will the warming in the Netherlands reach twice the global average warming as seen over the last few decades. Trends may temporarily become somewhat larger or smaller due to natural variations. On top of these long-term changes and variations there are also the changes in the year-to-year temperature variations. Temperature differences between winters decrease somewhat because very cold winters become much less likely. Temperature differences between summers increase somewhat because the temperature increase is largest for the warmest summers.

The temperature difference between day and night reduces slightly. The increase in maximum temperature is slightly less than the increase in minimum temperature.

Comparison with KNMI'06

The winter warming in KNMI'14 is somewhat stronger than in KNMI'06, whereas the largest value for summer warming (+2.3 °C in the W_H scenario) is lower compared to KNMI'06 (+2.8 °C in the W+ scenario).
In most of the recent climate model calculations, summer warming is less pronounced than in the models used for the 2006 scenarios. This is due to less pronounced soil drying over large parts of the European continent in recent calculations (see page 13).

Temperature extremes

Similar to the KNMI'06 scenarios, the coldest days in winter and warmest days in summer will warm most (Figure 5). On the other hand, mild days in winter and cool days in summer show relatively modest changes.
For winter, this leads to a considerable reduction in the number of frost days with minimum temperature below zero. The reduction in the number of ice days with maximum

temperature below zero is even larger. In the warmest scenario, W_H, the number of ice days reduces from seven days at present to one day per winter for the period around 2050. In the most moderate scenario, G_L, there are still four ice days occurring per winter.
For summer, the scenarios indicate an increase in the number of tropical nights with minimum temperature at or above 20 °C and summer days with maximum temperature at or above 25 °C. Record-breaking daily temperatures are still possible under all scenarios, but become much less likely for cold extremes in winter and more likely for warm extremes in summer.

Regional differences

For temperature changes, regional differences within the Netherlands are expected. These are most pronounced for the extremes in the W_H scenario. On the warmest summer days, the temperature in the southeast of the Netherlands increases by about 1 °C more than in the northwest in that scenario (Figure 5). This amplifies the regional temperature differences between inland and the coast compared to the current climate.
In constrast, the warming in the east is greater than in coastal areas in cold winter days, which reduces the present regional differences.

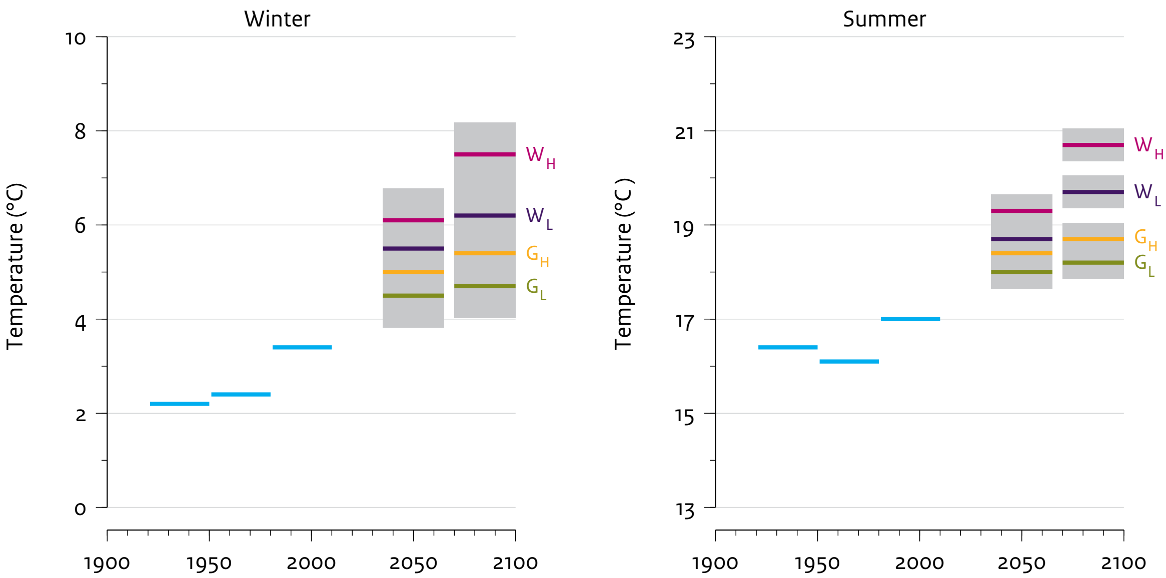


FIGURE 4 Winter and summer temperature in De Bilt (Netherlands): observations (three 30-year averages, in blue), KNMI'14 scenarios (2050 and 2085, in four colours) and natural variations (in grey). These are natural variations for 30-year averages.

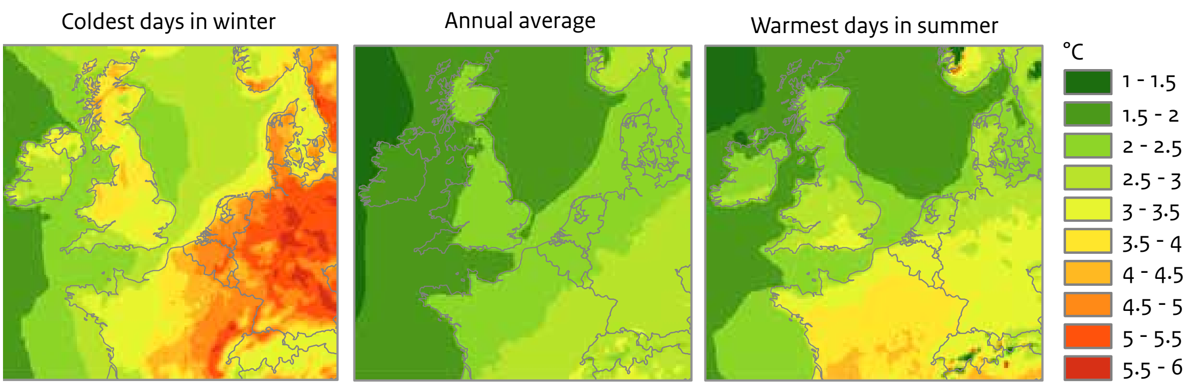


FIGURE 5 Temperature change on the coldest days in winter (left) and the warmest days in summer (right) compared to the annual average warming (middle) in the W_H scenario for 2050 relative to 1981-2010.

Precipitation

Observations

IPCC: Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901. There is medium confidence of a human-induced contribution to these precipitation changes since 1950. The amount of water vapour in the atmosphere has increased globally since the 1970s. This is consistent with the observed warming, because warm air can contain more moisture [3].

The Netherlands has seen an increase of 26% in annual precipitation between 1910 and 2013. The increase was 14% between 1951 and 2013 (Figure 6). All seasons except summer have become wetter.
The number of days per year with at least 10 mm precipitation in winter and the number of days with at least 20 mm precipitation in summer increased (Figure 7). On average, these thresholds of moderate extremes are exceeded several times a year at any given location in the Netherlands. The largest increase of these moderate extremes is observed in the coastal regions. The total number of days with precipitation above 0.1 mm, known as 'wet days', does not exhibit a trend.
Because of the temperature increase also the amount of water vapour in the atmosphere has increased significantly since 1950. This trend partly explains the observed increase in mean precipitation amount. The effect on precipitation extremes is even greater. Observations show that the hourly intensity of the most extreme showers increases by about 12% per degree of warming.

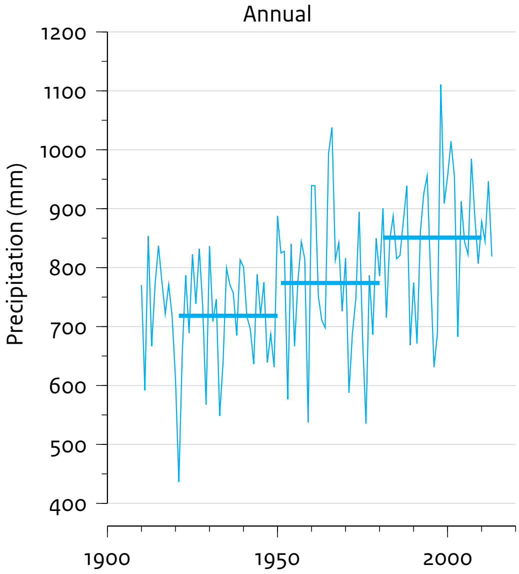


Figure 6 Observed annual precipitation for the Netherlands.

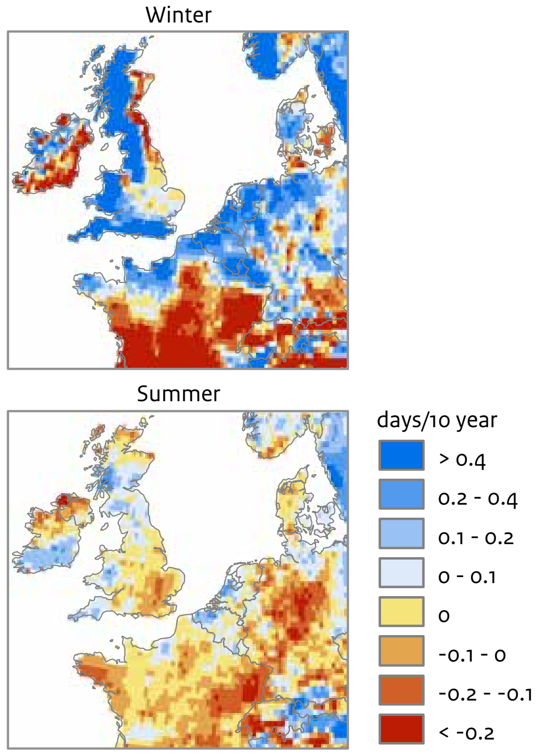


Figure 7 Observed trends in the number of winter days per year with at least 10 mm precipitation (top) and summer days per year with at least 20 mm precipitation (bottom) between 1951 and 2013. Source: www.ecad.eu.

Future

IPCC: Changes in precipitation in response to the warming over the 21st Century will not be uniform over the globe. The contrast in precipitation between wet and dry regions, and between wet and dry seasons, will generally increase [3].

The mean precipitation increases in all scenarios, except for summer. This is primarily due to the increase in water vapour in the air in a warming climate.
Model calculations disagree about the sign of change in mean precipitation in summer, and this is reflected in the scenarios (Figure 8). Models differ on how the air circulation over Europe will change, on the degree of soil drying and the associated changes in clouds and precipitation.

Two scenarios (G_L and W_L) exhibit a small increase in mean precipitation in summer, whereas the other two (G_H and W_H) show a considerable reduction. The percentage reduction is largest in summers that are already dry.

Comparison with KNMI'06

The G_H and W_H scenarios exhibit strong drying in summer. However, the drying is less extreme compared to the G+ and W+scenarios in KNMI'06 in which the air circulation changes in a similar way. New analyses suggest that recent results are more credible [3)]. The latest climate model calculations provide only very limited support for summer drying as strong as in the driest KNMI'06 scenarios. Confidence in those models that predict extreme future drying is low, because these are the same models that are too dry in their simulation of the current climate.

Precipitation extremes

In all scenarios, precipitation extremes increase throughout the year, even in the G_H and W_H scenarios with an overall drying in summer. This is primarily due to the increase in water vapour in the air in a warming climate.
Such precipitation extremes can be caused by two meteorological phenomena: fronts associated with depressions, or rain showers caused by vertical instability of the atmosphere. Fronts are typical of winter, whereas showers are typical of summer, but often a combination of both occurs. While fronts are well resolved in the climate models used for developing the scenarios, rain showers, which cause the extreme precipitation peaks in summer, are not. Consequently, the change in precipitation extremes for a particular summer scenario is quite uncertain. Also, rain showers are less dependent on changes in air circulation, but more dependent on the processes acting on the local scale. Therefore, a lower and upper value is provided for all scenarios in summer.
In the scenarios with an overall drying in the summer, G_H and W_H, the probability for moderate extremes, such as summer days with at least 20 mm precipitation, could either increase or decrease. But the probability for heavy rain showers increases in all scenarios, albeit with a large uncertainty band.

Regional differences

Within the Netherlands, differences in precipitation changes will be small. Model calculations suggest that the changes along the coast may differ somewhat from those inland. This would be consistent with observations. In a small number of model calculations, the precipitation changes along the coast are approximately 5-10% larger than inland. However, most of the model calculations do not exhibit systematic coastal effect within the Netherlands.
The coastal precipitation effect depends critically on the interactions between changes in air circulation, the temperature difference between land and sea, and the absolute temperature rise. The overall effect is considered too uncertain and therefore outside the scope of the KNMI'14 scenarios.

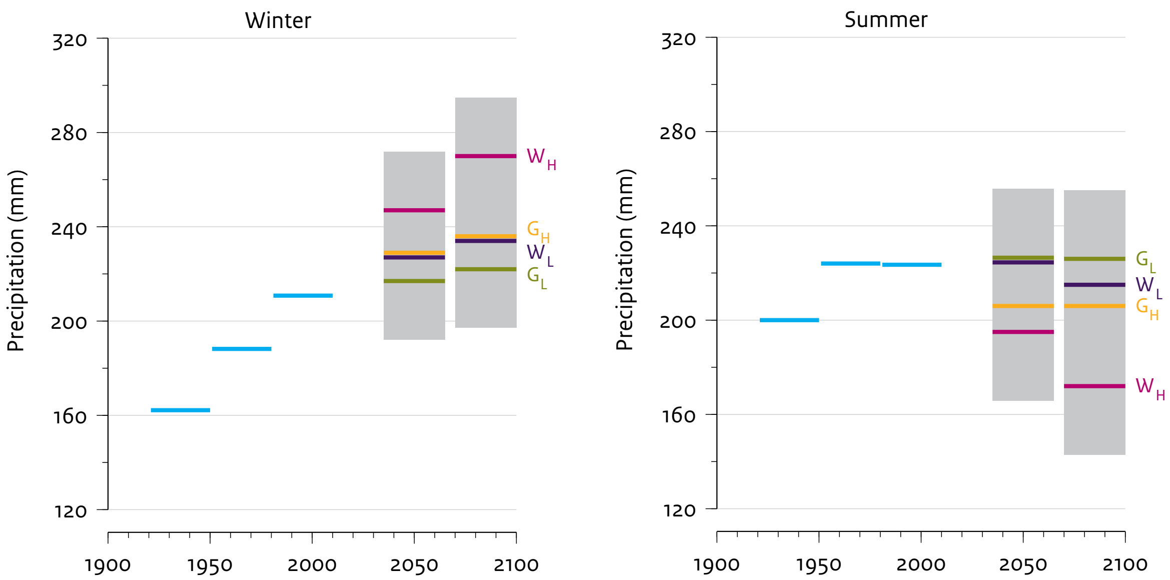


Figure 8 Precipitation climate in the Netherlands: observations and KNMI'14 scenarios for 2050 and 2085.

Sea level

Observations

IPCC: Over the period 1901–2010, global mean sea level rose by about 19 cm. The mean rate of global sea level rise was 1.7 mm/year between 1901 and 2010, and 3.2 mm/year between 1993 and 2010. For the North-East Atlantic Ocean, the rise in sea level is close to this global average (Figure 9) [3].

Observations along the Dutch North Sea coast yield a mean rate of change of 1.8 mm/year since 1900. An acceleration in sea level rise as seen in the global average cannot be distinguished from natural variations for the North Sea basin [6]. For the North Sea basin the natural variations, which are related to variations in the wind, are much larger than for the global mean sea level.

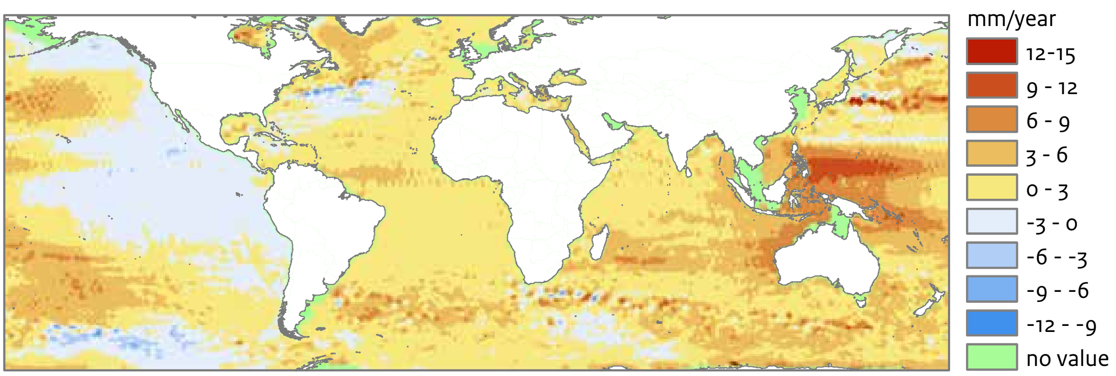


FIGURE 9 Rate of change in sea level for the period 1993–2012. Note that values for the Dutch coast cannot be derived from these satellite data [3].

Future

IPCC: Global mean sea level will continue to rise during this century. Under all IPCC emission scenarios the rate of sea level rise will very likely exceed 2.0 mm/year due to increased ocean warming and increased loss of mass from glaciers and ice sheets [3].

The potential future sea level rise along the Dutch North Sea coast (Figure 10) has been estimated taking into account several different factors, including changes in ocean expansion due to temperature and salinity changes and mass loss from glaciers and the Greenland and Antarctic ice sheets. The effects of self-gravitation have also been taken into account, i.e. the fact that melt water from land ice masses will not be evenly distributed over the oceans because of associated changes in the Earth's gravitational field [7]. Land subsidence, e.g. related to the compaction of peat, is not included in the scenarios, because this varies widely along the Dutch coastline and reliable estimates for the coming years are not available.
A lower and upper value for the sea level rise at the North Sea coast is provided, for all scenarios. No distinction was made between the L and H scenarios because changes in air circulation over Europe have minor impact on long term sea level rise. In each scenario the rate of sea level rise along the Dutch coast in 2050 and 2085 is higher than the mean rate of change observed since 1900.

Comparison with KNMI'06

The KNMI'14 scenarios show a sea level rise of up to 40 cm by 2050 relative to 1981-2010. This upper value for 2050 is about 5 cm higher than the upper value in the KNMI'06 scenarios, and in the Delta Scenarios. This difference is primarily due to the fact that the total contributions from the Greenland and Antarctic ice sheets are now estimated to be larger. In addition, the expansion of the North Sea itself has been included in KNMI'14. KNMI'06 was based on calculations for the northeast Atlantic Ocean because data for the North Sea were lacking.
In the KNMI'14 scenarios, the sea level rise along the Dutch coast in 2085 is between 25 and 80 cm. By the year 2100, the upper value is 100 cm. This value seems much higher than the upper value of 85 cm in KNMI'06.

The difference is primarily due to the fact that in KNMI'14 the 95% upper value is reported as is usual in the new IPCC report [3], whereas for KNMI'06 the 90% upper value was reported. The KNMI'06 95% upper value corresponds to an increase of 95 cm. The ultimate difference of 5 cm more sea level rise in KNMI'14 is primarily due to increased contributions from the Antarctic ice sheet and ocean expansion.

Beyond 2100

Because of the length of time it takes for all the oceans and ice sheets to respond to the warming of the atmosphere, sea level rise is expected to continue for centuries, even if the concentrations of greenhouse gases were to stabilize. By the year 2300, the sea level rise in the North Sea area has been estimated at between 50 cm and several metres [8].

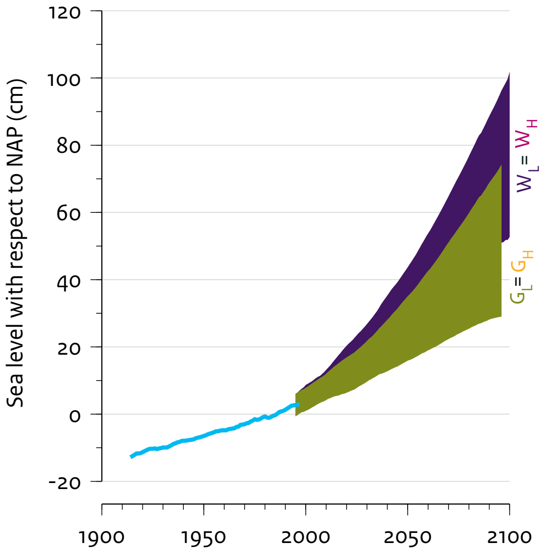


Figure 10 Observed sea level at the Dutch North Sea coast and the projections in the KNMI'14 scenarios. Smooth series have been plotted instead of 30-year averages, because sea level rise is a process with gradual increases. To show the full extents of W_L and W_H this band has been slightly extended.

Wind and storm

Observations

IPCC: From the 1950s to the 1990s, the mid-latitude westerly winds have increased in speed, but this increase has been largely offset by recent reductions. It is likely that the storm track has shifted poleward since the 1970s. The storm track is the band of strong westerlies at about 10 km height in which storms develop and are carried along [3].

Long-term direct wind observations are sparse, prone to instrumental changes and not available over open sea. Therefore, other indirect observation methods are often used, such as pressure observations. For the North Sea region, indirect measurements of storminess based on pressure observations indicate relatively high values at the beginning and at the end of the 20th century. Mid-century and in recent years storms have been fewer in number (Figure 11).
By contrast, direct surface observations of storminess over the Netherlands show a decreasing trend since the early 1960s. This reduction in wind speed over the Netherlands is partly due to urbanization. Urbanization leads to an increase in surface roughness which results in a decrease in surface wind speed. Coastal stations, however, generally show no decreasing trend in storminess since the 1960s.

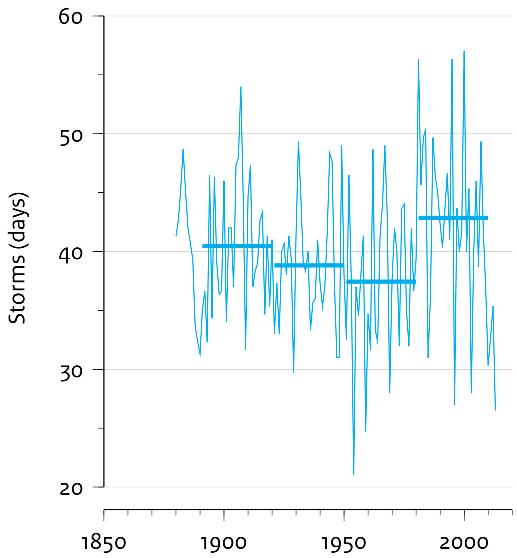


Figure 11 Indicator for storminess over the North Sea.

Future

IPCC: The number of mid-latitude storm depressions will not change by more than a few percent. There is low confidence in the magnitude of storm track changes over Europe [3].

The human-induced changes in wind speed are small in the KNMI'14 scenarios. This is consistent with the KNMI'06 scenarios. The changes in the scenarios are within the natural variation range, both for average wind speed throughout the year and for storms in winter.

Wind direction changes

Not only the strength of the storms is important, but also the wind direction. Northerly winds over the North Sea cause the highest sea surges along the Dutch coast. The scenarios indicate that strong winds from this direction will not change much in future.
The number of days with southerly to westerly wind directions, the prevailing wind direction, will increase in the G_H and W_H scenarios in winter, and decrease in the G_L and W_L scenarios (Figure 12). This is consistent with the changes in air circulation used for the scenario classification. In summer, the number of days with southerly and westerly wind directions will decrease in all scenarios, with the largest decrease occurring in the H scenarios.

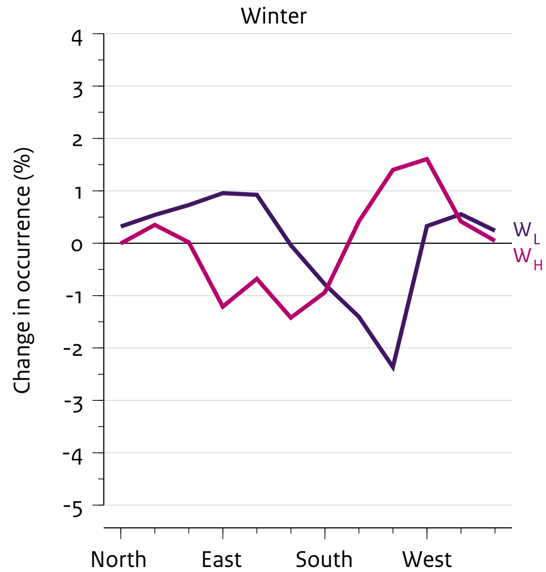


Figure 12 Changes in wind direction at the Dutch coast in winter for the W_L and W_H scenarios for 2085.

Visibility, fog, hail and thunderstorms

Observations

Future

Visibility and fog

Average visibility in the Netherlands has clearly improved in recent years. The occurrence of fog, defined as visibility of less than 1 km, has steadily declined from an average of about 500 hours per year around 1956 to about 200 hours per year around 2002 (Figure 13). There are considerable regional differences within the Netherlands, with coastal stations currently experiencing about 60 hours less fog per year than inland stations.

The increased visibility and associated reduction in the prevalence of fog is almost entirely due to the reduction in air pollution.

The positive trend in visibility over the Netherlands will continue in the future, albeit at a lower rate. For 2050 the average number of hours of fog per year is estimated at 190. After 2050 only a small further reduction is expected (Figure 14). The changes are the same in all four scenarios, because the assumed future reductions in air pollution are the same.

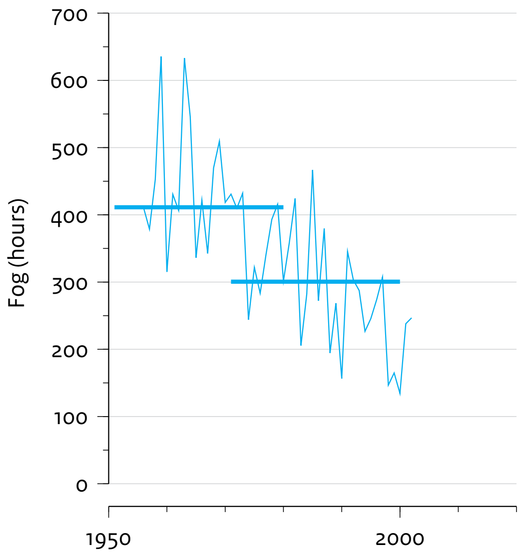


Figure 13 Observed annual number of hours of fog (visibility less than 1 km) for the Netherlands.

Hail and thunderstorms

IPCC: Because of lack of observations and insufficient studies confidence is low for global trends in the frequency and intensity of hail and thunderstorms over the past decades [3].

In the Netherlands hail and thunderstorms will become more severe in the future. More water vapour implies more heat released from condensation, which will induce stronger vertical motions in clouds with increased hail and lightning frequencies, and larger hailstones. For each degree of warming the number of lightning strokes increases by about 10-15% .

The biggest changes are seen in the W_L and W_H scenarios. There extreme hail occurs at least twice as often in 2050 compared to the reference period 1981-2010. These estimates are based on climate model calculations and the relationship between atmospheric water vapour and vertical velocity.

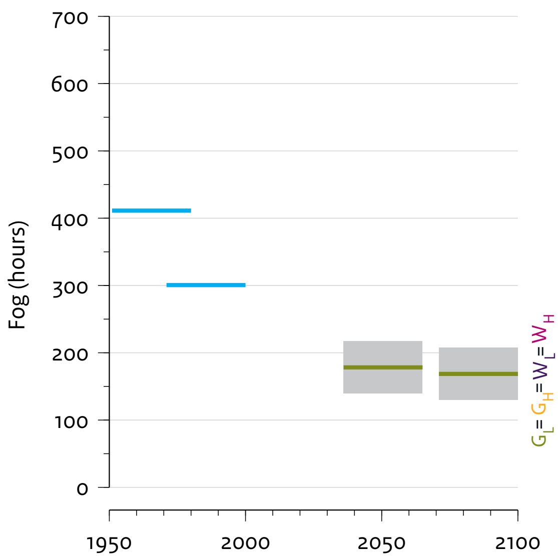


Figure 14 Observed fog (visibility less than 1 km) climate for the Netherlands, and KNMI'14 scenarios. At the end year of visual fog observations in 2002, the annual number of hours of fog has decreased already to about 200.

Clouds, solar radiation, evaporation and drought

Observations

Future

Clouds and solar radiation

No significant trend in overall cloudiness has been observed in the Netherlands since the 1950s. Solar radiation has seen an increase of 9% between 1981 and 2013 (Figure 15). This period overlaps with the reference period for the scenarios 1981-2010. The recent brightening is partly as a result of a more transparent atmosphere following the successful abatement of air pollution. Observations show that solar radiation has also increased under cloudy conditions. This suggests that the clouds have become more transparent as a result of the reduced air pollution.
The increase in solar radiation contributes about 0.2 °C to the total temperature increase of about 1 °C in the Netherlands between 1981 and 2013.
In the G_H and W_H scenarios a small but significant decrease in cloudiness occurs in future summers. This is due to more easterly winds. Consequently, summertime solar radiation increases in these scenario's.

Evaporation

Potential evaporation refers to the amount of evaporation that would occur if sufficient water is available in the soil. During summer this has increased by 12% in De Bilt between 1958 and 2013. This increase was calculated using the Makkink formula for potential evaporation over grassland which is also used in operational evaporation bulletins for the agricultural sector. More evaporation is due to increases in temperature and solar radiation, both contributing about equally. Data from Wageningen University and Research Centre show that the potential evaporation has already increased since 1928 [9].
Observations under reference conditions at the Cabauw Experimental Site for Atmospheric Research (CESAR) between 1979 and 2013 show a similar trend in the directly observed evaporation.
The Makkink formula can also be used to calculate approximate changes in potential evaporation under future climate conditions. In these scenarios the potential evaporation increases linearly with solar radiation. In addition, the potential evaporation increases by about 2% per degree of temperature rise. Actual evaporation changes may differ from these potential evaporation scenarios, because actual evaporation depends critically on soil water availability.

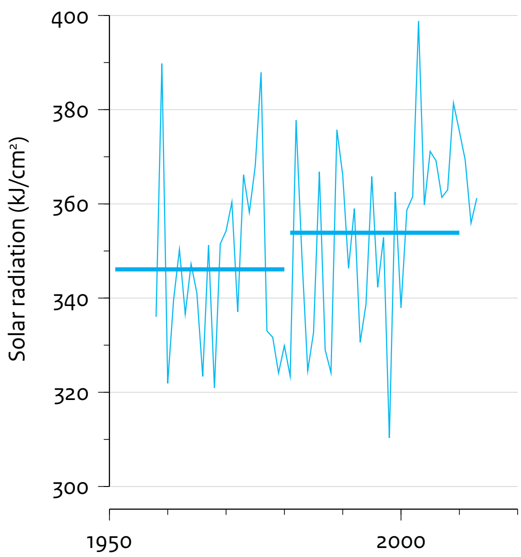


FIGURE 15 Observed annual solar radiation at the Earth's surface in De Bilt.

Drought

IPCC: Confidence is low for a global-scale trend in drought since the middle of the 20th Century [3].

In the Netherlands, a small increase in drought has been seen in the observations since 1951. This trend is likely to continue in the future. Drought indicators, such as the precipitation deficit during the growing season (from 1 April to 30 September) increase more strongly in the G_H and W_H scenarios than in the G_L and W_L scenarios. This reflects the changes in precipitation and potential evaporation used for the drought calculations.

Climate in 2030

As time progresses, the different IPCC emission scenarios result in increasingly distinct global temperature rise (Figure 2). Around 2030 however – just over 15 years from now – the calculated global temperature rise is almost the same for the different emission scenarios. The spread in the model calculations around 2030 is mainly the result of model uncertainty and natural variations.

In response to the growing demand for near-term information, an additional scenario has been developed for 2030. The table below provides the central estimates for some of the indicators in the table on page 1. These values for 2030 were obtained from the averages of all available model calculations. More indicators can be found at www.knmi.nl/climatescenarios.

For most indicators, the scenario changes for 2030 are relatively small compared to the natural variations. At this short time scale the natural variations are relatively important. Currently, it cannot be predicted whether the natural variations around 2030 will be positive or negative. However, an indication of just their magnitude is useful for many applications. Comparing the 2030 central estimates with the four vertices scenarios for 2050 or 2085 is not straightforward. The 2030 values can best be compared with the averages over all four scenarios for 2050 and 2085. Because average values have been calculated for 2030 against vertices scenarios for 2050 and 2085, the 2030 values are higher than the lowest scenario (G_L) values for 2050 for several temperature indicators.

Season [A)]	Variable	Indicator	Climate [B)] 1981-2010 = reference period	Central estimate of change value for 2030 [C)] (2016-2045)	Natural variations averaged over 30 years [D)]
Year	Sea level at North Sea coast	absolute level [E)]	3 cm above NAP	+10 tot +25 cm	±1.4 cm
		rate of change	2.0 mm/year	+1 to +6 mm/year	±1.4 mm/ year
	Temperature	mean	10.1 °C	+1.0 °C	± 0.16 °C
	Precipitation	mean amount	851 mm	+5%	± 4.2%
	Solar radiation	solar radiation	354 kJ/cm²	+0.2%	± 1.6%
	Evaporation	potential evaporation (Makkink)	559 mm	+2.5%	± 1.9%
	Fog	number of hours with visibility < 1 km	300 hour [G)]	-100 hour	± 39 hour
Winter	Temperature	mean	3.4 °C	+1.2 °C	± 0.48 °C
	Precipitation	mean amount	211 mm	+8.5%	± 8.3%
		10-day amount exceeded once in 10 years [I)]	89 mm	+9%	± 11%
		number of wet days (≥ 0.1 mm)	55 days	+1.5%	± 4.7%
	Wind	mean wind speed	6.9 m/s	+0.5%	± 3.6%
		highest daily mean wind speed per year	15 m/s	-1.0%	± 3.9%
		number of days between south and west	49 days	+2.5%	± 6.4%
Spring	Temperature	mean	9.5 °C	+0.8 °C	± 0.24 °C
	Precipitation	mean amount	173 mm	+5.5%	± 8.0%
Summer	Temperature	mean	17.0 °C	+0.9 °C	± 0.25 °C
	Precipitation	mean amount	224 mm	+0.2%	± 9.2%
		daily amount exceeded once in 10 years [I)]	44 mm	+1.7 tot +10%	± 15%
		maximum hourly intensity per year	15.1 mm/hour	+5.5 tot +11%	± 14%
		number of wet days (≥ 0.1mm)	43 days	+0.5%	± 6.4%
	Solar radiation	solar radiation	153 kJ/cm²	+1.9%	± 2.4%
	Humidity	relative humidity	77%	-0.6%	± 0.86%
	Evaporation	potential evaporation (Makkink)	266 mm	+3.5%	± 2.8%
	Drought	mean highest precipitation deficit during growing season [J)]	144 mm	+4%	± 13%
Autumn	Temperature	mean	10.6 °C	+1.0 °C	± 0.27 °C
	Precipitation	mean amount	245 mm	+5.5%	± 9.0%

Future weather

Besides information on the changes in climate as provided in the scenario tables on pages 4 and 19, many applications require sound information on associated future weather conditions. For engineering issues, in particular, complete time series corresponding to the scenarios are required, e.g. of daily precipitation amounts.
There are a number of techniques available for generating quantitative 'future weather' information, for example by considering regions with a similar climate or months with a similar climate, by performing calculations with high resolution models, or by statistical transformation of historical records.

Regions with a similar climate

To obtain a first impression of the future weather associated with each scenario, regions can been identified that currently exhibit temperature and precipitation conditions similar to the future climate of the Netherlands. To illustrate this, Figure 16 shows regions for which the present-day climate is similar to the climate of Amsterdam in 2050 under the KNMI'14 scenarios. Amsterdam will have winters in 2050 under the W_H scenario that are similar to current winters in Nantes or Bordeaux, for example.

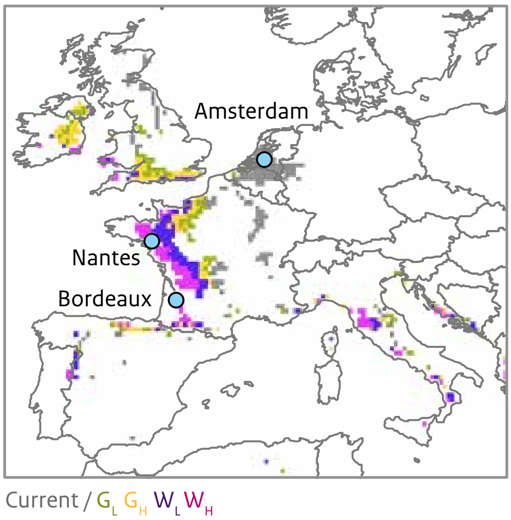


Figure 16 Regions with current winter climate similar to the winter climate of Amsterdam in 2050 under the KNMI'14 scenarios. Based on average temperature and precipitation only.

Similar months

Another way of addressing the future weather conditions involves considering neighbouring calendar months with a similar climate as the climate calculated for a particular month in the future. As an example, in De Bilt (the Netherlands), the January and February months in the W_H scenario around 2050 will resemble the current March month in terms of temperature (Figure 17). Average monthly temperatures of about 18 °C, which in the present climate occur only in July, will be exceeded during all three summer months (Jun, Jul, Aug) on average in the future.

Highly detailed models

A more complete picture of possible future weather can be obtained from highly detailed models. These models are currently computationally too expensive to generate the KNMI 14 scenarios, but they can be used for case studies. Figure 18 shows an example of two corresponding weather patterns, in the current and in the future climate. It concerns a two-day rainfall event in August 2010 that caused severe flooding in the eastern part of the Netherlands. With the detailed model this situation has been transformed into a 2 °C warmer climate according to the W_H scenario, resulting in a detailed map of climate indicators at a spatial scale of 2.5 km.

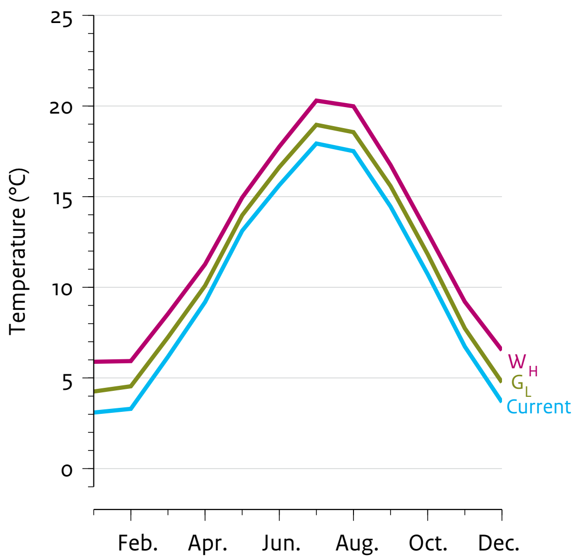


Figure 17 Seasonal cycle of temperature for the current climate (De Bilt, 1981-2010) and the future climate around 2050 for the G_L and W_H scenarios.

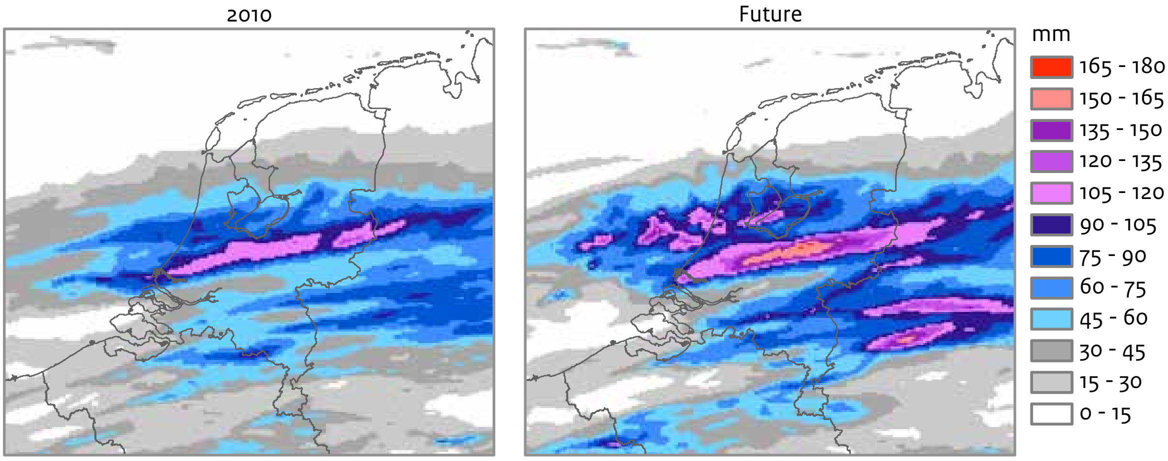


Figure 18 An event with more than 100 mm precipitation in two days in August 2010 (left), and its transformation into a 2 °C warmer climate (right).

The detailed model adequately reproduces the precipitation peak of 130 mm near the German border as observed by the precipitation radar in August 2010. This extreme event in the future climate is associated with considerable increases in the amounts of precipitation. The peak precipitation increases from 130 mm to 180 mm. The area with a precipitation total exceeding 100 mm almost doubles.
Using this method, it is now feasible to simulate consistent future weather situations, which means that a far more detailed assessment can be made of the disruptive impacts of such extreme events.

> *Time series transformation*

Software to transform observed daily records of temperature and precipitation into time series representative of the future climate was developed as part of the KNMI'06 scenarios. In the transformed time series the changes in the seasonal means and the moderate extremes are equal to those in the scenarios.
This software package has been used successfully for many applications, including the Dutch Delta Programme. An upgraded version of this package is available for the KNMI'14 scenarios, which now also includes solar radiation and evaporation. This package was also used to derive several indicators in the scenarios table on page 4.

KNMI'14 climate scenarios in practice

Examples of impact studies based on the KNMI'14 scenarios are provided below for water management, the urban residential environment, agriculture and nature. The examples provide an overview of the risks and opportunities associated with a changing climate in the Netherlands.
Updating the risks and opportunities that were assessed using the KNMI'06 scenarios [10] will take time, but significant deviations from the risks and opportunities based on these earlier studies presented in the table below are not expected. The reason is that the overall changes in the current scenarios do not differ that much from the KNMI'06 scenarios. Climate is also only one of several relevant factors in many of these risk assessments.

Coastal impacts	Storm surges will show little change, but sea level rise will continue; the process of sea level rise is relatively slow but requires continued monitoring and coastal protection measures
Flooding	Increased winter rainfall will increase peak discharge and flooding risk of the Rhine, Meuse and smaller rivers
Water resources	In two of the four scenarios drought will increase and this will lead to water shortages, water quality issues and salinization; sea level rise will contribute to salt water intrusion
Health	Temperature rise will lead to reduced mortality during winter and increased mortality in summer; during hot summers air quality will deteriorate; there is great uncertainty about possible trends in infectious diseases ; further increase in the number of 'allergy days' due to extension of the growing and flowering season
Mobility	Traffic disruption due to heavy showers may increase; slippery roads under icy conditions and damage to roads become less likely but rutting will increase during summer heat waves
Energy	Energy demand for heating houses, factories and offices will decrease, but more energy will be required for air conditioning; cooling water supply for electricity production will reduce
Agriculture	Potential crop yields will increase with a longer growing season and higher CO_2 concentrations, but changes in precipitation and the prevalence of extreme events could threaten harvests; dry years will present a particular challenge
Nature	Risks are greatest for ecosystems that depend on precipitation, e.g. heathlands, dry grasslands, rain-fed moorland pools and raised bogs; fens in nature reserves surrounded by deeply drained polders that depend on the inlet of surface water are also highly susceptible; increased risk of natural fires
Recreation	The number of attractive recreation days increases

Water management

Compound extremes

Significant impacts may occur from a moderately extreme event when it coincides with another event. One recent example was described by the Noorderzijlvest Water Board. It concerns the drainage of water from an area in the north of the Netherlands into the Wadden Sea. Where there are no pumps available, surplus water can only be drained into the sea by the force of gravity. For this the inland water level must be higher than the sea level. In January 2012, intense rainfall combined with storm surges made it almost impossible to drain the surplus water. This resulted in extremely high inland water levels.
Future weather calculations using highly detailed models provided a comprehensive assessment of the potential impacts of these situations under future conditions (Figure 19).

Wooden pile foundations

Fluctuations in ground water levels depend on the amount of precipitation. Changes in precipitation in a future climate could result in ground water levels (temporarily) falling below the top of the wooden piles that have long been used as the foundation for old buildings in many Dutch city centres. Consequently, these wooden piles may start to rot resulting in damage of the foundations of the building. Engineers of the city of Amsterdam have calculated for a test location that under the driest summer in the G_L scenario the lowest ground water level would be about 5 cm higher than at present. This implies that there would be less pile rot. However, under the W_H scenario, in which more prolonged dry summer periods occur, the lowest ground water level would be the same or about 5 cm lower. This implies that pile rot will increase only slightly.

'Elfstedentocht': Eleven cities speed skating marathon

The likelihood of skating on natural ice is regarded as a national (Dutch) indicator of climate change. The expected temperature rise is greatest for the coldest winter days and reduces the likelihood of long periods with frost and hence of skating ice.
The Netherlands Environmental Assessment Agency (PBL) has calculated the changes in the probability of an 'Elfstedentocht' speed skating marathon under the climate conditions described in the KNMI'14 scenarios for 2050. In the present climate this probability is 15% per year. The probability decreases in all scenarios: to 2% for G_L, 0.6% for G_H, 0.4% for W_L, and 0.2% for W_H in 2050. These probabilities are smaller than those calculated for the KNMI'06 scenarios (with a minimum of 0.6% for W+), because the warming of the coldest winter days is much greater in KNMI'14.

> *Urban residential environment*

Air quality and climate

Future air quality is primarily determined by changes in the emission of pollutants from industry, traffic, and other human activities. Changes in climate also play a role, the extent of which depends on the chemical component. For surface ozone, changes in temperature and solar radiation as well as transport will affect future concentrations. This includes long-distance transport from polluted regions and downward transport from the ozone layer. Surface ozone is mostly a summertime problem due to the seasonality of photochemical production, with high temperatures and a high incidence of sunlight accelerating local ozone formation.
For particulate matter (PM10) at ground level, rain and wind changes are the most important factors. With northerly and westerly winds, relatively clean air is transported from the North Sea to the Netherlands, whereas for southerly or easterly winds more polluted air is transported from the continent. PM10 is a year-round concern.

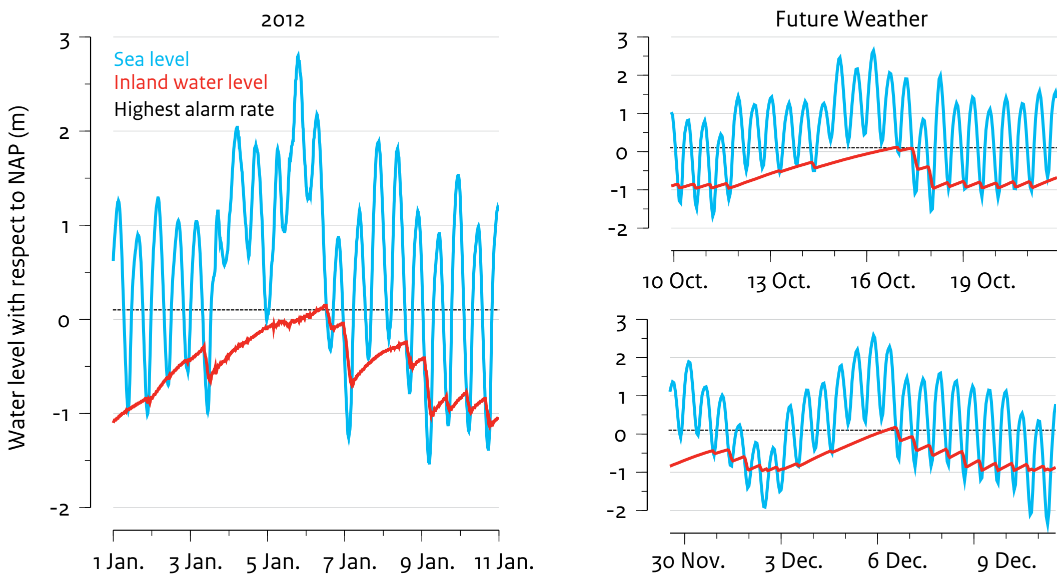


FIGURE 19 Example of events with restricted discharge options when inland water level (red) is lower than sea level (blue) also during low tide. This led to flooding on 6 January 2012 (left). Two similar future weather events (right).

Changes in ozone and particulate matter

A preliminary estimate of the effects of climate change on future surface ozone and particulate matter in the Netherlands has been made using the four KNMI'14 scenarios. These estimates disregard possible additional improvements in air quality resulting from future policy measures on pollutant emissions and the introduction of clean technologies. Under the G_H and W_H scenarios, the average summertime ozone increase is greater than in the G_L and W_L scenarios. Additional warming and solar radiation lead to additional ozone formation in the G_H and W_H scenarios. The average ozone concentration of 89 µg/m³ observed at six stations during the period 2003-2006 will increase to 97 µg/m³ under the G_L scenario and to 108 µg/m³ under the W_H scenario in 2050, an increase of 9% and 21%. The EU directive on surface ozone requires that citizens are informed when the ozone concentration exceeds 180 µg/m³. This occurred for on average 11 days per year between 2003 and 2006, usually in the southeast of the Netherlands. The scenario calculations indicate that this number will increase in 2050 to 14 days per year for G_L and 19 days per year for W_H. For particulate matter the uncertainty in the computed changes is greater than for surface ozone. The annual average concentration of 30 µg/m³ observed between 2003-2006 will increase by 2% for the G_L and W_L scenarios and by 5% for the G_H and W_H scenarios in 2050.

UV levels

The ozone layer high up in the atmosphere is starting to recover as a result of international measures to reduce the emission of ozone depleting substances. These measures were adopted in the Montreal Protocol in 1987. Observations by the KNMI in De Bilt show that the ozone layer has become thicker since about the year 2000. Full recovery to 1980 levels in the Netherlands is expected by about 2035 [12)]. Full recovery of the ozone hole over Antarctica will take two decades longer.
The future UV radiation received in the Netherlands depends not only on the ozone layer, but also on future cloudiness. The small but significant decrease in cloudiness during summer as expected in the W_H scenario and, to a lesser extent, in the G_H scenario, will partially undo the reduction in UV exposure expected due to the recovering ozone layer.

Urban heat islands

More than 40% of the Dutch population lives in an urban environment where climate change and air quality issues are reinforced by urban heat island effects. This concerns the phenomenon that urban areas experience elevated temperatures compared to their rural surroundings.
The heat island effect is greatest at night-time and can vary strongly within a city (Figure 20). It depends on building density and vegetation prevalence, as well as on cloudiness, wind speed and direction. Studies by the Netherlands Organisation for Applied Scientific Research (TNO), Wageningen UR and KNMI show that the temperature difference resulting from the heat island effect is of the same magnitude as the scenario changes in temperature for 2050. This implies that the thresholds for heat stress will be exceeded much more often in urban areas compared to rural areas. The indicators for the number of days above a particular temperature threshold in the scenarios table on page 4 apply to rural areas only.

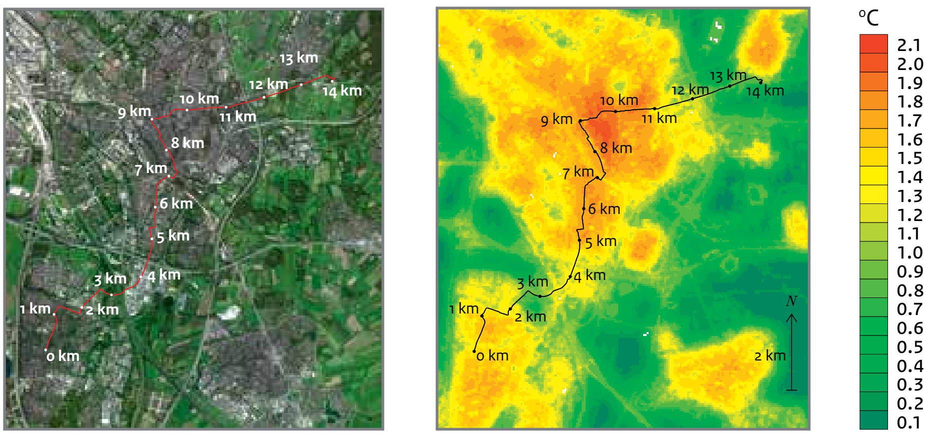


FIGURE 20 Night-time urban heat island effect for Utrecht, the Netherlands (330,000 inhabitants) averaged over the year (right). Based on a land use map (left) and mobile temperature and humidity measurements taken on a bicycle in commuter traffic along the indicated route [13)].

Human health and mortality

Temperature rise will lead to enhanced mortality during summer due to heat stress. In contrast, mortality will decrease during winter. TNO and Maastricht University (ICIS) have assessed the effects of temperature on mortality in the Netherlands. They found that in the current climate, heat waves have a more immediate effect than cold spells. Preliminary calculations by ICIS using the KNMI'14 scenarios suggest that in the future the decrease in cold-related deaths during winter will exceed the increase in heat-related deaths in summer.

Road transport

The more frequent occurrence of extreme weather, such as extreme precipitation, is a feature of climate change that could disrupt road traffic. The warming, however, also has positive effects. As an example, an indicator for slippery road conditions has been calculated (Figure 21). This indicator provides the number of days per year with snowfall, precipitation under thawing conditions and precipitation under freezing conditions. In recent years the value of this index agreed well with the number of salt sprinklings.
The results indicate that slippery road conditions will become less prevalent under all KNMI'14 scenarios, but considerable year-to-year differences will remain due to natural variability. Salt sprinkling will probably be required less often in the future.

Energy consumption for heating

Due to the expected temperature rise, the energy demand to heat houses, factories and offices will decrease in future. Energy consumption for heating shows a clear relationship with the 'number of heating degree-days'. The number of heating degree-days is defined as the sum of the deviations from 17 °C for all days with an average temperature below 17 °C. The Dutch gas production and trading companies NAM and GasTerra use this index to estimate future gas and energy consumption [14].
Relative to 1981-2010 the number of heating degree-days will be about 10% less in the G_L scenario and 20% less in the W_H scenario in 2050 (Figure 22). However, the energy consumption for air conditioning is likely to increase in these scenarios.

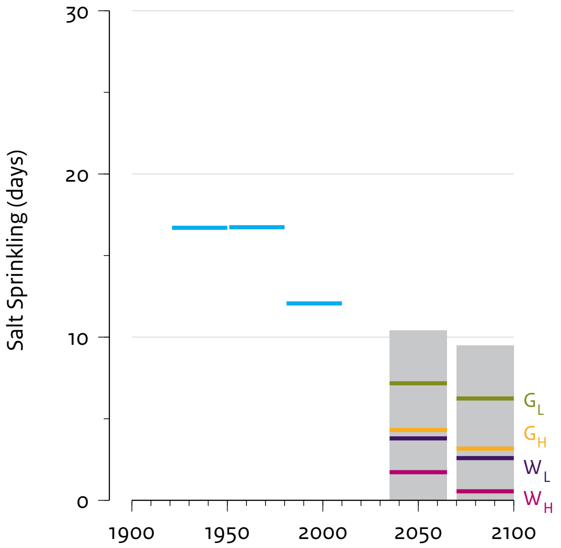


Figure 21 Indicator for the observed number of days per year at De Bilt requiring salt sprinkling on icy roads, and KNMI'14 scenarios for 2050 and 2085.

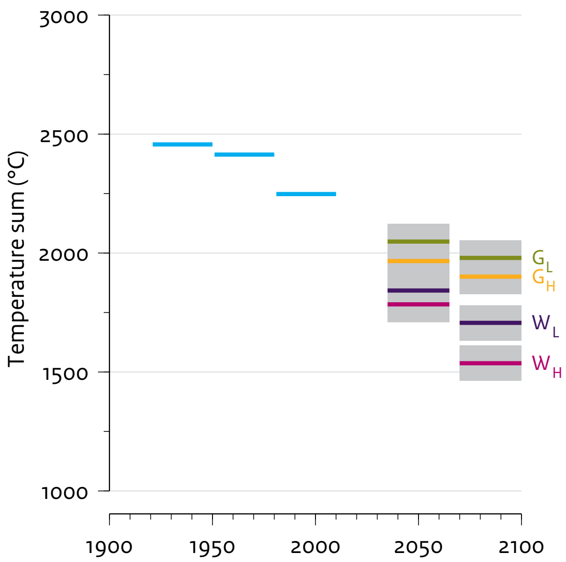


Figure 22 Number of heating degree-days as an indicator of gas and energy consumption in De Bilt, and KNMI'14 scenarios for 2050 and 2085. Heating degree-days: sum of the deviations from 17 °C for all days with an average temperature of less than 17 °C; e.g. a daytime temperature of 14 °C adds 3, and a daytime temperature of -2 °C adds 19 degree-days.

> *Agriculture and nature*

Growing season and the agro climate calendar

Increasing CO_2 concentrations and temperature may lead to higher crop yields owing to an extended growing season in the future (Figure 23). But changes in precipitation and the occurrence of extreme weather conditions, such as heavy showers, hail, drought, or summertime ozone stress, could threaten harvests.
Wageningen UR has projected the potential effects of climate change on decisions taken by individual potato farmers over a calendar year, focusing in particular on the timing of extremes relative to the growing stage of the crop. This calendar indicates how climate factors relevant to potato yields change in frequency in two scenarios for 2050. For example, increased precipitation delays the ploughing and planting dates in early spring, heat waves threaten the harvest in summer, and milder winters cause storage difficulties due to sprouting.

Pollen allergy

Increasing temperatures are expected to lead to an extension of the flowering season and thus an increase in the number of 'allergy days'. New allergenic species could possibly appear in the Netherlands.
Human allergy symptoms therefore will occur earlier in the season. Wageningen UR has calculated that under KNMI'14 the season for birch pollen around 2050 starts 9 days earlier on average compared to the reference period 1981-2010, i.e. on 5 April instead of 14 April. The season for grass pollen starts 10 days earlier on average, i.e. on 18 May instead of 28 May. The dates differ per scenario and vary widely from year to year.

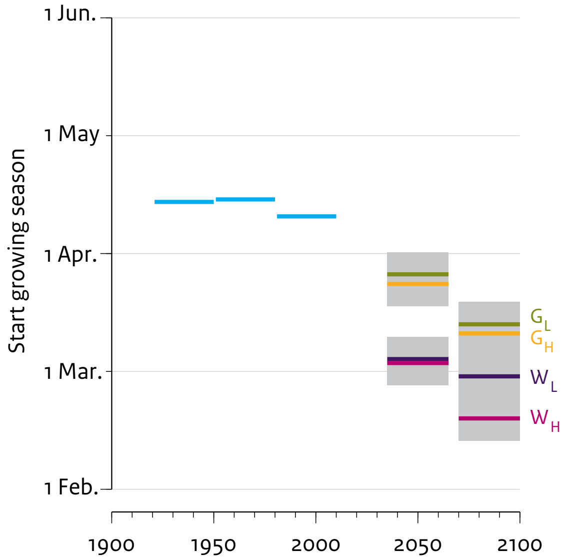


FIGURE 23 Start of the growing season in De Bilt, and KNMI'14 scenarios for 2050 and 2085. The growing season starts on the calendar day when the mean temperature exceeds 5 °C, and continues until at least 1 July.

KNMI’14 and KNMI’06 compared

The table below compares the new KNMI’14 climate scenarios with the previous scenarios of 2006. What do the differences tell us about the credibility of the KNMI’06 scenarios which have been integrated in the Delta Scenarios underpinning the Dutch Delta Programme?
The recent scientific evidence assessed in the latest IPCC report, on which KNMI’14 is based, does not differ substantially from the evidence in the previous IPCC report on which KNMI’06 was based. Consequently, the overall changes in KNMI’14 described on page 7 are similar to those in KNMI’06. This indicates that the general characteristics of the scenarios are robust.
KNMI’14 adds detail and provides a richer picture of the future climate of the Netherlands than KNMI’06. The KNMI’14 scenarios include more climate variables and indicators than the KNMI’06 scenarios, reflecting the diversity of users’ needs. The KNMI’06 scenarios remain possible scenarios for climate change in the Netherlands. But some characteristics of KNMI’06 are less likely given the current state of knowledge. KNMI will provide users with guidance when judging the significance of the differences for their application.

KNMI’06	KNMI’14
Four scenarios for future climate change in the Netherlands	Four scenarios for future climate change in the Netherlands
Up to 35 cm sea level rise in 2050 and up to 85 cm sea level rise in 2100 (=95 cm when corrected for the different definition of the upper value than in KNMI’14)	Up to 40 cm sea level rise in 2050, 80 cm in 2085 and 100 cm in 2100
Severe summer warming and drying in the G+ and W+ scenarios with changes in air circulation	Less summer warming and drying in the G_H and W_H scenarios with changes in air circulation
Coastal precipitation effect added in 2009 [7]	Coastal precipitation effect judged too uncertain to be included
No information on hourly precipitation change	Estimate of maximum hourly precipitation intensity
Based on SRES-A1b emission and land use scenarios [3]	Based on RCP4.5, RCP6.0 and RCP8.5 emission and land use scenarios [3]
Based on 5 GCMs and 10 RCMs	Based on EC-Earth and RACMO2 incorporating the projected changes from 250 GCM calculations
Time horizons 2050 (2036-2065) and 2100 (twice the changes of 2050, except for sea level)	Time horizons 2030 (2016-2045), 2050 (2036-2065) and 2085 (2071-2100, the maximum possible time horizon because GCM calculations run to 2100)
Reference period 1976-2005	Reference period 1981-2010 (= climate atlas period [2])
Set of 5 climate variables and 10 climate indicators	Set of 12 climate variables and 22 climate indicators, including fog, clouds, solar radiation, and evaporation
No information on natural variations	Natural variation estimates included for the 30-year period of the scenarios
No regional differentiation	Regional differentiation for robust changes such as mean temperature
User involvement mainly after scenario development	User involvement during each stage of scenario development
Time series transformation tool provided	Time series transformation tool and option for tailored future weather calculations provided
Few examples of user applications	Main risks and opportunities of climate change for the Netherlands summarized on the basis of more examples of user applications and literature

AR: Assessment Report
EC-Earth: KNMI global climate model
GCM: General Circulation Model
IPCC: Intergovernmental Panel on Climate Change
RACMO2: KNMI climate model for Europe
RCM: Regional Climate Model
RCP: Representative Concentration Pathway
SRES: Special Report on Emission Scenarios

Background information

Climate scenario definition

IPCC: A climate scenario is a plausible representation of the future climate that has been constructed for investigating the potential consequences of human-induced climate change [3].

Current state of science

The KNMI'14 scenarios reflect our current scientific knowledge. In the Netherlands this is partly generated in scientific programmes such as Climate Changes Spatial Planning, Knowledge for Climate, as well as research funded by the Netherlands Organisation for Scientific Research and the European Union. The scenarios are firmly grounded in the extensive knowledgebase available in the international scientific literature. Only assumptions that are supported by ample scientific evidence have been included [15]. Assumptions that lack robust scientific evidence, such as a complete shut down of the warm Gulf Stream during this century, have therefore not been considered. Extreme scenarios with a low probability were also not included.

KNMI applied the following criteria in selecting the future climate scenarios in this report: credibility (are the scenarios plausible, authoritative and consistent?), relevance (are the scenarios fit-for-purpose?) and legitimacy (are the scenarios transparently constructed and described?) [16]. An international advisory board guided the KNMI'14 scenario development process [17].

The more than 250 calculations with climate models performed for the recent IPCC report form the basis of the KNMI'14 scenarios. The emphasis was put on plausible human-induced changes that are broadly supported by the climate models rather than on a few outliers. In addition, knowledge about governing processes in the climate system obtained from observations has been used.

The scenarios have been developed for a wide variety of end-users. Whether they will respond to the requirements of specific users will ultimately depend on their perception of risks, experience in dealing with uncertainty, and their sense of urgency or priority [18].

Extreme scenarios: low probability, high impact

In climate science it is accepted that a large degree of global warming will increase the risk of a major abrupt transition in the climate system [19]. However there is as of yet no firm quantitative basis for the direction and magnitude of such a transition. Therefore, developing such transitions into extreme scenarios is beyond the scope of KNMI'14. Nevertheless, some examples have been provided below.

Some climate models indicate a slow but complete shut down of the warm Gulf Stream before 2100. This reduces the warming over Europe in all but one of these models.

A few models indicate an abrupt decline in Arctic sea-ice cover during warming scenarios, resulting in a strong temperature increase over the North Pole area. This may impact the formation of storms that affect Europe.

Another effect featured in some climate models is a much stronger drying of the soil in southern Europe. This 'desertification' of the Mediterranean will favour easterly winds over the Netherlands, leading to very warm and dry summers.

There are two other relevant processes that are either not included or not well represented in current climate models. The first is a collapse of the West Antarctic ice sheet. At present this ice sheet is losing mass by increased iceberg calving. Once a collapse has been initiated, for which no indications exist at present, the mass loss might be much greater than accounted for in the KNMI'14 sea-level rise scenarios.

The second process is the possibility of remnants of tropical hurricanes hitting Europe. Observations show that over the last two decades Atlantic hurricanes form more often in the eastern Tropics compared to the Caribbean. A large proportion of these hurricanes move directly to the north, and travel to Western Europe. The chances of Atlantic hurricanes to form in the eastern Tropics will increase due to global warming, and therefore also the probability of remnants of hurricanes hitting Western Europe. New experiments performed by KNMI with a highly detailed climate model have confirmed this. It will result in an earlier and more severe storm season in the Netherlands.

Scenario classification: why in this way?

Selecting the amount of global warming as the first classification criterion ensures that both the differences between future emission scenarios and the spread in the model calculations for one particular emission scenario are included in the KNMI'14 scenarios. The spread in the model calculations is due to uncertainties in the representation of the climate in the models, in which small-scale processes, e.g. in clouds, play an important role.
Selecting the changes in air circulation as the second classification criterion for changes in dominant wind patterns over Europe is similar to the procedure followed in the KNMI'06 scenarios.

Some global climate models calculate reduced warming over the North Atlantic Ocean and enhanced warming in the subtropics in winter. The resulting temperature gradient over Europe causes more frequent westerly winds in winter, which bring mild and more humid weather to the Netherlands. Some models calculate reduced warming over the North Atlantic Ocean and enhanced warming in Central Europe in summer. This creates more easterly winds, which results in warm, dry weather in the Netherlands.

Example of the role of natural variations

Natural variations are larger for precipitation than for temperature, larger for extremes than for the mean, larger for single locations than area averages, and for the Netherlands compared to Europe.
As an illustration, Figure 24 shows the future changes in summer precipitation in the Netherlands derived from eight calculations with the same climate model and the same scenario for future greenhouse gas emissions. The average indicates a gradual decrease in summer precipitation, which is the overall signal depicted in the scenarios. The individual model calculations behave differently due to the chaotic nature of the climate system. As a result, the actual future climate, as represented by any individual model calculation rather than the model average, may differ from that indicated by the scenarios. For example, three of the eight calculations shown in Figure 24 excert precipitation increases until about 2050, due to natural variations in the climate, followed by strong decreases thereafter.
Observed trends in the recent history deviating from the long-term scenario changes are therefore not necessarily incompatible. These observed trends typically represent the results of past human-induced climate change superimposed on natural variations. The contributions made by each of these two factors cannot easily be distinguished at present.
At which point in time the human-induced climate change for the Netherlands depicted in the scenarios (the signal) can be distinguished from natural variations (the noise) depends on the variable and indicator concerned. For example, for precipitation this point in time lies further ahead than for temperature, because the signal-to-noise ratio for precipitation is smaller than for temperature.

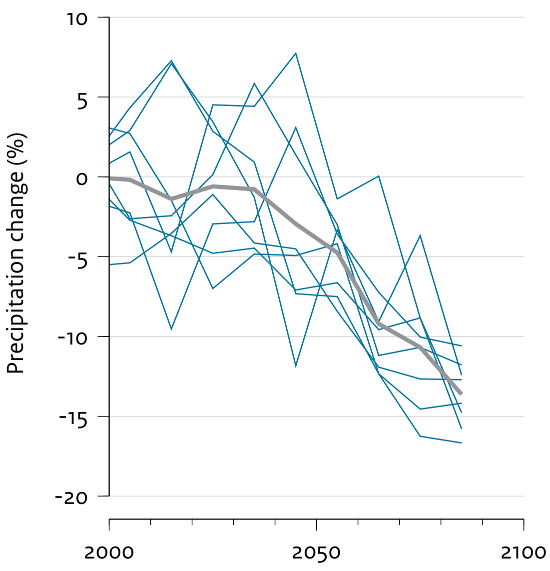


Figure 24 Future changes in summer precipitation (30-year averages relative to 1981-2010) in the Netherlands according to eight calculations using the same climate model (blue lines). Grey line: average.

How have the scenarios been constructed?

For the KNMI'14 scenarios, the outcomes of all IPCC model calculations [3] have been analysed. Additional model calculations have been performed using the KNMI climate models EC-Earth and RACMO2. In total, more than 1,200 years of climate data for the Netherlands have been produced with an unprecedented spatial resolution of about 10 km. This resolution is four times as high as in the KNMI'06 scenarios.
Based on the IPCC model calculations, a set of eight different calculations was selected for each of the four KNMI'14 scenarios. This selection was guided by the two criteria to distinguish the scenarios: global mean temperature increase and change in air circulation. Altogether these 4 x 8 = 32 calculations cover the relevant bandwidth of the changes projected by the other IPCC models. By analysing multiple calculations performed for each scenario it was also possible to distinguish the climate change (the signal) from the natural variations (the noise).
In addition to these climate model calculations for a number of indicators, such as precipitation extremes, information from observations and very detailed models has been used. For more extensive information on the methodology, please refer to the scientific report [1].

Reduced warming since 1998

The fact that climate models had difficulties in predicting the reduced global warming since 1998 is not necessarily a sign of inadequacy for future climate projections. One of the causes of this recent levelling-off is natural variation. Climate model calculations used for the construction of the KNMI'14 scenarios are not intended to accurately predict the direction and timing of natural variations, whether positive or negative, but both strongly affect short-term trends. This natural variation 'phase' could potentially be predictable for the near future. This can be done by initializing the climate model with observations from the slowly varying parts of the climate system, like the oceans, in particular. However, attempts to predict the phase in natural variations 10-20 years ahead have met with little success so far.

KNMI'14 climate scenarios and IPCC emission scenarios

IPCC: CO_2 concentrations have increased by 40% since pre-industrial times. Atmospheric CO_2 increase has caused the largest contribution to climate change since 1750 and will cause further changes in future. The models assessed by the IPCC make use of four different pathway scenarios of greenhouse gas emissions, pollutant emissions and land use changes. These scenarios represent different developments in world population, economy and technology (RCPs, Representative Concentration Pathways) [3].

The four emission scenarios (RCPs) used by the IPCC cannot be linked one-to-one to the four KNMI'14 climate scenarios for the Netherlands. The KNMI scenario classification is based on the spread in climate model calculations, which in the short term contributes more to the different outcomes than the spread in greenhouse gas and pollutant emissions.
In order to compare the two, Figure 25 shows how the global temperature increases for the KNMI'14 scenarios agree with the global temperature increase in 2050 calculated for the different emission scenarios. The G_L and G_H scenarios match the lower end of the scenarios RCP4.5 and RCP6.0, in which the concentrations stabilize. The W_L and W_H scenarios match the high emission scenario. For 2085, this relationship is the same. The lowest emission scenario, RCP2.6, which assumes a relatively strong reduction in greenhouse gas emissions, was not used to develop the KNMI'14 scenarios. The G_L and G_H scenarios are fairly close to the average global temperature rise for RCP2.6. But the lower limit global temperature rise for RCP2.6 is not covered by KNMI'14. To describe the effect

Top-down and bottom-up application

The construction of the KNMI'14 scenarios follows a typical top-down information chain approach as adopted in the IPCC future emission scenarios, using different climate model calculations, a set of downscaling steps and statistical post-processing, to eventually arrive at an assessment of impacts of climate change for the Netherlands. But the scenarios have also been designed to serve as a benchmark for bottom-up application in various sectors to support adaptation planning.
This bottom-up application of the KNMI'14 scenarios follows a reverse chain of analysis: after defining vulnerability to potential impacts, for example for flooding due to sea level rise, an assessment of the probability of climate characteristics that lead to these impacts is made. In this case the KNMI'14 scenarios inform the user if and when the threshold probability of flooding is exceeded. Historical high-impact events transposed to future climate conditions through the future weather concept (see page 20) can be used to guide this bottom-up process.

Evaluation of climate model differences

Differences between model calculations of the future climate depend on assumptions used in scenarios for future greenhouse gas emissions, pollutant emissions and land use changes. In addition, the phase of the natural variations may differ for the different model calculations. Further differences can arise because each model is constructed in its own specific way. Therefore, under the same emission scenarios the various models will calculate different values for the global mean temperature change, the 'climate sensitivity'. Local processes and stronger natural variations will further enlarge the differences between model calculations for Europe and especially for a small region like the Netherlands.
The fundamental understanding of how the climate system operates and its predictability has undoubtedly increased in recent years. With the increase in spatial resolution of the latest global climate models, many processes are now described more realistically. Current satellite observations also provide unprecedented opportunities for model evaluation, especially, related to cloud processes. As a result, many continental-scale features of climate change are being simulated correctly, including the observed continental-scale surface temperature patterns and trends since 1951 [3].
Nevertheless, climate models still have their weaknesses and careful and critical expert judgement remains a necessity. For example, it is imperative to judge whether or not climate models calculate a climate sensitivity that is too low or too high, or collectively deviate in another aspect. Good agreement between observed and calculated changes for the past decades does not automatically mean that the model can predict the future. Conversely, poor agreement does not exclude this capability either.

of this lower limit on climate change in the Netherlands an additional scenario is necessary, consistent with a strong worldwide reduction of the use of fossil fuels.

Climate scenarios of neighbouring countries

National climate scenarios play an important role in helping society manage climate change in a systematic manner. Standardized scenarios make the results comparable across different applications and sectors. Although climate scenarios have been produced in many Western European countries over the past 25 years, very few countries have pursued a coordinated national approach such as in the Netherlands.
In each country that has constructed national climate scenarios, global climate model calculations performed for the IPCC were taken as a starting point. However, the methodology for constructing the national scenarios varies from one country to another. Recently, two countries have exploited the increase in computational power and the application of new statistical methods to construct 'probabilistic climate scenarios'. The UK [20] now provides probability scenarios for future changes in, e.g., temperature and precipitation. In Switzerland [21] probabilities have been assigned to three possible outcomes for each emission scenario (low, middle, and high).

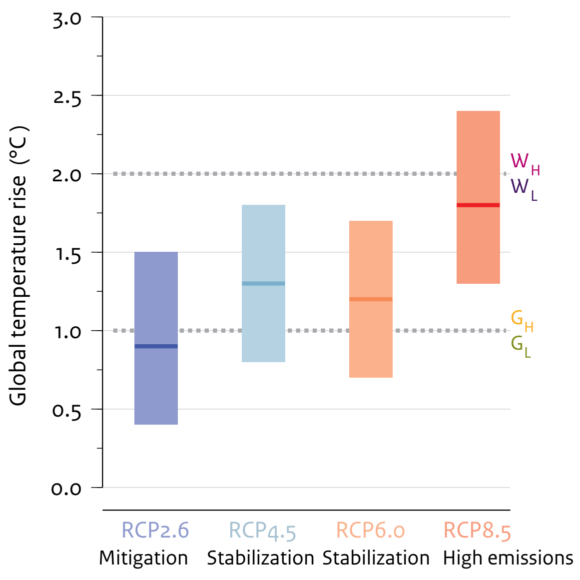


Figure 25 Global temperature rise around 2050, relative to 1981-2010, as adopted in the KNMI'14 scenarios (horizontal lines) and calculated for the four IPCC emission scenarios (RCPs; vertical bars for model spread, with a line for the central estimates).

The fact that the IPCC emission scenarios did not incorporate quantitave probablity renders it difficult to develop full probabilistic scenarios of future climate change in the Netherlands. KNMI has deliberately chosen to continue to develop a set of four discrete scenarios without probabilities. The reasons for this approach are: 1) discrete scenarios are easier to communicate because each scenario can be associated with a narrative, which contributes to its utility; 2) discrete scenarios offer the best guarantee that changes for many different climate indicators can be made available, which also contributes to their utility; and 3) discrete scenarios explicitly include the relevant prevailing uncertainties, such as global temperature rise and changes in air circulation, which adds to credibility and interpretability.

Europe wide efforts are underway to construct coordinated European climate change scenarios and other cross-border climate services.

Evaluation of IPCC emission scenarios

In order to assess to what extent the four RCPs are realistic, the scenario pathways between 2000 and 2012 have been compared to the actual observed increase in concentrations of CO_2 and other greenhouse gases for the period 2000-2012. In general, the observations indicate that the observed pathway is somewhere in the middle of the RCP range, except for aerosol particles and tropospheric ozone for which the observed concentrations are larger than the RCP range. Aerosols have a cooling effect on the climate whereas tropospheric ozone is the third most important human-induced greenhouse gas after CO_2 and methane. If the observed trends continue, the global temperature increase calculated for the four RCPs as shown in Figure 25 will be reached sooner than 2050 or later. This means that the validity of the KNMI'14 scenarios will shift proportionally in time.

The future evolution of aerosol particles and ozone will vary per region and depends critically on the assumed implementation of air quality policies. All four RCPs assume the implementation of stringent air quality policies and major reductions in emissions well before 2030. However, satellite observations of the amount of aerosol particles over the oceans over the 10-year period 2000-2009 show hardly any trend in global mean concentration. A decrease has been observed over Europe and the United States and an increase over China and India. Over all these regions the observed concentrations of ozone are higher than in the RCPs. Ozone concentrations are related to NO_2 concentrations which have increased almost everywhere (Figure 26) and worldwide by 7% between 2005 and 2012.

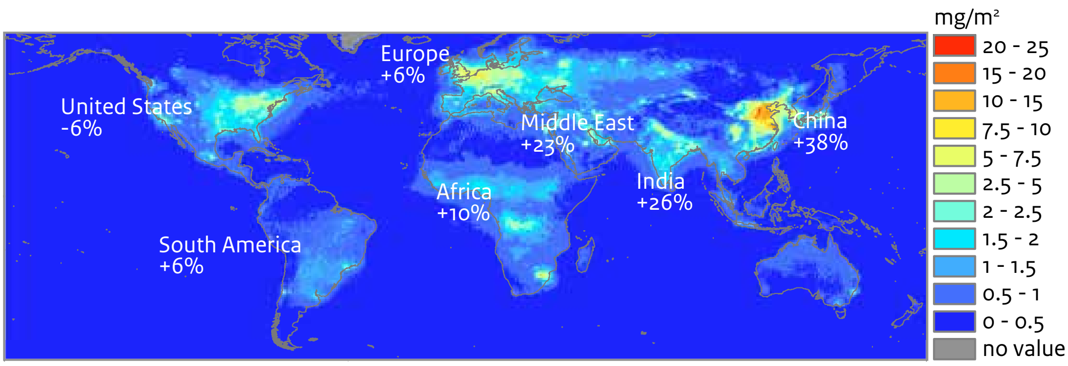


FIGURE 26 Observed changes in NO_2 concentration per region between 2005 and 2012. Underlying map shows NO_2 concentration in 2012. NO_2 is a good indicator for emissions of ozone and other greenhouse gases and pollution by human activity.

Additional tailoring

The generic KNMI'14 scenarios provide a comprehensive package of reports and online information. They are targeted to a diverse group of policy advisors, engineers and scientists preparing the Netherlands for future climate change.
To develop a product that meets their requirements, several stakeholder workshops were held in 2010, 2012 and 2013, and a user board was set up.
However, not all user requests could be included in the development of the scenarios. The diversity of the requests was simply to large to do so. For specific users and applications, KNMI will be able to provide further details based on the KNMI'14 scenarios. For example, KNMI will be able to provide more information on compound extremes, multi-day precipitation totals, and rainfall duration.
Additional climate scenarios can also be developed on request, e.g., exploring a wider range of possible future climates, including speculative low probability / high impact situations (see page 28). These extreme scenarios may be useful for stress tests when attempting to determine at what point in time particular adaptation strategies will no longer be adequate.
Finally, KNMI will support sectors with follow-up work, which includes providing advice on good practices in scenario use.

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