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More information?

More information about the new climate scenarios for the Netherlands, how they are constructed, and applications can be found at the following website: [www.knmi.nl/climatescenarios](http://www.knmi.nl/climatescenarios).

The scientific justification can be found in the KNMI-publication WR 2006-01 "KNMI Climate Change Scenarios 2006 for the Netherlands".

For questions related to this brochure you can also contact KNMI climate desk: [klimaatdesk@knmi.nl](mailto:klimaatdesk@knmi.nl), telephone: +31 30 22 06 850.

KNMI is the Dutch national centre for information on weather, climate and seismology



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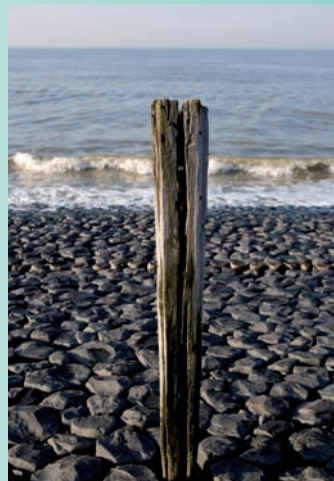
## Climate in the 21st century *four scenarios for the Netherlands*





# Climate in the 21st century

*four scenarios for the Netherlands*



# Introduction

The climate of the Netherlands is changing. How it will change depends mainly on the global temperature rise as well as on changes in the air circulation patterns in our region (Western Europe) and the related changes in the wind.

Based on the most recent results from climate research, KNMI presents four new climate scenarios for the Netherlands. They replace the scenarios that were drawn up in 2000 for the National Commission on Water management in the 21st century.

A schematic overview of the new scenarios is shown in **Figure 1** (inside back cover). In **Table 1** (inside back cover) the climate change in the year 2050 is expressed in numbers for each scenario.

## What are climate scenarios?

Climate scenarios are consistent and plausible pictures of possible future climates. They are intended for use in studies exploring the impacts of climate change, and to formulate possible adaptation strategies.

Climate scenarios are not long-term weather forecasts: they are not concerned with predicting the weather on a certain day. Rather, they provide information on the characteristics of the average weather and the chance of weather extremes.

The KNMI'06 climate scenarios present pictures of the changes in temperature, precipitation, wind, and sea level for a climatological period of 30 years. The scenarios for 2050 are, therefore, representative for the climate around 2050 (between 2036 and 2065). Likewise, the climate in the baseline year 1990 is described with data from 1976 to 2005.

The numbers per KNMI'06 climate scenario (**Table 1**) do not include information on year-to-year variability and longer-term natural fluctuations, which also occurred in the past. Especially for wind these natural fluctuations are relatively large compared with the changes in the scenarios.

## How were the KNMI'06 climate scenarios constructed?

In formulating the new scenarios, recent results from a large number of climate models have been analysed. These models are used by scientists to examine the human influence on the worldwide and regional climate.

During the construction of the scenarios that were published in 2000 only the results of a limited number of climate models were available. Those only gave good information on global warming and sea level rise. The change in precipitation in the Netherlands in these scenarios was estimated using the statistic relation between precipitation and temperature in historic observational series. It was assumed that this relation would not change in the future and neither the air circulation patterns.

With the new analyses the relation between global warming, changes in air circulation above Western Europe and climate change in the Netherlands was mapped systematically. For the first time this was done by combining results from a large number of global and regional climate models and observational series.

## Dealing with uncertainty

Climate models differ considerably in their calculation of global temperature rise. This is caused by uncertainty regarding future emissions of greenhouse gasses and aerosols, which, in turn, depend on such factors as future population growth, and economic, social and technological developments. Besides this, our understanding of the complex processes in the climate system is still limited. For example, the influence of water vapour, clouds, snow and ice on the Earth's solar and thermal radiation balance and hence the temperature still requires improvement. Some processes are not included at all. None of the climate models used in this study have an active carbon cycle. Besides, there are fundamental limits to the predictability of complex systems, such as the climate system.

Uncertainty further increases when we go from a global scale to a regional scale, such as Western Europe or the Netherlands. At this scale, air circulation plays an important role. Most climate models calculate a clear change in circulation patterns above Western Europe. However, the magnitude and direction of change differ between models.

To be able to deal with these uncertainties, KNMI selected four climate scenarios from the broad range of possible futures. These scenarios are considered most relevant for Dutch policies. For these situations, as far as possible, a complete picture of our future climate is presented. Each of the specific scenarios is plausible. However, with our current knowledge it is not possible to indicate which scenario is most probable.

Each of the four climate scenarios gives only one number for the change per variable, except for sea level rise where a range is presented (see Table 1). These numbers are uniform for the Netherlands: there is no differentiation by province or county. These numbers can also be used as indicative values for the river basins of the Meuse and Rhine (except for the Alps).

## How does our climate change?

A number of key characteristics of climate change in the Netherlands and surrounding areas are common across all the scenarios:

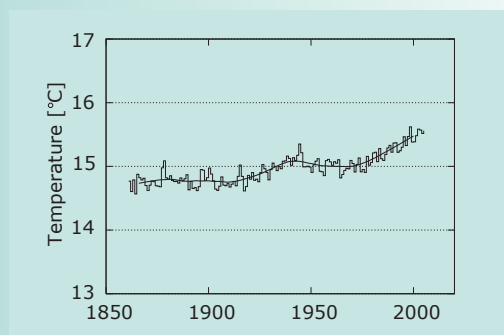
- ▶ temperature will continue to rise. Mild winters and hot summers will become more common;
- ▶ on average, winters will become wetter and extreme precipitation amounts will increase;
- ▶ the intensity of extreme rain showers in summer will increase, however the number of rainy days in summer will decrease;
- ▶ the calculated change in wind is small compared to the natural fluctuations;
- ▶ the sea level will continue to rise.

# I Temperature

## Observed worldwide

Since 1900 the global temperature has risen on average by  $0.8^{\circ}\text{C}$  (Figure 2). Most of this increase took place in the past 30 years. From 1975 onwards, global temperature increased by  $0.5^{\circ}\text{C}$ . Based on comparison of model calculations and observations, it can be concluded that in the past 30 years the temperature increase was mainly anthropogenic in nature. Before 1975 the temperature rise was caused mainly by natural processes.

The temperature has not increased evenly over the earth. The increase was largest above the continents in the Northern Hemisphere.

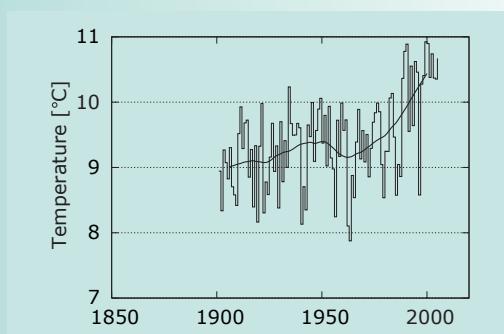


► **Figure 2** Global mean annual temperature between 1860 and 2005. The thick black line represents the 30-year moving average. Source: CRU/UKMO.

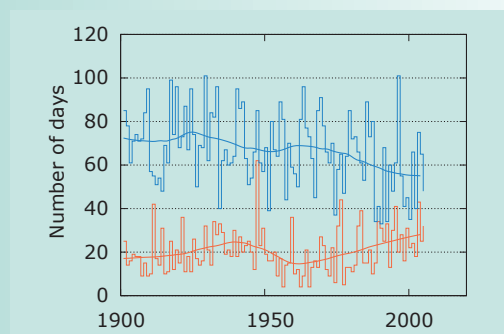
## Observed in the Netherlands

In the Netherlands the temperature has risen, on average, by  $1.2^{\circ}\text{C}$  since 1900 (Figure 3). This increase resulted in a decrease of the number of frost days and an increase of the number of summer days (Figure 4). The ten warmest years since 1900 consist entirely of years after 1988.

During the past 20 years, the months February and March have seen the largest increases in temperature. Apart from global warming, this was also due to an increase of the number of days with southwesterly winds. In the Netherlands the dominant wind direction has a clear effect on the temperatures our country experiences. During winter, westerly winds, which convey air from the sea, give rise to milder temperatures. Easterly winds (from the continent) in summer cause temperatures to be higher. It is not yet clear whether the observed increase of 'warm' winds in February and March is connected with the human influence on the climate, or if it is only the product of natural fluctuations.



► **Figure 3** Average annual temperature in De Bilt between 1900 and 2005. The thick black line represents the 30-year moving average.



► **Figure 4** Number of frost days (minimum temperature  $< 0^{\circ}\text{C}$ ; blue) and number of summer days (maximum temperature  $\geq 25^{\circ}\text{C}$ ; orange) in De Bilt between 1900 and 2005. The thick lines represent the 30-year moving averages.

## Future worldwide

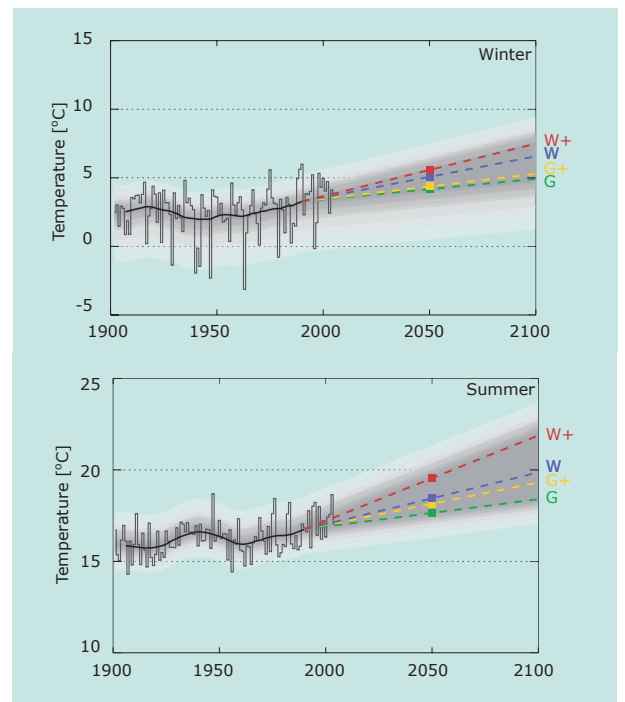
Climate models calculate a global mean temperature increase of 1°C up to 6°C for the year 2100, compared to 1990.

In Europe the average temperature will probably increase slightly faster than the world average. In the Scandinavian countries especially winter temperatures will increase more rapidly than the global average, and in southern Europe summer temperatures will increase more rapidly.

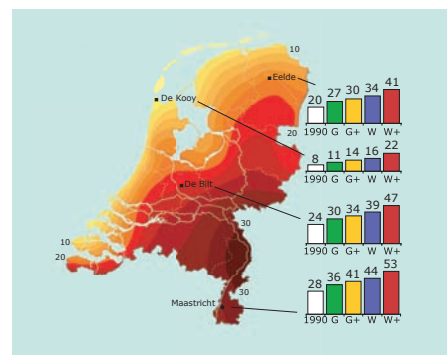
## Future in the Netherlands

In the KNMI'06 climate scenarios the temperature increase in the Netherlands does not equal global temperature rise. The Netherlands is located at the edge of a continent, which warms faster than the global average. At the same time, it is located close to the northeastern part of the Atlantic Ocean, for which most climate models calculate a relatively slow temperature increase. The scenarios with changes in air circulation show a faster warming than the scenarios that do not include such changes.

The four scenarios show a warming by 2050 of 0.9°C up to 2.3°C in winter and 0.9°C up to 2.8°C in summer (Figure 5 and 6). Note that these numbers are with respect to the baseline year 1990 (the average for 1976-2005). The observed temperature rise between 1990 and 2005 is comparatively high: on average more than 0.5°C. This does not mean necessarily that the lowest scenarios for 2050 are too conservative. Also natural fluctuations clearly affect the observed temperature increase. Since these fluctuations will also continue in the future, it is possible that in the coming decades we will temporarily experience a period with relatively colder weather.



► **Figure 5** Temperature in De Bilt between 1900 and 2005 and the four climate scenarios for 2050 (coloured points). The thick black line represents the 30-year moving average of the observations. The thick coloured and dashed lines connect each climate scenario with the baseline year 1990. The grey band represents the year-to-year variation, derived from the observations.



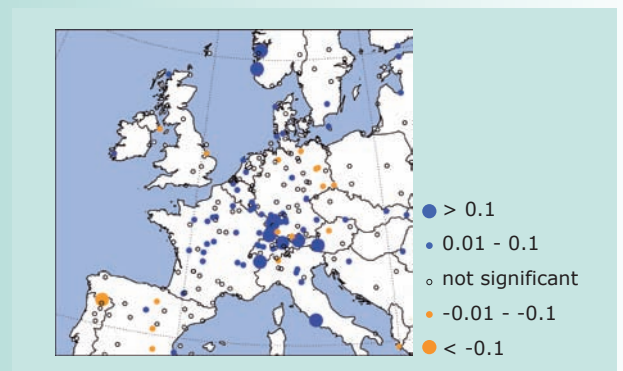
► **Figure 6** Map with the observed number of summer days (maximum temperature  $\geq 25^\circ\text{C}$ ) per year for 1971-2000, and for four locations in the Netherlands the climate scenarios for 2050. The differences in summer days between the four locations are due to the differences in the current climate.

# 2 Precipitation

## Observed worldwide

In the temperate regions in the Northern Hemisphere - to which northwest Europe belongs - precipitation increased, on average, by 5 to 10% within the 20th century. This increase is caused partly by the fact that warmer air can contain more water vapour. The increase in the strength of the westerly circulation also has played a role.

For Europe as a whole, the intensity of extreme precipitation has increased in the past 50 years. Just as in many other regions in the world, the number of extremely wet days increased in many places in Europe (Figure 7).

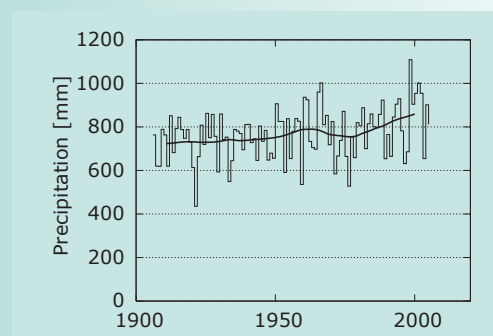


► **Figure 7** Trends in number of days per year with at least 20 mm precipitation, measured at European weather stations between 1946 and 2004. Source: eca.knmi.nl.

## Observed in the Netherlands

In the Netherlands, the annual precipitation amount increased by 18% from 1906 on (Figure 8). This is especially caused by an increase in winter (+26%), spring (+21%) and autumn (+26%), while in the summer the precipitation amount has hardly changed (+3%).

In winter, also the extreme multi-day precipitation amounts increased. The highest 10-day total precipitation per winter increased with 29% since 1906. In summer no clear trend in extreme precipitation has been found.



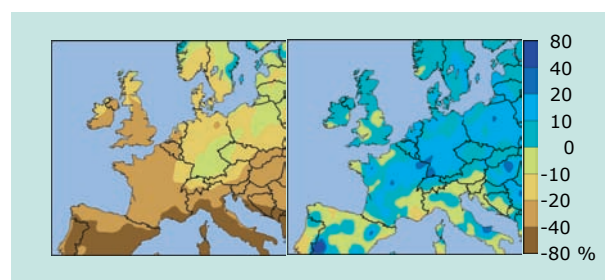
► **Figure 8** Total annual precipitation in the Netherlands (average of 13 stations) between 1906 and 2005. The thick black line represents the 30-year moving average.

## Future worldwide

Climate models calculate an increase in total annual precipitation for the temperate regions and a decrease in the subtropics. However, the calculations vary considerably among themselves.

For southern Europe nearly all climate models calculate a decrease in summer precipitation and an increased chance for drought. For northern Europe the change in precipitation is less consistent.

For Europe as a whole, an increased chance of prolonged heavy precipitation and short intense showers is calculated (Figure 9).

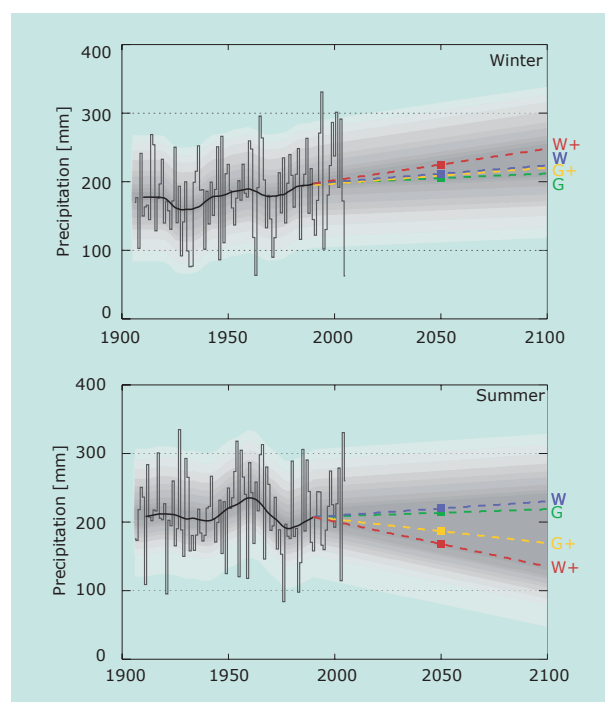


► **Figure 9** Illustration of the typical change in spatial precipitation patterns in the W+ scenario for summers around 2050 compared to 1990. The maps are constructed using results of the KNMI regional climate model RACMO2. At left the change in average summer precipitation, and at right the change of the intense showers (daily precipitation sum exceeded once every 10 years). The average precipitation is decreasing almost everywhere, whereas the precipitation amount in heavy showers is increasing.

## Future in the Netherlands

In the G and W scenarios (those without significant change in air circulation patterns) precipitation increases both in summer and winter with approximately 3% per degree global temperature increase. In the G+ and W+ scenarios (those with significant change in air circulation patterns) precipitation increases more in winter (about +7% per degree C) and decreases in summer (about -10% per degree C; Figure 10 and Table 1). The decrease in summer precipitation can be attributed mainly to the decrease in the number of rainy days.

In all scenarios, the average precipitation amounts on extremely wet summer days increase due to the occurrence of heavier rain showers (largest increase in the W scenario). In winter the relative increase of the extreme 10-day precipitation amounts is approximately the same as the increase of the average precipitation amount, for all 4 scenarios.



► **Figure 10** Precipitation in the Netherlands (average of 13 stations) between 1906 and 2005, and the four climate scenarios for 2050 (coloured points). The thick black line represents the 30-year moving average of the observations. The thick coloured and dashed lines connect each climate scenario with the baseline year 1990. The grey band represents the year-to-year variation, derived from the observations.

# 3

# Windstorms

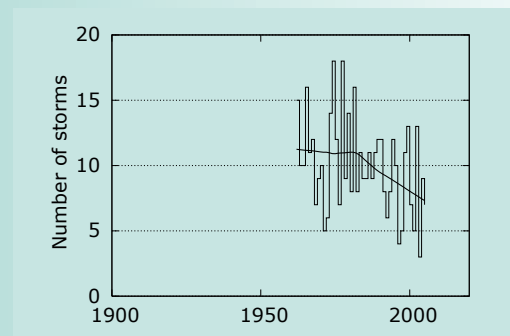
## Observed worldwide

In the temperate regions, the number of storms and their strength is especially dependent on the strength and the flow pattern of the circulation in the upper air. In previous decades, above the northern part of the Atlantic Ocean this circulation has become stronger than it was before. Besides, the flow pattern was displaced to the north. It is not clear to what degree (if at all) this change in air circulation is related to the enhanced greenhouse effect, caused by humans.

## Observed in the Netherlands

Measurements at KNMI-stations in the Netherlands show that the total number of 'storms' ( $\geq 6$  Bft inland, or  $\geq 7$  Bft along the coast) has decreased since 1962 (Figure 11). On average, these events occur about 10 times per year. However, at present we experience 20-40% less of such 'storms' when compared to the beginning of the sixties.

The Netherlands is too small and the observational series too short to detect changes in the number of heavy storms (at least 10 to 11 Bft). These storms occur in the Netherlands too seldom for trend detection, on average less than once per year.

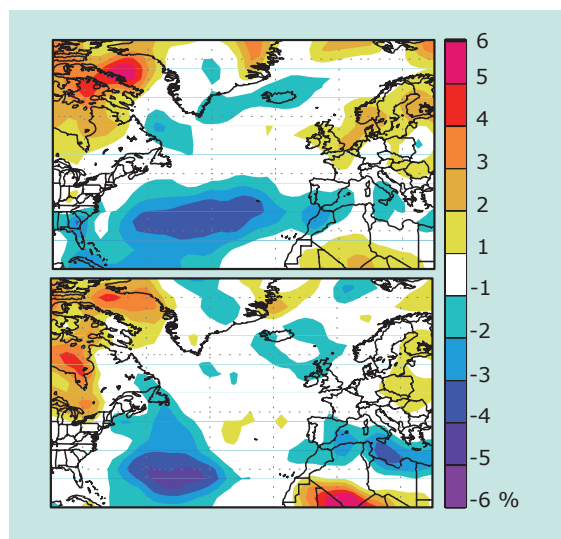


► **Figure 11** Observed number of 'storms' (strength  $\geq 6$  Bft inland, or  $\geq 7$  Bft along the coast) in the Netherlands (average of 13 stations) between 1962 and 2005. The thick black line represents the 30-year moving average.

## Future worldwide

Climate models calculate, on average, a slight decrease in the number of storms at temperate latitudes in the Northern Hemisphere. Besides, there are indications that the strength of the heaviest storms increases, although these indications are very uncertain.

For the wind climate in Western Europe it is important how global warming may induce changes in air circulation patterns. These determine the number, strength and the path followed by depressions. Therefore, they affect the future storm climate. Model calculations for air circulation patterns in our region vary considerably among themselves.



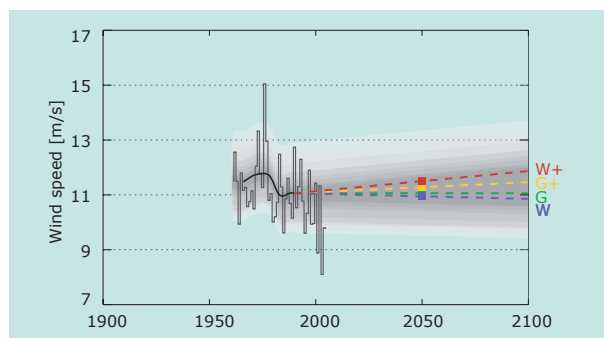
► **Figure 12** Change in the maximum daily wind speed per year around 2050 compared with 1990, calculated with climate models representative for the G+ and W+ scenarios (top) and for the G and W scenarios (bottom).

## Future in the Netherlands

In the G and W scenarios the maximum daily wind speed per year hardly changes ( $\leq 1\%$ ). The climate models which have been used for the G+ and W+ scenarios show a slight increase in the maximum daily wind speed per year (Figure 12). The strength of the heaviest storms, that currently occur less than once per year, also shows a slight increase above northwest Europe.

The change of the maximum daily wind speed per year of approximately +2% per degree global temperature rise in the G+ and W+ scenarios, is relatively small compared to the natural year-to-year variation and the long term natural fluctuations (Figure 13). In none of the scenarios, the currently observed decreasing trend in the total number of storms in the Netherlands continues to the same degree.

Storm surges along the Dutch coast are associated with storms coming from western to northern directions. The model calculations used for the four scenarios show only small changes in the number of storms from these directions.



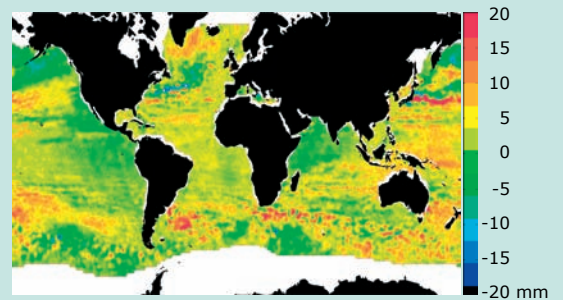
► **Figure 13** Maximum daily wind speed in De Bilt between 1962 and 2005, and the four climate scenarios for 2050 (coloured points). The thick black line represents the 30-year moving average of the observations. The thick coloured and dashed lines connect each climate scenario with the baseline year 1990. The grey band represents the year-to-year variation, derived from the observations.

# 4

# Sea level

## Observed worldwide

According to measurements in coastal areas and with sea-based buoys, the sea level rose by 1 to 2 mm per year since 1900. Especially between 1930 and 1960 and in the past decade the increase was relatively large. Satellite measurements since 1993 show a global average sea level rise of approximately 3 mm per year, with strong regional variations between -20 up to +20 mm per year (Figure 14). These local variations are due to changes in circulation patterns in the air and in the oceans. It is currently not clear to what degree the observed acceleration of sea level rise in the past 13 years has been caused by the enhanced greenhouse effect.

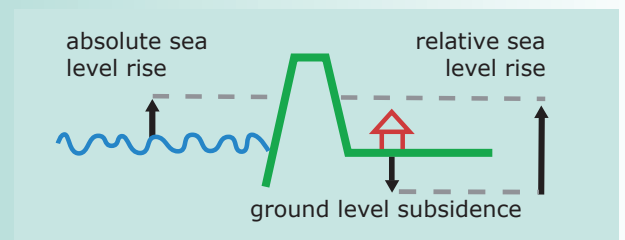


► **Figure 14** Sea level rise in mm per year between 1993 and 2004 as measured by satellites. Source: Leuliette et al., *Marine Geodesy*, 2004.

## Observed in the Netherlands

Between 1993 and 2004, the sea level in the northeastern part of the Atlantic Ocean (including the North Sea) also increased approximately 3 mm per year. From 1900 on, the sea level rise in the North Sea was on average 2 mm per year, or 20 cm in the 20th century (Figure 16). The water level in the North Sea is affected by the sea level rise in the Atlantic Ocean, but also by changes in the wind and current driven pressure exerted on the water column.

The total impact along the Dutch coast (= relative sea level rise) is larger, since subsidence of the ground level also has to be taken into account (Figure 15). During the 20th century this subsidence in the Netherlands varied on average between 0 and 4 mm per year, depending on the exact location.



► **Figure 15** Schematic presentation of the difference between absolute and relative sea level rise, as a result of ground level subsidence.

## Future worldwide

Oceans react slowly to air temperature rise. Therefore, the sea level rise in the next few decades is rather insensitive to the rate of air temperature increase. Only after 2050 does the rate of global warming become more important.

Due to the slow reaction of the oceans, the sea level will continue to rise long after 2100, even if greenhouse gas concentrations stabilise.

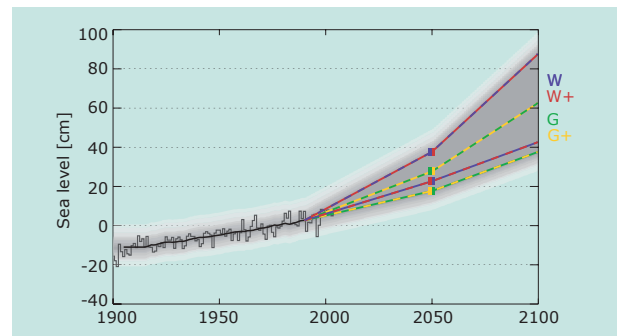
In addition, if large scale melting of the large ice sheets also takes place, a sea level rise of a few meters within a few centuries can be expected.

## Future in the Netherlands

Climate models show large differences among themselves with regard to the sensitivity of sea level rise to increased air temperatures. In order to represent this uncertainty, a range of sea level rise is given for each scenario, instead of only one number. The scenarios vary due to the differences in global temperature rise, but not due to the changes in air circulation.

The new KNMI'06 climate scenarios only present the absolute sea level rise, which is almost the same as the sea level rise compared to NAP (Dutch height system). To calculate the relative sea level rise for a particular location, information on the local ground level subsidence should be added to the scenario data.

The absolute sea level rise along the Dutch coast around 2050 varies in the scenarios between 15 and 35 cm (Figure 16). Around 2100 the sea level rise varies between 35 and 85 cm. The sea level will continue to rise after 2100, and in 2300 it will amount to 1 m up to 2.5 m.



► **Figure 16** Average annual sea level along the Dutch coast compared to NAP ( $\approx$  absolute sea level rise) between 1900 and 2004, and the scenarios for 2050 (coloured points). The thick black line represents the 30-year moving average of the observations. The thick coloured and dashed lines connect each scenario with the baseline year 1990. The grey band represents the year-to-year variation, derived from the observations. Source observations: RWS-RIKZ.

## Discharge of Rhine and Meuse

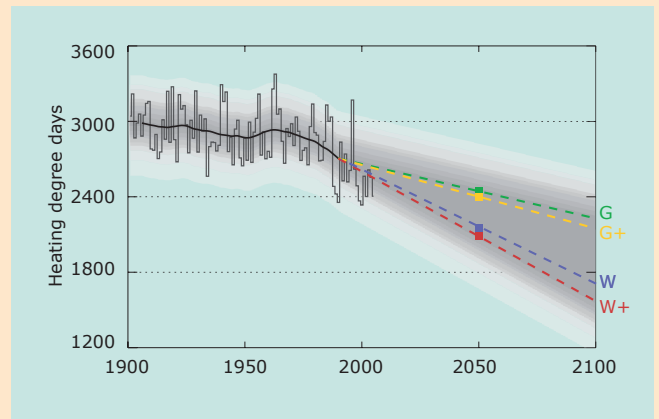
In the Netherlands, just as elsewhere in the river basins of the Rhine and Meuse, the expected increase in winter precipitation will lead to increased peak discharges. This is especially true for the W+ scenario. Moreover, in mountainous areas more precipitation will occur in the form of rain rather than snow. This will lead to an increase in the Rhine's discharge during winter. On the other hand, for the W+ scenario the average precipitation in summer clearly decreases and the evaporation increases (when there is sufficient water available). As a result, the discharges of the Rhine and Meuse decrease, leading more often to navigation problems.



Lower river discharges combined with high temperatures also negatively affect water quality and the available amount of cooling water. In combination with sea level rise, lower river discharge rates allow increased salt water intrusion from the sea.

## Energy use for heating

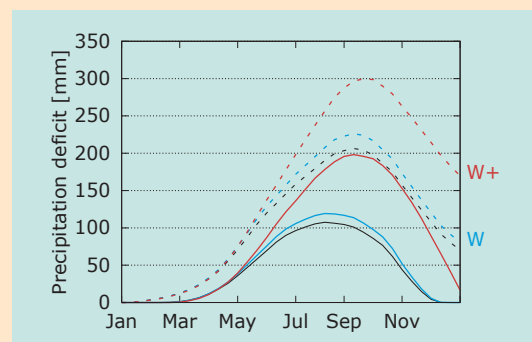
Due to the expected temperature increase the energy need for heating of houses, factories and offices will decrease. The energy need for heating shows a clear relation with the number of heating degree-days (the sum of the deviations from 17°C for all days with an average temperature < 17°C; e.g. a day temperature of 14°C adds 3, and a day temperature of -3°C adds 20 degree-days). Depending on the climate scenario, the number of heating degree-days around 2050 will decrease by 9% (G scenario) up to 20% (W+ scenario), compared to 1990 (Figure 17).



► **Figure 17** Number of heating degree-days per year in De Bilt between 1900 and 2005, and the four climate scenarios for 2050 (coloured points). The thick black line represents the 30-year moving average of the observations. The thick coloured and dashed lines connect each climate scenario with the baseline year 1990. The grey band represents the year-to-year variation, derived from the observations.

## Agricultural production

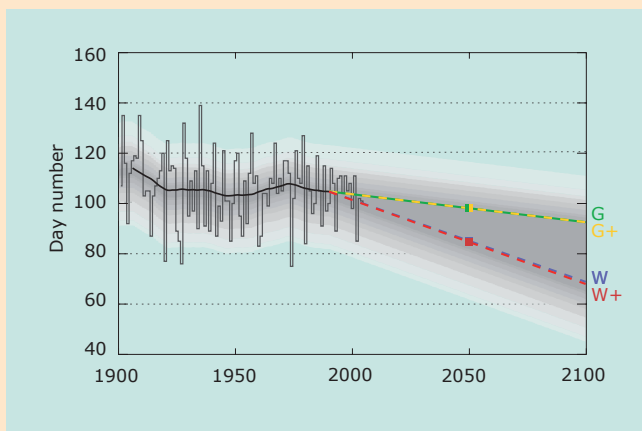
In the Netherlands an increase of temperature and CO<sub>2</sub>-concentration in the air may have a favourable impact on agricultural production, among others of grasslands. However, in the G+ and W+ scenarios the favourable effect may be cancelled out (partly) by the larger chance of water shortage in summer (Figure 18), especially in higher elevation sandy regions. The same scenarios also have extra wet winters, as a result of which grasslands in the lower parts of the Netherlands may become swampier in spring, hindering grazing and mowing.



► **Figure 18** Cumulative precipitation deficit (= difference between precipitation and potential evaporation) in the Netherlands (average of 13 stations) for the historical climate (1906-2000; black), and two climate scenarios for 2050 (W and W+). For each date, the continuous lines represent the maximum precipitation deficit that is exceeded in 50% of the years; the dashed lines represent the maximum deficit that is exceeded in 10% of the years. Potential evaporation is the evaporation in case of optimal water availability.

## Growing season

**D**ue to the higher temperatures in winter and spring, the growing season of many plants will start earlier, a trend that has already been observed over the past years (see [www.natuurkalender.nl](http://www.natuurkalender.nl)). A temperature of 5°C is often used as the threshold above which plants start to grow. The first day in the year at which the average day temperature reaches 5°C and after which it remains above 5°C until the first of July can be used as an indication for the start of the growing season. According to this definition, on average the growing season will start between 6 days (G and G+ scenarios) and 19 days (W+ scenario) earlier in 2050 compared with 1990 (Figure 19).

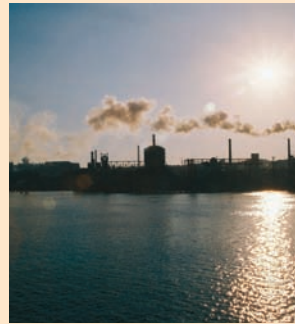


► **Figure 19** Day number in the year at which the average day temperature reaches 5°C and after which it remains above 5°C until the first of July in De Bilt between 1900 and 2005, and the four climate scenarios for 2050 (coloured points). The thick black line represents the 30-year moving average of the observations. The thick coloured and dashed lines connect each climate scenario with the baseline year 1990. The grey band represents the year-to-year variation, derived from the observations.

## Wind energy

**T**he observed decrease in wind speed in the past decades in the Netherlands has consequences for the energy production of wind turbines. The maximum energy production of the wind turbines has decreased. The scenarios do not give reason to believe that wind energy production will remain lower in the future. The scenarios with more westerly wind (G+ and W+) seem to indicate a (slight) increase in the long-term. However, for the wind energy sector, the year-to-year variation and long term fluctuations are of much greater importance than the relatively small changes present in the scenarios.

\*) For a more complete overview of 'Impacts of climate change in the Netherlands' the reader is referred to the publication with the same title issued by the Netherlands Environmental Assessment Agency (MNP), 2005.



## Air quality

**W**eather conditions, such as wind direction and solar radiation intensity largely affect air quality, since they affect the supply and formation of polluting substances. Periods of smog in summer (high ozone concentrations) frequently coincide with heat waves (high radiation intensity). In case emissions remain the same, an increase of the number of tropical days (maximum temperature  $\geq 30^{\circ}\text{C}$ ) will increase the chance of summer smog, especially in the W+ scenario. In winter, the chance of smog decreases in the G+ and W+ scenarios, since in these scenarios westerly winds from the sea which are associated with relatively clean air are more dominant.



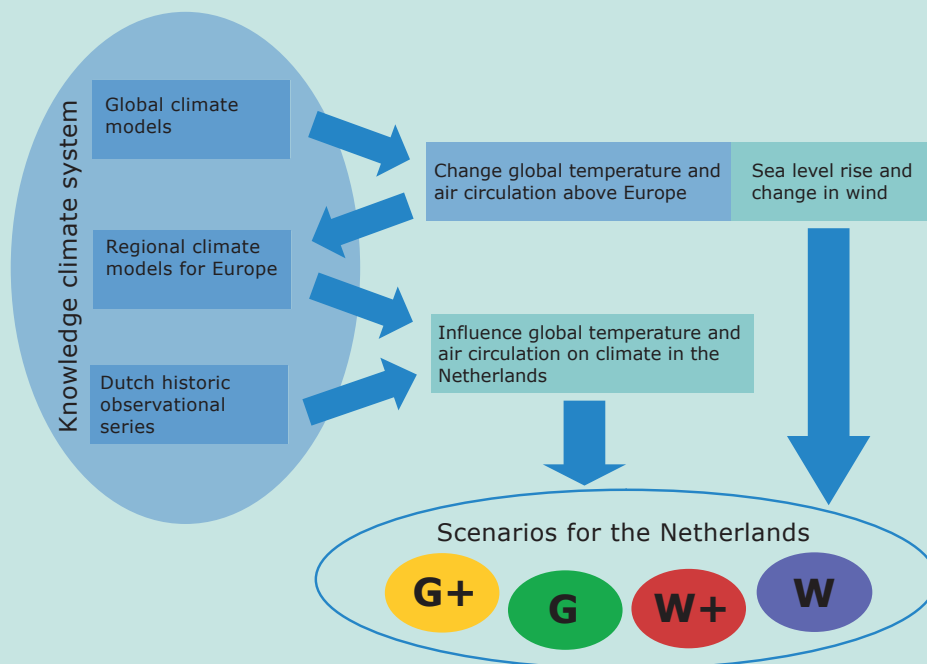
## Eleven cities tour

**T**he chance of long periods with frost will decrease due to the expected temperature rise. As a consequence, in all four scenarios the expected number of 'Eleven cities tours' decreases. In the W+ scenario, which has the strongest temperature rise as well as changes to air circulation patterns, the decrease will be strongest. The chance decreases more than could be expected on the basis of the average temperature increase only, since in this scenario the temperature of the coldest winter days increases more than the average.

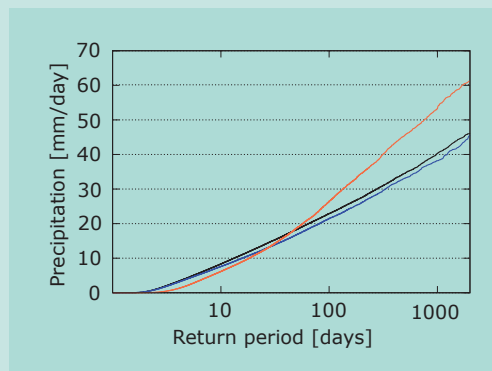
# Justification

The global temperature rise, as calculated by the most important global climate models (GCMs), has been used as starting point for constructing the new climate scenarios for the Netherlands. Additionally, it was analysed how the air circulation patterns above Western Europe could change based on data from the same climate models. These global large-scale projections have been ‘translated’ to more detailed changes in temperature, precipitation, evaporation, wind, and sea level in the Netherlands. For this, a large number of regional climate models (RCMs) for Europe were used in addition to long-term observational series from Dutch stations. The methodology is illustrated schematically in [Figure 20](#). The quality of the GCMs and RCMs used in this work was examined by comparing the accuracy and consistency of current climate simulations against observations ([Figure 21](#)).

Knowledge of the climate system, published in scientific publications, forms the basis for the new scenarios. An elaborate description with all relevant sources and references to the scientific literature can be found in the KNMI-publication WR 2006-01 ‘KNMI Climate Change Scenarios 2006 for the Netherlands’.



► **Figure 20** Schematic presentation of the methodology used for the construction of the KNMI'06 climate scenarios. The blue rectangles describe the sources of the scenario information in the green rectangles. The arrows symbolise the information flow. Information about the climate system at global, regional, and local scales was used for the climate scenarios



► **Figure 21** Comparison between simulated (blue) and measured (black) precipitation on summer days in the Rhine river basin. For the simulations the KNMI regional climate model RACMO2 was used. The figure shows the relation between the precipitation amount and a certain return period. The precipitation amount for a return period of 100 indicates that once every 100 days this amount is exceeded. Model calculations for 1961-1990 exhibit a good match with the observations. Therefore, the simulations for the future (red) are also considered reliable. The simulations for 2071-2100 show a slight decrease in low precipitation amounts, and a strong increase in larger precipitation amounts. Other climate models project the same trends. This information is the basis for the increase of the extreme precipitation in summer in all scenarios.

### Choice +1°C and +2°C

The uncertainty band width in global temperature rise in 2100 (+1°C up to +6°C compared to 1990) of recent GCM simulations is slightly broader than the band width presented in the third report of the Intergovernmental Panel on Climate Change (IPCC, 2001). For the new KNMI scenarios, we used global temperature increases in 2100 of +2°C and +4°C (with associated temperature increases in 2050 of +1°C and +2°C, respectively). These temperatures lie within the GCM range.

The global temperature rise of +2°C in 2050 or in 2100 should not be confused with the +2°C target that is specified by the Dutch government and the EU as the maximum admissible global temperature rise to prevent dangerous anthropogenic interference with the climate system.

This policy objective refers to a stabilisation of 2°C above the pre-industrial level, whereas the KNMI'06 climate scenarios

present changes with respect to 1990. Also IPCC uses the same baseline year (1990) in its reports.

The global temperature increase of +2°C in 2100 compared to 1990 is the same as used in the old 'central' KNMI scenario, published in 2000. The increase of +4°C in 2100 is consistent with the old 'high' scenario.

### Choice changed or unchanged air circulation patterns

Most of the used GCMs (selected on the basis of a good representation of the current air circulation patterns above Europe), show either hardly any change in air circulation in summer and winter, or a clear change in both seasons. On the basis of this finding, a choice was made for two scenarios with change in air circulation and two scenarios without. The last two scenarios link up well with the old scenarios, which also had no change in air circulation.

### What is not included in the scenarios?

The new KNMI scenarios do not account for any possible occurrences associated with abrupt climate change, for example as a result of a complete collapse of the 'Gulf Stream' or the unexpectedly fast melting off of large ice sheets in Greenland and West Antarctica. The simulation of these types of events is relatively poor in climate models due to incomplete scientific knowledge about these phenomena. Besides, the indications for abrupt changes in the observations are also very uncertain.

The scenarios neither include phenomena where it is not clear if they are physically realistic, such as 'super' storms that are much heavier than ever occurred in Europe. Whenever new insights become available on this topic, they will be included in the next update of the scenarios.

In several figures in this brochure, the year-to-year variation is represented with grey bands. These bands have been made

# Justification

assuming that the variation in the past will remain the same in the future. The year-to-year variation is not included explicitly in the scenarios. The questions as to whether this year-to-year variation will change in the future still needs further analysis.

## Tailored climate scenarios

Climate scenarios for different time horizons, scenarios for spring and autumn, or scenarios using a different global temperature increase, can not always be obtained by simple linear interpolation or extrapolation.

As in the past, KNMI will continue to make tailored climate scenarios, in addition to the four general scenarios in this brochure, for example scenarios for 2025 or scenarios with more detail, such as representative time series for the future climate. For specific users, the consequences of the earlier-mentioned abrupt changes with large consequences will be quantified, for example the impact of abrupt melting of ice sheets on sea level rise after 2100.

## Relation with MNP scenarios

Climate models use assumptions about future emissions of greenhouse gases and dust particles in the 21st century. These emission scenarios are connected to 'story lines' on how the world population, economy, and technology will develop. The Netherlands Environmental Assessment Agency (MNP) uses such story lines for the construction of socio-economic scenarios for the Netherlands. However, these story lines cannot be coupled 1 by 1 to the KNMI'06 climate scenarios.

Uncertainty concerning future emissions of greenhouse gases and dust particles causes only a small part of the differences between the scenarios for 2050. Most of the uncertainty is caused by differences in model calculations due to our limited knowledge of the climate system. However, in general, the G and G+ scenarios both match better to the

story lines B1 (strong Europe) and B2 (regional communities) of the MNP, whereas the W and W+ scenarios both match better to the story lines A1 (global economy) and A2 (transatlantic market).

## IPCC reports

In 2007 the fourth assessment report of the IPCC will appear. In the period before this report, many new model simulations have been carried out. The analyses of these model results are currently being published in the scientific literature. Both the most recent model results and publications have been used for the construction of the KNMI'06 climate scenarios. This means that the new scenarios use the same sources and results as the upcoming fourth IPCC-report.

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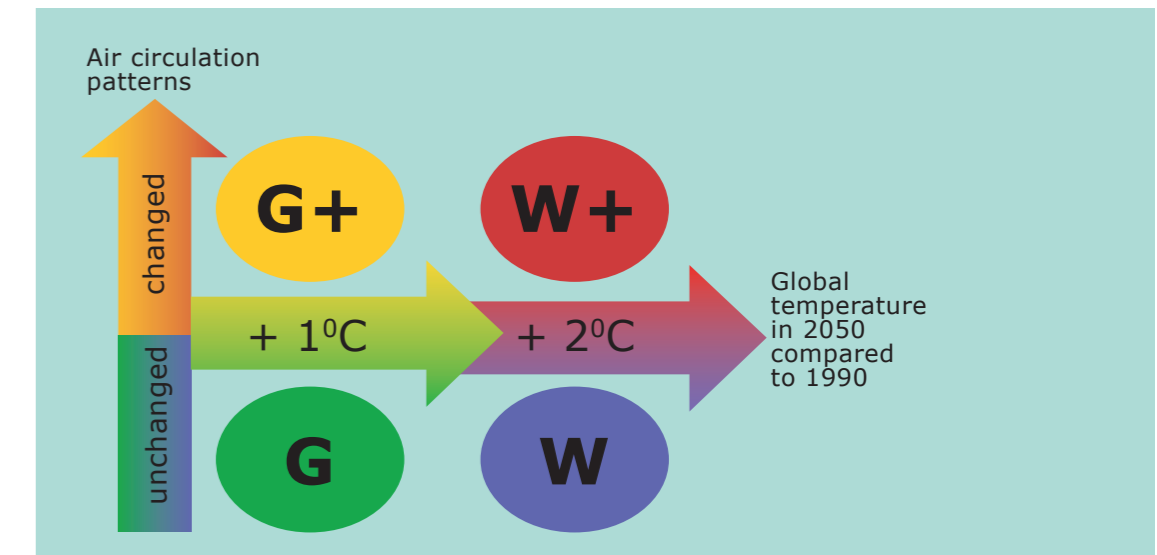
## Circulations

1.000

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► **Figure 1**

Schematic overview of the four KNMI'06 climate scenarios. For explanation see the legend below.



G	Moderate*	1°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
G+	Moderate +	1°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds
W	Warm	2°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
W+	Warm +	2°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds

Legend for the KNMI'06 climate scenarios. \* 'G' is derived from 'Gematigd' = Dutch for 'Moderate'

► **Table 1**

Climate change in the Netherlands around 2050<sup>1</sup>, compared to the baseline year 1990<sup>2</sup>, according to the four KNMI'06 climate scenarios.

		G	G+	W	W+
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		no	yes	no	yes
Winter <sup>3</sup>	average temperature	+0.9°C	+1.1°C	+1.8°C	+2.3°C
	coldest winter day per year	+1.0°C	+1.5°C	+2.1°C	+2.9°C
	average precipitation amount	+4%	+7%	+7%	+14%
	number of wet days (≥ 0.1 mm)	0%	+1%	0%	+2%
	10-day precipitation sum exceeded once in 10 years	+4%	+6%	+8%	+12%
Summer <sup>3</sup>	maximum average daily wind speed per year	0%	+2%	-1%	+4%
	average temperature	+0.9°C	+1.4°C	+1.7°C	+2.8°C
	warmest summer day per year	+1.0°C	+1.9°C	+2.1°C	+3.8°C
	average precipitation amount	+3%	-10%	+6%	-19%
	number of wet days (≥ 0.1 mm)	-2%	-10%	-3%	-19%
Sea level	daily precipitation sum exceeded once in 10 years	+13%	+5%	+27%	+10%
	potential evaporation	+3%	+8%	+7%	+15%
	absolute increase	15-25 cm	15-25 cm	20-35 cm	20-35 cm

<sup>1</sup> data on changes in 2100 can be found at [www.knmi.nl/climatescenarios](http://www.knmi.nl/climatescenarios)

<sup>2</sup> the climate in the baseline year 1990 is described with data from the period 1976 to 2005

<sup>3</sup> 'winter' stands for December, January and February, and 'summer' stands for June, July and August